Polarization in p-p Elastic Scattering at High Energies

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Some recent data on polarization in p-p elastic scattering are briefly surveyed and their characteristics reviewed. A new 28 GeV/c measurement of A, the analyzing power is presented. A few interesting theories are also briefly discussed. We plan more measurements of A soon and plan to measure A_{NN} when the polarized beam comes on at the A.G.S.

1. INTRODUCTION

The Ann Arbor convention for spin parameters(1) in high energy scattering experiments will be used. Specifically, L, S, and N denote respectively the spin components longitudinal, transverse in plane and normal out of the scattering plane. The single spin observable, the analyzing power, is denoted by A_N or A and is equal to the polarization parameter P, assuming that time reversal invariance holds.

Employing the formalism of Wolfenstein and Ashkin(2), it can be shown(3) that for polarized beams on polarized targets (both normal), the scattering cross-section is: $\frac{d\sigma_f}{d\Omega} = \frac{d\sigma_0}{d\Omega}\,[1+(P_B+P_T)A + P_B P_T\, A_{NN}]$ where $d\sigma_0/d\Omega$ is the scattering cross-section of an unpolarized beam on an unpolarized target.

2. EXPERIMENTAL DATA FOR A AND A_{NN}

As a typical example of a high energy spin experiment, the recently published measurements of A and A_{NN} at 6 GeV/c(4) are shown in Fig. 1. One notes the following salient features:

i) A=0 at $90°_{cm}$ and A→0 at 0°.
ii) A has a big dip around $P_\perp^2 = 0.7\ (\text{GeV/c})^2$.
iii) $A_{NN} \neq 0$ at $90°_{cm}$ but rises to a maximum.
iv) A_{NN} has more structure than A.
v) The sharpness with which A falls to 0 at $90°_{cm}$ matches the sharpness with which A_{NN} rises to a maximum at $90°_{cm}$.

It is well known that because of rotational invariance and particle identity effects, $A(\theta) = -A(\pi-\theta)$. Thus, A is anti-symmetric about $90°_{cm}$ and so A=0 at $\theta_{cm}=90°$. Also, A=0 at 0° because of rotational invariance.

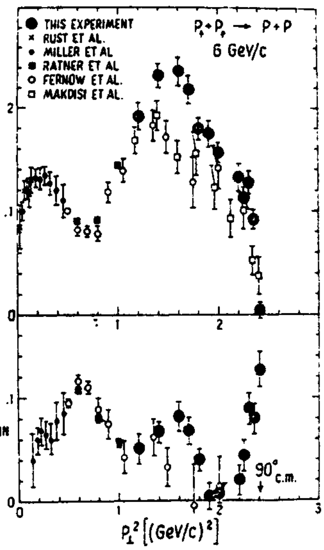


Fig. 1. Plots of A and A_{NN} vs. $P_\perp^2$ at 6 GeV/c(4)

The big dip at about 0.7 $(\mathrm{GeV}/c)^2$ is near the first break in the unpolarized elastic scattering cross-section. It probably indicates an interference effect between the diffraction amplitude and the amplitude in the medium $P_\perp^2$ region. Symmetry laws require that $A_{NN}(\theta)=A_{NN}(\pi-\theta)$ and so A_{NN} is symmetric about $90°_{cm}$. The sharp 90° structure in A_{NN} is very interesting but so far has not been well explained.

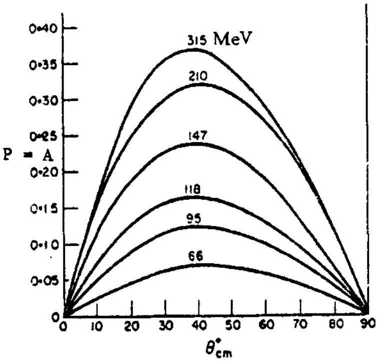


Fig. 2. Plot of A vs θ_{cm} at low energies[5].

In Fig. 2 are shown some schematic curves of A based on data for low energies.[5] The curves are smooth and contain no dip, probably because $(P_\perp^2)_{max}$ has not reached the medium $P_\perp^2$ region.

A complete set of the five amplitudes[5,6] (moduli and phases) which constitute the p-p elastic scattering matrix M was obtained by the University of Geneva group[7] at 579 MeV. A similar determination at high energies would be severely restricted due to the 3-spin scattering experiments required.

Recently, we have measured A in 28 GeV/c $p+p_\uparrow \to p+p$[8] at the Brookhaven AGS. The experimental set-up is shown in Fig. 3. An

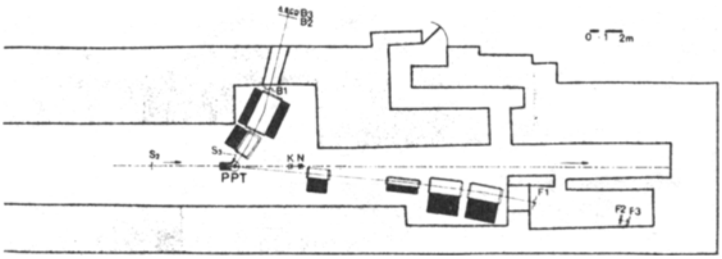


Fig. 3. Schematic layout of E-748 at the AGS.

unpolarized beam in the new D-line is scattered by our polarized target (PPT). The scattered protons are detected by the forward F counters in the spectrometer. The corresponding recoil protons from the target are detected by the backward, B, counters. An elastic event is then denoted by the coincidence F·B and subtractions are made for accidentals and other backgrounds. With an unpolarized beam, $P_B=0$ so that: $\frac{d\sigma_f}{d\Omega} = \frac{d\sigma_0}{d\Omega}(1+P_T A)$. If the event rates with the target spins up ($\uparrow$) and down ($\downarrow$) are defined by $N(\uparrow)$ and $N(\downarrow)$, then A is obtained from: $A = \frac{1}{\langle P_T\rangle} \cdot \frac{N(\uparrow)-N(\downarrow)}{N(\uparrow)+N(\downarrow)}$.

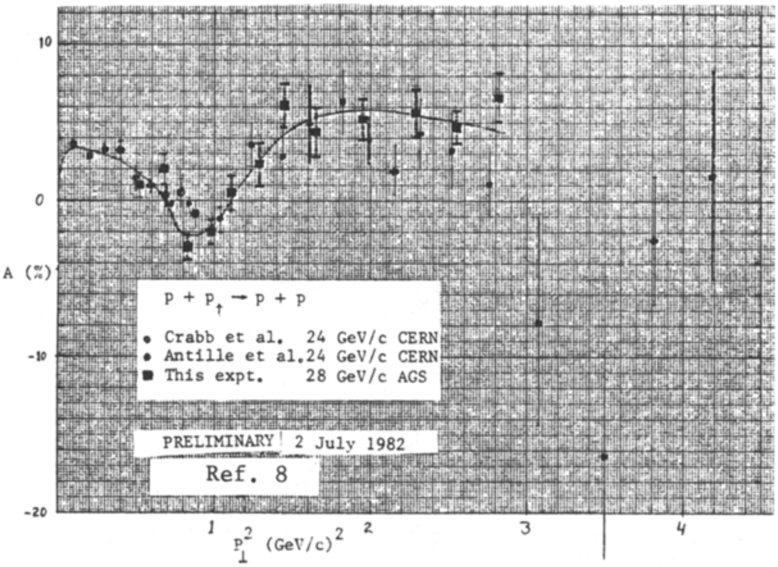
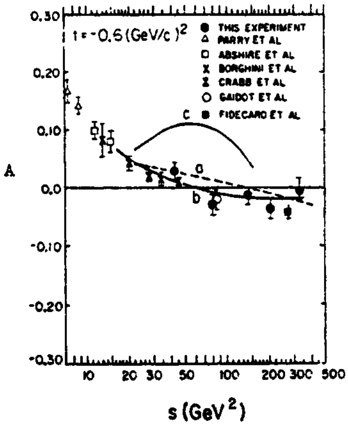


Fig. 4. Plot of A vs. $P_\perp^2$ at 24 and 28 GeV/c.

The preliminary results are shown in Fig. 4. The data agrees quite well with that of the 24 GeV/c CERN data(9). We also see a dip near 0.9 (GeV/c)^2 but we have not yet seen their second dip near 3 (GeV/c)^2. We expect to cover this large $P_\perp^2$ region in the near future.

To observe the trend of the first dip, we consider some higher energy data. The dip seems to be at -t~1.1 GeV^2 at 100 GeV/c and -t~1.35 GeV^2 at 300 GeV/c(10). Unfortunately the error bars become large in the interesting region of the dip. More accurate data near the dip was obtained by Fidecaro et al(11) at CERN together with the unpolarized cross-section for comparison. The dip appears at about 1.3 GeV^2 at 150 GeV/c and about 1.4 GeV^2 at 200 GeV/c corresponding to the first break in the elastic differential cross-section. Not only does the dip shift to higher (-t) or $P_\perp^2$ values with higher energies, but also the dip becomes deeper. The energy dependence at fixed (-t) was explored by Corcoran et al.(12) and typical data at -t=0.6 GeV^2 is shown in Fig. 5. We conclude that generally A becomes more negative with increasing energy.

The very interesting structure in A_{NN} at 90°$_{cm}$ is reproduced in Fig. 6(13). A recent data compilation(14) gave a rather complete picture of A_{NN} at 90°$_{cm}$ at intermediate and low energies.



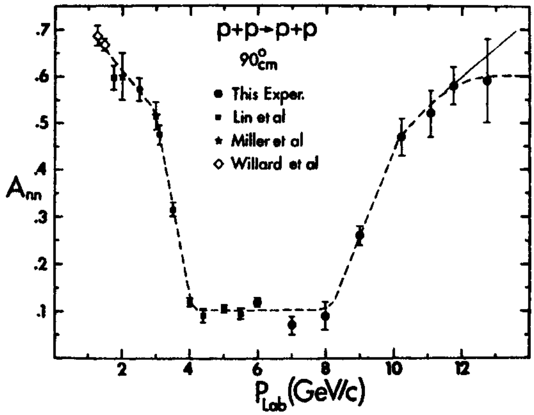


Fig. 5. Plot of A vs. s at fixed $t=-0.6\ (\mathrm{GeV}/c)^2$.(12)

Fig. 6. Plot of A_{NN} vs. P_{Lab} at $90°_{cm}$.(13)

Note that $90°_{cm}$ is a very special point of symmetry where A=0. It follows that the ratio of the spin parallel to spin-antiparallel cross sections is given by:

$$\frac{\frac{d\sigma}{d\Omega}(\uparrow\uparrow)}{\frac{d\sigma}{d\Omega}(\uparrow\downarrow)} = \frac{1 + A_{NN}\ (90°)}{1 - A_{NN}\ (90°)} .$$

$A_{NN}=-1$ corresponds to scattering from pure anti-parallel initial spin states as required by the Pauli Exclusion Principle spin at very low energies and is obeyed at (0→20 MeV). $A_{NN}=+1$ corresponds to scattering from pure parallel initial states of spin and is the case near 160 MeV. A second peak near 700 MeV (1.3 GeV/c) may indicate the presence of a dibaryon resonance. From the value $A_{NN}=+0.6$ at 12.5 GeV/c, the highest energy explored so far, one obtains $d\sigma(\uparrow\uparrow):d\sigma(\uparrow\downarrow) = 4$, indicating a dominance of parallel scattering at high energies. This interesting effect needs to be followed up to higher energies. A QIM model predicts a turnover at larger $P_{\perp}^2$(15). Quite a few models prefer lower A_{NN} values.

A_{LL} data at $90°_{cm}$ are more scarce and seem to lie mostly between +0.2 and +0.1 at several points between 1 and 11.75 GeV/c.(16) However, it does seem to follow the same pattern as A_{NN} showing that $(2A_{NN}-A_{LL})$ very roughly equals 1. That equality was suggested by QCD models for very high energies. Accurate measurements of A_{SS} are even scarcer but might prove valuable for putting more constraints on theories.

3. THEORIES

A few of the theories proposed to explain these spin experiments will be briefly mentioned. As pointed out in the major review article of Bourrely, Leader and Soffer[17], the interpretation of polarization and other parameters can prove quite difficult. The phase shift analyses of Bystricky, Lehar et al.[14] are quite successful at low and intermediate energies. The absorption Regge model fits [e.g. that of Kane and Seidl[18]] are somewhat successful phenomenologically at high energies.

Quark models and QCD models such as those of Brodsky et al. [19] and Farrar et al.[20] have some difficulty in getting good fits. Helicity conservation, an important prediction of QCD for high energies requires that $A_{NN}=-A_{SS}$ at all angles. At 11.75 GeV/c, this seems to be obeyed at $90°_{cm}$ and at a few other angles but for some angles, the equality is not too good[21]. Also, the fact that $A_{NN}\approx-A_{SS}$ even at low energies (400-600 MeV)[14] for most angles suggests that some helicity conserving mechanism might already be present there. More direct measurements of A_{NN} and A_{SS} at high energies are needed to understand this relation.

The eikonal theories are somewhat successful. They start from: $M = \frac{ip_{cm}}{2\pi}\int d^2b\ e^{i\vec{q}\cdot\vec{b}}\ (1-e^{i\chi(b)})$, where $\vec{q}$ is the three momentum-transfer. The dependence of the eikonal χ on the impact parameter b differentiates the different eikonal models.

a) With spin-orbit dependence, $\chi=\chi_c(b)+\chi_{ls}(b)\ \vec{\sigma}\cdot(\vec{b}\times\hat{\ell})$ and some assumptions, Halzen and Durand[22] derived the derivative relation $P(\theta)\ d\sigma_0/d\theta\propto\partial/\partial\theta\ (d\sigma_0/d\theta)$ which connects the dip to the break.
b) With spin-orbit and spin-spin dependence, Waikaizumi[23] was able to fit the data at 6 and 12 GeV/c quite well.
c) Using the Chou-Yang model[24] of spinning hadronic matter, Bourrely et al[25] were quite successful in getting good fits to the A data in general. In Fig. 7, although the fit at 24 GeV/c is quite fair at the first dip, their prediction for the second dip is somewhat inconsistent with data. This conclusion is reinforced by our 28 GeV/c data.

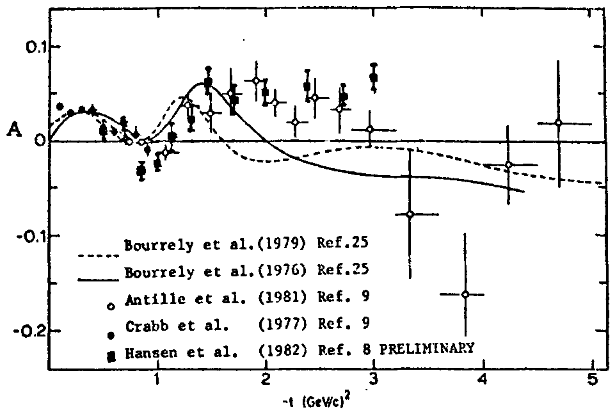


Fig. 7. Comparison of two theoretical models of Bourrely et al with the 24 and 28 GeV/c data.

In general, more accurate data at high $P_\perp^2$ for spin parameters seems certainly needed. We hope to soon obtain precise A and A_{NN} data on $p+p\to p+p$ at high $P_\perp^2$ with the AGS polarized proton beam.

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