Addressing the physics of the ridge by 2- and 3-particle correlations at STAR

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Abstract

We present new results on 2-particle azimuthal ($\Delta \phi$) correlation relative to event plane and 3-particle pseudorapidity ($\Delta \eta$) correlation at mid-rapidity in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, measured by the STAR experiment. While jet-like correlation is symmetric, ridge is found to be asymmetric when trigger particle azimuth is between in- and out-of-plane. The charge ordering properties between associated and trigger particles are exploited to separate jet-like and ridge contributions in 3-particle $\Delta \eta$-$\Delta \eta$ correlations. We found that like-sign triplets are dominated by ridge. The separated ridge, while narrow in $\Delta \phi$, is extremely broad in $\Delta \eta$. The ridge particles are not only uncorrelated to the trigger particle in $\Delta \eta$, but also uncorrelated between themselves.

1. Introduction

The observation of the ridge, a long range pseudorapidity ($\Delta \eta$) correlation at near-side [1], in dihadron correlations has motivated many theoretical investigations [2, 3]. Understanding the formation mechanism of the ridge may provide insight into the early dynamics of relativistic heavy ion collision. We investigate the ridge using two tools: dihadron correlation relative to event plane and 3-particle $\Delta \eta$-$\Delta \eta$ correlations. We discuss what have already been learned from previous studies [4, 5] and present new findings at this conference.

The ridge magnitude was found to decrease with trigger particle azimuth relative to event plane ($\phi_s = \phi_{\text{trig}} - \psi_{\text{EP}}$) from in-plane ($|\phi_s| \sim 0^\circ$) to out-of-plane ($|\phi_s| \sim 90^\circ$) [4]. Motivated by our data, Chiu and Hwa [3] proposed the Correlated Emission Model (CEM) where the ridge is formed by correlated particle emission due to aligned jet propagation and medium flow and predicted asymmetric near-side $\Delta \phi$ correlations. We present a study of this asymmetry from our data. We found the ridge is asymmetric and the asymmetry peaks at $\phi_s \sim 45^\circ$.

The broadness of the ridge was found to be event-by-event from 3-particle $\Delta \eta$-$\Delta \eta$ correlations [5]. By further analyzing their charge dependence, we may separate jet-like and ridge components without assuming the shape of the ridge in $\Delta \eta$. We find like-sign triplets are dominated by ridge and use this observation to separate the jet-like and ridge components. We find jet-like correlation is narrow, and ridge is broad and approximately uniform in $\Delta \eta$.

2. Dihadron correlation relative to event plane

Dihadron correlations are studied for trigger particles separately in $\phi_s > 0^\circ$ and $\phi_s < 0^\circ$ for 20-60% Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The $p_T$ ranges of the trigger and associated particles
are $3<p_{T}^{trig}<4$ GeV/c and $1<p_{T}^{assoc}<2$ GeV/c, respectively, and both within $|\eta|<1$. The event plane angle is constructed from particles outside the $p_{T}$ range used in the correlation study. The dihadron correlation signal obtained for each $\phi_{s}$ slice has a large background contribution from anisotropic flow ($v_{2}$ and $v_{4}$). The construction and subtraction of this background is described in detail in Ref. [6]. The jet-like yield is obtained from the difference between the raw correlation in $|\Delta \eta|<0.7$, containing both jet-like component and the ridge, and that in $|\Delta \eta|>0.7$ (scaled by $\Delta \eta$ acceptance factor) containing presumably only the ridge component. The systematic uncertainties are largely canceled in the jet-like result. To obtain the near-side ridge, we fit the away-side correlation within $|\Delta \eta|>0.7$ to two Gaussian of the same width, and then subtract the extrapolated fit to the near-side to remove away-side leakage to the ridge [7]. The remaining is the near-side ridge $\Delta \phi$ correlation.

We analyze the asymmetry parameter of the $\Delta \phi$ correlations by $A = \frac{N_{(0,1)} - N_{(-1,0)}}{N_{(0,1)} + N_{(-1,0)}}$ where $N_{(a,b)} = \int_{a}^{b} \frac{1}{N_{\text{trig}}} dN_{\text{assoc}} d\Delta \phi$. Figure 1 shows $A$ for jet-like and ridge $\Delta \phi$ correlations as a function of $\phi_{s}$ for 20-60% Au+Au collisions. The shaded bands represent the systematic uncertainties in the flow estimation. Also shown by the black curve is the prediction from CEM.

![Figure 1: Asymmetry parameter for jet-like and ridge azimuthal correlations as a function of $\phi_{s}$ for 20-60% Au+Au collisions. The shaded bands represent the systematic uncertainties in the flow estimation. Also shown by the black curve is the prediction from CEM.](image)

20-60% Au+Au collisions. The ridge is found to be asymmetric with the maximum asymmetry appearing at $\phi_{s} \sim 45^\circ$, while jet is symmetric. The ridge asymmetry is persistent for different associated $p_{T}$. The ridge asymmetry is qualitatively consistent with the CEM prediction [3], suggesting that formation of the ridge may be due to jet-flow alignment. However, we note that CEM does not have dynamics depending on particle $p_{T}$, nor does it have mechanisms to create correlations between particles separated by large $\Delta \eta$. In general, the ridge $\Delta \phi$ asymmetry may be obtained by models which incorporate interplay between jet propagation and radial flow.

### 3. Three particle $\Delta \eta$-$\Delta \eta$ correlations

We have analyzed the 3-particle $\Delta \eta$-$\Delta \eta$ correlations data in $d$+Au, 40-80% and 0-12% Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [5]. The trigger and associated particles are restricted to $|\eta|<1$ and $|\Delta \phi|<0.7$. The $p_{T}$ ranges are $1<p_{T}^{assoc}<3<p_{T}^{trig}<10$ GeV/c. We further analyze different charge combinations in an attempt to separate the jet-like and ridge components and their structures. The 3-particle correlation raw signal is obtained from all triplet of one trigger and two associated particles from the same event. The signal is binned in $\Delta \eta_{1}$ and $\Delta \eta_{2}$, the pseudorapidity differences between the associated particles and the trigger. Combinatorial background arises when one or neither of the two associated particles are correlated with the trigger particle besides flow correlation. Details about background construction, systematic uncertainties and correction factors can be found in Ref. [5]. The 2- and 3-particle correlation yields are corrected for the centrality-, $p_{T}$- and $\phi$-dependent reconstruction efficiencies for associated particles and the $\phi$-dependent efficiency for trigger particles, and are normalized per corrected trigger particle.
Figure 2 shows the dihadron $\Delta \eta$ correlation between associated and trigger particles on the near-side ($|\Delta \phi|<0.7$) in 0-12% Au+Au collisions. The correlation is separated for like-sign and unlike-sign pairs. There are more unlike-sign than like-sign pairs at $|\Delta \eta|\sim 0$. This is due to the charge ordering in jet fragmentation. At larger $|\Delta \eta|>0.7$, the unlike-sign and like-sign correlations are similar indicating the ridge particles have no charge dependence. Correlation in same-sign triplets should be dominated by ridge correlation because the probability of a jet fragmenting into 3 same-sign particles in our $p_T$ range is negligible. Therefore, we separate the charge ordered triplets in 3-particle $\Delta \eta$-$\Delta \eta$ correlations with like-sign triplets ($AA^{like}T^{like}$) and like-sign associated pairs with an opposite-sign trigger particle ($AA^{like}T^{unlike}$).

Figure 3(left) shows the background subtracted 3-particle $\Delta \eta$-$\Delta \eta$ correlations for $AA^{like}T^{like}$ in 0-12% Au+Au collisions. The average correlation signal seems to be uniform over $\Delta \eta$-$\Delta \eta$ region. To quantify this we study the average signal as a function of $R$ on $\Delta \eta$-$\Delta \eta$ plane, shown in Fig 3(right) for $AA^{like}T$ ($AA^{like}T^{like}$+$AA^{like}T^{unlike}$) and $AA^{like}T^{like}$ in 0-12% Au+Au collisions. $AA^{like}T$ contains both jet-like and ridge contributions while $AA^{like}T^{like}$ is dominated by ridge. Since the ridge at large $\Delta \eta$ is identical for like-sign and unlike-sign trigger-associated pairs in dihadron correlations, it should also be the same at large $\Delta \eta$ in $AA^{like}T^{like}$ and $AA^{like}T^{unlike}$ because the change from the dihadron to trihadron correlation is the addition of third particle of the same charge sign. Therefore, the total jet-like component can be obtained by: Jet = $3(AA^{like}T^{unlike})$.
Figure 4: Average signal of the jet-like and ridge as a function of $R$ on $\Delta \eta$-$\Delta \eta$ plane for $3<p_{T}^{trig}<10$ GeV/c and $1<p_{T}^{assoc}<3$ GeV/c in 0-12% Au+Au collisions. The curves are Gaussian fits to the data.

- $A_{AA}^{like-T^{like}}$, where the factor of 3 takes into account the jet contribution from $A_{AA}^{like-T^{unlike}}$ and $A_{AA}^{unlike-T}$ charge combinations. The ridge can then be obtained by subtracting the jet-like component from the total 3-particle correlation where all charge combinations are included. Alternatively the ridge can be taken simply as 4 times $A_{AA}^{like-T^{like}}$. The two methods yield consistent results.

Figure 4 shows the average signal of the separated ridge and jet-like components from 3-particle $\Delta \eta$-$\Delta \eta$ correlations as a function of $R$ on $\Delta \eta$-$\Delta \eta$ plane for 0-12% Au+Au collisions. The jet-like component is narrow and symmetric between $\phi$ and $\eta$ having a Gaussian width $\sigma_{\Delta \eta} \sim 0.25 \pm 0.09$. The separated ridge, while narrow in $\Delta \phi$, is extremely broad with Gaussian width $\sigma_{\Delta \eta} \sim 1.53 \pm 0.41$. The ridge is also consistent with a uniform distribution within our acceptance with reasonable $\chi^2$/NDF.

4. Summary

In summary, we have presented dihadron correlations relative to event plane for Au+Au 20-60% collisions. While jet-like correlation is symmetric, ridge is found to be asymmetric when trigger particle azimuth is between in- and out-of-plane. The asymmetry is qualitatively consistent with the correlated particle emission model prediction, suggesting the formation mechanism of the ridge may be due to alignment of jet propagation and medium flow.

We have used the charge ordering properties to separate the jet-like and ridge components via 3-particle $\Delta \eta$-$\Delta \eta$ correlations in 0-12% Au+Au collisions. This stems out of the observation that like-sign triplets are dominated by the ridge. We found that the jet-like correlation is narrowly confined, and the ridge is broadly distributed being approximately uniform in $\Delta \eta$ in our measured acceptance. Except small angle correlation in azimuth, the ridge particles appear to be uncorrelated not only with the trigger particle, but also between themselves in $\Delta \eta$.

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