A FIRST MEASUREMENT OF THE HELICITY ASYMMETRIES FOR POLARIZED PROTON COLLISIONS AT SQRT(S)=200 GEV*

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In May of 2003, RHIC provided the first collisions of longitudinally polarized protons, at $\sqrt{s}$=200 GeV. We report on and discuss the results for the longitudinal spin asymmetry for π^0 production, which is sensitive to the polarization of the gluons in the polarized protons.

1. Introduction

We naively expected, just 15 years ago, that the spin of the proton would be carried by its valence quarks. The pioneering studies of the proton spin structure in the 1970s,[1] using polarized electrons from the SLAC accelerator as a probe, saw just what everyone expected: the quarks, selected by deep inelastic scattering (DIS), were highly polarized. At CERN a muon experiment (EMC) was mounted that had naturally polarized muons from the parity-violating pion decay incident on a polarized proton target. They probed lower quark momentum fraction x than SLAC, due to their high beam energy. They found in 1989[2] that the polarization carried by the quarks and anti-quarks, when averaged over x, was actually very small, a major surprise. Since then, a series of DIS experiments[3] has learned that only about 20% of the proton spin is carried by the quarks and anti-quarks in the proton. Therefore, a combination of the gluon spin and orbital angular momentum of the quarks and gluons must carry 80% of the proton spin.

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The gluon is a key to the proton spin puzzle. The DIS experiments are sensitive to the quark and anti-quark electric charges in nucleons, and cannot probe the gluon directly, so the gluon polarization in the proton is still largely unknown.[4] RHIC, colliding polarized protons, provides an opportunity to study the proton with strongly-interacting probes.[5] At collider energy, hard scattering dominates and we study the spin structure of one of the colliding protons by probing with polarized quarks and gluons from the other colliding proton. The polarization of the gluons can be directly measured, as well as the polarization of the quarks and anti-quarks.

2. Colliding Longitudinally Polarized Protons at RHIC

Polarized RHIC consists of two counter-rotating accelerator/storage rings with collisions at six interaction regions.[6] Polarimeters based on coulomb-nuclear interference in small angle proton-carbon elastic scattering provide 2% polarization measurements for each beam every hour of a typical 6 hour store.[7] The beams are bunched, typically 5×10^{10} protons per 1 ns long bunch, with 55 bunches per ring spaced 200 ns apart. We select the polarization sign for each bunch as the protons are loaded into RHIC, so that the experiments see spin combinations of $(++, +-, -+, --)$ for the two beams in collision, with the spin changing every 200 ns.

The polarized proton collision program began in 2002 with transversely polarized proton collisions. In 2003 we had the first collisions, at $\sqrt{s}$=200 GeV, with longitudinally polarized protons. The stable spin direction in RHIC is vertical. To measure helicity asymmetry, sensitive to gluon polarization in the proton, spin rotators were installed around the PHENIX and STAR experiments to rotate the spin to longitudinal for collision, and then back to vertical to maintain vertical polarization around RHIC. Both experiments searched for processes that could monitor the polarization direction at collision. At PHENIX we discovered that neutrons produced to very forward angle display a left-right asymmetry for vertically polarized proton collisions.[8] Fig. 1 shows this left-right asymmetry for a run with vertical polarization (spin rotators off), and no asymmetry for spin rotators on. With no observed transverse asymmetry, and with the polarization measured by the independent RHIC polarimeters, we concluded that the spin at collision was fully longitudinal (97 to 99%).

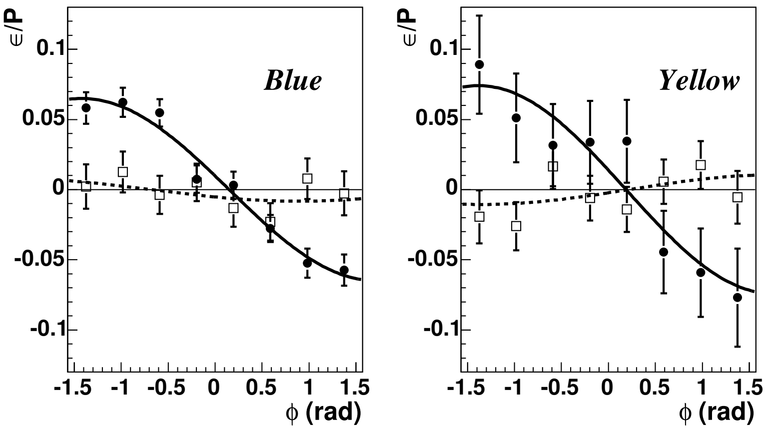

Figure 1. Asymmetry as a function of azimuthal angle for forward neutron production. The solid points and curve correspond to the spin rotators off, and the open points and dashed curve were with the spin rotators on. Blue and Yellow refer to the two RHIC rings.

3. The Double Helicity Asymmetry for π^0 Production at PHENIX

The PHENIX detector features fine-grained electro-magnetic calorimeters with towers $\Delta\phi\times\Delta\eta$=0.01×0.01, covering 2×90° in azimuth (ϕ), and 0.7 in pseudo-rapidity (η), centered at mid-rapidity. An inclusive π^0 cross section has been reported covering from 1-14 GeV/c in p_T, which is described over the entire range by next-to-leading order perturbative QCD calculations.[9]

Using the pQCD description, the π^0 cross section in the lower p_T region is primarily from gluon-gluon scattering, with a roughly 30% contribution from gluon-quark scattering.[10] A measurement of the double-spin asymmetry, $A_{LL} = (\sigma_{++} - \sigma_{+-})/(\sigma_{++} + \sigma_{+-})$, is approximately proportional to the gluon polarization for the gluon from one beam × the polarization of the gluon from the other beam, for gluons at $x \simeq p_T(\pi^0)/100$ GeV. The notation σ_{++} refers to the cross section for production of π^0 at a given p_T and mid-rapidity with like helicity beams ($++$ or $--$), and σ_{+-} refers to production with unlike helicity beams, $+-$ and $-+$.

The asymmetry measurement involves counting the number of observed π^0 versus the spin combinations of the beams. Experimentally, $A_{LL} = 1/P^2 \times (N_{++} - R \cdot N_{+-})/(N_{++} + R \cdot N_{+-})$. P is the beam polarization for the two beams, 27% in 2003. $R = L_{++}/L_{+-}$, the ratio of luminosity for like vs. unlike beam helicity combinations. Our result[11] for A_{LL} is shown in Fig. 2. The uncertainties for the asymmetry measurement itself are dominated by statistics. The uncertainty from the absolute beam polarization normalization, not shown in the figure, is 32% from each beam due to lack of knowledge of the polarimeter analyzing power, giving a ±65% scale uncertainty for the results. Two theory curves are also shown, for large and small gluon polarizations.[12] The curve GRSV-max uses a polarized gluon distribution equal to the unpolarized distribution at the input scale of Q^2=0.6 GeV^2, with an NLO pQCD calculation for π^0 production.

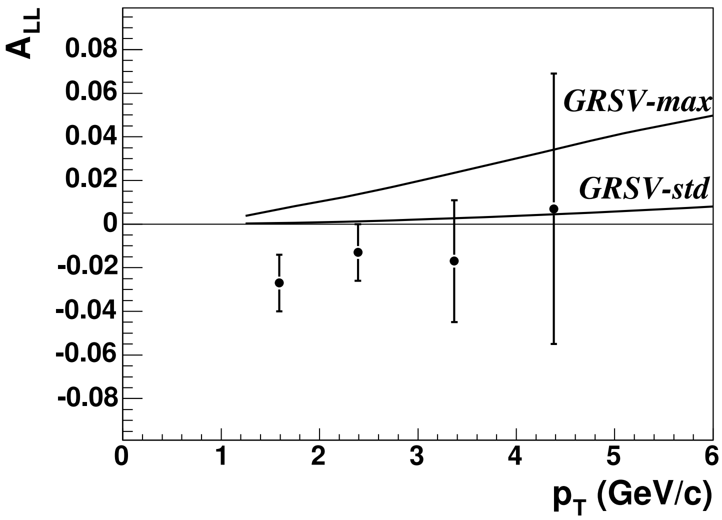

Figure 2. The measured double helicity asymmetry versus mean p_T for π^0 production. A scale uncertainty of ±65% is not shown. The curves are theoretical calculations for a range of possible gluon polarizations.

4. Discussion and Plans

We have calculated confidence levels for the theory curves in the figure, with a range due to the polarization scale uncertainty. The results are consistent with the GRSV-std curve with CL=16-20%. The results are less consistent with a large gluon polarization, GRSV-max, with CL=0.02-5%. The confidence levels do not include a theoretical uncertainty, which will require global fitting for the parton distributions and fragmentation distribution. There is possible contamination from soft physics in the lowest

p_T bin. This is discussed in our paper.[11] The results here have uncertainties on the gluon polarization comparable to the uncertainties from global fits to the world inclusive DIS data.[13] Our first results show a preference for smaller gluon polarization.

There are a number of important probes of gluon polarization at RHIC. Jet and π^0 production are high cross section probes with several competing subprocesses. The new understanding of the cross section with NLO pQCD calculations [9,14] makes these high cross section probes a very sensitive way to study gluon polarization. In the immediate future, we will push to higher p_T for π^0, and also study charged pions. As we reach higher luminosity, the golden probe of direct photon production will become accessible. This probe is dominated by the Compton subprocess, $q + g \rightarrow \gamma + q$. Therefore, direct photons will provide a precise measurement of the gluon polarization. We will also measure heavy quark production asymmetries that result from the gluon-gluon subprocess. Beyond gluon polarization, we will measure the parity-violating production of W bosons at $\sqrt{s}$=500 GeV. The $W^{\pm}$ parity-violating asymmetries directly probe the anti-quark polarization in the proton, identified by flavor.

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