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SIMPLE s HELICITY STRUCTURE AT THE NUCLEON-NUCLEON VERTEX OF THE POMERON AND MESON EXCHANGES : EXPERIMENTAL EVIDENCE AND CONNECTIONS WITH DUALITY

R. Odorico
CERN -- Geneva

R.Garcia
Centro Atomico Bariloche and
Instituto de Fisica Balseiro
(CNRA y UNC), Bariloche

C.A. Garcia - Canal
Departamento de Fisica,
Universidad Nacional de
La Plata

ABSTRACT

Experimental evidence in favour of an almost pure s helicity non-flip character at the nucleon-nucleon vertex of the Pomeron, f^0 and ω exchanges is discussed. Further we discuss some connections with duality of this phenomenon and the related feature of ρ and A_2 exchanges which present an essentially helicity flip coupling at the NN vertex.

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As is known, the simple Regge pole model meets considerable difficulties in describing the existing high energy data [1]. Neglecting small effects, like $\pi^- p \to \pi^0 n$ polarization, this is essentially due to : i) the factorization properties, and ii) the definite parity, of Regge poles. If we suppose that Regge poles must be sizeably corrected because of absorption, properties i) and ii) are spoiled, and the possibility of getting agreement with experiments is reopened [1]. However, in such a picture the connection between the high energy data and the properties of the relevant resonances in t channel is more loose. In order to fully exploit it, one needs a quantitatively reliable theory of absorption, which is lacking at present [1]. In such a situation it becomes then of considerable interest to single out characteristics of the t channel resonance pole which are not spoiled by absorption, and thus remain unaffected in the observed high energy exchange. Absorption is supposed to act like

$$\left(f^s_{\lambda\mu}\right)_{absorbed} = f^s_{\lambda\mu} + \sum_{\mu'} f^s_{\lambda\mu'} \otimes P_{\mu'\mu}$$

where $f^s_{\lambda\mu}$ are the s channel helicity amplitudes, $P_{\mu'\mu}$ is the Pomeron exchange, and $\otimes$ indicates the convolution product [1]. If the Pomeron is pure s helicity non-flip, i.e., $P_{\mu'\mu}$ is diagonal, each s channel helicity amplitude receives only its own contributions. That is, in this hypothesis for the Pomeron, if an exchange does not originally couple at a vertex to some s helicity configuration, it maintains this property also when it is absorbed.

This note is devoted to a discussion of the evidence in favour of an almost pure s helicity non-flip character at the nucleon-nucleon vertex of the Pomeron, f^0 and ω exchanges. Furthermore, we point out some connections with duality of this property of f^0 and ω and the related feature of ρ and A_2 exchanges, which are known to be essentially s helicity flip at the NN vertex.

New accurate measurements of the proton-proton polarization have been recently made at CERN [2]. The data show a considerably steep decrease with energy. In Fig. 2 we have plotted the quantity

$$d\sigma/dt \times \text{Polarization} \times p_{LAB}$$

against the lab. momentum p_{lab} at $t = -0.23 \pm 0.025\ (\text{GeV/c})^2$, where, as can be seen in Fig. 1, statistical errors are generally smaller. In a Regge picture this quantity should behave like

$$p_{LAB}^{\alpha_{Pom} + \alpha_x - 1} \simeq p_{LAB}^{\alpha_x}$$

if the polarization is due to the interference of the Pomeron with a Regge term behaving like $p_{lab}^{\alpha_x}$. As is indicated in Fig. 2, data would then require roughly $-0.9 < \alpha_x < -0.25$. The fact that α'_{pom} is different from zero, as the shrinking of the forward peak indicates, modifies only slightly these bounds. They are shifted to the right by $\alpha'_{pom} \times |t| \simeq 0.5 \times 0.23 \simeq 0.12$, if one assumes for α'_{pom} the Serpukhov value [3]. The polarization parameter $P(t)$ expressed in terms of s channel helicity amplitudes reads [4]

$$I \cdot P(t) = \mathrm{Im}\left(f^s_{++,+-} \cdot \left(f^s_{++,++} + f^s_{++,--} + f^s_{+-,+-} - f^s_{+-,-+}\right)^*\right)$$

where I is the intensity for scattering two unpolarized protons. From $np \to pn$ and $\bar{p}p \to \bar{n}n$ differential cross-section data, it is known that ρ and A_2 exchanges are small in NN scattering [5]. One would expect a relevant contribution to the polarization from the interference of ω and f^0 with the Pomeron. Data indicate that this contribution is small. Looking at the above expression for the polarization, a natural way to interpret this fact is to suppose that all the three exchanges P, f^0 and ω couple weakly to $f^s_{++,-+}$, i.e., to the simple helicity flip amplitude which directly controls the strength of the polarization. This would mean to suppose that P, f^0 and ω couple weakly to nucleon-nucleon s helicity flip. This, a priori, is not the only possibility. However, it is difficult to find other hypotheses which remain consistent like this one, in the presence of absorption. Indeed what we need here is an explanation valid for a rather broad interval of t, and generally absorption mixes amplitudes which are not s channel helicity amplitudes. Thus for instance to suppose that P, f^o and ω are pure t channel, and not s channel, helicity non-flip would also account for data, however, it is extremely unlikely that this hypothetical character of f^o and ω exchanges would be preserved by absorption. On the other hand, we are not allowed to neglect absorption, since it should produce such a relevant effect as the cross-over zero at $t \simeq -0.15\ (\mathrm{GeV}/c)^2$ in ω exchange.

The hypothesis of the vanishing of the s helicity flip coupling at the NN vertex of P, f^o and ω exchanges is supported by other independent facts. About ω exchange, one can observe :

i) the isoscalar anomalous magnetic moment of the nucleon $\mu'_{I=0}$ is nearly zero $(\mu'_{I=0} = -0.065)$ [6]. In the coupling

$$\bar{u}\left(\gamma_\mu + \frac{\mu'}{2M}\sigma_{\mu\nu}q_\nu\right)u\ \omega_\mu$$

$\mu' = 0$ means (independently of q^2) pure helicity non-flip, for high values of the momenta of the initial and final nucleons. If one believes in the vector dominance model [7], this datum then hints at a pure helicity non-flip character of the coupling ωNN of the ω resonance to NN;

ii) μ' near zero at the ωNN vertex also results from the extensive fits with meson exchanges to low energy NN scattering by Bryan and Scott [8];

iii) the forward dip in π^o photoproduction [9] requires that ω exchange couples weakly, at least at $t \simeq 0$, to the s channel helicity amplitude $f^s_{+\frac{1}{2};-\frac{1}{2},+1}$, i.e., that it couples weakly to s helicity flip at the NN vertex. As is known, an unabsorbed ω exchange with definite parity would decouple automatically at $t = 0$, independently of its dynamical features. However, the lesson of the long dispute about pion conspiracy [1] is that absorptive corrections can transform a dip into a peak, and therefore this latter explanation cannot be considered as sufficient.

If ω exchange has a small s helicity coupling at the NN vertex, exchange degeneracy (in KN and NN scattering) requires that also f^0 exchange possesses the same feature. Independent evidence in this sense and in favour of a s helicity non-flip Pomeron is provided by pion-nucleon scattering data.

a) One can extract information from phase shifts through continuous moment sum rules [10]. The high energy leading terms of the s channel helicity flip amplitude are provided only by the invariant amplitude A *). One finds that $A^{(+)}$ which should contain the leading P and P' ($P' \equiv f^0$ exchange) s helicity flip contributions, is dominated by a term with $\alpha(0) < 0$. More exactly one finds $\alpha(0) = -0.54$ with the CERN phase shifts $\alpha(0) = -0.11$ with the Glasgow ones and $\alpha(0) = -0.60$ with the Berkeley ones. The approximate relation [11] $A'^{(+)} \equiv A^{(+)} + (\nu/1-t/4M^2)B^{(+)} \simeq B^{(+)}$ which resulted from previous work with CMRS, already suggested qualitatively this fact, but the mixing in $B^{(+)}$ of P, P' and the extra contribution with lower α, which is still sizeable at 2 GeV/c, prevented from a more quantitative conclusion [12].

b) The π^+p and π^-p polarizations exhibit an almost complete mirror symmetry at high energy [13]. The dominant term in the sum $P_{\pi^+p} + P_{\pi^-p}$ of π^+p and π^-p polarizations is proportional to $\mathrm{Im}(f^s_{++}(P+P') \cdot f^{s*}_{+-}(P+P'))$. This quantity must therefore be small. One is left with two possibilities : i) $f^s_{+-}(P+P')$ is small, ii) $f^s_{++}(P+P')$ and $f^s_{+-}(P+P')$ have the same phase (this would be, for instance, the case if P and P' were pure t channel helicity non-flip). Like in the case of pp polarization, however, the possibility ii) is extremely unlikely in the presence of sizeable absorption. Indeed we know that absorption operates more strongly on f^s_{++} than on f^s_{+-}, and one expects the absorptive corrections of P and P' to be rather different in magnitude and shape [1].

c) The preliminary measurements of the R parameter [14] also hint at a small helicity flip coupling of the Pomeron [Cohen-Tannoudji, Ref. 14].

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*) The amplitudes A and B are defined by the conventional decomposition

$$\bar{u}\left(-A + \tfrac{1}{2} i (q_1 + q_2)_\mu \gamma_\mu B\right) u$$

See, e.g., J. Hamilton and W.S. Woolcock, Revs.Modern Phys. 35, 737 (1963).

Each of the above pieces of evidence, if taken separately, suffers in some degree either of quantitative uncertainty or of ambiguity. In particular, the uniqueness of our interpretation of the pp and π p polarization data relies heavily on the hypothesis of the presence of a strong absorption, which spoils almost everything except s channel helicity characteristics. Though, looking at independent data, this hypothesis is rather reasonable, it is always a hypothesis. But it seems to us that if one considers all the above facts together, very little place is left for alternative explanations.

P, f^o and ω exchanges would not be alone to have a definite s helicity flip character at the NN vertex. Several facts indeed indicate that ρ and A_2 (related between themselves by exchange degeneracy) are there almost pure s helicity flip. Near $t=0$, this is supported by : i) the hooks near the forward direction present in the differential cross-sections of π N and KN charge exchange, and $\pi^- p \rightarrow \eta n$ [15], and ii) by the small values of π N and KN total cross-section combinations corresponding to ρ and A_2 quantum numbers [16]. Moveover, iii) if we suppose that the value of the μ' parameter characterizing the coupling of the ρ resonance to NN

$$\bar{u} \left(\gamma_\mu + \frac{\mu'}{2M} \sigma_{\mu\nu} q_\nu \right) u \, \rho_\mu$$

is not far from the value $\mu'_{I=1} = +1.85$ [6] of the isovector anomalous magnetic moment of the nucleon, then the coupling ρ NN turns out to be almost pure helicity flip (in the direct channel) for large values of the nucleon momentum (it would be exactly helicity flip for $\mu' = +2$); iv) that $\mu'_{NN} \simeq +2$ is also supported by the low energy fits with meson exchanges to NN scattering [8].

The recent measurements at SLAC [17] of the density matrix of the neutral ρ photo-produced from protons, have shown that, in the interval of t explored $[|t| \leq 0.4 \; (\mathrm{GeV/c})^2]$, the Pomeron couples weakly to helicity flip at the $\gamma\rho$ vertex. This, together with that we have concluded about the PNN coupling, seems to indicate that helicity non-flip is a general characteristics of diffraction [18].

The simple structure at the NN vertex of the exchange degenerate pairs of exchanges $f^o-\omega$ and $\rho-A_2$ awaits for some theoretical understanding. Here we merely observe that for f^o and ρ this simple structure comes out if we make an assumption concerning duality [19]. This assumption is that in π N scattering the s channel helicity amplitudes have approximately a structure like that suggested by dual resonance models [20]. If we consider two resonance poles in different variables (s and t for instance), they always intersect in the Mandelstam plane (i.e., in the plane of s, t and u variables). The dual resonance models [at least those we know at present [20]] require that the two resonance poles must have the same residue at the intersection point. Let us suppose that this is approximately true at the intersections of baryon resonances with boson resonances in the amplitudes $A'' = A+(s-u/4M^2)B$ *) and A, which correspond at high energy and at fixed t to s channel helicity non-flip and helicity flip, respectively. Since we have resonances in all three channels, we get some consistency conditions. In particular, we find that the presence of, say, the f^o in one of the two amplitudes, A" or A, excludes the presence of the ρ in the same amplitude, and vice versa. In s channel helicity amplitudes (with kinematical singularities in t removed) the residues of the baryon resonances have definite signs for $t \geq 0$ (since Hacobi polynomials have zeros only in the physical region). In particular, they have the same sign at $t = m_\rho^2$ and $t = m_{f^o}^2$. For A" and A, one can verify that this latter fact remains true also at low energies for all the observed resonances. This implies (see Fig.3) that if ρ and f^o appear in the same amplitude, their residues must have the same relative sign both at large s and at large u. This is because when ρ and f^o intersect the s or u channel baryon resonances, the residues of ρ and f^o, as we have supposed above, must match those of the latter at the intersection points. Since the residue of the ρ resonance is odd in s-u, and that of the f^o is even, one gets an inconsistency. We know from total cross-section data that f^o exchange is sizeably present in A". Therefore by this argument one concludes that ρ must be absent from A", and f^o must be absent from A. A further conclusion one gets is that the relevant baryon resonances should have at $t > 0$ residues in A" and A of equal sign in one channel (s or u), and of opposite sign in the other. This, in other words, means that the relevant baryon resonances in $\pi^+ p$ must have all the same value of $P(-1)^{J-\frac{1}{2}}$ (where P is the parity relative to the nucleon and J is the spin), and this value must be opposite to that owned by the relevant baryon resonances

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*) The amplitude A" coincides with the conventional A' of Singh for not too large values of t.

in $\pi^- p$. Experimentally this is true. The dominant resonances in $\pi^+ p$ belong to the Δ_δ series which has $P(-1)^{J-\frac{1}{2}} = -1$, while in $\pi^- p$ the N_α and N_γ series which have $P(-1)^{J-\frac{1}{2}} = +1$ are predominant.

Summarizing, we have presented some evidence from which it seems reasonable to conclude that the Pomeron, f^0 and ω exchanges are pure s helicity non-flip at the NN vertex. This feature of f^0 and ω recalls the analogous one of ρ and A_2 exchanges which are known to be almost pure s helicity flip at the NN vertex. Moreover, it has been shown that an explanation for these features of meson exchanges can be found requiring that in πN scattering s channel helicity amplitudes have approximately a structure like that suggested by dual resonance models. Such an assumption gives also some predictions for the parity of the prominent baryon resonances in πN scattering, which turn out to be in agreement with data. It remains, however, to see if all this is just a coincidence occurring in πN scattering, or if this assumption has a more general validity. A thorough analysis in this sense is outside the scope of this note.

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FIGURE CAPTIONS

Figure 1 : Angular dependence of pp polarization at 3.67, 6 and 14 GeV/c. See Ref. 21) for data.

Figure 2 : Energy behaviour of the quantity $(d\sigma/dt) \times Pol \times p_{lab}$ in pp scattering. The solid lines refer to energy behaviours of the type $(p_{lab})^{\alpha_x}$ for the values of α_x specified in the figure (see also the text). For polarization data, see Ref. 21). For the differential cross-section we have used interpolations of the existing data [see Ref. 22) for the data used]. The errors in the figure include only the statistical errors of polarization data.

Figure 3 : Sketch of the relative positions in the Mandelstam plane of the baryon resonances and the ρ and f^0 boson resonances in πp elastic scattering (see the text).

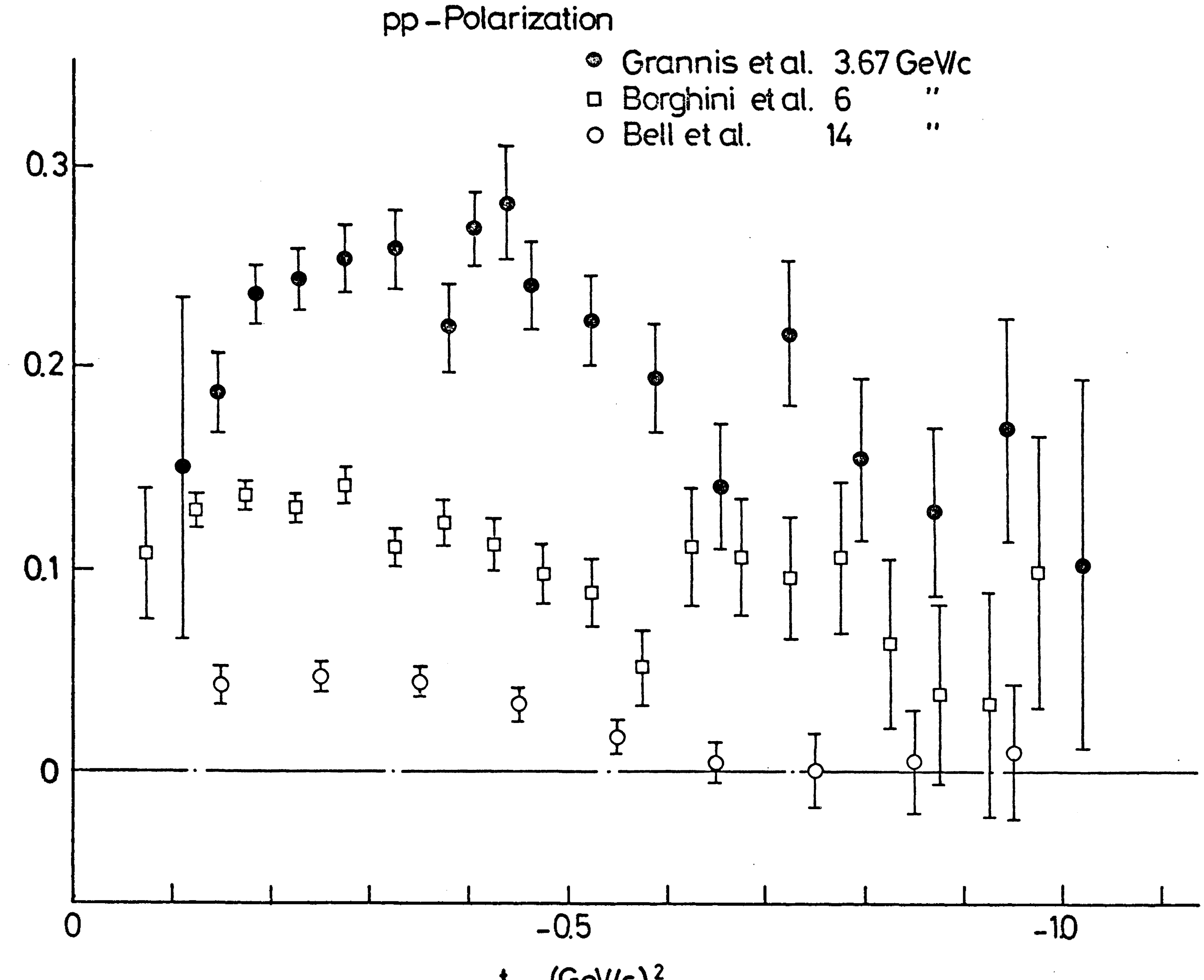

pp - Polarization
Grannis et al. 3.67 GeV/c
Borghini et al. 6 "
Bell et al. 14 "
0.3
0.2
0.1
0
0
-0.5
-1.0
t (GeV/c)²

FIG.1

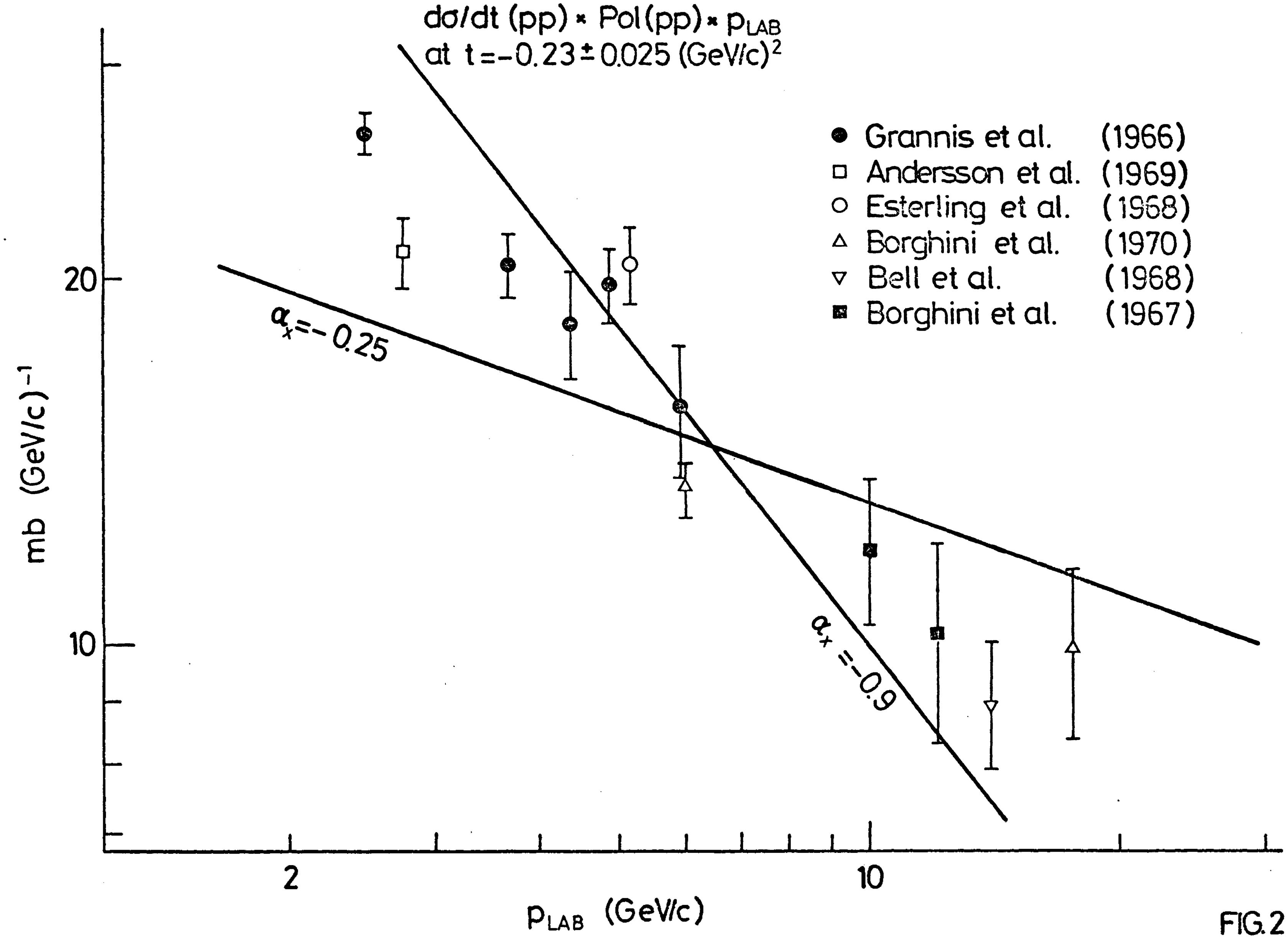
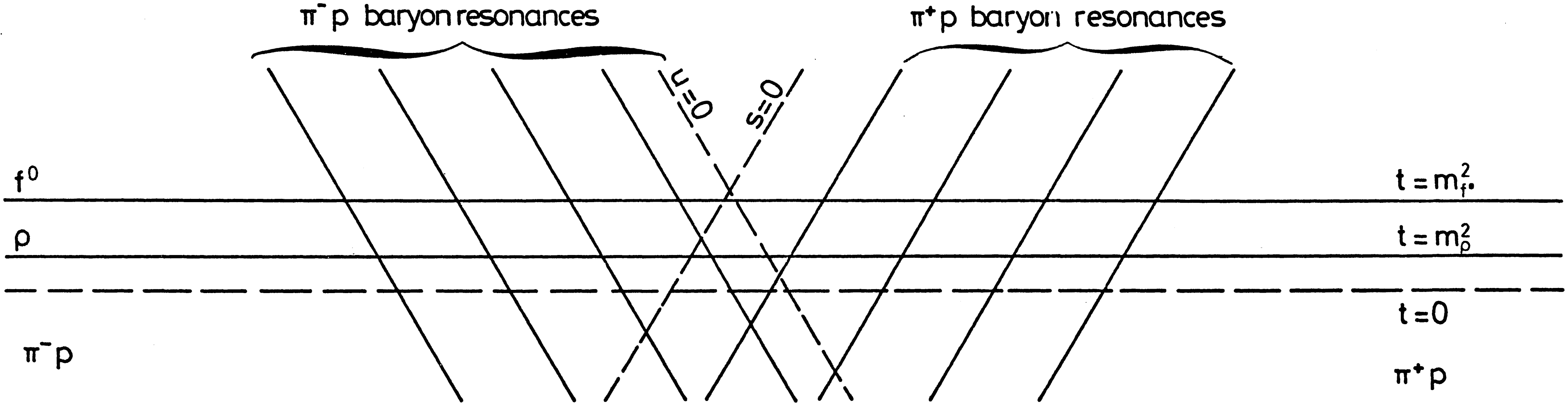

dσ/dt (pp) × Pol(pp) × p_LAB
at t=-0.23±0.025 (GeV/c)²
Grannis et al. (1966)
Andersson et al. (1969)
Esterling et al. (1968)
Borghini et al. (1970)
Bell et al. (1968)
Borghini et al. (1967)
α_x=-0.25
α_x=-0.9
mb (GeV/c)⁻¹
20
10
2
10
p_LAB (GeV/c)

FIG. 2



π⁻p baryon resonances
π⁺p baryon resonances
u=0
s=0
f⁰
ρ
t = m²f°
t = m²ρ
t = 0
π⁻p
π⁺p

FIG. 3