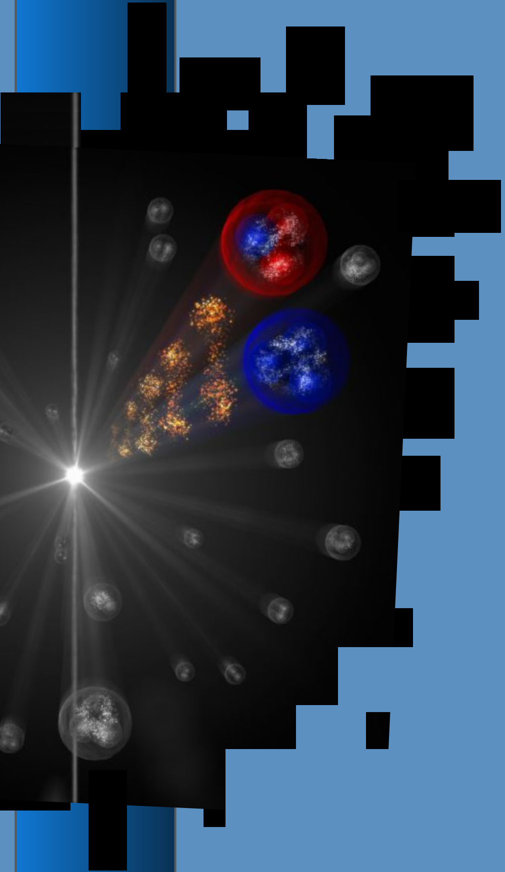


Novel constraints for the multi-strange meson-baryon interaction using correlation measurements

Otón Vázquez Doce (INFN - Frascati)

WPCF 2024 - 17th Workshop on Particle Correlations and Femtoscopy
Toulouse, November 5th 2024

(Multi-)strange meson-baryon systems and exotic states

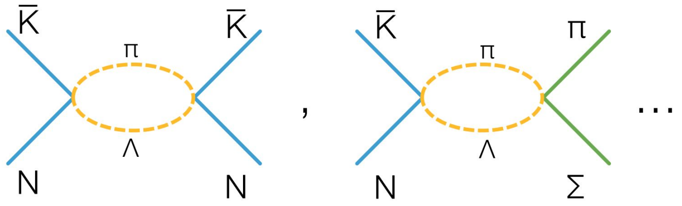
Interactions between mesons and baryons involving strangeness

→ Landmark for hadron-hadron interaction studies

Presence of a **rich coupled-channel dynamics**

→ Systems sharing same quantum numbers (B,S,Q) relatively close in mass

→ On- and off-shell processes from one channel to the other



Several candidates for exotic states with **molecular nature**

→ Typically observed close to channel thresholds

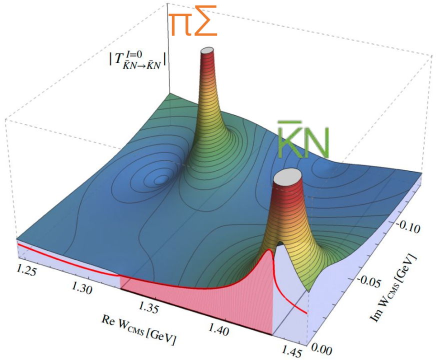
→ Main example given by the **two-pole Λ(1405) state**

J. M.M. Hall et al. Phys. Rev. Lett. 114 (2015) 13

U. G. Meißner Symmetry 12 (2020) 6, 981

→ New Belle-ALICE data: Analogous behaviour in the S=-2 sector!

Ξ(1620)-Ξ(1690): coupled to K̄-Λ, K̄-Σ, Ξπ.



M. Mai Eur. Phys. J. Spec. Top. 230, 1593–1607 (2021)

S=-1 meson-baryon interaction: **$\bar{K}$N interaction**

Large attractive interaction in isospin I=0 channel

→ Responsible for formation of Λ(1405) below (and very close to) $\bar{K}$N threshold

Chiral SU(3) EFT ⇒ Molecular state with two poles $\bar{K}$N-Σπ

Scattering calculation on the lattice

→ Coupled channel analysis find 2 poles; still not physical masses. J. Bulava et al., arXiv:2307.10413 [hep-lat]

S=-1 meson-baryon interaction: **$\bar{K}N$ interaction**

Large attractive interaction in isospin I=0 channel

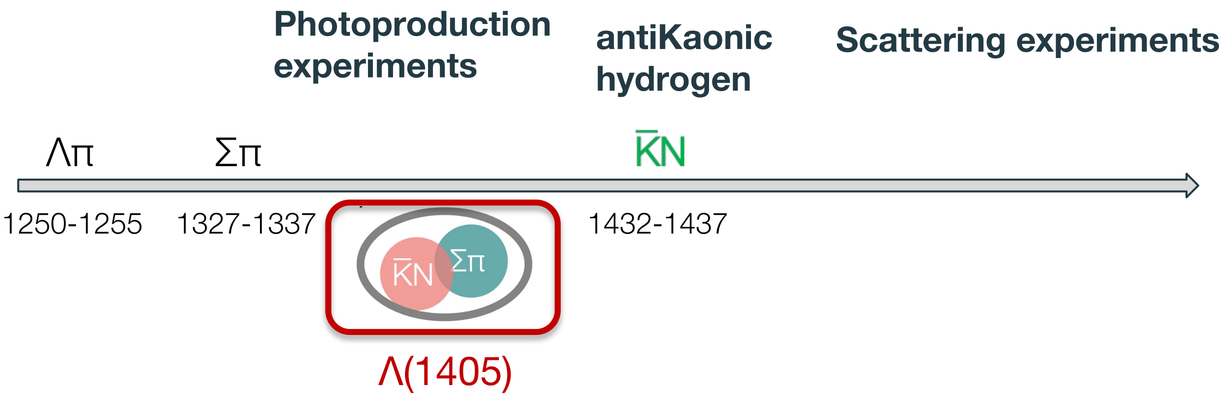
→ Responsible for formation of Λ(1405) below (and very close to) $\bar{K}N$ threshold

Chiral SU(3) EFT ⇒ Molecular state with two poles $\bar{K}N$-Σπ

Scattering calculation on the lattice

→ Coupled channel analysis find 2 poles; still not physical masses. J. Bulava et al., arXiv:2307.10413 [hep-lat]

Experimentally: studied with different approaches but scarce statistics available from scattering data above $\bar{K}N$ threshold



S=-1 meson-baryon interaction: **$\bar{K}N$ interaction**

Large attractive interaction in isospin I=0 channel

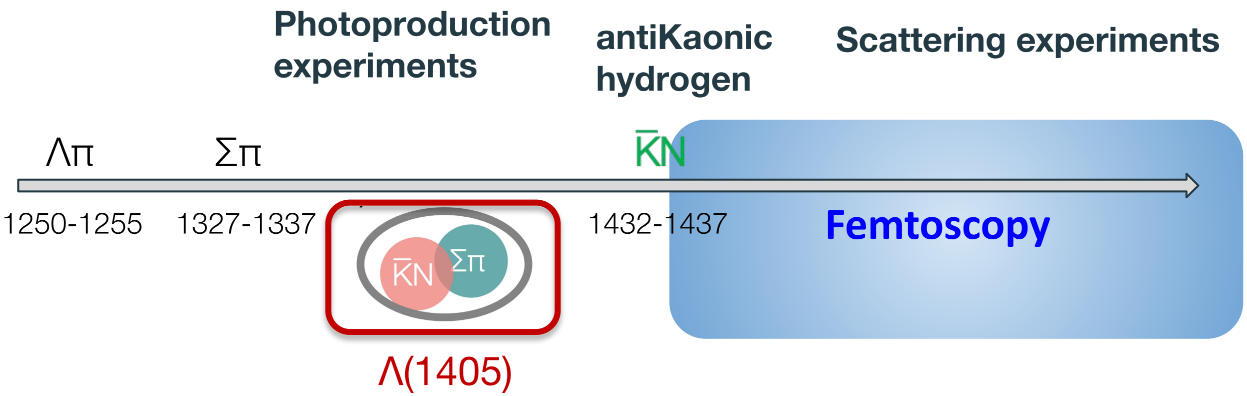
→ Responsible for formation of Λ(1405) below (and very close to) $\bar{K}N$ threshold

Chiral SU(3) EFT ⇒ Molecular state with two poles $\bar{K}N$-Σπ

Scattering calculation on the lattice

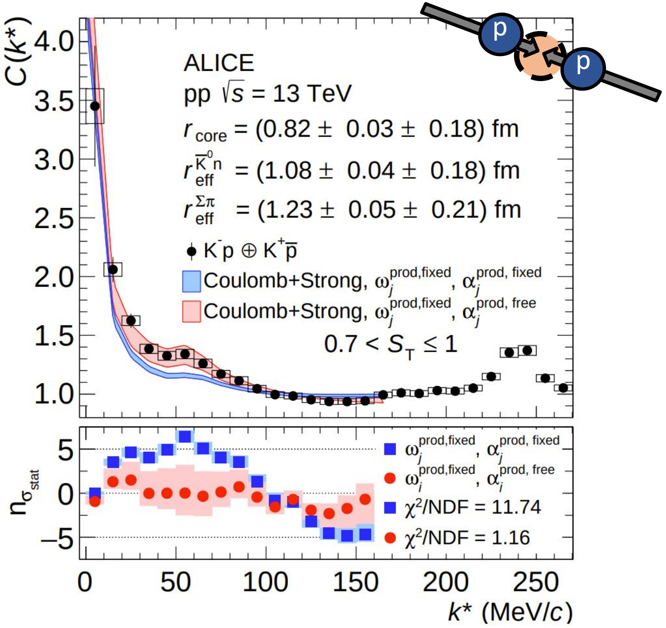
→ Coupled channel analysis find 2 poles; still not physical masses. J. Bulava et al., arXiv:2307.10413 [hep-lat]

Experimentally: studied with different approaches but scarce statistics available from scattering data above $\bar{K}N$ threshold



High-precision data on S=-1 sector above threshold

Femtoscopy delivers the **most precise data above K⁻-p threshold**
→ Crucial input for low-energy chiral effective potentials

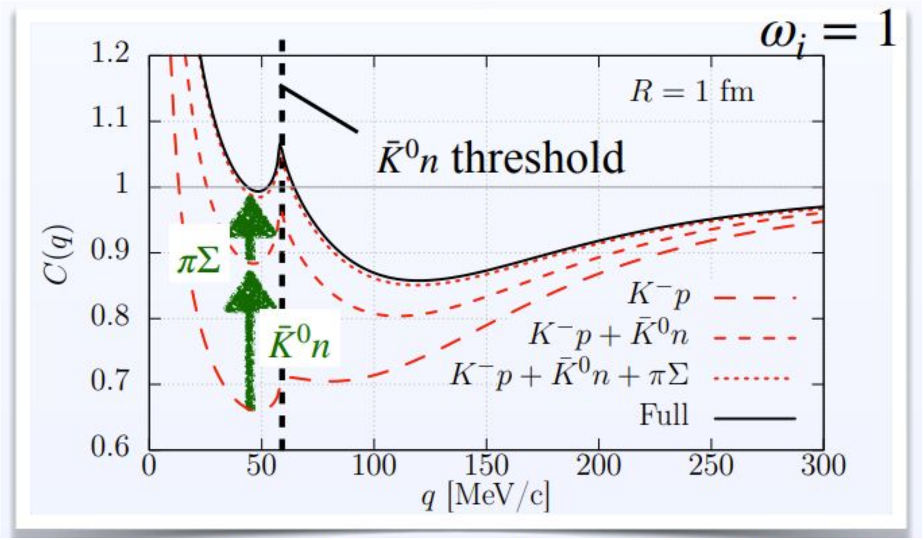


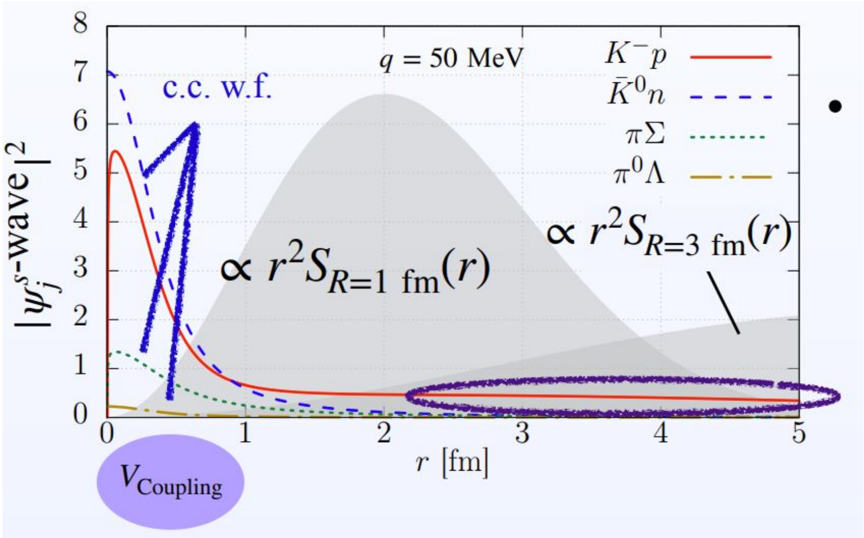
Data:
ALICE Coll. Phys. Rev. Lett. 124, 092301 (2020)
ALICE Coll. Eur. Phys. J. C 83, 340 (2023)
ALICE Coll., Phys. Lett. B 822, 136708 (2021)

Strong interaction: Kyoto model
K. Miyahara et al., Phys. Rev. C98, 2, (2018) 025201

High-precision data on S=-1 sector above threshold

→ Strength of coupled channels significantly reduced in small systems



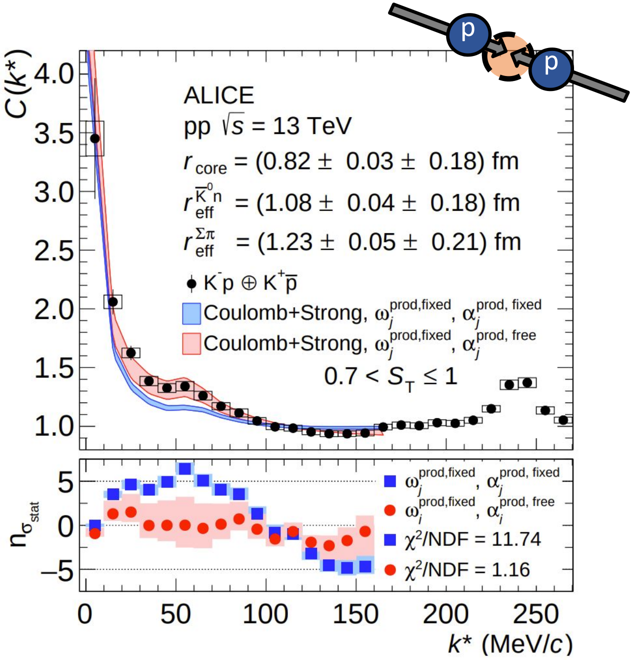


Y. Kamiya et al., Phys. Rev. Lett. 124, 132501 (2020)

High-precision data on S=-1 sector above threshold

Data: ALICE Coll. Phys. Rev. Lett. 124, 092301 (2020)
ALICE Coll. Eur. Phys. J. C 83, 340 (2023)
ALICE Coll., Phys. Lett. B 822, 136708 (2021)
Strong interaction: K. Miyahara et al., Phys. Rev. C98, 2, (2018) 025201

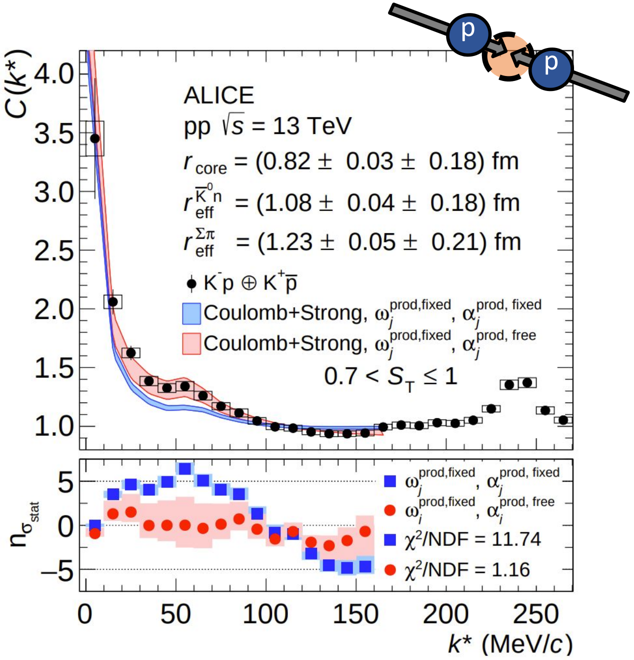
Femtoscopy provides a **quantitative test of coupled channels**



High-precision data on S=-1 sector above threshold

Femtoscopy provides a **quantitative test of coupled channels**

Data: ALICE Coll. Phys. Rev. Lett. 124, 092301 (2020)
ALICE Coll. Eur. Phys. J. C 83, 340 (2023)
ALICE Coll., Phys. Lett. B 822, 136708 (2021)
Strong interaction: K. Miyahara et al., Phys. Rev. C98, 2, (2018) 025201



Correlation function with coupled channels:

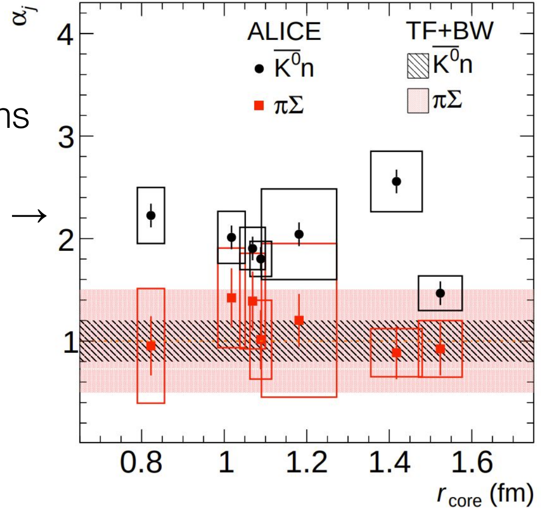
$$C_{K^-p}(k^*) = \int d^3r^* S_{K^-p}(r^*)|\psi_{K^-p}(k^*,r^*)|^2 + \sum_j \omega_j \int d^3r^* S_j(r^*)|\psi_j(k^*,r^*)|^2$$

$$\omega_j = \alpha_j \times \omega_j^{prod}$$

ω_j^{prod} = production yields (thermal model)
+ production p_T spectrum (blast-wave)
+ pair kinematics

Differential study across coll. systems

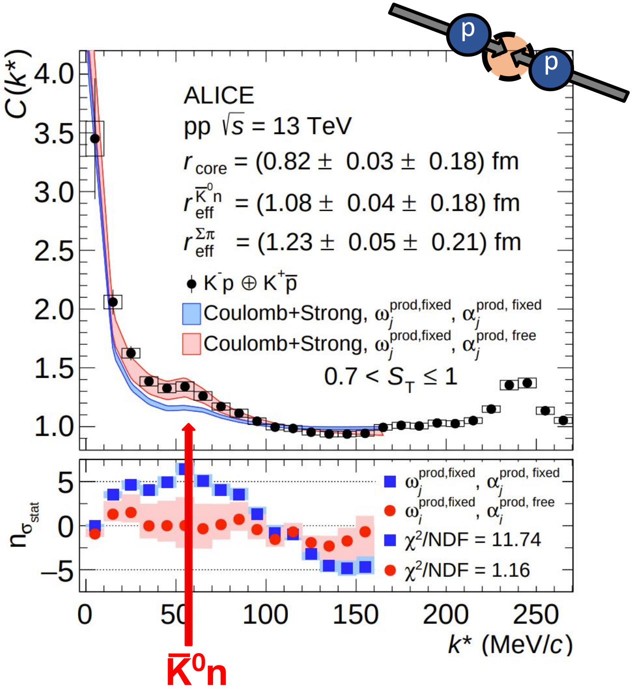
The model does not reproduce the strength of the $\overline{K}^0$-n channel →



High-precision data on S=-1 sector above threshold

Femtoscopy provides a **quantitative test of coupled channels**

Data: ALICE Coll. Phys. Rev. Lett. 124, 092301 (2020)
ALICE Coll. Eur. Phys. J. C 83, 340 (2023)
ALICE Coll., Phys. Lett. B 822, 136708 (2021)
Strong interaction: K. Miyahara et al., Phys. Rev. C98, 2, (2018) 025201



Correlation function with coupled channels:

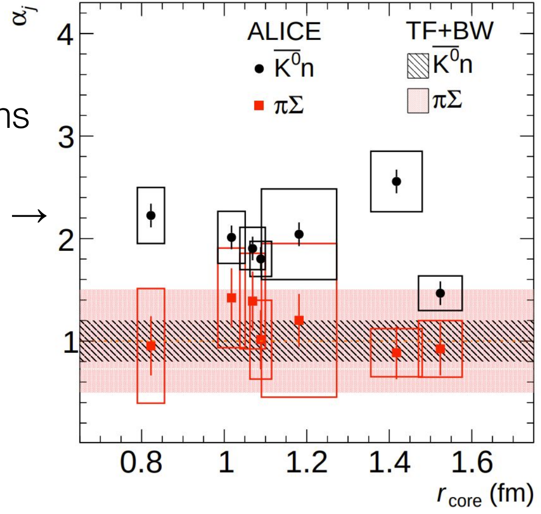
$$C_{K^-p}(k^*) = \int d^3r^* S_{K^-p}(r^*)|\psi_{K^-p}(k^*,r^*)|^2 + \sum_j \omega_j \int d^3r^* S_j(r^*)|\psi_j(k^*,r^*)|^2$$

$$\omega_j = \alpha_j \times \omega_j^{prod}$$

ω_j^{prod}= production yields (thermal model)
+ production p_T spectrum (blast-wave)
+ pair kinematics

Differential study across coll. systems

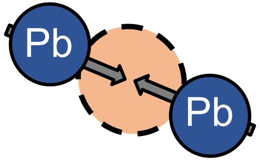
The model does not reproduce the strength of the $\overline{K}^0$-n channel →



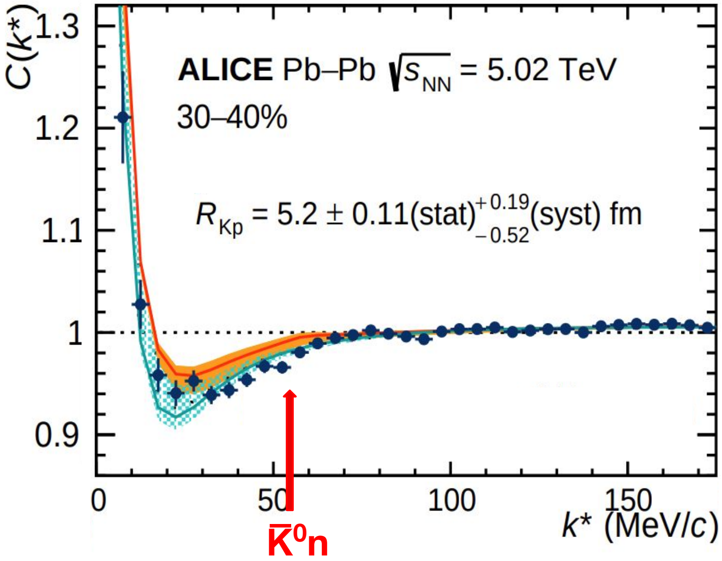
High-precision data on S=-1 sector above threshold

Large systems: **Pb-Pb collisions**, up to r~9fm

Strength of coupled channels significantly reduced



Data: ALICE Coll. Phys. Rev. Lett. 124, 092301 (2020)
ALICE Coll. Eur. Phys. J. C 83, 340 (2023)
ALICE Coll., Phys. Lett. B 822, 136708 (2021)
Model: K. Miyahara et al., Phys. Rev. C98, 025201 (2018)



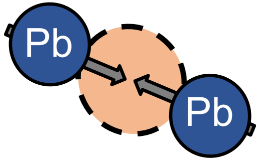
⇒ Kyoto model

⇒ Fit to the scattering parameters R. Lednický Phys. Atom. Nucl. 67 (2004) 72

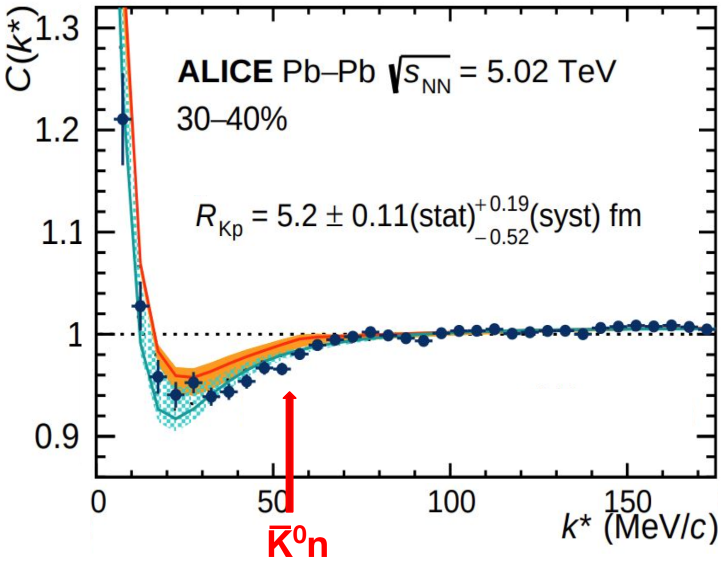
High-precision data on S=-1 sector above threshold

Large systems: **Pb-Pb collisions**, up to r~9fm

Strength of coupled channels significantly reduced

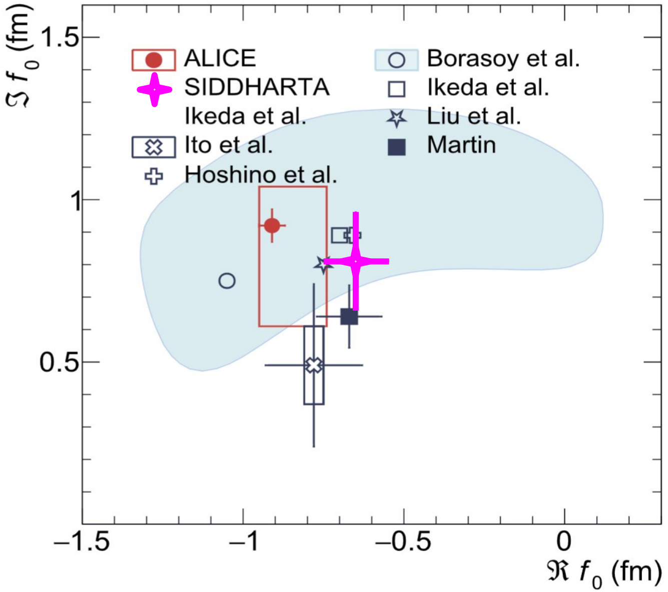


Data: ALICE Coll. Phys. Rev. Lett. 124, 092301 (2020)
ALICE Coll. Eur. Phys. J. C 83, 340 (2023)
ALICE Coll., Phys. Lett. B 822, 136708 (2021)
Model: K. Miyahara et al., Phys. Rev. C98, 025201 (2018)



⇒ Kyoto model

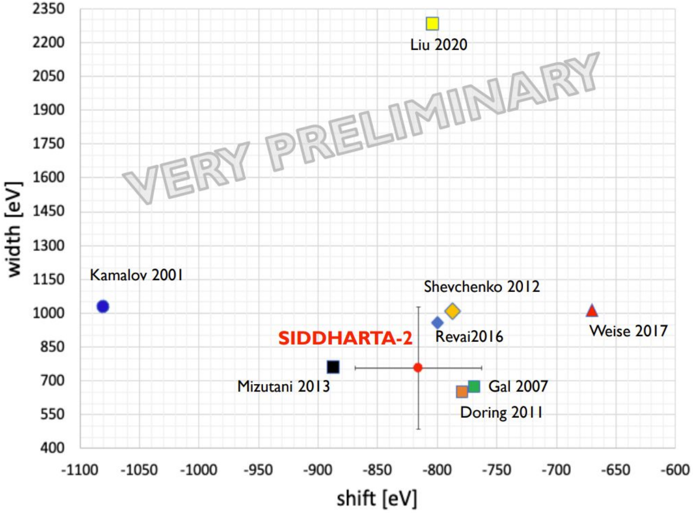
⇒ Fit to the scattering parameters R. Lednický Phys. Atom. Nucl. 67 (2004) 72



⇒ AntiKaonic-hydrogen and K-p femtoscopy scattering parameters compatible

High-precision data on S=-1 sector above threshold

F. Sgaramella @ STRONG2020 workshop 2024

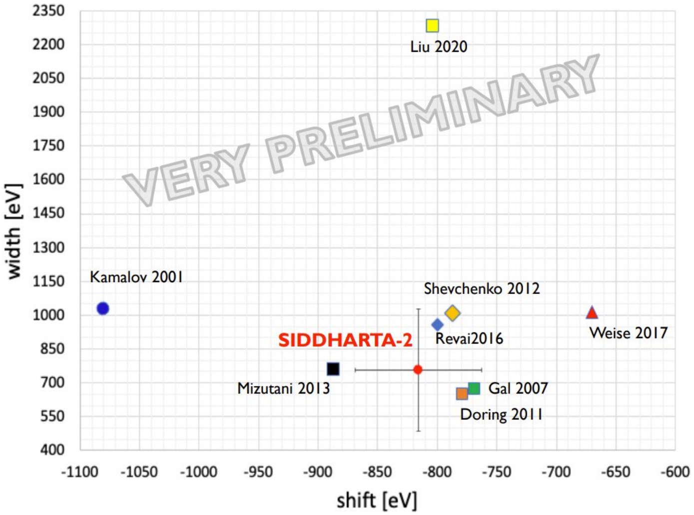


The quest to unveil the I=1 $\bar{K}N$ interaction:

Femtoscopy can complement current effort by SIDDHARTA-2 antiKaonic-deuterium measurement

High-precision data on S=-1 sector above threshold

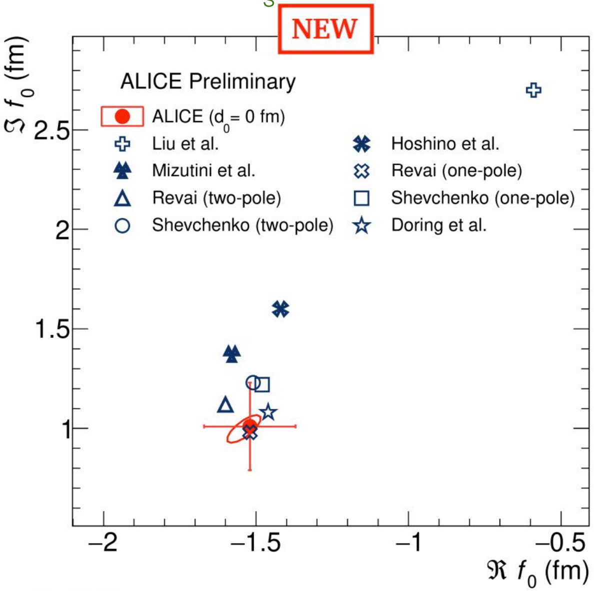
F. Sgaramella @ STRONG2020 workshop 2024



The quest to unveil the I=1 $\overline{K}N$ interaction:

Femtoscopy can complement current effort by SIDDHARTA-2 antiKaonic-deuterium measurement

⇒ K^-d and K^0_sp femtoscopy (ALICE)



S=-1 meson-baryon interaction

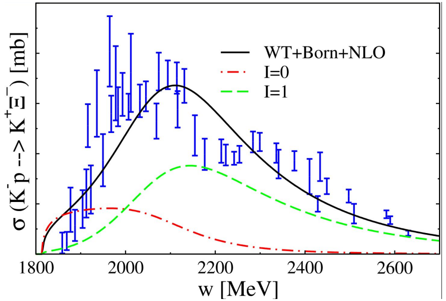
$\bar{K}N$ interaction description with effective chirally models able to describe the data in a wide energy range

→ Help on fixing of the NLO constants

→ Incorporate channels sensitive to the I=1 component

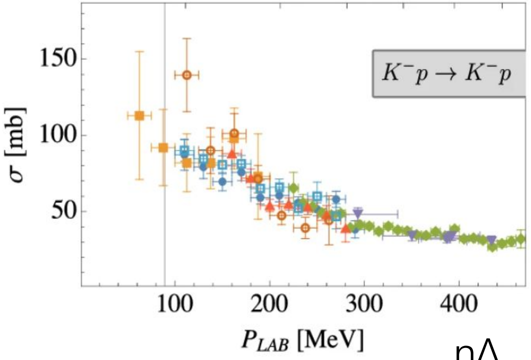
Sensitivity to I=1 component

A. Feijoo et al., Phys. Rev. C99, 035211 (2019)



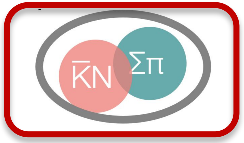
Scattering experiments

M. Mai Eur. Phys. J. Spec. Top. 230, 1593 (2021)



Photoproduction experiments

Λ(1405)



antiKaonic hydrogen

SIDDHARTA Coll. PLB 704 (2011)

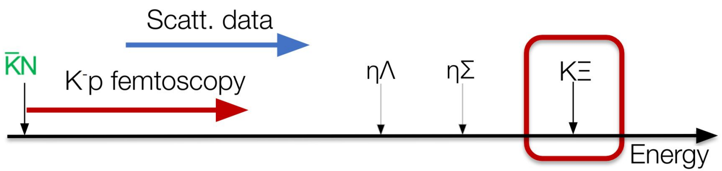
Λπ	Σπ		$\bar{K}N$	ηΛ	ηΣ	KΞ	
1250-1255	1327-1337		1432-1437	1633	1740	1815	**Energy**

Femtoscopy can also give explore the several relevant coupled channels

Accessing the $\Xi^{-}K^{+}$ system with femtoscopy

Femtoscopy delivers precise data at low momenta on the interaction between Ξ and kaons

→ Important constraints for **I=1 channel** of S=-1 meson-baryon interaction



Modeled assuming Lednický-Lyuboshits wavefunction with Coulomb (S-wave only)

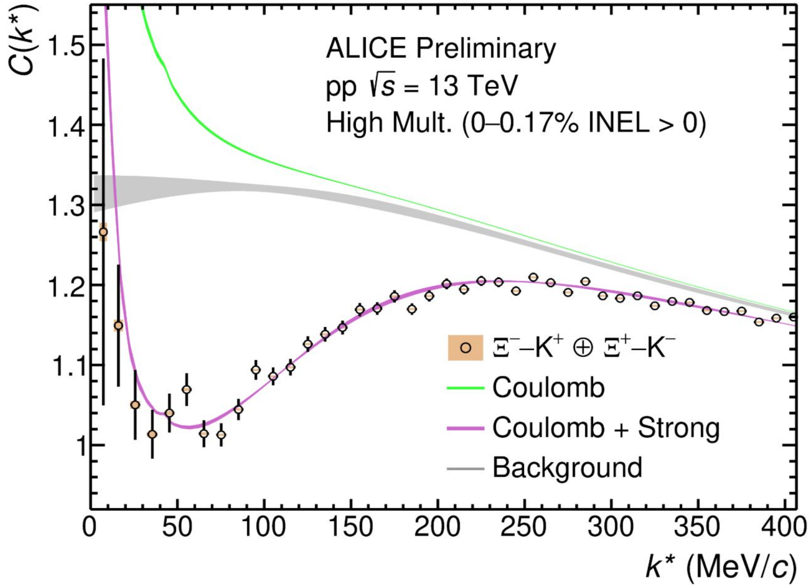
R. Lednický, Phys. Part. Nucl. 40: 307-352 (2009)

→ Coulomb + strong repulsive interaction assumption agrees with the data

→ Determination of scattering length from best fit:

$$\Re f_0 = -0.61^{\pm 0.02(stat)}_{\pm 0.07(syst)}$$

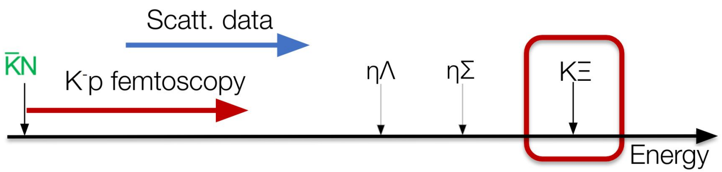
$$\Im f_0 = \mathbf{0.41}^{\pm 0.04(stat)}_{\pm 0.11(syst)}$$



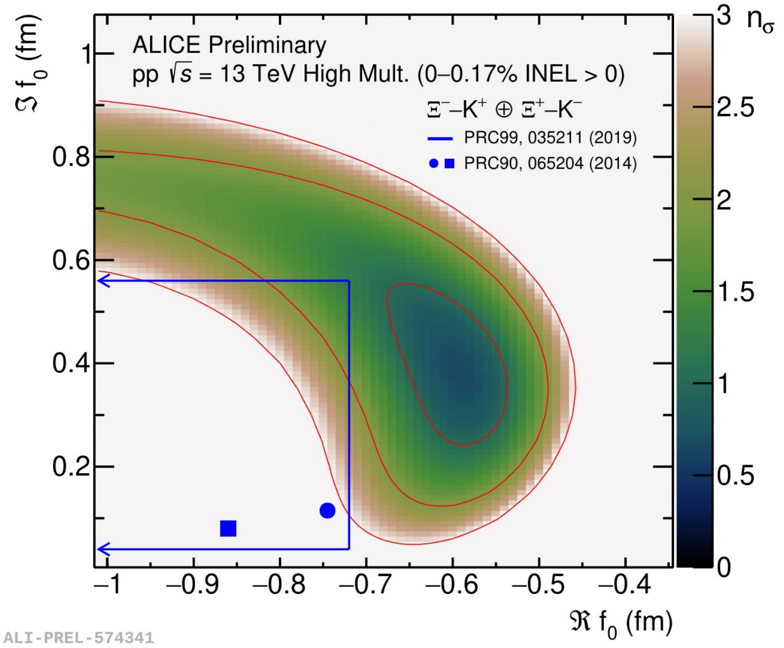
Constraining the $\Xi^{-}K^{+}$ scattering parameters

Heat map: Comparison of data with modeling assuming different values of ($\Re f_0$, $\Im f_0$)

→ Delivered in terms of number of standard deviations (n_σ) in $k^* \in [0,250]$ MeV/c



Allowed values for f_0 from **state-of-the-art chiral calculations** at next-to-leading order and phenomenological potentials **constrained** to **available scattering data ⇒** Higher precision constraints can be delivered with femtoscopy



Moving to the S=-2 sector

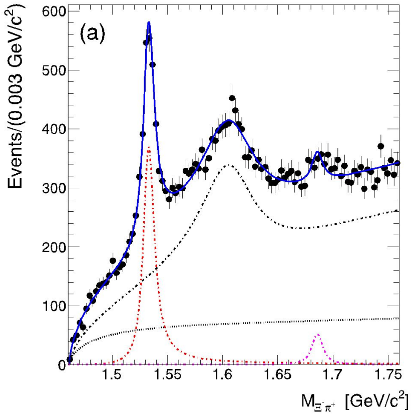
Scattering experiments challenging with increasing strangeness

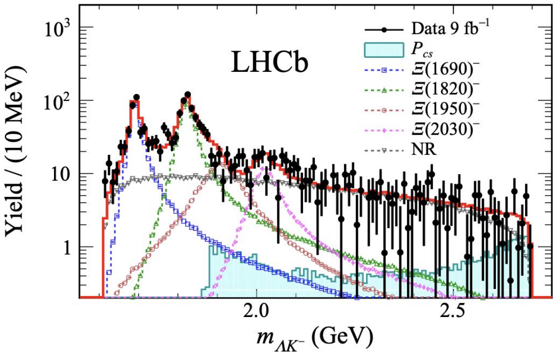
→ Ξ(1620) lying across the $\bar{K}\Lambda$ threshold as molecular candidate, poorly known: πΞ–$\bar{K}\Lambda$ molecule?

Intensive searches via spectroscopy measurements

→ Combine different production mechanisms/decay channels to reveal the nature of the state

Ξ(1620)
Belle Coll.,
Phys. Rev. Lett 122 (2019)





Ξ(1690)
LHCb Coll.
Sci. Bull. 66 (2021)

Ξπ	$\bar{K}\Lambda$	$\bar{K}\Sigma$	ηΞ	
1449-1461	1609-1613	1683-1691	1870	**Energy**

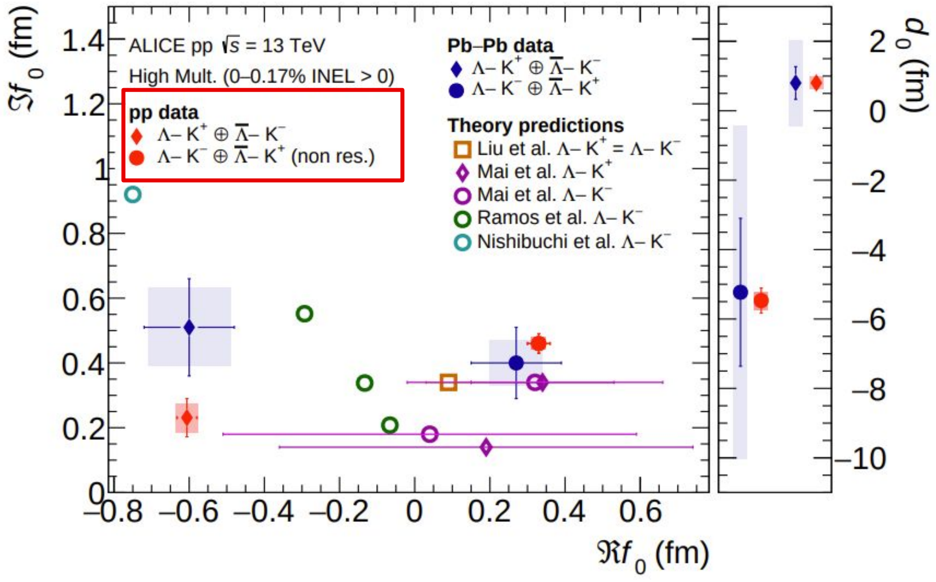
Femtoscopy approach: accessing the interaction between the constituents

Accessing the S=-2 meson-baryon interaction

ΛK^0 femtoscopy studied in Pb–Pb collisions by CMS (see the next talk by R. Pradhan) and ALICE

ALICE studied also ΛK^+ and ΛK^- pairs both in Pb–Pb and pp collisions
→ Determination of the real and imaginary part of the scattering length and effective range using the Lednicky model

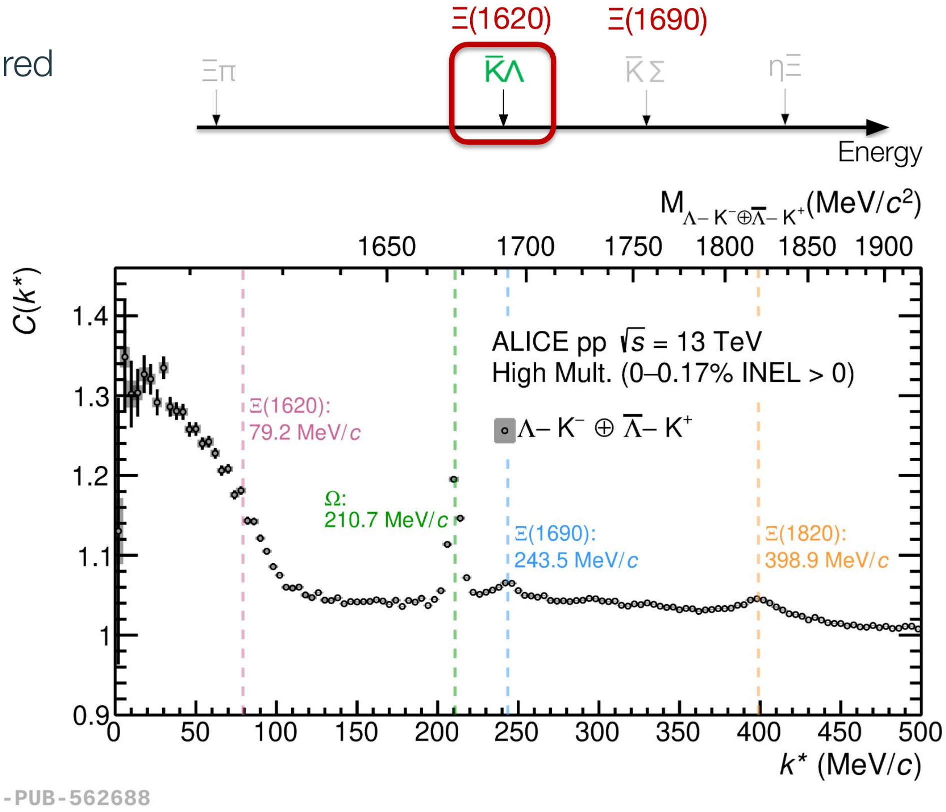
Data:
Pb–Pb: CMS Coll. Phys. Lett. B 857 (2024) 138936
ALICE Coll. Phys. Rev. C 103 (2021)
pp: ALICE Coll. Phys. Lett. B 845 (2023) 138145



Accessing the S=-2 meson-baryon interaction

Study of the resonant structures present in the measured ΛK^- correlation function in pp collisions

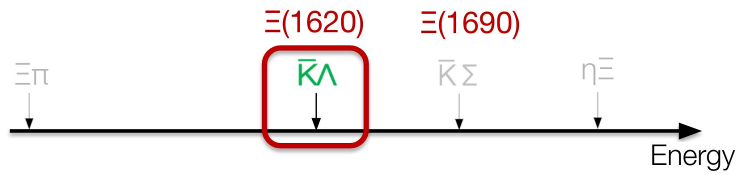
ALICE Coll. Phys. Lett. B 845 (2023) 138145



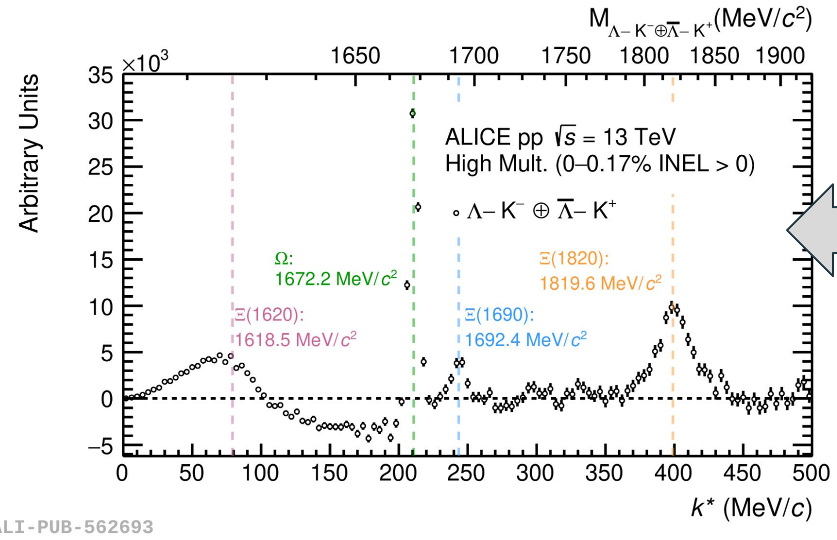
Accessing the S=-2 meson-baryon interaction

Study of the resonant structures present in the measured ΛK^- correlation function in pp collisions

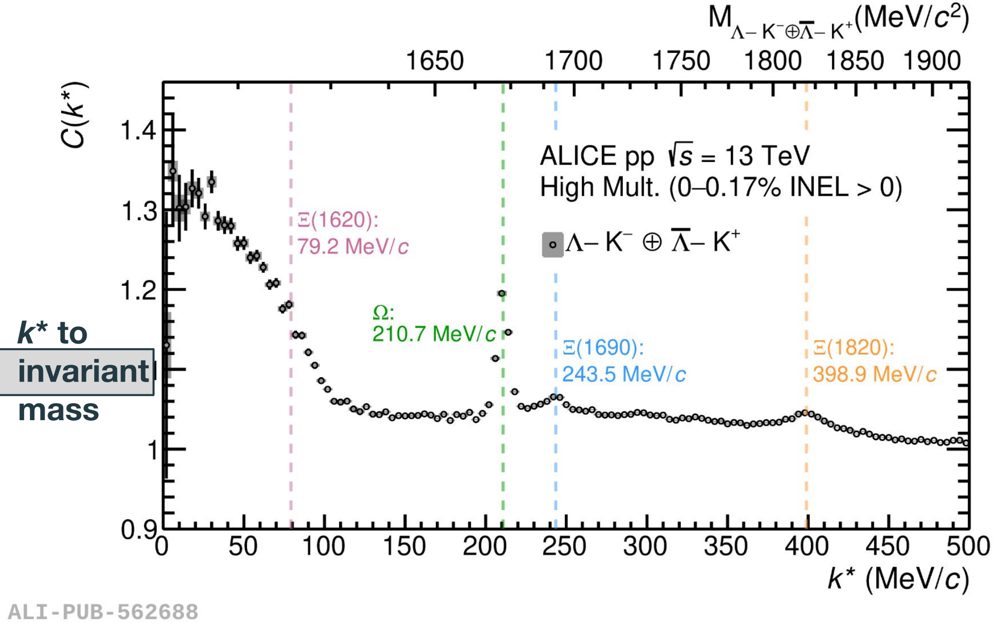
ALICE Coll. Phys. Lett. B 845 (2023) 138145



First experimental evidence of $\Xi(1620) \longrightarrow \Lambda K^-$



***k** to invariant mass**



K⁻Λ correlations and the S=-2 meson-baryon sector

Study of the resonant structures present in the measured ΛK⁻ correlation function in pp collisions

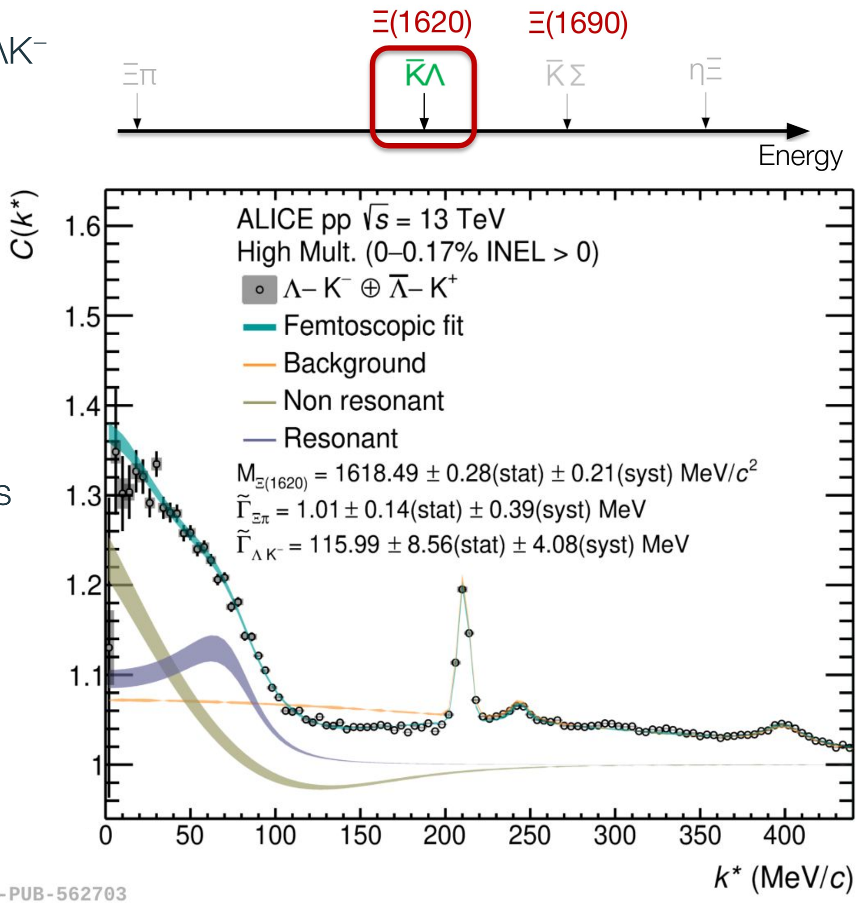
ALICE Coll. Phys. Lett. B 845 (2023) 138145

Low k^* region description including Ξ(1620):

→ Interplay between resonant (Flatté-like) and non-resonant interaction

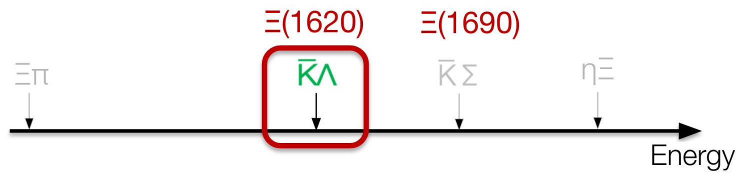
⇒ Ξ(1620) and Ξ(1690) properties

- Overall compatible with previous Belle and LHCb results
- Indication of a large coupling of Ξ(1620) to ΛK⁻



Femtoscopy data as a constraint

Employ ALICE data in pp to **constrain effective chiral potentials** to explore this multi-strange sector
V. Mantovani Sarti et al. arXiv: 2309.08756

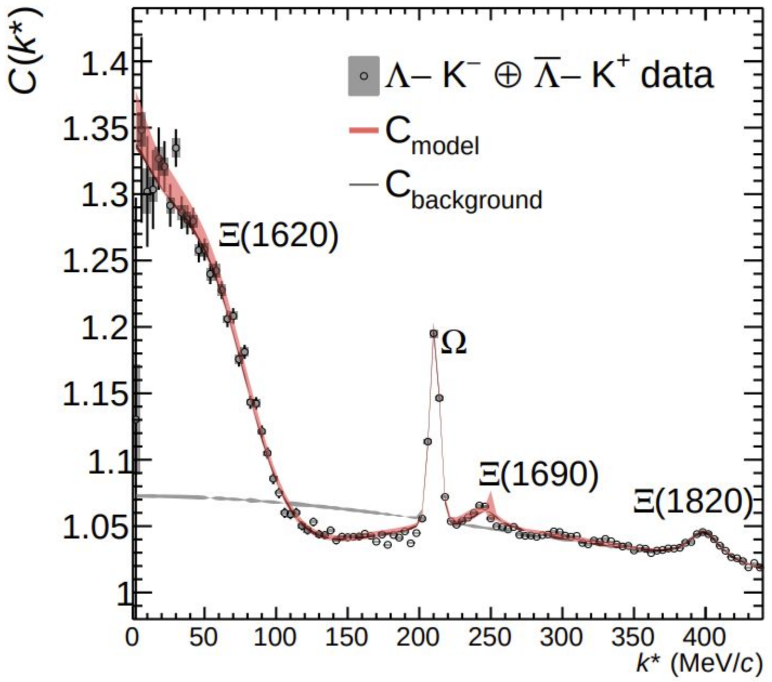


Fit the parameters of state–of–the–art UχPT NLO Lagrangian that **dynamically generates** the Ξ(1620) and Ξ(1690) states in the coupled channels approach

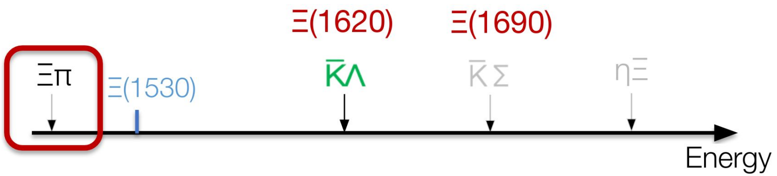
→ **large sensitivity of femtoscopy data to NLO LECs**

→ Ξ(1620): not a πΞ–KΛ molecule but a narrower ηΞ bound state with small or negligible coupling to other channels

→ Ξ(1690): KΣ quasi-bound state



The Ξ⁻ π⁺ correlation in HI collisions



STAR Preliminary data in Au-Au collisions

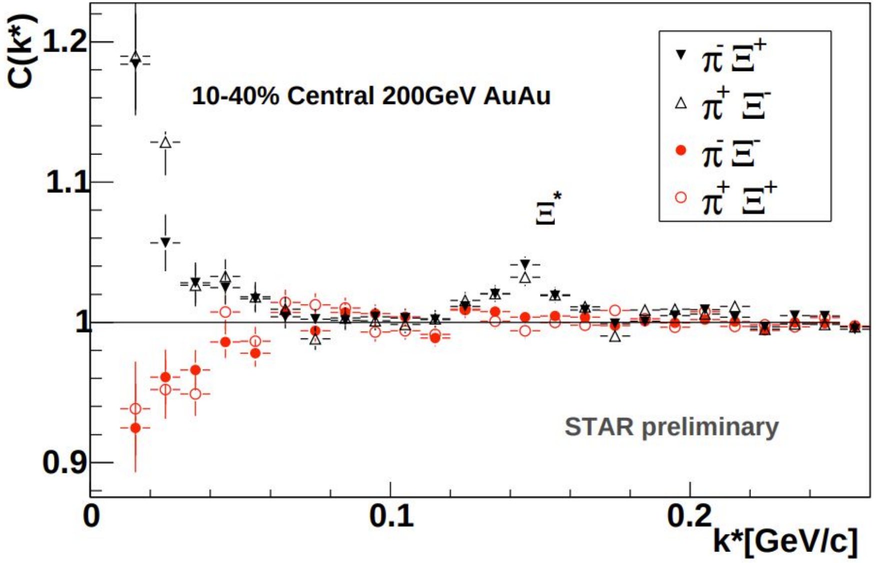
P. Chaloupka arXiv:nucl-ex/0510064

Enhancement in the low k* region described by Coulomb FSI

Lednicky model to describe the resonant part (Ξ*) through resonant strong interaction

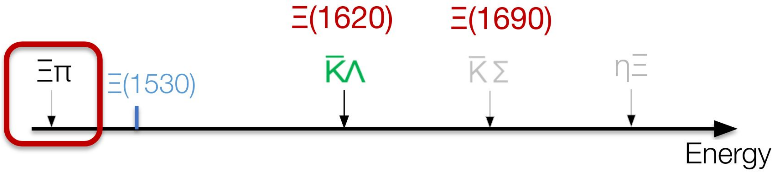
R. Lednicky, Phys.Part.Nucl.Lett. 8 (2011) 9, 965-968

→ Large sensitivity to the height of the Ξ(1530) region to the system size and effects of Ξ elliptic flow



The Ξ^- π^+ correlation in pp collisions

ALICE $\Xi^-\pi^+$ femtoscopy in pp collisions



Several states visible in the measured correlation

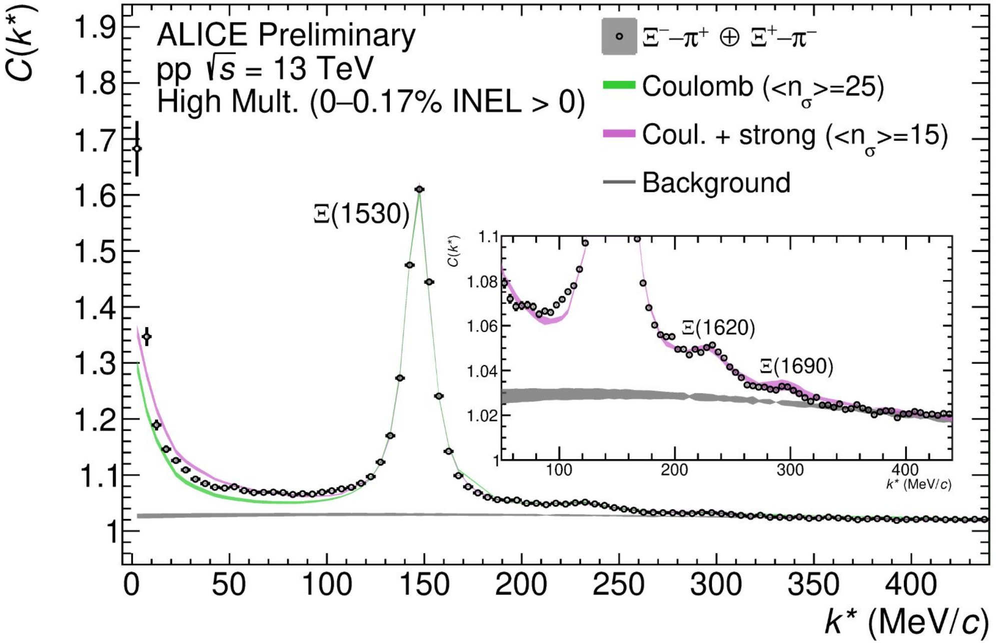
- $\Xi(1530)^0 \to \Xi^-\pi^+$ (B.R. 100%)
- Ξ(1620) and Ξ(1690) as observed by Belle

Evidence of strong attractive interaction

Rather shallow attractive interaction

$$\Re f_0 = 0.089^{\pm 0.007(stat)}_{\pm 0.009(syst)}$$

$$\Im f_0 = \mathbf{0.007}^{\pm 0.003(stat)}_{\pm 0.005(syst)}$$



Conclusions and outlook

Femtoscopy is a **complementary tool** to provide precision data on hadron-hadron interactions to **study exotic states**
$\rightarrow$ **Delivers often the most precise data at low momenta in many channels, in some cases the only data!**

- Novel high-precision constraints on S=-1 and S=-2 baryon interactions available with correlation data
- Input for low-energy effective chiral lagrangians

$\Rightarrow$ Possibility to explore other relevant systems and extend them to other sectors (charm!) with **ongoing experiments!**

Thank you for your attention!