BARYON–BARYON CORRELATIONS AT THE STAR EXPERIMENT*

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Two-particle femtoscopy allows one to study the properties of matter created during heavy-ion collisions. It makes the study of space-time evolution of the source possible and may be applied to many different combinations of hadron pairs. Two-baryon femtoscopy provides additional information about source characteristics, not accessible by the two-pion femtoscopy. In this paper, we present the correlation functions obtained for identical and non-identical pairs of protons and antiprotons for Au+Au collisions at different collision energies.

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1. Introduction

Solenoidal Tracker At RHIC (STAR) is one of experiments conducted at Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL). The main goal of the STAR experiment is to measure the properties of matter created during heavy-ion collisions at ultrarelativistic energies and to study the formation of matter and the properties of interactions between hadrons. For many years, STAR has been collecting data from Au+Au collisions at different energies: 7.7, 11.5, 19.6, 27, 39, 62.4, 130, and 200 GeV. The Beam Energy Scan (BES) program [1], which includes colliding energies below $\sqrt{s_{NN}} = 62.4$ GeV, is mainly focused on exploration of the phase transition between hadron gas and quark–gluon plasma, and on the search for the critical point of quantum chromodynamics. The highest collision energy $\sqrt{s_{NN}} = 200$ GeV enables a measurement of hot and dense matter after QGP formation.

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2. Details of analysis

The correlations of two particles are measured in the momentum difference variable $k^* = \frac{Q_{\mathrm{inv}}}{2} = \frac{1}{2}\sqrt{(p_1 - p_2)^2 - (E_1 - E_2)^2}$. The correlation function is defined as a ratio: $C(k^*) = \frac{A(k^*)}{B(k^*)}$. Pairs of correlated particles which come from the same event enter into the numerator $A(k^*)$ and the pairs of uncorrelated particles from different events into the denominator $B(k^*)$. All particles are measured and identified with the Time Projection Chamber (TPC) and the Time-of-Flight (TOF) detectors.

The centrality selection is based on the uncorrected primary charged particle multiplicity in the pseudorapidity region as measured by the TPC detector. The centrality classes are calculated as a fraction of this multiplicity distribution. Glauber calculations are performed using the Monte Carlo calculation. The centrality bin defined as 0–10% corresponds to the most central collisions amounting to 10% of the total cross section, while 70–80% are the most peripheral collisions. Almost 200 millions of minimum bias events collected in year 2010 are divided into three centrality bins: central (0–10%), midcentral (10–30%), and peripheral (30–80%). All particles are identified using the energy loss in the TPC detector ($\mathrm{d}E/\mathrm{d}x$). Protons and antiprotons are chosen in the transverse momentum range: $0.4 < p_{\mathrm{T}} < 2.5$ GeV/c and in the rapidity window $|y| < 0.5$. Each track is extrapolated to the primary vertex. If the shortest distance between track and the vertex exceeds 1 cm, the track is discarded. This removes a significant fraction of non-primary track candidates. Information derived from TOF detector allows one to estimate the mass of particle, and we require the mass square to be between 0.76 and 1.03 GeV/c^2. The particle purity is not taken into account as it is estimated as almost 100%. The effects of track-splitting and -merging are also taken into account.

3. Results for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

Figure 1 presents the measured correlation functions of proton–proton, antiproton–antiproton, and the ratio of proton–proton and antiproton–antiproton for the collision energy $\sqrt{s_{NN}} = 200$ GeV. Correlation functions for baryon–baryon and antibaryon–antibaryon pairs are assumed to be consistent with each other within uncertainties [2]. The scattering length, f_0, is a parameter that determines low-energy scattering and d_0 is the effective range of strong interaction between two particles. It corresponds to the range of the potential in extremely simplified scenario — the square well potential. From these studies, parameters f_0 and d_0 are estimated for antiproton–antiproton pairs and they are found to be consistent with those for proton–proton pairs (Fig. 2).

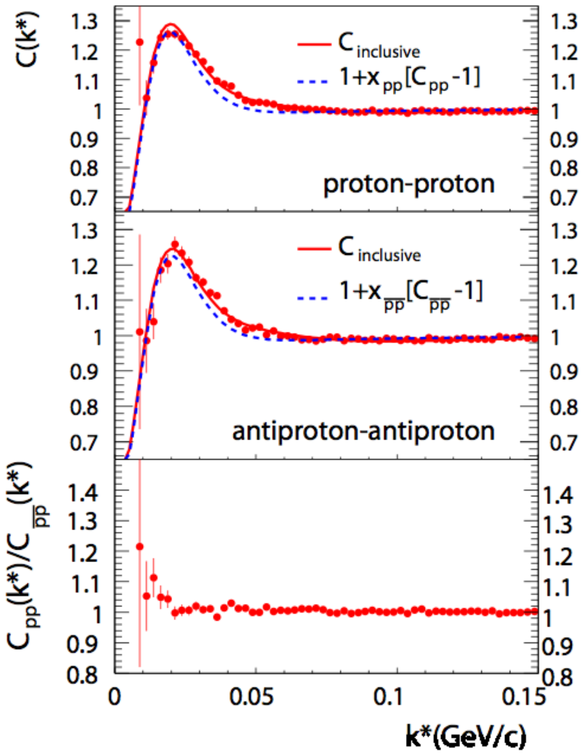

Fig. 1. Correlation functions for proton–proton, antiproton–antiproton and the ratio of these correlation functions for $\sqrt{s_{NN}} = 200$ GeV [2].

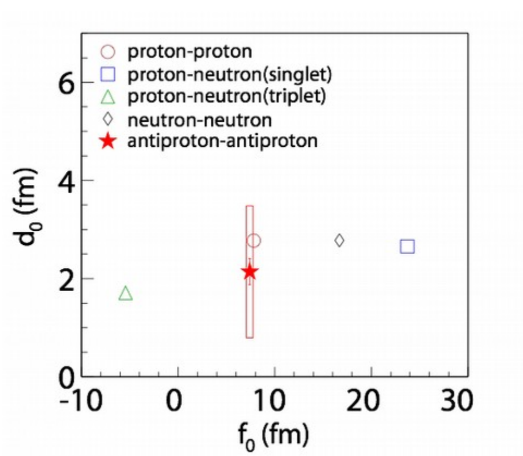

Fig. 2. Parameters od strong interactions for different hadron pairs [2].

4. Results for Au+Au collisions at BES program

Figure 3 presents results of proton–proton correlation functions for $\sqrt{s_{NN}} = 39$ GeV for three different centralities. Figure 4 shows results for proton–antiproton correlation functions for the same centrality classes. Centrality dependence is clearly seen. Table I shows the centrality dependence of protons and antiprotons source sizes measured for identical and non-identical pairs. The results for identical pairs are consistent with each other within uncertainties, however, discrepancies between identical and non-identical baryon pairs occur due to the measurements of residual correlations coming from weakly-decaying particles which were not removed from the measured correlation functions. Table II shows results of proton–proton, antiproton–antiproton and proton–proton systems for different collision energies, where the correction for residual correlations are not yet done.

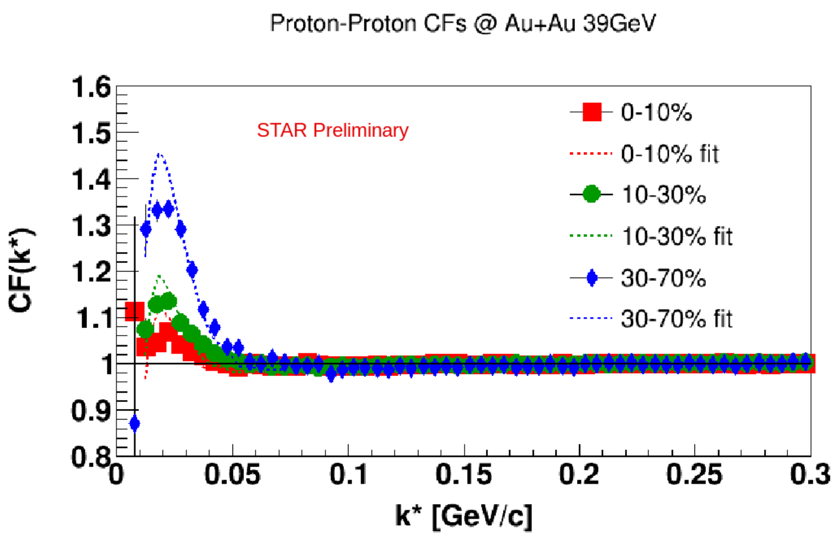

Fig. 3. Proton–proton correlation functions for different centrality classes for $\sqrt{s_{NN}} = 39$ GeV [3].

TABLE I

Source sizes $R_{\rm inv}$ for various baryon (antibaryon) pairs with statistical and systematic uncertainties (due to purity correction only).

Centrality	$R_{\rm inv}$ p–p [fm]	$R_{\rm inv}$ $\bar{p}$–$\bar{p}$ [fm]	$R_{\rm inv}$ p–$\bar{p}$ [fm]
0–10%	$4.00 \pm 0.15 \pm 0.02$	$3.82 \pm 0.20 \pm 0.03$	$3.39 \pm 0.12 \pm 0.14$
10–30%	$3.61 \pm 0.13 \pm 0.17$	$3.68 \pm 0.15 \pm 0.11$	$2.69 \pm 0.10 \pm 0.12$
30–70%	$2.72 \pm 0.07 \pm 0.07$	$2.95 \pm 0.11 \pm 0.08$	$2.56 \pm 0.09 \pm 0.12$

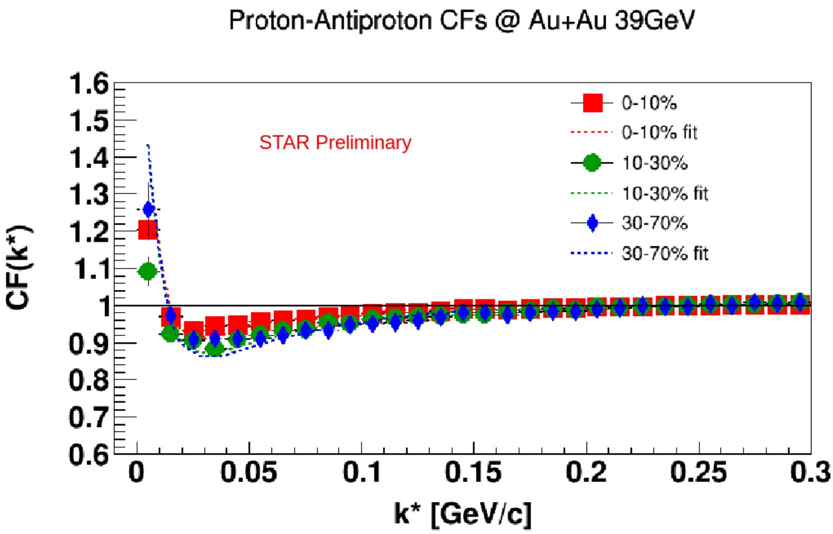

Fig. 4. Proton–antiproton correlation functions for different centrality classes for $\sqrt{s_{NN}} = 39$ GeV [3].

TABLE II

Source sizes R_{inv} for various baryon pairs with uncertaities: statistical and systematic one due to purity correction.

$\sqrt{s_{NN}}$ [GeV]	R_{inv} p–p [fm]	R_{inv} p–$\bar{p}$ [fm]
7.7	$3.59 \pm 0.16 \pm 0.19$	—
11.5	$3.66 \pm 0.08 \pm 0.05$	$3.30 \pm 0.42 \pm 0.28$
19.6	$3.82 \pm 0.15 \pm 0.06$	$3.32 \pm 0.25 \pm 0.13$
27	$3.80 \pm 0.12 \pm 0.08$	$3.49 \pm 0.25 \pm 0.16$
39	$4.00 \pm 0.15 \pm 0.02$	$3.39 \pm 0.12 \pm 0.14$

5. Summary

We have presented the current status of the proton–proton, antiproton–antiproton, and proton–antiproton femtoscopy measurements for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and at BES program energies at STAR. The scattering length and effective range parameters of strong interaction of protons and antiprotons are measured for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. From studies performed in the frame of BES program, invariant source sizes are extracted for proton–proton, proton–antiproton and antiproton–antiproton pairs. As the effect of residual correlations is not taken into account in the present analysis, it would be reflected in discrepancies between the source sizes estimated for identical and non-identical combinations of protons and antiprotons.

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