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EXPERIMENTAL DETERMINATION OF PARITY DOUBLET CONTRIBUTIONS IN BARYON EXCHANGE REACTIONS

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ABSTRACT

Very simple relations between differential cross-sections and polarizations in backward scattering (baryon exchange) which allow an experimental separation of parity doublet contributions are pointed out. We show, for instance, that in πN elastic scattering, the cross-sections with nucleon polarization parallel or antiparallel to the normal of the scattering plane are, respectively, proportional to unnatural or natural parity exchange. A rapid survey of available experimental data in πN elastic scattering and $\pi^- p \to K^0 \Lambda$ exhibits unexpected features.

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1. INTRODUCTION

In this paper we are specifically concerned by the study of scattering reactions $1+2 \rightarrow 3+4$ (s channel) for which the crossed u channel $\bar{3}+2 \rightarrow \bar{1}+4$ has half-integer total spin (baryon exchange channel). We intend to show that from very simple polarization measurements, which have been actually performed in some interesting cases, it is possible, in a model independent way to disentangle the contributions of different u channel naturality states. This means, for instance, that one can extract from the available experimental data the two contributions of parity doublet partners, something which has been claimed in the past to be beyond experimental observation.

We recall that the occurrence of parity doublets, for baryon exchange models, is required by analyticity properties of scattering amplitudes, but that the experimental evidence for the existence of both partners either as resonances or as leading crossed channel singularities is very weak and debatable. We then believe that the experimental analysis we are proposing here will considerably help in solving these still open questions.

The derivation of our results is analogous to the one followed in meson exchange [1]. It is therefore quite surprising that such a straightforward extension has not been noticed until now.

2. PARITY CONSERVING AMPLITUDES

The general procedure to obtain parity conserving amplitudes in any channel for meson exchange [2] or baryon exchange [3] is well known. We therefore only sketch the main results.

Using the transformation property under parity of a two-particle state

$$\mathcal{P} \, | J M \lambda_{\bar{3}} \lambda_2 \rangle = \eta_{\bar{3}} \, \eta_2 \, (-)^{J - s_3 + s_2} \, | J M - \lambda_{\bar{3}} - \lambda_2 \rangle \tag{1}$$

we define partial wave helicity amplitudes $M^{J\pm}_{\lambda_{\bar{1}} \lambda_4 \lambda_{\bar{3}} \lambda_2}$ corresponding to transition with natural (plus sign) or unnatural parity (minus sign) as follows :

$$M^{J\pm}_{\lambda_{\bar{1}} \lambda_4 \lambda_{\bar{3}} \lambda_2} = \left[M^{J}_{\lambda_{\bar{1}} \lambda_4 \lambda_{\bar{3}} \lambda_2} \pm \eta_{\bar{3}} \eta_2 (-)^{1/2 - s_3 + s_2} M^{J}_{\lambda_{\bar{1}} \lambda_4 - \lambda_{\bar{3}} - \lambda_2} \right] / \sqrt{2} \tag{2}$$

where η_i is the intrinsic parity of particle i, and the naturality of a given baryonic state is defined by $\eta\,(-)^{J-\frac{1}{2}}$.

We now sum over partial waves to get the total u channel helicity amplitudes. Assuming *) $|\cos\theta_u| \gg 1$ allows to define total helicity amplitudes $M^{u\pm}_{\lambda_{\bar{1}}\lambda_4\lambda_{\bar{3}}\lambda_2}$ with given naturality

$$M^{u\pm}_{\lambda_{\bar{1}}\lambda_4\lambda_{\bar{3}}\lambda_2} \simeq \left[M^{u}_{\lambda_{\bar{1}}\lambda_4\lambda_{\bar{3}}\lambda_2} \pm i\varepsilon\, M^{u}_{\lambda_{\bar{1}}\lambda_4-\lambda_{\bar{3}}-\lambda_2}\right]/\sqrt{2} \tag{3}$$

with

$$i\varepsilon = \eta_{\bar{3}}\,\eta_2\,(-)^{1/2-s_3+s_2}\,e^{i\pi(\lambda_2-\lambda_{\bar{3}})} \tag{4}$$

Finally using factorization properties of the crossing matrix (no leading order approximation), we derive an analogous expression for the total s channel helicity amplitudes

$$M^{s\pm}_{\lambda_3\lambda_4\lambda_1\lambda_2} \simeq \left[M^{s}_{\lambda_3\lambda_4\lambda_1\lambda_2} \pm i\,\eta_2\eta_3\,(-)^{s_3-\lambda_3}(-)^{s_2-\lambda_2} M^{s}_{-\lambda_3\lambda_4\lambda_1-\lambda_2}\right]/\sqrt{2} \tag{5}$$

In the following we shall consider Eqs. (3) and (5) as rigorous equalities, as is usually assumed in the most standard reggeization procedure, though we are perfectly aware that these relations are strictly valid only to leading order in $1/s$. Furthermore, we know that for baryonic channel, the unequal mass kinematics makes difficult to have $|\cos\theta_u| \gg 1$ around $u=0$.

So far, we have been dealing only with helicity amplitudes, which are of a more common use. It is important to realize that more simple and general properties can be obtained using transversity amplitudes [4], whose relation with helicity amplitudes can be written as follows :

$$T^{s}_{\tau_3\tau_4\tau_1\tau_2} = \sum_{\lambda_i} D^{s_1}(R)^{\lambda_1}_{\tau_1}\, D^{s_2}(R)^{\lambda_2}_{\tau_2}\, D^{s_3}(R^*)^{\lambda_3}_{\tau_3}\, D^{s_4}(R^*)^{\lambda_4}_{\tau_4} \Big[M^{s}_{\lambda_3\lambda_4\lambda_1\lambda_2} + \\ + \sigma\, i\,\eta_2\eta_3\,(-)^{s_3-\lambda_3}(-)^{s_2-\lambda_2} M^{s}_{-\lambda_3\lambda_4\lambda_1-\lambda_2}\Big] \tag{6}$$

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*) We define $\cos\theta_u$ in such a way that for $s \to +\infty + i\varepsilon$, fixed negative values of u, then $\cos\theta_u \to +\infty + i\varepsilon$.

where

$$\sigma = \eta_2 \eta_3 (-)^{1/2+\tau_3-\tau_2}$$

Because σ does not depend on helicity indices, relation (6) expresses the fact that transversity amplitudes are actually naturality conserving amplitudes. A similar result can be obtained for boson exchange in the t channel $\bar{4}2 \to 3\bar{1}$ with $\sigma = \eta_1 \eta_3 (-)^{\tau_1 - \tau_3}$. We are presently investigating these problems in the most general cases [5].

3. EXPERIMENTAL QUANTITIES

We now relate experimental accessible quantities to bilinear expressions containing only M^+M^{+*} or M^-M^{-*}. These experimental quantities involve the determination of a baryon polarization, and the present work is restricted to the simple cases where the polarized baryon is associated (in the u channel) to a spin zero meson. In other words, we shall only consider the two following types of reactions :

i) $a + p\uparrow \to$ (spin zero meson) $+ d$; pseudoscalar or scalar meson production on polarized target (or with polarized beam). Examples of this kind of reaction are $\pi p\uparrow \to \pi N$, $Kp\uparrow \to KN$, $\gamma p\uparrow \to \pi N$, $\bar{p}p\uparrow \to \pi\pi$, etc.;

ii) (spin zero meson) $+ b \to c + B\uparrow$; final baryon polarization measurement in pseudoscalar meson induced reactions. For example $\pi N \to K\Lambda$, $KN \to \pi\Lambda$, $\pi N \to K^*Y^*$, etc.

[Notice that in the preceding definitions, a, b, c, d are arbitrary spin and parity particles, or sets of particles; this includes the inclusive reactions $a + p\uparrow \to$ (spin zero) $+ X$ and (spin zero) $+ b \to X + B\uparrow$.]

1) Polarized target experiments

For polarized nucleon target, the cross-section can be written in the following way :

$$\frac{d\sigma^{pol.}}{du} = \frac{d\sigma^{un.}}{du}\left(1 + P(u)\, \vec{P}.\vec{n}\right) \qquad (7)$$

where $\vec{n} = (\vec{p}_1 \times \vec{p}_3)/|\vec{p}_1 \times \vec{p}_3|$ is the unit vector normal to the scattering plane, $d\sigma^{un.}/du$ the unpolarized cross-section, $P(u)$ the polarization parameter, and $\vec{p}$ the polarization vector.

Both $d\sigma^{un.}/du$ and $P(u)$ are related to helicity amplitudes by the well-known expressions

$$\frac{d\sigma^{un.}}{du} = \frac{1}{2}\sum_{\lambda_1\lambda_4}\left\{|M_{0\lambda_4\lambda_1 1/2}|^2 + |M_{0\lambda_4\lambda_1 -1/2}|^2\right\}$$

$$P(u)\,\frac{d\sigma^{un.}}{du} = \sum_{\lambda_1\lambda_4}\left\{\mathrm{Im}\, M_{0\lambda_4\lambda_1 1/2}\, M^{*}_{0\lambda_4\lambda_1 -1/2}\right\} \tag{8}$$

which, in terms of naturality conserving amplitudes (5), transform into the astonishingly simple relations

$$\frac{d\sigma^{un.}}{du} = \frac{1}{2}\sum_{\lambda_1\lambda_4}\left\{|M^{+}_{0\lambda_4\lambda_1 1/2}|^2 + |M^{-}_{0\lambda_4\lambda_1 1/2}|^2\right\}$$

$$P(u)\,\frac{d\sigma^{un.}}{du} = \frac{\eta_3}{2}\sum_{\lambda_1\lambda_4}\left\{|M^{+}_{0\lambda_4\lambda_1 1/2}|^2 - |M^{-}_{0\lambda_4\lambda_1 1/2}|^2\right\} \tag{9}$$

Therefore, from the knowledge of the cross-section and of the polarization, one deduces the experimental cross-sections for natural or unnatural parity exchange, given by

$$\frac{d\sigma^{\pm}}{du} = \frac{d\sigma}{du}\left(1 \pm \eta_3\, P(u)\right) \tag{10}$$

In the case of πN scattering ($\eta_3 = -1$), Eqs. (9) and (10) yield the remarkable relations

$$\frac{d\sigma^{\pm}}{du} = \frac{d\sigma}{du}\left(1 \mp P(u)\right)$$

$$P(u)\,\frac{d\sigma}{du} = |M^{-}|^2 - |M^{+}|^2 \tag{11}$$

which deserve some comments :

i) contrary to common belief on the Regge pole theory, the polarization cannot vanish unless two Regge trajectories with opposite naturalities are simultaneously exchanged (remember anyhow that for baryon exchange the evasive mechanism is not allowed, which forbids single Regge exchange);

ii) the polarization and the cross-section are independent of the relative phase of natural and unnatural parity exchanges. This exhibits strongly how much all amplitude analyses, so far performed, are model dependent;

iii) in the backward direction $(\sqrt{u} \simeq 0)$ there is a well-known conspiracy mechanism, the MacDowell symmetry [6], such that $|M^-(\sqrt{u}=0)| = |M^+(\sqrt{u}=0)|$, which is consistent with the vanishing of the polarization. Let us remark that this property is in fact not specific of backward scattering. For instance in $\pi N \to \rho N$, the definite naturality cross-sections $\sigma_1^{\pm} = \rho_{11} \pm \rho_{1-1}$ are equal for $t=0$, because ρ_{1-1} has to vanish due to angular momentum conservation;

iv) for elementary nucleon exchange, the polarization is obviously zero because the Born term contributes only to the invariant B amplitude, $B = g^2/(m^2-u)$, which is furthermore a real quantity. Equation (11) seems to imply the paradox that exchange of a $\frac{1}{2}^+$ particle yields equal contributions to the opposite parity amplitudes M^+ and M^-. This mystery is immediately solved when one writes down the relation between $M^{\pm}$ and B, as given for instance in the textbook of Barger and Cline [7]

$$F^{\pm} = \mp \frac{g^2}{\sqrt{2u}} \left[(m \mp \sqrt{u}) - \frac{\mu^2}{m \mp \sqrt{u}} \right] \tag{12}$$

It is clear from Eq. (12) that F^+ and F^- have, respectively, a pole for $m = \pm\sqrt{u}$, and that F^+ and F^- are not equal for $u > 0$ as well as for $u < 0$. But it is anyhow easy to be convinced that $|F^+| \equiv |F^-|$ for $u < 0$, because $F^+(\sqrt{u}) = F^{-*}(\sqrt{u})$;

v) in the meson baryon case $(0^- + \frac{1}{2}^+ \to 0^- + \frac{1}{2}^+)$ the M^+ and M^- amplitudes defined above are nothing else than the transversity amplitudes $T^s_{0\frac{1}{2}0\frac{1}{2}}$ and $T^s_{0-\frac{1}{2}0-\frac{1}{2}}$, respectively.

2) Polarization measurements of a final state baryon

For more generality in this case, we use the density matrix formalism. It is not difficult to check that one can construct density matrix element combinations $\rho^{\pm}_{\lambda_4 \lambda'_4}$ which explicitly split the density matrix into its natural and unnatural parity components (when particle 1 has spin zero). These combinations are given by

$$\rho^{\pm}_{\lambda_4 \lambda'_4} = \rho_{\lambda_4 \lambda'_4} \pm i\, \varepsilon(\lambda'_4)\, \rho_{\lambda_4 -\lambda'_4} \tag{13}$$

with

$$\varepsilon(\lambda_4') = -\eta_1 \eta_4 (-)^{s_4 - \lambda_4'}$$

and

$$\frac{d\sigma}{du} \rho^{\pm}_{\lambda_4 \lambda_4'} = \frac{1}{4} \sum_{\lambda_2 \lambda_3} M^{\pm}_{\lambda_3 \lambda_4 0 \lambda_2} M^{\pm *}_{\lambda_3 \lambda_4' 0 \lambda_2} \tag{14}$$

Equation (13) is particularly meaningful when the density matrix elements are measured in a parity violating decay of particle 4, because in that case one can reach both their real and imaginary parts.

For $\pi N \to K \Lambda (\Sigma)$ or $KN \to \pi \Lambda (\Sigma)$, the density matrix is entirely described by the two independent elements $\rho_{\frac{1}{2}\frac{1}{2}} = \rho_{-\frac{1}{2}-\frac{1}{2}} = \frac{1}{2}$ and $\rho_{\frac{1}{2}-\frac{1}{2}} = -\rho_{-\frac{1}{2}\frac{1}{2}} = -\frac{i}{2} P_y(\theta)$, because the Λ polarization is always perpendicular to the scattering plane. Then Eq. (13) can be rewritten as

$$\begin{aligned} \frac{d\sigma^{\pm}}{du} &= 2 \frac{d\sigma}{du} \rho^{\pm}_{1/2\, 1/2} \\ &= \frac{d\sigma}{du} (1 \mp P_y(u)) \end{aligned} \tag{15}$$

in agreement with Eq. (11).

At last we consider the reaction $\pi N \to K Y^*_{\frac{3}{2}^-}$ with the two step decay :

$$Y^*_{3/2^-} \to \Lambda \pi \quad ; \quad \Lambda \to N \pi$$

The relevant experimental quantities to be measured are the four independent real combinations

$$\begin{aligned} \rho^{\pm}_{33} &= \rho_{33} \pm \mathrm{Im}\, \rho_{3-3} \\ \rho^{\pm}_{11} &= \rho_{11} \mp \mathrm{Im}\, \rho_{1-1} \end{aligned} \tag{16}$$

and the two complex ones

$$\rho^{\pm}_{31} = \rho_{31} \pm i \rho_{3-1} \tag{17}$$

The above expressions are not relevant for Δ production, as for instance in $\pi N \rightarrow \pi\Delta$, because they require measurement of Im $\rho_{\lambda\lambda'}$, which, in turn, is not possible without observing the rescattering of the decaying nucleon from the Δ.

4. COMPARISON WITH EXPERIMENT

We now present a short survey of experimental data. We used the highest available energy polarization data for $\pi^- p \rightarrow \pi^- p$ at 6 GeV/c from Dick et al. [8], for $\pi^+ p \rightarrow \pi^+ p$ at 6 GeV/c from Dick et al. [9] with interpolated differential cross-section data at 5.9 GeV/c from Owen et al. [10], and for $\pi^- p \rightarrow K^0 \Lambda$ at 6.2 GeV/c from Beusch et al. [11]. The splitting between natural and unnatural parity exchange using Eqs. (11) and (15) is presented in Figs. 1, 2 and 3 for $d\sigma^{\pm}/du$. Error bars have been computed by adding the quoted experimental errors on polarization and cross-section.

We do not intend here to enter into a detailed comparison between these experimental results and theoretical models or explanations, though we found by going through the available literature that a number of claims has to be revised. We just want to point out some qualitative features of the data.

i) For $\pi^- p \rightarrow \pi^- p$, where only Δ_δ and Δ_γ can be exchanged, we remark, in Fig. 1, that both contributions are roughly of the same order of magnitude. The Δ_δ contribution is smooth and structureless, though there is a definite indication for a structure around $u \simeq -0.2$ for the Δ_γ cross-section, a reflection of the maximum in polarization observed at this point.

ii) For $\pi^+ p \rightarrow \pi^+ p$ the situation is not so clear due to the large number of contributing trajectories. It is anyhow apparent in Fig. 2 that both sets of opposite naturality contribute with equal strength in the near backward direction, that both have the dip structure and that (N_α, N_γ) dominate strongly for larger values of u.

iii) The preceding results have to be contrasted with those obtained in Fig. 3 for $\pi^- p \rightarrow K^0 \Lambda$ which are probably even more striking. One observes a dominant and structureless contribution associated with Σ_β exchange and a sharp minimum for Σ_α around $u = -0.2$. It is not our purpose to say whether this mimumum is associated with a wrong signature nonsense zero of the Σ_α or with a subtile cancellation between Σ_α and Σ_γ, as in the model of

Barger, Cline and Matos [12]. The only point we want to emphasize is that the leading contribution is not given by the nearest singularity and that, in general, it should be so. Consider in fact the situation in which one amplitude, say M^+, has a pole close to the physical region, while another one, say M^-, has none. Then the contribution of $|M^+|^2$ to the cross-section will be a rapidly decreasing function of momentum transfer, though the contribution of $|M^-|^2$ will be less steep. As both amplitudes should be equal for $u \simeq 0$, the leading contribution in the physical domain will therefore be given by the less singular amplitude. In other words, one may enforce the contributions of a parity doublet partner by requiring that this partner does not materialize as a real particle. The parity doublets are even worse than the hydra of Lerna, they are growing stronger when you kill them.

Let us finally remark that the present situation, and the shape of the curves in Fig. 3, is very similar to the forward photoproduction cross-sections $\sigma_{/\!/}$ and $\sigma_{\perp}$. They are both equal for $t = 0$. The parallel cross-section, dominated by the pion pole is sharply peaked and goes to zero very rapidly. The perpendicular cross-section does not have the pion pole and therefore gives a smooth and dominant contribution. Equivalently, the Λ polarization in $\pi^- p \to K^0 \Lambda$ looks very similar to the π^+ or π^- asymmetry in photoproduction.

iv) We want to show now that accurate upper and lower bounds on the isospin $\frac{1}{2}$ contributions (N_α, N_γ) and (N_β, N_δ) to πN backward scattering, can easily be obtained within the present experimental information. Triangular inequalities between cross-sections and polarizations of isospin related processes are known for a long time [13]. Due to the fact that cross-sections and polarizations can be expressed as an incoherent sum or difference of naturality conserving amplitudes, it is possible to obtain separate bounds for each naturality. Use of the combination $M_{++} \pm iM_{+-}$ has been in fact already advocated by Michael et al. [14] and by Barger and Olsson [15] to compute easily triangular inequalities between differential cross-sections and polarizations. One obtains

$$\frac{1}{2}\left(3\sqrt{\sigma^{\pm}_{\pi^+}} - \sqrt{\sigma^{\pm}_{\pi^-}}\right)^2 \leq 2\sigma^{\pm}_{1/2} \leq \frac{1}{2}\left(3\sqrt{\sigma^{\pm}_{\pi^+}} + \sqrt{\sigma^{\pm}_{\pi^-}}\right)^2 \tag{18}$$

where σ_{π^+}, σ_{π^-} and $\sigma_{\frac{1}{2}}$ are respectively the $\pi^+ p$, $\pi^- p$ and isospin $\frac{1}{2}$ exchange differential cross-sections, and the $\pm$ upper index refers, of course, to the natural or unnatural parity contributions.

Inequality (18) makes use only of π^+ and π^- elastic data. The preceding bounds can be improved by using at the same time the charge exchange differential cross-section, σ_{π^0}, from which one can compute the $\sigma_{\frac{1}{2}}$ cross-section

$$\sigma_{1/2} = \frac{1}{2}\left(3\left(\sigma_{\pi^+} + \sigma_{\pi^0}\right) - \sigma_{\pi^-}\right) \tag{19}$$

and

$$\sigma_{1/2}^{\pm} = \sigma_{1/2} - \sigma_{1/2}^{\mp} \tag{20}$$

From (18) and (20) we derive the new inequality

$$\sigma_{1/2} - \frac{1}{4}\left(3\sqrt{\sigma_{\pi^+}^{\mp}} + \sqrt{\sigma_{\pi^-}^{\mp}}\right)^2 \leqslant \sigma_{1/2}^{\pm} \leqslant \sigma_{1/2} - \frac{1}{4}\left(3\sqrt{\sigma_{\pi^+}^{\mp}} - \sqrt{\sigma_{\pi^-}^{\mp}}\right)^2 \tag{21}$$

We found that the best bounds were in general obtained by using the lower bound in (18) and the upper bound in (21). Results of our analysis are presented in Fig. 4, for (N_α, N_γ) and (N_β, N_δ) contributions at 6 GeV/c, using the charge exchange data of Boright et al.[16]. All experimental errors have been included to define the allowed domains. The bounds in (18) or (21) are so good that the extension of the domains merely reflects the experimental uncertainties, and use of central experimental data values, for instance, leaves an extremely thin path for both contributions. It is particularly interesting to observe on Fig. 4 how severe are the bounds for (N_α, N_γ) and how much is this contribution separated from (N_β, N_δ) for $|u| > 0.2\ (\mathrm{GeV}/c)^2$.

5. CONCLUSIONS

We have shown that it is very easy and straightforward to compute, on a purely experimental ground, from the cross-section and polarization the contributions of both partners of a parity doublet in backward scattering. We have found that both partners do contribute to the scattering and that in general the unobserved partner (i.e., the one which does not materialize as a low-lying resonance) gives an important and sometimes dominant contribution. Anyhow, we do not claim to have definitely settled the baryon exchange puzzle.

There seems to be some systematic dip structure associated with (N_α, N_γ) or $(\Sigma_\alpha, \Sigma_\gamma)$ exchanges. But on the other hand, we do not understand the completely different behaviours of (N_β, N_δ) in $\pi^+ p \to \pi^+ p$ and of $(\Sigma_\beta, \Sigma_\delta)$ in $\pi^- p \to K^0 \Lambda$. Measurement of the charge exchange cross-section $\pi^- p \to \pi^0 n$ on a polarized proton target, as well as the backward pion photoproduction $\gamma N \to \pi N$ on a polarized target would be of great help in disentangling the various contributions. Study of other associated productions with hyperon polarization measurement would be also very valuable. We also mention that measurement of the A and R parameters gives an evaluation of the relative phases between the two opposite naturality contributions, in meson baryon $(0^- \frac{1}{2}^+ \to 0^- \frac{1}{2}^+)$ backward reaction, namely

$$\begin{aligned} A\sin\theta + R\cos\theta &= 2\,\mathrm{Im}\, M^- M^{+*}/(|M^+|^2 + |M^-|^2) \\ A\cos\theta - R\sin\theta &= 2\,\mathrm{Re}\, M^- M^{+*}/(|M^+|^2 + |M^-|^2) \end{aligned} \tag{22}$$

Finally, expressions given in this paper can be extended to multiparticle or inclusive reactions as, for instance, $a + p\uparrow \to$ (spin zero) + X or (spin zero) + b $\to X + B\uparrow$. These reactions and others will be studied in a forthcoming publication [5].

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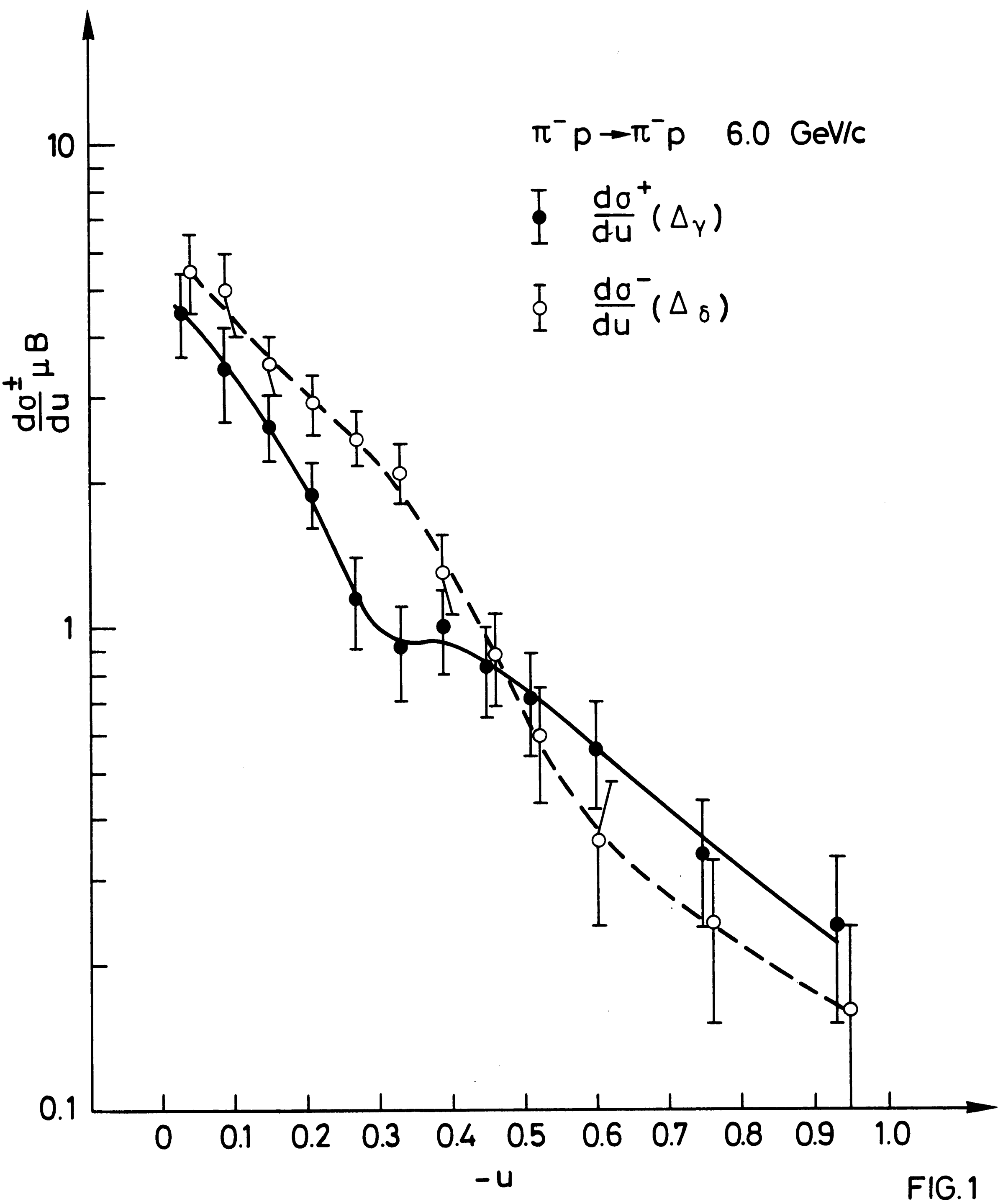
FIGURE CAPTIONS

Figure 1 : Backward $\pi^- p \to \pi^- p$ scattering at 6 GeV/c. Data points are from Refs. 8) and 10). The lines (full line for natural parity exchange, dashed line for unnatural parity exchange) are free hand-fit through experimental points.

Figure 2 : Backward $\pi^+ p \to \pi^+ p$ scattering at 6 GeV/c. Data points are taken from Refs. 9) and 10), and curves are as in Fig. 1.

Figure 3 : Backward $\pi^- p \to K^0 \Lambda$ scattering at 6.2 GeV/c. Data points are from Ref. 11) and curves are as in Fig. 1.

Figure 4 : Bounds on the isotopic spin $\frac{1}{2}$ exchanges in backward πN scattering at 6 GeV/c obtained from inequalities (18) and (21). Experimental data used are from Refs. 8), 9), 10), 11) and 18).



$\pi^- p \to \pi^- p$ 6.0 GeV/c
$\frac{d\sigma^+}{du}(\Delta_\gamma)$
$\frac{d\sigma^-}{du}(\Delta_\delta)$
$\frac{d\sigma^\pm}{du}$ µB
10
1
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
-u

FIG.1

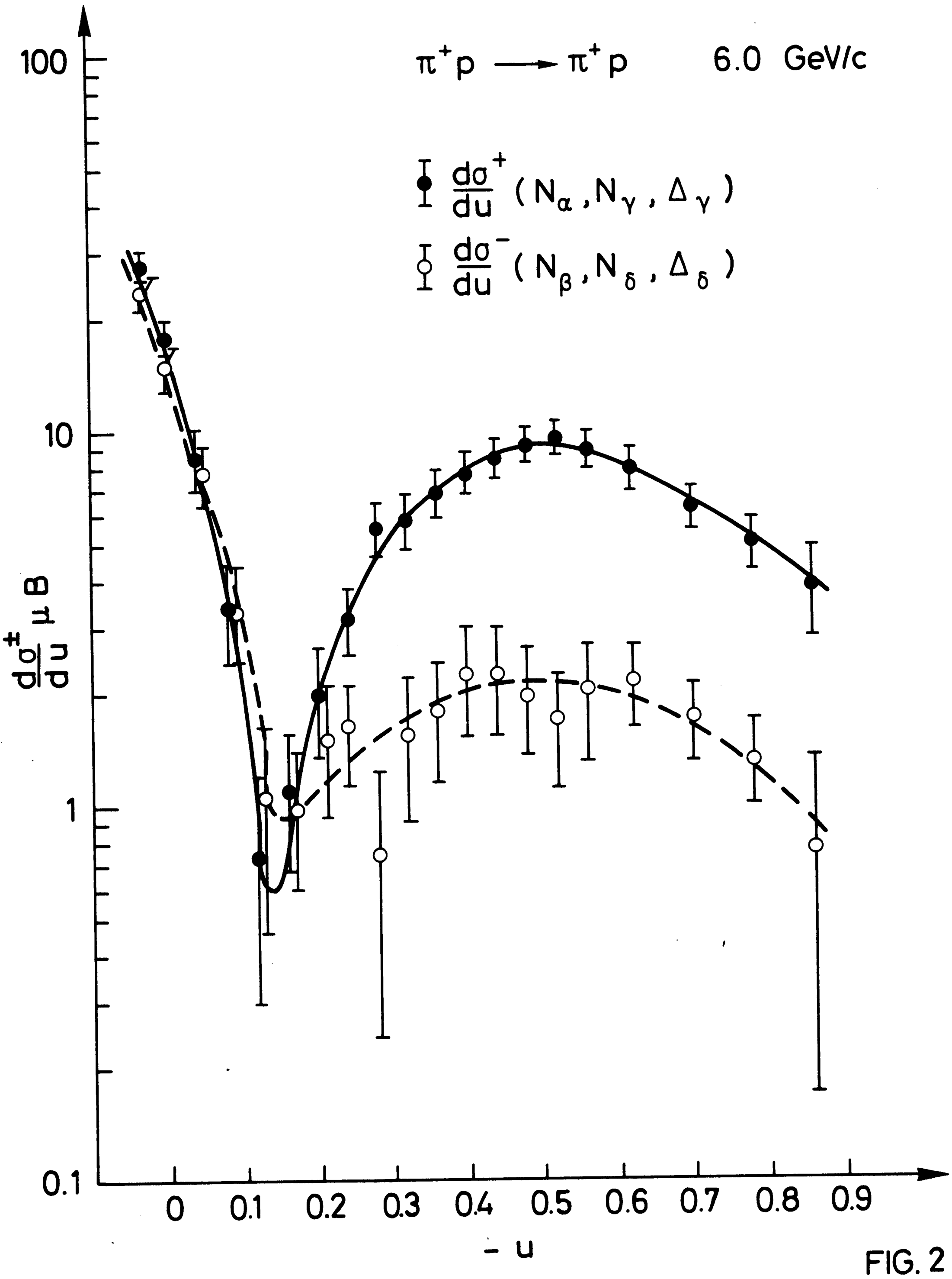
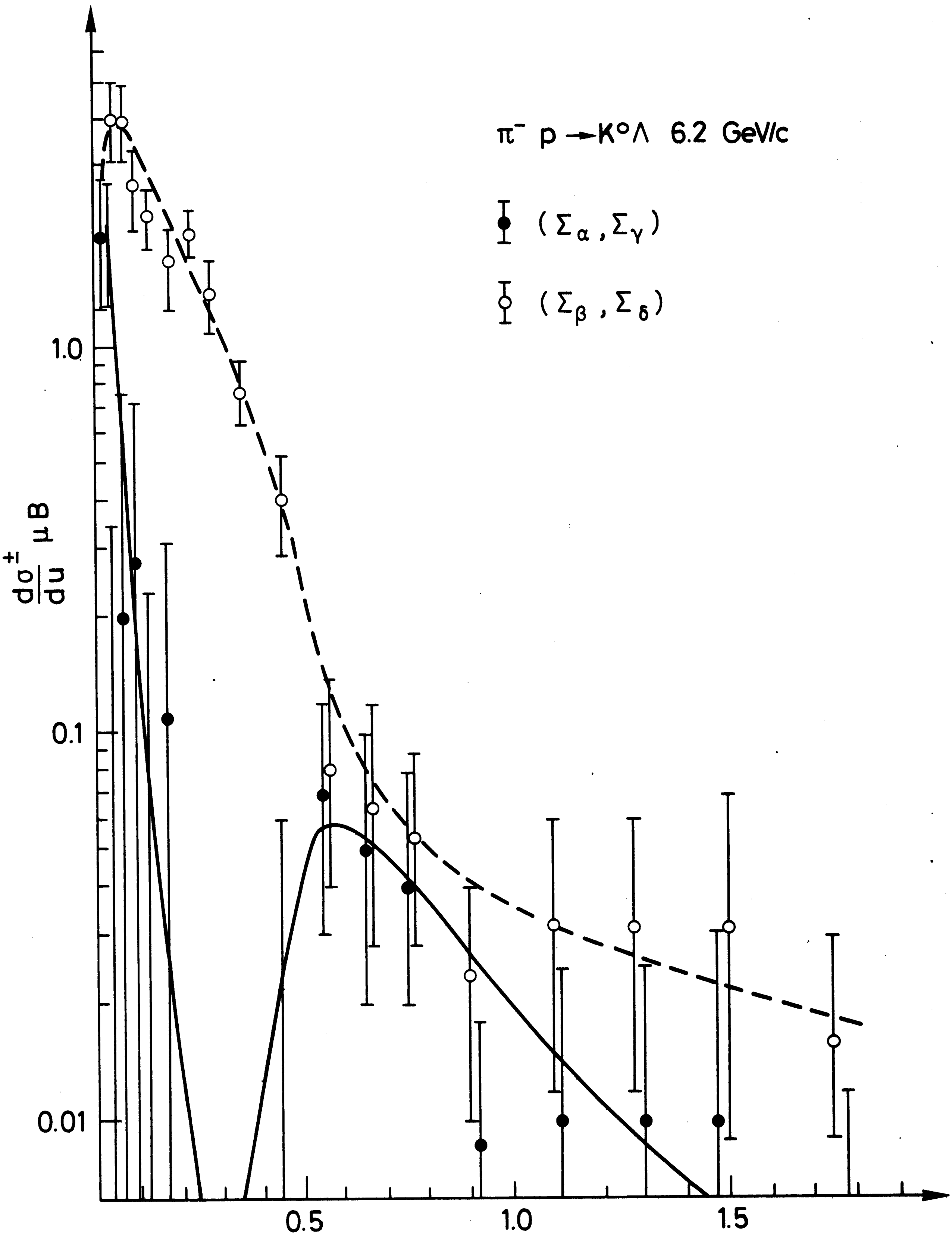
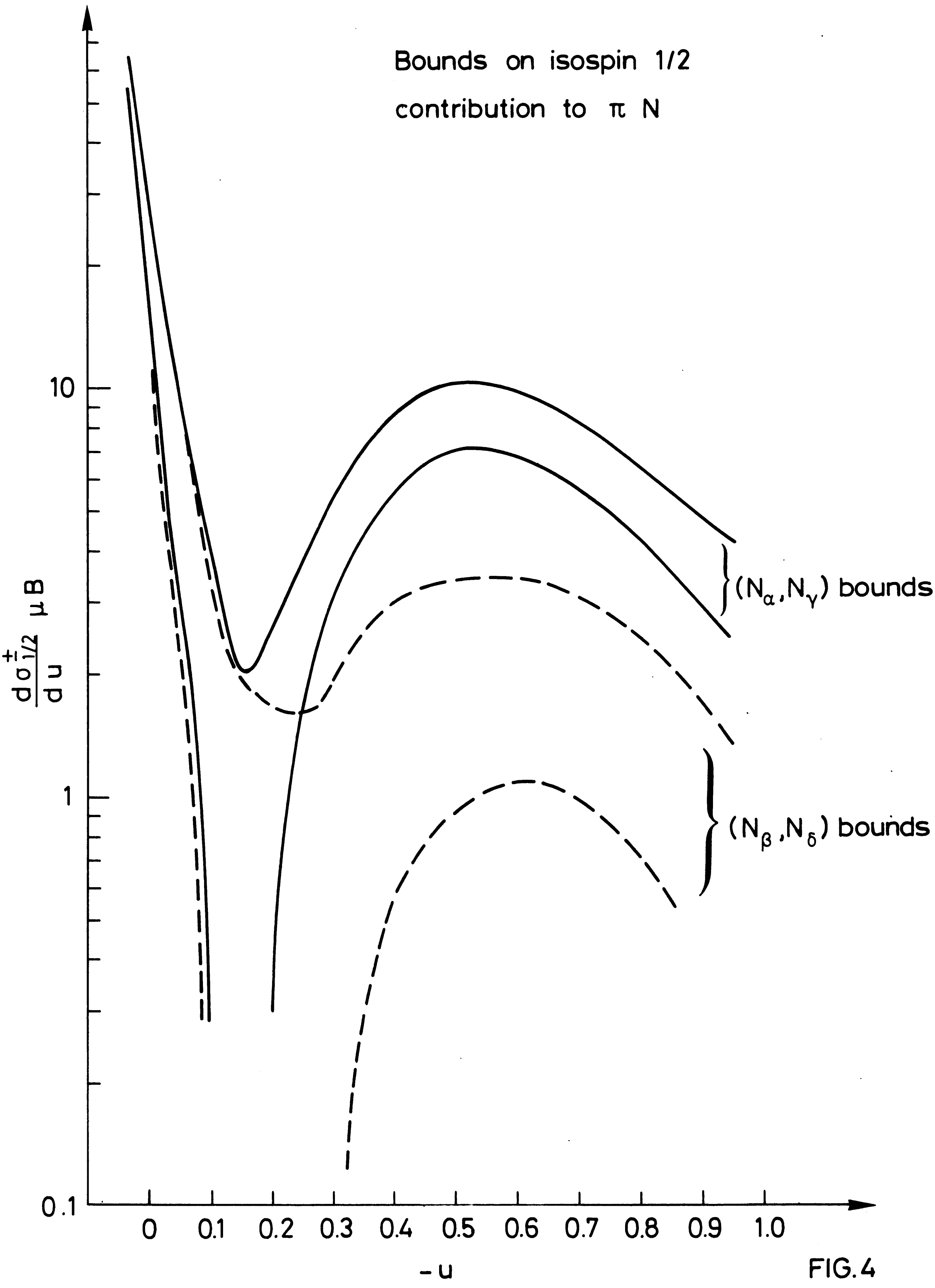

$\pi^+ p \longrightarrow \pi^+ p$ 6.0 GeV/c
$\frac{d\sigma^+}{du} (N_\alpha, N_\gamma, \Delta_\gamma)$
$\frac{d\sigma^-}{du} (N_\beta, N_\delta, \Delta_\delta)$
$\frac{d\sigma^\pm}{du}$ μB
100
10
1
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
$-u$

FIG. 2



$\pi^- p \to K^\circ \Lambda$ 6.2 GeV/c
$(\Sigma_\alpha, \Sigma_\gamma)$
$(\Sigma_\beta, \Sigma_\delta)$
1.0
0.1
0.01
$\frac{d\sigma^\pm}{du}$ μB
0.5
1.0
1.5
$u_{max} - u$

FIG. 3



Bounds on isospin 1/2
contribution to π N
$\frac{d\sigma^{\pm}_{1/2}}{du}$ μB
10
1
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
-u
(N_α, N_γ) bounds
(N_β, N_δ) bounds

FIG.4