Czech Technical University in Prague

European Research Council

Hyperonic interaction studies at the LHC to understand Neutron Stars

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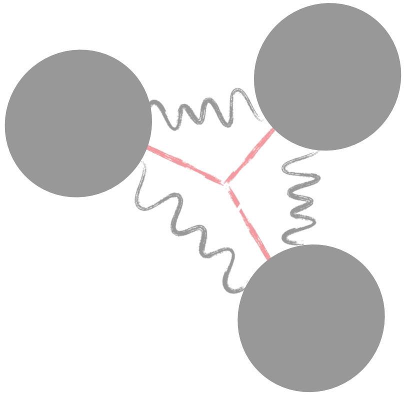


6th Jagiellonian Symposium on Advances in Particle Physics and Medicine
Krakow, Poland
10 July 2026

On behalf of …

L. Fabbietti

V. Mantovani Sarti

L. Šerkšnytė

D. Mihaylov

A. Riedel

M. Korwieser

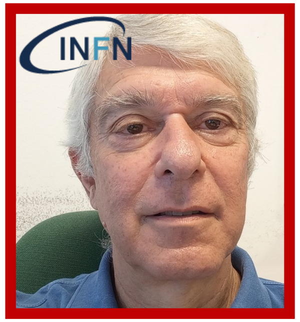
G. Mantzaridis

W. Rzesa

J. Haidenbauer

I. Vidaña

A. Kievsky



E. Garrido

… and many others!

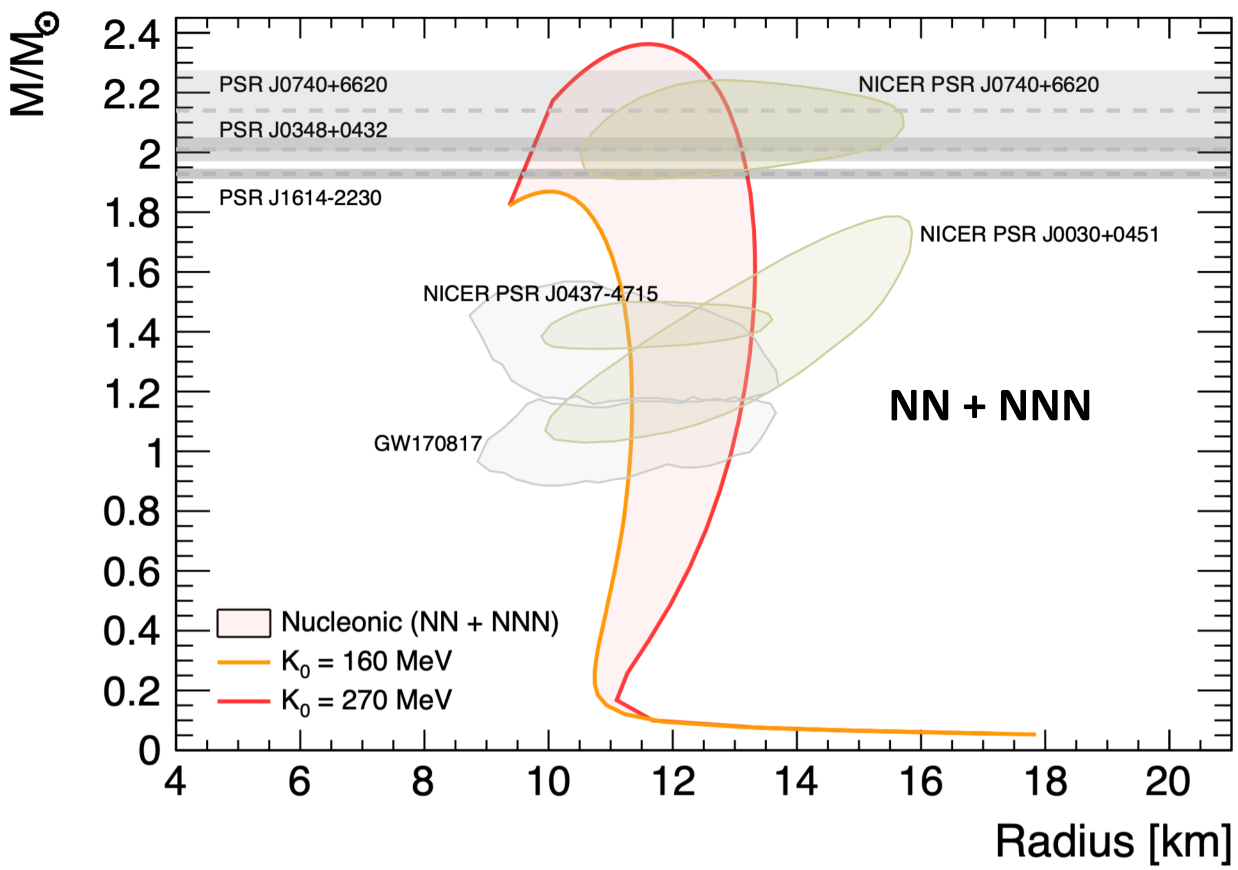
Strangeness in neutron stars

- Nuclear force contribute to guarantee the gravitational stability of the star

$$\rho_{Core} \geq 2 - 3\ \rho_0$$

- Production of hyperons is energetically possible via weak process

$$n\, n \rightarrow n\, \Lambda$$
$$n\, n \rightarrow p\, \Sigma^-$$
$$\ldots$$



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

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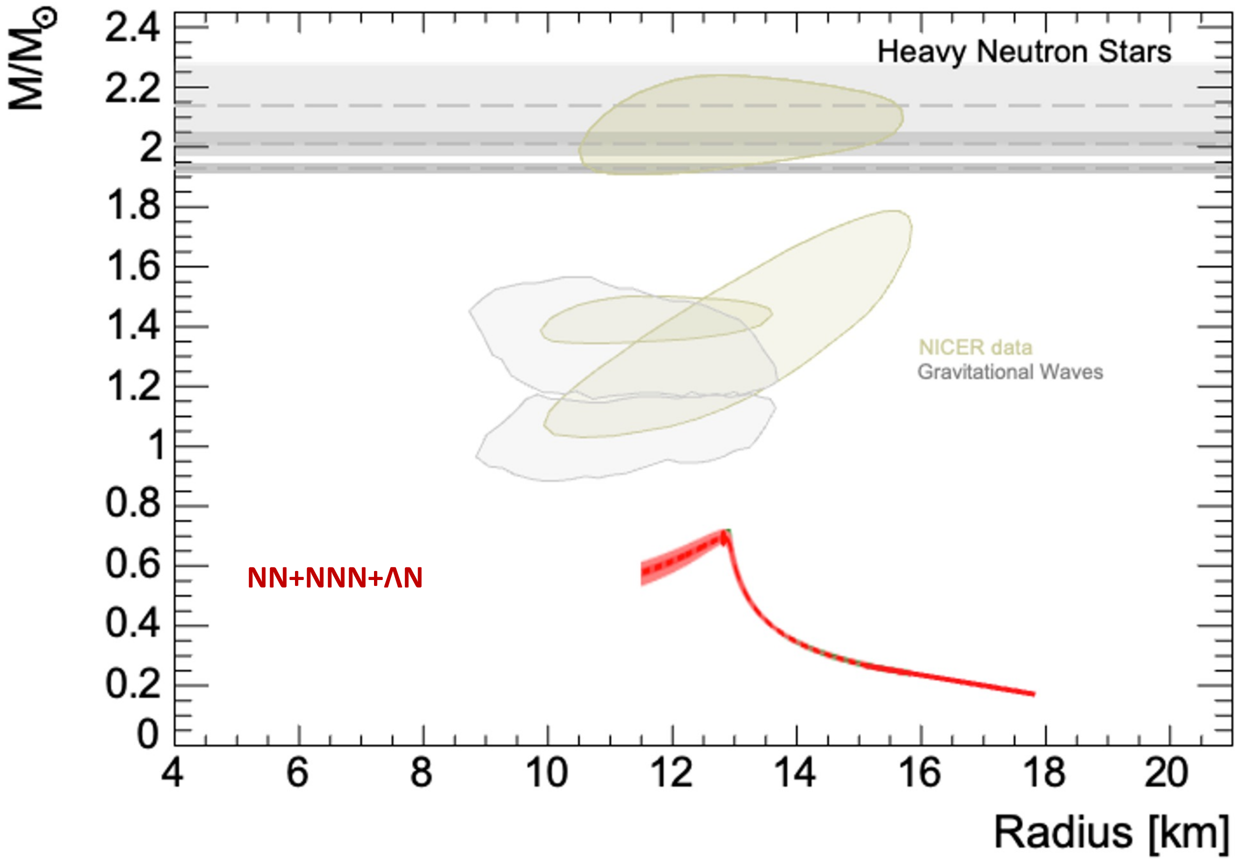
- Inclusion of hyperons results in a softening of the equation of state



Models anchored to scattering data

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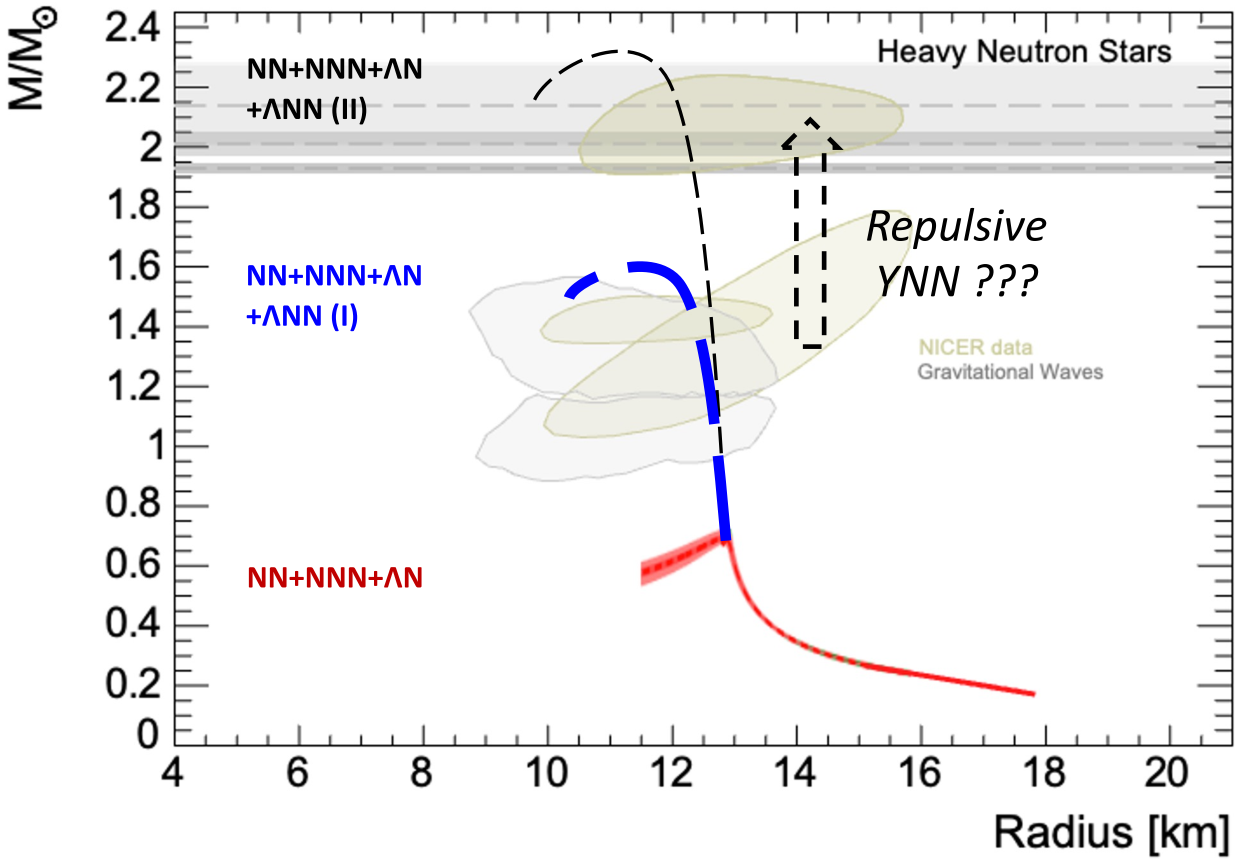
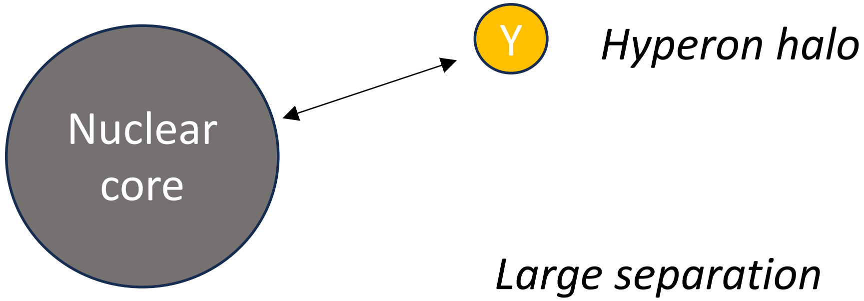
- Inclusion of hyperons results in a softening of the equation of state
- Three-body forces can help but…
  … **YNN interaction are largely unknown!**



Models anchored to scattering data and hypernuclei

Average distances with baryon density

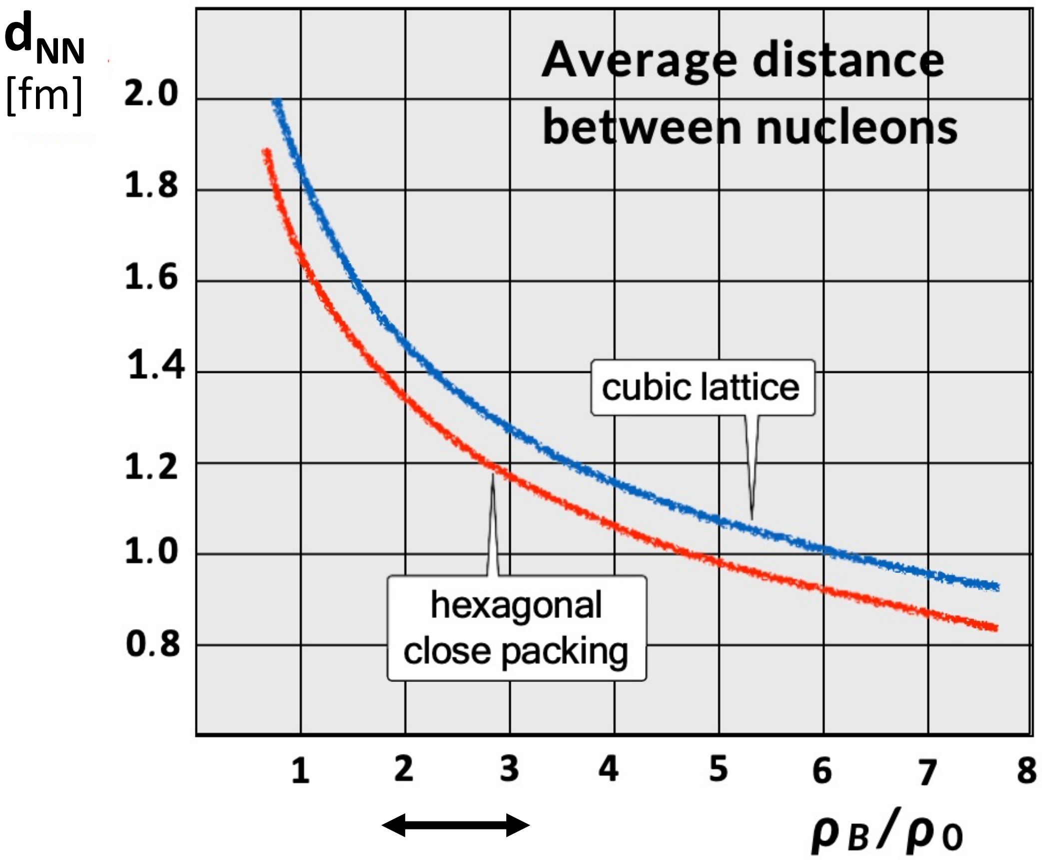
- Naïve representation of a hypernucleus



Large separation
(e.g. 10 fm in hypertriton)

ALICE Coll., Phys. Rev. Lett. 131, 102302

Plot credits: W. Weise

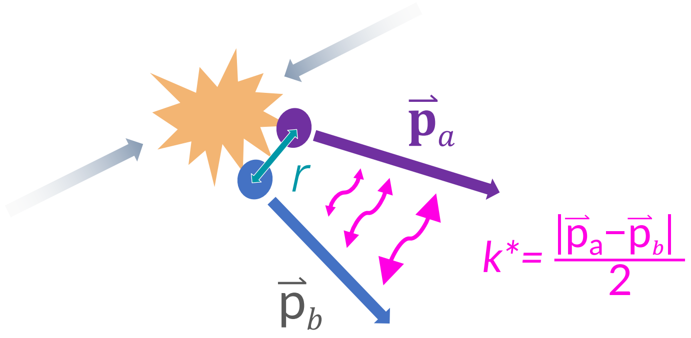


Core of neutron stars

- How the YNN interaction evolves to the smaller scales?

Necessary to control the size of the system

Femtoscopy for interactions

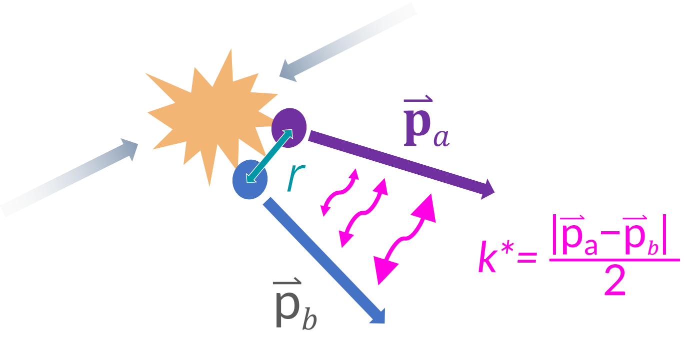


$$C(k^*) = \int S(\vec{r})\left|\psi(\vec{k}^*, \vec{r})\right|^2 d\,\vec{r} = \mathcal{N}(k^*)\,\frac{N_{\mathrm{same}}(k^*)}{N_{\mathrm{mixed}}(k^*)}$$

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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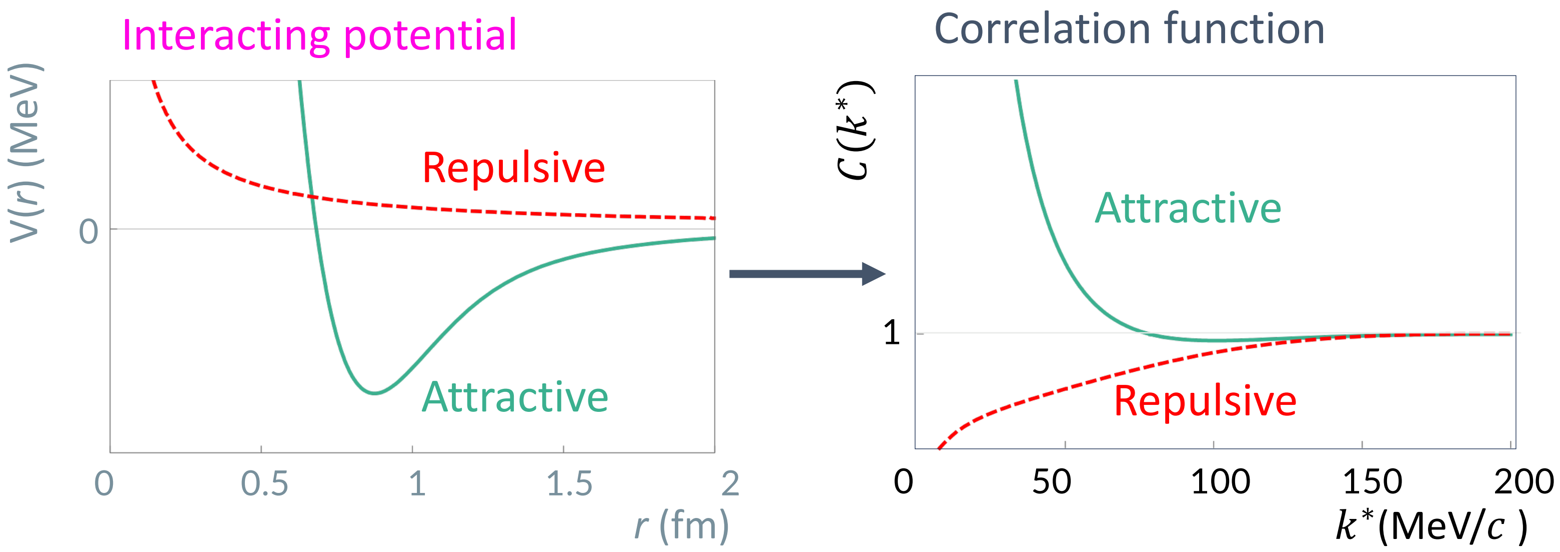
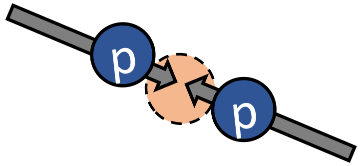
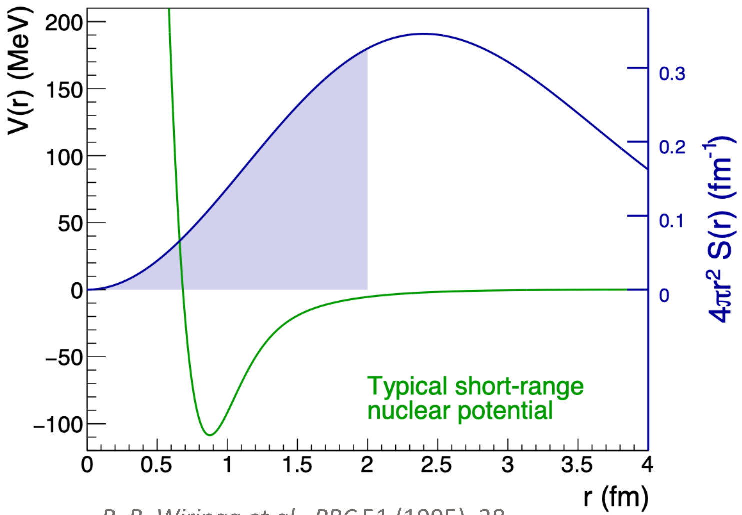


Measuring $C(k^*)$ → **constraining the source $S(\vec{r}\,)$** → study the interaction

Small and large colliding systems at LHC: from pp to Pb-Pb

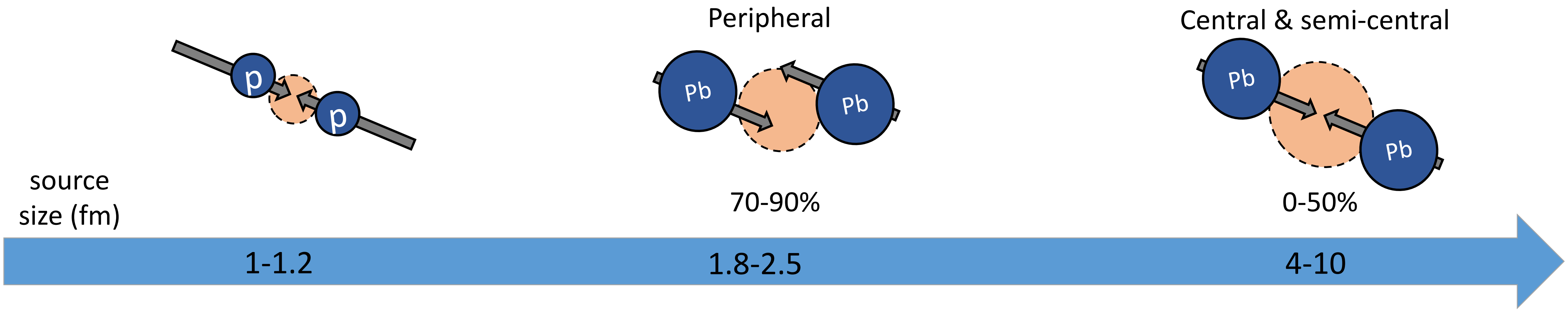


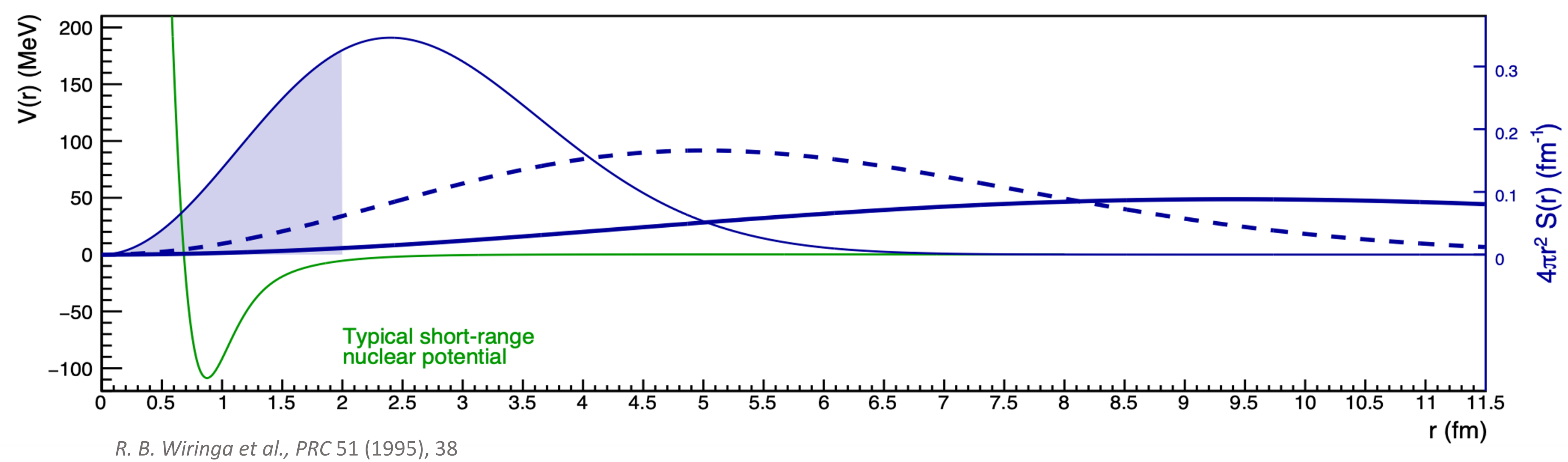
source
size (fm)



R. B. Wiringa et al., PRC 51 (1995), 38

Small and large colliding systems at LHC: from pp to Pb-Pb





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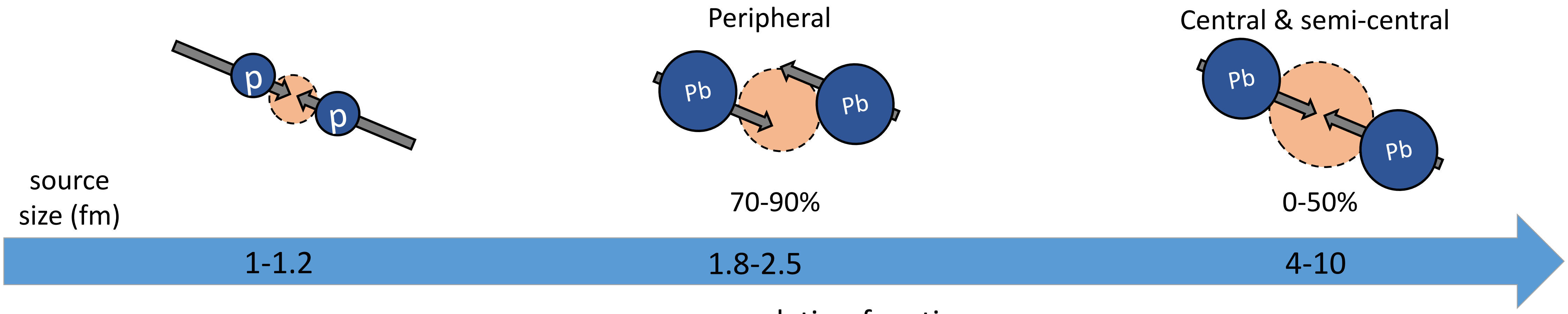
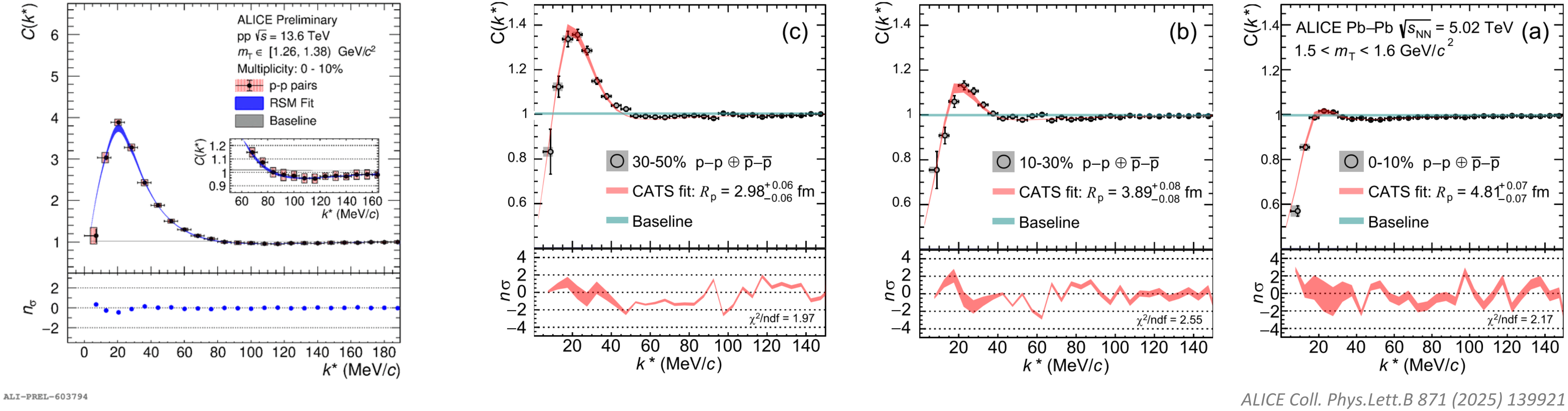


p-p correlation function

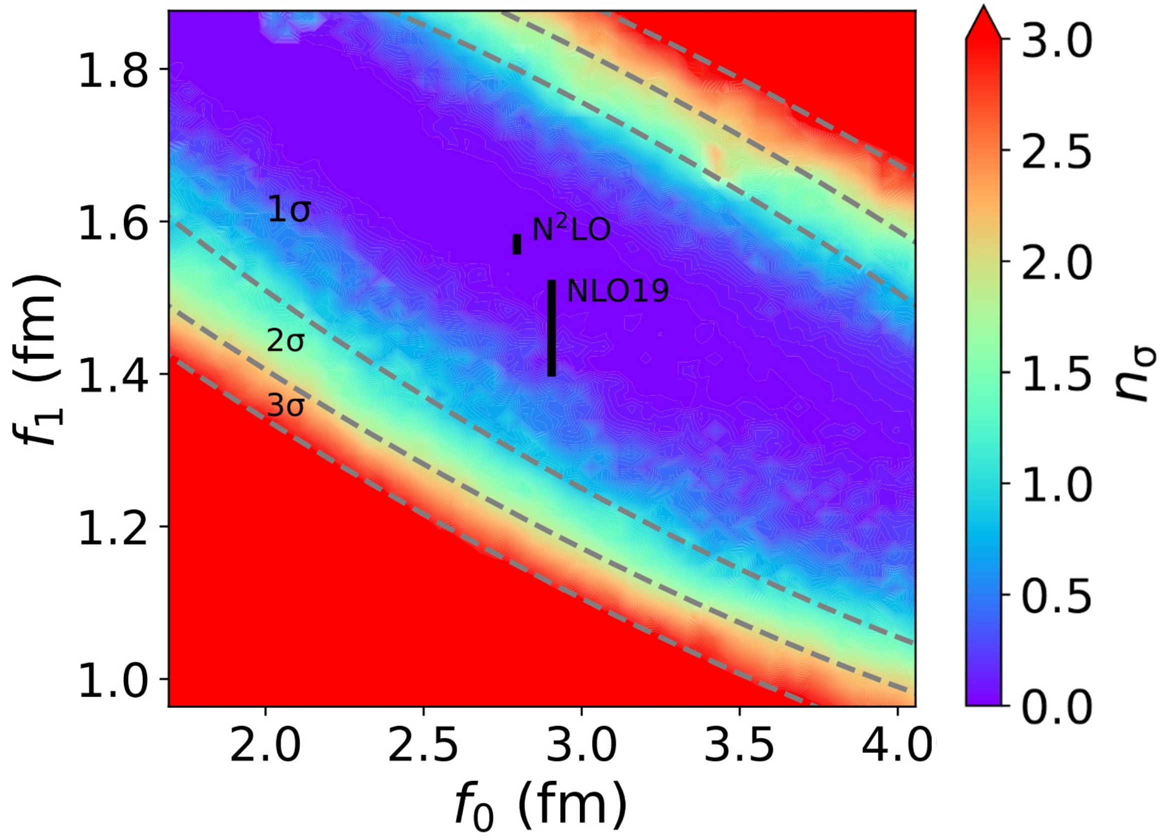


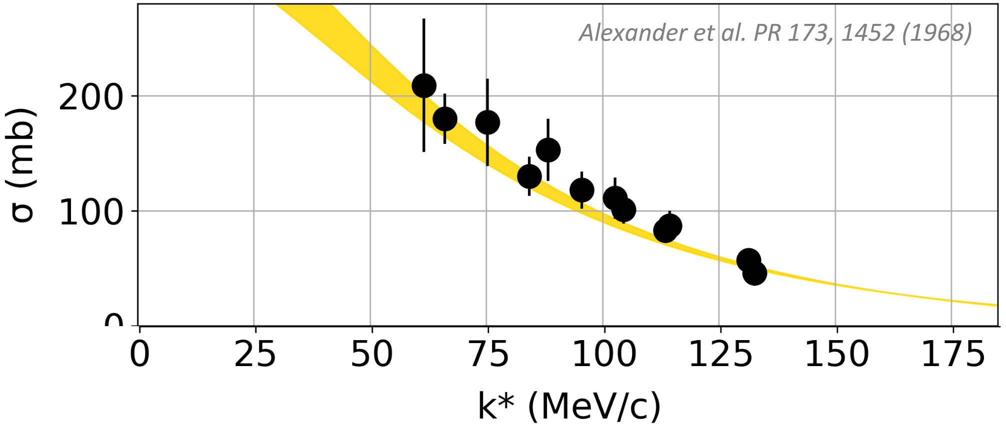
ALICE Coll. Phys.Lett.B 871 (2025) 139921

The pΛ interaction before femtoscopy

- Spin-0 and Spin-1 scattering length from scattering data
- Agreement with N2LO and NLO19

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

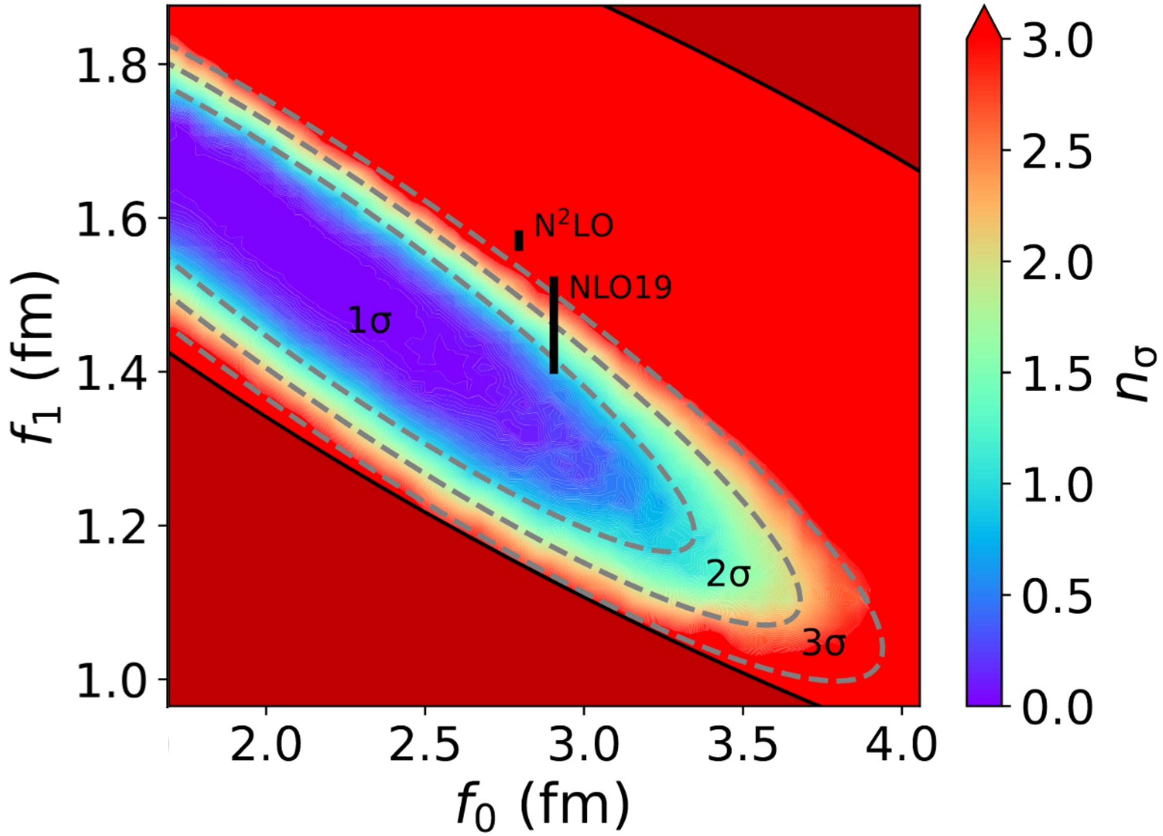


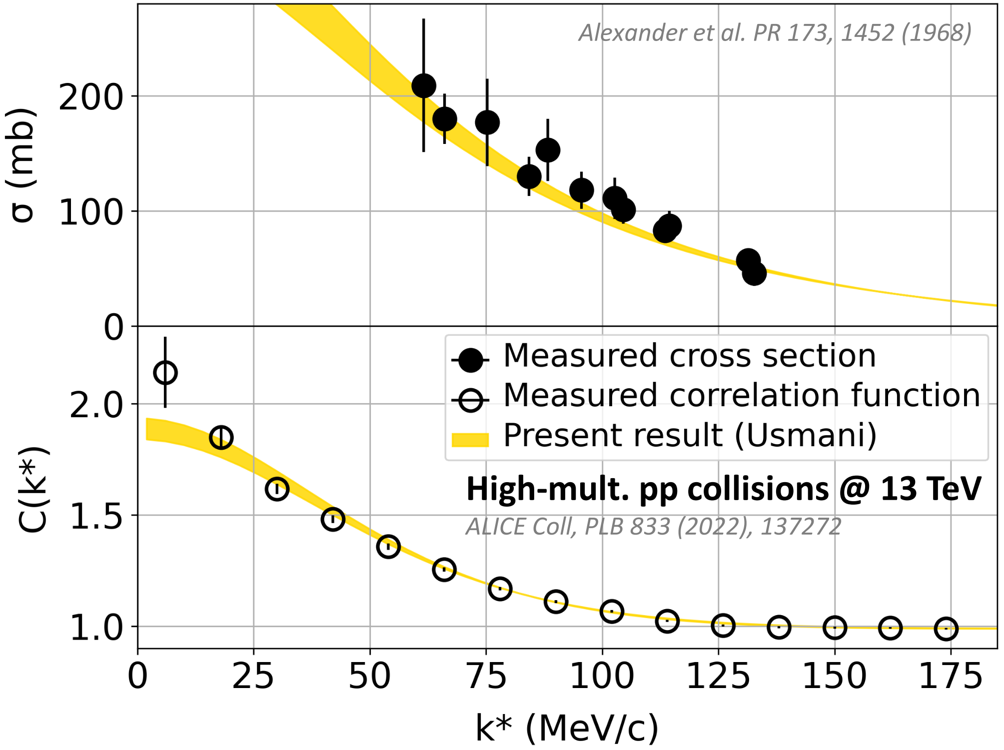


The pΛ interaction in the femtoscopy era

- Combined analysis of femtoscopic and scattering data

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

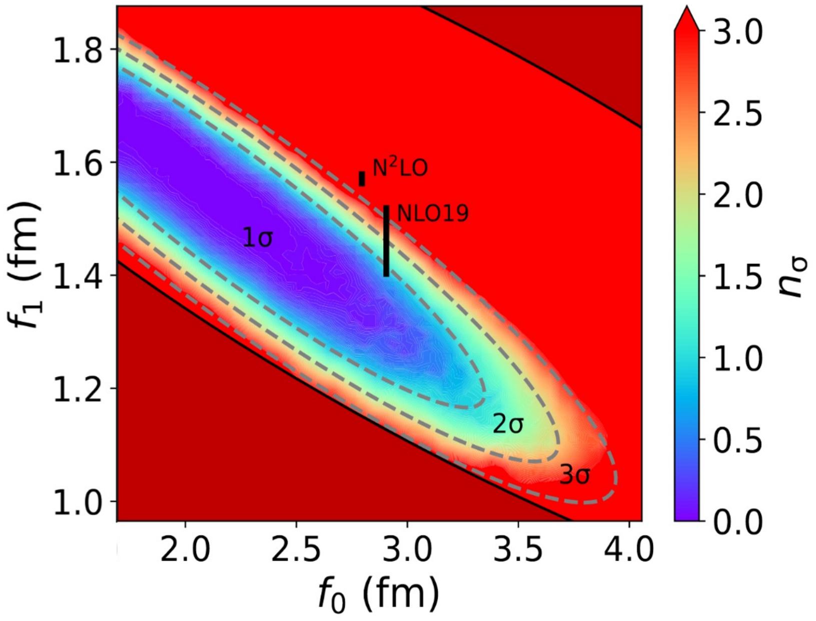




Selected results with strange hadrons

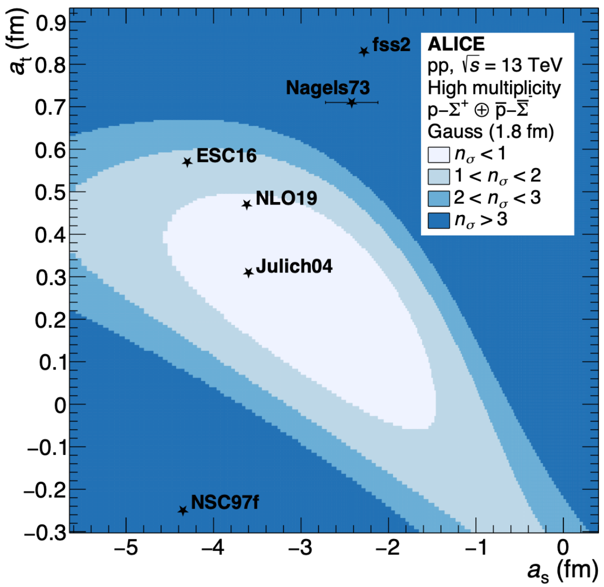
- Most precise measurement of the p-Λ scattering parameters

Scattering + femtoscopy



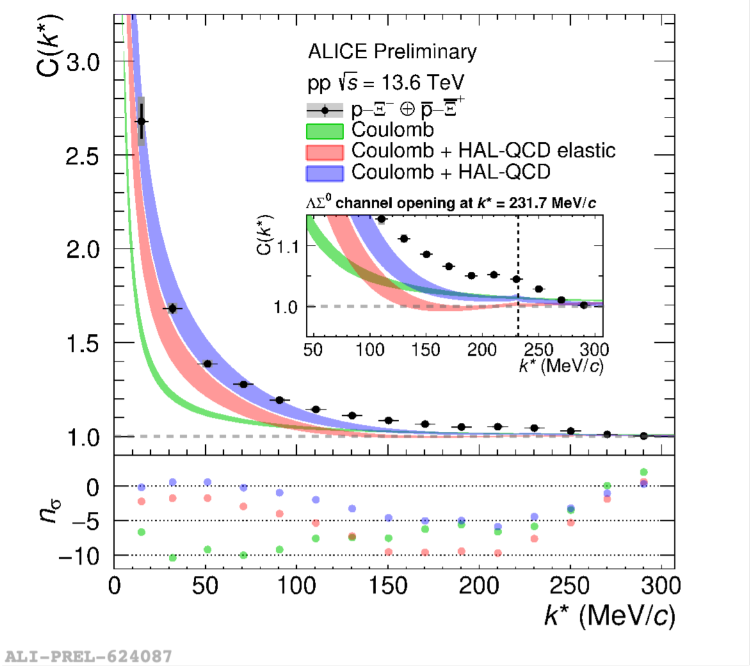
D. Mihaylov, J. Haidenbauer and V. Mantovani Sarti, PLB 850 (2024) 138550

- First measurement of the p-Σ⁺ scattering parameters



ALICE Coll., PLB 874 (2026) 140252

- Evidence of an attractive p-Ξ⁻ interaction



New precise experimental inputs for EFTs

Test of Lattice QCD

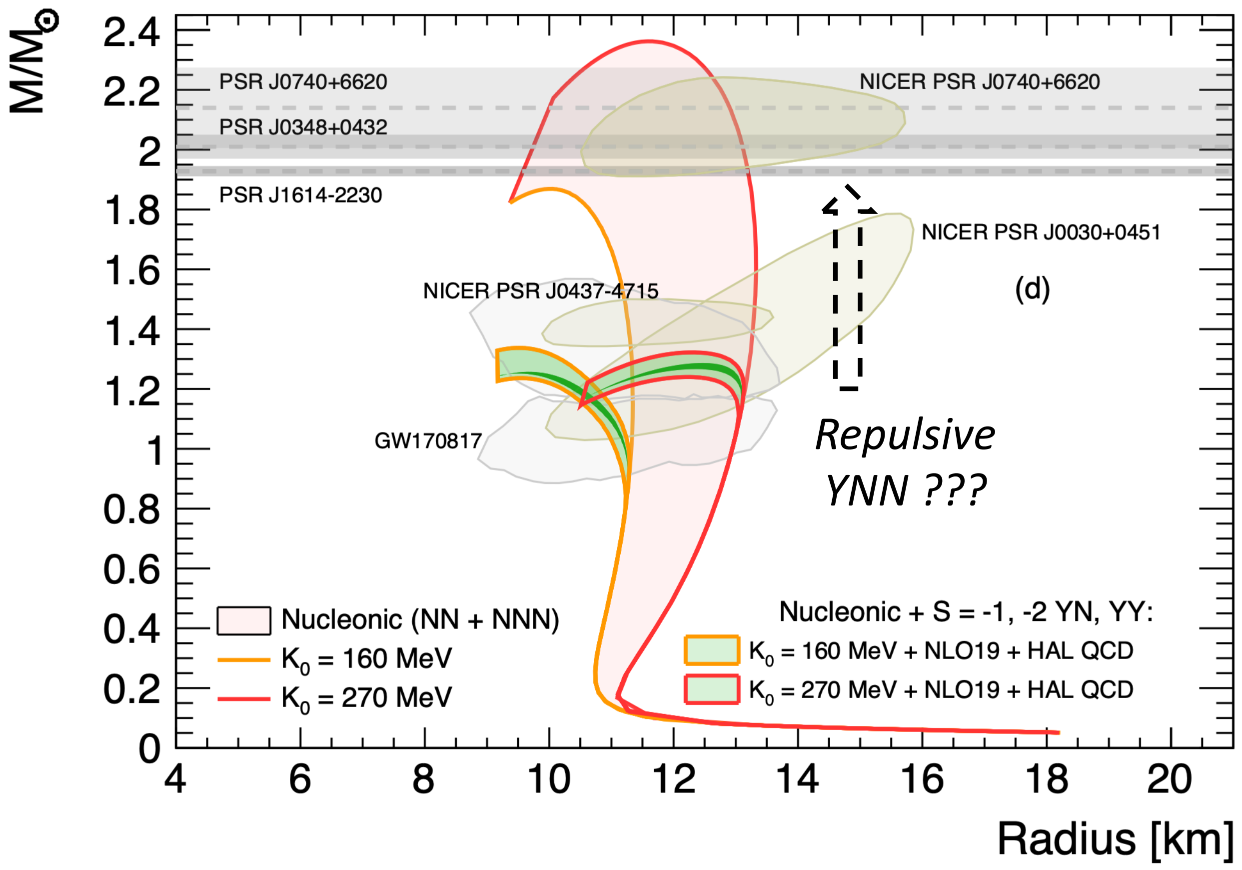
Strangeness in neutron stars

- 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

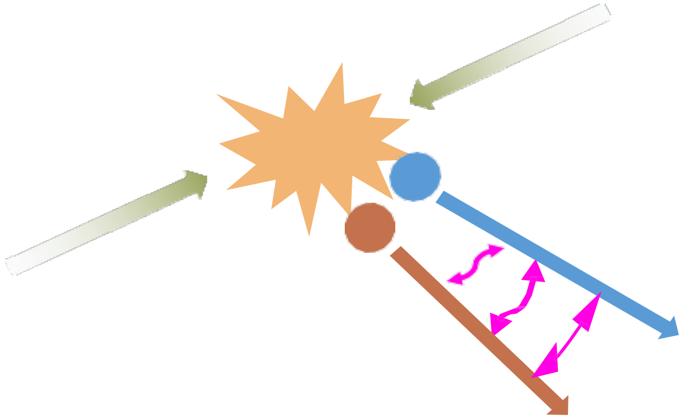
  I. Vidaña, V. Mantovani Sarti, J. Haidenbauer, D. Mihaylov, L. Fabbietti, EPJ.A 61 (2025) 3, 59

- Next step: inclusion of three body interaction involving hyperons

Can we provide precise information from femtoscopy measurements?



Femtoscopy: from two- to three-particle correlations



Two-particle correlations:

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

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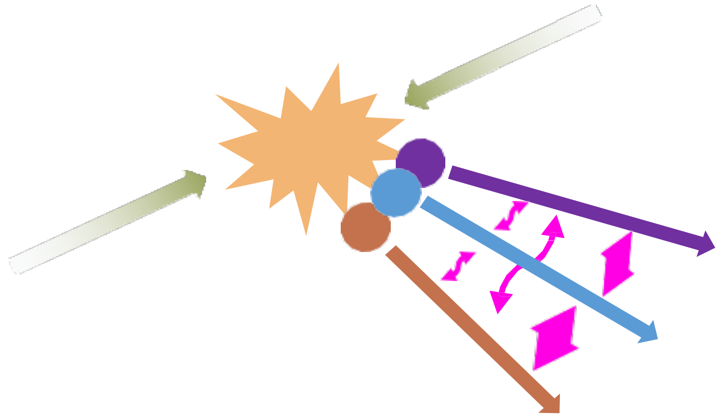
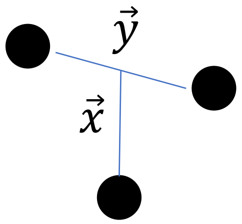


Three-particle correlations:

$$C(Q_3) = \frac{N_{same}(Q_3)}{N_{mixed}(Q_3)} = \int S(\rho)|\psi\,(Q_3,\rho\,)|^2\,\rho^5\,d\rho$$

Three-body wave function

Jacobi coordinates



Hyperradius

$$\rho = \sqrt{x^2 + y^2}$$

L. E. Marcucci et al., FP. 8, 69 (2020).
RDG et al. EPJC 82 (2022) 244
ALICE Coll., EPJ A 59, 145 (2023)

Hypermomentum

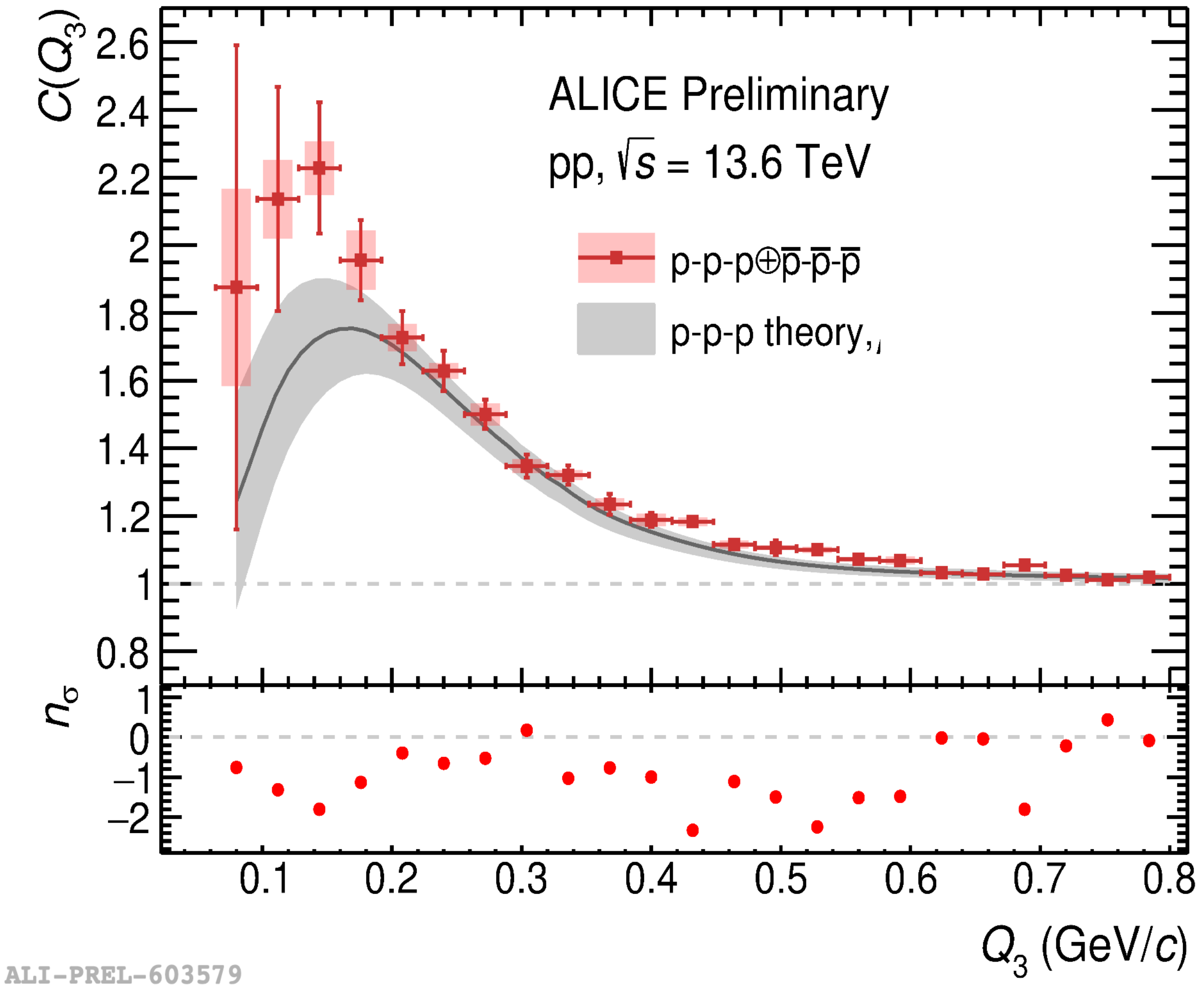
$$Q_3 = \sqrt{-q_{12}^2 - q_{23}^2 - q_{31}^2}$$

RDG et al. EPJC 82 (2022) 244
ALICE Coll., EPJ A 59, 145 (2023)

p-p-p correlation function

- First ever full description of three-body correlation function with free hadrons
- Calculations can describe the the data within 1.67σ

Novel way to study many-body interactions via three free baryon scattering 3->3



E. Garrido et al., Phys.Lett.B 868 (2025) 139731

p-p-Λ correlation function in pp collisions

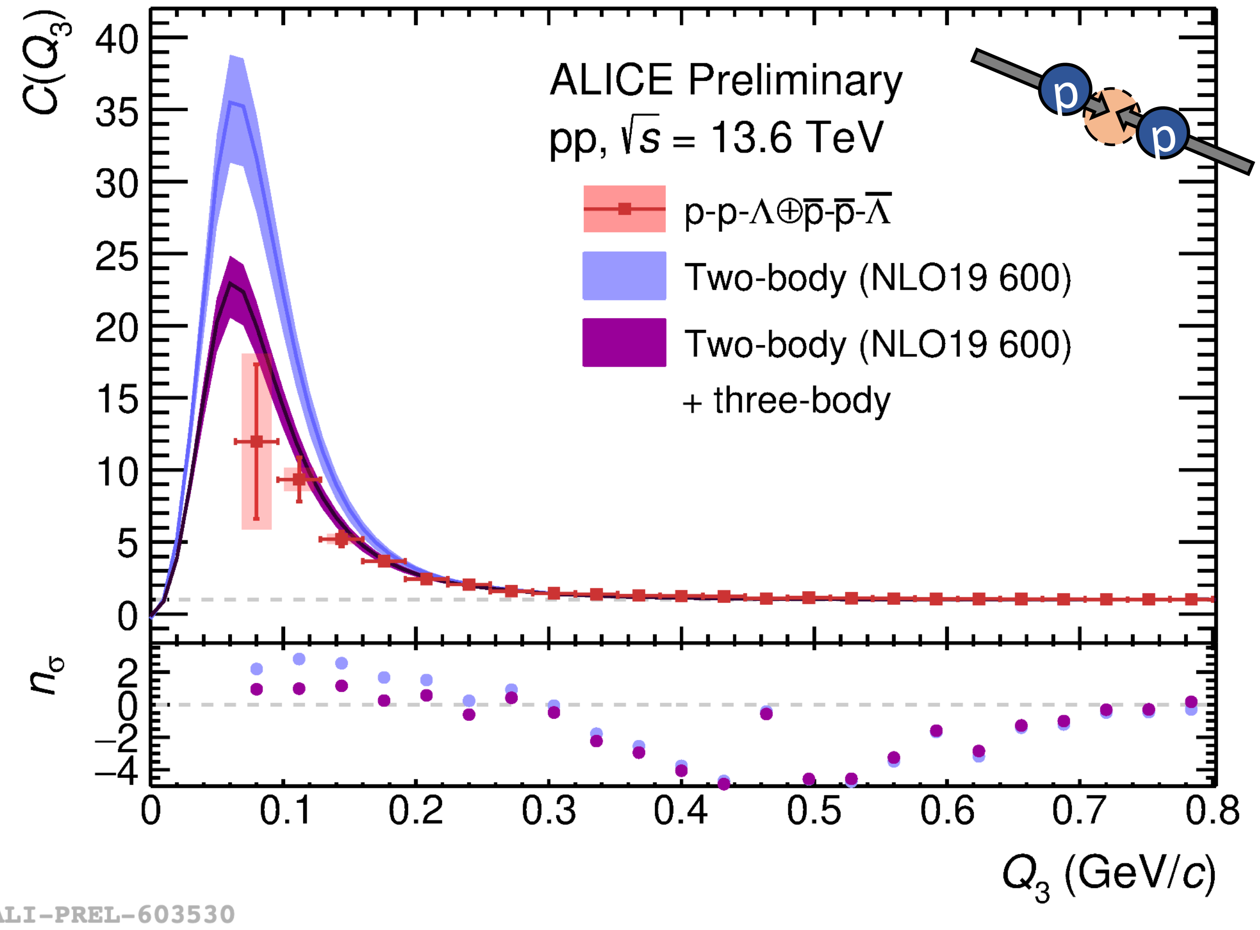
- Significant deviation from the absence of three-body interaction: **3.7σ at Q_3 < 0.2 GeV/*c***

- Three-body force constrained to the hypertriton binding energy

  *E. Garrido, **RDG, L. Fabbietti** et al., PRC 110 (2024) 5, 054004*

  0.7σ agreement with the data at Q_3 < 0.2 GeV/*c*

Ongoing analysis with full Run 3 data!!



Calculations: E. Garrido et al., PRC 110 (2024) 5, 054004

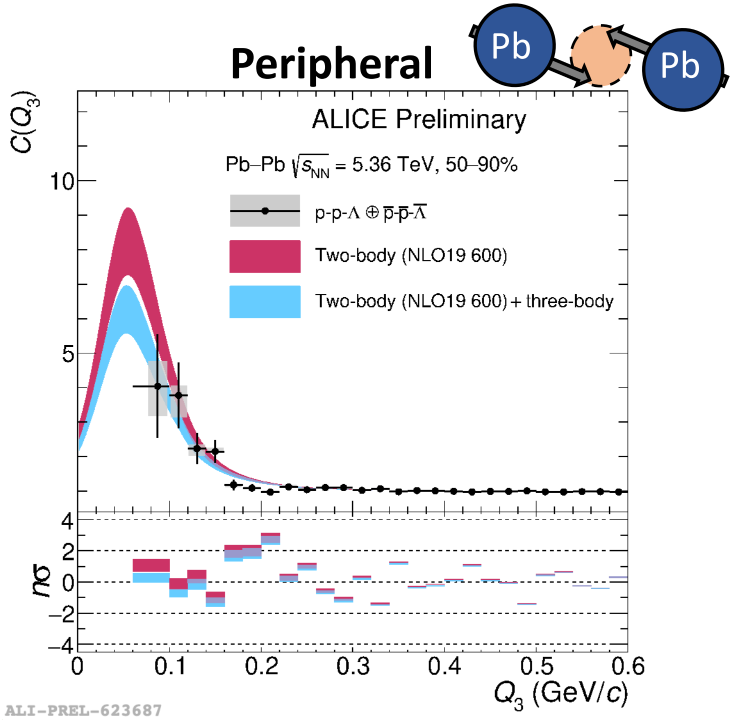
p-p-Λ correlation function in Pb–Pb collisions

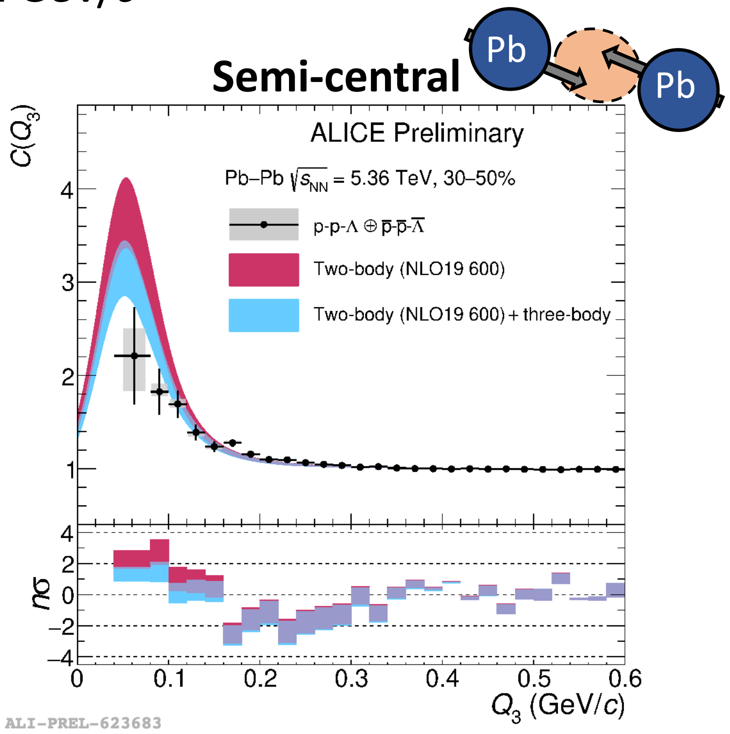
Theory:

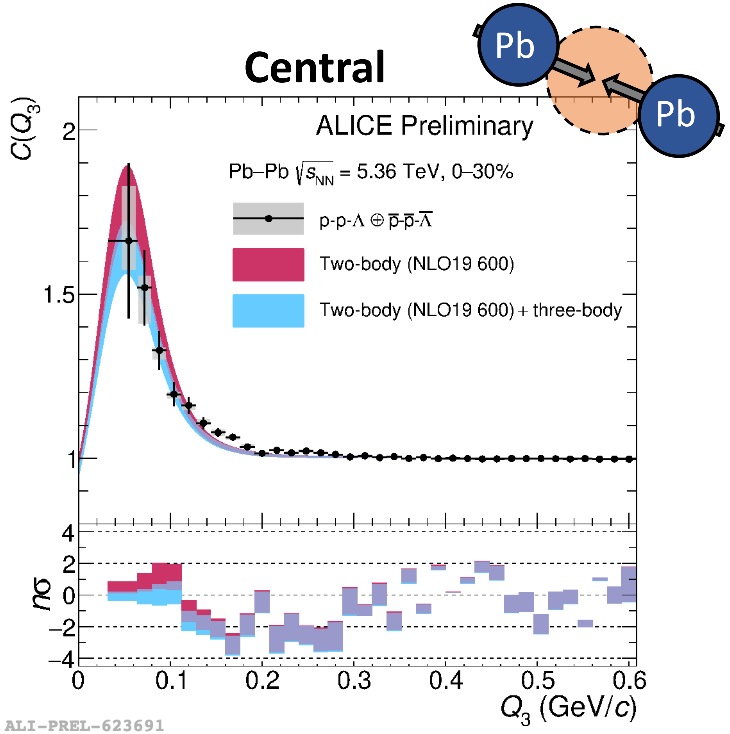
- Preliminary calculations with Gauss NLO19 (600)
  J. Haidenbauer, U.-G. Meißner, and A. Nogga, EPJ A 56, 91 (2020)
- Three-body force anchored to 3- and 4-body hypernuclei
  E. Garrido et al., PRC 110 (2024) 5, 054004
- Interaction signal expected at $Q_3 < 0.2$ GeV/*c*

Measurements:

- Agreement with absence of three-body interactions in central collisions
- Deviations observed in semi-central and peripheral collisions







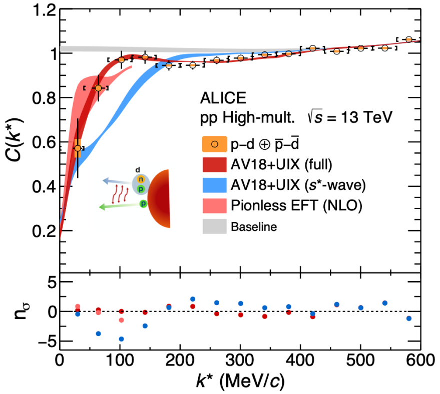
Other three-body measurements

S = 0
NNN

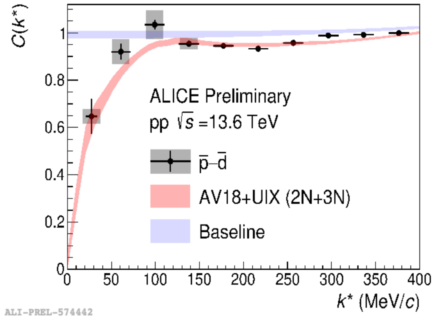
S = -1
NNΛ, KNN

S = -2
NNΞ

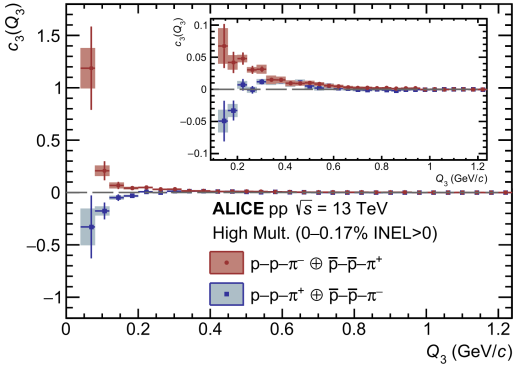
p-d



ALICE Coll., PRX 14 (2024) 3, 031051

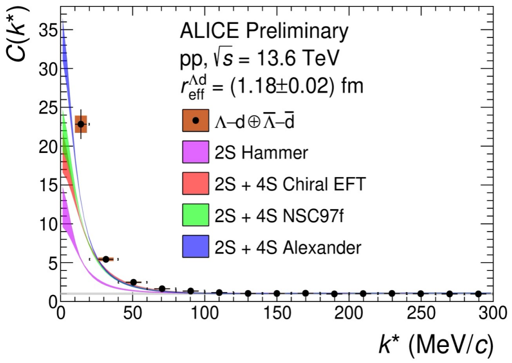


p-p-π

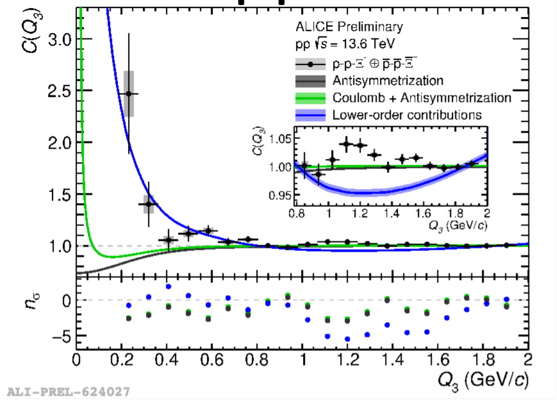


ALICE Coll., EPJ A 61 (2025) 8, 194

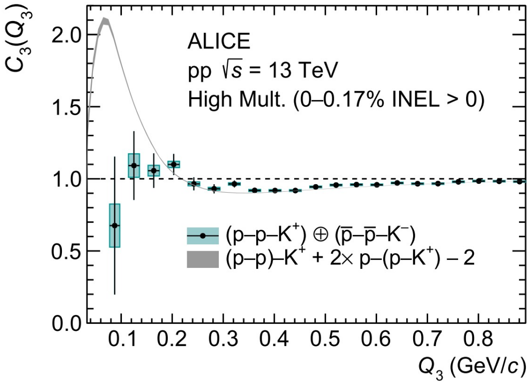
Λ-d

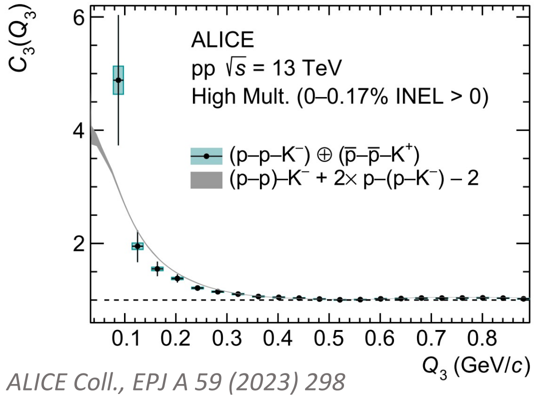


p-p-Ξ⁻



p-p-K





ALICE Coll., EPJ A 59 (2023) 298

Summary and Conclusions

- Feasibility of high precision measurement for hadron-hadron interactions by means of the femtoscopy technique appied to pp and Pb-Pb collisions at the LHC has been demonstrated.
- Close collaboration with theoreticians in the interpretation of the correlation functions.
- New hyperon-nucleon scattering parameters haven been extracted and a new EoS for baryonic matter containing hyperons has been calculated. Experimental uncertainties on two-body interactions are propagated.
- The largest neutron star mass obtained with such an approach is still far from the heavist masses measured.
- The feasibility of the direct measurement of three body effects by means of three baryons correlation is under study.
- Ongoing analysis with the full statistics from Run 3.

Stay tuned for much more.

Thank you for your attention

p-p-Λ correlation function

- Reference calculations:
  → two-body NN and ΛN interactions provide an overbinding of the hypertriton

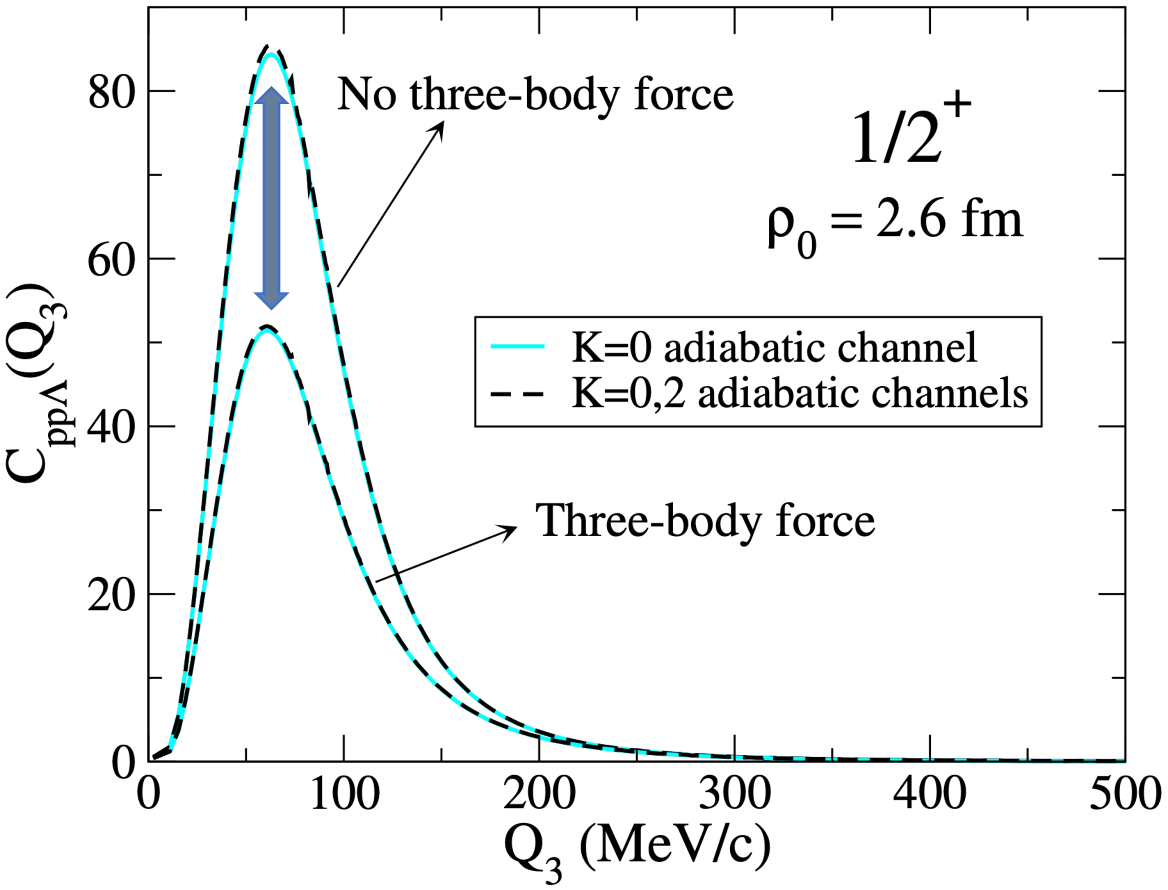
  BE(${}^{3}_{\Lambda}$H) = 2.904 MeV   exp: 2.39 MeV

  *E. Garrido, **RDG, L. Fabbietti** et al., PRC 110 (2024) 5, 054004*

  Binding energy from: https://hypernuclei.kph.uni-mainz.de

  → three-body ΛNN interaction

- **ΛNN interaction gives 40% effect**: only one partial wave (K=0) significantly contributes



E. Garrido et al., PRC 110 (2024) 5, 054004

Source function in pp collisions at the LHC

- Emitting source function anchored to p-p correlation function

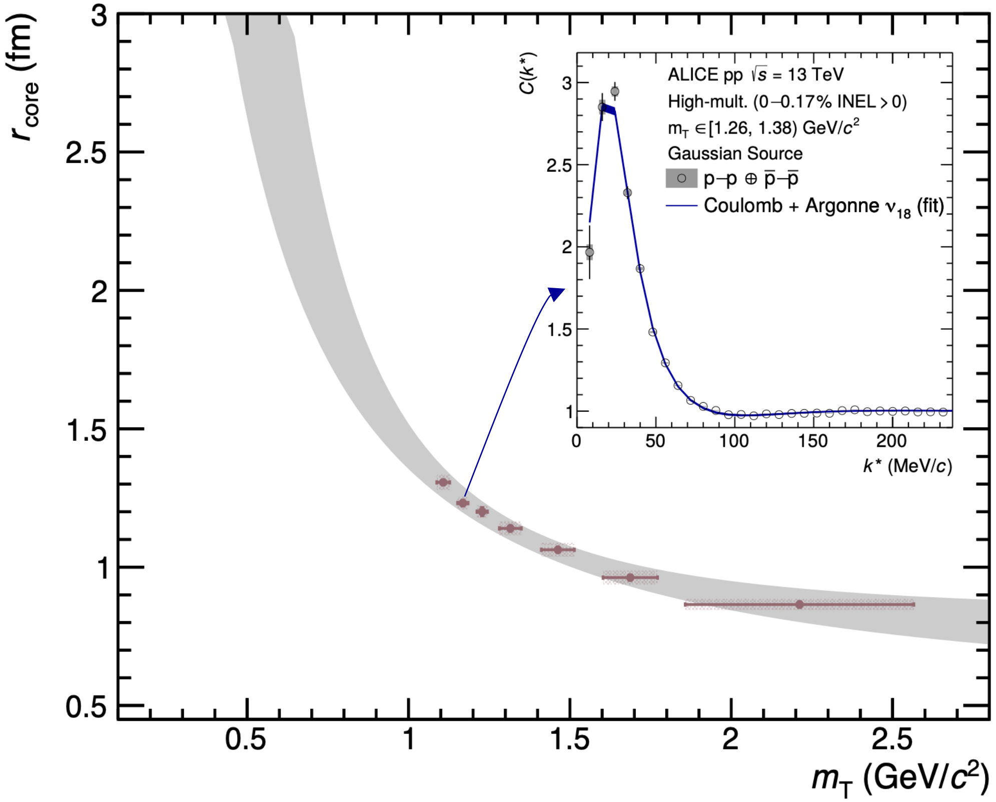
$$\underbrace{C(k^*)}_{\text{measured}} = \int S(\vec{r}\,)\underbrace{\left|\psi(\vec{k}^*,\vec{r}\,)\right|^2}_{\text{known interaction}} d^3\vec{r}$$

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

Source function in pp collisions at the LHC

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

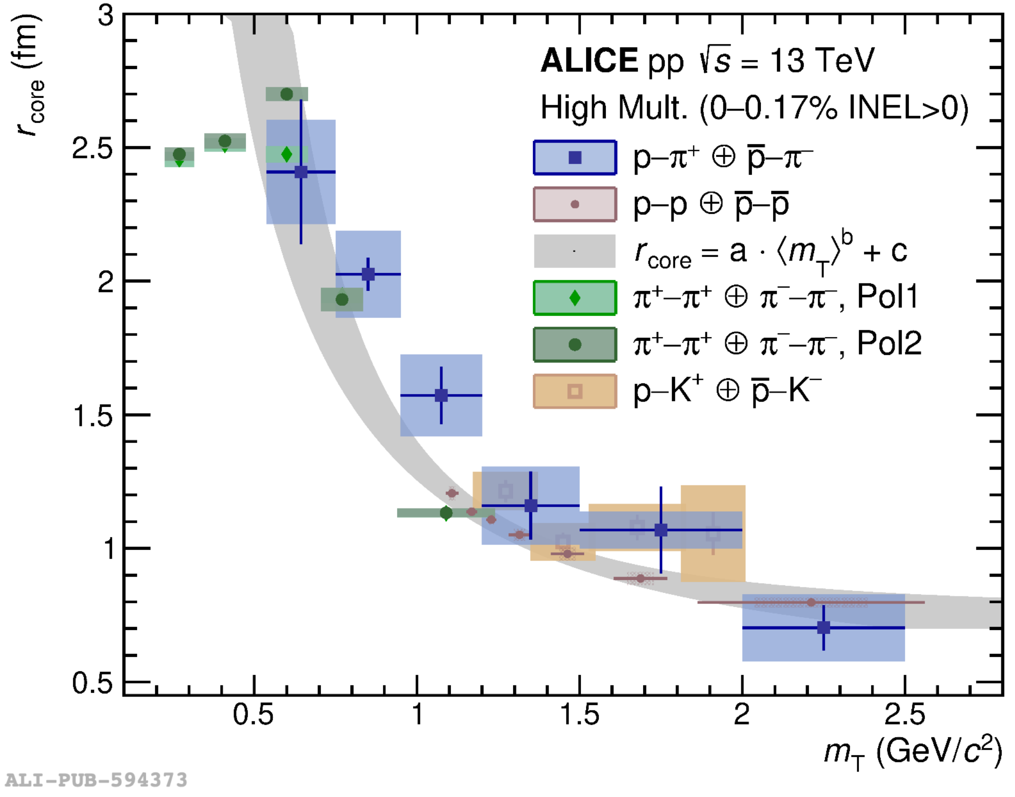
measured known interaction

- Gaussian parametrization

$$S(r) = \frac{1}{(4\pi r_{core}^2)^{3/2}} \exp\left(-\frac{r^2}{4r_{core}^2}\right) \times$$ Effect of short lived resonances (cτ ~ 1 fm)

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

- One common 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*



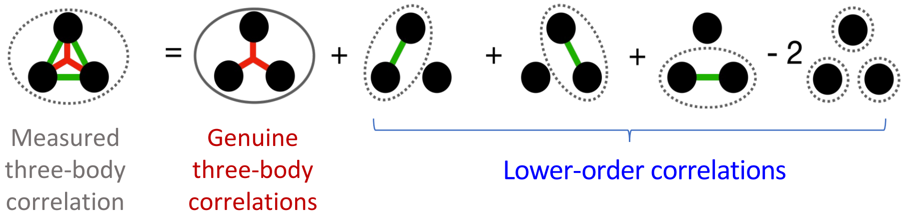
ALICE Coll., PLB, 811 (2020), 135849;
ALICE Coll., EPJ C 85 (2025) 2, 198;
ALICE Coll., EPJ A 61 (2025 8, 194

p-p-Ξ^- correlation function

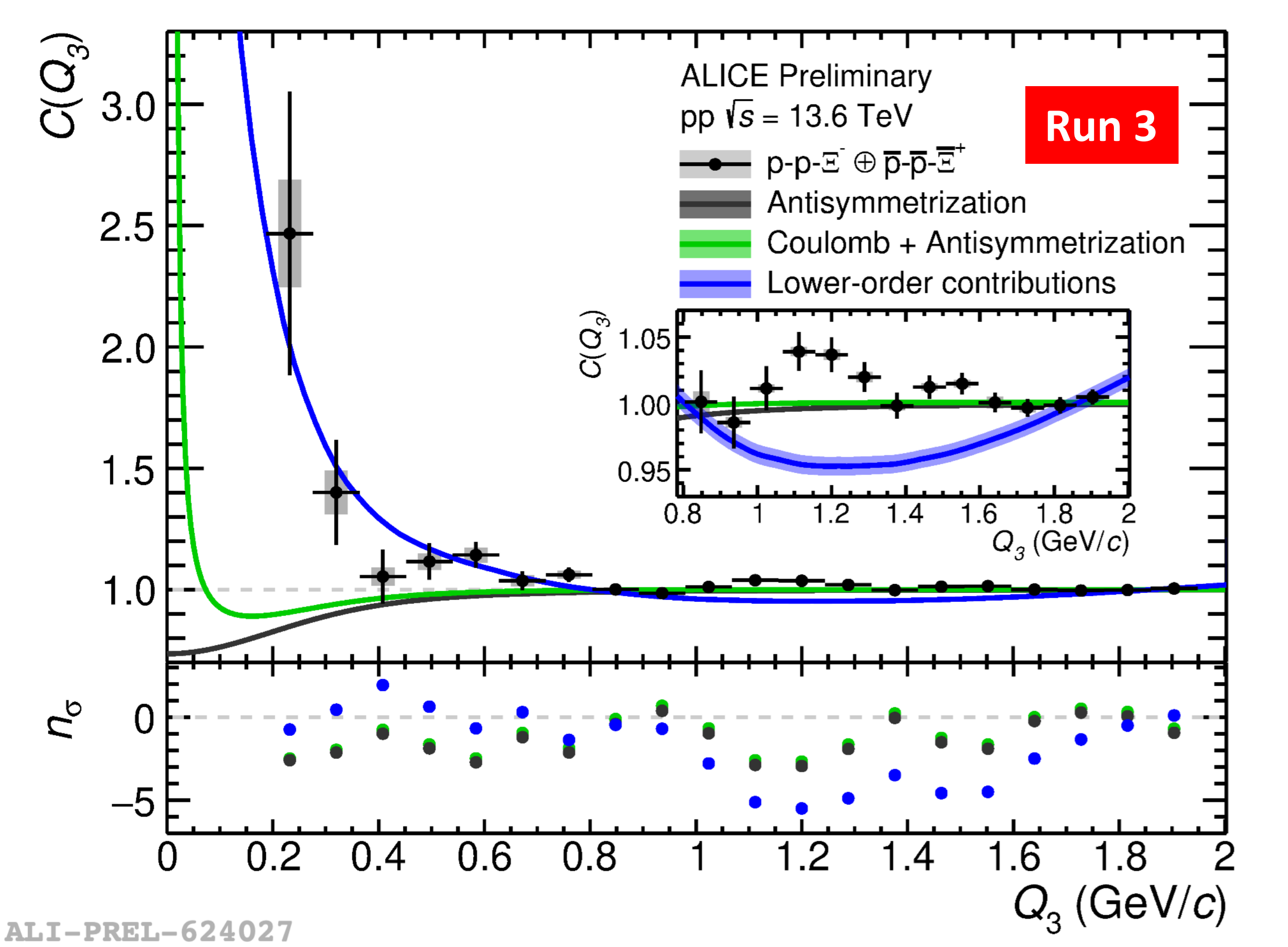
- First measurement of p-p-Ξ^- final state interaction: **3.5 σ significance at Q_3 < 1 GeV/*c***

- Strong interaction with cumulant expansion method (no three-body dynamics) provides **0.6 σ agreement at Q_3 < 1 GeV/*c***

Credits: L. Šerkšnytė



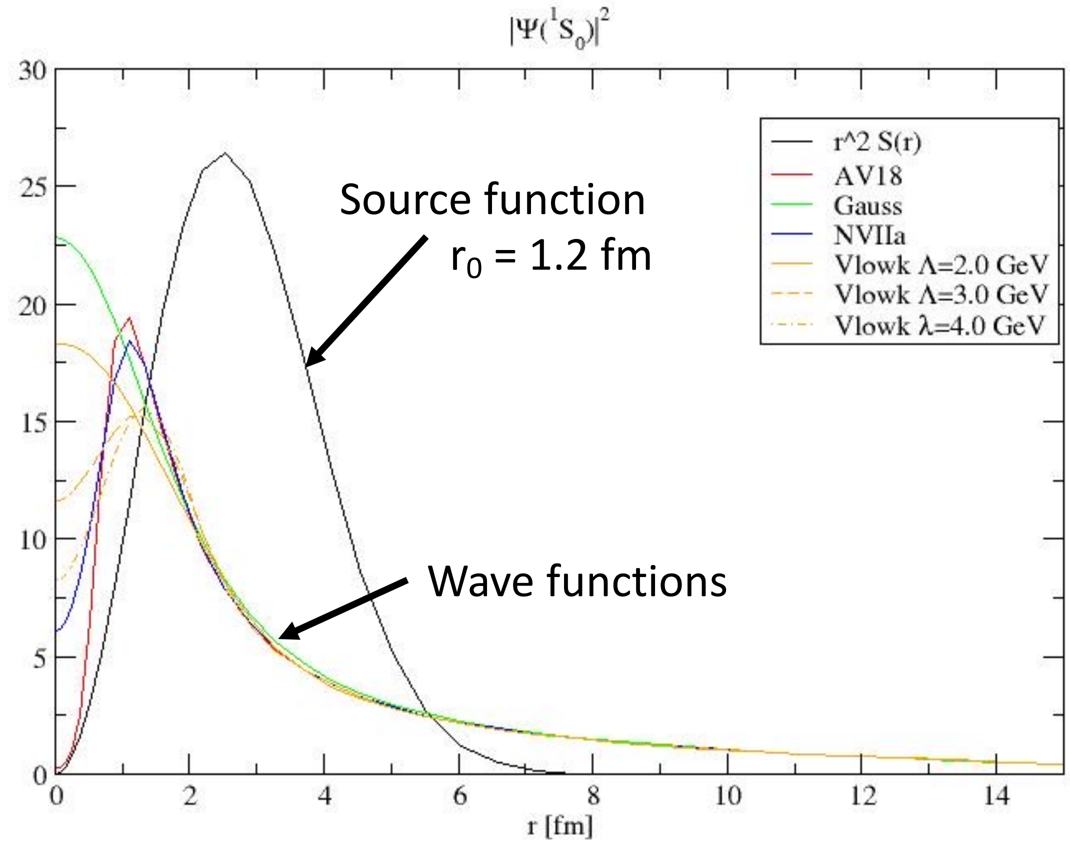
- **Significant deviation observed in the range 1.0 GeV/*c* < Q_3 < 1.8 GeV/*c***

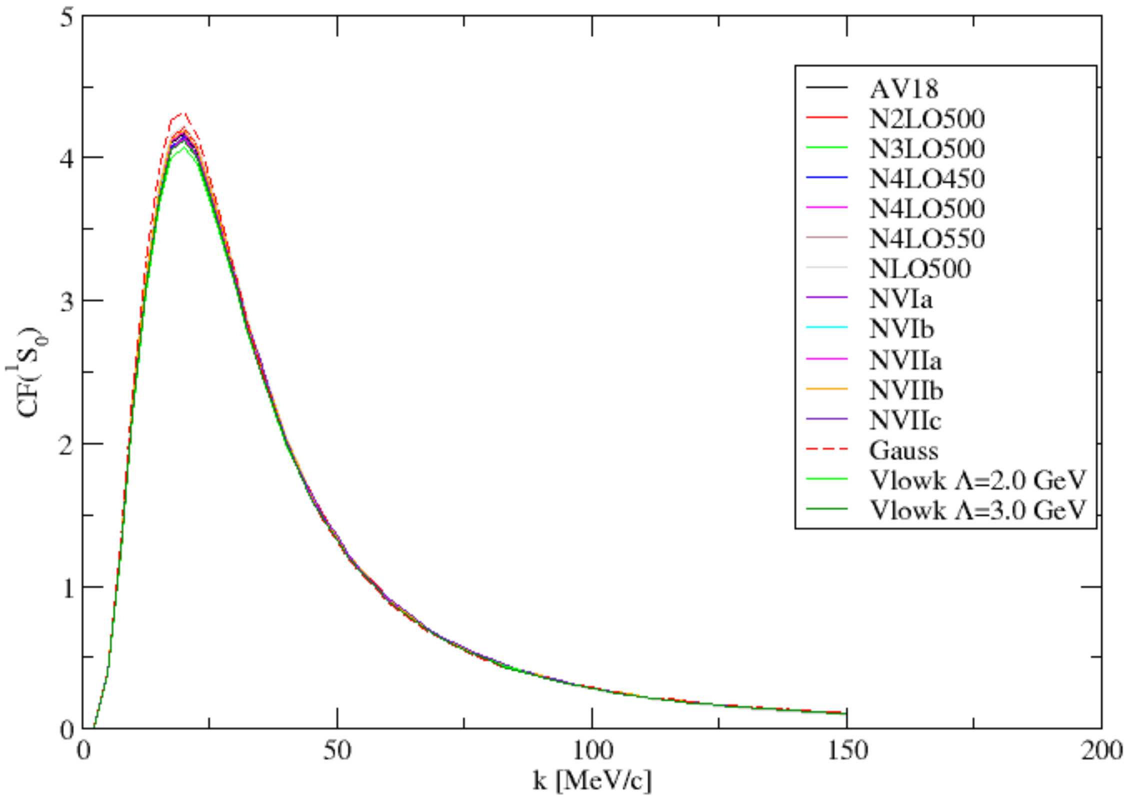


Calculations: M. Schäfer based on A. Kievsky at al., PRC 109 (2024) 3, 034006

Scan of p-p wave functions

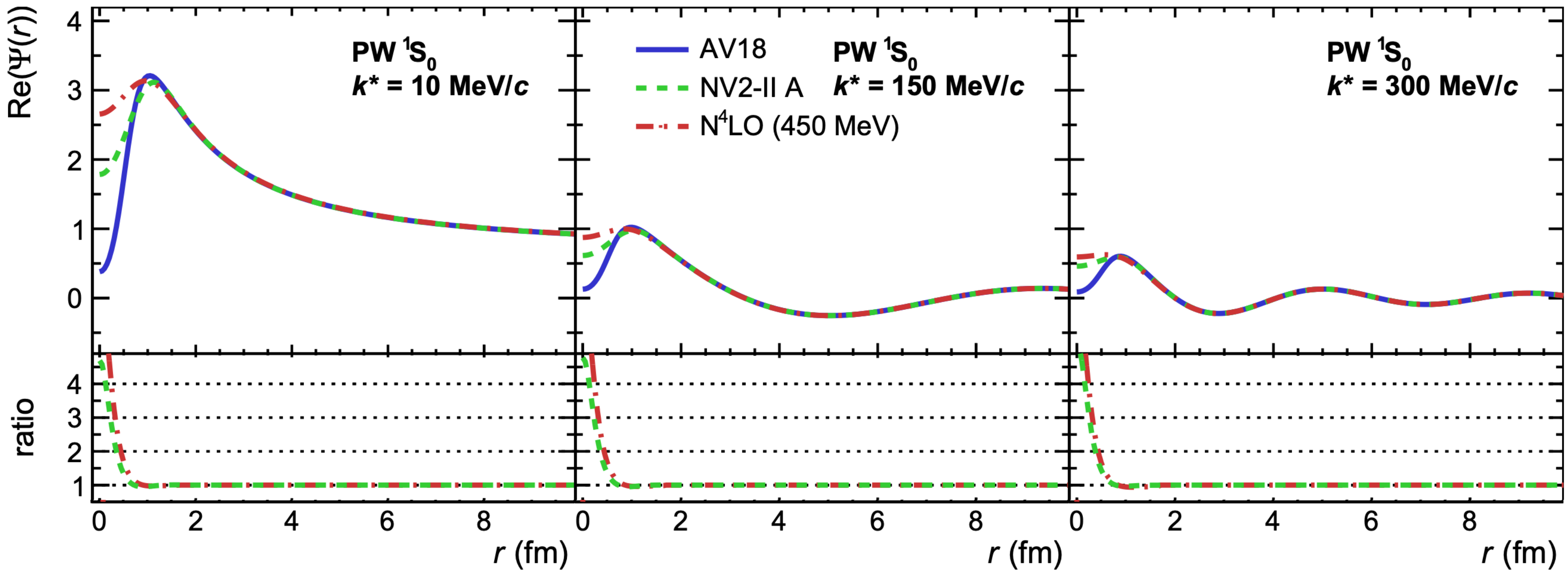
Courtesy A. Kievsky and M. Viviani





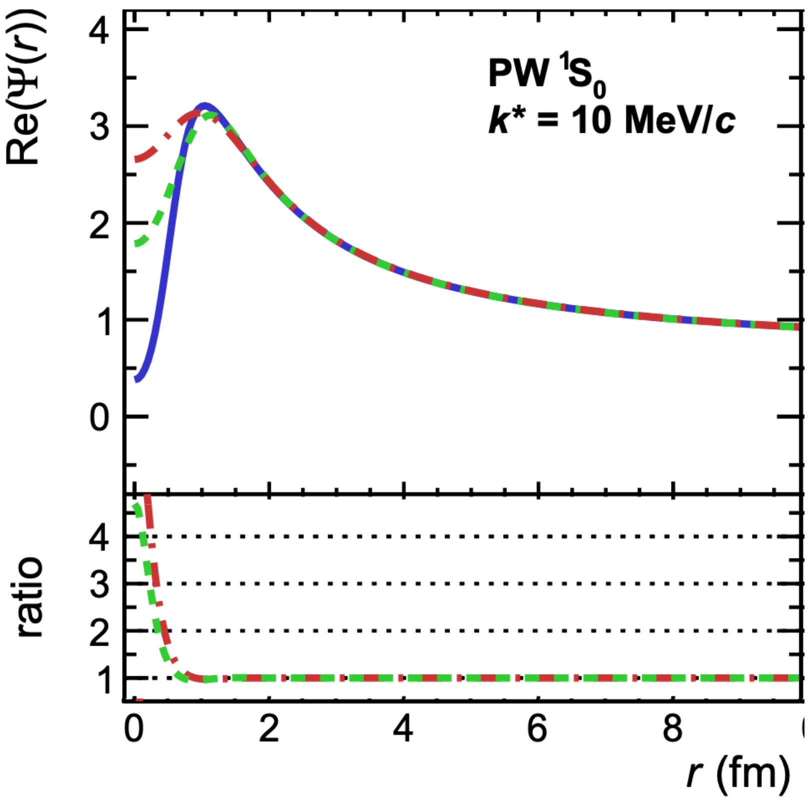
For a systematic study of the effect of different NN interaction in the correlation function see
M. Göbel, A. Kievsky, Phys.Lett.B 869 (2025) 139835

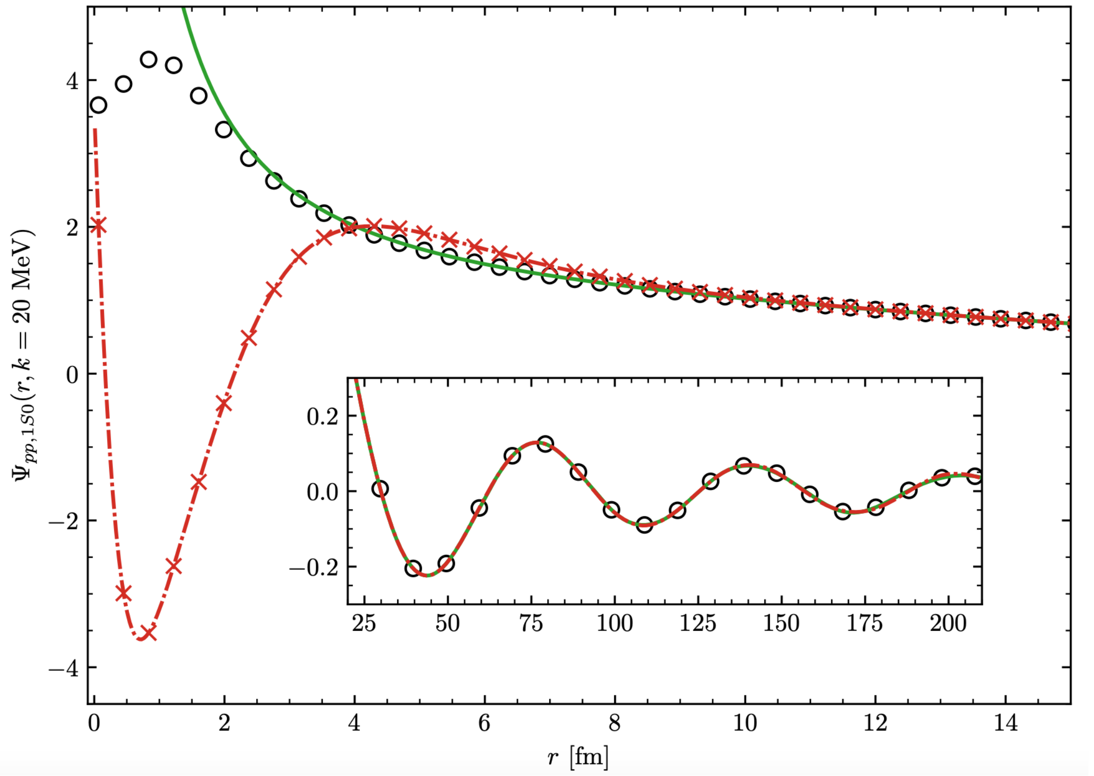
Scan of p-p wave functions



Realistic wave functions from AV18, Norfolk potentials and N^{4}LO$^+$ EFT.

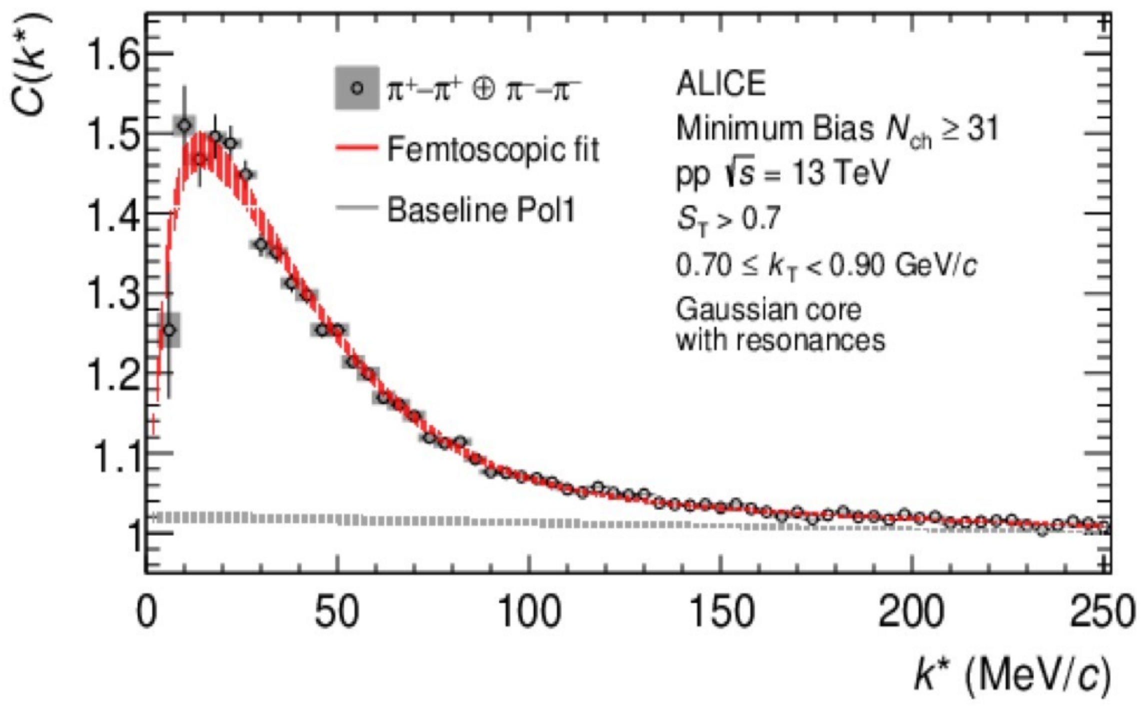
Scan of p-p wave functions



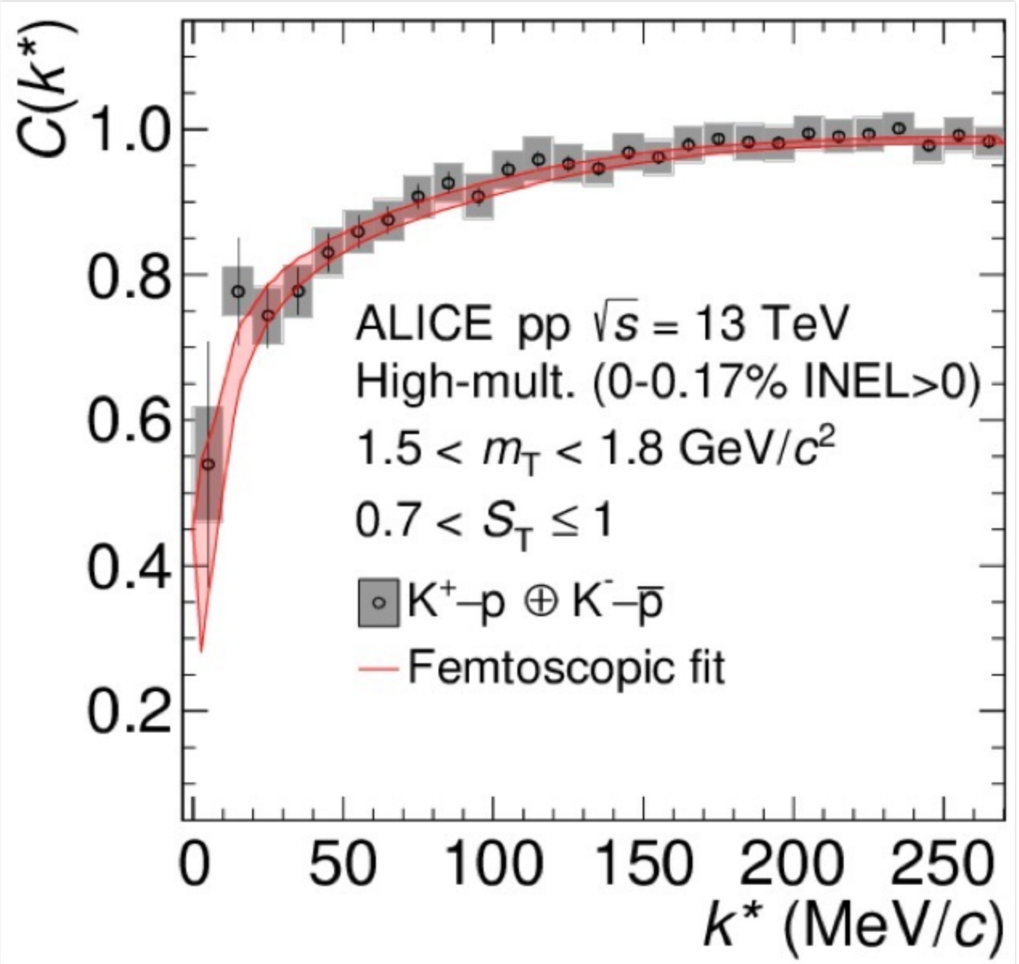


E. Epelbaum et al., Phys.Rev.Lett. 136 (2026) 21, 212301

Source function in pp collisions at the LHC



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



ALICE Coll., PLB, 811 (2020)

ALICE detector

Excellent tracking and particle identification (PID) capabilities

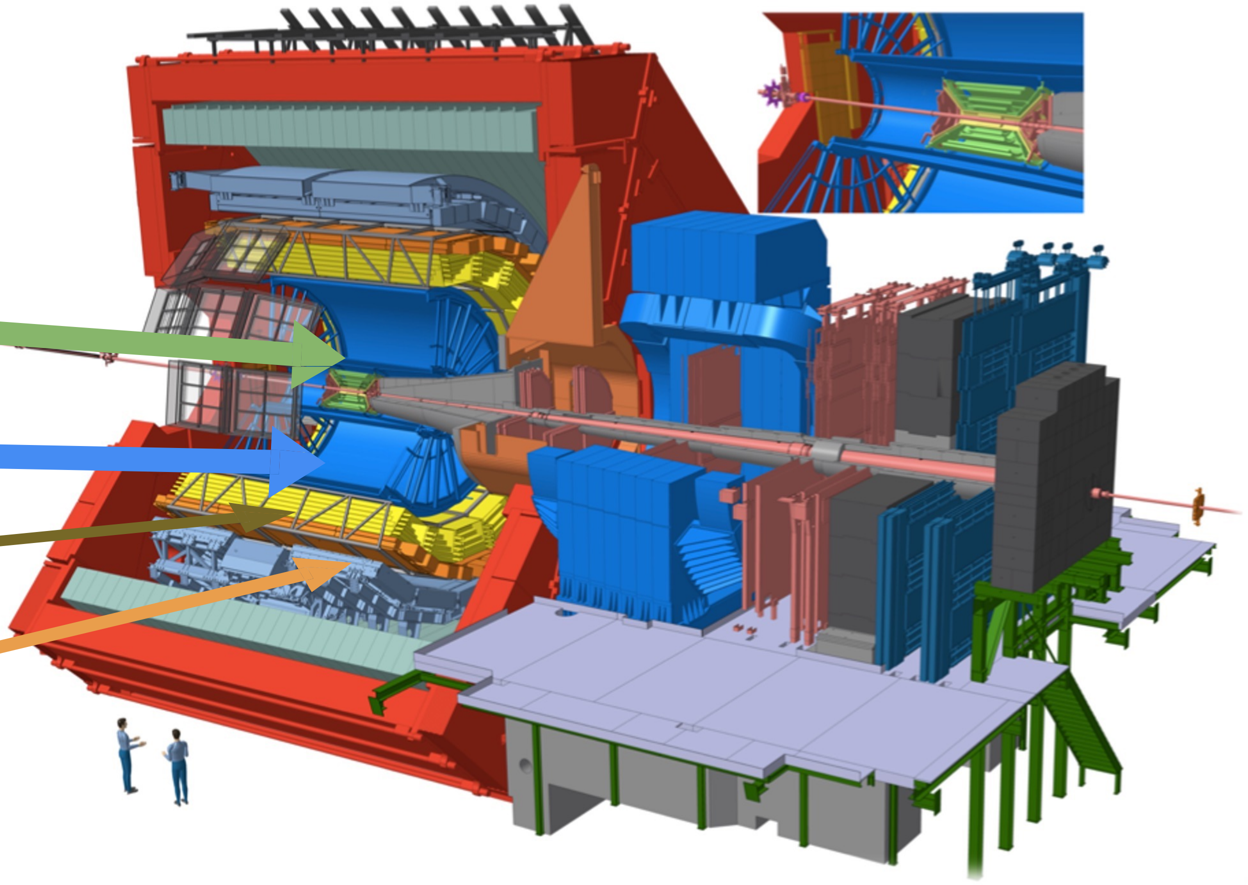
- Run 2 data: 2015 – 2018
- Run 3 data: 2022 – 2026

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

Time Projector Chamber
Tracking, PID (dE/dx)

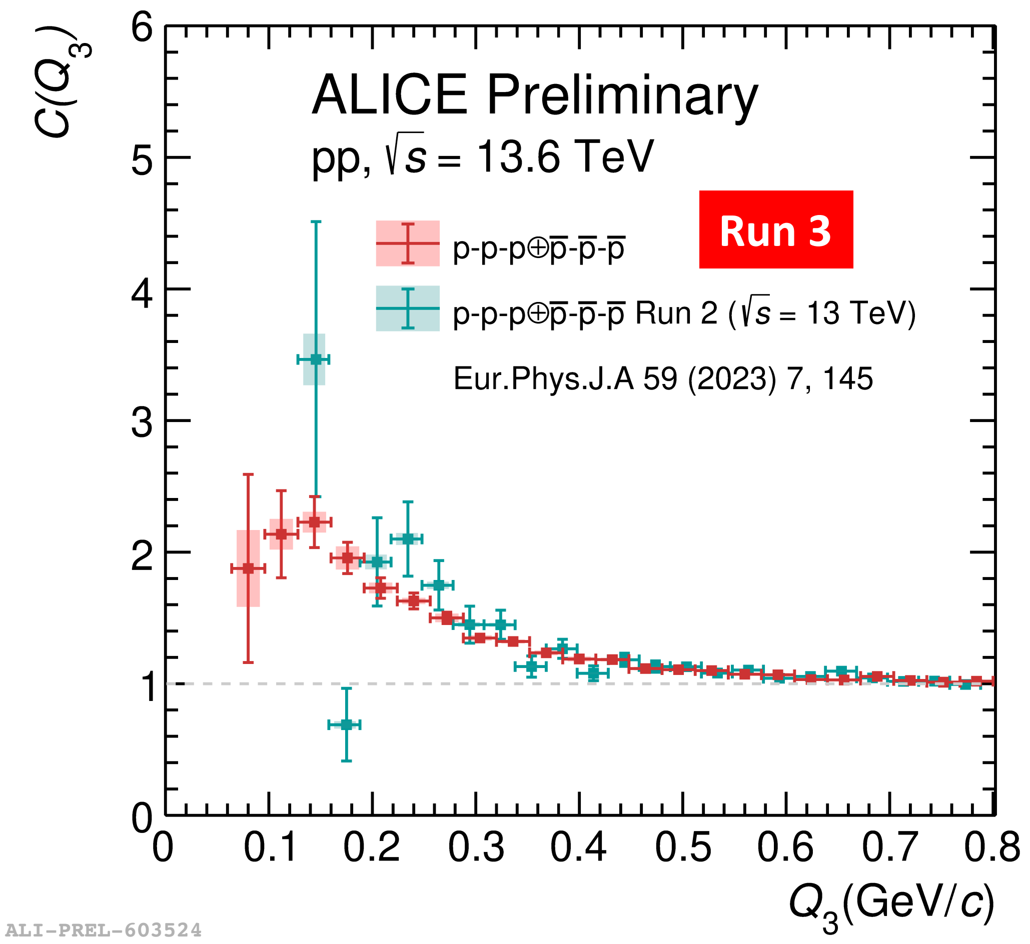
Transition Radiation Detector

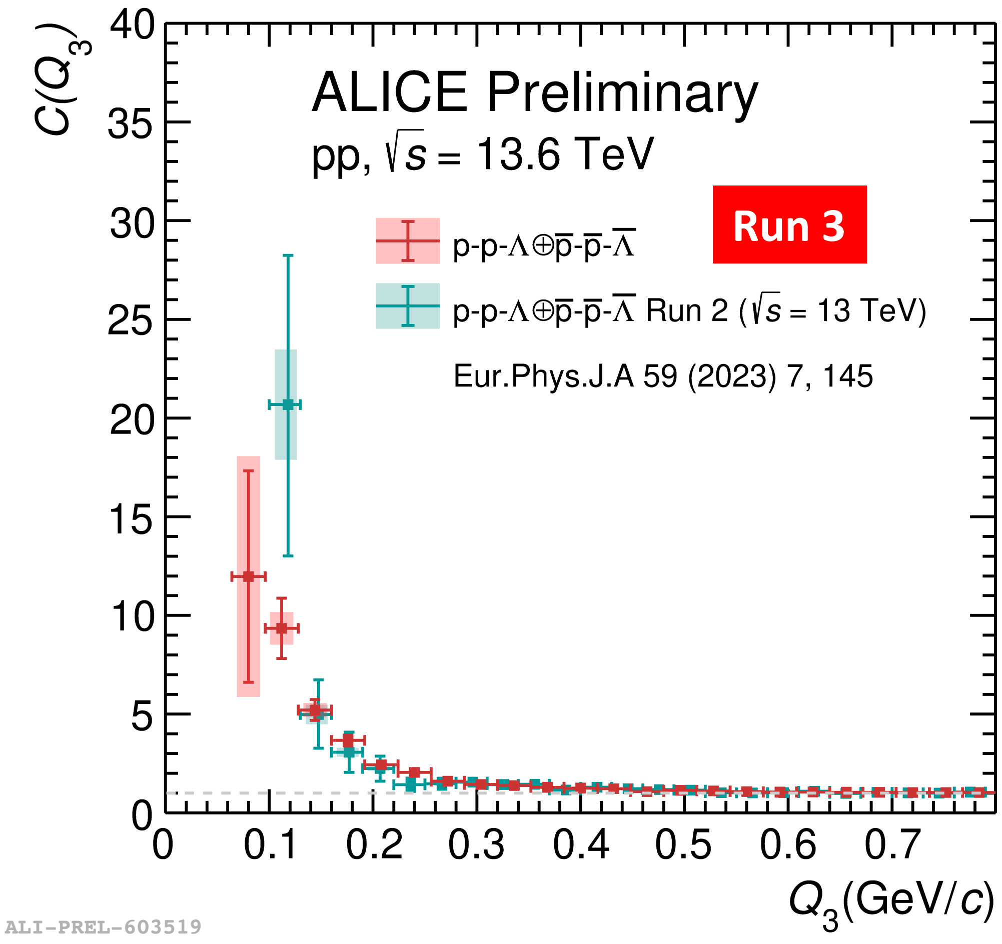
Time Of Flight detector
PID (TOF measurement)



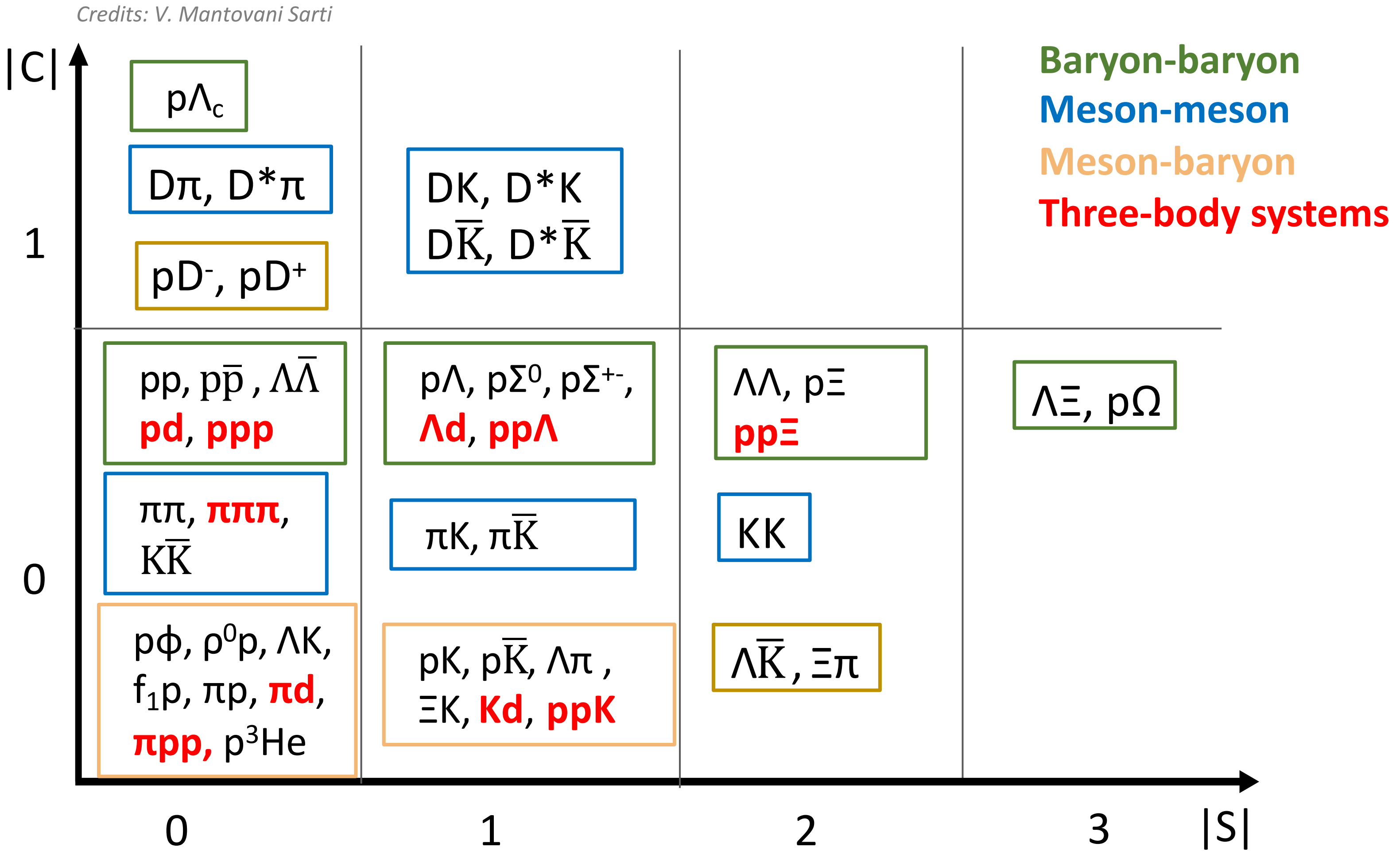
p-p-p and p-p-Λ correlation functions in Run 3

- New Run 3 results by ALICE: significant improvement in statistics and more data in the low Q_3 region





Femtoscopy measurements at the LHC



ALICE Collaboration:

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PRX 14 (2024) 3, 031051
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PRC 109, 024915 (2024)
EPJC 85 (2025) 2, 198
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