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

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High-energy heavy-ion collisions produced at RHIC produce a dense partonic matter called quark gluon plasma (QPG). The goal of this project is to elucidate the properties of this matter through measurements of hard-scattered partons that probe the matter by traversing through it. In particular, the project focuses on measurements of per-trigger yields of recoil jets produced in Au+Au collisions, in comparison to p+p collisions. The trigger particle is a direct photon (γ) or a neutral pion (π^0). In a γ-triggered jet event, the direct photon provides a calibrated benchmark for the total energy of the jet particles on the recoil side of the trigger (opposite in azimuth), since photons don't interact strongly and thus escape the medium without energy loss. Two papers were recently published in Physical Review Letters and Physical Review C, respectively [1,2]. Brookhaven National Laboratory issued a press release about these results in June 2025 [3]. A third paper on medium-induced acoplanarity of recoil jets in central Au+Au collisions has been submitted to Physical Review Letters [4]. In these papers, the recoil jets were reconstructed with charged particles only and are referred to as "charged jets". Current efforts are ongoing to reconstruct the "full jets", which include the neutral energy as well. The neutral energy is included by adding the tower energies of the Barrel Electromagnetic Calorimeter (BEMC) [5] to the jet reconstruction algorithm.

The Run-9 dataset in p+p collisions and its corresponding embedding was analyzed to obtain the p+p baseline result. Full-jet reconstruction was performed using the anti-k_T algorithm from the Fastjet package [6]. In this analysis, charged tracks with transverse momentum p_T between 0.2 and 30 GeV/c, as

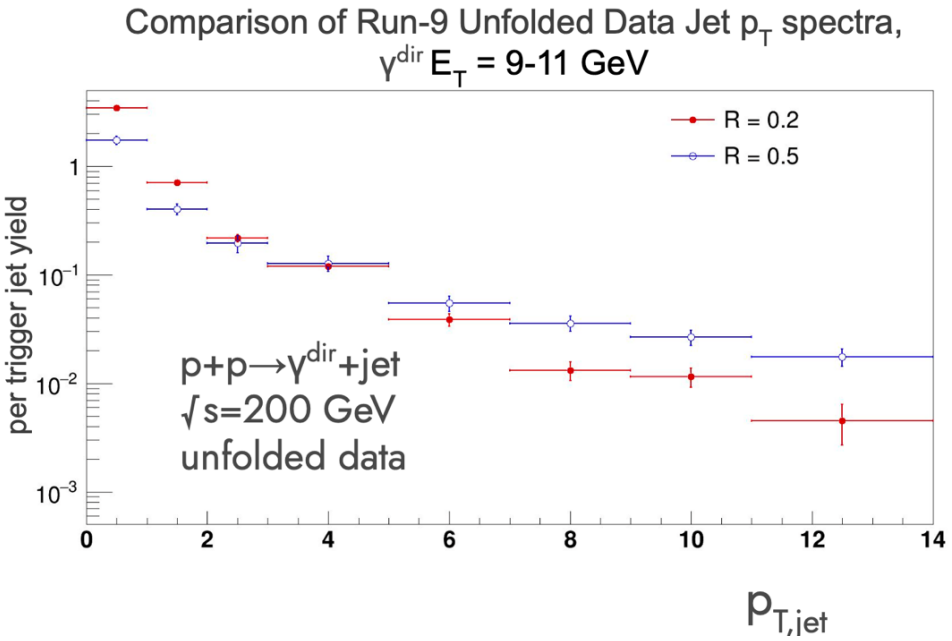

Fig. 1. The fully corrected semi-inclusive jet p_T spectrum, on the recoil side of a photon trigger with E_T between 9 and 11 GeV, for R=0.2 and R=0.5 jets.

well as BEMC towers with transverse energy E_T above 0.2 GeV are considered as constituents. A fiducial cut is made on the pseudo-rapidity of the jet axis, $|\eta_{jet}| < (1 - R_{jet})$, where R_{jet} is the jet resolution parameter associated with the radial size of the jet. Two values of jet resolution parameter are considered, R_{jet} =0.2 and R_{jet} =0.5, to vary the size of the reconstructed jets. Fig. 1 shows the corrected full jet p_T spectra on the recoil side of a γ_{dir} trigger with E_T=9-11 GeV, for both values of R_{jet}. Corrections are done by unfolding the raw spectrum with a "response matrix", which encodes the measured jet p_T vs. true jet p_T due to detector resolution and inefficiencies, and then correcting for the jet-finding efficiency. Both of these corrections (the response matrix and the jet-finding efficiency) are determined from simulated (PYTHIA) jets embedded into zero-bias p+p data.

In Au+Au collisions, the analysis is more challenging because the "combinatorial" background in the reconstructed jet spectrum is significant. Combinatoric jets are randomly clustered tracks and towers into "jet" objects by the jet reconstruction algorithm. These are subtracted using "mixed events", which are constructed from random tracks and towers from different events. This technique destroys all physics correlations between the tracks/towers, thus resulting only in a spectrum of combinarorial background. In the past year, we have focused on including the BEMC towers in these mixed events. Fig. 2 shows our latest ability to quantify the combinatoric part of the full "jet" spectrum, as measured in Au+Au collisions. The top panel shows the measured jet yields as a function of p_{Tcorr}, which is the jet p_T corrected for the average underlying event energy (and can therefore be less than 0). The red is the jet spectrum measured in real events, while the blue is the jet spectrum constructed from mixed events. The bottom panel is the ratio of the spectrum measured in real events to that constructed from mixed events.

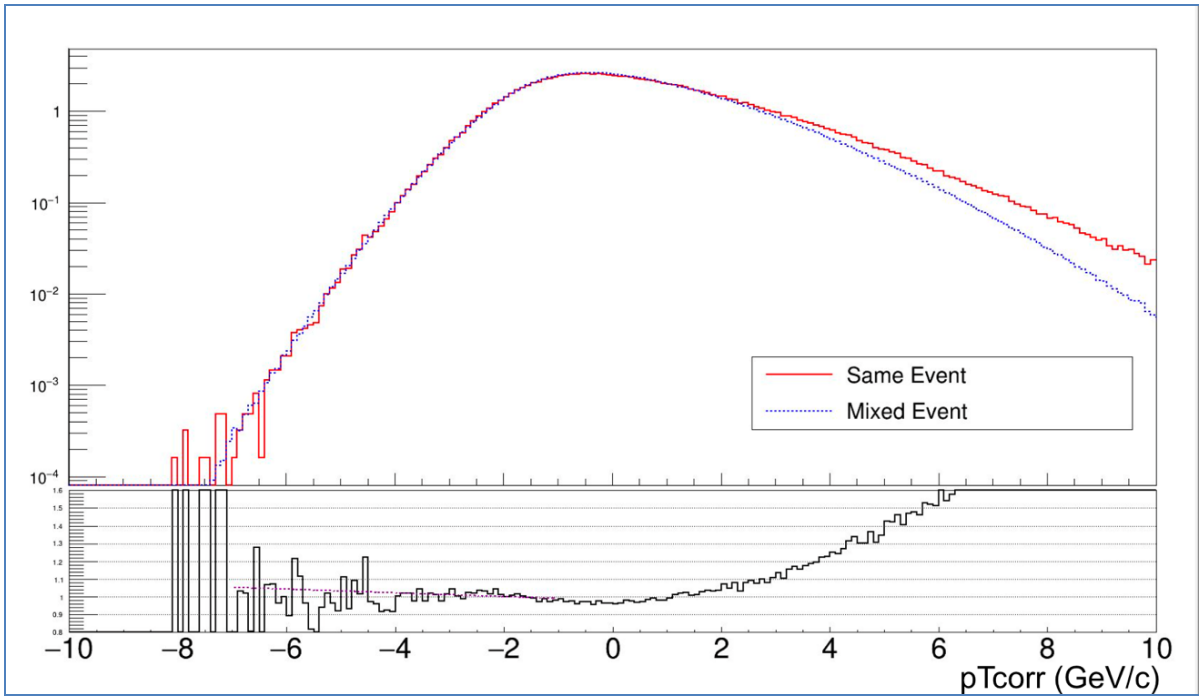

Fig. 2. (Top panel) Reconstructed jet yields as a function of $p_{T,corr}$, which is the jet p_T corrected for the mean background energy, in Au+Au collisions, uncorrected for detector effects and efficiencies. The red is the measured spectrum and the blue is the spectrum constructed from mixed events to quantify the combinatoric jets. (Bottom panel) The ratio of the red to blue curves (measured spectrum divided by the combinatoric spectrum).

The ratio~1 in the bottom panel shows that the spectrum for $p_{Tcorr}<0$ is well described by the mixed events over many orders of magnitude, which is expected as the spectrum here should be dominated by combinatoric jets. The ratio>1 for $p_{Tcorr}>0$ is indicative of the physical jets, not present in the mixed events. The mixed-event spectrum will be subtracted from the measured spectrum, before correcting for detector resolution and inefficiencies (as described in the previous paragraph, regarding the corrections applied to the spectrum measured in p+p collisions).

The next steps in the analysis are 1) to determine the response matrix and jet-finding efficiency from simulated jet events embedded into Au+Au minimum bias data, 2) unfold the measured jet spectrum (corrected for combinatorial background), and 3) determine the systematic uncertainties in the measurement. Finally, the recoil-jet spectra will be compared for γ and π^0 triggers, for jet radii $R_{jet}=0.2$ and $R_{jet}=0.5$, and for Au+Au collisions and p+p collisions.

[1] STAR Collaboration, Phys. Rev. Lett. **134**, 232301 (2025).

[2] STAR Collaboration, Phys. Rev. C **111**, 064907 (2025).

[3] https://www.bnl.gov/newsroom/news.php?a=122311

[4] STAR Collaboration, https://doi.org/10.48550/arXiv.2505.05789.

[5] STAR Collaboration (2003). The STAR barrel electromagnetic calorimeter. Nucl. Instrum. Methods Phys. Res. **A499**, 725 (2003).

[6] M. Cacciari and G. Salam, Phys. Lett. B **641**, 57 (2006); M. Cacciari, G. Salam and G. Soyez, JHEP **0804**, 005 (2008); http://fastjet.fr.