Study of baryon-antibaryon interactions with the femtoscopy method

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Studies of baryon-antibaryon strong interactions can provide parameters for theoretical models, shed light on hypothetical bound states and aid to understand annihilation processes. Femtoscopy offers a unique method to access such information. Few studies have already been performed, e.g. [1], [2], [3], [4], however further research can still improve our knowledge.

Baryon—antybarion interactions

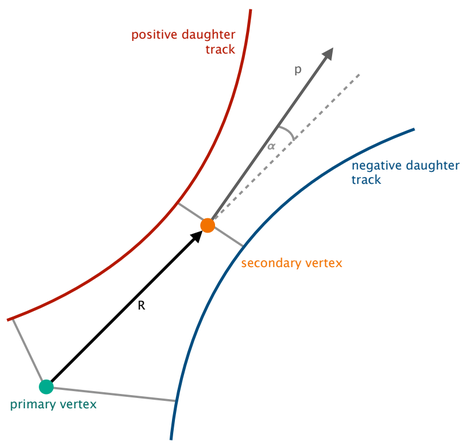
Strong interactions at low relative momentum (k^*) can be described with the scattering parameters:

f_0 - *scattering length* $\left(\Re f_0, \Im f_0\right)$
d_0 - *effective potential length*

Inner structure of proton, Λ, and Ξ^- particle.

The $\Re f_0$ corresponds to elastic interactions and $\Im f_0$ part to inelastic.
f_0 is also closely related to the cross section.

Experimental data



Example of Λ decay geometry.

Heavy ion collisions are a great source of baryon and antibaryons.

Sometimes, only decay products are detected, e.g.:

$\Xi^- \rightarrow \Lambda + \pi^-$ *BR* (99.887 ± 0.035) %

$\Lambda \rightarrow p\pi^-$ *BR* (63.9 ± 0.5) %

After reconstruction, cuts are applied to determine the particle type.

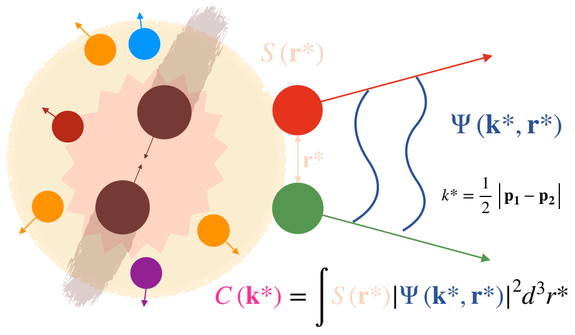
Limited identification precision needs to be considered.

Femtoscopy

Femtoscopy focuses on correlations of particle pairs at low k^*.

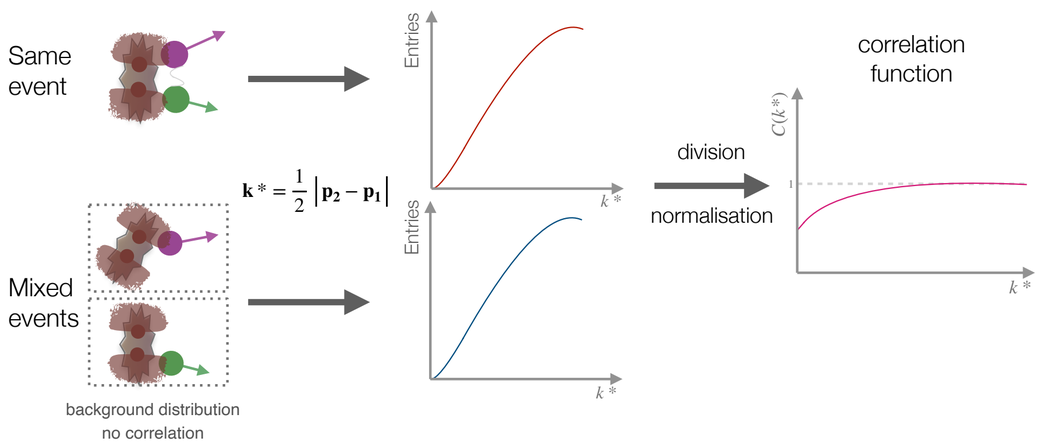
The shape of the correlation function depends on:

- particle-emitting source,
- Final State Interactions (FSI),
- quantum statistics effects.



Idea of femtoscopy.. Based on figure from Wloleta Rzęsa, PhD thesis

Experimental correlation function can be calculated as presented below:

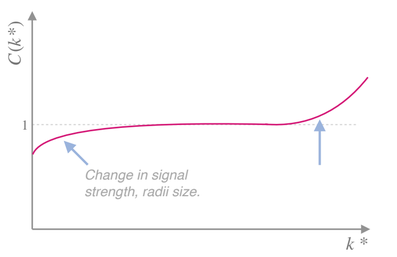


Non-femtoscopic background

Examples of background effects in CF include mini-jets, conservation laws and collective flow.

To remove it from raw CF:

- those effects can be reproduced with simulations,
- raw data can be fitted with chosen polynomial in k^* where no femtoscopic signal is expected.



Visual representation of background effect on correlation function.

Fitting procedure

Lednicky-Luboshitz model connects correlations with scattering parameters and particle emitting source size R, when only strong interactions are present:

$$C(k^*) = 1 + \sum_\sigma \rho_\sigma \left[\frac{1}{2} \left| \frac{f(k^*)}{R} \right|^2 \left(1 - \frac{d_0^\sigma}{2\sqrt{\pi} R} \right) + \frac{2\Re f(k^*)}{\sqrt{\pi} R} F_1\left(2k^* R\right) - \frac{\Im f(k^*)}{R} F_2\left(2k^* R\right) \right]$$

The sum is over pair spin states - omitted when dealing with spin-averaged parameters. F_1 and F_2 are known functions.

It allows to extract $\Re f_0$, $\Im f_0$ and d_0 from the CF fit.
For charged particles other approaches are taken to account for Coulomb interactions.

Considerations

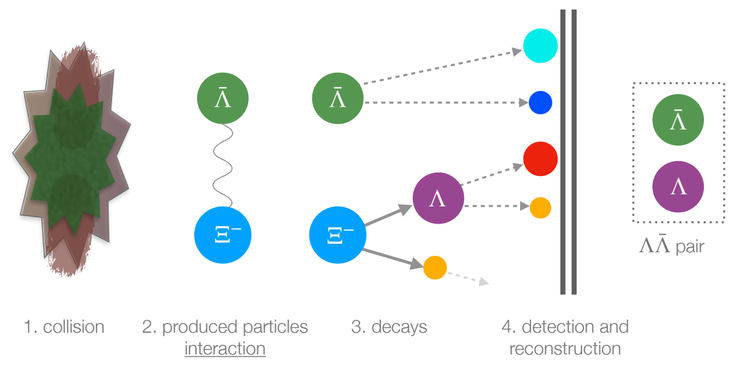
- detectors' momentum resolution - probability that a pair with k^*_{truth} is reconstructed with k^*_{reco} is estimated with simulations and the fitting function can be accordingly smeared,
- radii scaling - radii dependance on the event's multiplicity (related to centrality) can be assumed. Then, only one radii needs to be fitted and the rest is calculated.

$$R = \alpha \sqrt[3]{N} + \beta$$
Possible radius dependance on multiplicity N. α and β parameters can be determined in the fitting process.

Residual correlations

It is difficult to distinguish particles from the collision and from secondary decays.

In the illustration beside, including such $\Lambda\bar{\Lambda}$ pair introduces contribution from $\Lambda\Xi^-$ interactions in CF.



To consider this, the fitting function can take form [5]:

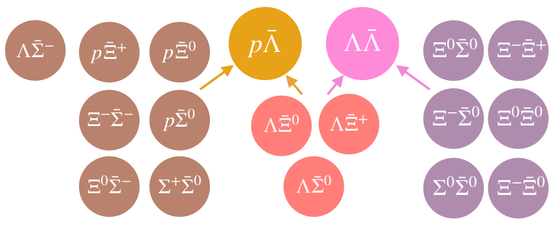
$$C(k^*) = 1 + \sum_i \lambda_i \frac{\int C_i(k_i^*) T(k_i^*, k^*) dk_i^*}{\int T(k_i^*, k^*) dk_i^*}$$

λ - fraction of primary and residual pairs in a sample (estimated with simulations)

T - matrix describing probability of a residual pair with k_i^* decaying into pair with k^*

Radius may be different for residual pairs. It is often assumed to follow relation with transverse mass: $R = \frac{a}{\sqrt{m_T}}$. (a is calculated based on primary pair radius)

It is beneficial to simultaneously fit multiple pairs and consider their shared parameters through residual correlations.



Possible residual correlations for chosen pairs, based on figure from [1].

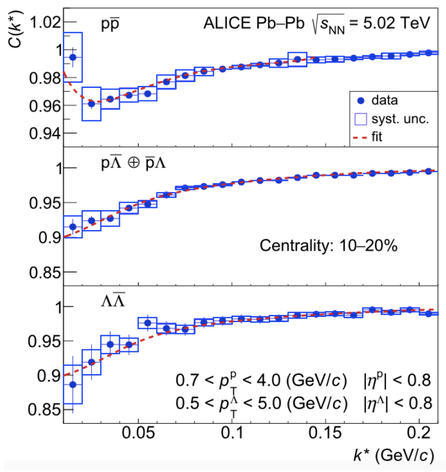
Past studies

Among few studies of this kind [1], [2], [3], [4], the most extensive one was published by ALICE Collaboration [1]:

- $p\bar{p}$, $p\bar{\Lambda}$ and $\Lambda\bar{\Lambda}$ CFs were simultaneously fitted,
- $\Re f_0$, $\Im f_0$ and d_0 were extracted for all pairs, and by considering residual correlations, for heavier pairs.

Authors pointed out:

- similar results for all pairs,
- non-zero $\Im f_0$ (associated with annihilation),
- negative value of $\Re f_0$ (this could imply repulsive interactions or bound states formation).



Three of CFs obtained by authors. Source: ALICE Collaboration, Physics Letters B 802 (2020) 135223

Future studies

In Warsaw University of Technology we are:

- researching different particle pairs, including strange baryons like Λ and Ξ,
- analysing new ALICE data from Pb-Pb collisions to obtain better accuracy.

References
[1] ALICE Collaboration, Measurement of strange baryon-antibaryon interactions with femtoscopic correlations, Physics Letters B 802, 135223, 2020
[2] J. Niedziela, Ph.D. thesis, Investigation of the source size and strong interaction with the femtoscopic correlations of baryons and antibaryons in heavy-ion collisions registered by ALICE, CERN-THESIS-2017-274, 2017
[3] A. Kisiel et. al., Extracting baryon-antibaryon strong-interaction potentials from $p\bar{\Lambda}$ femtoscopic correlation functions, Physical Review C 89, 054916,2014
[4] ALICE Collaboration, Investigating the role of strangeness in baryon– antibaryon annihilation at the LHC, Physics Letters B, 2022, 829, p. 1–15, 2022
[5] A. Kisiel, Baryon-(anti-)baryon interaction cross-section measurement with femtoscopy technique in HIC, PoS(Hadron2017)162

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