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

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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 are currently being 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 the medium response.

The Run-14 "L2Gamma" triggers in Au+Au collisions have been fully analyzed for charged jets recoiling from a high-energy neutral (π^0 or γ) trigger [5]. Fig. 1 shows the charged-jet spectra for a sample of triggers (γ_{rich}) enriched to be direct photons, using cuts on the transverse shower profile as measured by the Barrel Shower Maximum Detector, for increasing cuts on the trigger transverse momentum. In this figure, the result has not been corrected for instrumental effects, but clearly shows the growing signal of "true" jets over combinatorial jets, as estimated by a mixed-event technique [6].

In addition to the reconstruction of jets with charged particles, we are working to include the calorimeter hits in the jet reconstruction, extending the photon- or π^0-triggered charged-jet measurement to a full-jet measurement. Since this is quite challenging, we are concentrating on the p+p data set for now.

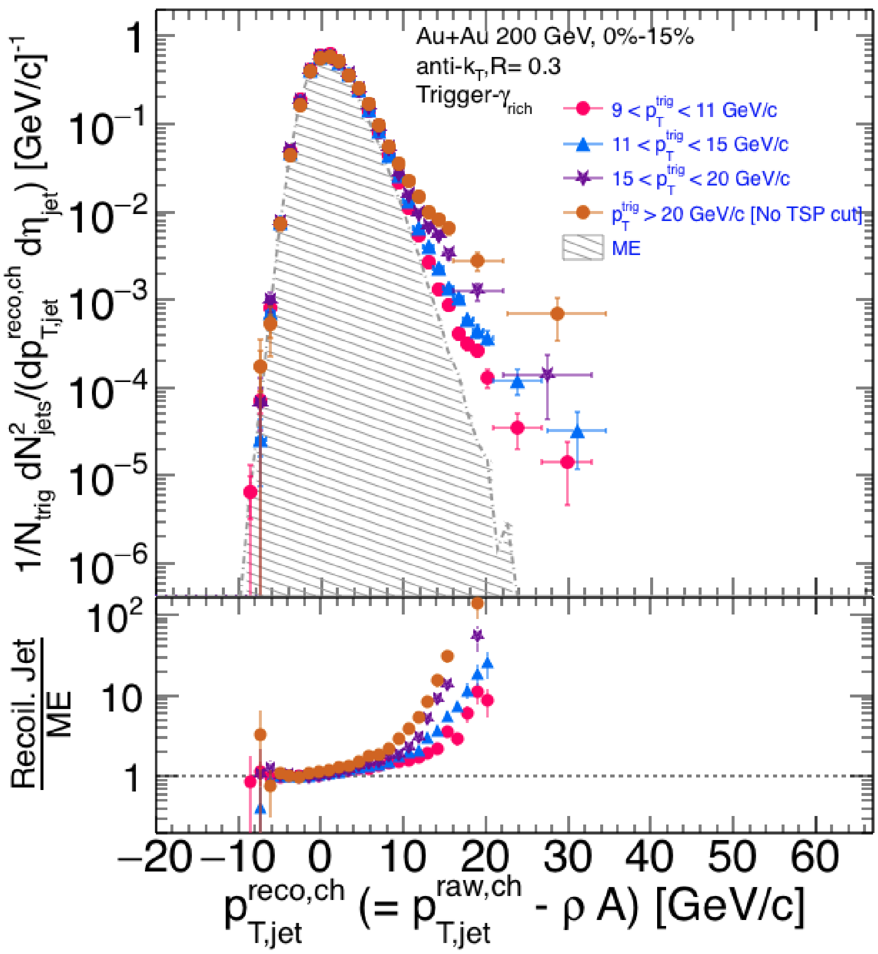

FIG. 1. Reconstructed charged-jet transverse-momentum spectrum recoiling from photon-rich triggers with different cuts on transverse momentum (p_T), using the high-statistics Run-14 Au+Au data set. The hatched histogram shows the estimated combinatorial jets from mixed events (ME). The bottom panel shows the ratio of the measured spectrum in real events to the spectrum from mixed events. The signal (yields greater than 1) increases for increasing trigger p_T.

Fig.2 shows the charged-jet (upper panels) vs. full-jet (lower panels) spectra recoiling from π^0 vs. γ_{rich} triggers in p+p collisions, for three trigger energy ranges (E_T = 9-20 GeV, E_T = 9-11 GeV, and E_T = 11-15 GeV). The full jets show more of a pronounced structure in the p_T range corresponding to the trigger energy, presumably because all of the energy is measured, while some of the energy is missing when reconstructing jets from only the charged particles. Also shown for each case is a ratio of the spectrum recoiling from π^0 triggers to that recoiling from γ_{rich} triggers. The difference in the spectra is expected because π^0 triggers are from a parton fragmentation, for which the parent parton (and therefore the recoiling jet) has a higher energy than the trigger particle, while direct photons carry the full energy corresponding to the recoil jet. The ratio has been compared to PYTHIA, and agrees when including the estimated purity of our γ_{rich}-trigger sample.

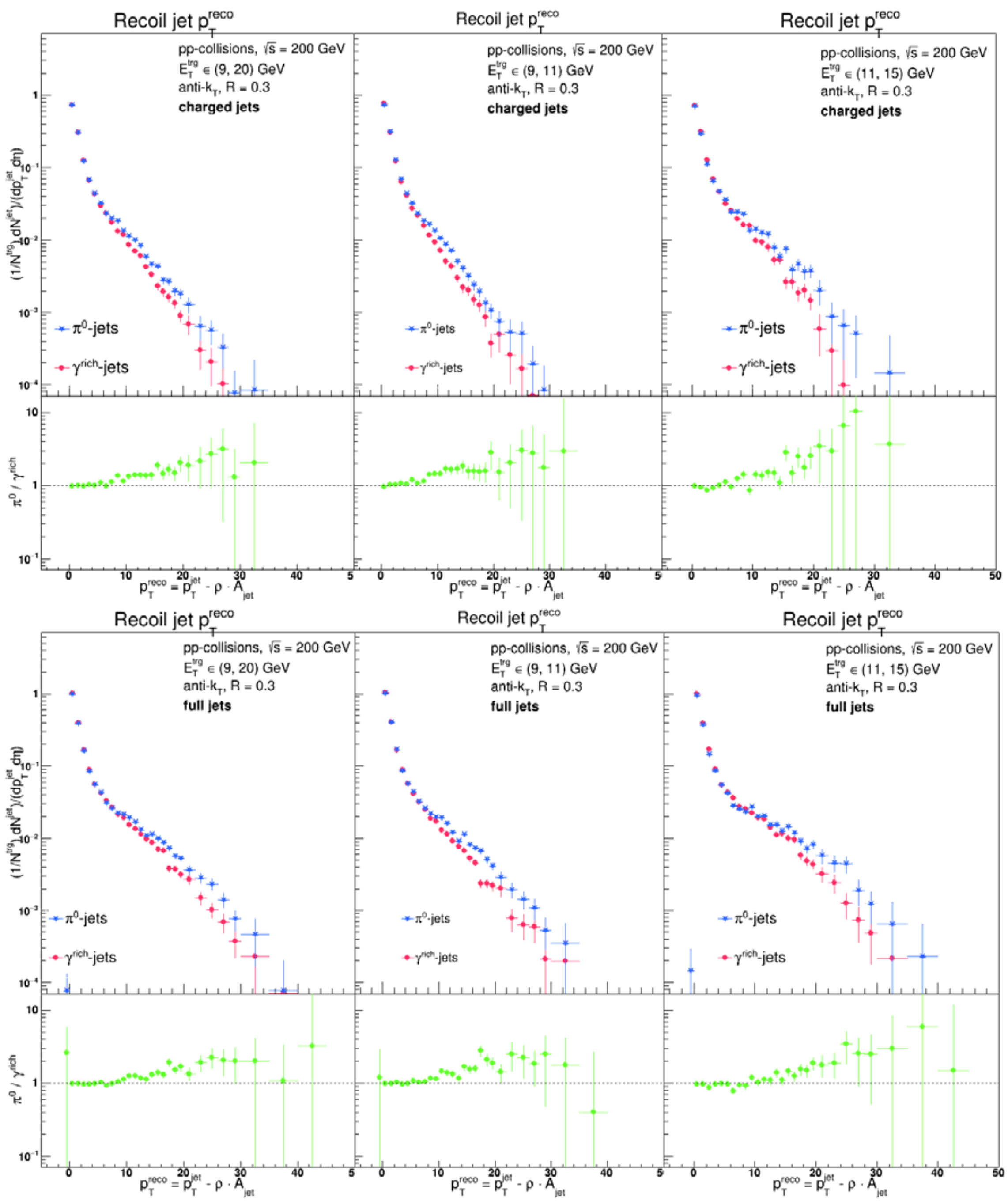

FIG. 2. Fully reconstructed jets (upper 3 panels) vs. charged jets (lower 3 panels) recoiling from a π^0 (blue) vs. γ_{rich} (red) triggers, for three different trigger energy ranges: 9-20 GeV (left), 9-11 GeV (middle), 11-15 GeV (right). Also shown in green is the ratio of the spectrum recoiling from a π^0 trigger to that recoiling from a γ_{rich} trigger, for each case.

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 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.

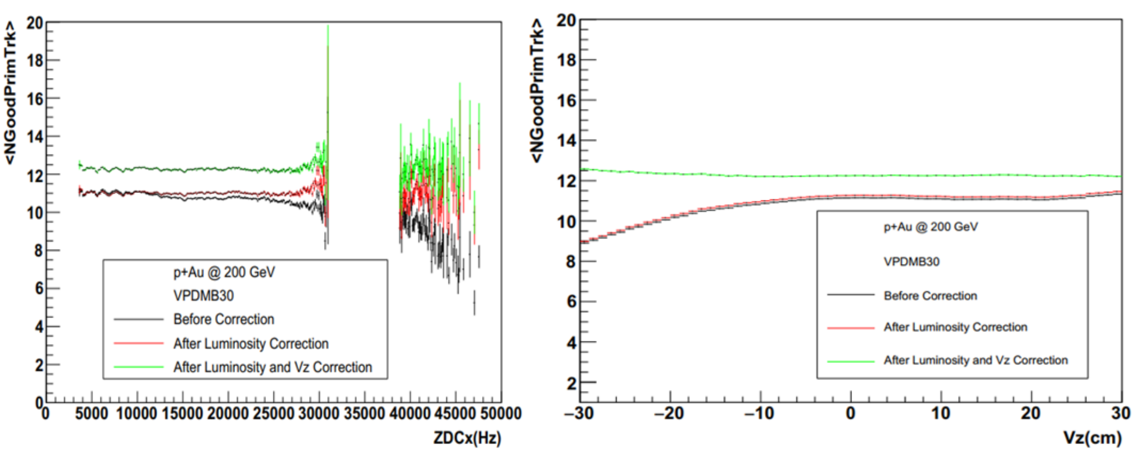

FIG. 3 Average number of good primary tracks, before (black) and after (green) correcting the vertex and luminosity dependence, (Left) as a function of ZDC interaction rate and (Right) as a function of vertex z-position.

We have worked on the quality assurance and a centrality determination for the 2015 p+Au data set. In the previous reporting period, we performed a centrality determination for p+Au collisions, based on the number of good primary tracks in an event. In the current reporting period, we calculated corrections for the centrality determination, including trigger bias, vertex dependence, and luminosity dependence. Fig. 3 shows the effect of the corrections on the average number of good primary tracks in an event.

For the studies of charmonium production in p+A collisions, we have started working on extracting J/Ψ yields, as a function of p_T and centrality. Fig. 4 shows the mass distribution of muon pairs (unlike-sign in black and like-sign in blue) that were has obtained as a function of p_T. The next step will be to extract the yields as a function of centrality and perform efficiency corrections.

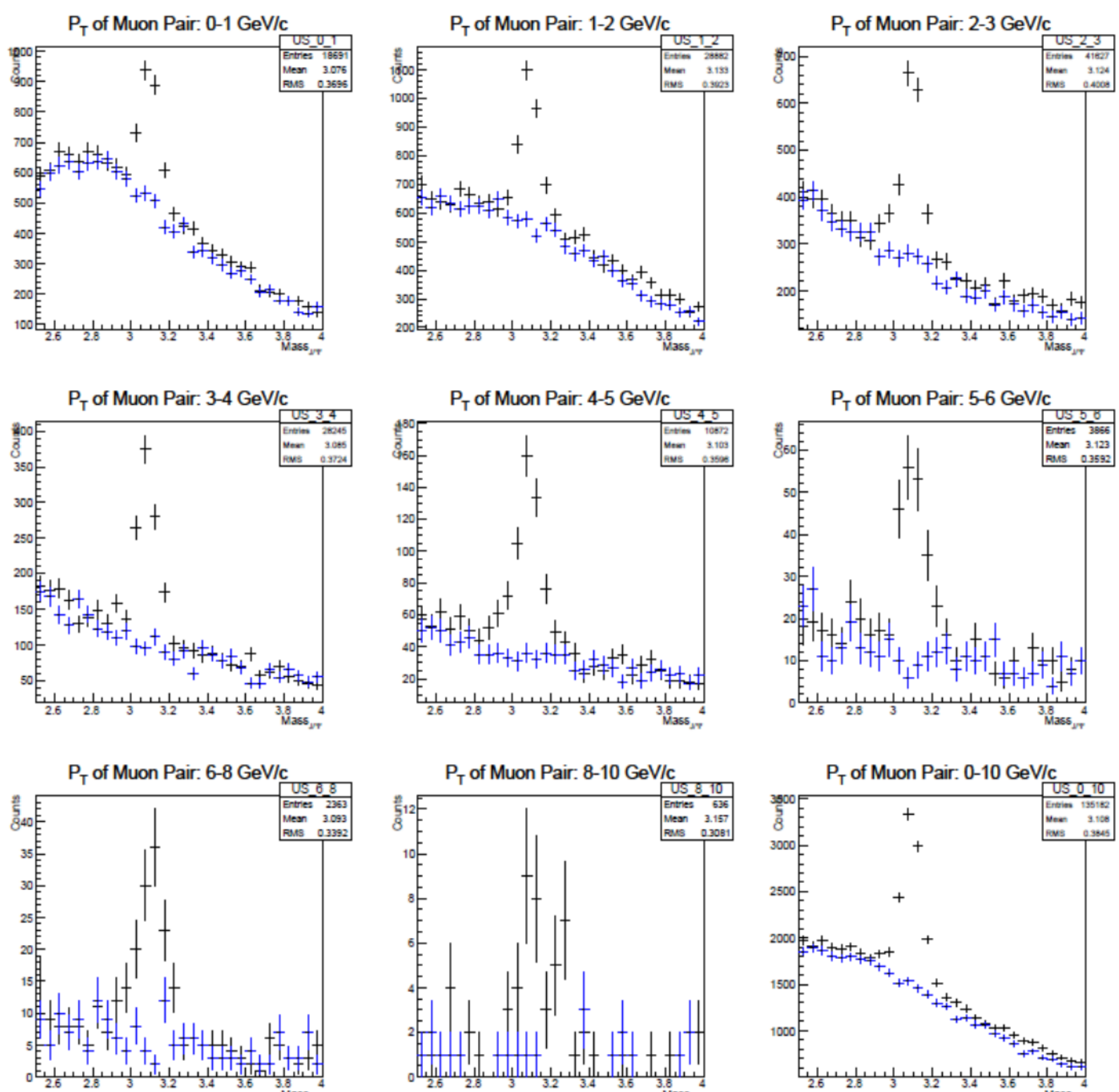

FIG. 4 Mass distributions for muon pairs: unlike-sign pairs in black and like-sign pairs (background) in blue, with each panel showing a different range of pair p_T. There is a clear signal of J/Ψ at the mass ~ 3.1 GeV/c^2.

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