

Full jet reconstruction in 200 GeV p+p, d+Au and Au+Au collisions by STAR

Jan KAPITAN* for the STAR Collaboration

Nuclear Physics Institute, Academy of Sciences of the Czech Republic

E-mail: kapitan@rcf.rhic.bnl.gov

Measurements of inclusive hadron suppression and di-hadron azimuthal correlations have provided important insights into jet quenching in hot QCD matter. However, they do not provide access to the energy of the hard-scattered partons and are limited in their sensitivity since they can be affected by biases toward hard fragmentation and small energy loss.

Full jet reconstruction in heavy-ion collisions enables a complete study of the modification of jet structure due to energy loss, but is challenging due to the high multiplicity environment. Study of jet production and properties in d+Au and p+p collisions provides important baseline measurement for jet studies in heavy-ion collisions.

We report measurements of fully reconstructed jets in p+p, d+Au and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV from the STAR experiment at RHIC. Measurement of initial state nuclear effects in d+Au collisions utilizing di-jet azimuthal correlations is presented together with similar measurement in p+p collisions. Inclusive jet p_T spectra and fragmentation functions in p+p and central Au+Au collisions are reported, with subsequent studies of jet nuclear modification factor, jet energy profile and modifications in the fragmentation function due to jet quenching.

European Physical Society Europhysics Conference on High Energy Physics

July 16-22, 2009

Krakow, Poland

*Speaker.

1. Introduction

Jets are remnants of hard-scattered partons, which are the fundamental objects of pQCD. At RHIC, they can be used as a probe of the hot and dense matter created in heavy ion collisions. Baseline measurements in elementary collision systems can be used to isolate initial state effects from medium modification. In particular, measurement of the nuclear k_T broadening [1], the transverse momentum of a jet pair, in d+Au collisions is important.

Interaction and energy loss in the medium leads to jet quenching in heavy ion collisions. Until recently, it was studied indirectly using single particle spectra and di-hadron correlations [2]. These measurements are however limited in the sensitivity to probe partonic energy loss mechanisms due to well known biases [3].

Developments in theory (for example [4, 5]) and experiment (STAR detector upgrades, increased RHIC luminosity) finally enabled full jet reconstruction in heavy ion collisions [6]. Full jet reconstruction reduces the biases of indirect measurements and enables access to qualitatively new observables such as energy flow and fragmentation functions. We will present and discuss recently reported measurements of jet spectra [7] and fragmentation functions [8].

2. Jet reconstruction

The present analysis is based on $\sqrt{s_{NN}} = 200$ GeV data from the STAR experiment, recorded during 2006-2008. The Barrel Electromagnetic Calorimeter (BEMC) detector is used to measure the neutral component of jets, and the Time Projection Chamber (TPC) detector is used to measure the charged particle component of jets. In the case of a TPC track pointing to a BEMC tower, its momentum is subtracted from the tower energy to avoid double counting (electrons, MIP and possible hadron showers in the BEMC). To reduce possible BEMC backgrounds, the jet neutral energy fraction is required to be within (0.1, 0.9).

Recombination jet algorithms kt and anti-kt, part of the FastJet package [4], are used for jet reconstruction. To subtract the background, a method based on active jet areas [5] is applied event-wise: $p_T^{Rec} = p_T^{Candidate} - \rho \cdot A$, with ρ estimating the background density per event and A being the jet active area. To reject fake jets (“jets” found by jet finder unrelated to hard scattering), one has to either select sufficiently high jet p_T , or statistically subtract fake jet yield (see [7, 8] for details).

3. Nuclear k_T broadening

Year 2007-2008 p+p and d+Au data were used for this study, with BEMC high tower (HT) online trigger requirement (one tower with $E_T > 4.3$ GeV). For d+Au system, the Beam Beam Counter detector, located in the Au nucleus fragmentation region, was used to select the 20% highest multiplicity events. An upper $p_T < 15$ GeV/c cut was applied to TPC tracks due to uncertainties in TPC tracking performance at high- p_T .

Resolution parameter $R = 0.5$ was used for jet finding and a cut $p_T > 0.5$ GeV/c applied for tracks and towers to reduce background. Due to the asymmetry of the colliding d+Au system, the background is asymmetric in η . This dependence was fit with a linear function in η and included in the background subtraction procedure. To study detector effects, Pythia 6.410 and GEANT

detector response simulations were used. Jet reconstruction was performed at MC level (PyMC) and at detector level (PyGe). To study effects of the d+Au background, PyGe events were added to minimum bias triggered d+Au events (PyBg).

To select a clean di-jet sample two highest energy jets ($p_{T,1} > p_{T,2}$) in each event were used, with $p_{T,2} > 10$ GeV/c [9]. Distributions of $k_{T,raw} = p_{T,1} \sin(\Delta\phi)$ were constructed for di-jets and Gaussian widths, $\sigma_{k_{T,raw}}$, were obtained for the two jet algorithms and two (10 – 20 GeV/c, 20 – 30 GeV/c) $p_{T,2}$ bins.

Figure 1 shows that the widths are similar for PyMC, PyGe and PyBg distributions, due to the interplay between jet p_T and $\Delta\phi$ resolutions. Figure 2 shows an example of the $k_{T,raw}$ distributions for data. The extracted values are $\sigma_{k_{T,raw}}^{p+p} = 2.8 \pm 0.1$ (stat) GeV/c and $\sigma_{k_{T,raw}}^{d+Au} = 3.0 \pm 0.1$ (stat) GeV/c. Possible nuclear k_T broadening therefore seems rather small.

The systematic errors coming from a weak dependence on the $|\Delta\phi - \pi|$ cut for back-to-back di-jet selection (varied between 0.5 and 1.0) and differences between the various selections ($p_{T,2}$ range, jet algorithm) are estimated to be 0.2 GeV/c. In addition, uncertainties in BEMC calibration and TPC performance in the high luminosity environment in 2007-2008 run are under study. Given the similarities between p+p and d+Au datasets, these are expected to be highly correlated.

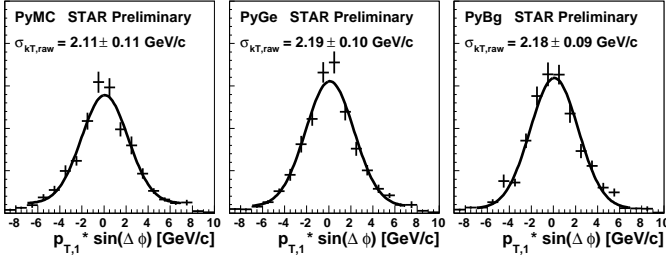


Figure 1: Distributions of $k_{T,raw} = p_{T,1} \sin(\Delta\phi)$ for simulation (anti-kt algorithm, $10 < p_{T,2} < 20$ GeV/c).

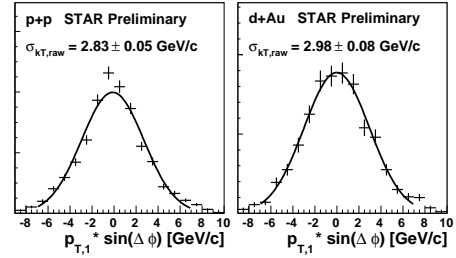


Figure 2: Distributions of $k_{T,raw}$ for p+p, d+Au. Cuts and algorithm as in Figure 1.

4. Inclusive jet spectra

Most central (0-10%) minimum bias triggered Au+Au data from 2007 and jet patch triggered p+p data from 2006 were used for this study. Details on trigger and correction for its bias can be found in [7]. To minimize fragmentation biases, a minimal cut $p_T > 0.2$ GeV/c was used for tracks and towers. To study the jet energy profile, two resolution parameters ($R = 0.2$, $R = 0.4$) were used.

In order to compare the jet p_T spectrum in Au+Au to p+p collisions, one has to correct for additional smearing due to background fluctuations. They are assumed to be Gaussian with width obtained by embedding Pythia jets into Au+Au events. Further corrections (p_T independent tracking efficiency, jet energy resolution, unobserved neutral energy) were applied [7].

Figure 3 shows R_{AA}^{jet} , the ratio of jet yield in Au+Au over the binary collision scaled jet yield in p+p. R_{AA}^{jet} is expected to be close to unity for an unbiased jet reconstruction (with possible small deviations due to initial state effects). For $R = 0.4$, R_{AA}^{jet} is compatible with unity with large uncertainties, while for $R = 0.2$, the jets are significantly suppressed. The differences between kt and anti-kt algorithms are most likely due to different sensitivity to heavy ion background. Figure 4 shows the ratio of jet p_T spectra for $R = 0.2$ over that for $R = 0.4$ separately for p+p and Au+Au.

The ratio is strongly suppressed in Au+Au with respect to p+p, indicating substantial broadening of jet structure in heavy ion collisions.

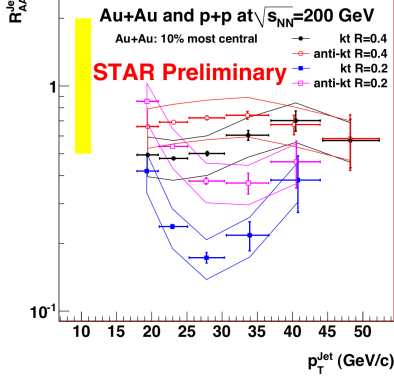


Figure 3: Jet R_{AA} , yellow band shows jet energy scale uncertainty. Taken from [7].

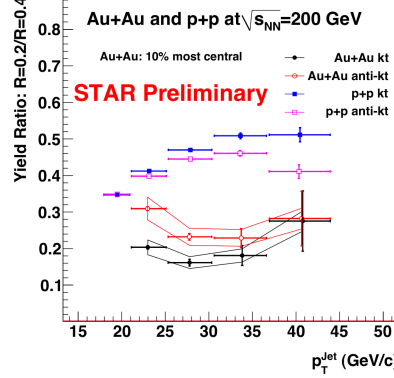


Figure 4: Ratio of jet yields for $R = 0.2$ and 0.4 for p+p and Au+Au collisions. Taken from [7].

5. Fragmentation function measurement

Insight into the jet structure is provided by studying the jet fragmentation function (FF). In-medium softening of the FF with respect to p+p reference should be observable in Au+Au collisions with an unbiased jet population [10]. Recoil jets on the away side of a BEMC HT triggered ($E_T > 5.4$ GeV) jet are used for this study, to maximize the medium path length (and therefore possible FF modification). The online HT trigger condition is the same for p+p (2006) and 0-20% most central Au+Au (2007) data.

Anti-kt algorithm with a resolution parameter $R = 0.4$ was used. The jet p_T is not corrected for instrumental effects yet and is marked $p_{T,rec}$. Further information on corrections and unfolding can be found in [8]. For the trigger jet, a cut $p_{T,rec} > 10$ GeV/c was applied to minimize fake jet contribution and $p_T > 2$ GeV/c was applied to tracks and towers to achieve similar jet energy scale in p+p and Au+Au. On the other hand, a minimal $p_T > 0.15$ GeV/c cut on tracks and towers was applied to recoil jets to minimize the biases. The recoil jet energy was determined using a resolution parameter $R = 0.4$, whereas charged hadrons in a larger cone ($R = 0.7$) around the jet axis were used to construct the FF. Background of the FF was subtracted event-wise using the charged hadron p_T distribution in out of cone area.

Figure 5 shows the ratio of recoil jet p_T spectra in Au+Au to p+p, indicating a strong suppression of recoil jets in Au+Au. This is in contrast to the expected value of unity for unbiased jet reconstruction. Figure 6 shows the ratio of the recoil jet FF in Au+Au to p+p for $p_{T,rec}^{recoil} > 25$ GeV/c. No strong modification of the fragmentation function for $z_{rec} \gtrsim 0.2$ is observed.

Significant suppression of recoil jets together with the absence of strong FF modification in Au+Au could be explained by broadening of the quenched recoil jets, causing an energy shift towards lower energies and artificial hardening of FF. Alternatively, a part of recoil jet population may not be recovered due to strong broadening. In this case the measured FF in Au+Au may be that of surviving recoil jets, i.e. those with little modification (such as tangential emission or punch through jets) [8].

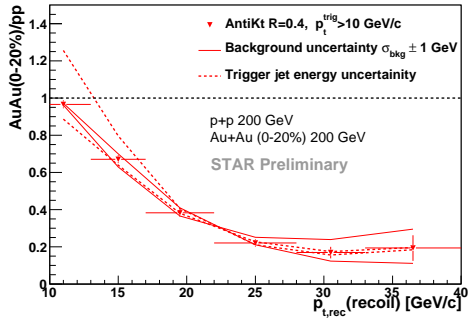


Figure 5: Ratio of recoil jet p_T spectra in Au+Au to p+p. Taken from [8].

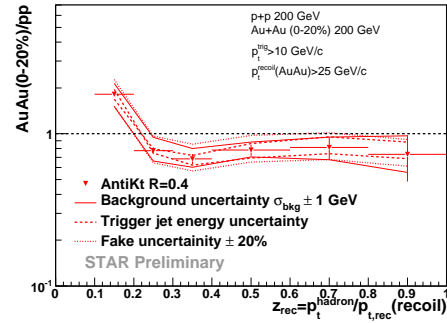


Figure 6: Ratio of $z_{\text{rec}} = p_T^{\text{hadron}} / p_{T,\text{rec}}^{\text{recoil}}$ distributions in Au+Au to p+p. Taken from [8].

6. Summary

Results from the full jet reconstruction in $\sqrt{s_{\text{NN}}} = 200$ GeV p+p, d+Au and Au+Au collisions from the STAR experiment are presented. A study of jet k_T broadening in p+p and d+Au collisions indicates that nuclear effects are rather small. Measurements of inclusive jet cross section as a function of resolution parameter and of recoil jet p_T spectrum and fragmentation functions indicate significant broadening of the jet structure in heavy ion collisions as compared to p+p data.

Acknowledgement

This work was supported in part by GACR grant 202/07/0079 and by grants LC07048 and LA09013 of the Ministry of Education of the Czech Republic.

References

- [1] I. Vitev, Phys. Lett. **B562**, (2003) 36-44.
- [2] J. Adams et. al., Phys. Rev. Lett. **91**, (2003) 072304. J. Adams et. al., Phys. Rev. Lett. **97**, (2006) 162301. S. S. Adler et. al., Phys. Rev. Lett. **96**, (2006) 202301. B. I. Abelev et.al., Phys. Lett. **B655** (2007) 104.
- [3] T. Renk, Phys. Rev. **C78**, (2008) 034904.
- [4] M. Cacciari, G. Salam, Phys. Lett. **B641**, (2006) 57. M. Cacciari, G. Salam, G. Soyez, JHEP **0804**, (2008) 063.
- [5] M. Cacciari, G. Salam, Phys. Lett. **B659**, (2008) 119. M. Cacciari, G. Salam, G. Soyez, JHEP **0804**, (2008) 005.
- [6] J. Putschke (STAR), Eur. Phys. J. **C61**, (2009) 629-635. S. Salur (STAR), Eur. Phys. J. **C61**, (2009) 761-767.
- [7] M. Ploskon (STAR), arXiv: 0908.1799.
- [8] E. Bruna (STAR), arXiv: 0907.4788.
- [9] J. Kapitan (STAR), arXiv: 0907.3830.
- [10] N. Borghini, U. A. Wiedemann, arXiv:hep-ph/0506218. S. Sapeta, U. A. Wiedemann, Eur. Phys. J. **C55**, (2008) 293-302.