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Measurements of Elastic and Quasi-Elastic Scatterings of pp and $\bar{p}p$ from ~ 20 to 40 GeV/c

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ABSTRACT

We propose a systematic study of elastic and quasi-elastic scatterings of pp and $\bar{p}p$ in the forward region ($|t| \lesssim 1.5$ GeV^2) from ~ 20 to 40 GeV/c by using the single-arm spectrometer of NAL Exp. 7 (D. Meyer et al.) without any essential change. The physics interests in this energy region warrant a precise comparison between pp and $\bar{p}p$ as a function of s(t) for fixed t(s). Therefore it is essential to use the same experimental apparatus and analysis procedures in order to minimize possible systematic errors.

The possible future experiments at Serpukhov will not be able to produce sufficient flux in the secondary $\bar{p}$ beams to answer the physics questions raised in this proposal.

I. Physics Justification

We propose to study the difference between p and $\bar{p}$ in both elastic and quasi-elastic scatterings in the region from ~ 20 to 40 GeV/c where the pp elastic peak is still shrinking whereas the $\bar{p}p$ elastic peak may be expanding. Furthermore the recent data from the CERN ISR show that the slope for pp elastic scattering at 500 and 1000 GeV/c does not change much from ~ 60 GeV/c (see Fig. 1)[1]. Precise measurements of both pp and $\bar{p}p$ reactions in the region from 20 to 40 GeV/c with the same apparatus appears to be a very interesting study for us to pursue.

The limited $\bar{p}$ flux at Serpukhov will not permit accurate measurement of the cross sections as we propose here.

A. Cross-Over Phenomenon in Elastic and Quasi-Elastic Scattering

Experimentally the differential cross sections for $\bar{p}p$, pp elastic scatterings have a cross-over point at $|t| \sim 0.15$ GeV^2 at 8 GeV/c, as seen in Fig. 2. This cross-over point occurs because (1) the total cross section for $\bar{p}p$ is larger than the total cross section for pp and so the optical point (t=0) is higher for $\bar{p}p$ than for pp,and (2) the slope of the $\bar{p}p$ elastic scattering is greater than that of pp elastic scattering. Until now, the cross-over point has been poorly determined experimentally because (1) experiments for pp and $\bar{p}p$ were <u>not</u> done at the same beam momentum or the <u>same</u> t or with the <u>same</u> apparatus so as to minimize the effects of systematic errors, and (2) statistics have been poor to measure this subtle effect. Therefore, in this experiment we propose to measure both pp and $\bar{p}p$ elastic scattering with sufficient statistical significance to determine the cross-over point at several beam momenta from 20-40 GeV/c.

One model proposed by Harari[2] predicts this cross-over as well as other interesting features at $|t| = 0.6$ and ~ 1 GeV^2. His argument can be briefly outlined as follows. Since pp is exotic in the s channel, only the Pomeron (P) is expected to contribute to the t-channel elastic scattering amplitudes:

$$\frac{d\sigma}{dt}(pp \to pp) \sim |P|^2 \quad .$$

However, $\bar{p}p$, being non-exotic, has an elastic scattering amplitude with an additional term "J_o" representing the spin-non-flip contribution of whatever additional Regge trajectories are present, and can be written as:

$$\frac{d\sigma}{dt}(\bar{p}p \to \bar{p}p) \sim |P + "J_o"|^2 .$$

Therefore the difference between these two reactions:

$$\frac{\frac{d\sigma}{dt}(\bar{p}p \to \bar{p}p) - \frac{d\sigma}{dt}(pp \to pp)}{2\sqrt{\frac{d\sigma}{dt}(pp \to pp)}} \sim "J_o" \qquad (1)$$

is a measurement of "J_o". If one evaluates "J_o" with currently available data in the 8-16 GeV/c region, "J_o" indeed resembles a zero-order Bessel function with $J_o = 0$ at the cross-over point $|t| \sim 0.2$ GeV^2 as well as minima at $|t| \sim 0.6$ GeV^2, <u>another</u> cross-over point at $\sim |t| \sim 1.0$ GeV^2 (See Fig. 3 and 4)[3]. In fact the "J_o" is parameterized as $Ae^{bt} J_o(r\sqrt{-t})$, b and r are related to the impact parameter. In this respect, it is extremely interesting to examine the energy dependence for this parameterization.

This same argument can be made for quasi-elastic processes such as

$$pp \to pN_{\frac{1}{2}}(1688)$$
$$\bar{p}p \to \bar{p}N_{\frac{1}{2}}(1688). \qquad (2)$$

There is, in fact, some preliminary indication that a cross-over may occur for reaction (2), see Fig. 5. We propose to determine this cross-over effect for all quasi-elastic processes to $|t| \approx 1.5$ GeV^2 and compare them with those from elastic processes. Therefore, accurate measurements using the same experimental apparatus as well as analysis procedures are essential in order to minimize possible systematic errors.

B. Slope of Elastic and Quasi-Elastic Differential Cross Sections as a Function of Energy

Differential cross sections, $d\sigma/dt$, for forward scattering have been parameterized by $\sim Ae^{bt}$ where the logarithmic dependence of the differential cross section as a function of $|t|$ is approximately linear. The value of $b_+(b_-)$ for the scattering of p ($\bar{p}$) on protons as functions of s can elucidate the behavior of exchange trajectories in the t channel, in particular the leading one such as the Pomeranchuk. In the energy regions where the data are available, one already has observed some striking behavior as illustrated in Fig. 1. The value of b_+ is increasing as a function of s up to ($s \sim 100$ GeV^2 or $P_{Lab} \simeq 60$ GeV/c) whereas the value of b_- is decreasing. This behavior implies the pp diffraction peak is shrinking whereas the $\bar{p}p$ peak is expanding. The most interesting energy region would appear to be somewhere between 20 and 40 GeV where b_+ and b_- may meet. Two possibilities exist. One is that b_+ and b_- will intersect and cross over. A second possibility is that the b_- at the cross-over region will turn upward. This would imply that the $\bar{p}p$ diffraction peak expands from low energy up to $\sim$ 20 GeV, then shrinks. Either possibility requires intensive study. Therefore, we consider the energy region between 20 and 40 GeV of fundamental importance based on this observation.

Of course, we will also obtain the slope of the differential cross sections for the quasi-elastic processes during the same run and see how they compare to the elastic. It is interesting to note, in this respect, that the slopes, b, for the various $N^{*+}_{\frac{1}{2}}$'s produced by either pp or $\bar{p}p$ interactions are very different[4].

II. Experimental Apparatus

Our plan now is to utilize the apparatus of approved experiments at NAL. We have considered the apparatus for Experiment #7 (D. Meyer et al.) as well as Experiment #104 (D. Ritson et al.) and have consulted with both groups. However, from our past experience at lower energy (8-16 GeV/c), we prefer the non-focusing magnetic spectrometer employing wire chambers (proportional and spark type) as detectors and a Cerenkov counter for particle identification as described in Experiment #7. Professor Meyer has expressed willingness to let our group to use their spectrometer with no essential change in the setup after completion of their approved experiment in the higher energy region. We anticipate very little or no time delay in changing over from Exp. #7 to this experiment provided our experiment is scheduled right after #7. Although this experiment is not a collaborative effort with Exp. #7, we have indicated that any sub-group who are involved in Exp. #7 and who are interested in this proposal are more than welcome to join us.

III. Time Estimate

This study will cover $|t|$ range from 0.04 GeV^2 to 1.5 GeV^2 with an experimental accuracy of ±5% at moderate $|t| \sim 1.0$ GeV^2 with $\Delta t = \pm 0.1$ GeV^2, and ±2% at small $|t|$. We plan to run at 20,30 and 40 GeV/c for both pp and $\bar{p}p$. The estimated running time is outlined below based on the apparatus shown in Exp. #7.

	$\bar{p}p$	pp
40 GeV/c	125 hrs.	20 hrs.
30 GeV/c	112 hrs.	20 hrs.
20 GeV/c	97 hrs.	20 hrs.

TOTAL $\sim$ 400 hrs.

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3. H.A. Gordon and K-W. Lai, to be published.
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6. K. Foley, et al., Phys. Rev. Letters 11, 425 (1963).
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M. Holder et. al. Phys. Letters 35B 355 (1971)

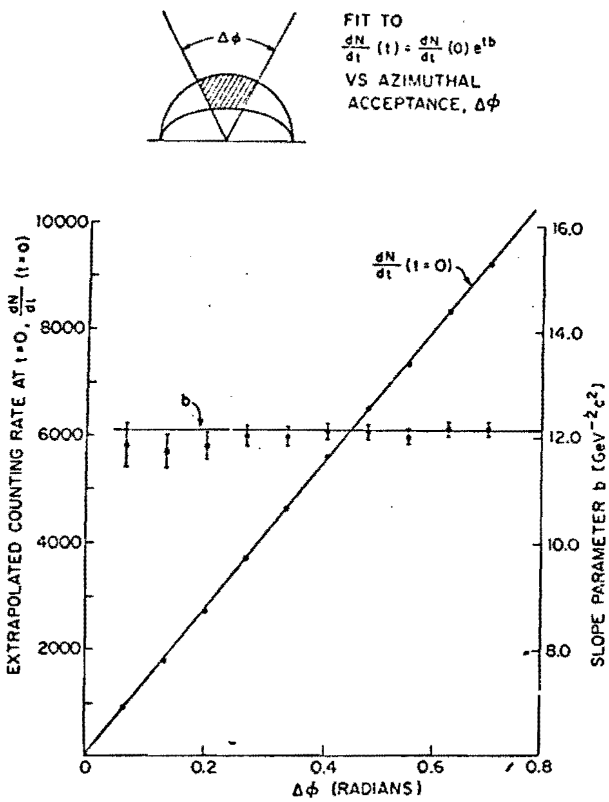

Fig. 5b. Dependence for the 15 GeV/c data of the fitted slope and intercept at t = 0 on the region of azimuthal angle accepted for fitting.

Fig. 5a shows the t dependence of the 15 GeV/c data and the fitted line. Table 1 gives the slope parameters for all the data.

A comparison of these slope values with lower energy data is shown in fig. 6. A linear extrapolation from the lower energy point is clearly impossible. Taken at face value, data suggest that the diffraction peak shrinking in s, is reduced as s increases. Additional study of this effect is continuing.

We are greatly indebted to Professor F. M. Pipkin and his group for supplying us with spark chambers. Two of us (J. P. and C. R.) would like to express their gratitude to the Harvard Physics Department for financial support and for the cooperation in the difficult task of fulfilling both teaching and research.

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Dr. H. Sens and F. Bonaudi have been very helpful in the scheduling and installation of the experiment. We wish to thank Mr. J. Ogilvie for programming assistance and Messrs. G. Barisone, A. Beninati, S. Bianconi, K. Bussmann, R. Hammerström, H. Hauer, C. Leporati, A. Morelli and P. Poggi for their technical help.

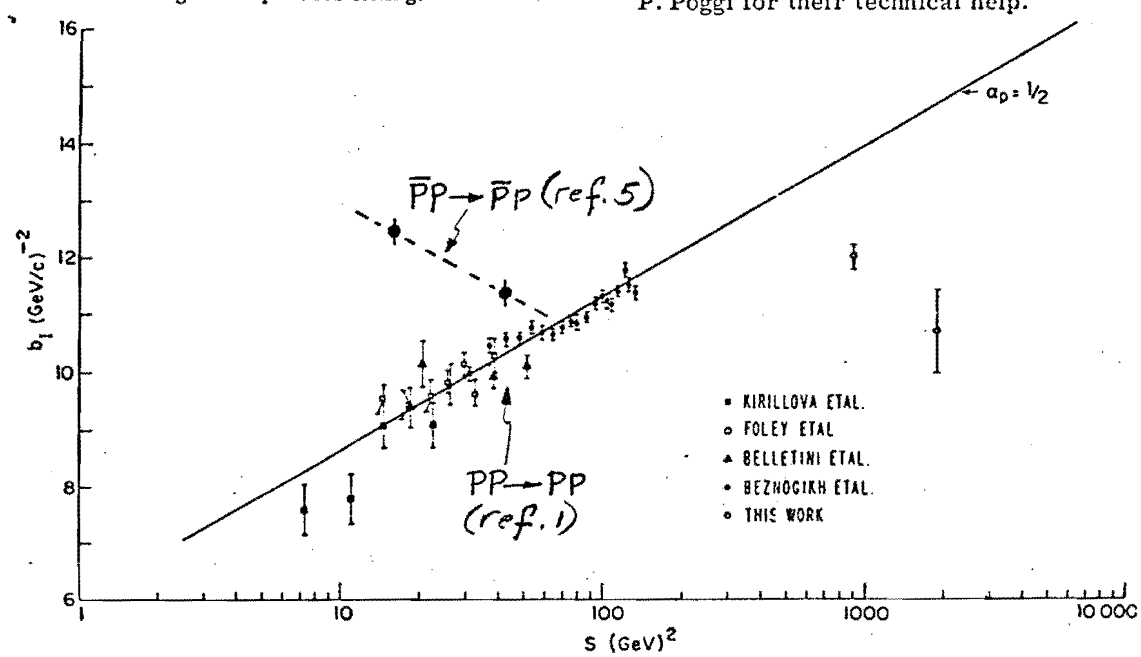
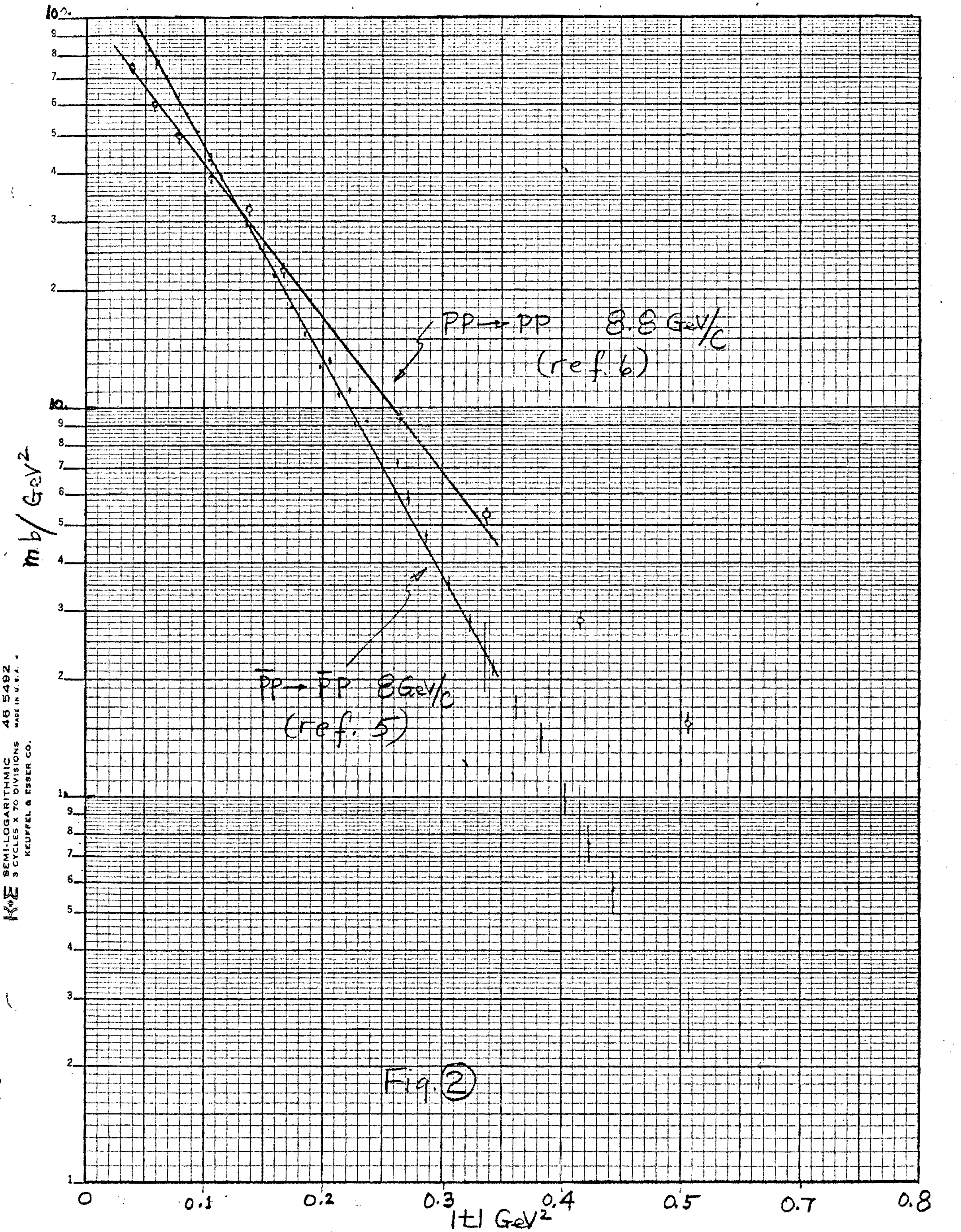


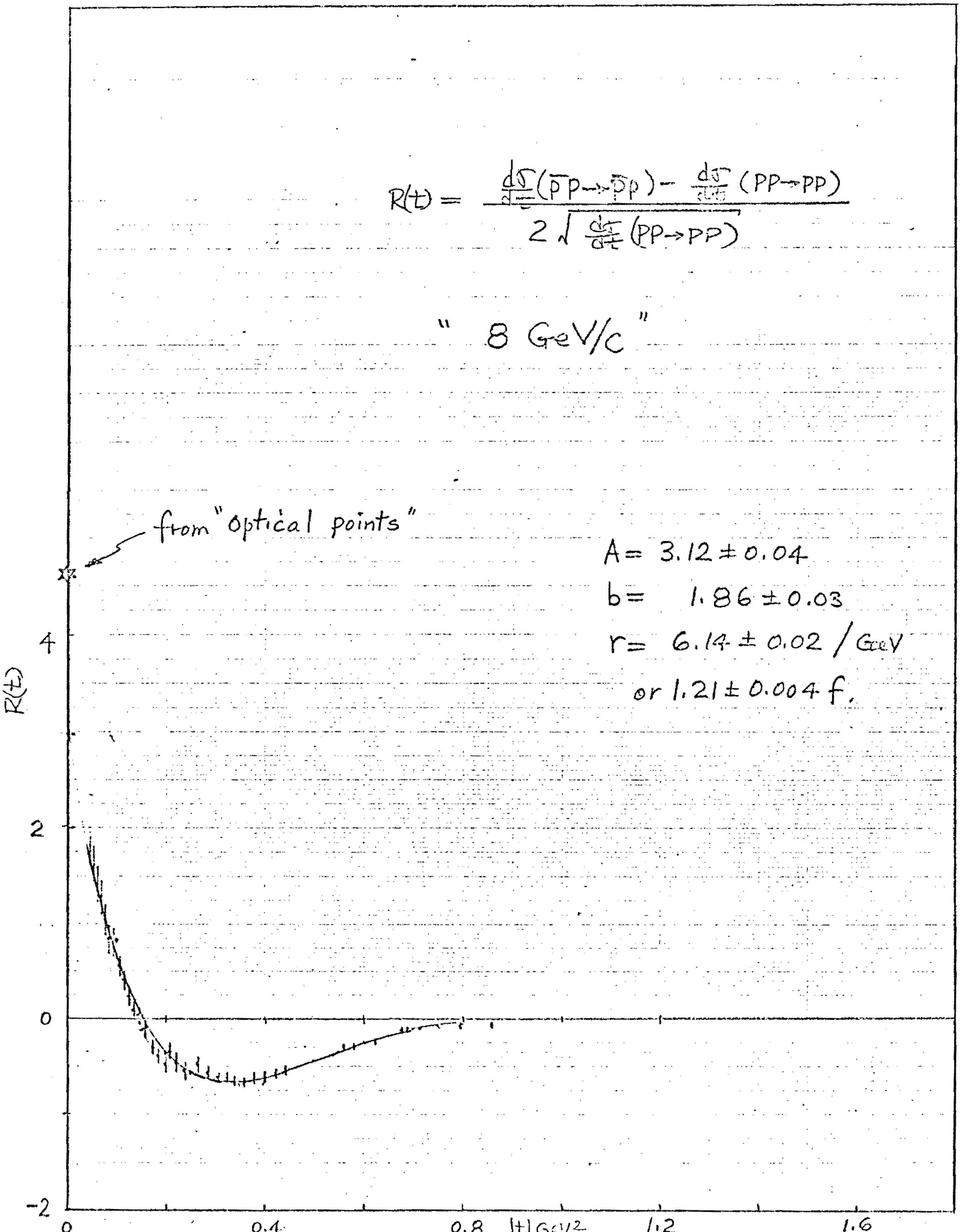
Fig. 6. Present world data for the slope parameter b of the pp elastic scattering diffraction peak.

Fig. (1)



PP → PP 8.8 GeV/c
(ref. 6)
$\bar{P}P \to \bar{P}P$ 8 GeV/c
(ref. 5)
mb/GeV^2
|t| GeV^2
0
0.1
0.2
0.3
0.4
0.5
0.7
0.8
K+E SEMI-LOGARITHMIC 46 5492
3 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

Fig. 2



R(t) = [dσ/dt (p̄p → p̄p) − dσ/dt (pp → pp)] / [2 √(dσ/dt (pp → pp))]
" 8 GeV/c "
from "optical points"
A= 3.12 ± 0.04
b= 1.86 ± 0.03
r= 6.14 ± 0.02 / GeV
or 1.21 ± 0.004 f.
R(t)
4
2
0
−2
0
0.4
0.8
|t| GeV²
1.2
1.6

Fig (3)

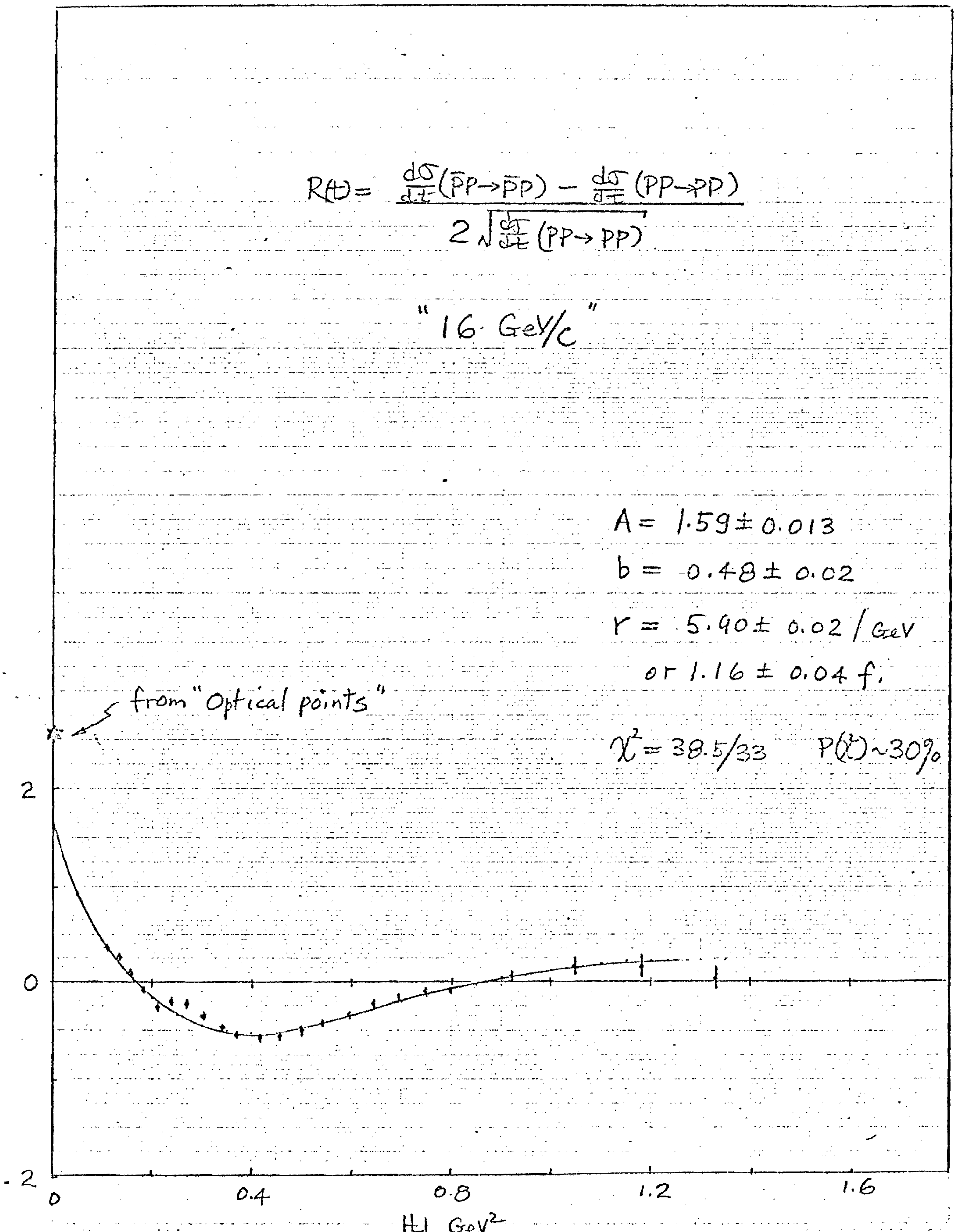
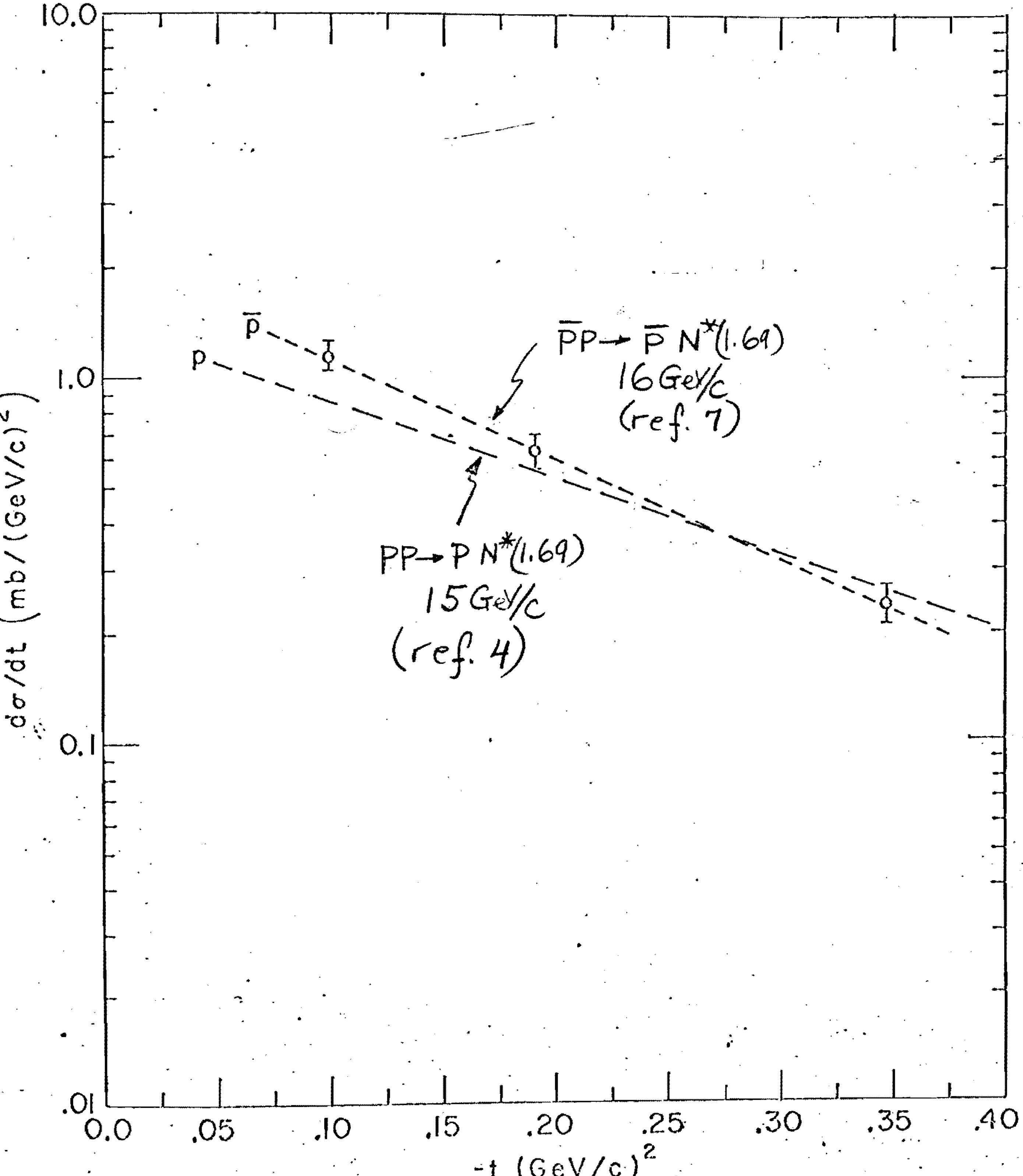

$R(t) = \dfrac{\frac{d\sigma}{dt}(\bar{p}p \to \bar{p}p) - \frac{d\sigma}{dt}(pp \to pp)}{2\sqrt{\frac{d\sigma}{dt}(pp \to pp)}}$
"16 GeV/c"
$A = 1.59 \pm 0.013$
$b = -0.48 \pm 0.02$
$r = 5.90 \pm 0.02$ / GeV
or 1.16 ± 0.04 f.
$\chi^2 = 38.5/33$ $P(\chi^2) \sim 30\%$
from "Optical points"
2
0
-2
0
0.4
0.8
1.2
1.6
|t| GeV^2

Fig. (4)



10.0
1.0
0.1
.01
0.0
.05
.10
.15
.20
.25
.30
.35
.40
dσ/dt (mb/(GeV/c)²)
-t (GeV/c)²
p̄
p
p̄p → p̄ N*(1.69)
16 GeV/c
(ref. 7)
pp → p N*(1.69)
15 GeV/c
(ref. 4)

Fig. 5

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Measurements of Elastic, Quasi-Elastic and Some Inelastic Scatterings of Particles (π^+, K^+, p) and Anti-particles (π^-, K^-, $\bar{p}$) on Protons from $\sim$ 20 to 60 GeV/c

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A B S T R A C T

We propose a systematic study of elastic, quasi-elastic (and some inelastic scatterings) of particles and anti-particles on protons in the forward region ($|t| \lesssim 1.5$ GeV^2) by using a single-arm spectrometer in the energy regions immediately above those now accessible. About forty reactions will be studied at four different energies. This study will cover the ranges of s from ~ 39 GeV^2 to 100 GeV^2 and $|t|$ from ~ 0.04 GeV^2 to 1.5 GeV^2 with an experimental accuracy of $\pm$ 5% at moderate $|t| \sim 1.0$ GeV^2 with $\Delta t \simeq 0.1$ GeV^2, and $\pm$ 2% at small $|t|$.

The fundamental importance of physics interests in this region, which are outlined in this proposal, warrants a precise comparison between particle and anti-particle cross sections on protons, $\frac{d\sigma}{dt}$ (s,t), as a function s(t) for fixed t(s). This experiment will provide these accurate measurements by using the same experimental apparatus as well as analysis procedures in order to minimize poss ble systematic errors.

Finite but small cross sections for large momentum transfers (up to $\lesssim 1.5$ GeV^2) require high intensity in the incident beams. This is particularly the case for $K^{\pm}$ and $\bar{p}$. Therefore we feel that only the NAL machine can provide such secondary beams with high flux (10^7 per pulse). The possible future experiments at Serpukov will not be able to produce sufficient flux in the secondary $K^{\pm}$ or $\bar{p}$ beams to answer the important physics questions raised in this proposal.

This proposed experiment is separated into two energy ranges, 20-40 GeV/c and 40-60 GeV/c. The results and experience at the lower range will determine the desirability of pursuing the higher range. The Medium Energy High Resolution Beam (#27) of the Meson Laboratory appears to be a good match to the experimental needs.

I PHYSICS JUSTIFICATIONS

We list the reactions to be investigated in this proposed experiment in Table I. We shall discuss in turn the physics justifications for elastic, quasi-elastic and inelastic processes.

TABLE I

ELASTIC	QUASI-ELASTIC	INELASTIC
$\pi^+ p \rightarrow \pi_c^+ p$ $\pi^- p \rightarrow \pi_c^- p$	$\rightarrow \pi^+_c (N^*_{\frac{1}{2}}, \Delta^+)$ $\rightarrow \pi^-_c (N^*_{\frac{1}{2}}, \Delta^+)$	$\rightarrow K^+_c (\Sigma^+, \Sigma(1385)^+)$
$K^+ p \rightarrow K^+_c p$ $K^- p \rightarrow K^-_c p$	$\rightarrow K^+_c (N^*_{\frac{1}{2}}, \Delta^+)$ $\rightarrow K^-_c (N^*_{\frac{1}{2}}, \Delta^+)$	$\rightarrow \pi^-_c (\Sigma^+, \Sigma(1385)^+)$
$pp \rightarrow p_c p$ $\bar{p}p \rightarrow \bar{p}_c p$	$\rightarrow p_c (N^*_{\frac{1}{2}}, \Delta^+)$ $\rightarrow \bar{p}_c (N^*_{\frac{1}{2}}, \Delta^+)$	

1) Incident momentum settings - 20, 30, 40, 60 GeV/c

2) t-region: t_{min} to $1.0 (GeV/c)^2$ or greater

3) Accuracy: $\Delta t \simeq \pm 0.05 \ (GeV/c)^2$ at $|t| \simeq 1 \ GeV^2$

$$\left[\Delta\left(\frac{d\sigma}{dt}\right) \Big/ \frac{d\sigma}{dt}\right] \sim \pm 2\% \text{ for small } |t|$$
$$\sim \pm 5\% \text{ for } |t| \simeq 1.0 \ (GeV/c)^2$$

X_c: charged particle to be measured by the spectrometer.

1. Elastic Scattering

Differential cross sections, $\frac{d\sigma}{dt}$, for forward scattering have been parameterized by $\sim Ae^{bt}$ where the logarithmic dependence of the differential cross section as a function of $|t|$ is approximately linear. The values of $b_+(b_-)$ for the scattering of particles (anti-particles), π^+, K^+ and $p(\pi^-$, K^- and $\bar{p})$ on protons as functions of s can elucidate the behavior of exchange trajectories in the t-channel, in particular the leading one such as the Pomeranchuk. In the energy regions where the data [(1)] are available one already has observed some striking behavior of fundamental importance. To be more specific, one can illustrate this behavior with either pp and $\bar{p}p$ or K^+p and K^-p as shown in Fig. 1. and Fig. 2. The values of b_+ for both cases are increasing as a function of s whereas the values of b_- for both cases are decreasing. This behavior implies the pp and K^+p diffraction peaks are shrinking whereas the $\bar{p}p$ and K^-p diffraction peaks are expanding. The most interesting energy region would appear to be somewhere between 20 - 60 GeV where b_+ and b_- may meet. Two possibilities exist; one is that b_+ and b_- will cross-over. This feature would be difficult to explain by any known theory such as the Regge-pole.[(2)] A second possibility is that the b_- at the cross-over region will turn upward. This would imply that K^-p and $\bar{p}p$ diffraction peaks expand from low-energy up to $\sim$ 20 GeV, then shrink. Either possibility requires intensive theoretical study. Therefore, we consider the energy region between 20 - 60 GeV of fundamental importance based on this observation as well as others discussed below.

Elastic (and quasi-elastic) scattering in the forward region has been studied in terms of t-channel exchange trajectories as shown below:

REACTIONS	I = 0 TRAJECTORIES	I = 1 TRAJECTORIES
$\pi^{\pm}p$	P (Pomeron) and P'	$\pm\rho$
$K^{\pm}p$	P, P'$\pm\omega$	$\pm\rho$, A_2
pp, $\bar{p}p$	P, P'$\pm\omega$	π, $\pm\rho$, A_2

Systematic investigations from a single experiment, such as the one we are proposing, to measure the difference of cross sections between particle and antiparticle on proton as a function of s(t) for fixed t (s),

$$\delta(s,t) = \left[\frac{d\sigma_+}{dt}(s,t) - \frac{d\sigma_-}{dt}(s,t) \right]$$

can shed light on the apparent constant difference between particle and antiparticle total cross sections on protons as suggested by the Serpukhov data[1]. If the difference, $\delta(s,t)$, has no strong energy dependence in this energy region, this, of course, could suggest that additional new trajectories with $\alpha_o \simeq 1$ are needed. Quantum numbers of these possible new trajectories are $I^G = 1^+$ for the $\pi^{\pm}p$; $I^G = 0^-$, $1^{\pm}$ for $K^{\pm}p$, $I^G = 0^{\pm}$, $1^{\pm}$ for $\bar{p}p$ and pp.

It is also well known that most forward scattering cross-sections in the moderate t-region ($\sim$0.5 to 1.0 GeV) are full of "dips" or "breaks". This phenomena has been observed in the $\pi^{\pm}p$, K^-p, $\bar{p}p$ but not K^+p and pp[1]. This observation may be correlated with the fact that no strong resonances exist in the direct channel for K^+p and pp from the duality point of view. There are, of course, many conjectures[2] to explain these breaks and dips as a function of t for fixed s or of s for fixed t. It is, however, generally true that different models predict different behavior expecially for moderately large t regions($\sim$1 GeV^2).

Therefore, measurements in this t region provide sensitive tests for different models. The cross sections are still finite and measurable in this energy and momentum transfer region as we propose in this experiment.

2. Quasi-elastic Scattering

One of the beauties of this single-arm spectrometer experiment is that one can accumulate elastic as well as inelastic data simultaneously in the same set up during the runs. Therefore, all the tests stated in the elastic scattering section can also be applied to the quasi-elastic processes ($\pi^{\pm}p \to \pi^{\pm}N^{*+}_{\frac{1}{2}}$, $K^{\pm}p \to K^{\pm}N^{*+}_{\frac{1}{2}}$ and $p\ (\bar{p}) \to p\ (\bar{p})\ N^{*+}_{\frac{1}{2}}$) since the quantum numbers (or trajectoreis) involved in the t-channels are identical in both cases. However, one can examine one additional conjecture concerning the diffractive porcesses responsible for the high energy inelastic cross sections by comparison of particle and anti-particle quasi-elastic cross sections on protons. If, for example, there were finite differences between $\sigma_{+}(\pi^{+}p \to \pi^{+}N^{*}_{\frac{1}{2}}(1688)^{+})$ and $\sigma_{-}(\pi^{-}p \to \pi^{-}N^{*}_{\frac{1}{2}}(1688)^{+})$, then one has to introduce a non-diffractive contribution to these inelastic processes. The general belief of approximately constant cross section as function of energy as evidence for diffractive scattering would have to be modified. It is interesting to note, in this respect, that slopes, b_{-}, for various $N^{*+}_{\frac{1}{2}}$ productions are very different,[(3)] and may indicate that interference between the diffractive and non-diffractive processes are not negligible for various $N^{*}_{\frac{1}{2}}$'s production.

3. Inelastic Scattering:

One of the most puzzling problems facing particle physics to date is the absence of exotic states (states that cannot be constructed from the $(q\bar{q})$ system for mesons and the (qqq) system for baryons). Experimentally, there are two possible ways to search for exotic mesons. One is to observe these objects in production experiments; however, this effort has been without success experimentally thus far.[4] The other approach, which may be more sensitive, is to detect the interference effect between possible exotic and allowed states via virtual processes. To be more specific in the meson cases, accurate determinations of ratios of cross sections such as $\sigma(\pi^+ p \rightarrow \pi^+ \Delta^+)/\sigma(\pi^- p \rightarrow \pi^- \Delta^+)$, as well as their differential cross sections can reveal the possible existence of I = 2 exotic meson states of spin parity ($J^P = 0^+, 1^-, 2^+, \ldots$).

Recent theoretical conjectures concerning duality and exchange degeneracy can also be examined in some inelastic meson-baryon scattering processes[5] in this experiment. Inelastic processes such as $K^+ p \rightarrow K^+ \Delta^+$ and $K^- p \rightarrow K^- \Delta^+$ are channels to check the conjecture of <u>strong</u> exchange degeneracy ($\alpha(t)$ and $\beta(t)$) between the vector (ρ) and tensor (A_2) Reggee trajectories if no exotic resonance exists in the K^+N system. Similarly, the pion induced reactions such as $\pi^+ p \rightarrow K^+ \Sigma^+$ vs. $K^- p \rightarrow \pi^- \Sigma^+$ and $\pi^+ p \rightarrow K^+ \Sigma(1385)^+$ vs. $K^- p \rightarrow \pi^- \Sigma(1385)^+$ provide additional checks on the <u>weak</u> exchange degeneracy ($\alpha(t)$ only) between the strangeness $\pm$ 1 vector ($K^*_{\frac{1}{2}}(890)$ and tensor ($K^*_{\frac{1}{2}}(1420)$) Regge trajectories.

II EXPERIMENTAL APPARATUS

Our plan is to extend the high resolution single-arm spectrometer technique, which has been used so successfully in the study of two-body final states in the 6 - 30 GeV/c region, up to 60 GeV/c. The basic instrument is a non-focusing magnetic spectrometer employing wire chambers (proportional and spark type) as detectors and a Čerenkov counter for particle identification. This technique has been characterized by the ability to produce reliable, high-statistics data, with good absolute cross sections and an absence of systematics; this is due primarily to the easily-calculated geometry and the transparency of the corrections that need be made. Its versatility has also been established, a single experimental run in a negative beam at the AGS gave significant $d\sigma/dt$ data on 17 different two-body reactions.[6]

Experience in the 10 - 30 GeV/c region has shown that a clear analysis of the data requires a momentum resolution of $<$ 100 MeV/c (i.e., FWHM of the elastic peak) independent of P_{inc}, and an angular resoltuion $\propto 1/p$, hence both dp/p and $d\theta$ go as $1/p$. If one keeps a fixed spectrometer geometry, which clearly is attractive in carrying out precision measurements, it becomes impractical to design for a dynamic range of incident momentum greater than four. The smallest P_{inc} determines the θ aperture, while the highest P_{inc} determines the mean angle of deflection.

The incident beam plus spectrometer system described below was designed to achieve the following basic specifications:

1. Overall momentum resolution of $\pm$ 35 MeV/c or better
2. Resolution on scattering angle of $\pm$ 0.1 mrad.
3. Momentum acceptance at a given θ of $\sim$ 2.5 GeV/c

4. Counting rates sufficient to allow precision measurements of elastic cross sections out to $|t| \approx 1.5$ GeV/c^2

A. <u>Incident Beam</u> - The "Medium Energy Beam" of Experimental Area 2 (as described in "Notice to NAL Users" - 3/26/70) is well suited to our needs. The more complete requirements are as follows:

1. <u>Specifications</u>

Momentum Range	20 - 60 GeV/c
Flux ($\pi^{\pm}$)	$\leq 10^7$/sec
Momentum Resolution	$\pm$30 MeV/c (at 30 GeV)
$\theta_{\text{Horizontal}}$ Resolution	$\pm$ .07 mrad
Image Diam. at H_2 Target (98% of beam)	$\leq$ 0.5 cm
$\theta_{\text{Horizontal}}$ Divergence at H_2 Target	$\leq$ 2 mrad (FW)

2. <u>Special Requirements</u>

Three Threshold Cerenkov Counters for Particle Tagging

Two - 20m x 50cm diam.

One - 10m x 50cm diam.

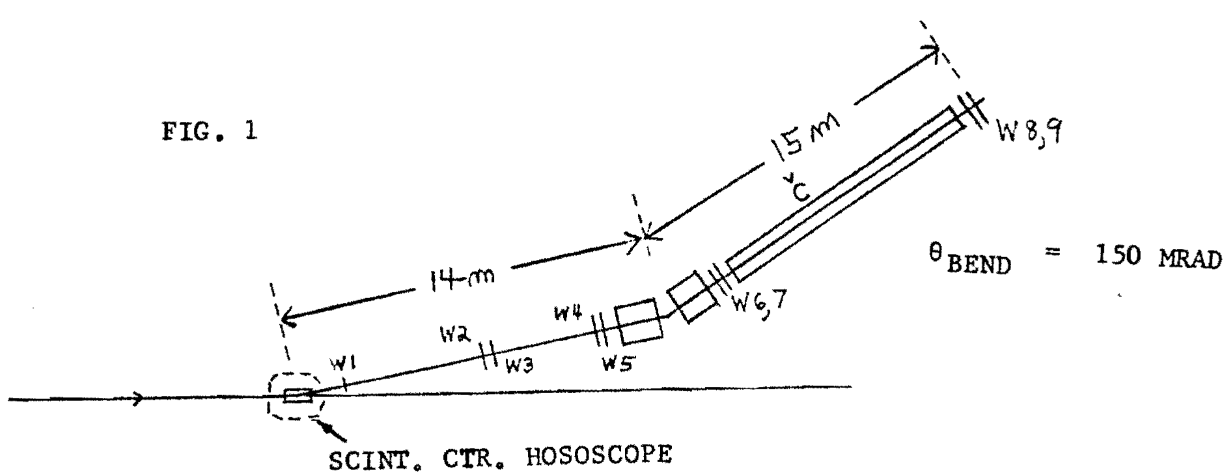
B. <u>Spectrometer</u> - The proposed system is a reasonably conventional non-focusing spectrometer with rectangular aperture (see Fig. 1). The new features are: (1) use of proportional wire chambers in the front leg to allow the 10^7 beam intensity; (2) insertion of an 11m. threshold Čerenkov counter between the chambers in the back leg to make a more compact system and (3) a counter hodoscope surrounding the H_2 target to allow an indication of charge multiplicity (it could also be included in the trigger logic to enhance certain classes of interactions.)

1. Basic Parameters

Momentum Resolution (at 40 GeV/c)	± 25 MeV/c
θ Resolution	± 0.07 mrad
Aperture (θ_H x θ_V)	12 x 7 mrad
Momentum bite (over 2/3 of the 12 mrad)	≥ 3 GeV/c
Particle Identification	11m. Threshold Cerenkov
Maximum Event Rate	700/sec
Target Length (H_2)	60 cm (~ 6 Liters)
Minimum detectable scattering angle θ	5 mrad

2. Spectrometer Geometry - The basic dimensions are given in Fig. 1; the mean deflection angle of 150 mrad allows a rather companct system, total length ~ 30m. We plan to cover a range of θ_{LAB} from 5 to 80 mrad, requiring six angle settings of the spectrometer. One could also cover this range by steering the incident beam, but this technique has no compelling advantages for a spectrometer of this size. Past experience indicates the spectrometer could be moved from one angle setting to another in ~ 6 hrs.

FIG. 1



Chambers Wi:

Chamber	Coordinates	Size H x V	Type
W1	X,Y	3" x 1"	Charpak
W2	X,Y	6" x 2.5"	"
W3	X,U	6" x 2.5"	"
W4	X,Y	9" x 4.5"	"
W5	X,U	9" x 4.5"	"
W6	X,Y	10" x 5"	Wire Spark Chamber
W7	X,Y	10" x 5"	"
W8	X	20" x 9"	"
W9	X	20" x 9"	"

Resolution Assumed:

W1 → W5 ± 0.5 mm, Multi-track capability

W6 - W9 ± 0.25 mm, One-track capability

Bending Magnets:

Two - 9" x 4" x 72" @ 40 kg

Alternative:

Four - 12" x 4" x 72" @ 20 kg

Čerenkov:

11m long by 60cm diam.; at 50 GeV/c - H_e gas at 1.4 atoms, at 15 GeV/c - CO_2 at 1.2 atmos.(gauge). When set at K threshold counts π's at ≥ 95% efficiency.

C. On-Line Computing Requirements - Experience with a similar spectrometer has demonstrated that an on-line computer is essential for efficient use of beam time. Two levels of on-line computing can be distinguished: (1) monitoring the detectors and other hardware, a turn-around time of ~ 1 minute is required; (2) monitoring the physics results, a turn-around time of ~ ½ hour is acceptable. Function (1) is most efficiently carried out on a small computer (e.g. PDP-9 or PDP-15) without floating point hardware, while (2) needs a larger computer with fast floating point calculation capability (e.g. CDC 6600 or PDP-10). We feel strongly that the most economical system - both from the point of view of capital investment and physicist manpower investment - is a small dedicated computer with a two-way link to a large batch-processing computer. Such a system using a PDP-9 to CDC 6600 link is just about to go into operation at BNL. For this experiment, the type of requirement on a CDC 6600 would be ~ 5% of the central processor core and 30_{10}K of central memory (non-resident).

III ESTIMATED RUNNING TIME

To estimate the running time for this experiment we have extrapolated the existing data for elastic scattering and (some) diffraction phenomena to 60 GeV/c. We have used the compilation of elastic scattering by Fox and Quigg(7) as well as the parameterization of the data to the form

$$\frac{d\sigma}{dt}(s,t) = f(t)\left[\frac{s}{s_o}\right]^{2(\alpha_{eff}(t) - 1)} \quad \text{- - - - (1)}$$

where $s_o = 1$ and $\alpha_{eff}(t)$ is the effective trajectory calculated for each projectile $\pi^\pm$, $k^\pm$, p and $\bar{p}$ as a function of t (see Fig. 3). We will use $\bar{p}p$ elastic scattering for all our calculations as an example, because the $\bar{p}$ flux is about 100 times lower than the π flux and about 5 times lower than the K flux based on the Serpukhov data(8). Since cross sections for $\bar{p}p$ elastic scatterings are about the same order of magnitude as that of the other projectiles, estimated running times for $\bar{p}$ will be more than sufficient for the others. Now as an example of the extrapolation procedure, taking $\Delta\sigma$ ($\bar{p}p \to \bar{p}p$) = 6.2 $\pm$ 2 μb for $0.9 < |t| < 1.1$ $(GeV/c)^2$ at 16 GeV/c and α_{eff} ($|t|$ = 1.0 Gev/c) = 0, equation (1) yields $\Delta\sigma$ = 0.9 μb at 40 GeV/c for the same t interval. In this way we have extrapolated all the elastic cross sections and the cross section for $Ap \to AN^*_{\frac{1}{2}}(1688)^+$ where data exists as shown in Fig. 4. As is shown in Fig. 3, in many cases $\alpha_{eff}(t)$ is not too well determined. We used the lowest value of α_{eff} which gives a lower estimate of the cross section.

From the horizontal angular acceptance of the spectrometer ($\pm$ 6 mr), the values of angular settings are calculated which are necessary to span the regions of interest $|t| < 1.0$ $(GeV/c)^2$. Four settings of spectrometer are necessary for <u>all</u> incident moments in this experiment, and only the first two are required at 40 GeV/c.

The value of the cross section $\Delta\sigma$ at the largest t value for a particular setting at a given beam momentum can be evaluated from the following empirical formula in order to obtain the running time in hours:

$$n(\text{hrs.}) = N_o \frac{\sqrt{t}}{24\ P \frac{d\sigma}{dt}\ \Delta t}$$

where N_o is number of counts in Δt for a given incident momentum P in GeV/c and a given differential cross section, $\frac{d\sigma}{dt}$, in $\mu b/(GeV/c)^2$. For elastic processes, we have demanded 3% and 5% statistical accuracy for low $|t|$ < 0.5 respectively, and for $\Delta t = 0.05\ GeV^2$, and a 5 to 10% accuracy for all quasi-elastic processes. In this way we have calculated the number of hours required at each setting of the apparatus and the totals are listed in Table II.

Table II

ESTIMATED RUNNING TIME

Particles \ Momentum	Testing	20 GeV/c	30 GeV/c	40 GeV/c	60 GeV/c
$\bar{p}p$ $\bar{k}p$ π^-p	100 hrs.	150 hrs.	300 hrs.	300 hrs.	600 hrs.
pp k^+p π^+p	50 hrs.	20 hrs.	50 hrs.	50 hrs.	100 hrs.
Sub-total	150 hrs.	170 hrs.	350 hrs.	350 hrs.	700 hrs.
	1020 hrs. (phase I)				700 hrs. (phase II)

Note:

As stated in the abstract of this proposal, we plan to do p[illegible]rst. Results and experience from this phase I run will determine the desirability of pursuing the phase II of this experiment.

				COST
IV	Equipment Construction and Cost Estimates			
	A.	Incident Beam		
		1.	Threshold Čerenkov Counters	
			Two: 20m x 50cm Diam. (1 atmos, gauge)	NAL
			One: 10m x 50cm diam. (1 atmos, gauge)	NAL
	B.	Spectrometer		
		1.	Proportional wire chambers	
			5 chambers (~ 1200 wires)	12K
		2.	Bending magnets	NAL
		3.	Wire spark chambers	
			4 chambers (magnetostrictive or core)	4K
		4.	Čerenkov counters	
			11m x 60cm; (1 atmos. gauge)	4K
		5.	Scintillation counters 30 counters	15K
		6.	Liquid Hydrogen Target (6 liters)	NAL
	C.	Electronics and Interfaces		
		1.	Spark chamber pulsing electronics	7K
		2.	Computer interface for reading out detectors	25K
		3.	Digital voltmeter system for maintaining magnets, etc.	8K
		4.	Miscellaneous special purpose control logic	12K
		5.	Standard counting logic circuitry	NAL
		6.	Scintillation counter power supplies	NAL
		7.	Trailer for electronics, air conditioned and furnished	10K

IV <u>Equipment Construction and Cost Estimates</u> (continued) — COST

D. <u>On-Line Computing</u>

	COST
1. Dedicated small computer (e.g. PDP-15 or perhaps PDP-11) with 16K memory, magnetic tape transport, line printer, teletype, fast drum, scope display, and link to large computer	NAL
2. Large computer (e.g. CDC 6600) 5% of central processor, 30_{10}K core	NAL
3. Magnetic tape ~ 400	4K

V <u>Personnel</u>

	STAFF	RES. ASSOC.	GRAD. STUD.
Purdue	3	1	2
BNL	2	2	–
NAL	1 (?)	–	–
TOTALS	5 + 1 (?)	3	2

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7. G.C. Fox and C. Quigg, "Compilation of Elastic Scattering Data", UCRL-20001 (1970) unpublished.

8. Yu. B. Bushnin, et al., Phys. Letters 29B, 48 (1969).

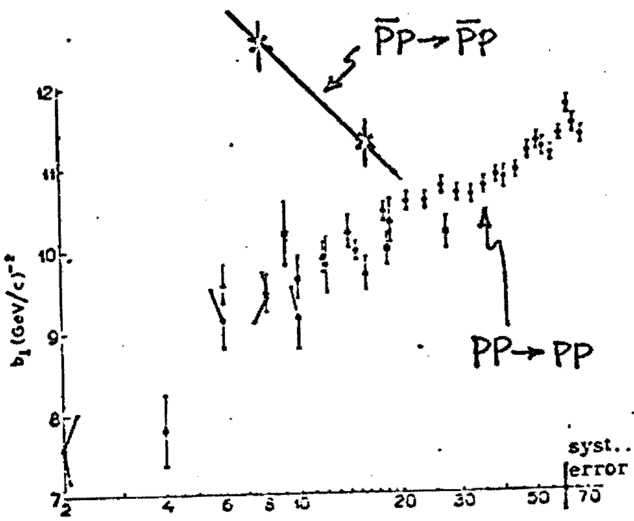


Fig. 2. The results of the measurements of the slope parameter. O : this experiment; ○: ref. 2; □: ref. 4; Δ: ref. 3.

Fig. 1

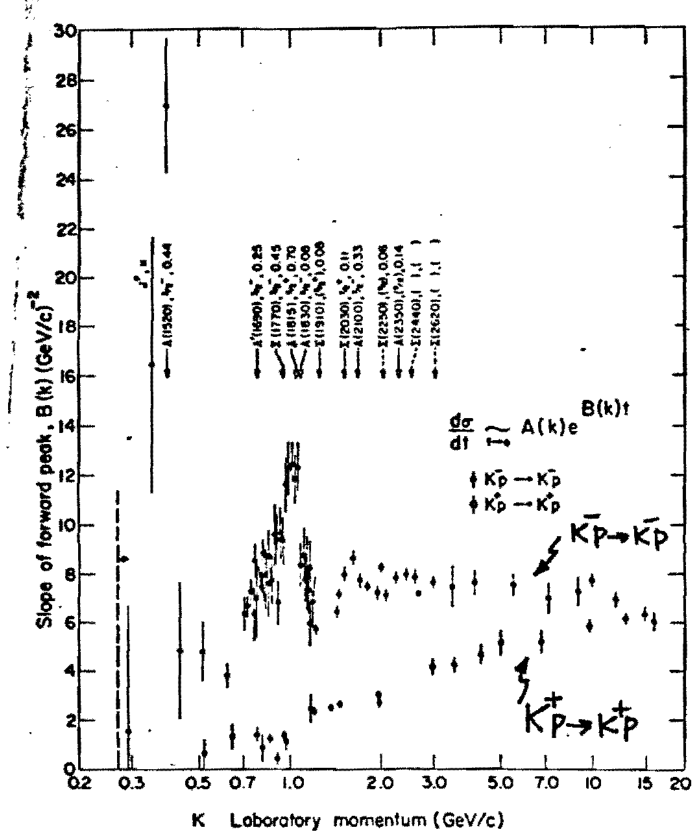


Fig. 20. Variation as a function of incident lab. momentum of the slope B obtained by fitting the relation $d\sigma/dt = \text{Const.}\ e^{Bt}$ to small angle K^+p and K^-p elastic scattering. Taken from ref. 24.

Fig. 2

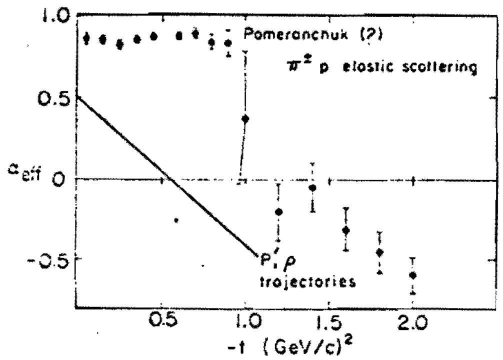


FIGURE 10

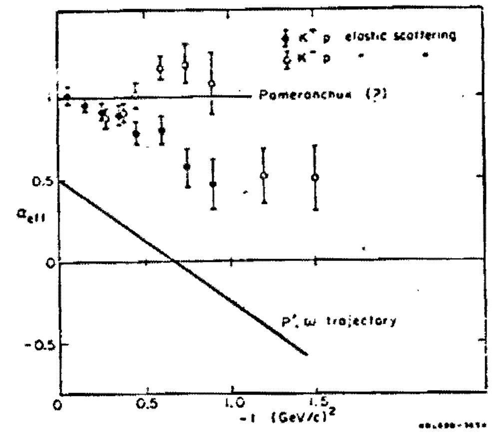


FIGURE 11

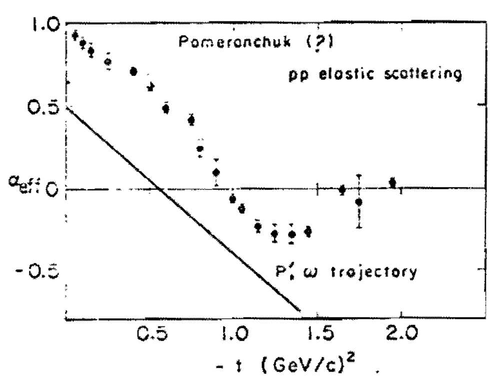


FIGURE 12

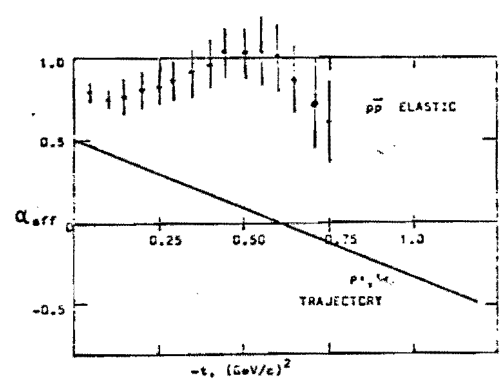
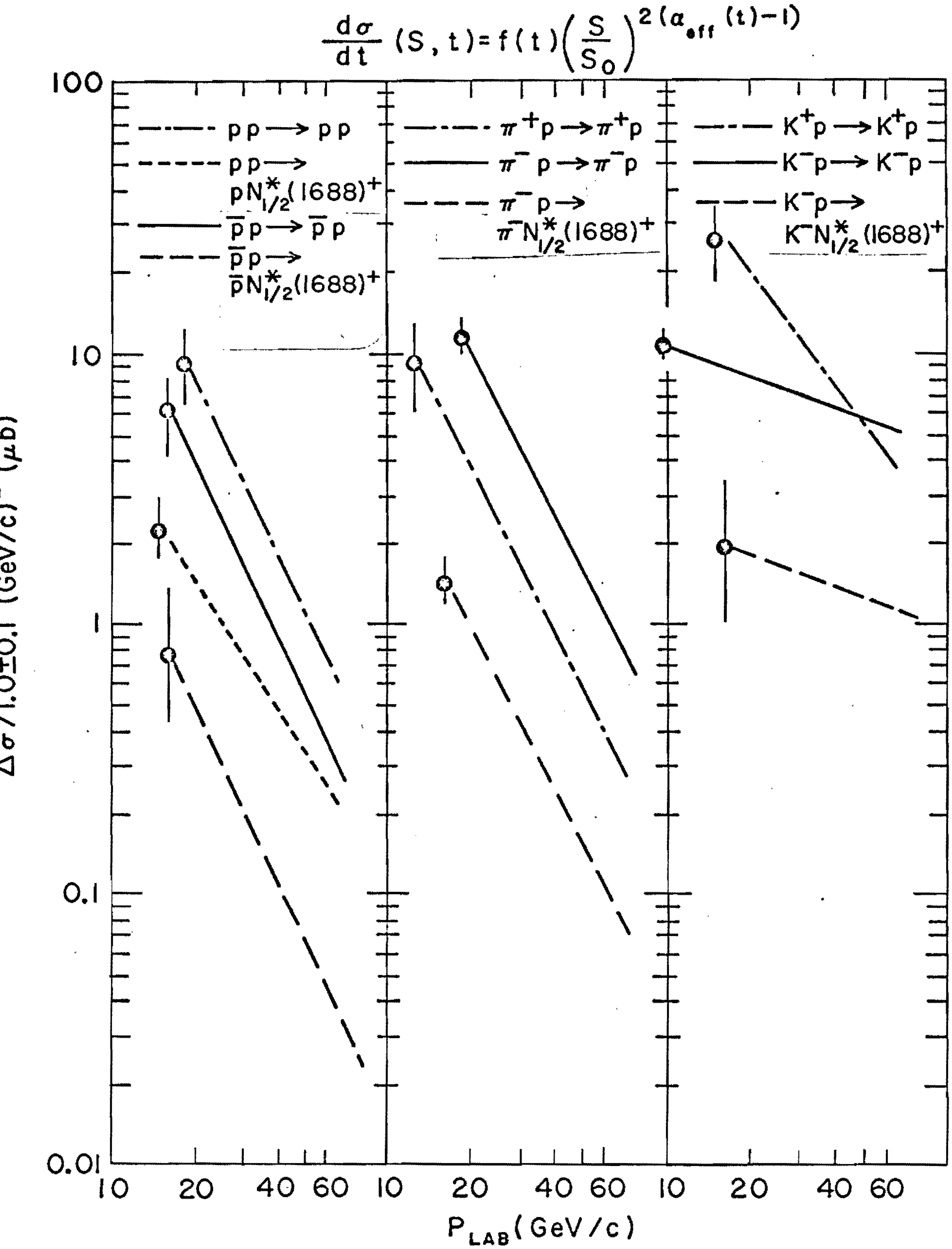


FIGURE 13

Fig.3



$\frac{d\sigma}{dt}(S,t) = f(t)\left(\frac{S}{S_0}\right)^{2(\alpha_{eff}(t)-1)}$
pp → pp
pp → pN*1/2(1688)+
p̄p → p̄p
p̄p → p̄N*1/2(1688)+
π+p → π+p
π−p → π−p
π−p → π−N*1/2(1688)+
K+p → K+p
K−p → K−p
K−p → K−N*1/2(1688)+
Δσ/1.0±0.1 (GeV/c)² (μb)
100
10
1
0.1
0.01
10
20
40
60
P_LAB (GeV/c)

Fig. 4