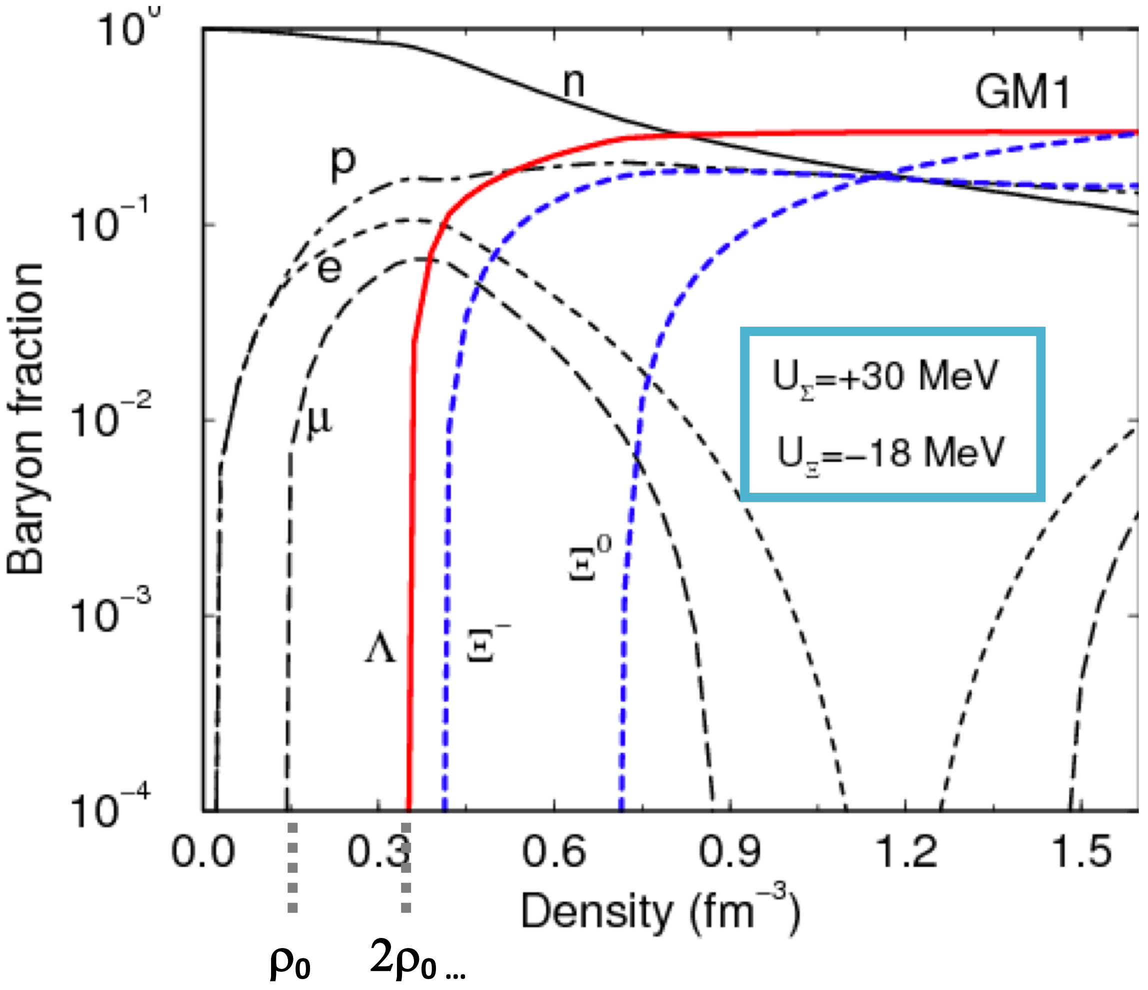
Unprecedented precision studies of the N-Ξ interaction via the femtoscopy method

Bernhard Hohlweger on behalf of the ALICE Collaboration
XIV Workshop on Particle Correlations and Femtoscopy
4th June 2019

Where does theory on neutron stars take us?

- At finite densities: Production of Hyperons
- Onset depends on:
  - **Mass**
  - **Single Particle** Potential in pure neutron matter (PNM)



J. Schaffner-Bielich, Nucl. Phys. A 804 (2008), 309-321

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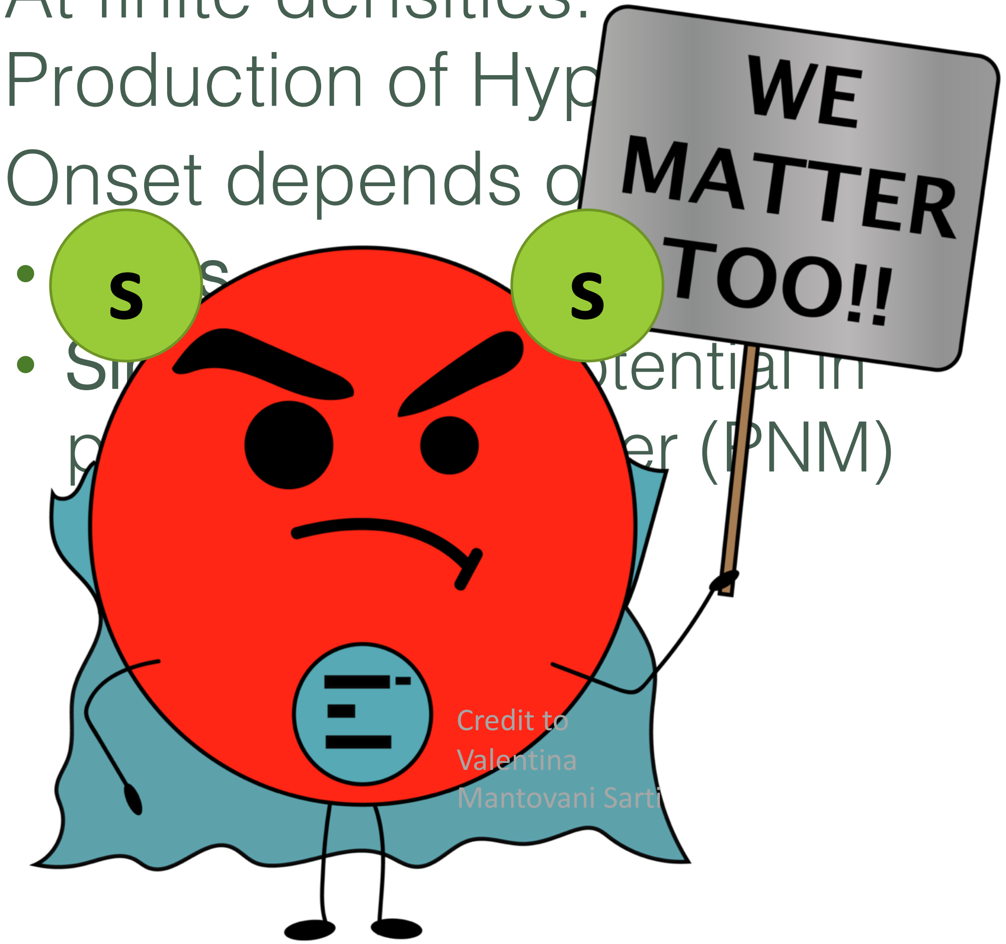

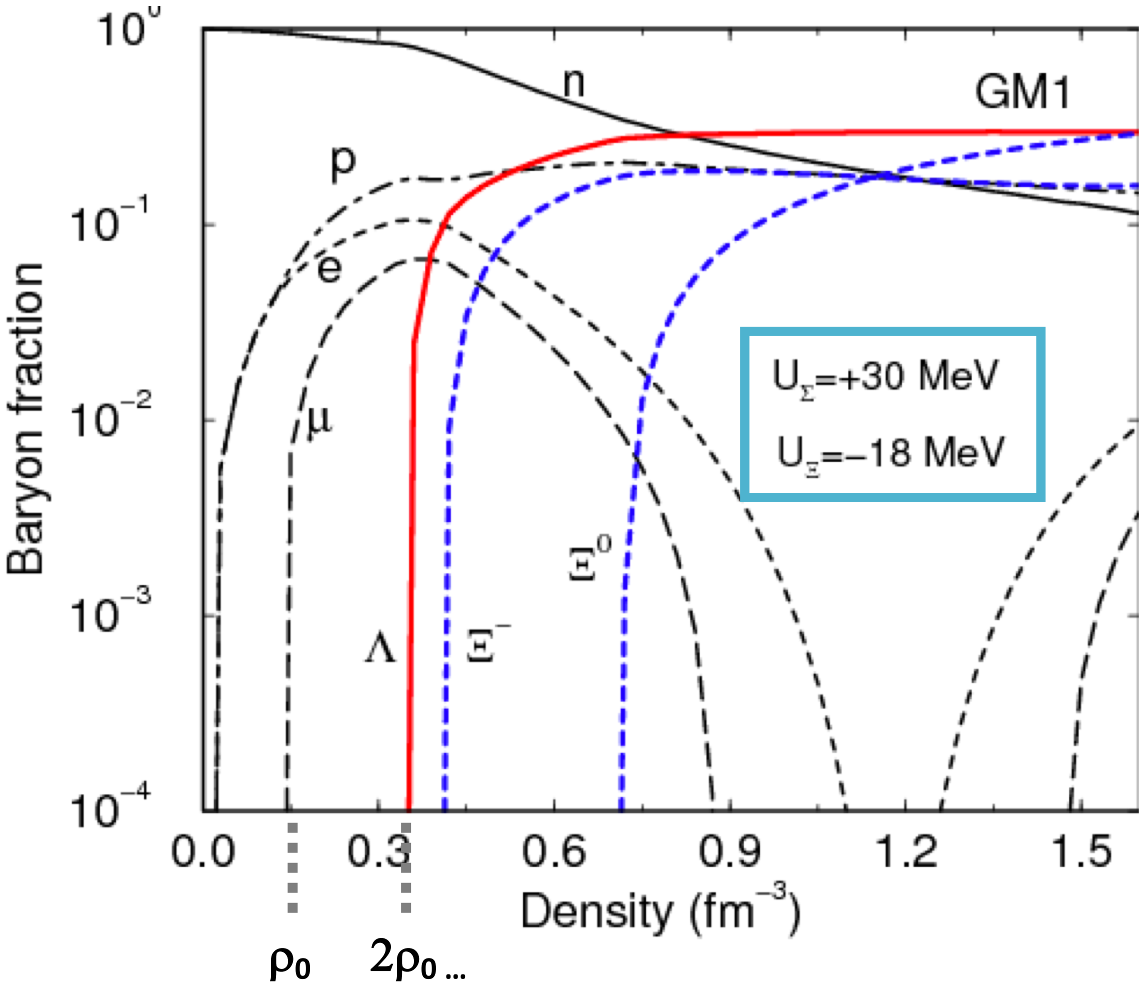

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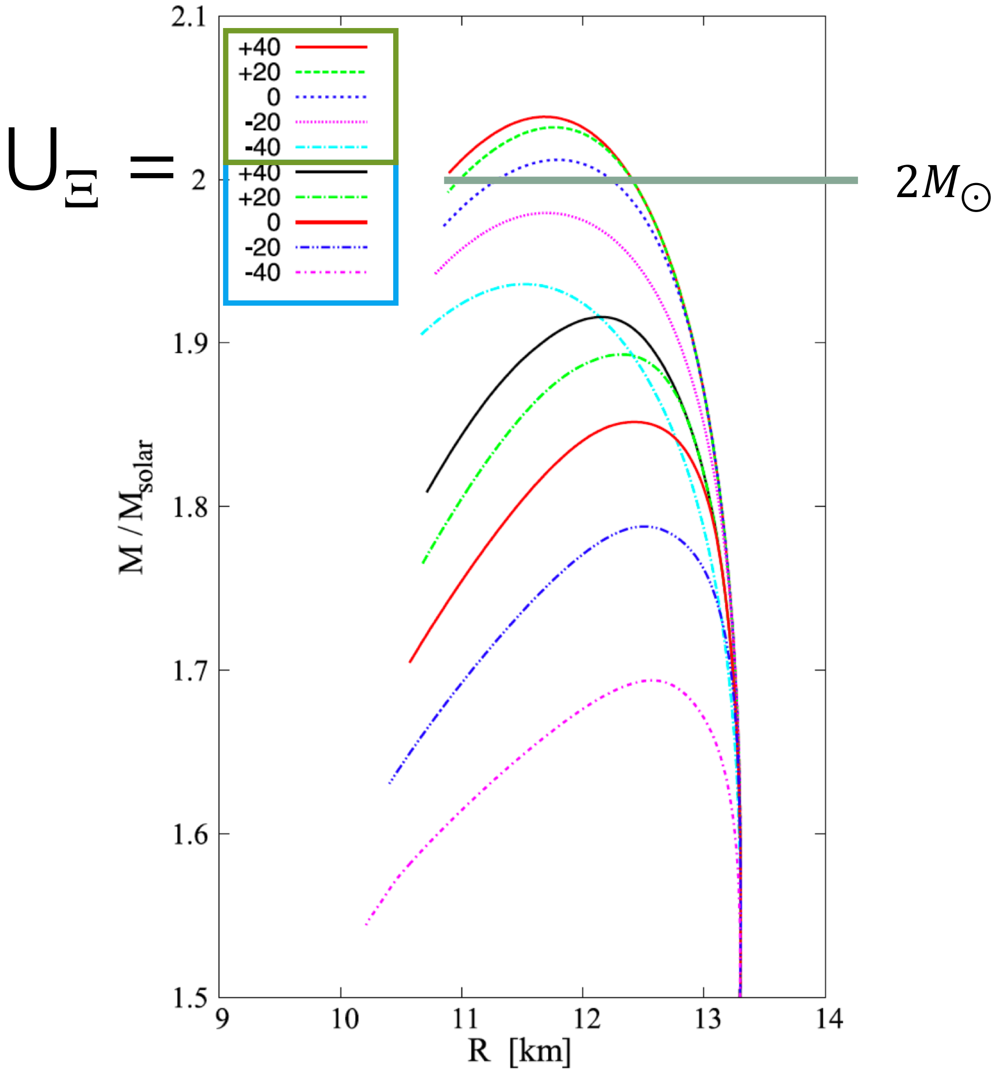
Exemplary EoS with Ξ Baryons

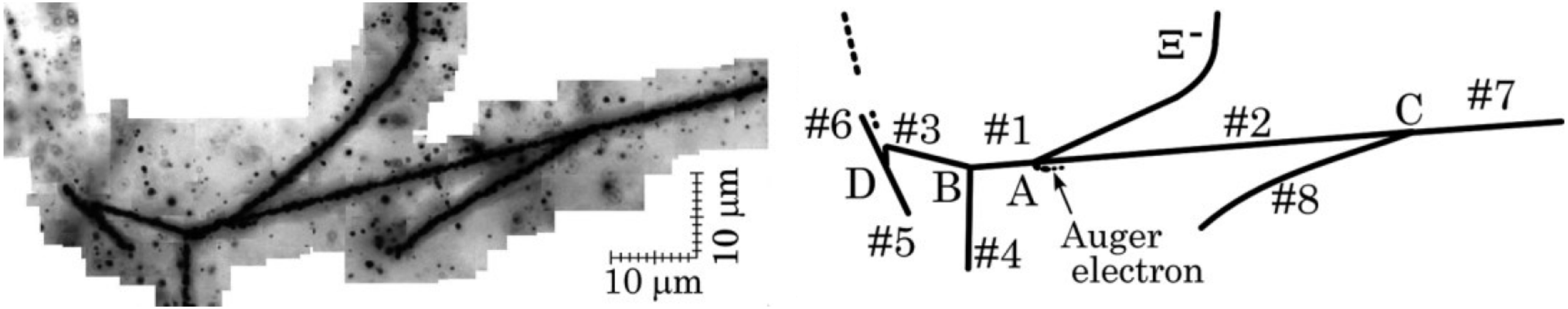
- Scan of different single particle potentials U_Ξ in pure neutron matter
- Ingredients:
  - Attractive U_Λ = - 30 MeV fitted to data from Hypernucleii
  - Assumes repulsive U_Σ = 30 MeV
  - With and without repulsive Hyperon Hyperon interaction



S. Weissborn et al., Nuclear Physics A 881 (2012) 62-77

Data on Ξ interaction

- Kiso Event: Ξ^- hyper nucleus
- Points towards an attractive interaction
  - Hyper nucleus binding energy $\boldsymbol{B_{\Xi^-} = 4.38 \pm 0.25}$ MeV



K. Nakazawa et al. PTEP 2015, 033D02

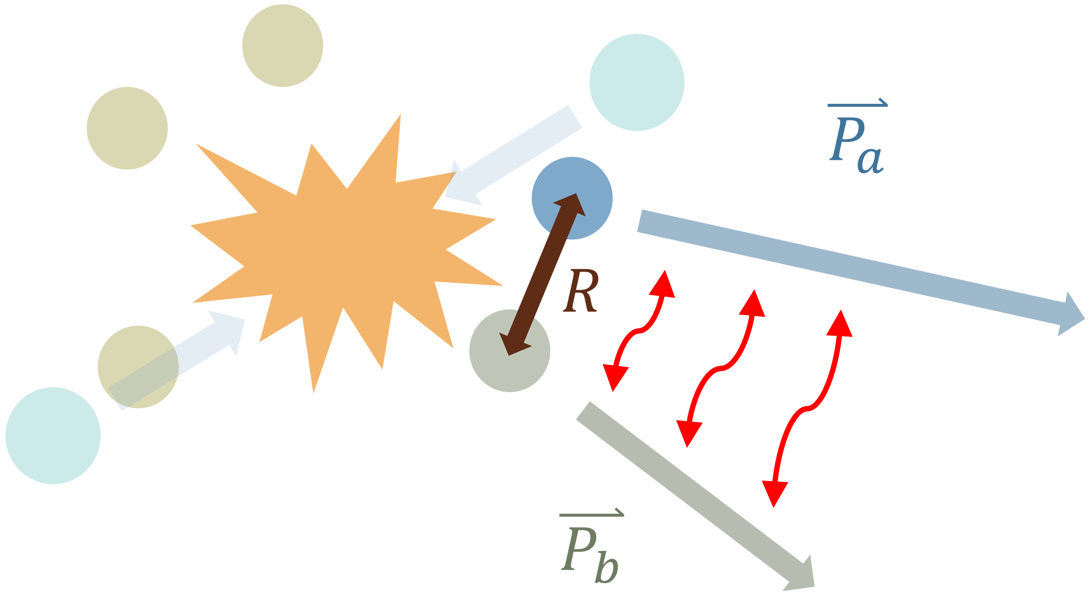
Femtoscopic measurement

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

with $\mathrm{k}^* = \frac{1}{2}|\mathbf{p}_\mathrm{a}^* - \mathbf{p}_\mathrm{b}^*|$ and $\mathbf{p}_\mathrm{a}^* + \mathbf{p}_\mathrm{b}^* = 0$

- $|\psi(k^*,\boldsymbol{r})|$ via numerical solving the Schrödinger Equation with CATS

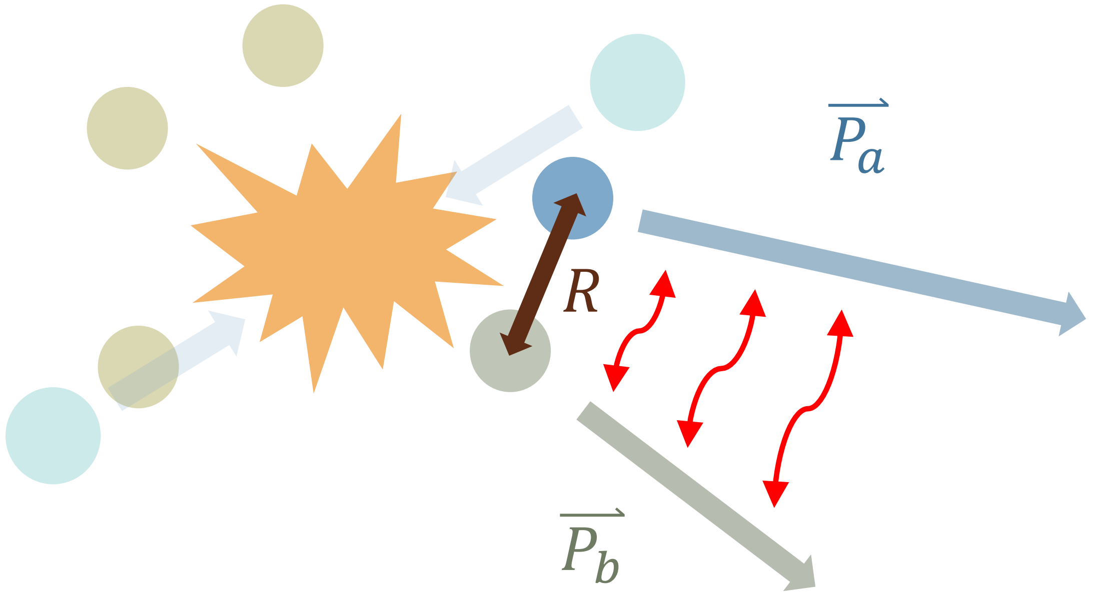
(D.L. Mihaylov et al., Eur. Phys. J. C78 (2018) no.5, 394)



Femtoscopic measurement

- $C(k^*) = 1 + \lambda_{genuine}\left(C_{genuine}(k^*) - 1\right) + \sum_{ij} \lambda_{ij}\left(C_{ij}(k^*) - 1\right)$
  with $\mathrm{k}^* = \frac{1}{2}|\mathbf{p}_\mathrm{a}^* - \mathbf{p}_\mathrm{b}^*|$ and $\mathbf{p}_\mathrm{a}^* + \mathbf{p}_\mathrm{b}^* = 0$
- Total correlation function accounts for:
  - Genuine correlation
  - Residual correlations
  - Finite momentum resolution

Details see: Phys. Rev. C 99 (2019), 024001



- Non Flat Baseline: $C_{fit}(k^*) = (a + bx) \cdot C_{model}(k^*)$

Analysis in the p-Pb system

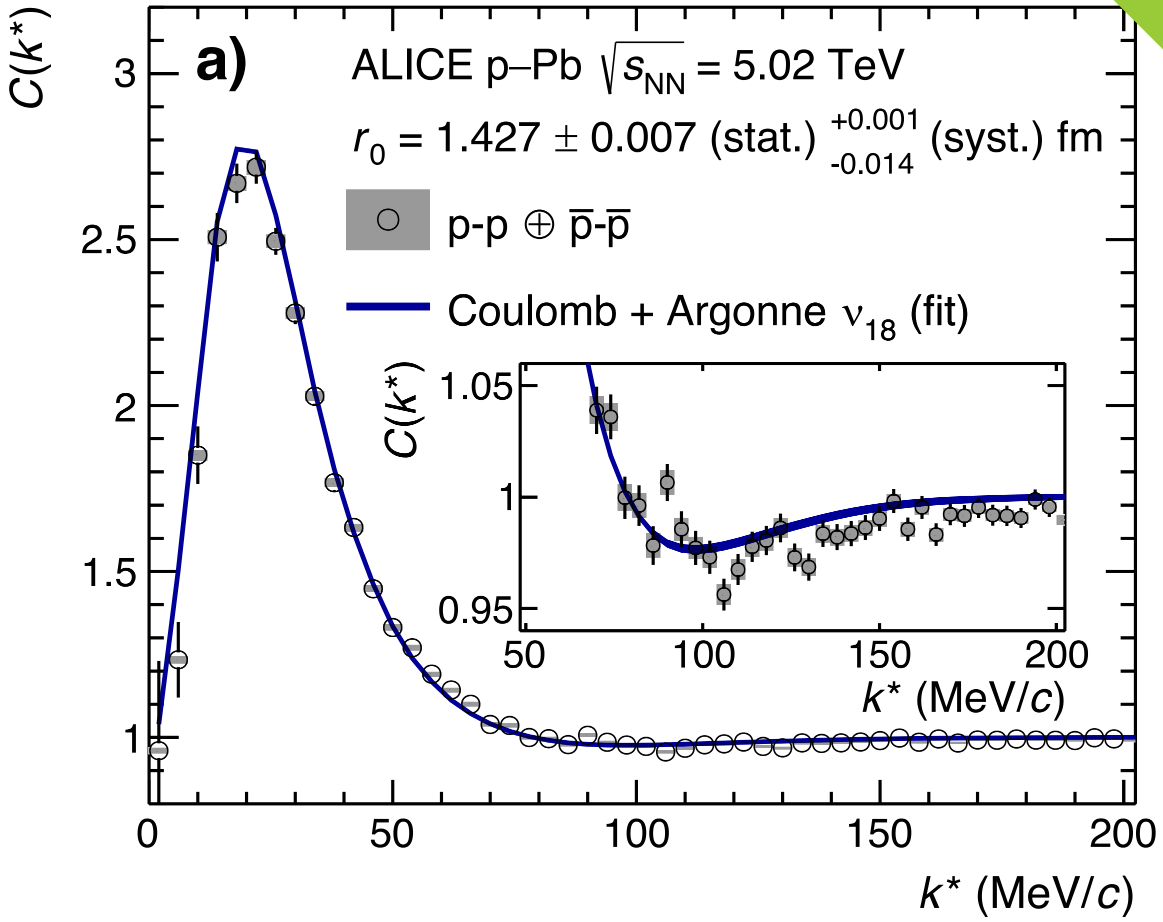
Minimum Bias

https://arxiv.org/pdf/1904.12198.pdf (Submitted to PRL)

The p-p correlation function

p-Pb

- Constrain the source $S(\boldsymbol{r})$ via the p-p correlation function
  - In **p-Pb analysis**: Gaussian source
- $|\psi(k^*, \boldsymbol{r})|$ → p-p interaction:
  - Argonne ν_{18} strong interaction potential
  - Coulomb interaction & Quantum statistics



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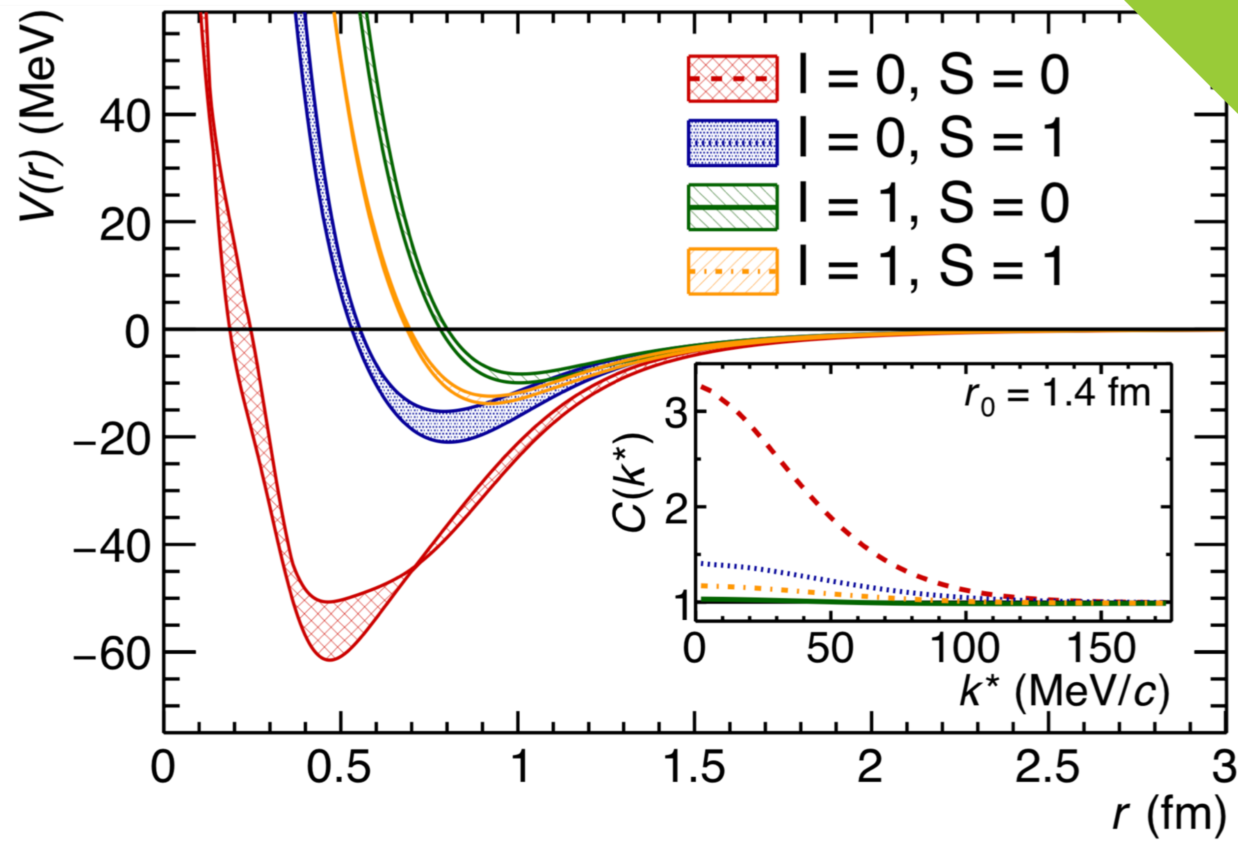
Measurement of the p-Ξ interaction

p-Pb

	I = 0	I = 1	Detectable
n-Ξ^-	✗	✓	No
p-Ξ^0	✗	✓	Difficult
p-Ξ^-	✓	✓	Yes
p-Ξ^+	✓	✗	Difficult

- p-Ξ^- interaction:
  No direct observation
  1) Coulomb only
  2) Coulomb + HAL-QCD strong potential (lattice calculation)

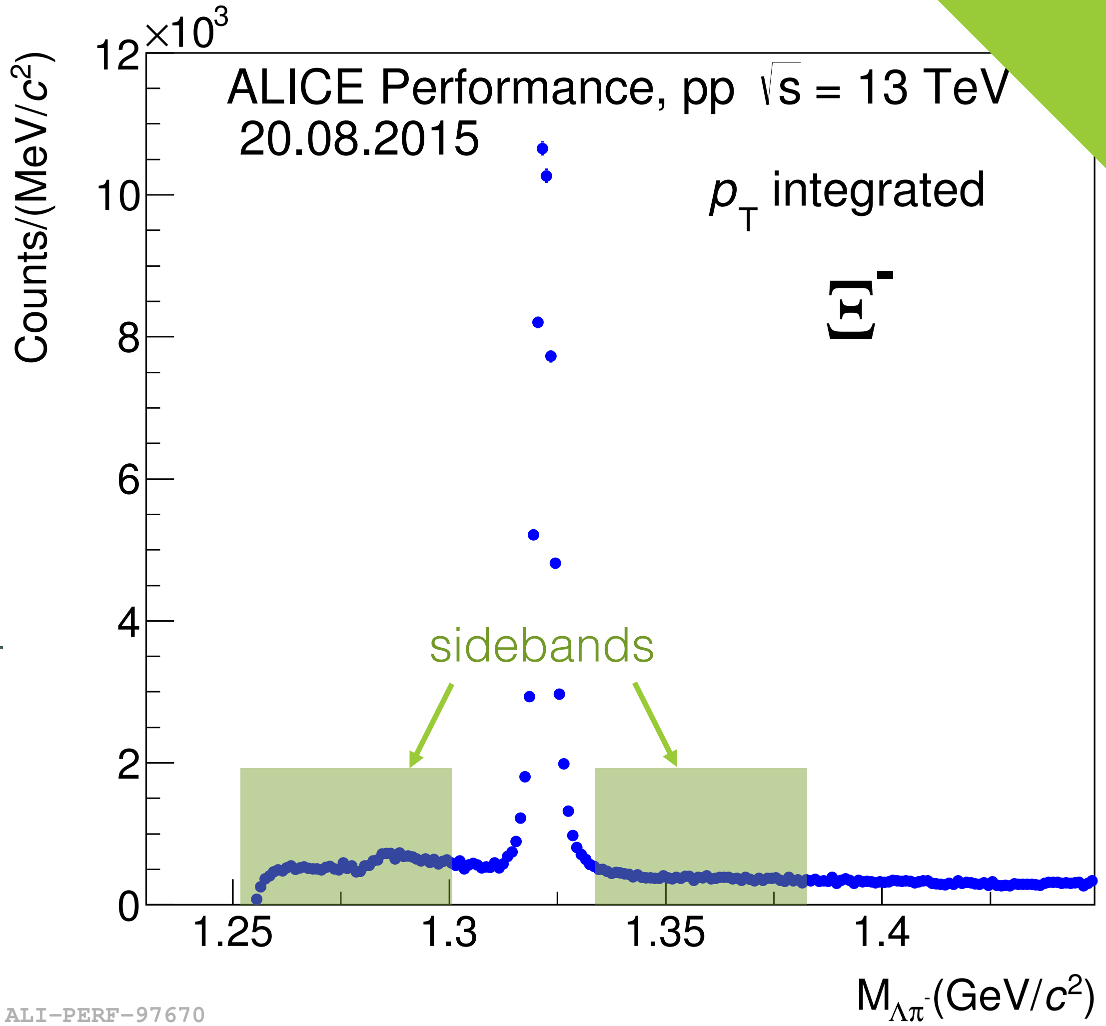


HAL QCD Collaboration, arXiv:1809.08932

$$C(k^*) = \frac{1}{8}\cdot\left(C^{S=0}_{I=0} + C^{S=0}_{I=1}\right) + \frac{3}{8}\cdot\left(C^{S=1}_{I=0} + C^{S=1}_{I=1}\right)$$

Measurement of the p-Ξ⁻ interaction

- Treatment of residual correlations
  - p-Ξ⁻(1530)
    $\rightarrow \lambda_{p-\Xi^-(1530)}$ pair contribution ~ 8.2 %
  - Misidentification of Ξ⁻
    - Ξ⁻ Purity ~ 92 %
      $\rightarrow \lambda_{p-\tilde{\Xi}}$ pair contribution ~ 8.5 %
    - $C_{p-\tilde{\Xi}}(k^*)$ from the sidebands of the Ξ⁻ selection

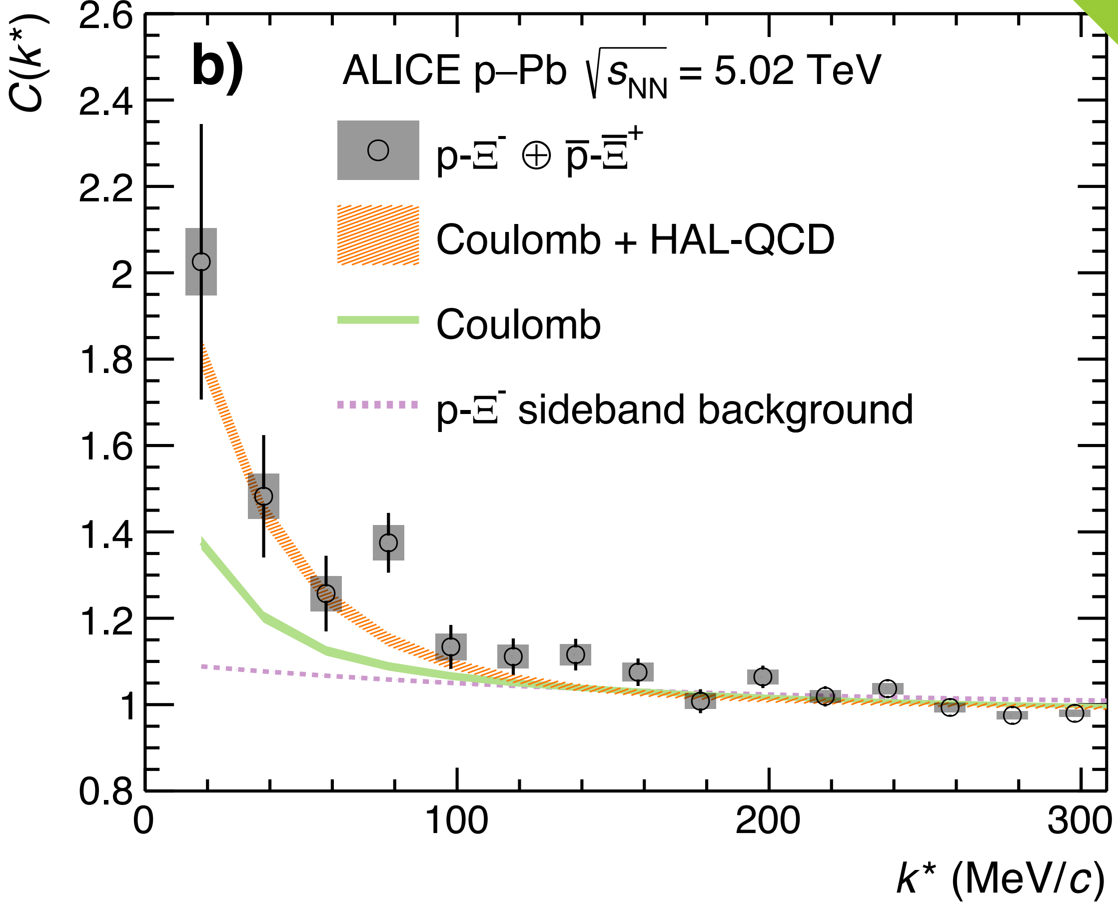


ALI-PERF-97670

Measurement of the p-Ξ⁻ interaction

p-Pb

- Treatment of residual correlations
  - p-Ξ⁻(1530)
  - Misidentification of Ξ⁻
- Results:
  - Coulomb only hypothesis excluded by > 3 σ
  - HAL-QCD potential significantly improves agreement with the data



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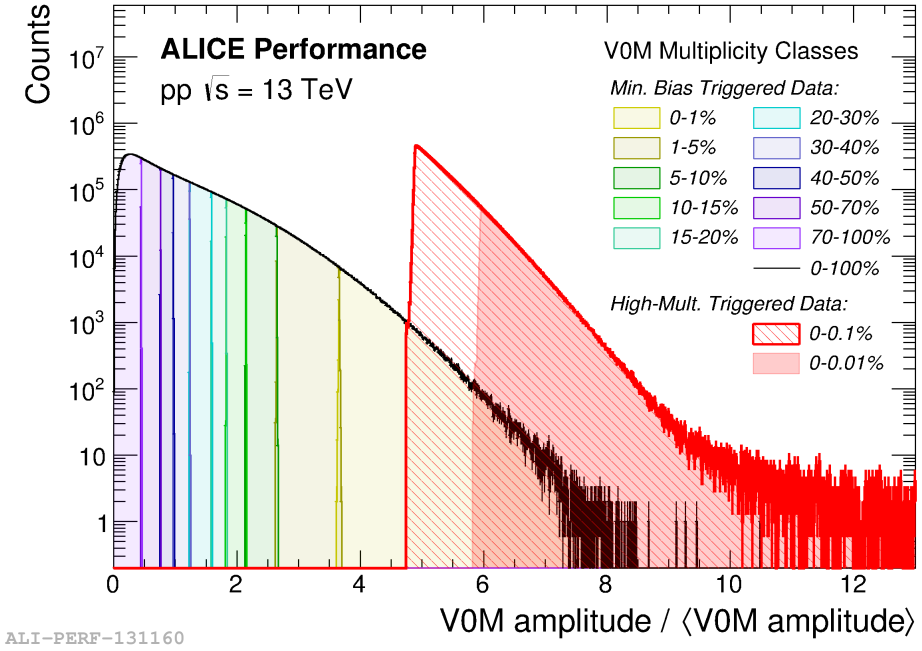
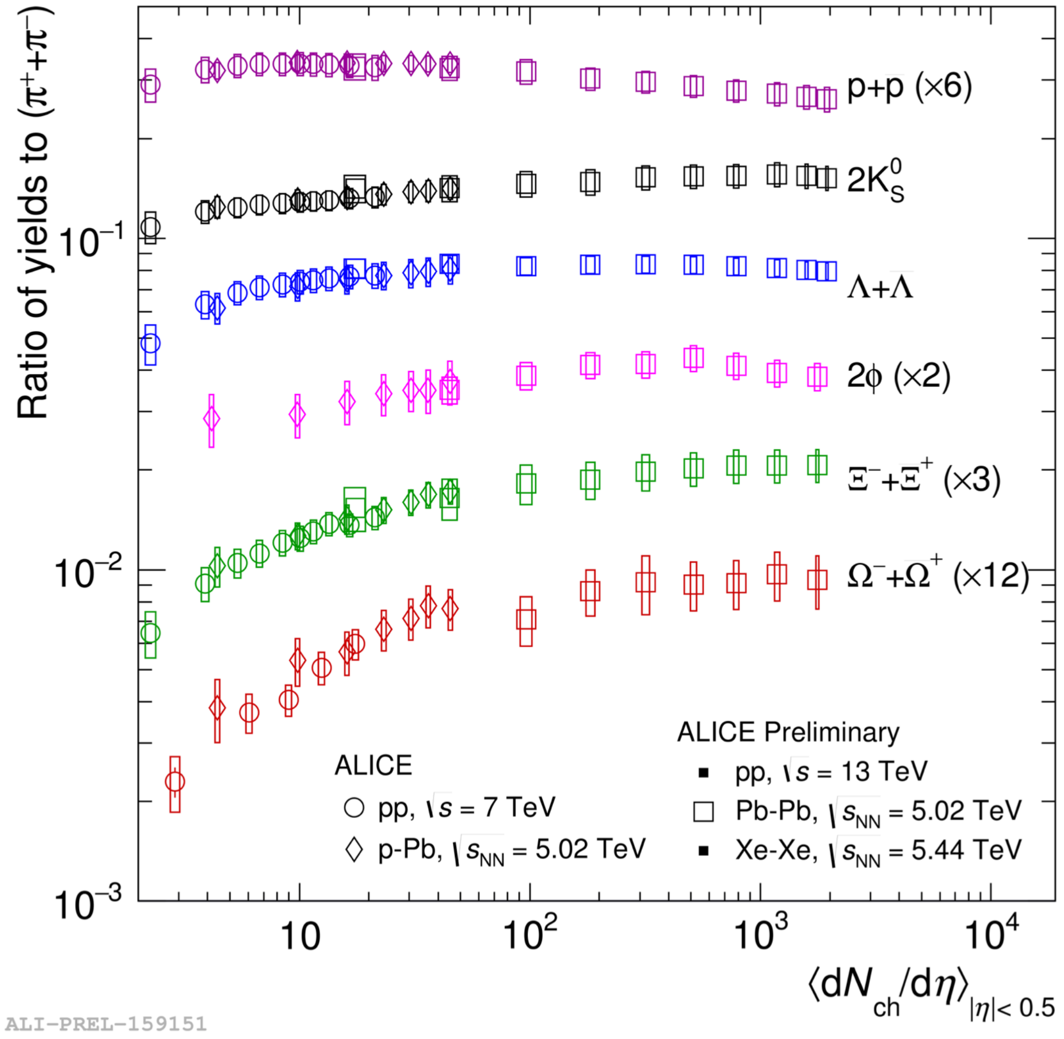
Analysis in the p-p system

High Multiplicity Triggered

High Multiplicity Dataset

- Increased average multiplicity & production of hyperons
  - Significant increase in amount of pairs by a factor of 5-10

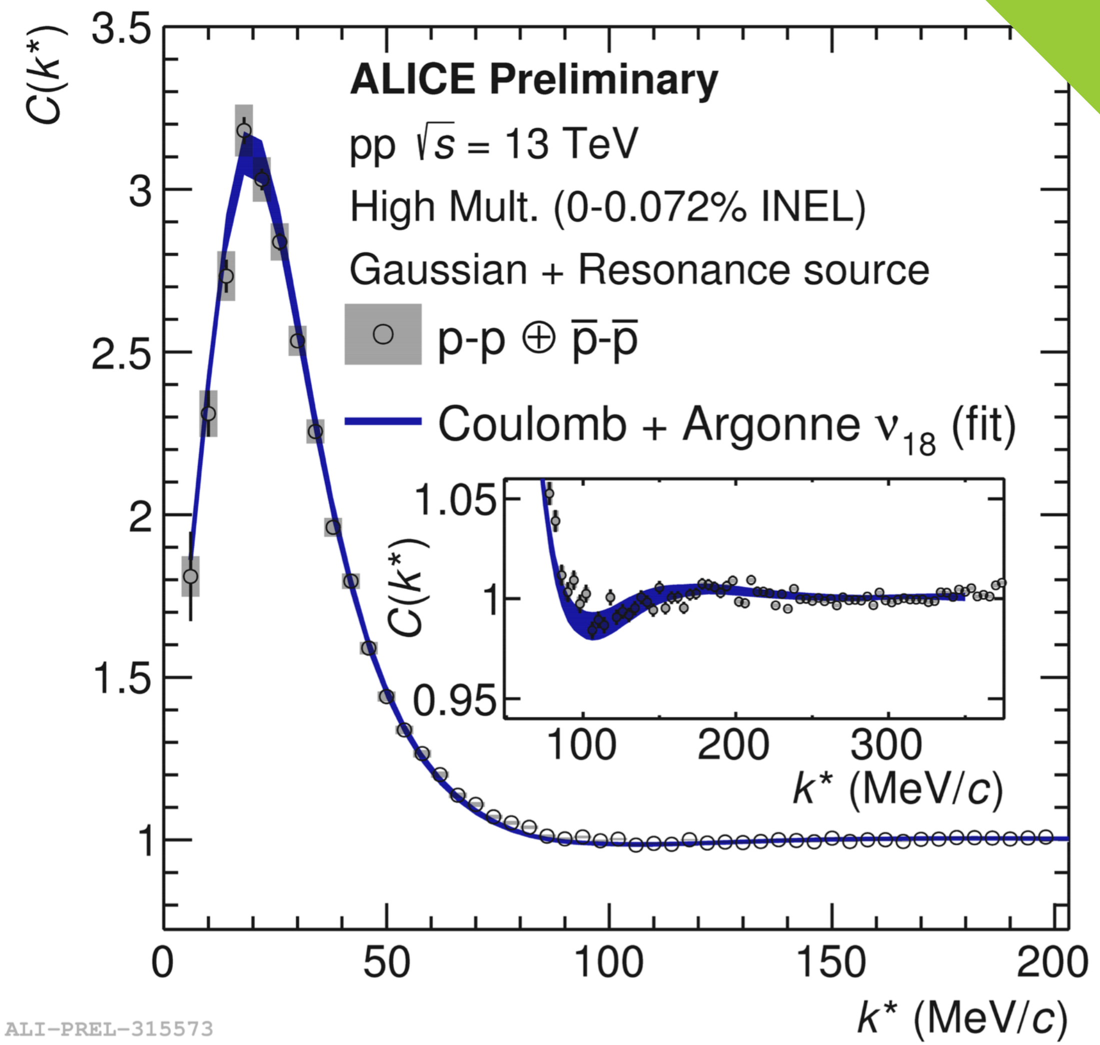




Great precision, great responsibility

pp HM

- Constrain the source $S(\mathbf{r})$ via p-p correlation function
- Specific contributions from strong decaying resonances for the different pairs
  - Statistical Hadronization Model
- For all pairs: shared Gaussian core



Great precision, great responsibility

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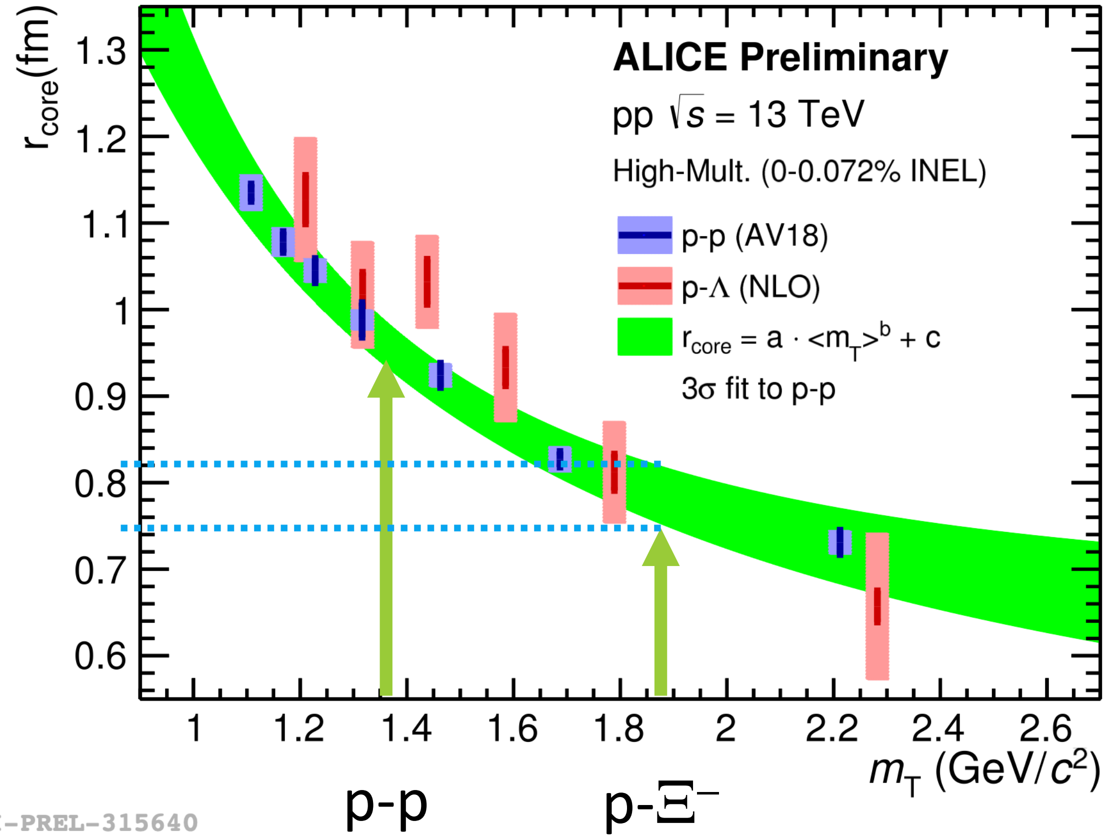
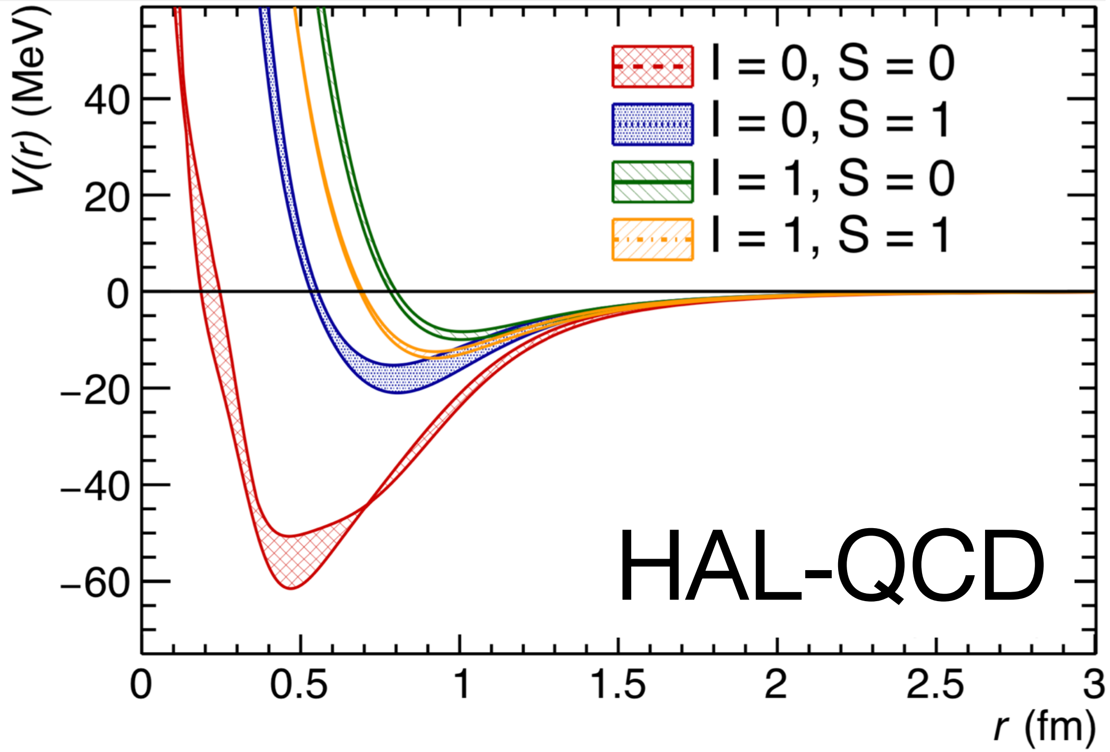
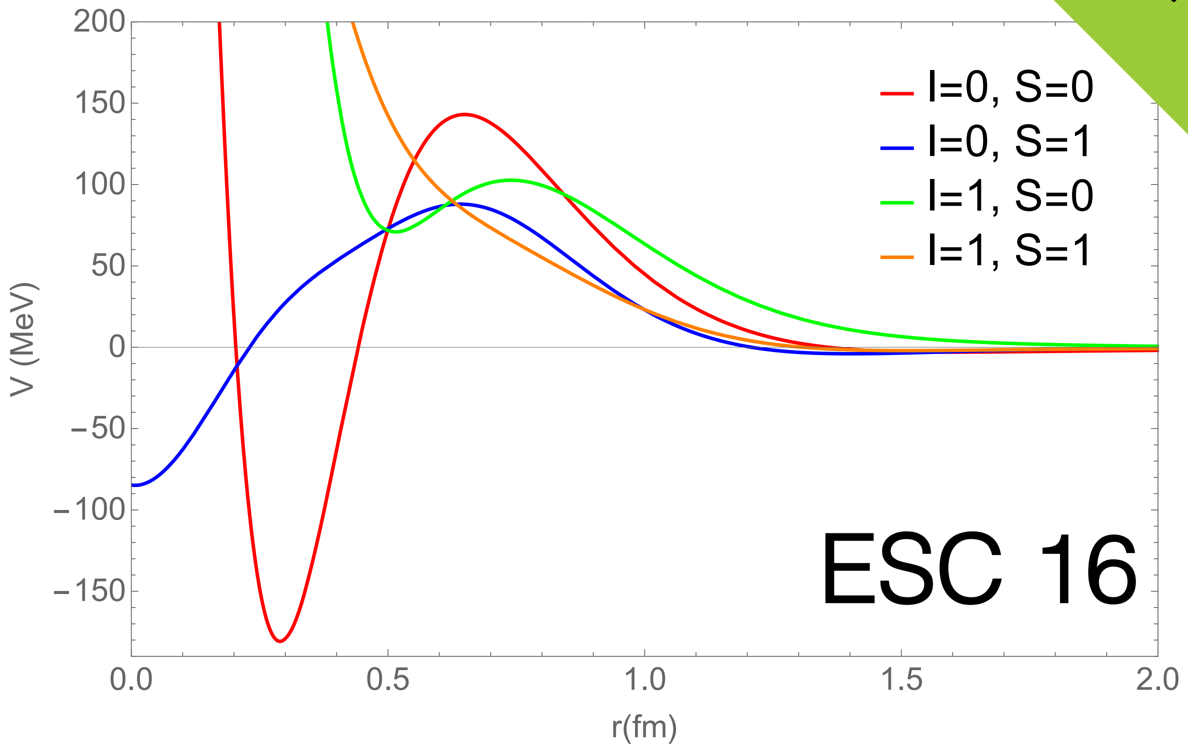
- Constrain the source $S(r)$ via p-p correlation function
- Specific contributions from strong decaying resonances for the different pairs
  - Statistical Hadronization Model
- For all pairs: shared Gaussian core
  - Scaling with m_T



Modelling of the p-Ξ^- interaction

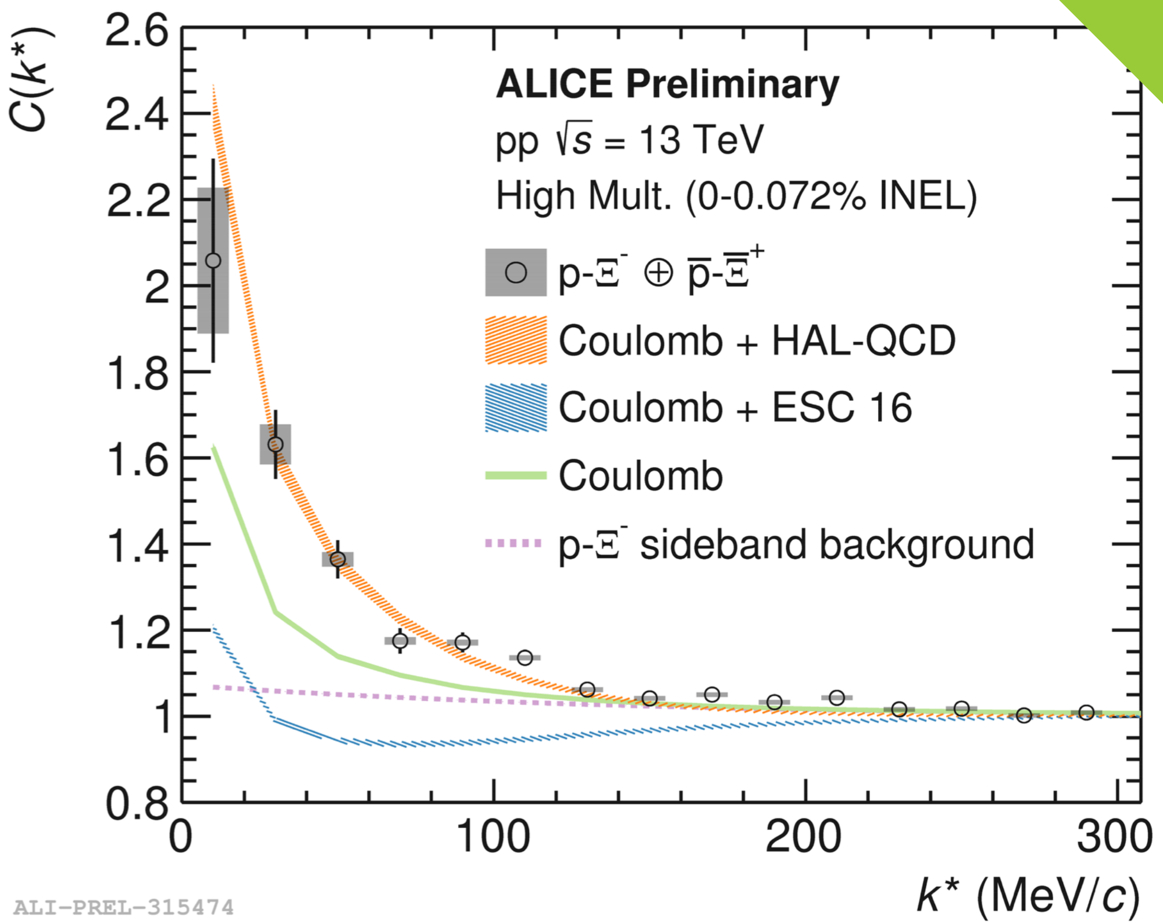




- HAL QCD: Lattice calculations
- ESC 16: Meson exchange model
- Kiso event described by both HAL-QCD and ESC16

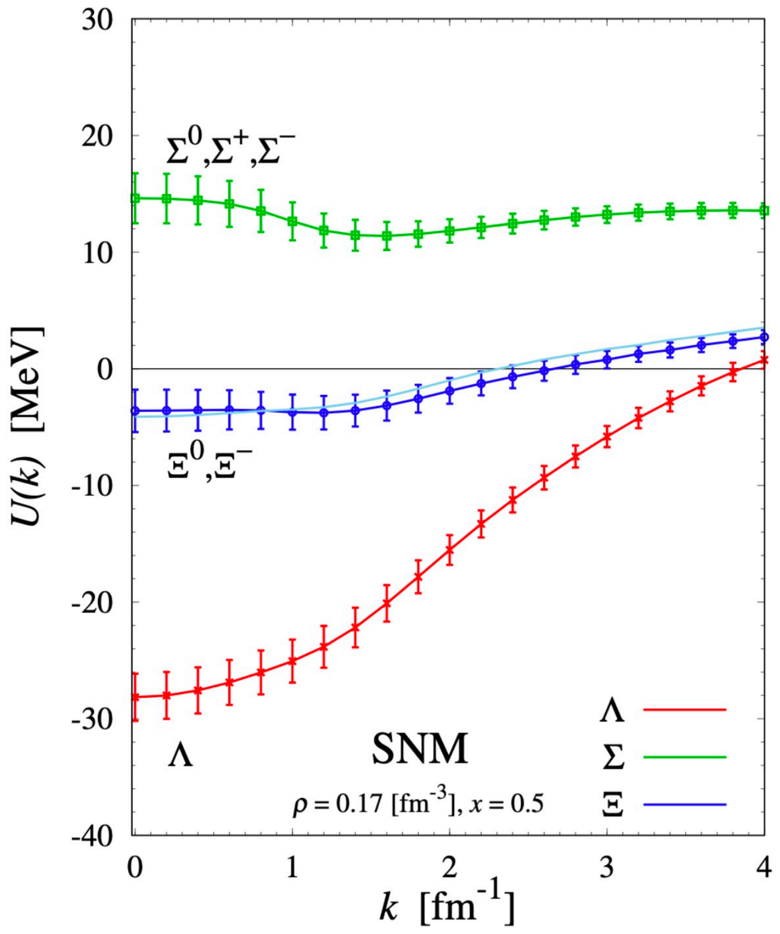
Measurement of the p-Ξ⁻ interaction

- Treatment of residual correlations
  - p-Ξ⁻(1530)
  - Misidentification of Ξ⁻
- Results:
  - Coulomb only: > 5.7 σ
  - HAL-QCD Potential: (1.3-2.5) σ
  - ESC 16 Potential: > 18 σ



Implications for neutron stars

- In medium: Many body interaction – particle experiences an average potential
  - ➢ Single particle potential
- Hypernucleii: Symmetric nuclear matter
  - Shallow attractive U_{Ξ^-} agrees with Kiso Event



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Implications for neutron stars

- In medium: Many body interaction – particle experiences an average potential
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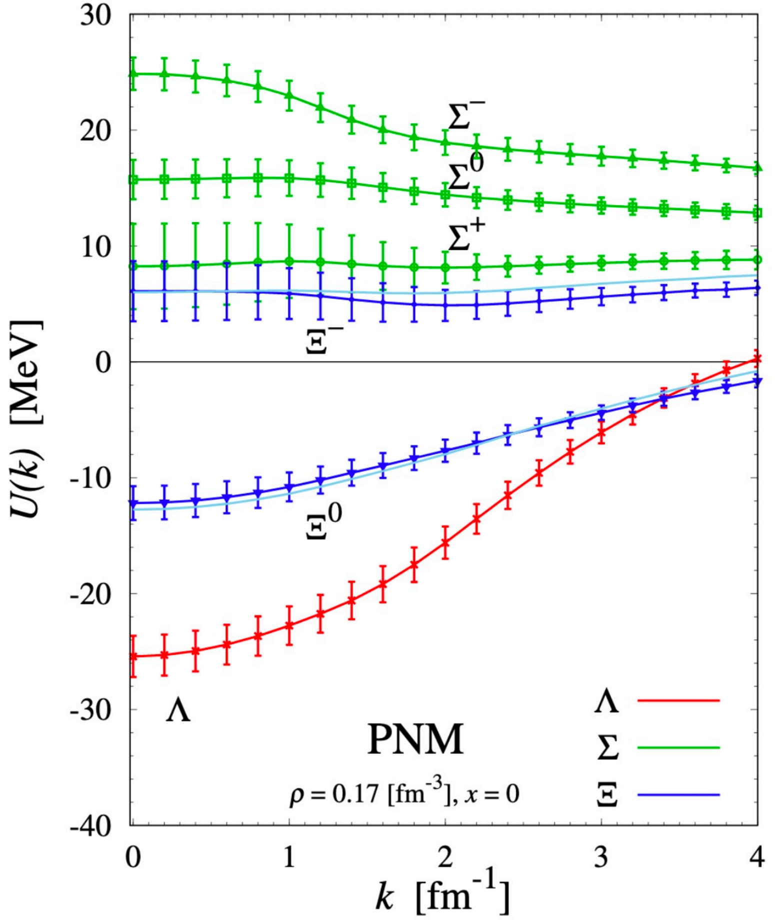
- Hypernucleii: Symmetric nuclear matter
- Neutron star: Pure neutron matter
  - Slightly repulsive $U_{\Xi^-} \sim 6$ MeV/c



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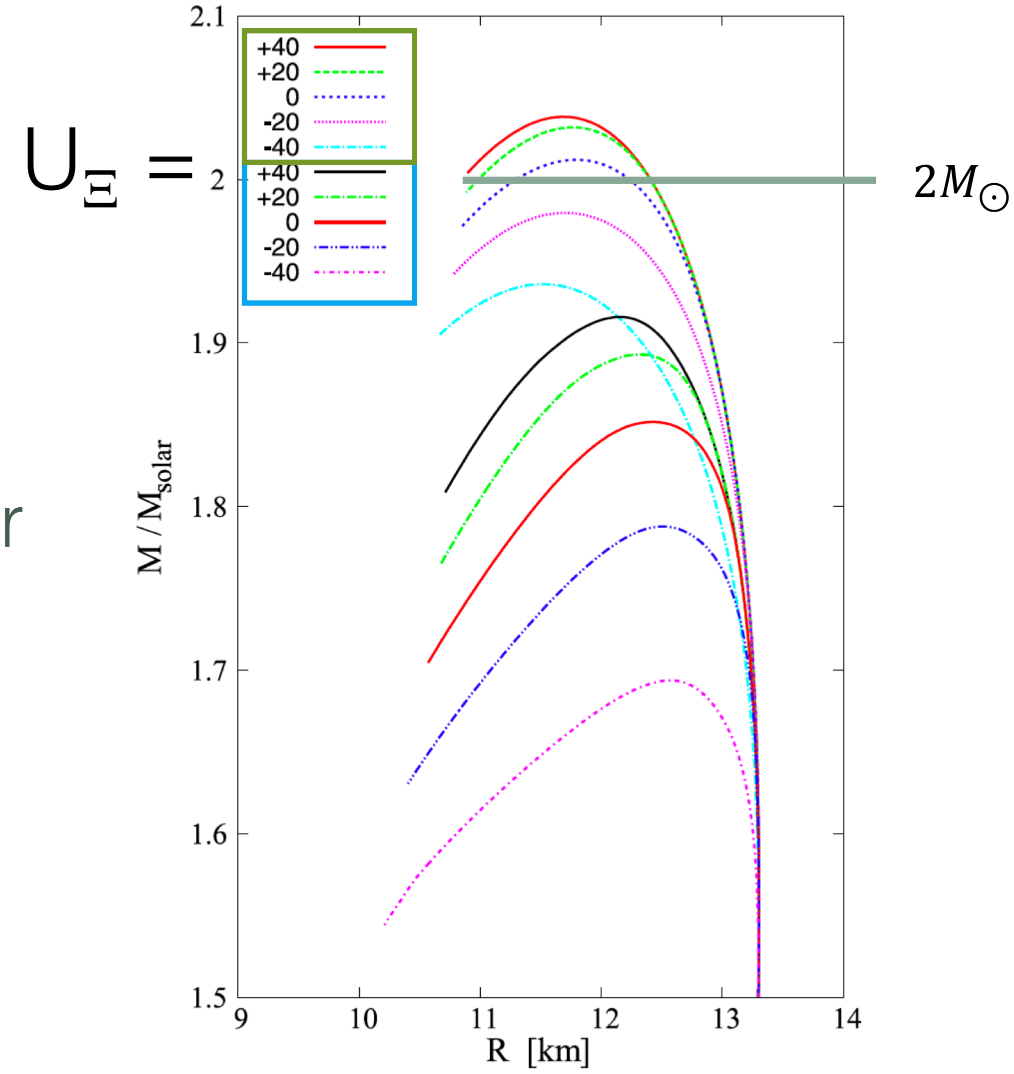
  - Slightly repulsive U_{Ξ^-} ~ 6 MeV/c



S. Weissborn et al., Nuclear Physics A 881 (2012) 62-77

Implications for neutron stars

- In medium: Many body interaction – particle experiences an average potential
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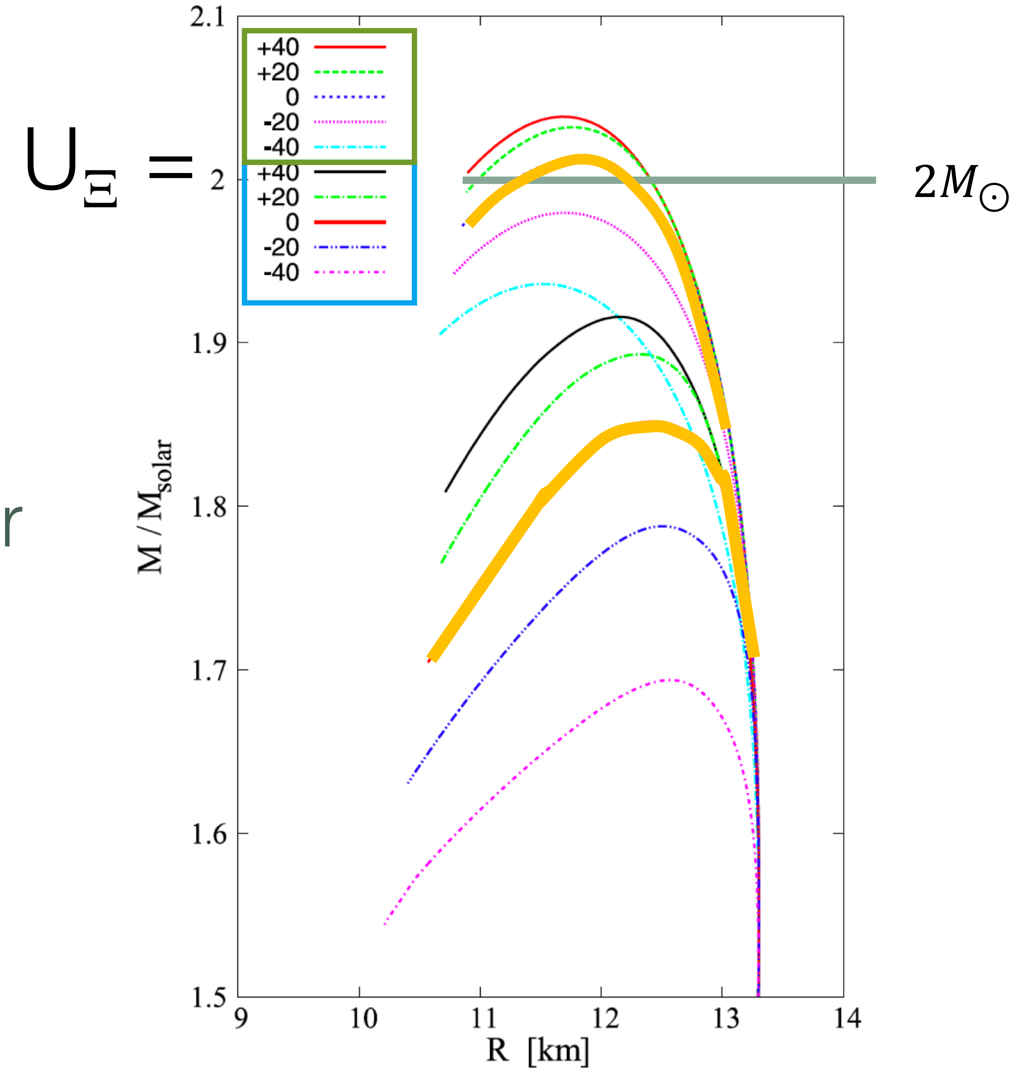
- Hypernucleii: Symmetric nuclear matter
- Neutron star: Pure neutron matter
  - Slightly repulsive U_{Ξ^-} ~ 6 MeV/c
- Crucial input for theory



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Summary and Outlook

- First direct observation of an attractive p-Ξ^- interaction
  - Test of HAL-QCD model allows to apply this to the description of neutron stars
- Increased sensitivity in high multiplicity triggered pp collisions
  - Femtoscopic measurements sensitive to differences in potentials
- For the future: Study correlation function of the excited $\Xi^0(1530)$ state
  - $\Xi^0(1530) \rightarrow \Xi^- + \pi^+$
  - I = 1 & S = 1 + 2

	I = 0	I = 1	Detectable
n-Ξ^-	✗	✓	No
p-Ξ^0	✗	✓	Difficult
p-Ξ^-	✓	✓	Yes
p-Ξ^+	✓	✗	Difficult

Backup