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BOX 2 FOLDER 7

[HEPAP] [1972-1973], meeting agenda, minutes, correspondence, reports

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UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

July 26, 1973

TO : HIGH ENERGY PHYSICS ADVISORY PANEL MEMBERS

B. C. Barish	B. Richter
D. B. Cline	J. L. Rosen
J. W. Cronin	J. R. Sanford
T. H. Fields	G. F. Tape
L. J. Laslett	V. F. Weisskopf, Chairman
F. E. Low	W. A. Wenzel
R. R. Rau	

FROM : Walter D. Wales, Executive Secretary

SUBJECT: TRANSMITTING MINUTES OF HEPAP MEETING 6/20-21/73, NAL

Enclosed are the minutes of our last meeting. I have also included an analysis of the funding worksheets. I suspect I have done sufficient analysis to completely obscure any information the worksheets contained.

The next meeting is still scheduled for October 3-4, 1973, in Washington.

Enclosures:
1. HEPAP Minutes, 6/20-21, 1973
2. Analysis of HEPAP FY 1975 Worksheet - 6/73

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

July 25, 1973

MINUTES

HIGH ENERGY PHYSICS ADVISORY PANEL

National Accelerator Laboratory

Batavia, Illinois

June 20-21, 1973

The preliminary agenda for the High Energy Physics Advisory Panel (HEPAP) meeting, the agenda for the National Accelerator Laboratory (NAL) presentation, and the agenda for the public portions of the meeting are attached (A1-6).

The evening session, which had been scheduled for June 20, was canceled.

Participants:

HEPAP

V.F. Weisskopf, Chairman
D.B. Cline
J.W. Cronin
T.H. Fields
L.J. Laslett
F.E. Low
R.R. Rau
J.L. Rosen
J.R. Sanford
W.A. Wenzel
W.D. Wales, Exec. Secy.

NSF

A. Abashian, Program Dir. for Elementary Particle Physics
M. Bardon, Head, Physics Section

AEC

J.M. Teem, Director, Div. of Phys. Res.
H.L. Kinney, Spec. Asst. to Dir., Div. of Phys. Res.
W.A. Wallenmeyer, Asst. Dir. for HEP, Div. of Phys. Res.
C.R. Richardson, HEP, Div. of Phys. Res.
N.W. Dean, HEP, Div. of Phys. Res.

Discussion of Visit of Chinese HEP Delegation

W. Wallenmeyer outlined the tentative agenda for the discussions with the visiting Chinese high energy physicists which will be held on Friday, June 22, at 1717 H Street. The meeting will begin with a briefing at 10:45 am, followed by a luncheon at which some members of the Commission are expected. This will be followed by an informal meeting at 2:00 pm. Some members of the Panel stressed that it was very important to try to keep the collaborations between the Chinese and American high energy physicists on as informal a level as possible. Members of the Panel who had met with the Chinese Delegation when they were visiting the various national laboratories pointed out that the Chinese physicists were very interested and extremely well informed.

JCAE Report Authorizing Appropriations for FY 1974

H. Kinney read the part of the FY 1974 JCAE Authorization Report pertaining to high energy physics. The Committee has approved the recommendations of the Division of Physical Research for funding in FY 1974 ($250M), but has added to those recommendations a total of $500,000, of which $300,000 has been added to the High Energy Physics Program for operation of the Bevalac. The Report questions the status of low priority machines, especially at a time when the National Accelerator Laboratory is coming into full operation. The report also expresses the Committee's satisfaction that the High Energy Physics Program is being efficiently administered.

Report of Bubble Chamber Working Group (BCWG)

C. Richardson outlined the history of the BCWG. The Group was formed to examine, on a national scale, the costs, safety, and operating procedures of bubble chambers throughout the program. The Group was formed after discussions with Laboratory Directors. It contains bubble chamber operating staff, safety representatives, and administrators (from the AEC). The list of members and the initial charge to the Group are attached (A7-10). C. Richardson reported that the meetings of the Group have been especially beneficial in establishing new lines of communication among the sectors represented on the Group. The Group has met at each bubble chamber and in Washington, and is now writing a report on its activities.

NAL Orientation and Site Tour

R. Wilson welcomed the Panel to the laboratory and briefly described the "exhaustive and exhausting" tour which was planned for the rest of the afternoon. The Panel and members of the Directorate then went to a bus which had been provided.

The tour began with a visit to the main accelerator control room. The accelerator was running at an intensity of about 10^{12} p/p. This intensity was deliberately low at the request of the experimenters then using the beam.

The Panel was then taken to the C-0 experimental area where D.D. Jovanovic discussed the operation of the hydrogen jet target. He pointed out that utilizing the internal beam on the jet was equivalent to a beam of 10^9 p/p on a 30 centimeter liquid hydrogen target. The target is cooled with liquid helium. Frozen hydrogen from the jet accumulates for two hours. The target is then raised and the frozen hydrogen sublimated for about one-half hour, after which the cycle is repeated. At the present time the system consumes approximately 30 liters of liquid helium each hour.

Jovanovic discussed Experiment #36 which is studying pp elastic scattering for t values between .005 and 0.1 $(GeV/c)^2$. The experiment has taken data for incident proton energies between 20 and 400 GeV. The recoil proton is detected with solid state detectors at angles of 88^o and 90^o in the laboratory.

Experiment #67 is using the jet to search for mass bumps in the region between 1.5 and 10 GeV via the reaction $p + p \rightarrow p + x$. This experiment employs a range telescope set at an angle of 60^o to the proton beam to detect the secondary proton. The "Jacobian peak" method is used to identify the missing mass. The Panel visited the experimental trailer of the Experiment #67 group and was shown a missing-mass plot which covered the range from 1-5 GeV/c^2.

Experiment #63 and Experiment #120, each looking for photons produced

by high energy protons, are also set up in the C-0 area. In addition to the gas jet, a rotating carbon whisker target is also used.

J. Peoples showed the Panel through the Proton Area. The control room for the area is now temporarily located in a Portakamp above the proton pits. This control room will be moved to the concrete bunker which is now being built near the upstream section of the Proton Area. This bunker will contain the power supplies and all controls for the area. An observation tower will be built on the top of the bunker.

The Panel then visited Experiment #100 which is now set up in Proton East. This experiment is designed to search for particles produced with very high momentum transfer. The experiment uses a secondary beam line, set at an angle of 77mr to the primary beam, to select the momentum of particles produced in the target. Two large Cerenkov counters are used to measure the velocity of the particles and a calorimeter and muon detector are set at the end of the apparatus to distinguish among electrons, muons, and hadrons. The angle selected corresponds to 90^{o} in the center-of-mass.

The proton beam passes through the building which contains the front end of Experiment #100 into a second pit where Experiment #87 will be run. This new pit is built of concrete rather than sheet pile and is a much more satisfactory building in all respects.

R. Wilson noted that in retrospect the utilization of the sheet piling had not been a satisfactory approach to the construction of underground experimental areas. It is expected that Experiment #87, which will utilize a broad band photon beam, will be partially set up at the end of the next month.

J. Appel showed the group the apparatus which is being set up in Proton Center for a di-lepton search (Experiment #70). The apparatus can be set at angles of 50, 63, 97, and 103mr. The momentum analysis is done with a vertical bend while the angular measurement is made in the horizontal direction. The detector system itself contains a scintillator hodoscope, a matrix of lead-glass blocks for electrons, a calorimeter for hadron identification, and a muon detector. The entire apparatus contains many counters but no spark chambers. The first arm of the detector is being set up. Two arms will eventually be needed.

L.W. Mo described the apparatus which has been set up for muon scattering (Experiment #98). The experiment uses the University of Chicago's cyclotron for magnetic analysis and the Rochester cyclotron as part of a muon detector. Large spark chambers are used to detect wide-angle particles in front of the magnet and small-angle particles behind the magnet. The limit on the q^2 which can be attained by the experiment will be determined by the muon flux available.

F. Sciulli described the operation of the narrow-band neutrino experiment (Experiment #21). The neutrinos to the apparatus originate from the decay of momentum-analyzed beams of K and π mesons. The apparatus presently contains 170 tons of steel. The basic calorimeter, which is 5' x 5' x 48', contains a spark chamber every 28". The hadron energy is measured by sampling the hadron shower with liquid scintillator planes placed every 4" within the calorimeter. A toroidal magnet behind the calorimeter is used in conjunction with wire spark chambers to measure the momentum of secondary mesons. The magnet currently used is smaller than desirable. A larger, 12' diameter, magnet is expected within the next six months. A particularly attractive feature of this neutrino experiment is the fact that the sign of the incident neutrinos can be predetermined. The group has 112 reconstructed events from a run of January which provide a lower limit on the mass of the W meson of 4.5 GeV/c^2.

R. Lundy showed the group through the Meson Area. A water-cooled target and beam dump is currently being installed. The target can handle a beam of 5×10^{12} p/p without cooling. The entire target load is operated under vacuum to prevent degeneration of the optical quality of the secondary lines.

A liquid hydrogen target has been placed in the neutral line (M3) for the measurement of the neutron total cross section (Experiment #4I).

The pion charge exchange experiment (Experiment #111) is now in place and nearly ready to run in the M2 beam. The K^{o} experiment in M4 (Experiment #82) is being installed in an underground pit behind the Meson Area detector building. New extensions to the building using the standard Wonder-building construction are now being prepared for the elastic scattering experiments and for the hyperon beam dump.

W. Fowler and R. Orr showed the group through the 15' bubble chamber facility. Twenty-four-hour shifts had been started a week previously. At the time of the HEPAP meeting it was hoped to begin to transfer liquid to the chamber within three days. Fowler indicated that the chamber might be pulsed within the next three weeks. He hoped, based on the CERN experience with their metal piston, that the chamber might operate with its metal piston with fields as high as 15 kilogauss. The laboratory is also having a fiber glass piston fabricated. (Note: The chamber cool-down and filling test was successful. Pulsing and track photography will be attempted during the next cool-down and fill, which is now expected in August.)

A.K. Mann and W. Ford described the operation of the apparatus which utilizes the wide band neutrino beam (Experiment #1A). The calorimeter for this experiment consists of four 6' long tanks of liquid scintillator, each 12' square. Wide-gap spark chambers are placed between each of these tanks to measure the angles of

the particles produced in the calorimeter. Magnets 12' in diameter and effectively 16' long are placed behind the calorimeter to measure the momenta of the muons produced.

The tour of the laboratory facilities was completed (the next day) by a visit to the work being done on the energy doubler. B. Strauss described the work being done on the magnets and indicated that the laboratory was preparing to do tracking tests on two "identical" shell model magnets. D. Edwards described the work being done on the refrigeration system. He expects that the present refrigerator will be in operation some time during July delivering 150 to 200 liters per hour. The cooling loop which is being installed in the Protomain building is expected to be completed by fall. He hopes to be ready to install completed prototype magnets in this test loop by winter.

NAL Presentation (June 21)

R. Wilson began the presentation by outlining some of the laboratory priorities. He indicated that the basic job of the laboratory at the present time is to get on with the experiments. The Directorate meets with the experimenters every two weeks to review their (the experimenters') needs, ambitions, and frustrations. The experimenters have emphasized that a long, smooth spill is important. The present spill has considerable ripple in it which reduces its utility to experimenters. (Note: The laboratory has recently made considerable improvement in the beam structure during spill.)

The splitters in the switchyard operate with about 1% loss. All experimental areas have been operating simultaneously. The splitters and the multiple experimental areas permit a great deal of flexibility in the laboratory operation. There have been as many as twelve experiments running simultaneously, with more setting up or testing.

The slow extraction efficiency is usually around 90% and occasionally as high as 95%. The primary worry in this respect has not been so much the fact that the beam is lost for experimental use, but the fact that so much of the beam is left in the accelerator. A "happy surprise" has been the discovery that the losses in the machine are not causing nearly so much thermal damage or radioactivity buildup as had been anticipated. It appears that the accelerator could be operated at full design intensity with an extraction efficiency as low as 90%. Wilson pointed out in response to a question that the primary reason for the increases in the extraction efficiency had been the work of Helen Edwards and her co-workers. He also pointed out that the difficulties with the extraction were still not completely understood but that continued tuning would be done.

Wilson indicated that (1) the machine would get to full intensity, and (2) getting there would be difficult. The linac is operating according to design but the booster has been limiting the final delivered intensity. Wilson noted that increases in intensity

would come about in part by increasing the effective size of the aperture which would in turn result in a larger emittance. Wilson also indicated that they were concerned that the degradation of optical quality expected with higher intensity might limit the extraction efficiency.

The main loss in the main ring occurs in the first few turns. The transmission is occasionally above 80% but is more typically around 50%. Wilson believes that a transmission consistently above 90% can be achieved. He pointed out that reliable operation of the linac and the two accelerators present complicated problems. The reliability of the accelerator system (in terms of delivering beams to experimenters) is about 50% and improving slowly. Wilson indicated that there was no specific problem which was the primary source of the accelerator downtime. He indicated that with so many parts, each one had to be extremely reliable for the entire system to work. He stated that the laboratory will spend money in any way which will improve the reliability, but they are at present doing everything they know. He stated that the laboratory had good and dedicated people working on the problem and that funding was not a limitation.

The machine ran well at 400 GeV in April and May. The intensity at that energy was the same as at the lower energy. The experiments run include some bubble chamber exposures, the experiments in C-O,

and the neutrino experiments. The machine energy is now defined as 300 plus or minus 100 GeV.

There have been no problems thus far with Commonwealth Edison. The formal agreement with the utility covers only runs at 200 GeV. The laboratory is now negotiating for a formal contract which will cover 300 GeV operation. The voltage fluctuation at this latter energy is about at the limit acceptable to Commonwealth Edison. Wilson indicated that a capacitor bank (about $100,000 worth) in series with the accelerator power supplies would eliminate the voltage fluctuation and permit operation at 400 or 500 GeV. The capacitor bank does not, of course, change the overall energy usage problem, which can only be solved by running at lower energies or by cycling at lower rates at the higher energies.

Wilson outlined the history of the doubler project. It is anticipated that a 45 kilogauss superconducting magnet in the main ring tunnel would permit operation at 1000 GeV. The present main ring would be used as a booster. The activity on the project began last fall when P. Reardon and about ten other staff members began to meet twice weekly to discuss the problems. As a result of these discussions it was discovered that the present power supply could be used to operate both the doubler and the present ring and that space was available for cryogenic equipment. The laboratory received permission during the past winter to spend up to $1.5M in plant funds on the

doubler project. The previous work on the project has been retroactively charged to plant funds. The doubler group has built several model magnets which work satisfactorily. They are approaching the project in stages and trying to design a very conservative system. They plan to inject at 10 kilogauss and are designing for a cycle time of 100 seconds. One boundary condition on the project is that it must not interfere with the operation of the accelerator. The group plans to build adequate models to gain confidence of the construction techniques and field quality. After that they plan to install 200 feet of superconducting magnets in the Protomain tunnel and operate that as a complete system. The next step would be to install 200 feet of superconducting magnets between service buildings in the main ring without interfering with the experimental program. After this step, they would attempt to install a system in two service buildings. It would not be until this point was reached that a guarantee could be given that the doubler would work. Any use of construction funds, beyond the $1.5M which has been approved for the doubler prototype work, must be approved first by URA and then by AEC.

The model magnets which have been made run at a 10 second cycle rate. It is assumed that the doubler, for very high energies, could be run simultaneously with main ring operation for experimental use at lower energies. Extraction from the doubler should not be an insurmountable problem. It would be planned to use fast extraction to the Neutrino and Proton Areas first.

Wilson stated that the Meson Area now accepts proton beam at 300 GeV. The secondary intensity is higher because of this energy but the energies of some of the secondary beams must be raised. Superconducting magnets may be used to raise the secondary beam energy.

Wilson referred to the muon laboratory as another "skeleton" in NAL's closet. The beam at the present proton intensity is 10^4 per pulse. The laboratory is building 4" x 6" superconducting magnets for the muon beam line. With these magnets, the muon beam should deliver an intensity of 10^6 muons per pulse at the NAL design intensity. Wilson pointed out that the experimenters in Experiment #26 and in Experiment #98 were both doing constructive experiments at a range exceeding that available at SLAC. He indicated that the q^2 range could be most easily extended by raising the muon energy. However, Wilson admitted that planning the muon and neutrino beams for simultaneous operation from the same target had been a mistake since the factor of two in experimental use had been more than wasted by the compromises which had been made in beam design. He indicated that the summer study would probably make recommendations for both muon physics and for electron/photon physics. Wilson stated that he expected to have constructed 40' of superconducting magnets for the muon line this fall. A complete system with refrigerators will be installed. The whole doubler group (ten people) is now working on these magnets. Since the magnets will

not be located near the primary target, shielding is not expected to be a problem.

Wilson pointed out that good muon physics could be done at the present level and that experiments were scheduled for two years in the present facility. He described himself as being "arrogantly apologetic" with respect to the muon facility.

Of the 80 experiments which have been approved thus far, 16 have been finished and 17 are in progress. As indicated in the Situation Report (A11-12), there are 20 approved experiments on which nothing will be done in the coming year. The Proton Area has itself been something of an experiment and has not been as flexible as hoped. Wilson indicated that there had been no discussion at the Program Advisory Committee (PAC) meeting concerning the results from the ISR. However, he noted that most of the experiments had been approved prior to the results from the ISR. The ISR results should make the PAC meeting this summer more interesting - those experiments which merely represent interpolation between low energies and ISR energies may get less priority.

Members of the Panel asked what effect the low budget was having on NAL operation. Wilson indicated that he intended to "make do" and would get the necessary money some way. He indicated the most critical shortage was in operating funds. He is supplementing

these by using plant funds in the "gray" region as much as he feels permissible. He indicated that in FY 1973 there had been an effective transfer of $4M from plant to operating funds. Wilson referred to the design report to justify a need for $60M annually (in 1967 dollars) for effective operation. He stated that there were not enough people to operate the laboratory efficiently and that the service provided experimenters was worse than at other laboratories. The Panel discussed the problem of how operating funds should be related to machine energy but did not achieve a reasonable consensus.

Wilson indicated that he had spent or committed about $210M of the original $250M authorized for the accelerator construction. He expected to spend another $10M on completing parts of the experimental area; that would leave $30M for other projects or for relief of shortages of operating funds. The question was raised as to whether he would use this $30M to supplement operations if there were no restrictions on its use. He indicated that he would have to study the situation. He pointed out that the power bill alone makes expenditures for superconducting magnets (from capital funds) extremely sensible. He also indicated his concern about the inevitability of the First Law of Funding (next year's operating funds = last year's operating funds). He felt that utilization of plant and capital equipment funds for relief of operating funds

shortages at NAL was only deferring the problem and would eventually magnify the effect of NAL's operation on other laboratories in the High Energy Physics Program.

Accelerator Performance

L.C. Teng reviewed the present operational status of the accelerator. The linac routinely delivers a current of 70 milliamps. Its emittance meets the design specifications. The operation of the linac has been satisfactory except for the lifetime of the 7835 tubes.

The linac delivers 12×10^{11} protons per turn to the booster. The beam in the booster is reduced to 6×10^{11} protons for each turn injected. Ten pulses from the booster to the main ring yield 6×10^{12} protons per main ring pulse. The beam in the main ring has been at best 4×10^{12} protons per pulse.

The loss in the booster occurs in the first 3 milliseconds. The problem appears to be the momentum spread of the injected beam. The momentum spread (Δ p/p) is .4% after injection into the booster compared to a design spread of .16%. Increased RF voltage in the booster would solve the loss problem but a factor of 4 would be needed. The solutions which NAL is currently pursuing are to install a debuncher prior to injection into the booster and/or to debunch the beam in the linac by programming the linac voltage (à la BNL). The BNL solution will be tried first.

Although the design calls for 4-turn injection into the booster, at the present time less than 2 turns can be captured at full efficiency due to aperture limitations. The best injection thus far corresponds to 1.3 turns. Sextupole and octupole correction magnets are being installed to try to remove the aperture limitations.

The main ring aperture is also smaller than anticipated. Trim sextupoles are being installed and trim octupoles will be installed to improve the quality of the remanent fields. The effects of these correction schemes in both the booster and the main ring should be apparent by early fall.

The main ring magnets are now being given hi-pot and inductance tests during routine shutdown and removed if necessary. An average of one magnet per week is being replaced. Magnet failures during operation are at a level of about one every three weeks. They do not represent a serious source of downtime - the most recent magnet failure resulted in a total of only 4½ hours of lost beam. The few failures which have occurred in the new magnets have been due to water leaks at butt joints. A sleeve joint is being installed to cure this problem. It is possible that butt joint leaks may have been the source of some of the earlier problems. The financial impact of the magnet replacement program is less than $1M. Wilson pointed out that although operation was far from being satisfactorily reliable, the last experimental run delivered 10^{17} protons in 10^{5} pulses for a 10^{12} p/p average.

Experimental Operations

J.R. Sanford reviewed the record of operations for experiments over the past year. During the recent past an average of 60 hours per week has been delivered for experiments (A13). At the present time 120 hours per week are scheduled for high energy physics and an attempt is being made to devote large blocks of time (many weeks) to experimental operation at a single accelerator energy. A second graph (A14) indicated how the energy and intensity have changed since the accelerator began operation. The effort at the accelerator at the present time is to get the intensity into the 10^{13} p/p region.

Sanford reviewed the emerging style of the experimental areas. The Internal Target Area is utilizing thin targets and multiple traversals of the primary beam to investigate p-p and p-C collisions. An advantageous feature of this arrangement is that data can be taken while the energy changes from 30 GeV to 300 GeV. The laboratory is considering installing a second target in this area to permit increased experimental usage.

The Meson Area has been developed for general purpose secondary beams of energies less than 300 GeV. The first experiments emphasize measurements of total and differential cross section for a variety of particles. At the present time approximately 2½ of the expected beams in the area are operational. The beams in the area, with the exception of the test beam (M5), should all be operational by fall.

The Neutrino Area has been set up for very specialized beams and for specialized facilities. It contains the neutrino and muon beams, the two bubble chambers, and neutrino horn, and the massive neutrino and muon experiments.

The Proton Area has been designed for use with the primary proton beam. The heavy earth shielding permits very high intensities and higher energies. At the present time the area has achieved about 1/3 of its planned capacity. Proton East and Proton Center both use heavy targets. Proton East currently has set up in it an experiment to search for particles at large $p_\perp$ and will be used for later photon experiments. Proton Center contains an experiment being set up search for heavy leptons. Proton West has been designed for a series of experiments utilizing transmission targets. This part of the area is the least developed.

Sanford referred to the Situation Report (A11-12) which appears approximately every other month and to Experimental Program Lists 1, 12, and 21, which were included in the material distributed to HEPAP. He pointed out that List 21 indicates the backlog for each beam. He was not pessimistic about this backlog but felt that the laboratory could chew into it if they could afford the necessary power and manpower. He indicated that if he assumed an average of 100 hours per month for experimental operation the queues range from 1-3 years in length. He again emphasized the value of the

Situation Report in understanding the current status of the experimental program.

Experimenters' Reports

A.K. Mann described Experiment #1A. The experiment is designed to measure total cross sections and to search for heavy leptons and W bosons. The experiment accepts neutrinos and antineutrinos indiscriminately and detects low energy (greater than 0.1 GeV) hadrons. A broad-band neutrino beam with maximum intensity between 30-50 GeV is used. At the present time 181 of 298 events detected at 300 GeV have passed analysis tests. Since the experimenters have another 1000 events at 300 GeV and 1000 at 400 GeV, they expect to have 700 analyzed events in hand within a month. Mann showed a comparison of the neutrino and antineutrino cross sections which, within large errors, agree with expectations. He pointed out that neutrino experiments at this time in this energy region are ideal to distinguish scaling mechanisms from phenomena due to new particles. He outlined the event rate expected with detector and accelerator improvements and emphasized the need for detecting muons at much larger angles. Mann also described the operation of Experiment #21. This experiment utilizes a dichromatic neutrino beam and uses a somewhat simpler detector to distinguish between the two energy bands. The intensity of the beam used is much less but a gain is made in having sign-selected neutrinos.

P. Piroué described the operation of Experiment #100 which is now running in Proton East. The experiment was proposed to look at secondary hadrons at high $p_\perp$, to search for W production via high transverse momenta muons, and to look for new long-lived particles. The results from the ISR have made the first goal of their experiment particularly topical. Protons are incident on targets of beryllium, tungsten, and tantalum. A secondary beam at 77mr corresponding to 90° in the p-p center-of-mass is momentum-analyzed and passed through two Cerenkov counters, dE/dx counters, shower counters, a calorimeter, and a muon detector to identify the secondary particles. The experiment first received beam three weeks ago and has now started taking data. The Cerenkov counters utilize mirrors to focus the ring of Cerenkov radiation into one of two detector channels. Very preliminary results using negative beam indicate the secondary beam consists of 72% π^-, 21% K^-, and 7% antiprotons.

Heavy Ion Physics

A.K. Kerman discussed the scientific significance of the Bevalac with the Panel. He pointed out that the subject should be carefully defined and that it should appropriately be called relativistic heavy ion physics which is, by definition, high energy physics. Kerman pointed out that he had long been interested in heavy ion physics but that he had become interested in relativistic heavy ion physics, which is quite a different subject, only a year ago. He recalled the Omnitron project and pointed out that the nuclear

physicists, even at LBL, were not enthusiastic about it. He suggested that possibly medical pressure, the lower cost of the Bevalac, and the fact that it operates in the parasitic mode had made the Bevalac project possible.

Kerman suggested that relativistic heavy ions would be useful for two separate kinds of studies. First, it should be possible to make different kinds of nuclei in the debris of the collision. One could imagine finding very exotic (for example, more than 1 lambda) nuclei or nuclei with a large number of protons or neutrons in the debris of the collisions. It is possible in this way to explore new places in the n-p-Λ diagram. In addition, there are some experimental advantages in having the center-of-mass of the collision moving rapidly. For example, a study of $C^{12}(p, np)C^{11}$ cannot easily be done at high energies, whereas the reaction $p(C^{12}, C^{11})pn$ can be readily studied.

A second use for relativistic heavy ions is the study of reaction mechanisms. By studying the diffractive dissociation of incident heavy ions one might be able to study the wave function of the projectile. There is also some interest in a "bulls eye" collision where the system left after the collision might thermalize at temperatures corresponding to about 200 MeV. Nothing is known about the physics which would appear when such high temperatures are introduced into high density matter.

Kerman pointed out that traditional nuclear physicists are not interested in relativistic heavy ions since they have too many other problems already and would prefer to continue to work on the machines they already have available. There are no experimentalists (except at the Bevatron) who are becoming committed to experiments with relativistic heavy ions. Although high energy physics does not want to give up the money to support this program, it is really high energy physics, involving high energy techniques, high energy personnel, and a high energy machine.

There was some discussion of the differences between LAMPF, to which nuclear physicists have made commitments, and the Bevalac, to which they are reluctant to make commitments. It was pointed out that work at LAMPF has a guaranteed payoff whereas work with relativistic heavy ions is very speculative. In addition, it was pointed out that the approximately $3M operating cost of the Bevalac was impossible to sustain from funds presently available from low and medium energy physics. Several low energy physicists from ANL who visited the HEPAP meeting pointed out that the operating costs of the proposed $25M heavy ion machine would be less than that of the Bevatron. They also stated that low energy heavy ions are much more interesting for nuclear physicists than relativistic heavy ions. Rather than support the Bevalac project they will continue to hope that a low energy heavy ion machine will be built. It is clear that most nuclear physicists think that physics with

relativistic heavy ions is high energy physics while most high energy physicists think that it is nuclear physics.

CEA Recycling

W. Wallenmeyer reviewed the status of CEA. The accelerator is now shut down and the AEC is negotiating with Harvard to decide what equipment will be surplus and where it will be sent. The receiver of the equipment will pay for both the shipping and packing. Harvard has proposed that the AEC walk away and leave the accelerator intact as Harvard property which they would then sell or scrap. They would plan to use the offices and the high bay area for the Harvard high energy physics group. Harvard feels that if the accelerator is removed by the AEC, then the AEC should pay for site restoration. It appears at the present time that the value of the components of the CEA is considerably more than the costs of site restoration. At the present time it appears that three laboratories, BNL, NAL, and LBL/SLAC, might want the entire accelerator for use in colliding beam work. However, it also appears that none of these laboratories will be in a position to make a firm request for several months. BNL and NAL are considering using electrons from CEA for e-p collisions and LBL/SLAC would like to use the accelerator in connection with PEP. The Panel consensus is that although a quick decision on whether to accept Harvard's offer would be desirable, the AEC should in fact delay its decision, and the laboratories who might be interested in the machine should try to

firm up their plans as quickly as possible. It was also suggested by some of the more skeptical members of the Panel that it might be useful to study the cost effectiveness of previous moves such as the installation of the BNL injector at the Bevatron and the recommissioning of the Cornell 2 GeV electron accelerator as a booster at ANL.

Executive Sessions

W. Wales described the book which had been prepared for HEPAP's use. The book contained budget information, material on the NAL experimental program, and information on possible construction projects for FY 1975. W. Wallenmeyer reviewed the AEC's FY 1974 budget and pointed out the differences between the President's budget and the Interim Financial Plan. The Spring Agency Plan for FY 1975 was also discussed.

M. Bardon reviewed the NSF budgets. He indicated that he expected that the energy of the Cornell Electron Synchrotron would be increased to 15 GeV by making minor RF improvements.

The Panel discussed the implications of the funding required for the operation of NAL. It appears that at the present overall funding level, "full blown" operation of NAL implies shutdown of other accelerator laboratories. The Panel discussed the possibility of finding ways to use construction funds at NAL to permit more efficient use of operating funds. However, it was suggested that NAL was

already doing whatever they could in this respect.

The Panel also discussed the superconducting storage rings proposed at ANL, the 4 GeV mini-project contemplated by LBL, the improvement programs at Cornell, and the proposed Recirculating Linear Accelerator (RLA) at SLAC. A subpanel was authorized to examine the physics justifications for RLA. This committee will report to J. Teem prior to the end of July. (The members of this committee are J. Rosen, Chairman; B. Richter, and Richard Wilson.)

The Panel was briefed on recent interactions with the Soviet Union with respect to a joint colliding beams accelerator. This project, at the present time, appears to be dead.

The next meeting of the Panel was scheduled for October 3-4, 1973, in Washington.

FINAL PRELIMINARY AGENDA
6/12/73

AGENDA

HIGH ENERGY PHYSICS ADVISORY PANEL

National Accelerator Laboratory

Batavia, Illinois

June 20-21, 1973

Wednesday, June 20, 1973

1:00	PM	EXECUTIVE SESSION Agency Presentations FY 1975 Projections	Snake Pit
2:00	PM	Report of Bubble Chamber Working Group (C.R. Richardson)	Curia
2:30	PM	Discussion of Visit of Chinese HEP Delegation (HEPAP)	Curia
3:00	PM	NAL Presentation and Site Tour (NAL Staff)	
6:30	PM	Dinner	Cafeteria
8:00	PM	Evening Session Physics in People's Republic of China (V.F. Weisskopf) Outlook in HEP (V.F. Weisskopf, HEPAP, and Audience)	Auditorium

Thursday, June 21, 1973

9:00	AM	NAL Presentation (NAL Staff)	Curia
11:00	AM	NAL Discussion (HEPAP and NAL Staff)	Curia
12:30	PM	Lunch with NAL Staff	
1:30	PM	Discussion of Potential of Heavy Ion Physics (A.K. Kerman)	Curia
3:00	PM	CEA Recycling: Progress and Problems (W.A. Wallenmeyer)	Curia

Thursday, June 21, 1973, cont.

4:00	PM	EXECUTIVE SESSION NAL Budget Discussion Five-Year Projections FY 1974 - 1975 Construction Projects (ANL, LBL, SLAC, Cornell) Possible New US-USSR Joint Project	Snake Pit
6:30	PM	Dinner	Cafeteria
7:30	PM	EXECUTIVE SESSION (continued)	Snake Pit
10:00	PM	Adjourn	

PRELIMINARY FINAL AGENDA
6-20-73

AGENDA

HIGH ENERGY PHYSICS ADVISORY PANEL

National Accelerator Laboratory

Batavia, Illinois

June 20-21, 1973

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7:30	PM	EXECUTIVE SESSION (continued)	Snake Pit
10:00	PM	Adjourn	

AGENDA FOR NAL PRESENTATION TO HEPAP

WEDNESDAY, JUNE 20, 1973

3:00	Welcome	R. R. Wilson
3:15 - 6:30	Tour	D. R. Getz
	a) Accelerator Center	L. C. Teng P. Livdahl
	b) Internal Target Area	D. Jovanovic
	c) Proton Area	J. Peoples
	d) Meson Area	R. A. Lundy
	e) Neutrino Area	J. R. Orr
6:30	Dinner in NAL Cafeteria	
	After dinner at R. R. Wilson's	

THURSDAY, JUNE 21, 1973

9:00 - 9:45	General Program Review	R. R. Wilson
9:45 - 10:15	Accelerator Status Report	L. C. Teng
10:15 - 10:30	Coffee Break	
10:30 - 11:30	A Few Experiments in Progress	
	Neutrino and Anti-neutrino Interactions (1A)	A. Mann
	30" Bubble Chamber Program	J. Lach
	Study of Charged Particles Produced at Large Angles in pp Collisions	P. Piroué
11:30 - 12:00	Current Research Facilities and Operations	J. R. Sanford
12:00 - 12:30	Research Problems	E. L. Goldwasser
12:30 - 1:30	Lunch	Cafeteria
1:30 - 2:00	Visit and Description of Energy Doubler	D. Edwards

AGENDA

HIGH ENERGY PHYSICS ADVISORY PANEL

National Accelerator Laboratory

Batavia, Illinois

June 20-21, 1973

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4:00 PM	EXECUTIVE SESSION	Snake Pit

BUBBLE CHAMBER WORKING GROUP

Co-Chairmen:

Clarence R. Richardson
Division of Physical Research
U. S. Atomic Energy Commission
Washington, D. C. 20545
301-973-3367

Robert P. McGee
Division of Physical Research
U. S. Atomic Energy Commission
Washington, D. C. 20545
301-973-3367

Members:

Halsey L. Allen
National Accelerator Laboratory
Post Office Box 500
Batavia, Illinois 60510
312-231-6580

Jay O. Hunze
U. S. Atomic Energy Commission
Safety Division
Chicago Operations Office
9800 South Cass Avenue
Argonne, Illinois 60439
312-739-2088

F. Russell Huson
National Accelerator Laboratory
Post Office Box 500
Batavia, Illinois 60510
312-231-6600

E. Gale Pewitt
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439
312-739-4881

Albert G. Prodell
Brookhaven National Laboratory
Upton, New York 11973
516-345-4658

Don D. Reeder
Department of Physics
University of Wisconsin
Madison, Wisconsin 53706
608-262-8798

Robert Watt
Stanford Linear Accelerator Center
Stanford University
Post Office Box 4349
Stanford, California 94305
415-854-2757

Arnold Weintraub
(Alternate: Robert Eicher)
Division of Operational Safety
U. S. Atomic Energy Commission
Washington, D. C. 20545
301-973-3161

Advisor:

H. Paul Hernandez
(Alternate: Glenn Eckman)
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
415-843-5275

William A. Wallenmeyer, Assistant Director, High Energy Physics Program,
Division of Physical Research

PROPOSED FORMATION OF AN INFORMAL WORKING GROUP TO REVIEW THE MANAGEMENT ASPECTS OF BUBBLE CHAMBER OPERATION

As has been decided in recent informal discussions, there seems to be a strong and growing need for more detailed scrutiny of various aspects of our bubble chamber facilities. The best way to answer our needs is felt to be through the auspices of an informal working group of experts.

The following three-phased approach, developed with Phil McGee and Walter Wales, is suggested as a possible method of forming such a group.

PHASE I

It is felt that the first step should be informal discussions with the various laboratory HEP program directors (i.e., Goldwasser, Rau, Panofsky, Wenzel, and Cork) stating our concerns and the intended function of the group. This is important not only from the standpoint of assuring their cooperation, but also in order to get the benefit of their insight concerning the charge to the group and its possible membership.

PHASE II

The next step would be the formation of a central group, chaired by someone in the Division of Physical Research, with fairly limited membership. This might be constituted as follows:

AEC members:	2 Research Division (e.g.,Richardson, McGee)
	1 Operational Safety (e.g., Arnold Weintraub)
Laboratory members:	5 bubble chamber experts (e.g., Prodell, Pewitt, Huson, Watt, Hernandez)
	1 safety expert (e.g., A. Schlafke, or H. Allen)

At-large members: 2 total (maximum) from industry, university or perhaps CERN

The charge to the group might be as stated in the enclosed draft. There is also enclosed a list of other possible bubble chamber experts.

It is felt that since the charge to the group is apt to be rather broad, it would be cumbersome to have a central group large enough to have expertise in all the possible areas of cognizance. Therefore, it seems more practicable to form subgroups as needed to address each issue in its turn.

PHASE III

This would be the actual formation of ad hoc subgroups as the need arises.

Clarence R. Richardson
High Energy Physics
Division of Physical Research

Enclosures:
as stated

Charge to Committee

The advent of very large bubble chambers makes it timely to re-evaluate the management of bubble chamber facilities, giving special attention to costs, operation, safety, and special gas problems. We would appreciate it if you would serve on an informal working group which would attempt to review the management aspects of bubble chamber operation. We hope the group might collect information on present practices and then work our specific recommendations where appropriate.

Some of the specific items we expect this group to consider include:

(1) Operations with superconducting/high field magnets.

(2) Annual operating costs.

(3) Multiple pulsing and/or rapid cycling.

(4) Whether the current or planned procedures provide assurance of a mechanically safe operation.

(5) Procedures for periodic evaluation of operation.

(6) Operator training.

(7) Sharing/pooling supplies of rare/expensive gases.

(8) Other.

J. R. Sanford
6-18-73

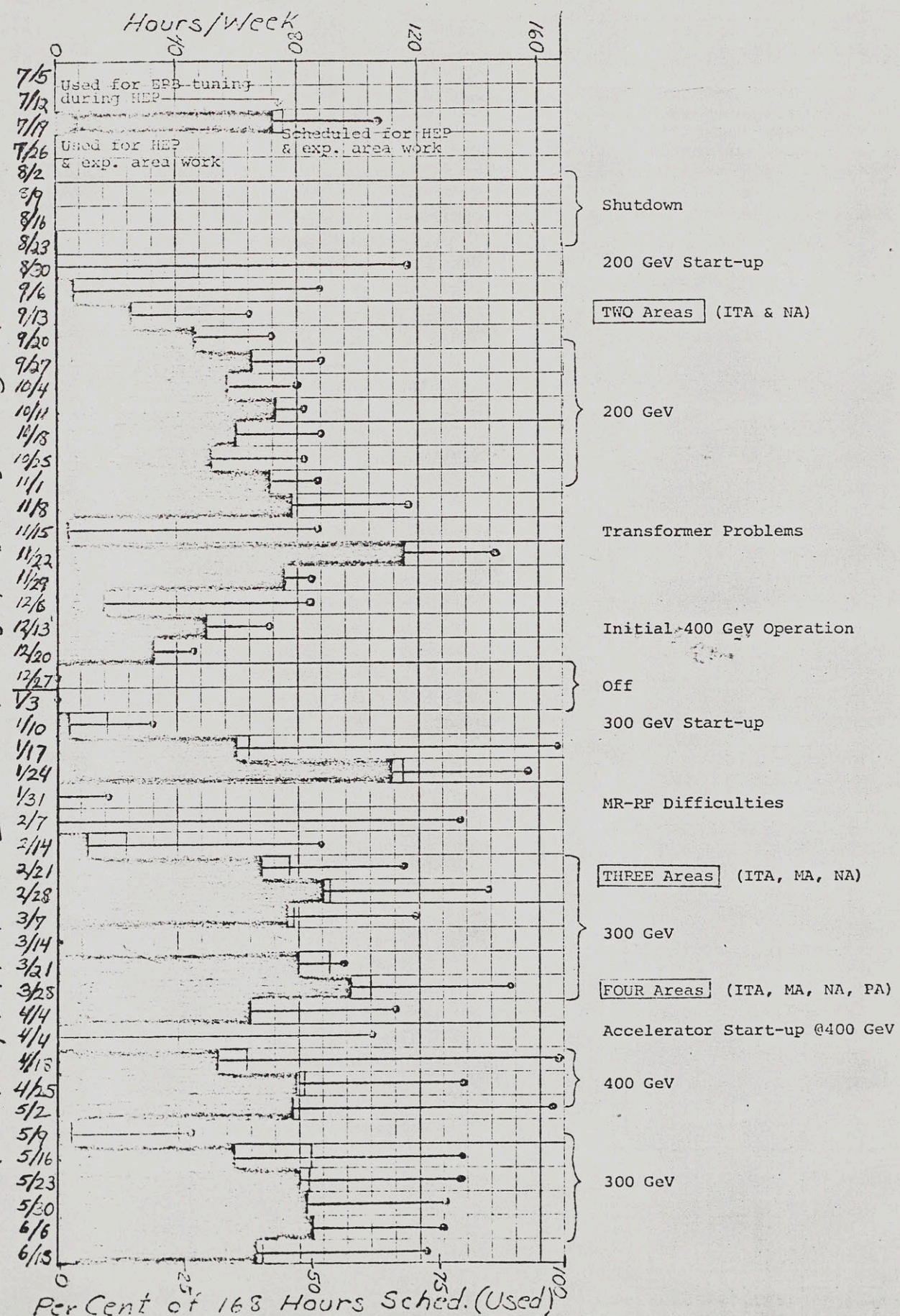
ACCELERATOR LABORATORY
PROGRAM SITUATION REPORT

The experim... at NAL is summarized below. The experiments are listed under categ... their circumstance as of June 13, 1973. Publications are reques... about the experiments marked *.

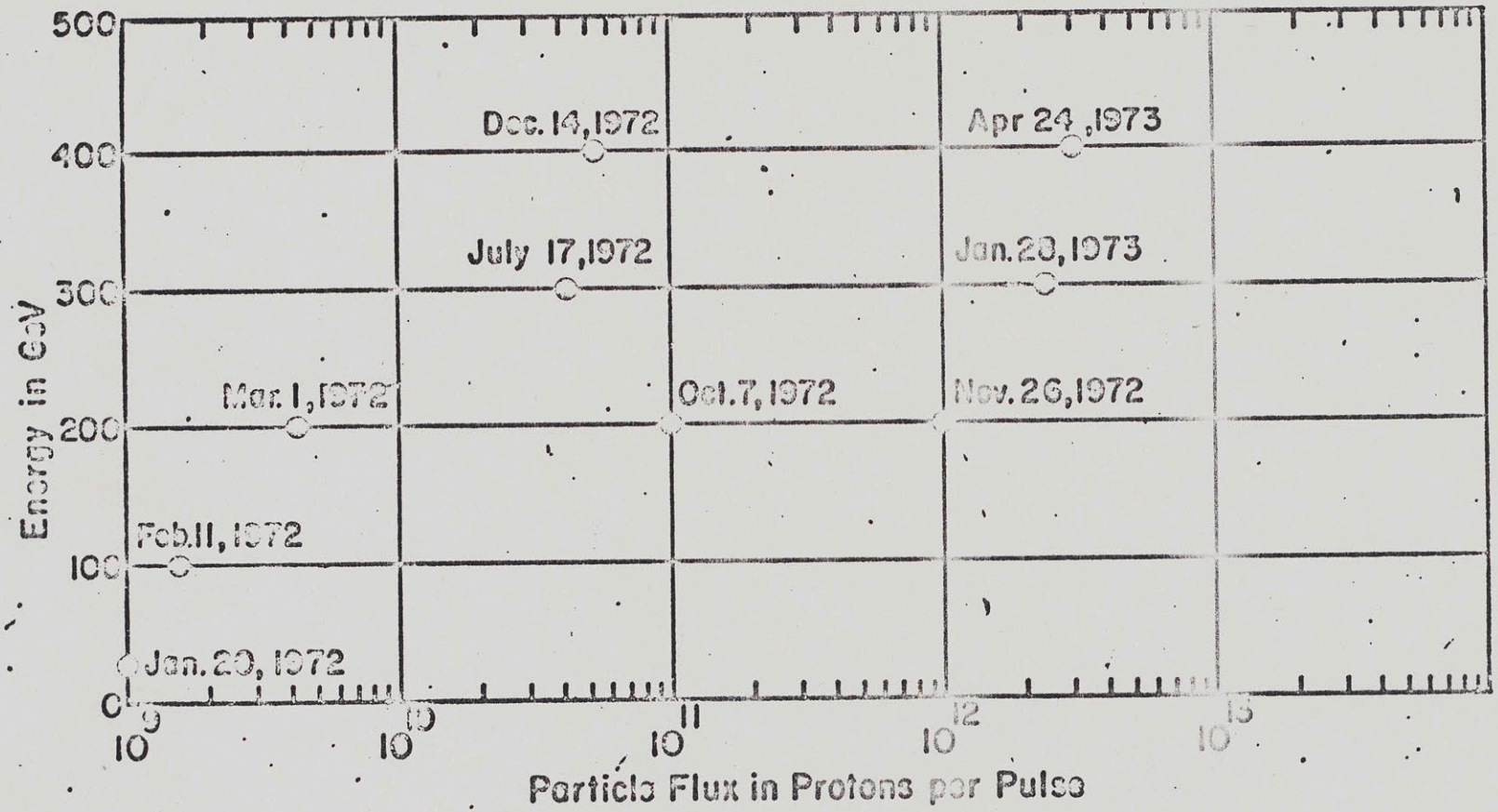
	Spokesman	Extent of Run to Date	Date Completed
A. 16 Exper... completed:			
*Proton-...	Franzini	120 hours	May 9, 1973
*30-Inch ...	Malamud	51,000 pix	June 1, 1973
*Quark ...	Leipuner	500 hours	June 11, 1973
Emulsion ...	Gierula	4 stacks	Sept. 20, 1972
*Emulsion ...	King	1 stack	Sept. 20, 1972
Emulsion ...	Malhotra	1 stack	Sept. 20, 1972
*Emulsion ...	Jain	1 stack	Sept. 20, 1972
*Emulsion ...	Hebert	5 stacks	Sept. 20, 1972
Emulsion ...	Kusumoto	11 stacks	Sept. 20, 1972
*Photon ...	Cline	1,200 hours	May 29, 1973
*30-Inch ...	Huson	48,000 pix	March 10, 1973
*30-Inch ...	Fields	67,000 pix	Nov. 27, 1972
Emulsion ...	Niu	13 stacks	Sept. 20, 1972
*Emulsion ...	Lord	6 stacks	Sept. 20, 1972
Emulsion ...	Tretyakova	3 stacks	Sept. 20, 1972
*Proton-...	Sannes	1,050 hours	May 9, 1973
B. 17 Exper... ss:			
*Neutrino ...	Cline	350 hours	
30-Inch ...	Smith	10,000 pix	
Neutron ...	Longo	450 hours	
*Neutrino ...	Barish	300 hours	
Muon #...	Chen	350 hours	
*Proton-...	Cool	700 hours	
*Particl...	Walker	1,300 hours	
Proton-...	Sannes	200 hours	
Quark ...	Yamanouchi	300 hours	
*Monopo...	Carrigan	3 targets exposed	
*Nucleon ...	Weisfield	25 bombardments	
Particl...	Piroue	200 hours	
*30-Inch ...	Lander	Tuning	
*30-Inch ...	Ferbel	33,000 pix	
30-Inch ...	VanderVelde	12,200 pix	
Particl...	Lederman	100 hours	
*Massive ...	Frankel	2 targets exposed	
C. 3 Experi... ge:			
Lepton ...	Lederman	100 hours	
Muon #...	Mo	Starting	
30-Inch ...	Pless	(few test pix)	

EXPERIMENTAL PROGRAM SITUATION REPORT (continued) 6-18-73

	Spokesman	Comments
D. 12 Experiments Being Installed:		
Elastic Scattering #7	Meyer	
Neutral Hyperon #8	Pondrom	
Neutron Dissociation #27	Rosen	
Elastic Scattering #69A	Sandweiss	
K^{o} Regeneration #82	Telegdi	
Diffraction Dissociation #86A	Lubatti	
Photoproduction #87A	Lee	
Elastic Scattering #96	Ritson	
Total Cross Section #104	Kycia	
Beam Dump #108	Awschalom	
Pion Charge Exchange #111	Tollestrup	
30-Inch π^{-}-p @ 100 #125	Morrison	
E. 13 Experiments to be Set Up in the Coming Year:		
15-Foot Anti-Neutrino/H_2 #31A	Derrick	
15-Foot Neutrino/H_2 #45A	Nezrick	
Photon #95A	Cox	
Super Heavy Elements #142	Stoughton	
30-Inch π^{-}-p @ 300 #143	Kalbfleisch	
Super Heavy Elements #147	Hebert	
15-Foot EMI #155	Peterson	
Emulsion/protons @ 100&200 #181	Carey	
Particle Search #184	Mann	
Proton-deuteron Elastic #186	Melissinos	
Emulsion/protons @ <400 #189	Ritson	
Multigamma Test #192	Guiragossian	
Emulsion/protons @ 300 #195	Lim	
F. 20 Other Experiments:		
Monopole #3	Ross	
Neutron Elastic Scattering #4II	Longo	
Proton-proton Elastic #6	Krisch	
Neutron Backward Scattering #12	Reay	
Monopole #22	Collins	
Inclusive Scattering #23A	Rothberg	
Photon Total Cross Section #25A	Caldwell	
15-Foot Neutrino/H_2-Ne #28A	Fry	
TANC #32	Hofstadter	
Detector Development #34	Huggett	
Muon Search #48	Adair	
Multiparticle #51	von Goeler	
15-Foot Neutrino/H_2-Ne #53A	Baltay	
Polarized Scattering #61	Chamberlain	
Monopole #74	Fleischer	
Charged Hyperon #97	Lach	
Multiparticle #110A	Pine	
Long-Lived Particles #115	Stevenson	
15-Foot Anti-Neutrino/H_2-Ne #172	Bingham	
15-Foot Anti-Neutrino/H_2-Ne #180	Mukhin	



(1972) Specific Week Starting on Indicated Wed. (1973)


500
400
300
200
100
0
Energy in GeV
Dec. 14, 1972
Apr 24, 1973
July 17, 1972
Jan. 20, 1973
Mar. 1, 1972
Oct. 7, 1972
Nov. 26, 1972
Feb. 11, 1972
Jan. 20, 1972
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
Particle Flux in Protons per Pulse

PRIVILEGED INFORMATION

KEY TO ANALYSIS OF HEPAP FY 1975 WORKSHEET

▽ - Agency Plan Distribution. The "Agency Plan Less 10%" analysis shows both Case I and Case II distributions.

- Average and standard deviation for all responses.

- Average and standard deviation when responses outside twice standard deviation are neglected.

PRIVILEGED INFORMATION

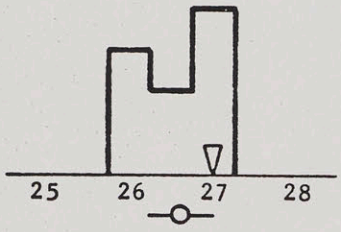
PRIVILEGED INFORMATION

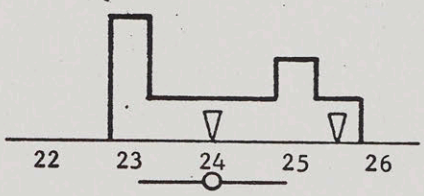
ANALYSIS OF HEPAP FY 1975 WORKSHEET - 6/73

AGENCY PLAN TOTAL

AGENCY PLAN LESS 10%

AGS





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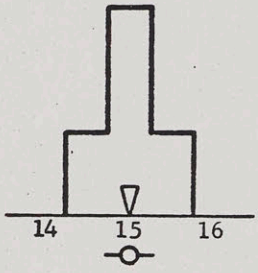

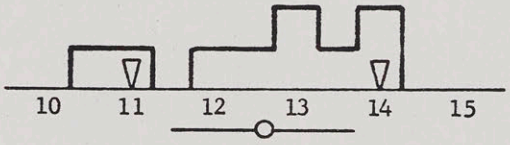

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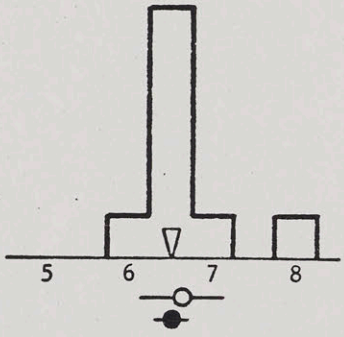

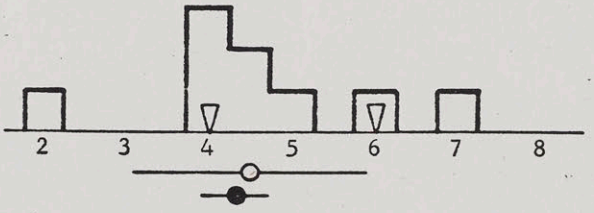

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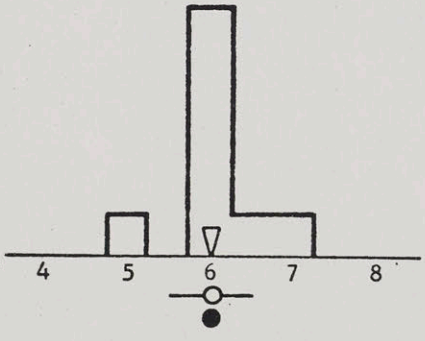

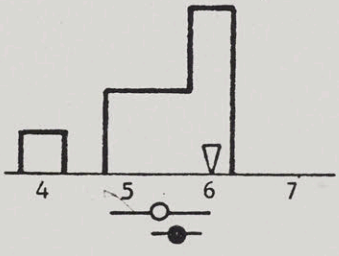

PRIVILEGED INFORMATION

ANALYSIS OF HEPAP FY 1975 WORKSHEET - 6/73

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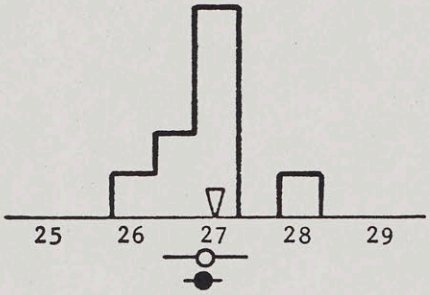
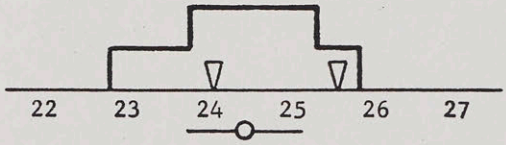
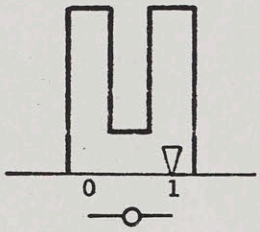
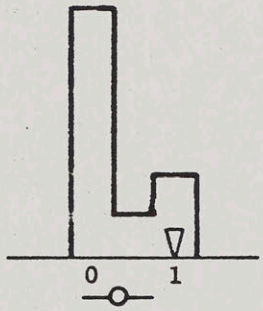
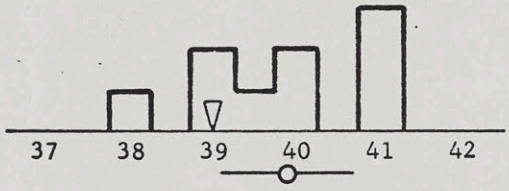
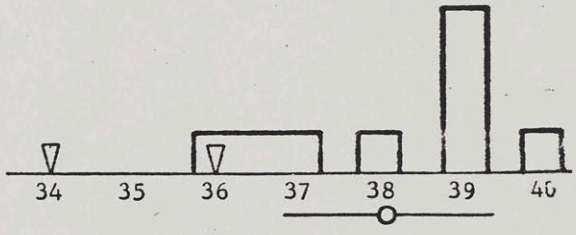
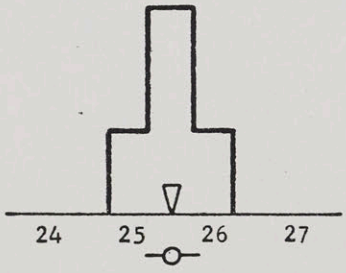
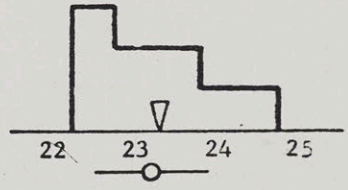
SLAC		
RLA		
NAL		
UNIVERSITIES		

November 14, 1972

Dr. W. J. Willis
Brookhaven National Laboratory
Associated Universities, Inc.
Upton, L.I., New York 11973

Dear Bill:

I have received your answer of October 26th to my letter in which I mention the general concern about the management of NAL. I would like to ask you whether you permit me to show your letter to the members of HEPAP?

I hear some vague rumors that there is a users revolution under way. They seem to plan some kind of statement asking for the resignation of Wilson. I am a little concerned about such developments because they may badly backfire. In particular, Congress may interpret it in a bad way and our financial support may suffer. The only possible way to have Wilson leave without major detrimental effects is an apparently voluntary resignation from him. This can only be negotiated by discreet negotiation with URA members and with other people with influence. An open revolution would be disasterous.

I feel rather uneasy about the situation and any answer positive or negative would be helpful.

Sincerely yours,

Victor F. Weisskopf

VFW:dle

November 14, 1972

Dr. Burton Richter
Stanford Linear Accelerator
Stanford University
Stanford, California 94305

Dear Burt:

I heard from Sidney Drell that you had a good conversation with John Teem about the role of HEPAP. I myself have talked with him, before the latest cut, and I emphasized in rather strong terms that our work as advisors could function only if we can be given information about the budgets and if important decisions are made after discussions with us.

In regard to the latest cut, it is my opinion that Wallenmeyer was under pressure to get figures out immediately. Under these conditions, however, the only thing that he should have done, was give an exact apportionment of the funds to each institution. To play favorites or "unfavorites" under such conditions is wrong policy. He had no time to think about it and no time to get advice from anybody. I plan to raise this issue at the next meeting.

With best regards,

Sincerely yours,

Victor F. Weisskopf

VFW:dle

October 16, 1972

Professor William J. Willis
Department of Physics
Yale University
New Haven, Connecticut 06520

Dear Bill:

May I bother you with business of HEPAP in spite of the fact that you are no longer a member. We continue to get letters of concern about the situation at NAL. In our last HEPAP meeting we discussed the possibilities of helping out, but we could not find much we could do. HEPAP advises the AEC and one should not tamper with the independence of the Laboratory directors from the AEC; it is an important value. I was advised, however, to send some of the letters we received to you since you are the Chairman of the Program Advisory Committee. You will find here enclosed part of a letter from Burton Richter concerning the situation at NAL and a letter by Bill Walker to Gerry Phillips who is a trustee of NAL. Please treat them as confidential and use them only as background information.

I would be interested to know your reaction and your advice what we or other people could do to improve the situation.

With best regards,

Sincerely yours,

Victor F. Weisskopf

VFW:dle

enclosures

Bev - 2096
Harry Heckman
December 1972

HEAVY ION RESEARCH AT THE BEVATRON: A PRELIMINARY EXPERIMENTS LIST

I. High Energy Physics

Experiment	Description
1. Total nuclear cross sections of high energy heavy ions. Program: 1-2 years	Measures a) σ_{AB}(total) for beam particle A and target nucleus B, and b) angular distribution of transmitted primary and secondary beam particles. Experiment will give information on the principle of factorization and energy dependence of the total (elastic + inelastic) cross sections. Beam and target nuclei will include p, d, ^{4}He and ^{12}C. Transverse momenta will be measured in the interval $0 \leq -t \leq .02$ in intervals of $-\Delta t = .002$.
2. Fragmentation of heavy ion beam particles. Program: Long term, open ended	
a) Single particle inclusive reactions	a) Experiment measures the partial differential cross section $\partial^3\sigma^x_{AB}/\partial_p{}^2\partial y$ for the reaction A+B→X+anything. Using a variety of beam and target nuclei, data on the production of secondary nuclei X versus energy will test theories of scaling, factorization, multiparticle reactions and principle of "nuclear democracy" for large baryon-numbered systems.
b) Total partial cross sections for fragmentation of beam projectiles.	b) The total cross sections $\sigma_{AB}{}^x$ for the production of nuclear isotopes will give information on nuclear radii, α-clustering, coulomb effects, etc. Energy dependencies will also test factorization principle for fragment production. Data will be pertinent to cosmic ray physics, where fragmentation cross section data are necessary for determining source composition and lifetimes of the primary cosmic rays.

c) Correlation effects in the fragmentation of heavy ion beam particles

c) Double, triple, and greater correlations in inclusive reactions can be studied to examine further the overall nuclear fragmentation process. Final state interactions can be investigated to search for the production of highly excited nuclear fragments. Data on multiplicities, angular and transverse momentum distributions will be important to theories of multi-nucleon cascades in matter.

3. π, K and hyperon production in heavy ion collision.

Program: Long term, open ended

Single and multiple production of π mesons can be examined for coherent production, production via compound nucleus formation and cooperative emission, and "fire-balls". K-meson and hyperon production in nucleus-nucleus collisions may yield secondary beams of high energy hypernuclei, affording new opportunities in hypernuclear physics.

4. Elastic scattering of nuclear systems.

Program: 3 - 5 years

High precision experiments on the elastic (and inelastic) scattering distributions in nucleus+nucleus interactions will be examined as function of beam energy, mass and spin states of the projectile and target nuclei. Of particular interest would be studies of spin zero systems, i.e., collisions between ^{4}He, ^{12}C, ^{16}O, etc. Heavy ion elastic scattering experiments test the Glauber Multiple Scattering Model, a model that treats scattering as a multiple process. Such tests are relevant to quark models, since, if quarks exist, all processes are multiple.

5. Production of meson resonances.

Program: ~2 years

Reactions like:

$d + d \rightarrow \alpha +$ missing mass

$\rightarrow dd +$ missing mass

have the advantage of selecting I=0 mesons that have not been easily separated from other I-spin states in previous πN studies. In particular, the

$\omega \rightarrow 2\pi$ branching ratio could be obtained using the above reactions.

6. Deuteron stripping, neutron beams.

Program: Long term

The highly collimated, mono-energetic neutron beam produced by the stripping of deuterons offer a wide range of possible experiments. As examples

i) $np \rightarrow d + \eta$
$\hookrightarrow \mu^+ + \mu^-$

ii) $np \rightarrow pn$ (elastic charge exchange scattering)

iii) Polarized neutron beams produced by the stripping of polarized deuterons.

II. Nuclear Physics

Experiment	Description
1. Nuclear spallation of heavy target nuclei under heavy ion bombardment. Program: Long term, open ended	Heavy ion beams with energies up to a GeV/nucleon expand greatly the experimental possibilities for studying the dynamic properties of nuclear matter. The very high angular momentum states and excitation energies possible will alter the mass and charge distribution of fragmentation products from heavy target nuclei. Evaporation spectra are dependent upon whether the nucleus has a pancake or elongated shape. New phenomena that can be looked for are shock-waves in nuclear matter, collective effects in the development of intra-nuclear cascades and holes "punched-out" of nuclei. Such mechanisms affect a depression of the Coulomb barrier and differences in deposition energy.
2. Energy dependence of spallation products in nucleus-nucleus collisions. Program: ~3 years	This study would concentrate on the changes in the nucleon cascade and evaporation spectra below and above the thresholds for π, K and hyperon production.
3. Quasi-elastic scattering between heavy ions and nuclear structures. Program: ~1 year	Particle clustering in nuclei can be examined in detail by the use of high energy beams of ^{4}He, ^{12}C, etc. Work can extend early 184" cyclotron experiments on (α, 2α) reactions. Evidence for carbon clustering via (C, 2C) quasi-elastic scattering, oxygen clustering, etc. could be specifically sought.
4. Nuclear structure far from line-of-mass stability. Program: ~1 year (for initial investigation; could develop into long-term effort).	Preliminary Bevatron experiments on the fragmentation of heavy ion beams has revealed that it is likely that all isotopes (with $T_{1/2} \geq 20$ nsec) having mass numbers $A \leq A$ (beam projectile) are produced with velocities equal to the beam velocity at 0^{o} in the laboratory. Such

isotopes can be detected and uniquely identified. As beams heavier than A~40 become available, systematic studies of proton-rich nuclei will be of specific interest. Too, high energy heavy ion collisions with heavy target nuclei offer expanded opportunities to study the neutron-excess isotopes.

5. High momentum transfers in fragment production.

Program: ~1-2 years

Poorly understood are the mechanisms for production of nucleon fragments of high transverse momenta. Heavy ion beams will be used to investigate systematically the production of fragments with high transverse momenta, and the dependence on energy and mass of the projectile and mass of target nucleus. This work complements the high energy fragmentation experiments, described in I-2 above, that principally involve interactions having small momentum transfers.

III. Cosmic Ray Astrophysics

Experiment	Description
1. Fragmentation cross sections of heavy ions in interstellar matter. Program: Long term	The fragmentation cross sections of cosmic ray heavy ions with interstellar hydrogen and helium nuclei are of key importance to the determination of the primordial source composition and age of the cosmic rays. The lack of laboratory data on these fragmentation cross sections has become a principal impediment to progress in the area of cosmic ray research. All cross sections pertinent to the cosmic ray problem will be measured for energies $0.01 \lesssim E \leq 2.1$ GeV/nucleon. These data will be obtained as part of the high energy experiments described in I-2, and nuclear physics experiment II-1.
2. Calibration and development of cosmic ray detectors. Program: Short runs, but will be a long-term effort.	The availability of primary and secondary beams of stable (and unstable) nuclides will be used to improve the reliability and accuracy of cosmic ray detectors. Particular emphasis will be on improving methods for charge and isotopic mass analyses. The ability to carry out absolute calibration experiments will be important to the search for super heavy cosmic rays.
3. Cross sections for the loss and capture of 1K electrons at high energies. Program: One or two scheduled runs, about 160 hours each.	Cosmic ray nuclei that decay only by K-electron capture (i.e. 53 Mn, $\tau = 2 \times 10^6$ yrs.) can also serve as age indicators of the cosmic rays. Atomic capture cross sections are dominated by radiative capture at high velocities, and can be estimated from the inverse of the relativistic photoeffect. Loss cross sections can only be estimated from crude non-relativistic forms. A measurement of these cross sections at high velocities will enable one, in principle, to distinguish between disc and halo containment (i.e., density of matter traversed) of cosmic ray ions.

IV. Atomic Processes

Experiment	Description
1. Ionization processes of heavy ions in matter. Program: Several short experiments, ≈ 100 hrs total.	Experiments necessary to extend range-energy of heavy to high energies. Related phenomena to be studied are range straggle, rates of energy loss, effective charge, range extension owing to charge neutralization, and energy density deposited as a function of distance from the ionizing track.
2. Equilibrium and non-equilibrium electronic charges at high velocities. Program: Depending on scope and accuracy, several runs of ≈ 100 hrs over 1-2 yrs.	Cross sections for electron loss and gain for nuclei with energies above ≈ 10 MeV/nucleon will be measured. Bevalac will furnish heavy atomic nuclei to elucidate closed K-, L- and M- shell effects. Study will have immediate application to improve methods of heavy ion acceleration.
3. Radiation damage in materials. Program: Short, perhaps parasitic runs.	High rates of energy loss of heavy ions in matter lead to radiation damage important to studies of (a) (etchable) track formation in plastics and mica, (b) effects on solid state detectors, superconductivity, etc., and (c) lunar material.
4. Lamb-shift studies with heavy ions. Program: Long term	Direct test of relativistic quantum electrodynamics using highly stripped heavy ions. i) Hydrogen-like ions that can be produced at high velocities ($\beta \approx 0.95$) will be used to measure the Lamb shift by quenching in a motional electric field. ii) Hydrogen- and helium-like heavy ions at high velocities will be used to measure the lifetimes of states which decay by forbidden transitions (i.e., relativistic magnetic dipole, electric and magnetic quadrupole, etc.).

DRAFT

E. J. Lofgren
1/22/73

POLICY WITH RESPECT TO THE HIGH ENERGY HEAVY-ION PROGRAM

The Bevatron presently is open to all users in the field of high-energy particle physics. Experimental proposals are reviewed by a committee (3 from inside the Laboratory, 5 from without), and recommendations are made to the Laboratory Director. The same committee has an advisory role with respect to the development of new facilities and policies at the Bevatron. Presently about 60% of the Bevatron use is by experimenters outside the Laboratory, and 40% by inside users.

It is porposed that the same general principles--open to all users, schedule and policy guided by committees reporting to the Director, and encouragement of outside users--apply to the operation of the Bevatron and the Bevalac with heavy-ions for any purpose. The detailed implementation of the principles may differ in the various fields of experimentation to accommodate to the needs of the field.

Physical Science

The physical science aspects of the High Energy Heavy-Ion Program can be handled by the Bevatron Scheduling Committee with some modification of its membership. It is proposed that three of the eight members should be scientists with an interest in the field of heavy-ions. It is believed that this modification of the present committee is better than establishment of a separate one for heavy-ions because of the overlapping interests and functions, and to avoid problem of coordination of two separate committees.

Biological and Medical Sciences

The Biological and Medical Sciences differ so much from the Physical Sciences that it will be necessary to have a separate committee to advise in that area. It is proposed that a Heavy-Ion Biomedical Advisory Committee be formed. It should consist, initially, of 5 members--2 from within the Laboratory and 3 from without. It could be made larger in the future as necessary.

The Committee would be concerned with all biological, medical and radiological experimental programs done with Bevatron or Bevalac beams. It

would advise on the development of facilities, on scheduling procedures, on means to insure that the facility is open to outside users, and on means to gain the necessary support from funding agencies. The committee would alsp have a role--analogous to that of the Bevatron Scheduling Committee--in the actual scheduling process. The exact nature of that role remains to be worked out with the advice of the Committee when it becomes active. Due regard must of course be taken of the special nature of some biomedical programs, and especially therapeutic programs, as compared to physical research programs.

Brief Statement on History and Beam Capability of Berkeley SuperHILAC, Listing of Research Topics in Nuclear Chemistry and Physics

The original Berkeley Hilac when completed in 1957 consisted of a 600KV Cockroft Walton injecting into a two-section Alvarez linear accelerator; ions emerging from a "prestripper" section were raised in charge-to-mass ratio in a stripper foil before final acceleration in the "post stripper" section to a final energy of 10.3 MeV/nucleon. The original 3.2% duty cycle was raised to 25% with major changes in the RF system in 1964. Ions of He through Ne were available at intensities of several microamperes and Ar ions at 0.25 microampere level. This accelerator operated on a 21 shift/week schedule for research during most of the period 1965-71.

The Hilac was shutdown in February 1971 and rebuilt almost in its entirety into the SuperHILAC. The same scheme of two Alvarez linear accelerators separated by a stripper was retained but design was based on much lower charge-to-mass ratios for the ions in both sections, so that useable beams of much heavier ions could be developed. The machine has two injectors. The first is the old Cockroft-Walton upgraded to 800KV and retained for acceleration of ions up through ^{40}Ar. The SuperHILAC started operation in the fall of 1972 with this injector and by January 1973 has achieved performance superior to the old Hilac. Ion energies are continuously variable to 8.5 MeV/nucleon. The SuperHILAC, with the 800KV ion source, will serve as the injector for the BEVALAC project. A 3MV Dynamitron has been built as a second ion source for the SuperHILAC to supply ions of Kr, Xe and untimately of all ions between Ar and U. By January 1973 small beams of Kr had been accelerated and used in preliminary research but the Dynamitron was still not debugged and performing to specifications. Full operation is projected by summer 1973.

Nuclear Chemical and Physical Research Topics of Past 12 Years (partial list)

Synthesis of new elements: mendelevium (101), nobelium (102), lawrencium (103), rutherfordium (104), and hahnium (105).

Synthesis of ~80 new isotopes of transuranium elements.

Detailed study of α-decay and spontaneous fission decay properties of transuranium nuclei.

Coulomb excitation of nuclei.

Compound nucleus reactions, gamma-ray de-excitation of compound nuclei.

Angular momentum effects in heavy ion reactions.

Lifetimes of rotational states.

Nuclear isomerism.

Measurement of quadrupole and higher moments of nuclei.

Investigation of single particle and collective levels in nuclei.

Rotational bands in even and odd nuclei.

Coriolis effects in nuclei with very high angular momentum.

On-line studies of short lived alpha-emitting isotopes of elements 76-92; identification of 50 new isotopes.

Observation of transitions between electronic states in hydrogen like and helium like atoms of Si, S, and Ar.

Study of spontaneous fission isomers.

Search for new regions of nuclear deformation.

Properties of fission induced by heavy ions.

Recoil properties of reaction products.

Range-energy relationships for accelerated heavy ions.

Particle identifier studies of heavy ion reaction products.

Radiochemical study of heavy ion reaction products.

Research Topics to be Pursued at SuperHILAC

Search for new elements in predicted island of stability near element 114.

Development of physical techniques for on-line identification of atomic number, charge, decay mode and decay half life of reaction products.

Search for new elements 106-7.

An expanded program of Coulombic excitation studies: Possible observation of spins as high as 34.

Search for nuclear Josephson effect.

Study of quantum electrodynamics at high fields during transient existence of nuclei with atomic number up to 184.

Study of reaction mechanisms with all available off-line and on-line techniques including radiochemistry, γ-ray and x-ray measurement, particle identification, multiparameter experiments, etc.

New measurements of allowed and forbidden transitions between atomic states in hydrogen-like and helium-like stripped atoms of high Z elements.

Search for angular momentum limits to nuclear stability.

Study of nuclear fission.

Search for new modes of collective excitation of heavy targets and projectiles.

Range-energy relations.

Calibration of track registration characteristic of heavy ions in dielectric material.

Study of new nuclei far removed from stability.

Study of Coulomb barrier threshold behavior as related to shapes and deformabilities of target and projectile.

Study of one nucleon and multi-nucleon transfer reaction.

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LBL-1703

SUMMARY OF INTERNATIONAL PROGRESS ON SUPERCONDUCTING MAGNETS

William S. Gilbert

March 1973

Prepared for the U.S. Atomic Energy Commission
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SUMMARY OF INTERNATIONAL PROGRESS ON SUPERCONDUCTING MAGNETS*

William S. Gilbert

Lawrence Berkeley Laboratory
University of California
Berkeley, California

As presented at the 1973
Particle Accelerator Conference

February 28, 1973

Summary

Superconducting pulsed magnets for use in high field synchrotrons and storage rings and dc dipoles and quadrupoles for use in beam transport lines are reviewed. Operating and construction plans for the immediate future are presented.

Introduction

The largest scale use of superconducting magnets to date has been in the field of high energy physics. Ever since superconductivity was discovered by Kamerlingh Onnes in 1911, the concept of lossless electromagnets has attracted the attentions of a number of prominent physicists, metallurgists, and other specialists. The continuing advances in solid state and metal physics resulted in the discovery and development of hard, type II, high field superconductors in the 1950's. Several high field alloys and compounds were fabricated and in 1961, Kunzler at Bell Labs produced a 7.0 Tesla field in a solenoid wound with Nb_3Sn wire. Within two years a 10 Tesla field was produced with Nb_3Sn wire in a small bore solenoid.

Vigorous efforts were launched to build a variety of superconducting magnets since the benefits were obvious but the full extent of the difficulties were not. The first major difficulty was the brittle nature of the high critical field, high critical temperature superconductor Nb_3Sn, which made magnet fabrication difficult for small simple solenoids and not feasible for those magnets in which the fragile wires would be subjected to large forces. Flexible Nb_3Sn ribbon conductor was developed and the mechanical problem was thereby partially solved but at the cost of creating a conductor unstable against flux movement. Solenoids have been developed with fields as high as 150 kG using the ribbon conductors but larger magnets and saddle shaped windings have suffered badly degraded performance due to this flux jump instability. Diamagnetic currents in the relatively wide ribbon also make it difficult to construct high precision magnet fields -- magnetic field errors of less than one part in 10^3.

The ductile alloy NbTi is strong and easy to fabricate but has a lower critical field and temperature than Nb_3Sn. Early NbTi conductor showed degraded performance due to flux jump instability. The development of stable twisted multifilament NbTi - copper composite in 1968-1969 marks the beginning of the growing successful programs in accelerator and transport type magnet development. The relatively small apertures required in accelerators and beam transport lines result in the need for the highest possible current densities in order for the superconducting magnets to compete most favorable with the conventional room temperature alternatives. Extremely large volume magnets as are found in bubble chamber magnets are attractive on a simple electrical power saving basis. This power saving is not as dramatic with the smaller aperture accelerator magnets.

Superconducting magnets are only lossless at a constant magnetic field. A hysteresis loss occurs upon every field change so a pulsing field, as is intrinsic to a synchrotron, results in a cyclical or ac loss. For this reason pulsed magnets require more development effort than do dc magnets and so we consider them separately. Recently, storage rings have become of increasing physics interest so hybrid magnets of very slow pulsing rate have been studied.

Why Develop Superconducting Magnets?

As will be developed later in this paper, an impressive number (>10) of NbTi conductor magnets have operated at or above 40 kG peak field, both for pulsed and non-pulsed operation. Reliable operation of similar systems in the 40 - 60 kG field range can be confidently projected in the next few years. It seems appropriate to ask, at this time, what advantages are in prospect for the users of superconducting magnets to compensate for the trouble and expense of supporting this new technology. Table I lists some of the Pros and Cons of superconducting magnet systems vis a vis conventional magnets.

TABLE I - S.C. Magnets' Virtues

PROS	CONS
Zero power dissipation - dc	Requires liquid helium cryogenic system
Low power dissipation - ac	Losses are at 4.2°K (500 watts/watt)
High current density	- - - - - -
High field (20 - 100 KG) capability	- - - - - -
Compact magnets - less shielding	- - - - - -
Field stability - persistent mode	Field instability - flux jumps. Poor field quality- diamagnetic effects.
Economy - will cost less	But now costs more.
10^{-9}- 10^{-10} Torr vacuum- Cryopumping.	Requires extra vacuum system for thermal insulation.
New field - Improvements are likely.	Present magnets are well developed. We have enough troubles as it is.
Reduced scale of accelerators and beam-lines.	

With the exception of special advantages associated with high current density (25 kA/cm^2 at 5T) the chief potential advantages of superconducting magnet systems are reduced capital and operating costs and more compact accelerators and beam lines based on the higher available magnetic field. Beam lines have been studied by Meuser[1] and Smith and Haskell[2]. Meuser compared a complete experimental area for the 200 GeV accelerator and

* This work performed under the auspices of the Atomic Energy Commission.

replaced the 164 conventional magnets with equivalent superconducting magnets with peak fields of 40 kG. The capital plus the 10 year operating costs of both systems were the same within estimating error. Smith and Haskell compared only the capital costs of focusing elements for beams of 1-1000 GeV energy with the superconducting elements operating up to peak fields of 100 kG. They found that at the higher energies and the higher fields the superconducting costs were as much as an order of magnitude lower than the conventional. But at lower energies and fields of about 40 kG the costs were comparable.

Synchrotron and storage ring peak energies scale with peak magnetic field so the examples of higher energy accelerators at present sites through the use of superconducting accelerator magnets are numerous. Many feel that the present sites are as large as may be provided for the forseeable future so the only way to achieve still higher energy is through increased guide field. It also appears that the cost per GeV should be lower with superconducting magnets.

Nb_3Sn Ribbon Transport Magnets

Nb_3Sn in the form of a thin relatively wide ribbon has been produced by RCA (now CSCC), GE (now Intermagnetic General), CSF, and a few other companies on a smaller scale. A number of high field solenoids and Helmholtz coils have been built. A few special shape magnets for fusion research have been built as has a beam septum magnet at BNL. Our interest here is with dipoles and quadrupoles that have been built for beam transport. Table II lists this data.

All these magnets were badly degraded (50-75% short sample) due to flux jumping in the ribbon conductor and the peak fields were less than 50 kG which can be more reliably and cheaply achieved with NbTi conductor magnets. No laboratory reported plans to built transport magnets using the ribbon Nb_3Sn conductor.

One program to use an improved ribbon tape in fusion research is planned at Lawrence Livermore Laboratory[3]. This improved ribbon would incorporate a nickel instead of a stainless steel structural substrate to improve thermal conductivity and flux jump stability. Pure aluminum might also be used for improved dynamic stability. If these improvements succeed, a complex magnet winding with fields of 100 kG and current density of 7000 A/cm^2 is planned.

Figures 1 - 3 show some of the Nb_3Sn magnets listed in Table II. It should be pointed out that many

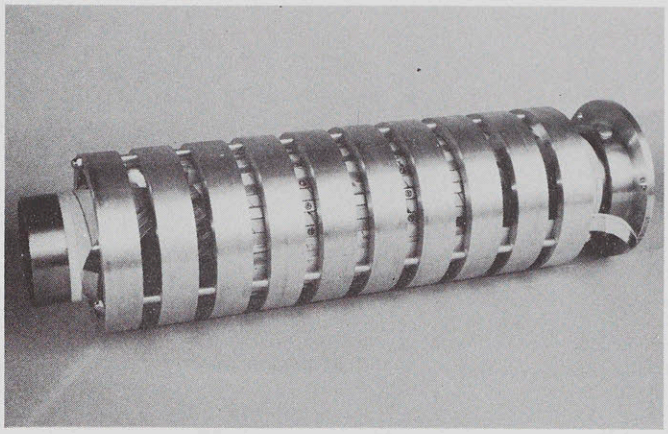

Figure 1 - IGC Dipole (Nb_3Sn)

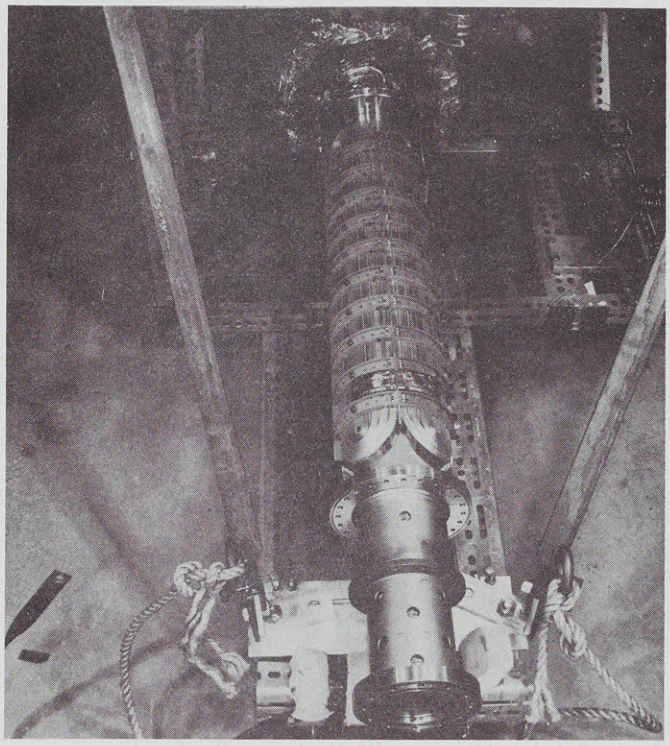

Figure 2 - BNL Quad (Nb_3Sn)

TABLE II - Ribbon Nb_3Sn Transport Magnets

Organization	Type	Bore Diam. cm	Length cm	Peak Field kG (Gradient kG/cm)	Stored Energy kJ	Date Tested	Warm Bore Cryostat	Comments
General Electric	Quad	7.2	20	26 (7.2)	3	1969	No	General Electric superconducting business is now conducted by Intermagnetics General Corp.(IGC)
	Dipole	7.2	20	21	4	1970	No	
BNL	Quad	10	60	32 (5.5)	19	1968-69	No	2 built.
	Dipole	9.5	100	43	60	1971	Yes?	Close fitting iron core in helium
Siemens for IEKP Karlsruhe	Quad	15.5	100	29 (3.5)	76	1970	Yes	Warm bore aperture = 12 cm.
Hitachi	Quad	6 ?	--	30 (10)	--	--	--	IGC Nb_3Sn tape.

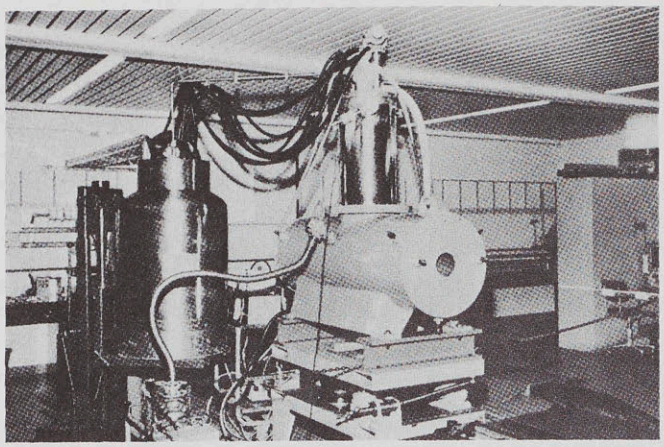

Figure 3 - Siemens (IEKP) Quad in Cryostat

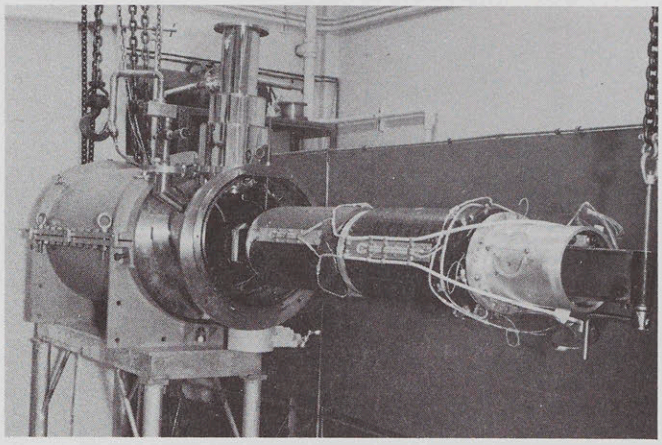

Figure 4 - LASL Quads - Cryostat

smaller, developmental, or unsuccessful magnets have not been listed in the Nb_3Sn table above nor in the NbTi tables to follow.

NbTi-Composite Transport Magnets - Quadrupoles

The early single core NbTi-copper conductor was flux jump unstable unless overly thick copper was used. Therefore, except in the case of solenoids, magnet performance was excessively degraded and average current densities were low. Transport magnets were successfully built soon after multifilament conductor was developed, and even more so after the roles of twisting and intrinsic stability were understood. In Table III we list a number of successful quadrupole transport magnets. Figures 4 - 6 illustrate some of the magnet systems appearing in Table III.

TABLE III - Composite NbTi - Quadrupole Transport Magnets

Organization Group	Winding Bore Dia cm	Length cm	Peak Field kG	G kG/cm	Stored Energy kJ	Date Tested	Warm Bore Cryostat	Comments
Oxford Inst. Co. - CERN	13	75	45	5.7	200	1970	No	Untwisted multifilament conductor.
Los Alamos Scientific Laboratory	20 (15 warm)	~40 (each)	40	3	40 (each)	1970	Yes	Doublet in 1 Cryostat. Persistent mode operation. Magnetic fields mapped. Possible beam line use 1973 (2 quadrupoles)
CERN								
Morpurgo	3	30	25	14.2	small	1970	Yes	In use for hyperon physics experiment for about 2 years. (2 quadrupoles)
	3	60	25	14.2	1 - 2	1970	Yes	
Asner-Leroy	13 (9 warm)	90	~40	5	25	1972	Yes	Close fitting, liquid helium temp. iron.
SACLAY	26 (20 warm)	68	45	3.5	670	1971?	Yes	Doublets used in Saturne physics experiment in 1972. Pion fluxes increased by factor of 2.6. (2 quadrupoles, O.G.A.I and O.G.A.II).
	36 (30 warm)	67	40	2.3	770	1972	Yes	
LBL	25 (20 warm)	63 (each)	45	2.8	190 (each)	1971 1972 (in cryo)	Yes	Doublet in single cryostat Bevatron beam line 1973. (2 quadrupoles)
NAL								
R. Fast Energy Doubler Group	10	300	~22 (12 at pole)	2.5	45	1972	Yes	Iron dominated magnetic circuit.
	10	300	[15-30]	[2-4]	--	[1973]	Yes (Cold)	High current density-- conductor dominated magnetic circuit.
Siemens for IEKP, Karlsruhe	6	30 for doublet	~20	3	small	1972	No	In helium-cold bore of proton linear accelerator. Iron core. Seven more doublets to follow.

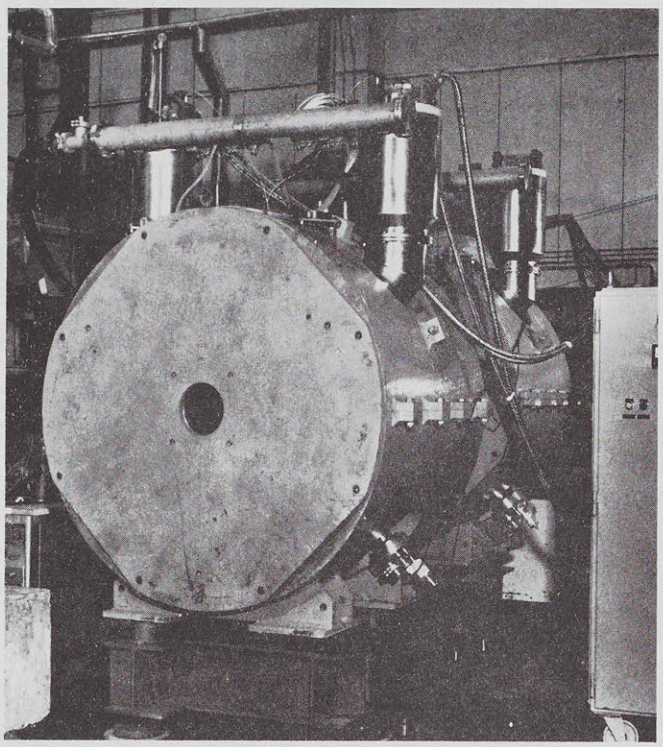

Figure 5 - Saclay Quads in Cryostats

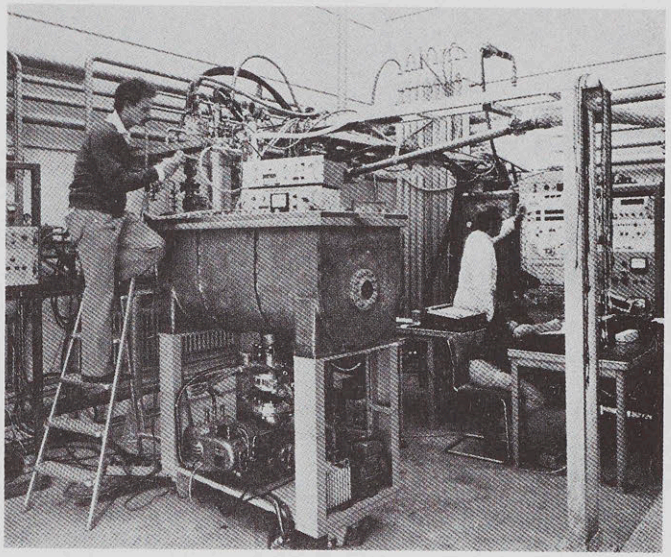

Figure 6. CERN Quad

NbTi Transport Magnets - Dipoles

Dipoles tend to be more difficult to build than quadrupoles since for equivalent sizes and peak magnetic fields, the forces and stored energy are greater in the dipole. Several successful dc dipoles have been built and more are planned in the immediate future. These are listed in Table IV. Figures 7 - 10 refer to some of these listed dipoles.

TABLE IV - Composite NbTi - Dipole Transport Magnets

Organization	Winding Bore Diam. cm	Length cm	Dipole Field kG	Stored Energy kJ	Date Tested	Warm Bore Cryostat	Comments
ANL	10 10	90 90	27 [35]	~50 [~80]	1972 [1973]	No No	Design field. Magnet finished--testing to begin Feb. 1973
BNL Danby	8.5 (Cold bore)	50	46	64	1972	No	Two 183 cm long dipoles are to be in service at the BNL 30 GeV beam line to produce an 8° bend about July 1973. Cold iron -- window frame type construction.
"	8.5 (Cold bore)	183	[40]	[175]	[1973]	Yes (cold bore)	
CERN Kesseler	13.2 (warm)	195	34	370	1972	Yes	Beam operation at CERN-PS in summer 1973
LBL	10	~35	35	25	1969	No	Cold iron flux return.
	29 (20 warm)	83	40	655	1971 1972	No Yes	Installed -- Bevatron Beam Line -- 1973 warm iron flux return.
NAL R. Fast	5 x 13 (warm)	300	25	112	1972	Yes	76 cm long model tested in 1970.
"	20 x 60 (warm)	180	18	600	1972	Yes	Analysis magnet -- to be operated 1973. 2 large gap magnets to be built in 1973.
"	10 (warm)	300	~23	~120	1971	Yes	35 kG design. Fabrication by Airco - Temescal. Warm iron flux return.
Energy Doubler Group	7.6 x 12.7 (Cold bore)	300	[30]	--	[1973]	Yes (Cold bore)	High current density coils planned. Warm iron flux return
	7.6 x 12.7 (Cold bore)	300	[45]	--	[1973]	Yes (Cold bore)	High current density coils planned. Warm iron flux return

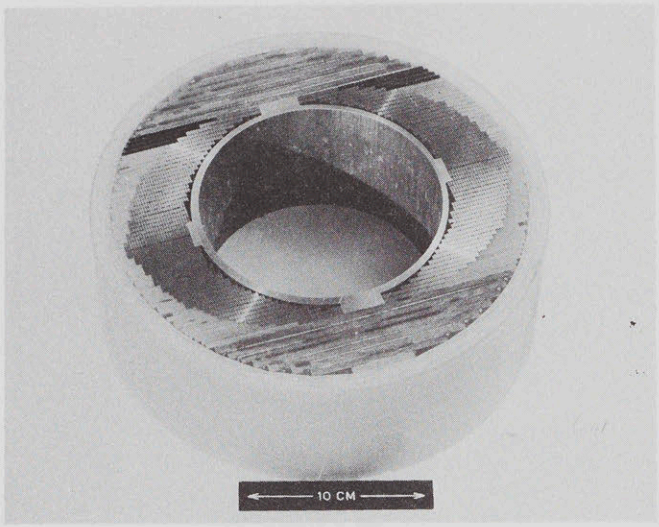

Figure 7 - CERN Dipole

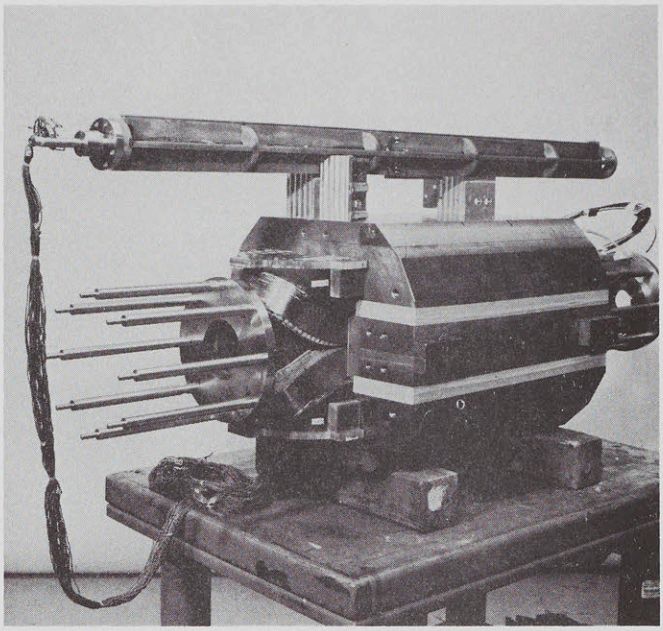

Figure 9 - BNL Dipole

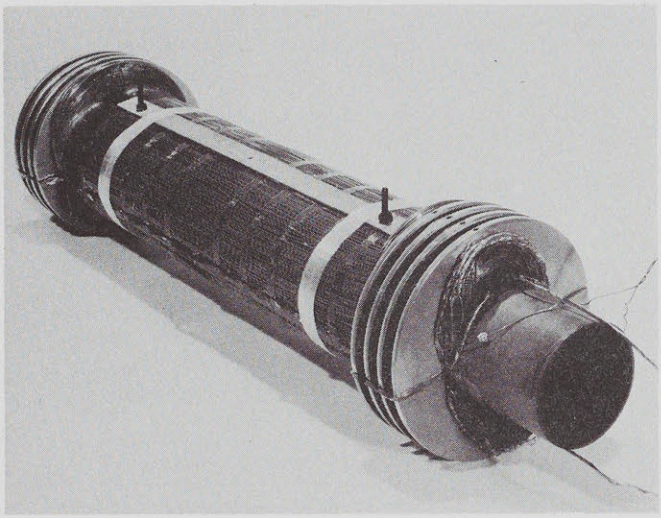

Figure 8 - ANL Dipole

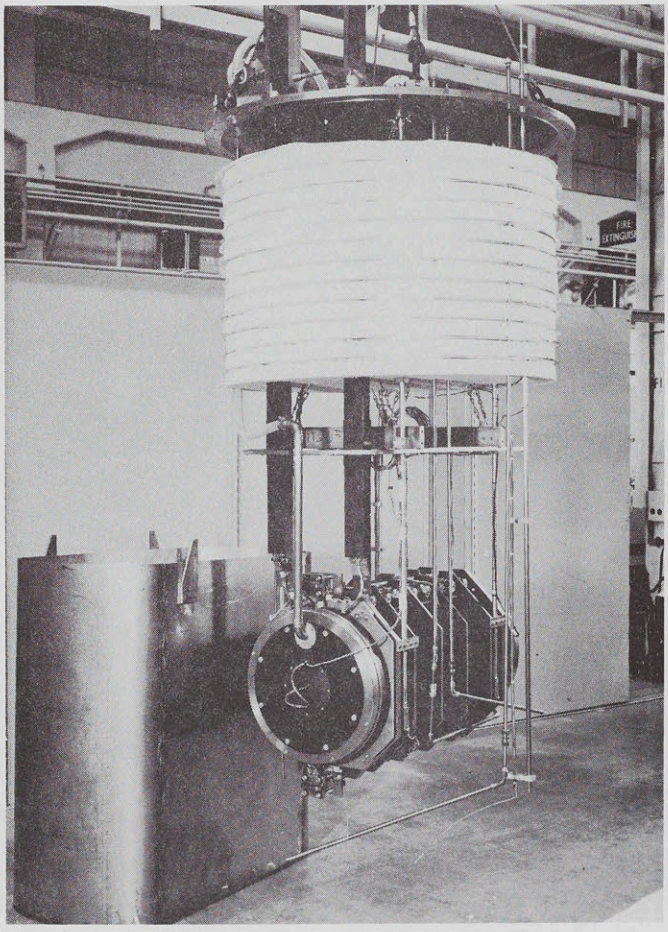

Figure 11 - RHEL AC4

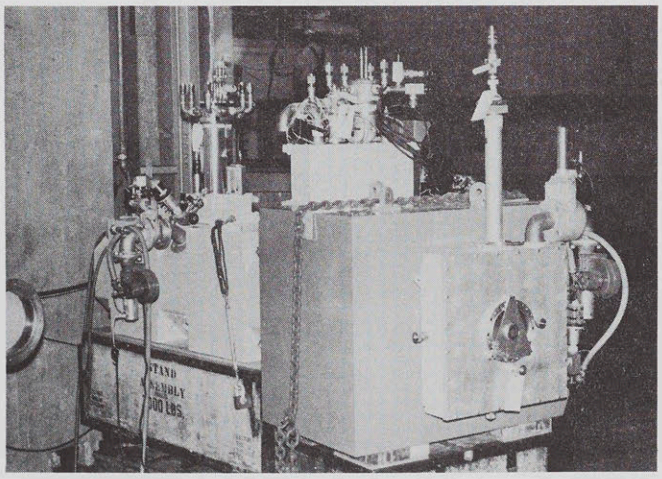

Figure 10 - LBL Dipole and Quad Doublet

Pulsed Accelerator Magnets

NbTi filaments of the smallest possible dimension (test magnets have been made containing 4-5μ diameter filaments) have been developed in order to reduce the hysteresis loss associated with pulsed magnets. Although the technical problems associated with the building of low loss, high field, pulsed dipoles are severe, impressive progress has been made -- in large part due to considerable efforts by a number of major accelerator laboratories, both in this country and in Europe. In fact, higher dipole fields have been achieved in pulse magnets than in dc transport dipoles.

Special attention is called to recent results on Rutherford's AC4 pulse dipole which reaches 50.1 kG and pulses to 49 kG with a 2-second rise time or 4-second cycle[4]. Throughout the entire excitation range the sextapole component of magnetic field is less than 5×10^{-3} times that of the dipole. A number of other successful pulsed magnets are listed in Table V[5]. Figures 11 - 14 illustrate some of these magnets.

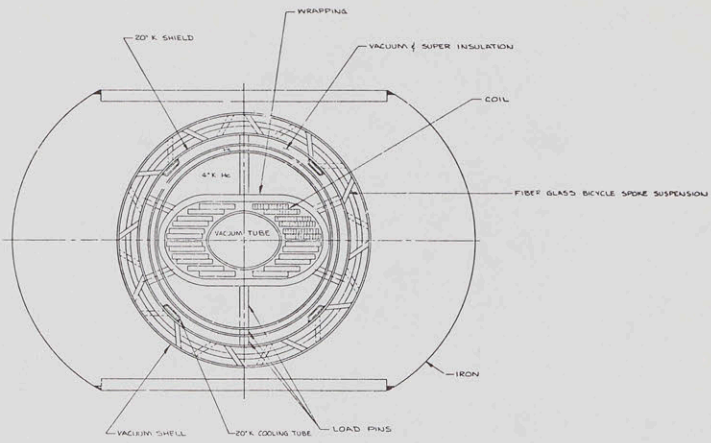

Figure 12 - NAL Doubler Magnet

TABLE V - NbTi Pulsed Dipoles - Accelerator Oriented

Organization	Winding Bore Dia. cm	Length cm	Dipole Field kG	Stored Energy kJ	Iron Flux Return	Minimum Rise Time	Date Tested	Warm Bore Cryostat	Comments
BNL	5	35	41	6	Yes	Very slow 50-100s	1972	No	10 dipoles tested - various conductors.
	8	90	[40]	[38]	Yes	" "	1973	No	2 identical magnets Isabelle Program
	8	290	[40]	[~120]	Yes	" "	[~1974]	Yes	Isabelle Prototypes. Metal impregnated cable
Karlsruhe IEKP	4 x 8	40	40	- -	Yes	Slow 10-20s	1973	No	DT - Race track coils. Upturned ends. InSn soldered cable
	8	140	[45]	[128]	Yes	" "	April 1973	?	D2a - Cos θ coils. InSn soldered cable
	8	[140-280]	[45]	[150-300]	Yes	Med. 5-10s ium	[1974]	Yes	D2b-D3 magnets in design stage
LBL	7.5	40	39	22	Yes	Very fast 0.5s	1972	No	8 dipoles tested in series.
	7.5	40	[45]	[29]	Yes	" "	April 1973	No	2 "identical" dipoles uniformity test.
	[10-14]	[100-200]	[45]	[>100]	Yes- cold or warm	" "	[1973 - 1974]	Yes	In design stage.
NAL	5	90	27	20	No	Very slow >30s	1972 - 1973	No	Energy Doubler program.
	3.8	30	30	6	No	Very slow >30s	1972 - 1973	No	
	5.5	90	[40-45]	[20-40]	Yes	Slow ~30s	[Mid-1973]	Yes (Cold)	4 magnets in this group
	5.5	600	[45]	[180]	Yes	Slow ~30s	[Late 1973]	Yes (Cold)	1 magnet in this group.
	5.5	600 each	[45]	[180]	Yes	Slow ~30s	[1974]	Yes (Cold)	10 magnets in this group.
RHEL	10		39	58					
	8	40	45	--	No	Very fast 1s	1971 1972	No	AC 3.
	9	50	50	82	Yes	" "	1972	No	AC 4.
	[9 - 10]	[100-200]	[45]	>150	Yes	" "	[1973 - 1974]	Yes	AC 5.
SACLAY	10	50	[60]	[280]	Yes	Med. 5-20s	Early 1973	Yes	MOBY
	11	150	[50]	[~700]	Yes	" "	[1973 - 1974]	Yes	ALEC

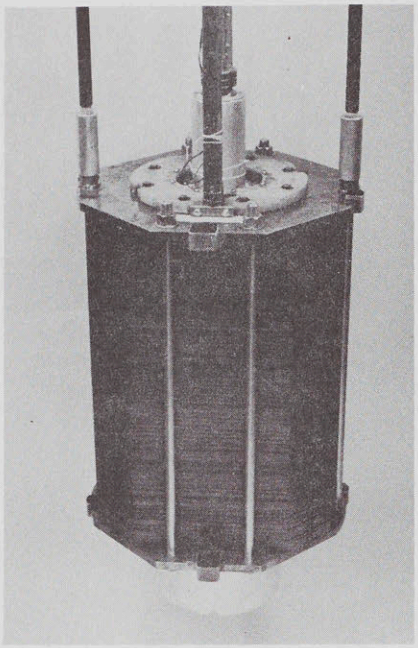

Figure 13 - LBL Pulse Dipole #8

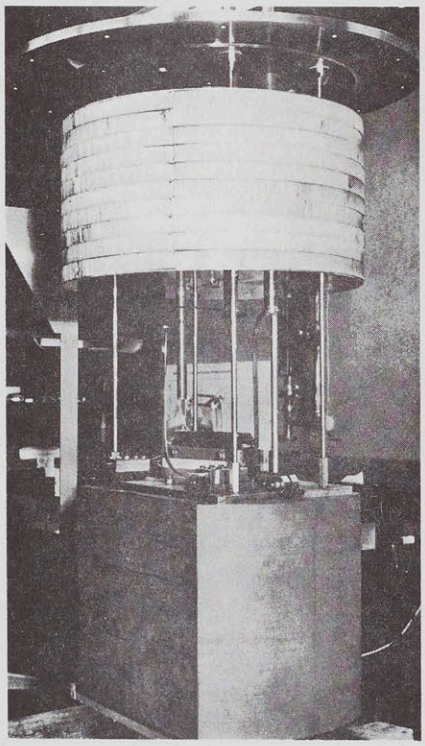

Figure 14 - IEKP DT Dipole

Evolutionary Development of Superconducting Magnet Systems

Although long range predictions are risky, superconducting projects one to two years in the future are already in the design or authorization stage due to the usual lead times. Tables III, IV, V contain the details of several ambitious transport and accelerator magnet programs. There is relatively little overlap in the detailed specifications since each laboratory's goals are different. The following similarities exist:

1. No laboratory is using ribbon Nb_3Sn -- All are using twisted mulifilament NbTi.
2. Magnet construction and testing is continuing. Degradation in performance still occurs. Field quality is being measured and improved.
3. Cryostat and cryogenic engineering development is being emphasized since these aspects generally lag the magnet development.
4. Long time and large scale operations of superconducting magnet systems are planned in order to move this technology from the magnet laboratory to the accelerator experimental beam area and to the accelerator itself.
5. Peak usable fields in the NbTi magnets will gradually rise from the present 40 kG to 60 kG in a few years.
6. Multifilament high field superconductors, such as Nb_3Sn and V_3Ga, might allow accelerator and transport magnets to operate at fields of 60 - 100 kG in 5-10 years.

Acknowledgements

I wish to extend my thanks to the superconducting magnet fraternity around the world who supplied me with their most recent results, plans, drawings and photographs. In order to make the comparisons that appear in the various tables, it was necessary to calculate some quantities that were not supplied -- any errors so generated are mine. All of the photographs in this paper were supplied by the laboratory that built the particular magnet. Many excellent photographs could not be used due to space limitations.

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Private communications from the various laboratories were received, Jan.-Feb., 1973.
ANL- J. R. Purcell; BNL - W. B. Sampson, G. Danby; CERN - G. Kesseler, M. Morpurgo, D. Leroy, A. Asner, P. E. Hanley (Oxford Inst.); IGC - C. H. Rosner; Karlsruhe (IEKP) - W. Schauer, M. A. Green; LASL - W. V. Hassenzahl; NAL - R. W. Fast, P. J. Reardon, B. P. Strauss; RHEL - J. H. Coupland; SACLAY - J. Perot.

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TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720

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LBL-1714
(SLAC-PUB-1219)

PEP LATTICE DESIGN

R. Bangerter, A. Garren, L. Smith,
P. Morton and J. Rees

March 1973

Prepared for the U.S. Atomic Energy Commission
under Contract W-7405-ENG-48

LBL-1714

PEP LATTICE DESIGN

R. Bangerter, A. Garren, and L. Smith

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
and

P. Morton and J. Rees

Stanford Linear Accelerator Center
Stanford, California 94305

Summary

Details of the current lattice design for PEP, the proton-electron-positron colliding beam system[1] will be described. This system allows collisions of protons up to 150 GeV with electrons or positrons up to 15 GeV, by storing the proton beams in a superconducting storage ring and the electrons or positrons in a concentric conventional ring, and allows collisions between electrons and positrons in the same ring up to 15 GeV.

Introduction

This design evolved from the concept put forward by Pellegrini et al.[2] which proposes the achievement of high luminosities by use of single short bunches of a relatively modest number of particles in each of the colliding beams. The performance goal of the present design is the attainment of a luminosity of about 10^{32} cm^{-2} sec^{-1} for center-of-mass energies up to about 100 GeV in proton-electron collisions.

The machine consists of two concentric rings, separated vertically except in four interaction regions designed with zero, or perhaps small, crossing angles. See Fig. 1. In plan view the two rings look nearly identical, each consisting of four 200-meter-radius arcs separated by four 200-meter-long straight sections. For electron-positron experiments both bunches would counter-circulate in the e-ring, while for proton-electron or proton-positron experiments protons would be stored in the p-ring and either electrons or positrons in the e-ring, with suitable choice of polarities in the magnets.

In the normal single-bunch mode envisioned, two opposite interaction regions would be used simultaneously; in a two-bunch mode all four could operate at once with the same total luminosity and RF power, provided that twice the total number of protons and the same total number of electrons were stored.

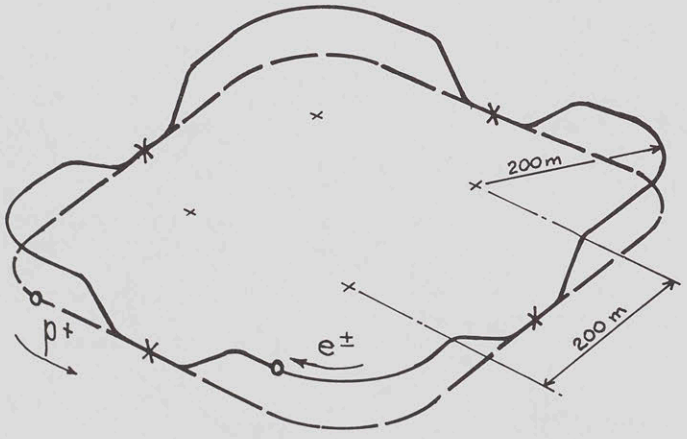

Fig. 1. Schematic diagram of PEP ring configuration.

For protons with energies between 70 and 150 GeV interacting with 15-GeV electrons, we expect a luminosity of 10^{32} cm^{-2} sec^{-1} at each of the two collision points, and a decline at lower proton or electron energies. A luminosity of 0.6×10^{32} cm^{-2} sec^{-1} is predicted for electron-positron collisions at 15 GeV.

Design Considerations

The principal parameters affecting performance in the proton-electron mode at peak energies are listed in Table I, the beam dimensions being determined by the emittances given in Table II. The number of protons used is in the range of existing synchrotrons, and the number of electrons corresponds to a reasonable level of radiated power. Of course the short bunch lengths required imply high peak currents, which fact makes imperative a careful theoretical and experimental study of collective phenomena.

It has become apparent to us that the performance of a PEP-type device will probably be limited by the beam-beam interaction rather than by practical limitations on particle phase-space density. This interaction sets a limit to the allowable transverse particle density, so the interaction cross section must be carefully adjusted. To obtain a suitable area we have used normalized proton emittances much larger than those available from AG synchrotrons, and in fact comparable to those measured in the Bevatron. The electron horizontal emittance is determined by lattice properties and energy, and the vertical emittance by horizontal-vertical betatron coupling. Even though we have employed maximum coupling, the electron area is uncomfortably small.

A finite crossing angle increases effective cross-sectional area, but this approach was discarded for the basic configuration since more stored particles

Table I. Peak Energy p-e Operating Parameters

		p		e±	
Momentum (maximum)	P	150		15	GeV/c
Number of Particles	N	5×10^{12}		5×10^{12}	
Luminosity (each int. point)	$\mathcal{L}$		10^{32}		$cm^{-2}s^{-1}$
Number of RF Bunches	n_B		1		
Length of Each Interaction Region	L_I		20		m
Crossing Angle	2δ		0		deg
Interaction Point Parameters:					
beta-function - horizontal	β^*_x	4.19		0.6	m
- vertical	β^*_z	0.45		0.11	m
dispersion - horizontal	η^*_x	-0.20		-0.96	m
- vertical	η^*_z	0		0	m
Interaction Point Amplitudes:					
bunch length	σ_l	13		1.6	cm
momentum spread	$\sigma_{\Delta p/p}$	1.2×10^{-3}		1.15×10^{-3}	
dispersion width	σ^*_{xp}	0.024		0.11	cm
betatron width	σ^*_{xb}	0.140		0.026	cm
total width	σ^*_x	0.142		0.113	cm
total height	σ^*_z	0.026		0.011	cm
Beam-Beam Tune Shifts:					
horizontal	$\Delta\nu_x$	0.023		0.019	
vertical	$\Delta\nu_z$	0.024		0.025	

Table II. Orbit Parameters

		p-ring	e-ring	
Betatron frequencies - horizontal	ν_x	23.25	31.25	
- vertical	ν_z	15.25	27.25	
Phase advance-normal cells	$\mu_x/2\pi$	80.2	79.7	deg
	$\mu_z/2\pi$	75.8	77.5	deg
Transition energy	γ_t	20.7	28.3	
Beta-function max.-cells	β_{max}	28.5	28.5	m
Dispersion maximum-cells	η_{max}	1.20	1.22	m
Beta-function max.-straight	$\bar{\beta}_x$	1047	2110	m
	$\bar{\beta}_z$	3417	1879	m
Dispersion maximum-straight	$\bar{\eta}_x$	-0.31	-6.94	m
Normalized Emittances/π				
$\epsilon_x = 6\sigma_{xb}\,\sigma_{x'b}\,\beta\gamma$ (95% of beam)	ϵ_x	0.045	2.033	cm-rad
σ_{xb} = rms betatron ampl.	ϵ_z	0.015	2.033	cm-rad
$\epsilon_\ell = 6\sigma_\ell\,\sigma_{\beta\gamma}$	ϵ_ℓ	15.	386	cm
Injection				
Assumed injection energy	E_i	5	15	GeV
Momentum spread	$\pm\Delta p/p$	10^{-3}	0.75×10^{-3}	
Betatron amplitudes*-horiz.	a_{bet}	4.13	1.18	cm
vert.	b_{bet}	2.69	1.19	cm
Synchrotron amplitude	a_s	0.12	0.12	cm
Proposed apertures - horiz.	a	5.5	2.5	cm
- vert.	b	4.0	2.5	cm
Maximum apertures in insertions at 70 GeV, 15 GeV:	$\bar{a}$	12.	12.	cm
	$\bar{b}$	14.	12.	cm

*For protons the beam radii used for aperture are $\sqrt{6}\sigma$, for electrons 6.5σ is used, for a quantum lifetime of 10^5 sec at 15 GeV.

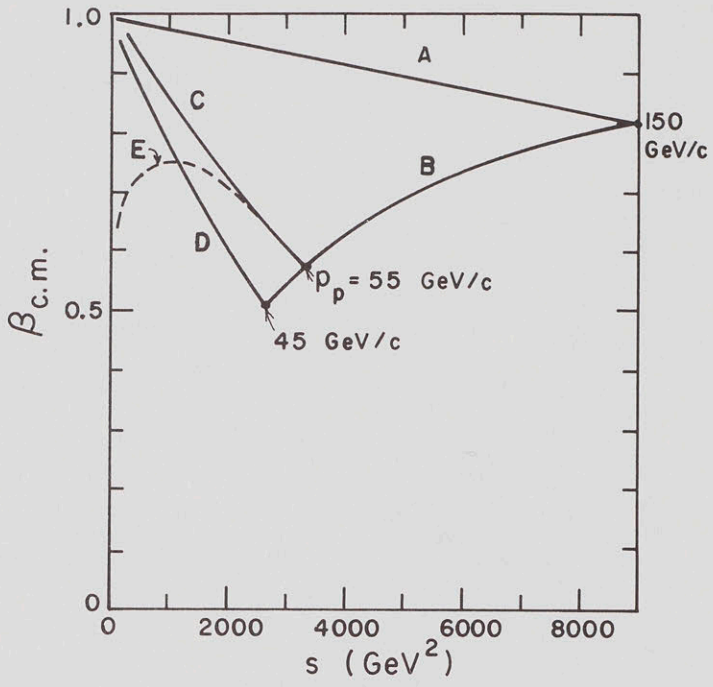

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Fig. 2. Values of Center-of-mass energy squared (s) and velocity ($\beta_{c.m.}$) accessible with synchronism of bunches.

Curves A: E_e varied.

B: E_p varied.

C: s_{min} determined by aperture needed for injection.

D: s_{min} with 2-cm extra aperture width.

E: adjustable dog-leg in p-ring.

are required for the same luminosity--too much more, in our opinion, if common quadrupoles are to be avoided--and the experimental configuration becomes more complicated. Instead, the minimum β-values have been increased substantially from the 15 cm suggested in Ref. 2 for protons and the 5 cm suggested for electrons, and in addition horizontal dispersion has been introduced. With this combination of measures we have limited the linear tune shifts $\Delta\nu_x$ and $\Delta\nu_z$, which measure the strength of the beam-beam interactions, to values below 0.025, a number found to be sufficiently small in electron storage rings. However, it should be noted that recent results suggest that this value may be pessimistic for electrons, and there are theoretical grounds to suspect it may be optimistic for protons. We thus obtain the operating parameters of Table I which give the desired luminosity of 10^{32} cm^{-2} sec^{-1}, with reasonable apertures and RF requirements.

In the lattice as presented, large β-values in some quadrupoles lead to high natural chromaticity ($pd\nu/dp$). The presence of dispersion in these quadrupoles makes it possible to remove the chromaticity with nearby sextupoles, but the sextupoles cause serious nonlinear effects. Modifications will be made to correct this condition.

For electron-positron experiments at 15 GeV, we contemplate operating with electron parameters similar to those of Table I, except that there would be 2.5×10^{12} particles in such beam, the same total radiated power, and a luminosity of 0.6×10^{32} cm^{-2}sec^{-1}.

The range of accessible operating energies and the corresponding luminosities has not yet been completely mapped out. However, we plan to cover the proton energy range from about 70 to 150 GeV with 15-GeV electrons or positrons at full luminosity, and complete parameter sets are now in hand for both ends of this range. (We have also calculated quadrupole settings for proton injection and acceleration.) The procedure proposed is to assume that proton emittance varies inversely with momentum, and to let the proton β_x^* and β_z^* vary directly. In this way the beam sizes, tune shifts, and luminosity remain constant. Below 70 GeV one can no longer decrease β^* without increasing quadrupole apertures in the nearest doublet, above those proposed here, since these vary as $(\beta^*)^{-1}$.

For different proton energies it is necessary to change the closed-orbit path length to maintain synchronism between the two colliding bunches. This will be done by varying the ratio of magnetic field to momentum to change the radial position of the proton bunch. Because the proton beam width at injection is larger than it is at the experimental operating energies, there will be sufficient aperture available to maintain synchronism between 55 and 150 GeV. (See Fig. 2). A further decrease would require provision of extra aperture or lattice changes. Changes of electron energy can also be made in order to alter the center-of-mass energy; these do not entail synchronism problems, but will require selection of other interaction point parameters.

Description of the Lattice

In order to simplify the description we shall treat separately the periodic structure of normal cells that comprises most of the circular arcs, and the matched insertions that are composed of the (horizontally) straight sections and adjacent portions of the arcs. The orbit lattice and parameters are summarized in Tables II and III.

A. Normal Cells

The central portion of each arc is made up of 14 identical separated function FODO cells, with the

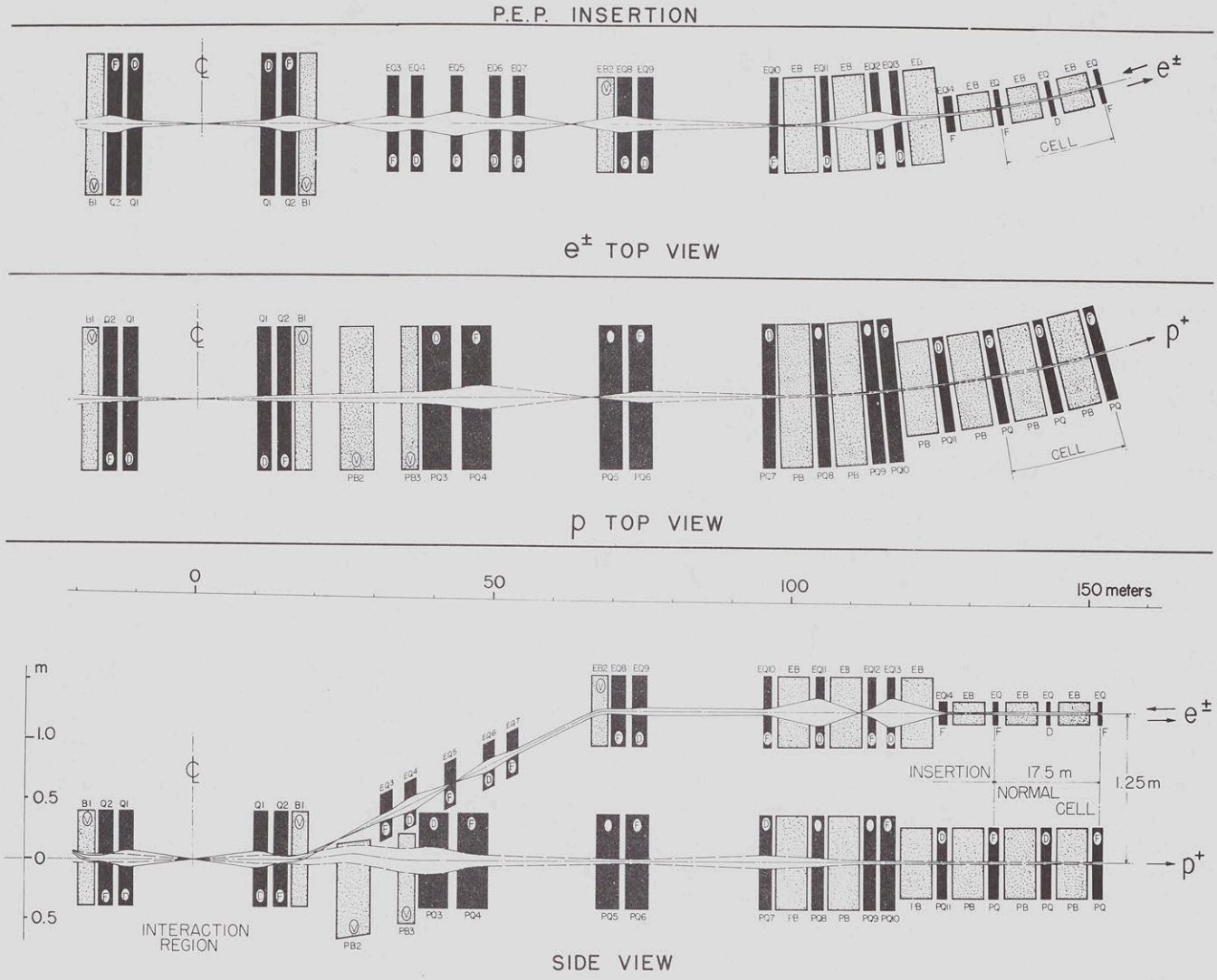

Fig. 3. Diagrams of insertion structure. Quadrupoles are dark, dipoles shaded. Beam profiles represent 70-GeV protons and 15-GeV electrons.

Table III. Lattice Parameters

		p-ring	e-ring	
Total Radius	R	327	327	m
Gross Radius Circular Arcs	R_n	200	200	m
Straight Section Length	L_S	200	200	m
Bending Radius	ρ	125	125	m
Magnetic, Field, Peak	B_o	40	4	kg
Gradient in Cell Quadrupoles	G	450	106	kg/m
Number of Superperiods	N_p	4	4	
Total Number of Cells	N_{CT}	72	72	
Number of Normal Cells	N_C	56	56	
Cell Length	L_C	17.5	17.5	m
Dipole Length		5.45	5.45	m
Quadrupole Length		1.70	0.70	m
Length of Cell Drifts		0.80	1.30	m
Vertical Separation of Rings		1.25		m

elements of the electron arc directly above the corresponding elements of the proton arc. One normal cell is shown in Fig. 3, to the right of the insertion structure.

The separated function configuration was chosen to insure positive damping in all three modes of oscillation for the electrons, to simplify construction of the superconducting magnets, and to insure flexibility in manipulation of the operating point. The last feature is particularly important because of the need to conserve aperture by moving into the low-β configuration only after the protons have been accelerated and their amplitudes decreased.

Having decided on a separated function lattice, a FODO focusing structure was chosen for the normal cells, since this provides the most efficient use of azimuthal space for bending and focusing.

The cell length results from a compromise between a desire for high proton energy, high electron emittance (to moderate the beam-beam effect), and low electron radiated power on the one hand and for small aperture and low RF overvoltage requirements in both rings on the other hand. The former considerations call for long cells and the latter for short cells.

B. Insertions

Figure 3 shows the right half of the symmetric insertion structure and Table I gives beam properties at the interaction region center point proposed for p-e collisions at 150 and 15 GeV respectively, with zero crossing angle. The beam envelopes shown in Fig. 3 correspond to 15-GeV electrons and 70-GeV protons, the lowest energies contemplated for experiments at full luminosity. This combination sets the aperture requirements in most of the insertion magnets since,

Table IV. Radiofrequency Systems*

		p-ring	e-ring	
Radiofrequency	f	146	350	MHz
Harmonic Number	h	1000	2400	
Power Dissipated in Cavities		5	1	MW
Power Radiated by Beam			4.2	MW
Peak RF Voltage	$\hat{V}$	93	51	MV
Quantum Lifetime			1	day
Total Shunt Impedance		2000	2500	MΩ
Total Accelerating Cavity Length†		150	100	m

*For p-ring, only the 3rd stage system, used during p-e experimentation, is tabulated.

†Includes all three proton RF systems.

as mentioned above, injection and acceleration would be carried out without the sharp focus at the interaction point.

There is a clear region (free of magnets) of ±10 meters for experimental apparatus at the interaction regions. The two beam lines are separated by the vertical bending magnet B1, the electrons rising to their ring 1.25 meters above, and the protons returning to the elevation of the interaction point under the action of PB2 and PB3 to reenter their ring.

The focusing characteristics of the insertions are dominated by the sharp focus at the low-β interaction point and the first doublet to which the beam freely expands. For the electrons the first doublet is Q1, Q2, but for the protons the first effective doublet is PQ3, PQ4, since the electron doublet has little effect on the relatively high-momentum protons. The first doublet arrests the beam-widening, and together with the succeeding quadrupoles to the right it provides an exact match to the proper beta-function and dispersion values of the normal cells. A small vertical crossing angle may be produced by adding a vertical dipole to the electron insertion above PB2.

The first electron doublet Q1, Q2 produces a focus in the electron beam at the position of the proton vertical septum magnet PB2. The vertical dispersion η_z introduced by the vertical bends is removed in the electron insertion by adjusting EQ3, EQ4 so that η_z is zero in the center of EQ5 and by making the segment between B1 and EB2 symmetric about EQ5 in its focusing pattern. In the proton beam, η_z is equal to the vertical beam displacement from the interaction region level through the dog leg between B1 and PB3, and hence returns to zero after PB3.

For p-e^+ collisions the polarities of the vertical bending magnets and of all e-ring quadrupoles are reversed so that the e^+ and e^- beams are identical; the proton beam bends downward in the dog leg but is otherwise unchanged, although slight tuning changes must be made due to the reversal of polarities in Q1 and Q2.

The portion of the insertion structure immediately to the left of the first normal cell resembles two normal cells, at least with respect to the horizontal bending. However, the quadrupoles differ in length and gradient, since they function as part of the matching structure of the insertion, and one of them has been replaced by a doublet (PQ9, 10 and EQ12, 13).

Adequate space for RF and injection systems is provided to the right of PQ4 and PQ6 in the p-ring, and to the right of EQ7 and EQ9 in the e-ring.

Computations

Choice of the interaction point parameters was aided by the interactive computer program SHINE. The lattice design was carried out in a manner similar to that used for SPEAR.[3] We first designed the cells using program SYNCH,[4] then the insertions using an interactive version of TRANSPORT,[5] and again SYNCH to obtain orbit functions through the complete ring. This procedure is iterated to obtain reasonable ν-values. The insertion was designed by starting at the interaction point with the desired orbit parameters, and ending at the center of the first F-quadrupole of the normal cells. At that point six conditions are imposed to match the orbit functions to the cells.

Acknowledgements

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TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720

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(SLAC-PUB-1220)

PROTON-ELECTRON-POSITRON DESIGN STUDY

The LBL-SLAC Storage Ring Study Group
(Presented by Tom Elioff)

March 1973

Prepared for the U.S. Atomic Energy Commission
under Contract W-7405-ENG-48

LBL-1746

PROTON-ELECTRON-POSITRON DESIGN STUDY*

The LBL-SLAC Storage Ring Study Group+

Presented by
Tom Elioff

Lawrence Berkeley Laboratory
Berkeley, California

Introduction

The PEP study, a joint effort by SLAC and LBL scientists, has been directed primarily toward the design of a high energy proton-electron and electron-positron colliding beam system with center-of-mass energies of ∿100 GeV and 30 GeV, respectively. A device with this capability would extend greatly the frontiers for the investigation of elementary particle phenomena.

High-Energy Physics has a continual appetite for experimentation at higher energies as each energy step in the past has provided new discoveries, new theories, and new puzzles in the elementary particle regime. Further steps now appear to be very difficult. It has become increasingly clear that the next large advance in experimental capability cannot be undertaken by the methods of 'conventional' accelerators from the financial viewpoint. Thus it is believed that devices such as PEP offer a way to achieve the necessary scientific advances within the present constraints.

This general outlook may appear optimistic at the present time; however, it is necessary that we strive to maintain a balance between our present needs and future programs. The AEC has stressed in its report[1] to the JCAE that new high-energy facilities are vital to the total program viability and are essential ingredients to scientific progress, to the development of new technology, and to the opening of new avenues of research. The intent of this response is at least promising.

We should not lose perspective with regard to the time element--that is--we are presently in the stage of development for the next generation of high-energy storage rings which is comparable to the early stages of the 200 BeV Design Study. In this regard, the present study is consistent with the time scale involved both for successful authorization and responsible technical development which would insure a successful operating device.

History

The idea for PEP sprang from considerations for higher energy electron-positron (e^+e^-) colliding beam devices. In the first-order optimization of an e^+e^- system[2] beyond SPEAR, the bending magnets were operating at very low fields (∿4kG). Mel Schwartz pointed out that, with conventional magnets, a proton ring with nearly five times the electron energy could be placed in the same enclosure. This resulted in the original consideration for PEP[3] that was presented at the 1971 International Accelerator Conference by Pellegrini, Rees, Richter, Schwartz, Möhl, and Sessler.

Both experimentalists and theorists in particle physics at LBL and SLAC were highly enthusiastic regarding the implications of such a device and its significant potential in weak and electromagnetic interactions. The overall scale of a project of this type was appropriate such that both laboratories could contribute significantly, and an informal joint study was founded.

The first step was a physics study originally headed by G. Chew and S. Drell to clarify the physics objectives and the feasibility of experiments to obtain these objectives. The results[4] were overwhelmingly encouraging and provided added impetus to move forward with the conceptual design of the PEP storage ring system. As a result, a sub-group of accelerator physicists and engineers from both SLAC and LBL has been working toward the design goals. There are many problems yet to be resolved; however, we will try to indicate the direction we are now headed and some of the physics projections.

PEP System

The present PEP design has evolved to the two-ring configuration shown schematically in Fig. 1.

The top ring is the electron (or positron) magnetic structure that is designed for an energy capability of 15GeV. The lower ring is a superconducting system which would contain protons up to 150 GeV. The configuration has four-fold symmetry with four straight sections and hence a minimum of four interaction areas.

The electron energy of 15 GeV was determined to first order by matching the e^+e^- available energy to that which might ultimately be available in pp collisions at NAL. The size of the ring is then determined by keeping the power radiated by the electron beam to a level that is considered commensurate with a practical RF system. This leads to an overall size slightly greater than a mile in circumference, or about 1/4 of the NAL ring size. A conservative value of 40 kG for the dipoles of the proton lattice then obtains the projected proton energy of 150 GeV.

Because of the variety of experimental possibilities and the long time interval for some experiments, a minimum of four interaction areas is considered necessary. There could be multiple crossings within one or more of the insertion regions, but this will be reconsidered at a later time. In the normal mode all of the particles in each ring are concentrated in a single short bunch in order to optimize the luminosity while minimizing the number of stored particles. As illustrated in Fig. 1, the electron (or positron) bunch and the proton bunch collide every turn in each of the two opposite low β interaction points. It is also possible to operate in a two-bunch mode in which all four interaction areas could be used simultaneously with the same total luminosity and RF power, provided that twice the number of protons and the same number of electrons were stored.

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* Work supported by the U. S. Atomic Energy Commission

+ M. Allen, R. Avery, J. Augustin, R. Bangerter, S. Berman, E. Close, T. Elioff, A. Garren, W. Gilbert, E. Hartwig, M. Lee, P. Morton, V. K. Neil, J. Rees, B. Richter, R. Sah, A. Sessler, L. Smith, L. Stevenson, H. Weidemann, W. Wenzel.

Protons and electrons rotate in the directions indicated for e^-p collisions. For e^+p collisions, positrons are substituted for electrons. In the case of e^+e^- reactions, the proton ring is not used (apart from common elements near the interaction point), and the electrons and positrons counter-rotate in the same ring in the same manner presently utilized at SPEAR.

A schematic of the insertion region is shown in Fig. 2 to illustrate the necessary gyrations to achieve the collision of the two bunches at the interaction point. The solid lines indicate the trajectories for e^-p collisions. For e^+p collisions, the dipoles nearest the interaction point (vertical bends) are reversed, and the protons would follow the dashed trajectory.

Zero-crossing angle is the interaction mode presently being studied as first priority. This gives a definite focus for the initial studies and eliminates complications that would arise due to the fact that the first quadrupole doublets are common to both beams. Also, the system is more suitable to solenoid fields for detectors with minimum perturbation on the circulating beams. We of course intend to be flexible and provide the capability for finite crossing-angles because it may be advantageous for increasing the luminosity and providing flexibility for overall experimental requirements. It is believed that this can be accomplished by rearrangement of magnets near the interaction point. This will be investigated in more detail.

Fig. 3 shows the detail of the lattice system along with the envelope of the beam dimensions. The elements of the interaction region mentioned above are shown more explicitly. A comprehensive report on the considerations for the lattice system has been given in a separate paper[5] by Al Garren. The first standard cell of the normal lattice structure is shown on the right. This is an FODO cell of 17.5 meters length. Next are two matching cells which together with the remaining quadrupoles shown achieve the low β interaction point and match the phase space of the normal cell. The three unmarked quadrupoles PQ5, PQ8, PQ9 are necessary to confine the proton beam at injection, when not operating in the low β mode shown here, and thus maintain minimum aperture for the elements in the insertion region. A transition to the low β mode would take place after acceleration.

An element-free region of 20 meters is provided about the interaction point. This is believed to be the minimum free space required for experimental apparatus and detectors. Some of the other relevant parameters are listed in Table I. A more complete list of parameters is given in reference 5.

A design luminosity of 10^{32} $cm^{-2}sec^{-1}$ was considered necessary to achieve reasonable interaction rates particularly for large momentum transfer events. This is theoretically achieved with the lattice system described. The number of particles in each bunch is relatively small at 5×10^{12}. For the geometry outlined, this corresponds to 4.2 megawatts of power radiated by the electron beam. While the number of particles is modest, the beam densities are formidable at the interaction point. The number of protons and the beam sizes are chosen to maintain the tune shifts below the canonical value of .025 in order to obtain maximum luminosity consistent with the incoherent beam-beam limit. While this tune shift limit appears experimentally verified for electrons, there is no comparable information as to the appropriateness of the limit for the proton beam. Some dispersion is required at the interaction point to widen both the

TABLE I

PEP PARAMETERS

		Protons	Common	Electrons
Maximum Momentum (GeV/c)		150		15.0
Number of Particles		5×10^{12}		5×10^{12}
Luminosity (cm^{-2} sec^{-1})			1.0×10^{32}	
Average Radius (m)			327	
Vertical Separation (m)			1.25	
Total Number of Cells			72	
Length of Standard Cell (m)			17.5	
Length of Straight Section (m)			200	
Dipole Field (kG)		40		4.0
Quad. Field-F (kG/m)		460		107
Quad. Field-D (kG/m)		446		105
Dipole Length (m)		5.4		5.4
Quad. Length (m)		1.7		0.7
Interaction Point:				
Bunch Length (cm)		64		9
Total Width (cm)		.70		.55
Height (cm)		.13		.055
Half Apertures Required:				
Standard Cells	h (cm)	5.5		2.5
	v (cm)	4.0		2.5
Max. in Insertion Elements	h (cm)	12.0		12.0
	v (cm)	14.0		12.0

electron and proton beam of the present design in order not to violate this assumed limit.

The limitations for minimum beam size at the interaction point result in relaxed requirements for the injected proton beam emittance. For example, with the 11 x 8 cm full aperture for the normal cells noted in Table I, the emittance and intensity assumed are consistent with that which is possible from a single turn extracted from the Bevatron at 6 GeV. Electron injection is obviously consistent with the SLAC capabilities. At this time, overall injection methods and systems remain to be optimized.

The RF systems in PEP are non-trivial as the system for the electron ring must supply $\sim$ 4 megawatts of power radiated by the beam. Total power of $\sim$ 5 megawatts is required at 350 MHz. However, elements of the system are similar to what is required by the SPEAR improvement project for energy upgrading to 4.5 GeV. Hence the operation of that system will serve as a PEP prototype.

The proton RF system is also formidable due to the requirements for an extremely short bunch length. At present, a 3-step process is visualized whereby an initial RF system operating at 1.6 MHz (10th harmonic) and $\sim$ 100 kV peak voltage will be used to accelerate the beam to full energy. A second system at 30 MHz and 3 MV peak will be turned on to compress the bunch from 11 meters down to $\sim$ 3 meters, after which the first system is turned off and a third system operating at 102 MHz (700th harmonic), and 60 MV peak voltage will be utilized for final compression to 64 cm.

While the technical aspects appear feasible in terms of hardware, the problems of maintaining the

short bunch lengths over a long time period may still be troublesome. Bunch lengthening effects which are not completely understood are evident at electron storage rings. In the proton case, it is possible that RF noise could lead to loss of beam and hence loss of luminosity. Preliminary tests have been under way at the Bevatron to investigate low RF noise levels on a bunched coasting beam at the Bevatron. These have been discussed in a separate paper by Hartwig.[6] Preliminary conclusions indicate that systems can be built with the requisite noise tolerance.

The effort toward a superconducting magnet system for the protons is motivated in part by the physics; i.e., going beyond the projected energy where "weak" interactions might become comparable to "strong" interactions. Therefore, for the same amount of real estate, one would obtain the largest extension of experimental capabilities. In addition, there is the practical matter of power costs. While the electron lattice involves small low-field magnets, the proton magnets are considerably larger and, if conventional, would be operated up to $\sim$ 20 kG. The storage ring is essentially a d.c. device, and initial estimates for operation of a 70 GeV ring of the size noted here resulted in a power cost of $\sim$ \$5M/year (assuming 2/3 operation efficiency). A second proton ring would double this figure. BNL estimates[7] for a 'conventional' ISABELLE were \$16M to \$19M. These figures are already at or greater than the total power costs for all accelerators in high-energy physics. If one further speculates, backed by the trends of the last two years, that power costs will increase significantly by the time such a device is operational, one arrives at an unacceptable level of operating costs.

The success of achieving high-field, low-loss magnets[8] at LBL and Rutherford in the last year with construction methods amenable to production techniques has provided an additional degree of confidence that the superconducting system can be successfully achieved. As part of the PEP program, several magnet models are under construction to observe possible differences in two identically constructed magnets, as well as to study low-field effects and the suitability of various correction windings.

PEP Physics

Conventional electron and proton accelerators have both been successful over the years in achieving new insights toward our understanding of elementary particles. There are also numerous tie-points which promote a complimentary relationship between the results from the two classes of machines. A classic example is the early electron-scattering experiments at Stanford for which the theoretical interpretation of the nucleon charge distribution predicted the existence of the ρ and ω mesons which were later discovered with the help of proton accelerators. More recent examples of experiments from electron machines which provide new suggestions for hadron structure include the results from deep inelastic electron-scattering experiments at SLAC and hadron production from electron-positron colliding beam experiments at Adone and CEA.

One line of reasoning is that the overall complementary of the two research lines can be aided best by advancing the available interaction energy in both cases. Table II will help to show this perspective. The available energy at SLAC is near that of the AGS and the PS. Beyond this, NAL, the ISR and CERN II readily leave the electron interactions behind in terms of available energy. PEP would restore the overall balance to the total program. There is an obvious need to extend the ep interaction energy relative to SLAC. Of major importance is the unique capability of PEP to explore new features of lepton-hadron interactions in a direct manner. A few specifics of the PEP physics possibilities are mentioned below.

TABLE II

Device	Primary Energy* or (Equivalent)	$E^*_{c.m.}$	Storage Ring Energy* or (Equivalent)	
BEVATRON	6	3.8	(.9)	p x p
SLAC	22	6.1	(3.5 x 2.0)	e x p
AGS/PS	30	7.7	(2.9)	p x p
NAL	200	19.5	(8.8)	p x p
	500	31	(14.4)	p x p
ISR	(1750)	58	28	p x p
PEP	(5100)	100	15 x 150	e x p
		30	15 x 15	e x e
ISABELLE	(86,500)	402	200	p x p

* Energies in GeV

Deep Inelastic Electron Scattering. This is a class of electron-proton collisions with high momentum transfer, and hence collisions that can most effectively probe the electro-magnetic structure of the nucleon at arbitrarily small distances. This local interaction is in sharp contrast to hadron-hadron scattering in which the basic interaction is exceedingly complex. Inelastic scattering experiments at SLAC have already yielded unexpected and revealing results which show that the inelastic cross-sections do not vary independently with the mass and energy of the photon exchanged in the process, but depend instead on the ratio of these two parameters. This behavior, called "scaling" has led to new developments in the concepts of the proton structure, and indicate a possible substructure of point-like constituents.

PEP would greatly extend the inelastic scattering measurements far into unknown regions. Fig. 4 shows the range of momentum transfer squared (Q^2) and energy transfer (ν) that are available at the maximum beam energies. The numbers in each segmented region that are not in parenthesis correspond to the event rate-per-day for a luminosity of $10^{32} cm^{-2}$ sec^{-1}. While the event rate is not overly impressive at high-momentum transfers, the total rate is expected to be inversely proportional to the square of the center-of-mass energy, and thus increases considerably at lower beam energies. The significant point here is that the maximum momentum transfer squared and energy transfer presently available at SLAC is 25 $(GeV/c)^2$ and 20 GeV, respectively, which is not well-resolved from the zero of the ordinate and abscissa of the scale shown in Fig. 4. Most of the large Q^2 events occur at large scattering angles in the laboratory and are experimentally accessible. The LBL-SLAC study group[4] concluded that experimental signatures are sufficiently unique that

these types of events can be readily identified with existing detectors.

The observation of the scaling behavior at PEP energies would imply that one is observing the asymtotic behavior of the proton structure, and that the carriers of the electromagnetic current in the proton are structureless and light. Observation of a scaling breakdown would indicate a new regime for hadron phenomena, for example, as might be expected from parton or quark production.

In the inelastic scattering process, $e + p \rightarrow e + X$, the details of the many possible combinations of hadronic constituents in X, such as multiplicities, momentum distributions, correlations, etc., will also be important in verifying various theoretical models. For example, final state hadrons for high Q^2 and ν values may emerge tightly in jet-like distributions according to parton models. Thus new information from PEP is expected to have an enormous impact on the understanding of nucleon structure.

For the class of experiments with low-momentum transfers if the forward scattered electron is tagged, the photon exchanged is uniquely identified, and it is possible to extend equivalent photo-production experiments such as total cross-sections, single particle inclusive results, and reactions with special final states to new energy regions.

Weak Interactions. Some of the most exciting possibilities for new discoveries are found in this area. Weak processes, such as $e + p \rightarrow \nu + X$, will be in an energy region where they may effectively become strong. Weak interactions involving neutrinos (ν) up to $\sim$ 5 GeV from present accelerators can be described by the same Fermi theory proposed for β decay processes involving extremely low energies. The total cross-section for the above process would be expected to increase as the square of the center-of-mass energy, becoming comparable to some electromagnetic processes or even to large momentum transfer components of strong interactions at $\sim$ 60 GeV center-of-mass.

In Fig. 4, the numbers in parentheses show the reaction rates/day for the neutrino production process at the highest PEP energy (Center of Mass Energy = $\sim$100 GeV). The dashed line O-O shows approximately where the reaction rates are comparable with the electron inelastic scattering. In the region above O-O, the weak interaction process would be greater than the large Q^2 electron scattering rates. There would be a total of $\sim$ 300 neutrino events per day if this extrapolation is valid.

Equally important would be the discovery of the breakdown of the Fermi theory and hopefully the knowledge of the mechanism. A possibility widely predicted would be the mediation of this reaction by the intermediate vector boson (W particle) of suspected mass in the 30 GeV region which would be readily produceable with PEP. In either situation, a new list of experimental questions on the weak interaction process would be initiated and PEP should be able to provide many of the answers.

Electron-Positron Reactions. The physics of e^+e^- reactions has been reviewed at length elsewhere.[2,4] The importance is noted by the e^+e^- colliding beam facilities already in operation and under construction. The e^+e^- system allows the study of hadron final states (as well as lepton pairs) with the unique quantum numbers of the virtual photon of the annihilation process. Information on hadronic systems can thus be obtained in a clean and unique manner.

Results from Adone and the CEA which indicate much larger hadron cross-sections than anticipated have increased the motivation to achieve higher energies in order to determine the energy dependence of the cross-sections as well as the asymtotic behavior. This determination, as well as other detailed studies of the hadron systems produced, are important with regard to the predictions of the various constituent models of the nucleon.

In addition, at the higher energies, if heavy leptons (with properties similar to muons) exist, they should be produced in a simple and direct way. Also the W-particle mentioned earlier might be effectively produced by the e^+e^- process with a favorable cross-section. An additional outcome of PEP e^+e^- experiments would be a test of the validity of quantum electrodynamics to dimensions an order of magnitude smaller than presently confirmed.

SUMMARY

The LBL-SLAC joint study has made considerable progress during the past year in establishing the conceptual design for PEP. We hope to optimize more fully the various parameters associated with PEP during the coming year and work toward a comprehensive understanding of the many problems, such as the limitations imposed by various beam instabilities and field tolerances. It is also desired to achieve optimum flexibility with regard to the experimental conditions that may be required by various experiments and detection systems.

The method of colliding beams provides the most economical means of achieving significant energy gains. In particular, there are no large scale experimental areas which comprise the dominant part of the operating costs at conventional accelerators. Extensive shielding requirements are not envisioned, and there are no demands for sophisticated extraction systems, target-handling facilities, or extensive utility distribution systems. Hopefully the superconducting elements will minimize the power costs and thus, in general, PEP should not cause a significant perturbation on the total operating costs of the High-Energy Physics Program.

At this point in time it is believed that PEP will provide the most advantageous extension of parameters for the fundamental investigations of elementary particles. The physics potential already mentioned has led LBL and SLAC to consider PEP as the top priority item for future construction. We are further enticed by speculation that the expectations for the dominance of weak interaction cross-sections might even lead to unifying principles which would combine the understanding of our basic forms of interaction. In any case, new discoveries and new challenges are expected with a high degree of confidence.

Lastly, Figures 5 and 6 provide a plan view of PEP on the LBL and SLAC sites respectively, illustrating how such a device could be readily incorporated with the existing facilities.

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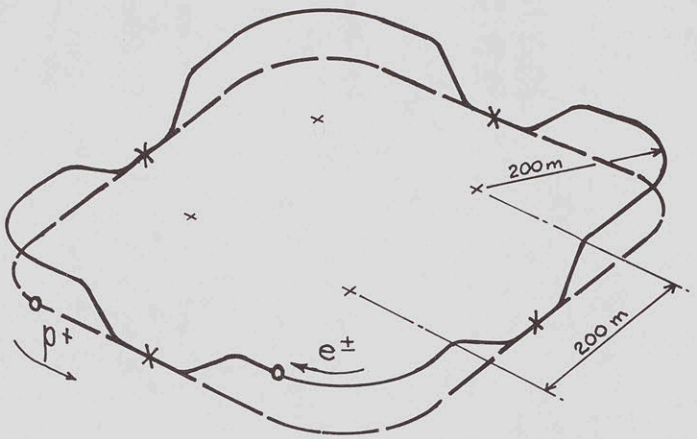

P.E.P. Configuration

Fig. 1
Schematic of PEP Configuration

XBL732-2326

Fig. 2
Schematic of an Insertion Region with zero-crossing angle

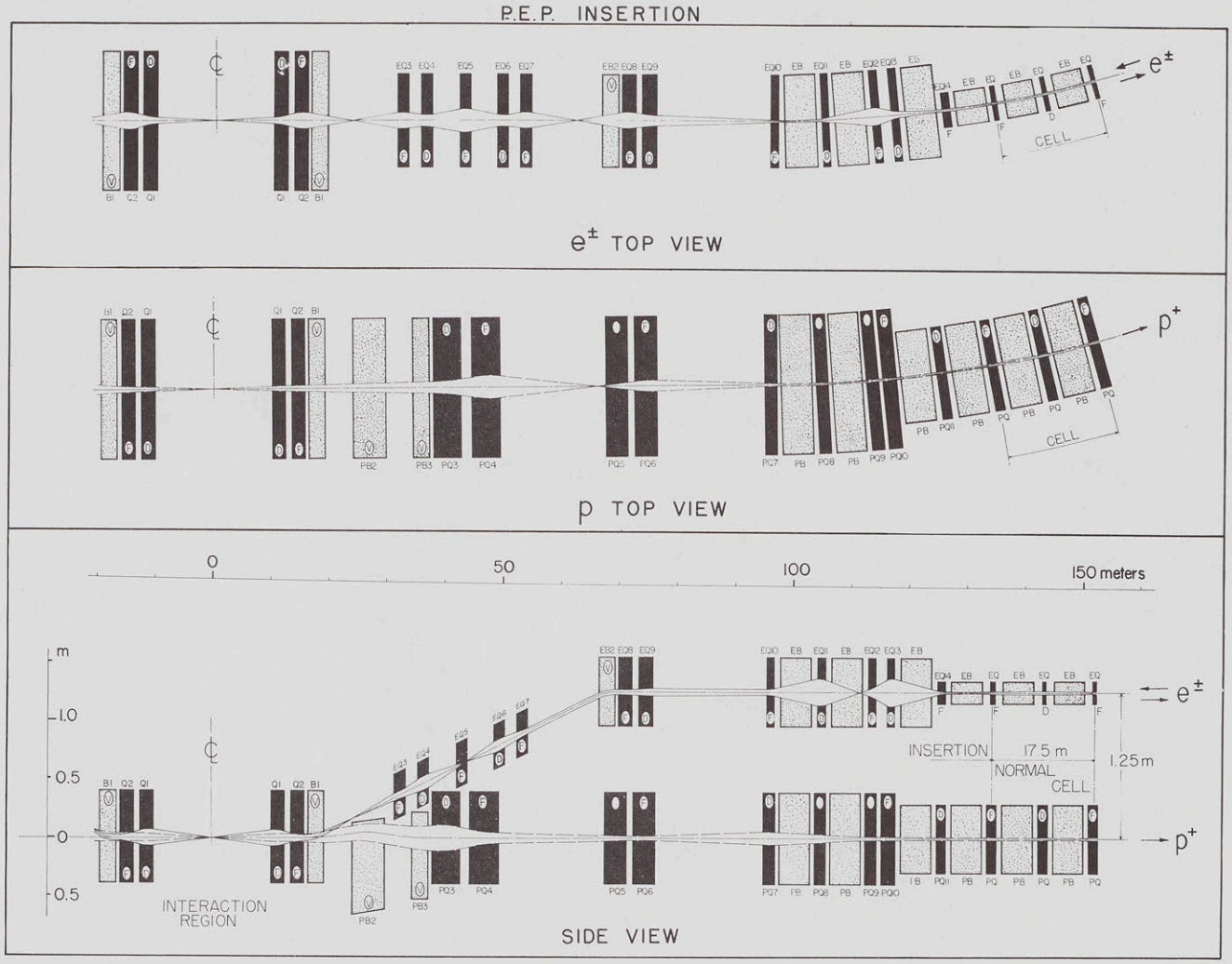

Fig. 3

Detailed Structure of the Insertion Region

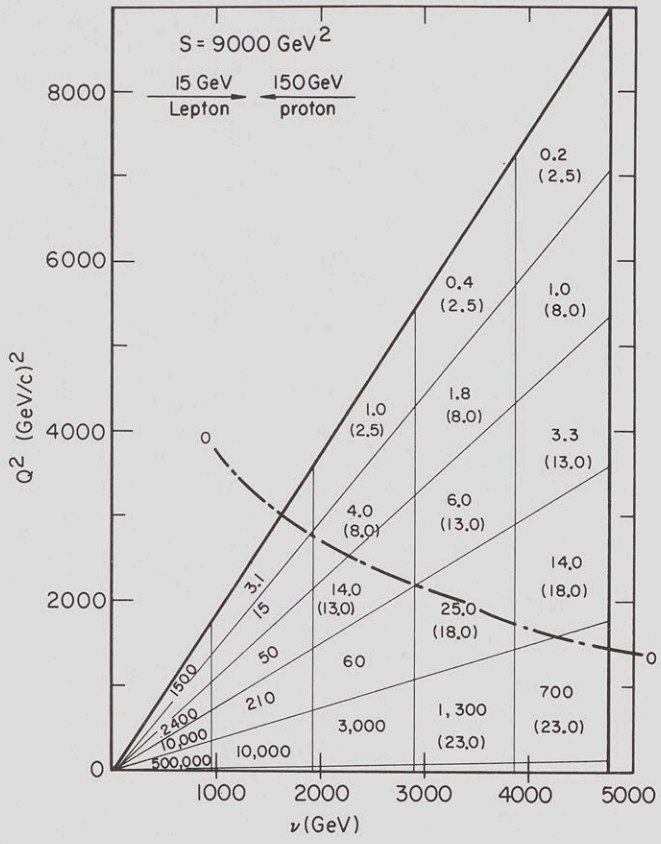

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Fig. 4

Kinematic range for inelastic lepton scattering of 15Gev leptons on .150 Gev protons. Numbers in the domains correspond to projected inelastic electron scatterings per day for $L = 10^{32}$ cm^{-2} sec^{-1}. Numbers in parentheses correspond to the events per day for the process $\ell + p \rightarrow \nu +$ (anything).

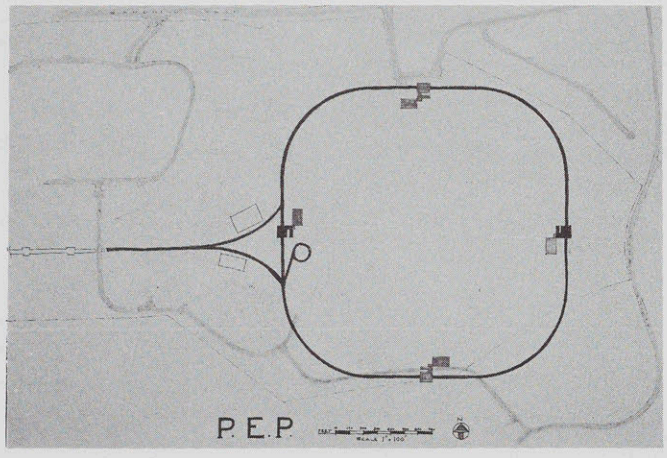

Fig. 5

Possible PEP configuration on the SLAC site. The structure at the far left is the end of the SLAC electron accelerator. The two squares outlined represent experimental end-stations A and B.

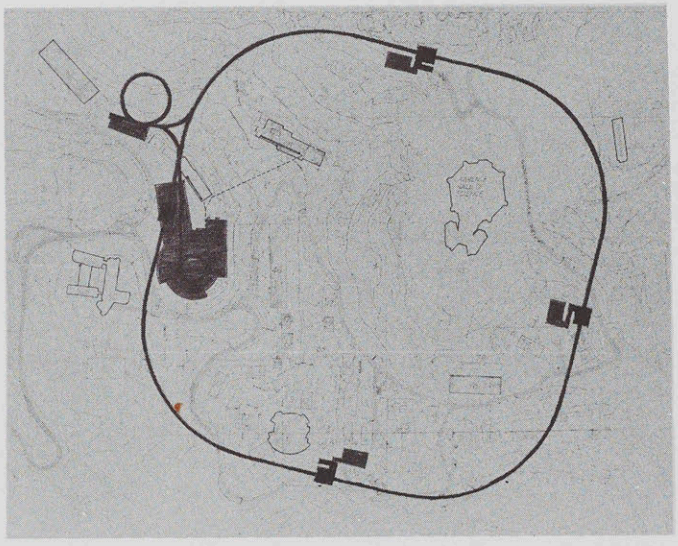

Fig. 6

Possible PEP configuration on the LBL site. The dark structure centered on the left side of the large ring is the Bevatron complex. The interaction region on the left side is shown within the existing experimental hall.

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TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720

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SUPERCONDUCTING BEAM-TRANSPORT MAGNETS FOR THE BEVATRON

William S. Gilbert, Robert B. Meuser, Ferd Voelker,
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William S. Gilbert, Robert B. Meuser, Ferd Voelker, Robert A. Kilpatrick,
William F. Eaton, Fred L. Toby, Robert C. Acker

Lawrence Berkeley Laboratory
University of California
Berkeley, California

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Introduction

Two superconducting dc beam-transport magnets have been built and tested, and they are being installed on a secondary particle beam of the Bevatron. They are a dipole (bending magnet) and a quadrupole doublet (focusing magnet). Both have clear room-temperature aperture diameters of 8-in., iron flux-return yokes, and will be cooled by a Cryogenic Technology, Inc. Model 1400 refrigerator. Nominal field strengths are 40 kG and 6 kG/in. respectively. Sufficient controls, instrumentation, and interlocking are provided to permit routine operation by the Bevatron operating crew. The main parameters are shown in Table 1. Drawings of the magnets appear in Figs. 1 and 2.

Chronology

The specifications were established in December of 1969. A 10-in. aperture diameter was specified for the dipole. However, a cryostat for a 6-in.-bore dipole had been partially built, starting in mid-1968, but the project had been cancelled. In the interest of economy, the decision was made to use the cryostat for the Bevatron dipole magnet. The bore diameter specification had to be reduced to 8-in. to provide sufficient room for the thickness of winding required to produce the specified field strength.

Two practice layers for one pole of each magnet were wound and tested in May 1970. Winding of the dipole started in mid-1970. Various groups of layers were run in liquid helium as the fabrication progressed. The fabrication was completed, and the dipole winding was tested in a vertical dewar with no iron yoke in December 1970. In March 1971 the modifications to the Dipole cryostat were completed and the cryostat was tested. Leaks developed in the gasketed joints in the helium vessel. The magnet was installed, and after unsuccessful attempts to get the gasketed joint to maintain a seal, the joints were welded. In August 1971 the magnet was operated and was transitioned three times at central field values of 33.5, 37.5, and 40.2 kG.

* This work performed under the auspices of the Atomic Energy Commission.

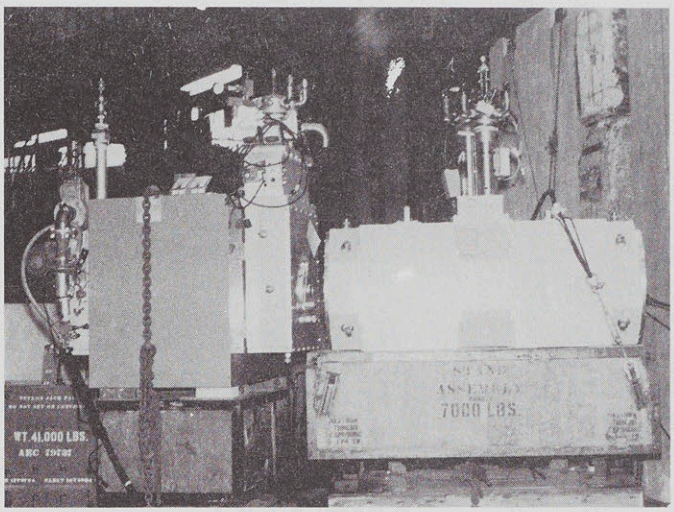

Figure 3 The magnets during installation at the Bevatron

By March 1971 one quadrupole winding had been completed. The superconductor was old, reworked material of poor quality. It was decided to delay construction of the second quadrupole until better material could be obtained. Winding of the second quadrupole was completed in August 1971, and at that time the doublet was tested in a vertical dewar without iron. Shortly thereafter the cryostat was completed and the windings were installed.

The project was delayed by the greater priority placed on the pulsed-magnet program during the latter part of 1971 and most of 1972. In September the decision of where to install the magnets at the Bevatron was made. Both magnets were operated on the 500 Inc. Model 1200 refrigerator, and extensive magnetic field measurements made, in December 1972. Installation at the Bevatron started early in February 1973.

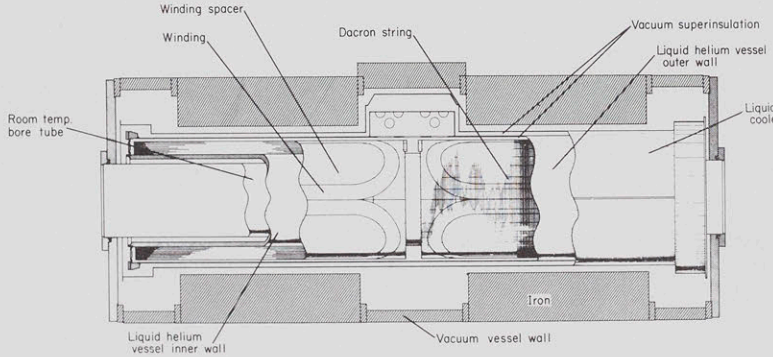

Figure 2 Superconducting quadrupole doublet

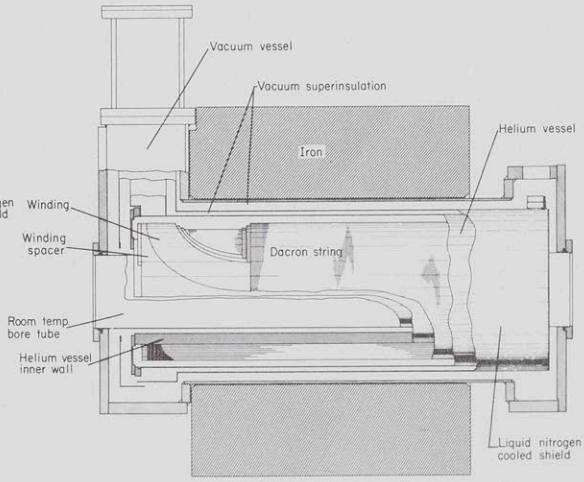

Figure 1 Superconducting dipole magnet

TABLE 1 - Parameters

		Dipole	Quadrupole Doublet
Dimensions			
Aperture diam.	in (cm)	7.9 (20.1)	7.9 (20.1)
Helium vessel inside diam.	in (cm)	8.93 (22.7)	9.0 (22.9)
Winding inside diam.	in (cm)	11.43 (29.0)	9.95 (25.3)
Winding outside diam.	in (cm)	14.87 (37.8)	12.73 (32.3)
Iron yoke inside diam.	in (cm)	20.0 (50.8)	16.0 (40.6)
Iron yoke outside dimensions	in (cm)	48x40 (122x102)	26 sq (66 sq)
Iron yoke length	in (cm)	31.1 (79.9)	20 (50.8) each
Effective magnetic length	in (cm)	32.85 (83.4)	24.9 (63.2) each
Overall winding length	in (cm)	40.5 (102.9)	29.0 (73.7)
Overall length of cryostat	in (cm)	53.3 (135.4)	69.4 (177)
Gross weight	lb (kG)	16000 (7000)	8000 (3600)
Windings			
Total conductor	ft (in)	16500 (5030)	8500 (2600) each
Number of turns per pole	- -	1162	422
Number of layers	- -	12	10
Performance			
Magnetization curve slope			
Field at mid-length		67.0 G/A	9.04 G/in-A (3.56G/cm-A)
Integral (-∞ to + ∞)		2201 G-in/A(5590 G-cm/A)	225 G/A
Maximum performance achieved			
Current, without iron	A	622 [1]	778 [1] | 804 [1]
Current, with iron	A	600 [1]	600 [2] | 750 [2]
Field at mid-length with iron		40.2 kG	5.42(2.13)[2] | 6.78(2.67) [2] kG/in(kG/cm)
Integral (-∞ to +∞)		1321 kG-in (3355 kG-cm)	1350 | 168.8 kG
Stored energy	kJ	0.66 MJ at 40 kG	0.15 MJ each at 2.4 kG/cm

[1] Went normal.
[2] did not go normal.

Performance

Maximum Field Strength Achieved

The dipole was transitioned twice without iron, reaching about 90% of short-sample current on the second transion (Fig. 4). After the coil was installed in its cryostat and the iron was added, it was transitioned three times, reaching essentially 100% of the short sample characteristic on the third one, and showing a large training effect.

The quadrupoles were each transioned once without iron, then again when powered in series (Fig. 5). After being installed in the cryostat with the iron yoke they were operated but were not transitioned, as the performance goal had been met.

Magnetic Field Measurements

Extensive magnetic field measurements were performed on both magnets. Each magnet was operated for about two weeks on the Model 1200 refrigerator. Detailed results of the measurements will be presented in internal reports; we present a brief summary here.

Three types of measurements were made: a) rotating-coil multipole measurements, b) longitudinal field profiles, using a short coil that moved along a track, and c) long-coil field integral measurements on a 5 x 5-in. grid.

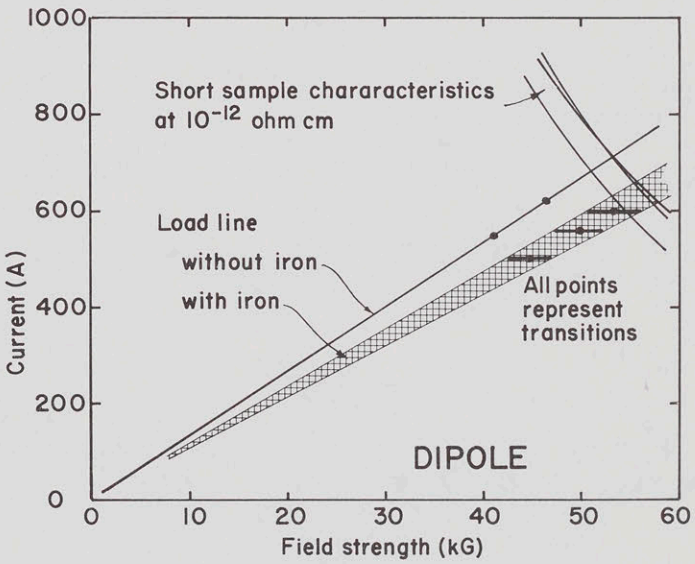

Figure 4 Load lines and short-sample characteristics; dipole.

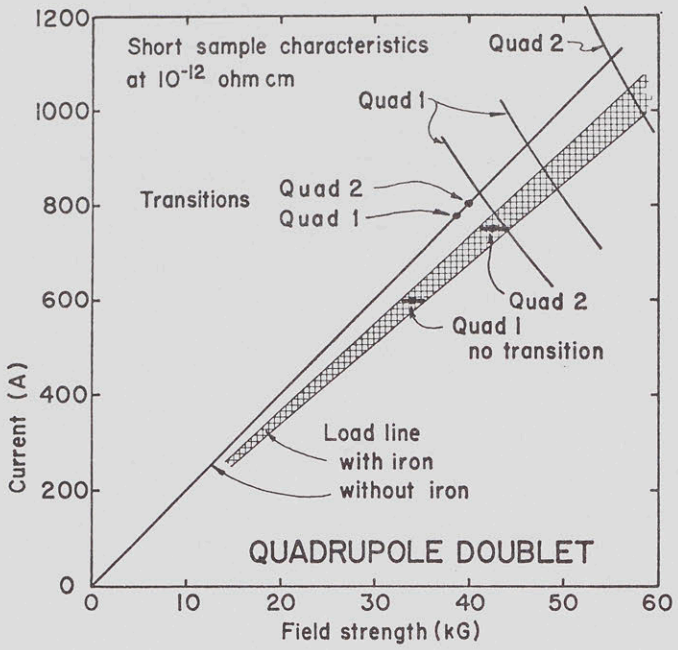

Figure 5 Load lines and short-sample characteristics; quadrupole doublet

Dipole. Integral field maps showed a maximum deviation of 0.1% over the 5 x 5-in. grid at all current values with the exception that two of the corner points (4-in. radius) showed deviations as great as 0.3% at an intermediate field value. Rotating coil measurements showed a sextupole component, referred to a 3.5-in. radius, of 0.4% and a 14-pole component of 0.2%. All others were below 0.1%. Harmonic content did not change with field strength.

Quadrupoles. Twelve-pole component of the integrated field, referred to a 3.5-in. radius, is 0.4 to 0.5%, and the 20-pole about 0.2%. Dipole component was about 0.3%, indicating a displacement of the magnetic axis from the geometric axis of the cryostat flanges, of about .010-in. All other multipole components are below 0.1%. The two quadrupoles are essentially indentical, and the relative magnitudes of the multipole components are independent of excitation.

Winding Design

From the start, our interest centered on magnets comprised of cylindrical layers of varying width. Such magnets are usually made by winding the conductor directly into its proper shape. In 1967 we made such coils by winding flat, racetrack-shaped coils and subsequently bending them to a cylindrical contour. Such a magnet has sizable field aberations at the ends, and the overall length is considerably longer than the effective magnetic length. This is not the case with windings having turned-up ends. However, as the coil diameter at the ends is no greater than that of the straight portions, the design of the cryostat is simplified, and the winding takes less time. Therefore the bent racetrack coil shape was adopted for the Bevatron magnets.

The winding configurations -- the number of turns in each layer -- were determined by trial and error; the method scarcely deserves the dignity of being called an "iterative procedure". Computations were aided by mini-computer programs executed on the BRF -- an on-line Teletype I/O linked to the CDC 6600 computer. The program calculates the integral of the multipole components of the field from the distribution of the integral of the longitudinal components of the current. In an alternate mode, the program calculates simply the two-dimensional field components. The iron is assumed to be infinitely permeable and to extend to infinity in all directions. In fact, however, the iron is considerably shorter than the winding, and the effect of the iron on the field produced by the ends is uncertain. It turned out that it did not make a great difference whether the iron was considered to be totally effective or totally ineffective at the ends.

Another program was used to calculate the three-dimensional field at various points, and especially at points in the end region where the conductor is subjected to the highest fields. In the mathematical model, the winding is a system of straight-line segments of filaments. As the field goes to infinity at a filament, a certain amount of witchcraft must be invoked to obtain results in which one can have confidence, but that is possible. The effect of iron is not included in the calculations, but its effect is estimated, so there is some uncertainty as to the true value of the magnetic field in the end region of the winding.

In principle it is possible to design the winding to give a good field in a two-dimensional sense, and to vary the lengths of the layers so as to also give a good field in the integral sense. This decreases the effective length, and for our low aspect ratio magnets, the decrease was deemed to be intolerable. Therefore, all winding layers have the same overall length, and the turns in each layer are adjusted to minimize the aberrations in the integral field, by making the two-dimensional field aberrations cancel those produced by the ends. The uncorrected central field has aberrations of the order of 3%.

TABLE 4 - Winding dimensions

Layer Number	Dipole		Quadrupole	
	No. of turns per pole	θ (deg.)	No of turns per pole	θ (deg.)
1	148	81.04	61	37.63
2	148	79.12	61	36.65
3	146	76.24	60	35.12
4	146	74.51	60	34.25
5	87	43.41	30	16.71
6	87	42.47	30	16.31
7	75	35.84	30	15.94
8	75	35.09	30	15.57
9	67	30.71	30	15.23
10	67	30.10	30	14.90
11	58	25.55		
12	58	25.06		
Total turns	1162		422	
Inside radius	14.57 cm		12.69 cm	
Outside radius	18.83 cm		16.12 cm	

θ is angular semi-width of the layer, measured from bisector of poles. Radii are to center of the Dacron cord.

We investigated the possibility of staggering the lengths of the adjacent layers to decrease the bulk current density at the point where the field is highest, thereby reducing the peak field. For a fixed overall length, and a fixed relationship between the maximum field and current, the decreased effective length that accompanied the decrease in maximum field resulted in a net decrease in bending and focusing power.

Conductor

Characteristics of the various conductors and their useage are shown in Tables 5 and 6.

TABLE 5 - Conductors

Conductor designation	Cu. S.C.	No. of filaments
A	2.7	130
B	3.0	120
C	3.3	62
D	2.0	246

"C" was reworked from untwisted conductor originally measuring 0.052 x 0.127 in. All conductor measures .045 x .090, has a twist rate of 1 to 2 turns per inch, and was supplied by Cryomagnetics, Inc. "D" is Cryomagnetics "W" material; 1300A at 50 kG at 10^{-12} ohm-cm, oxide coated.

TABLE 6 - Conductor Placement

Application	Conductor
Dipole, layers 1 - 9	A and B
Dipole, layers 10 - 12	B and C
Quadrupole 1	Mostly C, some B
Quadrupole 2	All D

Coil Construction

The conductor, measuring 0.045 x 0.090 in., is wrapped with 1/8-in.-wide by 0.005-thick silicone-impregnated fiberglass tape having thermosetting adhesive on one side (Scotch Electrical Tape No. 67), to provide turn-to-turn insulation. The tape is applied with about 50% coverage to provide ventilating passages between turns. Each flat racetrack-shaped coil is wound around a central island. The island consists of three layers of epoxy-fiberglass sheet between which are placed sheets of 0.005-in.-thick B-stage epoxy impregnated fiberglass cloth. The flat winding and island are encased in an envelope of 1/8-in. soft aluminum sheet. The envelope, winding, and island are pressed into the final shape between matched cylindrical dies, and are baked to set the resin in the islands.

A set of the bent windings is transferred to the magnet. Filler pieces of epoxy-fiberglass, made in the same manner as the islands, are installed at the ends. Windings are secured with a wrapping of braided Dacron cord. (Ashaway Line and Twine Mfg. Co., #50 Dacron cord, white). The cord is applied under a tension of 60 lb -- about half of the breaking strength -- with a pitch of 0.080 inches. The diameter of the cord is 0.049 in., and it squishes out somewhat when wrapped, leaving spaces of about 0.020 in. between turns. The cord serves as layer-to-layer insulation, provides passages for helium permeation, and provides the sole restraint against the magnetic bursting force -- some 500 000 lb. for the dipole -- which seems like a lot to ask of a piece of string. The cumulative pre-tension in the cord generates a compressive stress of 7000 psi in the 1-1/4-in.-thick steel tube on which the dipole is supported. The cord has a negative coefficient of thermal expansion, which would tend to make it loosen when the magnet is cooled. It also has an increasing elastic modulus with decreasing temperature, however. That, together with the prestressing, causes a tightening of the string as it cools in spite of the negative coefficient of expansion. The thermal stress in the cord at helium temperature is about double the room-temperature pre-stress, which should be pretty close to the breaking point. However, we have used the cord on many systems and have tested it rather extensively, and have never had a failure.

The stainless steel support tube is subjected to bending forces tending to make the cross section elliptical, and in addition, to hoop compression resulting from the tension in the cord. The combined stress, for the dipole, is about 65 000 psi, compared with a 0.2% offset yield strength of 89 000 psi at 20 K (Kromark 55).

Cryostats

Dipole Cryostat (Fig. 1)

The stainless steel tube to which the winding is secured serves as the inner wall of the helium vessel. A flanged thin-walled cylinder slightly larger than the outer wall. The ends are covered by plates that are bolted and gasketed to the cylinders. The 0.010-in. Mylar gaskets did not make a reliable seal at liquid helium temperature, and the joints were eventually welded. Risers at the ends, in which the various utilities are carried, are attached to the vessel with Conoseal flanges.

The helium vessel is surrounded with multilayer insulation consisting of 20 layers of 1/4-mil Mylar, aluminized on both sides, and separated by two layers of Nylon netting. A stainless steel liquid nitrogen cooled shield surrounds the helium vessle. The nitrogen shield is covered with multilayer insulation having only one layer of netting between layers of Mylar. The warm-bore tube is wrapped with multilayer insulation in the middle of which are sandwiched strips of soft aluminum foil which are attached to the end plates of the nitrogen shield. The nitrogen shield is supported from the helium vessel on fiberglass cones. A welded aluminum vacuum vessel surrounds the liquid nitrogen shield. The iron flux-return yoke is made in two pieces that are assembled over the cylindrical center region of the vacuum vessel.

Support of the helium vessel is provided by an overconstrained system of ten titanium tension rods Two sets of four rods each fix the vertical and lateral position at each end, and resist rotation about the longitudinal axis. An additional pair of tension rods, running the entire length of the vessel, provide longitudinal constraint. A point on each support rod is thermally connected to the liquid nitrogen shield. The rods are as thin as structural integrity permits, and as long as the dimensions of the vessel will accommodate, in order to minimize the heat leak. As a result, the system is rather springy. Pegs which project inward from the vacuum vessel can be screwed into contact with the helium vessel. These "shipping stops" relieve the support-rod system of shock loads while the vessel is moved about. They are electrically insulated from the vacuum vessel, and can be used as micrometers to monitor the position of the helium vessel when it is cold.

The measured heat leak is 5 ℓ/hr at full current.

Quadrupole Cryostat (Fig. 2)

The quadrupole cryostat has few features in common with the dipole cryostat, which was designed more than a year earlier. One of the end plates of the helium vessel is welded to the stainless steel tube that carries the winding. The other end plate is welded to the outer cylindrical shell, and a turned-in flange is provided at the other end. Sheet Mylar gaskets provide the seals. Access port covers in the middle of the vessel are similarly gasketed. The outer cylindrical wall of the helium vessel is thin, and as it is in good thermal contact with the cold helium it cools rapidly. The opposite is true for the inner cylinder. The result is a great difference in the rate of thermal contraction of the two cylinders, causing the heads to dish. To decouple the dishing of the head -- which might tend to make the gasket leak -- from the flanges, circumferential grooves are cut into the end plates to form flexural hinges (Fig. 6). It was not possible to make the hinges so thin as to keep the bending stresses below the yield strength should the magnet be cooled too rapidly. Therefore, temperature sensors were placed on the shells to enable regulation of the cooling rate so as to keep the temperature difference below about 30 C.

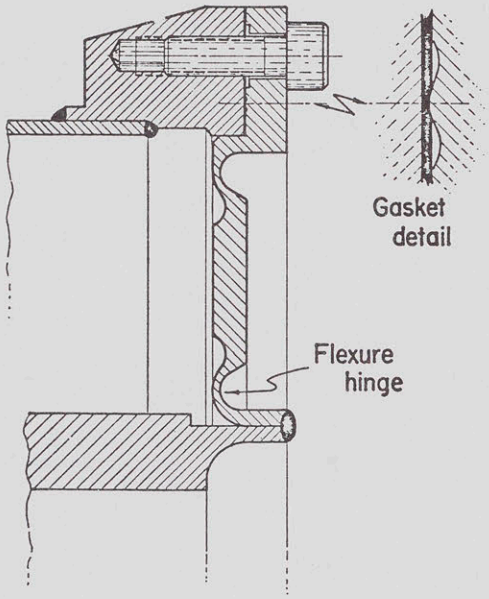

Figure 6 Quadrupole helium-vessel closure

Support of the coils is provided by an over-constrained system of eight short epoxy-fiberglass compression struts (Figs. 7 and 8). The four struts at each end do not lie in a plane, as the tension rods on the dipole do, but rather lie on the surface of a cone. They therefore provide longitudinal constraint, so additional struts are not needed for that purpose.

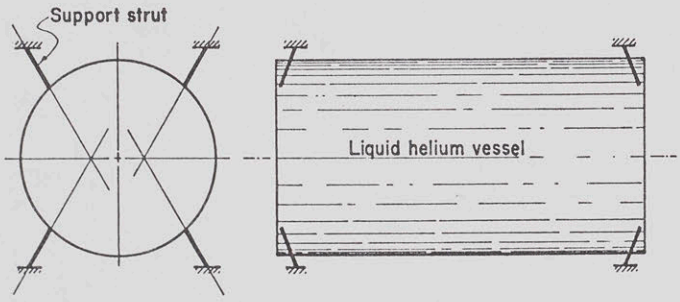

Figure 7. Quadrupole helium-vessel support system; schematic

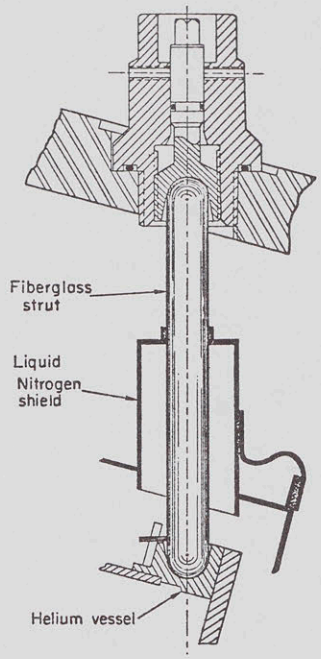

Figure 8 Quadrupole support-strut detail

The struts are canted at an angle chosen to minimize thermal stresses. If the strut does not change length as the helium vessel is cooled, then the condition for zero thermal stress is that the strut be normal to a line connecting the cold end of the strut with the point on the vessel that is not supposed to move; the centroid in the present case (Fig. 9). If the strut changes length too, the angle must be slightly different. The struts can be quite short without causing excessive heat leak. They were, therefore, placed entirely outside of the helium vessel and require no increase in the length of the vacuum vessel. As the support system is quite stiff and strong, no shipping stops are provided.

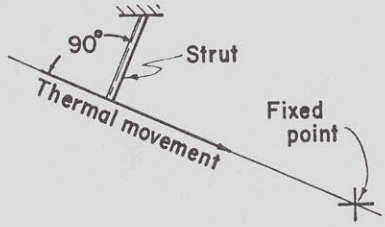

Figure 9 Strut arrangement for zero thermal stress

The iron flux-return yokes serve as part of the vacuum vessel. Each yoke is made of four 5-in.-thick plates of SAE 1010 steel which are ground flat on the mating surfaces. Just prior to assembly, a bead of Dow Corning Silastic 732 RTV is applied to the surface of each plate near the edge of the hole. Upon assembly, the Silastic squashes flat, cures, and provides a vacuum seal. The plates are joined by skip welds on the outside. Finally, the hole is finish bored. A fabricated steel section is bolted and gasketed between the two yokes, and a similar section attached to each end. Aluminum plates cover the ends. A flangeless 8-in.-diam. bore tube, sealed to the end plates with external O-rings, completes the vacuum envelope.

The measured heat leak is 7 ℓ/hr at full current.

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TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720

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CURRENT UNDERSTANDING OF ERA

L. Jackson Laslett

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L. Jackson Laslett

Lawrence Berkeley Laboratory
University of California
Berkeley, California

Introduction

The electron ring accelerator has appeared to constitute a particularly attractive, or at least a conceptually straightforward, means for the acceleration of ions by use of collective fields. The potential advantages of collective-field acceleration were emphasized for many years by Veksler.[1] The report by Kolomenskii at the 1967 Accelerator Conference in Cambridge of an active electron-ring development program at Dubna,[2] under the direction of V.P. Sarantsev, stimulated the initiation of similar experimental programs and related theoretical studies by several other groups. It was hoped by many at that time that the formation of a high-quality ring of relativistic electrons would provide a holding field as great as at least a few hundred MV per meter and that acceleration of the ring then would permit trapped positive ions to be brought to high energies in a relatively short distance.[2,3] Other potentially useful characteristics of such an accelerator were also recognized -- as the availability of output beam pulses of short duration and the ability to accelerate simultaneously heavy ions of diverse charge/mass ratio.[4]

Now that electron-ring programs have been in progress for several years at a number of laboratories, it is indeed timely to inquire concerning our present degree of understanding with respect to the basic physical phenomena that can act to limit the performance of an electron-ring accelerator. It would appear premature at this time to attempt to specify the competitive economic position that such an accelerator could occupy for various applications -- more relevant at the moment is a quantitative and confirmed understanding of ring behavior, and of the implications of this behavior. Much of the effort during the past years of course necessarily has been devoted to the assembly of experimental equipment and, on the theoretical side, to the examination of alternative concepts for ring-formation and use. Nevertheless, quantitative experiments have been performed (and are being continued), related theoretical and computational analyses have been carried through, and useful information concerning relevant phenomena also has become available from work with synchrotrons and storage rings. These activities have led, as I hope to indicate, to an apparently good degree of understanding concerning several phenomena of importance, while a considerable amount of joint experimental and theoretical effort with respect to other phenomena remains to be completed before the performance capabilities of electron-ring accelerators can be confidently forecast. We of course have been encouraged during this work by the reported success of the Dubna group[5] in achieving He^{++}-ions of 30 MeV energy by magnetic-expansion acceleration through a distance estimated as 0.4m.

Problems of Basic Interest

The problems for which basic understanding and control are the most critical appear to be the following:

The stability with respect to single-particle betatron-oscillation resonances,

The stability with respect to collective oscillations of the electron beam -- transverse and longitudinal,

The stability with respect to collective electron-ion oscillations,

The radiation of energy by an intense ring beam during passage through an electric-acceleration structure, and

The selection of design parameters that conform to fundamental physical restrictions and lead to "optimized" performance.

Single-Particle Resonances

Early electron-ring experiments[6] at several laboratories have revealed beam loss or a degradation of beam quality attributable to single-particle betatron resonances -- notably at field-index values n = 0.5, 0.36, 0.25, and 0.2.[7] It is noteworthy that even the difference resonances associated with n = 0.5 or 0.2 evidently can lead to unacceptably large axial amplitudes through the resonant coupling of axial and radial betatron oscillations.

Analytic studies of betatron resonances of course have been made[8] for application to more conventional devices, and the analyses can be directly adapted[9] to describe such resonant behavior in an electron-ring compressor. One's understanding of these phenomena should be considered sound, particularly since the analyses can be monitored and the results readily checked by means of computer calculations. The phenomena do exist, however, and should be controlled in practical compressor designs.

Significant beam deterioriation as a result of betatron resonances can be avoided by suitable design of the compression cycle, so as to obtain a variation of n with time ("n-trajectory") that neither leads to the crossing of resonant values immediately after injection nor to slow traversal of such values at any stage of the compression cycle. The reduction of large spatial non-linearities of the magnetic field can also be desirable. In the case of inhomogeneous resonances, which are driven by azimuthal variations of the field, reduction of azimuthal inhomogeneities also can be helpful -- as has been shown experimentally by, for example, some recent experiments[6c] at Garching relating to the n = 0.25 resonance.

Attention to the points just mentioned should permit suppression of resonant beam loss and preclude any significant degradation of beam quality. Rapid compression cycles, which can be attractive for other reasons, have been favored by some workers[10] as an effective technique for reducing resonant effects. It should be noted that betatron resonances other than those mentioned here may warrant attention if the field at the orbit does not exhibit median-plane symmetry or if an azimuthal component of magnetic field is present. Thus if a supplemental azimuthal magnetic field ("H_θ-field") is provided, as has been advocated in some reports,[11] the $\nu_z = 1/3$ single-particle resonance may become prominent[12] and require study. During acceleration of the ring, moreover, when some ion focusing will be present but the axial magnetic field will provide negligible axial focusing and orbit curvature introduces some defocusing,[5,13] supplemental image focusing (e.g., by a suitably slotted cylinder-like screen or "squirrel

cage"[11a]) or use of an H_ϕ-field[11] may be desirable.

Coherent Oscillations

Coherent beam oscillations have been observed, and in many cases stabilized, in a large number of particle-handling devices. There also has been a great amount of analytic work devoted to this topic, for which the results considered most relevant to electron-ring performance have been summarized in a recent paper.[14] The collective phenomena of course are driven by self-generated electro-magnetic fields, whose magnitude and phase will be significantly influenced by the surroundings and that possibly may be resonant with the vacuum chamber within which the beam is situated. It has been found convenient in recent work to characterize the effective $\vec{\mathcal{E}} + \vec{v} \times \vec{B}$ driving field that arises in this way by a complex "coupling impedance",[15] defined as $Z_M = - C \mathcal{E}_{eff}/I_M$, where C is the orbit circumference and I_M is the current of the associated collective-oscillation mode. In some instances measurements of Z_M can conveniently be made by electrical means.[16]

The dynamical analysis of a potential collective instability customarily commences with the Vlasov equation, which normally is linearized about a simple (e.g., unmodulated) equilibrium state, and the nature of complex solutions ω to the resulting dispersion equation are then sought for various assumed distribution functions that can provide some Landau damping.[17] In the event that any of the simplifying assumptions required for the analysis appear to be unrealistic, recourse may be had to alternative techniques of a computational nature and simulation programs[18] relating to phenomena occurring in electron-ring devices have begun to be applied for this purpose.

Transverse Coherent Stability -- The transverse stability of a coasting (unmodulated) beam, moving in the presence of walls of a high conductivity and a thickness at least as great as several skin depths, has been investigated analytically and the results applied in assessing the possible performance characteristics of electron-ring accelerators.[14] The results indicate that, for the assumed conditions, the transverse collective stability of a high quality ring beam can easily be achieved by the Landau damping normally associated with only a modest amount of energy spread.

Some experiments during the latter part of 1970 with Compressor 4 at Berkeley did show, however, a radial instability of this nature at certain radii and the associated radio-frequency signals were observed to be of frequency $(M-\nu_r)\omega_\odot/2\pi$ with $M = 1$.[19] The circumstances of these particular experiments were somewhat special in that, as one feature, the thin metallic side walls of the chamber, situated about 3.5 cm to either side of the ring beam, had a surface resistance $R_s \cong 50\Omega/\square$ to permit virtually unimpeded penetration by the pulsed inflector field. Recognizing this special nature of the side walls, Lambertson pointed out that radial oscillations of the beam current could induce wall currents whose magnetic fields would act regeneratively on the oscillating beam and that a specific analysis (valid for large R_s) would be desirable. Neglecting the somewhat smaller effect of wall currents arising from the motion of electrostatically induced charges, the e-folding growth rate of a collective radial oscillation in the absence of Landau damping could be estimated as[20]

$$\frac{1}{\tau_G} \cong \frac{N r_e \beta^2 c (M-\nu_r)}{4\pi \gamma \nu_r h R R_s} Z_o f(h/R)$$

for a ring of radius R containing N particles, where r_e is the classical electron radius, $Z_o = \sqrt{\mu_o/\epsilon_o} = 377$ ohms, and the curvature factor f is of the order of $1/2$. With the parameters characteristic of Compressor 4 at that time, a ring beam of no more than 5×10^{11} electrons thus could be expected to lead to growth rates of the order of 1.6 μsec^{-1} (for $M = 1$) unless suppressed by Landau damping, and for more intense beams ($N \cong 10^{13}$) the growth rate to be suppressed would be correspondingly greater (e.g., 32 μsec^{-1}).

Landau damping of the transverse collective oscillations is provided most effectively by energy spread in the circulating beam and stability requires an energy spread sufficiently great that[21]

$$\left|(E\, \partial S/\partial E)(\Delta E/E)\right| > 1/\tau_G,$$

where

$$S \equiv (M - \nu_r)\omega_\odot$$

and

$$E\, \partial S/\partial E = - \frac{1}{\beta^2}\left[(M-\nu_r)\left(1 - \frac{1-n}{\gamma^2}\right) + R \frac{\partial \nu_r}{\partial R}\right] \frac{\omega_\odot}{1-n}$$

with $\partial \nu_r/\partial R$ typically a negative quantity. Following a suggestion of Sessler concerning the possibility of a strong cancellation of terms within the square bracket of the equation for the damping coefficient $E\, \partial S/\partial E$, it was found[22] that eddy currents induced in the windings of the Stage-2 compression coils indeed did result in the Landau damping coefficient for the radial mode $M = 1$ becoming essentially zero some 20 μsec following injection. Substitution of a coil formed of stranded conductors served to suppress the eddy currents and raised the damping coefficient sufficiently that the radial instability was no longer observed. A corresponding re-design of the Stage-2 and Stage-3 coils of Compressor 5 (through use of thin-walled stainless-steel tubing) has likewise removed the similar undesired suppression of $E\, \partial S/\partial E$ at certain radii in that device, with the result that the calculated value for this quantity remains above 550 μsec^{-1} throughout the compression cycle.[23] Thus, although the nature of the walls of a compression chamber may be modified in future designs, the effectiveness of the Landau damping coefficient for suppressing collective radial instabilities appears to be understood and reasonably effective. Further control of this damping coefficient can be obtained, if desired, through the introduction of a supplemental azimuthal magnetic field.[24]

An alternative way of examining the effect of resistive walls may be useful for application to an injected beam with considerable radial or azimuthal structure -- especially when investigating the dynamical consequences computationally. In introducing this alternative approach, it is helpful first to think of a line of charge and current suddenly established in the mid-plane between two parallel resistive walls. At that instant full strength electric and current images should arise (since the side plates will momentarily shield the exterior region from the beam), and the effective $\vec{F} = \vec{\mathcal{E}} + \vec{v} \times \vec{B}$ image field in the interior will be small ($\propto 1/\gamma^2$) for β close to unity. Due to the resistance of the side plates, however, the induced currents will re-distribute and attenuate in a calculable way, with the result that the effective $\vec{\mathcal{E}} + \vec{v} \times \vec{B}$ field at any point in the interior will grow in magnitude to approach the field $\vec{\mathcal{E}}$. The changing magnetic image field does not exhibit an identical time behavior at all points, but for computational purposes the change of the image-field focusing coefficient may be conveniently characterized by a time constant that calculations indicate is of the order of $\tau_W = \mu_o h/2R_s$ (MKS). In orbit computations with a beam that is shifting its

location, the effective image field at each of many sampling points in the interior then may be continually updated by means of differential equations that contain the "time constant" τ_W as a parameter:

$$\frac{dF(\vec{r})}{dt} = \frac{1}{\tau_W}\left[\sum_k \lambda_k E_1(\vec{r},\vec{r}_k) - F(\vec{r})\right] ,$$

where $E_1(\vec{r},\vec{r}_k)$ is the (electric) field initially developed at $\vec{r}$ by a unit line charge at $\vec{r}_k$.

This type of analysis of the electromagnetic problem, if applied to a line current oscillating transversely about the axis of a resistive circular tube and the results expressed in a Fourier form, appears to give agreement (for $R_S < Z_o/2$ and wall thickness $< 1.7\ \delta$) with values of the quantity V (customarily employed in perturbation treatments of beam stability) obtained from a program[25] based on general methods developed at CERN by Zotter.[26] To the extent that this is correct, the quantity $1/\tau_G$ for a growing collective oscillation of specific frequency, should (as mentioned before) be proportional to $1/R_S$ when the wall resistance is high but should be directly proportional to R_S for walls of rather low resistance [$\rho_V/\delta < R_S < \mu_o h\omega/2 = \mu_o h(M-\nu_r)\omega_o/2$]. We thus have been led to employ walls with a surface resistance considerably less than $1\Omega/\square$ -- for example $1/15\ \Omega/\square$ ($\tau_W \cong 300$ nsec) -- while providing one or more small windows for introduction of the inflector field. The adoption of low resistance walls, moreover, also should be favorable with respect to a longitudinal collective instability. Dynamical computations with respect to the transverse instability then indicate growth rates distinctly less than 1 μsec^{-1} for circulating beams of 10^{13} electrons in the absence of Landau damping and accordingly, as we have found, a very moderate energy spread may suffice for the suppression of this instability.

Longitudinal Coherent Stability -- The potential longitudinal (azimuthal) coherent instability of an intense beam has been seen to develop and is of considerable interest in connection with synchrotron accelerators,[27] storage rings, and electron-ring devices. The necessity of avoiding this particular potential instability indeed may present a major limitation to the attainable performance of electron-ring devices. Experimental work at Berkeley on the formation of rings of various intensities has shown that a greater amount of energy spread is necessarily present when stable rings of high intensity are achieved. The analytic result for the stability limit, expressing the maximum permissible number of particles in terms of a longitudinal coupling impedance Z_M for the mode M of interest,[28]

$$N = |\eta| \frac{\gamma R}{2\beta^3 r_e} \frac{Z_o}{|Z_M|/M} \left(\frac{\Delta E}{E}\right)^2$$

(in which $|\eta| = |(1-n)^{-1} - \gamma^{-2}| \cong (1-n)^{-1}$ for an electron-ring device), has been confirmed experimentally at CERN -- especially in a series of careful experiments with the I.S.R.[29]

The achievement of high-quality rings accordingly requires that the longitudinal coupling impedance Z_M -- or, strictly, $|Z_M|/M$ -- be kept low for a large number of modes. Careful design of an electron-ring device therefore will undertake to suppress the coupling impedance for low modes by the use of (longitudinally) conducting material close to the beam, will attempt to avoid (or to degrade) electro-magnetic resonances, and will aim for an impedance characteristic that for the higher mode numbers is close to that characteristic of a beam in free space ($|Z_M|/M \propto M^{-2/3}$). Calculations have been made of the values of Z_M/M for a wide variety of configurations potentially suitable for an electron-ring device, of which one[30] indicated the utility of situating the ring beam, at the time of its release from the magnetic well, between a pair of coaxial conducting tubes and preferably close to the inner member of the tube pair.

It will be recognized that the location of a conducting surface with little radial clearance to the beam, in the interests of reducing $|Z_M|/M$, precludes the presence of substantial energy spread, that will act to provide Landau damping but that also will lead to an increased radial spread of the beam. A good design would need to achieve, therefore, a suitable balance between these effects. Also, of course, a conducting surface of simple design, if situated at a radius only slightly smaller than that of the ring beam, necessarily must reduce the effectiveness of a pulsed (or RF) electric field intended to accelerate the ring in an electric acceleration column. In the successful magnetic-acceleration experiments reported from Dubna[5] it is difficult to see how values of $|Z_M|/M$ as low as would be required theoretically for stability could have been present throughout the acceleration. We may conclude, therefore, that the maintenance of azimuthal stability under such conditions should be no more difficult than is suggested by the present theory.

Stability with respect to azimuthal collective oscillation of course is essential throughout the compression stage of an electron-ring compressor. The situation immediately following injection may, in particular, be rather different than that just discussed. Specifically, the beam may have an initial density modulation of substantial magnitude as a result of the injection process. The beam also may be composed of several rather distinct turns, it may have a progressive energy variation along its length, and the amplitude of betatron oscillations may be significantly great. Simulation programs seem particularly attractive for the study of the de-bunching (or bunching) of circulating beams immediately following injection. We have begun to make simple computations of this nature at Berkeley, and the early results appear to be in general agreement with expectations -- it remains to be seen whether use of such programs can realistically be extended to give insight into the interpretation of experimental results obtained under various conditions with rings that have survived for many hundreds of turns.

Collective Electron-Ion Oscillations

The possibility of unstable transverse collective oscillations of ions vs. electrons in an electron-ring accelerator was considered in several early papers,[3] and recently has been examined in greater detail with respect to both dipole and quadrupole modes by Zenkevich and Koshkarev.[31] Ion-electron instabilities of the type described by this analysis indeed appear to have been observed in conventional accelerators such as the Bevatron.[32] The work of Zenkevich and Koshkarev certainly indicates that the achievement of stability with respect to this type of motion can restrict the performance of an electron-ring accelerator -- at least with respect to the number of ions that can safely be trapped by the electron ring beam. A further, somewhat detailed, examination[33] of the influence of Landau damping, of intra-species forces, and of image effects suggests, moreover, that these effects in practice will not prove to be significantly helpful.

Radiation Reaction

The radiation reaction experienced by an intense electron ring in passing through a periodic structure

(as in an electric-acceleration column) was of considerable concern during the past years,[3] especially because it was uncertain whether the energy loss from this mechanism would increase with γ_z. The situation seems now to have become clarified, as a result of experimental work at SLAC,[34] computations by Keil,[35] and analytic calculations.[36] The conclusion, as summarized in a recent panel discussion,[37] is that the radiation loss per cell fortunately exhibits no γ dependence over a wide range of energies, the electron-ring dimensions do not affect the loss in a critical way, but the reaction force is substantial unless the bore of the acceleration column is large.

Expected Performance Characteristics

The selection of "optimum" parameters for a complete electron-ring compressor and acceleration system would be an extensive task and, moreover, would be influenced by the figure-of-merit considered appropriate to the application of interest. Information to stimulate discussion can be gained, however, by employing[14] current concepts to up-date an earlier analysis[38] -- with particular emphasis on the holding field for protons that could be produced by a stable electron ring at the end of compression. To present a highly simplified summary, one may express the useful holding field (in the absence of safety factors) as[39]

$$e\mathcal{E} \cong \frac{Ne^2}{\pi R(\sigma_a+\sigma_b)} \frac{1}{\alpha}$$

for a ring of N electrons, of major radius R, and with radial and axial minor dimensions of standard deviation σ_a, σ_b, while α is a factor that should be at least as great as 2 for magnetic acceleration.[14]

If we now confine our attention solely to the important requirement of azimuthal collective stability and write[30]

$$|Z_M|/M = 300 \frac{h}{R-h} \sim 1200\ \sigma_a/R \text{ ohms}$$

for a ring situated a distance $h = 4\sigma_a$ from a conducting tube, the stability limit occurs for

$$N = \frac{377}{2400} \frac{\gamma R^2}{r_e \sigma_a} \left(\frac{\Delta E}{E}\right)^2$$

and

$$e\mathcal{E} = \frac{377}{2400\pi\alpha} \frac{\gamma R}{\sigma_a(\sigma_a+\sigma_b)} \left(\frac{\Delta E}{E}\right)^2 (m_o c^2).$$

With $\Delta E/E$ at most given by $2.36\sigma_a/R$ (betatron-oscillation amplitude small) and $\sigma_a \gg \sigma_b$, then

$$e\mathcal{E} = \frac{377\ (2.36)^2}{2400\pi\alpha} \frac{\gamma}{R} m_o c^2.$$

For highly relativistic particles circulating in a guide field of strength B gauss, $\gamma/R = (e/m_o c^2)B$, and, for electrons, $\gamma/R = 5.867 \times 10^{-4} B$. We thus obtain, with $\alpha = 2$,

$$e\mathcal{E} = \frac{377\ (2.36)^2}{(2400\pi)\ 2} (5.867 \times 10^{-4})(0.511 \times 10^6)B$$

$$= 41.7\ B \text{ ev/cm for } B \text{ in gauss}$$

$$= 4.17\ B \text{ MeV/m for } B \text{ in kilogauss.}$$

Thus for $B = 20$ kilogauss and magnetic acceleration of the electron ring, the maximum effective acceleration field for trapped ions becomes approximately 83 MV/m, which could be attractive for some applications, although recognition of additional constraints may lead to smaller estimates for this field.[14] Higher values of the guide field B of course could lead to larger values of the useful acceleration field [as has been noted by Möhl (ERAN-178)], but such an increase would not necessarily be advantageous economically.

Conclusion

In conclusion, one can state that understanding of beam stability has been, and continues to be, particularly important to development of the ERA. The situation in this regard appears to be reasonably well in hand for single-particle resonances and for transverse collective motion. Knowledge concerning characteristics of the longitudinal instability is being acquired experimentally. There is available a considerable volume of theory pertaining to this phenomenon and to electron-ion collective motion also. Work at present is actively continuing with the object of establishing the connection between experimental observations and the theory. Simulation programs are beginning to aid in extending the theoretical work, and most importantly, it is gratifying that the experimental programs of several ERA groups have arrived at the point where quantitative experiments can be designed and conducted to test our present understanding and to stimulate its further advance.

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TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720

UNIVERSITY OF CALIFORNIA

LAWRENCE RADIATION LABORATORY
BERKELEY 4, CALIFORNIA

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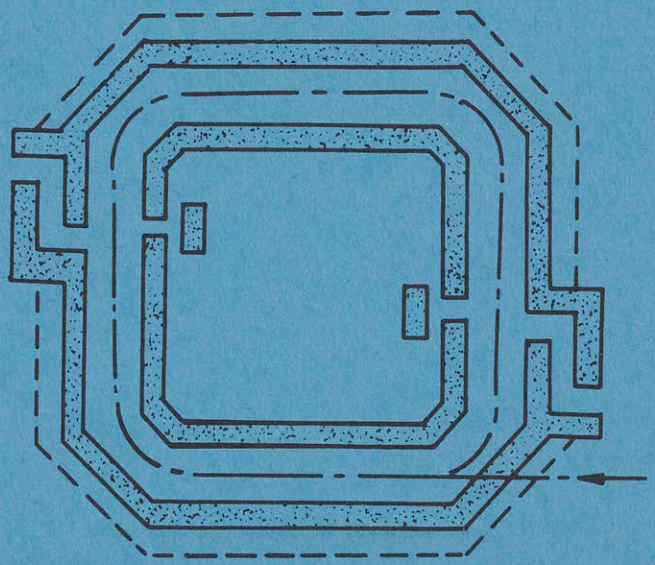
TO: HEPAP MEMBERS

The paper enclosed is to be included with the material sent to you for the HEPAP Meeting on October 3.

SUPERCONDUCTING ACCELERATOR MINIPROJECT

(Concept and Intent)

Sept. 1973



Accelerator Study Group
Lawrence Berkeley Laboratory
University of California, Berkeley

SUPERCONDUCTING ACCELERATOR MINIPROJECT
(Concept and Intent)

Accelerator Study Group*

Lawrence Berkeley Laboratory
University of California
Berkeley, California

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A. INTRODUCTION

The Miniproject is the planned development of a relatively small (~4 GeV) superconducting synchrotron and storage ring system. As it is the first system of this kind, the project is envisioned as a design exercise and experiment in accelerator technology. Some of the concepts are outlined in this report. It is expected that these features will become better defined as the evolving design develops to best meet the needs of the national high-energy physics programs.

The intent is to investigate in a comprehensive manner the overall feasibility of a superconducting system and thus more rapidly bring the projected advantages of superconducting technology into utilization. It is desired to

*See p. 29

derive information which will help to insure that the planning and design at future superconducting synchrotrons and storage rings will be carried out in the most knowledgeable manner. Clearly the engineering design and the construction experience gained from the Miniproject will be valuable; however, equally important are the new techniques and emphases that will arise out of actual operating experience. Finally, assuming a successful operating machine, there are a number of important experiments with circulating protons that will provide better understanding of the dynamics of high-current stored beams and thus will serve to guide efforts toward high luminosity in future storage machines.

1. Background

Colliding beam systems appear to offer the most advantageous method for a large-scale extension of experimental parameters in elementary particle physics. The successes of the ISR at CERN and of SPEAR at SLAC—as well as ACO, ADONE, VEPP-3, and CEA—have forcefully indicated this direction. The importance and widespread interest in colliding beam physics are evidenced by a number of studies active at this time. The PEP, ISABELLE, and EPIC studies, in particular, involve proton storage rings with energies in excess of 100 GeV. The NAL energy doubler program is seeking to provide an extension of the conventional accelerator system with a proton ring in excess of 500 GeV.

In each case, superconductivity provides for a significant advantage in magnetic field strength; hence, for a given energy, it makes possible a reduction in physical size of the ring system. In addition, superconductivity offers the possibility of substantial reduction in operating costs with respect to power utilization. This aspect could be of critical importance in the future.

Superconducting beam elements have been constructed successfully at various laboratories; however, there are a number of problems to be resolved before a high degree of confidence can be placed in their full-scale utilization for a large accelerator system. There is no operating experience with a system of this kind. Such experience will undoubtedly point out unforeseen problems and will indicate further developments to be undertaken in order to achieve reliable operations. The Miniproject will provide the experience and expedite the developments on a modest but realistic scale.

With a similar goal for advancing the state of the art of new accelerator technology, the HEPAP subpanel on Advanced Accelerator Concepts (1971) set up the following criteria for small-scale projects. The project should:

a) make use of new ideas on technology in a practical way;
b) be built at an existing laboratory;
c) be useful and exploitable for research;
d) cost on the order of 1 M$/year.

The HEPAP subpanel further outlined the advantages of such a plan:

1) It would bring about the solution of many unsolved and unforeseen engineering problems.
2) It would provide experience for more intelligent selection of new technology items.
3) It would bridge the gap between the present and the next generation of accelerators.

The Miniproject is believed to meet effectively the general criteria advanced by the HEPAP subpanel.

2. Purpose

The fundamental goal is to prove in a comprehensive manner the feasibility of constructing and operating a superconducting accelerator system. In size and concept the project should provide a system flexible enough that modifications, improvements, and beam experiments can be incorporated as new ideas or specific problems arise. It will be advantageous to have close liaison and collaboration with other laboratories so that specific design features related to their interest can be accommodated.

This goal necessarily involves the realities of instrumenting and operating a complete synchrotron with cryogenic magnets, which will force attention to the interaction between the new magnet types and the many other necessary components in the ring. The design must provide for injection, beam disposal, rf acceleration, beam storage, ultra-good vacuum systems, and instrumentation for the determination and implementation of field corrections and beam studies. It will be learned to what extent these functions are compatible with the cryogenic features of the accelerator, or will force modifications of the design. A less complete test of superconducting magnet units would not provide realistic information on how to live in a superconducting environment at an accelerator. The interaction of other components with the main magnets is an important factor in synchrotron-storage ring design

and cost which will be given appropriate emphasis in this trial of the new technology.

It is necessary to know what modifications in operating care and maintenance will be required by superconducting systems compared with conventional magnet systems. The total aspects of large-scale refrigeration systems, helium distribution, radiation damage, and other engineering and material design problems will be ascertained to fully evaluate the overall economics.

The procedures required for achieving magnet design criteria under production conditions will be determined. Also, various methods for field corrections as required can be experimentally verified. In addition, long-term fatigue effects or possible changes in the superconducting elements can be noted. Finally, the suitability of cryopumping and other vacuum techniques will be investigated.

3. Potential for Extended Research

Some of the present design considerations for high-energy colliding beam devices are making new demands, for example, on beam densities, magnet tolerances, and rf systems. Although theoretical calculations are helpful in defining potential limitations, it will be necessary to study experimentally the problems created by the new demands and to provide appropriate solutions.

The Miniproject should be able to provide additional information with regard to some of the beam effects in question. The relatively long straight sections provide space for such things as special diagnostic components, low-β insertions, or additional rf systems to accomplish strong bunching—as required, for example, in the PEP device now under study. Effects of rf noise, beam loading, etc., would also be evaluated. A vacuum pressure of $\leq 10^{-10}$ torr will permit long storage times, and the available shielding will be adequate for circulating intensities up to 5×10^{12} protons.

In the recent PEP Summer Study, a number of problems were discussed for which various devices such as SPEAR, the ISR, the Doris e^-p project, and the LBL Miniproject would provide important contributions toward future storage rings. Listed below are some suggested studies or experiments for the Miniproject:

1) Bunch stability. This covers investigation of numerous effects:
   a) coupling of the beam to its surroundings,
   b) bunch-broadening phenomena (transverse and longitudinal),
   c) multibunch effects,

d) rf noise,

e) intrabeam scattering.

2) Beam-vacuum interaction. What are the effects on bunched and unbunched beams for various current levels?

3) Problems in achieving low-β. What are the limits for β_{max}, chromaticity? Investigation of correction elements and tolerances.

4) Investigation of new diagnostics for measurement of bunch length and size.

5) Self-bunching possibilities. Can short bunch lengths be achieved via high-frequency passive cavities?

6) Tolerances achievable with superconducting elements with beam as a diagnostic.

7) Investigation of methods for correction elements, i.e. superconducting or conventional, lumped or distributed?

8) Flexibility for lattice structure variations and trial of different types of superconductor.

9) Investigation of radiation damage effects and fatigue effects on superconducting elements.

10) Investigation of cold-bore vs. warm-bore vacuum systems. Effects with bunched and unbunched beams.

11) Studies of crossing transition energy and the limiting conditions.

12) Simulation of beam-beam effects with electron beams or external conductors.

4. General Features

The maximum proton energy for the Miniproject is approximately 4 GeV. The main field elements are comprised of 16 dipoles and 32 quadrupoles which are arranged in a lattice structure of ~ 24-meters diameter. The loosely packed structure with four-fold symmetry and relatively long straight sections is desirable for maximum flexibility in development and experimentation. The general goal for intensity is ~ 5×10^{12} protons. The acceleration or magnet rise time is ~ 5 seconds, which will allow initially a repetition rate of 6 pulses/minute. The beam could also be stored at a given energy for as long as desired or practicable. The pulse rates are determined by the initial magnet power supply and refrigeration system.

These general parameters, which are described more fully in latter sections, were selected in order to obtain an accelerator system of reasonable scale, and yet be within a practical cost region. They are, of course, subject

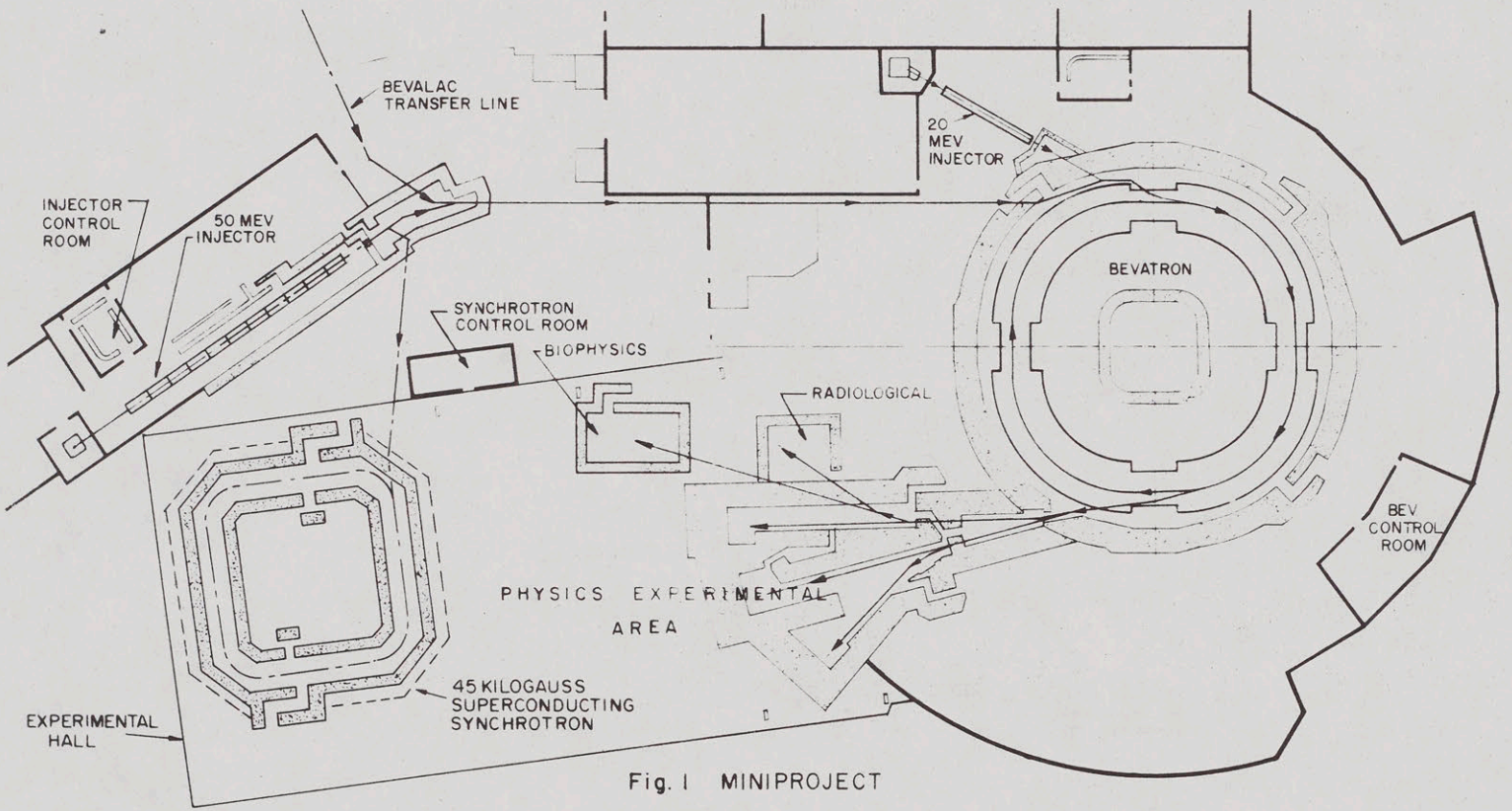

Fig. 1 MINIPROJECT

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to refinement as the system is studied in greater detail.

The overall orientation of the ring is shown in Fig. 1. The new 50-MeV linac for the Bevatron will be used for injection as it is conveniently located near the Miniproject site. This site is within the Bevatron experimental annex building, which provides a heavy-duty concrete floor for the foundation, 30-ton crane coverage, and outlets from the existing underground utility tunnel that are ideally located near the center of the ring. This location is not expected to cause any major interference with the Bevatron experimental areas. Besides locally available water and electrical power, there also are local mechanical and electronics shops and other maintenance-type support.

The ring geometry and the location of principal components are shown in Fig. 2. The injection line and beam dump area are located in the south straight section. The beam is injected in the vertical plane from beneath the magnet ring. The east straight section is used for the low-frequency rf accelerating station. The other two straight sections are planned for experimental use and diagnostics. In Fig. 2, for example, passive high-frequency cavities to be utilized for bunch compression are indicated in the west straight section.

The beam elevation is ~ 48" above the floor, and the shielded enclosure is 7' × 7'. Mechanical pumps, power supplies, cold boxes, etc., will be located in the center of the ring. Tentative location of the control room and compressor area is shown in Figs. 1 and 2, respectively.

B. LATTICE SYSTEM

The magnet lattice proposed for the synchrotron is a rounded square of which one quadrant (equivalent to a cell or superperiod) is shown in Fig. 3. The separated function alternating gradient structure has reflection symmetry about the centers of the long straight sections and about the centers of the arcs. The focusing structure consists of eight quadruplets of FDDF lenses. The distances between the quadruplet centers are alternately 9.5 m and 12.5 m; the former contain the 6-meter drifts, the latter contain the dipoles. One could also characterize the lattice as containing eight cells and four superperiods, or four cells with bending separated by four straight section insertions. The principal advantages of this lattice are the following:

1. The presence of sufficient straight section length and number for rf, injection, beam dump or extraction systems, and for correction, monitoring, and experimentation.

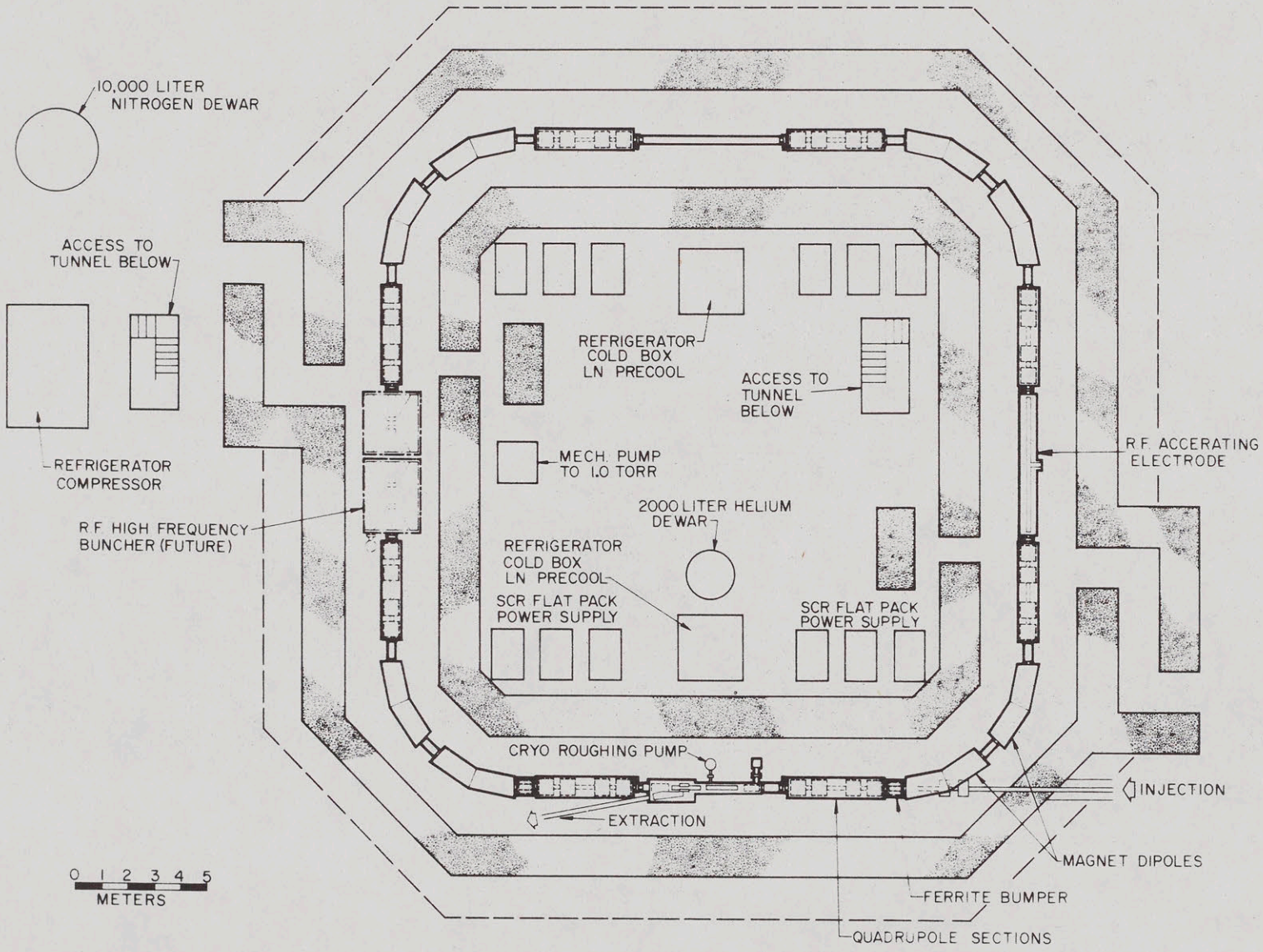

Fig. 2. Ring geometry.

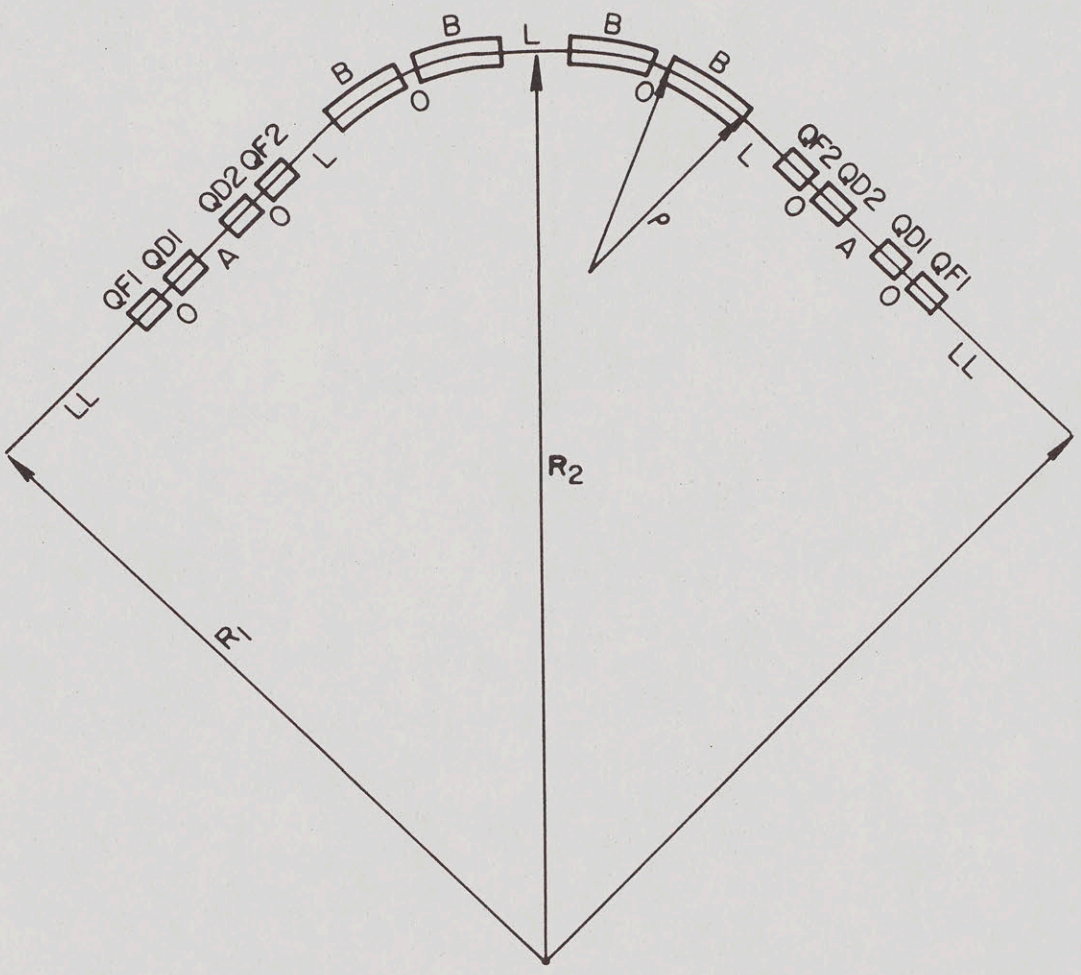

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Fig. 3. Quadrant of synchrotron.

Circumference/2π	R	14 m	Quadrupole length	0.6 m
Inscribed radius	R_1	12 m	Dipole length B	1.4 m
Circumscribed radius	R_2	14.9 m	Drift lengths: LL	3.0 m
Magnetic radius	ρ	3.565 m	O	0.2 m
Cell length	L_c	22.0 m	A	0.7 m
Circumference	C	88.0 m	L	1.0 m

2. The periodicity four has a working point $\nu_x = \nu_y = 3\frac{1}{4}$ where there are no structure resonances lower than 5th order in the half-integer square.
3. The transition energy $\gamma_t \sim 8$ is well above the peak energy; crossing transition with 5×10^{12} protons would be difficult at best. (In a regular FODO lattice one has $\gamma_t \sim \nu$, rather than $\gamma_t \sim 3\nu$ as we have here. The difference arises from the alternation of open and bending cells, and the strong QF2 lenses that push the off-momentum orbit to negative values in the dipoles.)
4. The lattice can be run at different ν values, and γ_t can be varied independently of the tunes over a wide range.

The most obvious disadvantage is larger apertures than would obtain in a simple FODO lattice with the same number of quadrupoles. On the other hand, the grouping of quadrupoles and dipoles in the structure outlined above has certain simplying features from the construction standpoint. Other alternatives to the lattice proposed here are being evaluated. The lattice parameters are listed in Table I; betatron functions are shown in Fig. 4.

C. SUPERCONDUCTING SYSTEMS

1. Magnet Design

LBL pulse dipole program. LBL has been developing low-loss, rapidly pulsed, relatively small-bore dipoles for potential use in superconducting synchrotrons. Central dipole fields of 40 kG have been achieved in a 3-inch I. D. dipole, about 1-foot long, with a maximum repetition rate of one pulse per second. A similar scaled-up design is contemplated for the Miniproject, which operates both as a cycled synchrotron and as a constant field storage ring.

Conductor and coil construction. Multifilament NbTi-in-copper wires are cabled together and compacted to form a rectangular conductor of 2000 to 3000 amperes capacity. The filaments are 5 to 10 μ diameter for minimum hysteresis loss and maximum flux jump stability. The cables are insulated with a spiral wrap of tape with a heat setting epoxy coating. The insulated cables are wound and bent to final form in a fixture, and then this shape is fixed by heating the assembly in an oven. The individual coils are then assembled on the bore tube with the various spacer blocks to form a rigid structure. The coils are permeable to helium and have excellent cooling and heat-removal qualities.

Table I. Lattice parameters

Magnetic field	B_0	45.0 kG
Design momentum	P	5.0 GeV/c
Kinetic energy	T	4.15 GeV
Quadrupole gradients:		
QF1		130.0 kG/m
QD1		-140.0 kG/m
QD2		-147.4 kG/m
QF2		198.1 kG/m
Number of cells	N	4
Betatron frequencies	$\nu_x = \nu_y$	3.25
Transition energy	γ_t	7.94
Beta function maxima:	$\hat{\beta}_x$	15.2 m
	$\hat{\beta}_y$	18.7 m
Dispersion maximum	$\hat{\eta}_x$	3.11 m
Injection (vertical stacking)		
Energy	E_{inj}	50 MeV
Linac emittance	ϵ_L	2π cm-mrad
Linac current	I_L	100 mA
Number of injected turns	n	20
Captured intensity	N_p	5×10^{12} protons/pulse
Stacked emittances	ϵ_H, ϵ_V	$4\pi, 16\pi$ cm-mrad
Bunched momentum spread	$\Delta p/p$	± 0.004
Required apertures (good field radii):		
Quadrupoles		8 cm*
Dipoles		5 cm

*Does not include considerations for injection orbit bump.

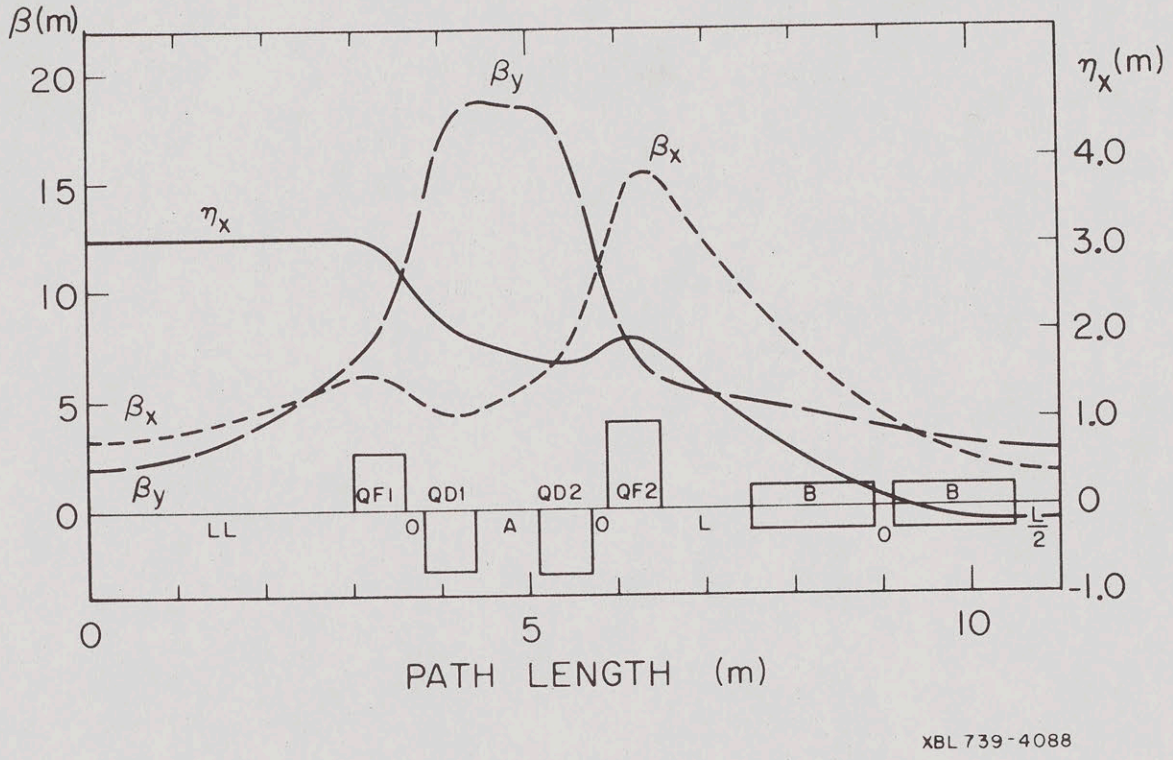

Fig. 4. Betatron functions.

Pulse rate. A magnet rise time of 5 seconds to full field has been chosen as appropriate for the Miniproject to demonstrate the applicability of pulsed superconducting magnets to proton synchrotrons. Shorter rise times, as low as 1 second, should not complicate the conductor or magnet fabrication unduly; and higher repetition rates could then be obtained by adding to the magnet power supplies and refrigeration plant.

Cold vs. warm iron. These relatively large aperture magnets can have larger hysteresis losses in a cold close-fitting iron return yoke than in the magnet superconductor. For pulse use, one may well wish to use warm iron and some added superconductor. Both options are being studied.

Curved vs. straight dipoles. Two types of magnets are being considered: magnets that are curved to conform better to the particle beam trajectory, and straight magnets. Straight magnets must be either very large in cross section or very short. Both factors tend to make them more expensive. But curved magnets are more difficult to build and therefore more expensive than straight magnets of the same size. A preliminary analysis indicates that curved magnets must cost 1.5 times as much as straight magnets of the same size in order for the costs of the two types of magnet systems to be equal. Large-cross-section straight magnets also have greater hysteresis losses and more stored energy. These factors tend to increase the cost of the magnet power supplies and the refrigeration system, and therefore tend to favor the curved-magnet system. Sketches of the curved magnet design are shown in Figs. 5 and 6.

2. Cryogenic System

Refrigeration system components. The cryogenic system includes: the helium refrigerator; the room-temperature helium supply system, including compressor, warm gas distribution, purification and storage, the cold-helium transfer lines, and J-T valves; the liquid nitrogen distribution system; and the installation of the system.

The refrigeration system is based on existing technology. The refrigerators contemplated are CTI model 4000 machines. These machines have reciprocating expanders (each machine has two expanders for redundancy and extra capacity during cooldown). Each CTI model 4000 machine will develop 950 W at 4.4°K or 750 W at 3.5°K. Helium is supplied to each machine at a pressure of 19 bar (270 psia), a temperature of 300°K, and at the rate of 100 gs^{-1} (1200 SCFM). Each refrigerator generates the above rates when it is

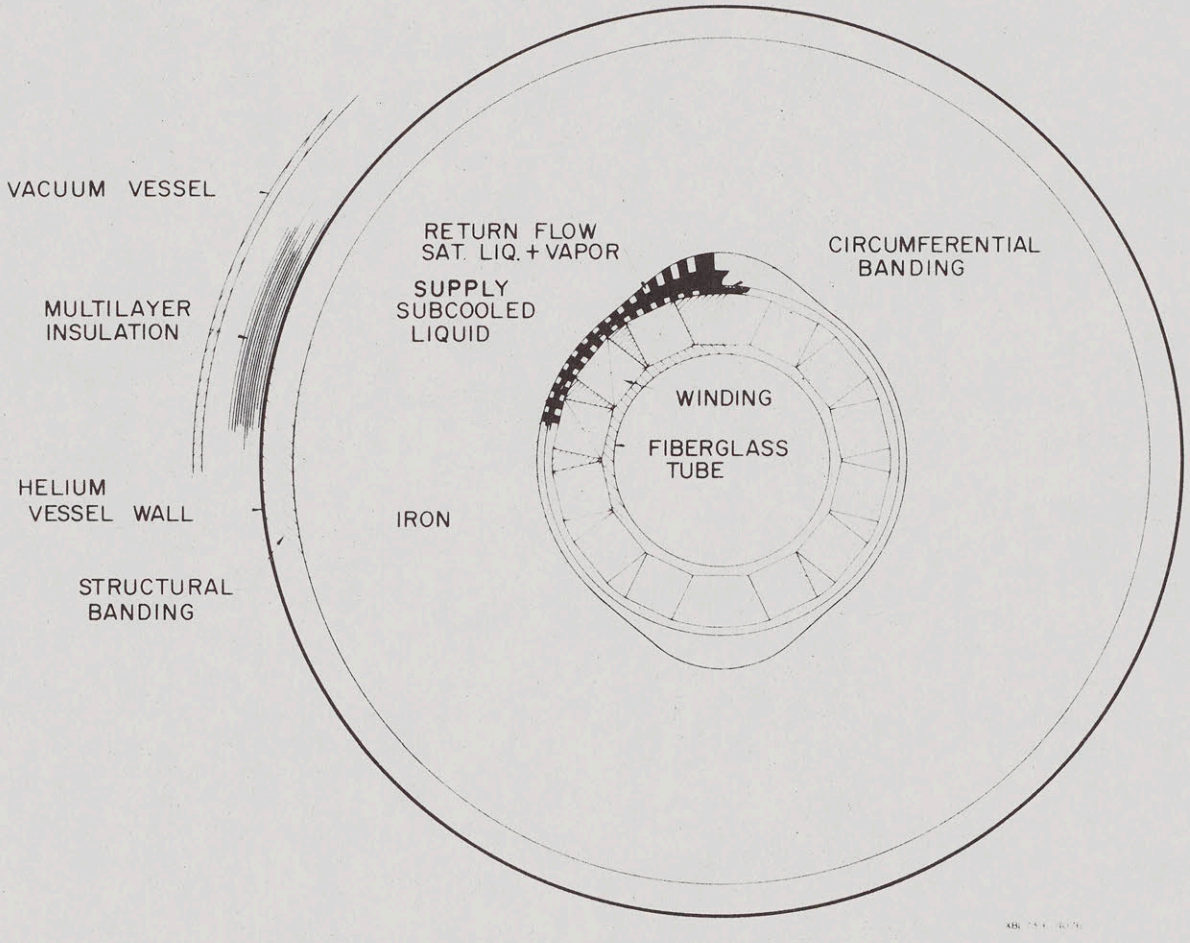

Fig. 5. Cross section of superconducting dipole.

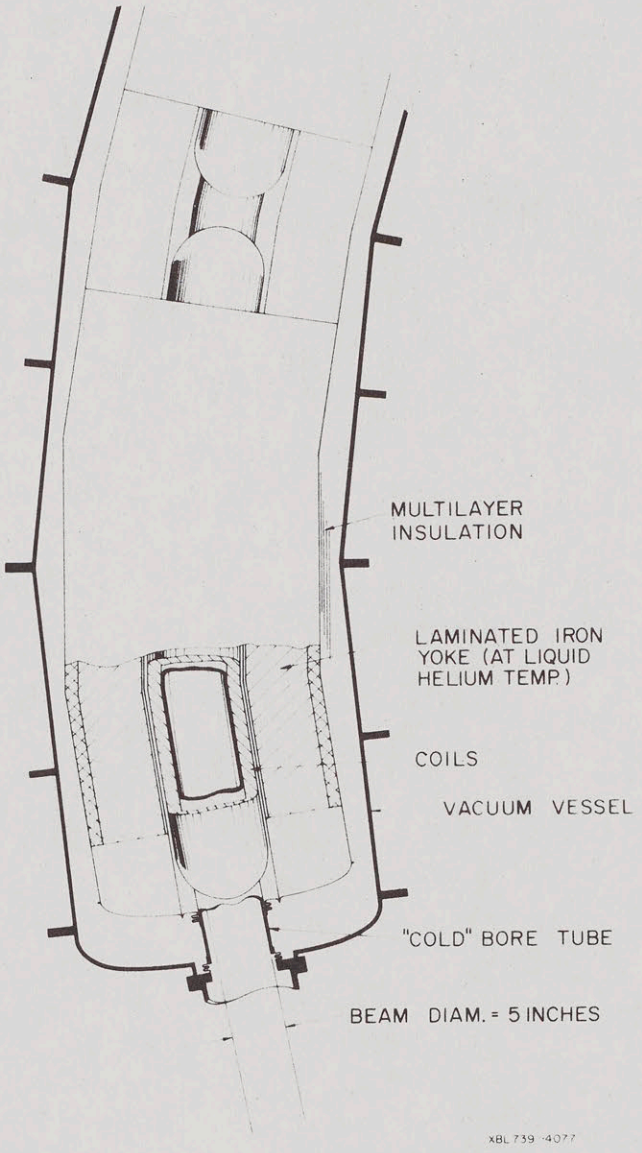

Fig. 6. Cut-away-view of superconducting "curved" dipole.

supplied with liquid nitrogen at the rate of 11 gs^{-1} (50 l/hr). Without nitrogen precooling, each refrigerator will develop 650 W at 4.4°K using one expansion engine. The refrigeration rate goes up to 850 W when both expansion engines are used.

The cold helium transfer line system is similar to a system now being completed at Karlsruhe. The transfer line system consists of a pair of rigid co-axial transfer lines. Each rigid line is assumed to supply 16 flexible co-axial transfer lines similar to those built for IEKP Karlsruhe by Vacuum Barrier Corporation in Woburn, Mass. J-T valves are installed at the end of each of the flexible transfer lines.

The primary mode of helium storage is in the form of liquid in a 2000 liter dewar. Secondary storage consists of 100 liquid liters of gas storage at atmospheric pressure and 400 liquid liters of storage at 16 bar (213 psig). Helium gas will be supplied to the system from a helium tube trailer. A purification loop is included with each refrigerator. The compressors for each refrigerator will require 450 kW of electrical energy.

Heat loads. The heat load comes from two sources: static heat leaks into the cryostats and vacuum pumps, and dynamic losses due to eddy currents and superconductor ac loss. Heating due to radiation or beam dumping into the magnets is assumed to be of low magnitude or infrequent.

The dipole magnets are housed two to a cryostat. The length of each cryostat is 3.2 m; the average static heat leak is 5 W per meter of 16 W per cryostat. There are 8 dipole cryostats. Each dipole cryostat has one pair of 2000-A electrical leads entering the liquid helium environment. Each pair of leads requires 20 W of refrigeration. The quadrupole magnets are housed four to a cryostat. There are 8 such cryostats, each being 2.0 m long. With 5 W per meter average heat load, the heat leak is 10 W per cryostat. An additional 20 W refrigeration is required for the electrical leads.

Twenty cryogenic vacuum pumps are assumed, including four cryogenic roughing pumps. The roughing pumps require 20 W each, while the high vacuum pumps require 5 W each. The two types of pumps do not operate concurrently. The total refrigeration allowance for the vacuum system is 80 W at 4.4°K and 1 to 2 kW at 80°K.

The transfer line losses are divided into two parts: the primary rigid lines and the flexible lines. Each of the two rigid lines is 16 m long and has

a heat leak of 1 W per meter. The flexible lines have a heat leak of 0.5 W per meter plus 0.75 W for each end. There are eight 6-m long lines, eight 7-m long lines, and twenty 8-m long lines. The expected heat load for the rigid lines is 32 W. For the flexible transfer lines, the expected heat load is 186 W. A summary of the static heat loads is shown in Table II.

Table II. Summary of the static heat loads at 3.5 to 4.4°.

Component	Heat Load (W)
Dipole magnet cryostats	128
Quadrupole magnet cryostats	80
Electrical leads (dipoles and quadrupoles)	320
Vacuum pumps	80
Transfer lines	218
TOTAL	826

The dynamic loss (superconductor ac losses) is estimated to be 5000 J per cycle for the dipoles and 500 J per cycle for the quadrupoles. The eddy currents are assumed to be small (about 1 W per meter at 0.2 Hz). The calculated dynamic loss is 278 W at 0.05 Hz, 560 W at 0.1 Hz, 700 W at 0.124 Hz, 935 W at 0.167 Hz, and 1140 W at 0.2 Hz.

Slow pulsed (0.02 Hz) or dc operation is possible on a single CTI model 4000 machine. Rapid pulsing of the Miniproject will require two model 4000 machines. If the refrigerators run at 3.5°K, the maximum magnet pulse rate is about 0.1 Hz (10-second cycle). If the operating temperature at the refrigerator is raised to 4.4°K, the maximum pulse rate increases to 0.18 Hz (a 5.5-second cycle). The use of two model 4000 machines appears to be a good match for the Miniproject. It should be pointed out that other options are available. Two model 4000 machines have been used to estimate cost and system performance.

3. Magnet Power Supply

The bending magnets power supply consists of seven 100-V 2500-A dc power supplies, each with a silicon controlled rectifier bypass, and one 100-V 2500-A dc power supply with a paralleled transistorized series-regulated 50-V 2500-A dc power supply. A magnetic field rise time of 5 seconds

requires 50 V of excitation for each of 16 magnets—each magnet having a 12.7-cm bore and 1.5-m length. Thus there are two magnets connected in series between each of the eight power supplies, all in series; the full magnetic field is realized at 2500 A. A single electrical ground reference is provided to limit the potential to ground to no more than 50 V. All power supplies are current regulated to 0.01%.

To provide the zero B dot at a given value of B the only voltage required is that necessary to supply the resistive drops and scr bypass drops. At the required field the 100 V dc power supplies are turned off; the magnet current then commutates into the seven bypasses and the 50-V power supply. The 50-V power supply with the series regulator establishes the zero B dot for the flat-top period. At the end of the flat-top period the 100-V power supplies are momentarily control fired in the rectification mode until the magnet current commutates into the 100-V power supplies; then the control angle is shifted to inversion to absorb the volt-seconds from the magnet. The energizing and de-energizing periods of the magnet are approximately the same length.

The peak power required from the electrical power grid to excite the bending magnets is 2 MW or 2.1 MVA; the average power depends on the pulse profile but can be 1.26 MVA for a 5-sec rise, 5-sec fall with zero flat-top and zero off times.

The quadrupole magnets require only one 100-V 2500-A dc power supply to energize all the quadrupole magnets in series.

The dc bus arrangement for the 16 bending magnets and 8 associated power supplies is a series loop folded back on itself to provide a zero field within the circumference of the ring.

The ac electrical power for the major loads requires transforming the LBL 12-kV power to 480 V for local distribution. The 12-kV power is available via an existing unused 15-kV power circuit breaker connected to the Bevatron pulsed regulated feeder; there is sufficient copper and reserve capacity to power the Miniproject; however, there is insufficient existing transformer capacity on hand. The major loads are: (1) power supplies (1.5 MVA), (2) cryostats (1.3 MVA), and (3) rf power (1.0 MVA). One 3.2-MVA 12-kV to 480-V 3-phase power transformer and associated 480-V distribution are required, and could be located at the centroid of electrical load density within the center of the Mini ring.

D. VACUUM SYSTEM

The Miniproject Vacuum System will be designed to operate at pressures in the region of 10^{-10} to 10^{-12} torr. It will have a vacuum volume of roughly 1000 ft^3 and a surface area of about 1000 ft^2. The basic vacuum requirement is that beam interactions with the residual gas and chamber wall be controlled so that beam loss is negligible and cascading pressure instabilities will not occur. The vacuum pumping will be essentially cryogenic throughout. The magnet cryostat insulating vacuums will be separate from the synchrotron main vacuum, and super-insulation will be kept out of the hard vacuum. The straight sections will contain cryopanels at around 4°K; for the curved sections, we propose to utilize the large and economical pumping speed of the 4.2°K cold bore magnets. The vacuum system will be bakeable to about 300°C, as a natural result of the use of ultra-high vacuum materials; but in practice the cold bore magnets need not be baked. It is not expected that routine bakeout will be required, except where the injection line approaches the ring.

1. Magnet Sections

Three options for magnet aperture cross-sections are considered. Each contains a dc clearing field, and the clearing electrodes in each design can be degassed of physisorbed H_2 at a low temperature by passing a dc current linearly through them. Differential thermal expansion due to degas heating should not be serious, and the electrodes will probably only require heating to about 50°K. Beam image currents and magnet eddy currents will create a heat load to the magnet bore of the order of a watt per meter. Although this is a small part of the total refrigerator heat load, adequate heat transfer must be provided.

Alternate 1: Cold bore—360° around the beam (Fig. 7a). In this case the extremely high pumping speeds will balance the high gas desorption rates up to some synchrotron ion beam current limit. The limit could be higher than beam currents planned for the accelerator. All desorbed gases are recondensed after one traversal of the bore, except H_2 which makes about three traversals, provided the concentration of hydrogen on the wall is less than one monolayer. One monolayer is easily achieved by the staged pumpdown and conditioning cycle described below. A comparison of this case with the experimental data from from CERN can be made with the Monte Carlo computer program of John Chubb (Culham Laboratory), which is presently in operation at LBL (Levinson, Milleron, and Davis, Vacuum Symposium Transactions 1960). In addition, a basic, absolute analysis should be made using the best available experimental data on ion production cross sections, desorption rates, etc. The best analysis likely at this time should be tested experimentally before the simple cold bore alternate is rejected.

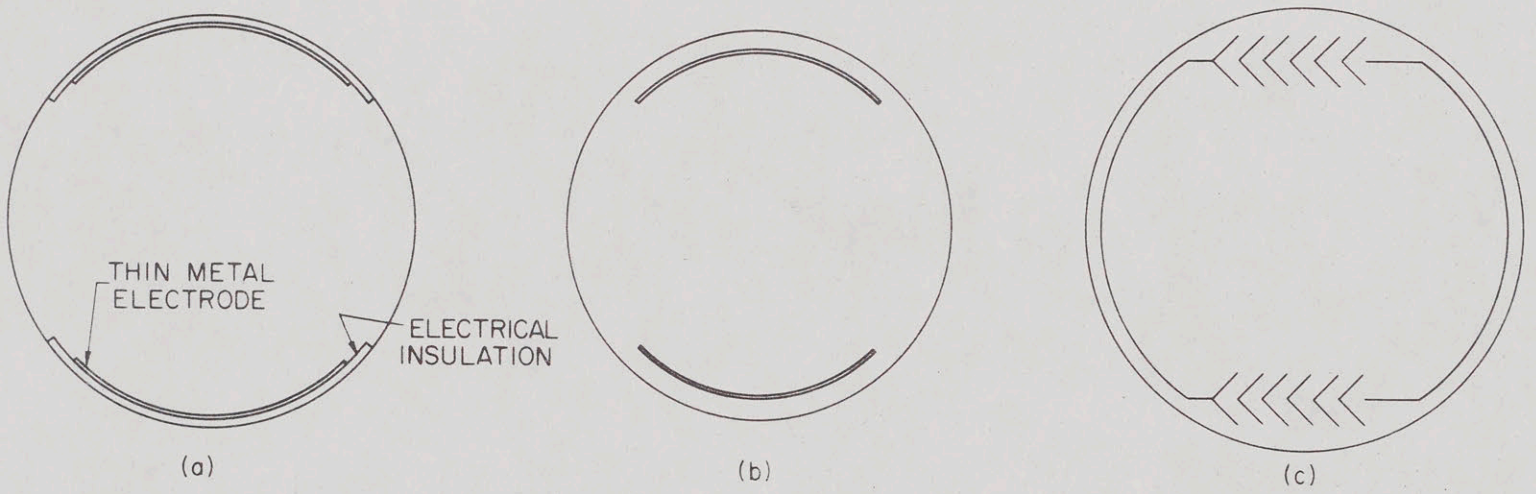

Fig. 7(a). Cold bore with cold electron clearing electrodes. (b). Cold bore with 80°K electron clearing electrodes. (c). Cold bore with optically opaque 80°K baffle.

Alternate 2: Cold bore with "warm" (30 to 80°K) clearing electrodes (Fig. 7b). By flash heating and/or by steady controlled temperature, the clearing electrodes can be depopulated of adsorbed gas. Because of the magnetic field, scattered electrons and ions are preferentially directed toward the electrodes instead of the cryodeposit, possibly raising the beam current limit. This alternate may be less expensive to achieve with ultra-high vacuum materials than Alternate 1. The pumping speed for H_2 at 80°K is approximately 50 1/sec per square inch of exposed 4.2°K surface (projected area).

Alternate 3: Cold bore with optically opaque "warm" (30 to 80°K) baffle (Fig. 7c). In this design, ions are not allowed to strike the cryodeposit; and a large pumping speed per unit length of beam line is retained 130 1/s for H_2 per in.^{2} of chevron baffle area—allowing for sticking coefficient and the low baffle temperature). Baffles may be thin stainless steel sheet.

2. Straight Sections

There is considerable equipment in the straight sections, and the cryopumping geometry will have to be compatible with the rf and injection system components in their respective sections. Distributed cryopumping will be used where possible, and used in short lengths or rings where necessary. An example of a high pumping speed straight section panel geometry is shown in Fig. 8. Here, clearing and beam image electrodes are provided, should these elements be necessary, and the beam scattered ions will not strike the cryodeposit.

3. Roughing and Conditioning Systems

The system will be pumped from one atmosphere to one torr by a mechanical pump. The pressure in the roughing line will be held above one torr by the automatic addition of boil-off nitrogen gas, preventing oil backstreaming in the gas phase. An eight-foot length of roughing line will be kept at 80°C so that oil is prevented from creeping back along the wall (Fig. 9).

Pumping from one torr to a few microns could be accomplished by a valved, bare-surface cryopump operating at 20°K or less (Fig. 10). Equipment essentially identical to these two stages of roughing has been operating at the SuperHILAC for the past two years. In the Miniproject we may wish to be able to rough each quadrant separately and to extend the finish roughing to 10^{-7} torr before cooling the straight section cryopump and the magnet bore. A valved, bare-surface quick-cycling cryopump is planned for each quadrant, which may require one intermediate thermal cycle at 10^{-3} torr.

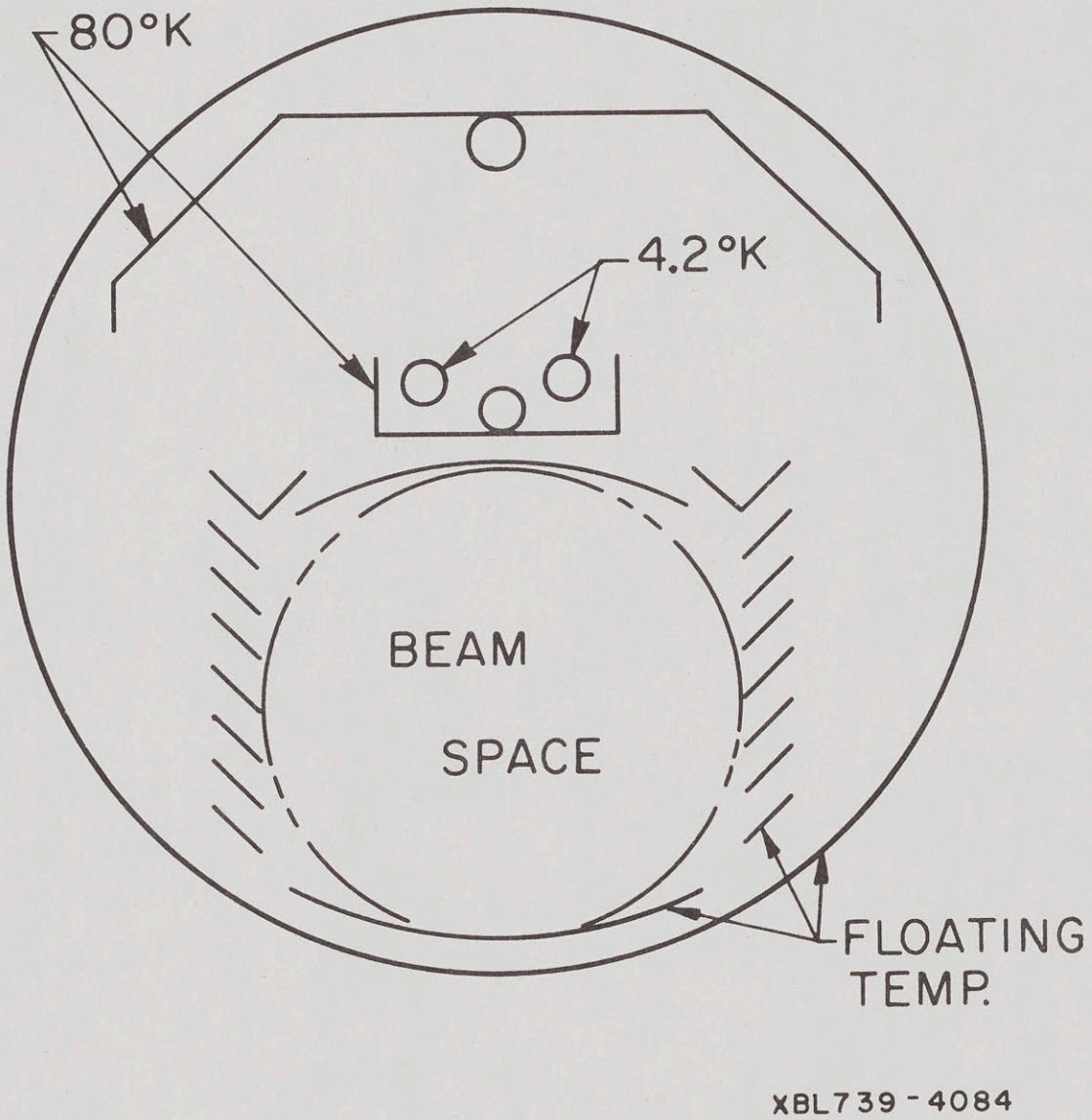

Fig. 8. Possible cryopanel for long straight sections in which beam ions do not strike cryodeposit.

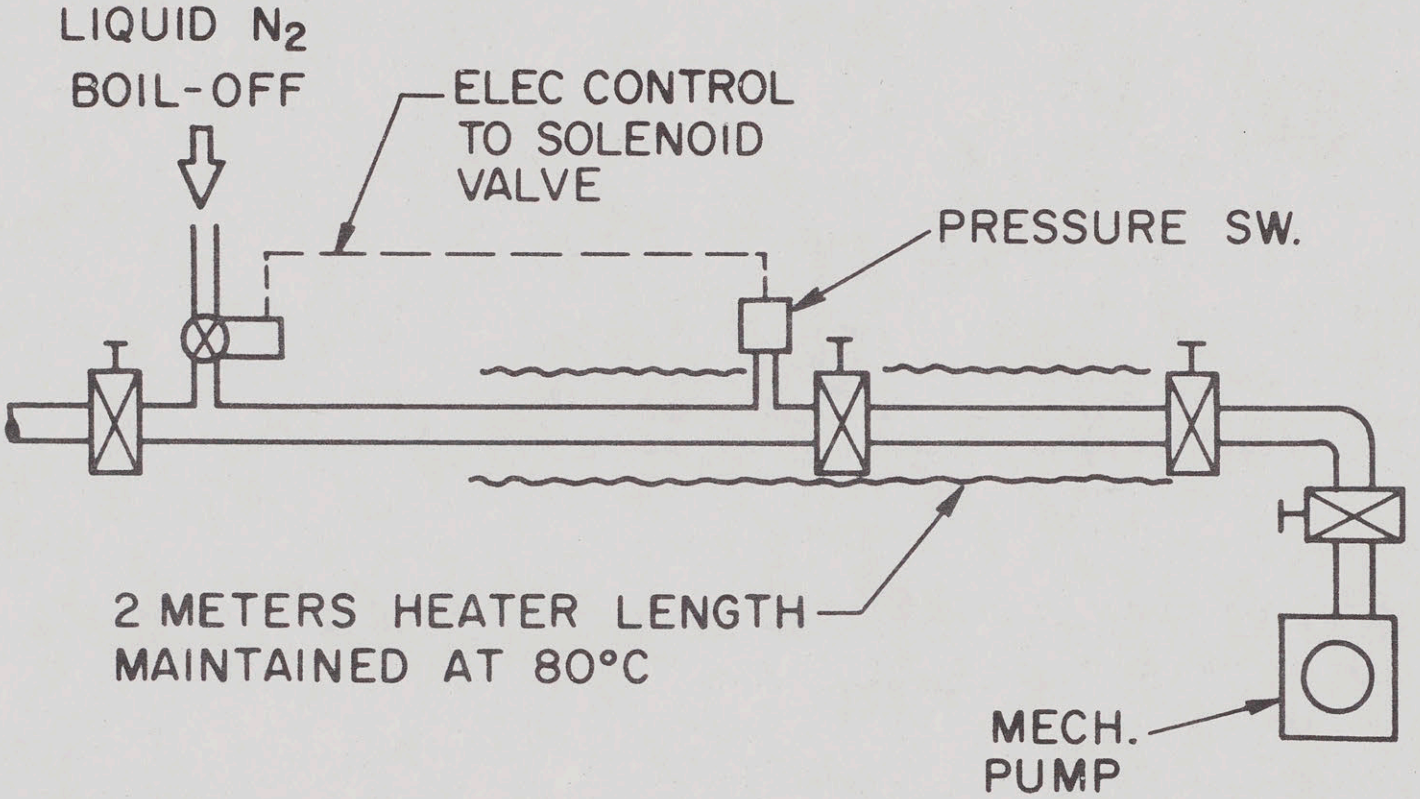

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Fig. 9.

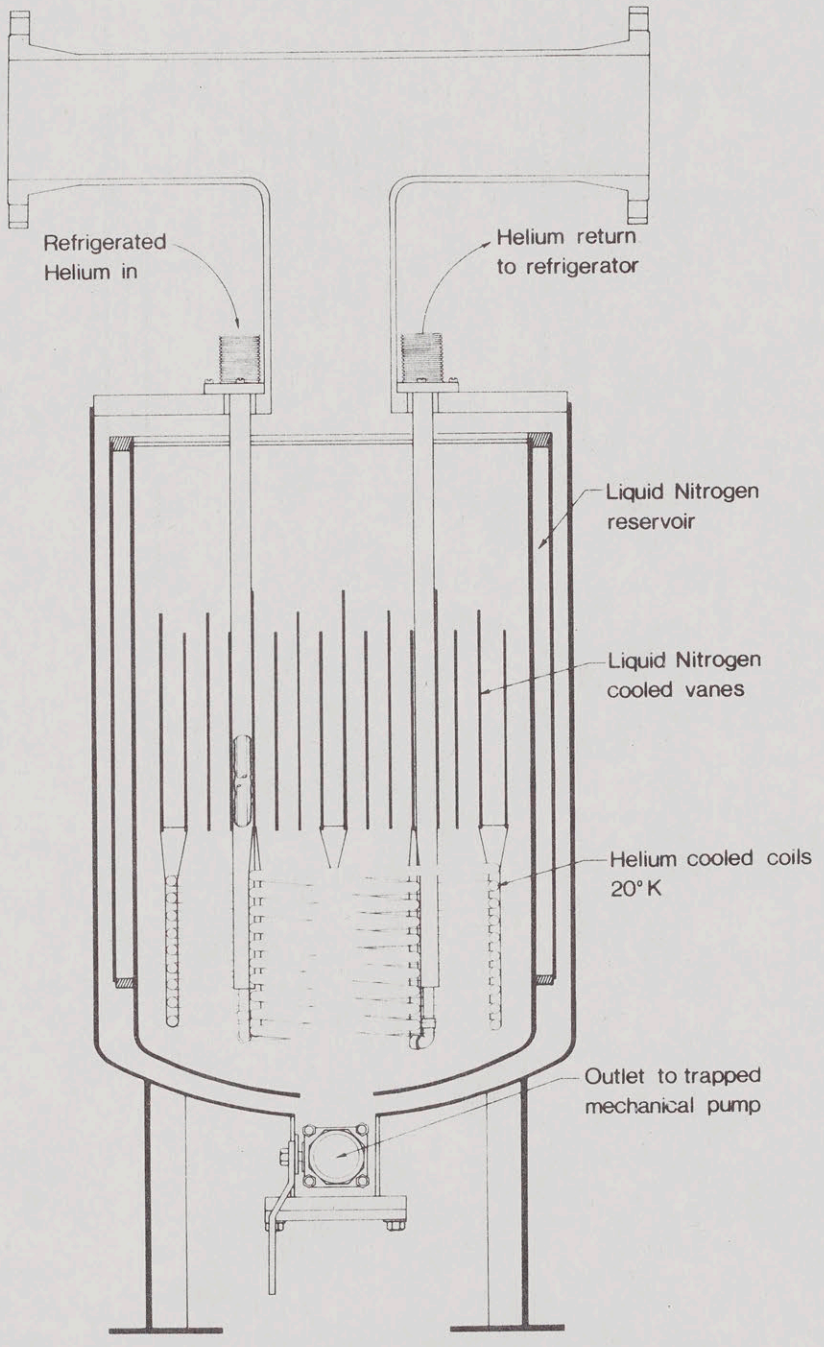
Super Hilac
Refrigerated
Helium in
Helium return
to refrigerator
Liquid Nitrogen
reservoir
Liquid Nitrogen
cooled vanes
Helium cooled coils
20°K
Outlet to trapped
mechanical pump
Cryogenic roughing pump
1 Torr to 10⁻³ Torr
XBL 725 5621

Fig. 10.

Conditioning pumps will carry off the hydrogen desorbed during the 50°K degas cycle. Valved ion pumps or H_2-CO_2 cryosorption pumps are among available methods from which a selection will be made on the basis of H_2 gas load calculations. These could be the same pumps used to finish the roughing.

4. Components

The system will be made of austenitic stainless steel, probably nitrogen enriched and heat treated to 1000°C in a vacuum furnace, as was done at CERN. The stainless will then be fabricated into components. Chemical polish (Diversey DS-9) cleaning will be considered on all stainless components before fabrication. The minimum number of flanges will be used; and components that are expected to be rarely removed will be welded in such a way that they are easily opened. These flanges may be made thin and designed in a way that will prevent metal chips from entering the vacuum system. Isolation valves will be located at the end of each cold bore quadrant so that the sections can be let up to air without warming the magnets, as shown on the general arrangement drawing. The magnet cool-down and warm-up is a slow process and will take on the order of a week. There will also be an automatically closing and interlocked valve located between the 50-MeV injector and the synchrotron to mutually protect the system from an accident in either.

The flanges may be of the Batzer type or perhaps the Varian Conflat commercial flanges. The Varian flange system would require some modification so that it will survive a 300°C bakeout with high reliability. This might be done by modifying the flanges and the bolting to allow some spring effect in order to track any creep of the stainless steel flanges or the copper gaskets. The Batzer joint has been very successful at Livermore on high vacuum systems using aluminum foil as a gasket material. The vacuum valves would have metal gaskets or bellow seals, except the gate itself which would have a Viton O-ring. These valve assemblies can be prebaked and baked at 200°C. Any valve which contains a Viton O-ring, which will outgas heavily, must be located where the O-ring will look at nearby pumping so that the local area where the vacuum load is increased will be minimized. Relief valves will protect the vacuum system against cryodeposit burst during warm-up.

Tubular cryopumps may be used near the end of the injection line to isolate the 10^{-7} torr vacuum from the injector. They will be mildly bakeable routinely and cycled independently into one of the cryo-roughing pumps.

5. Operations

The vacuum system will be routinely let up to dry nitrogen in order to minimize the atmospheric helium. A residual gas analyzer must be continuously available. For leak hunting, deuterium may be used as a trace gas without modifying the standard helium leak detector. Leak detector sensing heads can be provided with a saw tooth accelerating voltage to operate as low molecular range analyzers. Four such heads could be built into the system. If helium is a problem, it can be pumped by ion pumps located on each of the straight sections. Large amounts of helium can be swept out with nitrogen when pumping in the viscous range, as is the practice at the SuperHILAC.

Hydrogen gas may be pumped by adsorption on condensed gases such as CO_2. The rate of depositing CO_2 is important, and provisions must be made to assure a uniform deposit.

E. RF SYSTEM

It appears desirable to have the capability of picking up the total beam either in a single bunch or in several bunches. Accordingly, the rf system takes the following form. A drift tube of from 4 to 5 meters long will be installed in a straight section. This will be tuned by an appropriate ferrite reactor similar to the present Bevatron system for the required frequency swing. The harmonic number will initially be 1, so that essentially the full ring of particles can be picked up in the rf bucket. There are several possible modes of operation in the rf system which are described below.

1. If it is desired to have the entire beam in one bunch, the procedure would be to pick up the beam with harmonic #1 and accelerate it to 4 GeV, using perhaps 5 kV on the drift tube. The rf voltage is then raised to 3×10^4 volts for a σ_ℓ of 3 meters. Next, the rf frequency drive is shifted to the 11th harmonic, and the voltage on the drift tube is raised to 5×10^5 volts. At this frequency the drift tube is a half-wavelength long, so the energy gain is double the voltage on the tube. This will give a σ_ℓ of approximately 0.7 m. Parasitic cavities may then be tuned with $h \Rightarrow 30$ and a voltage of 3-1/2 million volts, which would further reduce the σ_ℓ to approximately 0.25 m. Next, other parasitic cavities may be used so that the h may be shifted up to approximately 80 if desired.

2. To produce eleven bunches, the beam can be accelerated with a few kilovolts of harmonic number 1; then the rf is turned off, allowing the beam to debunch and be picked up again on the 11th harmonic. For two or three bunches in the machines, the beam will be accelerated at a few kV using harmonic #1; then the drive will be shifted to a higher frequency, without doing the tight initial bunching, so that the beam will exist in at least three rf buckets of the 11th harmonic.

The rf system appears to require the long drift tube for the initial pick-up at the fundamental frequency. RF tubes can be obtained which are capable of supplying 1 MW CW power in the frequency under 30 MHz. The low level drive which supplies the second frequency, namely, the 11th harmonic, is relatively inexpensive. The dc power supply is estimated at ~ 2 MW and should provide a CW power capability of 1 MW in a frequency range of 800 kHz to 27.5 MHz. This will not be continuous over that range. Rather, the frequency will be adjustable from 800 kHz to roughly 2.5 MHz, and then would be stepped to 27.5 MHz. This system utilizes the drift tube for both frequency ranges. It is not necessary to make modifications to do the switching in the present concept. Note that the ferrite system is required to provide the frequency swing to accommodate the injection at 50 MeV. Cost estimates do not include parasitic cavities.

F. SHIELDING

It is assumed that the Miniproject will have a maximum intensity of up to 5×10^{12} protons per pulse, at an energy of ~ 4 GeV. The fundamental goal of the Miniproject can readily be achieved with single-particle dynamics; hence an intensity of $\leq 10^{11}$ ppp is certainly adequate for the first round of tests.

To determine the shielding, two limitations are imposed on the design: (a) the integrated dose at the site boundary shall not exceed 10 mrem per year; (b) site personnel protection shall follow the existing rules and safety practices at accelerator installations. The flux and energy are sufficiently large that several steps have to be taken to meet both requirements.

(1) The normal mode of operation shall include deceleration of the beam and dumping at an energy below 150 MeV.

(2) Aperture limitations which can stop the primary beam will be utilized.

(3) For extended running at 5×10^{12}, a more sophisticated beam dump with fast extraction is planned.

If random loss at full energy is the exception, and if critical areas are made inaccessible for personnel during operation, a 5-ft shielding wall is adequate for the first round of testing. A 3- to 5-ft roof over the aperture limitation will meet the site boundary requirement.

G. COST ESTIMATE

A preliminary schedule indicates that the project would be completed by the end of FY 1976 if midyear funding is made available in January 1974. The total scientific and design manpower would be around 37 man-years and the shop work about 45 man-years. The cost estimate based on the current parameters shown in Table I indicates a preliminary total cost of $3.7 million without EDIA and contingency (see Table III).

Table III. Cost estimate for Miniproject (In $ K)

	TOTAL
Injection (switch, transport, and infl.)	300
Cryomagnets (16 dipoles, 6" coil i.d., 8 triplets; 1 sec to full field)	800
Cryosystem (1 pulse every 10 sec)	800
Vacuum system	340
RF system	500
Beam steering and monitor	200
Controls	300
Ring magnet power supplies, including distribution (5 sec rise; 1 pulse every 10 sec)	310
Shielding installation (no cost included for blocks)	125
Utilities	50
TOTAL	3725

LBL ACCELERATOR STUDY GROUP

R. Avery
E. Close
J. Colonias
T. Elioff
A. Garren
M. Green
W. Gilbert
H. Grunder
W. Hartsough
E. Hartwig
P. Hernandez
W. Holley
D. Keefe
G. Lambertson
J. Laslett
E. Lofgren
K. Lou
J. McCaslin
R. Meuser
R. Peters
W. Salsig
L. Smith
J. Staples
R. Thomas
F. Voelker
H. Vogel
D. Wolgast