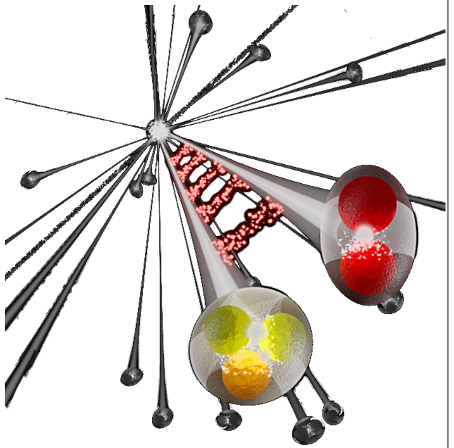
Czech
Technical
University
in Prague

Probing the interaction of the Ξ hyperon with nucleons using femtoscopy in ALICE

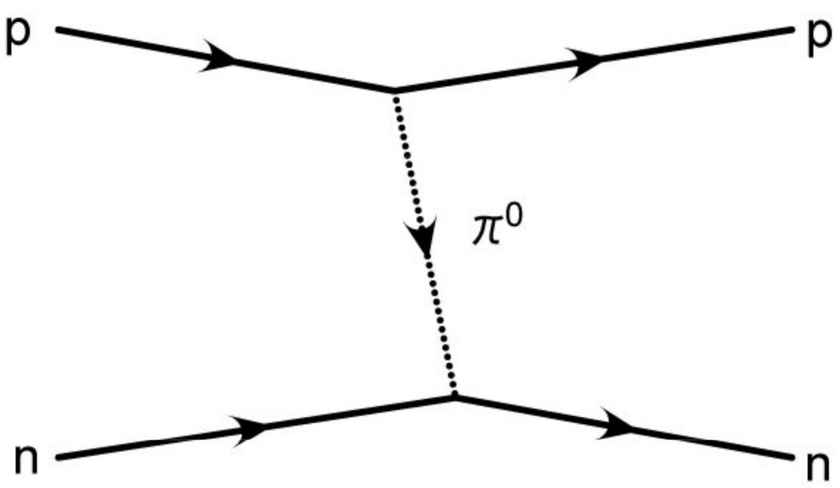


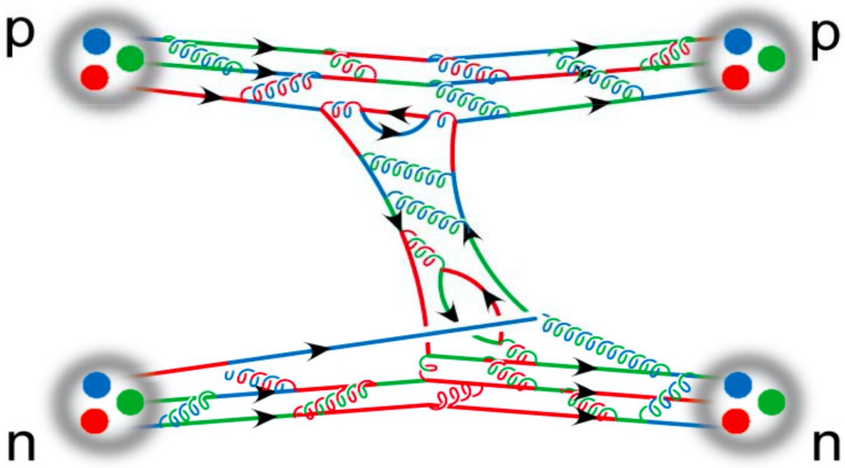
Raffaele Del Grande[1,*], Georgios Mantzaridis[2]
[1]Czech Technical University in Prague
[2]Technical University in Munich
*raffaele.del.grande@fjfi.cvut.cz

On behalf of the ALICE Collaboration

Hadronic interactions

Low energy hadronic interactions:

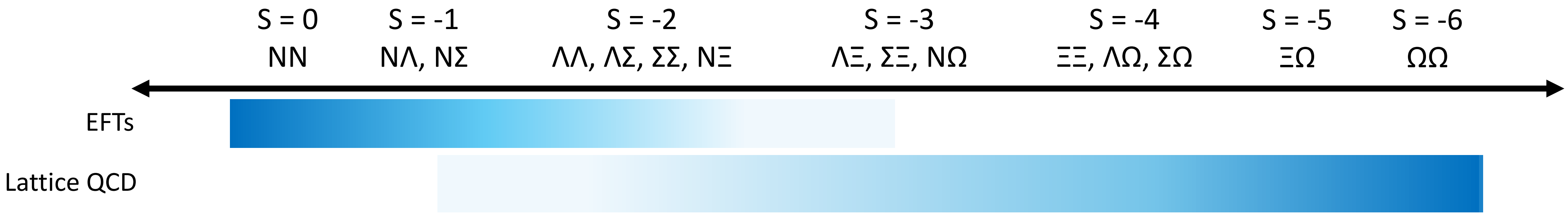




Effective Field Theories (EFT)
- hadrons as degrees of freedom
- low-energy coefficients constrained by data

Lattice QCD
- quarks and gluons as degrees of freedom
- unstable for low mass hadrons

Theory and experimental data



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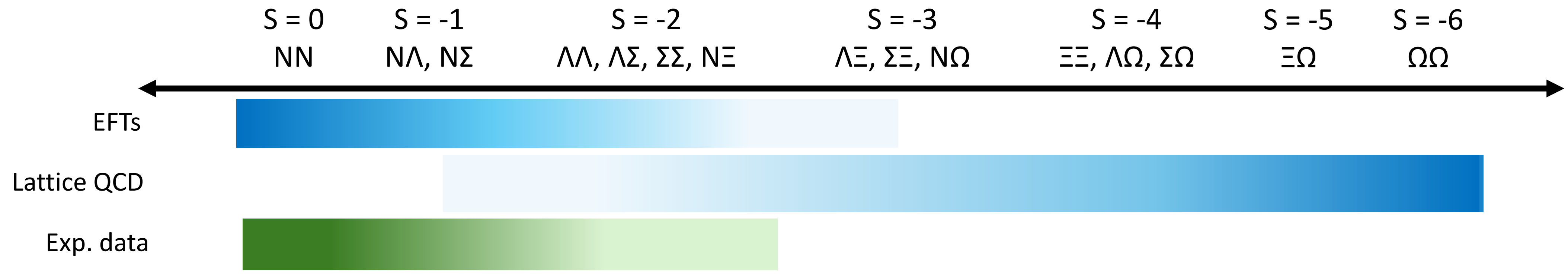
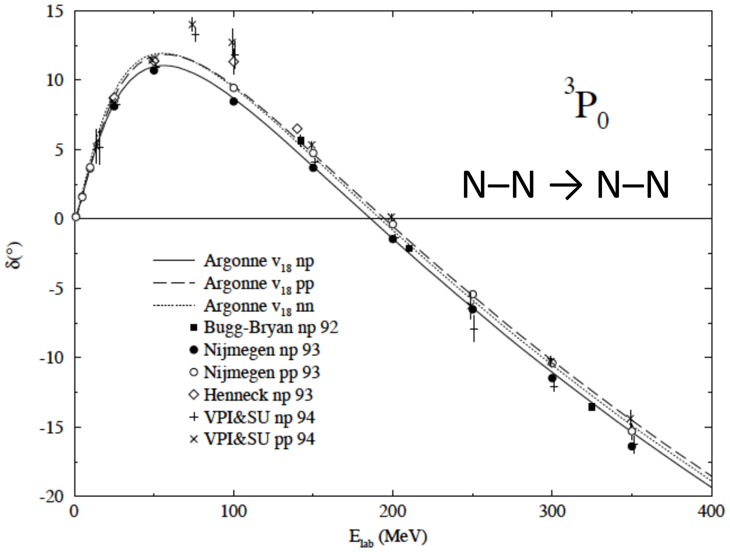
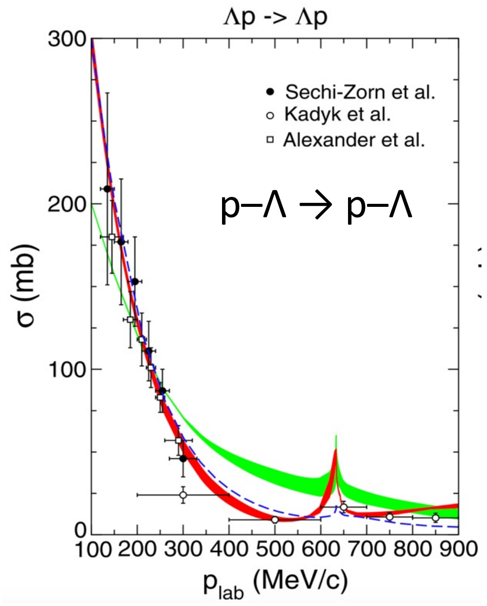
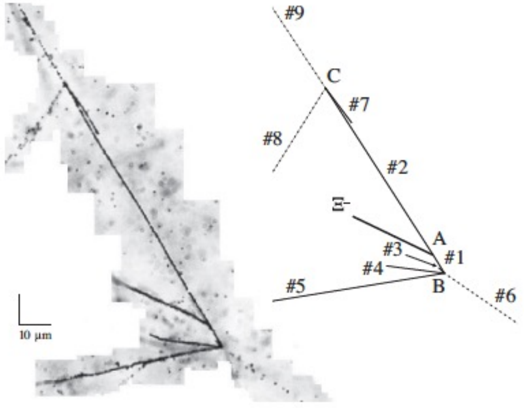




R. B. Wiringa et al. PRC 51 (1995)



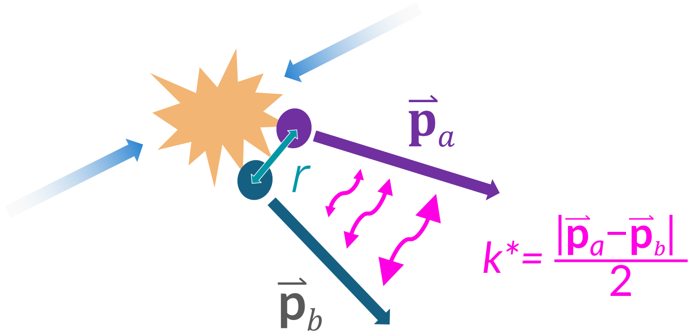
J.Haidenbauer et al. NPA 915 (2013)



Ξ hypernucleus

J-PARC E07 Coll. PRL 126 (2021)

Femtoscopy for interactions

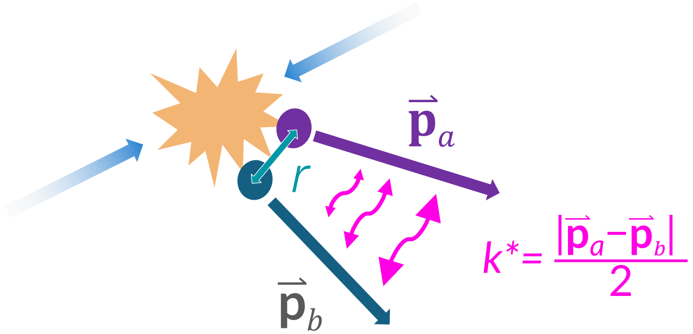


$$C(k^*) = \int S(\vec{r}\,)\left|\psi(\vec{k}^*, \vec{r}\,)\right|^2 d\,\vec{r} \;= \mathcal{N}(k^*)\,\frac{N_{\mathrm{same}}(k^*)}{N_{\mathrm{mixed}}(k^*)}$$

Two-particle wave function

M. Lisa, S. Pratt et al., ARNPS 55 (2005), 357-402
L. Fabbietti et al., ARNPS 71 (2021), 377-402
D. Mihaylov et al., EPJC 78 (2018), 5, 394

Femtoscopy for interactions



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Two-particle wave function

M. Lisa, S. Pratt et al., ARNPS 55 (2005), 357-402
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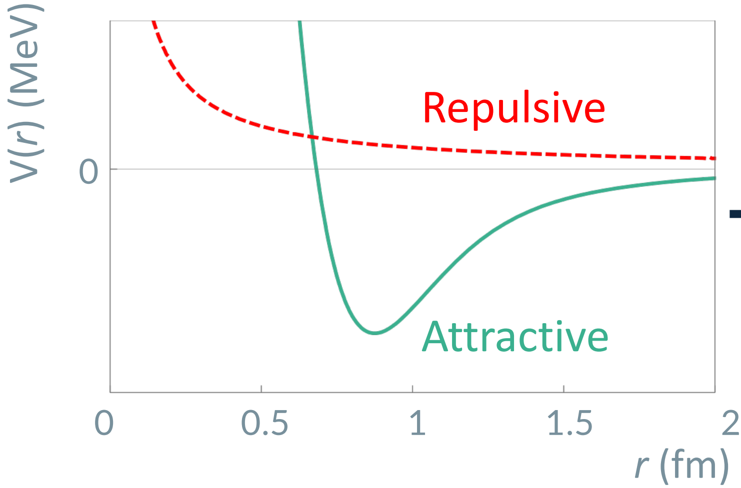
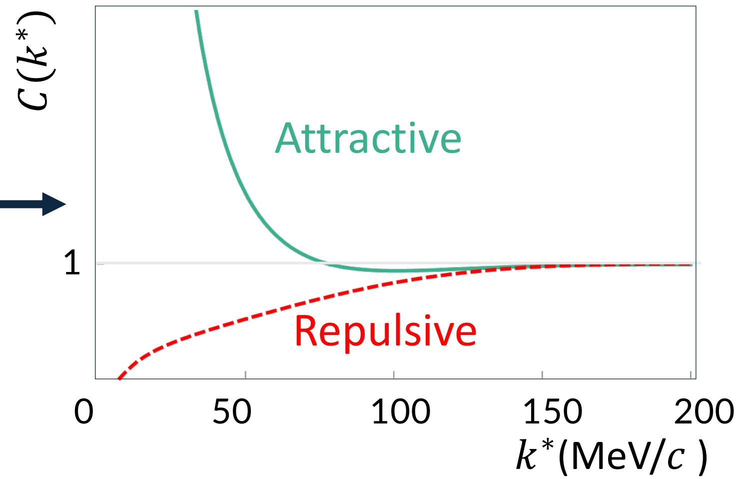
Interacting potential



Correlation function



Measuring $C(k^*)$ → fixing the source $S(\vec{r}\,)$ → study the interaction

Source function in pp collisions at the LHC

- Emitting source function anchored to p-p correlation function

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

measured known interaction

- Gaussian parametrization

$$S(r) = \frac{1}{(4\pi r_{core}^2)^{3/2}} \exp\left(-\frac{r^2}{4 r_{core}^2}\right) \times$$

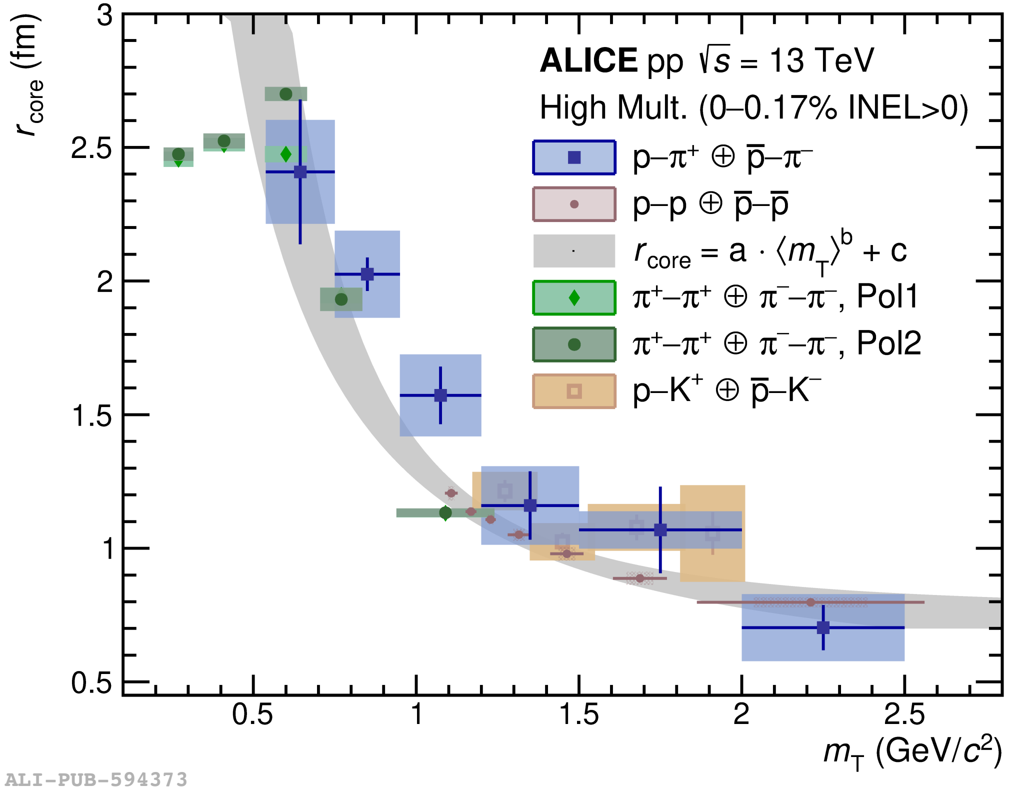
Effect of short lived resonances (cτ ~ 1 fm)

ALICE Coll., PLB, 811 (2020), 135849

- One universal source for all hadrons (cross-check with K⁺-p, π-π, p-Λ, p-π)

- **Small particle-emitting source created in pp collisions at the LHC**

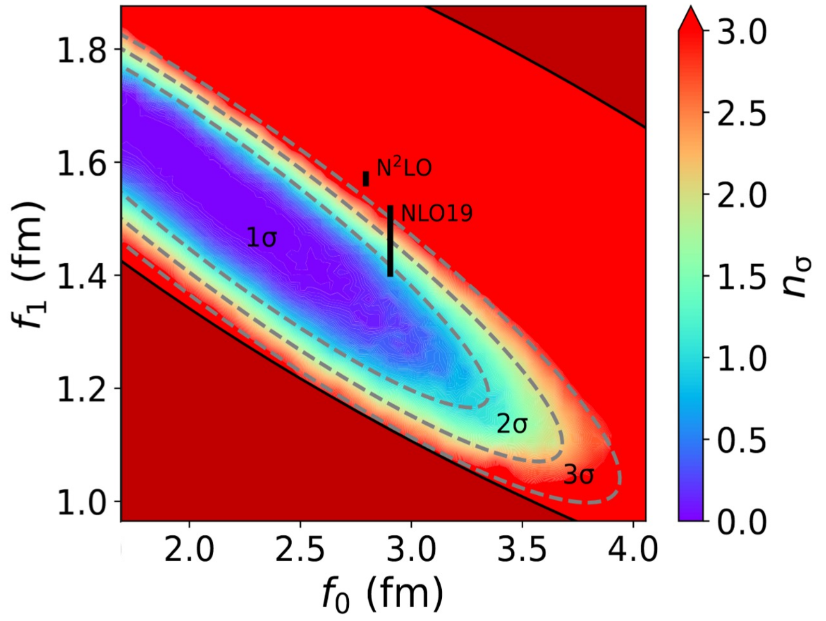
ALICE Coll., PLB, 811 (2020), 135849; ALICE Coll., EPJ C 85 (2025) 2, 198; ALICE Coll., EPJ A 61 (2025 8, 194



ALICE Coll., PLB, 811 (2020), 135849; ALICE Coll., EPJ C 85 (2025) 2, 198; ALICE Coll., EPJ A 61 (2025 8, 194

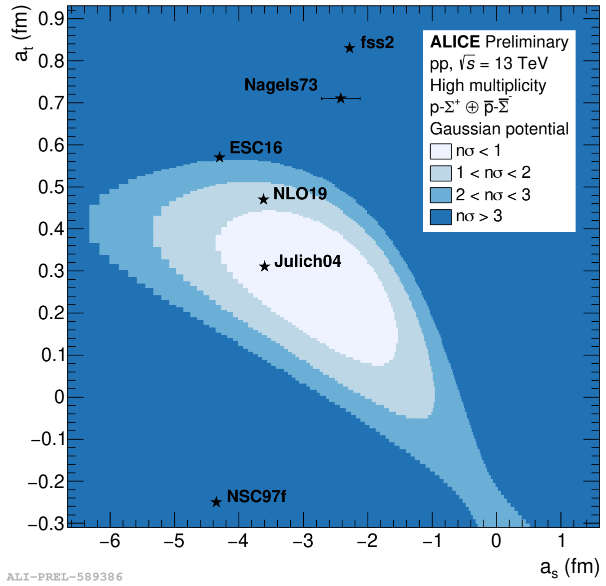
Selected results from ALICE Run 2 data

- Most precise measurement of the p-Λ scattering parameters

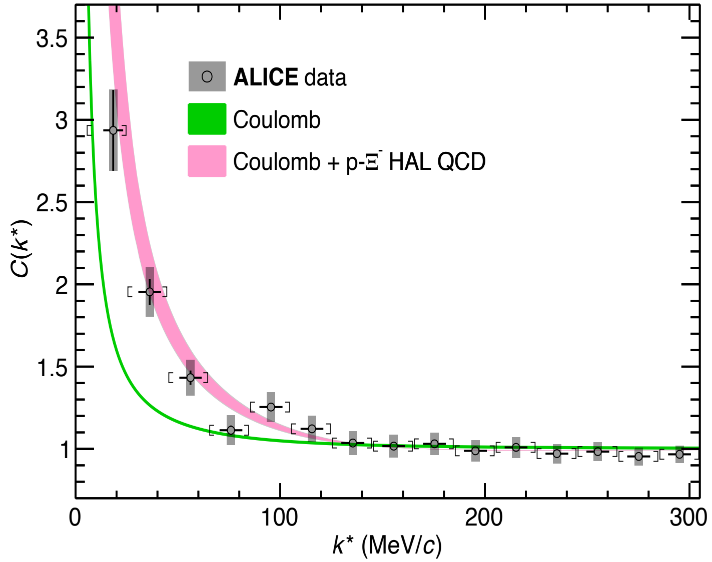


D. Mihaylov, J. Haidenbauer and V. Mantovani Sarti, PLB 850 (2024) 138550

- First measurement of the p-Σ^+ scattering parameters



- Evidence of an attractive p-Ξ^- interaction



ALICE Coll., Nature 588 (2020) 232

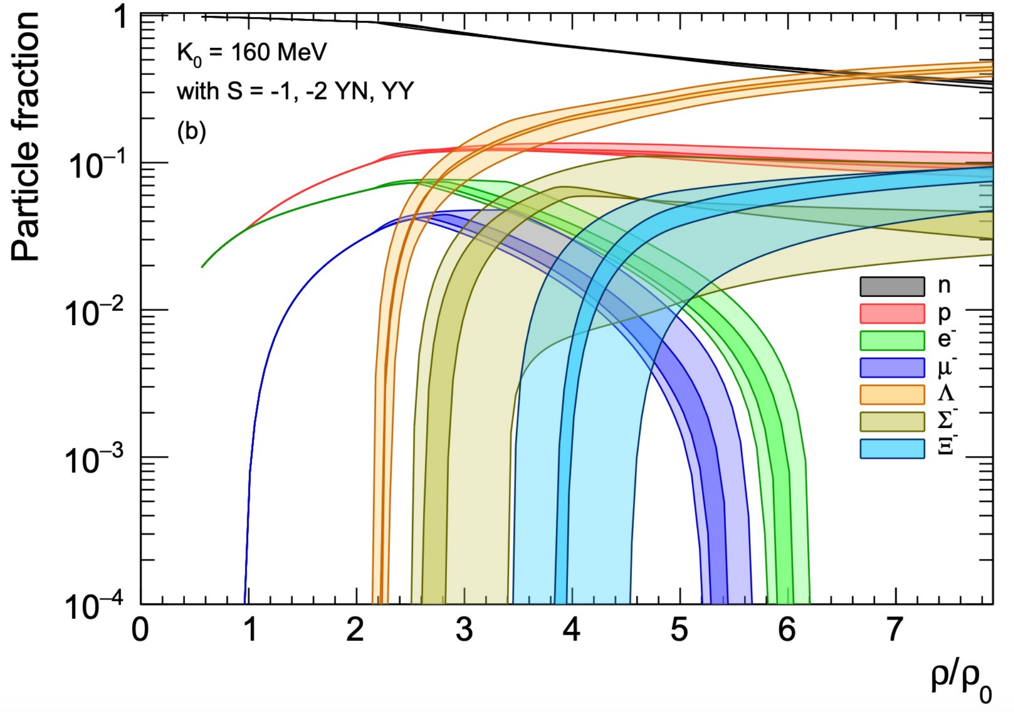
New precise experimental inputs for EFTs

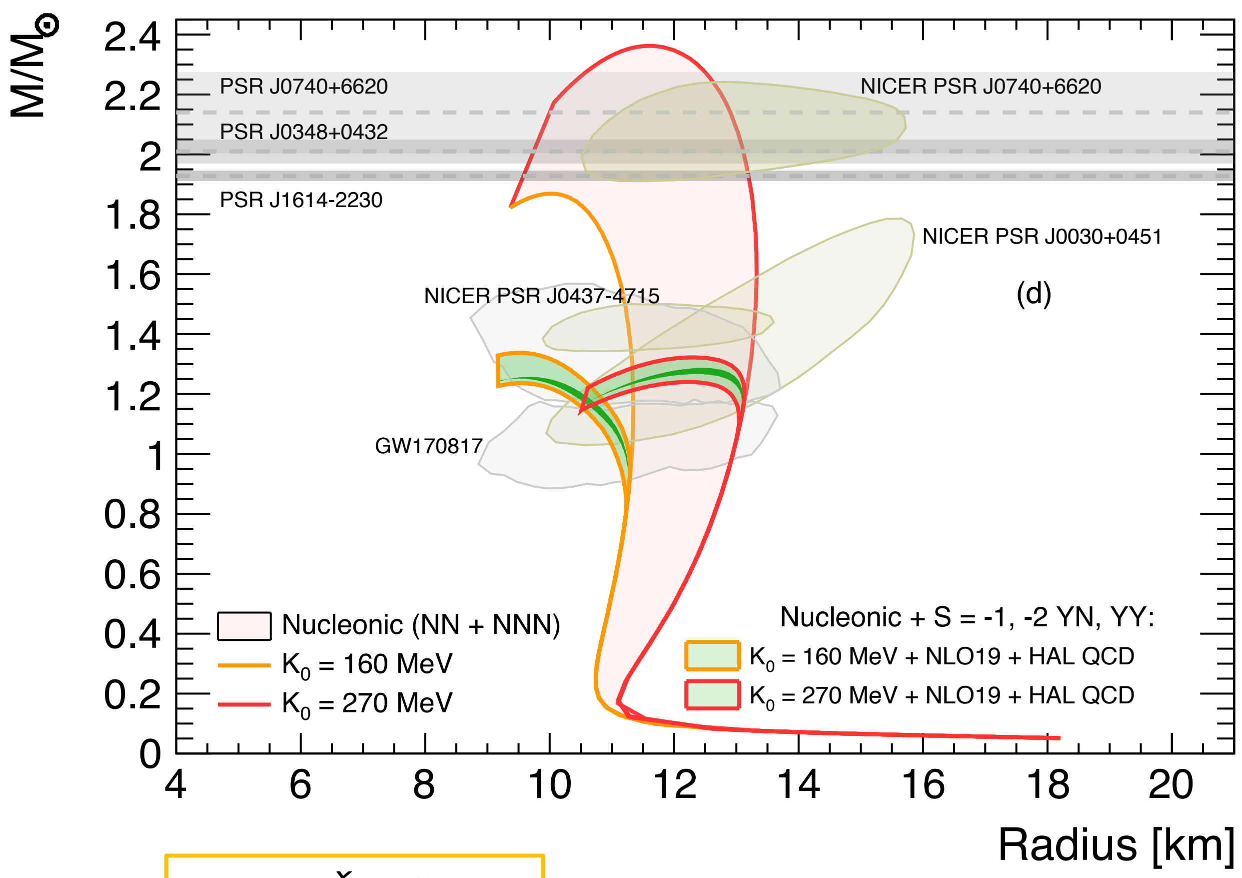
First tests of Lattice QCD

Strangeness in neutron stars

- Equation of state with *state-of-the-art interactions* for NN, NNN, YN (S=-1 and S=-2) and YY fail to reproduce observed heavy neutron stars

I. Vidaña, V. Mantovani Sarti, J. Haidenbauer, D. Mihaylov, L. Fabbietti, EPJ.A 61 (2025) 3, 59





Talk L. Šerkšnytė

Strangeness in neutron stars

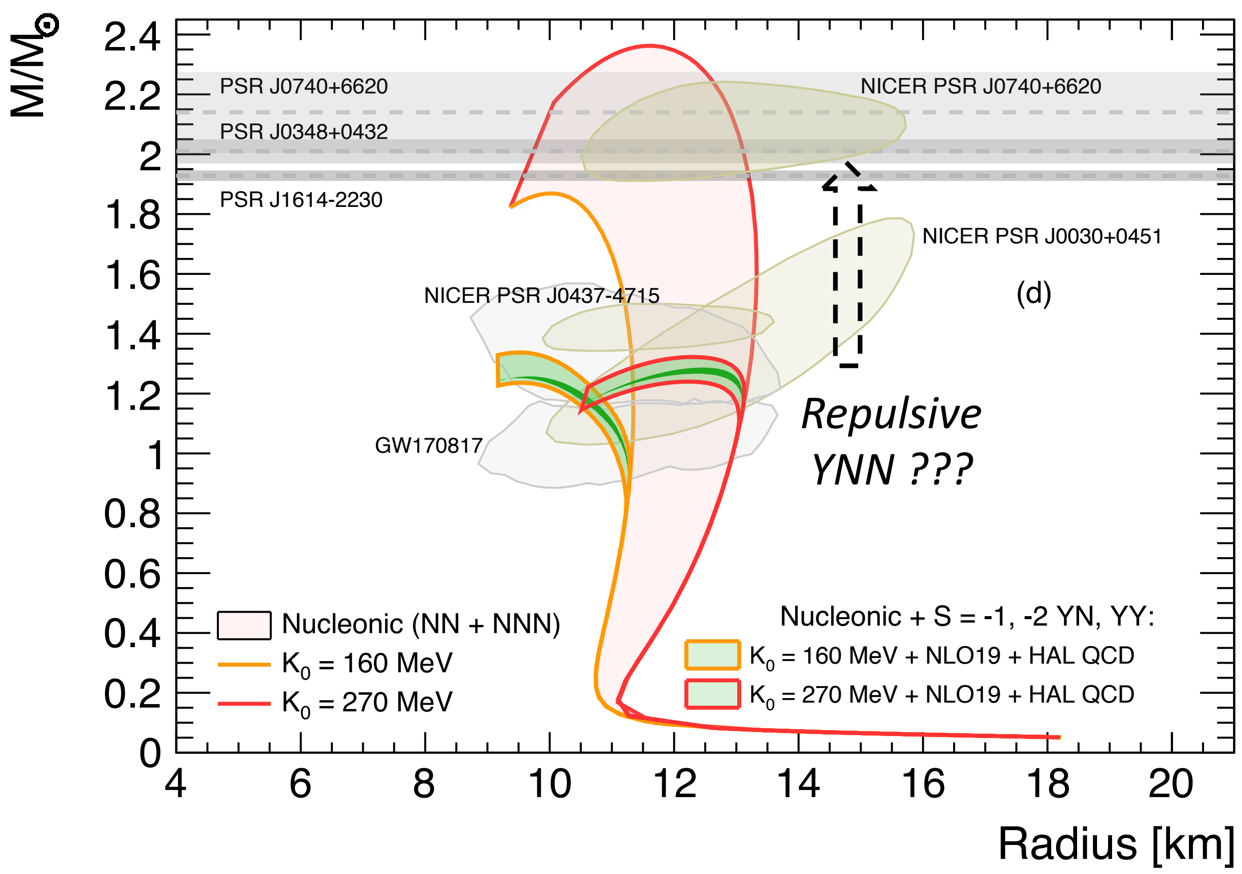
ALICE

- Equation of state with *state-of-the-art interactions* for NN, NNN, YN (S=-1 and S=-2) and YY fail to reproduce observed heavy neutron stars

  I. Vidaña, V. Mantovani Sarti, J. Haidenbauer, D. Mihaylov, L. Fabbietti, EPJ.A 61 (2025) 3, 59

- Next step: inclusion of three body interaction involving hyperons
  - *ΛNN interaction:* p-p-Λ and Λ-d correlations analyses ongoing in ALICE

Talk L. Šerkšnytė



Strangeness in neutron stars

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- Next step: inclusion of three body interaction involving hyperons
  - *ΛNN interaction:* p-p-Λ and Λ-d correlations analyses ongoing in ALICE

    Talk L. Šerkšnytė

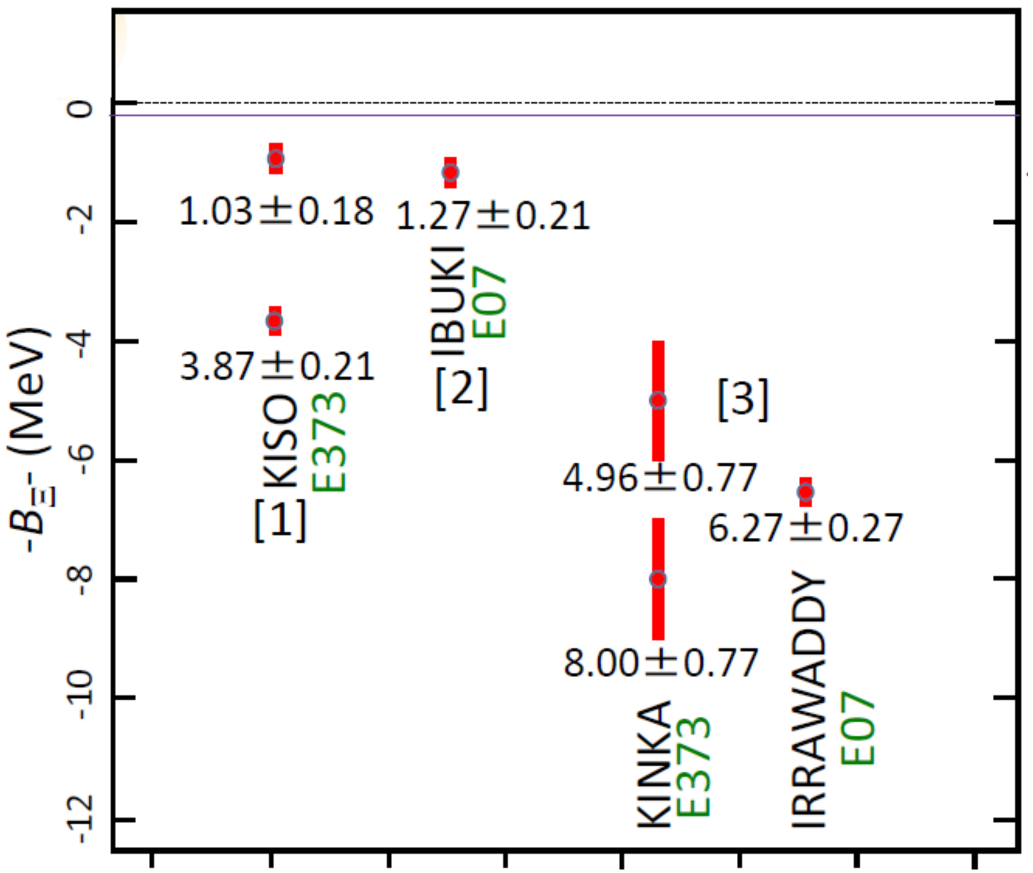
  - *ΞNN interaction:* scarce knowledge from hypernuclei

  Only a few measurements of Ξ-hypernucleai are available

  K. Nakazawa, PTEP 2015, 033D02 (2015)
  M. Yoshimoto, PTEP 2021, 073D02 (2021)
  S. H. Hayakawa (J-PARC E07), PRL 126, 062501 (2021).

- Goal: more precise information from p-Ξ^- and p-p-Ξ^- correlation measurements from ALICE

Plot credits: K. Nakazawa



[1] K. Nakazawa, PTEP 2015, 033D02 (2015)
[2] S. H. Hayakawa (J-PARC E07), PRL 126, 062501 (2021)
[3] M. Yoshimoto, PTEP 2021, 073D02 (2021)

ALICE detector in Run 3

- Run 3 data: 2022 – present
- Detector upgrades: ITS (vertex detector), TPC (main tracker)
  New detectors: FIT (multiplicity), MFT (muons)

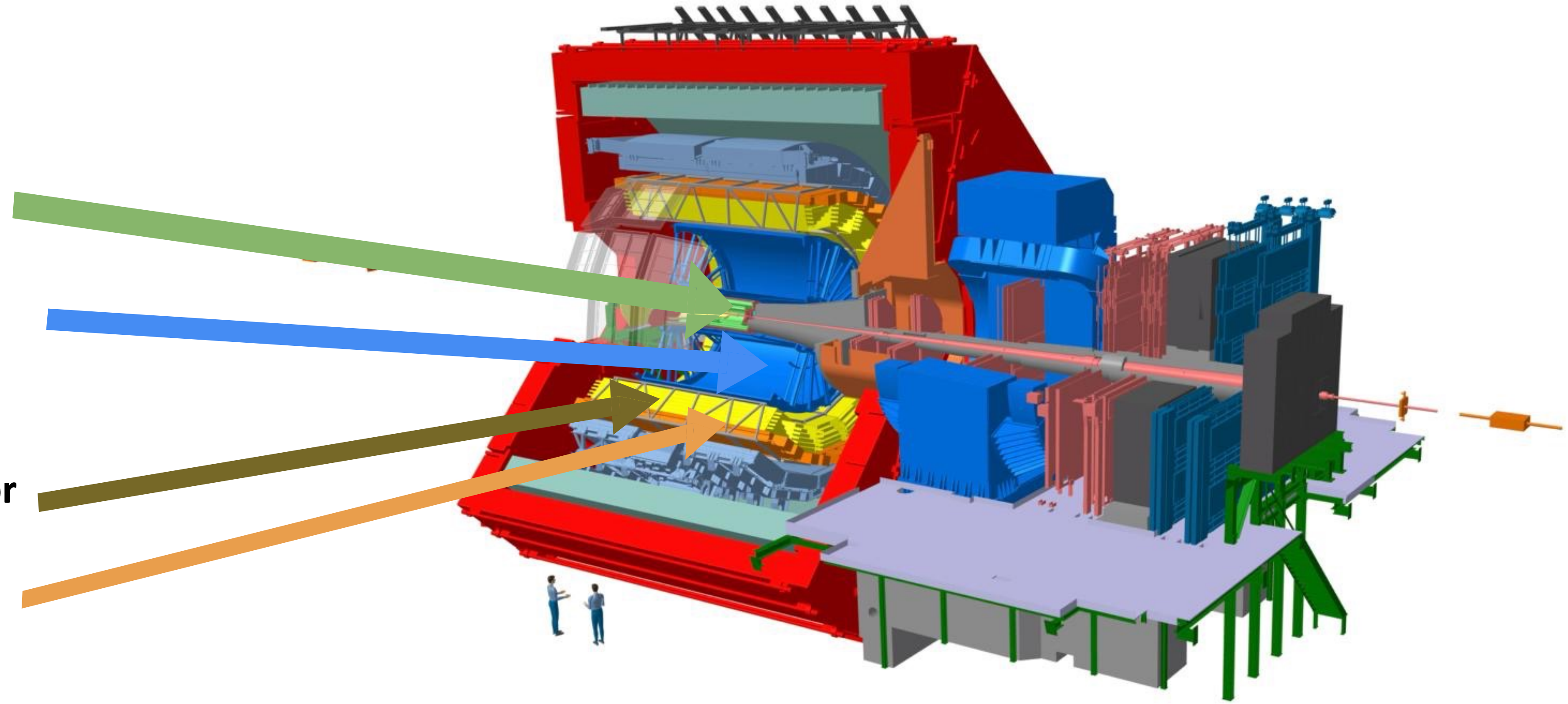
Plenary talk
O. Vazquez Doce

Inner Tracking System
Tracking, vertex, PID (dE/dx)

Time Projector Chamber
Tracking, PID (dE/dx)

Transition Radiation Detector

Time Of Flight detector
PID (TOF measurement)



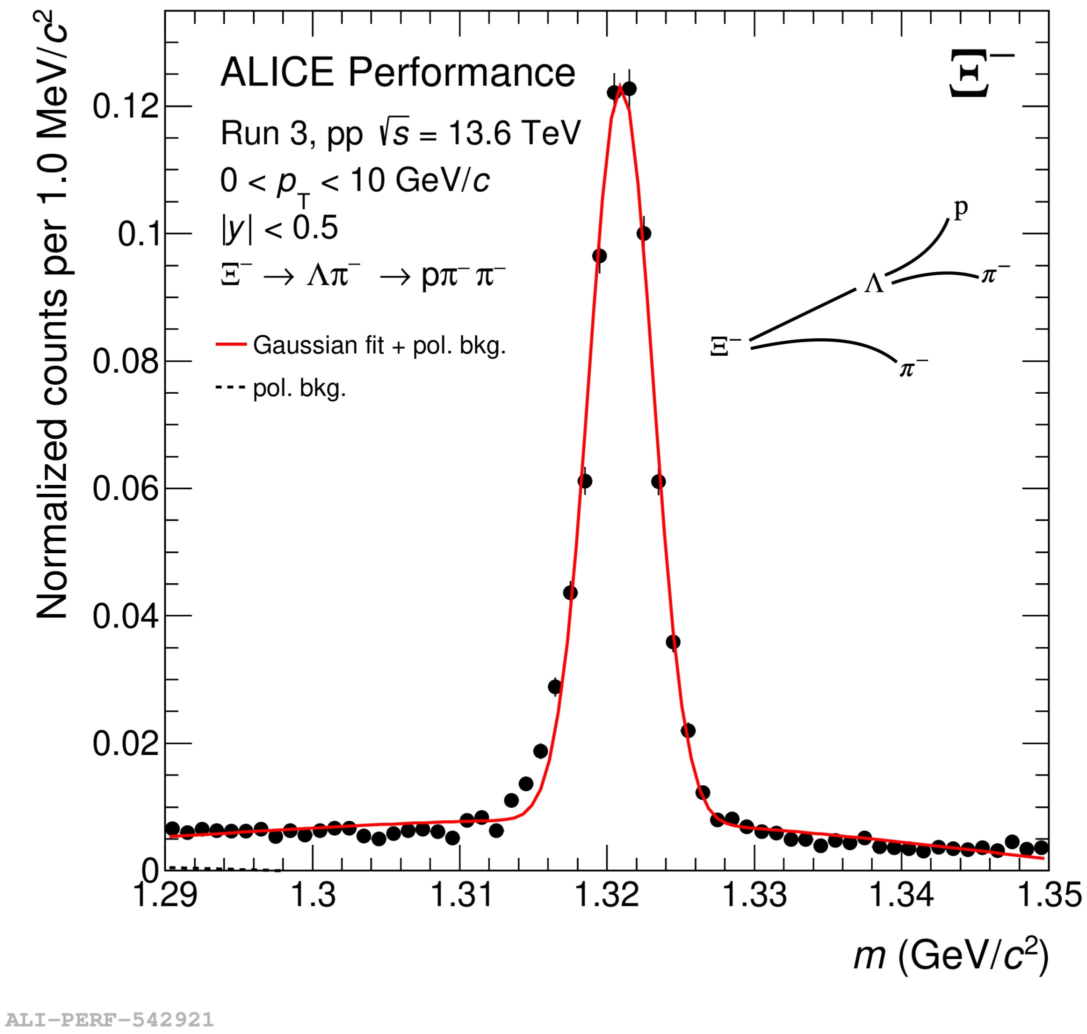
Data set and particle purities

Analyzed dataset

- Minimum Bias pp collisions at $\sqrt{s} = 13.6$ TeV collected by the ALICE detector during LHC Run 3 in 2022-2024
- Integrated luminosity: 10.95 pb^{-1}

High purity particle selection

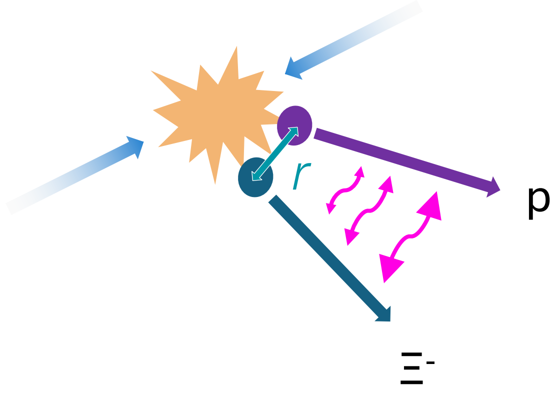
- Ξ purity: ~ 93 % for k* < 200 MeV/*c*
- Proton purity: > 95 % for k* < 200 MeV/*c*



Modelling of the correlation function

$$C_{p-\Xi^-,model}(k^*) = \boxed{\lambda_{gen} C_{p-\Xi^-}(k^*)} + \lambda_{p-\Xi^-_{\Xi^-(1530)}} C_{p-\Xi^-_{\Xi^-(1530)}}(k^*) + \lambda_{p-\tilde{\Xi}^-} C_{p-\tilde{\Xi}^-}(k^*) + \lambda_{flat}$$

Genuine p-Ξ correlations



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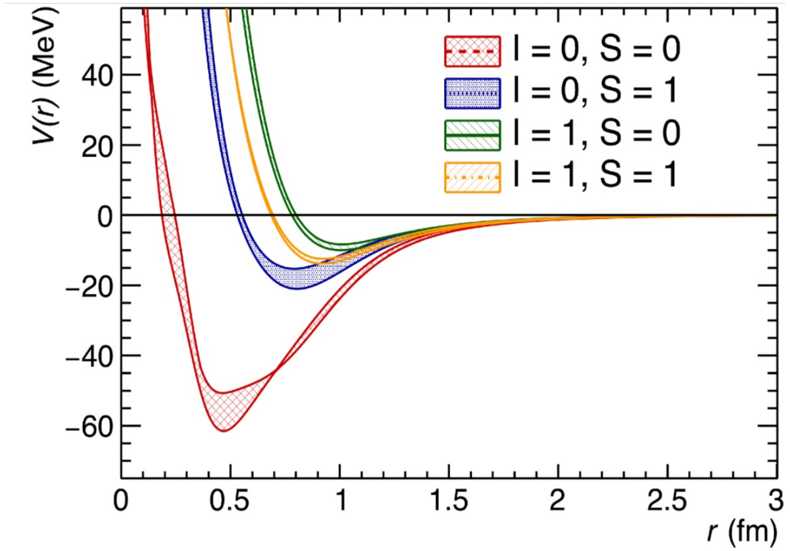
Genuine p-Ξ correlations

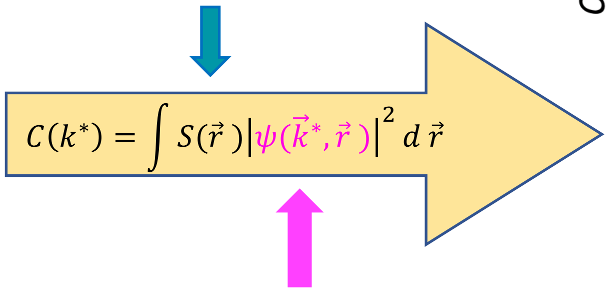
Local potentials for the NΞ interactions



HAL QCD Coll. NPA 998 (2020)

r_{core} = 0.8 fm

ALICE Coll., PLB, 811 (2020), 135849;
ALICE Coll., EPJ C 85 (2025) 2, 198;
ALICE Coll., EPJ A 61 (2025 8, 194



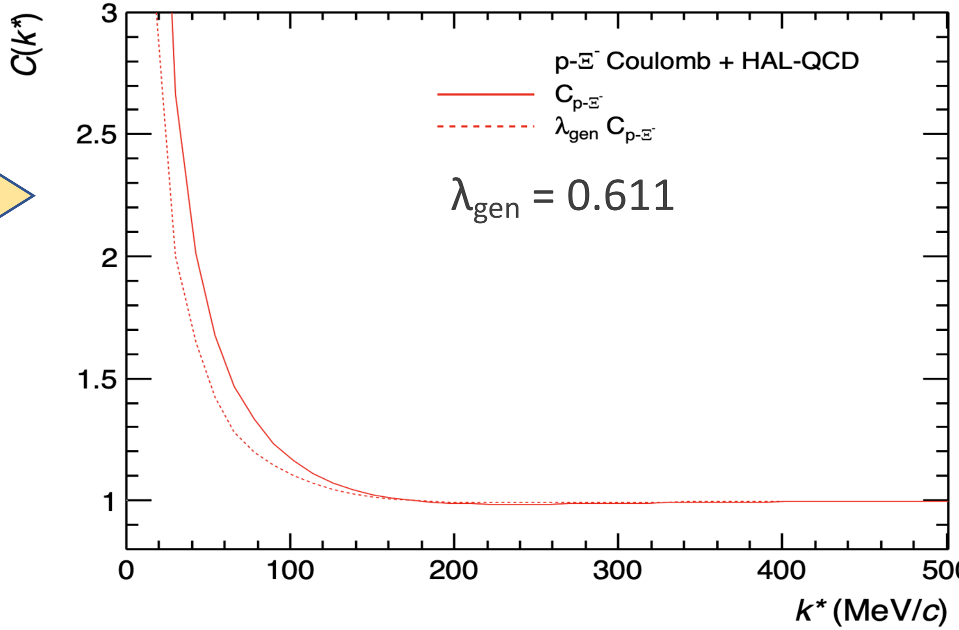
$$C(k^*) = \int S(\vec{r}\,)\left|\psi(\vec{k}^*,\vec{r}\,)\right|^2 d\vec{r}$$

Schrödinger equation

D. Mihaylov et al., EPJC 78 (2018), 5, 394

Correlation function

$$C(k^*) = \frac{1}{8}C_{I=0,S=0}(k^*) + \frac{3}{8}C_{I=0,S=1}(k^*) + \frac{1}{8}C_{I=1,S=0}(k^*) + \frac{3}{8}C_{I=1,S=1}(k^*)$$



Modelling of the correlation function

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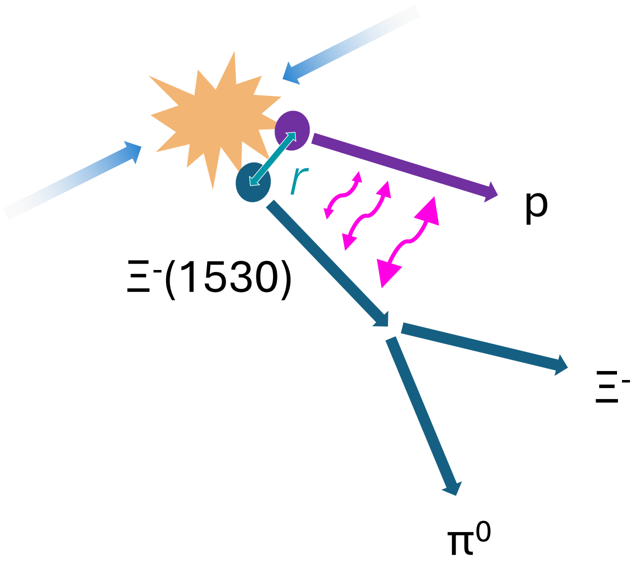
p-Ξ(1530) feed-down



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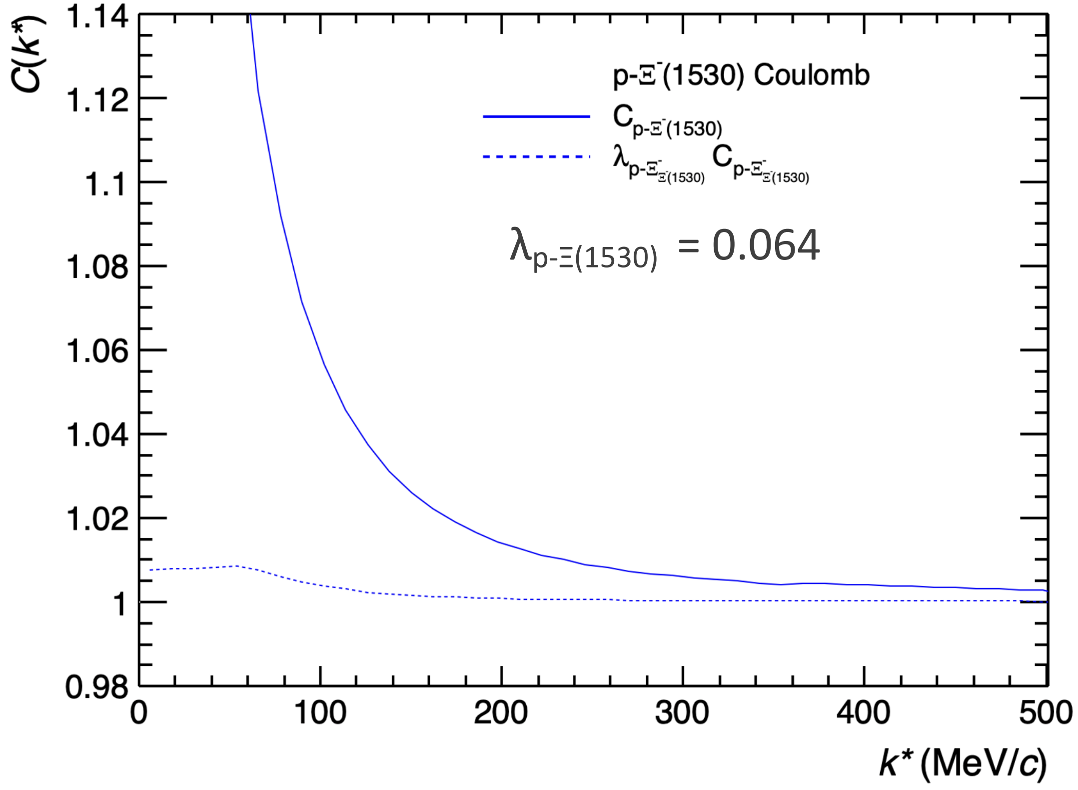
p-Ξ(1530) feed-down

- λ parameters extracted from particle purities and fractions
- Only Coulomb interaction is assumed
- Same source of p-Ξ^-
- Decay matrix $\Xi^-(1530) \rightarrow \Xi^-\pi^0$ applied



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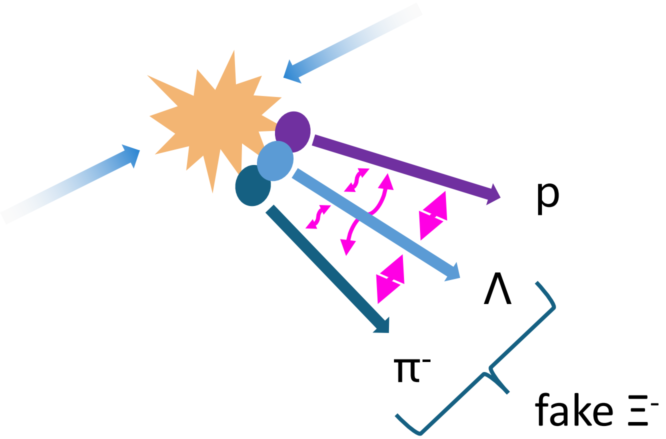
Ξ misidentification



Modelling of the correlation function

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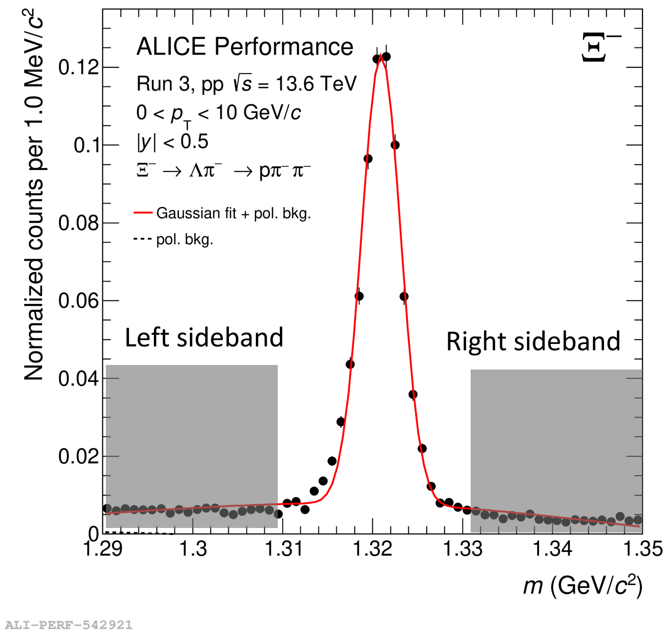
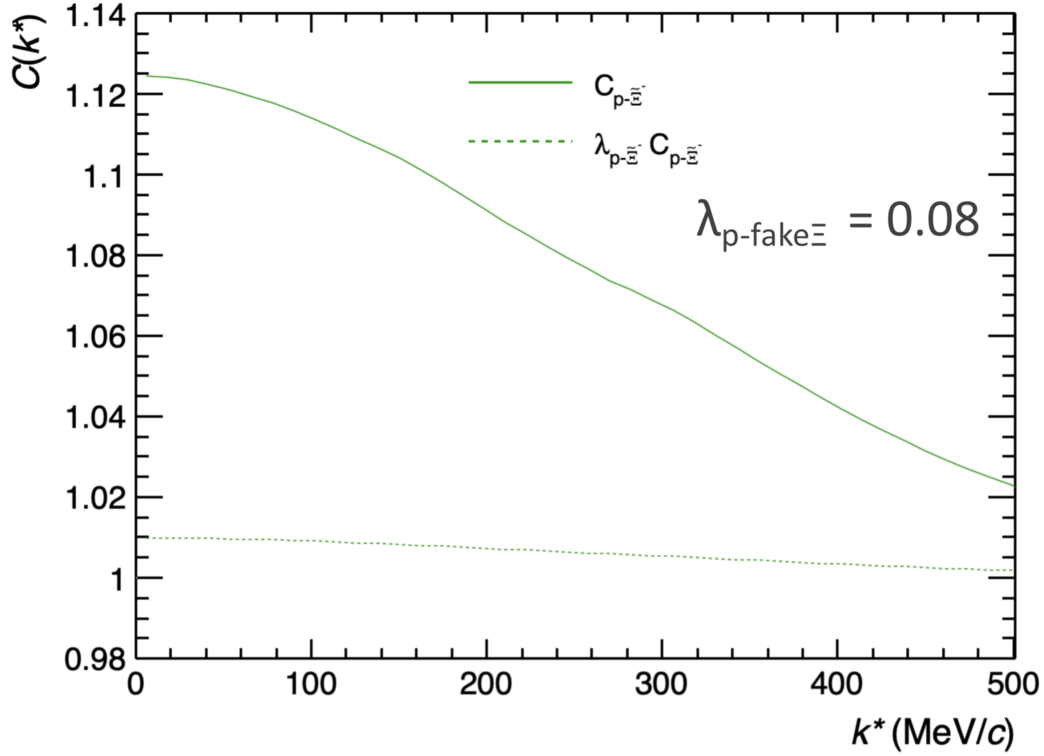
Ξ misidentification

Computed as p-($\Lambda\pi^-$) correlation function:

- Data driven approach using sidebands
- Projector method

RDG, L. Šerkšnytė, L. Fabbietti, V. Mantovani Sarti, D. Mihaylov EPJC 82, 244 (2022)

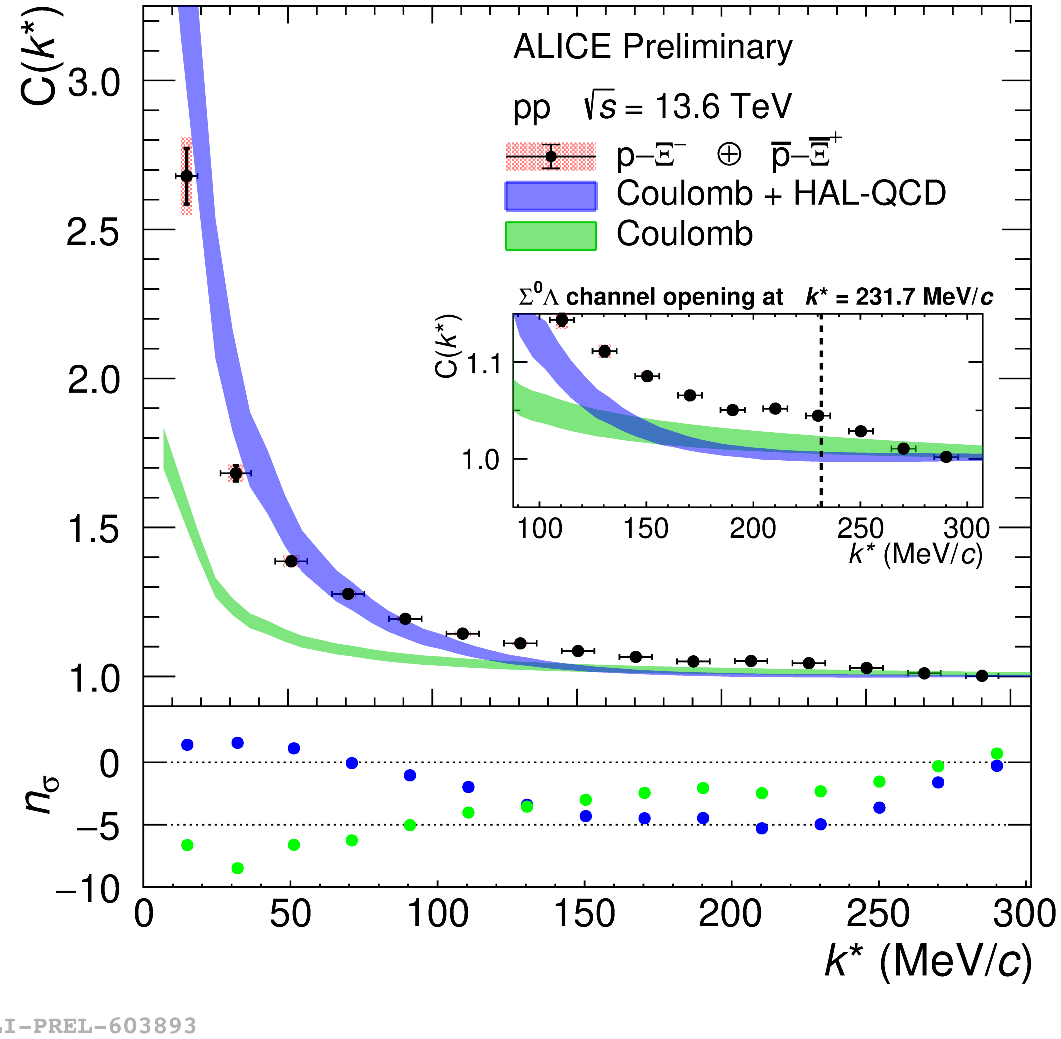




p-Ξ^- correlation function from Run 3

- Increased number of p-Ξ pairs by a factor 2 w.r.t. Run 2 data at k* < 200 MeV/c
- Coulomb attraction cannot describe the experimental data
- Evidence of an attractive strong interaction
- **Clear signal of the Λ-Σ^0 channel coupling visible in the data, not included in the lattice potential**

HAL QCD Coll. NPA 998 (2020)



Conclusions and Outlook

Conclusions

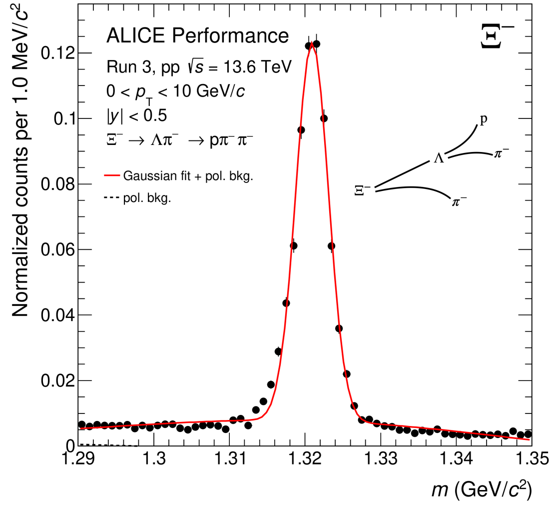
- Clean Ξ^- signal can be reconstructed with preliminary Run 3 data
- Evidence of an attractive p-Ξ^- strong interaction
- Preliminary Run 3 result challenges Lattice calculations
- Clear signal of the Λ-Σ^0 channel coupling visible

Outlook

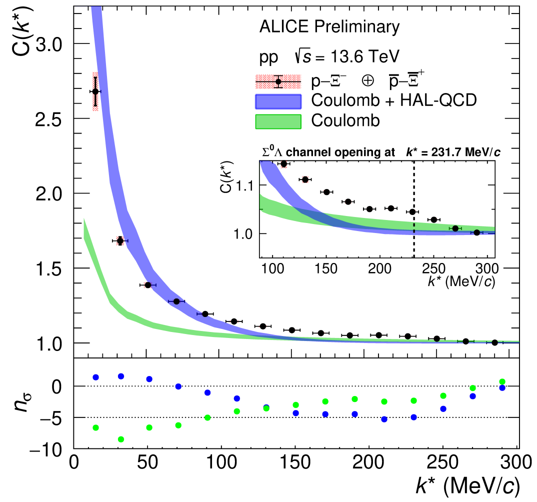
- More p-Ξ pairs expected at the end of Run 3
- Inclusion of the p-Ξ^- $\rightarrow$ Λ-Σ^0 coupling in the modelling of the genuine correlation function
- Extend the measurement to three-body p-p-Ξ and Ξ-d correlation function

More about femtoscopy measurements in ALICE:

Plenary talk
O. Vazquez Doce



ALI-PERF-542921



ALI-PREL-603893

Thank you for your attention

Non-femto correlations and Systematics

Non-femtoscopic correlations included:

$$C_{\text{tot,p–}\Xi^-}(k^*) = C_{\text{non-femto}}(k^*) \cdot C_{\text{model,p–}\Xi^-}(k^*).$$

Flat polynomial fitted in the region [300,500] MeV/c.

Parameter	Default	Variation Low	Variation up
r_{Core}	0.80 fm	0.72 fm	0.88 fm
λ_i	see Tab. $\boxed{5}$	-10%	+10%
Fit Range p–Ξ^-	500 MeV/c	400 MeV/c	600 MeV/c
Baseline	Normalization a	Normalization a + Slope b·x	
HAL-QCD: stat. unc.	$t/a = 12$	23 Jackknife variations	
HAL-QCD: eucledian times	12	11	13

Source function in pp collisions at the LHC

- Emitting source function anchored to p-p correlation function

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

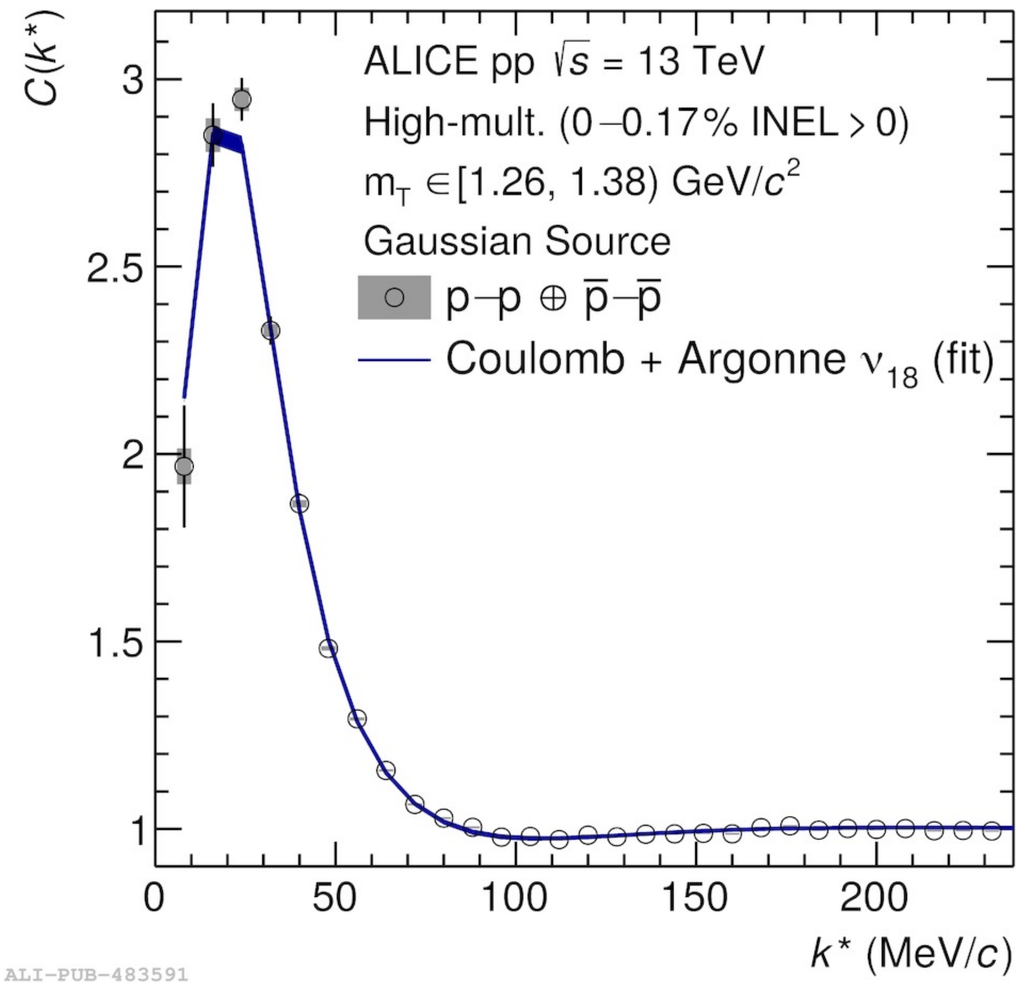
measured — known interaction

- Gaussian parametrization

$$S(r) = \frac{1}{(4\pi r_{core}^2)^{3/2}} \exp\left(-\frac{r^2}{4 r_{core}^2}\right) \times$$

Effect of short lived resonances (cτ ~ 1 fm)

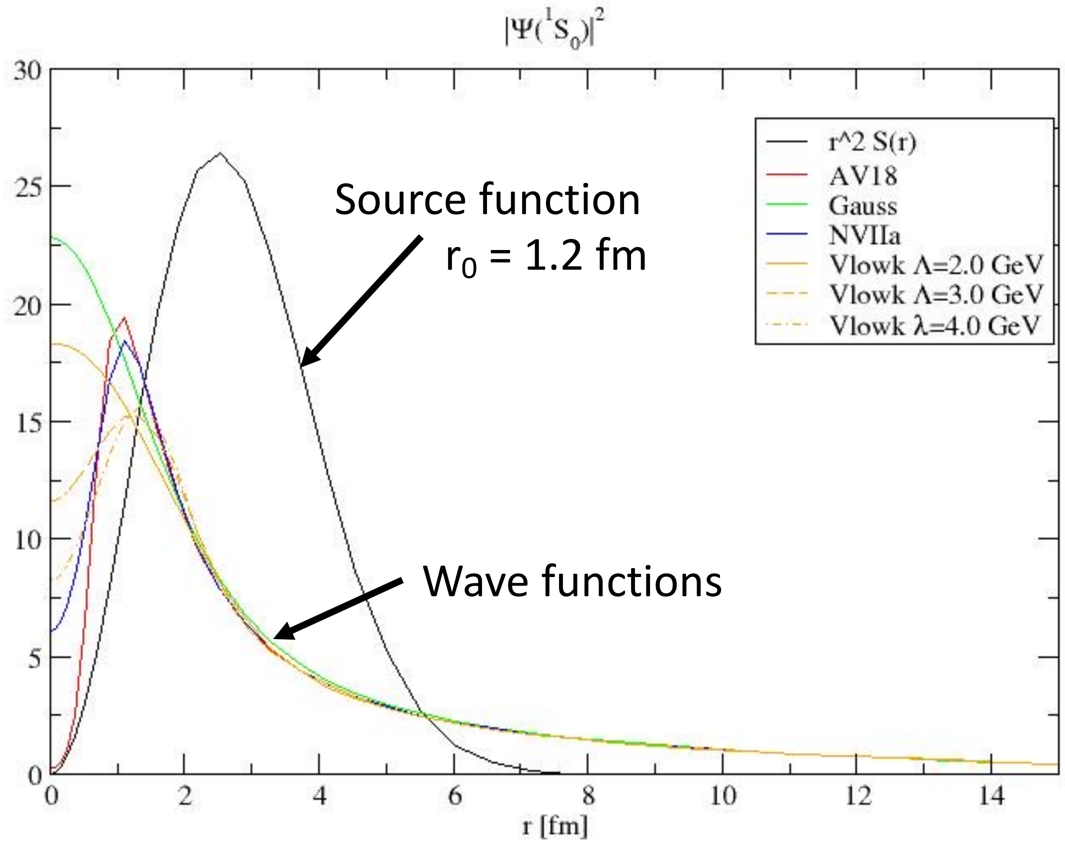
ALICE Coll., PLB, 811 (2020), 135849

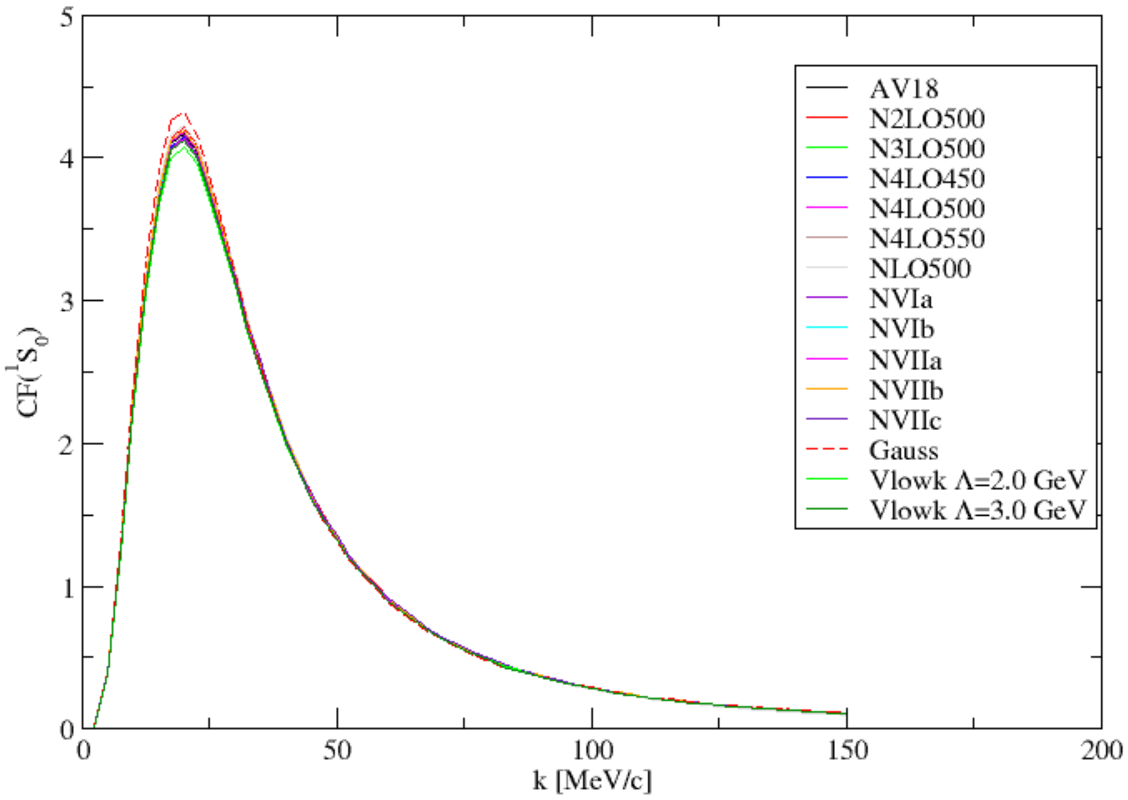


ALICE Coll., PLB, 811 (2020)

Scan of p-p wave functions

Courtesy A. Kievsky and M. Viviani





For a systematic study of the effect of different NN interaction in the correlation function see
M. Göbel, A. Kievsky, arXiv:2505.13433v1