The STAR W spin physics program in 2009 and beyond

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The STAR Collaboration is embarking on measurements of the parity violating single-spin asymmetry A_L for $W^+(W^-)$ bosons produced in longitudinally polarized p+p collisions at $\sqrt{s} = 500$ GeV at Relativistic Heavy Ion Collider (RHIC). Those asymmetries are sensitive to helicity distribution functions for quarks and anti-quarks. The charge-sign reconstruction of charged leptons from W decays at forward rapidity requires an upgrade of the STAR tracking based on a novel design of triple-GEM detectors.

1 Motivation

Polarized DIS [1] experiments show that the total quark and anti-quark contribution to the proton spin, summed over all flavors, is surprisingly small. Inclusive DIS measurements provide sensitivity only to the combined contributions of quarks and anti-quarks. However progress in constraining $(\Delta\bar{u}(x) - \Delta\bar{d}(x))$ has been achieved by incorporating SIDIS data [2, 3] in global QCD analysis [4]. The production of W bosons in high energy collisions of polarized protons at RHIC provides independent and direct sensitivity to the helicity of u, $\bar{u}$, d, and $\bar{d}$ quarks in the proton through the maximal parity violating single spin asymmetry A_L.

The unpolarized cross sections for W^+ and W^- differential in the W boson rapidity y_W and the scattering angle θ^* of the decay lepton in the W centre-of-mass system is given as follows

$$\left(\frac{d^2\sigma}{dy_W\, d\cos\theta^*}\right)_{W^+} \sim u(x_1)\bar{d}(x_2)(1-\cos\theta^*)^2 + \bar{d}(x_1)u(x_2)(1+\cos\theta^*)^2 \tag{1}$$

and

$$\left(\frac{d^2\sigma}{dy_W\, d\cos\theta^*}\right)_{W^-} \sim d(x_1)\bar{u}(x_2)(1+\cos\theta^*)^2 + \bar{u}(x_1)d(x_2)(1-\cos\theta^*)^2 \tag{2}$$

The characteristic dependence on the θ^* is a direct consequence of the underlying V-A interaction. The rapidity of produced W bosons caries information about the momentum fraction of the initial $q\bar{q}$ system $x_{1(2)} = \frac{M_W}{\sqrt{s}}\, e^{+(-)y_W}$. At STAR only the final state charged lepton is measured in W decays. For the small momentum of produced Ws at forward/backward lepton rapidity $|y_{lep}^{lab}| > 1$ one can reconstruct x_1, x_2 directly from the measured lepton p_T and rapidity. The weak production processes involved are parity violating, yielding large longitudinal single spin asymmetries which will be measured as the relative difference between the yield of left-handed (N_-^W) and right-handed (N_+^W) Ws produced in collision of a longitudinally polarized proton beam with an unpolarized proton beam

$$A_L^W = \frac{1}{P}\frac{N_+^W/\mathcal{L}_+ - \mathcal{N}_-^{\mathcal{W}}/\mathcal{L}_-}{N_+^W/\mathcal{L}_+ + \mathcal{N}_-^{\mathcal{W}}/\mathcal{L}_-} \tag{3}$$

where $+,-$ signs denote the helicity of the polarized beam, P is its magnitude, and $\mathcal{L}_{+(-)}$ stand for helicity dependent relative luminosities. Asymetries $A_L^{W^+}(\eta_{lep})$ and $A_L^{W^-}(\eta_{lep})$ will be measured separately for W^+ and W^- as a function of the pseudorapidity of the detected lepton, η_{lep}.

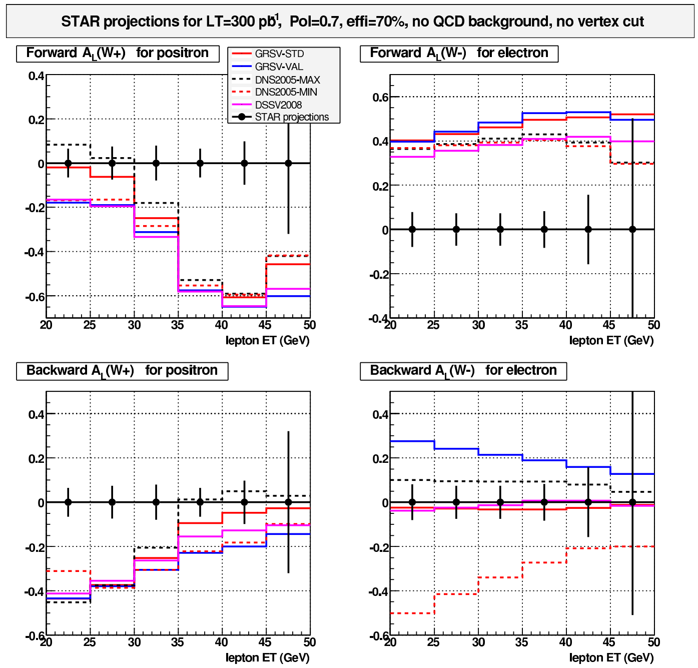

Figure 1: Projected sensitivity of STAR for parity violating A_L for $W^{+(-)}$ assuming an integrated luminosity of 300 pb^{-1} and beam polarization of 70%.

The theoretical framework of the measurement of the longitudinal single-spin asymmetry A_L for Ws as a function of the leptonic rapidity is well developed and has been presented in [5]. The global analysis framework has recently been completed to allow the extraction of quark and antiquark distribution functions using measured A_L at RHIC as input in a full global analysis [4]. Predictions shown in fig. 1 are based on resummation calculations [5], assuming STAR will acquire an integrated luminosity of 300 pb^{-1} with an average polarization of 70%. With this running time STAR would confirm the known polarization of quarks shown in the top panels and deepen our understanding of anti-quark polarization as shown on the bottom panels, in particular for the $\bar{u}$.

2 Experiment

The STAR experiment is one of two large collider experiments at the Relativistic Heavy Ion Collider (RHIC). RHIC provides polarized proton beams with a pp center of mass energy of $\sqrt{s} = 500\ GeV$. Each beam consists of up to 120 bunches, with alternating patterns for the sign of the polarization assigned to the bunches. The direction of the polarization axis of each beam can be selected by setting of the spin rotator magnets installed around the STAR interaction region. During the first 500 GeV run in 2009, an average beam polarization of 35% has been achieved.

The cross section of the STAR detector [6] is shown in fig. 2. The subsystems critical for the W measurements are barrel (BEMC) and endcap (EEMC) calorimeters with full azimuthal coverage spanning pseudorapidities $|\eta| \leq 0.98$ and $1.08 \leq \eta \leq 2.0$, respectively. The STAR Time Projection Chamber (TPC) allows reconstruction of charged tracks with $|\eta| < 1.3$. The Forward GEM Tracker (FGT) extends tracking capability up to η=+2. Despite the asymmetric pseudorapidity calorimeter coverage $\eta \in [-1, +2]$ STAR will measure A_L over $\eta \in [-2, +2]$ by using the longitudinal polarization of both the beam heading toward

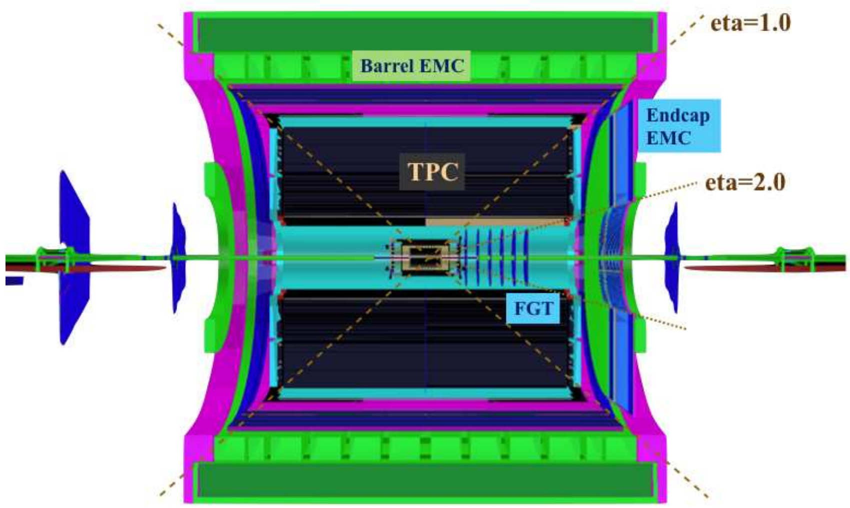

Figure 2: Essential STAR detector components are calorimeters BEMC, EEMC and trackers TPC, FGT.

and away from the endcap calorimeter.

There are three main challenges of the W measurement at STAR

- Acquire sufficient integrated luminosity with high beam polarization. Our just completed run is encouraging. Furter beam development and substantial running in the coming years will be required.
- Suppression of QCD background over W signal events by several orders of magnitude is accomplished by using information about transverse and longitudinal profile of the electromagnetic (EM) shower in the highly segmented EM calorimeters ; requiring an isolation criteria suppressing jet events; and vetoing di-jet events based on the measured away-side energy.
- Discrimination of $W^+(W^-)$ requires distinguishing between high p_T $e^{+(-)}$ through their opposite charge sign, which in turn requires precise measurement of track curvature. At mid rapidity, STAR will rely at first on the existing TPC augmented in the future by high precision inner silicon detectors [7]. At forward rapidity, new tracking capabilities will be provided by the FGT currently under construction at MIT [8].

3 Forward GEM Tracker

The Forward GEM Tracker shown in fig. 3, consist of six triple-GEM disks positioned along the beam line within the STAR detector (see fig. 2) and optimized to provide adequate tracking for leptons from W decay. The geometry has been chosen as part of an integrated tracking upgrade for the STAR experiment. The GEM disks will be positioned inside the inner field cage of the STAR TPC. Each triple-GEM disk is subdivided into quarter sections whose boundaries are aligned with respect to the TPC sector and EEMC boundaries to maximize usable active area.

The FGT detector uses GEM foils to amplify the charge deposited by the passage of an ionizing particle. The signal is read out on a separate surface designed as two orthogonal layers of strips with pitch optimized for reconstruction of the track curvature in the transverse plane. A spatial resolution of $70\mu m$, efficiencies in excess of 95%, and a time resolution of reconstructed clusters of 12 ns are expected to be reached in high-rate data taking [9].

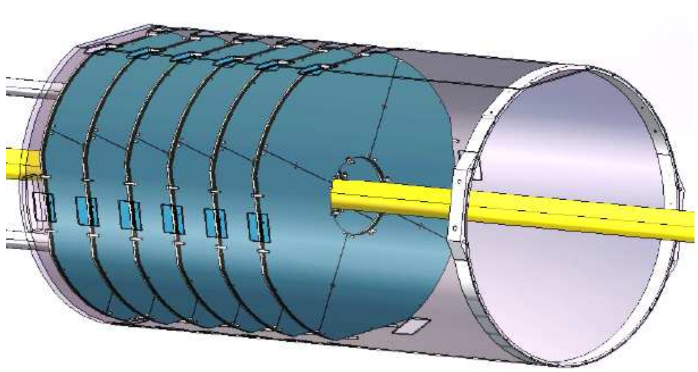

Figure 3: The forward GEM Tracker will extend STAR tracking capability.

A number of variations about FGT optimum design and anticipated performance have been considered to test the robustness of the resulting charge sign discrimination of high-pT tracks in the STAR EEMC acceptance region. The design anticipates usage of the beam line constraint, precise hit information from six triple-GEM disks, hits at forward η from the TPC, and the electromagnetic cluster hit information from the shower-maximum detector of the STAR EEMC. This combined information will be sufficient to achieve a tracking efficiency of 80% and correct charge reconstruction over 80% for a Z vertex distribution width of about 30 cm. Precise hit information from the fast inner tracking system (IST and SSD) is useful to enhance the acceptance for $Z < 0$. However, those hits are not mandatory for the W physics program.

4 Summary

An upgraded STAR detector will be able to distinguish electrons from positrons from W decay. Expected RHIC luminosity and polarizations will be sufficient to measure parity violating A_L for W^+ and W^- with sufficient accuracy to constrain the $\Delta\bar{d}(x)$ and $\Delta\bar{u}(x)$ distributions extracted from the global analysis fit. A $10pb^{-1}$ sample acquired by STAR in run 9 is expected to yield about 350 reconstructed W events and help to advance future analysis.

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