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PROTON FEMTOSCOPY AT STAR

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The analysis of two-particle femtoscopy provides a powerful tool to study the properties of matter created in heavy-ion collisions. Applied to identical and nonidentical hadron pairs, it makes the study of space-time evolution of the source in femtoscopic scale possible. Baryon femtoscopy allows extraction of the radii of produced sources which can be compared to those deduced from identical pion studies, providing additional information about source characteristics. In this paper we present the correlation functions obtained for protons and antiprotons for Au + Au collisions at $\sqrt{s_{NN}} = 62.4$ and 200 GeV. On the other hand, as STAR experiment participates in the Beam Energy Scan (BES) program, we present theoretical predictions of $p-p$, $\overline{p}-\overline{p}$ and $p-\overline{p}$ femtoscopic measurements, based on UrQMD simulation for $\sqrt{s_{NN}} = 5{-}39$ GeV.

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INTRODUCTION

Solenoidal Tracker At RHIC (STAR) [1] is one of the experiments conducted at Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL). The STAR experiment is designed to measure the properties of hot and dense matter created in heavy-ion collisions at ultrarelativistic energies, where the transition from hadronic matter into partonic stage of the Quark–Gluon Plasma (QGP) is expected to occur. This gives the opportunity to study the formation of matter and the properties of interactions between hadrons. For over ten years, STAR has been collecting data from various nuclear collisions: $p+p$, $d+$ Au, Au + Au and Cu + Cu at different energies: 22, 62, 130, 200 GeV. Starting in 2010, STAR has been taking part in the Beam Energy Scan (BES) program [2] which intends to measure the properties of particles production at the following collision energies: $\sqrt{s_{NN}} = 5$, 7.7, 11.5, 17.3, 27 and 39 GeV. Two main goals of this program are to search for turn-off of new phenomena already established at RHIC (understood as QGP formation) and to search for signatures of a phase transition between Hadron Gas and QGP state, and a location of a Critical Point.

The correlation effect is determined by the distance separating emission points in space and time. By analyzing the momentum correlations it is possible to access information about source characteristics which cannot be measured directly. Identical baryon correlations reflect the properties of the Quantum Statistics and of the Final State Interactions: Coulomb and Strong. Nonidentical baryon pairs are sensitive to the final-state interactions only. In this paper we present results for proton femtoscopy from Au + Au collisions at $\sqrt{s_{NN}} = 62.4$ and 200 GeV and UrQMD simulations [3] for all collision energies of BES program.

Two-proton correlations were intensively measured before at AGS (BNL) [4], SPS (CERN) [5,6] and SIS (Darmstadt) [7] energies. However, the STAR experiment has measured correlations of all the three combinations of protons and antiprotons for the first time and has a unique possibility to measure two-proton femtoscopy at the same experimental conditions, for different collision energies providing a complex description of proton interferometry.

1. DATA ANALYSIS AND SIMULATIONS

The correlations of two particles are measured in the momentum difference variable $k^* = Q_{\rm inv}/2 = 1/2\sqrt{(p_1 - p_2)^2 - (E_1 - E_2)^2}$. To measure the correlation effect, we define the correlation function as a ratio: $C(k^*) = A(k^*)/B(k^*)$. We put pairs of particles coming from the same event (correlated) into numerator $A(k^*)$ and the pairs of particles from different events (not correlated) into denominator $B(k^*)$. Particles which come from Au + Au collisions at $\sqrt{s_{NN}} = 62.4$ and 200 GeV are registered using the main STAR detector, the Time Projection Chamber (TPC). All minimum bias events are divided into three centralities according to the percentage of total cross section of the collision: central (0–10%), midcentral (10–30%), and peripheral (30–80%). Protons and antiprotons are measured in the rapidity window $|y| < 0.5$. Particles are selected using the energy loss in the detector (dE/dx). Protons and antiprotons are chosen in momentum range: $0.4 < p_T < 0.8$ GeV/c. Tracks are extrapolated to a primary vertex. If the shortest distance between track and the vertex exceeds 3 cm, the track is discarded, removing a significant fraction of nonprimary track candidates. The effect of tracks splitting and merging is taken into account, such tracks as well as the contribution from e^+e^- candidates from γ conversion are discarded. The background of the correlation function is constructed by mixing different events according to similar Z-vertex position and multiplicity. Data are corrected for purity, detector resolution effects and Residual Correlations (RCs) arising from decay channels, a complete description of all applied corrections can be found in [10]. To fit experimental correlation functions, we use CorrFit tool [8], which finds the best theoretical correlation function taking into account the minimal value of χ^2 test divided by the number of degrees of freedom.

In order to simulate collisions at $\sqrt{s_{NN}} = 5$, 7.7, 11.5, 17.3, 27 and 39 GeV, version 3.3 of UrQMD model [9] is used. Identical particle cuts as in the experiment are applied here: the transverse momentum of each particle is within $[0.4, 0.8]$ GeV/c and the rapidity interval must be in $y < |0.5|$.

2. RESULTS FOR Au + Au COLLISIONS AT 62.4 AND 200 GeV

Figure 1 shows extracted source sizes from $p-p$, $\bar{p}-\bar{p}$ and $p-\bar{p}$ correlation functions for Au + Au collisions at $\sqrt{s_{NN}} = 62.4$ and 200 GeV for different centrality bins. For all systems the width and height of correlation function decrease and source size increases with increasing centrality. The values of fit give consistent description within all centralities and energies for all identical systems. The agreement between results for identical and nonidentical particle correlations is good; however, small discrepancies do remain. These results indicate that all corrections should be applied together as all of them influence measured correlation functions strongly. Such results are described in [10].

3. UrQMD SIMULATION FOR BES

The main goal of UrQMD simulation is to determine required number of minimum bias events for $p - p$, $\bar{p} - \bar{p}$ and $p - \bar{p}$ correlation functions for three centrality classes and six collision energies at estimated accurancy. We assume the correlation effect is present for $k^* < 50$ MeV/c and the width of one bin of correlation function is 5 MeV/c (10 points of correlation function are considered). In case of statistical error bar of order of 10%, the mean value of 100 pairs per one bin of correlation function is required (1000 pairs at correlation

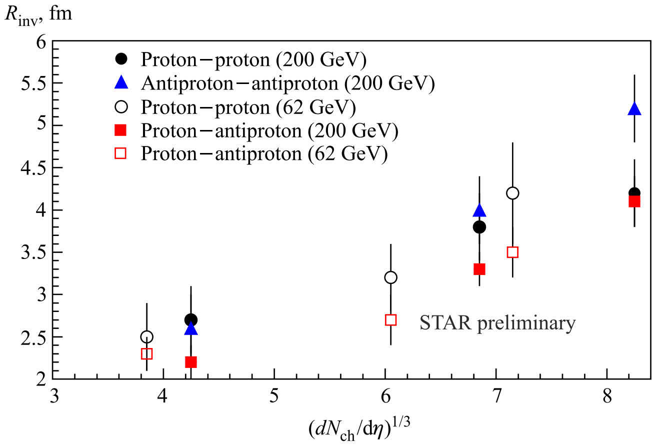

Fig. 1. Results of source sizes of proton femtoscopy with all corrections applied for Au + Au collisions at $\sqrt{s_{NN}} = 62.4$ and 200 GeV as a function of charged particle pseudorapidity density $(dN_{\rm ch}/d\eta)^{1/3}$

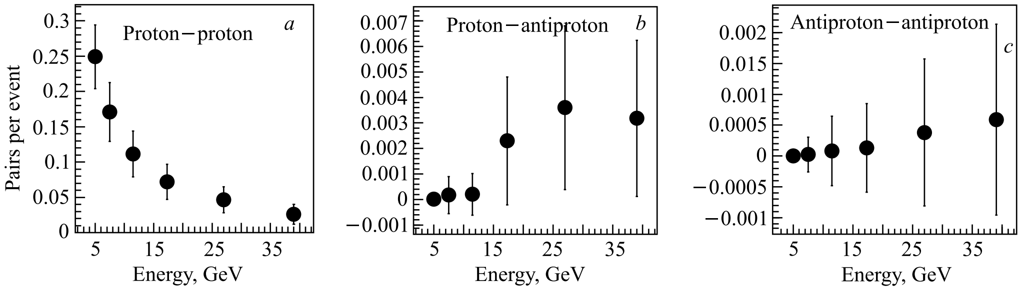

Fig. 2. Mean values of numbers of proton–proton (*a*), proton–antiproton (*b*) and antiproton–antiproton (*c*) pairs with $k^* < 50$ MeV/*c* for minimum-bias collisions as a function of collision energy from UrQMD model. RMS values represent error bars

region). In case of error bar of order of 5% (1%), 4000 (25000) pairs are required. The distributions of mean numbers of $p - p$, $p - \overline{p}$, $\overline{p} - \overline{p}$ pairs per one minimum-bias event for $k^* < 0.05$ GeV/*c* as the function of collision energy are shown in Fig. 2. For each collision energy the distribution of numbers of pairs for considered k^* interval is calculated, the mean and RMS values are taken. The table presents these numbers for three centrality classes separately.

In order to calculate correlation function of order of assumed error bar, one needs to scale the average number of pairs according to the required number of minimum-bias events.

4. SUMMARY

We have presented preliminary results on $p - p$, $\overline{p} - \overline{p}$ and $p - \overline{p}$ femtoscopy for Au + Au collisions at $\sqrt{s_{NN}} = 62.4$ and 200 GeV per nucleon. Due to the large STAR dataset the analysis could be reformed for three collision centralities. Measurements of proton femtoscopy are consistent within each centrality. Results of UrQMD simulation for BES program allow

Mean and RMS values of distributions of numbers of pairs for $k^* < 50$ MeV/c for collision energies $\sqrt{s_{NN}} = 5, 7.7, 11.5, 17.3, 27, 39$ GeV from UrQMD model. All numbers are multiplied by 10^6

Energy/centrality		$p-p$	$\bar{p}-\bar{p}$	$p-\bar{p}$
5 GeV:	30–80%	8088 ± 9685	0 ± 0	0 ± 0
	10–30%	93969 ± 30760	0 ± 0	0 ± 0
	0–10%	147217 ± 31563	0 ± 0	15 ± 17
7.7 GeV:	30–80%	4663 ± 7448	0 ± 0	3 ± 7
	10–30%	59146 ± 24837	8 ± 12	70 ± 46
	0–10%	107035 ± 32656	16 ± 25	99 ± 59
11.5 GeV:	30–80%	2566 ± 4293	21 ± 39	8 ± 16
	10–30%	35929 ± 19085	20 ± 27	68 ± 45
	0–10%	73960 ± 26108	41 ± 38	125 ± 62
17.7 GeV:	30–80%	1655 ± 562	10 ± 17	82 ± 52
	10–30%	22826 ± 14061	44 ± 36	770 ± 763
	0–10%	47379 ± 19885	77 ± 59	1444 ± 967
27 GeV:	30–80%	1121 ± 1237	24 ± 31	83 ± 84
	10–30%	14235 ± 9704	158 ± 166	1072 ± 1022
	0–10%	31271 ± 15358	197 ± 160	2446 ± 1665
39 GeV:	30–80%	568 ± 804	1011 ± 205	12 ± 25
	10–30%	7962 ± 6806	211 ± 87	998 ± 626
	0–10%	17427 ± 10375	364 ± 253	2115 ± 1560

one to estimate the statistics needed for two-proton femtoscopy with estimated accuracy. STAR experiment will create a complex measurement of $p-p$, $\bar{p}-\bar{p}$ and $p-\bar{p}$ femtoscopy for various collision energies and centralities.

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