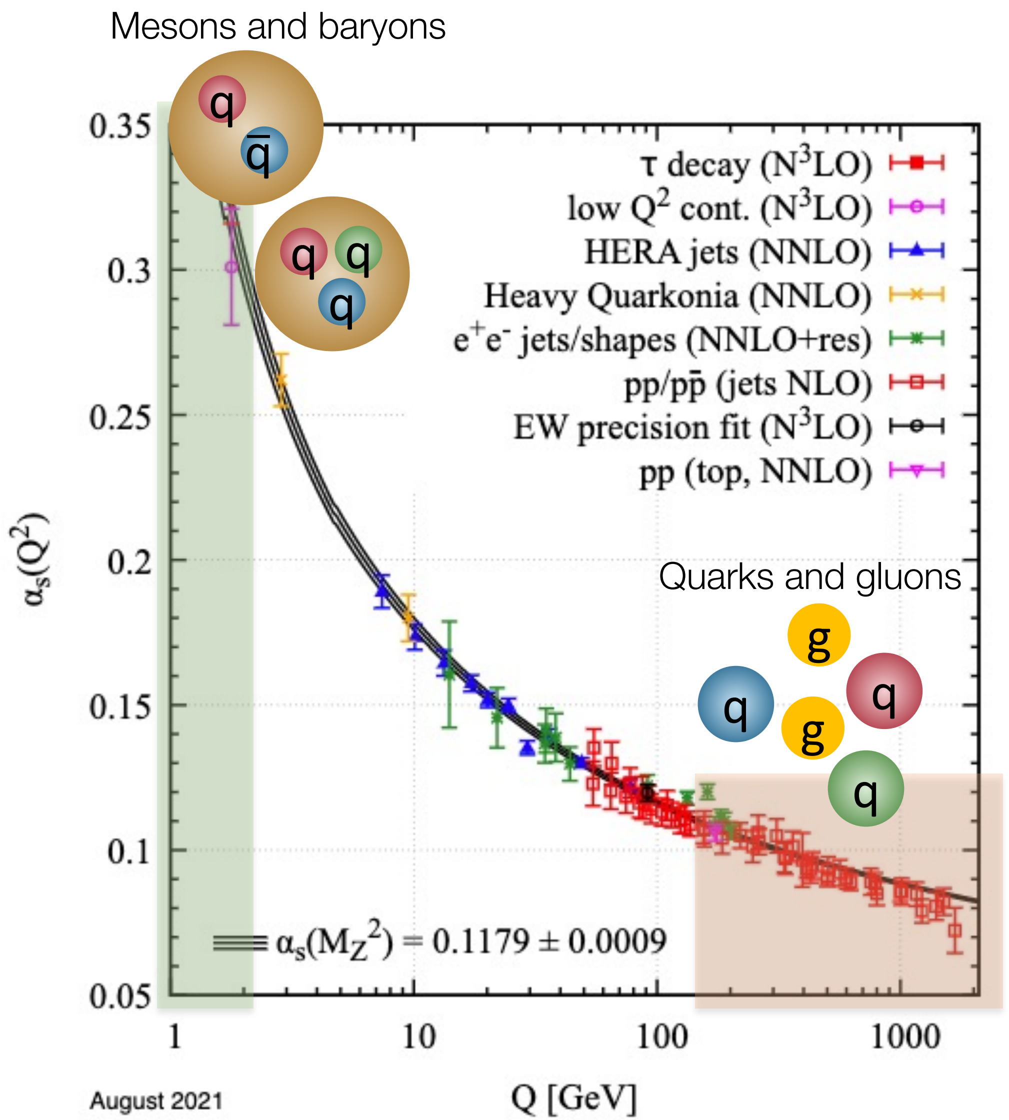
A laboratory for QCD: how to employ LHC to study hadron-hadron interactions

V. Mantovani Sarti (TUM)

Hadron2023, June 05-09 2023 Genova

valentina.mantovani-sarti@tum.de

Strong interaction between hadrons



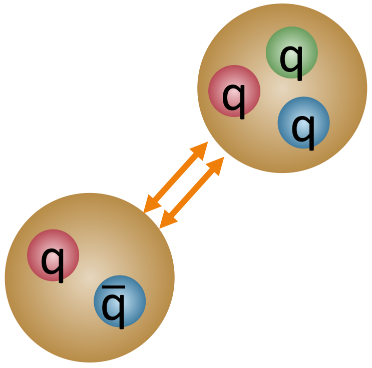
PDG, Prog.Theor.Exp.Phys 2022, 083C01(2022)

- Understanding how QCD evolves from high-energy to low-energy regime

How do hadrons emerge?

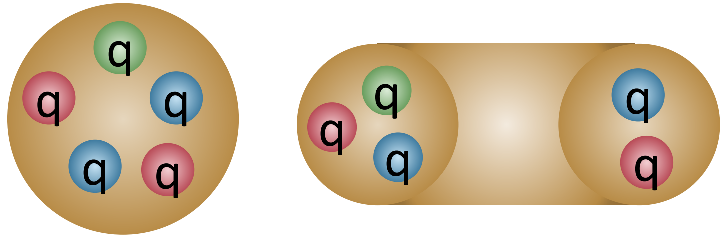
How do hadrons interact?

2-body and many-body interactions

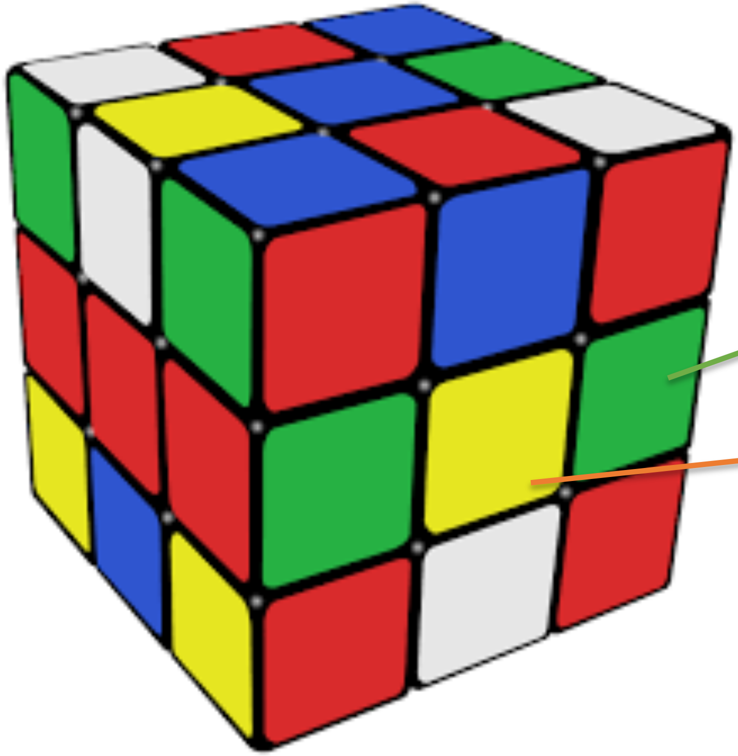


How is the QCD spectrum organized?

Bound states/resonances
Conventional and exotic states



The many facets of QCD



- Interplay between elastic and inelastic contributions in the strong interaction

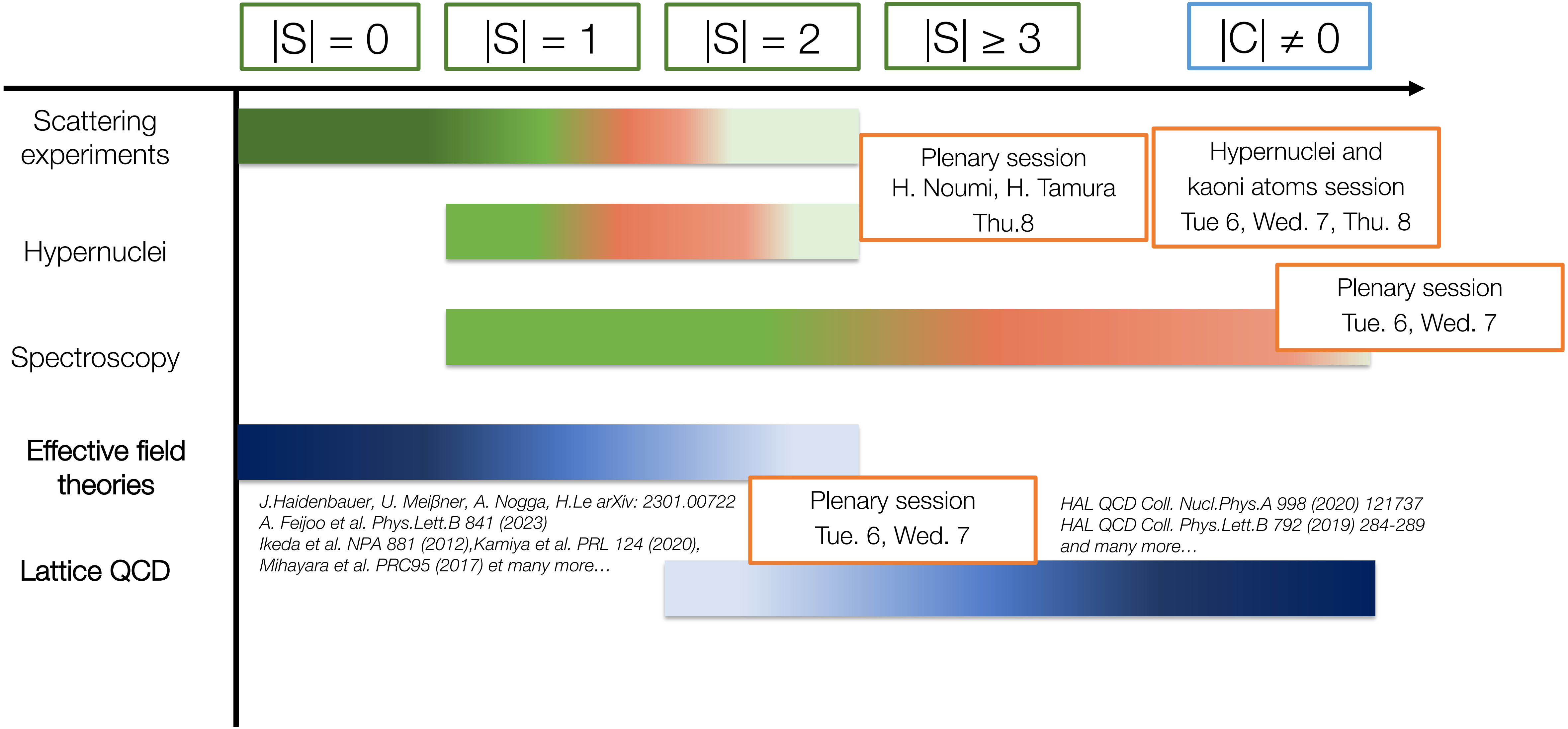
Bound states, resonances, …
Heavy quark sector

Coupled-channel dynamics, annihilation,…
Important to assess existence and nature of bound states

- Large amount of data at 2-body and many-body level for interactions involving u and d quarks (NN, NNN)

What about interactions involving strange and charm hadrons?

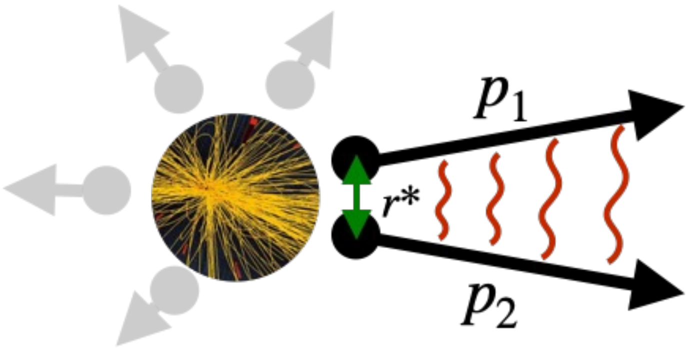
Understanding and measuring the hadronic interactions



Understanding and measuring the hadronic interactions

The femtoscopy technique at the LHC

Talk by D. Mihaylov
Today 17:40

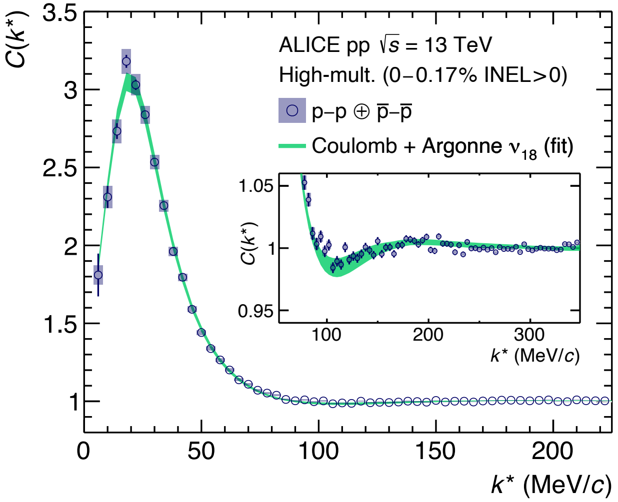


- Access to the **short-range dynamics** between hadrons[1,2]:

$$C(k^*) = \int S(\vec{r}^*) \left|\psi(\vec{k}^*, \vec{r}^*)\right|^2 d^3\vec{r}^* = \mathcal{N}(k^*) \frac{N_{\mathrm{same}}(k^*)}{N_{\mathrm{mixed}}(k^*)}$$

Emitting source anchored to p-p correlation data [3]
→ Universal emitting source for particles in small colliding systems
→ Interparticle distances ~1-2 fm

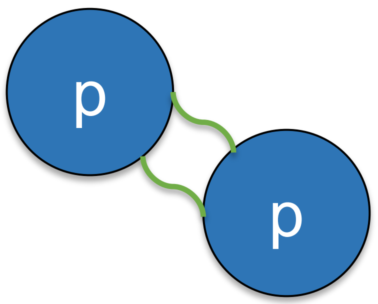
Two-particle wave function[4]
→ Profile of $C(k^*)$ vs nature of the interaction



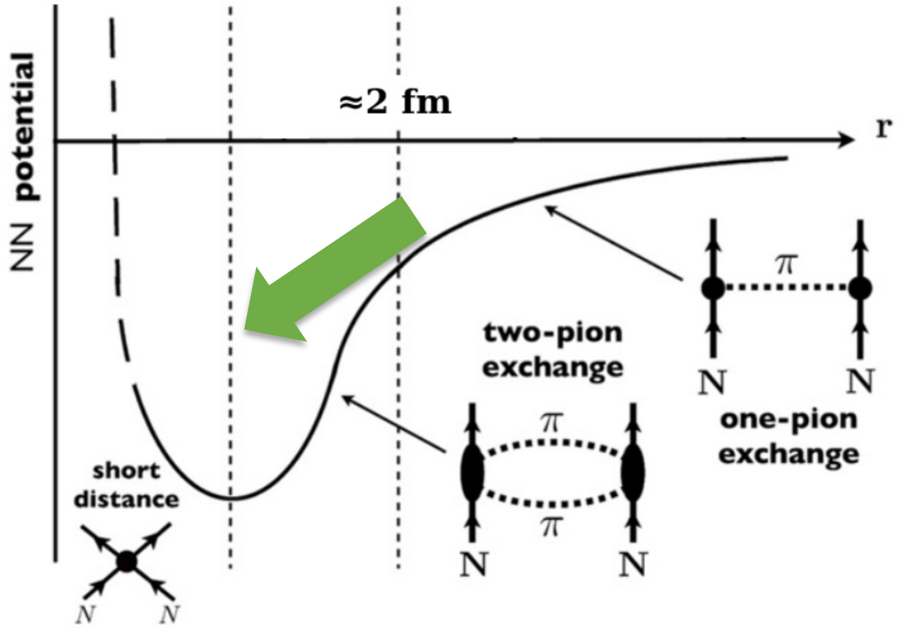
$$C(k^*) \begin{cases} > 1 & \text{Attractive} \\ < 1 & \text{Repulsive} \\ \gtrless 1 & \text{Bound state} \end{cases}$$

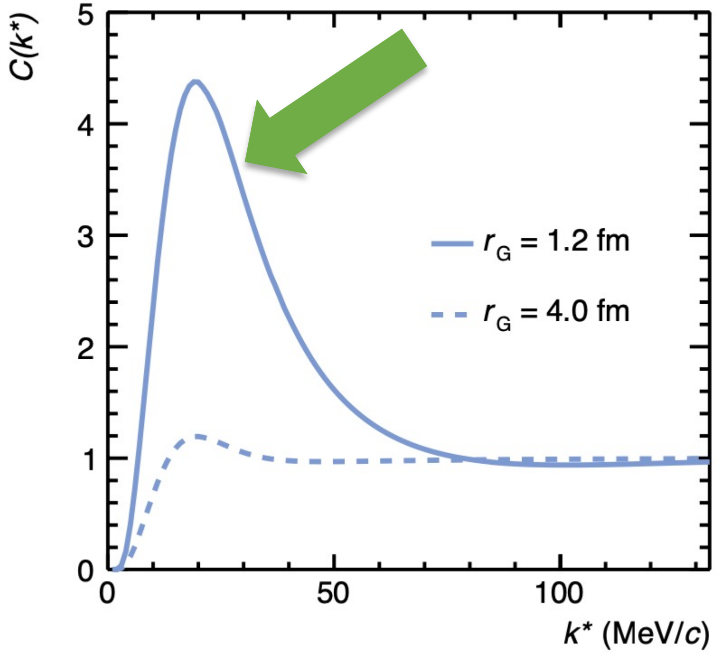
[1] M.Lisa, S. Pratt et al, Ann.Rev.Nucl.Part.Sci. 55 (2005), 357-402
[2] L. Fabbietti, VMS and O. Vazquez Doce ARNPS 71 (2021), 377-402
[3] ALICE coll., PLB, 811 (2020), 135849
[4] D. Mihaylov et al., EPJC 78 (2018), 5, 394

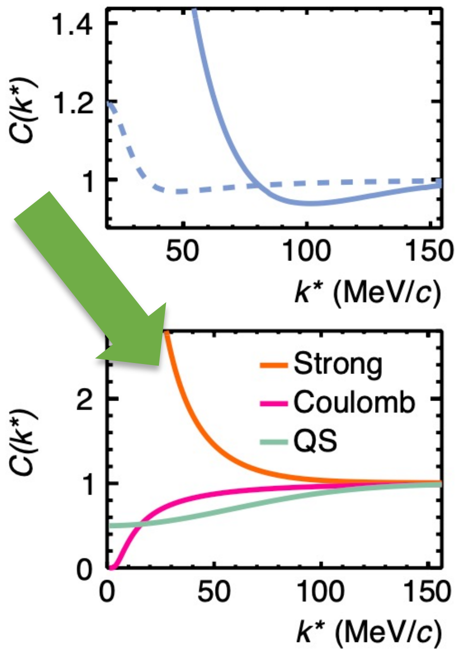
From small to large colliding systems



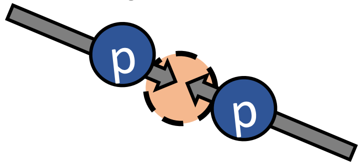
- Undist. fermions (QS)
- Coulomb (++)
- Strong interaction

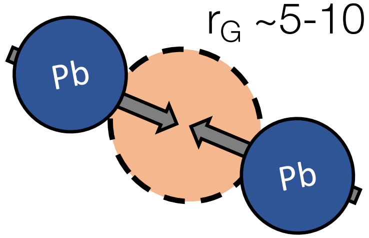






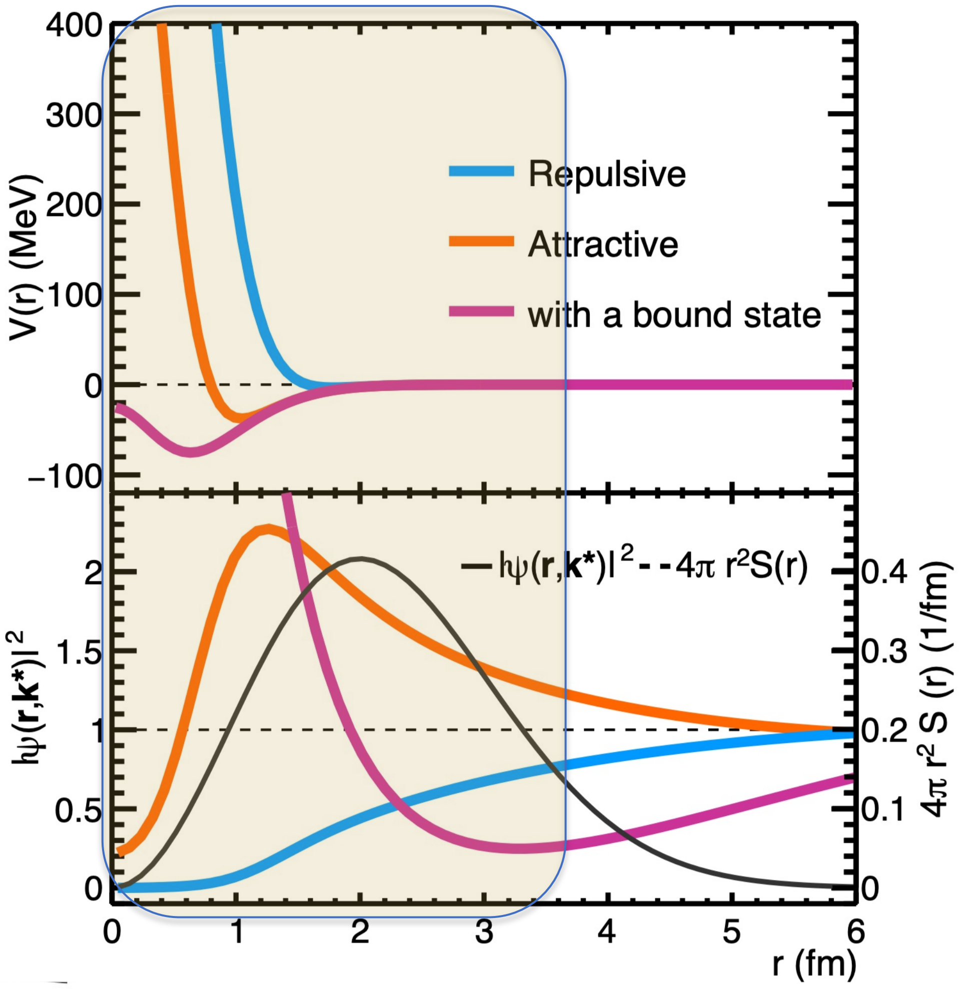
- As the source size increases:
  - less sensitive to short-range interaction
  - decrease of the signal strength



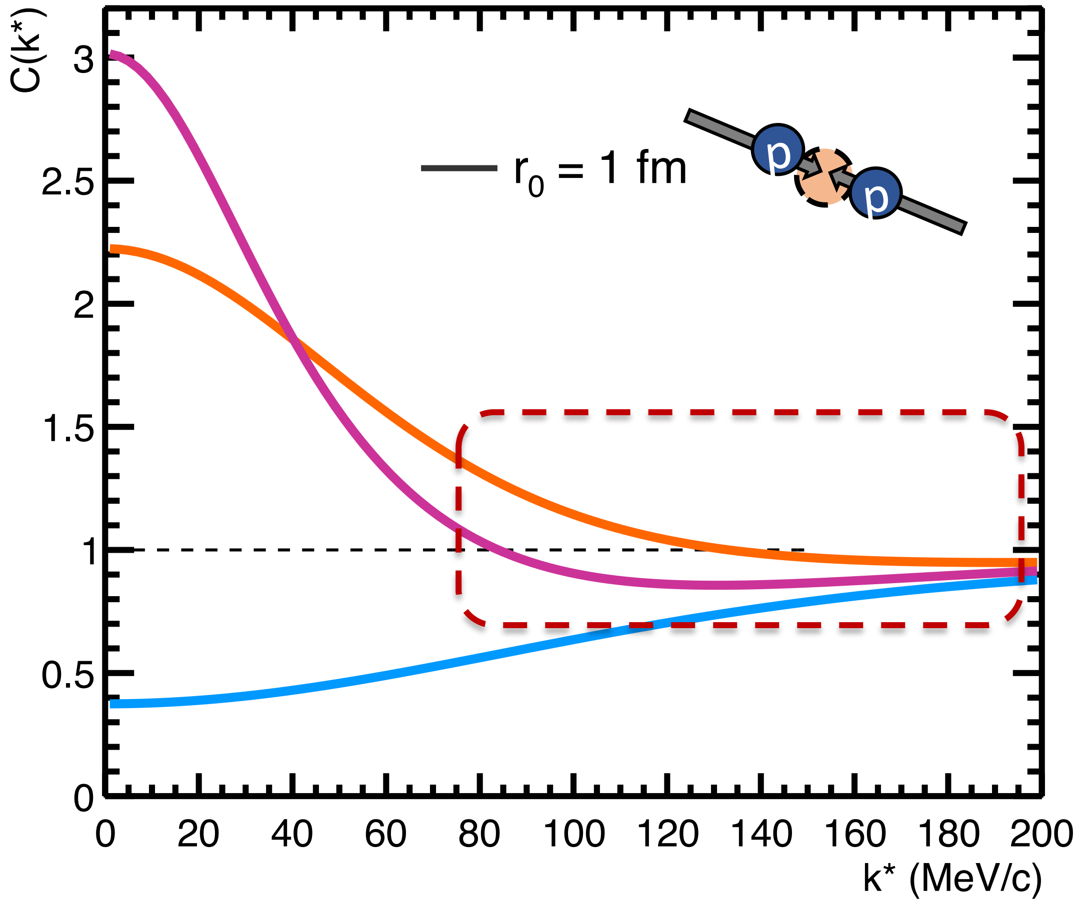


Probing different ranges of the interaction

- For an attractive potential supporting a bound state
  → Interplay between the (large) scattering length a_0 and the source size

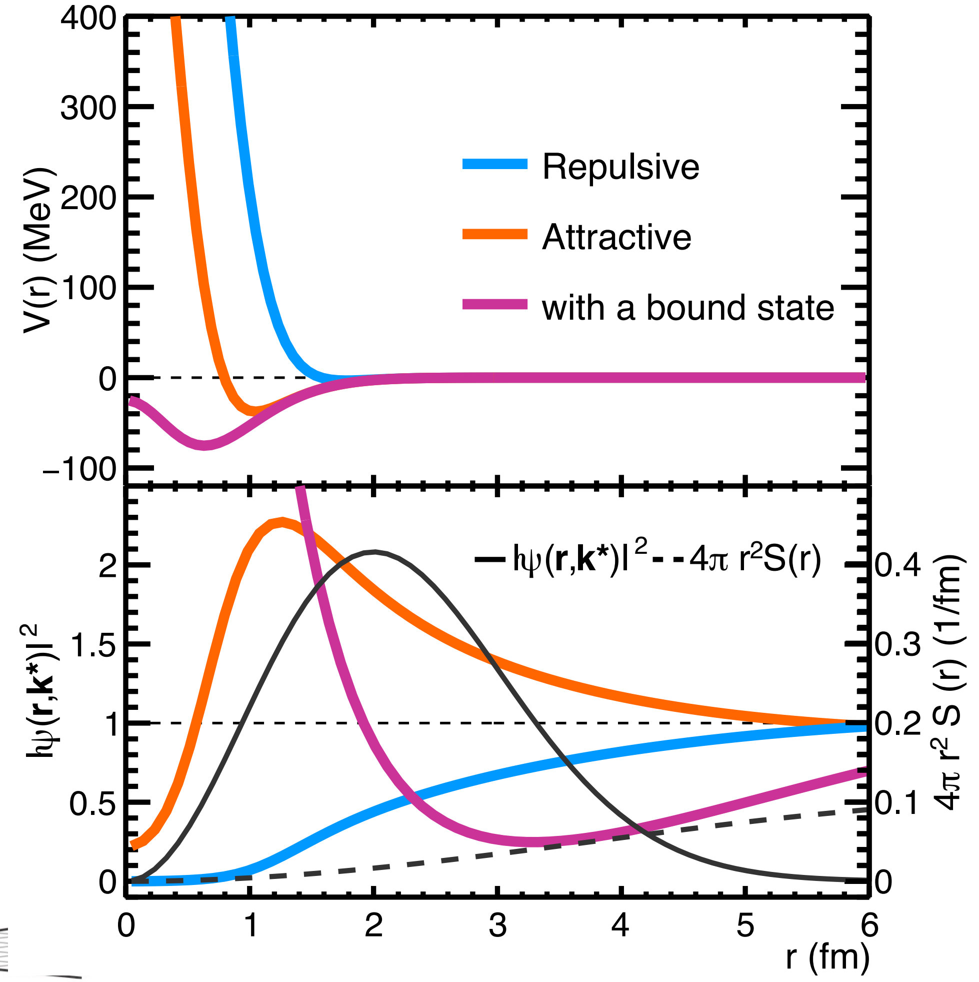


L. Fabbietti, VMS and O. Vazquez Doce ARNPS 71 (2021), 377-402

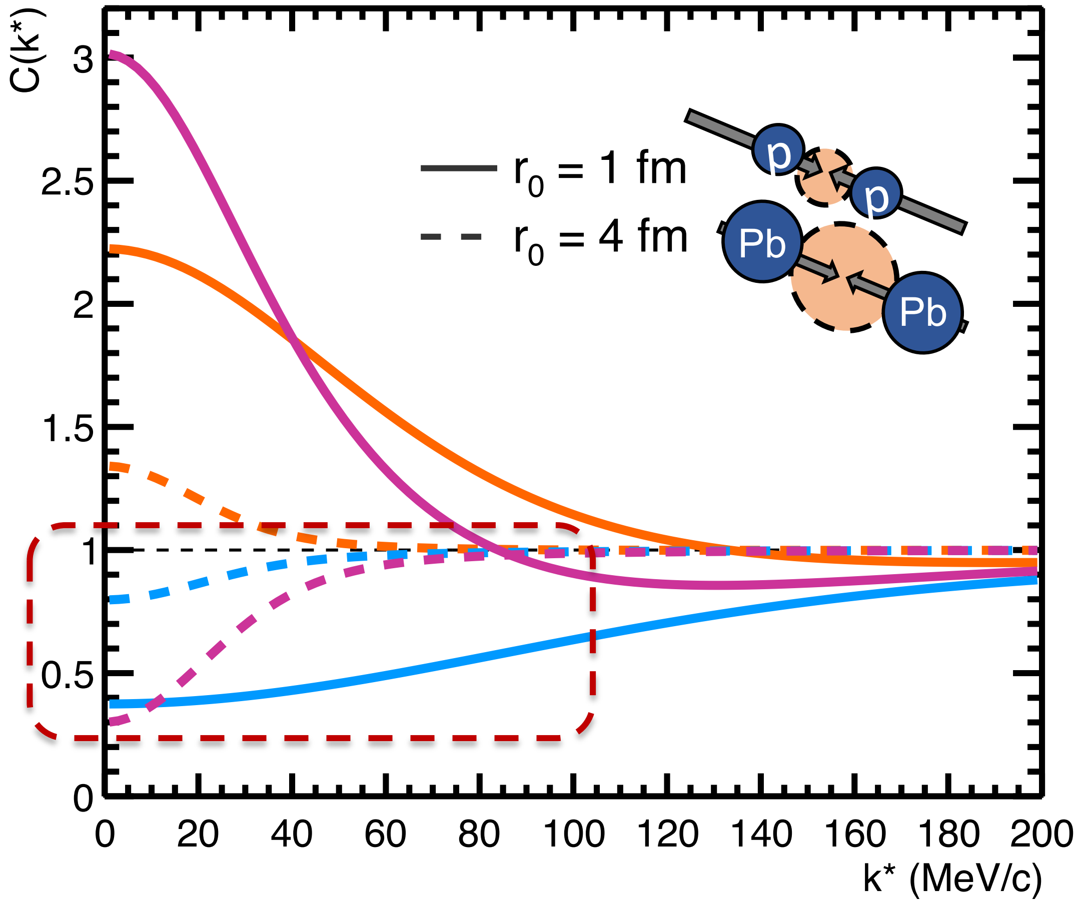


Effect of bound states on the correlation function

- For an attractive potential supporting a bound state
  → Interplay between the (large) scattering length a_0 and the source size

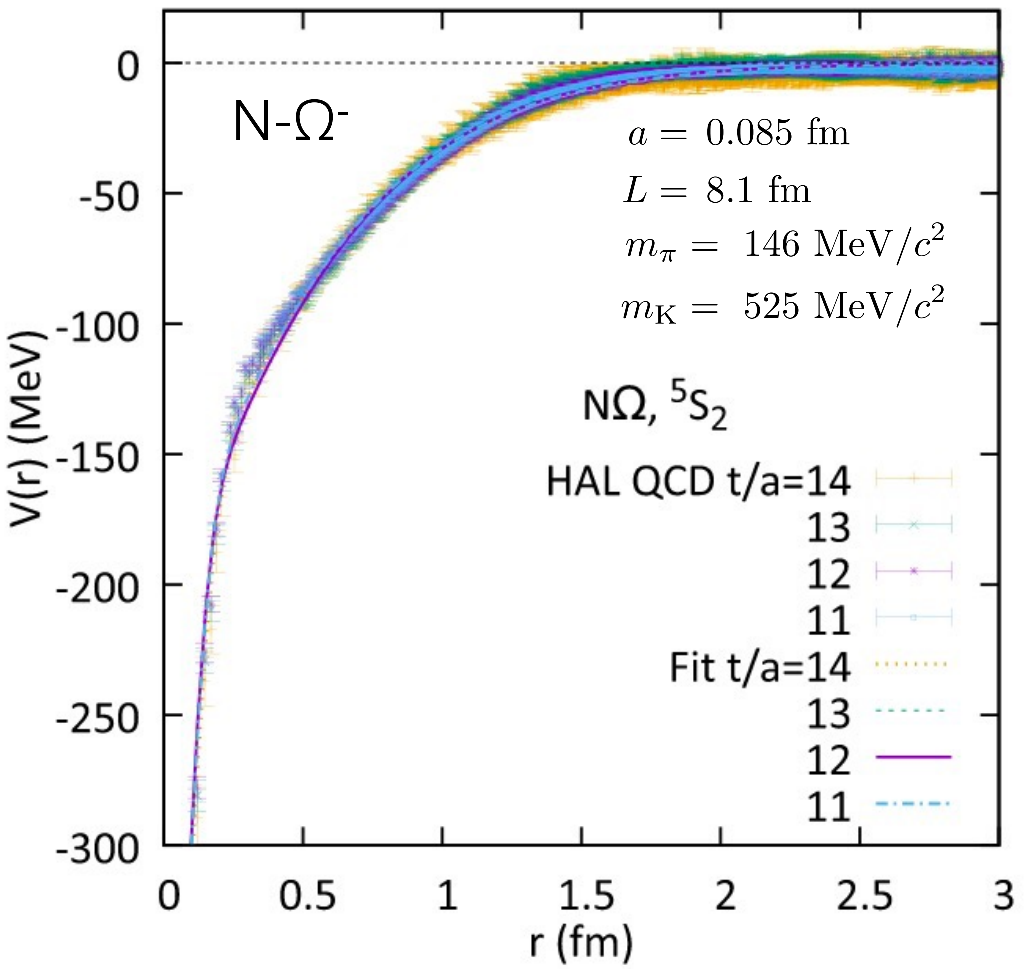


L. Fabbietti, VMS and O. Vazquez Doce ARNPS 71 (2021), 377-402



The $p\Omega^-$ interaction and first test of lattice potentials

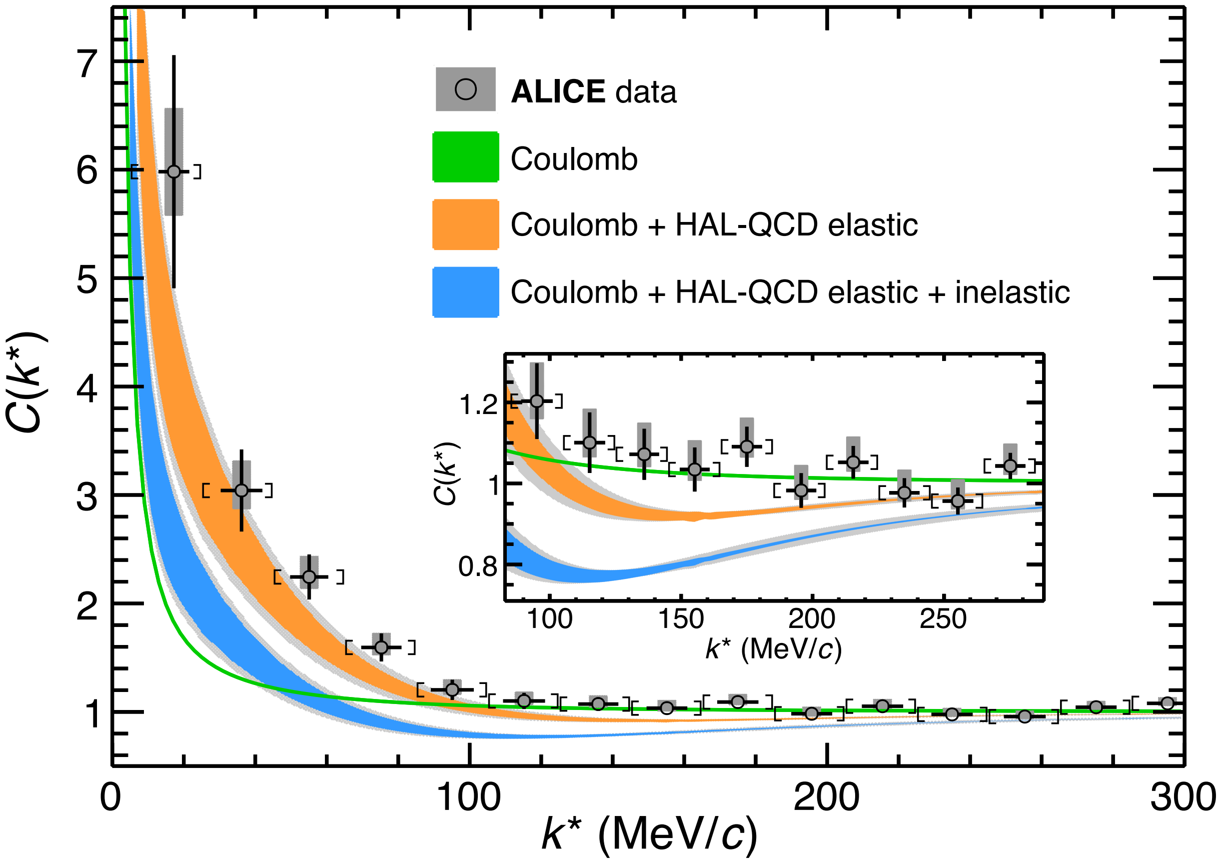
- Available NΩ lattice potentials at physical quark masses[1]
- Very attractive potential in $^5S_2$ state
  → Formation of a loose bound state with B.E~1.5 MeV
  → Looking for another dibaryon after deuteron!
- Inelastic channels (e.g. $p\Omega^- \rightarrow \Lambda\Xi^-$) in $^3S_1$ not yet calculated on the lattice
  → First measurements of $\Lambda\Xi^-$ by ALICE indicates a weak coupling[2]



[1] HAL QCD Coll. PLB 792 (2019)
[2] ALICE Coll. arXiv:2204.10258, accepted by PLB

p–Ω⁻ correlation function in pp at 13 TeV

ALICE Coll. Nature 588, 232–238 (2020)



- Enhancement above Coulomb
  → Observation of the strong interaction
- Missing potential of the $^{3}S_{1}$ channel
  → Test of two cases:
  - Inelastic channels dominated by absorption
  - Neglecting inelastic channels
    → Favoured!
- So far, no indication of a bound state
  → Extend the measurements to p-Pb and Pb-Pb in Run 3 and Run 4
- Access to Ω-Ω in Run 3 and Run 4 with ALICE[1]

[1] ALICE Public Note ALICE-PUBLIC-2020-005

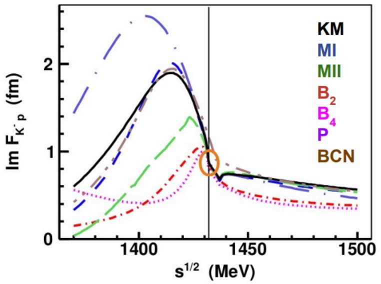
Meson-baryon interactions with strangeness

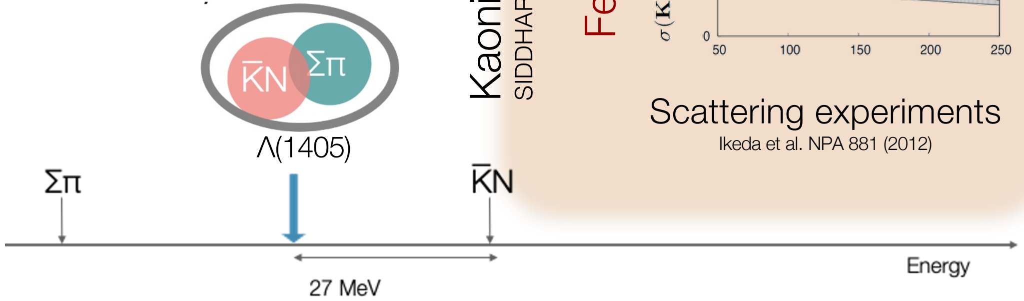
S = -1

Strangeness

$\bar{K}N$

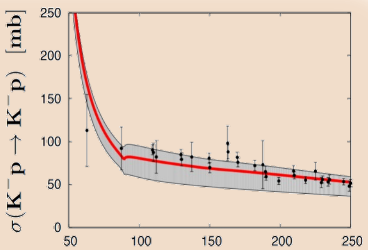
Talk by R. Lea
Thur. 15:42





Kaonic hydrogen
SIDDHARTA PLB 704 (2011)

Femtoscopy[1]



Scattering experiments
Ikeda et al. NPA 881 (2012)

K^-p correlations measured by ALICE in different colliding systems[1]
→ Improve understanding on **Λ(1405) molecular state**[2]

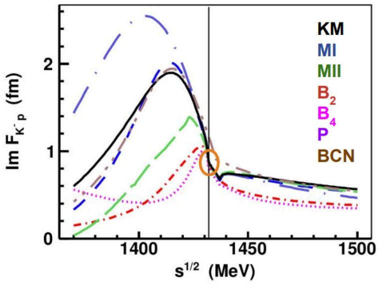
[1]pp: ALICE Coll. PRL 124 (2020)
Pb-Pb:ALICE Coll. PLB 822 (2021)
pp,p-Pb,Pb-Pb: ALICE Coll. EPJC 83 (2023)
[2] M. Mai EPJ.ST 230 (2021), 6, 1593-1607

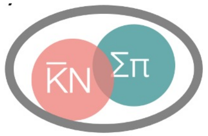
Meson-baryon interactions with strangeness

S = -1 | S = -2 | Strangeness

K̄N

Talk by R. Lea
Thur. 15:42

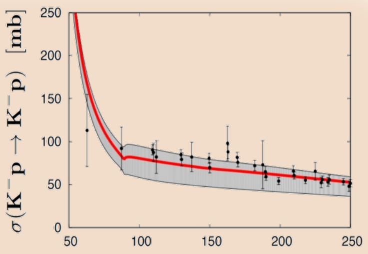




Λ(1405)

Kaonic hydrogen
SIDDHARTA PLB 704 (2011)

Femtoscopy[1]



Scattering experiments
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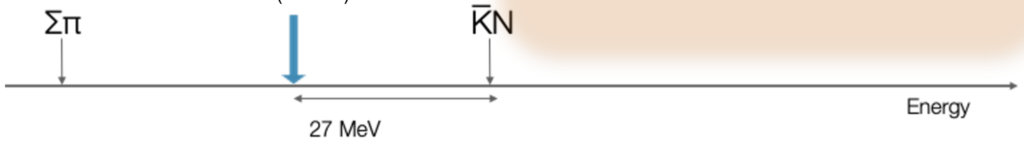
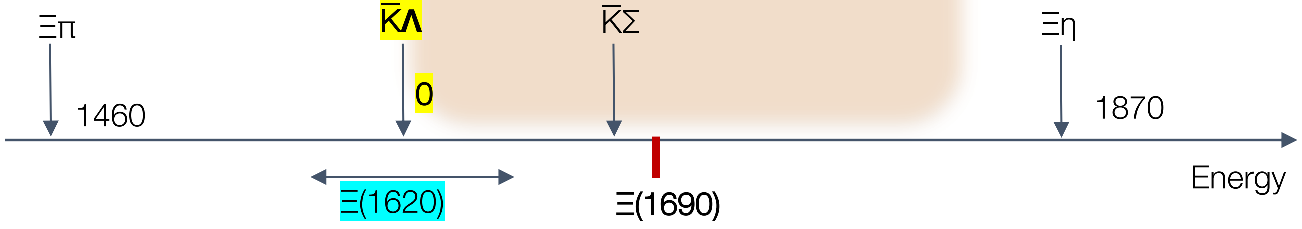


K̄Λ

Femtoscopy
in Pb-Pb[3,4]



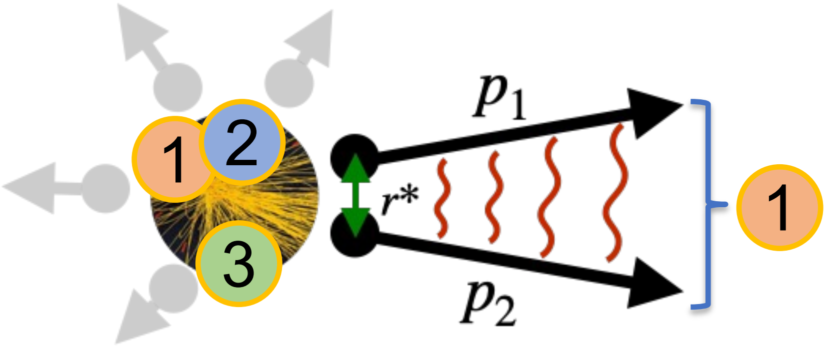
K⁻p correlations measured by ALICE in different colliding systems[1]
→ Improve understanding on **Λ(1405) molecular state**[2]

Similar scenario for **Ξ(1620)** state?
→ Shed light on the nature of this state[4]

[1]pp: ALICE Coll. PRL 124 (2020)
Pb-Pb:ALICE Coll. PLB 822 (2021)
pp,p-Pb,Pb-Pb: ALICE Coll. EPJC 83 (2023)
[2] M. Mai EPJ.ST 230 (2021), 6, 1593-1607

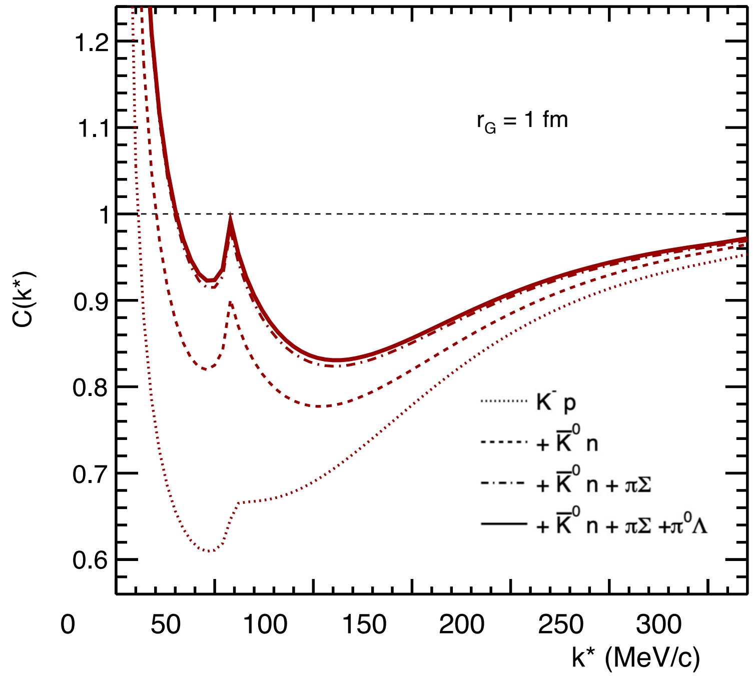
[3] ALICE Coll. PRC 103 (2021),CMS Coll. arXiv:2301.05290
[4] CMS Coll. arXiv: 2301.05290
[4] Belle coll. PRL 122 (2019)

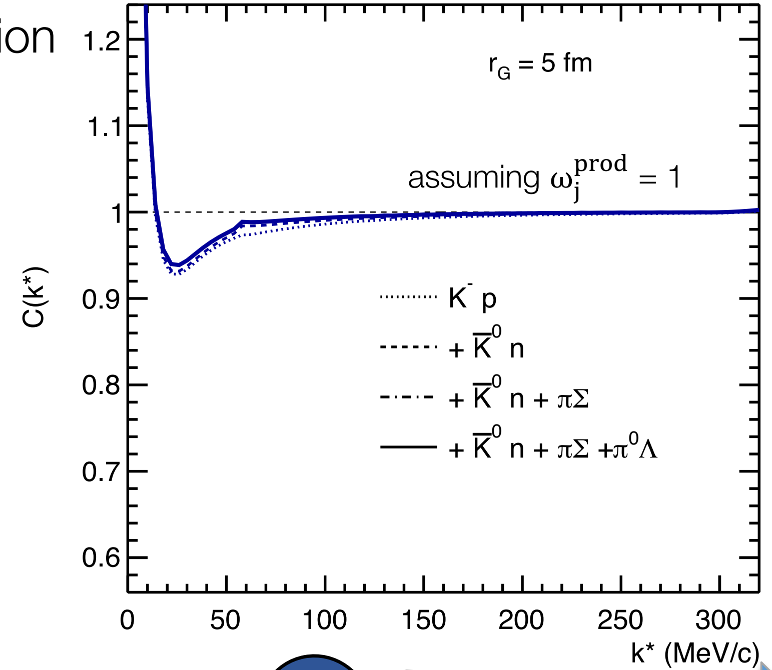
Inelastic channels and source size dependence

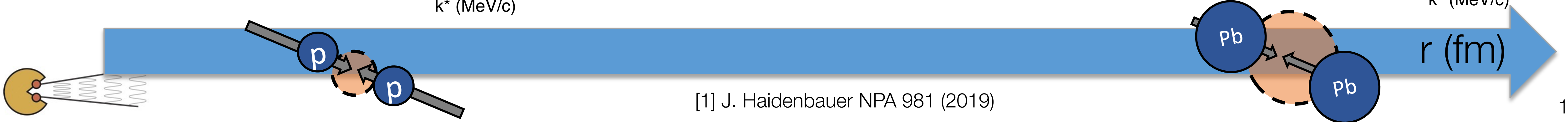


$$C(k^*) = \underbrace{\int S(r)\, |\psi_{1\to1}(k^*, r)|^2\, d^3r}_{\text{elastic}} + \underbrace{\sum_{j\neq1} \omega_j^{prod} \int S(r) \left|\psi_{j\to1}\left(k_j^*, r\right)\right| d^3r}_{\text{inelastic}}$$

- Below/above threshold channels
  → Affecting strength and profile of the correlation[1]
- Negligible as the source size increases
  → Mostly driven by elastic interaction

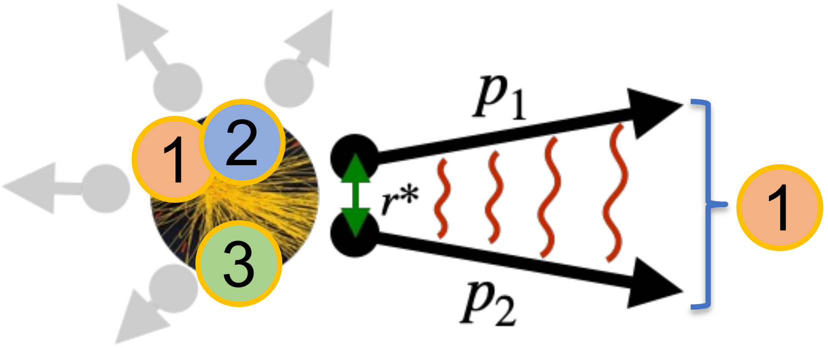






[1] J. Haidenbauer NPA 981 (2019)

Inelastic channels and source size dependence



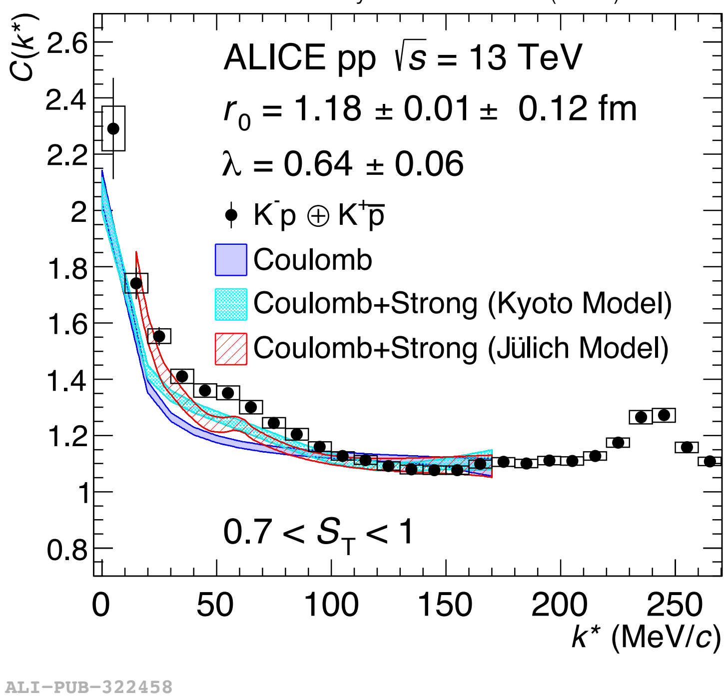
$$C(k^*) = \int S(r)\ |\psi_{1\to1}(k^*, r)|^2\, d^3r + \sum_{j\neq1} \omega_j^{prod} \int_j S(r) \left|\psi_{j\to1}\left(k_j^*, r\right)\right| d^3r$$

elastic — inelastic

- Below/above threshold channels
  → Affecting strength and profile of the correlation[1]

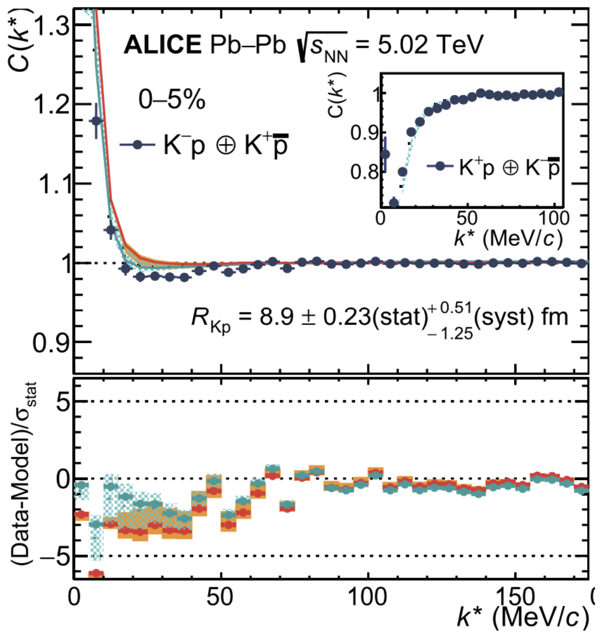
  Negligible as the source size increases
  → Mostly driven by elastic interaction

ALICE Coll. Phys.Rev.Lett. 124 (2020)



Talk by R. Lea
Thur. 15:42

ALICE Coll. Phys.Lett.B 822 (2021)



[1] J. Haidenbauer NPA 981 (2019)

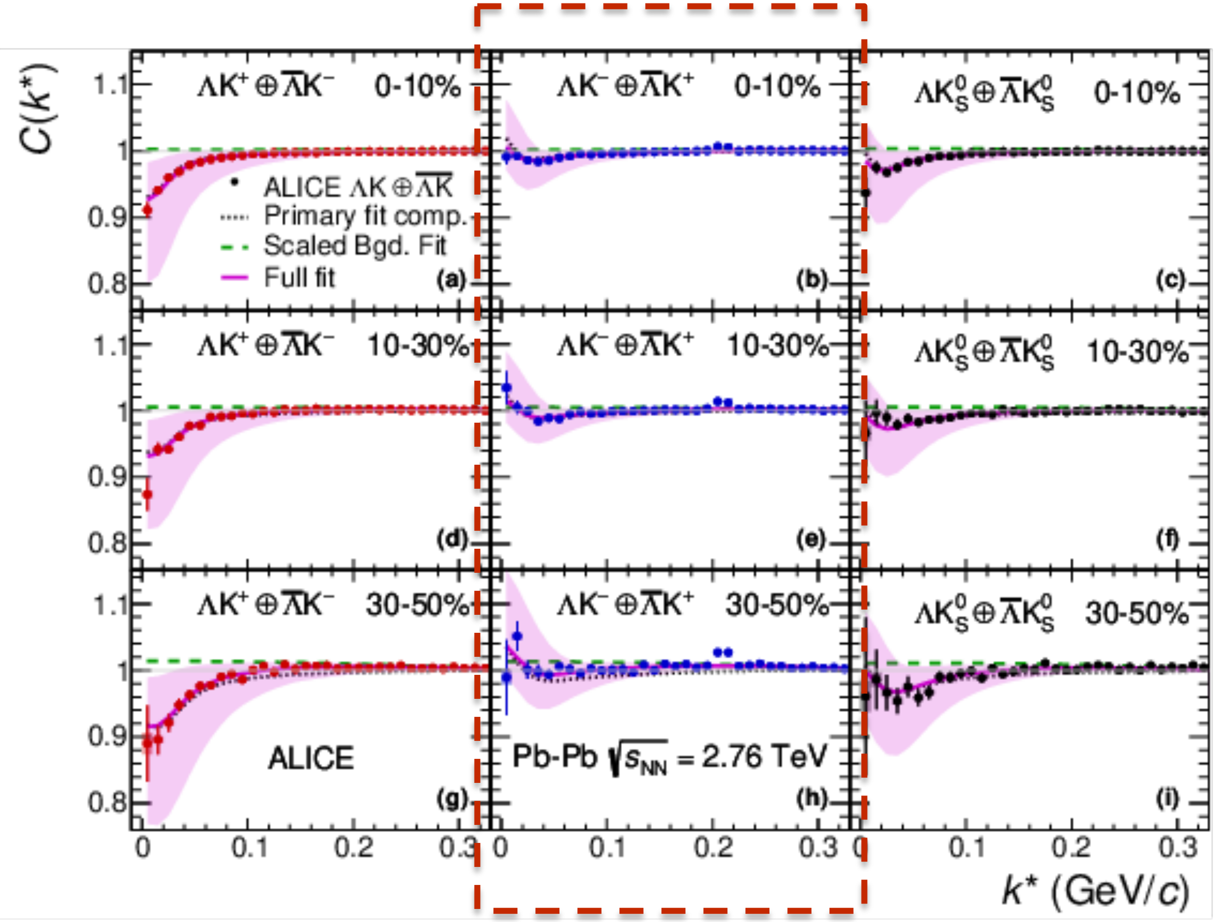
Moving to ΛK^- correlations…

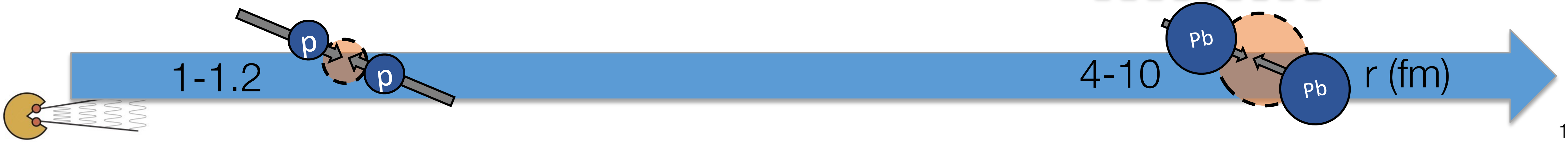
- Correlations in Pb-Pb
  → First measured scattering parameters available!
  → Only evidence of Ω in most central events

How does the correlation look like in pp collisions?

Presence of $\Xi(1620)$?

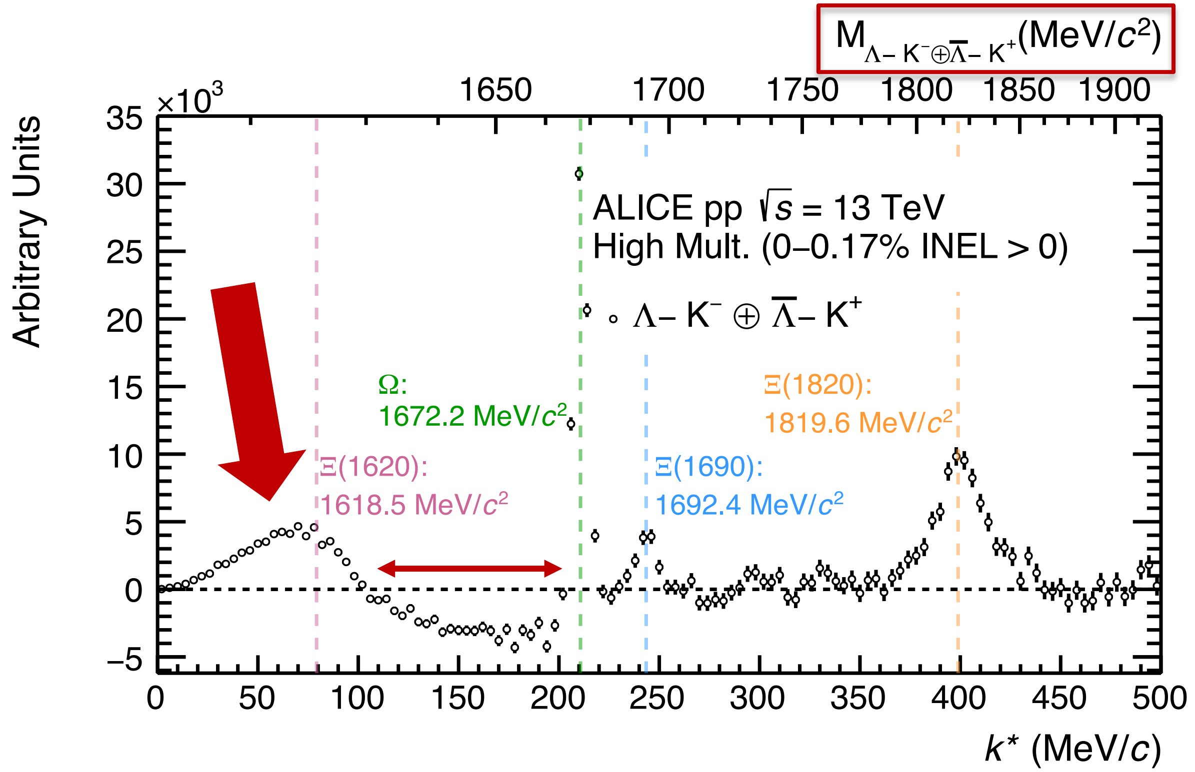
ALICE Coll. PRC 103 (2021)



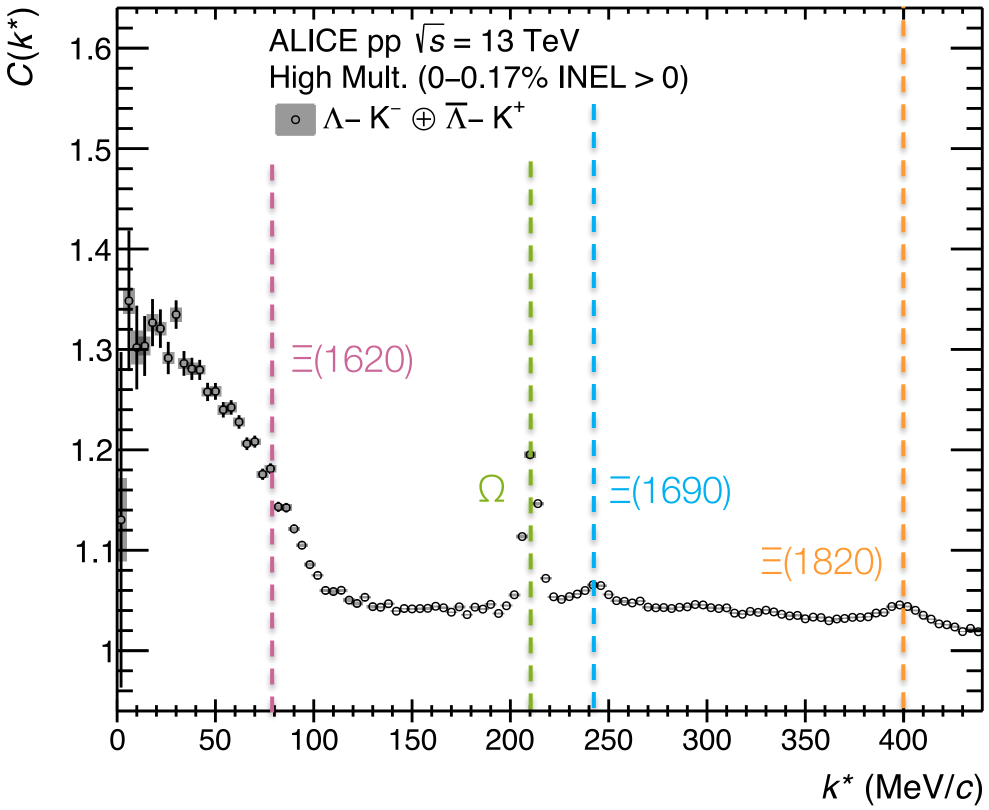


The ΛK⁻ correlation in pp collisions

- Several peak structures in the measured correlation
- Invariant mass from same and mixed event distributions used to build the correlation
  - Ξ(1620) just above the threshold
    → First experimental evidence of decay into ΛK⁻



ALICE Coll. arXiv: 2305.19093



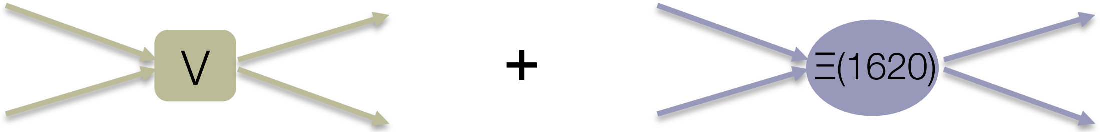
The ΛK^- correlation in pp collisions

Sill distribution
Talk by F. Giacosa
Today 16:55

- Data modeled with the Lednicky-Lyuboshits formula[1]

Non resonant

Resonant



Assuming the effective-range expansion

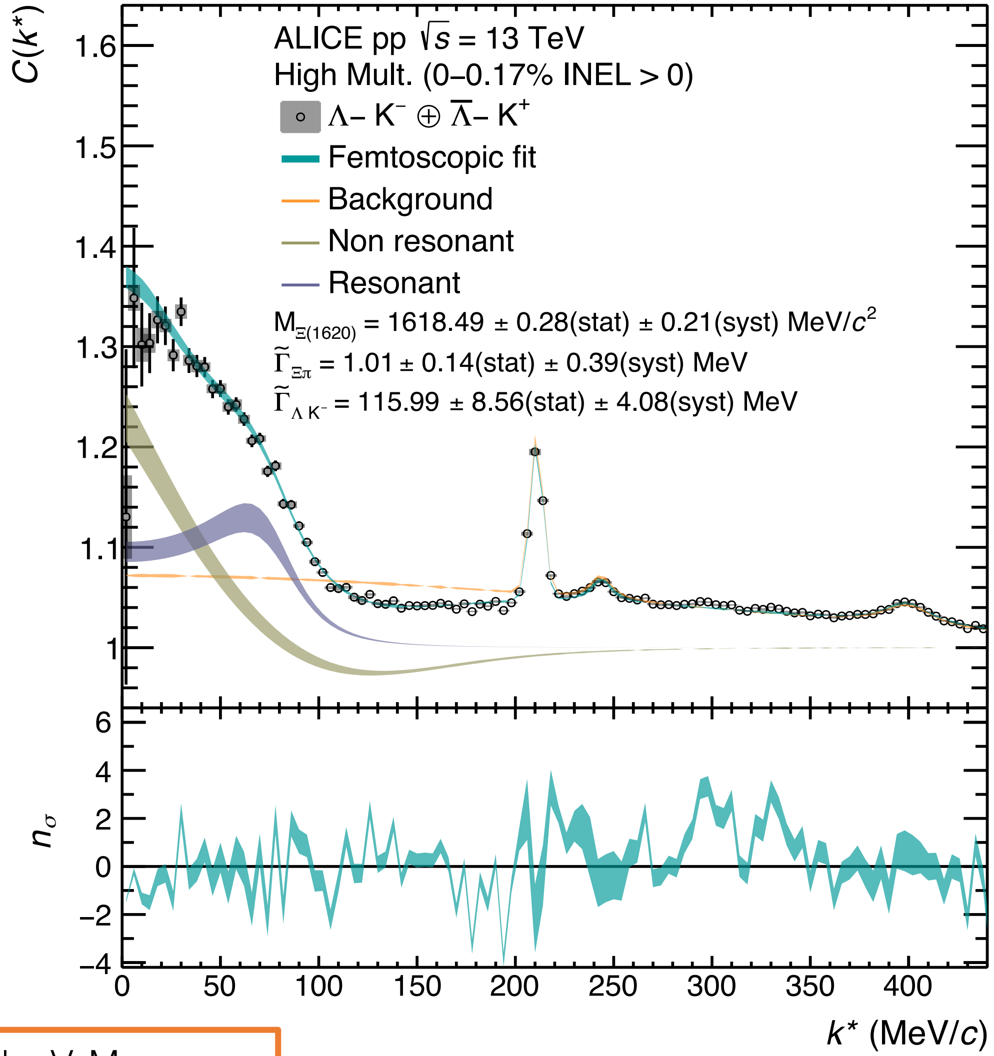
Assuming a Flattè-like amplitude[2] for Ξ(1620)

- **Ξ(1620) properties** and scattering parameters
  → Mass in agreement with Belle[3]

$$M_{\Xi(1620)} = 1618.49^{\pm 0.28(stat)}_{\pm 0.21(syst)}$$

  → Indication of a large coupling of Ξ(1620) to ΛK^-
  → Non-resonant scattering parameters in agreement with ALICE Pb-Pb results[4]

- High-precision data to constrain effective chiral theories and to understand the Ξ(1620) nature[5,6]



ALICE Coll. arXiv: 2305.19093

[1] R. Lednicky, V. Lyuboshits SJNP 35 (1982)
[2] F. Giacosa et al. EPJA 57 (2021), 12, 336
[3] Belle coll. PRL 122 (2019), 7, 07250
[4]ALICE coll. PRC 103 (2021)), 5, 055201
[5] A. Ramos et al. PRL 89 (2002), 252001
[6] A. Feijoo et al. PLB 841 (2023), 137927

Talk by V. Magas
Today 15:14

Accessing the strong interaction with charm hadrons

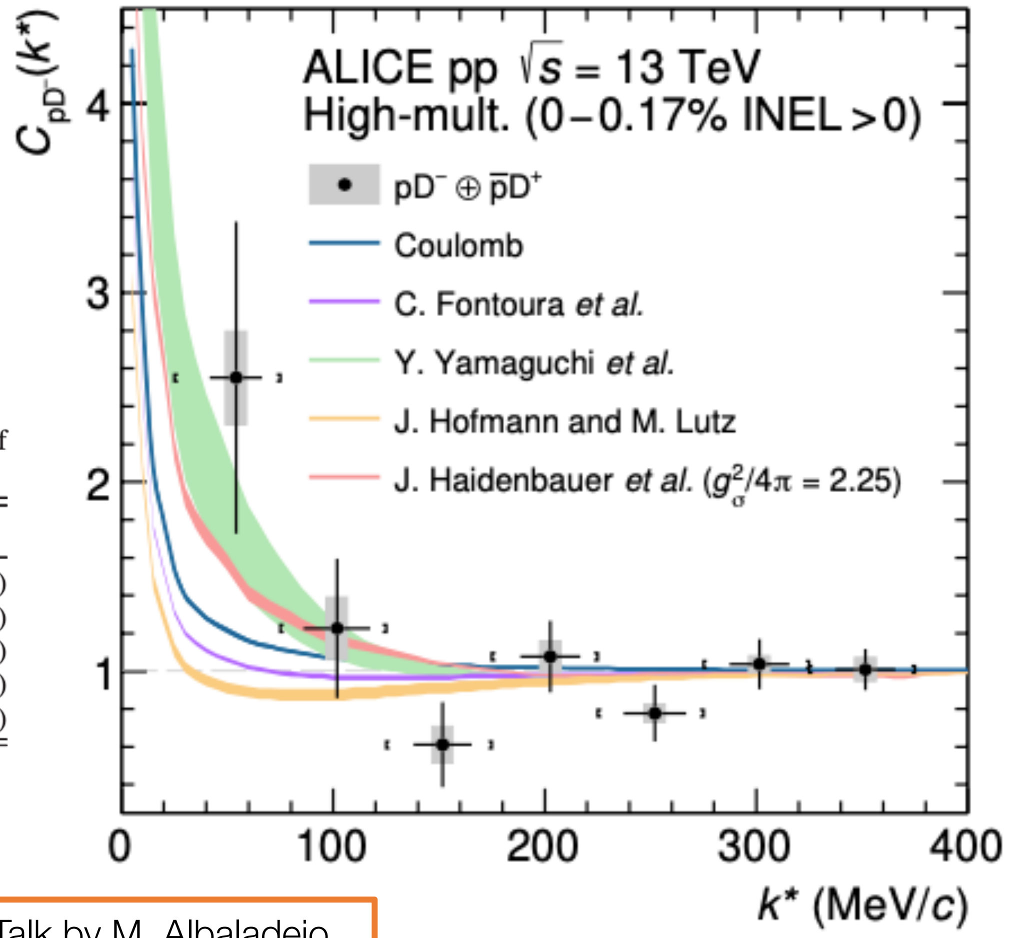
- First measurement of the genuine correlation between protons and D⁻ mesons
  → Important input in studies and searches for charm nuclear states[1]
- Comparison with available models
  → Indication of an attractive interaction
  → Compatible also with the formation of bound state

TABLE I. Scattering parameters of the different theoretical models for the $N\bar{D}$ interaction [22–25] and degree of consistency with the experimental data computed in the range $k^* < 200$ MeV/c.

Model	$f_0(\mathrm{I}=0)$	$f_0(\mathrm{I}=1)$	n_σ
Coulomb			(1.1–1.5)
Haidenbauer *et al.* [22] ($g_\sigma^2/4\pi = 2.25$)	0.67	0.04	(0.8–1.3)
Hofmann and Lutz [23]	−0.16	−0.26	(1.3–1.6)
Yamaguchi *et al.* [25]	−4.38	−0.07	(0.6–1.1)
Fontoura *et al.* [24]	0.16	−0.25	(1.1–1.5)

- Preliminary results on Dπ and DK correlations measured by ALICE
  → Structure of $D_0^*(2300)$ and signatures in Dπ correlations[2]

ALICE coll. PRD 106 (2022), 5, 052010

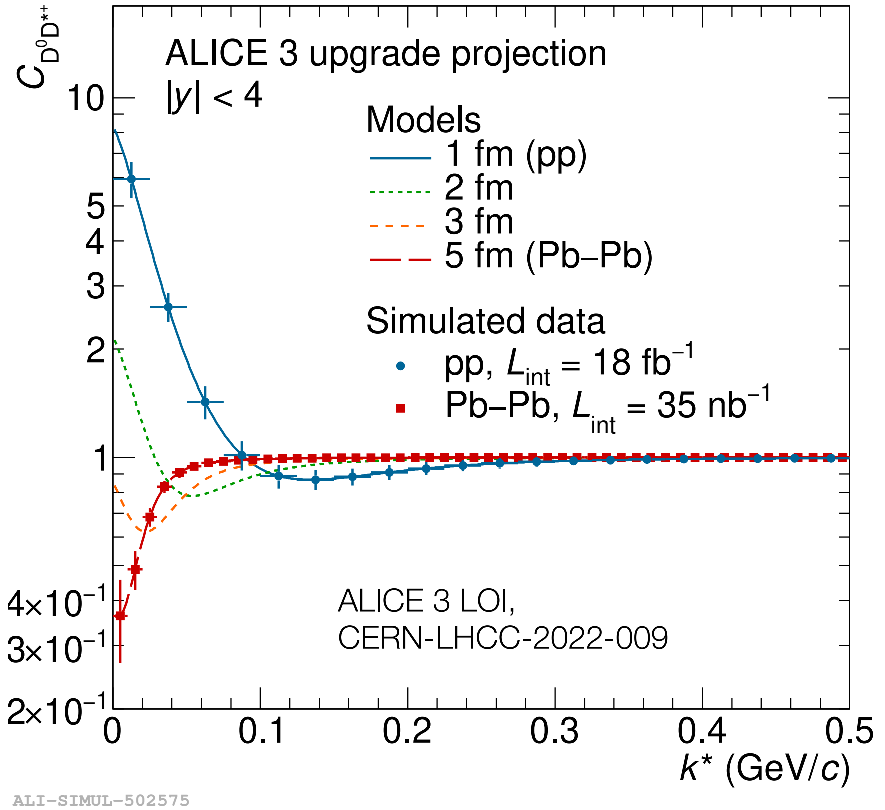


Talk by M. Albaladejo
Tue 6 15:10

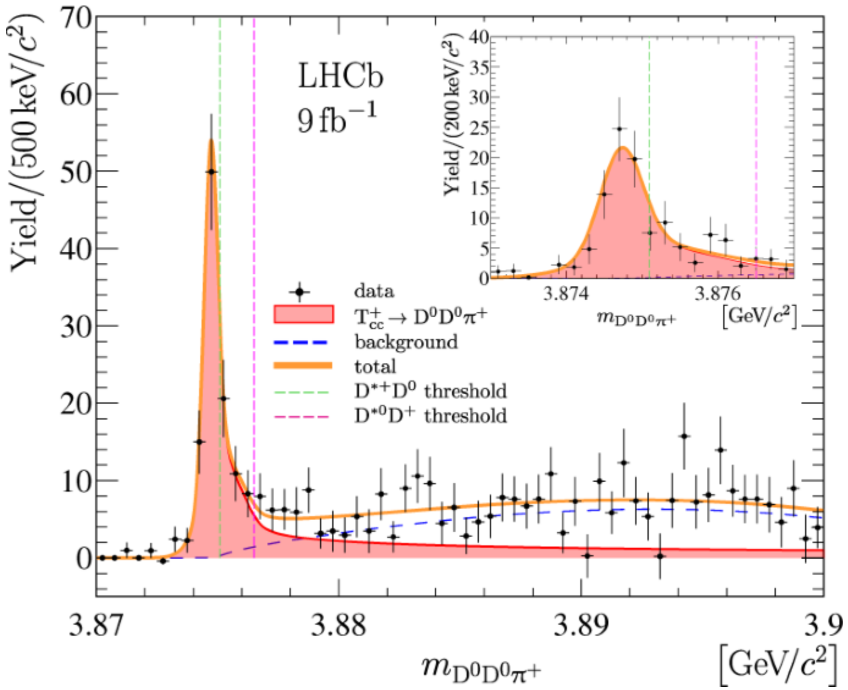
[1] A. Hosaka et al. Prog. Part. Nucl. Phys. 96 (2017), 6, 062C01
[2] M. Albaladejo et al. arXiv:2304.03107

Correlations and exotic states for a charming future

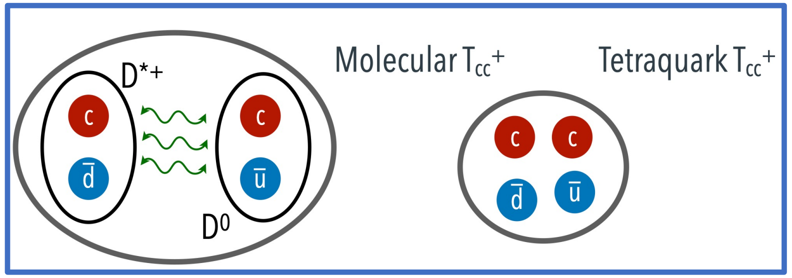
- Exotic charm states as T_{cc}^{+} observed at LHCb
- Investigate its nature with ALICE 3 in Run 5 and Run 6 via DD* correlations
  → **Complementarity** between spectroscopy and femtoscopy



LHCb, Nature Physics 18 (2022)
LHCb, Nature Comm. 13 (2022)



- Interplay between source size and scattering length
  → Size-dependent modification on the C(k*) and insights into the nature of T_{cc}^{+}



Conclusions and outlooks

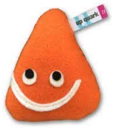
- **Femtoscopy** technique as a **complementary tool** to provide high-precision data on **hadron-hadron interactions**

- Access to strong interaction involving **strange** and **charm** hadrons
  - **most precise data** at low momenta available
  - input for **low-energy effective lagrangians** and test of **lattice potentials**

- **Many more correlations to come with on-going Run 3 and future LHC runs**

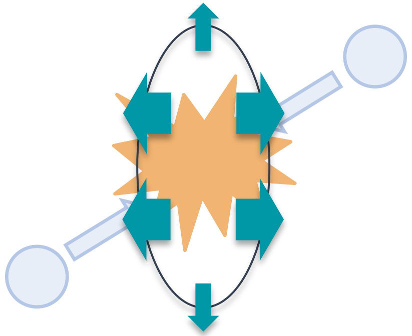
Femtoscopy menu of the week

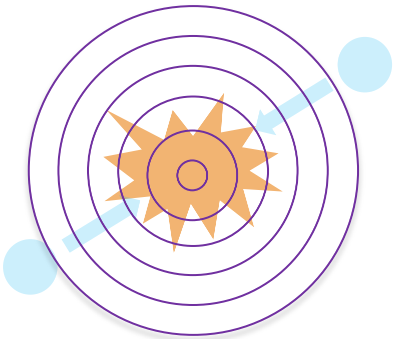
- *Femtoscopy in small systems at LHC*
  D. Mihaylov, Mo. 5 17:40
- *Femtoscopy with kaons and deuterons*
  W. Rzesa, Wed. 7 14:24
- *Three-particle interactions with femtoscopy*
  L. Serksnyte, Wed. 7 15:12
- *YN interaction for EoS with femtoscopy*
  M. Lesch, Thur. 8 15:12
- *$K^{-}p$ femtoscopy and coupled-channels*
  R. Lea, Thur. 8 15:42



Additional slides

A source to rule them all





Anisotropic + Radial

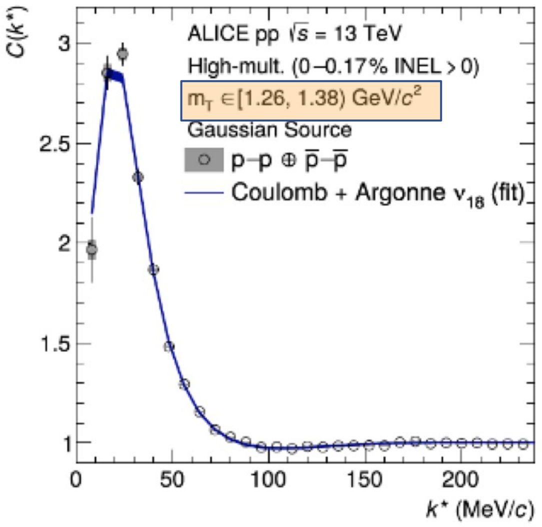
pressure gradients

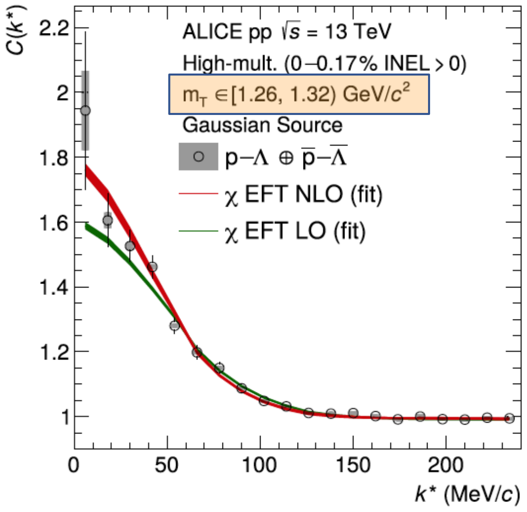
Different effect on different masses

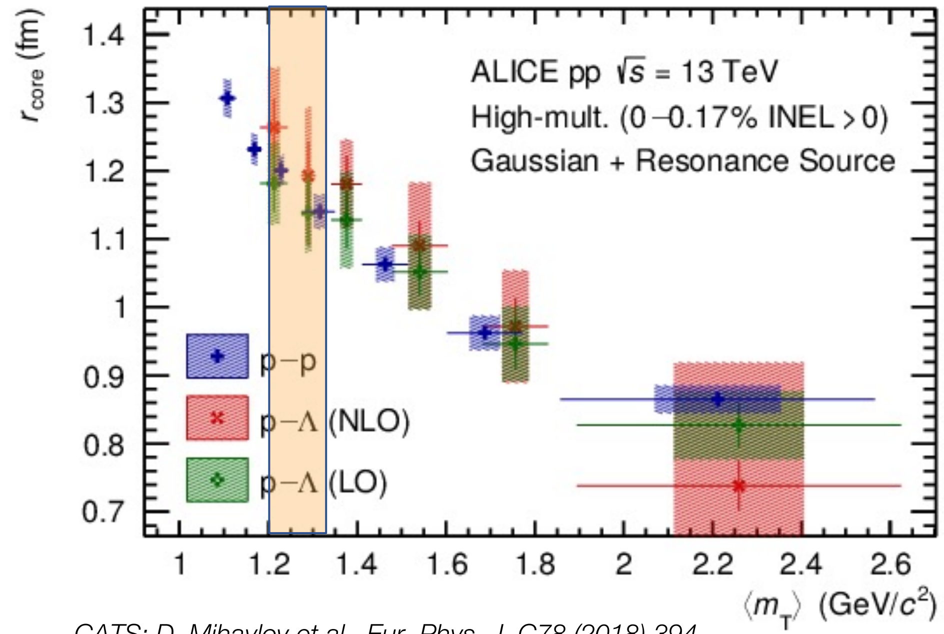
$$C(k^*) = \int S(r) \left|\psi(\vec{k}^*, \vec{r})\right|^2 d^3r$$

$$S(r) = G(r, r_{core}(m_T)) = \frac{1}{(4\pi r_{core}^2)^{3/2}} \exp\left(-\frac{r^2}{4r_{core}^2}\right) \otimes \frac{1}{s}\exp\left(-\frac{r}{s}\right)$$

ALICE Coll., PLB, 811 (2020)







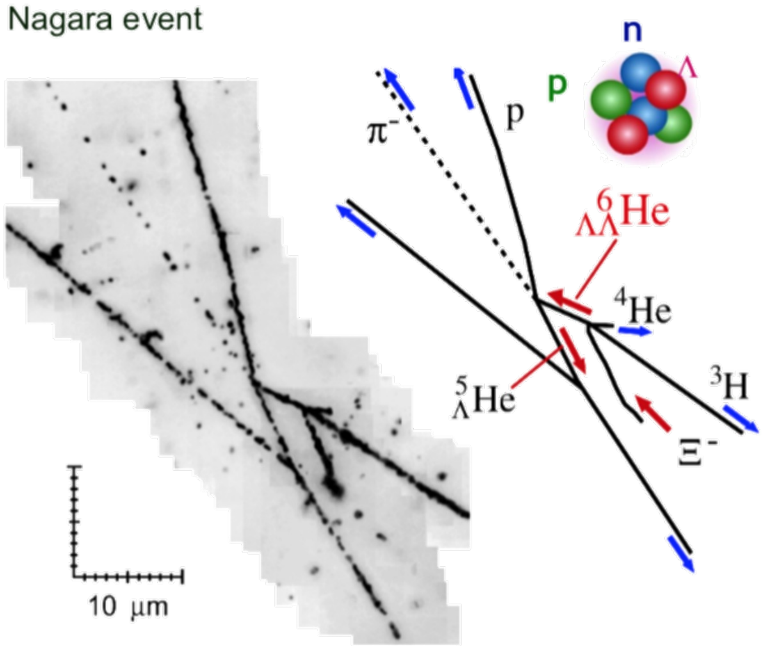
CATS: D. Mihaylov et al., Eur. Phys. J. C78 (2018) 394

|S|=2 : ΛΛ interaction and the H-dibaryon

- H-dibaryon: hypothetical bound state of *uuddss*
  - No final experimental evidences so far
  - Recent lattice QCD calculations at physical point with ΛΛ-NΞ coupled-channel(*) → no bound state around ΛΛ or NΞ threshold (**)

- Double-Λ hypernuclei measurements
  - weak attractive interaction
  - H-dibaryon binding energy $B_{\Lambda\Lambda}$ = 6.91 ± 0.16 MeV

Can we improve the knowledge on the ΛΛ interaction and the fate of the H dibaryon?



$^{6}_{\Lambda\Lambda}He \rightarrow {}^{5}_{\Lambda}He + p + \pi^-$

$\Delta B_{\Lambda\Lambda}$ = 0.67 ± 0.17 MeV

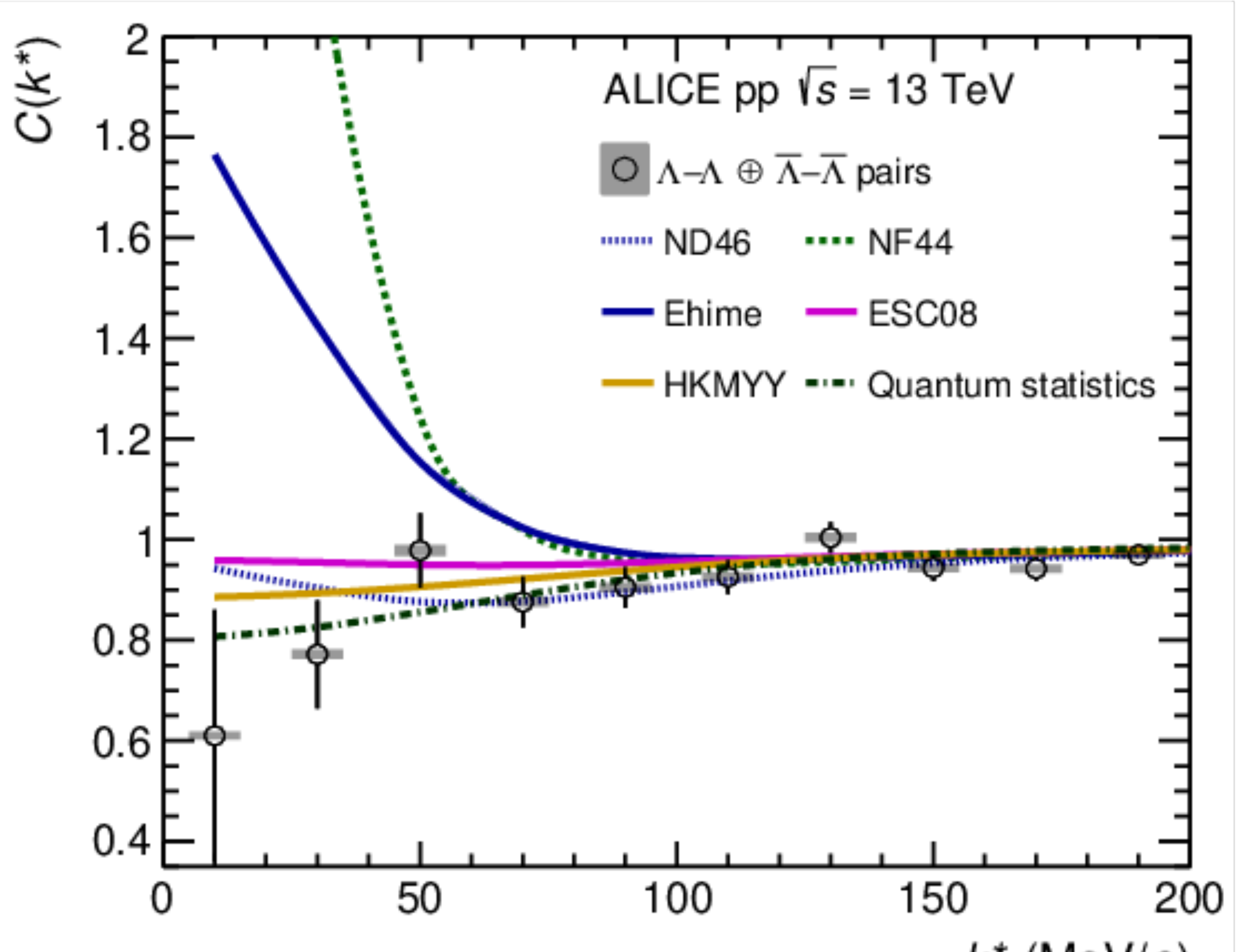
H. Takahashi et al., PRL 87 (2001) 212502

(*) HAL QCD Coll. Nucl.Phys.A 998 (2020) 121737
A. Ohnishi et al., Few Body Syst. 62 (2021) 3, 42
Y. Kamiya et al., PRC 105 (2022)

(**) ALICE Coll. Phys. Rev. Lett 123, (2019) 112002
ALICE Coll. Nature 588, 232–238 (2020)

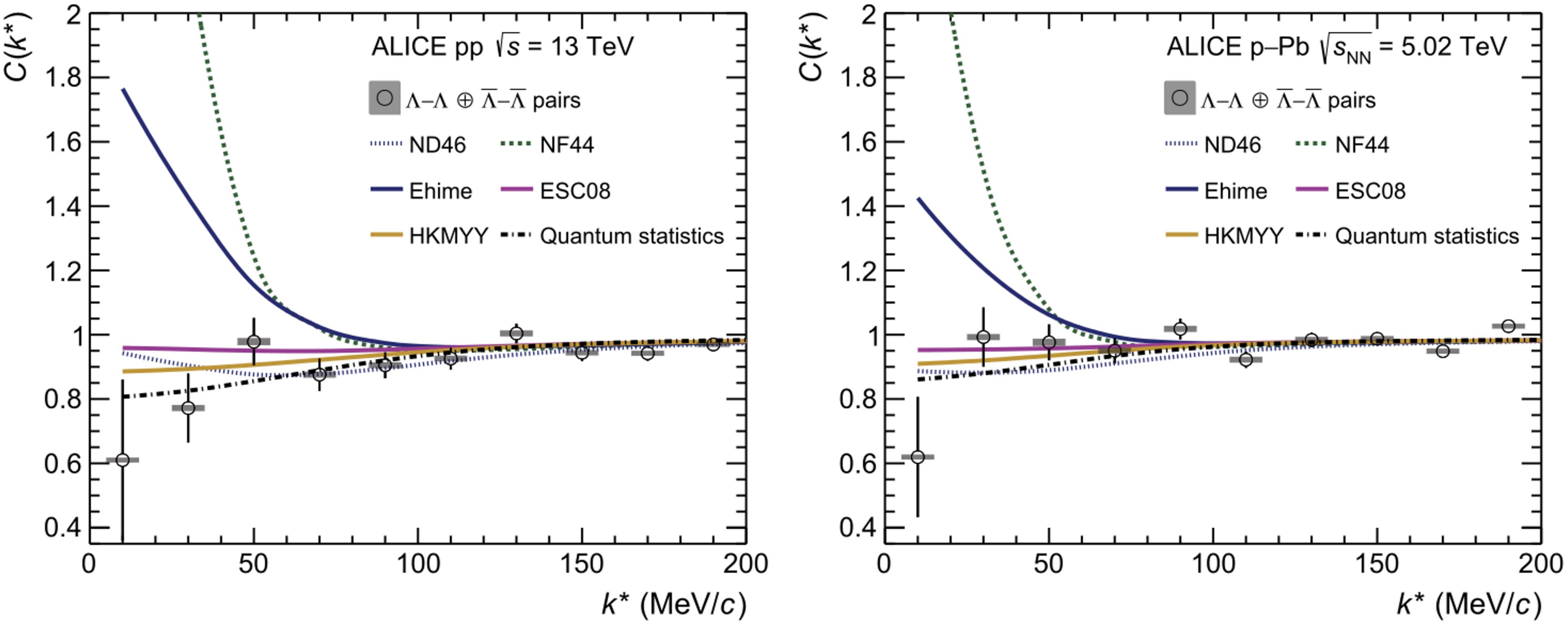
|S|=2 : ΛΛ interaction models

- ΛΛ correlation measured in pp MB 13 TeV and p-Pb 5.02 TeV
- Comparison with available theoretical models
  - large attraction and very weakly bound state discarded
  - data compatible with a bound state (ND46) or shallow attraction (ESC08)
- Scan in scattering parameter space and express agreement data/model in number of σ deviations



ALICE Coll. Phys.Lett.B 797 (2019) 134822

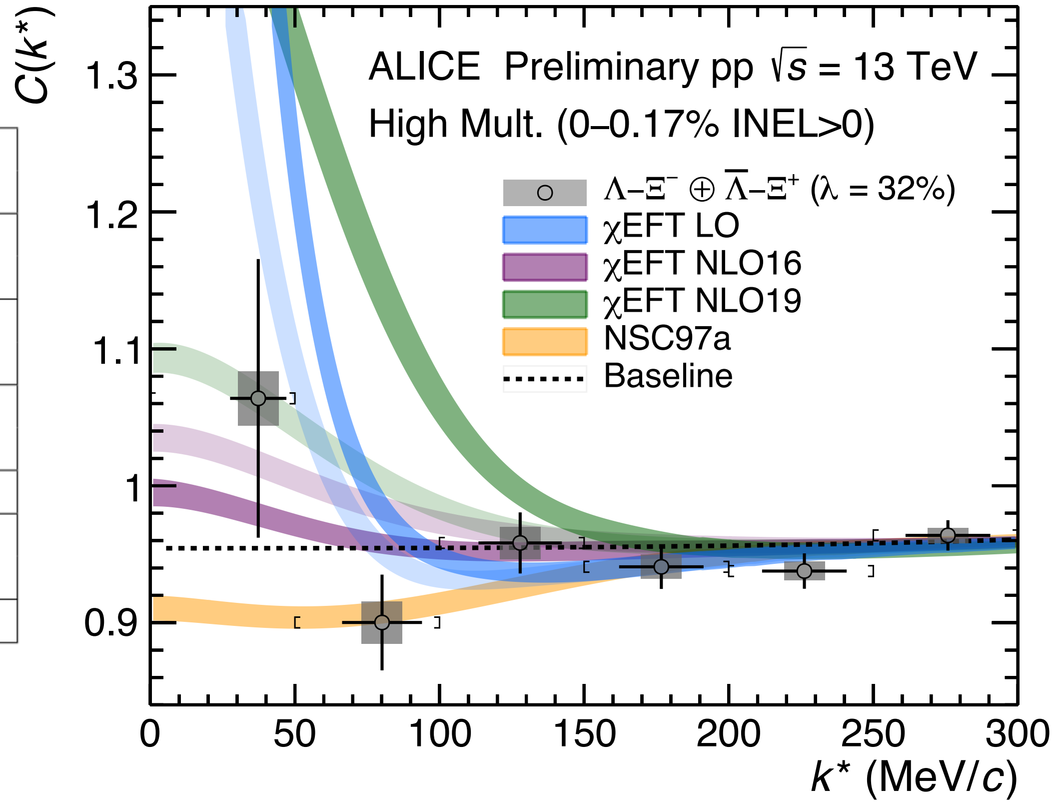
Λ-Λ correlations



Phys.Lett.B 805 (2020) 135419

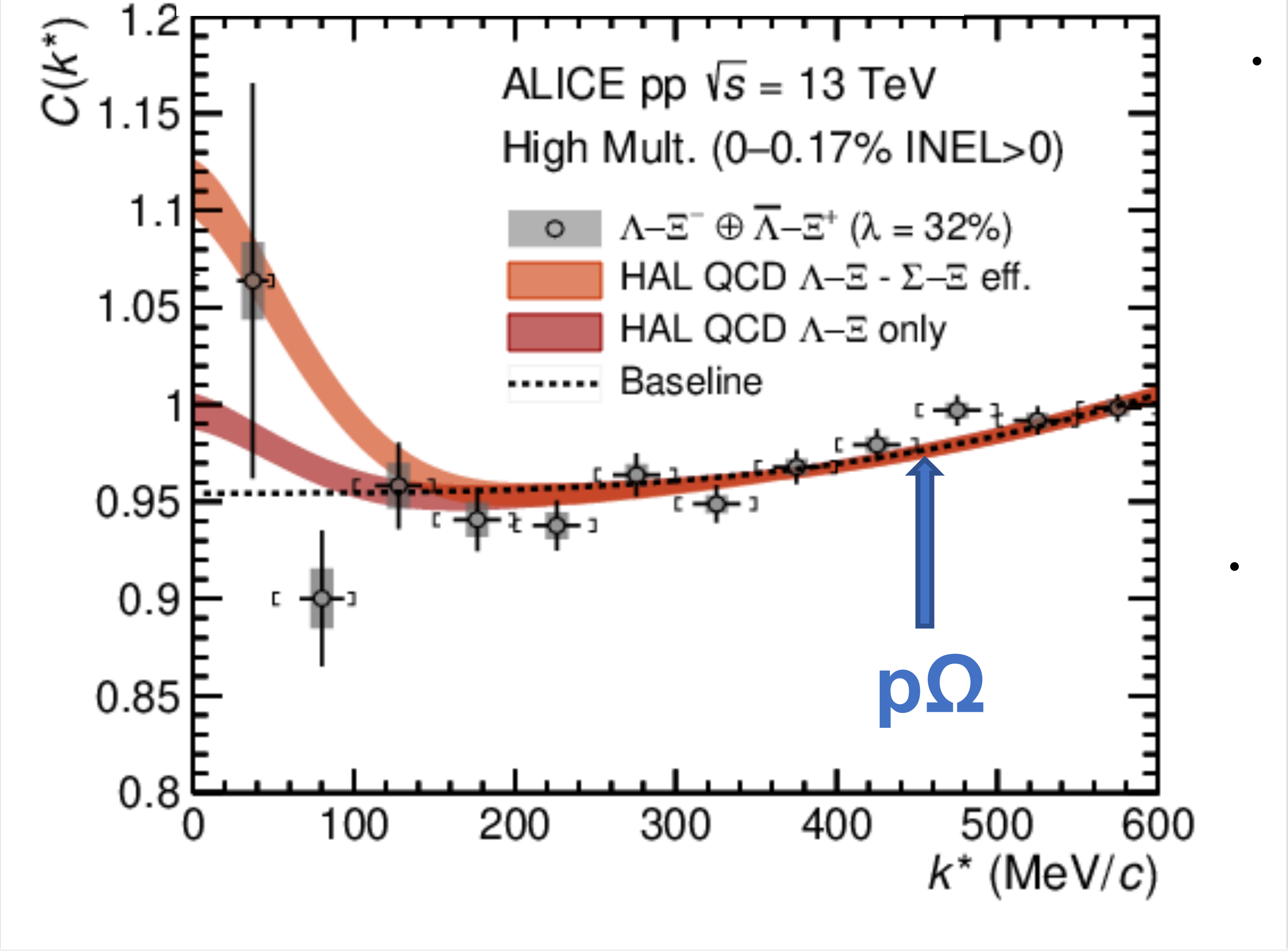
ΛΞ correlation in pp HM 13 TeV

potential	cut-off (MeV) / version	singlet f_0^0	singlet d_0^0	triplet f_0^1	triplet d_0^1	n_σ
χEFT LO [11]	550	33.5	1.00	−0.33	−0.36	3.06 – 5.12
	700	−9.07	0.87	−0.31	−0.27	0.78 – 1.60
χEFT NLO16 [14]	500	0.99	5.77	−0.026	142.9	0.56 – 0.93
	650	0.91	4.63	0.12	32.02	0.91 – 1.61
χEFT NLO19 [15]	500	0.99	5.77	1.66	1.49	5.47 – 7.26
	650	0.91	4.63	0.42	6.33	1.30 – 2.10
NSC97a [12]		0.80	4.71	−0.54	−0.47	0.68 – 1.04
HAL QCD [2]	ΛΞ–ΣΞ eff.	0.60	6.01	0.50	5.36	1.43 – 2.34
	ΛΞ–ΛΞ only	–	–	–	–	0.64 – 1.04
Baseline		–	–	–	–	0.78



ALI-PREL-516888

|S| = 3: Λ-Ξ⁻ interaction – with femtoscopy



- Unknown contribution from coupled channels in Lattice QCD calculations
  → Coupling ΛΞ–ΣΞ sizable in HAL QCD calculation
  → No sensitivity yet ("No coupling" 0.64 nσ vs. „Coupling" 1.43 nσ)
- No NΩ cusp visible
  → Hint to negligible NΩ-ΛΞ coupling

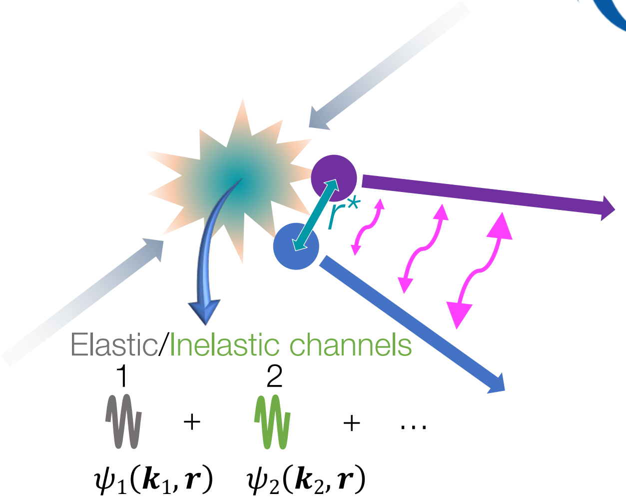
(*) *N. Ishii et al.. EPJ Web of Conferences 175, 05013 (2018)*

Coupled-channels in femtoscopy

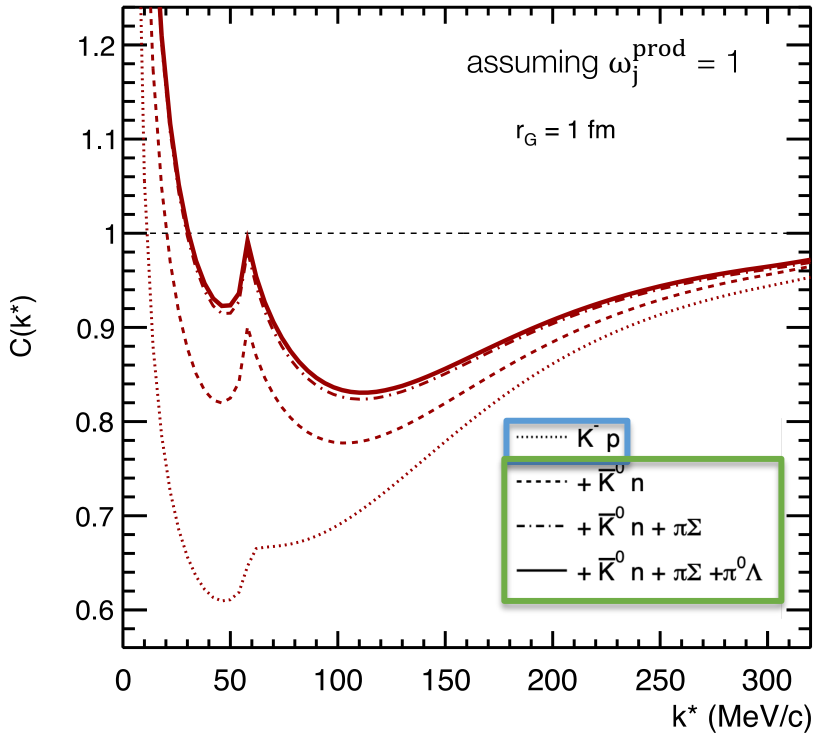
$$C(k^*) = \int S(\vec{r}^*)\ \left|\psi_{1\to1}(\vec{k}^*,\vec{r}^*)\right|^2 d^3r^* + \sum_{j\neq1} \omega_j^{prod} \int S_j(\vec{r}^*)\ \left|\psi_{j\to1}(\vec{k}_j^*,\vec{r}^*)\right|^2 d^3r^*$$

elastic
1 → 1

inelastic
2,3,… → 1



- Conversion weights ω_j^{prod}
  - Produced pairs in j channel as initial states
    → Depend on yields and kinematics
    - Thermal models(1) and transport models (2)
- Wave functions $\psi_{j\to1}\left(k_j^*, r^*\right)$
  - Above threshold: modify the shape of CF
    → cusp structure e.g. $\overline{K}^0 n$
  - Below threshold: increase the strength of CF
    → shift upward of CF e.g. Σπ



(1) Thermal Fist: V.Vovchenko, H. Sotecker Comput. Phys. Commun. 244, 295 (2019)
(2) EPOS: K.Werner et al. arXiv:1006.2967

R. Lednický, et. al. Phys. At. Nucl. 61 (1998)
J. Haidenbauer NPA 981 (2019)
Y. Kamiya et al. PRL 124 (2020)
L. Fabbietti, VMS, O. Vazquez Doce Ann.Rev.Nucl.Part.Sci. 71 (2021)

Overview on S=-2 meson-baryon sector

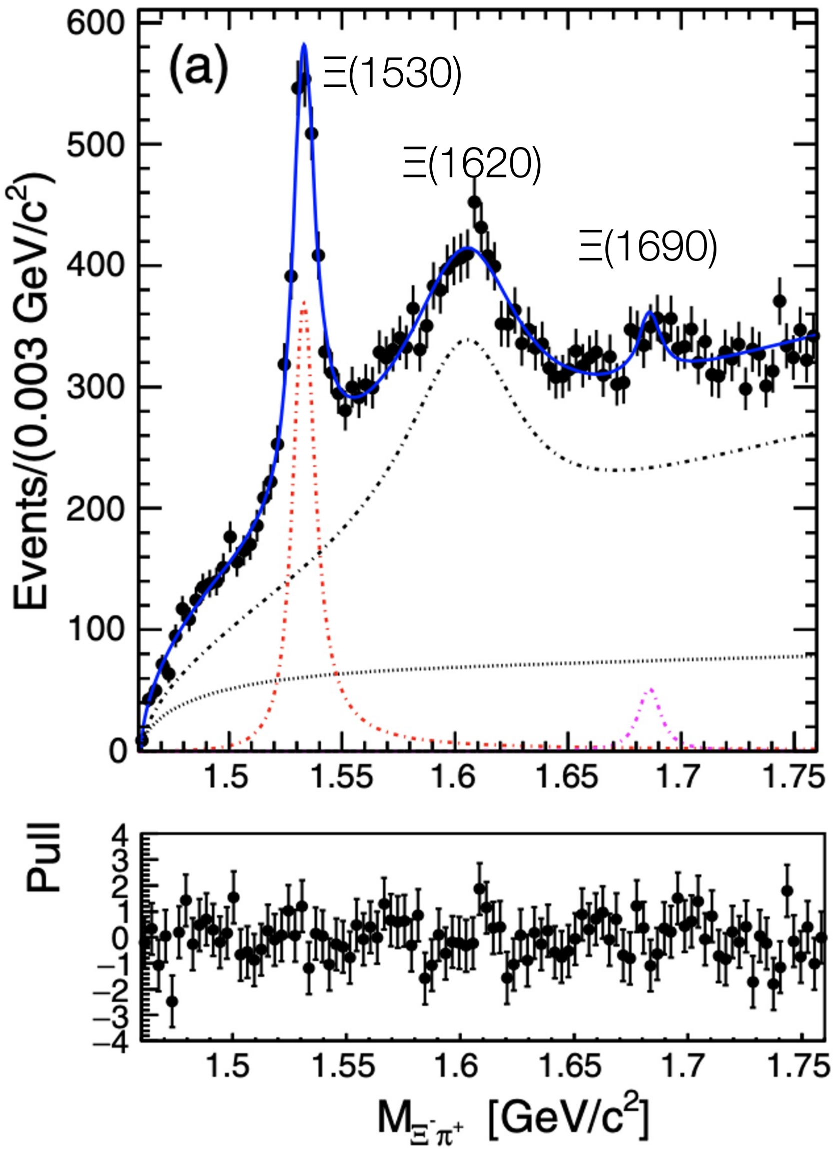
- **Poorly constrained experimentally**
  → Effective lagrangians anchored to S=-1 sector[1]

- **Ξ(1620)** and Ξ(1690)[2] dynamically generated states within coupled-channel models
  → Ξ(1620) observed by Belle in πΞ decay but currently only **1 star in PDG**

- Recent development of chiral calculations at NLO[3]

Need for high-precision data to constrain model´s parameters

Belle Coll. PRL 122 (2019)



[1] A. Ramos er al. PRL 89 (2002)
[2] LHCb coll. Sci.Bull. 66 (2021)
[3] A. Feijoo et al. PLB 841 (2023)

LO χPT calculations:
C. Garcia-Recio et al. PLB 582 (2004)
D. Gamermann et al. PRD 84 (2011)
T. Sekihara PTEP 2015 (9) (2015)
T. Nishibuchi and T. Hyodo, EPJ Web Conf 271 (2022)

Scattering parameters for ΛK⁻

ALICE Coll. arXiv: 2305.19093

- Indication of an attractive non-resonant interaction
  → In agreement with ALICE Pb-Pb results[1]

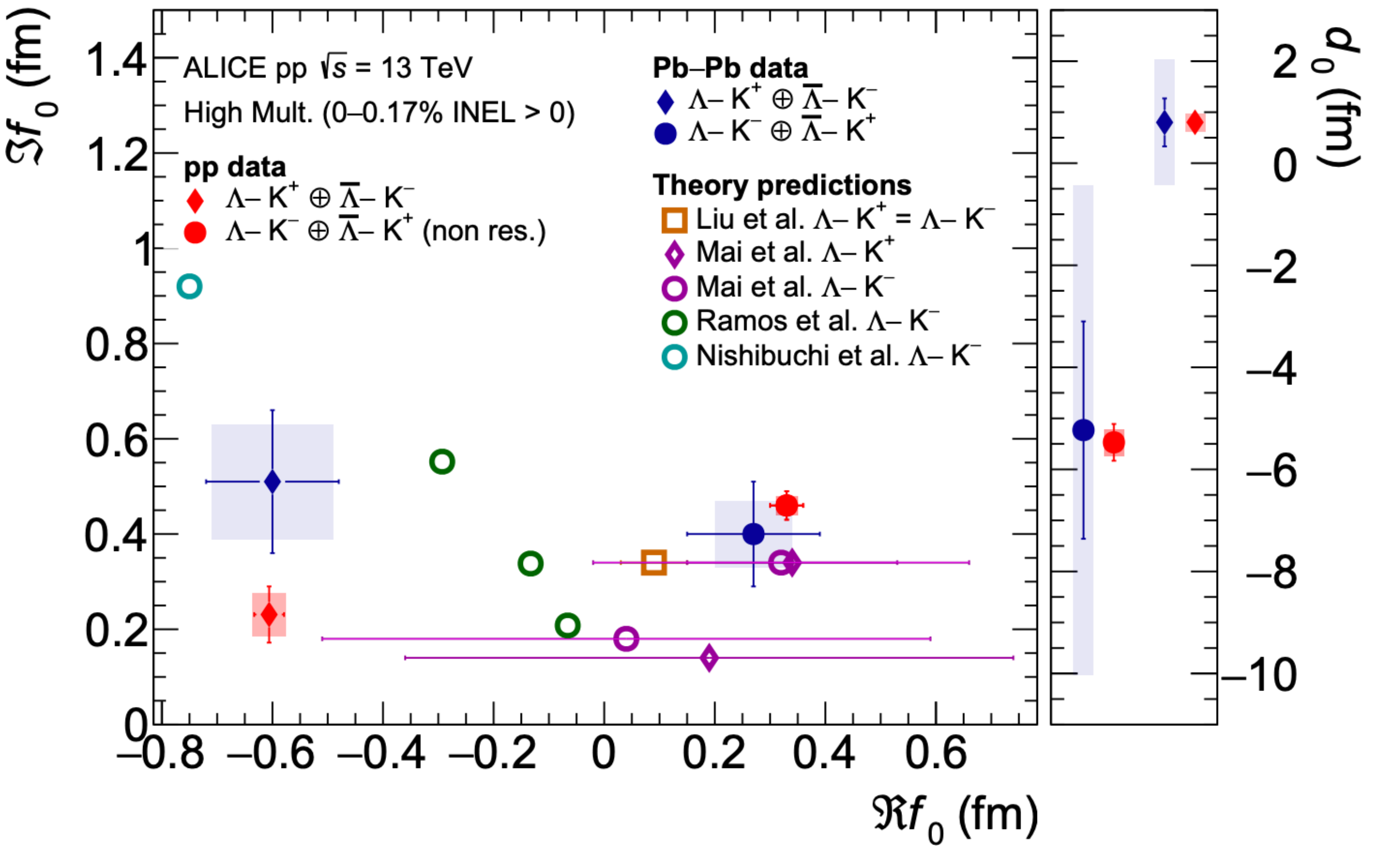
- Available models far from converging on similar results

  → Parameters fixed based on SU(3) flavour symmetry, isospin symmetry

  → Mainly anchored to πN or K̅N data

  → Ξ(1620) typically lying below threshold

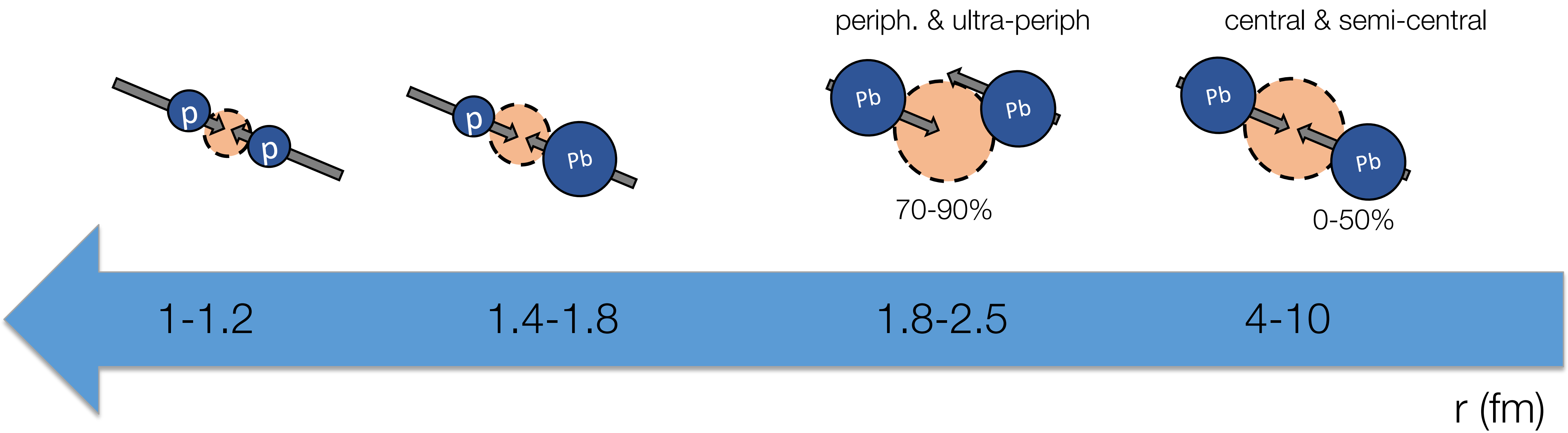
- High-precision data to constrain effective chiral theories and to understand the Ξ(1620) nature



UχPT at LO: Ramos et al. PRL 89 (2002), Nishibuchi et al. EPJ Web Conf 271 (2022)
χPT at NLO: Liu et al. PRD 75 (2007), Mai et al. PRD 80 (2009)

Small vs large colliding systems

- By changing the colliding system we can probe distances ranging from 1 fm up to 10 fm
- Accessing the strong interaction → relative distances of ~1 fm → pp
- Small interparticle distance → doorway to studying large densities



Modeling of the correlation function

- Lednicky-Lyuboshits analytical formula
  - assuming a gaussian source
  - relies on the asymptotic behaviour of wf
    → scattering parameters as inputs, eff.

$$C_{LL}(k^*) = 1 + \frac{1}{2}\left|\frac{f}{r_0}\right|^2 \left[1 - \frac{d_0}{2\sqrt{\pi}r_0}\right] + \frac{2\mathcal{R}[f]F_1(2k^*r_0)}{\sqrt{\pi}r_0} - \frac{\mathcal{I}[f]F_2(2k^*r_0)}{r_0}$$

$$f(k^*) \approx \left(f_0^{-1} + \frac{1}{2}d_0k^{*2} - ik^*\right)^{-1}$$

  - might break down for small sources
    widely used in large colliding systems

R. Lednicky, V.L. Lyuboshits Sov. J. Nucl. Phys. 35 (1982)

- CATS framework
  - local potentials, wavefunctions, gaussian and beyond sources
  - relies on the exact wavefunction
    → behaviour at short-distances

$$\Psi_k(\vec{r}) = R_k(r)Y(\theta),$$

$$C_{th}(k^*) = \int S(\vec{k}^*,\vec{r}^*)\left|\Psi(\vec{k}^*,\vec{r}^*)\right|^2 d^3r^*.$$

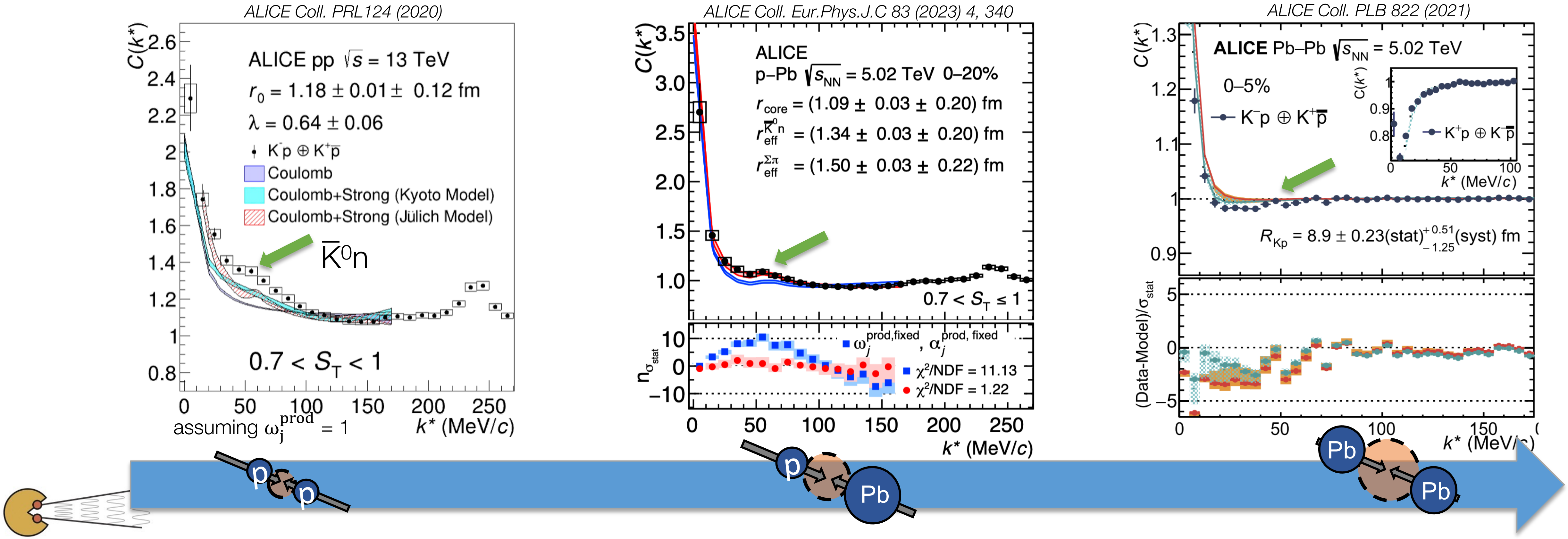
  - works for small and large sources

CATS Framework: D. Mihaylov et al., Eur. Phys. J. C78 (2018) 394

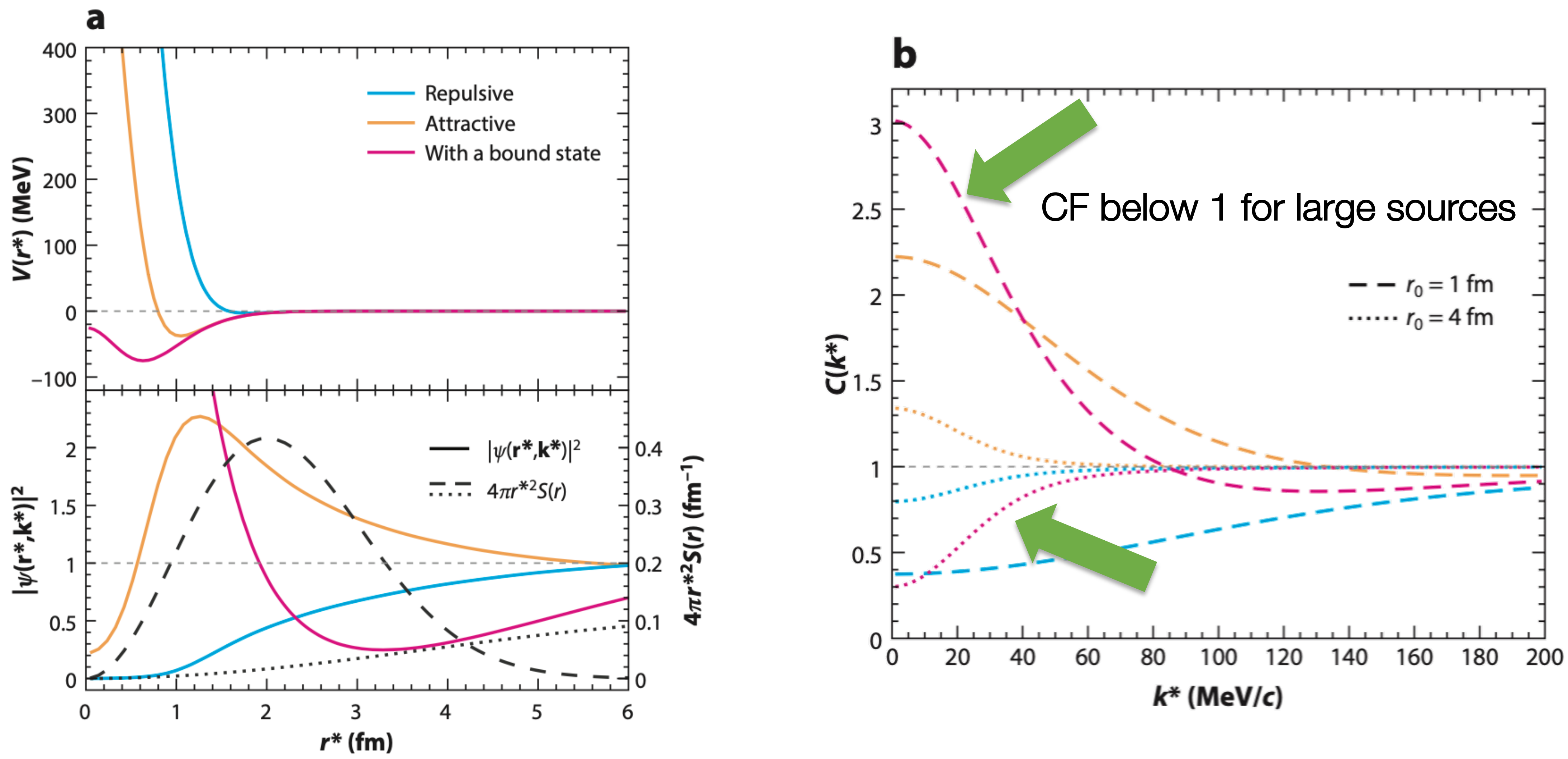
K⁻p femtoscopy: constraining the inelastic dynamics

χEFT Kyoto model:
Ikeda et al. NPA 881 (2012), PLB706 (2011)
Kamiya et al. PRL 124 (2020)
Mihayara et al. PRC95 (2017)

- Measurement in pp collisions
  → First experimental evidence of the opening of $\bar{K}^0$n channel (k*~ 60 MeV/*c*)
- Extending the measurements to p-Pb and Pb-Pb colliding system
  → Interplay source size and coupled-channel dynamics in the correlation
  → Constraints for coupling to $\bar{K}^0$n and Σπ
- Three- particle ppK± correlations and K^0_s p data available soon!

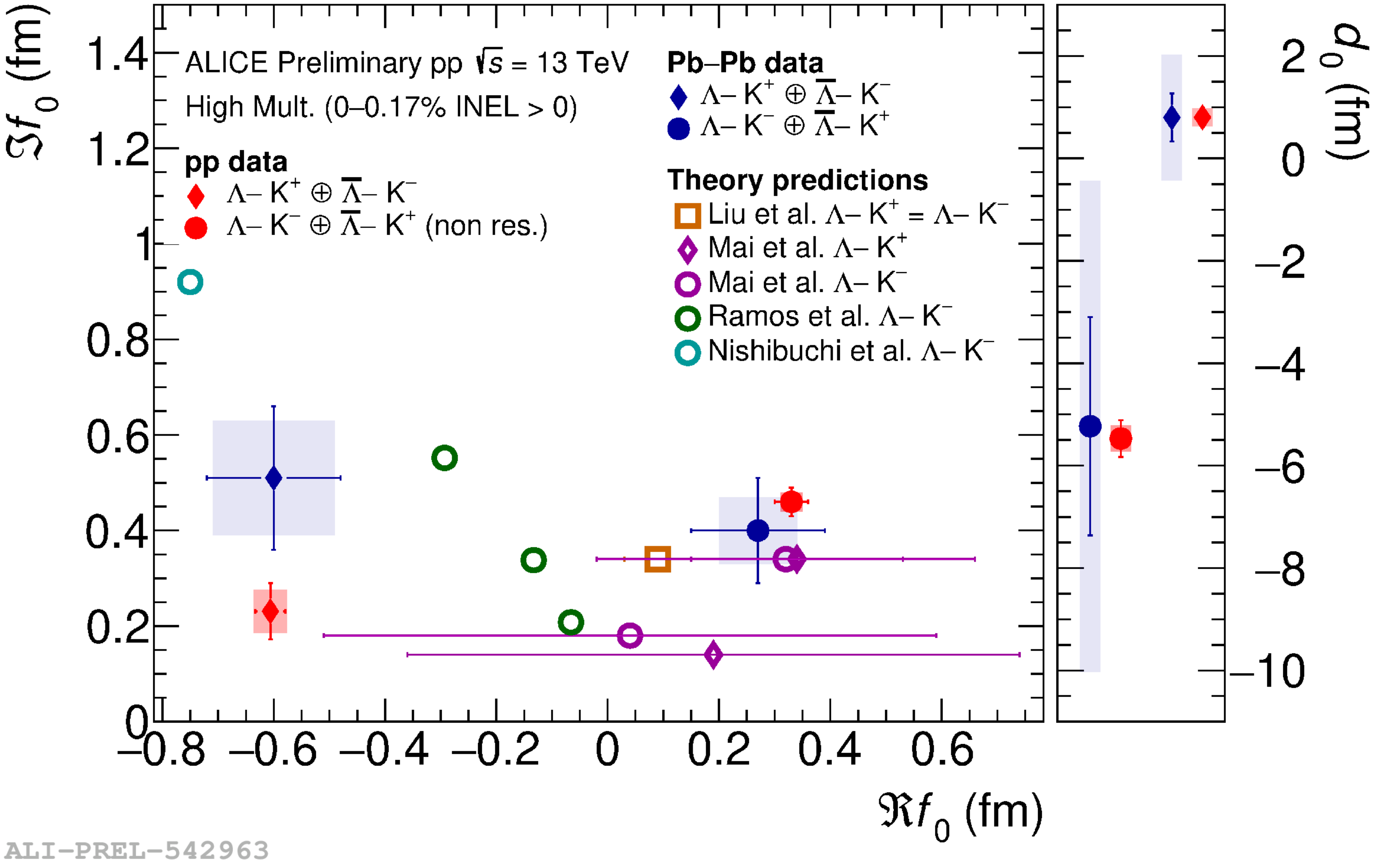


Study the strong interaction: bound states and correlations



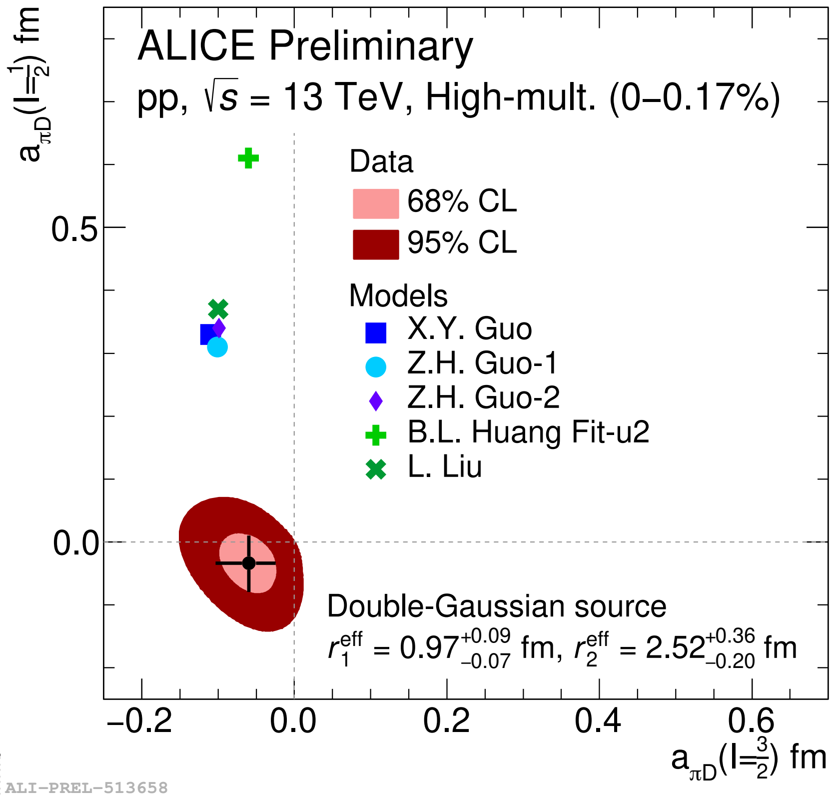
V.Mantovani Sarti, L. Fabbietti, O. Vazquez Doce Ann. Rev. NPS 71 (2022)

Scattering parameters for ΛK and ΛK̄



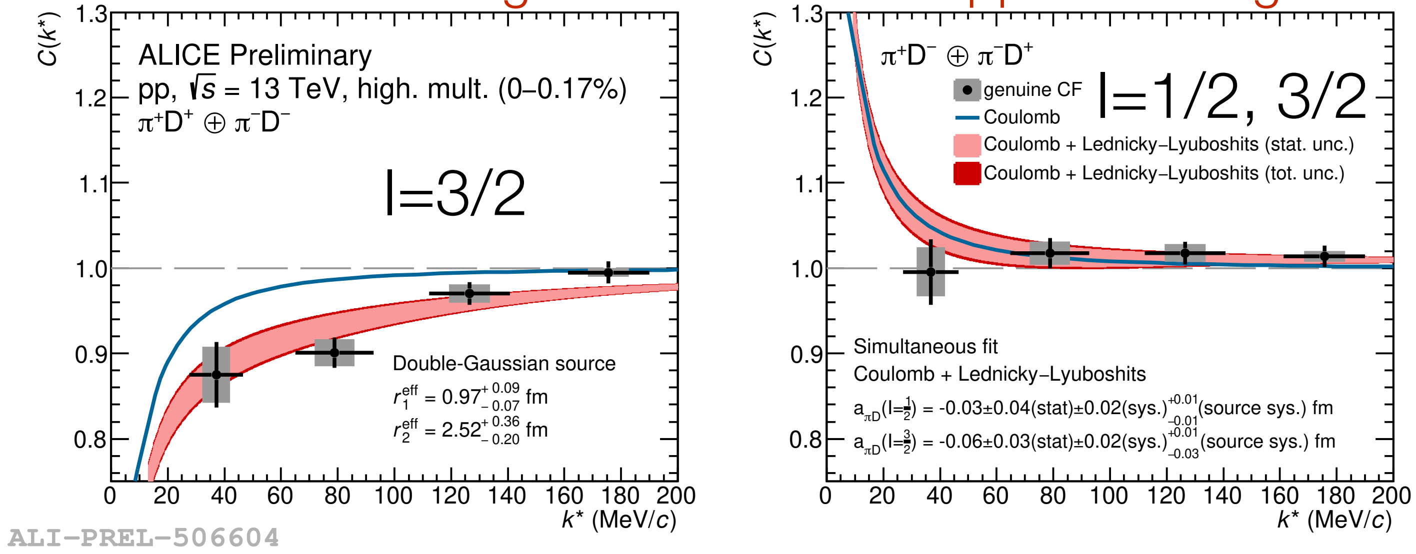
Dπ correlations in pp collisions

- Available predictions from LQCD calculations constraining mostly I=3/2
  (X.-Y. Guo et al. PRD 98 (2018))
  → $|a_0|$ ~0.1-0.5 fm, much smaller wrt to light-light and light-strange hadronic interactions



Same charge

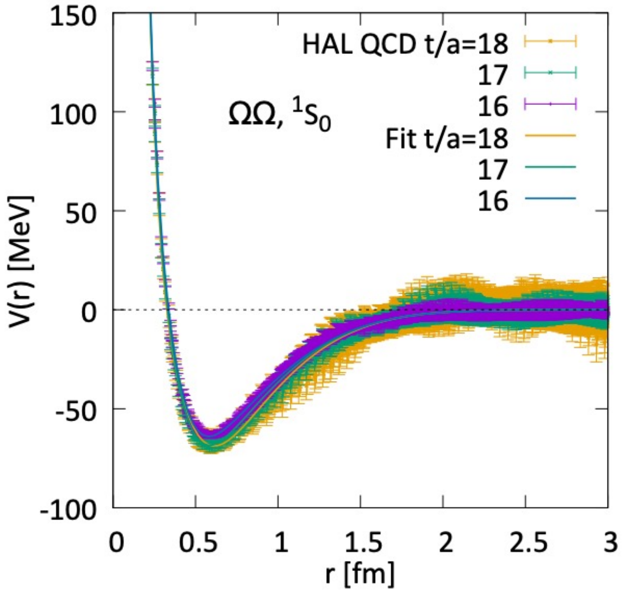
Opposite charge



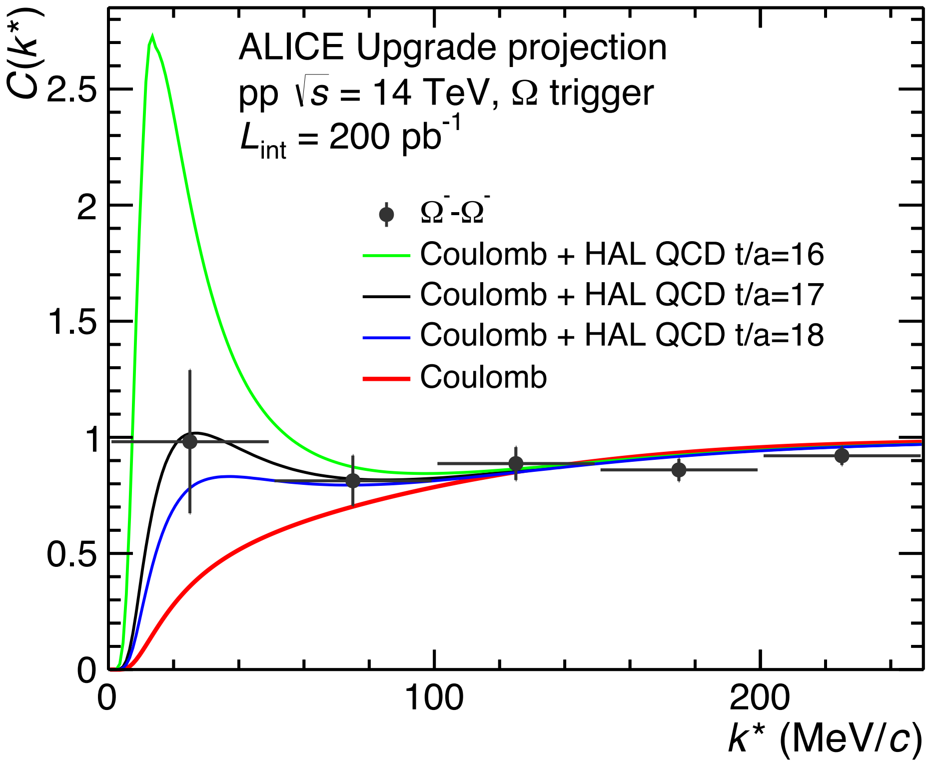
- Extraction of scattering lengths for both isospin channels
  → I=3/2 in agreement with models
  → I=1/2 significantly smaller than models
- Rather shallow interaction between D and π!
- Ongoing DK analyses show compatibility with Coulomb only!
  → work in progress for D*K and D*π

ΩΩ correlation with future LHC runs

- Most strange dibaryon predicted by lattice potentials[1]
  → B. E ~1.6 MeV



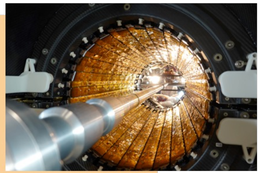
- Thanks to enhanced statistics of Run 3
  → similar precision to the current p–Ω Run 2 (30% at k* = 50 MeV/c)



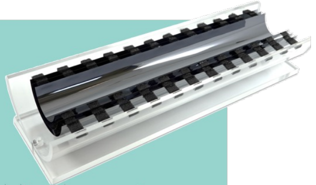
CERN-LHCC-2020-018 ; LHCC-G-179
Future high-energy pp programme with ALICE

ALICE 3 detector

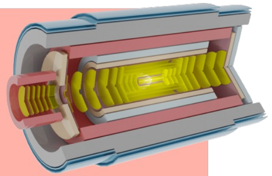
GEM-based TPC, ITS2, MFT
50x readout capability
3x tracking precision

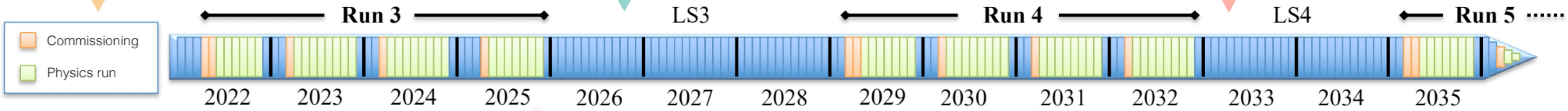


ITS3, FoCal
3x tracking precision
2x efficiency at low p_T + forward γ

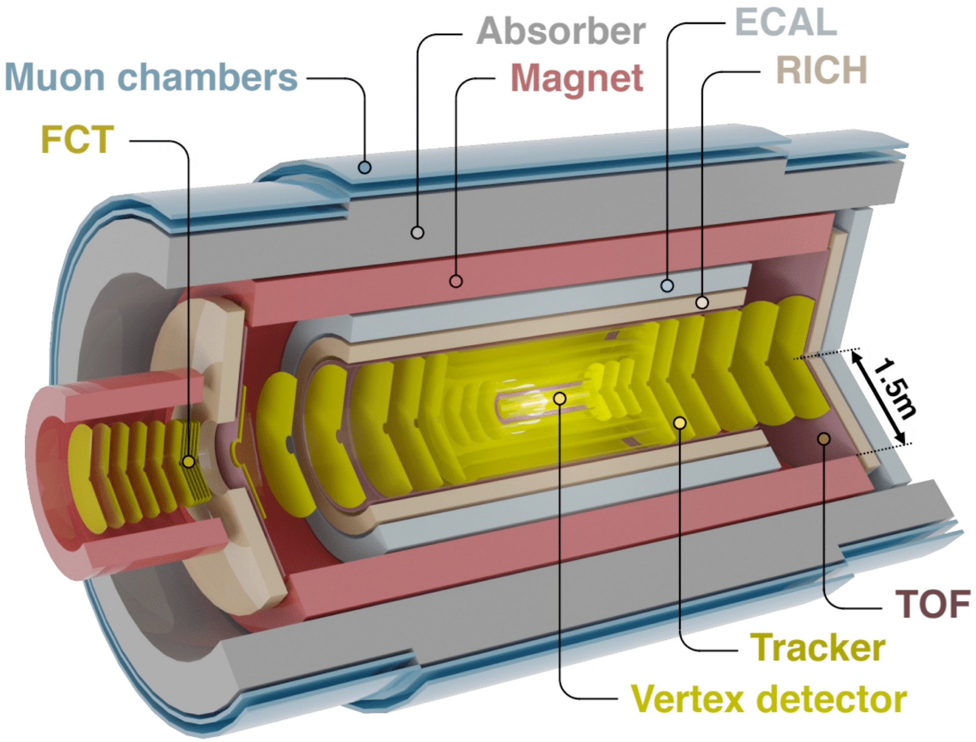


ALICE 3
Ultra-thin dedicated
heavy-ion experiment

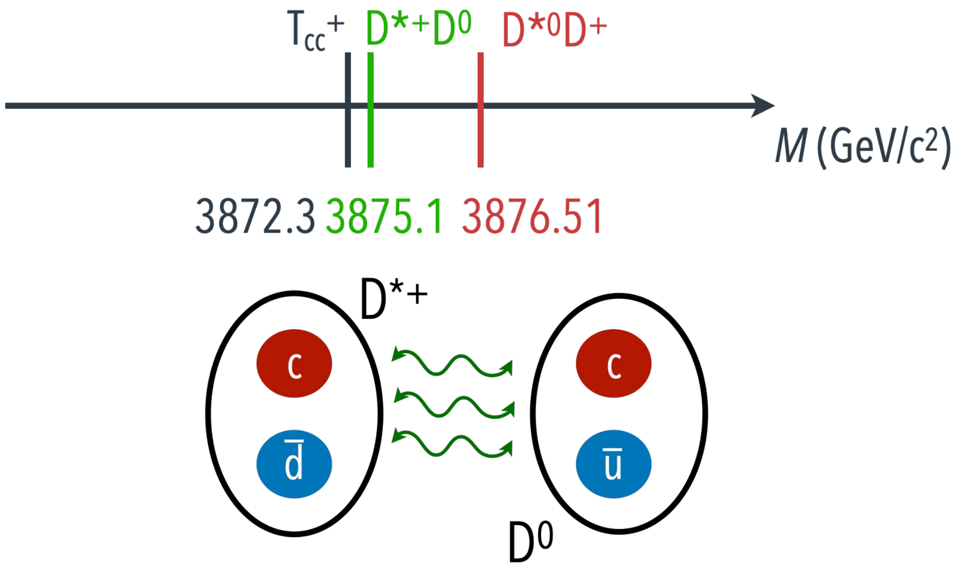




- Each upgrade improves
  1. Spatial resolution (improves reconstruction of weakly-decaying particles)
  2. Readout capability (improves integrated luminosity)
- Excellent pointing resolution (~10μm, p= 200 MeV/c) + large acceptance (|η| < 4)
  → secondary vertices and decay chains
  - All silicon tracker with σ_p/p ~1%
  - First tracking layer at 5 mm from primary vertex
- Excellent hadron and lepton PID
  - Silicon-based TOF and RICH
  - Muon chambers with absorber
- x5 more AA luminosity than Run 3&4 → DD* correlations!!



Expected performance for the measurement of DD* correlations



- D^{*+} meson: reconstructed in $D^{*+} \to D^{0}\pi^{+}$ channel
- D^{0} meson: reconstructed in $D^{0} \to K^{-}\pi^{+}$ channel

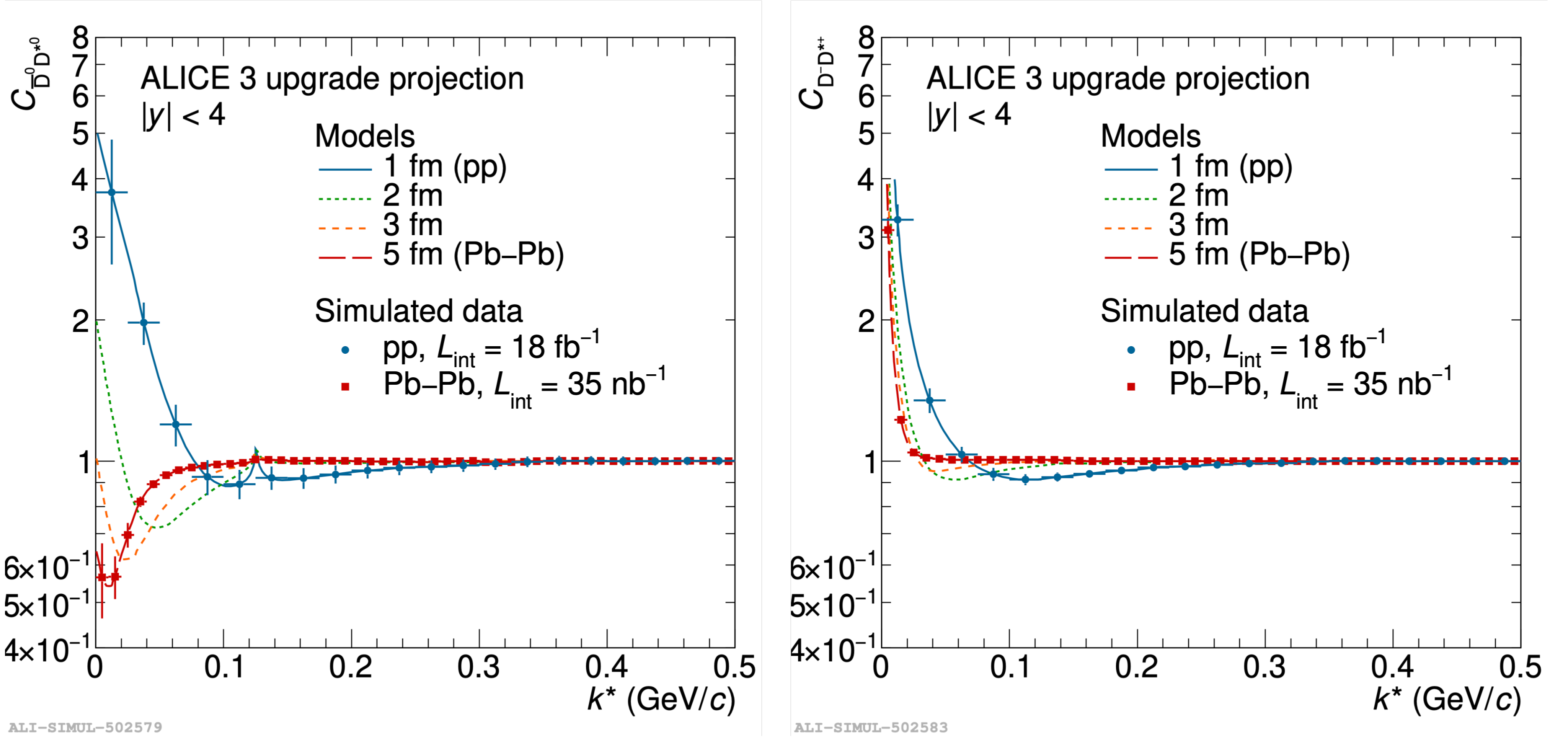
Challenge: significant contribution from decays of resonances

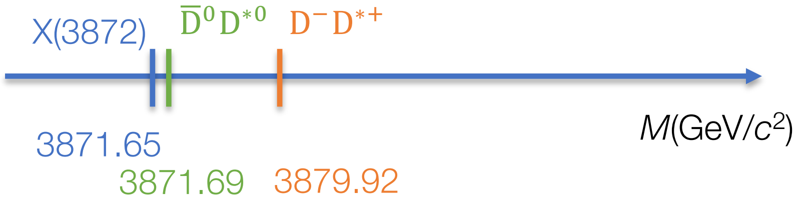
1. $BR(D^{*+} \to D^{0}\pi^{+}) = (66.7 \pm 0.5)\%$
2. $BR(D^{*0} \to D^{0}\pi^{0}) = (64.7 \pm 0.9)\%$
3. $BR(D^{*0} \to D^{0}\gamma) = (35.3 \pm 0.9)\%$

PDG, Prog. Theor. Exp. Phys. 2020 083C01

- Fast simulation strategy
  - Simulate PYTHIA8 events and select events with D^{*+} and D^{0} meson pairs
  - Combine pairs of D^{*+} and D^{0} mesons from same events and mixed events, weighting according to their efficiency
  - D^{0} from D^{*+} decays are excluded (assuming that experimentally we can set an invariant-mass veto on $D^{0}\pi$ pairs)
  - Scale same event and mixed event distributions according to expected number of events
  - Scale same event distribution according to theoretical predictions
  - Compute expected statistical uncertainty according to expected signal and background yields

$D\bar{D}^*$ correlations





- Inversion of the correlation function not observed for $D^- D^{*+}$ because the X(3872) is ’far’ (148 MeV) from the mass threshold with respect to $\bar{D}^0 D^{*0}$ (~200 KeV).

Correlations function can confirm a molecular state scenario.