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Measuring baryon-(anti-)baryon interaction cross-sections with femtoscopy in Heavy-Ion Collisions

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Abstract

Two-particle correlations at low relative momentum (femtoscopy) are used to study the space-time dynamics of the source created in heavy-ion collisions. The same method can be used in a novel way to study the Final State Interaction potential for various particle pairs. The parameters are also directly related to the relevant interaction cross-sections. Of special interest are correlations of baryons, where the strong interaction often dominates. The femtoscopic technique offers a unique opportunity to study this interaction in such systems. In this work we discuss the similarities and differences of such measurement for baryon-baryon and baryon-antibaryon pairs.

Keywords: femtoscopy, baryon-baryon interaction, cross-section, baryon-antibaryon interaction

1. Femtoscopic formalism and baryon interaction

The analysis of the femtoscopic correlations of baryons has a long history (see e.g. [1, 2]). Recently such analyses have been also performed in heavy-ion collisions at ultrarelativistic energies [3, 4, 5, 6]. Most of the analyses involve baryon-baryon (BB) correlations, sometimes together with the corresponding antibaryon-antibaryon ($\bar{B}\bar{B}$) ones. The two are expected to be the same, and indeed the recent measurements from ALICE and STAR have shown that the interaction parameters for pp and $\bar{p}\bar{p}$ pairs are identical. However in the pioneering work [3] the STAR Collaboration measured simultaneously the baryon-baryon (BB) and baryon-antibaryon ($B\bar{B}$) correlation function and found a strong disagreement of the extracted source parameters between the $p\Lambda$ and $\bar{p}\Lambda$ systems. This was unexpected, as heavy-ion collision models universally predict a very similar source size for both systems. This apparent discrepancy was later explained, and found to be an effect of residual correlations (RC) [7, 8]. The RC have been explicitly not taken into account in [3], where the discrepancy was reported, but were included in all the latest analyses [4, 5, 6]. This explanation brings an interesting question: why are the RC a major contribution to the $B\bar{B}$ correlations, while the BB and $\bar{B}\bar{B}$ correlations are influenced only slightly? In this work we show that such difference is actually expected and is a result of the nature of the strong interaction in both pair systems.

The formalism that is usually used in baryon correlation analyses has been formulated by Lednicky and Lyuboshitz in [9]. It takes into account the strong interaction between baryons, as well as effects of quantum statistics for identical particles. A more complete version of the formalism, which includes the Coulomb interaction for charged particles as well is given in [10]. It is necessary to use the complete formalism for pp pairs, while for the other ones considered in this work the formalism with strong interaction and

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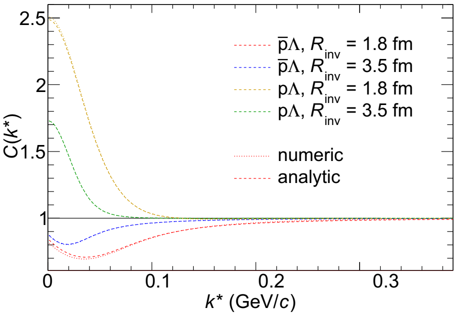

Fig. 1. (Color online) Correlation functions for $p\Lambda$ and $\bar{p}\Lambda$ systems for two example invariant radii, calculated with two methods (see text for details).

quantum statistics is sufficient. The influence of the shape of the interaction potential, the collective flow, as well as feed-down corrections (although not usig the complete residual correlation formalism) have been also discussed recently in [11].

The strong interaction is considered only for the s-wave, and uses the effective range approximation. The scattering amplitude f then takes the form:

$$f(k^*) = \left(\frac{1}{f_0} + \frac{1}{2} d_0 k^{*2} - ik^*\right)^{-1}, \tag{1}$$

where f_0 is the scattering length and d_0 is the effective range of the interaction, while k^* is the momentum of one of the particles in the rest frame of the pair. Both f_0 and d_0 are complex, in particular a non-zero imaginary part of f_0 signals the existence of the annihilation channel in a given interaction. Scattering amplitude is trivially connected to the total scattering cross-section σ, namely $\sigma = 4\pi |f|^2$. Two particles interacting via the Strong Final-State Interaction only will have a Bethe-Salpeter amplitude:

$$\Psi\left(\vec{k^*}, \vec{r^*}\right) = \exp\left(-i\vec{k^*}\vec{r^*}\right) + f(k^*)\frac{\exp(ik^* r^*)}{r^*}, \tag{2}$$

where $\vec{r^*}$ is the space-time separation between the two particles at the time of their creation. Ψ is a superposition of the plane-wave and the outgoing spherical wave. Then the correlation function is expressed with the help of the source function $S(\vec{r^*})$, which can be interpreted as a probability to emit two particles from two points separated by a given r^*:

$$C\left(\vec{k^*}\right) = \int S\left(\vec{r^*}\right)\left|\Psi\left(\vec{k^*}, \vec{r^*}\right)\right|^2 d^4 r^*. \tag{3}$$

If S is a Gaussian in the Pair Rest Frame (PRF) with a single-particle width R_{inv}, then the integral Eq. (3) can be carried out analytically and gives the "Lednicky&Lyuboshitz" model formula for the correlation function, first introduced in [9]:

$$C(\vec{k^*}) = 1 + \sum_S \rho_S \left[\frac{1}{2}\left|\frac{f(k^*)}{r_0}\right|^2\left(1 - \frac{d_0^S}{2\sqrt{\pi}r_0}\right) + \frac{2\Re f(\vec{k^*})}{\sqrt{\pi}r_0}F_1(2k^* r_0) - \frac{\Im f(\vec{k^*})}{r_0}F_2(2k^* r_0)\right], \tag{4}$$

where F_1 and F_2 are known functions (see [9] for the definition). This formula is used in all above-mentioned experimental works on baryon correlations.

2. Constraints on the analytical formula

All considerations of baryon interaction are intrinsically limited by our knowledge of the strong interaction potential for baryon pairs. In particular the behavior of the potential at small distances is not known [12].