The study of proton-kaon interactions with the ALICE at the LHC
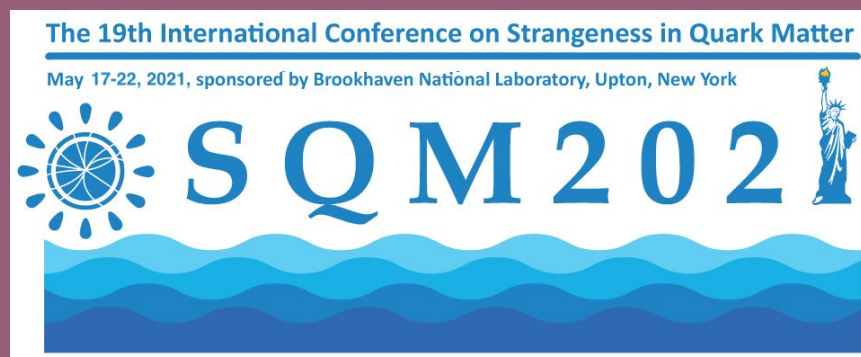
Georgy Kornakov of behalf of the ALICE Collaboration

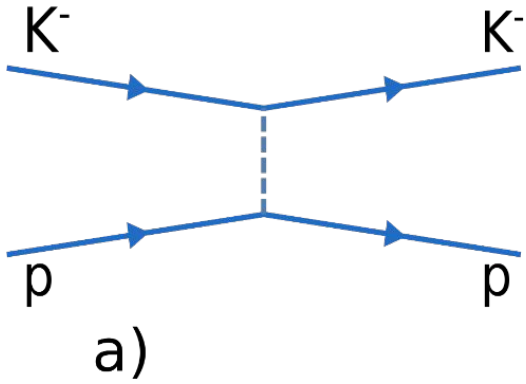The 19th International Conference on Strangeness in Quark Matter

May 17-22, 2021, sponsored by Brookhaven National Laboratory, Upton, New York

SQM2021

WARSAW UNIVERSITY OF TECHNOLOGY
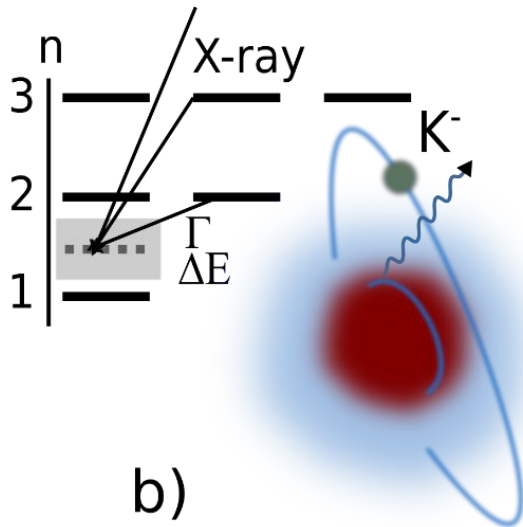
Experimental techniques for K-p interaction

Scattering

K⁻   K⁻

p   p

a)
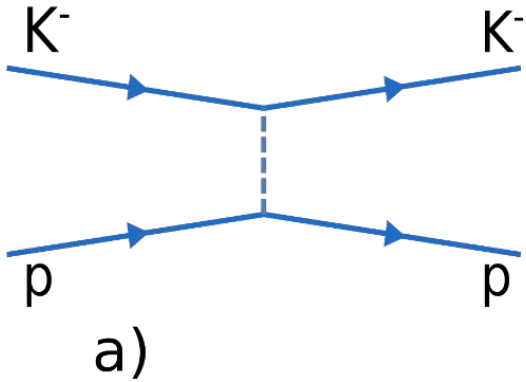
Experimental techniques for K-p interaction

Scattering

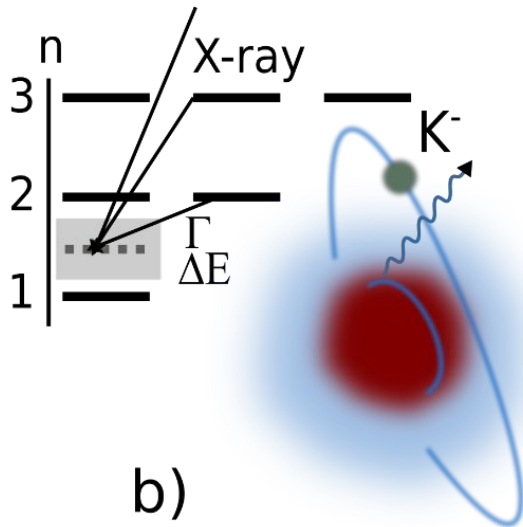

a)

Exotic atoms

b)

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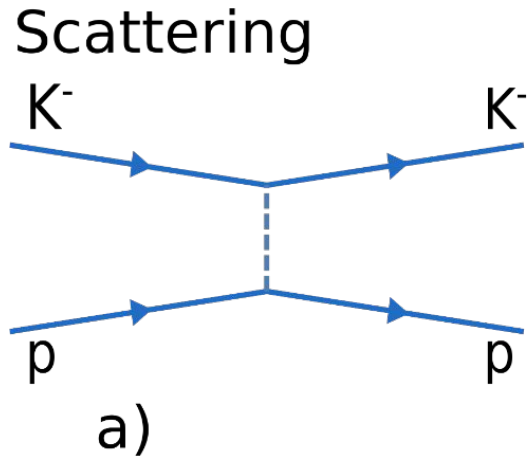
Experimental techniques for K−p interaction

Scattering
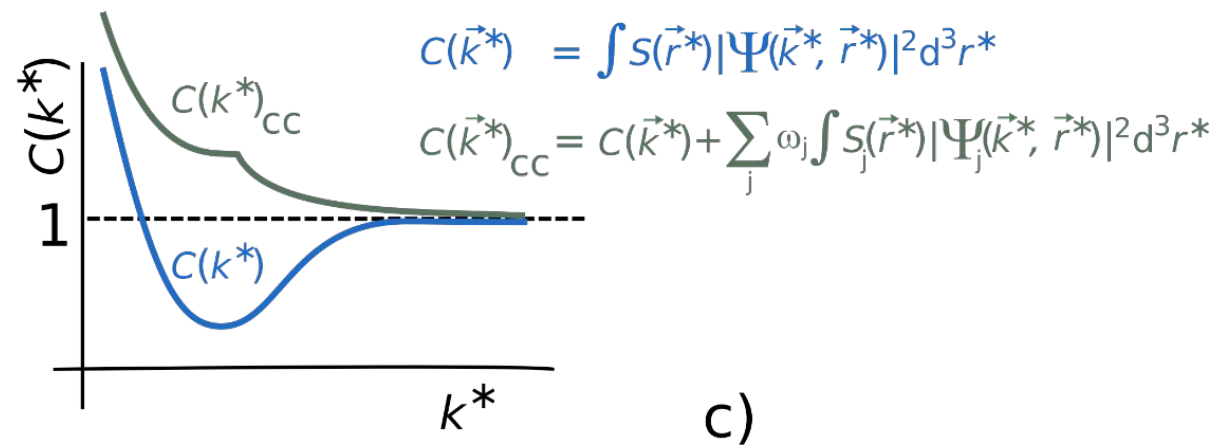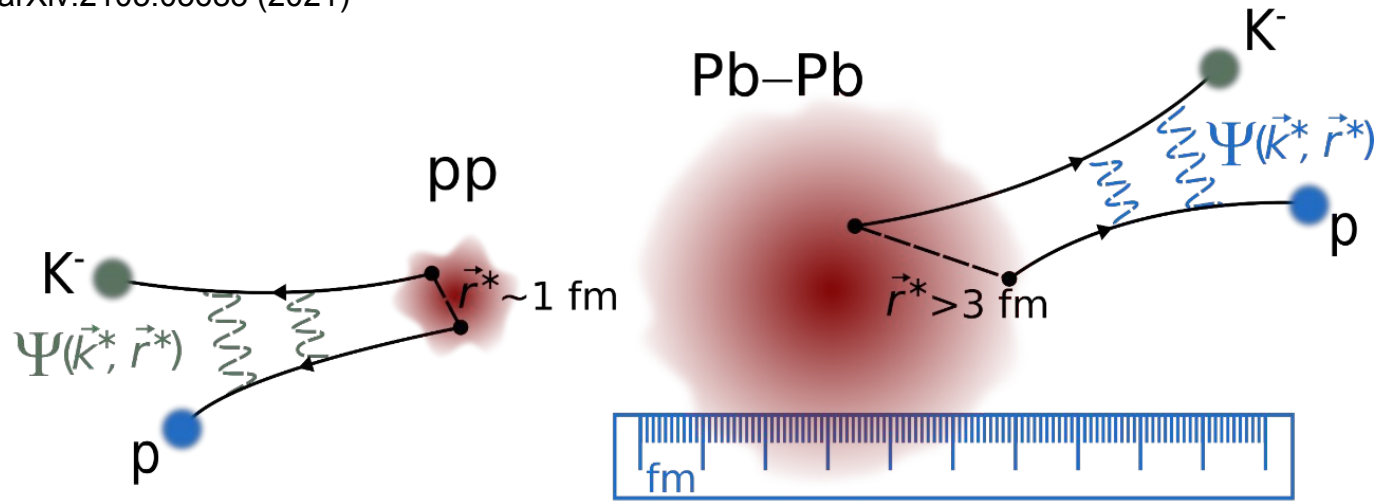
Exotic atoms

ALICE Collaboration,
arXiv:2105.05683 (2021)

Femtoscopy

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

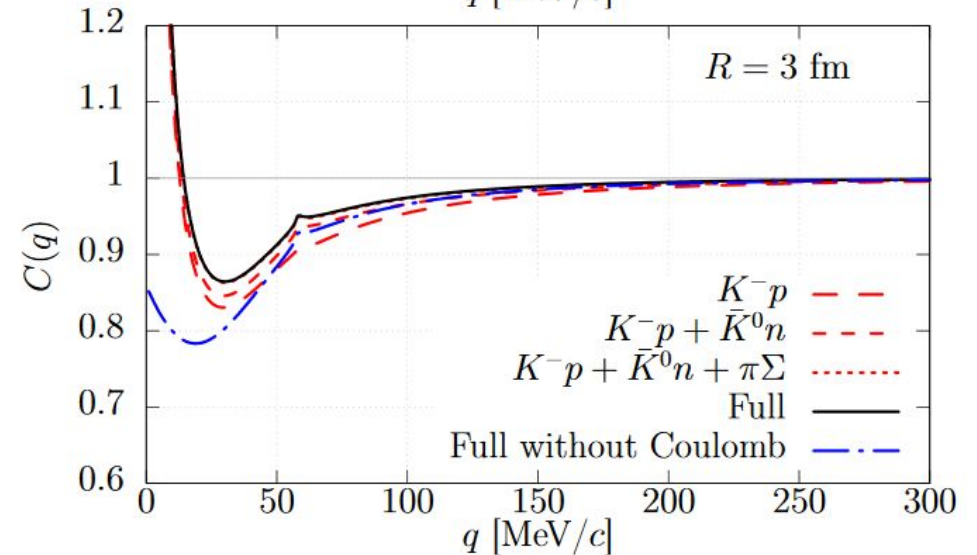$$C(\vec{k^*})_{cc} = C(\vec{k^*}) + \sum_j \omega_j \int S_j(\vec{r^*})|\Psi_j(\vec{k^*}, \vec{r^*})|^2 d^3 r^*$$

Kaon-proton femtoscopy

Kaon-proton interaction

Kyoto model with coupled channels

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

$\overline{\mathrm{K}}$N threshold

Λπ	Σπ	Λ(1405)	K^{0}n	Λ(1520)
-177 MeV/c^2	-100 MeV/c^2	-27 MeV/c^2	58 MeV/c	243 MeV/c

Kaonic atoms

Scattering experiments

femtoscopy

arXiv:1911.01041 PRL124.132501
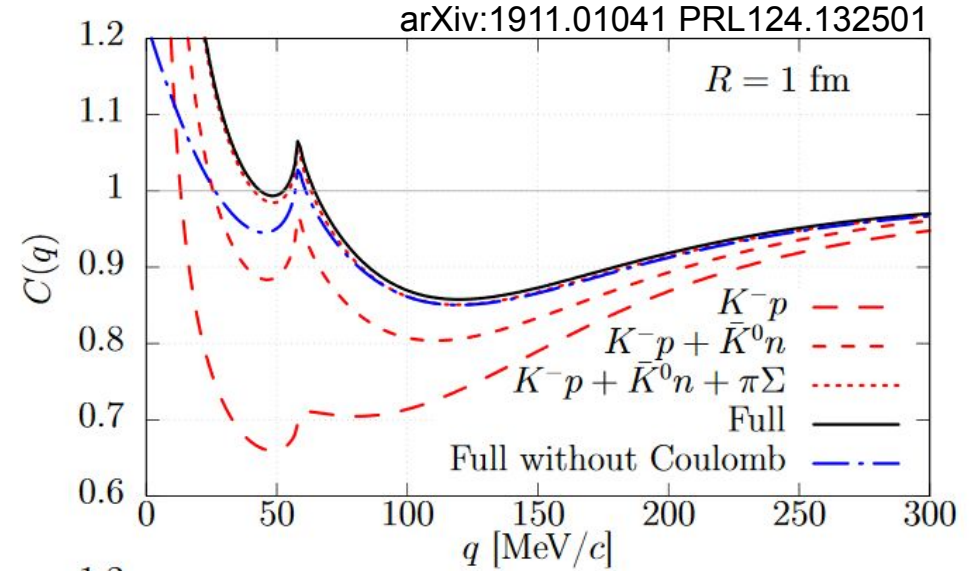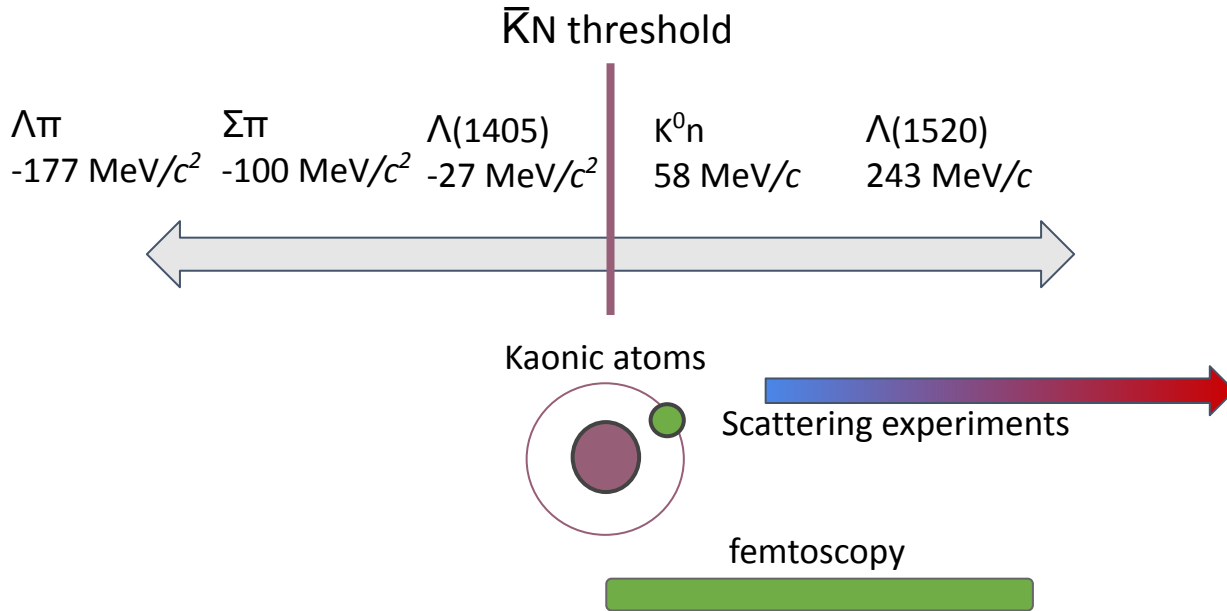
Kp in pp: first evidence of coupled channels

ALICE Collaboration,
arXiv:1905.13470 (2019)

ALI-PUB-322719

ALI-PUB-322458
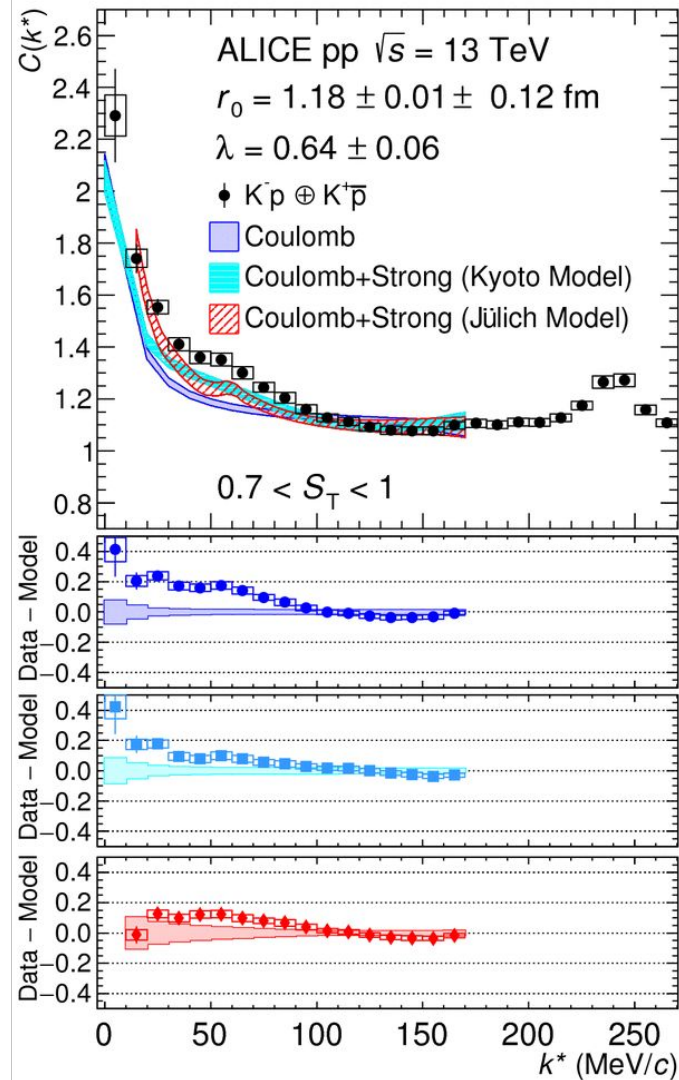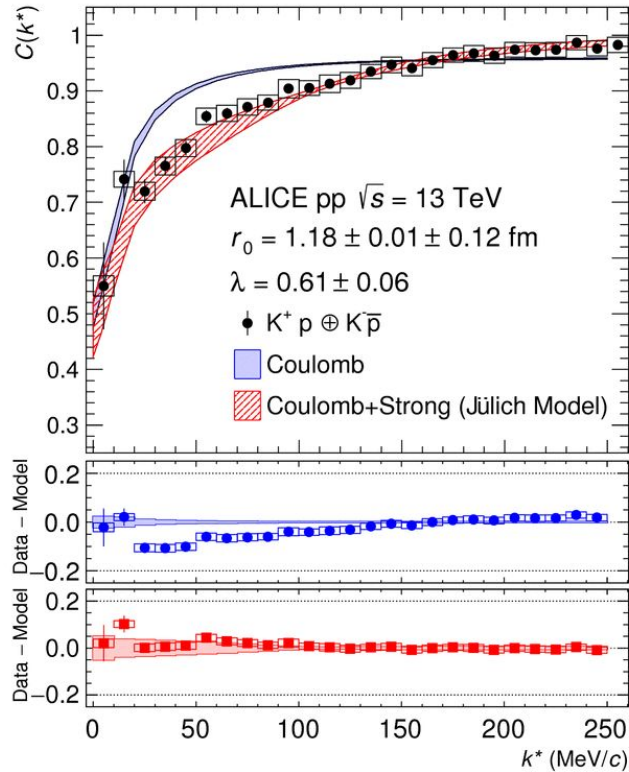
- First experimental evidence for the opening of the $K^0 n$ isospin breaking channel.
- Constraints for low-energy QCD chiral models.

K_s^0 − proton system

$$|K_s^0 p\rangle = \frac{1}{\sqrt{2}}\left[|K^0 p\rangle - |\bar{K}^0 p\rangle\right]$$

ALICE

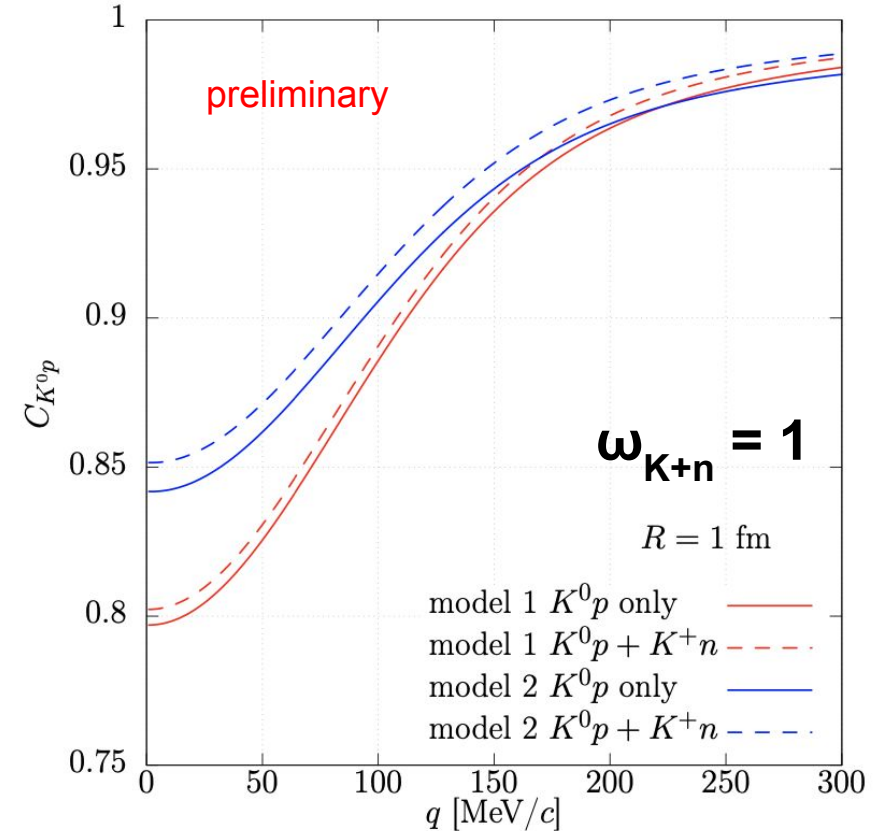- combination of strong eigenstates

$$C_{K_s^0 p} = \frac{1}{2}\left[\boxed{C_{K^0 p}} + C_{\bar{K}^0 p}\right]$$

- Weak strong repulsion

- 1 coupled channel (CC) below threshold: K^+n
  - predicted to be a weak coupling (solid vs dashed)

- Calculations from Aoki-Jido xEFT model for KN *K. Aoki and D. Jido, PTEP 2019, 013D01 (2019), 1806.00925.*
  - 2 solutions: difference in scatt. ampl. above p_{lab} ~400 MeV (k^* ~200 MeV) for p-waves
  - negligible in s-waves

preliminary

$\omega_{K+n} = 1$

$R = 1$ fm

model 1 $K^0 p$ only
model 1 $K^0 p + K^+ n$
model 2 $K^0 p$ only
model 2 $K^0 p + K^+ n$

Courtesy of Y. Kamiya

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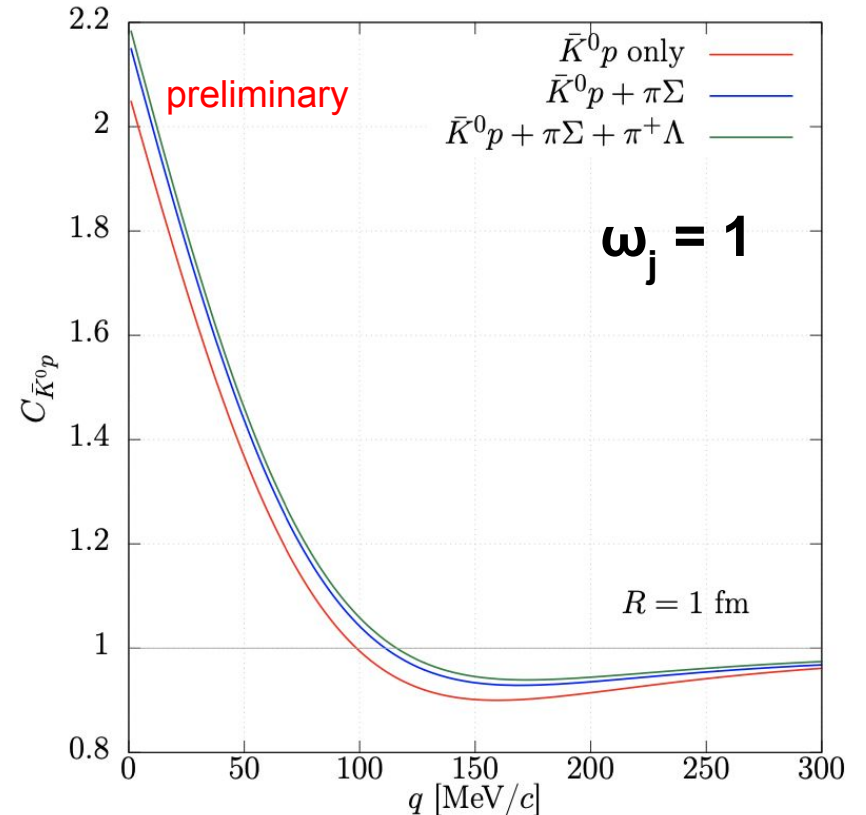
K_s^0 − proton system

$$|K_s^0 p\rangle = \frac{1}{\sqrt{2}}\left[|K^0 p\rangle - |\bar{K}^0 p\rangle\right]$$

ALICE

- combination of strong eigenstates

$$C_{K_s^0 p} = \frac{1}{2}\left[C_{K^0 p} + \boxed{C_{\bar{K}^0 p}}\right]$$

- Moderate attraction

- 3 CC below threshold: $\pi^0\Sigma^+$, $\pi^+\Sigma^0$, $\pi^+\Lambda$
  - large $\pi\Sigma$ coupling (as in K⁻-p)

- Calculations from Kyoto xEFT model for antiKN used for K⁻p *(K. Miyahara, T. Hyodo, and W. Weise, Phys. Rev. C98, 025201 (2018), 1804.08269; Y.Kamiya, T.Hyodo, K.Morita, A.Ohnishi and W.Weise, Phys. Rev. Lett. 124 (2020) no.13,132501)*
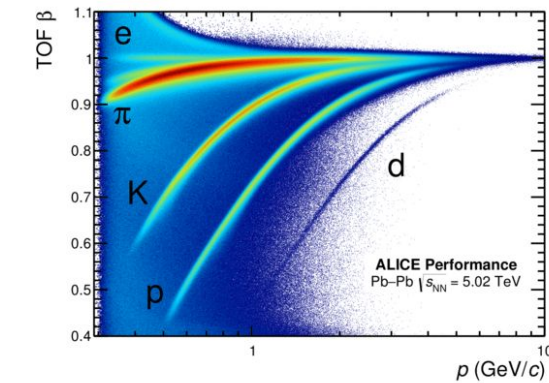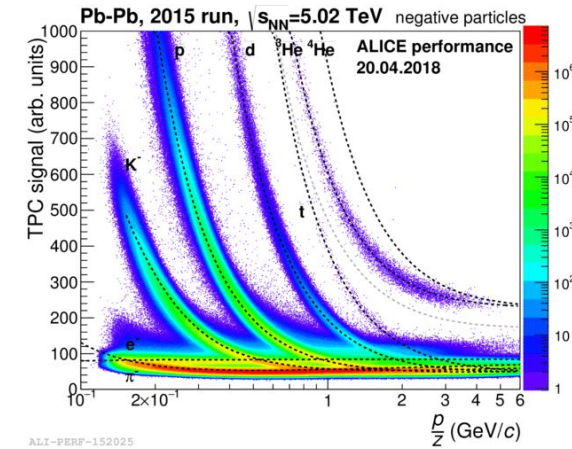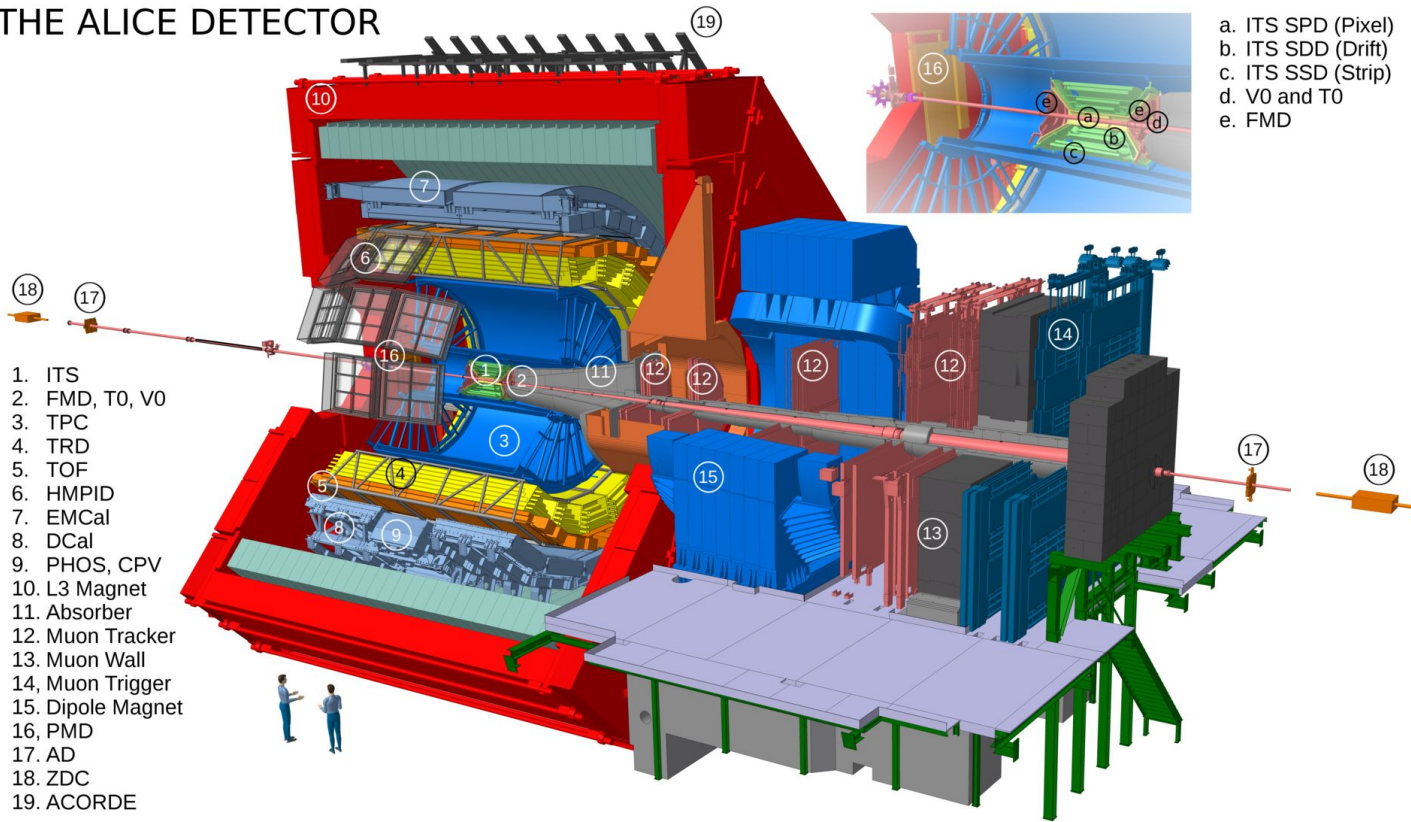
preliminary

$\bar{K}^0 p$ only
$\bar{K}^0 p + \pi\Sigma$
$\bar{K}^0 p + \pi\Sigma + \pi^+\Lambda$

$\omega_j = 1$

$R = 1$ fm

q [MeV/c]

Courtesy of Y. Kamiya

Kaon-proton femtoscopy

Data analysis

THE ALICE DETECTOR

a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD

1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
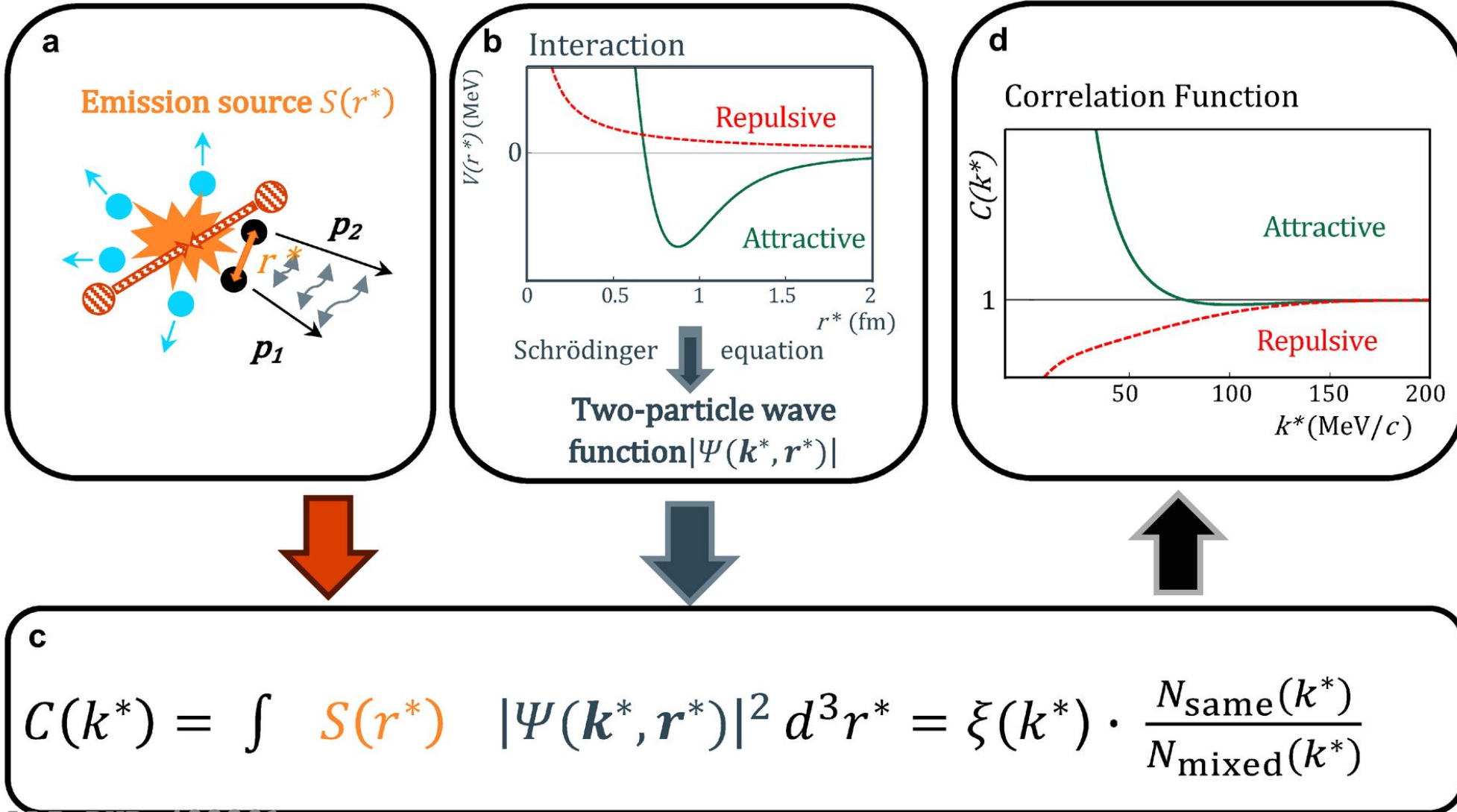14. Muon Trigger
15. Dipole Magnet
16. PMD
17. AD
18. ZDC
19. ACORDE

- K_s^0p analysis in pp collisions at $\sqrt{s}$ = 13 TeV
- K^-p analysis in Pb−Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

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Kaon-proton femtoscopy

Correlation measurement of the strong interaction

$$C(k^*) = \int \; S(r^*) \; |\Psi(\boldsymbol{k}^*, \boldsymbol{r}^*)|^2 \, d^3 r^* = \xi(k^*) \cdot \frac{N_{\text{same}}(k^*)}{N_{\text{mixed}}(k^*)}$$

ALI-PUB-483391

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K − p analyses
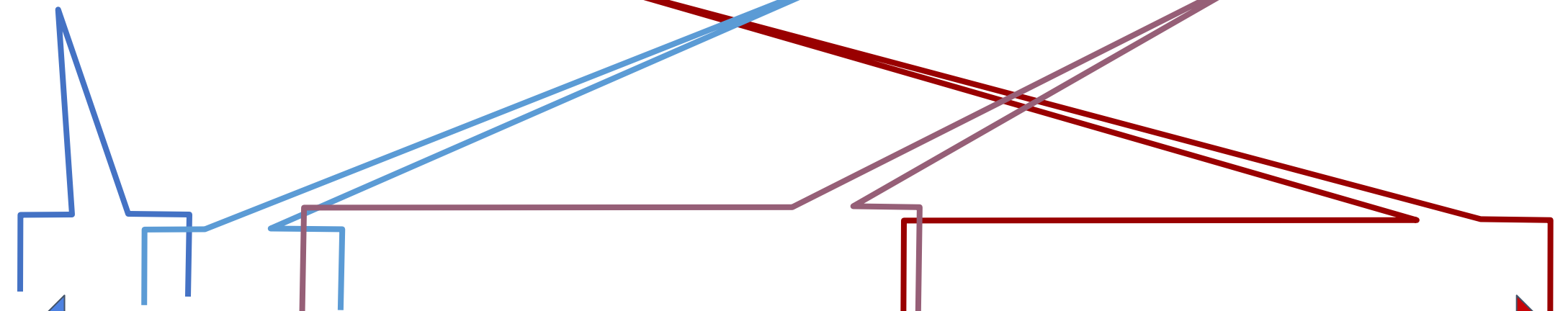
K$_s^0$p in pp
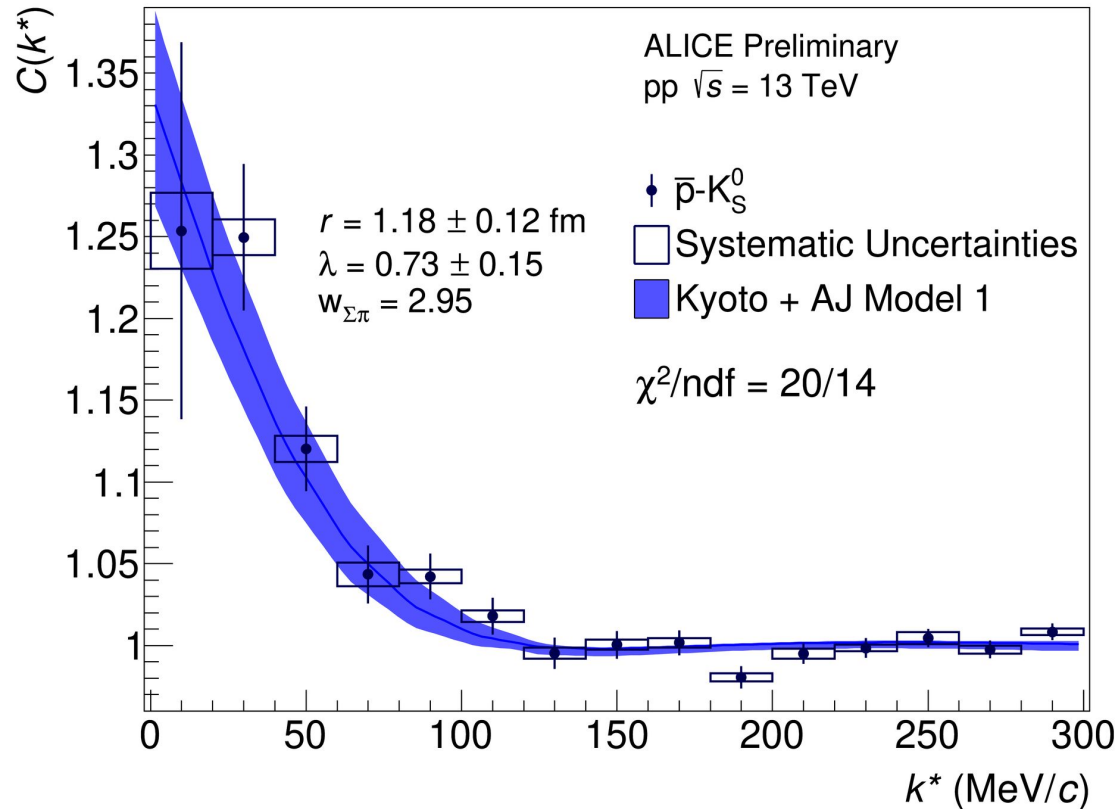
$$|K_s^0 p\rangle = \frac{1}{\sqrt{2}} \left[|K^0 p\rangle - |\bar{K}^0 p\rangle \right]$$

$$C_{K_s^0 p} = \frac{1}{2} \left[C_{K^0 p} + C_{\bar{K}^0 p} \right]$$

$pK_S^0 + \bar{p}K_S^0$

NEW

ALICE Preliminary
pp $\sqrt{s}$ = 13 TeV

r = 1.18 ± 0.12 fm
λ = 0.73 ± 0.15
$w_{\Sigma\pi}$ = 2.95

$\bar{p}$-K$_S^0$
☐ Systematic Uncertainties
■ Kyoto + AJ Model 1

χ^2/ndf = 20/14

ALI−PREL−487659

2σ between 0 and 300 MeV/c

Theoretical correlation function obtained using CATS (*D.L. Mihaylov et al., EPJ C78,394(2018)*)

- theoretical **wave functions** for the **K^{0}p** and **anti-K^{0}p** and coupled channels provided by Chiral Effective Theory group (*Y. Kamiya et T. Hyodo*)

- **Gaussian source** function with r=1.18±0.12 fm (*ALICE Collaboration, Phys. Rev. Lett. 124, 092301 (2020)*)

- Conversions **weights ω = 1** for K^{0}p, K$^+$n, and π$^+$Λ; **ω$_{\Sigma\pi}$ = 2.95** (*Y.Kamiya, T.Hyodo, K.Morita, A.Ohnishi and W.Weise, Phys. Rev. Lett. 124 (2020) no.13,132501*)

georgy.kornakov@pw.edu.pl

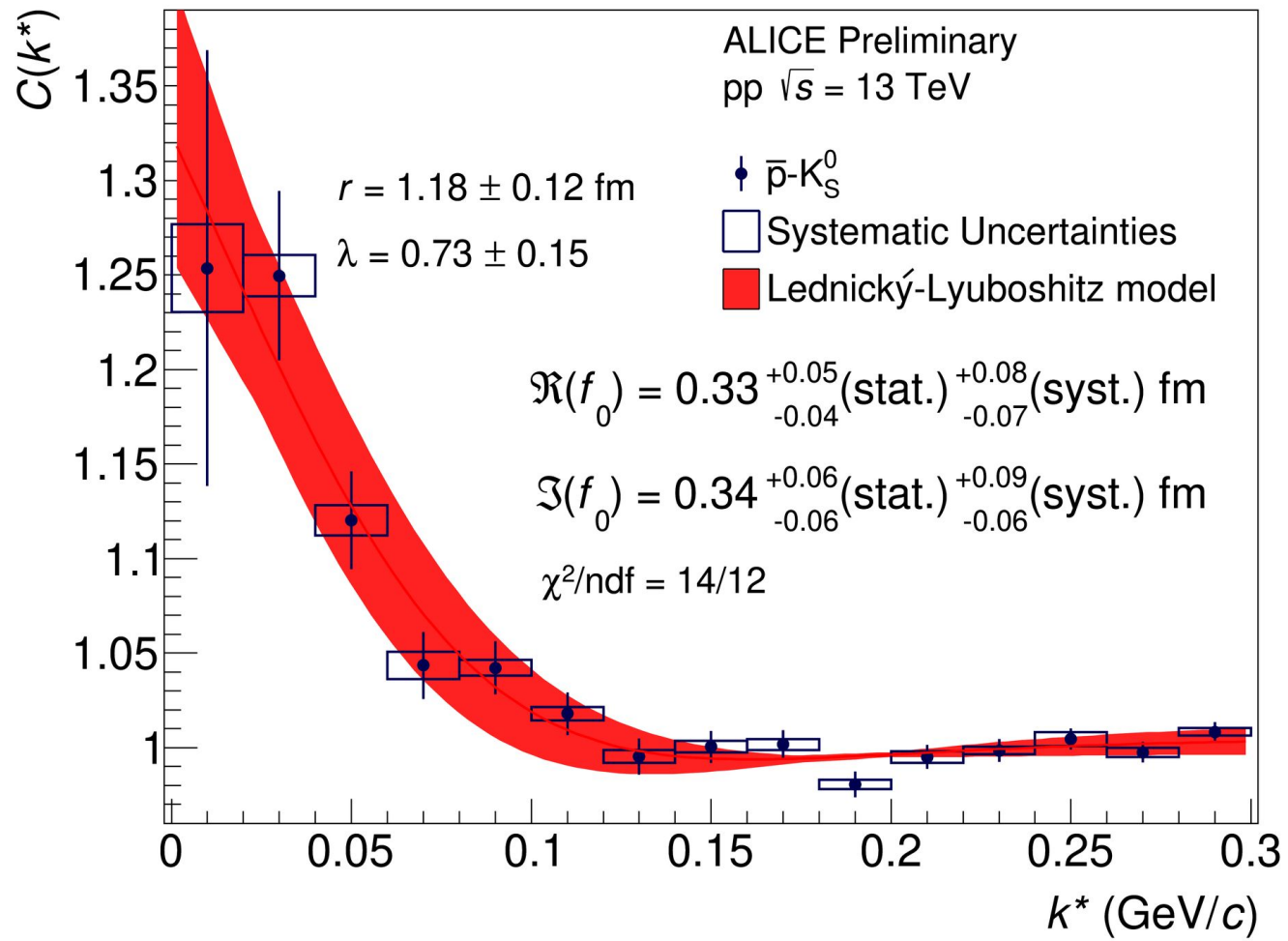Kaon-proton femtoscopy

K^{0}p in pp: results with Lednický−Lyuboshitz model

NEW

ALICE Preliminary
pp $\sqrt{s}$ = 13 TeV

- $\bar{\text{p}}$-K^0_S
- □ Systematic Uncertainties
- ■ Lednický-Lyuboshitz model

$r = 1.18 \pm 0.12$ fm

$\lambda = 0.73 \pm 0.15$

$\Re(f_0) = 0.33^{+0.05}_{-0.04}$(stat.) $^{+0.08}_{-0.07}$(syst.) fm

$\Im(f_0) = 0.34^{+0.06}_{-0.06}$(stat.) $^{+0.09}_{-0.06}$(syst.) fm

χ^2/ndf = 14/12

ALI−PREL−487630

Experimental techniques for K⁻p interaction

Femtoscopy
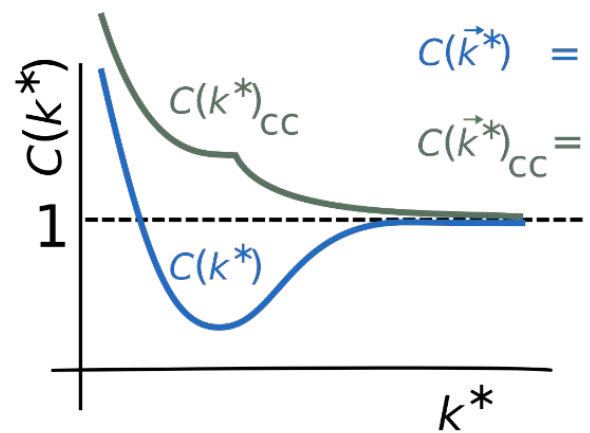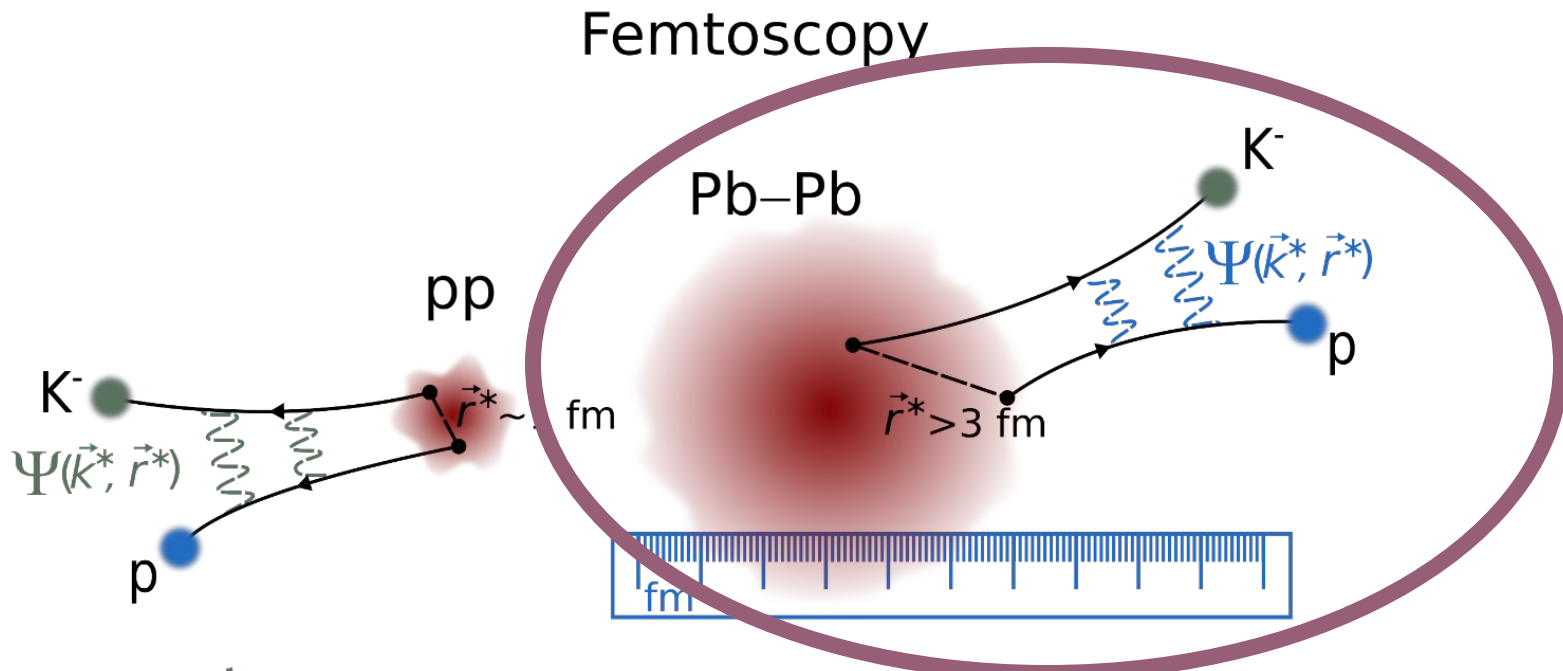
ALICE Collaboration, arXiv:2105.05683 (2021)

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

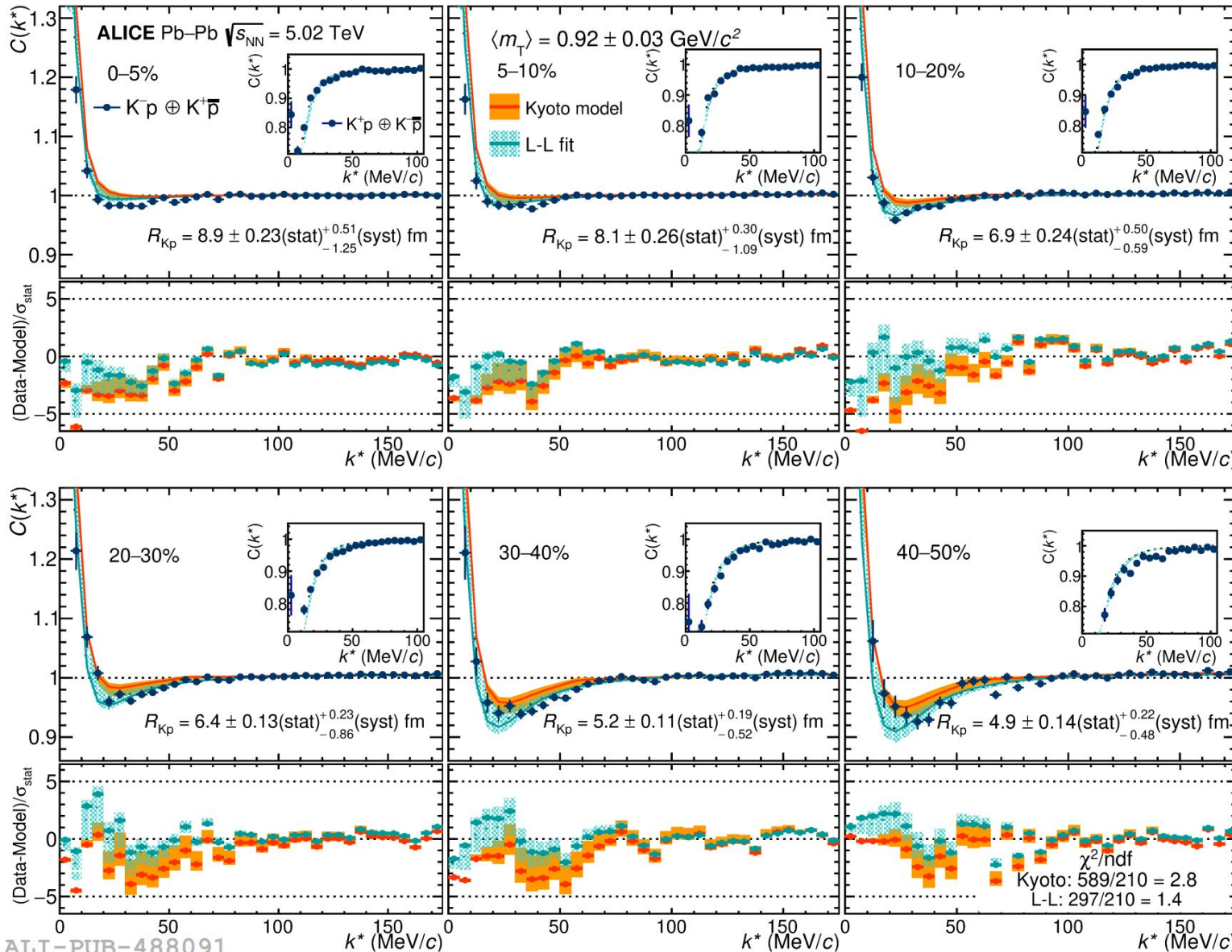$$C(\vec{k^*})_{CC} = C(\vec{k^*}) + \sum_j \omega_j \int S_j(\vec{r^*})|\Psi_j(\vec{k^*}, \vec{r^*})|^2 d^3 r^*$$

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Kp in Pb−Pb: coupled channels? 🏴 NEW

ALICE Collaboration,
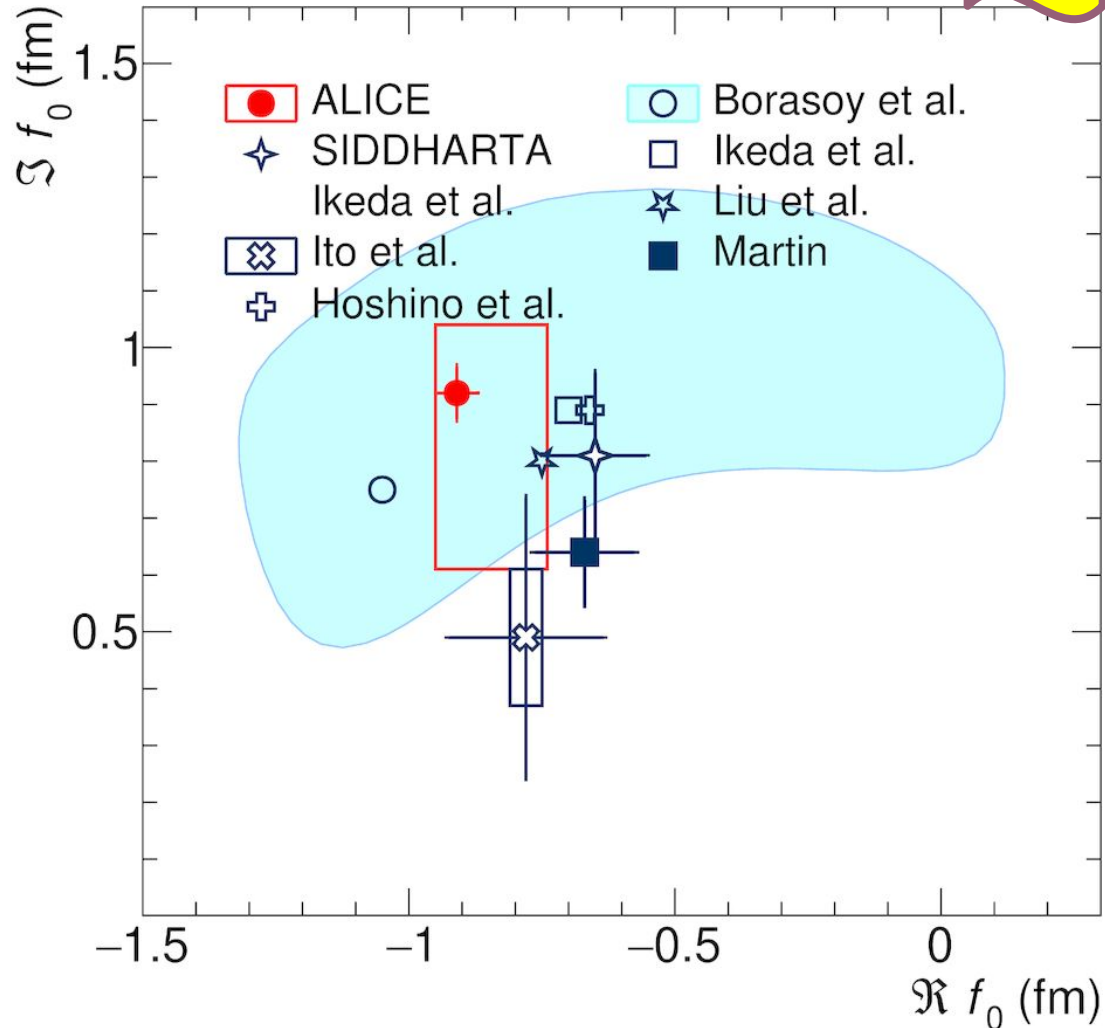arXiv:2105.05683 (2021)

- No $K^0 n$ structure
- Simultaneous description (and fit) of the correlation functions for 6 centralities (0-50%) with two parameters and 6 radii
- Radii constrained from $K^+ p$

K⁻p Scattering length

ALI-PUB-488096

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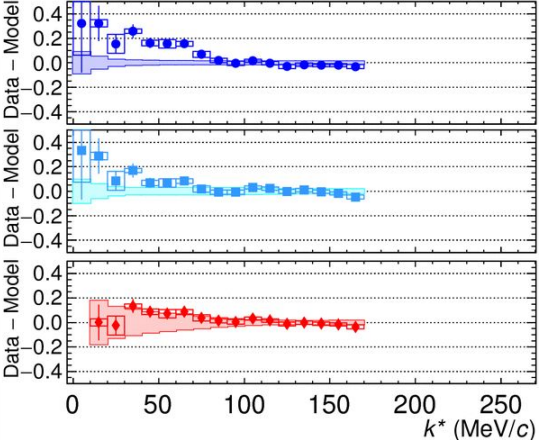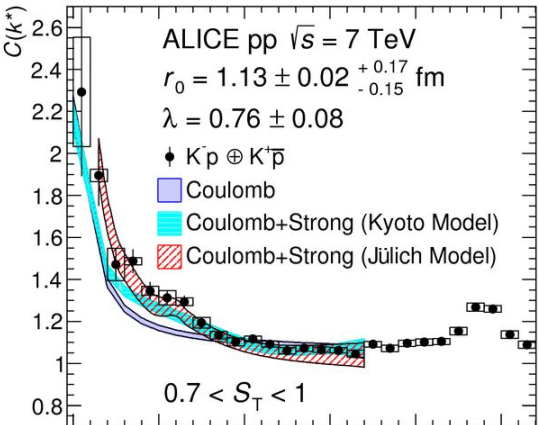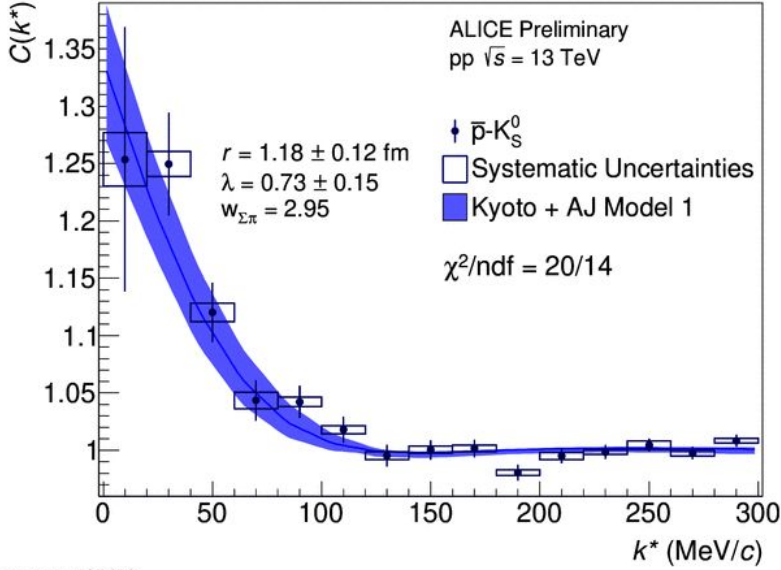- Complementary to exotic atoms and scattering experiments

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Summary

ALICE Collaboration,
arXiv:1905.13470 (2019)

ALICE Collaboration,
arXiv:2105.05683 (2021)

NEW

$$|K_s^0 p\rangle = \frac{1}{\sqrt{2}} \left[|K^0 p\rangle - |\bar{K}^0 p\rangle \right]$$

NEW

pp

Pb–Pb (40–50 %)

1 (fm)   2   4   10

Kaon-proton femtoscopy