Ref.TH.1109-CERN

POLARIZATION EFFECTS IN pp AND $\bar{p}p$ SCATTERING AT HIGH ENERGIES

M. Jacob and J. Weyers *)

CERN - Geneva

A B S T R A C T

A simple model is developed which allows a qualitative understanding of the observed structures in the pp polarization data and leads to predictions for the $p\bar{p}$ polarization.

---

*) On leave of absence from University of Louvain, Louvain, Belgique.

Ref.TH.1109-CERN
27 November 1969

Duality [1] and the absence of resonances with exotic quantum numbers lead to exchange degeneracy between Regge trajectories [2]. For polarizations, drastic predictions follow from the set of exact relations provided by exchange degeneracy. In particular, any charge-exchange reaction with no direct channel resonances should not show any polarization effect. Such predictions should not, however, be always expected to be meaningful. Duality, indeed, is expected [3] to lead to only approximate statements and polarization as an interference effect, is sensitive to relatively small terms which can be neglected in the analysis of cross-sections. First of all duality, as it is used for leading trajectories, has very little to say about low partial waves. Since their relative importance increases with momentum transfer, any polarization prediction derived from duality is, a priori, limited to low momentum transfers. In addition, the implications of duality are meaningful only to the extent that there are leading trajectories which actually dominate, through strong couplings and high intercepts, the imaginary part of the non-diffractive piece of the scattering amplitude. For example, one can clearly differentiate proton neutron elastic and charge-exchange scattering on the ground that the ω and the P' trajectories are known to play a dominant rôle in elastic scattering whereas only low intercept (π) or weakly coupled (ρ) trajectories are relevant for charge-exchange scattering. For these weakly coupled or low lying trajectories, it is likely that their effect will be overshadowed by Regge cut contributions. These cut contributions for which very little detailed information exists as yet are anyhow expected to take over at large momentum transfer [4]. It is therefore only in the low momentum transfer region of elastic scattering processes such as meson-nucleon, nucleon-nucleon and antinucleon-nucleon that the polarization predictions derived from exchange degeneracy can be put to a serious test.

It is furthermore quite remarkable that existing polarization data, and in particular $\pi^{\pm}p$ scattering data [5] can be understood, at least qualitatively, in terms of an interference between a diffractive background with no helicity flip and a helicity flip term which is dominated by the Regge contribution. In the case of processes like Kp or pp, with no direct channel resonances, exchange degeneracy is then directly tested. With such a simplified description of polarization effects, predictions also follow for K^-p and $\bar{p}p$ scattering.

In this note we restrict our discussion to pp and $\bar{p}p$ scattering and develop a model which allows a qualitative understanding of the observed polarization in pp scattering. It then leads to a set of predictions for the polarization in $\bar{p}p$ scattering.

The Regge contribution is limited to the P' (or f^0) and ω trajectories. Near $t = 0$, these trajectories are known to be exchange degenerate [2),6)]. Our present picture of meson-meson scattering requires the two trajectories to coïncide. Relations among their residues, however, which are imposed in meson-meson scattering, should become less reliable for meson-nucleon scattering and even less so for nucleon-nucleon scattering [3)].

The CERN data on polarization in pp [7)] show the following qualitative features : it decreases with energy like $s^{\alpha(t)-1}$ where $\alpha(t)$ is the P' trajectory and it presents some significant [8)] structures around $t = -0.6$ and $t = -1$ GeV^2. A narrow dip at $|t| \simeq 0.6$ GeV/c^2 is a very significant feature of data obtained by different groups in the neighbourhood of 6 GeV/c [5),7),8)]. In our model, the dip at $t = -0.6$ is explained by the breaking of exchange degeneracy with increasing transfer whereas the structure around $t = -1$ calls for rescattering corrections to the diffractive and Regge parts of the amplitude. Several detailed Regge fits and predictions have already been made for the pp and $\bar{p}p$ polarizations [8),9)]. Our aim in this note is to show that a qualitative understanding of the main features of the data is possible keeping only leading terms. Our starting point is similar to the one taken in some previous calculations [9)]. Nevertheless we prefer here to follow the effect of leading and sound terms, rather than consider them within a detailed model as previously done. The details of all models hitherto considered seem to be unsafe when a polarization is calculated. For the $\bar{p}p$ polarization, our model leads to the following predictions : starting only as $t^{\frac{3}{2}}$, it remains, from $t = 0$ to about $t = -0.6$ GeV^2, smaller, but of the same sign, as in pp ; around $t = -0.6$ GeV^2 the two polarizations become equal and before one reaches $t = -1$ GeV^2, the $\bar{p}p$ polarization is expected to change sign.

Of the five independent amplitudes two correspond to no helicity flip, two to double helicity flip and one to a single flip. The double and single helicity flip amplitudes are respectively proportional to $|t|/4m^2$ and $\sqrt{|t|/4m^2}$. Since we concentrate our attention to the low t region, the double helicity flip amplitudes can be neglected. Furthermore, with the exchange of a natural parity trajectory, the two helicity non-flip amplitudes become equal [10]. We are thus led to the following low transfer formula for the polarized cross-section :

$$\frac{d\sigma}{dt} \simeq |\varphi_{NF}|^2 - 2P\sqrt{\frac{|t|}{4m^2}}\, \mathrm{Im}\left\{ \varphi_F^* \varphi_{NF} \right\} \tag{1}$$

The sum of the two non-flip and the single flip amplitudes have been respectively denoted by φ_{NF} and $(t/4m^2)^{\frac{1}{2}}\varphi_F$; P is the expectation value of the target spin component along the normal to the reaction plane. To the same approximation, the measured right left asymmetry Δ is related to P by

$$\Delta = 2P\sqrt{\frac{|t|}{4m^2}}\, \frac{\mathrm{Im}\left\{\varphi_F^* \varphi_{NF}\right\}}{|\varphi_{NF}|^2} \tag{2}$$

We have isolated in front of φ_F a factor $(|t|/4m^2)^{\frac{1}{2}}$; the flip amplitude φ_F so defined has then no kinematical singularity at $t = 0$ and can be parametrized in terms of standard Regge contributions.

In the model considered here the flip amplitude in pp and $\bar{p}p$ is dominated by the contributions of the P' and ω trajectories and they are written as

$$\varphi_F^{p} = \beta_{P'}(t)\left(1 + e^{-i\pi\alpha_{P'}(t)}\right)(\alpha' s)^{\alpha_{P'}(t)} + \beta_{\omega}(t)\left(1 - e^{-i\pi\alpha_{\omega}(t)}\right)(\alpha' s)^{\alpha_{\omega}(t)} \tag{3a}$$

$$\varphi_F^{\bar{p}} = \beta_{P'}(t)\left(1 + e^{-i\pi\alpha_{P'}(t)}\right)(\alpha' s)^{\alpha_{P'}(t)} - \beta_{\omega}(t)\left(1 - e^{-i\pi\alpha_{\omega}(t)}\right)(\alpha' s)^{\alpha_{\omega}(t)} \tag{3b}$$

whereas the non-flip amplitudes can be parametrized as follows

$$\varphi_{NF}^{p} = P(s,t) + \gamma_{p'}(t)\left(1+e^{-i\pi\alpha_{p'}(t)}\right)(\alpha' s)^{\alpha_{p'}(t)} + \gamma_{\omega}(t)\left(1-e^{-i\pi\alpha_{\omega}(t)}\right)(\alpha' s)^{\alpha_{\omega}(t)} \quad (4a)$$

$$\varphi_{NF}^{\bar{p}} = P(s,t) + \gamma_{p'}(t)\left(1+e^{-i\pi\alpha_{p'}(t)}\right)(\alpha' s)^{\alpha_{p'}(t)} - \gamma_{\omega}(t)\left(1-e^{-i\pi\alpha_{\omega}(t)}\right)(\alpha' s)^{\alpha_{\omega}(t)} \quad (4b)$$

with $P(s,t)$ the non-flip diffractive contribution [9]. Exchange degeneracy requires $\alpha_{p'}(t) = \alpha_{\omega}(t) = \alpha(t)$ with $\alpha(t) \simeq \frac{1}{2} + \alpha' t$ and $\beta_{p'}(t) = \beta_{\omega}(t) = \beta(t)$ and $\gamma_{p'}(t) = \gamma_{\omega}(t)$. These predictions, however, are expected to become more and more inaccurate with increasing $|t|$. For the diffractive piece of the scattering amplitude we will assume, as a first approximation, the "Pomeron" trajectory to be flat, i.e., $P(s,t) = isf(t)$ with $f(t) \simeq e^{-A|t|}$. At present energies, the polarization effects for low transfers $(t \ll -1\,\mathrm{GeV}^2)$ are essentially independent of the precise behaviour, flat or almost flat, of the diffractive piece of the amplitude. For larger momentum transfers, however, and especially around $t \simeq -1\,\mathrm{GeV}^2$ where a break in $d\sigma/dt$ can be interpreted as evidence that rescattering effects start dominating the pp amplitude, the precise nature of the "Pomeron" trajectory becomes crucial for a qualitative understanding of polarization effects.

In the small t region, as emphasized before, we expect exchange degeneracy to be very good and the dominant Regge contribution to be to the flip amplitude, i.e., $\gamma(t) \ll \beta(t)$. We therefore write

$$\Delta_{pp} = 4P\sqrt{\frac{|t|}{4m^2}}\,\beta(t)\,(\alpha' s)^{\alpha(t)-1}$$

$$\Delta_{\bar{p}p} = 4P\sqrt{\frac{|t|}{4m^2}}\,\beta(t)\cos\pi\alpha(t)\,(\alpha' s)^{\alpha(t)-1} \quad (5)$$

Both polarization effects are thus expected to decrease as $s^{\alpha(t)-1}$. This seems to be born out well by the pp data between 6 and 14 GeV [5),7)].

Both polarization effects are also of the same sign

$$\Delta_{\bar{p}p} = \cos \pi\alpha(t)\ \Delta_{pp} \tag{6}$$

with $\alpha(0) \simeq \frac{1}{2}$, this leads to a $p\bar{p}$ polarization increasing only as $|t|^{\frac{3}{2}}$ and becoming equal to the pp polarization in the neighbourhood $|t| = 0.6(\mathrm{GeV}/c)^2$ where $\alpha(t)$ vanishes.

The same assumptions used together with factorization and SU(3) symmetry imply that the polarizations in pp and π^+p scattering should be of the same sign.

In the intermediate t region we are not allowed to neglect the breaking of exchange degeneracy any more. Since the breaking in the trajectory functions $\alpha_{P'}(t)$ and $\alpha_\omega(t)$ only adds small oscillations but does not alter our qualitative conclusions we will continue to ignore it. The breaking in the residue functions, on the other hand, will have an appreciable effect and has to be taken into account. Writing

$$\begin{aligned} \varphi_F^p &= \left(B_1(t) + B_2(t)\, e^{-i\pi\alpha(t)}\right)(\alpha' s)^{\alpha(t)} \\ \varphi_F^{\bar{p}} &= \left(B_2(t) + B_1(t)\, e^{-i\pi\alpha(t)}\right)(\alpha' s)^{\alpha(t)} \end{aligned} \tag{7}$$

$$\begin{aligned} \varphi_{NF}^p &= P(s,t) + \left(C_1(t) + C_2(t)\, e^{-i\pi\alpha(t)}\right)(\alpha' s)^{\alpha(t)} \\ \varphi_{NF}^{\bar{p}} &= P(s,t) + \left(C_2(t) + C_1(t)\, e^{-i\pi\alpha(t)}\right)(\alpha' s)^{\alpha(t)} \end{aligned} \tag{8}$$

with

$$\begin{aligned} B_1(t) &= \beta_\omega(t) + \beta_{P'}(t)\ ; \quad B_2(t) = \beta_{P'}(t) - \beta_\omega(t) \\ C_1(t) &= \gamma_\omega(t) + \gamma_{P'}(t)\ ; \quad C_2(t) = \gamma_{P'}(t) - \gamma_\omega(t) \end{aligned} \tag{9}$$

Exchange degeneracy leads to nonsense choosing according to Gell-Mann; as a result all $\beta(t)$ and $\gamma(t)$ defined in Eqs. (3) and (4) should be slowly varying functions of t in the region of interest. Assuming the B's and C's to be smooth, we obtain for the polarization, as long as the Pomeron remains the dominant term in the non-flip amplitude

$$P_{pp} \simeq f(t)\left(B_1(t) + B_2(t)\cos\pi\alpha(t)\right)(\alpha' s)^{\alpha(t)-1}$$

$$P_{\bar{p}p} \simeq f(t)\left(B_2(t) + B_1(t)\cos\pi\alpha(t)\right)(\alpha' s)^{\alpha(t)-1}$$

In order to reproduce the significant structure shown by the data at $t \simeq -0.6$ GeV^2, we have to assume that $B_2(t)$ is negative while exact exchange degeneracy would give a flat polarization ($B_2 = 0$). This is the only qualitative feature which we take from the polarization data as they now stand.

For $\bar{p}p$ we then predict a maximum in the polarization for the same momentum transfer (i.e., $t \simeq -0.6$ GeV^2) and at that point the two polarizations become equal.

Neglecting the ω P' interference should be more and more justified as the energy increases. At 15 GeV the neglected effect could be of the order of 10% of the dominant one at low $|t|$ values.

If our parametrization remains valid, we expect a recurrent structure in the vicinity of $t = -1.6$ GeV^2. However, already in the neighbourhood of $t = -1$ GeV^2, the polarization will depend sensitively on the precise behaviour of the diffractive contribution. Furthermore, the double flip amplitudes could also begin to contribute significantly. Limiting ourselves to the non-flip diffractive amplitude, we expect it to be balanced by the rescattering corrections. This has to happen if they are called for in order to explain the observed structure in the differential cross-section [11] near $t = -1$ GeV^2. As a result, the contribution to the polarization we restricted ourselves to is no longer the dominant one. Let us note that since rescattering effects are larger for $\bar{p}p$, the break in the cross-section should occur for a lower $|t|$ value [12].

The next term to consider in the polarization is then the ω P' interference term which, with the breaking of exchange degeneracy already introduced, reads

$$\left(B_2 C_1 - C_2 B_1\right) \sin \pi\alpha(t) \qquad \text{for } pp,$$

$$\left(C_2 B_1 - B_2 C_1\right) \sin \pi\alpha(t) \qquad \text{for } \bar{p}p$$

C_1 as defined in Eq. (9) is large compared to C_2 and negative near $t = 0$ since $\sigma_{\bar{p}p} > \sigma_{pp}$. In the model this leads then to a negative value for the real part of the forward amplitude and a correct order of magnitude of 30% at, say, 15 GeV/c. However, C_1 should change sign when the rescattering corrections to the Regge amplitude are also included. The contribution to the polarization coming from the $C_2B_1 \sin \pi\alpha(t)$ term is expected to be smaller than the one from B_2C_1. In any case, they have opposite signs.

All rescattering corrections can be consistently introduced using the unitarization procedure of Baker and Blanckenbecler [13]. As a result a change of sign of $C_1(t)$ is expected to occur much before $t = -1$ GeV^2 yet neatly after the cross-over point ($t \simeq -0.2$ GeV^2) when it is also explained in terms of rescattering corrections.

We cannot use the rescattering corrections thus obtained to actually compute effects on the polarization. These corrections lead to Regge branch points which are known to be present on general grounds [14]. The sign of the discontinuity across the cut can also be shown to be correct [4]. The magnitude of the effect cannot, however, be trusted.

We take the attitude that such effects are indeed responsible for the structure observed in the differential cross-section and the cross-over phenomenon, their sign being as required for this. This leads us to also expect a change of sign in the real part of the non-flip amplitude. With the same guiding lines we also expect the flip amplitude, which vanishes in the forward direction, to be much less corrected than the non-flip one. This is known to lead to the correct sign prediction for the polarization in π nucleon charge exchange [4),15)] which is typically a rescattering (or absorption) correction effect.

The pp polarization should therefore rise again after the dip observed around $t = -0.6$; but this rise being mainly associated with the ω P' interference should lead to a conspicuous effect only at low energy. The fact that the 14 GeV CERN data [7)] show an almost zero polarization between -6 and -1 GeV^2 supports this point of view.

The main point is that it leads to a prediction for the $\bar{p}p$ polarization : it should change sign before $t \simeq -1$ GeV^2. (At low energies, where the rescattering corrections are much larger than for pp scattering, it could be for a transfer as low as $t \simeq -0.7$.)

If we allow for a small slope in the diffractive part of the amplitude, described as a single Regge contribution, the real part of the non-flip amplitude which is so added, would affect the polarization for large transfers but would not modify the interpretation of the low t structures thus given.

In conclusion, our simple model leads to a qualitative understanding of the observed polarization in pp scattering and allows predictions for the $\bar{p}p$ polarization.

Δ_{pp} shows some structure at $t = -0.6$ GeV^2 which we take as evidence for the breaking of exchange degeneracy. The structure at $t = -1$ GeV^2 calls on the other hand for rescattering corrections to the Regge amplitude.

Our predictions for $\Delta_{\bar{p}p}$ can be summarized as follows :

- the energy dependence is the same as for Δ_{pp} ;
- for $0 < t < -1$ $\Delta_{\bar{p}p}$ which rises as $|t|^{\frac{3}{2}}$, has the same sign as ${}_{pp}$ but is smaller, essentially by a factor $\cos \pi \alpha(t)$. In particular near $t = -0.6$ GeV^2 the two polarizations become equal and $\Delta_{\bar{p}p}$ does not change sign ;
- finally, before one reaches $t = -1$ GeV^2 we expect $\Delta_{\bar{p}p}$ to change sign.

If we cannot attempt at present to interpret pp polarization data at higher transfers $1 < |t| < 2$ GeV/c^2, we would highly welcome $\bar{p}p$ data extending up to 1 GeV/c^2.

We are very grateful to Dr. L. Dick for communication of his latest results at 6 and 14 GeV/c and to Dr. C. Michael for discussions on Regge phenomenology.

REFERENCES

1) K. Igi - Phys.Rev.Letters 9, 76 (1962) ;

A. Logunov, L.D. Soloviev and A.A. Tavkhelidze - Phys.Letters 24B, 181 (1969) ;

K. Igi and S. Matsuda - Phys.Rev.Letters 18, 625 (1967) ;

R. Dolen, D. Horn and C. Schmid - Phys.Rev. 166, 1768 (1968).

2) J.L. Rosner - Phys.Rev.Letters 21, 950 (1968) ;

H.J. Lipkin - Nuclear Phys. B9, 349 (1969) ;

M. Kugler - Phys.Rev. 180, 1538 (1969) ;

R.H. Capps - Phys.Rev.Letters 22, 215 (1969) ;

J. Mandula et al. - Phys.Rev.Letters 22, 1147 (1969).

3) J. Mandula, J. Weyers and G. Zweig - Phys.Rev.Letters 23, 266 (1969).

4) J. Finkelstein and M. Jacob - Nuovo Cimento 56, 681 (1968).

5) M. Borghini et al. - Phys.Letters 21, 114 (1966) ; 24B, 77 (1967).

6) See, e.g., : P. Auvil and F. Halzen - CERN Preprint TH. 1106 (1969).

7) M. Borghini et al. - To be published. This includes in particular accurate pp data at 14 GeV.

8) N.E. Booth et al. - Phys.Rev.Letters 21, 651 (1968).

9) See among others :

V. Barger - "Topical Conference on High Energy Collisions of Hadrons", CERN (1968) ;

W. Rarita et al. - Phys.Rev. 165, 1615 (1968) ;

L. Durand III and R. Lipes - Phys.Rev.Letters 20, 637 (1968) ;

A. Capella et al. - Nuovo Cimento 63, 1141 (1969) ;

R.C. Arnold and R.K. Logan - Phys.Rev. 177, 2318 (1969).

10) C. Itzykson and M. Jacob - Nuovo Cimento 28, 250 (1963).;

11) G. Cohen-Tannoudji et al. - Nuovo Cimento 55, 412 (1968).

11) J.V. Allaby et al. - Phys.Letters 25B, 156 (1967).

12) O. Czyzewski et al. - Phys.Letters 15, 188 (1965) ;

W.M. Katz et al. - Phys.Rev.Letters 19, 265 (1967).

13) M. Baker and R. Blanckenbecler - Phys.Rev. 128, 415 (1962) ;

M. Jacob and S. Pokorski - Nuovo Cimento 61, 233 (1969).

14) S. Mandelstam - Nuovo Cimento 30, 1127, 1148 (1963) ;
V.N. Gribov - J.E.T.P. 26, 414 (1968).

15) C. Chiu and J. Finkelstein - Nuovo Cimento 48, 820 (1967) ;
G. Cohen-Tannoudji et al. - Nuovo Cimento 48, 1075 (1967).