SPIN DEPENDENCE IN HIGH-$P_\perp^2$ ELASTIC pp AND np SCATTERING

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ABSTRACT

Using the polarized proton capability of the Argonne ZGS we recently made $90°_{cm}$ measurements of elastic $p_\uparrow p_\uparrow$ scattering from 6 to 11.75 GeV/c, determining the parallel and anti-parallel pure initial spin state cross sections and the associated spin-spin parameter A_{nn} with the spins normal to the scattering plane. We find that the parallel to anti-parallel cross section ratio rises dramatically from 1.2±.06 at $P_\perp^2$=3.3 $(GeV/c)^2$ to 3.2±.4 at 4.8 $(GeV/c)^2$, similar to the $P_\perp^2$ dependence previously observed at the fixed laboratory momentum of 11.75 GeV/c. We have also extended our measurements at 6 GeV/c and find that A_{nn} has a small but sharp rise at $90°_{cm}$. In addition a month of 12 GeV/c polarized deuteron acceleration in the ZGS enabled us to measure A_{nn} at two points at 6 GeV/c for $n_\uparrow p_\uparrow$ elastic scattering: A_{nn}=-.17±.04 at $P_\perp^2$=.8, A_{nn}=-.19±.05 at $P_\perp^2$=1.0. These values are opposite in sign from the $p_\uparrow p_\uparrow$ results at the same momentum.

INTRODUCTION

The last few years our group has been studying the effects of spin states on elastic proton-proton scattering, attempting to measure these spin dependences out to the highest energies and momentum transfers available. The accelerator, the Argonne ZGS, is presently unique in its capability of accelerating polarized protons — intensities of nearly 10^{11} polarized protons per pulse have been accelerated to 11.75 GeV/c, with proton beam

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polarizations over 60%. The ZGS accelerator will be turned off this fall, the end of September, so future work on high energy spin-spin interactions will depend on the development of a polarized proton capability in one of the higher energy alternating gradient machines.

These spin-spin forces appear to have a dramatic $P_\perp^2$ dependence. As reported earlier[1)] we observed that at a beam momentum of 11.75 GeV/c the ratio of the spin parallel to anti-parallel cross sections, the spin normal to the scattering plane, rises from approximately unity to four as $P_\perp^2$ goes from 3 to 5 $(\mathrm{GeV/c})^2$. Here we present the results of our recent $p_\uparrow p_\uparrow$ spin-spin measurements at $90°_{cm}$, now varying the laboratory beam momentum, covering the same $P_\perp^2$ range. We also have been able to make limited spin-spin measurements at 6 GeV/c in $n_\uparrow p_\uparrow$ elastic scattering and will compare them to our $p_\uparrow p_\uparrow$ 6 GeV/c results.

EXPERIMENT

The general layout of our experiments for $p_\uparrow p_\uparrow$ elastic scattering is shown in Fig. 1. The proton beam from the ZGS, incident from the left, is polarized up and down on alternate pulses. The beam polarization is determined by measurements of the spin dependent asymmetry in the scattering of the polarized beam off a liquid hydrogen target; the asymmetry parameter, A, is known from previous measurements. The beam then passes through a polarized proton target (PPT) of $C_2H_6O_2$, with a target proton polarization typically in the 70% range. Because of radiation damage with high beam intensities, the target material had to be annealed twice a day and changed every few days. Elastic scattering events from the PPT are identified with a two-arm magnetic spectrometer. Background from non-hydrogen events is estimated using hydrogen-free teflon beads to replace the target material.

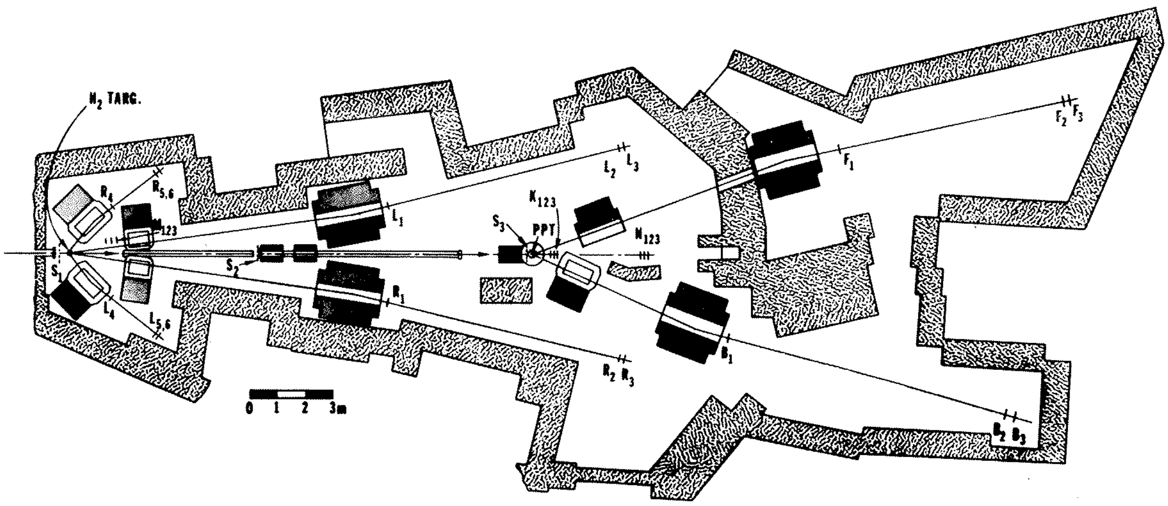

FIGURE 1: Layout of the experiment. The polarized beam passes through the liquid H_2 target and its polarization is measured. The beam then scatters in the polarized proton target (PPT) and the elastic events are counted by the F and B counters. The M,N, and K counters are intensity monitors, while S_1,S_2, and S_3 monitor the beam position.

For the neutron experiment the ZGS beam was 12 GeV/c polarized deuterons, therefore ∿ 6 GeV/c neutrons and protons, with polarization ∿ 50%. The hydrogen target polarimeter system discussed above was used to monitor the polarization of the protons in the deuteron - equivalent to the neutrons. Quasielastic n or p scatterings off the hydrogen in the PPT were again detected with the two arm spectrometer, with momentum analysis now only on the recoil proton (B) side. The forward neutron was detected with an anticoincidence counter followed by a brass-scintillator sandwich on the high energy forward (F) branch; the forward protons were detected with a single counter.

The accelerated deuteron intensity was 10^9/pulse, much lower than for protons, which limited our np data to two points.

In both experiments the observed polarization dependent cross sections, $d\sigma/dt\ (P_B,P_T)$, can be used to determine the associated Wolfenstein parameters: the asymmetry parameter, A, and initial state correlation parameter, A_{nn}, all spins normal to the scattering plane. The relation is:

$$\frac{d\sigma}{dt} = \langle\frac{d\sigma}{dt}\rangle [1 + (P_B+P_T)A + P_BP_T\ A_{nn}] \qquad (1)$$

The pure spin state cross sections are then:

$$\frac{d\sigma}{dt})_{\uparrow\uparrow} = \langle\frac{d\sigma}{dt}\rangle (1 + 2A + A_{nn})$$

$$\frac{d\sigma}{dt})_{\downarrow\downarrow} = \langle\frac{d\sigma}{dt}\rangle (1 - 2A + A_{nn})$$

$$\frac{d\sigma}{dt})_{\uparrow\downarrow} = \frac{d\sigma}{dt})_{\downarrow\uparrow} = \langle\frac{d\sigma}{dt}\rangle \quad (1 - A_{nn}). \qquad (2)$$

At $90°_{cm}$ in pp scattering A=0, and the parallel spin up and parallel spin down cross sections become equal.

RESULTS: 90° CENTER OF MASS EXPERIMENT

The present experiment went from a beam momentum of 6 GeV/c to 11.75 GeV/c, $P_\perp^2$ = 2.4 to 5.09 $(GeV/c)^2$. The constraint that A=0 at $90°_{cm}$ in pp elastic scattering was satisfied within the experimental errors.

Our present $90°_{cm}$ results, and those of earlier experiments[2)3)] are shown at the left in Fig. 2. Plotted is the ratio of the spin parallel cross section to the anti parallel cross section. From relations (2), since A=0, this ratio is

$$\frac{\frac{d\sigma}{dt})_{parallel}}{\frac{d\sigma}{dt})_{antiparallel}} = \frac{1 + A_{nn}}{1 - A_{nn}} \qquad (3)$$

This cross section ratio, rather flat and nearly unity in the intermediate $P_\perp^2$ region, increases quite dramatically, going from 1.2±0.06 at $P_\perp^2$ = 3.3 $(GeV/c)^2$ to 3.2±.4 at $P_\perp^2$ = 4.8 $(GeV/c)^2$, and appears to level off at ∿4 at the higher $P_\perp^2$. This rise with $P_\perp^2$ is remarkably similar to that observed in

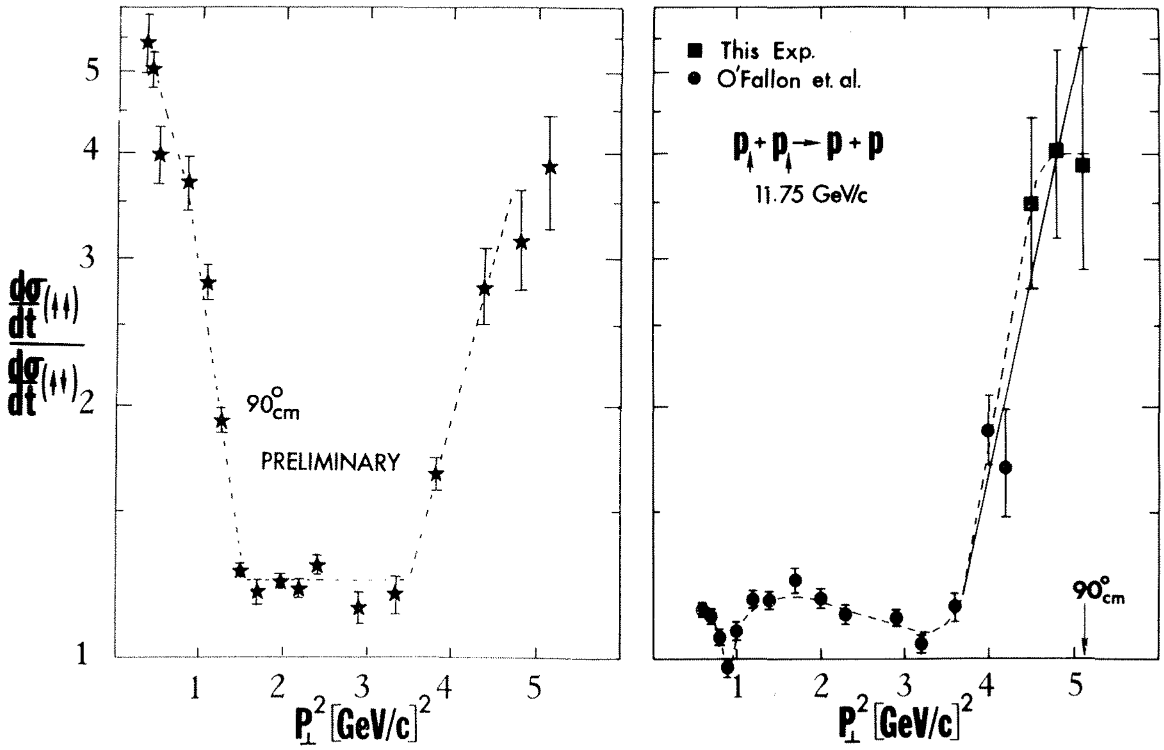

FIGURE 2: Plots of the $P_\perp^2$ dependence of the ratio of the differential elastic pp cross section in pure initial spins states. Left: $90°_{cm}$, varying beam momentum; the data for $P_\perp^2 > 2.4$ (GeV/c)^2 are from this experiment, the rest from Refs. 2), 3). Right: fixed beam momentum, 11.75 GeV/c, varying scattering angle; the plot is from Ref. 1). Both plots show similar high $P_\perp^2$ behavior: the spin parallel cross section increases dramatically relative to the spin antiparallel over the $P_\perp^2$ range of 3 to 5 (GeV/c)^2.

our previous experiment[1)] at fixed beam momentum, 11.75 GeV/c, where the scattering angle was varied. These results are shown at the right in Fig. 2, also plotted using relation (3). Both ratios appear to rise over the same $P_\perp^2$ range.

np AND pp 6 GeV/c EXPERIMENTS

We obtained data from the 12 GeV/c polarized deuteron experiment at $P_\perp^2$ = .8 and 1 (GeV/c)^2. The values of A and A_{nn} for pp elastic scattering in our deuterium experiment agree with our more precise pp 6 GeV/c results,[4)] giving us support for our np A_{nn} data. These are presented in Fig. 3. Also shown are our 6 GeV/c pp A_{nn} results - the sharp rise at $90°_{cm}$ is recent data. The large negative A_{nn} in np scattering is quite interesting. The antiparallel spin-spin interaction is larger than the parallel - opposite from the pp case.

We would like to thank E.F. Parker and the ZGS staff for their efforts in successfully accelerating the world's first high energy polarized deuteron beam, and in continuing the outstanding operation of the ZGS. We

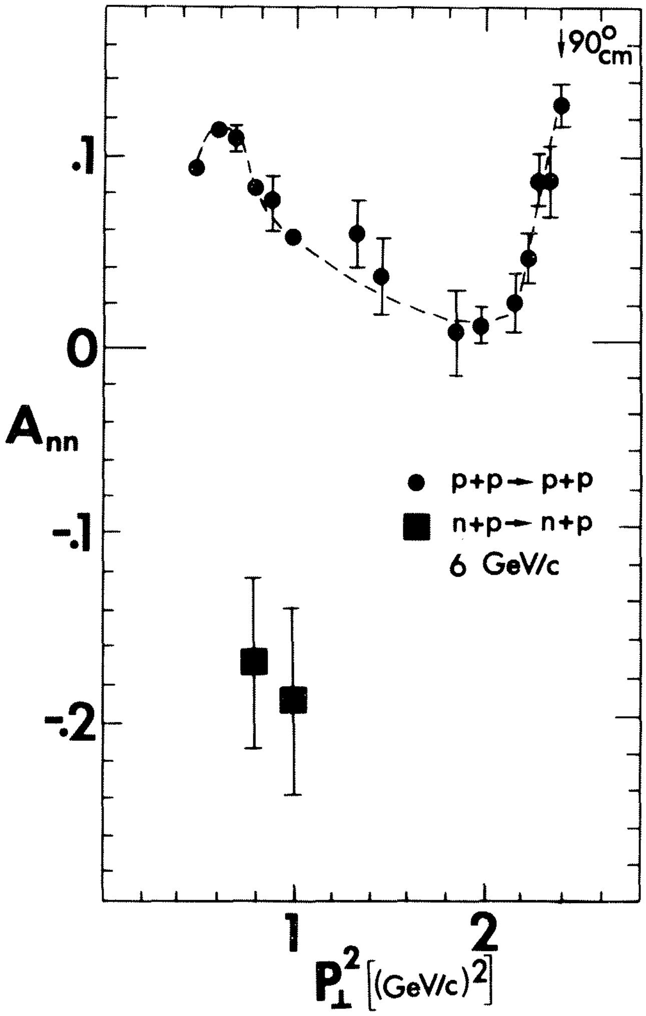

FIGURE 3: The spin-spin correlation parameter A_{nn} plotted against $P_\perp^2$ at 6 GeV/c beam momentum. Top: proton-proton elastic scattering. Bottom: neutron-proton elastic scattering. The np and pp results are quite different.

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