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POLARIZED PROTON BEAM PHYSICS AND RELATED TOPICS

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We shall concentrate on recent results from the polarized proton beam facility at the Argonne Zero Gradient Synchrotron (ZGS). The data presently available have been taken at 6 GeV/c in two months of beam time. Eventually after a more complete experimental survey, the polarized beam promises to give us new insights into the spin dependence of the amplitudes in a variety of nucleon nucleon interactions.

First we underline some features of the beam that are important in designing experiments:

1. The spin direction is reversed at the polarized source as often as experiments require. Spin up and spin down extracted beams have otherwise identical properties.

2. Having a relatively small number of depolarizing resonances, the ZGS may well be the highest energy machine that can accelerate polarized beam.

3. The extracted intensity ($\sim 3 \times 10^8$/pulse) is adequate to study large angle scattering, parity nonconservation and other rare phenomena.

4. The extracted polarization ($\sim 65\%$) is sufficient for studying inelastic reactions, which would be far more difficult with polarized targets.

5. The proton spin vector can be oriented in any direction, so that spin correlations can be measured both in the scattering plane and along the normal.

6. Deuterium targets can be used to look at p-n processes. In the future a polarized neutron beam could be made by accelerating and stripping deuterons.

Turning to elastic scattering, the forward np elastic cross-sections reported by Longo[1] are equal to those for pp out to $t = -3 GeV^2$ at ZGS energies. Evidently isovector exchanges have different phase or spin dependence from the dominant pomeron contribution. To understand the origin of the flip amplitude we must at least measure the np elastic polarization. If purely diffractive models work,[2,3] the np and pp polarizations will be equal, whereas if the flip amplitude is governed by ρ and A_2 exchange they will be mirror symmetric. There is clearly some odd-C exchange in the flip amplitude since pp and $\bar{p}p$ polarizations are markedly different even at 40 GeV/c.[4]

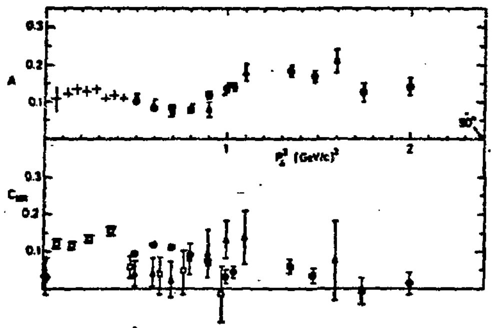
We can classify the five pp elastic amplitudes as N_o, N_1, and N_2 (helicity non flip, single flip, and double flip natural parity) plus A_1 and π (unnatural parity exchange). Whether A_1 and π correspond to $I_T=1$ exchanges is an experimental question. So far the spin correlations have all been measured with spins along the production normal and so give us non-interfering combinations of natural (N.P.) and unnatural (U.P.) parity exchanges. Eventually by measuring spin correlations in the production plane between the beam and target protons, one can isolate π- pomeron interference and get rather unique phase information.

At $t = -.5 GeV^2$, the Michigan-A.N.L.-St Louis group has measured all five independent cross-sections with spins along the normal using polarized beam and target with a recoil polarimeter.[5] The three largest cross-sections are combinations of N.P. amplitudes which conserve spin along the normal (↑↑→↑↑, ↑↓→↑↓, ↓↓→↑↑); the spinflip transitions (↑↑→↓↓ and ↑↓→↓↑) given by $|\pi \pm A_1|^2$ are much smaller. The Wolfenstein parameters at $-t = .5$ are Cnn = .10 ± .03, Dnn = .81 ± .06, and Knn = .14 ± .06, and from these we can deduce the fraction of U.P. exchange.

$$\frac{\pi^2+A_1^2}{N_o^2+2N_1^2+N_2^2} = .105 \pm .033, \text{ and } \frac{2Re\,\pi^* A_1}{\pi^2+A_1^2} = .2 \pm .3$$

If π and A_1 were really due to $I_T=1$ exchange, we would predict an np charge exchange differential cross section ~9 X bigger than the experimental value; thus it appears that "π" and "A_1" are mainly $I_T=0$ (Pomeron cuts?).

The spin correlation Cnn has been measured over a wide range of t by the Michigan-ANL-St Louis[5] and the Northwestern-ANL groups[6], as shown in figure 1 together with the ordinary polarization "A". Assuming that N_o is the dominant amplitude we can estimate the amplitude components $N_1^{\perp}$ and $N_2^{\prime\prime}$, which are



▲ Michigan-A.N.L.-St.Louis (1973)
● Michigan-A.N.L.-St.Louis (1974)
□ Northwestern-A.N.L.
◆ Michigan-A.N.L.-St.Louis "opitcal point"
✚ Borghini et al., ref. 19.

Fig. 1 Polarization parameter A and spin correlation Cnn for pp→pp at 6 GeV/c (preliminary).

respectively perpendicular and parallel to N_o in the complex plane,

$$\frac{N_1^{\perp}}{|N_o|} = A/2 \approx -.05 \text{ for } -t<1 \text{ GeV}^2$$

$$\frac{N_2^{\parallel}}{|N_o|} = -Cnn/2 \approx -.06 \text{ for } -t<1 \text{ GeV}^2$$

At t=0 we can extract $ImN_2/ImN_o \approx -.02\pm.03$ from the optical theorem applied to the total cross-sections from the Michigan group.[7] By comparison with Cnn data at 1 GeV/c,[8] the energy dependence appears to be similar for Cnn and for A, namely $\sim 1/p_{lab}$ at $-t=.2$ GeV^2. To obtain the missing components, $N_1^{\parallel}$ and $N_2^{\perp}$, it is necessary to measure the spin rotation parameter; we can then estimate $N_1^{\parallel}$ from R and $N_2^{\perp}$ from the correlation between R and the beam spin. Of course, one can measure all spin correlations and solve for the amplitudes.

From analysis of Coulomb interference data, it has been argued that N_2 and A_1 do not vanish at t=0 even at high energies, and this can be tested by systematic measurements of the spin dependence of σ_{TOT}[9].

Inelastic reactions have been studied at 6 GeV/c with the Effective Mass Spectrometer. The Chicago-A.N.L.-Ohio State group has measured the five spin correlations in inclusive $p_{\uparrow}p \rightarrow \Lambda_{\uparrow} X$[10]. If N.P. exchange ($K^*$) were dominant at the $p_{\uparrow}\Lambda_{\uparrow}$ vertex, then spin would be conserved along the normal and it would be possible to produce an energetic polarized Λ beam. Unfortunately with 1800 out of 10,000 Λ's analyzed, the spin transfer from $p_{\uparrow}$ to $\Lambda_{\uparrow}$ is consistent with zero in all kinematic regions. Likewise the induced Λ polarization is essentially zero everywhere.

Production of N^* and Δ^{++} has been investigated by the A.N.L. group in reactions such as

$$p_{\uparrow}p \rightarrow p\pi^+n \quad (10^6 \text{ events})$$

$$p_{\uparrow}p \rightarrow p\pi^+\pi^-p \quad (10^5 \text{ events})$$

with 20% of the data from the first reaction analyzed so far[11]. The $p\pi^+$ system is produced fast forward in the laboratory with small momentum transfer from the polarized beam. Although Δ^{++} dominates the mass spectrum, there is non-resonant S and P wave (S_{13} and P_{13}) under the Δ^{++}, and 15 correlations including 9 spin dependences are measured as functions of mass and t. It is gratifying to discover that at small t where π exchange dominates, it is possible to identify $ImS_{13}^* P_{33}$ and $ImP_{13}^* P_{33}$ from the spin correlations in the $p\pi^+$ decay distribution.

The unpolarized Δ^{++} production density matrix elements in the s channel are qualitatively consistent with the "Poor Man's Absorption Model" (P.M.A)[12], which correctly predicts a zero in ρ_{31} at $-t=.02$ GeV^2 and a sharp forward spike in $\rho_{33}\frac{d\sigma}{dt}$, both due to strong π cuts. The new spin dependence probes the phase differences in the Δ^{++} production amplitudes. In terms of transitions from proton helicity $+\frac{1}{2}$ to the four Δ^{++} helicity states, they measure

$$2A_{11} = \rho_{11}^{\uparrow} - \rho_{11}^{\downarrow} \propto \text{Im}\left[\left(\tfrac{1}{2} \rightarrow \tfrac{1}{2}\right)^*\left(\tfrac{1}{2} \rightarrow -\tfrac{1}{2}\right)\right]$$

$$2A_{33} = \rho_{33}^{\uparrow} - \rho_{33}^{\downarrow} \propto \text{Im}\left[\left(\tfrac{1}{2} \rightarrow \tfrac{3}{2}\right)^*\left(\tfrac{1}{2} \rightarrow -\tfrac{3}{2}\right)\right]$$

The t channel asymmetries are plotted in figure 2.

The naive quark model relates the amplitudes for $pp \rightarrow \Delta^{++}n$ to the exotic $K^+n \rightarrow K^{*o}p$, by allowing only 6 of the 16 Δ^{++} production amplitudes to be independent.[13] Four relations for the unpolarized

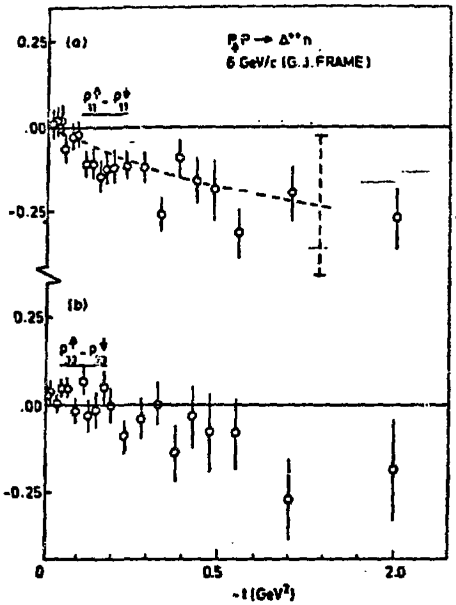


Fig. 2 Asymmetries in $pp \to \Delta^{++}$ at 6 GeV/c in the t-channel (a) $\rho_{11}\uparrow - \rho_{11}\downarrow$ and (b) $\rho_{33}\uparrow - \rho_{33}\downarrow$. The dashed curve is an estimate of $-\mathrm{Im}\rho_{10}(K^{*o})/\sqrt{2}$.

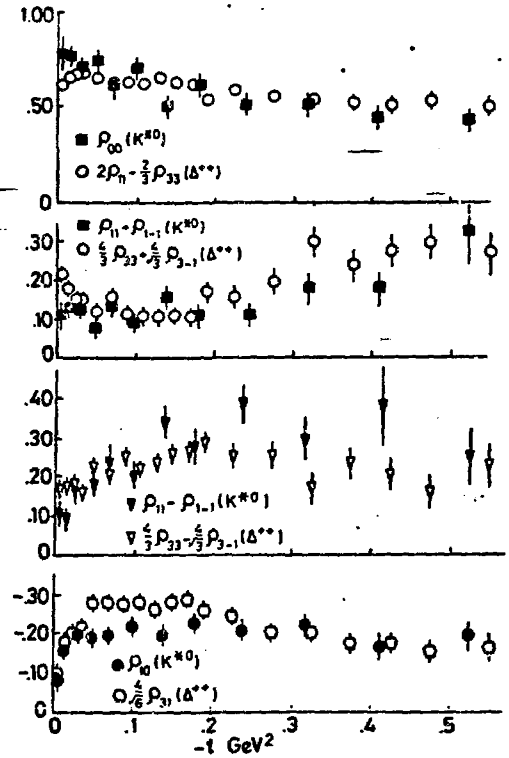


Fig. 3 Quark model relations for $K^+n \to K^{*o}p$ and $pp \to \Delta^{++}n$ at 6 GeV/c, data from ref. 11 and 14.

density matrix elements are shown in figure 3, and they work surprisingly well. The quark model can also relate $A_{11} = -\mathrm{Im}\,\rho_{10}(K^{*o})/\sqrt{2}$, and from amplitude analysis of ρ, ω, K^{*o} and $\bar{K}^{*o}$ production it can be argued that $\mathrm{Im}\rho_{10}(K^{*o})$ has a large contribution from interfering π pole-ρ cut.[14] Consistent in sign and magnitude with A_{11}. The data agrees roughly with the quark requirement $A_{33} = 0$.

New polarized target measurements on backward $\pi^-p \to p\pi^-$ have been reported at 2.9 GeV/c by the A.N.L. group[15] and at 3.5 GeV/c by the CERN-Trieste group.[16] Beyond $-u \approx .4$ GeV^2, the polarization fluctuates dramatically with energy, as shown in figure 4. These results seem to say that high mass N^*

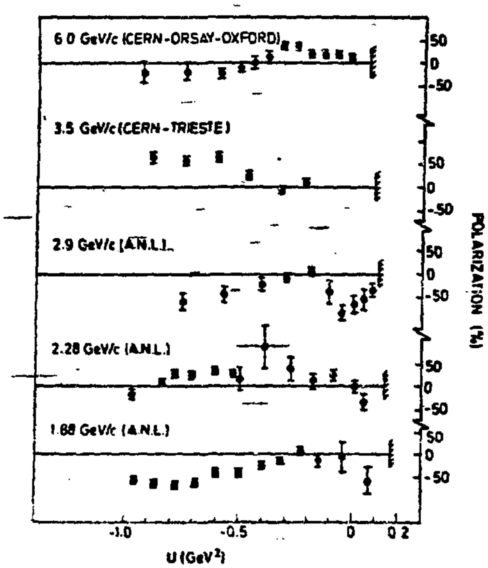


Fig. 4 Backwards π^-p elastic polarization (ref. 15, 16) at five energies.