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Measurements of jet and soft activity in $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV p+Au collisions at STAR

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Abstract:
Measurements of the jet nuclear modification factor in $p(d)$+A collisions at the LHC and RHIC have unexpectedly indicated that jet yields are suppressed and/or enhanced as a function of event activity (EA). Recent preliminary measurements from STAR in p+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV demonstrate correlations between high-Q^2 parton scatterings and EA measured at backward (Au-going) rapidities or underlying event (UE) at mid-rapidity. The measurements at STAR disfavor jet quenching as an explanation for the suppression of jet yield observed in high-EA collisions and indicate that these correlations result from the early stages of proton-ion collisions. In these proceedings, we show correlations of backward-rapidity EA with mid-rapidity UE, as well as measurements of EA-dependent modifications to charged hadron spectra and jets. In particular, we present measurements of the UE for various EA selections and discuss its kinematic dependence on jet pseudorapidity and transverse momentum (p_{T}) as a means of examining the correlation between initial hard scatterings and soft processes. We also investigate the EA dependence of high-p_{T} hadron and jet properties—including fully corrected jet substructure observables—to study the impact of initial and final state effects.

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1. Introduction

Jets are highly energetic sprays of collimated particles produced from the hard scattering of partons in a collision. Due to the small time and length scales of these collisions, jets are useful probes to study these collisions. The final-state particles constituting the jet leave a signal in detectors and their reconstructed four-momentum vectors can be recombined to obtain a proxy of the hard-scattered parton. This is done using jet clustering algorithms, such as those offered in the software package FastJet [1], and this process allows for comparison between theory and experiment. Not all final-state particles in the detector will be from the hard scattering; the underlying event (UE) arises from all interactions other than the hard scattering in a collision, and because it creates the same detector signal as particles within a jet, it provides some level of contamination to jets [2].

Jets produced in proton-proton (p+p) collisions provide a cleaner comparison to theory and are also commonly used as a baseline of comparison for jets in heavy-ion collisions or small systems, such as p+A. For example, measurements sensitive to jet quenching are commonly used to probe for existence and properties of the quark-gluon plasma (QGP) in heavy-ion collisions [3]. Suppression of jet yields in central heavy-ion collisions is interpreted as resulting from jet interaction with QGP and is a principle signature of QGP formation. However, ATLAS and PHENIX have also observed significant jet modification in small systems, such as $p(d)$+A collisions, which is unexpected as these systems are generally thought to have too small an initial energy density for the formation of a QGP [4][5].

Centrality is often quantified using particle production in a collision, which is mostly "soft" particles with transverse momentum $p_{\mathrm{T}} < 2$ GeV. Specifically, this study uses event activity (EA) at backward rapidity and underlying event at mid-rapidity. As the centrality is not well-defined in p+Au collisions, this study uses EA as a proxy. Rather than this observed jet yield modification arising from jet-medium interaction as in heavy-ion collisions, perhaps there are correlations between the hard scattering and the soft particle production used to classify event centrality.

2. Measurement

This analysis uses $\sqrt{s_{\mathrm{NN}}} = 200$ GeV p+Au data recorded by the STAR experiment in 2015. The main detector sub-components of concern are the Barrel Electromagnetic Calorimeter (BEMC), the Time Projection Chamber (TPC), and the inner ring of the Beam-beam Counter (BBC) in the Au-going direction. The BEMC is composed of towers, which are used in jet reconstruction if their transverse energy depositions are within $0.2 \leq E_{\mathrm{T}} \leq 30.0$ GeV and also provides an online trigger ($E_{\mathrm{T}} > 5.4$ GeV). The TPC measures charged tracks with $0.2 \leq p_{\mathrm{T}} \leq 30.0$ GeV/c, and has the same kinematic acceptance as the BEMC: both are located at mid-rapidity ($|\eta| < 1$) and have full azimuthal coverage ($0 \leq \phi \leq 2\pi$) [6]. The BBC is a scintillating detector at backward rapidity ($-5.2 < \eta < -3.3$) that measures charged particle production in the Au-going direction; because it is far away in rapidity from the BEMC and TPC, its signal will be unaffected by the leading and recoil jet particles. The inner BBC signal sum in the Au-going direction is defined as EA; the events with the smallest signal (70-90% range) are designated as low-EA events and the events with the highest signal (0-30% range) are designated as high-EA events.

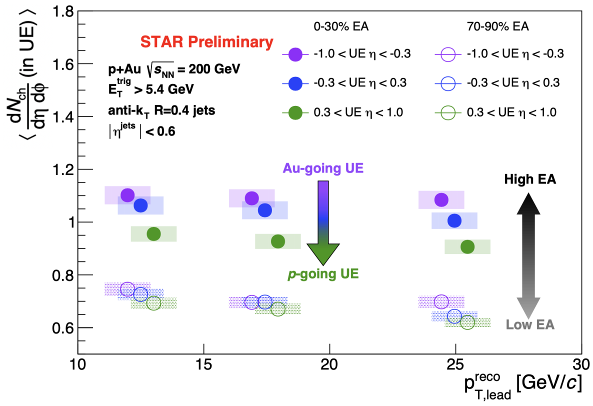

Figure 1: The UE in high-EA events (closed markers) is larger than low-EA events (open markers), and does not show a significant dependence on the $p_{\mathrm{T,lead}}^{\mathrm{reco}}$ within these EA selections. Additionally, the UE is larger in the Au-going direction (purple) and smaller in the *p*-going direction (green).

This study uses $R = 0.4$ anti-k_{T} jets clustered using BEMC towers and TPC tracks fully within the detector kinematic acceptance: $|\eta_{\mathrm{lead}}| < 1 - R$, and $10 \leq p_{\mathrm{T,lead}}^{\mathrm{reco}} \leq 30$ GeV/c. In addition, the BEMC tower that fires the trigger is required to have energy $E_{\mathrm{T}} > 5.4$ GeV/c and to be within the leading jet radius ($|\phi_{\mathrm{lead}} - \phi_{\mathrm{trig}}| < R$) or the recoil region ($|\phi_{\mathrm{lead}} - \phi_{\mathrm{trig}}| > \pi - R$). The UE is defined as the charged particle multiplicity in a $\sim 64^{\circ}$ region perpendicular to the leading jet axis.

3. Results

The UE is shown differentially with respect to EA and $p_{\mathrm{T,lead}}^{\mathrm{reco}}$ in Fig. 1; it is higher in events with a larger EA as measured by the Au-going BBC. Additionally, the UE is larger in the Au-going direction, consistent with the asymmetry of the collision. When measured using these EA selections, the UE does not have a significant dependence on $p_{\mathrm{T,lead}}^{\mathrm{reco}}$, however Fig. 2a shows a clear anti-correlation between EA and $p_{\mathrm{T,lead}}^{\mathrm{reco}}$ when measured inclusively in EA. Events binned by higher (lower) jet p_{T} have a lower (higher) average EA, classifying them as more peripheral (central). In agreement with this suppression of high-p_{T} jets in high-EA events, Fig. 2b shows that the yield of semi-inclusive high-p_{T} jets per charged hadron trigger is suppressed in high EA events relative to low EA events. The suppression is comparable for jets on the trigger and recoil side. In addition to jet yields, the jet substructure observable jet mass, $M = \sqrt{E^2 - \mathbf{p}^2}$, is studied. There is no significant change of the jet mass distribution between low and high EA events. Additionally, the *p*+Au jet mass distribution is consistent with QCD predictions as well as STAR *p*+*p* jet mass [7].

4. Conclusion

This study of $\sqrt{s_{\mathrm{NN}}} = 200$ GeV *p*+Au collisions in STAR reveals that EA is correlated with UE multiplicity and anti-correlated with high-Q^2 jets despite a large separation in rapidity. Due to this large phase space gap, this implies a correlation between the soft particle production (EA and UE) and the hard scattering early in the collision. The semi-inclusive jet spectra are suppressed in high EA and high UE events, and the suppression is comparable between the trigger and recoil-side

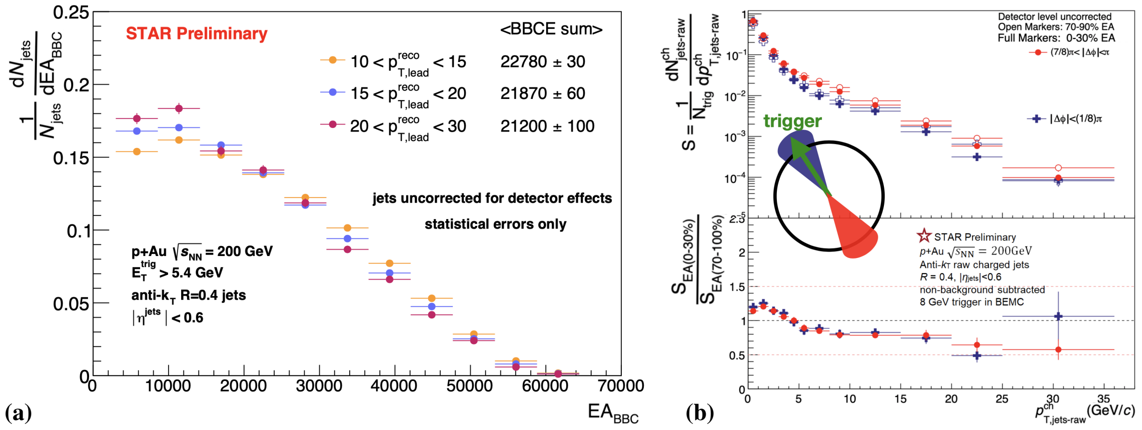

Figure 2: (a) EA distributions as a function of $p_{\mathrm{T,lead}}^{\mathrm{reco}}$ are shown. The mean EA values show a clear anti-correlation between $p_{\mathrm{T,lead}}^{\mathrm{reco}}$ and EA which is also visible in the reversal of ordering of the points. (b) Semi-inclusive trigger and recoil charged jet yields per-charged-trigger are shown for high and low EA. Charged jet yields are suppressed in high-EA events with respect to low EA events, and this suppression is comparable between the trigger and recoil jets.

jets, an observation that is inconsistent with a naive image of jet quenching in the medium. The jet mass and groomed jet mass distributions measured in p+Au collisions are independent of EA and consistent with p+p jet mass–this measurement has no signs of medium-induced jet mass modification. Jet modification is not observed in these studies of p+Au collisions, and there are no indications of final-state or in-medium interactions such as jet quenching. These data indicate that the EA and Q^2 correlations are likely resultant of early time effects.

References

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