Baryon-(anti-)baryon and baryon-meson interaction cross-section measurement with femtoscopy technique in heavy-ion collisions

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Abstract: Interaction cross-sections for baryon pairs are of fundamental interest and they are actively investigated theoretically. They are known well for pairs of common (anti-)baryons, however there is a lack of precise data for heavier baryons, including the ones carrying strangeness. The so-called kaonic atoms are also investigated theoretically and their properties crucially depend on the kaon-nucleon interaction. The two-particle correlation formalism (femtoscopy) is sensitive to the interaction kernel for a pair of particles, which is related to the pair interaction cross-section [1]. The formalism is extensively used to measure two-particle correlations in heavy-ion collisions. In particular the collisions at RHIC and LHC produce simultaneously large number of baryons and antibaryons and even larger number of kaons. We show how this formalism can be used to extract the cross-sections from the femtoscopic baryon-(anti)-baryon correlation functions [2], as well as from proton-charged kaon functions. The analysis is complicated by the presence of the so-called “residual correlations” arising from weak decay products in the measured sample. We show how this effect can be exploited to gain further insight into the cross-sections of even heavier baryons. We discuss the limitations of the measurement technique and estimate the discovery potential of currently available and soon-to-be-collected heavy-ion collision datasets at RHIC and at the LHC.

Formalism

The correlation function is a ratio of the conditional probability to observe two particles together, divided by the product of probabilities to observe each of them separately. Experimentally it is measured by dividing the distribution of relative momentum of pairs of particles detected in the same collision (event) by an equivalent distribution for pairs where each particle is taken from a different collision.

The femtoscopy technique focuses on the mutual two-particle interaction. For two identical particles the wave-function is (anti-)symmetrized. The Final State Interaction (FSI) are the Coulomb when both particles are charged and strong for two hadrons. Out of those the Strong interaction is of particular interest, as for some pair types it is still not fully understood. This is the focus of this work.

In femtoscopy an assumption is made that the FSI of the pairs of particles is independent from their production. The two-particle correlation can then be written as [1,2]:

\[ C(k) = \frac{\int S(r, k') \Psi^*_{1}(r, k') \Psi_{2}(r, k') \, r \, dr}{\int S(r, k') \, r \, dr} \]

where \( r \) is the pair relative separation at creation, \( k' \) is the momentum of the first particle in the Pair Rest Frame, \( S \) is the source function giving the probability to emit a given pair from a certain separation. \( \Psi \) describes the state of the Strong component and it is the solution of the Quantum scattering problem with the inverse time direction.

\[ \Psi^*_{1}(r, k') = e^{-ik'r} + f^* \frac{e^{-ik'r}}{r} \]

where \( f \) is the scattering amplitude and the \( S \) superscript denotes spin dependence. Coulomb modifies this formula slightly, and it is (anti-)symmetrized for identical particles. The femtoscopic correlation function is then the particle emitting source viewed through the interaction lens.

**Overview:**

- **Figure 1** shows the strong FSI correlation function for selected interaction parameter sets.
- **Figure 2** demonstrates residual correlation contributions.
- **Figure 3** illustrates the Kp Coulomb+Strong correlation function sensitive to interaction parameters.

**Connection to cross-section**

In the effective range approximation the scattering amplitude in the s-wave can be expressed as:

\[ f^s(k) = \frac{1}{k} \sum f_i(k) \]

where \( f_i \) is the scattering length and \( d_i \) is the effective range. The interaction cross-section \( \sigma \) is then simply:

\[ \sigma = 4\pi f^2 \]

For a Gaussian source with directionally-averaged radius (width) \( r \), the correlation function is then given analytically \( f_i \) and \( f \) are known functions [2]).

This functional form is fitted to the experimental femtoscopic correlation function and the \( f_i \) and \( d_i \) can be extracted as fitting parameters. However simultaneous fitting of \( r \) as well as \( \sigma \) is not possible. Fig. 1 shows that the function is sensitive to the value of the interaction parameters (for pA the known interaction parameters from experiment were used).

The system size must be fixed in the fitting process, based on precise femtoscopic measurements for other pairs as well as on model assumptions on how the size changes between pairs of different mass. With that assumption the parameters can be extracted.

**Summary:**

The femtoscopic correlation function is directly sensitive to the parameters of the strong interaction potential parametrization and the interaction cross-section. For pairs of baryons the residual correlations come from heavier (strange) baryon pairs must also be taken into account. Current experimental setup and datasearch should allow for measurements of interactions of protons and lambda and different collisions in STAR and ALICE. Similarly the Kp femtoscopic correlation function can be used to measure the relevant strong interaction, which may have direct consequences for the so-called “kaonic atom” studies, and the strangeness-baryonic matter interaction. ALICE and STAR should enable such measurement with at least 0.5 fm precision for real and imaginary part of \( f_i \).

**Kaon-proton correlation**

The correlation for Kp pairs comes from Coulomb interaction as well as the strong interaction containing the meson-baryon annihilation channel. This is the strangeness-baryonic matter interaction that is also the focus of intense investigation via the “kaonic atom” studies. In Fig. 3 example correlation functions are shown for different sets of interaction parameters. The correlation is clearly sensitive to the interaction cross-section at LHC should be possible to obtain data precise enough to distinguish between the values. It should be possible to measure in AA collisions at ALICE the real and imaginary component of \( f_i \) to at least 0.5 fm precision.

**References:**