Toward understanding relativistic heavy-ion collisions with the STAR detector at RHIC

D.M. Anderson, Y. Liu, S. Mioduszewski, N. Sahoo, and the STAR Collaboration

This project is a study of high-energy heavy-ion collisions at the Relativistic Heavy Ion Collider (RHIC). The focus of the study is on two probes of the dense, partonic matter created in these collisions: 1) direct-photon-triggered jets (and their correlations) and 2) heavy-quarkonium production and suppression.

1. Investigating Energy Loss through Photon-Triggered Jet Measurements

The hard production of a direct photon back-to-back with a jet (γ-jet) is a probe of the parton energy loss in heavy-ion collisions [1]. In the "γ-jet" coincidence measurement, the measured energy of the trigger particle (the photon) serves as a calibrated baseline for the total energy of the jet particles on the recoil side (i.e. opposite in azimuth) of the trigger. The mean-free path of the γ in the medium is large enough so that its momentum is preserved, regardless of the position of the initial scattering vertex. Thus it does not suffer from the geometric biases, i.e. the non-uniform spatial sampling of hadron triggers due to energy loss in the medium, of e.g. π^0 triggers. Because of the difference in path length traversed, on average, between a direct-γ and a π^0 trigger, comparisons of γ-jet to hadron(π^0)-jet measurements can provide insight into the path-length dependence of the energy loss.

As the dominant background to direct photons are π^0 (decaying to two photons), the Barrel Shower Maximum Detector (BSMD) has provided the capability of distinguishing direct photons from neutral pions via the transverse shower shape. Our group has used this method in the measurement of direct photon+hadron correlations [2]. The γ-hadron correlation studies can be extended to studies of γ-triggered jet reconstruction measurements (as has been done at the LHC [3, 4]). The away-side jet will then be reconstructed in coincidence with triggers selected as direct photon candidates or (for p_T<20 GeV using the shower shape with the BSMD) identified π^0 triggers. The advantage of this should be the ability to reach lower energy fragments in the jet to study jet-shape modification and possible redistribution of energy.

First, we carried out a charged-jet reconstruction analysis on the available 2011-Run Au+Au collisions. Here, only charged tracks are included in the jet reconstruction. The result, presented at Quark Matter 2017 [5], is shown in the left panel of Fig. 1.

The 2014-Run "L2Gamma"-triggered events (events with a high-energy calorimeter signal) in Au+Au collisions were recently reconstructed. We have begun the quality assurance of the 2014-Run L2Gamma triggers and plan to carry out the γ-jet analysis on this data set.

In addition, we carried out some studies of full-jet reconstruction (including both charged tracks and neutral energy measured with the electromagnetic calorimeter) on the 2009-Run p+p collisions. A result of the raw, uncorrected spectra of charged jets vs. full jets is shown in the right panel of Fig. 1.

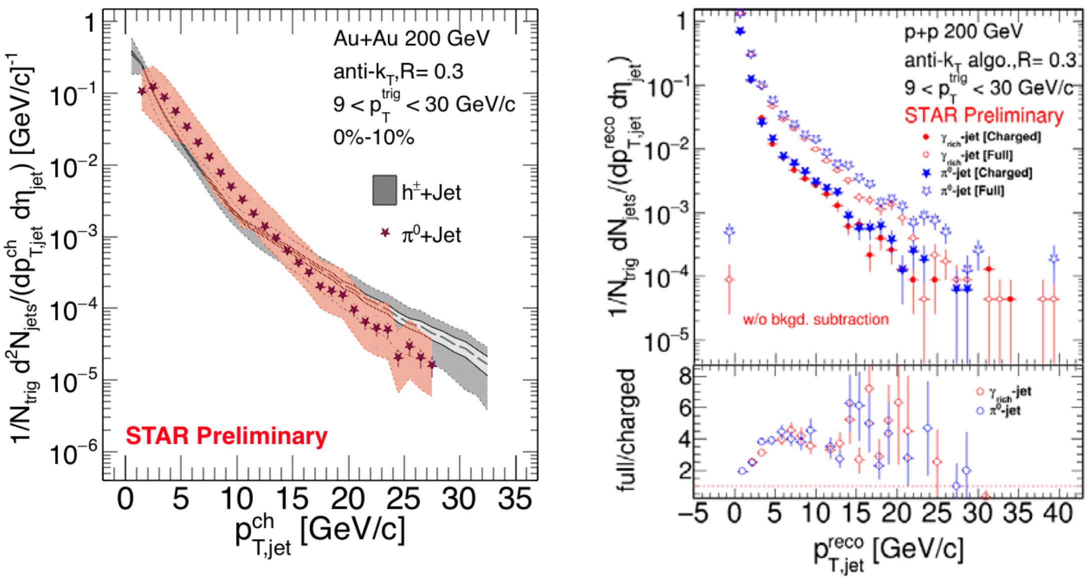

FIG. 1. (Left) Preliminary π^0-triggered charged-jet measurement compared to recently published result of charged-hadron-triggered charged-jet measurement [6]. (Right) Studies of charged-jet reconstruction vs. full-jet reconstruction in Run-9 p+p data (uncorrected for efficiencies and background fluctuations).

2. Unraveling Cold Nuclear Matter Effects in J/Ψ Suppression

The J/ψ has long been considered one of the most promising direct probes of deconfinement. According to theoretical predictions in 1986 [7], the produced $c\bar{c}$ pair will not be able to form a J/ψ bound state in the QGP, if a sufficiently high temperature is reached where the screening radius is smaller than the binding radius of the J/ψ resonant state. The "Debye" screening radius is the distance at which the color charges of two quarks are screened from one another, so that the confinement force is not able to hold the quarks together. A suppression in the yield of J/ψ was first observed in Pb+Pb collisions by the NA50 experiment at the CERN SPS (see, for example, [8]).

At RHIC, the predicted suppression of J/ψ due to screening in the QGP is much larger than the suppression observed at the SPS due to the higher initial density of the produced medium [9]. The RHIC measurements, however, show a level of suppression similar to NA50 at mid-rapidity [10], which is significantly smaller than expectations due to color screening effects alone. This can be understood in a scenario where charmonium is regenerated due to the large initial production of charm + anti-charm quarks at $\sqrt{s_{NN}}$= 200 GeV, in conjunction with their possible thermalization in the created medium [11]. If charm quarks (partially) thermalize in RHIC collisions, then the coalescence of $c\bar{c}$ could lead to a smaller than expected suppression [12].

With counteracting effects, it is a challenge to disentangle the suppression from the regeneration. Further complicating this task is that the J/ψ-particle yields that are measured are not all primordial; some ~40% are feed-down from χ_c (approximately 30%) and ψ′ (approximately 10%) decays. Since the survival rate of different charmonium states may be different, due to the different sizes, it is important to know these feed-down fractions precisely. In addition, there are cold nuclear matter effects [13], including modification of the parton distribution functions ("shadowing") and partonic multiple scattering, that also lead to suppression of heavy quarkonium and need to be disentangled from QGP suppression. In order to quantify effects of deconfinement, cold nuclear matter effects (via p+A collisions) must be measured and disentangled.

We have worked on the quality assurance and a centrality determination for the 2015 p+Au data set. The (raw) distributions of numbers of primary tracks, shown in Fig. 2, are for the classification of events into “centrality” or “event activity”. They don’t yet include corrections due to trigger efficiency, luminosity, and vertex dependence. However, the data are compared to event-generator simulations with the experimental conditions and efficiencies imposed, showing good agreement. These results were also presented the Quark Matter 2017 conference in a poster. Once finalized, we will be able to build on this event classification to carry out quarkonium studies in p+Au collisions.

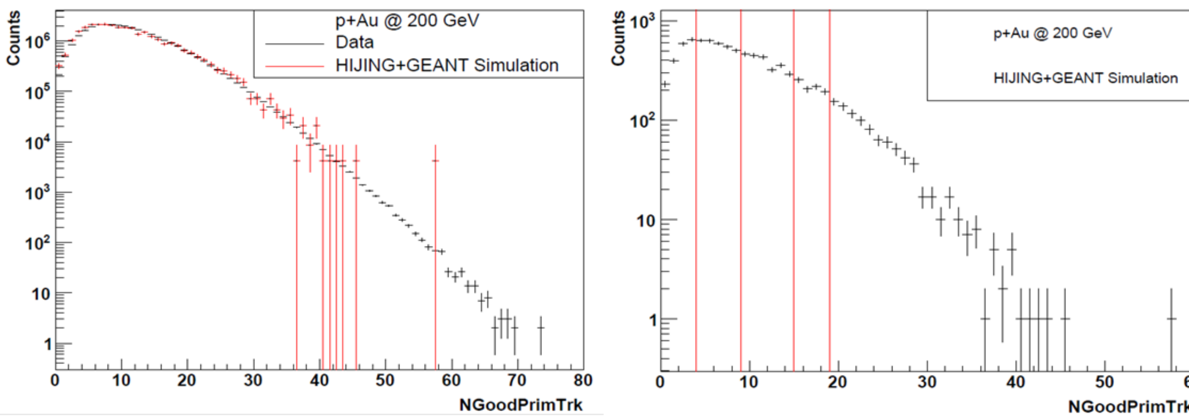

FIG. 2. Number of good primary tracks. (Left) Data vs. HIJING with trigger conditions applied. (Right) Centrality cuts, shown as red vertical lines on un-biased HIJING distribution, selecting 0-10% (<Ncoll>=8.3), 10-20% (<Ncoll>=7.1), 20-50% (<Ncoll>=6.0), and 50-80% (<Ncoll>=4.1) of the total cross section.

[1] X.N. Wang, Z. Huang, and I. Sarcevic, Phys. Rev. Lett. **77**, 231 (1996).
[2] L. Adamczyk *et al.* [STAR Collaboration], Phys. Lett. B **760**, 689 (2016).
[3] S. Chatrchyan *et al.* [CMS Collaboration], Phys. Lett. B **718**, 773 (2013).
[4] [ATLAS Collaboration], ATLAS-CONF-2012-121.
[5] N.R. Sahoo for the STAR Collaboration, arXiv:1704.04814 [nucl-ex].
[6] L. Adamczyk *et al.* [STAR Collaboration], arXiv:1702.01108v1 [nucl-ex].
[7] T. Matsui and H. Satz, Phys. Lett. B **178**, 416 (1986).
[8] M.C. Abreu *et al.* [NA50 Collaboration], Eur. Phys. J. C **39**, 335 (2005).
[9] L. Grandchamp, R. Rapp, and G.E. Brown, Phys. Rev. Lett. **92**, 212301 (2004); A. Capella and E.G. Ferreiro, Eur. Phys. J. C **42**, 419 (2005).
[10] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **98**, 232301 (2007).
[11] P. Braun-Munzinger and J. Stachel, Phys. Lett. B **490**, 196 (2000).
[12] L. Grandchamp and R. Rapp, Phys. Lett. B **523**, 60 (2001).
[13] R. Vogt, Phys. Rev. C **71**, 054902 (2005).