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DIFFERENTIAL CROSS SECTIONS FOR THE REACTION $p + p \rightarrow \pi^+ + d$ BETWEEN 2.1 and 8.9 Gev/c

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This letter reports the results of measurements of the differential cross section for the reaction

$$p + p \rightarrow \pi^+ + d \qquad (1)$$

performed at incident proton momenta of 2.1, 3.6, 4.1, 4.5, 6.6 and 8.9 Gev/c, and for a deuteron emission angle of 60 mrad in the laboratory system.

The kinematics of reaction (1) are such that deuterons emitted forward in the c.m. system and detected at 60 mrad laboratory angle have momenta about 300 Mev/c higher than elastically scattered protons, and consequently higher than lighter particles emitted in the p - p interaction. In a momentum region of so little background, the deuteron peak from reaction (1) can be isolated by measuring, with good resolution, the momentum spectrum of the positively charged particles emitted by the interaction of mono-energetic protons with a proton target.

The internal beam of the CERN proton synchrotron was used at a beam intensity of 2-6 x 10^{11} protons per pulse and a repetition time of 1.5 sec. The stability of the beam energy was better than two parts in a thousand. Targets of CH_2 and C were alternately flipped into the beam. The positively charged secondaries emitted at 60 mrad to the beam were analyzed by a magnetic spectrometer consisting of the following components :

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i) A collimator, 6.5 mm wide, located 36 m from the target.

ii) Four 2 m bending magnets centered at 42 m from the target, which were excited by the same generator. The magnetic field was kept constant within one part in 10^3.

iii) A counter system consisting of 5 double coincidence channels which analyzed, simultaneously 5 momenta differing one from another by ~ 0.2%. The bending angles defined by these telescopes were about 220 mrad. At a distance of 86 m from the target, the defining scintillators of each channel (6 mm wide, 10 cm high) subtended a solid angle of 10^{-7} sterad. Vacuum pipes and He bags kept the scattering of the particles along the spectrometer to a minimum. The overall momentum resolution of the system was less than 1%.

Momentum spectra of the secondariesfrom the p - p collisions were obtained from the CH_2 and C spectra by subtraction, using the Be^7 activity of the target to find the subtraction constant, and the measured values [1] of the Be^7 cross section to obtain absolute cross sections. The elastic p - p cross sections obtained are in good agreement with those found in other experiments[2]. At 2.1 Gev/c, an accident during the experiment prevented the measurement of the Be^7 target activity, and absolute cross sections at this point were not obtained.

The six momentum spectra obtained are shown in Fig. 1. The proof that the observed smaller peaks are indeed produced by deuterons from reaction(1) rests on the following facts. First, at the incident proton momentum of 2.1 Gev/c the time of flight of the particles in the smaller peak, measured over a 10 m flight path, was found to be 43 ns, as expected if the particles were deuterons. (The expected time of flight for protons was 36 ns, for π mesons 33 ns). Second, the mass of the particle accompanying the deuteron, as deduced from the momenta at which the deuteron peaks were observed, was equal to that of the π meson within 50 Mev.

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Table 1 gives the cross sections obtained, the errors quoted take into account both the statistical fluctuations and those due to the subtraction method. Fig. 2a shows the differential cross sections from this experiment together with those deduced from other observations[3]. The available total cross section data [3,4] are given in Fig. 2b.

In a counter experiment at 1.3 Gev/c Mescheryakov et al[3] found an angular distribution of the form $1 + (4.4 \pm 3.1)\cos^2\Theta_{c.m.}$ while at 2.84 Gev/c B. Sechi Zorn[3], using a H_2 bubble chamber, found approximately $1 + 2\cos^2\Theta_{c.m.}$ In the 2 - 4 Gev/c momentum range a laboratory angle of 60 mrad corresponds to $\cos\Theta_{c.m} \doteq 0.96$ and the difference between the differential cross section at 0^o and at 60 mrad can be neglected. Hence the results of Collins et al[3], obtained at $\Theta_{c.m.} = 180^o$, were transformed to $\Theta_{lab} = 0^o$ and plotted in Fig. 2a without further correction.

A possible explanation of the sharp peak in Fig. 2a might be a very rapid narrowing of the angular distribution which could, at a fixed laboratory angle of observation, lead to first a rise and then a rapid fall in the differential cross section as the distribution moved inside the angle of observation. The data available on the angular distribution, up to 2.84 Gev/c, do not seem to support this possibility although a violent change between 2.84 and 4.10 Gev/c cannot be excluded. If the angular distribution does not change rapidly over the peak, Fig. 2a can be considered to reflect the shape of the total cross section for reaction (1), and indeed the points of Fig. 2b are not inconsistent with this.

It appears therefore that the sharp peak arises from a radical change in angular distribution, from a peak in the total cross sections, or from the combination of both effects. In any of these cases a resonant behaviour in the cross section for reaction (1) is suggested at a di-proton mass of 2.9 Gev. The width of the peak, in the di-proton rest system, is ± 100 Mev.

The mechanism for an effectively resonant di-proton interaction is not clear but it is interesting to remark that the sum of the masses of the nucleon and the 1.92 Gev pion-nucleon isotopic spin 3/2 state is 2.86 Gev, very close to the observed peak. A similar numerical coincidence occurs at the strong low energy peak, shown in Fig. 2b, for which the total c.m. energy is 2.16 Gev, just the sum of the masses of the nucleon and the first pion-nucleon resonance (3/2, 3/2). A calculation by S. Mandelstam[5] has shown that contributions from the (3/2, 3/2) state are necessary to produce a rapid drop in cross section on the high energy side of the low energy peak. These remarks suggest a connection between the high energy deuteron peak and the higher nucleon resonances but any such suggestion is obviously very tentative.

We wish to thank the CERN proton synchrotron machine division for operating the accelerator under the stringent and non-standard conditions necessary for this experiment. Thanks are also due to Dr. A.N. Diddens, for aid in the latter runs of the experiment, and to Drs. A. Stanghellini, and M. Nauenberg for useful discussions. We are grateful to R. Donnet, C.A. Sherwood and C.A. Stahlbrandt for their assistance with the experimental equipment and to B. Carlson for assistance with the data reduction.

Table I. Differential cross sections for the reaction $p + p \rightarrow \pi^+ + d$ at 60 mrad laboratory angle. Po is the incident proton momentum and E* is the total energy in the c.m. system.

Po(Gev/c)	$\left(\frac{d\sigma}{d\Omega}\right)_{Lab} \frac{\mu b}{st}$	E^* (Gev)	$\cos\Theta_{c.m.}$	$\left(\frac{d\sigma}{d\Omega}\right)_{c.m.} \frac{\mu b}{st}$
3.6	150 ± 15	3.0	0.97	7.7 ± 0.8
4.1	80 ± 10	3.1	0.96	4.0 ± 0.5
4.5	75 ± 10	3.3	0.96	3.7 ± 0.5
6.6	16 ± 2	3.8	0.96	0.68 ± 0.09
8.9	6 ± 2	4.4	0.95	0.22 ± 0.07

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REFERENCES

* Permanent address, A.E.R.E., Harwell, Didcot, Berks, England.

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1. E. Baker, G. Friedländer and J. Hudis, Phys. Rev. 112, 1319 (1958).
   P.A. Benioff, Phys. Rev. 119, 316 (1960).
   J.B. Cumming, G. Friedländer, J. Hudis and A.M. Poskanzer, Phys. Rev. 127, 950 (1962).

2. W.A. Wenzel, B. Cork, and C.W. Causey, Jr., Phys. Rev. 107, 859 (1957).
   T. Fujii, G.B. Chadwick, G.B. Collins, P.J. Duke, N.C. Hien, Phys. Rev. 128, 1836 (1962).
   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).

3. M.G. Mescheryakov, B.S. Neganov, N.P. Bogachev, V.M. Sidorov, Dokl. Akad. Nauk - SSSR, 100, 673 (1955).
   F. Turkot, G.B. Collins, T. Fujii, M.A.R. Kemp, J. Menes, and J. Oostens, Bull. Am. Phys. Soc. 7, 620 (1962); to be published, and private communication. We are grateful to this group for allowing us to use their data before publication.

B. Sechi Zorn, private communication. We are grateful to Mrs Sechi Zorn for allowing us to use her data before publication.

4. T.H. Fields, J.G. Fox, J.A. Kane, R.A. Stallwood, and R.B. Sutten, Phys. Rev. 95, 638 (1954).
M.G. Mescheryakov, and B.S. Neganov, Dokl. Akad. Nauk. SSSR, 100, 677 (1955).
F.S. Crawford, M.L. Stevenson, Phys. Rev. 97, 1305 (1955).
A.P. Batson, B.B. Calwick, and L. Riddiford, Proc. Roy. Soc. A251, 218 (1959).
G.A. Smith, H. Courant, E.C. Fowler, H. Kraybill, J. Sandweiss, and H. Taft, Phys. Rev. 123, 2160, (1961).
B. Sechi Zorn, Bull. Am. Phys. Soc. 7, 349 (1962).

5. S. Mandelstam, Proc. Roy. Soc. A244, 491 (1958).

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FIGURE CAPTIONS

Figure 1 The Momentum spectra of secondaries from p - p collisions for various incident proton momenta. The p - p elastic scattering peaks are drawn on different scales from the deuteron peaks as indicated.

For the 2.1 Gev/c data the scales are arbitrary.

The mass scales, m_x, located above the deuteron peaks give the momentum expected for the deuteron emitted in the reaction $p + p \rightarrow x + d$, where x has mass m_x.

Figure 2(a) Laboratory differential cross sections for the reaction $p + p \rightarrow \pi^+ + d$ as a function of incident proton momenta and of the total energy in the di-proton rest system (E^*). The data are taken from this experiment and from reference 3.

(b) Total cross sections for the reaction $p + p \rightarrow \pi^+ + d$ The data are taken from references 3 and 4.

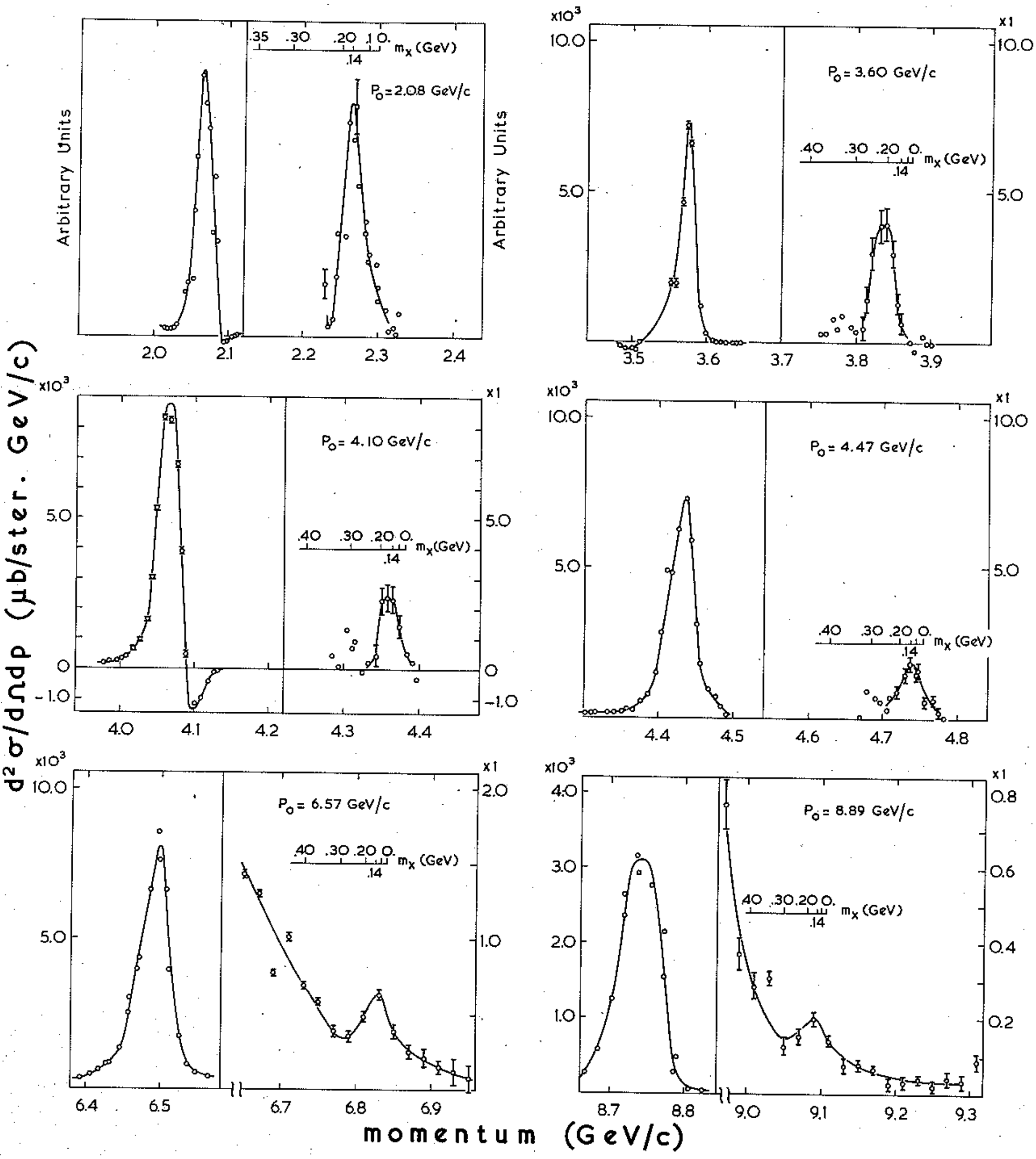
P₀ = 2.08 GeV/c
Arbitrary Units
m_x (GeV)
P₀ = 3.60 GeV/c
P₀ = 4.10 GeV/c
P₀ = 4.47 GeV/c
P₀ = 6.57 GeV/c
P₀ = 8.89 GeV/c
d²σ/dΩdp (μb/ster. GeV/c)
momentum (GeV/c)

Fig. 1

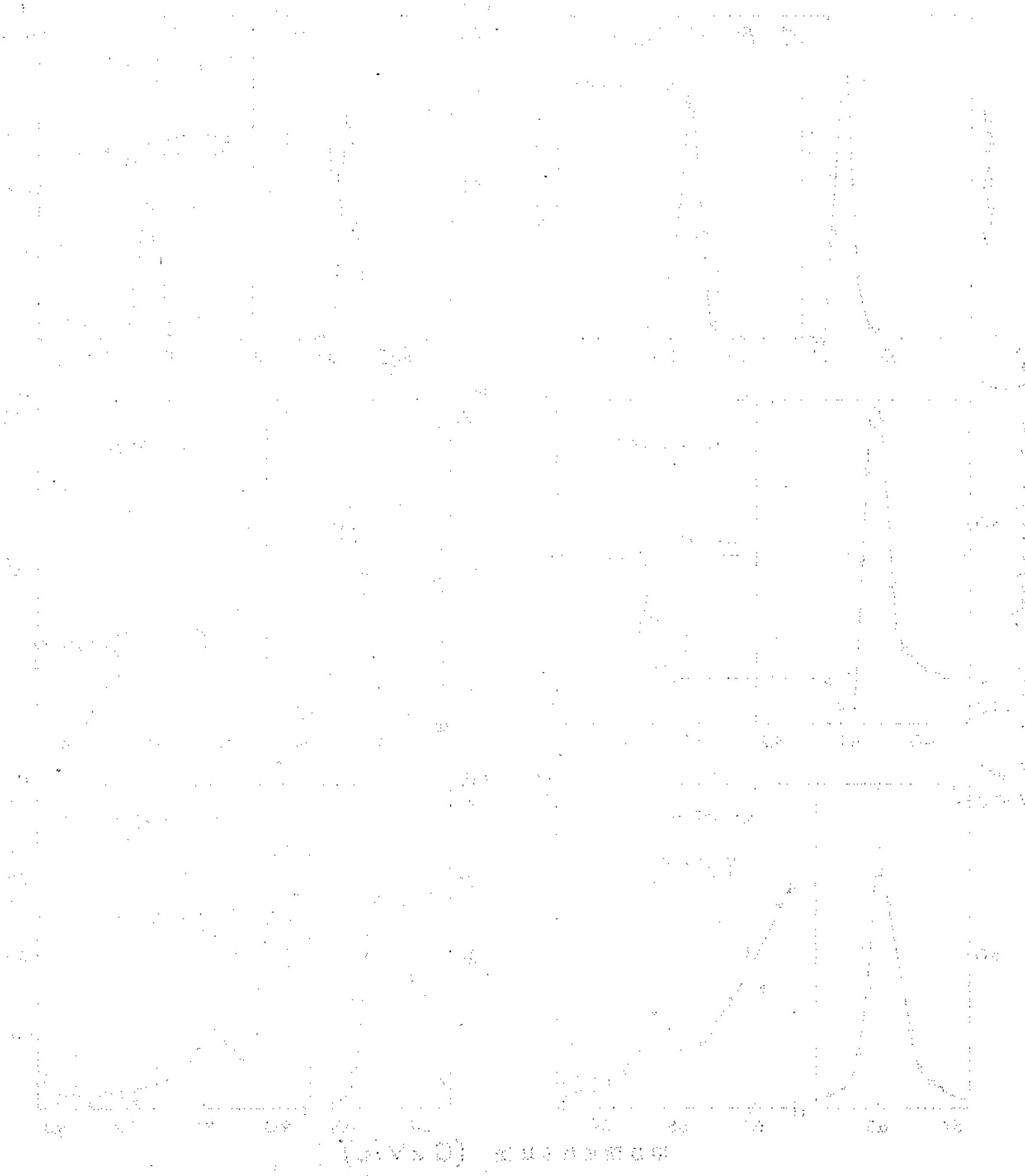

Fig. 1

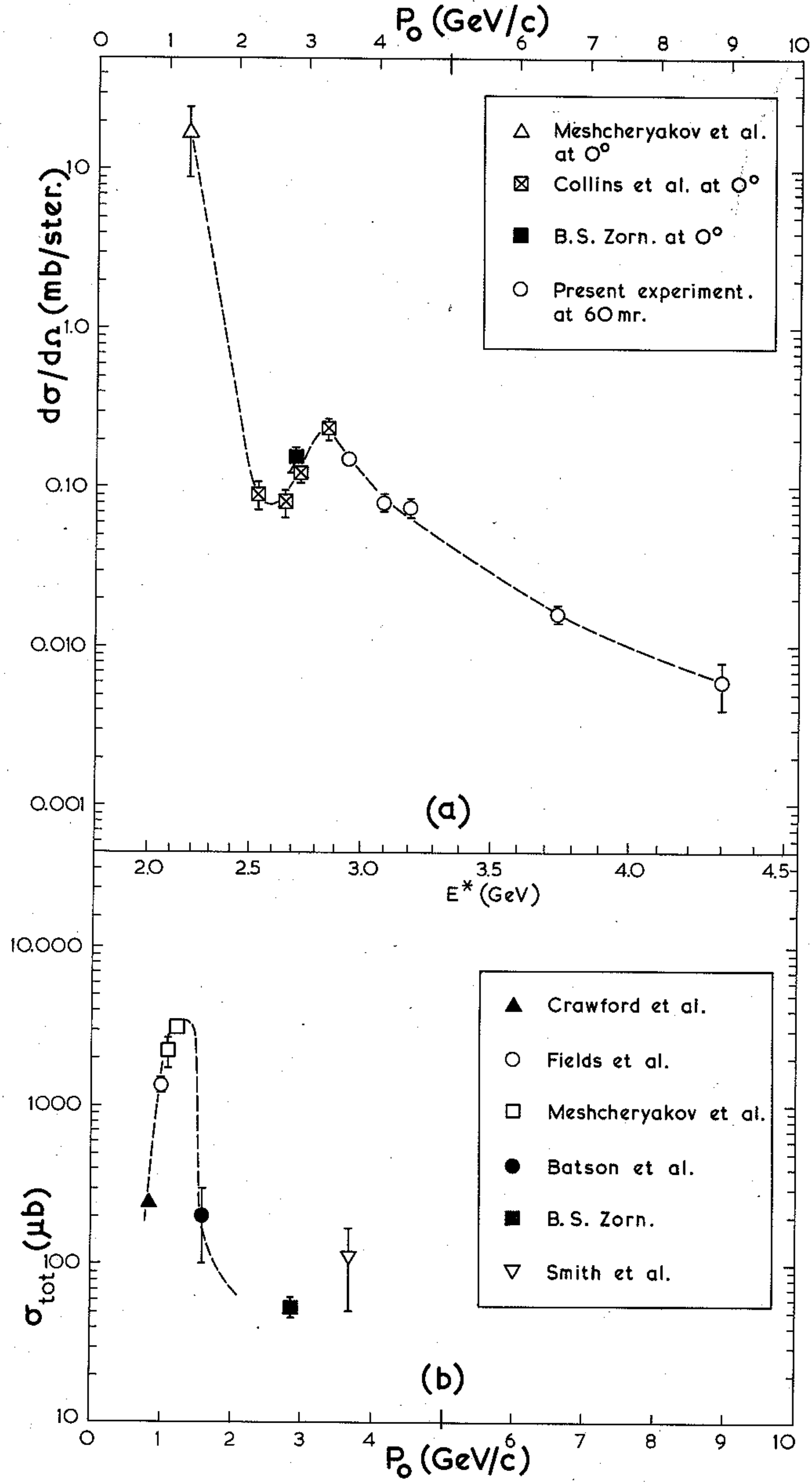

Fig. 2

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