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Inclusive spectrum of charged jets in central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV by STAR

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Jets are collimated sprays of particles arising from the fragmentation of hard-scattered partons in high-energy collisions. In collisions of heavy nuclei, jets serve as probes of the hot and dense nuclear matter created, and the study of the modification of their structure due to interaction with the surrounding medium (known as "jet quenching") is an important tool for understanding the medium properties.
Jet quenching can be studied via single particle and few-particle correlations, however, only full jet reconstruction can lead to a comprehensive understanding of jet quenching and corresponding medium properties. Due to the large and fluctuating background, full jet reconstruction in heavy-ion collisions is an extremely challenging task.
In this proceedings a new measurement of the inclusive spectrum of charged jets in central Au+Au collisions at center of mass energy $\sqrt{s_{NN}}$=200 GeV, by the STAR collaboration at RHIC is presented. An experimental technique is utilized, in which the jet reconstruction is stable against emission of an additional soft hadron ("infrared safety"), even in the high-multiplicity environment. The large combinatorial background is suppressed by a threshold cut on the leading hadron of each jet candidate. The influence of the background density fluctuations on the inclusive jet spectrum is then corrected by an iterative unfolding technique based on Bayes's Theorem.

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1. Motivation

At high energy density (about 1 GeV/fm^3) Quantum Chromodynamics (QCD) predicts a transition between confined, hadronic matter and a new, deconfined state of matter - the Quark-Gluon Plasma (QGP) [1] where quarks and gluons rather than hadrons are expected to be the dominant degrees of freedom over length scales larger than that of nucleon. Experiments studying the collision of heavy nuclei at high energy at both the Relativistic Heavy Ion Collider (RHIC) [2], and recently at the Large Hadron Collider (LHC) [3, 4], have made several key observations that point to the formation of a hot, dense and strongly coupled system - possibly the Quark Gluon Plasma.

A QCD jet is a correlated spray of hadrons arising from the fragmentation and hadronization of a virtual quark or gluon which is generated in a hard momentum transfer between partons in the nucleus-nucleus collisions. However, the definition of a jet is not unique, and various jet reconstruction algorithms have been developed that satisfy certain criteria (collinear and infrared safety, numerical robustness, speed) that allow them to be applied to both experimental data and perturbative QCD calculations in a systematically well-controlled and comparable way. Jet production rate is calculable using perturbative QCD. It can be compared to the measurements in elementary proton-proton collisions, with a good agreement found over a broad kinematic range of next-to-leading-order (NLO) perturbative QCD calculations and the measurements [5].

Jets, as large momentum transfer probes, are well calibrated tools to study the properties of the matter created in heavy-ion collisions. The scattered partons generated in a hard momentum exchange are created in the initial stages of the ollision. They propagate through the medium, where their form observed jets of hadrons. However, their fragmentation is expected to be modified relative to the vacuum case by interactions with the dense, colored medium (jet quenching) [6]. This modification of parton fragmentation provides sensitive observables to study properties of the created matter.

Jet reconstruction in the environment of a high energy nuclear collision is a challenging task, due to the large and complex underlying background, whose magnitude is comparable to the highest jet energies accessible at RHIC, and whose local fluctuations within an event can easily disturb measured jet distributions.

Jet quenching was therefore initially accessed using inclusive production of hadrons with high transverse momentum (p_{T}) and semi-inclusive correlations. They were observed to be strongly suppressed in central A-A collisions when compared to p-p collisions at both RHIC and LHC [7, 8].

Since jet quenching results in softening of the distribution of hadronic fragments within a jet, selection of jets containing high p_{T} hadrons biases the observed population against jets that have undergone significant energy loss in the medium. High p_{T} hadron probes provide therefore only indirect and biased information on the parton evolution in the medium. The aim of full jet reconstruction is to measure jet modifications due to energy loss without imposing any strong bias.

Our main goal is to perform jet measurements at the STAR experiment at RHIC using the same techniques and algorithms as at the ALICE experiment at the LHC so the results can be directly compared.

2. Jet Reconstruction and Analysis

Data from 0-10% most central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV measured by the STAR experiment at RHIC during Run 2011 are used in this analysis.

Charged tracks from the Time Projection Chamber (TPC) are used as an input for the jet reconstruction. All tracks are required to have $p_{\mathrm{T}} > 200\mathrm{MeV}/c$. FASTJET software and its implementation of k_{T} and anti-k_{T} algorithms [9] are used for the jet reconstruction. Anti-k_{T} algorithm is then used to reconstruct signal jets whereas k_{T} algorithm is used for the calculation of background energy density. Jet resolution parameter R (which roughly corresponds to the radius of jet cone $R \sim \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$) is chosen to be $R = 0.4$ and $R = 0.2$. The fiducial jet acceptance is then $|\eta| < 1 - R$ in pseudorapidity and full azimuth. Jet is defined as the output of anti-k_{T} algorithm in order to overcome the difficulties arising from complex relations between hard jet component and underlying fluctuating background. The separation of hard jets from background is left to a later step.

In the next step, reconstructed jet transverse momentum p_{T}^{rec} is corrected for the background energy density

$$p_{\mathrm{T}}^{corr} = p_{\mathrm{T}}^{rec} - \rho \cdot A \tag{2.1}$$

where $\rho = \mathrm{med}\{\frac{p_{\mathrm{T},i}^{rec}}{A_i}\}$ is the event-wise median background energy density calculated using the k_{T} algorithm, i runs through all reconstructed jets in the event and A is the jet area calculated using the FASTJET method [10].

In order to determine the response of the jet to the presence of the highly fluctuating and complex background we embed a simulated jet (single particle, Pythia jet) with known transverse momentum (p_{T}^{emb}) into a real event and calculate δp_{T} given by

$$\delta p_{\mathrm{T}} = p_{\mathrm{T}}^{rec} - \rho \cdot A - p_{\mathrm{T}}^{emb} = p_{\mathrm{T}}^{corr} - p_{\mathrm{T}}^{emb} \tag{2.2}$$

It was shown, that the δp_{T} distribution is practically independent on the choice of the fragmentation model of the embedded jet [11]. With the knowledge of the δp_{T} and with use of a Monte Carlo (MC) generator, a response matrix of the system can be callculated which maps the true p_{T} distribution to the measured one.

In the final step, the measured p_{T}^{corr} distribution is "unfolded" using an iterative unfolding technique based on Bayes' theorem [12]. However to make the unfolding process converge, one has to reduce the background prior the unfolding [13]. To do so, a cut on jet area [10] $A > 0.4$ in case of $R = 0.4$ and $A > 0.09$ for $R = 0.2$ is applied. Moreover a cut on the transverse momentum of the leading hadron ($p_{\mathrm{T}}^{leading}$) of the jet is imposed. Such a cut still allows the jet to have a large part of its energy carried by the soft hadrons, which is essential for the unbiased jet quenching studies.

3. Results

Since an iterative unfolding technique is used, one has to choose an optimal number of iterations. Using the MC simulations, 4 to 5 iterations were determined as a sufficient number. Unfolded results should be comparable for two successive iterations if the process converges. Such

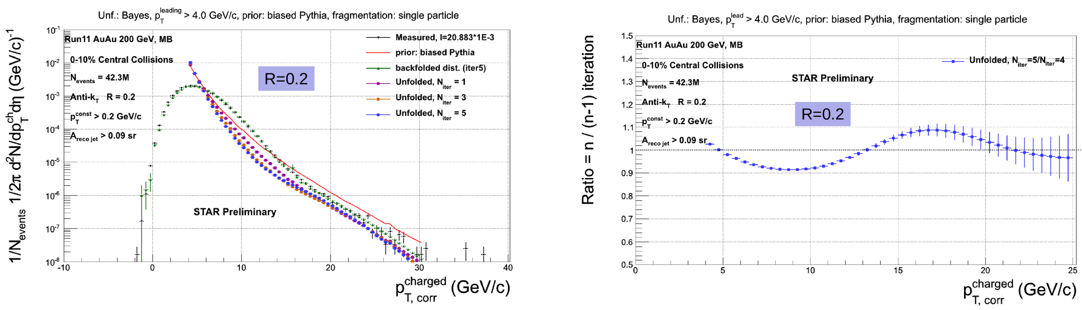

Figure 1: Left: The unfolded p_T spectrum of charged jets in central Au+Au collisons for several iterations. Right: Ratio of unfolded spectra for 4th and 5th iteration. The jets were reconstructed with anti-k_T algorithm with R=0.2 and $p_T^{leading} > 4$GeV/c.

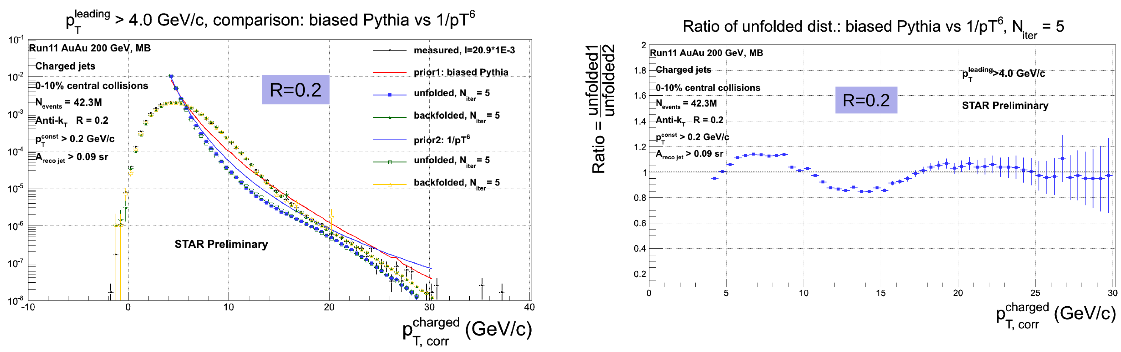

Figure 2: Left: The unfolded p_T spectrum of charged jets in central Au+Au collisons for two choices of prior: p_T^{-6} and "biased Pythia". Right: Ratio of unfolded spectra. The jets were reconstructed with anti-k_T algorithm with R=0.2, $p_T^{leading} > 4$GeV/c.

a comparison is shown in Fig. 1. A less than 10% difference between the 4th and 5th iteration has been achieved.

As a starting point for the iterative unfolding technique, one has to choose prior p_T distribution. Ideally, the unfolded result should be independent on the choice of the prior. In practice, however, this holds only until the prior is chosen reasonably close to the expected result. In our study we compare results obtained from two physically reasonable priors: p_T^{-6} spectrum and spectrum of Pythia jets with imposed $p_T^{leading}$ cut ("biased Pythia"). Fig. 2 compares unfolded spectra for these two choices of priors. A difference of less than 20% has been achieved.

4. Conclusion and Outlook

We have showed that the Bayesian iterative unfolding of p_T spectrum of inclusive charged jets converges and is not significantly dependent on the choice of prior distribution. Jets were reconstructed with $R = 0.2$ in this analysis and $p_T^{leading} > 4$GeV/c showed up as a sufficient value to make the unfolding converge.

As a next step a different unfolding technique - Singular Value Decomposition (SVD) [14] will be used as a crosscheck in order to verify the results of Bayesian unfolding. Final step will be the full jet reconstruction using the information from the Barrel ElectroMagnetic Calorimeter (BEMC).

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