Future Investigations of the Flavor Dependence of Sea Quark Helicities at STAR

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Abstract. The flavor dependence of polarized and unpolarized quark distributions in the nucleon can lead to insights into the formation of the sea. Drell-Yan measurements have pointed to flavor asymmetries in the unpolarized distributions. Collisions at $\sqrt{s} = 500$ GeV with polarized protons at RHIC will soon allow investigations of the flavor separated polarized quark distributions via $W$ production to complement measurements from semi-inclusive DIS. We report on STAR's current plans, tracking upgrade, and expected sensitivities.

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INTRODUCTION

The identity of the nucleon comes from the valence quarks, 2 up and a down for a proton, 2 down and an up for neutron. But high energy scattering processes such as deep inelastic scattering (DIS) and hadronic reactions, e.g. Drell-Yan (DY) and jet production, reveal that, in addition, there is a sea of quarks, anti-quarks and gluons residing in the nucleon. Moreover the distributions of these change with the scale or momentum transfer of the scattering. Much of this conference is devoted to reports on understanding how the spin of the nucleon is assembled from the intrinsic spin and orbital motion of these partons. One important aspect of this quest is separating how the various flavors of the quarks and anti-quarks differ in their contributions and exploring whether something more might be learned beyond the distributions themselves.

Simplified pictures of the origin of anti-quarks in the nucleon give dramatically different expectations for the ratios of $\bar{u}$ to $\bar{d}$ quarks in a proton. In perturbative QCD they arise in quark/anti-quark pair creation and, since the $\bar{u}$ and $\bar{d}$ masses are small, one would expect roughly equal numbers. On the other hand, if one considers the long range nuclear force mediated by pions, the proton has a component that is made of a neutron and a $\pi^+$ resulting in an expected excess of $\bar{d}$ quarks. (For a general overview see Ref. [1].) The E886 DY experiment by the NuSea collaboration has generated significant interest by demonstrating clear asymmetries in the momentum fraction ($x$) dependent distributions of $\bar{u}$ and $\bar{d}$ [2]. Corrections to pQCD models for generating the sea accounting for Pauli blocking effects have not been able to explain the data. A number of models, some related to quark bag models, and some chiral symmetry motivated are consistent with the unpolarized data. However they tend to make different predictions for the helicity dependence of the flavor asymmetry, with chiral quark soliton models predicting larger asymmetries for the polarized distributions than the bag models [3].
In a recently published global analysis\cite{4}, the first to include both DIS and RHIC data, the most favored distributions demonstrate significant differences between the $\bar{u}$ and $\bar{d}$ helicity dependent distributions denoted by $\Delta\bar{u}$ and $\Delta\bar{d}$. However the uncertainties overlap and symmetric distributions are still allowed. In the following I will describe how measurements of W production in polarized proton-proton collisions at RHIC can provide further constraints on these distributions focusing in particular on the proposed measurements and techniques in the STAR detector.

**W PRODUCTION AT STAR**

While sensitivity to flavor separated distributions in DIS is primarily through coincident detection of hadrons in the exit channel\cite{5,6}, the sensitivity in polarized proton-proton collisions will be attained via W production carried out at $\sqrt{s} = 500$ GeV in RHIC. The production mechanism is primarily through the channel where a $u$ quark combines with a $\bar{d}$ anti-quark to produce a W$^+$ and likewise a $d$ with a $\bar{u}$ to produce a W$^-$. In addition, the V-A coupling of the weak interaction allows only left-handed quarks to combine with right-handed anti-quarks providing a maximal parity violating signal and thus the necessary spin determination. Finally, the handedness of the neutrinos in the W decay results in a partial transfer of the initial state kinematics, $q$ and $\bar{q}$ relative momentum fractions, into the final state decay products. The required measurements consist of determining $A_L$, the change in cross section with a single beam spin helicity flip, for W$^+$ and W$^-$ for flip of each beam independently. The two W$^+$ measurements provide sensitivity to two linear combinations of $\Delta u(x)$ and $\Delta \bar{d}(x)$ and the two W$^-$ measurements to $\Delta d(x)$ and $\Delta \bar{u}(x)$. At forward angles for W$^-$ the measurements separate almost completely into the two pure distributions.

At STAR we will focus on the W decay mode producing electrons or positrons, W$^+ \rightarrow e^+ + \nu$ or W$^- \rightarrow e^- + \bar{\nu}$. The momentum of the high $p_T$ leptons will be measured with electromagnetic calorimeters and the crucial charge sign with tracking in a magnetic field. The STAR detector\cite{7} covers a full $2\pi$ in azimuth and is embedded in a solenoidal magnet with field strength of 0.5 T. A major portion of the internal volume is occupied by a large time projection chamber (TPC) to track charged particles over a radius from 0.6m to 1.9m. The existing tracking should be sufficient for pseudo-rapidity (scattering angle) $|\eta| < 1$ ($\theta > 37^\circ$). Outside of the TPC reside two Pb/scintillator sampling electromagnetic calorimeters with the barrel covering -1 $< \eta < 1$ and the endcap covering 1.1 $< \eta < 2$ ($38^\circ > \theta > 15^\circ$). The calorimeters each have longitudinal segmentation to help in providing background rejection as will be discussed below. These include separate read out of the first few layers of the calorimeters to provide a pre-shower signal and fine position resolution shower maximum detectors to measure the transverse shower profile. In addition, the endcap calorimeter has a separately read out final layer to provide a post-shower signal.

To increase the reliable tracking range to $\eta \sim 2$ a Forward GEM Tracking upgrade\cite{8} has been proposed and funded. Six GEM chambers transverse to the beam will be placed between the TPC and the beam in line with the endcap calorimeter. The <80$\mu$m resolution of these planes along with a transverse beam constraint, points from the TPC where
FIGURE 1. Projected sensitivity for 300 pb\(^{-1}\). At left is shown the parity violating asymmetry for \(W^+\) production as measured by positron detection. The asymmetry is plotted vs. the positron pseudo-rapidity. The curves represent predictions at NLO based on a range of PDFs that fit current data. At right are the same quantities for \(W^-\) production detected as electrons.

available, and the hit in the calorimeter shower max detector should provide sufficient charge sign separation for the 20 GeV/c < \(p_T\) < 40 GeV/c electrons and positrons of interest.

SIMULATIONS AND PROJECTED SENSITIVITY

Extensive simulations have been carried out to verify that the \(W\) signal can be separated from the voluminous hard pQCD hadronic backgrounds present and then estimate realistic expected statistical errors on the measurements including remaining necessary background subtraction and projected integrated luminosities. Pythia, which agrees well with NLO calculations of \(W\) yields\(^9\), was used with GEANT models of our detector for these studies.

The signal for the channel of interest is an isolated electron with \(p_T > 20\) GeV/c and a neutrino escaping undetected. The primary backgrounds are QCD jets which happen to have a particle that deposits a similarly high \(p_T\) in an electromagnetic calorimeter. The STAR detector is not sufficiently hermetic to reconstruct the neutrino with missing transverse energy. Thus we employ three classes of cuts to reject background while preserving the signal. The first is isolation around the electron candidate. Tracks and hits in the calorimeter within \(r<0.45\) in \(\eta-\phi\) space are used to reject backgrounds based on the accompanying jet particles. The second class rejects events with tracks and
calorimeter energy opposite in \( \phi \) from the candidate, as most jets will have its partner of the dijet within the acceptance. Finally details of the candidate interaction in the detector are used, such as the transverse profile at the shower maximum detector and energy in the pre- and post-shower detectors. The calorimeters are only one hadronic interaction length long so most hadrons do not deposit a large fraction of their energy in the calorimeter. Mesons, such as \( \pi^0 \)s, which decay electromagnetically need to be rejected by a lack of hits in the tracking system. Up to 30% conversions are allowed while still giving the background rejection considered here and sets a requirement on material in front of the tracking system. Together these cuts reduce the original background by up to a factor of 1000 while preserving over 80% of the signal and we find that for \( p_T > 28 \text{ GeV/c} \) the signal to background is better than 1:1.

The projected sensitivity of our measurements for both electrons and positrons with 300 \( \text{pb}^{-1} \) of integrated luminosity is shown in Fig. 1. The asymmetries from the two beams have been combined into one plot by assigning negative pseudo-rapidity to scattering into the hemisphere from which the respective beam came. Also shown are projections for a range of recent parton distribution functions consistent with current data. For the \( W^- \) projections one sees significant sensitivity to the current range of uncertainty in \( \Delta \bar{u}(x) \) for \( \eta < 0 \). For \( \eta > 0 \) the narrow range of projections reflects the relatively well known valence \( \Delta d(x) \) distribution. For \( W^+ \) there is no clean separation between \( \Delta \bar{d}(x) \) and \( \Delta u(x) \) but still significant sensitivity for the central \( \eta \) range which can be used in constraining global fits to the parton distribution functions.

A run with polarized proton collisions at 500 GeV is planned to begin early in 2009. In this first run at that energy we project we could collect as much as 10 \( \text{pb}^{-1} \). With polarization above 50% this should be sufficient to measure a statistically non-zero \( A_L \) for the \( W^+ \) channel and put us on track for the full statistics measurement.

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