Kaon-proton femtoscopy in Pb-Pb collisions with ALICE at the LHC

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ALICE

Introduction – femtoscopy technique

Femtoscopy allows one to measure space-time characteristics of the source of particles using particle correlations in momentum space.

Theory

$$C(\vec{q}) = \int S(\vec{r})|\Psi(\vec{q}, r)|^2 d^3 r$$

$S(\vec{r})$ – source emission function

$\Psi(\vec{q}, r)$ – pair wave function

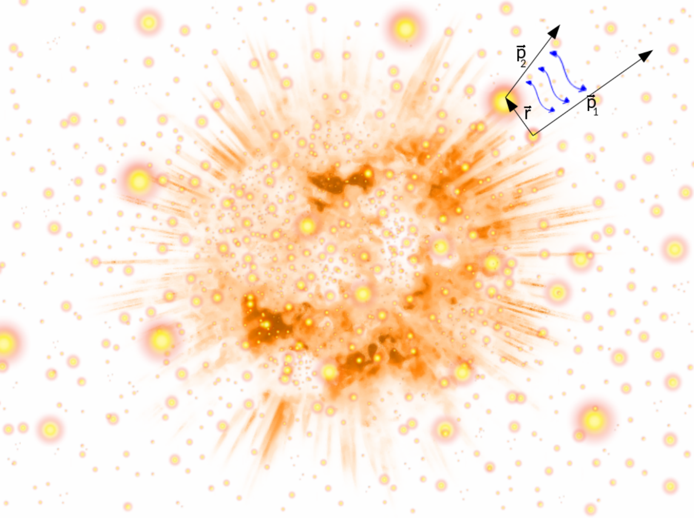
$$\vec{q} = \vec{p_1} - \vec{p_2}$$

Experiment

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

$$C(\vec{k^*}) = \frac{A(\vec{k^*})}{B(\vec{k^*})} = \frac{correlated\ \ pairs}{uncorrelated\ \ pairs}$$

$$\vec{k^*} = \frac{\vec{p_1} - \vec{p_2}}{2}$$



Correlation functions

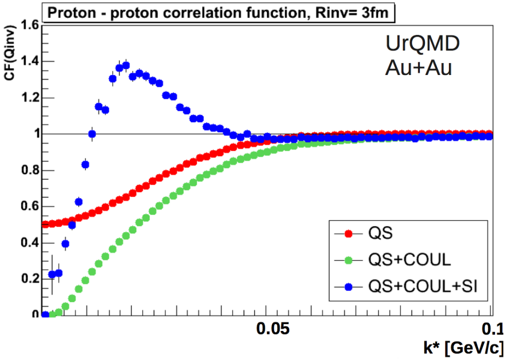
The main sources of correlation for particles in their final states:

Quantum statistics (QS)

- Bose-Einstein QS
- Fermi-Dirac QS

Final-state interaction (FSI)

- Coulomb interaction (COUL)
- Strong interaction (SI)

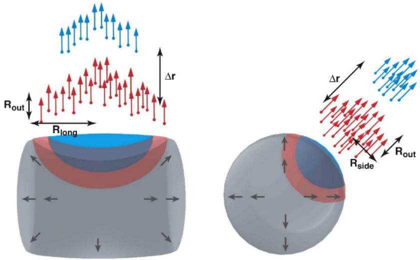


from H. Zbroszczyk, Ph.D. thesis

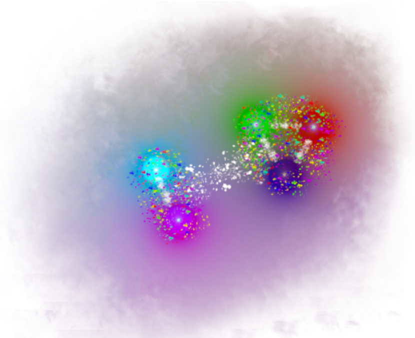
Motivation - why study kaon-proton (Kp) correlation functions?

HBT radii

Radii describe observed correlations at low relative momentum of both particles and are a part of the source emission function ($S(\vec{r})$). They correspond to the size of the region from which particles are emitted with similar velocities. **The HBT radii have never been measured for Kp pairs from Pb-Pb collisions.**



from Ann.Rev.Nucl.Part.Sci.50:357-402,2005



Strong force

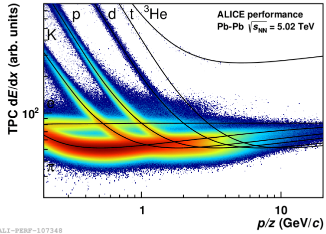
Scattering parameters that describe the strong interaction for K^-p, $K^+\bar{p}$ are very poorly known. This study can shed more light on nuclear equation of state in order to better understand the properties of matter under extreme conditions (e.g. the matter inside neutron stars).

ALICE detector and data sample

Data sample collected by the ALICE experiment at the LHC, from Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV:

- 6 centrality classes: 0-5%, 5-10%, 10-20%, 20-30%, 30-40%, 40-50%
- 4 pairs: K^+p, K^-p, $K^+\bar{p}$, $K^-\bar{p}$

Track reconstruction with the TPC detector.
Particle identification with TPC and TOF detectors.



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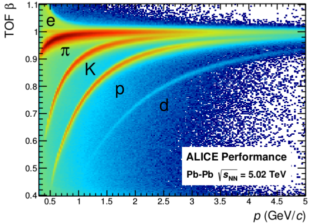

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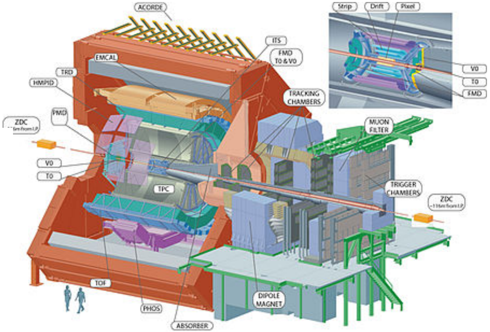


Model: Lednický-Lyuboshitz

$$C(\vec{q}) = \int S(\vec{r})|\Psi(\vec{q},r)|^2 d^3 r,$$

$$S(\vec{r}) \sim e^{-|\vec{r^*}|^2/(4R^2)}$$

The HBT radius

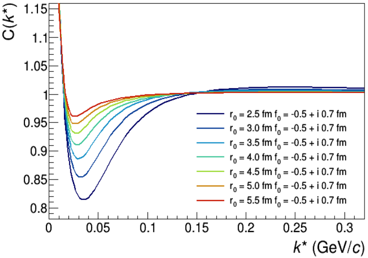
$$|\psi(r^*,k^*)| = \sqrt{A_C(\eta)}\left[exp(-ik^*r^*)F(-i\eta,1,i\xi) + f_c(k^*)\frac{G}{r^*}\right]$$

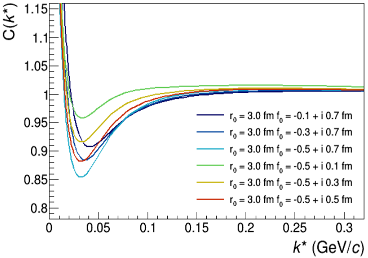
Component related with the strong interaction

$$f_c(k^*) = \left(\frac{1}{f_0} + \frac{d_0 \cdot k^{*2}}{2} - \frac{-2h(k^*a_c)}{a_c} - ik^*A_C(k^*)\right)^{-1},$$

scattering length

where $a_C = -83.59$ fm, $A_C(k^*)$ is the Gamow factor for kaon–proton unlike-sign pairs, $d_0 = 0$, $\zeta = k^*r^*(1+\cos\theta^*)$, θ^* is the angle between k^* and r^*, $\eta = 1/(k^*a_C)$, F, G and h are known.

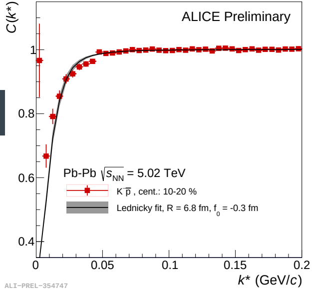


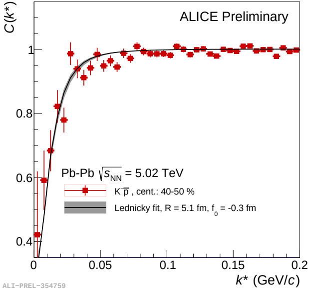


Lednický-Lyuboshitz model, ref.: R. Lednicky and V. L. Lyuboshits, Sov. J. Nucl. Phys. 35, 770 (1982), [Yad. Fiz.35,1316(1981)]

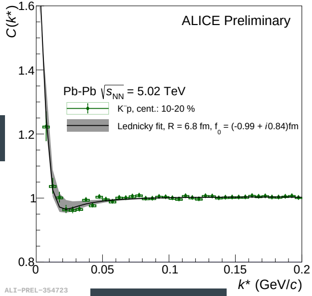
Correlation functions & fit

$K^-\bar{p}$

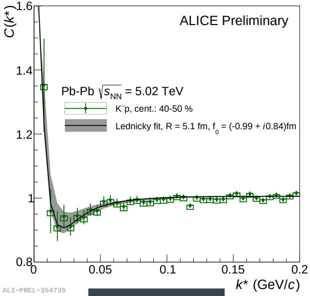




K^-p



cent. 10-20%



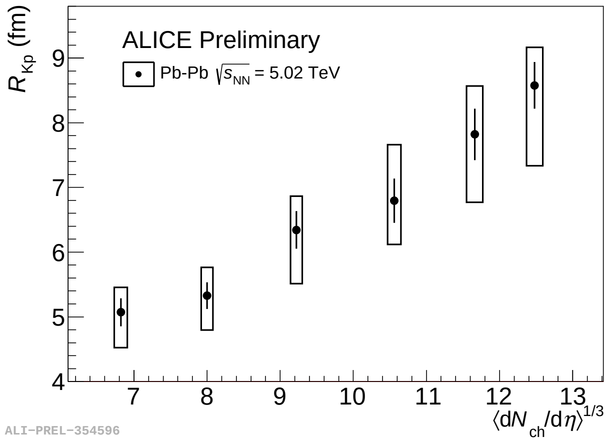
cent. 40-50%

The radius for given centrality is extracted from K^+p and $K^-\bar{p}$ pairs for which scattering lenght is known.

Obtained radii are further fixed in K^-p and $K^+\bar{p}$ pairs in order to estimate scattering length for them.

Results – radii and scattering parameters

HBT radii

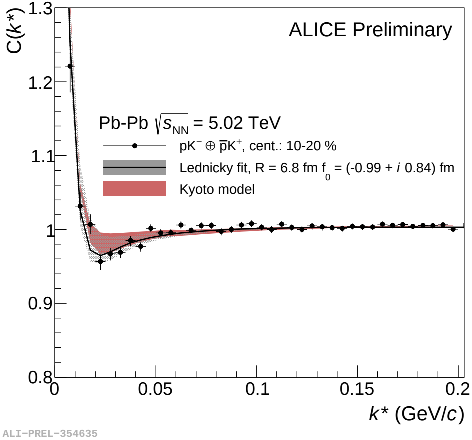


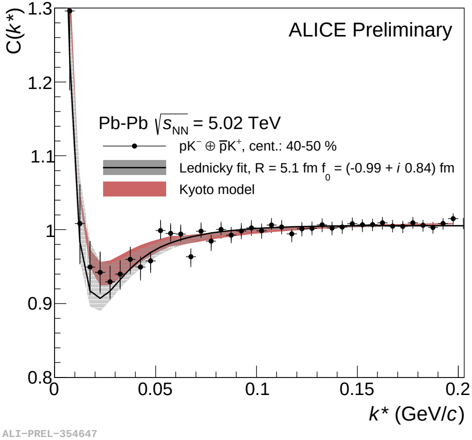
Scattering length

$$Re(f_0) = \text{-}0.99 \pm 0.05(stat)^{+0.49}_{-0.07}(syst)$$

$$Im(f_0) = 0.84 \pm 0.07(stat)^{+0.49}_{-0.26}(syst)$$

Comparison – different model

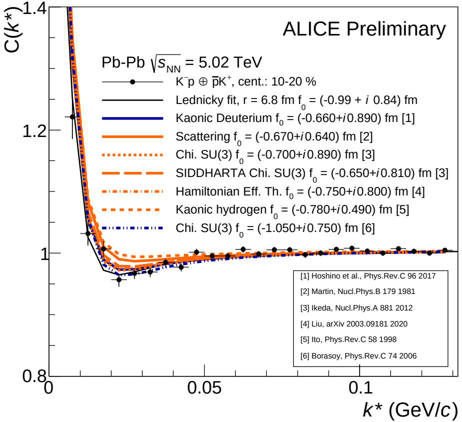




The fit obtained with using Lednicky-Lyuboshitz model were compared with predictions from the Kyoto model. Results from both are in agreement.

Kyoto model, ref.: Y. Kamiya, T. Hyodo, K. Morita, A. Ohnishi and W. Weise, Phys. Rev. Lett. 124 no. 13, (2020), arXiv:1911.01041,
D. Mihaylov, V. Mantovani Sarti, O. Arnold, L. Fabbietti, B. Hohlweger and A. Mathis, Eur. Phys. J. C 78 no. 5, (2018) , arXiv:1802.08481

Comparison – different scattering parameters



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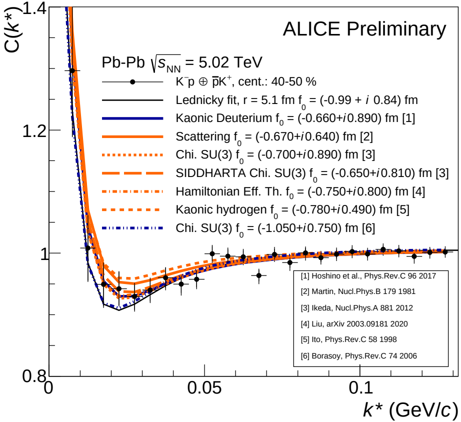

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Available in the literature theoretical estimations and measurements of scattering parameters together with calculated radii were used for theoretical prediction of correlation functions. Most of them are in good agreement with the data.

Summary

- Radii that describe observed correlations at low relative momentum of kaon-proton pairs produced in Pb–Pb collisions have been calculated in 6 centrality classes.
- The study on correlation functions of kaon-proton pairs is a different method that allows for the estimation of poorly known scattering parameters for $K^{-}p$, $K^{+}\bar{p}$ pairs.
- Obtained results are in agreement with different measurements, theoretical estimations and models.

Thank you for your attention :)