Dihadron correlations at high p_T

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Abstract. Jet quenching in the matter created in high energy nucleus-nucleus collisions provides a tomographic tool to probe the medium properties. Recent experimental results from the Relativistic Heavy-Ion Collider (RHIC) on characterization of jet production via dihadron correlations at high transverse momentum are reviewed. Expectations from the dihadron measurements for the lower energy $\sqrt{s_{NN}}$=62.4 GeV RHIC run are discussed.

1. Introduction

Jets of hadrons come from fragmentation of high energy quarks or gluons scattered with a large momentum transfer. Jets produced in ultra-relativistic heavy-ion collisions at RHIC probe nuclear matter at extreme conditions of high energy density. Energetic partons propagating through the medium are predicted to lose energy via induced gluon radiation, with the energy loss depending strongly on the color charge density of the created system and the traversed path length [1]. Attenuation of jets enables tomographic analysis of the created matter using the jet effectively as an external probe of the medium [2]. At RHIC, high transverse momentum (p_T) measurements of hadron production have revealed three different observations related to jet quenching: strong suppression of the inclusive hadron spectra [3], large azimuthal anisotropies with respect to the reaction plane orientation [4], and strong suppression of the back-to-back azimuthal correlations [5]. Recent high p_T measurements performed with d+Au collisions [6, 7, 8, 9] confirm that the nuclear attenuation observed in central Au+Au collisions is due to final-state interactions of jets in the dense matter formed in heavy ion collisions. A comprehensive review of the RHIC data and theory is given in [10], while most recent experimental results on jet production at RHIC are summarized in [11]. I will review the dihadron correlation measurements at high p_T at the top RHIC energy ($\sqrt{s_{NN}}$=200 GeV) and discuss the expectations from the lower energy $\sqrt{s_{NN}}$=62.4 GeV run.

2. Suppression of away-side correlations: jet quenching

Hard scattered partons fragment into a high energy cluster (jet) of hadrons which are distributed in a cone of size $\Delta\eta\Delta\phi$ =∼ 0.7 in pseudorapidity and azimuth. The large multiplicities in nuclear collisions make full jet reconstruction impractical. Instead, correlations of high p_T hadrons are used for the identification of jets on a statistical basis. The relative azimuthal angle distributions of dihadrons reveal jet-like correlations that are characterized by the peaks at $\Delta\phi = 0$ (near-side correlations) and at $\Delta\phi = \pi$ (back-to-back).

Striking evidence of in-medium effects on dihadron correlations is presented in Figure 1. The left panel shows the relative azimuthal angular distribution between trigger hadrons of $p_T^{\rm trig}$=4-6 GeV/c and associated hadrons (2 GeV/c< $p_T^{\rm assoc} < p_T^{\rm trig}$) measured in central Au+Au collisions, compared to that in p+p and d+Au collisions. Correlations of high p_T hadrons at small relative angles are seen to be essentially unaffected by the medium (the strength of the near-side correlations is consistent with that measured in p+p and d+Au collisions). In sharp contrast, the away-side (back-to-back) correlations are strongly suppressed in the most central Au+Au collisions. The right panel shows the variation of back-to-back suppression with azimuthal orientation of the jets relative to the reaction plane for non-central Au+Au collisions. Elliptic flow subtracted distributions [13] show larger suppression of the back-to-back correlations for the out-of-plane trigger particles than for in-plane. These observations are naturally predicted by jet quenching models, where the energy loss of a parton depends on the density of and distance traveled through the medium. The high p_T trigger biases the initial production point to be near the surface so the near-side correlations should be similar to those seen in p+p collisions. The away-side correlations are suppressed in the dense medium, and more suppressed when the trigger hadron is emitted perpendicular to the reaction plane.

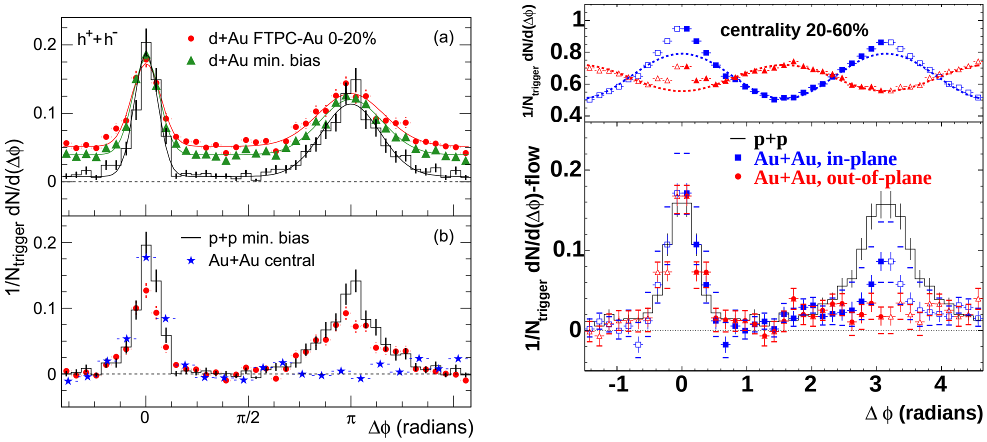

Figure 1. Left: STAR data [8] on dihadron azimuthal correlations in p+p, d+Au and central Au+Au collisions. Right: STAR data [12] on modification of the dihadron correlations in Au+Au collisions with respect to reaction plane, compared to p+p.

3. Enhancement of near-side correlations: recombination of shower partons with thermal quarks?

One of the puzzles of the dihadron correlation measurements is the observation of stronger (compared to p+p) correlations on the near-side for trigger and associated hadrons at lower p_T. In the left panel of Figure 2, the ratio of associated yields measured in Au+Au and p+p collisions for trigger particle intervals $p_T^{\rm trig}$=4-6 GeV/c

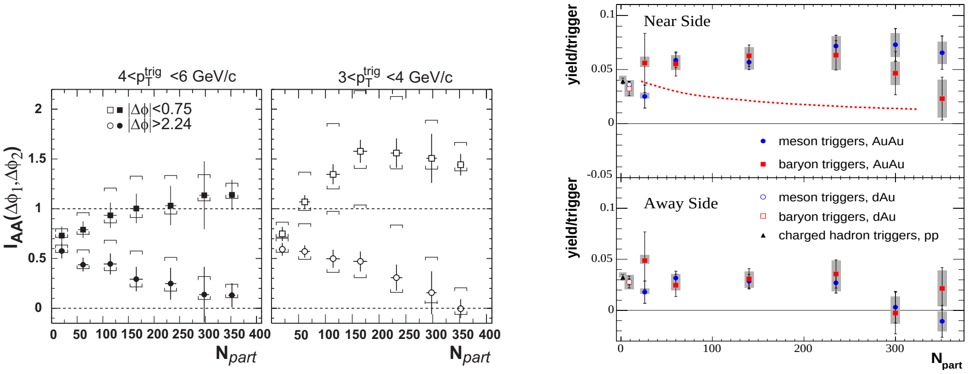

Figure 2. Left: STAR data [5] on AA/pp ratios of the near ($|\Delta\phi| < 0.75$ rad) and away-side ($|\Delta\phi| > 2.24$) correlations in Au+Au collisions. Right: PHENIX data [14] on the associated yield per trigger for the near and away-side correlations in p+p, d+Au and Au+Au collisions.

and p_T^{trig}=3-4 GeV/c is shown. The ratio should be unity if the hard-scattering component of Au+Au collisions is simply a superposition of p+p collisions unaffected by the nuclear medium. The away-side correlations are suppressed in the most central collisions for both intervals of p_T^{trig}. However, for the lower value of p_T^{trig}, the near-side correlations show an enhancement of about 50% in mid-central Au+Au collisions compared to p+p. This enhancement is also observed for baryon and meson triggers with p_T^{trig}=2.5-4.0 GeV/c which are associated with the unidentified charged particles of p_T^{assoc}=1.7-2.5 GeV/c (right panel of Figure 2). The near-side associated yields per baryon/meson trigger almost double in mid-central Au+Au collisions compared to p+p and d+Au. These observations are incompatible with vacuum fragmentation of hard scattered partons and do not emerge naturally from a model focusing on the medium modification of the fragmentation function due to energy loss. At the same time, other aspects of particle production in central Au+Au collisions at RHIC in the p_T-range of 2-5 GeV/c are also incompatible with jet fragmentation in simpler systems, such as large p/π ratio and different suppression of proton/pion [15] and lambda/kaon yields [16]. Models based on coalescence/recombination of thermal/shower partons [17, 18, 19] are successful in qualitatively describing these features [20]. However, the models which assume no correlations among the quarks before recombination are incompatible with dihadron measurements. Currently, there are different theoretical approaches to reconcile the recombination mechanism of hadronization with experimental observations of finite dihadron correlations. One approach is to treat the fragmentation process as the result of recombination of shower partons created by a hard parton. In a heavy-ion collision environment, recombination of thermal and shower partons leads to the different structure of jets from that produced in p+p collisions [21]. Such thermal-shower recombination is then expected to dominate the shower-shower recombination (the only source of dihadron correlations in p+p collisions) in the intermediate p_T range. Another recent suggested scenario is that correlated emission of hadrons may arise from recombination of correlated partons from a quasi-thermal medium [22]. The model lacks quantitative description of the origin of correlations in the parton phase, but it does show that if correlations among quarks exist, they are amplified by the hadronization process via recombination. These theoretical efforts may provide a plausible explanation for the dihadron correlation measurements in the intermediate p_T range.

4. What to expect from dihadron measurements at lower energies?

The yield of single inclusive high p_T hadrons has been observed to be substantially suppressed (by a factor of 3-5 for $p_T >$ 6 GeV/c) in the most central Au+Au collisions at $\sqrt{s_{NN}}$= 130 and 200 GeV compared to the expectation from p+p collisions at the same beam energy. Figure 3 (left) shows the STAR preliminary inclusive charged hadron spectra measured at $\sqrt{s_{NN}}$=62.4 GeV, compared to that measured at $\sqrt{s_{NN}}$= 17, 130 and 200 GeV. Steeper spectra are measured for lower energies, similar to p+p collisions. The right panel of Figure 3 shows the PHENIX preliminary data on the nuclear modification factor (R_{AA}), or the ratio of nuclear geometry scaled yields measured in central Au+Au collisions to the p+p reference data. The observed suppression of the π^0 yield at $\sqrt{s_{NN}}$=200 GeV is similar to that measured at the lower energy for p_T >5-6 GeV/c, as predicted [25].

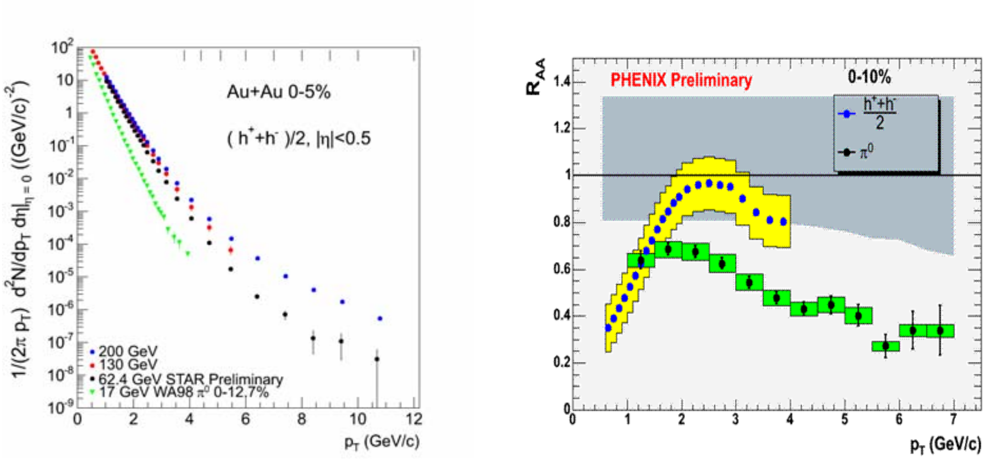

Figure 3. Left: STAR preliminary data [23] on the inclusive charged hadron p_T spectra in central Au+Au collisions at $\sqrt{s_{NN}}$=62.4 GeV, compared to that measured at $\sqrt{s_{NN}}$= 17, 130 and 200 GeV. Right: PHENIX preliminary data [24] on the nuclear modification factor R_{AA} measured for charged hadrons and π^0's in central Au+Au collisions at $\sqrt{s_{NN}}$=62.4 GeV.

Let us examine whether steeper spectra measured at the lower energy affect dihadron correlations. For this purpose we employed the PYTHIA event generator (v. 6.131) [26] for p+p collisions at $\sqrt{s}$=62.4 and 200 GeV. The event generator was run with default parameters (only multiple interactions were switched off) and with and without initial and final state QCD radiation (parton showers). Figure 4 (left) shows the parton yields generated by PYTHIA at $\sqrt{s}$=62.4 and 200 GeV. Again, calculations show steeper parton spectra at the lower energy. For transverse momenta about 10 GeV/c, quark scatterings dominate at $\sqrt{s}$=62.4, whereas at $\sqrt{s}$=200 GeV contributions of quarks and gluons are comparable.

For dihadron correlations, we selected trigger particles (charged pions, kaons, (anti)protons) with p_T^{trig}=4-6 GeV/c, and paired them with associated particles satisfying 2 GeV/c $< p_T^{\mathrm{assoc}} < p_T^{\mathrm{trig}}$. The particles were restricted to $|\eta|$ <0.9. Figure 4 (right) shows the azimuthal distributions of associated particles in p+p collisions at $\sqrt{s}$=62.4 and 200 GeV from PYTHIA. The strength of the near-side correlations is much smaller (by about a factor of 3) at $\sqrt{s}$=62.4 GeV compared to that at $\sqrt{s}$=200 GeV, while the away side is similar for both energies. Initial and final state QCD radiation effects make correlations wider on the near and away sides for both energies and also weaker on the away side. The reduction of the near-side correlation strength with energy, however, does not strongly depend on whether partons are allowed to shower in the calculation.

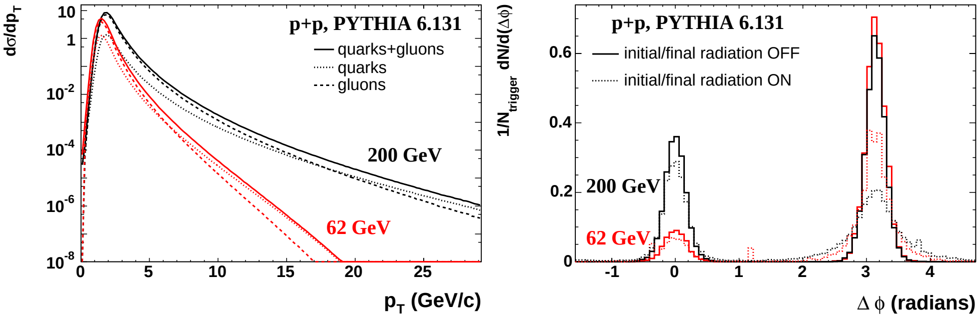

Figure 4. Left: Parton cross section calculated in PYTHIA for p+p collisions at $\sqrt{s}$=62.4 and 200 GeV. Multiple interactions and initial and final state QCD radiation were turned off. Right: Dihadron azimuthal distributions from PYTHIA for $p_T^{\rm trig}$=4-6 GeV/c and 2 GeV/c $< p_T^{\rm assoc} < p_T^{\rm trig}$.

To gain a better understanding of this observation, we switched off the initial and final state QCD radiation in the generator (which makes unambiguous association of charged hadrons to their original parent parton difficult) and studied the p_T distributions of partons associated with the near and away-side peaks separately (Figure 5). The distributions corresponding to the cases when trigger hadron originates from the fragmentation of a quark or a gluon are also shown in Figure 5. On the near side, the mean transverse momentum of the parent parton is $\langle p_T \rangle$=11.7 GeV/c for $\sqrt{s}$=200 GeV and 9.1 GeV/c at $\sqrt{s}$=62.4 GeV. On the away side, the mean transverse momentum of the parent parton is $\langle p_T \rangle$=9.5 GeV/c for $\sqrt{s}$=200 GeV and 7.0 GeV/c at $\sqrt{s}$=62.4 GeV. The difference of ~2 GeV/c between the near and away side $\langle p_T \rangle$-values is due to the trigger bias in the dihadron correlations: to observe a near-side peak one needs a parton of at least p_T=6 GeV/c, fragmenting into the trigger hadron of p_T=4 GeV/c and associated hadron of p_T=2 GeV/c, whereas on the away side the parton p_T can be just 4 GeV/c. In addition, due to the different slopes of the parton p_T distributions at the two energies, both near and away side correlations for fixed $p_T^{\rm trig}$ and $p_T^{\rm assoc}$ correspond to larger (by about ~ 2 GeV/c) original parton p_T at higher energy. From the parton distributions shown in Figure 4 one can show that the ratio of the cross sections corresponding to the near and away $\langle p_T \rangle$'s is about 0.3 at $\sqrt{s}$=200 GeV and about 0.1 at $\sqrt{s}$=62.4 GeV, or a factor of ~3 between the two energies. The difference in the steepness of parton cross sections at the two energies causes the change in the fragmentation of those partons contributing trigger particles: for fixed $p_T^{\rm trig}$=4-6 GeV/c, the fraction of the momentum of the parent parton carried by the trigger hadron is $\langle z_{\rm trig} \rangle$=0.64 at 200 GeV and 0.76 at 62 GeV. Higher $\langle z \rangle$ of trigger particles at lower energy reduces the probability that an associated particle

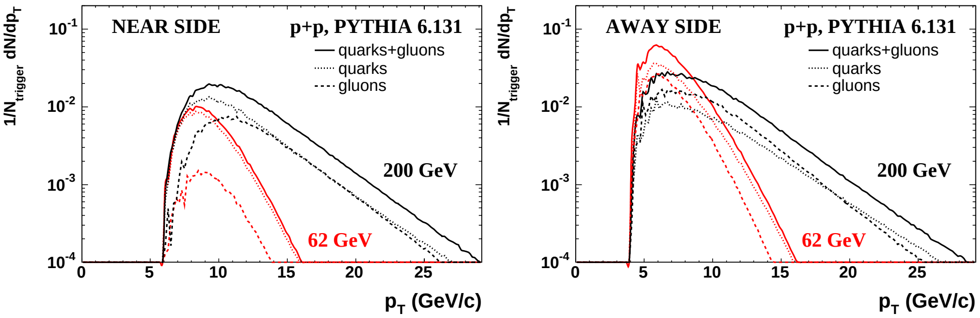

Figure 5. Parton p_T distributions associated with the near (left) and away (right) side dihadron correlations.

will satisfy the threshold p_T^{assoc} concurrently.

Another potentially important difference between the two energies is the lower value of the Bjorken x=0.1 at higher energy (compared to x=0.2-0.3 at 62.4 GeV) for p_T^{trig}=4-6 GeV/c and p_T^{assoc}=2-4 GeV/c. One can see from Figure 5 that the near-side correlations of hadrons at $\sqrt{s}$=62.4 GeV come predominantly from fragmentation of quarks, while at $\sqrt{s}$=200 GeV there is a sizable contribution from gluons (about 40%). Gluon fragmentation is characterized by larger hadron multiplicities which should appear as stronger near-side correlations in the dihadron distributions. Figure 6 compares the dihadron azimuthal distributions from PYTHIA for trigger hadrons originating from either quark or gluon fragmentation. Indeed, stronger correlations are observed for gluon fragmentation, but the gluon/quark ratios at the two energies cannot fully account for the "suppression" of the near side correlations at $\sqrt{s}$=62.4 GeV. Thus we conclude that the predominant reason for the weaker near-side correlations at the lower energy is the steepness of the parton cross section. This effect should also exhibit itself for the dihadron measurements in Au+Au collisions.

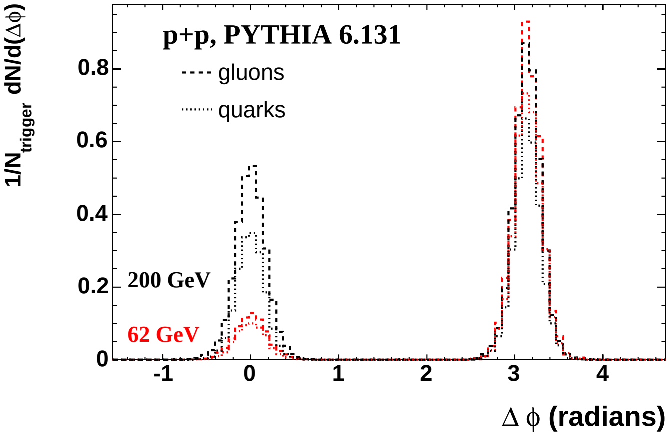

Figure 6. Dihadron azimuthal distributions from PYTHIA for trigger hadrons originating from quark or gluon fragmentation.

The fact that at lower energy 4 GeV/c hadrons come primarily from fragmentation of quarks, while at higher energy they come from an approximately equal mix of quarks and gluons, may help in understanding the mechanism of the partonic energy loss in heavy-ion collisions.

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