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ABSTRACT

Differential cross-sections for elastic proton–proton scattering have been measured for incident momenta of 3, 5, and 7 GeV/c. The protons scattered backwards in the CM system are detected with scintillation counters following analysis with a magnetic spectrometer. Polyethylene and carbon targets were used for scattered momenta between 500 and 4000 MeV/c, and a gaseous hydrogen target was used for scattered momenta below 600 MeV/c. With a few exceptions, the statistical errors are smaller than 1% for the lower momentum transfers, and increase to 5% for 90° scattering in the center of mass. The cross sections at high momentum transfer are nearly independent of momentum transfer but depend upon incident energy, a result consistent with experiments at higher energy.

PROTON–PROTON ELASTIC SCATTERING[7,8]

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INTRODUCTION

The composite particle theory of Chew, Frautschi, and others based on the analytically continued S-matrix leads to definite predictions about the behavior of elastic proton–proton scattering at high energies.[1,2] This, in addition to the continuing use of a variety of optical models with short-range phase shifts, has generated much interest in the detailed diffraction patterns. A test of the Regge Pole hypothesis requires a rather broad range of momentum transfer and incident energy in the high energy region. This report describes the measurement of the cross section at three Bevatron energies for momentum transfer in the range .01 $(GeV/c)^2$ to 5.8 $(GeV/c)^2$.

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[7]This work was done under the auspices of the U. S. Atomic Energy Commission.

[8]For presentation at the 1964 International Conference on High Energy Physics, Dubna, U.S.S.R., August 5–15, 1964.

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(1) G. F. Chew and S. C. Frautschi, Phys. Rev. 123, 1478 (1961); Phys. Rev. Letters 7, 394 (1961); 8, 41 (1962).

(2) S. C. Frautschi, M. Gell-Mann, and F. Zachariasen, Phys. Rev. 126, 2204 (1962).

Further interest in the small angle scattering centers around an accurate measurement of the forward scattering amplitude and the effects of Coulomb interference and spin-flip scattering.

EXPERIMENTAL ARRANGEMENT

The experimental apparatus is shown in Fig. 1. The scattering target was placed in the external proton beam (EPB) of the Bevatron. Three momentum spectrometers were arranged around the target and are referred to as: the high momentum channel (HMC), low momentum channel (LMC), and the third channel (3rd). The use of each of these is described below.

HIGH MOMENTUM CHANNEL

The (HMC) was used to measure the cross sections for proton recoil angles between 25 and 70 degrees in the laboratory and momenta up to 4 GeV/c. A polyethylene or carbon target was placed in the EPB. The angle was varied by moving the target along the EPB line and the circular magnet was used to steer the protons into the HMC. A quadrupole focusing magnet followed by a vertical deflection completed the momentum analysis. For protons scattered from a parallel monoenergetic beam, the double dispersion (vertical and horizontal) implies a two-dimensional spatial correlation among the three parameters, missing mass, production angle, and momentum. The quadrupole lens was adjusted to produce a line focus for each missing mass. From this pattern the elastically scattered protons were readily selected by a "line" scintillation counter telescope with a momentum resolution of approximately one percent. General background was subtracted by the carbon-polyethylene-difference method; and inelastic background from proton-proton interactions was estimated from the measured missing mass spectrum.

3rd CHANNEL

At 7 GeV/c for the highest momentum transfer (90° cm scattering), the inelastic scattering is so much larger than the elastic scattering that momentum analysis of the recoil proton with the HMC was not sufficient to measure the elastic cross section accurately. In this case the 3rd channel was used to detect the complementary proton in coincidence with the proton detected in the HMC.

LOW MOMENTUM CHANNEL

In operation the LMC was similar to the HMC. Elastically scattered recoil protons between 55 and 90 degrees could be studied. The laboratory momenta of these protons are from 75 to 600 MeV/c. Because of the low energy of these particles a gaseous hydrogen target was used. The effective target size and the production angle were determined by a movable collimator placed at the entrance to the 1st magnet of the LMC.

CALIBRATION OF THE EXTERNAL BEAM MONITOR

The EPB flux was measured with an ionization chamber placed in the EPB behind the experiment. The absolute calibration of this chamber was carried out with two counter telescopes (T_1 and T_2) placed in the EPB. The 1st (T_1) was designed to count only those particles that would pass through the targets used in the experiment. The second (T_2) was placed in the EPB ~ 16 m downstream from the experiment and was large enough so that all particles that passed through T_1 could be counted in T_2. The Bevatron was run at low beam intensity (10^4 to 10^5 particles per pulse) and the ratios of T_2/T_1 measured. Then ~ 2 m of concrete was placed between T_1 and T_2 and T_2/T_1 was again measured to determine the effective attenuation factor (~ 100) for the concrete. The beam intensity was then raised to $\sim 10^6 - 10^7$ particles per pulse and the ionization chamber was calibrated against T_2.

The differential cross sections are shown in Fig. 2. The data for $0 \leq t \leq 1.2$ $(\mathrm{GeV}/c)^2$ are shown in Fig. 3 in more detail. The statistical errors are smaller than the plotted points except for those points where error bars are shown.

At each momentum the measured cross sections were extrapolated to give the cross sections at $t = 0$. From the known total cross sections[3] and the optical theorem we find that the ratio of real to imaginary scattering amplitude $D(t = 0)/A(t = o) \approx 30\%$, in agreement with the calculation of Söding[4] using dispersion relations. The precision with which this measurement can be made is limited at present partly by the uncertainty in the total cross section measurements.

The cross sections at high momentum transfer are nearly independent of momentum transfer, but depend upon the incident momentum. This result is consistent with experiments at higher incident momenta.[5] The effect may be attributed to hard core scattering. An alternative explanation has been proposed by Fast, Hagedorn, and Jones,[6] in terms of the statistical model.

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(3) A. N. Diddens, E. Lillethun, G. Manning, A. E. Taylor, T. G. Walker, and A. M. Wetherell, Phys. Rev. Letters 9, 32 (1962).

(4) P. Söding, Phys. Letters 8, 285 (1964).

(5) G. Cocconi, V. T. Cocconi, A. D. Krisch, J. Orear, R. Burinstein, D. B. Scarl, W. F. Baker, E. W. Jenkins, and A. L. Read, Phys. Rev. Letters 11, 499 (1963).

(6) G. Fast and R. Hagedorn, Nuovo Cimento 27, 208 (1963).
G. Fast, R. Hagedorn, and L. W. Jones, Nuovo Cimento 27, 856 (1963).
L. W. Jones, Phys. Letters 8, 287 (1964).

For high energy p-p scattering at high momentum transfer this model gives

$$\frac{d\sigma}{dt} = \frac{\sigma_t}{2\, q^2 E_c} \exp\left[- 3.27\, (E_c - 1.88) \right] \qquad (1)$$

where σ_t is the total cross section excluding diffraction scattering; E_c is the total center of mass energy in GeV and q is the center of mass momentum of each proton.

Equation (1) is plotted in Fig. 4 along with the experimental results. The fit is surprisingly good in view of the rather low center of mass energies (2.7 to 3.9 GeV) available in this experiment, and the very simple assumptions of the theory.

At intermediate momentum transfers, $0.1\ (\mathrm{GeV/c})^2 \leq |t| \leq 1\ (\mathrm{GeV/c})^2$, the data show the well known shrinking of the diffraction pattern with increase of incident energy.[7,8,9,10] Tests of the Regge hypothesis using this data are now being carried out. A single pole fit is probably not of great interest because of the limitations pointed out by many authors, and more particularly by the fact that much of the scattering data at high energies

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(7) B. Cork, W. A. Wenzel, and C. W. Causey, Jr., Phys. Rev. 107, 859 (1957).

(8) A. N. Diddens, E. Lillethun, G. Manning, A. E. Taylor, T. G. Walker, and A. M. Wetherell, Phys. Rev. Letters 9, 108 (1962); 9, 111 (1962)

(9) K. J. Foley, S. J. Lindenbaum, W. A. Love, S. Ozaki, J. J. Russell, and L. C. L. Yuan, Phys. Rev. Letters 10, 376 (1963); 11, 503 (1963).

(10) D. O. Caldwell, B. Elsner, D. Harting, A. C. Helmholz, W. C. Middelkoop, B. Zacharov, P. Dalpiaz, S. Focardi, G. Giacomelli, L. Monari, J. A. Beaney, R. A. Donald, P. Mason, and L. W. Jones, Phys. Letters 8, 288 (1964).

does not fit such a model.[9,11] On the other hand there is good evidence that a multiple pole model can probably account for most of the presently observed features of high energy scattering of the strongly interacting particles with intermediate momentum transfers.[12,13,14]

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(11) C. C. Ting, L. W. Jones, and M. L. Perl, Phys. Rev. Letters 9, 468 (1962).

(12) F. Hadjioannou, R. J. N. Phillips, and W. Rarita, Phys. Rev. Letters 9, 183 (1962).

(13) W. Rarita and V. L. Teplitz, Phys. Rev. Letters 12, 206 (1964).

(14) G. F. Chew and W. Rarita, private communication.

FIGURE LEGENDS

Fig. 1 The experimental arrangement. Three separate magnetic spectrometers were used to measure the scattering cross sections for secondary momenta between .075 and 4.0 GeV/c at laboratory angles from 25° to 90°.

Fig. 2 The elastic scattering cross section for the entire four-momentum transfer region studied. The lines are drawn to connect points with the same incident momentum and do not represent any attempt to fit the data.

Fig. 3 The low momentum transfer measurements of the cross section shown in more detail than in Fig. 1. The curves are drawn only to connect points with the same incident momentum and do not represent a fit to the data.

Fig. 4 Fit to the statistical model described in Reference 6. The experimental points represent the cross section measurements at $|t| = |t \text{ max}|$ or $\theta_{cm} = \pi/2$.

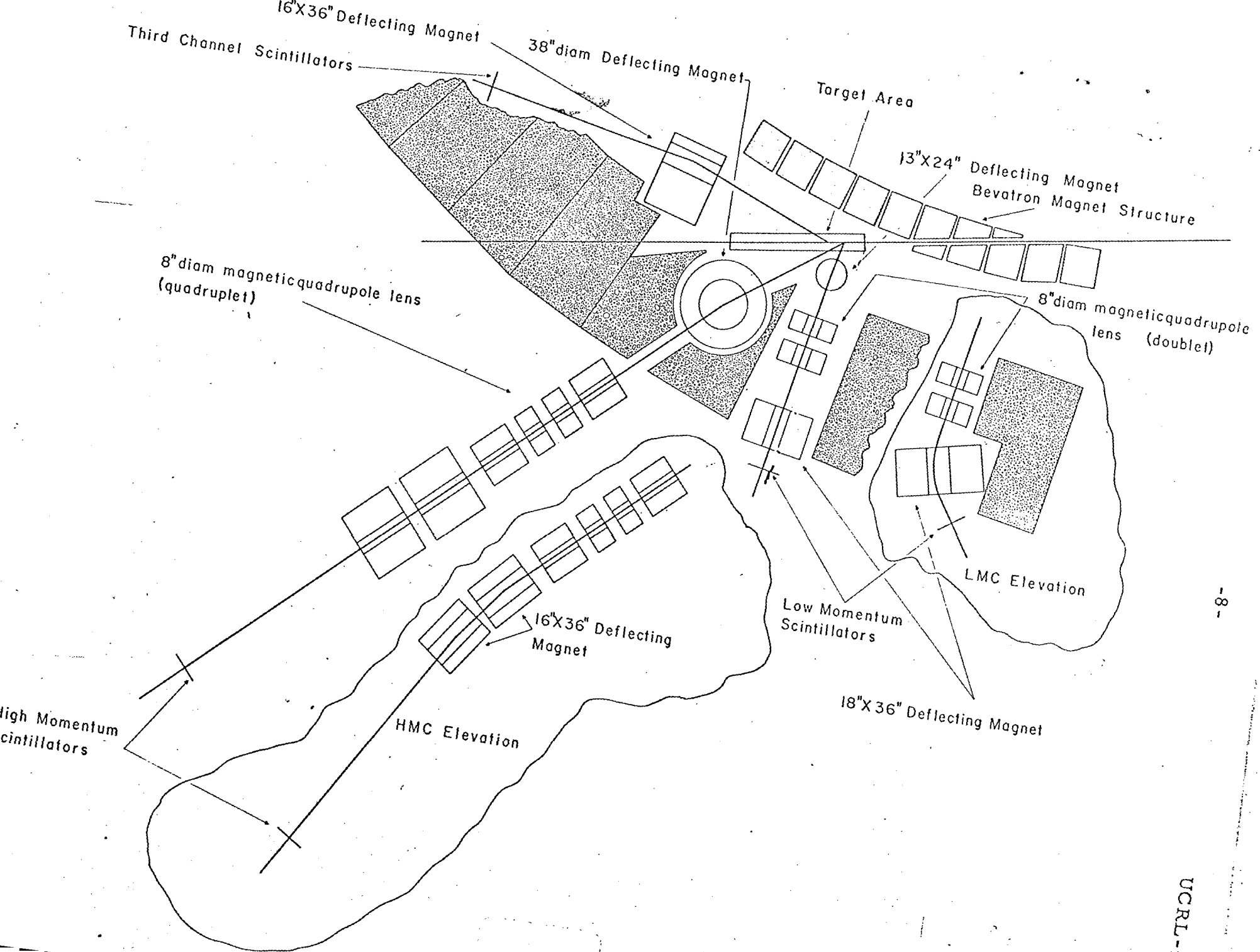

Fig. 1

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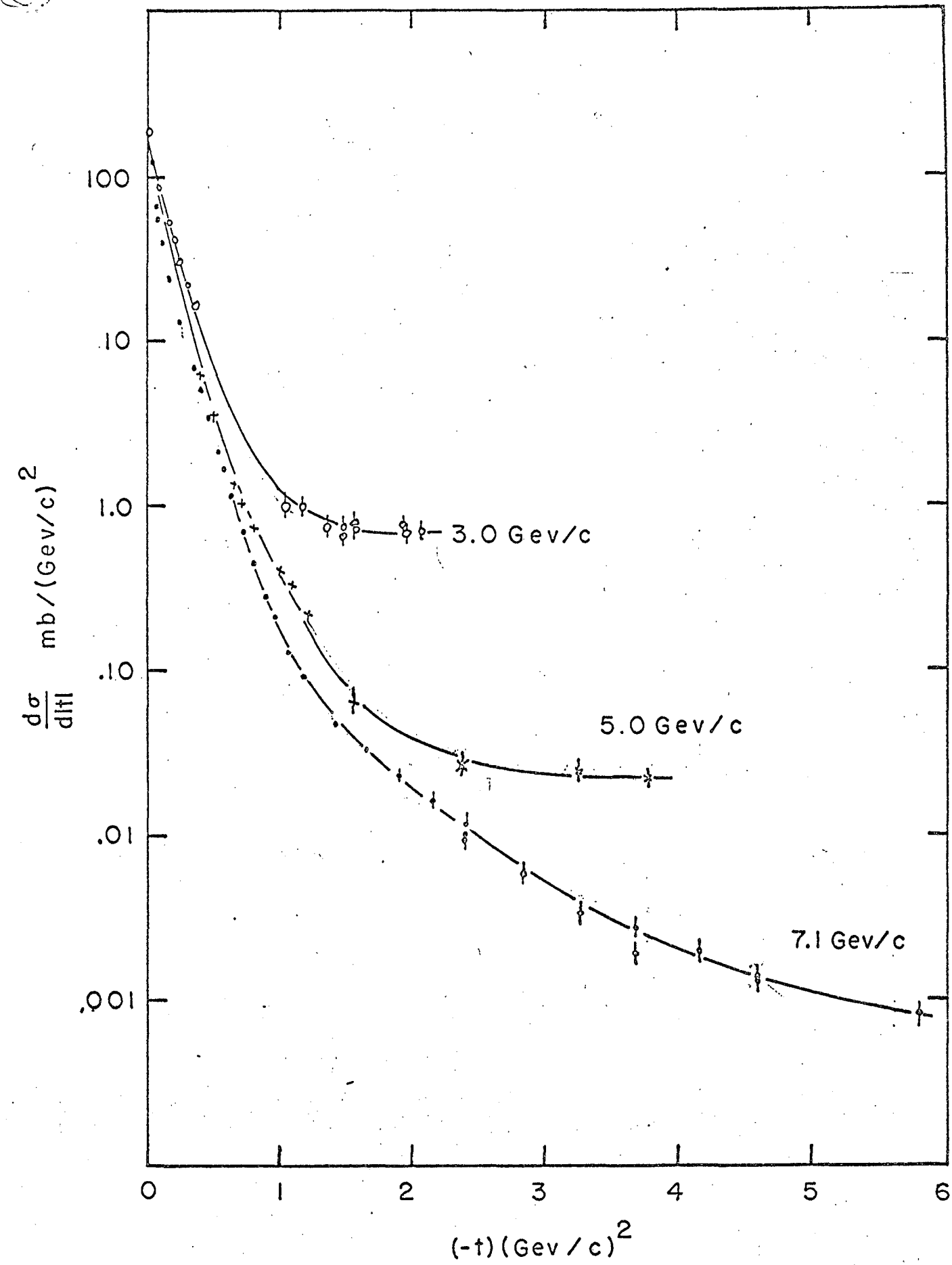
100
10
1.0
.10
.01
.001
$\frac{d\sigma}{dlt|}$ mb/(Gev/c)^2
3.0 Gev/c
5.0 Gev/c
7.1 Gev/c
0
1
2
3
4
5
6
(-t)(Gev/c)^2

Fig. 2

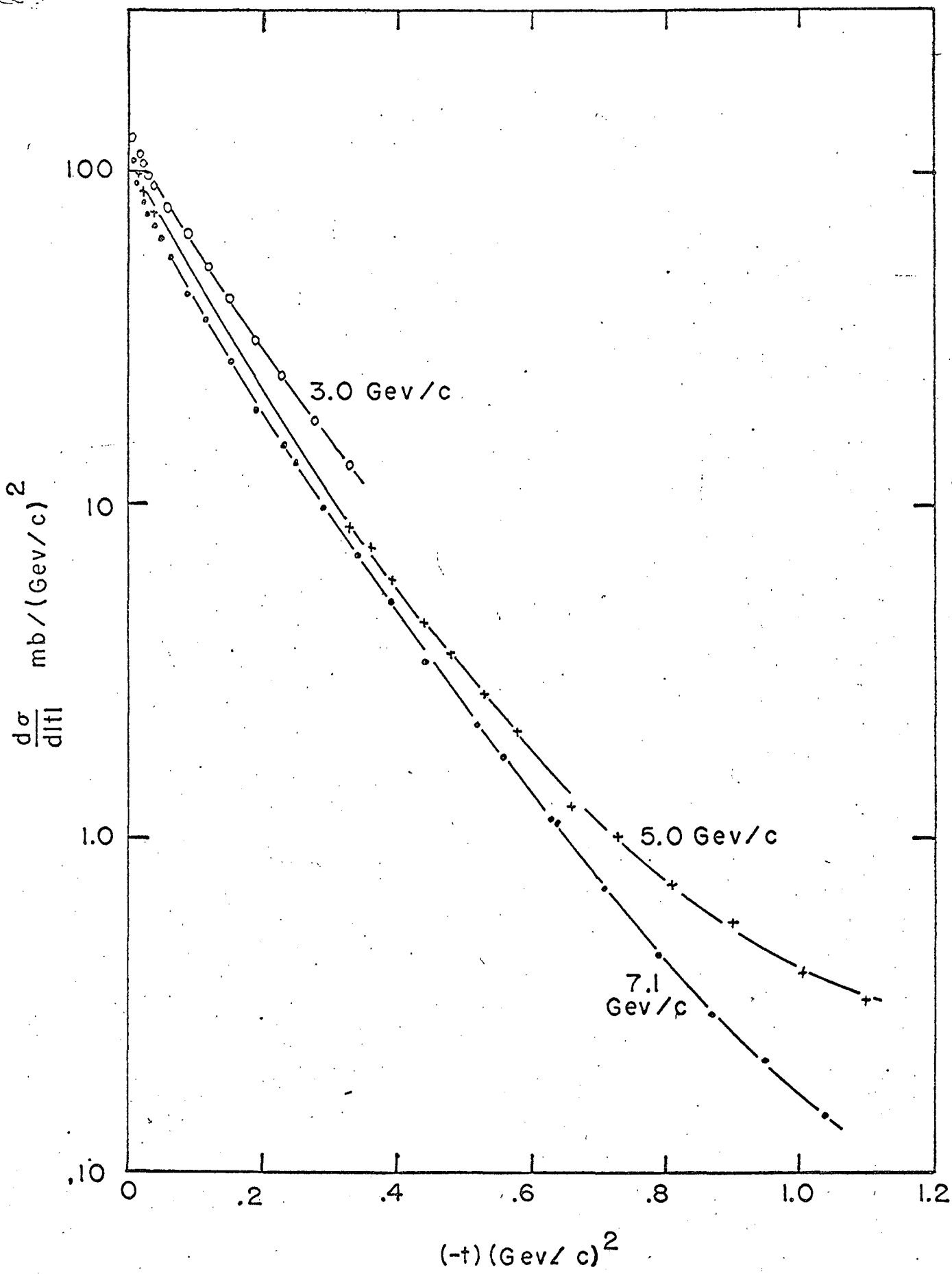
100
10
1.0
.10
0
.2
.4
.6
.8
1.0
1.2
3.0 Gev/c
5.0 Gev/c
7.1 Gev/c
$\frac{d\sigma}{d|t|}$ mb/(Gev/c)^2
(-t) (Gev/c)^2

Fig. 3

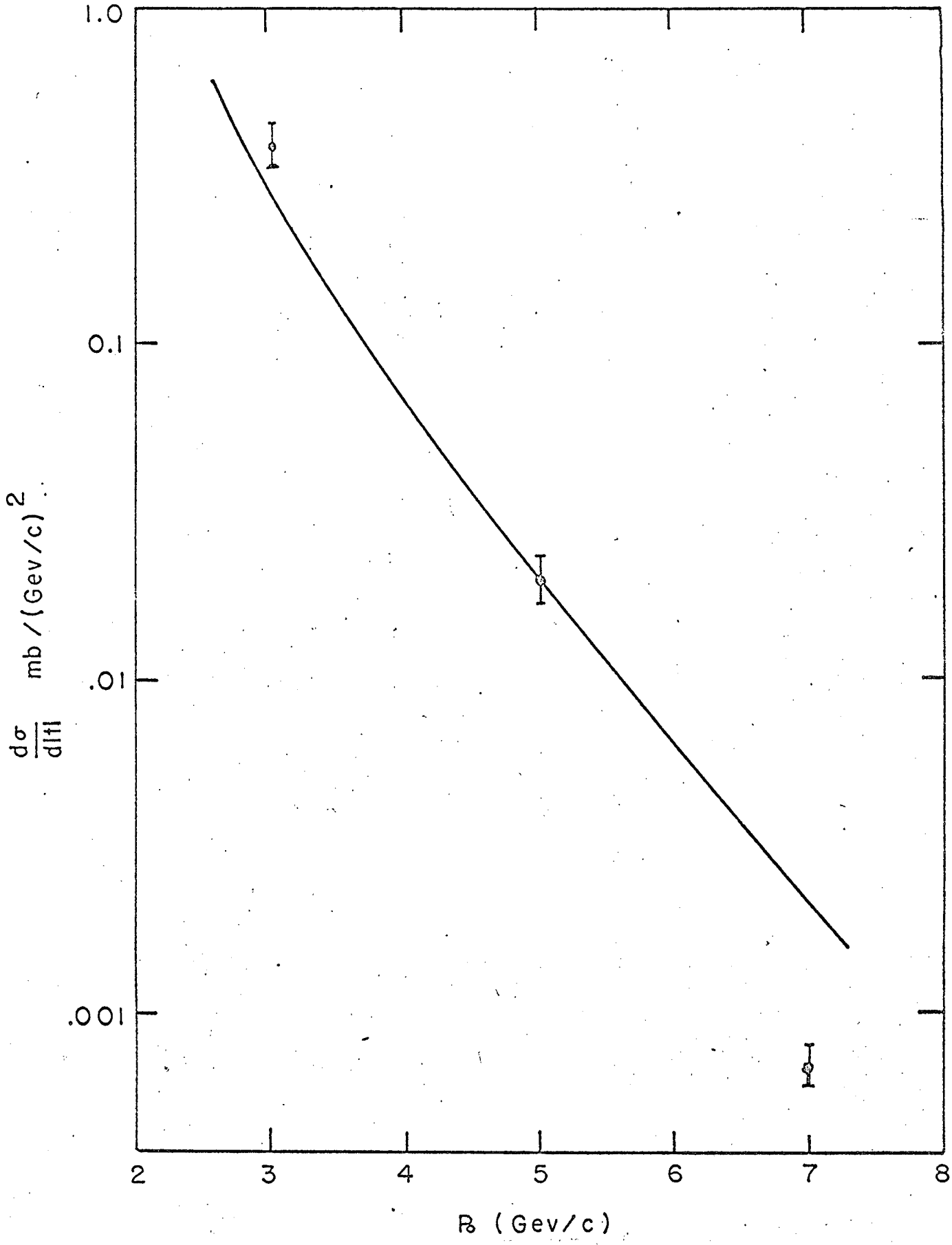

Fig. 4

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