Vol. 1 (2008) *Acta Physica Polonica B Proceedings Supplement* No 3

PROBE THE QGP VIA DIHADRON CORRELATIONS: JET QUENCHING AND MEDIUM-RESPONSE*

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(Received October 16, 2008)

We summarize the dihadron correlation results from RHIC, focusing on the high p_{T} region and lower p_{T} region for the away-side. The former is consistent with fragmentation of jets that surviving the medium, while the latter suggests the redistribution of the energy from the quenched jets. We also discuss the role of the jet in the intermediate p_{T}.

PACS numbers: 27.75.–q

1. High p_{T} correlation: jet quenching

Early results from RHIC has established the creation of the strongly interaction partonic matter in central Au+Au collisions. The current focus of the community is to characterize its dynamical properties. One of the most useful tools at our disposal is the hard-scattered jets and dijets. These (di)jets are created early in the collision and can subsequently probe the space-time evolution the QGP via the jet-medium interactions. Both the single- and away-side dihadron yield at high p_{T} are strongly suppressed, consistent with jet quenching picture, where jets traversing the medium suffer significant energy loss or even totally absorbed by the medium.

The strong suppression implies that the center of the medium is extremely opaque. This and the steeply falling parton spectra effectively lead to a bias on the energy loss, where the observed high p_{T} single hadrons and dihadron pairs mainly come from those (di)jets that suffer minimal interaction with the medium. In fact, dihadron data at $p_{\mathrm{T}} > 5\,\mathrm{GeV}/c$ [1, 2] reveal characteristic jet-like peaks for the near-side ($\Delta\phi \sim 0$) and the away-side ($\Delta\phi \sim \pi$), consistent with fragmentation of almost unmodified jets.

Because the observed jets suffers small energy loss, their usefulness as a tomography tool is limited. The information about jet-medium interaction are mostly derived indirectly from the suppression factors such as R_{AA}

* Presented at the XXXVII International Symposium on Multiparticle Dynamics, Berkeley, USA, August 4–9, 2007.

and I_{AA}. These factors basically represent the survival probabilities, and they are not very sensitive to the details of energy loss mechanisms in the high $p_{\rm T}$ region). The situation, however, can be somewhat improved if we combine both single- and dihadron measurements and consider R_{AA} and I_{AA} simultaneously.

To first order, the suppression of the single hadron yield can be described by either a downward shift (absorption) [3] or left shift (energy loss with a fixed fraction) [4]. A more general form can contain both contributions,

$$P(\Delta E) = a[(1-b)\delta(\Delta E) + b\delta(\Delta E - E)] + (1-a)\delta(\Delta E - E_0)\,.$$

If we only consider the downward shift, a simple calculation show that $I_{AA} > R_{AA}$, simply because there is more matter to transverse for away-side jet of the survived jets than for single jets. Since experimental data suggests that $I_{AA} \approx R_{AA}$, clearly downward-shift only is not sufficient.

On the other hand, the suppression caused by left-shift term depends on both the energy loss itself as well as on the input parton spectra shape. The expected binary scaled $p+p$ single hadron yield (in $dN/dp_{\rm T}$) has a power-law shape with a power of 8 [5]; the away side spectra associated with the leading hadron, however, is much flatter with a power of 4.8 [6]. For the same amount of left shift, we expect $I_{AA} < R_{AA}$.

Following the prescription in Ref [6], the fractional energy loss $S_{\rm loss}$ is related to the suppression factor as $S_{\rm loss} = 1 - ({\rm R_{AA}\ or\ I_{AA}})^{1/({\rm n}-1)}$. So if we require $I_{\rm AA} = R_{\rm AA} = 0.2$, then the away hadron energy loss fraction would be $S^{I}_{\rm loss} = 1 - 0.2^{1/(4.8-1)} = 0.345$, much bigger than the single hadron energy loss fraction $S^{R}_{\rm loss} = 1 - 0.2^{1/(8-1)} = 0.23$, as expected (about 50% more energy loss).

2. Intermediate and low $p_{\rm T}$ correlations: medium response

Simple energy conservation arguments suggest that the energy of the quenched jets should be transported to intermediate and low $p_{\rm T}$ single hadrons or hadron pairs. The shape and yield of such "jet-induced" contribution could be sensitive to the properties of the medium, such as the opacity, transport coefficient, speed of sound, *etc.*

Many studies show strong modifications of the near- and the away-side $\Delta\phi$ distributions in this $p_{\rm T}$ region. Fig. 1 shows a representative subset of the per-trigger yield distributions arranged by increasing pair transverse momentum from [2]. At low $p_{\rm T}$, the near-side jet-induced pairs peak at $\Delta\phi \sim 0$, but the peak is broadened and enhanced with respect to $p+p$ collisions; The away-side jet-induced pairs peaks at $\Delta\phi \sim \pi \pm 1.1$ [2,7] with a local minimum at $\Delta\phi \sim \pi$. Going from low to high $p_{\rm T}$, the away-side evolves from a broad, roughly flat away-side peak to a local minimum at

$\Delta\phi \sim \pi$. At high p_{T}, jet shape for Au+Au gradually becomes peaked as for $p+p$, albeit suppressed. These modification patterns reflect characteristics of the energy transport of the quenched partons in both p_{T} and $\Delta\phi$.

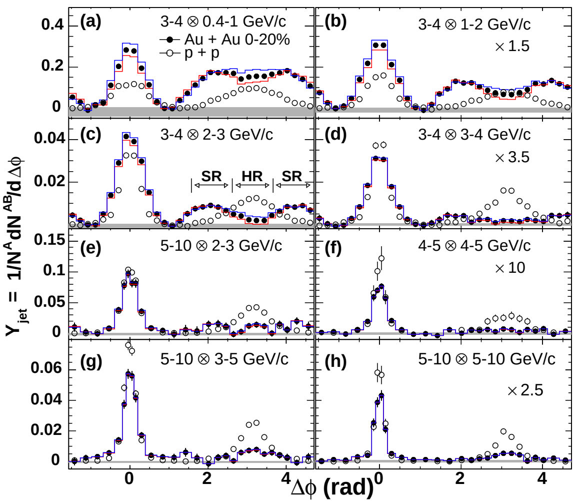

Fig. 1. Per-trigger yield *versus* $\Delta\phi$ for various trigger and partner p_{T} ($p_{\mathrm{T}}^{A} \otimes p_{\mathrm{T}}^{B}$), arranged by increasing pair momentum (sum of p_{T}^{A} and p_{T}^{B}), in $p+p$ and 0–20% Au+Au collisions.

The evolution pattern of the away-side jet shape with p_{T} suggests separate contributions from a medium-induced component centered at $\Delta\phi \sim \pi \pm 1.1$ (shoulder region, SR) and a fragmentation component centered at $\Delta\phi \sim \pi$ (head region, HR). A detailed analysis of this p_{T} dependence of the away-side modification in the two regions can be found in [2]. The enhancement of the SR seems to be limited at $p_{\mathrm{T}} < 4\,\mathrm{GeV}/c$, and its yield shows a universal slope independent of trigger p_{T}. The suppression of the HR yield reflects the jet energy loss.

The patterns of the near-side jet shape and yield in Fig. 1 also suggest enhancement and broadening at intermediate p_{T}. This medium modification was shown to be related to a long range correlation component in $\Delta\eta$ [8]. It was shown to be flat up to $|\Delta\eta| \sim 2$ and was referred to as the η "Ridge". The ridge yield seems to dominate over the jet yield at $p_{\mathrm{T}} < 4\,\mathrm{GeV}/c$, and it has a universal spectra slope independent of trigger p_{T} as well. All these observations suggest the shoulder yield and near-side ridge yield reflects some intrinsic properties of the medium.

Further insight into the physics that drives the SR yield can be obtained by the studying its $\sqrt{s}$ dependence. In particular, it is interesting to see whether the two-component picture applies at much lower collision energy.

Results from the two collision energies ($\sqrt{s_{NN}}$ = 200 and 17.2 GeV from PHENIX [9] and CERES [10]) for $1 < p_T^B < 2.5 < p_T^A < 4\,\mathrm{GeV}/c$ are shown side by side in Fig. 2. The away-side shapes are strongly non-Gaussian in both cases. But the 17.2 GeV data looks almost flat at the away-side.

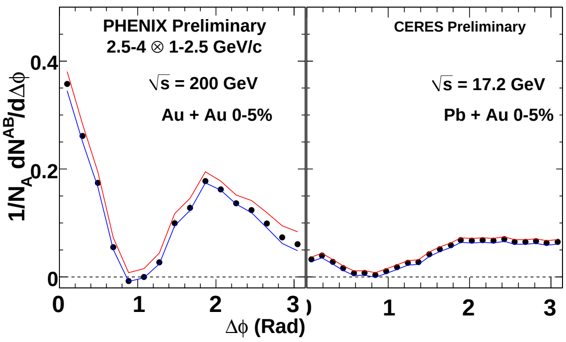

Fig. 2. (a) Per-trigger yield in 0–5% central Au+Au collisions from PHENIX at $\sqrt{s_{NN}}$ = 200 GeV. (b) Per-trigger yield in 0–5% Pb+Au collisions at $\sqrt{s_{NN}}$ = 17.3 GeV from CERES [10].

The 17.2 GeV data is from CERES and is carried out in $0.1 < \eta < 0.7$ in the CM frame at $\sqrt{s_{NN}} = 17.3$ GeV [10]. Its pseudo-rapidity widow of 0.6 is close to 0.7 for PHENIX, thus the corresponding jet yield can be compared with PHENIX results after applying an upward correction of $0.7/0.6 = 1.17$. The maximum of SR in CERES is about half that of the PHENIX value, whereas the yield at the HR is surprisingly close to the PHENIX value. The former might suggest a weaker medium effect at lower energy, while the latter could be a combined result of a lower jet multiplicity and a weaker jet quenching at SPS. Further detailed study of the energy dependence of the punch-through and the medium-induced components can elucidate the onset of jet quenching and medium response.

Many mechanisms for this energy transport have been proposed for the near-side [11–18] and away-side [13–15, 19–26]. Most of these models are quite qualitative in nature. They typically focus on either jet shape or jet yield, near-side or away-side, high p_T or low p_T. The fact that both near- and away-side distributions are enhanced and broadened at low p_T and that the modifications limited to $p_T \lesssim 4\,\mathrm{GeV}/c$, above which the jet characteristics qualitatively approach jet fragmentation, may suggest that the modifications mechanisms for the near- and away-side are related. A model framework including both jet quenching and medium response, which can describe the full p_T evolution of the jet shape and yield at both near- and away-side is required to understand the parton-medium interactions. Our data provide valuable guidance for such future model development.

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