Czech
Technical
University
in Prague

STRANGE-MATTER:

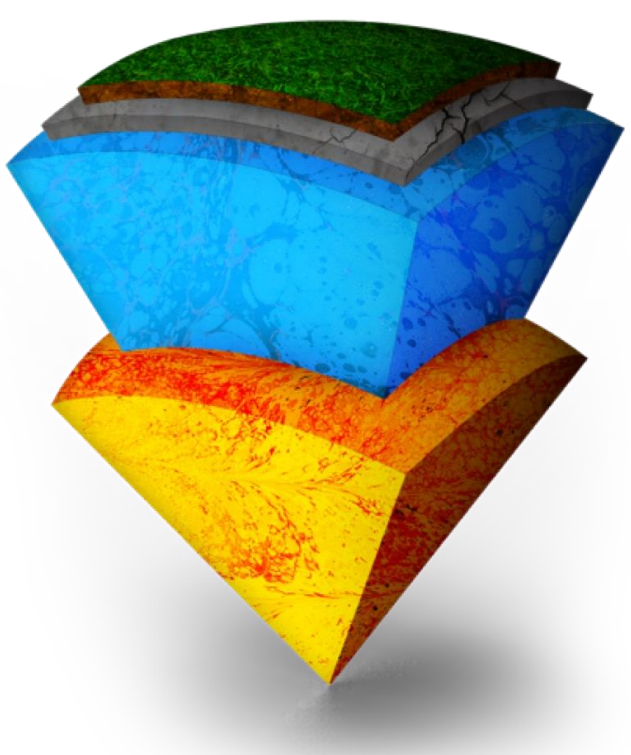
*Advanced Studies on **Strange** Hadronic **Matter***

Raffaele Del Grande
Czech Technical University in Prague
raffaele.del.grande@fjfi.cvut.cz

Hyperons in neutron stars?

$R \sim 10 - 15$ km

M $\sim 1.5 - 2\ M_{\odot}$

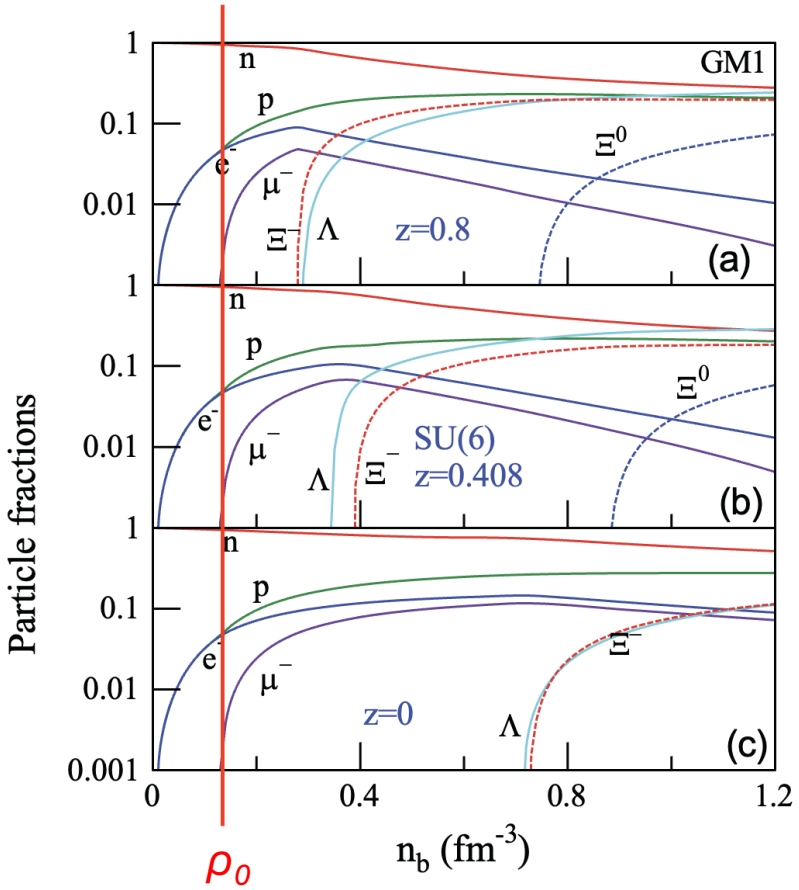


Baryon density

Outer crust:
Ions Electrons
Neutrons

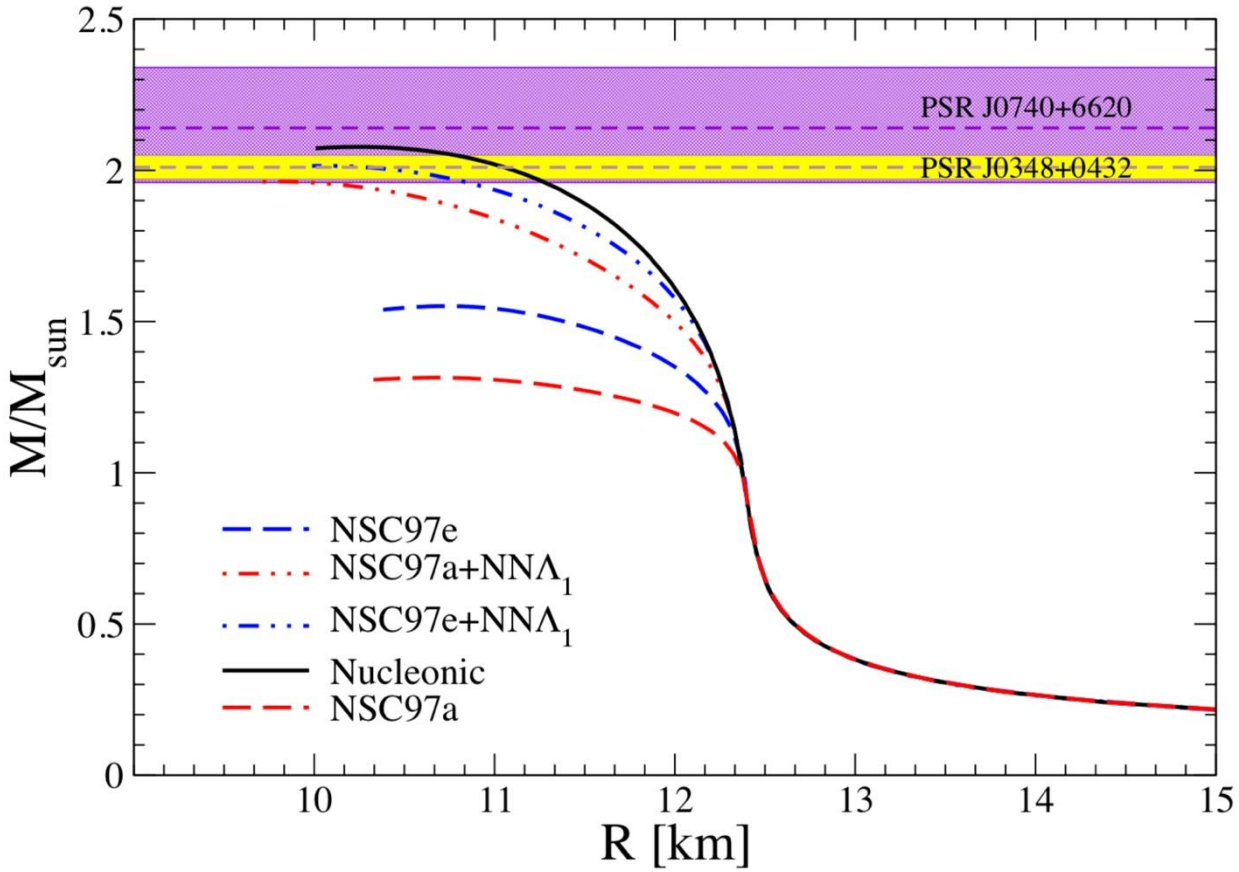
Inner core:
Neutrons?
Hyperons?
Kaon condensate?
Quark-matter?
Axions?

Hyperons are expected to appear at $\rho > \rho_0$ for energetic reasons.



Hyperons in neutron stars?

Loteta, Vidaña & Bombaci, EPJA 55, 207 (2019)



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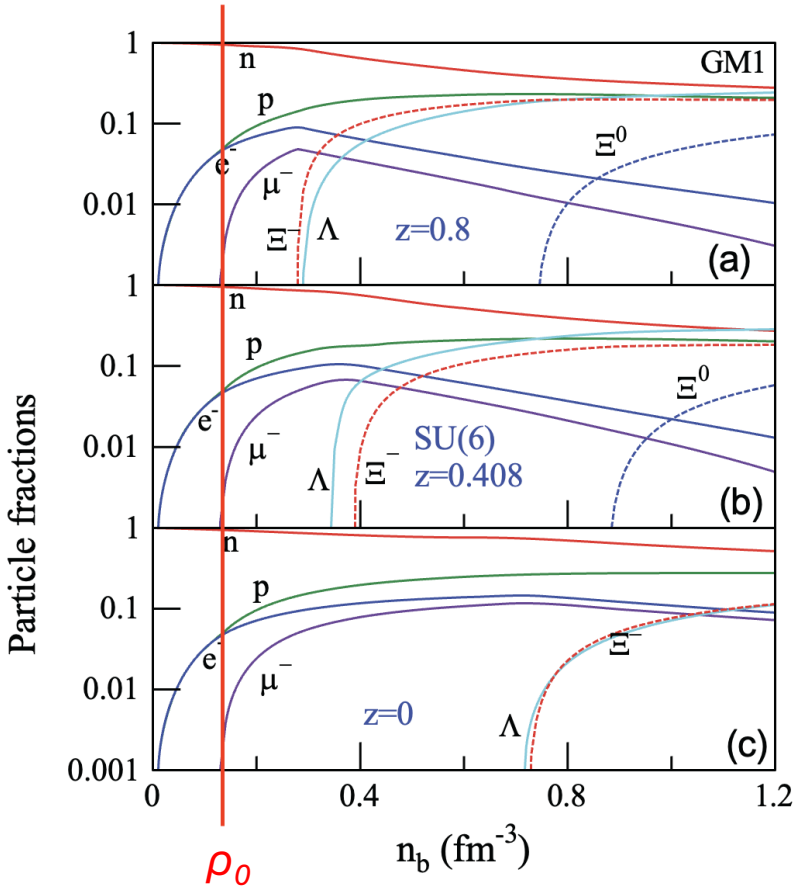


One success of THEIA networking activities

Measured correlations by ALICE and scattering data

pΛ (pΣ^0), pΞ, ΛΛ

V.Mantovani Sarti
TUM

D.Mihaylov
TUM/Sofia Uni

Potentials in vacuum

Tuned NLO19 NΛ chiral potentials

ΛΛ, NΞ LQCDpotentials

J.Haidenbauer
Julich FZ

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

Le Fèvre et al. NPA 945 (2016)

EoS with 2-body YN, YY

Mass vs Radius NSs

I. Vidaña
INFN Catania

BB interactions at finite ρ

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

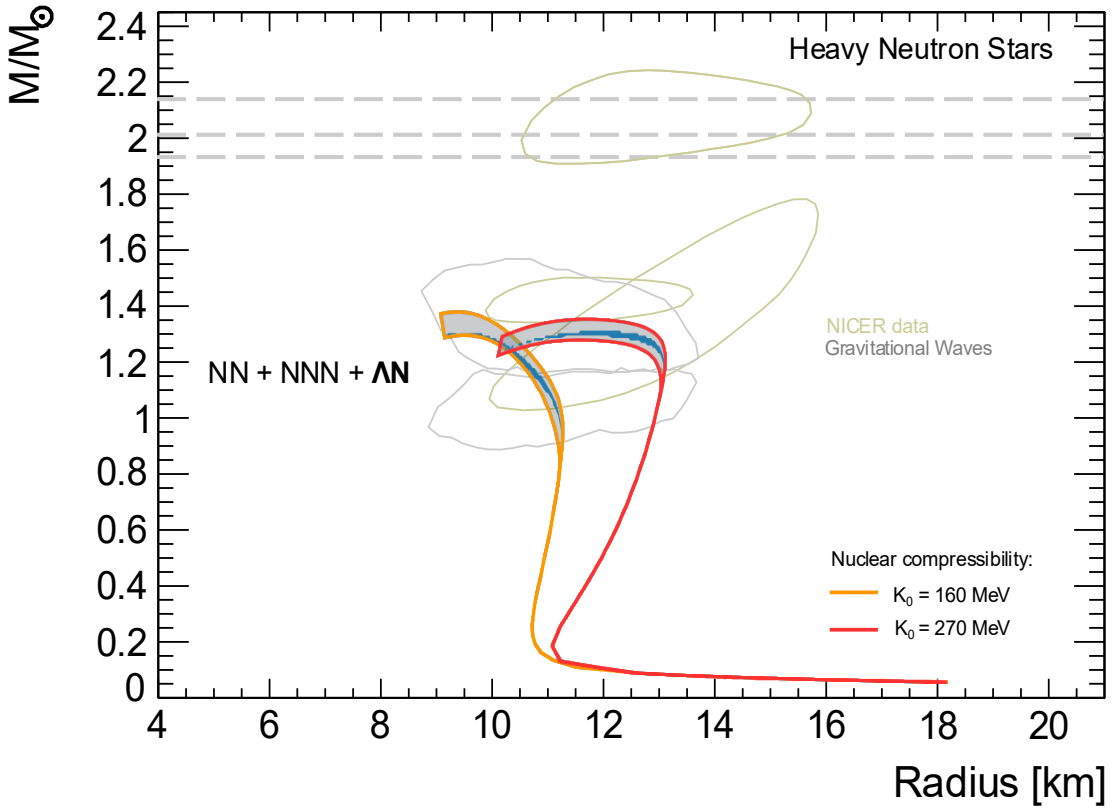
Vidaña et al. PRC 62 035801 (2001)

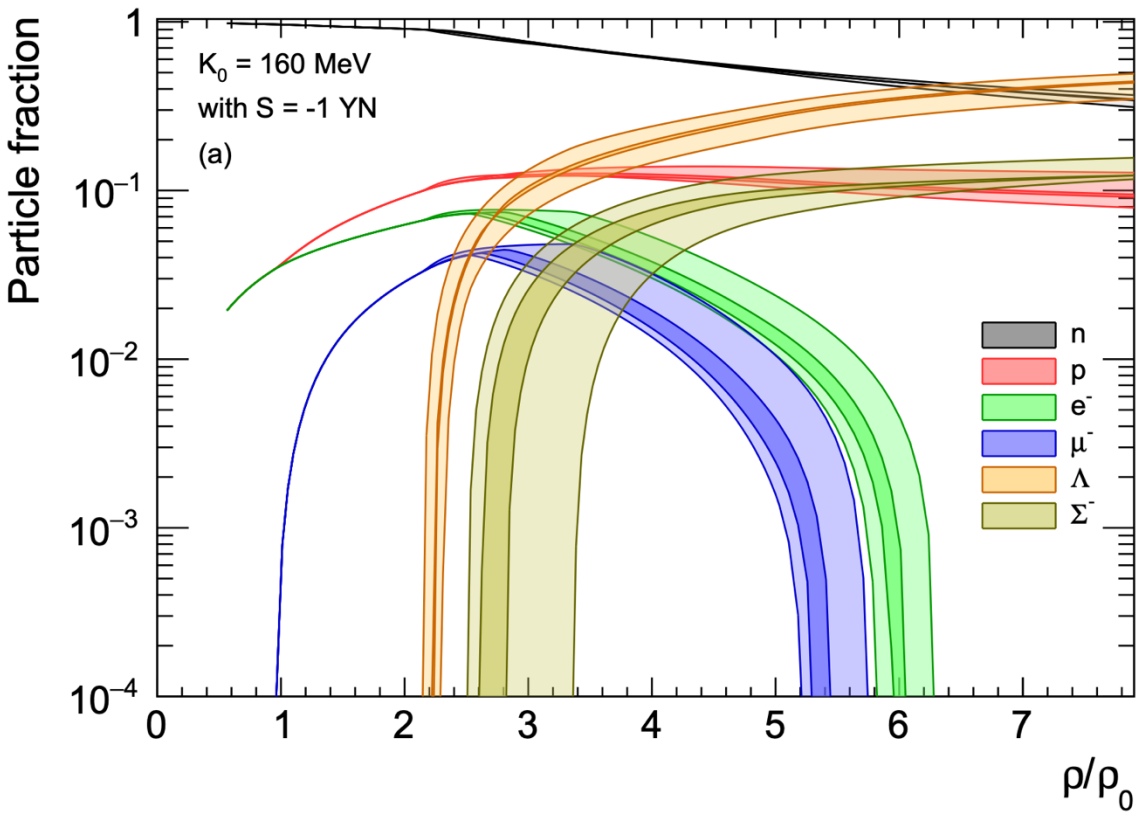
I. Vidaña
INFN Catania

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

Towards a realistic equation of state of neutron stars

- Hyperons appear in the core of NSs at $\rho \sim 2\rho_0$
- *State-of-the-art interactions* for NN, NNN, YN (S=-1 and S=-2) and YY fail to reproduce observed heavy NSs





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

Towards a realistic equation of state of neutron stars

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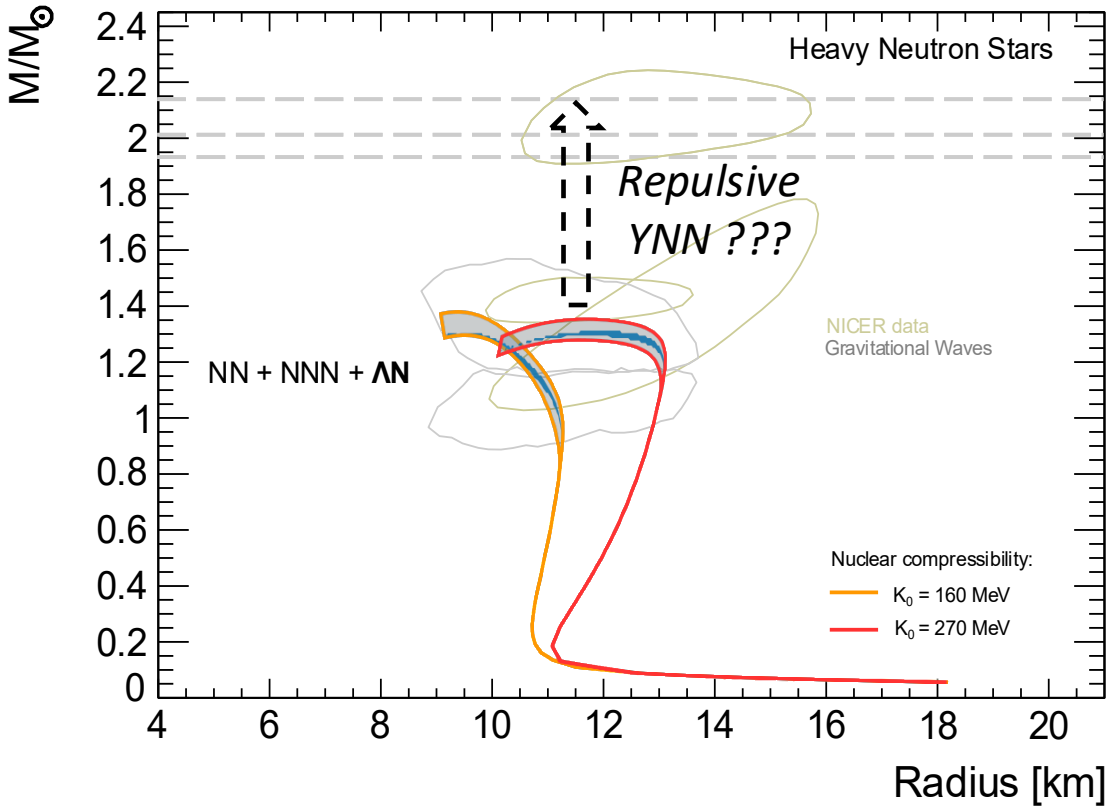


Open questions

- Charge symmetry breaking?

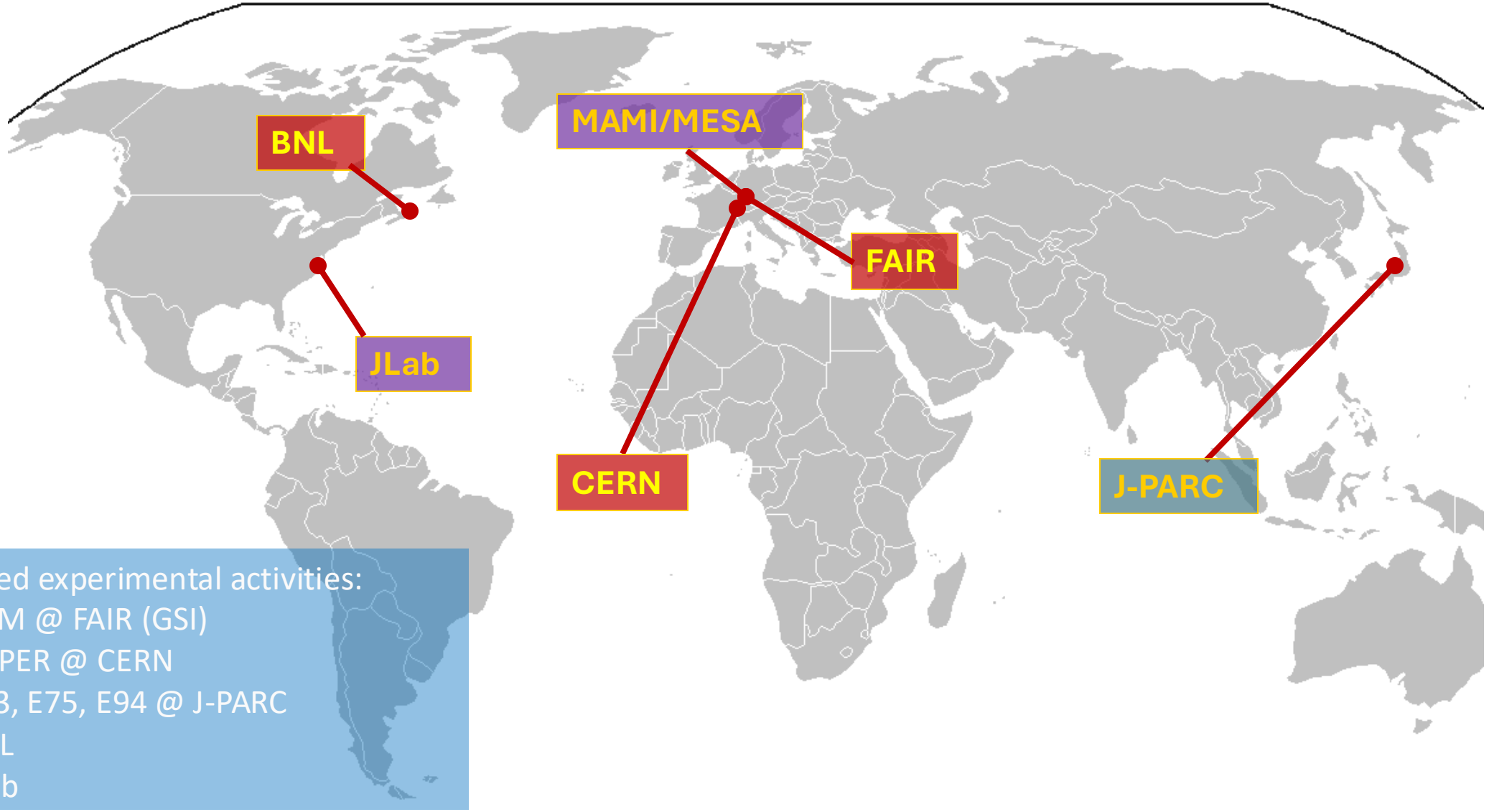
  Λ p versus Λ n

- Momentum dependence of the YN interaction?
- Strength of the ΛNN interactions?
  (also other YNN, YYN, YYY forces)

- Isospin and energy dependence of K^-N interaction?

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

Connection to worldwide infrastructures

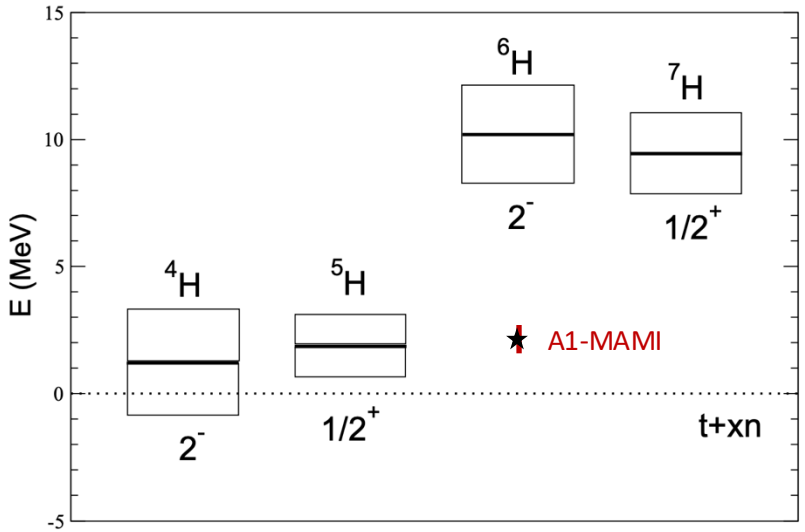


Planned experimental activities:

- CBM @ FAIR (GSI)
- HYPER @ CERN
- E63, E75, E94 @ J-PARC
- BNL
- JLab

Task 1: Neutron rich nuclei and hypernuclei

- New insights on the Λ-multi-neutron interactions
- **A1-MAMI**: Stronger interaction between the neutrons in ^{6}H than expected from recent theoretical calculations

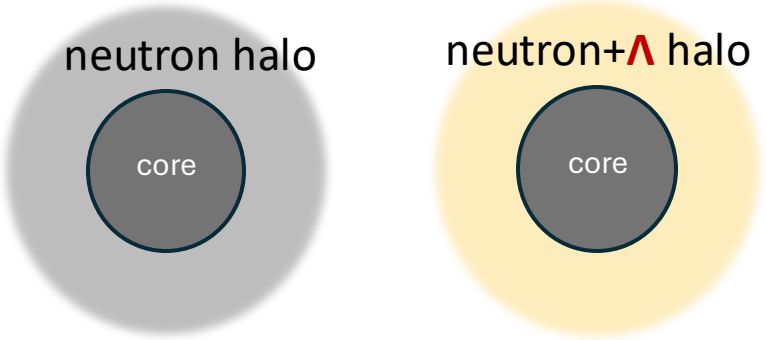


T. Shao et al., PRL134 (2025), 162501
E. Hiyama et al., PLB833 (2022) 137367

Future studies (MAMI):

- ^{6}Li(e, e'pπ^{+})^{5}H
- ^{4}He(e, e'pπ^{+})^{3}n
- ^{7}Li(e, e' π^{+}π^{+})^{7}H
- ^{4}He(e, e' π^{+} π^{+})^{4}n

Naïve picture: Core nucleus + Halo



Complementary studies with hypernuclei:

- JLab: spectrocopy of $^{48}_{\Lambda}$K and $^{208}_{\Lambda}$Tl
- J-PARC: spectroscopy studies on Λ- and Ξ-hypernuclei (*completed*: E70, E73, E96; *planned*: E63, E75, E94)
- HYPER@CERN: a new single-Λ hypernuclei program at the Antimatter Factory at CERN LOI: CERN-SPSC-2025-013 / SPSC-I-263

Extract information on the interaction between neutrons and Λ hyperons.

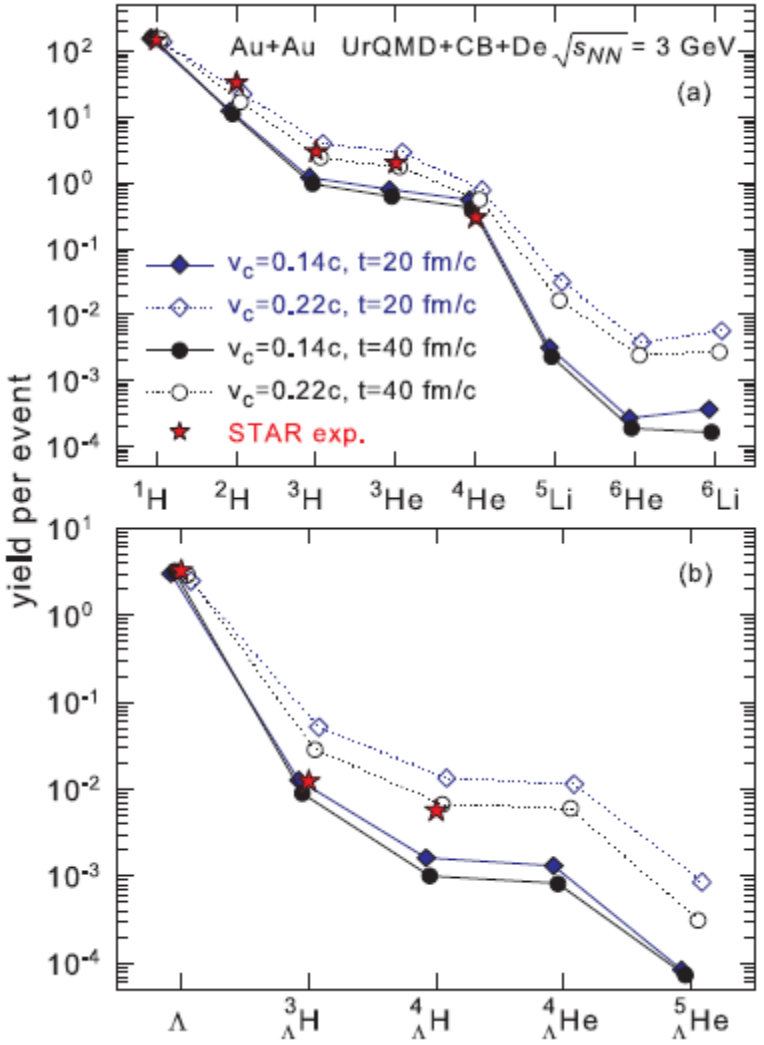
Task 2: Nucleosynthesis of hypernuclei

Collisions of relativistic ions are promising reactions leading to the nucleosynthesis of nuclei/hypernuclei, exotic nuclei with very different isospin.

1. The **hadronization** reaction process (transition from quark-gluon plasma to hadrons). The first process takes place at high density and can be understood with transport models, e.g., UrQMD describes the dynamical production of baryons.
2. The **nucleation** takes place at subnuclear density (during the expansion and cooling down the matter) and can be described with statistical multifragmentation models (SMM).

Theoretical novelty: a new statistical mechanism related to the **nuclear liquid-gas type phase transition** is suggested.

N. Buyukcizmeci , T. Reichert, A. S. Botvina, M. Bleicher, PRC 108, 054904 (2023)



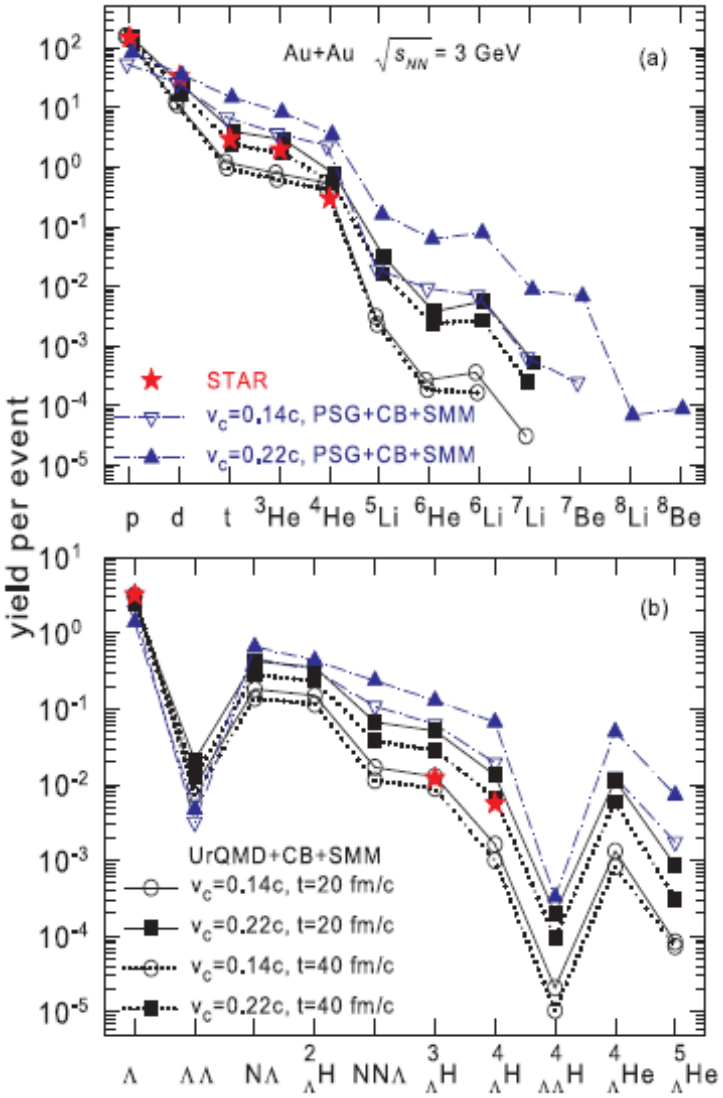
Task 2: Nucleosynthesis of hypernuclei

Advantage of relativistic HI collisions:

- Abundant yield of exotics and double strange hypernuclei: NNΛ , ΛΛ (H-dibaryons) and others, which are difficult to produce in conventional hypernuclear experiments
- HI collisions produce hypermatter and allow for the investigation of the hyperon and nucleon interaction: There is a hyper-nucleosynthesis at low (subnuclear) density

Yields of the produced particles are necessary to probe the nucleation mechanism

Predictions for future R3B and CBM experiments at FAIR/GSI

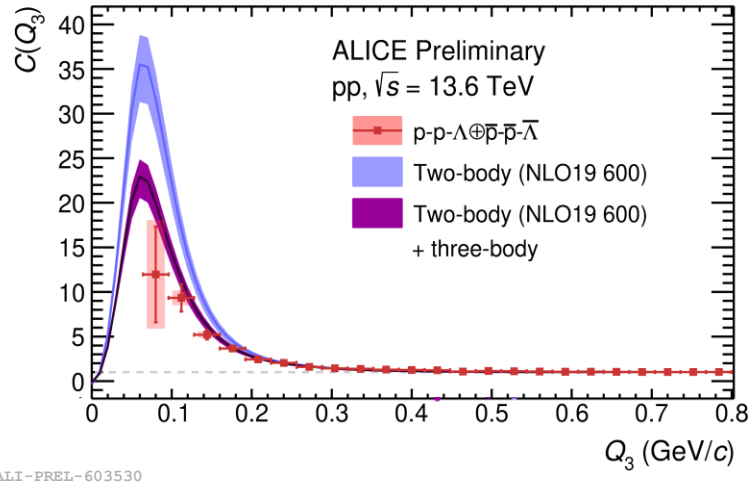


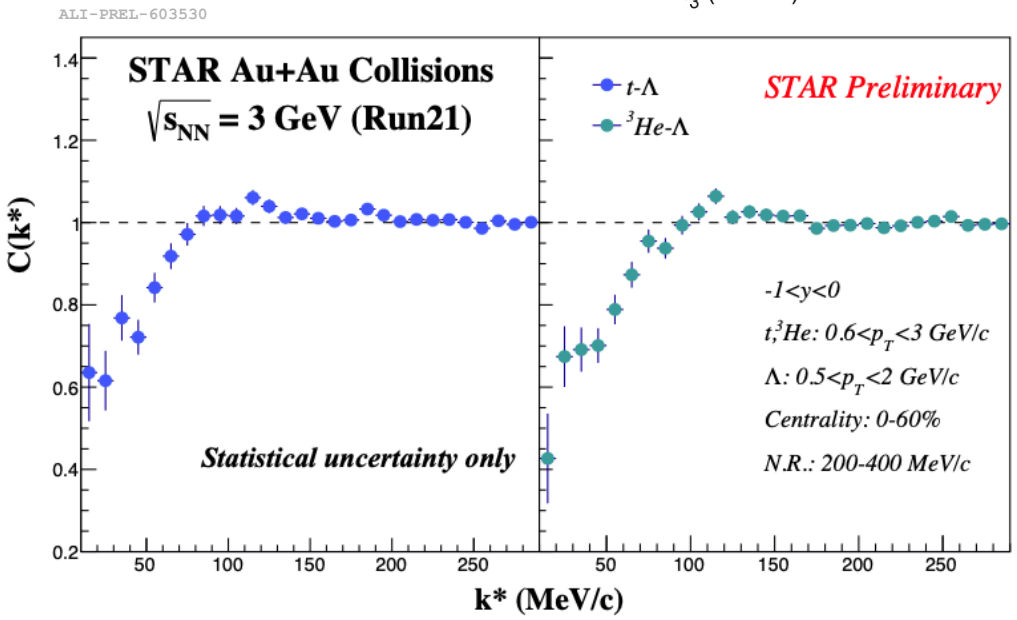
N. Buyukcizmeci , T. Reichert, A. S. Botvina, M. Bleicher, PRC 108, 054904 (2023)

Task 3: YN and YNN interaction studies using femtoscopy

- Femtoscopy is used to probe low-energy interactions of strange hadrons *L. Fabbietti et al., ARNPS 71 (2021), 377-402*
- Planned analyses (ALICE Run 3) to study isospin dependence:
  - Three-particle systems: p-p-Λ, p-p-Σ, p-p-Ξ
  - Hyperon-deuteron: Λ-d, Σ-d, Ξ-d
- Complementary measurements ongoing or planned at STAR@RHIC
- Additional insight expected from femtoscopy of non-strange systems (p-p-p, p-d) in search for trineutron (n-n-n) states at RIKEN and R3B@FAIR

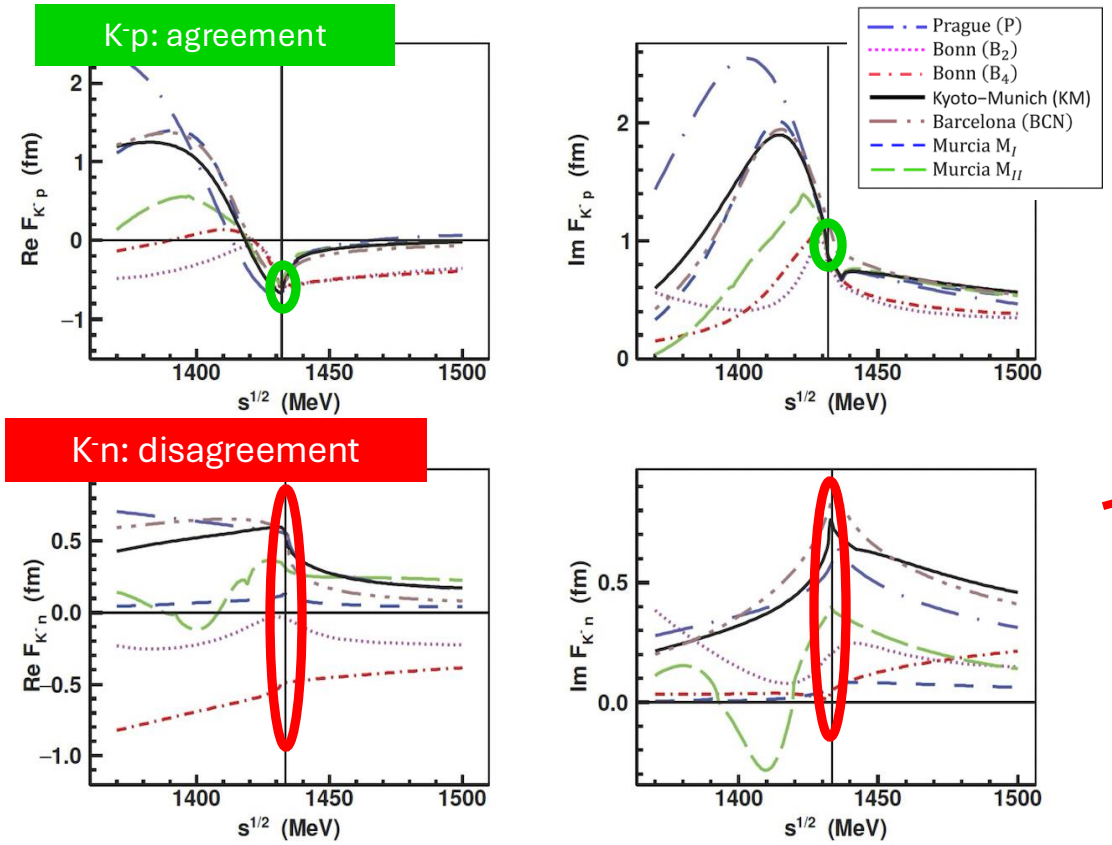
Constrain ΛNN interaction (isospin dependence) and provide input for EoS



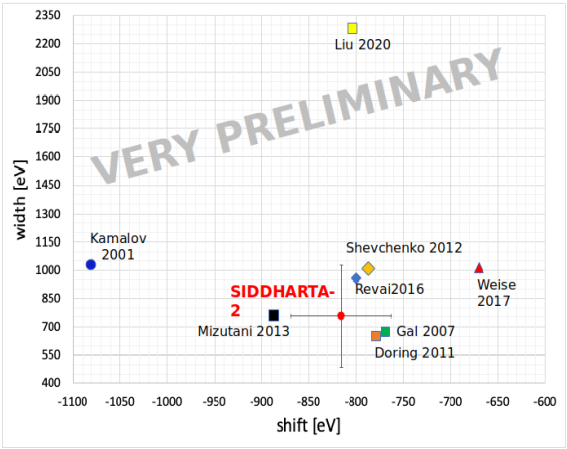


Task 4: K⁻-nucleon interaction and bound state properties

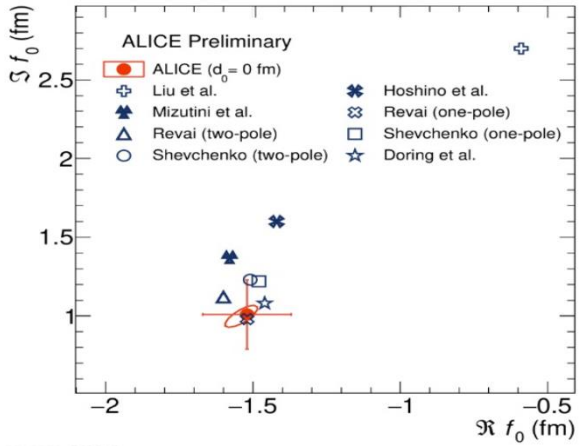
- Theoretical models in agreement for K⁻p near threshold (constrains from KH **measurement by SIDDHARTA**)
- Complete disagreement for K⁻n amplitudes at threshold due to lack of data → **new measurement of K⁻d by SIDDHARTA-2**



A. Cieplý et al. AIP Conf. Proc. 2249, 030014 (2020).



A. Scordo @ QNP 2024

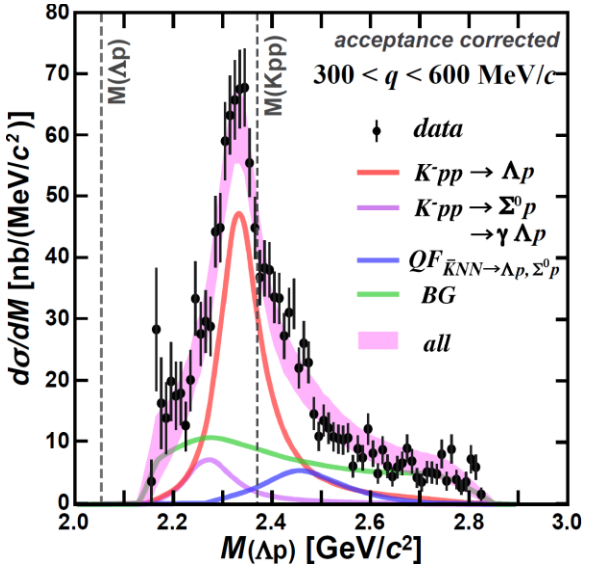


Possible combined analysis and crosscheck with femtoscopy @ ALICE

W. Rzesa @ HADRON 2023

Task 4: K^--nucleon interaction and bound state properties

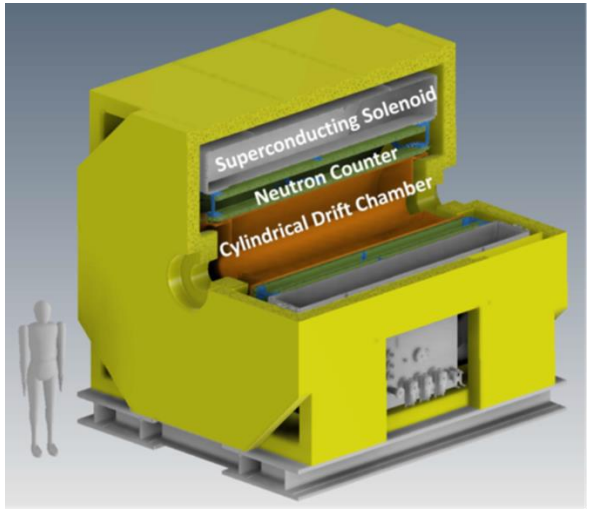
Understanding the properties of kaonic bound states, contribute to determine the energy dependence of the K^-N interaction in the energy region below the K^-N mass threshold.



At J-PARC:

- The "K^-pp" bound state in $^3He(K^-,\Lambda p)n$ was observed
  - ✓ *PLB789(2019)620., PRC102(2020)044002*

  There is still discrepancy between theoretical few-body calculations and experiment, mainly due to the magnitude of Γ_{Kpp}
- Hints of mesonic decays of "K^-pp"
  - ✓ *PRC110(2024)014002*
- Observed the sign of the "K^-ppn" in $^4He(K^-,\Lambda d)n$
  - ✓ will be published soon with x3 statistics
- **New project has started from "K^-ppn" (E80), aiming at the systematic study of kaonic nuclei**
  - Constructing a large solenoid spectrometer
  - Will start in early 2027



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U. Valencia
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Members of STRANGE-MATTER

U. Barcelona
U. Bochum

31 institutions
11 countries
≥ 100 permanent scientists, postdocs
≥ 50 active PhD/Master students

U. Tohoku
U. Tokyo
U. Valencia
U. Washington

Financial request (4 years)

Travel money **40 000 € /year**

- Primarily for supporting travel of the participants to common meetings and for the annual workshop organized by STRANGE-MATTER
- < 400€ per scientist and per year

Outreach and trainings **20 000 € /year**

- Organise outreach activities and trainings for young researchers.

Indirect costs **15 000 € /year**

Total requested budget: **300 000 €**

Thank you for your attention!