Faculty of Physics
WARSAW UNIVERSITY OF TECHNOLOGY

Studying the kaon-proton strong interactions with ALICE at the LHC

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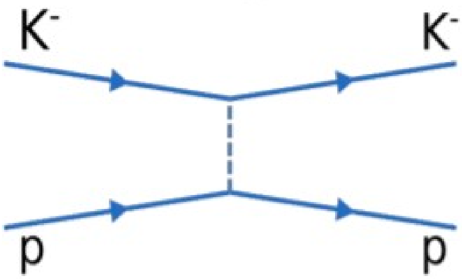
on behalf of the ALICE Collaboration

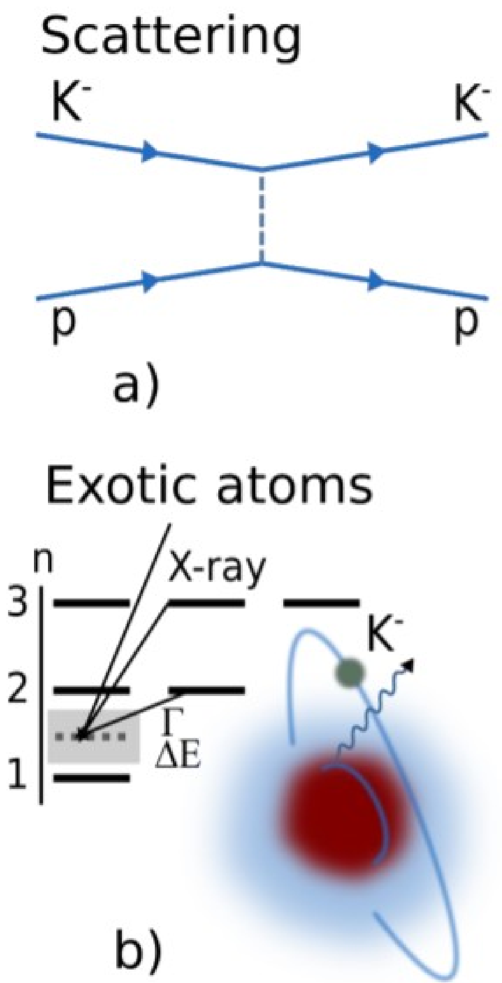
HADRON 2021
29 July 2021

Experimental study of Kp interaction

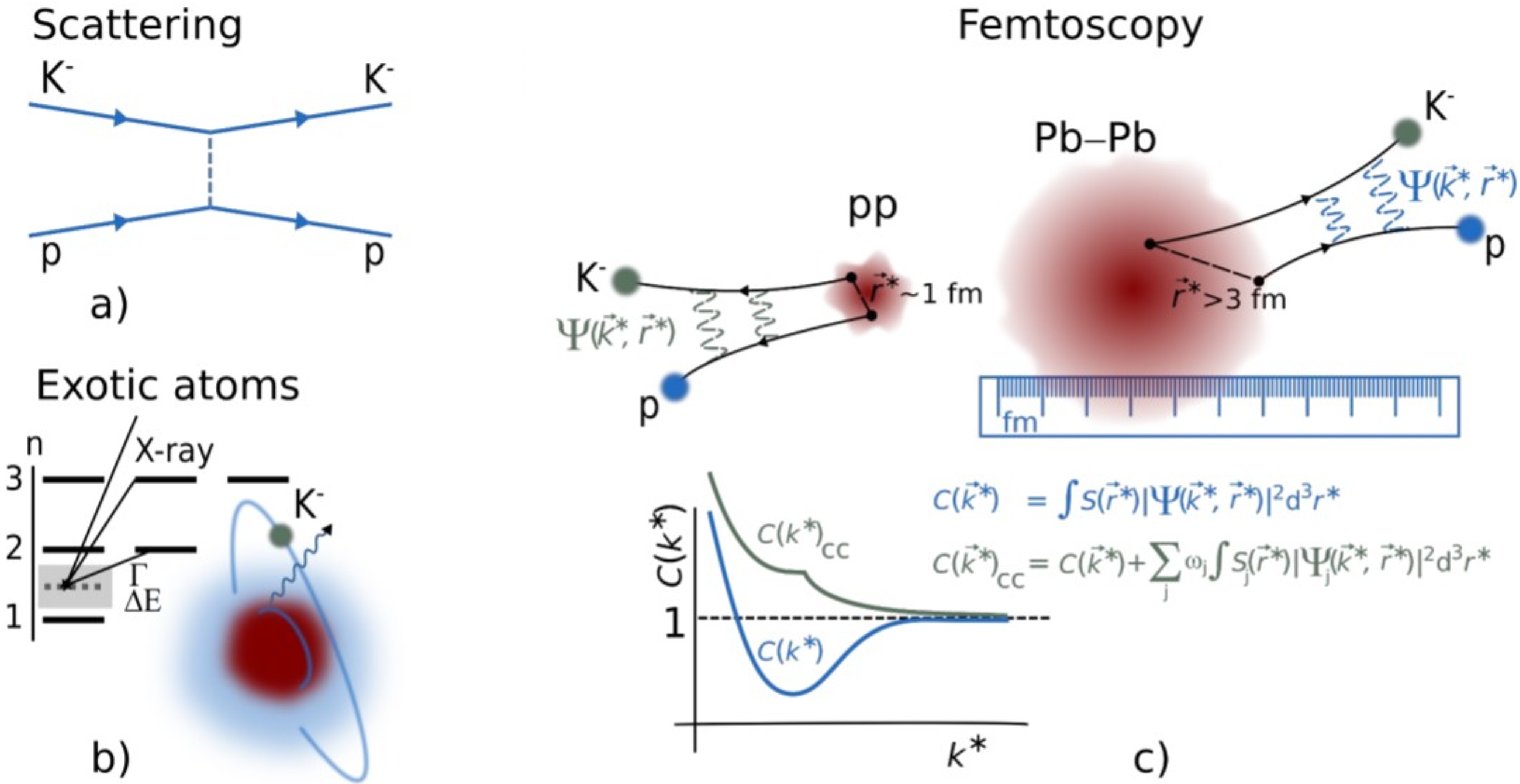
Scattering



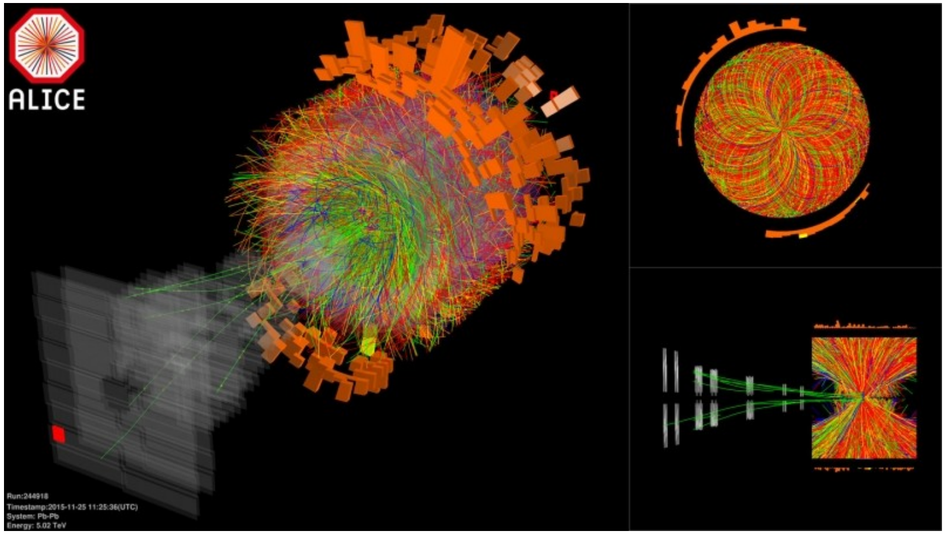
Experimental study of Kp interaction



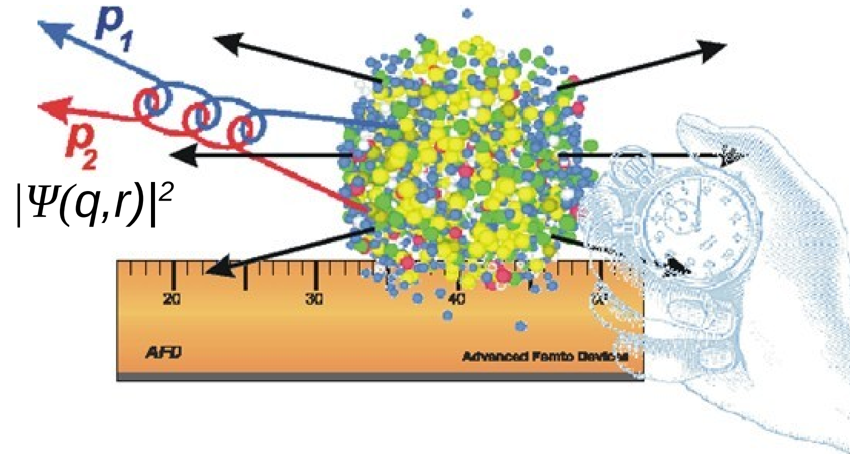
Experimental study of Kp interaction



Femtoscopy technique



from M. Lisa and S. Pratt



- **Femtoscopy – measures space-time characteristics of the source using particle correlations in <u>momentum space</u>**

$$\vec{q} = \vec{p}_1 - \vec{p}_2$$
$$\vec{r} = \vec{x}_1 - \vec{x}_2$$

$$C(\vec{p}_1, \vec{p}_2) = \frac{P_{12}(\vec{p}_1, \vec{p}_2)}{P_1(\vec{p}_1) P_2(\vec{p}_2)}$$

experiment

$$C(\vec{q}) = \frac{A(\vec{q})}{B(\vec{q})}$$

$A(\vec{q})$ - correlated pairs (“same events”)

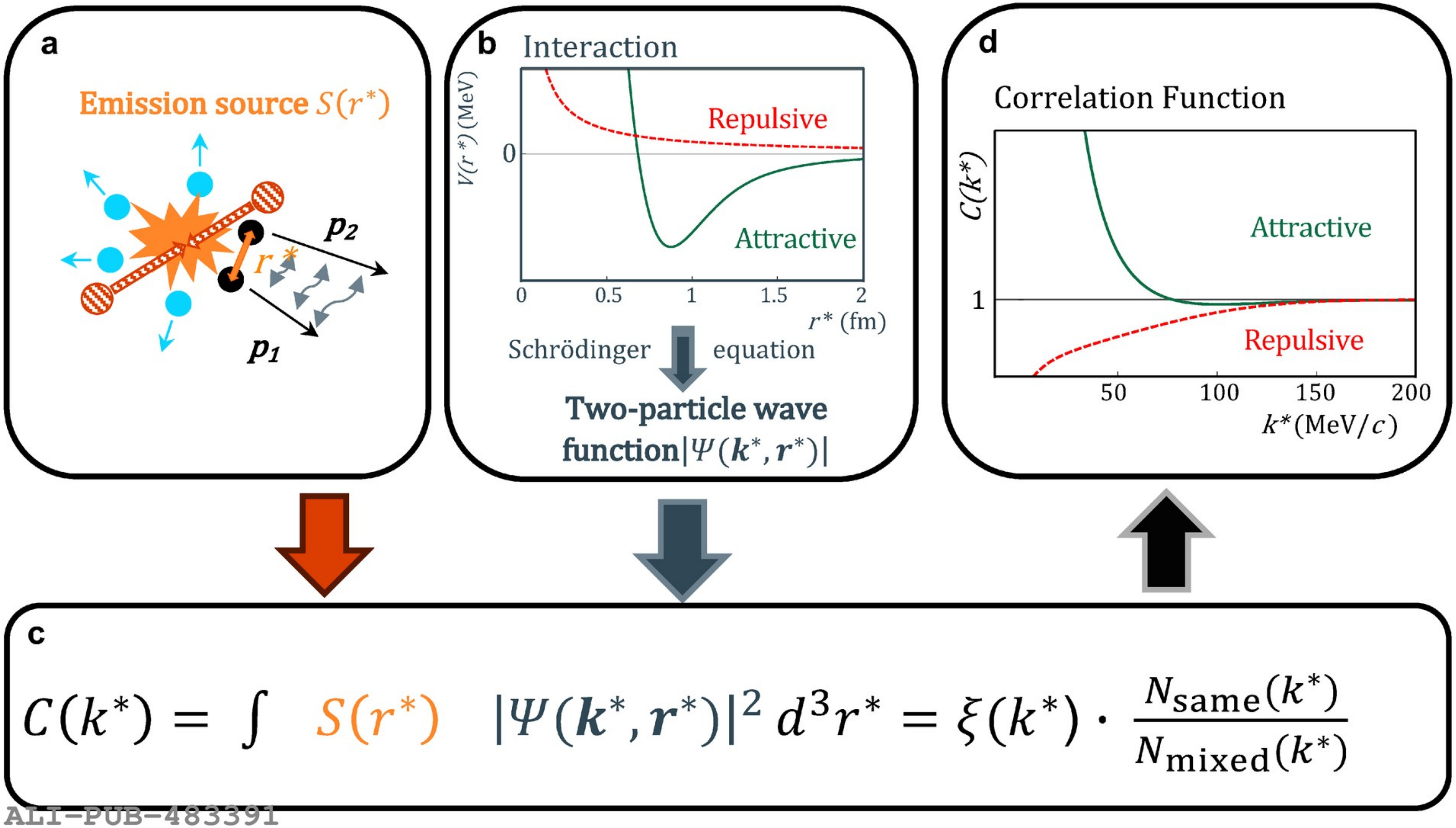
$B(\vec{q})$ - uncorrelated pairs (“mixed events”)

theory (models)

$$C(\vec{q}) = \frac{\int d^3 r\, S_{12}(\vec{q}, \vec{r}) |\Psi(\vec{q}, \vec{r})|}{\int d^3 x_1 S_1(\vec{x}_1, \vec{p}_1) \int d^3 x_2 S_2(\vec{x}_2, \vec{p}_2)}$$

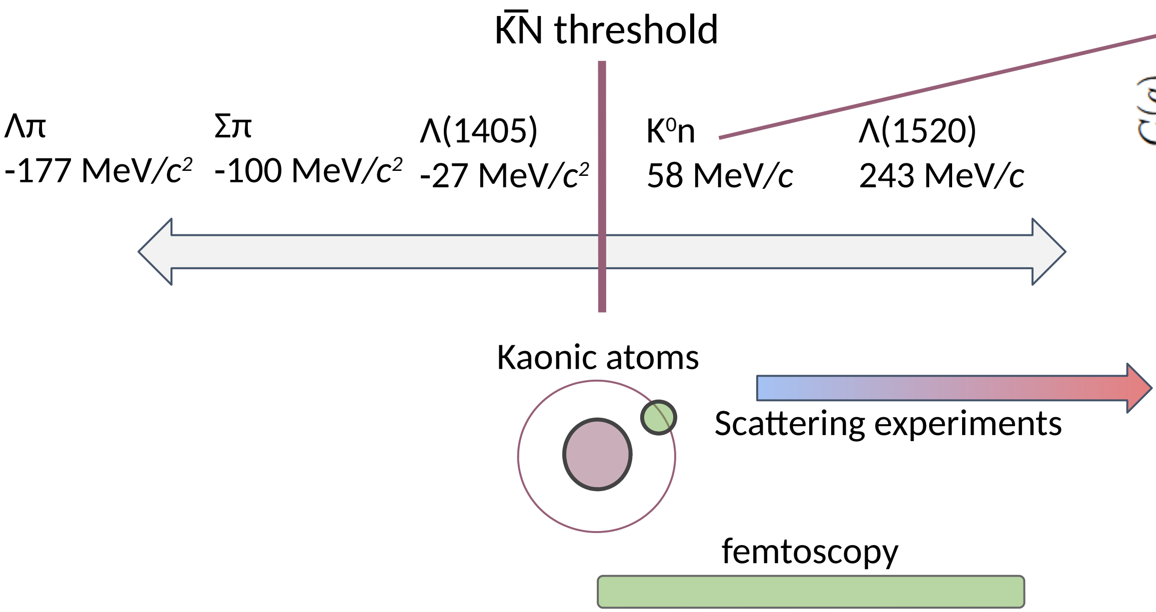
$$C(\vec{q}) = \int d^3 r\, S(\vec{q}, \vec{r}) |\Psi(\vec{q}, \vec{r})|$$

Strong interaction from femtoscopy

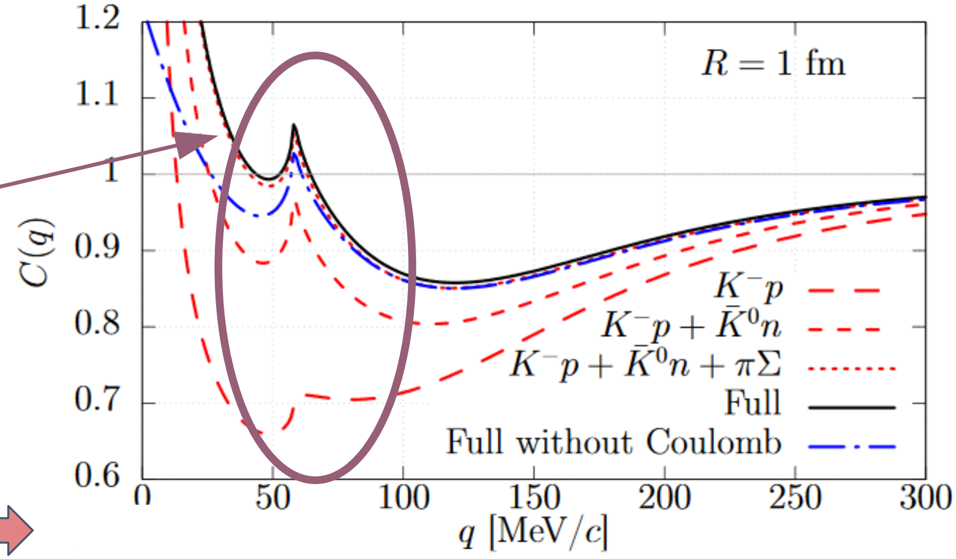


Kyoto model
with coupled channels

$$C(\boldsymbol{q}) = \int d^3r \sum_j \omega_j S_j(\boldsymbol{r}) |\Psi_j^{(-)}(\boldsymbol{q}, \boldsymbol{r})|^2$$



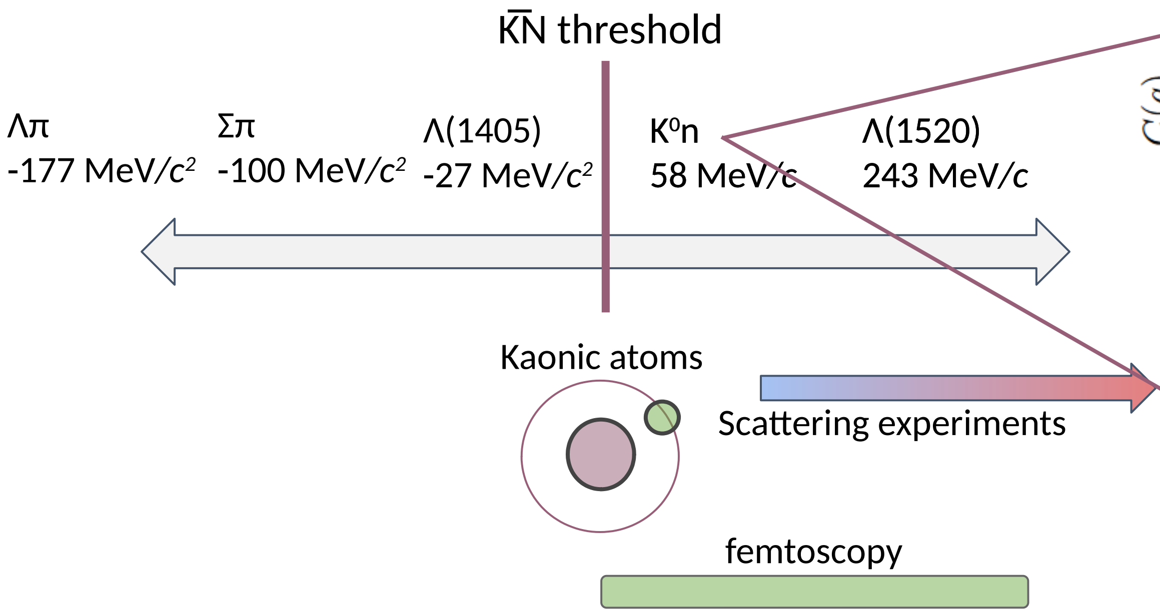
PRL 124 (2020) 132501



- Clear cusp structure visible for small radii

Kyoto model
with coupled channels

$$C(\boldsymbol{q}) = \int d^3r \sum_j \omega_j S_j(\boldsymbol{r}) |\Psi_j^{(-)}(\boldsymbol{q}, \boldsymbol{r})|^2$$



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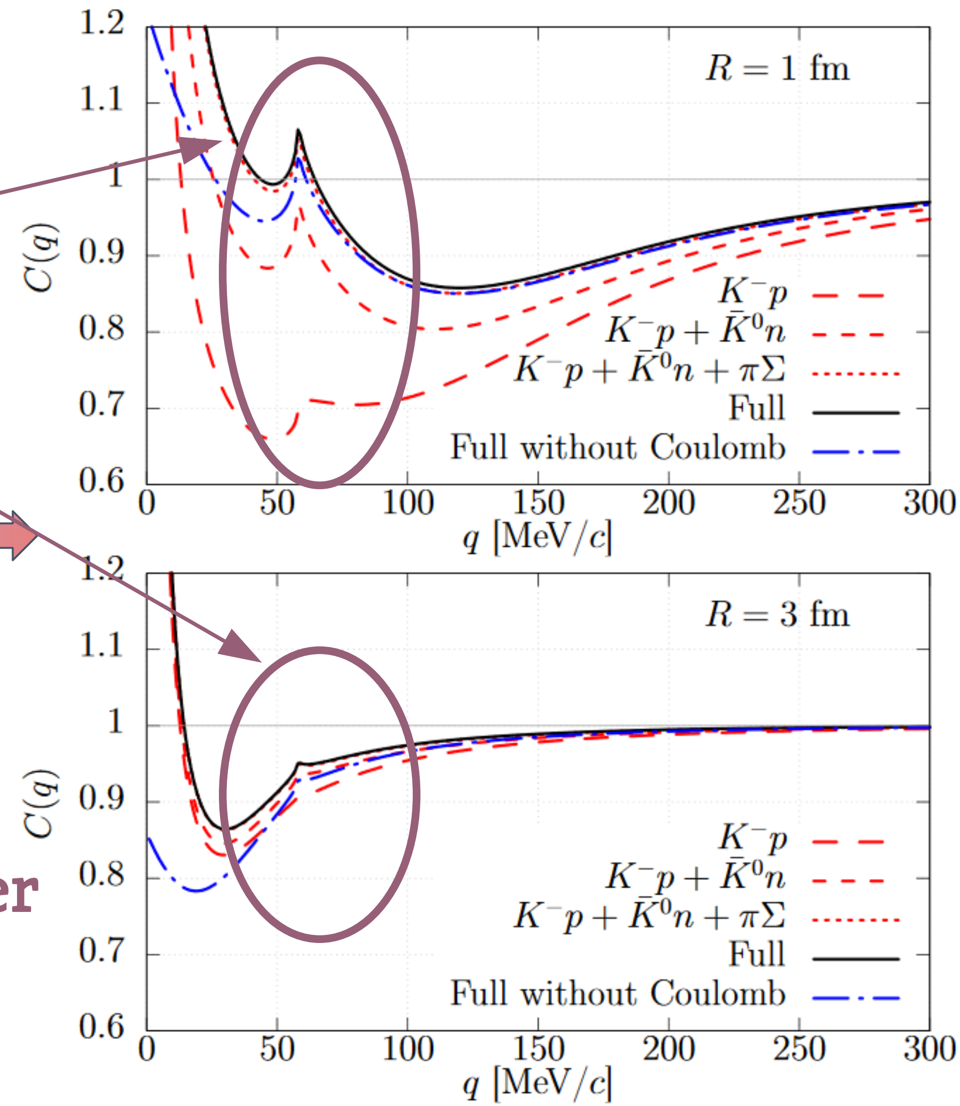


- Cusp structure fading out for larger radii

Lednický & Lyuboshitz model

$$C(q)=\int S(r)|\Psi(q,r)|^2 d^3r \qquad q=2\cdot k^* = p_1 - p_2$$

measured correlation

emission function (source size/shape)

pair wave function (includes cross section)

pair wave function → $\Psi^{(+)}_{-\vec{k}^*}(\vec{r}^*) = \sqrt{A_C(\varepsilon)}\frac{1}{\sqrt{2}}\left[e^{-i\vec{k}^*\times\vec{r}^*}F(-i\varepsilon,1,i\zeta^+) + f_C(\vec{k}^*)\frac{\tilde{G}(\rho,\varepsilon)}{r^*}\right]$

scattering amplitude → $f_C^{-1}(k^*) = \frac{1}{f_0} + \frac{1}{2}d_0 k^{*2} - \frac{2}{a_C}h(k^* a_C) - ik^* a_C$

$\tilde{G}$ is the combination of the regular and singular s-wave Coulomb functions

F is the confluent hypergeometric function

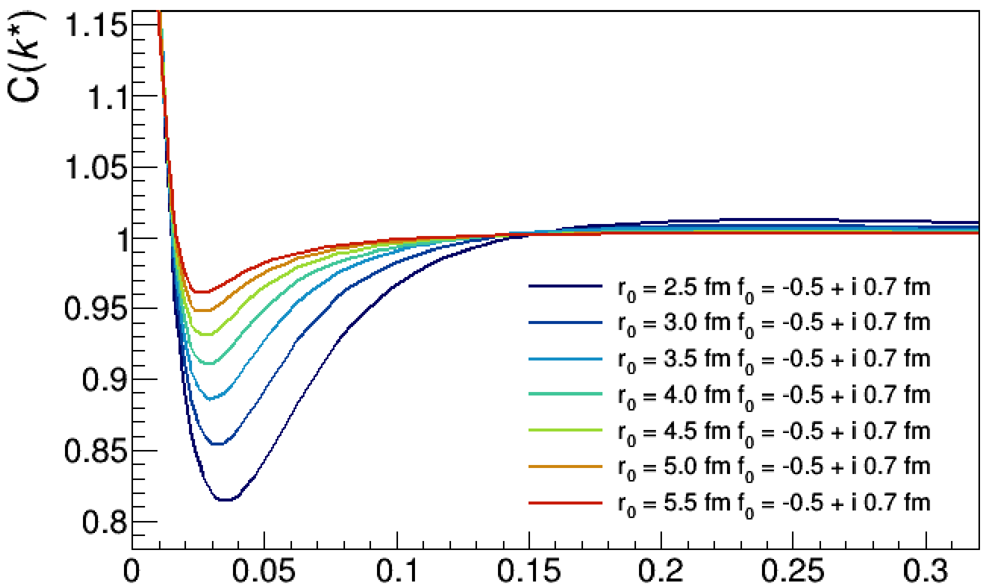
$h(\varepsilon) = \varepsilon^2 \sum_{n=1}^{\infty}[n(n^2+\varepsilon^2)]^{-1} - \gamma - \ln|\varepsilon|$ ($\gamma = 0.5772$ is the Euler constant)

A_C is the Gamow factor, $\zeta^{\pm} = k^* r^*(1 \pm \cos\theta^*)$, $\varepsilon = 1/(k^* a_C)$

Bohr radius of the pair ($a_C = -83.59$ fm for K^-p pairs)

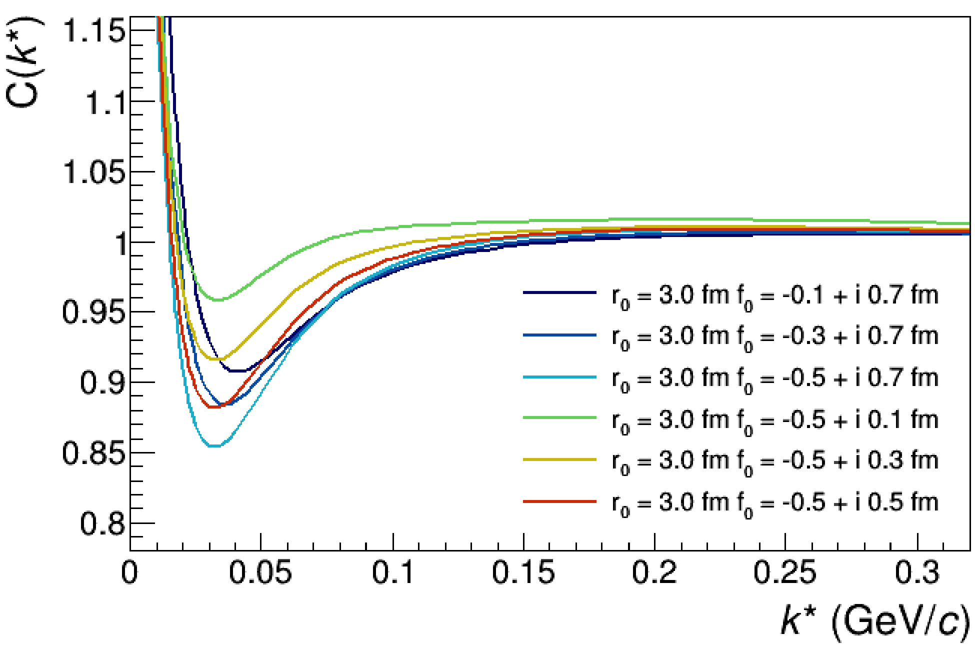
- **Numerically solvable (Coulomb + strong)**
- The correlation function is characterized by **three parameters**:
  - **radius** R, **scattering length** f_0, and **effective radius** d_0
  - $d_0=0$ **effective range approximation**
  - **cross section** σ **(at low** k^***)** is simply: $\sigma = 4\pi|f|^2$

Lednický & Lyuboshitz model



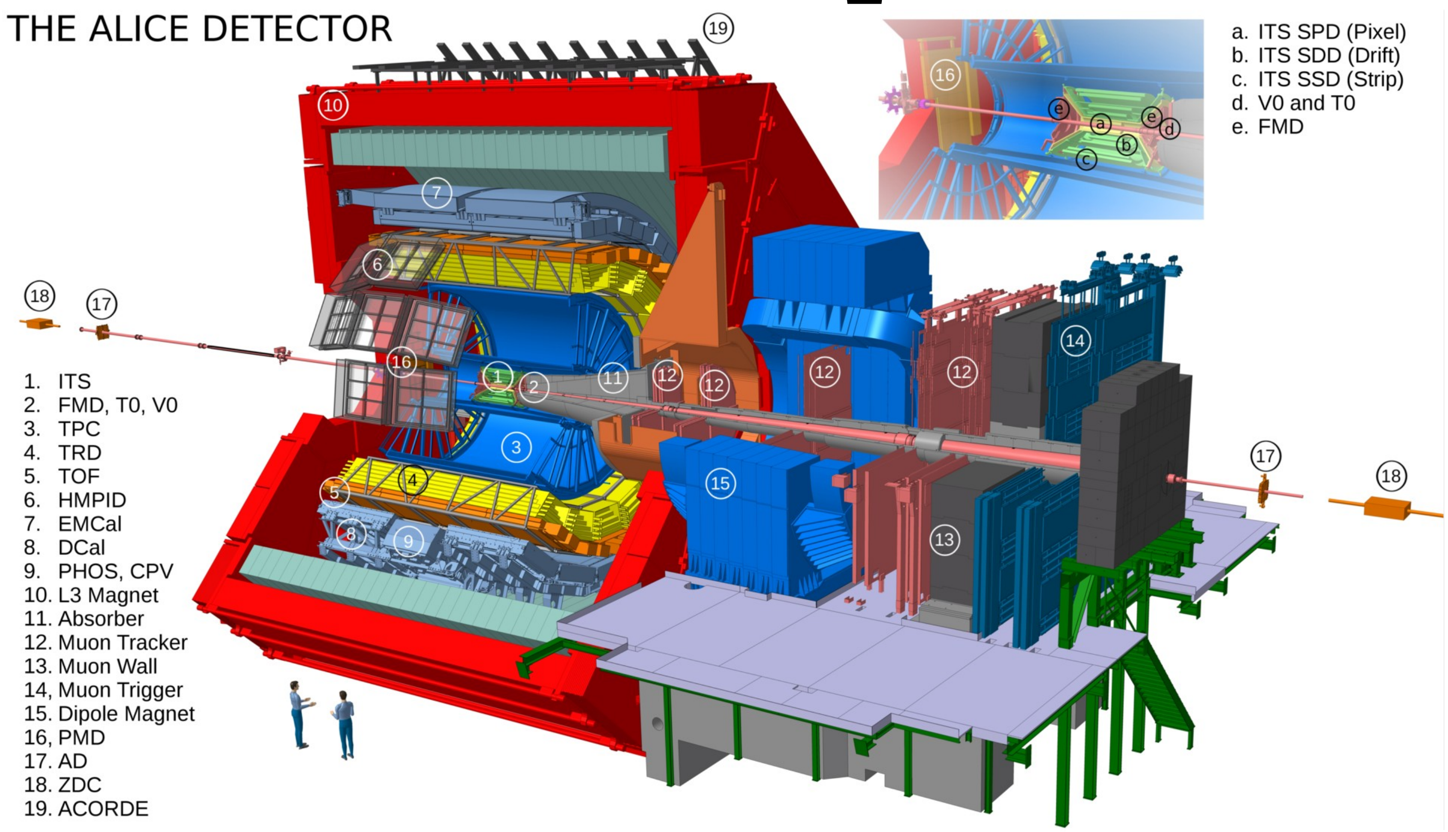
Change with R
Constant f_0

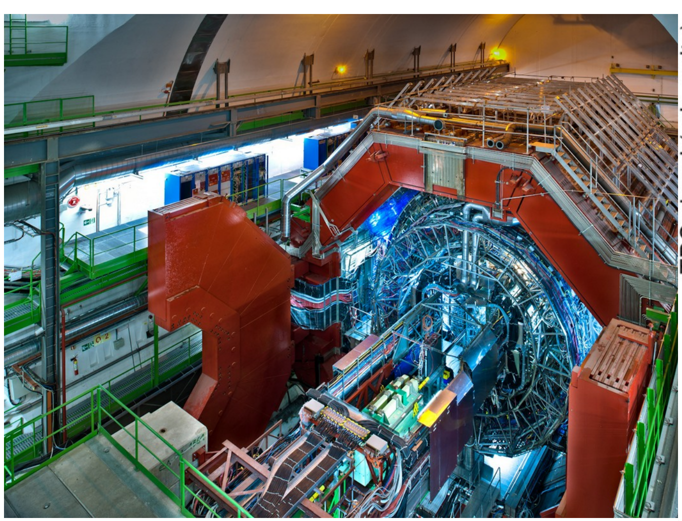
K^-p

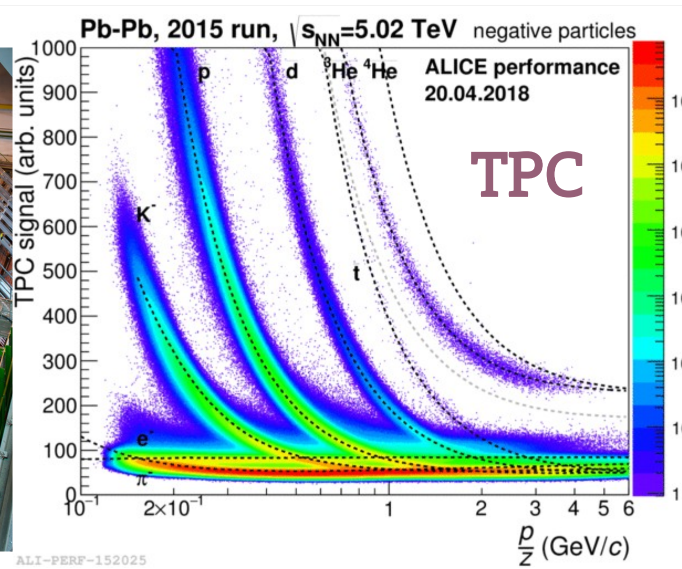


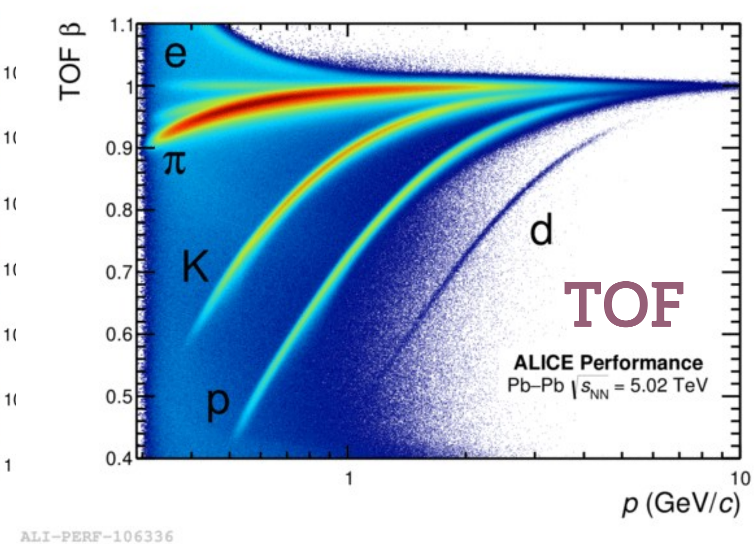
Change with f_0
Constant R

The ALICE experiment

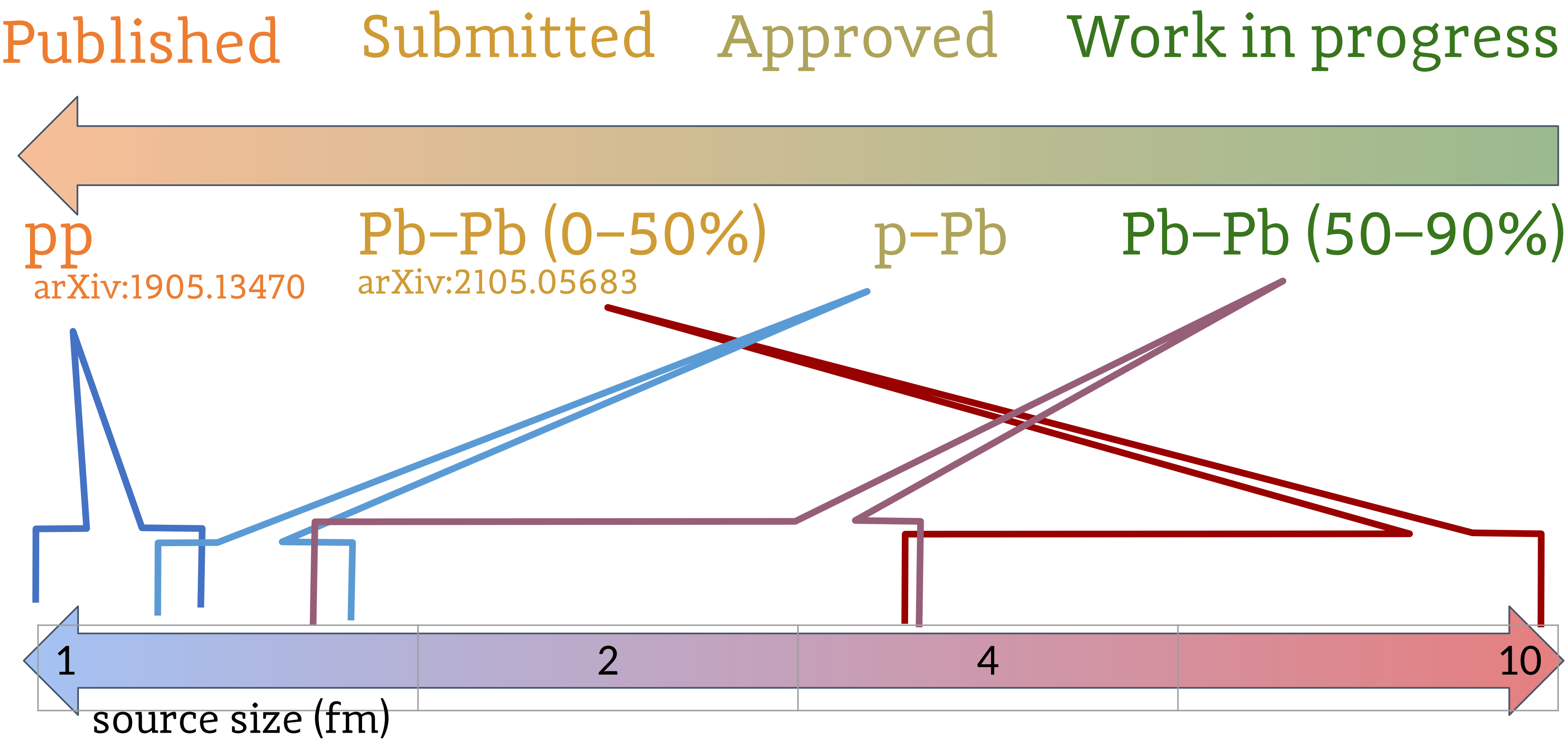






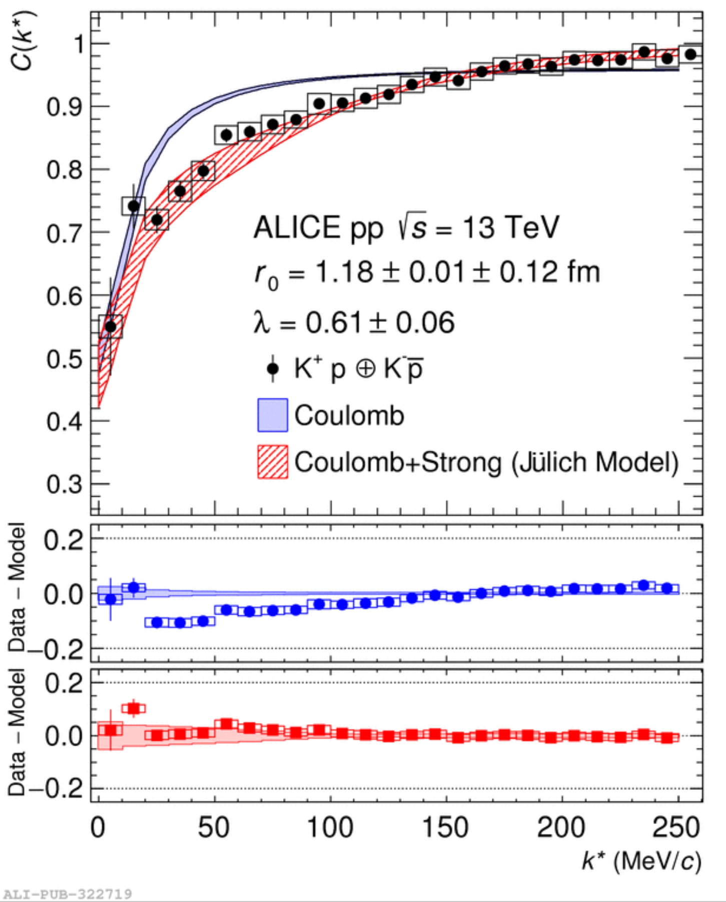


Status of $K^{-}p$ femtoscopy in ALICE



Proton-kaon correlations in pp

K^+p



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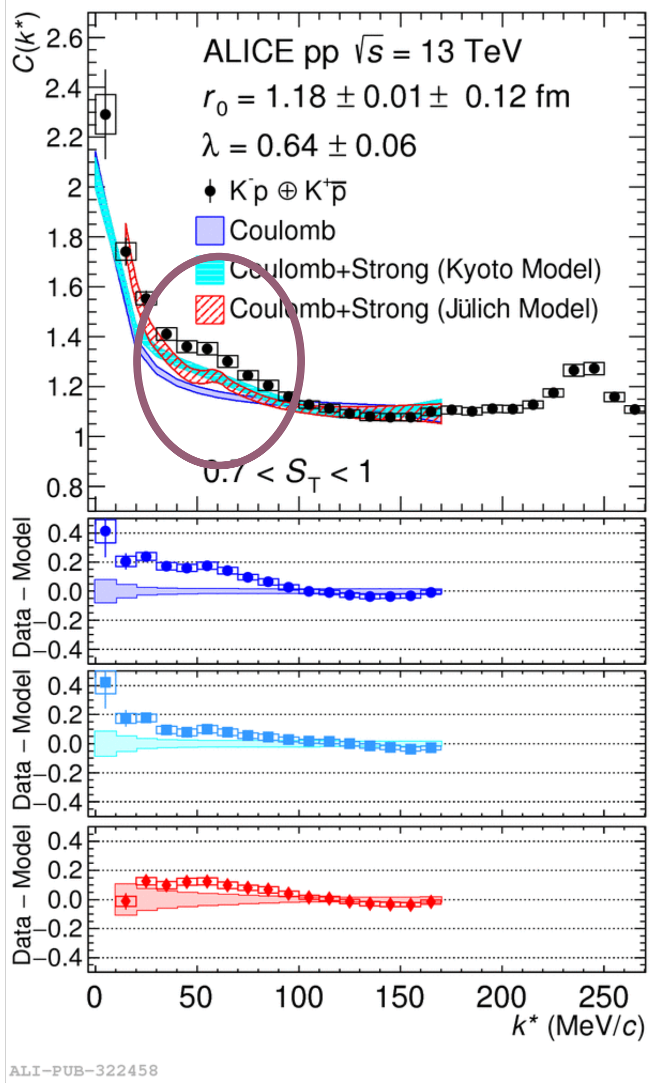
K^-p

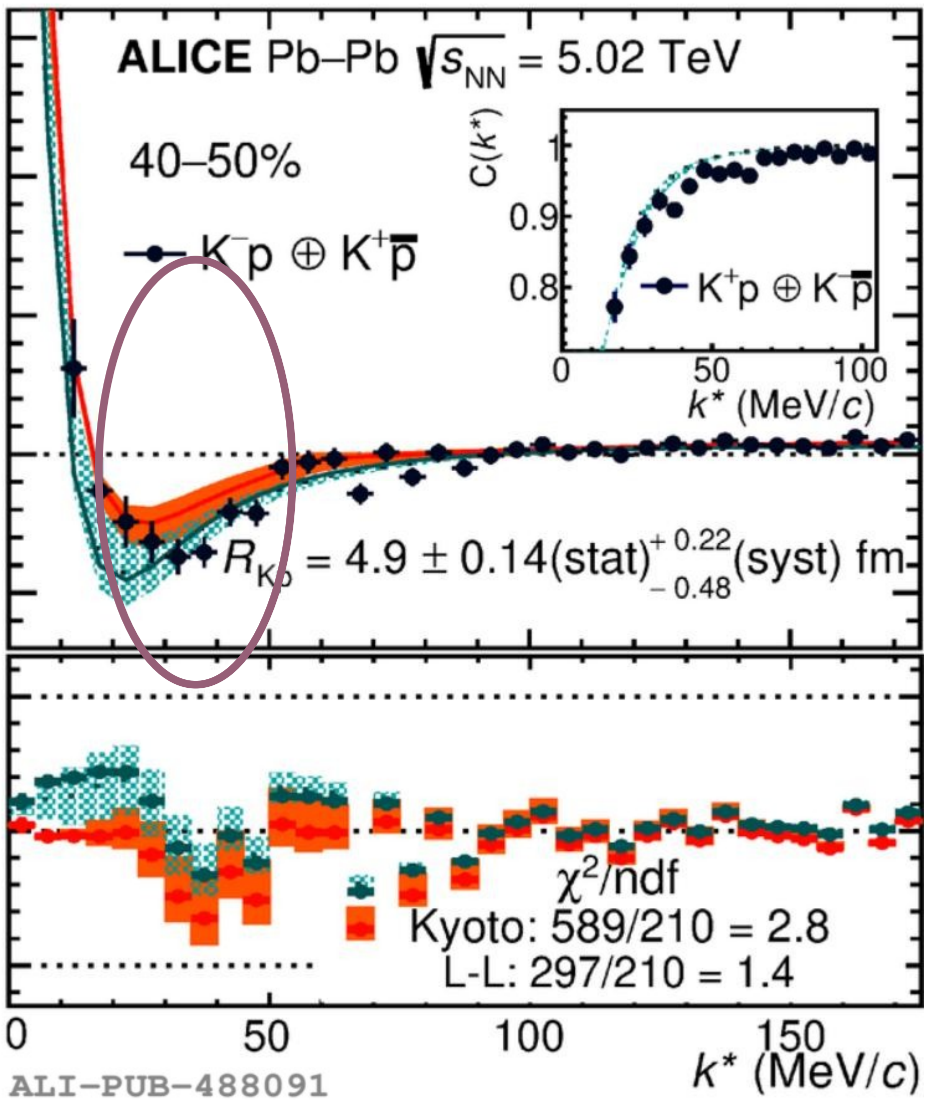


- First experimental evidence for the opening of the K^0n isospin breaking channel.
- Constraints for low-energy QCD chiral models.

Proton-kaon correlations in Pb–Pb

https://arxiv.org/abs/2105.05683

NEW!



- No K^0n structure visible
- Radii constrained from K^+p pairs

Proton-kaon correlations in Pb–Pb

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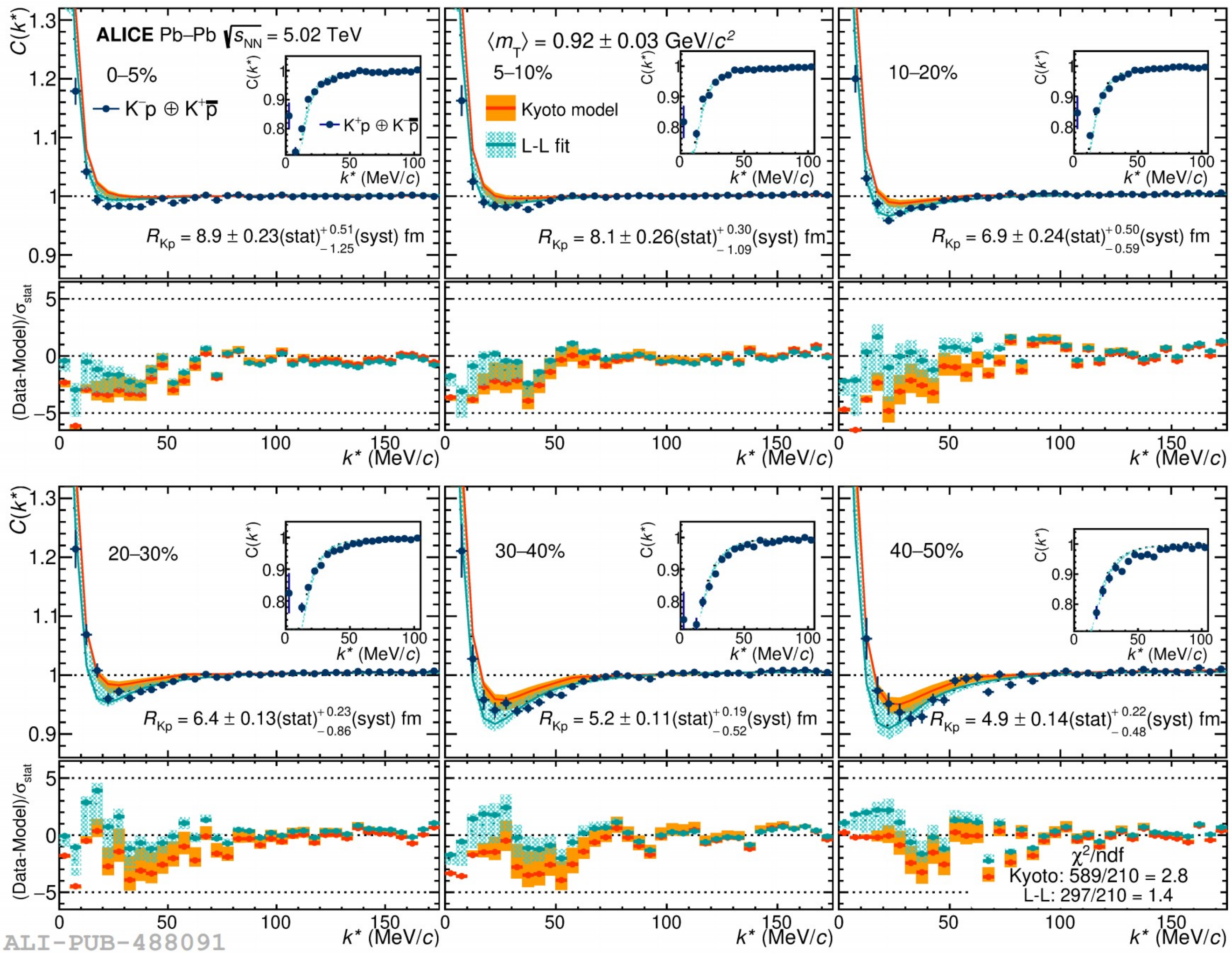
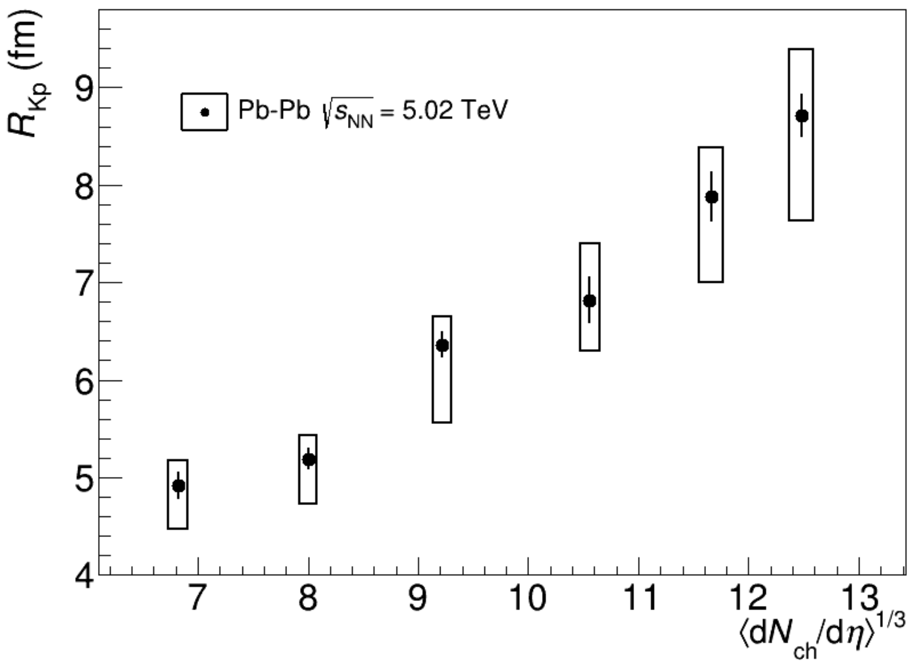
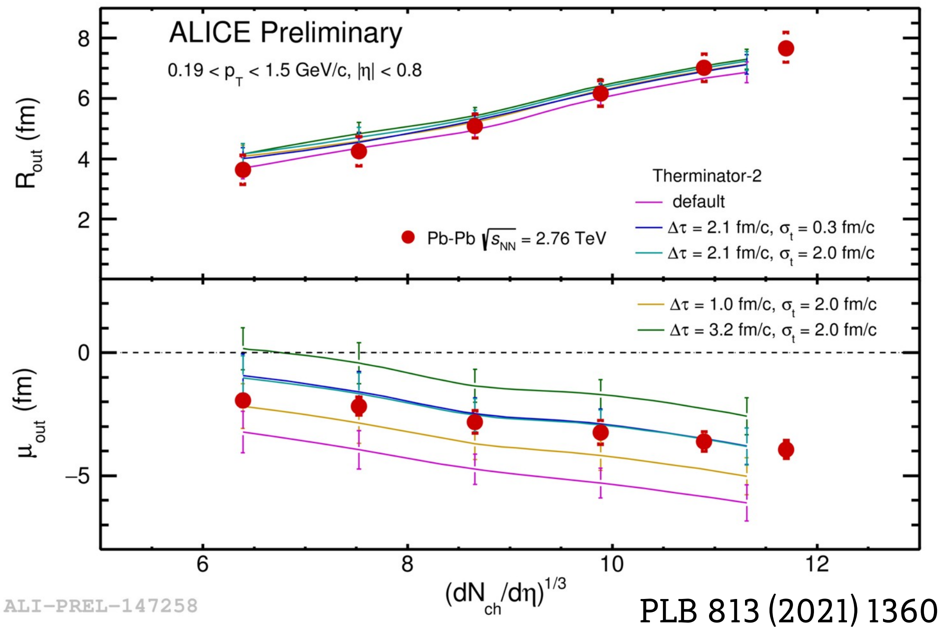


- No K^0n structure visible
- Radii constrained from K^+p pairs
- Simultaneous description (and fit) of the CFs for 6 centralities with two parameters and 6 radii

Proton-kaon correlations in Pb–Pb





PLB 813 (2021) 136030

Kp

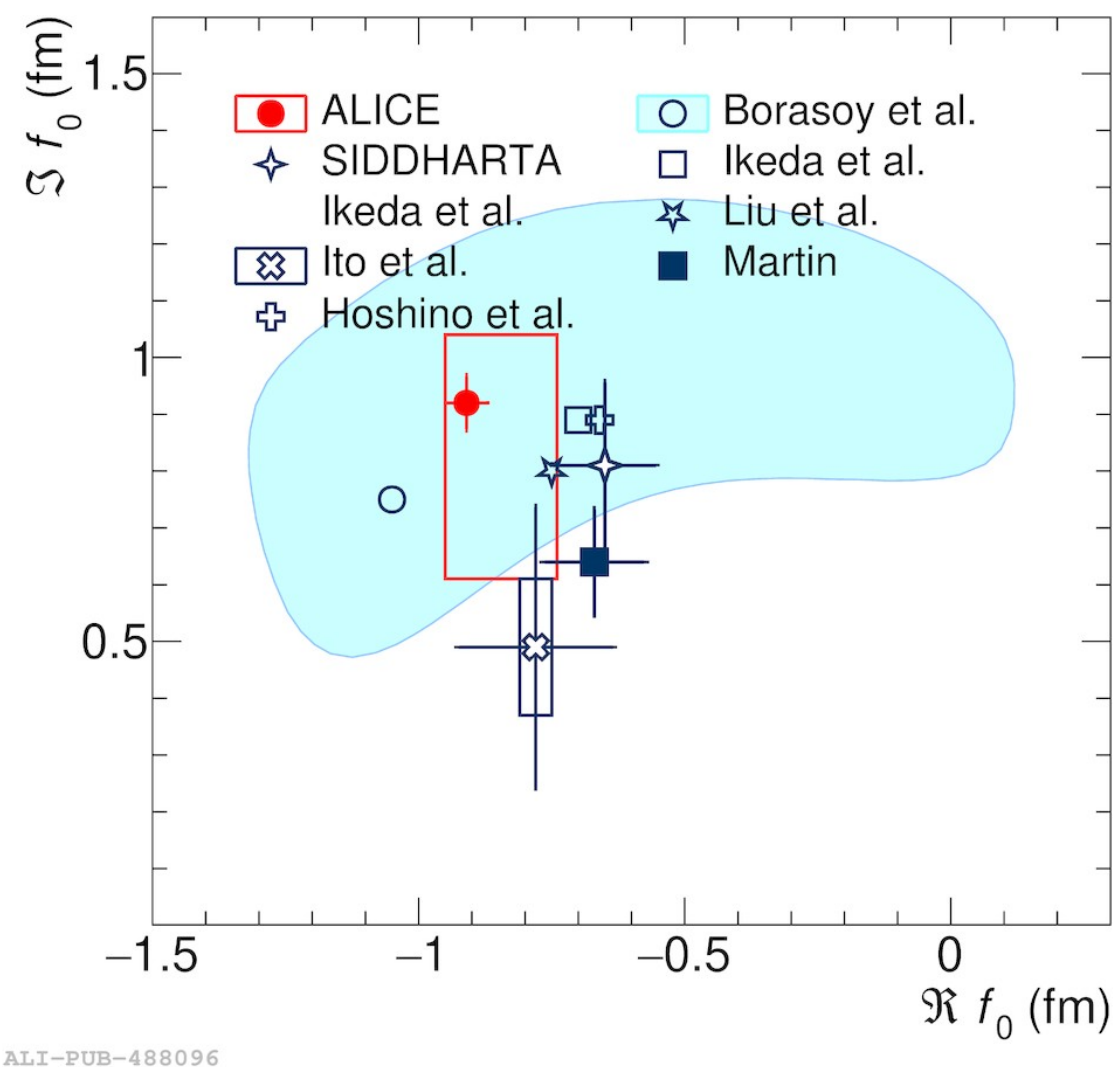
πK

- Radii well constrained from scalings
- Radii follow scaling with cube root of charged particle multiplicity density and <m_T> as predicted by hydrodynamics calculations

K⁻p scattering length

https://arxiv.org/abs/2105.05683

NEW!



- Re f_0 and Im f_0 in agreement with available data and calculations!
- Complementary to exotic atoms and scattering experiments

K⁻p scattering length

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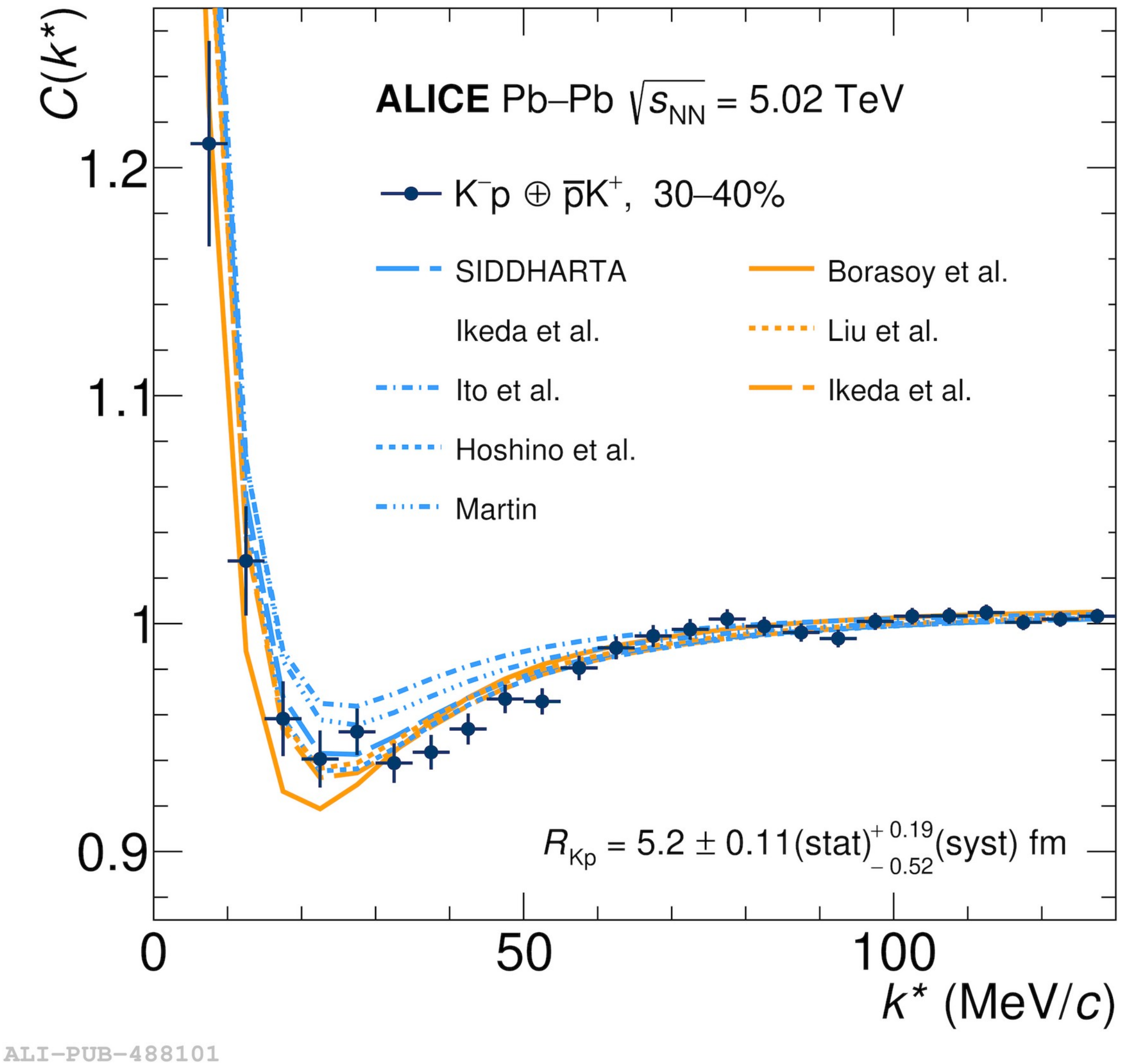

- Re f_0 and Im f_0 in agreement with available data and calculations!
- Complementary to exotic atoms and scattering experiments
- Plotted with L&L model for comparison

K^-p scattering length

https://arxiv.org/abs/2105.05683

NEW!

Model calculation:	$\Re f_0$ (fm)	$\Im f_0$ (fm)	χ^2/ndf
Lednický–Lyuboshitz fit to data	$-0.91 \pm 0.03(\text{stat})^{+0.17}_{-0.03}(\text{syst})$	$0.92 \pm 0.05(\text{stat})^{+0.12}_{-0.33}(\text{syst})$	1.4
Kyoto [39, 76]	–	–	2.8
Lednický–Lyuboshitz with fixed parameters from:			
Kaonic deuterium (Hoshino et al.) [74]	−0.66	0.89	2.0
Scattering experiments (Martin) [71]	−0.67±0.1	0.64±0.1	3.3
Chiral SU(3) (Ikeda et al.) [17, 18]	−0.7	0.89	1.9
SIDDHARTA chiral SU(3) [17, 18]	−0.65±0.1	0.81±0.15	2.3
Hamiltonian EFT (Liu et al.) [73]	−0.75	0.80	1.9
Kaonic hydrogen (Ito et al.) [72]	−0.78±0.15	0.49±0.25	4.2
Chiral SU(3) (Borasoy et al.) [75]	−1.05±0.5	0.75±0.4	1.6

- Chi-square values show Kyoto model is slightly worse than L&L calculations, requiring further developments

Summary

- ALICE has measured Kp correlations in various collision systems (pp, Pb–Pb) and source sizes
- At very small ranges (1 fm in pp) the coupled channel effects are dominant
- For larger sources neither the cusp from $K^0 n \rightarrow K^- p$ isospin breaking channel nor enhancement due to below threshold coupled-channel effects are visible, providing access to the $K^- p \rightarrow K^- p$ process
- Radii are constrained with K+p pairs and they follow hydrodynamic scalings


THANK YOU!
Teotihuacán
ISMD 2017