Abstract

The STAR Collaboration reports measurements of back-to-back azimuthal correlations of di-$\pi^0$ produced at forward pseudorapidity ($2.6 < \eta < 4.0$) in $p+p$, $p+Al$ and $p+Au$ collisions at a center-of-mass energy per nucleon-nucleon pair of 200 GeV. A clear suppression of the correlated away-side yields is observed in $p+Au$ and for the first time in $p+Al$ collisions, compared with the $p+p$ data. The enhanced suppression found in $p+Au$ with respect to $p+Al$ collisions exhibits the saturation scale ($Q_s^2$) dependence on the mass number $A$. The observed suppression of back-to-back pairs as a function of event activity and transverse momentum points to non-linear gluon dynamics arising at high parton densities.

1 Introduction

Collisions between hadronic systems, i.e., $p+A$ and $d+A$ at the Relativistic Heavy Ion Collider (RHIC) provide a window to the parton distributions of nuclei at small momentum fraction ($x$). Several RHIC measurements [1–5] have shown that the hadron yields at forward rapidities (deuteron going direction) are suppressed in $d+Au$ collisions relative to $p+p$ collisions at $\sqrt{s_{NN}} = 200$ GeV. Possible mechanisms leading to the suppression include gluon saturation [6] and energy loss [7,8]. Meanwhile, the contributions from double-parton interactions to the $d+A \rightarrow \pi^0\pi^0X$ cross section are suggested as an alternative explanation of the suppression [9]. Therefore, it is important to carry out the same measurement in $p+A$ collisions, which are theoretically and experimentally cleaner compared to $d+A$ collisions.

The density of gluons per unit transverse area is expected to be larger in nuclei than in nucleons at a given $x$; thus, nuclei provide a natural environment to study non-linear gluon evolution. Gluons from different nucleons can interfere and amplify the total transverse gluon density by a factor of $A^{1/3}$ for a nucleus with mass number $A$. The color glass condensate (CGC) framework [10, 11] predicts that a quark or gluon scattering at forward angles (large rapidities) will interact coherently with gluons at low-$x$ in the nucleus [12]. As a result, for di-hadron correlations on the
In each pair, trigger \( \pi \) is defined as the subtraction, representing the back-to-back near-\( (\Delta \phi = 0) \) and away-side \( (\Delta \phi = \pi) \) peaks, together with a constant for the pedestal, from \( \Delta \phi = -\pi/2 \) to \( \Delta \phi = 3\pi/2 \). The near-side peak, dominated by two \( \pi^0 \)'s coming from the same jet, encodes nuclear modifications to the parton fragmentation. This proceeding will not discuss the near-side physics, and focuses on the study of the away-side peak. The area of the away-side peak is the integral of the correlation function from \( \Delta \phi = \pi/2 \) to \( \Delta \phi = 3\pi/2 \) after pedestal subtraction, representing the back-to-back \( \pi^0 \) yields per trigger particle; the corresponding width is defined as the \( \sigma \) of the away-side peak according to the fit.

Figure 1 shows the comparison of forward back-to-back di-\( \pi^0 \) correlation function in MinBias \( p+p \), \( p+Al \) and \( p+Au \) collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \). The area and width of away-side peak from different collisions are shown, together with their statistical uncertainties. In the left panel, in the low \( p_T \) regime, a clear suppression is observed in \( p+A \) compared to the \( p+p \) data. The away-side associated \( \pi^0 \) yield per-trigger in \( p+Au \) \( (p+Al) \) is suppressed by about a factor 1.7 (1.2) with respect to \( p+p \) collisions. The enhanced suppression in \( p+Au \) relative to \( p+Al \) at the same collision

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### 2 Experiment and Dataset

Datasets for \( p+p \), \( p+Al \) and \( p+Au \) collisions were recorded in 2015. The \( \pi^0 \)'s were reconstructed from photons, which were identified with the STAR forward meson spectrometer (FMS). The FMS is an electromagnetic calorimeter covering a pseudorapidity range from 2.6 to 4.0 [15]. The collision events are triggered by FMS based on the transverse energy deposition. The \( p+Al \) and \( p+Au \) samples are separated into different event activity (E.A.) classes based on the energy (\( \Sigma E_{BBC} \)) deposited in the inner sectors of the beam beam counter (BBC) at backward direction (aluminum and gold going direction, \( 3.3< -\eta < 5.0 \)), where \( \Sigma E_{BBC} \) is the ADC sum from all 16 BBC tiles. The STAR BBC is a scintillator detector which measures minimum-ionizing particles [16]. The samples without any E.A. selections are minimum bias (MinBias) data. The energy and \( p_T \) of the photon candidates are required to be above 1 GeV and 0.1 GeV/c, respectively. The reconstructed \( \pi^0 \)'s \( p_T \) is above 0.5 GeV/c. The energy asymmetry of \( \pi^0 \)'s photon components \(|E_1 - E_2|\) is required to be below 0.7, where \( E_1 \) and \( E_2 \) are the photon energies. The selected mass range of the \( \pi^0 \) candidates is between 0.07 and 0.2 GeV/c^2.

### 3 Results

The corrected correlation function as described in Sec. 1 is fitted with two individual Gaussians at the near- \( (\Delta \phi = 0) \) and away-side \( (\Delta \phi = \pi) \) peaks, together with a constant for the pedestal, from \( \Delta \phi = -\pi/2 \) to \( \Delta \phi = 3\pi/2 \). The near-side peak, dominated by two \( \pi^0 \)'s coming from the same jet, encodes nuclear modifications to the parton fragmentation. This proceeding will not discuss the near-side physics, and focuses on the study of the away-side peak. The area of the away-side peak is the integral of the correlation function from \( \Delta \phi = \pi/2 \) to \( \Delta \phi = 3\pi/2 \) after pedestal subtraction, representing the back-to-back \( \pi^0 \) yields per trigger particle; the corresponding width is defined as the \( \sigma \) of the away-side peak according to the fit.
Figure 1: Comparison of the correlation functions vs. azimuthal angle difference between forward (2.6 < η < 4.0) π^0 pairs in MinBias p+p, p+Al and p+Au collisions at √s_{NN} = 200 GeV. Left panel: the trigger π^0's p_T (p_T^{trig}) = 2−2.5 GeV/c and the associated π^0's p_T (p_T^{asso}) = 1−1.5 GeV/c; right panel: p_T^{trig} = 3−5 GeV/c and p_T^{asso} = 2−2.5 GeV/c. The area and width of away-side peaks are shown in each panel as described in the text.

energy supports an A dependence of Q^2 as predicted in [10, 13]. The suppression decreases with increasing p_T of the π^0's. In the high p_T range, no suppression is observed in p+A compared to p+p collisions as can be seen in the right panel of Fig. 1. The parton momentum fraction x with respect to the nucleon inside the nucleus increases with the p_T of the trigger and associated π^0's. Q can be approximated as the average p_T of di-π^0. The low x and Q^2 regime, where the gluon density is large and expected to be saturated, can be accessed using low p_T di-π^0 pairs. When the π^0 p_T is high, the probed x (Q^2) will not be sufficiently small to reach a non-linear regime. The phenomenon of broadening is not observed in p+A collisions, which is consistent with the similar measurement in d+Au collisions by the PHENIX experiment [5].

In Fig. 2, ratios of the away-side peak area for di-π^0 correlations from p+Al and p+Au collisions to that from MinBias p+p collisions are shown for different event activity classes. The systematic uncertainties of the area arise from non-uniform detector efficiency as a function of φ, and estimated as the following. We started with a physical-like correlation without detector effects. A correlation with detector effects included was obtained by applying weights according to the φ distributions from data, and then a mixed event correction was applied to the correlation as done in real data analysis. The difference between the input physical-like and the corrected correlation is taken as the systematic uncertainty. An enhanced suppression in high activity events is observed in p+Au and p+Al data, and the significance of the stronger suppression in the highest E.A. than the lowest E.A. in p+Au (p+Al) collisions is 3.1 (1.7) σ. Less suppression is observed in p+Al compared to p+Au, which is consistent with the results at low p_T from MinBias p+Al and p+Au data shown in the left panel of Fig. 1.
4 Conclusion

In summary, measurements of azimuthal correlations of di-$\pi^0$ at forward rapidities ($2.6 < \eta < 4.0$) are performed using 2015 200 GeV $p+p$, $p+Al$ and $p+Au$ data at STAR. A clear suppression of away-side yields is observed in $p+A$ in comparison with $p+p$ collisions at low $p_T$. The suppression is enhanced at higher E.A. and for pairs probing smaller $x$ (and $Q^2$) with lower di-$\pi^0$'s $p_T$. No increase in the width of the azimuthal angular correlation is seen within experimental uncertainties. The presented results are the first measurement of the nuclear effect dependence on $A$, where we observe that the suppression is enhanced with larger $A$.

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