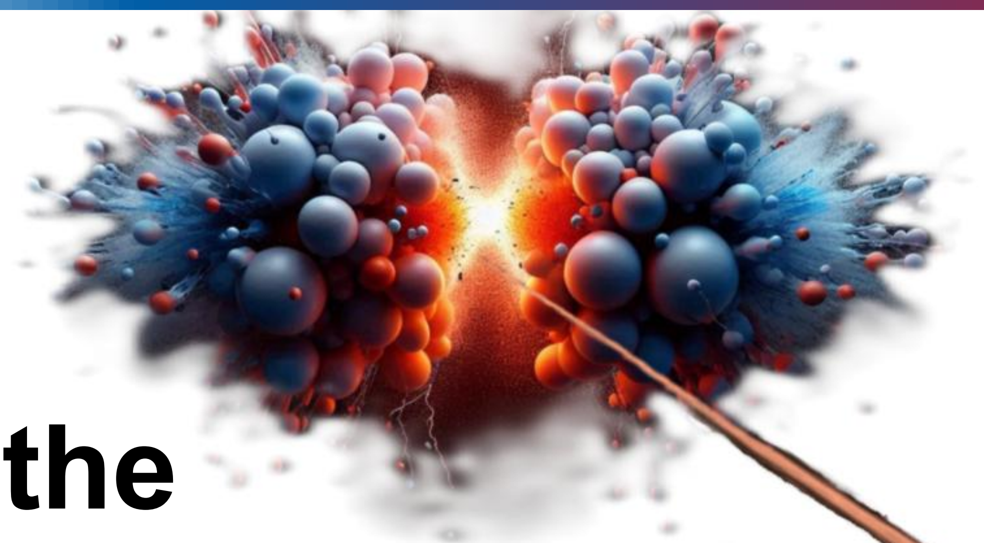
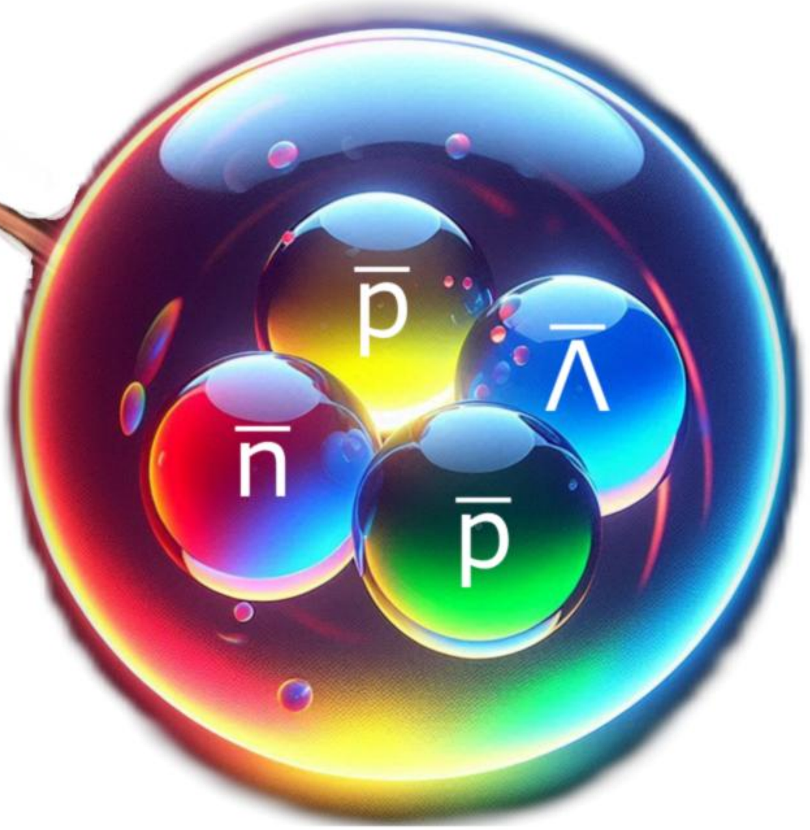
GOETHE UNIVERSITÄT FRANKFURT AM MAIN

ALICE



Examining the nucleosynthesis process with (anti)hypernuclei at the LHC



Janik Ditzel

EMMI Physics Day 22.07.2025

ALICE, *Phys.Rev.Lett.* 134 (2025) 16, 162301

Introduction

- Hypernuclei consist of nucleons and hyperons
- Decay weakly after a few centimeters ($c\tau \approx$ 5-7 cm) into two or more daughters
- Lightest known hypernucleus hypertriton:

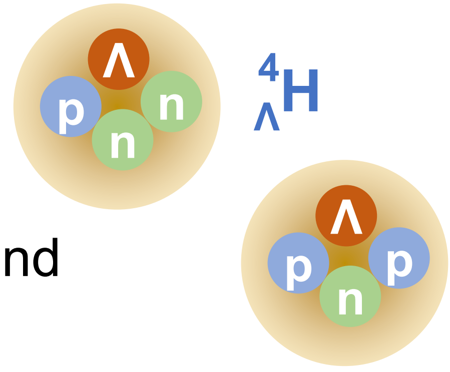
Recently measured by ALICE!
ALICE, Phys. Rev. Lett. 131, 102302 (2023)

$B_\Lambda \approx$ 100 keV → $r_{d\Lambda} \approx$ 10 fm
Hildenbrand et. al., Phys. Rev. C 100, 034002 (2020)

- Heavier hypernuclei at the LHC:

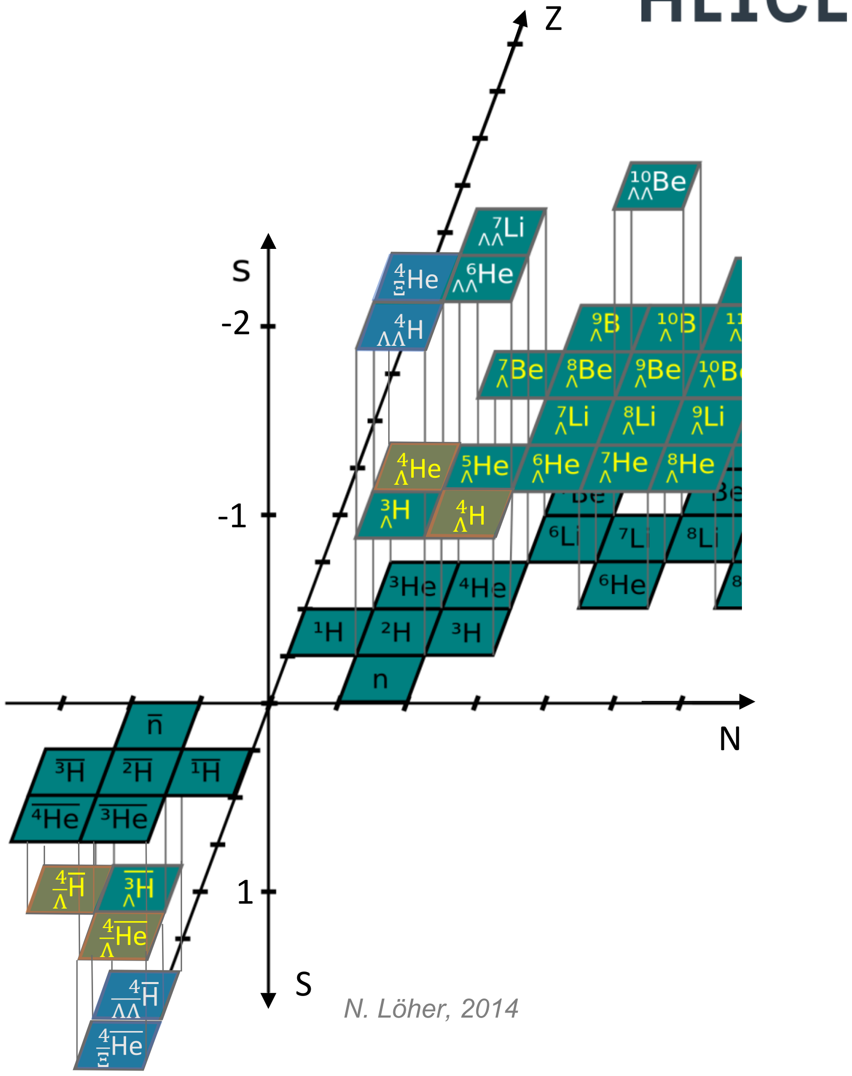
$B_\Lambda \approx$ 2 MeV → $r \approx$ 2 fm
Yamamoto et. al., Phys. Rev. Lett. 115, 222501 (2015)

A = 4 hypernuclei are more bound and each has an excited state
Schäfer et. al., Phys. Rev. C 106, L031001 (2022)



${}^4_\Lambda$H

${}^4_\Lambda$He



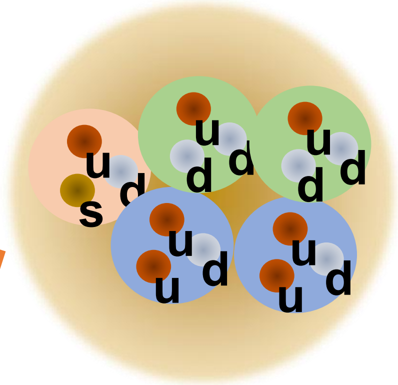
N. Löher, 2014

Motivation

Hypernuclei are interesting objects because:

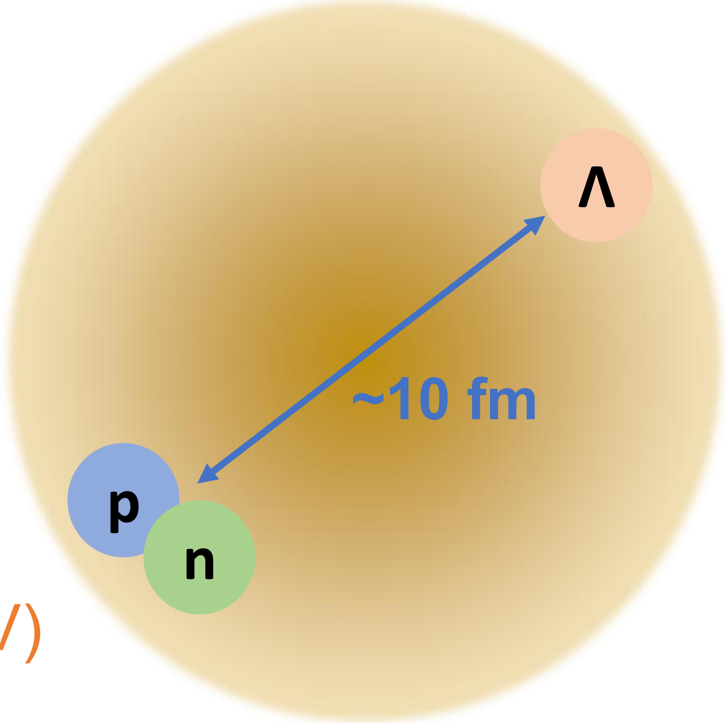
1) Λ hyperons in a system of nucleons allow for the formation of interesting bound states, e.g. the hyperhelium-5 or the hypertriton

Gal et. al., Rev. Mod. Phys. 88, 035004 (2016)



$^{5}_{\Lambda}\mathrm{He}$

$B_\Lambda \approx$ O(MeV)



$^{3}_{\Lambda}\mathrm{H}$

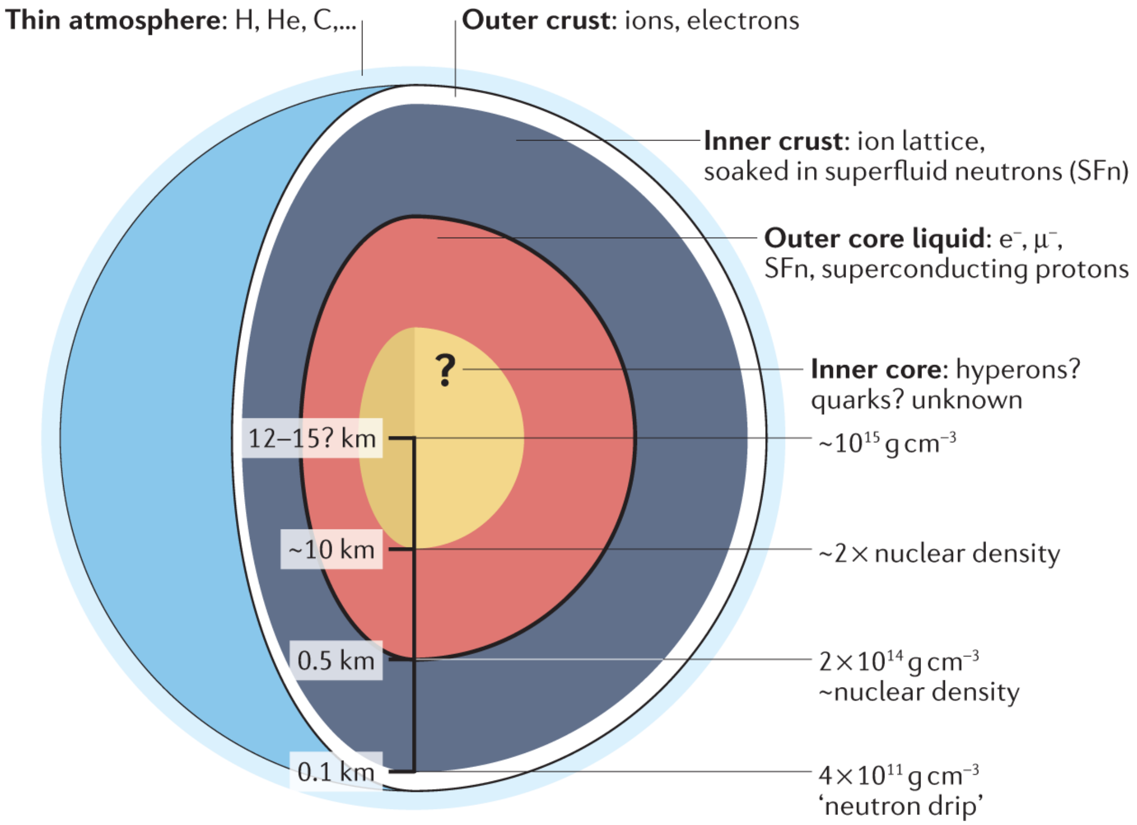
$B_\Lambda \approx$ O(keV)

Motivation

Hypernuclei are interesting objects because:

1) Λ hyperons in a system of nucleons allow for the formation of interesting bound states, e.g. the hyperhelium-5 or the hypertriton

2) Hyperons in neutron stars? Very dense objects (mass > 2 solar masses while having a radius of a few km)



Yunes et. al., Nature Reviews Physics 4, 237-246 (2022)

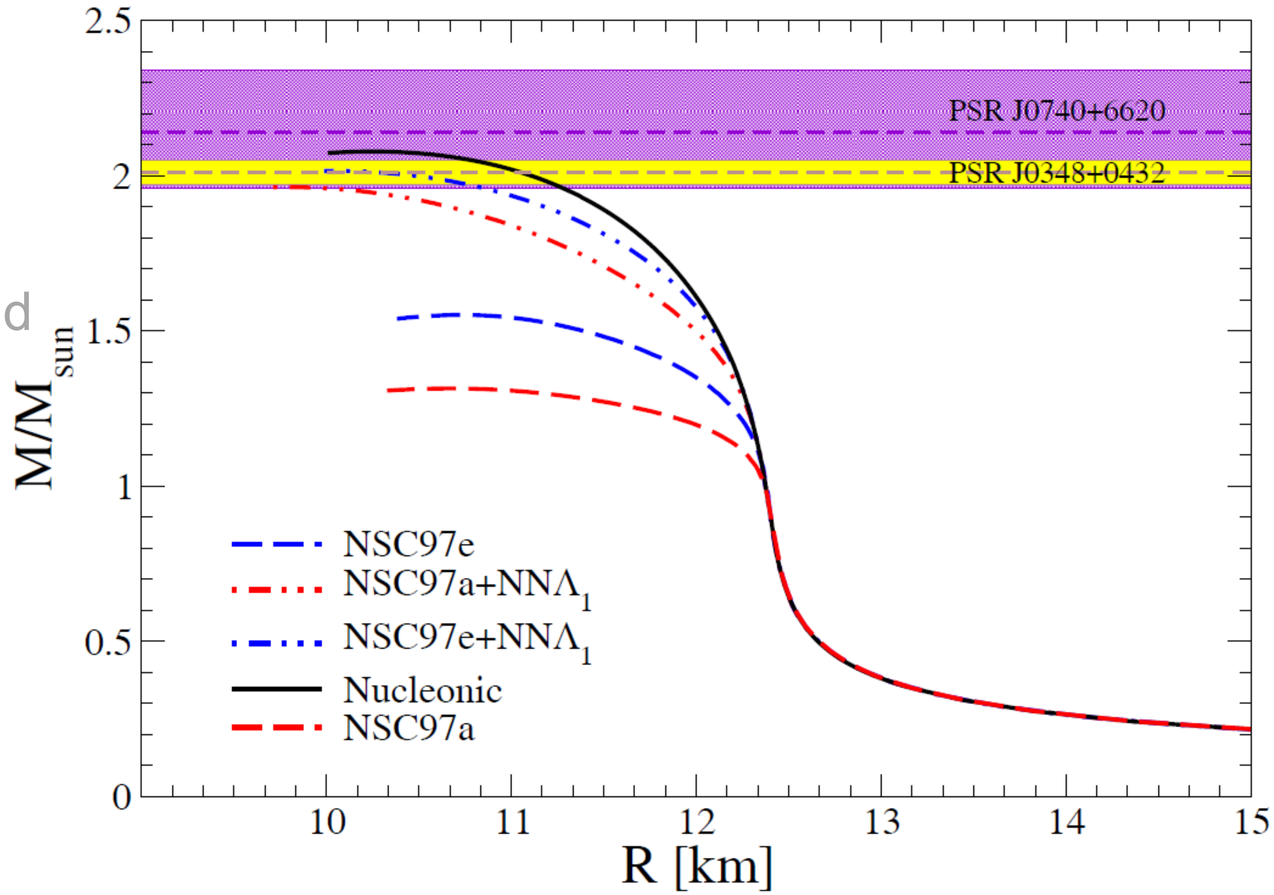
Motivation

Hypernuclei are interesting objects because:

1) Λ hyperons in a system of nucleons allow for the formation of interesting bound states, e.g. the hyperhelium-5 or the hypertriton

2) Hyperons in neutron stars? Very dense objects (mass > 2 solar masses while having a radius of a few km)

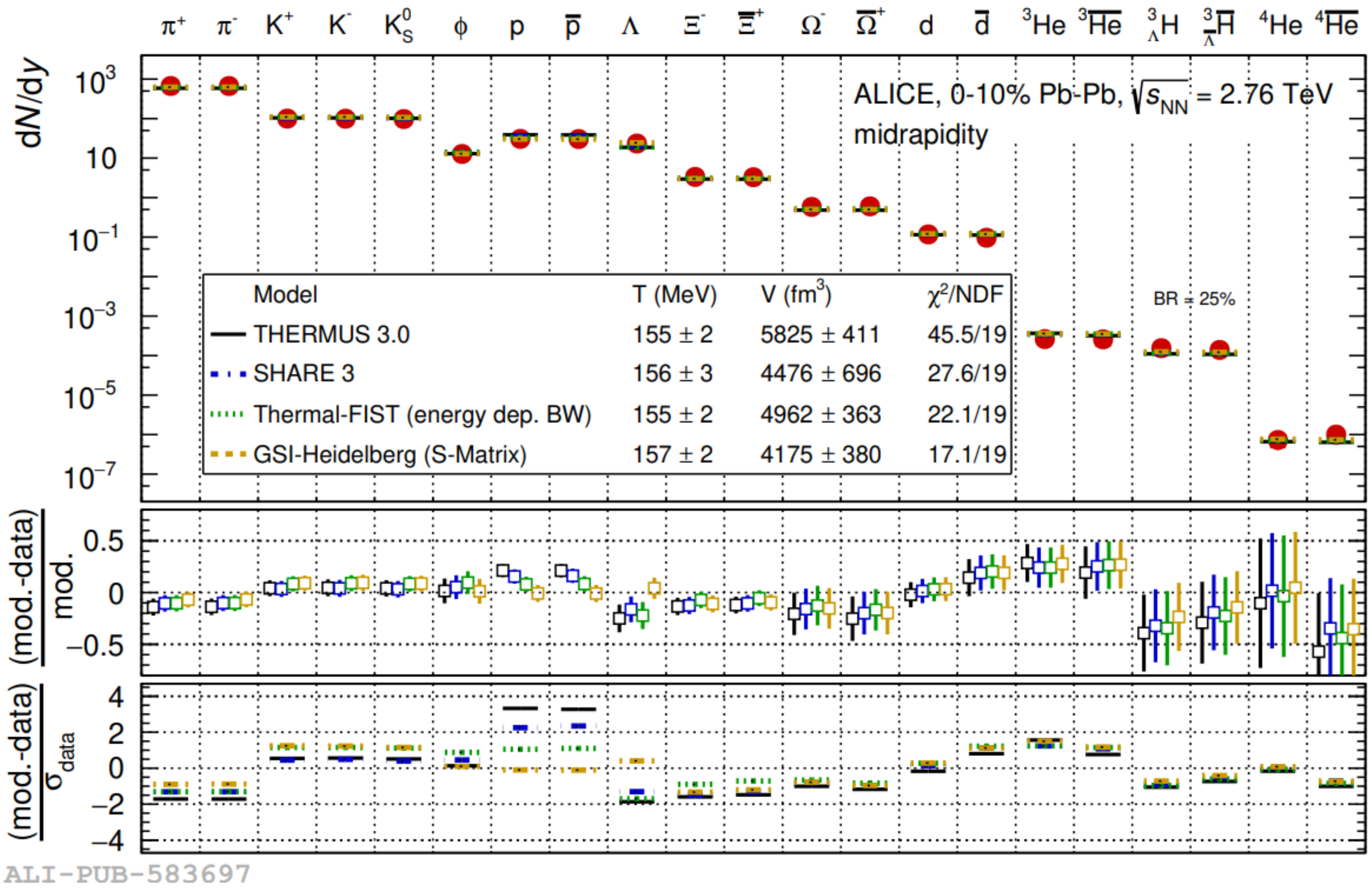
→ improve the understanding of the Λ-N and Λ-Λ interaction



D. Logoteta, I. Vidana, I. Bombaci, Eur. Phys. J. A (2019) 55: 207

Production

- In large colliding systems, the integrated yield of several particle species is well described over orders of magnitude by the Statistical Hadronization Model (SHM)
- SHM also takes into account the population of excited states by their spin degeneracy
- SHM assumes hadron abundances from statistical equilibrium at the common chemical freeze-out temperature T_{ch} = 155 MeV

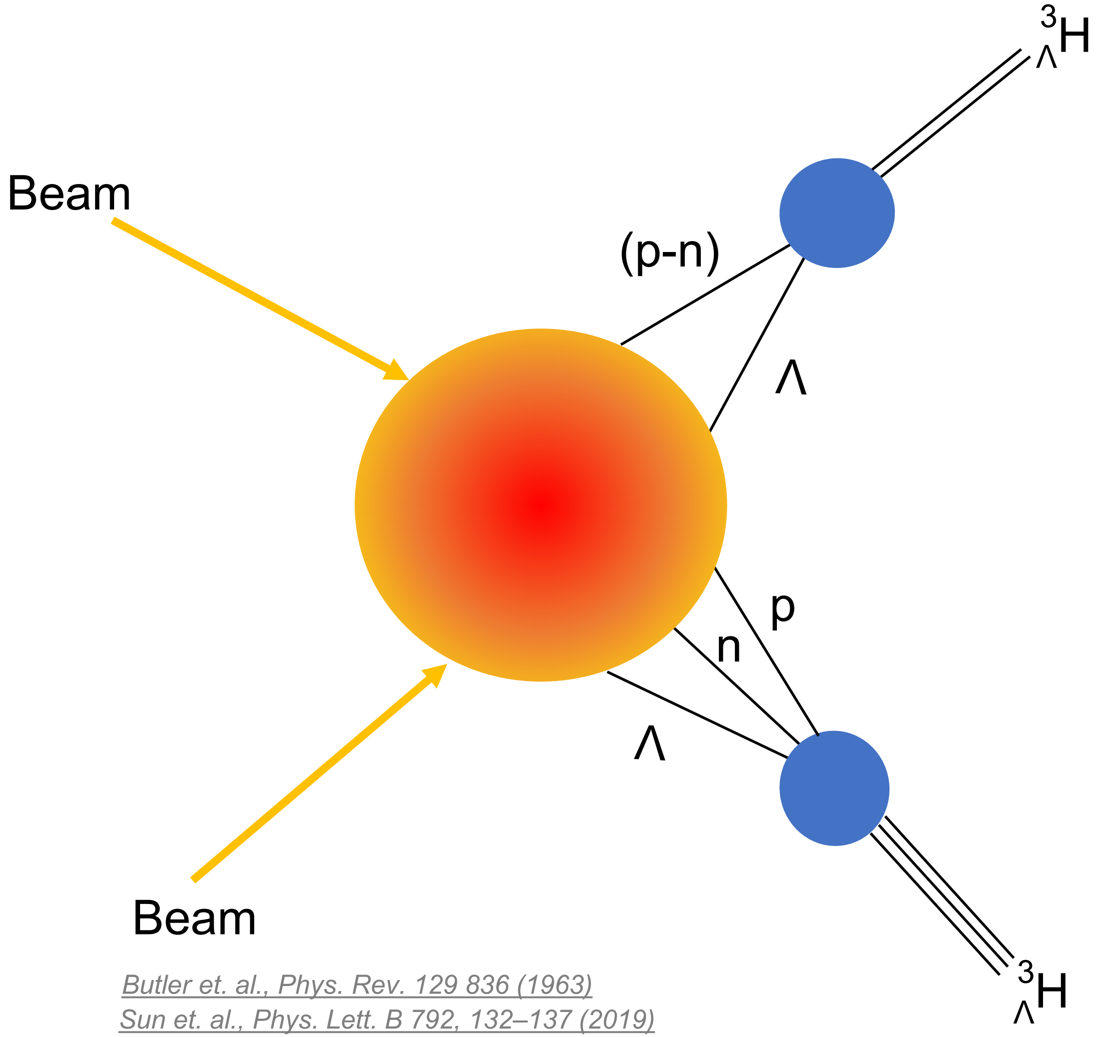


ALICE, Eur. Phys. J. C 84 (2024) 813

Production

Coalescence Model:

- Nucleons that are close in phase space at the freeze-out can form a nucleus via coalescence
- The formation probability is given by the overlap between the nuclear wave functions and the phase space of the nucleons
- The closer hadrons in the phase space → the higher the probability to form a nucleus
- The coalescence mechanism employs different wave functions of the (hyper)nucleus

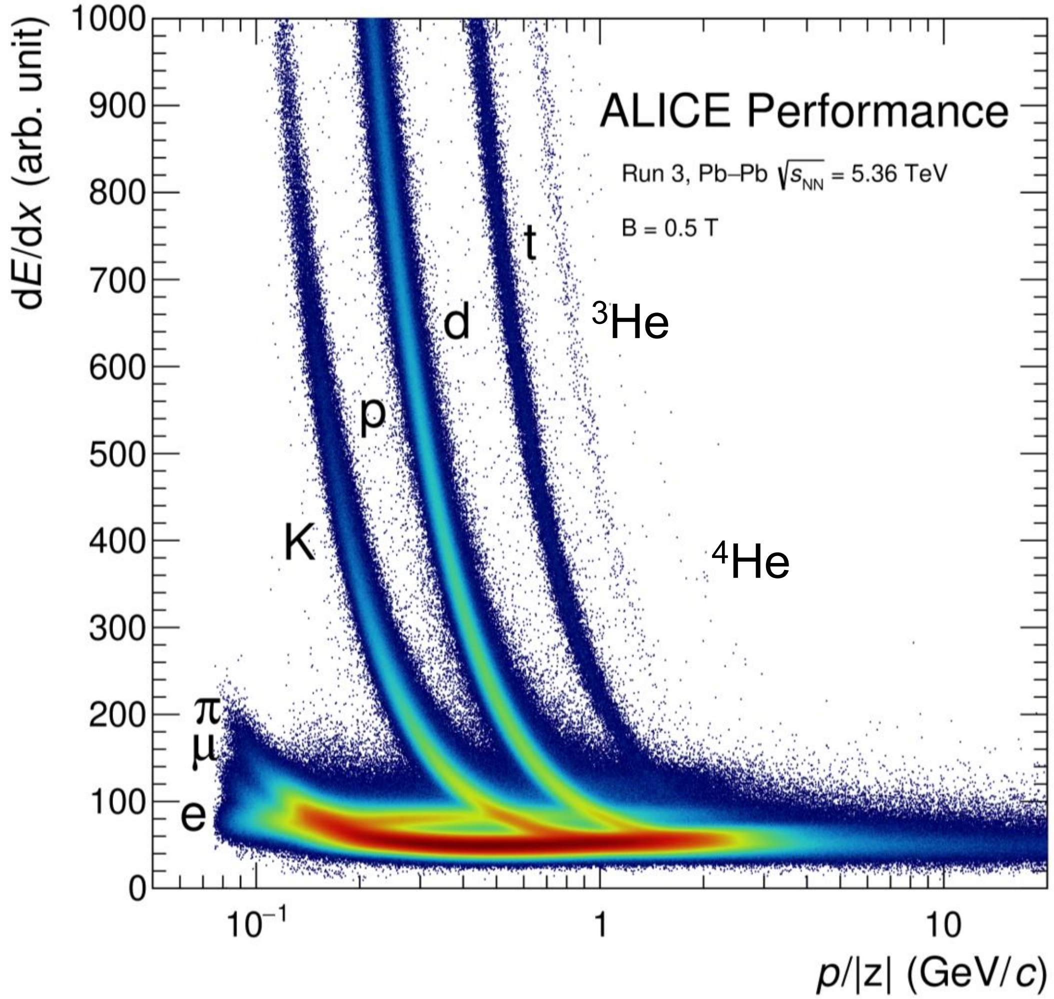


Butler et. al., Phys. Rev. 129 836 (1963)
Sun et. al., Phys. Lett. B 792, 132–137 (2019)

Reconstruction

- **Step 1**: find and identify the daughter particle tracks
  - Using TPC PID via the specific energy loss
  - Excellent separation of different particle species

Particle	Decay mode	Branching Ratio
${}^{3}_{\Lambda}H$	${}^{3}He + \pi^{-}$ + c.c. d + p + π^{-} + c.c.	~25% ~40%
${}^{4}_{\Lambda}H$	${}^{4}He + \pi^{-}$ + c.c.	~50%
${}^{4}_{\Lambda}He$	${}^{3}He$ + p + π^{-} + c.c.	~29%



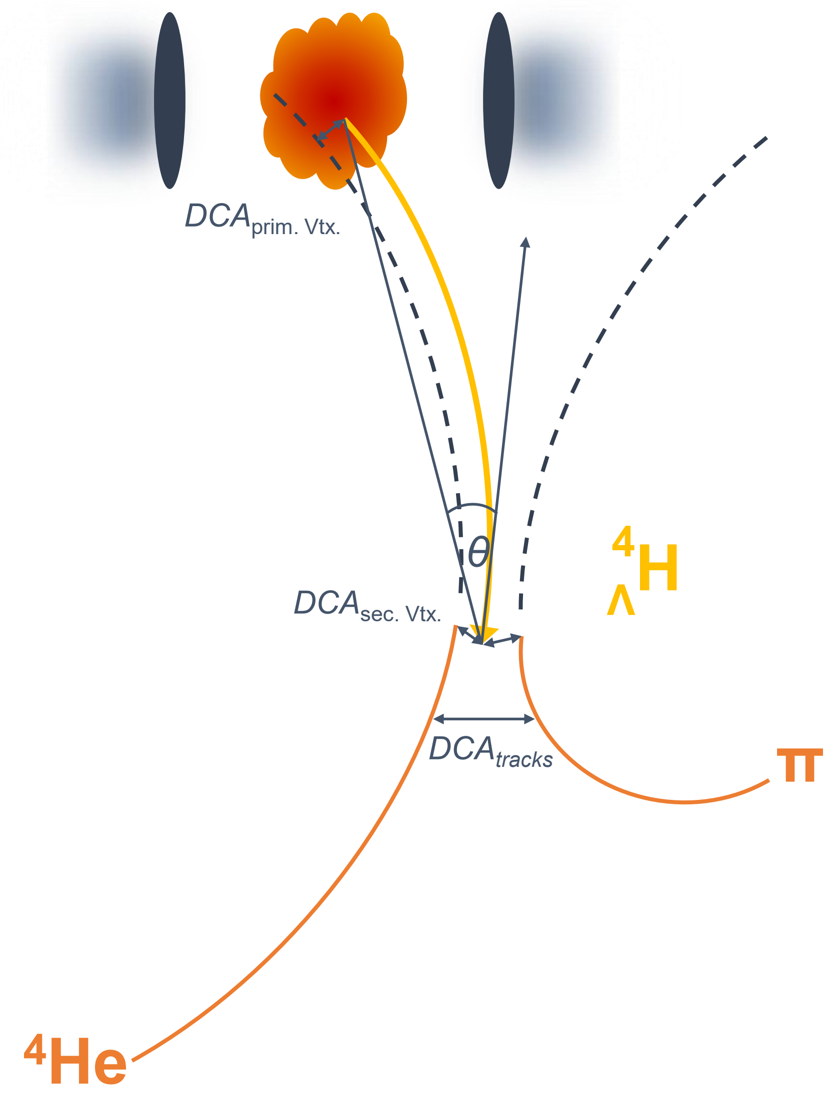
ALI-PERF-529714

Reconstruction

- **Step 1**: find and identify the daughter particle tracks
- **Step 2**: reconstruct the decay vertex of the hypernucleus

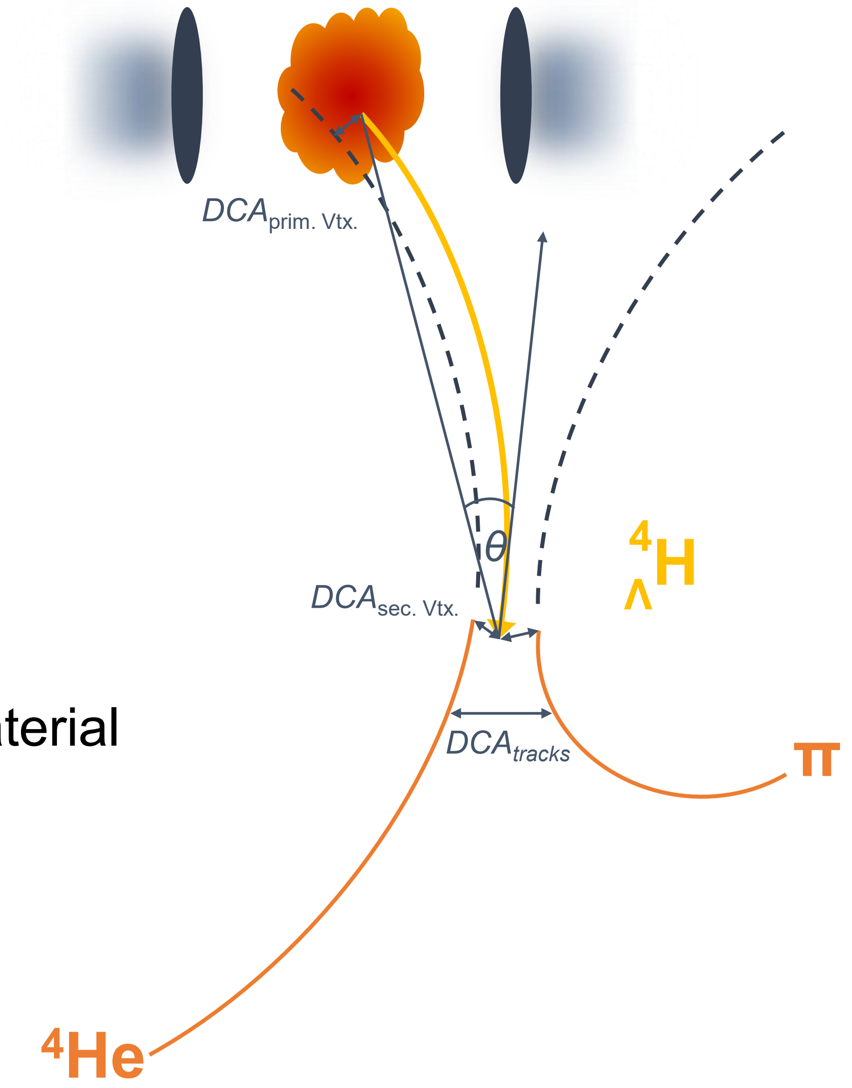
  - The identified daughters are assumed to come from a common vertex
  - Their tracks are matched by algorithms to find the best possible decay vertex

  - Challenge: huge combinatorial background
  - Solution: topological and kinematical cuts



Reconstruction

- **Step 1**: find and identify the daughter particle tracks
- **Step 2**: reconstruct the decay vertex of the hypernucleus
- **Step 3**: apply corrections
  - Tracking efficiency and detector acceptance
  - Branching ratio and absorption in detector material



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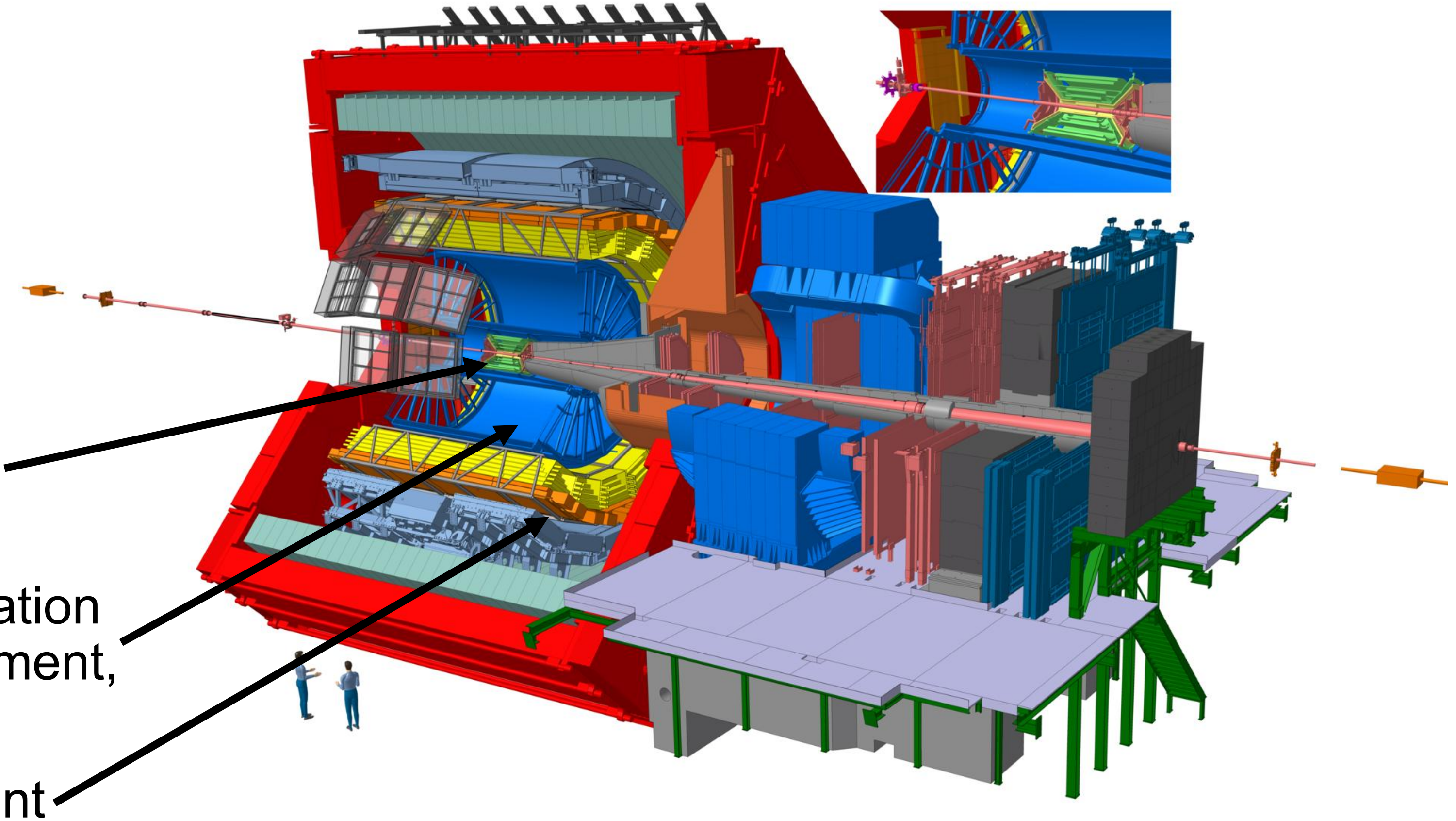
ALICE

ALICE detector in Run 2

Specialized in tracking and particle identification from low to high momenta using different detector technologies

Main features for this purpose:

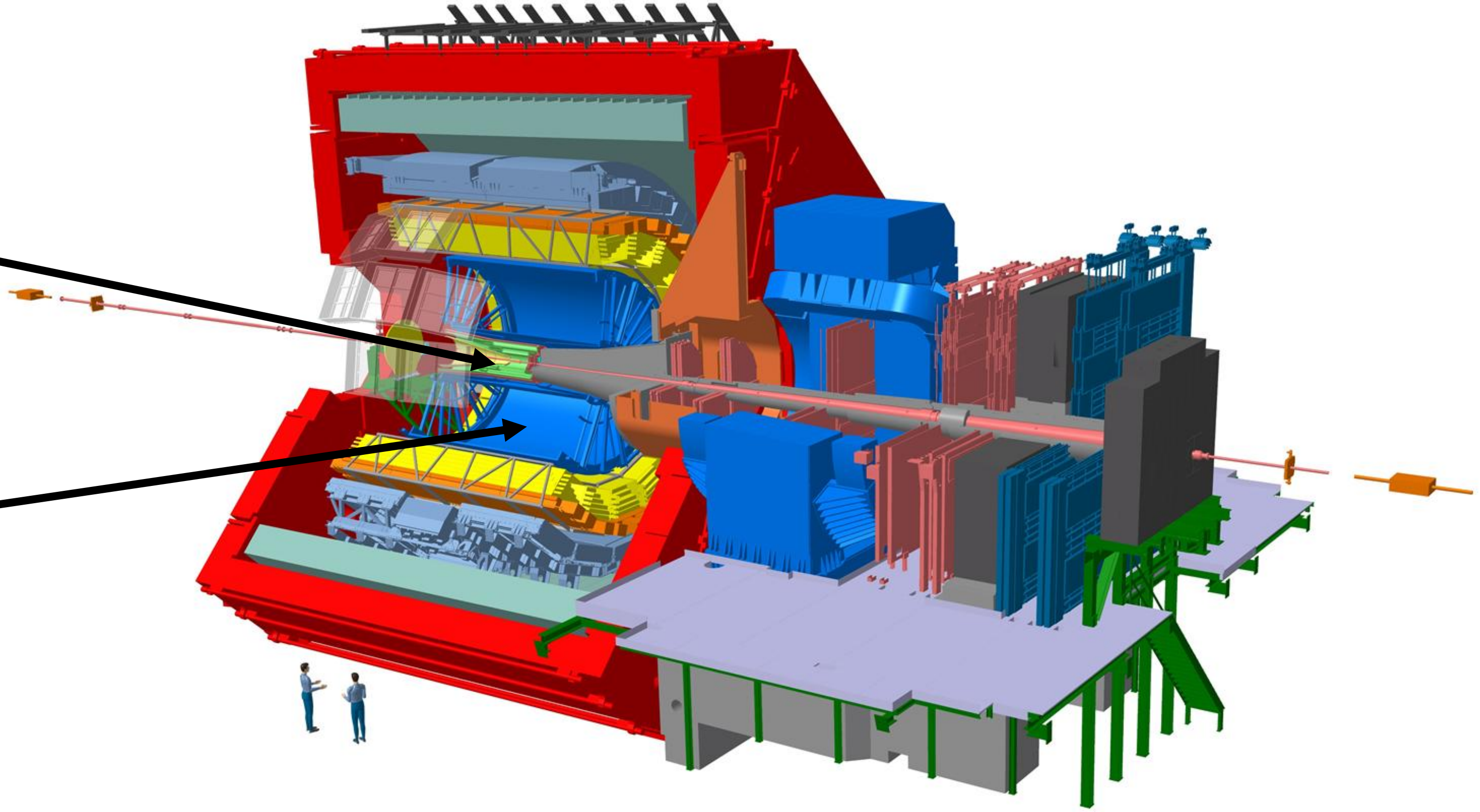
- ITS for primary and decay vertex reconstruction, tracking
- TPC for charged particle identification via specific energy-loss measurement, tracking
- TOF for time-of-flight measurement



ALICE detector in Run 3

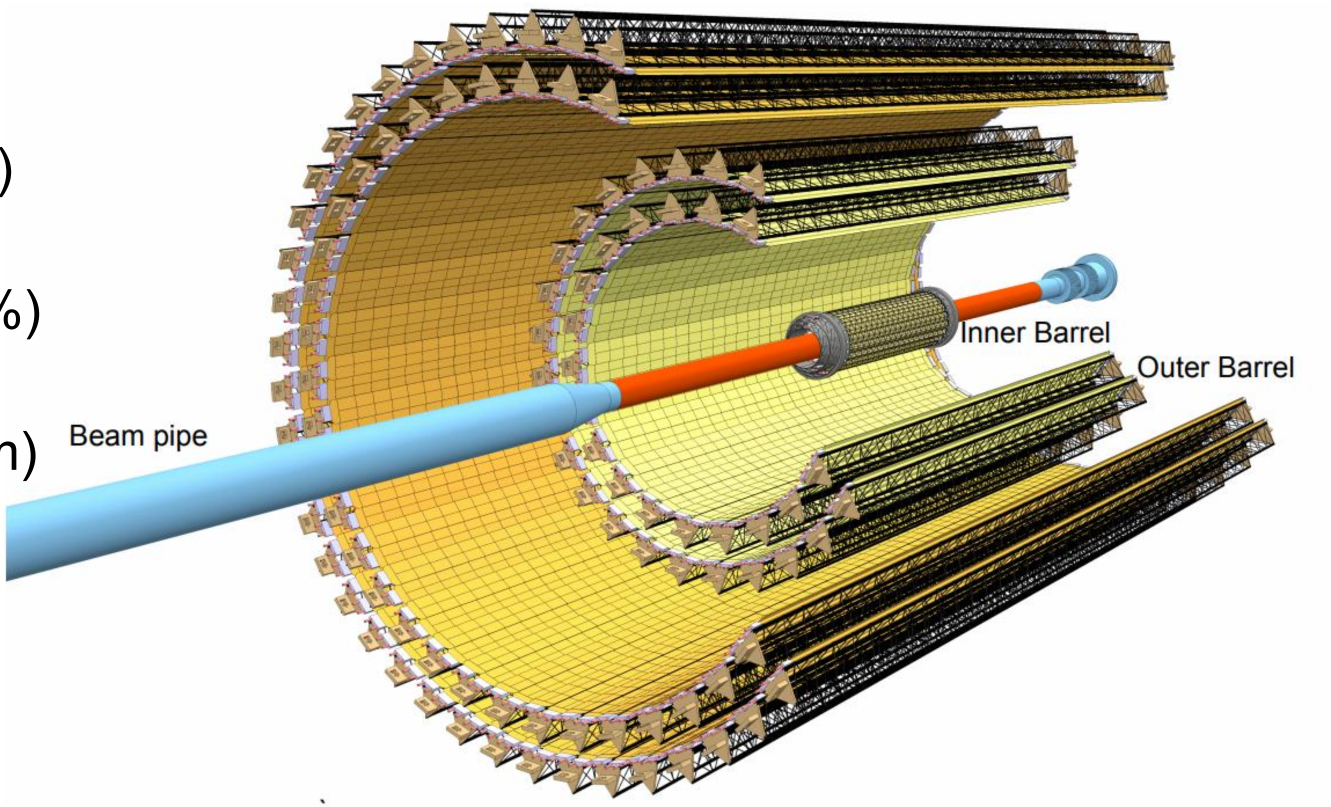
- Upgraded ITS2:
  better pointing resolution
  →improved finding of
  (decay) vertices

- Upgraded TPC:
  continous readout
  cope with higher IR



ITS2

- Fully pixel detector
- Equipped with seven layers
  located in Inner (3) and Outer Barrel (4)
- Material budget per layer reduced
  significantly w.r.t. ITS1 (1.14% → 0.35%)
- Innermost layer closer to the
  beam pipe w.r.t. ITS1 (39 mm → 23 mm)
- PID capabilities through the
  mean charge deposit per ITS layer
- Tracking of the hypernucleus itself

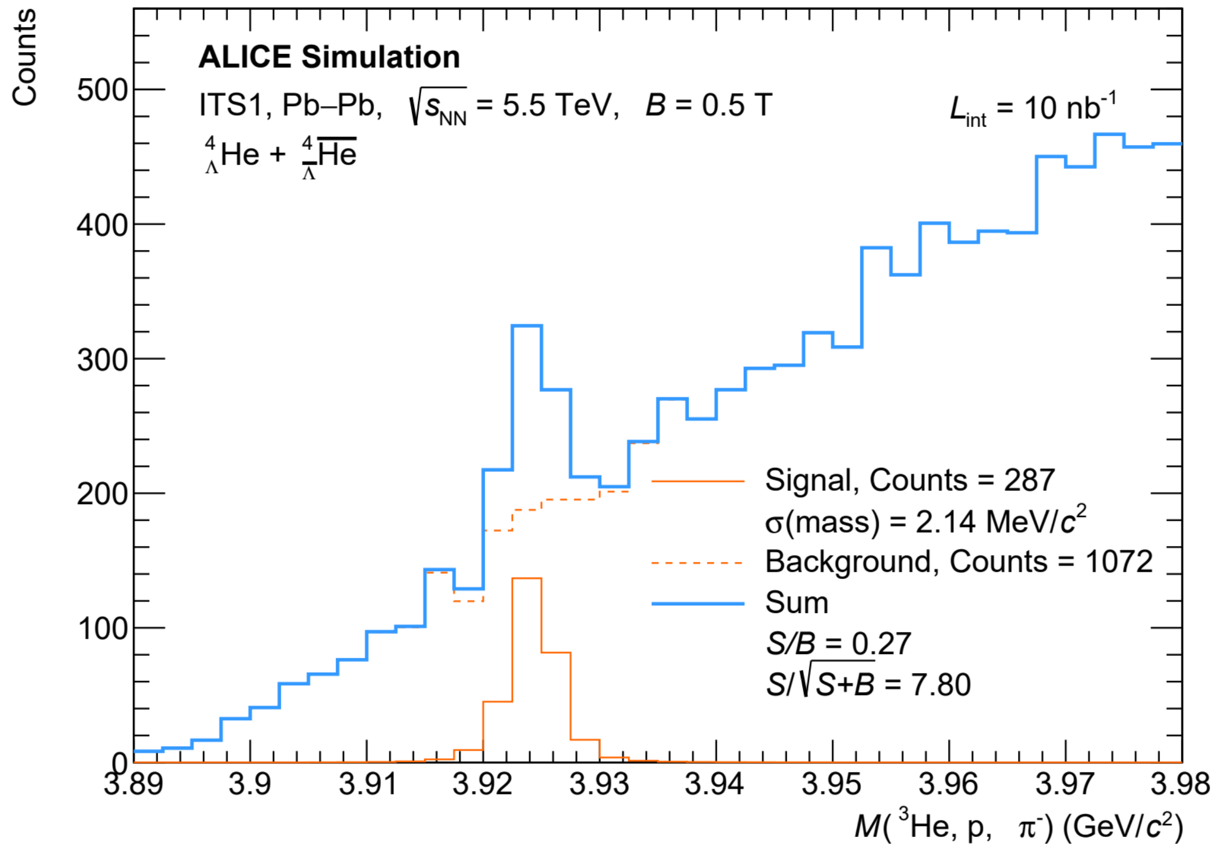


ALICE, J. Phys. G: Nucl. Part. Phys. 41 087002 (2014)

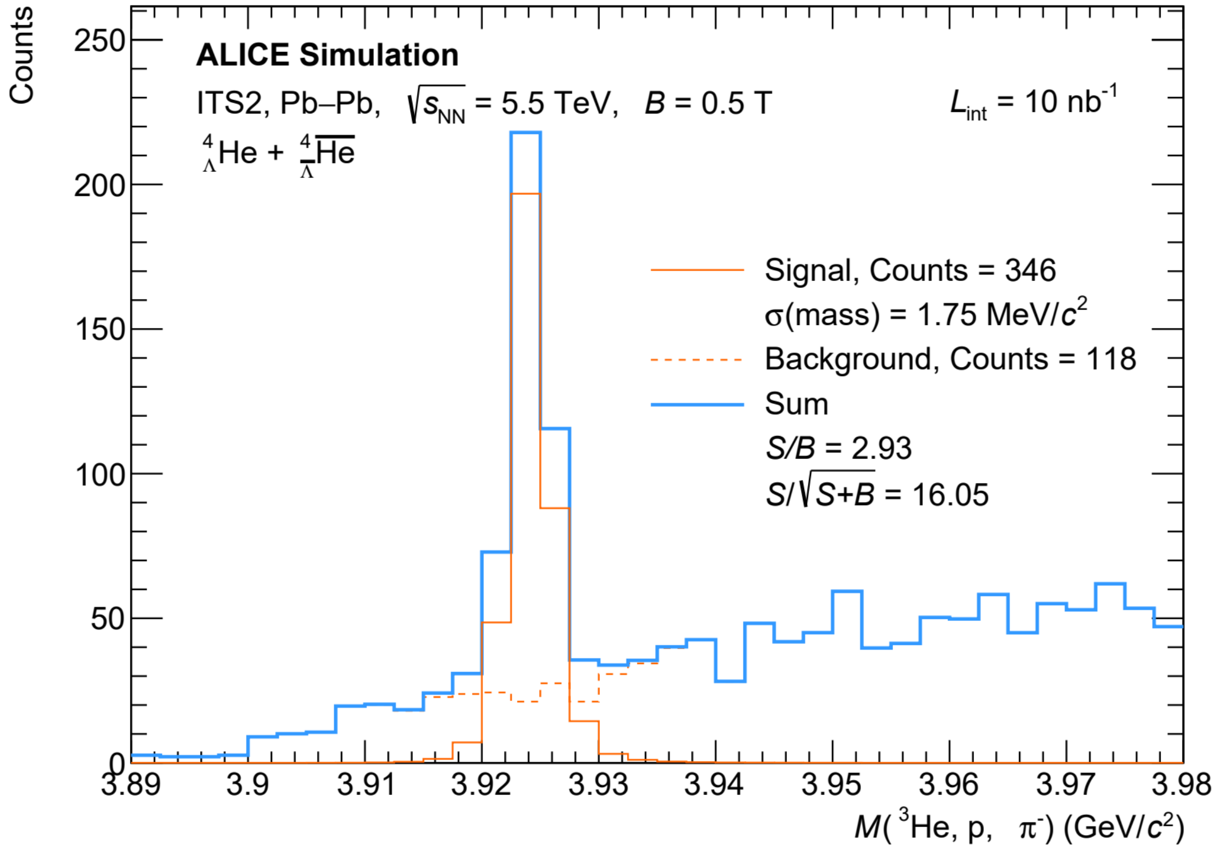
ITS1 vs. ITS2

Fixed set of selection criteria

ITS1



ITS2



ALICE, ITS3 public note

Datasets

Run 2

pp, $\sqrt{s_{NN}}$ = 13 TeV

p–Pb, $\sqrt{s_{NN}}$ = 5.02 TeV

Pb–Pb, $\sqrt{s_{NN}}$ = 5.02 TeV

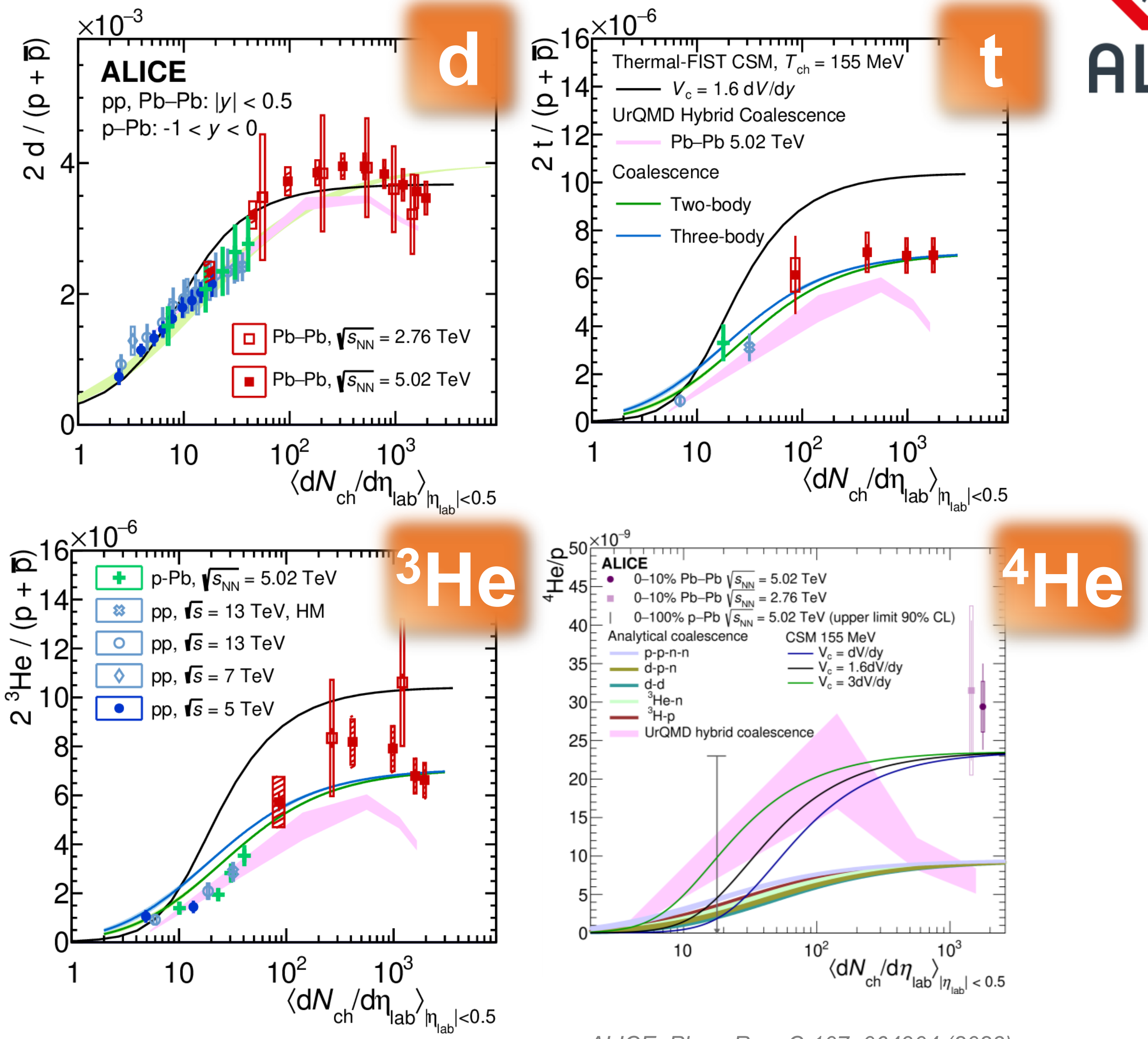
Run 3

pp, $\sqrt{s_{NN}}$ = 13.6 TeV

(Pb –Pb, $\sqrt{s_{NN}}$ = 5.36 TeV)
→ analyses ongoing!

Nuclei production

- Nucleus-to-Proton ratio for deuterons, tritons, helium-3 and alpha
- Measured in different collision systems and center-of-mass energies
- Comparison to SHM and Coalescence predictions



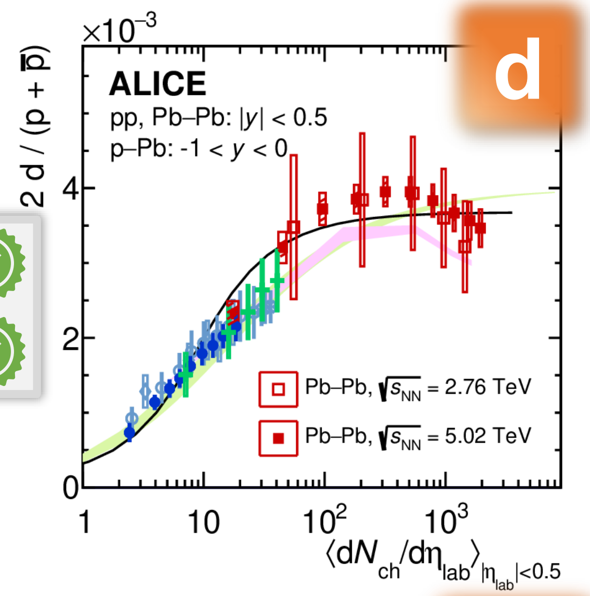
ALICE, Phys. Rev. C 107, 064904 (2023)
ALICE, Phys. Lett. B 858 138943 (2024)

Nuclei production

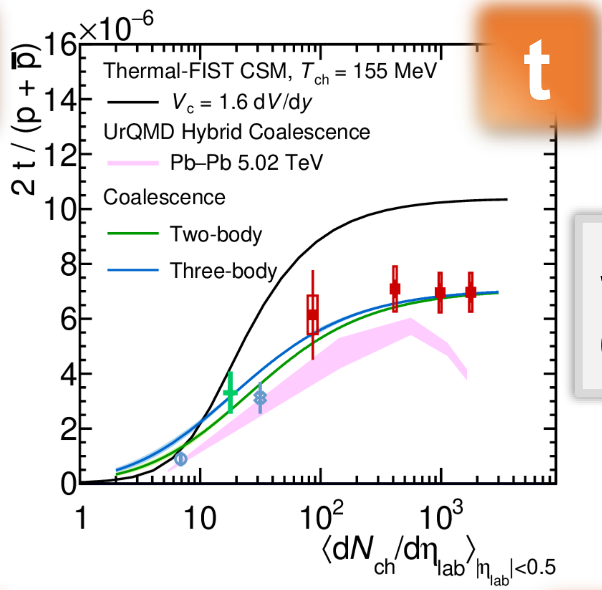
- Nucleus-to-Proton ratio for deuterons, tritons, helium-3 and alpha
- Measured in different collision systems and center-of-mass energies
- Comparison to SHM and Coalescence predictions

→ ??

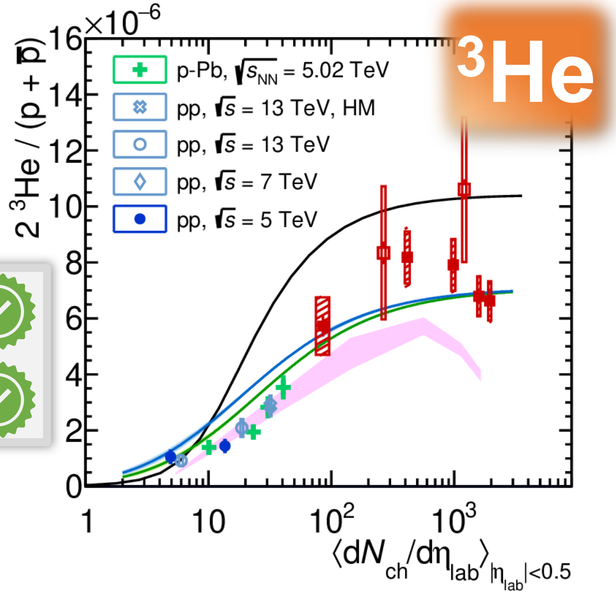
- Need new probes to understand the production mechanism!



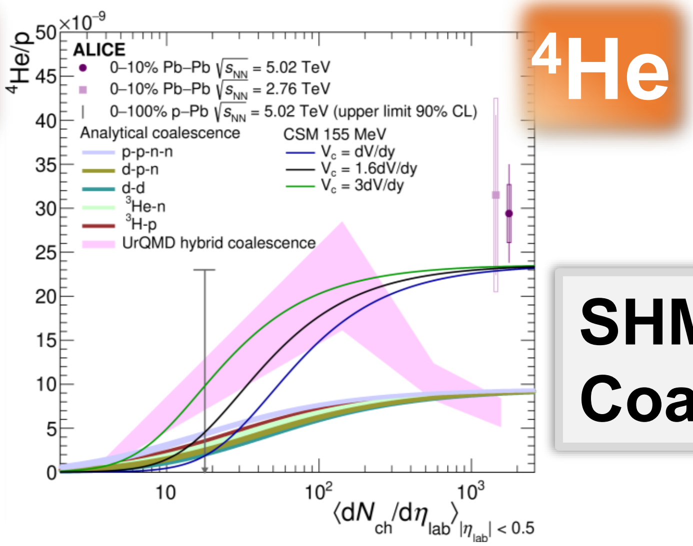
SHM ✓
Coal. ✓



SHM ✗
Coal. ✓



SHM ✓
Coal. ✓



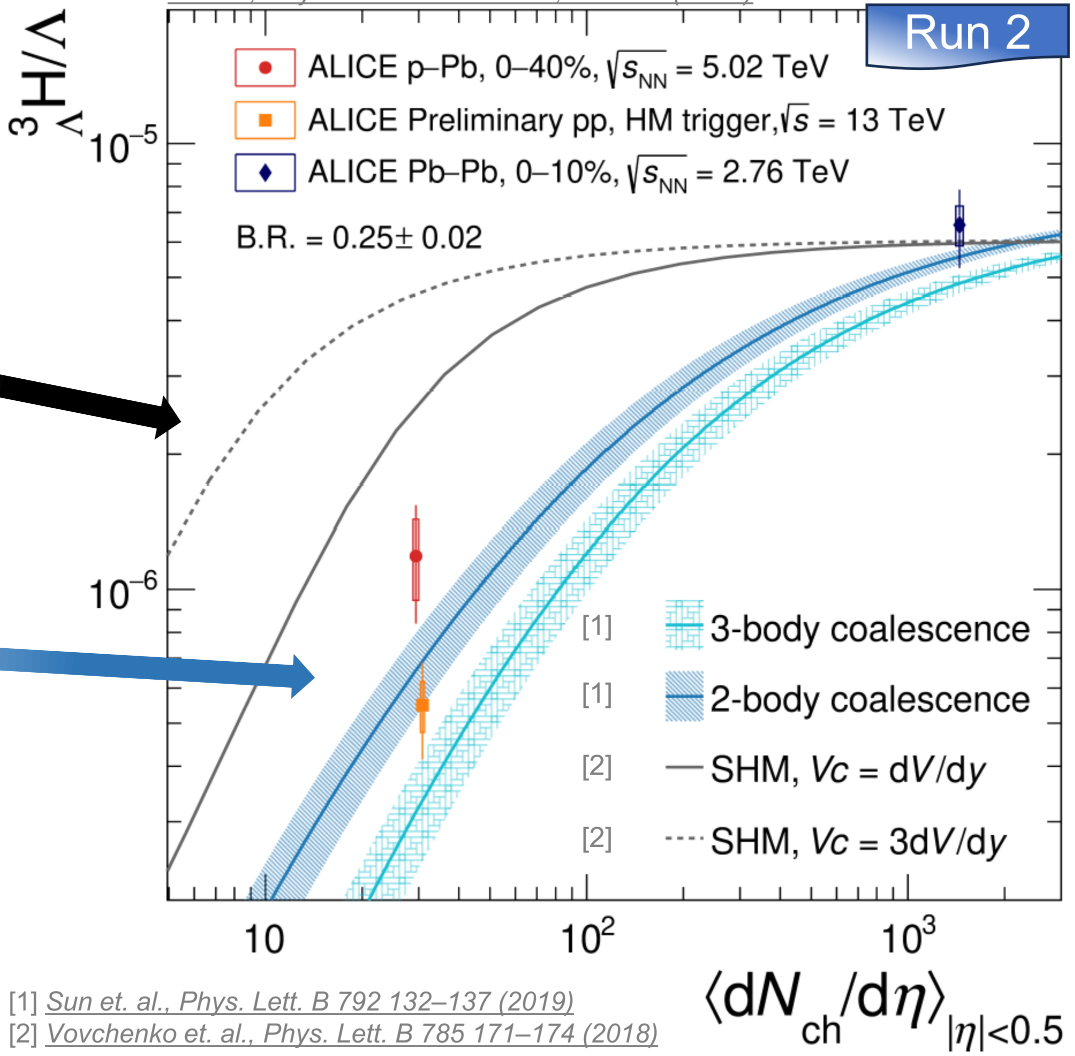
SHM ✓
Coal. ✗

ALICE, Phys. Rev. C 107, 064904 (2023)
ALICE, Phys. Lett. B 858 138943 (2024)

Hypertriton in small systems

- Extremely sensitive to the nuclei production mechanism
- For statistical hadronization models (SHM) the object size is not relevant
  → suppression due to canonical conservation of quantum numbers
- In a coalescence picture large suppression of the production in small systems expected due to the large object size
- Measurements in Run 2 pp and p—Pb collisions favor the coalescence approach

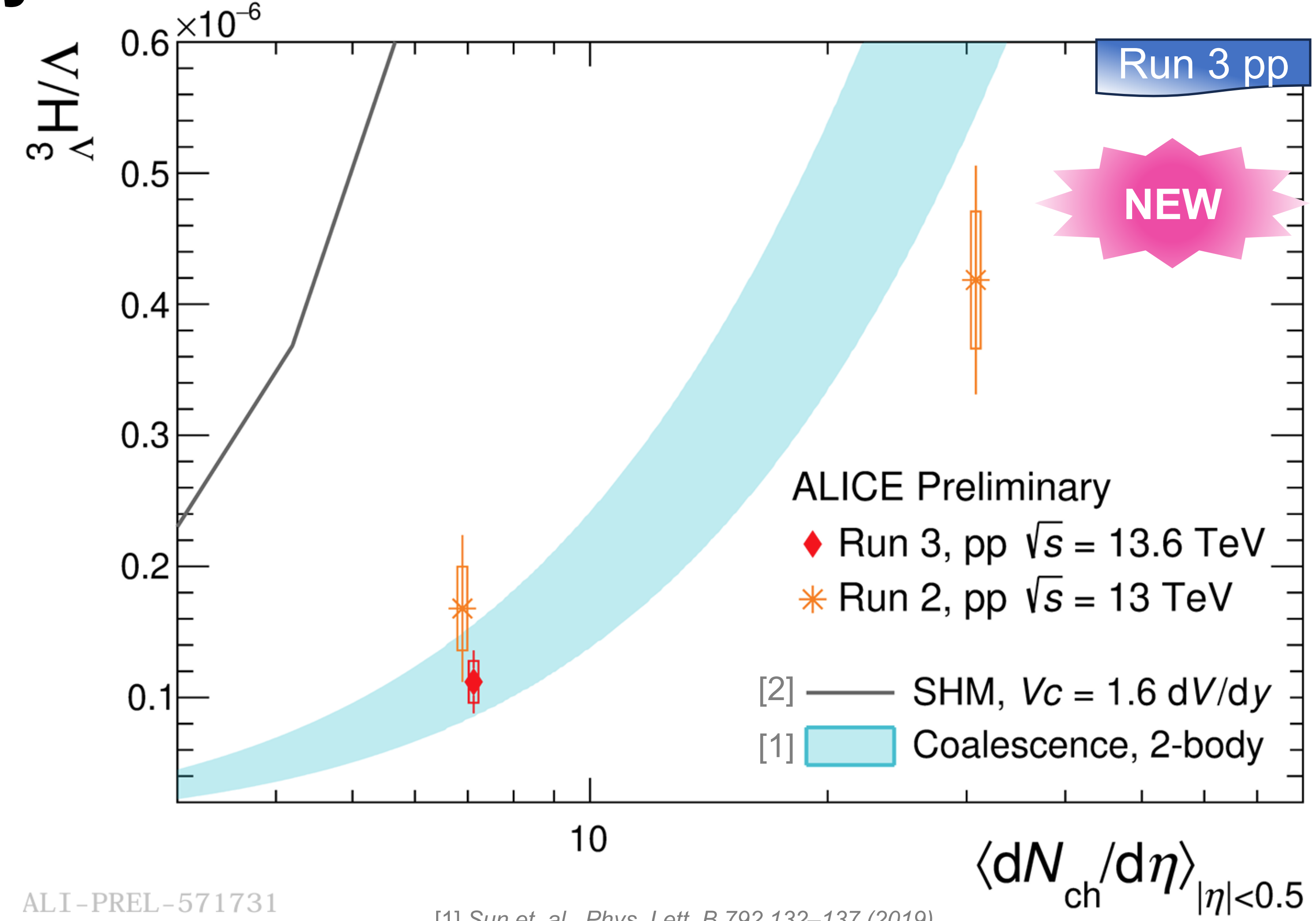
ALICE, Phys. Rev. Lett. 128 25, 252003 (2022)



[1] Sun et. al., Phys. Lett. B 792 132–137 (2019)
[2] Vovchenko et. al., Phys. Lett. B 785 171–174 (2018)

Hypertriton in small systems

- Twice the precision w.r.t. Run 2
- Compatible with the Run 2 preliminary results
- New measurement also favours the coalescence approach

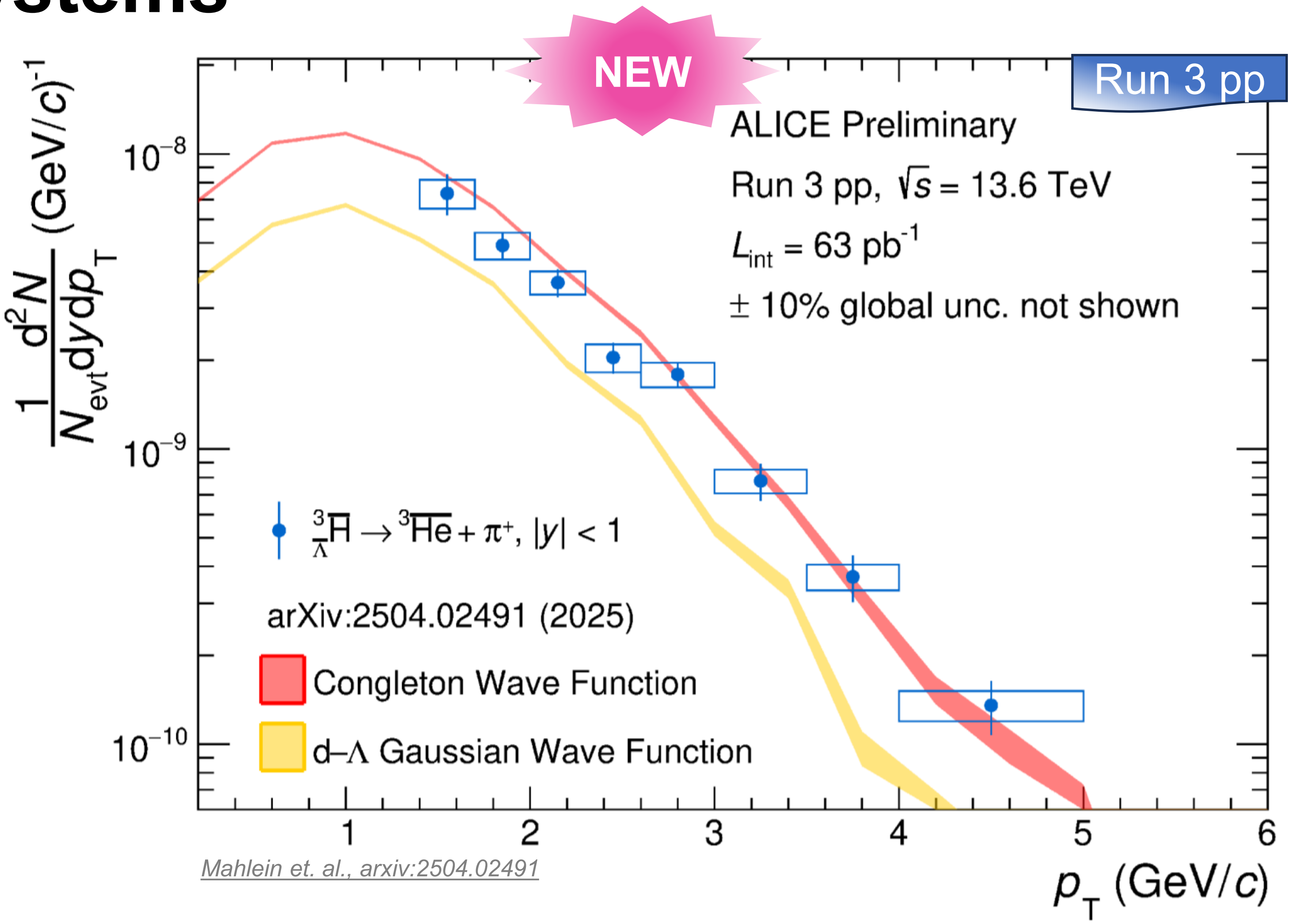


[1] Sun et. al., Phys. Lett. B 792 132–137 (2019)
[2] Vovchenko et. al., Phys. Lett. B 785 171–174 (2018)

Hypertriton in small systems

- High statistics in Run 3 pp collisions at 13.6 TeV
- Results obtained from antimatter
- Compared to a new, advanced coalescence model employing a realistic nucleus wave function
- Allows to analyze the hypertriton wave function

First p_T - differential measurement of $^{3}_{\Lambda}H$ production in pp

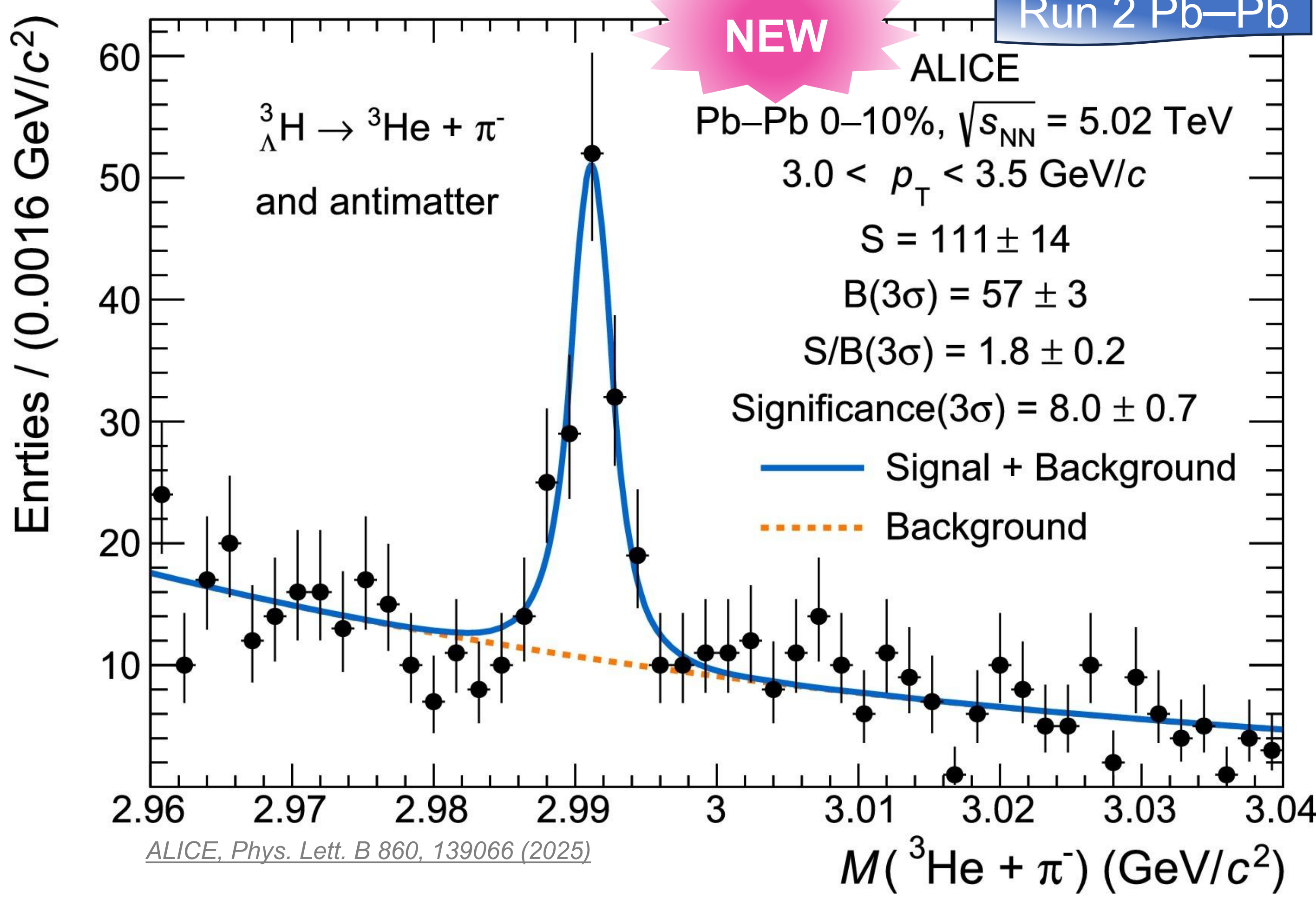


Mahlein et. al., arxiv:2504.02491

Hypertriton production in Pb—Pb collisions

- First p_T - differential measurement of the ${}^{3}_{\Lambda}H$ production in Run 2 Pb—Pb collisions at 5.02 TeV

Do hypernuclei have similar freeze-out parameters as ordinary nuclei?



ALICE, Phys. Lett. B 860, 139066 (2025)

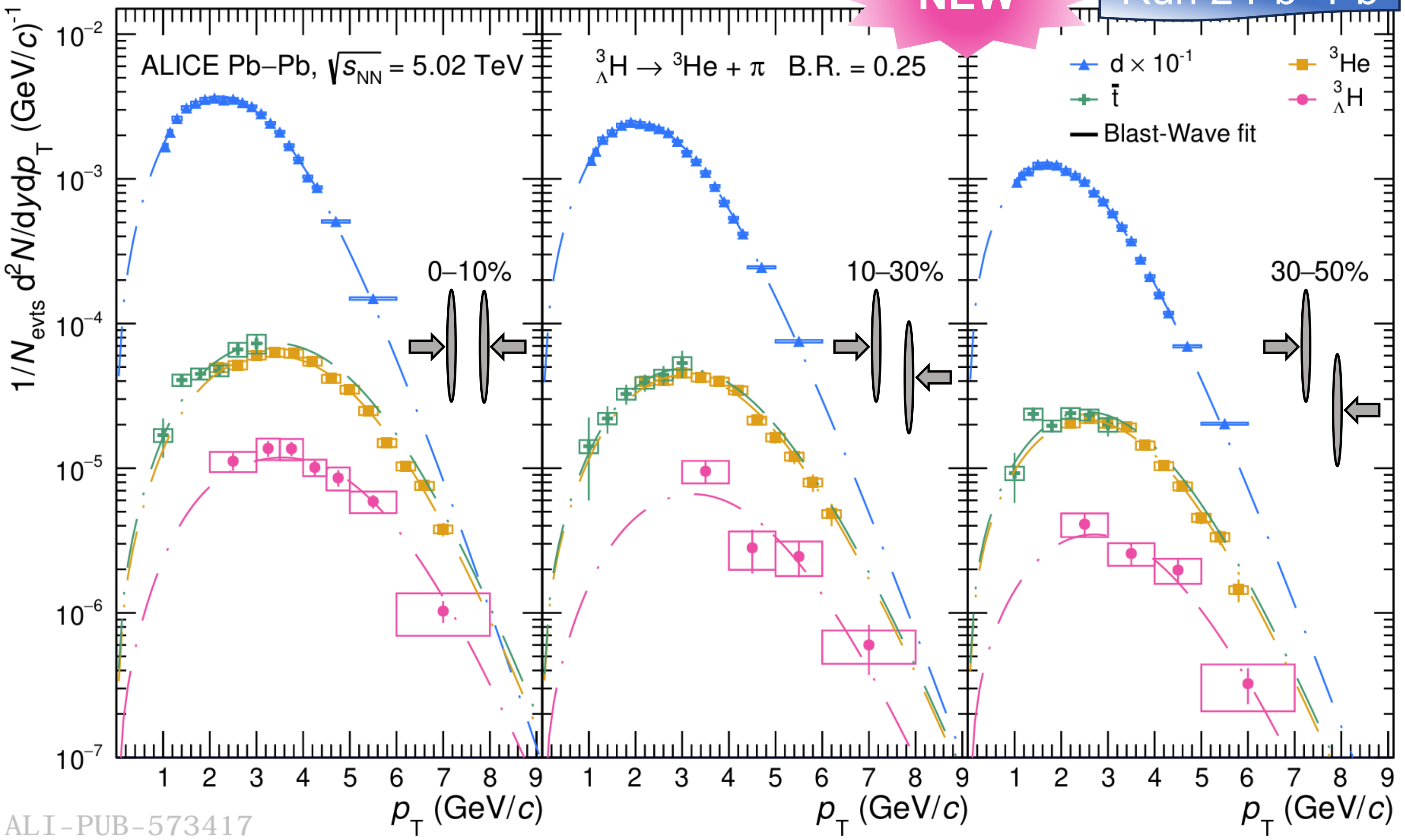
Hypertriton production in Pb—Pb collisions

- First p_T - differential measurement of the ${}^3_\Lambda H$ production in Run 2 Pb—Pb collisions at 5.02 TeV
- Performed a combined Blast-Wave fit to deuterons, tritons, helium-3 and ${}^3_\Lambda H$
- Parameters are compatible with the ones obtained from ordinary nuclei

ALICE, Phys. Lett. B 858, 138943 (2024)

NEW

Run 2 Pb—Pb



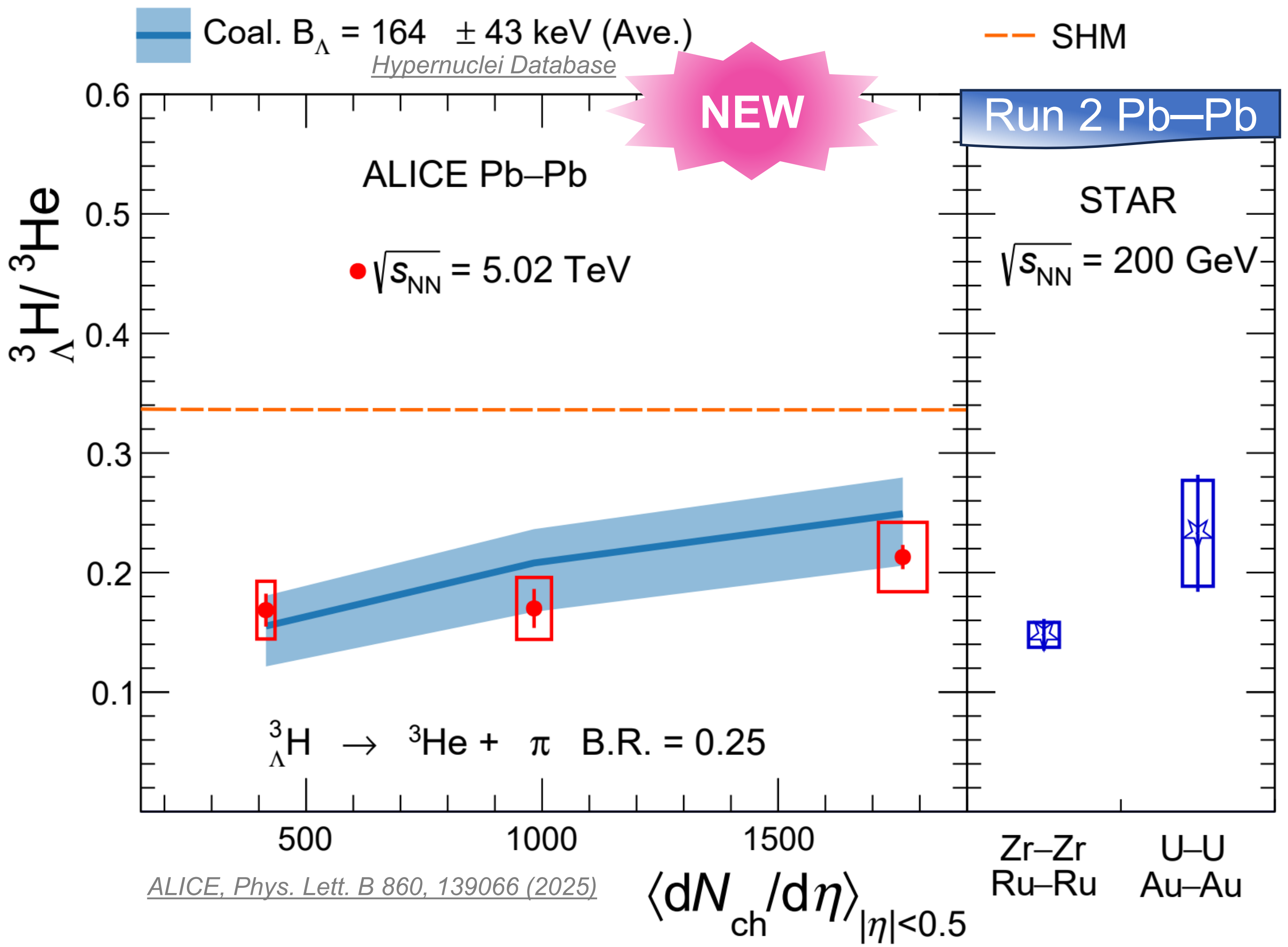
ALICE, Phys. Lett. B 860, 139066 (2025)

Hypertriton production in Pb—Pb collisions

- Coalescence prediction is more sensitive to multiplicities
- SHM prediction stays constant at large multiplicities
- Well-described by the coalescence model, and compatible with the B_Λ value measured by ALICE
- Shows a suppression for the ${}^{3}_{\Lambda}H$ / ${}^{3}He$ ratio vs. the multiplicity as suggested by the STAR results

STAR Collaboration, Nature 632 8027, 1026-1031 (2024)

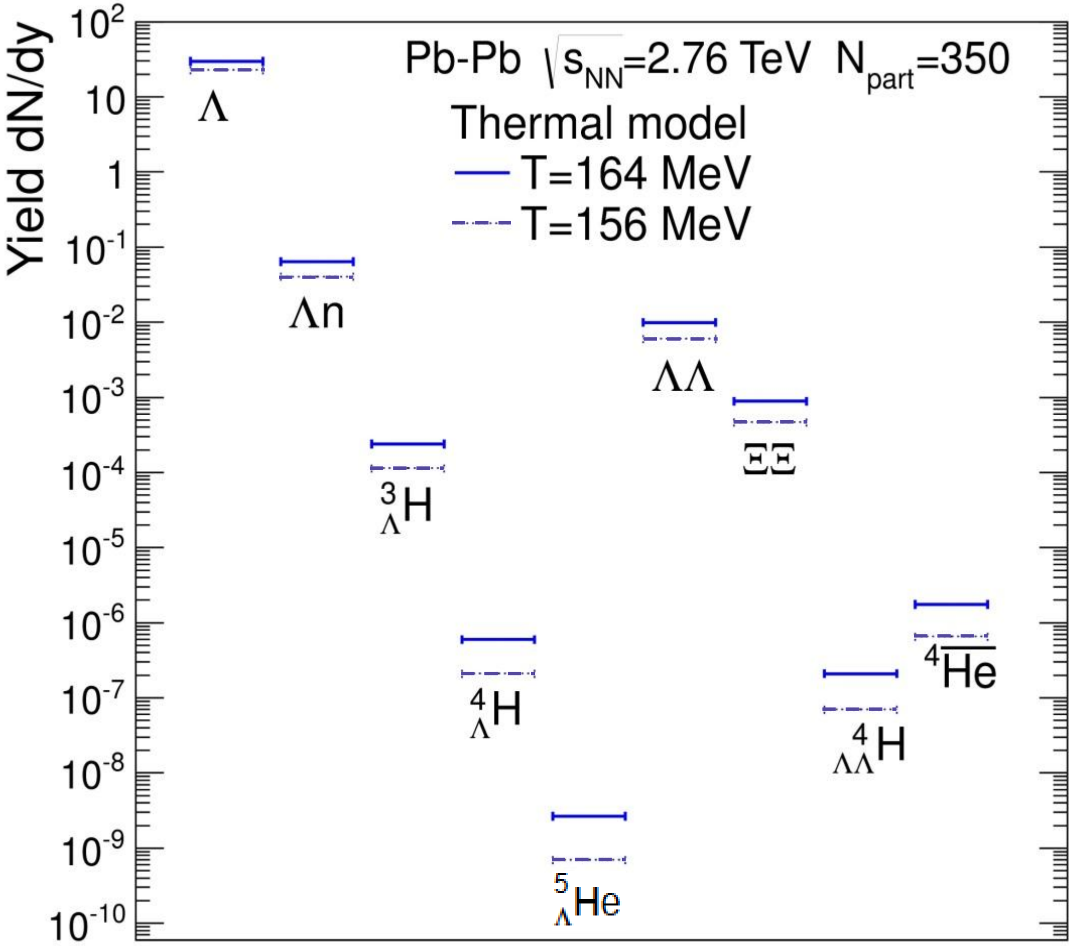
Multiplicity dependence of the ${}^{3}_{\Lambda}H$ / ${}^{3}He$ ratio



ALICE, Phys. Lett. B 860, 139066 (2025)

A = 4 hypernuclei in ALICE

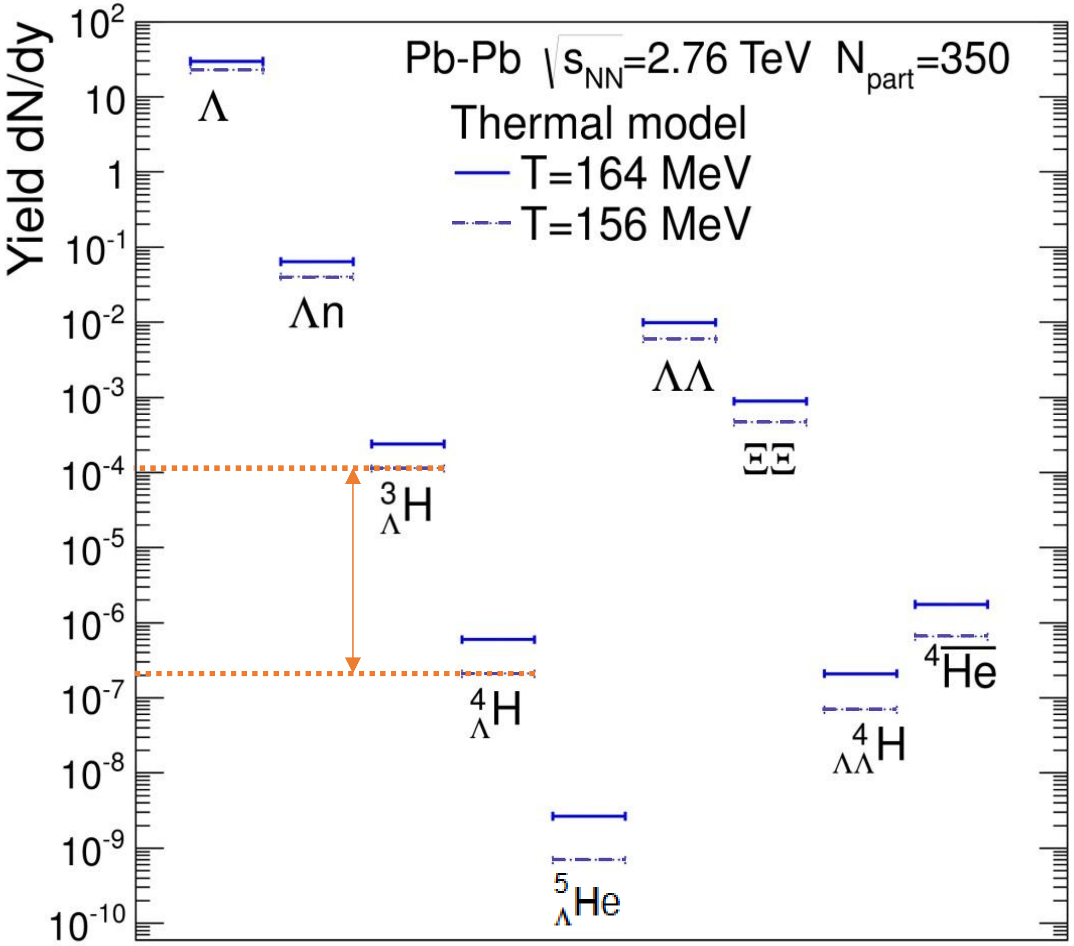
- Expectations for hypernuclei from the statistical hadronization model at T_{ch} = 156 MeV



A. Andronic, private communication
model from A. Andronic et al., Phys. Lett. B 697, 203 (2011)

A = 4 hypernuclei in ALICE

- Expectations for hypernuclei from the statistical hadronization model at T_{ch} = 156 MeV
- Penalty factor by adding one nucleon to a particle ≈ 300 in Pb—Pb collisions



A. Andronic, private communication
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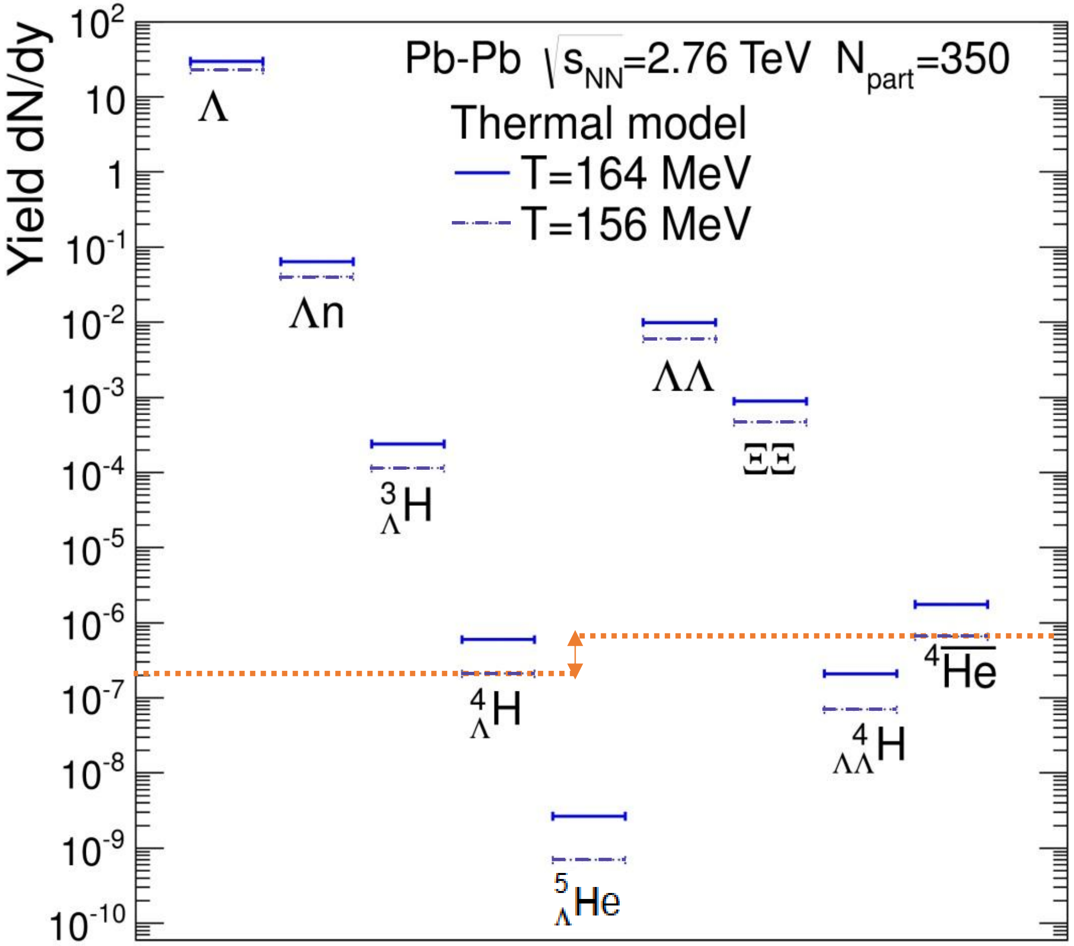
A = 4 hypernuclei in ALICE

- Expectations for hypernuclei from the statistical hadronization model at T_{ch} = 156 MeV
- Penalty factor by adding one nucleon to a particle ≈ 300 in Pb—Pb collisions
- Further suppression due to strangeness content
- Large statistics needed

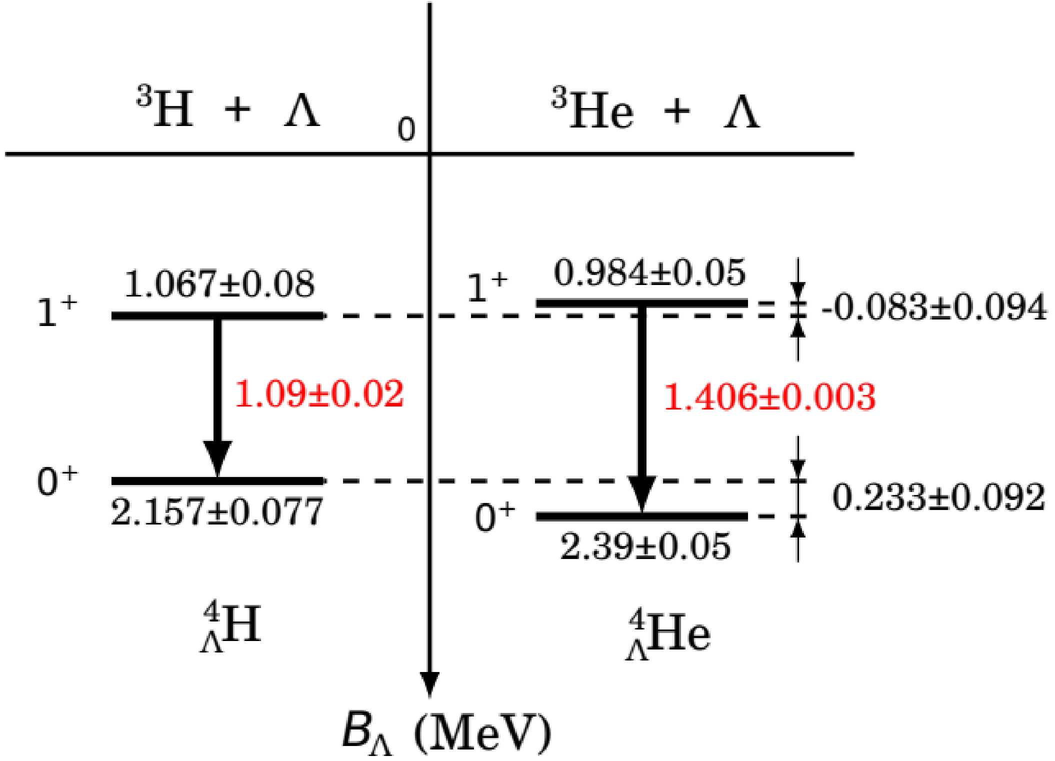


A. Andronic, private communication
model from A. Andronic et al., Phys. Lett. B 697, 203 (2011)

A = 4 hypernuclei in ALICE

- A = 4 hypernuclei are more bound and each has an excited state
  Phys. Rev. Lett. 115, 222501 (2015)
- The yields of these hypernuclei are enhanced with respect to the ground state due to the feed-down from higher mass states
- Also the yields of the SHM scale with the spin degeneracy
- Resulting in a total enhancement of a factor 4 for both hypernuclei
  B. Dönigus, EPJ Web Conf. 276, 04002 (2023)

$B_\Lambda \approx 2$ MeV

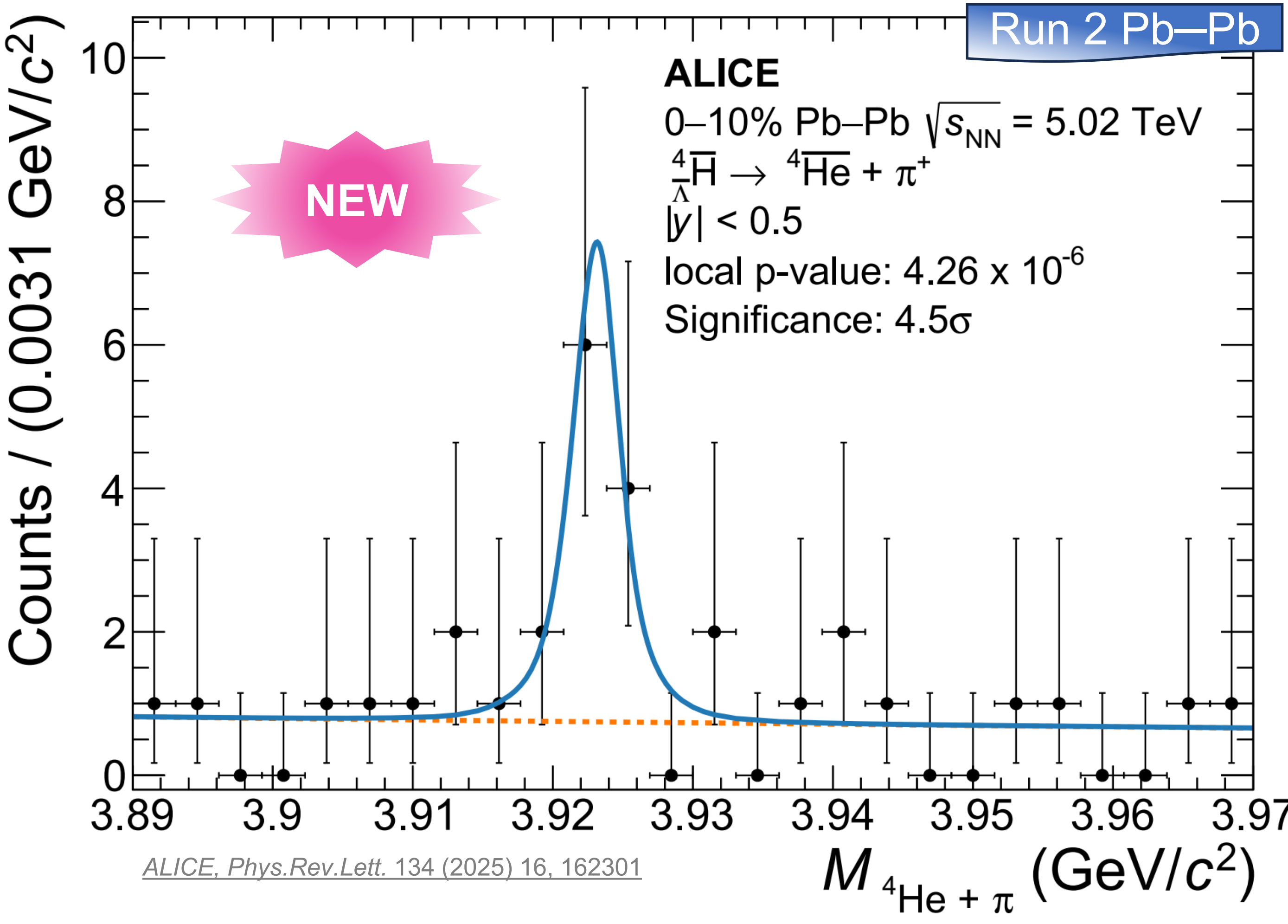


M. Schäfer et. al., Phys.Rev.C 106, L031001 (2022)

A = 4 hypernuclei in ALICE

- First measurements of A = 4 (anti)hypernuclei at the LHC
- Determination of their production yield and mass
- Run 2 Pb—Pb collisions at 5.02 TeV
- Examined in the decay modes:

$$^{4}_{\Lambda}H \rightarrow {}^{4}He + \pi^{-} + c.c.$$
$$^{4}_{\Lambda}He \rightarrow {}^{3}He + p + \pi^{-} + c.c.$$

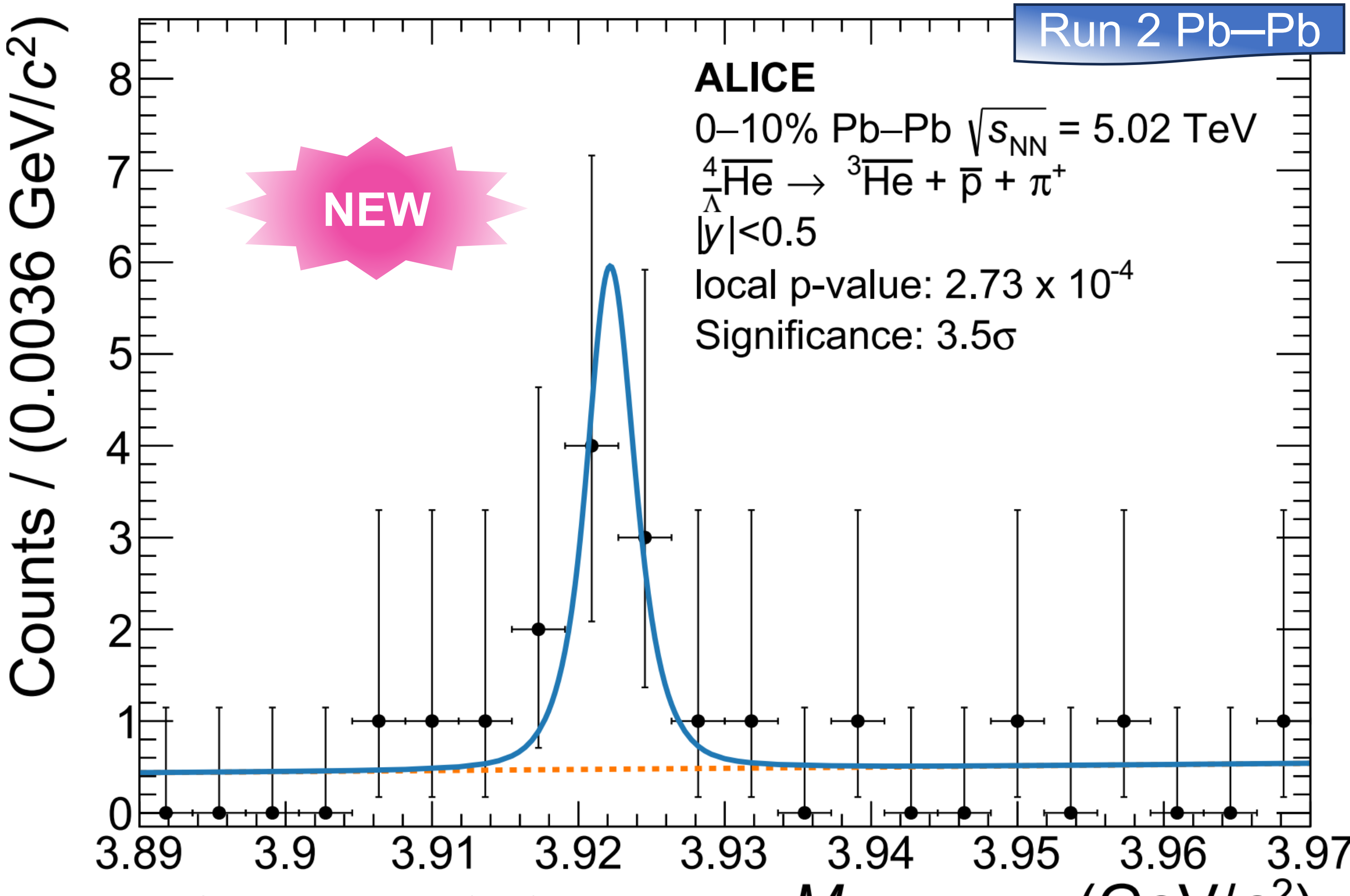


ALICE, Phys.Rev.Lett. 134 (2025) 16, 162301

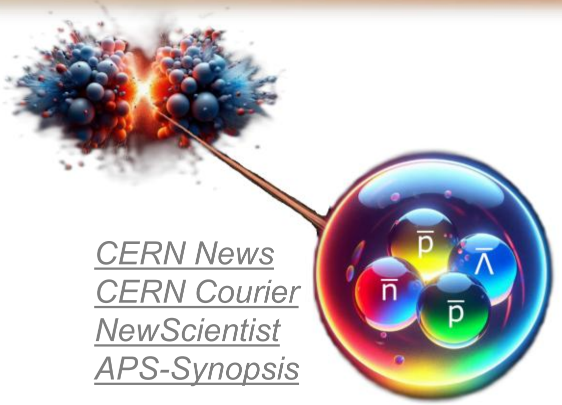
A = 4 hypernuclei in ALICE

- First measurements of A = 4 (anti)hypernuclei at the LHC
- Determination of their production yield and mass
- Run 2 Pb—Pb collisions at 5.02 TeV

First evidence for $^{4}_{\bar{\Lambda}}\overline{\mathrm{He}}$ ever!



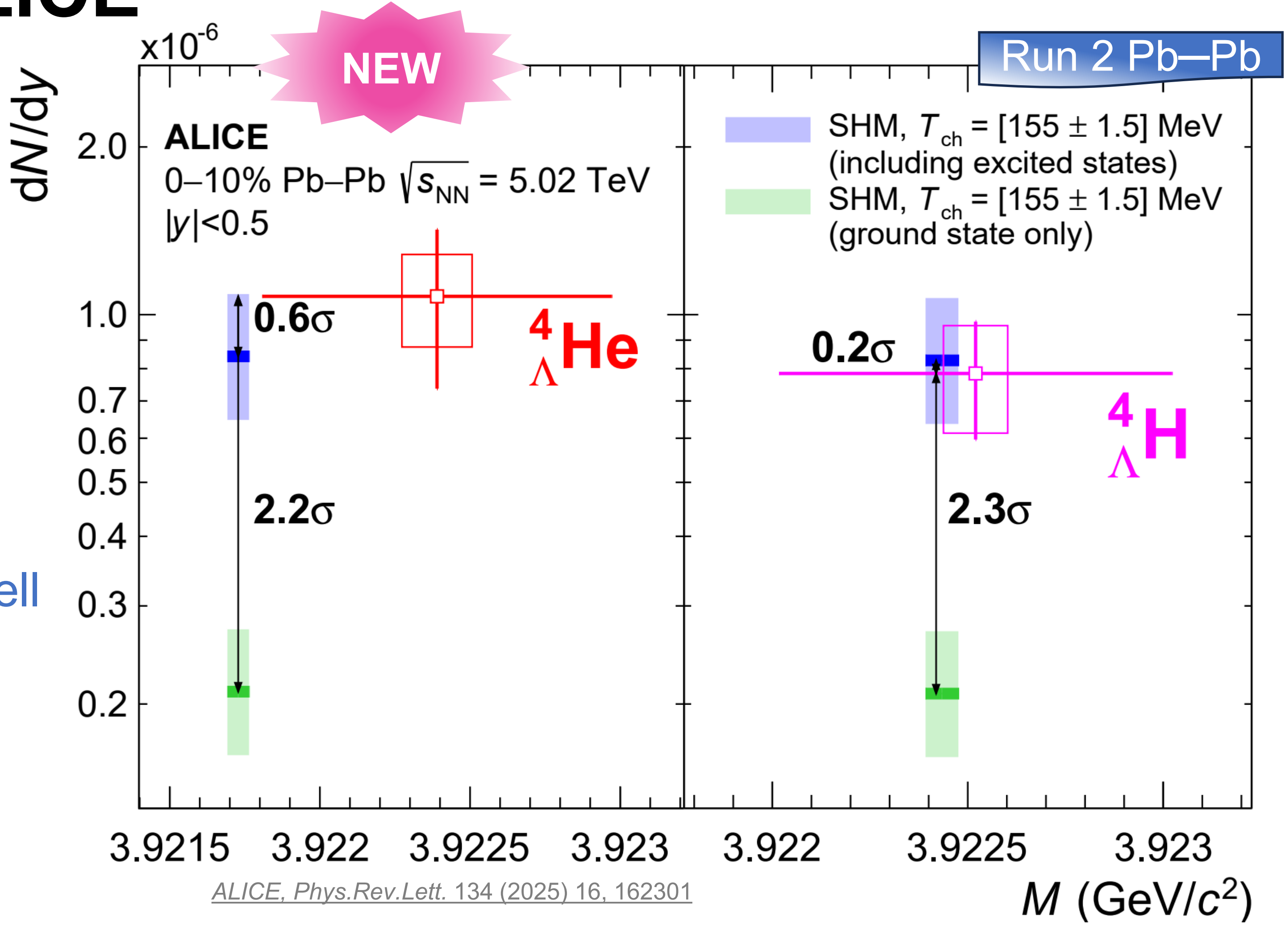
ALICE, Phys.Rev.Lett. 134 (2025) 16, 162301



CERN News
CERN Courier
NewScientist
APS-Synopsis

A = 4 hypernuclei in ALICE

- First measurement of the (anti)hyperhelium-4 production yield
- Testing the dependence of the yields of the SHM with the spin degeneracy
- Combined deviation to ground-state only > 3σ
- Our yields confirm the SHM as a well working model for the prediction of the yields of compact hypernuclei

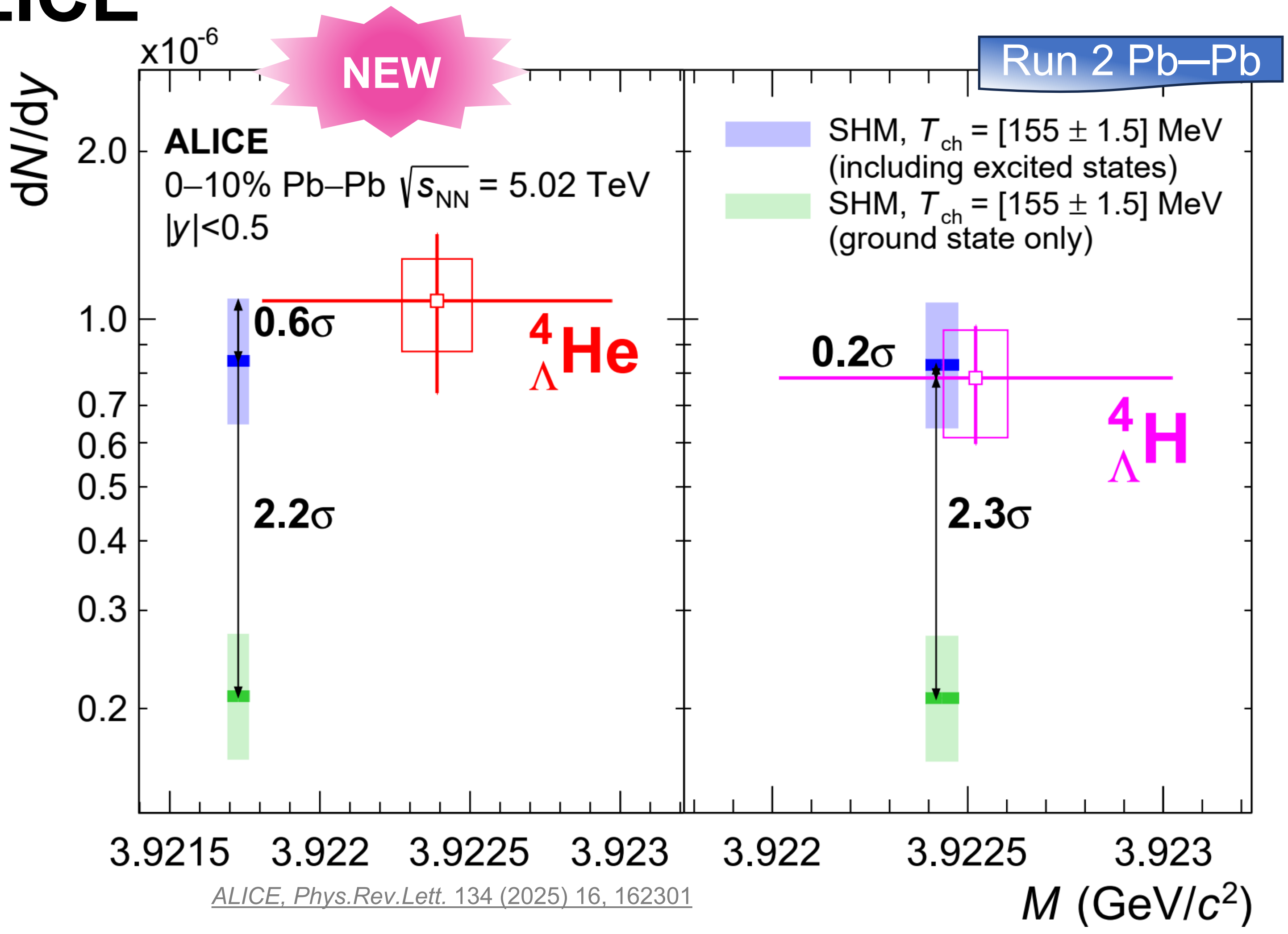


ALICE, Phys.Rev.Lett. 134 (2025) 16, 162301

A = 4 hypernuclei in ALICE

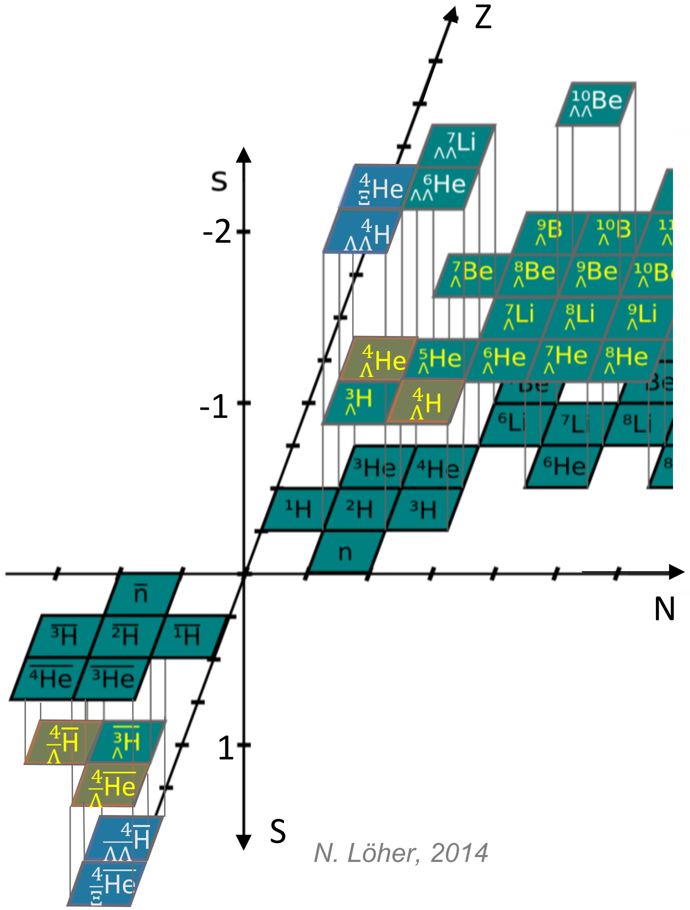
Shedding light on the
charge-symmetry breaking:

- Currently dominated by statistical uncertainties
- With more data,
  a high precision measurement will be feasible like for the Λ hyperon
  ALICE, Phys. Rev. D 108, 032009 (2023)

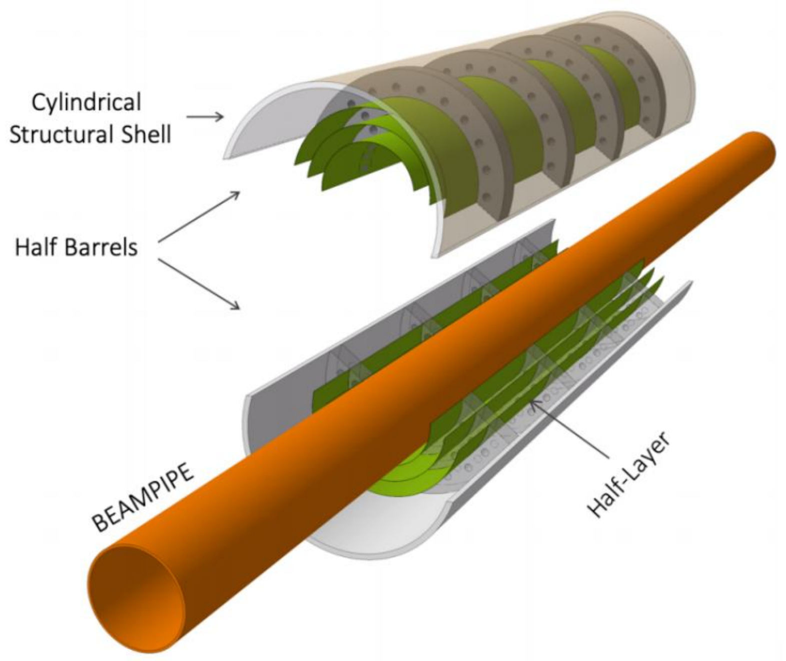


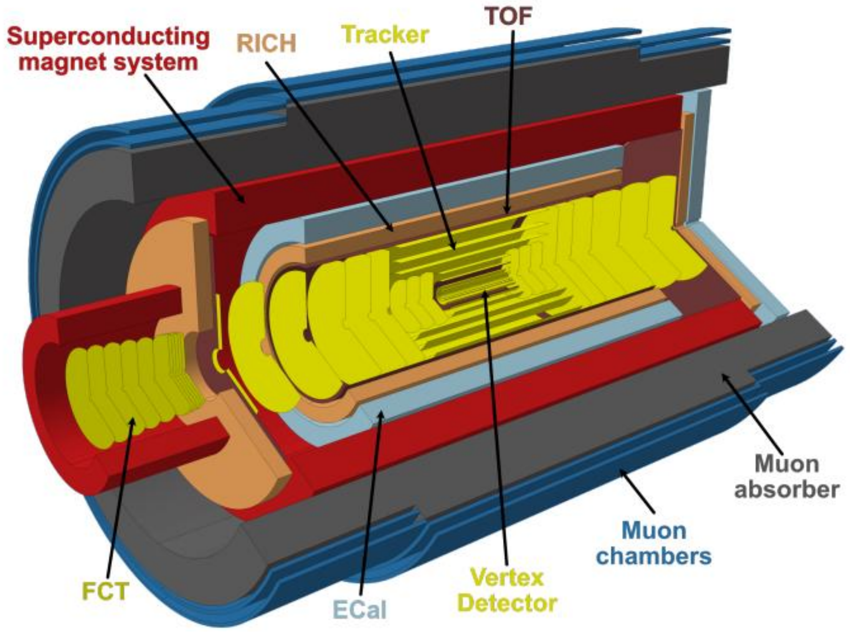
ALICE, Phys.Rev.Lett. 134 (2025) 16, 162301

What comes next?



N. Löher, 2014





2028

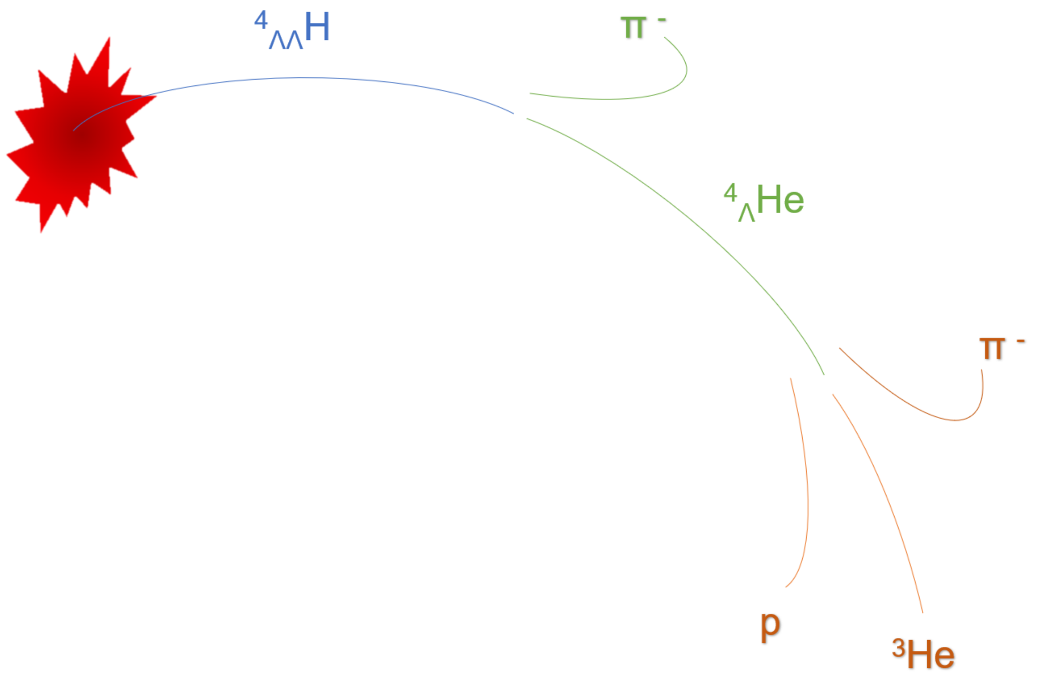
2035+

Search for multistrange hypernuclei

- What about multistrange hypernuclei?
- More difficult to reconstruct due to cascading decays
- Lightest double hypernucleus: ${}^{4}_{\Lambda\Lambda}\mathrm{H}$
- Decay mode:

$${}^{4}_{\Lambda\Lambda}\mathrm{H} \rightarrow {}^{4}_{\Lambda}\mathrm{He} + \pi_{sec}$$
$$\hookrightarrow {}^{3}\mathrm{He} + p + \pi$$

- Mass expected to be 4.106 GeV/c^2
- Existence theoretically still unclear and experimentally not found yet

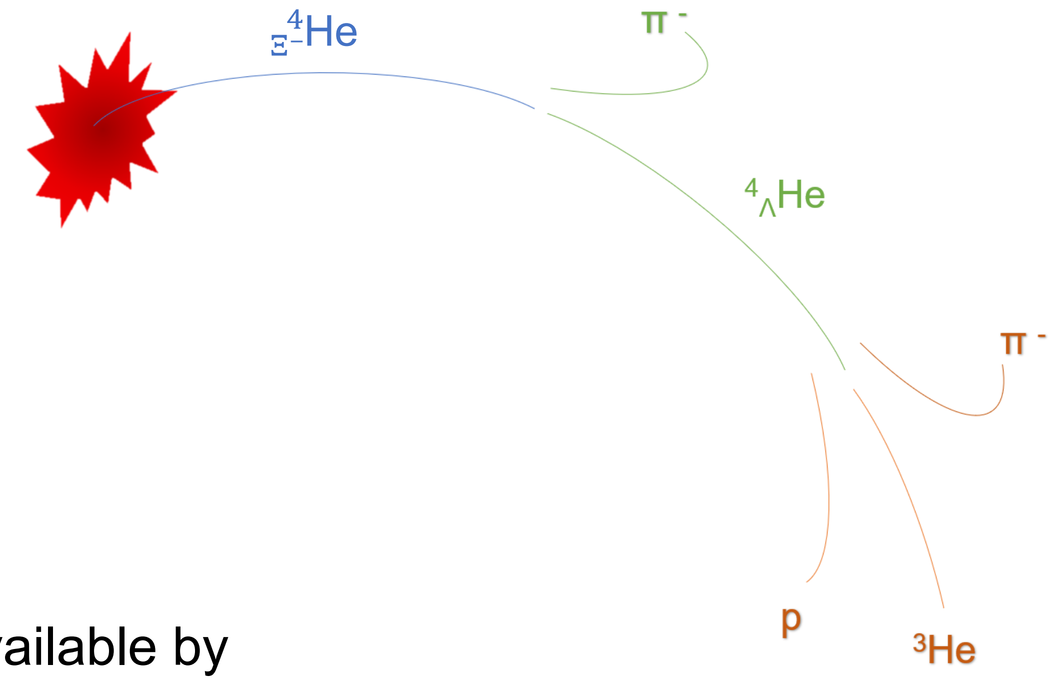


Search for multistrange hypernuclei

- Possibly also: ${}^{4}_{\Xi^-}\mathrm{He}$
- Decays in the same way as ${}^{4}_{\Lambda\Lambda}\mathrm{H}$

$${}^{4}_{\Xi^-}\mathrm{He} \rightarrow {}^{4}_{\Lambda}\mathrm{He} + \pi_{sec}\ (\Xi^- \rightarrow \Lambda + \pi^-)$$
$$\hookrightarrow {}^{3}\mathrm{He} + p + \pi$$

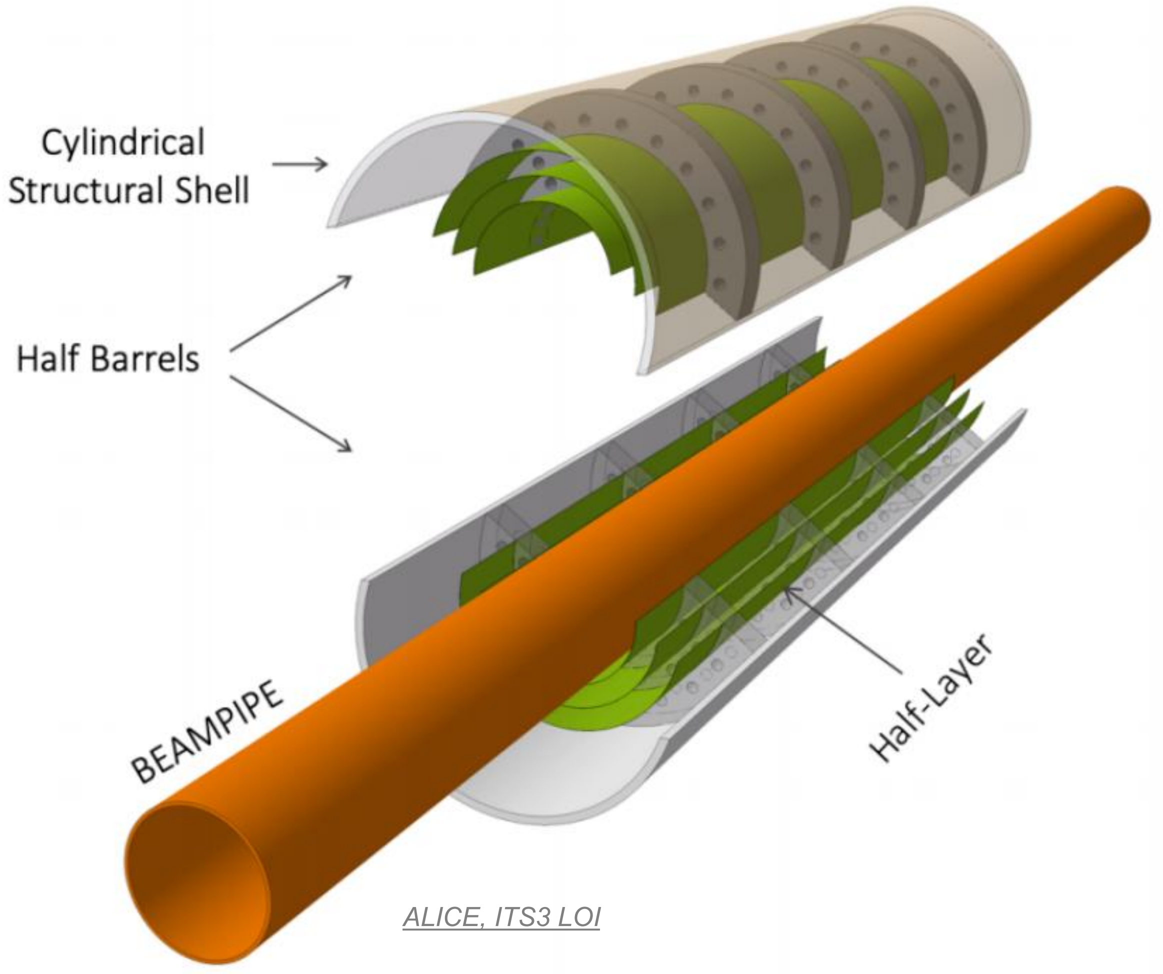
- Mass expected to be 4.126 GeV/c^2 by calculations using recent information from the Ξ^- potential A. Gal et. al., Phys.Lett.B 820 (2021) 136555
- Special features: Possibility to create atomic structures; excited states? A. Gal et. al., arxiv:2308.12041
- Experimentally not found yet
- Only poor information on the Λ-Λ interaction available by (anti)doublehypernuclei and femtoscopy measurements
  → further measurements are needed!



ITS3

- Upgrade of the ITS2 Inner Barrel
  → replaced by real half cylinders
  of bent, thin silicon
- Wafer-scale sensors in 65 nm technology
- Material budget per layer reduced once more by ~ 1/7
- First tests with micro model ongoing

- What does this mean for the reconstruction of (anti)hypernuclei?

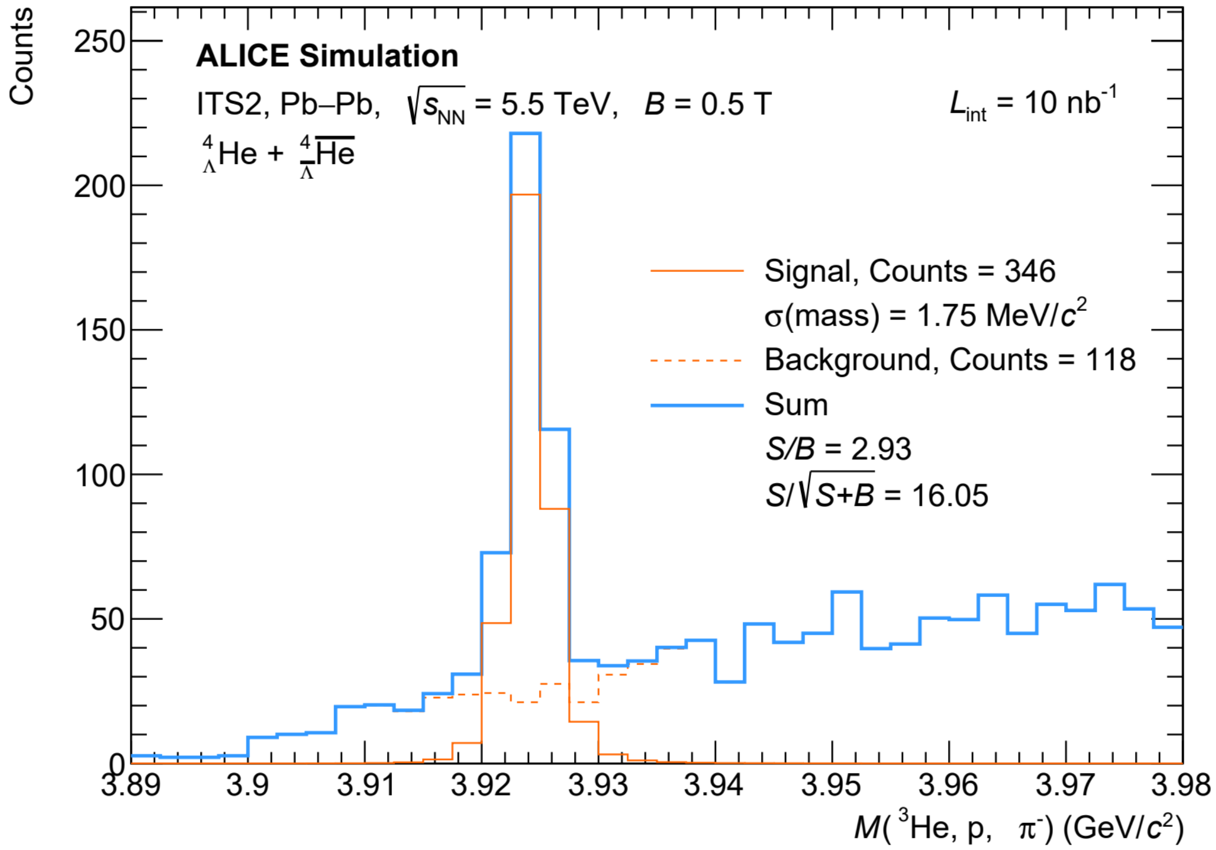


ALICE, ITS3 LOI

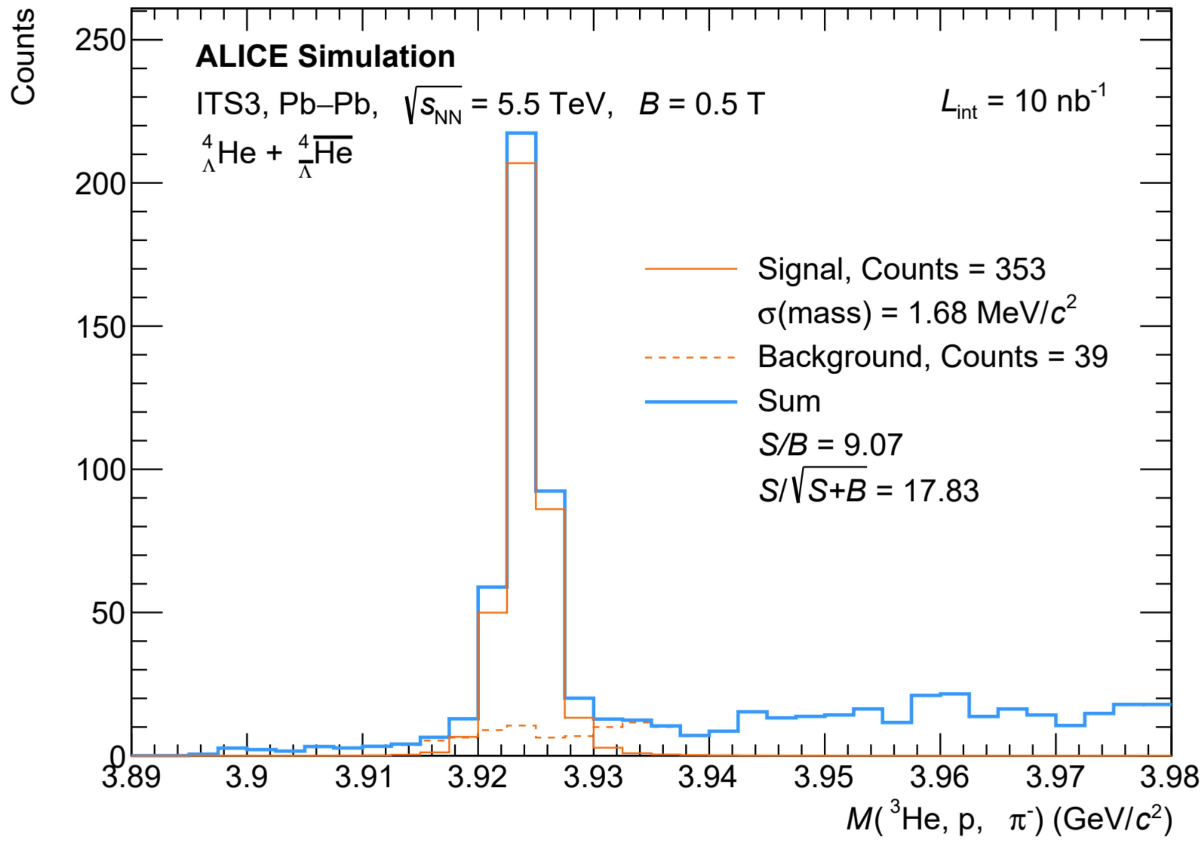
ITS2 vs. ITS3

Fixed set of selection criteria

ITS2



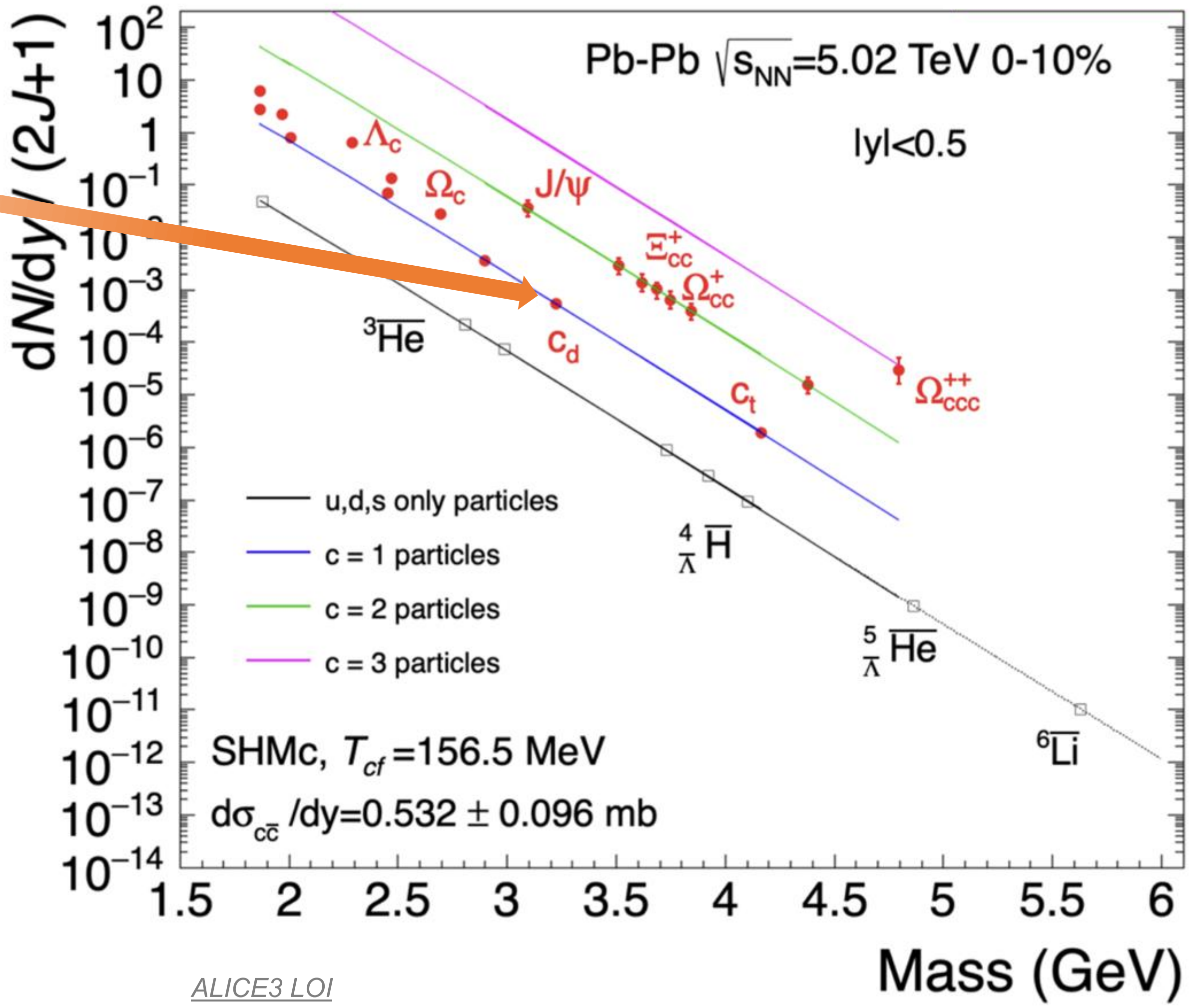
ITS3



ALICE, ITS3 public note

Search for charmed nuclei

- c-deuteron ($\Lambda_c^+ n$)
  - Decay mode:
    $$\Lambda_c^+ n \rightarrow d K^- \pi^+$$
    (most promising)
  - mass ≈ 3.226 GeV/c^2
  - $c\tau$ ≈ 60 µm



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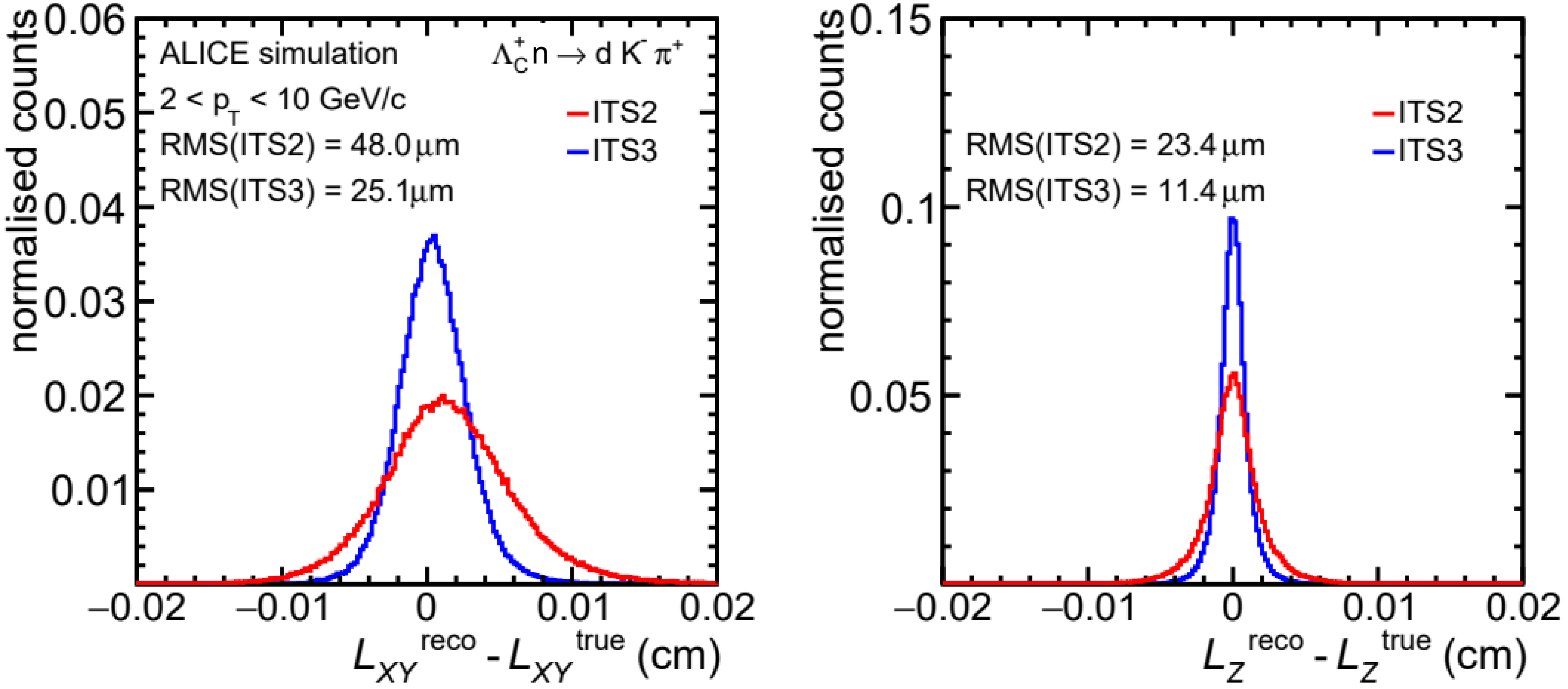
  - $c\tau$ ≈ 60 µm

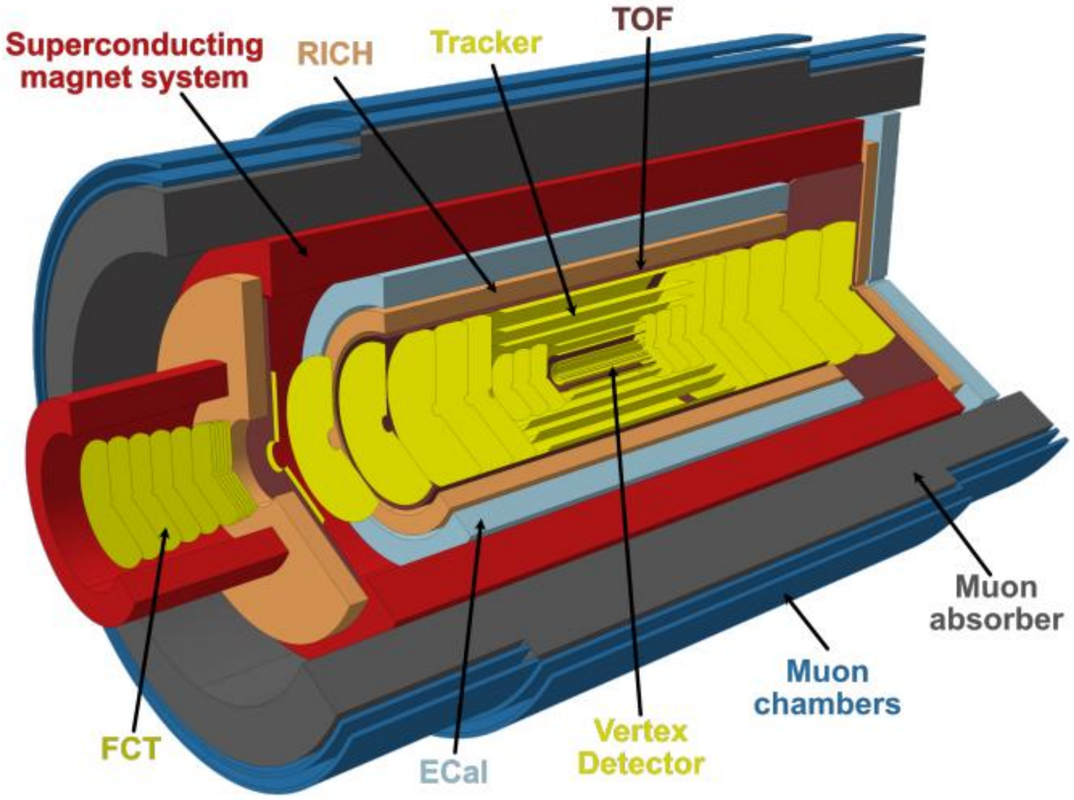
- Strong improvement on the decay-length resolution with ITS3



ALICE, ITS3 public note

ALICE3

- Compact, low mass, all-silicon detector
- Retractable vertex detector
- Super-conducting magnet system
- Current status: R&D phase
- To be installed > 2035



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  - Decay mode:
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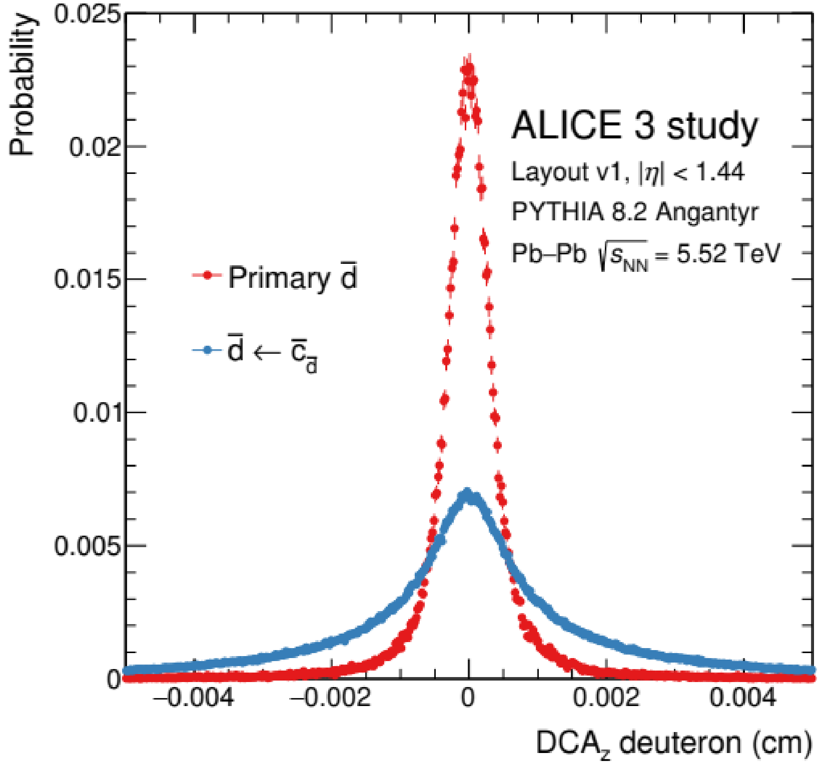
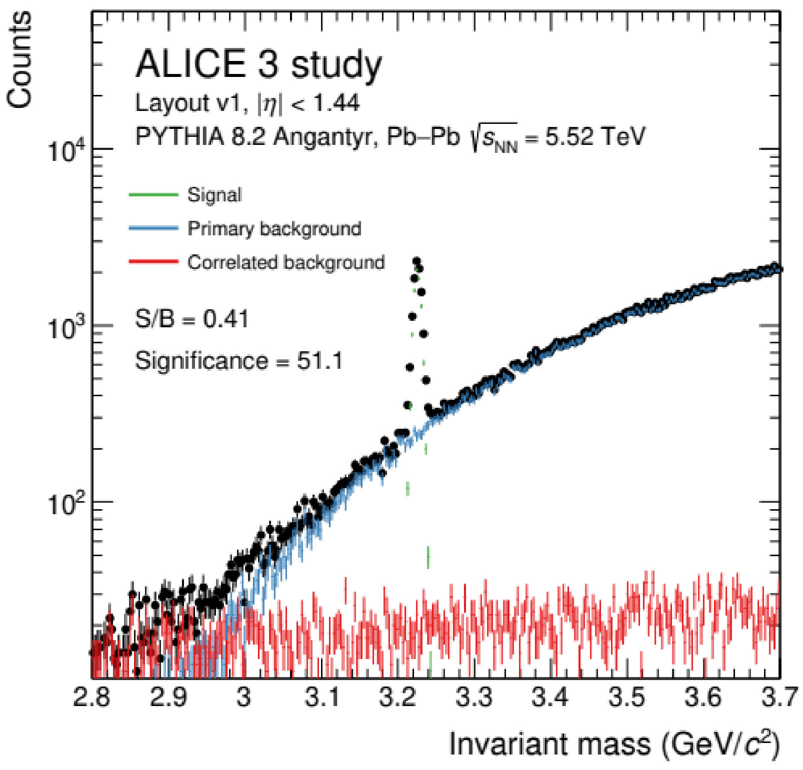
  - $c\tau$ ≈ 60 μm

- Expected to be even better for ALICE3

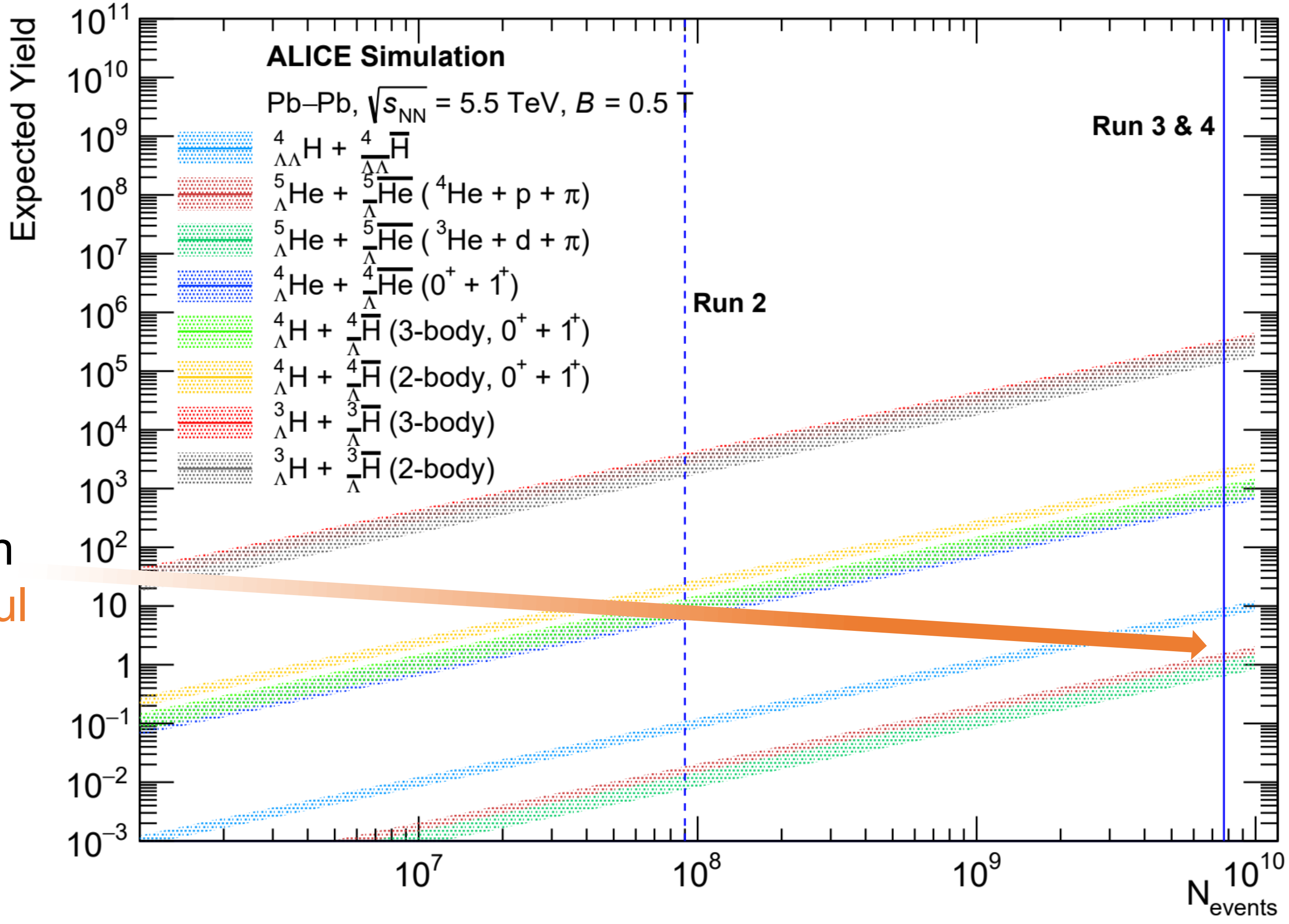




ALICE3 LOI

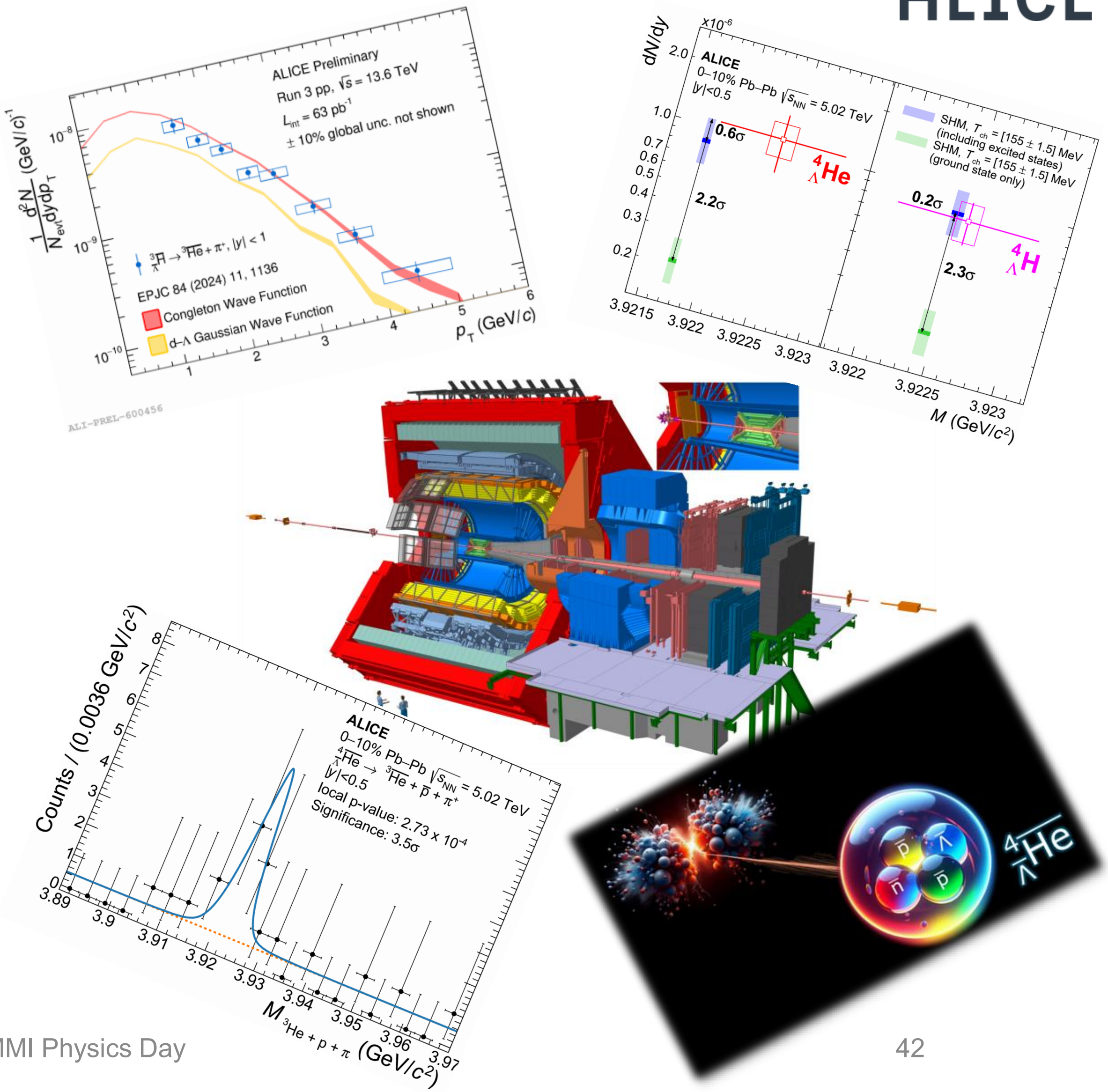
Search for A>4 hypernuclei

- Expected raw counts for hypernuclei from the statistical hadronization model at T_{ch} = 156 MeV
- Penalty factor by adding one nucleon to a particle ≈ 300 in Pb—Pb collisions (1000 in pp collisions)
- With the combined statistics of Run 3 & Run 4 we might reach a handful of a A=5 (anti)hypernuclei
- New reconstruction methods and machine learning might enable for more!



Summary

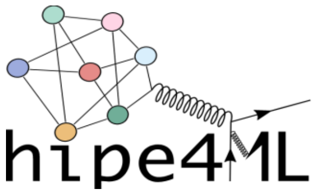
- The study of the production of light (anti)hypernuclei in high-energy collisions allows to analyze their inner structure
- This may also give the possibility of a more conclusive answer to the question of the production mechanism
- The measurement of the production of A = 4 (anti)hypernuclei provides an important test for the dependence of the spin degeneracy of the production models and insights on the charge-symmetry breaking
- The large amount of high precision heavy-ion data of the LHC Run 3 could reveal more (strange) exotic objects as $^{4}_{\Xi^-}$He or $^{4}_{\Lambda\Lambda}$H and enable for precise studies to obtain important information for the EoS of neutron stars



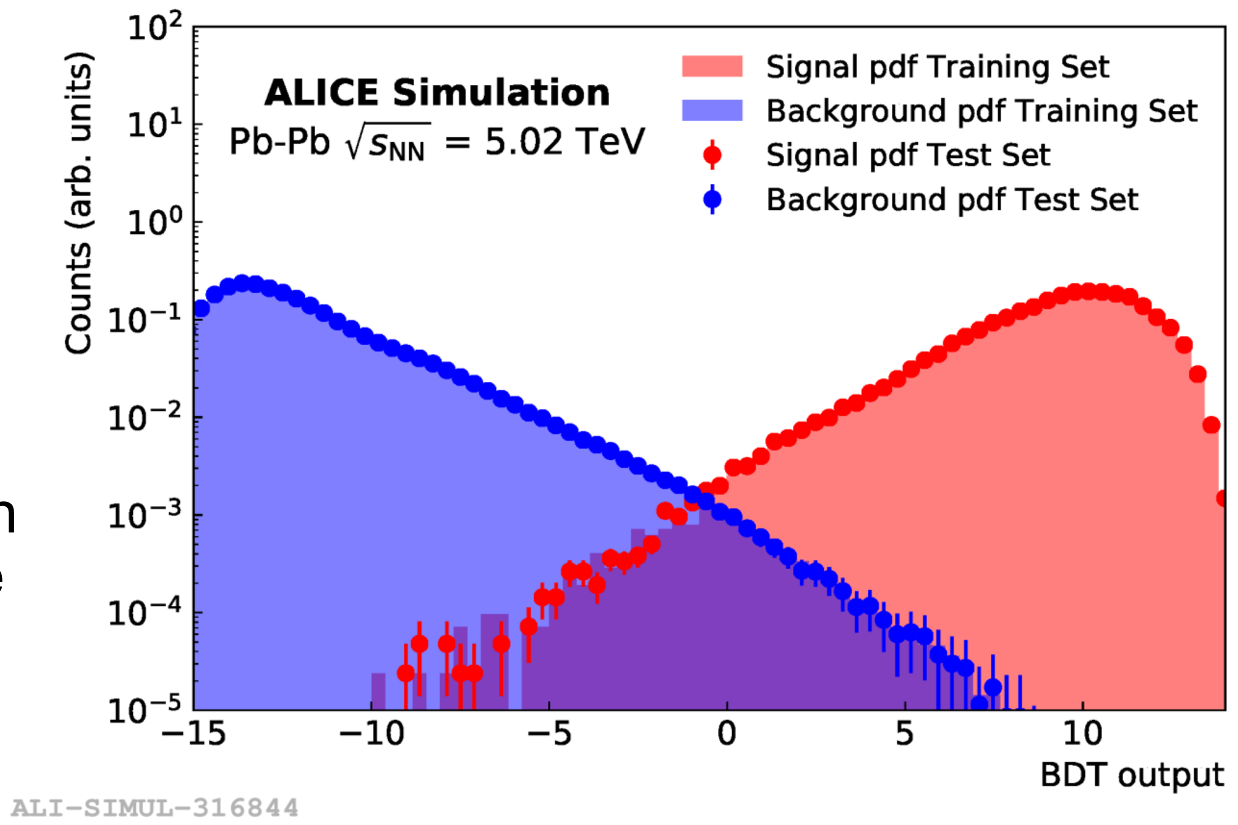
Backup

Signal extraction

- Using a machine learning approach (Boosted Decision Tree) for the signal extraction
- A machine is trained and tested using a dedicated MC sample with injected hypernuclei and a background sample
- The result is a model that is applied on the data and allows a selection via the BDT output value



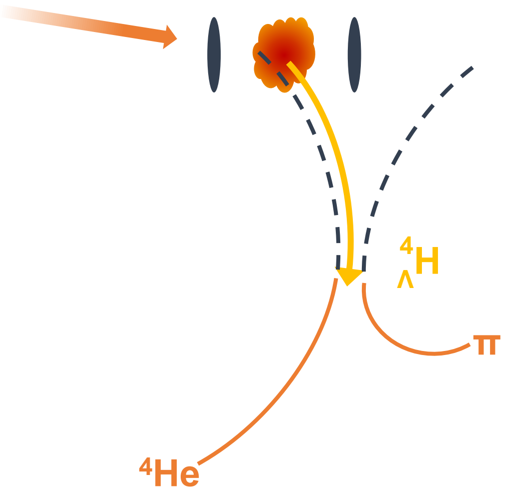
https://hipe4ml.github.io/

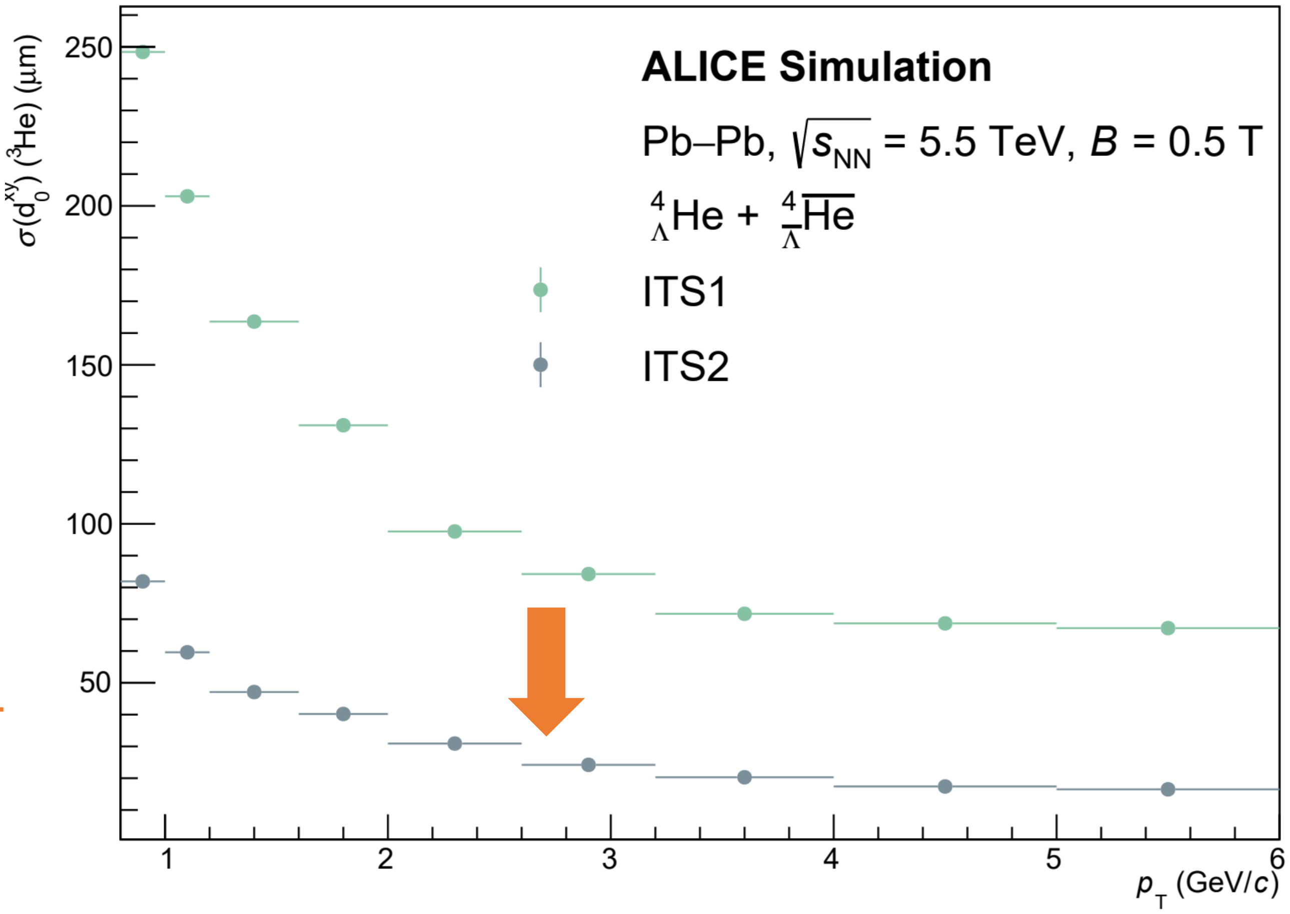


ITS2

- DCA$_{xy}$-resolution of helium-3 tracks of background candidates of $^{4}_{\Lambda}$He
- DCA$_{xy}$-distribution of signal candidates expected to have larger distance to the primary vertex

→ up to five times higher resolution!





ALICE, ITS3 public note

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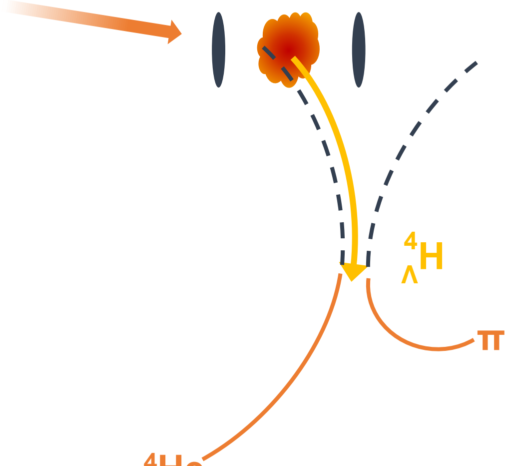
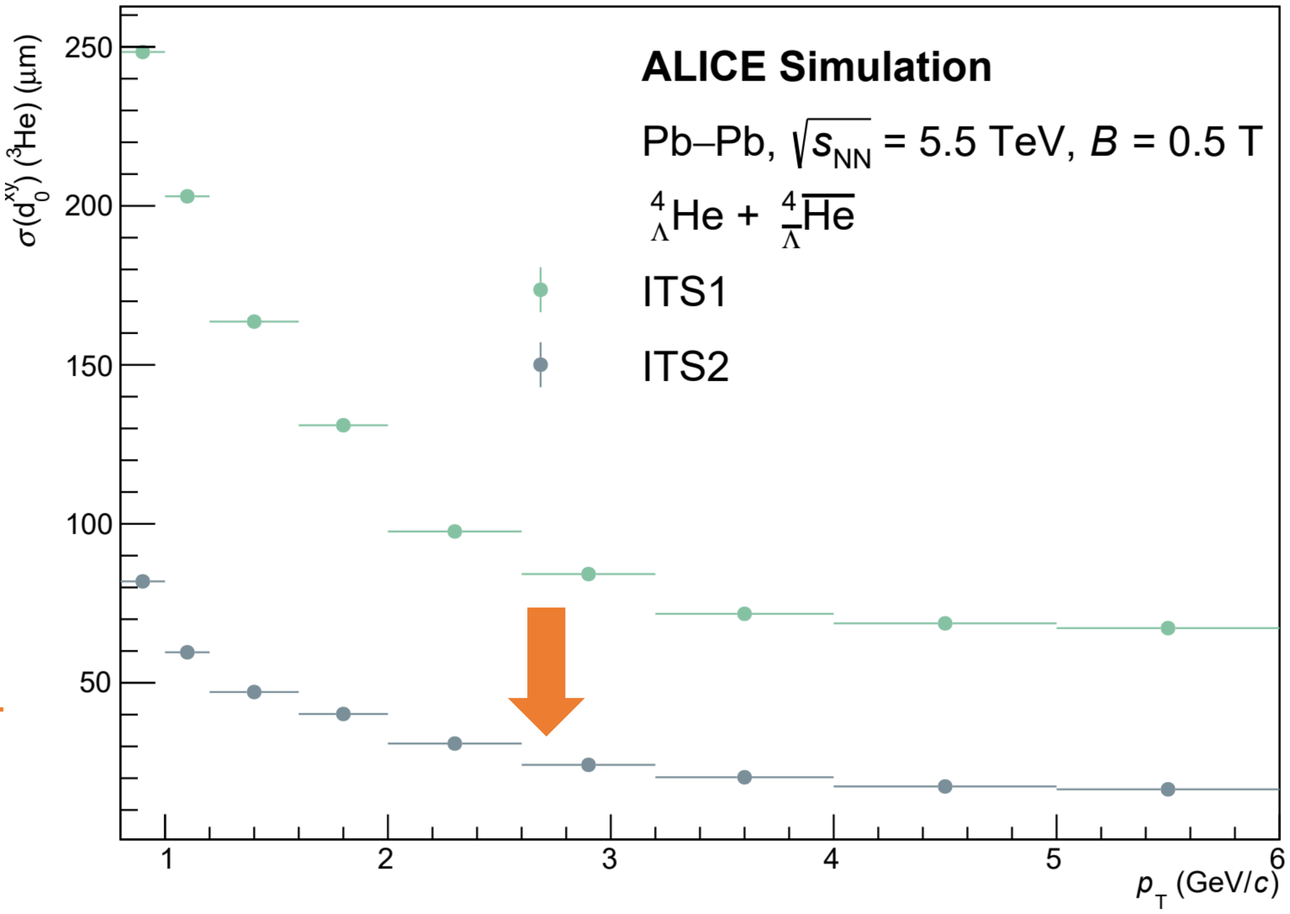


→ up to five times higher resolution!

- Additionally:
  - PID capabilities through the mean charge deposit per ITS layer
  - Tracking of the hypernucleus itself



ALICE, ITS3 public note

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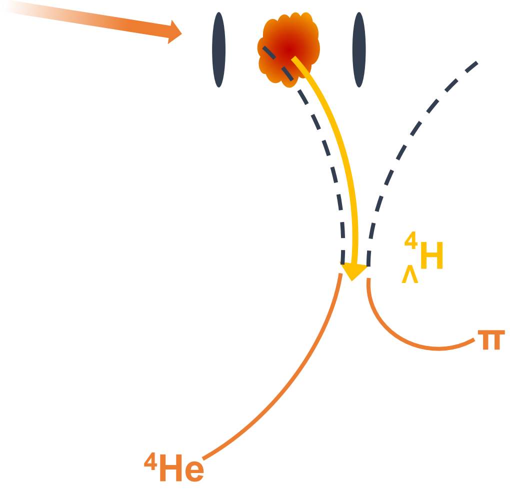
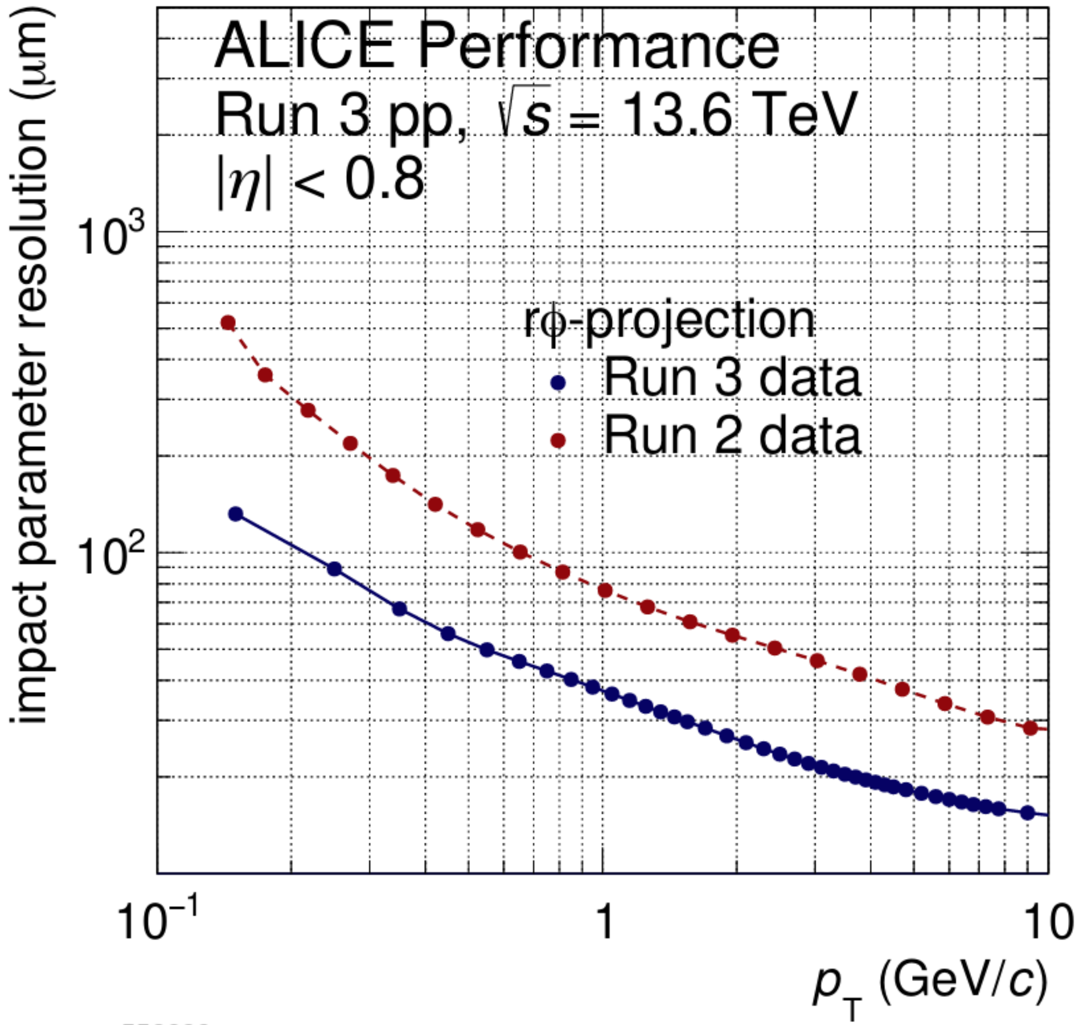
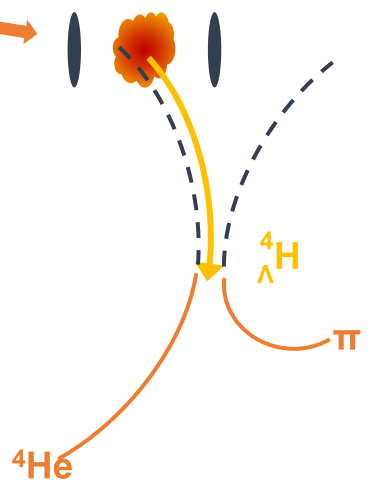


→ great improvement visible in data!

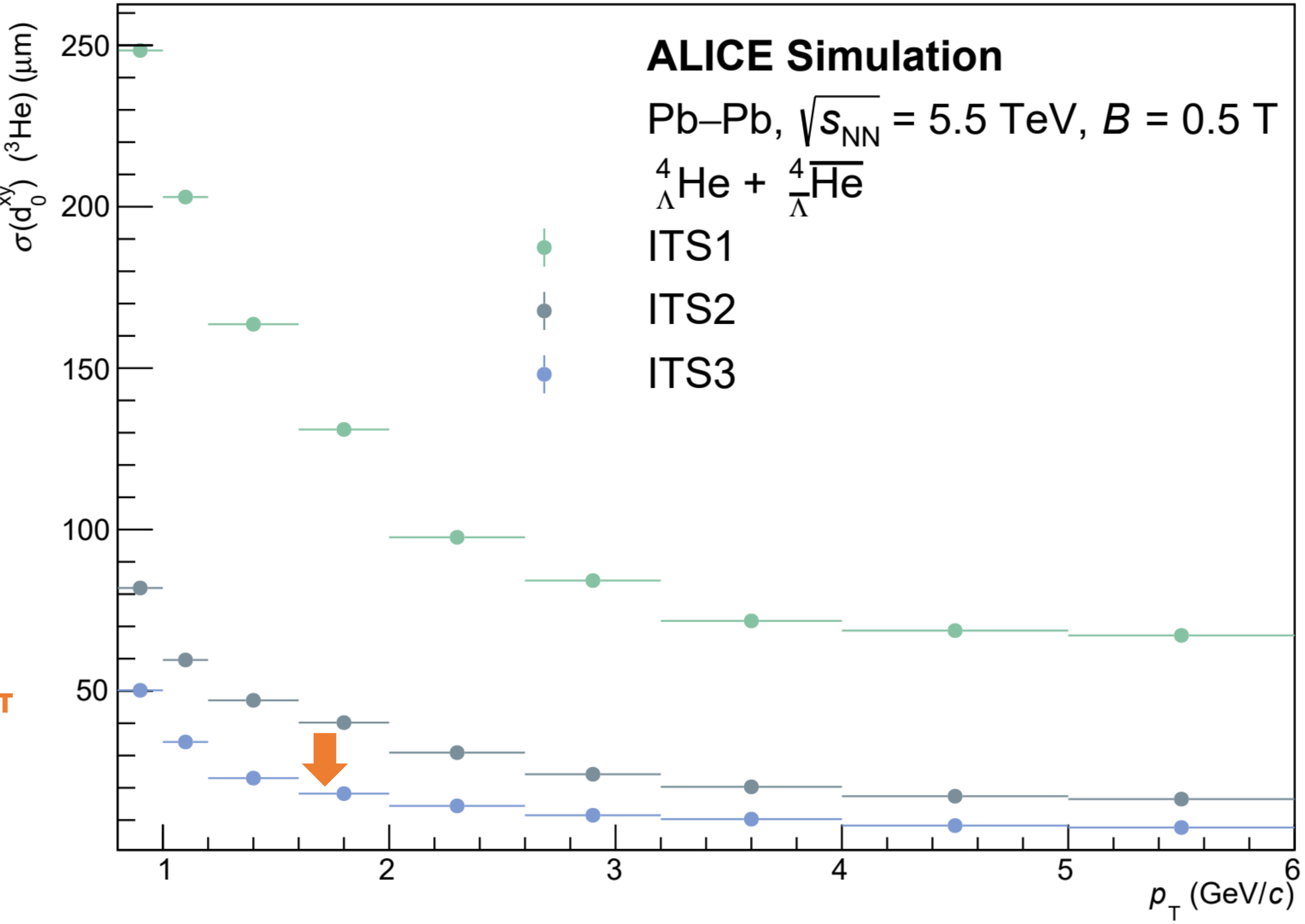


ITS3

- DCA$_{xy}$ -resolution of helium-3 tracks of background candidates of ${}^{4}_{\Lambda}$He
- DCA$_{xy}$ -resolution of signal candidates expected to have larger distance to the primary vertex



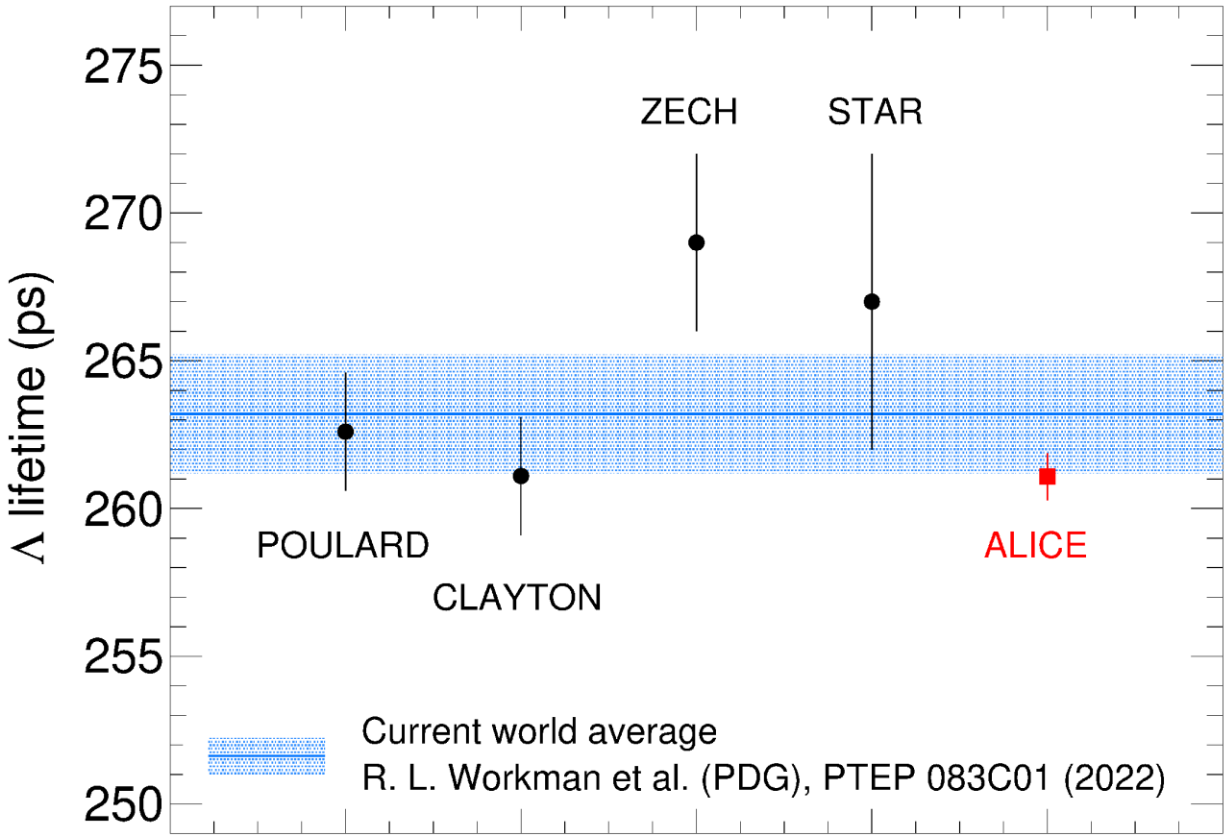
→ two times higher resolution expected!



ALICE, ITS3 public note

Free Λ lifetime

- Recent measurement in Run 2 Pb-Pb collisions at 5.02 TeV
- New, extremely precise measurement of the free Λ lifetime as reference for the hypertriton lifetime
- This measurement is factor ~3 more precise than the PDG value

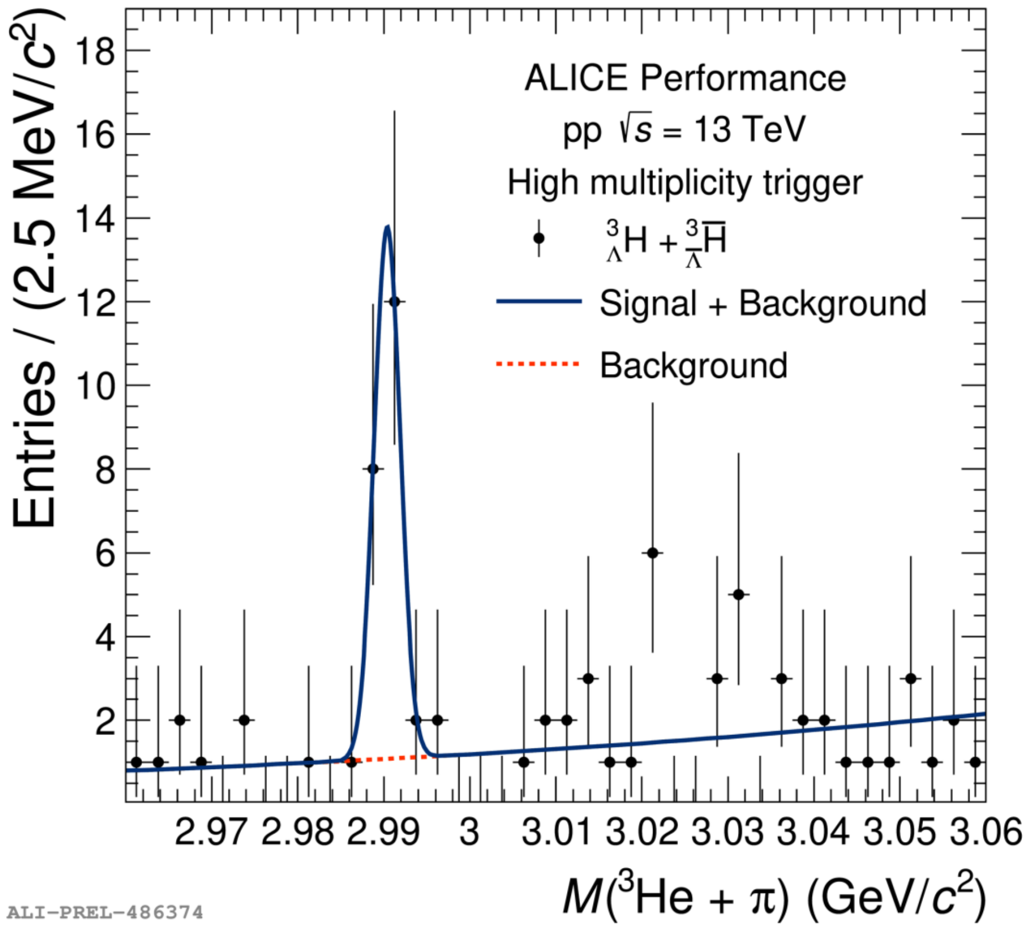


ALICE, Phys. Rev. D 108, 032009 (2023)

ALI-PUB-561575

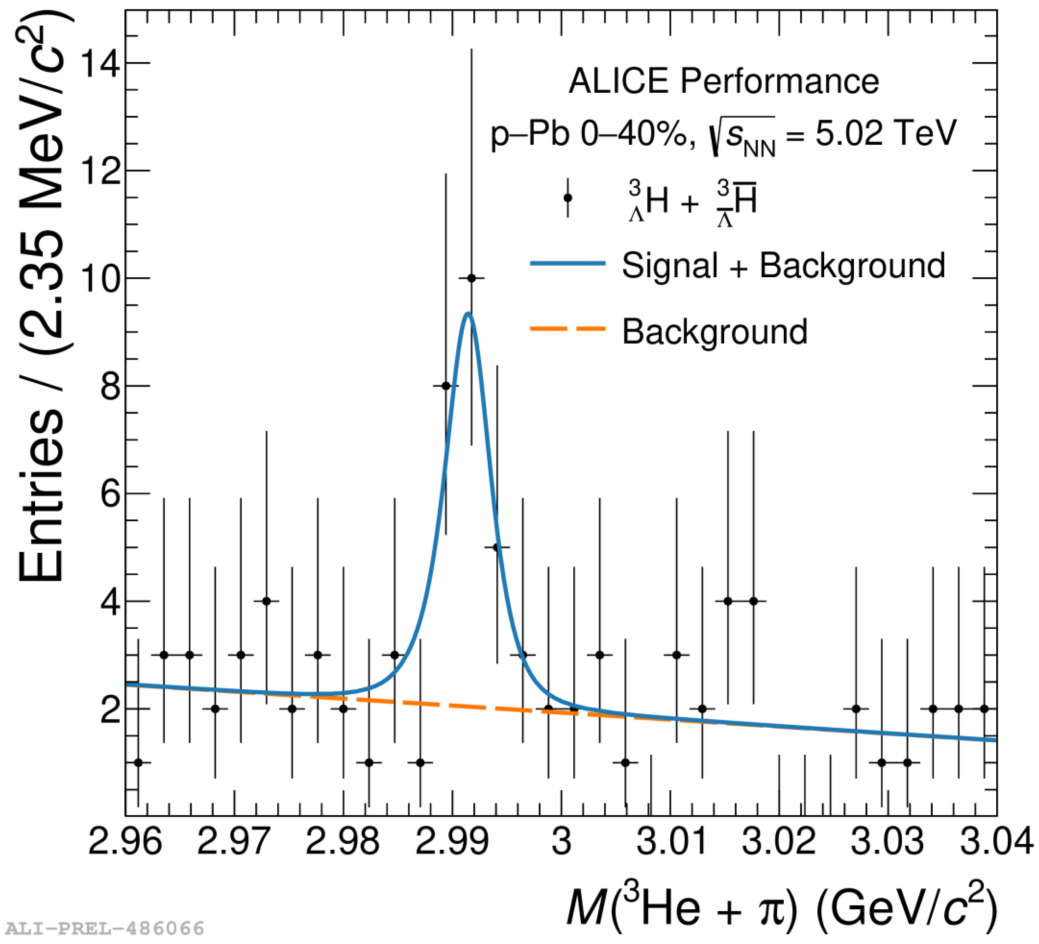
Hypertriton measurement in pp

- First measurement of the hypertriton in Run 2 pp collisions at 13 TeV
- Topological and kinematical cuts applied to optimize the signal-to-background ratio and improve the significance in a traditional analysis



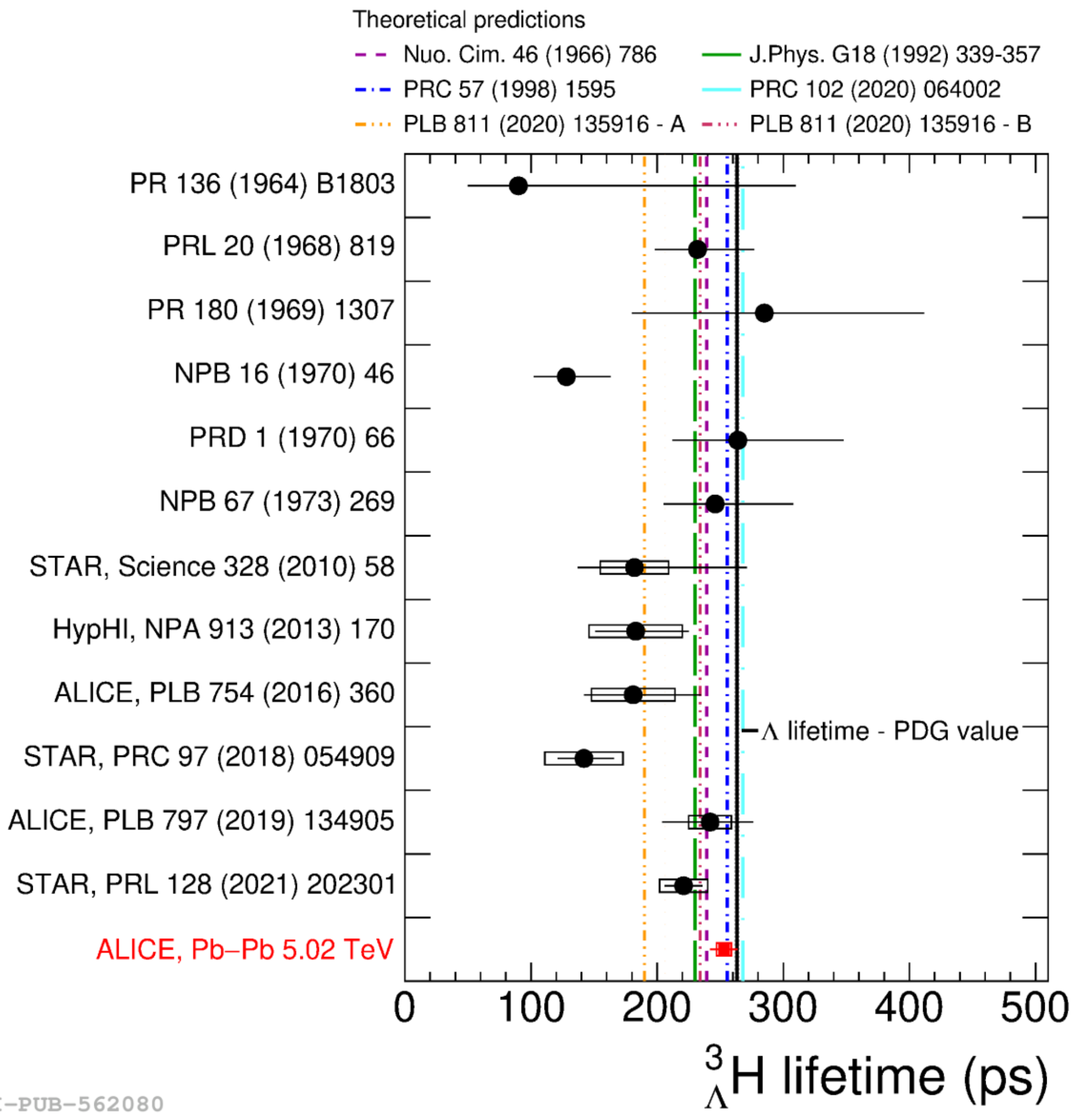
Hypertriton measurement in p-Pb

- First measurement of the hypertriton in Run 2 p-Pb collisions at 5.02 TeV
- Signal extraction by using a machine learning approach
- Using a boosted decision tree (BDT) and hyper parameter optimisation



Hypertriton lifetime

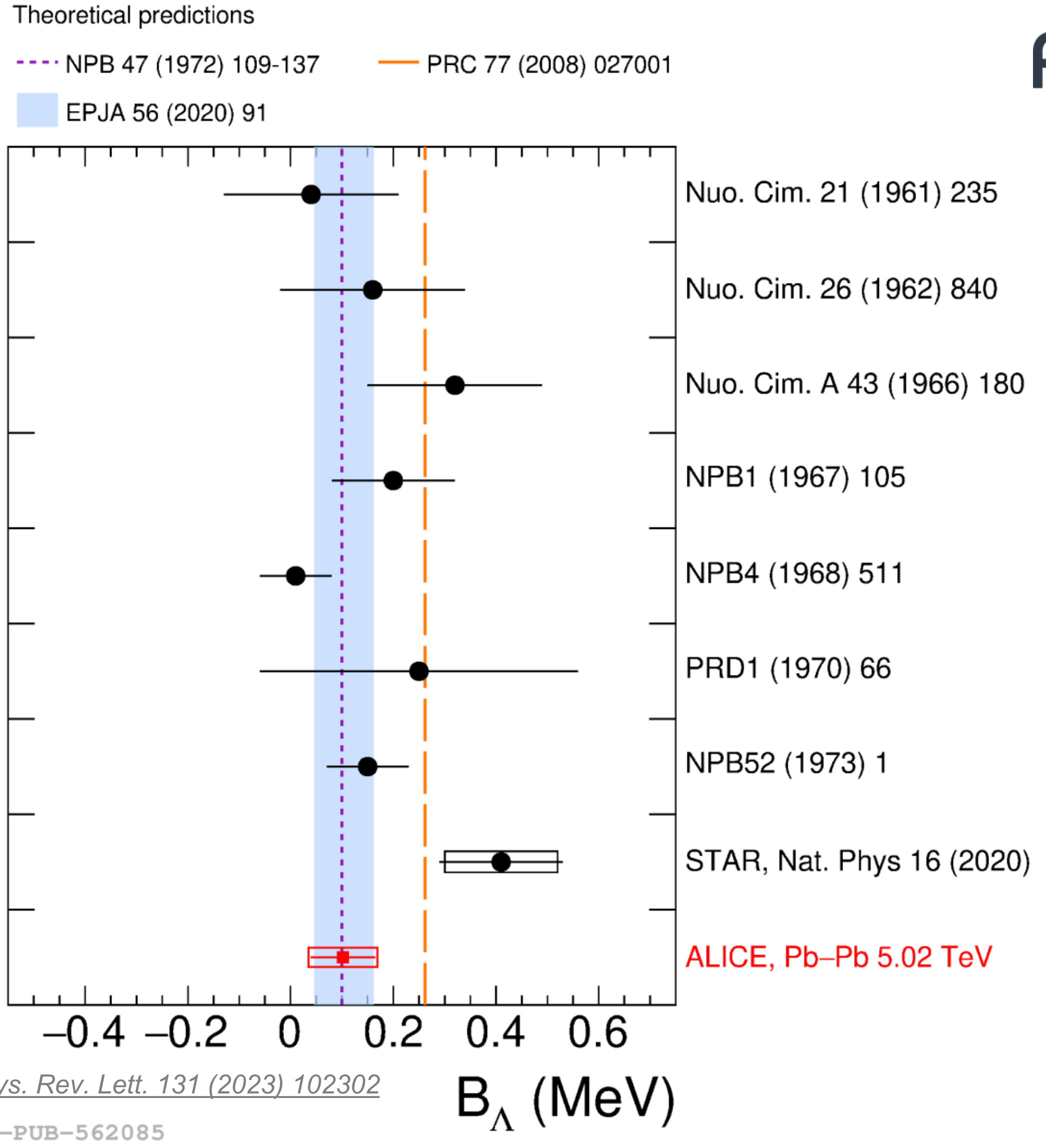
- Recent measurement in Run 2 Pb-Pb collisions at 5.02 TeV
- Is compatible with the free Λ lifetime within its uncertainties
- New result pushes the world average lifetime a little up



ALICE, Phys. Rev. Lett. 131 (2023) 102302

Hypertriton binding energy

- Recent measurement in Run 2 Pb-Pb collisions at 5.02 TeV
- Is compatible with the latest theoretical predictions



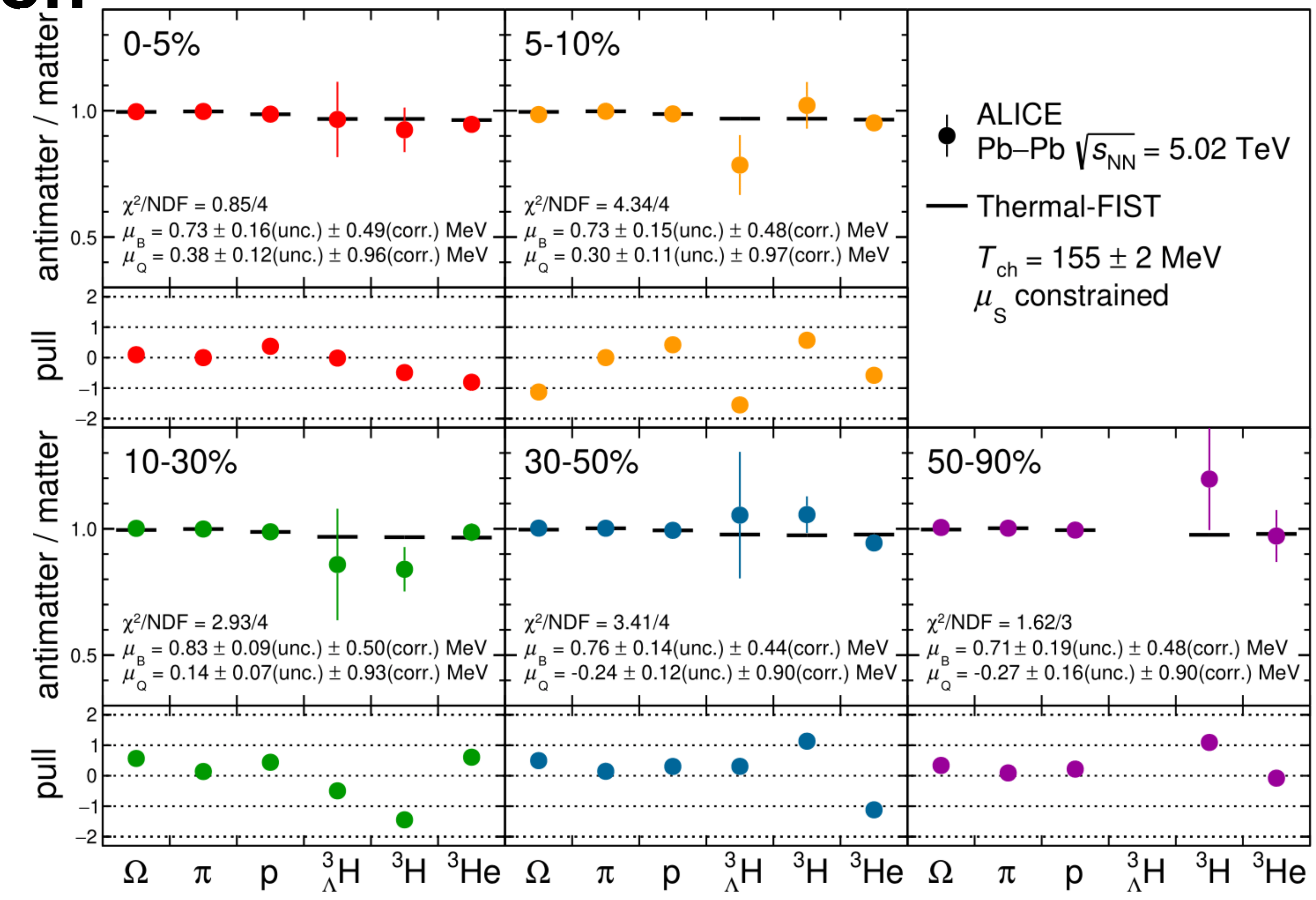
ALICE, Phys. Rev. Lett. 131 (2023) 102302

[NPB47(1972)] Dalitz et. al. Nuc. Phys. B, Vol. 47, Issue 1, Pages 109-137 (1972)
[arXiv:1711.07521] Lonardoni et. al., arXiv:1711.07521 [nucl-th]
[PRC77(2008)] Fujiwara et. al., Phys. Rev. C 77, 027001 (2008)
[EPJ56(2020)] F. Hildenbrand, H.-W. Hammer, Phys. Rev. C 100, 034002 (2020)

Hypertriton production

- Antiparticle-to-particle ratios compared to SHM predictions at T_{ch} = 155 ± 2 MeV and using the obtained μ_B for different centrality bins

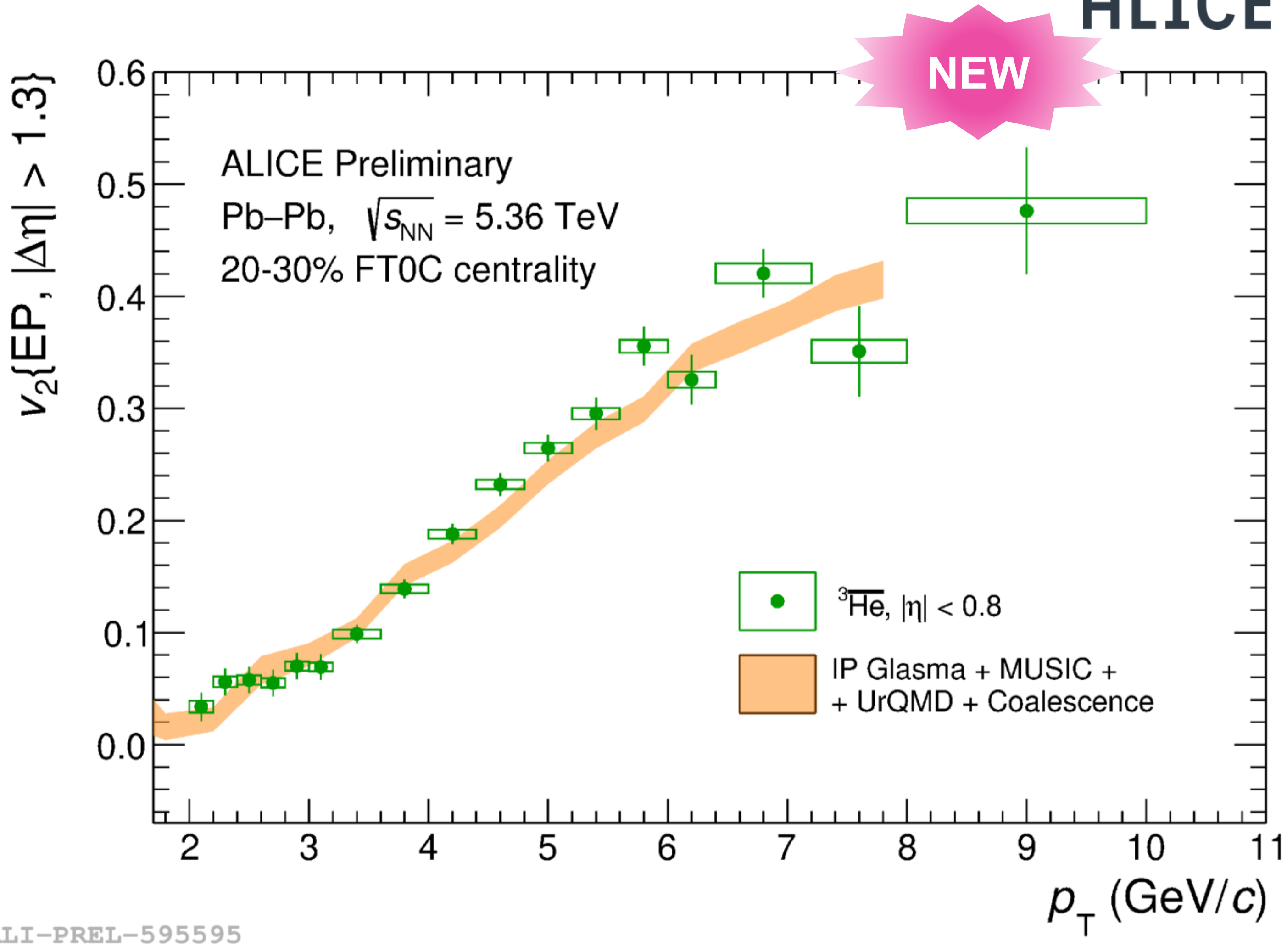
ALICE, Phys. Rev. Lett. 133, 092301 (2024)



(Hyper)nuclei flow

- Precise measurement of antihelium-3 elliptic flow in Run 3 Pb-Pb collisions at 5.36 TeV
- Measured in several centrality classes
- Compared to a hydro model with a coalescence afterburner
- Large amount of $^{3}_{\Lambda}$H candidates in Run 3 Pb-Pb collisions at 5.36 TeV

Can we measure the flow of hypernuclei?



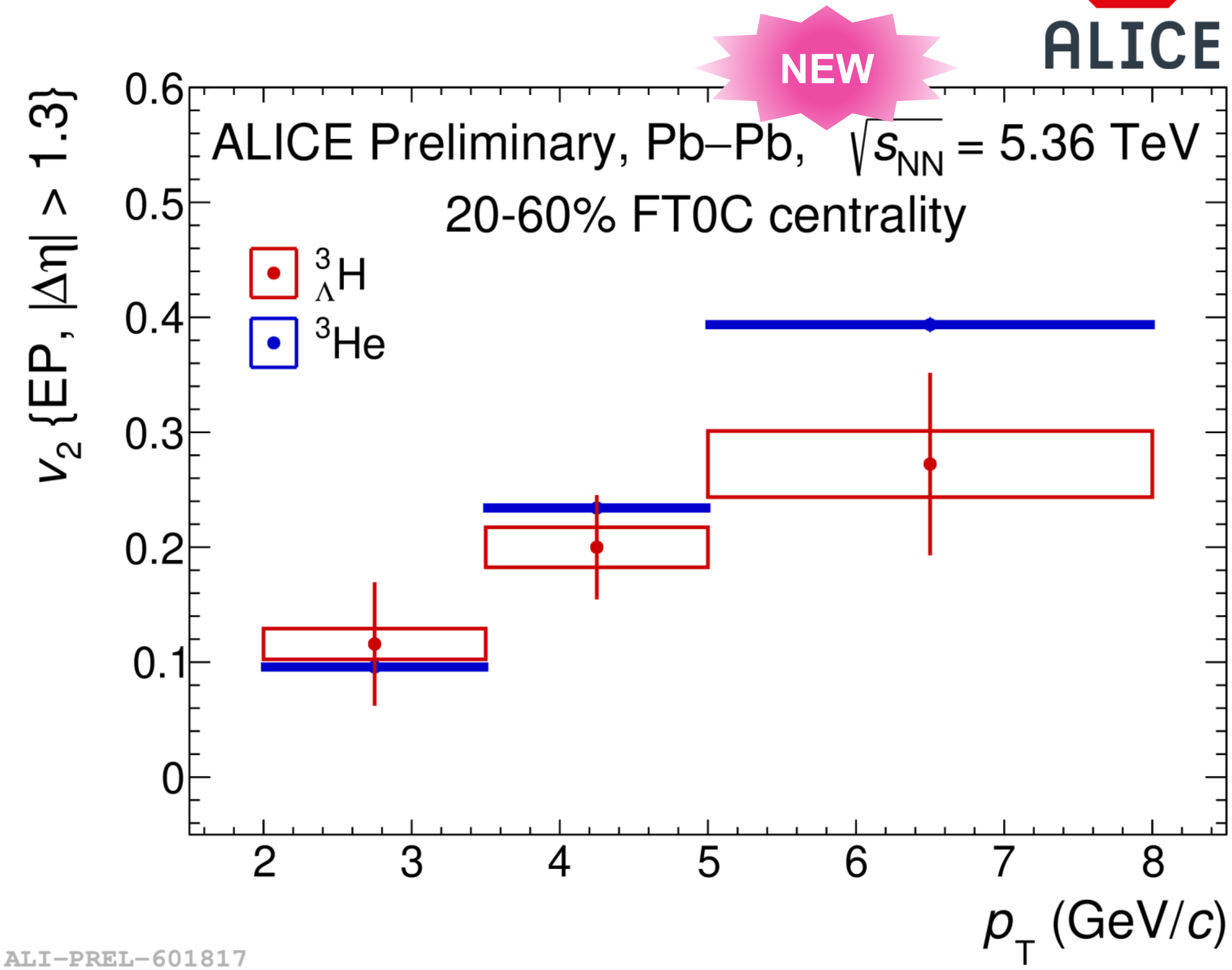
Hypernuclei flow

- v_2 of the ${}^{3}_{\Lambda}$H compared to helium-3 in Run 3 Pb-Pb collisions at 5.36 TeV
- Follows the same increasing trend with p_T (and centrality)

$$v_n\{EP\} = \frac{1}{R_n}\langle cos[n(\varphi - \psi_n)]\rangle$$

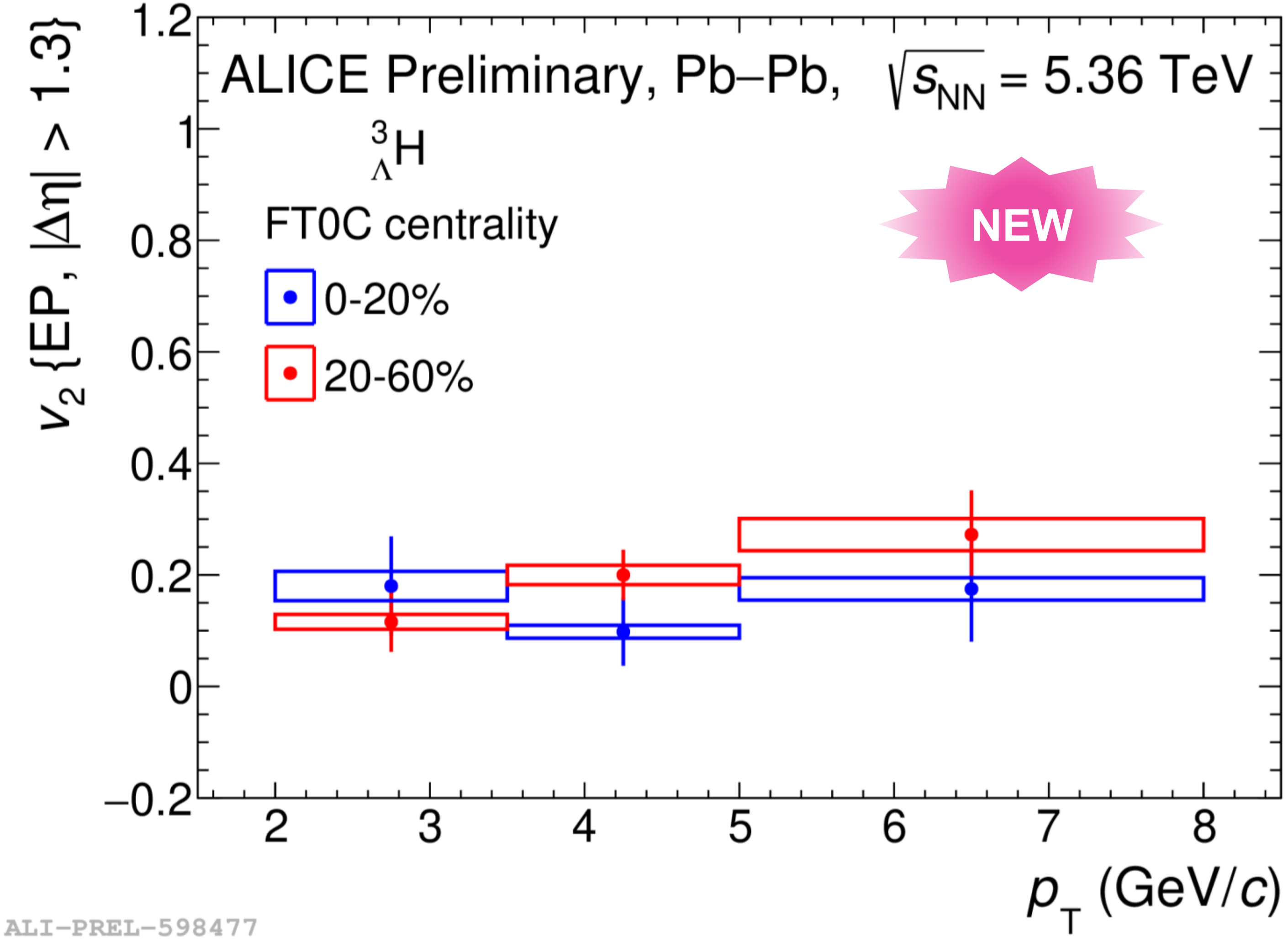
φ: angle of interest
ψ: event plane angle
R: resolution of the measurement

First measurement of ${}^{3}_{\Lambda}$H elliptic flow



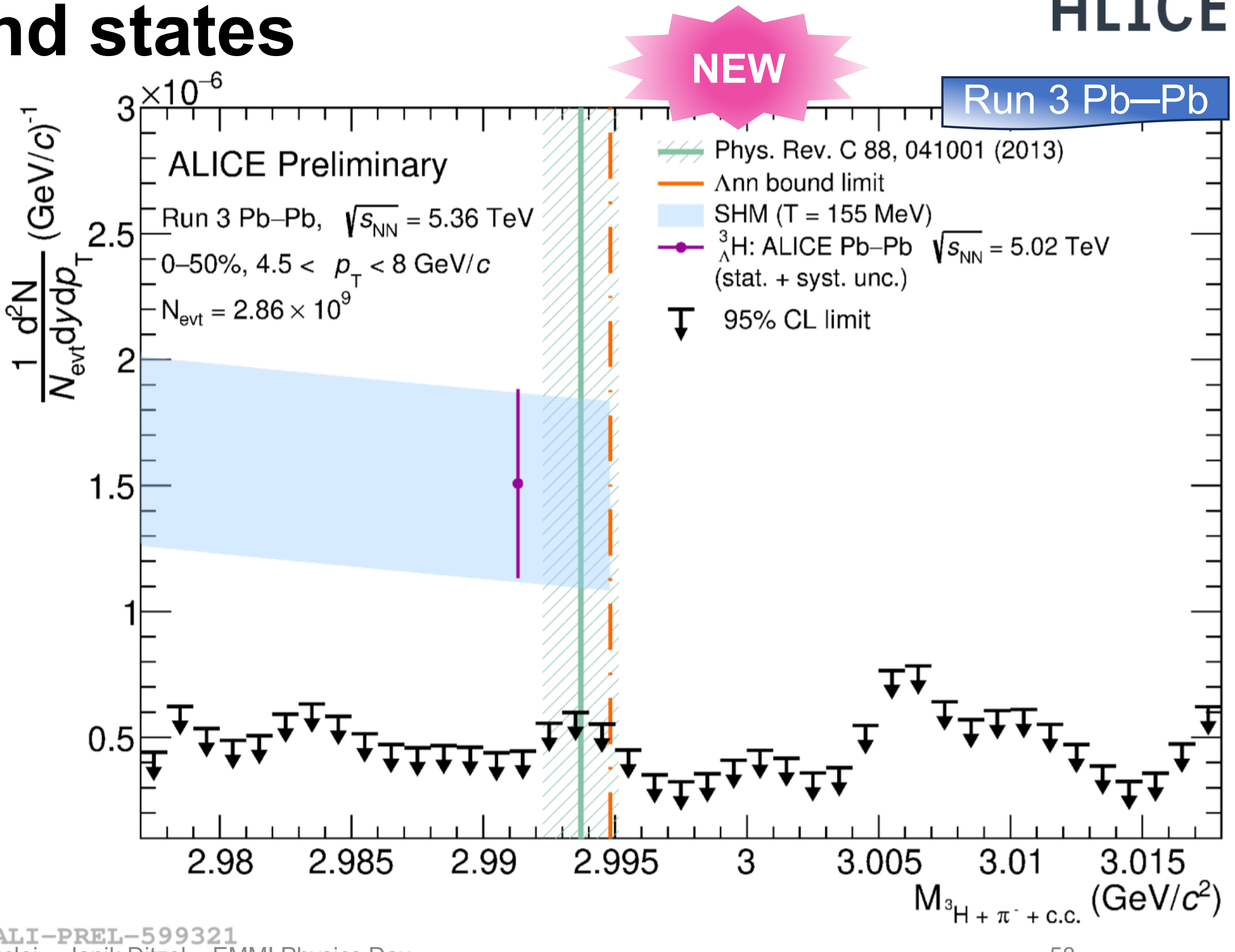
Hypernuclei Flow

- v_2 of the $^{3}_{\Lambda}H$ compared to helium-3 in Run 3 Pb-Pb collisions at 5.36 TeV
- Elliptic flow follows an increasing trend with centrality and p_T



Search for exotic bound states

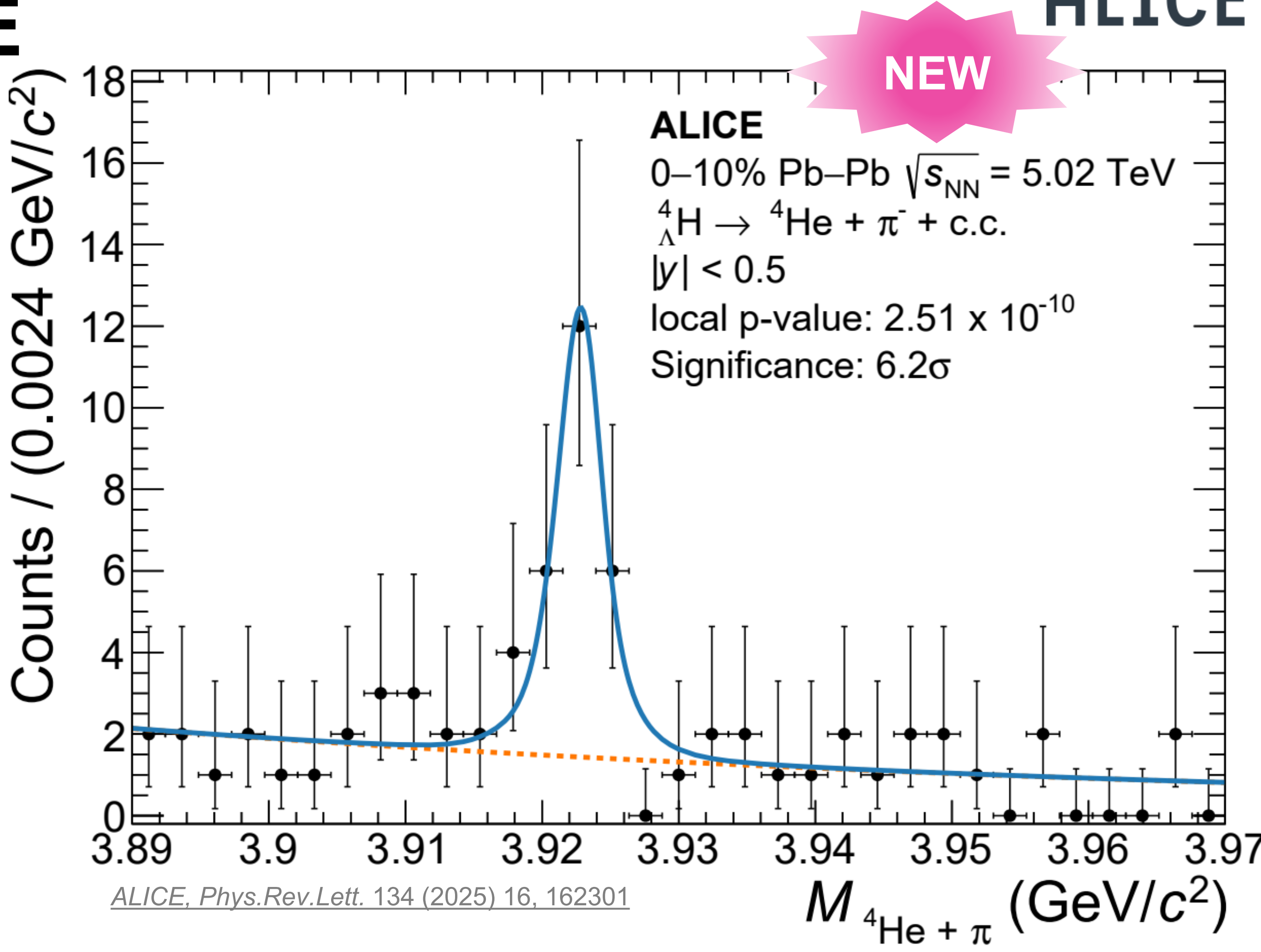
- Search for Λnn bound state in Run 3 Pb–Pb collisions at 5.36 TeV
- Decay mode: Λnn → ^{3}H + π⁻
- No significant excess found in data
- Set an upper limit for the expected yield



A = 4 hypernuclei in ALICE

- First measurements of A = 4 (anti)hypernuclei at the LHC
- Determination of their production yield and mass
- Run 2 Pb-Pb collisions at 5.02 TeV
- Examined in the decay modes:

$$ {}^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \pi^{-} + \mathrm{c.c.} $$
$$ {}^{4}_{\Lambda}\mathrm{He} \rightarrow {}^{3}\mathrm{He} + p + \pi^{-} + \mathrm{c.c.} $$



ALICE, Phys.Rev.Lett. 134 (2025) 16, 162301

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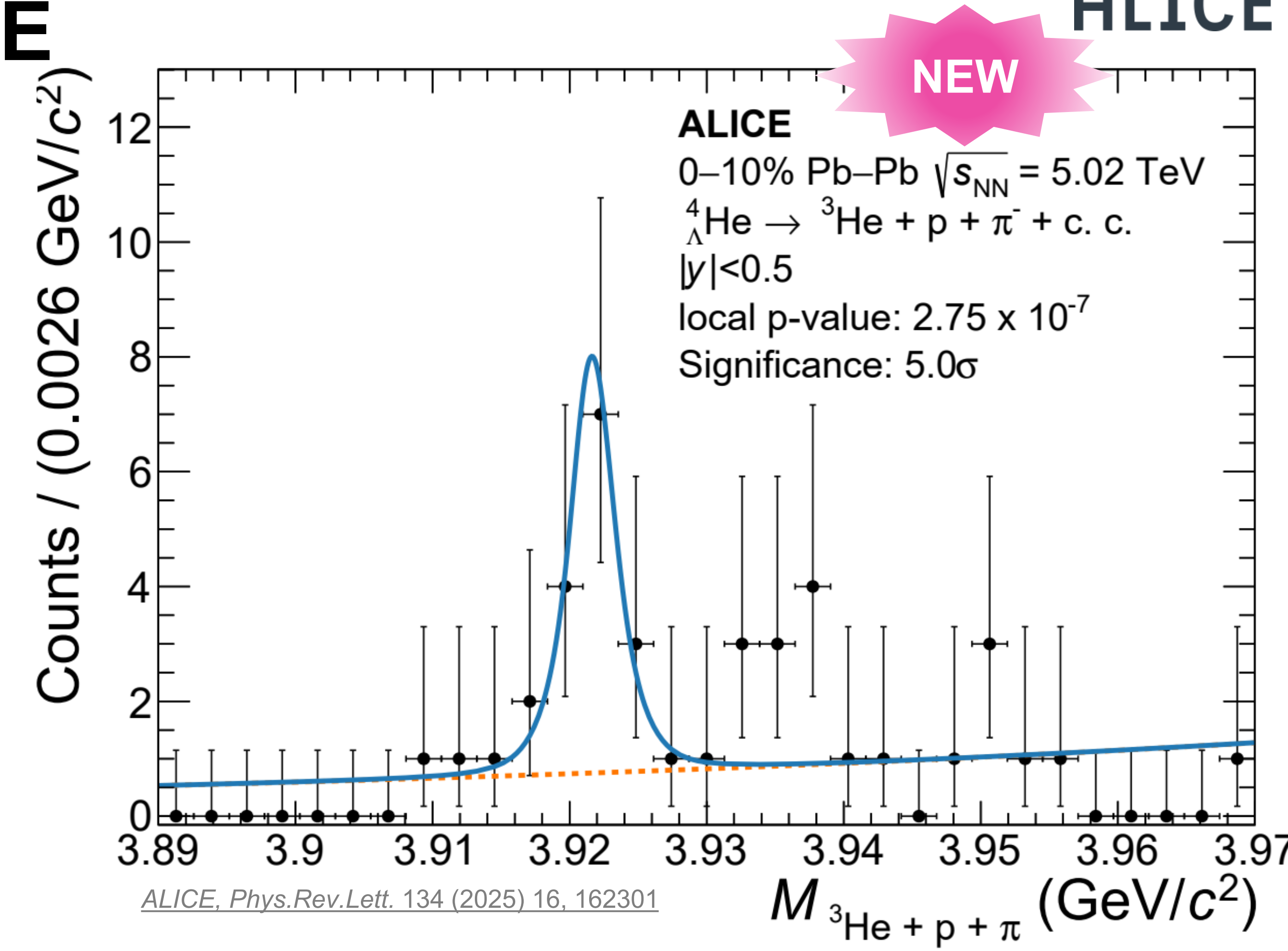


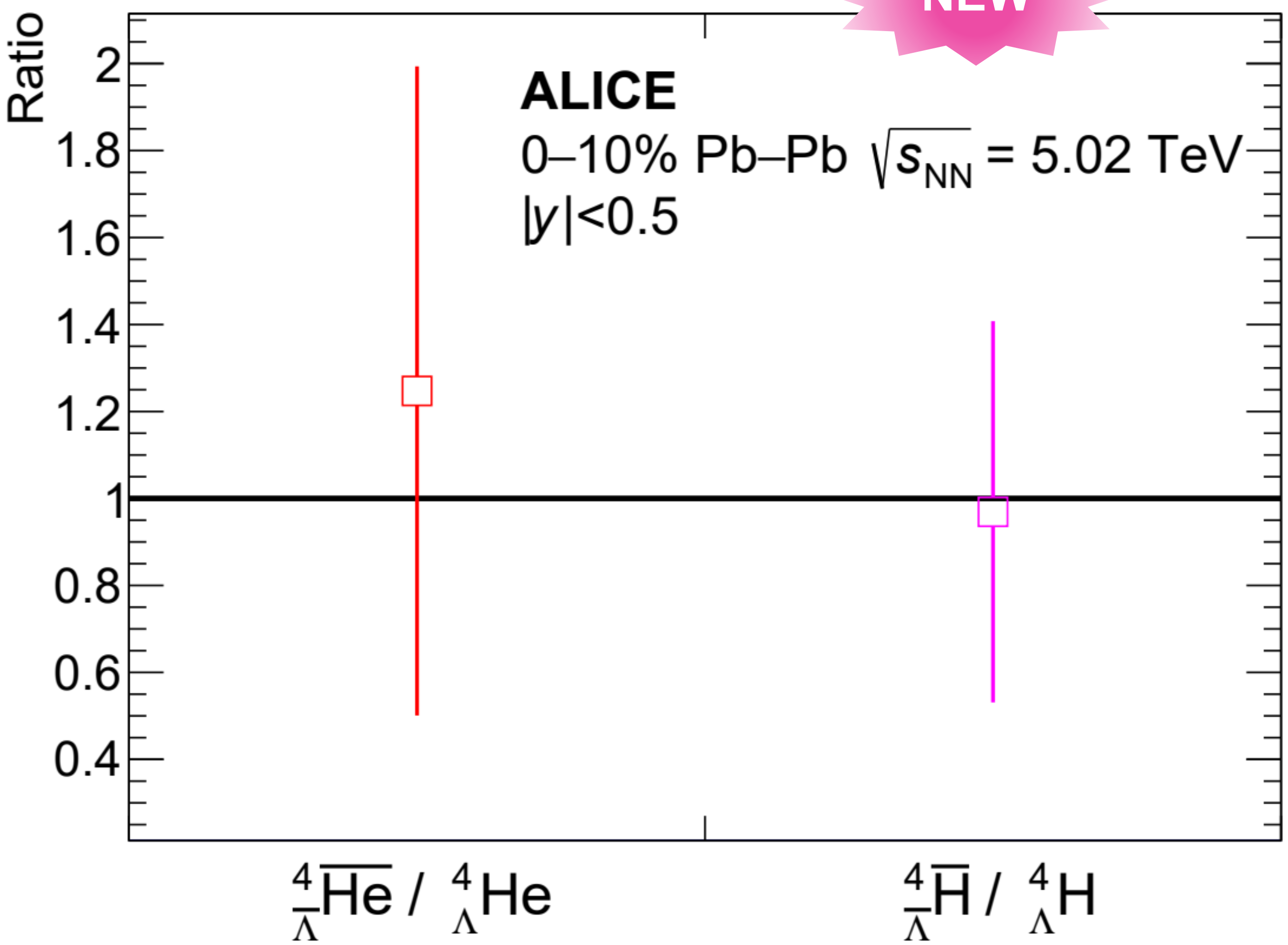
ALICE, Phys.Rev.Lett. 134 (2025) 16, 162301

A = 4 hypernuclei in ALICE

- Antiparticle-to-particle ratio is consistent with unity within the uncertainties
- Agrees with a baryochemical potential close to zero
- (Hyper)nuclei with larger mass number are more sensitive to the bayrochemical potential

ALICE, Phys.Rev.Lett. 134 (2025) 16, 162301

NEW



Search for multistrange hypernuclei

- **Nagara event** (KEK-E373):

  - Observing ${}^{6}_{\Lambda\Lambda}\mathrm{He}$ in emulsion
  - $B_{\Lambda\Lambda}({}^{6}_{\Lambda\Lambda}\mathrm{He}) = 6.91 \pm 0.16$ MeV
    → $\Delta B_{\Lambda\Lambda} \approx 0.67 \pm 0.17$ MeV
  - likely unbound ${}^{4}_{\Lambda\Lambda}\mathrm{H}$ system

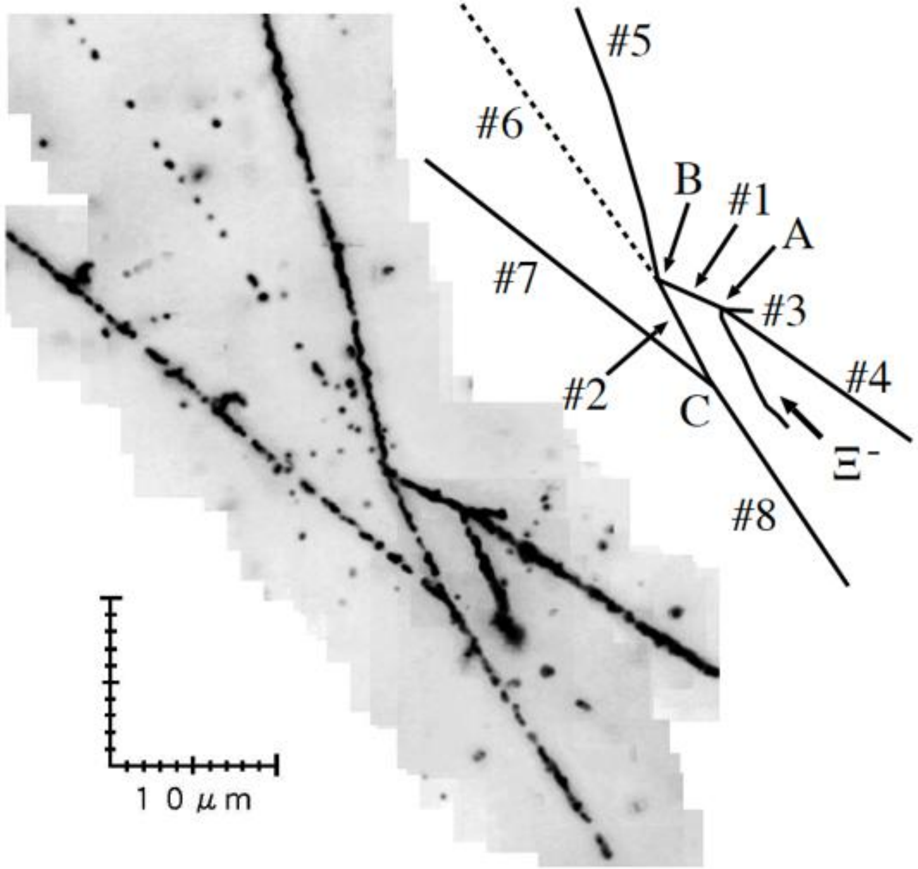


Figure and information by E. Friedman, A. Gal, HYP2022

A: Ξ^- **atomic capture** $\Xi^-_{3D} + {}^{12}\mathrm{C} \to {}^{6}_{\Lambda\Lambda}\mathrm{He} + t + \alpha$

B: **weak decay** ${}^{6}_{\Lambda\Lambda}\mathrm{He} \to {}^{5}_{\Lambda}\mathrm{He} + p + \pi^-$

C: ${}^{5}_{\Lambda}\mathrm{He}$ **nonmesonic weak decay to 2** $Z=1$ **recoils + n.**

Search for multistrange hypernuclei

- **Femtoscopy studies by ALICE**
  - Study the correlation of Lambda pairs in pp and p—Pb collisions
  - Allows for an attractive Λ-Λ potential
  - Binding energy (Λ-Λ) obtained:

$$\Delta B_{\Lambda\Lambda} = 3.2^{+1.6}_{-2.4}(\text{stat})^{+1.8}_{-1.0}(\text{syst})\ \text{MeV}$$

  - ${}^{4}_{\Lambda\Lambda}$H could be bound!

→ Need to improve our understanding of the Λ-Λ interaction by measuring (anti)doublehypernuclei (e.g.)

ALICE, Phys. Lett. B 797 (2019), 134822