A_N of Single Heavy Flavor Decay Muon in the PHENIX Experiment at RHIC

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Transverse single-spin asymmetries provide valuable information about the spin structure of the nucleon. At RHIC energies, heavy-flavor production is dominated by gluon-gluon fusion, and the subsequent decay into high p_T electrons or muons can be observed statistically in a collider detector like PHENIX. The transverse single-spin asymmetry in heavy-flavor production originates from the initial state correlation between the internal transverse momentum of the parton and the transverse spin of the nucleon (similar with the known Sivers effect). The measurement of transverse single-spin asymmetry of single muons from heavy flavor decay at RHIC serves as a clean probe and would provide important information on the gluon Sivers function. In 2012, the PHENIX experiment collected 9.2 pb^{-1} integrated luminosity in transversely polarized $p + p$ collisions at $\sqrt{s} = 200 \text{ GeV}$ with a polarization of 60%. The signal-to-background ratio was improved by a factor of two compared to the previous RHIC 2006 and 2008 results in high transverse momentum region ($p_T > 3 \text{ GeV}$). The recent PHENIX preliminary results of transverse single-spin asymmetries of single heavy flavor decay muon at forward-rapidity will be shown and the possible improvement on this measurement in 2015 with the help of the FVTX detector will be discussed.

Keywords: Transverse single spin asymmetry; Heavy flavor; Single muon.

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1. Introduction

In the parton distribution functions that may be accessed in spin asymmetries for hard-scattering reactions involving transversely polarized protons, the Sivers function is particularly interesting because it encapsulates the correlations between a partons transverse momentum inside the proton, and the proton spin vector.¹ As such it contains information on orbital motion of partons in the proton. The heavy

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flavor production, where gluons participate directly, play a key role in the study of the gluonivers function.²

For $\sqrt{s} = 200\text{GeV}$ collisions at the Relativistic Heavy Ion Collider (RHIC), single muon production is dominated by muons from pion or kaon decays at a modest muon transverse momentum p_T ($1 < p_T < 3\text{GeV}/c$); whereas, at high p_T ($3 < p_T < 10\text{GeV}/c$), it is dominated by muons from open heavy flavor production. Therefore, these high p_T inclusive muons come dominantly from heavy flavor decay, which are dominantly produced through gluon-gluon fusion and therefore give a direct sensitivity to the integral over k_T to the gluonivers function in the Twist-3 formalism.^{3,4}

2. Experimental Setup

The muons are detected by the PHENIX Muons Arms (as shown in Fig. 1), which consist of two independent spectrometers at both forward and backward directions of the interaction point, corresponding to $1.2 < |\eta| < 2.4$ for the North arm and $1.2 < |\eta| < 2.2$ for the South arm.⁵ Each spectrometer, consists of a muon tracker (MuTr) and a muon identifier (MuID), is designed with sufficient geometric acceptance (one steradian), momentum resolution, and muon identification capabilities to permit the study of vector meson production and heavy quark production (through both muon pairs and single muons).

The MuTr consists of 3 layers of cathode strip readout wire chambers situated in a magnetic field. The chamber resolution is designed as 0.1 mm at each cathode plane to achieve $\Delta p/p < 3\%$ at $3 < p_T < 10\text{GeV}/c$. Upstream of each muon arm,

Fig. 1. The side view of the PHENIX detectors.

there is an absorber made of copper which covers all of the geometrical acceptance of the muon arm in order to reduce hadron background in the muon arms. The MuID consists of 5 sandwiches of plastic proportional tubes and steel/copper absorber with 10 interaction length. It is used to form a trigger for muon events as well as a road (rough track) finder to help locate tracks in the MuTr. In order to get a good efficiency for identification of muons, minimum momentum of $2\text{GeV}/c$ is required for the muon tracks. Upstream of the muon arms, closer to the beam, there is a pair of Beam Beam Counter (BBC). The counters can determine z position of collision point by measuring timing difference between north and south BBC detectors.

3. Data Analysis

3.1. Inclusive single muon measurement

The PHENIX muon arms are not capable to identify the open heavy flavor muons which are always buried in the background as Fig. 2 shows. These physical background sources primarily manifest themselves as either punch-through hadrons or muons from hadron decay, both of which can penetrate to the last gap of the MuID, thereby entering into the pool of inclusive muon candidates. The estimation of physical background sources is performed using a data-constrained hadron cocktail Monte-Carlo simulation. In this analysis, we made the open heavy flavor measurement through an indirect statistical measurement, which estimates and statistically subtracts all background not from the semi-leptonic decay of heavy flavor mesons.

Fig. 2. Particle flux in muon arms.

3.2. Asymmetry calculation

The transverse single spin asymmetry A_N is obtained for the blue and yellow beam separately by considering the polarization of only one beam, the polarization of the other beam being averaged to zero.

We used maximum likelihood method for the asymmetry calculation on both inclusive muons and background. The likelihood ζ is defined as below:

$$\zeta = \prod f \cdot (1 \pm R_L \cdot P \cdot A_N \cos(\phi_i)) \quad (1)$$

where f is any correction factor, $\pm$ depends on the spin direction, $R_L = \frac{L^\uparrow}{L^\downarrow}$ is the relative luminosity measured with BBC detector, P is polarization, ϕ_i is the azimuthal angle for each track. We just look for A_N which would made $\log \zeta$ to reach maximum. Then this A_N will be our result. For some mathematical calculation purpose, the likelihood function is usually written into log format as:

$$\log \zeta = \sum \log(1 \pm R_L \cdot P \cdot A_N \cos(\phi_i)) + \log f \quad (2)$$

when $\log f$ is independent of A_N , it wouldn't affect the final A_N finding and can be ignored.

The statistical uncertainty of the asymmetry can be derived by:

$$\sigma(A_N) = \left(-\frac{\partial^2 \zeta}{\partial A_N^2}\right)^{-1} \quad (3)$$

3.3. Inclusive and background asymmetry estimations

The Monte-Carlo simulations performed in the single muon cross section measurement clearly show tracks stopped before the last MUID gap are mostly from punch through hadrons, which can use for background asymmetry estimation. Therefore, We can extract the open heavy flavor decay muon asymmetry (A_N^{Phys}) by subtracting the background asymmetry (A_N^{BG}) from the inclusive muon asymmetry (A_N^{Incl}) as Eq.4 and Eq.5 show.

$$A_N^{Phys} = \frac{A_N^{incl} - r \cdot A_N^{BG}}{1 - r}, \quad (4)$$

$$\delta A_N^{Phys} = \frac{\sqrt{(\delta A_N^{incl})^2 + r^2 \cdot (\delta A_N^{BG})^2}}{1 - r}, \quad (5)$$

4. Summary and Outlook

In 2012, the PHENIX experiment measured the transverse single spin asymmetries A_N of open heavy flavor decay muons as a function of x_F and p_T as shown in Fig. 3 and 4. In the measurement, the statistical uncertainties, especially in high p_T region, have been significantly improved from previous measurements. The asymmetries are

Fig. 3. x_F dependent single muon physics asymmetries.

Fig. 4. p_T dependent single muon physics asymmetries.

consistent with zero in current statistics, which are also consistent with previous PHENIX results.

The PHENIX experiment had installed forward silicon vertex detector(FVTX) in 2012, which significantly improved the collision vertices resolution for muon arm events from 5 cm to 0.2 mm.⁶ With the help of these precise vertices measurement, it becomes possible to statically differentiate the displaced vertices between D-meson, B-meson and hadron decay muons background. RHIC is going to have another transverse polarized $\sqrt{s} = 200\text{GeV}$ p+p collision in 2015. We expect the signal to background ratio for open heavy flavor muon measurement will be significantly improved in this run, which would help extend our measurement to be low statistics higher p_T region.

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