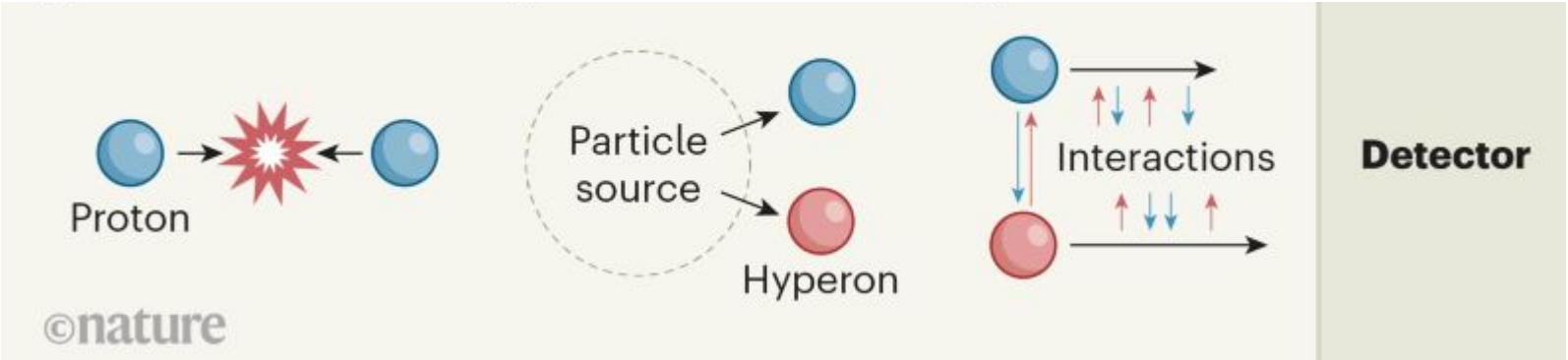
(anti)Kaon-proton femtoscopy in pp and Pb-Pb collisions with ALICE

Otón Vázquez Doce (LNF -INFN)

Frascati, 25 November 2021
Fundamental physics with exotic atoms and radiation detectors

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 754496

Two-particle correlations as a tool for studying h-h interactions



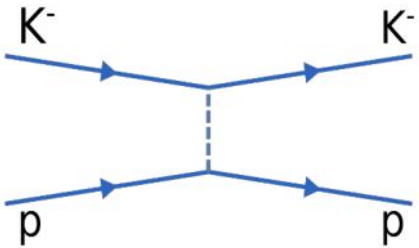
https://www.nature.com/articles/d41586-020-03393-z

Femtoscopy (HBT) analyses in **Heavy Ions Collisions**:

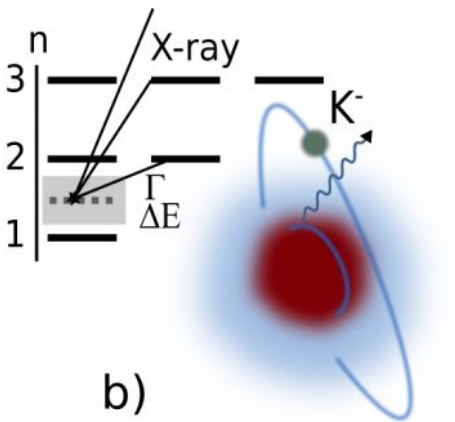
- Study pairs of particles with “known” interaction
- Centered in **study the dimensions of the source** (2-5 fm)

Experimental study of Kp interaction

Scattering

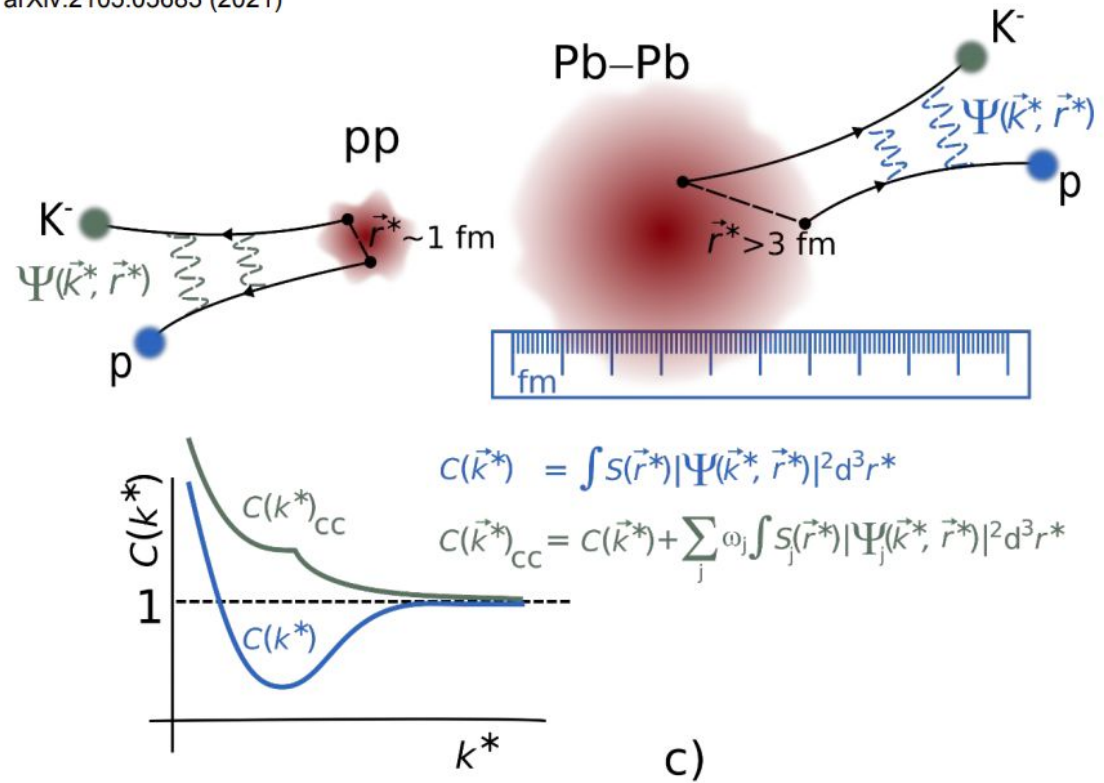


Exotic atoms



ALICE Collaboration,
arXiv:2105.05683 (2021)

Femtoscopy



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

$$C(\vec{k}^*)_{cc} = C(\vec{k}^*) + \sum_j \omega_j \int S_j(\vec{r}^*)|\Psi_j(\vec{k}^*, \vec{r}^*)|^2 d^3r^*$$

The two-particle correlation function

Based on the correlation function $C(k^*) = \frac{P(\vec{p_a}, \vec{p_b})}{P(\vec{p_a})P(\vec{p_b})}$, with $k^* = |\vec{p}_2^* - \vec{p}_1^*|/2$ and $p_1^* = -p_2^*$

Theoretically formulated: $$C(k^*) = \int S(r^*) \left|\Psi\left(k^*, \vec{r^*}\right)\right|^2 d^3r^*$$

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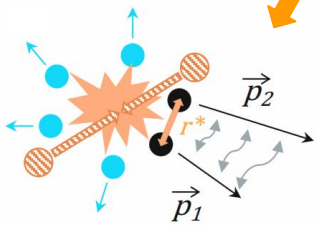

Emission source $S(r^*)$

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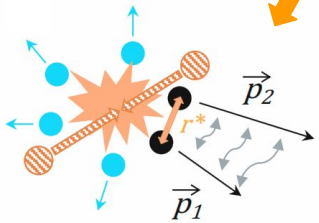

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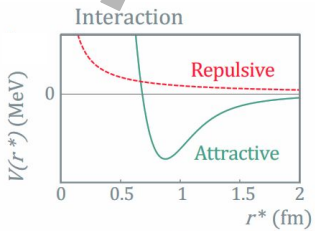

Schrödinger equation

Two-particle wave function

$\Psi(k^*, \vec{r^*})$

The two-particle correlation function

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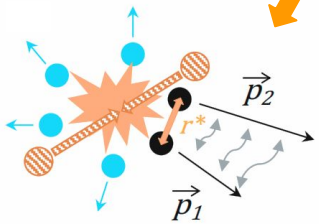

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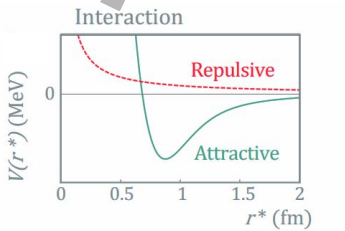

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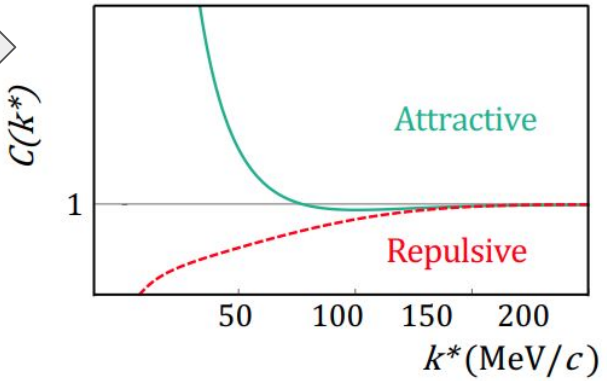

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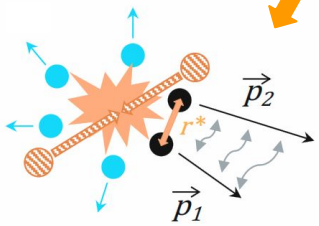

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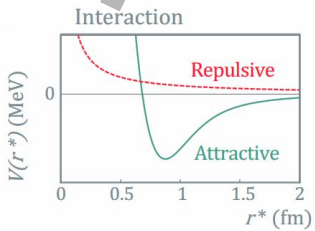

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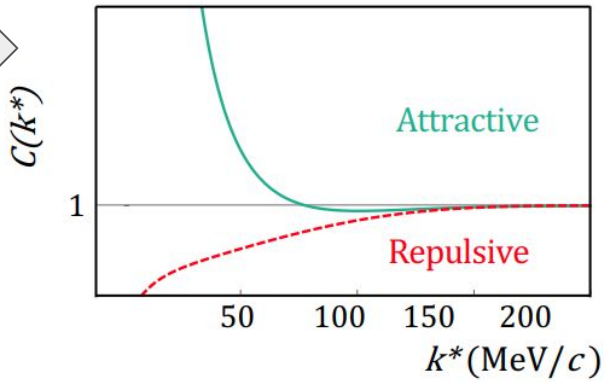

Experimentally obtained:

$$C(k^*) = \xi(k^*) \otimes \frac{N_{\text{same}}(k^*)}{N_{\text{mixed}}(k^*)}$$

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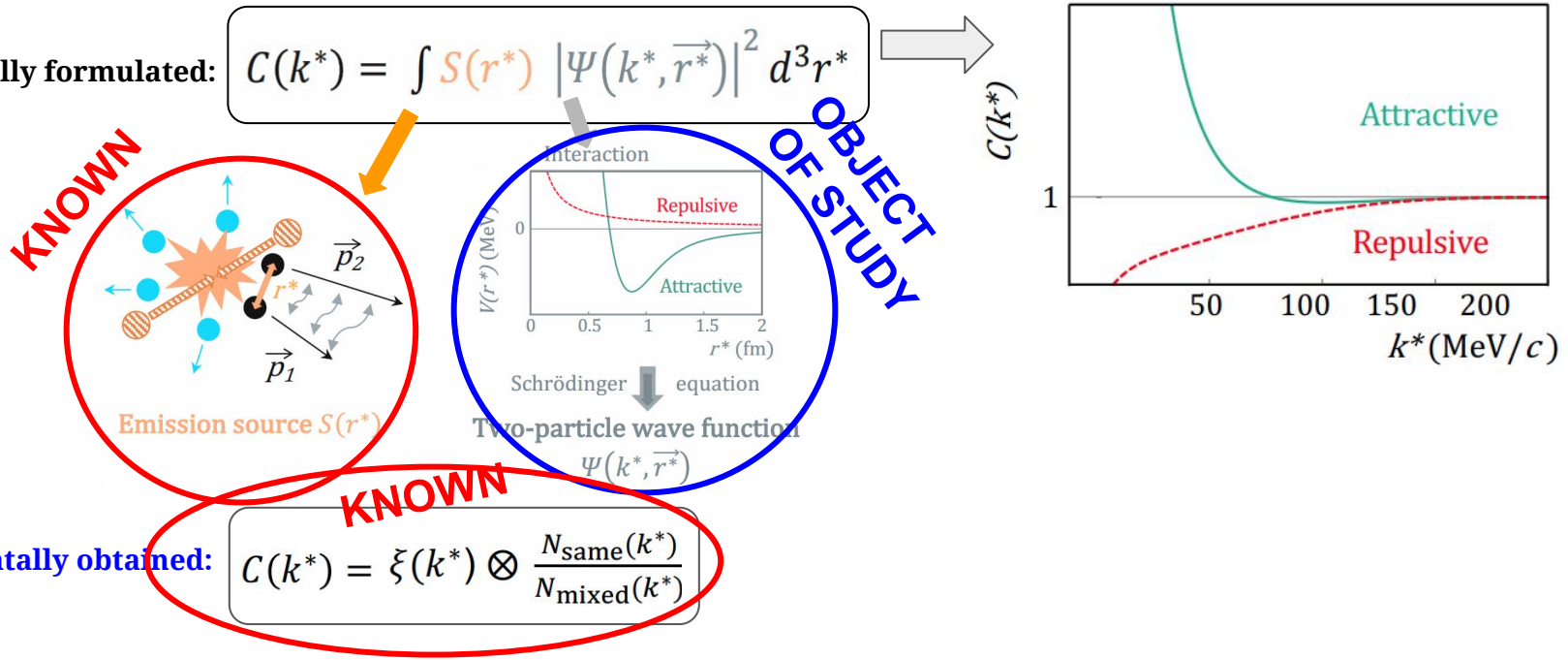
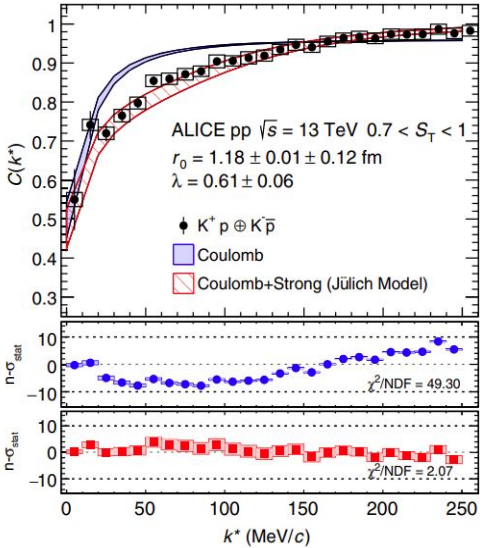


Experimentally obtained:

K-p correlations in pp collisions

"Scattering Studies with Low-Energy Kaon-Proton Femtoscopy in Proton-Proton Collisions at the LHC", ALICE Coll. Phys. Rev. Lett. 124 (2020) 092301



- K^+-p correlation used as a benchmark to study K^--p

Jülich meson exchange model: Eur. Phys. J. A47, 18 (2011)

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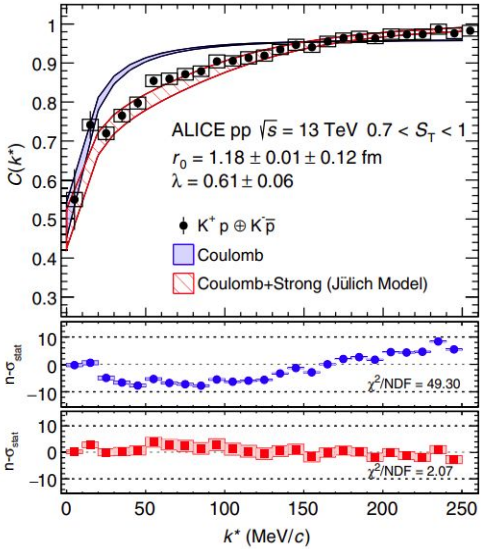

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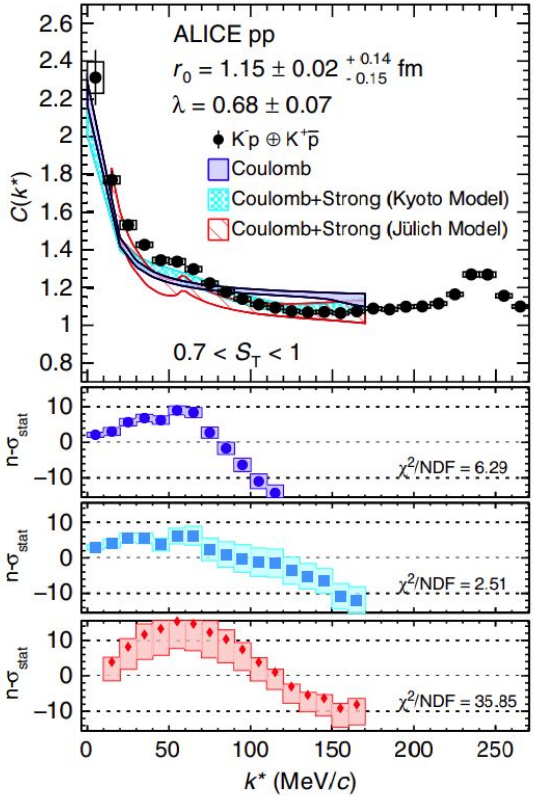

Coulomb potential only

Coulomb + Chiral Kyoto model

Phys. Rev. C93 no. 1, 015201 (2016)

Coulomb + Jülich meson exchange model

Nucl. Phys. A 981 (2019)

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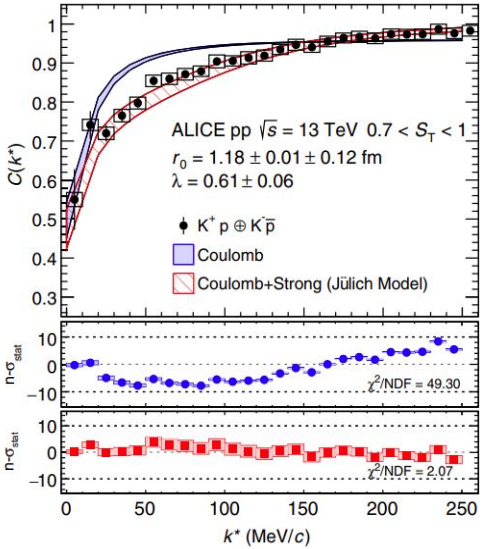
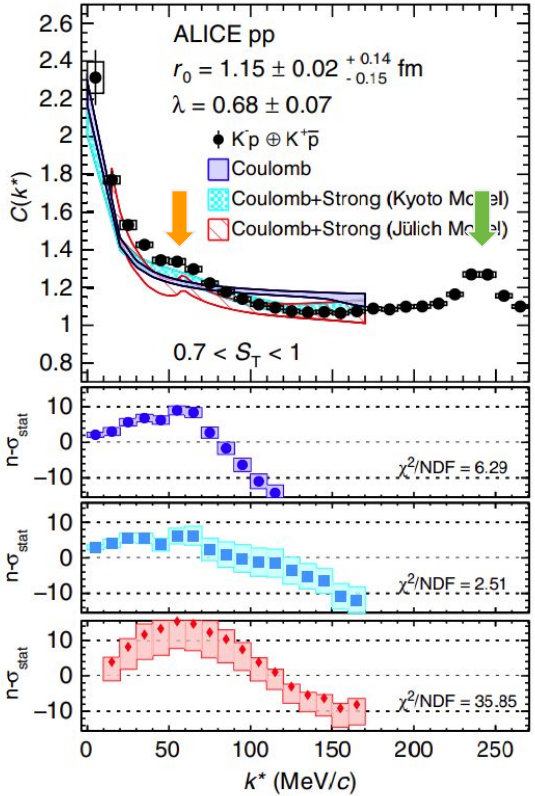


- K^+-p correlation used as a benchmark to study K^--p
- S_T > 0.7 selection removes mini-jet background

Jülich meson exchange model: Eur. Phys. J. A47, 18 (2011)



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⇒ Bump close to the K^0n threshold→ (58 MeV/c in CM frame)

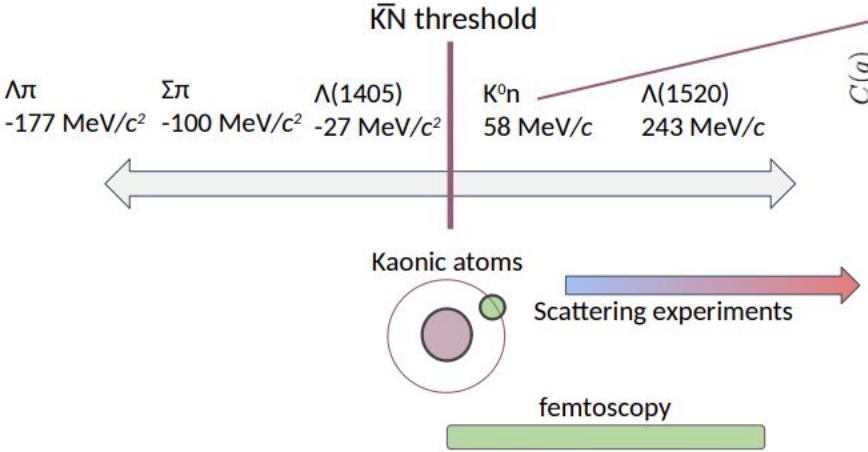
First experimental evidence of the opening of the K^0n isospin breaking channel

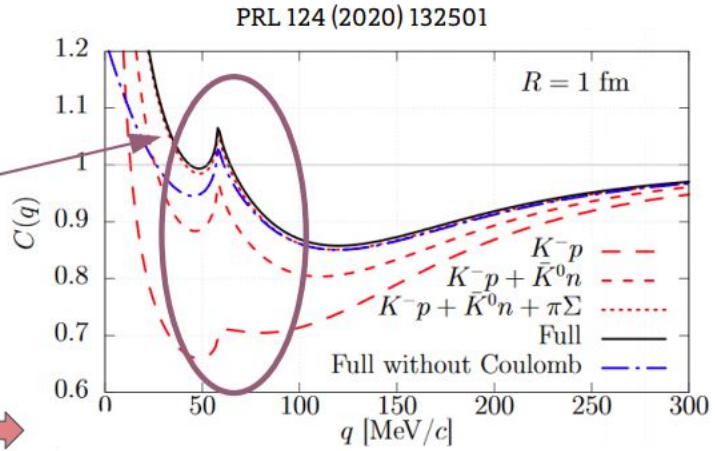
Coupled channel effect

$$M(K^-p) + 5\,\mathrm{MeV} = M(n\bar{K}^0)$$

n	p
$\bar{K}^0$	K^-

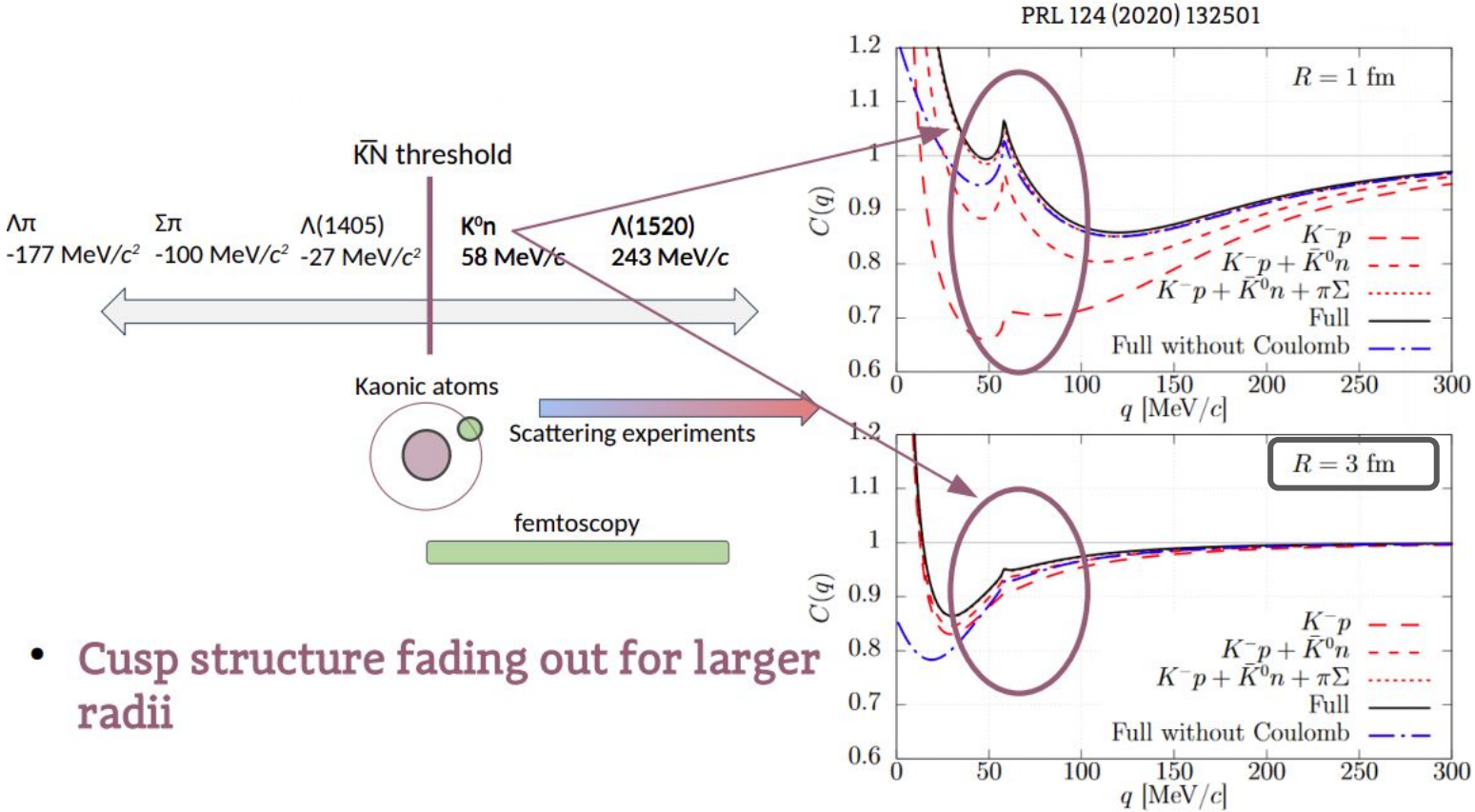
Effect of coupled channels





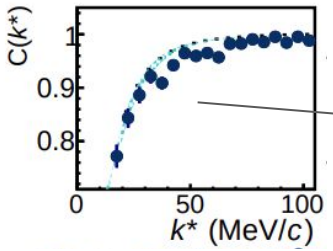
The Kyoto model was updated after the publication of k-p femtoscopy in pp by ALICE and now, with the inclusion of coupled channels, fits the ALICE data.

Effect of coupled channels



- Cusp structure fading out for larger radii

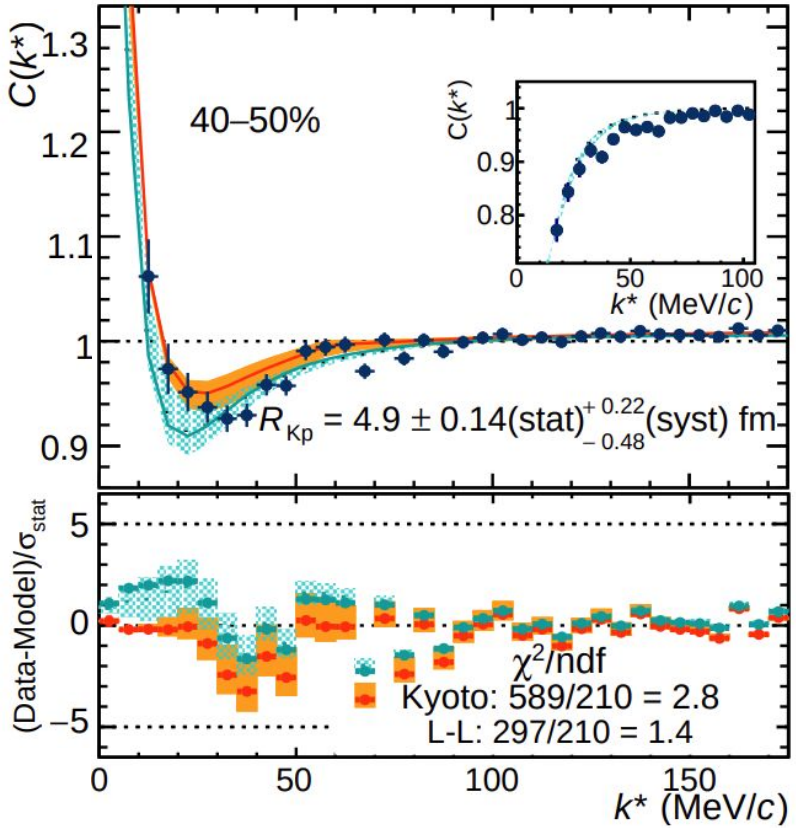
K-p correlations in Pb-Pb collisions



Physics Letters B 822 (2021) 136708

- Radius is constrained by K^+-p
  - known interaction ⇒ determination of the radius

K-p correlations in Pb-Pb collisions



Physics Letters B 822 (2021) 136708

- Radius is constrained by K^+-p
  - known interaction ⇒ determination of the radius

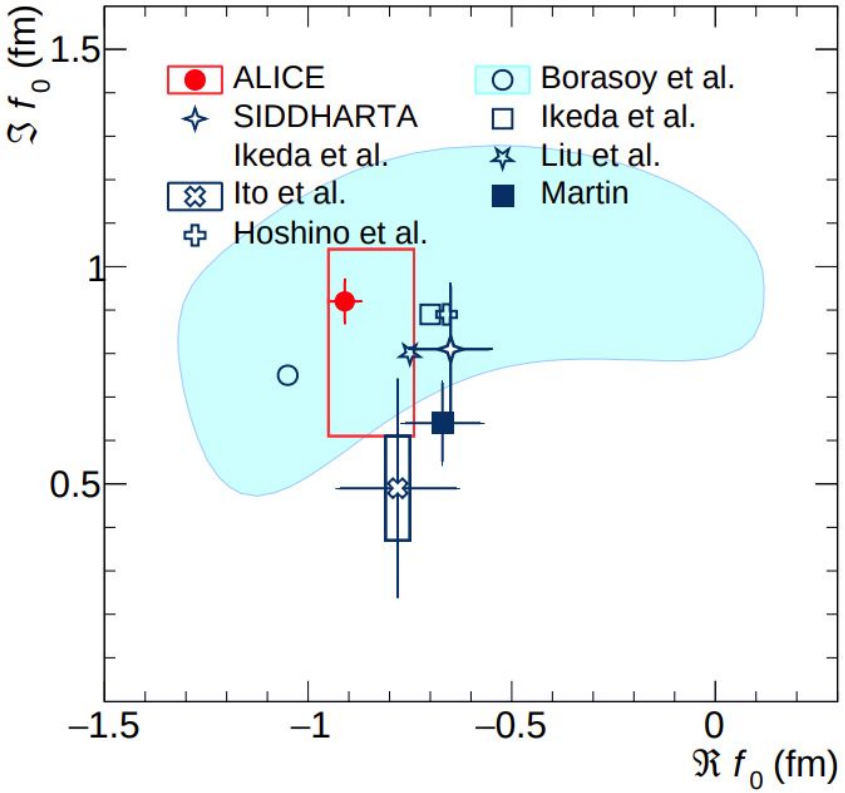
K^--p correlations in Pb-Pb collisions

- Cyan line:
  - Kyoto model with SIDDHARTA constraint
- Orange line:
  - Fit to the scattering parameters (better χ^2)

$$\frac{\Re f_0\ (\mathrm{fm})}{-0.91 \pm 0.03(\mathrm{stat})^{+0.17}_{-0.03}(\mathrm{syst})}$$

$$\frac{\Im f_0\ (\mathrm{fm})}{0.92 \pm 0.05(\mathrm{stat})^{+0.12}_{-0.33}(\mathrm{syst})}$$

K-p correlations in Pb-Pb collisions



https://arxiv.org/abs/2105.05683

Re f0 and Imf0 in agreement with the most precise data and recent calculations

Approach complementary to exotic atoms and scattering experiments

Run3-4 of the LHC starting in 2022:
- boost in statistics (by 2 orders of magnitude)
- new tracking devices with better resolution and PID: reduce the systematic errors

What about kaon-deuteron?

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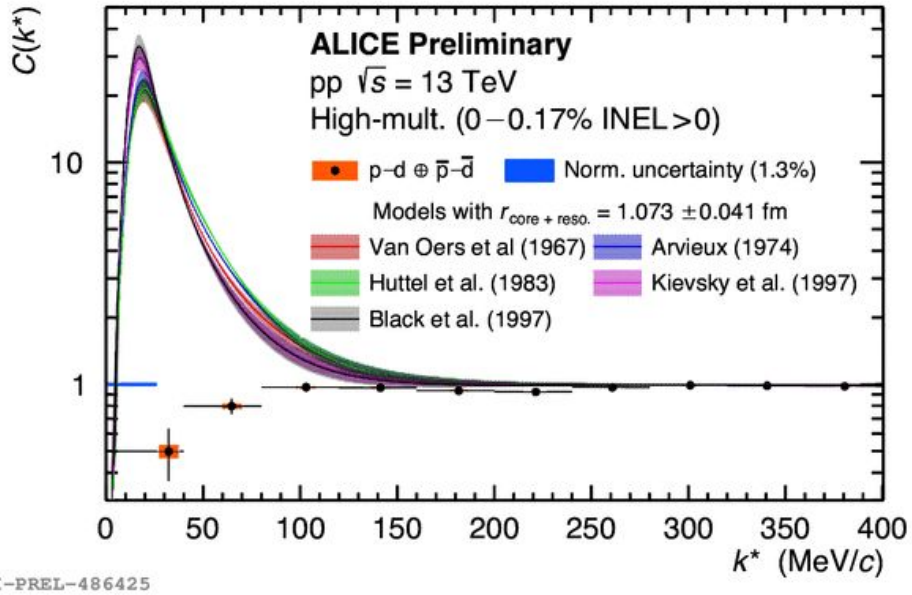
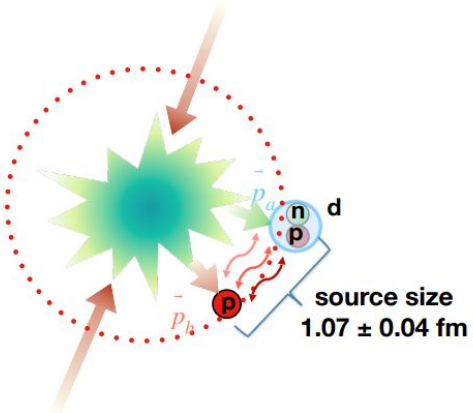


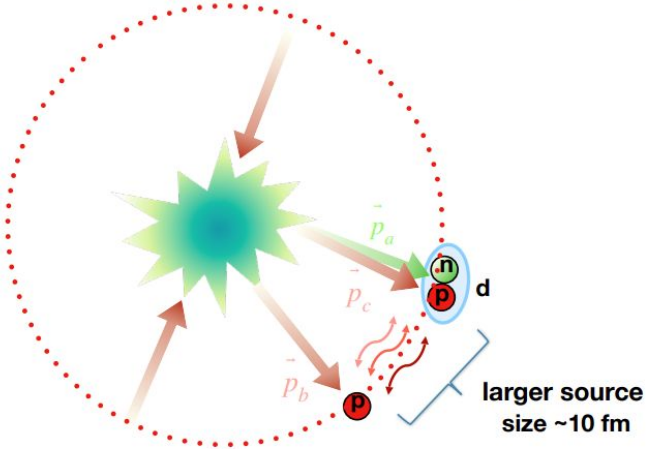
Femtoscopy measurements with deuterons are for now contradictory

What about kaon-deuteron?

Case I : p (Λ) and d are formed at the same time



Case II : delayed formation of d



Femtoscopy measurements with deuterons are for now contradictory

Outlook

- The LHC provides **precise testing of the hadron-hadron interaction** at distances starting at 1 fm.
- Correlation data complements other approaches.
  - For some channels (multi-strange particles) constitute the only precise data
- Upcoming LHC data taking will provide the possibility of carrying out new and differential studies and investigate 3-body interactions.