Cross Section and Asymmetry Measurement of Very Forward Neutral Particle Production at RHIC

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Although air shower observations at the surface of the earth have been developed in order to understand the origin of the ultra high energy cosmic rays, the observations have uncertainties in interpretation of the observed data from the present phenomenological nuclear collision models. Precision measurements of the very forward particle production in the collider experiments improve understanding of particle production processes in the nuclear collisions, and provide large influences on interpretation of the observed data and the origin of the cosmic rays. On the other hand, a large 10% single transverse-spin asymmetry in neutron production from transversely polarized proton collisions was found at the RHIC collider at BNL. It has provided a valuable input for understanding particle production processes in the polarized proton collisions. We will have a new collider experiment at RHIC which has a high resolution and a wide coverage of transverse momentum measurements in order to figure out elementary processes of the air shower generation.

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1. Introduction

In the collider experiments, limited measurements have been performed in the very forward region due to structural limitations of accelerators. In 1990s and 2000s, very forward particle production measurements were performed at HERA electron-proton collider and Tevatron proton-antiproton collider. The results were interpreted with elementary processes based on QCD. Recently there are precision measurements of proton-proton colliders at RHIC and LHC for further understanding.

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A large 10% single transverse-spin asymmetry (SSA) in neutron production from transversely polarized proton collisions was found at RHIC in 2002,¹ and improved understanding of the production mechanism with an one particle exchange has been given by following experiments^{2,3} and theoretical studies.⁴

On the other hand, the LHCf experiment has been performed at LHC for understanding cosmic ray generation from the collider experiment data.⁵ Although air shower observations at the surface of the earth have been developed in order to understand the origin of the ultra high energy cosmic rays, the observations have uncertainties in interpretation of the observed data from the present phenomenological nuclear collision models. Precision measurements of the very forward particle production in the collider experiments improve understanding of particle production processes in the nuclear collisions, and provide large influences on interpretation of the observed data and the origin of the cosmic rays.

We will have a new collider experiment at RHIC, so called RHICf experiment, which uses one of LHCf detectors⁶ (which is called RHICf detector) with a high resolution and a wide coverage of transverse momentum measurements in order to improve the studies performed at RHIC and LHC. RHIC is a dedicated machine for QCD physics and it will enable us flexible operation towards our physics goals.

2. Physics Goals

The SSA of neutron found at RHIC provides an important clue to study elementary processes in the air shower generation because the large SSA indicates there are dominant contributions from processes which strongly interfere each other. The asymmetry measurement of neutral particle production at RHIC provides interference measurement with one pion exchange with spin flip, so it is sensitive to a Reggeon exchange without spin flip. It provides understanding of the elementary process.⁴ The SSAs of very forward neutrons were measured³ at collision energies of 62 GeV, 200 GeV and 500 GeV as shown in Fig. 1, although a transverse-momentum resolution of the data was limited. In the RHICf experiment, we will have an improved transverse-momentum resolution using the RHICf detector.

In order to reconstruct the air shower generated by the cosmic rays, various nuclear collision models have been developed, but the models have theoretical uncertainties. The LHCf experiment has measured very forward neutral particle cross section at collision energies of 0.9 TeV and 7 TeV for testing the models. The results have shown average behavior of the models, and given strong limitation on improvement of the models. Because the nuclear collision models have different collision energy dependence, measurements at different collision energies will test the models. Figure 2 shows comparison of theory model calculations of collision energies at $\sqrt{s} = 500$ GeV (RHIC energy), 14 TeV (LHC energy), and 50 TeV. The test at 510 GeV collision energy will be performed by the RHICf experiment. The kinematic coverage is very limited in the very forward measurement with low energy collisions at LHC, but that at RHIC is optimized in the similar collision energy.

Fig. 1. Measured asymmetries (A_N) of very forward neutron production as a function of transverse momentum (p_T).

In the RHICf experiment, we will obtain precision measurements of very forward neutral particles (neutron, photon, neutral pion) at a collision energy of 510 GeV in addition to higher energy data up to 13 TeV at LHC. These data of various collision energies will provide understanding of air shower generation and limitations on the origin of the ultra high energy cosmic rays.

3. Experimental Setup

The RHICf detector will be located in front of the Zero-Degree Calorimeter (ZDC)⁷ in the north side of the PHENIX detector, 18m from the PHENIX collision point. In this area, all charged particles are swept out by the last dipole magnet for colliding beams at RHIC, and only neutral particles are detected.

The RHICf detector consists of two sampling EM (electromagnetic) calorimeters with 44 interaction-length tungsten, 16 layers of scintillators, and 8 layers of silicon strip detectors; one with 25mm $\times$ 25mm and another with 32mm $\times$ 32mm cross section. The ZDC detector is a sampling hadron calorimeter composed of Cu-W alloy absorbers with PMMA-based optical fibers. By using EM and hadron calorimeters, detection, identification and energy measurement of photons and neutrons are performed. The RHICf detector is fixed with a manipulator which moves the RHICf detector up and down. A schematic view of the RHICf detector installation and the structure of the calorimeter are shown in Fig. 3.

Fig. 2. Comparison of theory model calculations of neutral pion production cross section with collision energies at $\sqrt{s} = 500$ GeV (RHIC energy), 14 TeV (LHC energy), and 50 TeV.

Fig. 3. A schematic view of the RHICf detector installation and the structure of the calorimeter.

4. Experimental Plan

We have proposed to have a dedicated run for 1 week in 2016 with 510 GeV polarized proton collisions,⁸ and we are preparing for it. One of the LHCf detector will be removed from LHC in June 2015 after the LHCf experimental run. It will arrive at BNL in 2015 autumn, and will be installed in the north tunnel area of the PHENIX experiment.

In the dedicated RHICf run, we will use the normal accelerator condition of the RHIC except beta function value at the PHENIX collision point $\beta^* = 10$ m in order to have parallel beam collisions. We need 12 hours to have much enough luminosity for cross section measurements of photons, neutrons, and neutral pions including transverse-momentum scan with the manipulator. The SSA can be measured with the same data set with higher statistics than the measurements in the past. We have discussed with the PHENIX experiment to have one week of dedicated data acquisition period including a few days of beam tuning. During a dedicated RHICf beam time, the detector is moved on the beam line to cover wide kinematic regions. Otherwise, the detector is located out of the beam line. We will take synchronized data of the PHENIX detector (ZDC, etc.), and analyze them with event-by-event diffractive or non-diffractive selection.

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