Medium properties and jet-medium interaction from STAR

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We report recent STAR results on medium modification of 2- and 3-particle correlations in heavy-ion collisions at RHIC. In particular properties of an additional extended correlation in pseudo-rapidity (“the ridge”), not present in p+p or d+Au collisions, are discussed. Next, the shape modification of the away-side correlation peak at low- and intermediate-\(p_T\) is investigated to look for signals of Mach cone shock waves or Čerenkov gluon emission.

Di-hadron azimuthal correlations are commonly used to study jet-like processes in heavy-ion collisions at RHIC. It has been observed that both near- and away-side correlation peaks show striking differences to p+p and d+Au measurements. In this paper we discuss recent measurements of azimuthal (\(\Delta\phi\)) and pseudo-rapidity (\(\Delta\eta\)) correlations in the STAR experiment using 2- and 3-particle correlation techniques, identified particles and different collision systems (d+Au, Cu+Cu, Au+Au) in order to obtain more insight into the particle production mechanism at RHIC.

1 Near-side correlation: The ridge

One of the notable findings in heavy-ion collisions at RHIC has been the observation of an additional long-range \(\Delta\eta\) correlation on the near-side, the ridge, which is absent in p+p and d+Au collisions[12]. This observation has triggered a lot of interest in theoretical community and a large variety of models explaining the ridge origin have appeared since then[3].

To quantify the strength of the ridge-like correlations, the measured correlations are decomposed into a jet-like component centered at \(\Delta\phi \sim 0\), \(\Delta\eta \sim 0\) and a ridge component extended in \(\Delta\eta\) a top of elliptic flow (\(v_2\)) modulated background. It has been observed that the yield of charged particles in the ridge associated with a charged trigger particle increases linearly from peripheral to central Au+Au collisions, while that in jet remains approximately independent of
centrality and similar to values in d+Au collisions. This observation is also confirmed for various trigger particle species studied in Figure 1. Within statistical and systematic errors the ridge is independent of the trigger species. Comparing two different collision systems, Cu+Cu and Au+Au, the ridge yield is within errors same at the same number of participants, \( N_{\text{part}} \).

Further, it has been shown that the ridge yield persists up to \( p_T \approx 6 \text{ GeV/c} \) and is approximately independent of \( p_T^{\text{trig}} \) while the jet yield is increasing with \( p_T^{\text{trig}} \) in line with jet fragmentation. The analysis of the \( p_T \) spectra of associated charged particles revealed that the inverse slope extracted from an exponential fit is for the ridge-like correlations independent of \( p_T^{\text{trig}} \) and only by \( \approx 50 \text{ MeV} \) larger than that of the inclusive \( p_T \) spectrum.

Next the results on particle composition in the jet and ridge are discussed. Figure 2 shows the \( p_T \) dependence of \( p/\pi \) and \( \Lambda/K_0^* \) ratios in the jet and ridge together with the values from inclusive \( p_T \) spectra. While the baryon/meson ratios for the jet agree with the ratio measured in p+p, the ratios in the ridge are similar to that from the inclusive measurements. This observation thus supports ridge models where hadronization is based on parton recombination.

Figure 3 shows the dependence of the ridge on the orientation of the event plane. While the ridge yield decreases with the increasing azimuthal angle difference between the trigger particle and the event plane, the jet-like yield is constant as the function of the angular difference. This could indicate a strong near-side “jet”-medium interaction in event plane resulting in the ridge formation and a minimal interaction perpendicular to the reaction plane.

Studies of 3-particle \( \Delta \eta_1 \times \Delta \eta_2 \) correlations, where \( \Delta \eta(2) = \eta^{\text{trig}} - \eta^{\text{assoc}(2)} \), are expected to further constrain the physics origin of the ridge. First studies of such correlations for charged particles with \( p_T^{\text{trig}} = 3-10 \text{ GeV/c} \) and \( p_T^{\text{assoc}} =1-3 \text{ GeV/c} \) are displayed in Figure 4. A clear jet-like peak is present at \( (\Delta \eta_1, \Delta \eta_2) \sim 0 \) in both, d+Au and Au+Au collisions. In addition, a uniform overall excess of associated particles is observed in Au+Au collisions implying no correlation (within errors) exists between the particles in the ridge.
Figure 3: Ridge and jet yields from di-hadron correlations in non-central (20-60%) Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV as a function of angular difference between the trigger particle and the event plane. The lines are systematic uncertainties due to elliptic flow subtraction.

Figure 4: Three-particle correlations in $\Delta \eta$ for small azimuthal angle difference ($\Delta \phi < 0.7$) between associated particles and trigger particle for minimum bias d+Au (a) and Au+Au (b,c) collisions at $\sqrt{s_{NN}} = 200$ GeV.

2 The away-side peak: shape modification

STAR has previously reported a strong suppression of away-side di-hadron correlation peak for $p_{T}^{\text{trig}} = 3-6$ GeV/c and $p_{T}^{\text{assoc}} > 2$ GeV/c\cite{9}. Later it has been observed that this suppression is accompanied by an enhanced production of low-$p_T$ associated particles ($p_{T}^{\text{assoc}} > 0.15$ GeV/c) resulting in a broader, double peaked distribution at $\Delta \phi \sim \pi$\cite{10}. Physics mechanisms suggested to explain the away-side peak shape modification include Mach cone shock waves generated by a parton propagating through the medium\cite{11} or Čerenkov gluon radiation\cite{12}.

In order to distinguish among various physics mechanisms, we investigate 3-particle $\Delta \phi_{1} \times \Delta \phi_{2}$ azimuthal correlations using one trigger and two associated particles. The background subtracted correlations in d+Au and central Au+Au collisions are shown in Figure 5\cite{14,15}. The background has been subtracted using a two component model assuming that one component (“jet”) is correlated with the trigger and the other is not except indirect correlations via anisotropic flow\cite{16}. In Au+Au collisions, the associated particles on the away side populate a cone around $\Delta \phi = \pi$ with 4 peaks 1.4 radians away from $\Delta \phi = \pi$, which are not observed in d+Au collisions. The observed cone angle is independent of collision centrality and $p_{T}^{\text{assoc}}$ (cf. Figure 6), favouring the physics picture based on shock waves rather than Čerenkov gluon radiation, in which the cone angle would decrease with increasing $p_{T}^{\text{assoc}}$. A model independent analysis based on 3-particle cumulants\cite{17,18} has not seen a clear evidence of such a conical emission but it is not excluded that the conical emission is masked by flow terms, or too weak to be visible in the cumulant analysis. We remark, that the effects of momentum conservation for the $p_{T}$ selection used were not accounted for in either of the mentioned analyses.

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