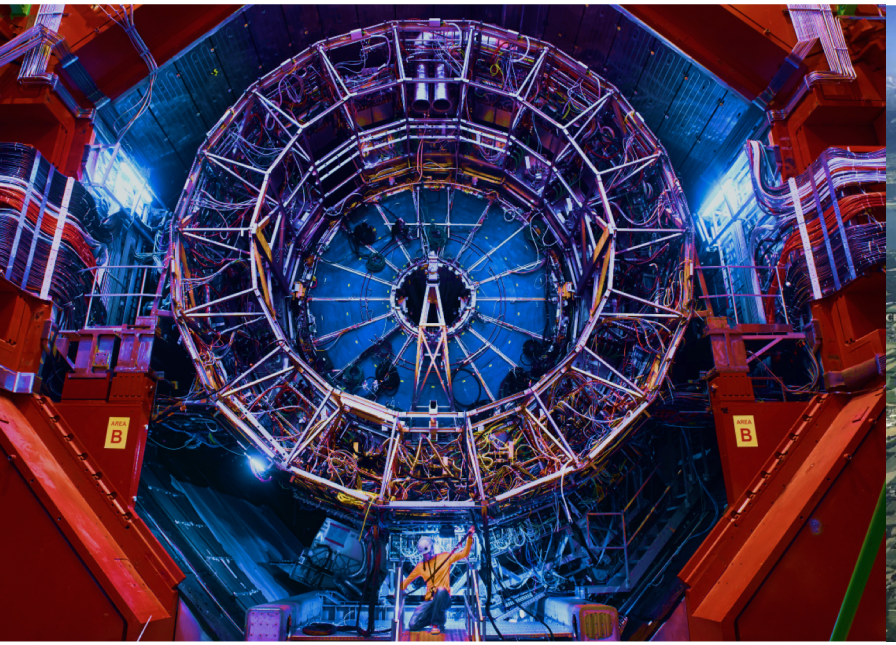
Nuclear Physics at the LHC

A unique doorway to investigate the hyperon-puzzle in neutron stars and to enable the search for dark matter in cosmic rays



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JENAS meeting 26th August 2020

Nuclear Physics at the LHC

- High energy LHC experiments provide a unique laboratory for nuclear and hadron physics studies that have a wide breadth of possible applications to astrophysics.

- A **very targeted** and **truly interdisciplinary** proposal focused on

1. High precision studies of hyperon-nucleon (Y-N) and hyperon-hyperon interactions → **fundamental to study the EoS of neutron stars**

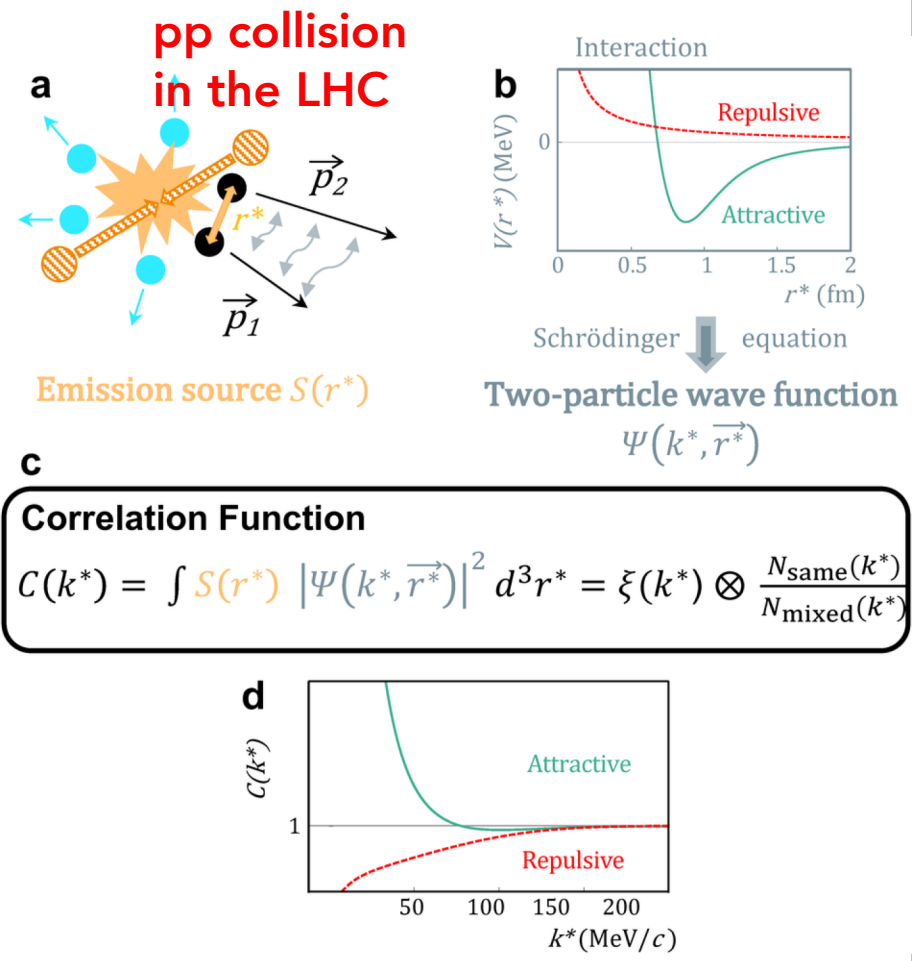
2. Formation process and properties of light anti- and hyper-nuclei → **pivotal ingredient in searches for dark matter in cosmic rays**

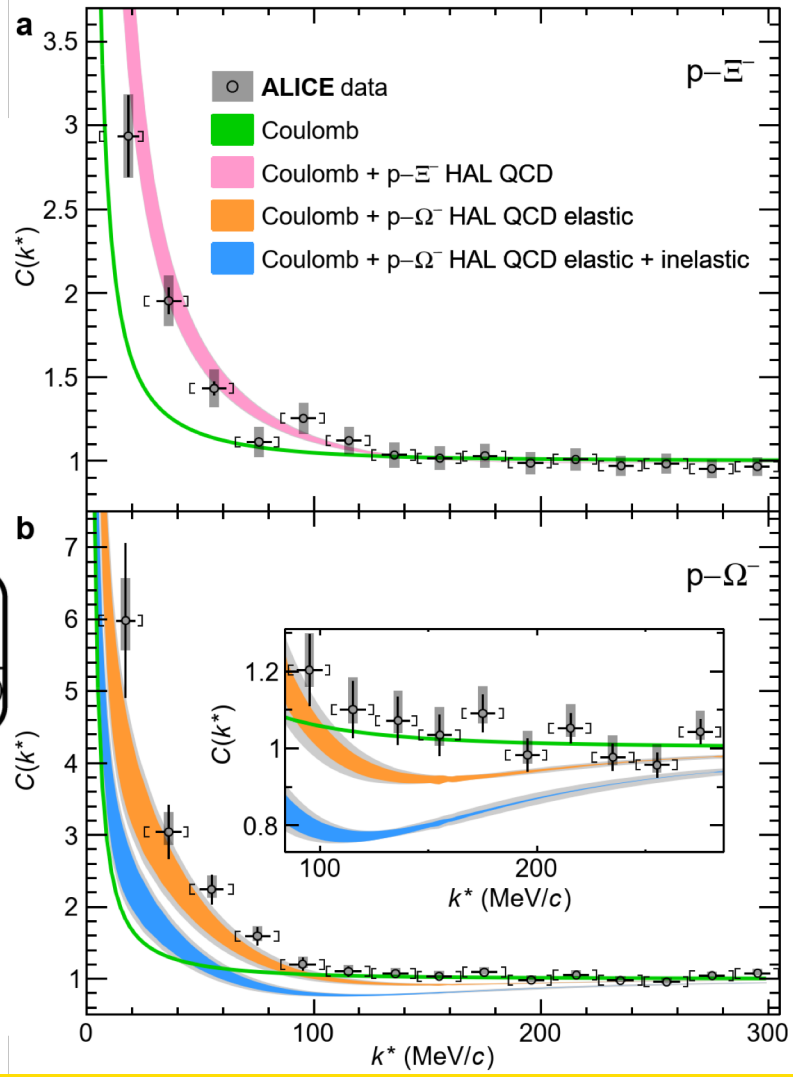
- Web page available since yesterday: https://indico.ph.tum.de/event/4492/overview

→ Will be circulated to the communities for endorsement after this meeting.

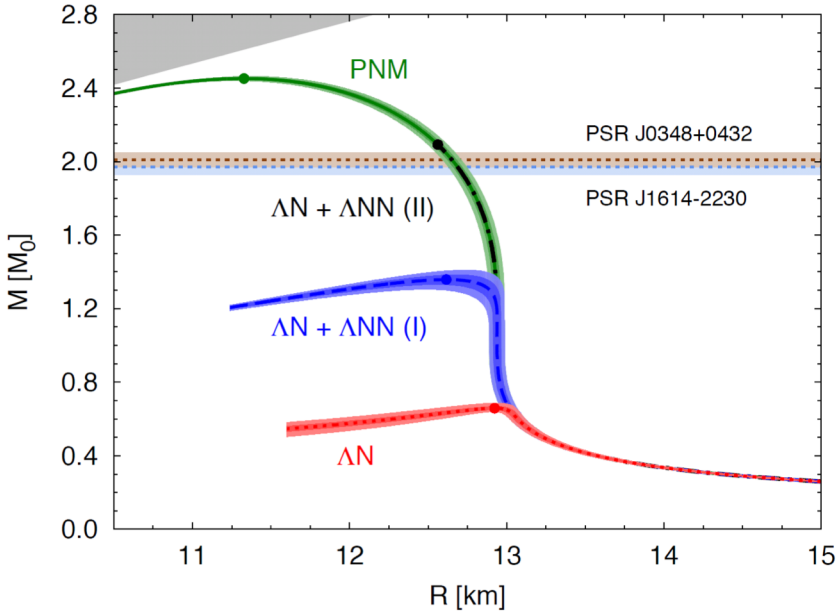
Hyperon-nucleon and nucleon-nucleon interactions

[ALICE, arXiv:2005.11495]





EoS of neutron stars

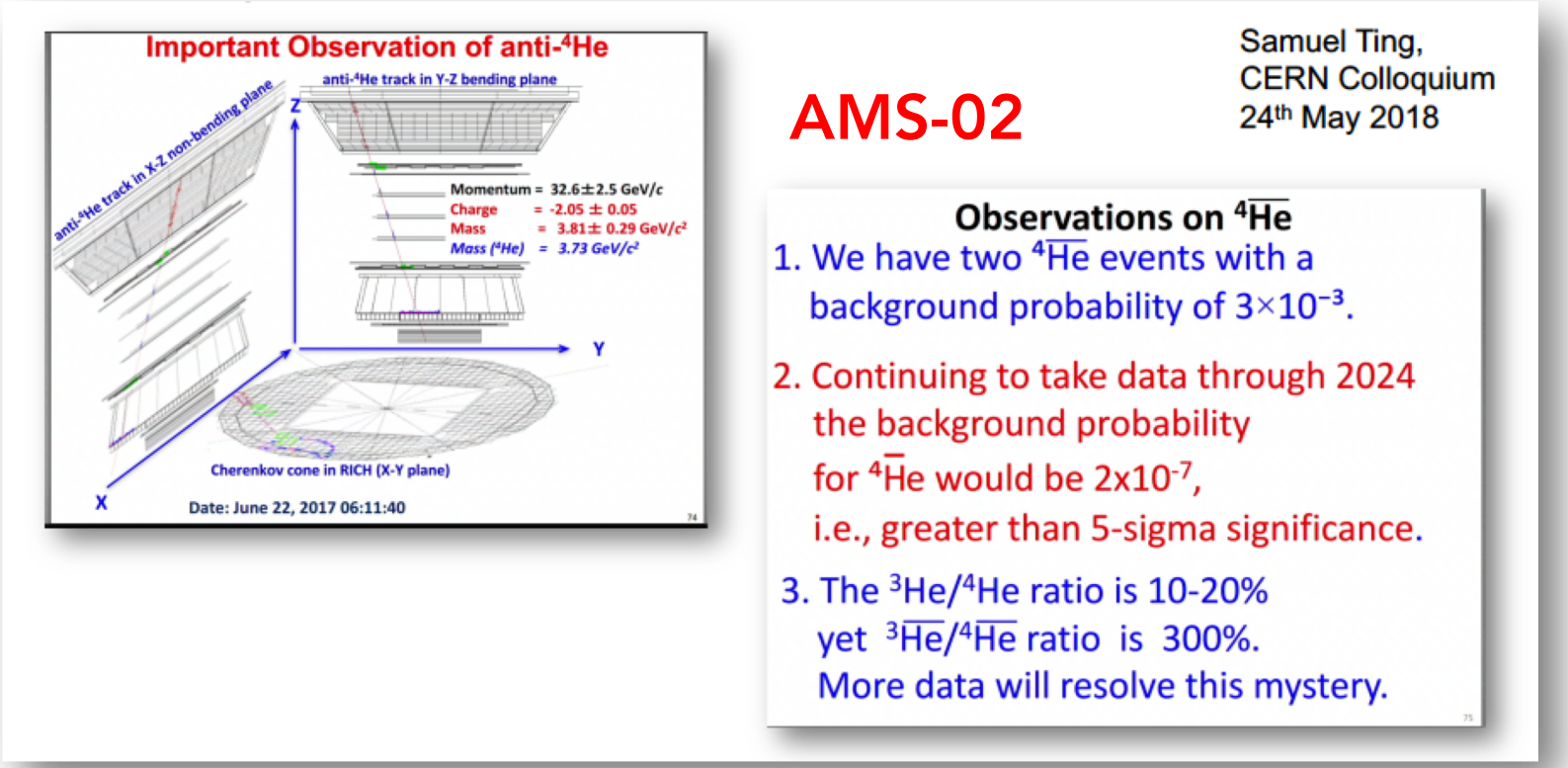


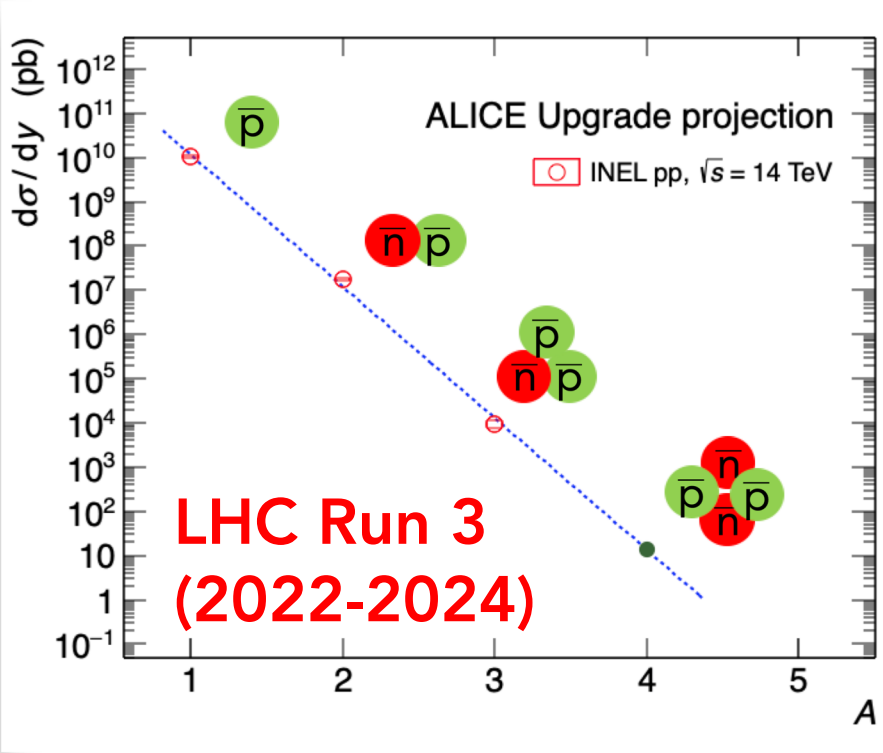
[D. Lonardoni, A. Lovato, S. Gandolfi, F. Pederiva Phys. Rev. Lett. 114, 092301 (2015)]

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**.

Anti-matter in space and in the laboratory

- Space-borne experiments like AMS or balloon experiments like GAPS look for anti-nuclei that are produced in the annihilation of dark matter particles.
- The background rates in these searches are constrained by collider-based experiments like ALICE at the LHC.

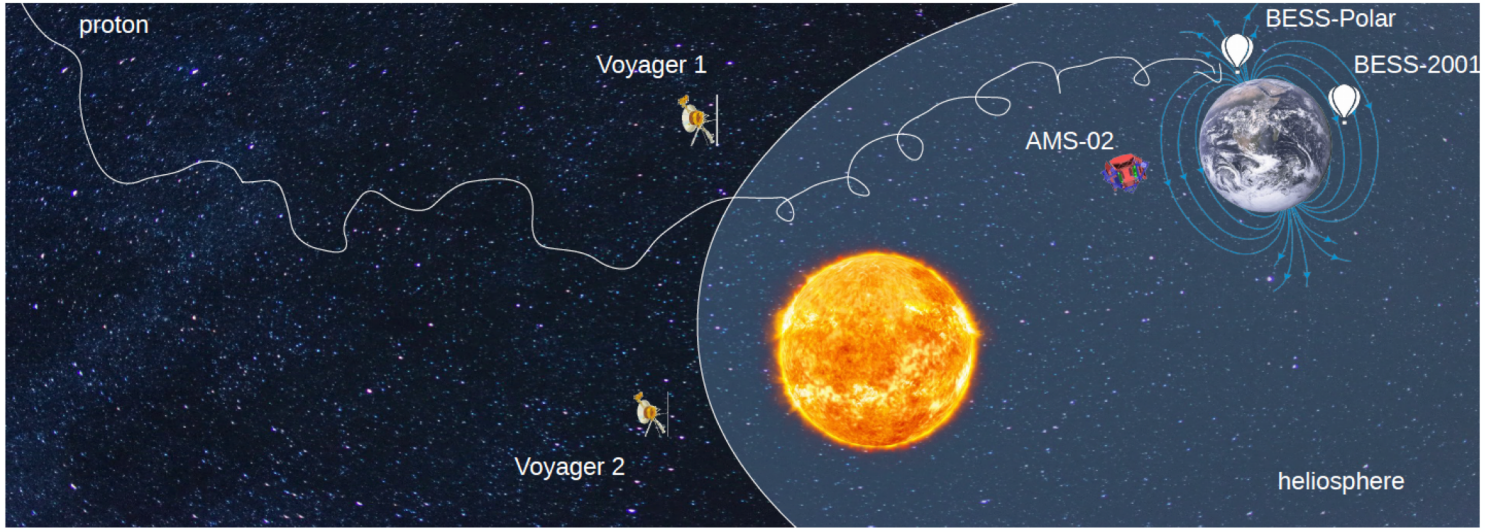


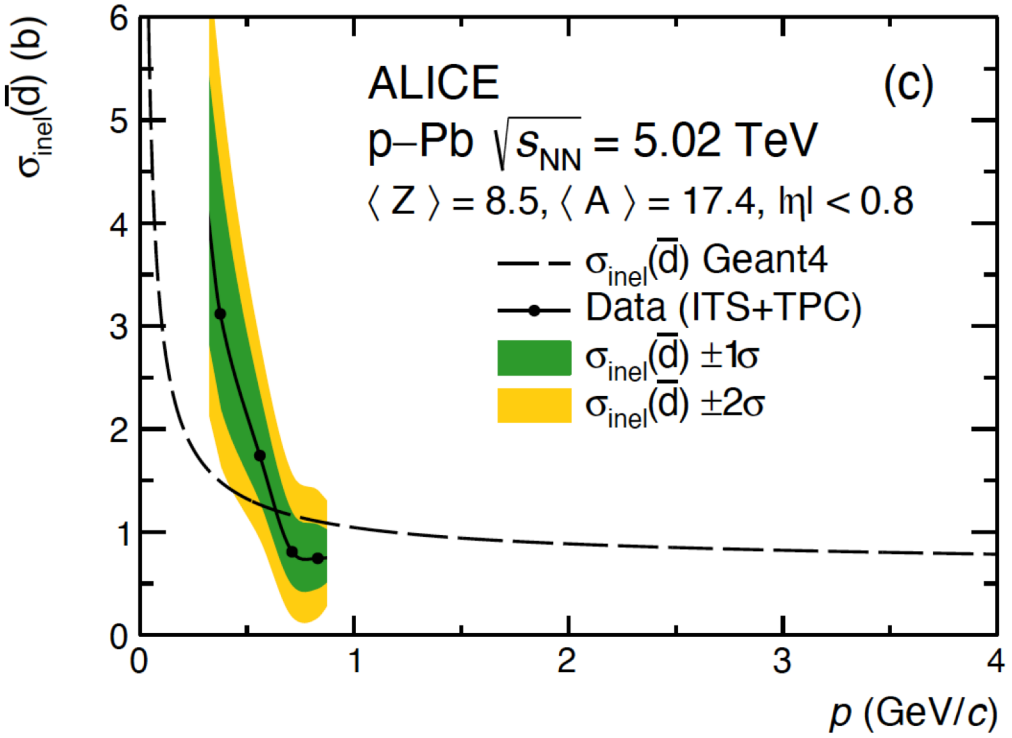


Hadronic interaction of anti-nuclei with interstellar matter

→ What is the mean free path of anti-nuclei in the galaxy?

[ALICE, 2005.11122]





→ Very rough estimate (for educational purposes):

$$\lambda = \frac{1}{n \cdot \sigma} \qquad \lambda \approx \frac{1}{\frac{1}{\mathrm{cm}^{-3}} \cdot 6 \cdot 10^{-24}\,\mathrm{cm}^2} \approx 1.7 \cdot 10^{21}\,\mathrm{m} \approx \underline{180000\,\mathrm{ly}}$$

Cross section from ALICE measurement

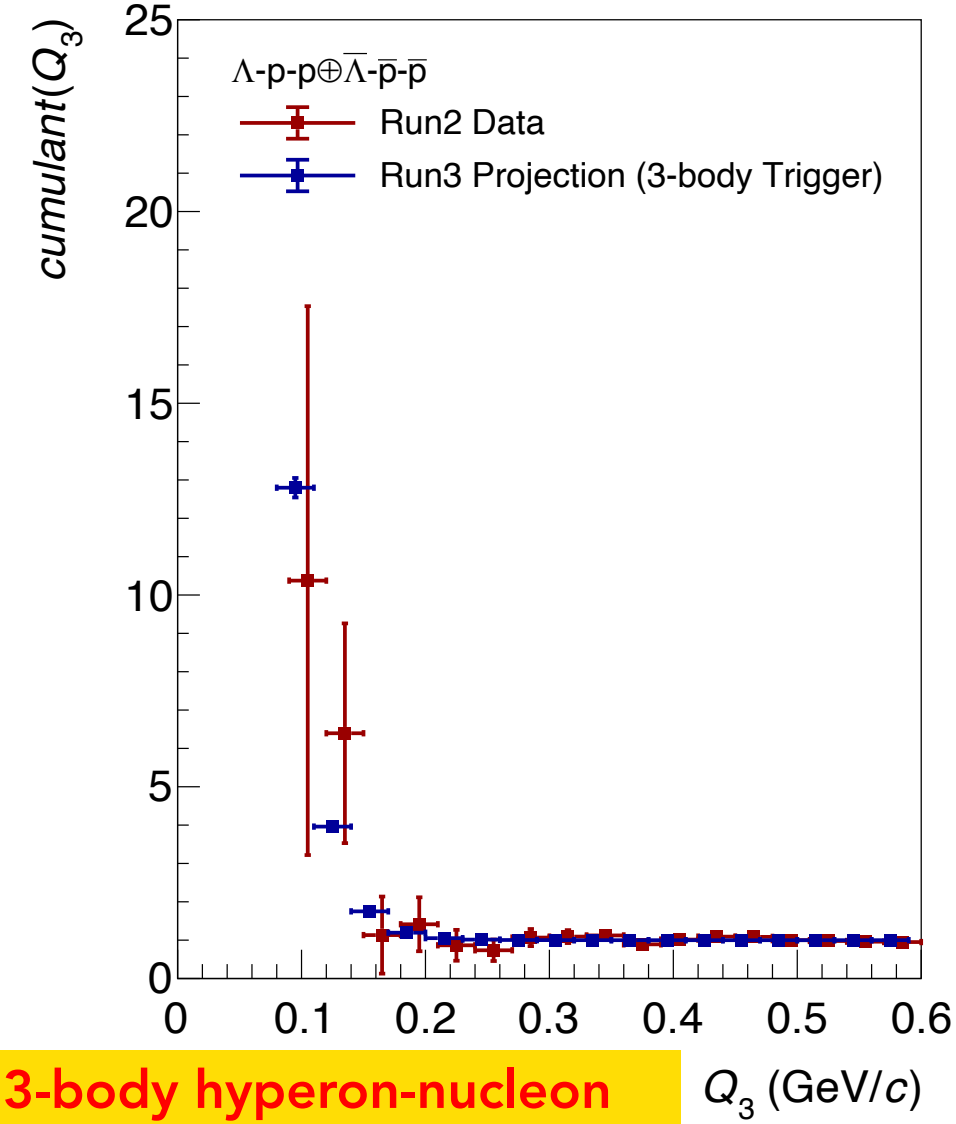
Number density of hydrogen and He atoms in universe

Linking Y-N interactions and the coalescence process

- Production rates of light anti- and hyper-nuclei crucially depend on the extended wave-functions of these objects.

- This closely links the physics of nuclear structure and the hyperon-nucleon potentials with cosmic ray and heavy-ion physics.

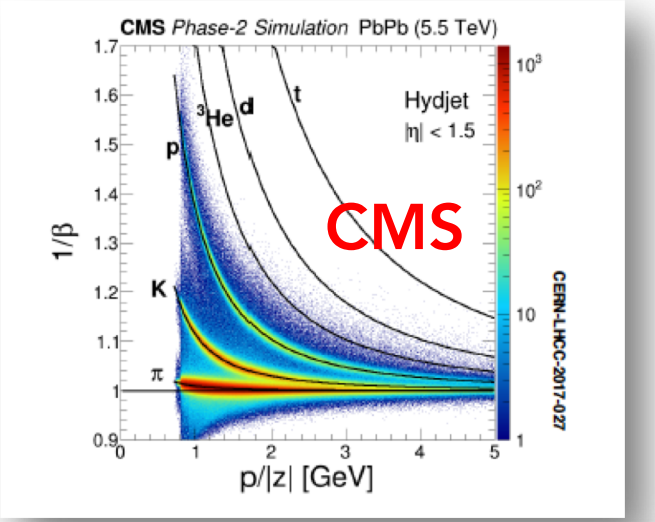
- Correlations are unique probes of the strong interaction among the constituents of anti- and hyper-nuclei and can provide quantitative information on the nuclei wave-functions.

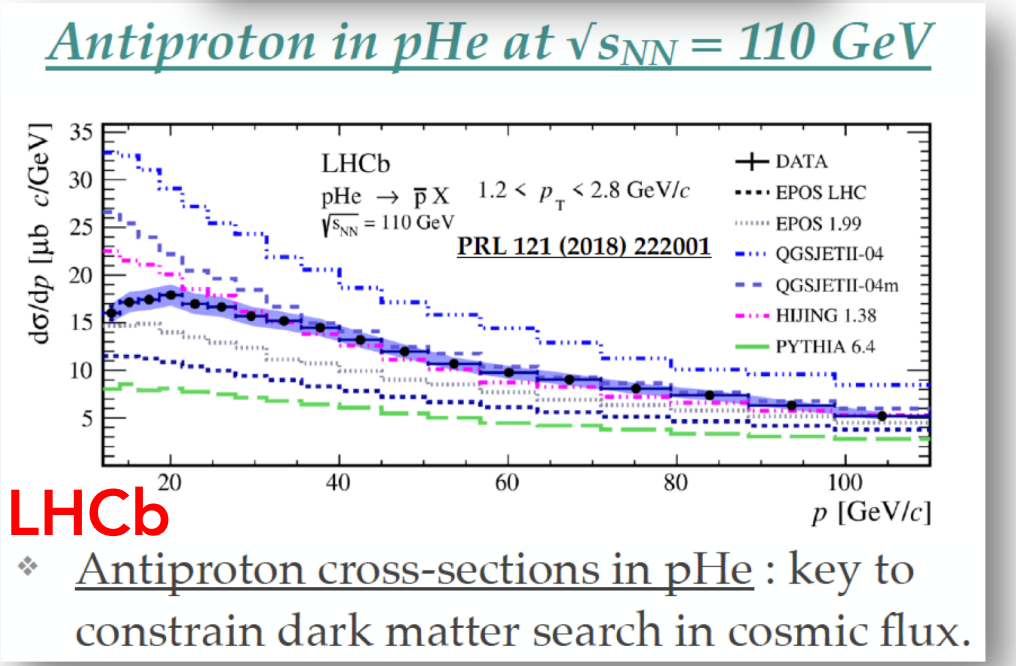


Genuine 3-body hyperon-nucleon interaction accessible in LHC Run 3 (2022-2024)

Ongoing activities and future prospects

- A rich interdisciplinary physics program awaits us in the upcoming years at LHC (not only in ALICE)!
- A number of nice workshops combining two out of the three communities took already place, for instance:
  - CERN TH institute in May 2020 on anti- and hyper-nuclei bringing together nuclear physics and high energy physics [link].
  - Anti-deuteron workshop bringing together cosmic ray and high energy physics community [link].
  - XSCRC2019 [link]
- We now have to start to truly bring together all three communities simultaneously.
  - A starting point could be the MIAPP workshop in April-May 2021 in Munich [link].





Thank you!