Constraining (anti)nuclei measurements relevant for astrophysics with ALICE

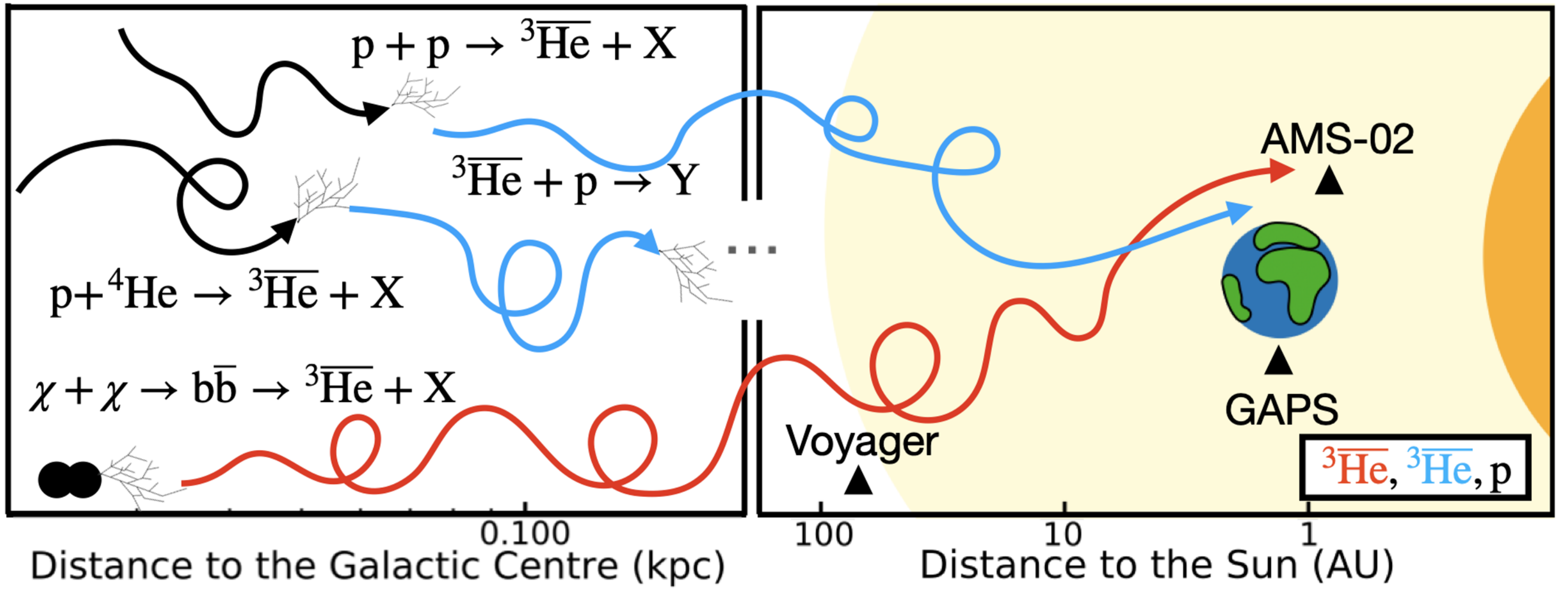
Chiara Pinto on behalf of the ALICE Collaboration

Technische Universität München

Quark Matter 2023

Houston, TX – Sept., 6th

Motivation



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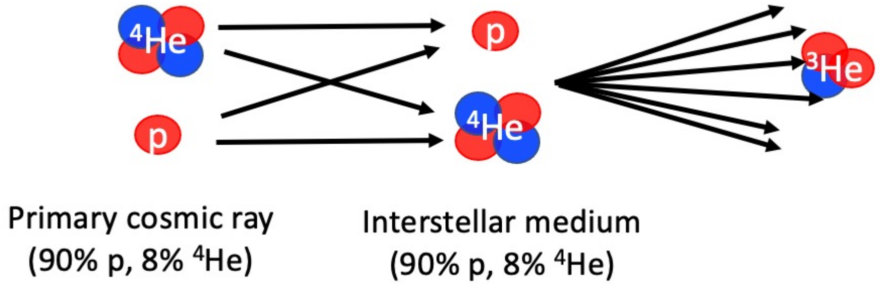

Nature Phys. (2023) 19, 61–71

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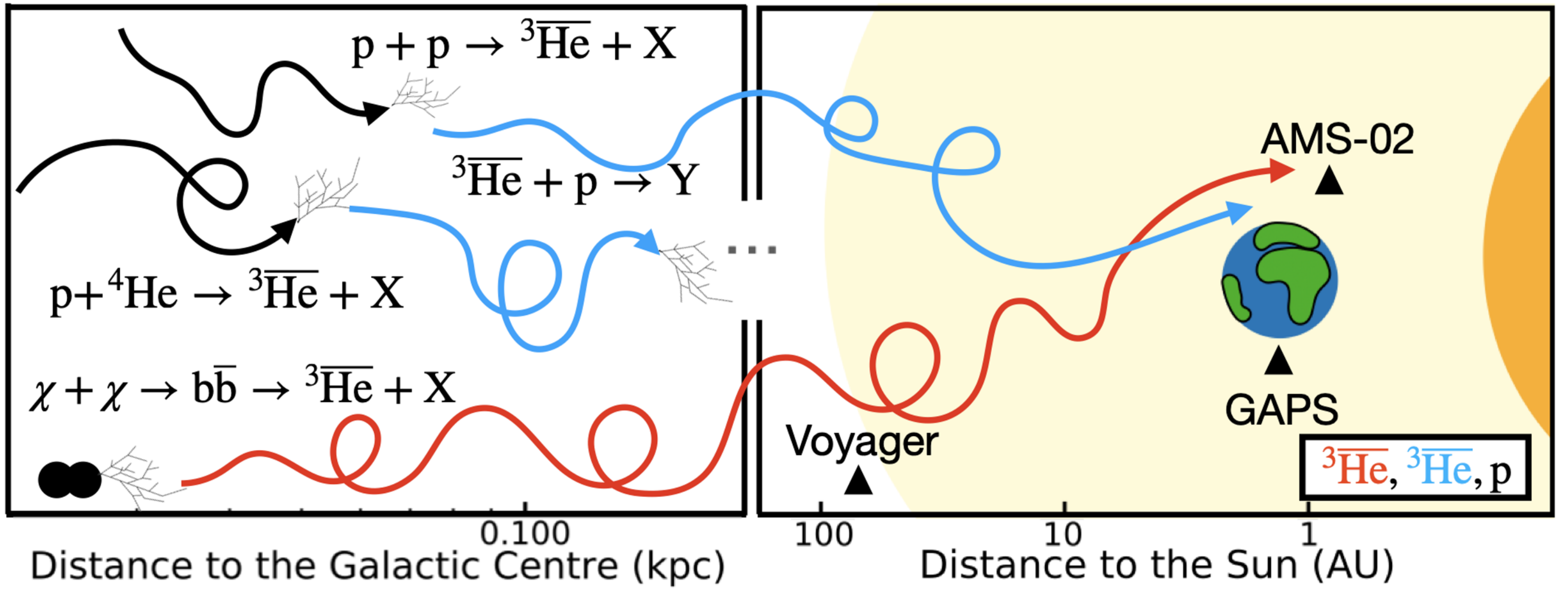

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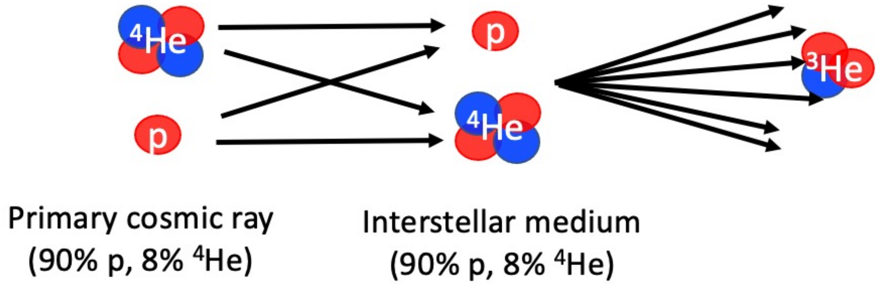

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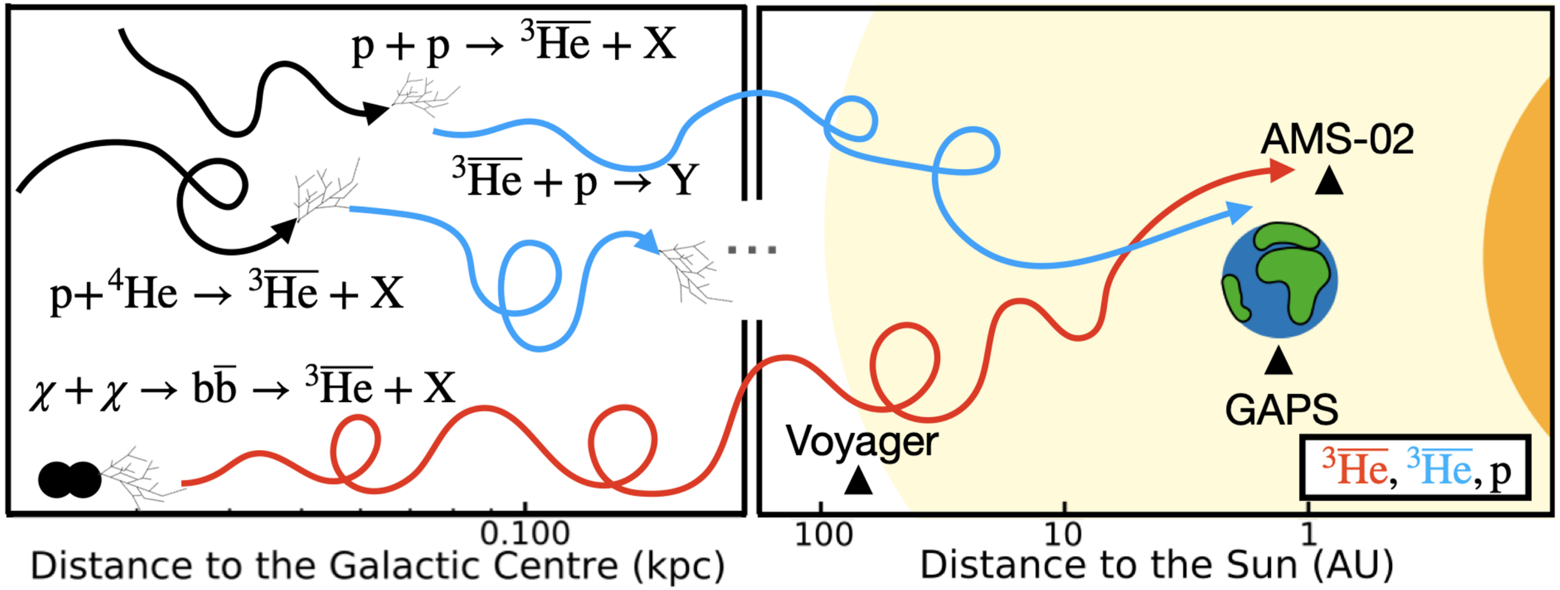

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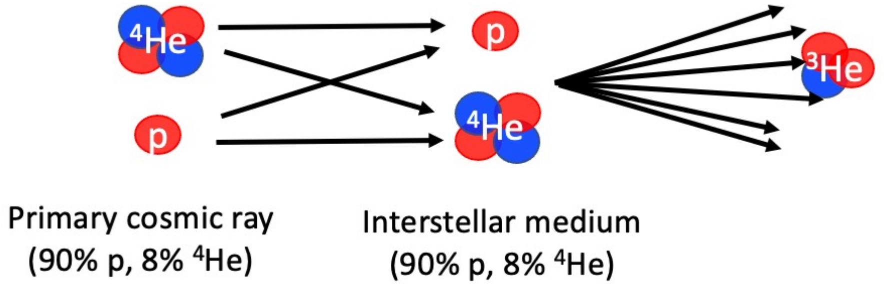

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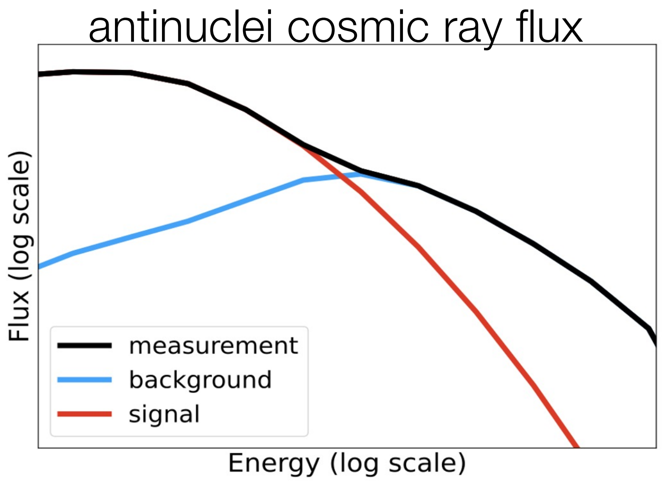

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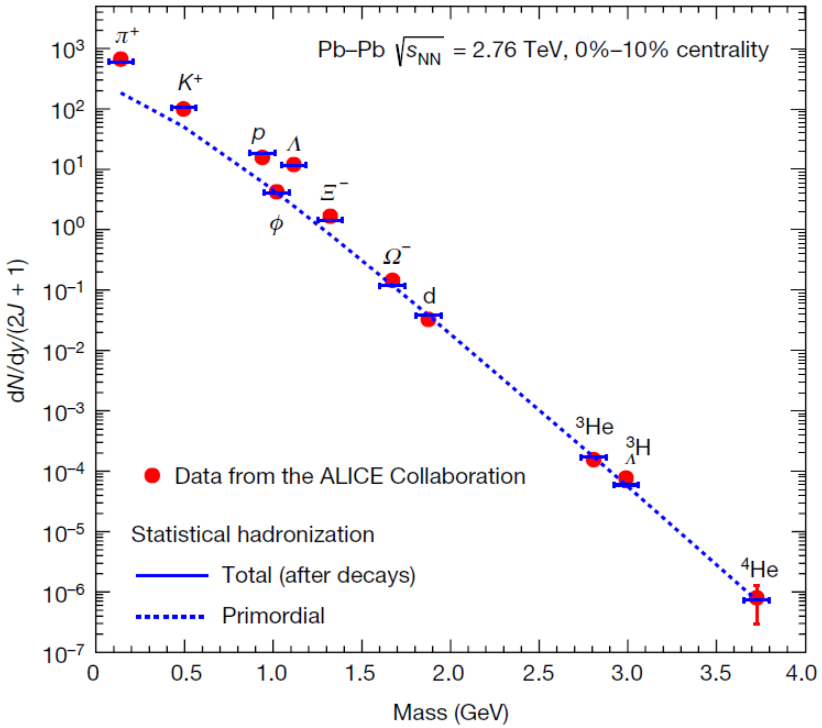
Modelling the production of (anti)nuclei

Statistical models (SHM)

- Hadrons emitted statistically from a source in local chemical equilibrium
- $dN/dy \propto \exp(-m/T_{chem})$
- $T_{chem} \approx 156$ MeV



Andronic et al., Nature 561, 321–330 (2018)

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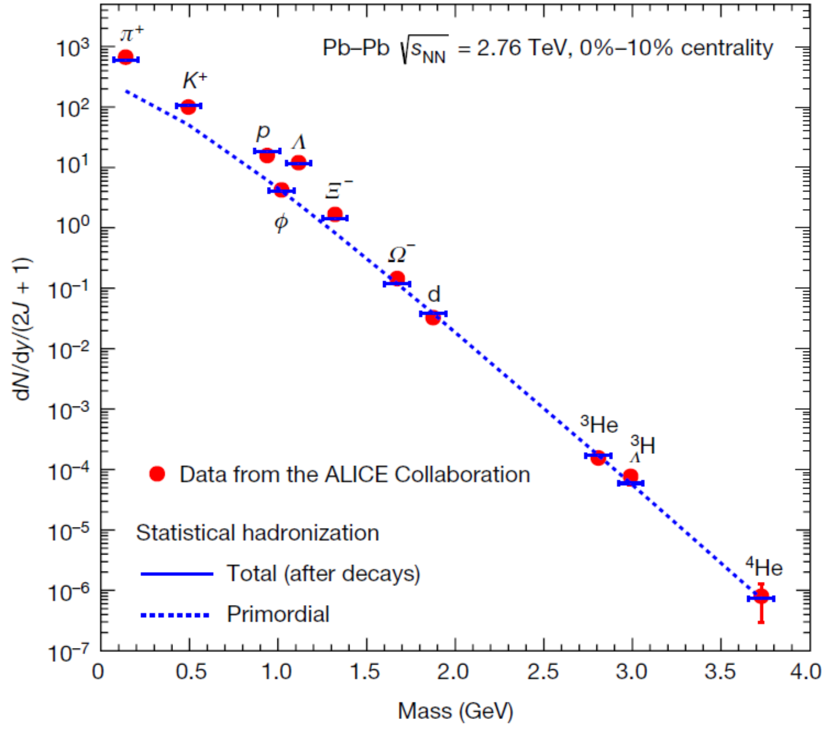
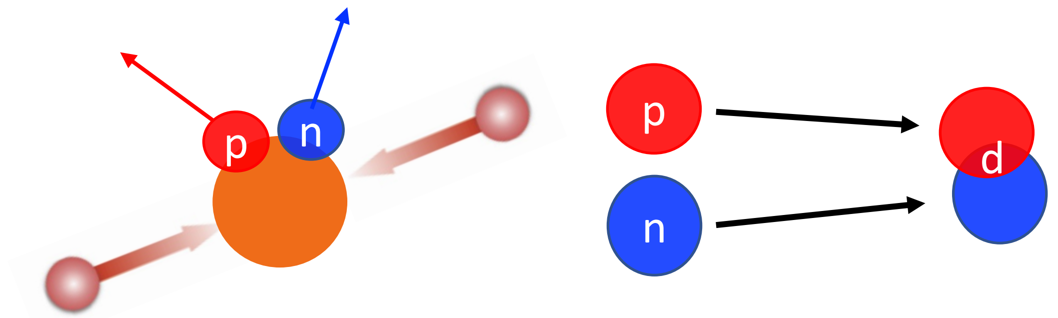


Andronic et al., Nature 561, 321–330 (2018)

Coalescence models

- (Anti)nuclei arise from the overlap of the (anti)nucleons phase-space distributions with the Wigner density of the bound state
- Microscopic description



- Coalescence parameter B_A connected to coalescence probability

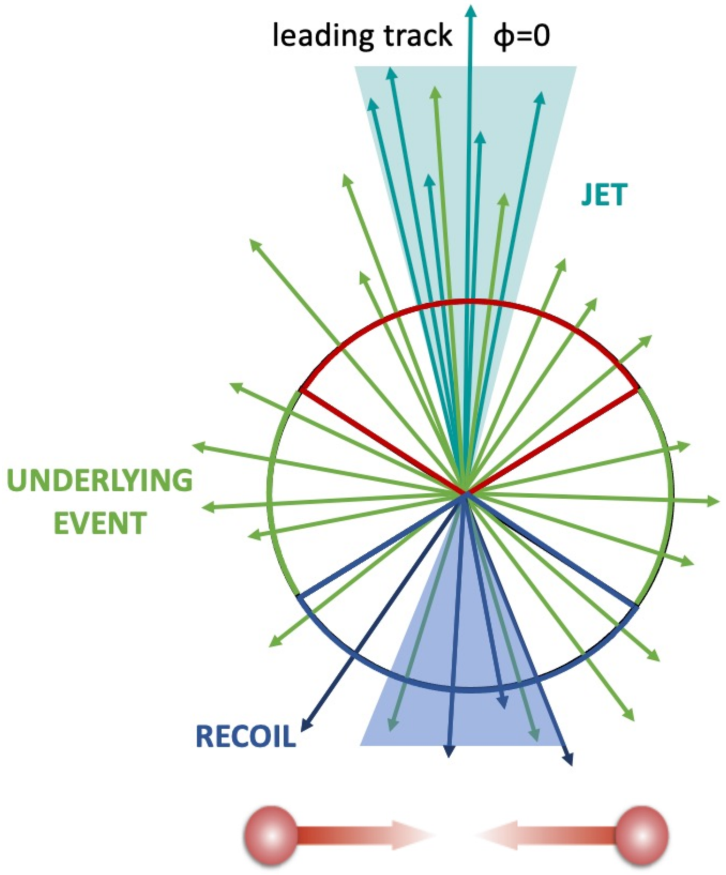
$$B_A(p_T^p) = E_A \frac{d^3 N_A}{d\,p_A^3} \Bigg/ \left(E_p \frac{d^3 N_p}{d\,p_p^3} \right)^A \Bigg|_{p_T^p = p_T^A / A}$$

Butler et al., Phys. Rev. 129 (1963) 836
Mahlein et al., arxiv:2302.12696

Nuclear production in and out of jets

- Powerful tool to investigate coalescence mechanism is the study of nuclear production in and out of jets
- In jets nucleons are created close to each other in phase-space

→ **Study B_2 in and out of jets**: jets obtained simply by subtracting the UE from the Toward region (Jet + UE)



Toward: $|\Delta\phi| < 60°$

Transverse: $60° < |\Delta\phi| < 120°$

Away: $|\Delta\phi| > 120°$

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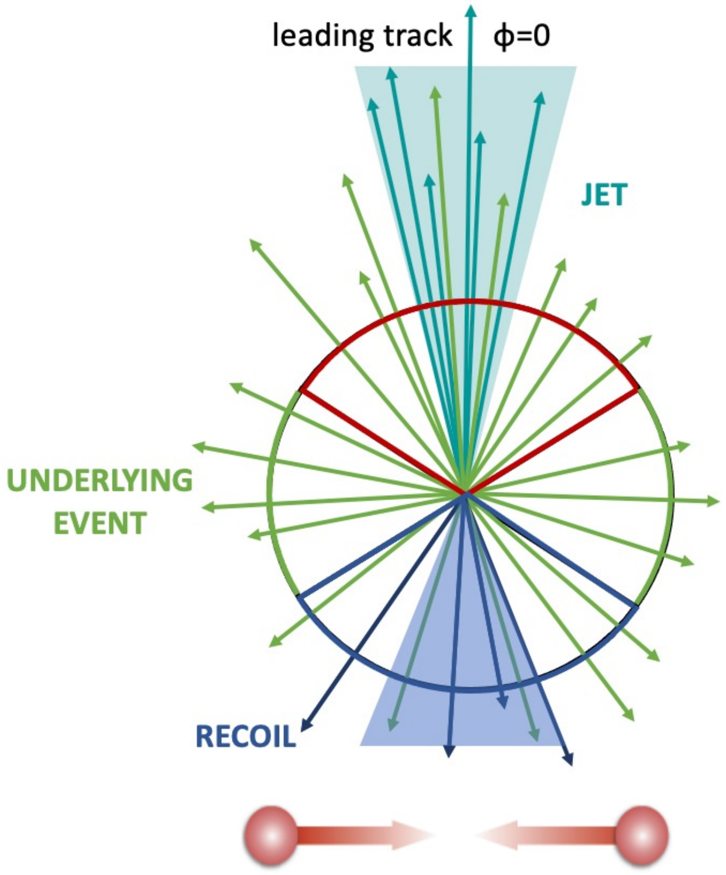
- Studying the antideuteron production in jets in small systems (pp, pA) is important to understand and model nuclear production
- Production models are crucial to study cosmic rays
- Antideuteron in the Galaxy is produced in interactions of cosmic rays (p, ^{4}He) with kinetic energies of ~300 GeV



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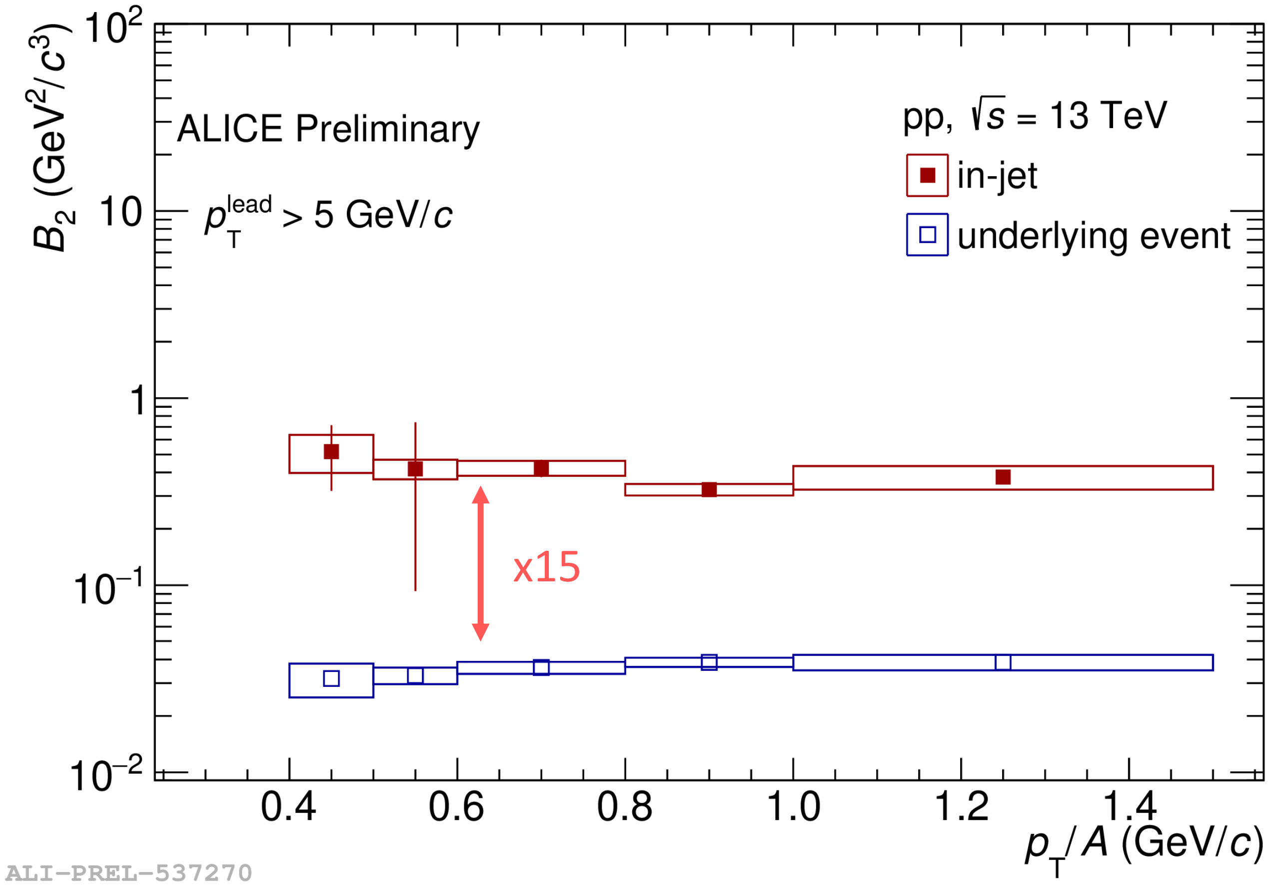
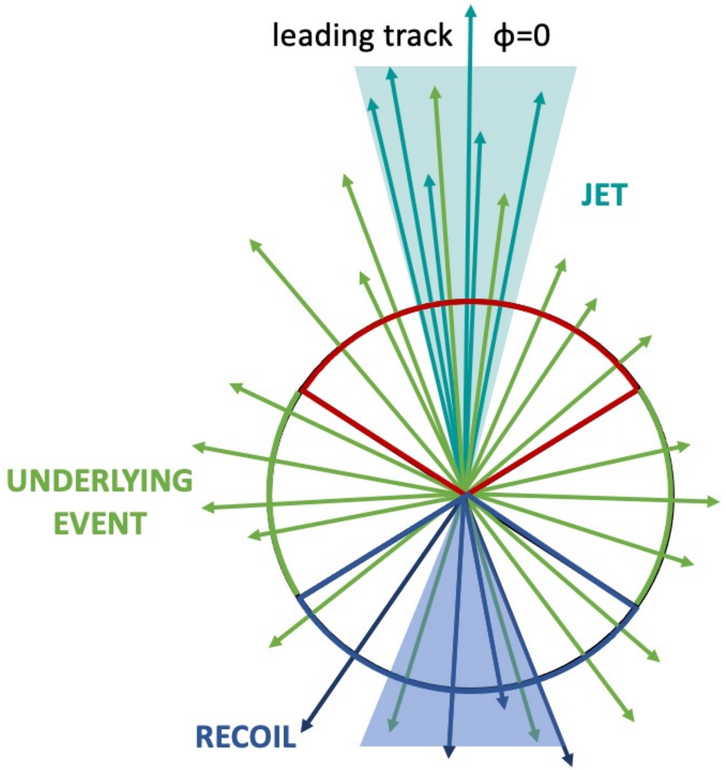
Serksnyte et al., Phys. Rev. D 105 (2022) 8, 083021

Coalescence parameters in and out of jets





- *Enhanced deuteron coalescence probability in jets wrt UE is observed for the first time in pp collisions*
- Due to the reduced distance in phase space of hadrons in jets compared to those out of jets → favors coalescence picture

Phys.Rev.Lett. 131 (2023) 4, 042301

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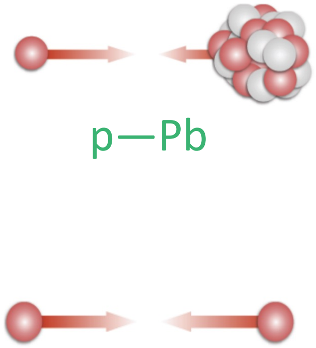
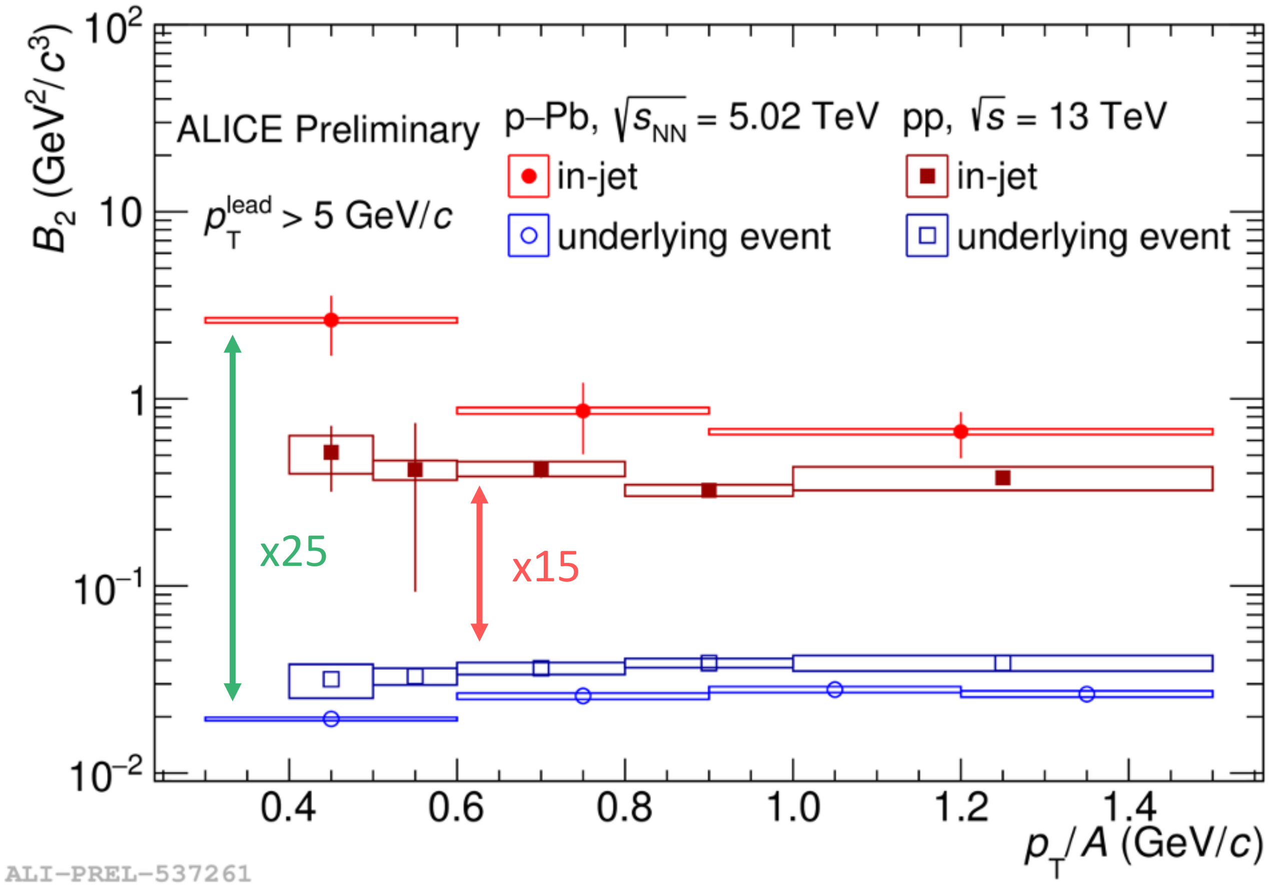
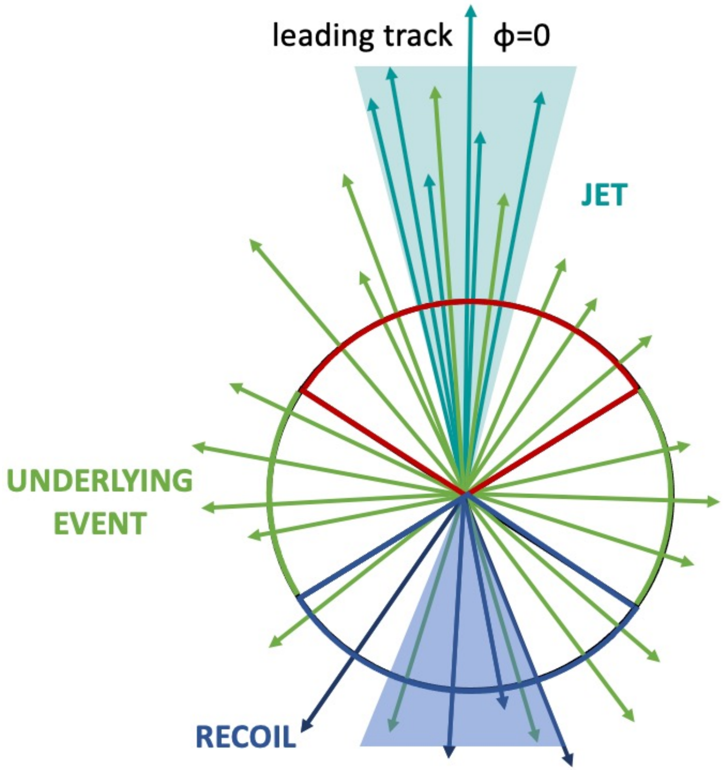


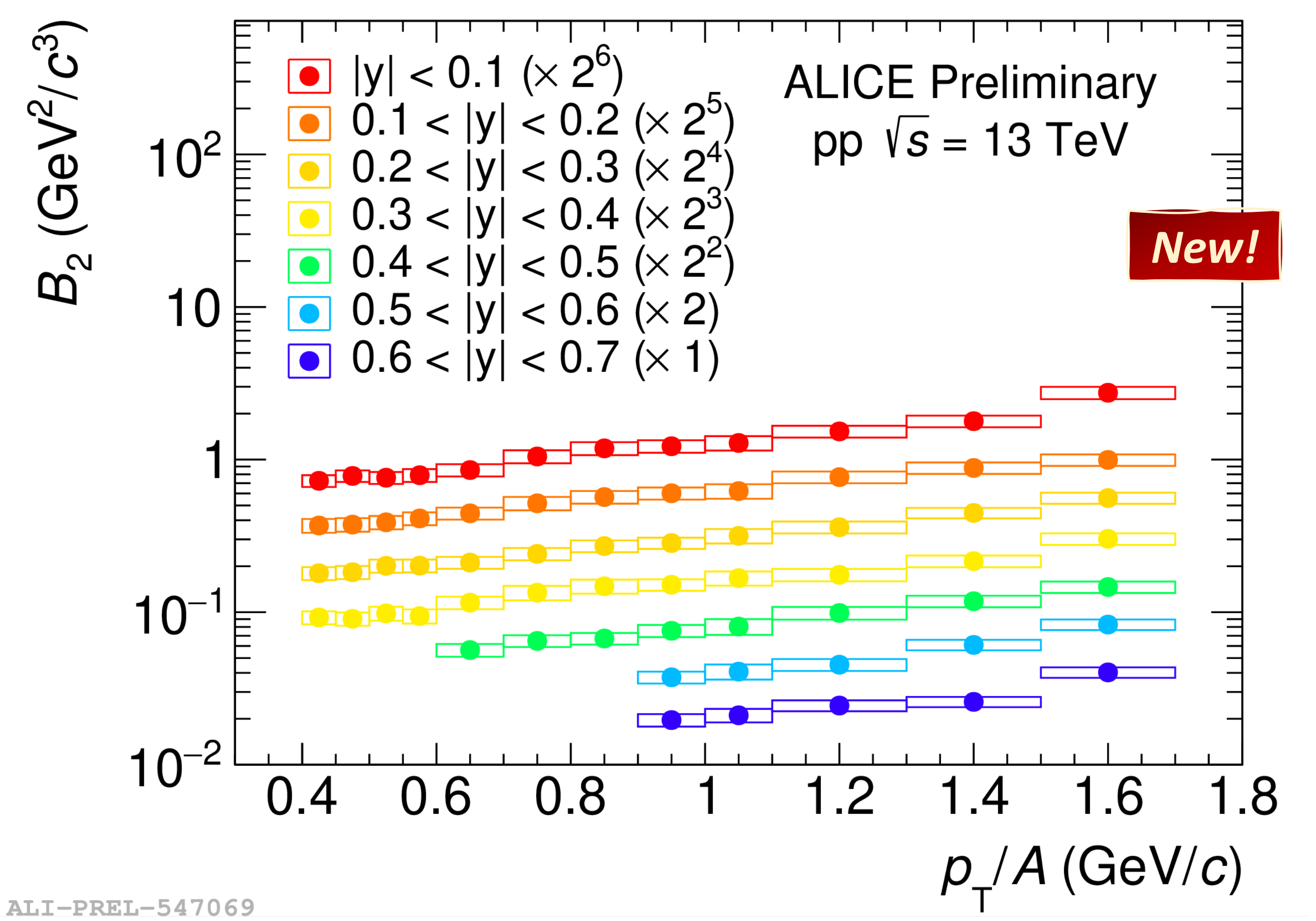




- B_2 in-jet in p—Pb is larger than B_2 in-jet in pp
  → *could be* related to the different particle composition of jets in pp and p—Pb
- B_2 in UE in p—Pb is smaller than B_2 in UE in pp due to the larger source size in p—Pb
  (pp(1): r_0~ 1 fm, p—Pb(2): r_0~ 1.5 fm)

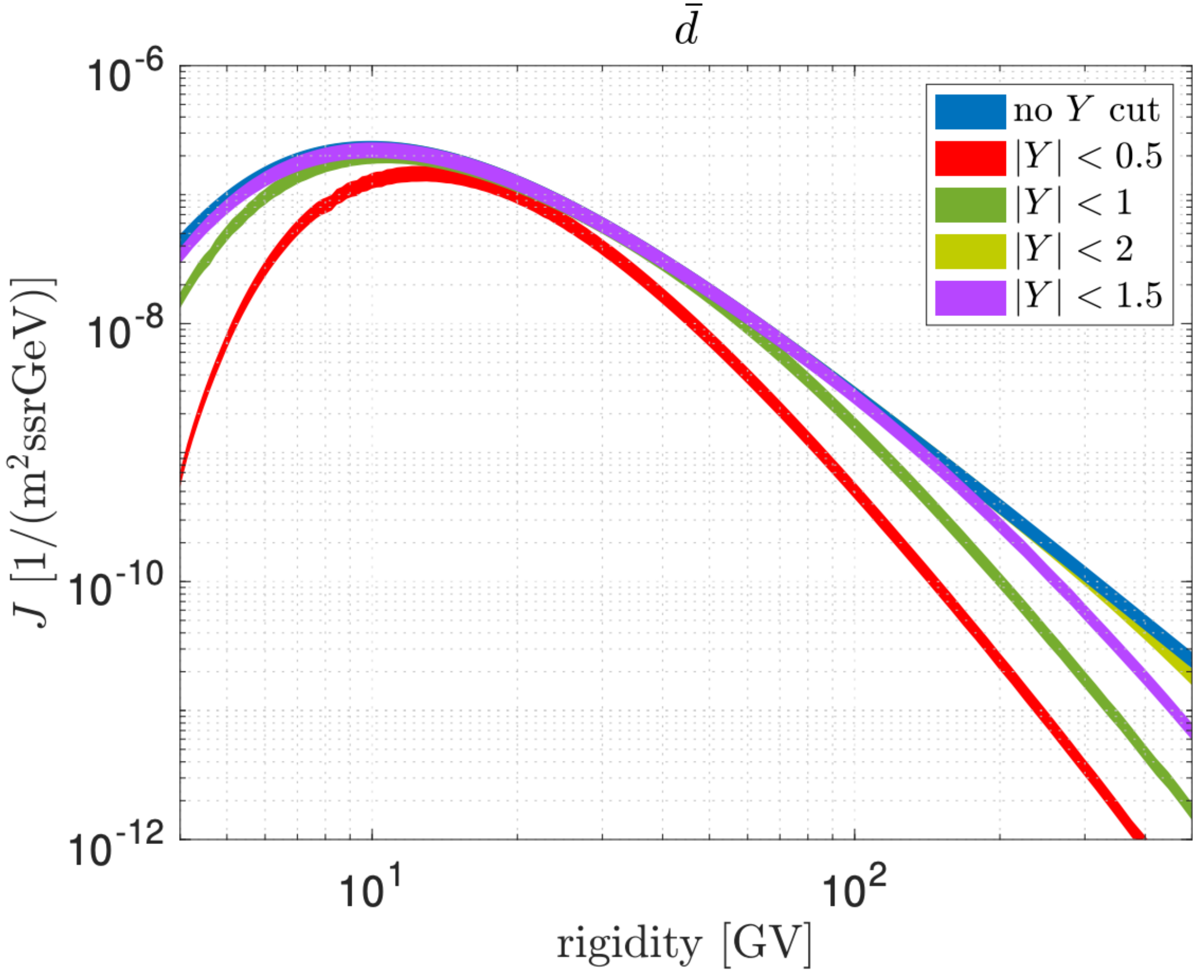
1 Phys.Rev.C 99 (2019) 024001
2 Phys.Rev.Lett. 123 (2019) 112002
Phys.Rev.Lett. 131 (2023) 4, 042301

Coalescence parameter vs. rapidity



- ALICE measurements cover the midrapidity region (|y|<0.5), while astrophysical models extrapolate to forward region
- Current acceptance of ALICE detector allows us to extend the measurement of antinuclei up to y = 0.7
- Rapidity and p_T dependence of B_2 is extrapolated to forward rapidity using coalescence model + Pythia 8.3 and EPOS as event generators

Antideuteron flux predictions vs. *y*



- Model predictions based on ALICE measurements are used as input to calculate antideuteron flux from cosmic rays* → dominant background in dark matter searches

- Most of the antideuteron yield from $|y| < 1.5$ → well in reach with future ALICE3[(1)] detector acceptance ($|y| \lesssim 4$)

Production models needed in astrophysics
→ Rapidity coverage is in reach of accelerator experiments
→ Extrapolation to lower energies (~GeV) is needed

K. Blum, arxiv:2306.13165
* K. Blum, Phys.Rev.D 96 (2017) 10, 103021
1 arXiv:2211.02491

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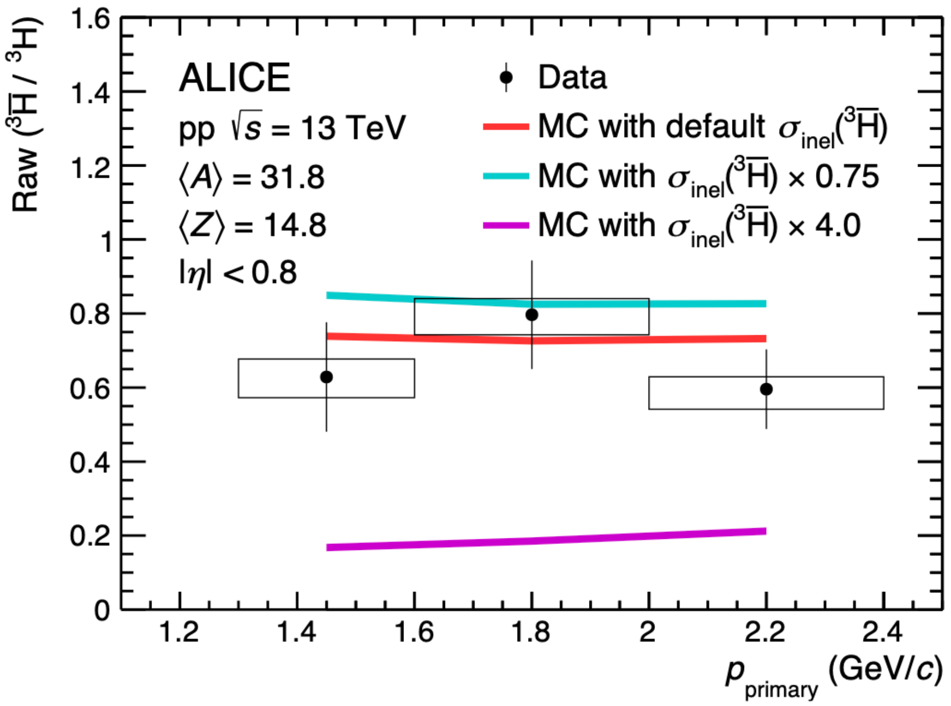
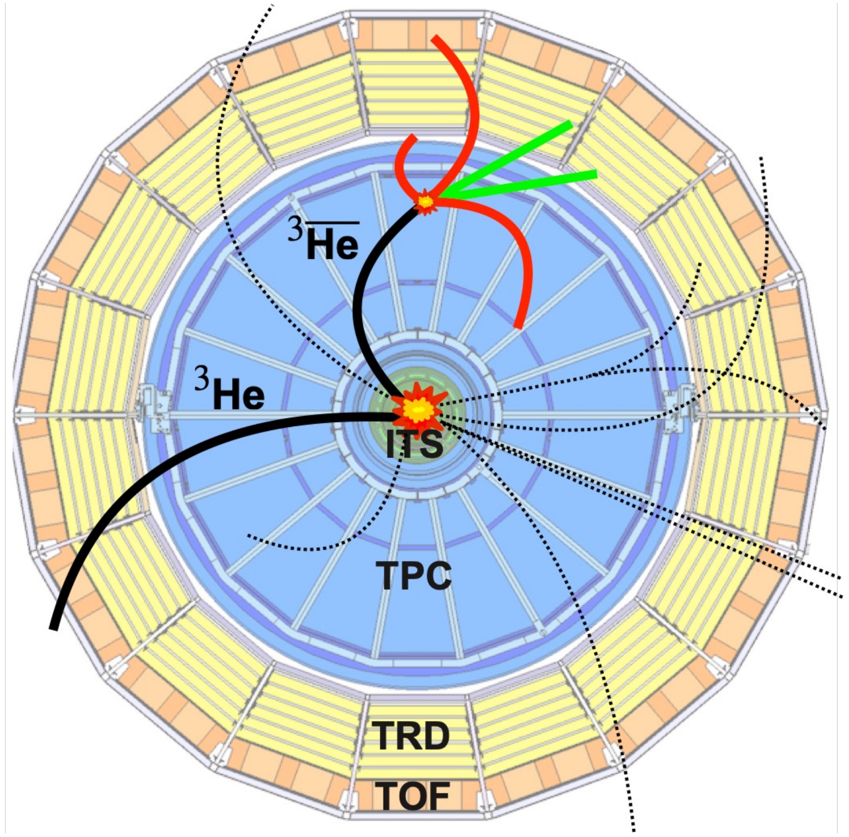
Antimatter-to-matter ratio

- Measurement of reconstructed **anti^{3}H/^{3}H** ratio and compare to MC simulation expectations





Phys.Rev.Lett. 125, 162001 (2020)
arXiv:2307.03603 [nucl-ex]

New!

Sketch adapted from: Nature Phys. (2023) 19, 61–71

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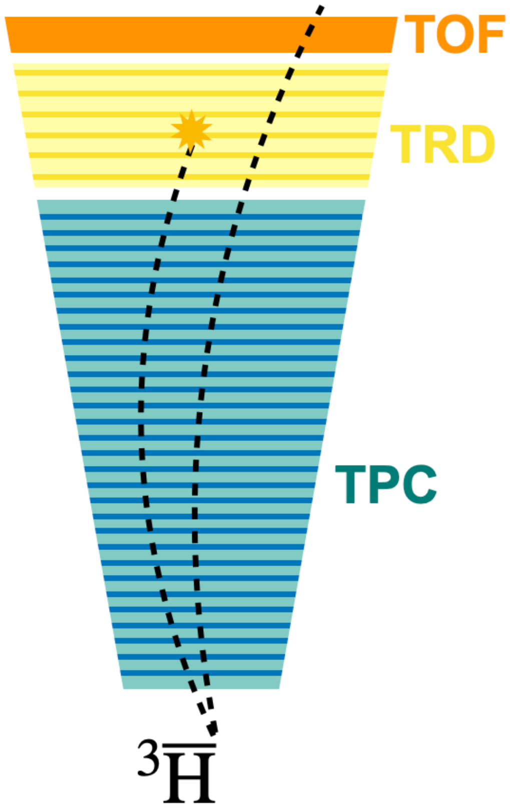

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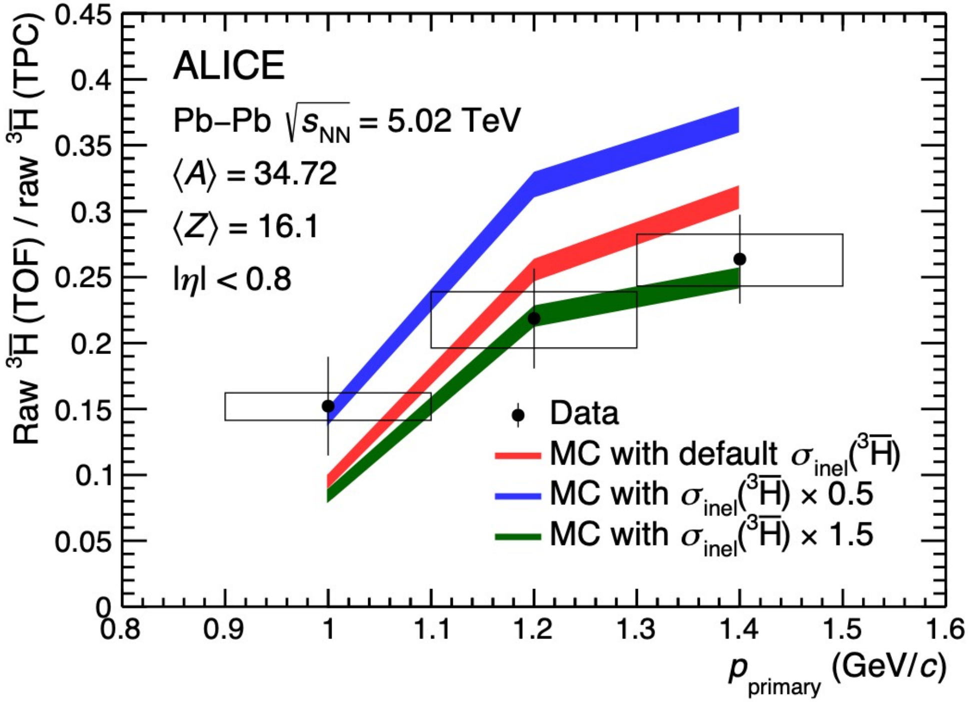

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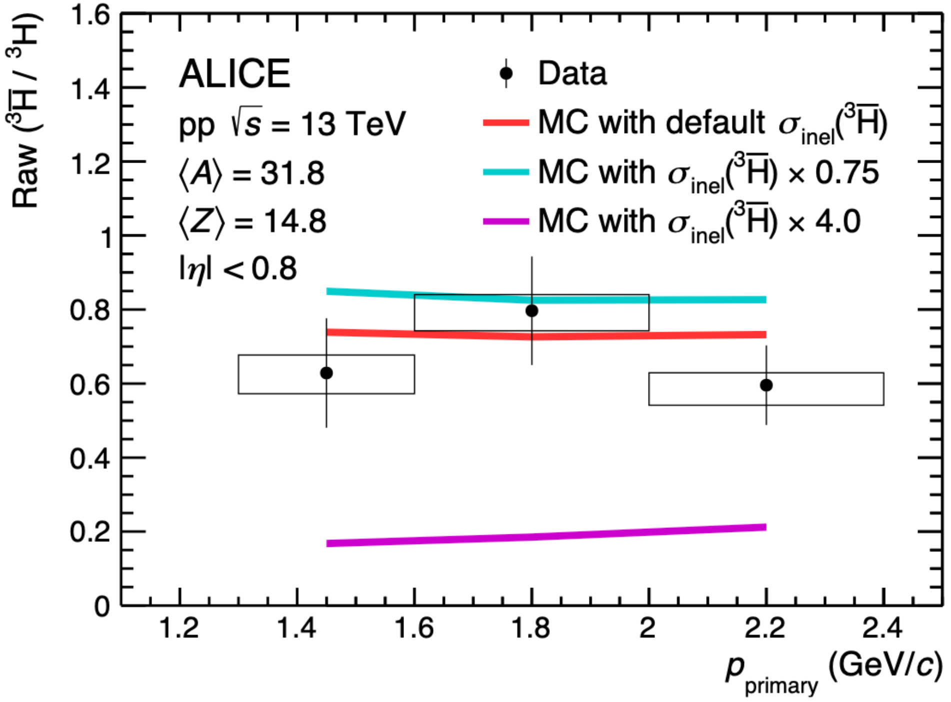

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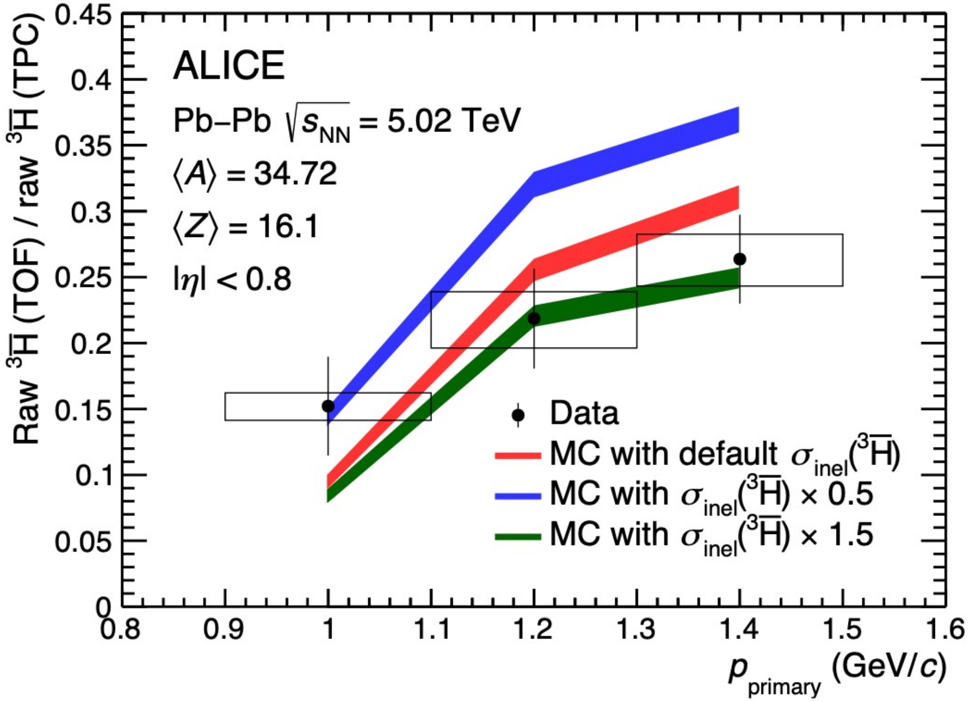

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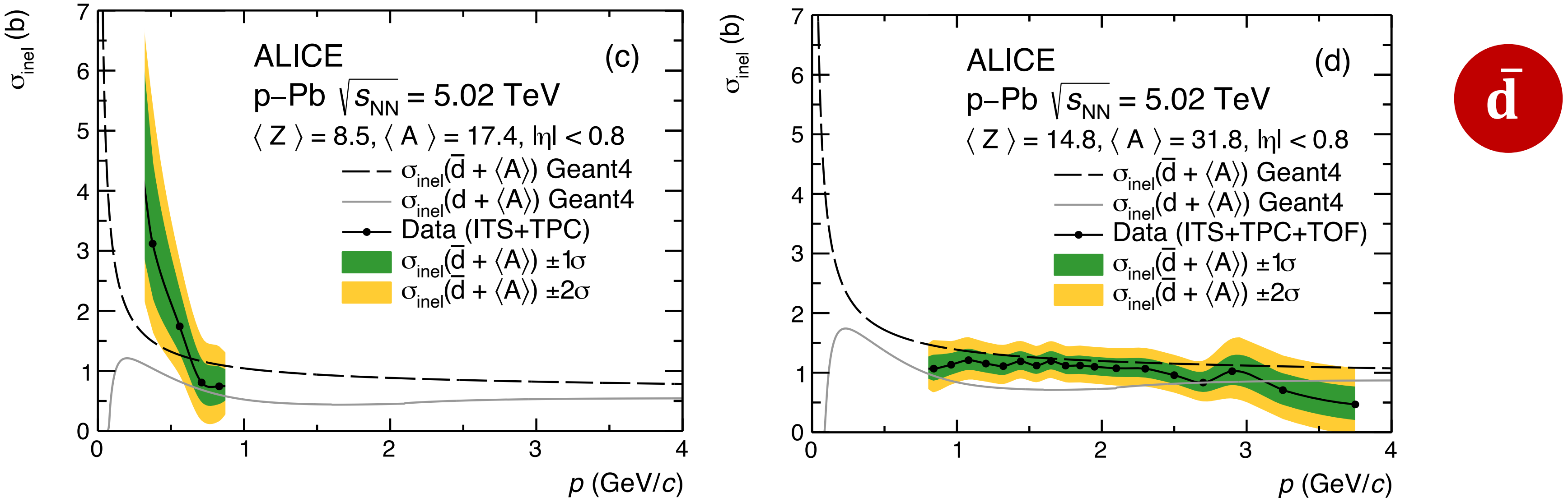

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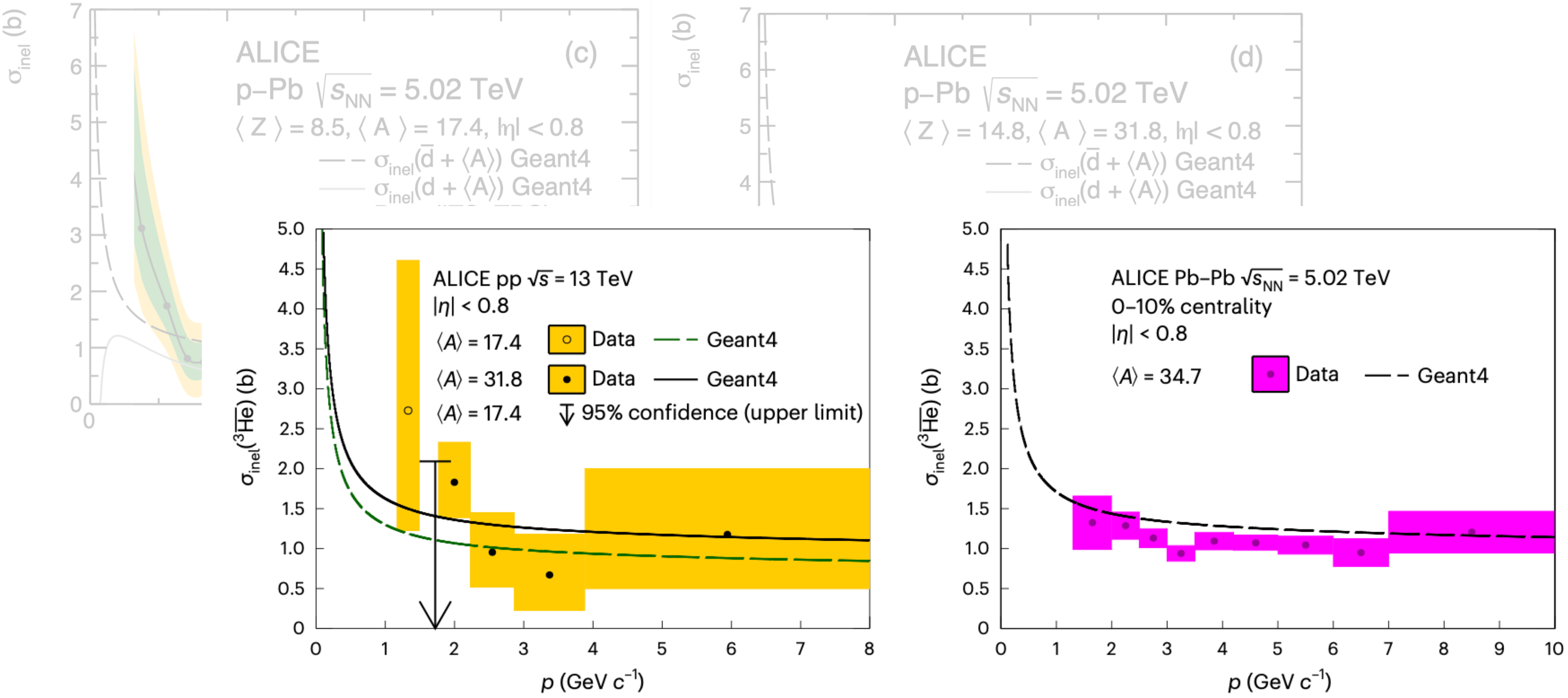

$^{3}\overline{\mathrm{He}}$

antid: Phys.Rev.Lett. 125, 162001 (2020)

anti^{3}He: Nature Phys. (2023) 19, 61–71

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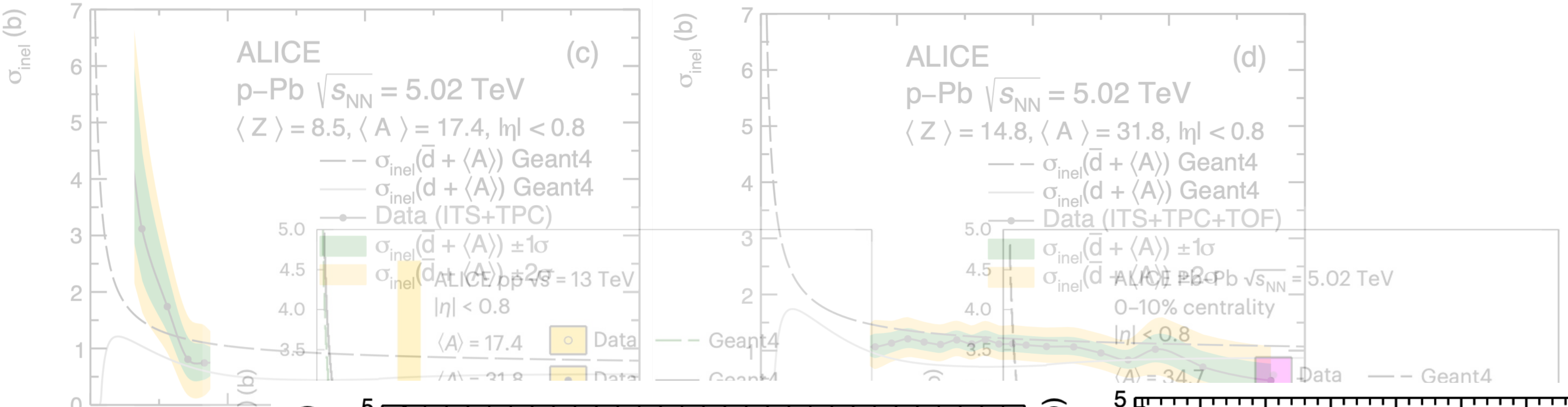

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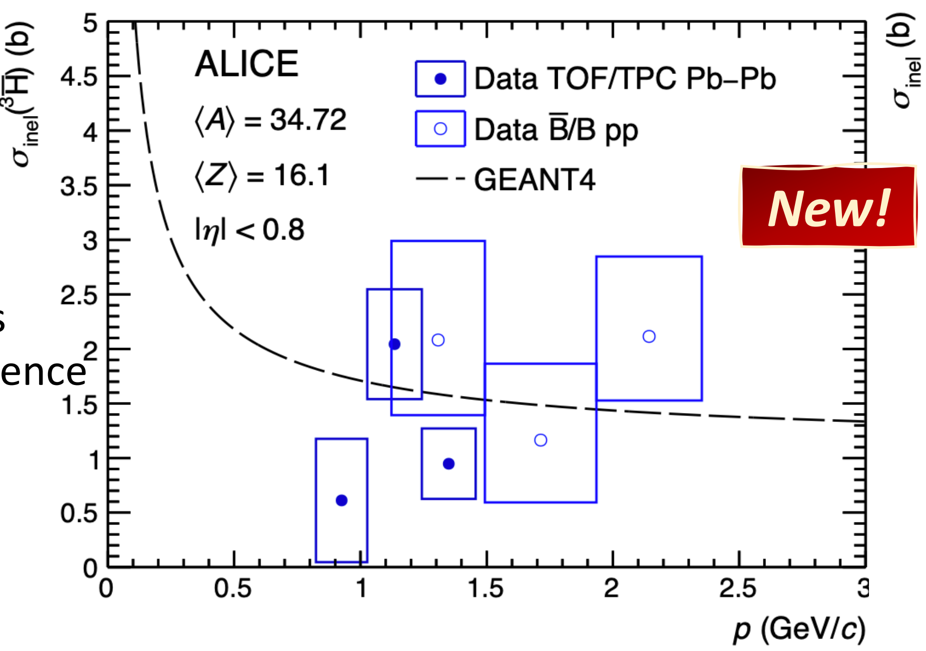

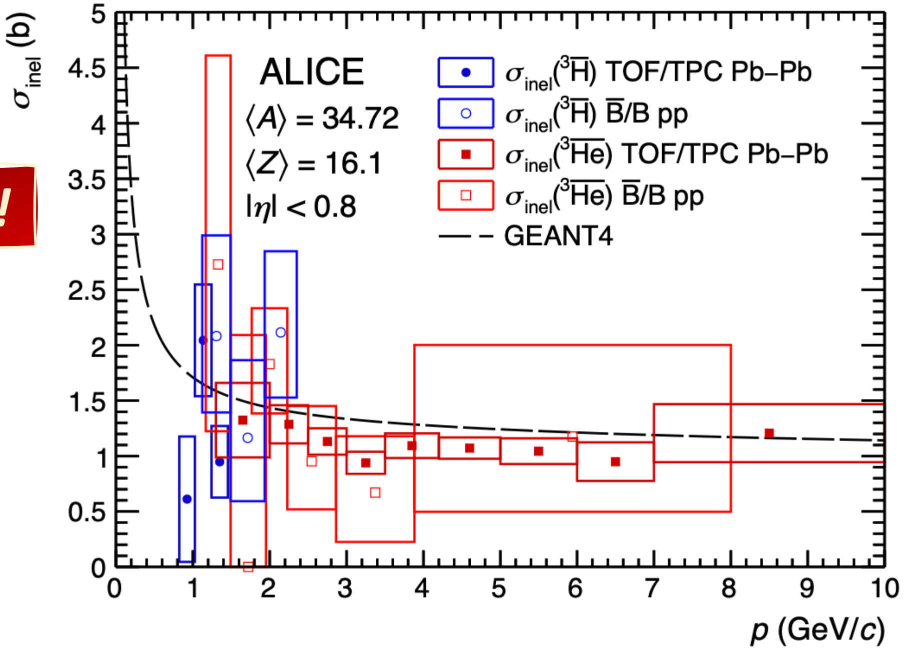

→ Complements previous measurements
→ Allows for the study of isospin dependence
→ Extends the *p* range of $^{3}\overline{\mathrm{He}}$

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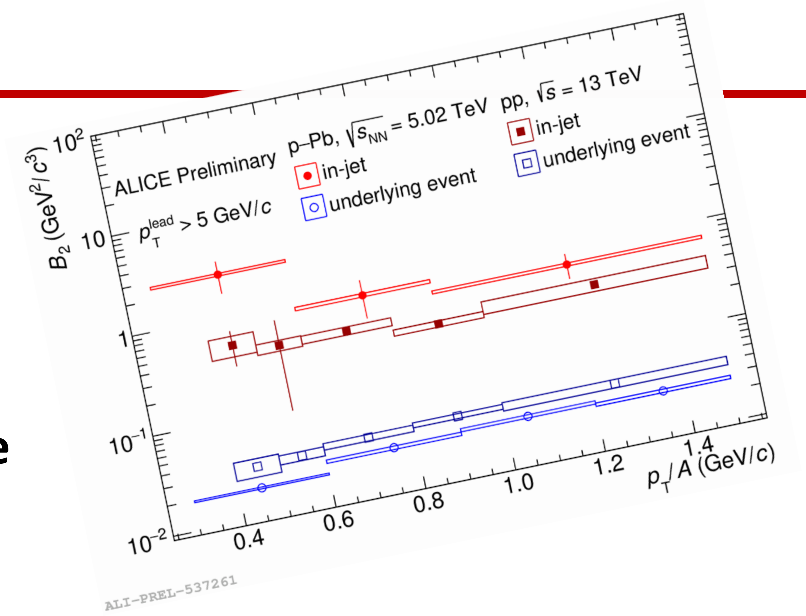

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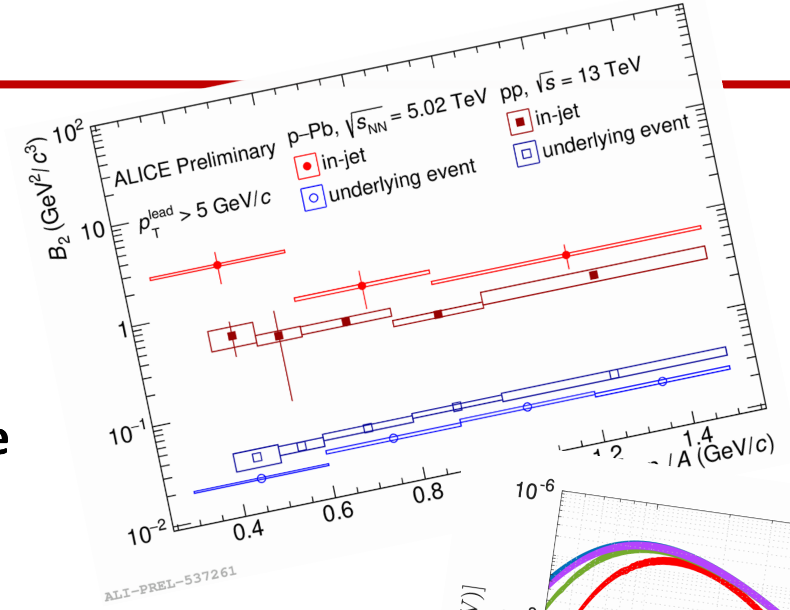

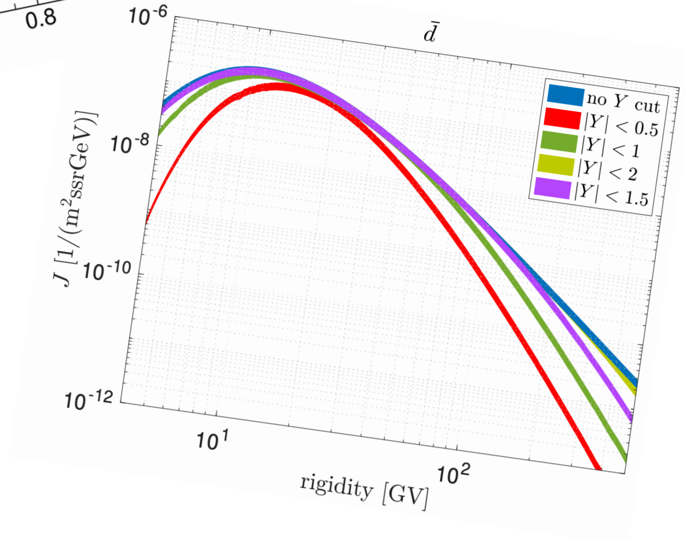

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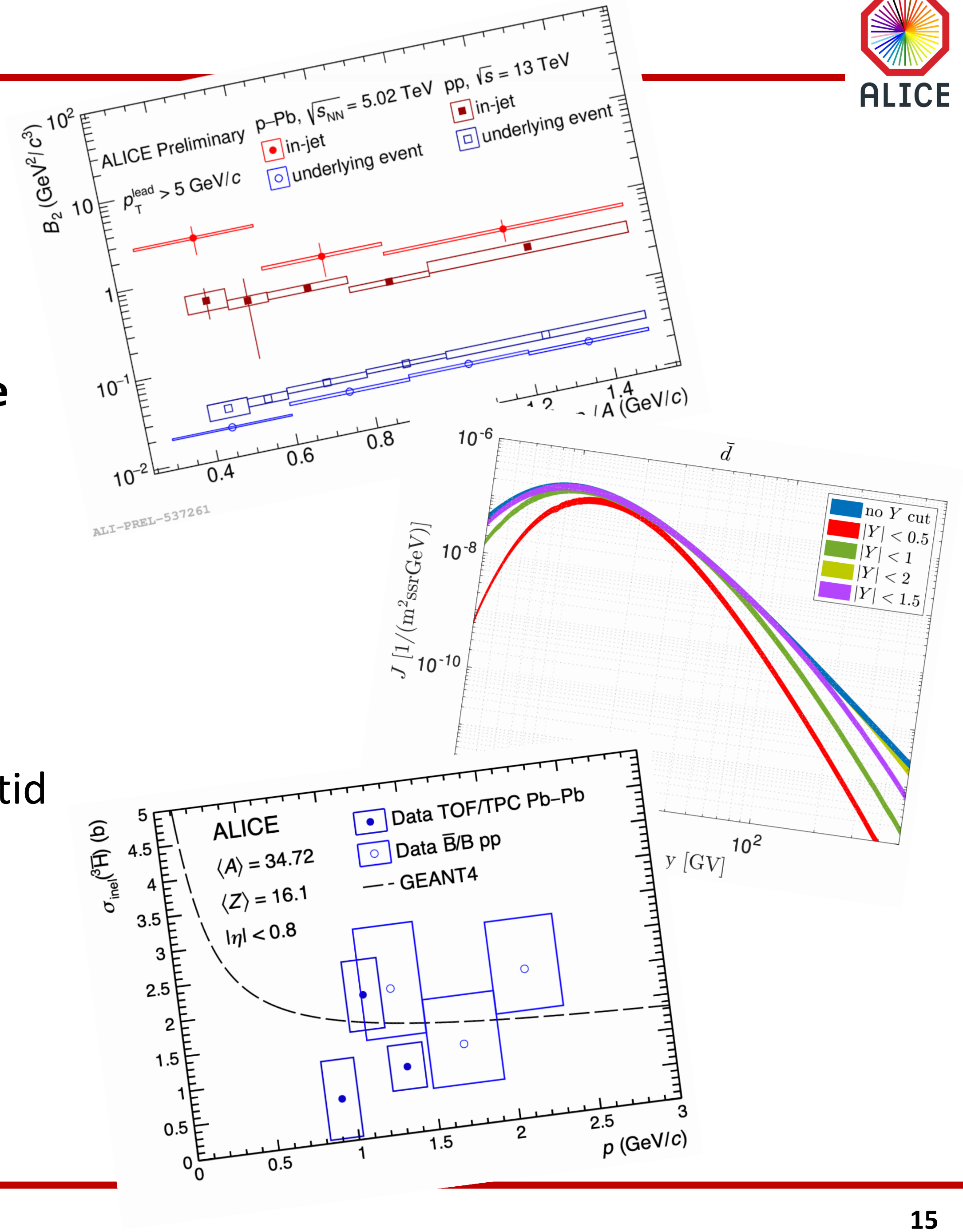

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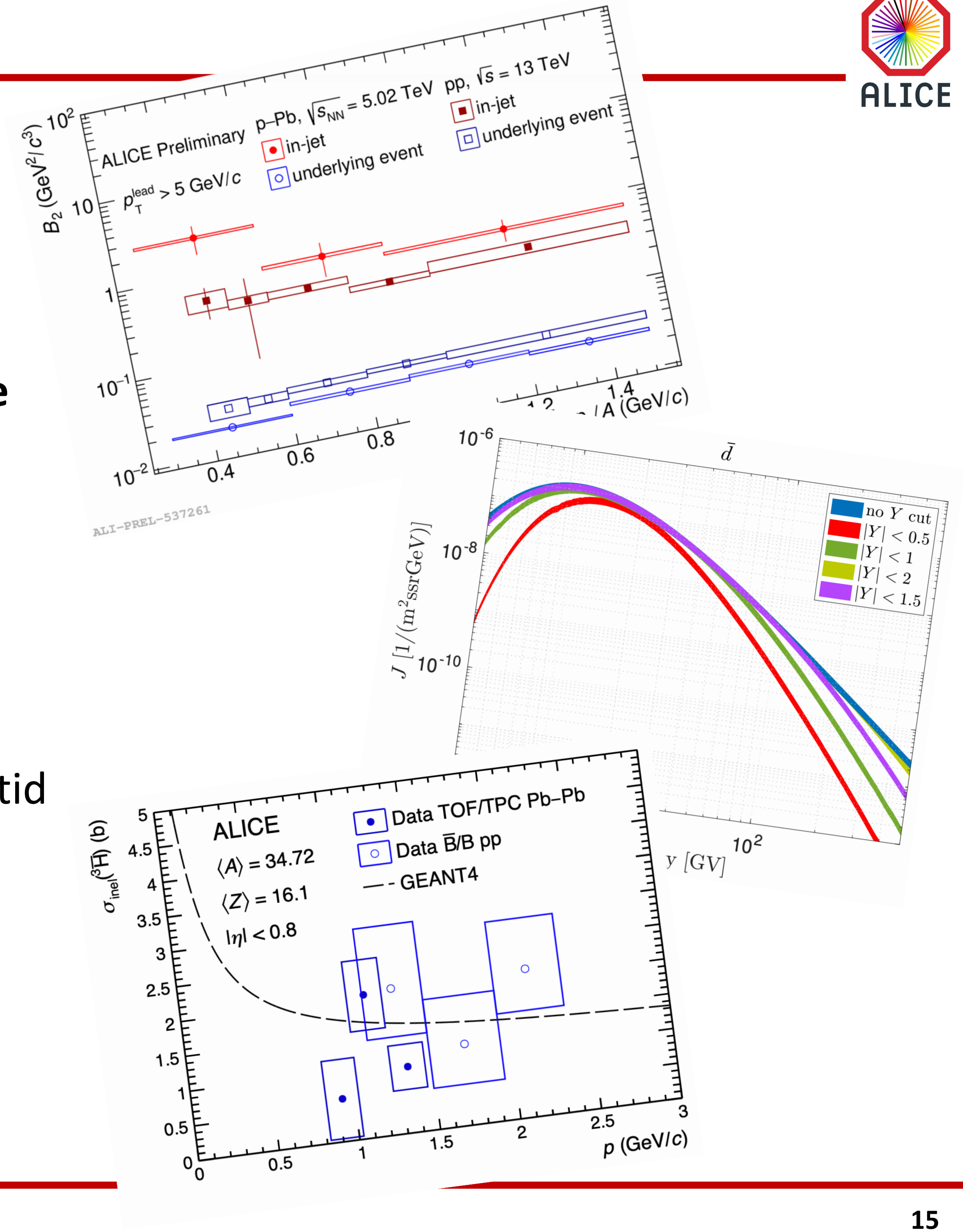
I. Vorobyev's talk
Wed. 8:50



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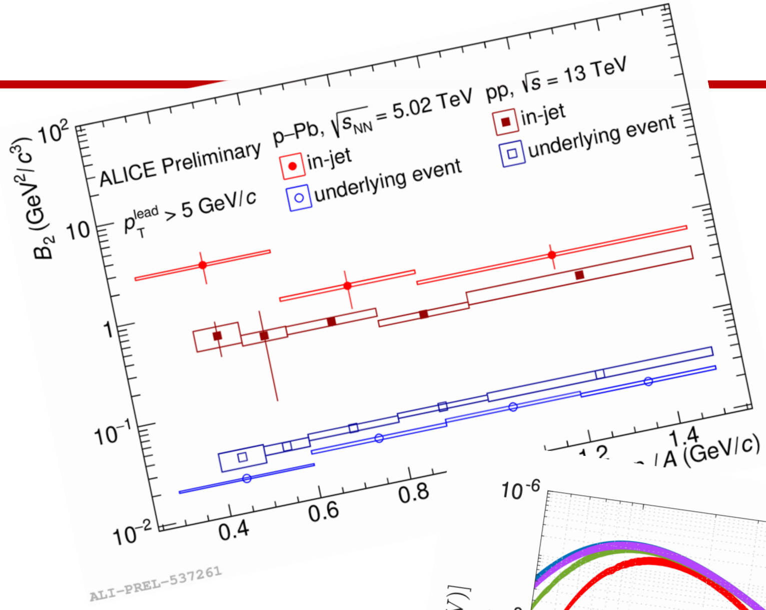
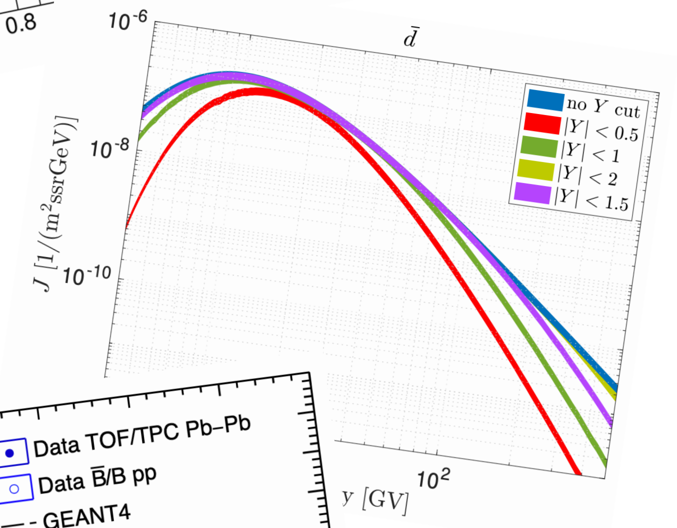
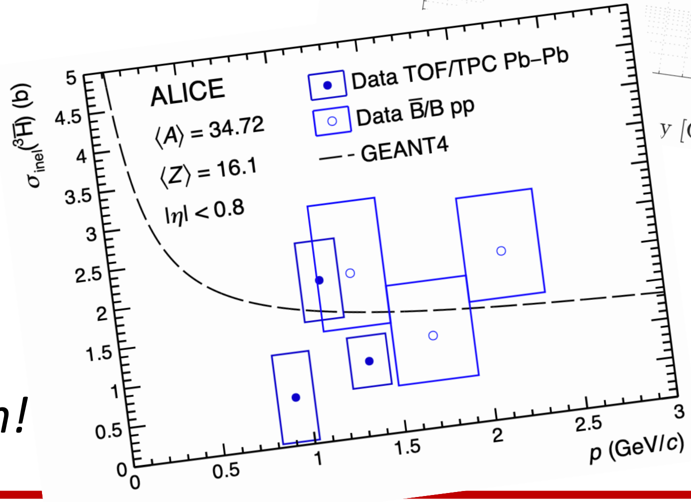


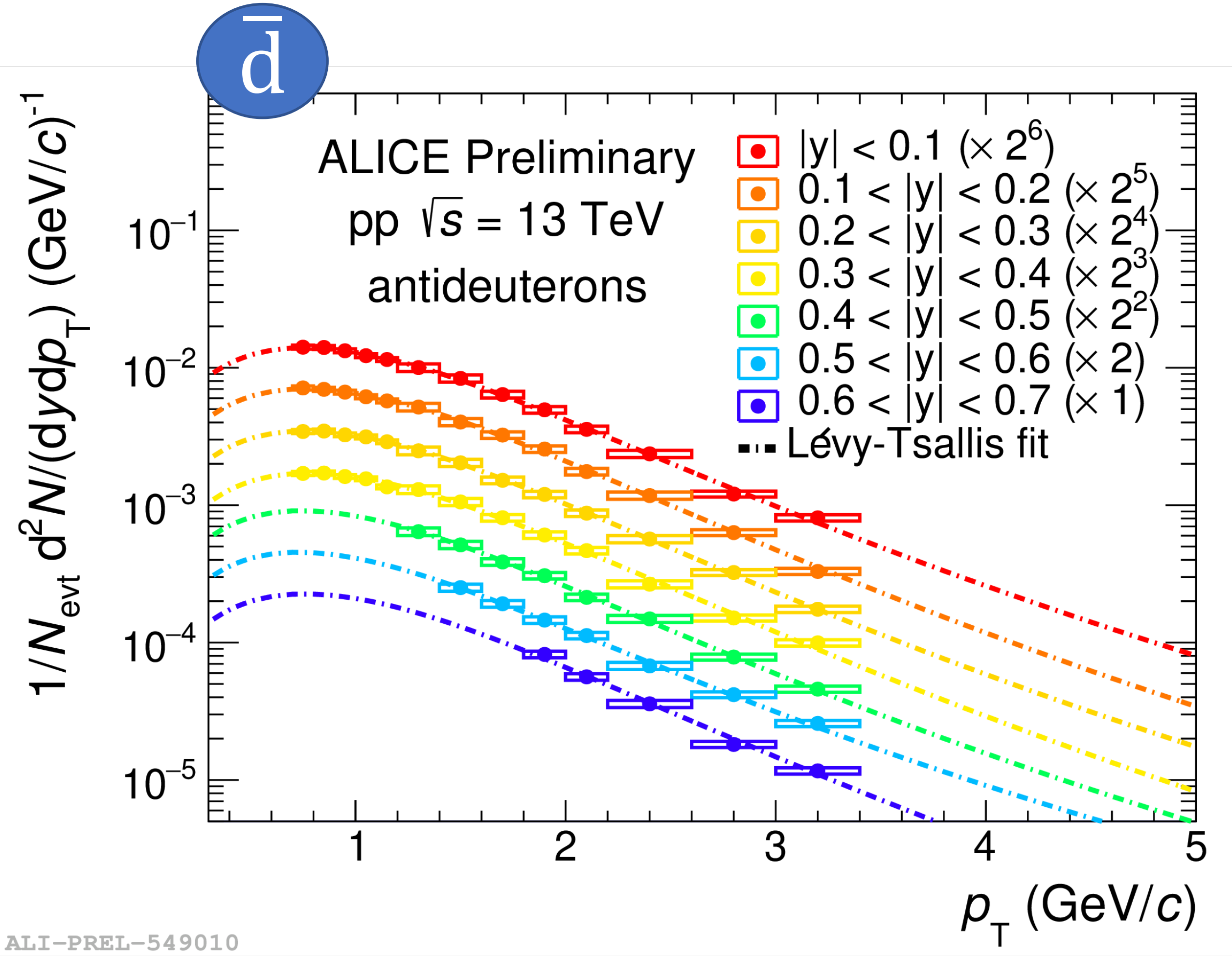


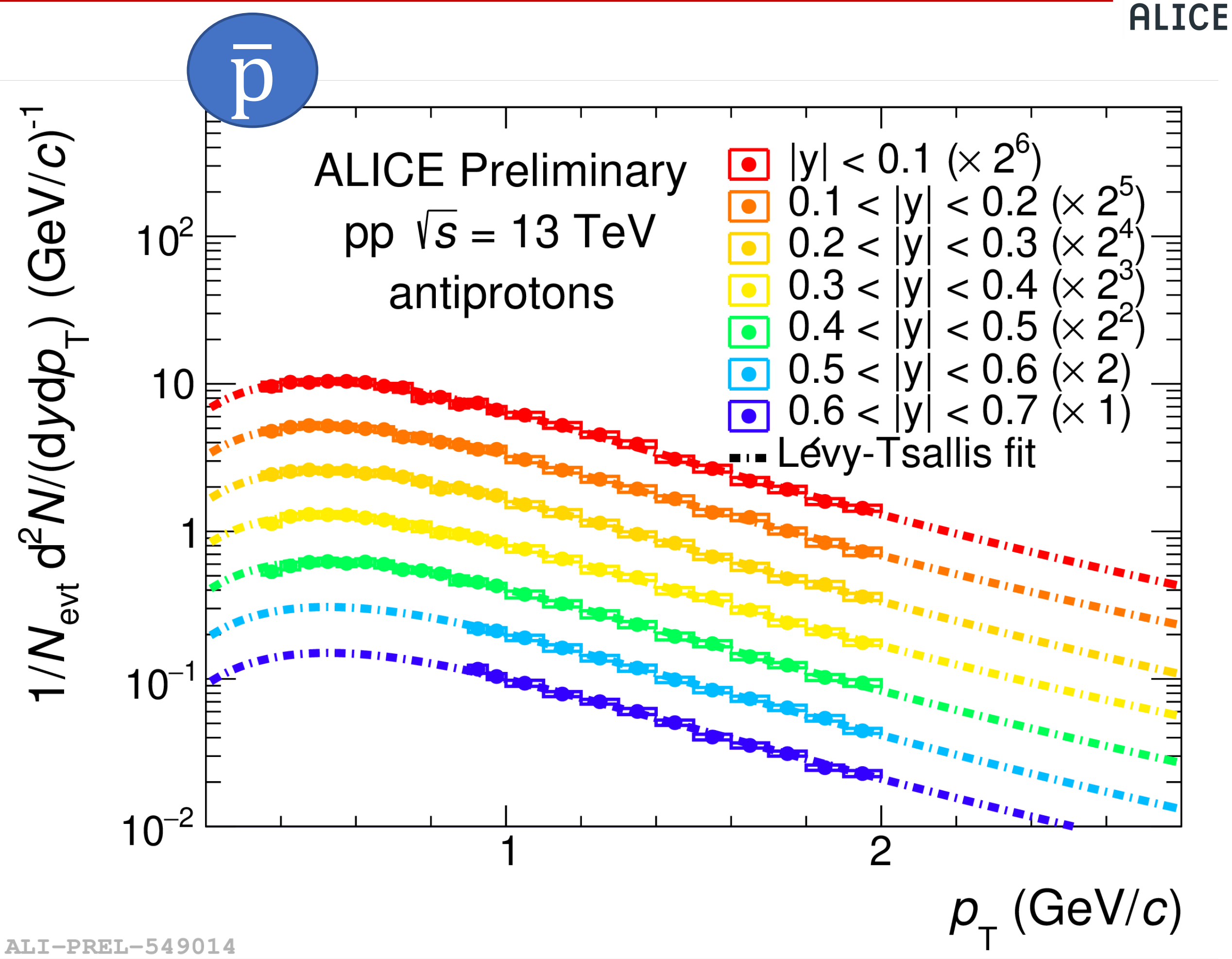


Thank you for your attention!

Backup

Spectra as a function of rapidity

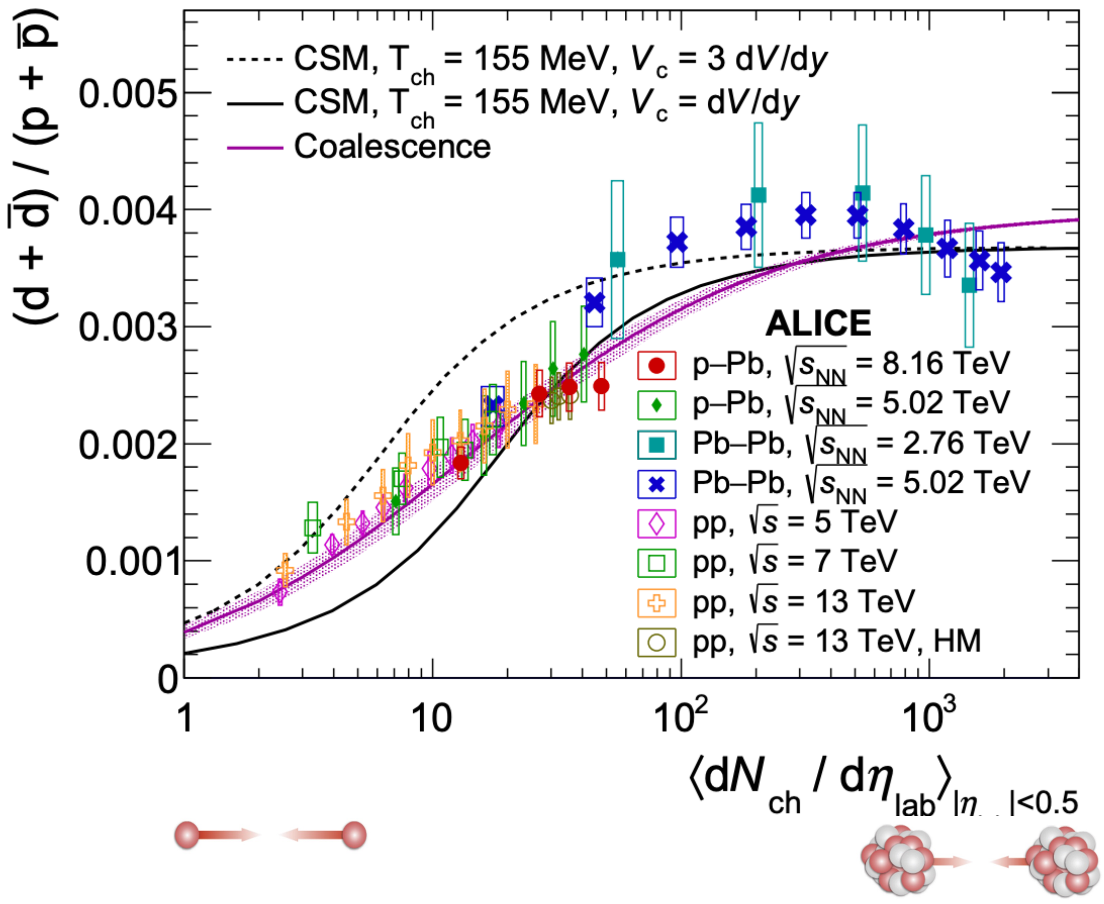


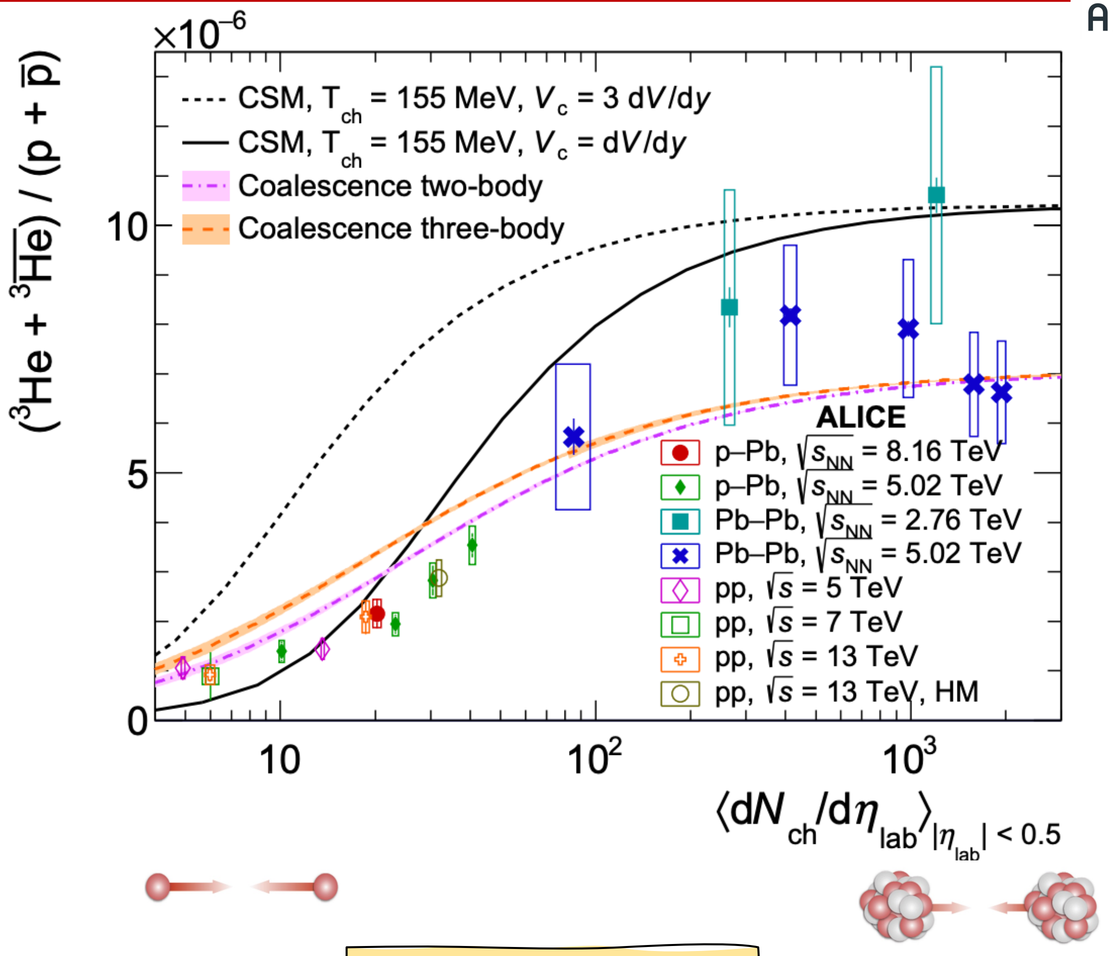


- Current acceptance of ALICE detector allows to extend the measurement of antinuclei up to $y = 0.7$
- All rapidity classes show a common trend with y, for both species (ratio to $|y| < 0.1$ is ~1)

New!

Production of (anti)nuclei





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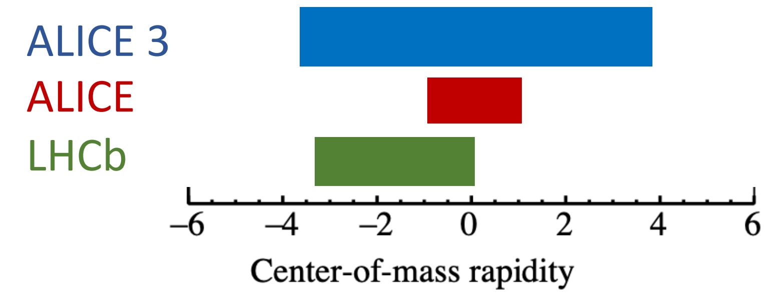
- Production of (anti)nuclei has been extensively measured by ALICE
- Coalescence model describes well the data for A = 2, 3
- ALICE measurements cover the midrapidity region (|y|<0.5), while astrophysical models extrapolate to forward region

arxiv:2212.04777

Strategy

IDEA

- Study of rapidity dependence of antiprotons and antideuterons
- Coalescence parameter B_2 as a function of rapidity
- Comparison with a simple coalescence model

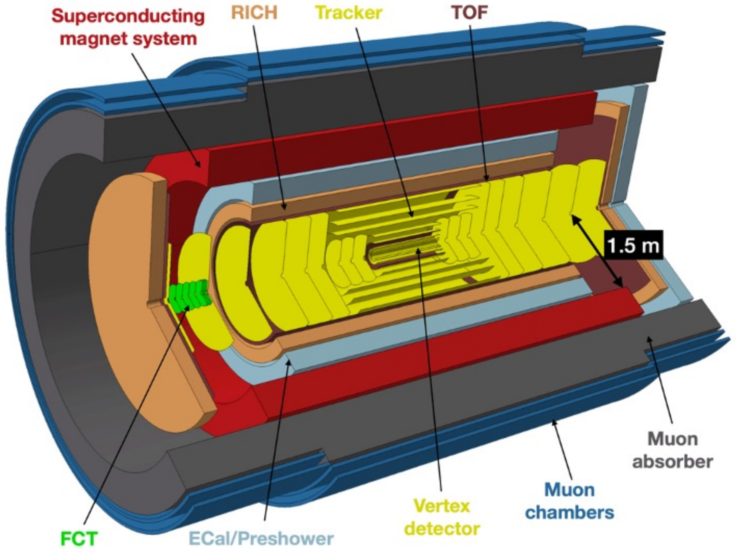


DATASET

- pp collisions @ 13 TeV, full 2016 + 2017 + 2018 ESD tracks
- ~ $1.6 \cdot 10^9$ events (after selection cuts)

MC (JIRA)

- 2016 pp, 13 TeV - Pythia8 Monash2013 + injected (hyper)nuclei – based on G4



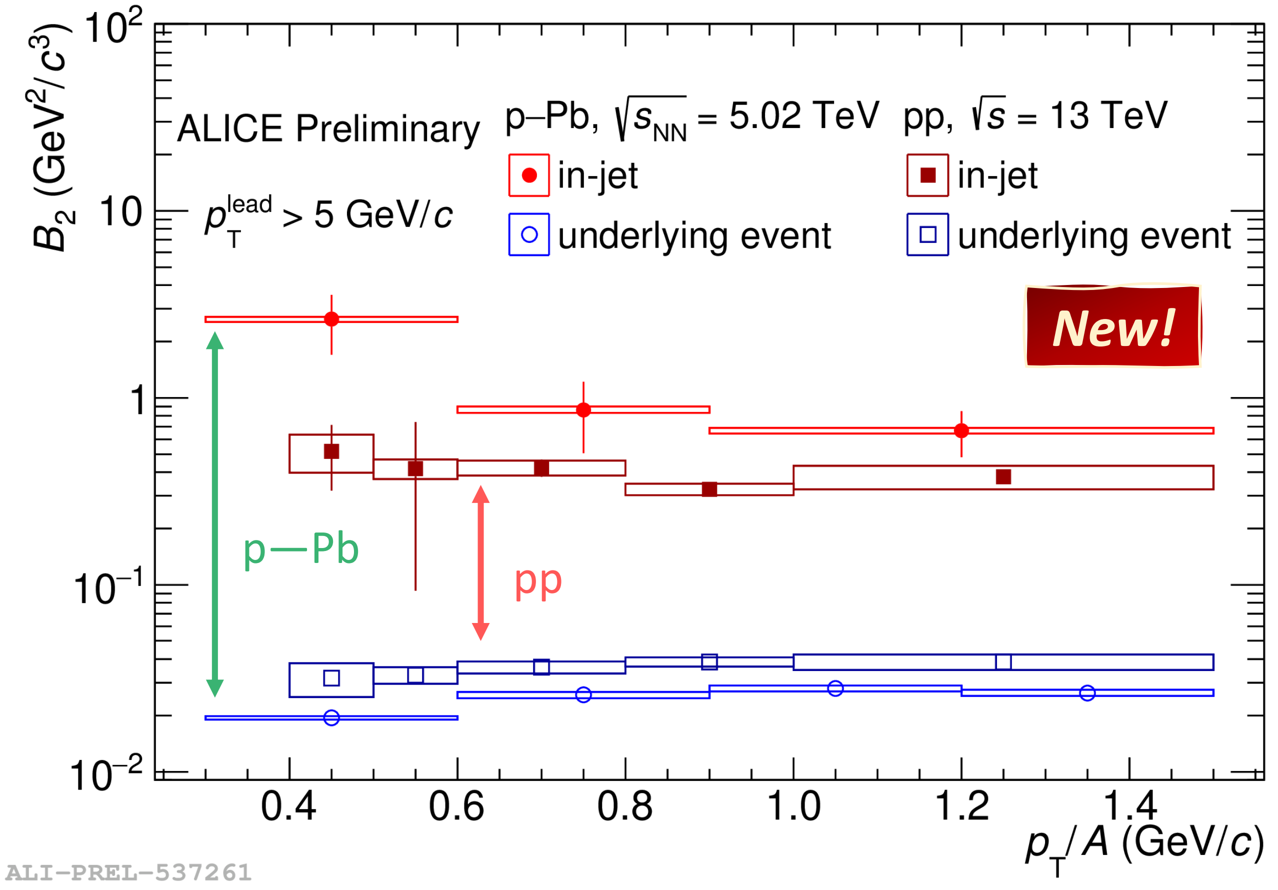
RESULTS

- Measurements up to y=0.7
- y-differential measurements will be possible with ALICE 3 (rapidity coverage → $|y| \lesssim 4$) (eprint:1902.01211 [physics.ins-det])

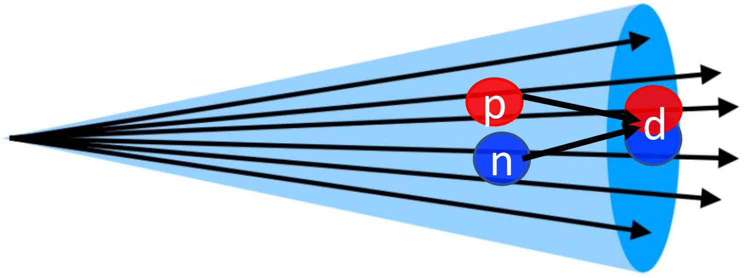
Analysis Note

Coalescence parameters in and out of jets

ALICE



- B_2 in-jet even more enhanced than B_2 in UE in p—Pb collisions (factor ~25)
- B_2 in-jet in p—Pb is larger than B_2 in-jet in pp → *could be* related to the different particle composition of jets in pp and p—Pb
- B_2 in UE in p—Pb is smaller than B_2 in UE in pp due to the larger source size in p—Pb (pp[1]: r_0~ 1 fm, p—Pb[2]: r_0~ 1.5 fm)



Phys.Rev.Lett. 131 (2023) 4, 042301
[1] Phys.Rev.C 99 (2019) 024001
[2] Phys.Rev.Lett. 123 (2019) 112002

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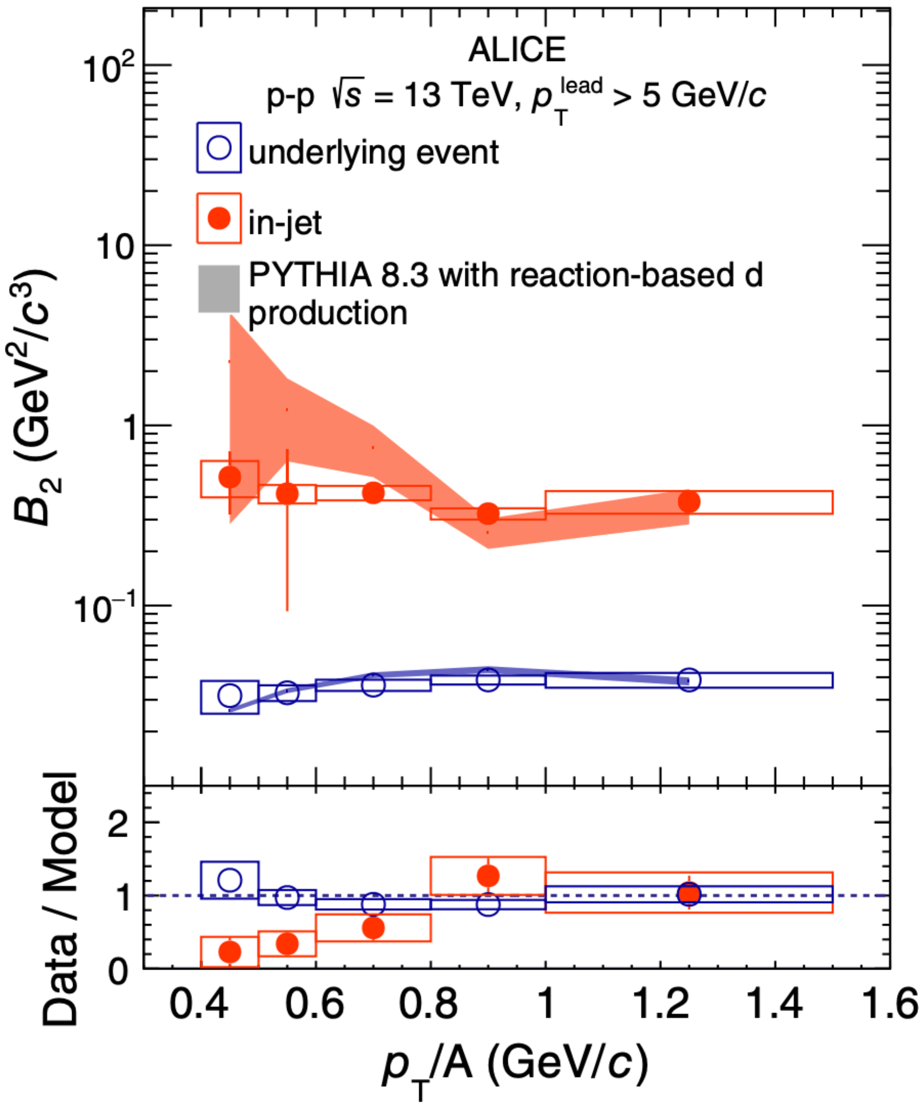
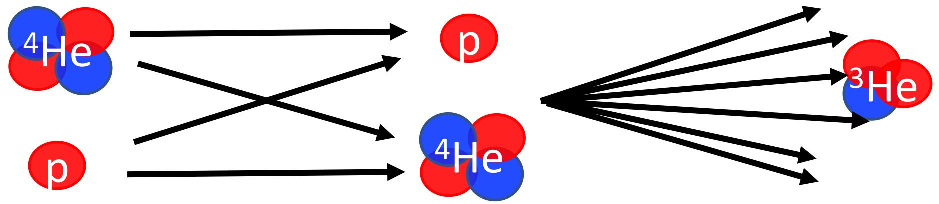


- B_2 in-jet ~ 15 times larger than B_2 in UE
- *Enhanced deuteron coalescence probability in jets wrt UE is observed for the first time in pp collisions*
- Due to the reduced distance in phase space of hadrons in jets compared to those out of jets → favors coalescence picture



Primary cosmic ray
(90% p, 8% ^{4}He)

Interstellar medium
(90% p, 8% ^{4}He)

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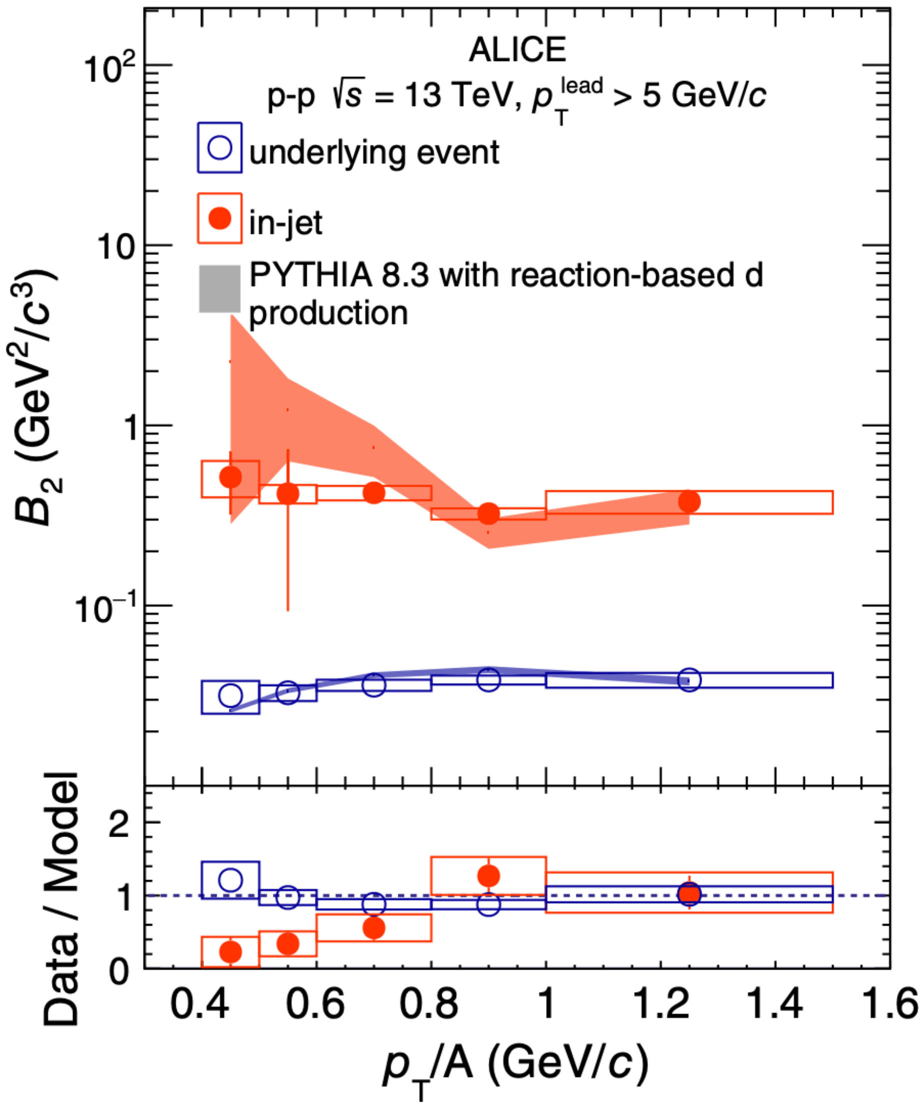

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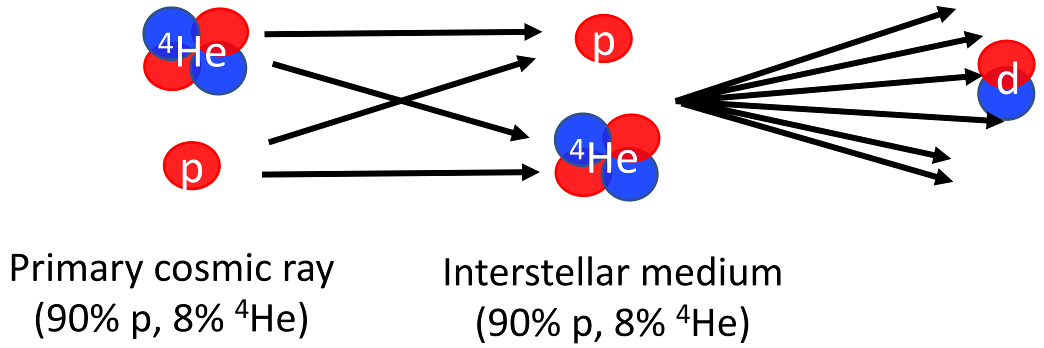

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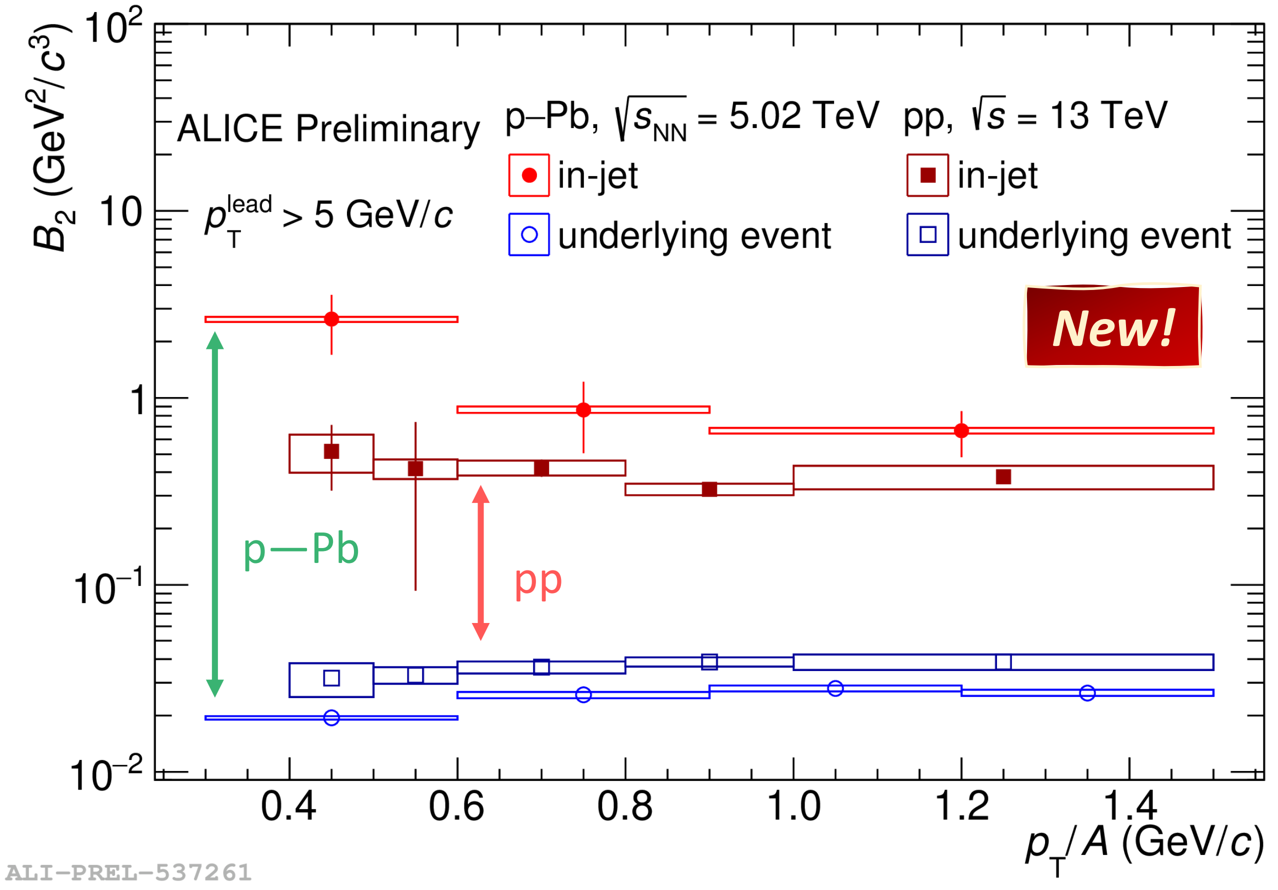

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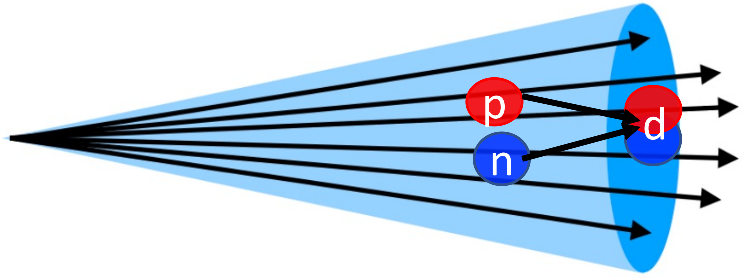

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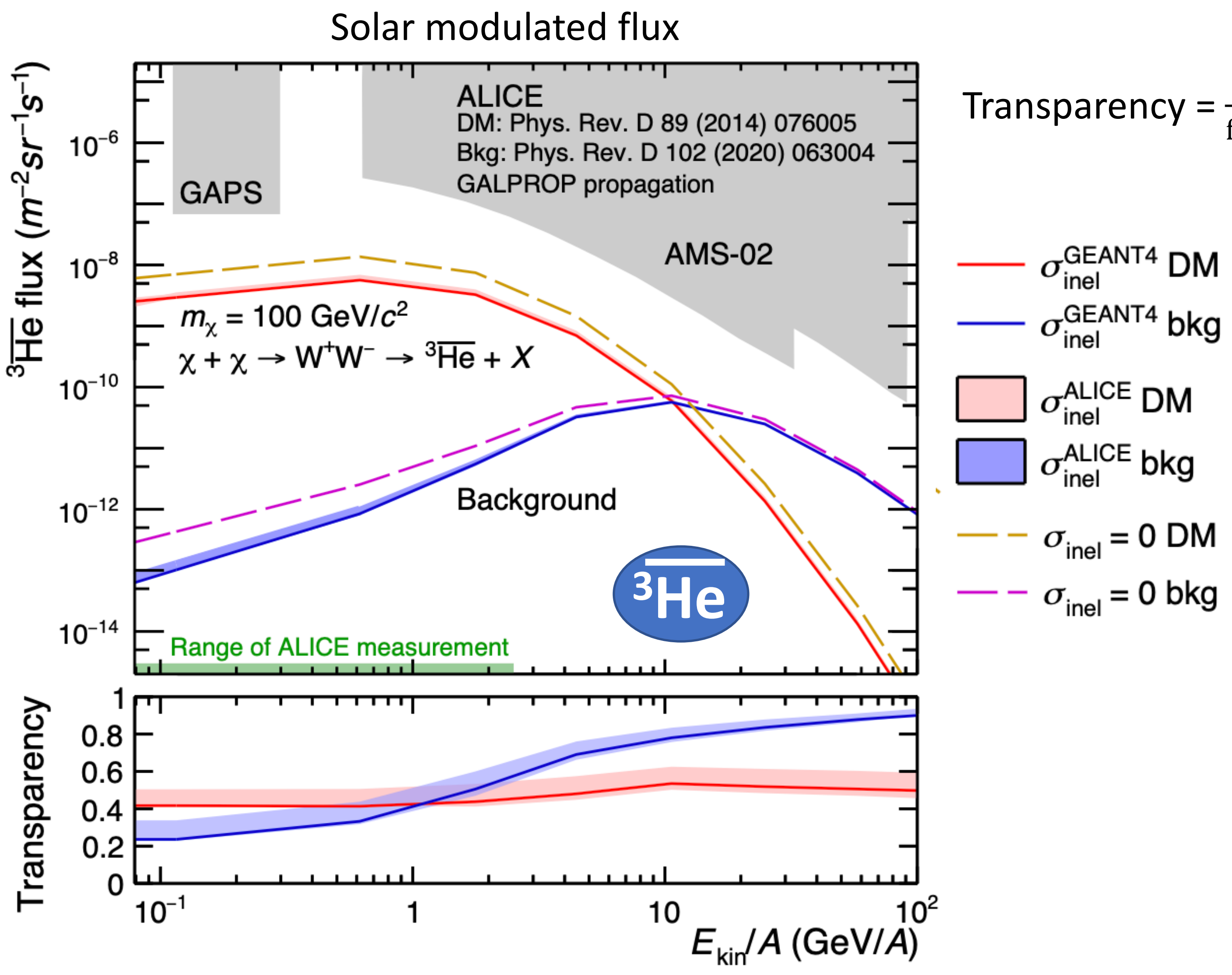
Transparency of Galaxy to anti^{3}He

ALICE



$$\text{Transparency} = \frac{\text{flux with annihilation}}{\text{flux without annihilation}}$$ = (legend ratio) for bkg (DM)

Fluxes are model dependent

- **Our Galaxy is rather constantly transparent to ^{3}He passage**
- Data are in good agreement with Geant4 predictions
- Uncertainties on Transparency only due to absorption measurements (10-20%)

anti^{3}He: Nature Phys. (2023) 19, 61–71