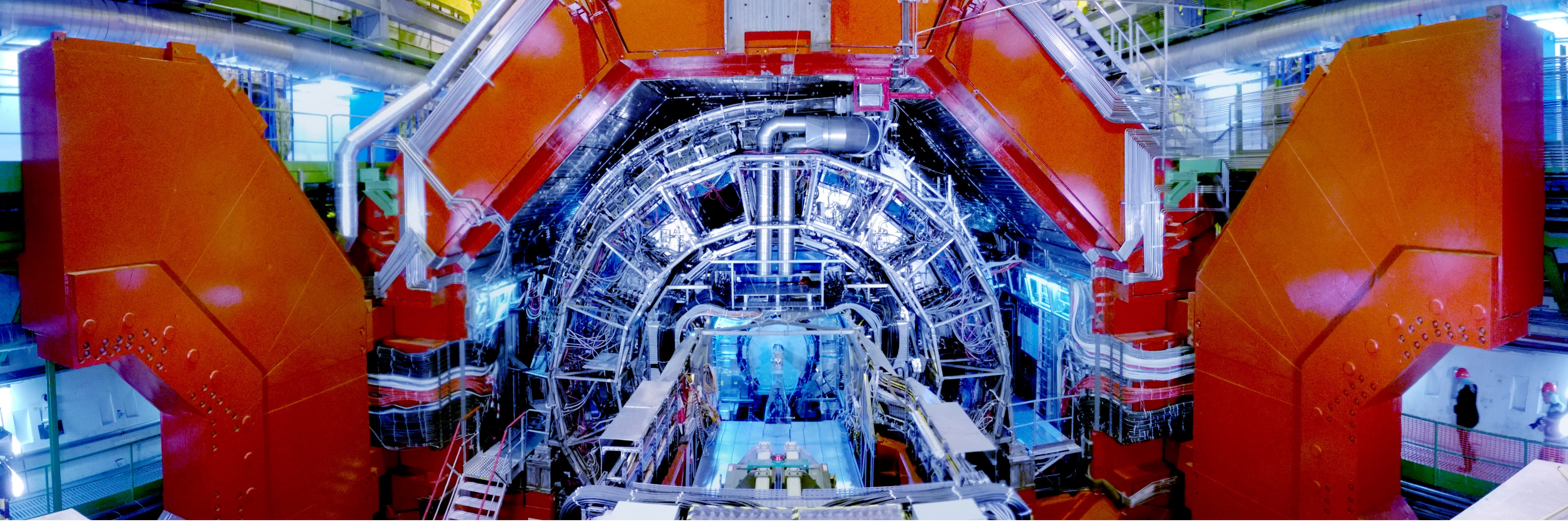


Constraining the p–Σ^0 interaction for the first time employing femtoscopy in ALICE

Andi Mathis on behalf of the ALICE Collaboration
Technische Universität München

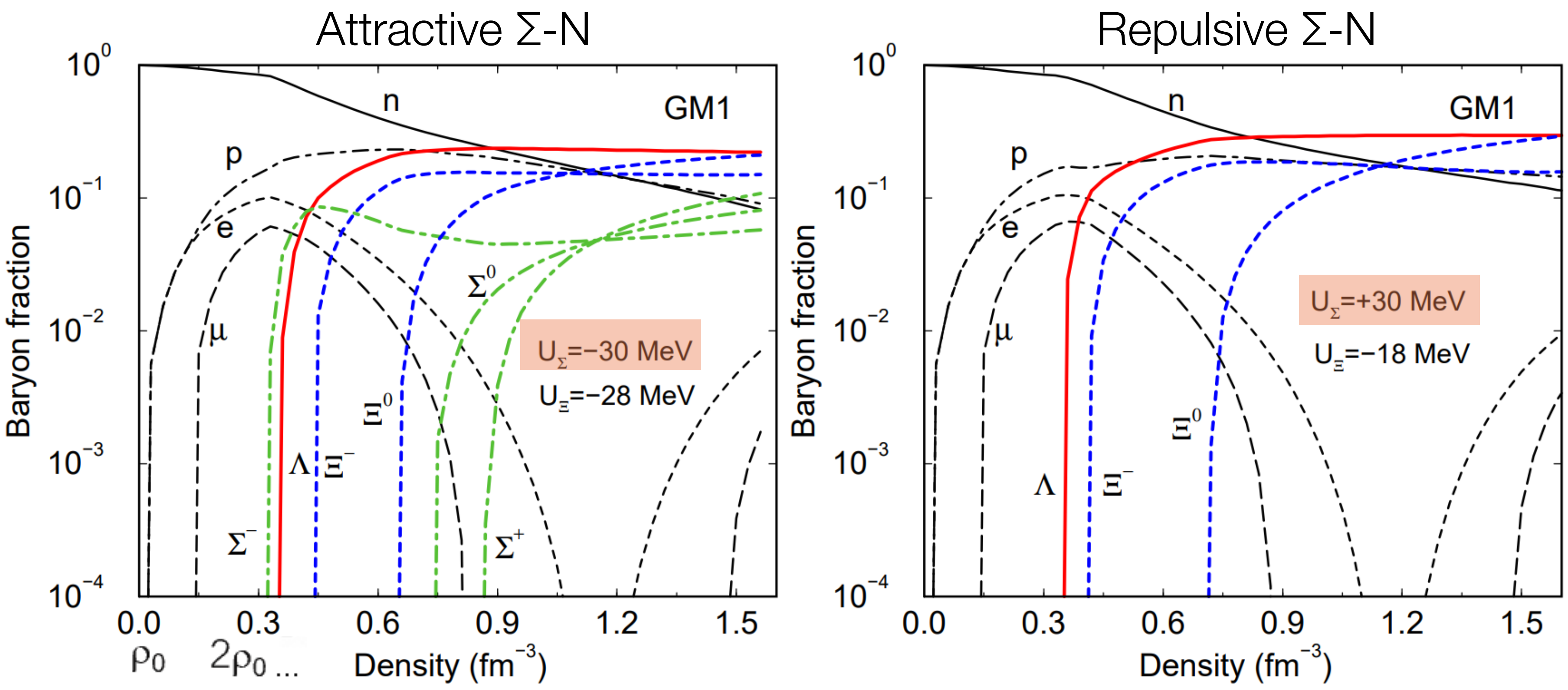
XIV Workshop on Particle Correlations and Femtoscopy

4 June 2019

SFB 1258 Neutrinos Dark Matter Messengers

ALICE

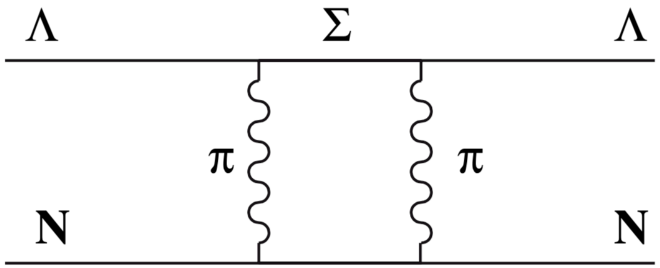
Motivation – Study the Σ-N interaction



J. Schaffner-Bielich, Nucl. Phys. A 835 (2010) 279

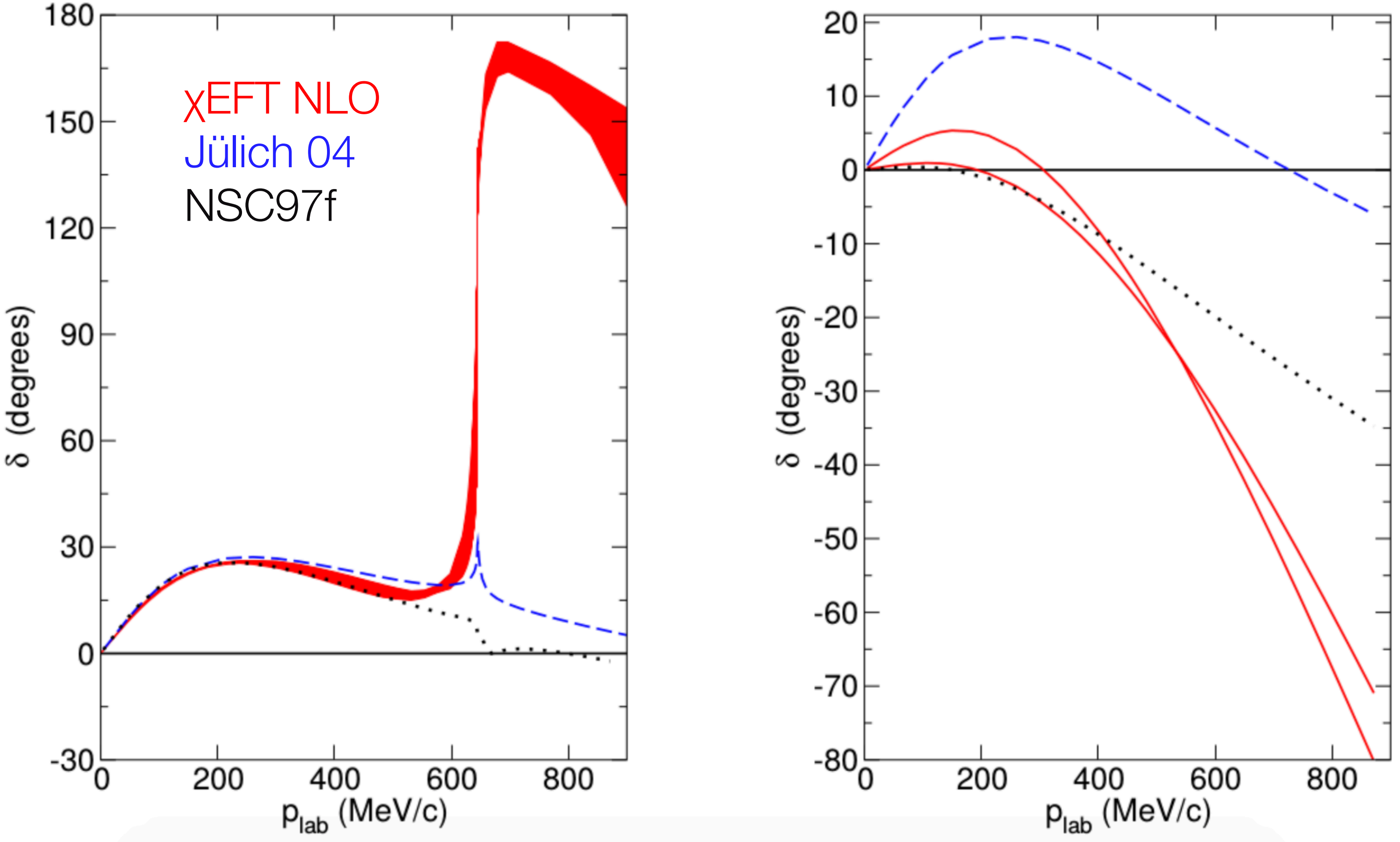
- The Σ-N interaction is not well constrained
  - Many-body interactions and couplings become increasingly important at higher densities

Influence of the Σ-N – Λ-N coupled channel



- Small mass difference between Σ and Λ: ~80 MeV/*c*
- Repulsion for Λ-p when the Σ-N – Λ-N coupled channel is neglected
  - Shift of hyperon appearance towards higher densities
  - See also the previous talk by D. Mihaylov about p-Λ

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.

Λ–Λ femtoscopy

pp $\sqrt{s}$ = 7 & 13 TeV (min. bias)
p–Pb $\sqrt{s_{NN}}$ = 5.02 TeV

arXiv:1905.07209 (submitted to PLB)

Λ–Λ interaction

- No scattering data
- The observed double Λ hyper-nuclei events predict a shallow Λ–Λ attraction H. Takahashi et al., PRL 87 (2001) 212502.
  - $B_{\Lambda-\Lambda} = 6.91 \pm 0.16$ MeV
- Femtoscopic analysis in heavy-ion collisions (STAR) extremely inconclusive, due to the unconstrained residual signal

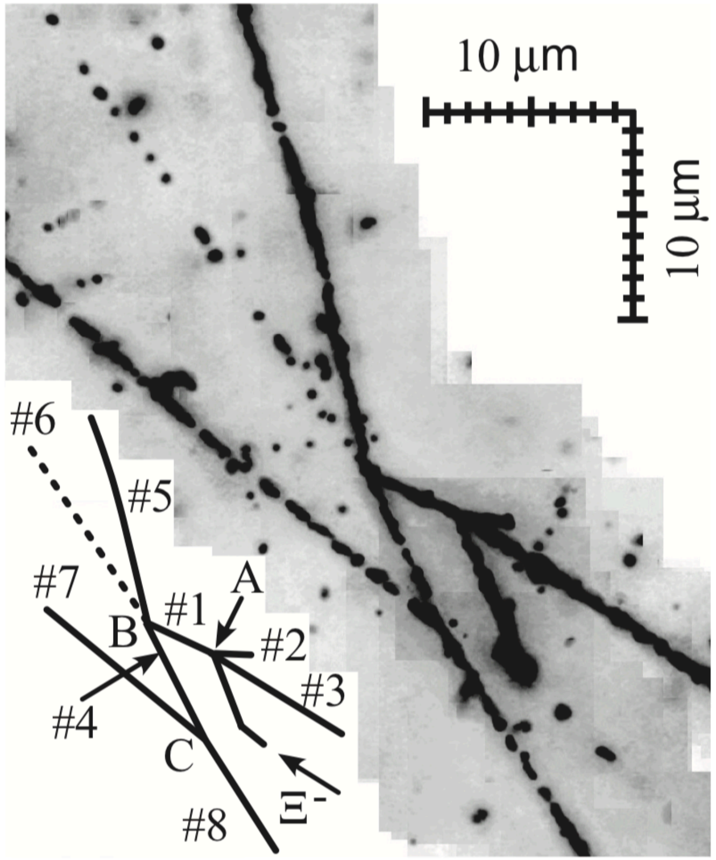
Original analysis by STAR
PRL 114 (2015), 022301.

Reanalyisis by Morita *et al.*
PRC 91 (2015), 024916.

Repulsive potential?

Attractive potential?

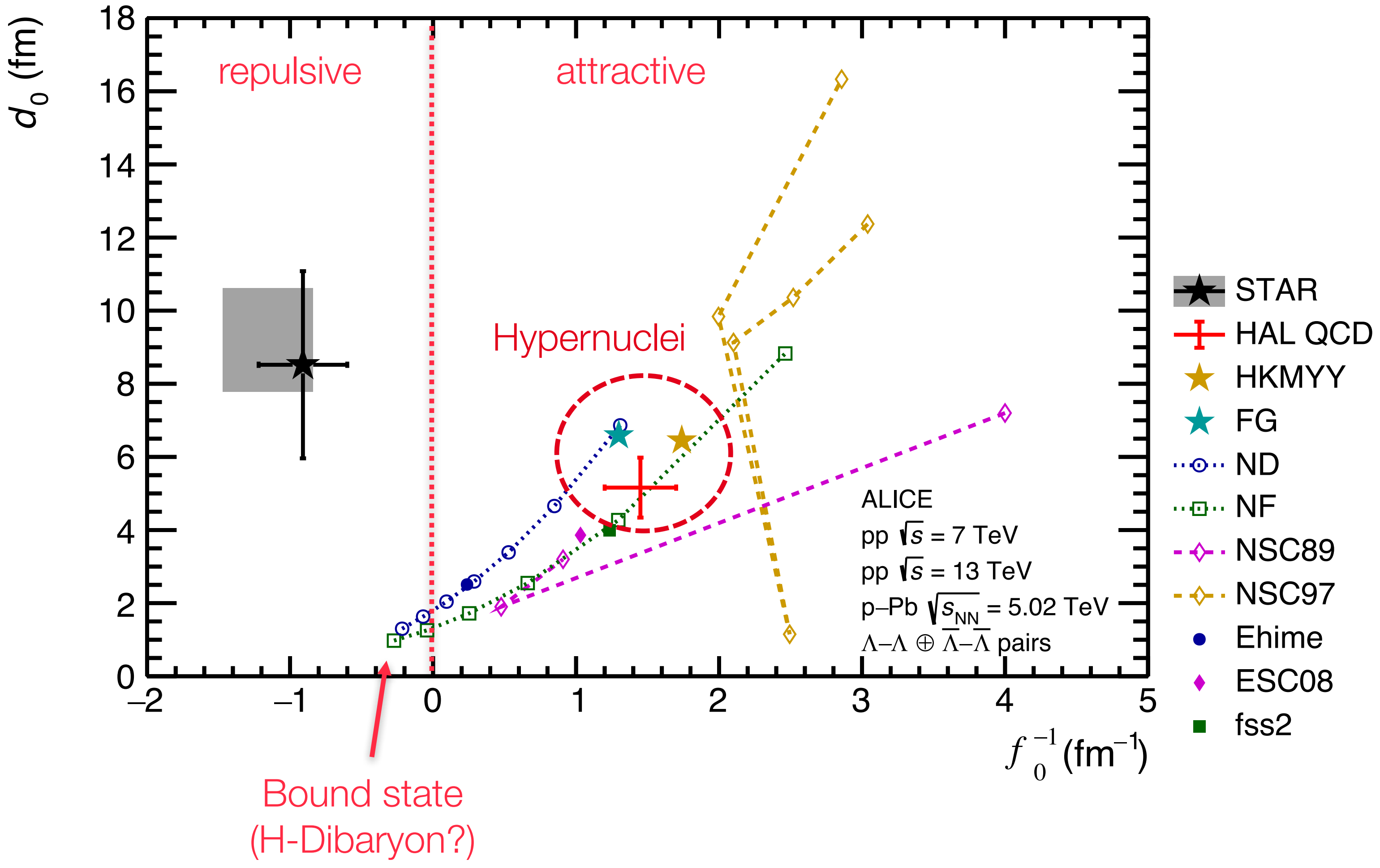
Small scattering length ($|f_0| \leq 1$ fm)
Large effective range ($d_0 \geq 4$ fm)



J. K. Ahn *et al.*, PRC 88, 014003 (2013)

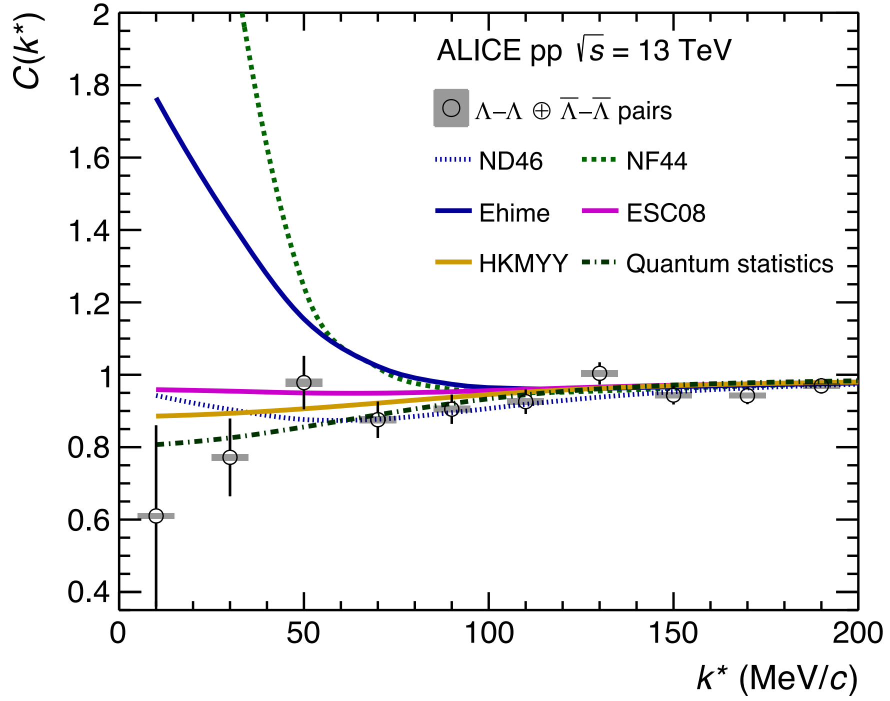
Λ–Λ interaction

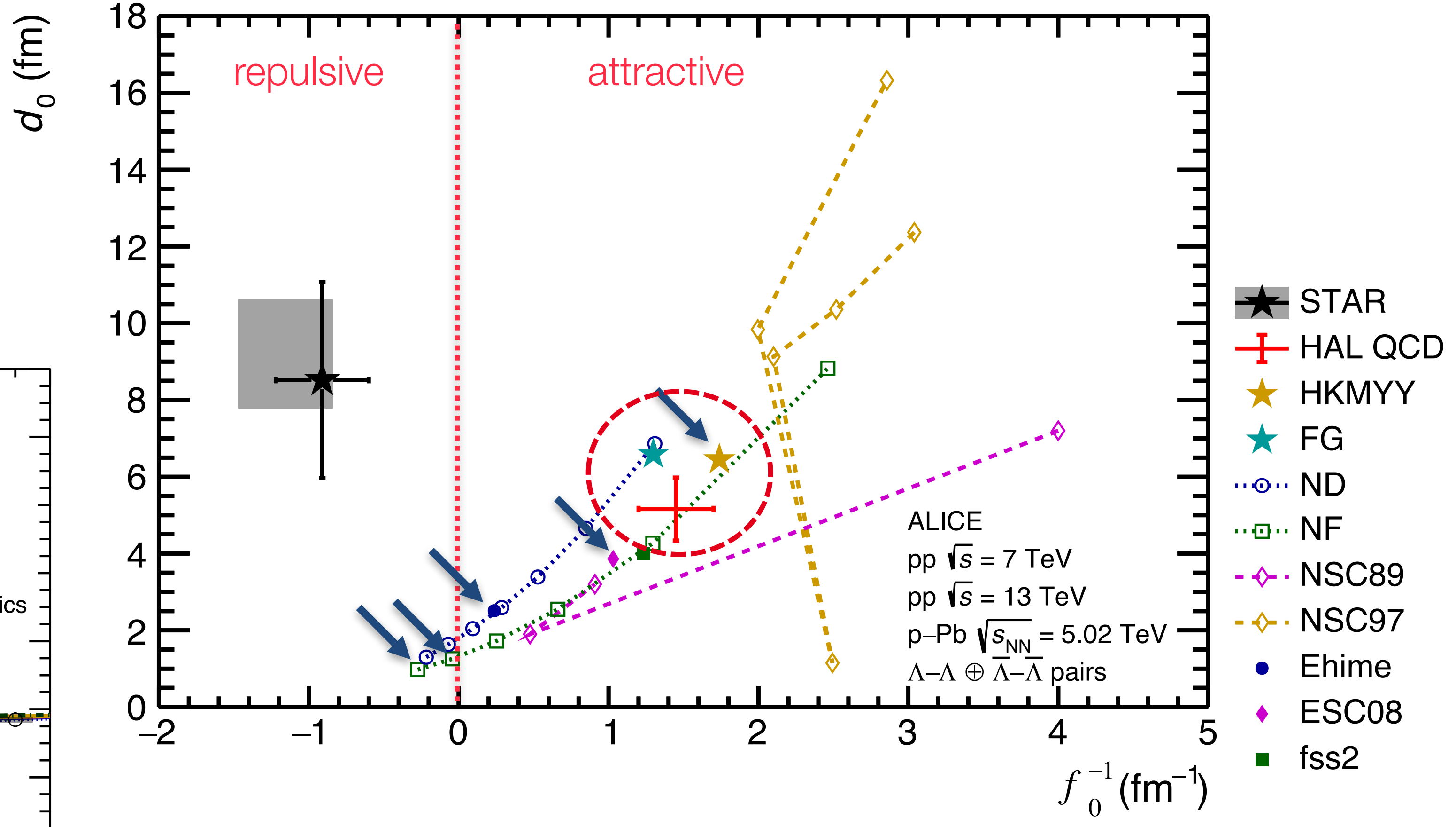
- Theoretical models and experimental measurements cover a wide range in the scattering parameter phase space
  - Measurement: STAR Collab., PRL 114 (2015) 022301.
  - Models from K. Morita *et al.*, PRC 91 (2015) 024916.
  - HAL QCD: K. Sasaki and T. Hatsuda (HAL QCD Collab.), private communication.



Λ–Λ interaction

- Theoretical models and experimental measurements cover a wide range in the scattering parameter phase space
- Measured correlation function provides the required precision!

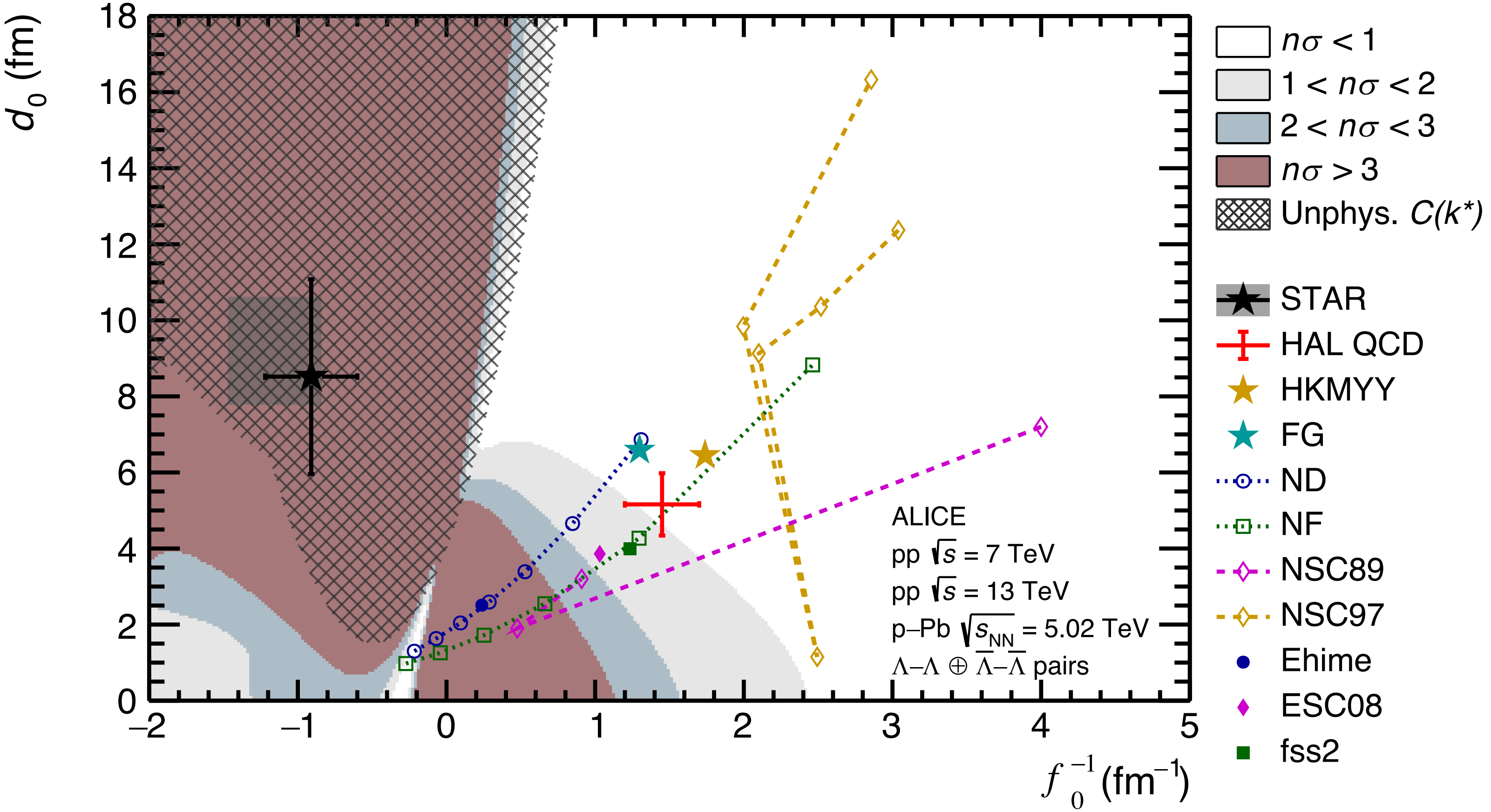




Λ–Λ femtoscopy

- Combination of all analyzed datasets
  - pp 7 & 13 TeV
  - p–Pb 5.02 TeV

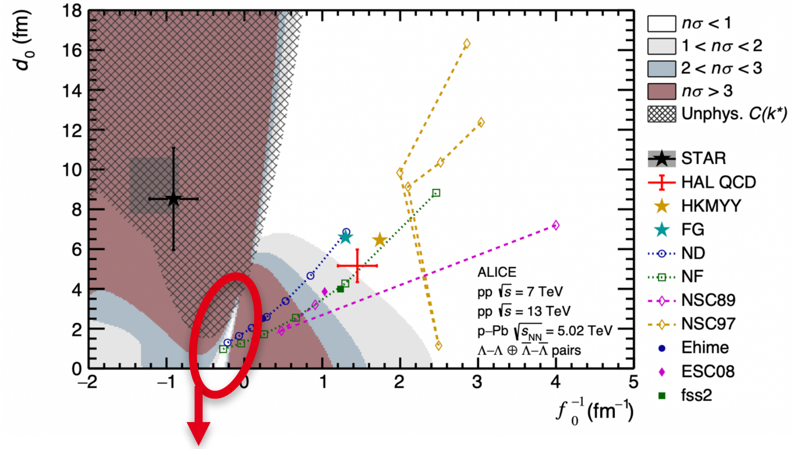
- Test of the agreement between data and the prediction by the Lednický model in nσ
  - Under the hypothesis of a common, Gaussian source
  - Small source size limits the prediction power of the Lednický model

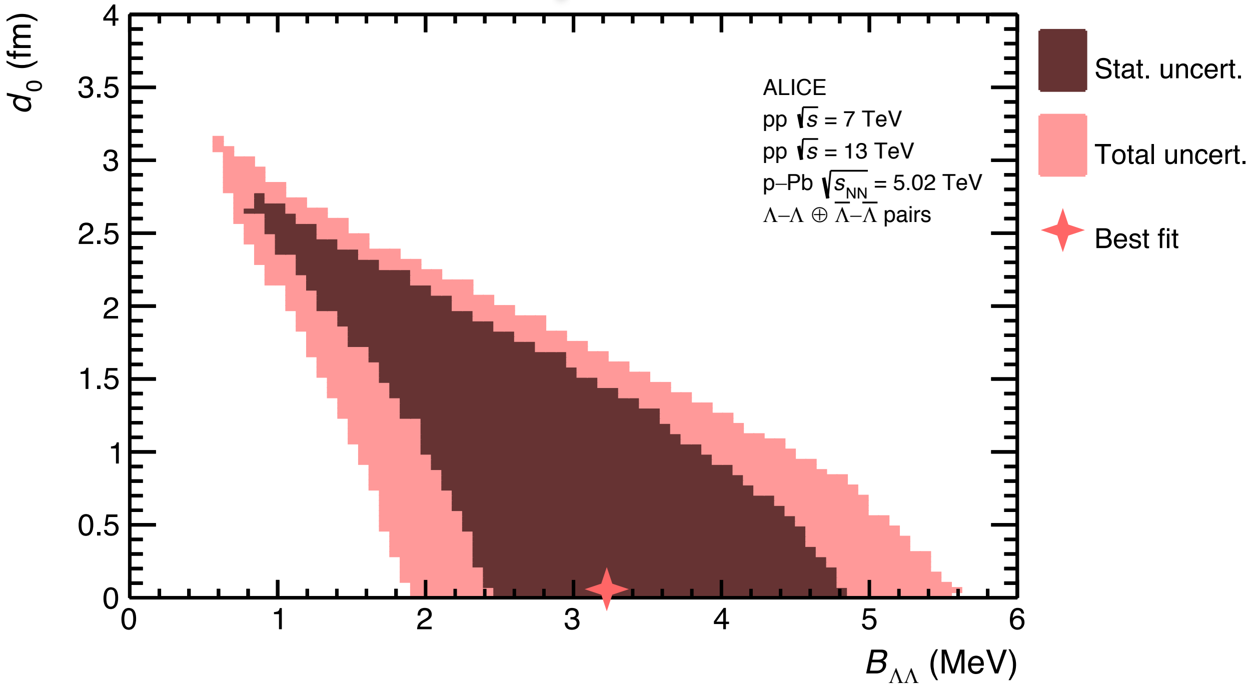


Λ–Λ femtoscopy – H-Dibaryon

$$B_{\Lambda\Lambda} = \frac{1}{m_\Lambda d_0^2} \cdot \left(1 - \sqrt{1 + \frac{2d_0}{f_0}}\right)$$

S. Gongyo et al., PRL 120 (2018) 212001.
P. Naidon and S. Endo, Rept. Prog. Phys. 80 (2017) 056001.





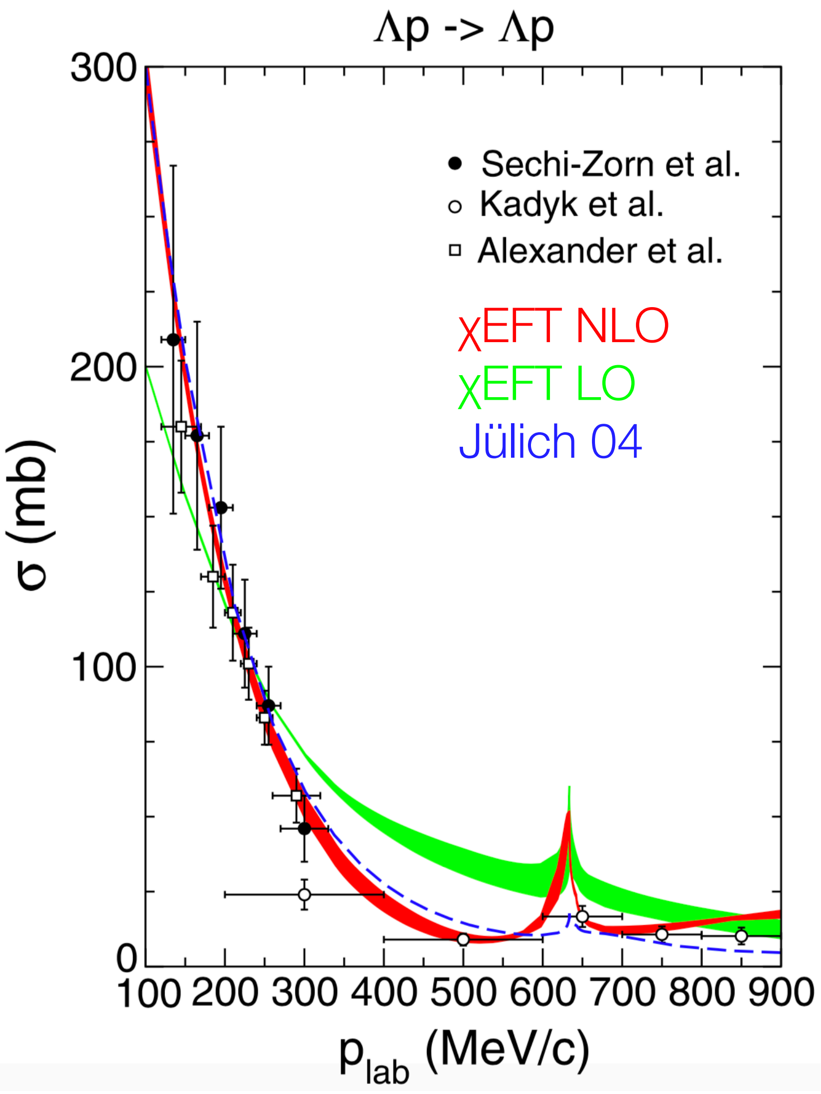
- H-Dibaryon: Tight constraints on the allowed binding energy
  - $B_{\Lambda-\Lambda} = 3.2^{+1.6}_{-2.4}\,(\text{stat.})^{+1.8}_{-1.0}\,(\text{syst.})$ MeV
  - More stringent than previous measurements

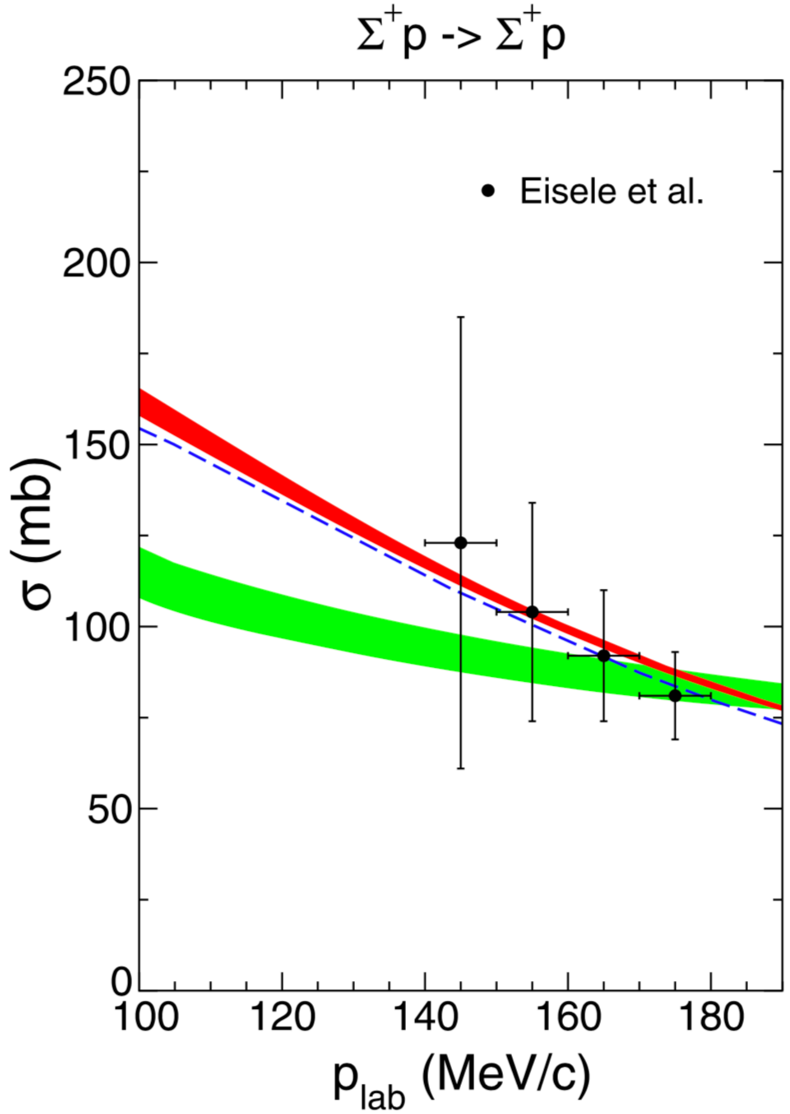
- For more details see arXiv:1905.07209

p–Σ^0 femtoscopy

pp $\sqrt{s}$ = 13 TeV (high multiplicity)

Σ-N interaction – scattering experiments



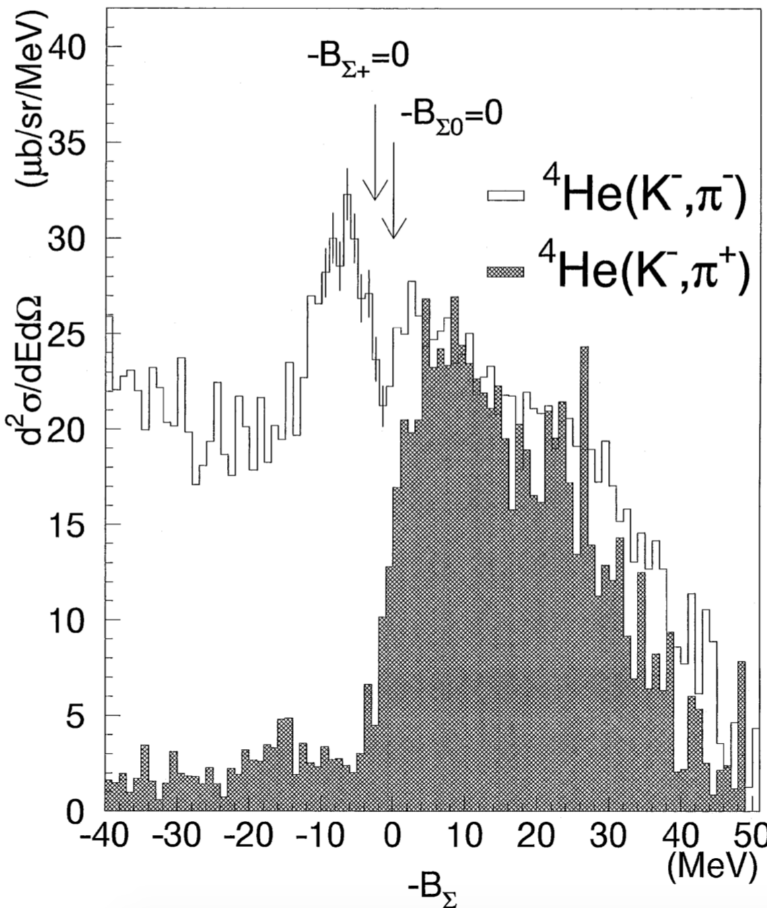


J. Haidenbauer et al., Nucl. Phys. A 915 (2013) 24.

Σ-N interaction – Hypernuclei

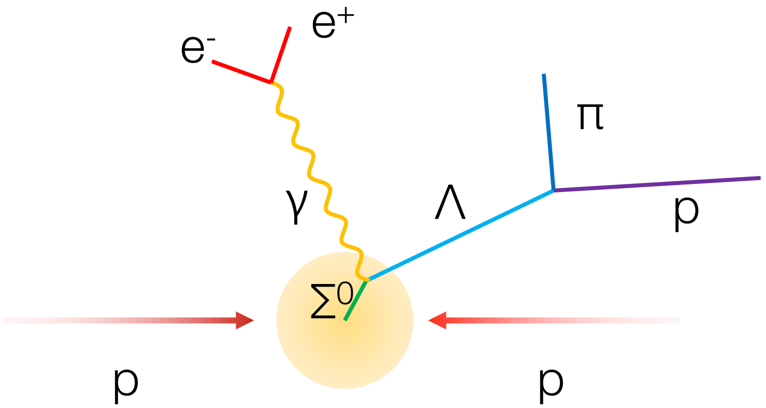
- Experimental evidence for the formation of ${}^{4}_{\Sigma}\mathrm{He}$
  - $\mathrm{B}_{\Sigma^+} = 4.4 \pm 0.3(\mathrm{stat}) \pm 1.0(\mathrm{syst})$ MeV
    T. Nagae et al., PRL 80 (1998), 1605.
  - $\mathrm{B}_{\Sigma^+} \sim 2.3$ MeV
    R. S. Hayano et al., PLB231 (1989), 355.

  - Different theoretical approaches predict both attractive and repulsive interactions
    - Experimental data are too scarce for a final conclusion



T. Nagae et al., PRL 80 (1998), 1605.

Reconstruction

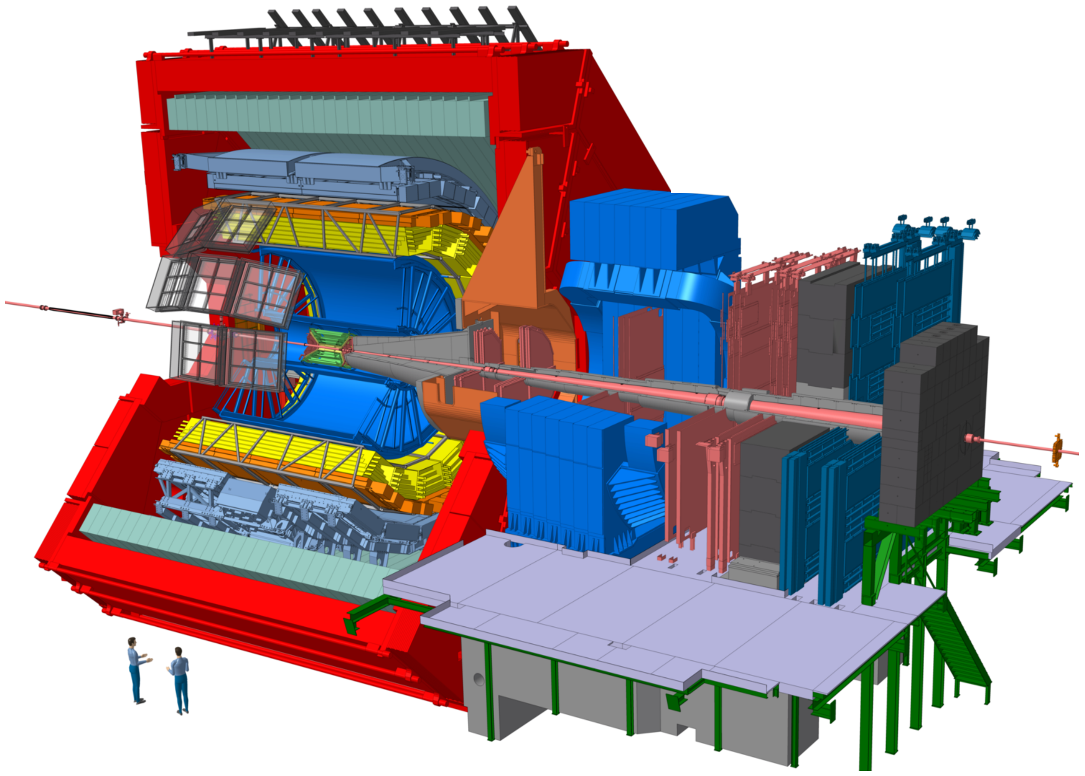


$\Sigma^0 \rightarrow \Lambda\, \gamma$ (BR: almost 100 %)

- Identification of the subsequent decays in the ALICE central barrel (ITS – TPC)

Photon conversion

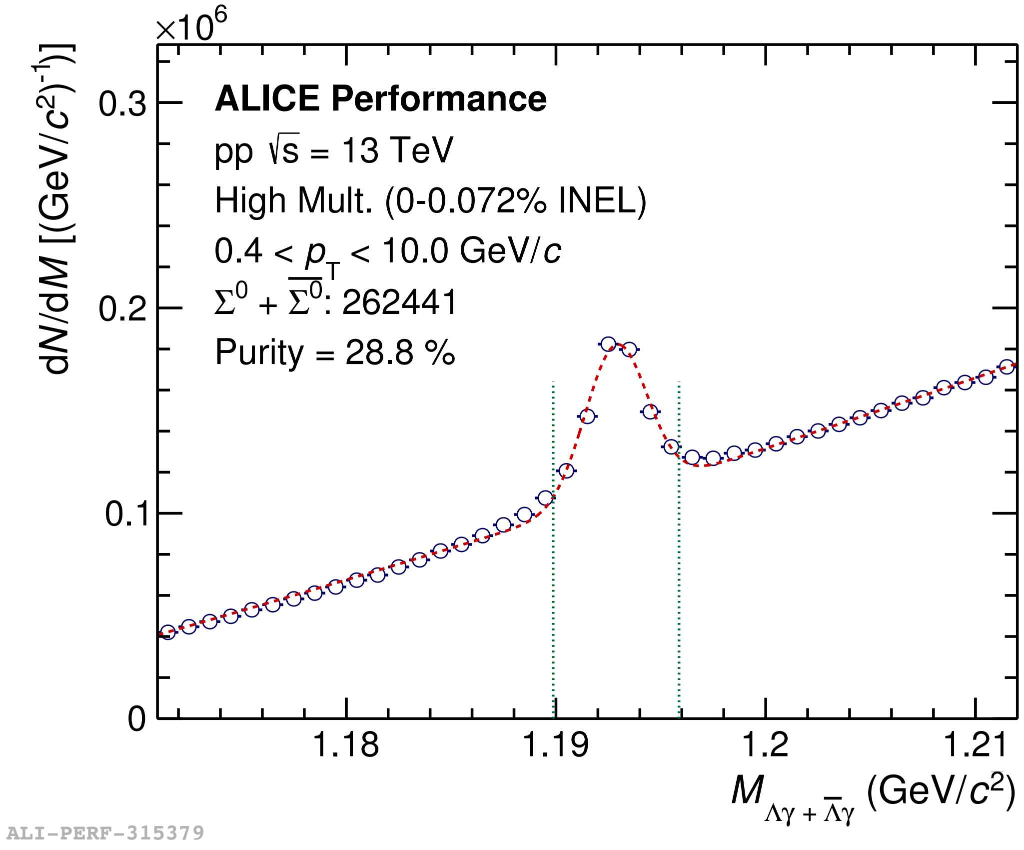
- Conversion in detector material of ITS and TPC
  - $|\eta| < 0.9,\ 0 < \varphi < 2\pi$
- $X / X_0 = (11.4 \pm 0.5)$ %
- Conversion probability ~ 8% in ALICE central barrel



Reconstruction

$\Sigma^0 \rightarrow \Lambda\gamma$ (BR: almost 100 %)

- pp $\sqrt{s}$ = 13 TeV ~1 × 10^9 high multiplicity events
- More than 250,000 candidates
- Purity ~30 %



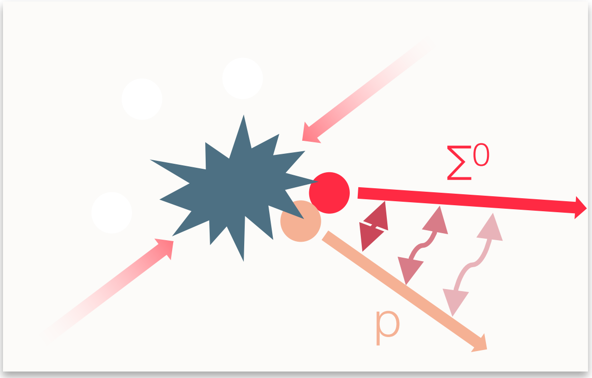
Sidebands

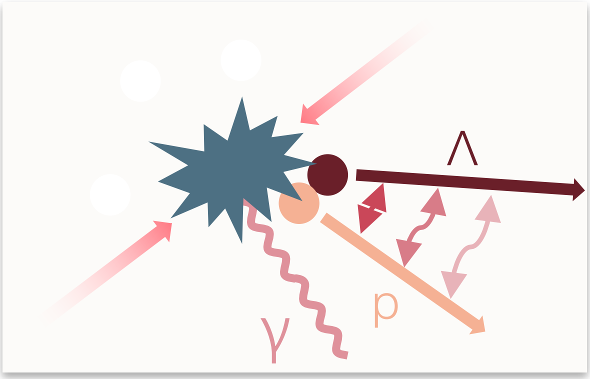
$\Sigma^0 \rightarrow \Lambda\gamma$ (BR: almost 100 %)

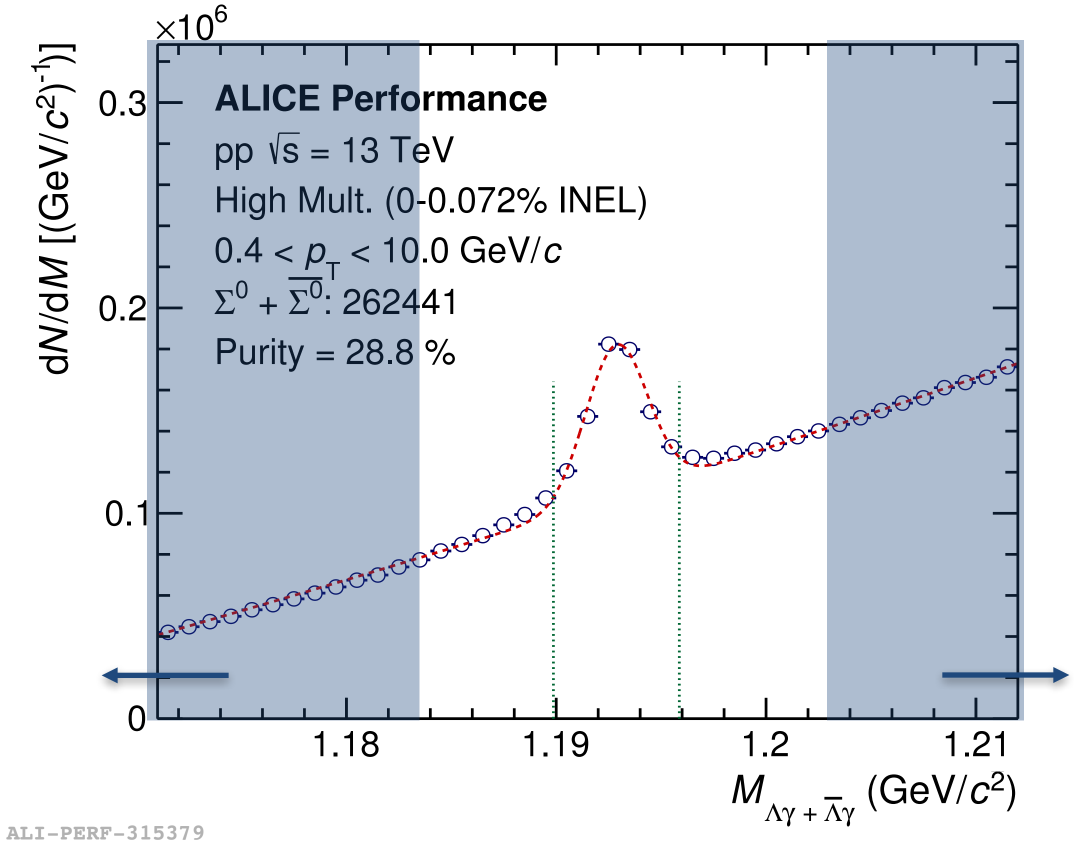
- pp $\sqrt{s}$ = 13 TeV ~1 × 10^9 high multiplicity events
- More than 250,000 candidates
- Purity ~30 %

Sidebands

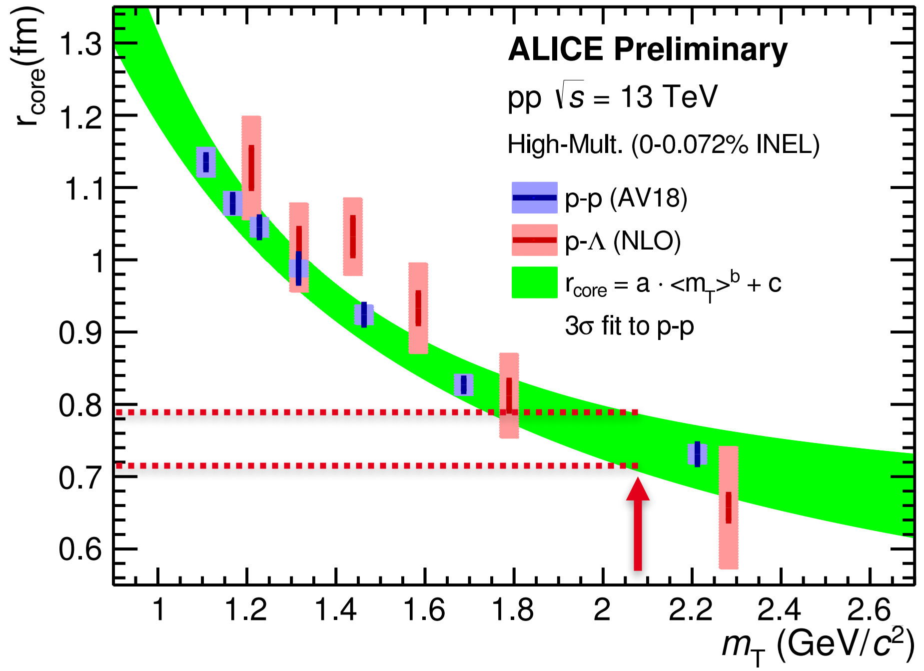
- Investigation of the correlation in the sidebands crutial
  - Genuine p–Σ^0 vs. p–$(\Lambda\gamma)_{combinatorial}$







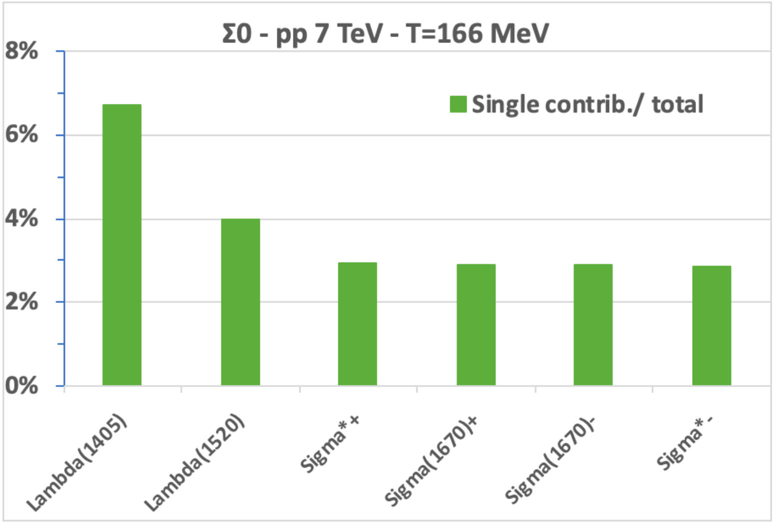
Modelling of the correlation function



ALI-PREL-315640

m_{eff} = 1581.73 MeV/c^2

$c\tau_{eff}$ = 4.28 fm

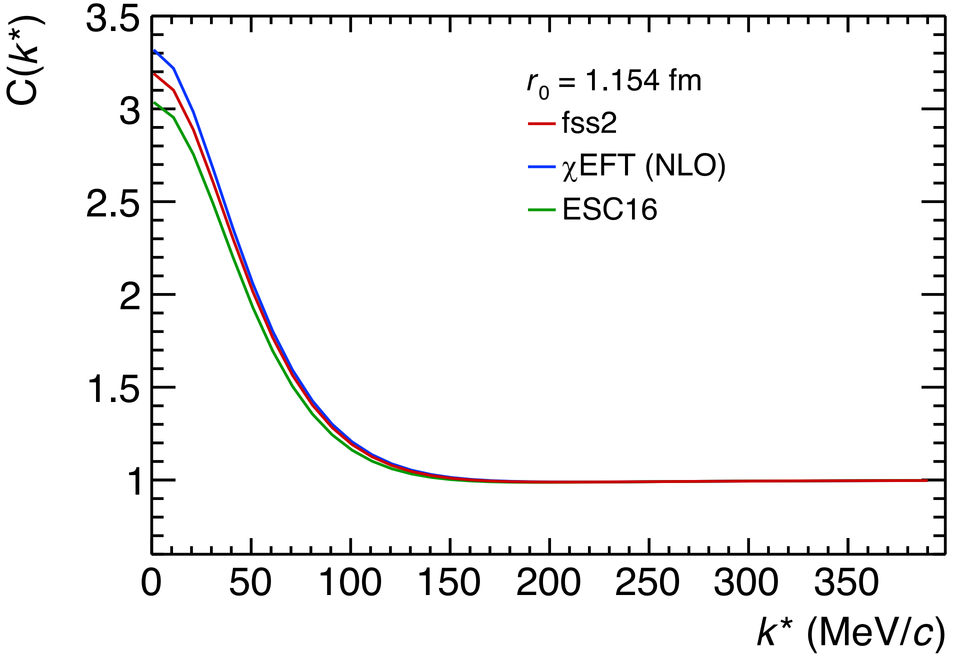


F. Becattini, Priv. Comm.

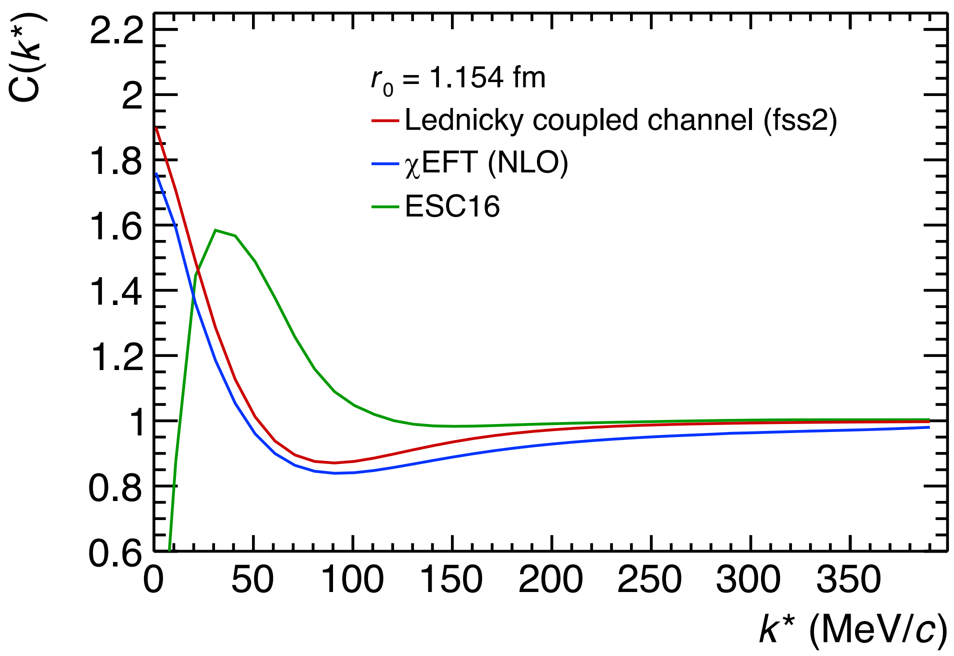
- Constrain the source via the p–p correlation function
- Contributions from strong decaying resonances for the different pairs
  - Statistical Hadronization Model
- For all pairs: shared Gaussian core
  - Scaling with m_T
  - For the p–Σ^0 this results in r_{core} = 0.75 ± 0.04 fm

Theoretical models

p–Λ



p–Σ0



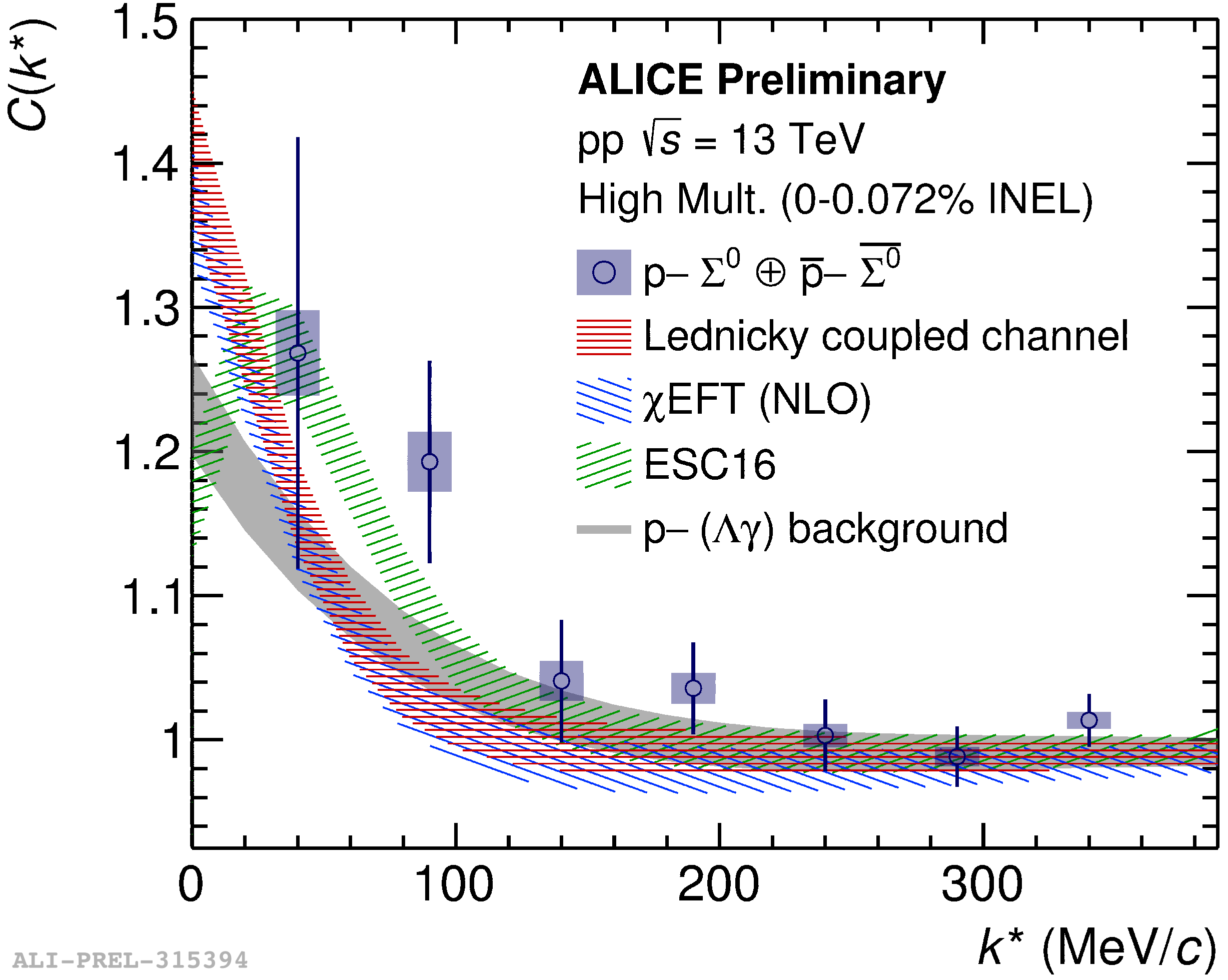
- Lednický model explicitly considering the coupling to p–Λ and n–Σ^+ A. Stavinskiy *et al.*, arXiv:0704.3290.
  - Scattering parameters extracted from the fss2 model Y. Fujiwara *et al.*, Progr. in Part. and Nucl. Phys. 58 (2007) 439.
- χEFT at NLO J.Haidenbauer *et al.*, Nucl. Phys. A 915 (2013), 24.
  - The p–Σ^0 wave function is used as an input to CATS D.L. Mihaylov *et al.*, Eur. Phys. J. C78 (2018) no.5, 394.
- ESC16 M. M. Nagels, T. A. Rijken, and Y. Yamamoto, PRC 99 (2019) 044003.
  - The p–Σ^0 wave function is used as an input to CATS

Results

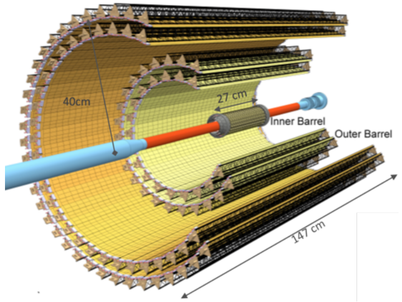
First measurement of the p–Σ^0 interaction

- Correlation function is above the background
- Sensitivity to the strong interaction, even though the uncertainties are sizable
- No sign of repulsion

Model ($k^* < 150$ MeV/c)	Lednický (fss2)	χEFT (NLO)	ESC16
nσ	0.8 – 2.3	1.0 – 2.6	0.4 – 1.6

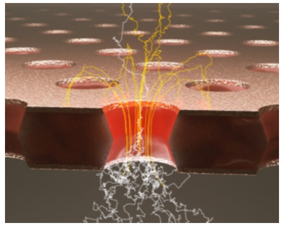


ALICE Upgrades for LHC Run 3 & 4



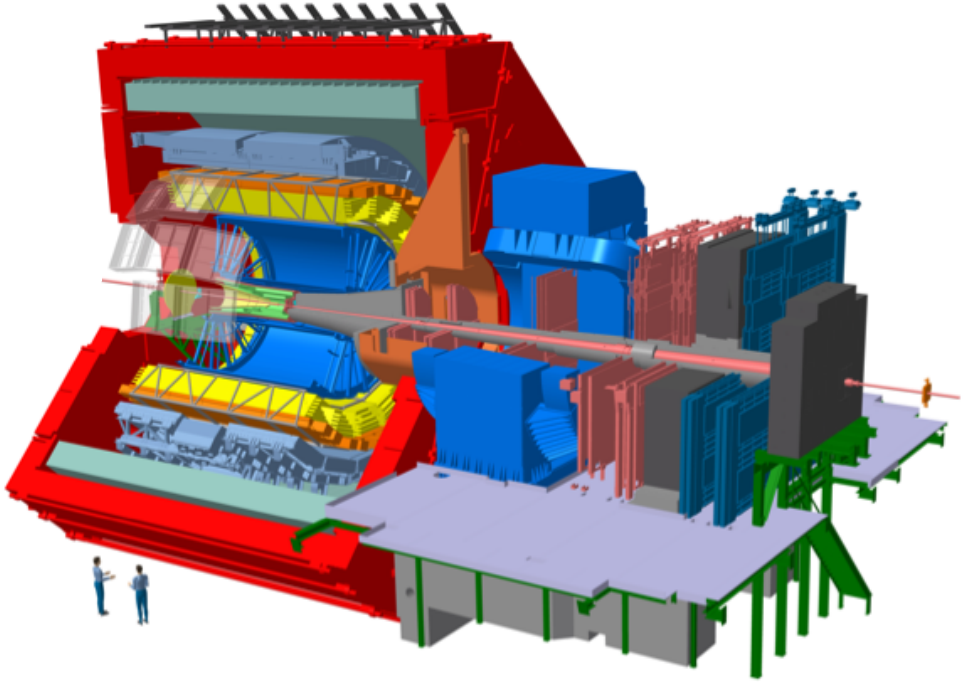
New Inner Tracking System (ITS)

- Completely new 7-layer ITS detector using CMOS MAPS technology
- Improved resolution, less material, faster readout



New TPC Readout Chambers (ROCs)

- Gas Electron Multiplier (GEM) technology and new electronics (SAMPA)
- Continuous readout at 50 kHz in Pb–Pb (~50× compared to Run 2)



Readout upgrade

- Integrated Online-Offline system (O^2)
- Record and digest Pb–Pb data at 50 kHz

→ pp sample will be enhanced by a factor ~500

Summary

- Constraining the Λ–Λ scattering parameters
  - Compatible with an slightly attractive potential
  - Constraining the allowed binding energy of a H-Dibaryon

    $B_{\Lambda-\Lambda} = 3.2^{+1.6}_{-2.4}\,(\mathrm{stat.})^{+1.8}_{-1.0}\,(\mathrm{syst.})$ MeV

- First measurement of the p–Σ^0 correlation function
  - Further experimental data are needed to precisely pin down the interaction
  - No sign of repulsion

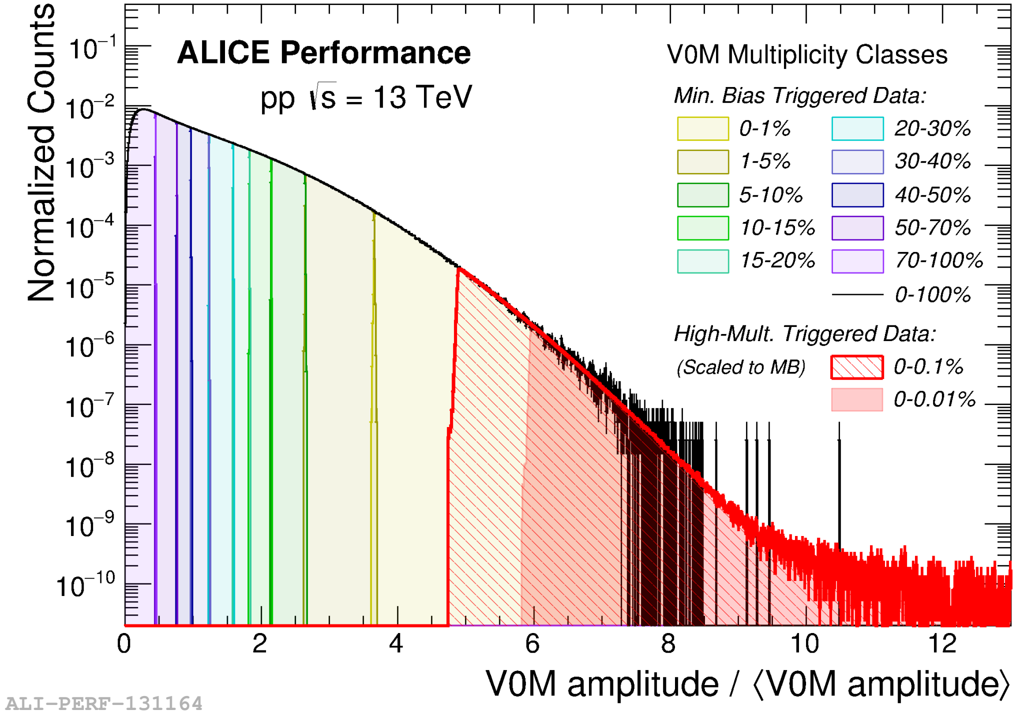
- ALICE Upgrades for Run 3 & 4 will enable the required precision!

Thank you for your attention

Data set

- Rich data set of LHC RUN2 pp $\sqrt{s}$ = 13 TeV (2016/17/18)
  - High Multiplicity: **~ 1 x 10^9 Events**

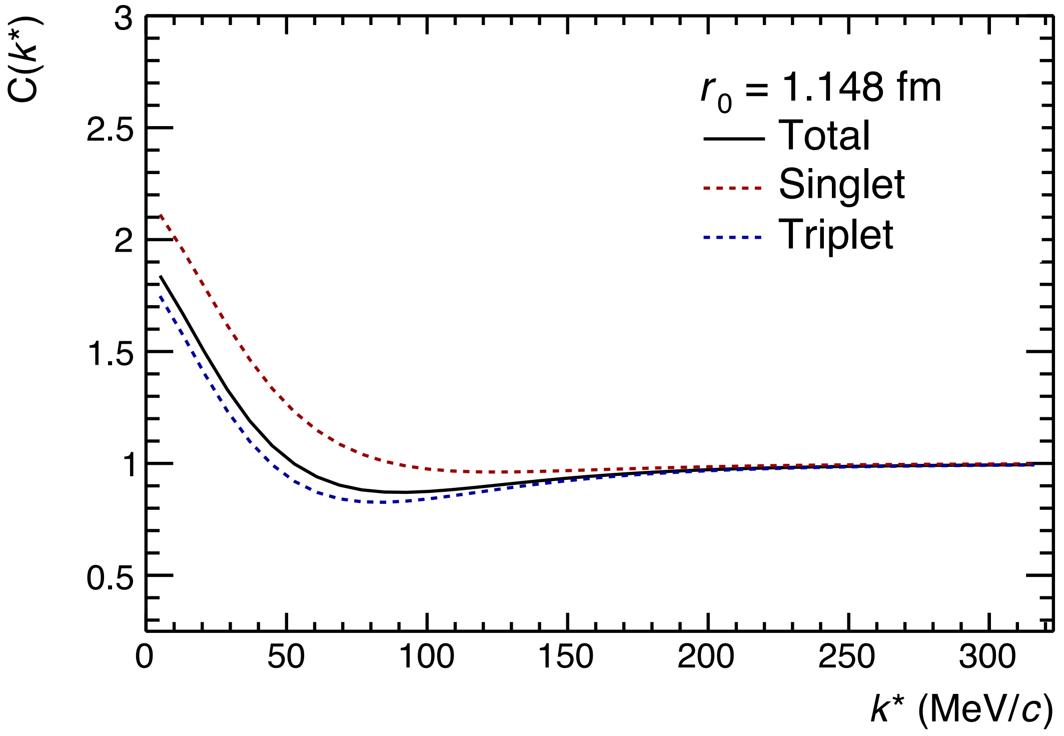
- High Multiplicity Trigger (HM)
  - Based on threshold in the measured V0 amplitude
  - Great for femtoscopy since we study particle pairs!



Models

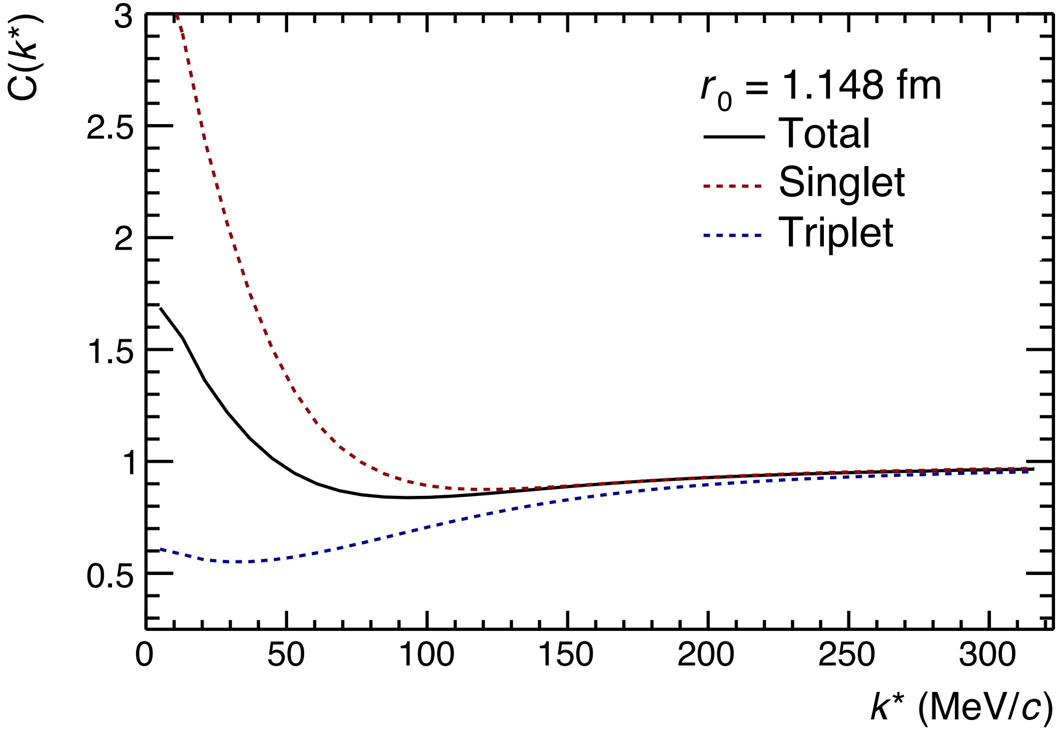
- Lednicky model taking explicitly into account the coupling to p–Λ and n–Σ^+
  - A. Stavinskiy *et al.*, arXiv:0704.3290.
  - Scattering parameters extracted from the fss2 model
    (Y. Fujiwara *et al.*, Progress in Particle and Nuclear Physics 58 (2007) 439–520.)

	$f_{(S=0)}$ (fm)	$d_{(S=0)}$ (fm)	$f_{(S=1)}$ (fm)	$d_{(S=1)}$ (fm)
I =1/2	-1.1	-1.5	-1.1+ *i* 4.3	-2.2 - *i* 2.4
I =3/2	2.51	4.92	-0.73	-1.22



Models

- χEFT at NLO
  - J.Haidenbauer *et al.*, Nucl. Phys. A 915 (2013), 24.
  - The p–Σ^0 wave function (including all couplings) is used as an input to CATS (D.L. Mihaylov *et al.*, Eur. Phys. J. C78 (2018) no.5, 394)



Models

- ESC16
  - M. M. Nagels, T. A. Rijken, and Y. Yamamoto, PRC 99 (2019) 044003.
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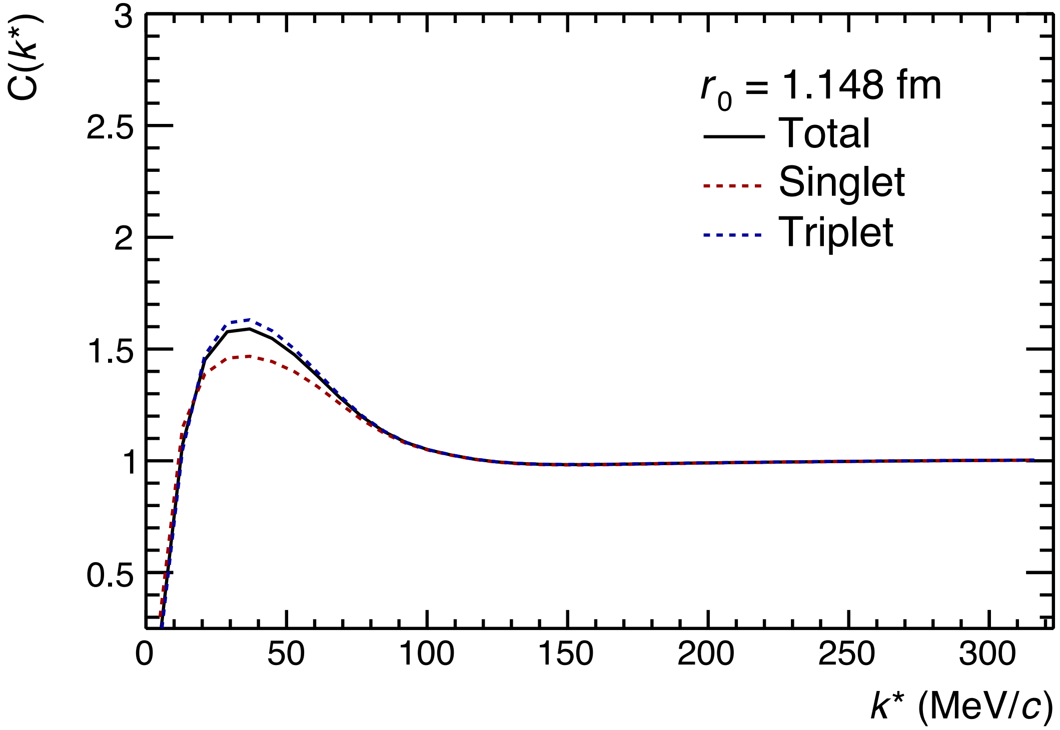
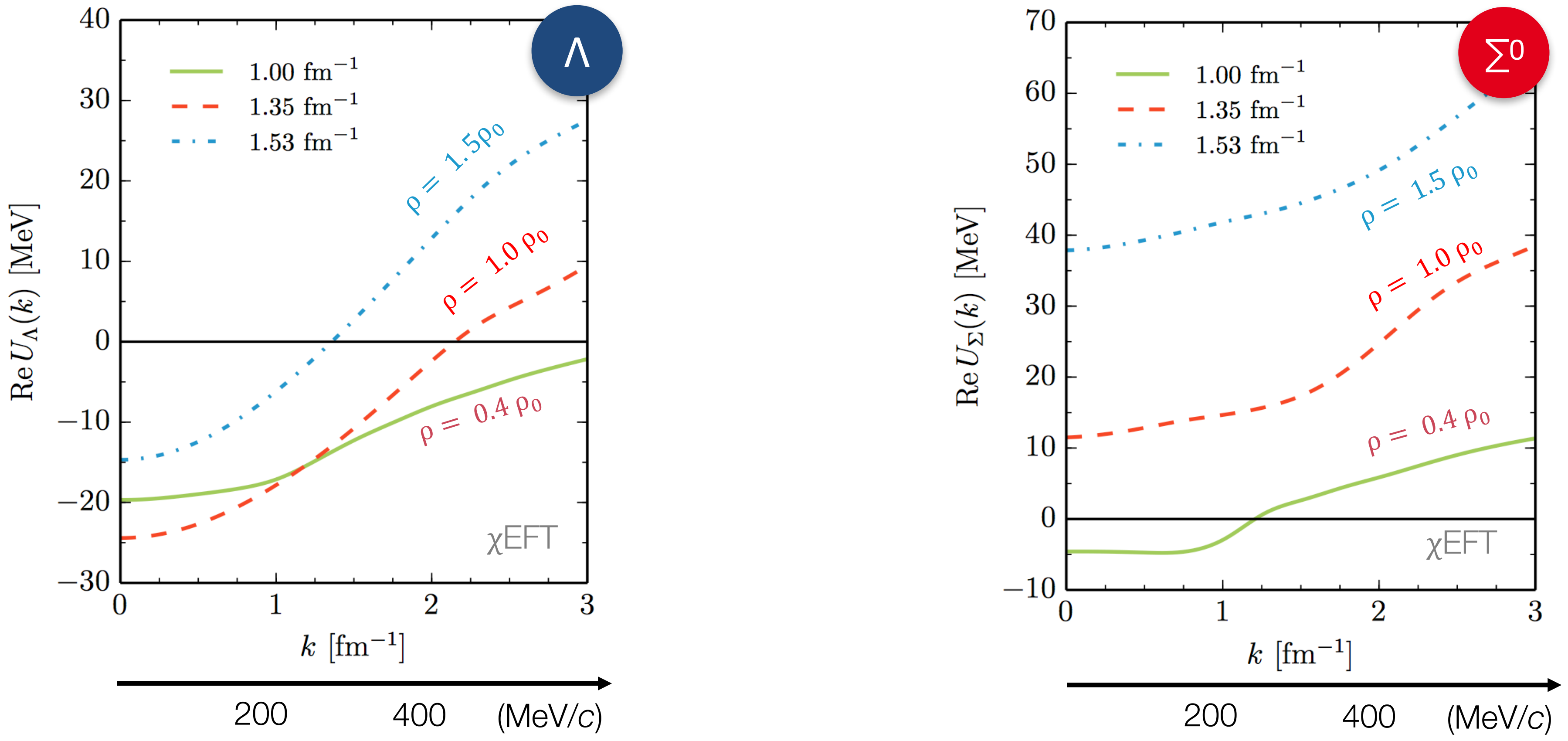


Hyperons inside nuclear matter



Petschauer et al., Eur. Phys. J. A 52, 15 (2016)