Measurement of hypertriton production in ALICE

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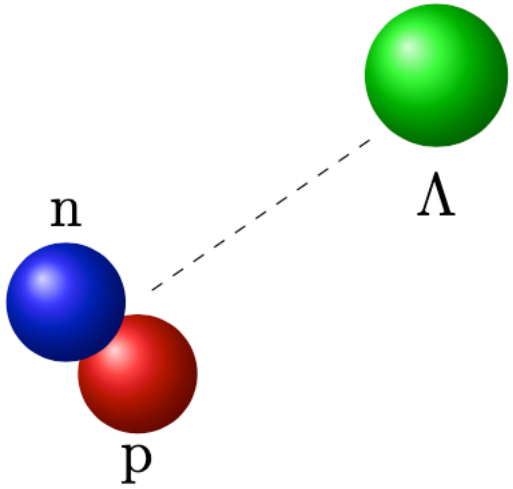
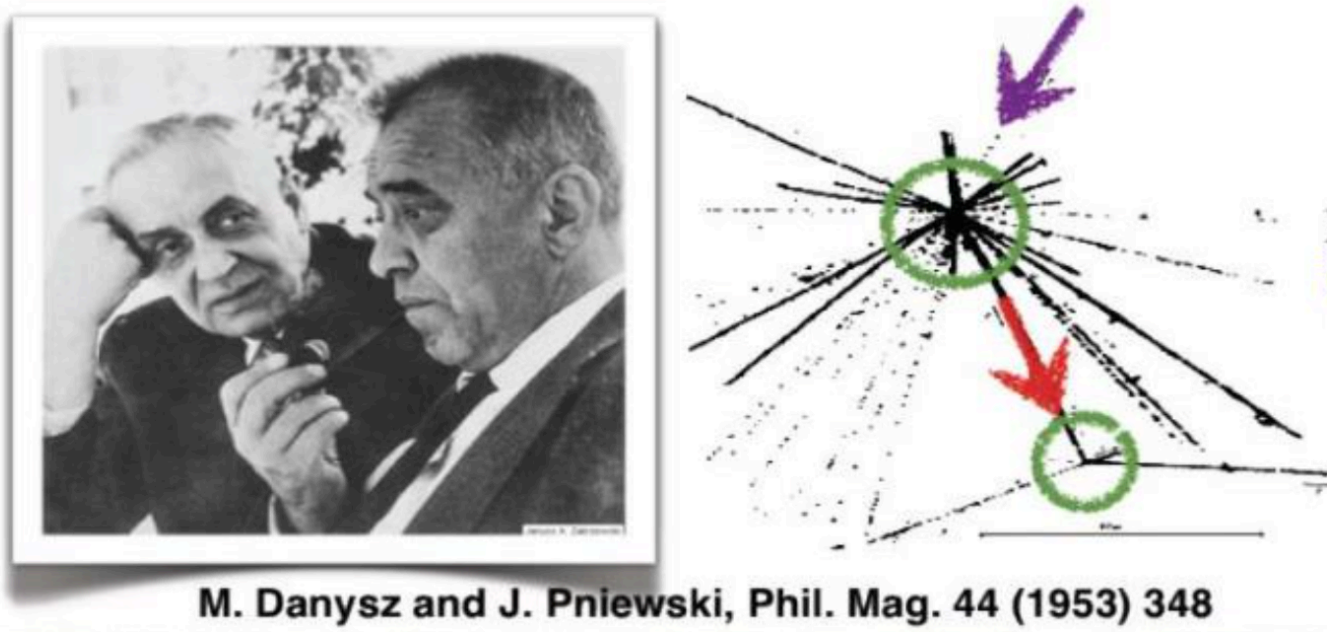
Hypertriton





M. Danysz and J. Pniewski, Phil. Mag. 44 (1953) 348

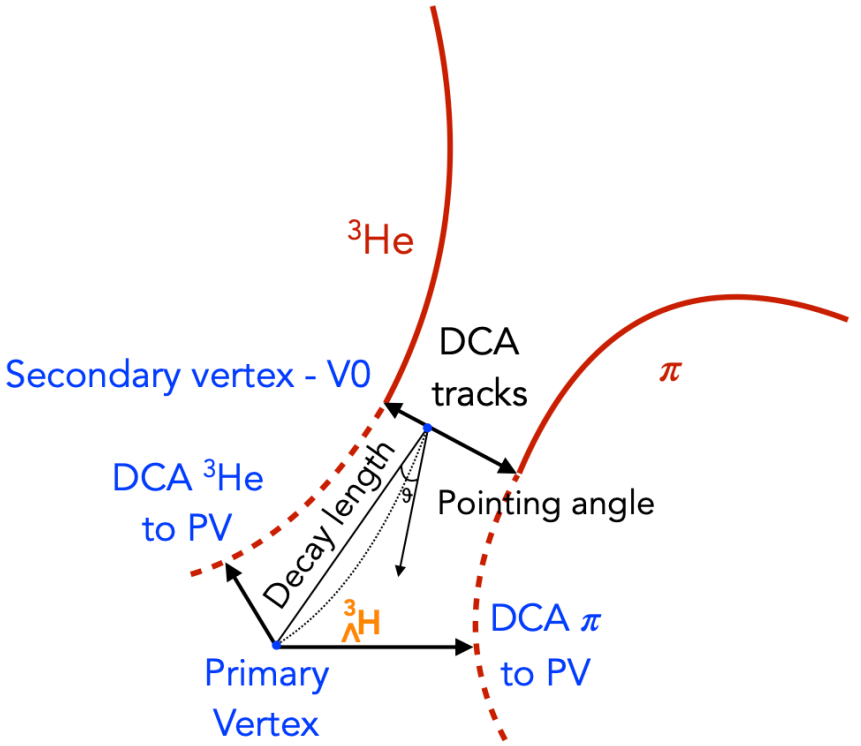
- Hypertriton is the lightest known hypernucleus
- Bound state of a proton, a neutron and a Λ hyperon

- The first hypernuclei was discovered in 1950s in a cosmic ray experiment via emulsion plate.
- Unique nuclear system can be used as probes to study hyperon-nucleon(Y-N) interaction

Decay channel

Channel	Γ (sec^{-1})	Branching Ratio (%)
$^3He + \pi^-$ and $^3H + \pi^0$	0.146×10^{10}	37.34
$d + p + \pi^-$ and $d + n + \pi^0$	0.235×10^{10}	60.09
$p + p + n + \pi^-$ and $p + n + n + \pi^0$	0.368×10^{8}	0.94
All mesonic channels	0.385×10^{10}	
$d + n$	0.67×10^{7}	0.17
$p + n + n$	0.57×10^{8}	1.46
All nonmesonic channels	0.64×10^{8}	
All channels	0.391×10^{10}	

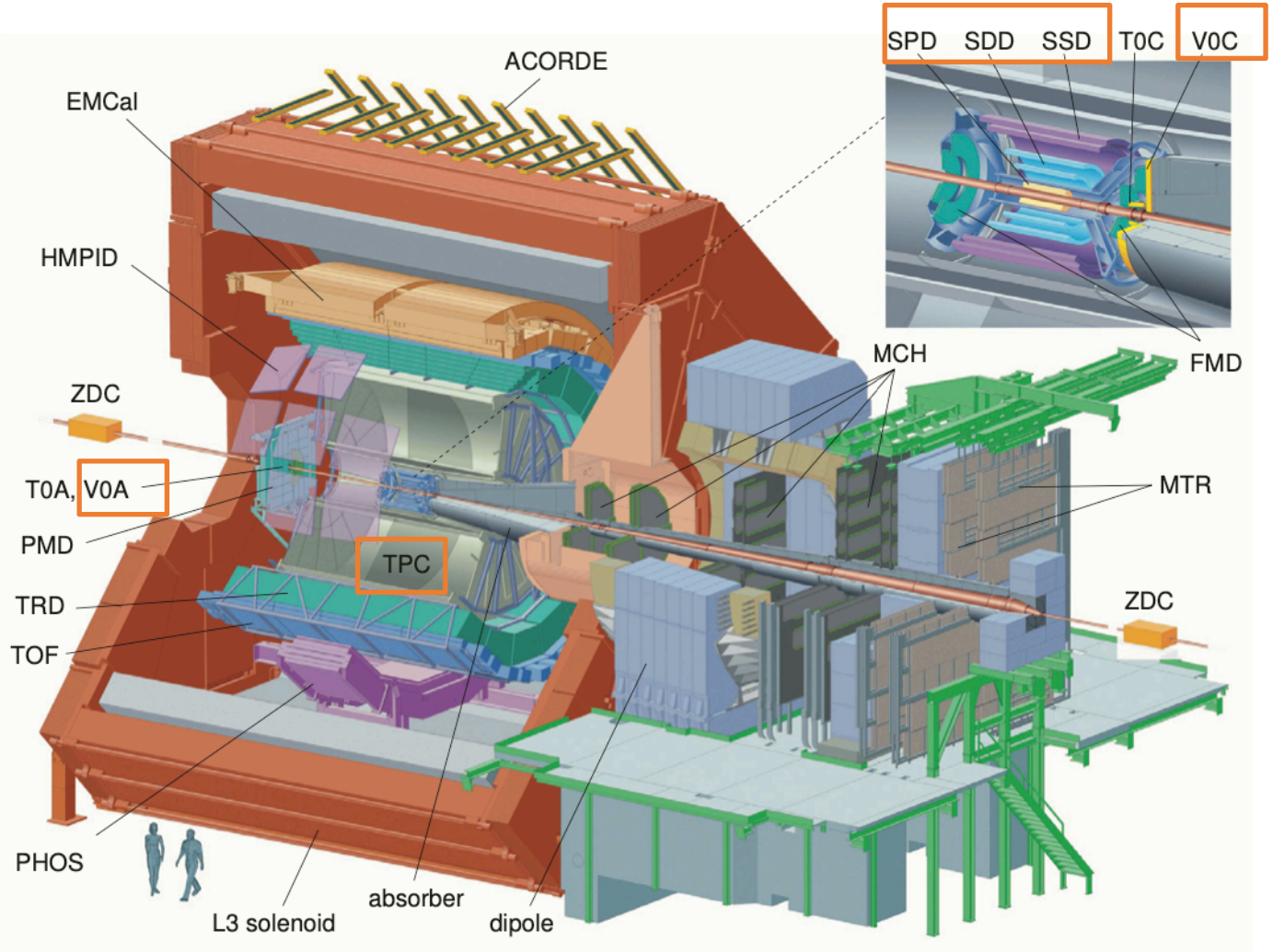
Kamada et al., PRC 57, 1595(1998)



- Weak mesonic decay channels are used to reconstruct hypertriton
- Now only ${}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^-$ is studied by ALICE, the 3-body decay should be doable with LHC Run3 data

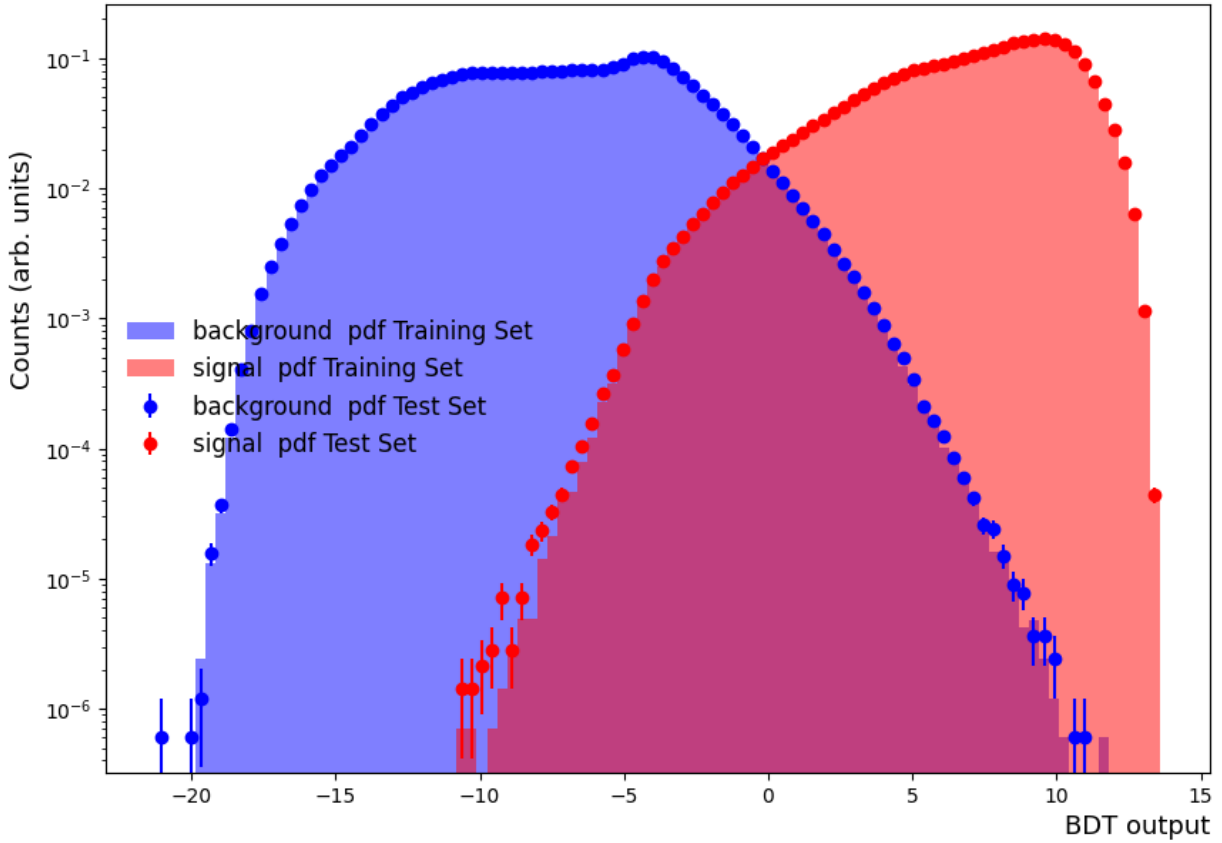
ALICE setup

- ${}^{3}_{\Lambda}\mathrm{H}$ are mainly reconstructed using both the Inner Track System (ITS) and the Time Projection Chamber (TPC)
- ITS reconstructs charged-particle trajectories and measures precisely the position of the interaction vertices
- TPC identifies charged particles by measuring their specific energy loss
- V0 determines the MB and central trigger



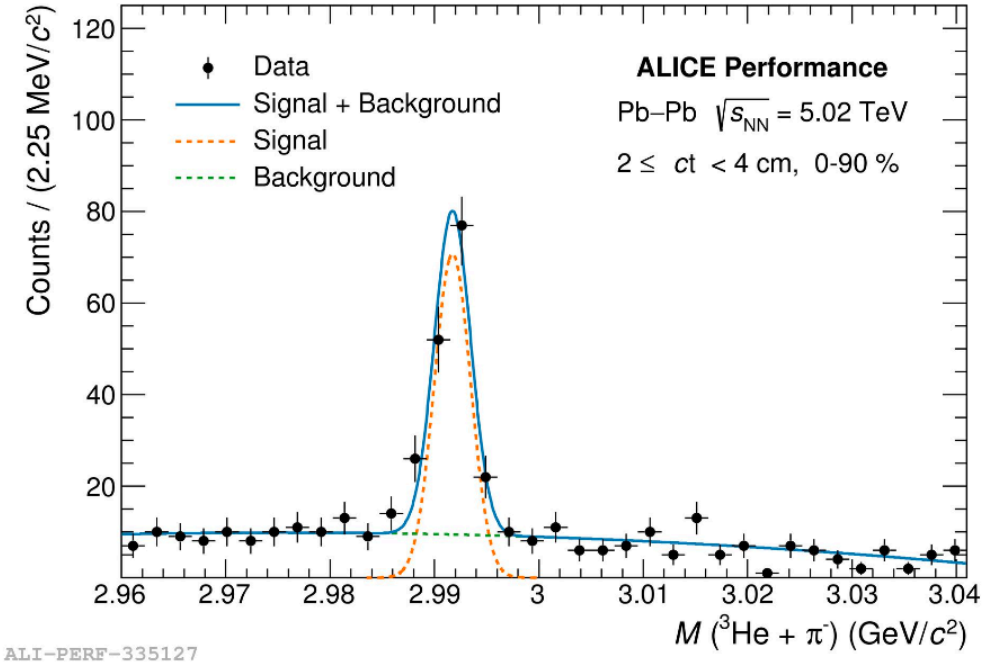
Machine Learning

- A machine learning environment hipe4ml based on BDT is widely-used in ALICE
- BDT score based on the features of each hypertriton candidate, the candidates with a higher score are regraded as more likely to be a true signal.
- The BDT threshold is selected to balance the statistics and the purity of signal
- Same performance in both training and test set, indicating no overfit phenomenon of the BDT model

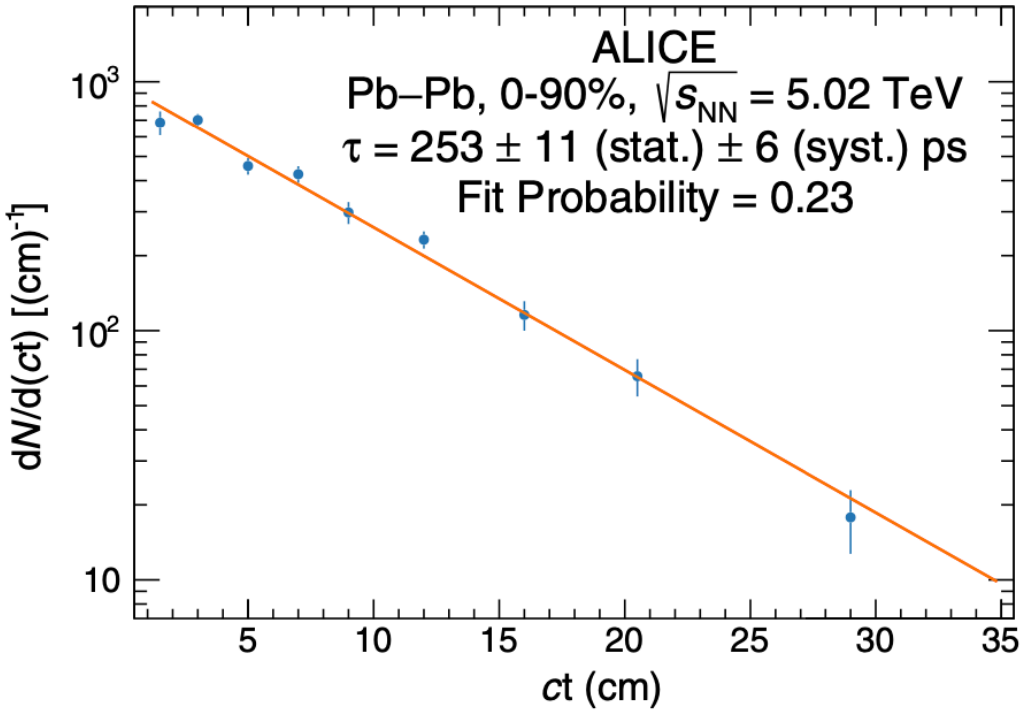


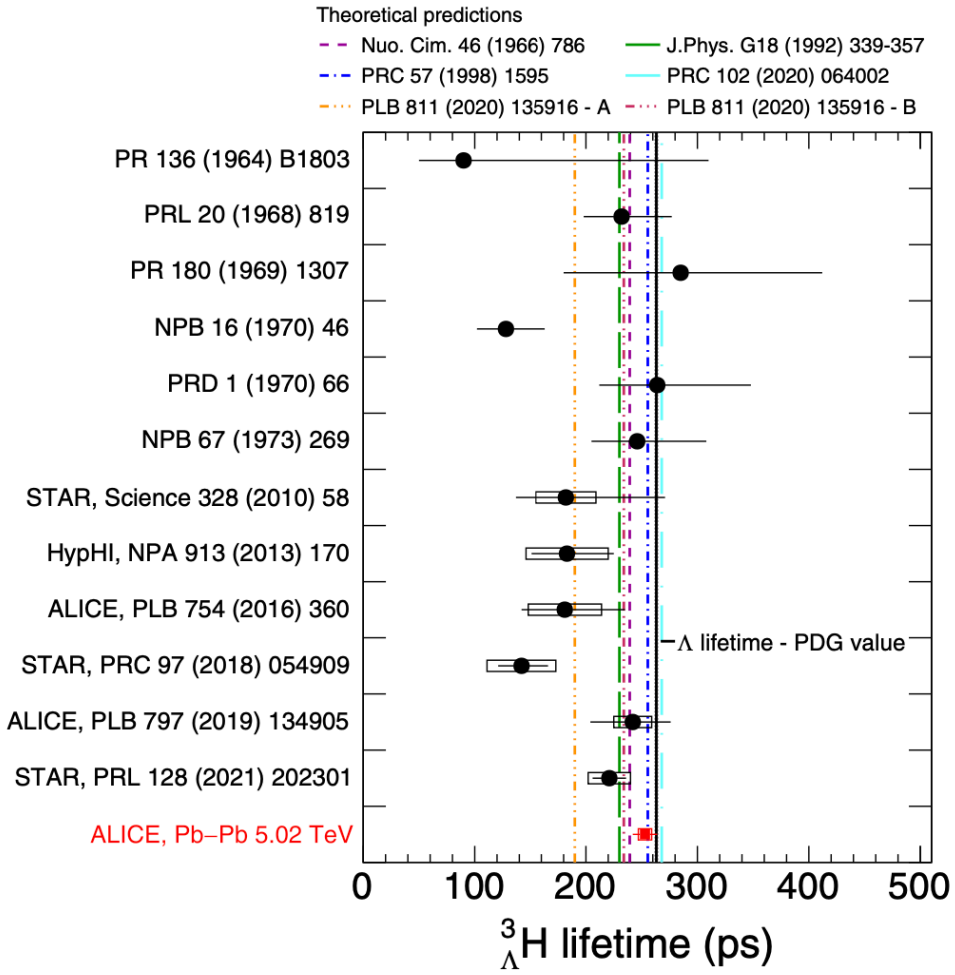
Signal extraction

- Unbinned maximum likelihood fit and a combination model for signal and background is applied via RooFit
- Different background and signal functions to evaluate the systematic uncertainties
- Hypertriton yield comes from the sum of the measured spectra + the Blast-Wave fit integral where no data points are available



Hypertriton lifetime and B_Λ

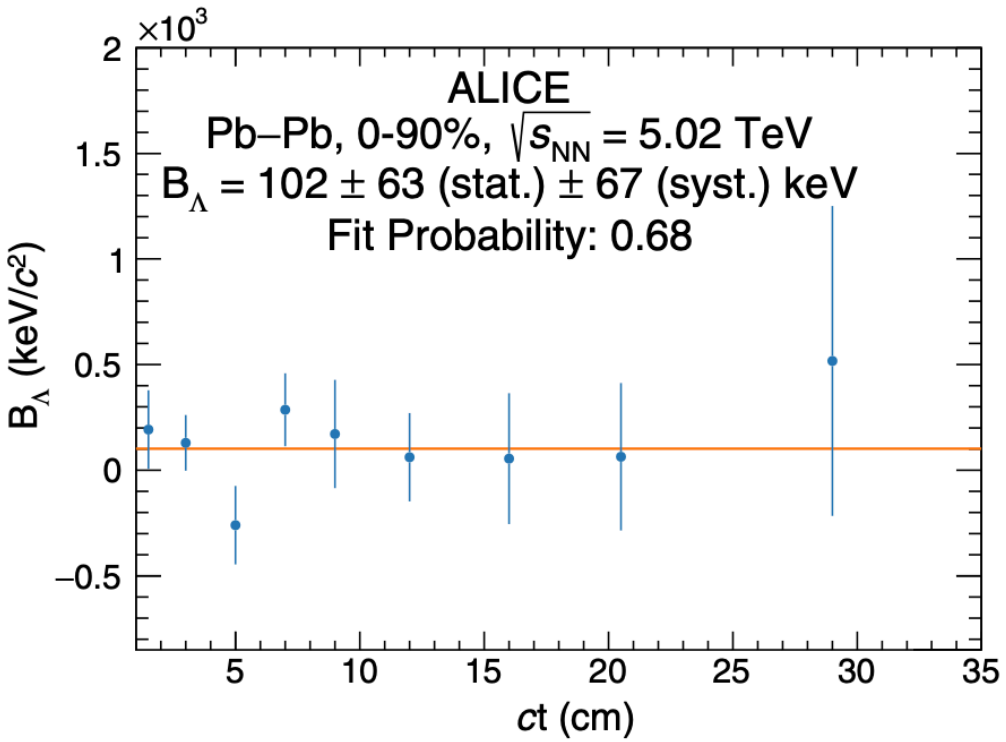




PRL 131, 102302 (2023)

- Most precise $^3_\Lambda\mathrm{H}$ lifetime result shows $\tau(^3_\Lambda\mathrm{H}) \approx \tau(\Lambda)$

Hypertriton lifetime and B_Λ



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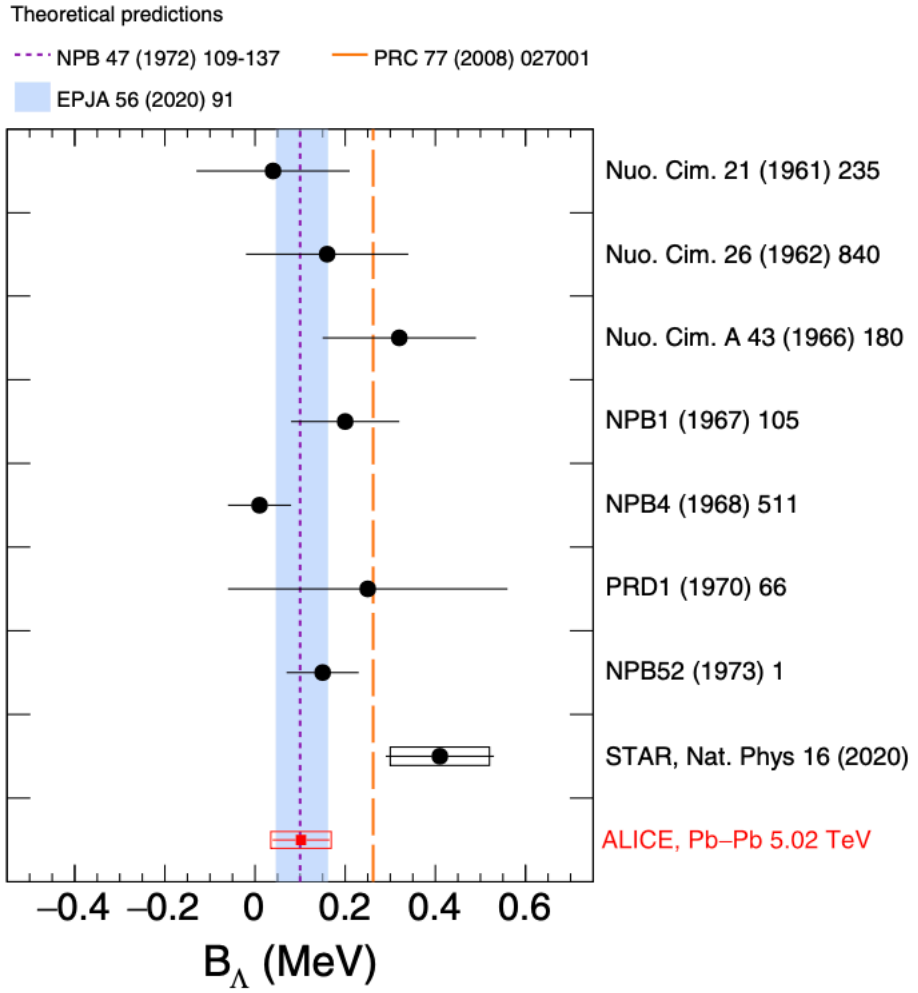


- Precise measurement needed to solve the discrepancy between ALICE and STAR

Model prediction of hypertriton production

Loosely bounded hypertriton is expected to have a radius extension around 5fm, such large nuclei size results in significant deviation in different models

- SHM (statistical hadronization model):
  - Ideal hadron resonance gas in thermal equilibrium at the chemical freeze-out stage
  - In the canonical formulation it considers conserved baryon number, electric charge and strangeness

V. Vovchenko, B. Dönigus, and H. Stoecker, PLB 785 (2018) 171–174

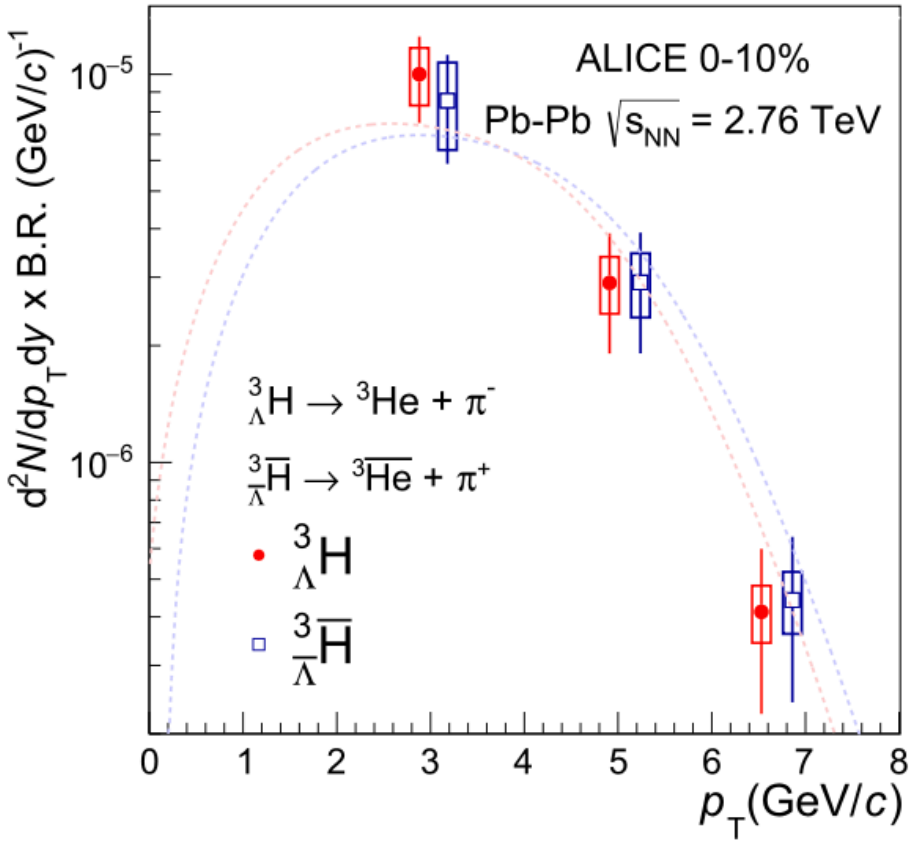
- Coalescence model
  - The production is obtained from the overlap between source distribution function (f) and Wigner function (W) of light nuclei

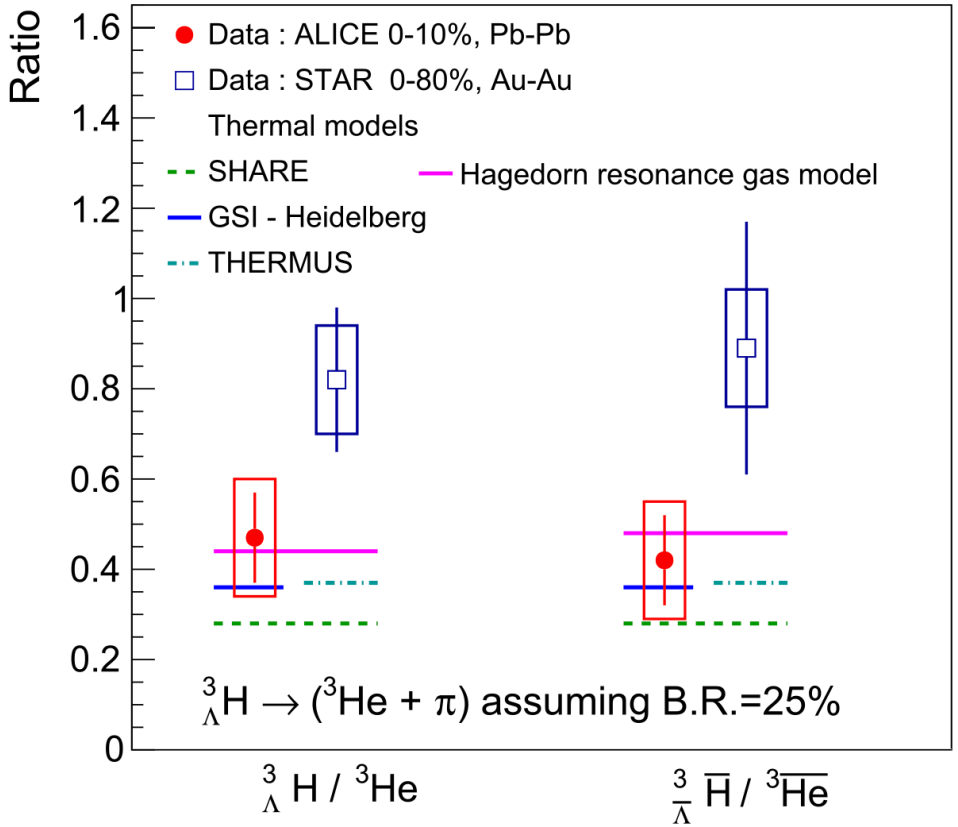
For hypertriton: $N_{^3_\Lambda\mathrm{H}} = g \int d^3x d^3k f_p f_n f_\Lambda W_{^3_\Lambda\mathrm{H}}$

K. J. Sun, C. M. Ko, and B. Dönigus, PLB 792, 132-137(2019)

Hypertriton production in Pb-Pb 2.76TeV

- Result of LHC Run1 data, topological cuts are used rather than machine learning method
- First measurement of hypertriton production with ALICE

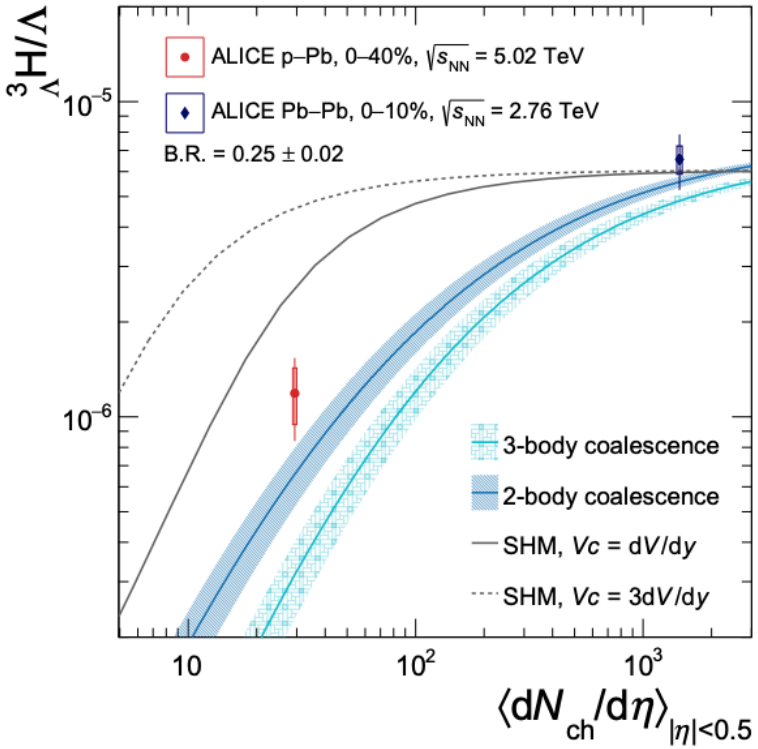


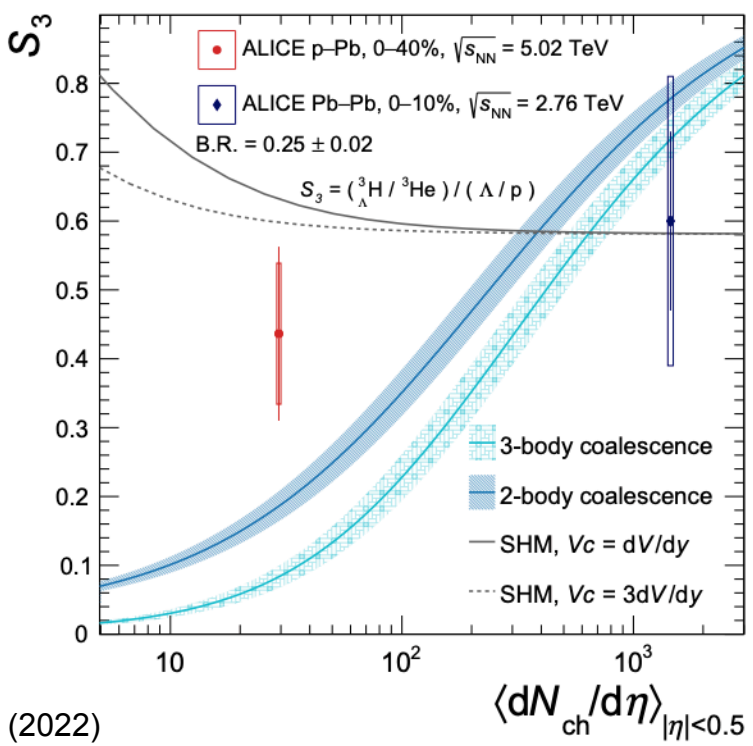


ALICE Collaboration / Physics Letters B 754 (2016) 360–372

Hypertriton production in p-Pb 5.02 TeV

$$S_3 = ({}^3_\Lambda\mathrm{H}/{}^3\mathrm{He})/(\Lambda/p)$$



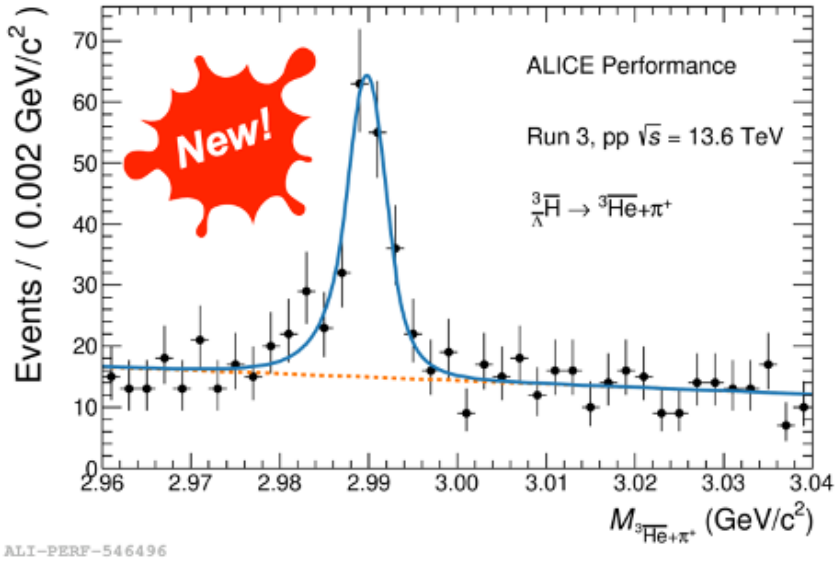


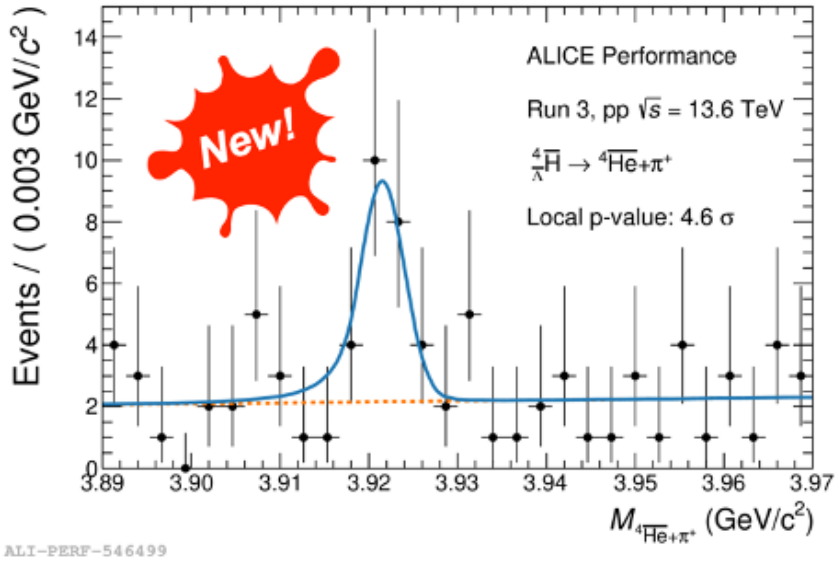
PRL 128, 252003 (2022)

- Measurements in better agreement with coalescence model
- Further analysis required to figure out the nuclear production mechanism, especially for low multiplicity cases
- Potential measurement in pt dependence of hypertriton yield in large systems

Performance in LHC Run3

- In QM 2023, hypernuclei performance plots in run3 pp collisions are shown





(Anti)(hyper)nuclei with ALICE | I. Vorobyev | Quark Matter 2023

- Better statistics and significance are expected!

Summary

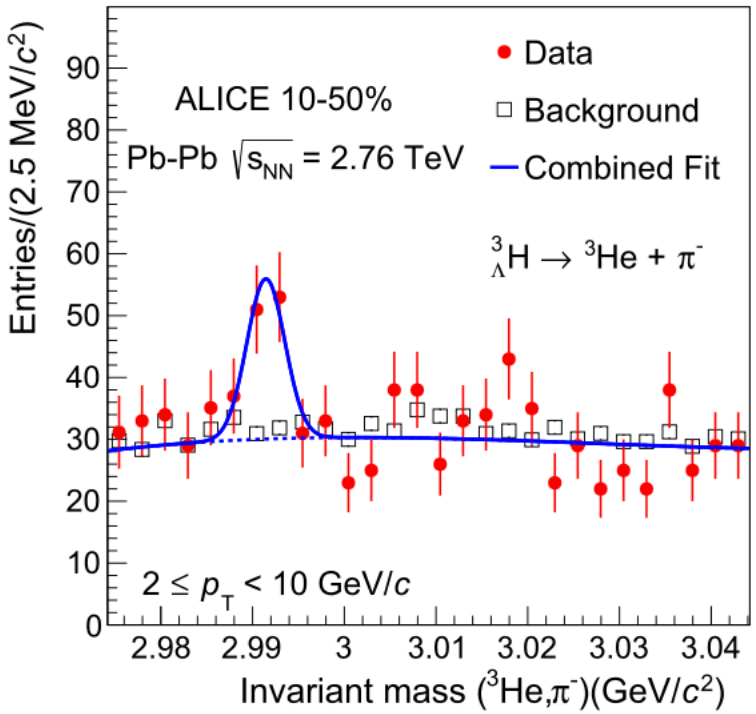
- Most precise measurement of ${}^{3}_{\Lambda}\mathrm{H}$ lifetime and B_{Λ} via heavy-ion collisions
  - Indicate a weakly bound structure of ${}^{3}_{\Lambda}\mathrm{H}$

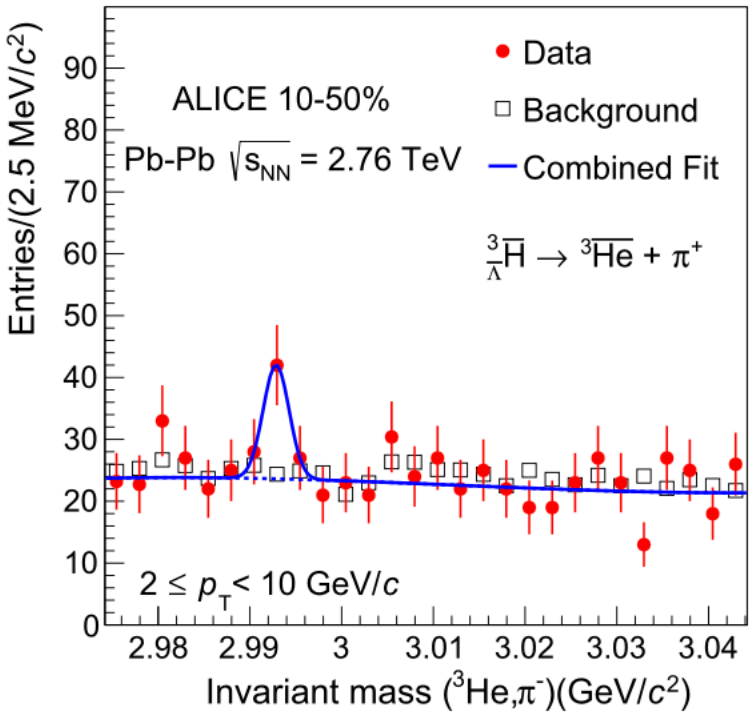
- Measurement of ${}^{3}_{\Lambda}\mathrm{H}$ production
  - Probe to distinguish among different nucleosynthesis mechanisms
  - Newest results in Pb-Pb will be coming soon

- Outlook with the new Run3 data:
  - More precise lifetime and B_{Λ} results
  - ${}^{3}_{\Lambda}\mathrm{H}$ production in pp collisions
  - Ratio of 3-body decay channel

Thanks for your attention!

Backup





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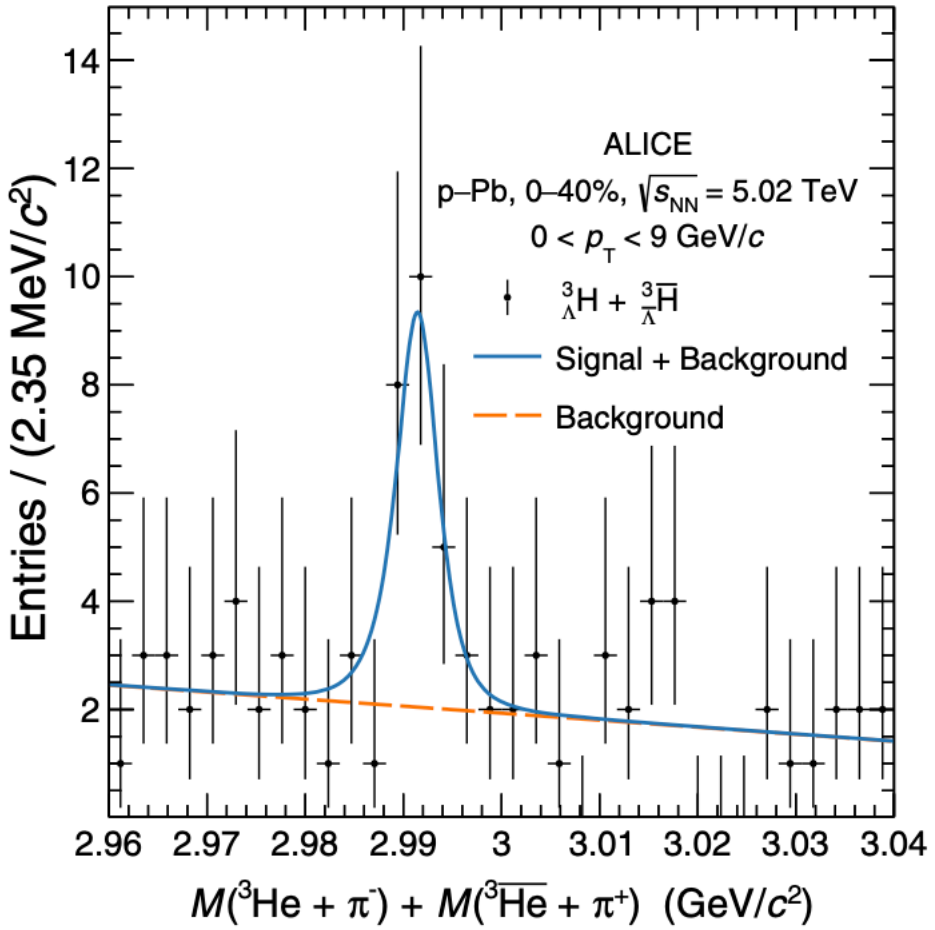

PRL 128, 252003 (2022)