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# NAL PROPOSAL 177 (REVISED)

# EARLY MEASUREMENT OF 200 AND 400 GEV PP LARGE ANGLE ELASTIC SCATTERING

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## I. Abstract

The proton-proton angular distribution would be determined in the region $4<-t<20$ Gev$^2$ at 200 Gev/c and $10<-t<20$ Gev$^2$ at 400 Gev/c by measuring both scattered protons after magnetic analysis with proportional wire chambers in Proton West. Cross sections as low as $10^{-38}$ cm$^2$/Gev$^2$ could be measured with an average beam intensity ~$10^{11}$ protons/sec.

*Pending approval of the appropriate authorities.

## II. Physics Justification

Preliminary results from the ISR presented by Rubbia[1] at the XVI International Conference on High Energy Physics Sept. 1972 show for the first time a sharp dip in PP elastic scattering (at $-t=1.3$ Gev$^2$). The dip is followed by a factor of 3 rise in cross section and the suggestion of a second dip at $-t \sim 5$ Gev$^2$. These results are shown in Fig. 1. It is seen that within statistics, $d\sigma/dt$ is the same at 500 Gev/c and 1500 Gev/c laboratory beam equivalent. This is quite different from the case at lower energies (up to 30 Gev/c) where all hadron-proton elastic cross sections are dropping with energy ($\sim 1/S^2$ for PP and $\sim 1/S^3$ for $\pi$P) for fixed t in the region $-t>3$ Gev$^2$. If this same power law were to hold up to 1500 Gev/c, the two ISR cross sections would be a factor 10 apart rather than the same. The new ISR results suggest that the infinite energy diffraction curve for PP has been reached at least by 500 Gev (it could even be below 200 Gev).

Although no dip is seen at lower energies, there is a kink at $-t= 1.3$ Gev$^2$ which first appears at about 10 Gev/c. So far the ISR results are in agreement with the curves predicted by Durand and Lipes.[2] They also predict a second and even more dramatic dip at $-t=6$ Gev$^2$, and for higher momentum transfer they predict $(d\sigma/dt)/(d\sigma/dt)_0$ should fall not far below $G_E{}^4(t)$ (the e-p form factor). Chou and Yang make similar predictions.[3]

We note that if sharp dips or high Fourier components are seen at $p_\perp \sim 2$ Gev/c, this could imply sharp structure at distances considerably smaller than one fermi. Certainly it is important to do a careful, high statistics search for the second (and perhaps third) dip. At the second dip $d\sigma/dt$ is expected[2] to be $10^{-35}$ cm²/Gev² which is too small for the ISR, but easy for this experiment.

It is also important to determine whether or not asymtopia has been reached below 500 Gev/c as implied by the ISR results. This can be accomplished by doing accurate measurements at 200 and 400 Gev/c in the same t region.

In our estimate of rates we use the ISR results as far as they go (up to $-t \sim 4$ Gev²) and we use the lowest prediction of Durand and Lipes for higher t. (See Fig. 2). Our rates are such that we can measure both 200 and 400 Gev/c angular distributions up $-t \sim 20$ Gev² at beam intensities below $10^{12}$/pulse in Proton West. By comparison, the limit in t for the ISR should be ~5 Gev².

## III. Experimental Method

We are proposing a method to measure PP elastic scattering at very large t-values which should be feasible in the early years of NAL operation where beam intensity will be at a special premium. Our design assumes an average intensity $10^{11}$ protons/sec (or $4 \times 10^{11}$ protons/pulse) delivered to our target. This should adequately account for simultaneous or alternate targeting of other experimental areas.

Cross sections as low as $d\sigma/dt \sim 10^{-38}$ cm²/Gev² could be measured due to the large solid angle of the geometry proposed. Hence even the lowest curve of Ref. 2 could be measured up to $-t \sim 25$ Gev². The average azimuth angle bite is $\Delta\phi = 0.11$

radians. The $\Delta t$ bite is large enough to permit simultaneous measurement of the angular distribution from $-t = 4$ to 10 $Gev^2$ or from 10 to 20 $Gev^2$. The full solid angle as defined by the lower energy particle (called the slow arm particle) is $\Delta\Omega_s = .02$ sr. in the lab system.

Both scattered protons will be measured after magnetic analysis using proportional chambers as shown in Figs. 3, 4, and 5. Cornell and Northeastern members of our group have used proportional chambers with 1.2mm wire spacing in a previous AGS experiment which gave a measured rms spatial resolution better than ±0.3mm with ~100% efficiency using a 30nsec time gate. In this proposal we assume rms spatial resolution of ±0.5mm. As shown in Fig. 3 the slow arm chambers would be 16" high times 20" wide. The width of the chambers and trigger counters is reduced a factor of 10 by utilizing kinematical focussing. (The larger angle protons have less momentum and are deflected more so that after the magnets the rays no longer diverge.)

As shown in Fig. 5, the fast arm chambers would be 3" high and 10" wide. Fortunately the 1.5" gap of the BM 5-1.5-120 magnets is closely matched in $\Delta\phi$ to the 8" gap of the BM109. In order to cover $4<-t<20$ $Gev^2$ at 200 Gev/c, two runs are required with a move of the magnets between the two runs. Then $10<-t<20$ $Gev^2$ could be measured at 400 Gev/c in a third run with no magnet moves of the slow arm. The two magnet positions for the slow arm are shown in Fig. 3 and 4. The magnet positions for the fast arm are shown in Fig. 5. An alternate scheme would be to put $M_3$ ~300" further upstream using it as a septum magnet (the main beam passes through an iron pipe placed between the magnet coils).

We have been asked to compare our experimental approach to that of Proposal No. 6 where one point is taken at a time using much higher beam intensity to make up for the much smaller solid angle. Not only does our approach measure a large range of angles at once (with improved resolution), but it can be done at any NAL energy at higher or lower t-values than No. 6 with 1/100 as much beam, 200 times more solid angle using 1/4 as much magnet power with no extra tunnels to be dug. A detailed comparison follows:

1. We can run at any energy of which NAL is capable. It is an important part of our experiment to run at the highest practical energy (we call it 400 Gev/c). No. 6 cannot run above 200 Gev/c.

2. If necessary we could run at t-values outside the region $4<-t<20$ Gev$^2$. This cannot be done by No. 6 with their existing magnets and proposed new tunnels.

3. We run all data "points" simultaneously over a factor of 2 range in t. This eliminates the rather large point to point relative errors which other experimenters have experienced when taking one point at a time. Certainly we are not at the mercy of irreproducibility in monitoring and beam quality.

4. We estimate at least a factor of 100 improvement in signal to inelastic background over No. 6. This is because our detectors have an rms spatial resolution of at least ±0.5mm and an angular resolution better than ±0.1mrad. Our higher track resolution also permits elimination of a larger source of background; viz., tracks which do not originate from the target. We can tell whether or not a track originates from a poleface or a collimator.

5. We ask for a factor 100 less beam intensity.

6. We have a factor 200 more solid angle by utilizing kinematical focussing in the slow arm. We have the freedom to adjust the binning and bin widths of the experimental points. This permits us to get to cross sections a factor 50 smaller than No. 6 when running at the same beam intensity.

7. In case there should be a significant subtraction for inelastic background our coplanarity and opening angle histograms not only display the intrinsic resolution curves (limited by the primary beam emittance), but permit a higher statistics determination of the inelastic background.

8. Our maximum power requirement is 455 KW compared to 1,900 KW specified in No. 6. (The power station which supplies all 3 Proton Areas is rated at 1,500 KVA.)

9. We use the experimental area in Proton West as is without requiring further excavations for beam pipes or tunnels. No.6 still requires about 1/4 mile of additional excavation.

Event rates

We can estimate the event rates by using the cross sections from Reference 2 shown in Fig. 2. These are tabulated at a few widely spaced t-values in Table I along with the predicted number of events/day. The following is a sample calculation for the bin $-t = 19 \pm 1.5$ Gev$^2$. The number of elastic scatters is:

$$N_{pp} = N_p n_H \frac{d\sigma}{dt} \Delta t \frac{\Delta\phi}{2\pi}$$

where $N_p = 10^{11}$ protons/sec $= 8.64\times10^{15}$ protons/day

$n_H = 4.2\times10^{23}$ target protons/cm$^2$ for a 4" long liquid hydrogen target

$d\sigma/dt = 10^{-37}$ $cm^2/Gev^2$

$\Delta t = 3$ $Gev^2$ and $\frac{\Delta\phi}{2\pi} = 0.017.$

$N_{pp} = (8.64x10^{15})\ (4.2x10^{23})(10^{-37})\ (3)(.017)$

$= 18.5$ events/day

At the same beam intensity Proposal No. 6 would obtain 0.5 events/day at $-t = 19$ $Gev^2$ because of smaller $\Delta t$ and $\Delta\phi$ bites. In the same day our experiment would also have measured all the other angles down to $-t = 10$ Gev as well as 18 events at $-t = 19$ $Gev^2$. Two weeks of running would give over 200 events at our highest t point. We would like the equivalent of 2 weeks of running for each of our 3 runs or a grand total of 6 weeks. Hence our request for running time is a total of $4x10^{17}$ protons delivered to our target. Testing could be done under lower intensity conditions or while other experiments were running or testing in Proton West.

Table I

| -t | $\Delta t$ bite | $d\sigma/dt$ | events/day |
|---|---|---|---|
| 4 $Gev^2$ | $\pm$ .1$Gev^2$ | $3.10^{-33}$ | 25,000 |
| 8 | $\pm$ .2 | $10^{-35}$ | 240 |
| 12 | $\pm$ .5 | $10^{-36}$ | 61 |
| 19 | $\pm$1.5 | $10^{-37}$ | 18.5 |
| 25 | $\pm$ 3 | $10^{-38}$ | 3.7 |

Background

We shall consider 4 classes of background: (a) accidental coincidences of single particles produced in two separate target interactions (single arm background); (b) true coincidences of two particles produced in the same interaction (inelastic background); (c) background not coming from the target; (d) general room background (slow neutrons).

(a) Single Particle Production.

Now that the scaling of production cross sections has been shown to work up to ISR energies, we can take 25 GeV/c and 30 GeV/c results from CERN and BNL and scale them up to 200 GeV/c using $Ed^3\sigma/dp^3$ as a function of x and $p_\perp$ only. Allaby, et al.[4] show that $Ed^2\sigma/p^2d\omega dp \approx 2\times10^{-26}$ $cm^2/sr\ GeV^2$ in the region $.5 < x < 1$ at low $p_\perp$. (See Fig. 5 of Ref. 4). Their Fig. 7 and the results of Anderson, et al.[5] show that this cross section should be multiplied by $F(p_\perp) \approx \exp(-6p_\perp)$ for $0 < p_\perp < 2$ GeV/c. Recent IRS results[6] show this same exponential dependence except that above $p_\perp = 1.5$ GeV/c the exponent decreases from 6 to 3 $GeV/c^{-1}$. This is what we used for $F(p_\perp)$ in the following estimates. For the single particle cross section we use

$$d^2\sigma/d\Omega dP \approx 2 \times 10^{-26} PF(p_\perp).$$

Numerical integrations over the P-$\Theta$ acceptances of our telescopes gives $N_F = 200$ particles/pulse for the $10 < -t < 20$ run at 200 GeV/c for the fast arm and $N_S = 15$ particles/pulse for the $10 < -t < 20$ runs for the slow arm. We should be able to achieve a $10^{-9}$ sec resolving time by recording the time of flight between

$S_3$ and $S_6$ and after-the-fact correcting for position in the two scintillators. If our rates in the two arms were 200/sec and 15/sec there would only be one accidental/week. Whatever accidentals we do encounter will be eliminated by the coplanarity and opening angle cuts.

(b) Inelastic Background

This section consists of two parts. In the first part we estimate the absolute number of inelastic events under our elastic peak after appropriate cuts. In the second part we compare our elastic to inelastic ratio to that of Proposal No. 6.

We have assumed that the cross section for PP $\rightarrow$ ($PN^{*+}$ or $N^{*+}P$) followed by $N^{*+} \rightarrow P + \pi^0$ is 13 times the elastic at all t-values and for N* masses up to 2 Gev. This is a pessimistic assumption considering the existing data on this part of the mass spectrum. Monte Carlo inelastics and elastics were generated using the above prescription. A coplanarity cut was made ($\phi_{measured} - \phi_{predicted}$) $\leq 0.5^\circ$ for the fast arm based on the slow arm measurement. (Note that the fast or slow arm measuring accuracy is better than $\Delta\phi_{rms} = 0.1^\circ$.) All our estimates were made without using proportional chamber PC4. Also the correlation between position and angle in the slow arm was ignored. All these pessimistic assumptions gave ~10% uniform background under the elastic peaks as displayed in the ($\theta_{meas} - \theta_{pred}$) histograms. We conclude that 10% is an upper limit for our inelastic background. If the inelastic background should be this large we shall be able to measure it to an accuracy of ± 10% even for our high t points. So the uncertainty in the background subtraction would be ~1% of the signal.

In comparing the signal to inelastic background for Proposals No. 177 and 6, we assumed that a particular hodoscope element in each arm fired. In No. 6 the back hodoscope elements are 2.4"x2.4" and 1"x1". In No. 177 all hodoscope elements are 0.04"x0.04". In each case we calculate the elastic signal feeding into the two arms. It is proportional to $d\sigma/d\Omega$. We also calculate the inelastic signal feeding into the two arms which is proportional to some unknown two particle inclusive cross section $\frac{d\sigma}{dP^s d\Omega^s dP^F d\Omega^F}$. In taking the ratio of the two signal to background ratios, these unknown cross sections cancel out giving the result that $\frac{(S/B)_{177}}{(S/B)_6} > 100$.

(c) Non-target Background

In Reference 7 which was also a two-armed, large-angle PP elastic experiment the main source of tracks in the telescopes at large t was not the target, but from particles scattering from magnet polefaces and collimator edges. In that experiment there was 40" of collimator plus 72" of magnet iron or copper as further collimation in the slow arm which is comparable to our present situation. Here we have the advantage of 20 times less interaction rate and three times as much bending. Since the slow arm kinematics are the same at 30 and 200 Gev/c, we do not expect high fluxes of tracks through all 3 elements in the slow arm. In the fast arm, outscattering from iron collimators or polefaces is small at 200 Gev/c. Page 139 of Reference 9 shows that a collimator wall tilted at $10^{-3}$ rad to a 2 mm wide beam gives only 0.06% outscattering from iron.

Another source of possible tracks through the entire fast arm telescope might be the decay muons from low energy pions which happened to be pointing in the direction of the magnet M3 aperture. Such muons would be partially captured because of reverse bending in the magnet yokes. Crude estimates give $5\times10^4$ muons/pulse as an upper limit. We expect that an accurate calculation will give a significantly smaller number and we plan to make such a calculation.

Our track resolution is such that we can tell whether or not a track extrapolates back to the target. Hence the above non-target backgrounds can be eliminated completely in the data analysis. This is not the case for No. 6.

Beam halo cannot trigger the entire fast arm telescope because of its angle to the beam. However, it could contribute to the singles rates in the detectors. We assume that muons at a distance of 5 ft. from the beam are removed before they enter Proton West. Actually we could tolerate a muon flux in a ring (5±1) ft from the beam of $3 \times 10^8$/pulse.

As a general precaution we have made sure that any straight line from the target to any of our detectors except PC4 must travel through $\sim$40 collision lengths. PC4 is not necessary at all for the success of this experiment; however, it would improve resolution and provide useful calibrations, so we intend to give it a try. We have estimated the total charged particle flux through it by the same method that we estimated the rates through PC3. We obtained the result $\sim$200,000 particles/pulse which is safe for a proportional chamber with 30 nsec resolving time.

(d) Neutron Background

The only source remaining which could possibly produce high singles rates in our detectors are neutrons which are expected to be the main component of general room background. There are two main sources of neutrons: the $5 \times 10^9$ interactions/pulse in our hydrogen target, and the $4 \times 10^{11}$ interactions/pulse in the beam dump. Reference 9 shows that a 200 Gev parent proton being absorbed in iron results in a grand total of about 1000 daughter neutrons. The absorption length for these neutrons in iron is about 100 gm/cm$^2$ and about 80 gm/cm$^2$ in concrete.[8,9]

In order to take advantage of the inverse square law, we propose to place iron collimators just downstream of the target to catch all secondaries except those pointed down the beam pipe and those pointed toward the 1.5"x 5" aperture of M3. If we assume the inverse square law and that the $5x10^{12}$ neutrons/pulse produced in the collimators near the target have to traverse $\sim$3 collision lengths, there will be about $4x10^5$ neutrons/pulse passing through PC6. Since the efficiency of our proportional chambers to neutrons is $\sim 10^{-3}$ we might get $\sim$500 sparks/pulse due to neutrons from the target. An additional attenuation factor of $10^{-4}$ can be obtained by placing 10 ft of concrete shielding just inside the tunnel entrance as shown in Fig. 3.

The hole in the beam dump points a beam of neutrons at $180 \pm 1.8^o$. Even though our detectors are outside this backscattered neutron beam, it is of interest to see what the neutron singles rate would be if PC5 were moved closer to the beam and hit directly by these neutrons. We assume $4x10^{14}$ neutrons/pulse are produced at an average distance of 3 collision lengths inside the beam dump (this is consistent with Table 5 of Ref. 8). Assuming they are all produced isotropically (actually most of them go forward) there would be a flux of $1.4x10^7$ neutrons/pulse through PC5 or $\sim 1.5x10^4$ sparks/pulse. This is an extreme upper limit because the neutrons pointing back toward our detectors must travel through several feet of iron and concrete comprising the beam dump. (We assume the outer layer of the beam dump will be low Z such as concrete.) An attenuation factor of $10^{-3}$ due to the beam dump brings our rate down to several sparks/pulse or perhaps 200 counts/pulse in the scintillation counters. Even if all 3 scintillation counters had singles rates of $10^6$/sec, the fast arm rate due to 3-fold accidentals would be ~100/sec.

An independent estimate of the neutrons from the beam dump can be obtained by using the first entry in Table 5 of Ref. 8. If one multiplies the neutron flux figure by 10 to convert from 20 to 200 Gev/c, one obtains ~1000 neutrons/pulse passing through PC5, 6, and 7.

NAL Requirements

The magnets needed are summarized in Table II. We would hope that the 3 external beam magnets (BM 5-1.5-20) and the BM 109 would be supplied by NAL. $M_1$ is a smaller septum or C-type magnet. Its field volume could be 5"x18"x40" at 18 KG. It could be a PPA 18D40. If no such magnet is available, the experimenters are prepared to build it.

Table II: Magnets

| | type | gap height | gap width | gap length | $\int Bdl$ | power |
|---|---|---|---|---|---|---|
| M1 | 18D40 | 5" | 18" | 40" | 828 KG-in | 150KW |
| M2 | BM 109 | 8 | 24 | 72 | 1090 | 155 |
| M3-M6 | BM5-1.5-120 | 1.5 | 5 | 120 | 1800 | 50 (for each of 3) |
| | | | | | | 455 KW total |

Our requirements for beam are a total of $2.5 \times 10^{17}$ slow-extracted 200Gev/c protons delivered to our target in Proton West and $1.5 \times 10^{17}$ 400 Gev/c protons. The liquid hydrogen target would be 4" long and about 1" diameter. It and the slow arm could be located in the main pit of Proton West as shown in Fig. 4, or it could be in the smaller pit which connects to the side tunnel at $22^\circ$. Concrete bricks would be used to build up a shield wall 5 to 10 ft thick downstream of the target. The kind of shield wall we have in mind could be used in the earlier Exp. No. 63 as well. Such a neutron shield is a necessity for No. 63. We would use the same monitoring devices to be built and calibrated by No. 63. We would need at least a bicycle link to an NAL computer for fast processing of sample data.

Equipment supplied by the experimenters

We would supply the complete trigger system and the proportional wire chamber system interfaced to our own PDP 11 with tape drives and monitoring displays. We could supply all special collimators other than standard shielding bricks and blocks. We are prepared to construct magnet M1 and to supply the liquid hydrogen target and compressor if necessary.

## References

1. Results shown in invited paper by G. Giacomelli, XVI International Conference on High Energy Physics, Sept. 1972.
2. Durand and Lipes, Phys. Rev. Letters 20, 637 (1968).
3. Chou and Yang, Phys. Rev. Letters 20, 1213 (1968).
4. Allaby, et al., CERN preprint 24 March 1972.
5. Anderson, et al., Phys. Rev. Letters 19, 198 (1967).
6. Preliminary ISR results of CERN-Columbia-Rockefeller Collaboration, reported by J.C. Sens, 4th International Conference on High Energy Collisions, Oxford, April 1972.
7. Cocconi, et al., Phys. Rev. 138, 165 (1965).
8. K. Goebel and J. Ranft, CERN 70-16, May 27, 1970.
9. J. Ranft, Particle Accelerators 3, 129 (1972).

## Captions

Fig. 1 Preliminary ISR results of the ACGHT Collaboration, Rubbia, et al., from Reference 1. Curves A and B are theoretical predictions of Durand and Lipes. Both the 500 and 1500 GeV/c results are shown.

Fig. 2 Large angle PP elastic scattering data showing energy dependence of $d\sigma/dt$ in the region 10 to 30 GeV/c. For comparison the most pessimistic predictions of Durand and Lipes and Chou and Yang are shown along with the e-P form factor to the 4th power.

Fig. 3 Layout of slow arm showing kinematical focusing. PC are proportional wire chambers. S are scintillation counters. The magnets are described in Table II.

Fig. 4 Same as Fig. 3 except that target location has been moved to the large pit in Proton West.

Fig. 5 Layout of fast arm showing the three different runs. An alternate layout would use M3 as a septum magnet. Then the center of M3 would be 200" from the target.

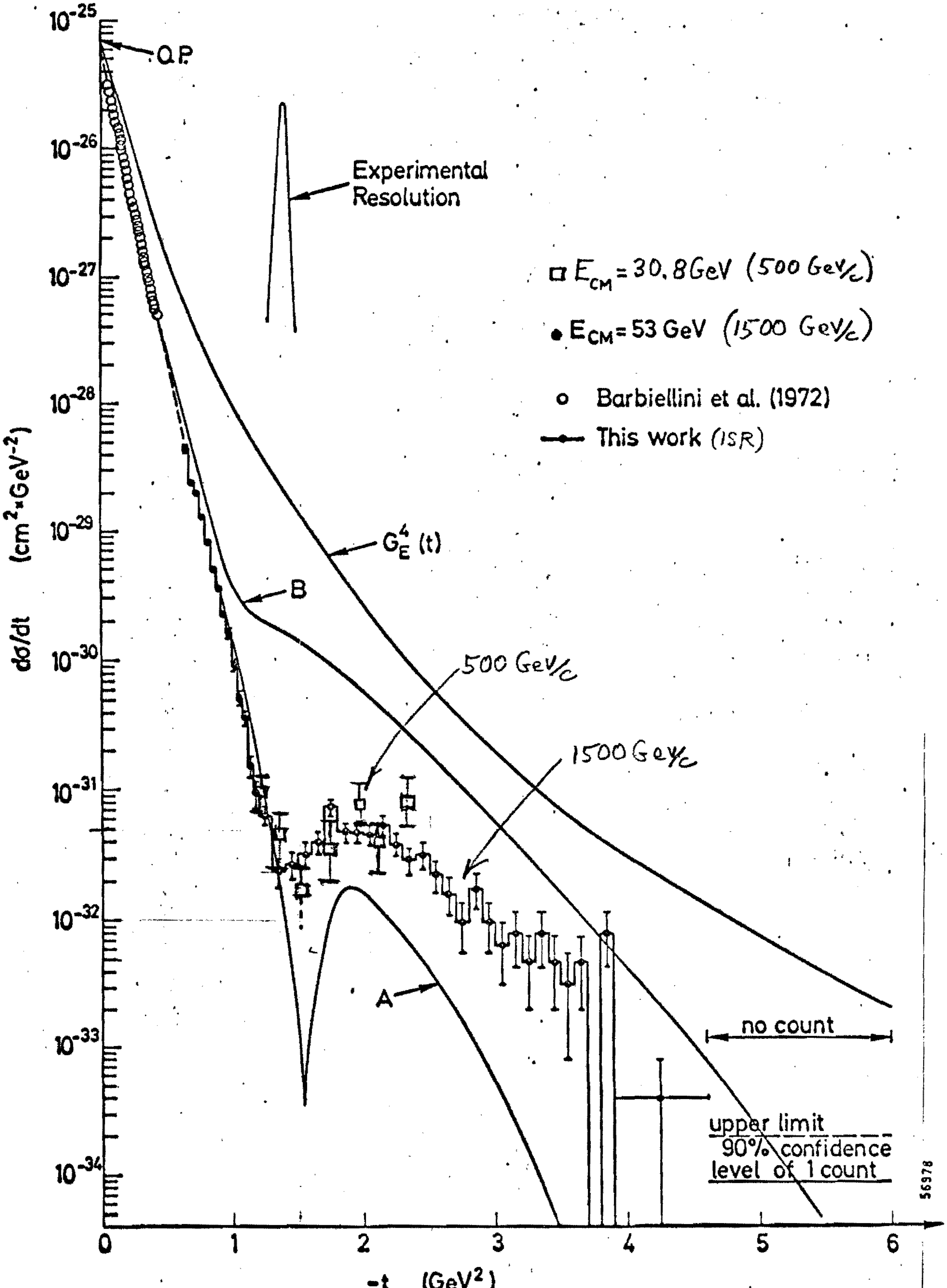
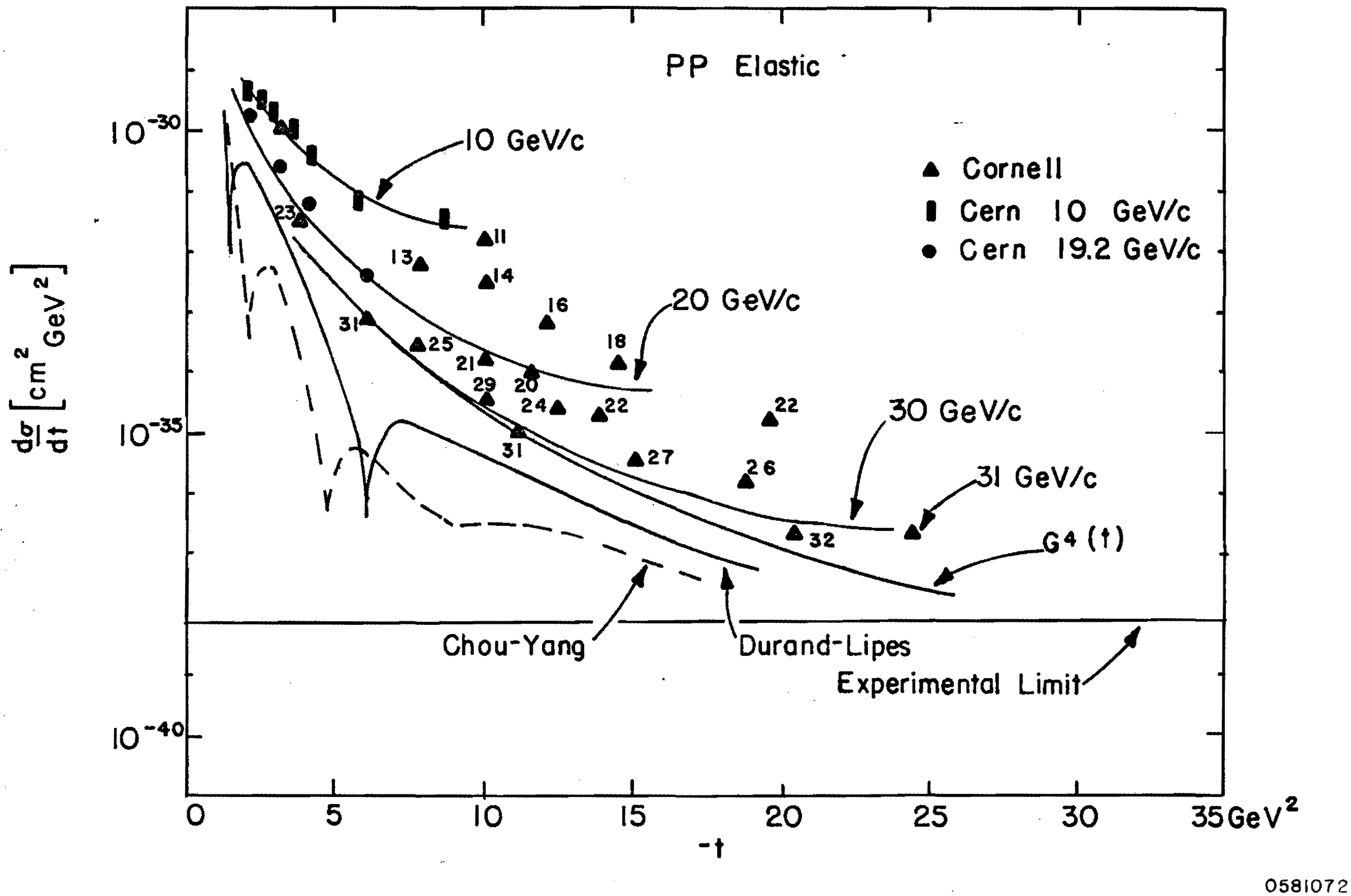
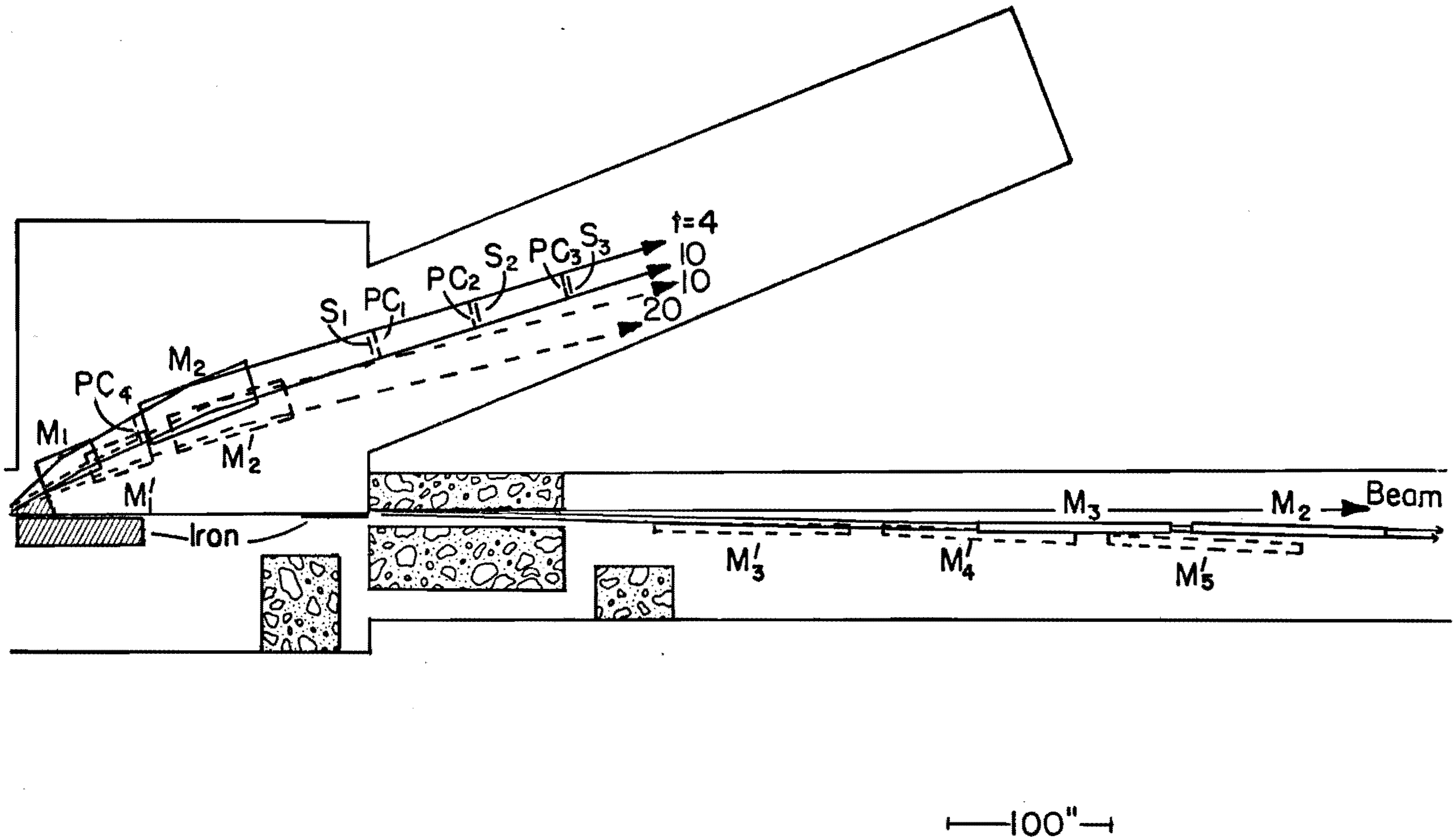

10^-25
10^-26
10^-27
10^-28
10^-29
10^-30
10^-31
10^-32
10^-33
10^-34
O.P.
Experimental
Resolution
□ E_CM = 30.8 GeV (500 GeV/c)
• E_CM = 53 GeV (1500 GeV/c)
○ Barbiellini et al. (1972)
This work (ISR)
dσ/dt (cm² × GeV⁻²)
G_E^4 (t)
B
500 GeV/c
1500 GeV/c
A
no count
upper limit
90% confidence
level of 1 count
56978
0
1
2
3
4
5
6
-t (GeV²)

FIG. 1



PP Elastic
10 GeV/c
20 GeV/c
30 GeV/c
31 GeV/c
G4 (t)
Cornell
Cern 10 GeV/c
Cern 19.2 GeV/c
Chou-Yang
Durand-Lipes
Experimental Limit
$10^{-30}$
$10^{-35}$
$10^{-40}$
$\frac{d\sigma}{dt}\left[\frac{cm^2}{GeV^2}\right]$
0
5
10
15
20
25
30
35 GeV$^2$
-t
0581072

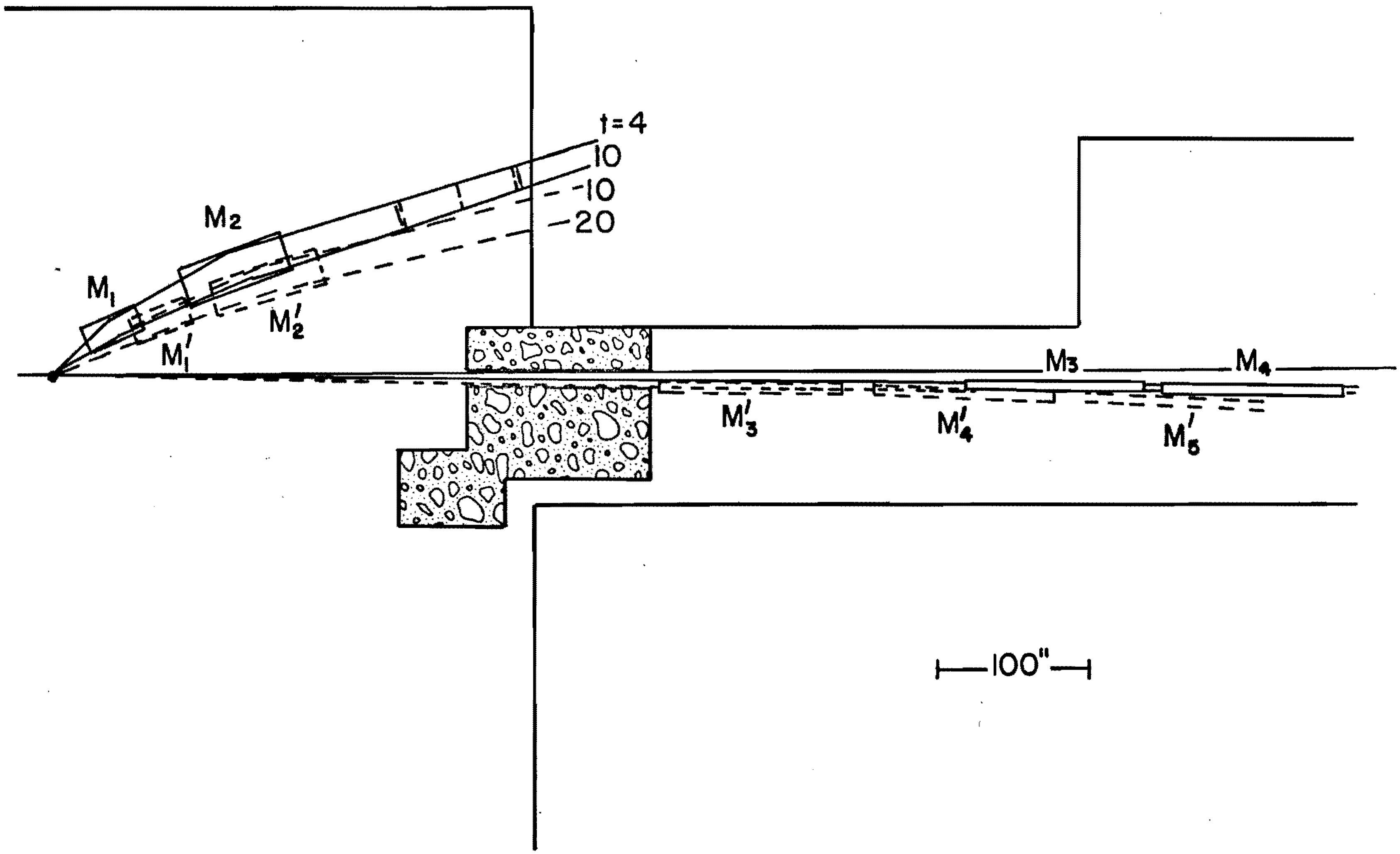

FIG. 2




200 GeV PP $4 < -t < 10$ and $10 < -t < 20$ GeV$^2$

FIG. 3

0581072




200 GeV PP 4 < -t < 10 and 10 < -t < 20 GeV$^2$

FIG. 4

0581072

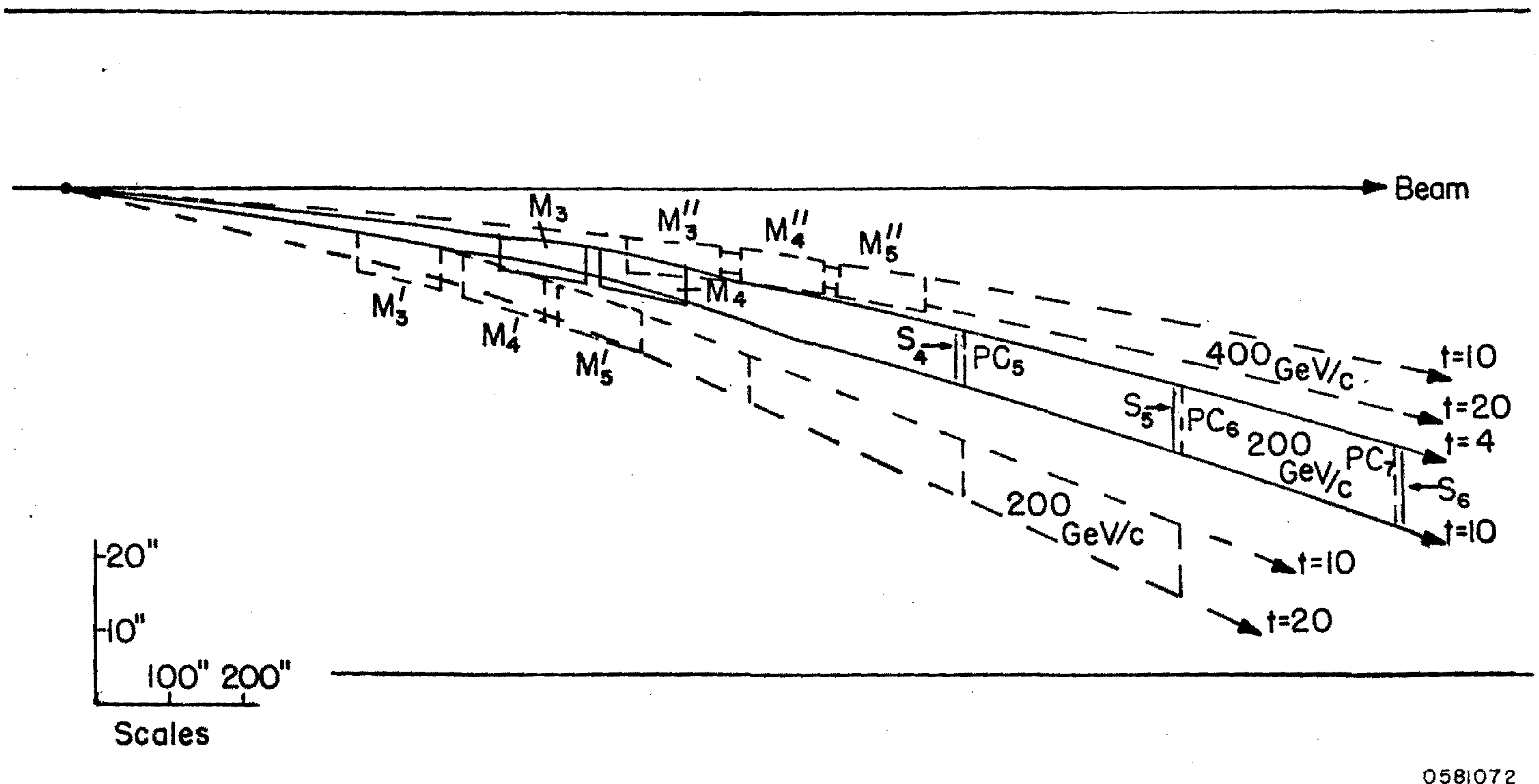

Beam
M3
M''3
M''4
M''5
M'3
M'4
M'5
M4
S4
PC5
400 GeV/c
t=10
t=20
t=4
S5
PC6
200 GeV/c
PC7
S6
t=10
200 GeV/c
t=10
t=20
20"
10"
100" 200"
Scales
0581072

FIG. 5

NAL PROPOSAL No. 177

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NAL Proposal June 8, 1972

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## I. Abstract

The 200 Gev PP angular distribution would be determined in the region $5 < -t < 13$ Gev$^2$ by measuring both scattered protons after magnetic analysis with proportional wire chambers in Proton West. Cross sections as low as $5 \times 10^{-39}$ cm$^2$/Gev$^2$ could be measured with an average beam intensity of $\sim 10^{12}$ protons/pulse.

II. Physics Justification

So far all measurements of hadron-proton elastic scattering above $-t \sim 1$ Gev$^2$ show a rapid drop in cross section with increasing energy for fixed t. The experimental situation for large angle PP elastic scattering is shown in Fig. 1. This obvious energy dependence is disturbing to many because the simplest diffraction models predict that $d\sigma/dt$ at fixed t should be independent of S. Several theorists including Serber; Chou and Yang; Durand and Lipes; Abarbanel, Drell and Gilman have predicted that the S dependence for PP elastic scattering should disappear above 30 Gev/c; i.e., the 30 Gev/c PP angular distribution would correspond closely to the infinite energy curve. These and other theorists have pointed out that the PP 30 Gev/c curve corresponds closely to $G^4(t)$, the 4th power of the e-P form factor.(1) If $G^2(t)$ is the probability that one proton be undisturbed after a central collision, they reason that the square of this would correspond to the joint probability that both protons survive the collision. We shall call the $G^4(t)$ curve the optimistic assumption.

On the other hand, the experimental results up to 30 Gev/c show a $1/S^2$ drop in $d\sigma/dt$ for fixed $p_\perp$.(2) Our pessimistic assumption is that the $1/S^2$ drop continues all the way to 200 Gev/c. This is also plotted in Fig. 1 and tabulated in Table I. Even if the pessimistic curve turns out to be true, the experiment proposed here will measure the angular distribution from $-t=5$ to 13 Gev$^2$. With a relatively small change in magnet positions a second geometry covering the region $13 < -t < 30$ Gev$^2$ would be possible. Of course this second geometry would be worthwhile only if the true cross section were larger than the pessimistic curve.

III Experimental Method

We are proposing a method to measure PP elastic scattering at very large t-values which should be feasible in the early years of NAL operation where beam intensity will be at a special premium. We are planning on the basis of $\sim 10^{12}$ protons/pulse on our target averaged over the duration of the experiment. This should adequately account for simultaneous or alternate targeting of most of the experimental areas.

Cross sections as low as $d\sigma/dt \sim 5\times10^{-39}$ cm$^2$/Gev$^2$ could be measured due to the large solid angle of the geometry proposed. Hence even the pessimistic curve of Fig. 1 could be measured up to $-t=13$Gev$^2$. The average azimuth angle bite is $\Delta\phi = 0.11$ radians. The $\Delta\theta$ bite is large enough to permit simultaneous measurement of the angular distribution from $-t=5$ to 13 Gev$^2$. The full solid angle as defined by lower energy particle (called the slow arm) is $\Delta\Omega_s = .02$ sr. in the lab system.

Both scattered protons will be measured after magnetic analysis using proportional chambers as shown in Figs.2, 3, and 4. Our group has used proportional chambers with 1.2mm wire spacing in a previous AGS experiment which gave an rms spatial resolution of $\pm 0.3$mm with $\sim$ 100% efficiency using a 30 nsec time gate. As shown in Fig. 2 the slow arm chambers would be 16" high times 10" wide. The width of the chambers and trigger counters is reduced a factor of 10 by utilizing kinematical focussing. (The larger angle protons have less momentum and are deflected more so that all rays can be made to intersect.)

As shown in Fig. 3 the fast arm chambers would be 3" high times

12" wide. Fortunately the 1.5" gap of the BM 5-1.5-120 magnets is closely matched in $\Delta\phi$ to the 8" gap of the BM109. The first BM5-1.5-120 is used as a "septum magnet"; i.e., it deflects the scattered protons, but not the proton beam. The proton beam passes through an iron pipe which is in a weak field region between the coils. Fig. 5 shows an alternate scheme which eliminates the need for a septum arrangement and uses 2 instead of 4 BM 5-1.5-120's.

Another experimental approach would be to take one point at a time using much higher beam intensity to make up for the smaller solid angle. This is the approach of NAL Proposal No. 6. Our approach differs from Proposal No. 6 in the following respects:

1. We ask for a factor 40 less beam intensity.

2. We have a factor 200 more solid angle.

3. We use proportional chambers which will give $\pm$ .5mm spatial resolution and $\pm$0.1 mrad angular resolution on both tracks. This permits a large improvement in the elastic to inelastic ratio. Also it permits after-the-fact elimination of particles which do not originate from the target.

4. Coplanarity and opening angle histograms not only display the true resolution curves (limited by the beam emissivity), but permit an accurate, high statistics determination of the inelastic background (if there is any).

5. We use kinematical focussing on the slow arm.

6. Our power requirements are 600 KW compared to 1,900 KW specified in Proposal No. 6.

7. We can improve the coincidence time resolution of the trigger by using the track position to correct after-the-fact for light pulse travel time in the scintillator.

8. The rather large point to point relative error due to irrepro-

ducibility of monitoring and beam conditions is eliminated by running all data "points" simultaneously.

9. We use the experimental area in Proton West as is without requiring further excavations for beam pipes. (In Fig. 5 we propose an alternate geometry which requires ~100 ft of pipe.)

<u>Event rates</u>

We can estimate a reliable upper and lower limit to the event rates by using the optimistic and pessimistic cross sections from Fig. 1. These are tabulated in Table I along with the predicted number of events/day. The following is a sample calculation:

The number of elastic scatters is

$$N_{pp} = N_p n_H \frac{d\sigma}{dt} \Delta t \frac{\Delta\phi}{2\pi}$$

where $N_p = 10^{12}$ protons/pulse $= 2.16\times10^{16}$ protons/day

$n_H = 4.2\times10^{23}$ target protons/cm$^2$ for a 4 inch long target

$d\sigma/dt = 6.8\times10^{-39}$ cm$^2$/Gev$^2$ is the pessimistic assumption for $-t=12$ Gev$^2$

$\Delta t = 3$ Gev$^2$ and $\frac{\Delta\phi}{2\pi} = 0.0175$ .

$$N_{pp} = (2.16\times10^{16})(4.2\times10^{23})(6.8\times10^{-39})(3)(.0175)$$

$$= 3.2 \text{ events/day}$$

One could obtain about 100 events as a lower limit for our largest angle point in about 30"ideal" days of running. Hence our request for running time is $6.5\times10^{17}$ protons delivered to our target. Testing could be done under lower intensity conditions or while other experiments were running or testing in Proton West.

Table I

| | Pessimistic Assumption | | | Optimistic Assumption | |
|---|---|---|---|---|---|
| t | $\Delta$t bite | $d\sigma/dt$ | events/day | $d\sigma/dt$ | events/day |
| 6 | $\pm0.5$ Gev$^2$ | $1.2\times10^{-35}$ | 1900 | $1.4\times10^{-33}$ | $2.2\times10^{5}$ |
| 10 | $\pm1$ | $1.2\times10^{-37}$ | 38 | $2\times10^{-35}$ | $.63\times10^{4}$ |
| 12 | $\pm1.5$ | $6.8\times10^{-39}$ | 3.2 | $5\times10^{-36}$ | 2400 |

Background

Now that scaling of production cross sections has been shown to work up to ISR energies, we can take 25 Gev/c and 30 Gev/c results from CERN and BNL and scale them up to 200 Gev/c using $Ed^3\sigma/dp^3$ as a function of x and $p_\perp$ only. Allaby, et al[3] show that $\frac{E\,d^2\sigma}{p^2 d\omega\, dp} \approx 2\times10^{-26}$ cm$^2$/sr Gev$^2$ in the region $.5 < x < 1$ and for $p_\perp = .2$ Gev/c (see Fig.5 of Ref.3). Their Fig. 7 shows that this cross section should be multiplied by a factor $5\times10^{-7}$ when averaging over our region of $p_\perp$. Hence we use

$$\frac{E\,d^2\sigma}{p^2 d\omega\, dp} \approx 10^{-32} \quad \text{or} \quad \frac{d^2\sigma}{d\Omega\, dP} \approx P\times10^{-32}$$

For the fast arm the number of particles/pulse coming from the target will be

$$N_F = N_P\, n_H \frac{d^2\sigma_F}{d\Omega\, dP}\, \Delta P_F\, \Delta\Omega_F$$

$$= (10^{12})(4.2\times10^{23})(200\times10^{-32})(29)(1.3\times10^{-5})$$

$$= 317$$

For the slow arm

$$N_S = N_P\, n_H \frac{d^2\sigma_S}{d\Omega\, dP}\, \Delta P_S\, \Delta\Omega_S$$

$$= (10^{12})(4.2\times10^{23})(5\times10^{-32})(.28)(2\times10^{-2})$$

$$= 118$$

We should be able to achieve a $10^{-9}$ sec resolving time by recording the time of flight between $S_3$ and $S_6$ and correcting for position in the two scintillators. Then the accidental rate would be 0.8/day. Nearly all of these accidentals will be eliminated by the coplanarity and opening angle cuts.

Other sources of background would be poleface and collimator scattering, backscattering from the beam stop, beam halo, and degraded room radiation (particularly slow neutrons).

In the case of the slow arm, the shielding and distances are comparable to that of the AGS large angle PP experiment where the background rates were low.[(4)] In that experiment there was only one bending magnet on the slow arm compared to two for this experiment.

Background will probably be most serious for the fast arm which is in the same tunnel with the beam. Here the four magnets act as a series of four 10 ft long iron collimators and give ~50 collision lengths of shielding for most of the secondaries produced in the target. (Any straight line from the target to the detectors must pass through at least 50 collision lengths.) Ten foot long iron collimators (24 collision lengths) would be placed between the target and first magnet in order to catch the rare large angle secondaries. Some slow neutrons from nuclear fragmentation might diffuse out sideways after several collision lengths. Some of them after scattering in the tunnel walls could be pointing toward the detectors. Let n be the number of neutrons per collision in the target which find their way out of the collimators. There will be $10^{10}$n such neutrons per pulse. The number pointing toward the detectors would be $2\times10^{4}$n/pulse. This seems quite safe considering possible values for n and the low efficiency of our detectors for slow neutrons. Most of the slow neutrons will diffuse through the earth from the source. To reach the detectors they must diffuse a distance of ~140 collision lengths which would require a prohibitive $2\times10^{4}$ collisions. Hence it seems that slow neutrons will be no problem.

Our vulnerability to slow neutrons or other sources of background can be simulated at this time by placing a scintillation counter ~160 ft downstream from an internal target in the main ring. We would measure the singles rate that is due to a given interaction rate in the internal target. We would like to make such a test in the main ring soon. If this main ring test (or equivalent data obtained by others) should indicate an unacceptable background; then a ~10 ft wall of shield blocks could be inserted between $M_3$ and $M_4$, or the fast arm could be constructed somewhat differently as shown in Fig. 5. In this case two instead of four BM 5-1.5-120 magnets would be used; however, it would be necessary to run a 2 ft diameter pipe about 70 ft to a small pit or tunnel of about 6 ft wide by 50 ft long. At this distance the scattered protons will have spread out by about 24 inches, so the fast arm proportional chambers would be about 4 inches high by 24 inches wide.

We would shield the detectors from backscattering from the beam dump. Beam halo will be no problem as long as the flux at 6±2 ft from the beam is less than 1% of the beam. Just in case singles rates are in the megacycle range for the fast arm, 3 scintillation counters will be used to develop the fast arm trigger pulse. The fast arm rate due to accidentals would be less than the 300 particles/pulse coming from the target.

NAL requirements

The magnets needed are summarized in Table II. We would hope that the 2 (or 4) BM 5-1.5-20's and the BM 109 would be supplied by NAL. $M_1$ is a smaller (~40" long) septum or C-type magnet. If no such magnet is available, the experimenters are prepared to build it.

Table II: Magnets

| | type | gap height | gap width | length | $\int B\,dl$ | power |
|---|---|---|---|---|---|---|
| $M_1$ | 18D40(PPA) | 6" | 18" | 40" | 828 KG-in | 150 KW |
| $M_2$ | BM 109 | 8 | 24 | 72 | 1366 | 270 |
| $M_3$-$M_6$ | BM5-1.5-120 | 1.5" | 5 | 120 | 1800 | 50 (for each of 2 or 4) |

Our requirements for beam are a total of $6.5\times10^{17}$ slow-extracted 200 Gev protons delivered to our target in Proton West. The liquid hydrogen target would be 4 inches long by about 1 inch diameter. We would need at least a bicycle link to an NAL computer for fast processing of sample data.

Equipment supplied by experimenters

We would supply the complete trigger system and the proportional wire chamber system with interface, tape drive, and monitoring displays. We would supply all special collimators other than standard shielding bricks and blocks. We are prepared to supply magnet $M_1$ and the liquid hydrogen target if necessary.

References:

1. C.B. Chiu, RMP 41, 640 (1969).
2. J. Orear, Physics Letters 13, 190 (1964) and A.N. Diddens "Proton-Proton Elastic Scattering Above 1 Gev", CERN preprint 1971.
3. Allaby, Diddens, Dobinson, Klovning, Litt, Rochester, Schlupmann, Wetherell, Amaldi, Biancastelli, Bosio, and Matthiae, CERN preprint 24 March 1972.
4. Orear, et al, Phys. Rev. 138, 165 (1965).

Figure Captions:

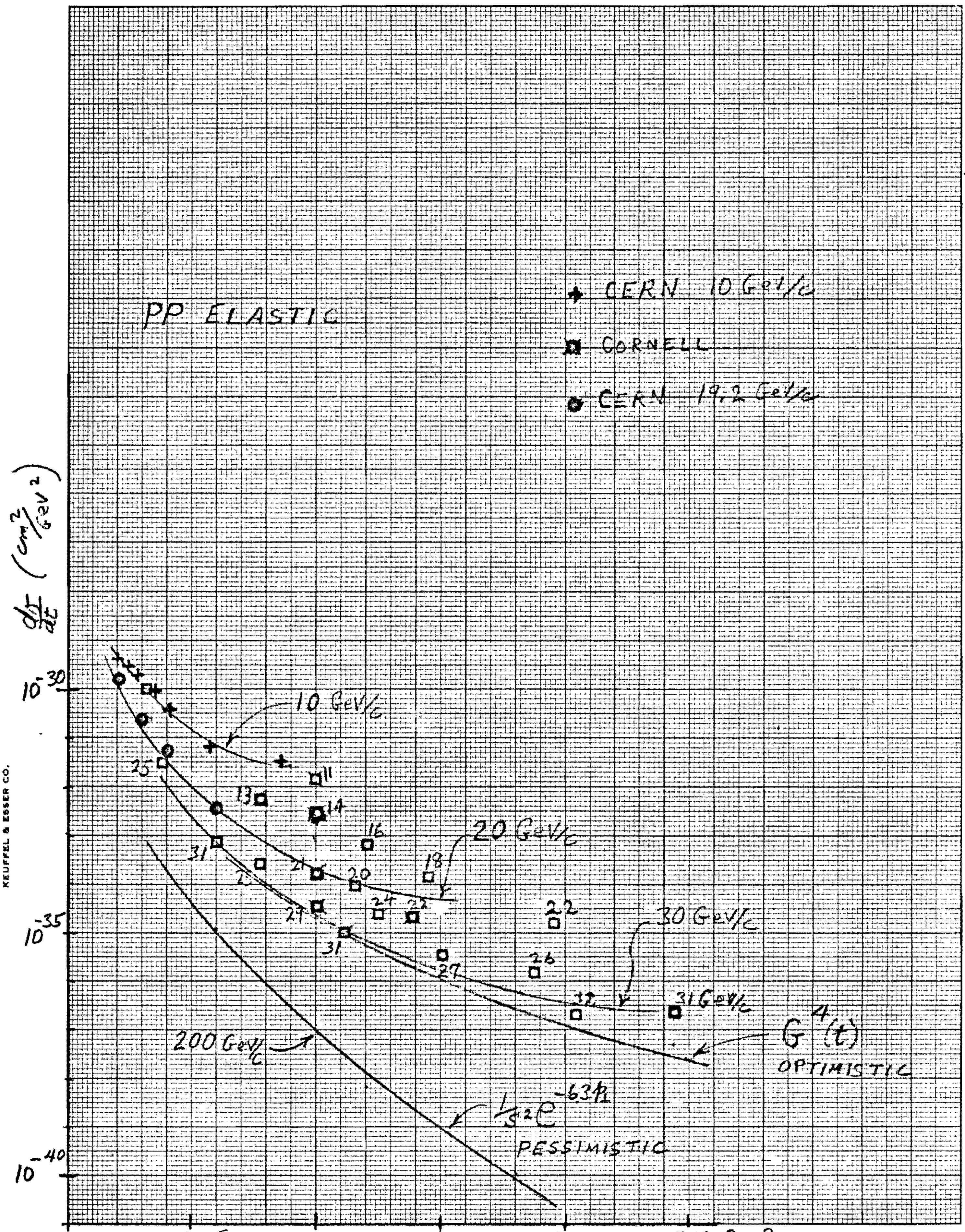
Fig.1. Large angle PP elastic scattering data showing drop in $d\sigma/dt$ with increasing energy. The "pessimistic" 200 Gev/c curve uses $d\sigma/dt = \frac{A}{s^2}\exp(-6.3p_\perp)$ where A= 7480 mb which fits all the data within a factor of 2.

Fig. 2. Layout of slow arm showing kinematical focusing. $M_1$ is a PPA 18D40 or a similar C or septum magnet. (Even a BNL 15C30 would do.) PC are proportional wire chambers. S are scintillation counters.

Fig.3. Layout of fast arm. $M_3$ has the 200 Gev/c beam travelling through an iron pipe between the coils.

Fig.4. Larger scale drawing showing both arms.

Fig. 5. Alternate scheme for fast arm which reduces background and the number of magnets.



PP ELASTIC
CERN 10 GeV/c
CORNELL
CERN 19.2 GeV/c
10 GeV/c
20 GeV/c
30 GeV/c
31 GeV/c
200 GeV/c
G^4(t)
OPTIMISTIC
1/s² e^(-6.3√-t)
PESSIMISTIC
dσ/dt (cm²/GeV²)
10^-30
10^-35
10^-40
0
5
10
15
20
25 GeV²
-t


FIG. 1

200 GeV/c PP

SLOW ARM

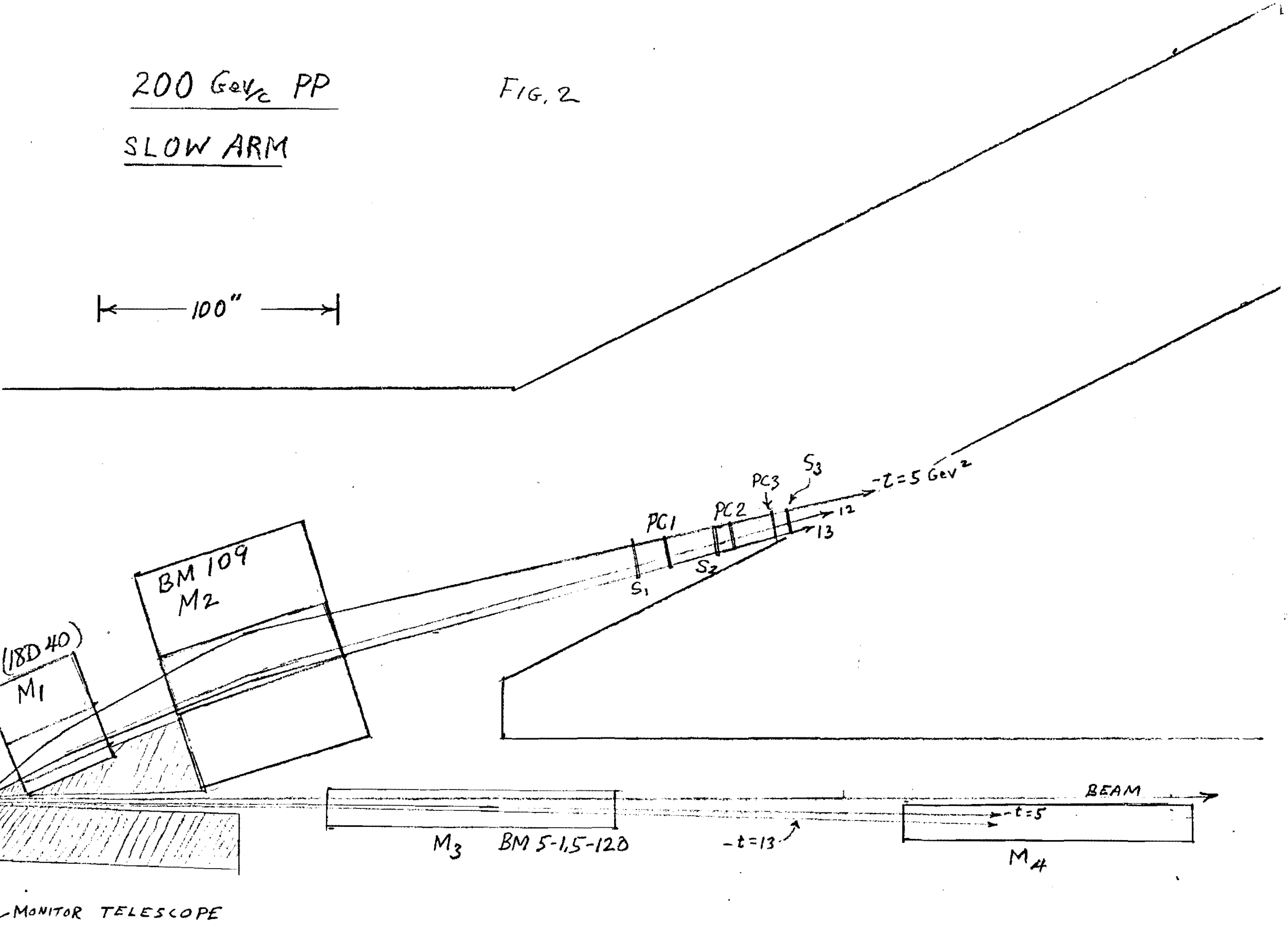
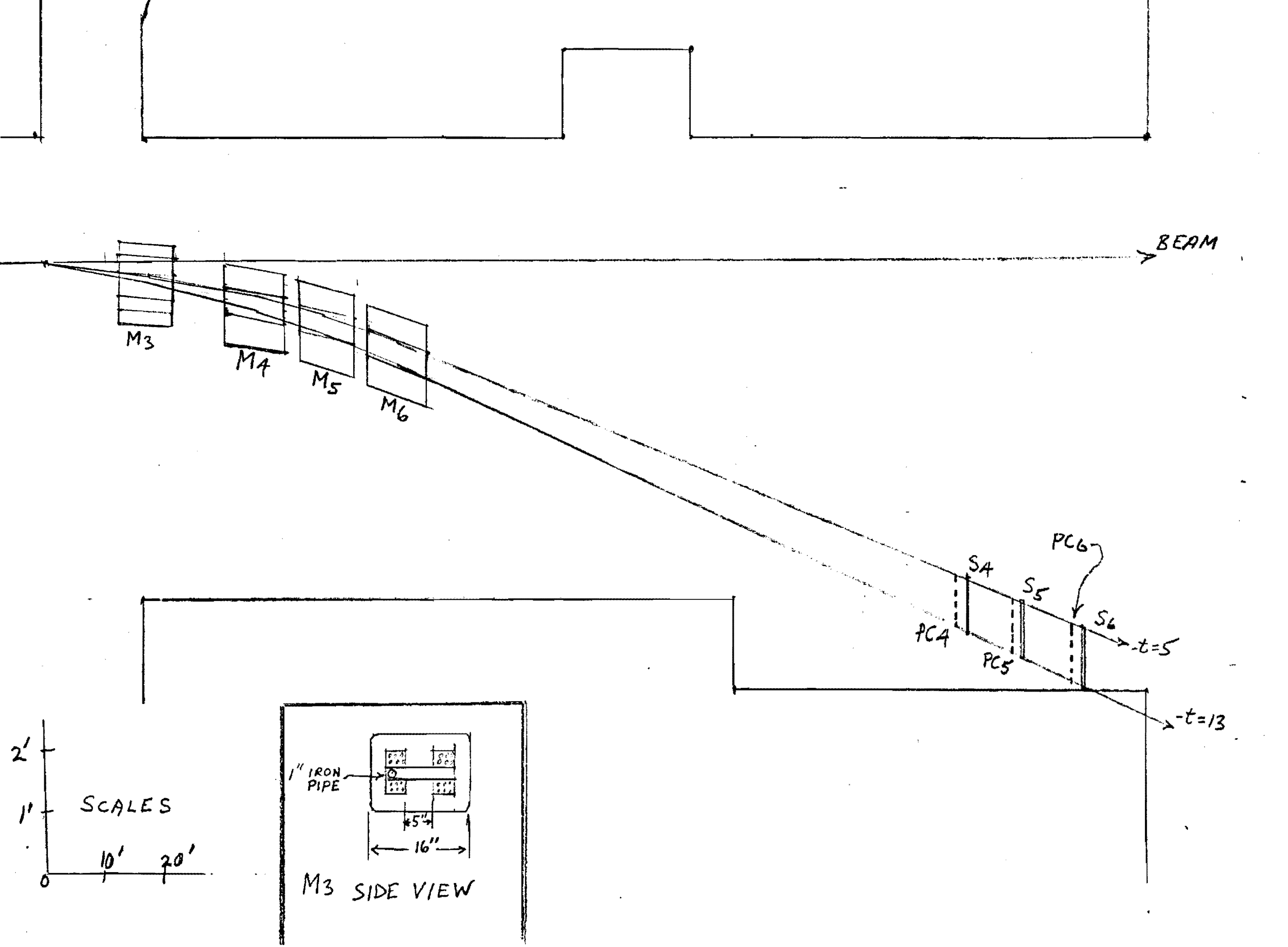
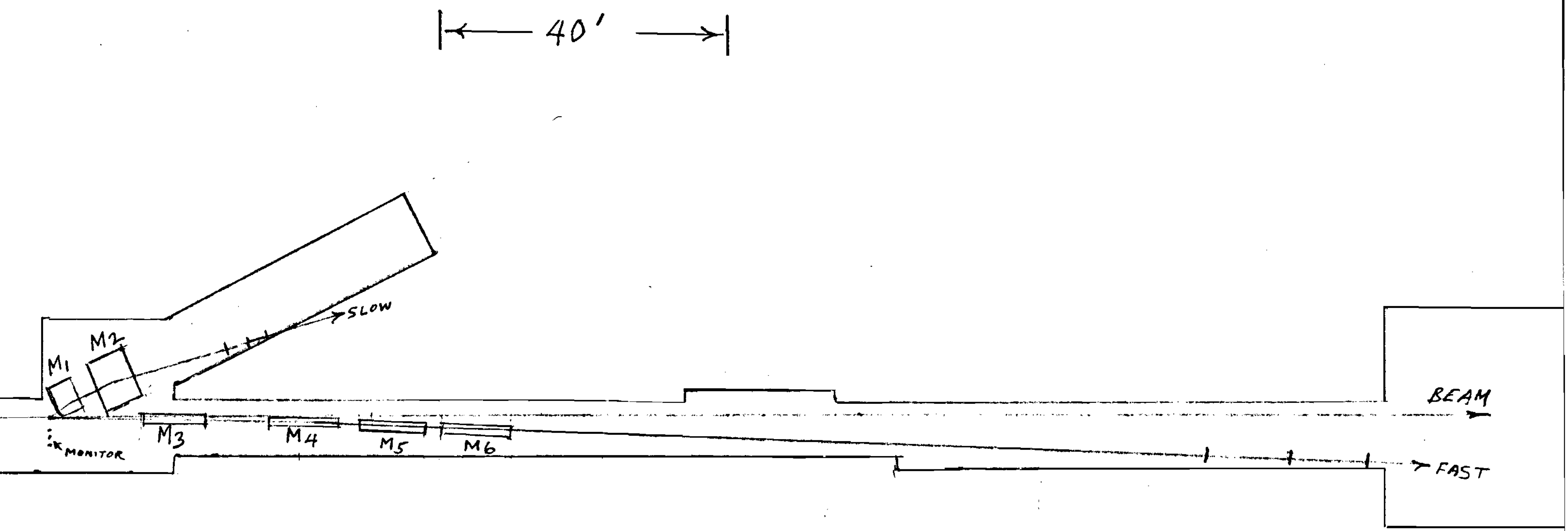



FIG. 2

200 GeV PP FAST ARM FIG, 3



200 GEV PP BOTH ARMS FIG. 4



200 GEV PP    FAST ARM ALTERNATE    FIG. 5