ASYMMETRY MEASUREMENT OF VERY FORWARD NEUTRAL PARTICLE PRODUCTION IN THE RHICf EXPERIMENT*

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(Received March 5, 2019)

Very forward neutral particle production was measured in the RHICf experiment for polarized $p+p$ collisions at $\sqrt{s} = 510$ GeV. An electromagnetic calorimeter was installed in the zero-degree area of the STAR experiment and took neutron, photon and neutral pion data at pseudorapidity $\eta > 6$. The cross-section measurement will give us new inputs to develop high-energy collision models which is essential to understand air-shower from ultra-high energy cosmic rays. The asymmetry measurement will enable us to understand the hadron collision mechanism based on QCD. The data were taken in 2017 RHIC run with three detector positions in order to cover wide kinematic regions. STAR detector data were also recorded for combined data analysis. We obtained preliminary results of the transverse single-spin asymmetry, A_{N}, of very forward π^0 which show large asymmetries even at low p_{T} and larger at high p_{T}.

DOI:10.5506/APhysPolBSupp.12.837

1. Introduction

Majority of energy flow from hadronic collisions is concentrated in the very forward region, but the reaction mechanism is insufficiently understood there. In order to decrease uncertainty and understand air-shower from ultra-high energy cosmic rays, it is essential to improve high-energy collision models based on measurements. Very forward neutral particle production

* Presented at the Diffraction and Low-x 2018 Workshop, August 26–September 1, 2018, Reggio Calabria, Italy.

was measured for polarized $p{+}p$ collisions at $\sqrt{s} = 510$ GeV at RHIC. We want to test the so-called Feynman scaling which shows energy-independent $x_{\rm F}$ (Feynman's x) and $p_{\rm T}$ (transverse momentum) distributions of the cross section of very forward particle production. The LHCf experiment reported a scaling of π^0 production cross section at two LHC energies, $\sqrt{s} = 7$ TeV and 2.76 TeV [1]. We will add another comparison at the RHIC energy, $\sqrt{s} = 510$ GeV. In order to cover comparable $p_{\rm T}$ range to LHCf measurements, we have to perform the measurement at RHIC where we can install the detector close from the interaction point.

One advantage at RHIC to study production mechanism based on QCD is a transverse single-spin asymmetry ($A_{\rm N}$) measurement of neutral particles. The asymmetry $A_{\rm N}$ is measured as a left–right asymmetry, $A_{\rm N} = (d\sigma_{\rm left} - d\sigma_{\rm right})/(d\sigma_{\rm left} + d\sigma_{\rm right})$, or azimuthal angular modulation from the transversely polarized proton collisions. Large $A_{\rm N}$s of hadron production have been measured in the forward pseudorapidity region, $1 < \eta < 4$, with wide collision energies [2–4]. These results have been explained with TMD (transverse-momentum-dependent) functions [5] and higher-twist functions [6, 7] as an initial-state effect and a final-state effect combined with transversity. The TMD functions are used in the Drell–Yan or weak boson production because they require two scales ($p_{\rm T}$ and Q^2), on the other hand, the higher-twist functions are used in hadron, photon, or jet production which has one scale ($p_{\rm T}$).

Although these asymmetries have been explained by hard scatterings, they are also suggested by recent measurements that they come from non-perturbative QCD effect, *e.g.* diffractive scattering. The AnDY experiment reported a small $A_{\rm N}$ of forward jet production [8] comparing with that of forward hadron production. It is explained not only by mixture or cancellation of u-quark jet and d-quark jet, but also by other non-perturbative QCD effects. The STAR experiment also reported multiplicity dependence of $A_{\rm N}$ of different number of photons [9]. It showed that $A_{\rm N}$ decreases as the event complexity increases, or jet-like events show small asymmetries. It poses a question, how much of the large $A_{\rm N}$ of π^0 comes from hard scattering. It is one of the motivations we measure the $A_{\rm N}$ of π^0 in the RHICf experiment.

2. Experiment

We installed one of the former LHCf electromagnetic calorimeters [10], which is called RHICf detector, in front of the STAR ZDC (Zero-Degree Calorimeter) as shown in Fig. 1 for the cross section and the asymmetry measurement of very forward neutral particle production. Wide-$p_{\rm T}$ region up to 1.2 GeV/c was covered by changing the position of the RHICf detector vertically.

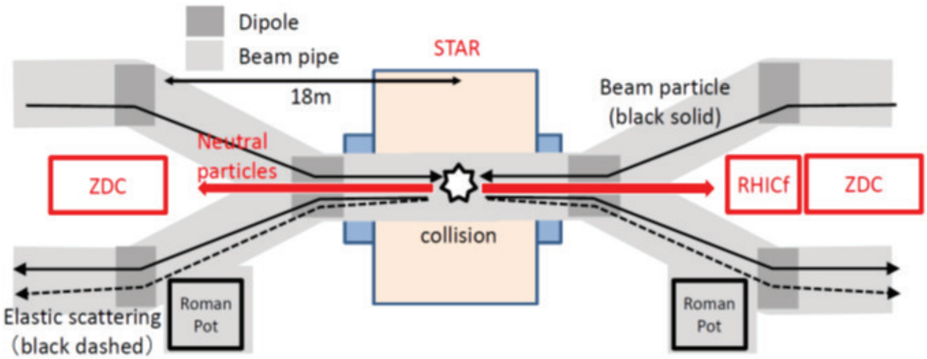

Fig. 1. A plan view of the experimental setup at STAR (not to scale). Shown are the principal component for the RHICf experiment.

The RHICf detector has two position-sensitive sampling calorimeters, TS (small tower) and TL (large tower), with tungsten absorbers ($44X_0$ and $1.6\ \Lambda_{\mathrm{int}}$), 16 GSO sampling layers, and 4 X–Y pairs of GSO-bar position layers with Multianode PMT readout. It has higher position resolution and gives higher p_{T} resolution than those of ZDC with SMD (Shower Maximum Detector).

We measure the A_{N} of very forward π^0s at RHIC in the transverse momentum region of $p_{\mathrm{T}} < 1$ GeV/c and the pseudorapidity region of $\eta > 6$ which were limited by the shadows of the DX magnet and the beam pipe. It is a non-perturbative QCD regime measurement at lower p_{T} than existing PHENIX and STAR measurements.

We also measure the A_{N} of very forward neutrons which was discovered to have a large asymmetry at RHIC [11, 12]. It was measured at three RHIC energies, 62 GeV, 200 GeV, and 500 GeV [13]. The results show a linear behavior of the p_{T} dependence, but they are not conclusive because there is no overlap between data from different collision energies. It may be a p_{T} dependence or $\sqrt{s}$ dependence. A linear behavior of the p_{T} dependence is explained theoretically by an interference of pion exchange and other Reggeon exchange. Improved p_{T} precision and wide p_{T} coverage will be given from the RHICf measurement.

In 2017 RHIC operation, we took data at $\sqrt{s} = 510$ GeV. A large $\beta^* = 8$ m was applied to make the angular beam divergence small for the parallel beam, and the luminosity was smaller than the usual RHIC operation, $L \sim 10^{31}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, as a result. The direction of the beam polarization was also adjusted from vertical polarization to radial polarization by using spin rotator magnets for the asymmetry measurement of large angle and high p_{T} particles detected by moving the detector position vertically. We took data with three vertical detector positions by using 3 kinds of triggers.

A shower trigger is a baseline trigger which requires hits in three consecutive GSO sampling layers of the TS or TL tower, and was operated with a large prescale factor < 30. Another trigger for two-photon events was made to use entire luminosity with no prescale factor. It requires hits in three consecutive layers in upstream seven sampling layers of both the TS and TL towers. We call this type of two photons, or π^0, Type-1. The other trigger was made for high-energy photon and Type-2 π^0 both of whose decay two photons are detected by the TS or TL tower. It requires a large energy deposit in the fourth sampling layer of the TS or TL tower, and was operated with a small prescale factor ~ 2. In total, 110 M events of data from about 700 nb^{-1} integrated luminosity in 27.7 hours of operation were accumulated in four days of dedicated RHIC operation as shown in Fig. 2. We recorded these triggered data both on the RHICf standalone data acquisition (DAQ) system and the STAR DAQ system.

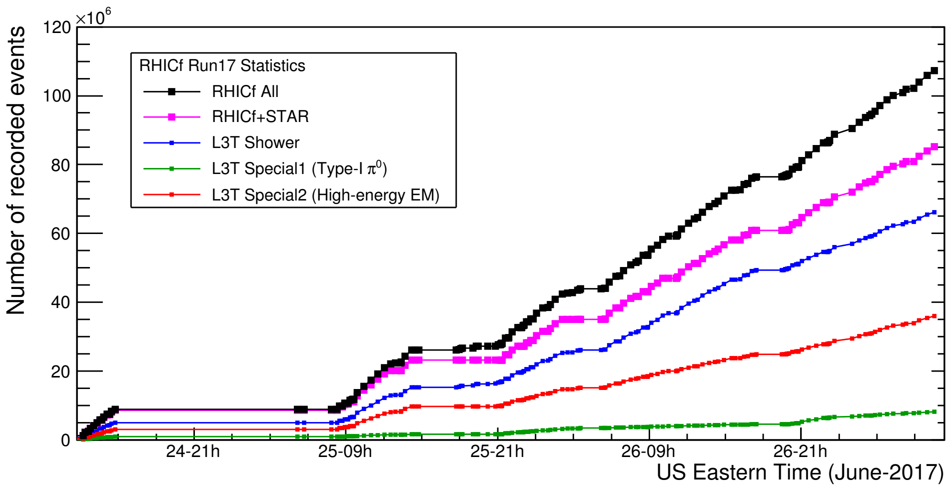

Fig. 2. Accumulated number of events for each trigger.

3. Analysis and result

Figure 3 (left) shows two-photon invariant mass distribution which presents π^0 peak width about 10 MeV/c^2. We selected 3-σ width region of the peak as π^0 candidates for Type-1 and Type-2 measurements. Figure 3 (right) shows x_{F} *versus* p_{T} distribution of the π^0 candidates. They distribute in the region of $p_{\mathrm{T}} < 1.0$ GeV/c and $0.2 < x_{\mathrm{F}} < 1.0$.

Figure 4 shows preliminary results of the very forward π^0 asymmetries. Background asymmetries were measured from the off-peak area of Fig. 3 (left). They were consistent with zero and subtracted in Fig. 4. Error bars show statistical uncertainties, and error boxes show systematic uncertainties which include those from beam-center correction, acceptance correction, polarization, and background asymmetry subtraction. The results show large asymmetry up to 0.1 even at low $p_{\mathrm{T}} < 0.6$ GeV/c, where we have interest to know production mechanism mainly from non-perturbative QCD. The A_{N} becomes larger, more than 0.1, at high $p_{\mathrm{T}} > 0.6$ GeV/c, where contribution from hard scattering may be expected.

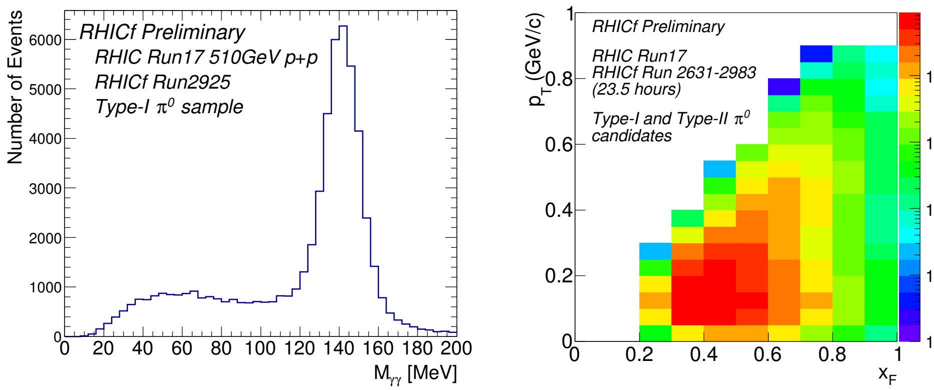

Fig. 3. (Left) Two-photon invariant mass distributions. (Right) x_{F} *versus* p_{T} distribution of the π^0 candidates.

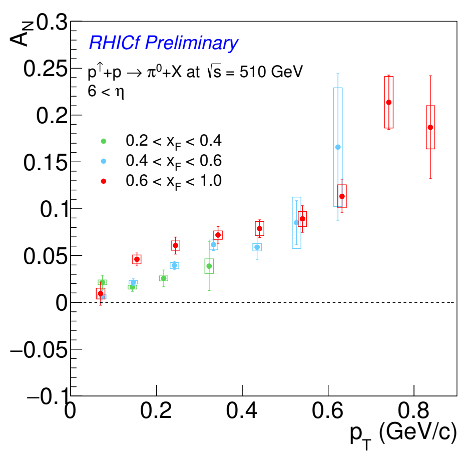

Fig. 4. Preliminary results of the very forward π^0 asymmetries.

4. Summary

We had a successful operation in 2017 for the RHICf experiment with RHICf data acquisition (DAQ) system combined with the STAR DAQ system. We obtained preliminary A_{N} results of very forward π^0 which show large asymmetries even at low p_{T} and larger at high p_{T}. Combined analysis of STAR + RHICf data will be performed to study production mechanism of these large A_{N} from both perturbative and non-perturbative QCD point of view by defining event types with other forward detectors and Roman Pot detector of the STAR, and using multiplicity dependence of cross sections and asymmetries. Neutron analysis will also be performed with the RHICf detector and STAR ZDC, and asymmetries of STAR forward and midrapidity detectors will be studied with tagged neutron and/or π^0 at RHICf.

We thank the staff of the Collider-Accelerator Department at Brookhaven National Laboratory, the STAR Collaboration and the PHENIX Collaboration to support the experiment. This program is partly supported by the Japan–US Science and Technology Cooperation Program in High Energy Physics and the National Research Foundation of Korea (No. 2016R1A2B 2008505).

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