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Semi-Inclusive Jet measurements in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV at STAR

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Jets represent an important tool to explore the properties of the hot and dense nuclear matter created in heavy-ion collisions. However, their reconstruction presents a challenging task due to the extremely large and fluctuating background that overwhelms the true hard jet population. We present recent measurements of charged jets in Au+Au collisions, by the STAR collaboration at RHIC, where the background is suppressed via a new technique based on event mixing. The measured observable is the semi-inclusive yield of recoil jets from a high p_{T} hadron trigger. This jet measurement allows a comparison of jet quenching at RHIC and the LHC and provides new constraints on theoretical calculations of jet quenching.

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1. Introduction

Jet reconstruction in the environment of heavy-ion collisions has to correct for the large and highly fluctuating background. A way to avoid the bias on the jet fragmentation caused by imposing a momentum cut on the jet constituents is to bias the event selection instead. This can be done by selecting a high momentum hadron trigger. Jets reconstructed on the away side in azimuth will be completely unbiased with respect to their fragmentation (there is no need to impose a cut on the constituents' momenta). On the other hand such a jet population will be biased towards larger path-length in the medium. We measure an observable of this process which is calculable by means of pQCD, the semi-inclusive recoil jet yield per trigger.

2. Experimental Setup

The data were recorded by the STAR experiment at the Relativistic Heavy Ion Collider (RHIC) in Brookhaven National Laboratory, USA. The STAR detector has full azimuthal coverage and possesses a tracking ability via a large Time Projection Chamber (TPC) which tracks and identifies charged particles down to a transverse momentum of 100 MeV/c. The TPC is surrounded by a Barrel Electromagnetic Calorimeter (BEMC), Time Of Flight (TOF), a Muon Telescope Detector (MTD) and a solenoidal magnet with field strength of 0.5 T. Further information about the STAR experiment and the TPC can be found in [1, 2].

The data were recorded with a Minimum Bias (MB) trigger during the 2011 RHIC run, for Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV. Two collision centrality classes were selected, corresponding to the 0-10% (central) and 60-80% (peripheral) percentile intervals of the distribution of raw TPC multiplicity. Events are required to have the z position of the primary vertex within 30 cm of the center of the TPC.

3. Jet Reconstruction

Charged jets are reconstructed from TPC charged tracks. The TPC tracks were required to have transverse momenta $p_{\mathrm{T}} > 0.2$ GeV/c, pseudo-rapidity $|\eta| < 1$ and at least 15 TPC space-points. The tracks were clustered into jets using the anti-k$_{\mathrm{T}}$ algorithm implemented in the FastJet software package [3, 4]. The jet area A was then calculated using the population of soft "ghost particles" [5]. Each reconstructed jet p_T is adjusted for background energy on an event-by-event basis according to

$$p_{\mathrm{T,jet}}^{\mathrm{reco}} = p_{\mathrm{T,jet}} - \rho \times A \tag{3.1}$$

where ρ is the background energy density calculated for each event as the median jet energy density $\frac{p^{i}_{\mathrm{T,jet}}}{A_i}$ from all reconstructed jets in the event, excluding 2 (peripheral) or 3 (central events) hardest jets in the event. The background jets are reconstructed using the k$_{\mathrm{T}}$ algorithm.

The size of the reconstructed jet is determined by the jet resolution parameter R, with R = 0.3 for the results reported here. All jets are required to lie within the fiducial rapidity acceptance $|\eta| < 1 - R$. Jets accepted for the recoil distribution have their centroid within 45 degrees of the trigger axes, opposite in azimuth to the triggger hadron,

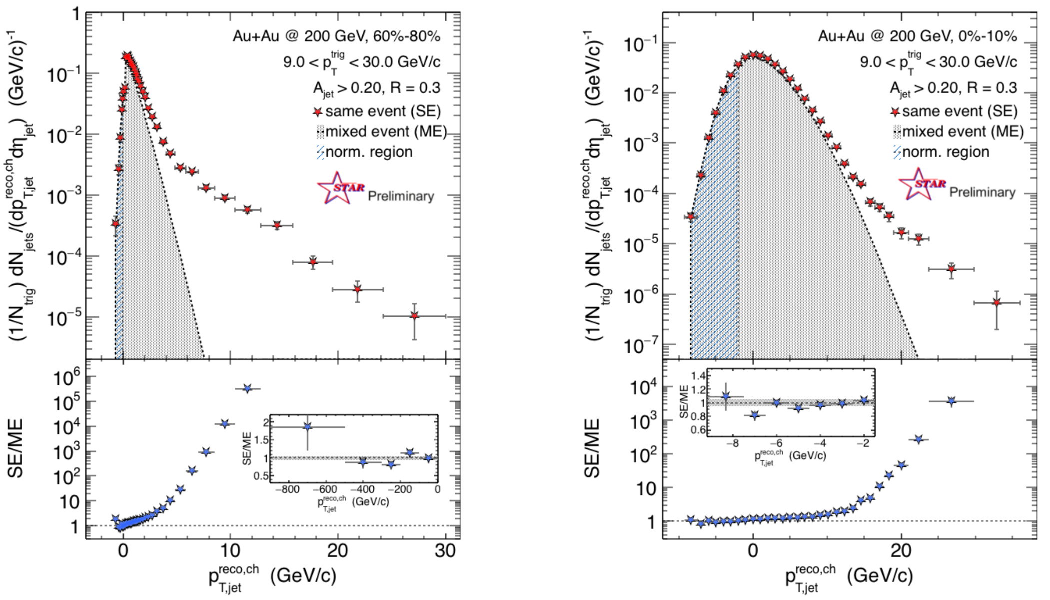

Figure 1: Raw recoil jet spectrum and mixed event (top panel) and their ratio (bottom panel) in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Left: peripheral (60-80%) collisions, right: central (0-10%) collisions.

$$|\phi_{Jet} - (\phi_{Trig} + \pi)| \leq \pi/4. \tag{3.2}$$

Trigger hadrons lie in the interval $9 < p_T^{trig} < 20$ GeV/c. Event selection is based solely on the presence of a trigger hadron. All jets falling into the recoil acceptance are counted in the recoil spectrum, which is normalized per trigger and is constructed to be semi-inclusive.

4. Background Subtraction

In order to subtract the uncorrelated combinatorial background that is unavoidably present in a heavy-ion collision high multiplicity environment, a unique mixed event method was developed. The mixed event is generated by randomly selecting tracks from real events in the same centrality bin, event plane direction bin and primary vertex z position bin. Tracks with $p_T > 3$ GeV/c are discarded. A fully uncorrelated sample of tracks is thus created, which preserves essential features of the real events, such as the detector acceptance inefficiencies.

The jet analysis is then carried out on the mixed event (ME) population in the same way as for the real events (SE), but with the trigger hadron now chosen in a random direction. The resulting ME recoil jet spectrum is absolutely normalized, with a small adjustment in normalization to match the LHS of the real event spectrum. The normalization region was systematically varied and the resulting variance was included in the systematic uncertainties.

Fig. 1 shows both the same event and mixed event recoil charged jet spectra in peripheral and central Au+Au collisions, normalized per trigger yield. As one would expect, the background is much less severe in the peripheral collisions than in the most central ones. The bottom panels show the ratio SE/ME. There is excellent agreement of the ME background distribution with the

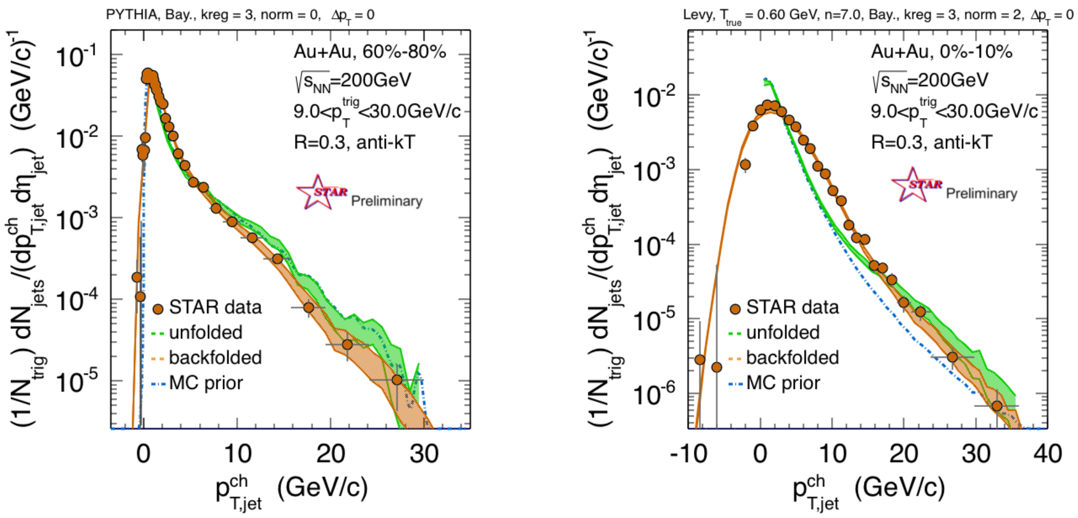

Figure 2: Example of unfolded recoil jet spectra for one particular prior distribution and regularization parameter value. Left: peripheral (60-80%) collisions, right: central (0-10%) collisions.

LHS of the SE; the ME distribution describes accurately the uncorrelated background in the SE distribution. In central collisions, the low momentum spectrum is dominated by the background. The correlated recoil jet signal is then extracted by subtracting the mixed event spectrum from the same event.

5. Results

The most significant effect which needs to be taken into account in this analysis is the large, fluctuating background. The jet response to such fluctuations is measured on an ensemble basis by embedding simulated jets into real events. By comparing the momenta of the embedded jet and the geometrically matched reconstructed jet one can evaluate the response in terms of the $\delta p_{\rm T}$ distribution

$$\delta p_{\rm T} = p_{\rm T,jet}^{\rm reco} - p_{\rm T,jet}^{\rm emb} = p_{\rm T,jet} - \rho \times A - p_{\rm T,jet}^{\rm emb}. \tag{5.1}$$

Knowing the $\delta p_{\rm T}$ distribution and describing the detector response by parametrization of the TPC tracking efficiency and momentum resolution, the fully corrected spectrum was obtained by the method of unfolding. Two different methods of unfolding have been used: Bayesian and Singular Value Decomposition (SVD) unfolding [6, 7]. The systematic uncertainty of the unfolded solution includes variation in the choice of prior and regularization parameter.

Fully corrected recoil jet spectra were obtained for a large number of different prior distributions and regularization parameter values. Fig. 2 shows two examples of unfolded results for two particular choices of unfolding method, prior distribution and regularization parameter. Spectra both in peripheral and central collisions are shown.

The ratio of recoil yield in central and peripheral collisions (I_{CP}) measures jet modification due to the medium. Fig. 3 shows the fully corrected spectra both in peripheral and central collisions

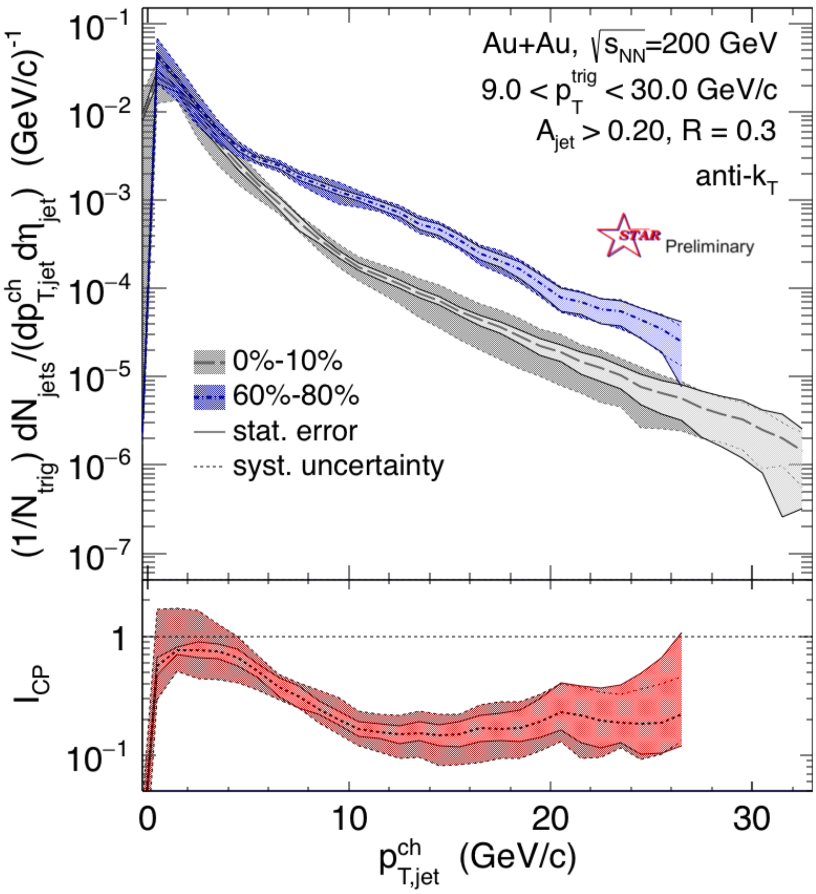

Figure 3: Upper panel: Fully corrected recoil-jet yield per trigger for central and peripheral Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Bottom panel: I_{CP}, ratio of fully corrected recoil jet spectra in central (0-10%) and peripheral (60-80%) Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.

(top panel) and their ratio I_{CP} (bottom panel). The systematic error includes unfolding uncertainty (prior choice, regularization parameter value) and uncertainty on the tracking efficiency. For low jet momenta $p_T < 5$ GeV/c, I_{CP} is close to unity. For higher jet momenta $p_T > 10$ GeV/c I_{CP} drops to ~ 0.2, which indicates significant jet suppression in central Au+Au collisions compared with peripheral collisions. This is a stronger suppression than observed in a similar measurement by the ALICE collaboration in Pb+Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. ALICE measured $I_{CP} \approx 0.6$ for $20 < p_{T,jet} < 100$ GeV/c with $R = 0.4$ [8]. However the jet p_T shift, the horizontal shift needed for the peripheral spectra to match the central spectra, is similar in both experiments. Therefore, the larger suppression observed at RHIC may be due to similar out-of-cone energy transport combined with a steeper falling spectrum at RHIC energies than LHC energies. The observed suppression could be also influenced by the different surface bias from different trigger particle p_T and collision energies at STAR and ALICE.

6. Summary and Outlook

Fully corrected semi-inclusive recoil jet spectra measured by the STAR experiment in 0-10% and 60-80% Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV have been presented. A stronger jet suppression is observed at RHIC energies than LHC energies, which however corresponds to a similar horizontal p_{T} shift in the jet spectrum.

The measurement will be extended by utilizing the high statistics 2014 data with more than one billion Au+Au events at $\sqrt{s_{NN}}$=200 GeV, together with incorporation of signals from the BEMC detector.

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