Measurement of the Spin Parameters A and A_{NN} in pp Elastic Scattering at the AGS*

D.G. Crabb
Randall Laboratory of Physics
University of Michigan
Ann Arbor, Michigan 48109

In a continuing study of spin effects in pp elastic scattering our group has used the AGS at Brookhaven National Laboratory to measure the analyzing power, A, and spin correlation parameter, A_{NN}, at several energies and over a range of momentum transfer.

Specifically, a systematic study of A has been carried out using the normal (unpolarized) proton beam at 28.3 GeV/c and a polarized target, while the advent of the polarized beam has enabled us to measure both A_{NN} and A in the 16.5 GeV/c to 18.5 GeV/c range. The improvement in intensity, polarization, and reliability of the polarized beam since commissioning in 1984 have allowed a systematic study at a single energy rather than the more scattered measurements possible in the earlier runs.

The experimental layout is shown in Fig. 1. The protons enter from the left and first strike a liquid hydrogen target. If the protons are polarized then the left-right asymmetry in proton-proton elastic scattering is measured in the high energy polarimeter, which consists of two double arm spectrometers using scintillation counters $L_1 - L_6$ and $R_1 - R_6$ to measure the scattering asymmetry. The analyzing power at a given energy is obtained from many previous measurements and is used together with the measured scattering asymmetry to calculate the beam polarization.

After the hydrogen target the protons continue on to interact in the polarized proton target. Elastic scatterings from this target are detected in the double arm spectrometer. Six magnets and an eight channel hodoscope system ensure that elastic events are selected cleanly with little background. A large range of beam energies and momentum transfer can be accommodated by various combinations of magnet position and field setting.

The polarized target consists of a conventional evaporation refrigerator, using a $^3He/^4He$ mixture as the coolant, operating at 0.5 K in 2.5 T field. During the course of the experiment two types of target materials have been used: radiation doped ammonia[1], for high beam intensities where radiation damage is a problem; and chemically doped ethylamine-borane ammonia[2], under less severe beam conditions. The measurement of background events from non-hydrogenous material was made by replacing the polarized material with teflon (CF_2).

The beam position and size at both the hydrogen and polarized target were monitored continuously by segmented wire ion chambers S_1, S_2, S_3, S_4 while the relative beam intensity was measured with an ion chamber, secondary emission chamber, and three counter telescopes M, N, and K. The absolute beam intensity was calculated from an aluminum foil irradiation.

A pp-elastic scattering event in the spectrometer was defined by a sevenfold FB coincidence between the appropriate channels of the $F = F_0F_1F_2F_3$ and $B = B_1B_2B_3$ arms. The normalized event rates N(i,j) in the four possible spin states for beam [$i = \uparrow$ *or* $\downarrow$ (up or down)] and target ($j = \uparrow$ *or* $\downarrow$) were obtained by measuring the quantities:

$$N(i,j) = \frac{Events(i,j)}{I(i,j)}$$

where N(i,j) is the number of elastic events corrected for accidentals and non-hydrogen background and I(i,j) is the relative intensity obtained by averaging the monitors. A and A_{NN} are then obtained from the relations:

$$A_{NN} = \frac{1}{P_B P_T}[\frac{N(\uparrow\uparrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow) + N(\downarrow\downarrow)}{N(\uparrow\uparrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow) + N(\downarrow\downarrow)}]$$

$$A_B = -\frac{1}{P_B}[\frac{N(\uparrow\uparrow) + N(\uparrow\downarrow) - N(\downarrow\uparrow) - N(\downarrow\downarrow)}{N(\uparrow\uparrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow) + N(\downarrow\downarrow)}]$$

$$A_T = -\frac{1}{P_T}[\frac{N(\uparrow\uparrow) - N(\uparrow\downarrow) + N(\downarrow\uparrow) - N(\downarrow\downarrow)}{N(\uparrow\uparrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow) + N(\downarrow\downarrow)}]$$

where P_B and P_T are the beam and target polarizations respectively. Of course for the case of unpolarized beam and a polarized target the analyzing power is simply.

$$A = A_T = \frac{1}{P_T}[\frac{N(\uparrow) - N(\downarrow)}{N(\uparrow) + N(\downarrow)}]$$

The results for the analyzing power measurements at 28.3 GeV/c[3] and 18.5 GeV/c[4] are shown in Fig. 2 and Fig. 3 respectively. The 18.5 GeV/c data is reminiscent of earlier data[5] at lower energies where the value of A peaks at around $P_\perp^2 = 1.5$ (GeV/c)^2 falls to a minimum and then rises again. In the older data there appear to be variations in peak width and value of the minimum. The quality of the data made it difficult to quantify any systematic variations. In the current data it is clear that the value of A is negative at the minimum. However, comparing these data with those at 24 and 28 GeV/c[5] it appears that A in this $P_\perp^2$ region is varying with energy, in that the peak value of A is considerably suppressed, dropping from $\sim$ 15% at 18.5 GeV/c to $\sim$ 5% at 24 and 28 GeV/c. Moreover, the peak width increases, delaying the onset of the minimum to about $P_\perp^2 = 3.5$ (GeV/c)^2.

While the low $P_\perp^2$ data (< 1 (GeV/c)^2) have been described quite well over a large range of energy through, in particular, the Regge pole approach[6], there has been only limited success in the medium $P_\perp^2$ region[7] (around the peak at 1.5 (GeV/c)^2). The measurements up to $P_\perp^2 = 6.5$ (GeV/c)^2 have been even more difficult to explain, particularly in the context of perturbative QCD (PQCD) where A must equal zero[8].

The A_{NN} data shown in Fig. 3 are plotted again in the three dimensional graph shown in Fig. 4. It is not clear how the structure of these data correlates with the structure of the older data from the ZGS. We note that the rise of A_{NN} to 60% around 12 GeV/c has never been satisfactorily explained, although there have been many attempts. The most recent is from Brodsky and de Teramond[9]. However, two general statements have been made on the trend of the data: one is the apparent oscillation in A_{NN} at 90° cm has been linked to the oscillation of the 90° cm pp differential cross-section around the general s^{-10} dependence[10]; second is that the peaking towards 90° cm at fixed momentum is due to particle identify effects[11].

It is clear from Fig. 4 that at least two sets of measurements of A_{NN} are necessary to address the validity of these two statements. One is a continuation of the 90°cm measurement from 12.75 GeV/c and the second is to extend a fixed momentum measurement to large values of θcm. The simultaneous measurement of A for the second case may give some insight into whether PQCD is applicable in this $P_\perp^2$ region. Though PQCD predicts that A = 0, it is clearly not the case at 28 GeV/c and $P_\perp^2 = 6.5$ (GeV/c)^2.

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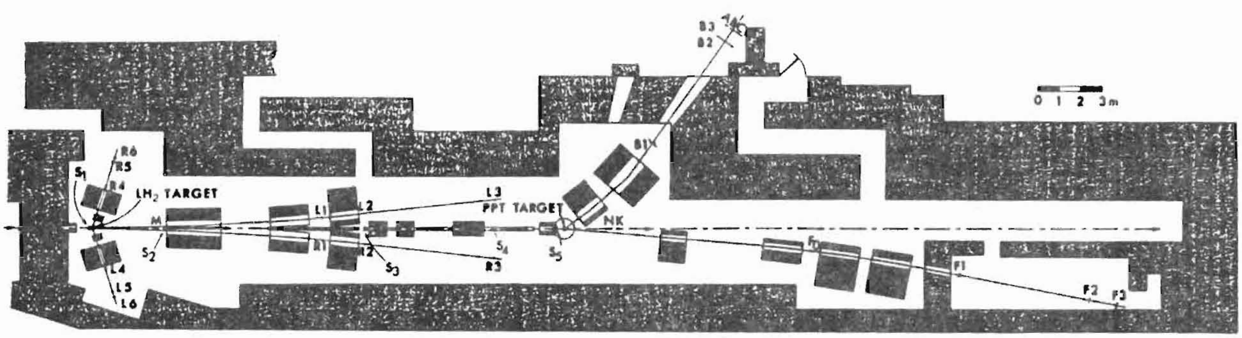

Fig. 1 Layout of the experiment. The high energy polarimeter on the left uses a liquid hydrogen target to measure the left-right asymmetry in p-p elastic scattering. The polarized proton beam then scattered in the vertically polarized proton target (PPT) and the elastic events were detected by the spectrometer which contained magnets for momentum analysis and the F and B scintillation counter hodoscopes. The M, N, and K counters were intensity monitors, while the S_1, S_2, S_4 and S_5 segmented wire ion chambers monitored the beam's position, size and angle.

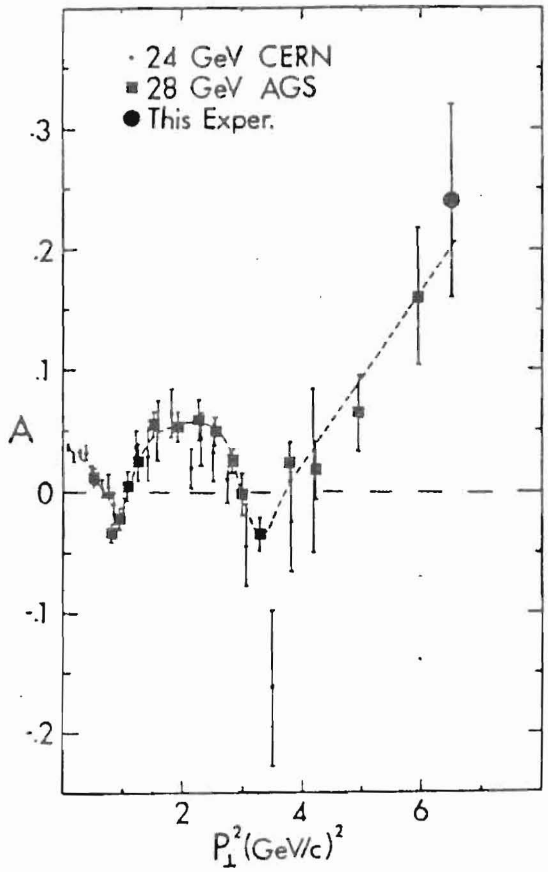

Figure 2.

Analyzing Power for Proton-Proton Elastic Scattering as a Function of $P_\perp{}^2$

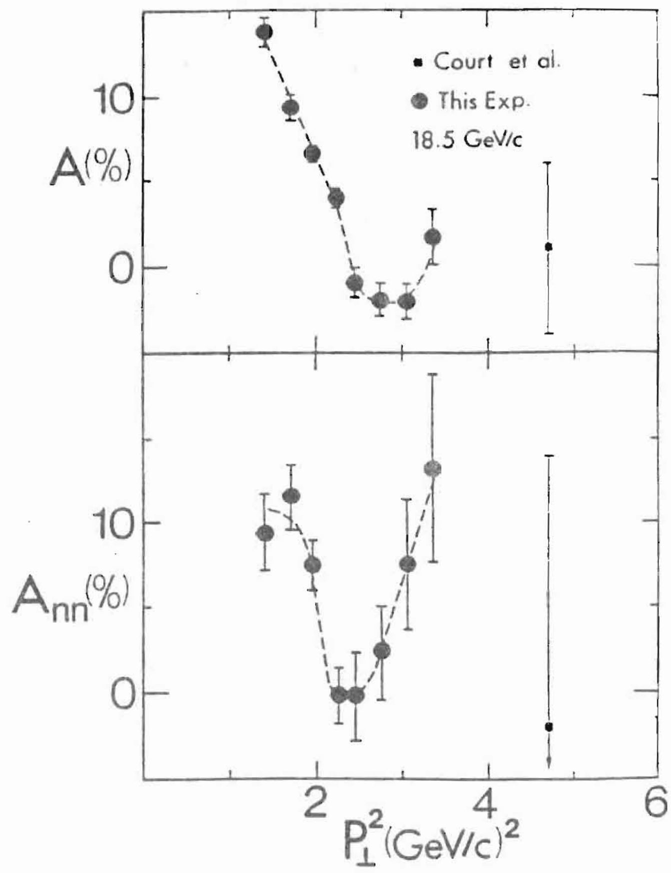

Fig. 3. Plot of the analyzing power, A, and the spin-spin correlation parameter, A_{nn}, as a function of momentum transfer squared for proton-proton elastic scattering at 18.5 GeV/c. The error bars include both statistical and systematic errors. The dashed lines are hand-drawn curves to guide the eye.

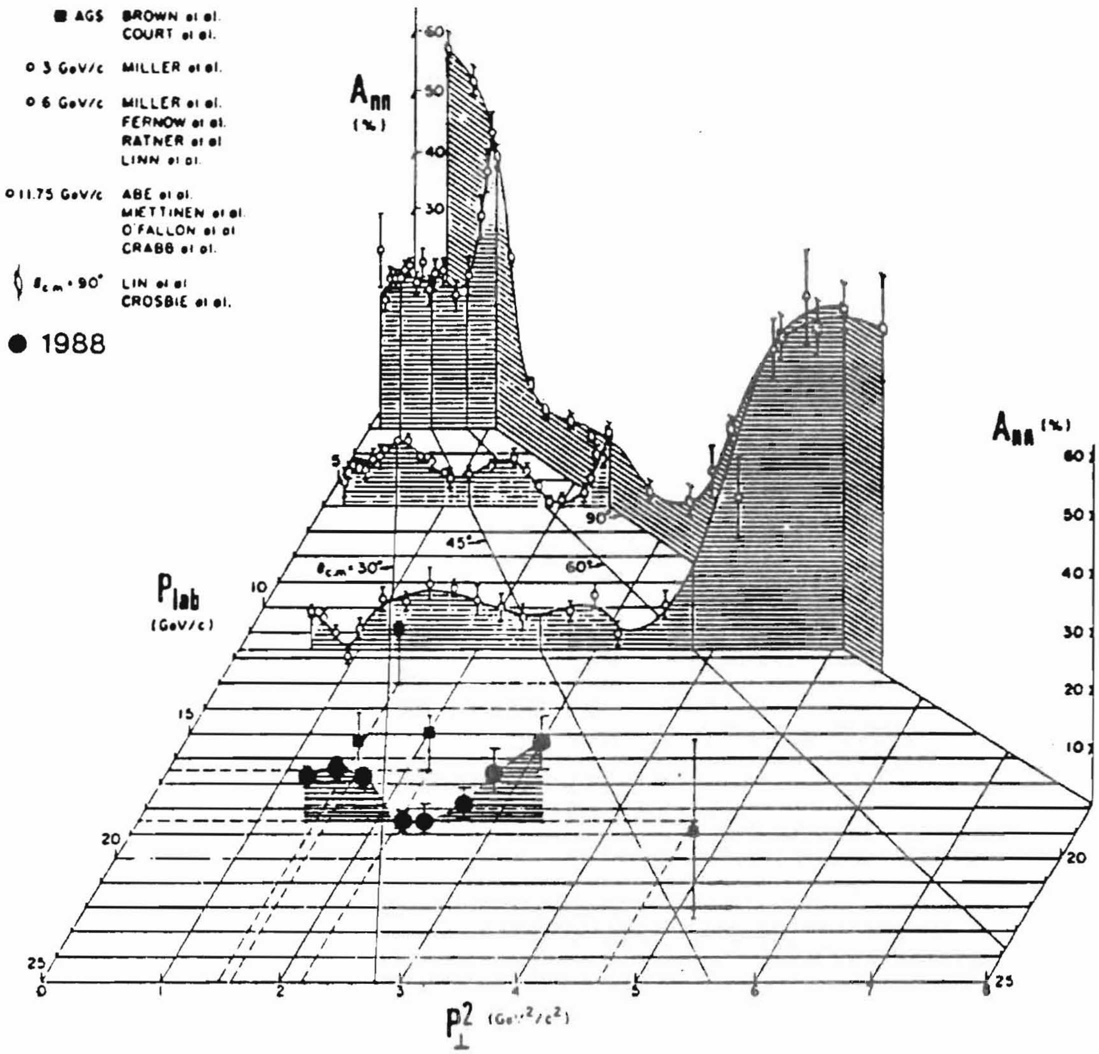

Fig. 4. Compilation Plot of High Energy A_{nn} Data.