Measurement of p-Ξ^- Correlation Function in Isobar and Au+Au Collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV with the STAR Detector

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Abstract. Understanding the strong interactions between baryons, especially hyperon-nucleon (Y-N) interactions, is crucial for comprehending the equation-of-state (EoS) of the nuclear matter and inner structure of neutron star. In these proceedings, we present the measurements of p–Ξ^- correlation functions with high statistics in Isobar (Ru+Ru, Zr+Zr) and Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV by the STAR experiment. With the Lednický-Lyuboshitz approach, the source size and strong interaction parameters of p–Ξ^- pairs are extracted.

1 Introduction

Baryon interactions are of fundamental interest in nuclear physics and astrophysics. Further, the EoS of the nuclear matter at high baryon density that governs the properties inside neutron stars depends on baryon interactions [1]. Among all the baryon interactions, interactions between Y-N and hyperon-hyperon (Y-Y) are of utmost importance to solve the hyperon puzzle [2]. p–Ξ^- interactions with $S = -2$ sector have long been of interest in theory and experiments as they are proposed to be a potential decay channel for the H-dibaryon (consisting of six quarks: *uuddss*) particle [3].

In heavy-ion collisions, two-particle femtoscopy is a powerful and unique method for extracting information about the spatio-temporal properties of the source, characterising the final state interactions (FSI), and searching for the possible bound states. In these proceedings, we present new results of p–Ξ^- correlation using high statistics data from Isobar and Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV by the STAR experiment.

2 Correlation Function

The observable of interest in femtoscopy is the two-particle correlation function. The correlation function can be expressed theoretically as $C(k^*) = \int d^3r^* S(r^*)|\Psi(r^*,k^*)|^2$, where k^* and r^* are the relative momentum and relative distance of the pair of interest in the Pair rest Frame (PRF) reference. $S(r^*)$ is the source function and $\Psi(r^*,k^*)$ represents the wave function of the pair of interest. Experimentally, this correlation function is computed as $C(k^*) = \mathcal{N}[A(k^*)/B(k^*)]$, where $A(k^*)$ is the correlated pairs in same-event, and $B(k^*)$ is the un-correlated background pairs obtained from mixed-events. The normalization parameter $\mathcal{N}$

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is chosen such that the mean value of the correlation function equals unity for k^* [200, 400] MeV/c.

The correlation function is parameterized using the Lednický-Lyuboshitz (LL) model [4], which considers a static spherical Gaussian source under a smoothness approximation [5], convoluted with an S-wave function. In LL model, the complex scattering amplitude $f^S(k^*)$ with Coulomb interaction is evaluated via the effective range approximation,

$$f^S(k^*) = [\frac{1}{f_0^S} + \frac{1}{2}d_0^S k^{*2} - \frac{2}{a_c}h(\eta) - ik^* A_c(\eta)]^{-1} \qquad (1)$$

where f_0^S is scattering length, d_0^S is effective range of the interaction, a_c is the Bohr radius, $h(\eta)$ is complex function, η and A_c are Coulomb related factor, and S denotes the total spin of the pair. A spin-averaged fit is considered in this work.

3 Results

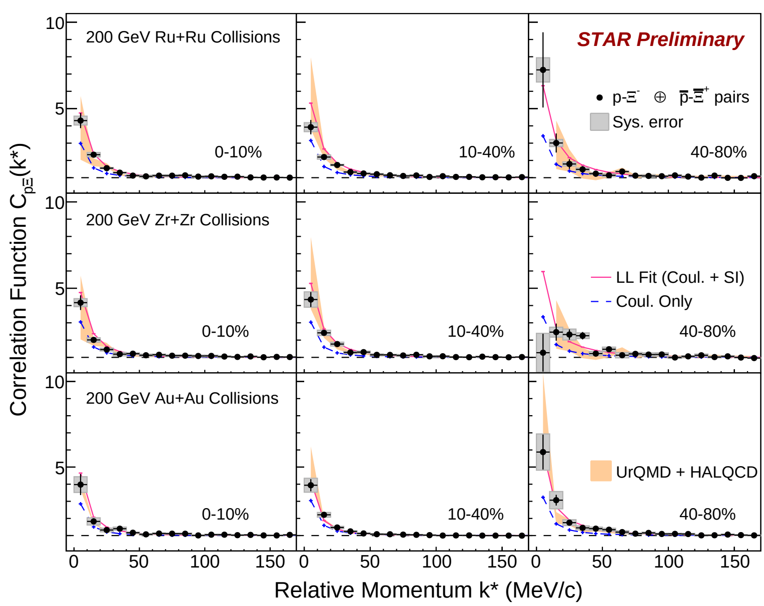

Figure 1. Measured p–Ξ^- correlation functions in 0-10% (left), 10-40% (middle) and 40-80% (right) centrality in Ru+Ru (top), Zr+Zr (middle) and Au+Au (bottom) collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. The black vertical bars and boxes represent the statistical and systematic uncertainties, respectively. In each colliding system, the measured correlation function of three centralities are fitted simultaneously with Lednický-Lyuboshitz function, shown as magenta lines, including effects of Coulomb and strong interactions. Correlation functions with pure Coulomb are shown as blue dashed line. The orange bands represent the results from UrQMD + HALQCD simulation [6-7].

Fig. 1 shows the measured p–Ξ^- correlation function as a function of k^* in three centrality bins in Isobar and Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. The measured correlation functions show clear enhancement at low k^* in all centrality classes and become more pronounced in peripheral collisions. The correlation functions are simultaneously fitted with LL model with five free parameters (Source size (R_G) for three centrality bins, a common f_0 and d_0) in each collision system using Bayesian method [8]. It is clear that only Coulomb interaction cannot account for the full measured correlation functions. Results of the UrQMD + HALQCD calculations [6-7] are shown as orange band in the Fig. 1. The p_T spectra of single particles from UrQMD model is employed to generate phase space, the interaction potential is provided by Lattice QCD [6-7]. The simulated model results describe the data reasonably well in all centrality classes.

Fig. 2 shows the probability density distribution of the strong interaction parameters f_0 and d_0 for p–Ξ^- pairs for each collision systems obtained from the LL fit. It is found that the f_0 and d_0 are consistent with Isobar and Au+Au collisions within 1σ. Using same fitting procedure, the results from UrQMD simulation are consistent with data within 1σ. The f_0 is determined in the range [0.57, 0.90] fm, which is relatively small, indicating that the attractive interaction between p–Ξ^- pairs is shallow. Fig. 3 panel (b) shows the comparison with HALQCD theory, it is observed that the HALQCD prediction is within good agreement with experimental data. This is the first time, the strong interaction parameters for p–Ξ^- pairs are extracted.

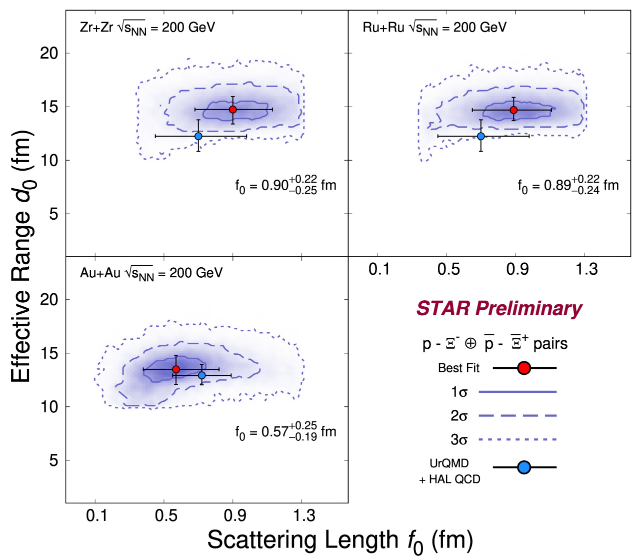

Figure 2. The p–Ξ^- spin-averaged scattering parameters (f_0) and effective range (d_0) obtained from simultaneously fit in Isobar and Au+Au collisions by Bayesian method. The best fit results are shown in red solid points. The purple bands and dashed lines represent the 1σ to 3σ standard deviations of the fit. The blue solid points represent the f_0 and d_0 extracted from UrQMD + HALQCD simulation with same method.

The obtained source size R_G for p–Ξ^- pairs in different centrality classes from the LL fit are presented in Fig. 3 panel (a). It is observed that the R_G exhibit a monotonic decrease from central to peripheral collisions. Among different collision systems, the extracted R_G tends to follow a linear distribution as a function of $dN_{ch}/d\eta$ (charged particles rapidity density). The same fitting were performed to UrQMD simulations and the resulting radius from model are close to data.

4 Summary

In these proceedings, we present the systematic measurements of p–Ξ^- correlation functions in Isobar and Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. For the first time, the source size and

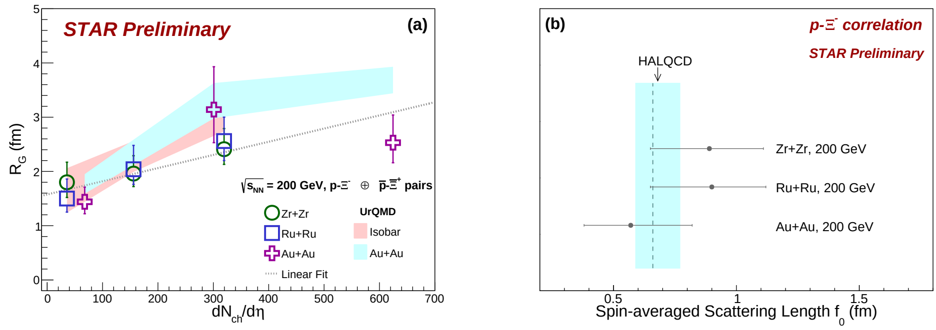

Figure 3. (a) p–Ξ^- source size R_G extracted from LL function as a function of $dN_{ch}/d\eta$ in Isobar and Au+Au collisions. The gray dashed line shows the linear fit to all data points. The pink and blue bands represent the R_G extracted from UrQMD + HALQCD simulation. (b) Comparison of p–Ξ^- scattering length f_0 between experimental data and HALQCD theory predictions. The black points represent extracted f_0 from Ru+Ru, Zr+Zr and Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV, respectively. The blue band represent theory prediction from HALQCD Collaboration, the width of band represents the statistical uncertainties [6].

strong interaction parameters are extracted for p–Ξ^- pairs in each collision systems with Lednický-Lyuboshitz approach. It is observed that, from central to peripheral collisions, the R_G decreases. Calculations from the transport model UrQMD coupled with Lattice QCD potential provide a good description to the data. The extracted strong interaction parameters (f_0, d_0) are consistent between Isobar and Au+Au collisions. The f_0 is a rather small value indicating there's a shallow (Compared to typical n-n interaction) attractive interaction in p–Ξ^- pairs. Our measurements provide strong constraints towards the understanding of Y-N interactions.

5 Acknowledgement

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