Di-$\pi^0$ correlations in $p+p$, $p+Al$ and $p+Au$ collisions at $\sqrt{s_{\text{NN}}} = 200$ GeV at STAR

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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 ($Q^2_s$) 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.

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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 $\sqrt{s_{\text{NN}}} = 200$ 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 $d+A \rightarrow \pi^0 \pi^0 X$ 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 away-side, the yield of associated hadrons is expected to be suppressed and the correlation peak is predicted to be broadened in \(p(d)+A\) collisions compared to \(p+p\) collisions [13,14].

In this contribution, we report measurements of back-to-back di-\(\pi^0\) correlations for \(p+Al\) and \(p+Au\) collisions relative to \(p+p\) collisions in the forward-rapidity region (\(2.6 < \eta < 4.0\)) at \(\sqrt{s_{NN}} = 200\) GeV. The use of different ion beams provides an opportunity to study the saturation scale \((Q_s^2)\) dependence on \(A\). The correlation function \(C(\Delta \phi) = N_{\text{pair}}(\Delta \phi)/(N_{\text{trig}} \times \Delta \phi)\) is measured, where \(N_{\text{pair}}\) is the yield of the correlated trigger and associated \(\pi^0\) pairs, \(N_{\text{trig}}\) is the trigger \(\pi^0\) yield, \(\Delta \phi\) is the azimuthal angle difference between the trigger and associated \(\pi^0\). In each pair, trigger \(\pi^0\) is the one with higher transverse momentum \(p_T^{\text{trig}}\); associated \(\pi^0\) is the one with lower \(p_T\) \((p_T^{\text{asso}})\). To remove detector acceptance effects, the measured correlation functions are divided by the correlation functions from mixed events.

## 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 \((\Sigma E_{\text{BBC}})\) 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 \(\Sigma E_{\text{BBC}}\) 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 shows the comparison of forward back-to-back di-\(\pi^0\) correlation function in MinBias \(p+p\), \(p+Al\) and \(p+Au\) collisions at \(\sqrt{s_{NN}} = 200\) 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 \(p+Al\) 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 energy supports an $A$ dependence of $Q^2_\pi$ as predicted in \cite{10,13}. The suppression decreases with increasing $p_T$ of the $\pi^0$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 $\pi^0$s. $Q$ can be approximated as the average $p_T$ of di-$\pi^0$. 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-$\pi^0$ pairs. When the $\pi^0$ $p_T$ 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 \cite{5}.

In Fig. 2, ratios of the away-side peak area for di-$\pi^0$ correlations from $p+Al$ and $p+Au$ collisions to that from MinBias $p+p$ collisions are shown for different event activity classes. The

![Figure 1: Comparison of the correlation functions vs. azimuthal angle difference between forward ($2.6 < \eta < 4.0$) $\pi^0$ pairs in MinBias $p+p$, $p+Al$ and $p+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV. Left panel: the trigger $\pi^0$s $p_T^{\text{trig}}$ ($p_T^{\text{trig}} = 2−2.5$ GeV/c) and the associated $\pi^0$s $p_T$ ($p_T^{\text{asso}} = 1−1.5$ GeV/c); right panel: $p_T^{\text{trig}} = 3−5$ GeV/c and $p_T^{\text{asso}} = 2−2.5$ GeV/c. The area and width of away-side peaks are shown in each panel as described in the text.](image1)

![Figure 2: Area ratio of away-side di-$\pi^0$ correlation at forward rapidities ($2.6 < \eta < 4.0$) for different event activity bins from $p+Al$ and $p+Au$ relative to MinBias $p+p$ collisions at $p_T^{\text{trig}} = 1.5−2$ GeV/c and $p_T^{\text{asso}} = 1−1.5$ GeV/c. The vertical bars around each data point indicate statistical uncertainties and the vertical bands indicate point-to-point systematic uncertainties. The width of the band is chosen for visibility and doesn’t reflect uncertainties.](image2)
systematic uncertainties of the area arise from non-uniform detector efficiency as a function of $\phi$, 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 $\phi$ 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 $3.1$ ($1.7$) $\sigma$. 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 $d\pi^0$ 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 $d\pi^0$'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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References


