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PROTON FEMTOSCOPY* **

Sebastian Siejka

for the STAR Collaboration

Faculty of Physics, Warsaw University of Technology
Koszykowa 75, 00-662 Warszawa, Poland

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Geometry and dynamics of the particle-emitting source in heavy-ion collisions at high energies can be inferred via the method of femtoscopy. The femtoscopy method uses effects of Quantum Statistics and Final State Interactions to determine the space-time properties of the source. Learning how the sizes of particle-emitting sources depend on different variables is an important step towards understanding heavy-ion collisions. The RHIC Beam Energy Scan (BES) program provides a unique possibility to study the energy dependence of the source sizes aside from the dependence from the centrality of the collision. The radii of the sources extracted from two-baryon femtoscopy along with those obtained from two-meson and meson–baryon correlations provide complementary information about the source characteristics. In this report, a status of the STAR analysis on femtoscopic correlations of protons and antiprotons in Au+Au collisions from the Beam Energy Scan is presented.

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1. Introduction

The analysis is based on data collected by the STAR experiment as a part of its Beam Energy Scan (BES) program. The main focus of the BES program is to map the Quantum Chromodynamics (QCD) phase diagram by collecting data on the Au+Au collisions at $\sqrt{s_{NN}}$ ranging from 7.7 up to 62.4 GeV [1]. The information about the source sizes can be obtained with the use of the femtoscopy method.

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2. The femtoscopy method

It is not possible to measure directly characteristics of particle-emitting sources created during the heavy-ion collisions. The femtoscopy method allows us to learn about the source through analysis of correlation functions of particles emitted from it. The correlation function (CF) (2.1) can be defined as a ratio between two-particle distribution (2.2) and a product of two single-particle distributions (2.3), which corresponds to the probability of observing two particles together divided by the probability of observing these particles separately

$$C(p_1, p_2) = \frac{P_2(p_1, p_2)}{P_1(p_1)P_2(p_2)}\,, \tag{2.1}$$

$$P_2(p_1, p_2) = E_1 E_2 \frac{\mathrm{d}N}{\mathrm{d}^3p_1 \mathrm{d}^3p_2} = \int \mathrm{d}^4x_1 S(x_1, p_1) \mathrm{d}^4x_2 S(x_2, p_2) \Psi(x_2, p_2 | x_1, p_1)\,, \tag{2.2}$$

$$P_1(p) = E \frac{\mathrm{d}N}{\mathrm{d}^3p} = \int \mathrm{d}^4x S(x, p)\,, \tag{2.3}$$

where $S(x, p)$ is the emission function and Ψ describes the pair mutual interaction.

Measurements can be performed for functions of identical particle combinations (*i.e.* proton–proton and antiproton–antiproton) and functions of non-identical particle combinations (*i.e.* proton–antiproton) (Fig. 1).

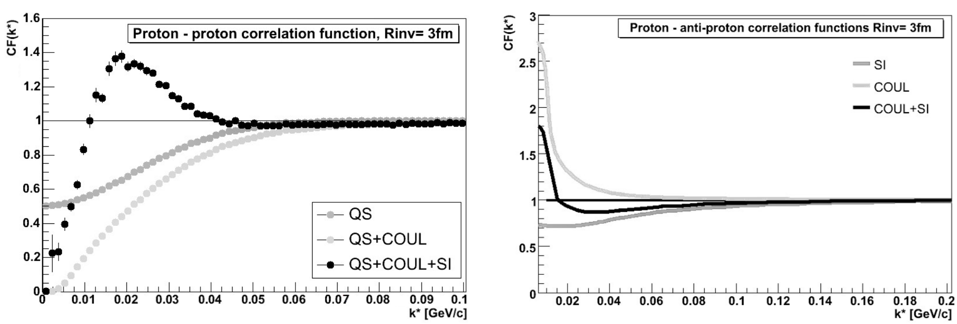

Fig. 1. Theoretical prediction of correlation functions from data generated by the UrQMD model for the source size of 3 fm. Left: identical proton–proton CF. Right: non-identical proton–antiproton CF [2].

The correlation function of identical baryons consists of Final State Interactions: Coulomb interactions (COUL on the plot) and Strong interaction (SI on the plot) as well as the Quantum Statistics (labeled QS on the plot). The baryon–antibaryon correlation function is affected only by the Final State Interactions.

3. Analysis

At the current stage, the analysis has been done for three of the BES $\sqrt{s_{NN}}$ energies: 7.7 GeV, 11.5 GeV and 39 GeV. The data has been selected according to the criteria listed in Table I.

TABLE I

List of used selection criteria.

Momentum (p)	$0.4 < p < 3.0$ [GeV/c]
Transverse momentum (p_{T})	$0.4 < p_{\mathrm{T}} < 2.5$ [GeV/c]
Pseudorapidity (η)	$-0.5 < \eta < 0.5$
Distance of closest approach (DCA)	DCA < 1 [cm]
Mass window	$0.76 < m < 1.03$ [GeV/c^2]
$N\sigma$	$-3.0 < N < 3.0$
Z vertex:	[cm]
— 7.7 GeV	$-70 < z < 70$
— 11.5 GeV	$-50 < z < 50$
— 39 GeV	$-30 < z < 30$

For each energy, the data has been divided into 3 centrality groups: the central collisions group made of 10% most central of all the collisions (labeled 0–10%), midcentral group made of 20% of all the collisions (10–30%) and peripheral group made of 40% of all the collisions (30–70%). Theoretical correlation functions were fitted to the data (Fig. 2) using CorrFit [3].

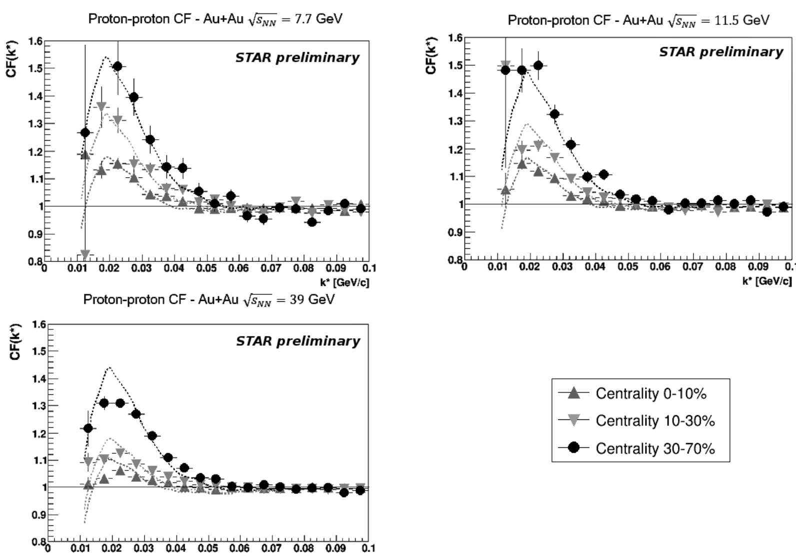

Fig. 2. Proton–proton correlation data with fitted correlation functions for different centrality classes and $\sqrt{s_{NN}}$.

Values of radii as well as statistical uncertainties were estimated based on χ^2 tests between measured correlation functions and functions fitted to the data — the best fits have been selected as results. Obtained radii have been compiled in Table II. Low statistics of antiprotons at lower energies did not allow us to extract radii for all centralities and energies.

TABLE II

Values of extracted radii in Au+Au collisions for three collision energies. Only statistical uncertainties have been estimated.

Centrality bin	39 GeV	11.5 GeV	7.7 GeV
Proton–Proton			
0–10%	4.03 ± 0.14 fm	3.661 ± 0.071 fm	3.59 ± 0.14 fm
10–30%	3.60 ± 0.14 fm	3.18 ± 0.14 fm	3.06 ± 0.14 fm
30–70%	2.766 ± 0.070 fm	2.65 ± 0.14 fm	2.53 ± 0.14 fm
Proton–Antiproton			
0–10%	3.56 ± 0.14 fm	2.88 ± 0.14 fm	2.30 ± 0.14 fm
10–30%	3.43 ± 0.42 fm	2.61 ± 0.42 fm	N/A
Antiproton–Antiproton			
0–10%	3.95 ± 0.14 fm	3.79 ± 0.21 fm	3.05 ± 0.14 fm

The data shows that there is a centrality dependence of source size. The radii increase with centrality at fixed $\sqrt{s_{NN}}$.

4. Summary

Proton femtoscopy is sensitive to Final State Interactions and Quantum Statistics effects and can be used to obtain source sizes from the correlation functions. The analysis has been done for three out of six BES energies. Each analysis has been divided into 3 centrality groups and in each case 3 systems have been checked: proton–proton, proton–antiproton and antiproton–antiproton. The extracted radii show a clear centrality dependence: radii increase with centrality at fixed collision energy.

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