Subtracting the Underlying-Event Energy in Reconstructed Jets in $\sqrt{s_{NN}}$ = 200 GeV Proton+Proton Collisions at STAR

CYCLOTRON INSTITUTE TEXAS A&M UNIVERSITY

C. Ostberg

Department of Physics, San Francisco State University

REU Student at the Cyclotron Institute, Texas A&M

Mentored by Professor Saskia Mioduszewski

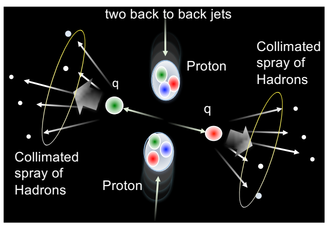
SAN FRANCISCO STATE UNIVERSITY

Abstract

Jets resulting from hard scatterings (i.e. scatterings with large momentum transfer) provide insight into parton energy loss in the hot, dense medium produced by ultra-relativistic heavy-ion collisions. Complementary measurements in the medium-free proton-proton environment establish a vacuum fragmentation reference. In a collision, energy that goes into the production of particles not originating from the hard scattering is background (referred to as the *underlying event*) that must be subtracted from the measured jet-energy. We present a study of different methods to subtract the underlying-event energy in 200 GeV proton-proton collisions recorded at the STAR experiment at RHIC.

Introduction

In ultra-relativistic collisions, the energy is high enough for "hard" scatterings to occur. These are characterized by a large momentum transfer between partons of the colliding baryons/nuclei. The hard-scattered partons then fragment into collimated sprays of hadrons, called "jets". These jets are used to probe the QGP in heavy ion collisions.



Not all of the energy from the collision goes towards the hard scattered jets. Uncorrelated soft particles are also produced, and contribute to the observed hard jet energy. These particles are what the background is composed of, and what must be subtracted.

Jet-Reconstruction

The Anti-kt algorithm is used to cluster the jets. This algorithm picks a particle in a region, and clusters other particles in near vicinity, in terms of azimuth (Δϕ) and pseudorapidity (Δη), to form a roughly conical jet.

[1]

$$d_{ij} = \frac{1}{\max(p_{ti}^2, p_{tj}^2)} \frac{\Delta R_{ij}^2}{R^2} \quad d_{iB} = \frac{1}{p_{ti}^2}$$

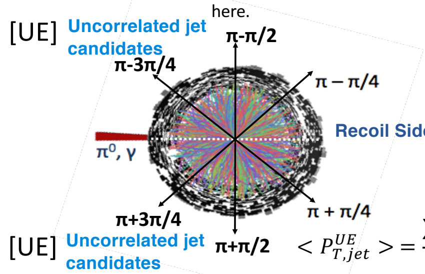
We control the area of the jet by changing the jet parameter R (or jet radius) in the equation above. $R \approx \sqrt{\Delta\varphi^2 + \Delta\eta^2}$ ($\eta = \ln(\tan^{-1}(\frac{\theta}{2}))$,θ is the angle between the jet and beam axis, φ = is the azimuthal angle in phase space). In this study R = 0.3 radians, and only charged particles are included in jet reconstruction.

Data Used to Reconstruct Jets:

- STAR Experiment data from 2009 RHIC Run.
- $\sqrt{s_{NN}}$ = 200 GeV proton-proton collisions
- Events with trigger particle of 9 < P_T < 30 GeV
- Charged tracks with 0.2 < P_T < 20 GeV

Methods

The figure below defines the "recoil" region (Δϕ = π ± π/4 with respect to the trigger particle) and the "UE" region (underlying-event region where Δϕ = ±π/2 − π/4 with respect to the trigger particle). There are two types of background: 1.) "combinatorial" jets – those clustered by the jet-finder, but not originating from hard scatterings, and 2.) underlying-event energy included in the clustering of the true "hard" jets. For R=0.3 (relatively small jets), the latter is expected to be small, but how small was studied here.



$$< P_{T,jet}^{UE} > = \frac{\sum_{i=0}^{N} P_{T,i}^{UE}}{N_{jets}}$$

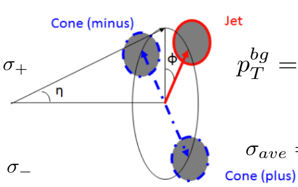
Method 1 uses reconstructed jets in the UE region (the two Uncorrelated jet regions shown above) and subtracts their P_T (transverse momentum) statistically from the recoil jets' P_T . This procedure subtracts an estimate of combinatorial jets, assuming the UE background is small enough to neglect.

Method 2 uses the average P_T ($< P_{T,jet}^{UE} >$) of the same UE jets, but instead subtracts it on a jet-by-jet basis from the recoil jets. This procedure subtracts an estimate of the UE energy, leaving combinatorial jets as a remaining background. These will be subtracted using a separate procedure described below.

Method 3 is also a jet by jet subtraction, but is more specific with how it calculates the average P_T. Circular areas with jet parameter R are created at φ +/- $\pi/2$, with respect to the recoil jet's φ, and at the same η as the recoil jet. There, the average P_T per area is found for each region (σ_+ and σ_-). These quantities are then averaged (σ_{ave}) and multiplied by the area of the recoil jet in order to scale it to the individual jets size (P_T^{bg}). Combinatorial jets are then subtracted as follows.

$$\frac{\sum p_T^{trk}}{A_{con}} = \sigma_+$$

$$\frac{\sum p_T^{trk}}{A_{con}} = \sigma_-$$



$$p_T^{bg} = \sigma_{ave} \times A_{jet}$$

$$\sigma_{ave} = \frac{1}{2}(\sigma_- + \sigma_+)$$

Combinatorial Jet Subtraction for Methods 2 and 3

Since negative jet energies are unphysical, we take entries in these bins to be an estimate of the contribution from combinatorial jets. Assuming the combinatorial jets show up as a symmetric distribution around zero energy (after UE energy subtraction), we fit a Gaussian function to the negative side of the distribution, reflect it to the positive side, and subtract the full Gaussian from the jet energy distribution.

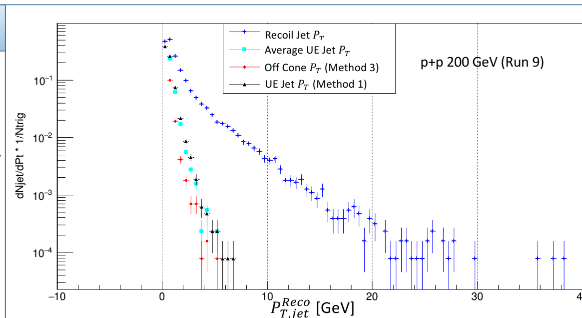


Figure 1 (Above): The raw recoil jet energy distribution (blue) before subtracting the backgrounds, as well as the energy distributions of the three background estimates

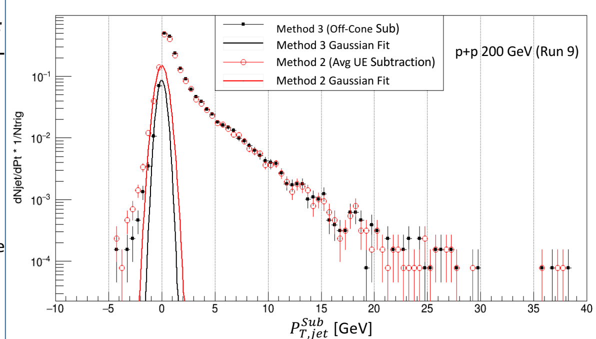


Figure 2 (Above): The jet-energy spectrum with UE energy subtracted via methods 2 and 3. Also shown are the Gaussian fits to the negative jet energies to estimate the combinatorial jet contributions.

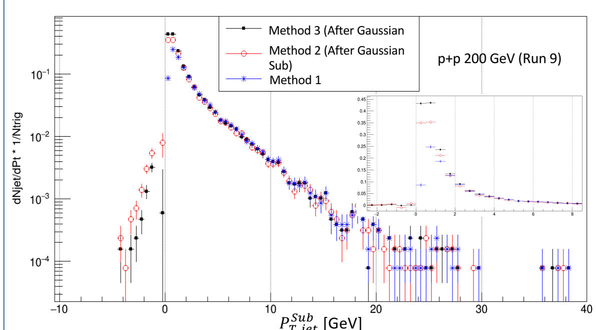


Figure 3 (Above): The background-subtracted jet-energy spectra for all 3 methods. The insert shows a zoomed-in view of the low jet-energy

Results

- The background-jet spectra in Fig. 1 fall much faster than the recoil-region jet spectrum, showing that the overall background energy is small, and the combinatorial jets are typically made up of a small number of soft (low energy) particles.
- Methods 2 and 3 result in similar UE-energy subtracted spectra (Fig. 2). The combinatorial jets are subtracted assuming the Gaussian distribution (fit to the negative jet energies).
- For jet energies greater than 1.5 GeV, all three methods agree in the background-subtracted results shown in Fig. 3.

Summary

- All 3 methods of subtracting background in the reconstructed charged jet spectrum agree within a few percent for energies greater than 1.5 GeV and within ~10% for energies greater than 1 GeV.
- Methods 2 and 3, which first subtract UE energy, and subsequently the combinatorial jet component, agree to within ~25% to the lowest jet energies measured.
- Since Method 1 assumes no UE energy, subtracting only combinatorial jets as a background, we can conclude that this assumption is good for R=0.3 and jet energy greater than 1 GeV.

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References

- [1] EPJC (2012) 72:1896
- [2] Z. Chang's thesis, "Inclusive Jet Longitudinal Double-Spin Asymmetry All Measurements in 510 GeV Polarized pp Collisions at STAR" (2016) and ALICE (perpendicular cones method) PRD 91, 112012(2015)