$\Delta\eta$–$\Delta\phi$ CORRELATIONS OF IDENTIFIED PARTICLES IN THE BEAM ENERGY SCAN PROGRAM AT STAR*

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The angular correlation function (CF) refers to the correlation of particles in the relative pseudorapidity and relative azimuthal angle. It is used to study strongly interacting matter properties at relativistic energies. Recent observations suggest that the study of CF of identified particles can provide more detailed insight into strongly interacting matter properties, in comparison with measurements of unidentified particles. In these proceedings, recent STAR experimental results of two-pion and two-proton CF are shown. The dependence of CF on collision energy and centrality is presented.

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1. Introduction

The angular correlation function (CF) refers to two-particle correlations in pseudorapidity difference ($\Delta\eta$) and azimuthal angle difference ($\Delta\phi$) phase-space. Analysis of CF allows studying interactions between particles, their production mechanisms, as well as particle–medium interactions. The shape of CF is affected by many mechanisms, *e.g.* Bose–Einstein correlations, early-stage dynamics (string fragmentations, quark coalescence), interactions within jets, jets–medium interactions, collective dynamics, and others. The recent findings show an unexpected structure in *pp* correlations: a negative CF at small $\Delta\eta$, $\Delta\phi$. It was observed both by the STAR experiment in Au+Au collisions [1, 2] and by the ALICE experiment in $p+p$ collisions [3]. It is likely that such a structure is a result of some mechanism concerning baryons rather that two-particle or particle–medium interactions.

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Currently, the most recent version of the AMPT model is able to quantitatively reproduce ALICE results [4], suggesting that quark coalescence and parton scatterings are essential to describe baryon production mechanisms.

In this paper, we focus on measurement of CF for pion or proton pairs. The data were recorded by the STAR experiment in the Beam Energy Scan (BES) program. This program was carried out at the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven Nation Laboratory (BNL) in 2010, 2011 and 2014. BES data give access to systems at different temperatures and baryon chemical potentials, allowing a search for signals of turn-off of Quark–Gluon Plasma (QGP) signatures, signals of phase-transition or phase-boundary and looking for the evidence of the Critical Point. In these proceedings, we focus on 10–20%, 30–40% and 60–70% central Au+Au collisions at $\sqrt{s_{NN}} = 7.7$, 11.5, 19.6 and 39 GeV. These results may help in disentanglement of correlation sources, providing essential input for constraining theoretical models of heavy-ion collisions.

2. Analysis method

2.1. Measurement of correlation function

The measured CF is defined as in [5]

$$\mathrm{CF} = \frac{\Delta\rho}{\sqrt{\rho_{\mathrm{ref}}}} = \frac{\bar{n}}{\mathrm{d}\eta\,\mathrm{d}\phi}\,\frac{\frac{1}{N_{\mathrm{sig}}}\,N_{\mathrm{sig}}(\Delta\eta,\Delta\phi)}{\frac{1}{N_{\mathrm{ref}}}\,N_{\mathrm{ref}}(\Delta\eta,\Delta\phi)}\,; \tag{1}$$

where: $N_{\mathrm{sig}}(\Delta\eta,\Delta\phi)$ is a number of pairs with a given $\Delta\eta$, $\Delta\phi$, and both particles are from the same event; $N_{\mathrm{ref}}(\Delta\eta,\Delta\phi)$ is a number of pairs with a given $\Delta\eta$ and $\Delta\phi$, where particles are from different (mixed) events; N_{sig} is a total number of pairs observed in the same events. N_{ref} is a total number of pairs obtained from mixed events, and prefactor $\frac{\bar{n}}{\mathrm{d}\eta\,\mathrm{d}\phi}$ is a detector efficiency corrected mean number of particles averaged over angular acceptance (in the case of this analysis, $\mathrm{d}\eta = 2$, $\mathrm{d}\phi = 2\pi$). This analysis is conducted with respect to the pairs charge combination (like-sign, LS, and unlike-sign, US) and particle type (π and p).

2.2. Analysis details

The collision vertex position along the beam axis (V_z) was required to be within 50 cm from the center of the TPC detector for 7.7 GeV, and within 30 cm for other energies. To avoid beam–beampipe collisions, only events that occurred within 2 cm from the beampipe axis were analyzed.

Applied cuts required tracks to be reconstructed from at least 15 space-points, originate from the primary vertex, and fall within the STAR acceptance of $|\eta| \leq 1$. The particle transverse momentum, p_{T}, had to be between

$0.2 \leq p_{\mathrm{T}} \leq 0.8$ GeV/c. To minimize contribution from splitted tracks, the ratio of a number of points used for reconstruction to the maximum number of available space-points was required to be greater than 0.51. Additionally, the average separation distance between two tracks had to be larger than 5 cm both along the beam axis and in the transverse plane. This cut was used to suppress the effects of pair losses due to the overlap or crossing of two tracks. Unfortunately, this method is not sufficient and this pair-related detector effect is still present in the data: it manifests as a dip in CF at a single bin at $\Delta\eta = 0$, stretching up to ± 3 bins in $\Delta\phi$ ($|\Delta\phi| < \pi/10$). The effect scales with the track density in the TPC volume. Thus, it is more impactful for pion–pion than for proton–proton correlations.

For particle identification, the information from the TPC detector was used. Particle energy losses for gas ionization ($\mathrm{d}E/\mathrm{d}x$) had to fall within 2 standard deviations (σ) from the expected value for each particle of interest at a given particle momentum [6]. Additionally, it was required that $\mathrm{d}E/\mathrm{d}x$ is greater than 3σ from expected value for other particles (considering pions, kaons, protons, and electrons). For statistical background estimation, a mixed event technique was used, *i.e.* a particle from analyzed (single) event was correlated with particles from other events with similar properties. To ensure that detector effects cancel out in numerator and denominator of Eq. (1), the analysis was conducted in 2 cm V_z bins, and 40 charged particles (N_{ch}) bins within each centrality class. Finally, CF is calculated as a weighted average over CF calculated in each V_z and N_{ch} bins, with weights being the relative number of pairs in analyzed events. The centrality was based on N_{ch}, corrected for the V_z-dependent detection efficiency.

3. Results

In this section, the near-side projections ($|\Delta\phi| \leq 0.12\pi$) of CF are presented. Results are grouped with respect to the particle type: like-sign (unlike-sign) pion–pion correlations, LS (US) $\pi\pi$, and proton–proton (proton –antiproton) correlations, pp ($p\bar{p}$). Afterwards, the conclusions regarding centrality and collision energy dependence are drawn.

Figure 1 shows centrality and collision energy dependence of CF for like-sign (left) and unlike-sign (right) $\pi\pi$ pairs. For like-sign pairs, a significant positive correlation is observed. It seems that this structure's amplitude grows, and the width gets smaller with more central events. There is a hint of the scaling of CF with collision energy: CF may be stronger for 19.6 GeV and 39 GeV compared with 7.7 and 11.5 GeV, assuming the Gaussian or exponential shape of this structure. It is hard to draw a definite conclusion as the point at $\Delta\eta = 0$ is strongly suppressed due to the pair-reconstruction related detector effects (Section 2). No other significant structures are observed. For unlike-sign pairs, there are two correlation structures observed: a strong short-range correlation, similar to like-sign CF, and a long-range triangular-shaped $\Delta\eta$ correlation, not observed for like-sign pairs. Again, there is a possible collision energy dependence of CF, although estimation of systematic uncertainties is essential to discriminate between results obtained for different $\sqrt{s_{NN}}$.

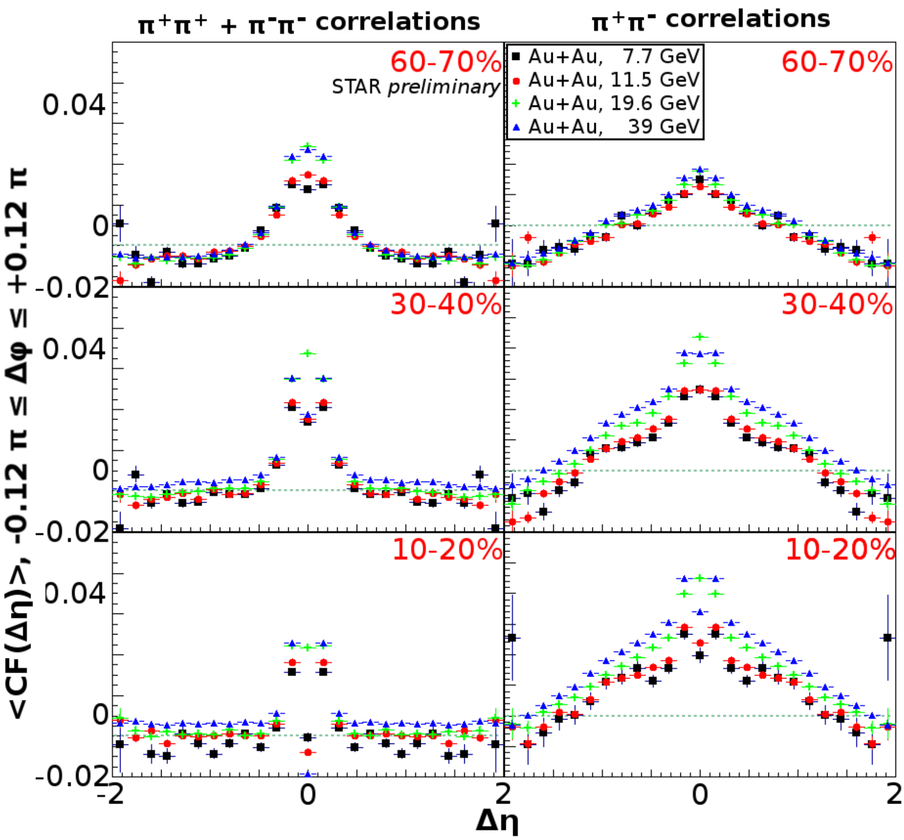

Fig. 1. (Color online) ($|\Delta\phi| \leq 0.12\pi$) projection of CF for like-sign (unlike-sign) $\pi\pi$ pairs (left (right) column) measured in Au+Au collisions at $\sqrt{s_{NN}} = 7.7$ (black squares), 11.5 (red circles), 19.6 (green crosses) and 39 GeV (blue triangles). Rows correspond to different centrality classes: 60–70% (top), 30–40% (middle) and 10–20% (bottom). Uncertainties are statistical only. The point at $\Delta\eta = 0$ is biased by detector-effects.

Figure 2 shows centrality and collision energy dependence of CF for pp (left) and $p\bar{p}$ (right) pairs. For pp, the wide negative correlation structure is present in all studied centralities and collision energies. It overlaps with a short-range positive correlation, most likely caused by final-state strong interactions between protons. These results show that such a structure has a weak dependence on centrality and collision energy if any. On the other hand, $p\bar{p}$ also show a negative correlation structure, but not as wide as in pp. This structure also weakly depends on the centrality and collision energy. The black squares correspond to 7.7 GeV, where due to the low number of produced $\bar{p}$, high fluctuations are expected, especially for $p\bar{p}$ pairs.

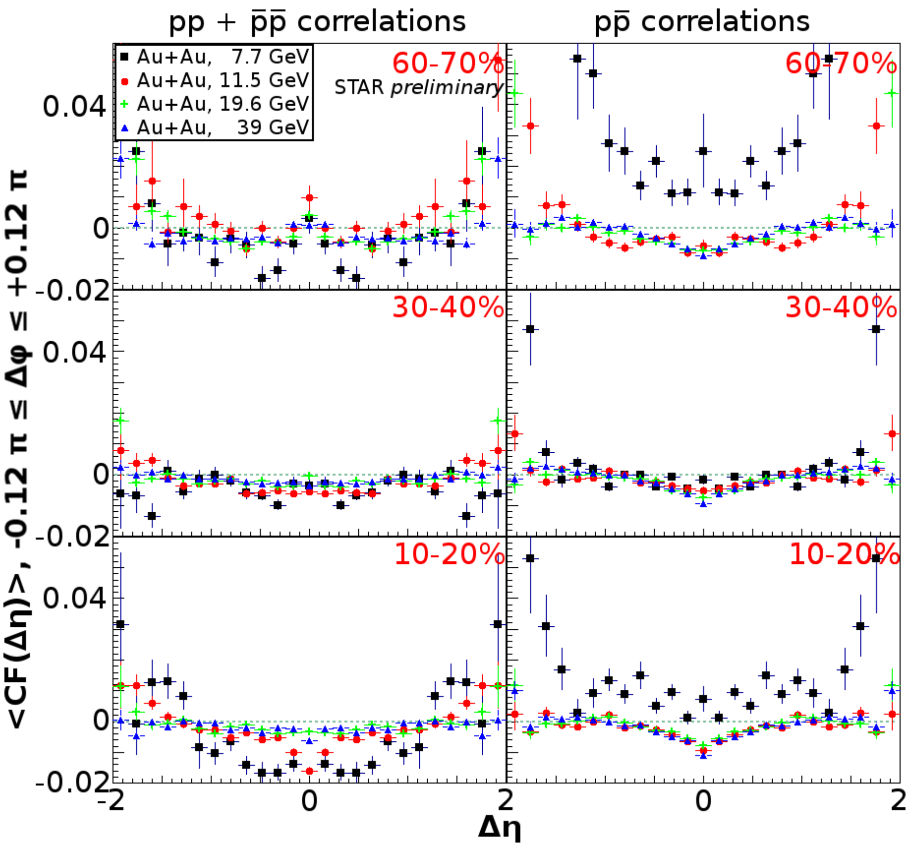

Fig. 2. (Color online) ($|\Delta\phi| \leq 0.12\pi$) projection of CF for pp and $p\bar{p}$ pairs (left and right columns, respectively) measured in Au+Au collisions at $\sqrt{s_{NN}} = 7.7$ (black squares), 11.5 (red circles), 19.6 (green crosses) and 39 GeV (blue triangles). Rows correspond to different centrality classes: 60–70% (top), 30–40% (middle) and 10–20% (bottom). Uncertainties are statistical only.

4. Summary

In this paper, the results of CF for $|\Delta\phi| \leq 0.12\pi$ were presented. For like-sign $\pi\pi$ pairs, a single, short-range correlation is observed. Its amplitude grows, and width shrinks with collision energy and with more central events. Similar conclusions may be drawn for unlike-sign $\pi\pi$ with the addition of another significant correlation structure: a long-range correlation, which might be explained as an effect of charge-ordering during string fragmentation processes.

For pp and $p\bar{p}$ correlations, a weak centrality and collision energy dependence is observed. Nevertheless, a negative correlation for pp is present in all studied centrality classes and collision energies of Au+Au collisions. It resembles ALICE observations from $p+p$ collisions and might be used to cross-check explanation offered by AMPT model in [4]. This work is still in progress and will involve other BES energies and corrections for pair-related detector effects.

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