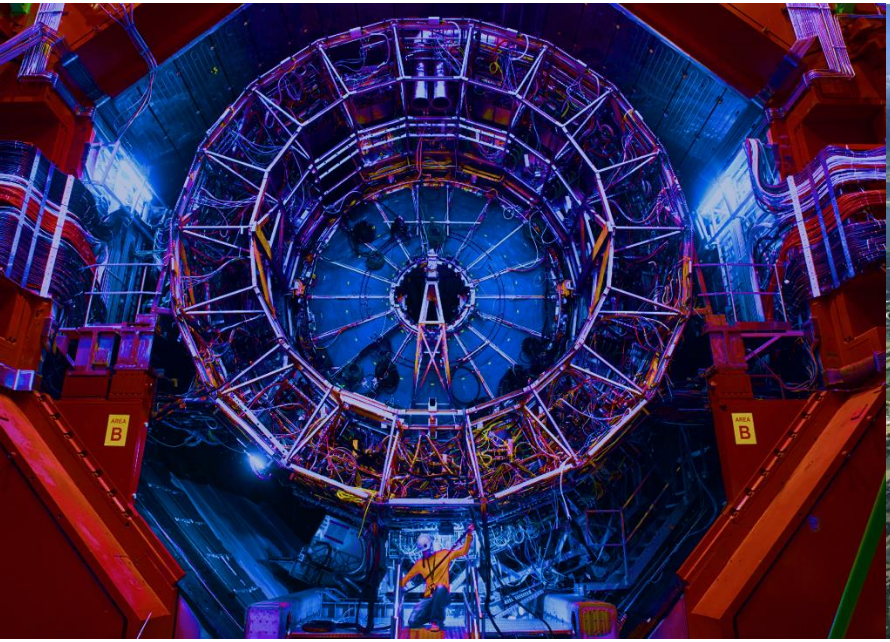
Nuclear physics at the LHC

- a JENA activity -



P. v. Doetinchem (Hawaii), L. Fabbietti (TUM), A. Kalweit (CERN), T. Linden (Stockholm)

ECFA plenary meeting, 15th November 2024

Outline

1. Brief history and status of the JENA activity “Nuclear Physics at the LHC”

2. Recent physics news based on August workshop

   - Antinuclei

   - Antiprotons

   - Neutron stars

JENAA

Joint ECFA-NuPECC-APPEC Activities

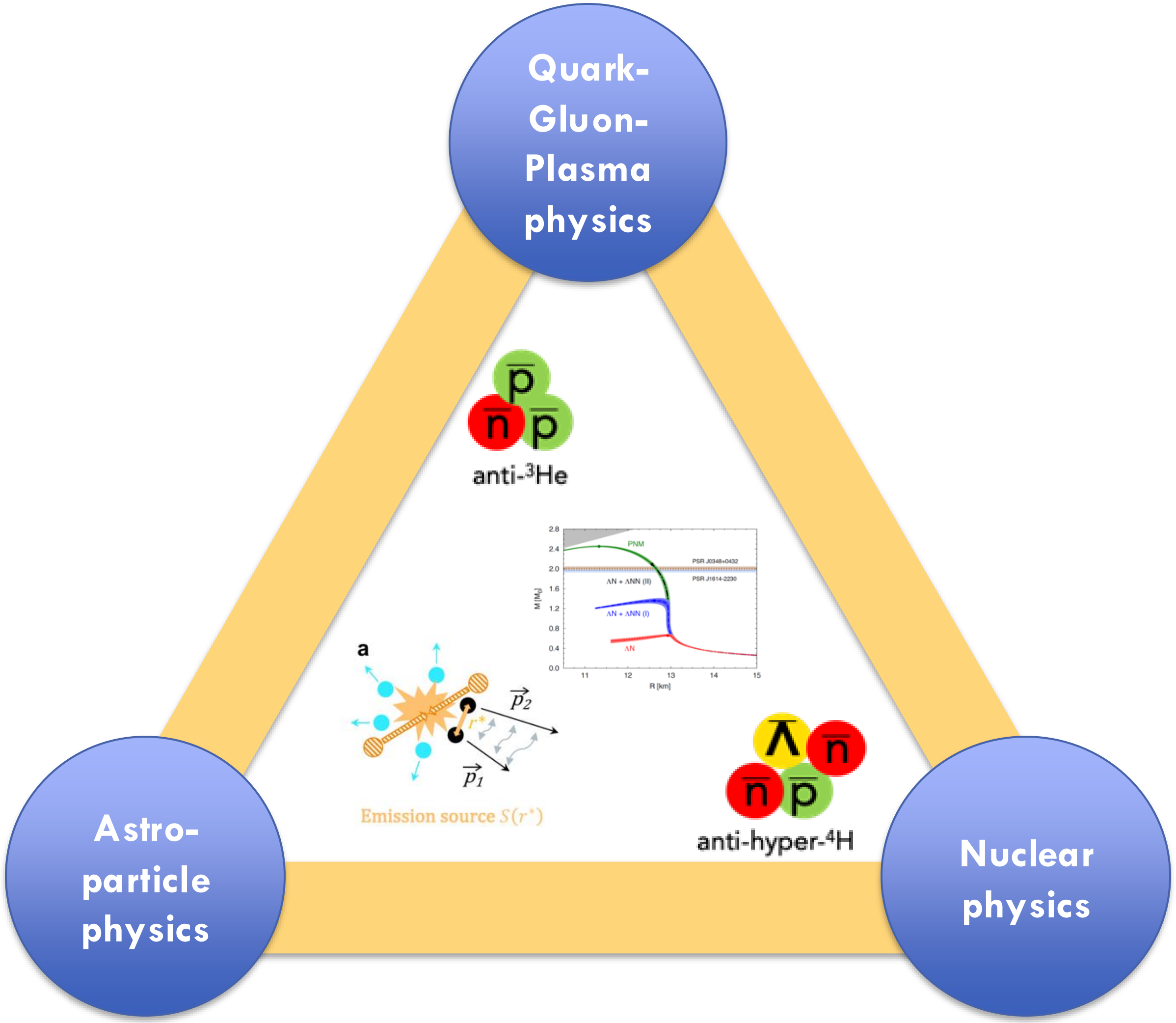
Brief history and status of "Nuclear physics at the LHC"

Introduction (1)

- The LHC is a TeV scale accelerator. Its primary goal is the study of high energy phenomena such as the Higgs Boson, Supersymmetry, Quark-Gluon Plasma, CP violation.

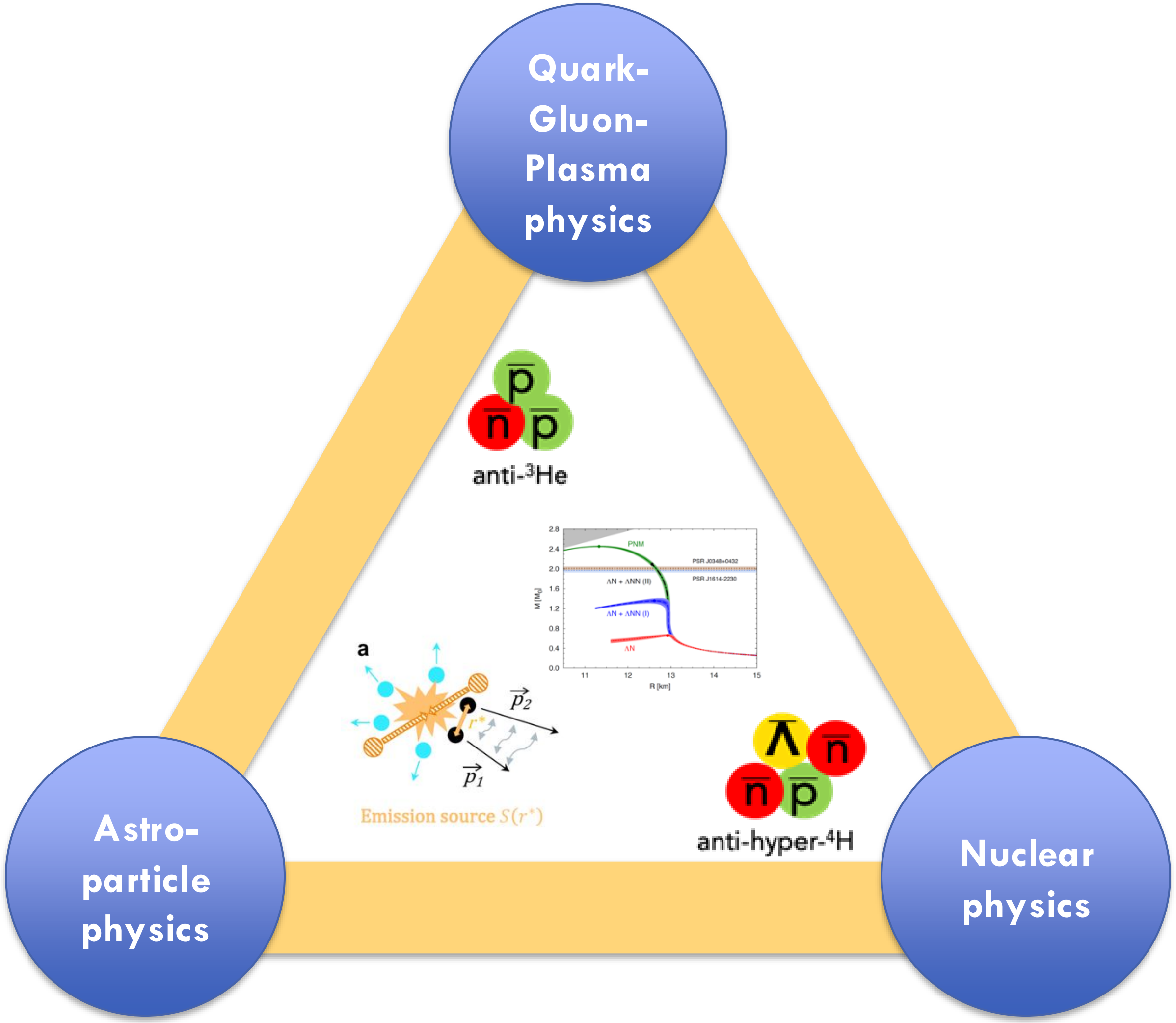
- At the same time, it delivers a plethora of groundbreaking measurements at the MeV (nuclear and hadronic physics) scale, e.g. precision studies on hyper-triton properties and measurements of the hyperon-nucleon strong interaction potential.

- Surprisingly, many of these results have strong implications for fundamental questions in astroparticle physics.



Introduction (2)

- Nuclei at the LHC aims at providing a platform that promotes the physics of antinuclei and hadronic interactions at high energy accelerators and in space
- Information exchange between the physicists in the three communities is essential to achieve the common physics goals
- The JENAS initiative provides a unique opportunity to put these topics into the focus



A brief history

- Started together with the first other initiatives in August 2020

- Very targeted and truly interdisciplinary initiative with very active research

- Many concrete activities:
  - Input provided for NUPECC long range plan
  - Future plans: white paper together with XSCRC workshop, input to European Strategy
  - Talks by LHC experiments in astrophysics conferences such as ISVHECRI
  - High level publications of experimentalists together with theorists
  - Advertisement in NUPECC news, ECFA newsletter, and APPEC news
  - Participation in Madrid event
  - Contributions to ALICE collaboration week
  - First “official” workshop at CERN in August: link

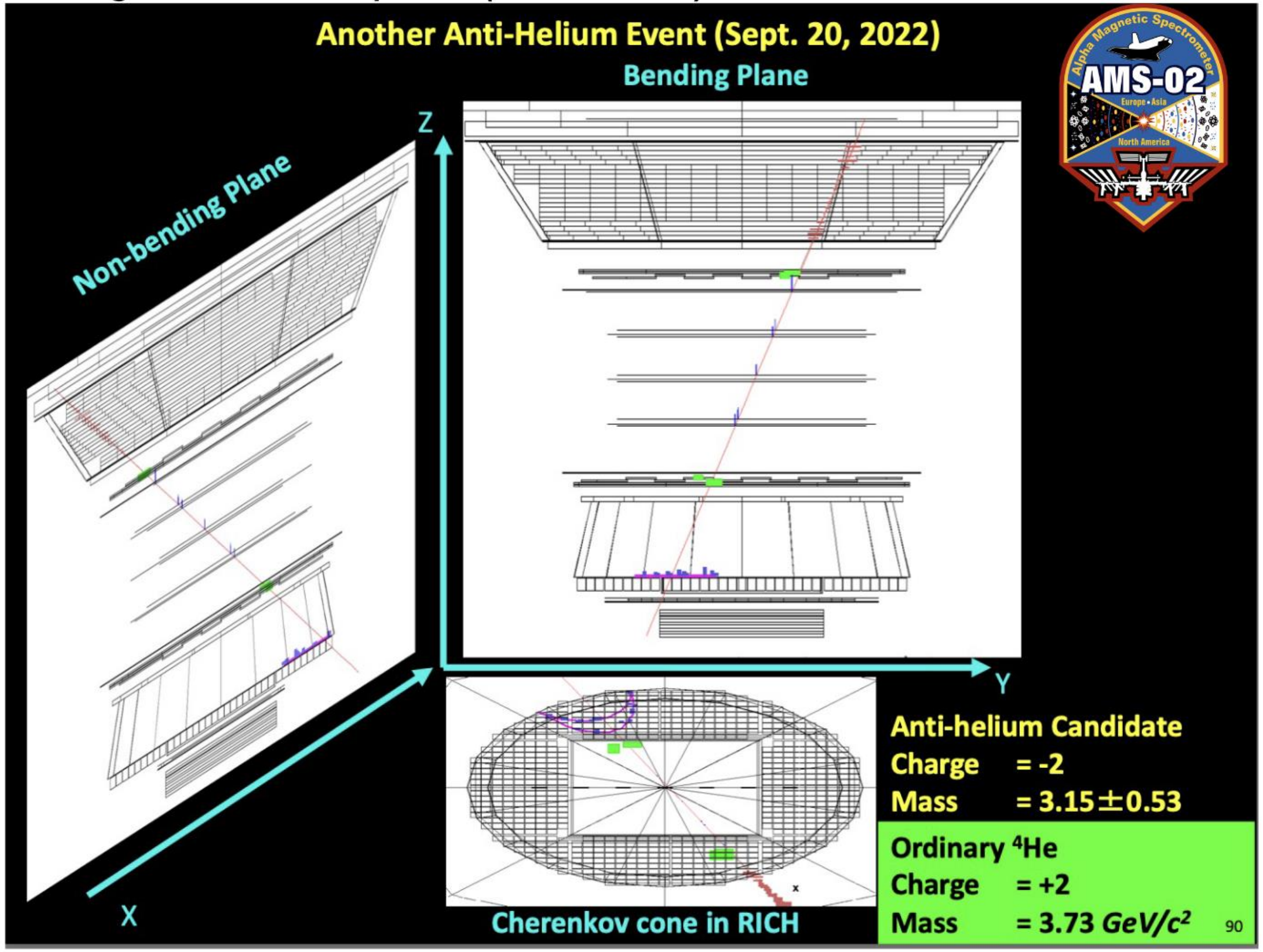
- No official member list, no hierarchy

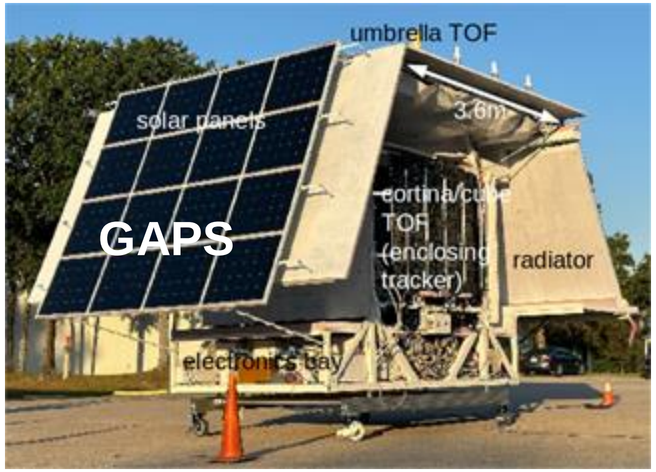
Recent physics news from August workshop:

Antinuclei

Search for antinuclei in space (1)

S. Ting, CERN colloquium (08.06.2023)



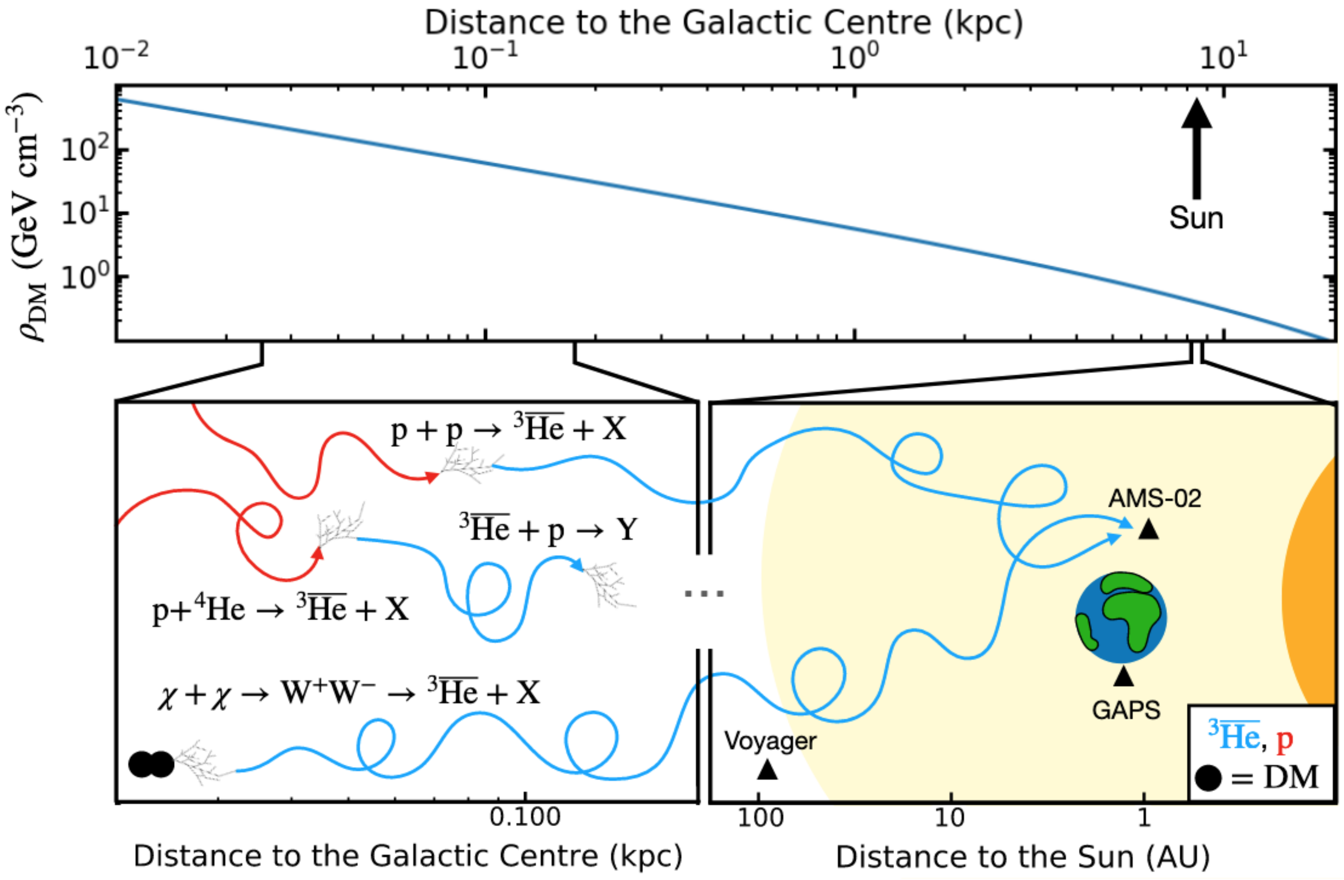


Search for antinuclei in space (2)

anti-helium3

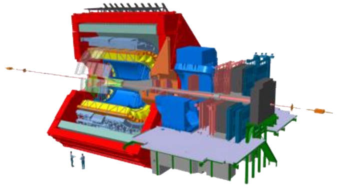
To-do list for collider based experiments:

- Understand antinuclei formation in background reactions
- Understand antinuclei formation in DM decays
- Understand interaction of antinuclei with matter to determine the transparency of the galaxy



[ALICE, *Nature Phys.* 19 (2023) 1, 61-71]

Search for antinuclei in space (3)

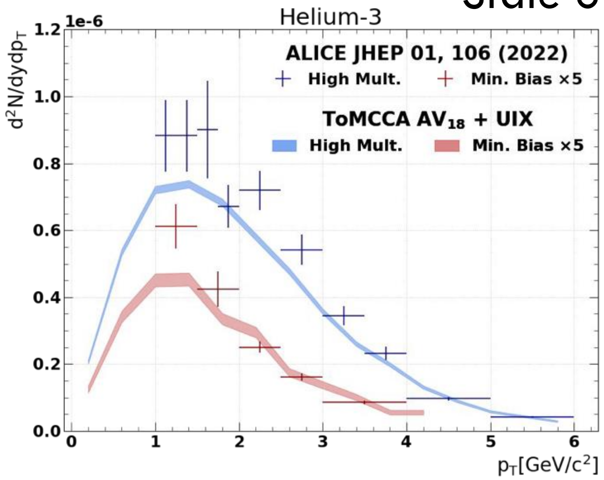


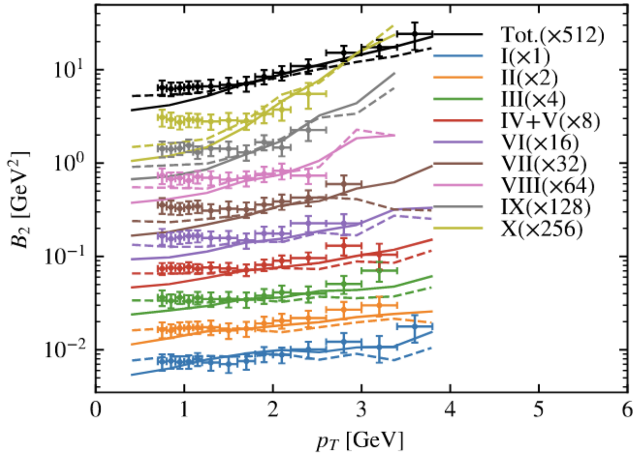
ALICE data: many antinuclei despite $T_{QGP} >> E_{binding}$

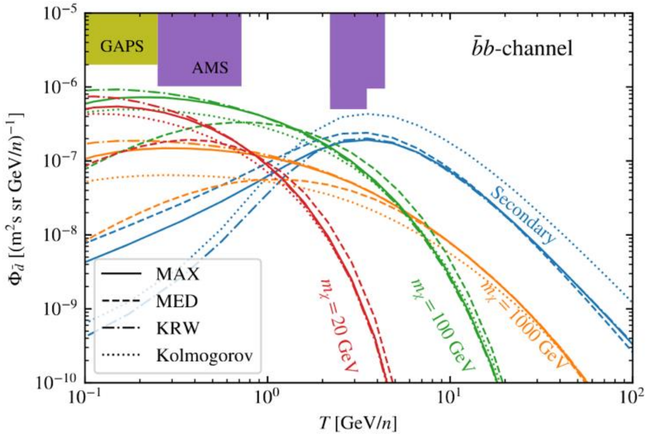
To-do list for collider based experiments:

- Understand antinuclei formation in background reactions: pp → anti-^{3}He
- Understand antinuclei formation in DM decays
- Understand interaction of antinuclei with matter to determine the transparency of the galaxy

State of the art coalescence models







Flux of anti-3He near earth

[M. Mahlein]

[M. Kachelrieß]

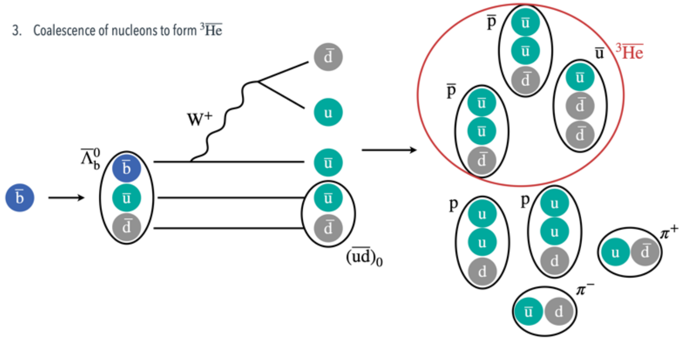
[M. Winkler, T. Linden]
[LHCb]

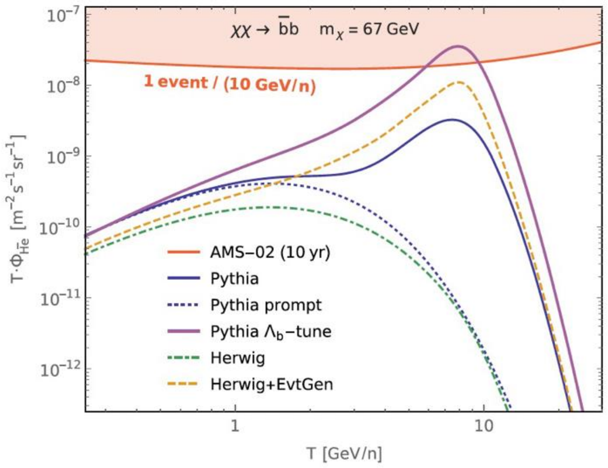
Search for antinuclei in space (4a)

$$\chi\chi \rightarrow b\bar{b} \rightarrow \overline{\Lambda}_b^0 + X \rightarrow {}^3\overline{He} + X$$

To-do list for collider based experiments:

- Understand antinuclei formation in background reactions
- Understand antinuclei formation in DM decays
- Understand interaction of antinuclei with matter to determine the transparency of the galaxy





→ Λ_b decays into antihelium could boost the signal from dark matter decays
→ However, the first LHCb measurement from this summer indicates a branching ratio that is significantly lower than the needed 10^{-6}

LHCb

$$\mathcal{B}(\overline{\Lambda}_b^0 \rightarrow {}^3\overline{He}pX) < 3.6 \times 10^{-8} \text{ at } 90\% \text{ CL}$$

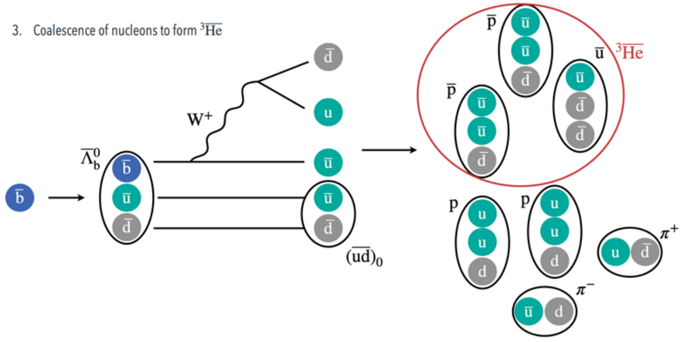
Search for antinuclei in space (4b)

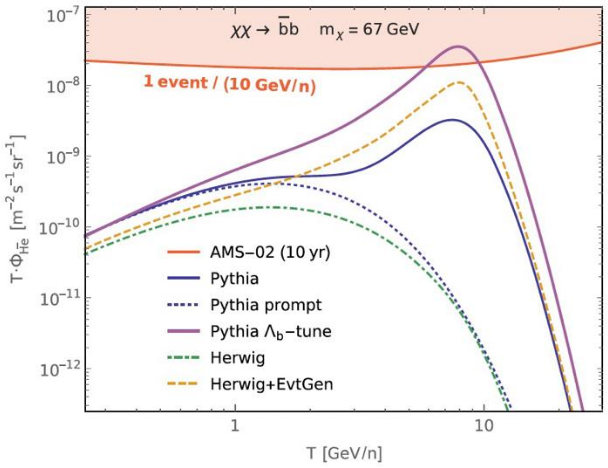
[M. Winkler, T. Linden]
[LHCb]

$$\chi\chi \to b\bar{b} \to \overline{\Lambda}_b^0 + X \to {}^3\overline{He} + X$$

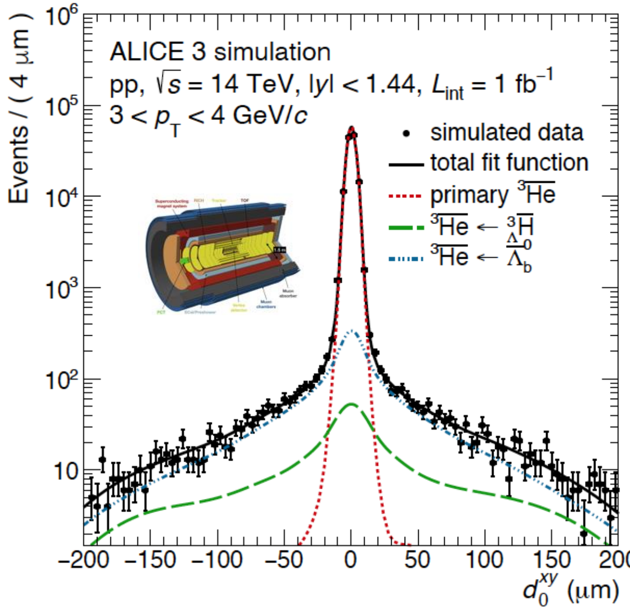
To-do list for collider based experiments:

- Understand antinuclei formation in background reactions
- Understand antinuclei formation in DM decays
- Understand interaction of antinuclei with matter to determine the transparency of the galaxy





ALICE3

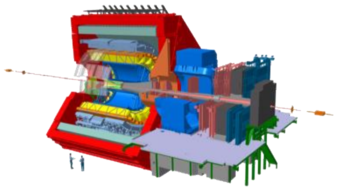


→ ALICE 3 can provide a fully inclusive measurement.

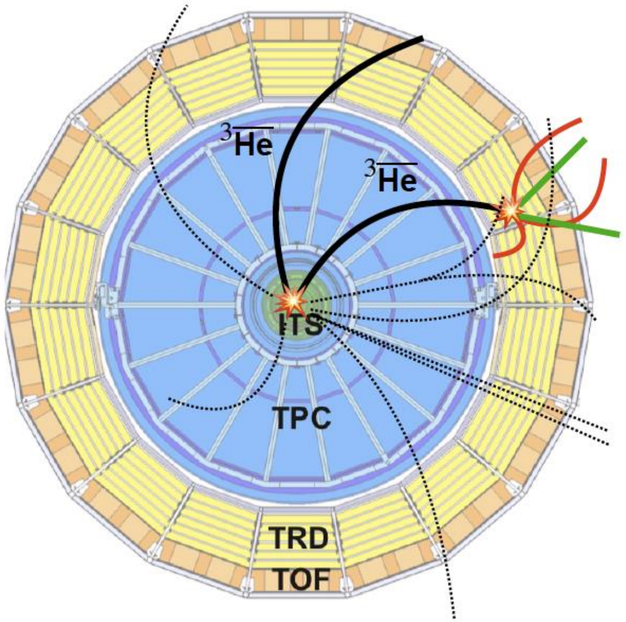
Search for antinuclei in space (5)

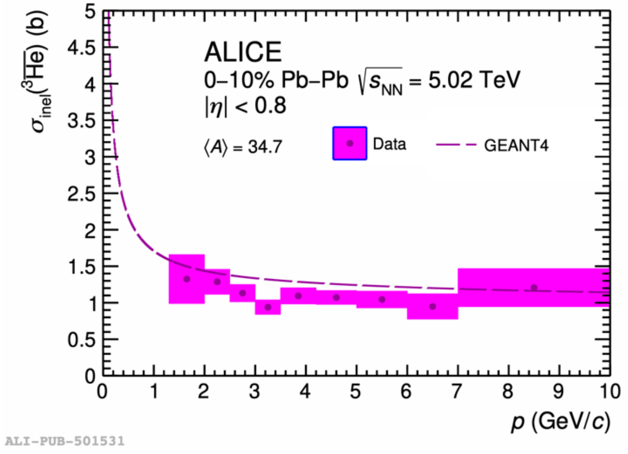
To-do list for collider based experiments:

- Understand antinuclei formation in background reactions
- Understand antinuclei formation in DM decays
- Understand interaction of antinuclei with matter to determine the transparency of the galaxy

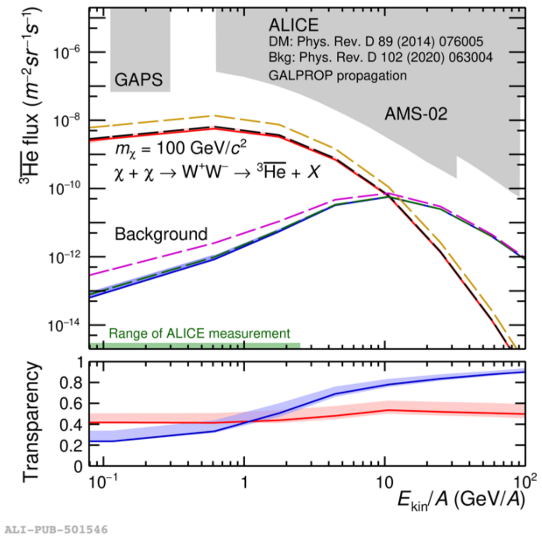


(1.) Measure antinuclei annihilations in ALICE detector





(2.) Propagate to cosmic ray flux

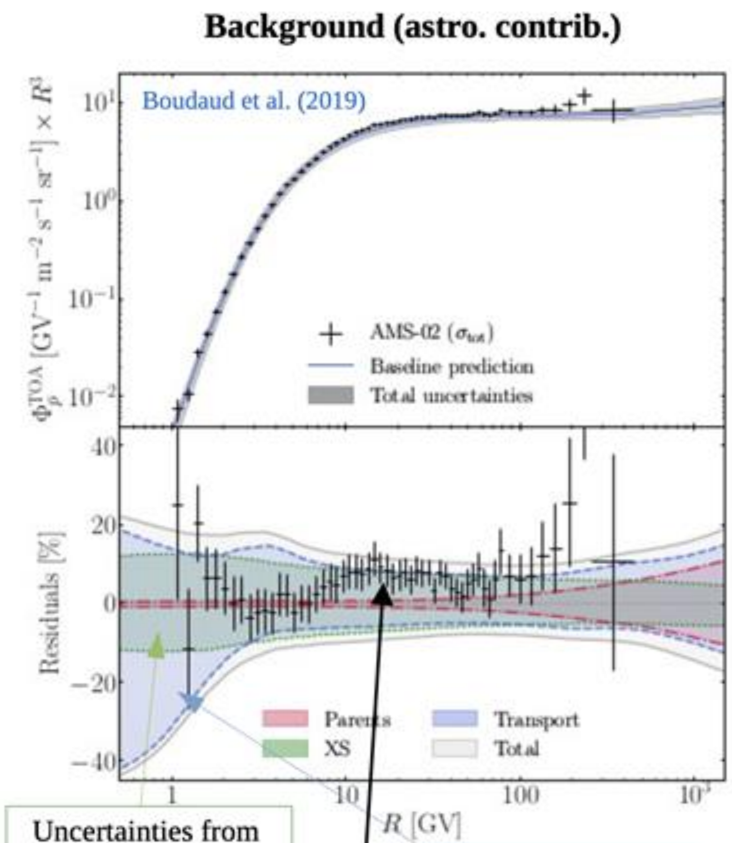


[ALICE, *Nature Phys.* 19 (2023) 1, 61-71]

Recent physics news from August workshop:
Antiprotons

Antiproton flux and LHCb SMOG results

[C. Lucarelli]
[LHCb]

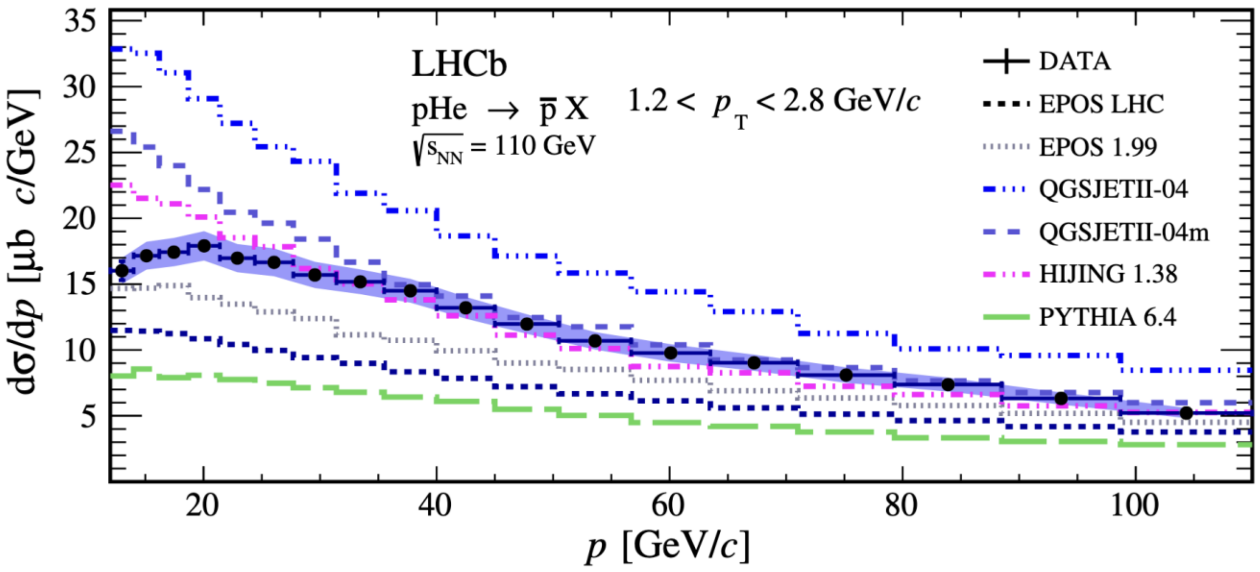


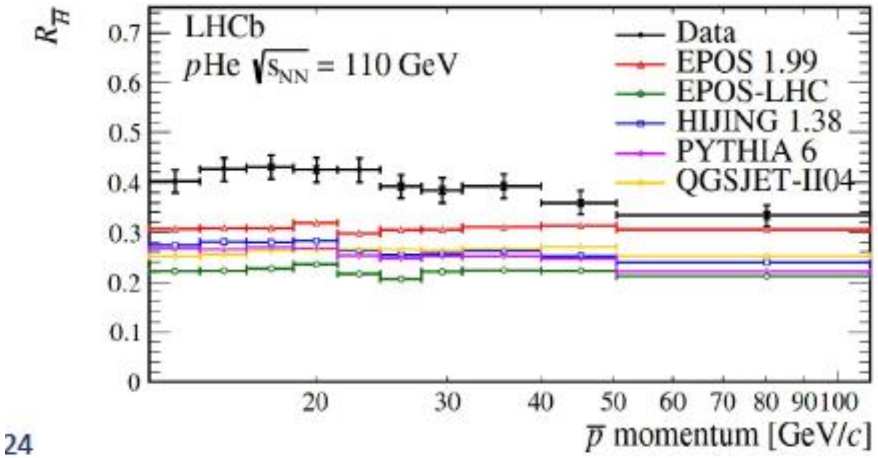
Uncertainties from pbar production (p,He)$_{CR}$ + (H,He)$_{ISM}$

Uncertainties from LiBeB nuclear XS

Cannot take full benefit of AMS-02 high-precision data

[N.B.: any future improvement on pbar data moot if no better XS!]





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More displaced anti-p than expected !

→ SMOG2, pp and pA, including H2, D2 and pO2 will shed further light on this observables

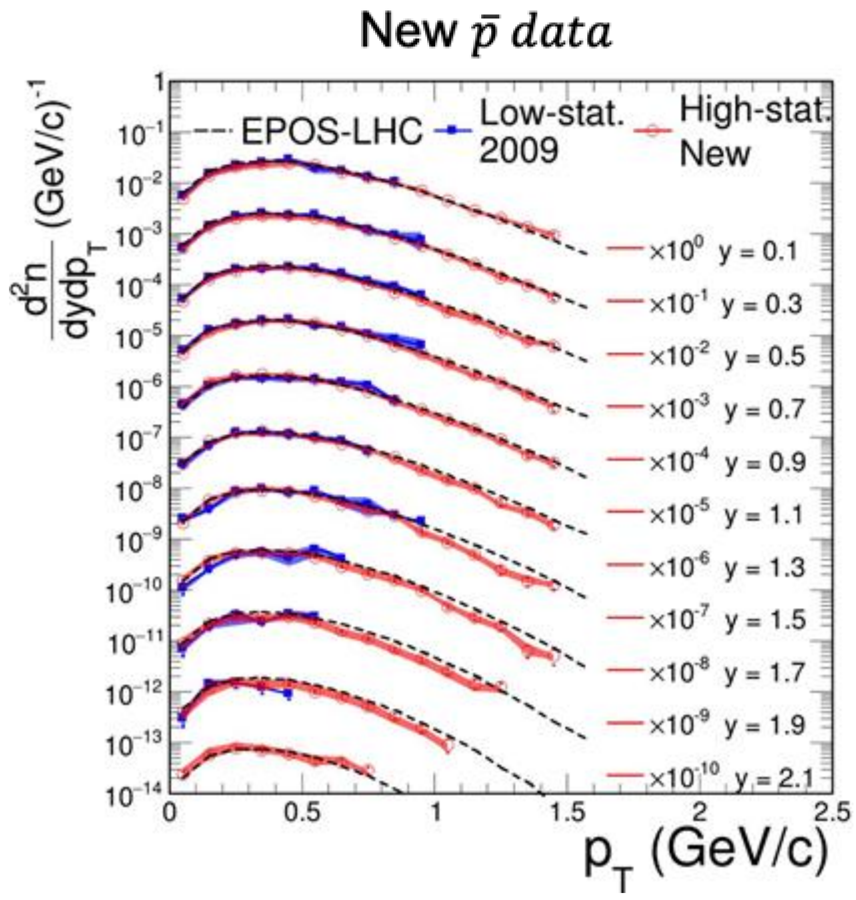
[D. Maurin]

Antiproton results from AMBER and NA-61

[A. Shukla]

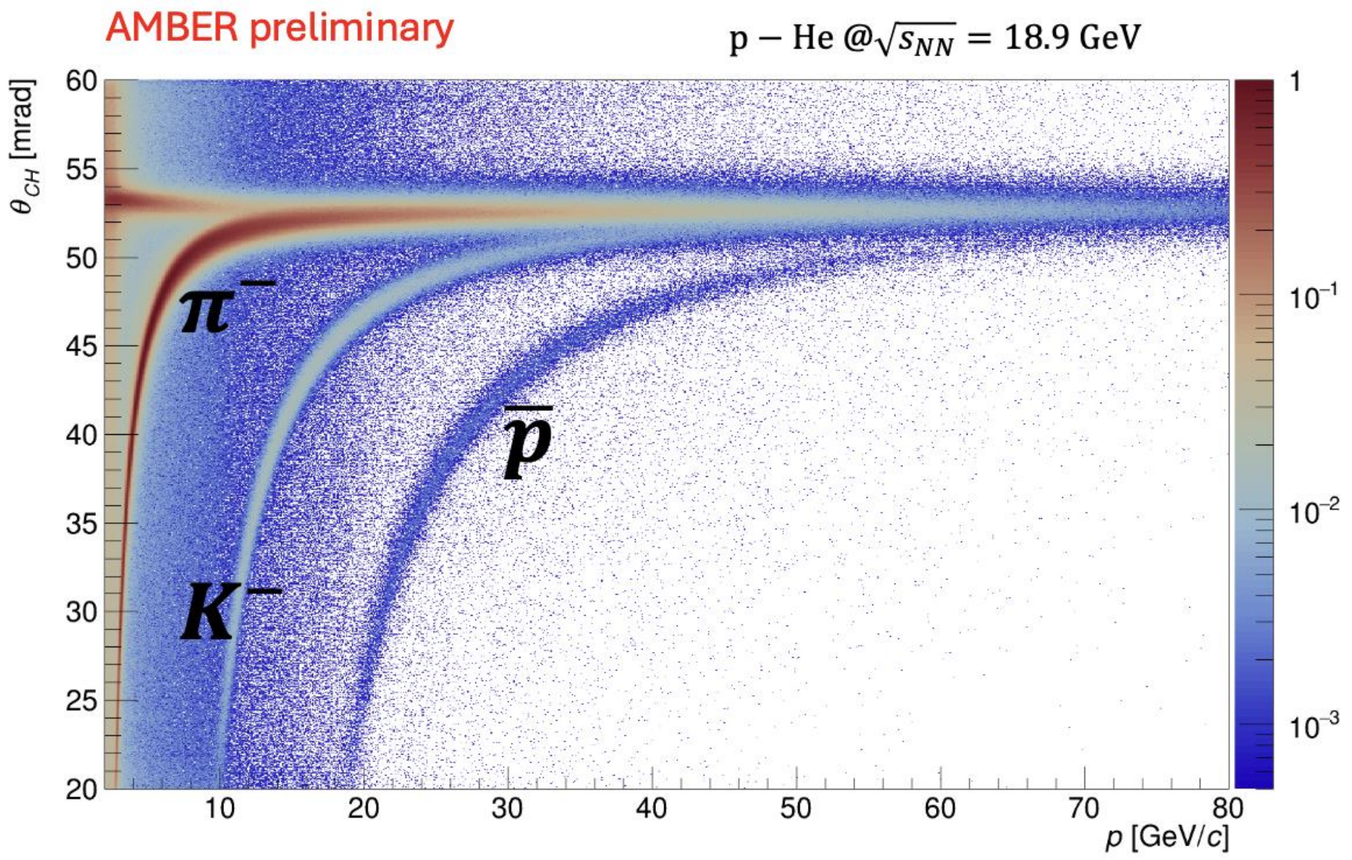
[D. Giordano]

NA-61: p+p collisions at 158 GeV



AMBER

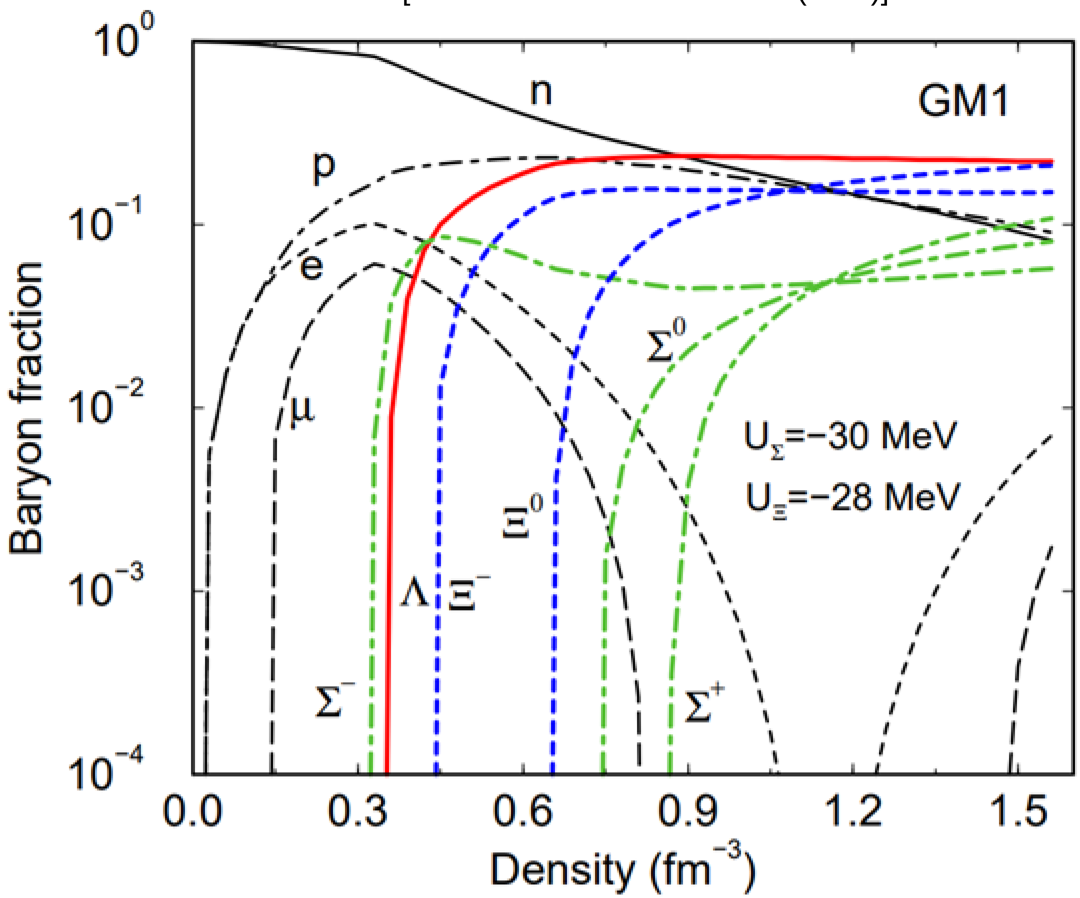
Apparatus for Meson and Baryon Experimental Research



Recent physics news from August workshop:
Neutron stars

Hyperon appearance in neutron stars

[J. Schaffner-Bielich NPA 835 (2010)]

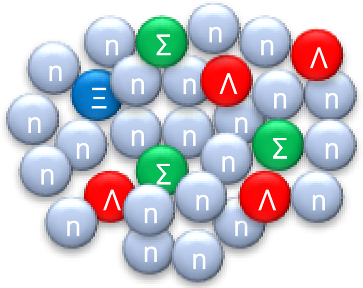


Neutron Stars: very dense, compact objects

→ What is the EoS?
  → What are the constituents to consider?
  → How do they interact?

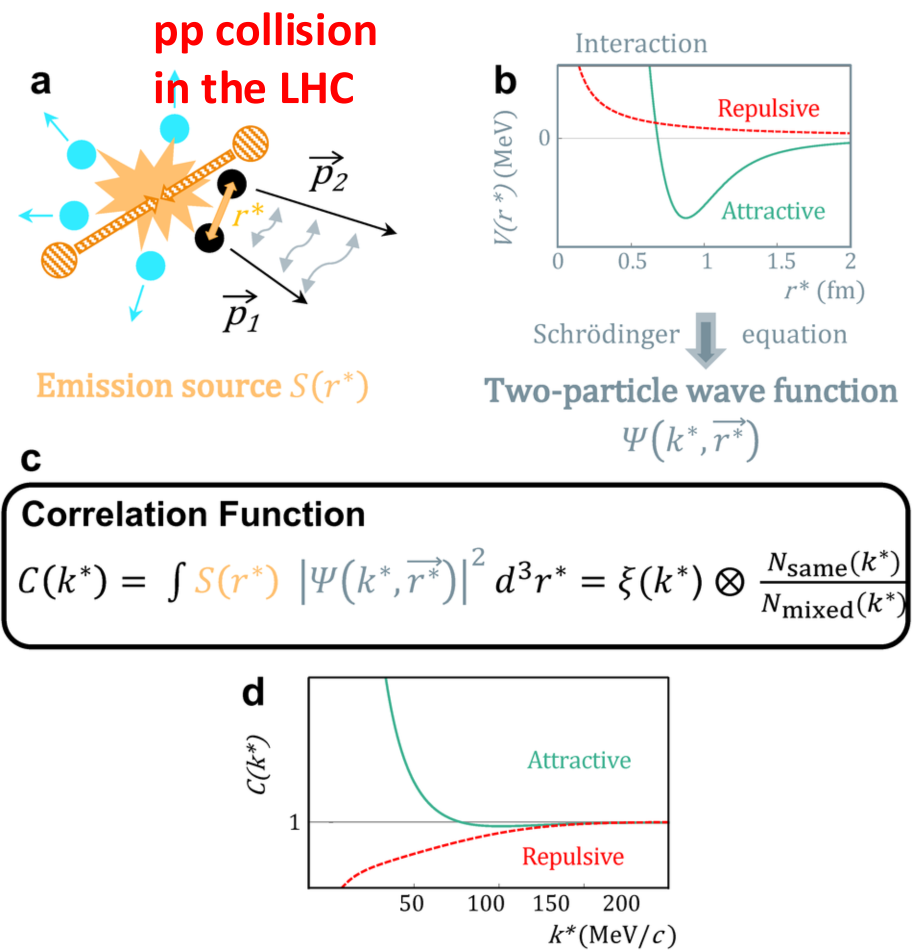
→ With increasing baryonic densities **hyperon** production becomes energetically favorable

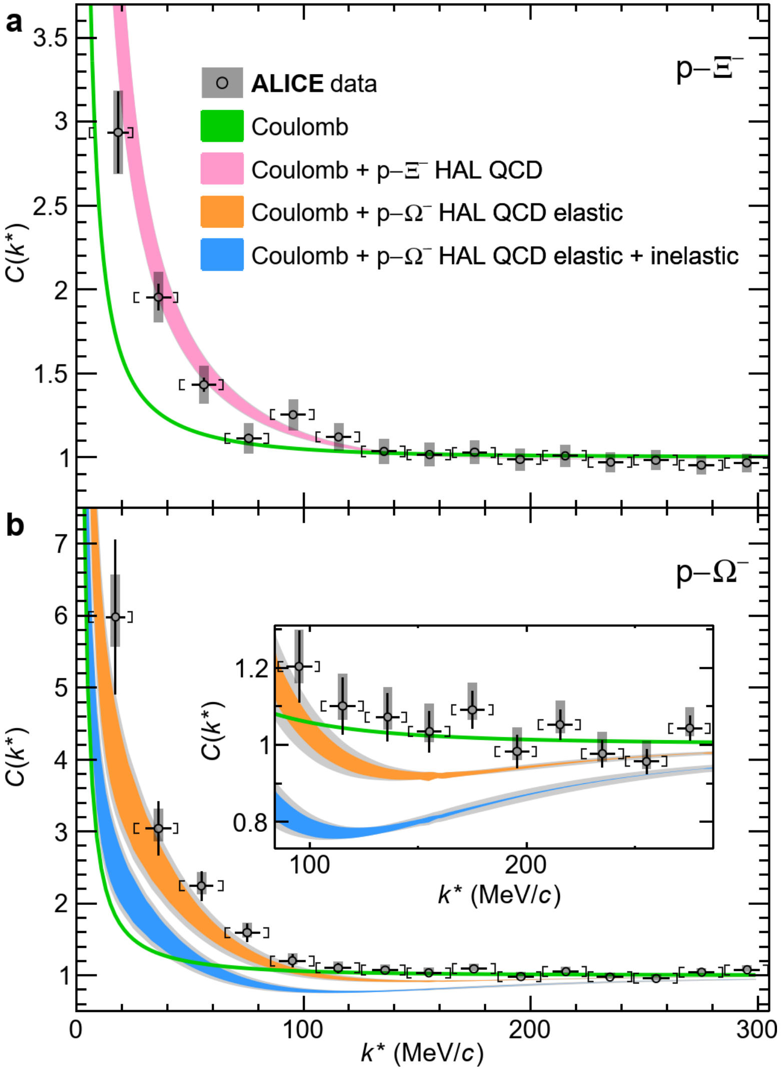
→ Exact composition strongly depends on constituent interactions and couplings!

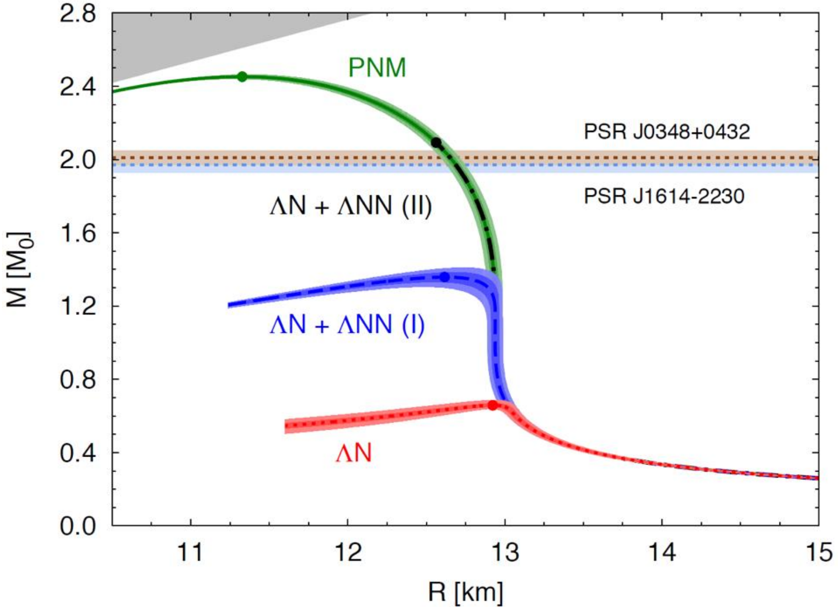


Correlation functions to study the strong interaction

[Nature 588 (2020) 232-238]



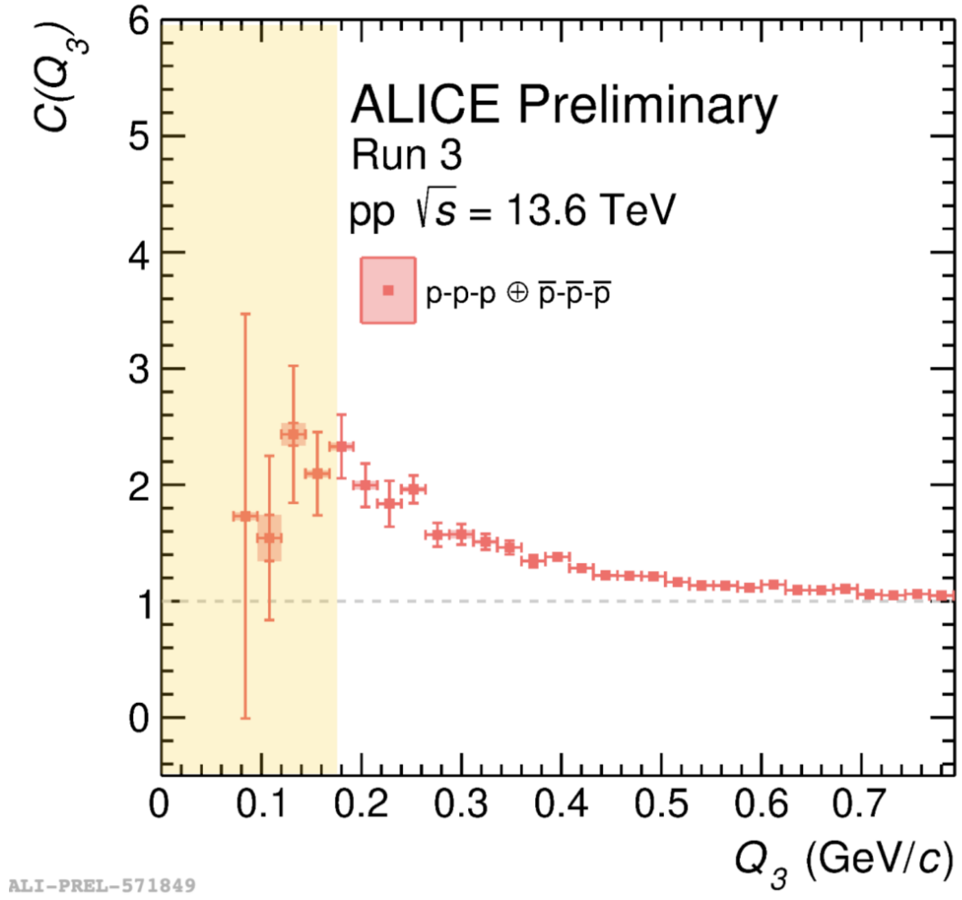


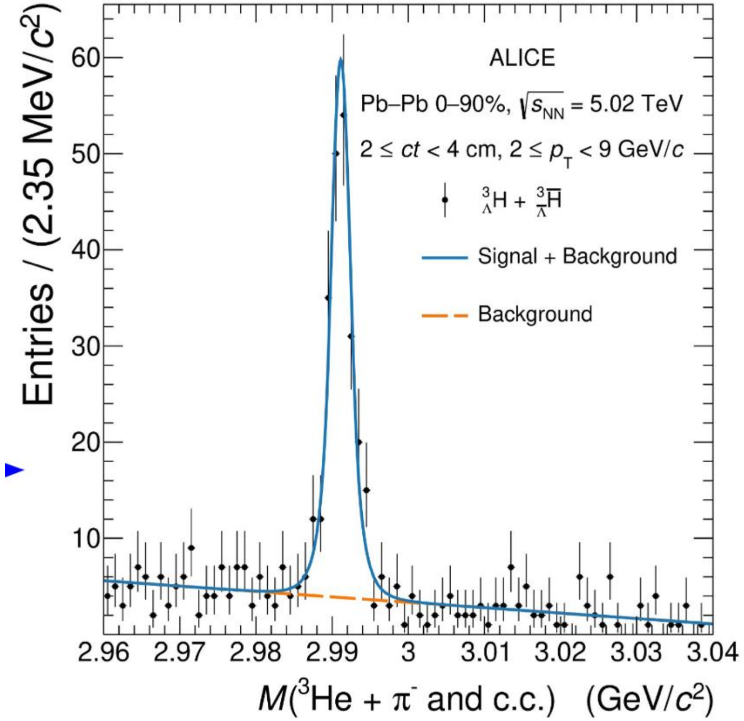


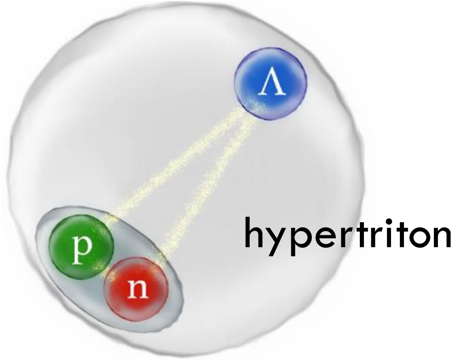
[D. Lonardoni, A. Lovato, S. Gandolfi, F. Pederiva Phys. Rev. Lett. 114, 092301 (2015)]

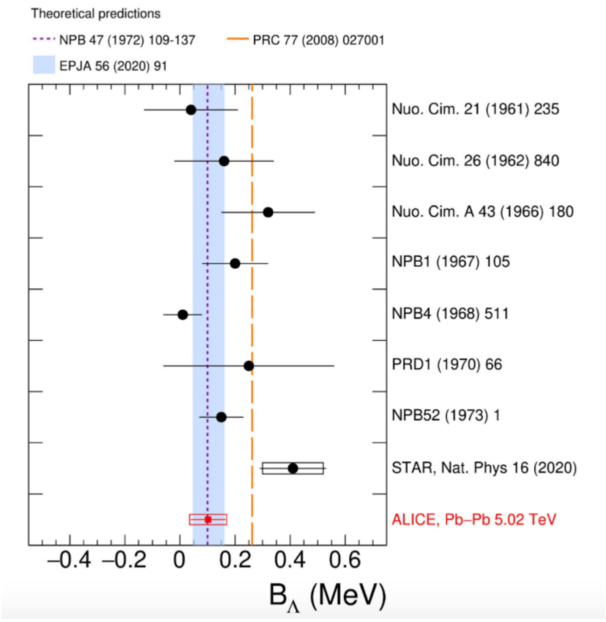
The novel results on hyperon-nucleon and hyperon-hyperon interactions provided by correlation studies at the LHC by ALICE are key to compute **more realistic equation of state for neutron stars containing hadrons with strange content.**

Genuine three-body interactions and hypernuclei









→ First look at three-body interactions looks promising. Precision results are awaited for LHC Run 3!

→ Binding energies of light hypernuclei like hypertriton are used to benchmark/tune the Λ–N interaction potential models.

[R. del Grande, L. Serksnyte]

[F. Mazzaschi]

Thank you!

→Nuclear physics at the LHC is a fascinating and very active area of research!

Please consider to join this effort if you are interested!