MEASUREMENT OF ANTI-QUARK POLARIZATION IN THE PROTON AND ITS FLAVOR DECOMPOSITION WITH PHENIX AT RHIC

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The polarization of anti-quark in the proton and its flavor dependence is one of the big uncertainties in the description of the spin structure of the nucleon. The single longitudinal-spin asymmetry, $\mathcal{A}_L$ in weak boson production is sensitive to such information due to $V-A$ nature of the interaction. The PHENIX detector system at RHIC is a suitable detector for the measurement and the sensitivity is discussed.

1 Anti-quark in the Proton

The spin structure of the proton has been investigated in scattering of polarized leptons off polarized nucleon target. Significant improvements in the precision of the experimental data revealed that quark carries only small fraction of the proton spin, and the importance of the role of the gluon, and anti-quark inside the proton has been addressed. In such analysis, flavor SU(3) is always assumed since lepton scattering itself is insensitive to flavor structure of the nucleon. Independent determination of the spin and flavor structure of the proton is crucial for full understanding of the internal structure of the nucleon.

The RHIC as a polarized pp collider offers very unique opportunity to pursue these studies, especially because of its high energy $50\leq \sqrt{s} \leq 500$ GeV, high luminosity of 2.0×10^{32} cm^{-2}sec^{-1} or more, and its high polarization of 70%. In pp collisions at $\sqrt{s}$=500 GeV, W production is copious. Since W production has a $V-A$ structure, the helicity of the participant quark and anti-quarks are fixed. Additionally the flavors are fixed to a good approximation. Therefore, the W production is very suitable probe to study spin-flavor structure of the proton.

In the following section, we describe the sensitivity of the PHENIX measurement of the anti-quark polarization and its flavor decomposition.

The detailed description of the PHENIX experiment can be found in Ref. 1.

2 Single Longitudinal-Spin Asymmetry $\mathcal{A}_L$ for W Production

The single spin asymmetry $\mathcal{A}_L$ for W^+ Production can be written as [2]

$$\mathcal{A}_L(pp \to W^+X) = \frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}. \quad (1)$$

Here $\Delta u(x)$ is the difference in the number densities for the up quark with helicity states parallel ($u^+(x)$) and anti-parallel ($u^-(x)$)to the proton helicity state and $u(x)$ is a sum of those number densities, i.e. $\Delta u(x) = u^+(x) - u^-(x)$ and $u(x) = u^+(x) + u^-(x)$. Similar definition applies to $\Delta\bar{d}(x)$ and $\bar{d}(x)$. For the W^- production, u and d should be exchanged. At the limit of $x_1 \gg x_2$ the asymmetry $\mathcal{A}_L$ asymptotically reaches to $\Delta u(x)/u(x)$ and in the limit of $x_2 \gg x_1$ it converges to $-\Delta\bar{d}(x)/\bar{d}(x)$. Such a condition can be achieved by detecting very forward or very backward lepton. In the PHENIX experiment, muon arms cover 1.2$\leq |\eta| \leq$2.4, forward and backward, and such condition is satisfied.

The production of W can be identified by the detection of lepton with high transverse momentum ($p_T \geq$ 20 GeV/c). A major background source is Z^0 production (~20%), however its effect can be estimated by detecting Z^0 with two muon arms. The yield of W in pp collisions at $\sqrt{s}$ =500 GeV with the p_T cut is summarized in Table 1. The integrated luminosity is assumed to be 800 pb^{-1} corresponding to 10 weeks with 70% efficiency. The proton beam polarization is assumed to be 70%.

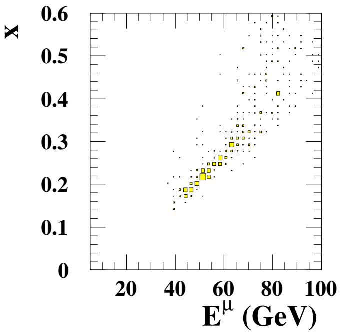

Figure 1: Correlation between muon energy and x carried by u-quark in W^+ production.

Since we cannot detect neutrino from the W decay, it is impossible to reconstruct partonic level kinematics from final state information. As shown in Figure 1, however, there is a good correlation between energy of muon and momentum fraction carried by initial quark, x. In the limit of $p_T^W \to 0$, the momentum of muon can be expressed as

$$p_\mu = \frac{\sqrt{s}}{4}[(1+\cos\theta)x_u + (1-\cos\theta)x_{\bar{d}}]. \quad (2)$$

Because of $V-A$ nature of W production, $d\sigma/d\cos\theta \sim (1+\cos\theta)^2$, and the first term in Eq.(2) dominates, the correlation between p_μ and x_u appears.

	W^-	W^+
acceptance for muon with $p_T \geq 20$ GeV/c	14%	4%
yield (both muon arms)	5100	5600
$\Delta\mathcal{A}_L$ (statistical only)	2%	2%
rapidity average	0.78±0.34	0.71±0.41
background from Z^0	1095(21.5%)	984(17.6%)

Table 1: Acceptance, yields, and backgrounds for W detection with high p_T muons in pp collisions at $\sqrt{s}$=500 GeV. Integrated luminosity of 800 pb^{-1} and beam polarization of 70% are assumed.

Once x_u is determined, $x_{\bar{d}}$ can be determined from another constraint, $M_W = \sqrt{x_u x_{\bar{d}} s}$.

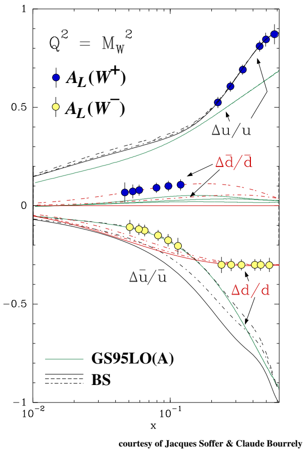

Figure 2: Models on polarized parton distribution functions and statistical limit of PHENIX sensitivity.

However, such correlation depends on the p_T distribution of W, and so does the geometrical acceptance. Studies are underway to evaluate systematic errors including the effect of background from Z^0. Figure 2 shows the statistical limit of our sensitivity to each polarized parton distribution, $\Delta\bar{u}(x)/\bar{u}(x)$ etc.

3 Future Prospect

The most important detector of this measurement, PHENIX Muon Arms, are to be completed in 2000, when the first polarized proton beam operation for physics at $\sqrt{s} = 200$ GeV is expected. In a few years from the start of the spin physics program, maximal energy and luminosity are expected to be realized.

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References

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