HADRON HADRON COLLIDER GROUP*

R. Palmer
Brookhaven National Laboratory, Upton, New York 11973

J. Peoples
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

C. Ankenbrandt, FNAL
C. Baltay, Columbia U.
R. Diebold, ANL
E. Eichten, FNAL
H. Gordon, BNL
P. Grannis, SUNY at Stony Brook
R. Lanou, Brown U.
J. Leveille, U. Michigan
L. Littenberg, BNL
F. Paige, BNL
E. Platner, BNL
H. Sticker, Rockefeller U.
M. Tannenbaum, BNL
H. Williams, U. Penn.
R. Wilson, Columbia U.

1. Introduction

The objective of this group was to make a rough assessment of the characteristics of a hadron-hadron collider which could make it possible to study the 1 TeV mass scale. Since there is very little theoretical guidance for the type of experimental measurements which could illuminate this mass scale, we chose to extend the types of experiments which have been done at the ISR, and which are in progress at the SPS collider to these higher energies. Initially we chose to call these experiments "bellwether experiments" for reasons of convenience. In the absence of any alternative predictions we assumed that the cross sections for these standard experiments could be obtained either by extrapolating perturbative QCD models of hadrons to center of mass energies of 40 TeV or by extrapolating phenomenological parameterization of data obtained from experiments done in the center of mass energy range of 20 to 60 GeV to 40 TeV. For each bellwether we asked up to what mass (or momentum transfer Q) could a significant (> 100) number of events be seen in 10^7 seconds. While it is unlikely that these bellwethers will be among the definitive experiments in the 1 TeV mass scale, some of them represent the background which will obscure new phenomena. It was our view that the new collider should have sufficient luminosity and energy so that at least some of these experiments could be done. History provides a warning that at least some bellwethers will be irrelevant. Elastic scattering serves as an example. In the early sixties it was judged very important to measure large angle lepton-hadron and hadron-hadron elastic scattering over the full kinematic range available. At the time, $\sqrt{s}$ was approaching 7.5 GeV. These experiments, which were done with difficulty, produced only a modest addition to our understanding of the structure of the nucleon. On the other hand, inelastic scattering processes which had much larger cross sections were crucial to our present understanding.

In order to gain a sense of the luminosity required to reach the 1 TeV scale, calculations were made on a matrix of energies and luminosities. Given this data, we hoped to get a fair idea not only of the energy required to reach a given scale, but whether there was a trade-off between energy and luminosity.

Considering the huge extrapolation of cross sections from 60 GeV to 40 TeV, there was no significant difference between the cross sections for pp or $\bar{p}p$ collisions. The numbers given were calculated for pp interactions.

Before listing the bellwether experiments chosen, it is appropriate to check in Websters to see exactly what a "bellwether" is. "1. a wether, or male sheep, which leads the flock, with a bell on his neck. 2. a leader of a thoughtless crowd." We hope definition 1 applies.

2. The Bellwether Experiments

#1 High Transverse Momentum Jets

This experiment was chosen because it is expected to reveal the dynamics of the interacting constituents. The rate for this process does not depend on the details of constituent hadronization, and it has the largest cross section of the experiments considered. Since jets have been seen at the SPS collider with the same convincing visual impact as jets at PEP and PETRA, it is expected that they will be easily identified at the 1 TeV scale. In the standard theory the behavior of the P_T distribution is qualitatively well known and any significant deviation would indicate either structure within the quarks or a massive object decaying into two jets. A calorimeter was assumed to cover $\Omega = \Delta y \Delta \phi = 10$ and an efficiency approaching 1 may be expected. Background is not found to be a problem in experiments of this type at the ISR or $\bar{p}p$ collider. Cross sections were obtained from Frank Paige using ISAJET.[1]

#2 High Transverse Momentum π°'s

Single π°'s were considered simply because they have been traditionally easy to identify in a large electromagnetic calorimeter. As for jets, the high transverse momentum π°'s can be used to study constituent scattering as well as explore possible unknown bound states. Experimentally π°'s can be more accurately measured than the less well defined jets but the cross section for π's is much smaller since they rarely carry a large fraction of their parent constituent. Again a solid angle of 10 and efficiency of 1 were assumed. Mike Tannenbaum used the phenomenological parameterization of the cross section[2]

*Work performed under the auspices of the U.S. Department of Energy.

$$E\frac{d^3\sigma}{dp^3} = 4 \times 10^{-29} \frac{(1 - x_T)^{12}}{p_T^5} \text{ cm}^{-2} \text{ GeV}^{-2} . \qquad (1)$$

This agrees fairly well with QCD calculations for $x_T > 0.1$.

#3 Direct Single Photons

Although these experiments are thought by some to represent a particularly clean probe of high transverse momentum quark or gluon interactions, they will only be a useful probe in the 1 TeV mass range if the ratio of the rates of direct $\gamma°$'s to $\pi°$'s is considerably greater than x_T as currently observed[3] at a $\sqrt{s}$ of 20 to 63 GeV. Since the primary interest in the single photon events is their total structure we took the view here that an "event by event" identification was required. The apparatus proposed consisted of a 1000 × 1000 matrix of 1 cm (or possibly 2 cm) square electromagnetic calorimeter towers. Such a device should separate γ's from π's down to the 1% level. The $\pi°$ cross section was assumed from (1). Paul Grannis then took the γ to $\pi°$ ratio to be equal to $x_T = 2p_T/\sqrt{s}$, a relation that is approximately true both experimentally and theoretically, at center of mass energies below 60 GeV.

#4 Drell-Yan Muon Pair Production

Lepton pairs provide an excellent probe of a wide range of high mass scale phonomena. Experimentally, pairs are easy to identify behind a hadron shield, although the measurement of their momenta does present a problem at the 1 TeV scale. This we will discuss later. Here we assume merely that it is possible and take a solid angle of 10 steradians, an efficiency of one, and use cross sections from Frank Paige using the QCD motivated program ISAJET.

#5 Heavy $Z°$'s Decaying to $\mu^+\mu^-$

While looking at the Drell-Yan pairs for #4, one will also be sensitive to heavy $Z°$'s (Z') if such things should exist. We assume that the basic coupling mediated by such a Z' boson is the same as for the standard Z. The effective Q^2 coupling of the heavy Z to quarks is then

$$G' = G\left(\frac{m(Z)}{m(Z')}^2\right).$$

Using this assumption Frank Paige calculated production rates using his QCD program. The apparatus is assumed to be the same as for #4. Unfortunately, we did not have the cross section as a function of acceptance and thus took a uniform acceptance factor of 50%. The acceptance will in fact be x_T dependent, larger at large x_T for the high luminosity machines, less at low x_T for the low luminosity cases.

#6 Technieta Production (η_T)

The technieta is a rather arbitrary selected example of a non-standard Higgs particle whose dominant decay is into the two heaviest quarks or leptons allowed, assumed here to be top quarks. Cross sections were obtained from a calculation by J. Leveille who warns, however, that the cross section for a technieta with mass above 1 TeV is somewhat arbitrary since the theory does not fit other observations in this case. Nevertheless, we will use these cross sections as a guide to this class of particles made by gluon-gluon interactions with a large cross section. The cross section is enhanced by the large number of technicolor permutations. Identification has been studied by C. Baltay using a) the mass of the jets, b) the presence of high transverse momentum leptons in the jets, and c) the presence of a higher than usual proportion of D mesons identified by a high resolution vertex detector.[4]

Plausible, although somewhat questionable, arguments show the signal to background ratio to be satisfactory with an efficiency for the signal of 10%. The detector assumed is a multipurpose larger solid angle (Ω = 10) device as discussed below.

#7 Gluino Production

The gluino is taken as an example of a particle predicted by super-symmetry. The mass scale is truly unknown, but the couplings allow calculation of cross sections as a function of mass and these were calculated by J. Leveille. The experimental situation was studied by L. Littenberg.[5] The gluino is expected to decay rapidly into a quark and anti-quark pair plus a photino, the interaction of which, being rather weak, will not be observed. The events are thus characterized by large missing momentum, but no associated leptons. The experiment would be performed in a general purpose detector with e and μ capability as discussed below.

The extraction of a gluino pair signal tends to be background rather than statistics limited. Thus the mass limits presented here take into account not only the signal cross section, but the signal/background ratio and estimates of the ability of the apparatus to distinguish between them. For energies up to $\sqrt{s}$ = 2 TeV, this was done quite carefully (see Aronson, et al.[5]). For higher energies, the assumptions used get progressively less reliable. In all cases > 1000 gluino events are required.

3. Matrix Results

Table I shows the mass scale limits obtained for each of the experiments for 4 energies and 3 luminosities.

Figure 1 shows that for luminosity of 10^{30} only strong interaction processes which are insensitive to the details of hadronization can be studied. These are basically jet experiment and particle searches for technicolor particles which decay into jets. It shows that other than an initial exploration of the 1 TeV mass scale, a luminosity of 10^{30} is too small. This conclusion is not sensitive to the collider energy.

Figure 2 shows that for a luminosity of 10^{32} the full set of the strong interaction bellwether experiments can be carried out. The standard electroweak experiments cannot be carried out. The TeV mass scale can be reached for $\sqrt{s}$ in the 5 to 10 TeV range (beam energies of 2.5 to 5 TeV.

The electromagnetic reactions (γ, $\mu^+\mu^-$) do not attain the 1 TeV scale even for $\sqrt{s}$ energies as high as 40 TeV and the x_T value reached is still only of the order of 0.01. Photons are still hard to separate from $\pi°$'s and probably unobservable for $\sqrt{s}$ greater than 20 TeV. The production of these interactions will be dominated by the sea of quark pairs and by gluons. Little will be learned of the valence structure of the nucleons. Incidentally, one notes how cross sections involving quark-anti-quark interactions do not rise with energy as quickly as those processes (η_T, gluino) which need gluon-gluon interactions.

Figure 3 shows the limits for $L = 10^{34}$. Leaving until later the question of whether such a luminosity can be used, one notes that if and when it can, there would be great advantages. Essentially all experiments reach the 1 TeV scale at a $\sqrt{s}$ of only 10 TeV.

With $\sqrt{s}$ of 40 TeV, we are observing scales approaching 10 TeV! Single photon to π° ratios are good and one is studying interactions in the $x_T = 0.3$ region.

Another way of looking at the same data is to plot contours of constant scale on a luminosity vs. energy diagram. This is done in Fig. 4a-f. To obtain a sense of the luminosity vs. energy trade-off, we might consider two representative luminosities of 3×10^{31} and 3×10^{32}. Reaching the 1 TeV scale requires c.m. energies as follows:

Process	Required E c.m. $L = 3 \times 10^{31}$	$L = 3 \times 10^{32}$	Factor
Jets	2 TeV	1.5 TeV	1.3
π°	14 TeV	5 TeV	2.8
η_T	7 TeV	3.5 TeV	2.0
gluino	55 TeV	20 TeV	2.7

There is considerable variation depending on the process being considered. However, as a rough rule of thumb in this energy region, a factor of 2 in energy is equivalent to a factor of 10 in luminosity.

Finally, we show Fig. 5, which gives the mass scales reached by two hypothetical machines a) a 5 on 5 TeV two ring pp collider with luminosity of 10^{33} which would fit on the FNAL site, and b) a 20 on 20 TeV one ring $\bar{p}p$ machine with luminosity of 10^{30} which would certainly require a new site. One notes that the limits are much higher for the lower energy high luminosity machine for all experiments considered.

One may also ask whether there are minimum and maximum usable luminosities for studying the physics of the 1 TeV scale. The maximum usable luminosity depends on acceptable signal-to-noise ratios. This question will be discussed in some detail in the next section. Minimum luminosities are much easier to determine.

Let us classify the possible types of cross sections for subprocesses at the 1 TeV scale. There are three basic types:

(1) Geometric cross section depends only on the characteristic size scale of the subprocess

$$\sigma_G \simeq \frac{4\pi}{(1\ \mathrm{TeV})^2} \simeq 10^{-32}\ \mathrm{cm}^2 .$$

An example of such a process is quark-quark scattering for quarks composite at the 1 TeV scale. However it should be noted that a geometric cross section with a 1 TeV scale is almost ruled out by present data for processes involving leptons. For more discussion see the work of Eichten, Peskin & collaborators in these proceedings.[6]

(2) Q.C.D. subprocesses which depend on the color couplings and appear first in order α_s^2 (1 TeV).

$$\sigma_{Q.C.D.} \sim \alpha_s^2\ (1\ \mathrm{TeV})\ \sigma_G \simeq 10^{-34}\ \mathrm{cm}^2 .$$

Bellwether experiments 1, 6, and 7 are such processes.

(3) Finally, those subprocesses which are electroweak occur in order α_{EM} (for example, Z° production, exp. 4) or order α_{EM}^2 ($\mu^+\mu^-$ production, exp. 5). The associated cross sections are

$$\sigma_{EM}\ (\text{first order}) \sim \alpha_{EM}\ \sigma_G \sim 10^{-34}\ \mathrm{cm}^2$$

$$\sigma_{EM}\ (\text{second order}) \sim \alpha_{EM}^2\ \sigma_G \sim 10^{-36}\ \mathrm{cm}^2 .$$

These cross sections set minimum quark or gluon luminosities in the subprocess. The quark and gluon luminosities per hadron are strongly dependent on x_F,[7] so we consider two representative c.m. energies, 5 and 20 TeV. For a minimum of 300 events/yr., we have

Process Type (1 TeV Scale)	$\sigma(\mathrm{cm}^2)$	Minimum Luminosity subprocess	E_{cm}=5TeV	E_{cm}=20TeV
Geometric	10^{-32}	3×10^{27}	10^{29}	5×10^{27}
Q.C.D.	10^{-34}	3×10^{29}	10^{31}	5×10^{29}
1st Order electroweak	10^{-34}	3×10^{29}	10^{31}	5×10^{29}
2nd Order electroweak	10^{-36}	3×10^{31}	10^{33}	5×10^{31}

The luminosities above are only absolute minimum luminosities. No consideration has been given to the efficiencies or backgrounds for any particular process. We see that in a number of the bellwether experiments these considerations significantly increase minimum acceptable luminosities.

4. Detectors

All the bellwether experiments except the single photons could be performed by a single large facility operated with different triggers. Figure 6 shows a conception of such a detector. It consists, starting from the inside, of:

(a) A high resolution vertex detector to identify events with short lifetime particles such as D mesons. The vacuum pipe in this region would be only about 1 cm diameter tapering slowly larger on either side. The device would presumably consist of all silicon strip detectors with perhaps four layers surrounding the pipe.

(b) A tracking chamber, probably a drift chamber with short drift length (~ 2 mm) to maximize rate capability.

(c) Calorimeters: electromagnetic on the inside, then hadron calorimeters, assumed to use uranium for high resolution ($dE/E \sim 30\%/\sqrt{E}$).

(d) Muon tracking: probably long drift chambers.

(e) Superconducting coil: length 30 m, diameter 11.6 meters, field 2 Tesla.

(f) Iron magnetic return: thickness 2.5 m, weight 33,000 tons.

(g) Concrete muon shield: thickness shown 6.5 m.

(h) Final muon tracking chambers.

The large magnet is required in order to measure 0.5 TeV muon momenta to 5% (this is at Q = 1 TeV). The position resolution assumed was 100 μ.

It is obvious that this conceptual design requires a lot of development. The size and cost would be reduced if the resolution of the muon tracking could be improved, or the requirements on resolution relaxed. It is discussed here as a stimulant, not a solution.

The cost of such a facility would be of the order of 100 million dollars. The cost could possibly be reduced if the iron were eliminated and ways found to live with the resulting stray fields.

The single photon experiment requires a finely divided electromagnetic calorimeter placed at a rather large distance from the vertex. If 1 cm × 1 cm divisions are used, the distance needed to differentiate a 0.5 TeV photon from a π° is 18 meters! Clearly, it cannot be placed within a general facility.

Other experiments requiring charged particle identification using Cerenkov detectors are also incompatible as would be a two arm spectrometer capable of precision measurement of 2 particle masses.

5. Detector Rate Capability

Although the subject aroused considerable controversy among the participants, there was agreement that the detectors which are essential to most of the experiments could, with some improvement, operate at a luminosity of 10^{32}. It should be noted that detectors which possess full tracking and calorimetry have operated at luminosities of 2×10^{31}. There have been short periods of operation with luminosities $\sim 10^{32}$ at the ISR.

Since the fundamental detector will be the calorimeter, it is worth noting how these detectors can perform for luminosities greater than 10^{31}. Since the inelastic cross section is expected to be about 10^{-25} cm^2 when $\sqrt{s}$ is greater than 20 TeV, the rate for minimum bias events will be one event every 100 nanoseconds with a luminosity of 10^{32}. Present day calorimeters have charge or light collection times of 100 to 200 ns. For example, the charge collection time of a liquid argon calorimeter is typically 200 ns and the fluorescence time of calorimeters using BBQ readout is $\sim$ 100 ns. Thus, at first glance calorimeter would appear to be limited to environments with a luminosity of 2×10^{31} to 5×10^{31}. Improvements which could reduce these collection times by factors of two to four are at least conceivable. Of more significance and hence hope is the fact that minimum bias events may be no more serious than a little extra electronic noise.

A more detailed Monte Carlo calculation by H. Gordon et al.[8] indicated that this may be true, if for instance, one is looking at high transverse momentum phenomena. Most events have very low central transverse energy and multiplicity. Provided one can ignore tracks of less than 1 GeV, he found that even at $L = 10^{33}$ the presence of a background of superimposed ordinary events had little effect on the measured properties of one high transverse energy event. Above $P_t \cong 10$ GeV, false jet triggers in a solid angle of $\Delta y = 1$ $\Delta\phi = \pi/2$ from a pile up of 10 minimum bias events would fall below the rate of true jet events. The false triggers are falling with P_T much faster than the true triggers so that by about $P_T = 30$ GeV the false triggers are negligible (less than 1%). The pile up adds about 1 GeV to the true jet momentum which again becomes negligible for sufficiently high P_T jets. Thus one can tolerate $L = 10^{33}$ cm^{-2} sec^{-1} for simple high P_T jet measurements.

Tracking chambers can in principle operate with resolutions of 20 to 50 nanoseconds. Thus, these devices can in principle operate in an environment of 10^{32} if the pattern recognition can be made to reject the large number of hits created by minimum bias events. Again there was little agreement that these techniques could be pushed beyond 10^{32}, as the conditions which will be obtained in a 10^{32} collider are so different from the experience at the ISR, Fermilab, and the AGS.

The only large solid angle experiment which can indisputably work at luminosities beyond 10^{32} would be the multimuon experiment in which only the multimuons are observed. This would require surrounding the interaction point with a dense material such as iron or tungsten. In principle these detectors could operate at 10^{33} or perhaps 10^{34}. Large acceptance muon detectors have operated in beam densities of $> 10^9$ protons/second only after the whole interaction region was very heavily shielded.

6. High Luminosity Machine Design

The luminosity L of a collider written in terms of the interaction length ℓ_i is independent of whether one has head-on collisions of bunches (of length ℓ_i), or finite angle crossing with crossing (length ℓ_i). Assuming that the beams are cylindrically symmetric at the crossing point,[9]

$$L = \frac{1}{c} \frac{f^2 N^2 \gamma}{E\beta} \ell_i d \ , \qquad (2)$$

where f is the frequency of rotation of particles in the rings, N the number of such particles [to include the $\bar{p}p$ case N^2 should be replaced by $N(p)\ N(\bar{p})$], γ is the energy, E is the invariant emittance, β is the focus parameter at the intersection, and d is the duty cycle (bunch length/spacing). For high luminosity, one prefers dc operation for experimental reasons, so $d = 1$. ℓ_i/β is bounded from tune shift considerations to some small value: We take $\ell_i = 1$ m, $\beta = 3$ m. E is typically $10\pi\ 10^{-6}$ meter steradians. If we wish to keep the number of photons as low as possible, then f should be high, thus preferring a high magnetic field; we take 10 Tesla giving f = 22 kHz for 5 TeV.

With these parameters one obtains 10^{34} luminosity with $1.2\ 10^{15}$ protons stored (this is the same number of protons as considered in the ICFA $\bar{p}p$ study and corresponds to 2 amps circulating; the ISR stores $\sim$ 50 amps). This is not unreasonable. The tune shift is given by[9]

$$\Delta\nu = \frac{r_o}{c} \frac{f\ N\ \ell_i d}{E} \ , \qquad (3)$$

which gives a value of 0.003 for the selected parameters.

R. Huson[10] discussed a scheme that would reduce the emittance E to only $1\ \pi\ 10^{-6}$ steradian meters. In this case, ℓ_i could be reduced to 10 cm, β left at 3 m and the luminosity and tune shift kept at 10^{34} and 0.003 respectively. This is clearly a better situation.

For experimental reasons it would be desirable to also have $\bar{p}p$ interactions in the same machine. A reasonable number of $\bar{p}$'s that might be collected is 10^{13} and if these were placed in one ring and $1.2\ 10^{15}$ p's in the other, one would get $L = 10^{32}$ and $\Delta\nu = 0.003$. This is if continuous beams are employed. Higher luminosities could be obtained by bunching, e.g., d = 0.1 gives $L = 10^{33}$, but the instantaneous luminosity is then 10^{34}. For some experiments this would not be a problem.

Another interesting question is how small an interaction region can be obtained for use with a high resolution vertex detector. Equation (2) shows a simple linear relation between L and ℓ_i so we could obtain $L = 10^{32}$ with $\ell_i = 1$ cm. The tune shift is negligible in this case.

7. Conclusions

Since the conclusions are so strongly dependent on our basic assumption for the cross section, we restate that assumption here. We have assumed that the cross sections for the phenomena of interest will be comparable to the cross sections obtained from extrapolating perturbative QCD in the variable m, or $\sqrt{-Q^2}$, from 30 GeV to 1000 GeV. These cross sections decrease with energy at least as fast as m^{-2} or Q^{-2}.

Our principle conclusion is that jet experiments and such particle spectra measurements of the type which have been done successfully at the ISR and which are in progress at the SPS collider can be extended to the 1 TeV mass scale without difficulty.

The luminosity which is required to explore the strong interactions at these energies is between 10^{31} and 10^{32}. Since a luminosity of 10^{30} will allow an initial exploration of this mass scale and, in particular, allow the study of quark (or gluon) compositeness at scales greater than 1 TeV, a physics program can be initiated before the collider reaches the luminosity goal.

Our second conclusion is that the collider should be designed for a minimum luminosity of 10^{32}, rather than 10^{30}.

This conclusion can be stated very succinctly by noting that if one must choose between one and two rings in order to reach 10^{32}, then one should choose two rings even at the cost of a modest reduction in $\sqrt{s}$. A rough rule of thumb is that a factor of ten in luminosity is worth a factor of two in energy for most processes.

Our final conclusion is that one should strive for the highest energy which can be achieved within the practical limits set by budgets.

We conclude that experiments can be done at luminosities of 10^{32} with only modest improvements to existing experimental methods. It is not out of the question that some calorimeter experiments can be done at luminosities of 10^{33} if significant advances in techniques are made.

The study of order α^2 electromagnetic phenomena such as Drell Yan requires luminosities between 10^{33} and 10^{34} if one is to reach the mass scale of 1 TeV. Such experiments can and must be done by observing muons beyond a wall of iron.

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TABLE I

Experiment	Luminosity $cm^{-2} sec^{-1}$	M or Q Limit TeV $\sqrt{s}=.8$ TeV	$\sqrt{s}=2$ TeV	$\sqrt{s}=10$ TeV	$\sqrt{s}=40$ TeV
#1 Jets	10^{30}	.36	.70	1.7	2.4
	10^{32}	.50	1.1	3.6	8.0
	10^{34}	.60	1.4	5.4	14.0
#2 π°	10^{30}	.16	.24	.34	.38
	10^{32}	.30	.54	1.1	1.6
	10^{34}	.42	.88	2.6	5.0
#3 γ	10^{30}	.07	.07	.06	.04*
	10^{32}	.12	.17	.18	.14*
	10^{34}	.18	.31	.46	.41
#4 $\mu^+\mu^-$	10^{30}	.10	.10	.10	.10
	10^{32}	.11	.18	.30	.40
	10^{34}	.20	.40	1.1	1.7
#5 Z	10^{30}	.10	.14	.30	.33
	10^{32}	.22	.45	1.2	1.6
	10^{34}	.32	.80	2.8	4.2
#6 η_T	10^{30}	.13	.30	.70	1.5
	10^{32}	.30	.60	2.0	5.0
	10^{34}	.40	.90	3.7	12.0
#7 Gluino	10^{30}	.06	.07	.20	.50
	10^{32}	.11	.22	.60	1.2
	10^{34}	.15	.35	1.3	2.1

*In these cases the γ/π° ratio is less than 1% and separation may not be possible.

Table I. The Matrix of highest observable M or Q for the different bellwether experiments at different energies and luminosities.

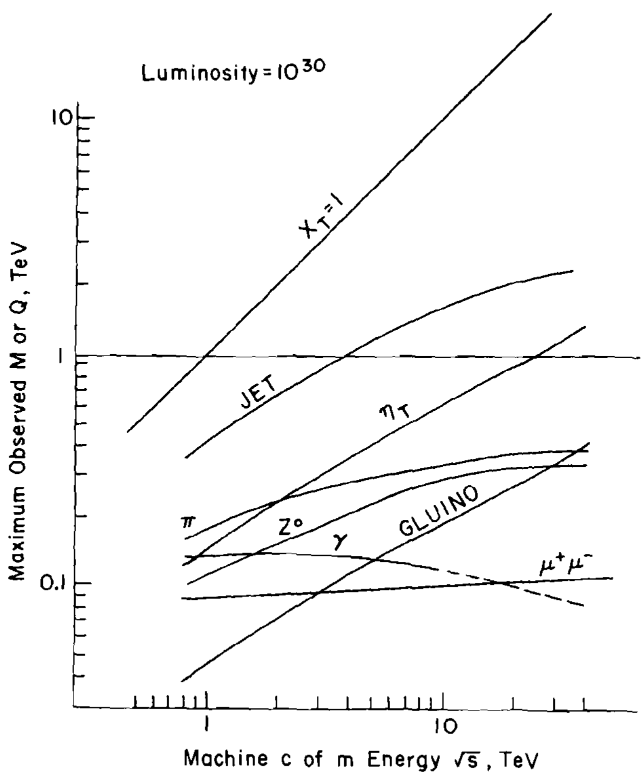

Figure 1. Plot of the highest obtainable M's or Q's verses machine energy for a luminosity of $10^{-30} cm^{-2} sec^{-1}$.

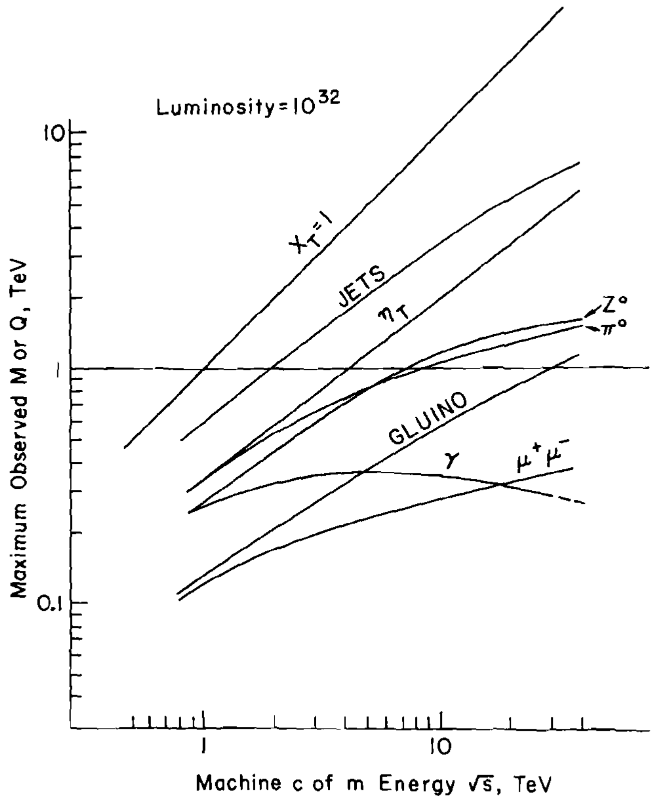

Figure 2. Plot of the highest obtainable M's or Q's verses machine energy for a luminosity of $10^{32} cm^{-2} sec^{-1}$.

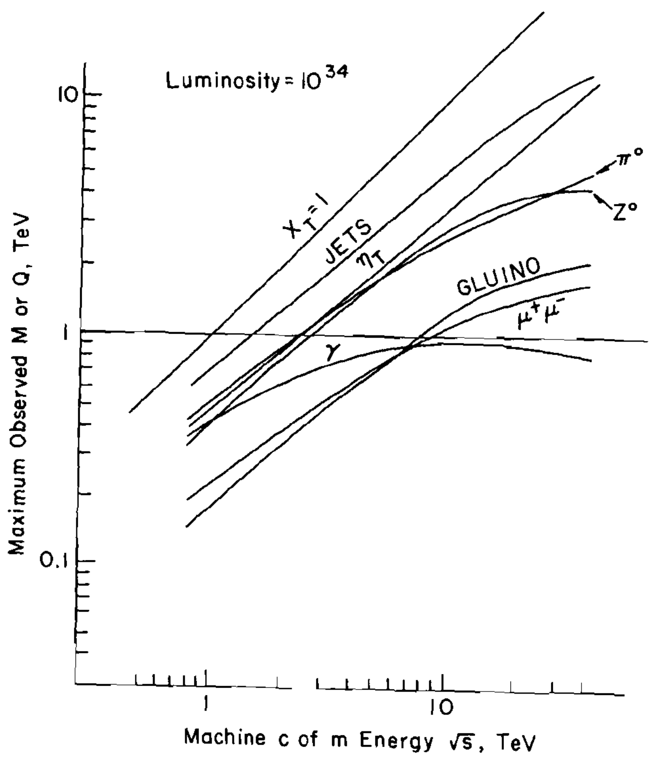

Figure 3. Plot of the highest obtainable M's or Q's versus machine energy for a luminosity of $10^{34} cm^{-2} sec^{-1}$.

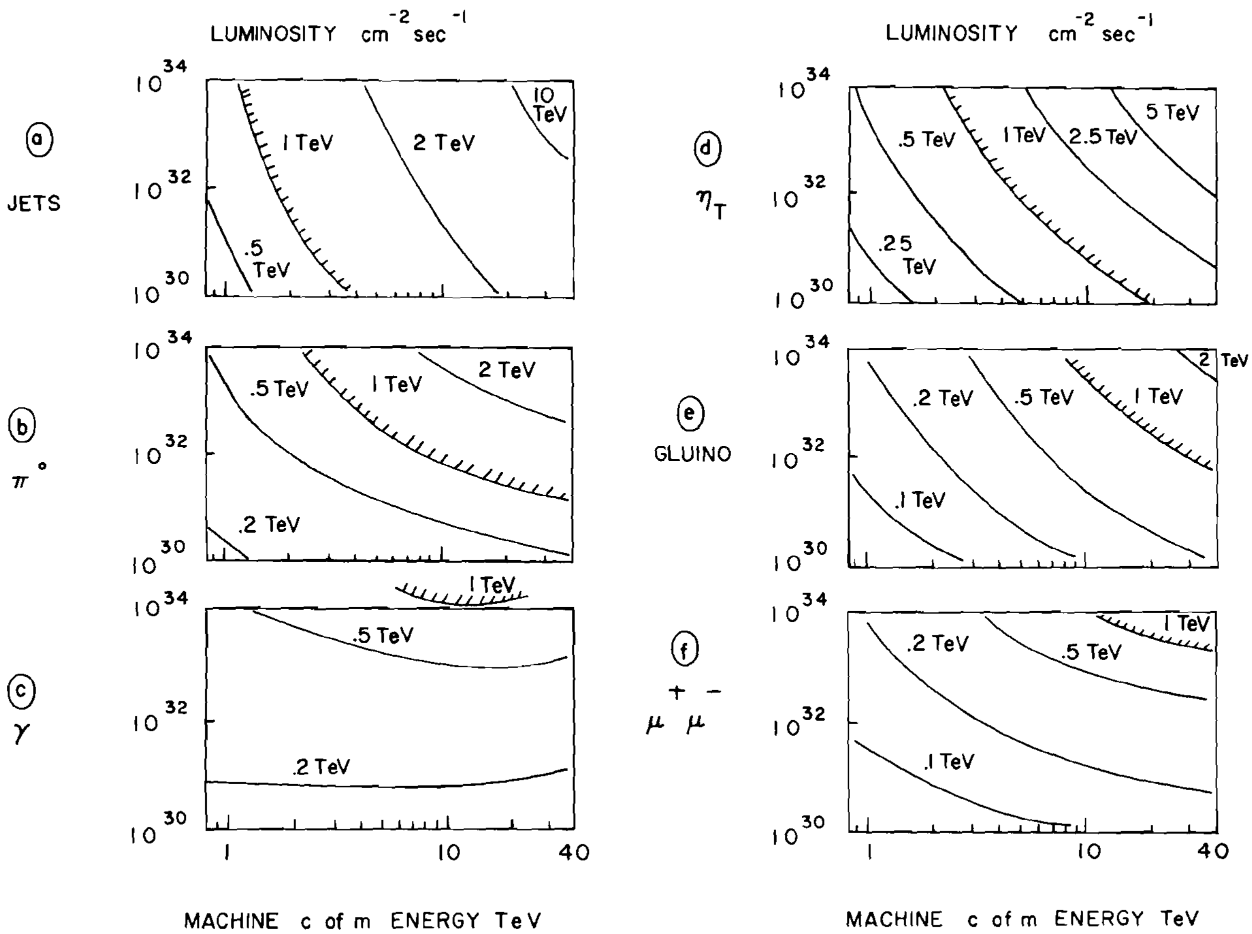

Figure 4. Contours of constant 'highest observable M or Q' on a luminosity vs. energy plot.

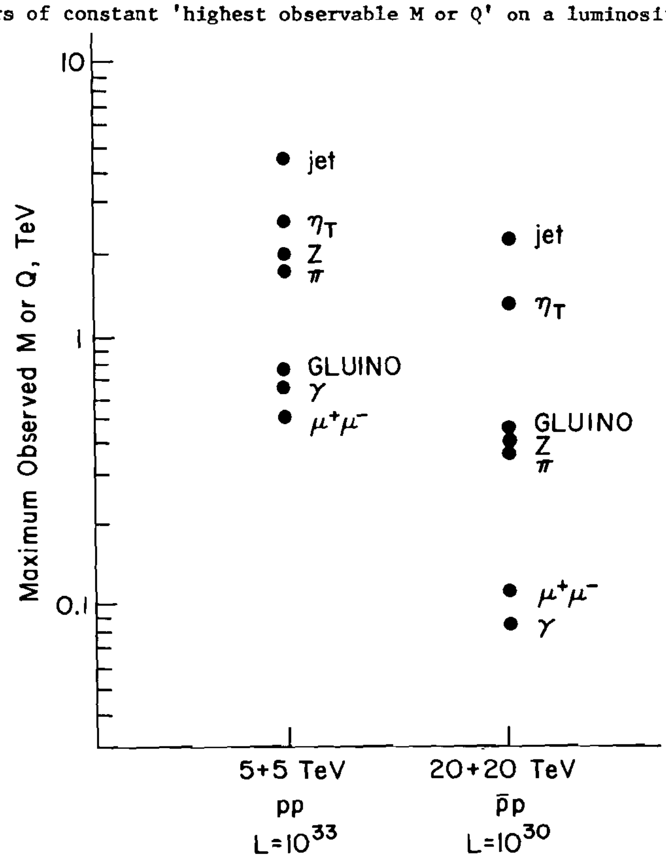

Figure 5. Comparison of M or Q Limits Accessible by Two Machines.

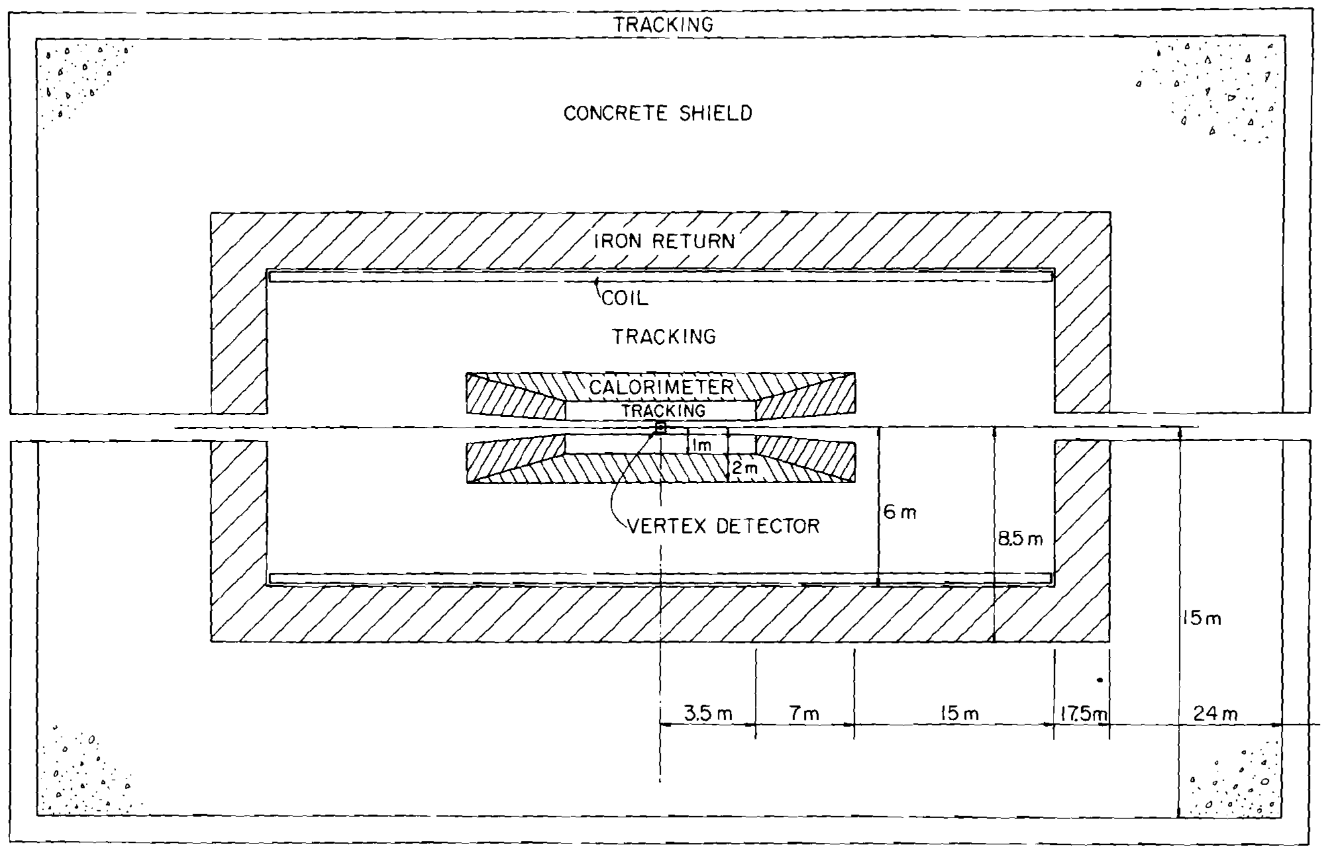

Figure 6. Conceptual sketch of a very large facility detector.

REPORT OF THE FIXED TARGET PROTON ACCELERATOR GROUP

Summarized by L. Pondrom

K. Abe, G. Bunce, G. Fisk, D. Garelick, J. Greenhalgh, R. Heinz, C. Hoffman, R. Lipton, D. Lowenstein, H. Lubatti, R. Macek, J. MacLachlan, L. Nodulman, M. Peskin, L. Ratner, K. Reibel, R. Ruchti, V. Sandberg, H.A. Thiessen.

I. Introduction

The fixed target proton accelerator group divided itself into two roughly equal parts. One sub-group concentrated on a high intensity (10^{14} protons/sec) moderate energy (30 GeV) machine while the other worked on a moderate intensity (5×10^{11} protons/sec) very high energy (20 TeV) machine. The proceedings of other workshops have been very helpful to both subgroups. Workshops concentrating on the proposed LAMPF II accelerator at Los Alamos[1] served as a framework for the deliberations of the first subgroup, whereas the studies by the International Committee for Future Accelerators were invaluable to the second[2].

Since accelerators have been operating in the 30 GeV energy range for years, it is possible to plan specific experiments for the high intensity version in detail. The subgroup was mainly interested in neutrino interactions and searches for rare decays of K mesons. A factor of ten increase in average intensity over the present Brookhaven AGS will provide significantly improved experiments in these and other instances.

The proposed 20 TeV machine would reach a maximum energy in the p-p center of mass of $\sqrt{s}$ = 190 GeV, less than half that currently available at the CERN $\bar{p}p$ collider, so it really is not practical to contemplate the construction of a fixed target machine to extend the available energy. For experiments where the total available energy is adequate, the fixed target option added to a $\bar{p}p$ 20 TeV collider ring has several attractive features: 1) High luminosity afforded by intense beams striking thick solid targets; 2) Secondary beams of hadrons, photons, and leptons; and 3) The versatility of a fixed target facility, where many experiments can be performed independently. The proposed experiments considered by the subgroup, including neutrino, photon, hadron, and very short lived particle beams were based both on scaled up versions of similar experiments proposed for Tevatron II at Fermilab and on the 400 GeV fixed target programs at Fermilab and CERN.

The experimental opportunities afforded by these new machines will be the subject of this summary. Construction techniques and cost estimates are covered in the report of the Accelerator Group in these proceedings.[3]

II. High Intensity Moderate Energy Proton Accelerator

The parameters chosen for this accelerator are:

$$E_p = 30 \text{ GeV}$$
$$I_p = 10^{14} \text{ protons/sec}$$
$$\text{duty factor} = 50\%$$

This is about a factor of 10 increase in intensity over the present Brookhaven AGS, which would allow either a corresponding increase in intensity of secondary beams, or improvement in the definition or purity of such beams, or both.

A. Neutrino Physics

The broad band neutrino beam at the AGS yields about 4.7×10^{17} ν_μ's per day, with half as many $\bar{\nu}_\mu$'s and less than 1% as many ν_e's.[4] The average energy is $\langle E_\nu \rangle = \langle E_{\bar{\nu}} \rangle$ = 1.4 GeV. The flux in a narrow band beam depends on the details of the design, but a factor of ten loss, or 4.7×10^{16} ν_μ's per day, seems to be a reasonable estimate. The new machine would therefore furnish a narrow band ν_μ beam with average intensity comparable to the present wide band beam.

A study of the differential cross sections for the neutral current reactions

$$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$$
$$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$$