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Measuring The Spin Structure of The Proton With the STAR Detector ar RHIC

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Abstract

A unique aspect of RHIC is the ability to collide beams of polarized protons at $\sqrt{s} = 200$ and 500 GeV. The STAR experiment will measure the spin structure functions for the sea quarks and gluons by measuring spin asymetries in W, Z, direct photon and jet production. Sensitivity expectations are presented.

1 Introduction and Motivation

A long standing puzzle in high energy physics is "what carries the spin of the proton?" Deep inelastic scattering experiments suggest less than half of the proton's spin is carried by the valence quarks (perhaps this should not be too surprising, considering that only half of the linear momentum of the proton is carried by the quarks); it is therefore highly desirable to measure the fraction of the proton's spin in the sea and gluons. It is important to make these measurements in a kinematic region where perturbative QCD is valid. Polarized pp collisions at RHIC collider energies satisfy both requirements.

2 The RHIC Collider and STAR Detector

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, when completed in 1999, will collide heavy ions (up to Au^{79+}) at collision energies expected to be high enough to create a hot, dense plasma of quarks and gluons. To clearly identify a phase transition to this Quark-Gluon Plasma, it is necessary to compare heavy ion collisions with pp collisions. A unique aspect of RHIC is that a polarization of 70-80% is expected for each proton beam for these collisions. Peak luminosities of $2 \times 10^{32}\mathrm{cm}^{-2}/\mathrm{s}$ for $\sqrt{s} = 500$ GeV collisions and $8 \times 10^{31}\mathrm{cm}^{-2}/\mathrm{s}$ for $\sqrt{s} = 200$ GeV are anticipated, resulting in data sets of 800 and 320 pb^{-1} respectively over two 100 day runs at 50% efficiency. Because *pp* running is not the primary focus of RHIC, these data sets will be collected over approximately three years.

The heart of the STAR Detector is a Time Projection Chamber covering the region $|\eta| \leq 1.0$, although tracks out to about $|\eta| \leq 1.8$ can be reconstructed. Inside of the TPC is a three layered Silicon Vertex Tracker, for precise measurement of track impact parameters. Outside of the TPC is the Central Trigger Barrel, a 240 slat scintillator hodoscope, and the Electromagnetic Calorimeter (EMC). The EMC uses a lead-scintillating tile design, with towers of 0.1×0.1 in $\eta - \phi$ space, upgradable to 0.05×0.05 with up to three layers of depth segmentation. At $\sim 5X_0$ there is a wire chamber with cathode strip readout to measure shower position and energy at the maximum development of the shower. The EMC is physically constructed as a barrel $|\eta| < 1.0$ and two endcaps $1.0 < |\eta| < 2.0$; at the time of the *pp* program we expect to have the barrel and one endcap completed. The overall detector resolution will be $\Delta p_T/p_T \sim .003p_T$ for vertex-constrained tracks and $\Delta E_T/E_T \sim .16/\sqrt{E}$ for electromagnetic energy.

3 Experimental Measurements

3.1 Overview

The overall strategy of STAR is to make the same sort of measurements that are used to constrain parton distribution functions at other hadron colliders with the additional consideration of proton polarization: e.g. photon, jet, heavy flavor and vector boson production.

The EMC will allow triggering on events with large electromagnetic energy deposition in the calorimeter, as well as specific patterns: e.g. energy deposition that is photon-like or jet-like. This opens up a rich physics program: triggering on direct photons, jets as well as electrons from Drell-Yan production and W,Z and heavy flavor decays.

3.2 W and Z production

W and Z bosons are produced via $q\overline{q}$ annihilation, a valence-sea process in *pp* collisions. W and Z production is therefore a probe of sea quarks. Because W production and decay is parity violating, the spin asymetries in this process can be quite large: several 10's of percent. A unique aspect of the RHIC spin program is the ability to measure the structure function h_1, which decouples from DIS measurements, but can be measured in the process $pp \to Z^0 + X$.

3.3 Direct Photon Production

The dominant production mechanism for direct photons is the so-called Compton process of $gq \to \gamma q$. Measuring the direct photon cross section provides constraints on the gluon density, and measuring the spin asymmetry additionally gives the polarization of the gluons. While the inclusive photon cross section is interesting, perhaps more interesting are measurements that include the recoil jet, because these events allow reconstruction of the momentum carried by the scattering partons.

3.4 Jet and Heavy Flavor Production

The jet cross section is several thousands of times larger than the direct photon cross section, so although the interpretation of an asymmetry in jet production is more difficult because of the competing processes $gg \to gg$, $gq \to gq$ and $qq \to qq$, the statistical power is substantially larger. STAR measures jet energy by combining tracking and electromagnetic calorimetry, rather than the more typical combination of electromagnetic and hadronic calorimetry, and using this method obtains a minimum E_T of 10-15 GeV and an energy resolution of roughly 30%. The energy resolution is dominated by physics effects such as out-of-cone corrections, not the intrinsic detector resolution.

The ability to identify and trigger on electrons and photons makes charmonium physics possible, with the added information of knowing the spin of the parent protons. In 500 GeV running, we expect 200,000 $J/\psi \to e^+e^-$ events, 4000 $\psi' \to e^+e^-$ events and 15,000 $\chi_{1,2} \to J/\psi\gamma$ events. At 200 GeV, the yields are approximately a factor ten smaller. Additionally, by reconstructing displaced tracks associated with high p_T electrons, we expect to reconstruct 16,000 $b \to eX$ decays at 500 GeV and 1,600 at 200 GeV.

4 Summary

The STAR experiment at RHIC will make contributions to QCD beyond quark-gluon plasma physics: measuring the structure functions and spin-dependent structure functions for the quarks, antiquarks and gluons that make up the proton. A table of expected yields and sensitivities for a few selected measurements is shown below:

Signal	$\sqrt{s}$ (GeV)	Events	x Range	Sensitivity
W^+	500	72,000	0.05-0.3	$\Delta u(x)/u(x) \sim 0.01 - 0.02$ $\Delta\overline{d}(x)/\overline{d}(x) \sim 0.01 - 0.02$
W^-	500	21,000	0.05-0.3	$\Delta d(x)/d(x) \sim 0.02 - 0.04$ $\Delta\overline{u}(x)/\overline{u}(x) \sim 0.02 - 0.04$
Z^0	500	3,200	0.05-0.3	$\Delta h_1/q \sim 0.2$
γ + jet	500	3×10^6	0.02-.3	$\Delta G(x)/G(x) \sim 0.03$
	200	3×10^5	0.05-.3	$\Delta G(x)/G(x) \sim 0.04$
Dijets	500	5×10^7	0.03-.4	$\Delta G(x)/G(x) \sim 0.03$
	200	2×10^7	0.08-.4	$\Delta G(x)/G(x) \sim 0.05$