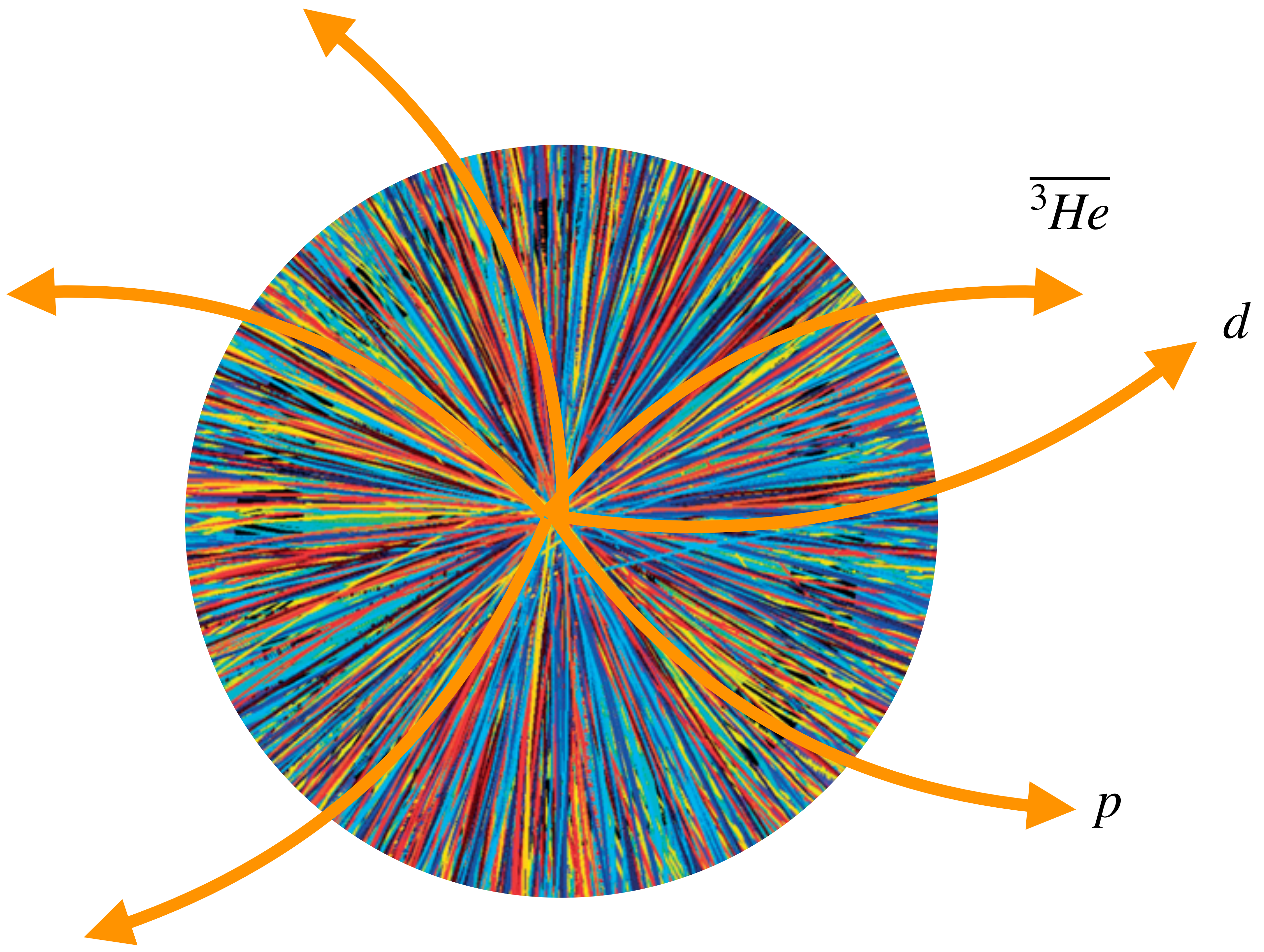
Antihelium-3 Inelastic Interactions at the LHC and in Our Galaxy

Laura Šerkšnytė
Technische Universität München
On behalf of ALICE Collaboration

International School of Nuclear Physics
42nd Course

The Large Hadron Collider



Study hadrons and nuclei:

Production mechanisms

Talk by Peter Braun-Munzinger

Strong interaction between hadrons

Talks by Laura Fabbietti, Raffaele del Grande

Inelastic cross-section

This talk

Outline

- Introduction
- Inelastic cross section measurements
- Cosmic ray propagation in the Milky Way
- Results

Introduction

We measure properties of hadrons and nuclei

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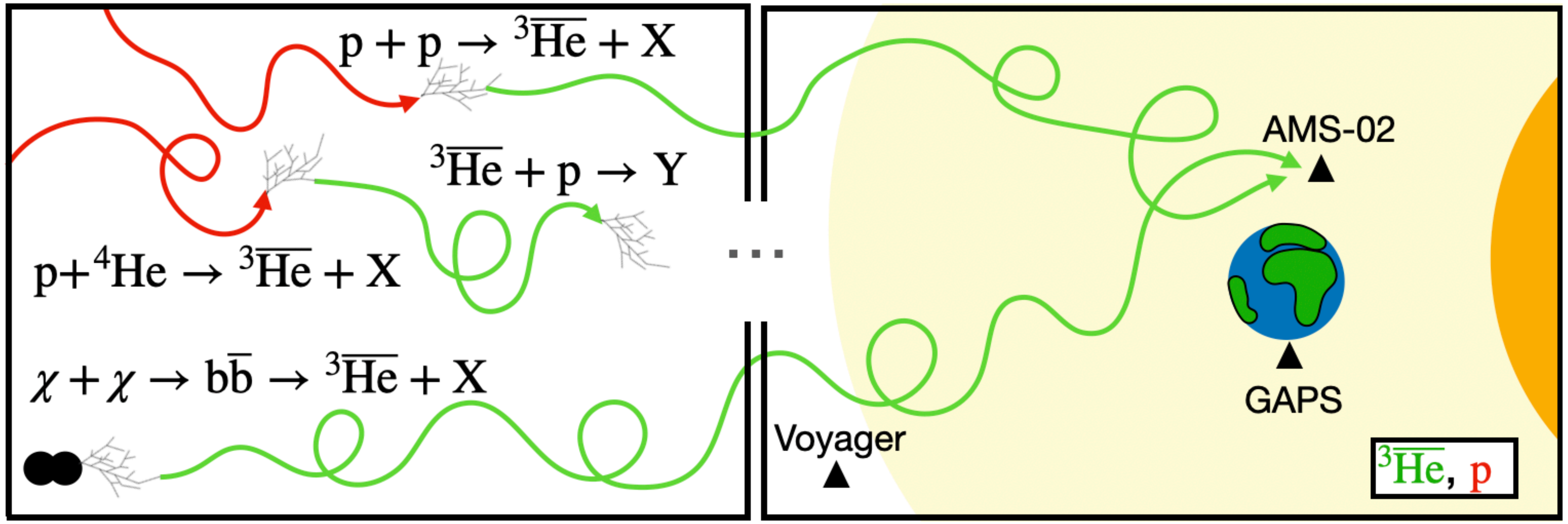
- Antinuclei cosmic rays: possible “smoking gun” signature of dark matter
- Essentially free of astrophysical background



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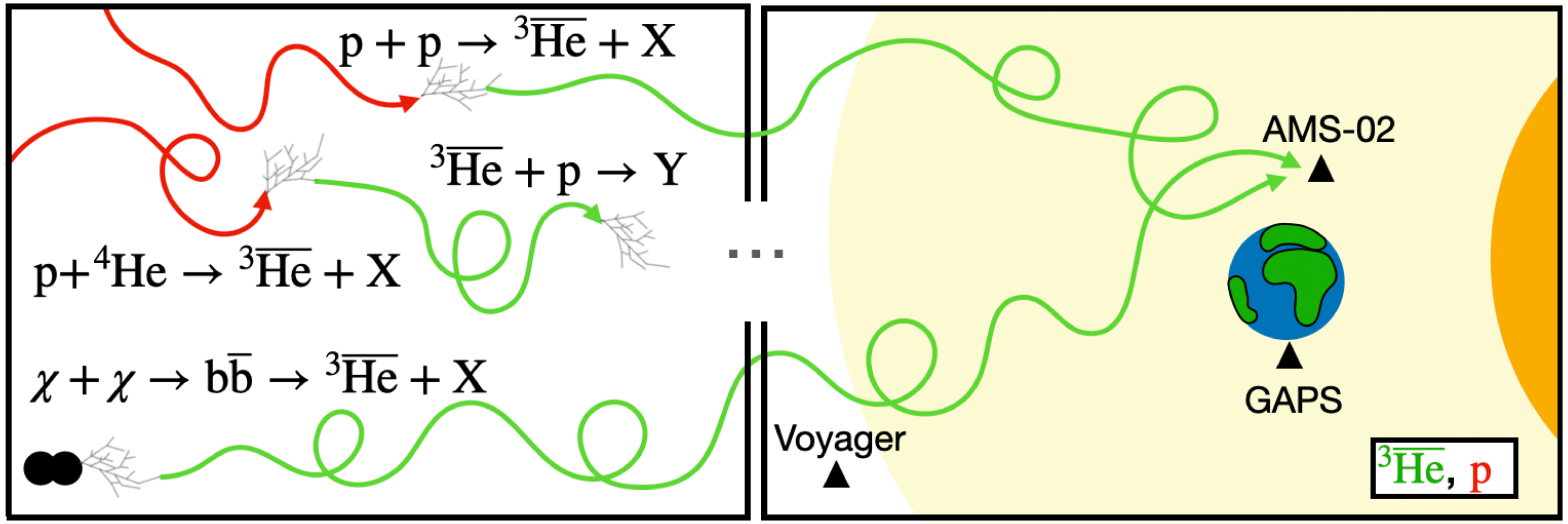
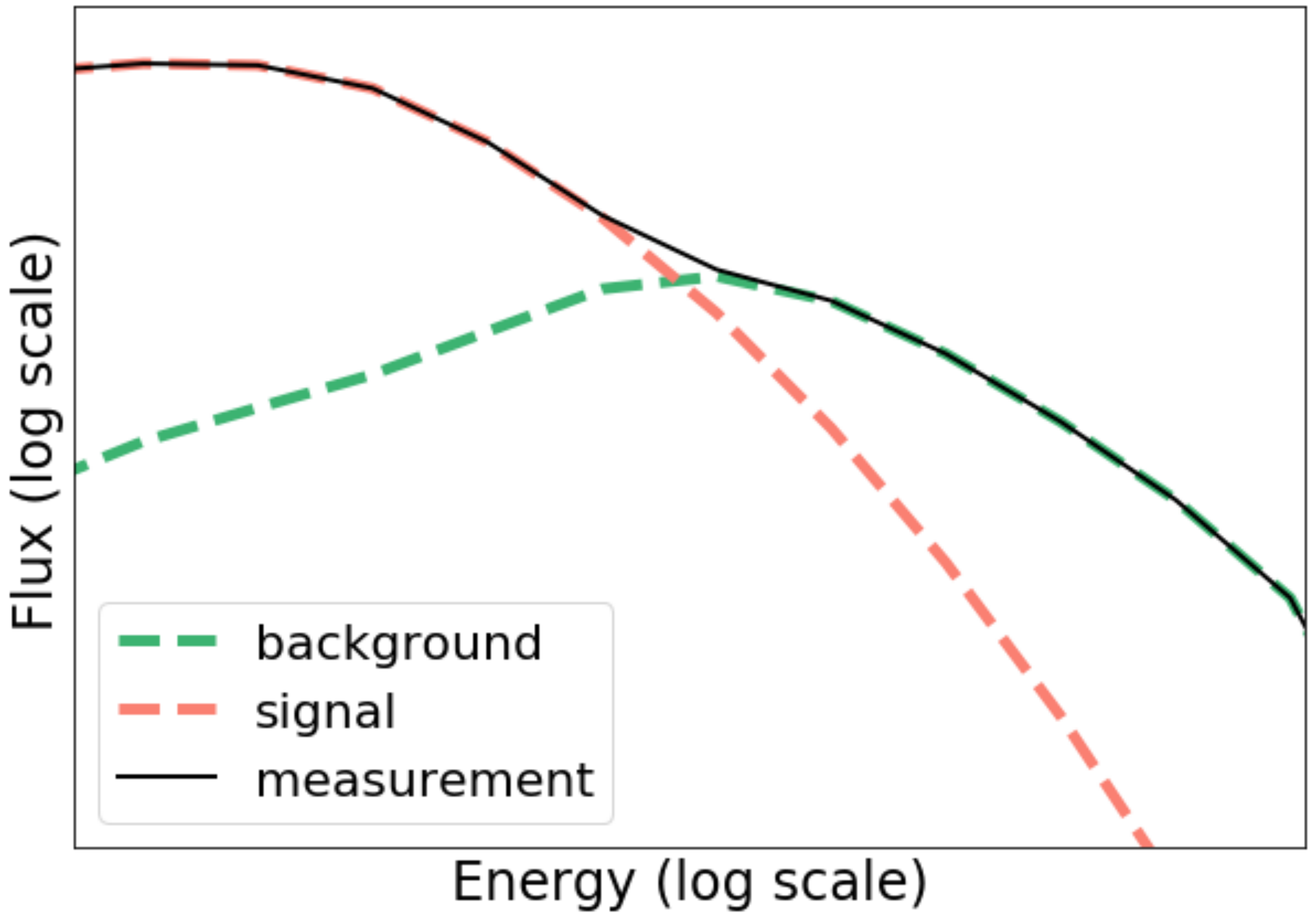
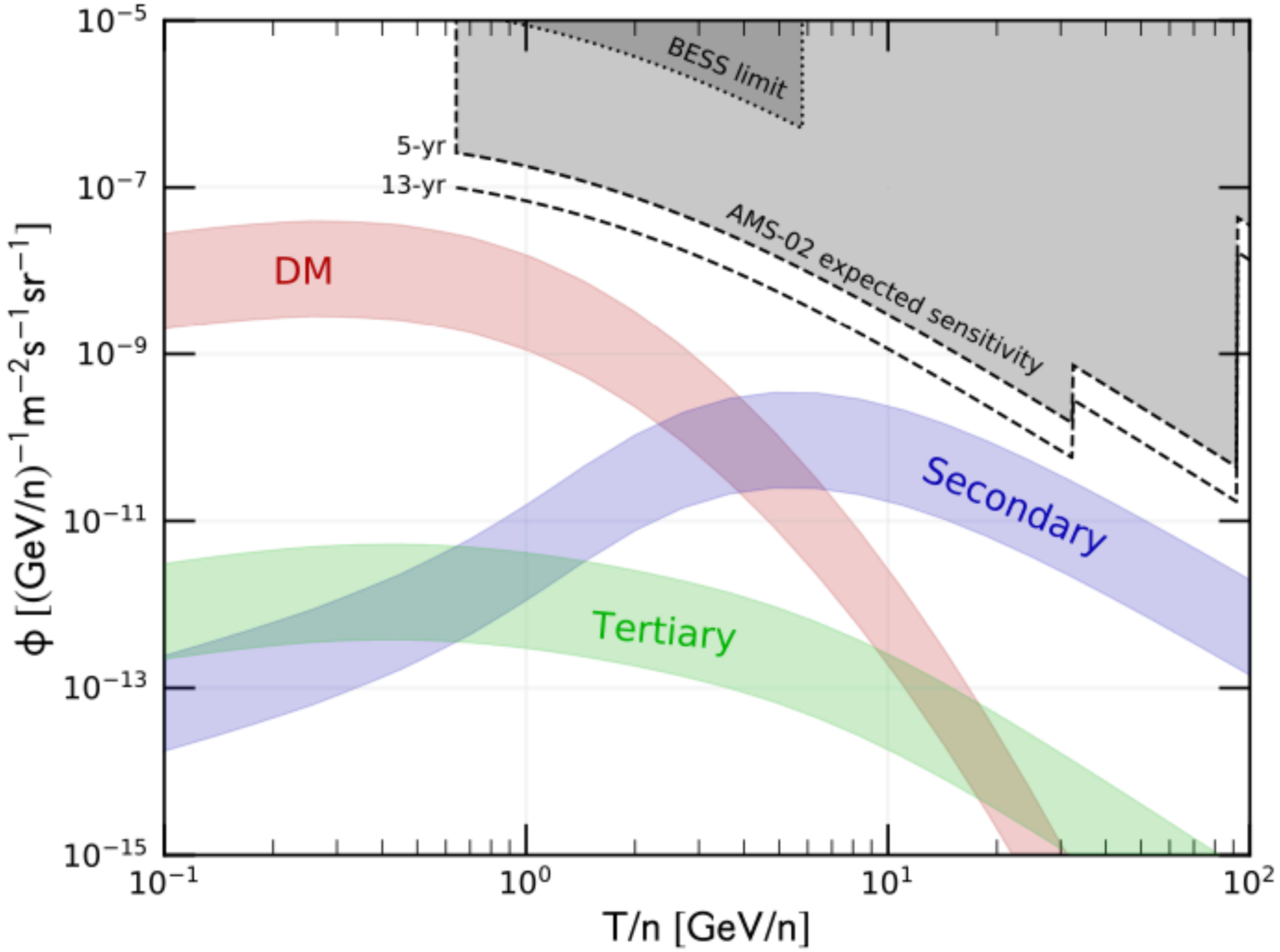




Current predictions for anti-^{3}He

- Production - constrained using collider measurements - order of magnitude uncertainty
- Propagation - constrained using cosmic ray measurements - around order of magnitude uncertainty
- Annihilation - no available data at low energies up to now - **uncertainty unknown**

Uncertainty due to coalescence probability [1]



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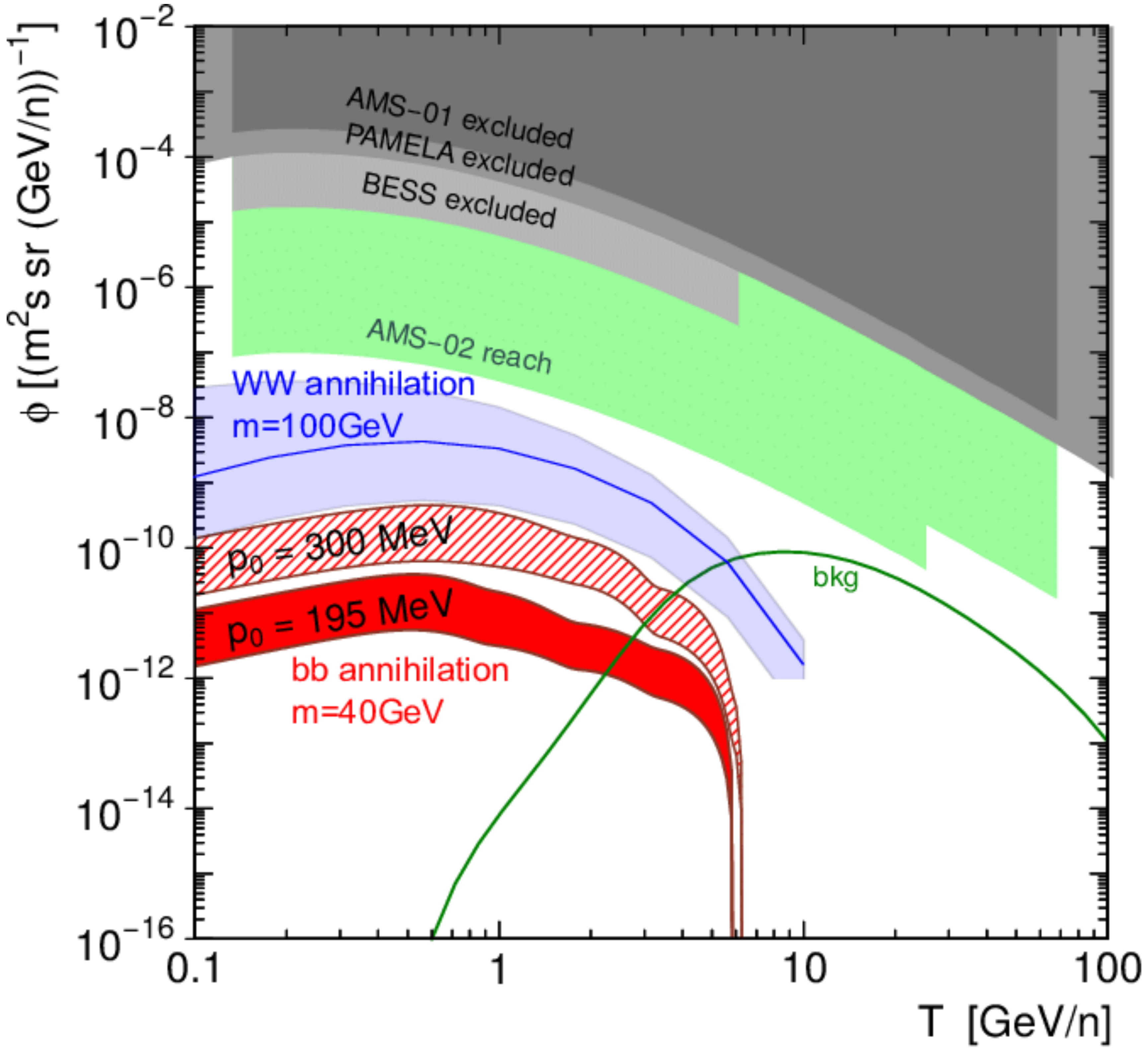

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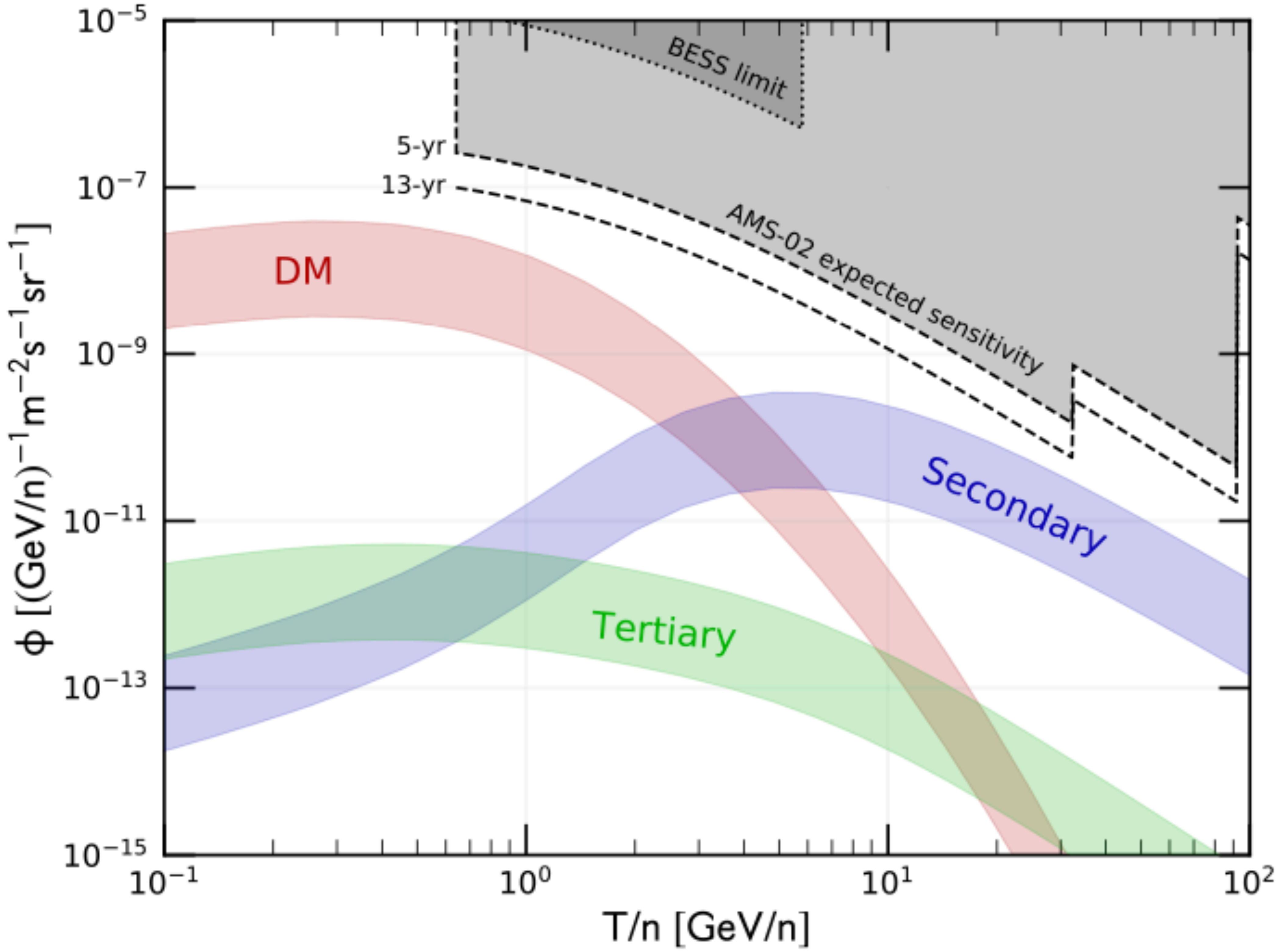

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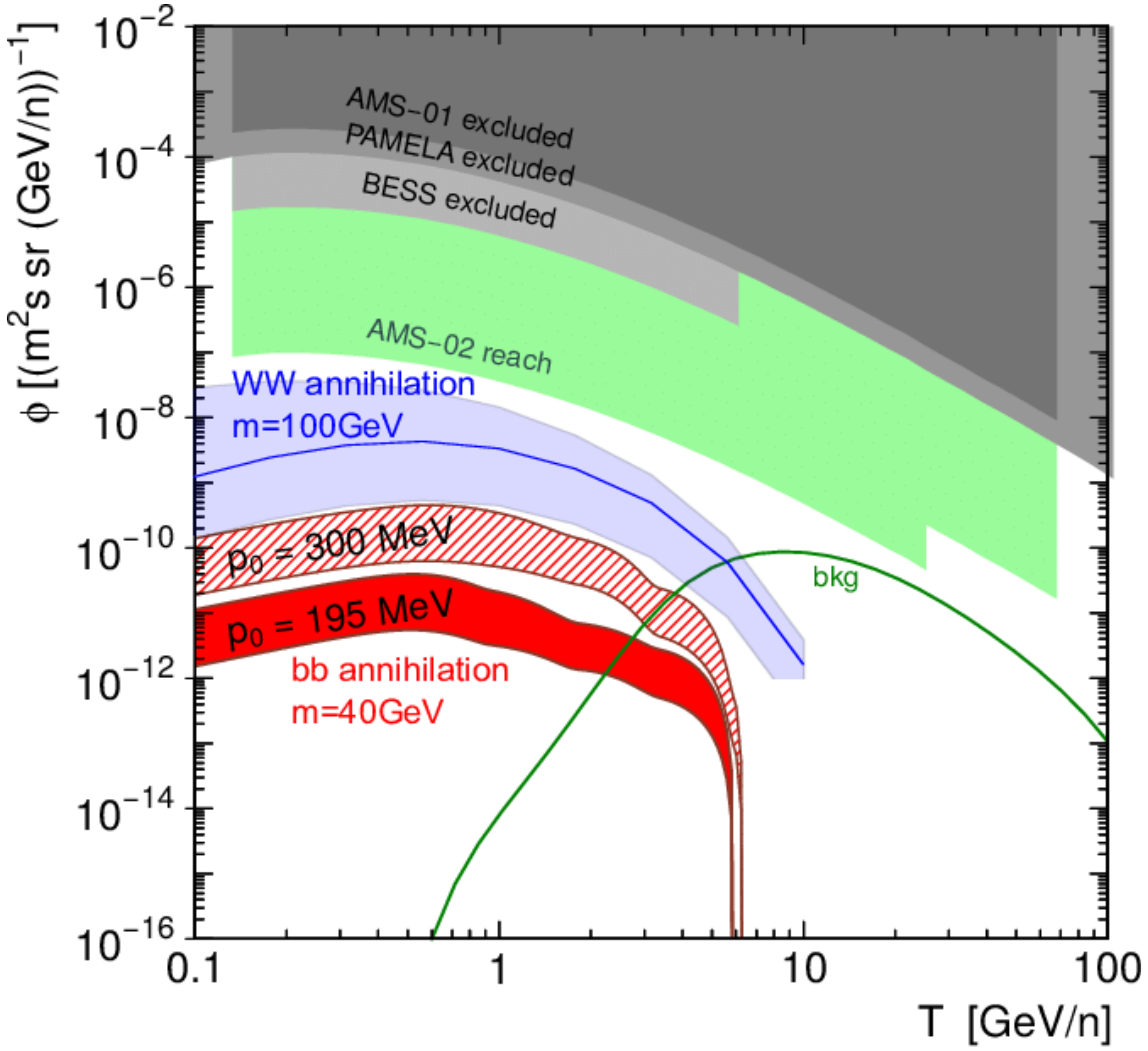

In this talk:

Anti-^{3}He inelastic cross section measurements

Annihilation effect on anti-^{3}He cosmic ray fluxes

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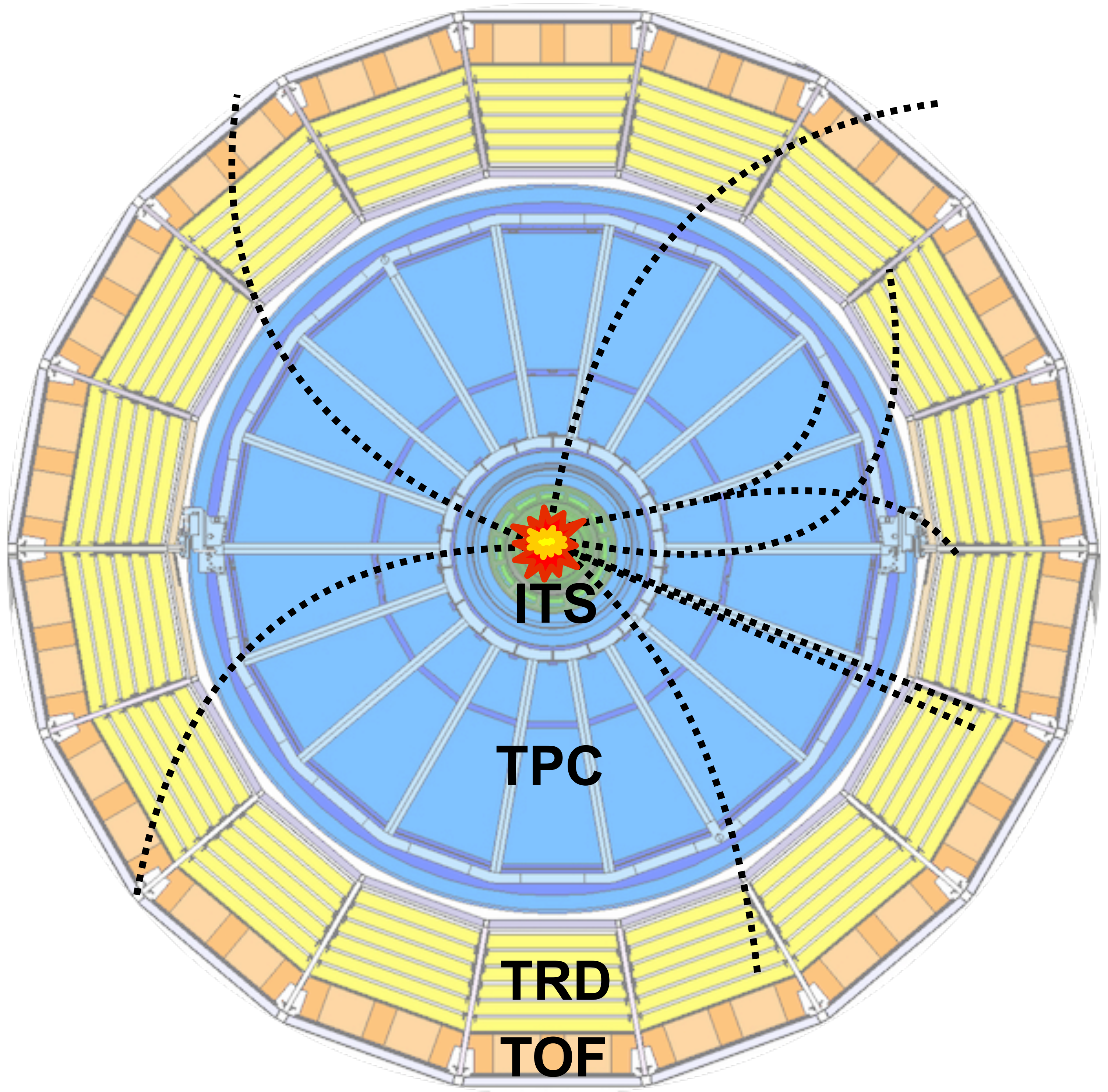
ALICE detector

General-purpose (heavy-ion) experiment at the Large Hadron Collider

- Excellent tracking and particle identification (PID) capabilities
- Most suitable detector at the LHC to study (anti)nuclei production and annihilation



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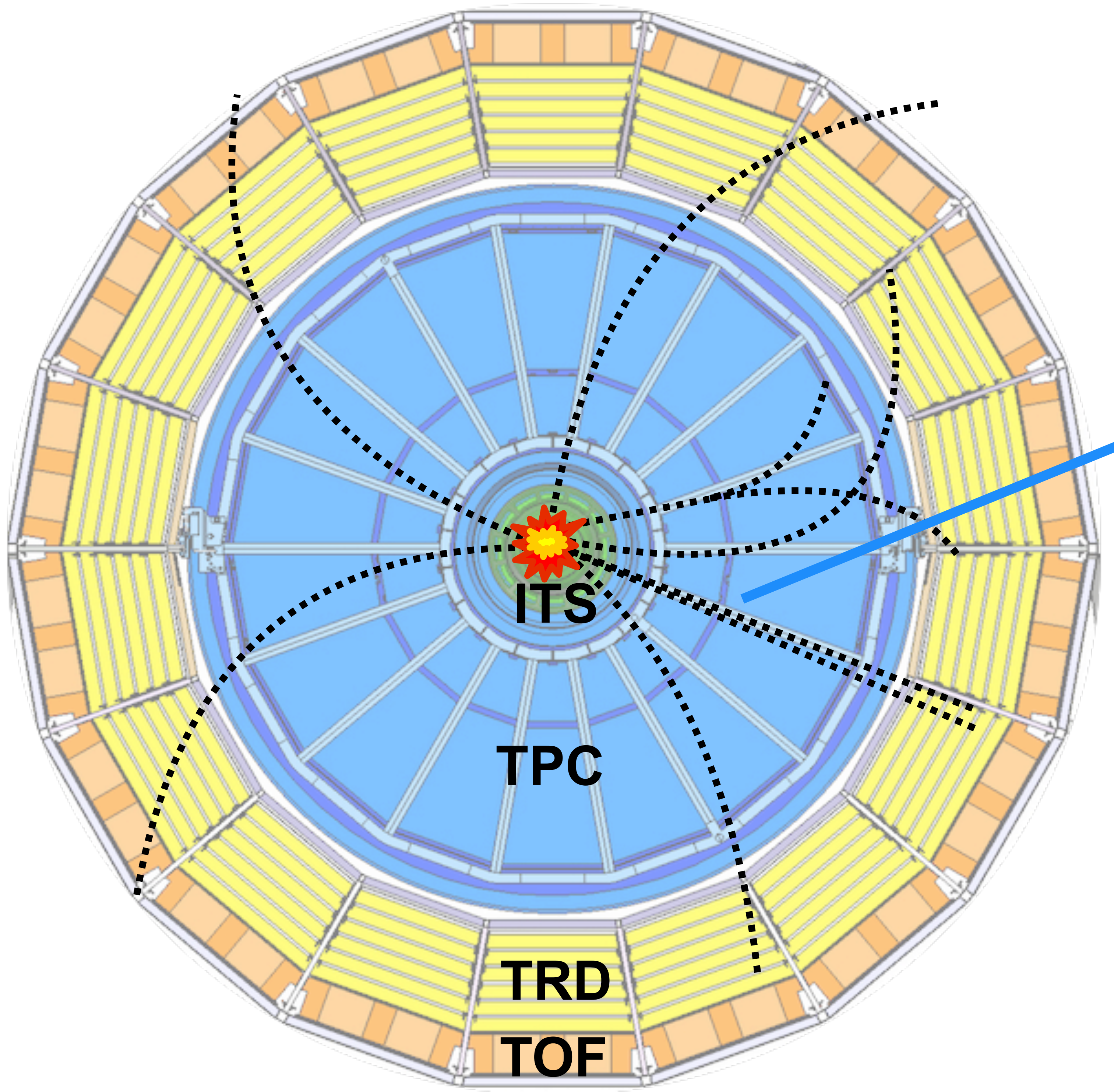
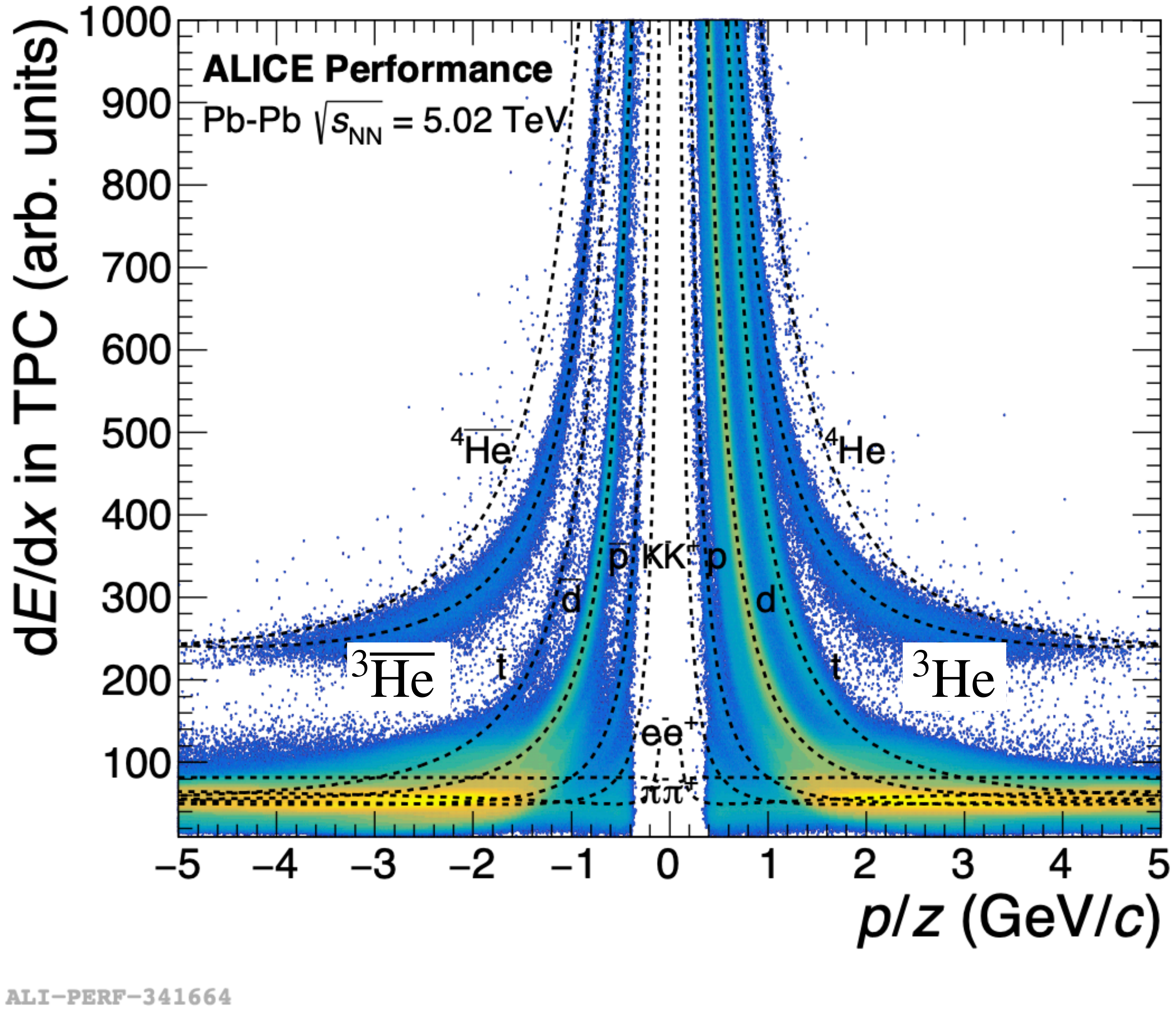
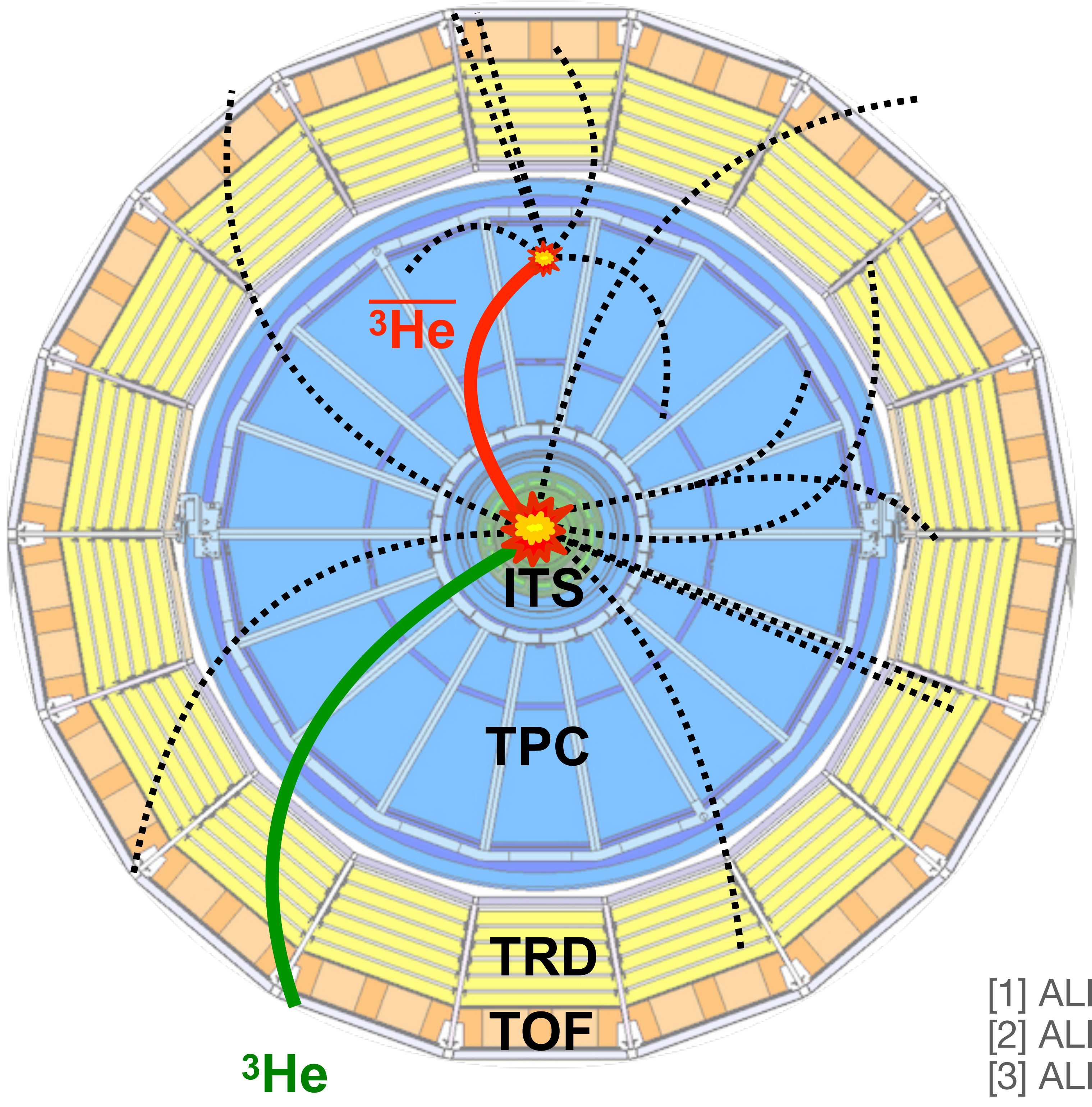




Methods of the measurements

Antimatter-to-matter ratio [2] (pp 13 TeV)

- Almost identical amount of particles and antiparticles produced [3]
- Measure reconstructed “anti-^{3}He/^{3}He” and compare results with MC simulations



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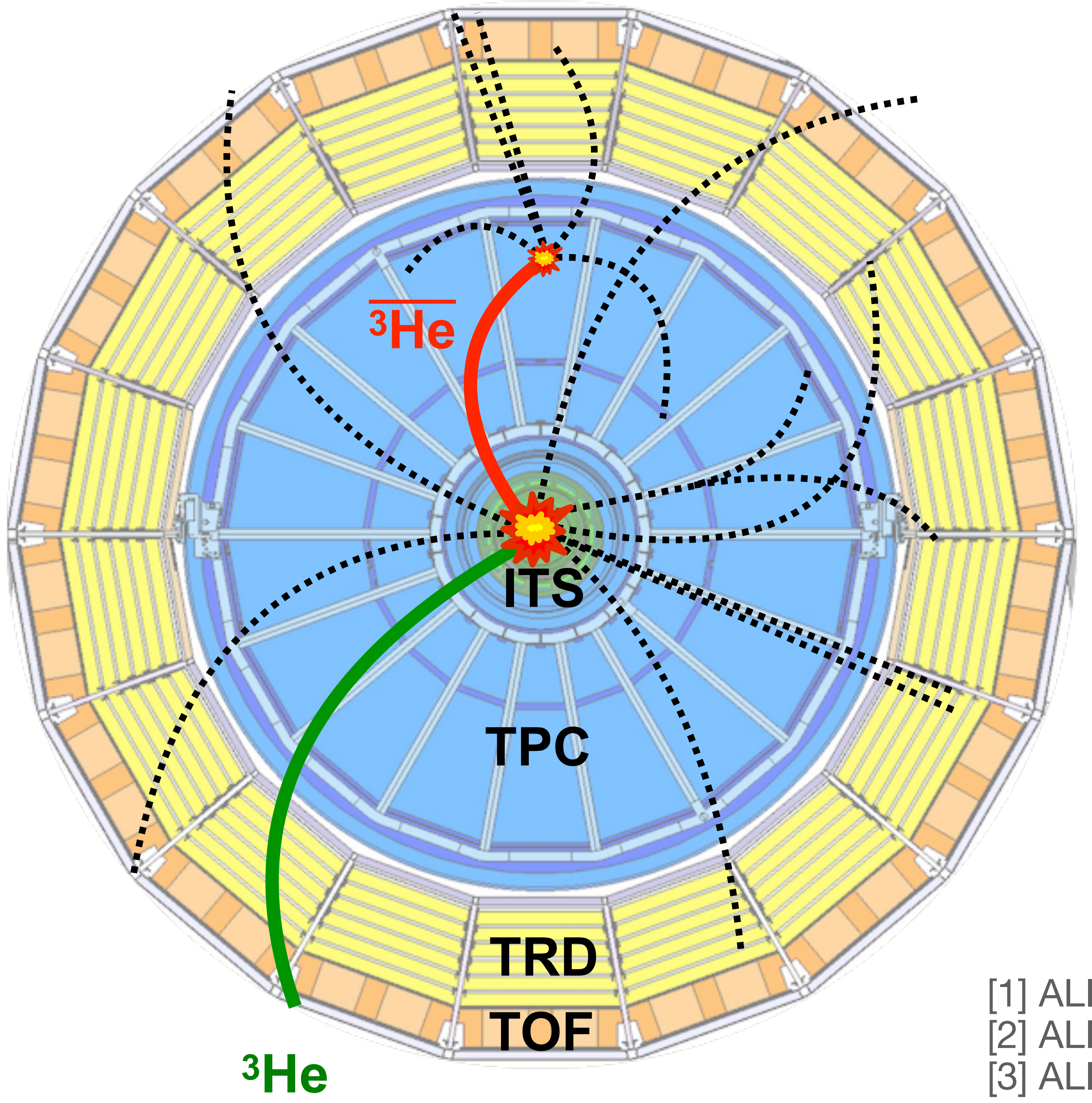
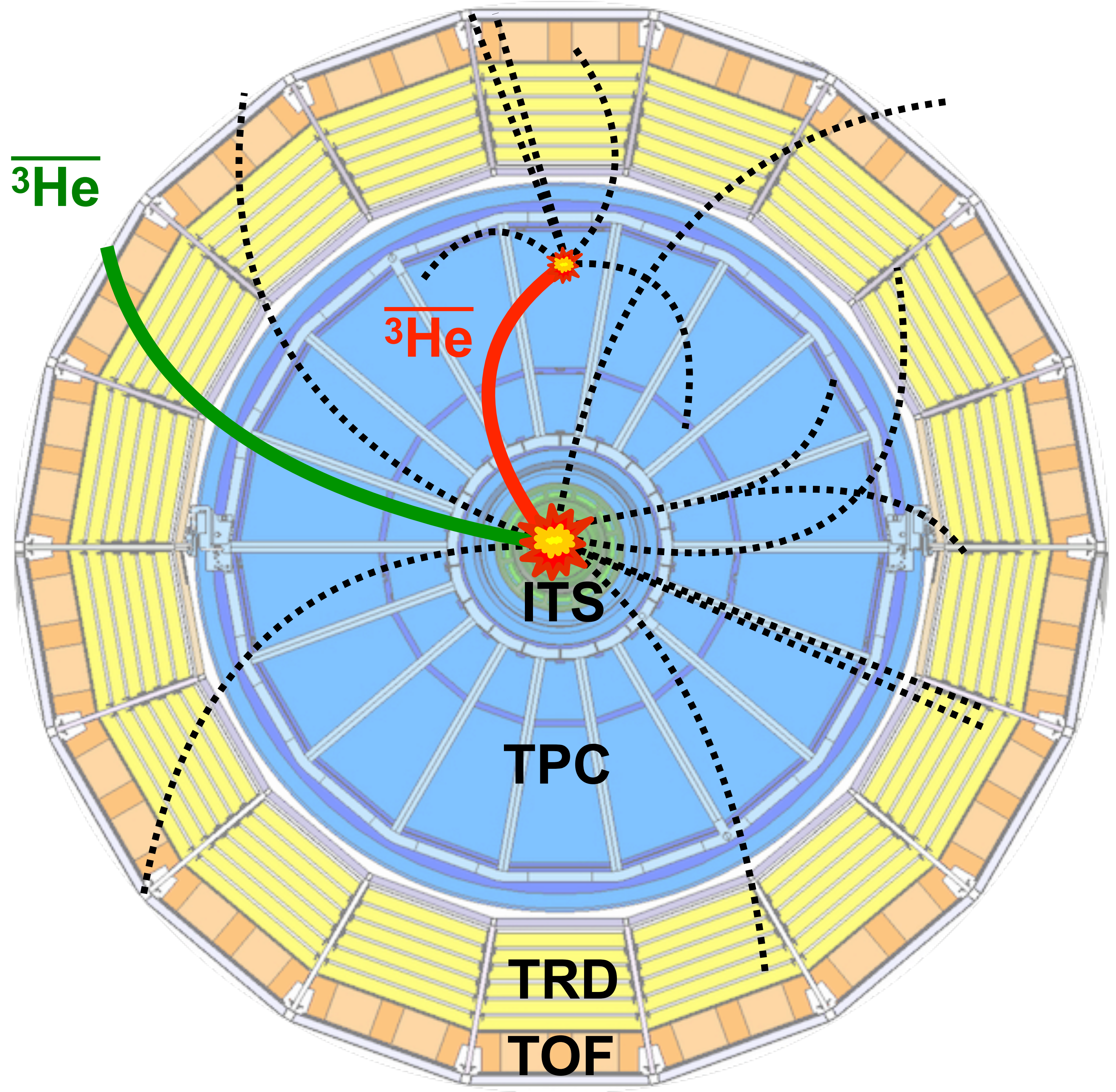


TPC-to-TOF matching (Pb-Pb 5.02 TeV)

- Measure “anti-^{3}He in TOF/anti-^{3}He in TPC” and compare results with MC simulations



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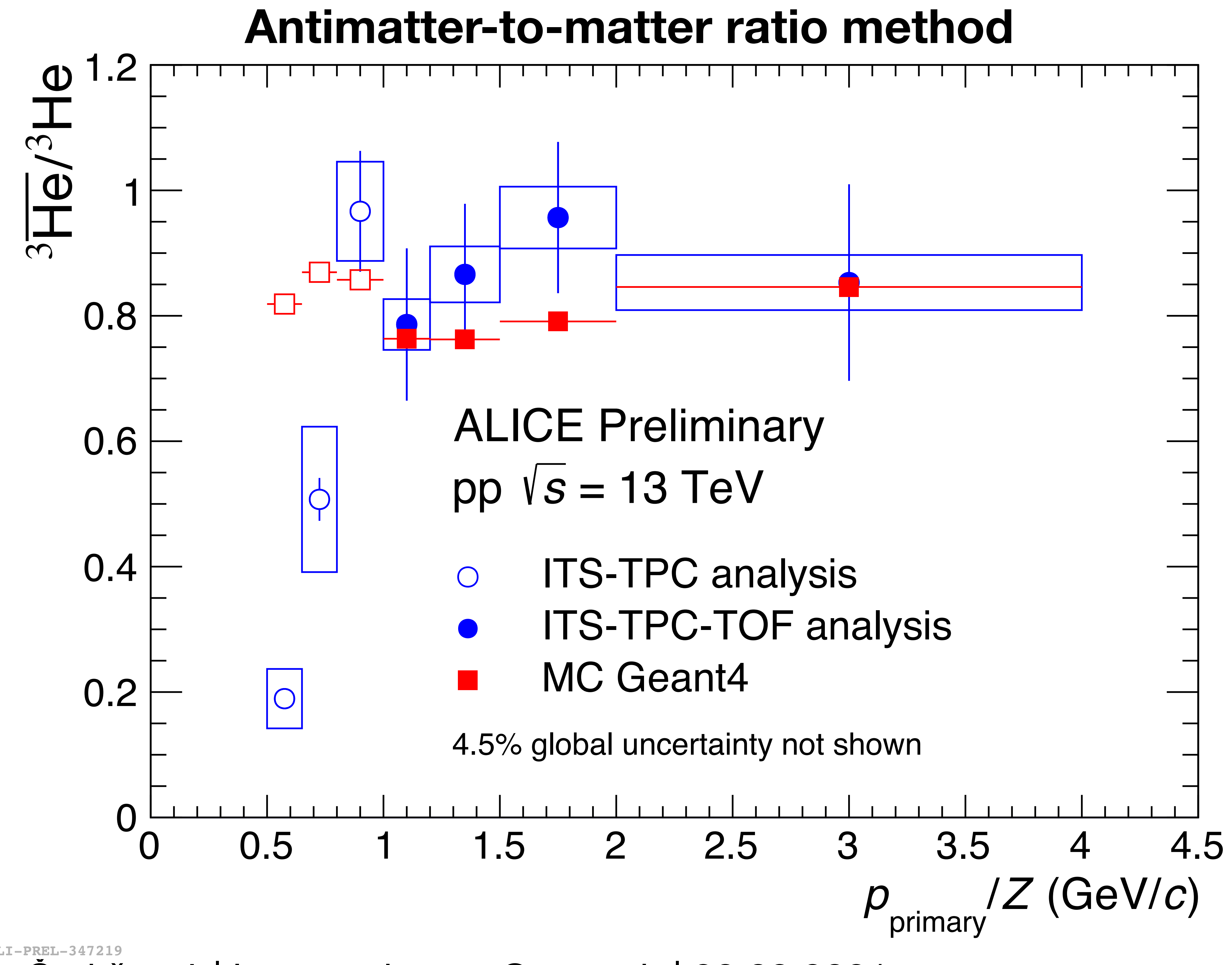
- Both methods compare the measured values to the Geant4 based MC simulations
- Inelastic cross section is extracted by varying the anti-^{3}He inelastic cross section in MC :
  - estimate a scaling factor to reproduce data



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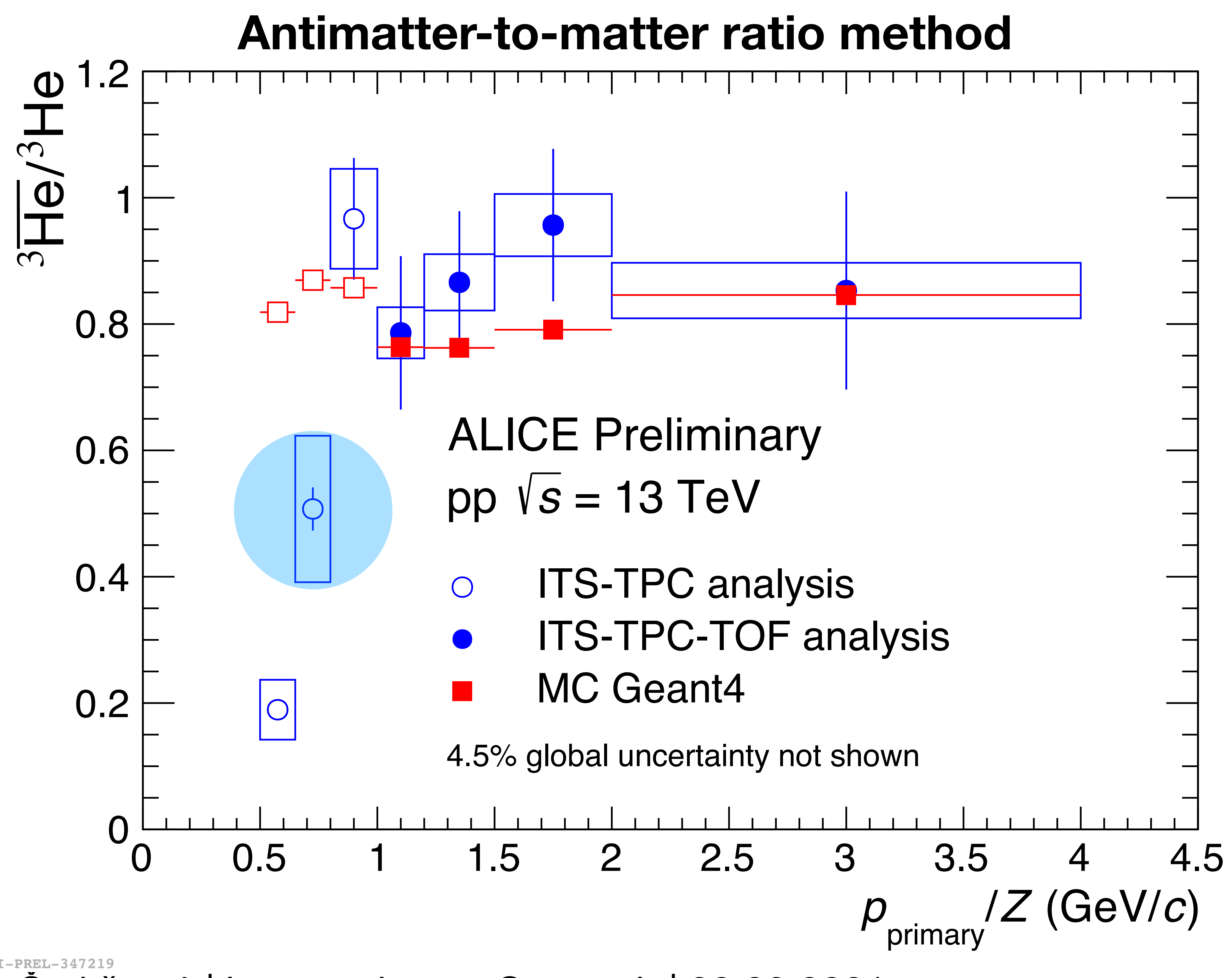

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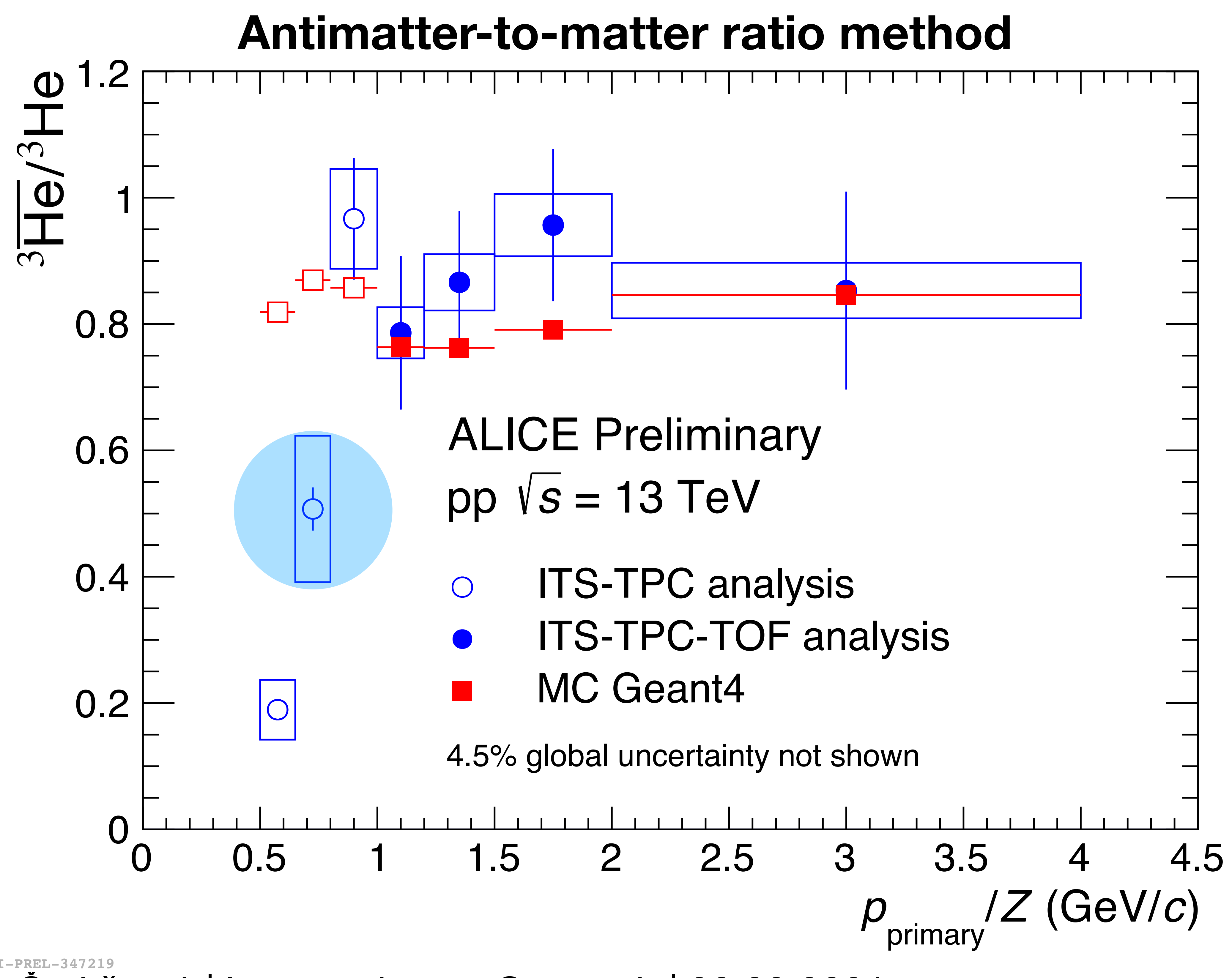
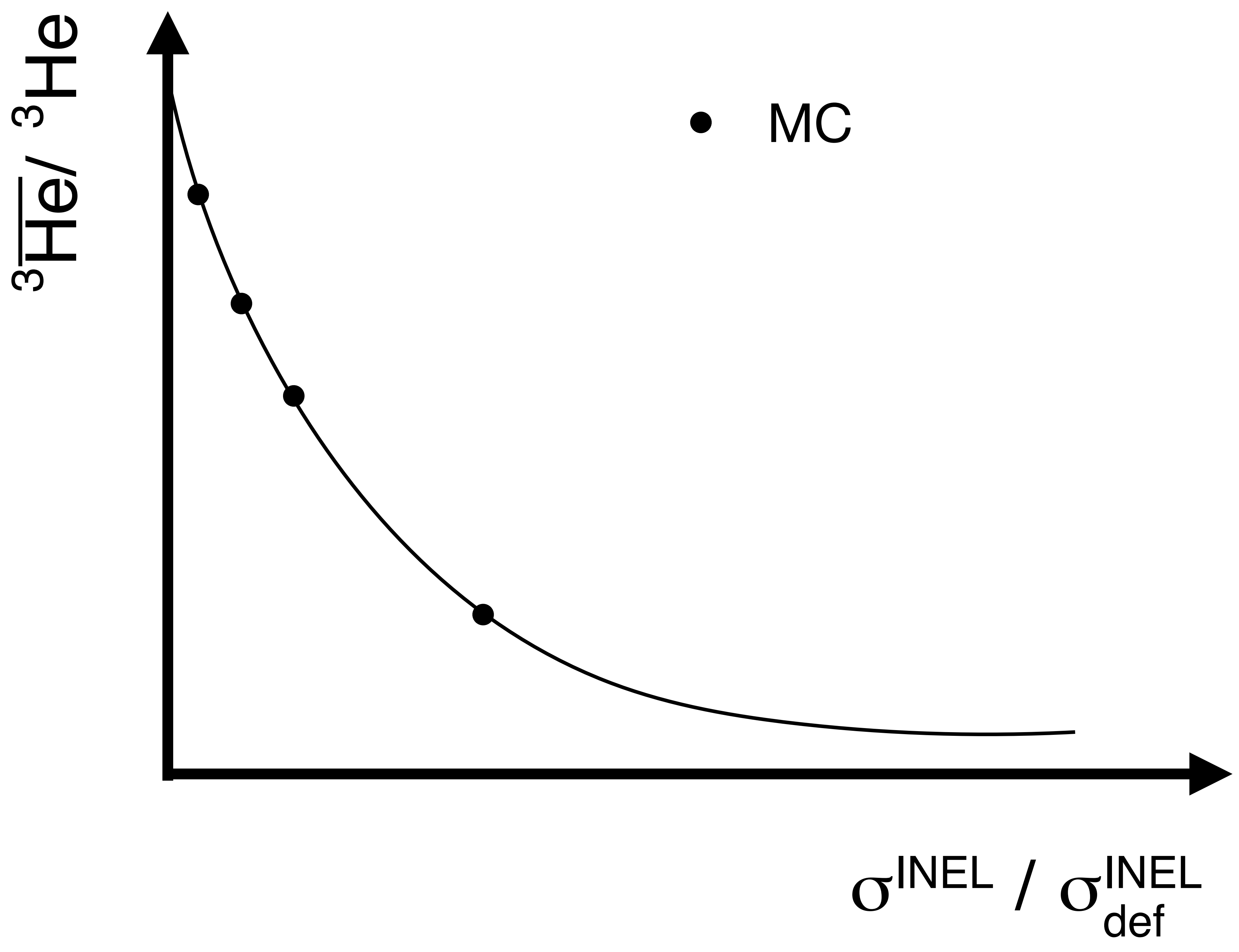


Lambert-Beer law: $\overline{\mathrm{B}}/\mathrm{B} \propto \exp(-\sigma_{\mathrm{inel}}/\sigma_{\mathrm{inel}}^{\mathrm{def}})$



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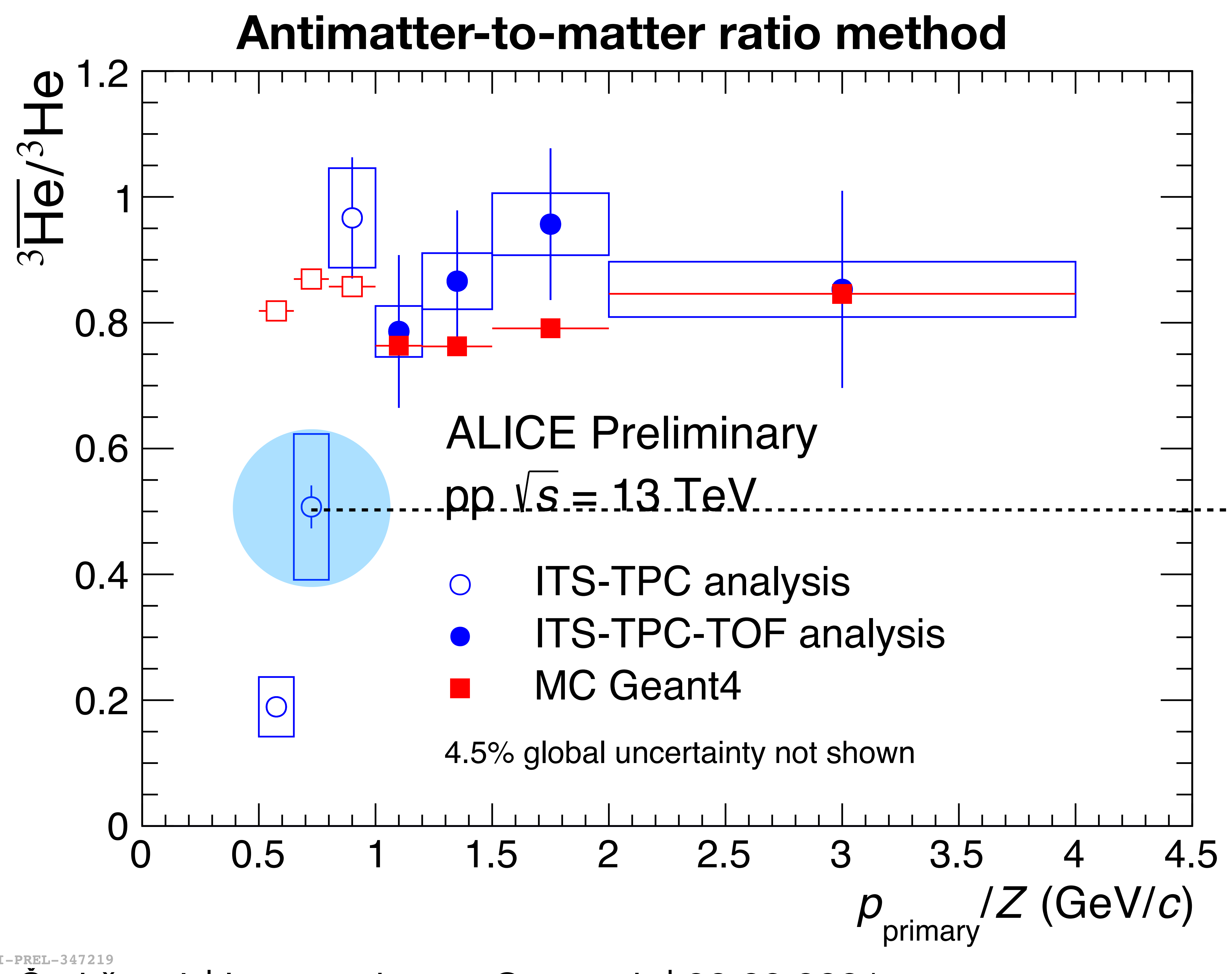

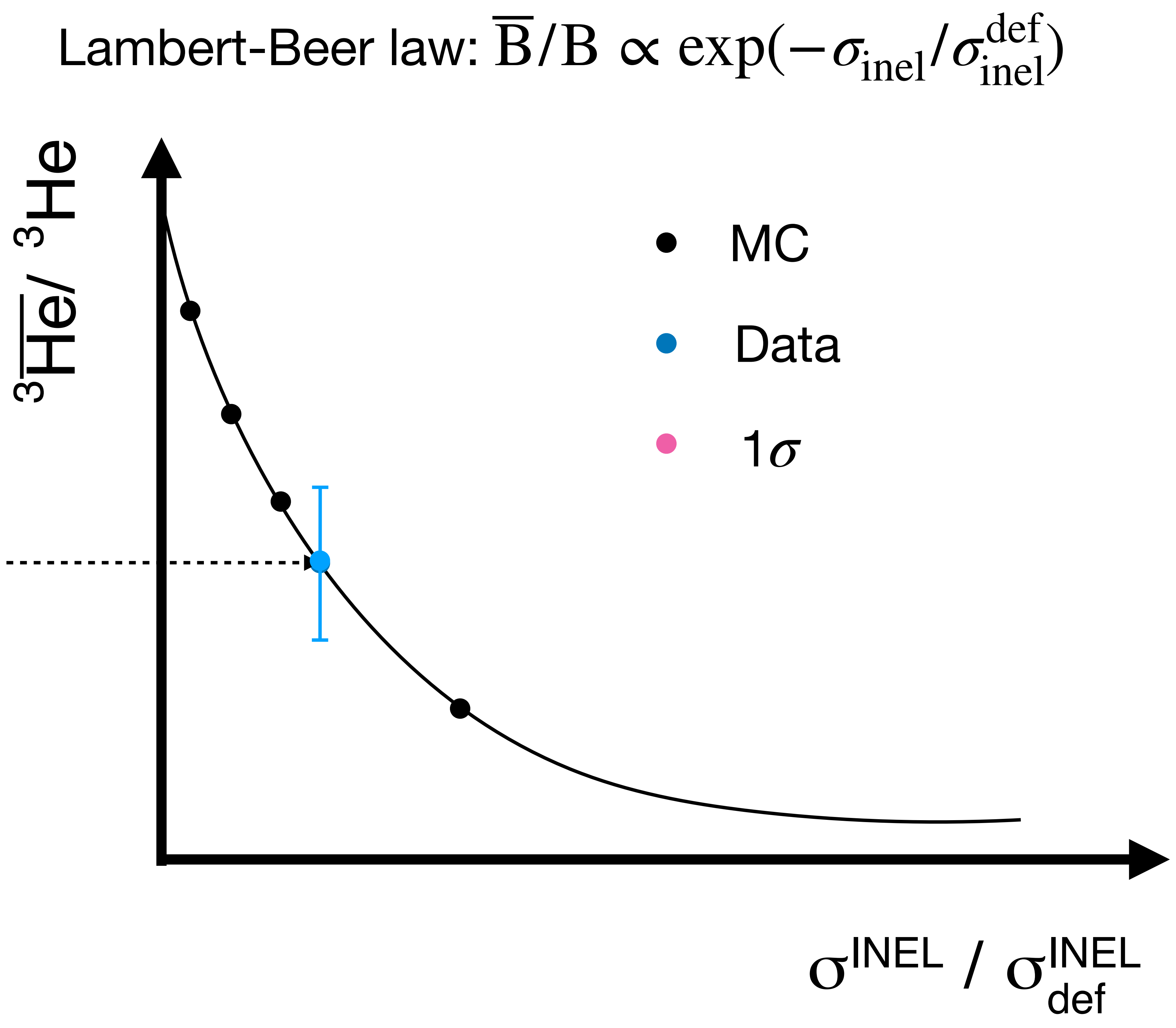

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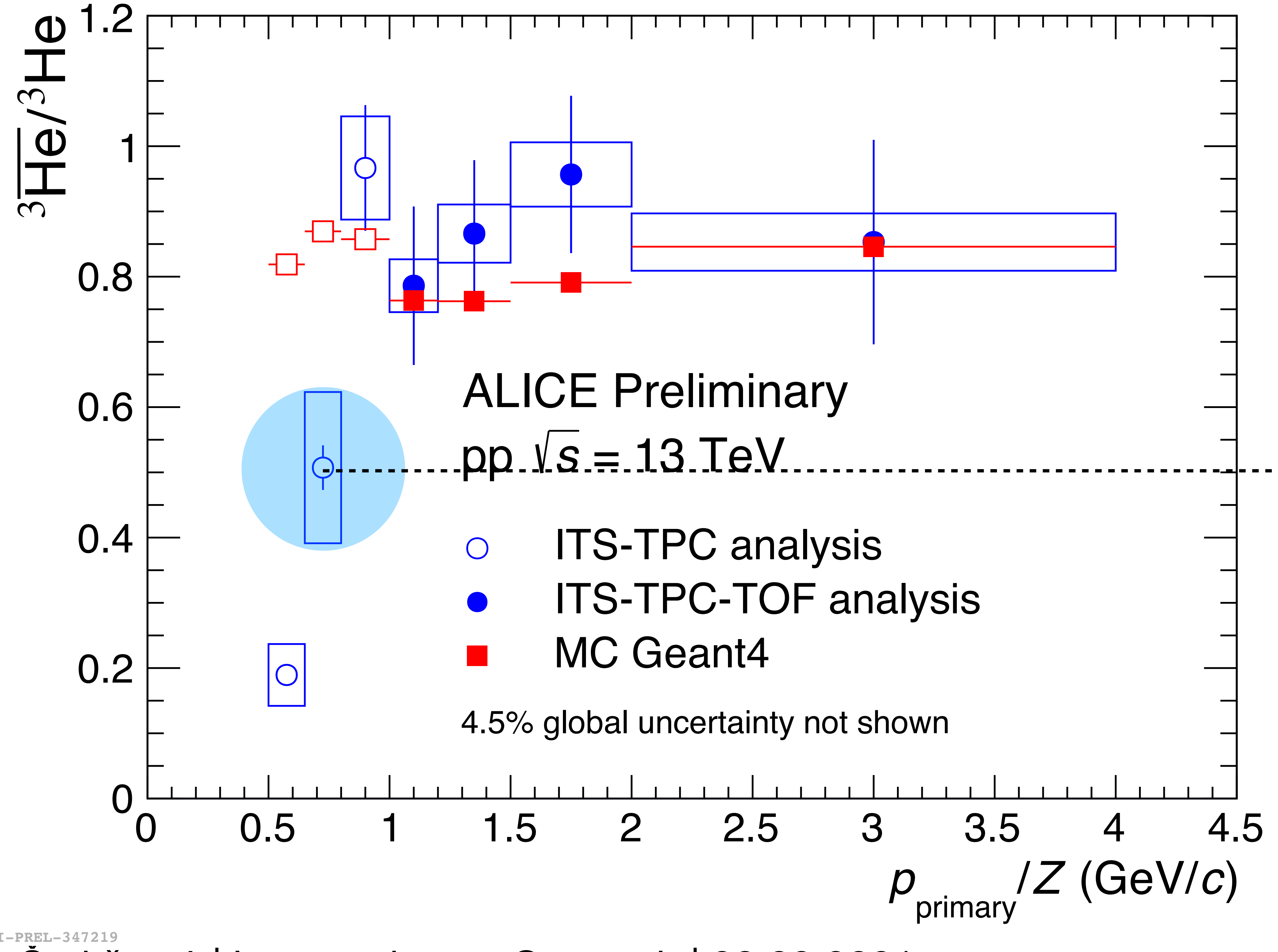
Antimatter-to-matter ratio method



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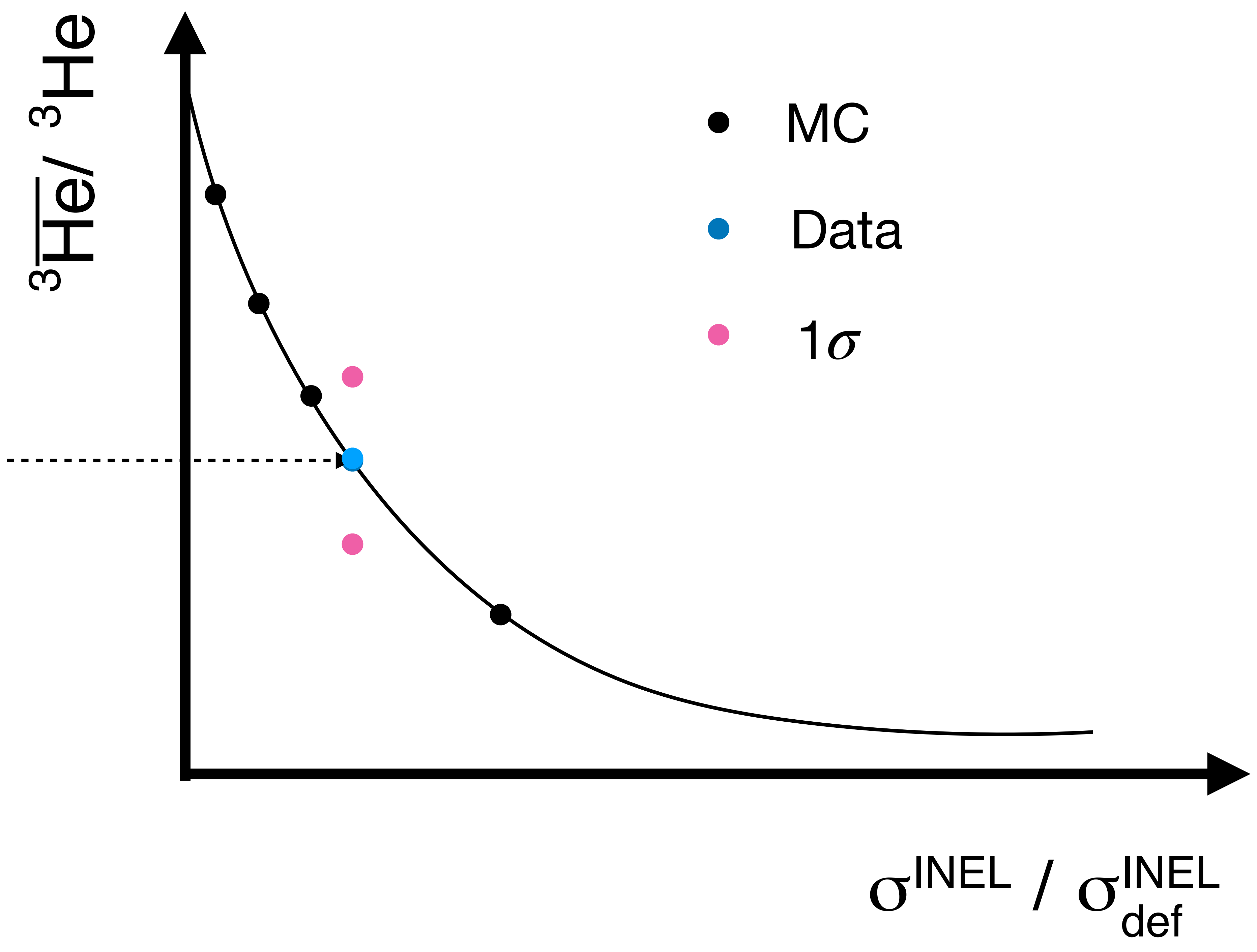

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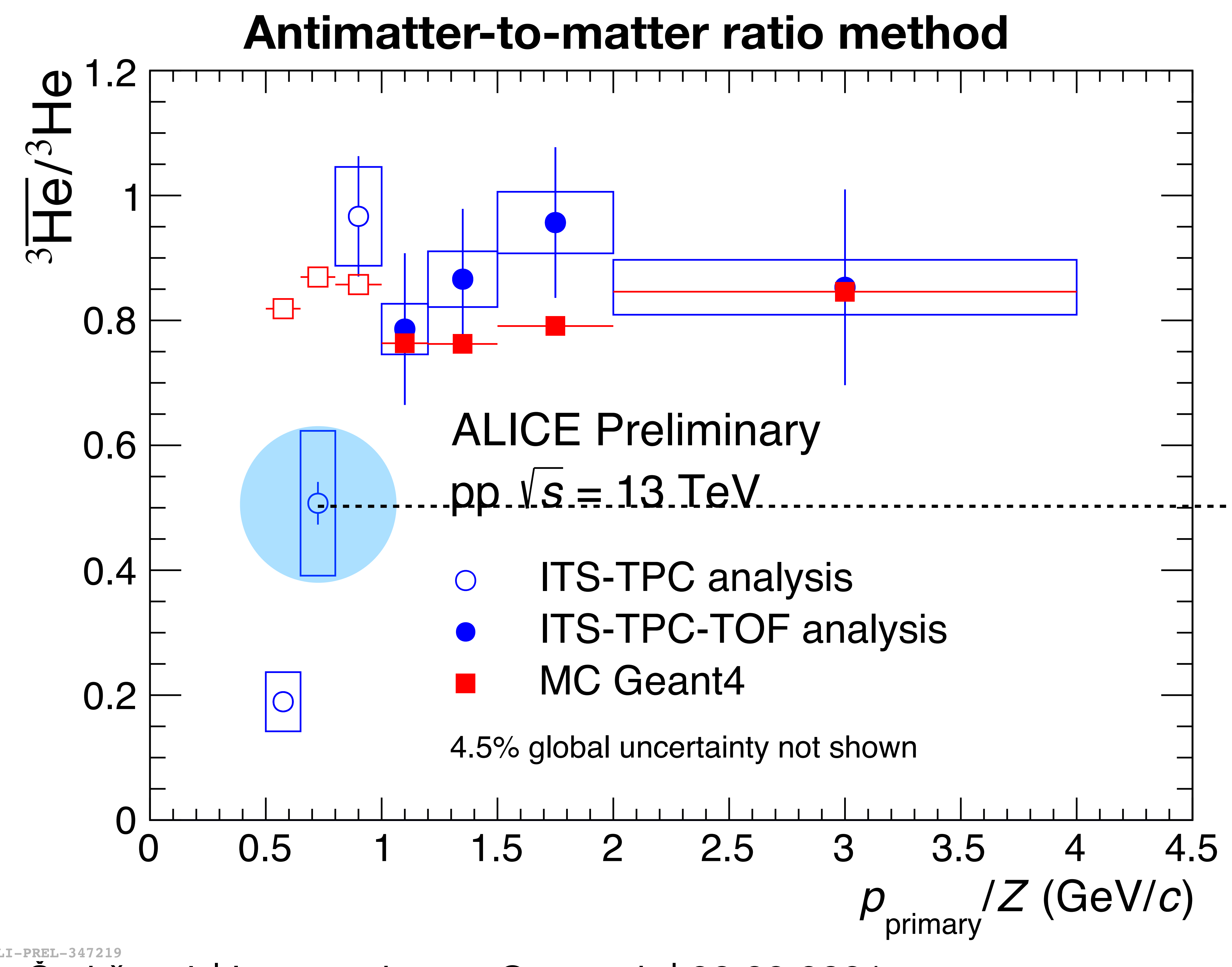

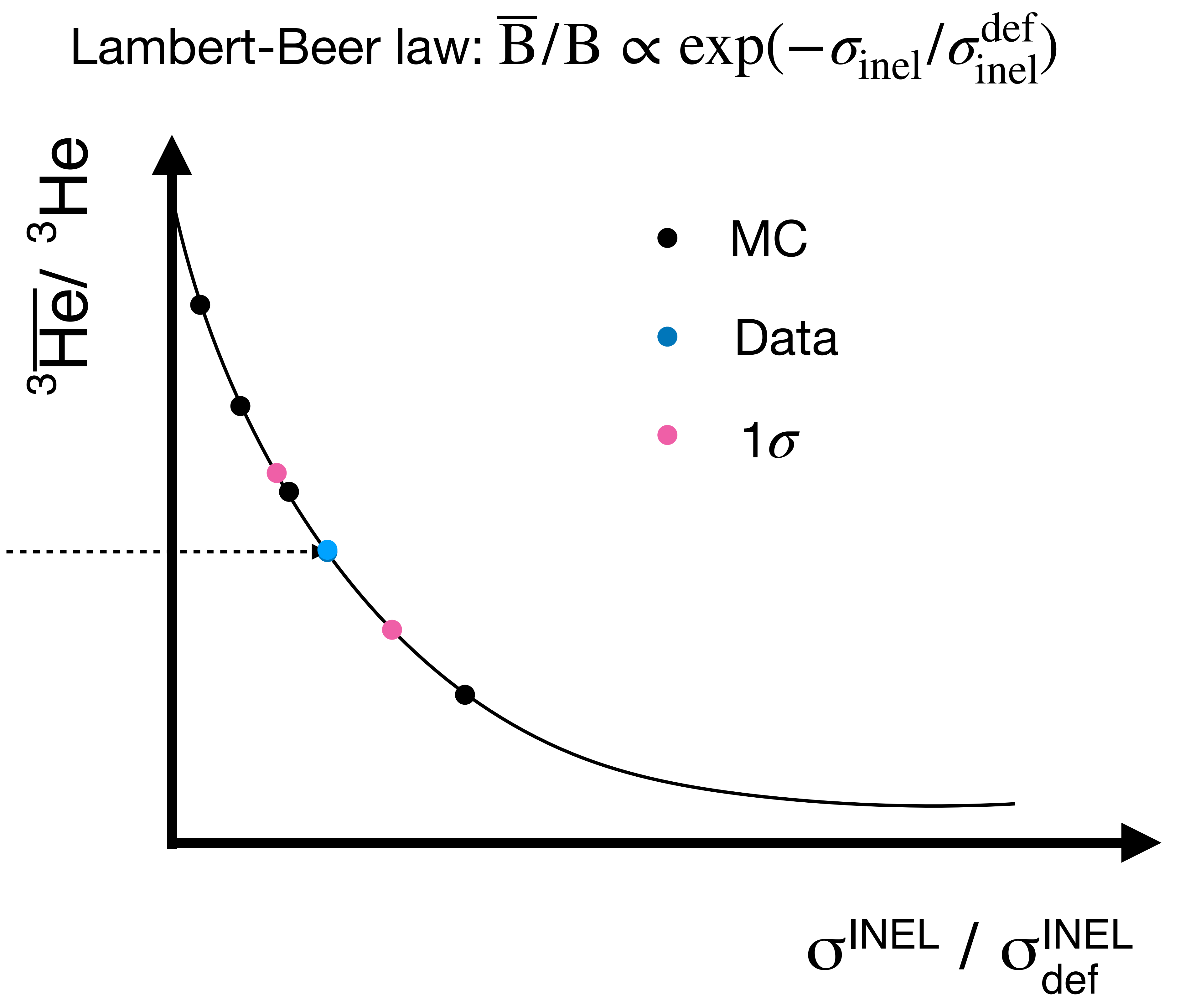

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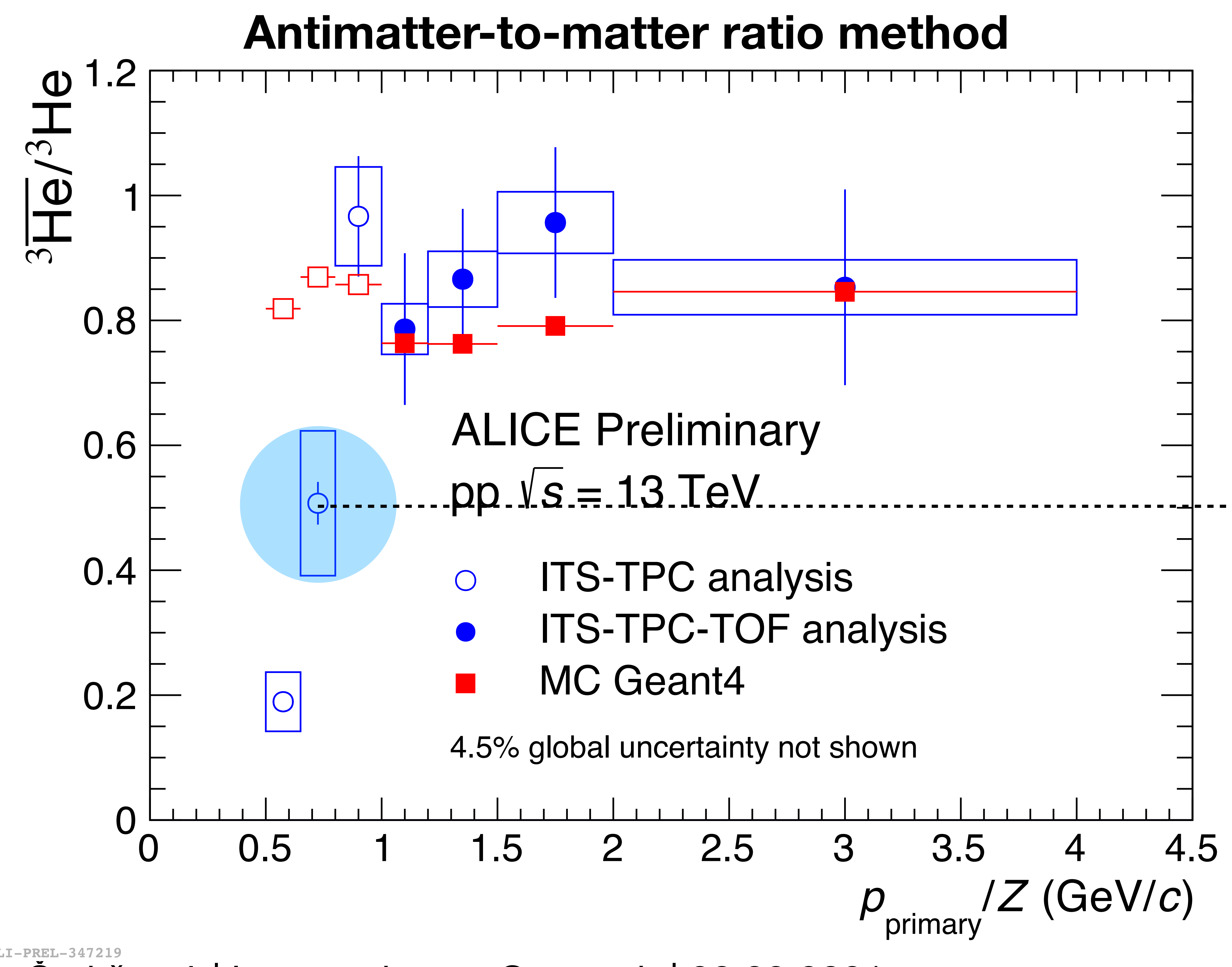
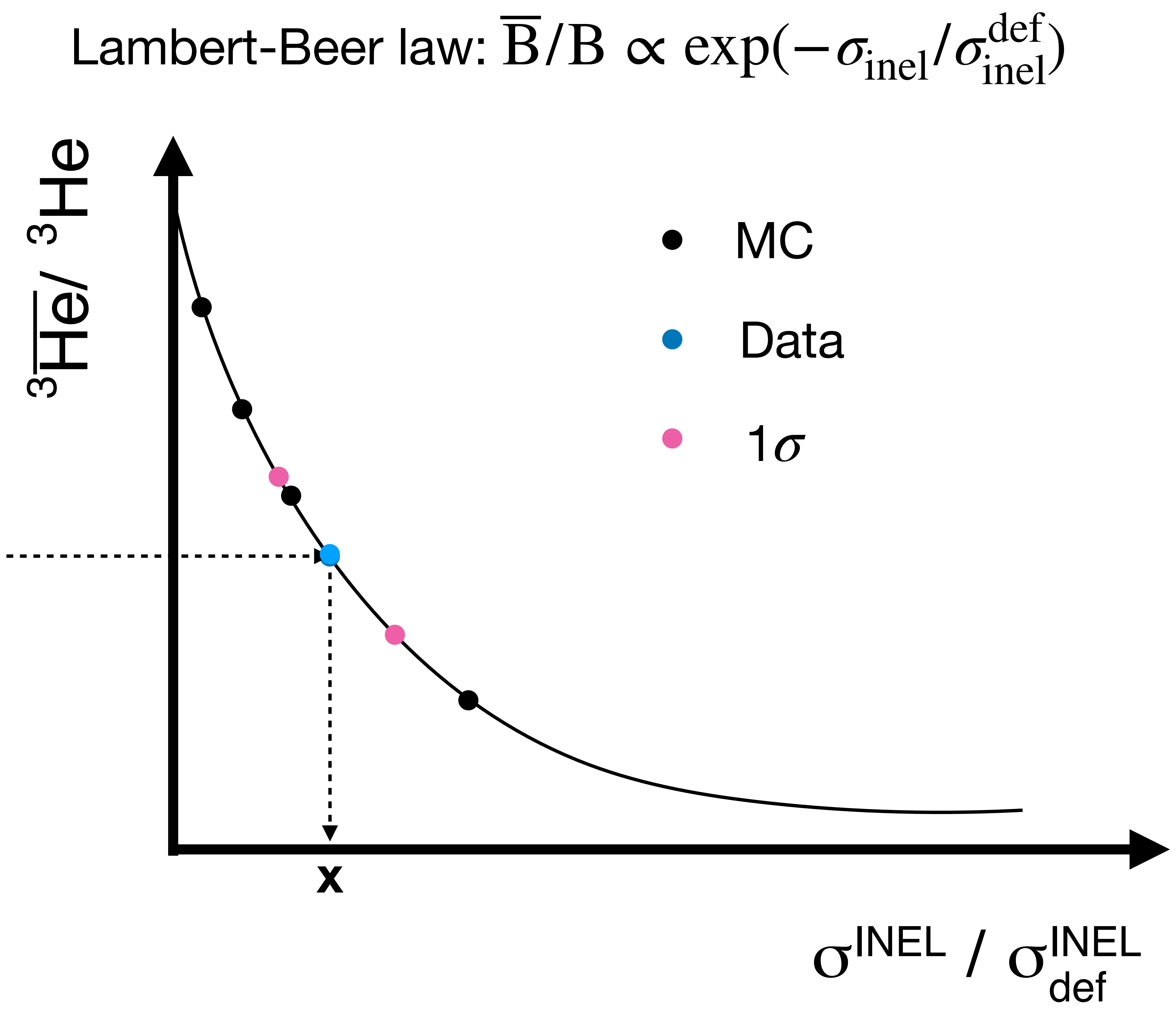
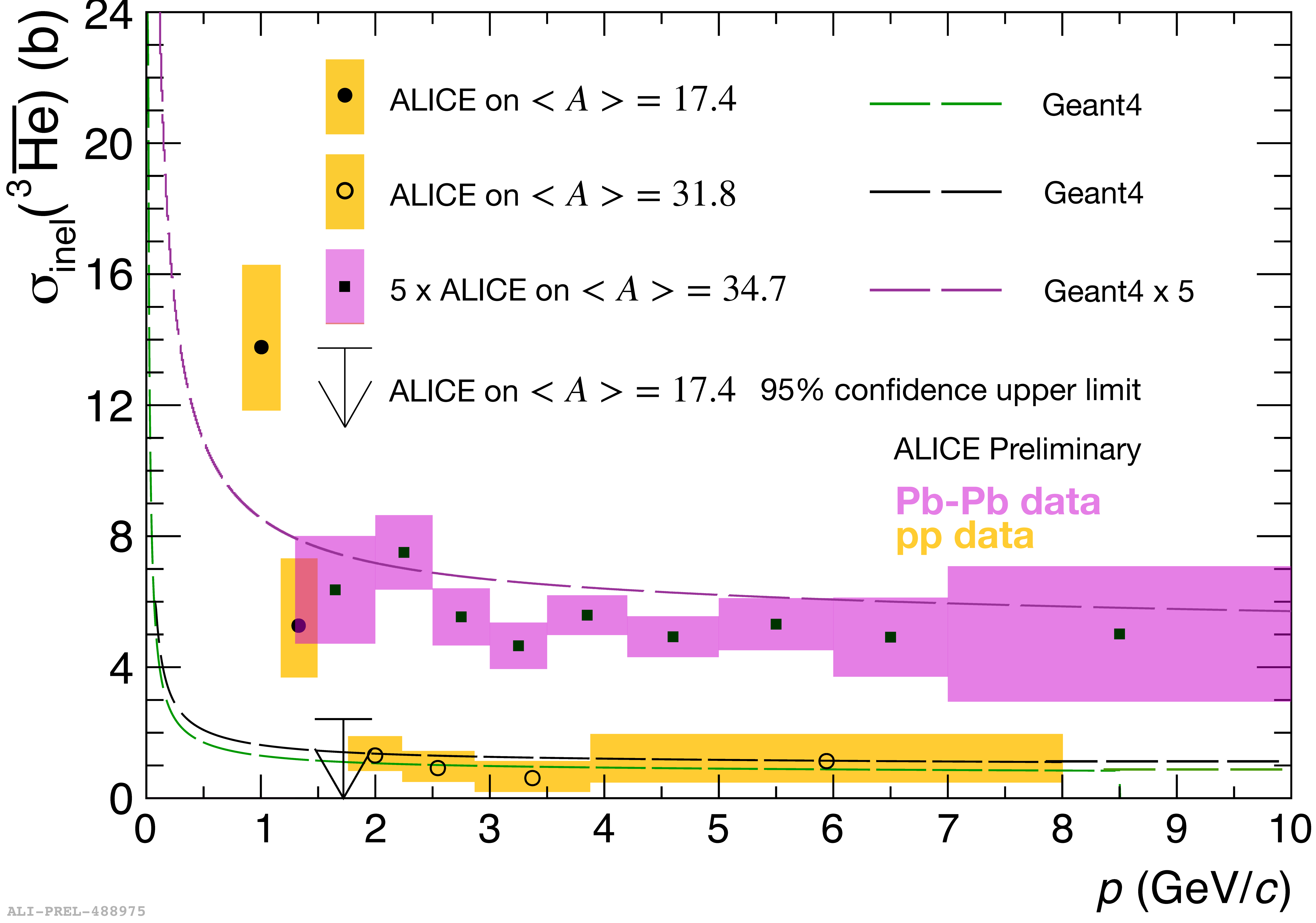




anti-^{3}He inelastic cross section

- Low-momentum region accessible only with the antimatter-to-matter ratio.
- High-momentum region measured with better precision using TPC-to-TOF matching method.

New Results



The low-momentum region shows steeper rise than expected from modelling.

For p > 2.5 GeV/c the data are ~20% below Geant4.

First antihelium-3 inelastic cross section measurements!

Cosmic rays in the galaxy

Transport equation

$$\frac{\partial \psi}{\partial t} = \boxed{q(\mathbf{r}, p)} + \boxed{\mathbf{div}(D_{xx}\mathbf{grad}\psi - \mathbf{V}\psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{\psi}{p^2} - \frac{\partial}{\partial p}\left[\psi \frac{dp}{dt} - \frac{p}{3}(\mathbf{div}\cdot\mathbf{V})\psi\right]} - \boxed{\frac{\psi}{\tau_f} - \frac{\psi}{\tau_r}}$$

Source Function

Propagation: diffusion, convection…

Fragmentation, annihilation

Can be numerically solved using GALPROP code! Publicly available at: https://galprop.stanford.edu. Propagation parameters can be constrained by available cosmic ray measurements[1].

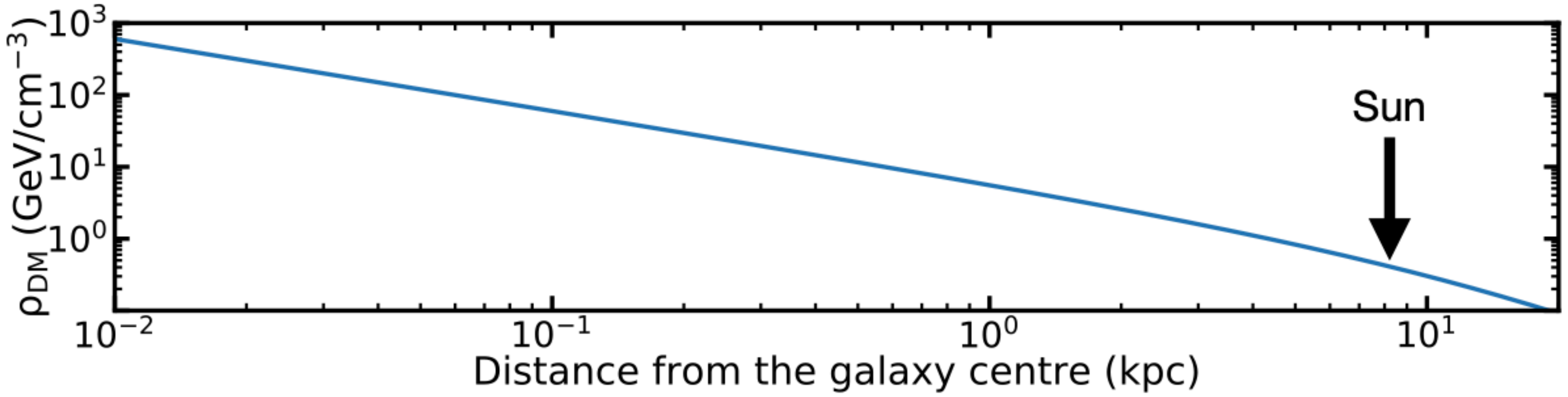
Implementation of antinuclei in GALPROP requires:

- source function: differential production cross section [2, 3]
- annihilation cross section

[1] Boschini et al, ApJS 250, 27 (2020)
[2] Shukla et al, Phys. Rev. D. 102, 063004 (2020)
[3] Carlson et al, Phys. Rev. D. 89, 076005 (2014)

anti-^{3}He source function: DM

$$q(\mathrm{r}, E_{kin}) = \frac{1}{2}\frac{\boxed{\rho^2_{\mathrm{DM}}(\mathrm{r})}}{m_\chi^2}\langle\sigma v\rangle\frac{dN}{dE_{kin}}$$



- ρ_{DM} - NFW profile [1]
- m_χ = 100 GeV for W^+W^- and $\mathrm{b\bar{b}}$
- $\langle\sigma v\rangle$ = 2.6x10^{-26} $\mathrm{cm^3s^{-1}}$ [2]
- dN/dE_{kin} from [1], obtained using PYTHIA 8.156 and event-by-event coalescence afterburner

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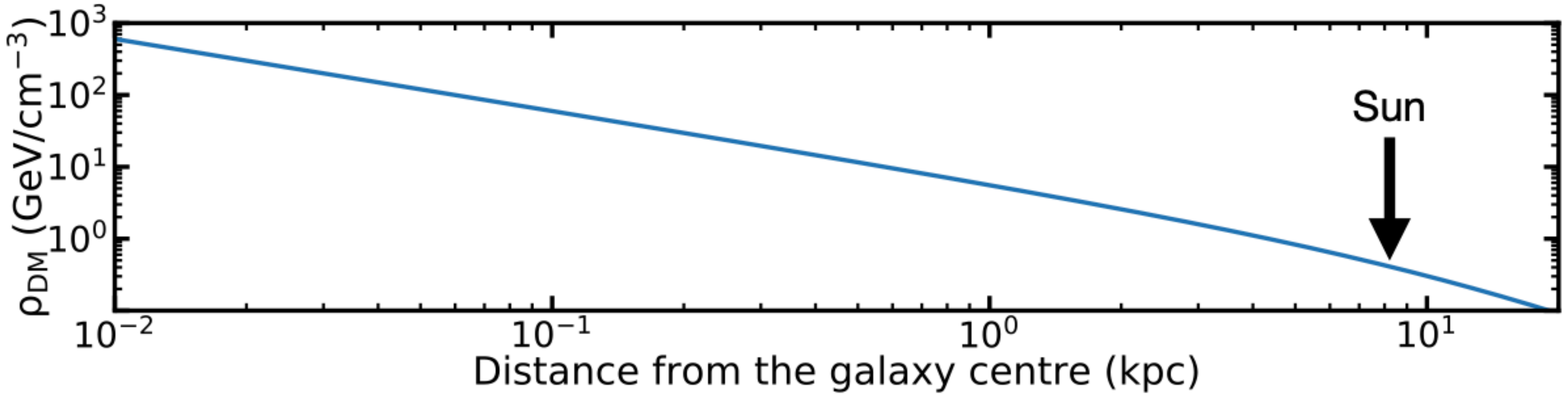

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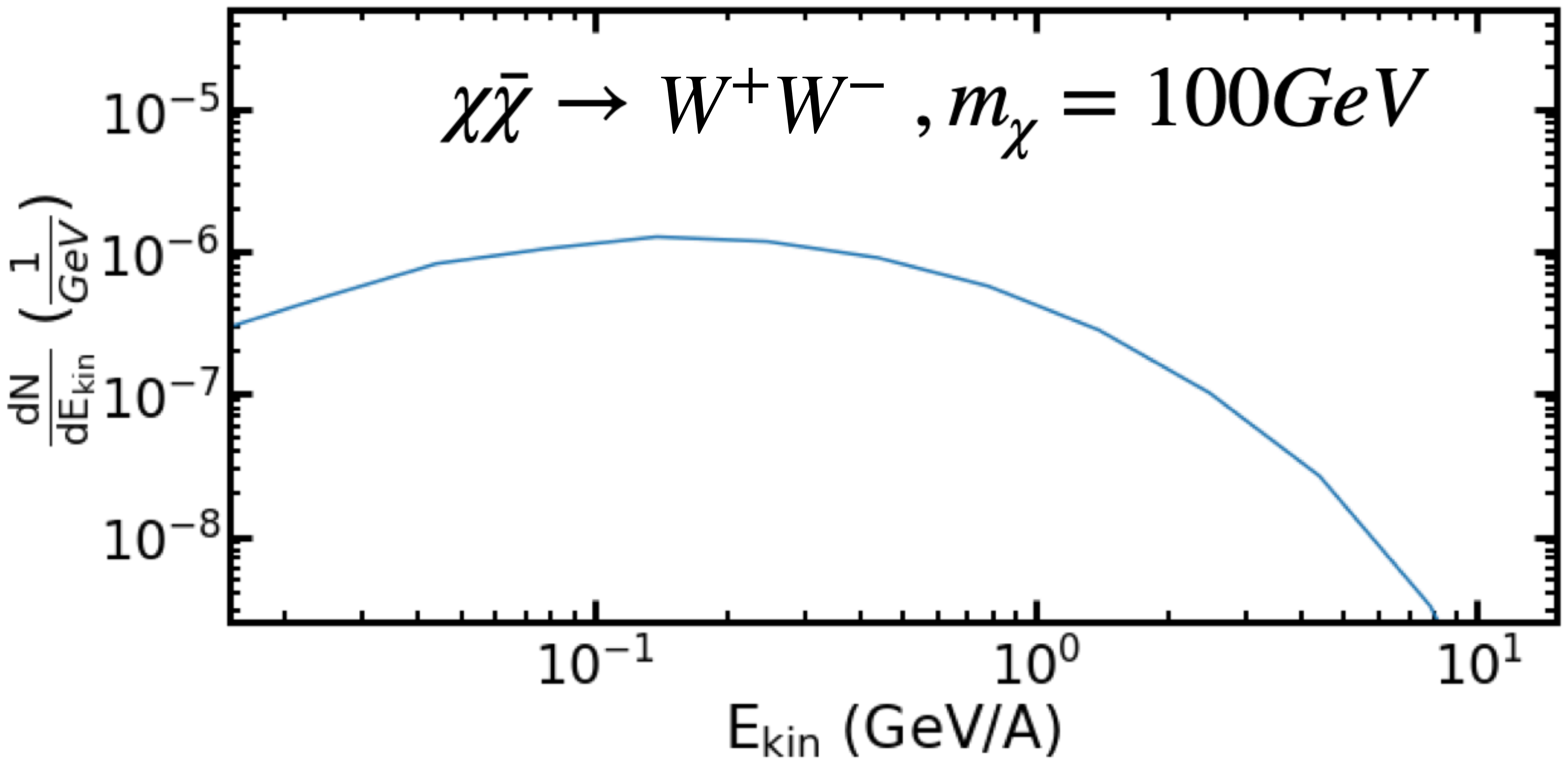

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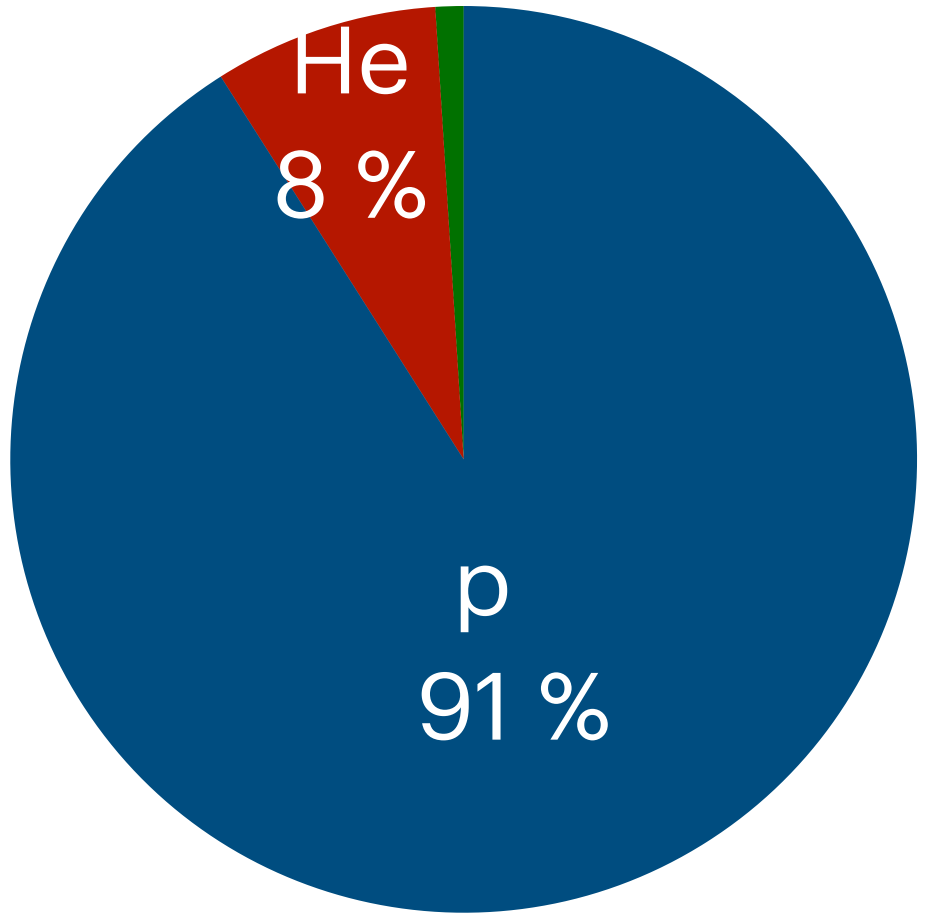
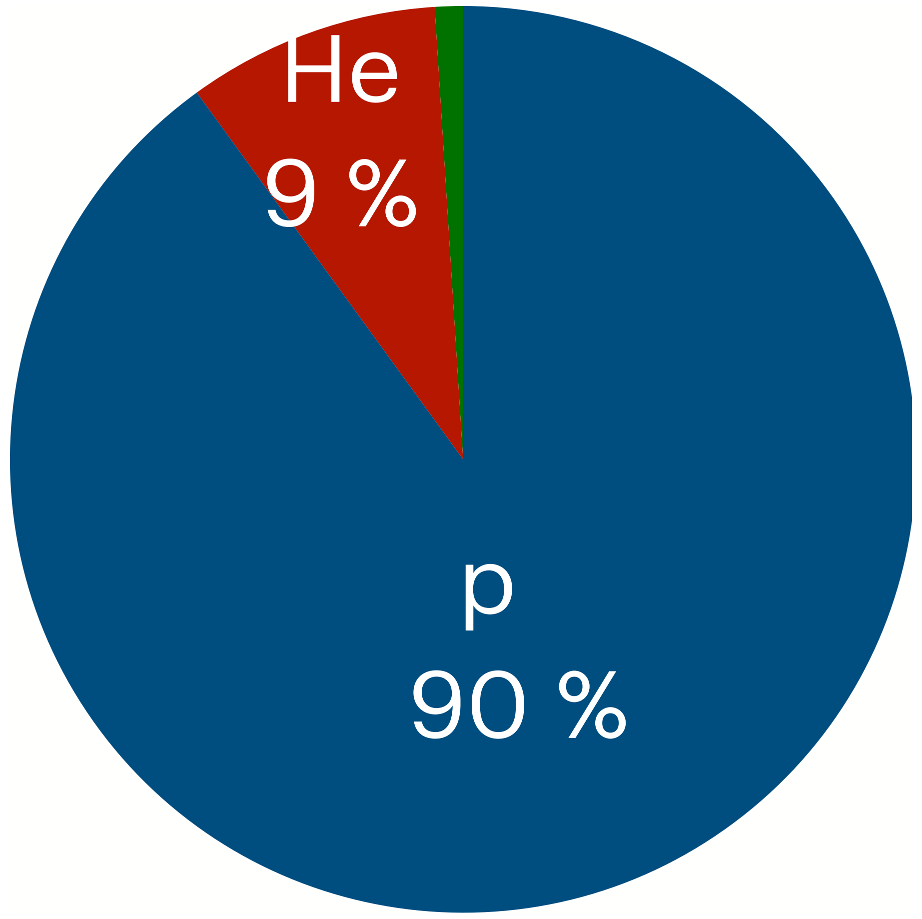
anti-^{3}He source function: CR+ISM

- Relevant collisions included: pp, p-He, He-p, He-He
- Production cross section in pp collisions from [1]; scaling factor $(A_T A_P)^{2.2/3}$ applied for the rest
- Production cross sections in [1] were obtained using EPOS LHC and event-by-event coalescence afterburner
- Validated using ALICE measurements

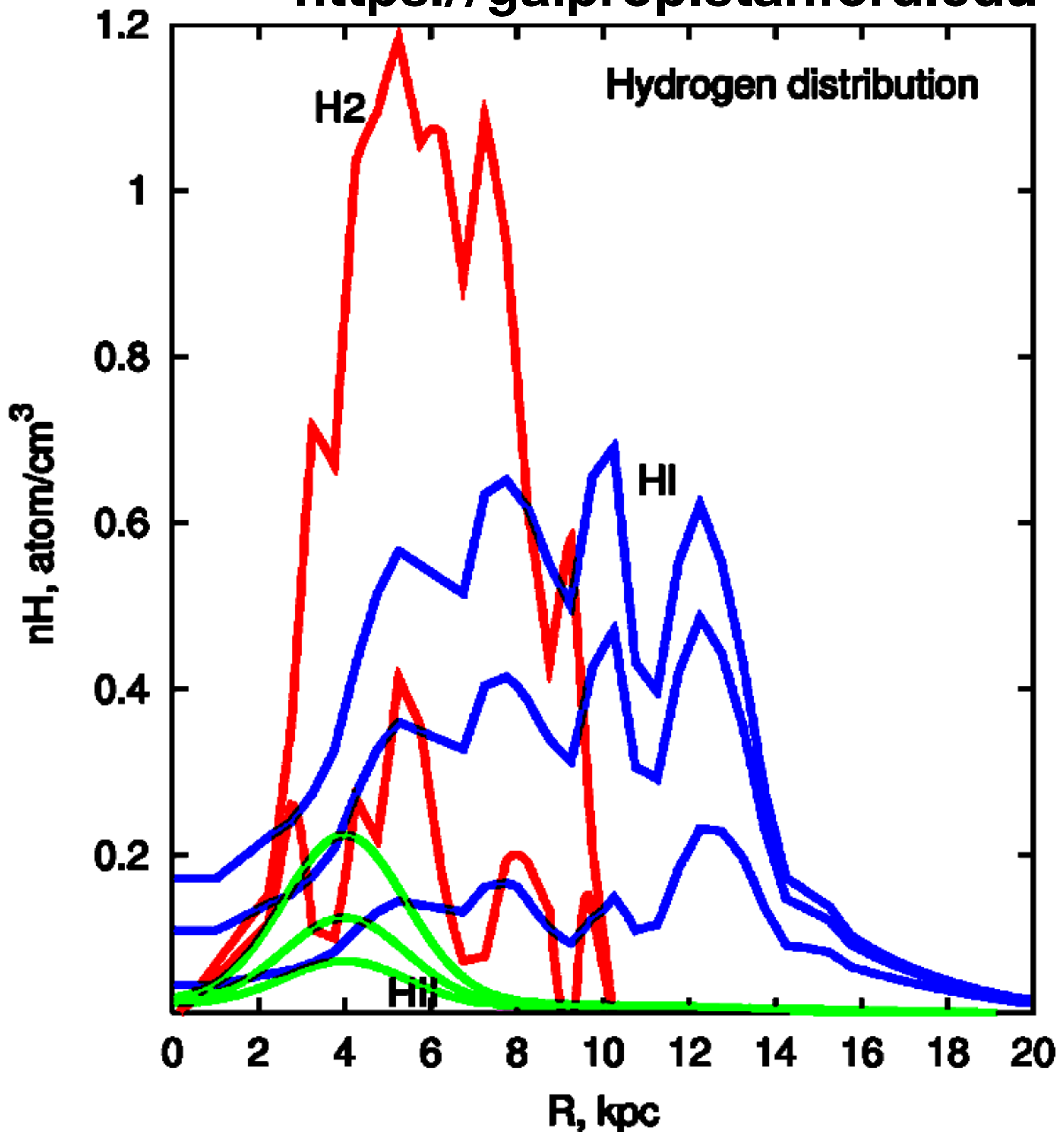


Cosmic Rays



Interstellar Gas

https://galprop.stanford.edu



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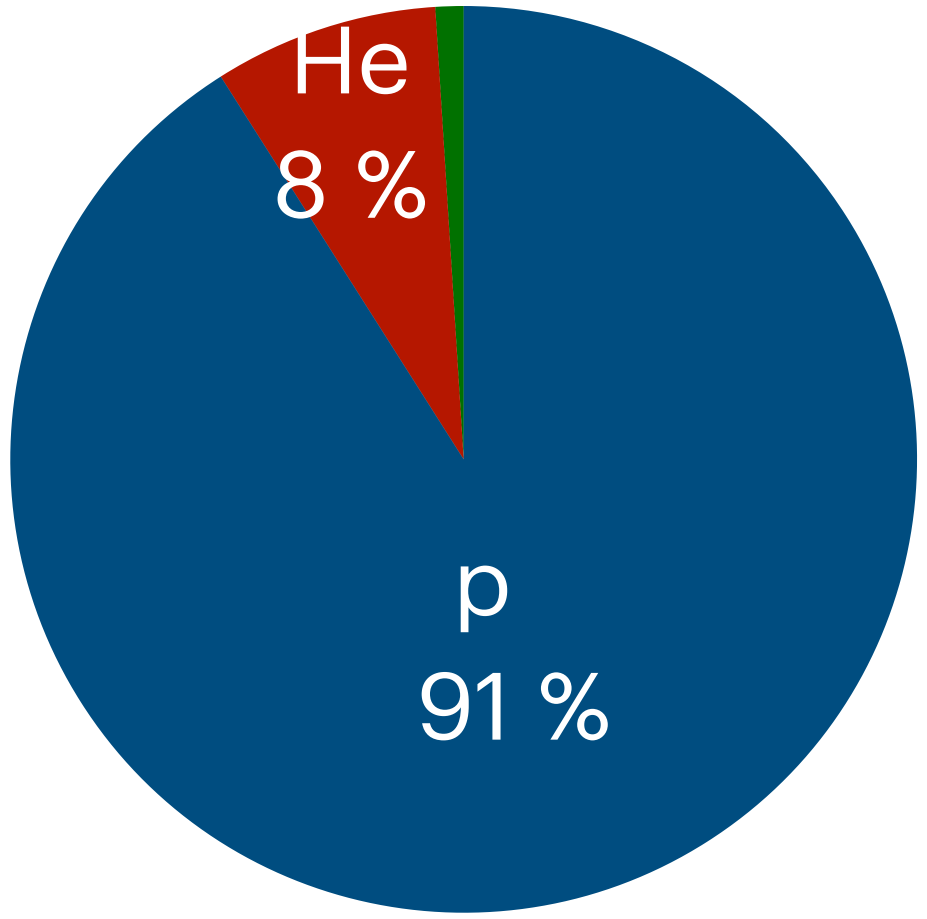

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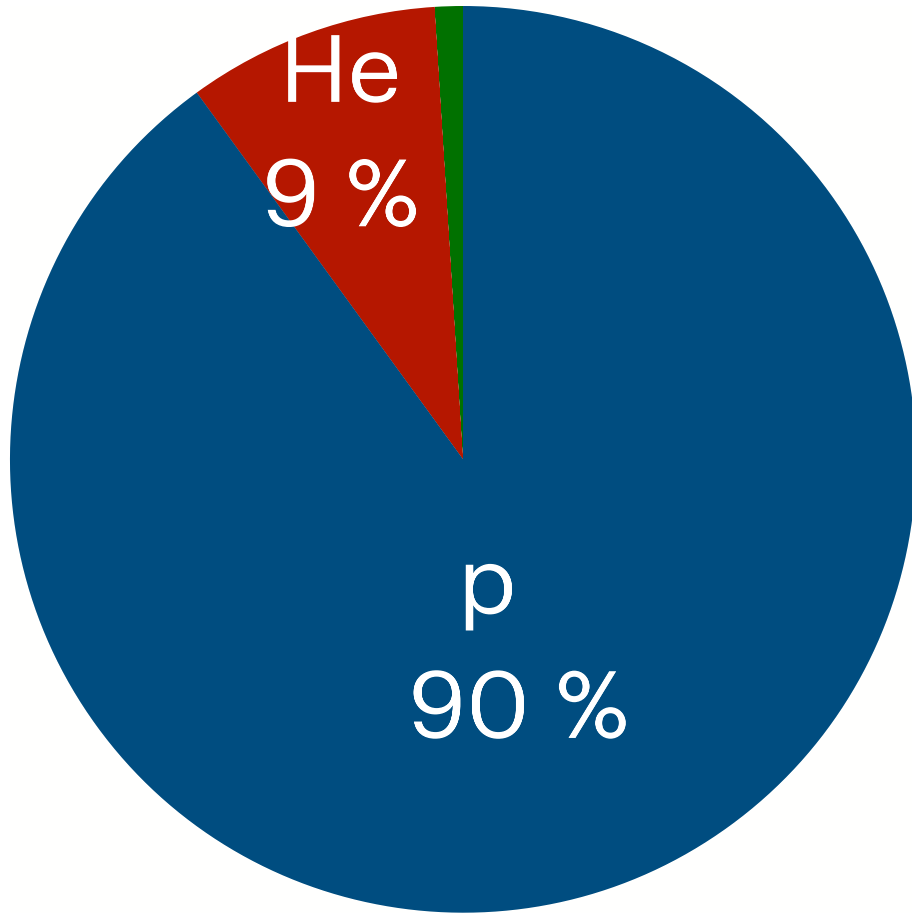

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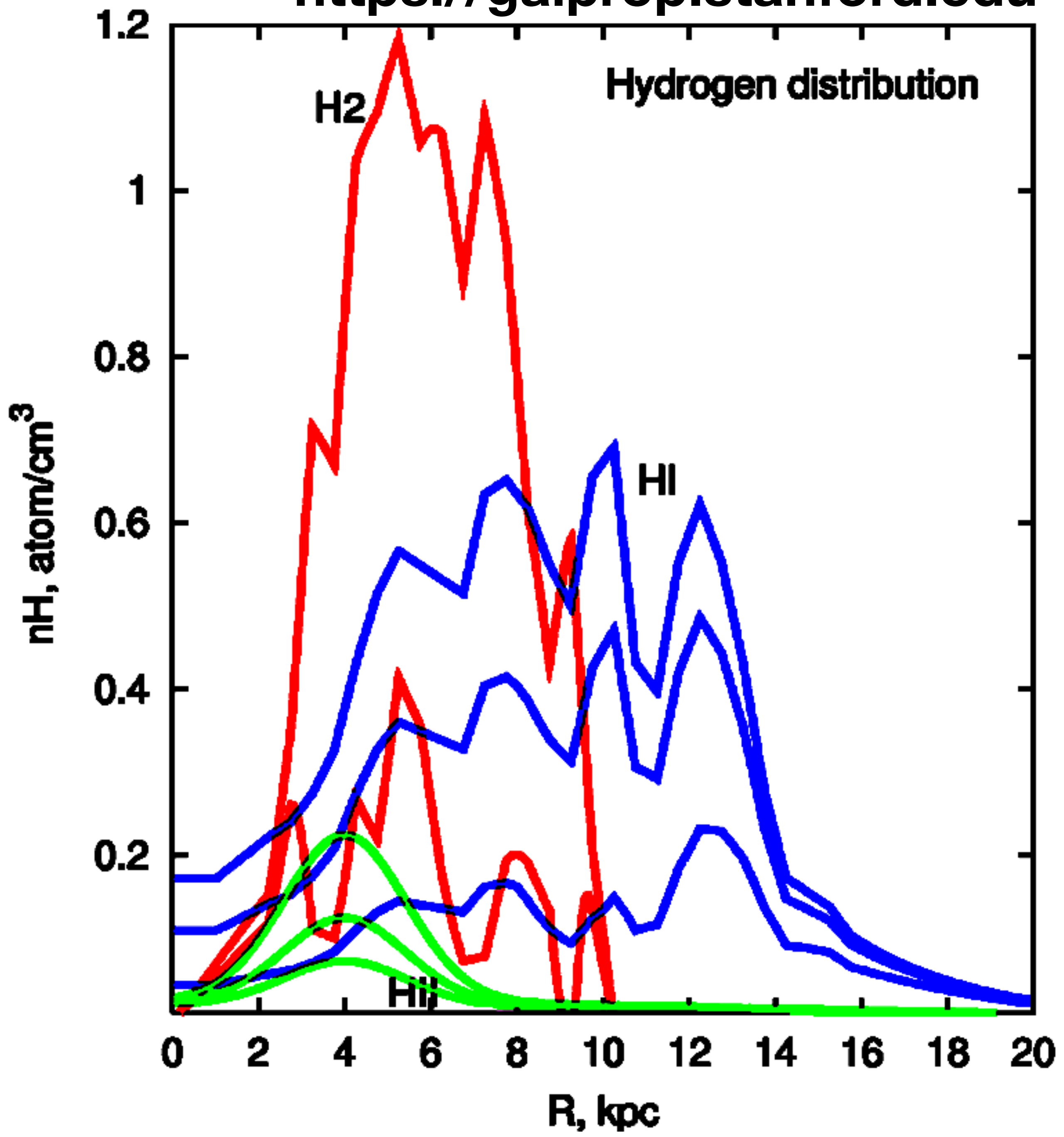
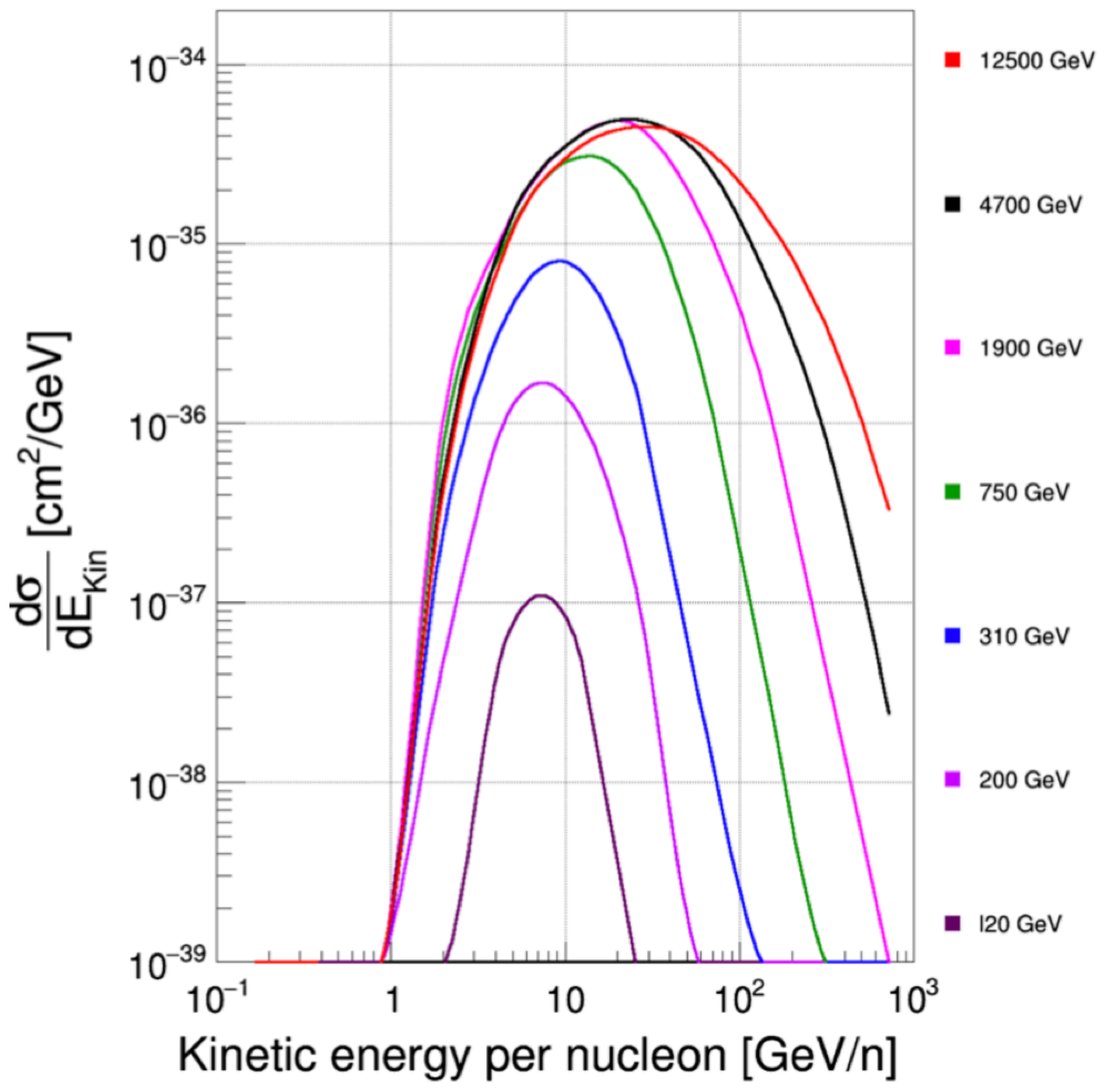


$p + p \rightarrow \overline{He^3} + X$ [1]



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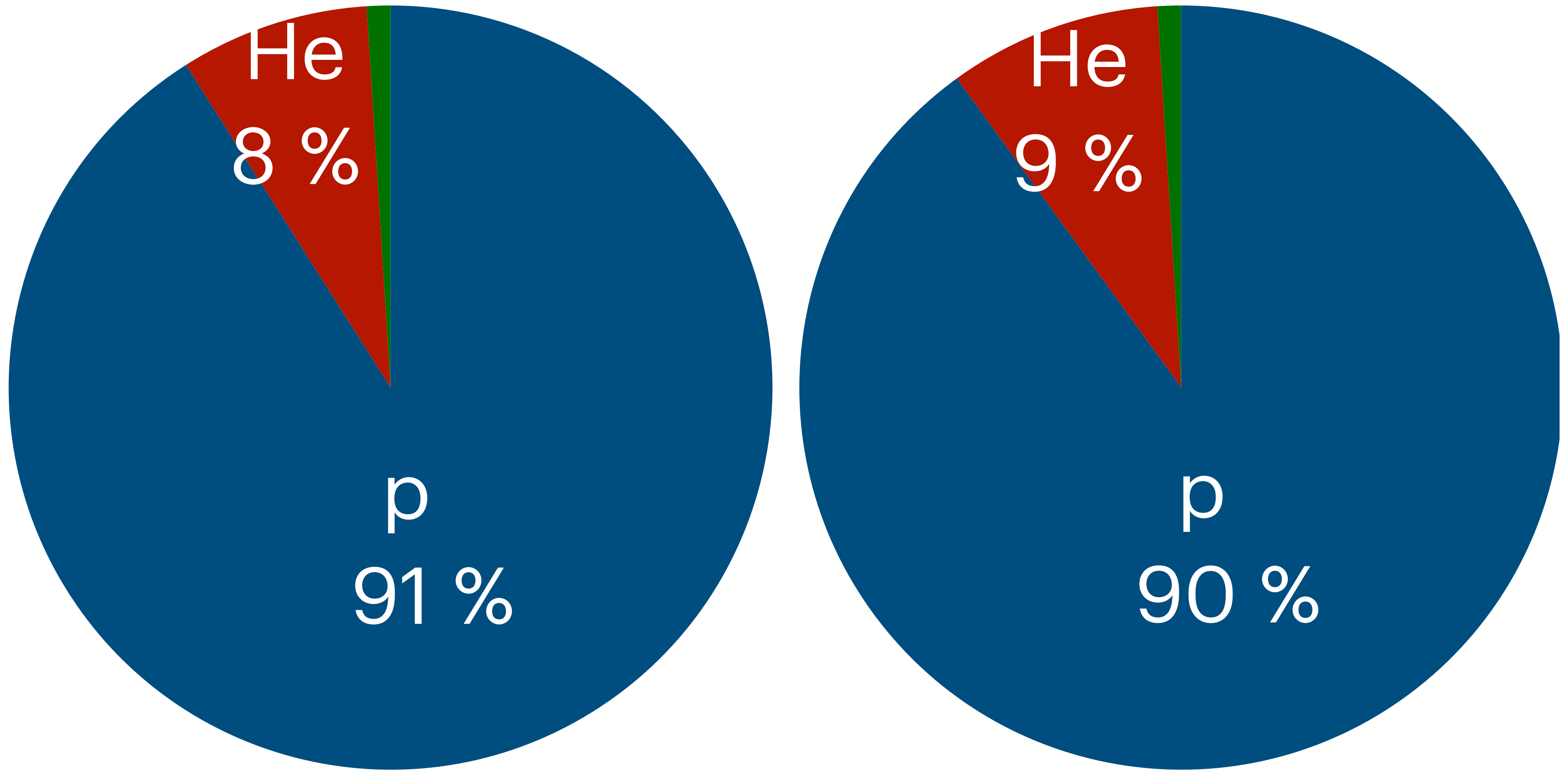

Cosmic Rays Interstellar Gas

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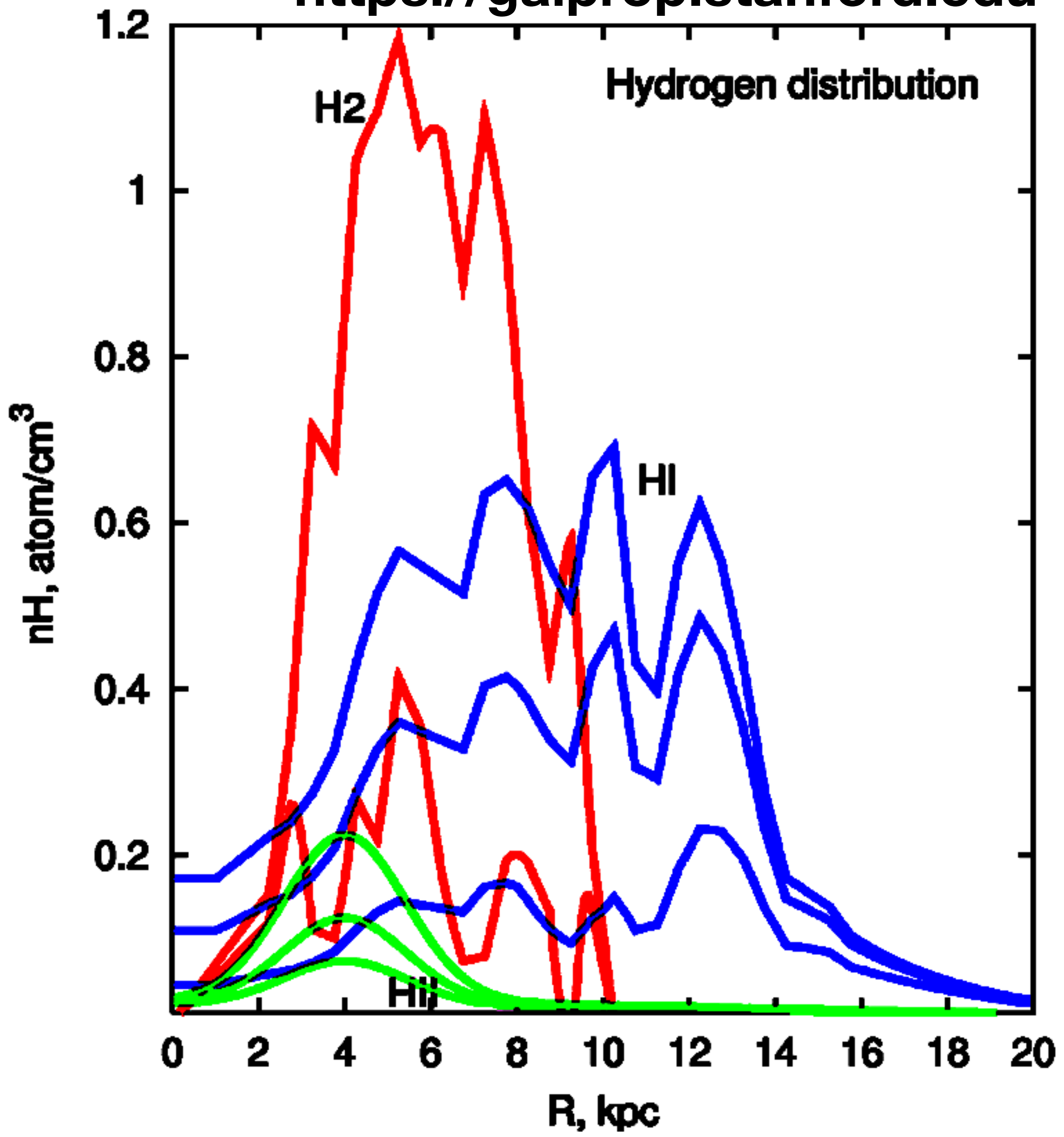
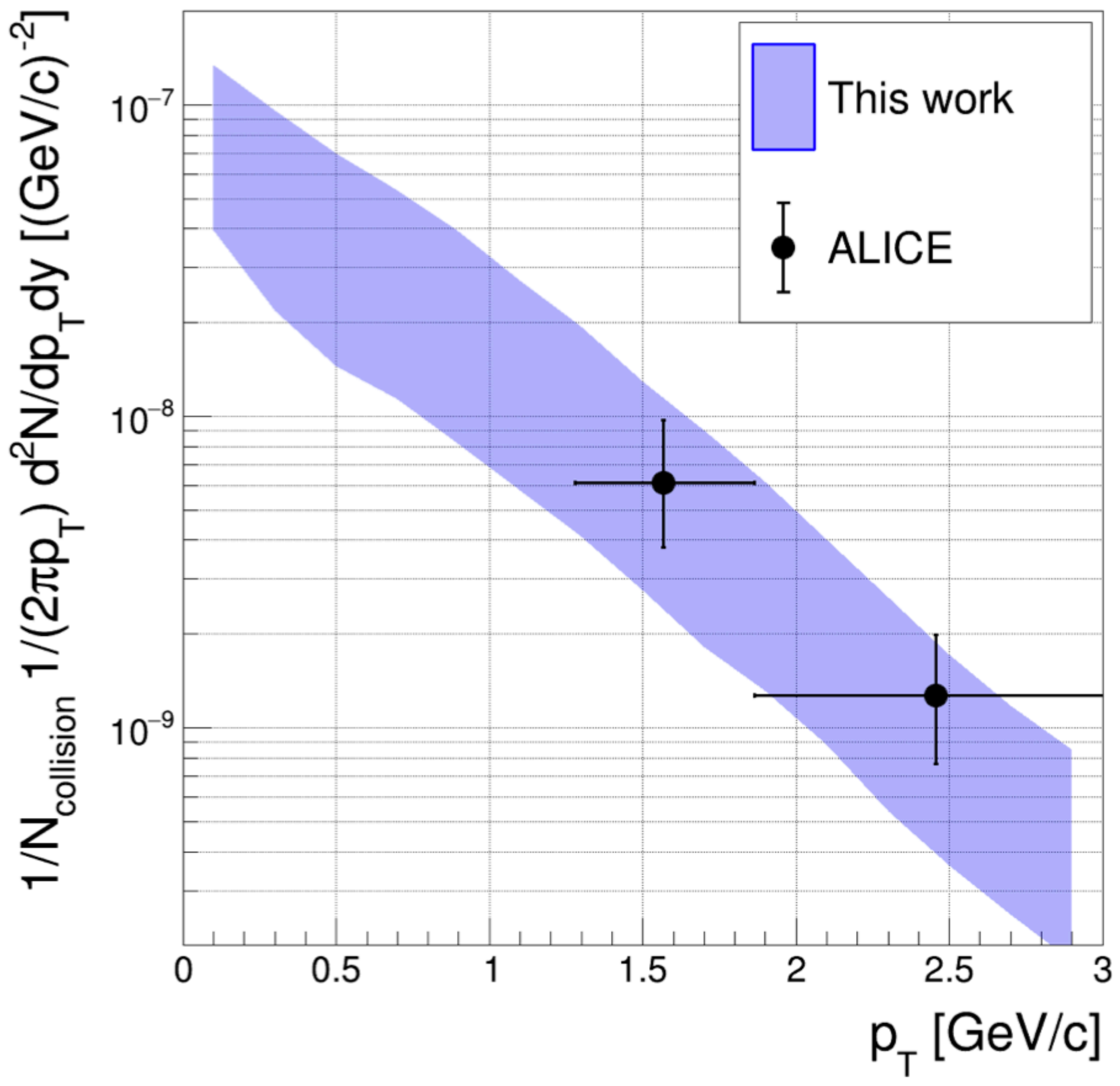


$^{3}\overline{\text{He}}$ validation with ALICE pp@$\sqrt{s}$ = 7 TeV [1]



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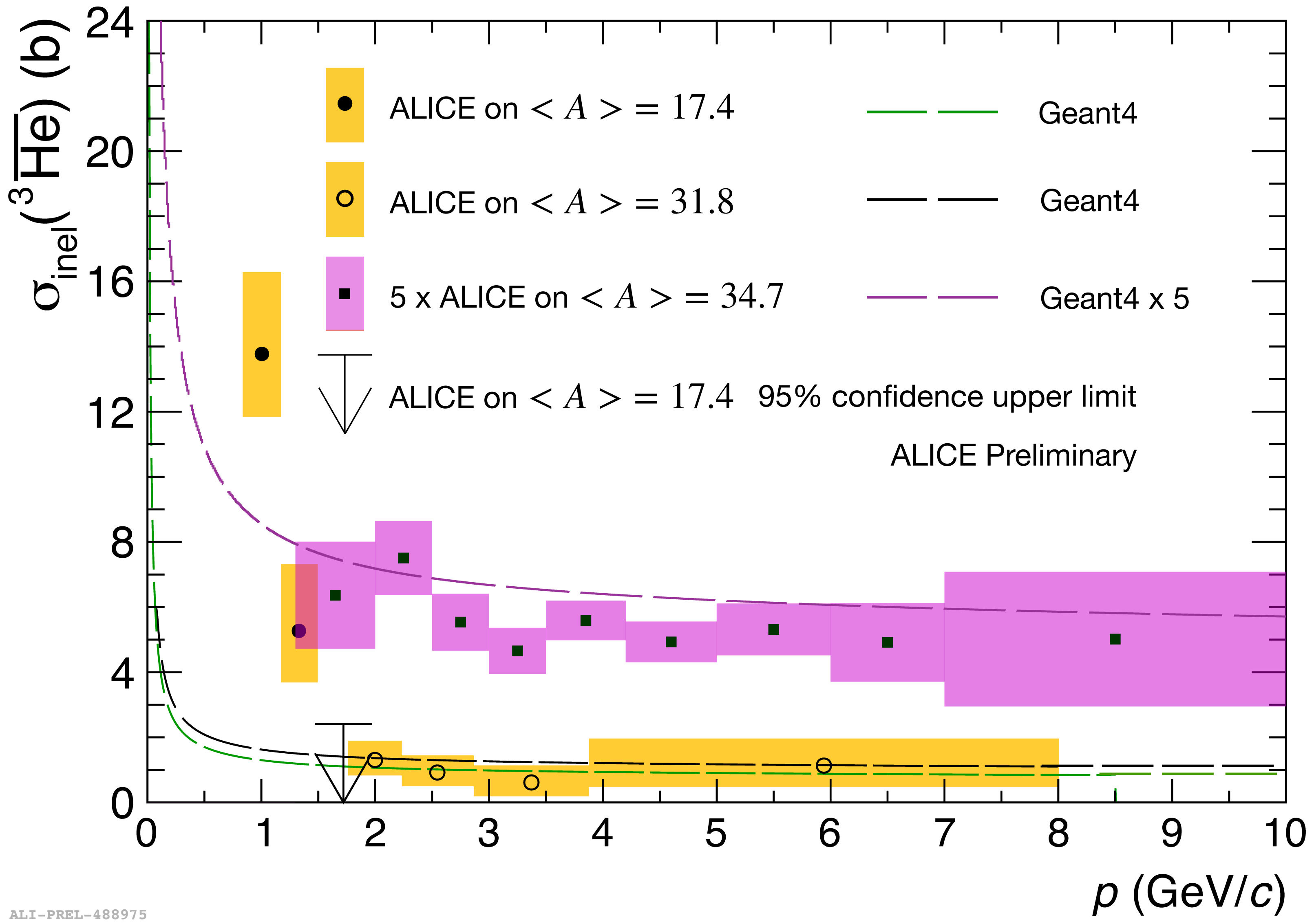
Annihilation cross section

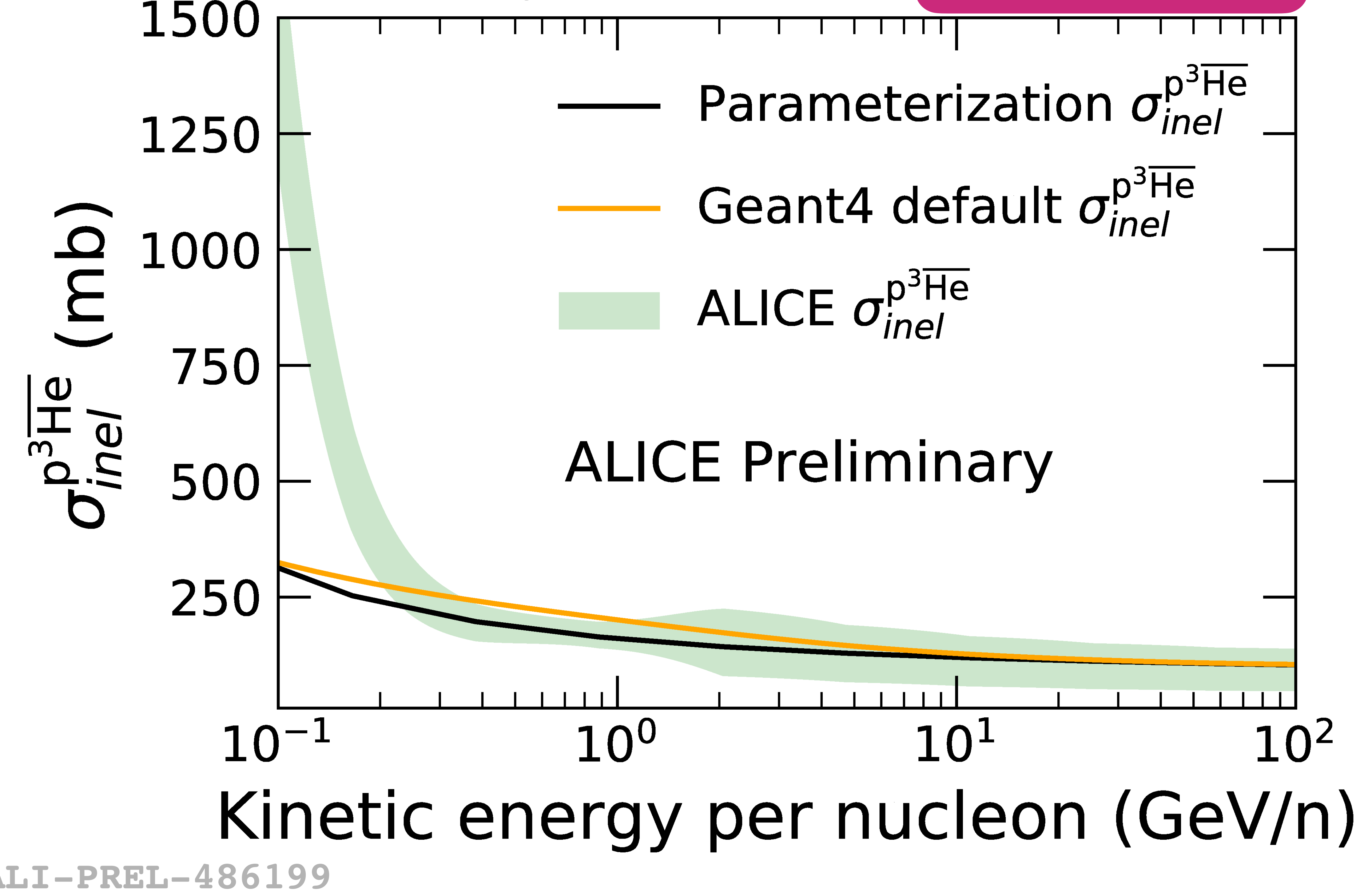
- ALICE measurement: anti-^{3}He inelastic cross section on heavy targets
- Cosmic rays: proton and ^{4}He targets
- Obtain correction factor for Geant4 parametrisation using ALICE measurement
- Use this correction factor for all target materials, 8% uncertainty on the A scaling

Measured by ALICE: <A> = 17.4, 34.7



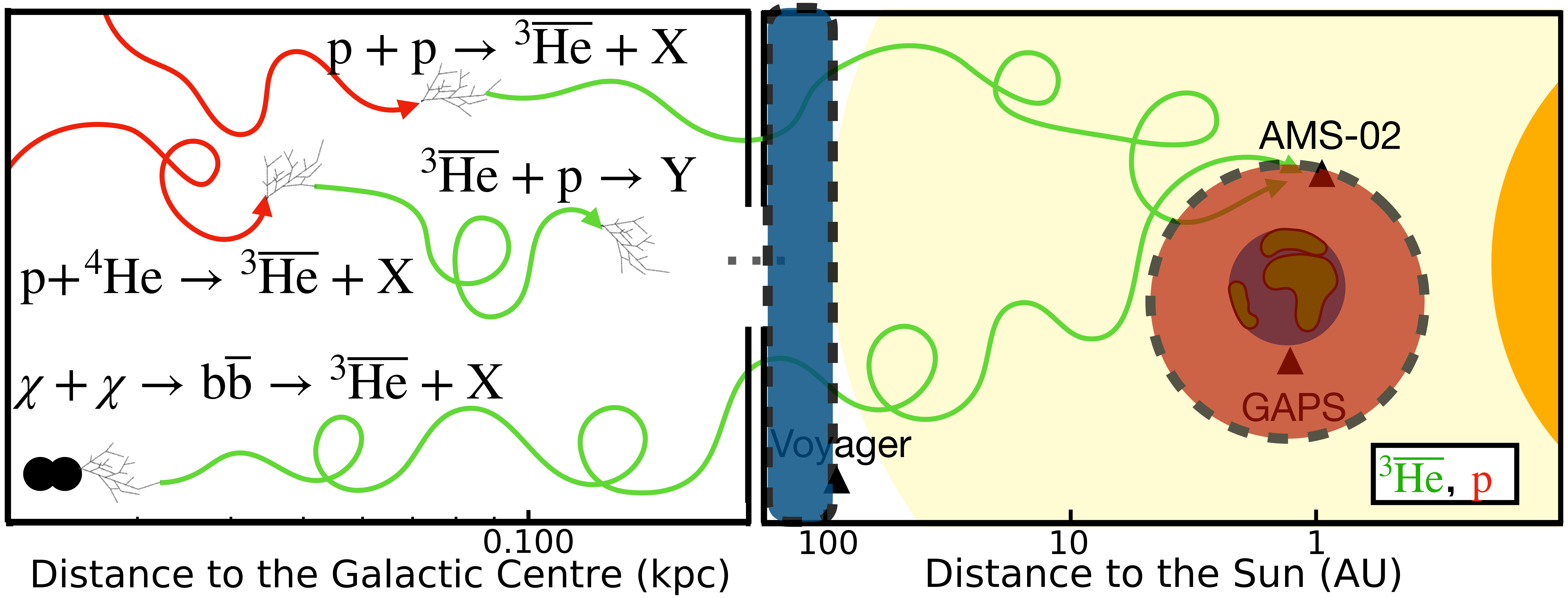
$$corr = \frac{\sigma_{ALICE}}{\sigma_{Geant4}}$$

Proton targets in ISM New Results



Cosmic rays fluxes

- Local interstellar flux - measured outside the heliosphere
- Solar modulated flux - measured close to Earth



Force-field approximation to account for solar modulation used with Fisk potential ϕ = 0.4 GV:

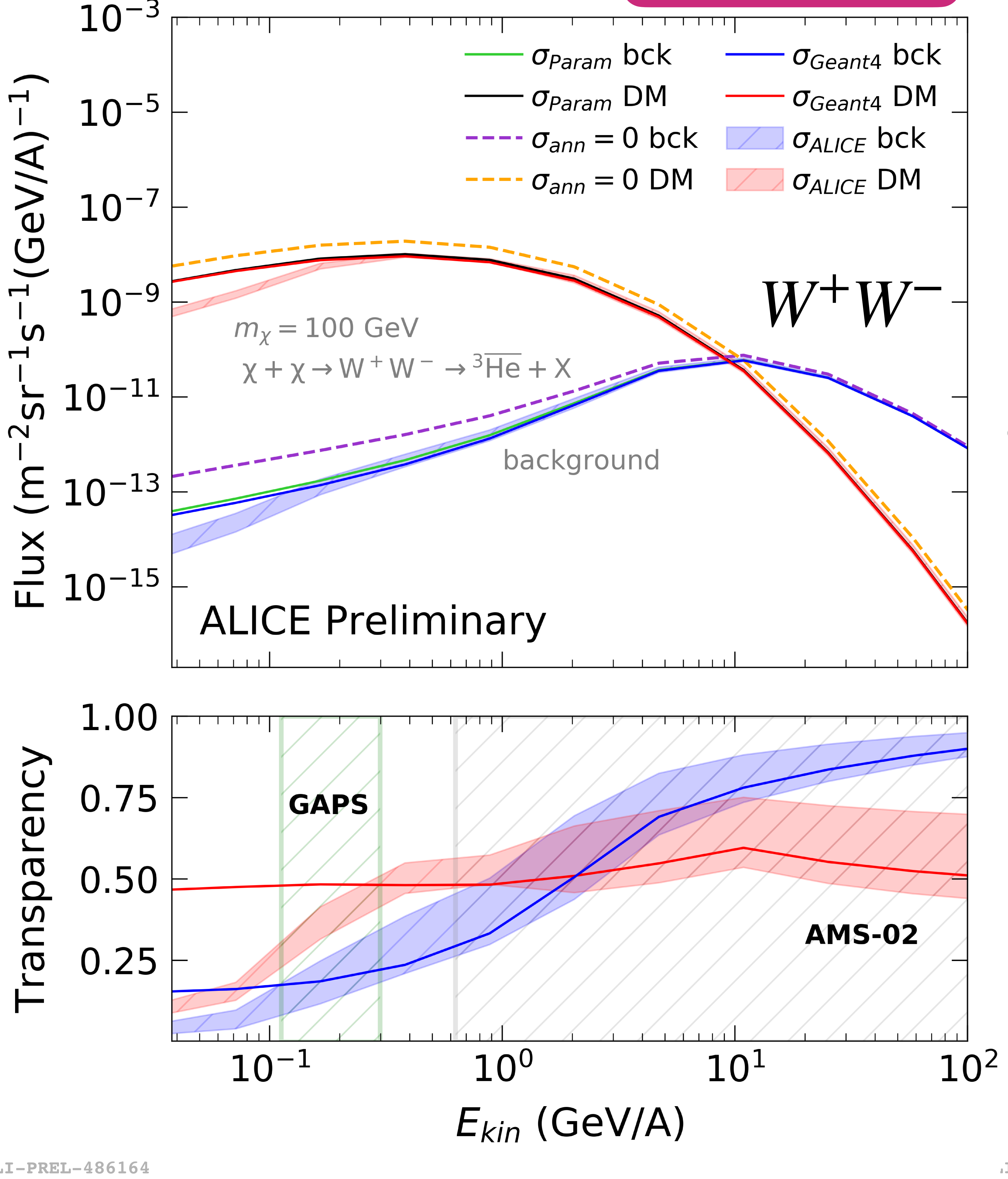
$$F_{mod}\left(E_{mod}, \phi\right) = F(E)\frac{(E - Z\phi)^2 - m^2_{^3He}}{E^2 - m^2_{^3He}}$$

$$E_{mod} = E - Z\phi$$

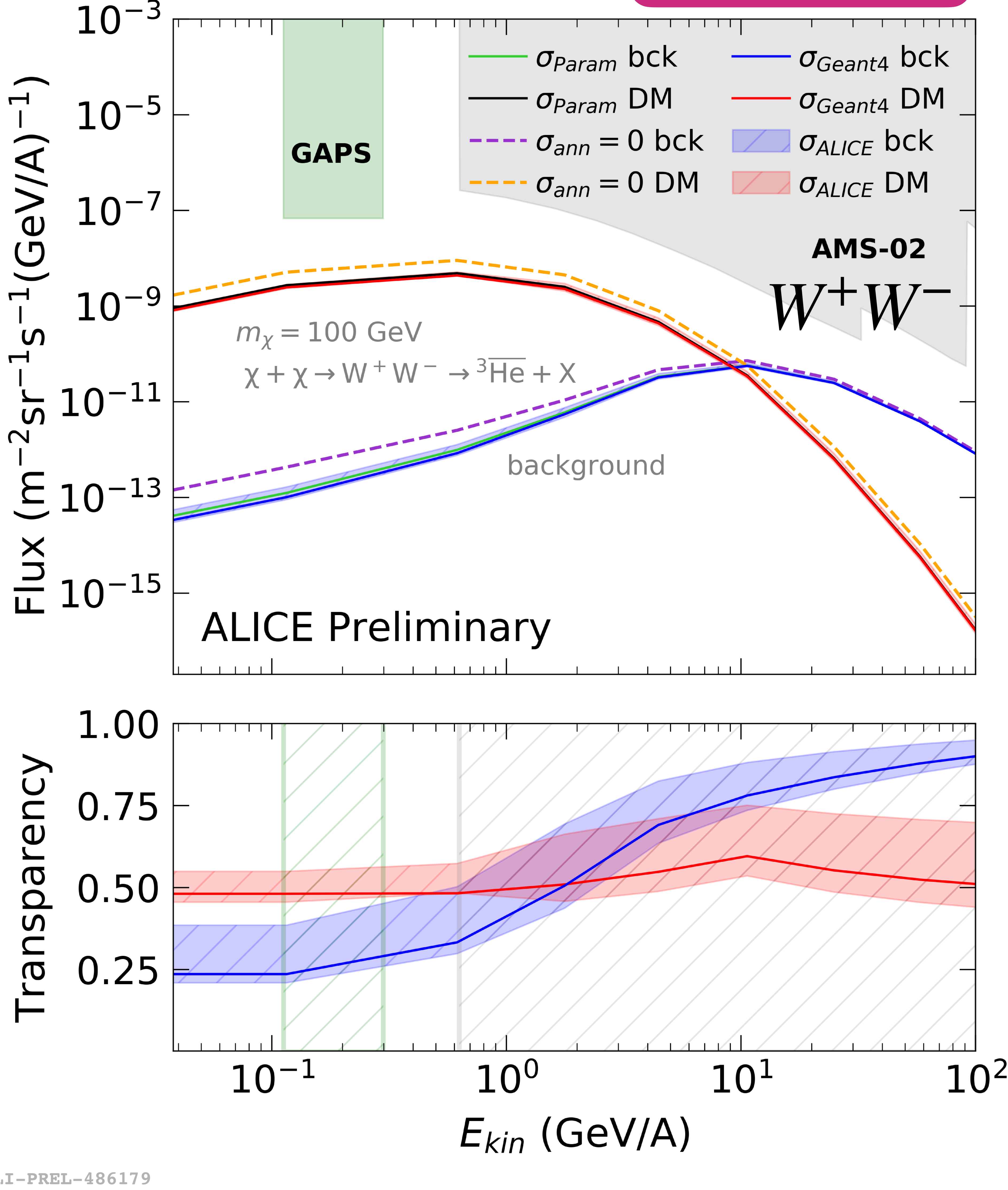
Estimated Fluxes

- ALICE absorption measurement allows to estimate interstellar flux in kinetic energy range > 0.04 GeV/A
- Uncertainties only from ALICE measurement, small compared to other uncertainties
- **Annihilation effect strongly depends on the cosmic ray flux shape**
- **Rather constant transparency of 50% for typical DM scenario and 25-90% for background**

Outside Solar System New Results



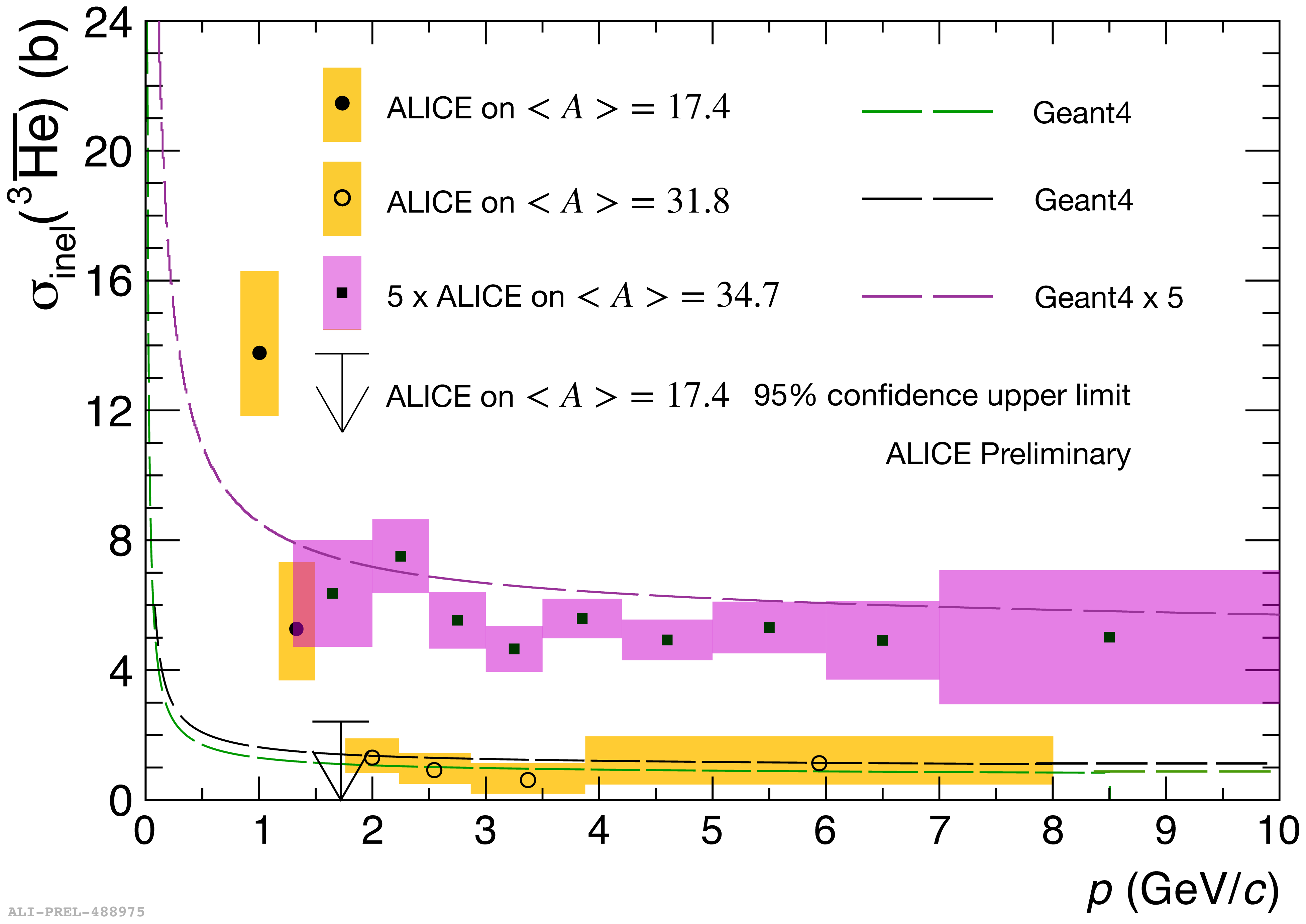
Earth proximity New Results

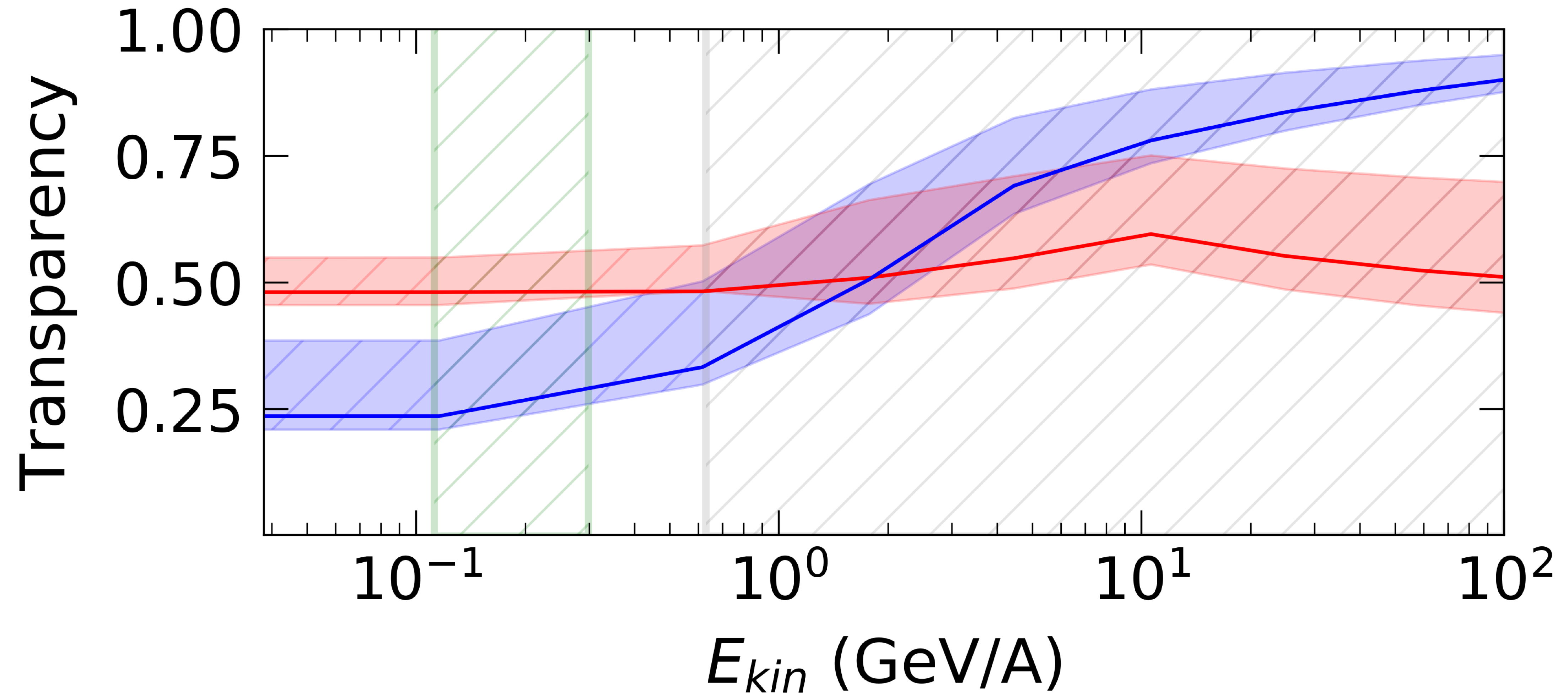


Summary and outlook

- First measurements of the anti-³He inelastic cross section in wide kinetic energy range from 0.04 GeV/A to 2.52 GeV/A.
- Impact of the ALICE measurements on anti-³He fluxes near Earth:
  - High transparency of the Galaxy to anti-³He fluxes
  - Uncertainties on cosmic ray fluxes from anti-³He σ_{inel} measurements are small compared to other uncertainties in the field

Essential reference for any studies of anti-³He in space!





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