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IMPLICATIONS OF NUCLEON-NUCLEON SPIN-POLARIZATION MEASUREMENTS

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IMPLICATIONS OF NUCLEON-NUCLEON SPIN-POLARIZATION MEASUREMENTS

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ABSTRACT

We interpret the available data on polarised nucleon-nucleon elastic scattering. By comparing these with the simplest exchange model predictions we can identify features of particular interest such as low-lying A_1-like and isoscalar exchanges, and a helicity-flip Pomeron component. Our maximum-simplicity Regge model is intended to facilitate interpretation of forthcoming pp amplitude analysis results.

EXCHANGE STRUCTURE OF pp SCATTERING

The elastic reaction $pp \to pp$ appears to be an excellent candidate for a study of hadron dynamics at low momentum transfer — it looks simple, highly symmetric and is particularly well-measured. In an exchange context, however, it has an embarassingly rich structure. The 5 amplitudes combinations N_n, U_n (N, U stand for natural, unnatural parity exchange respectively and n is total s-channel helicity flip) can have contributions from almost every known Regge exchange (see Table I). According to symmetry arguments and coupling systematics established from factorisation studies of many processes, these exchanges are expected to couple in a distinctive way as shown in Table I.

Table I Exchanges in pp Elastic Scattering

Amplitude	Dominant Contributions	Suppressed Contributions
N_0	$\mathbb{P}+f+\omega$	$\rho+A_2$
N_2	$\rho+A_2$	$\mathbb{P}+f+\omega$
N_1	$\rho+A_2/\mathbb{P}+f+\omega$	
U_0	A_1+Z	$D+Z_0$
U_2	$\pi+B$	$\eta+H$

The complex numbers which are the end product of pp amplitude analyses[1] will remain somewhat sterile quantities unless there exist

*Presented by A. C. Irving

model predictions of good theoretical pedigree, with which to compare them. We have constructed such a model[2] using the simplest possible amplitude structure satisfying SU(3), exchange degeneracy (EXD) and factorisation constraints[3] together with an f-dominated Pomeron amplitude. Details of this highly simplified, and hence predictive, model and of the relation between amplitudes and observables may be found in Ref.2. The basic model amplitudes (at 6 GeV/c and $t = -0.3$ GeV^2) are similar to those shown in Fig.1 except that U_0 ($A_1 + Z$ exchange), in common with other components having no Pomeron contribution, is purely real. In particular, the sign of each component is a theoretical prediction since the process is an elastic one.

As an example, the $A_1 + Z$ amplitude is predicted[2] by identification of the Feynman diagram

$$U_0(A_1) = \frac{g^2_{A_1pp}}{t - m^2_A} (\bar{u}\gamma_\mu\gamma_5 u)(\bar{u}\gamma^\mu\gamma_5 u) \qquad (1)$$

with the Regge pole expression. The coupling G_{A_1pp} is estimated using current algebra and axial vector dominance of the weak form factor. Using $A_1 - Z$ EXD, one obtains a real and negative prediction for U_0.

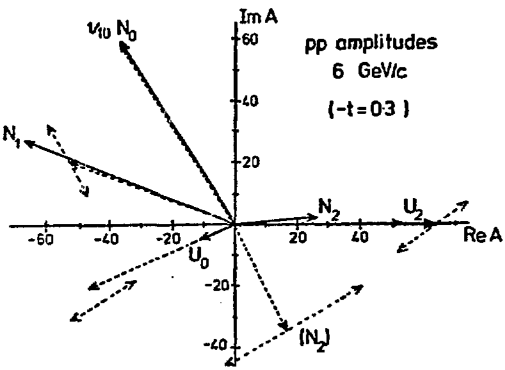

Fig.1 Argand plot of pp amplitudes. Solid vectors are the model of Ref.2. Dashed vectors are the tentative amplitude analysis results (and associated error estimates) of Ref.1.

The only non-real contribution in the basic model is due to Pomeron exchange whose flip and non-flip couplings are proportional to those of the ω and f.

COMPARISON WITH SPIN POLARISATION DATA

Of the many interesting features of the polarisation data in np and pp scattering, the following have particularly direct implications for exchange models.

A. The sizeable value of $\Delta\sigma^L_{tot}(\propto \mathrm{Im}\,U_0)$ measured at 6 GeV/c[4] implies a non-EXD A_1-like exchange. To account for this, we have put in an ad hoc imaginary contribution with the energy dependence of the A_1 $(\alpha_{A_1}(0) = -.19)$[2]. The agreement of our 12 GeV/c prediction with preliminary data[5] for $\Delta\sigma^L_{tot}$(Fig.2) shows this to be a reasonable approximation. Our description of the amplitude U_0 is reinforced by the measurement C_{LL} but will be most strongly tested by the triple scattering measurement H_{LSN}.[2]

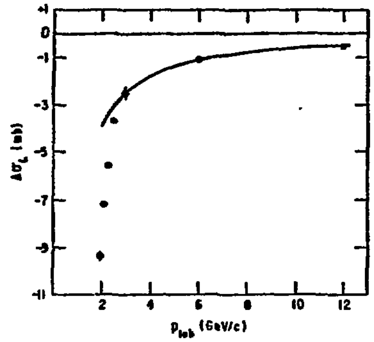

Fig.2. A comparison of model[2] and data[4] for the longitudinally polarised total cross-section difference $\Delta\sigma^L_{tot}(pp)$. The preliminary data point (☒) at 12 GeV/c is from Ref.5.

B. The isospin zero contribution to the nucleon-nucleon polarisation (P(pp) + P(pn)) shows an anomalously rapid energy dependence[6] which may be interpreted[7] as scalar ε and/or ω' exchange (see Fig.3).

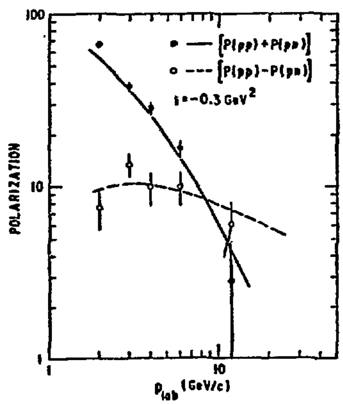

Fig.3. The isoscalar (●) and isovector (○) components of the NN elastic polarisation.[6] The model curves are from Ref.2.

In fact, a pole extrapolation estimate using knowledge of the on-shell coupling constant gives a good account of the magnitude of this low-energy effect as well as the correct sign (Fig.3). This exchange component also appears to play an important role in producing the highly energy dependent effects seen in C_{NN}.[2]

C. The negative polarisation measured in pp scattering for $|t| \gtrsim 0.4$ and $p_{LAB} \gtrsim 50$ GeV/c (and similar results in np scattering at lower energies) suggests a diffractive (i.e. mildly energy dependent) helicity flip amplitude component[8]. This has the sign predicted by eikonal models of the Pomeron with f-dominated couplings.[9] The implications for our simple model are that the real part of our helicity-flip Pomeron component must be reduced to reproduce this behavior. Fig.4 shows recent P(pp) data at 100 GeV/c[11] which illustrate this effect. Regge models with no helicity-flip pomeron predict very small but <u>positive</u> polarisation at 100 GeV/c.

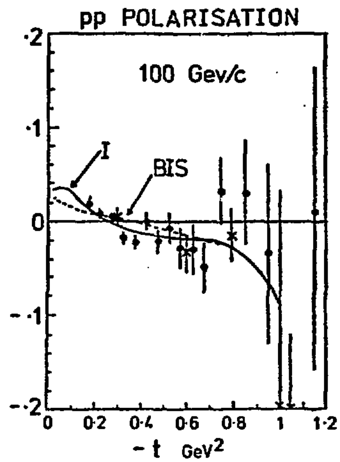

Fig.4. The pp elastic polarisation at 100 GeV/c (● Snyder et al, X Corcoran et al).[11] The curves marked I and BIS are predictions of Refs. 8 and 2 respectively and include electromagnetic corrections.

AMPLITUDE ANALYSIS

Fig.1 gives an example of our basic pp amplitude predictions modified as described in A, B and C above. The dashed argand vectors are the preliminary amplitude analysis results of Ref.[1] rotated to have our model phase for N_0 (not experimentally measurable for $t \neq 0$) and scaled to have the same magnitude for N_0 (trivially given by $\sqrt{\frac{d\sigma}{dt}}$). Since our model gives a good overall description of all available spin polarisation measurements (single, double and triple correlation) some degree of agreement is to be expected. The discrepancy in U_0 and N_2 is easily traced to the approximations made in the preliminary data analyses[10]

$$C_{LL} \sim U_0^{\parallel} \qquad \text{(2a)}$$

$$C_{NN} \sim N_2^{\parallel} \qquad (2b)$$

$$H_{NSS} \sim N_2^{\perp} \qquad (2c)$$

where $\parallel$ and $\perp$ refer to the direction of N_0 in the Argand plot. In our model, these appear to be bad approximations due to the large contributions from $\mathrm{Re}(N_2U_2^*)$, $|N_1|^2$ and $\mathrm{Im}(N_0N_1^*)$ to 2a, 2b and 2c respectively, in this t-range (near −0.3).

In any case, model amplitudes are vital in motivating, testing and interpreting pp amplitude analyses.

NON-ASYMPTOTIC CONTRIBUTIONS

The s-channel helicity components N_0, N_1, N_2, U_0 and U_2 are well-known to correspond to definite t-channel parity at leading order in 1/s only. Since many of the interesting exchange contributions in pp appear at low s only (e.g. "ε" and "A_1" exchange) it is essential to know what the exact parity content is. A detailed kinematical analysis[12] gives the results[2] shown in Table II.

Table II t-Channel Parity in s-Channel Helicity Amplitudes

Amplitude	Leading Contributions	1/s Contributions
$N_0 = \frac{1}{2}(\phi_1 + \phi_3)$	s^{α_N}	$s^{\alpha_U} \times 0(1/s)$
$N_1 = \phi_5$	s^{α_N}	$s^{\alpha_U} \times 0(1/s)$
$N_2 = \frac{1}{2}(\phi_4 - \phi_2)$	s^{α_N}	$s^{\alpha_U} \times 0(1/s)$
$U_0 = \frac{1}{2}(\phi_1 - \phi_3)$	$s^{\alpha_U}(A_1)$	$N_0(-t/2s)^*$
$U_2 = \frac{1}{2}(\phi_4 + \phi_2)$	$s^{\alpha_U}(\pi)$	none

*The factor −t/s comes from assuming factorising contributions to N_0. The factor of 1/2 results if one neglects their contribution to N_1.

We can safely neglect the $s^{\alpha_U - 1}$ contributions to "natural parity" combinations, but the natural parity (Pomeron) contamination is potentially important for $t \neq 0$ (i.e. in C_{LL})[2] and even at $t = 0$ (i.e. in $\Delta\sigma^L_{tot}$) if conspiratorial solutions are admitted. Stacey[13] has studied the latter possibility in detail.

It has been pointed out[12,13] that the A_1 or Z contribution to U_0 at $t = 0$ must vanish unless daughter contributions are present to satisfy an analyticity requirement on their 1/s "wrong naturality" contributions. Since there are many other theoretical reasons for the existence of daughter Reggeon contributions one need not be unduly worried by this curiosity.

OUTLOOK

Considerable light could be shed on the isospin decomposition of the pp amplitudes (Table I) by a selection of np elastic scattering spin measurements.[10] Our model suggest that $\Delta\sigma^L_{tot}$, C_{NN}, C_{SS} and H_{LSN} would be particularly valuable, as would C_{xx}(x = L,S,N) and D_{NN} measurements of np charge exchange in which spin correlation effects should be especially large.[2]

In the early seventies, amplitude analysis of $\pi N \to \pi N$ dealt an almost fatal blow to Regge exchange models. From the chaotic remains of these models some battered ideas on hadronic amplitude structure have struggled back into the daylight. Will the NN amplitude results be the coup de grace or will some totally new insight emerge? For my part, I expect these Regge ideas will still be around long after elephants have learned to fly and the A_1 has achieved respectability.

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