Ref.TH.2037-CERN

BACKWARD MESON-BARYON SCATTERING AND

GEOMETRICAL PROPERTIES OF BARYONIC EXCHANGES

J. P. Ader

CERN -- Geneva

ABSTRACT

On the basis of "b universality" hypothesis, Regge behaviour and SU(3) symmetry, we discuss processes of the type $0^-\frac{1}{2}^+ \to 0^-\frac{1}{2}^+$ at backward angles when significant data are available. Related annihilation processes by line - reversal are also studied and duality constraints are taken into account. On the whole a satisfactory scheme seems to emerge.

Ref.TH.2037-CERN

26 June 1975

1. INTRODUCTION

Detailed behaviour of two-body reactions at high energy, especially polarization features, are difficult to explain in a coherent and systematic way. Various modifications to standard Regge models are sometimes successful, sometimes encounter strong difficulties. The situation is particularly confusing for baryon exchanges. Very little is known on backward amplitudes; analyses so far performed remain ambiguous and rather model dependent; phenomenological tools as dispersion relations and fixed transfer finite energy sum rules are less powerful in the backward direction than in the forward one. Finally, the fact that different exchanged naturalities must be present simultaneously by analyticity requirement and the fact that several external quantum numbers can be generally exchanged, obscures the situation still further.

Essentially, after the work of Harari [1], it has been realized that amplitude spin properties may look simpler and more universal when studied in terms of s channel dynamics. In this spirit, a lot of applications have been recently made [2], all of which having in common the derivative relation for s channel helicity amplitudes with net helicity flip m :

$$M_m(s,t) = \lambda_m(s)(-t)^{\frac{m}{2}} \frac{d^m}{dt^m} M_o(s,t) \qquad (1)$$

where $\lambda_m(s)$ is a function of s only. This relation is the direct consequence of "b universality", i.e., for the exchange of a given set of quantum numbers in the crossed channel, the existence of a universal profile $f(s,b)$ in the impact parameter plane from which profiles for all m are readily obtained :

$$\tilde{M}_m(s,b) = b^m f(s,b) \qquad (2)$$

This relation with the further assumption that there exists one helicity amplitude that must be well described by a pure Regge pole exchange was proposed as a systematic for the phenomenology of few-body reactions under the name of Reggeometry [3]. An encouraging analysis of some basic processes, including πN backward scattering, has been performed, showing the ability for describing with some consistency both forward and backward scattering.

In the present work we intend to understand if this conjecture, together with duality prescriptions and SU(3) symmetry, is compatible with existing data on meson-baryon scattering at backward angles and annihilation processes associated by line-reversal. Available data can be classified into three important groups :

i) the three $\pi N \rightarrow N\pi$ charge states where much information is available [4)-7)] with the line reversed counterpart [8)] $\bar{p}p \rightarrow \pi^-\pi^+$;

ii) those with exchanged trajectories similar to the previous ones : $\bar{K}N \rightarrow Y\pi$; although available data are poor, this set is very interesting allowing direct SU(3) comparisons [9)];

iii) those with simple duality expectations because of exotic direct channel : $K^+p \rightarrow pK^+$ [8),10)] exotic crossed channel : $\bar{p}p \rightarrow K^-K^+$ [8)] or duality diagrams : $\pi^-p \rightarrow \Lambda K^o$ [11)]. Moreover, the large positive polarization measured in this last process, together with new A and R measurements at 5 GeV/c [12)], provide strong information on the spin structure of the amplitudes.

In order to obtain a description of all these data, we start by fixing the exchange parametrization from the study of πN reactions. Then unitary symmetry and duality are invoked to explain other reactions; we assume that in a given multiplet, amplitudes corresponding to different exchanges are scaled by the trajectory values : they remain the same, in shape and strength, apart from SU(3) coefficients and unavoidable kinematical breaking effects. Thus, from N_α and Δ_δ amplitudes, we are able to describe Σ and Λ exchanges in $K^+p \rightarrow pK^+$ and $\pi^-p \rightarrow \Lambda K^o$ with a reasonable limited number of parameters.

Let us emphasize that, in this scheme, the choice of the pure Regge amplitude for N and Δ trajectories reverberates on other trajectories and explains, in particular, the surprising breaking of line reversal relation between $K^+p \rightarrow pK^+$ and $\bar{p}p \rightarrow K^-K^+$ [8)]. We suggest that this fact is a general property of baryon exchanges having a non-flip amplitude (in the backward direction) well approximated by a pure Regge form. The derivative rule (1) applied to an exchange degenerate pair of trajectories led in all cases to the fact that the "real" process has a lower cross-section than the "rotating" one. We believe that the general compatibility here obtained, especially the good agreement of this choice with detailed spin measurements in $\pi^-p \rightarrow \Lambda K^o$, supports strongly this explanation.

A general presentation of the model is made in Section 2. Details are given with data discussion reaction by reaction in Section 3, whereas final comments and conclusions are collected in Section 4.

2. PRESENTATION OF THE MODEL

First we describe our parametrization, then discuss how unitary symmetry is applied and finally point out an interesting prediction on line reversed processes $K^+p \to pK^+$ and $\bar{p}p \to K^-K^+$.

2.1 Parametrization of N and Δ exchanges

The derivative relation (1) allows to construct one amplitude from the other once the amplitude of a pure Regge form is chosen, i.e., the geometry of the related exchange. We have already conjectured [3] that a peripheral geometry should be associated to the N_α trajectory and a central one to the Δ_δ; thus for both exchanges the s channel helicity amplitude, well approximated by a pure Regge pole exchange, is the non-flip one (in the backward direction). In fact, this choice is quite unavoidable as will be explained in Section 3.1. Consequently, let us start from an s channel non-spin flip amplitude of the form :

$$M_0(s,u) = \beta_0 \left[1 + 2\, e^{-i\pi \bar{\alpha}(u)} \right] \left(\frac{s}{s_0}\right)^{\bar{\alpha}(u)+\frac{1}{2}} \qquad (3)$$

where β_0 is the residue, s_0 is a scale factor and $\bar{\alpha}(u) = \alpha_0 + \alpha' u - \frac{1}{2}$ the linear trajectory.

By (1) the flip amplitude is straightforwardly deduced :

$$M_1(s,u) = \beta_1' \sqrt{u_m - u}\; \alpha' \left[\log\left(\frac{s}{s_0}\right) + 2\, e^{-i\pi\bar{\alpha}(u)} \left(\log\left(\frac{s}{s_0}\right) - i\pi \right) \right] \left(\frac{s}{s_0}\right)^{\bar{\alpha}(u)+\frac{1}{2}} \qquad (4)$$

where u_m is the limiting transfer value and β_1' may depend on the c.m. energy s. Such a parametrization is far from a conventional Regge one. With the choice :

$$\beta_1' = \beta_1 \left[\log\left(\frac{s}{s_0}\right) + \lambda - i\frac{\pi}{2} \right]^{-1} \qquad (5)$$

a usual Regge pole behaviour is restored asymptotically, whereas a cut-like contribution is controlled by the λ parameter :

$$M_1(s,u) = \beta_1 \sqrt{u_m - u}\ \alpha' \left[\left(1 + \tau e^{-i\pi\bar{\alpha}(u)}\right) + \left(\log\left(\frac{s}{s_0}\right) + \lambda - i\frac{\pi}{2}\right)^{-1} \left(i\frac{\pi}{2} - \lambda - \tau \left(i\frac{\pi}{2} + \lambda\right) e^{-i\pi\bar{\alpha}(u)} \right) \right] \left(\frac{s}{s_0}\right)^{\bar{\alpha}(u)+\frac{1}{2}} \tag{6}$$

In our fit we have used a polynomial transfer dependence in the residues β_0 and β_1. A very convenient choice *), which has perhaps a deeper significance [2] than an "ad hoc" parametrization, consists in taking Laguerre polynomials. Their derivative property :

$$L_m^{\alpha}(x)' = - L_{m-1}^{\alpha+1}(x) \tag{7}$$

and functional relation

$$L_m^{\alpha}(x) = L_m^{\alpha+1}(x) - L_{m-1}^{\alpha+1}(x) \tag{8}$$

guarantee b universality term-by-term for each trajectory with the following expansion of the residues :

$$\beta_i = G_i \sum_k c_k L_k^i(-uX) \tag{9}$$

where
$$X = \alpha' \log\left(\frac{s}{s_0}\right) \quad \left(\alpha' \log\left(\frac{s}{s_0}\right) - i\pi\right)$$

for the real (rotating) part of the amplitude; $(i = 0,1)$ and c_k are common constants to all amplitudes. Effectively, Eqs. (7) and (8) lead to :

$$\frac{d}{du}\left[e^{Xu} L_k^i(-uX)\right] = \frac{d}{du}\left[e^{Xu}\right] L_k^{i+1}(-uX)$$

Finally, duality partners N_γ and N_β of N_α and Δ_δ trajectories are included by modifying residues as follows :

$$G_i^{N(\Delta)} \longrightarrow G_i^{N(\Delta)}\left(1 \pm \varepsilon^{N(\Delta)}\right)$$

where the upper sign corresponds to the real part of the amplitude, the lower to the rotating phase one and $\varepsilon^{N(\Delta)}$ stands for the relative amount of N_γ to N_α (N_β to Δ_δ).

*) First suggested by G. Cohen-Tannoudji (private communication).

In our calculation the replacement of s by $s-\Sigma/2$ where Σ is the sum of squared external masses, has been made in order to take into account s-t symmetry. This replacement will turn out to be quite important in $K^+p \to pK^+$ where an asymptotic parametrization is expected to work down to rather low energy and where intercepts of dominant trajectories are very low.

2.2 Generation of other exchanges

In order to extend our N and Δ amplitudes to other processes, we apply SU(3) constraints to residues and trajectories : first we assume that in a given multiplet the same helicity amplitude is well approximated by a naïve Regge formula. Note that this does not induce the same geometry to the different members of the multiplet since strong kinematical SU(3) breakings are expected from mass differences. For instance, the impact parameter profile of $\mathrm{Im}\, M_0$ corresponding to the Σ_α trajectory is compared with the N_α one at 6 GeV/c in Fig. 1a. Whereas the latter displays a rather peripheral structure, a central one is obtained for the Σ_α trajectory, this strong change coming only from the difference between intercepts (cf., Table I):

$$\alpha_0^{N_\alpha} - \alpha_0^{\Sigma_\alpha} = .41$$

Unitary symmetry is also invoked as a first reasonable guess of the relative strength couplings, going from one reaction to another. The transfer dependence induced by Laguerre polynomials is taken as invariant as well as the flip/non-flip ratio. Symmetry breaking effects are allowed by considering different scale factors s_0 and λ parameters which simulate cut contributions. Finally, the conjectured symmetry is imposed *) at $u=0$ on the residues in the following way :

$$G_0' = C\, G_0 \left(\frac{s_0'}{s_0}\right)^{\alpha_0} \tag{10}$$

where the intercept α_0' of the new trajectory has been replaced by the one of the initial trajectory (N or Δ) in order to preserve the energy dependence given by Chew-Frautschi plots. The combined SU(3) Clebsch-Gordan coefficients and isospin factors C are given with corresponding exchange in Table II for reactions of interest.

---

*) Where and how the comparison must be made is not known, thus involving some unavoidable arbitrariness.

Duality is a necessary part of our analysis : an exchange degeneracy scheme must be prescribed such that Regge pole-like contributions possess a real phase in the exotic scattering $K^+p \to pK^+$ and a rotating one in the associated production $\pi^-p \to \Lambda K^0$, since then duality diagrams predict exchange degeneracy of resonances in $\bar{K}^0 p \to \pi^+\Lambda$. Evidence for this has been carefully discussed [13]. We are aware that duality requirements and SU(3) constraints, in general, are incompatible for baryonic trajectories; even without t channel duality constraints, no unique scheme seems to emerge [14]. However, for the two reactions considered here, some consistency may be obtained with the following prescriptions :

i) exchange degeneracy of trajectories between particles of alternating parity [i.e., (α,γ) and (β,δ) respectively];

ii) a value of the octet-octet mixing parameter $F = 0.25$; this value is compatible with experimental information on $\bar{K}N \to Y\pi$ reactions, and also explains why no indication of backward peak in $K^-p \to \Lambda\eta$ is observed [9];

iii) Λ_γ is a pure SU(3) singlet, in agreement with the observation that, if some mixing between the $\Lambda(1690)$ octet and the $\Lambda(1520)$ singlet is known, the mixing angle is small [15]; Σ_α and Σ_β are members of an octet as well as Λ_α, whereas Σ_δ is assigned to a decuplet. Lastly, for Σ_γ two opposite mixing possibilities exist [15] according to whether the $\frac{3}{2}^-$ state is at 1580 or 1665 MeV. The $\Sigma_\gamma(1580)$, the nearest of the Σ_α trajectory : $-0.75 + 0.9u$ is classified as predominantly in a decuplet and we finally choose a $(\Sigma_\alpha^8,\Sigma_\gamma^{10})$ exchange degeneracy.

Thus pairs $(\Sigma_\alpha^8,\Sigma_\gamma^{10})$ and $(\Sigma_\beta^8,\Sigma_\delta^{10})$ entering $K^+p \to pK^+$ with a real phase : $(1+e^{-i\pi\bar{\alpha}})+(1-e^{-i\pi\bar{\alpha}})$ would contribute as : $(1+e^{-i\pi\bar{\alpha}})-(1-e^{-i\pi\bar{\alpha}})$ in $\pi^-p \to \Lambda K^0$, in agreement with duality. Moreover, if the $(\Lambda_\alpha^8,\Lambda_\gamma^1)$ pair is real in $K^+p \to pK^+$, the singlet assignment and the octet parameter value $F = 0.25$ ensure that this contribution is of a rotating phase type in $\pi^+p \to K^+\Sigma^+$ and $\pi^-p \to K^+\Sigma^-$, in agreement with duality diagrams.

We must stress that a detailed and rigorous study of a baryon exchange degenerate scheme incorporating unitary symmetry is probably far beyond our actual knowldege, both theoretical and experimental, and it is not the aim of this work. Prescribing duality conditions which seem to be very natural, we want only to obtain from SU(3) reasonable restrictions on strength couplings, compatible with these duality constraints.

2.3 Line reversal prediction involving exchange degeneracy

An interesting prediction is implicitly contained in our parametrization. Taking an exact exchange degeneracy scheme for the non-flip amplitude and the pure Regge part of the flip one, we find in general for an exchange degenerate pair of trajectories, independently of parameter values :

$$\left| \frac{M_1\ (\mathrm{real})}{M_1\ (\mathrm{rot})} \right|^2 = 1 - \frac{\pi^2}{\log^2(\frac{s}{s_0}) + \pi^2} < 1 \qquad (11)$$

The equality of cross-sections, expected from exact duality, is broken by the non-Regge part of the flip amplitude in such a way that the "real" process will have a smaller cross-section than the "rotating" one. For asymptotic energies equality will be restored, but at presently available data, for which $\log(s/s_0)$ is of the same order of magnitude as π, the derivative relation combined with a strong dual hypothesis, leads to opposite predictions in the forward [16] and backward directions. The reason is that flip and non-flip amplitudes exchange their roles (a pure Regge flip amplitude is certainly a good approximation for the ρ pole), whereas the derivative relation remains the same. The propensity of real processes to have a bigger cross-section than the rotating one is well known [17] for meson exchanges, but the reverse for baryonic trajectories is a new and interesting prediction based on "b universality" hypothesis and the choice of a pure Regge non-flip amplitude.

As mentioned in the Introduction, a nice confirmation of this fact is given by the reactions $K^+p \to pK^+$ and $\bar{p}p \to K^-K^+$. As the comparison should be made at the same c.m. energy, some recipe is necessary to scale data at exactly the same value, lacking a measurement at convenient energy, thus introducing some ambiguity. However, the experiment of Eide et al. [8] shows clearly that the reversed line process ("rotating phase" type) is greater than the direct one ("real type"). Moreover, as all data points come from the same experiment, normalization discrepancies cannot be blamed for this effect. In these reactions three trajectory doublets are exchanged, and might obscure our prediction. However, given the small $\Sigma_\alpha - \Lambda_\alpha$ trajectory splitting and the SU(3) estimate of the weakness of the $\Sigma_\delta - \Sigma_\beta$ contribution, a unique phase must dominate the annihilation process.

Anticipating on the next section, and in order to illustrate this prediction, our results are shown on Fig. 2 for $s = 11.307\ \mathrm{GeV}^2$. Phase space and statistical factors have been taken into account by comparing $(d\sigma/dt)(\bar{p}p \to K^-K^+)$

with
$$\frac{1}{2}\left(\frac{q_{Kp}}{q_{\bar{p}p}}\right)^2 \frac{d\sigma}{du}(K^+p \to pK^+)$$

where q_{Kp} ($q_{\bar{p}p}$) is the Kp ($\bar{p}p$) c.m. momentum. A remark concerns the first measured forward point at $t = -0.35$ (GeV/c)^2 of $\bar{p}p \to K^-K^+$: our breaking of line reversal predicts equality of cross-sections; confirmation of this tendency would suggest a breaking mechanism in the non-flip amplitude also and/or a quite strong contribution of the $\Sigma_\delta - \Sigma_\beta$ pair.

Evidently, further tests would be desirable, besides the processes just mentioned, other connected reactions involving exchange degeneracy would be obtained from deuteron target experiments : $\bar{p}d \to \pi^- p$ and $\pi^+ d \to pp$. They are governed by N exchanges only, with the prediction :

$$\sigma(\bar{p}d \to \pi^- p) > \sigma(\pi^+ d \to pp)$$

3. COMPARISON WITH EXPERIMENT

3.1 πN scattering

First we extract N and Δ amplitudes from the πN study. The essential difference with our previous work [3] comes from the introduction of duality partners N_γ and N_β of N_α and Δ_δ, respectively. Of course, only the Δ_δ contributes to $\pi^- p$ scattering due to isospin. For the (Δ_δ, N_β) exchanges, a factor simulating a non-compensation mechanism is added : $G_o^\Delta \sim u + 0.5$ and corresponds to the change of sign of the $\pi^- p$ polarization at 6 GeV/c [6].

Let us discuss the choice of the geometry. The N_α trajectory must dominate σ^+ *). Two essential characteristics of these cross-sections : no turn-over in the very backward direction and a pronounced dip at the first nonsense value of the N_α trajectory, forbid a flip amplitude of pure Regge pole type <u>and</u> the relation (1) for the non-flip one; with such a choice, the flip amplitude would be dominant in order to reproduce the dip (since the nonsense zero would be washed out by integration in the non-flip amplitude), but a strong turn-over would be predicted near $u - u_m = 0$ in clear contradiction with data. For the $I = \frac{3}{2}$ exchange, the situation is more confusing : although isospin isolates it in $\pi^- p \to p\pi^-$, we have verified that both polarizations at

*) The indices +,-,o denote observables of respectively $\pi^+ p \to p\pi^+$, $\pi^- p \to p\pi^-$ and $\pi^- p \to n\pi^o$ (CEX).

6 GeV/c [6] and differential cross-sections [4] may be equally well reproduced by a pure Regge parametrization in the non-flip or in the flip amplitude. However, a clear test is given by the five pieces of information available at 6 GeV/c $(P^+, P^-, \sigma^o, \sigma^+, \sigma^-)$: a simple Regge behaviour for the Δ_δ trajectory in the M_1 amplitude leads to unsuccessful results. In fact, the two polarizations fix the sign of the flip, no-flip ratio of the dominant contributions N_α and Δ_δ. Then the relative sign of the non-flip N and Δ amplitudes must be such that the combinations $(2N+\Delta)/3$ and $\sqrt{2}/3(N-\Delta)$ corresponding to π^+p and CEX processes, respectively, reproduce correctly the cross-section behaviour in the very backward direction. Finally, higher transfer dependence of σ^+, P^+ and σ^o are predicted. The result is an inability to reproduce correctly both P^+ and 180^o σ^+, σ^o : with an equivalent χ^2 to those of the presented solution for σ^+, σ^o, σ^- and P^-, the P^+ polarization exhibits a maximum at $u \simeq -0.54$ $(GeV/c)^2$ of order -10%, in strong disagreement with data [7].

By contrast, our final result gives the correct answer, as can be seen from Figs. 3-6. Values of parameters are given in Table I and deserve some comments.

i) Note the rapid convergence of the Laguerre expansion.

ii) Data reject a N_γ contribution (~ 2% only !) as it could be easily guessed; this trajectory induces a breaking of the Regge positive signature phase and $\mathrm{Re}\, M_o^N$ is no longer zero at $u \sim -0.15$ $(GeV/c)^2$; the dip at this point, a well-known difficulty of this data set, would not be described by this model with a sizeable N_γ contribution (comparatively to N_α).

iii) On the contrary, the N_β contribution is welcome.

On the whole, a noticeable improvement with respect to our previous fit is obtained, especially for large transfers and for the structure of the CEX process (in fact a 30% amelioration of the χ^2). Discrepancies remain in the dip region : the σ^+ structure is not sufficiently deep and the CEX one is poorly described at 6 GeV/c, reaching its minimum too soon it rises too quickly to the secondary maximum, a kind of difficulty also encountered by conventional Regge cut models [18].

Predictions of the 5.0 and 6.2 GeV/c $\bar{p}p \to \pi^-\pi^+$ data [8] are shown on Fig. 5b. By kinematical effect, the transfer extremum is appreciably displaced towards negative values in this annihilation process (for instance, $u_m = 0.072$ in $\pi N \to N\pi$, $t_m = -0.079$ in $\bar{N}N \to \pi\pi$ at 5 GeV/c) and the backward peak is suppressed in the crossing since the more the energy is weak, the more the dip is near the boundary limit of the line reversed process. Hence a differential cross-section having its major peak at a high value of transverse momentum is predicted. Such an extraordinary structure has yet been observed at 2.3 GeV/c [19]. At 3 and 4 GeV/c, the expected dip disappears [20] and has not been measured for higher energies. Low energy effects can be important for $p_{lab} \lesssim 3$ GeV/c. An explanation of these data using a background term based on a quark re-arrangement process, has been proposed [21]. Our parametrization is not expected to be valid at low energies and cannot evidently explain the dip disappearance. However, the good agreement obtained for higher energies confirms the validity of our (N,Δ) interference.

3.2 $\bar{K}N \to Y\pi$ processes

SU(3) coupling predictions for N and Δ exchanges may be tested on $\bar{K}N \to Y\pi$ backward scattering data. It has been shown [9] that reactions $K^-p \to \Lambda\pi^0$ and $K^-p \to \Sigma^-\pi^+$ are roughly consistent with an F parameter ranging from 0.2 to 0.5. As with the value $F = 0.25$, our calculations bring nothing really new and confirm only the compatibility of this value with existing data, we shall not discuss them further.

3.3 $K^+p \to pK^+$

Now consider the processes governed by strange trajectories. Their amplitudes are obtained from the N_α and Δ_δ ones by applying SU(3), with $F = 0.25$, in the form stated by Eq. (9), except for symmetry breaking effects attributed to scale factors s_0 and simulating cut parameters λ; thus, except for those parameters, values of which are given in Table I, and obvious mass differences, the amplitude structures are directly deduced from the πN fit and duality requirements. For the Σ_δ trajectories, the $(u+0.5)$ factor of the Δ_δ contribution has been transposed as $(\alpha_\Sigma+0.5)$ in the Σ_δ amplitudes as it is convenient for a sense-nonsense factor.

Although backward data on K induced reactions are rather sparse and in spite of the lack of polarization measurements at high energy, the study of backward $K^+p \to pK^+$ scattering and its line reversed companion $\bar{p}p \to K^-K^+$ is meaningful. As already emphasized, the line reversal breaking observed at 5 GeV/c is predicted correctly. Moreover, measurements [22] of the $K_L \to K_S$ regeneration process at 180° allows an explicit comparison of Λ and Σ exchanges, this last reaction proceeding only via Σ exchanges. Finally, the fact that K^+p polarization at low energies is known to be at least positive [23) must be taken into account since duality suggests that high energy amplitudes should work adequately at quite low energies. For these reasons and although a priori three doublets of trajectories $(\Sigma_\alpha,\Sigma_\gamma)$, $(\Sigma_\beta,\Sigma_\delta)$ and $(\Lambda_\alpha,\Lambda_\gamma)$ are involved in this analysis, a consistent picture must emerge when all data are considered.

We have fitted the annihilation and scattering data [8),10)] simultaneously with the six symmetry breaking parameters given in Table I. [Note that $(\Sigma_\beta,\Sigma_\delta)$ contribution is of very secondary importance : a four-parameter fit would give equivalent results.] The K^+p polarization and the $K_Lp\rightarrow K_Sp$ differential cross-sections are predicted. A satisfactory over-all agreement is obtained : the line reversal process is quantitatively well described (Fig. 7b), whereas elastic polarizations are consistent with low energy data and cross-sections of regeneration process at 180° compare quite favourably with experiment, as shown in Figs. 8a and 8b.

Lastly, the importance of SU(3) constraints is illustrated on Fig. 7a at 5 GeV/c where a discrepancy exists near $u\sim 0$; a solution obtained by releasing the Σ_δ coupling is given (dashed line).

3.4 $\pi^-p\rightarrow\Lambda K^0$

Figure 9 represents our results at all available energies. Two solutions have been investigated. In the first one (solution I), a residue with a factor $\alpha_\Sigma+0.5$ is considered for the $(\Sigma_\delta,\Sigma_\beta)$ amplitudes, since sense-nonsense factors should be the same for all trajectories within a given multiplet. This parametrization (dot-dashed lines at 5 GeV/c) has trouble in fitting exactly the observable behaviour at large transfer : the energy dependence (not depicted) is correctly given, but the break of the cross-section and the polarization minimum around $u_m-u\sim 0.7$ $(\mathrm{GeV/c})^2$ are not explained.

On the other hand, considering the factor $u+0.5$ of the Δ_δ amplitudes as an effective transfer dependence of residues, we directly extrapolate this factor to the Σ_δ contribution. The results (solution II : solid curves) are in fair agreement with energy and transfer dependence of cross-sections (except at $p_{lab}=4$ GeV/c), especially with the break clearly observed at all energies around $u_m-u=0.7$ GeV/c^2. Concerning the spin parameters R, P and A, it should be noted that, not only the big polarization at low transfer, but also the minimum at $u_m-u\sim 0.7$ $(\mathrm{GeV/c})^2$ are reproduced, as well as the positive bump of the A parameter in the same transfer domain. A negative value of R is obtained.

It is interesting to see how observables are built up from the contributions of the two sets of exchanges. Dashed lines on Fig. 9 represent the $\Sigma_{\alpha\gamma}$ contribution to differential cross-section and polarization at 6.2 GeV/c. The break is attributed by our parametrization to the $\Sigma_{\delta\beta}$ amplitudes and thus, should be perhaps related to a similar structure present in $\pi^- p \to p\pi^-$ at large u (cf., Fig. 3). The polarization minimum is provided by the same contribution since a null polarization at $u_m - u \sim -0.6$ GeV^2 is given by the residue factor.

Although a rough agreement is obtained with the first solution, the correlation between amplitude zeros imposed by unitary symmetry via the Δ_δ sense-nonsense factor, is not verified by $\pi N \to K\Lambda$ data. Conversely, one cannot expect to learn very much about Σ_δ exchanges from the "ad hoc" parametrization described above. However, some lesson can be obtained from an impact parameter analysis : the profile functions corresponding to these two solutions, depicted on Fig. 1b together with the Δ_δ one, are quite different. The first possibility (factor $\alpha_\Sigma + 0.5$) exhibits an important peripheral part whereas solution II has a pronounced central character, more similar to the Δ_δ one. This must be contrasted with the clear change of geometry observed between N_α and Σ_α trajectories. Therefore, we conclude that if this change is convenient for Σ_α exchanges, the conservation of geometry seems to be more adequate for δ trajectories.

Before concluding, let us remark that our explanation of polarization observables, depending strongly on cut effects, is completely different from the interesting suggestion of Schmid and Storrow [24], where such contributions are completely neglected.

4. CONCLUSIONS

These exploratory fits, incorporating duality constraints show at least an over-all agreement of backward data with the derivative relation (1) and with SU(3) residue prescriptions. Kayser and Hayot [25] observed that angular distributions of $K^+p \to pK^+$ and $\pi^+p \to p\pi^+$ can be generated one from another using exact SU(3) symmetry. We confirm this result and, moreover, have observed that $\pi^- p \to \Lambda K^0$ is also compatible with a universal F parameter value 0.25. Cut effects induced by the derivative relation in flip amplitudes are quite important but are able to explain spin parameters and line reversal processes in a consistent way.

Among works having gone into relating various s channel helicity amplitudes by the derivative relation, most of them incorporate a pure Regge pole behaviour in some amplitude [3),16),26)], whereas model independent tests have been done recently [2)]. Altogether, these studies are quite encouraging. Barger and Phillips [16)] have underlined conflicts with some structures of the forward $\pi^- p \to \pi^0 n$ reaction. As we have emphasized, our description of πN backward scattering remains not completely correct. In fact, the pure pole assumption is probably an oversimplification of the underlying physics [2)] but remains an interesting working hypothesis. This analysis gives another confirmation of the validity of such an approach and, we hope, will renew interest for backward scattering phenomenology.

While finishing this work, we received new results on σ^0 from 2.6 to 8 GeV/c [27)] where the dip structure is much less pronounced and is displayed in the vicinity of $u \sim -0.3$ $(\text{GeV/c})^2$. This strong discrepancy between different measurements seems to come from the neglect of radiative corrections by previous authors. The study of these new data, together with previous results on other πN processes, may be meaningless since these effects could be also important in these reactions [28)]. However, assuming that σ^- and σ^+ would not be strongly affected by these corrections, we have studied the new πN data set at 6 GeV/c. The filling of the σ^0 dip is obtained with a strong N_β contribution $(\delta_N \sim 1.0)$. Other parameters are not drastically changed and essential results remain the same.

ACKNOWLEDGEMENTS

I would like to thank, in particular, R. Lacaze and R. Peschanski, for the many useful discussions and their stimulating interest during the course of this work. I am also grateful to J. Weyers for useful remarks. I wish to acknowledge W. Beusch for communicating data before publication.

TABLE I :

reaction	exchanges		parameters s_0	λ	ϵ	G_0/G_1	G_1C_0	G_1C_1	G_1C_2
$\pi N \to N\pi$	N_α		0.86	11.6	0.018	0.37	-326.2	31.2	-15.
	Δ_δ		2.33	1.	0.5	0.73	17.2	-1.3	1.
$KN \to NK$	Λ_α		0.24	15.	1				
	Σ_α		2.96	1.	1				
	Σ_δ		0.9	-3.3	1				
$\pi N \to K\Lambda$	Σ_α	sol. I	0.37	-11.8	-1				
		sol.II	0.314	-8.7	-1				
	Σ_δ	sol. I	0.25	1.47	-1				
		sol.II	2.15	-15.	-1				

trajectories	
N_α :	$-0.34 + 0.95u$
Δ_δ :	u
Λ_α :	$-0.68 + 0.95u$
Σ_α :	$-0.75 + 0.9\,u$
Σ_δ :	$-0.3 + 0.9\,u$

TABLE II :

reaction	exchanges decuplet	octet	singlet
$\pi^- p \to p\pi^-$	Δ^{10}		
$\pi^+ p \to p\pi^+$	$\frac{1}{3}\Delta^{10}$	$\frac{2}{3} N^8$	
$\pi^- p \to \pi^0 n$	$-\frac{\sqrt{2}}{3}\Delta^{10}$	$\frac{\sqrt{2}}{3} N^8$	
$K^- p \to \pi^0 \Lambda$		$\frac{1}{3\sqrt{3}}(2F+1)N^8$	
$K^- p \to \pi^- \Sigma^+$	Δ^{10}		
$K^- p \to \pi^+ \Sigma^-$	$\frac{1}{3}\Delta^{10}$	$\frac{2}{3}(2F-1)N^8$	
$\pi^- p \to K^0 \Lambda$	$\frac{1}{\sqrt{6}}\Sigma^{10}$	$\frac{4}{3\sqrt{6}}(1-F)(2F-1)\Sigma^8$	
$K^+ p \to K^+ p$	$\frac{1}{6}\Sigma^{10}$	$\frac{1}{3}(2F-1)^2\Sigma^8 + \frac{1}{9}(2F+1)^2\Lambda^8$	Λ^1

REFERENCES

1) H. Harari, Ann.Phys.(NY) 63, 432 (1971).

2) B. Schrempp and F. Schrempp, CERN preprint TH.2015 (1975), and references quoted therein.

3) J.P. Ader, R. Peschanski, R. Lacaze, G. Cohen-Tannoudji and C. Gilain, CERN preprint TH.1903 (1974), to be published in Nuovo Cimento.

4) D.P. Owen et al., Phys.Rev. 181, 1794 (1969).

5) J.P. Boright et al., Phys.Letters 33B, 615 (1970).

6) L. Dick et al., Nuclear Phys. B64, 45 (1973).

7) L. Dick et al., Nuclear Phys. B43, 522 (1972).

8) A. Eide et al., Nuclear Phys. B60, 173 (1973); paper contributed to the London Conference (1974).

9) V. Barger, F. Halzen and M.G. Olsson, Nuclear Phys. B49, 206 (1972);
C. Michael, review talk at the Batavia Conference (1972).

10) a) J. Banaigs et al., Nuclear Phys. B9, 640 (1969);
b) W.F. Baker et al., Phys.Letters 28B, 291 (1968).

11) W. Beusch et al., Nuclear Phys. B19, 546 (1970).

12) W. Beusch et al., CERN preprint (1975).

13) C. Schmid and J.K. Storrow, Nuclear Phys. B29, 219 (1971).

14) See, for instance, J. Mandula, J. Weyers and G. Zweig, Annual Rev.of Nuclear Sci. Vol.20, p.289 (1970).

15) A.J.G. Hey, P.J. Lichtfield and R.J. Cashmore, CERN preprint TH.1886 (1974).

16) V. Barger and R.J.N. Phillips, Nuclear Phys. B87, 221 (1975).

17) See, for instance, C. Michael, proceedings of the VIth Rencontres de Moriond (1971), Vol.II (Ed., J. Tran Thanh Van).

18) F. Hayot and B. Kayser, Nuovo Cimento 3A, 45 (1971);
F. Hayot and A. Morel, Phys.Rev. D8, 223 (1973).

19) T. Fields, W.A. Cooper, D.S. Rhines, J. Whitmore and W.W.M. Allison, Phys.Letters 40B, 503 (1972).

20) A. Brabson et al., Phys.Letters 42B, 287 (1972).

21) A. Donnachie and P.R. Thomas, Lettere al Nuovo Cimento 7, 285 (1973).

22) C.W. Brandenburg et al., Phys.Rev.Letters 30, 143 (1973).

23) R.D. Erlich et al., Phys.Rev.Letters 26, 425 (1971).

24) C. Schmid and J.K. Storrow, Nuclear Phys. B44, 269 (1972).

25) B. Kayser and F. Hayot, Phys.Rev. D6, 2423 (1972).

26) S. Humble, CERN preprint TH.1976 (1975).

27) C. De Marzo et al., Phys.Letters 56B, 487 (1975).

28) M.R. Sogard, Phys.Rev. D9, 1486 (1974).

29) W.F. Baker et al., Phys.Rev.Letters 32, 251 (1974) and Notre Dame preprint UND HEP 2-34 (1974).

30) V. Kistiakowsky et al., Phys.Rev. D6, 1882 (1972).

31) J. Schneider et al., Phys.Rev. Letters 23, 1068 (1969).

32) O.I. Dahl et al., Phys.Rev. 163, 1430 (1967).

FIGURE CAPTIONS

Figure 1 : Hankel transforms of the imaginary part of the a) N_α and Σ_α, b) Δ_δ and Σ_δ, non-flip amplitudes in arbitrary units versus impact parameter in fm. The two profiles of the Σ_δ trajectory correspond to the two solutions described in the text (solution I: dot-dashed line; solution II: dashed line).

Figure 2 : $\bar{p}p \to K^- K^+$ (full circles) compared with $K^+ p \to pK^+$ (open circles) at the same centre-of-mass energy : 11.307 GeV^2 [data from Ref. 8)].

Figure 3 : Differential cross-sections for $\pi^- p \to p\pi^-$ at 5.91, 9.85 and 13.73 GeV/c [data from Ref. 4)] and polarization at 6 GeV/c [data from Ref. 6)].

Figure 4 : Differential cross-sections for $\pi^+ p \to p\pi^+$ at 5.91, 9.85 and 13.73 GeV/c [data from Ref. 4)] and polarization at 6 GeV/c [data from Ref. 7)].

Figure 5 :
a) Differential cross-sections for $\pi^+ p \to p\pi^+$ at 180° plotted as function of lab. momentum [data from Ref. 29)].

b) Annihilation process with π^- forward at 5 and 6.2 GeV/c [data from Ref. 8)].

Figure 6 :
a) Differential cross-sections for $\pi^- p \to \pi^0 n$ at 5.9 and 10.1 GeV/c [data from Ref. 5)].

b) Momentum dependence of the $\pi^- p \to \pi^0 n$ differential cross-section at 180° [data from Ref. 30) (straight lines) and Ref. 31) (full circles)].

Figure 7 :
a) Differential cross-sections for $K^+ p \to pK^+$ at 3.55 GeV/c [Ref. 10a)], 5 GeV/c [Ref. 8)] and at 5.2 and 7.0 GeV/c [Ref. 10b)].

b) Annihilation process with K^- forward, at 5 and 6.2 GeV/c [data from Ref. 8)].

Figure 8 :
a) Momentum dependence of $KN \to NK$ differential cross-sections at 180° [figure from Ref. 22)].

b) $K^+ p \to pK^+$ polarizations with our predictions [data from Ref. 23)].

<u>Figure 9</u> : Differential cross-sections for $\pi^- p \rightarrow \Lambda K^0$ (left-hand side) at 2 GeV/c [Ref. 32)] 4 and 6.2 GeV/c [Ref. 11)] and at 5 GeV/c [Ref. 12)]. Right-hand side : momentum dependence at 180° of $d\sigma/du$ [data from Refs. 11) and 12)] and spin parameters at 5 GeV/c [Ref. 12)] together with polarizations at 4 and 6.2 GeV/c [Ref. 11)]. Solid curves are Solution II (see text), dashed lines at 6.2 GeV/c show the $\Sigma_{\alpha'\gamma}$ contribution only, and dot-dashed lines at 5 GeV/c represent Solution I.

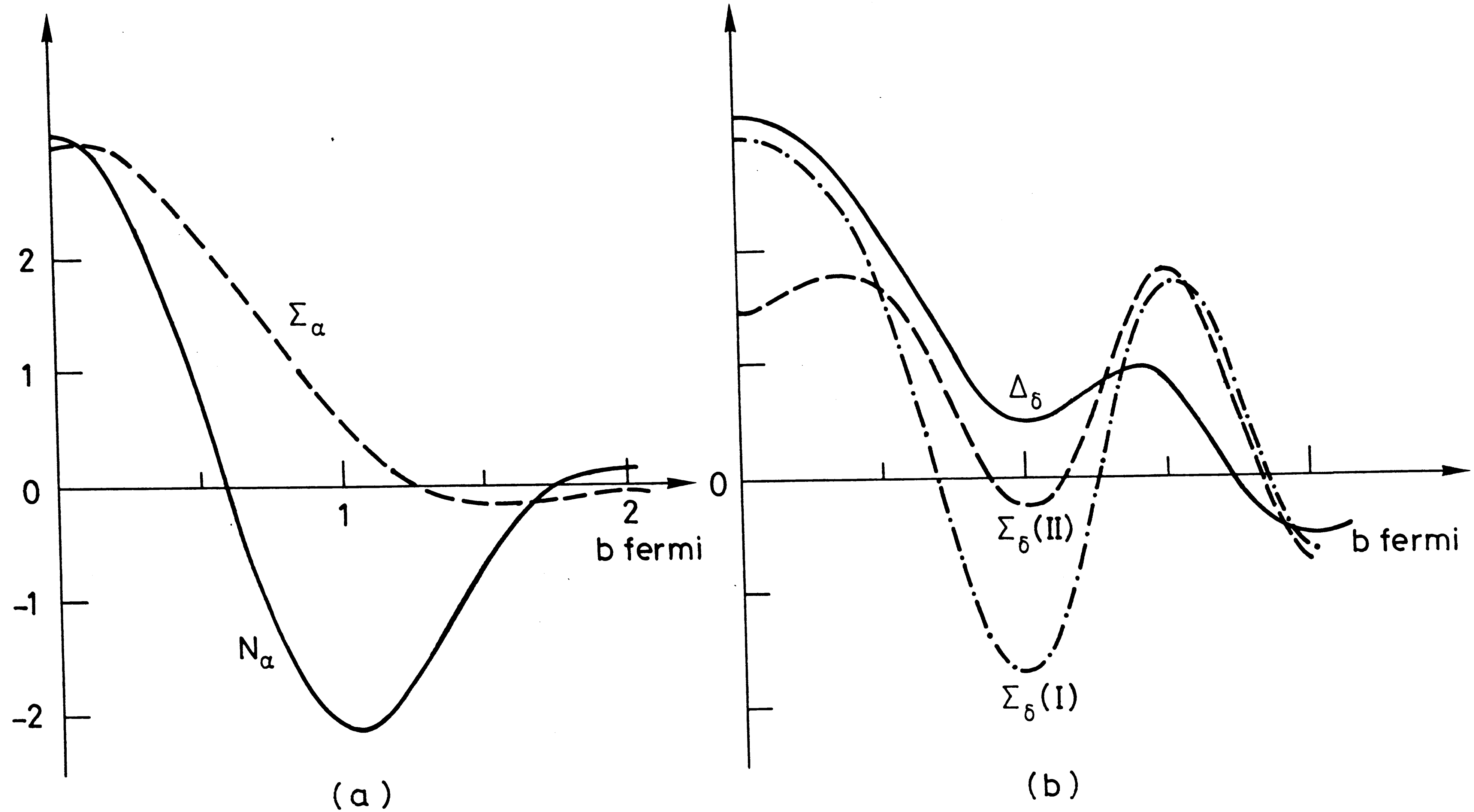


FIG. 1

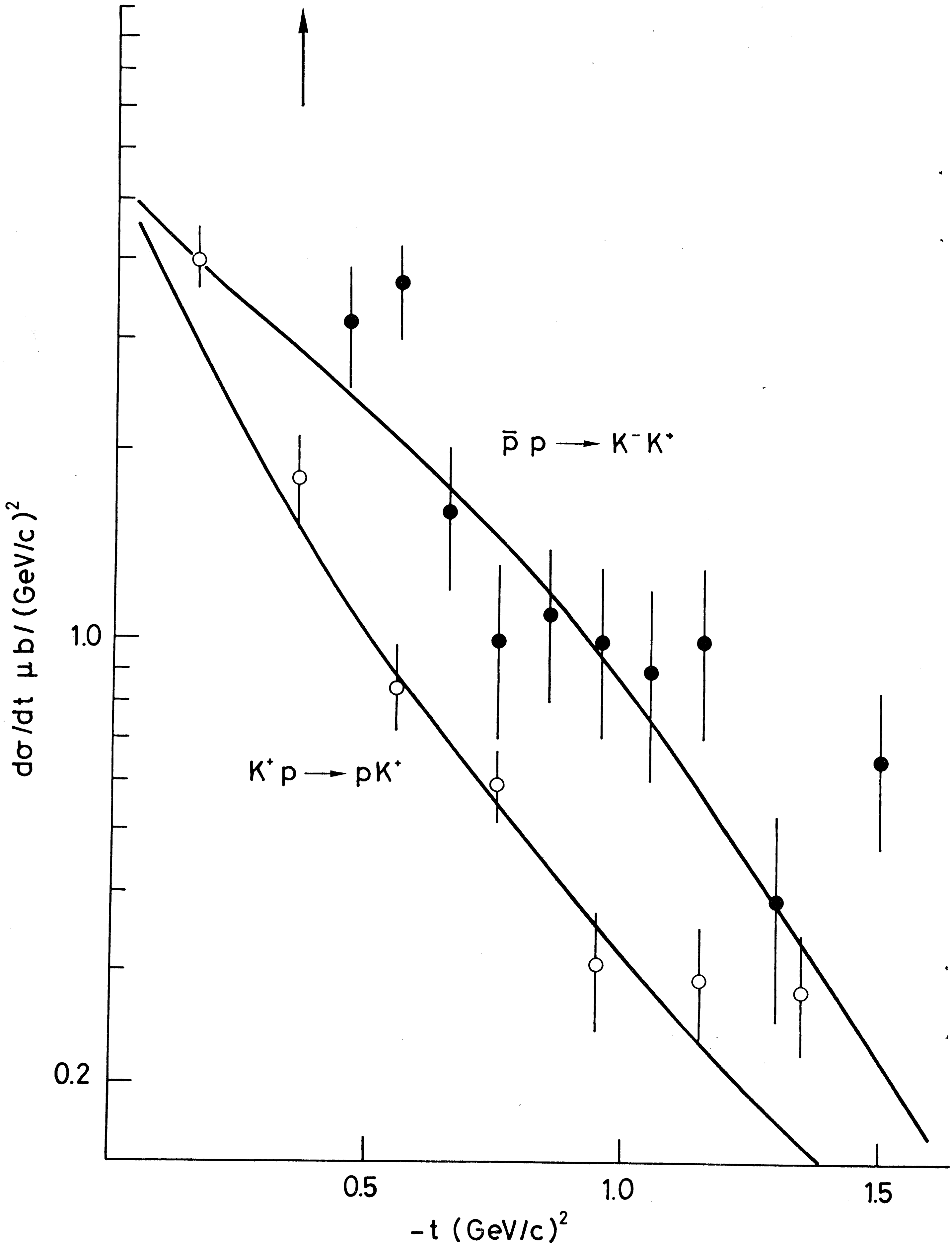
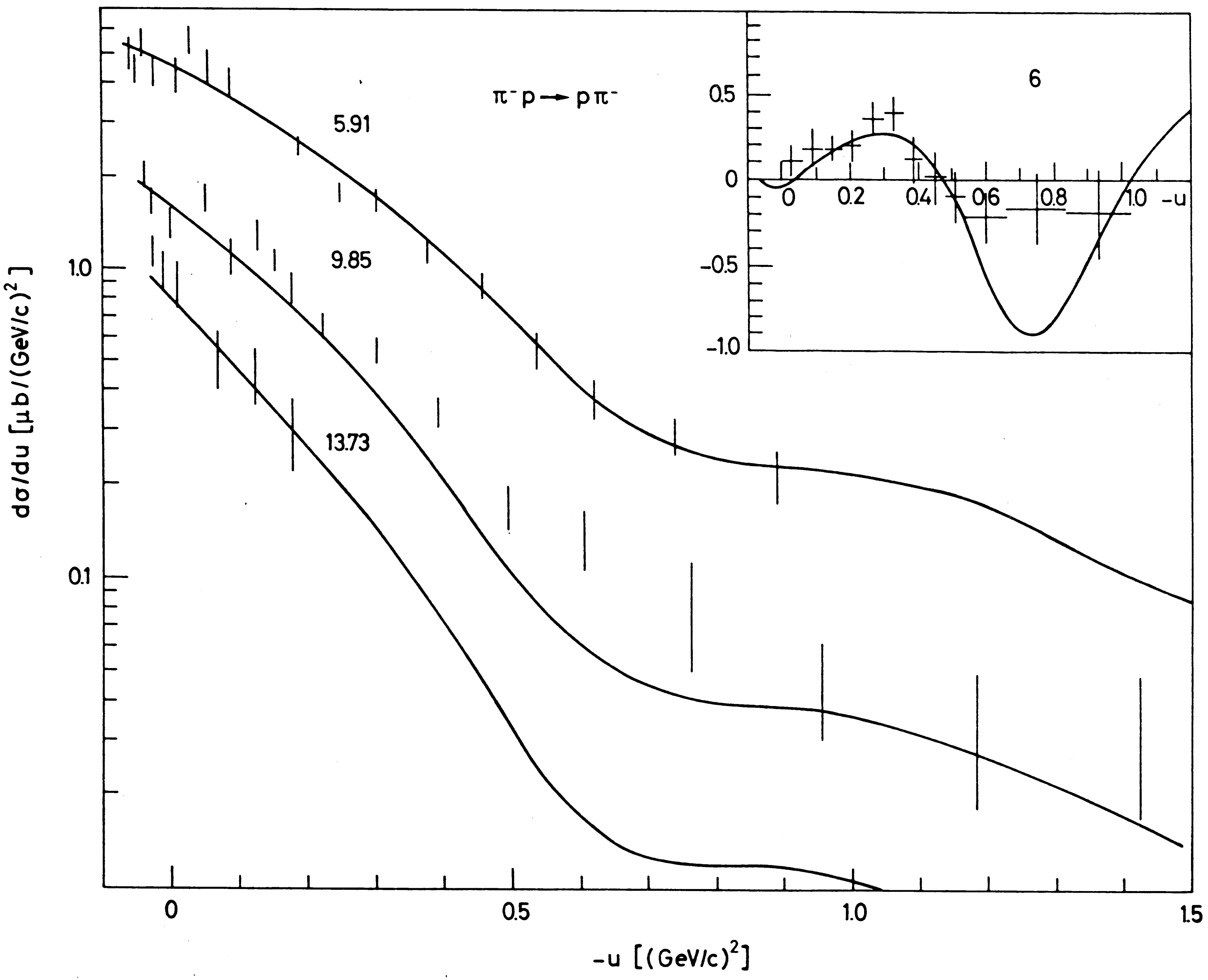
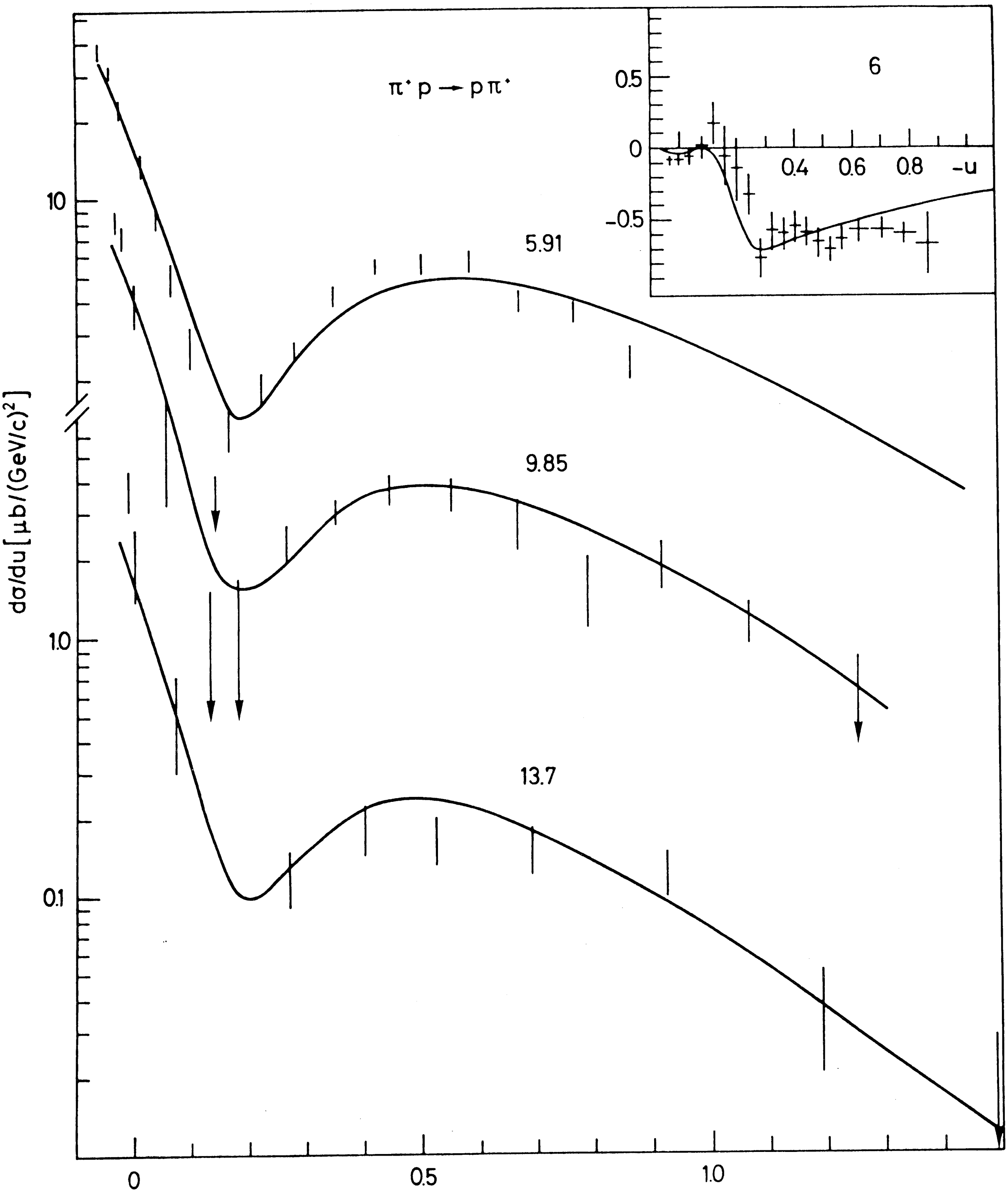


FIG. 2



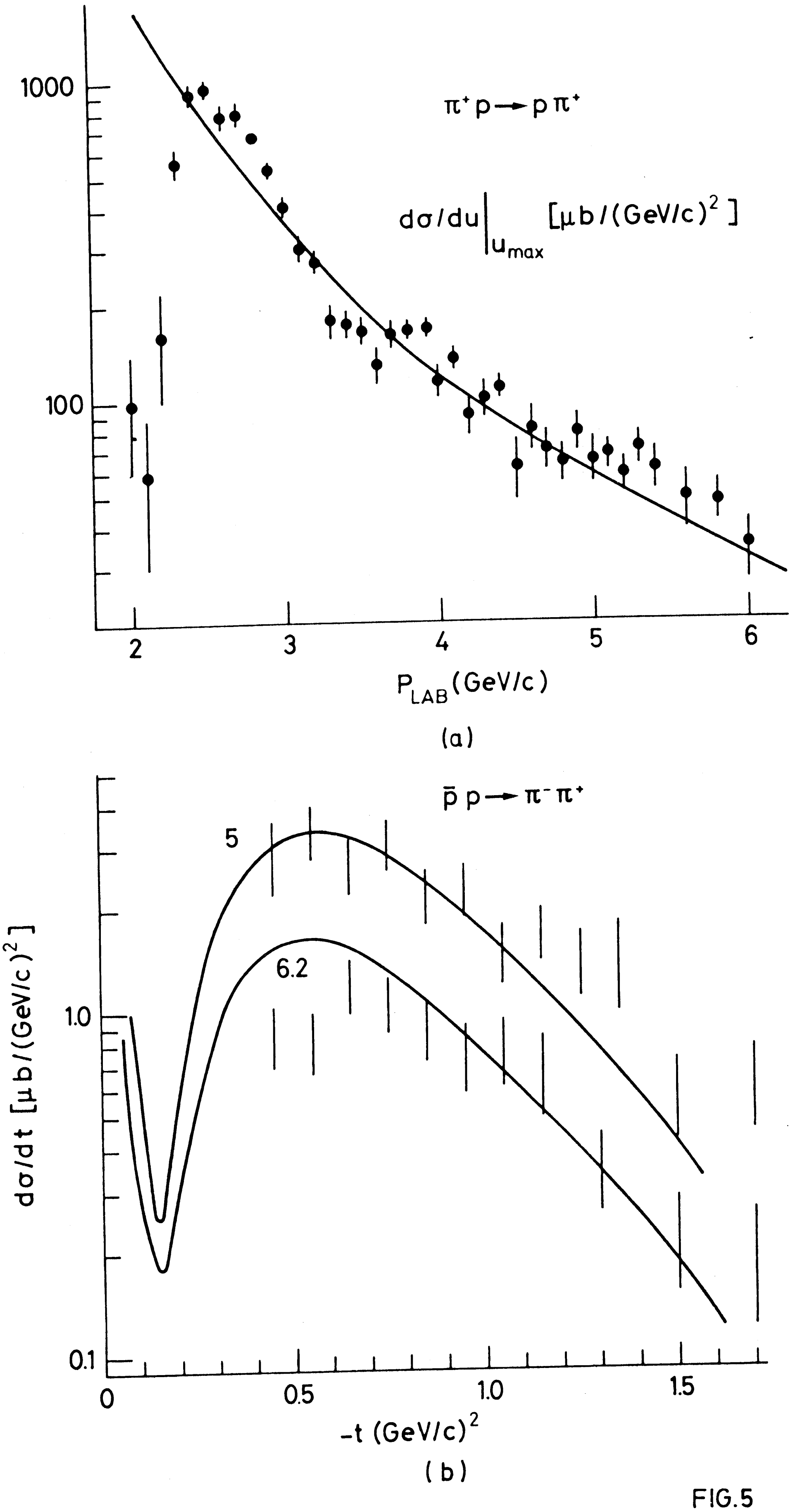
dσ/du [μb/(GeV/c)²]
1.0
0.1
π⁻p → pπ⁻
5.91
9.85
13.73
0
0.5
1.0
1.5
-u [(GeV/c)²]
6
0.5
0
-0.5
-1.0
0.2
0.4
0.6
0.8
1.0
-u

FIG. 3



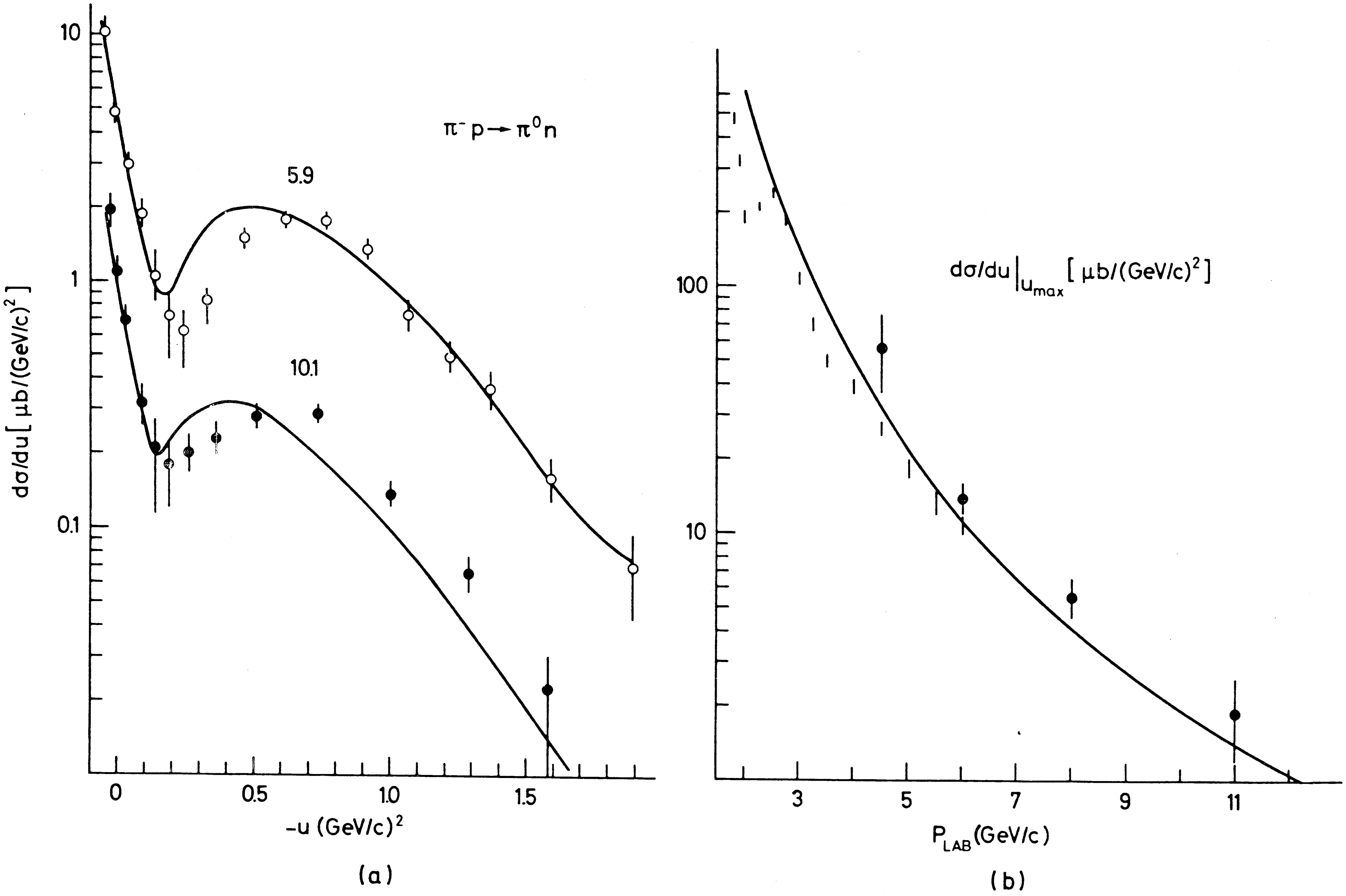
π⁺p → pπ⁺
5.91
9.85
13.7
6
0.5
0
-0.5
0.4
0.6
0.8
-u
10
1.0
0.1
dσ/du [μb/(GeV/c)²]
0
0.5
1.0
-u (GeV/c)²

FIG. 4



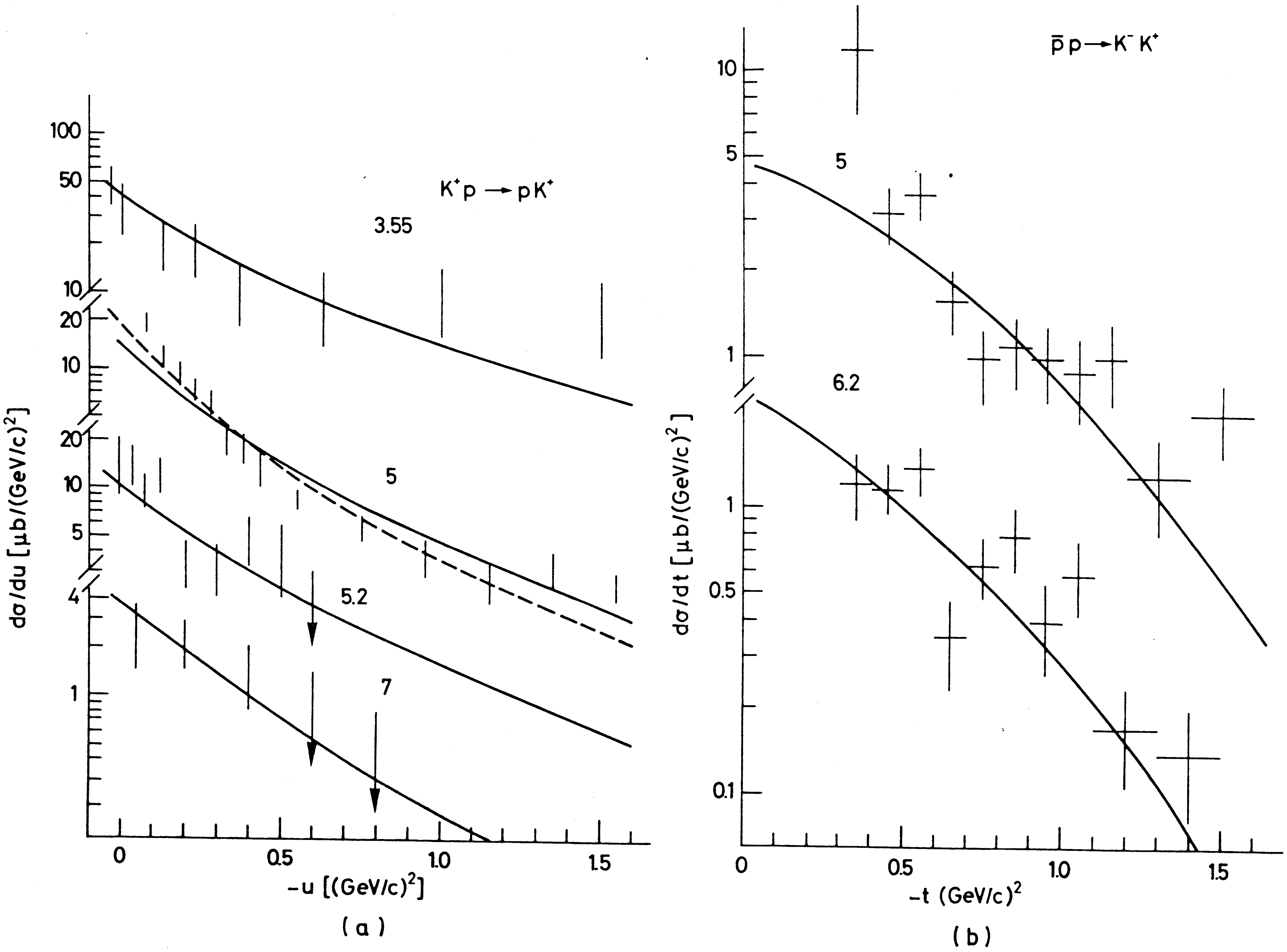
π⁺p → pπ⁺
dσ/du|umax [μb/(GeV/c)²]
1000
100
2
3
4
5
6
PLAB (GeV/c)
(a)
p̄p → π⁻π⁺
5
6.2
dσ/dt [μb/(GeV/c)²]
1.0
0.1
0
0.5
1.0
1.5
−t (GeV/c)²
(b)

FIG.5



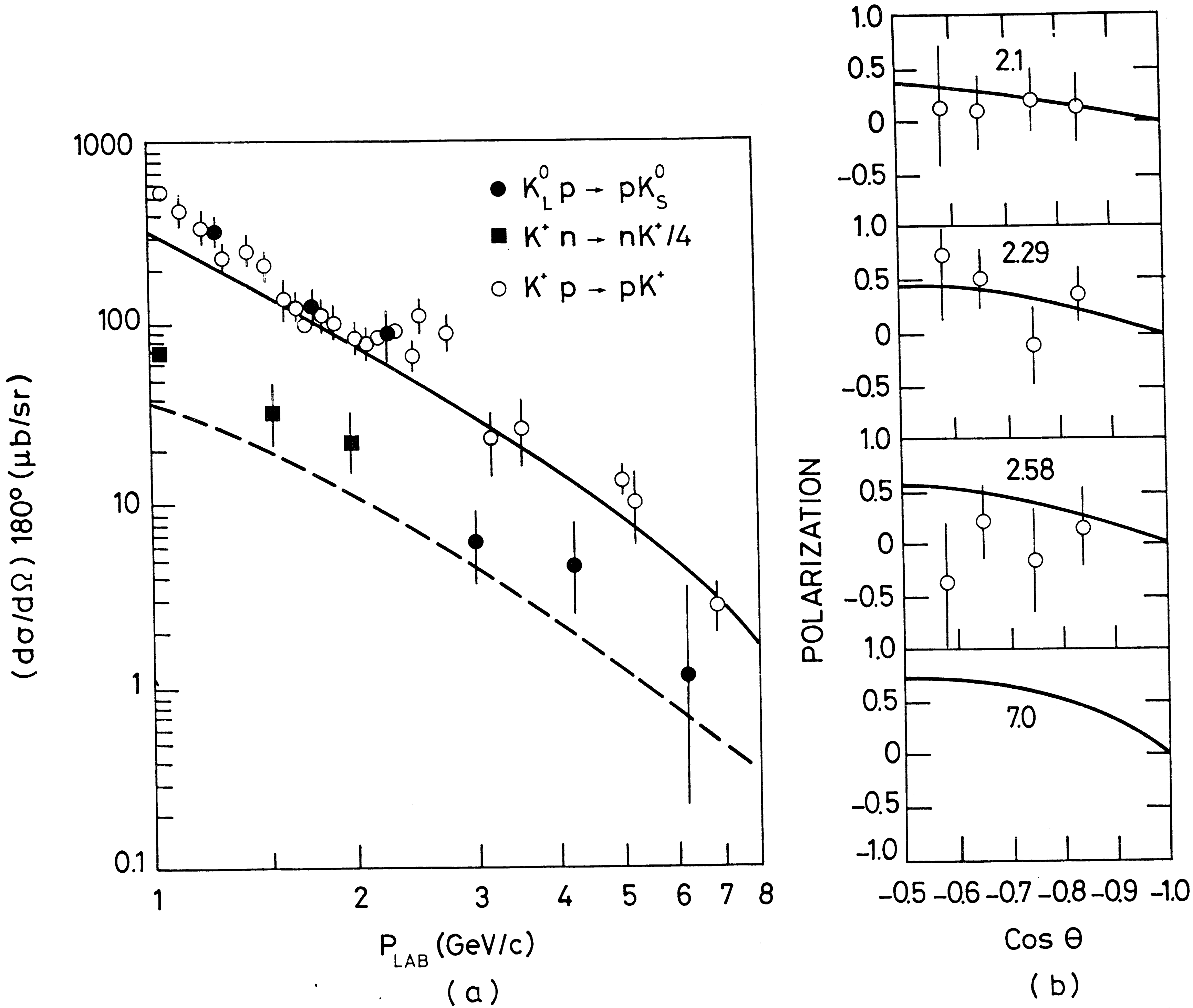
π⁻p → π⁰n
5.9
10.1
dσ/du [μb/(GeV/c)²]
10
1
0.1
0
0.5
1.0
1.5
-u (GeV/c)²
(a)
dσ/du|umax [μb/(GeV/c)²]
100
10
3
5
7
9
11
PLAB (GeV/c)
(b)

FIG. 6



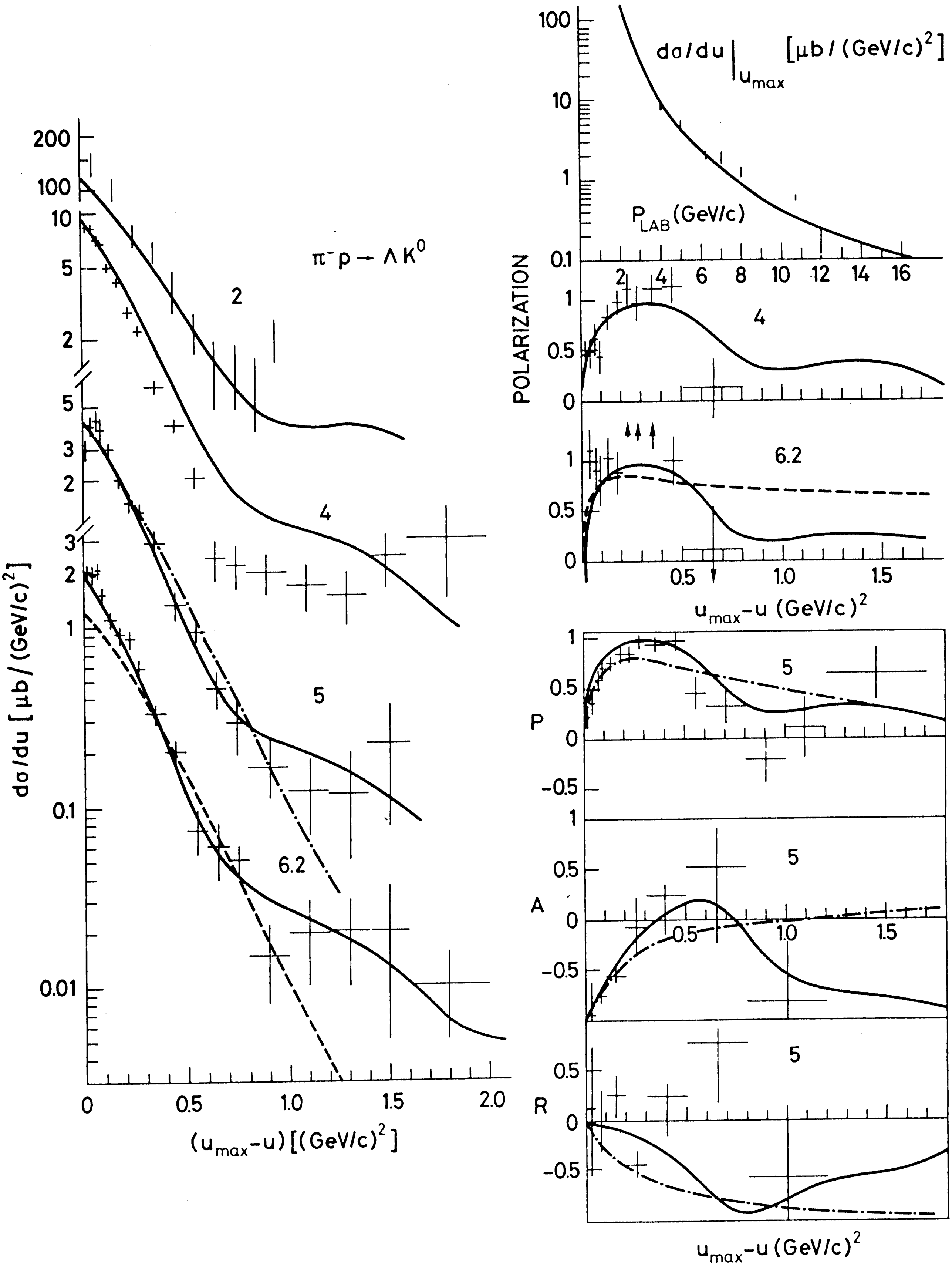
K⁺p ⟶ pK⁺
3.55
5
5.2
7
100
50
10
20
10
20
10
5
4
1
0
0.5
1.0
1.5
dσ/du [μb/(GeV/c)²]
-u [(GeV/c)²]
(a)
p̄p ⟶ K⁻K⁺
5
6.2
10
5
1
1
0.5
0.1
dσ/dt [μb/(GeV/c)²]
-t (GeV/c)²
(b)

FIG. 7



$K^0_L p \to pK^0_S$
$K^+ n \to nK^+/4$
$K^+ p \to pK^+$
(dσ/dΩ) 180° (μb/sr)
P_{LAB} (GeV/c)
(a)
2.1
2.29
2.58
7.0
POLARIZATION
Cos Θ
(b)

FIG.8



π⁻p → ΛK⁰
dσ/du [μb/(GeV/c)²]
(u_max−u) [(GeV/c)²]
dσ/du|u_max [μb/(GeV/c)²]
P_LAB (GeV/c)
POLARIZATION
u_max−u (GeV/c)²
P
A
R

FIG. 9