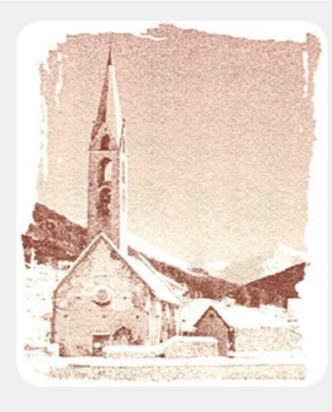


From neutron stars to LHC: investigating hadronic interactions with correlations

V. Mantovani Sarti (TUM)

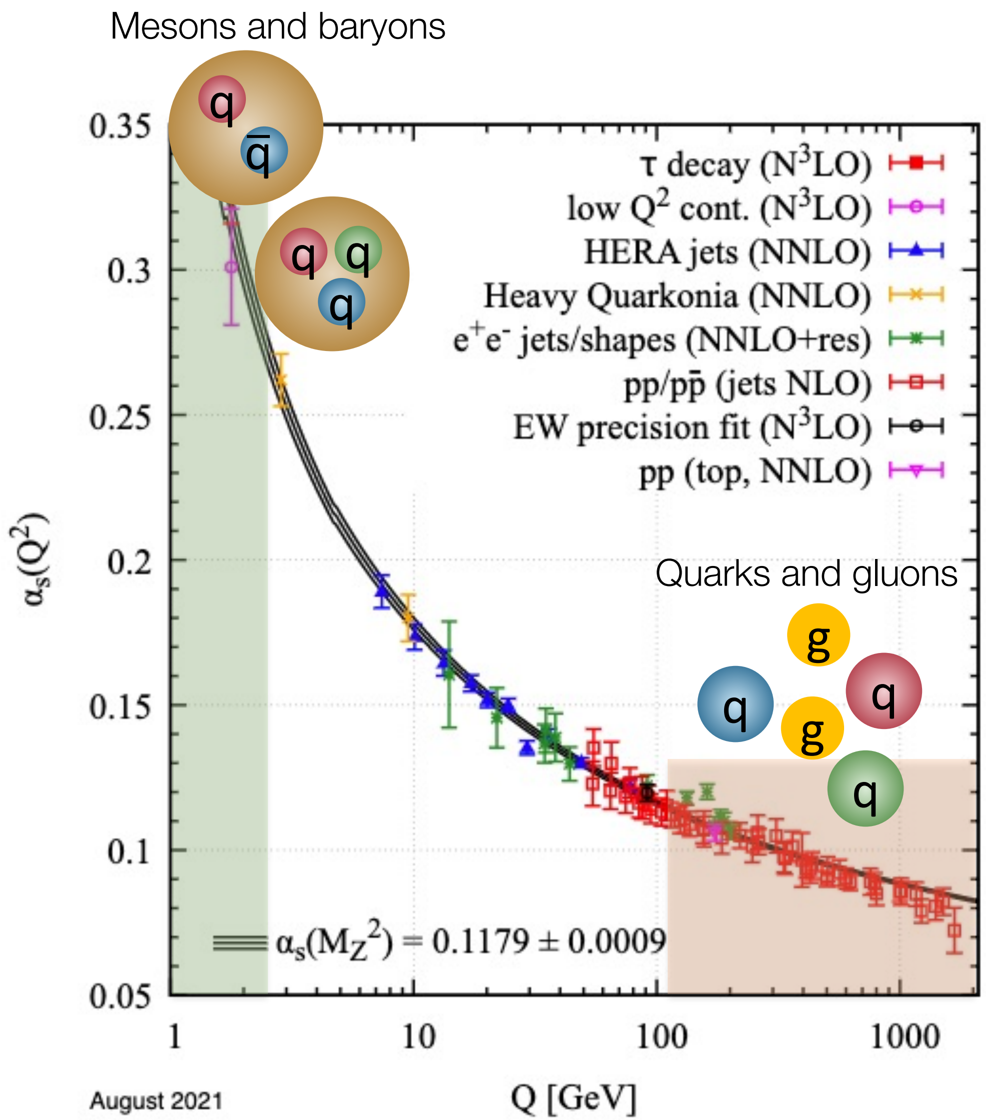
62nd International Winter Meeting on Nuclear Physics
January 19-23, 2026 Bormio, Italy

valentina.mantovani-sarti@tum.de

SFB 1258 Neutrinos Dark Matter Messengers

ORIGINS Excellence Cluster

Why do we want to understand hadronic interactions?

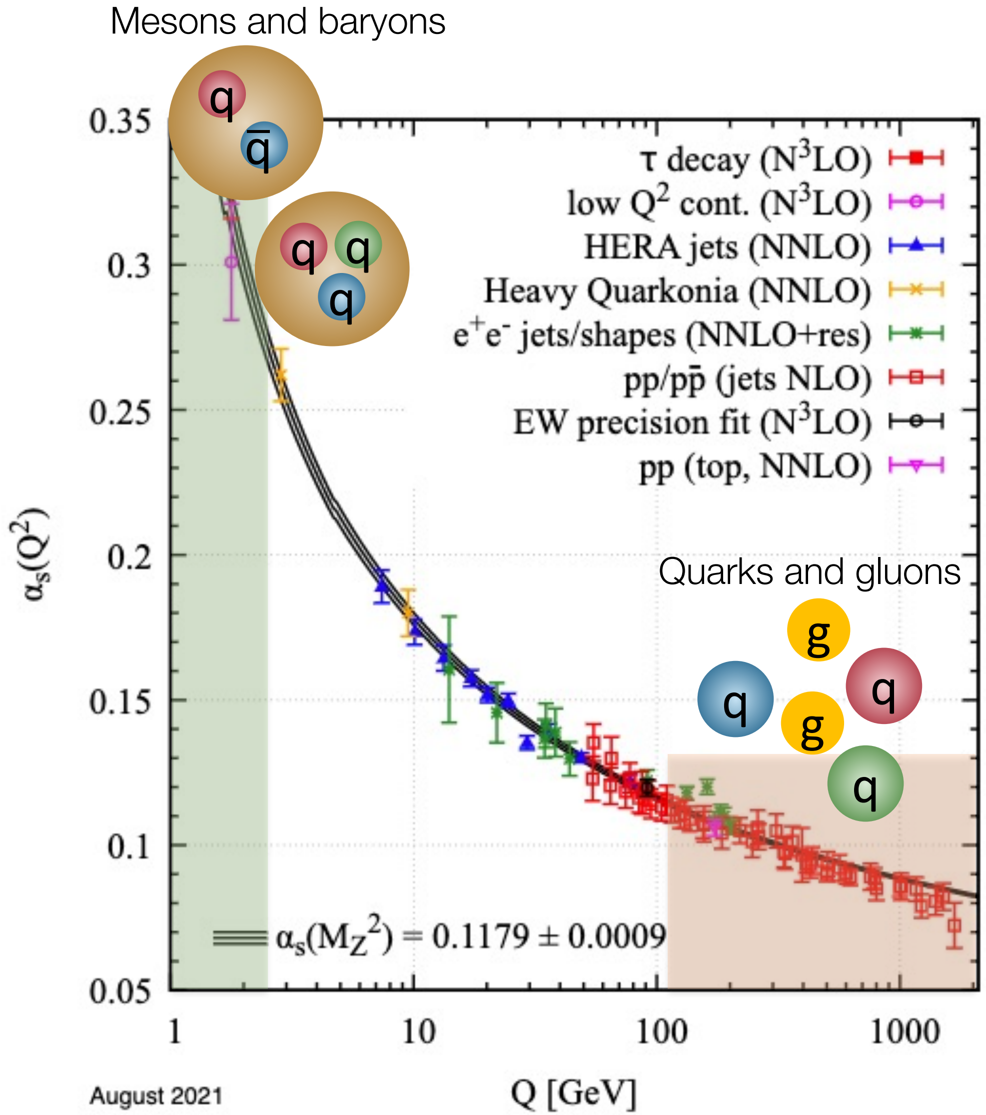


PDG, Prog.Theor.Exp.Phys 2022, 083C01(2022)

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

How do hadrons emerge?

Strong interaction between hadrons…from fm to km!



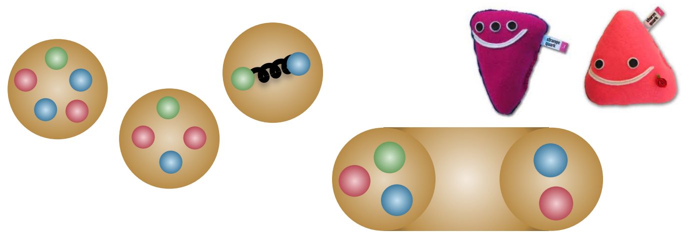
PDG, Prog.Theor.Exp.Phys 2022, 083C01(2022)

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

How do hadrons emerge?

How is the QCD spectrum organized?

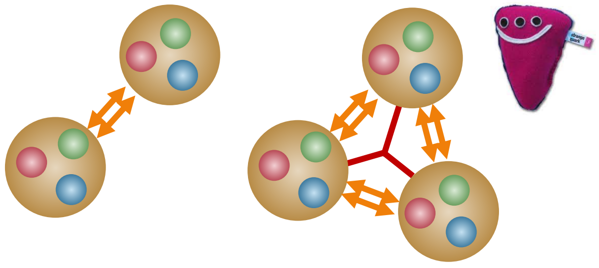
Bound states/resonances



Searches for exotic states

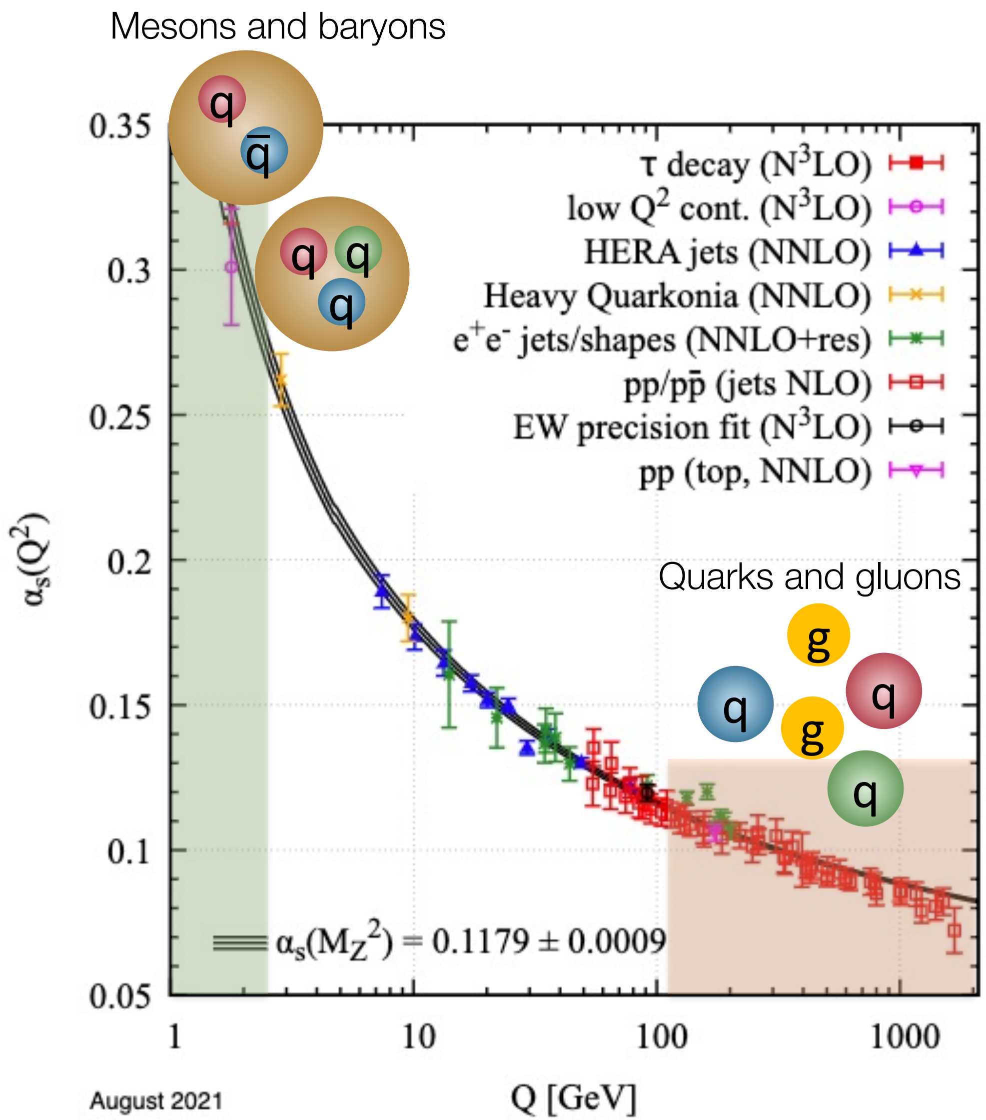
How do hadrons interact?

2-body and many-body interactions



Physics of neutron stars

Strong interaction between hadrons…from fm to km!



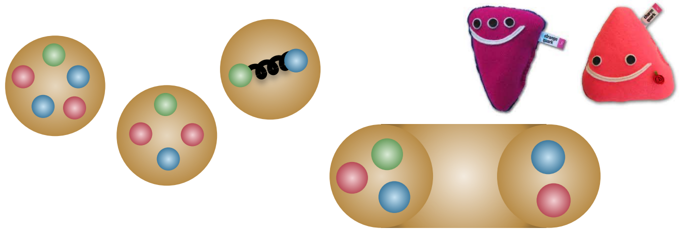
PDG, Prog.Theor.Exp.Phys 2022, 083C01(2022)

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

How do hadrons emerge?

How is the QCD spectrum organized?

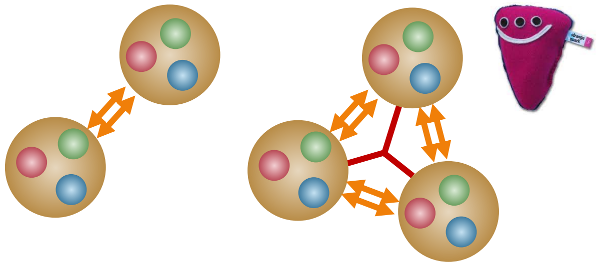
Bound states/resonances



Searches for exotic states

How do hadrons interact?

2-body and many-body interactions

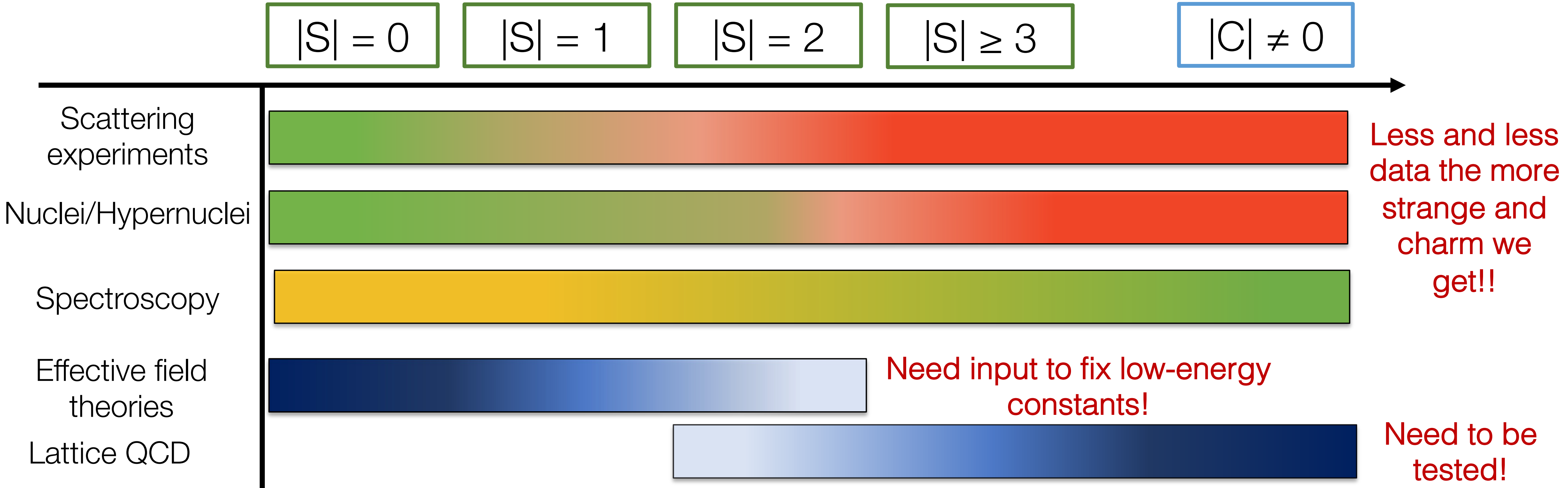


Physics of neutron stars

Need for experimental data!

valentina.mantovani-sarti@tum.de

Understanding and measuring the hadronic interactions



Need for high-precision data and complementary experimental constraints

Understanding and measuring the hadronic interactions

|S| = 0 | |S| = 1 | |S| = 2 | |S| ≥ 3 | |C| ≠ 0

Scattering experiments

Nuclei/Hypernuclei

Spectroscopy

Less and less data the more strange and charm we get!!

Effective field theories

Need input to fix low-energy constants!

Lattice QCD

Need to be tested!

Need for high-precision data and complementary experimental constraints

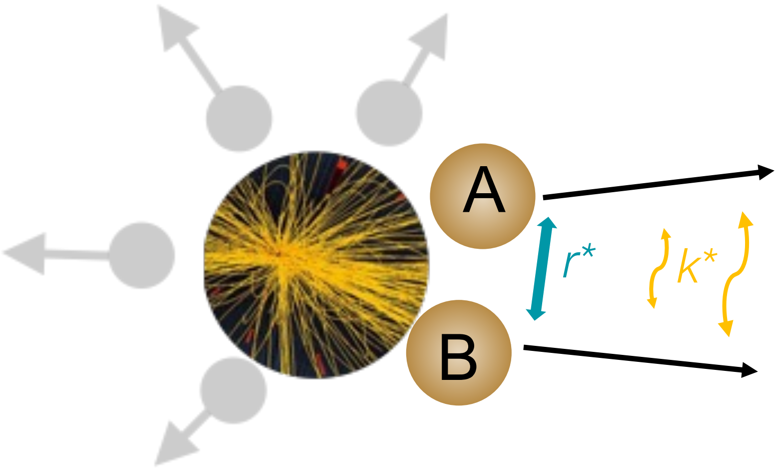
Correlations

Can we improve this scenario with femtoscopy at LHC?

Accessing hadronic interactions with correlations at LHC

$$\mathbf{C(k^*)} = \mathcal{N}(k^*)\,\frac{N_{\mathrm{same}}(k^*)}{N_{\mathrm{mixed}}(k^*)}$$

M.Lisa, S. Pratt et al, ARNPS. 55 (2005), 357-402
L. Fabbietti, VMS and O. Vazquez Doce ARNPS 71 (2021), 377-402



Accessing hadronic interactions with correlations at LHC

Koonin-Pratt equation

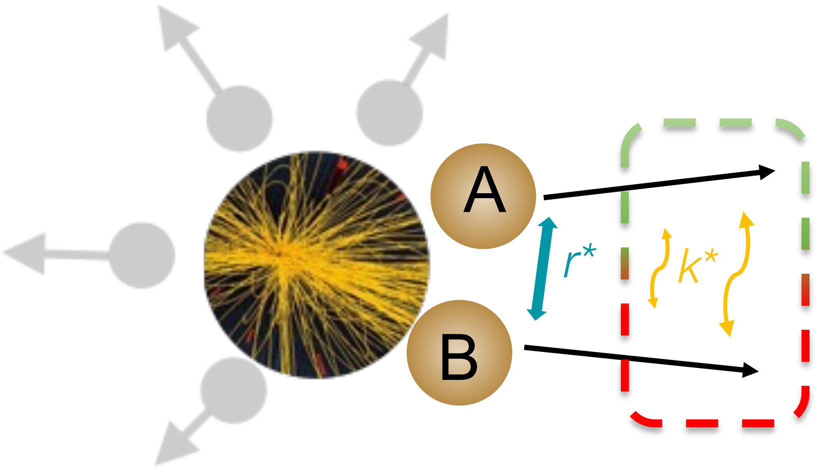
S. E. Koonin, Phys. Lett. B 70, 43 (1977)

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

M.Lisa, S. Pratt et al, ARNPS. 55 (2005), 357-402
L. Fabbietti, VMS and O. Vazquez Doce ARNPS 71 (2021), 377-402

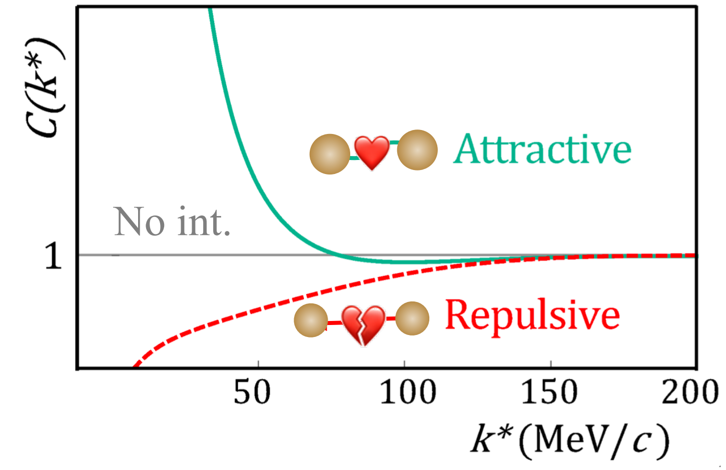
via solving exactly scattering equations or assuming asymptotic behaviour

CATS: D. Mihaylov et al. Eur.Phys.J.C 78 (2018) 5, 394
Lednicky Sov. J. Nucl. Phys. 35 (1982) 770



Interaction

ALICE Coll. Nature 588 (2020) 232-238



Correlation mapping 1-to-1 the nature of the interaction

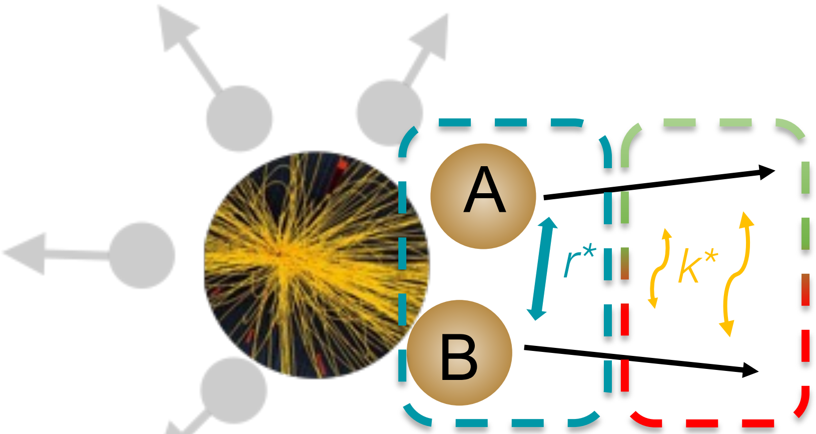
Accessing hadronic interactions with correlations at LHC

Koonin-Pratt equation
S. E. Koonin, Phys. Lett. B 70, 43 (1977)

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

M.Lisa, S. Pratt et al, ARNPS. 55 (2005), 357-402
L. Fabbietti, VMS and O. Vazquez Doce ARNPS 71 (2021), 377-402

Emitting source

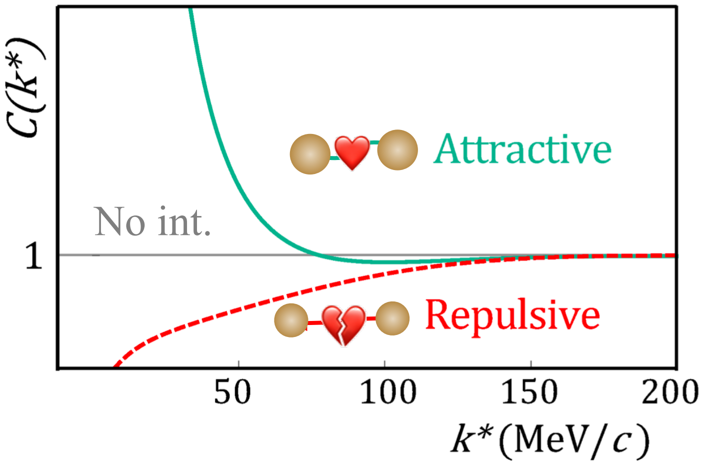


r^* ~1-2 fm

- Average relative r^*_{AB} distances at which particles are produced
- How much $\left|\psi(\vec{k}^*,\vec{r}^*)\right|^2$ do we sample?
- It depends on the collision system

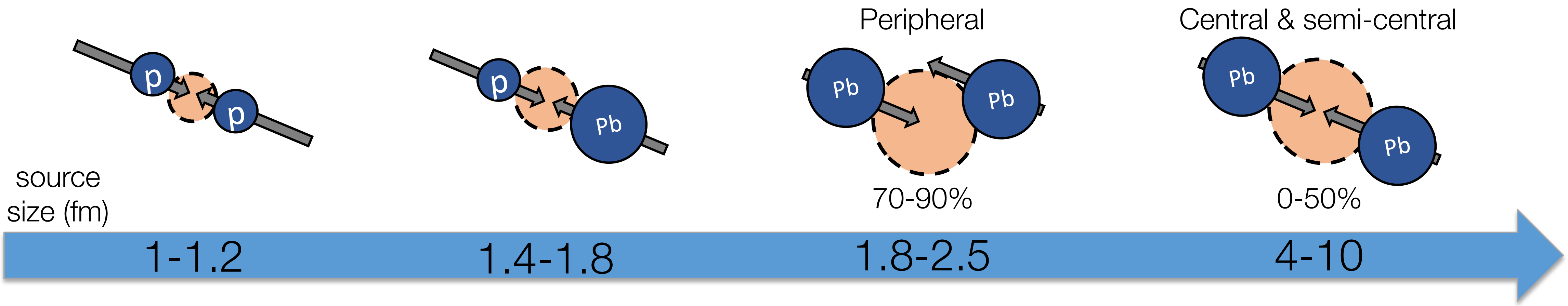
Interaction

ALICE Coll. Nature 588 (2020) 232-238

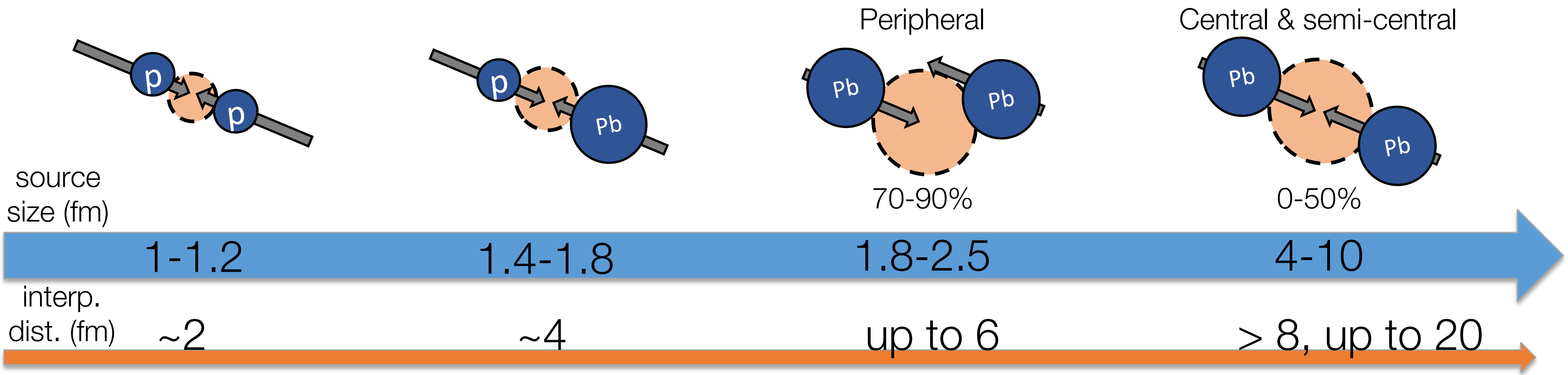


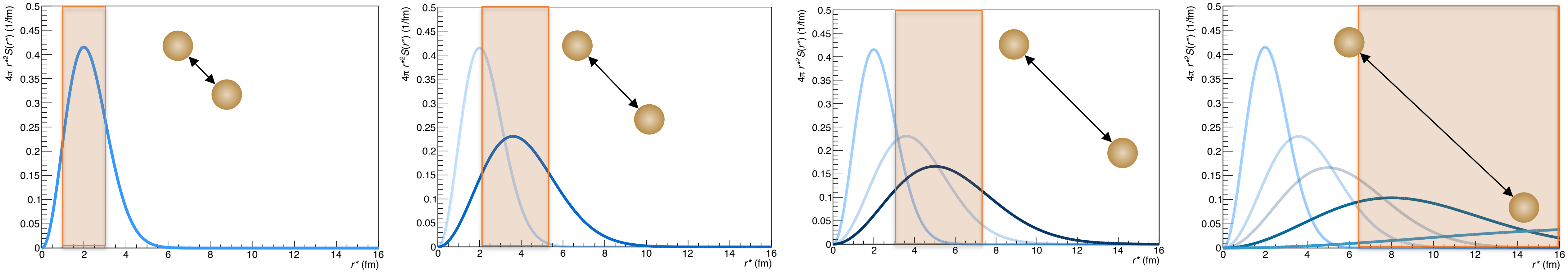
What ranges of inter-particle distances can we probe at LHC?

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



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

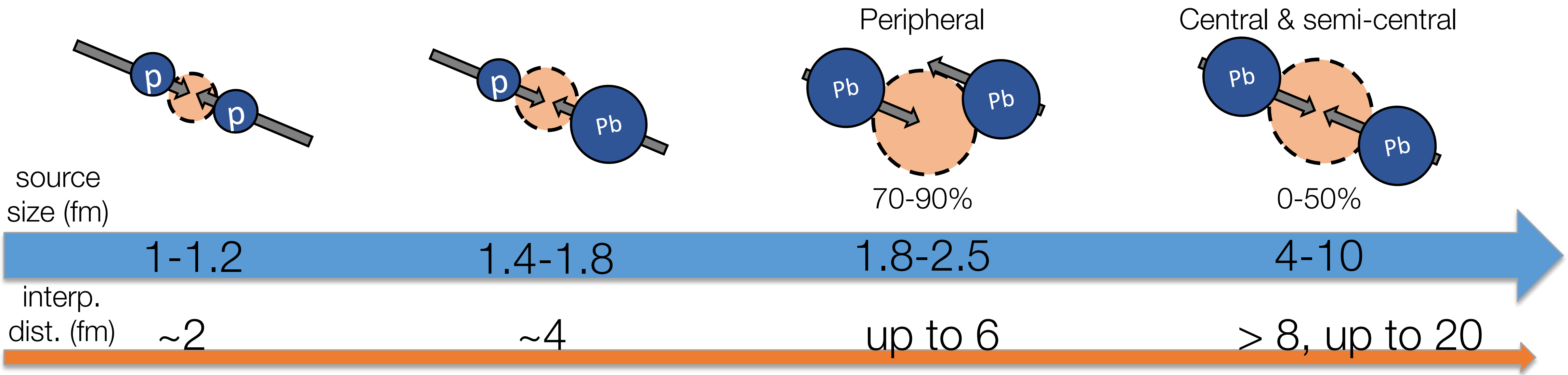


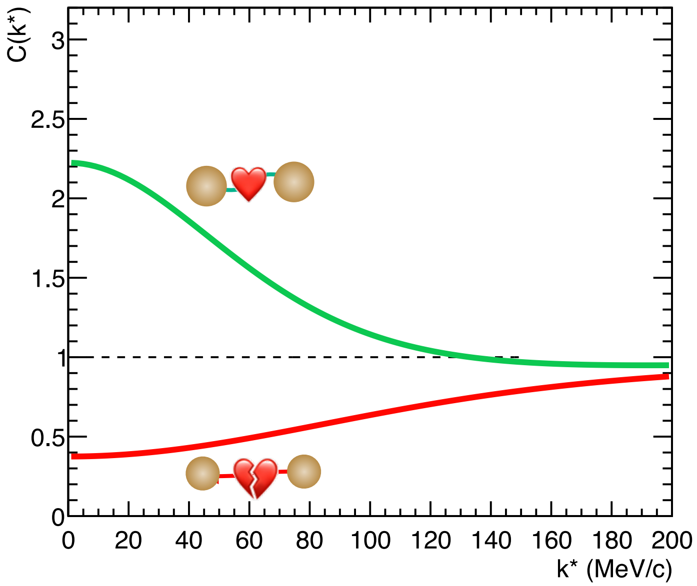


How does the signal in the correlation function changes with the source size?

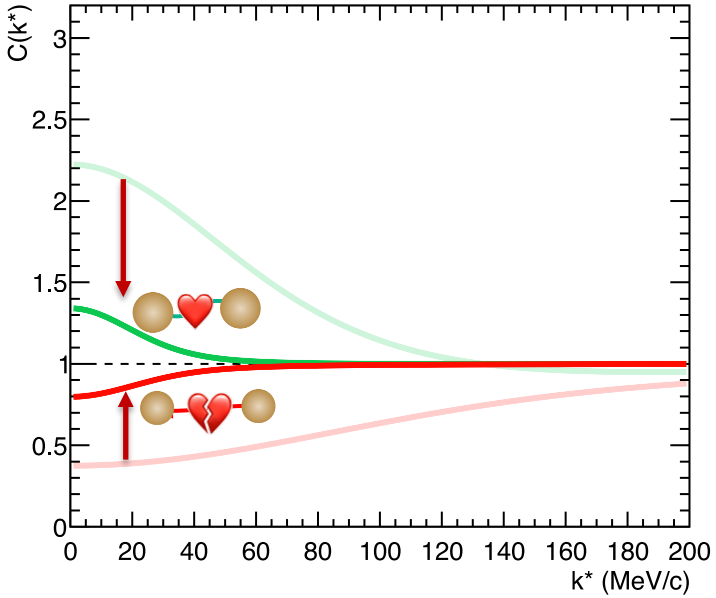
valentina.mantovani-sarti@tum.de

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



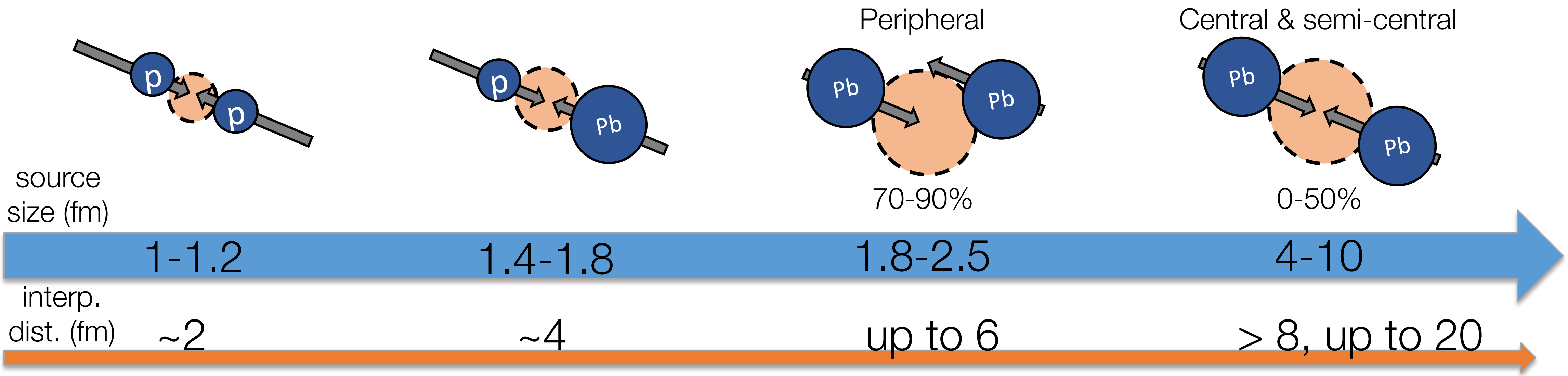


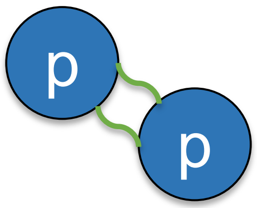
Decrease of signal strength for large source sizes



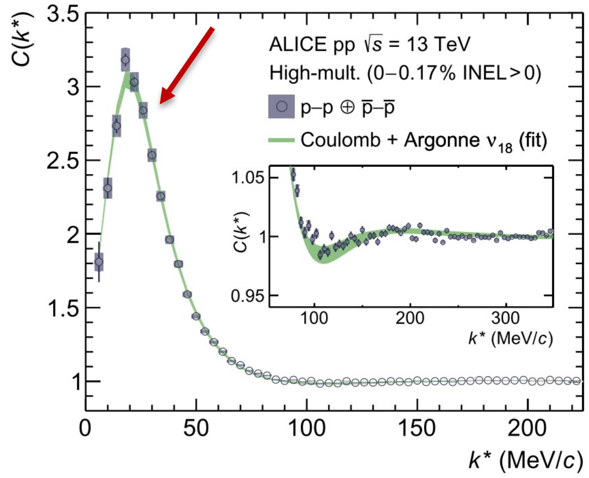
valentina.mantovani-sarti@tum.de

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

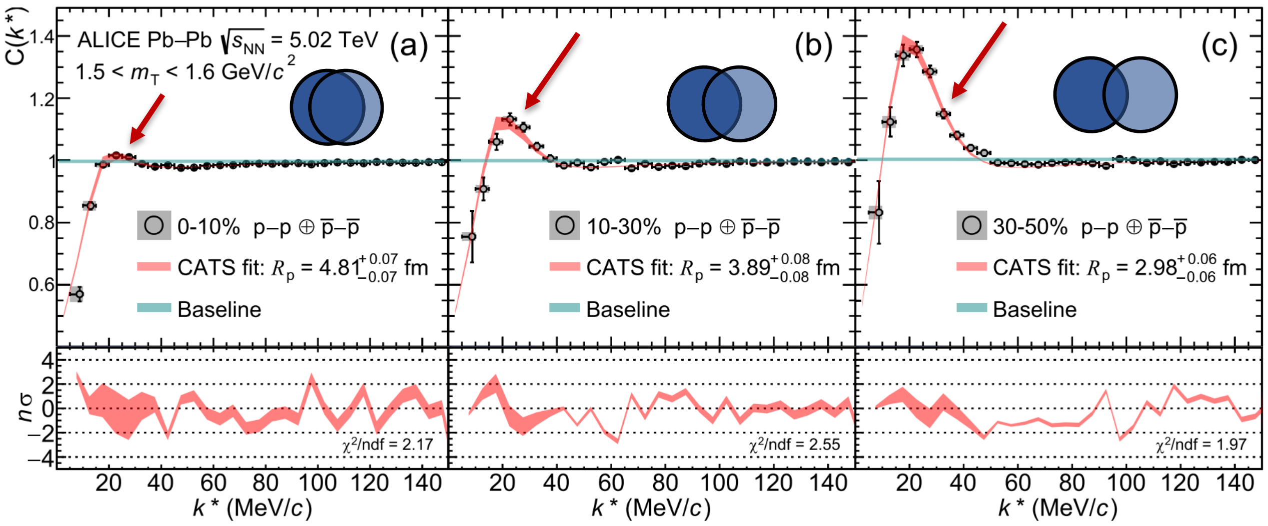




ALICE Coll. Phys.Lett.B 805 (2020) 135419

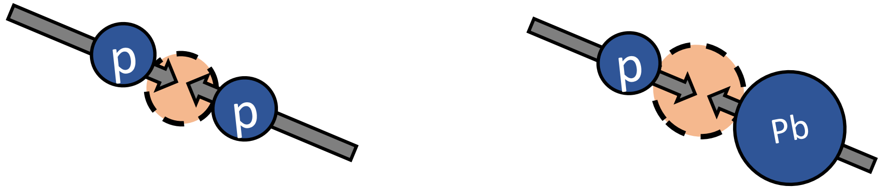


ALICE Coll. Phys.Lett.B 871 (2025) 139921

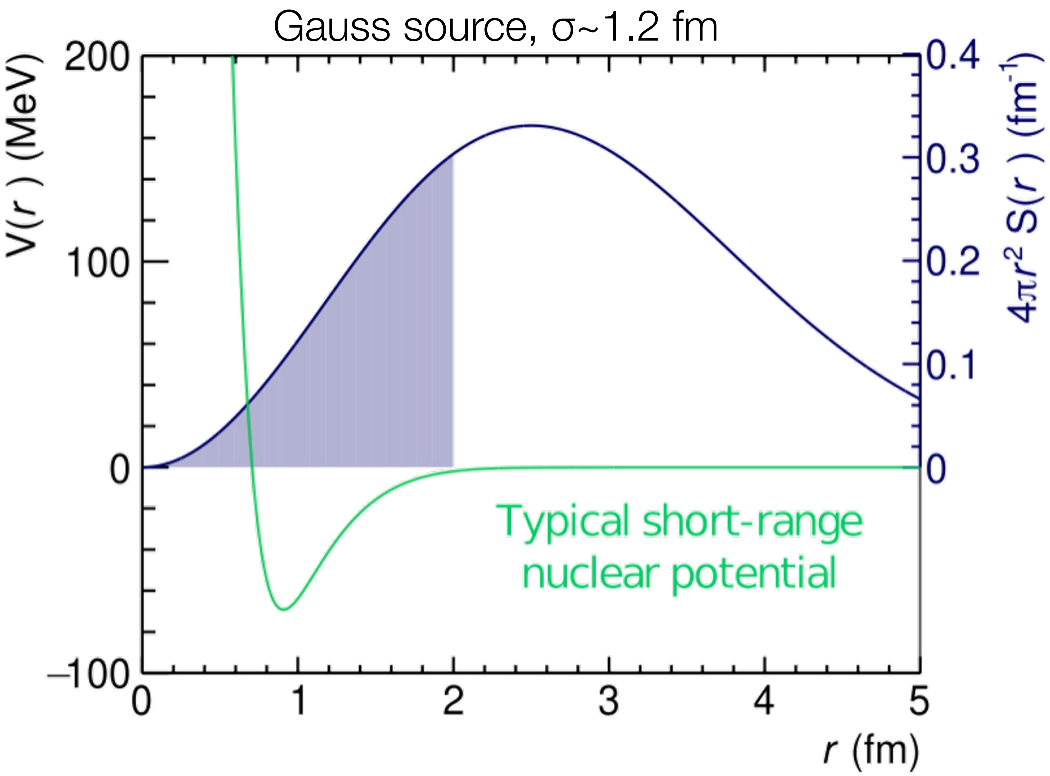


valentina.mantovani-sarti@tum.de

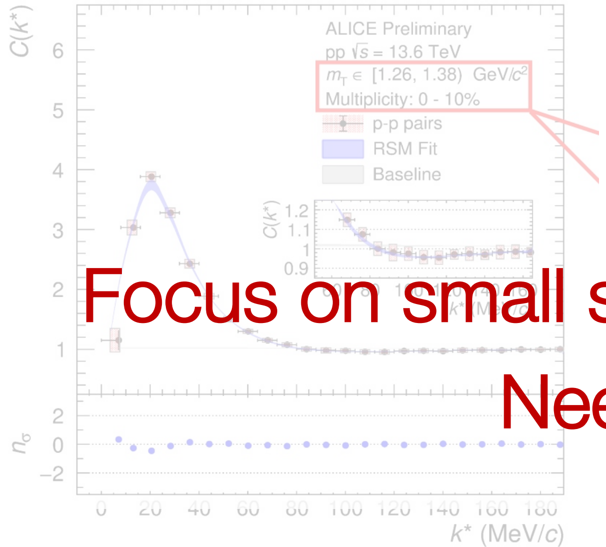
Small and large colliding systems at LHC: from pp to Pb-Pb

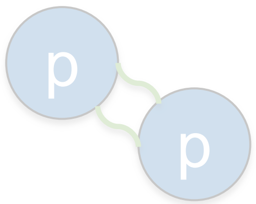


	pp	p-Pb
source size (fm)	1-1.2	1.4-1.8
interp. dist. (fm)	~2	~4



ALICE Coll.: Poster by A. Riedel QM 25



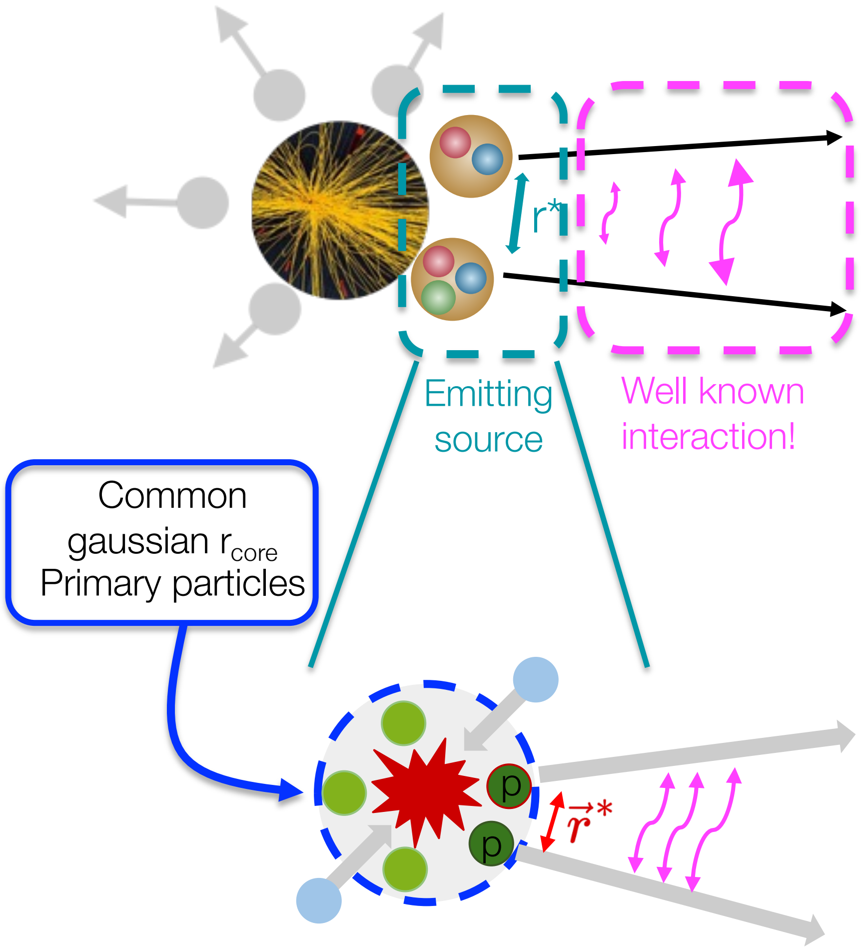


Focus on small systems to access the strong interaction

Need to constrain the source!!

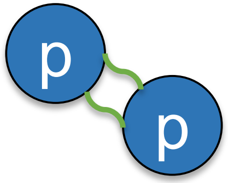
Data-driven modeling of the source in pp collisions

ALICE Coll. PLB 811 (2020) 135849,
Corrig. PLB 861 (2025)
Eur.Phys.J.C 85 (2025) 2, 1980
arXiv: 2502.20200,



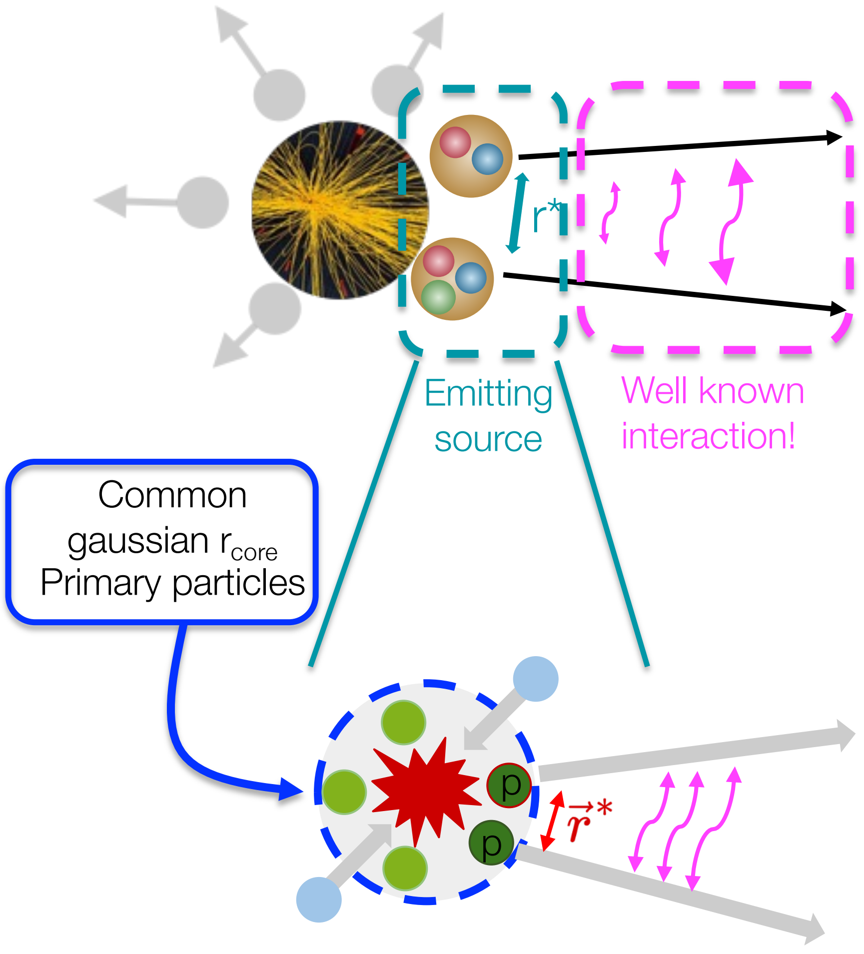
$$C(k^*) = \int S(\vec{r}^*) \left|\psi(\vec{k}^*, \vec{r}^*)\right|^2 d^3\vec{r}^*$$

1. Starting from a very well known interaction between two baryons **easily produce at LHC**!



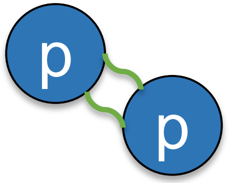
Data-driven modeling of the source in pp collisions

ALICE Coll. PLB 811 (2020) 135849,
Corrig. PLB 861 (2025)
Eur.Phys.J.C 85 (2025) 2, 1980
arXiv: 2502.20200,



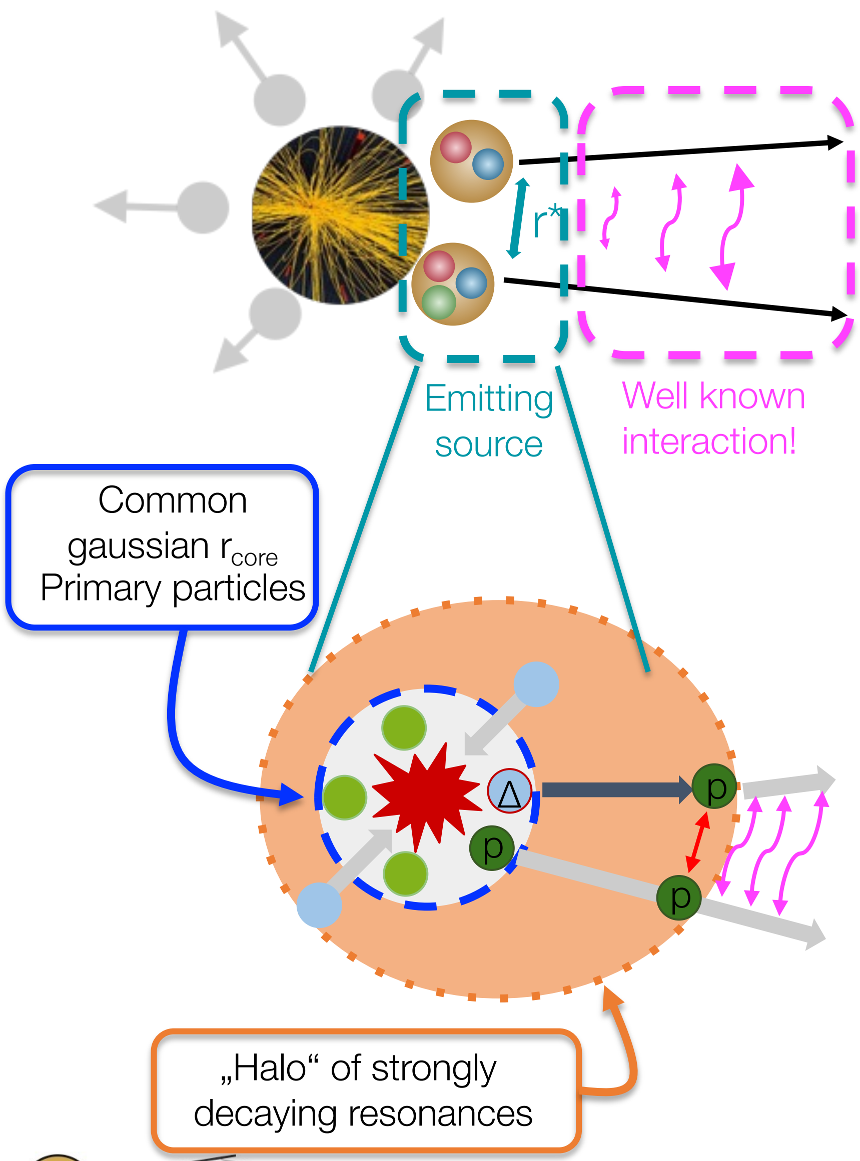
$$C(k^*) = \int S(\vec{r}^*) \; |\psi(\vec{k}^*, \vec{r}^*)|^2 \, d^3\vec{r}^*$$

1. Starting from a very **well known interaction** between two baryons **easily produce at LHC**!



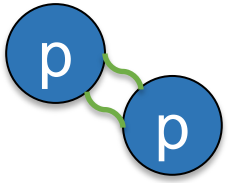
2. Modeling the source
   U. A. Wiedemann, U. W. Heinz, Phys.Rept. 319, 145-230 (1999)
   - Primary particles from common Gaussian core source
     - Observed **scaling with the transverse pair mass m_T**
     - Depending only on the mass of the pair

Data-driven modeling of the source in pp collisions



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

ALICE Coll. PLB 811 (2020) 135849, Corrig. PLB 861 (2025)
Eur.Phys.J.C 85 (2025) 2, 1980
arXiv: 2502.20200,



1. Starting from a very well known interaction between two baryons **easily produce at LHC**!

2. Modeling the source
   U. A. Wiedemann, U. W. Heinz, Phys.Rept. 319, 145-230 (1999)
   - Primary particles from common Gaussian core source
     - Observed scaling with the transverse pair mass m_T
     - Depending only on the mass of the pair
   - Strongly decaying resonances with cτ~1-2 fm ($\Delta \rightarrow p\pi$)
     - Non-gaussianity at large r^*, effectively enlarging the source
     - Depending on the particles in the pair
     - Yields & kinematics from SHM and transport models

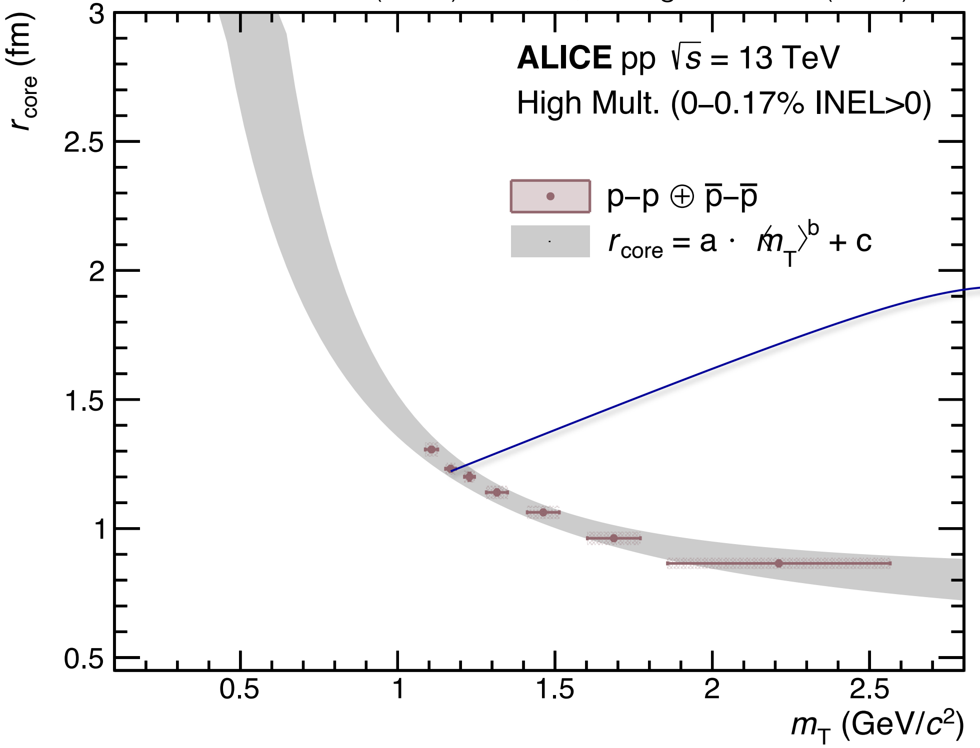
Scenario observed also in studies performed on **ππ pairs**

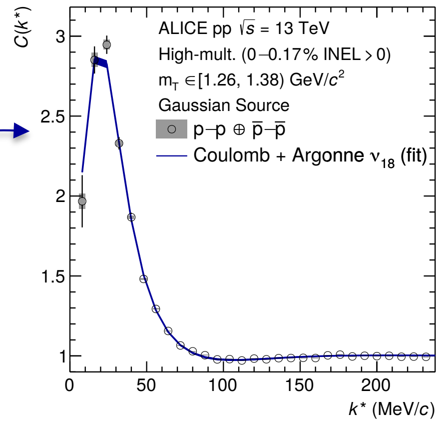
ATLAS Coll. Eur. Phys. J. C 75, 466 (2015), Phys. Rev. C 96, 064908, EPJC 82 (2022) 7, 608
CMS Coll. J. High Energy Phys. 05 (2011) 029, LHCB JHEP 12 (2017) 025
ALICE Coll., Phys. Rev. D 84, 112004 (2011), Eur.Phys.J.C 85 (2025) 2, 198

A common emitting source for baryon-baryon pairs

Baryon-baryon pairs

ALICE Coll. PLB 811 (2020) 135849, Corrig. PLB 861 (2025)



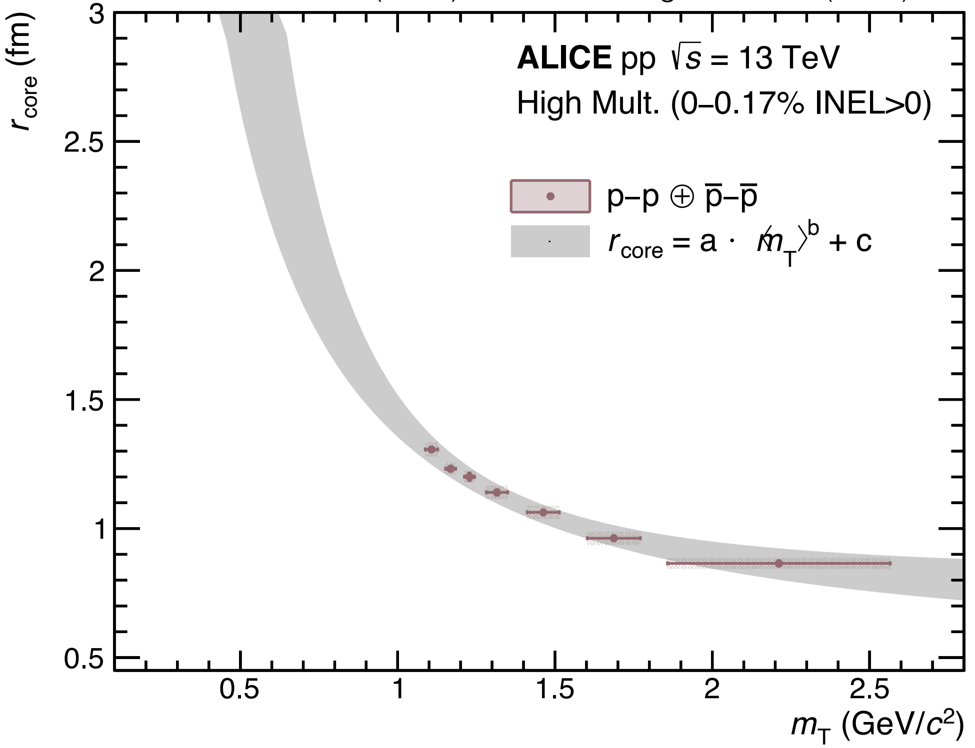


Scaling of core source size observed for baryons

The (common) emitting source in small colliding systems

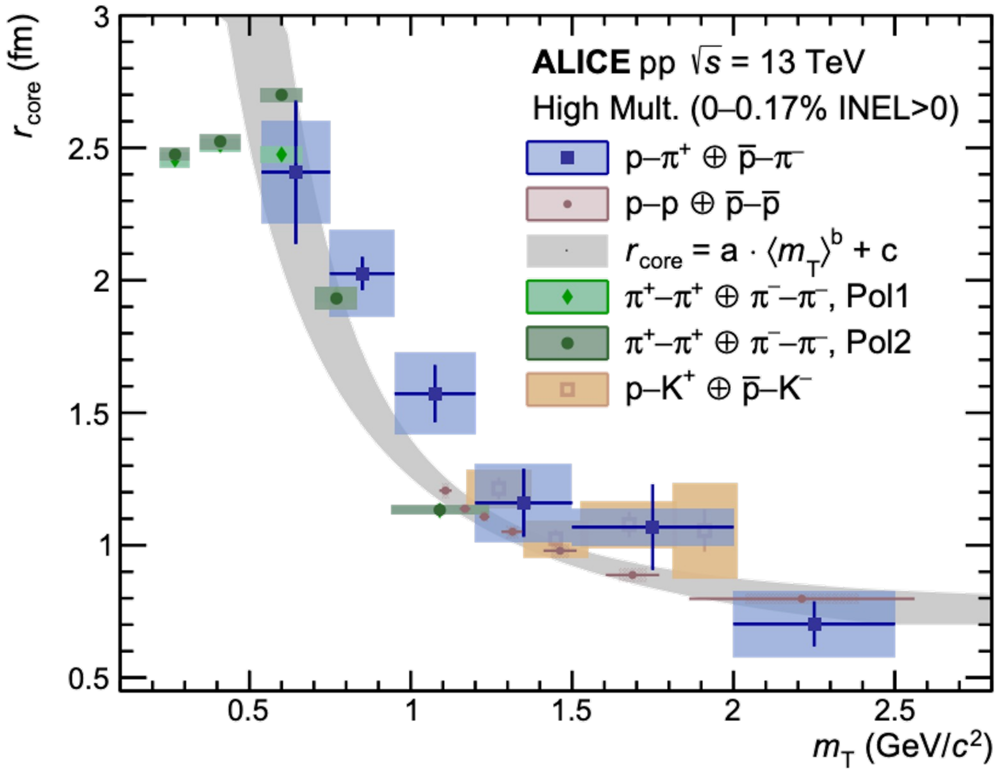
Baryon-baryon pairs

ALICE Coll. PLB 811 (2020) 135849, Corrig. PLB 861 (2025)



Meson-baryon and meson-meson pairs

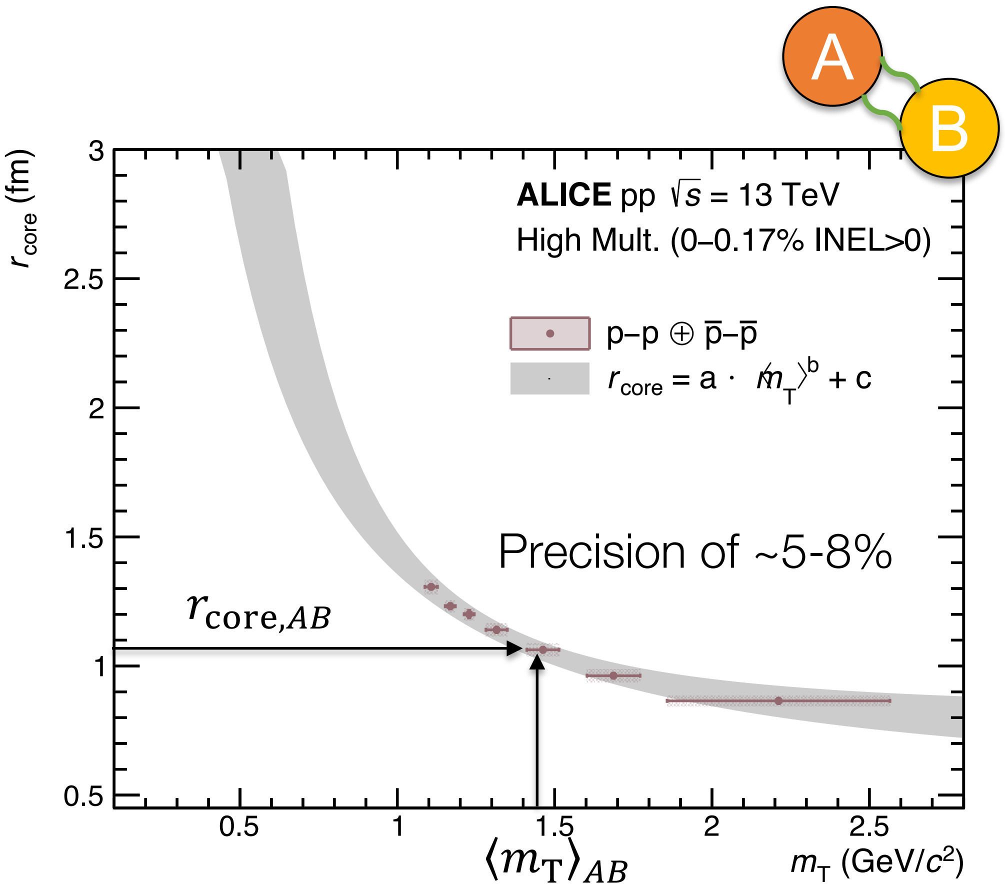
ALICE Coll. Eur.Phys.J.C 85 (2025) 2, 1980



Consistent scaling of the core source size in all hadron-hadron species

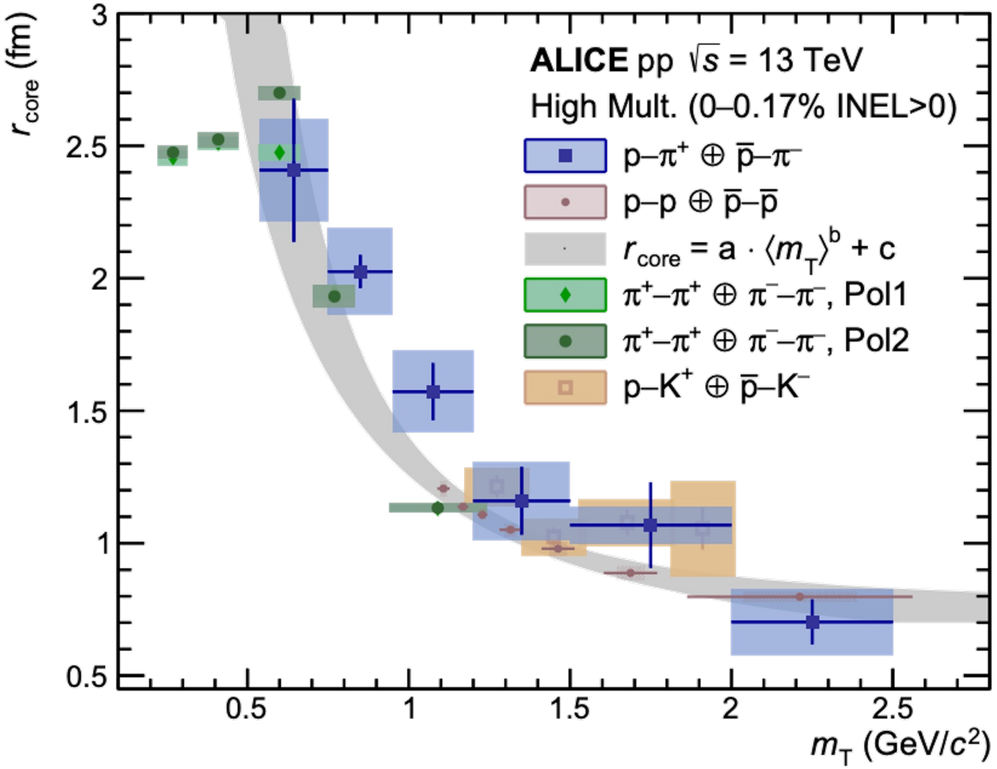
(Extension to multiplicity as well by [ALICE Coll. with Run 3])

A recipe to fix the source and constrain interactions



Meson-baryon and meson-meson pairs

ALICE Coll. arXiv: 2502.20200, Eur.Phys.J.C 85 (2025) 2, 1980



How can femtoscopy help us improving the knowledge on the strong interaction?

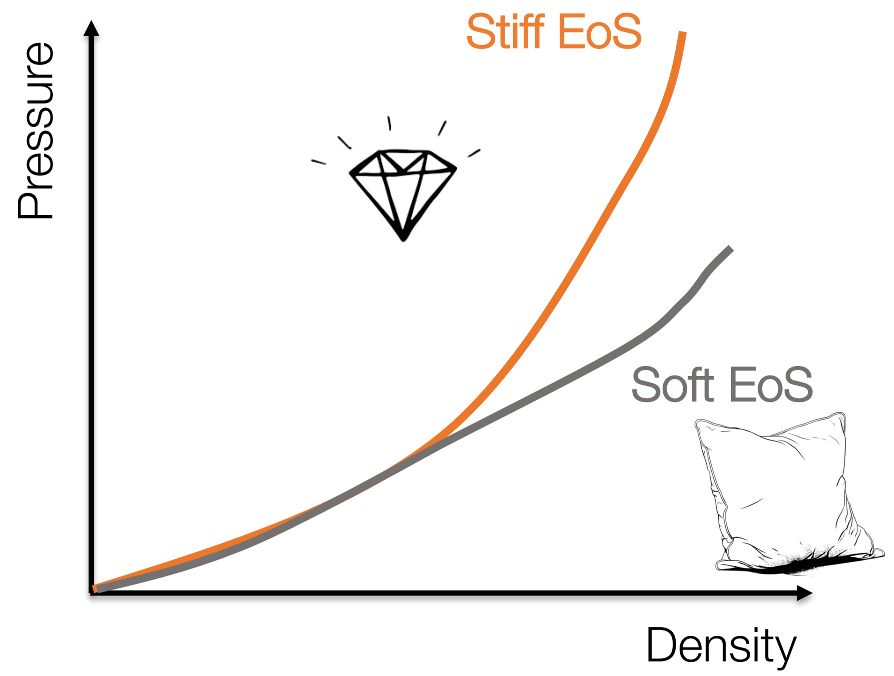
From the ΛN interaction to neutron stars

The equation of state of matter in the core of NS

Equation of State (EoS)

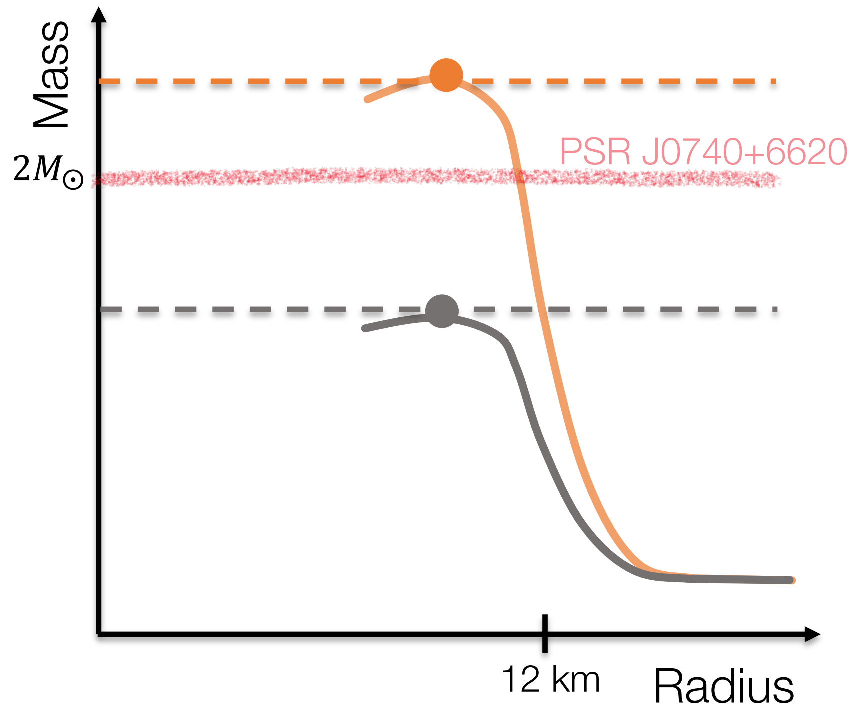
– relation between the **pressure and density**, depends on the constituents and their interaction

See talk by
A. Watts Mon. 9:00
J. Lattimer Fri 17:30



TOV eqns.

Observations of heavy NSs



What are the constituents to consider?

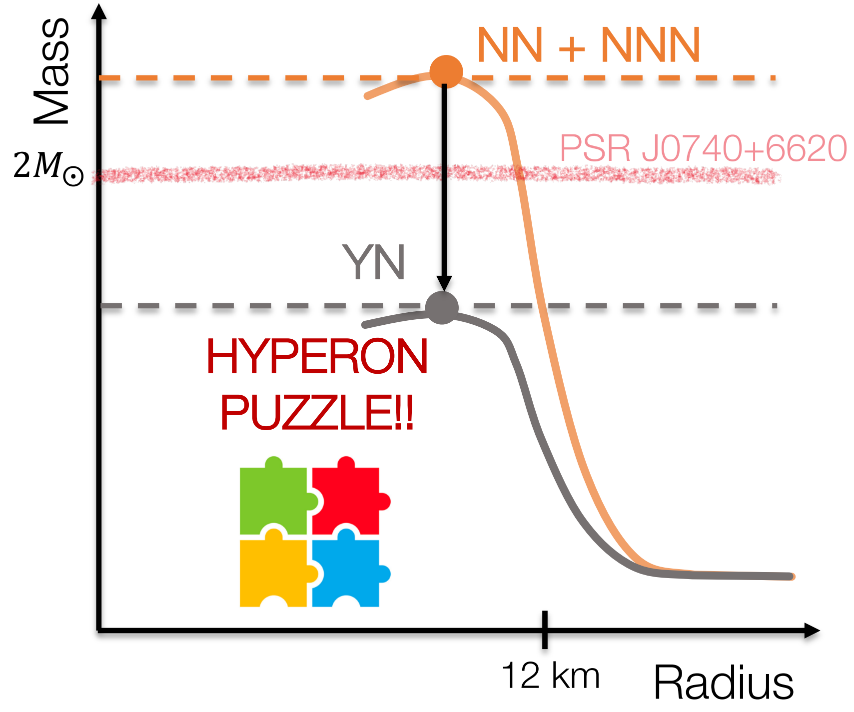
How do they interact in the NS medium?

valentina.mantovani-sarti@tum.de

Hyperons in neutron stars

- Production of hyperons in NS energetically favourable around 2-3 ρ_0
- Appearance of new degrees of freedom
  - Softening of EoS, incompatible with heavy measured NS

Hyperon puzzle!



Hyperons in neutron stars

- Production of hyperons in NS energetically favourable around 2-3 ρ_0

- Appearance of new degrees of freedom
  - Softening of EoS, incompatible with heavy measured NS

Hyperon puzzle!

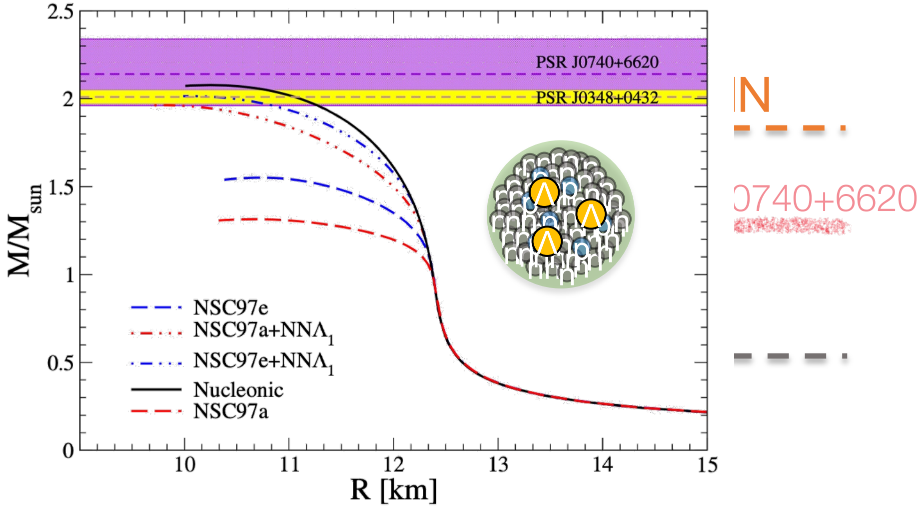
- Three-body ΛNN repulsive forces to stiffen EoS
  - How much repulsion?
    → Model-dependent

With Λ hyperons: D. Logoteta et al., Eur.Phys.J.A 55 (2019)
No Λ hyperons in NS: D. Gerstung et al., Eur.Phys.J.A 56 (2020)
No bound hypernuclei: D. Lonardoni et al., PRL 114 (2019)

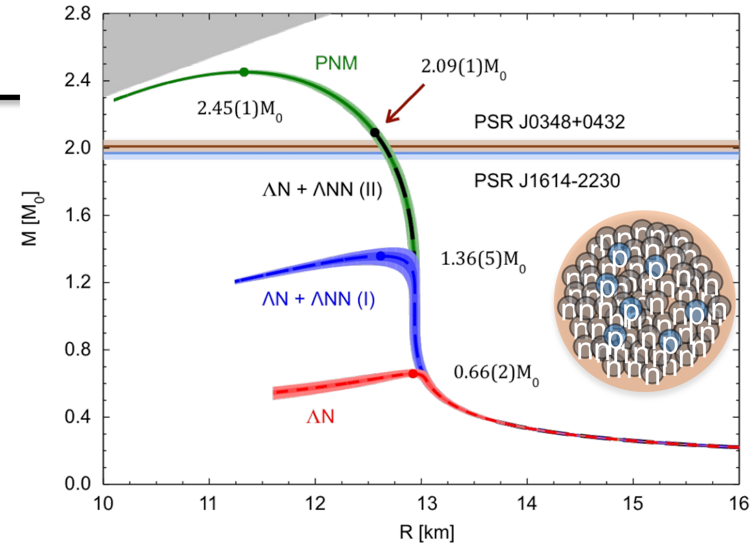
→ Need for more experimental constraints

- More exotics scenarios possible as well

D. Logoteta et al., Eur.Phys.J.A 55 (2019)



D. Lonardoni et al., PRL 114 (2019)



valentina.mantovani-sarti@tum.de

Hyperons in neutron stars

- Production of hyperons in NS energetically favourable around 2-3 ρ_0
- Appearance of new degrees of freedom
  - Softening of EoS, incompatible with heavy measured NS

Hyperon puzzle!

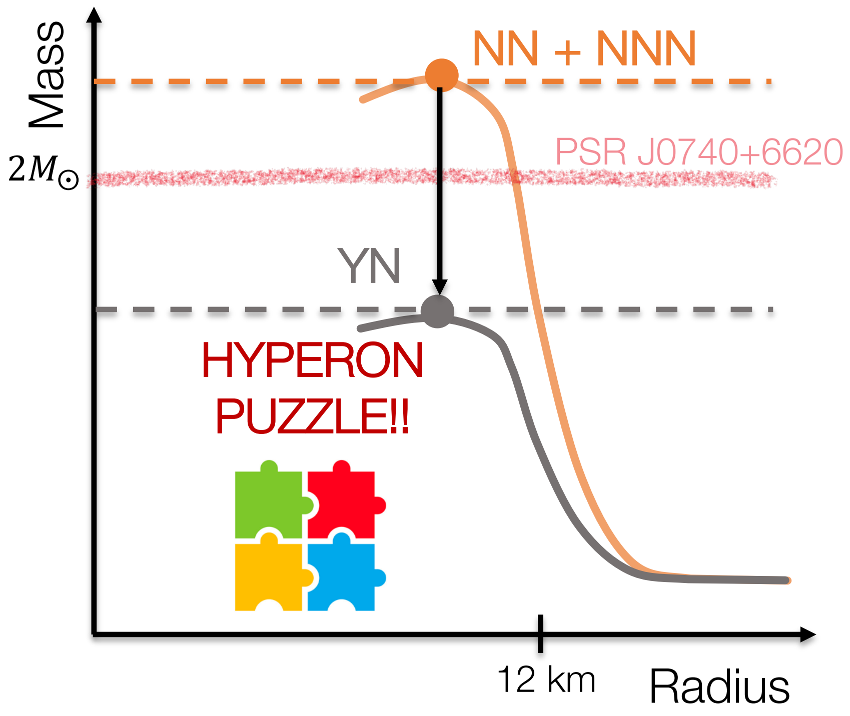
- Three-body ΛNN repulsive forces to stiffen EoS
  - How much repulsion?
    → Model-dependent

With Λ hyperons: D. Logoteta et al., Eur.Phys.J.A 55 (2019)
No Λ hyperons in NS: D. Gerstung et al., Eur.Phys.J.A 56 (2020)
No bound hypernuclei: D. Lonardoni et al., PRL 114 (2019)

→ Need for more experimental constraints

- More exotics scenarios possible as well

See also talk by:
W. Newton Wed. 11:00
A. Weiler Thur. 09:00

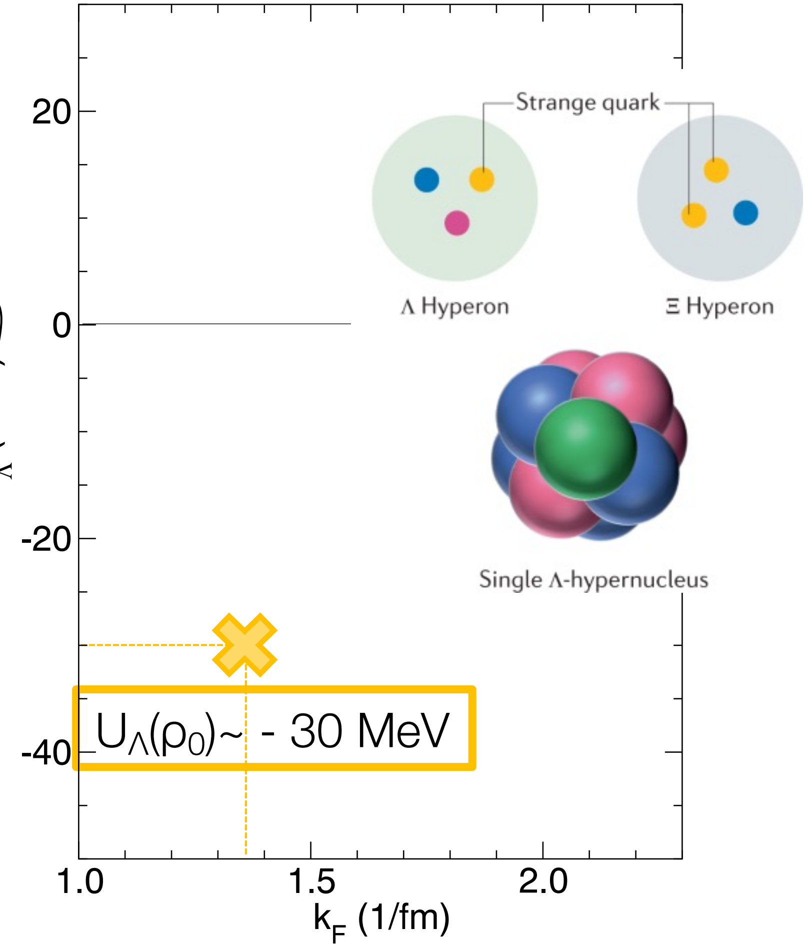


But how precisely do we know two-body YN and YY?

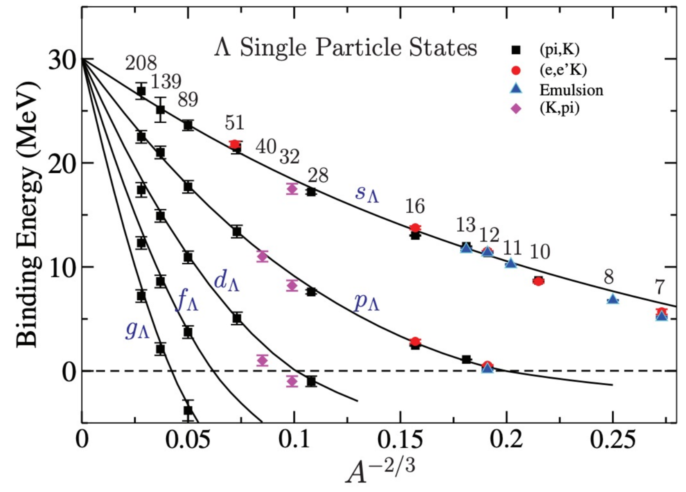
A key example: the interaction between Λ and nucleons

Single-particle potential:

- Average potential the **hyperon "feels"** in the medium
- Depends on **YN (YNN) interactions**



Gal, Hungerford,Millener. Rev. Mod. Phys., 88(3):035004, 2016

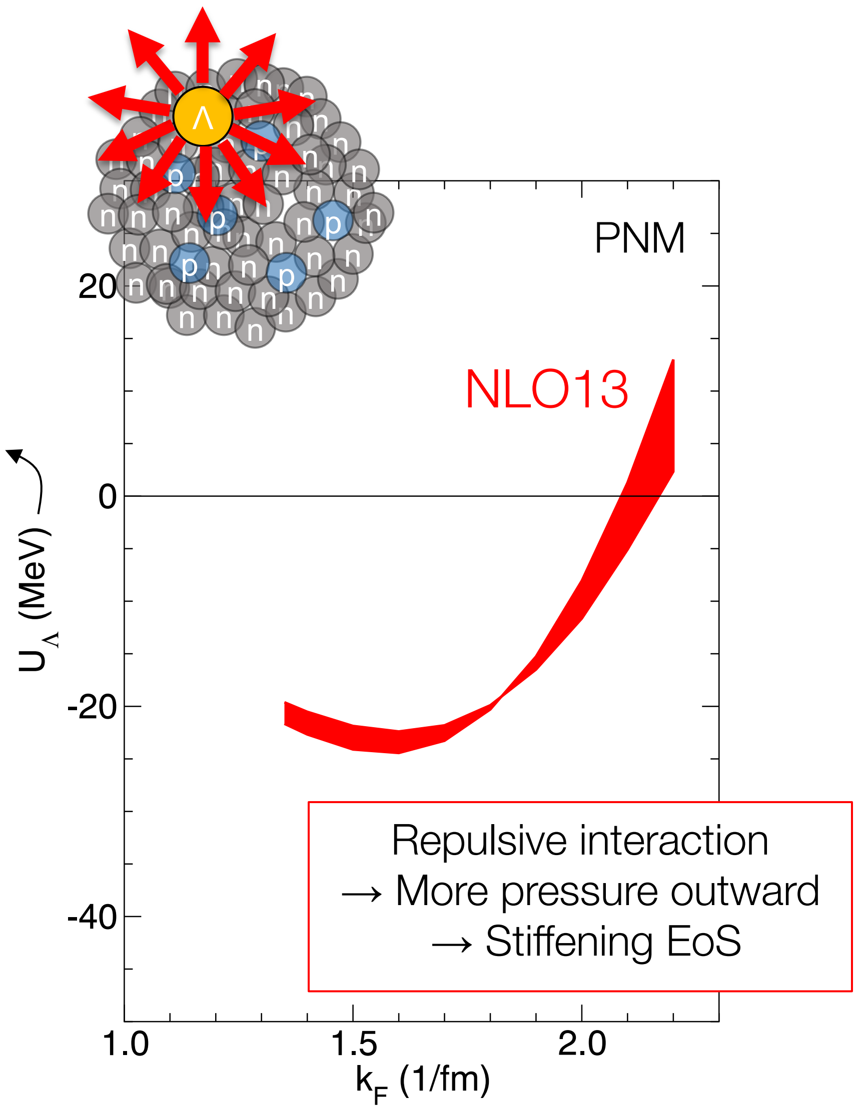


Woods-Saxon $V = 30.05$ MeV, $r = 1.165$ fm, $a = 0.6$ fm

A key example: the interaction between Λ and nucleons

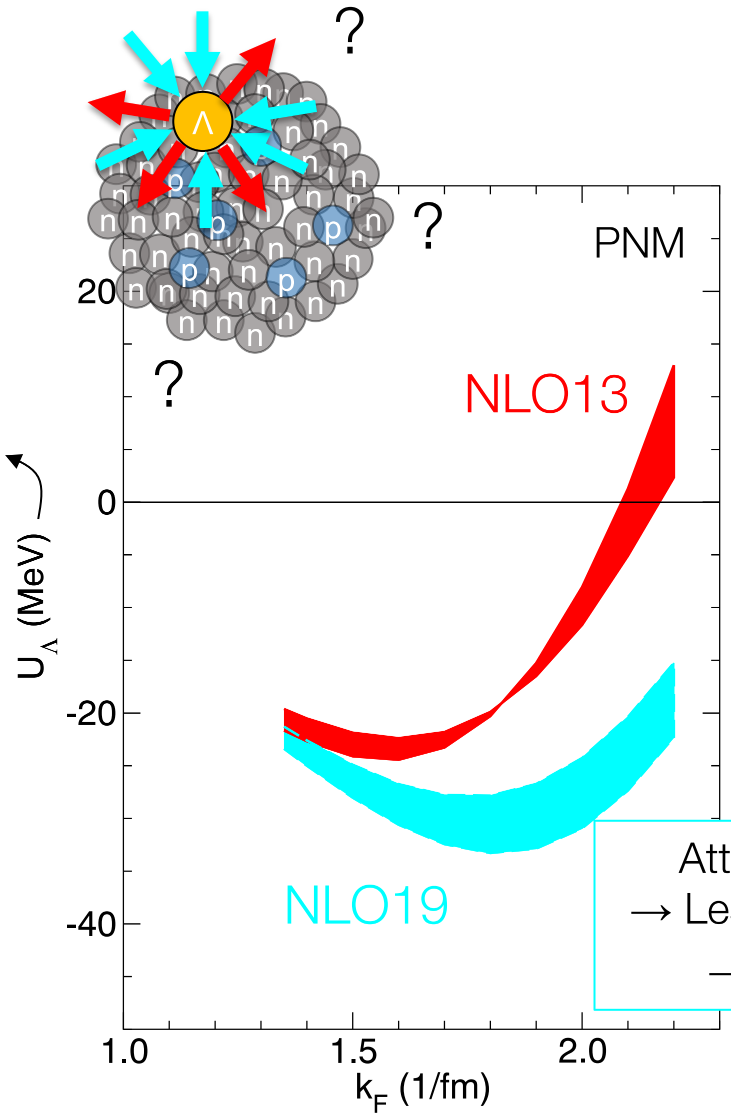
Single-particle potential:

- Average potential the **hyperon "feels" in the medium**
- Depends on **YN (YNN) interactions**



NLO13: J.Haidenbauer et al., NPA 915, 24 (2013)

A key example: the interaction between Λ and nucleons



Single-particle potential:

- Average potential the **hyperon "feels" in the medium**
- Depends on **YN (YNN) interactions**

Attractive interaction
→ Less pressure outward
→ Softening EoS

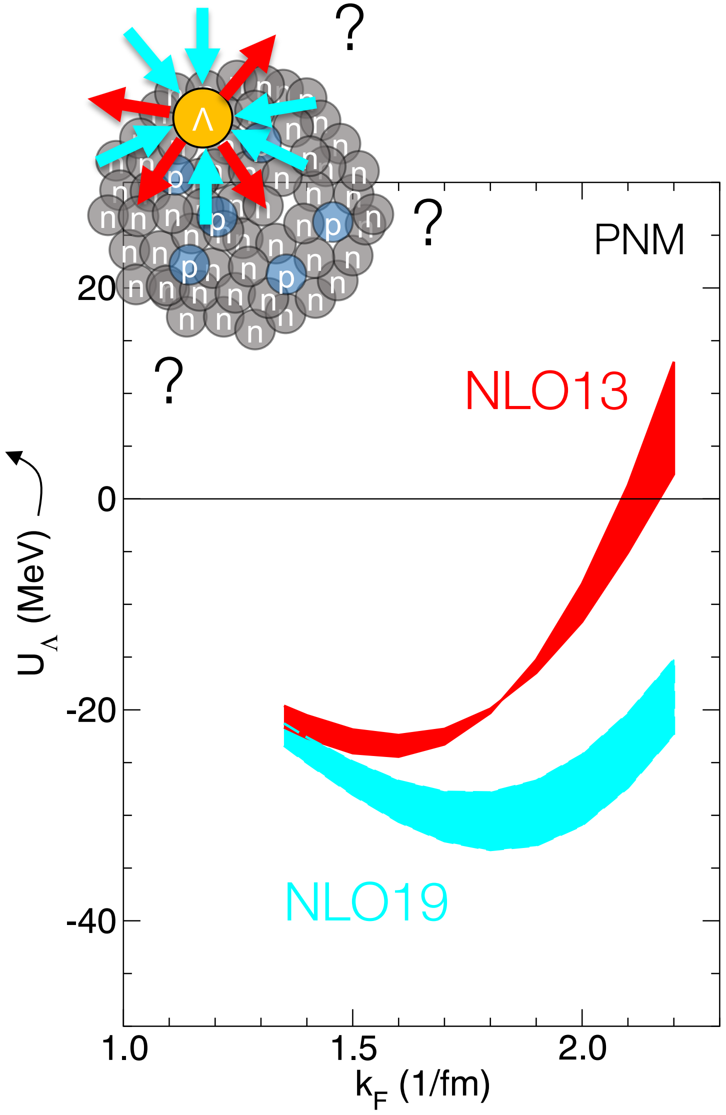
How can we discriminate between these two models?

NLO13: J.Haidenbauer et al., NPA 915, 24 (2013)
NLO19: J.Haidenbauer, U. Meiβner, EPJA 56 (2020)

The ΛN interaction via scattering data…

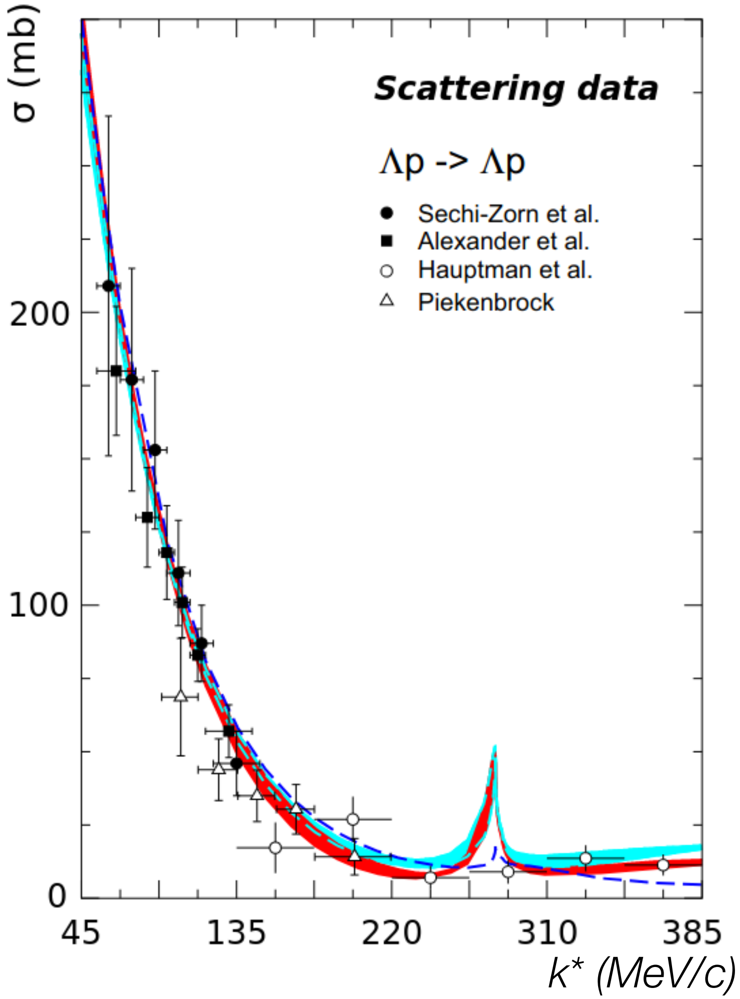
Single-particle potential:

- Average potential the **hyperon "feels" in the medium**
- Depends on **YN (YNN) interactions**



NLO13: J.Haidenbauer et al., NPA 915, 24 (2013)
NLO19: J.Haidenbauer, U. Meißner, EPJA 56 (2020)

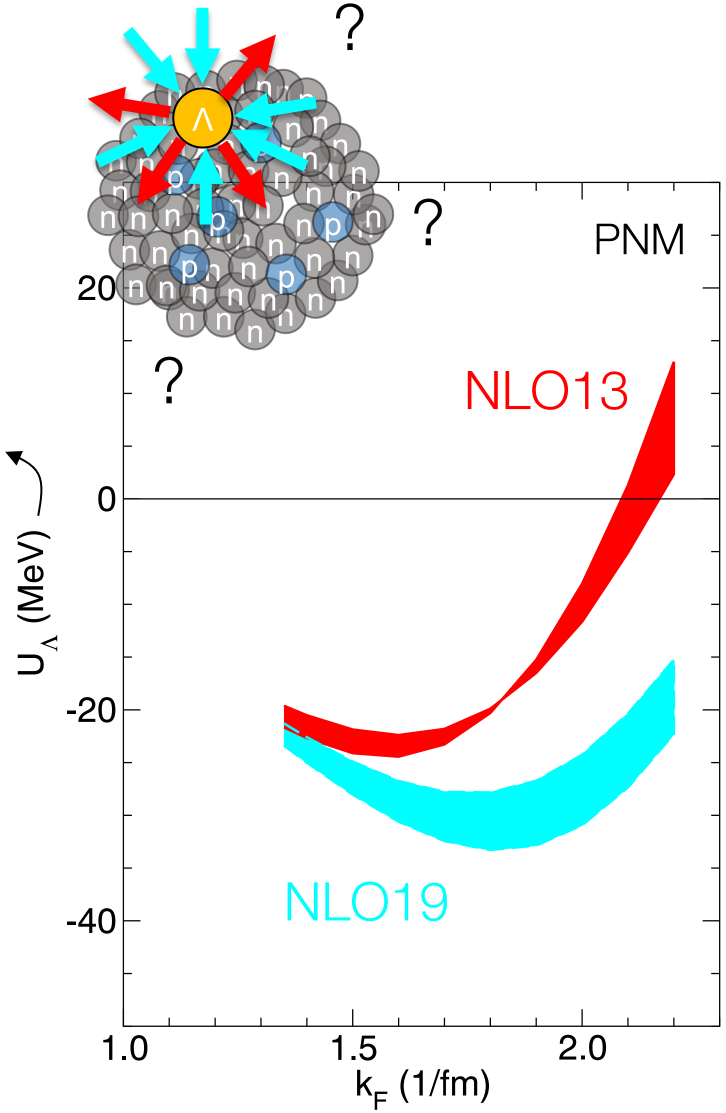
See talk by K. Miwa Tue. 12:10



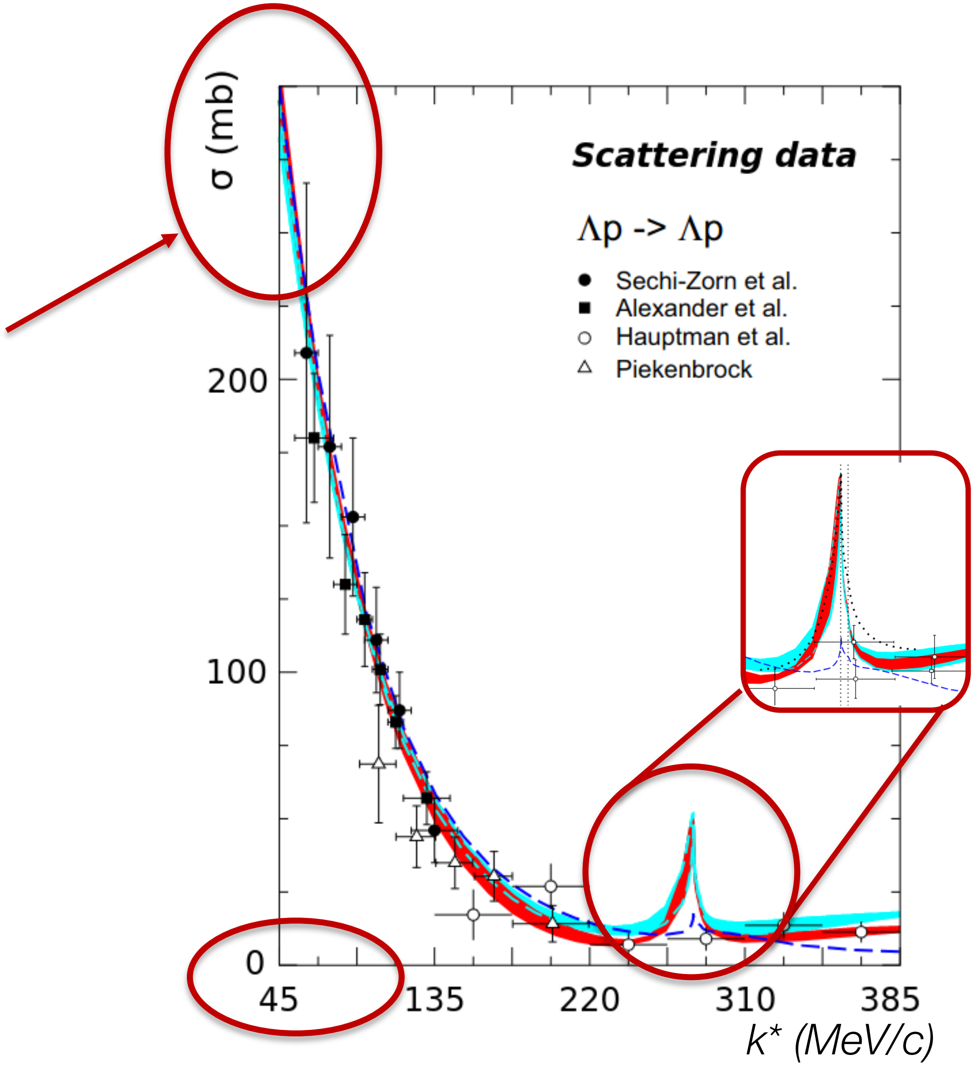
The ΛN interaction via scattering data…

Single-particle potential:

- Average potential the **hyperon "feels" in the medium**
- Depends on **YN (YNN) interactions**



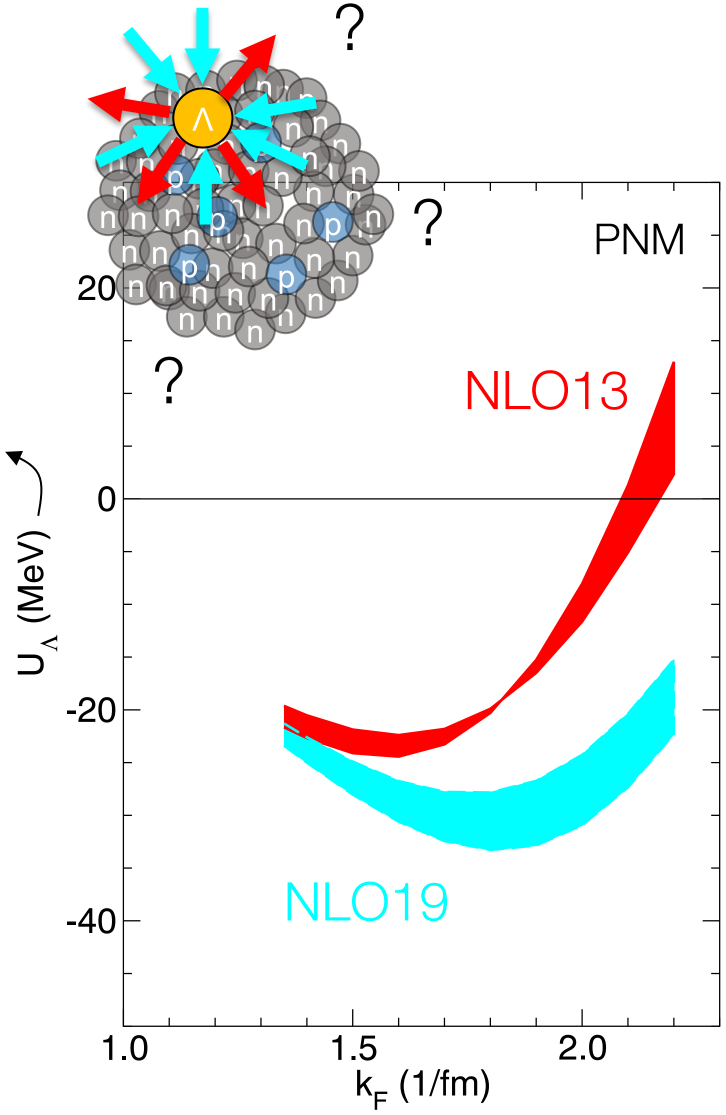
NLO13: J.Haidenbauer et al., NPA 915, 24 (2013)
NLO19: J.Haidenbauer, U. Meißner, EPJA 56 (2020)



The ΛN interaction via scattering data…

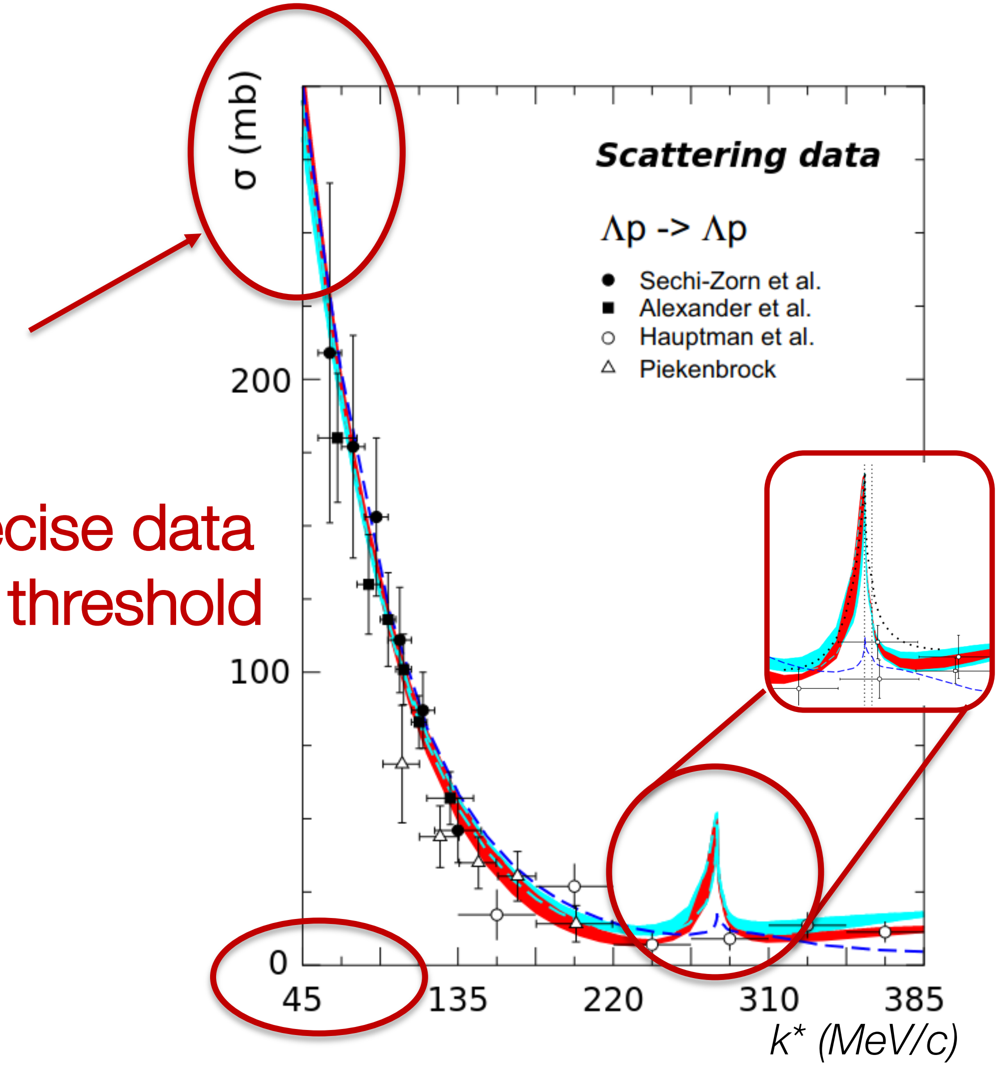
Single-particle potential:

- Average potential the **hyperon** "**feels**" **in the medium**
- Depends on **YN** **(YNN) interactions**



NLO13: J.Haidenbauer et al., NPA 915, 24 (2013)
NLO19: J.Haidenbauer, U. Meiβner, EPJA 56 (2020)

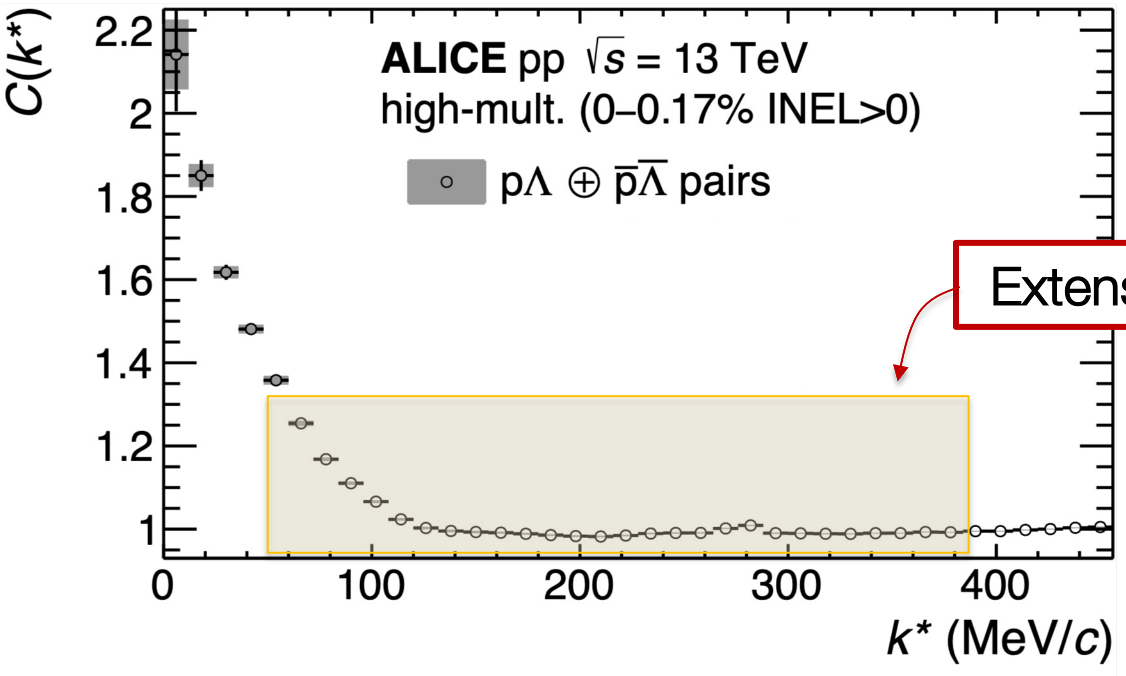
More precise data
Down to threshold



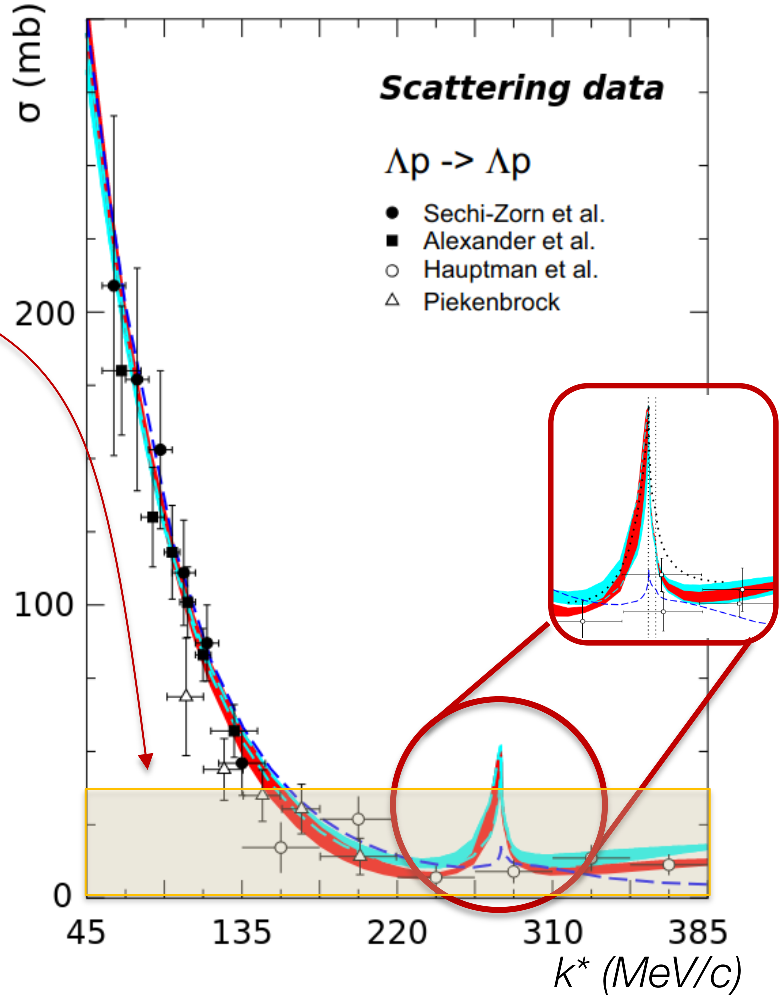
…vs the ΛN interaction via femtoscopy data

pΛ correlation function

ALICE Coll. PLB 833 (2022), 137272



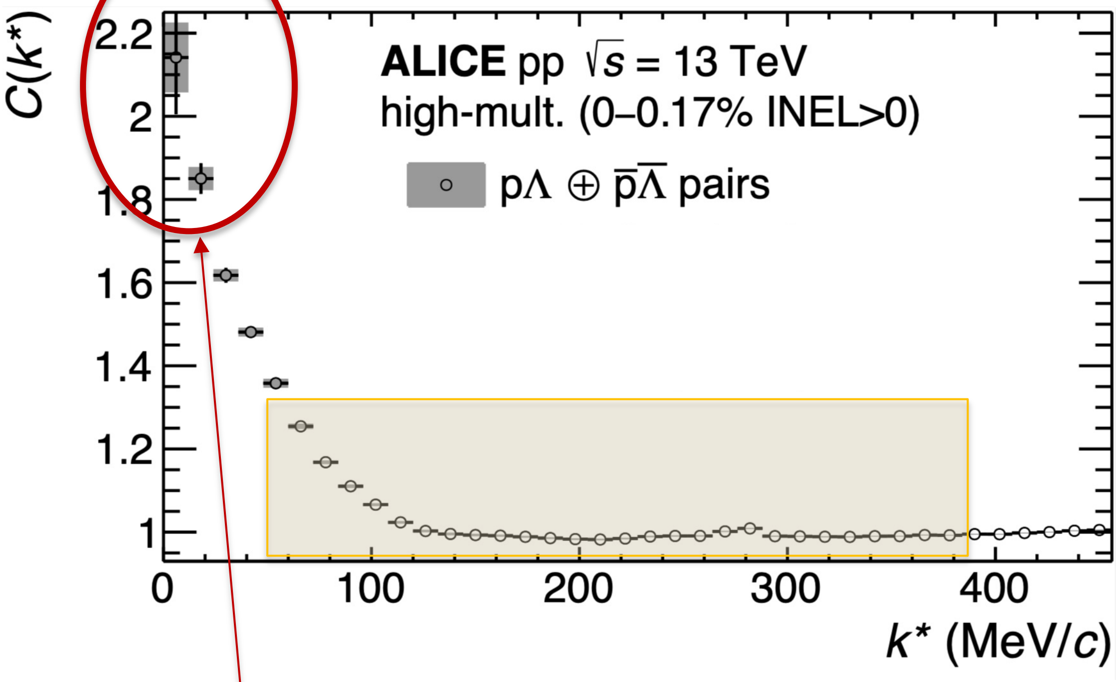
Extension of kinematic range

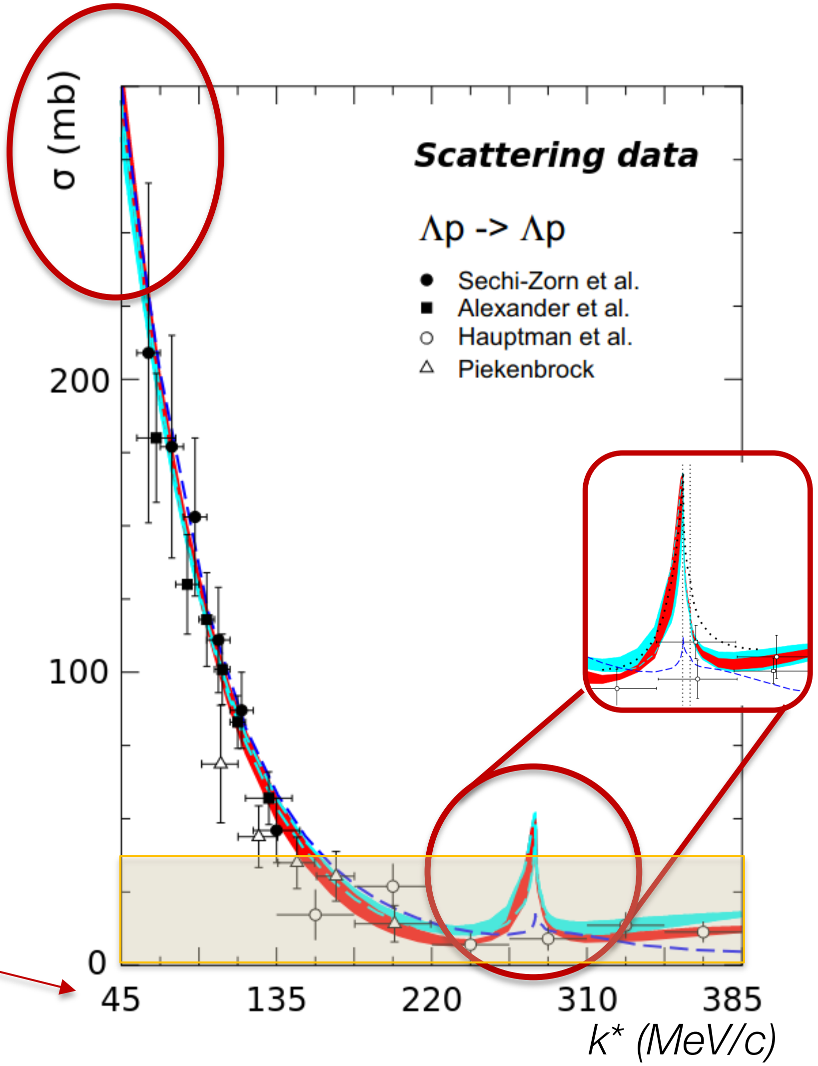


High-precision data on ΛN interaction at LHC

pΛ correlation function

ALICE Coll. PLB 833 (2022), 137272





Down to zero momentum

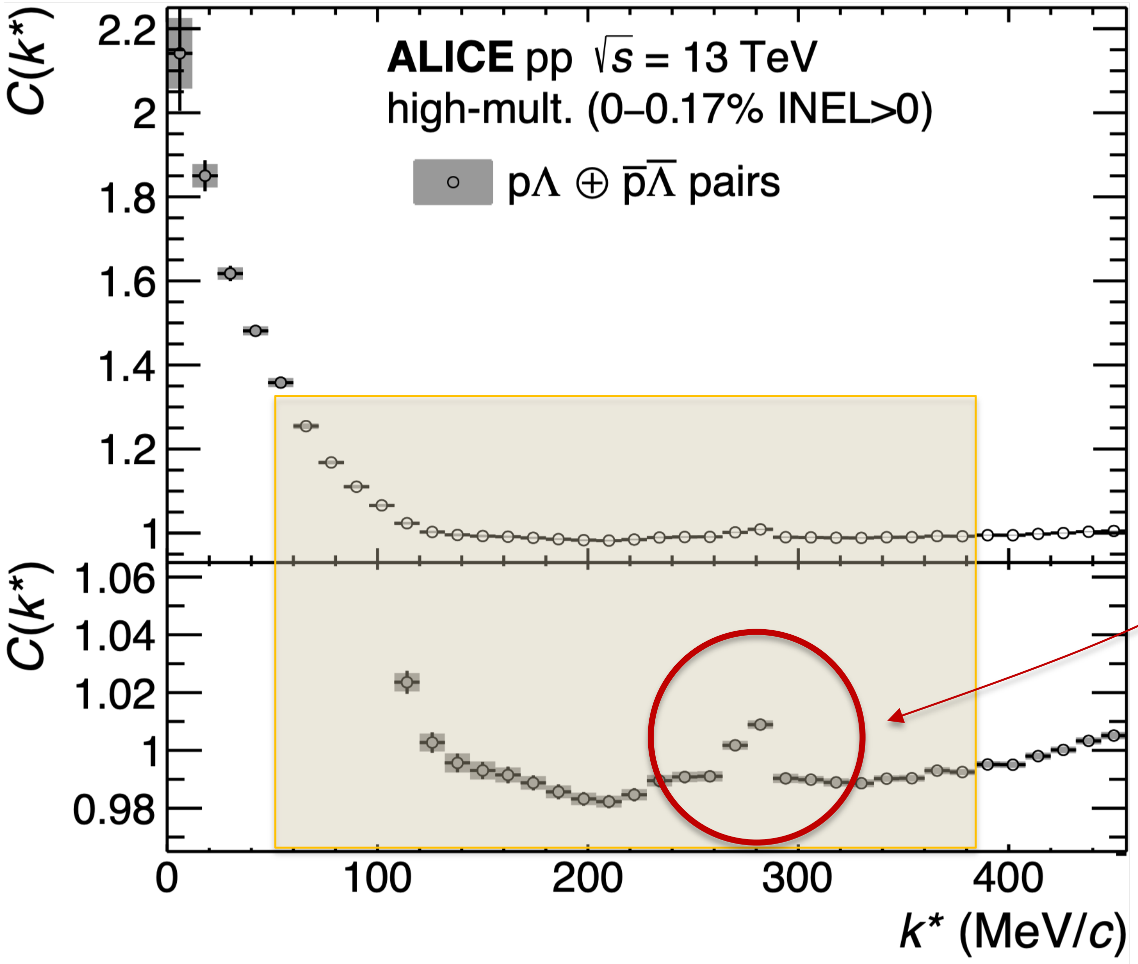
Achieving precision below few %!!

Most precise data on ΛN interaction

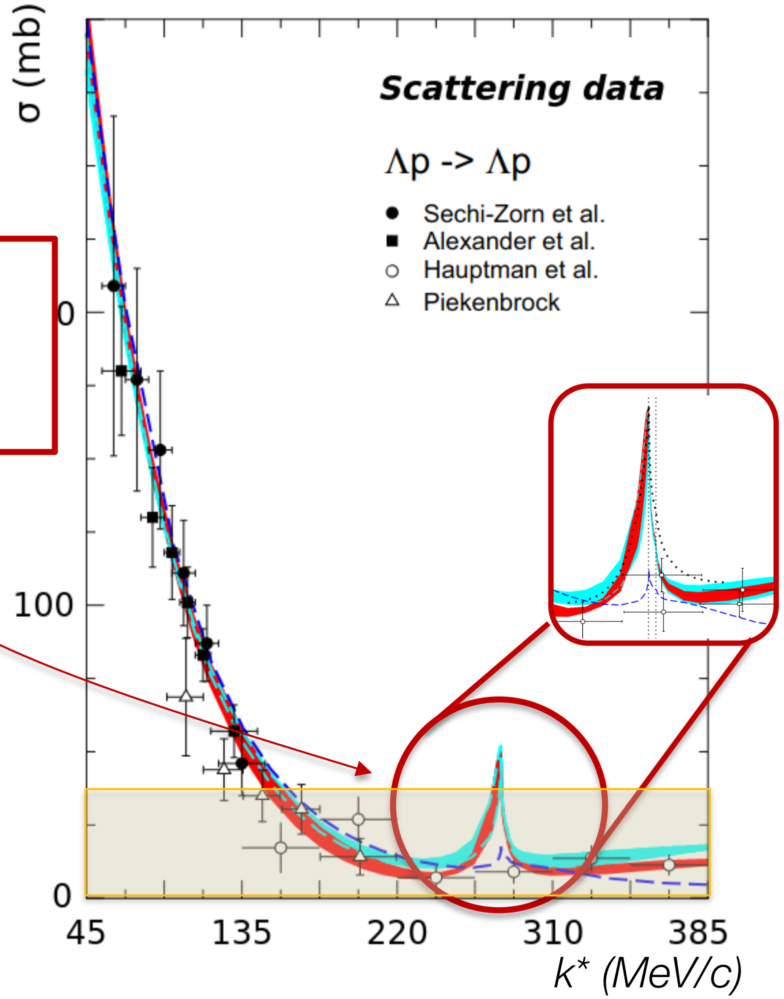
High-precision data on ΛN interaction at LHC

pΛ correlation function

ALICE Coll. PLB 833 (2022), 137272



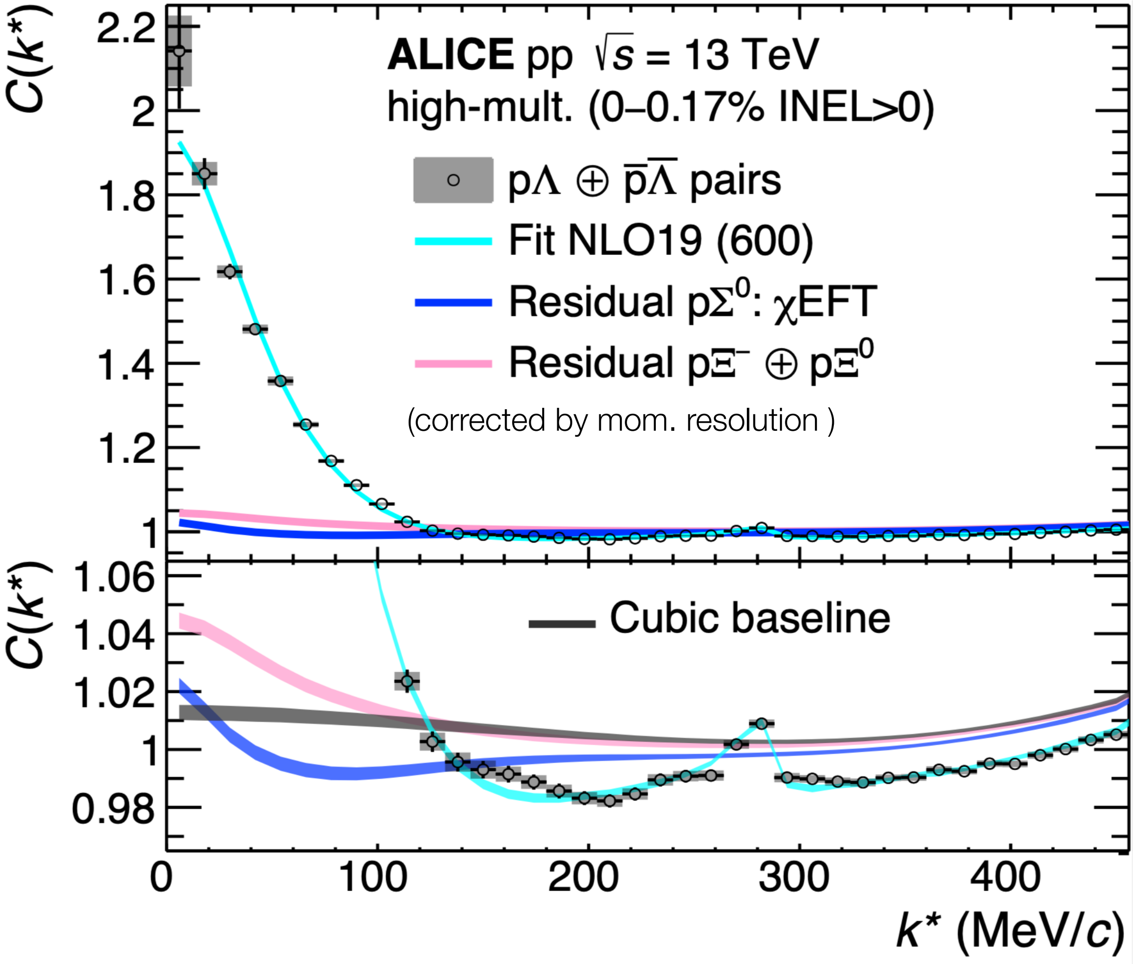
First experimental evidence of ΣN cusp in 2-body channel



High-precision data on ΛN interaction at LHC

pΛ correlation function

ALICE Coll. PLB 833 (2022), 137272



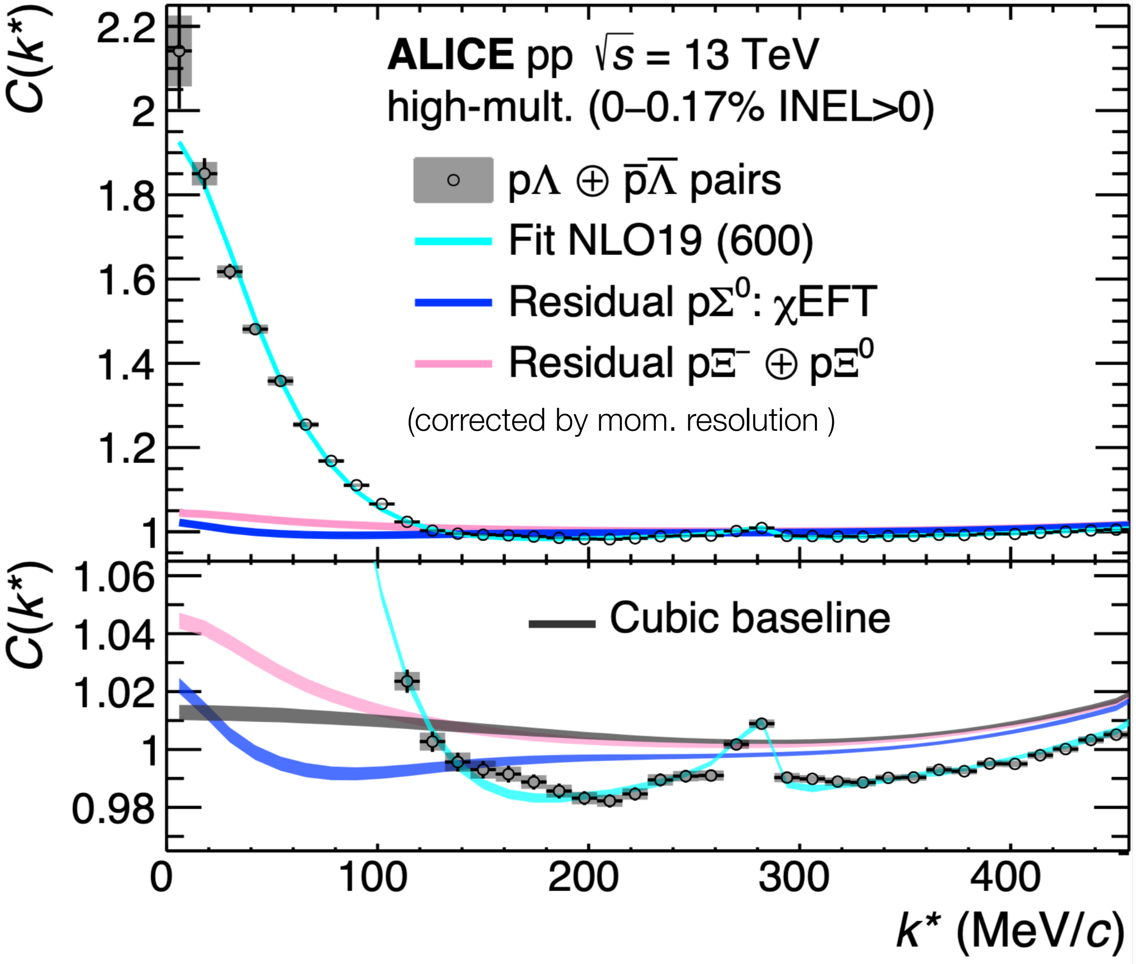
$$C(k^*) = \left[\sum_i \lambda_i C_i(k^*) + \lambda_{flat}\right] \cdot B(k^*)$$

Background

High-precision data on ΛN interaction at LHC

pΛ correlation function

ALICE Coll. PLB 833 (2022), 137272



$$C(k^*) = \left[\sum_i \lambda_i C_i(k^*) + \lambda_{flat}\right] \cdot B(k^*)$$

Background

$$\lambda_{p\Lambda} C_{p\Lambda}(k^*) + \lambda_{p(\Sigma^0)} C_{p(\Sigma^0)}(k^*) + \lambda_{p(\Xi)} C_{p(\Xi)}(k^*)$$

p Λ — S=0 & S=1 ΛN χEFT potentials at NLO (S-,D- PWs)

p Σ^0 Λ — ΣN χEFT potentials at NLO

J.Haidenbauer, U. Meiβner, EPJA 56 (2020)

p Ξ Λ — LQCD potentials at phys. mass

HAL QCD Coll. NPA 998 (2020) 121737

- Emitting core source size fixed from p-p scaling

$$r_{core} = 1.02 \pm 0.04 \text{ fm}$$

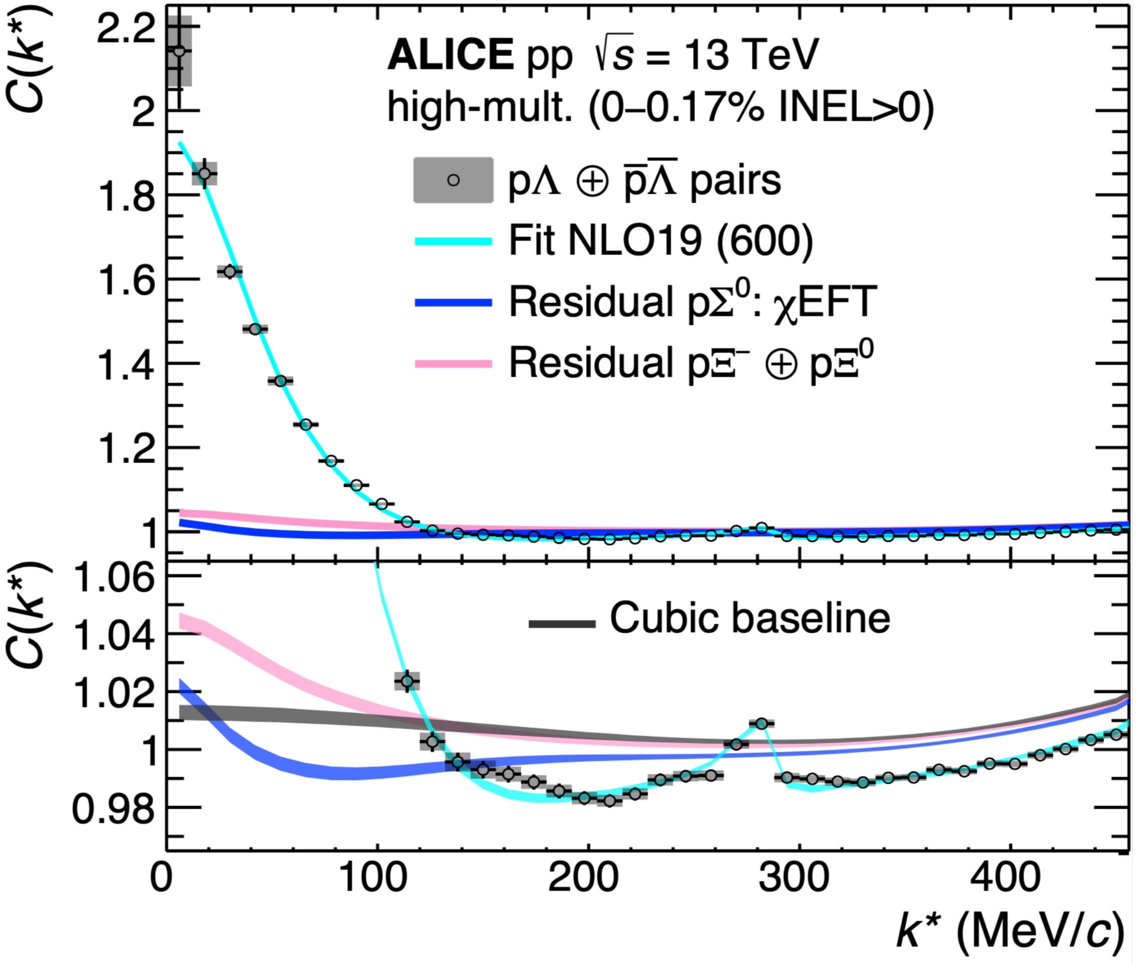
- Weights λ_{ij} depend on purity and origin of the particles in the pair, determined from Monte Carlo

Phys.Rev. C99 (2019) no.2, 024001

High-precision data on ΛN interaction at LHC

pΛ correlation function

ALICE Coll. PLB 833 (2022), 137272



Possibility to discriminate between different chiral potentials

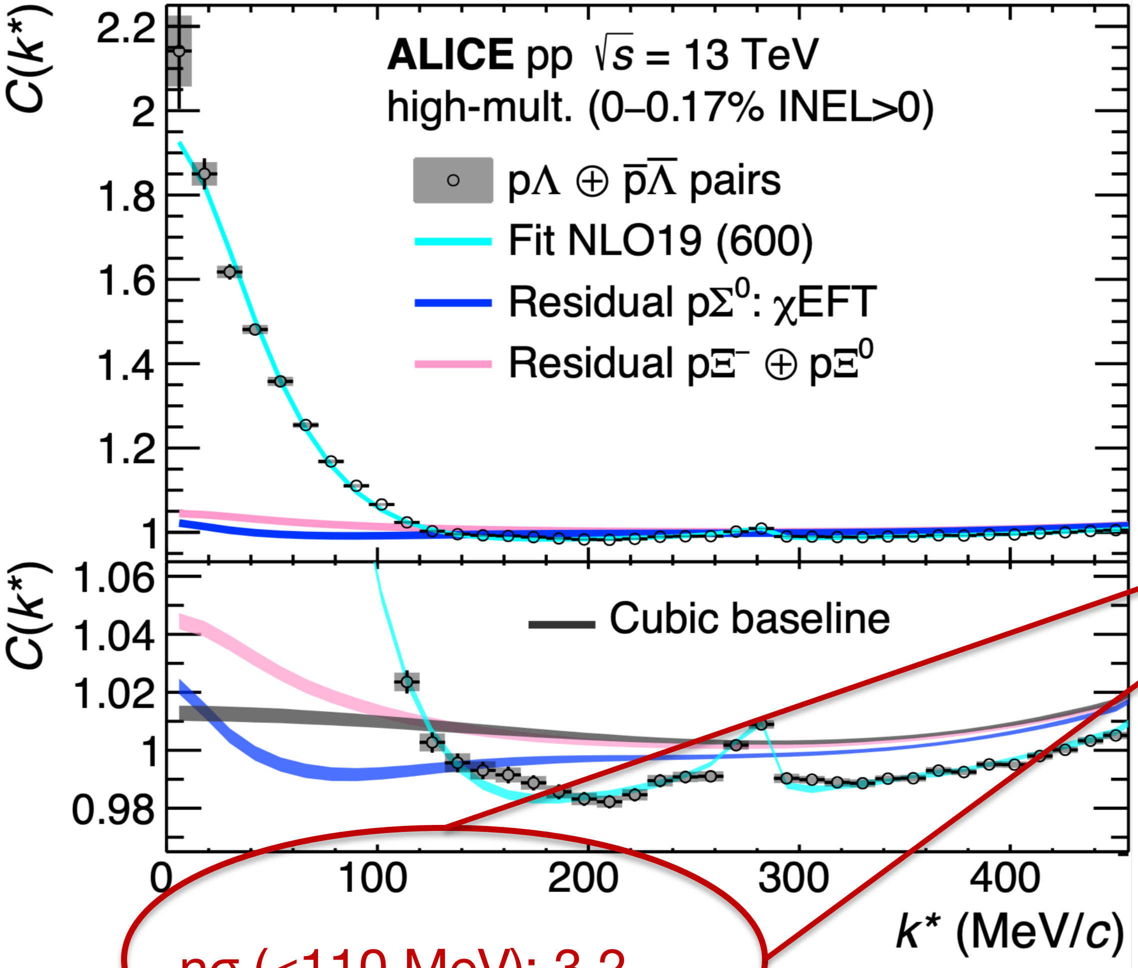
NLO19(600) favoured

$$f_0^{NLO19} = 2.91\ fm, f_1^{NLO19} = 1.41\ fm$$

High-precision data on ΛN interaction at LHC

pΛ correlation function

ALICE Coll. PLB 833 (2022), 137272



nσ (<110 MeV): 3.2

Possibility to discriminate between different chiral potentials

NLO19(600) favoured

$$f_0^{NLO19} = 2.91\ fm,\ f_1^{NLO19} = 1.41\ fm$$

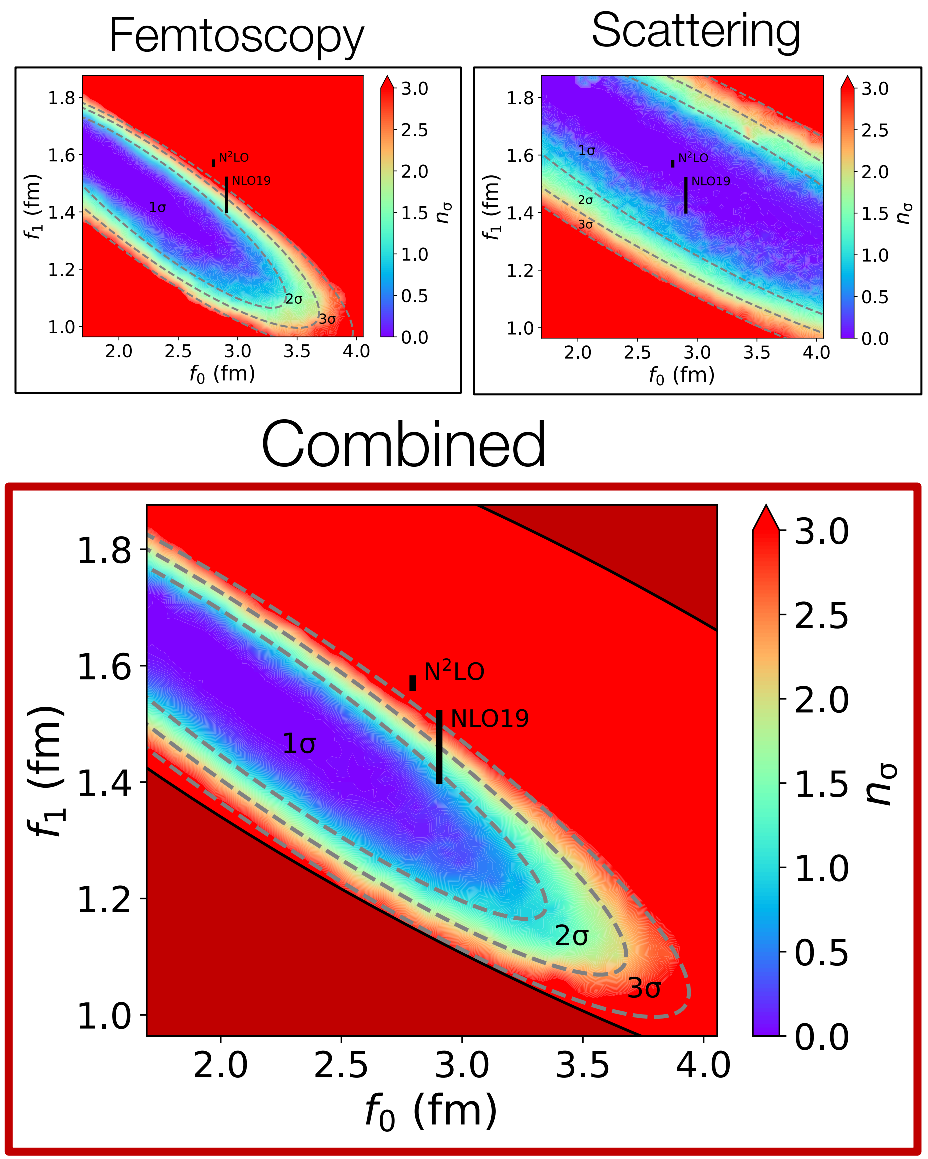
First-ever combined analysis using available pΛ scattering and correlation data

(and hypernuclei constraints)

valentina.mantovani-sarti@tum.de

Combining scattering and correlation data on pΛ

D. Mihaylov, J. Haidenbauer and VMS PLB 850 (2024) 138550



- First **combined analysis** of low-energy **pΛ scattering and correlation data**
  - 12 elastic pΛ cross-sections
  - pΛ correlation in 6 m_T ranges

    ALICE Coll. PLB 811 (2020) 135849
    CECA: D. Mihaylov et al. EPJC 83 (2023)

- **Tuning input parameters (LECs) of the chiral potentials** to reproduce the experimental data

- **Tightest constraints available on two-body pΛ singlet and triplet scattering parameters**

Best fits: $f_0 \in [2.10, 2.91]$, $f_1 \in [1.56, 1.32]$

Final outcome is a less attractive NΛ interaction

Combining scattering and correlation data on pΛ

D. Mihaylov, J. Haidenbauer and VMS PLB 850 (2024) 138550

- First combined analysis of low-energy pΛ scattering and correlation data
  - 12 elastic pΛ cross-sections
  - pΛ correlation in 6 m_T ranges

    ALICE Coll. PLB 811 (2020) 135849

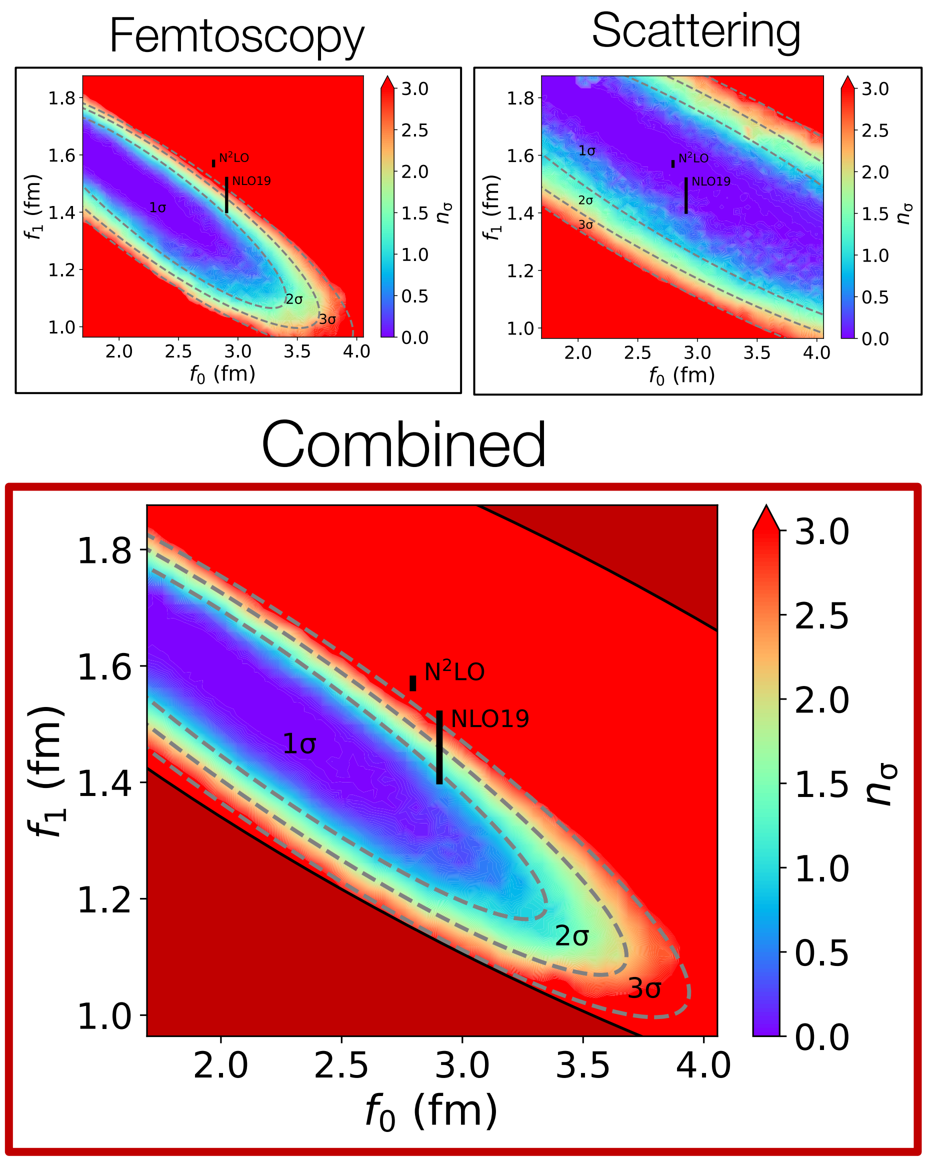
    CECA: D. Mihaylov et al. EPJC 83 (2023)

- Tuning input parameters of the chiral potentials to reproduce the experimental data

- Tightest constraints available on two-body pΛ singlet and triplet scattering parameters

Best fits: $f_0 \in [2.10, 2.91]$
$f_1 \in [1.56, 1.32]$

How does this updated ΛN interaction affect the Λ behaviour in a medium?

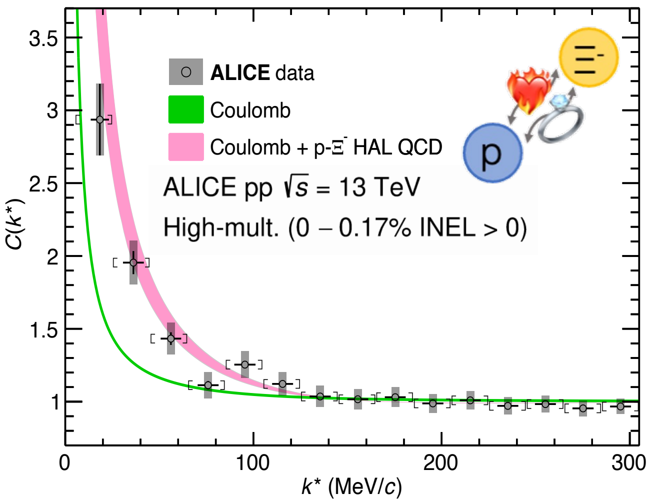


A bottom-up approach to build neutron stars with hyperons

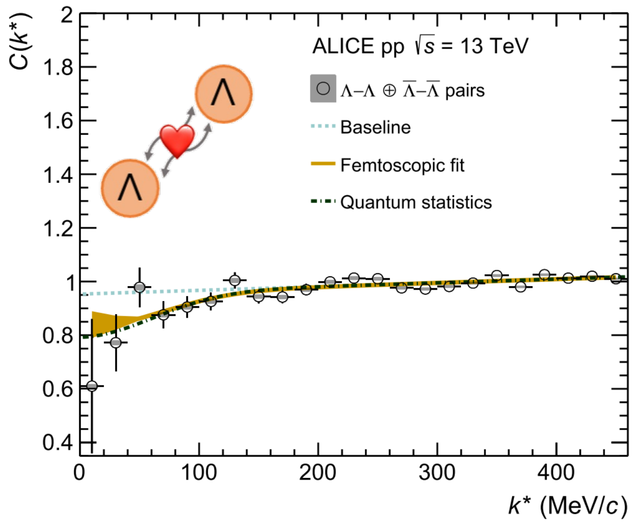
Work in collaboration with Dr. Vidaña, Dr. Mihaylov, Dr. Haidenbauer and Prof. Fabbietti

Eur.Phys.J.A 61 (2025) 3, 59

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



ALICE Coll. Physics Letters B 797 (2019)



Foundations:

NN(AV18)+NNN phen.

K=160, 270 MeV from HIC

Le Fèvre et al. NPA 945 (2016)

S. Huth et al., Nature 606 (2022) 276

ΛN-ΣN, ΛΛ and NΞ interactions tuned/validated on correlation data

NΞ: ALICE Coll. Nature 588 (2020) 232-238

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

ΛΛ-NΞ pot.: HAL QCD Coll. Nucl.Phys.A 998 (2020) 121737

A bottom-up approach to build neutron stars with hyperons

Work in collaboration with Dr. Vidaña,
Dr. Mihaylov, Dr. Haidenbauer
and Prof. Fabbietti

Eur.Phys.J.A 61 (2025) 3, 59

BB interactions at finite ρ

Brueckner-Hartree-Fock theory
with detailed propagation of
input uncertainties!!

Schulze et al. PLB 355 (1995)

Foundations:

NN(AV18)+NNN ph.
K=160, 270 MeV from HIC

Le Fèvre et al. NPA 945 (2016)
S. Huth et al., Nature 606 (2022) 276

ΛN-ΣN, ΛΛ and NΞ interactions
tuned/validated on correlation data

NΞ: ALICE Coll. Nature 588 (2020) 232-238
ΛΛ: ALICE Coll. Phys.Lett.B 797 (2019) 134822
ΛΛ-NΞ pot.: HAL QCD Coll. Nucl.Phys.A 998 (2020) 121737

A bottom-up approach to build neutron stars with hyperons

Work in collaboration with Dr. Vidaña, Dr. Mihaylov, Dr. Haidenbauer and Prof. Fabbietti

Eur.Phys.J.A 61 (2025) 3, 59

First realistic EoS with hyperons from hadronic physics

BB interactions at finite ρ

Brueckner-Hartree-Fock theory with detailed propagation of input uncertainties!!

Schulze et al. PLB 355 (1995)

Foundations:

NN(AV18)+NNN ph.

K=160, 270 MeV from HIC

Le Fèvre et al. NPA 945 (2016)

S. Huth et al., Nature 606 (2022) 276

ΛN-ΣN, ΛΛ and NΞ interactions tuned/validated on correlation data

NΞ: ALICE Coll. Nature 588 (2020) 232-238

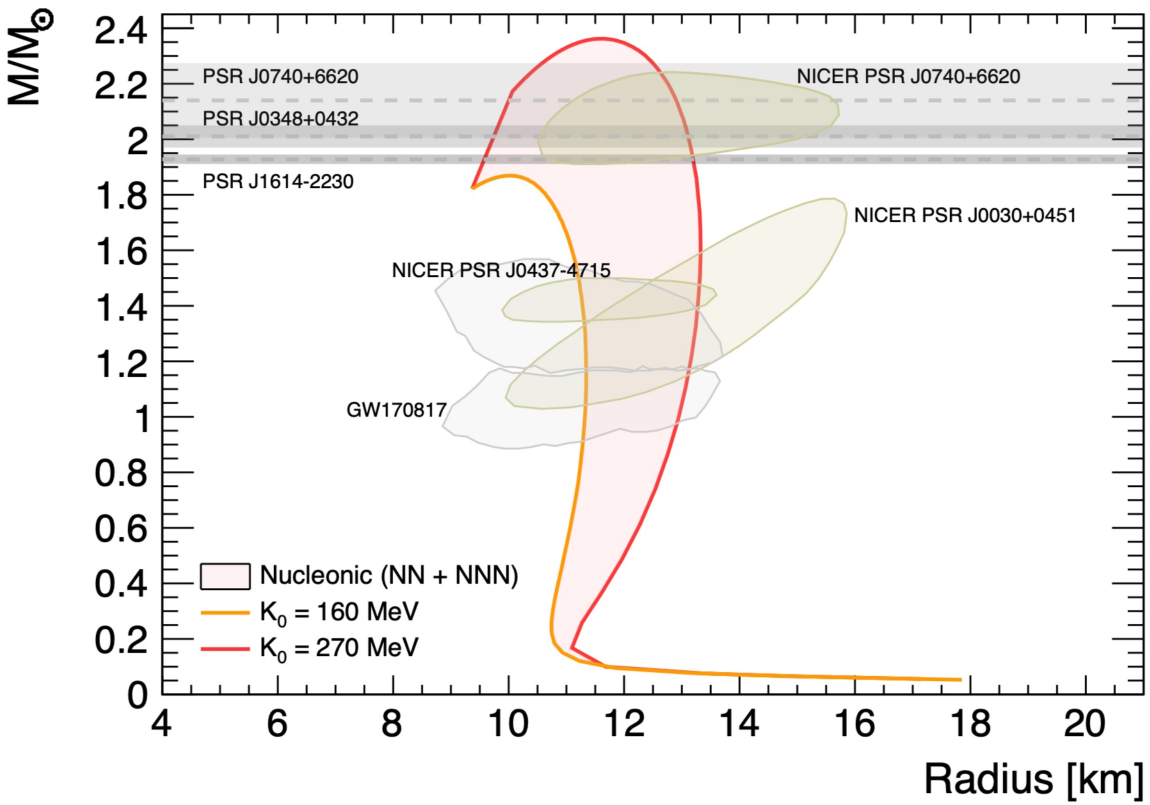
ΛΛ: ALICE Coll. Phys.Lett.B 797 (2019) 134822

ΛΛ-NΞ pot.: HAL QCD Coll. Nucl.Phys.A 998 (2020) 121737

A realistic EoS with hyperons from correlation data

- Pure nucleonic EoS easily reaching heavy NS

Vidaña, VMS, Haidenbauer, Mihaylov, Fabbietti Eur.Phys.J.A 61 (2025) 3, 59

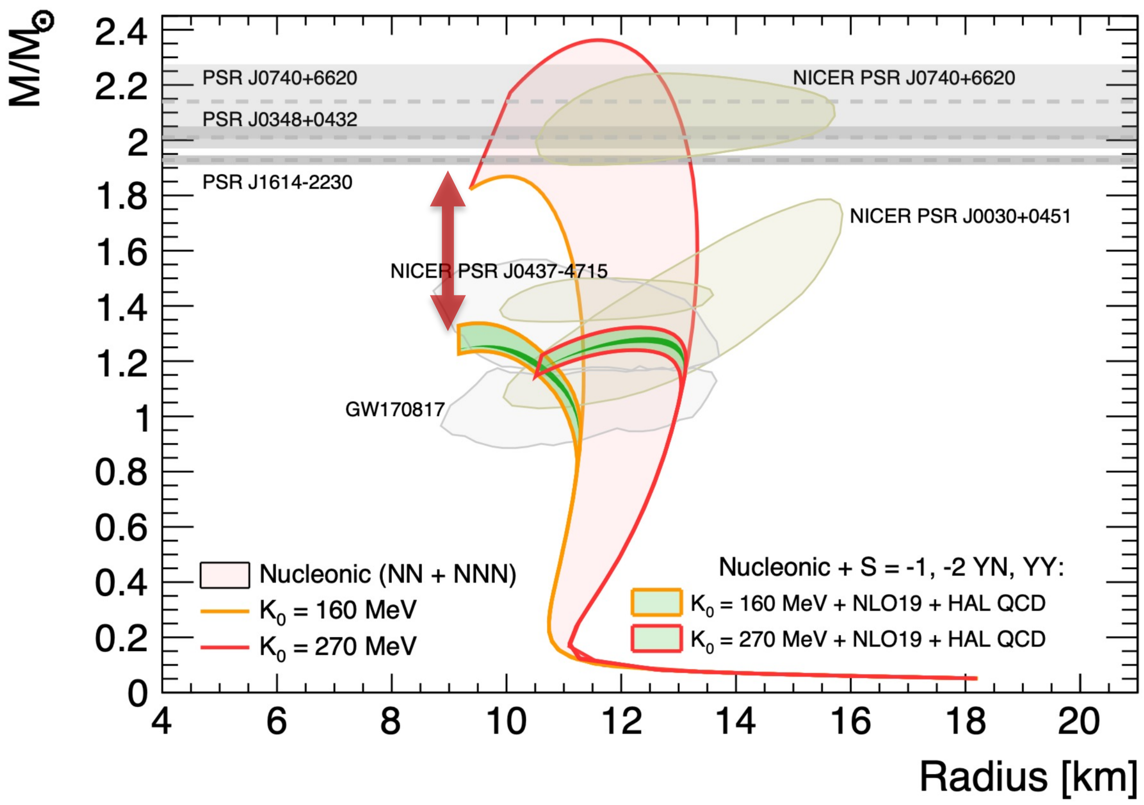


PSR J1614-2230: P. Demorest et al. Nature 467, 1081 (2010)
PSR J0348+0432: J. Antoniadis et al., Science 340, 6131 (2013)
PSR J0740+6620: H. T. Cromartie et al. (NANOGrav), Nature Astron. 4, 72 (2019)
GW170817: B. P. Abbott et al. (LIGO Scientific, Virgo), Phys. Rev. Lett. 119, 161101 (2017)
NICER: B. P. Abbott et al. (LIGO Scientific, Virgo), Phys. Rev. Lett. 119, 161101 (2017), T. E. Riley et al., Astrophys. J. Lett. 887, L21 (2019), T. E. Riley et al., Astrophys. J. Lett. 918, L27 (2021),S. Vinciguerra et al., Astrophys. J. 961, 62 (2024), T. Salmi et al., arXiv:2406.14466

A realistic EoS with hyperons from correlation data

- Pure nucleonic EoS easily reaching heavy NS
- State-of-the-art two-body YN and YY constrained to all available data softens the EoS
    - Maximum mass of roughly $1.4M_{\odot}$
    - Rather independent on the “stiffness” of the pure nucleonic EoS
- Propagation of uncertainty related to experimental data and theory can help quantifying the ”missing” gap to heavy NS

Vidaña, VMS, Haidenbauer, Mihaylov, Fabbietti Eur.Phys.J.A 61 (2025) 3, 59



Light shade: theoretical uncertainty (cut-off)

Dark shade: experimental uncertainty (comb. fit scatt. + femto, vars. lQCD potentials)

A realistic EoS with hyperons from correlation data

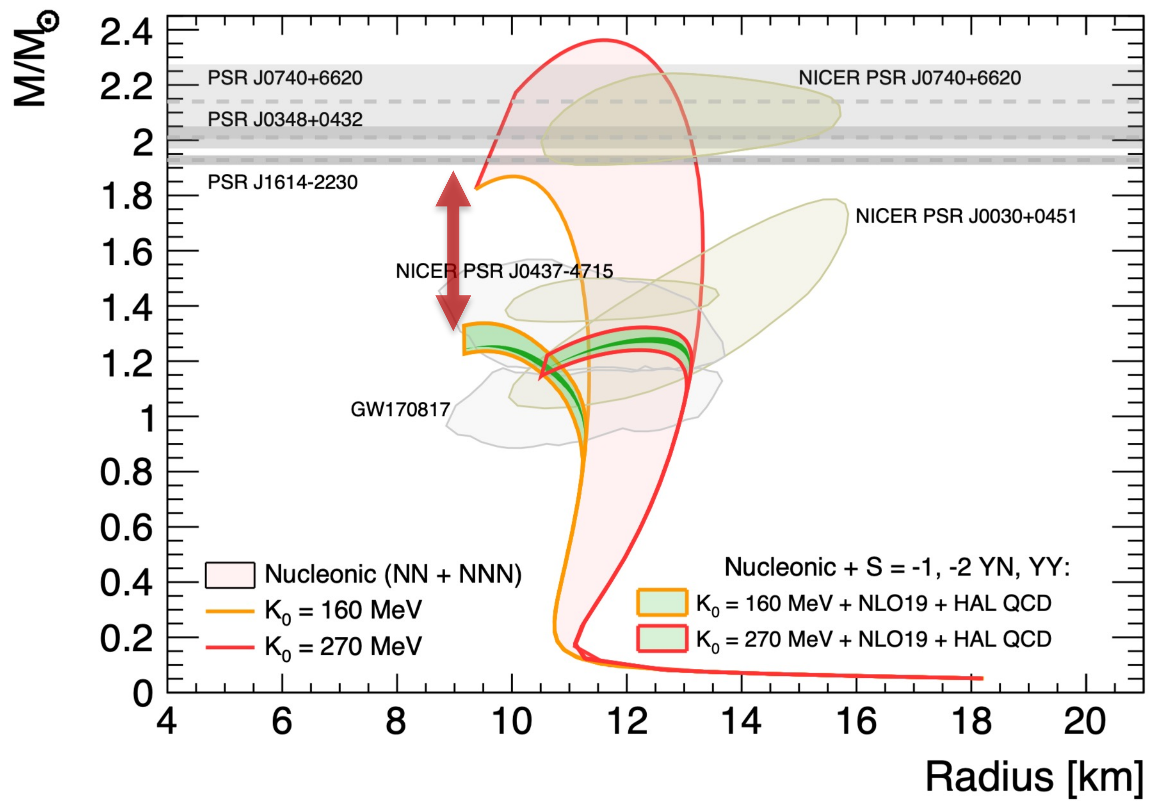
- Pure nucleonic EoS easily reaching heavy NS
- State-of-the-art two-body YN and YY constrained to all available data softens the EoS
  - Maximum mass of roughly $1.4M_{\odot}$
  - Rather independent on the “stiffness” of the pure nucleonic EoS
- Propagation of uncertainty related to experimental data and theory can help quantifying the ”missing” gap to heavy NS

Need for repulsion to obtain heavy NS!

YNN, more exotic scenarios with axions…

WIP with A. Weiler and group using multiπ-p correlations

Vidaña, VMS, Haidenbauer, Mihaylov, Fabbietti Eur.Phys.J.A 61 (2025) 3, 59

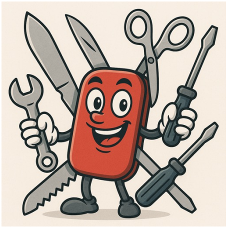


Light shade: theoretical uncertainty (cut-off)

Dark shade: experimental uncertainty (comb. fit scatt. + femto, vars. lQCD potentials)

SFB 1258 Neutrinos Dark Matter Messengers

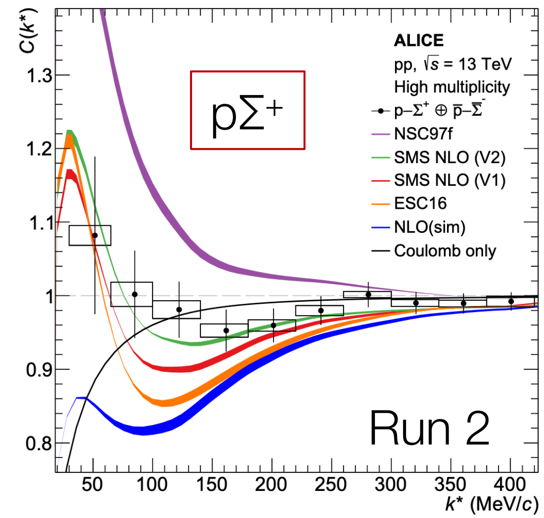
Towards a complementary future with correlations

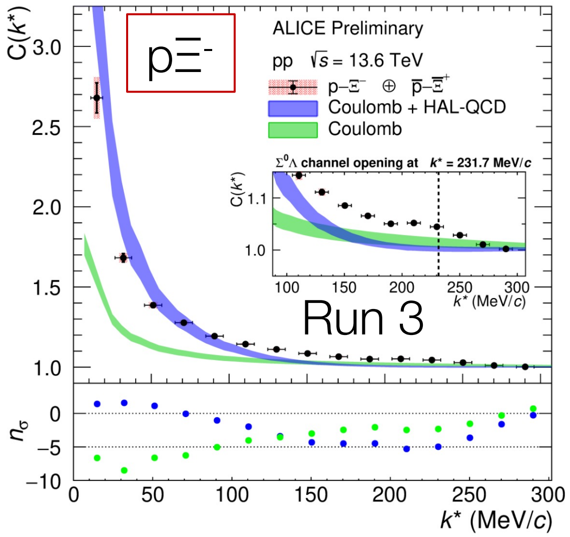


What can femtoscopy provide as input for the
physics of neutron stars and nuclei formation?

High-precision data on
2-body interaction with correlations involving Σ/Ξ baryons…
(Preliminary results shown at QM 2025 by [ALICE Run 3](#) and [BES-II STAR](#))

ALICE Coll. arXiv: [2510.14448](#) [nucl-ex]





… and **hadron-vector meson (Λϕ)!**

See poster by M. Korwieser

Femtoscopy
LHC, HL-LHC, STAR,HADES,J-PARC

Scattering data, Cusp-spectroscopy
J-PARC,JLAB

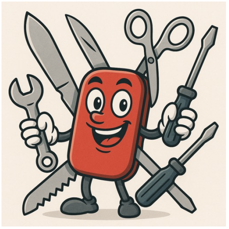
EoS for neutron stars

Hypernuclei
LHC, HL-LHC, STAR, J-PARC, FAIR,JLAB

See also talks by:
T. Nilsson Thur. 11:35
A. Toia Fri. 11:50

Physics Briefing Book: Input for the 2026 update of the European Strategy for Particle Physics
CERN Yellow Rep.Monogr. 8 (2025)

Towards a complementary future with correlations

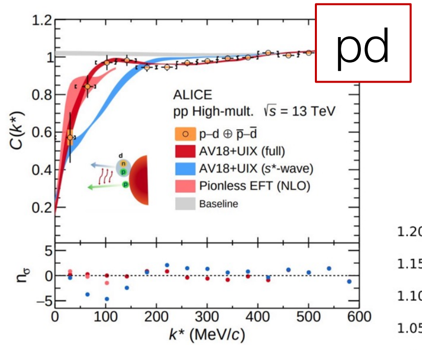


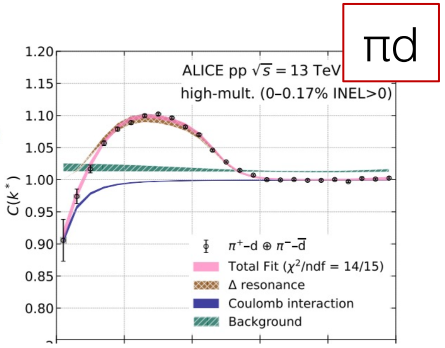
What can femtoscopy provide as input for the
physics of neutron stars and nuclei formation?

Tackling **three-body forces with hyperons with multi-particle and hadron-light nuclei correlations**

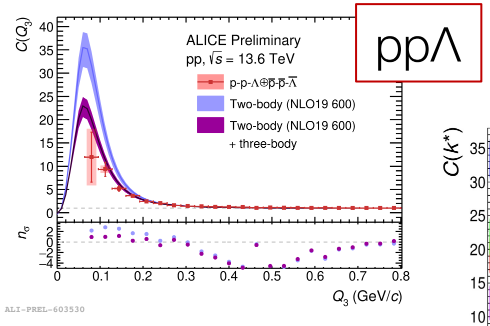
ALICE Coll. PRX 14 (2024) 3, 031051
ALICE Coll. Nature 648 (2025) 8093, 306-311
ALICE Coll. EPJA 59 (2023) 7, 145
STAR Coll. PLB 864 (2025) 139412

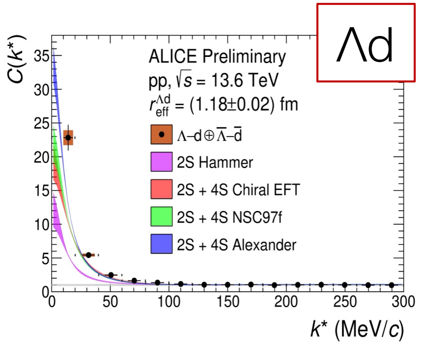
R. Del Grande et al. EPJC 82 (2022) 3
A. Kievsky et al. PRC 109 (2024) 3
E. Garrido et al. PRC 110 (2024) 5
E. Garrido et al. PLB 868 (2025)





Run 2





Run 3

Femtoscopy
LHC, HL-LHC,
STAR,HADES,J-PARC

Scattering data,
Cusp-spectroscopy
J-PARC,JLAB

EoS for
neutron stars

Hypernuclei
LHC, HL-LHC, STAR,
J-PARC, FAIR,JLAB

See also talks by:
T. Nilsson Thur. 11:35
A. Toia Fri. 11:50

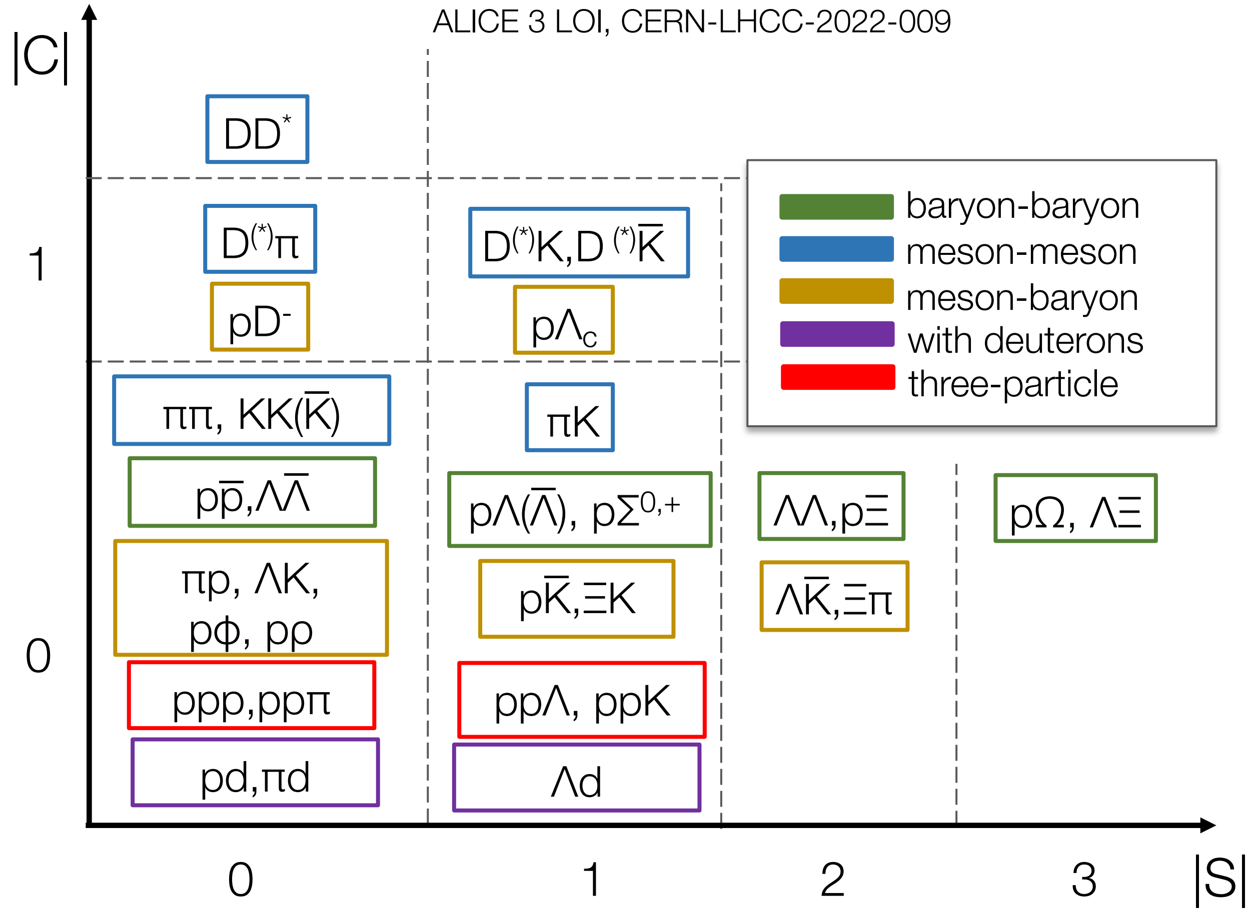
Physics Briefing Book: Input for the 2026 update of the European Strategy for Particle Physics
CERN Yellow Rep.Monogr. 8 (2025)

Conclusions and outlooks

- **Correlation measurements at LHC**
  - Unique tool able to provide high-precision data for nuclear & hadronic physics
  - Novel precision era to constrain hadronic interactions involving hyperons
- **Most precise data on ΛN, ΞN and ΛΛ interactions down to zero momenta**
  - Improved input for EoS of NS
  - First realistic EoS with available experimental constraints on two-body YN and YY
- **Future correlation studies with Run 3 and Run 4**
  - Involving Σ/Ξ baryons and exploring YNN interactions

More charming future with ALICE 3

ALICE 3 LOI, CERN-LHCC-2022-009



Harvesting correlations so far, and more to come!

ALICE Collaboration:

PRC 99 (2019) 2, 024001
PLB 797 (2019) 134822
PRL 123 (2019) 112002
PRL 124 (2020) 09230
PLB 805 (2020) 135419
PLB 811 (2020) 135849
Nature 588 (2020) 232-238
PRL 127 (2021), 172301
PLB 822 (2021), 136708
PRC 103 (2021) 5, 055201
PLB 833 (2022), 137272
PLB 829 (2022), 137060
PRD 106 (2022), 5, 05201
PL B 844 (2023) 137223
EPJA 59 (2023) 145
EPJC 83 (2023) 4, 340
PLB 845 (2023) 138145
EPJA (2023) 59:298
PRD 110 (2024) 3, 032004
PRX 14 (2024) 3, 031051
PLB 856 (2024) 138915
PRC 109, 024915 (2024)
EPJC 85 (2025) 2, 198
EPJA 61 (2025) 8, 194
PRC 112 (2025) 6 064003
arXiv: 2508.09867 [nucl-ex]
arXiv: 2510.14448 [nucl-ex]
Nature 648 (2025) 306-311

CMS Collaboration:

JHEP 03 (2020) 014
PLB 857 (2024) 138936
PRC 109 (2024) 2, 024914

STAR Collaboration:

Nature 527 (2015) 345-348
PRL114 (2015) 2, 022301
PLB 864 (2025) 139412
PLB 790 (2019) 490-497

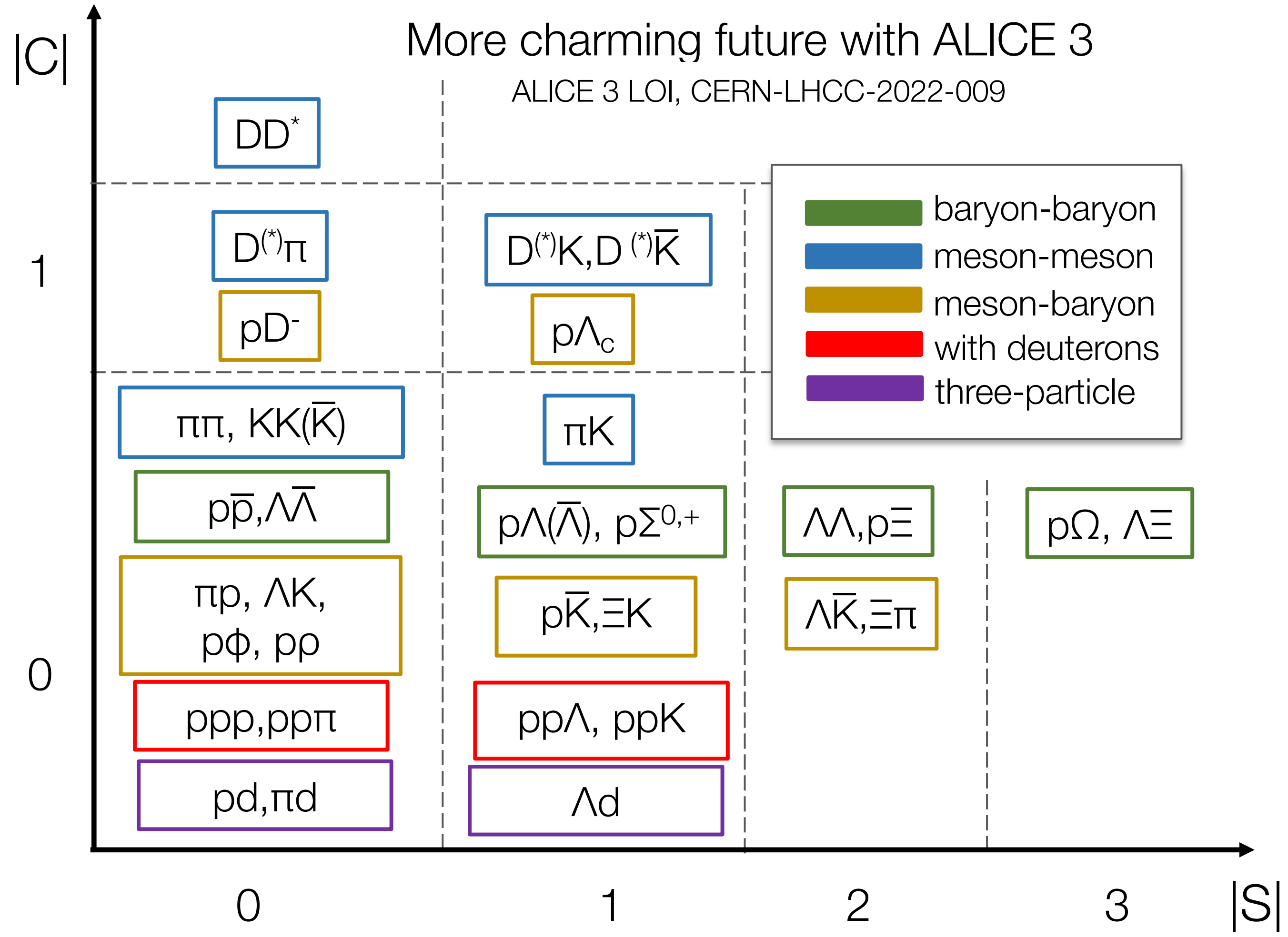
ATLAS Collaboration:

EPJC 75, 466 (2015)
PRC 96 (2017) 6, 064908
EPJC 82 (2022) 7, 608
PRC 96, 064908

HADES Collaboration:

PRC 82 (2010) 021901
PRC 94 (2016) 2, 025201

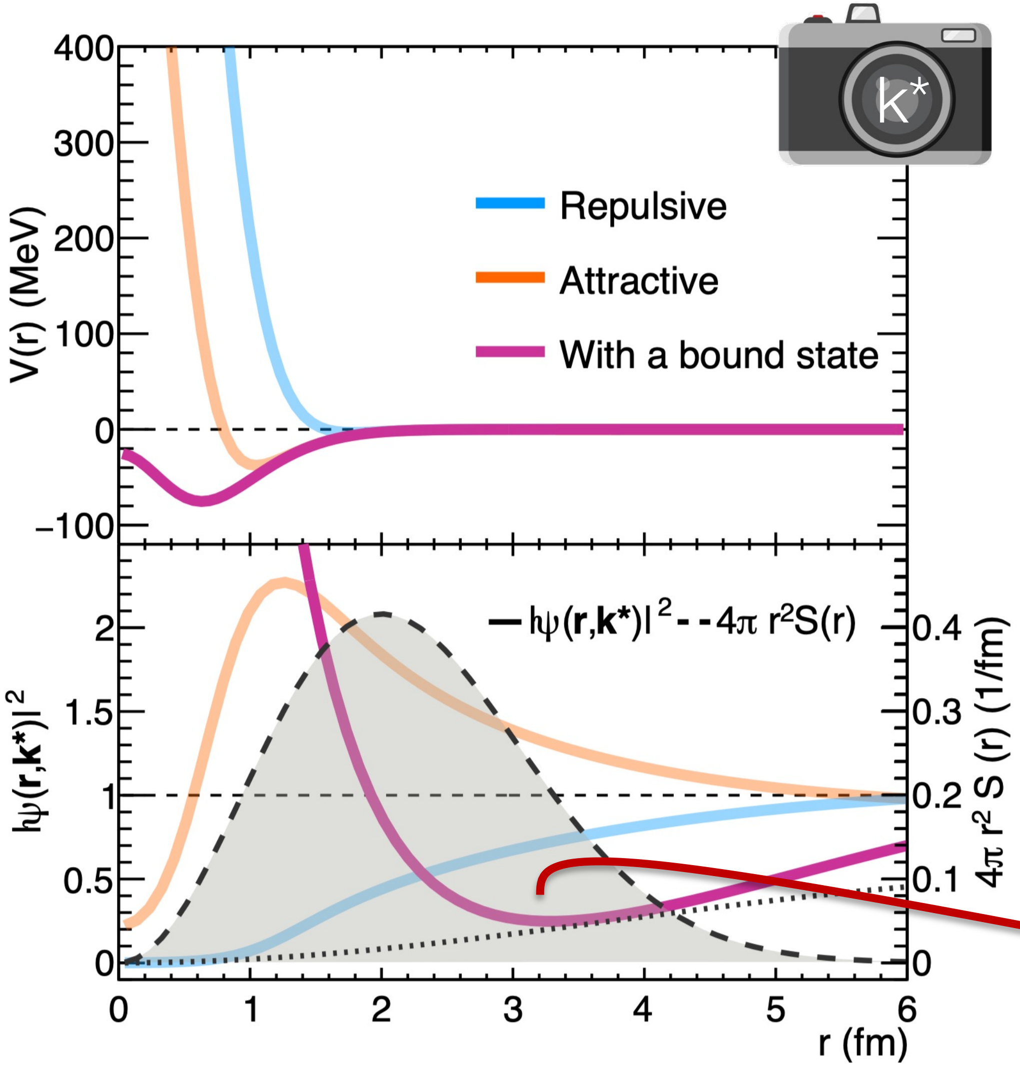
Latest theoretical studies on correlations:
Very very active on hep-inspire!!



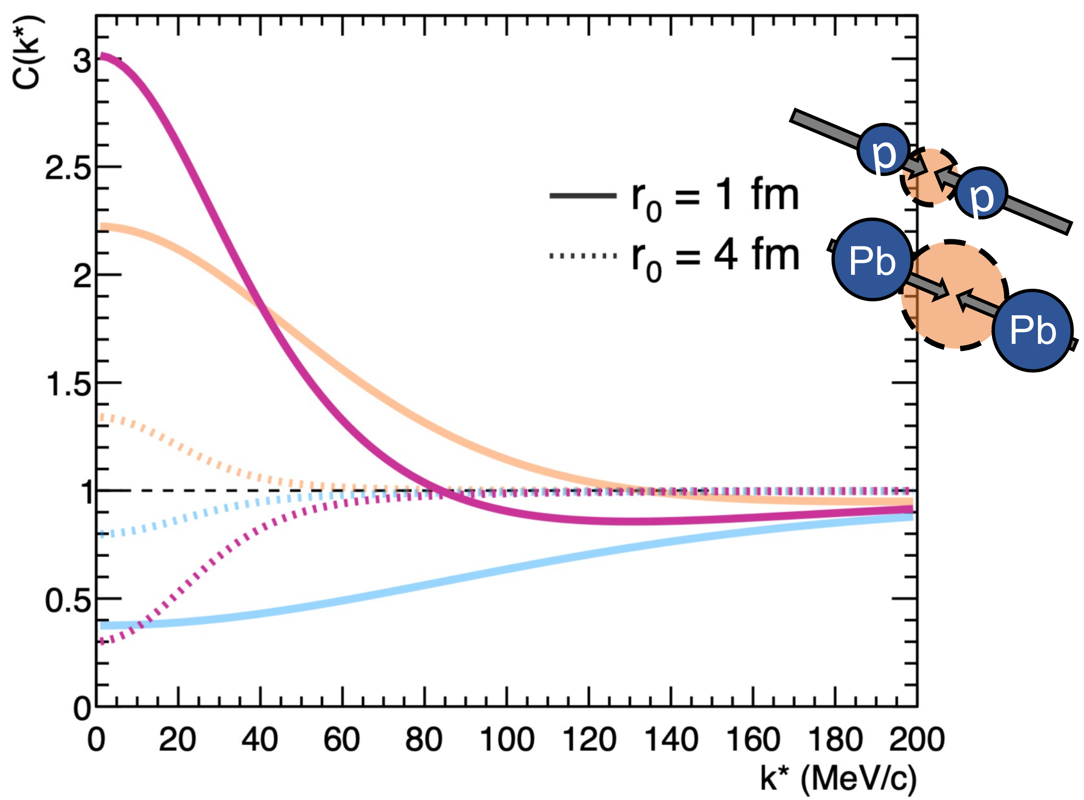
Additional slides

A clear signature for bound states

"What's inside the integral"



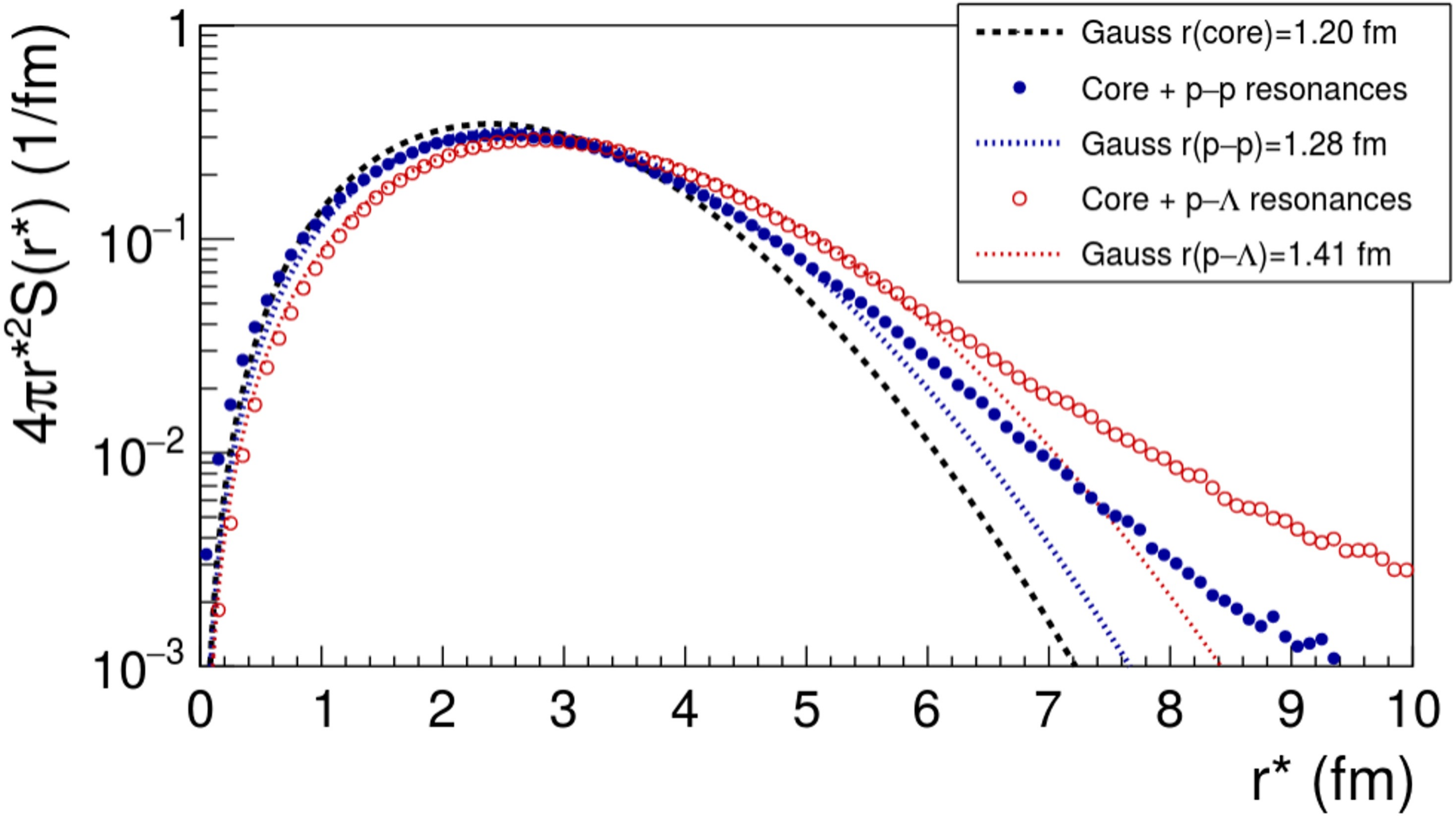
$$C(k^*) = \int S(\vec{r}^*)\, \left|\psi(\vec{k}^*, \vec{r}^*)\right|^2 d^3\vec{r}^*$$



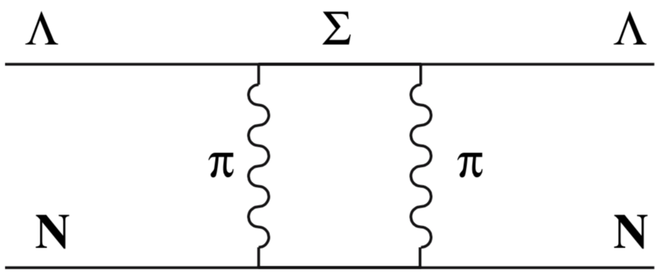
Correlation flips around unity when a bound state is present!

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

The common source - The source pdf

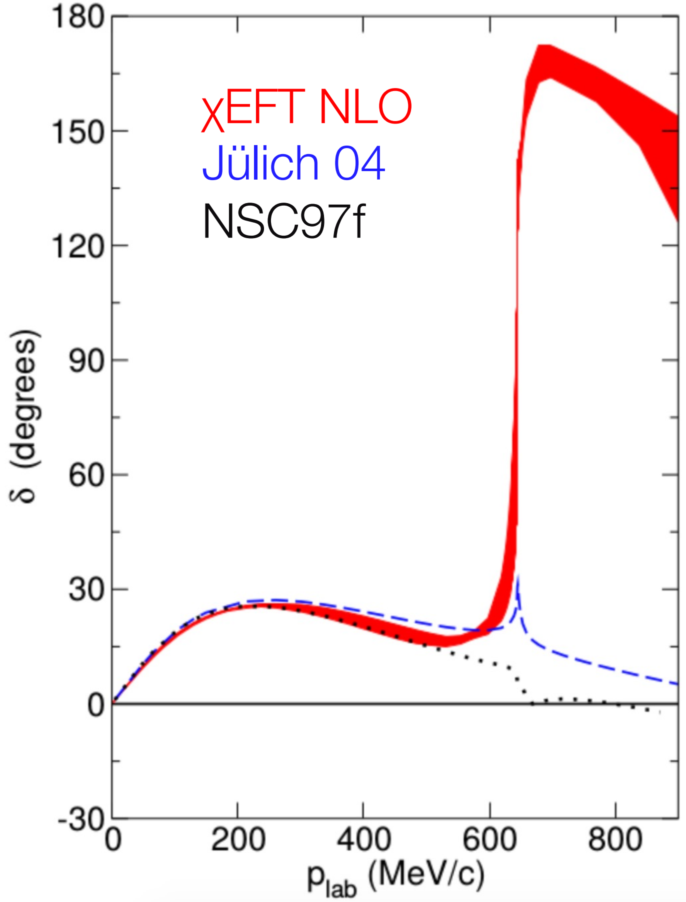


Influence of the ΛN – ΣN coupled channel

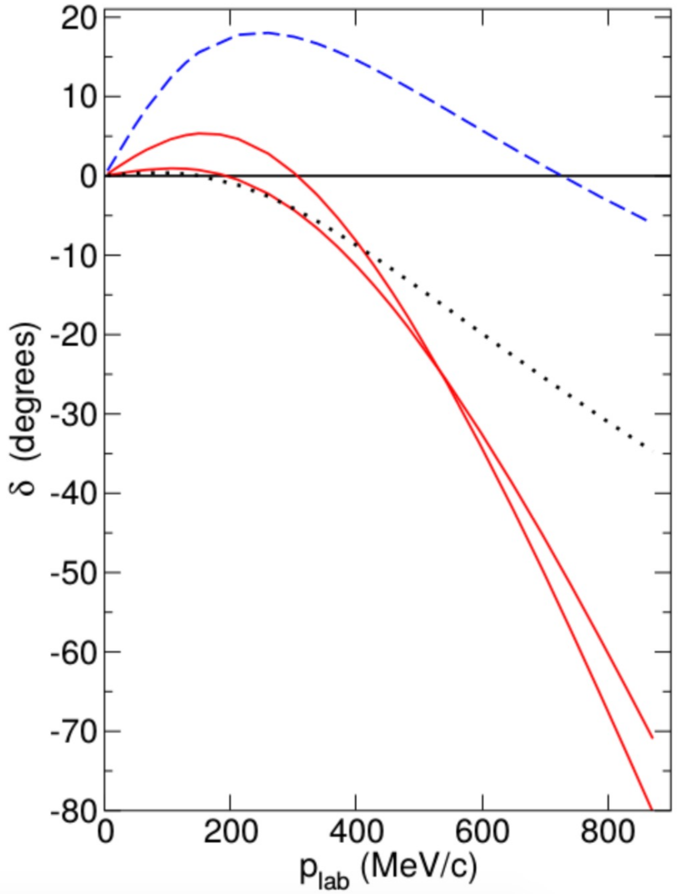


- ΣN-ΛN acts as an effective attraction
- Repulsion for Λ-p when the Σ-N – Λ-N coupled channel is neglected
  - strong coupling ⟹ dispersion repulsive effects ⟹ Shift of hyperon appearance towards higher densities
  - weak coupling ⟹ more attractive $U_\Lambda(\rho_0,0)$

Λ-p $^3S_1$
with the Σ-N – Λ-N coupling



Λ-p $^3S_1$
w/o the Σ-N – Λ-N coupling

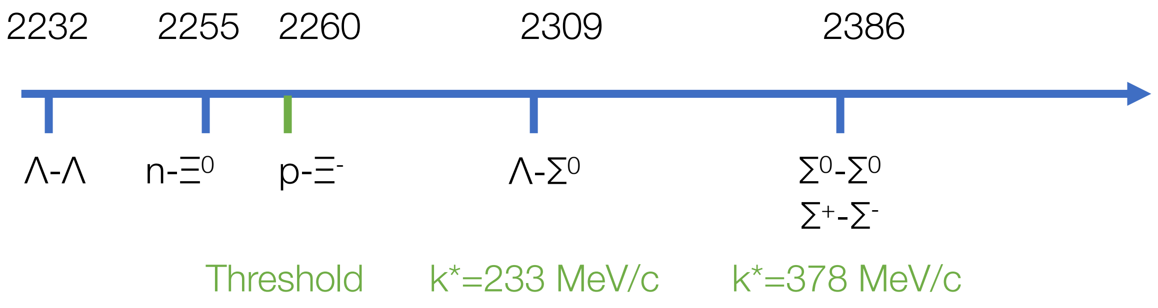


J. Haidenbauer *et al.*, Eur. Phys. A (2017) 53, 121.

Lattice QCD potentials of the |S| = 2 sector: p-Ξ^- interaction

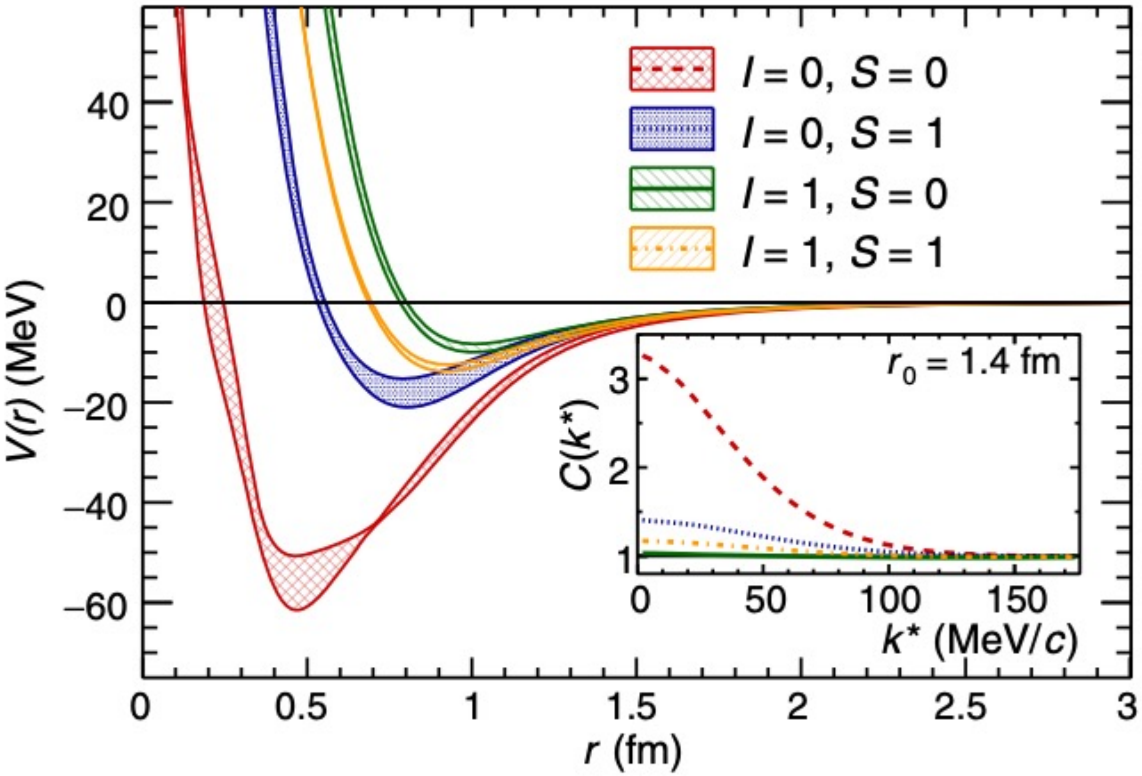
- Direct comparison to HAL QCD potentials near physical quark masses(*)

- Presence of coupled-channels



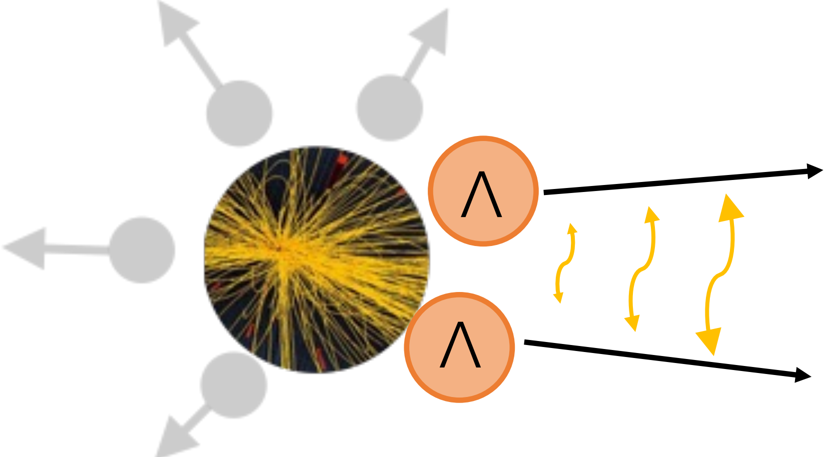
- Weak coupling to Λ-Λ channels expected from HAL QCD potentials
  - confirmed from femtoscopic (**) and hypernuclei measurements (***)

p-Ξ^- interaction

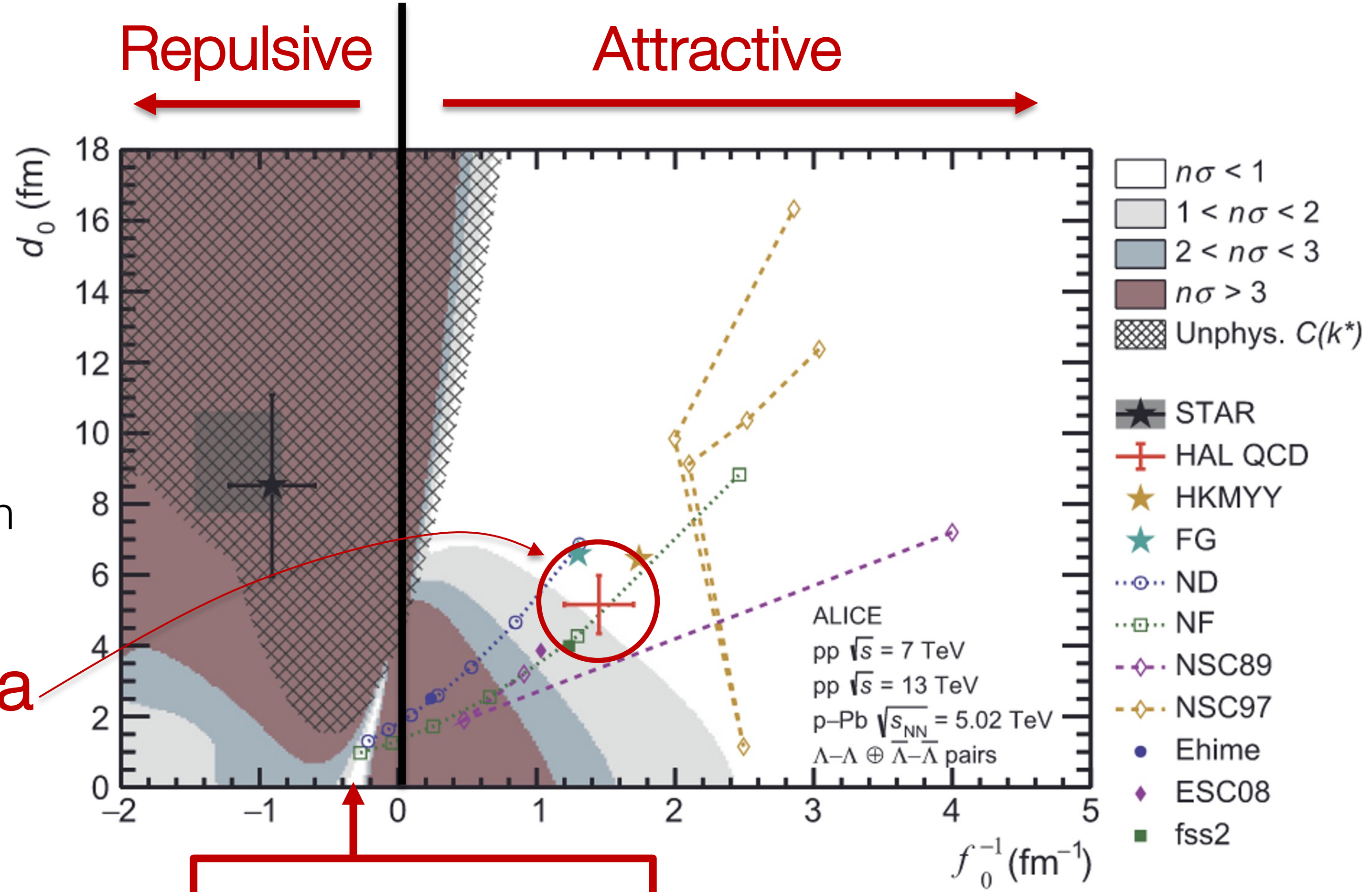


(*) T. Hatsuda Front. Phys. 13(6), 132105 (2018)
(**) ALICE Coll. Phys. Lett. B 797 (2019) 134822
(***) Hayakawa et al. Phys. Rev. Lett. 126, 062501 (2021)

Even more stranger things: the ΛΛ interaction at LHC



- Scan in scattering parameter space (f_0^{-1}, d_0) and express agreement data/model in number of σ deviations



Agreement with hypernuclei data and lattice QCD predictions

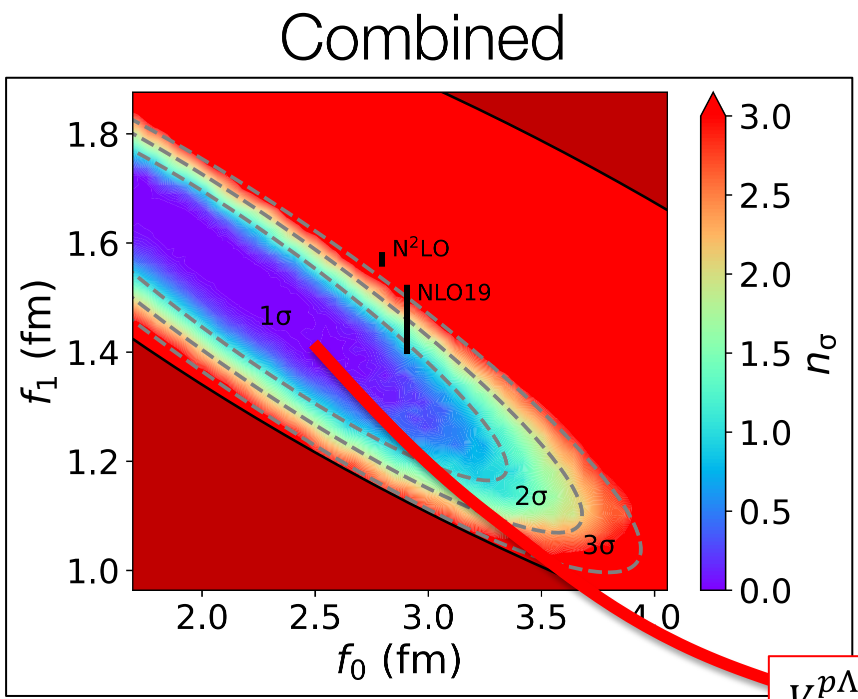
Room for a shallow bound state aka "H-dibaryon"

$$a_0^{(\Lambda\Lambda)} = -0.81 \pm 0.23^{+0.00}_{-0.13}\ [\text{fm}], \quad r_{\text{eff}}^{(\Lambda\Lambda)} = 5.47 \pm 0.78^{+0.09}_{-0.55}\ [\text{fm}],$$

HAL QCD Coll. Nucl.Phys.A 998 (2020) 121737

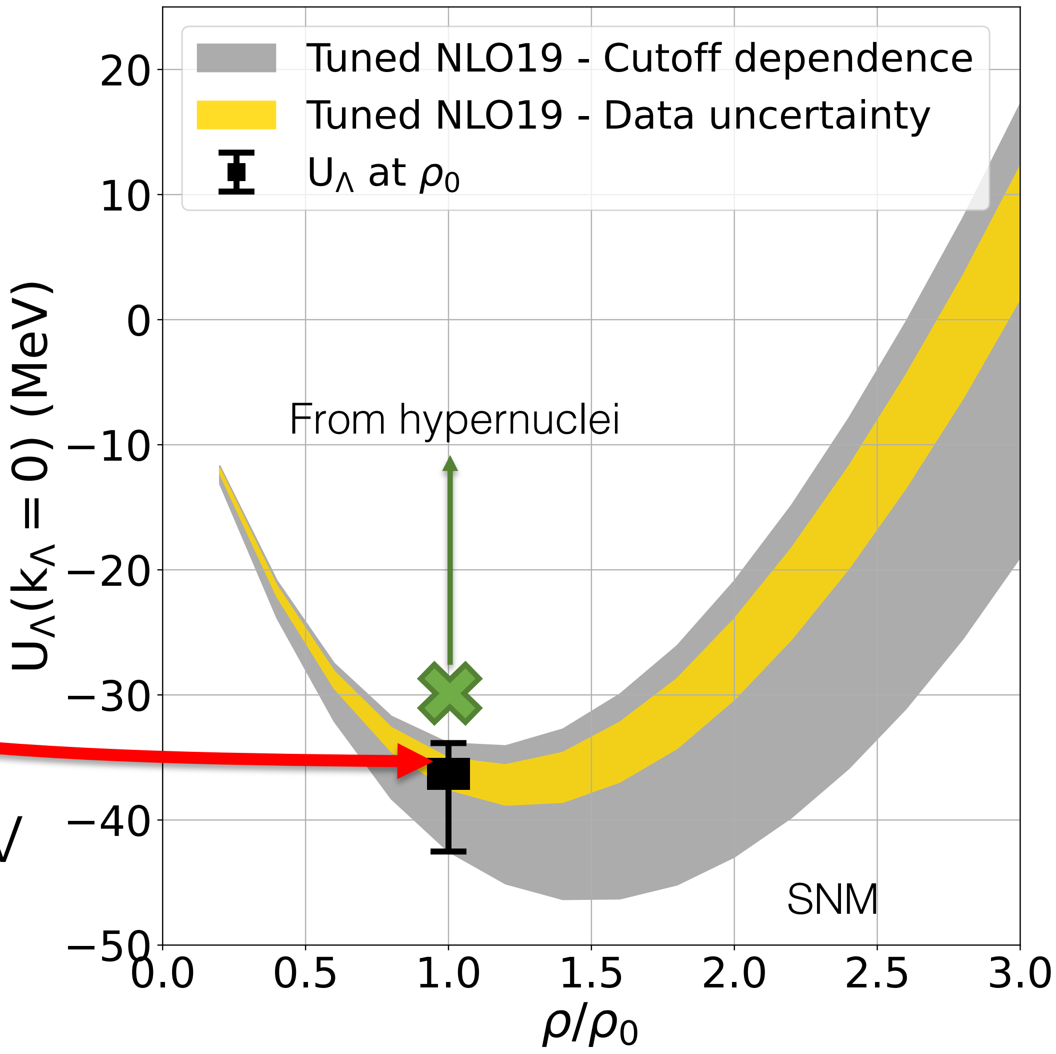
ALICE Coll. Phys.Lett.B 797 (2019) 134822

Quantifying the two-body contribution of U_Λ



$V^{p\Lambda}_{NLO19}$ in mom. space via G-matrix approach

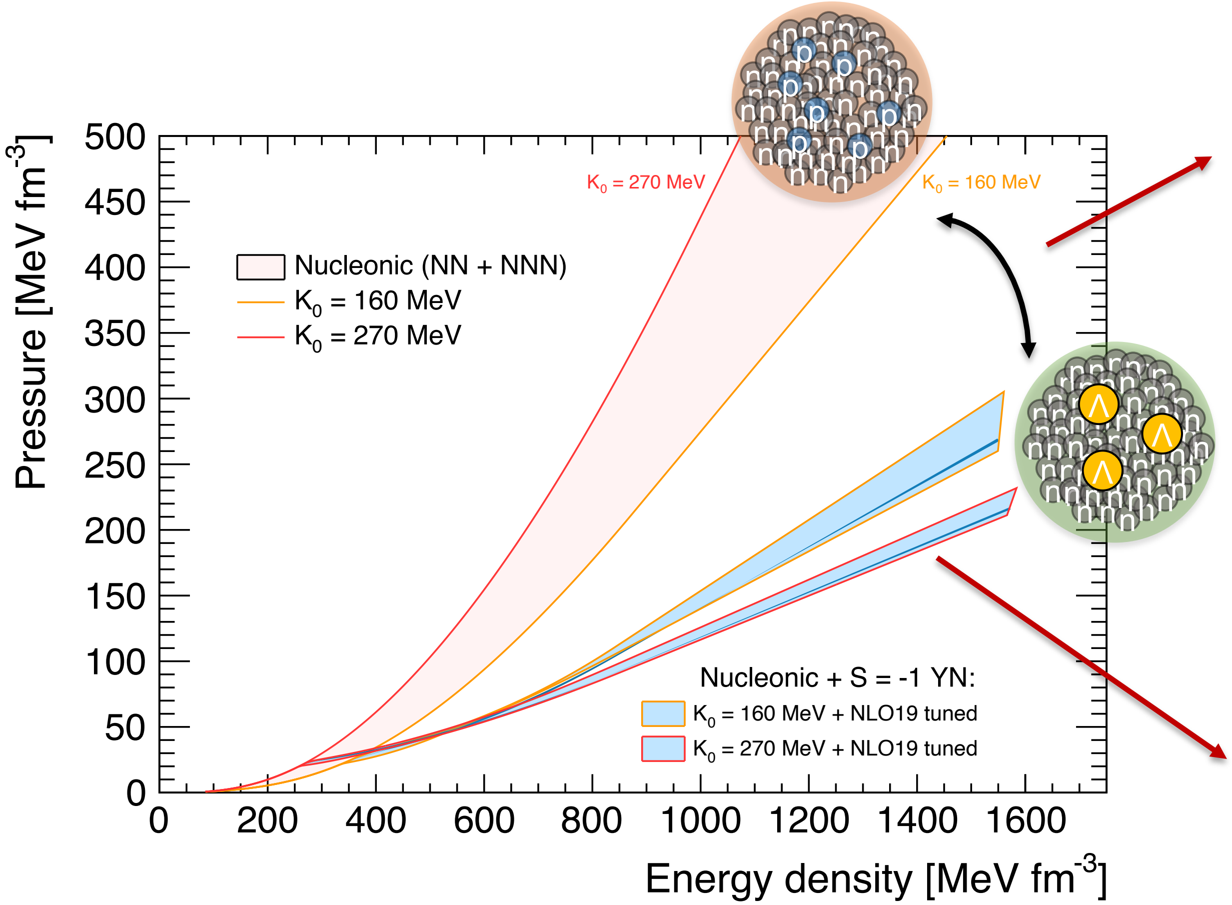
D. Mihaylov, J. Haidenbauer and VMS PLB 850 (2024) 138550



$$U_\Lambda^{2BF}(\rho_0) = -36.3 \pm 1.3(stat)^{+2.5}_{-6.2}(syst)\ \text{MeV}$$

Quantitative estimate of repulsion from 3BF ΛNN at ρ_0 !

Results with S=-1 YN interactions



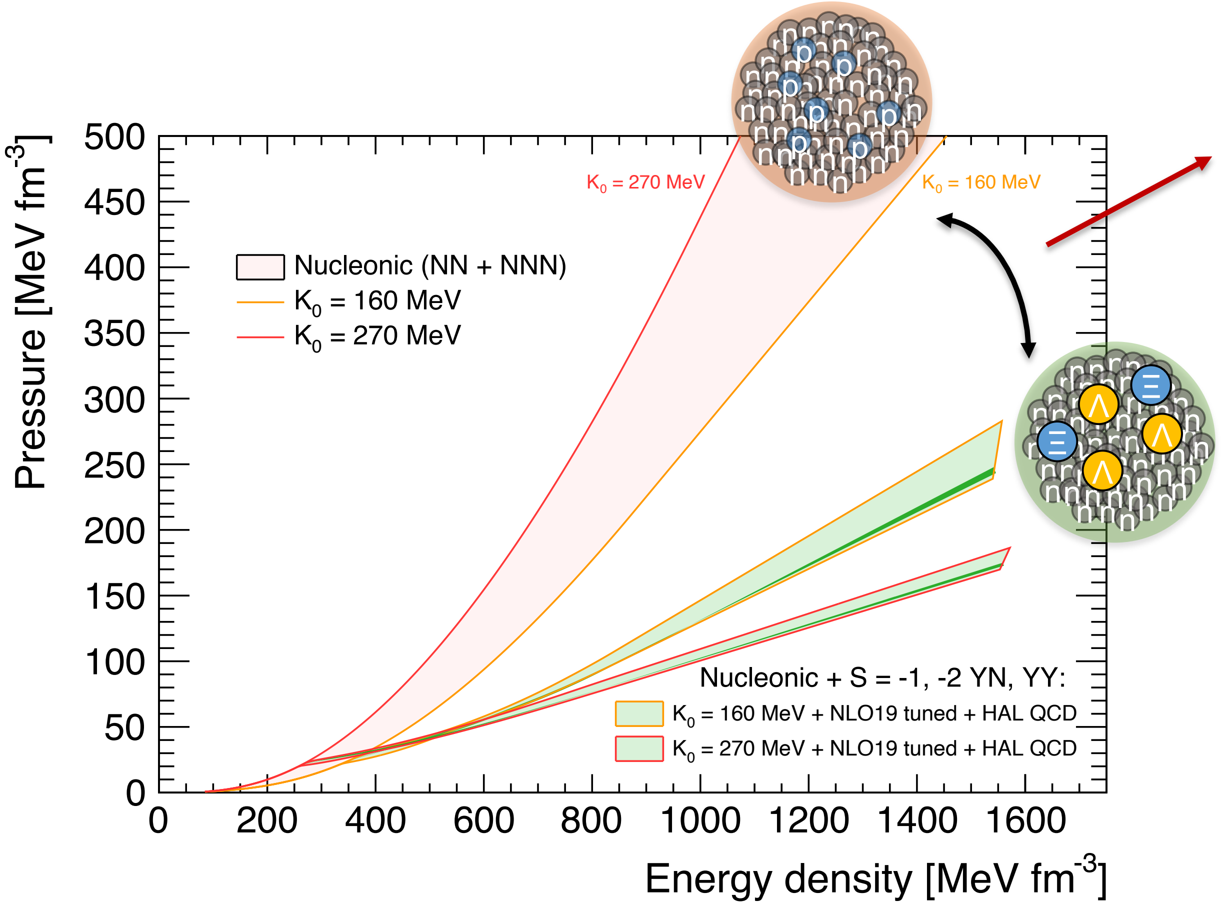
Inclusion of S=-1 YN leads overall to a softening of the EoS

Stiffest nucleonic EoS leads to even earlier onset of hyperons, even softer EoS!

Light shade: theoretical uncertainty (cut-off)

Dark shade: experimental uncertainty (comb. fit scatt. + femto)

Results with S=-1,-2 YN and YY interactions



Inclusion of S=-2 YN softens even more the EoS!

Light shade: theoretical uncertainty (cut-off)

Dark shade: experimental uncertainty (comb. fit scatt. + femto)

Compositions