POLARIZED PROTONS AT THE AGS AND HIGH $P_\perp^2$ SPIN EFFECTS

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ABSTRACT

At the AGS an intense polarized proton beam was for the first time successfully accelerated to 22 *GeV/c*, preserving a polarization of $\sim 45\%$. Using this polarized beam a surprisingly strong energy dependence of the spin-spin correlation parameter A_{nn} in high $p_\perp^2$ elastic proton-proton scattering was discovered.

A study of interactions based on measurements of cross sections and decay rates always involves averaging over the possible spin configurations of the system. To avoid that, and thus explore the interactions between pure quantum states, we have to study spin effects. In fact the correct description of spin effects is one of the most critical tests of any dynamical theory of hadronic interactions. Since the experimental hardware requirements are extraordinary, however, spin experiments mostly are second generation experiments and, more often than not, reveal unexpected properties of the interaction which are difficult to explain with the established theories.

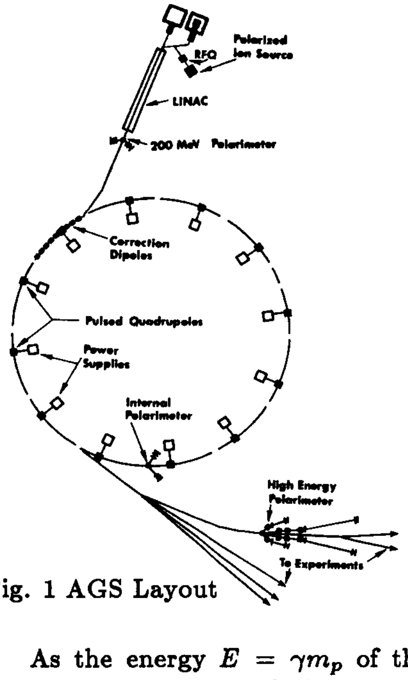
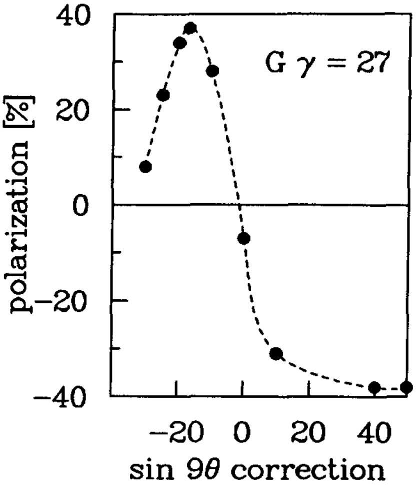


Fig. 1 AGS Layout

I will report here the investigations of double spin effects in elastic proton-proton scattering conducted from December 1985 to February 1986 at the AGS, Brookhaven Natl. Lab., as well as the results of commissioning of polarized proton beam at the AGS.

Fig. 1 shows the major hardware items installed for the polarized proton beam project in a collaboration of BNL, Michigan, Rice, Argonne and Yale. The pulsed polarized H^- ion source now operates at $25\mu A$. After acceleration through a RFQ and the Linac the polarization is for the first time measured at 200 *MeV* using elastic $p-{}^{12}C$ scattering. At the following injection into the AGS main ring the 2 electrons are stripped off the H^- ions, leaving the bare vertically polarized protons to be accelerated.

As the energy $E = \gamma m_p$ of the protons in the main ring increases to the maximum energy of about 22 *GeV* achieved during this run the protons encounter about 40 depolarizing resonances. The protons are depolar-



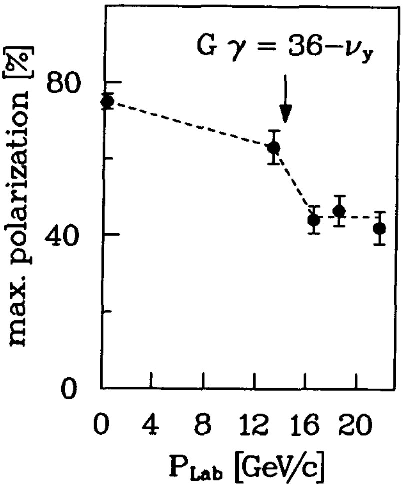


Fig.2 Polarization vs. amplitude of *sin9θ* correction (in arbitrary units)

Fig.3 Maximum polarization vs. beam momentum

ized whenever they see horizontal magnetic field components with a frequency equal to their precession frequency. The horizontal fields of the focussing elements in the ring cause 'intrinsic resonances' with the resonance condition $G\gamma = nP \pm \nu_y$ where G is the anomalous magnetic moment of the proton, ν_y the vertical betatron tune ($\sim$ 8.75 at the AGS), P the periodicity of the machine (12 at the AGS) and n an integer. However, since the strength of the resonance depends on how fast the protons cross the resonance, depolarization can be prevented by rapidly shifting the tune as the protons approach the resonance condition. In this way we successfully jumped 5 intrinsic resonances ($G\gamma = 0 + \nu_y, 12 + \nu_y, 36 - \nu_y, 24 + \nu_y$ *and* $48 - \nu_y$) with 10 fast pulsed quadrupole magnets which are capable of shifting the tune within $1.6\mu sec$.

Misalignements of the main bending magnets also lead to horizontal field components. The resonance condition for these 'imperfection resonances' is $G\gamma = n$. We passed about 35 imperfection resonances using 96 small pulsed dipole magnets to generate the appropriate harmonic corrections at the energies $E = nm_p/G$. It turns out that imperfection resonances are considerably stronger in the neighbourhood of the strongest intrinsic resonances ($G\gamma = 0 + \nu_y, 36 - \nu_y$) and that these resonances are more easily corrected using a harmonic which beats against an integer multiple of the periodicity of the AGS (e.g. the 9^{th} harmonic for $G\gamma = 27$ since $9 = 3 \times 12 - 27$) than with their primary harmonic. Fig. 2 shows the dependence of the polarization to the amplitude of the sine component of the 9^{th} harmonic correction at $E = 27m_p/G$. It also appeared that a 20% polarization loss near 14 GeV/c was caused by interference between the $G\gamma = 36 - \nu_y$ intrinsic resonance and the

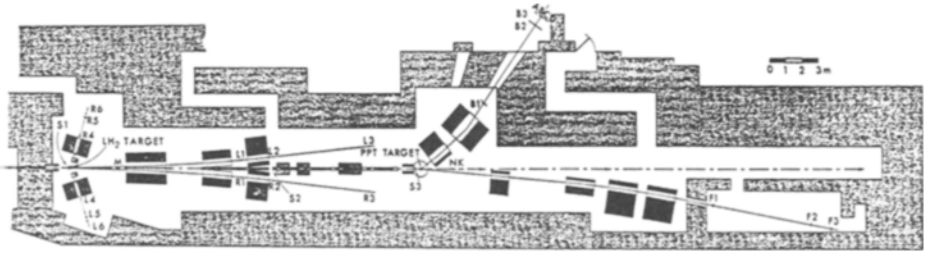


Fig.4 Layout of external polarimeter and spectrometer

$G\gamma = 27$ imperfection resonance. Decreasing the tune using slow quadrupole magnets increased the separation of these two resonances and indeed reduced the loss of polarization.

During these commissioning studies the polarization was monitored with two polarimeters. The internal polarimeter uses as a target a 0.1 *mm* nylon string inside the AGS ring and measures the left-right asymmetry in the p-nucleon scattering at $p_\perp^2 \sim .15\ (GeV/c)^2$. The external polarimeter is located in one of the extracted proton beam lines and measures the left-right asymmetry in proton-proton elastic scattering at $p_\perp^2 \sim .3\ (GeV/c)^2$. Fig. 3 shows the maximum polarization reached during the last run.

I will now turn to our experiment on spin effects on elastic proton-proton scattering, a collaboration of Michigan, BNL, Maryland, MIT, Notre Dame, Texas A&M and ETH (Zurich). The target and the spectrometer are located immediately down stream of the external polarimeter as shown in Fig. 4 The polarized proton beam with an intensity of up to 8×10^9 protons per 2.2 *sec* pulse is scattered from the University of Michigan polarized proton target. This target contains NH_3 beads which were irradiated at the MIT Bates Linac with a total dose of $5 \times 10^{16}\ e^-/cm^2$ to produce radicals with spin-unpaired electrons. The beads are cooled to $0.5°K$ by a ${}^3He - {}^4He$ evaporation refrigerator in a 2.5 T magnetic field. A 70 GHz microwave system drives the polarizing transitions and a 107 MHz NMR system continuously monitors the polarization of the hydrogen protons. The maximum target polarization was about 70% and the average polarization for our data run was $51 \pm 3\%$.

Elastic scattering events are detected in a double arm forward-backward spectrometer using 8 channel scintillation counter hodoscopes. Measuring the number of elastic events for the 4 pure initial spin states $N(beam, target)$ allows us to calculate the spin-spin correlation parameter A_{nn}:

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

where P_B and P_T are the beam and target polarizations respectively.

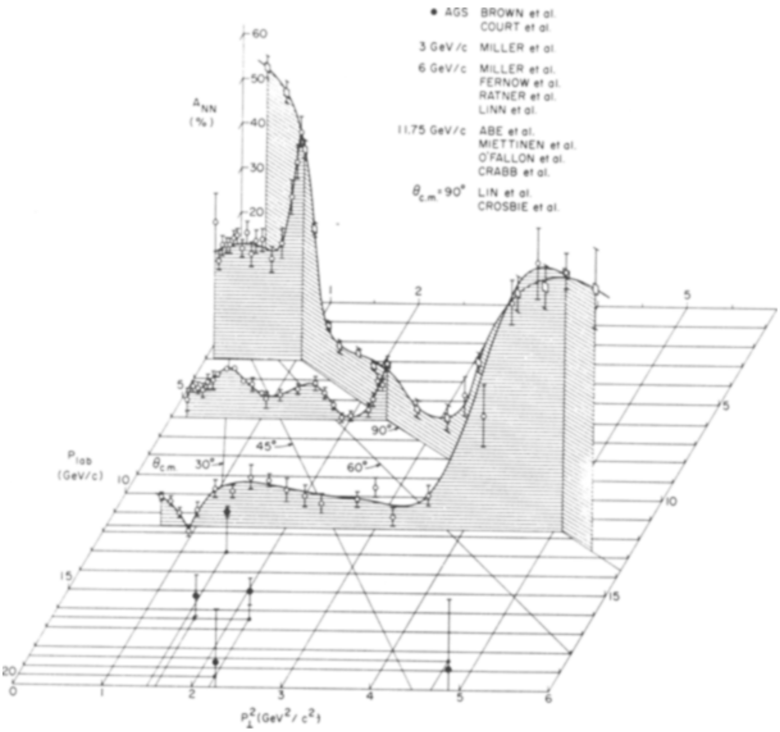


Fig. 5 A_{nn} measurements at high beam momentum

Measurements of A_{nn} at high momentum transfer were first performed with the polarized beam of the ZGS. Fig. 5 shows a compilation of A_{nn} measurements with a beam momentum greater than 3 GeV/c^1. A striking result of the ZGS data is that at $p_\perp^2 \approx 3.5$ $(GeV/c)^2$ A_{nn} starts to increase to a value of about 55% at $p_\perp^2 = 5.1$ $(GeV/c)^2$ [at $p_{lab} = 11.75$ GeV/c this corresponds to $\theta_{cm} = 90°$]. In fact this value of $p_\perp^2$ is believed to be the onset of the region where the scattering is dominated by direct interaction of the constituents of the protons. As can be seen in fig. 5 the sharp increase of A_{nn} occurs at the same $p_\perp^2$ if, instead of the incident beam momentum, the center-of-mass scattering angle is kept constant at 90°. This confirms that the large values for A_{nn} are indeed related to hard scattering and not just a reflection of the high degree of symmetry of the 90° scattering of identical particles.

With the polarized beam of the AGS we are now in the position to study A_{nn} at high $p_\perp^2$ at center-of-mass angles considerably different from 90°. Our main data run was taken at an incident beam momentum of 18.5 GeV/c at $p_\perp^2 = 4.7$ $(GeV/c)^2$ $(\theta_{cm} = 49°)$. The result $A_{nn} = -2 \pm 16\%$ is shown in fig. 6 together with lower energy ZGS measurements at the same $p_\perp^2$.

The observed surprisingly sharp decline of A_{nn} as a function of the incident beam energy for fixed $p_\perp^2$ indicates that being in a hard scattering region is not sufficient for large values of A_{nn}. It clearly is of great importance to extend the A_{nn} measurements to higher values of $p_\perp^2$ (and thus closer to $\theta_{cm} = 90°$) at fixed beam momentum as well as to higher beam momentum at fixed $p_\perp^2$.

Today the most favoured candidate for a dynamic theory of hadronic phenomena is without doubt quantum chromodynamics (QCD). In this high $p_\perp^2$ region it is believed that a perturbative calculation should be applicable. This assumption is supported by the success of the prediction that e.g. the cross section of pp elastic scattering goes like s^{-10}. For $\theta_{cm} = 90°$ a value of 1/3 is predicted for A_{nn} with possible oscillations around this value as suggested by the observed oscillations of the cross section around the s^{-10} behaviour[2]. However it is not yet clear how this fixed-angle prediction is related to our observed fixed-$p_\perp^2$ behaviour.

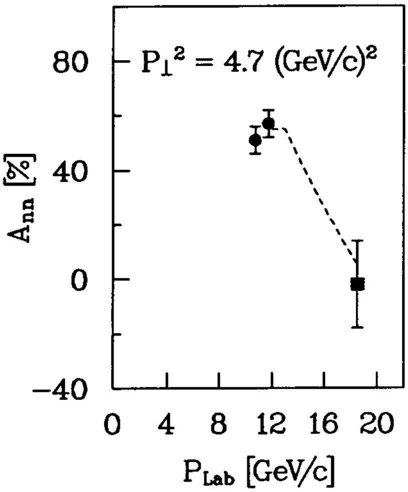


Fig. 6 A_{nn} vs. p_{Lab}

It certainly became clear that with the availability of a high energy high intensity polarized proton beam at the AGS a new and unique region for precision tests of our understanding of the dynamics of hadrons has opened up.

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