MEASUREMENT OF 3-SPIN PROTON PROTON ELASTIC SCATTERING CROSS SECTIONS AT 6.0 GeV/c*

T. A. Mulera

University of Michigan, Ann Arbor, MI 48109

ABSTRACT

The differential elastic p-p scattering cross section was measured at 6 GeV/c at the Argonne ZGS in the range $P_\perp^2 = 0.6 \rightarrow 1.0$ $(GeV/c)^2$ using a polarized target and a polarized beam. We simultaneously measured the polarization of the recoil protons with a well-calibrated carbon target polarimeter. All three polarizations were measured perpendicular to the horizontal scattering plane. Our results indicate that P and T invariance are both obeyed to good precision even at large $P_\perp^2$. The relative magnitudes of the 8 non-zero pure 4-spin transversity cross sections are quite different and we find that the double-flip cross sections are non-zero.

The ZGS polarized beam allows precise studies of high energy spin effects, especially when used with a polarized target. During the past few years our group[1] and the ANL-Northwestern group[2] have used a polarized beam and target to study the spin dependence of proton-proton elastic scattering. In the present experiment we have extended the earlier 6 GeV/c experiments by measuring in addition the polarization of the recoil protons.

The experimental apparatus is similar to that used in our earlier measurements[1]. The beam polarization, P_B, was measured using a high energy polarimeter consisting of a liquid hydrogen target and two double arm spectrometers. The polarimeter measured the left-right asymmetry in pp elastic scattering at 6.0 GeV/c and $P_\perp^2 = 0.5(GeV/c)^2$. The average beam polarization was $P_B = 75 \pm 5\%$. We scattered the polarized beam from the Michigan-Argonne PPT V polarized target[1]. The target protons' polarization has been as high as 85% but radiation damage to the target beads reduced the average P_T to 65 ±4%. Two NMR coils of different diameters averaged out the spatial dependence of the polarization due to beam-induced radiation damage.

Elastic scattering events from the polarized target were detected in another double arm spectrometer. Elastic events were determined by coincidences ($FB\bar{A}$) between the forward (F) and the recoil or backward (B) protons in which the anticounters A did not fire. The $FB\bar{A}$ accidentals were continuously monitored and subtracted. We measured our inelastic background by substituting teflon beads for the propanediol and by running event rate curves while varying the recoil magnet current. This background was subtracted from the measured FBĀ rates.

The polarization of the recoil proton (P_R) was measured with a carbon block polarimeter. Approximately 0.8% of the recoil protons rescatter from a 13 cm long carbon target into 4-fold scintillation counter telescopes. We obtained the recoil proton's polarization from the measured asymmetry for scattering to the right (BR) and left (BL) in the recoil polarimeter taking various biases into account. We measured the incident angle and position using two overlapping 5-channel hodoscopes placed just upstream of the carbon target. (See Figure 1).

The teflon background runs gave a BL + BR rate of 3.9 ±0.7% of the normal rate. Two types of accidentals were monitored continuously for both BL and BR and subtracted. We calibrated the hodoscope-polarimeter system by physically moving it into the main ZGS polarized beam and taking calibration runs with the polarized beam accelerated to the appropriate recoil momentum for each $P_\perp^2$ value. The fraction of events analyzed was essentially identical in both the data runs and calibration runs. We obtained a statistical error of about 4% in each recoil polarization.

The two-spin cross sections and their associated Wolfenstein parameters A and C_{nn} were obtained from the data as before[1]. However in this high statistics experiment we averaged out systematic errors such as beam drift by flipping the beam polarization on alternate pulses. This decreased our errors to about ±1/3%. Values of A and C_{nn} at each $P_\perp^2$ are given in Figure 2 and Table 1 and are in good agreement with earlier measurements[2,3].

Using the measured recoil polarization, P_R, and the beam and target polarizations, P_B and P_T, we obtained the eight normalized three spin cross section ratios

$$\sigma_{ij\to o\ell} = \frac{d\sigma}{dt}(ij\to o\ell)/\left\langle\frac{d\sigma}{dt}\right\rangle \qquad (1)$$

Our notation is σ(beam, target → scattered, recoil) and o denotes unmeasured, while i, j, and ℓ specify the transversity spin states ↑ or ↓. $\langle d\sigma/dt\rangle$ is the differential cross section for an unpolarized beam and target. In addition we measured the Wolfenstein parameters D_{nn} and K_{nn}. The parameter D_{nn} is the correlation between the recoil polarization P_R and the target polarization P_T and equals 1 when the spin-flip cross section is zero. Similarly K_{nn} is the correlation between P_R and the beam polarization P_B and measures the spin transfer. These parameters are given in Figure 2. Notice that D_{nn} may be moving further from 1 at large $P_\perp^2$ while K_{nn} may be moving toward 0. Our values of D_{nn} are smaller than those of Bryant et al[4] at the lower $P_\perp^2$.

Each of the pure 3-spin cross sections $\sigma_{ij\to o\ell}$ is the sum of two pure 4-spin cross sections. In addition parity invariance requires that all 8 single flip transversity cross sections equal zero. Using this plus rotational invariance and identical particle symmetry we can test for a possible parity violation by forming the experimental quantity

$$\epsilon_P = \sigma_{\uparrow\downarrow\to o\downarrow} - \sigma_{\downarrow\uparrow\to o\uparrow} = \sigma_{\uparrow\downarrow\to\downarrow\downarrow} - \sigma_{\downarrow\uparrow\to\uparrow\uparrow} \qquad (2)$$

Parity conservation requires ϵ_P to be zero. Our results for ϵ_P are 0.07 ±0.05 at $P_\perp^2$ 0.6; 0.08 ±0.06 at $P_\perp^2 = 0.8$; 0.00 ±0.08 at $P_\perp^2 = 1.0\ (\mathrm{GeV/c})^2$ **showing no evidence** for a parity violation at any $P_\perp^2$. Using time reversal invariance and the fact there is no evidence of a P violation we can form a quantity ϵ_T

$$\epsilon_T = \sigma_{\uparrow\uparrow\to o\downarrow} - \sigma_{\downarrow\downarrow\to o\uparrow} = \sigma_{\uparrow\uparrow\to\downarrow\downarrow} - \sigma_{\downarrow\downarrow\to\uparrow\uparrow} \qquad (3)$$

which tests T invariance. Our results for ϵ_T are: -0.01 ±0.05 at $P_\perp^2 = 0.6$; 0.02 ±0.06 at $P_\perp^2 = 0.8$; and 0.11 ±0.08 at $P_\perp^2 = 1\ (\mathrm{GeV/c})^2$ showing no evidence for a T violation.

In Fig. 3 we have plotted the five $d\sigma/dt\ (ij\to k\ell)$ against $P_\perp^2$. The $\langle d\sigma/dt\rangle$ we used is shown as a dashed line. We have also plotted the three initial 2-spin cross sections as bands whose widths correspond to the error at each $P_\perp^2$. These errors are much smaller than those of the 4-spin cross sections because the recoil polarization error does not contribute. The most important feature of Fig. 3 is that the different spin states have quite unequal cross sections. The parallel-up cross sections $d\sigma/dt(\uparrow\uparrow\to\uparrow\uparrow)$ and $d\sigma/dt(\uparrow\uparrow)$ are sometimes twice as large as the parallel-down $d\sigma/dt(\downarrow\downarrow\to\downarrow\downarrow)$ and $d\sigma/dt(\downarrow\downarrow)$. The double-flip cross sections, $d\sigma/dt(\uparrow\uparrow\to\downarrow\downarrow)$ and $d\sigma/dt(\uparrow\downarrow\to\downarrow\uparrow)$, are typically 10 times smaller than the non-flip.

Another very striking feature is the clear change in the spin dependence near $P_\perp^2 = 0.8(\mathrm{GeV/c})^2$ where $d\sigma/dt$ has a break. In the "diffraction peak" region below the break the $d\sigma/dt(ij\to k\ell)$ are all parallel to each other and $d\sigma/dt(\uparrow\uparrow\to\uparrow\uparrow)$ is about 50% larger than both $d\sigma/dt(\uparrow\downarrow\to\uparrow\downarrow)$ and $d\sigma/dt(\downarrow\downarrow\to\downarrow\downarrow)$. The cross sections have much more spin dependence in the region after the break where the $d\sigma/dt(ij)$ are again parallel but now with a slope of $\sim\exp(-3.5P_\perp^2)$. Here $d\sigma/dt(\uparrow\uparrow\to\uparrow\uparrow)$ is 100% larger than $d\sigma/dt(\downarrow\downarrow\to\downarrow\downarrow)$, while $d\sigma/dt(\uparrow\downarrow\to\uparrow\downarrow)$ is about halfway between.

There is some indication that the double-flip cross sections, especially $d\sigma/dt(\uparrow\uparrow\to\downarrow\downarrow)$, may be relatively larger after the break. This can also be seen by studying D_{nn} in Fig. 2. This effect is a few standard deviations and thus is not certain, but it is an interesting possibility. It would be very significant if the double flip cross section became dominant at very large $P_\perp^2$.

REFERENCES

* Work supported by the U.S. Energy Research and Development Administration. The other members of the collaboration were L. Ratner, M. Borghini, W. deBoer, A. Krisch, H. Miettinin, R. Fernow, J. Roberts, K. Terwilliger and J. O'Fallon.

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DISCUSSION

Chamberlain: (U. C., Berkeley) Could you remind me how much discrepancy there is between p_t^2 and $-t$?

Mulera: It's rather small.

Chamberlain: [I see.] They're close up to $-t = 1$, or something like that. $-t$ is about 1.13 when $p_t^2 = 1$. At $p_t^2 = 2$, $-t$ becomes 2.8.

Sandler: (Argonne) In reference to your K_{NN}, you said it was sort of approaching zero at larger $|t|$. My understanding is that a relevant question is whether K_{NN} is equal to C_{NN}. And there, I think, that statistically they appear equal.

Mulera: That question is relevant to the measurement of the unnatural parity magnitudes, just as is the [question of] D_{NN} being equal to one. That was slide three, I believe. Certainly, within statistics, that's true.

Neal: (Indiana) With regard to the D_{NN} plot at the bottom, could you tell me what the normalization uncertainty in D might be for your points. [It involves the] uncertainty in the knowledge of the polarization of the target and the carbon analyzing power?

Phillips: (Rice) I guess that the question is how much of the error bars is statistical and how much is absolute--a judgment of the absolute value of the numbers. Is that correct?

Neal: Yes. Or is it all statistical and there's a normalization hazard?

Mulera: Both are on the order of a few percent. The statistical and systematic errors are roughly equal.

Neal: I think the corresponding error for the Indiana points is several percent. It could be as much as 7 or 8 percent because of the calibration, so I think we should be a little cautious when we say there is a disagreement.

Mulera: Yes, the disagreement is not large.

Neal: Once you take into account the normalization?

Mulera: Right.

Fischbach: (Purdue) What are the prospects for improving the limits on parity violation and time reversal in these experiments?

Mulera: I think you're limited to a few percent measurement in this sort of thing. You are beat by the kind of rate you can do in a rescattering experiment. The people who are really trying to check parity are Anderson and Nagle and those people with their $\Delta\sigma_T$ on a nuclear target. They're claiming results [on the order of] one part in 10^6. We certainly can't do that in this kind of an experiment.

Chamberlain: [How do you know that the analyzing power of the recoil arm does not vary with the angle and position of the particle incident on the carbon rescatterer?]

Mulera: We tried to avoid this problem by the addition of this set of hodoscopes to measure how the particles were coming into the [carbon] target. The entire recoil arm, with the exception of the recoil magnet, of course, was moved into a beam of known polarization. So for each of these incoming angles and positions across the face of the target, the polarized beam was swept across the face of the target, and we were calibrated for each of these incoming channels.

Sandler: I want to make a comment about the question of parity violation, because we have the capability now to measure correlation parameters which are by themselves parity-violating parameters, such as asymmetries when the spin is in the scattering plane. In fact, I'll show you on Wednesday that those can be measured statistically to something like 0.001. In those cases, the major error is in [knowing whether the spin is] in fact in the scattering plane. For example, you may pick up some [transverse] polarization components that might foul you up.

TABLE 1

Summary of Wolfenstein Parameters at 6.0 GeV/c

The errors shown are point to point only. In addition there are normalization errors of ±.005 on A and C_{nn} and ±5% of the value of D_{nn} and K_{nn}

$P_\perp^2$ (GeV/c)^2	A	C_{nn}	D_{nn}	K_{nn}
0.6	.091 ±.003	.107 ±.004	.85 ±.03	.13 ±.03
0.8	.092 ±.003	.080 ±.004	.83 ±.04	.05 ±.04
1.0	.144 ±.003	.057 ±.004	.76 ±.05	.04 ±.05

APPENDIX

Tabular Data for Physics Letters 52B 243 (1974)

$P_\perp^2$ (GeV/c)^2	A	C_{nn}
.50	.101 ±.002	.093 ±.003
.60	.083 ±.004	.117 ±.005
.70	.081 ±.005	.110 ±.006
.80	.078 ±.007	.090 ±.010
.90	.119 ±.010	.075 ±.014
1.00	.138 ±.013	.030 ±.018
1.05	.139 ±.012	.043 ±.016
1.35	.184 ±.014	.058 ±.019
1.48	.169 ±.015	.035 ±.020
1.75	.126 ±.025	-.008 ±.035
2.00	.143 ±.023	.015 ±.030

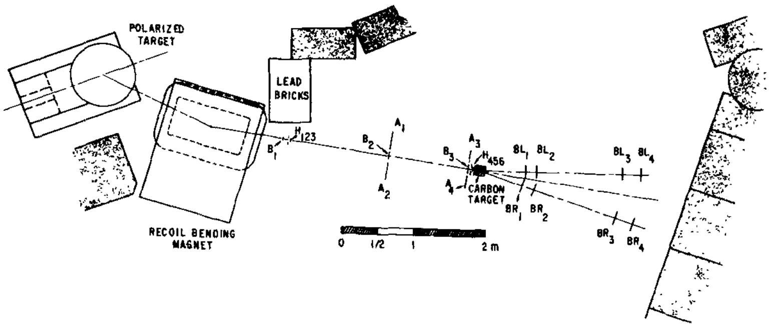

Figure 1. Layout of the recoil (B) arm and the B polarimeter

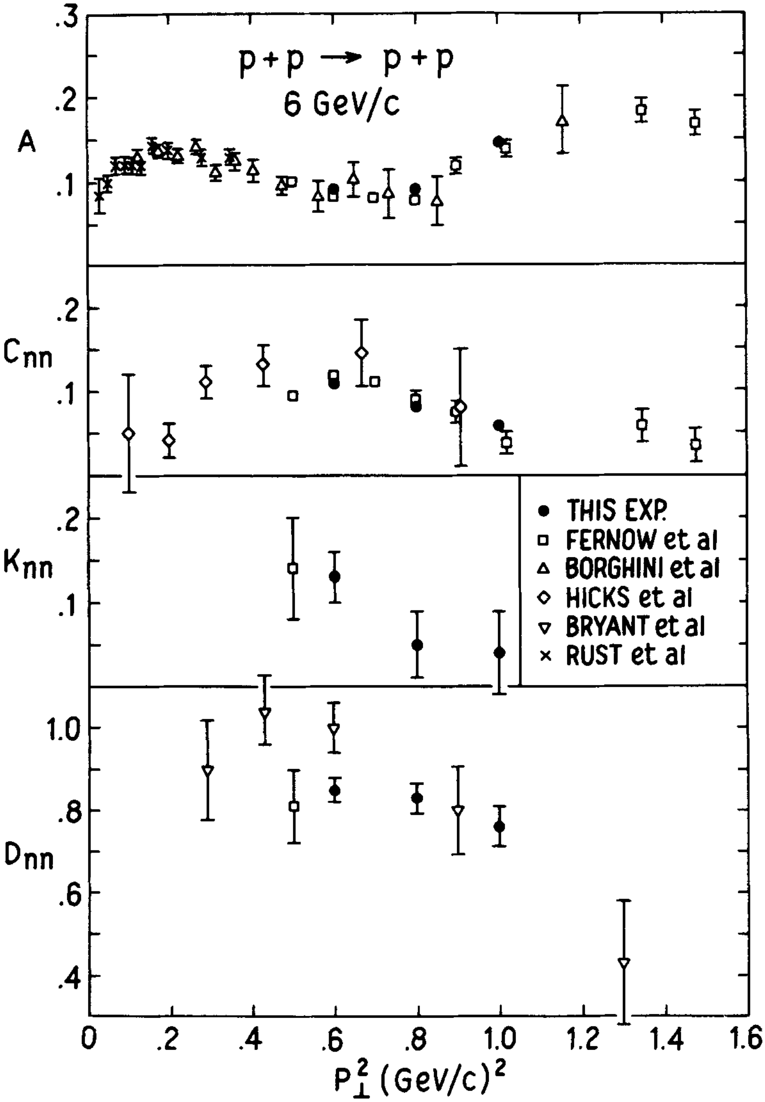

Figure 2. Wolfenstein parameters for p-p elastic scattering at 6 GeV/c are plotted against $P_{\perp}^{2}$.

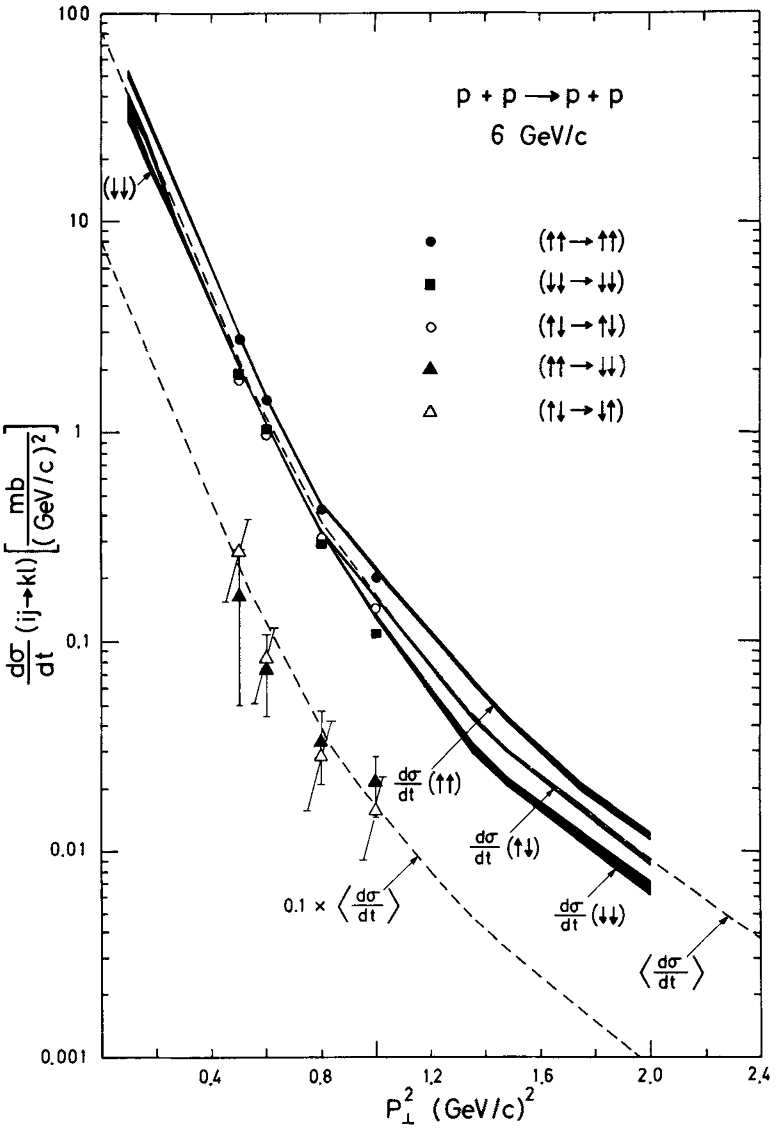

Figure 3. Plot of the pure 4-spin cross sections $d\sigma/dt(ij\rightarrow k\ell)$ for p-p elastic scattering at 6 GeV/c against $P_{\perp}^{2}$.