SPIN DEPENDENCE IN POLARIZED ELASTIC SCATTERING IN THE CNI REGION *

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The interference of the electromagnetic spin-flip amplitude with a hadronic spin-nonflip amplitude in elastic scattering leads to significant spin dependencies at very low momentum transfer t. Recent results on A_N and A_{NN} in polarized proton-proton elastic scattering at very low t using a polarized atomic hydrogen gas jet target and the 100 GeV/c polarized proton beam are at RHIC are presented. Our A_N pp data are well described with the electromagnetic spin-flip alone and do not support the presence of a large hadronic spin-flip amplitude. The double spin asymmetry A_{NN} is found to be consistent with zero over the whole measured t range, indicating that double spin-flip amplitudes do not play a role in this kinematical region.

1. Elastic Spin Observables

Interference phenomena in hadron collisions have often led to spectacular spin effects in the final state. This, for instance, occurs in the elastic scattering of transversely polarized protons at small angles, where the interference of a small spin-flip amplitude, that otherwise would be difficult to detect, with a large spin-nonflip amplitude leads to a sizeable analyzing power A_N. The region of low 4-momentum transfer squared t is associated with long distance phenomena, and therefore is in the domain of non-perturbative QCD, where no precise calculations can yet be made. This kinematical region is known as the Coulomb Nuclear Interference (CNI) region. In some sense elastic scattering of hadrons is the simplest and the most basic type of

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nuclear interaction, yet elastic scattering phenomena have eluded a detailed and satisfactory explanation from general principles for a long time.

Polarized experiments in this region allow us to explore the spin properties of QCD at large distances. With transversely polarized targets and/or beams, two independent spin observables can be measured: the analyzing power A_N, which is a measure of the *left–right* asymmetry of the cross section in the scattering plane normal to the beam or target polarization, and the double spin parameter A_{NN}:

$$A_N \frac{\mathrm{d}\sigma}{\mathrm{d}t} = -\frac{4\pi}{s^2} \mathrm{Im} \left[\phi_5^* \left(\phi_1 + \phi_2 + \phi_3 - \phi_4 \right) \right] \ , \tag{1}$$

$$A_{NN} \frac{\mathrm{d}\sigma}{\mathrm{d}t} = \frac{4\pi}{s^2} \left[2|\phi_5|^2 + \mathrm{Re} \left(\phi_1^* \phi_2 + \phi_3^* \phi_4 \right) \right] \ , \tag{2}$$

where $\frac{\mathrm{d}\sigma}{\mathrm{d}t}$ is the spin averaged cross section, each amplitude ϕ_i is the sum of the hadronic and electromagnetic components, ϕ_1 and ϕ_3 are the helicity-nonflip, ϕ_5 is the single helicity-flip, and ϕ_2 and ϕ_4 are the double helicity-flip amplitudes.

The dominant contribution to A_N comes from the interference between the electromagnetic (Coulomb) spin-flip amplitude (ϕ_5^{em}), which is generated by the proton's anomalous magnetic moment, and the hadronic (Nuclear) spin-nonflip amplitudes (ϕ_1^{had} and ϕ_3^{had}), which can be related to the total cross section σ_{tot} via the optical theorem[1]. The presence of a potential hadronic spin-flip amplitude interfering with the electromagnetic spin-nonflip one introduces a deviation in shape and magnitude for A_N calculated with no hadronic spin-flip[2].

Likewise, A_{NN} is generated from the interference between the double helicity-flip with the helicity-nonflip amplitudes. The t dependence of A_{NN} determines separately the real and imaginary parts of the double helicity-flip amplitude ϕ_2. The study of A_{NN} in pp elastic scattering at very small t has been suggested as a way to search for the Pomeron negative charge conjugate partener, the Odderon[3]. This suggestion, however, is highly speculative (note also that there is no experimental evidence for the Odderon, nor from pp nor from ep scattering).

2. $A_N(t)$: $p\, p^{\uparrow} \rightarrow p\, p$

Figure 1 shows the analyzing power A_N as a function of t for pp elastic scattering in the t range of $0.001 < |t| < 0.032$ GeV$^2/c^2$ at $\sqrt{s} \simeq 13.7$ GeV. The experiment used a polarized atomic hydrogen gas jet target and the

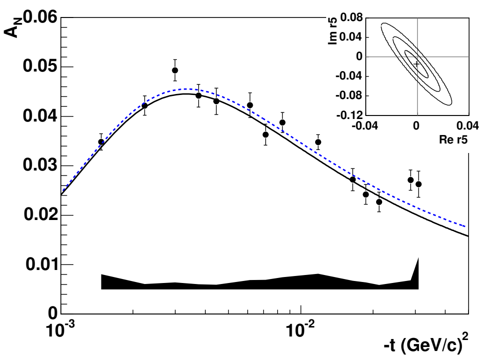

Figure 1. A_N as a function of t for $p\ p^{\uparrow} \rightarrow p\ p$ at 100 GeV/c. The errors on the data points are statistical. The lower band represents the total systematical error. The prediction for A_N with the electromagnetic spin-flip only is superimposed to the data (solid lane). The dashed line is a fit to the data allowing for a hadronic spin-flip contribution to A_N. Inset: r_5 and the 1-σ, 2-σ, and 3-σ confidence contours.

100 GeV/c polarized proton beam at RHIC. Elastic events were identified by detecting the recoil protons from pp scattering with a recoil spectrometer based on silicon detectors. For a description of the experimental setup and analysis see reference 4. The major sources of the measurement uncertainties come from the error on the target polarization, which represent an overall 2.0% normalization uncertainty, the false and acceptance asymmetries, event selection criteria, and the background from the residual target gas, which is already accounted for in the target polarization uncertainty.

In Figure 1 the A_N data are compared to the CNI prediction with no hadronic spin-flip[2]. The χ^2, taking into account all the measurement errors is 13.4 over 14 degrees of freedom, and are consistent with no hadronic spin-flip. The A_N data were also fitted with the CNI prediction allowing for a hadronic spin-flip contribution. The quality of the fit is similar to the case with no hadronic spin-flip ($\chi^2 = 11.1/12$ d.o.f.). The values obtained for r_5 are Re $r_5 = -0.0008 \pm 0.0091$ and Im $r_5 = -0.015 \pm 0.029$, the correlation parameter between Re r_5 and Im r_5 is -0.92. The results of the r_5 fit are shown as inset in Figure 1. These data do not support the presence of a large hadronic spin-flip amplitude at the energy of this measurement.

3. $A_{NN}(t)$: $p^{\uparrow}\ p^{\uparrow}\ \rightarrow p\ p$

In Figure 2 is shown the double spin parameter A_{NN}. While the extraction of A_{NN} requires both the target and the beam to be transversely polarized,

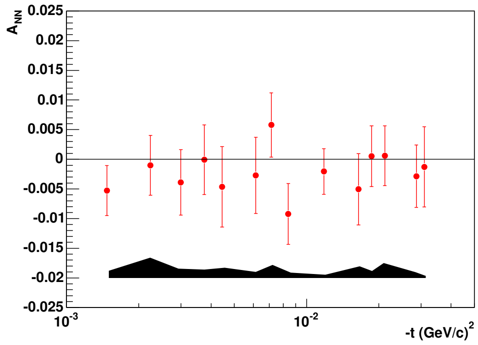

Figure 2. Preliminary A_{NN} data as a function of t for $p^{\uparrow}p^{\uparrow} \to p\, p$ at 100 GeV/c. The displayed errors on the data points show the statistical uncertainty. The lower band represents the total systematical error.

the knowledge of the polarization of one interacting proton only (beam or target) is sufficient, thanks to the symmetry properties for scattering of identical spin$-\frac{1}{2}$ particles. The statistical error on A_{NN} is about $2 - 2.5\times$ larger than the one on A_N, which reflects the fact that the beam polarization P_B for this measurement, was around 0.4[5]. The systematical error on A_{NN} is quite small compared to the statistical one, because we are comparing the same events but with different spin sortings (beam and target).

A_{NN} is found to be compatible with zero over the whole measured t range. This indicates that here the double helicity-flip amplitude ϕ_2 doesn't play a role and that the single spin-flip amplitude ϕ_5 is very small, as already concluded from the study of A_N. Highly speculative arguments on possible Odderon effects on A_{NN}, therefore, are ruled out.

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