Measurement of the hypertriton properties and production with ALICE

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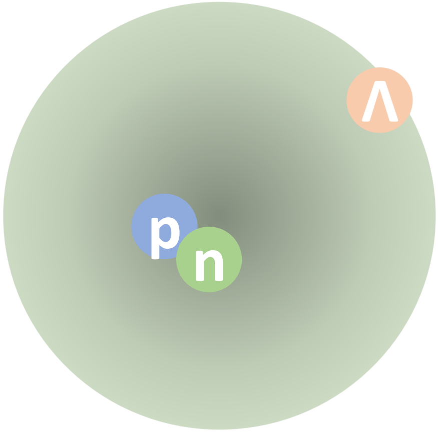
on behalf of the ALICE Collaboration

Hypertriton

- Λ, p, n bound state
- Lightest known hypernucleus and very loosely bound
- Mass ≈ 2.991 GeV/c^2
- Λ separation energy ≈ 130 keV
- Recent calculations predict a large radius for the hypertriton wave function $r_{\Lambda\text{-}d} = 10.79^{+3.04}_{-1.53}$ fm

F. Hildenbrand, H.-W. Hammer, Phys. Rev. C 100, 034002



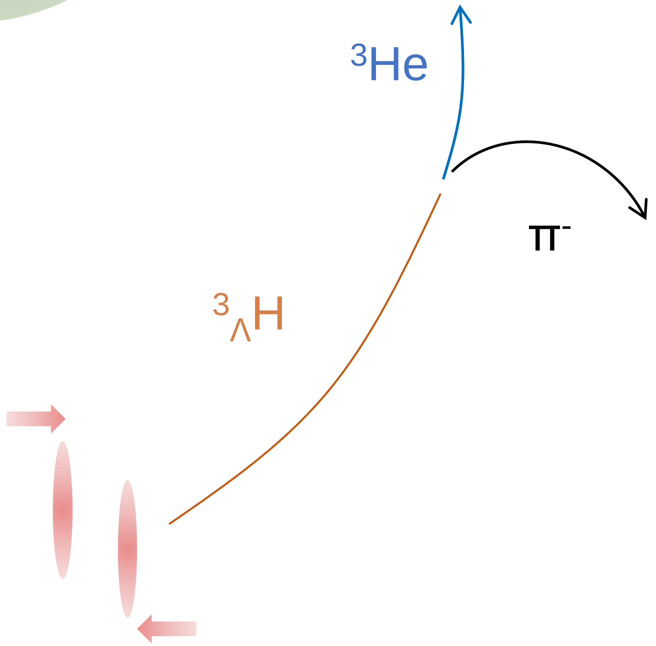
- Decay modes:

$^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{-}$

$^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{0}$

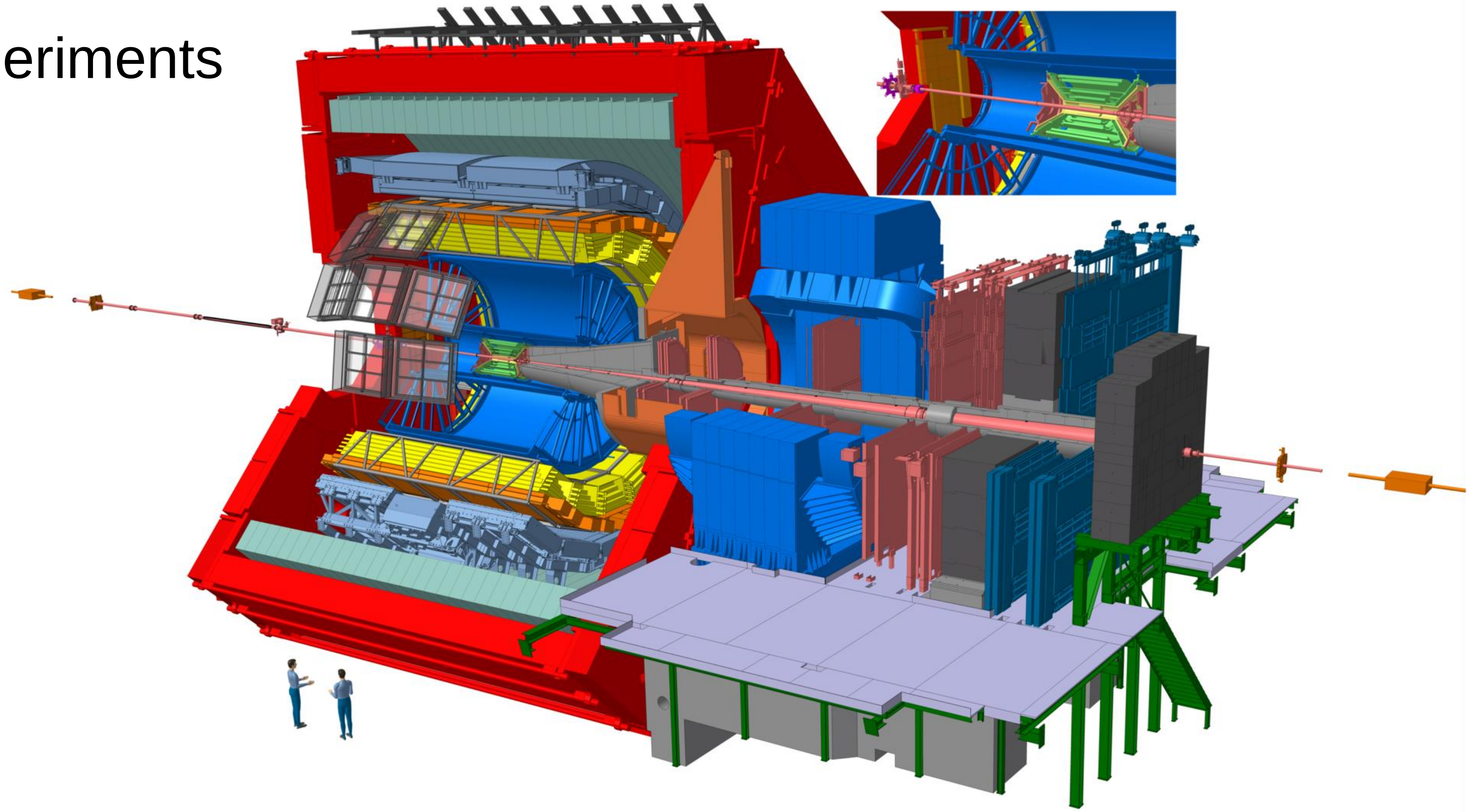
$^{3}_{\Lambda}H \rightarrow d + p + \pi^{-}$

$^{3}_{\Lambda}H \rightarrow d + p + \pi^{0}$



ALICE detector

- One of the four major LHC experiments
- Specialized in tracking and particle identification from low to high momenta using different detector technologies



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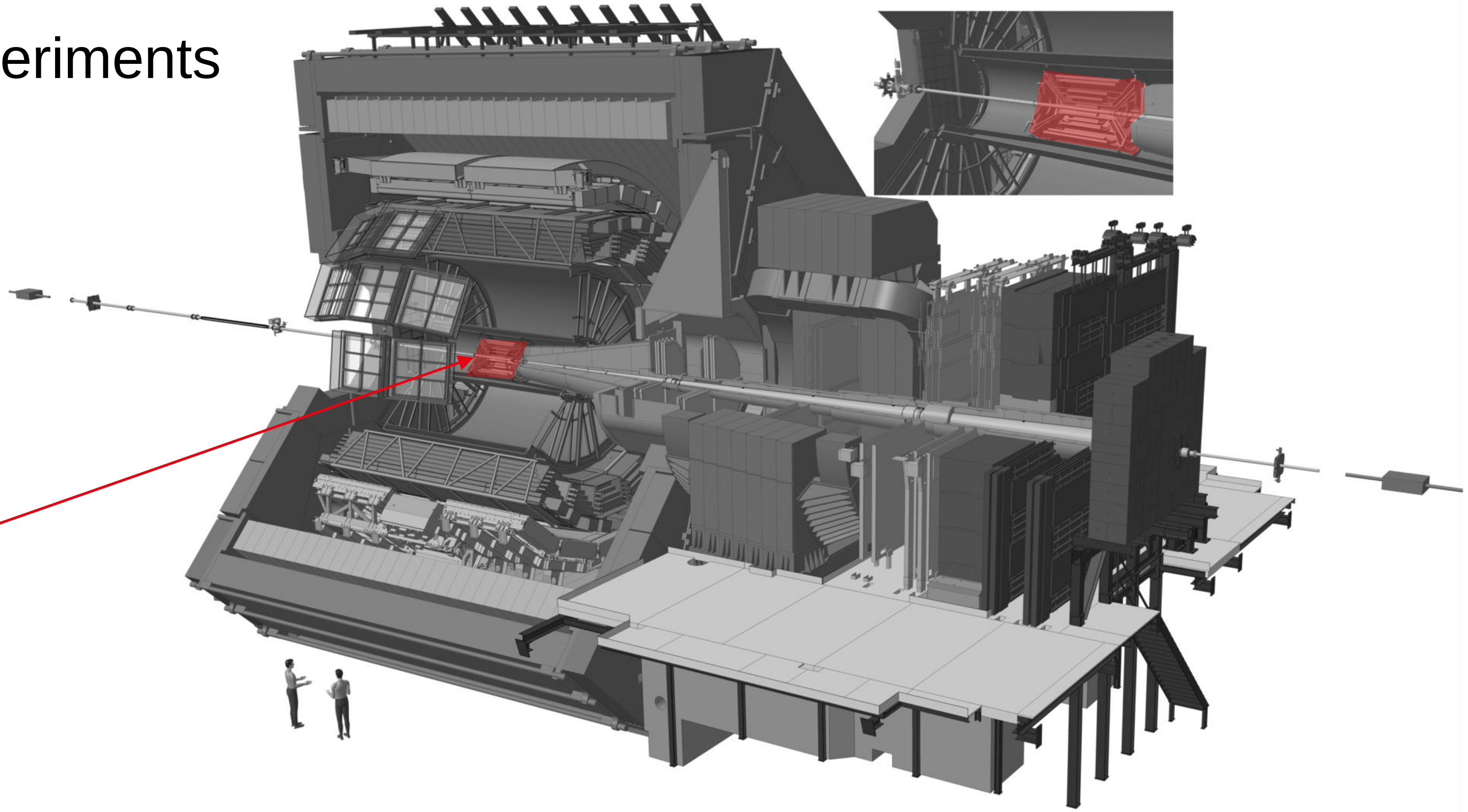

ITS (Inner Tracking System)

- Reconstruction of primary and decay vertices
- Track reconstruction
- Particle identification for low momentum particles

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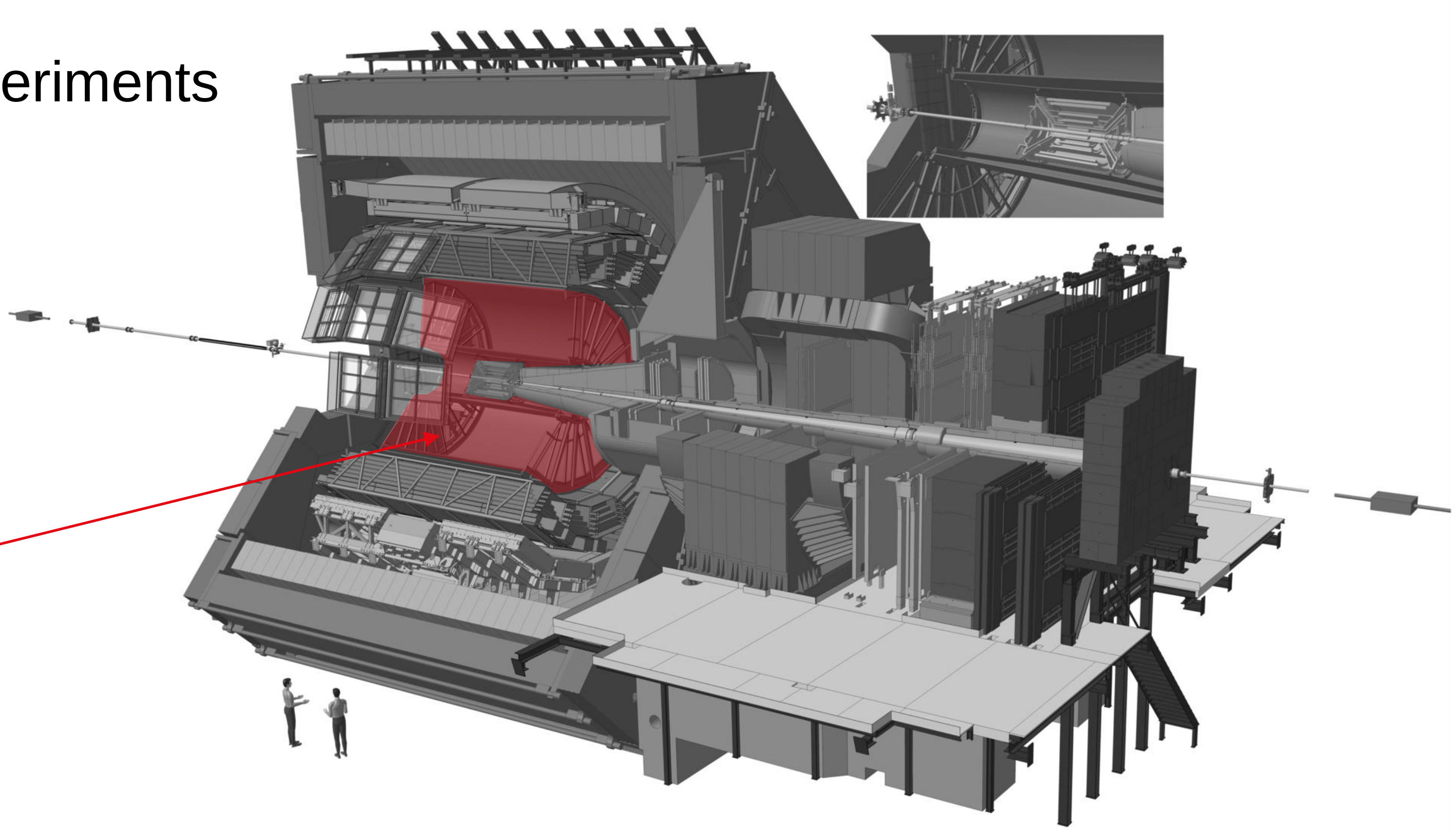

TPC (Time Projection Chamber)
- Tracking
- Particle identification via dE/dx measurement

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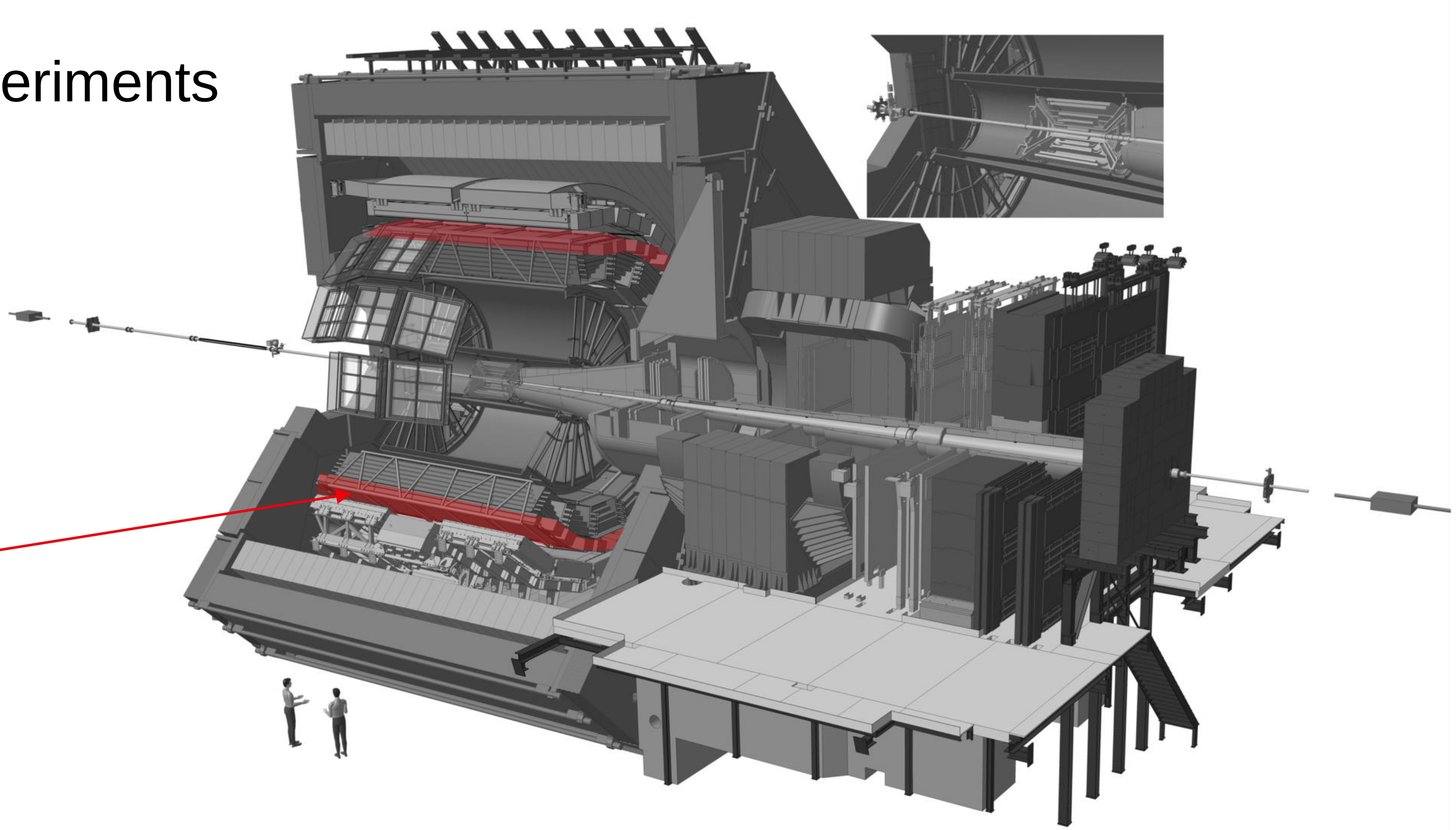

TOF detector (Time Of Flight)

- Particle identification with time-of-flight measurement

ALICE detector

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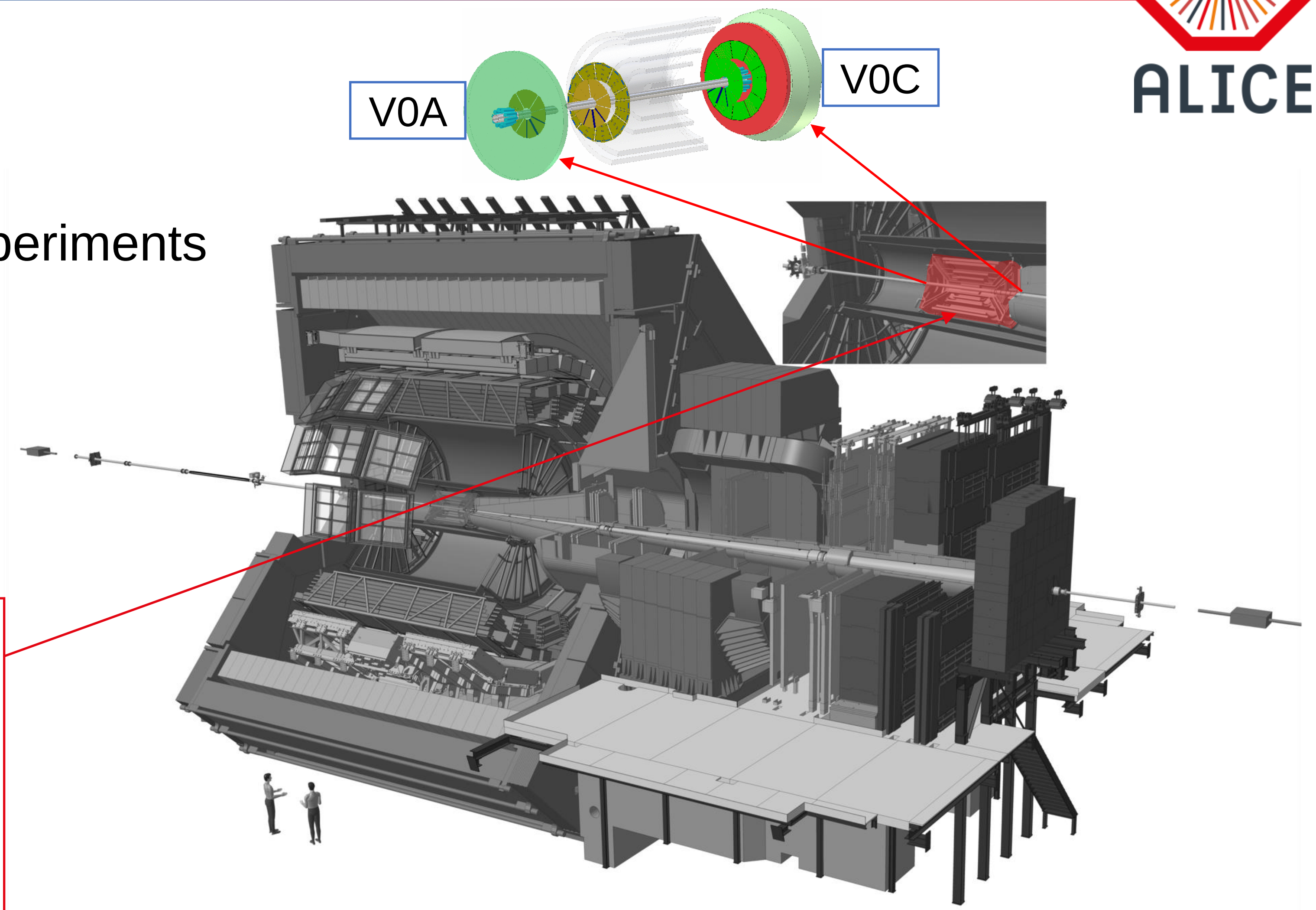
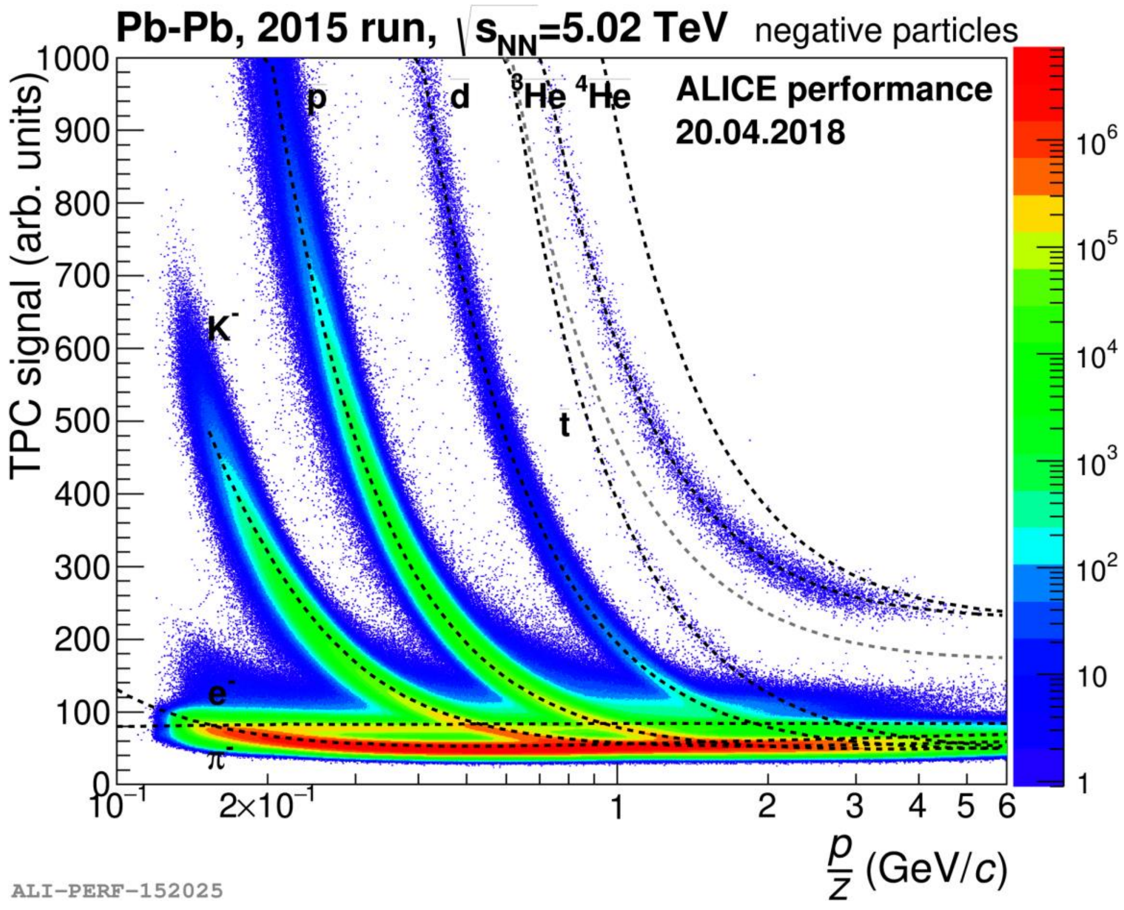


V0 detectors

- Centrality / multiplicity determination
- Trigger

Hypertriton reconstruction

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

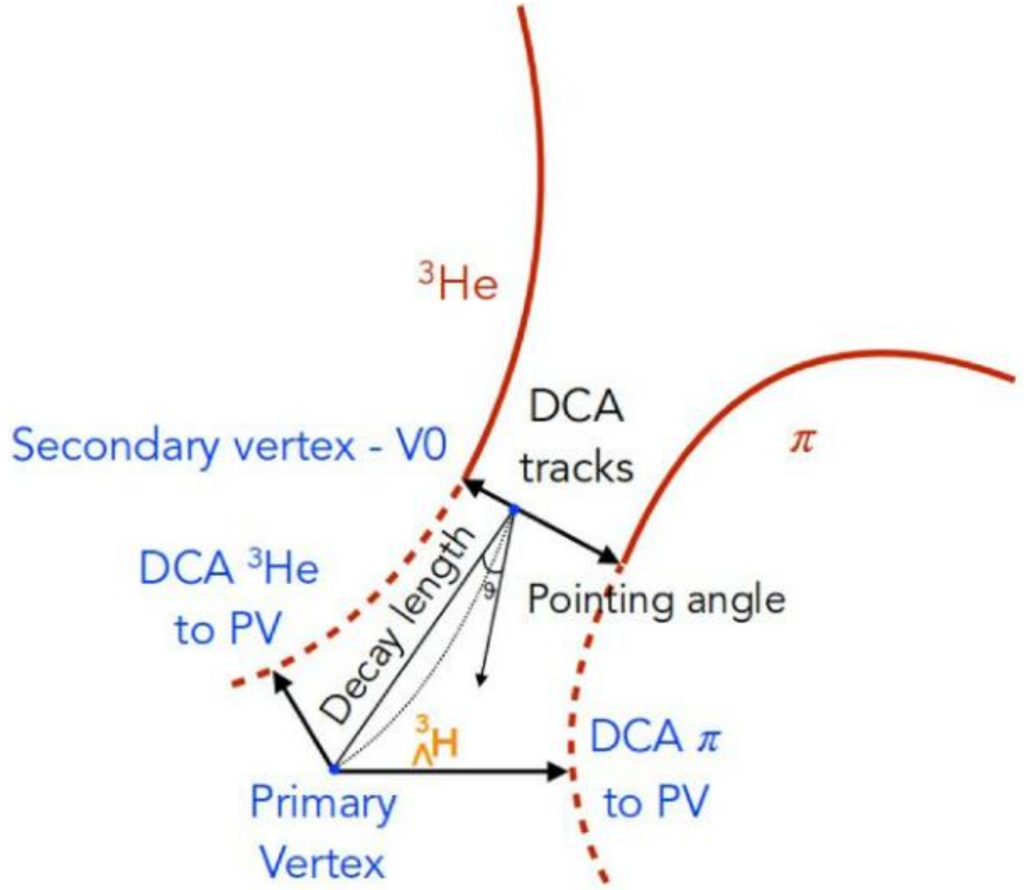


Hypertriton reconstruction

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

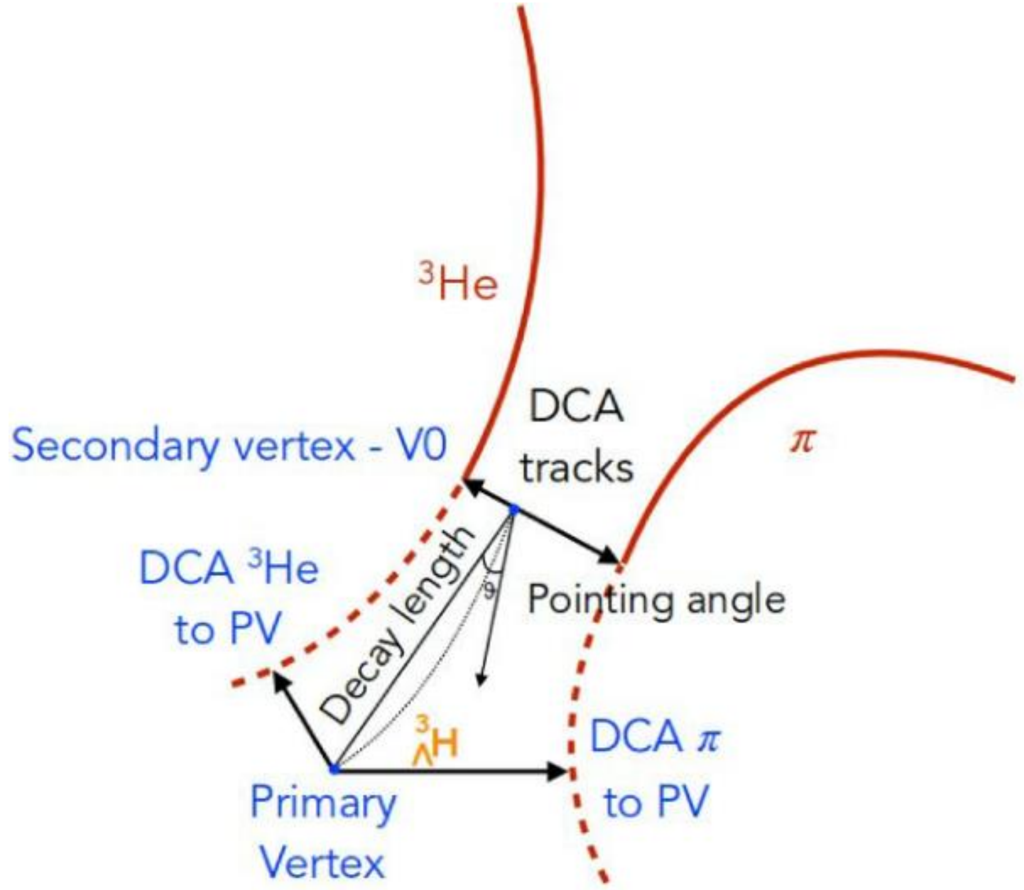
  - The identified daughters are assumed to come from a common vertex
  - Their tracks are matched by algorithms to find the best possible decay vertex

  - Problem: huge combinatorial background
  - Solution: topological and kinematical cuts or machine learning approach



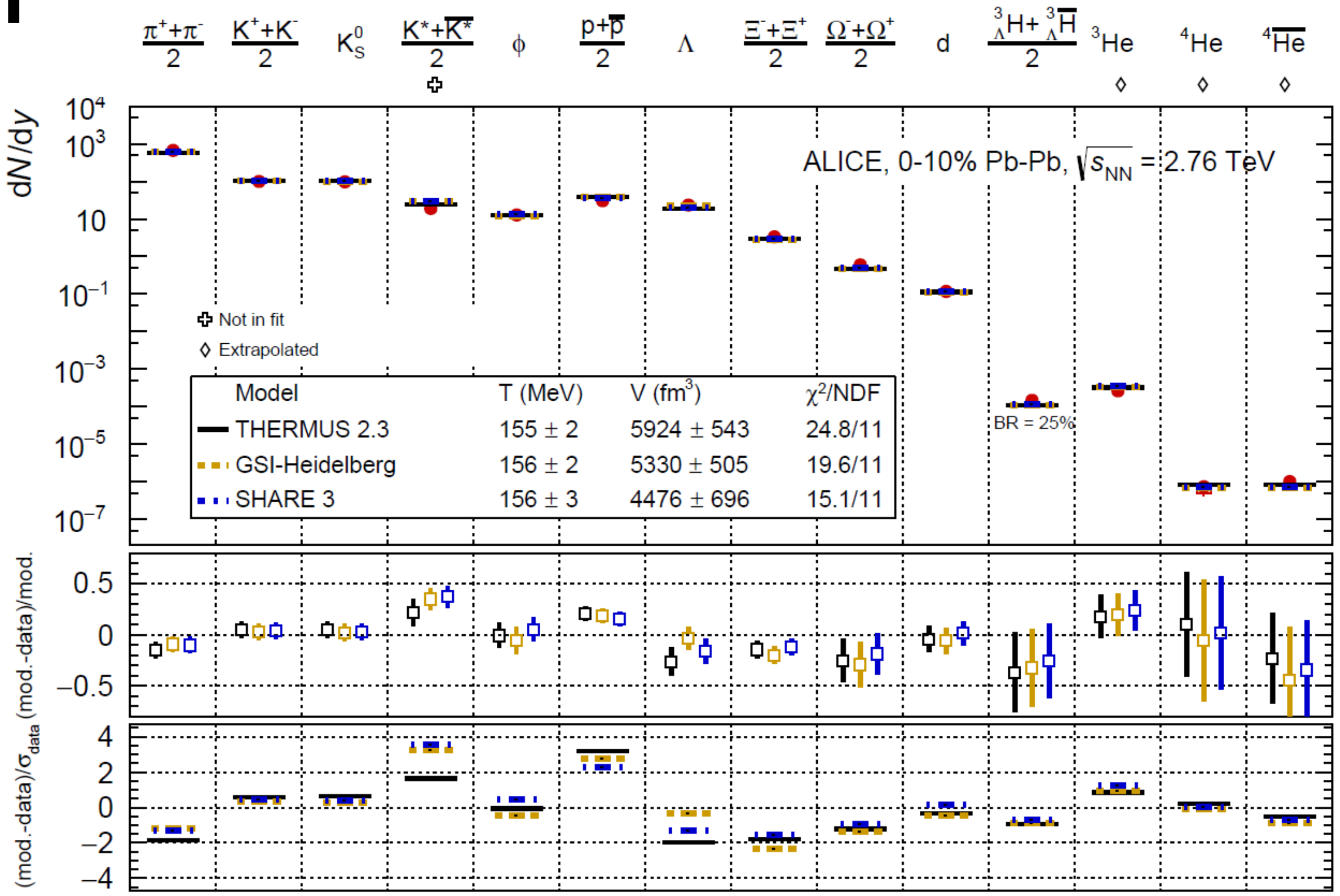
Hypertriton reconstruction

- **Step 1**: find and identify the daughter particle tracks
- **Step 2**: reconstruct the decay vertex of the hypertriton
- **Step 3**: applying corrections
  - Tracking efficiency and detector acceptance
  - Assuming a branching ratio of 25%



Hypertriton production

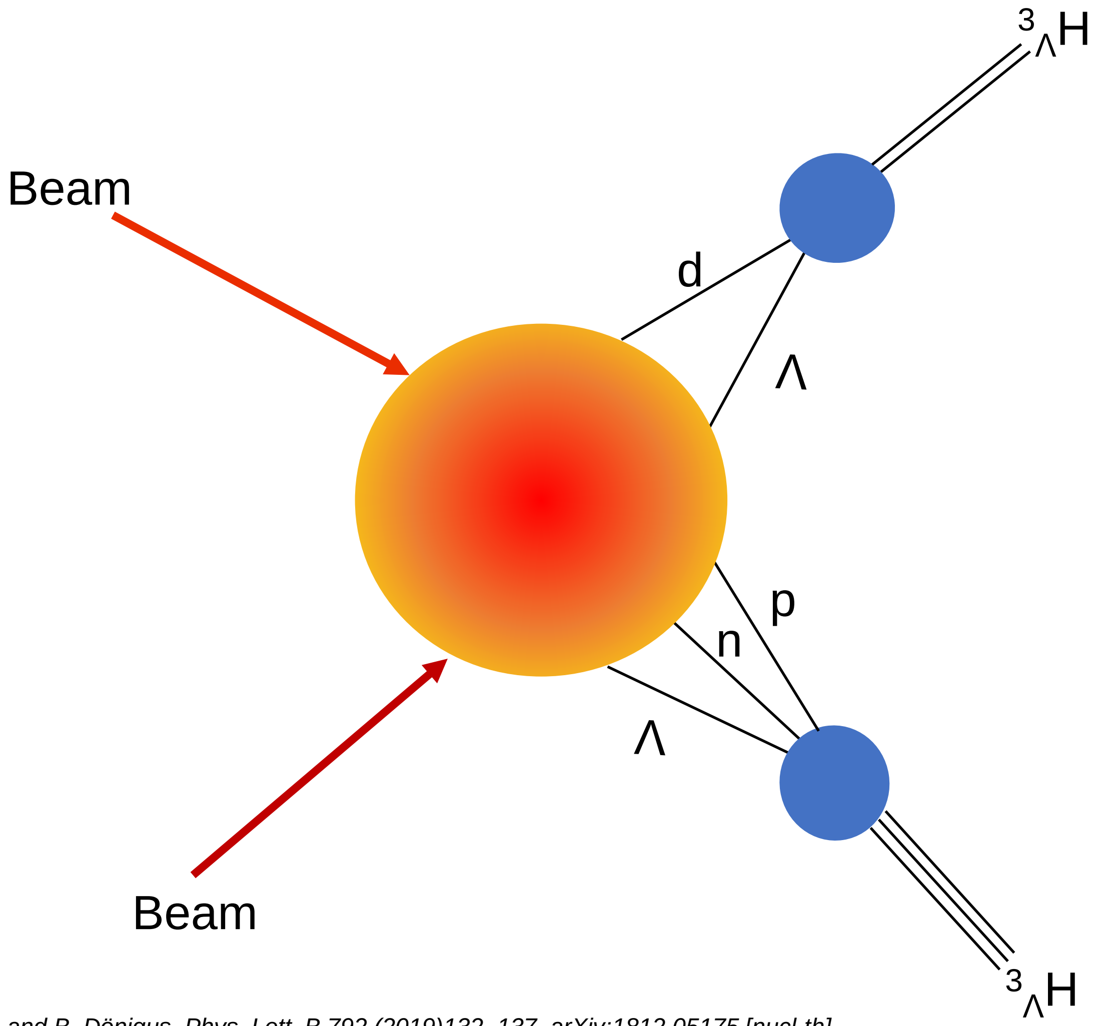
- Hypertriton production in heavy-ion collisions since LHC Run 1
- Integrated yield well described by the Statistical Hadronization Model (SHM)
- SHM assumes hadron abundances from statistical equilibrium at the common chemical freeze-out temperature T_{ch} = 156 MeV
  How hypernuclei can survive in this environment is not clear



Nucl. Phys. A 971 (2018) 1–20, arXiv:1710.07531 [nucl-ex]

Hypertriton production

- Hypertriton production in heavy-ion collisions since LHC Run 1
- Coalescence Model:
  Nucleons that are close in phase space at the freeze-out can form a nucleus via coalescence.
  The key concept is the overlap between the nuclear wave functions and the phase space of the nucleons

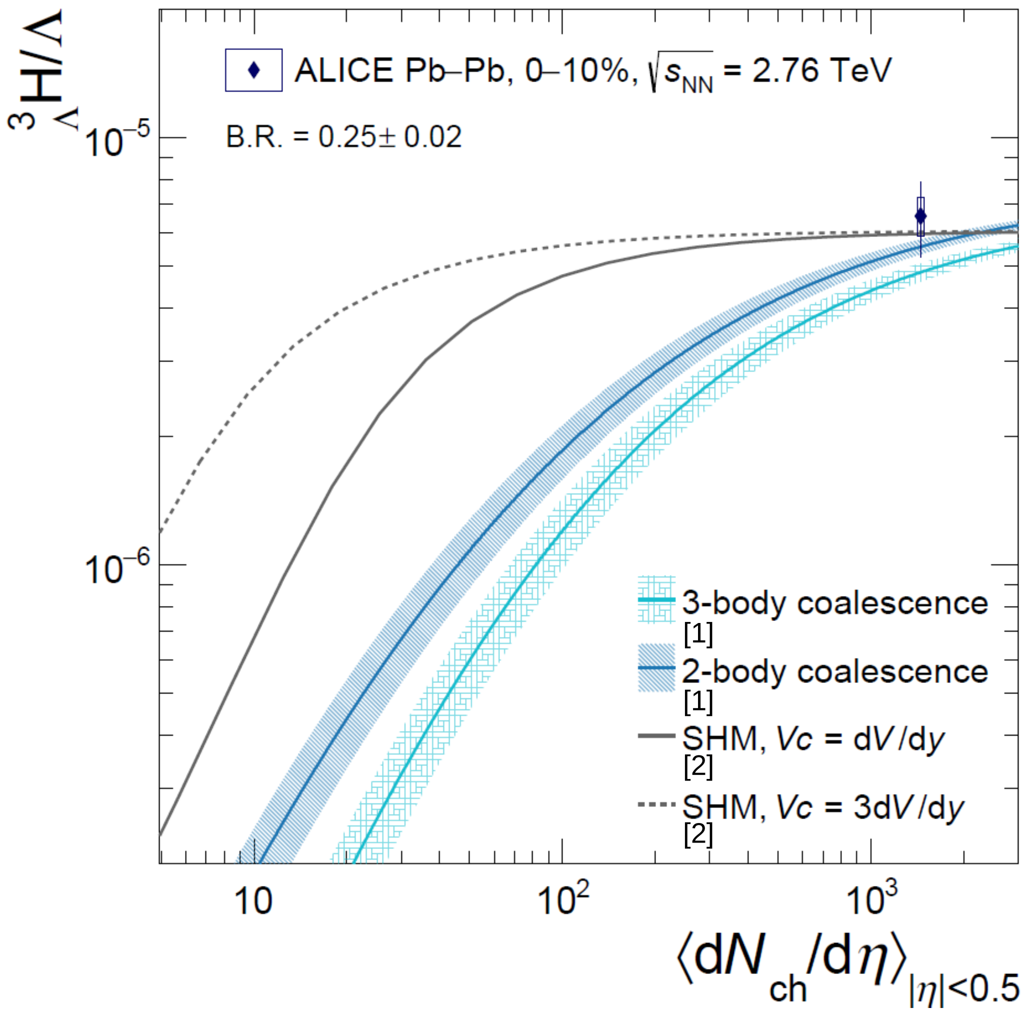


K.-J. Sun, C.-M. Ko and B. Dönigus, Phys. Lett. B 792 (2019)132–137, arXiv:1812.05175 [nucl-th]

Hypertriton in small systems

- $^{3}_{\Lambda}H$ / Λ ratio vs. multiplicity

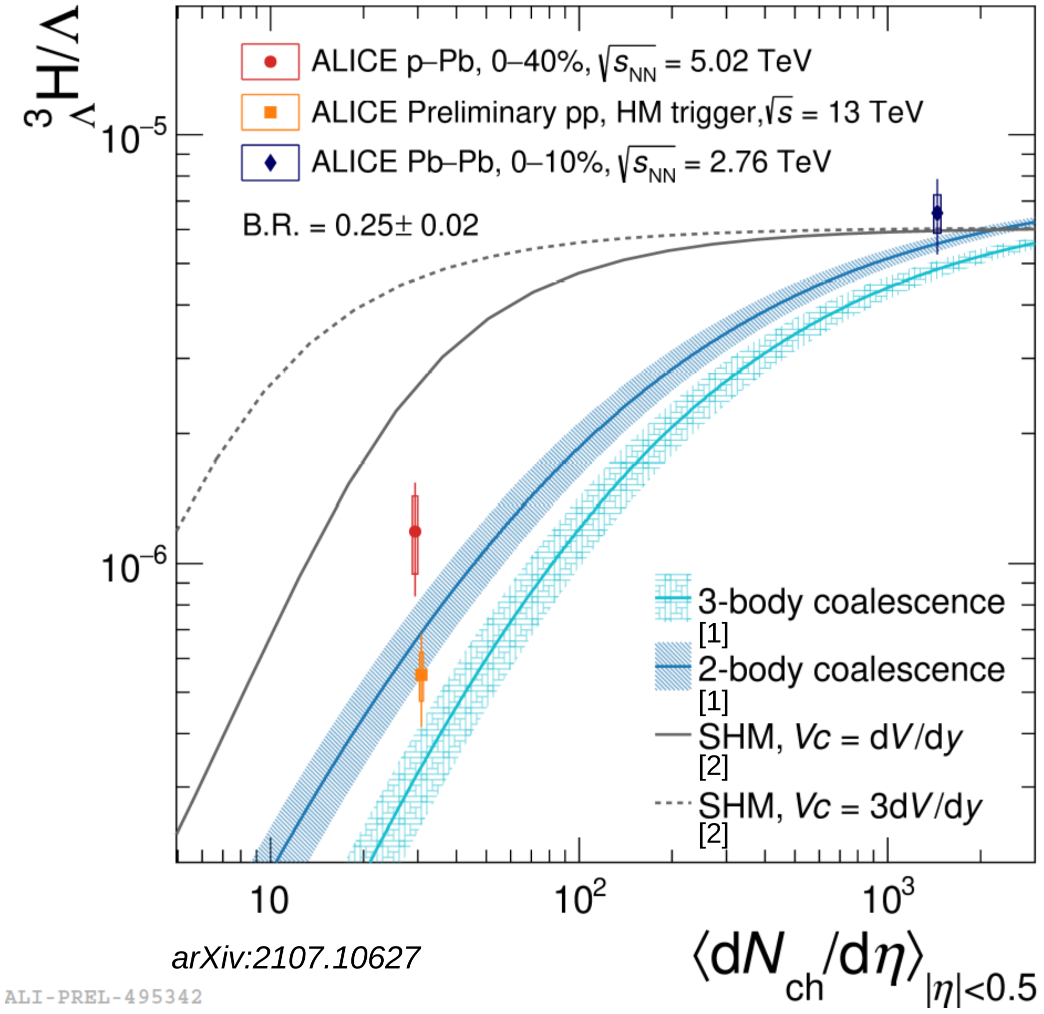
- Extremely sensitive to the nuclei production mechanism:
  - For statistical hadronization models (SHM) the object size is not relevant
  - In a coalescence picture large suppression of the production in small systems expected due to the object size



[1] *K.-J. Sun, C.-M. Ko and B. Dönigus, Phys. Lett. B 792 (2019)132–137, arXiv:1812.05175 [nucl-th]*
[2] *V. Vovchenko, B. Dönigus and H. Stoecker, Phys. Lett. B 785 (2018)171–174, arXiv:1808.05245 [hep-ph]*

$^{3}_{\Lambda}H$ / Λ ratio

- Measurements in pp and p-Pb: two new points at different multiplicities
- Points slightly favour the two-body coalescence
- But do not exclude three-body coalescence



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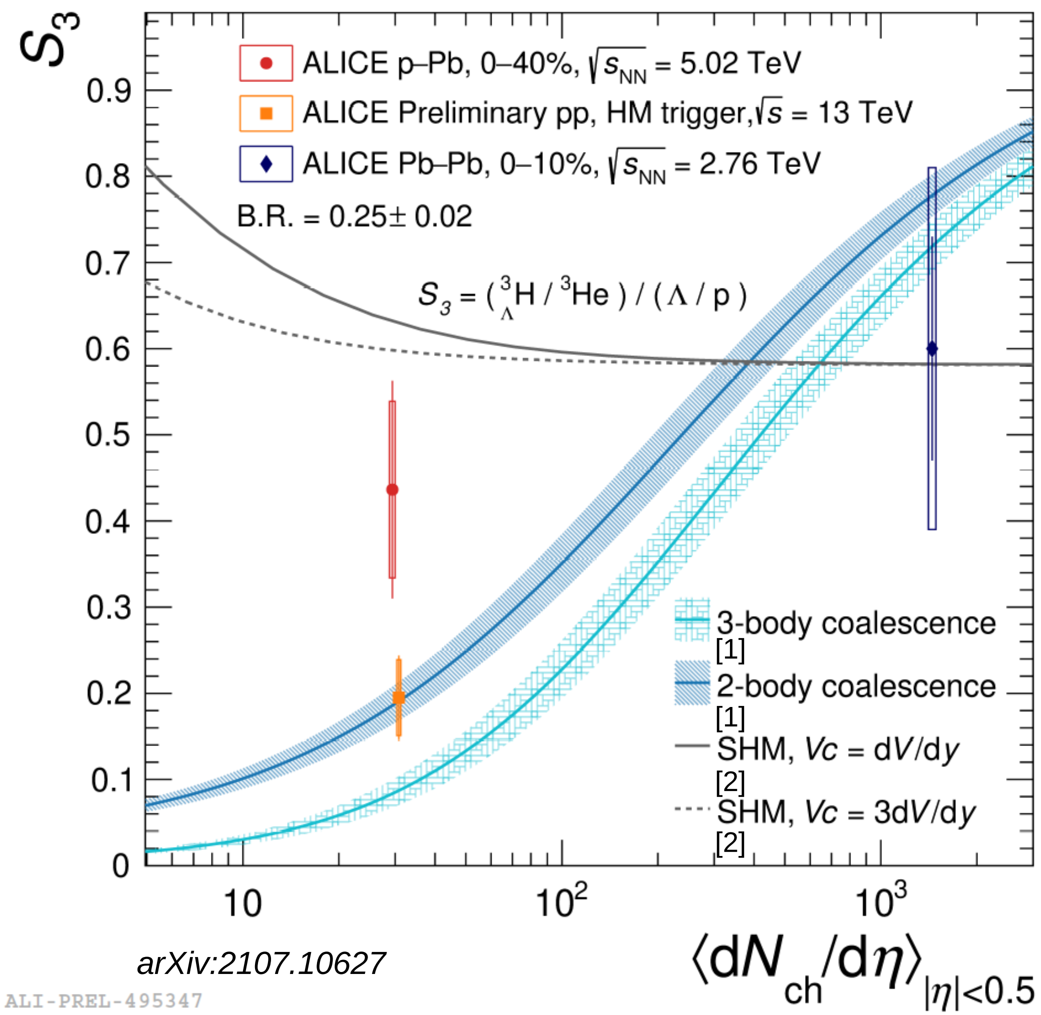
S_3

- $S_3 = ({}^{3}_{\Lambda}H \,/\, {}^{3}He) \,/\, (\Lambda \,/\, p)$ vs. multiplicity
- Strangeness population factor for the measurement of baryon-strangeness correlations
- Measurements in pp and p-Pb: two new points at different multiplicities
- Points slightly favour the two-body coalescence
- But do not exclude three-body coalescence



arXiv:2107.10627

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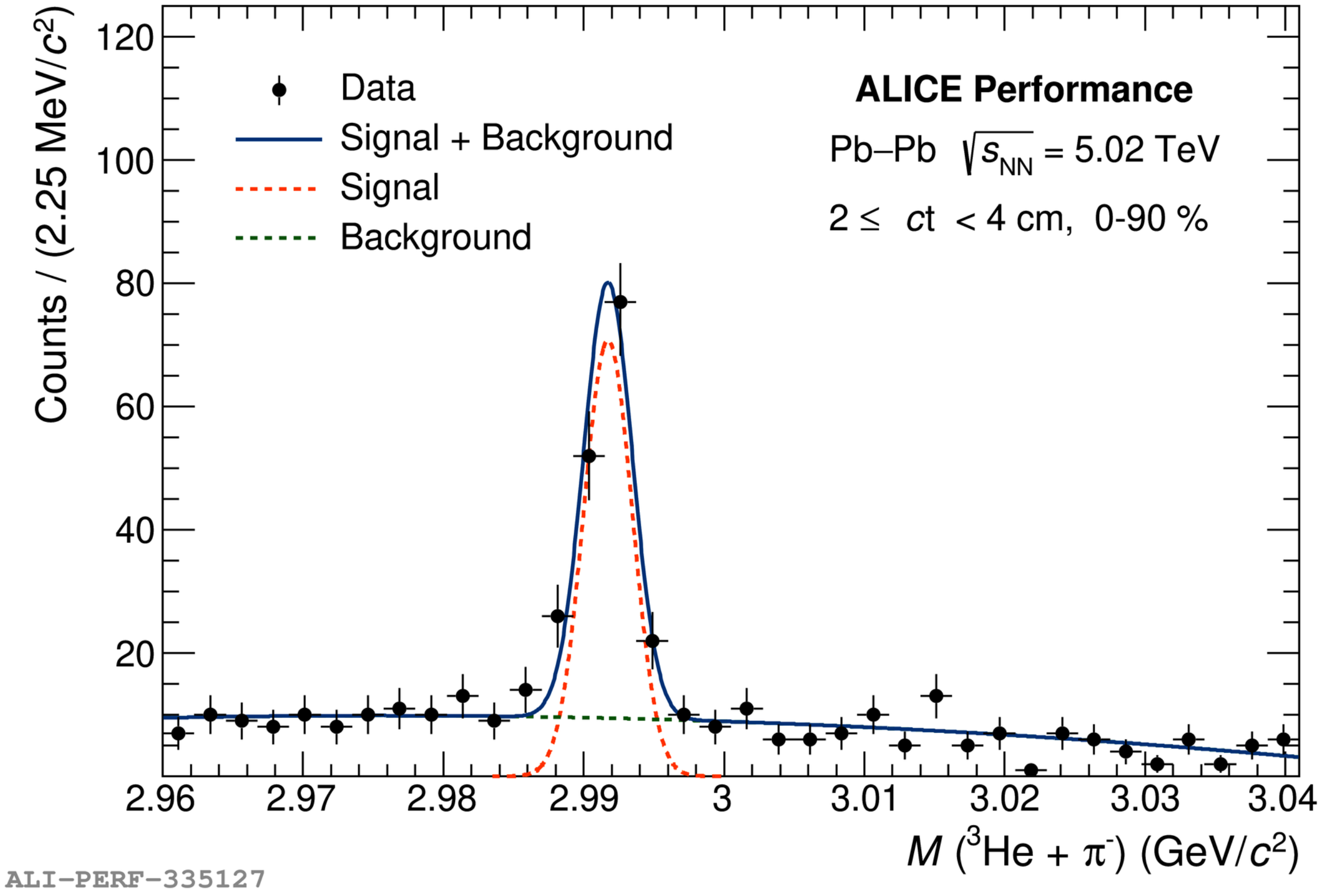
Hypertriton in Pb-Pb collisions

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

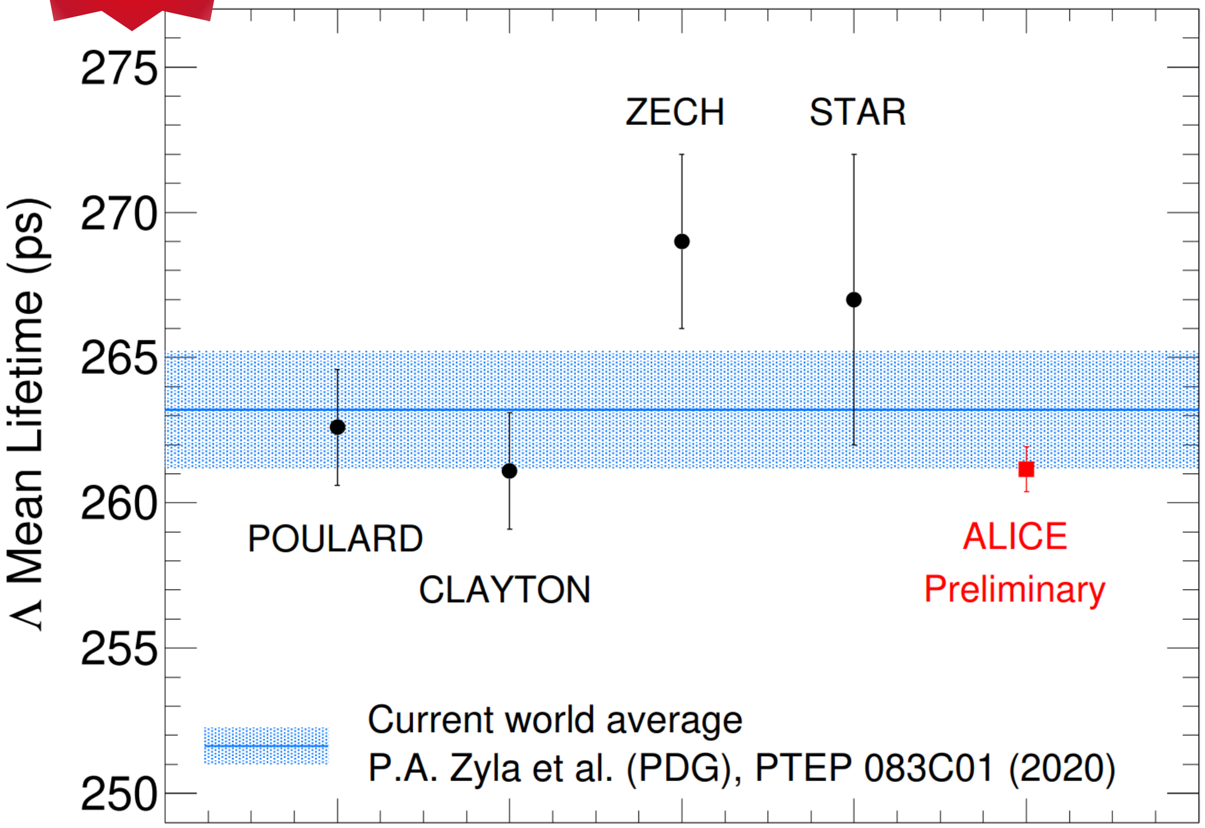


ALI-PERF-335127

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 ~3 more precise than the PDG value

NEW

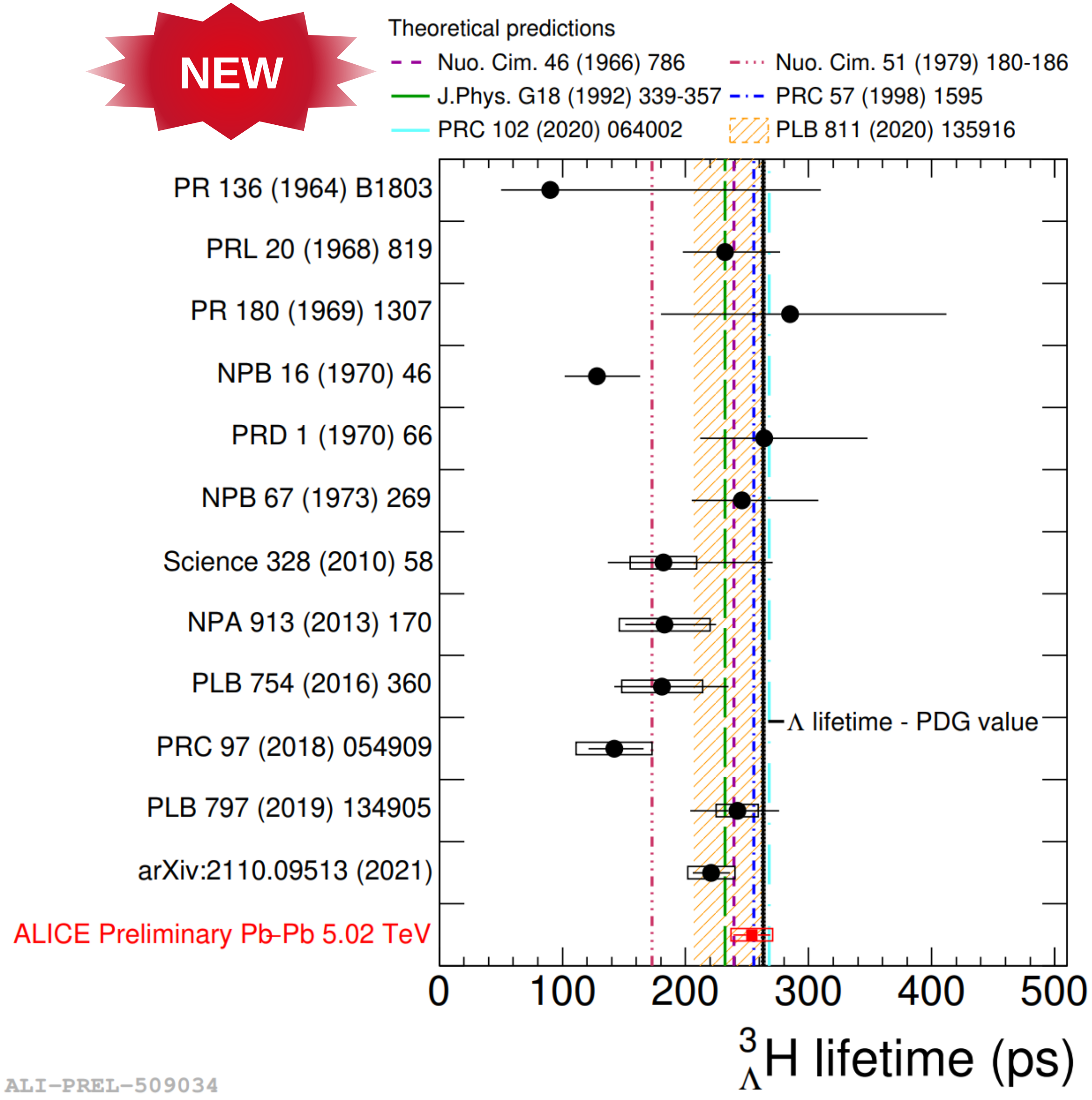


ALI-PREL-505548

Hypertriton lifetime

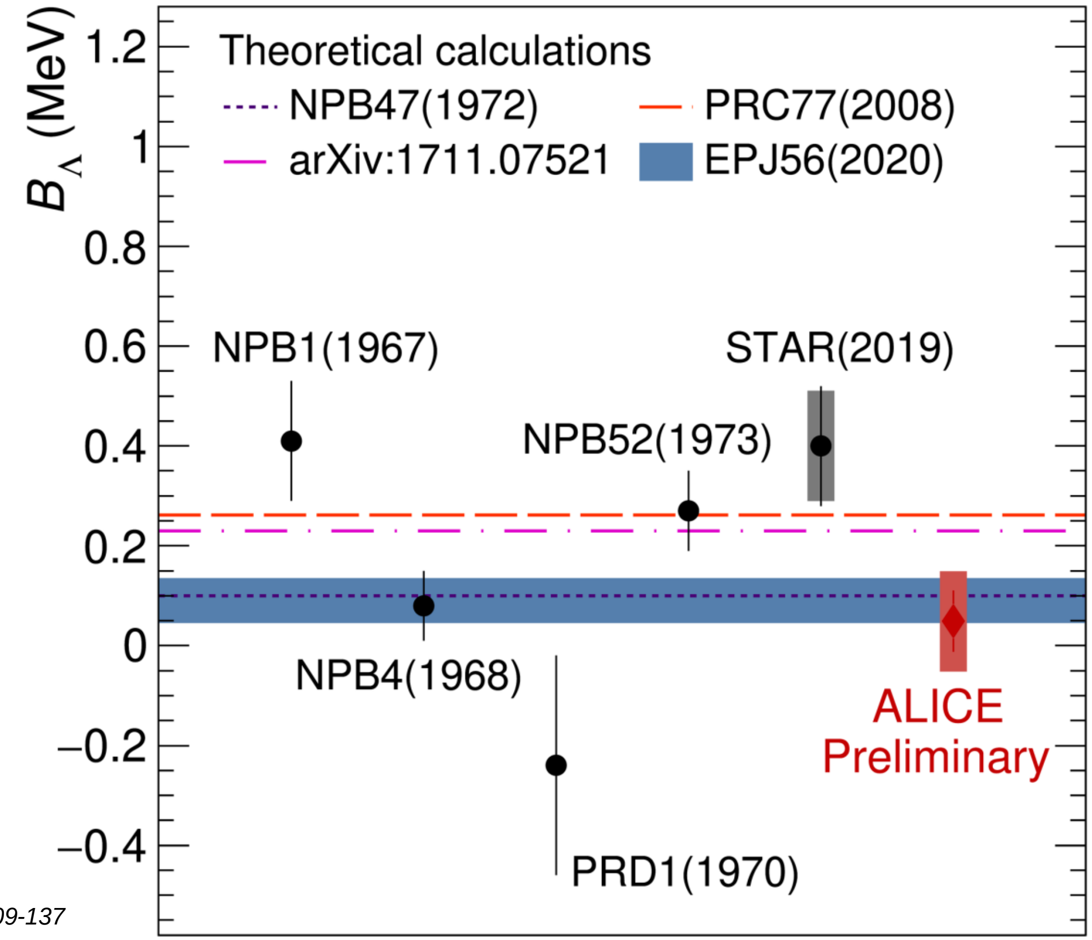
- Recent measurement in Run 2 Pb-Pb collisions at 5.02 TeV
- Is compatible with the free Λ lifetime within its uncertainties
- New preliminary result will push the world average lifetime a little up

NEW



Hypertriton binding energy

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



[NPB47(1972)] *R.H. Dalitz, R.C. Herndon, Y.C. Tang, Nuclear Physics B, Volume 47, Issue 1, 1972, Pages 109-137*
[arXiv:1711.07521] *Lonardoni, Diego and Pederiva, Francesco, arXiv:1711.07521 [nucl-th]*
[PRC77(2008)] *Fujiwara, Y. and Suzuki, Y. and Kohno, M. and Miyagawa, K., Phys. Rev. C 77, 027001*
[EPJ56(2020)] *F. Hildenbrand and H.-W. Hammer, Phys. Rev. C 100, 034002*

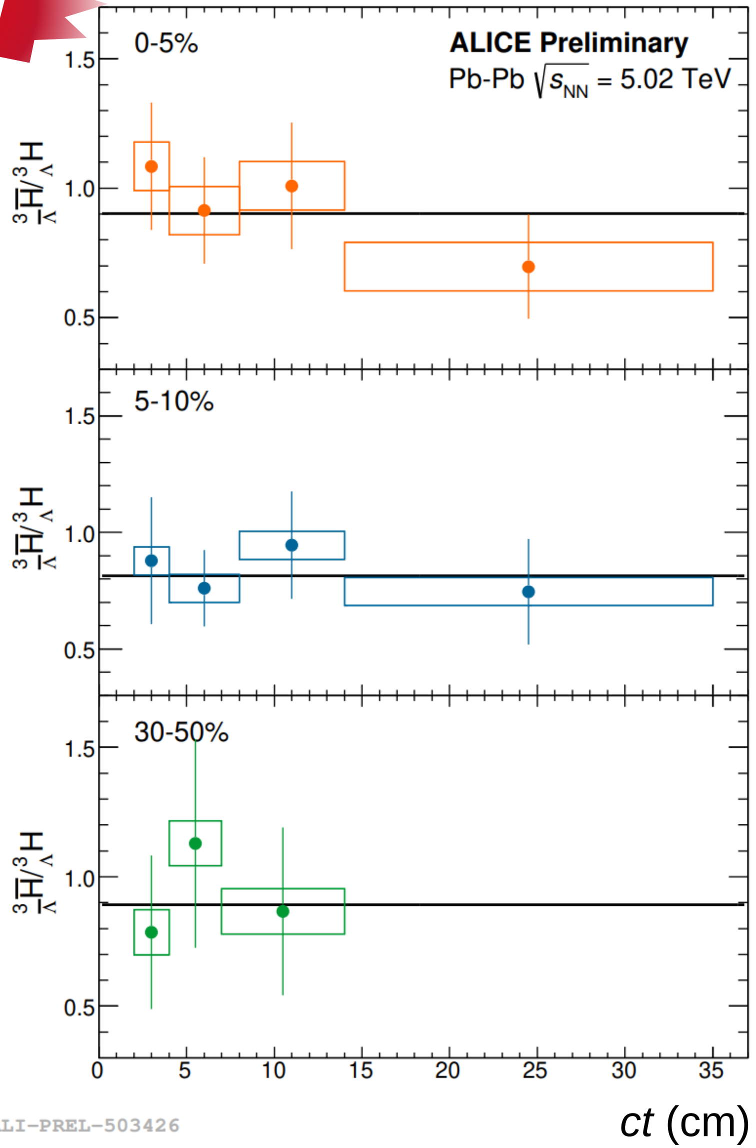
ALI-PREL-486370

Hypertriton production

- Recent measurement in Run 2 Pb-Pb collisions at 5.02 TeV
- Determination of the baryochemical potential including the hypertriton in different centrality bins
- Using antiparticle to particle ratios as input

$$\overline{h}/h \propto \exp\left[-2\left(B+\frac{S}{3}\right)\frac{\mu_B}{T} - 2I_3\frac{\mu_{I_3}}{T}\right]$$

NEW



0-5%

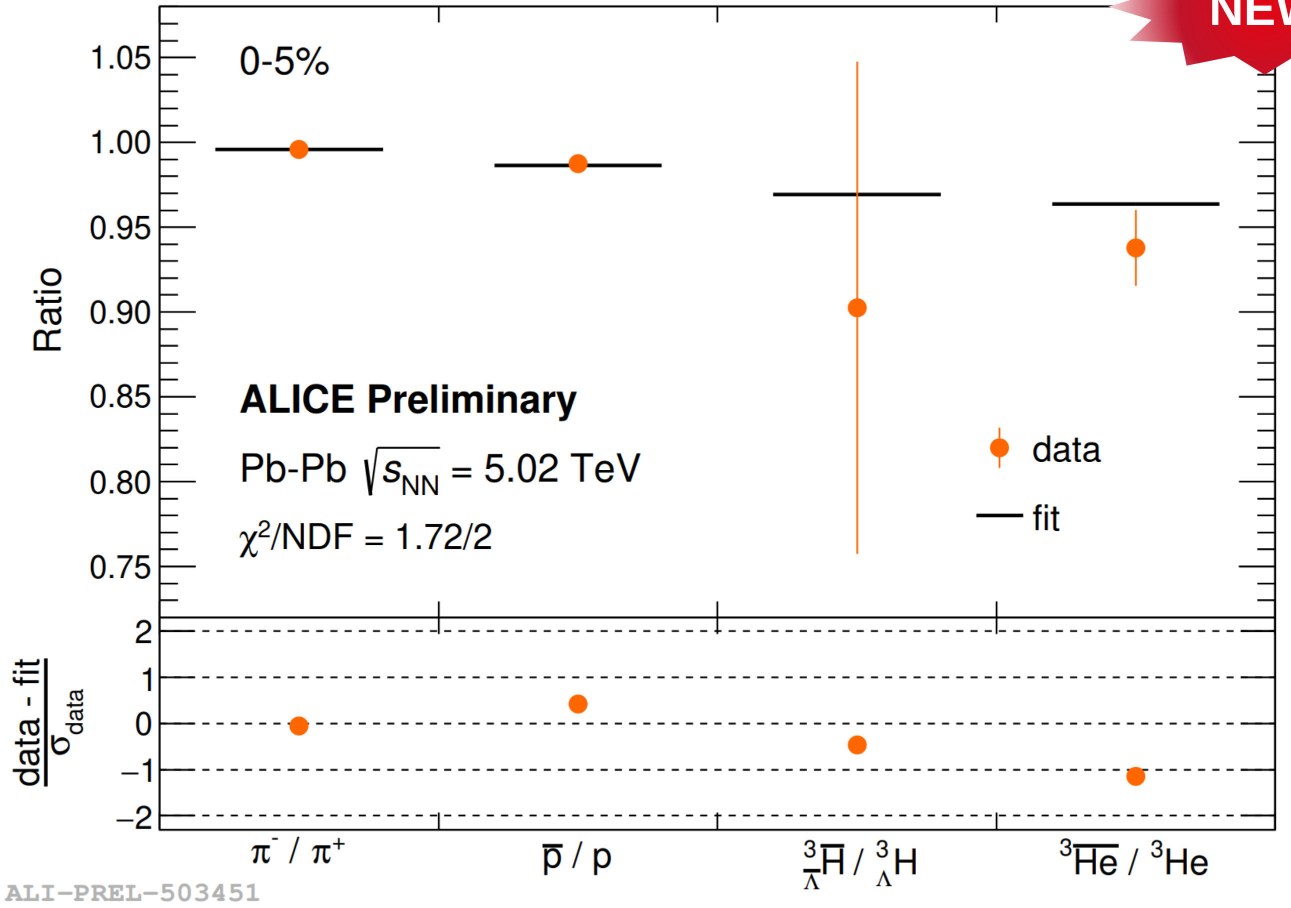
5-10%

30-50%

Hypertriton production

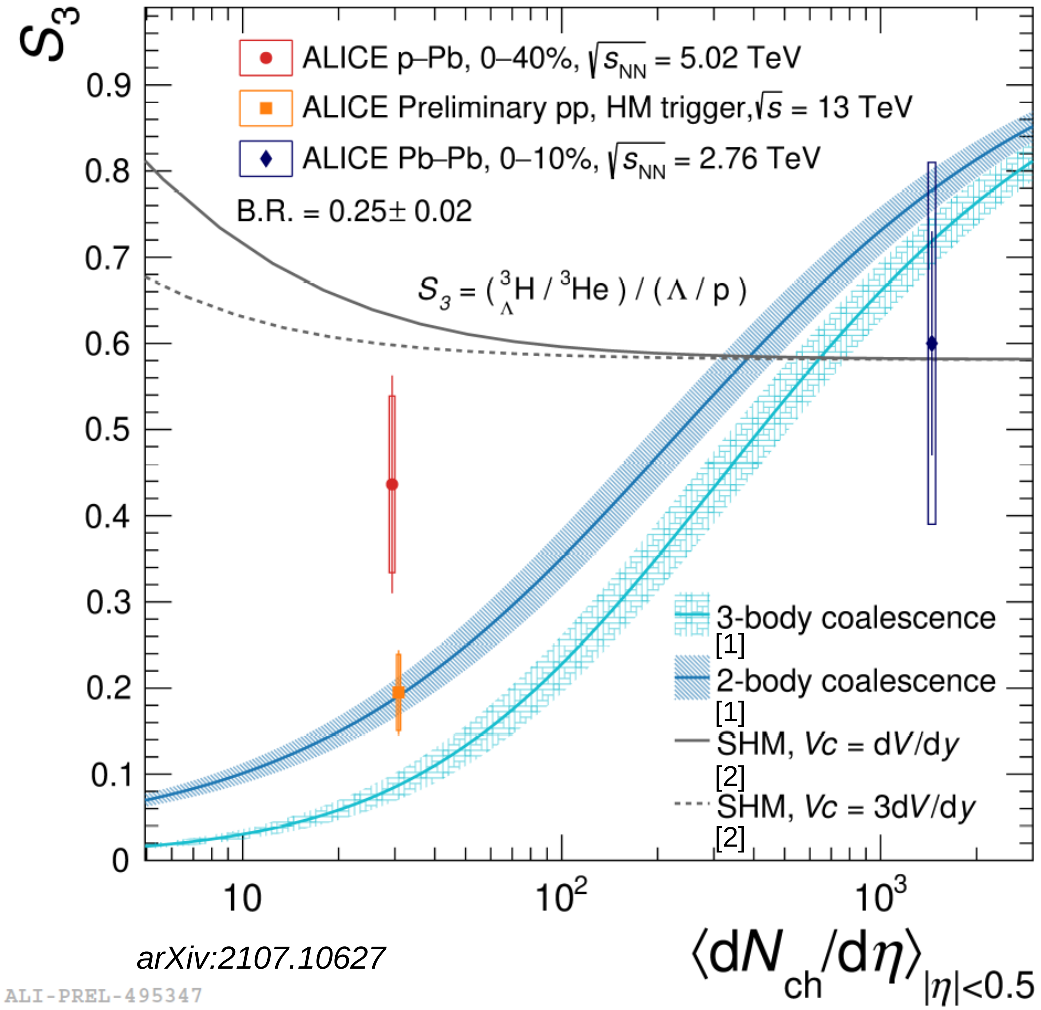
- Recent measurement in Run 2 Pb-Pb collisions at 5.02 TeV
- Fit to the data provides a value of μ_B close to zero in the most central collisions
- Antiparticle to particle ratio compared to SHM predictions at T_{ch} = 155 ± 2 MeV and using the obtained μ_B
- Very precise result even with large uncertainties for the hypertriton and a small overestimation for the ^{3}He

NEW



Outlook

- Studies of hypertriton production in different multiplicities are the key to explore the formation mechanism:
  - We are currently performing studies on a different triggered dataset, which will allow us to set another point
  - There is another p-Pb dataset available which could also give an additional point



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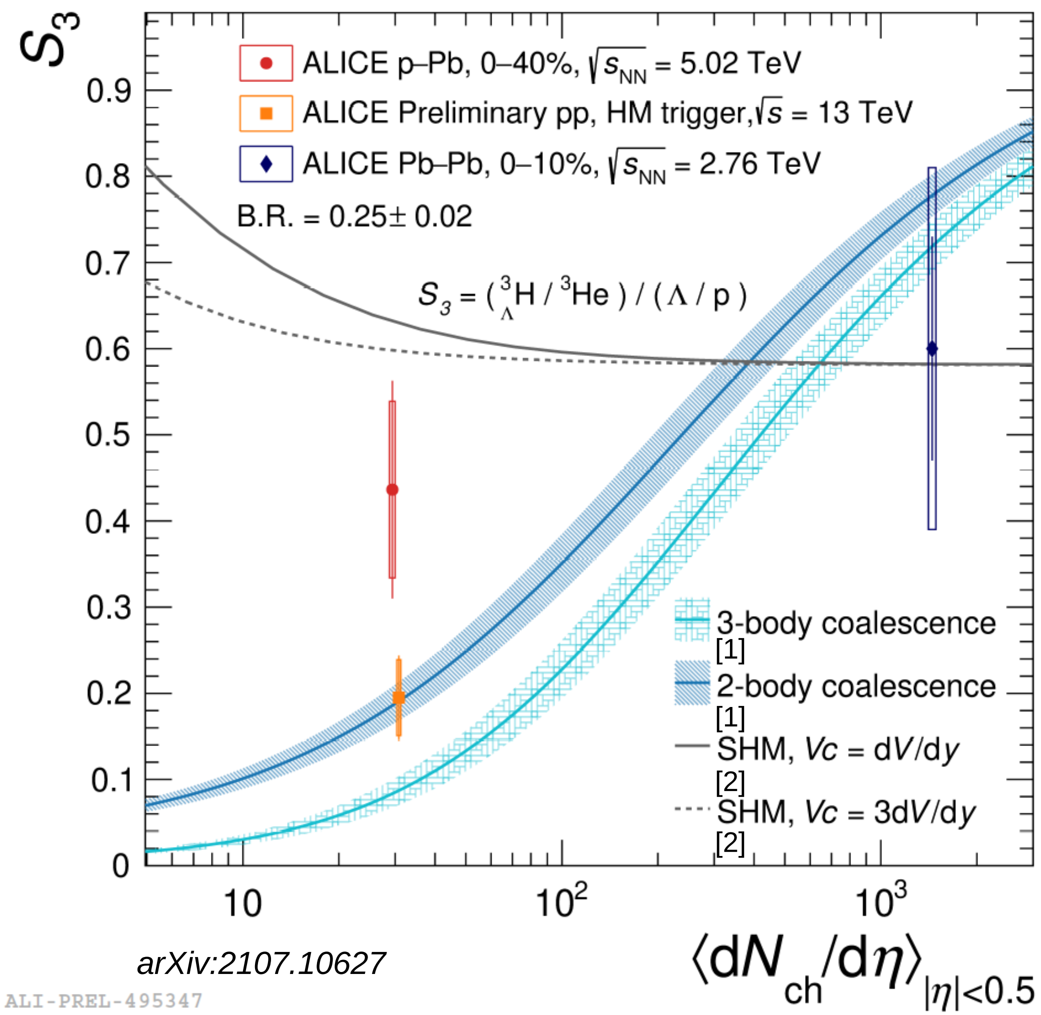
Outlook

- Studies of hypertriton production in different multiplicities are the key to explore the formation mechanism
- The upcoming Run 3 of the LHC will add significantly more statistics and high precision data also for small systems:
  - Expecting higher statistics, by running at 50 kHz collision rate
  - Upgrade of important detector parts, especially ITS and TPC



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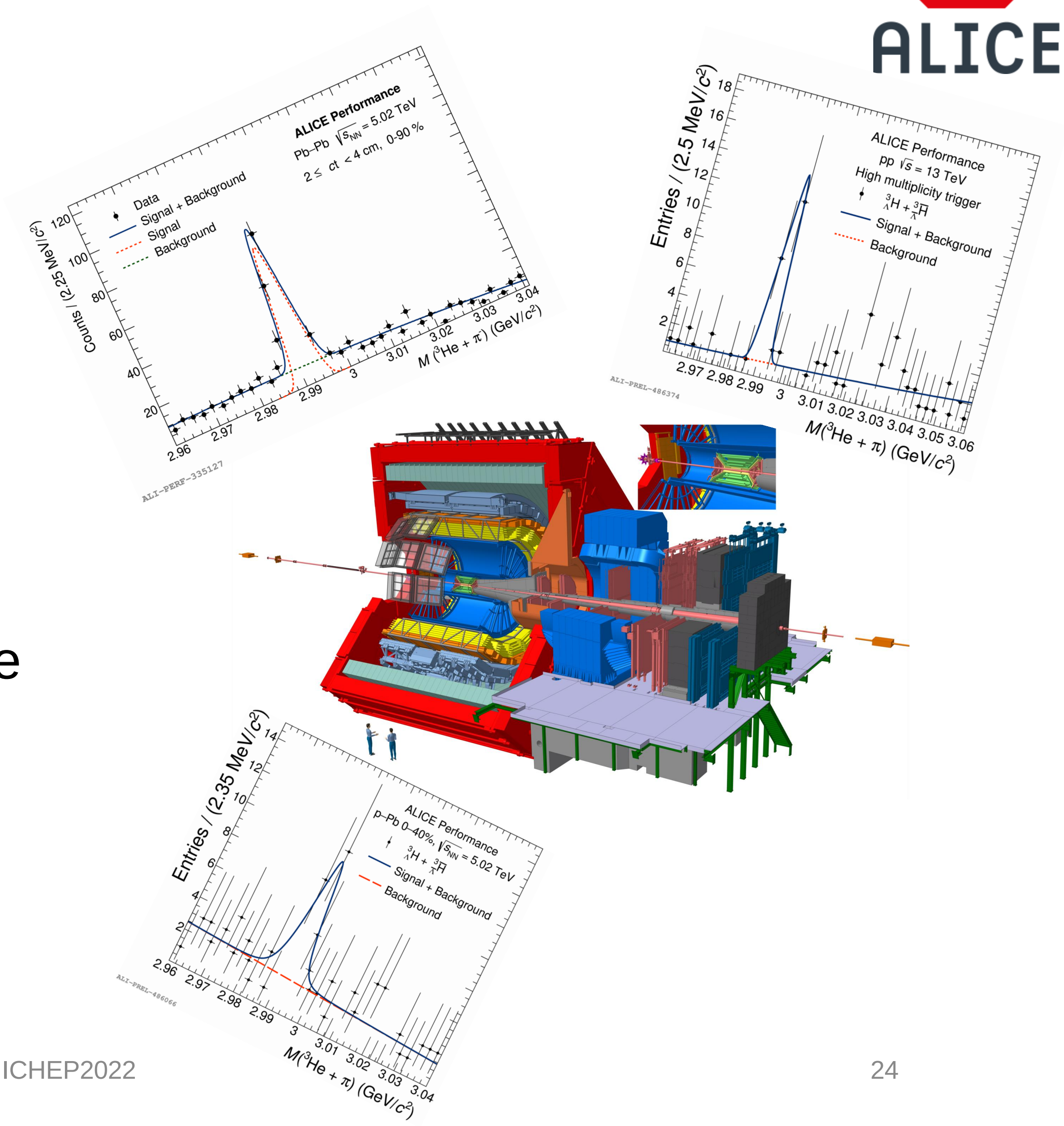
Summary

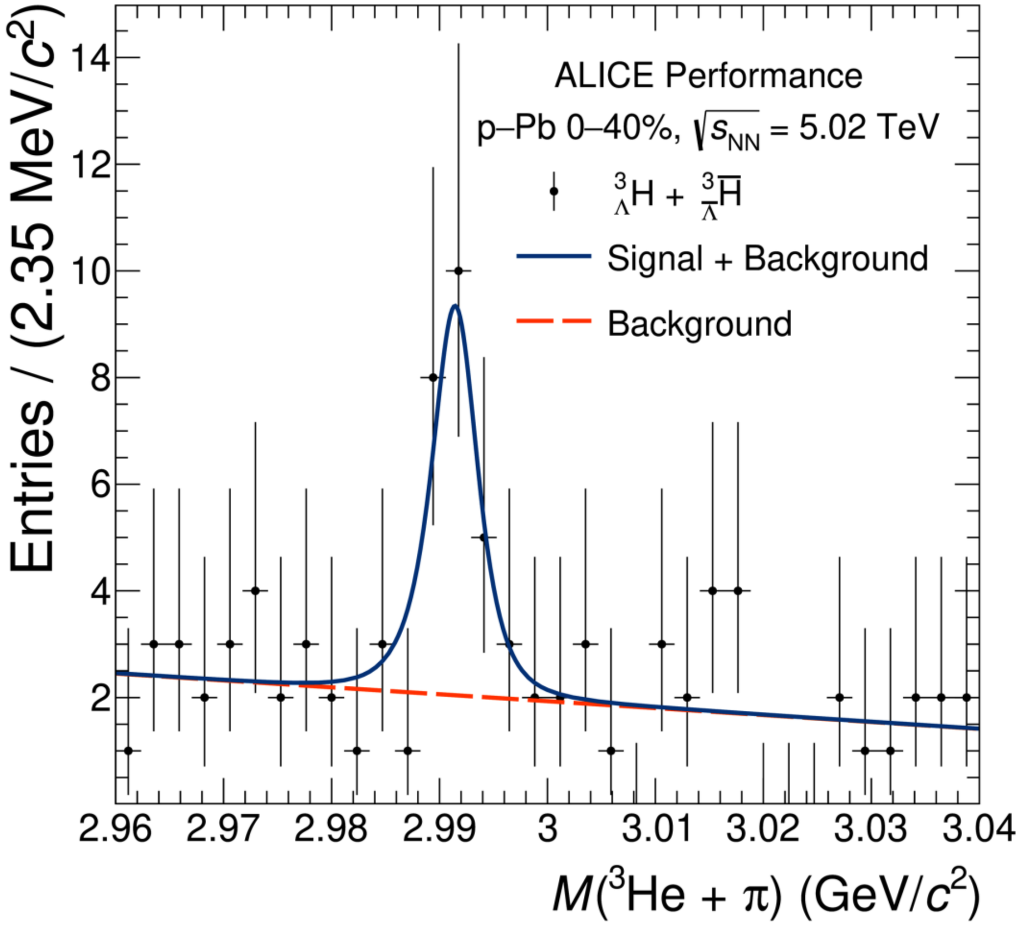
- ALICE is the perfect apparatus to study the production and properties of light (anti-)(hyper-)nuclei
- The latest results show small uncertainties and a good agreement with the theoretical predictions
- The upcoming Run 3 and Run 4 will add large statistics for the measurement of those particles and provide high precision data
- This may also give the possibility of a more conclusive answer to the question of the correct production model



Backup

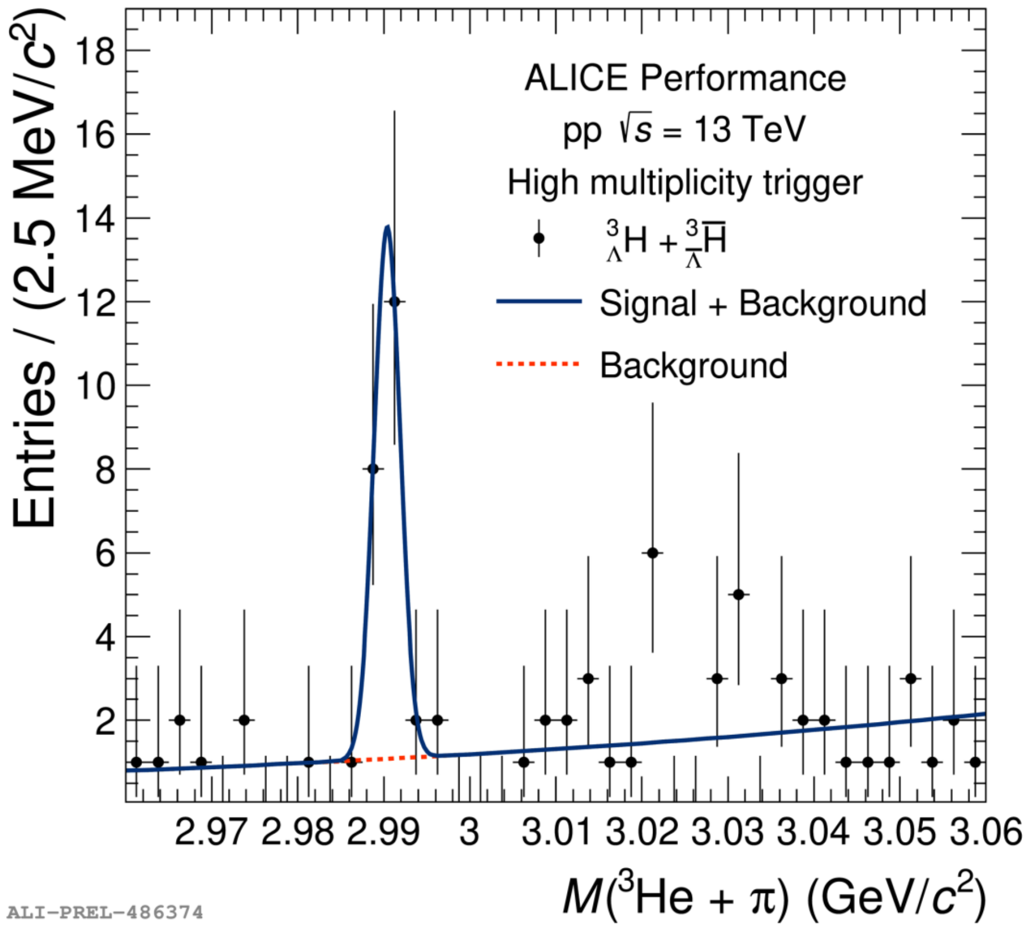
Hypertriton measurement in p-Pb

- 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 measurement in pp

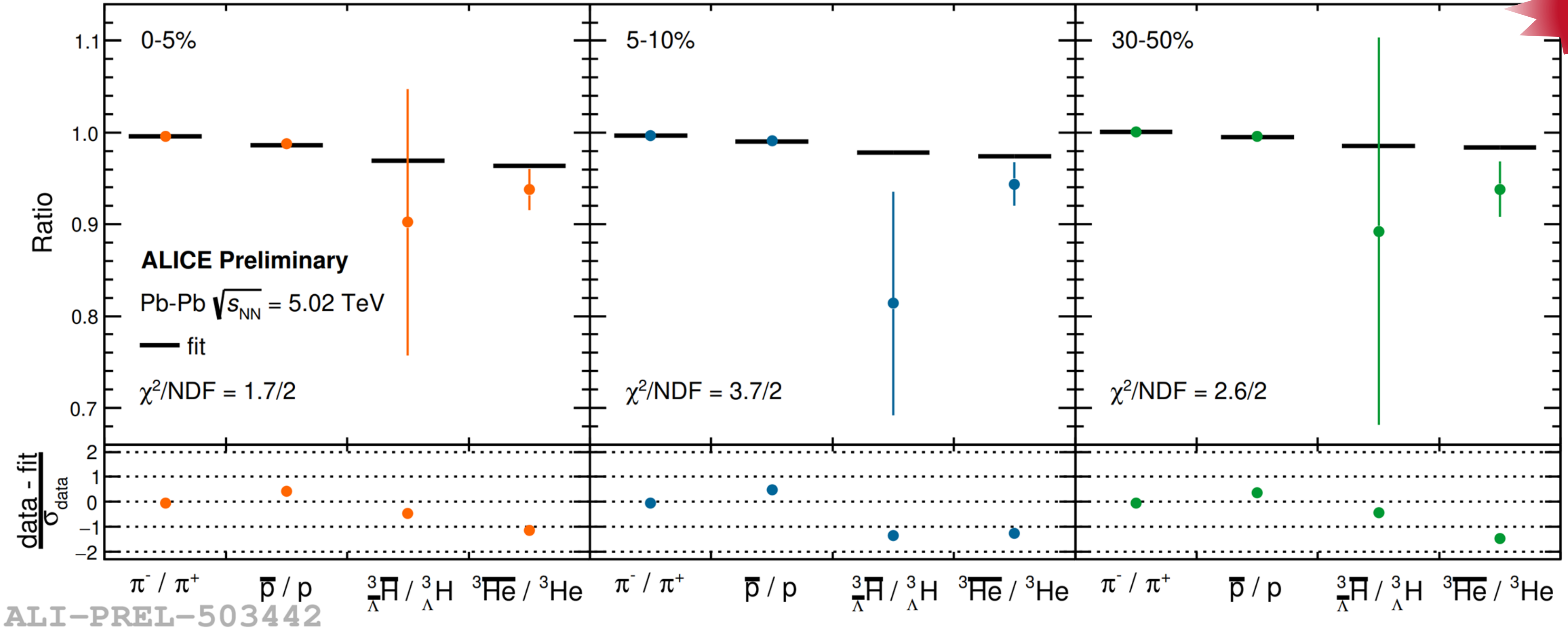
- First measurement of the hypertriton in Run 2 pp collisions at 13 TeV
- Topological and kinematical cuts applied to optimize the signal-to-background ratio and improve the significance in a traditional analysis



Hypertriton 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

NEW



Hypertriton production

- Baryochemical potential compared to SHM predictions at T_{ch} = 155 ± 2 MeV and using the obtained μ_B for different centrality bins, shown here as function of ‹N_{part}›