EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Nuclear Physics Division
Internal Report 68- 7
15 March, 1968

DIFFRACTION-LIKE STRUCTURE IN ELASTIC PROTON - PROTON SCATTERING AT LARGE MOMENTUM TRANSFERS

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Angular distributions of elastic proton-proton scattering at incident momenta of 8.1, 9.2, 10.1, 11.1 and 12.1 GeV/c have been measured over an angular range of 40° to 90° c.m.s. and between 60° and 90° at 7.1 GeV/c. This experiment was a continuation and extension of previous work$^{1)}$ performed between 8.1 and 21.3 GeV/c. In the former experiment a rather abrupt flattening beyond 60° c.m.s. was observed in the angular distributions for incident momenta around 8 - 11 GeV/c. Using a fit to the angular distribution of the form

$$\frac{d\sigma}{d\Omega} \sim \exp\left(-\frac{p \sin \Theta}{b}\right) \qquad (1)$$

(where p is the c.m.s. momentum in GeV/c and Θ the c.m.s. scattering angle) it was found that the parameter b changed sharply, from 0.118 GeV/c at 8.1 GeV/c to 0.294 GeV/c at 11.0 GeV/c. This observation was consistent with the results of Akerlof et al.$^{2)}$ who found a discontinuity or break in the behaviour of the 90° differential cross sections as a function of momentum.

The present experiment was undertaken to investigate the $p-p$ angular distributions at large momentum transfers in greater detail in the discontinuity region around 9 GeV/c and to extend the angular range studied. For example, whereas only 4 points on the angular distribution between 67° and 83° at 10.0 GeV/c were measured by Allaby et al.$^{1)}$, 18 were measured between 40° and 90° at 10.1 GeV/c in the present experiment.

The experimental technique involved detection of both protons emerging from CH_2 targets (thickness 0.5 to 3 gm cm^{-2}) bombarded by a long pulse extracted proton beam ($\sim 3 \cdot 10^{11}$ protons per pulse with an effective spill time of ~ 50 ms). The detection system consisted of two magnetic spectrometers, one on each side of the primary beam, each consisting of 2 bending magnets and a triple coincidence scintillation counter telescope. The first magnet in each spectrometer was a 2 m long C-magnet which could be rotated on a mobile chassis mounted on rails. The angle and position of the magnet could be readily changed by remote control³⁾. The second magnet was a 2 m long H-magnet placed on the axis of the fixed counter telescope. By appropriate choice of the positions, rotations and bending powers of the C-magnets and of the bending powers of the H-magnets, elastically scattered protons could be detected over the required range of momenta and c.m.s. angles. Elastic scattering events were defined by a coincidence between the left and right telescopes with a time resolution of ~ 2 ns obtained by means of a time to pulse height converter and pulse height analyser. The solid angle in the laboratory system, defined by the first counter of the right hand telescope, R_1, varied between 0.2 and $1.5 \cdot 10^{-5}$ sr. The alignment of the system was monitored by 4 scintillation counters placed in front of the left hand telescope, so as to frame the conjugate of the solid angle defined by R_1. A 50 cm long quadrupole magnet in the left hand spectrometer allowed the dimensions of the conjugate image of R_1 to be made compatible with the left side counters for all angles and momenta.

The monitoring of the beam intensity was done, as before¹⁾, using a secondary emission chamber and two independent counter telescopes for relative measurements. The absolute calibration was obtained from the amounts of ^{24}Na activity produced in thin aluminium foils placed in the beam. The activation cross section used was taken to be independent of momentum and equal to 8.6 ± 0.5 mb⁴⁾. The calibrations at any particular energy were reproducible to within ± 1%.

Elastic scattering events were counted at a rate of several hundred per hour and a complete angular distribution (40°-90°) was generally completed in a day with about 1000 counts at each angle. Measurements with carbon targets showed that the detection of protons within the acceptance of the spectrometer from proton-carbon collisions was negligible. The corrections applied for absorption and loss by multiple scattering were an estimated 15 to 21%. A Monte Carlo calculation to refine these estimates is in progress. Accidental coincidences and dead time losses gave rise to corrections usually less than about 5%.

The final uncertainties resulted from (a) the combination of statistical errors ($\sim \pm 3\%$) and estimated systematic errors ($\sim \pm 2\%$) in each angular distribution; (b) relative uncertainties from one momentum to another due to the monitor calibration ($\pm 1\%$). In addition, there is a scale error of $\pm 7\%$ due to the uncertainty in the ^{24}Na cross section$^{4)}$.

The cross sections obtained in the experiment are given in Figs. 1, 2, 3 and 4 together with other p-p data$^{1,5,6)}$ The numerical values of the cross sections are given elsewhere$^{7)}$. Fig. 1 gives $d\sigma/dt$ as a function of $\sin\Theta$. The new data show clearly that the cross sections cannot be expressed by an exponential in transverse momentum (equation 1). It appears, in fact, that a momentum dependent oscillatory structure is contained in the angular distributions and that their gradients near 90° change rapidly as the phase of the oscillation varies with momentum. This structure was manifested, but less completely, by the discontinuous behaviour described in the previous work$^{1,2)}$ The data from the present experiment at 12.1 GeV/c can be joined on to results at smaller angles ($\sim 35°$, Harting et al.$^{5)}$, Orear et al.$^{6)}$) only by means of a shoulder or a distinct change of slope.

The new data can be exhibited in the context of other results also by means of an Orear$^{8)}$ plot, Fig. 2, which gives $s(d\sigma/d\Omega)$ (where s is the square of the total c.m.s. energy and $(d\sigma/d\Omega)$ is in the centre of mass system) as a function of $p\sin\Theta$. The original fit of Orear$^{8)}$ to the older data (Cocconi et al.$^{5)}$) is indicated in Fig. 2. The data points in the range $1.2\ \text{GeV/c} \lesssim p\sin\Theta \lesssim 2.0\ \text{GeV/c}$ cluster into a quite well defined oscillation indicating that the phase of the structure evident in Fig. 1 depends essentially on $p\sin\Theta$, thus resembling a classical diffraction pattern. The radius of an opaque diffracting disc which would produce the oscillation shown in Fig. 1 is about 0.6 f.

Fig. 3 shows $d\sigma/dt$ as a function of $|t|$. In this representation the data show, at momenta above about 9 GeV/c a small shoulder at $|t| \approx 2\ (\text{GeV})^2$ and a discontinuity in the locus of the 90° points at $|t| \approx 6\ (\text{GeV})^2$. The shoulder resembles the structure which has been observed up to 12 GeV/c in $\pi^{\pm}$ - p angular distributions$^{6)}$.

In Ref. 1, Allaby et al. remarked that the large angle p - p cross sections[1,2,5] could be well represented by the formula

$$\frac{d\sigma}{dt} = B \exp(-s \sin\Theta/g) \qquad (2)$$

The present measurements at centre of mass angles as low as 40° do not fit onto this dependence. Fig. 4 shows that the data at angles smaller than about 50° fill up the break evident in Fig. 2 of Allaby et al.[1] A universal fit to all p - p scattering data has been proposed by Krisch[9] in terms of 3 Gaussian density distributions in the nucleon and by taking some account of identical particle effects. The flattening of the angular distributions[1] at large angles was to be explained, in particular, by such effects. The new data, however, seem to put the experimental situation in a new perspective, namely that measurements of complete angular distributions show structure effects not previously suspected. In fact, the break which stimulated these measurements seems now to be a result of the development of an oscillatory structure in the p - p angular distributions for incident momenta above about 9 GeV/c.

The structure resembles, qualitatively, a small secondary diffraction peak and it would seem natural to describe the situation by some kind of an optical model. One of the first discussions of high energy, large momentum scattering, stimulated by the early measurements of Cocconi et al.[5], was, in fact, given by Serber[10] in terms of an optical model. This model was incapable of giving any prediction about the energy dependence of the cross section but Serber pointed out that such a model might give the limiting behaviour at very high energies. Recently, Durand and Lipes[11] have evaluated a rather more elaborate diffraction scattering model of a type suggested by Chou and Yang[12]. The shape of the absorbing matter distribution in the proton was taken to be given, as suggested by Wu and Yang[13] by the electromagnetic form factor. In their evaluation Durand and Lipes used a dipole form, corresponding to a smooth structureless matter distribution. As is typical in a diffraction model calculation diffraction dips were predicted, the dips being more or less filled up depending upon the contribution of an adjustable real part in the amplitude. With plausible parameters Durand and Lipes predicted structure in the p - p scattering cross section resembling the phenomena observed. It appears that such a simple diffraction model, involving a matter distribution closely related to the proton's electromagnetic form factor may be sufficient to reproduce quite well the observed structure in high energy proton - proton scattering. Hence explanations of this behaviour in terms of a rather complicated proton density distribution 9) or by means of reactive threshold effects due to baryon pair production 1,14) seem to be unnecessary.

We are grateful to G. Cocconi for his participation in the initial planning of this experiment and to P. Preiswerk for continuous support. I. Jarstorff is to be thanked for her measurements of the aluminium monitor foils and V. Agoritsas for the provision of the secondary emission monitor. The members of the MPS division (Proton Synchrotron) provided excellent beam operation and expeditious layout of the experiment. The technical support of R. Donnet, M. Ferrat and C.S. Ståhlbrandt was, as always, of the highest order.

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FIGURE CAPTIONS

Fig. 1 : Proton-proton elastic scattering differential cross sections $d\sigma/dt$ (where t is the square of the 4- momentum transfer) as functions of $\sin \Theta$ (Θ is the c.m.s. scattering angle). The incident momenta in the laboratory system are indicated. The data are from references 1, 5 and 6 and the present experiment. The hand drawn curves through the experimental points serve simply to guide the eye.

Fig. 2 : Orear plot[8]) of p - p elastic differential cross sections. The data shown are from references 1, 5 and the present experiment. The broken line shows Orear's fit to the previous data of Cocconi et al.[5])

Fig. 3 : Proton - proton elastic differential cross sections as a function of $|t|$. The data are from references 1, 5, 6 and the present experiment. The loci of cross sections at fixed c.m.s. angle are indicated for 60°, 80° and 90°. The curves joining the experimental points are hand drawn to guide the eye.

Fig. 4 : Differential cross sections for p - p elastic scattering shown as a function of $s \sin \Theta$. The data are from references 1, 5 and the present experiment. The lines drawn in the figure indicate the fit (equation (2)) given by Allaby et al.[1])

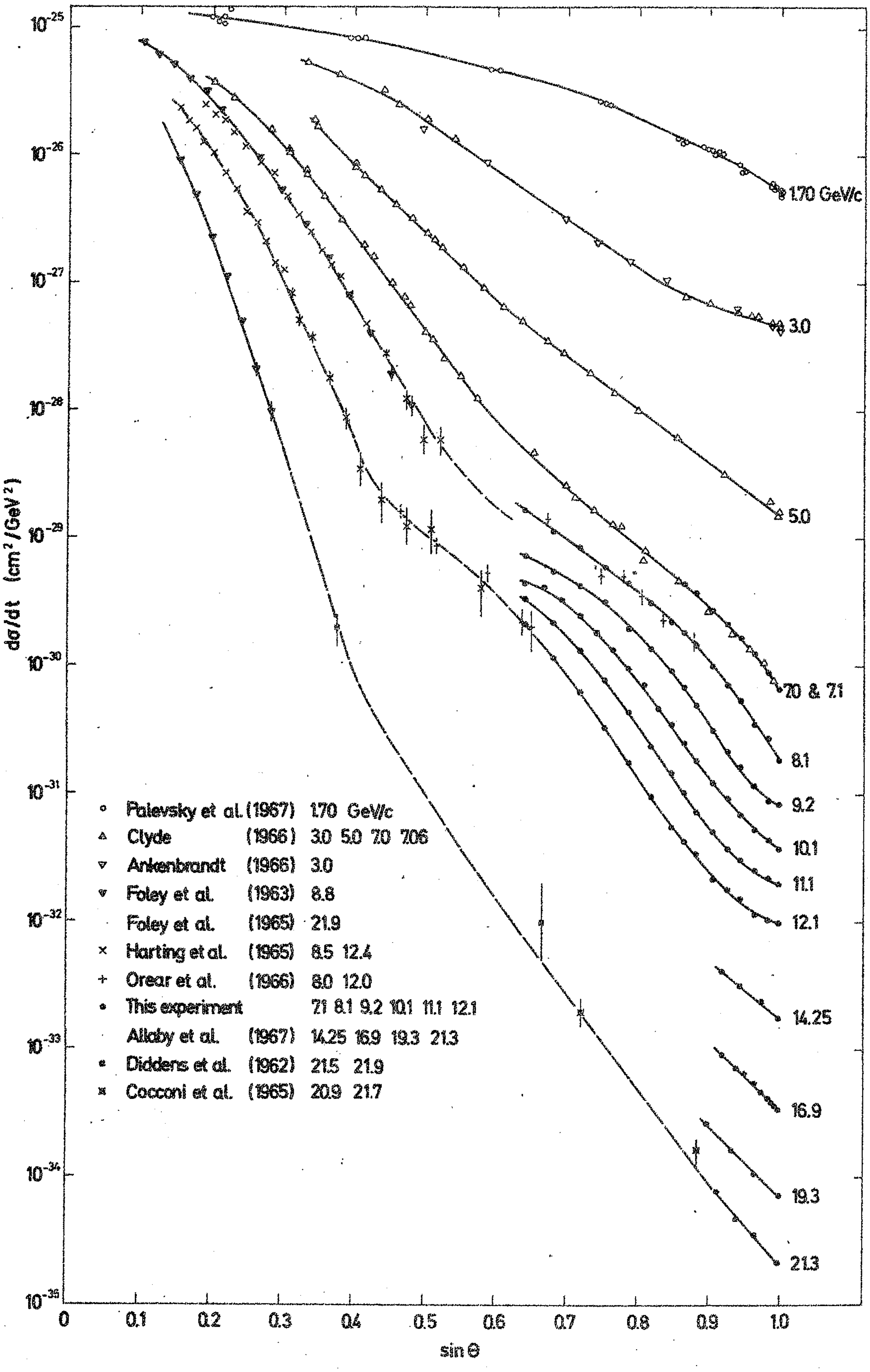

Fig. 1

DIA 32586

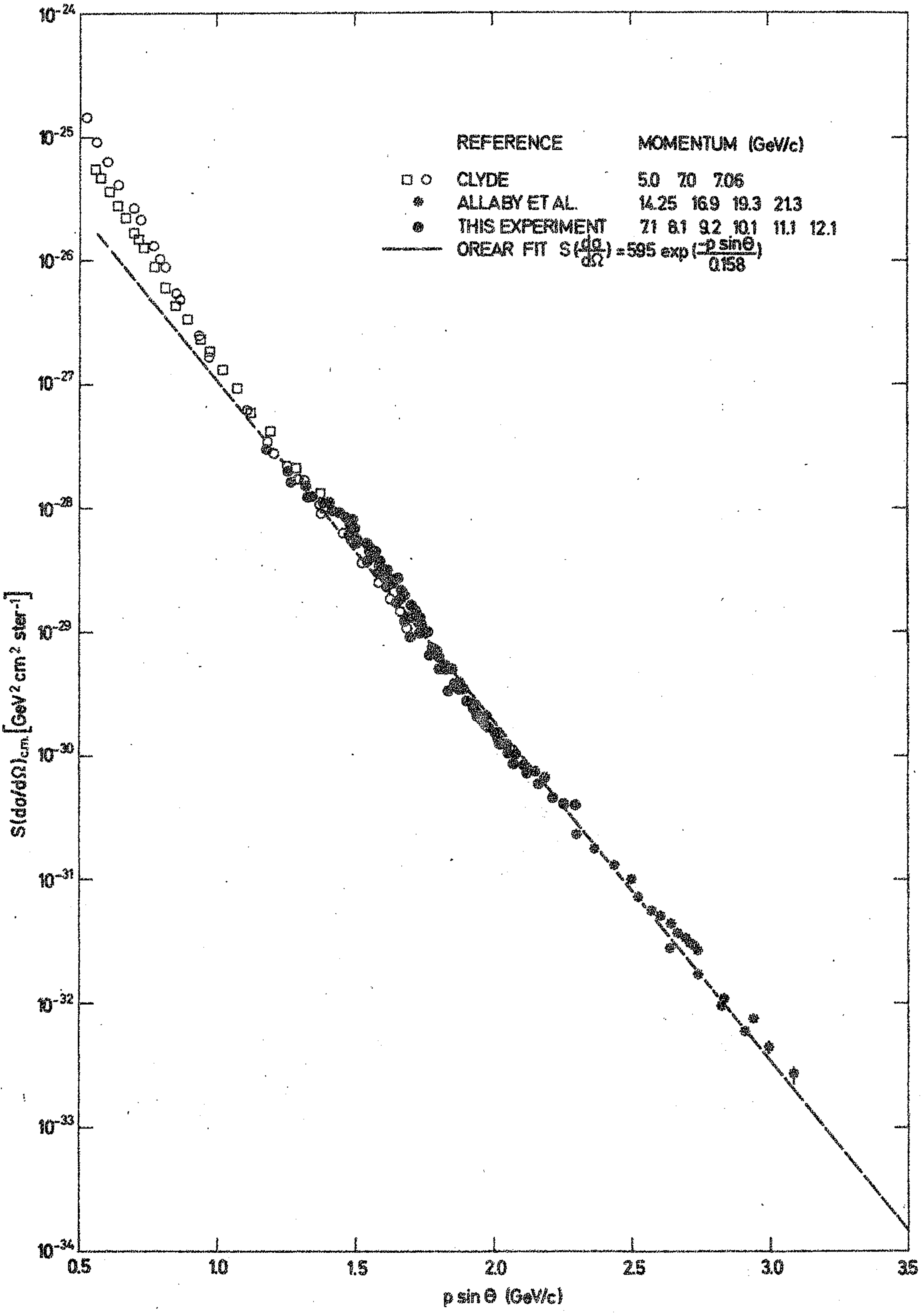

Fig.2

DIA 33047

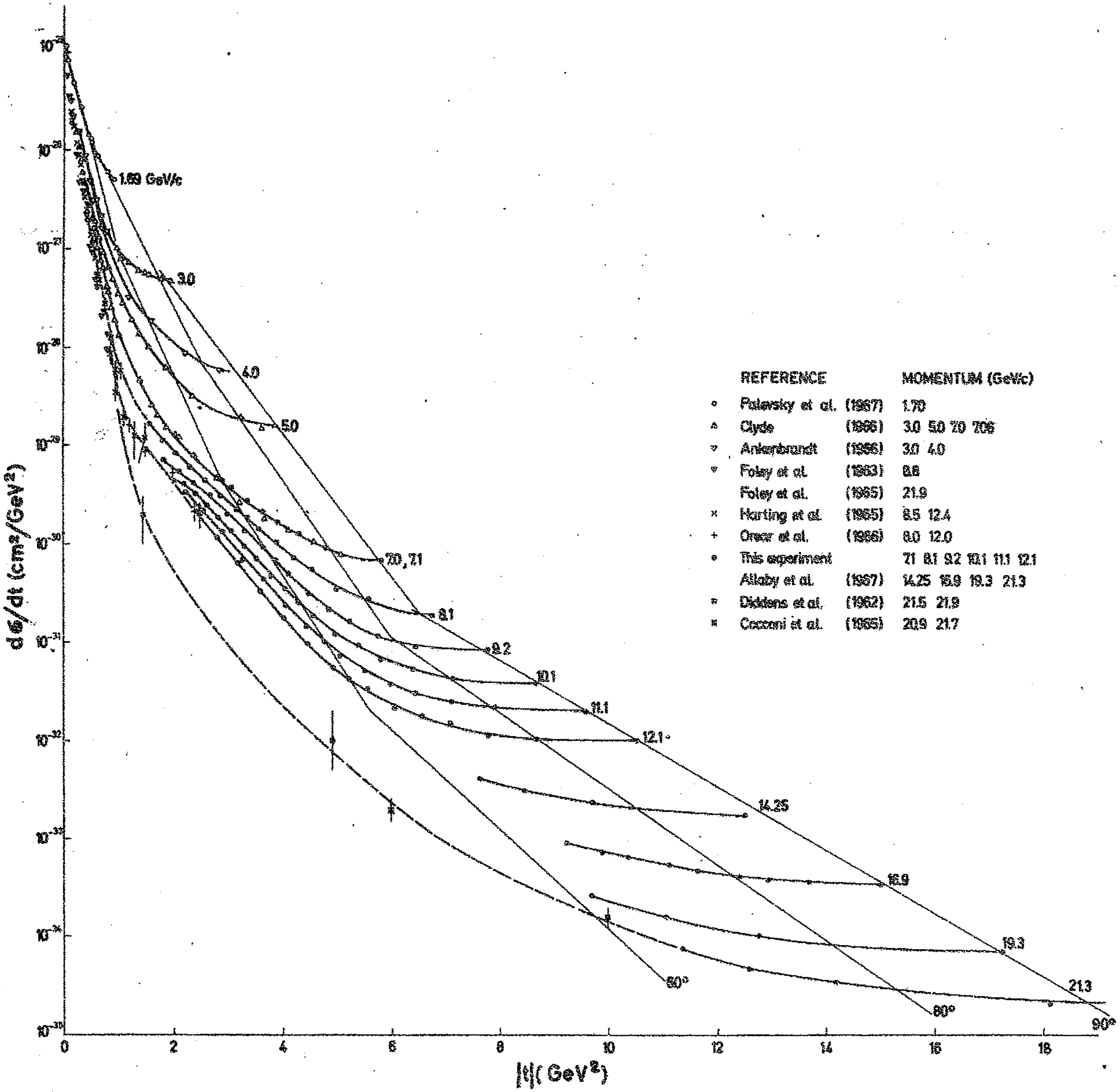
10^{-25}
10^{-26}
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
$d\sigma/dt$ (cm²/GeV²)
0
2
4
6
8
10
12
14
16
18
$|t|$ (GeV²)
1.69 GeV/c
3.0
4.0
5.0
7.0, 7.1
8.1
9.2
10.1
11.1
12.1
14.25
16.9
19.3
21.3
60°
80°
90°
REFERENCE
MOMENTUM (GeV/c)
○ Palevsky et al. (1967) 1.70
△ Clyde (1966) 3.0 5.0 7.0 7.06
▽ Ankenbrandt (1966) 3.0 4.0
▽ Foley et al. (1963) 8.8
Foley et al. (1965) 21.9
× Harting et al. (1965) 8.5 12.4
+ Orear et al. (1966) 8.0 12.0
● This experiment 7.1 8.1 9.2 10.1 11.1 12.1
Allaby et al. (1967) 14.25 16.9 19.3 21.3
▫ Diddens et al. (1962) 21.5 21.9
⌘ Cocconi et al. (1965) 20.9 21.7

Fig. 3

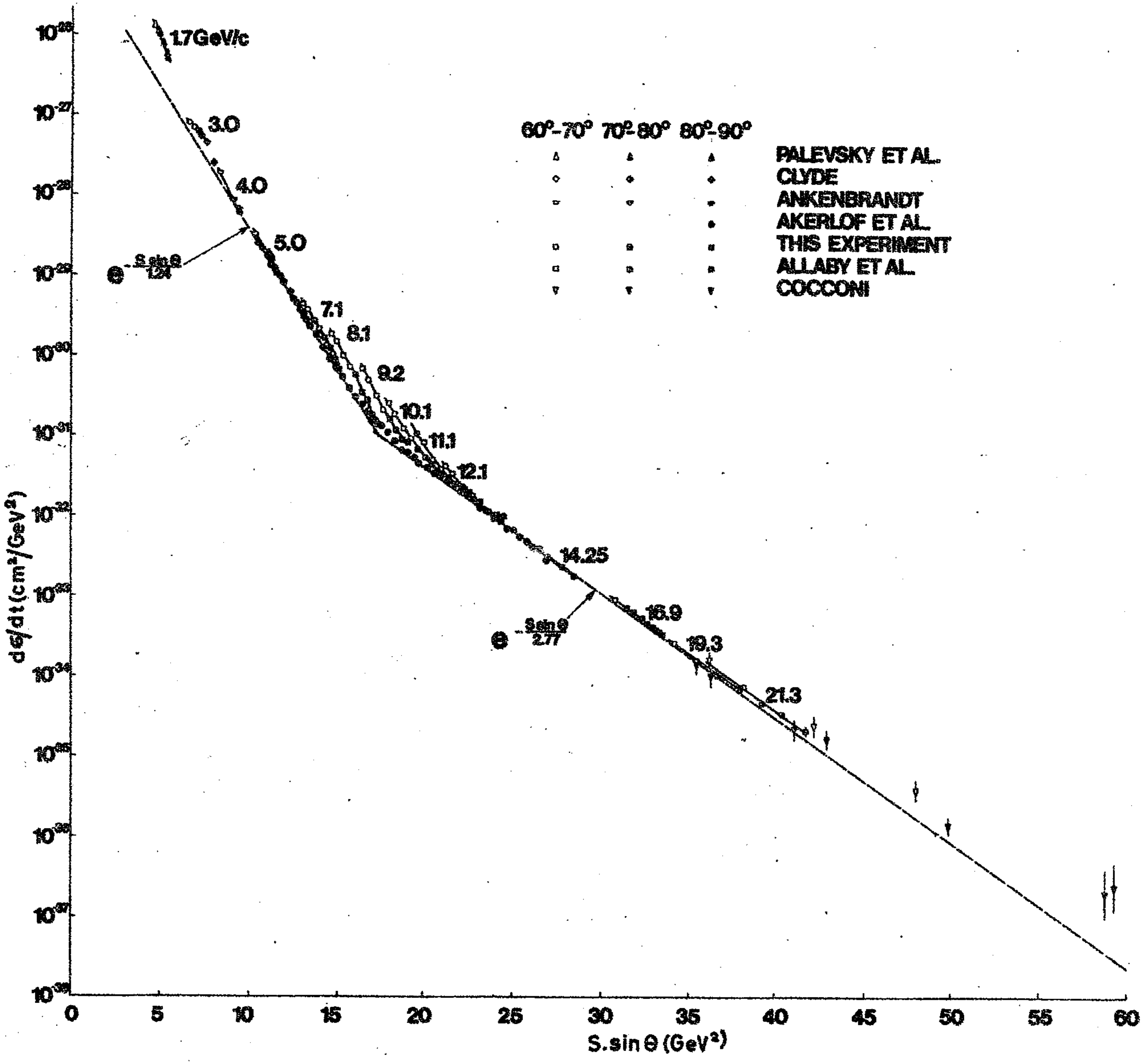
1.7GeV/c
3.0
4.0
5.0
7.1
8.1
9.2
10.1
11.1
12.1
14.25
16.9
19.3
21.3
$e^{-\frac{S\sin\theta}{1.24}}$
$e^{-\frac{S\sin\theta}{2.77}}$
60°-70°
70°-80°
80°-90°
PALEVSKY ET AL.
CLYDE
ANKENBRANDT
AKERLOF ET AL.
THIS EXPERIMENT
ALLABY ET AL.
COCCONI
$d\sigma/dt\,(cm^2/GeV^2)$
10^{-26}
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
10^{-38}
0
5
10
15
20
25
30
35
40
45
50
55
60
$S.\sin\theta\,(GeV^2)$

Fig. 4