L. Van Hove

R - 2994

HADRON COLLISIONS AT VERY HIGH ENERGIES

L. Van Hove

CERN, Geneva

We shall review a number of recent results and developments concerning hadron collisions, mostly ~~included~~ selected among contributions submitted to this Conference. We are mainly concerned with the high energy regions $p_{lab} \gtrsim 4$ or 5 GeV/c, although lower energy collisions will be mentione occasionally. A systematic review of experimental results, prepared by Dr. A. M. Wetherell, is included in these Proceedings as a separate paper. The contents of the report will be arranged as follows:

I. Two body collisions at low momentum transfers

  1. Pion proton forward collisions

    a) Real part of the forward elastic scattering amplitude

    b) $d\sigma/dt$ for $\pi^{\pm}p$ elastic scattering

    c) Polarization in $\pi^{\pm}p$ elastic scattering

    d) Polarization in $\pi^{-}p \rightarrow \pi^{0}n$

    e) Other two-body processes in πp collisions

2. Pion-proton backward scattering

3. Kaon proton collisions
    - a) Elastic scattering
    - b) Charge exchange process $K^- p \rightarrow K^0 n$
    - c) Other two-body processes in Kp collisions

4. Nucleon nucleon and antinucleon nucleon collisions
    - a) Total cross sections and forward elastic scattering amplitude
    - b) Elastic scattering
    - c) Charge exchange scattering

5. Isobar excitation and diffraction dissociation

II. Large angle scattering

1. New experimental results

2. Theoretical aspects

III. Multiple production of particles

1. Multiplicity distribution of pions

2. Correlations

IV Theoretical developments

1. Quark model and associated ~~mehteds~~ methods

2. Regge pole theory
    - a) Parity exchange
    - b) General masses and spins

V. Concluding remarks

Sections I to III will present new experimental data, comments on earlier data and theoretical considerations directly concerned with the reactions discussed. The more general theoretical developments are grouped in Section IV. Section V mentions a few of the outstanding problems which can be expected to attract considerable attention in the coming years.

I. Two body collisions at low momentum transfers

1. Pion proton forward collisions

a) Real part of the forward elastic scattering amplitude

A Dubna group[1] ~~has~~ presented new values of

$$\alpha = \frac{\mathrm{Re}A\,(s,0)}{\mathrm{Im}A\,(s,0)} ,$$

the ratio of real to imaginary parts of the scattering amplitude A (s,t) at t = 0, for $\pi^- p$ at two energies. They are

$$\alpha = -0.18 \pm 0.06 \qquad \text{at } p_{lab} = 3.5 \text{ GeV/c}$$

$$\alpha = -0.14 \begin{cases} +0.11 \\ -0.10 \end{cases} \qquad \text{at } p_{lab} = 6.1 \text{ GeV/c}$$

Fig. 1, from Barashenkov's contribution,[2] shows the predicted values of $\alpha_\pm$ for $\pi^\pm p$, as calculated from the forward dispersion relations (lower curves). The new values are fully compatible with the prediction for α. One should note the well known discrepancies between the high energy experimental values of $\alpha_\pm$[3] and the calculated curves, expecially their reversed order ($\alpha_+ > \alpha_-$ experimentally). If this ~~kind~~ trand would be confirmed considerable complications must be expected in the theoretical interpretation of the data[2,4].

2. Pion-proton backward scattering

3. Kaon proton collisions

    a) Elastic scattering

    b) Charge exchange process $K^- p \to K^0 n$

    c) Other two-body processes in Kp collisions

4. Nucleon nucleon and antinucleon nucleon collisions

    a) Total cross sections and forward elastic scattering amplitude

    b) Elastic scattering

    c) Charge exchange scattering

5. Isobar excitation and diffraction dissociation

II. Large angle scattering

1. New experimental results

2. Theoretical aspects

III. Multiple production of particles

1. Multiplicity distribution of pions

2. Correlations

IV Theoretical developments

1. Quark model and associated ~~mehteds~~ methods

2. Regge pole theory

    a) Parity exchange

    b) General masses and spins

V. Concluding remarks

b) $d\sigma/dt$ for $\pi^\pm p$ elastic scattering.

New data of a Michigan group for $\pi^\pm p$ from 2.3 to 4.0 GeV/c are reproduced in fig. 2[5]. They show a dip or shoulder around $t \simeq -0.6\ (\mathrm{GeV}/c)^2$. As illustrated by the solid lines on the figure, its position coincides closely with the dip of $d\sigma/dt$ for the charge exchange process $\pi^- p \to \pi^0 n$. The latter has been successfuly explained[6] in the Regge pole model as being due to vanishing of the the spin-flip amplitude for the value of t where the ρ trajectory $\alpha_\rho(t)$ vanishes ("non sense transition, unphysical signature"[6]; remember that α_ρ is the only Regge trajectory supposed to contribute to $\pi^- p \to \pi^0 n$.). Frautschi[7] proposes that also trajectories in the even signature nonet give vanishing spin-flip when they verify $\alpha(t) = 0$. Since the P' trajectory $\alpha_{P'}(t)$ probably passes through zero at about the same t as $\alpha_\rho(t)$, this effect could account for the dip or shoulder of $d\sigma/dt$ in elastic scattering. The structure would rapidly disappear with increasing energy, however, because the Pomeranchuk trajectory $\alpha_P(t)$ does not pass through zero (remember that $\pi^\pm p$ elastic scattering is described in terms of the P, P' and ρ trajectories with isospins and signatures 0+, 0+ and 1- respectively).

c) Polarization in $\pi^\pm p$ elastic scattering.

Data concerning the polarization parameter

$$P(t) = 2\,\mathrm{Im}\, f g^* / (|f|^2 + |g|^2)$$

have been presented by a CERN group for $\pi^- p$ at 6, 8, 10 GeV/c, and for $\pi^+ p$ at 6, 10, 12 GeV/c.[8] Part of the data and their Regge pole fit[9] are given in Figs. 3 and 4. The $\pi^+ p$ data agree well with the Regge pole prediction of Chiu et al[9], which were based on the earlier $\pi^- p$ polarization data. In particular, the prediction is confirmed that the polarization originates mainly from interference between the spin-flip contribution of the ρ ~~Regge~~ trajectory and the non-spin-flip part of the P and P' trajectories; this effect accounts for the reversal of sign of P(t) between π^-p and π^+p and for the vanishing of the polarization ~~assumed~~ around $t \simeq -0.6$ (GeV/c) where the ρ spin-flip contribution vanishes. At a more detailed level, the absence of marked energy variation of P (t) near its maximum around $t \simeq -0.2$ $(GeV/c)^2$, especially for π^-p, should be of some concern. As we shall remark again later on, slow energy variations of this sort, if established with good accuracy, may become indications of effects not accounted for in the Regge pole model.

d) <u>Polarization in $\pi^-p \rightarrow \pi^0n$.</u>

The charge exchange process $\pi^-p \rightarrow \pi^0n$ gave the Regge pole model its most striking success by leading to the experimental determination of a linear α_ρ (t) trajectory of slope ~1 $(GeV/c)^{-2}$, and by revealing the correctness of the dip mechanism at $t \cong -0.6$ $(GeV/c)^2$ mentioned above.[6] The dσ/dt curves are grouped in Fig. 5, and the α_ρ (t) trajectory, as well as α_R (t) determined from the sister reaction $\pi^-p \rightarrow \eta n$, are given in Fig. 6 taken from a contribution of K. A. Ter-Martirosyain to this conference.[10]

¶ The same $\pi^-p \rightarrow \pi^0n$ reaction now faces (the R trajectory, of isospin 1 and signature +, is associated with A_2 (1300) meson if the latter is 2^+) the Regge pole model with a new test, and requires inclusion of further corrections, especially at 6 GeV/c. Recent data of a Saclay-Orsay-Pisa collaboration[11], given in Fig. 7. show that the polarization parameter P (t) is as large as about 15% at 6 GeV/c, and that it may remain of the same order up to 11 GeV/c, although the 11 GeV/c results are not accurate enough in their present form to draw any definite conclusion. One finds for P (t) averaged over two t- intervals ~~of t-values~~ (p_{lab} in GeV/c, t in $(GeV/c)^2$) ; the following values:

t- interval	$0.015 \leq -t \leq 0.24$	$0.04 \leq -t \leq 0.24$
$p_{lab} = 6$	$+0.14 \pm 0.03$	$+0.16 \pm 0.03$
$p_{lab} = 11$	$+0.19 \pm 0.06$	$+0.24 \pm 0.07$

The Regge pole model is known to predict vanishing $P(t)$ on the basis of the ρ trajectory alone. To account for the data at 6 GeV/c various authors have introduced contributions of s-channel resonances [12,13,14] or an additional Regge pole ρ' with the same quantum numbers as ρ.[15,16] In all cases P (t) is predicted to drop by at least a factor 2 from 6 to 11 GeV/c.

While the experimental errors of the very recent 11 GeV/c data are still too large to reveal the energy variation of P (t), one may soon be led to discuss possible mechanisms explaining an eventual weak energy dependence of the $\pi^- p \rightarrow \pi^0 n$ polarization. One can envisage a small difference between the powers $s^{\alpha(t)}$, $s^{\alpha_1(t)}$ describing the energy variation of the spin-flip and non-spin-flip amplitudes (such an effect, while possible in the Regge pole model, is very natural in the coherent droplet model of Yang and Byers, a point recently studied by Le Bellac[17]); or one can complete Regge pole theory with additional singularities close to $\alpha_\rho (t)$, for which the Mandelstam cuts would probably be the most popular candidates. One would hope that these modifications would not affect too much the description of $d\sigma/dt$ for $\pi^- p \rightarrow \pi^0 n$, and of $d\sigma/dt$ and P (t) for $\pi^\pm p \rightarrow \pi^\pm p$. One should face nevertheless reasonable requirements of consistency, and acknowledge that if a Mandelstam cut associated with the ρ trajectory is important in $\pi^- p \rightarrow \pi^0 n$, the same may be true in $\pi^{\pm}p \rightarrow \pi^{\pm}p$ at least for the cut associated with the Pomeranchuk trajectory, so that this cut may profoundly affect the P' trajectory contribution.

e) Other two-body processes in π p collisions.

All other tow-body processes $\pi^{\pm}p \rightarrow$ A B (A and B being each a particle or a resonance) are of interest for a complete analysis of the high energy behavior of πp collisions. We quoted already $\pi^- p \rightarrow \eta n$ [18] which allows to determine the R trajectory. As shown by R. I. Thews and illustrated by the curves in Fig. 8, reaction $\pi^- p \rightarrow \pi^0 N^{**}$ can be fitted with the ρ trajectory, and $K^+ p \rightarrow K^0 N^{*++}$ by the ρ and R trajectories.[19] A Wisconsin group presented data on $\pi^+ p \rightarrow K^+ \Sigma^+$ at 3.23 GeV/c [20]; the differential cross section is shown in Fig. 9, whereas Fig. 10 gives the Σ^+ polarization. The dip of $d\sigma/dt$ near $t \simeq -0.6$ $(GeV/c)^2$ and the change of sign of the polarization in the same region are of particular interest, because the relevant Regge trajectories belonging to K^* (890 MeV, signature $\tau = -$) and to K^* (1410 MeV, $\tau = +$) are likely to vanish around $t \simeq -0.6$.

Many other $\pi p \rightarrow AB$ reactions have been studied, and information is available to some extent on $d\sigma/dt$ and on its energy variation. This material has recently been reviewed by Morrison [19] and is discussed in Jackson's report in the present conference. We shall limit ourselves to two comments. Firstly, the undeniable success of the peripheral model with absorption for the processes which experimentally seem to be dominated by π exchange (e.g. π p $\rightarrow \rho p$) should be accomodated in the Regge pole approach to high energy scattering, keeping in mind that higher trajectories can contribute (e.g. the ϕ and R trajectories). This requires an extension of the Regge pole model to unequal mass particles and higher spins, a difficult problem to which we shall return in Section IV of the

~~of the~~ present report. Secondly, the s and t dependence of $d\sigma/dt$ for $\pi p \to AB$ seems often to remain essentially unchanged when A (or B) is replaced by a non-resonant state of two particles A_1, A_2 having an effective mass, $m_{eff}(A_1A_2)$, close to the mass of A. Several experimental groups have fragmentary results pointing in this direction. They should be regarded as preliminary steps in the systematic study of three body final states, which are very likely to be amenable to a Regge pole type analysis. Ter-Martirosyan[10] remarks on the importance of this problem which has also been tackled by a theoretical group at CERN.[21]

2. Pion proton backward scattering

In a contribution to this conference, Selove[22] summarized the data on π p elastic scattering near the backward direction, in particular the data of the Cornell-BNL[23,24] and Pennsylvania group.[22] In addition, very recent data for $\pi^+ p$ in the 2-5 GeV range were reported by a Dubna group.[25] The Selove summary is presented in Figs. 11 ($\pi^+ p$) and 12 ($\pi^- p$), where the numbers on the curves denote the laboratory momentum, and "this expt" refers to the Pennsylvania group. While it would be highly desirable to have a single experiment cover at various energies the whole range $u \gtrsim -1$ (GeV/c)^2 $u = -$(4-momentum transfer from incident π to outgoing p)^2, the data are good enough to reveal a remarkable dip around $u = -0.2$ (GeV/c)^2 in $\pi^+ p$, no similar structure appearing in $\pi^- p$. Furthermore, the qualitative features of the energy variation of $d\sigma/du$ are also apparent.

Two mechanisms are currently invoked to explain πp backward scattering. The first, which is important at not too high energies, considers the effect of s-channel resonances. The relevant baryonic resonances, and their role in backward πp scattering, are treated in a contribution of Barger and Cline[26]. These authors group them in three families (Δ_δ, N_α, N_γ) forming remarkably long Regge recurrence series, as shown on Figs. 13 and 14. [for the two lower members of each family, the spin-parity assignment is known to be correct; some information concerning parity for higher resonances can also be obtained from estimating their contribution to forward $\pi^- p \rightarrow \pi^0 n$ and backward πp elastic scattering.[13]]

At higher energies (perhaps $p_{lab} \gtrsim 5$ GeV/c) the second mechanism for backward scattering is supposed to become dominant. It is the u-channel exchange of the baryonic Regge trajectories $\alpha_\Delta(\sqrt{u})$, $\alpha_N(\sqrt{u})$, $\alpha_{N'}(\sqrt{u})$ of Figs. 13 and 14 continued to lower u values (we write N for N_α and N' for N_γ). This mechanism is discussed in detail by Chiu and Stack in a contribution to the Conference[27]. The situation is complicated by the Gribov phenomenon, according to which, for each value of u, a fermion trajectory $\alpha(\sqrt{u})$ contributes twice, through its values $\alpha(+\sqrt{u})$ and $\alpha(-\sqrt{u})$. [Thus, for $u > 0$, two systems of particles are associated with $\alpha(\sqrt{u})$, one containing particles of mass M such that $\alpha(M) = 1/2, 5/2 \ldots$ or $3/2, 7/2 \ldots$, and the other containing particles of mass M' such that $\alpha(-M')$ has these values. The particles of mass M, M' have opposite parity. Figs. 12, 13 show only one such system for each trajectory. If a system contains a particle not found in nature one must assume that the residue of the Regge pole vanishes at the corresponding value of $\sqrt{u}$; according to Chiu and Stack this happens for a $1/2^-$ baryon of mass 850 MeV on the N trajectory]. For $u < 0$, the trajectory will give complex conjugate Regge poles $\alpha(\pm i |u|^{1/2})$.

Only α_Δ contributes to backward $\pi^- p$ scattering, all three trajectories to $\pi^+ p$. Since $d\sigma/du$ is experimentally smaller for $\pi^- p$ than for $\pi^+ p$,

delta (Δ)

and since the α_Δ contribution to π^+p is further reduced by the Clebsch-Gordon coefficient, Chiu and Stack neglect α_Δ altogether in π^+p. [This will have to be revised at higher energies if $\alpha_\Delta(0) > \alpha_N(0) \simeq \alpha_{N'}(0)$ as suggested by Figs.13, 14; the Regge pole theory would then require disappearance of the dip at $k \simeq -0.2\ (\mathrm{GeV}/c)^2$ for higher energies.] For $\alpha_N(\sqrt{u}) = -1/2$, one has a ~~non~~ nonsense transition of unphysical signature, so that the $\alpha_N(\sqrt{u})$ gives vanishing contribution both to spin-flip and non-spin-flip amplitudes. The corresponding value of u is close to $-0.2\ (\mathrm{GeV}/c)^2$ where $d\sigma/du$ for π^+p has its dip. Since $\alpha_{N'}$, having opposite signature, would give a non-vanishing contribution in this region, Chiu and Stack suppose that this latter trajectory is ~~weakly-~~ coupled very weakly and neglect it also. They are left with α_N as sole contributor to π^+p backward scattering and obtain a very satisfactory fit of the data, the dip originating from the vanishing of the N trajectory contribution when $\alpha_N(\sqrt{u}) = -1/2$.

3. Kaon proton scattering

a) Elastic scattering

New data on K^-p elastic scattering have been presented by a Northwestern University-Argonne collaboration at 4.1 and 5.5 GeV/c.[28] The diffraction peak is well described by the five-Regge-pole fit of Kp and πp scattering processes due to Phillips and Rarita[29] (the poles are P, P', R, ρ and one $I = 0$, odd signature pole ~~for~~ taken for simplicity to replace the $\phi\omega$ pair). Concerning backward scattering, the authors find an upper bound $\sigma(\theta_{cm} > \pi/2) < 2\ \mu b$ for the backward hemisphere, to be compared to $\sigma(\theta_{cm} > \pi/2) \sim 8\ \mu b$ for π^-p at similar energies. This effect, which can be explained by the absence of strangeness 1 baryons, is of course of considerable interest, and a detailed study of $d\sigma/dt$ in the backward hemisphere at various energies would be of great importance as an example of a small momentum transfer process for which no known particle or pole is available for exchange.

b) Charge exchange process $K^- p \to \bar{K}^0 n$.

A CERN-ETH (Zurich) collaboration presented new data on $K^- p \to \bar{K}^0 n$ at 5 and 7 GeV/c.[30] They are grouped in Fig. 15 with the 9.5 GeV/c data obtained earlier by the same authors.[31] The Regge pole predictions of Phillips and Rarita[29,32] are in fair agreement with the data, and the latter will undoubtedly allow an improved adjustment of the Regge pole parameters. The data show ~~the~~ interesting qualitative features similar to $\pi^- p \to \pi^0 n$: the peak shrinks as the energy increases, and a small dip ~~at t = 0,~~ is present at $t = 0$. There are differences, however. The real part of the amplitude is much smaller than the imaginary one at $t = 0$, due to compensation between ρ and R trajectory contributions. No dip is seen at $t \simeq -0.6\ (\mathrm{GeV}/c)^2$, a feature which will become of considerable importance if it is confirmed by more accurate measurements.

c) Other two-body processes in Kp collisions

A CERN-Brussels collaboration presented data on a variety of two-body reactions $K^+ p \to AB$, obtained at 3, 3.5 and 5 GeV/c.[33] They observe shrinking peaks and fit them, in oversimplified fashion, with single Regge poles. While more extensive data and multi-Regge pole fits are called for, it may be worth noting the interest of this particular ~~fit~~ set of reactions. Indeed, the absence of s channel resonances makes it plausible that a Regge pole analysis will be valid at lower energies than in all other meson-nucleon collisions.

4. Nucleon-nucleon and antinucleon-nucleon collisions.

a) Total cross sections and forward elastic scattering amplitude.

A compilation of σ_T(pp) and σ_T(pn) recently prepared by Wetherell is contained in Fig. 16. The inequality σ_T(np) > σ_T(pp) continues to hold up to $p_{lab} \simeq$ 19 GeV/c, but the data suggest that it might be reversed at higher energy. It would be of considerable interest to decide on this question by improving the accuracy of the pn data. Since pn scattering data are usually obtained from pd measurements, the whole question of deuteron effects (Glauber correction) is very important, and it would appear desirable to study ~~if~~ it for its own sake so as to develop a more accurate description of deuteron effects than is available at present. A number of theoretical investigations of the problem have been carried out recently.[34,35,36]

Chernev et al. have contributed new data on the ratio α_{pn} of real to imaginary parts of the forward amplitude for pn scattering from 1 to 10 GeV/c, derived from measurements of α_{pd}.[37] All available data are collected in Fig. 17, the black dots denoting the new results. The curve is the dispersion relation prediction of Carter and Bugg,[38] the shaded area representing the estimated uncertainties.

It is unfortunate that no data have yet been obtained for the ratio $\alpha_{\bar{p}p}$, a quantity which plays an important rôle in the high energy asymptotics of the NN and $\bar{\text{N}}$N systems. This problem is of considerable interest because α_{pp} is known to be of order -0.3 over a large energy range and does not show any tendency to approach zero as $p_{lab} \to \infty$; $\alpha_{\bar{p}p}$ and α_{pp} are related through crossing symmetry, and information on $\alpha_{\bar{p}p}$ would greatly help the theoretical analysis of the likely asymptotic behavior of both quantities.

b) Elastic scattering.

A Stanford-Michigan group[39], by an interesting method using a neutron beam from the Berkeley Bevatron, carried out extensive measurements on elastic np scattering from 2 to 6 GeV/c. The behavior of $d\sigma/dt$ is found to be very similar to the one of pp in the same energy range.

A California Institute of Technology group[40], having measured $\bar{p}p$ elastic scattering from 1.0 to 2.5 GeV/c, reports a dip in $d\sigma/dt$ around $t \sim -0.5$ $(GeV/c)^2$. Frautschi[7] connects this phenomenon with the dips in meson nucleon scattering ~~and~~ at similar t-values (see Section I.1.b. of this report). It will be very interesting to measure accurately $d\sigma/dt$ in this region at increasing energies. As is known, such dips do not occur in pp scattering.

We mention finally new polarization data for pp scattering at 6 and 10 GeV/c, presented by a CERN group.[41] The polarization is found to be of order 10% for $0.2 \lesssim -t \lesssim 0.5$ $(GeV/c)^2$ at both energies, but the lower energy data do not agree with earlier Berkeley work,[42] which gave an appreciable larger value (~18%). Here again the absence of visible energy variation may have important theoretical implications.

c) Charge exchange scattering.

A CERN-ETH group has measured the charge exchange process $\bar{p}p \rightarrow \bar{n}n$ at 5, 6, 7 and 9 GeV/c.[43] The results are presented in Fig. 18, where the curves are fits to the coherent droplet model. A more complete fit to all available np and $\bar{p}p$ charge exchange data has been carried out by Byers[44], who introduces a one-pion-exchange contribution in the coherent droplet model and is thereby able to reproduce all data, including the very narrow peak in np → pn at $|t| \lesssim 0.02$ $(GeV/c)^2$.

As is well known, the Regge pole model has been ~~unable to~~ unable so far to account for np and $\bar{p}p$ exchange data. The s-dependence of $d\sigma/dt$ for np and $\bar{p}p$ charge exchange at $t = 0$ cannot be fitted with the ρ and π poles. Whereas fits are possible by adding other poles with the same quantum numbers [like the ρ' pole used by Hogaasen et al.[15,16] to fit both these charge exchange processes and the 6 GeV/c polarization data in $\pi^- p \to \pi^0 n$], it seems more natural[45] to study first the role which would be played by Regge poles belonging to pseudoscalar and axial vector particles, which can couple to nucleons but not to pseudoscalar mesons. As was first recognized by Gribov and Volkov,[46,47] the properties of these poles are much more complicated than is the case for those belonging to the 1^- and 2^+ particles, in the sense that their positions and residues at $t = 0$ have to be related to each otherin a specified way if the scattering amplitude is to have its most general form without containing unacceptable singularities. This property, which the specialists now refer to as "conspiracy" between Regge poles, has attracted renewed attention recently (See Section IV. 2) but no results have been reported on the use of the pseudoscalar and axial poles for fitting actual NN and $\bar{N}N$ data.

5. Isobar excitation and diffraction dissociation.

An extensive study of the process $p + p \rightarrow p + p^*$ by the missing mass method has been carried out by a BNL-Carnegie Institute of Technology group[48] in the energy interval 6-30 GeV. The excitation of the isobars N^* (1.23 GeV; I = 3/2), N^* (1.52; 1/2), N^* (1.69; 1/2) and N^* (2.19; 1/2) is measured as a function of s and t. One observes in addition for small $|t|$ a bump which suggests an isobar N^* (1.4); the $N\pi$ system with isospin $I = 1/2$ may indeed have a pecularity at mass 1.4 GeV although it is regarded as doubtful whether it is a regular resonance. Fig. 19 gives the energy variation of the production cross sections, combining the above experiment with data at lower energy obtained in a Rutherford Laboratory experiment.[49] The constancy of the cross section for N^* ($I = 1/2$) states is of great interest. It undoubtedly illustrates the phenomenon of diffraction dissociation so often predicted to accompany diffraction scattering.[50,51] This phenomenon does not occur for the N^* ($I = 3/2$) because no isospin is exchanged in high energy diffraction. A theoretical discussion of the BNL-Carnegie Tech ~~twot~~ results has been presented at the Conference by Margolis and Rotsstein.[52] We also note that the pp missing mass experiment[48] has been extended to $pp \to ppX^o$, X unseen, by measuring the momenta of the two outgoing protons[53].

The phenomenon of diffraction dissociation is expected to occur also when the excited system is not in an isobar state, and it should manifest itself not only in diffraction on an elementary particle but also on complex objects as atomic nuclei. An illustration is foundin the work presented by an Orsay-Milan-Saclay-Berkeley Collaboration[54], which observed the process $\pi^- \to \pi^+ 2\pi^-$ at 16 GeV/c in a heavy liquid bubble chamber (the liquid being C_2F_5Cl). Fig. 20 represents the t distribution for three types of $\pi^+ 2\pi^-$ configurations (all, $\rho^o\pi^-$ and $f^o n^-$). The sharp peak for $t' = |t| - |t_{min}| \leq 0.1\ (GeV/c)^2$, which behaves as exp ($-80t'$), is evidence for a coherent dissociation on complex nuclei, whereas the slower decrease at larger t', behaving as exp ($-8\ t'$), is probably produced by dissociation on bound nucleons behaving as quasi-free particles.

II. Large Angle Scattering

1. New experimental results.

Among the new results in this field we mention first the np large angle scattering data from 2 to 6 GeV/c obtained in the Stanford-Michigan experiment mentioned earlier.[39] Here as in the case of small angles the np behavior is analogous to the one of the pp system. This remains true in the region of $\theta_{cm} \sim 90^\circ$ where the data show a remarkable amount of symmetry around the point $\theta_{cm} = 90^\circ$. Another important experiment was carried out by a CERN group[55] to detect possible fluctuations in $d\sigma/dt$ at large angles, as can be expected, following Ericson,[56] if the statistical model would be applied literally to the scattering process [as is well known the statistical model has been able to predict with remarkable success the magnitude of the cross section[57]] The fluctuations would originate from the fact that the phase and absolute value of the partial wave amplitudes would vary essentially at random from one angular momentum value to the next, each amplitude being itself a rapidly and randomly varying function of the energy. Detection of such fluctuations requires an angular resolution

$$\Delta\theta_{cm} << l^{-1}_{max} \simeq (k_{cm} r)^{-1}$$

where r is the dimension of the region of interaction, usually taken to be of order of one fermi. The experiment was carried out at 16.9 GeV/c, giving $l^{-1}_{max} \simeq 6^\circ$, whereas $\Delta\theta_{cm}$ was of order 0.8°. The incident momentum had a spread of 10-15 MeV/c leading to a resolution of about 2 MeV in the C.M. energy. Fig. 21 shows the experimental points and a few curves with simulated Ericson fluctuations. The latter were obtained by selecting the partial wave amplitudes $a_l = x_l + i y_l$ at random, with normal distributions for the real variables x_ℓ, y_ℓ verifying

$$\langle x_\ell \rangle = \langle y_\ell \rangle \sim 0, \quad \langle x_\ell^2 \rangle = \langle y_\ell^2 \rangle = 1/2 \exp\left(- \ell^2 / b k^2_{cm}\right)$$

b was given the value 10 $(\mathrm{GeV}/c)^{-2}$. The experimental results clearly indicate that such fluctuations are very unlikely to exist. The correctness of the statistical model's prediction for the values of $d\sigma/d\Omega$ at $\theta_{cm} = 90^\circ$ and all measured energies remains nevertheless as impressive as before. Fig. 22 shows an Orear type fit to the data

$$s \left(\frac{d\sigma}{d\Omega}\right)_{cm} = A \exp\left(-p_\perp / b\right)$$

One finds $b = 224 \pm 5$ MeV/c, a value distinctly different from the slope $b = 158 \pm 3$ MeV/c first proposed by Orear as a universal parameter.[58] It will be most interesting to have further data on the s and t dependence of large angle cross sections with the new precision illustrated by the experiment just discussed. It is also clear that large angle data would be of the greatest importance for inelastic two body processes of type $A + B \rightarrow C + D$ with C and/or D different from A and B.

2. Theoretical aspects.

While the statistical model remains unique in its ability to predict the magnitude of the large angle cross sections, other models have been considered, especially the one proposed by Wu and Yang.[59] As described in Drell's report, at this conference, this model fits well with the new DESY data for the proton magnetic form factor up to $t \simeq -10$ $(\mathrm{GeV}/c)^2$. In contributions to the present Conference, K. Huang[60] discussed on a model how an exponential drop of $d\sigma/dt$ with energy can be obtained along the lines suggested by Wu and Yang, whereas Domokos and Karplus[61] attempt to derive from field-theoretical considerations a relation of the Wu-Yang type between $d\sigma/dt$ and form factors.

Białas and Czyzewski[62] analyze available data on $\bar{p}p$ and np large angle scattering, show that the general behavior is the same for both reactions and note a forward-backward asymmetry which can be used as an argument against the statistical model. In another contribution,[63] the same authors propose a new mechanism for large angle πp scattering; it uses the effect of s-channel resonances assuming the latter to be given by very long and straight Regge recurrences as described by Barger and Cline[26] and illustrated in Figs. 13, 14, Finally we note two contributions by Logunov et al, one studying form factors and scattering amplitudes at large t in a new analytical representation[64] and the other discussing large angle scattering at high energy by a regular potential in the quasi-classical approximation, the scattering process taking place at classically forbidden angles.[65]

III. Multiple production of particles

A large amount of experimental material on multiple particle production is available, especially from bubble chamber work, and this amount will rapidly increase in coming years. It is very unfortunate that up to now no satisfactory procedures have been found for systematic extraction of dynamical information concerning the collision and production mechanisms involved. This is of course due to the great complexity of the material, and is very natural if we remember that the systematics of high energy two body collisions is only being developed since about four years("body" refers here to particles and resonances). The Regge pole type analysis on which this systematics is currently based has reached sufficient qualitative success to attempt its extension to rather broad classes of three or four body reactions, a programme which is recommended by some theoretical groups[10,21] and will probably give practical results if it covers sufficiently large energy interval.

The other extreme case of very high multiplicities probably presents altogether different problems, and the concepts, models and distribution functions currently used in analyzing the data are not very likely to reveal directly the most important dynamical elements. Strong interaction theory, on the other hand, has not made the slightest progress in the field of multiple particle production, and it is unlikely to do so before some new clues are obtained, as could hopefully be given by unconventional ways of grouping and treating the data.

In view of the general situation, we shall not attempt to review the many experimental contributions on multiple particle production presented at this Conference, and we shall rather describe a few of the points made by O. Czyzewski in a ~~lecture~~ review presented in the Discussion Session on High Energy Experiments. It is expected that this ~~lecture~~ review will be published separately.

1. Multiplicity distribution of pions.

Bartke and Czyzewski[66] have been able to test with ~~good~~ Some success the conjecture that, when one considers all events producing n pions (n is the total number of pions in the final state, including π^0's), the various isospin states of the n pion system allowed by charge and isospin conservation have about equal probabilities. If this is so, from the experimentally known cross sections σ_n^0 for producing $n\pi^\pm$ one can predict the cross sections $\sigma_n^{(m)}$ for producing $(n-m)\pi^\pm + m\pi^0$, $m \geq 1$. This can be compared with experiment, either by using experimental determinations of $\sigma_n^{(1)}$, or in a more stringent way by calculating the sum

$$\sigma_{\pi}^{(calc)} = \sum_{n} \sum_{m} \sigma_{n}^{(m)}$$

and comparing it with the measured total cross section σ_{π} for inelastic collisions without strange particle or antinucleon production. The agreement is surprisingly good in 4 and 8 GeV/c $\pi^{+}p$ collisions, as shown in the following table:

p_{lab}	4 GeV/c	8 GeV/c
σ_{π}	20.1 mb	17.9 mb
$\sigma_{\pi}^{(calc)}$	20.35 mb	18.29 mb

The errors are of the order of the mb. One might expect that the above treatment will give reasonable results if the average multiplicities are rather high and if mesonic resonances are only produced weakly. This seems to be the case in the collisions considered (nucleonic resonances should cause only a small violation of the statistical assumption in isospin space since only one baryon is involved). One might also try to use this method in other cases in order to estimate the abundance of resonance production.[67] The abundance of resonance production in six prong interactions of 8 GeV/c $\pi^{+}p$ is discussed in a contribution of the Warsaw group.[68]

2. Correlations.

Various interesting correlation effects have been seen in high multiplicity events. Thus, the Krakow group[69] presented evidence on $\langle p_{\perp} \rangle$ for nucleons and pions produced in 8 GeV/c $\pi^{+}p$ collisions, the average being taken over events with given pion multiplicity n (only events with no or one π^0 were considered). Whereas $\langle p_\perp \rangle$ decreases markedly for increasing n in the case of the pion transverse momentum, it is approximately constant for nucleons, as shown in Figs. 23 and 24. One notices large fluctuations at low multiplicities, an effect which is seen more clearly in Fig. 25 and is probably due to the abundance of resonance production and ~~and~~ two body processes in low multiplicity events. In the same experiment the distribution of c. m. angles between pairs of pions were measured. Fig. 26 shows a clear difference between pairs of like and unlike pions, in agreement with the effect first observed by G. Goldhaber et al.[70] and attributed to Bose-Einstein statistics.

Another strong correlation effect is seen in Fig. 27, now between $\langle p_\perp \rangle$ and $p_\parallel$ for charged pions produced in $\pi^- + p \to p + \pi^+ + 2\pi^- + m\pi^0$ (all m). This effect, which was found in a 7.5 GeV/c exposure in propane as part of an extensive analysis by a Dubna-Bucharest collaboration,[71] can perhaps be interpreted on the basis of relativistic phase space. It should not be separated, however, from the general and unsolved problem of understanding transverse and longitudinal momentum distributions, to which the other effects mentioned previously also belong.

IV. Theoretical Developments

1. Quark model and associated methods.

Although discussed little during the Conference, the quark model of high energy scattering should be mentioned as one of the most important steps in clarifying the relation between high energy collisions and SU_6 symmetry.[72,73,74,75] The principal assumption, beyond the quark structure of hadrons, is that the hadron-hadron scattering amplitude is the sum of quark-quark and antiquark-quark amplitudes, as expressed graphically in Fig. 28, where the f_i's denote the form factors for the hadronic transitions. They reduce to 1 for $A' = A$, $B' = B$ and $t = 0$. Some interesting relations obtained in the quark model are

$$\sigma_T(\pi N) = \frac{2}{3}\sigma_T(NN) \text{ in the limit of very high energy} \quad (1)$$

$$\sigma_T(K^+p) - \sigma_T(K^-p) = \sigma_T(\pi^+p) - \sigma_T(\pi^-p) + \sigma_T(K^+n) - \sigma_T(K^-n) \quad (2)$$

$$\sigma_T(\pi^+p) - \sigma_T(\pi^-p) = \sigma_T(K^+n) - \sigma_T(K^-n) \quad (3)$$

$$\sigma_T(K^+p) = \sigma_T(K^+n) \quad (4)$$

In addition to the additivity assumption, (1) uses the asymptotic properties of high energy cross sections (Pomeranchuk limit), (2) uses isospin invariance, (3) requires SU_3 symmetry, and (4) combines isospin invariance with an assumption of absence of charge exchange scattering between the two $I = 1/2$ quarks, as proposed by Lipkin.[76] Eq. (1) agrees very well with the measured cross sections extrapolated to constant limits for $s \to \infty$ [$\sigma_T(\pi N) \to \sim 22$ mb, $\sigma_T(NN) \to \sim 36$ mb if one takes into account the values of $\sigma_T(\bar{N}N)$ which should tend to the same limit as $\sigma_T(NN)$]. Eqs. (2) and (4) are very well satisfied for $p_{lab} \gtrsim 5$ GeV/c, whereas there is a reasonably small violation of (3) as is expected since the relation requires SU_3. Furthermore the additivity assumption itself should not be better than 10 or 20%.[75] We note that (3) and (4) are the Johnson Treiman relations originally derived from SU_6.[77] Under simple assumptions concerning the quark size one further derives for AB elastic scattering at small momentum transfers and very high energy

$$\frac{d\sigma}{dt} \Big/ \left[\frac{d\sigma}{dt}\right]_{t=0} = \left[G_A(t)\, G_B(t)\right]^2$$

where G_A, G_B are the electromagnetic form factors of A and B (in the Sachs definition for spin $\frac{1}{2}$ particles)[78], i.e. the same relation as proposed by Wu and Yang at high t [59]. The fit is excellent for pp scattering, using for $d\sigma/dt$ an extrapolation of pp and $\bar{p}p$ data to a common high energy limit. There is no doubt that the quark model with additive amplitudes has shown a great power of suggesting simple, successful relations of an unconventional type among high energy process. Spins can be readily incorporated [79].

As in the case of other successful applications of the quark model, one has tried to reach similar conclusions for hadronic properties by introducing different assumptions which do not require quarks to exist even as bound objects. In the case of high energy scattering this has been done mainly in two ways. Freund has formulated an assumption of universality through dominance of all couplings by meson states [80]. Cabibbo et al [81], on the other hand, combine the Regge pole model for elastic scattering (in the form where two meson nonets are exchanged) with the concepts of current algebra. They couple the even signature Regge poles to scalar currents, and the odd ones to vector currents, and they postulate current commulators as would follow from the quark model. This method can be applied at t=0 leaving out the spins; its extension to t≠0 and spin couplings has not been possible until now. Most of the quark model relations and some others are obtained, but Eq(1) now only holds in absence of SU_3 symmetry breaking. Furthermore, the model has the unexpected property that it can only be fitted to the total cross section data if one assumed all σ_T to decrease with s at the slow rate $s^{-\varepsilon}$, $\varepsilon = 0.075 \pm 0.008$. The resulting cross section variation at very high energy is illustrated in Fig. 29, where the curves from top to bottom refer to i) the average of σ_T (NN) and σ_T ($\overline{N}\overline{N}$), N denoting nucleons, ii) the average of σ_T (NN), iii) the average of σ_T (πN), and iv) the average of σ_T (KN). This remarkable suggestion of slowly decreasing total cross sections will be very stimulating for future experimentation at extremely high energies.

2. Regge pole theory.

a) Parity exchange.

In a very interesting contribution, Gribov[82] studies with respect to parity the effect of the Mandelstam cuts or branch points which are expected to be present in the relativistic scattering problem. He considers in particular the cut generated by exchange of several Pomeranchuk trajectories, the only one ~~to~~ which might give sizable contributions at very high energy. Consider, the reaction $A + B \rightarrow A' + B'$, with $t = (p^{\mu}_{A'} - p^{\mu}_{A})^2$. In the t channel reaction $A + \overline{A}' \rightarrow \overline{B} + B'$ one can define the "intrinsic" parity $P_r = (-1)^J P$, where J is the total angular momentum and P the parity of the $A + \overline{A}'$ state (we consider meson exchange). Gribov's point is that P_r is $+1$ for the Pomeranchuk pole contribution to the amplitude, whereas it is ± 1 for the Pomeranchuk cut contribution. This has important observational consequences. Take B = B' = proton. If A and A' are 0^- and 0^+ mesons respectively, the P pole does not contribute, the P cut does (P stands for Pomeranchuk). The cut produces a cross section with a slow, logarithmic decrease for $s \rightarrow \infty$. If there is no P cut, on the other hand, the cross section will decrease rapidly with s (exchange of η trajectory). A less striking difference occurs in the more readily available reaction $0^- + p \rightarrow 1^+ + p$. The amplitude for P pole exchange vanishes as $\sin\theta$ in the forward direction, while the P cut amplitude is small (in $\sqrt{-t}$) without vanishing. (Remember that $t < 0$

at $\theta = 0$ if the 1^- meson is heavier than the 0^- one). Although Gribov does not discuss such cases, ~~we~~ one may mention that the same distinction could be applied when A is a proton and A' a proton isobar, the importance of the P pole and P cut contributions being essentially reversed depending on the parity of the isobar.

b) General masses and spins.

The problems of Regge pole theory for reactions with unequal masses and/or general spin, which have been known for some time to contain major complications, have been tackled in some contributions and discussions during the Conference. It was realized that some of the complications which occur already in the spin 1/2 case with equal masses (nucleon-nucleon scattering), had been cleared up several years ago by Gribov and Volkov.[46,47]

Among the five amplitudes of the t-channel reaction $N\bar{N} \rightarrow N\bar{N}$, only three can remain independent when $t = 0$. Gribov and Volkov write the two resulting relations between the five amplitudes. They derive ~~frm~~ from them that, if the amplitudes belonging to the singlet state $^{3}J_{J}$ and the triplet state $^{1}J_{J}$ do not decouple altogether at $t = 0$ (i.e. if there are spin-dependent terms in the NN amplitudes at $t = 0$), their Regge poles must satisfy for $t = 0$ the relation

$$\alpha(^{1}J_{J},\ t = 0) = \alpha(^{3}J_{J},\ t = 0) \pm 1 = \alpha(^{3}(J \pm 1)_{J},\ t = 0)$$

where $\alpha(^{3}(J \pm 1)_{J},\ t = 0)$ is a Regge pole belonging to the ~~remaining~~ $N\bar{N}$ states $^{3}\ell_{J}$, ℓ $J \pm 1$). In addition, the residues develop singularities at $t = 0$, the effects of which must compensate each other in the total amplitude. In short, a "conspiracy" of several trajectories is needed to obtain a non singular spin-dependent amplitude at $t = 0$. As stressed by

Gribov and Volkov, the validity of the above relations between trajectories must be regarded as a consequence of the fact that the space-time symmetry of the system is higher for $t = 0$ than for $t \neq 0$.

Regarding collisions $A + B \rightarrow A' + B'$ in the unequal mass case, every Regge pole, when considered to higher order in the asymptotic expansion for $s = (p_A + p_B)^2 \rightarrow \infty$, is known to generate terms which are singular at $t = (p_A - p_{A'})^2 = 0$ (these singluarities are absent if $m_A = m_{A'}$ and $m_B = m_{B'}$). These singularities have been studied by Freedman and Wang[83] in the case of spinless particles. To eliminate them from the amplitude, they propose that each Regge trajectory $\alpha_j(t)$ is necessarily accompanied by daughter trajectories $\alpha_{j,k}(t)$, $k = 1, 2.....$, which verify $\alpha_{j,k}(0) = \alpha_j(0) - k$. The $\alpha_{j,k}$ should have the same quantum numbers as α_j, except for the signature which is opposite for odd k (being the same for k even). The daughter poles all have singular residues at $t = 0$, with such relations among them that the total amplitude remains regular at $t = 0$. All this is verified to hold in a model based on the ladder approximation and the Bethe ~~Salpeks~~ Salpeter equation.

It was reported that E. Leader had undertaken a study of the general case of arbitrary masses and spins, where the two types of conspiracies described above must somehow act simultaneously if the amplitude has to have its general spin dependence at $t = 0$ without becoming singular. While these developments complicate considerably the formalism of Regge pole theory [remember that each set of poles is expected furthermore to generate Mandelstam cuts], they are of ~~very~~ great theoretical interest. It should be hoped that their phenomenological implications will not increase too much the complexity of the Regge pole analysis of experimental data, which is already considerable.

V. Concluding Remarks

In summary, we would like to list some of the classes of questions which can be expected to play an important role in the near future.

1. In two-body meson-nucleon processes near the forward direction, the simple cases where few sets of quantum number can be exchanged and consequently few Regge trajectories contribute, will receive continued attention. Is it true that all relevant trajectories except the Pomeranchuk are about the same? Do they all contribute to dips? What is the actual slope α'_p of the Pomeranchuk trajectory? We know that it is much smaller than all other slopes determined so far, which are of order 1 $(\text{GeV}/c)^2$. Is $\alpha'_p = 0$ favored by the facts., or can one show that $\alpha'_p > 0$ with large probability? And, more immediately, what happens with effects, like polarization in $\pi^- p \rightarrow \pi^0 n$, which Regge poles do not explain?

2. In meson nucleon backward scattering the neat description in terms of Reggeized nucleon exchange will be scrutinized carefully as soon as new accurate data are available. A broad experimental programme is here desirable, including charge exchange and polarization phenomena.

3. The time has come to measure accurately those two-body processes at small momentum transfers where no known particles or resonances, and hence no Regge trajectories, can be exchanged. Examples are $\pi^- n \rightarrow \pi^+ N^{*-}$ forward, $K^- p \rightarrow K^0\, \Xi^0$ forward and $K^- p \rightarrow K^- p$ backward.

($\bar{N}N$ scattering, and $MN \Rightarrow AB$, $NN \rightarrow AB$,

4. In the whole field of NN and) $\bar{N}N \rightarrow AB$ reactions (N = nucleon, M = meson, A and B particles or resonances), many new data will accumulate, but a systematic interpretation will be difficult. Regge pole theory must be extended to include 0^- and 1^+ particle trajectories as well as to cope with spins $>$ 1/2 and unequal masses, and the "conspiracy" complications

described above must be faced. For two body inelastic processes, any theoretical interpretation must deal with decay distributions and decay correlations, a field where the absorption model is superior to any other and may therefore inspire further theoretical developments.

5. Large angle two-body processes have most intriguing properties, and more experimantal information, also on inelastic two body reactions, seems a prerequisite before much further theoretical insight can be gained.

6. The problem of deuteron effects in high energy scattering is of great theoretical and practical interest. It deserves attention for its own sake.

7. Many body reactions deserve more systematic study than has been the case in the past. Rough theoretical ideas, inspired by the Regge description of two body processes, are available to analyze three and four body reactions. The search for unconventional statistical properties and correlations in high multiplicity collisons may eventually lead to important clues for breaking the barrier imposed by the present lack of realistic dynamical models.

In conclusion, we feel that during the last few years, the field of high energy hadron collisons has made rapid progress, and the interplay between experiment and theory has been particulary close. At each stage, basing itself on known facts, theory presents various possible descriptions, or conjectures various possible forms of behavior, and new experiments make decisive choices among them. This procedure, which has worked so well in more advanced branches of physics, is beginning to bear fruit in hadron physics. One can be confident that it will continue to do so, provided theory in its development remembers that only nature can guide it through the maze of all suspected and unsuspected mathematical possibilities, and provided adequate experimental facilities, techniques and results become available for answering without undue delay some of the decisive questions.

The author wishes to thank R.J.N. Phillips, A.M. Wetherell and C.N. Yang for their excellent work as discussion leaders, and C Baltay and D. Cline for their invaluable help as scientific secretaries, especially in the preparation of this report.

REFERENCES

1. A. A. Nomofilov, I. M. Situik, L. A. Slepets, L. N. Strunov, and L. S. Zoliu, Measurements of the Real part of $\pi^- p$ Elastic Scattering Amplitudes in the Coulomb Interference Region at 3.5 GeV/c and 6.0 GeV/c, Report submitted to the XIII th Conference.
2. V. S. Barashenkov, Check of Dispersion Relations of High Energies, Report submitted to the XIII th Conference.
3. K. J. Foley, R. S. Gilmore, R. S. Jones, S. J. Lindenbaum, W. A. Love, S. Ozaki, E. H. Willen, R. Tammada, L. C. L. Yuan, Phys. Rev. Letters <u>14</u>, 862 (1965).
4. G. Hohler, J. Baachke, and R. Strauss, Phys. Letters <u>21</u>, 223 (1966).
5. C. T. Coffin, N. Dikmen, L. Ettlinger, D. Meyer, A. Saulys, K. Terwilliger, and D. Williams, $\pi^+ p$ Elastic Differential Cross Sections from 2.3 to 4.0 GeV/c, Report submitted to the XIII th Conference.
6. G. Höhler, J. Baacke, M. Schlaile, and P. Sonderegger, Phys. Letters <u>20</u>, 79 (1966); and

   F. Arbab and C. Chiu, UCLRL Report 16686 (1966).
7. S. Frautschi, Regge Trajectories and Minima in Differential Cross Sections, submitted to Phys. Rev. Letters (also submitted to the XIII th Conference).
8. M. Borghini, G. Coiques, L. Dick, K. Kuroda, L. di Lella, A. Michalowicz, P. C. Macq, and J. C. Olivier, Measurement of the Polarization Parameter in $\pi^{\mp} p$ and pp Elastic Scattering at 6.0, 8.0, 10.0, and 12.0 GeV/c, Report submitted to the XIII th Conference.

9. C. B. Chiu, R. J. N. Phillips, and W. Rarita, πN Polarization and Regge Poles, University of California Report UCRL-16940, also submitted to the XIII th Conference.

10. K. A. Ter-Martirosyan, Simplest Inelastic Processes at High and Very High Energies, Report submitted to the XIII th Conference.

11. P. Bonamy, P. Borgeand, S. Brehin, C. Bruneton, P. Falk-Vairaut, O. Guisan, P. Souderegger, C. Cauersasio, J. P. Guilland, J. Schneider, M. Yvert, I. Mannelli, F. Sergiavipietri, and L. Vincelli, $\pi^- p \to \pi^0 u$ Polarization at 6 GeV/c, Report submitted to the XIII th Conference, and a more recent paper by the same authors, New Results on High Energy $\pi^- p$ Charge Exchange Scattering on Polarized Target, submitted to the XIII th Conference.

12. R. J. N. Phillips, Resonance Tails and High Energy πN Charge Exchange, Submitted to Il Nuovo Cimento (also submitted to the XIII th Conference on High Energy Physics).

13. J. Baacke and M. Yvert, Regge Poles and Resonances in $\pi^- p$ Charge Exchange Scattering between 2.5 and 6 GeV/c, Report submitted to the XIII th Conference.

14. R. K. Logan and L. Sertorio, Urbana preprint (1966).

15. H. Högaasen and A. Frisk, Phys. Letters 22, 90 (1966).

16. H. Högaasen and W. Fisher, CERN preprint (1966).

17. M. Le Bellac, Il Nuovo Cimento XLII A, 443 (1966).

18. P. Guisan, J. Kirz, P. Souderegger, A. V. Stirling, P. Brogeand, C. Bruneton, P. Falk-Vairant, B. Amblard, C. Cauersasio, J. P. Guilland, and M. Ivert, Phys. Letters 18, 200 (1965).

19. R. I. Thews, MIT Preprint, Quoted in D. R. O. Morrison, Review of Inelastic Two-body Reactions, Report presented at the Conference on High Energy Two Body Reactions, Stony Brook, April 1966.

20. R. R. Koflev, R. H. Hartung, and D. D. Reeder, the Reaction $\pi^+ p \rightarrow \Sigma^+ K^+$ at 3.23 GeV/c, Report submitted to the XIII th Conference on High Energy Physics.

Chan Hong-Mo

21. ~~H. M.~~ Chan, H. Högaasen, and K. Kajantic, CERN ~~Preprint~~ Internal Report (1966).

22. W. Selove, Backward π p Scattering, Paper presented at the Conference on High Energy Two-body Reactions, Stony Brook, April 1966; H. Brody, R. Lanza, R. Marshall, J. Niedever, W. Selove, M. Shochet, and R. Van Berg, Phys. Rev. Letters <u>16</u>, 828 (1966).

23. W. R. Frisken, A. L. Read, H. Ruderman, A. D. Krisch, J. Orear, R. Rubinstein, D. B. Scarl, and D. H. White, Phys. Rev. Letters <u>15</u>, 309 (1965); and Phys. Rev. Letters <u>15</u>, 313 (1965).

24. J. Orear, R. Rubinstein, D. B. Scarl, D. H. White, A. D. Krisch, W. R. Frisken, A. L. Read, and H. Ruderman, Large Angle Pion-Proton Elastic Scattering at High Energies, Submitted to the Physcial Review (also submitted to the XIII th Conference).

25. T. Dobrowolski, B. I. Guskev, M. P. Likhachev, A. L. Lyubimov, Yu. A. Matulenko, V. S. Stavlavsky, and A. S. Vovenko, The Energy Dependence of the π^+p Elastic Scattering Cross Section near 180°, in the 2-5 GeV Range, Submitted to the XIII th Conference.

26. V. Barger and D. Cline, Regge Recurrence Parity Assignments for the s = 0 Regge Recurrences, Report submitted to the XIII th Conference on High Energy Physics.

27. C. B. Chiu and J. D. Stack, Regge Pole Model for Backward π^+p Scattering, Submitted to Phys. Rev. Letters (also submitted to the XIII th Conference).

28. J. Mott, R. Ammar, R. Davis, W. Kropac, A. Cooper, M. Derrick, T. Fields, L. Hyman, J. Loken, F. Schweingruber, and J. Simpson, K^--p Elastic Scattering at 5.5 and 4.1 GeV/c, Report submitted to the XIII th Conference.

29. R. J. N. Philips and W. Rarita, Phys. Rev. 139, 1336 (1965).

30. P. Astbury, G. Brautti, G. Finocchiano, A. Michelini, K. Terwilliger, D. Websdale, C. H. West, P. Zanella, W. Beusch, W. Fisher, B. Gobbi, M. Pepin, and E. Polgar, K^--p Charge Exchange of 5 and 7 GeV/c, Report Submitted to the XIII th Conference.

31. P. Astbury, G. Finocchiano, A. Michelini, C. Verkerk, D. Websdale, C. H. West, W. Beusch, R. Gobbi, M. Pepin, M. A. Pouchon, and E. Polgar, Phys. Letters 16, 328 (1965).

32. R. J. N. Philips and W. Rarita, Phys. Rev. Letters 15, 807 (1965).

33. Y. Goldschmidt-Clermont, V. P. Henri, B. Jongejans, A. Moisseev, F. Muller, J. M. Perreau, A. Probes, V. Yarba, W. de Baere, J. Debaisieux, P. Dufour, F. Grard, J. Heughebaert, L. Pape, P. Peeters, F. Verbeure, and R. Windmolders Two Body Channels in the Reactions of 3, 3.5, and 5 GeV/c Positive Kaons on Hydrogen: A Reggeized Summary, to be submitted to Phys. Letters (also submitted to the XIII th Conference on High Energy Physics.).

34. V. Franco and R. J. Glauber, Phys. Rev. 142, 1195 (1966); V. Franco, Phys. Rev. Letters 16, 944 (1966).

35. V. Franco and E. Coleman, University of California Preprint No. UCLRL 16993 (Aug. 1966).

36. C. Wilkin, BNL Preprint No. 10415 (July 1966).

37. Kh. Chernev, N. Dalkhazhav, P. Devinski, L. Khristov, L. Kirillova, Z. Korbel, P. Markov, V. Nikitiu, L. Rob, M. Shafranova, V. Sviridov, D. Tuvdendorzle, Z. Zlatanov, and L. Zoliu, Small Angle Proton-Deuteron Elastic Scattering at the Energy 1-10 GeV/c, Report submitted to the XIII th Conference.

38. A. A. Garter and D. V. Bugg, Rutherford Laboratory Preprint RPP/4/12 (1966).

39. M. N. Kraislev, F. Martin, M. L. Perl, M. J. Longo, and S. T. Powell, Phys. Rev. Letters 16, 1217 (1966).

40. B. Barish, D. Fong, R. Gomez, D. Hartill, J. Pine, A. Tollestrup, A. Maschke, and T. Zipf, Sumbitted to Phys. Rev. Letters for publication.

41. See Ref. 8.

42. P. Grannis, J. Arens, F. Betz, O. Chamberlain, B. Dieterle, C. Schultz, G. Shapiro, H. Steiner, L. Van Rossum, and D. Weldon, University of California Preprint UCRL 16750, March 1966 (Submitted to the Phy. Rev.).

43. P. Astbury, G. Brautti, G. Finocchiano, A. Michelini, D. Websdale, C. H. West, E. Polgar, W. Beusch, W. E. Fischer, B. Gobbi, and M. Pepin, The Charge Exchange $\bar{p}p \to \bar{n}n$ at 5, 6, 7, and 9 GeV/c, Report submitted to the XIII th Conference on High Energy Physics.

44. N. Byers, High Energy np Charge Exchange Scattering and One Pion Exchange, Report submitted to the XIII th Conference on High Energy Physics.

45. V. N. Melnikov and K. A. Ter-Martirosyan, K-meson and Nucleon Charge Exchange Reaction at High Energy, Report submitted to the XIII th Conference.

46. V. N. Gribov and D. V. Volkov, Proceedings of the 1962 International Conference on High Energy Physics at CERN (ed. by J. Prentki) p. 552.

47. D. V. Volkov and V. N. Gribov, J.E.T.P. 44, 1068 (1963); Engl. Translation Soviet Physics JETP 17, 720 (1963).

48. E. W. Anderson, E. J. Bleser, G. B. Collins, T. Fujii, J. Menes, F. Turkot, R. A. Carrigan, R. M. Edelstein, N. C. Hien, T. J. McMahon, and I. Nadelhaft, Peripheral and Central Proton-Proton Interactions in the Energy Range 6-30 BeV, Report submitted to the XIII th Conference (also Phys. Rev. Letters <u>16</u>, 855 (1966).

49. I. M. Blair, A. E. Taylor, W. S. Chapman, P. I. P. Kalmus, J. Litt, M. C. Miller, D. B. Scott, H. J.Sherman, A. Astbury, and T. G. Walker, Rutherford Laboratory Preprint RPP/M/15 (1966).

50. I. Ya. Pomeranchuk and E. L. Feinberg, Dokl. Akad, Nauk USSR <u>93</u>, 439 (1953), and Suppl. Nuovo Cimento <u>3</u>, 652 (1956).

51. M. L. Good and W. D. Walker, Phys. Rev. <u>120</u>, 1957 (1960).

52. B. Margolis and A. Rotsstein, A. Comparison of the Absorbtion Model and a Regge Pole Model for Nucleon Isobar Excitation, to be published in Il Nuovo Cimento (also submitted to the XIII th Conference).

53. H. L. Anderson, S. Fukui, D. Kessler, K. A. Klare, M. V. Sherbrook, H. J. Evans, R. L. Martin, E. P. Hincks, N. K. Sherman, and P. I. P. Kalmus, Missing Mass Spectrum from p-p Collisions at 12.3 BeV/c, Report submitted to the XIII th Conference.

54. J. F. Allard, D. Drijard, J. Hennessy, R. Huson, A. Lloret, J. Six, J. J. Veillet, G. Bellini, M. di Corato, E. Fiorini, P. Negri, M.Roller, J. Crussard, J. Ginestet, A. H. Tran, H. H. Bingham, C. Farwell, W. B. Fretter, H. J. Lubatti, W. Michael, and K. Moriyasu, Study of $\pi^+ 2\pi^-$ Final States Coherently Produced on Nuclei by 16 GeV/c π^-, submitted to Nuovo Cimento (also submitted to the XIII th Conference).

55. J. V. Allaby, G. Belletini, G. Cocconi, M. L. Good, A. N. Diddens, G. Matthiae, E. J. Sacharidis, A. Silverman, and A. M. Wetherell, The Large Angle Differential Cross Section of Proton Proton Elastic Scattering of 16.9 GeV/c, Report submitted to the XIII th Conference.

56. T. Ericson, CERN Report TH 406 (1964);
T. Ericson and T. Mayer-Kuckuk, CERN Report TH 686, to appear in Ann. Rev. of Nucl. Science, Vol 16 (1966).

57. R. Hagedorn, Nuovo Cimento 35, 216 (1965) and other papers there quoted.

58. J. Orear, Phys. Letters 13, 190 (1964).

59. T. T. Wu and C. N. Yang, Phys. Rev. 137, B 708 (1965).

60. K. Huang, Two-Body Reaction at High Energies and Large Angles, Report sumbitted to the XIII th Conference.

61. G. Domokos and R. Karplus, Speculations Concerning Large Angle Meson-Nucleon Scattering at High Energies, Report submitted to the XIIIth Conference.

62. A. Białas and O. Czyzewski, Nucleon-Nucleon and Nucleon-Antinucleon Elastic Scattering at High Momentum Transfers, Report submitted to the XIII th Conference.

63. A. Biatas and O. Czyzewski, Presented at the XIII th International Conference on High Energy Physics.

64. A. A. Logunov, M. A. Mestvirishvili, and I. N. Silin, Asymptotic Behavior of the Scattering Amplitude at Large Momentum Transfers, Report sumbitted to the XIII th Conference.

65. S. O. Alliluyev, S. S. Gershtein, and A. A. Logunov, Phys. Letters 18, 195 (1965).

66. J. Bartke and O. Czyzewski, Cross sections for "Central" Collisions and Multiplicity Distributions in Pion Production in Pion-Proton Collisions of 4-10 GeV/c, Report sumbitted to the XIII th Conference.

67. K. Zalewski, Private Communication.

68. M. Bardadin-Otwinowska, M. Danysz, T. Hofmokl, S. Otwinowski, H. Piotvowska, R. Sosnowski, M. Szeptycka, and A. Wroblewski, Six prong Interactions of 8 GeV/c in Hydrogen, Report sumbitted to the XIII th Conference.

69. J. Bartke, O. Czyzewski, J. Danysz, A. Eskreys, J. Loskiewicz, P. Malecki, K. Eskreys, K. Juszczak, D. Kisielewska, and W. Zielinski, Some Aspects of Many-Pion Production by 8 GeV/c π^+, Report presented to the XIII th Conference.

70. G. Goldhaber, S. Goldhaber, W. Lee, and A. Pais, Phys. Rev. 120, 300 (1960).

71. V. A. Beljakov, E. N. Kladnitkaja, E. S. Kuznetsova, E. Balea, C. Balea, A. Mihul, and M. Sabau, Four Prong $\pi^- p$ Interactions at 7.5 GeV Part I: Reaction $\pi^- + p \to p + \pi^+ + \pi^- + \pi^- + m\pi^0$, Report submitted to the XIII th Conference.

72. E. M. Levin and L. L. Frankfurt, JETP, P.R. 2, 105 (1957) [English Translation: Societ Physics JETP Letters 2, 62 (1966)].

73. H. J. Lipkin and F. Scheck, Phys. Rev. Letters 16, 71 (1966) and later papers by Lipin and collaborators.

74. J. J. J. Kokkedee and L. Van Hove, Nuovo Cimento 42, 711 (1966).

75. A systematic review is given in L. Van Hove, Lectures at 1966 Scottish Universities Summer School, CERN preprint (1966).

76. H. J. Lipkin, Phys. Rev. Letters 16, 1015 (1966).

77. K. Johnson and S. B. Treiman, Phys. Rev. Letters 14, 189 (1965).

78. L. Van Hove, Paper presented at the Conference on High Energy Two Body Collisions, Stony Brook (April 1966), CERN preprint (1966).

79. C. Itzykson and M. Jacob, Saclay preprint (1965).

80. P. G. O. Freund, Phys. Rev. Letters 15, 129 (1965).

81. N. Cabibbo, L. Horwitz and Y. Ne'eman, CERN preprint (1966) and N. Cabibbo, L. Horwitz, J. J. J. Kokkedee and Y. Ne'eman, CERN Preprint (also submitted to the XIII th Conference).

82. V. N. Gribov, On the possibility of experimental investigation of Mandelstam branch points, Report Submitted to the XIII th Conference.

83. D. Z. Free$\overset{d}{\wedge}$man and J. M. Wang, Regge Poles and unequal mass scattering process, Report Sumbitted to the XIII th Conference.

D. Cline
Sept. 9, 1966

Figure Captions

Fig. 1. A comparison of the energy dependence of the $\pi^- p$ charge exchange cross section (σ_{ex}) and of $\alpha^{\pm}$ (the ratio of real to imaginary part of the forward scattering amplitude in $\pi^{\pm} p$ scattering) with the predictions of forward dispersion relations as obtained by V. Barashenkov.[2] The dashed line represents the values of $(\sigma_{ex})_{minimum}$ assuming zero real amplitude and the hatched area shows the inaccuracies due to errors in total cross section measurements.

Fig. 2. Comparison of $\pi^+ p$ and $\pi^- p$ elastic scattering differential cross sections at laboratory momenta of 2.5, 3.0, 3.5 and 4.0 GeV/c by Coffin et al.[5] Also shown is a freehand fit to the $\pi^- p$ charge exchange in the same momentum region.

Fig. 3. The polarization P (t) versus the invariant four momentum transfer t for $\pi^- p$ elastic scattering at laboratory momenta of 6, 8 and 10 GeV/c as given by Borghini et al.[8] The theoretical curve is from a fit to the data by Chiu et al.[9]

Fig. 4. The polarization P (t) versus the invariant four momentum transfer t for $\pi^+ p$ elastic scattering at laboratory momenta of 6 and 10 GeV/c.[8] The theoretical curve is a prediction of the polarization by Chiu et al.[9] using a Regge pole model.

Fig. 5. The $\pi^- p$ charge exchange differential cross section at various laboratory momenta. The references to experimental data can be found in Ref. 6.

Fig. 6. The ρ and R trajectories as determined by Ter-Martirosyan[10] using a Regge pole fit to $\pi^- p \to \pi^0 n$ and $\pi^- p \to \eta n$ experimental data.

Fig. 7. The polarization P (t) in $\pi^- p$ charge exchange scattering as measured by Bonamy et al.[11] using a polarized target.

Fig. 8. Regge pole fit to the experimental data for (1) $\pi^- p \to \pi^0 N^{*0}$ (1238) and (2) $K^+ p \to K^0 N^{*++}$ (1238). The fit was made by R. I. Thews[19] assuming a Regge ρ contribution for reaction (1) and a Regge ρ and R contribution for reaction (2).

Fig. 9. The differential cross section for $\pi^+ p \to \Sigma^+ K^+$ for a laboratory momentum of 3.23 GeV/c measured by Kofler et al.[20]

Fig. 10. The Σ^+ polarization as a function of t for the reaction $\pi^+ p \to \Sigma^+ K^+$ at 3.23 GeV/c as measured by Kofler et al.[20].

Fig. 11. The differential cross section for π^+p elastic scattering near the backward direction. "This experiment" refers to the data of the Pennsylvania group reported by Selove.[22] References for the other data are given in Ref. 21.

Fig. 12. The differential cross section for π^-p elastic scattering near the backward direction. "This experiment" refers to the data reported by the Pennsylvania group reported by Selove.[22] References to the other data are given in Ref. 21.

Fig. 13. A proposed classification of the known I = 3/2 isobars on a Regge trajectory of u versus the isobar spin as suggested by Barger and Cline.[26] The filled boxes represent experimentally observed isobars whereas the open boxes represent predicted isobars. Only the two lowest mass isobars have experimentically determined spin and parity. Analysis of charge exchanges scattering[13] and backward π^+p elastic scattering[26] suggests positive parity for the 2450 and 2840.

Fig. 14. A proposed classification of the high mass I = 1/2 isobars on two Regge trajectories as suggested by Barger and Cline.[26] The filled boxes represent experimentally observed isobars whereas

the open boxes represent predicted isobars. The two lowest members of each trajectory are known to have the correct spin and parity for the Regge recurrence assignment. Analysis of charge exchange scattering[13] suggests negative parity for the 2640 in accordance with this classification. Analysis of backward $\pi^- p$ scattering[26] also suggests negative parity for the 2640 and the 3020.

Fig. 15. The differential cross section for the reaction $K^- p \rightarrow \overline{K}^o n$ at laboratory momenta of 5, 7 and 9.5 GeV/c as reported by Astbury et al.[31] The theoretical curves are for a Regge pole model fit of Phillips and Rarita.[32] In this fit only the 9.5 GeV/c data was used and, therefore, the 5 and 7 GeV/c theoretical curves are predictions of the model.

Fig. 16. The total cross sections for np and pp scattering. (The references are to be filled in by Wetherell) (There should also be some indicat as to which curve represents np and which pp)

[illegible] sheet

Fig. 17. The ratio of real to imaginary forward scattering amplitude for np elastic scattering. The filled circles represent the data presented by Chernev et al[37]. The theoretical curves are dispersion calculations of Carter and Bugg[38].

Fig. 18. The differential cross section for the reaction $\bar{p}p \rightarrow \bar{n}n$ for the momenta 5, 6, 7 and 9 GeV/c as measured by Astbury et al[43]. The theoretical predictions are for the coherent droplet model ~~as presented by N.~~ Byers.[44]

Fig. 19. The cross section for isobar production in the process $pp \rightarrow N^*p$ as a function of laboratory momentum. The experimental data comes from Anderson et al[48] and Blair et al.[49]

Fig. 20. Differential cross section for the process (a) $\pi + A \rightarrow$ ~~$3\pi + A$~~ $\pi^+ + 2\pi^- + A$ where A is a mixture of ~~hearing~~ heavy nuclei (C_2F_5Cl). The 3π system is shown to have an appreciable fraction of events of the type (b) $\pi + \rho$ and (c) $\pi + f^0$. The differential cross section for the subsample of events is shown as (b) and (c). The experimental results are reported by Allard et al.[54]

Fig. 21. Some cross sections generated according to the Ericson mechanism, compared with the experimental data for pp elastic scattering at 16.9 GeV/c reported by Allaby et al.[55]

Fig. 22. Experimental angular distribution for pp scattering at 16.9 GeV/c on a logarithmic scale. The best fit ~~line~~ and Orear's fit are shown for comparison.

Fig. 23. Average transverse momentum of pions as a function of multiplicity for multiple pion production by 8 GeV/c π^+. The experimental results were compiled by Bartke et al.[69]

Fig. 24. Average transverse momentum of the nucleon as a function of pion multiplicity for multiple pion production by 8 GeV.c π^+. Included on the graph are channels with a neutron in the final state as well as channels with a proton in the final state. The experimental results were compiled by Bartke et al.[69]

Fig. 25. Mean transverse momentum of pions and nucleons observed in multiple pion production in 8 GeV/c $\pi^+ p$ reactions. The experimental results are compiled by Bartke et al.[69]

Fig. 26. Distribution of C.M.S. angles between pions plotted separately for pions of like charge and unlike charge for the reaction $\pi^+ p \rightarrow p 4\pi^+ 3\pi^-$. These results are reported by Bartke et al.[67]

Fig. 27. The dependence of the average transverse momenta $\langle P_\perp \rangle$ of the π^- and π^+ on different intervals of longitudinal momenta in the C.M.S. for the reaction $\pi^- p \rightarrow p \pi^+ 2\pi^- + m(\pi^0)$ as reported by Beljakov et al.[71]

Fig. 28. Schematic representation of meson-nucl~~ear~~eon interaction as pictured in the quark model (A,A') represent~~s~~ ~~a~~ meson states and (B ,B') represent~~s~~ ~~a~~ baryon states.

Fig. 29. Theoretical fit of Cabibbo et al[81] to total cross section data using a Regge pole--current algebra model with a nonet of mesons. The curves starting from the top refer to (a)the average of the NN and $\bar{N}N$ ~~NN total, cross section and the ($\bar{N}N$)~~ total cross sections; (b)the average of the NN total cross sections; (c) the average of the πN total cross sections; (d) the average of the KN total cross sections.

Figure caption for new Fig. 16

Proton-proton and proton-neutron total cross sections. The errors on the data of Bugg et al. are less than or equal to the size of the points.

The data are from :

D.V. Bugg, D.C. Salter, G.H. Stafford, R.F. George, K.F. Riley and R.J. Tapper, Phys.Rev. 146, 980 (1966)

V. Galbraith, E.W. Jenkins, T.F. Kycia, B.A. Leontic, R.H. Phillips, A.L. Read and R. Rubinstein, Phys.Rev. 138, B913 (1965)

G. Bellettini, G. Cocconi, A.N. Diddens, E. Lillethun, J. Pahl, J.P. Scanlon, J. Walters, A.M. Wetherell and P. Zanella, Physics Letters 14, 164 (1965)

G. Bellettini, G. Cocconi, A.N. Diddens, E. Lillethun, G. Matthiae, J.P. Scanlon and A.M. Wetherell, Physics Letters 19, 341 (1965).

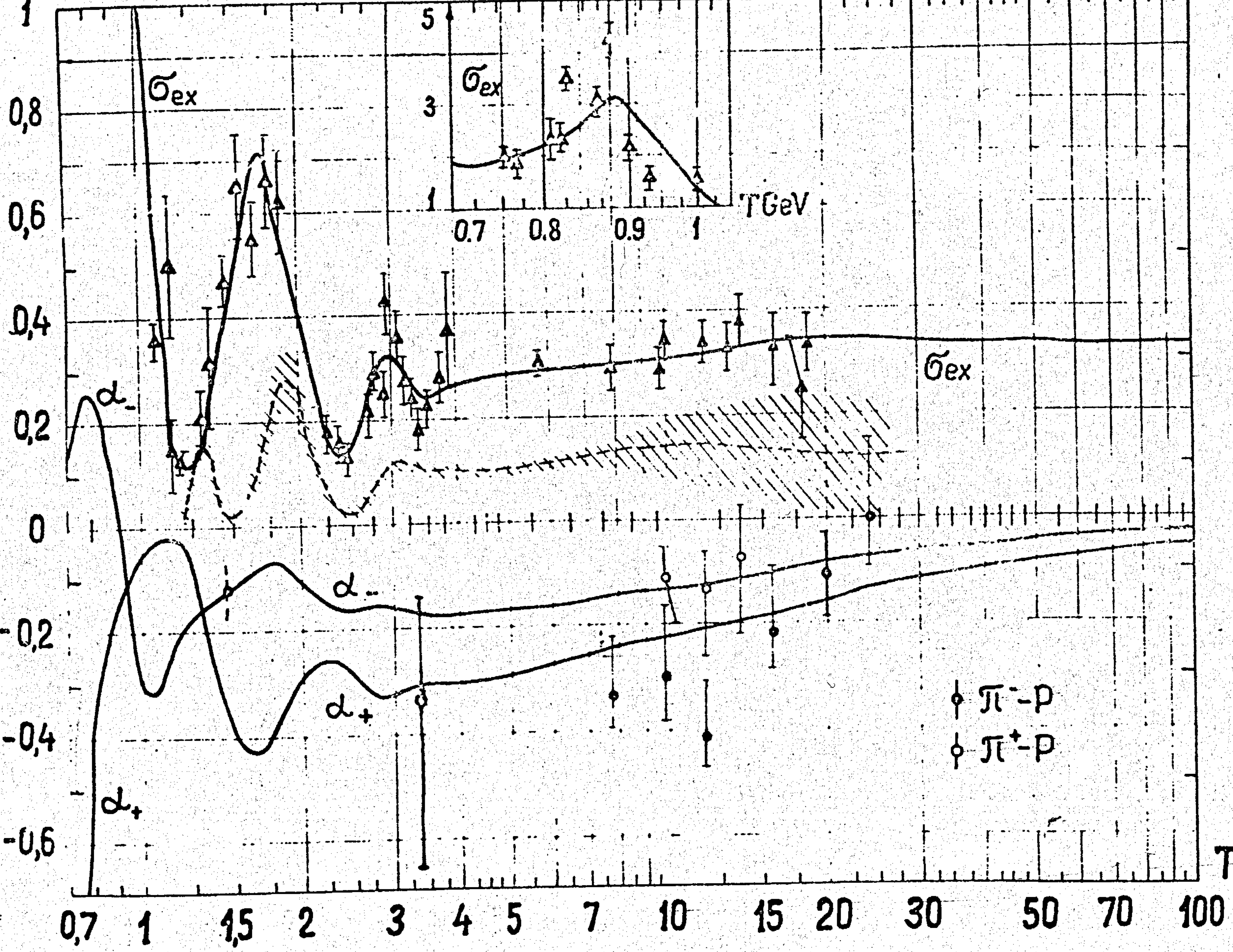
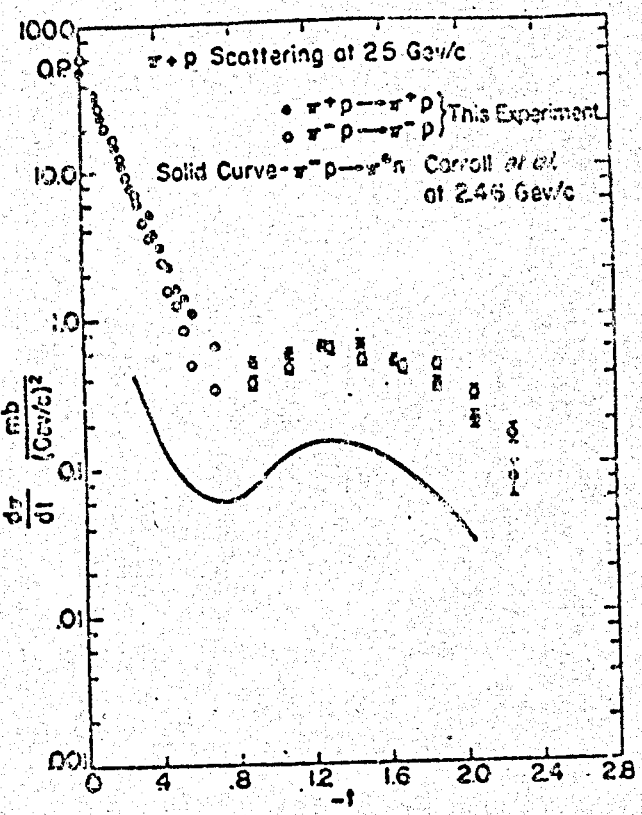
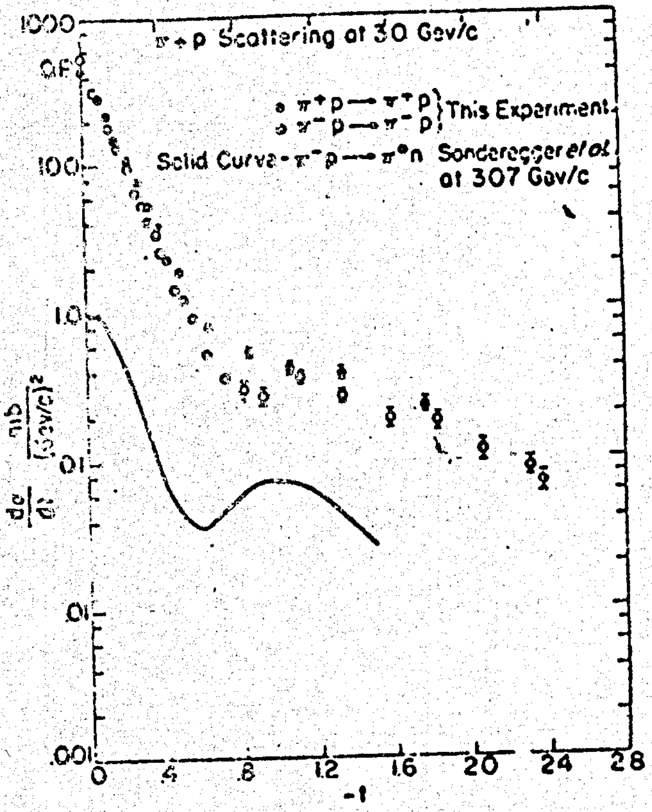

1
0,8
0,6
0,4
0,2
0
-0,2
-0,4
-0,6
σex
σex
α₋
α₋
α₊
α₊
5
3
1
σex
0.7
0.8
0.9
1
TGeV
π⁻-p
π⁺-p
TGeV
0,7
1
1,5
2
3
4
5
7
10
15
20
30
50
70
100

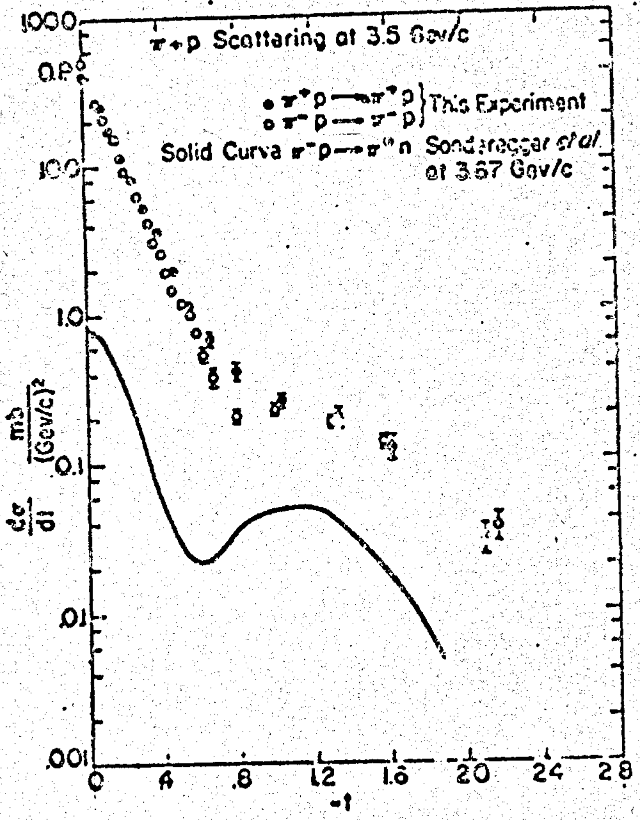
Fig.6



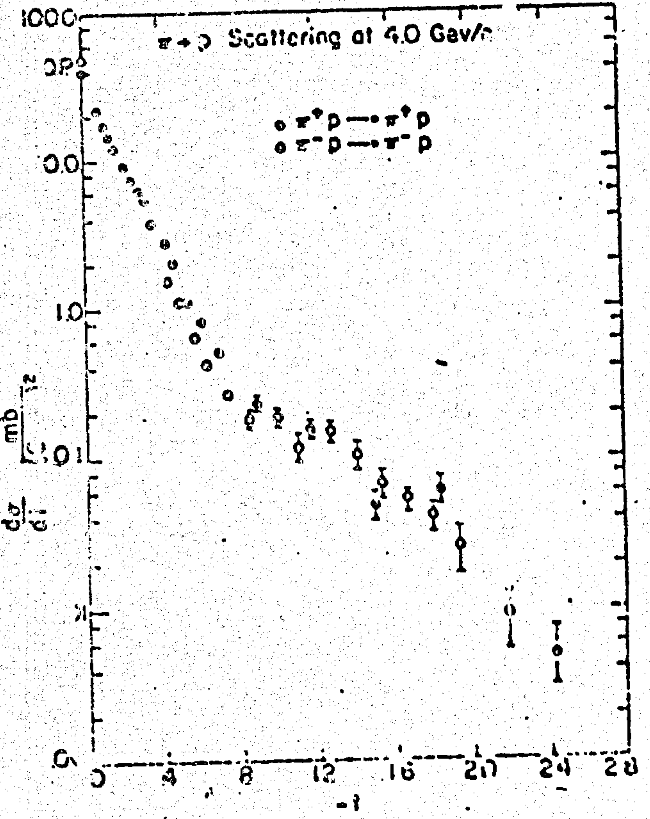
π + p Scattering at 2.5 Gev/c
● π⁺p → π⁺p
○ π⁻p → π⁻p
This Experiment
Solid Curve - π⁻p → π⁰n Carroll et al at 2.46 Gev/c
dσ/dt mb/(Gev/c)²
1000
OP
10.0
1.0
0.1
.01
.001
0
.4
.8
1.2
1.6
2.0
2.4
2.8
-t



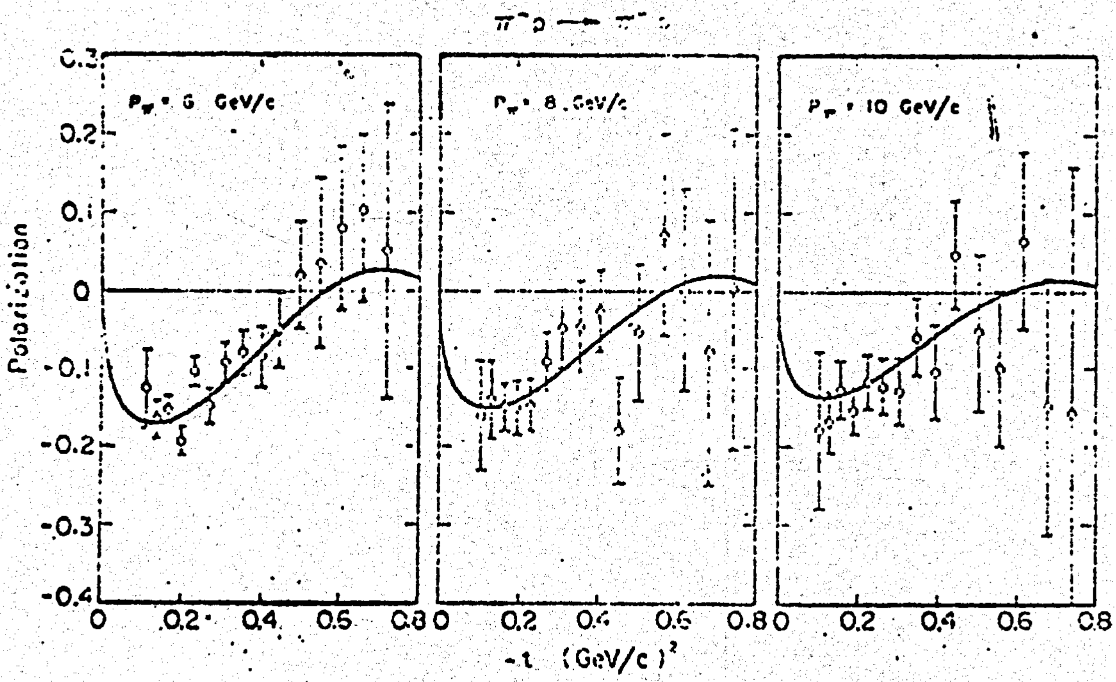
π + p Scattering at 3.0 Gev/c
● π⁺p → π⁺p
○ π⁻p → π⁻p
This Experiment
Solid Curve - π⁻p → π⁰n Sonderegger et al at 3.07 Gev/c
dσ/dt mb/(Gev/c)²
1000
OP
100
1.0
0.1
.01
.001
0
.4
.8
1.2
1.6
2.0
2.4
2.8
-t



π + p Scattering at 3.5 Gev/c
● π⁺p → π⁺p
○ π⁻p → π⁻p
This Experiment
Solid Curve π⁻p → π⁰n Sonderegger et al at 3.67 Gev/c
dσ/dt mb/(Gev/c)²
1000
OP
100
1.0
0.1
.01
.001
0
.4
.8
1.2
1.6
2.0
2.4
2.8
-t



π + p Scattering at 4.0 Gev/c
● π⁺p → π⁺p
○ π⁻p → π⁻p
dσ/dt mb/(Gev/c)²
1000
OP
10.0
1.0
0.1
.01
0
.4
.8
1.2
1.6
2.0
2.4
2.8
-t


$\pi^- p \rightarrow \pi^- p$
$P_\pi = 6$ GeV/c
$P_\pi = 8$ GeV/c
$P_\pi = 10$ GeV/c
Polarization
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
0.2
0.4
0.6
0.8
$-t$ (GeV/c)^2

MUB-15238

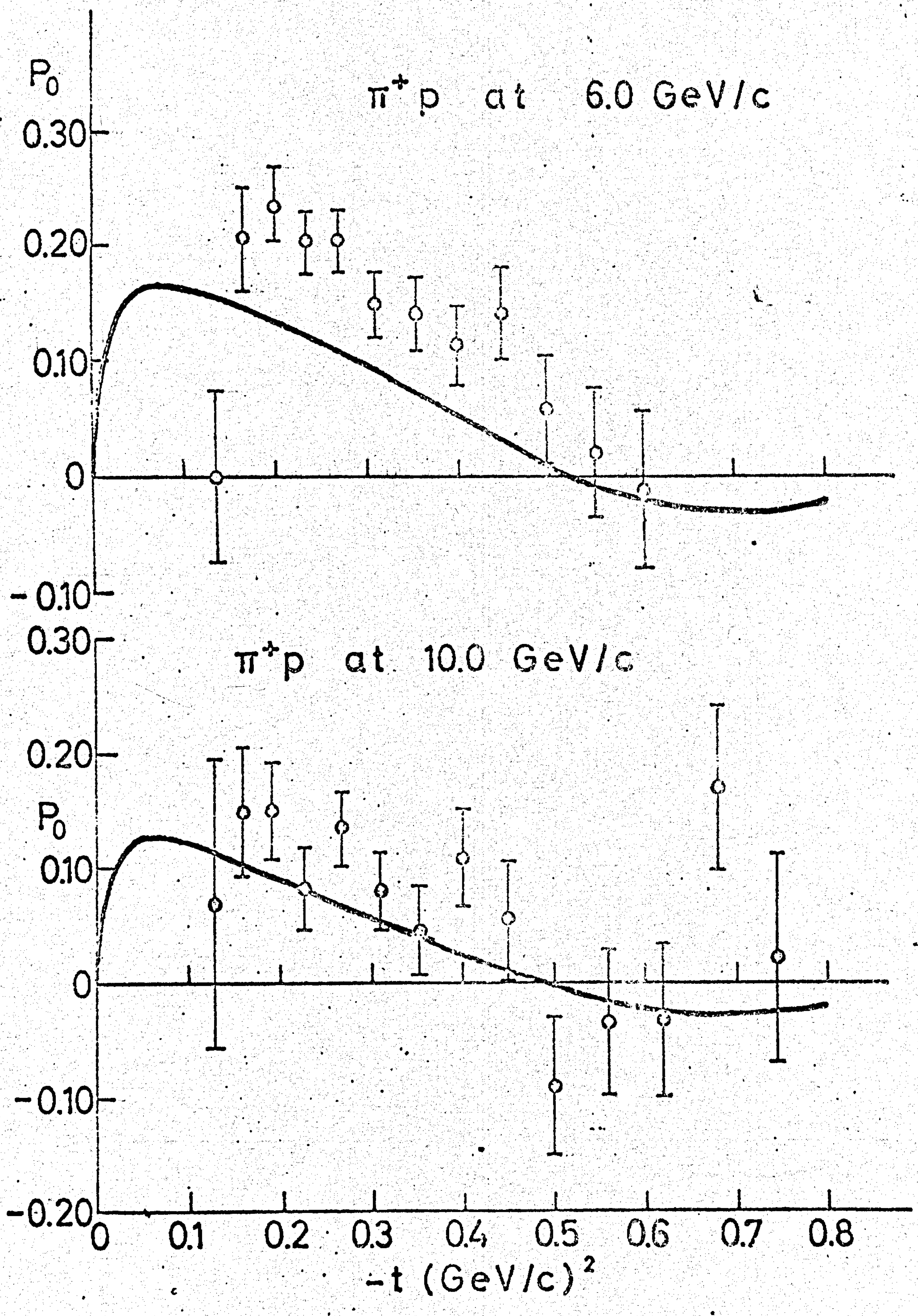
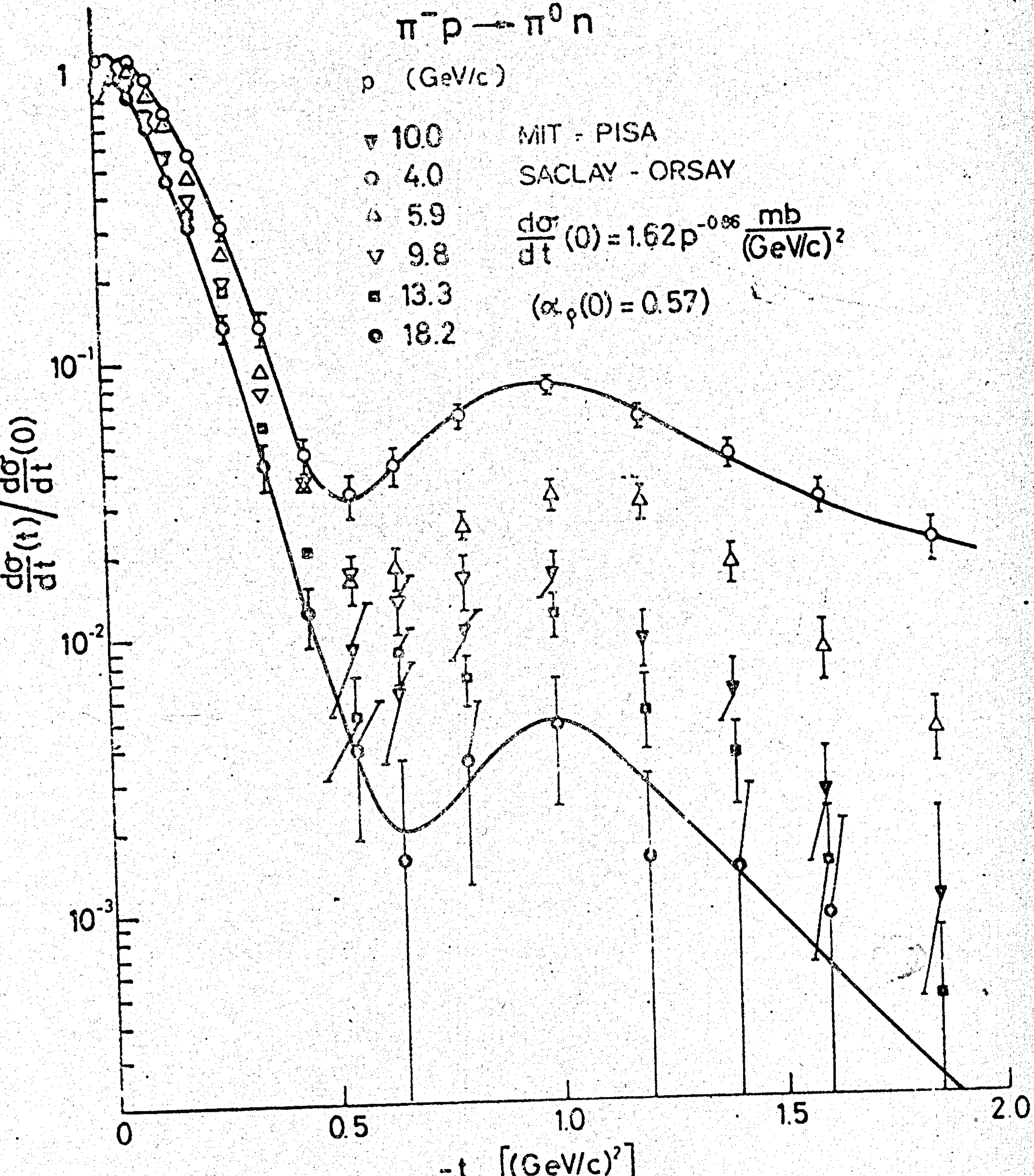
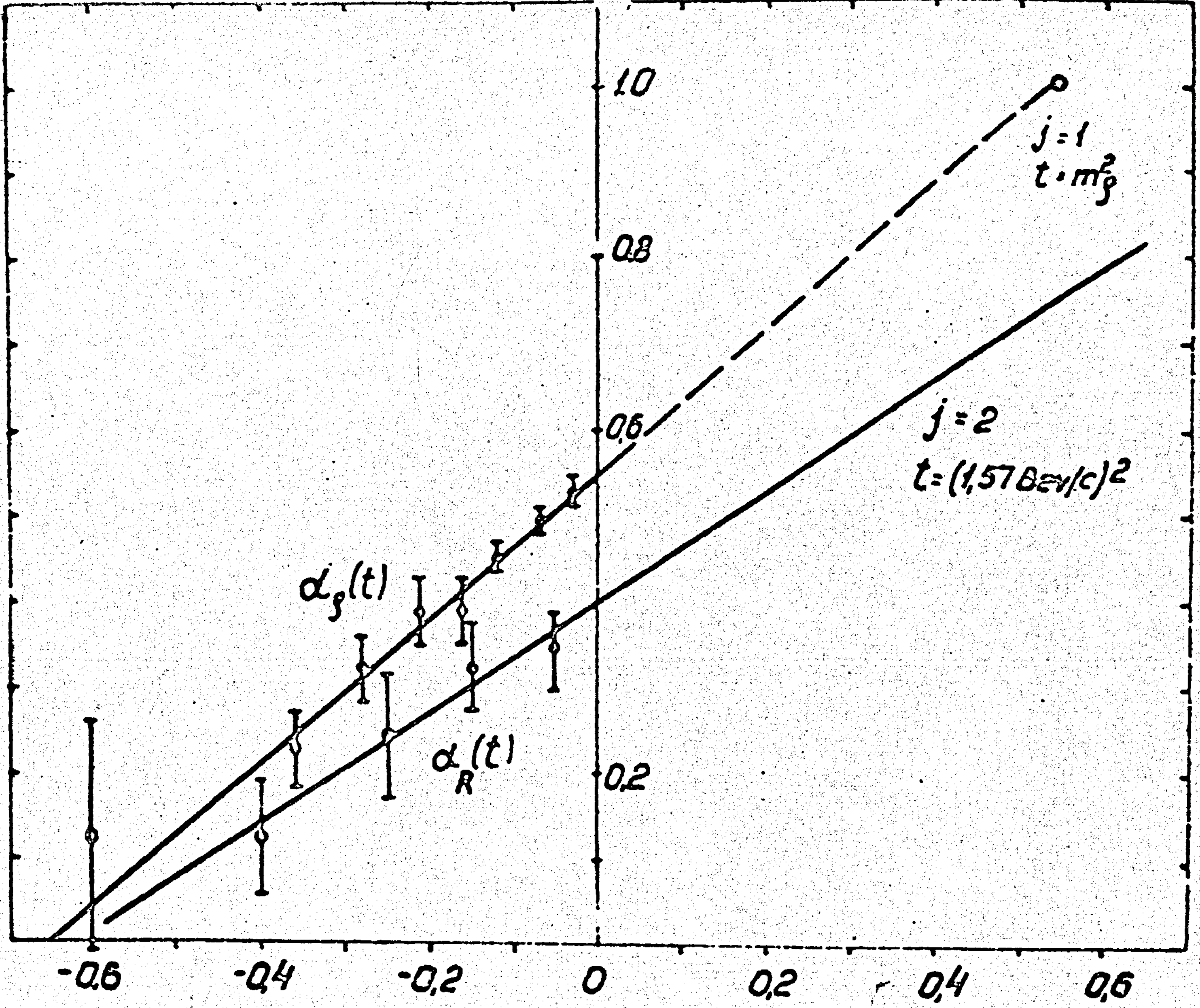

P0
π+p at 6.0 GeV/c
0.30
0.20
0.10
0
-0.10
0.30
π+p at 10.0 GeV/c
0.20
P0
0.10
0
-0.10
-0.20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
-t (GeV/c)²

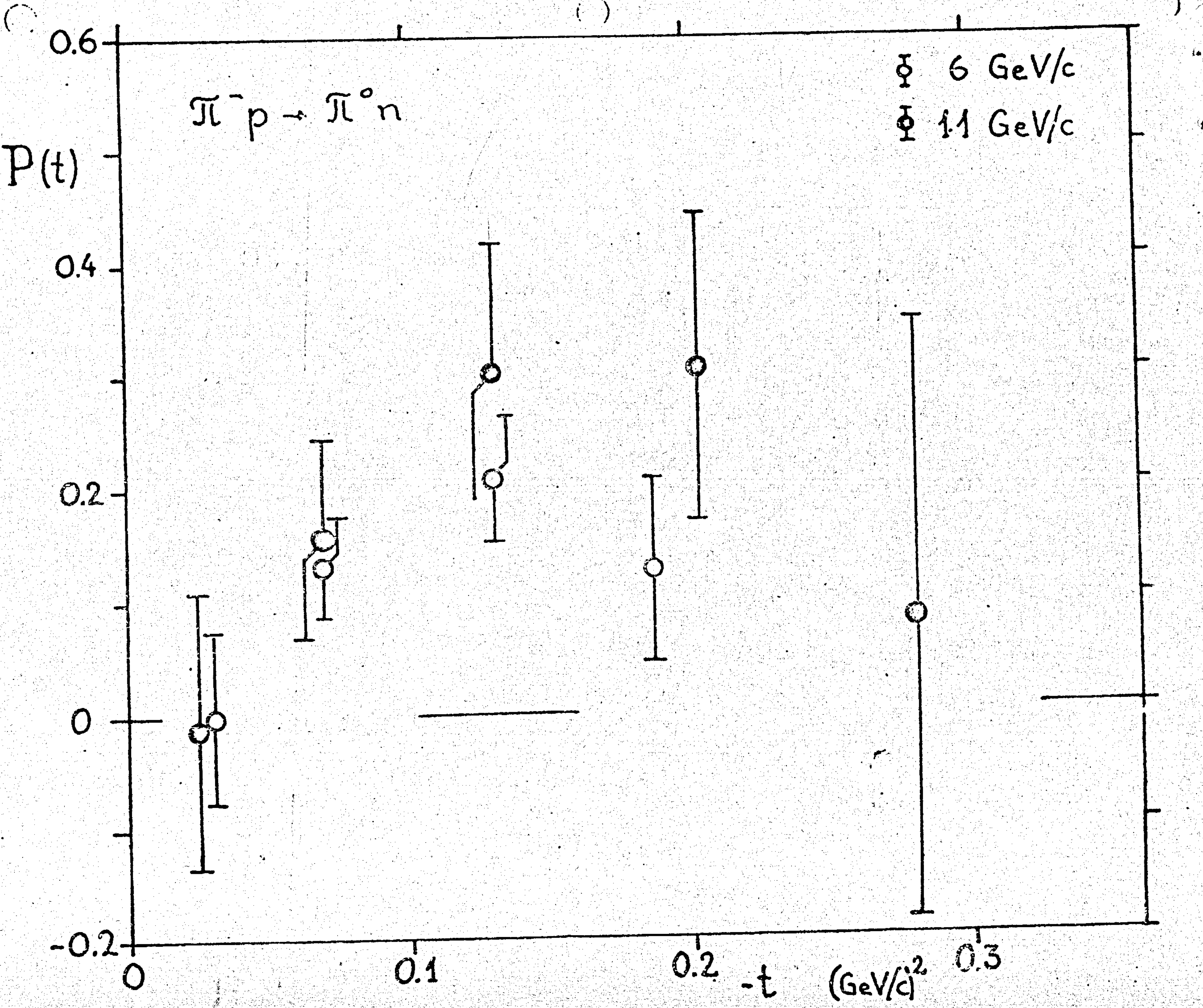
Fig-4


π⁻p → π⁰n
p (GeV/c)
▼ 10.0 MIT - PISA
○ 4.0 SACLAY - ORSAY
△ 5.9
▽ 9.8
■ 13.3
● 18.2
dσ/dt (0) = 1.62 p^-0.96 mb/(GeV/c)²
(α_ρ(0) = 0.57)
1
10⁻¹
10⁻²
10⁻³
dσ/dt(t) / dσ/dt(0)
0
0.5
1.0
1.5
2.0
-t [(GeV/c)²]

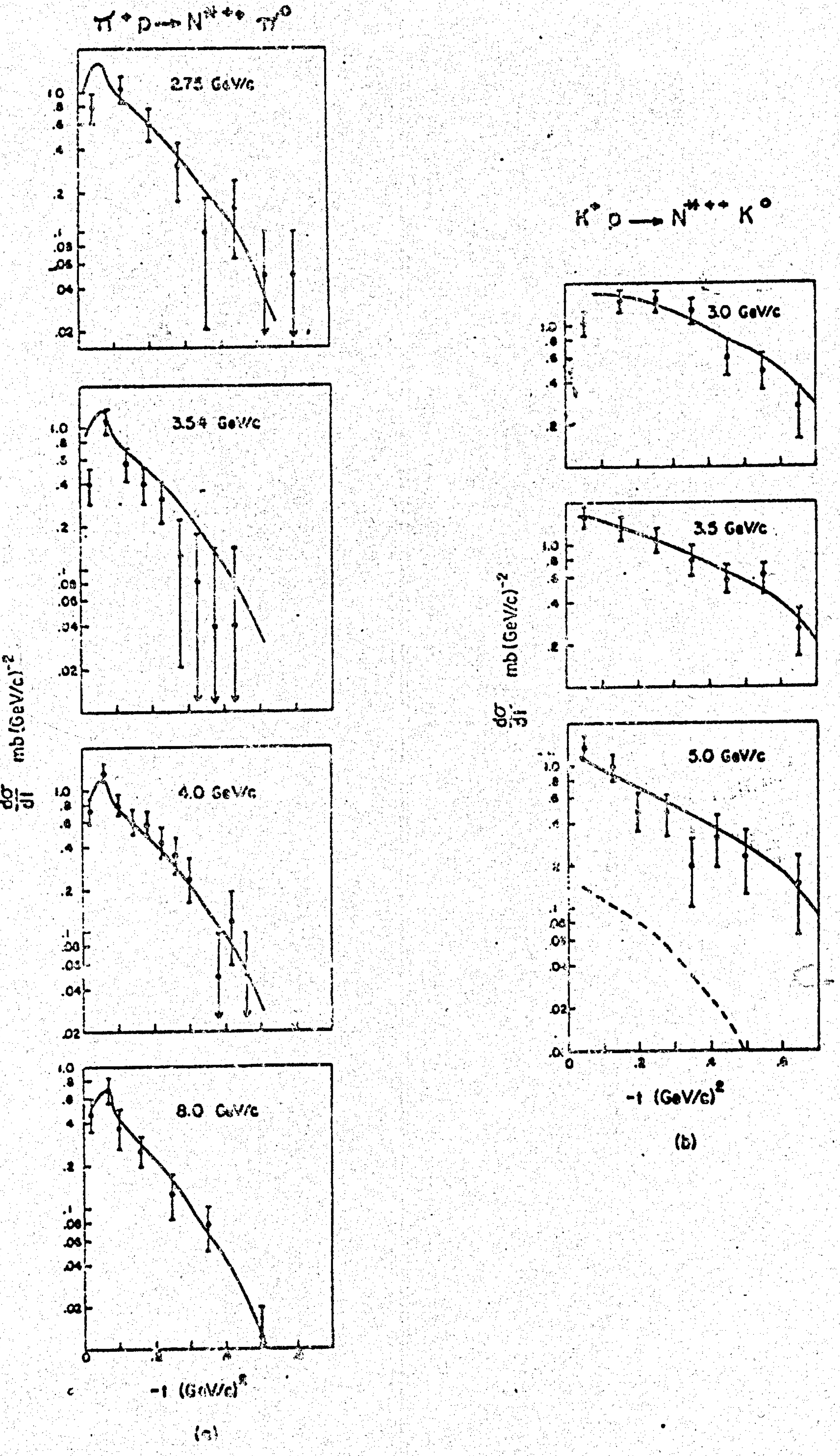


1.0
0.8
0.6
0.2
j = 1
t = m_ρ^2
j = 2
t = (1,57 Bev/c)^2
$\alpha_\rho(t)$
$\alpha_R(t)$
-0,6
-0,4
-0,2
0
0,2
0,4
0,6

Fig 2.

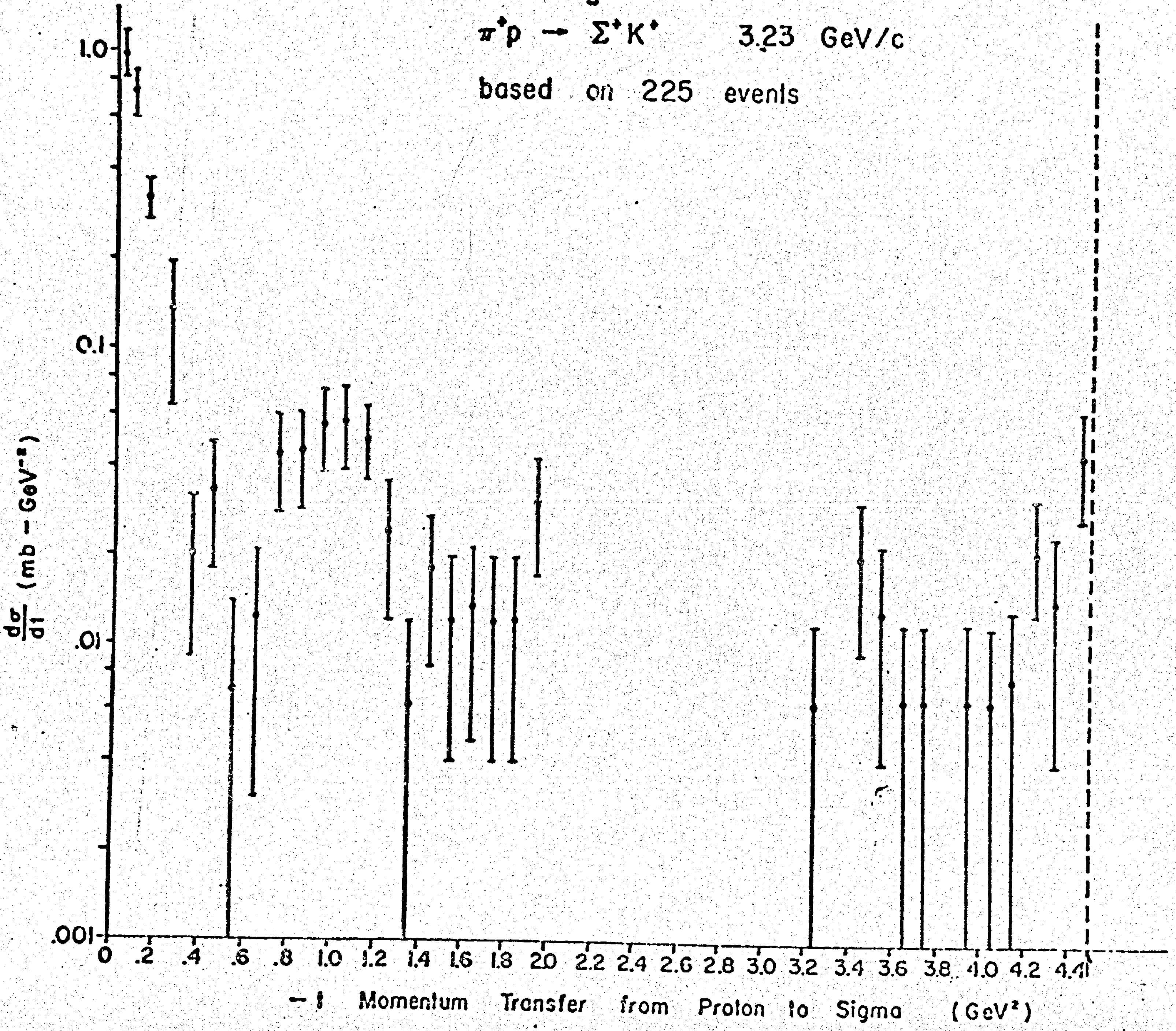


0.6
0.4
0.2
0
-0.2
P(t)
π⁻p → π°n
6 GeV/c
11 GeV/c
0
0.1
0.2
0.3
-t (GeV/c)²



$\pi^+ p \to N^{*++} \pi^0$
2.75 GeV/c
3.54 GeV/c
4.0 GeV/c
8.0 GeV/c
$\frac{d\sigma}{dt}$ mb(GeV/c)$^{-2}$
1.0
.8
.6
.4
.2
.1
.08
.06
.04
.02
0
.2
.4
.6
-t (GeV/c)^2
(a)
$K^+ p \to N^{*++} K^0$
3.0 GeV/c
3.5 GeV/c
5.0 GeV/c
$\frac{d\sigma}{dt}$ mb(GeV/c)$^{-2}$
-t (GeV/c)^2
(b)

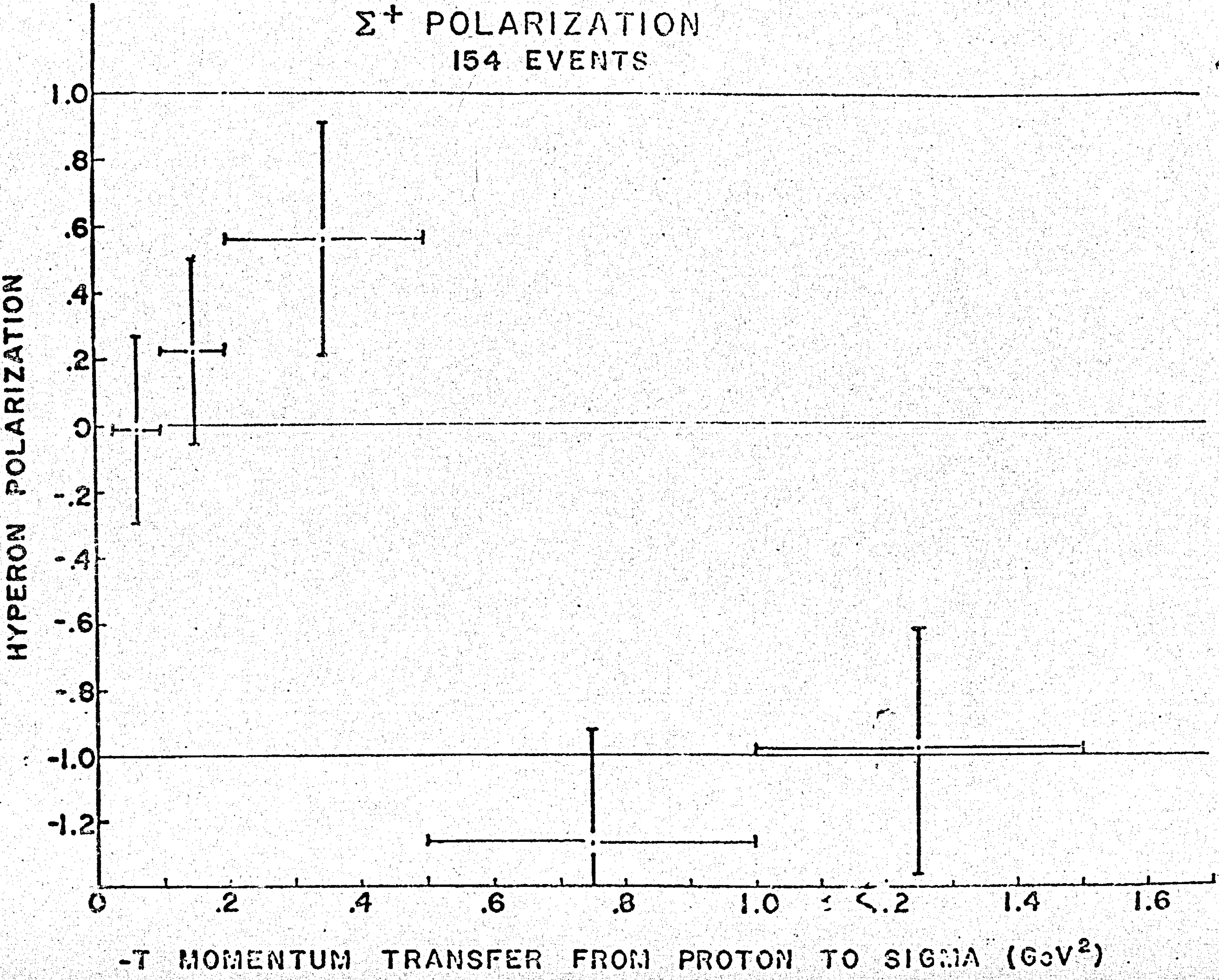
Figure 1.



$\pi^+ p \rightarrow \Sigma^+ K^+$ 3.23 GeV/c

based on 225 events

FIGURE 3



Σ^+ POLARIZATION

154 EVENTS

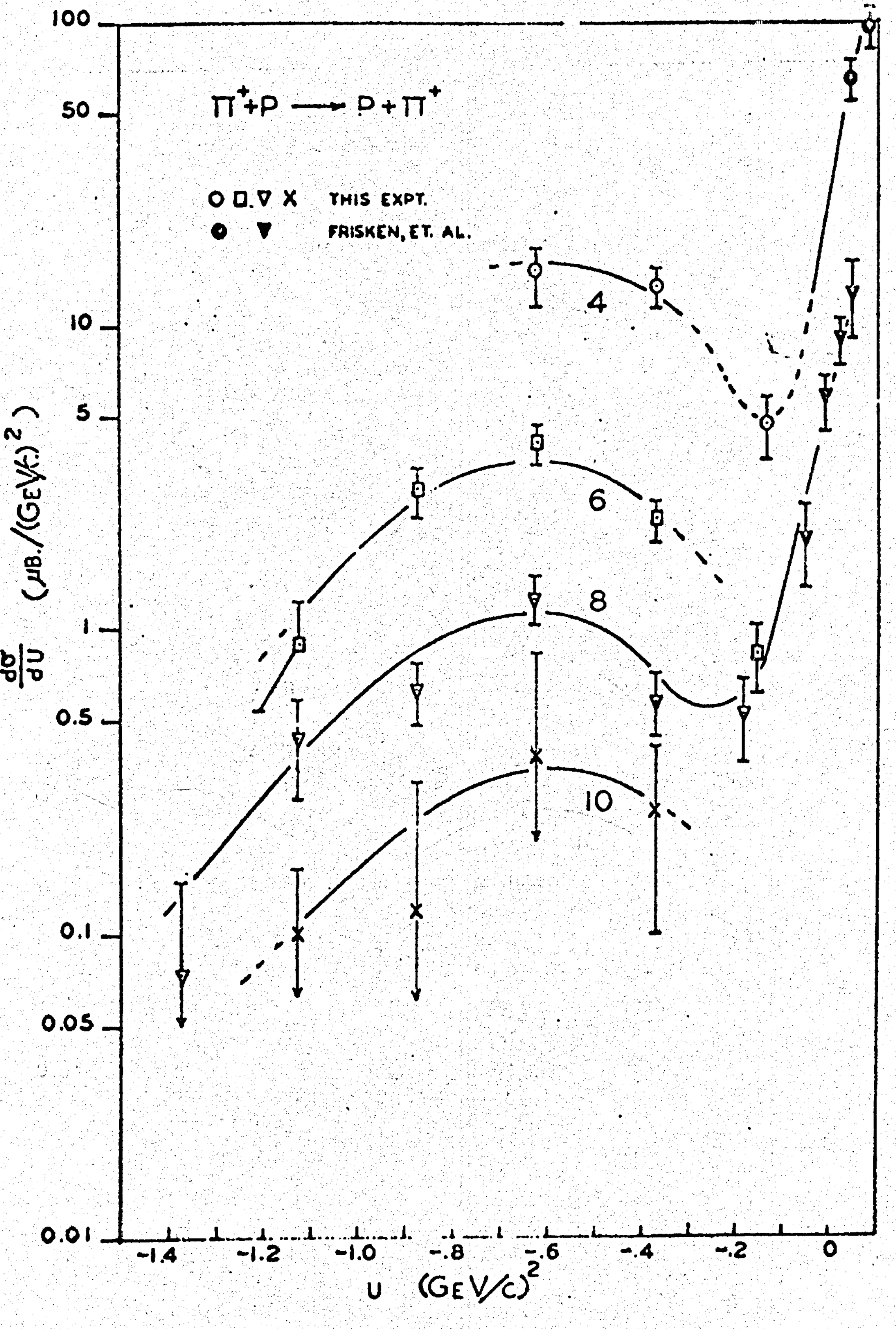
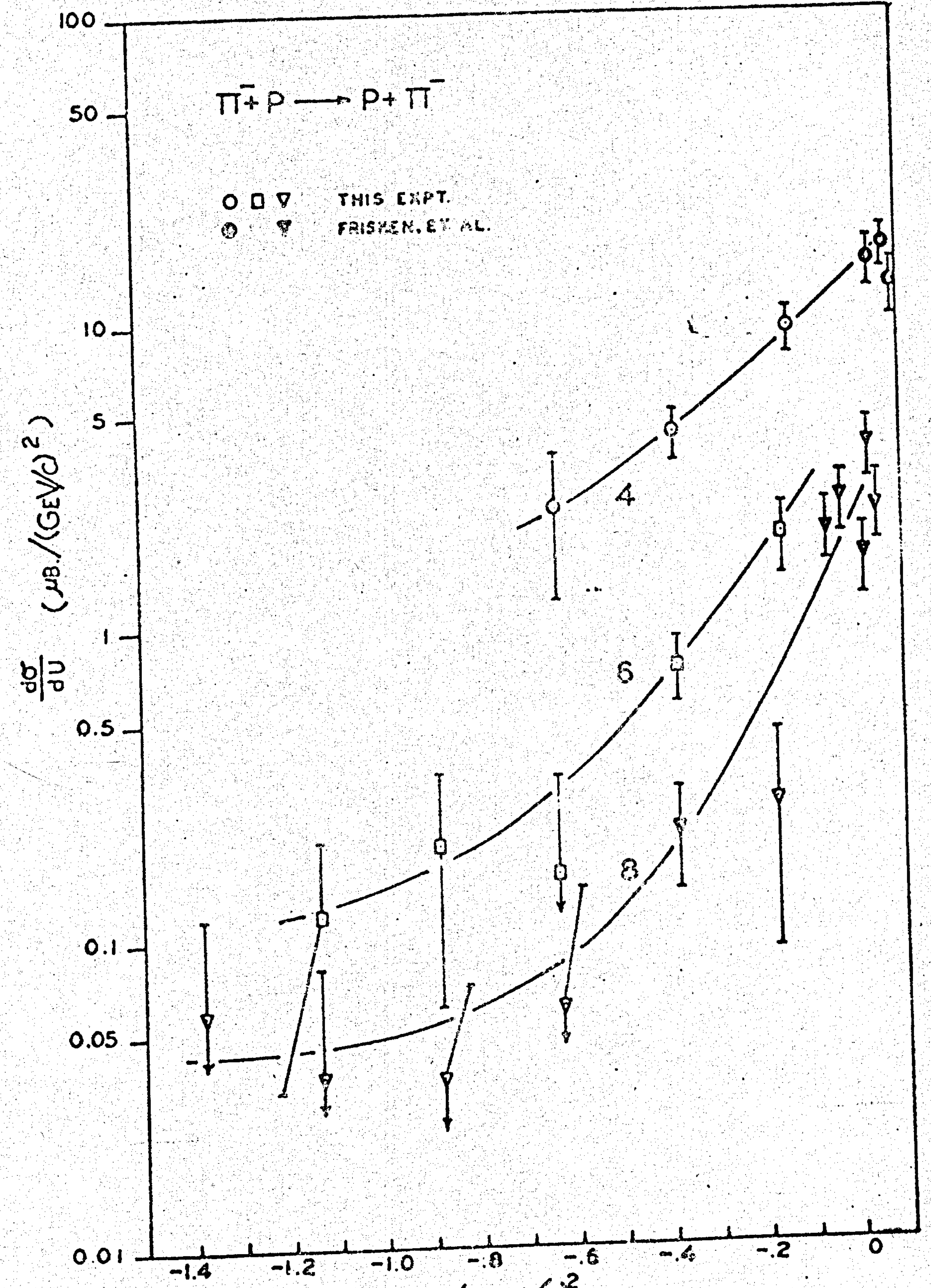
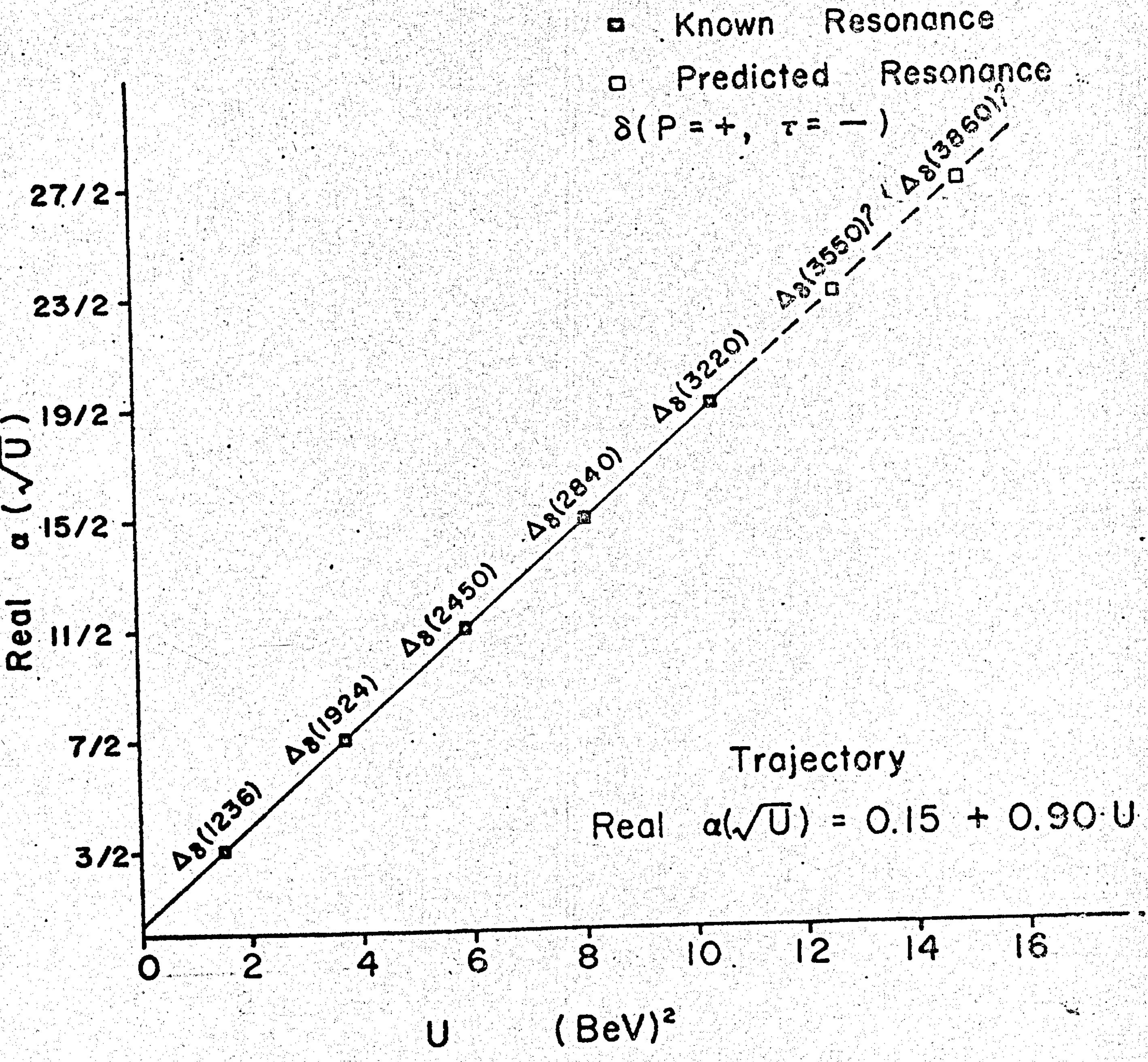

$\pi^+ + p \longrightarrow p + \pi^+$
○ □ ▽ X THIS EXPT.
● ▼ FRISKEN, ET. AL.
4
6
8
10
100
50
10
5
1
0.5
0.1
0.05
0.01
$\frac{d\sigma}{du}$ (μB./(GeV/c)^2)
-1.4
-1.2
-1.0
-.8
-.6
-.4
-.2
0
u (GeV/c)^2

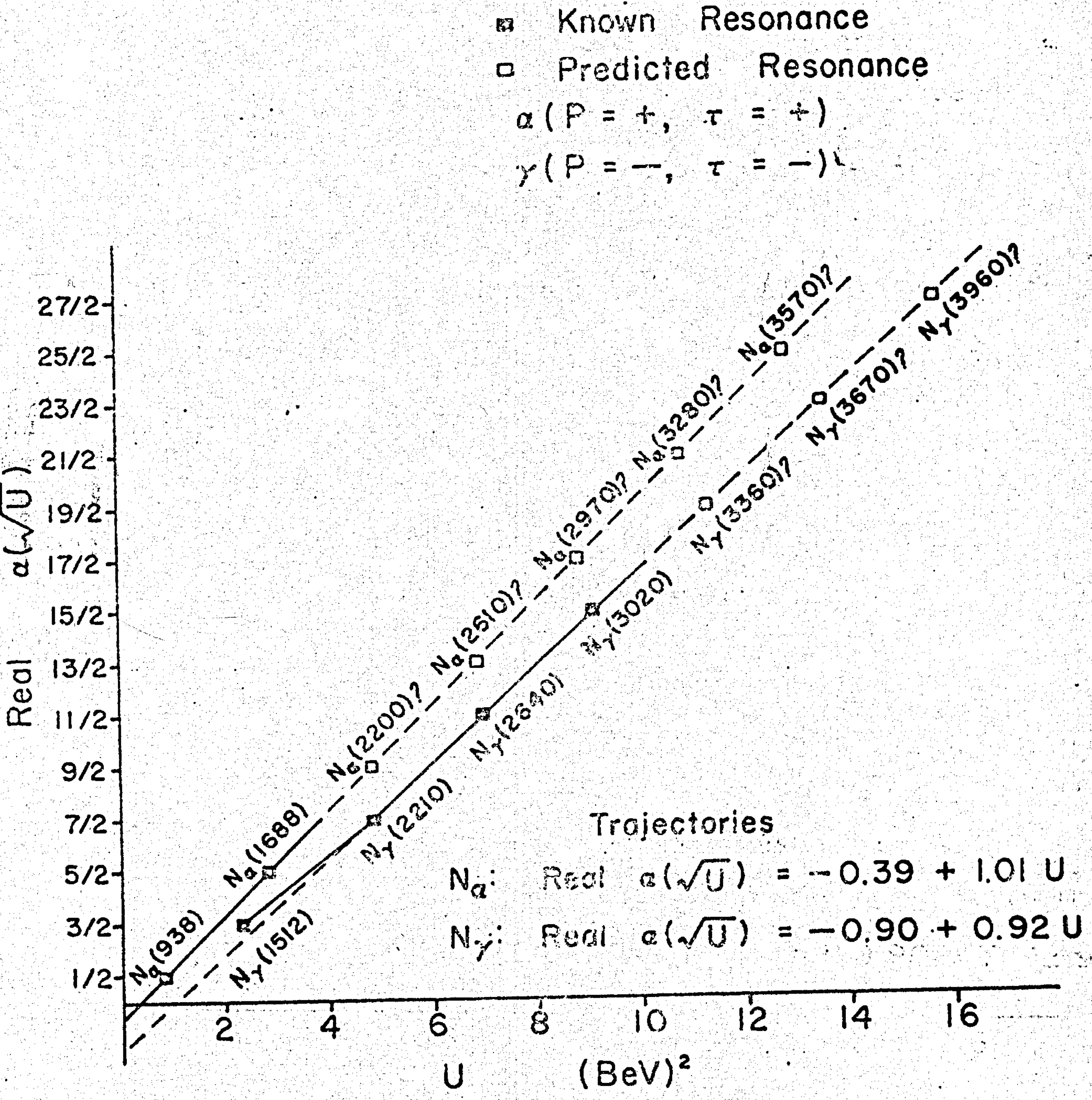
FIG. 8(a)

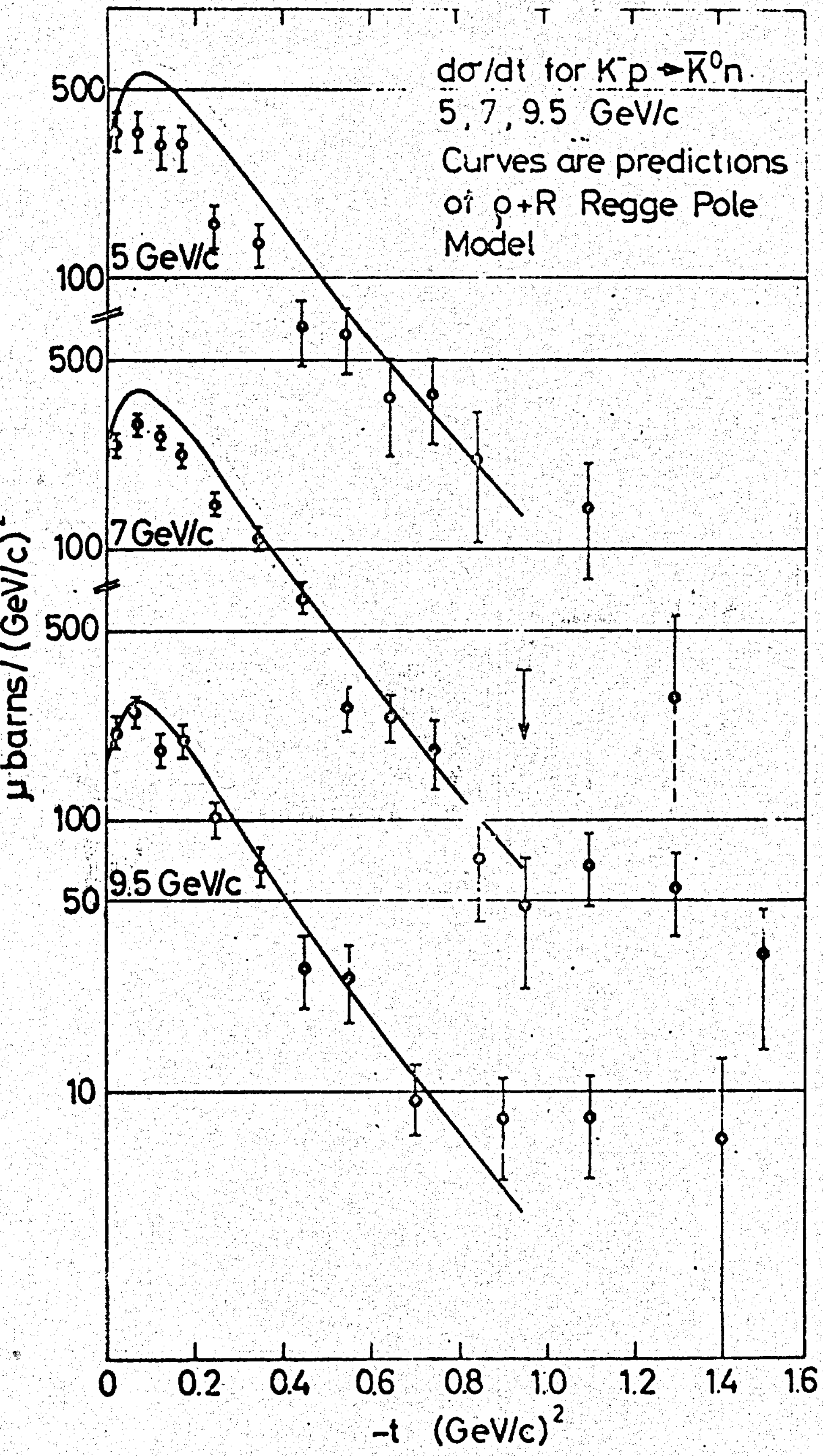
$\pi^- + p \longrightarrow p + \pi^-$
○ □ ▽ THIS EXPT.
⊙ ▼ FRISKEN, ET AL.
4
6
8
100
50
10
5
1
0.5
0.1
0.05
0.01
$\frac{d\sigma}{du}$ (μB./(GeV/c)^2)
-1.4
-1.2
-1.0
-.8
-.6
-.4
-.2
0
u (GeV/c)^2

I = 3/2, Y = +1 Regge Recurrences



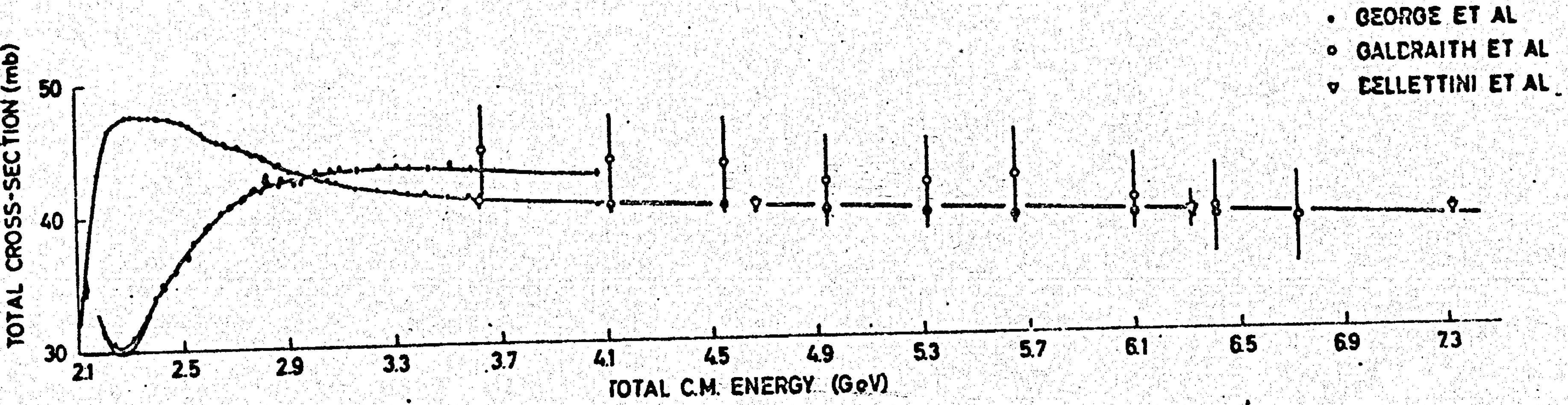
I = 1/2, Y = 1 Regge Recurrences



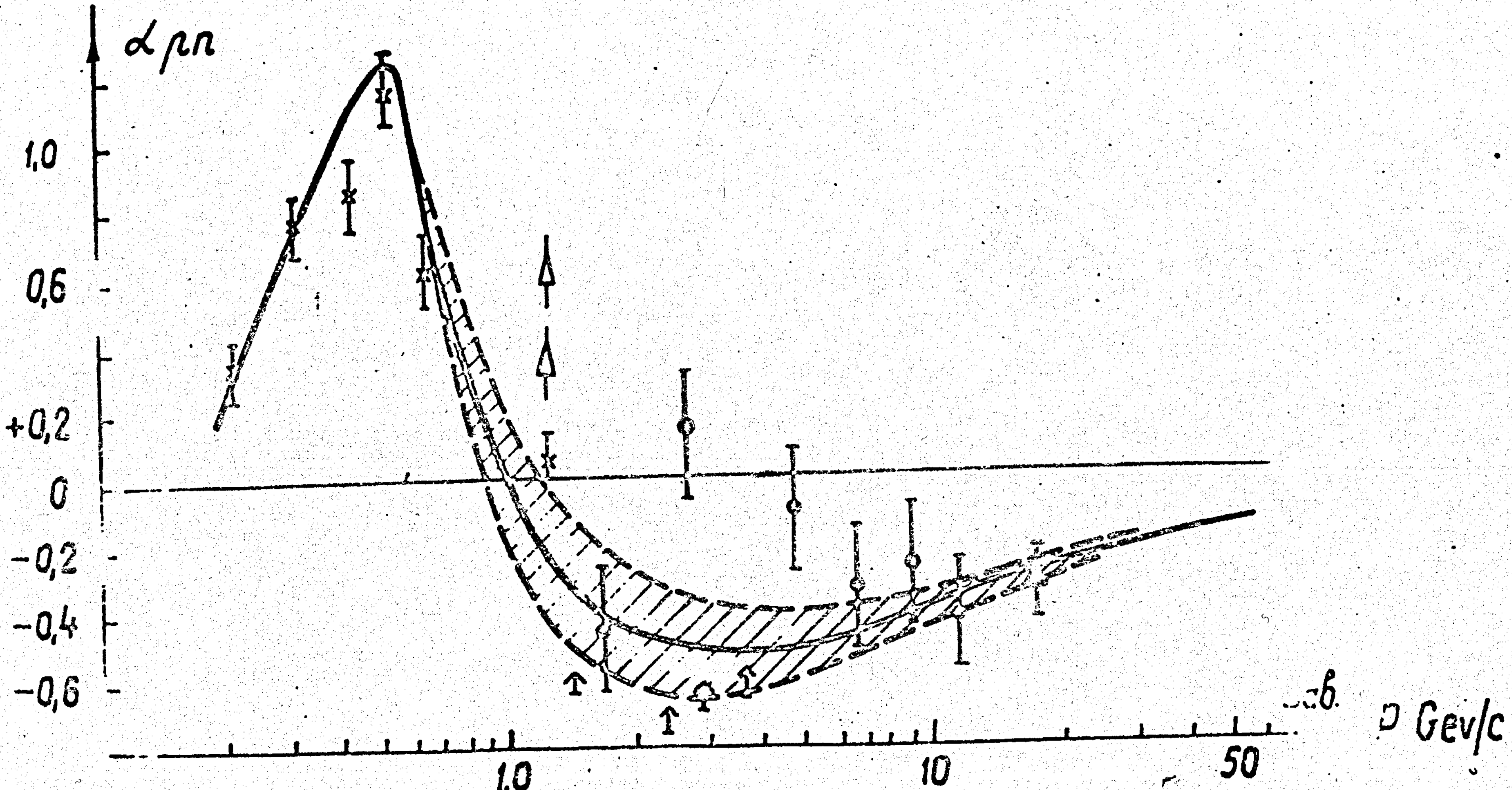


$d\sigma/dt$ for $K^-p \rightarrow \bar{K}^0 n$
5, 7, 9.5 GeV/c
Curves are predictions of ρ+R Regge Pole Model
5 GeV/c
7 GeV/c
9.5 GeV/c
500
100
500
100
500
100
50
10
μ barns/(GeV/c)^2
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
−t (GeV/c)^2

FIG 1



• GEORGE ET AL
○ GALBRAITH ET AL
▽ BELLETTINI ET AL
TOTAL CROSS-SECTION (mb)
50
40
30
2.1
2.5
2.9
3.3
3.7
4.1
4.5
4.9
5.3
5.7
6.1
6.5
6.9
7.3
TOTAL C.M. ENERGY (GeV)



αpn
1,0
0,6
+0,2
0
-0,2
-0,4
-0,6
1,0
10
50
б.
p Gev/c

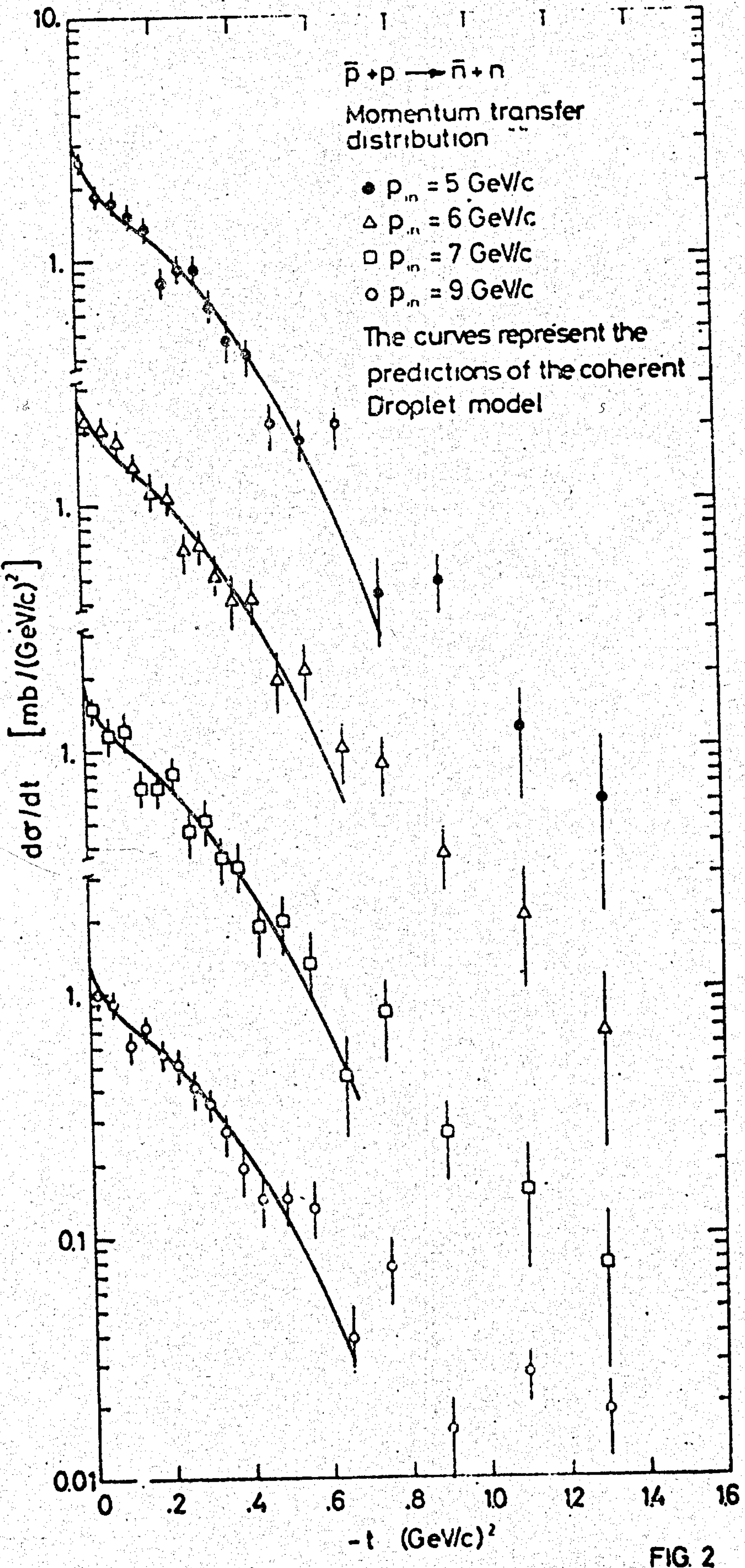
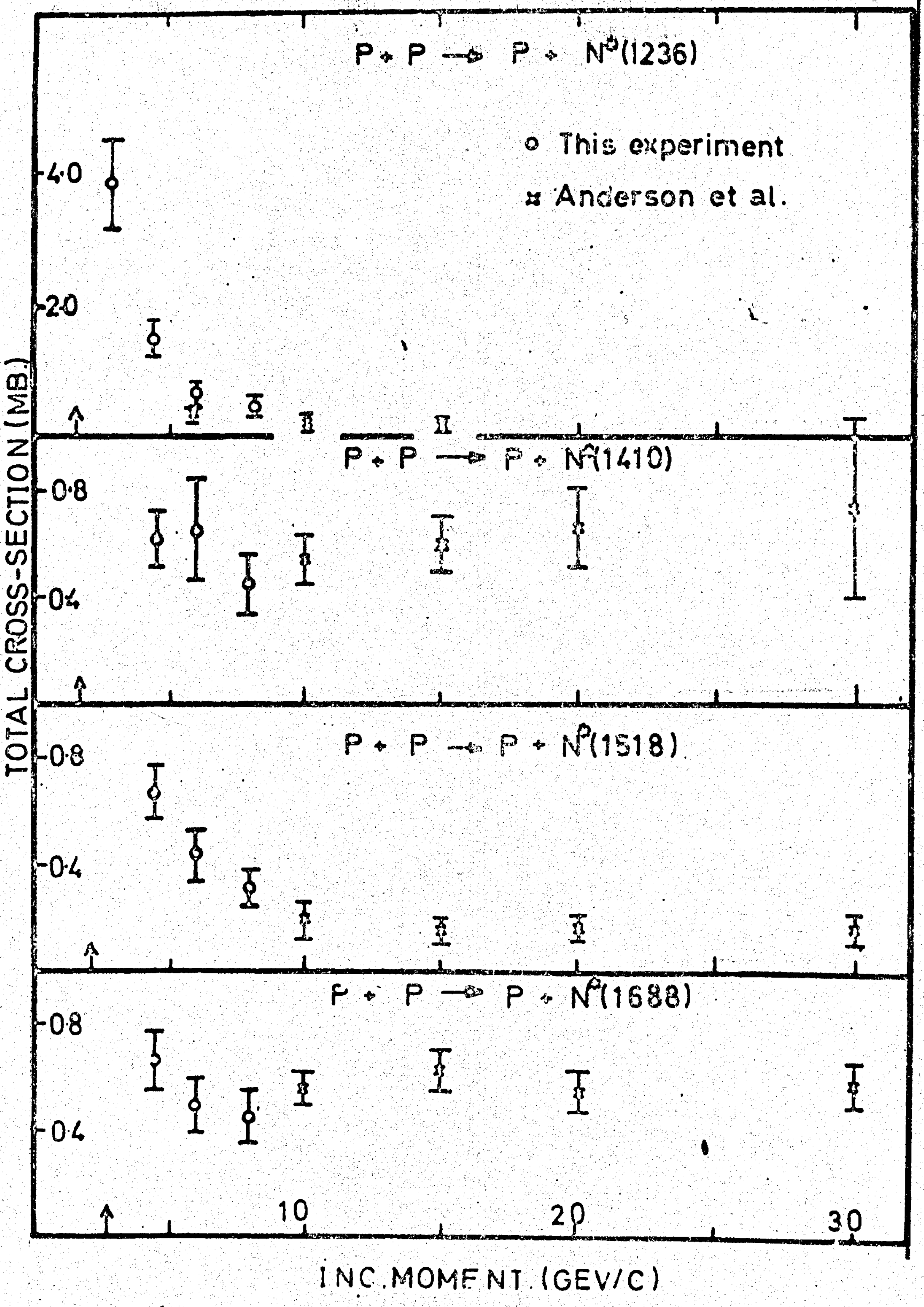
$\bar{p}+p \longrightarrow \bar{n}+n$
Momentum transfer distribution
● p_{in} = 5 GeV/c
△ p_{in} = 6 GeV/c
□ p_{in} = 7 GeV/c
○ p_{in} = 9 GeV/c
The curves represent the predictions of the coherent Droplet model
dσ/dt [mb/(GeV/c)^2]
10.
1.
1.
1.
1.
0.1
0.01
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
-t (GeV/c)^2

FIG. 2


P + P → P + N^p(1236)
o This experiment
¤ Anderson et al.
4·0
2·0
P + P → P + N^p(1410)
0·8
0·4
P + P → P + N^p(1518)
0·8
0·4
P + P → P + N^p(1688)
0·8
0·4
10
20
30
TOTAL CROSS-SECTION (MB.)
INC. MOMENT. (GEV/C)

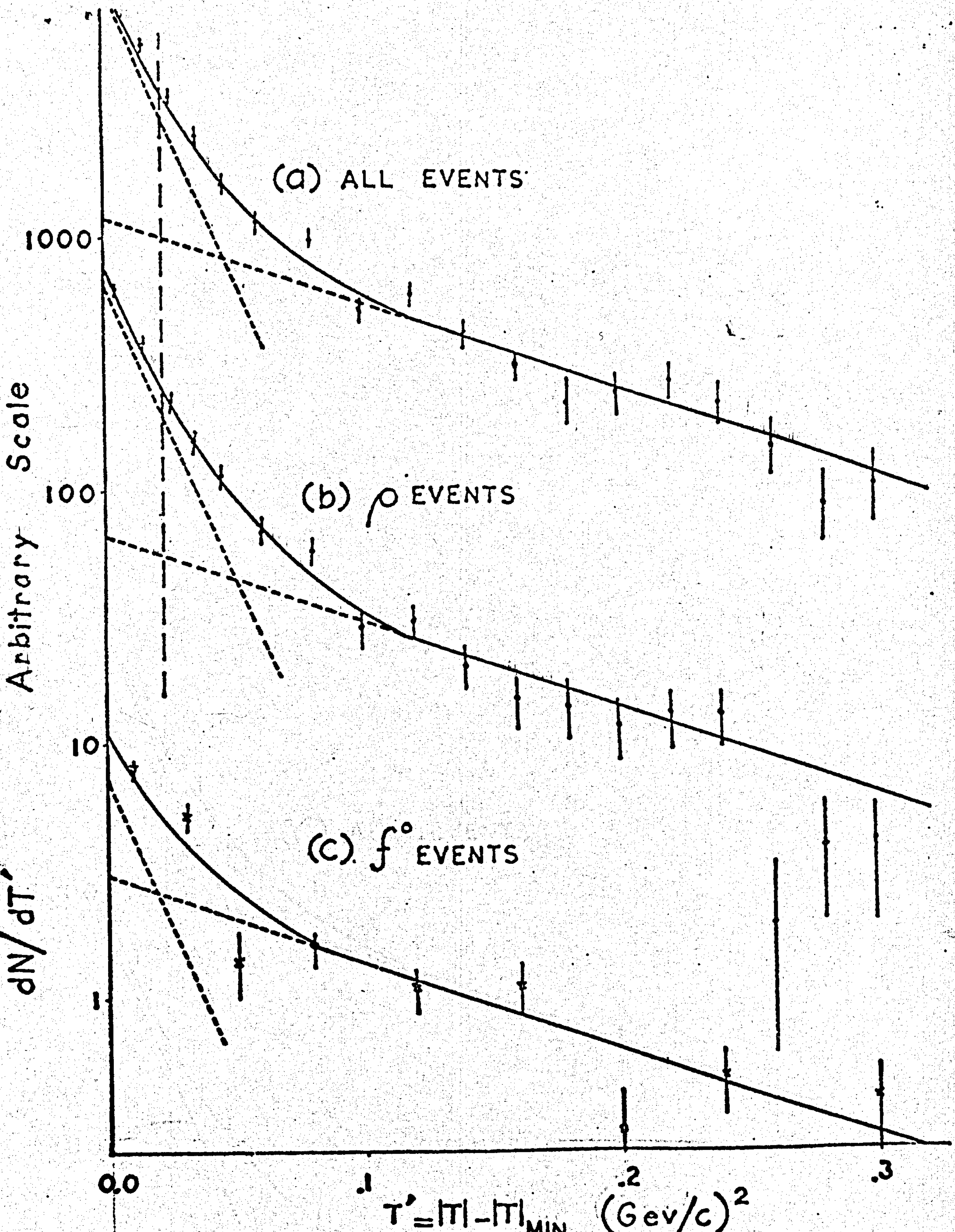
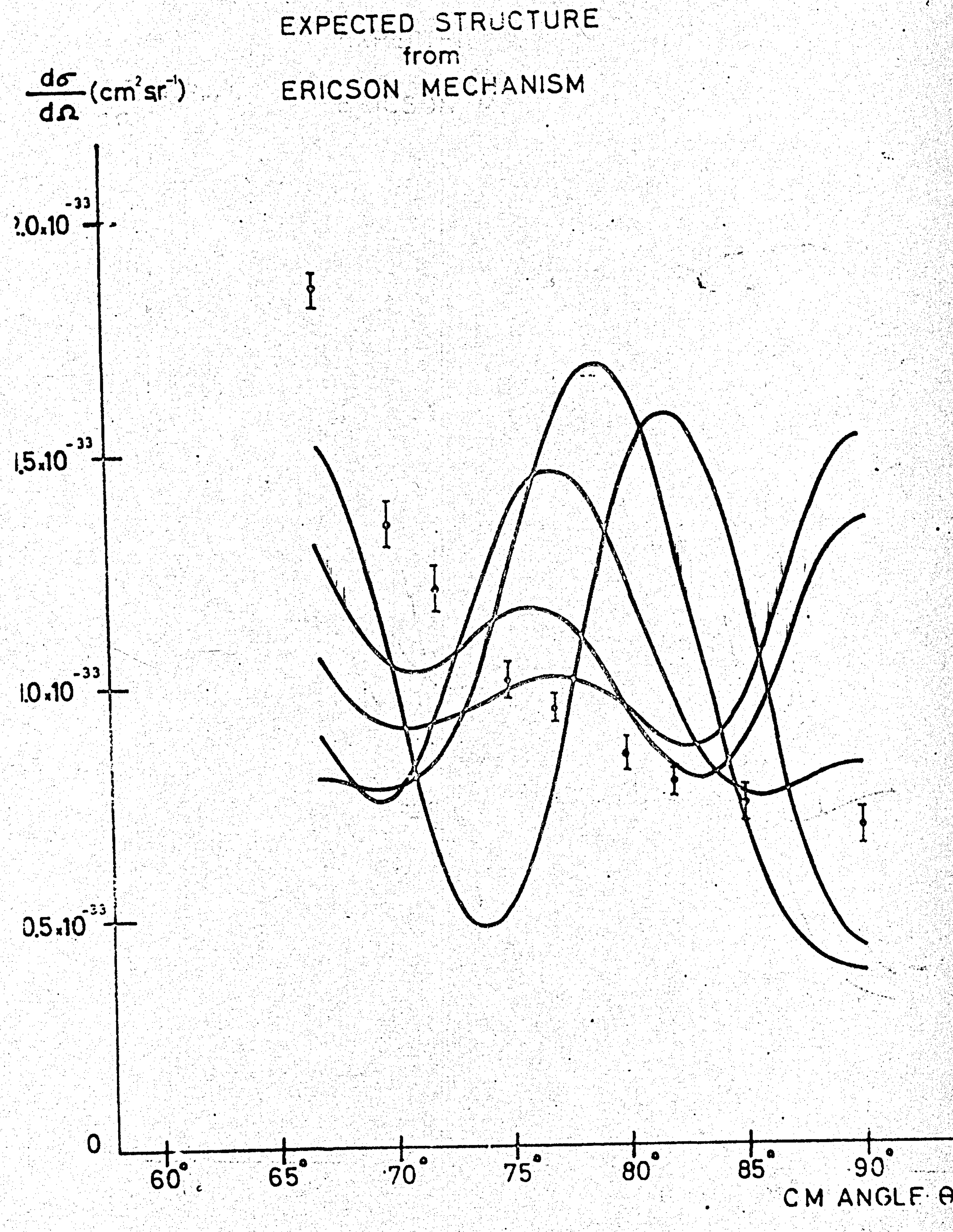
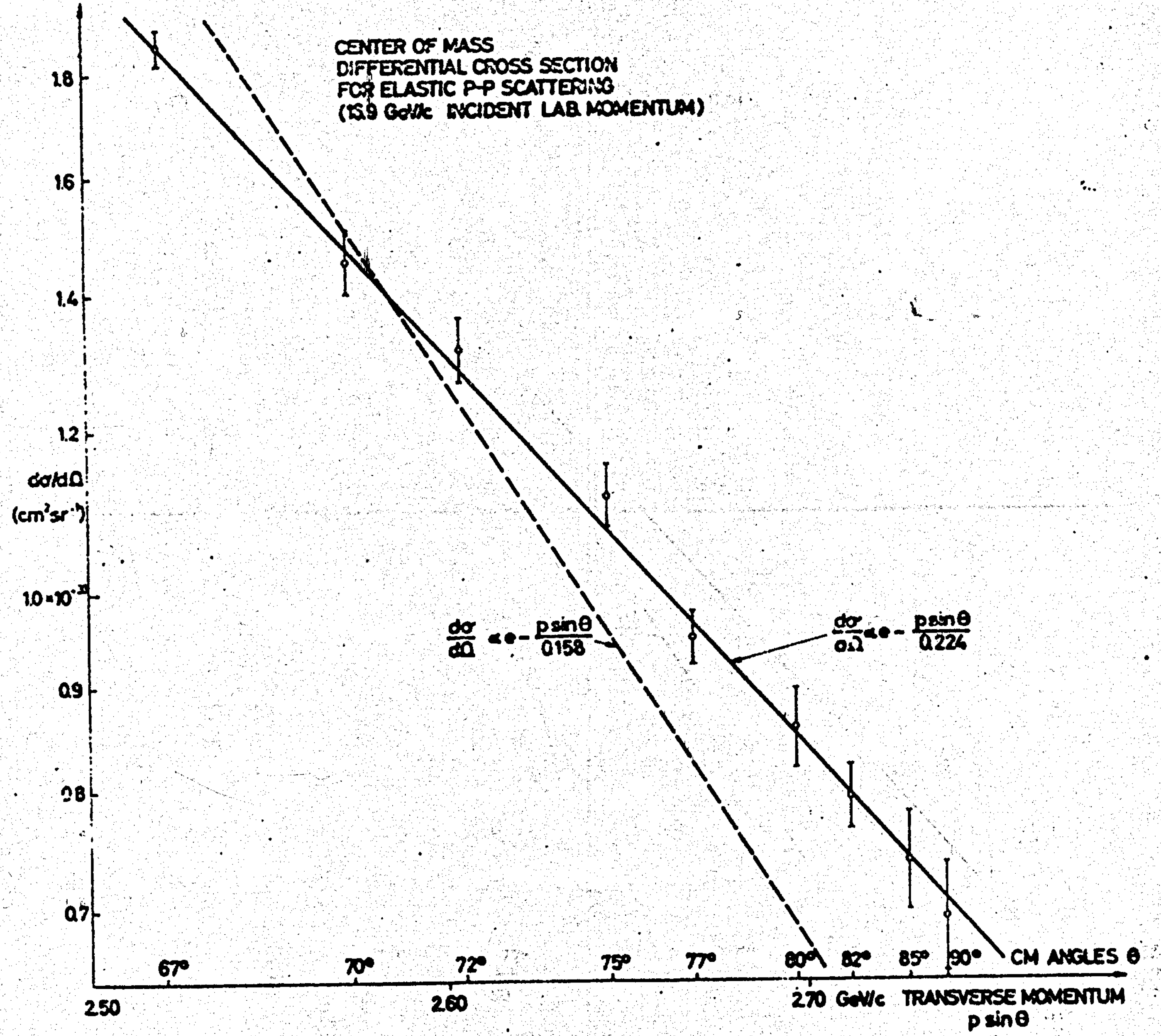
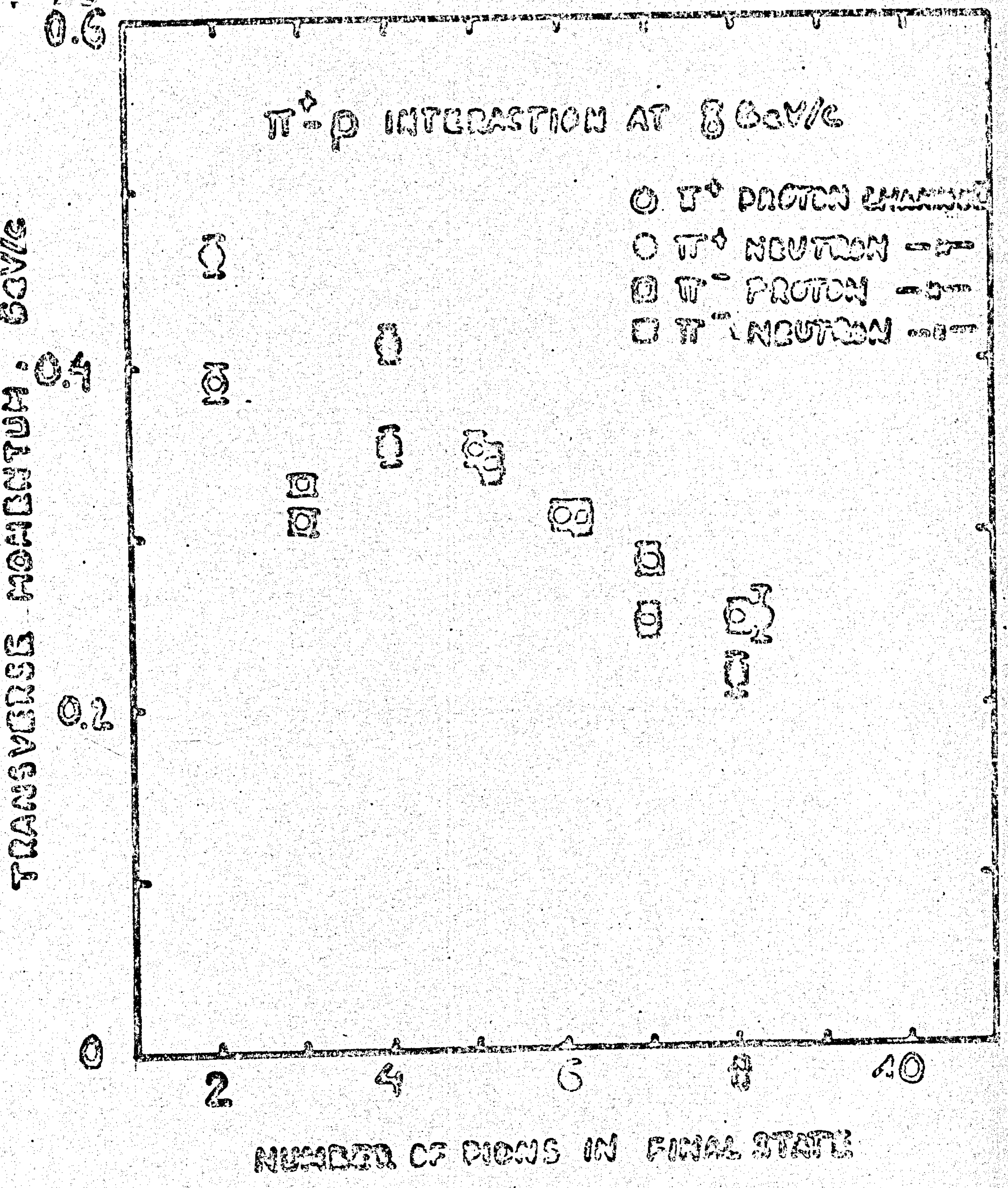

(a) ALL EVENTS
(b) ρ° EVENTS
(c). f° EVENTS
1000
100
10
1
dN/dT' Arbitrary Scale
0.0
.1
.2
.3
T'=|T|-|T|MIN (Gev/c)²

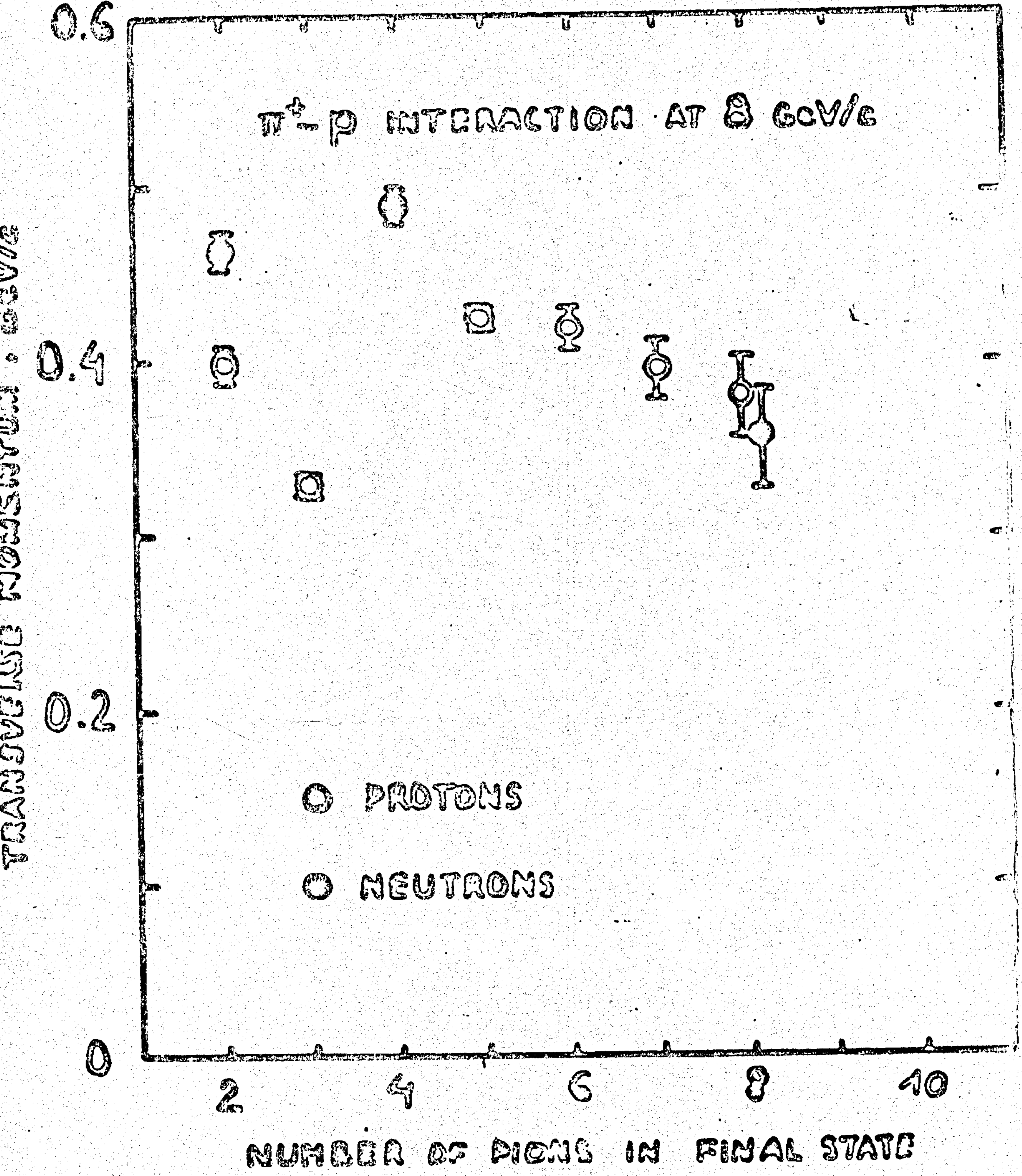
FIG.1

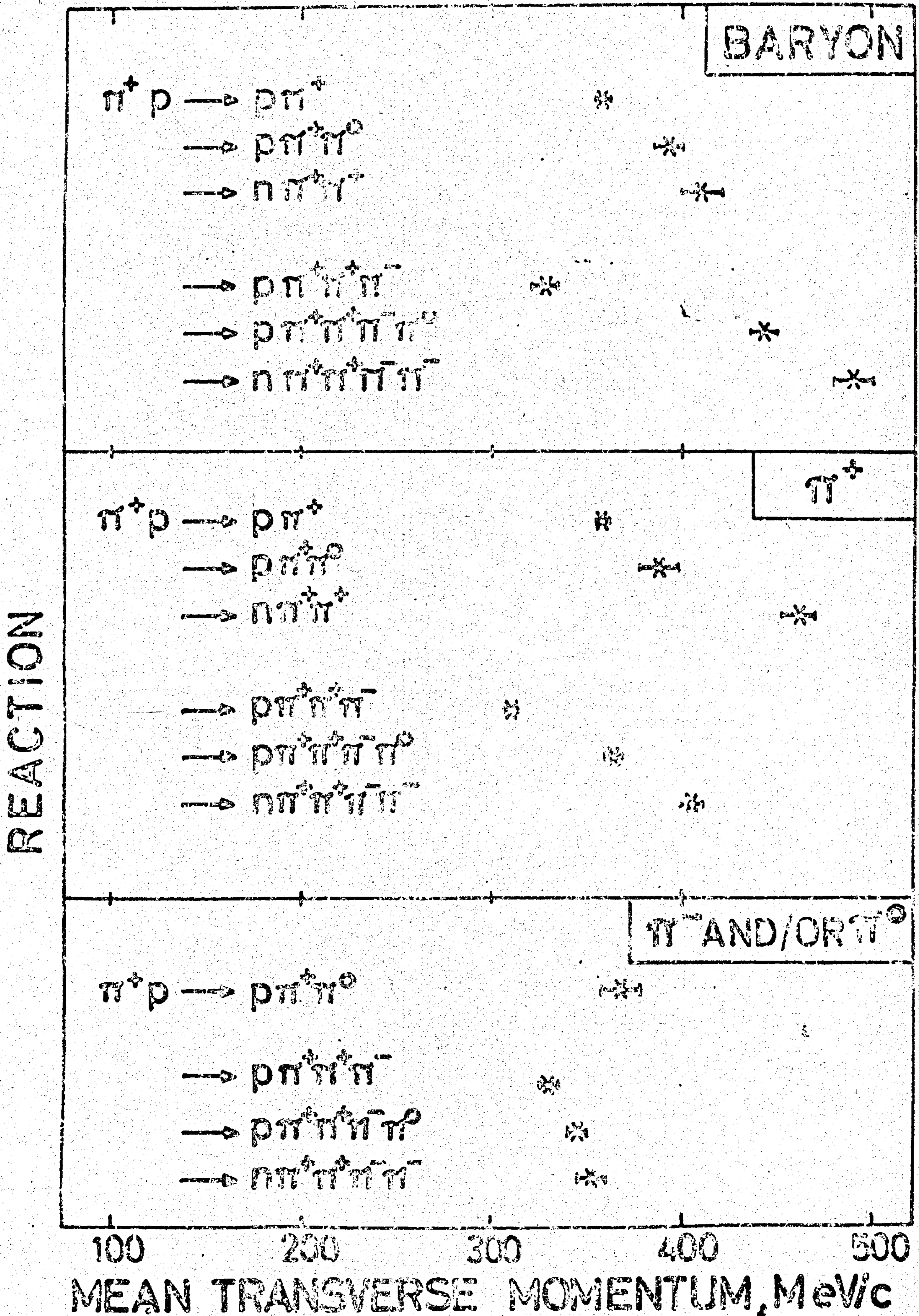


EXPECTED STRUCTURE
from
ERICSON MECHANISM

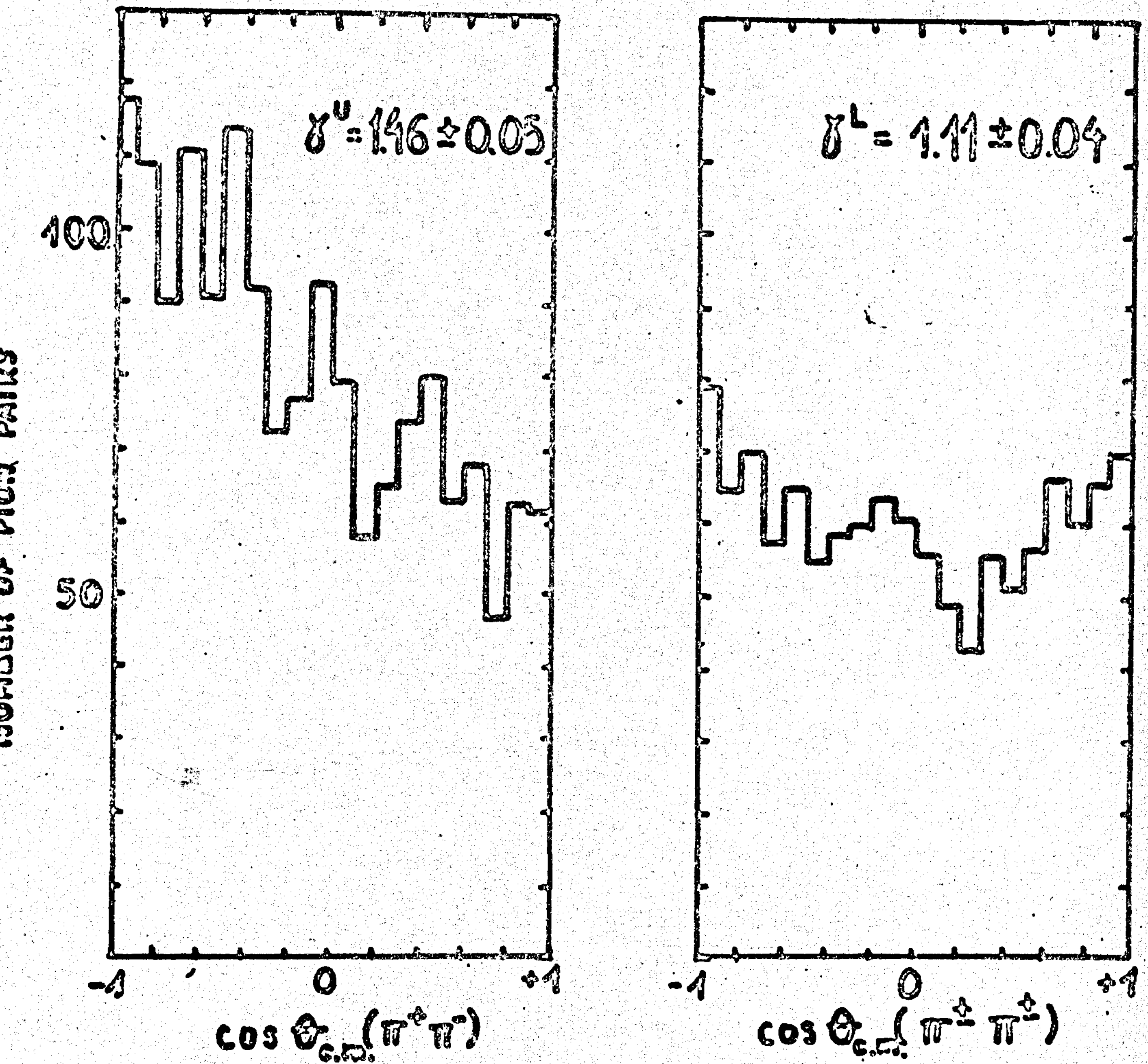

CENTER OF MASS
DIFFERENTIAL CROSS SECTION
FOR ELASTIC P-P SCATTERING
(15.9 GeV/c INCIDENT LAB MOMENTUM)
1.8
1.6
1.4
1.2
dσ/dΩ
(cm²sr⁻¹)
1.0×10^{-30}
0.9
0.8
0.7
$\frac{d\sigma}{d\Omega}\propto e^{-\frac{p\sin\theta}{0.158}}$
$\frac{d\sigma}{d\Omega}\propto e^{-\frac{p\sin\theta}{0.224}}$
67°
70°
72°
75°
77°
80°
82°
85°
90°
CM ANGLES θ
2.50
2.60
2.70 GeV/c
TRANSVERSE MOMENTUM
p sin θ


π⁺-p INTERACTION AT 8 GeV/c
π⁺ PROTON CHANNEL
π⁺ NEUTRON —"—
π⁻ PROTON —"—
π⁻ NEUTRON —"—
TRANSVERSE MOMENTUM, GeV/c
0.6
0.4
0.2
0
2
4
6
8
10
NUMBER OF PIONS IN FINAL STATE


π+-p INTERACTION AT 8 GeV/c
TRANSVERSE MOMENTUM , GeV/c
0.6
0.4
0.2
0
2
4
6
8
10
NUMBER OF PIONS IN FINAL STATE
○ PROTONS
● NEUTRONS


BARYON
$\pi^+ p \to p\pi^+$
$\to p\pi^+\pi^0$
$\to n\pi^+\pi^+$
$\to p\pi^+\pi^+\pi^-$
$\to p\pi^+\pi^+\pi^-\pi^0$
$\to n\pi^+\pi^+\pi^+\pi^-$
π^+
$\pi^+ p \to p\pi^+$
$\to p\pi^+\pi^0$
$\to n\pi^+\pi^+$
$\to p\pi^+\pi^+\pi^-$
$\to p\pi^+\pi^+\pi^-\pi^0$
$\to n\pi^+\pi^+\pi^+\pi^-$
π^- AND/OR π^0
$\pi^+ p \to p\pi^+\pi^0$
$\to p\pi^+\pi^+\pi^-$
$\to p\pi^+\pi^+\pi^-\pi^0$
$\to n\pi^+\pi^+\pi^+\pi^-$
REACTION
100
200
300
400
500
MEAN TRANSVERSE MOMENTUM, MeV/c

$\pi^+ p \to p\, 4\pi^+ 3\pi^-$ AT 8 GeV/c



9

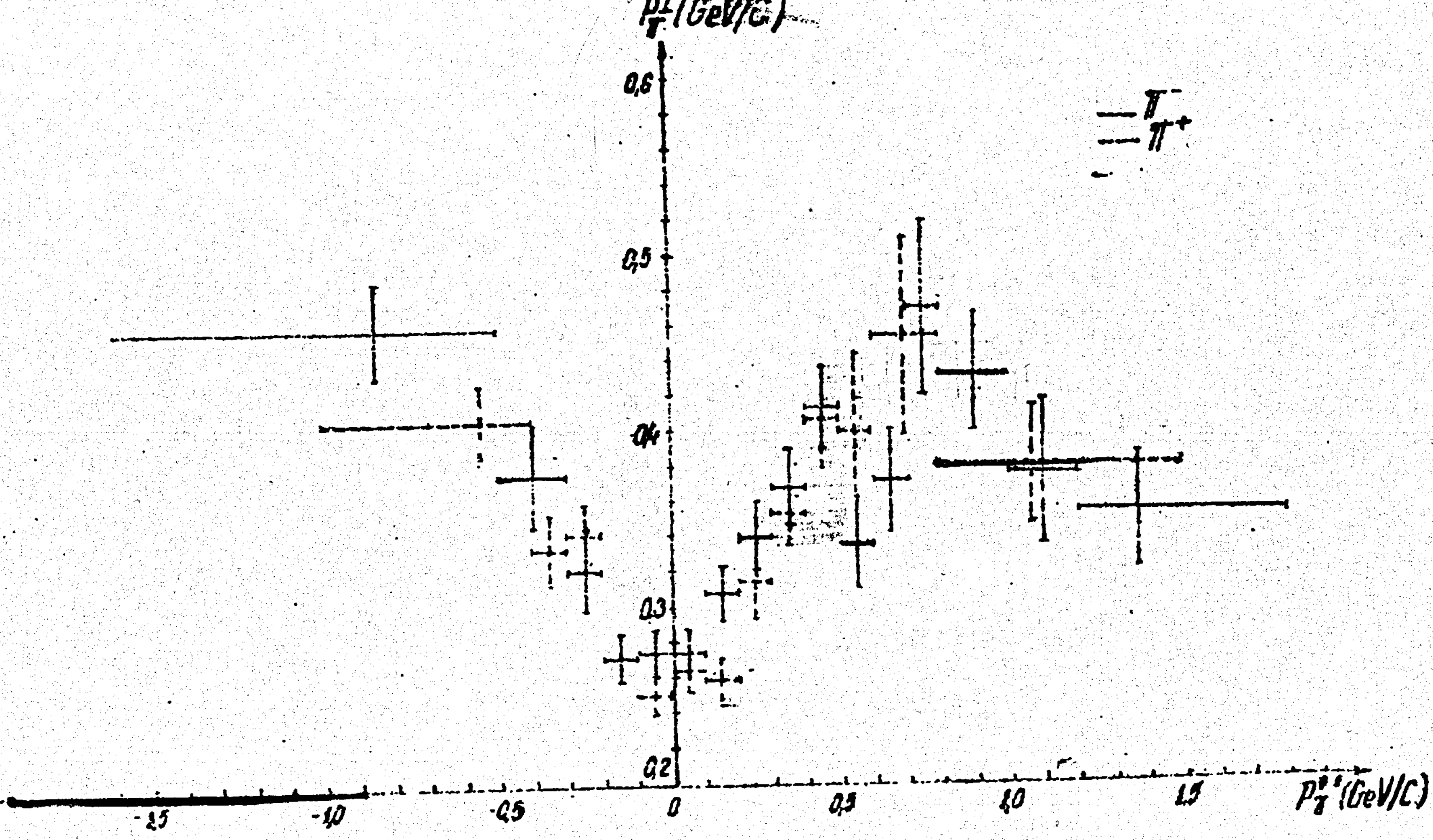
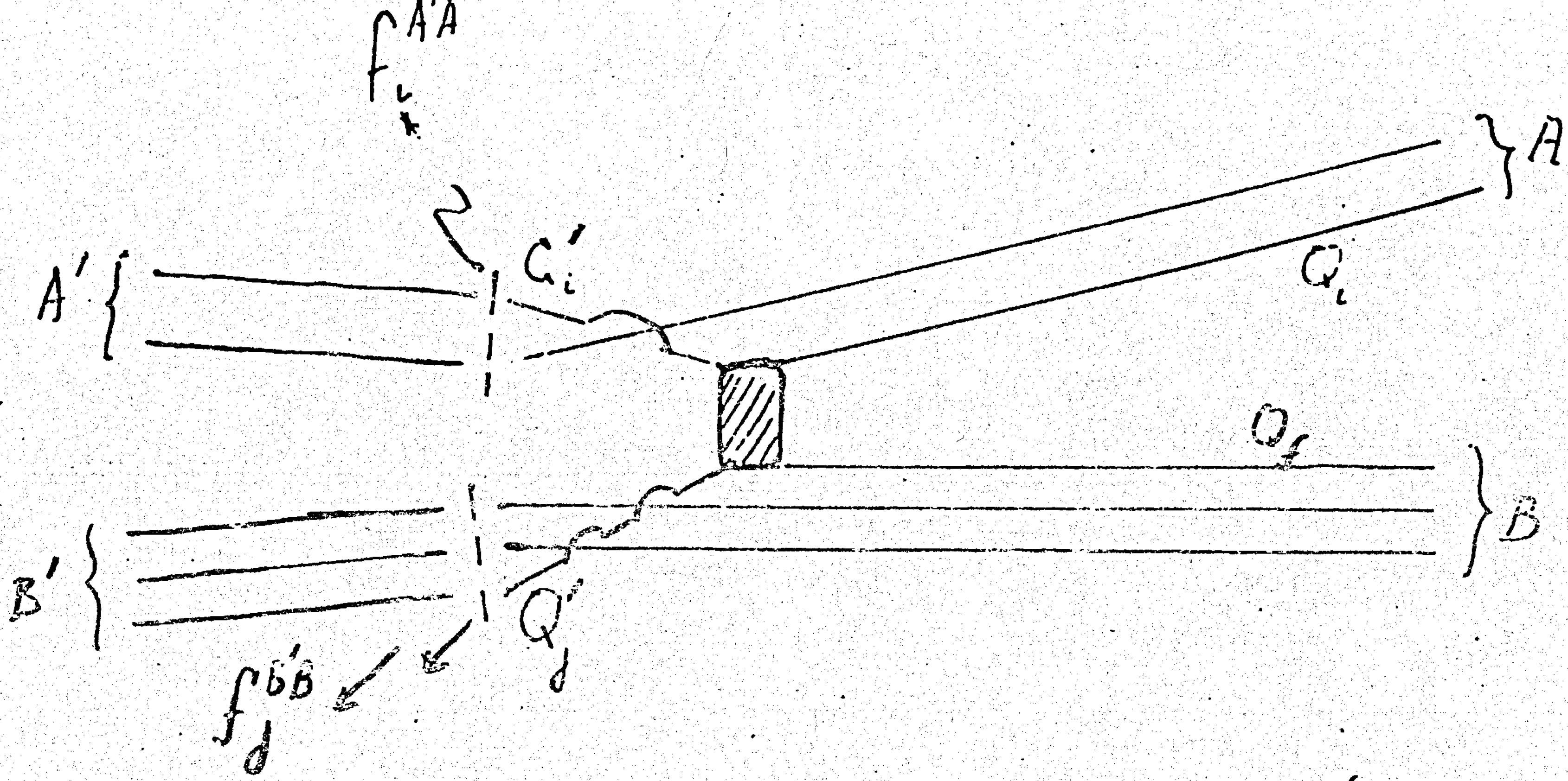
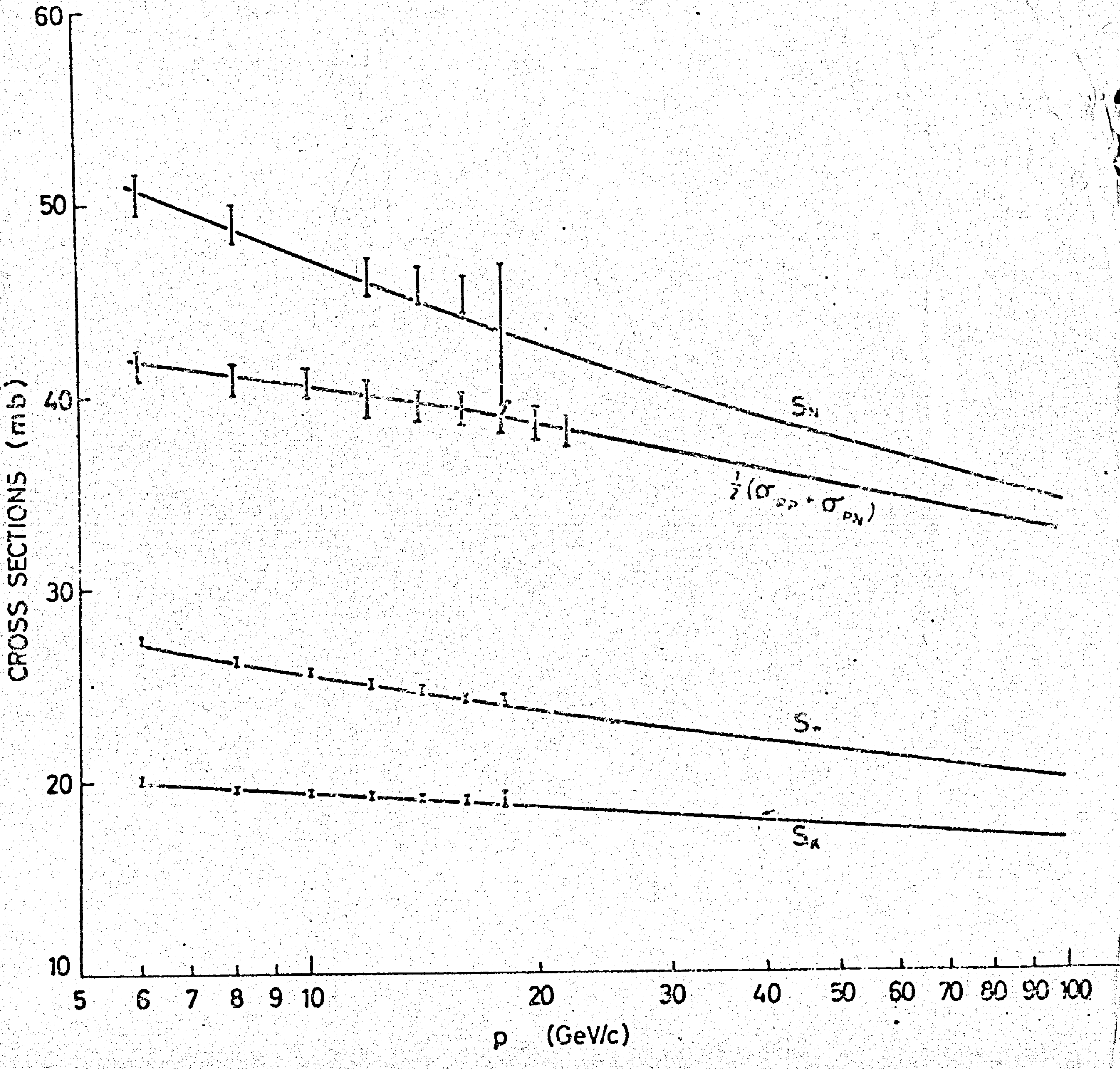

$\bar{P}_{\pi}^{\perp}$ (GeV/C)
0,6
0,5
0,4
0,3
0,2
π^-
π^+
-1,5
-1,0
-0,5
0
0,5
1,0
1,5
$P_{\pi}^{*\parallel}$ (GeV/C)

Fig. 7



$$\langle A'B' | T | AB \rangle = \sum_{i,j} \langle Q'_i Q'_j | T | Q_i Q_j \rangle f_i^{A'A}(t) f_j^{B'B}(t)$$



Издательский отдел Объединенного института ядерных исследований
Заказ 8439, Тираж 550, 4,6 уч.-изд. л.
Октябрь 1969 г.