The Longitudinal Spin Program at STAR

Robert V. Cadman for the STAR Collaboration

High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois 60439

Abstract. The STAR Collaboration has nearly completed installation of electromagnetic calorimetry covering the full azimuth and pseudorapidity range $-1 < \eta < 2$. These calorimeters are essential for the STAR spin program, which requires efficient triggers for high-p_T jets, mesons, and photons. The results of this program will constrain Δg, the gluon contribution to the proton spin.

Keywords: polarization, nucleon spin structure, RHIC spin, calorimeters
PACS: 13.88.+e, 14.20.Dh, 29.40.Vj

For more than two decades the spin structure of the nucleon has been studied intensely. Interest was piqued by a result from the European Muon Collaboration [1] which violated the Ellis-Jaffe Sum Rule (EJSR) [2]. This result, suggesting that the quarks accounted for less of the proton spin than had been expected, led to the so-called "Spin Crisis". Further measurements have confirmed the violation of the EJSR, and have generally agreed that the spins of quarks account for between 20% and 30% of the total proton spin [3].

Another possible contribution to the proton spin comes from the spin of the gluons. The gluon polarization has been studied in deeply inelastic lepton scattering (DIS) [4]. Complementary measurements are also possible in the polarized proton-proton collisions at the Relativistic Heavy Ion Collider (RHIC). At RHIC, the hard scattering of quarks and gluons will be used to constrain the spin-dependent parton distribution functions. Using assumptions including partonic $k_T = 0$ in the initial state, the momentum fraction x of the incident partons can be determined from a two-body final state (di-jets or γ+jet) on an event-by-event basis. Within these assumptions, it will be possible to map out $\Delta g(x)$ over a range of x, yielding a more detailed understanding of the proton's spin structure.

Although the primary purpose of RHIC is to collide heavy nuclei, an important program of polarized proton collisions has been made possible with the installation of spin rotators and Siberian Snakes in RHIC and in the Alternating Gradient Synchrotron. During the 2005 run, RHIC delivered collisions at $\sqrt{s} = 200$ GeV with polarizations $P > 0.4$ for each beam. Polarized proton collisions at $\sqrt{s} = 410$ GeV were briefly achieved. The machine is eventually expected to reach $\sqrt{s} = 500$ GeV.

The two large experiments at RHIC, PHENIX [5] and the Solenoidal Tracker At RHIC (STAR), are able to measure longitudinal spin observables due to spin rotators installed in each beam on both sides of each experiment. Both experiments have a goal of measuring Δg, the gluon contribution to the proton spin. The STAR Collaboration is primarily interested in measuring the partonic level processes $q+g \to q+g$, $g+g \to g+g$, and $q+g \to q+\gamma$. The double-spin longitudinal analyzing power in the pQCD limit is in each case proportional to the product of the polarizations of the incident partons. The analyzing powers of the partonic subprocesses are known from NLO pQCD. STAR will measure final state jets and high-p_T π^0's, the observable manifestations of the outgoing quarks and gluons. Initially these will be inclusive measurements. Di-jet coincidences have already been observed at STAR [6]. As the machine luminosity increases, measurements of spin observables for di-jets will be feasible. Eventually STAR plans to measure photon-jet coincidences, a channel which is a relatively clean signature of a gluon in the initial state. The STAR Endcap Electromagnetic Calorimeter was explicitly designed to obtain a clean signal from the direct photons produced in this channel with good suppression of the π^0 background.

Central to the baseline STAR experiment is a large Time Projection Chamber [7] which tracks charged particles in the pseudorapidity range $|\eta| < 1.4$. Additional detectors are required to trigger on the rare events of interest to the STAR spin program. These detectors include the Endcap and Barrel Electromagnetic Calorimeters [8], upgrades to STAR which will be completed before the 2006 run. The Barrel acceptance covers $|\eta| < 1.0$, while the Endcap covers $1.1 < \eta < 2.0$

The calorimeter electronics are designed to trigger when the largest single-tower energy deposition exceeds a programmable threshold and when any of 18 non-overlapping patches of $\eta \times \phi \approx 1 \times 1$ record an energy greater than another threshold. This second condition, the "jet-patch" trigger, is STAR's most efficient trigger for high-p_T jets. The single-tower trigger is sensitive primarily to single photons and π^0's. During the 2005 run, STAR took data with $> 50\%$ live time with unprescaled trigger thresholds set to $E_T \approx 3.5$ GeV for single towers and $E_T \approx 7$ GeV for the jet-patch trigger.

Both calorimeters are composed of alternating layers of lead and scintillator. The scintillators are cut into tiles covering $\eta \times \phi \approx 0.05 \times 0.05$ for the Barrel and $\eta \times \phi \approx 0.1 \times 0.1$ for the Endcap. The tiles are read out with wavelength-shifting (WLS) fibers. Both calorimeters have shower maximum detectors (SMD) at a depth of approximately 5 radiation lengths. The Barrel SMD is a wire proportional counter read out through strips on a printed circuit board. A 15×15 matrix of strips reads the ionization signal within an area corresponding to four towers. The Endcap has a novel SMD composed of triangular scintillator strips read out through WLS fibers. The Endcap strips are glued into 30 degree modules and are oriented at a 45 degree angle to the central radius of the module, as shown in Figure 1.

Installation of the Endcap was completed prior to the 2005 run. One-half of the Barrel (covering the full azimuth and $0 < \eta < 1$) was fully operational during the 2005 run. All detector components were installed. None of the $\eta < 0$ half of the Barrel was included in the trigger, and readout electronics were available for only one-half of the azimuth on the $\eta < 0$ side. The remaining electronics will be installed during the Summer 2005 shutdown, and the Barrel is expected to be fully operational for the following run.

The addition of these two calorimeters will allow STAR to trigger on jets and high-p_T π^0's, and the measurements allowed by these triggers will constrain Δg, the gluon contribution to the proton spin. Figure 2 shows estimates of the statistical precision for measurements at STAR of A_{LL} for inclusive jets with an integrated luminosity of 7 pb^{-1} and $P = 0.4$ for both beams [9]. These parameters reflect the goals of the 2005 run. The theory band in the figure shows the full physically allowed region. The central curve indicates the central value from fits to DIS data. The cusp on the lower edge of the theory band at $p_T \approx 18$ GeV/c reflects a change in the partonic channel which

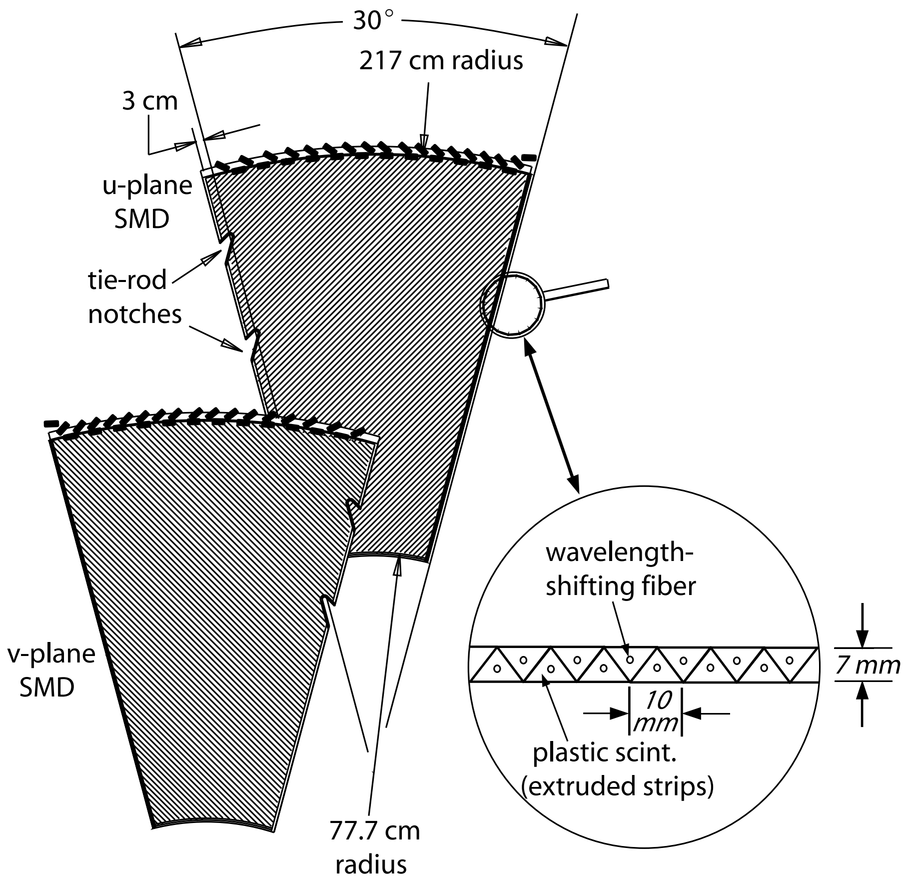

FIGURE 1. The Endcap Shower Maximum Detector. Two planes are shown as they would be installed in a single 30-degree sector, with the planes oriented such that the strips are perpendicular to those in the other plane, enabling reconstruction of a two-dimensional shower profile. A magnified view of the edge of a module shows the individual triangular scintillator strips.

dominates jet production, from $g+g$, which is insensitive to the sign of Δg, at lower p_T, to $q+g$ at higher p_T. The estimated experimental precision is based on realistic triggering and reconstruction efficiencies observed prior to the 2005 run, and assumes completed Barrel and Endcap Calorimeters. A significant fraction of the luminosity goal was achieved in the recently completed 2005 run, although only one-half of the Barrel was included in the trigger. The STAR Collaboration's eventual goals for $\sqrt{s} = 200$ GeV are to record more than 100 pb^{-1} of integrated luminosity with $P = 0.7$, improving the statistical precision of the measurements by two orders of magnitude compared to the projections in Figure 2. Ultimately, when integrated luminosity goals are reached at both $\sqrt{s} = 200$ GeV and $\sqrt{s} = 500$ GeV, STAR will measure $\Delta g(x)$ over the kinematic range $0.009 < x < 0.3$.

In summary, the STAR Collaboration has nearly completed calorimeter upgrades which will permit measurements sensitive to Δg. Initially STAR will measure A_{LL} for inclusive jets and π^0's at $\sqrt{s} = 200$ GeV. The ultimate goal is to study the x-dependence of $\Delta g(x)$.

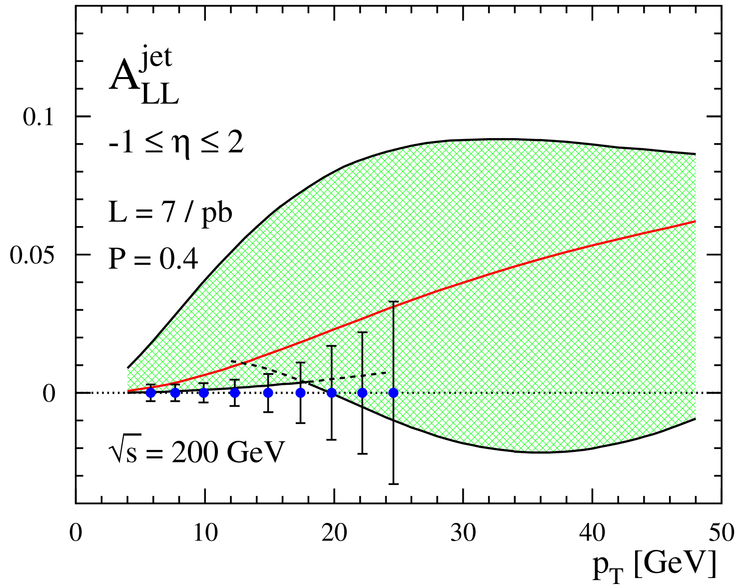

FIGURE 2. Projected precision of A_{LL} for inclusive jets at STAR with full calorimeter coverage over $-1 < \eta < 2$ and the full integrated luminosity requested for the 2005 run [9]. The band indicates the physically allowed range of A_{LL}. The central value from fits to DIS data is indicated by the central (red) curve.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy under Contract W-31-109-ENG-38. The STAR Collaboration is grateful for the assistance of the RHIC Operations Group and the RHIC Computing Facility and for the support of funding agencies from 13 nations.

REFERENCES

1. J. Ashman *et al.* (European Muon Collaboration), *Phys. Lett.*, **B206**, 364 (1988); *Nucl. Phys.*, **B328**, 1 (1989).
2. J. Ellis and R. Jaffe, *Phys. Rev. D*, **9**, 1444 (1974); **10**, 1669 (1974).
3. E. W. Hughes and R. Voss, *Annu. Rev. Nucl. Part. Sci.*, **49**, 303 (1999).
4. C. Bernet, these proceedings.
5. A. Deshpande, these proceedings.
6. T. Henry (STAR Collaboration), *J. Phys. G*, **30**, S1287 (2004).
7. K. H. Ackermann *et al.*, *Nucl. Instrum. Meth. Phys. Res.* **A499**, 624 (2003); M. Anderson *et al.*, *Nucl. Instrum. Meth. Phys. Res.* **A499**, 659 (2003).
8. M. Beddo *et al.*, *Nucl. Instrum. Meth. Phys. Res.* **A499**, 725 (2003); C. E. Allgower *et al.*, *Nucl. Instrum. Meth. Phys. Res.* **A499**, 740 (2003).
9. C. Aidala *et al.*, "Research Plan for Spin Physics at RHIC", Brookhaven National Laboratory report BNL-73798-2005, February 2005 (unpublished).