# ANGULAR CORRELATIONS OF PROTON AND ANTIPROTON PAIRS MEASURED IN AU+AU COLLISIONS AT $\sqrt{s_{NN}} = 19.6$ GeV BY THE STAR EXPERIMENT*

Andrzej Lipiec

Warsaw University of Technology, Koszykowa 75, Warszawa, Poland

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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 results from the ALICE experiment at the LHC show unexpected structures of CF in the proton–proton and antiproton–antiproton correlations. These observations suggest that study of CF of identified particles can provide more detailed insight into nuclear matter properties in comparison with measurements of unidentified particles. In this paper, recent STAR experimental results from the Au+Au collisions at $\sqrt{s_{NN}} = 19.6$ GeV from the RHIC's Beam Energy Scan will be presented.

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## 1. Introduction

The angular correlation function (CF) is a measure of correlation in relative azimuthal angle and pseudorapidity difference of two particles created during heavy-ion collision. CF allows to study particle production mechanisms, particle–medium interactions, and early-stage dynamics. For example, it is used to study jet physics [1], or to measure collective flow in the system created during ultra-relativistic ion collisions [2]. Analysis of CF can reveal small and unexpected signals — sometimes suppressed by a background of other measurements. An example of such an unexpected observation through CF was the collective flow in small systems, measured in high-multiplicity $p+p$ collision by the CMS experiment at the LHC [3]. These examples show, that CF is an essential tool used to study high-energy collisions. In this proceedings, the CF of proton–proton ($pp$) and proton–antiproton ($p\bar{p}$) pairs, measured in Au+Au at $\sqrt{s_{NN}} = 19.6$ GeV by the STAR experiment, is presented.

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## 2. Measurement of the correlation function of identified hadrons in the Beam Energy Scan program

The Beam Energy Scan program (BES) was carried out at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) in 2010, 2011 and 2014. Its primary goal is the exploration of the phase diagram of the strongly interacting matter: search for signals of turn-off of Quark–Gluon Plasma (QGP) signatures, signals of phase-transition or phase-boundary and looking for evidence of the Critical Point. In the frame of this program, the STAR experiment collected data with a single detector setup, of Au+Au collisions at $\sqrt{s_{NN}} = 7.7, 11.5, 14.5, 19.6, 27, 39$ and 62.4 GeV. The measured CF is defined as in [4]

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

where $N_{\mathrm{sig}}(\Delta\eta,\Delta\phi)$ is a number of pairs observed in a single event at given psudorapidity window and relative azimuthal angle; $N_{\mathrm{ref}}(\Delta\eta,\Delta\phi)$ is a number of pairs at given psudorapidity window and relative azimuthal angle obtained from mixed events; $N_{\mathrm{sig}}$ is a total number of pairs observed in a single event; $N_{\mathrm{ref}}$ 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 in 9 centrality bins: 70–80%, 60–70%, 50–60%, 40–50%, 30–40%, 20–30%, 10–20%, 5–10% and 0–5%. Additionally, the CF is measured with respect to the charge combination (Like-Sign, LS, and Unlike-Sign, US) and particle type.

## 3. Analysis details and results

This measurement was conducted by the STAR experiment. The data sample is 3 million of minimum-bias events of Au+Au collisions at $\sqrt{s_{NN}} = 19.6$ GeV. The collision vertex position along the beam axis ($V_z$) was required to be within 50 cm from the center of the TPC detector. 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: $|\Delta\eta| \leq 1$. The particle transverse momentum $p_{\mathrm{T}}$ had to be between $0.2 \leq p_{\mathrm{T}} \leq 0.8$ GeV/$c$. To avoid split tracks, the ratio of 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 beam axis and in transverse plane. This cut was used to suppress effects of pair losses due to the overlap or crossing of two tracks.

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 $2\sigma$ from the Bichsel function expected value for each particle of interest at a given particle momentum. Additionally, it was required that $\mathrm{d}E/\mathrm{d}x$ is greater than $3\sigma$ from expected value for other particles (considering pions, kaons, protons, and electrons). For statistical background estimation, a mixed event technique was used, *i.e.* particle from analyzed (single) event was correlated with particles from separate events. To ensure that detector effects cancel out in the nominator and denominator of Eq. (1), the analysis was conducted in 2 cm $V_z$ bins, and 40 charged particles ($N_{\mathrm{ch}}$) bins within each centrality class. Finally, CF is calculated as a weighted average over CF calculated in each $V_z$ and $N_{\mathrm{ch}}$ bins, with weights being the number of pairs in analyzed events. The centrality was based on $N_{\mathrm{ch}}$, corrected on the $V_z$-dependent detection efficiency.

Figure 1 shows this analysis results in three centrality classes of Au+Au collisions at $\sqrt{s_{NN}} = 19.6$ GeV: 60–70% (left), 30–40% (middle), and 5–10% (right) [5]. In the top row, the CF of $pp + \bar{p}\bar{p}$ pairs is presented. All plots exhibit similar structures: constant ridge at $\Delta\phi = \pi$, depletion centered at $\Delta\eta, \Delta\phi = (0, 0)$, and sharp, thin peak located at $\Delta\eta, \Delta\phi = (0, 0)$. The peak fades away with more central events, which may suggest that it is created by the final-state strong interactions of (anti-)protons. The presence of the depletion is consistent with the ALICE experiment measurements in $p + p$

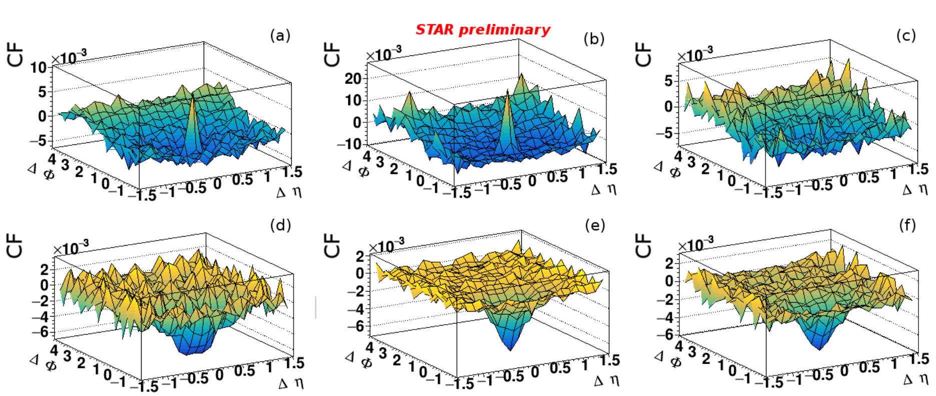


Fig. 1. Correlation function of $pp + \bar{p}\bar{p}$ (top), and $p\bar{p}$ pairs (bottom). Measured by the STAR experiment in 60–70% (a), (d), 30–40% (b), (e), and 5–10% (c), (f) central Au+Au collisions at $\sqrt{s_{NN}} = 19.6$ GeV [5].

at $\sqrt{s} = 7$ TeV. The bottom row shows CF of $p\bar{p}$ pairs. The dominant structure is a negative correlation, centered at $\Delta\eta, \Delta\phi = (0, 0)$, and with constant magnitude in all centrality classes.

## 4. Summary and conclusions

In this proceedings, the CF of $pp + \bar{p}\bar{p}$ and $p\bar{p}$ in different centrality classes of Au+Au at $\sqrt{s_{NN}} = 19.6$ GeV were presented. Depletion $pp + \bar{p}\bar{p}$ was also observed by the ALICE experiment at the LHC. Origin of this depletion is currently investigated within theoretical models of heavy-ion collisions. Several possibilities have been ruled out, like baryon number and energy conservation, Coulomb interactions, final-state interactions [6]. This analysis shows that such a shape is present not only in $p + p$ collisions, but also in different centralities of Au+Au collisions at $\sqrt{s_{NN}} = 19.6$ GeV. It suggests that the medium created during heavy-ion collision does not have a significant impact on the existence of this depletion. A strong anti-correlation observed in $p\bar{p}$ CF may exist when two particles disappear: either as a bound state of $p\bar{p}$, or more likely due to the annihilation process.

The future work will include other BES energies and a fit to data that will allow for disentanglement of different correlation structures. Such an extensive study will provide a lot of constraints for further theoretical models development.

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