Single Muon Production in Transversely Polarized p+p Collisions at $\sqrt{s} = 200$ GeV in the PHENIX experiment

H. Kobayashi* and A. Taketani[1†] for the PHENIX Collaboration[2†]

*RIKEN BNL Research Center, Building 510A, Upton, NY 11973-5000, U. S. A.
†RIKEN, 2-1 Hirosawa Wako Saitama 351-0198, Japan

Abstract. During the operation of the Relativistic Heavy Ion Collider (RHIC) in 2001-2002, the PHENIX experiment accumulated data on single muon production from collisions of transversely polarized protons at $\sqrt{s} = 200$ GeV. It was observed that the single muon sample is dominated by muons from pion and kaon decays. Subsequent transverse spin asymmetry analysis is discussed.

INTRODUCTION

The detection of single muons in proton-proton interactions using the Relativistic Heavy Ion Collider (RHIC) provide a means to study spin physics. For collisions at a $\sqrt{s}$ of 200 GeV, it is predicted that, at a modest muon transverse momentum p_T ($1 < p_T < 3$ GeV/c), single muon production is dominated by muons from pion or kaon decays; whereas, at high p_T ($3 < p_T < 10$ GeV/c), it is dominated by muons from open heavy flavor production. The heavy flavor production is dominantly created through the gluon-gluon fusion, so it allows one to measure the gluon polarization in the proton directly if the proton beams are longitudinally polarized.

During the RHIC running period in 2001-2002 (Run2), the beams were transversely polarized and a large number of low p_T single muons and a modest number of high p_T single muons were detected. Even though the sample is dominated by muons from pion or kaon decays, it is still interesting to look at the single-spin transverse asymmetry (A_N) for the single muon production because the Fermilab E704 experiment found large single transverse spin asymmetries in the reactions using polarized proton beams, ($p_\uparrow p \to \pi^+ X$ and $p_\uparrow p \to \pi^- X$) at $\sqrt{s} = 19.4$ GeV [1]. Specifically, they reported that the A_N for π^+ varied from 0 to 0.3 as a function of Feynman x (x_F) over the range $-0.2 < x_F < 0.9$. The A_N for π^- varied similarly in this range of x_F, but with an opposite sign. Similar large spin effects had been observed at lower energies in the BNL E925 experiment at 22 GeV/c incident proton beam energy ($\sqrt{s} = 6.56$ GeV) [2] and earlier in Argonne at 11.75 GeV/c ($\sqrt{s} = 5.00$ GeV) [3]. It is interesting to look at the

[1] Presenting author.
[2] For the full PHENIX Collaboration author list and acknowledgments, see Appendix "Collaborations" of this volume.

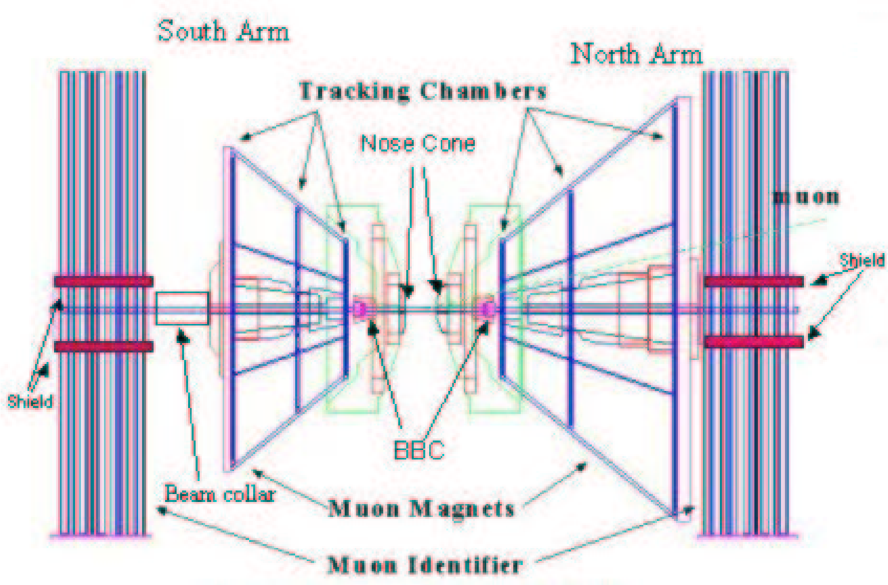

FIGURE 1. Apparatus of the PHENIX muon arms looking from side.

transverse spin asymmetry A_N for pion and kaon production through the inclusive muon production because it has never been measured at such a higher center of mass energy $\sqrt{s} = 200$ GeV. The $\sqrt{s}$ variation may help to isolate the model because it is expected that the perturbative QCD is applicable with less ambiguity at a higher energy.

Currently, there is no rigorous model that enables one to interpret the properties of these spin effects. Various theoretical models have been proposed to explain the analyzing powers observed in pion production. (1) higher twist effects [4], (2) correlation of $k_\perp$ and spin in the structure function [5, 6], or in fragmentation function [7, 8, 9], (3) orbital angular momentum of valence quarks inside a polarized hadron [10, 11, 12], and (4) a quark recombination model with a relativistic description for the parton-parton interaction [13].

EXPERIMENTAL SETUP

The RHIC is a collider accelerator which consists of two rings [14]. In Run2, transversely polarized beams colliding at $\sqrt{s}=200$ GeV was achieved. Siberian snakes were employed [15] to accelerate the beams without loosing their polarization. Polarimeters using Coulomb nuclear interaction were successfully used to measure the beam polarization [16]. The operation of these devices was commissioned as required for physics measurements.

The PHENIX detector consists of a central arm and two muon arms. The z-axis was defined on the beam line from the south to north direction. As shown in the figure 1, the muon arms are located in the forward regions covering the mid-rapidity range of $1.2 < |\eta| < 2.4$ over the full azimuthal range. The south muon arm, one of the two PHENIX muon arms, was operational during Run2 for the first time. The north muon arm has been installed for the coming 2002-2003 run (Run3). Each muon arm consists of a muon identifier (MuID) and a muon tracker (MuTr). The MuID consists of 5 sandwiches of plastic proportional tubes and steel absorber with 10 interaction length. It is used as a trigger counter 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 GeV$/c$ is required for the muon tracks. The MuTr consists of 3 layers of cathode strip readout wire chambers situated in a magnetic field. The chamber resolution is designed as 100μm at each cathode plane to achieve $\Delta p/p \sim 3\%$ at $p = 3 \sim 10$ GeV$/c$. Upstream of each muon arm, there is an absorber made of copper which covers all of the geometrical acceptance of the muon arm in order to reduce hadron multiplicity in the muon arms. 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.

ANALYSIS

In Run2, the PHENIX accumulated the integrated luminosity of 0.15 pb^{-1}. The polarization was 14% on average for one beam, 17% for the other beam.

The minimum bias event was defined as the BBC north-south coincidence or 1 layer penetration (shallow) of tracks in the MuID then 188 million events were obtained. To select muon track candidates, 4 layer penetration (deep) of tracks in the MuID was required then total number of tracks was reduced to 981k. After more detailed track quality cuts were applied, 203k tracks were obtained as a clean muon sample.

In the Figure 2, the vertex distribution is shown for all minimum-bias events (top right) and events with a muon track (top left). By dividing these two distribution, the muon yield was determined as a function of vertex position in z (bottom left). This distribution has a clear slope that indicates that there are more muons as the distance between the vertex position and the south muon arm increases. This feature is explained by the fact that the produced muons are dominated by pions or kaons for which the decay length before going into the absorber depends on the collision vertex position. The kink from the decay is negligible since it is small (kink angle for pion is $\theta_\pi < 0.01$ rad and that for kaon is $\theta_K < 0.1$ rad).

The number of muons originating from pion decay (N_π) can be expressed as:

$$N_\pi(L) = N_\pi^0 \exp\left[\frac{-L}{c\tau_\pi\gamma_\pi}\right] \tag{1}$$

where, as shown in the figure 3, L is the distance between the absorber and the collision point corrected by track polar angle θ. Together with muons coming from kaon decay (N_K), the total number of observed muons can be expressed as:

$$N_\mu(L) = N_\pi^0\left(1-\exp\left[\frac{-L}{c\tau_\pi\gamma_\pi}\right]\right) + N_K^0\left(1-\exp\left[\frac{-L}{c\tau_K\gamma_K}\right]\right) \tag{2}$$

$$\simeq L\left(\frac{N_\pi^0}{c\tau_\pi\gamma_\pi} + \frac{N_K^0}{c\tau_K\gamma_K}\right) \qquad (L \ll c\tau\gamma) \tag{3}$$

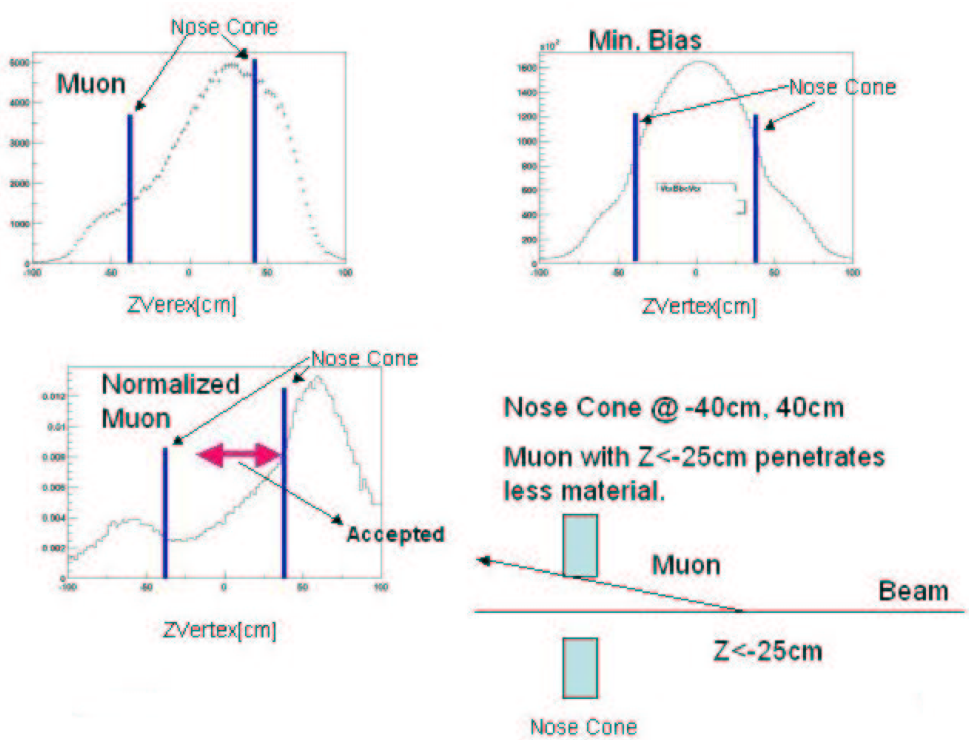

FIGURE 2. Vertex distribution of collisions that contains muon tracks (top left), minimum bias with BBC north-south coincidence (top right) and the muon track vertex divided by the minimum bias BBC vertex distribution (bottom left).

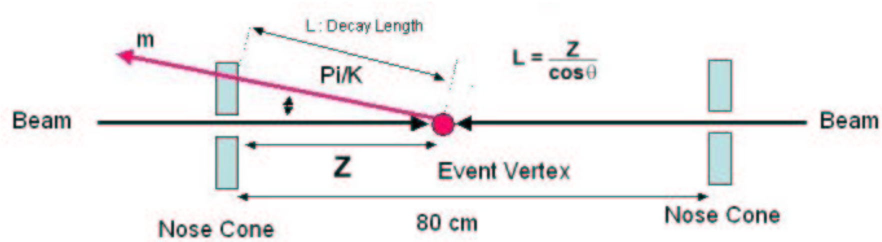

FIGURE 3. Schematic view of a collision vertex and the absorber (nose cone).

where the expression was simplified using the approximation $L \ll c\tau\gamma$.

The other possible contributions to the muon yield are muons from heavy flavor production and hadrons which punch-through the absorbers. These contributions do not depend upon L and thus result in an offset to the histogram at the bottom left of Figure 2. In order to determine the flat distribution, the function form of (3) plus offset was fitted. The vertex distribution of events with muon tracks can be reproduced by a simulation which taking into account of the in-flight decay of π and K. Figure 4 shows the simulated vertex distribution which reproduces the decay length dependence well.

Based on the vertex study, we can say that we are principally detecting muons from π and K decays. A study of the single spin transverse asymmetry is underway. Significance

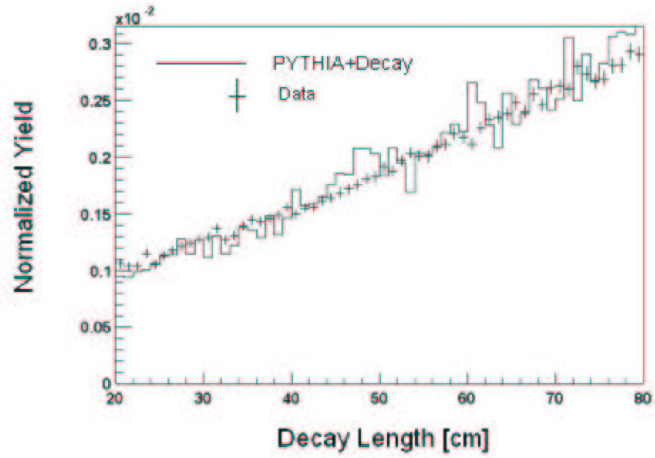

FIGURE 4. Comparison of the measured vertex distribution with a simulation.

of this measurement can be estimated from the statistics that we obtained from the vertex study. Statistics of $N_+ + N_- = 100$k and beam polarization $P_b = 0.2$ gives the statistical precision $\delta A_N = 0.015$ at average values $\langle x_F \rangle = 0.04$ and $\langle p_T \rangle = 1.5$ GeV$/c$.

SUMMARY

Single muons were observed in the transversely polarized proton-proton collision at $\sqrt{s} = 200$ GeV. Those are dominated by decays of π and K. Single spin asymmetry A_N measurement using single muon production is feasible with current data.

REFERENCES

1. D. L. Adams *et al.*, Phys. Lett. **B264**, 462-466 (1991).
2. C. E. Allgower *et al.*, Phys. Rev. **D65**, 092008 (2002).
3. W. H. Dragoset, *et al.*, Phys. Rev. **D18**, 3939-3954 (1978).
4. J. W. Qiu and G. Sterman, Phys. Rev. **D59**, 014004 (1999).
5. D. W. Sivers, Phys. Rev. **D41**, 83 (1990).
6. D. W. Sivers, Phys. Rev. **D43**, 261-263 (1991).
7. J. C. Collins, Nucl. Phys. **B396**, 161-182 (1993).
8. J. C. Collins, S. F. Hepplemann and G. A. Ladinsky, Nucl. Phys. **B420**, 565-582 (1994).
9. M. Anselmino, M. Boglione and F. Murgia, Phys. Rev. **D60**, 054027 (1999).
10. C. Boros,and Z. T. Liang and T. C. Meng, Phys. Rev. Lett. **70**, 1751-1754 (1993).
11. Z. T. Liang and T. C. Meng, Z. Phys. **A344**, 171-180 (1992).
12. S. M. Troshin and N. E. Tyurin, Phys. Rev. **D52**, 3862-3871 (1995).
13. K. Suzuki and N. Nakajima, H. Toki and K. I. Kubo, Mod. Phys. Lett. **A14**, 1403-1412, (1999).
14. H. Huang, These proceedings.
15. H. Huang, *et al.*, Phys. Rev. Lett. **73**, 2982-2985 (1994).
16. O. Jinnouchi, These proceedings.