HIGH ENERGY PHYSICS AT BROOKHAVEN NATIONAL LABORATORY

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Prior to discussing the present and future high energy physics plans at Brookhaven National Laboratory (BNL), I would like to make a few preliminary remarks. In earlier talks we heard about multi-TEV accelerators placed on large expanses of vacant land (deserts) and costing multibillions of dollars. These are fine, worthwhile speculative machines and ultimately the aim is indeed to get to this higher energy domain. However, I remind you that the uncertainty in the cost estimates of such new facilities is of the same order of magnitude as the present total yearly funding of high energy physics, ~$400M. If we can envision such large funding increases, then solving our present funding dilemma should be almost trivial. The present difficulties are illustrated in Figure 1 where total DOE funding for high energy physics since 1967 is plotted in FY 1983 dollars. One notes the disaster from FY 1973 to FY 1975, the partial restoration by FY 1977, and the slow but steady erosion of funding since 1978. In particular, the drop in 1982, which hopefully is being restored in 1983, has been a main detriment to the orderly carrying out of the agreed upon high energy program. In fact it is the shortfall of the 10-20% that is causing the stresses in the community and a restoration of this ~$40M by 1985 would allow for a balanced, complementary, and exciting program in the U.S. To put things in further perspective, I note in Figure 2 the record of past high energy physics projects and their costs. It is interesting to note costs in a fixed year $ (such as 1982) since we tend to recall uninflated numbers. For instance the cost of the SLAC linac project would be $446M in 1982 dollars, not to mention the Fermilab synchrotron project at $659M. For comparison, I note that the ISABELLE Project, as presented to the Trilling Committee, would cost $400M in 1982 dollars; not an unreasonable sum for such a forefront accelerator.

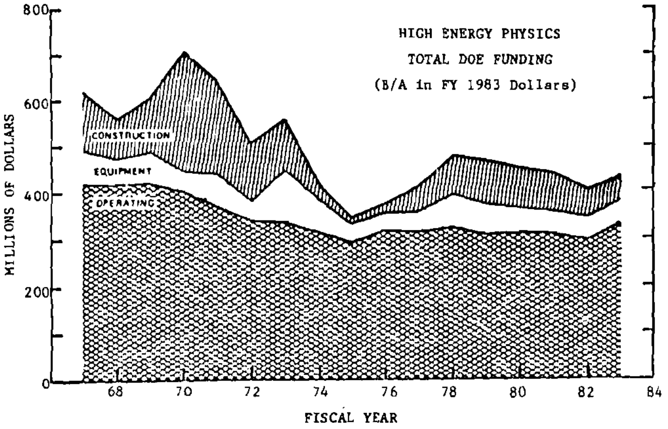

Figure 1.

The high energy plans at BNL are centered around the AGS and ISABELLE, or a variant thereof. At present the AGS is maintaining a strong and varied program. This last year a total of 4×10^{19} protons were delivered on target in a period of approximately 20 weeks. Physics interest is very strong, half of the submitted proposals are rejected (thereby maintaining high quality experiments) and the program is full over the next two years. The future colliding beam facility will utilize the AGS as an injector and will be a dedicated facility. It will have six intersection regions, run $> 10^7$ sec/year, and explore a new domain of energy and luminosity. As will be discussed shortly, common to all the considered alternatives is a large aperture proton ring. These possible choices involve pp, ep, and heavy ion variants. The long term philosophy is to run the AGS as much as possible, continuously to upgrade it in performance and reliability, and then to phase it down as the new collider begins operation.

Record of Past HEP Projects

Device	Site	Const. Start	Init. Test	Cost in Then Yr M$'s	Cost[2] in FY 82 M$
Bevatron	LBL	1949	1954	10	41[3]
Bevatron Improvement	LBL	1960	1964	10	41[3]
AGS	BNL	1953	1960	31	130[3]
AGS Improvement	BNL	1966	1972	49	157
Proton Synchrotron	FNAL	1969	1972	248	659
2 Mile Linac	SLAC	1962	1966	114	446
PEP	SLAC	1976	1980	78	114
CEA	Harvard	1957	1962	10	41
PPA	Princeton	1956	1963	12	49
PPA Addition	Princeton	1961	1965	11	43[3]
ZGS	ANL	1959[1]	1963	51	209[3]

1. Project rescoped in 1961.
2. Based on DOE inflation factors for construction.
3. No inflation factors available prior to 1962. Factor for 1962 was used for prior years.

Figure 2.

Status and Plans in High Energy Physics at BNL

The aim since 1978 has been to build a pp collider of 400 x 400 Gev with high luminosity, $\geq 10^{33}\,/\mathrm{cm}^2/\mathrm{sec}$. The construction funding levels have been

FY	'78	'79	'80	'81	'82
$M	5	23	41	35	15 = $119M.

The original design as outlined in the White Book of October 1981 would require $259M in 1982 dollars to complete. I noted earlier the deteriorating budget which has caused the present difficulties so that it seems prudent to us to look at ways to reduce the cost of this project. If one normalizes to the 1979 national high energy budget of $300M one notes the following subsequent shortfalls.

	Inflation Adjusted	
1979	$300M	
	↓	
1981	$376M	actual $352M - 6%
1982	$438M	actual $365M -17%
1983	$467M	actual $429M - 8%

The BNL response to this situation has been incorporated into the Blue Book, an agreement with DOE which is briefly summarized in the near and medium term goals.

Near and Medium Term Goals

- Complete the R&D necessary to establish a fully engineered and cost effective production prototype magnet based on the present cable design.
- Establish and demonstrate the capability to fabricate, in a reproducible and cost effective way, magnets based on the above design.
- Install and test a significant string of accelerator quality magnets (30-40).
- Within presently appropriated funds, proceed with the conventional and other construction necessary to preserve the existing investment and to provide those facilities which have a clear near-term utility.
- On a rapid basis, explore machine designs and options which might provide a lower cost approach to the existing ISABELLE design and lower cost alternate accelerator facilities.

Among the options there are four routes that are presently being pursued with different levels of effort. Again, the assumption is that there will be at least one superconducting ring.

1) Standard pp, (1 in 1). This design has been the major effort in the past years and the one in which we have achieved major technical success over the last year. We are now looking at various means to reduce the cost associated with this design. These are primarily engineering cost reductions, i.e., lower production costs. Now that we know what are the critical factors for producing good magnets and the design is relatively frozen, detailed estimates can be made of cost reductions that can be attained in the manufacturing techniques. The possibility is also being explored of using a combined function superconducting magnet, thereby eliminating all quadrupole magnets and reducing the cost.

Finally, in this category, there is also the possibility of a missing magnet scenario whereby one third of the dipoles are left out, thus reducing the cost as well as the energy, these magnets being restored later.

2) pp, Dual Aperture Magnets (2 in 1). In this case the aperture and coil packages are the same as in case 1; however, the iron is now coupled. While the expected parameters, such as energy and luminosity, of this system are the same as (1), the lattice is different and there are additional constraints on operations and performance due to the coupling of the two rings. Of course, this lattice contains only half the number of magnets but the same number of coils and apertures, thereby again reducing the cost.

3) An ep collider with an Option of Adding a Second p Ring Later. This would involve one cold p ring and a warm e ring in the same tunnel. The energies would be 20 Gev (e^-) x 400 Gev (p) with a luminosity of 6 x $10^{31}/cm^2/sec$. The AGS would be used as an injector for both the protons and electrons, the latter needing a new source and pre-injector for the AGS.

4) Heavy Ion Collider. This would involve two superconducting rings but with missing magnets. Since the 30 Gev x 30 Gev ISR is the machine which has attained the highest energy for light ions, one can relax the energy required and still be in a new domain. As such, cost savings can be achieved by removing 1/3 the dipole magnets (meshes with 1 in 1 at 300 Gev x 300 Gev pp) or possibly even 2/3 of the dipoles. Again a heavy ion injector is required which would involve the AGS and the BNL Tandems, possibly coupled with a cyclotron.

Technical Progress: Magnets

A key ingredient in any of the above colliders is, of course, magnet performance. The major changes made in the last year have been to adopt a cable superconducting geometry (instead of the previous braid) and to clamp the coils in split iron instead of using a shrink-fit. All else has remained roughly the same. The philosophy has been to engineer these magnets well, attend to detail, test all ideas on full aperture 5' length magnets, and then go on to full length 15' full aperture magnets for evaluation of final performance. Since the inception of the program a series of such magnets have been successfully constructed and tested.

Five 5' dipoles and eight full length 15' dipoles (LM 1-3, 5-8, and 9) have all performed well. In addition a full size quadrupole was successfully tested. Peak fields, well over 50 k gauss, and ramp rates of 100 A/sec (compared with the design value of 8 A/sec) have been routinely achieved. The remaining issues involve field quality, correction coils and quench protection. (Since the Snowmass meeting these three issues have also been resolved in at least three full length magnets.) The present magnet schedule and the decision time on the options are displayed in Figures 3 and 4. In essence one has to build a sufficient number of magnets on which to

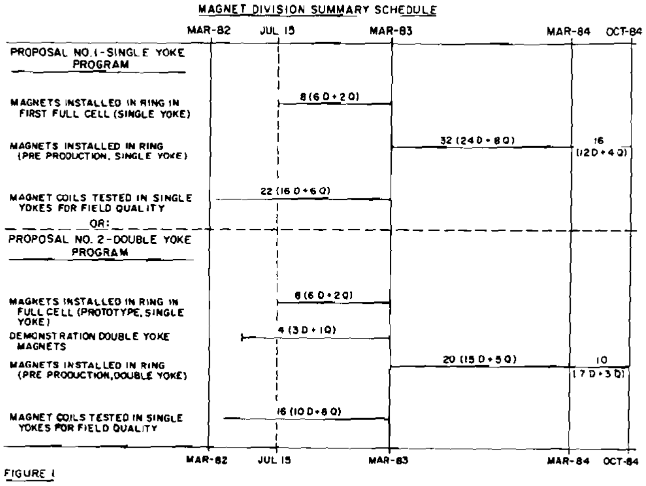

Figure 3.

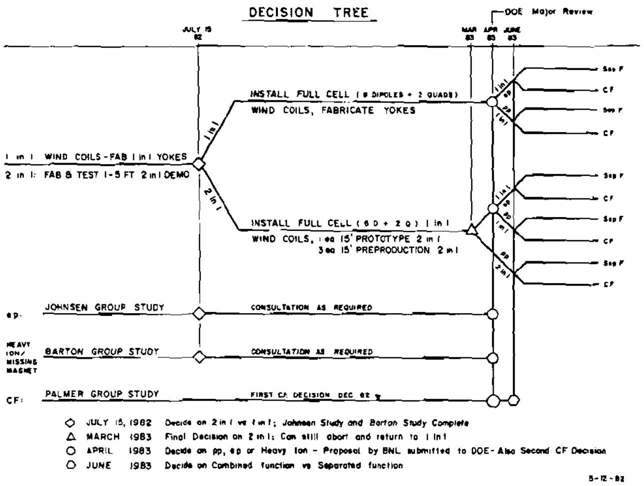

Figure 4.

base future decisions on a time scale that allows a two-in-one choice by March 1983 and single option by April 1983. Some characteristics of these magnets are displayed in Figures 5-8.

A few comments should be made concerning field quality. The accuracies required are a few parts in 10^4 in magnetic field components; the spatial placement of conductors is measured in mils. The usual method of expresssing the field is in terms of harmonics:

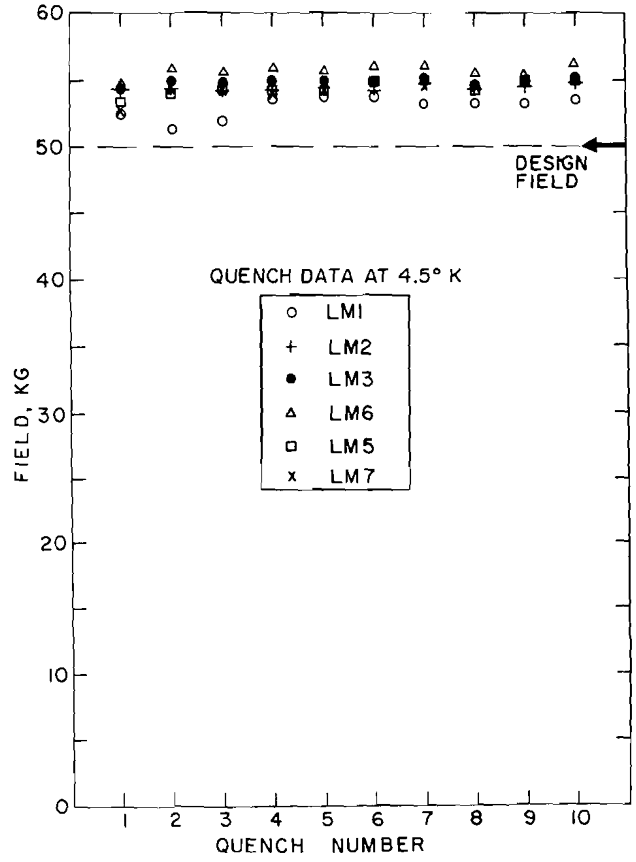

Figure 5.

$$B_y = B_0(1 + Xb_1 + X^2b_2 + X^3b_3 + \dots)$$
$$B_x = B_0(a_0 + Xa_1 + X^2a_2 + X^3a_3 + \dots)$$

where X = x/4.4cm, the edge of the aperture being at 4.4cm, and x is the distance off axis.

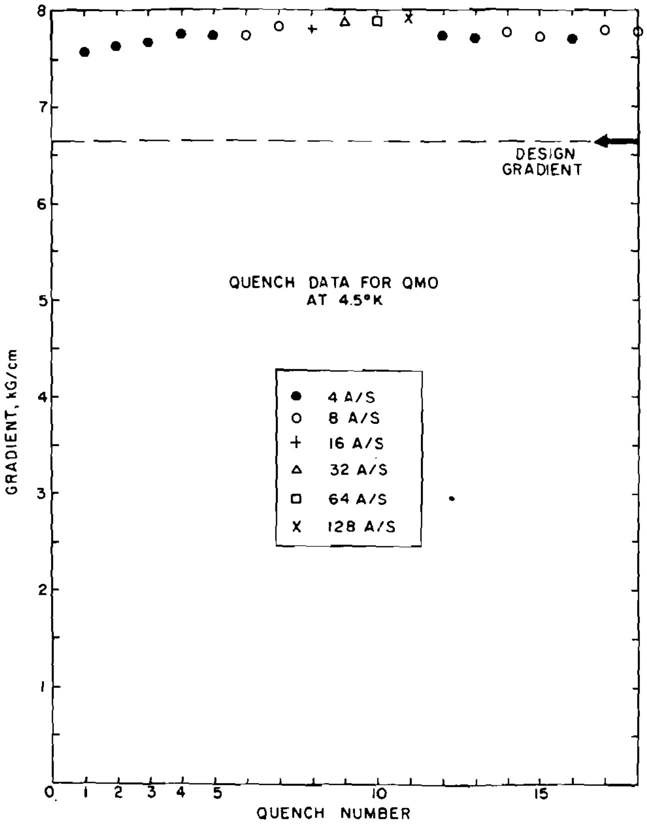

Figure 6.

In this parameterization all the a's and the odd b's are expected to be zero. Even b's are allowed, with the requirement that they have to be the same from magnet to magnet. Since the Snowmass meeting, four field quality magnets (LM8-11) have been tested. Figure 9 shows the deviations of the a_i and b_i from their sample means (from zero for the unallowed moments), divided by the tolerances required for machine operation. At three currents spanning the operating range, the moments are seen to be normally distributed with a standard deviation of about 1.0. Thus these magnets satisfy the ISABELLE field quality requirements.

Quench protection and trim coil studies have also been carried out since the meeting, with satisfying results. The magnets absorb their own energy without damage; nevertheless a double diode system will be used to shunt current around a quenching magnet. Trim coils operate above the design currents with no training problems.

To summarize performance of magnets: there is negligible training; the magnetic field attained is 5.5 ± .03 tesla at 4.5°K and 5.95 ± .05 tesla at 3.8°K; ramp rates for all magnets attain 80 amp/sec compared with a required 8 amp/sec; field quality, quench protection and trim coils all look good; and relaxation measurements indicate lifetimes of 20 years or more.

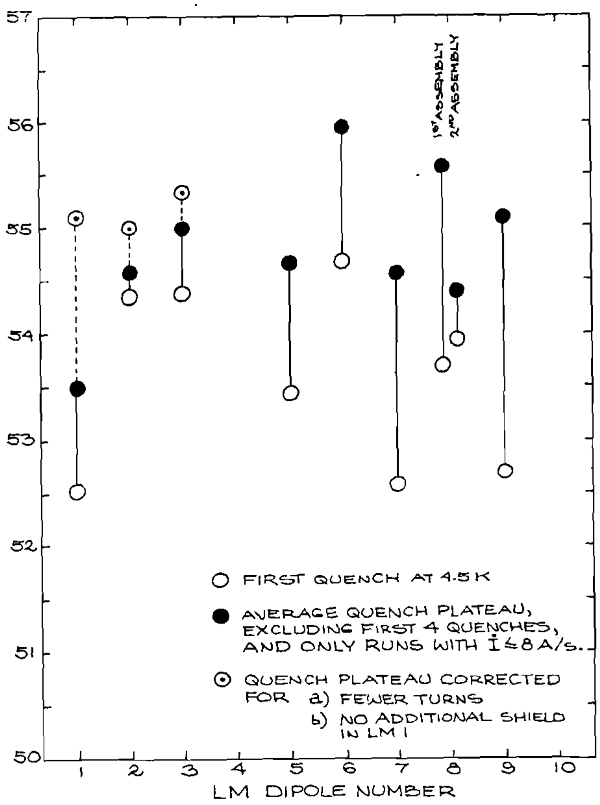

Figure 7.

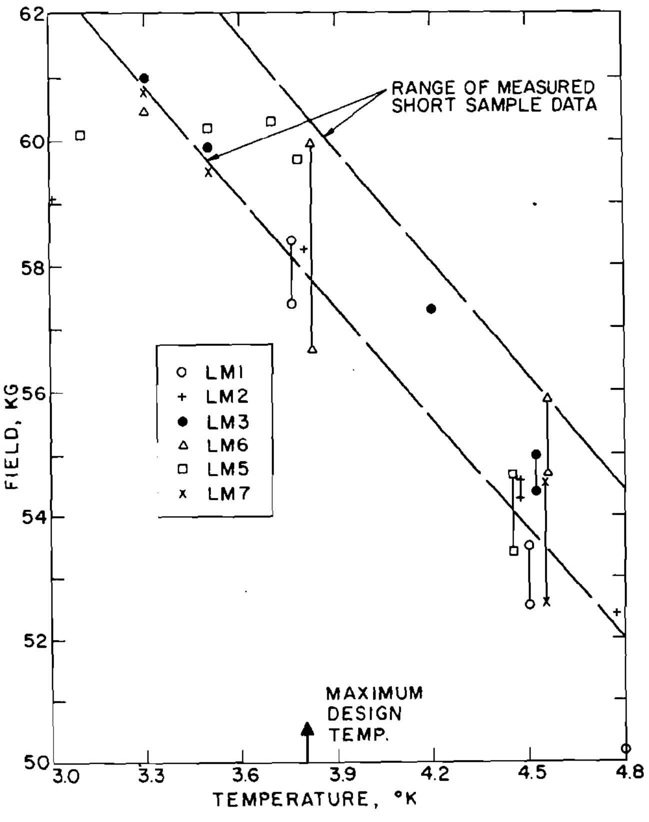

Figure 8.

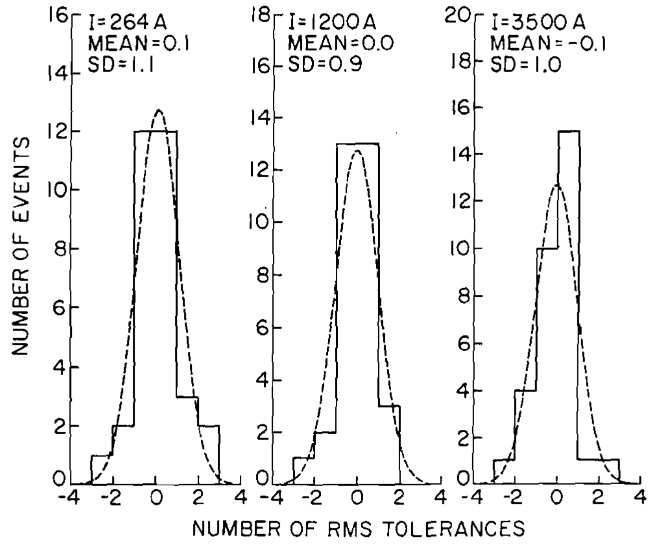

Figure 9.

As far as other systems are concerned, a production coil winding facility is being set up. There are presently 3 fixtures for dipole coils with one more in preparation, and 2 fixtures for quadrupole coils with one in preparation. In the cryogenic area one can make the following comments. The refrigeration plant is on order, with delivery of the cold boxes expected this fall and the compressors a year later. A full cell test of eight magnets (six dipoles and 2 quadrupoles) placed in the tunnel, interconnected, cooled to machine temperature by an R&D refrigerator, will take place by March 1983.

The civil construction has been going very well. The tunnel is essentially complete as well as four of the six experimental areas. There is a hold on the two additional areas due to the reduction of construction funds for the project, and we are using the time to reevaluate the configuration of both these areas.

My final remarks concerning the colliding beam facility have to do with luminosity. I remind you of the energy-luminosity correlation for past and future colliders. One notes that e$^+$e$^-$ machines have difficulty attaining luminosities > a few x 10^{31}/cm^2/sec and energy is very expensive, the cost scaling going as E^2 or E depending on circular or linear machines. The ISR has now attained luminosities of 10^{32}/cm^2/sec while the performance of $\bar{p}$p colliders is less than previously expected, the CERN beam collider attaining 5 x 10^{27}/cm^2/sec, an order of magnitude less than had been originally advertised. ISABELLE, by straightforward extrapolation from the ISR, should attain a luminosity of 2 x 10^{32}/cm^2/sec, increasing to >10^{33}/cm^2 sec. The importance of luminosity can be appreciated by noting that CEA had twice the energy of SPEAR but 10^{-3} of the luminosity, and as a result the unearthing of the rich and unexpected charm and lepton spectroscopy was all done at SPEAR. Figure 10 shows the energy luminosity profile for many electron and hadron colliders.

A similar ratio in these parameters is anticipated between ISABELLE and the $\bar{p}$p colliders. The significance of luminosity is not new; in fact its importance for deriving new physics was pointed out by that noted authority, Leon Lederman, and I quote:

"Very moderate intensities are required to explore low Q^2 (peripheral) behavior of collision cross sections since these do not decrease rapidly with s. The matter of new and totally unexpected physics however, i.e., nature at small distances, is probably associated with new thresholds or collisions which require large values of Q^2 and this sets a requirement on the intensities since it is moderately certain that ever increasing thresholds are characterized by ever decreasing cross sections. Since $Q_{max} = s$, it makes no sense to build rings where the maximum observable Q is << s. A reasonable match might be a design luminosity such that $Q_{obs} \approx 1/2$ or 1/3 of Q_{max} . . .

The luminosity required is $\geq 5 \times 10^{33}$ $/cm^2/sec^{-1}$. At this luminosity, ISABELLE is guaranteed to make at least one fundamental discovery! We conclude that a minimum design luminosity should yield $\geq 5 \times 10^7$ interactions/sec in a crossing region small enough to be viewed by finite sized apparatus."

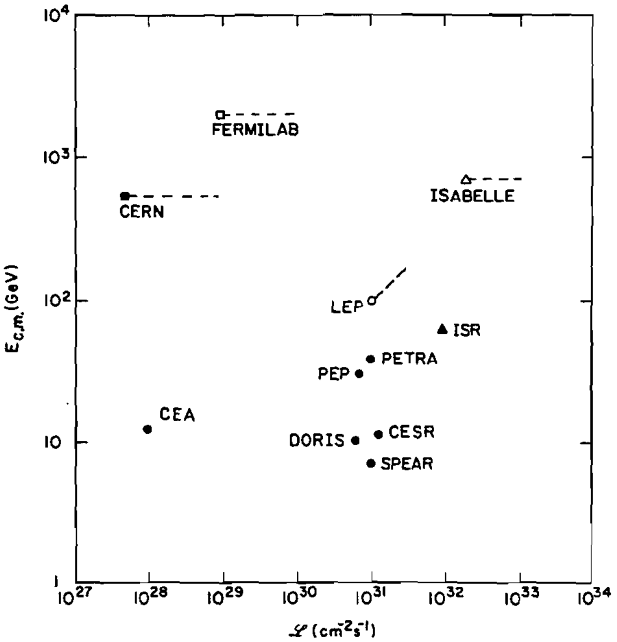

Figure 10.

Indeed, one needs high L to see high Q^2 which is the new physics. To emphasize this point one can do a single calculation:

$$10^{28} \times 10^{-33} \times 3 \times 10^{-2} \times 1/3 \times 10^{7} \approx 1$$

This is the number of $Z^0 \rightarrow e^+e^-$ that can be expected to be detected with a $\bar{p}p$ machine with energy of 500-600 Gev and a luminosity of 10^{28} and 10^7 seconds of data taking.

ISABELLE will be a dedicated facility designed as a collider with the ISR as a prototype. I believe one can state with some degree of confidence that it will reach its performance goals and have a high degree of reliability. Furthermore it will have six intersection regions, so it can serve a large section of the community.

The physics to be derived is being addressed at this workshop. Extensive discussions of such issues were held at the 1981 Summer Workshop at BNL last summer. I believe the comments I made then still hold, namely, the physics up to mass 100 Gev will be straightforward, very important, and interesting, but the breakthroughs are more likely in the higher mass range, up to 300 Gev, where the unexpected discoveries are likely to occur. Operationally the physics involves the detection of μ's, e's, γ's and jets. In effect jets take the place of the pions of the old days and we'll find ourselves doing 2 jet, 3 jet effective masses, and so on. Particle identification over limited solid angles will also be useful, but vertex detectors enabling one to detect new flavors with substantially reduced backgrounds would be even more useful. All in all, a most exciting project.

AGS Program

As noted in my preliminary remarks, the AGS is supporting an exciting, vibrant, and vital program. There are at present two modes of operation, Fast Extracted Beam (FEB) with a 1.4 second repetition rate and Slow Extracted Beam (SEB) with a 2 second repetition rate. The average intensity is 8×10^{12} protons per pulse with peaks at 10^{13} ppp. The FEB mode is mainly utilized for neutrino physics involving large detectors, 100-200 tons, placed at varying distances from the target, 300 meters and 1 kilometer. In the slow mode there is a one second flat top during which the beam emerges uniformly in time and it is split into four target stations: A, B, C, and D. These four are simultaneously illuminated and the fractions on each can be varied. A listing of the types of approved experiments is presented below, with their appropriate beam locations. The experimental program ran for 22 weeks in FY 1982. Over 200 users practice their trade at the AGS and, as can be seen, the program is sufficiently rich that there is a reasonable chance that one or more experimenters will uncover new results that will change the way we think about particle physics.

APPROVED EXPERIMENTS

A. Target Station
- CP Violation
- (MPS) Light Quark Spectroscopy
- (MPS) Gluonium
- Test Beam

B. Target Station
- Exotic 6 Quark States
- (MPS) Gluonium
- (MPS) Hyperon Radiative Decays
- Ω^- Production and Decay Modes
- Hyperon Polarization

C. Target Station
- Σ^- Magnetic Moment
- pp Total Cross Section
- Hypernuclear Spectroscopy
- Charm, Associated Production
- Polarized Σ^+ Radiative Decay
- $\Delta I = 1/2$ Rule
- $\bar{p}p$ Annihilation Cross Section
- $\bar{n}n$ Annihilation
- Large Angle Exclusive Reactions
- Rare K decays

D. Target Station
- pp Polarization
- QED in Muonic Helium
- Muon Spin Precession in Solids

U. Target Station
- ν Scattering
- ν Oscillations

There are also many activities under way for improving and expanding the capabilities of the AGS. These involve the following:

H^- injection--increase reliability and intensity of the proton beam	Aug. '82
Overhaul of the Siemens MG Set	Oct. '82
Upgrade of hypernuclear spectrometer	Dec. '82
Implementation of a stopping μ beam	April '82
Polarized proton acceleration, 1st test	Sept. '83
New north experimental area for ν experiments	Sept. '83
Internal target (I10) test beam	Under study
Upgrade of AGS Intensity	Under study

As can be seen the AGS is indeed an organic entity, constantly being upgraded to maintain and increase its performance. With the program and improvements under way and anticipated, this should lead to a vital program in the years ahead.

I hope these brief remarks bring you up to date on the plans and progress in the high energy physics programs at BNL and convey the excitement and enthusiasm for future projects.