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Reconstruction of neutral-triggered charged recoil jets in $\sqrt{s} = 200$ GeV p+p collisions at the STAR experiment

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Abstract. Jets — collimated sprays of hadrons — are produced by hard-scattered partons during the early stages of heavy ion collisions. Hence, they provide a valuable probe of the complex multi-particle dynamics within the hot, dense medium produced in such collisions. In particular, the study of jets recoiling from direct photons (γ_{dir}+jet) and those recoiling from energetic π^0 (π^0+jet) may shed light on the path-length and initial flavor (quark vs. gluon) dependence of the energy-loss experienced by a parton as it traverses the medium. We present here measurements of the yields of charged recoil jets tagged by γ_{dir} and π^0 in p+p collisions at $\sqrt{s} = 200$ GeV. These measurements will serve as a vacuum fragmentation reference for an upcoming measurement in Au+Au collisions.

1 Introduction

The collisions of ultra-relativistic heavy ions such as the Au+Au collisions studied at the Relativistic Heavy-Ion Collider (RHIC) produce an extremely hot, dense medium with properties consistent with those expected of a liquid of deconfined partons, the Quark-Gluon Plasma (QGP). One of the primary goals of RHIC is to obtain a quantitative and precise understanding of the complex multi-particle dynamics in this extreme state of matter.

An important signature of the formation of this medium is "jet quenching" [1]. As partons move through the medium, they lose energy via collisional and radiative interactions. This in-medium partonic energy loss results in a suppression of high energy particles relative to a collision system where no medium is expected to be produced (e.g. p+p).

Jets — collimated sprays of hadrons produced by the fragmentation of hard-scattered partons -— are a natural observable for probing this phenomenon. Jets are powerful probes due to the large momentum-transfers involved in their production, which makes them amenable to a perturbative QCD description. Additionally, they are produced in the earliest stages of the collisions and so are expected to be sensitive to the evolution of the medium.

A so-called "golden channel" to study jet quenching is jets tagged by "prompt photons" (γ_{prompt}), photons scattered from energetic partons. Since γ_{prompt} are color-neutral, they will not interact with the medium. It follows that the measured transverse energy of a γ_{prompt} will closely approximate the initial transverse energy of the recoiling parton. Thus, the recoiling parton and the ensuing jet serves as a well-calibrated probe of the in-medium energy loss [2]. In practice, however, γ_{prompt} can not be

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measured in isolation. Rather, a mixture of prompt, thermal, and fragmentation photons is measured. These are collectively referred to as "direct photons" ($\gamma_{\rm dir}$). For the energies considered here, the thermal contribution is negligible [3], but there is a sizable background due to hadronic decays which must be corrected for.

In order to gain insight into the path-length and flavor (quark vs. gluon) dependence of in-medium energy loss, $\gamma_{\rm dir}$-tagged recoil jets are compared to recoil jets tagged by an energetic π^0. Energetic π^0, being produced as part of a jet, are subject to jet-quenching, and thus triggering on them biases their production towards the surface of the medium [4]. On the other hand, $\gamma_{\rm dir}$ have no such bias. This implies that on average the recoil jets tagged by π^0 have a longer path-length through the medium than do recoil jets tagged by $\gamma_{\rm dir}$. Moreover, the production of $\gamma_{\rm dir}$ is dominated by (anti-)quark-gluon Compton scattering. So, the recoil jets tagged $\gamma_{\rm dir}$ are predominantly from (anti-)quarks.

These two observations, that energetic π^0 are biased towards surface production and that $\gamma_{\rm dir}$-tagged jets predominantly originate from (anti-)quarks, suggest that energy loss experienced by the recoil jets may differ between the two systems. Thus, it might be that the observed suppression of the recoil jets also differs. This suppression is quantified by $I_{\rm AA} \equiv D^{\rm Au+Au}/D^{\rm p+p}$, where $D^{\rm Au+Au}$ and $D^{\rm p+p}$ are the per-trigger yields of recoil jets in Au+Au and p+p, respectively. Presented in these proceedings are measurements of the $\gamma_{\rm dir}$- and π^0-tagged per-trigger charged recoil jet spectra in p+p collisions ($D^{\rm p+p}$), which will ultimately serve as vacuum-fragmentation (no medium) baselines for future measurements of I_{AA}.

2 The STAR Detector

The data were obtained by analyzing p+p collisions at $\sqrt{s}$ = 200 GeV recorded by the Solenoidal Tracker at RHIC (STAR) detector during the running year 2009. The two sub-systems of the STAR detector most relevant to jet measurements are the Time Projection Chamber (TPC) [5] and the Barrel (i.e. mid-rapidity) Electromagnetic Calorimeter (BEMC) [6]. The TPC is used to measure the transverse momentum ($p_{\rm T}$), azimuth (φ), and pseudorapidity (η) of charged particles, and the BEMC is used to trigger on p+p collisions which may contain an energetic π^0 or $\gamma_{\rm dir}$.

At approximately 5.6 radiation lengths into the BEMC at $\eta = 0$ sits the Barrel Shower Maximum Detector (BSMD). The BSMD is a grid of readout wires which is used to distinguish hadronic decays from single photons, and has a granularity of approximately 0.007×0.007 in the η-φ plane. Candidate triggers are identified as one to two BEMC tower clusters with transverse energy in the range of $E_{\rm T}^{\rm trg} \in (9, 20)$ GeV and a centroid whose pseudorapidity lies in the range $|\eta^{\rm trg}| < 0.9$. Single photons and π^0 are identified from these candidates based on their shower shape, which is quantified by the so-called "Transverse Shower Profile" (TSP):

$$\text{TSP} \equiv \frac{E_{\rm clust}}{\Sigma_i e_i r_i^{1.5}}$$

where $E_{\rm clust}$ is the total energy of the cluster, e_i is the energy of the $i^{\rm th}$ BSMD strip of the cluster, and r_i is the distance from the $i^{\rm th}$ BSMD strip to the centroid of the cluster [7]. The exponent of 1.5 in the denominator of the TSP was tuned via simulations to give maximal separation in TSP between $\pi^0 \to \gamma\gamma$ decays (which produce broader showers in the BEMC) and isolated $\gamma_{\rm dir}$ (which produce narrower showers in the BEMC). It should be noted that the opening angle of a 9 - 20 GeV π^0 decaying to two photons is small enough to be contained within one to two BEMC towers.

From the candidate triggers, the TSP is used to select a 95% pure sample of π^0 triggers and to select a sample of triggers with an enhanced fraction of $\gamma_{\rm dir}$, referred to as $\gamma_{\rm rich}$ triggers. The identified π^0 triggers have TSP < 0.08, and the $\gamma_{\rm rich}$ triggers have TSP $\in (0.2, 0.6)$. A representative TSP distribution is shown in Fig. 1. Finally, events tagged by π^0 and $\gamma_{\rm rich}$ triggers which have transverse energies of 9 - 11, 11 - 15, or 15 - 20 GeV are analyzed.

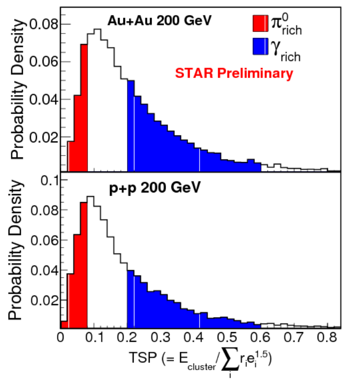

Figure 1: The TSP distribution in Au+Au and p+p collisions. The blue and red regions indicate the cuts used to identify the π^0 and $\gamma_{\rm rich}$ samples of triggers respectively. The figure is from [8].

The $\gamma_{\rm rich}$ background due to hadronic decays is estimated in a data-driven manner by comparing the near-side per-trigger azimuthal yields of the π^0 and $\gamma^{\rm rich}$ samples. For $E_{\rm T}^{\rm trg} \in (9, 11)$ GeV, the fraction of $\gamma_{\rm rich}$ triggers due to hadronic decays ($\mathfrak{B}$) is measured to be $\mathfrak{B} \approx 0.57$.

3 Corrected Recoil Jet Spectra

Jets are reconstructed from TPC tracks using the anti-$k_{\rm T}$ algorithm as implemented in FastJet 3.0.6 [9]. A resolution parameter of $R_{\rm jet} = 0.2$ was used for the data shown in these proceedings. The TPC tracks utilized in jet reconstruction were required to have $p_{\rm T}^{\rm trk} \in (0.2, 30)$ GeV/c and $|\eta^{\rm trk}| < 1$. Only the reconstructed jets which satisfy the following conditions are considered:

(i) the raw reconstructed ($p_{\rm T}^{\rm jet,raw}$) satisfies $p_{\rm T}^{\rm jet,raw} \in (0.2, 30)$ GeV/c;

(ii) the jet area ($A^{\rm jet}$) satisfies $A^{\rm jet} > 0.05$;

(iii) the jet axis satisfies $|\eta^{\rm jet}| < 1 - R_{\rm jet}$;

(iv) and the jet axis satisfies $\Delta\varphi^{\rm jet} \in (3\pi/4, 5\pi/4)$.

Here, $\Delta\varphi^{\rm jet}$ indicates the difference between the azimuthal angles of the trigger and the jet axis. A "recoil jet" is one whose axis satisfies condition (iv). The reconstructed jets are then corrected for the median background energy density via the standard ρ prescription:

$$p_{\rm T}^{\rm reco} = p_{\rm T}^{\rm jet,raw} - \rho \cdot A^{\rm jet}$$

where ρ is the median background energy density. The procedure to calculate ρ is described in detail in [9]. For the range of trigger energies presented in these proceedings, the correction $\rho \cdot A^{\rm jet}$ removes no energy on average for $R_{\rm jet} = 0.2$ jets. However, increasing $R_{\rm jet}$ increases the jet area, and for $R_{\rm jet} = 0.5$ jets, the procedure removes 20 MeV/c on average for the presented range of trigger energies.

The data are corrected for detector effects following the procedure utilized in a recent measurement of hadron-jet correlations by the STAR Collaboration [10]. The jet energy resolution is corrected for

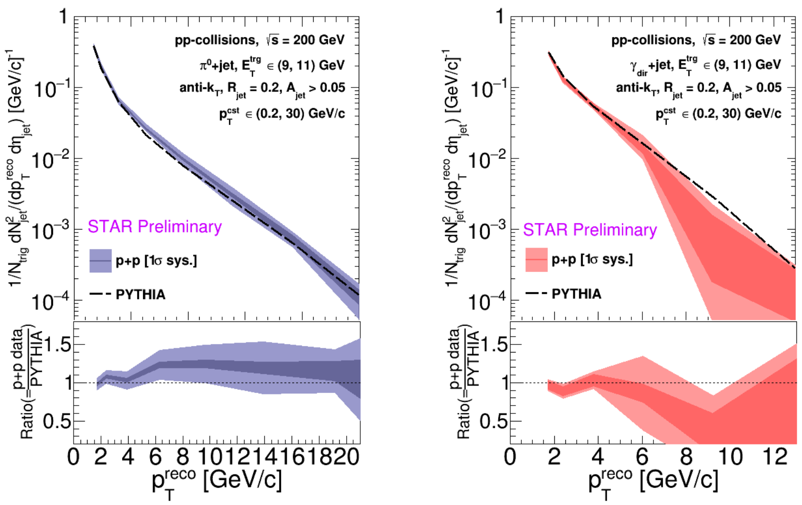

Figure 2: Corrected charged recoil jet spectra compared against PYTHIA 8. The darker bands indicate statistical uncertainty and the lighter bands indicate total uncertainty (statistical and systematic).

at the event-averaged ensemble level via an iterative unfolding algorithm based on Bayes' theorem as implemented in the RooUnfold software package [11]. The jet reconstruction efficiency is then corrected bin-by-bin. The fully corrected π^0- and $\gamma_{\rm dir}$-triggered charged recoil jet spectra for $E_{\rm T}^{\rm trg} \in (9, 11)$ GeV are compared against PYTHIA 8.1.85 [12] in Fig. 2.

The dominant systematic uncertainties are the unfolding process (which includes the choice of prior, number of iterations, etc.), and the tracking efficiency. However, in the case of the $\gamma_{\rm dir}$-tagged recoil jets, there is an additional systematic uncertainty associated with the subtraction of the background due to hadronic decays; this is the largest uncertainty of the $\gamma_{\rm dir}$-tagged recoil jets.

Within uncertainty, the corrected data are largely consistent with PYTHIA 8, though there is some tension between the two. It is known that at small $R_{\rm jet}$, PYTHIA 8 has difficulty describing jet spectra. Moreover, the shown PYTHIA 8 distributions were generated "out-of-the-box" with no additional tuning of the PYTHIA 8 simulations.

4 Summary and Future Work

Charged recoil jets with $R_{\rm jet} = 0.2$ tagged by energetic π^0 and $\gamma_{\rm dir}$ with $E_{\rm T}^{\rm trg} \in (9, 11)$ GeV have been reconstructed in p+p collisions at $\sqrt{s} = 200$ GeV. The fully corrected data compare favorably to PYTHIA 8 simulations. However, there is tension, particularly between the $\gamma_{\rm dir}$-triggered data and simulation. Corresponding measurements of charged recoil jet spectra for different values of $R_{\rm jet}$ and $E_{\rm T}^{\rm trg}$ ranges of 11 - 15 and 15 - 20 GeV are underway. This analysis will also be extended to full jets, i.e. jets consisting of TPC tracks and BEMC towers. The impact on the recoil jet spectra from incorporating the neutral component of the jet is striking: Figure 3 illustrates this by comparing a charged and full recoil jet spectrum generated in PYTHIA 8. The addition of the neutral component will enable more precise measurements of the recoil jets' energy and enable an easier comparison to theoretical calculations which will lead to a more complete picture of the dynamics of in-medium energy loss.

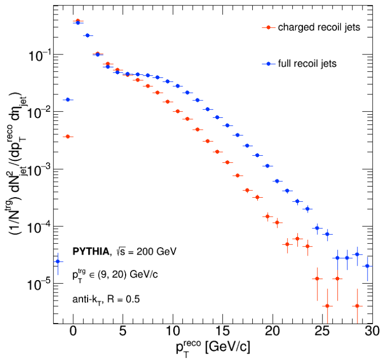

Figure 3: Charged and full $\gamma_{\rm dir}$ tagged recoil jet spectra for $R_{\rm jet}$ = 0.5 generated in PYTHIA 8.

References

[1] M. Connors, C. Nattrass, R. Reed, and S. Salur, RMP **90**, 025005 (2018)
[2] Wang et al., PRL **77**, 231 (1996)
[3] G. David, (2019) arXiv:1907.08893 [nucl-ex]
[4] T. Renk, PRC **88**, 054902 (2013)
[5] M. Anderson et al., NIM A **499**, 659 (2003)
[6] M. Beddo et al., NIM A **499**, 725 (2003)
[7] B. I. Abelev et al., PRC **82**, 034909 (2010)
[8] N. Sahoo and the STAR collaboration, NPA **956**, 621 (2016)
[9] M. Cacciari, G. P. Salam, and G. Soyez, EPJ C **72**, 1896 (2012)
[10] L. Adamcyzk et al., PRC **96**, 024905 (2017)
[11] T. Adye, (2011) arXiv:1105.1160 [physics.data-an]
[12] T. sjöstrand, S. Mrenna, and P. Z. Skands, Comput. Phys. Commun. **178**, 852 (2008)