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HIGH-ENERGY PROTON-PROTON SCATTERING

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This Letter reports measurements of p-p differential elastic cross sections for large momentum transfers. These data together with results of other measurements are analyzed by means of a single Regge pole term.

The new data presented in this Letter were obtained in a similar manner to that described in reference 1, except that the scattering angle was changed to 110 mrad. This extended the results to a value of -5.5 $(Gev/c)^2$ for the square of the four-momentum transfer (t).

The cross section for $C^{12}(p,3p3n)Be^7$ is used in the CH_2-C subtraction procedure to obtain the p-p cross sections. A recent measurement[2] of this cross section gives a value of 7.7 ± 0.4 mb, whereas 11 mb had been used for the previous experiments at 56 and 60 mrad[1]. The earlier data have been corrected accordingly, and small changes have been made to the normalization of the CH_2 and C spectra for the 12.99, 15.89, and 27.83 Gev/c data at ~ 56 mrad. It is these corrected values which appear in the table, together with the cross sections from the measurements at 110 mrad.

The combined results of these measurements, together with those in the previous letter[3] are plotted in Fig. 1 as $\left[\left(\frac{4\pi}{\sigma_T k}\right)^2 \frac{d\sigma}{d\Omega}\right]_{c.m}$ against $|t|$

This normalized cross section is equal to $\left(\frac{d\sigma}{dt}\right) / \left(\frac{d\sigma}{dt}\right)_{t=0}$

using the optical theorem for the forward scattering amplitude. Here k is the appropriate c.m. wave number and the p-p total cross section, σ_T , is taken from published values. The smallest cross section, obtained at 110 mrad and 21.46 Gev/c, corresponds to 3×10^{-32} cm^2/sr at 42° in the c.m. system. In this region the cross section still appears to be decreasing but with a slope $\sim 1/5$ of that for the small angle scattering.

Figure 2 shows the normalized cross sections plotted against $s/_{2M^2}$ for various values of $|t|$. s is the square of the c.m. energy and M is the nucleon mass. The cross sections for $|t| < 1$ were obtained by interpolation whereas for larger $|t|$ values, direct cross sections are plotted. Data from lower energies are also included[4,5]. Least square straight line fits have been made to the points for constant $|t|$ and the slopes of these lines exhibit a shrinking of the diffraction pattern.

Recent considerations of a Regge pole theory[6-9], and of a specific field theoretical model[10], have suggested that the diffraction cross section can be put in the form

$$\left(\frac{d\sigma}{dt}\right)\Big/\left(\frac{d\sigma}{dt}\right)_{t=0} = F(t)\ (s/_{2M^2})^{2(\alpha(t)-1)} \qquad (1)$$

The functional dependence of both F(t) and $\alpha(t)$ can be obtained from Fig.2. The slope of $\log\left[\left(\frac{d\sigma}{dt}\right)\Big/\left(\frac{d\sigma}{dt}\right)_{t=0}\right]$ with $\log\left[s/_{2M^2}\right]$ gives the value of $2(\alpha(t)-1)$ and the intercept at $s/_{2M^2}=1$ gives F(t). For $0 < |t| < 1(\mathrm{Gev}/c)^2$, it is found that a single function $\alpha(t)$ can be used in the momentum range 3 to 30 Gev/c. For larger momentum transfers, $\alpha(t)$ and F(t) can only be obtained by comparison of either one low-energy and one or two high-energy cross sections or by comparison of the two internal beam measurements at 56 and 110 mrad. The parameters thus determined have larger uncertainties.

The form of $\alpha(t)$ is given in Fig.3, which is split into two parts showing the $\alpha(t)$ obtained by taking all the data in Fig.2 and that obtained by taking only those above 9 Gev/c ($s/_{2M}2 = 10.5$). In the first case the function is quite well determined. It decreases essentially linearly from 1 at t=0 to zero at $t \approx -1.0$ $(Gev/c)^2$ and approaches -1 for larger momentum transfers. The determination of $\alpha(t)$ from the high-energy data alone is poor, but the same general shape is found. In the model of Amati, Fubini and Stanghellini[10] $\alpha(t)$ increases continuously from -1 at $t = -\infty$ to 1 at t=0.

The experimentally determined function F(t) is given in Fig. 4.

To summarize, it is clear that the data contained in Fig. 2 demonstrate conclusively a shrinking of the proton-proton diffraction pattern with increasing energy. As straight lines can be fitted through the points in Fig.2, within the experimental uncertainties, the general trend of the cross section with s and t is well represented by equation (1), which in the Regge pole theory results from a single term. Consequently, in the terminology of this theory, the trajectory, $\alpha(t)$, of the Pomeranchuk or vacuum Regge pole[7-9] has been obtained and also the form of F(t), a function related to the residue of the pole.

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FIGURE CAPTIONS

Figure 1 - Normalized elastic differential cross sections as a function of $|t|$ (square of four-momentum transfer).
The numbers attached to the points refer to the lab momentum of the incident proton.

Figure 2 - Normalized elastic differential cross sections as a function of $s/_{2M^2}$ (square of the c.m. total energy divided by twice the square of the nucleon mass). The points below $s/_{2M^2} = 10$ are taken from refs.4 and 5. The numbers attached to the lines give the appropriate $|t|$ values.

Figure 3 - The trajectory, $\alpha(t)$, derived from Fig.2.
(a) shows the trajectory obtained by taking all the data and (b) that obtained by only using data for $s/_{2M^2} \geqslant 10.5$.

Figure 4 - The form of $F(t)$ derived from Fig.2.

TABLE 1

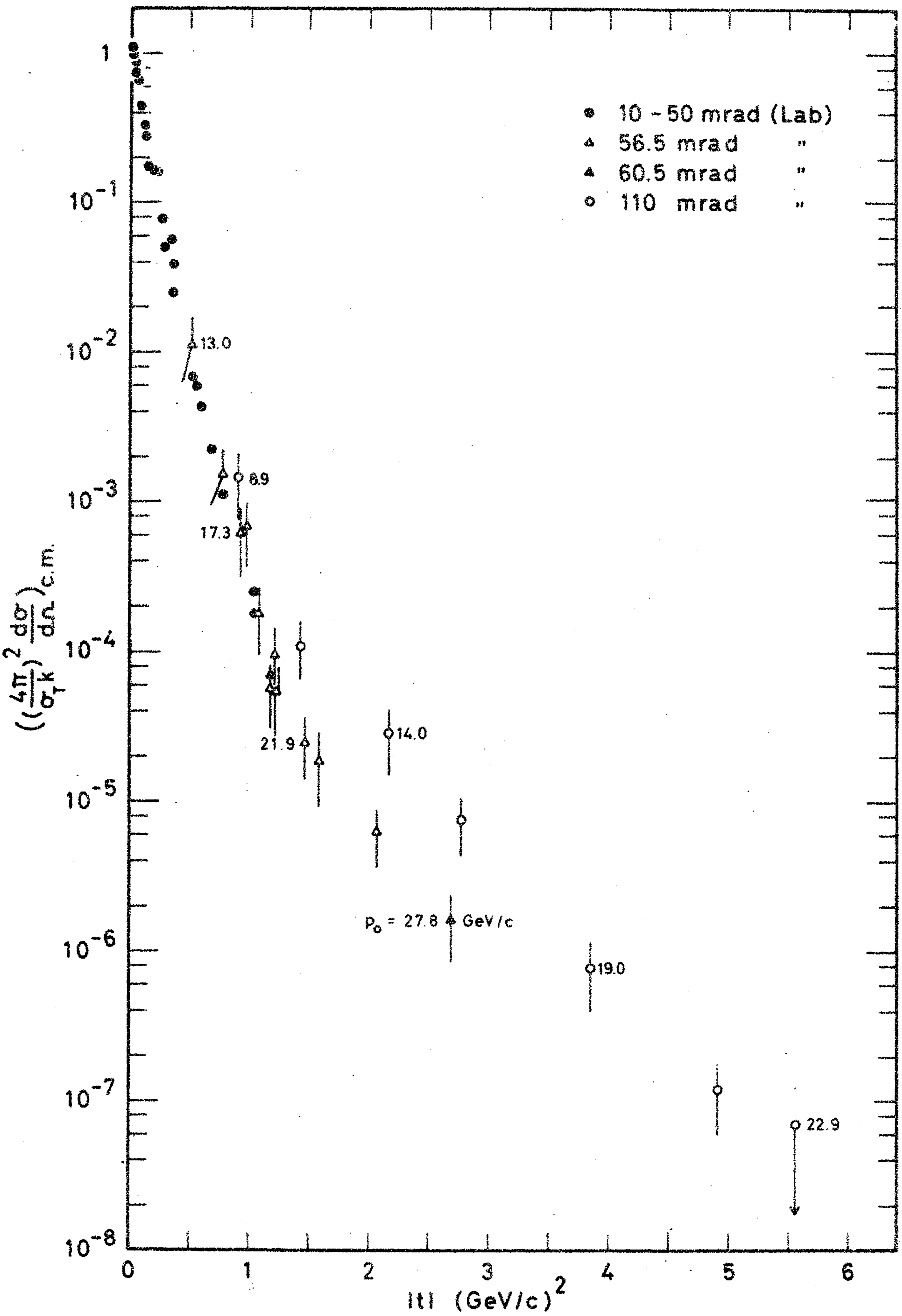
Elastic p-p Cross Sections

Θ_{lab} mrad	$(P_o)_{lab}$ Gev/c	$s/2M^2$	$-t$ $(Gev/c)^2$	$(d\sigma/d\Omega)_{lab}$ mb/sr	$\Theta_{C.M.}$ degrees	$\left(\frac{d\sigma}{d\Omega}\right)_{c.m.}$ mb/sr	$\left[\left(\frac{4\pi}{k\sigma_T}\right)^2 \frac{d\sigma}{d\Omega}\right]_{c.m.}$
56.5	12.99	14.8	0.524	45	17.5	1.6	$1.1\ 10^{-2}$
56.5	15.89	17.9	0.783	10	19.2	0.30	$1.6\ 10^{-3}$
56.5	17.30	19.4	0.925	4.5	20.0	0.13	$6.4\ 10^{-4}$
56.5	17.75	19.9	0.978	5.3	20.2	0.15	$7.0\ 10^{-4}$
56.5	18.69	20.9	1.084	1.5	20.7	0.039	$1.7\ 10^{-4}$
56.5	19.56	21.9	1.184	0.53	21.2	0.013	$5.7\ 10^{-5}$
56.5	19.75	22.1	1.206	0.90	21.3	0.022	$9.5\ 10^{-5}$
56.5	19.91	22.2	1.221	0.54	21.4	0.013	$5.6\ 10^{-5}$
56.5	21.88	24.3	1.474	0.28	22.3	0.0062	$2.5\ 10^{-5}$
56.5	22.74	25.2	1.590	0.24	22.6	0.0050	$1.9\ 10^{-5}$
56.5	26.02	28.7	2.071	0.10	24.2	0.0019	$6.3\ 10^{-6}$
60.5	18.29	20.5	1.184	0.56	21.9	0.015	$7.0\ 10^{-5}$
60.5	27.83	30.6	2.68	0.026	26.6	0.00047	$1.5\ 10^{-6}$
110	8.94	10.5	0.91	2.75	28.4	0.14	$1.45\ 10^{-3}$
110	11.28	13.0	1.43	0.31	31.5	0.013	$1.08\ 10^{-4}$
110	13.98	15.9	2.17	0.12	34.6	0.0044	$2.88\ 10^{-5}$
110	15.96	18.0	2.80	0.040	36.7	0.0013	$7.68\ 10^{-6}$
110	18.97	21.1	3.86	0.0055	39.5	0.00016	$7.55\ 10^{-7}$
110	21.46	23.9	4.91	0.0011	41.8	0.00003	$1.2\ 10^{-7}$
[illegible]	22.92	25.4	5.55	<0.0007*	43.0	<0.00002*	$<7\ 10^{-8}$*

The error in the differential cross section is estimated to be ± 50%.

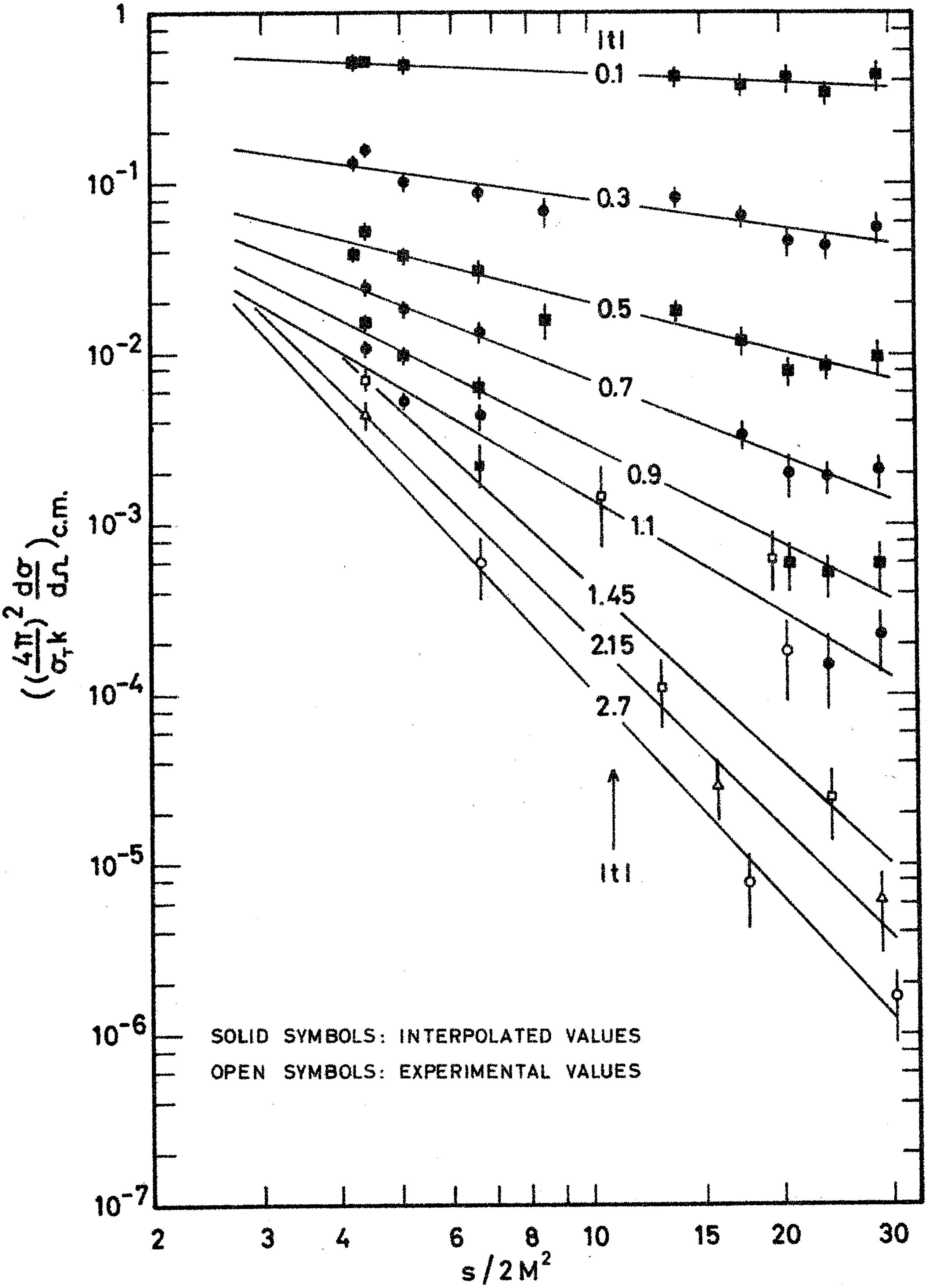
Θ, P_o are the scattering angle and incoming momentum. s is the square of the total c.m. energy, M the nucleon mass and -t the square of the four-momentum transfer. σ_T is the total p-p cross section and k the c.m. wave number.

* 95 % confidence level.



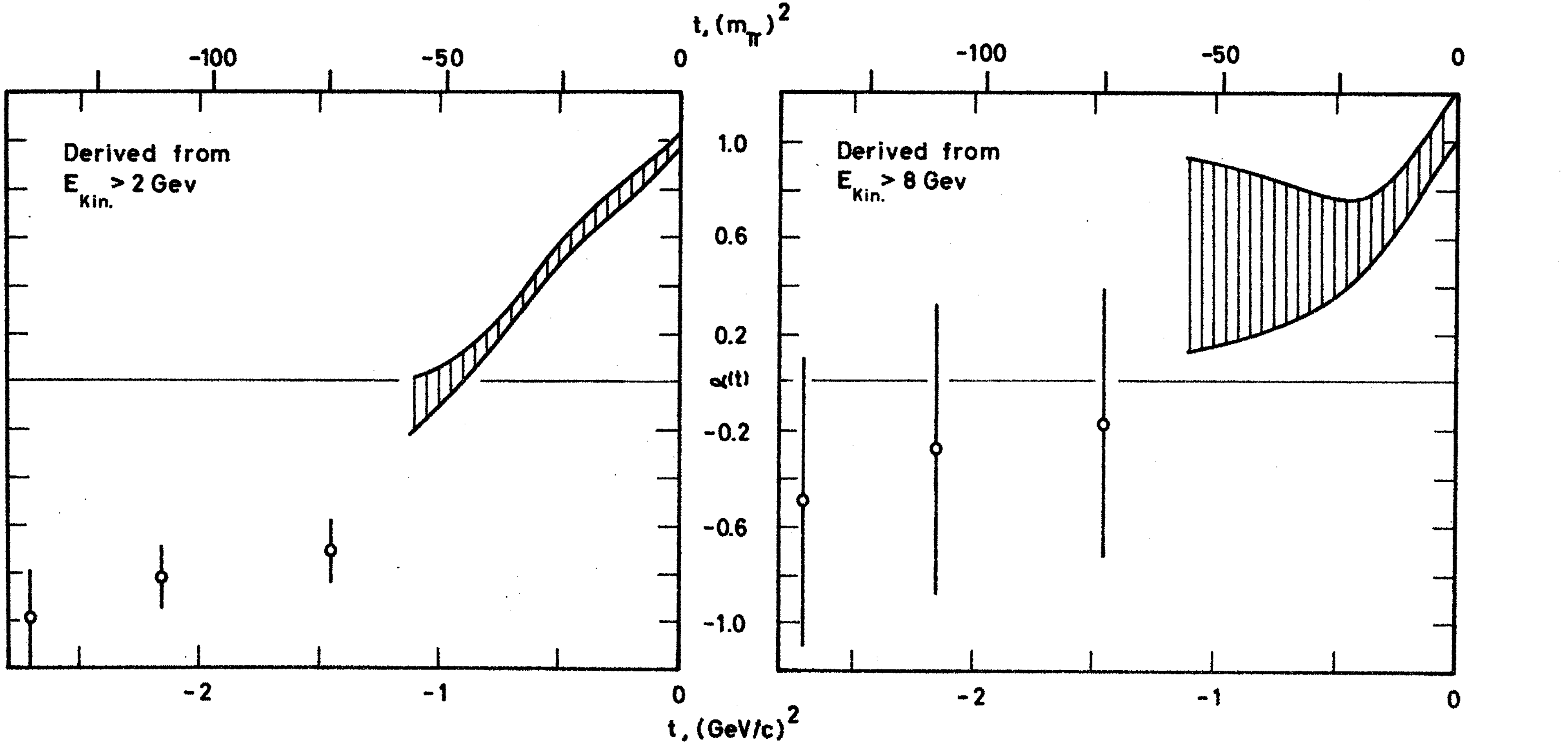
10 - 50 mrad (Lab)
56.5 mrad "
60.5 mrad "
110 mrad "
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
13.0
8.9
17.3
21.9
14.0
P₀ = 27.8 GeV/c
19.0
22.9
0
1
2
3
4
5
6
|t| (GeV/c)²
((4π/σ_T k)² dσ/dΩ)c.m.

DIA - 13969



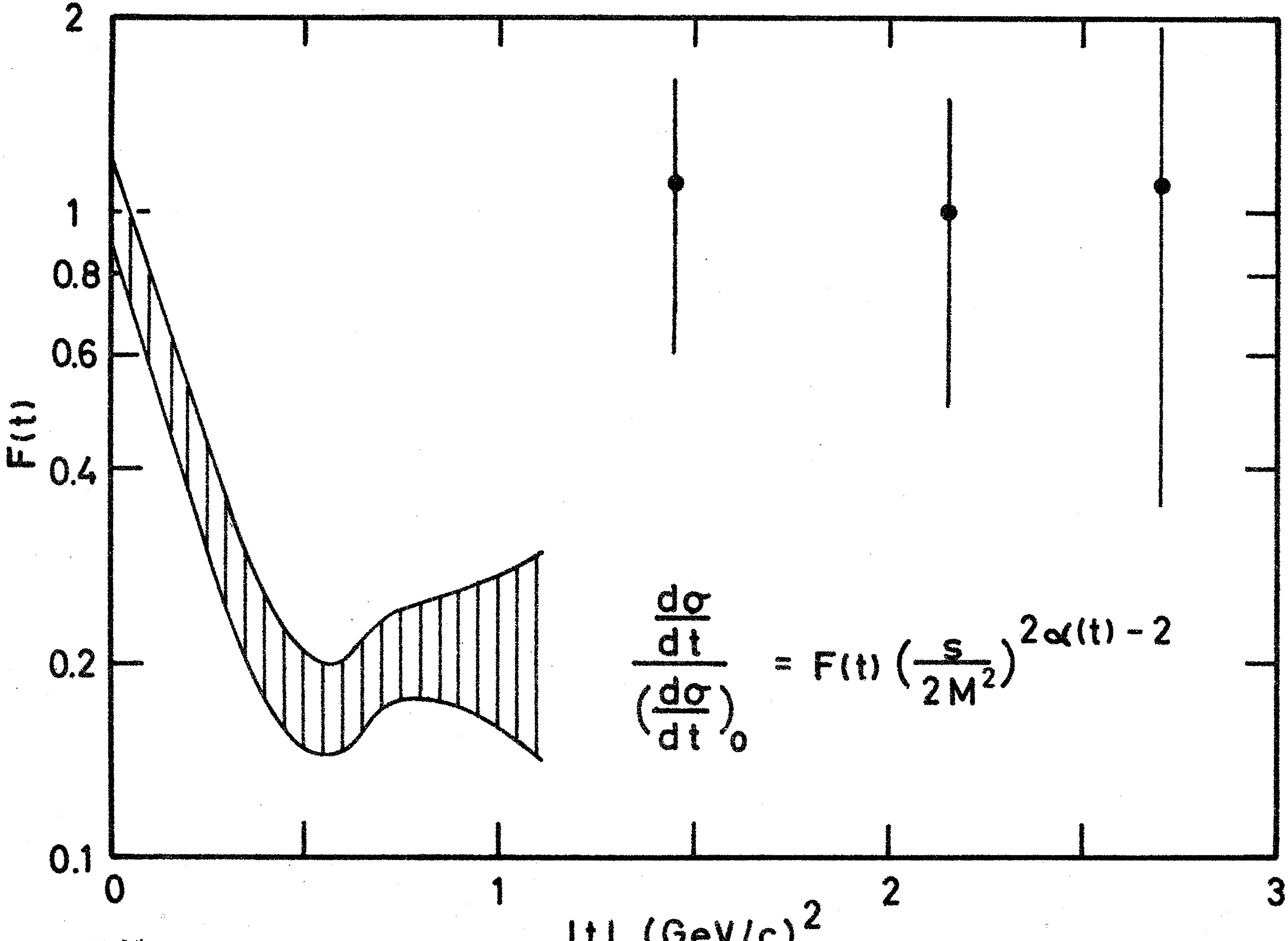
|t|
0.1
0.3
0.5
0.7
0.9
1.1
1.45
2.15
2.7
|t|
SOLID SYMBOLS: INTERPOLATED VALUES
OPEN SYMBOLS: EXPERIMENTAL VALUES
$\left(\left(\frac{4\pi}{\sigma_T k}\right)^2 \frac{d\sigma}{d\Omega}\right)_{c.m.}$
$s/2M^2$

DIA - 13968



t, $(m_\pi)^2$
-100
-50
0
Derived from
$E_{Kin.} > 2$ Gev
Derived from
$E_{Kin.} > 8$ Gev
1.0
0.6
0.2
$\alpha(t)$
-0.2
-0.6
-1.0
-2
-1
0
t, $(GeV/c)^2$

DIA - 13971



2
1
0.8
0.6
0.4
0.2
0.1
F(t)
0
1
2
3
|t|, (GeV/c)^2
$$\frac{\frac{d\sigma}{dt}}{\left(\frac{d\sigma}{dt}\right)_0} = F(t)\left(\frac{s}{2M^2}\right)^{2\alpha(t)-2}$$

DIA – 13970