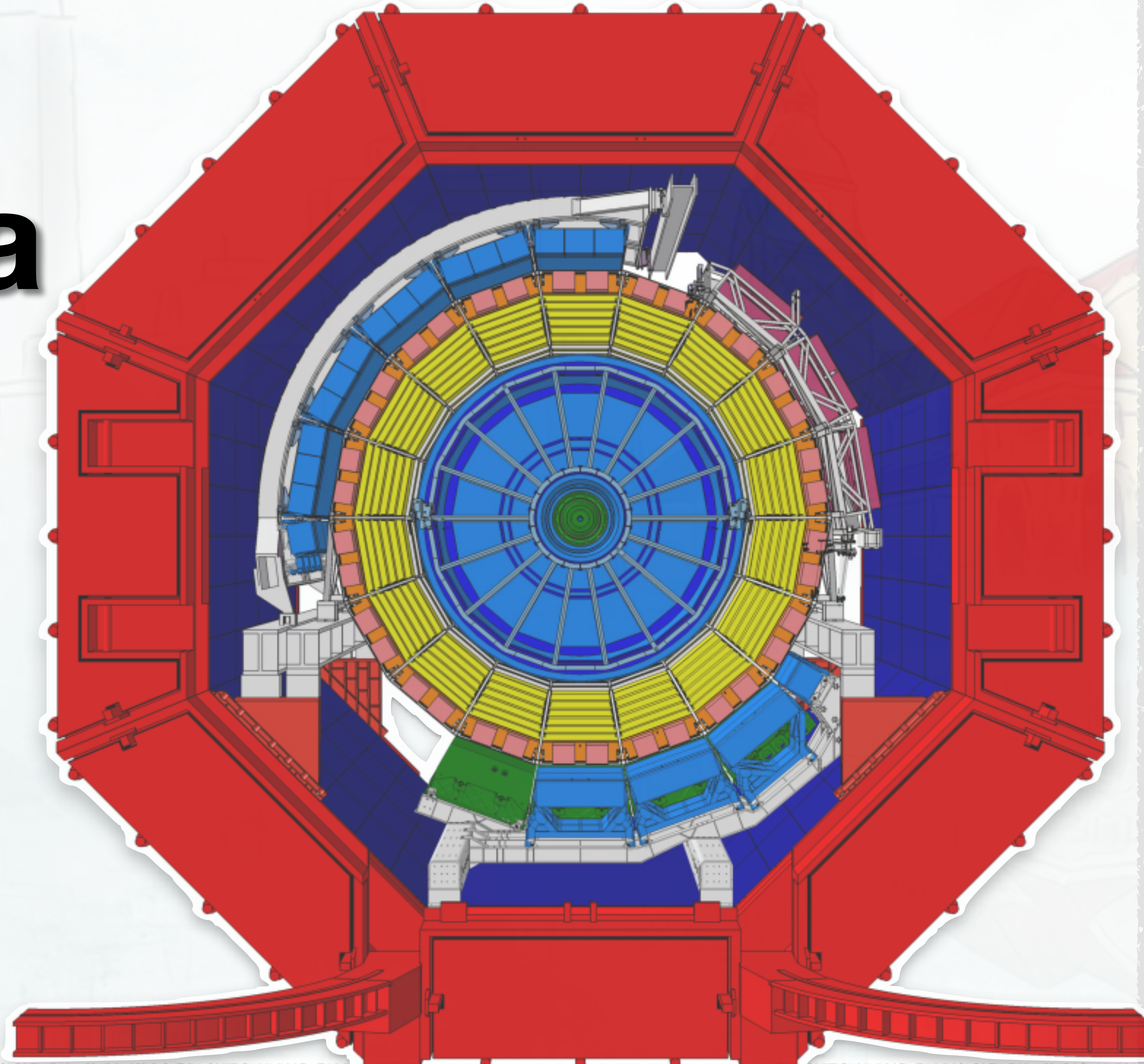
CLHCP 2024 QINGDAO

A review for hypernuclei and exotica in ALICE experiment

Zhengqing Wang (Fudan University)

16th/ November/ 2024



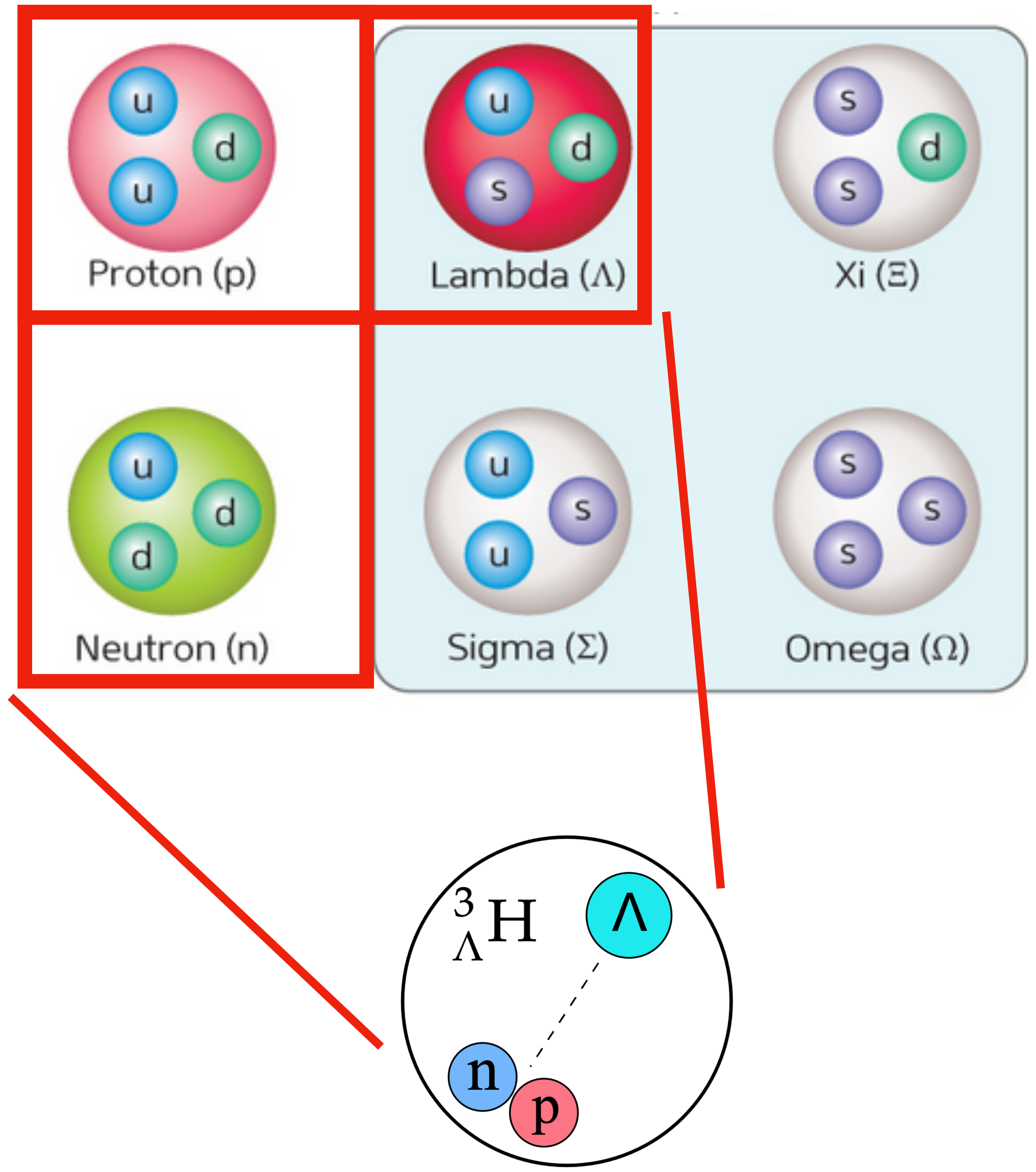
OUTLINE

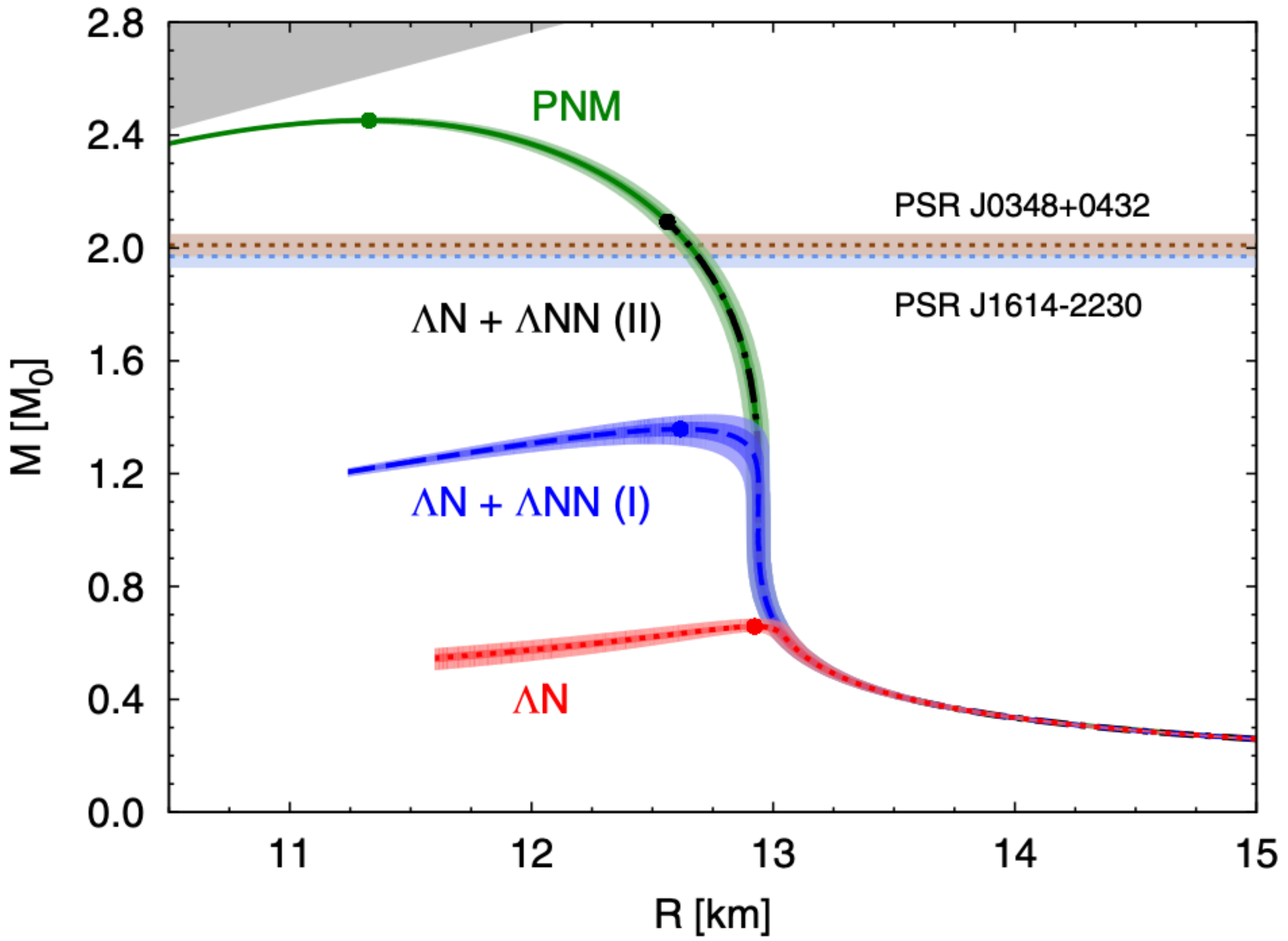
- Introduction to Hypernuclei
- Hypertriton Measurement
- Beyond Hypertriton
- Summary and prospects

Introduction to Hypernuclei

What is a hypernuclei?

- Hypernuclei: bound state of nucleons and hyperons





Phys.Rev.Lett. 114 (2015) 9, 092301

Why is it important?

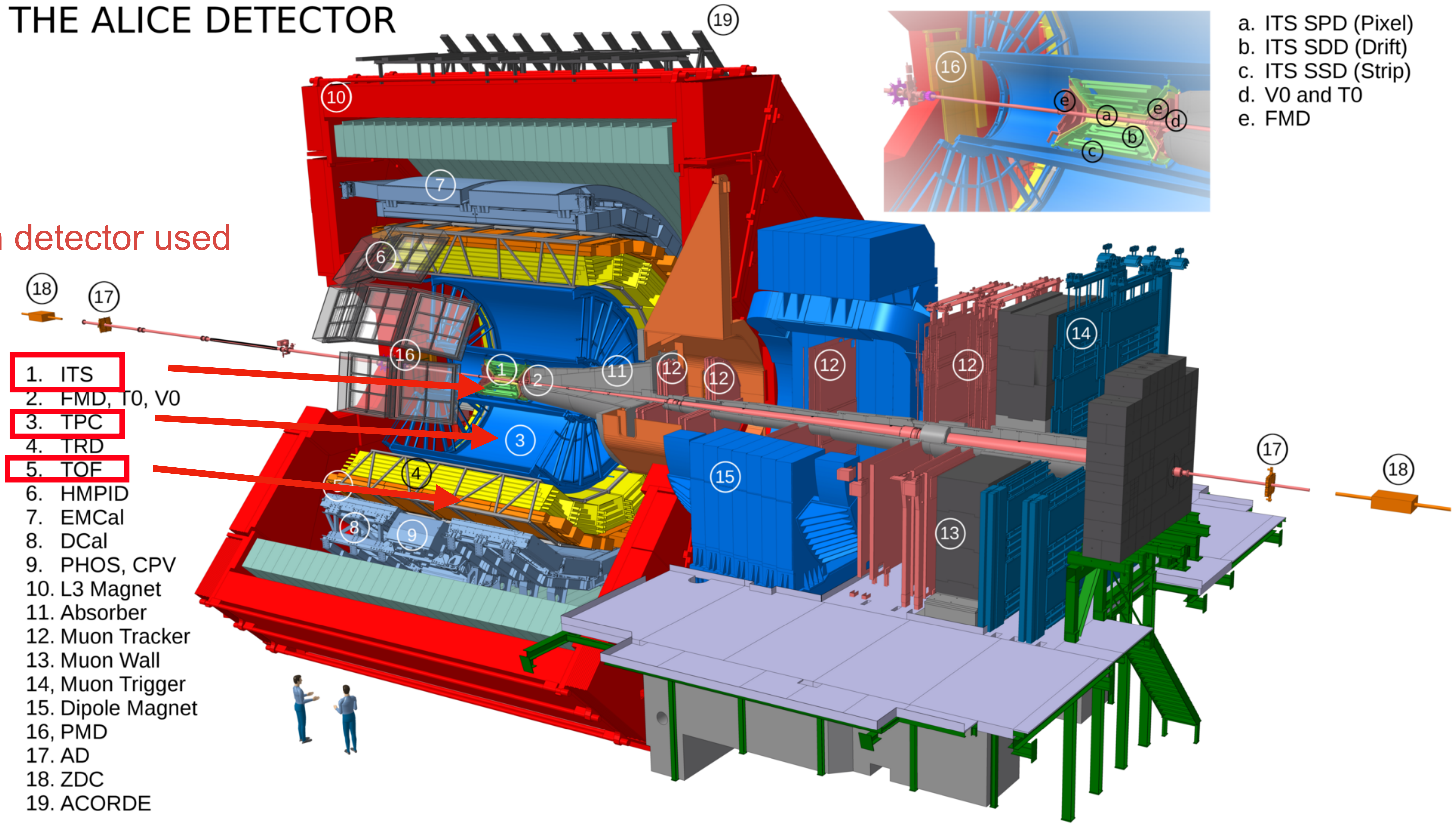
- Extend the nuclear chart to a third dimension (the strangeness one)
- Unique probes for studying the interaction of hyperons with the ordinary matter
- Probing the core of the neutron stars ($\Lambda - N - N$ interaction might solve the hyperon puzzle)

Introduction to Hypernuclei

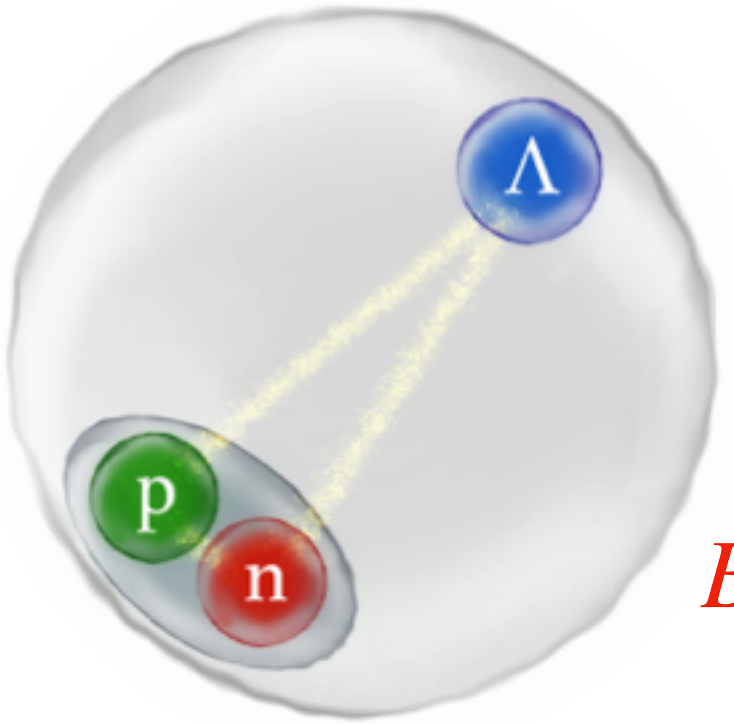
How to measure hypernuclei?

- Tracking
- Vertexing
- Particle Identification(PID)
- Decay topology cuts
- Invariant mass spectrum
- Yields, pt spectrum, etc

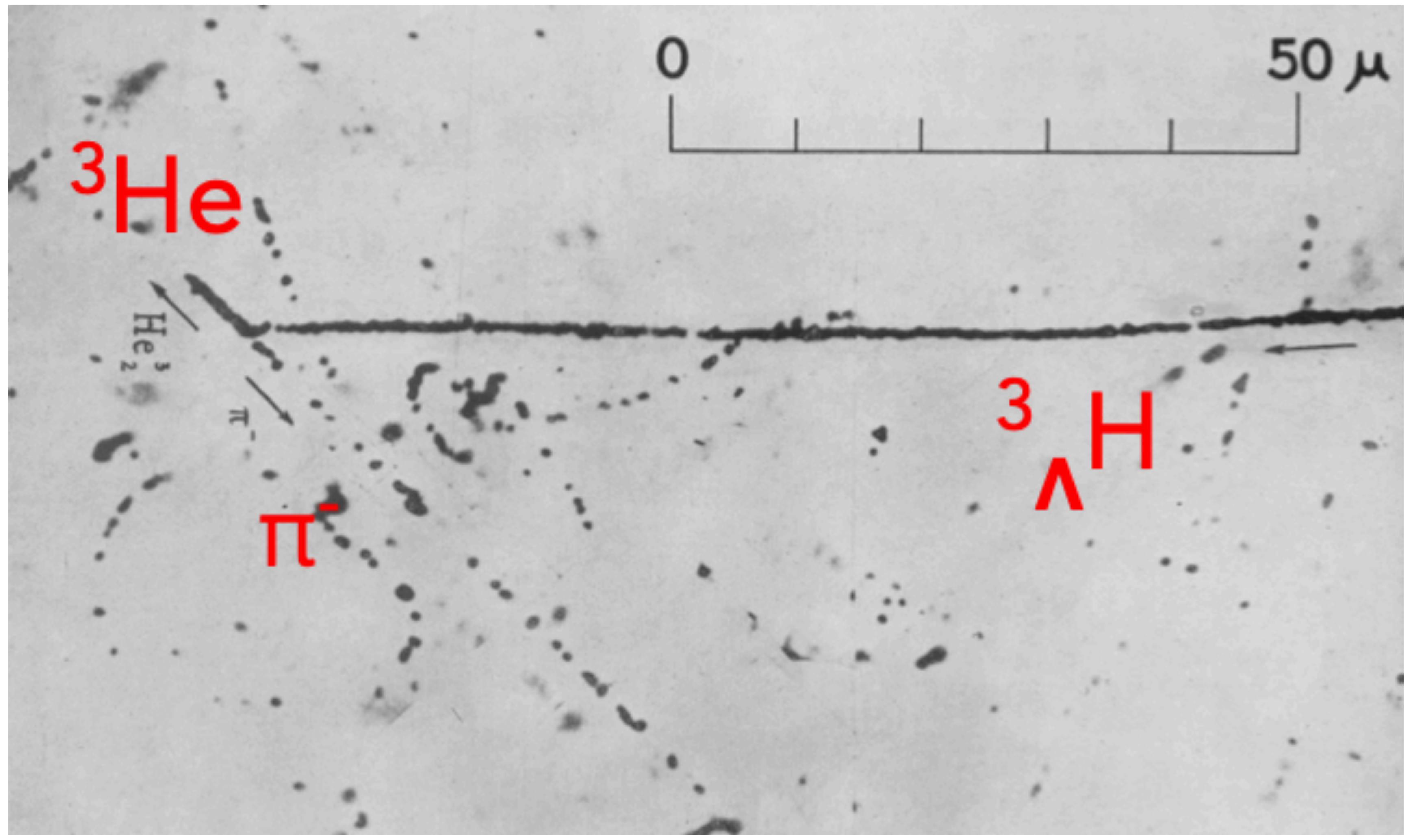
Main detector used



(Anti)Hypertriton - the lightest known hypernucleus



$B_\Lambda \approx 130 keV$, $r_{d\Lambda} \approx$ 10 fm



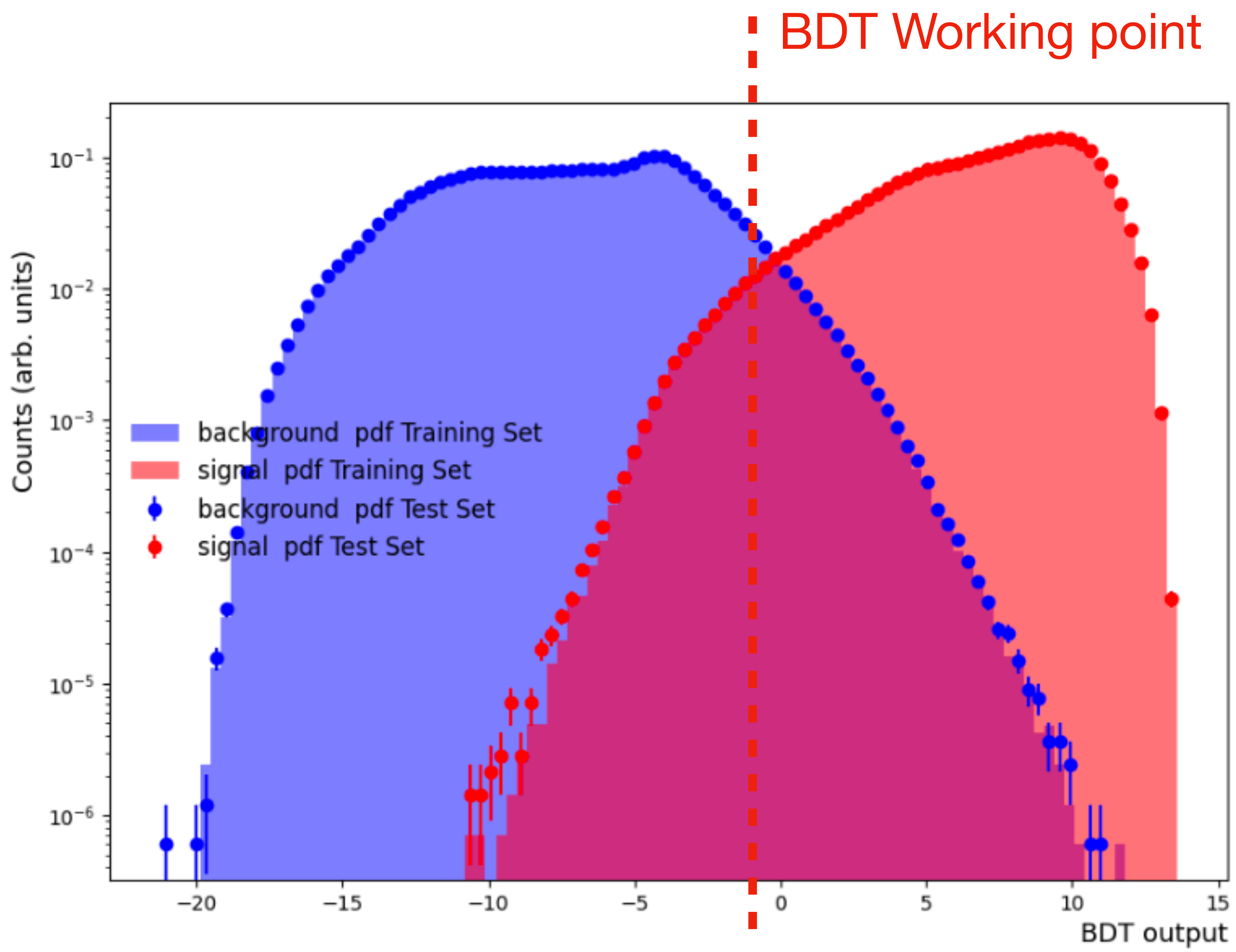
Bonetti et al., Il Nuovo Cimento 11.2, (1954)

- Bound state of a neutron a proton and a Λ
- Discovered in the 1950s by M.Danysz and J.Pniewski in cosmic ray
- Mass is around 2.991 GeV/c²
- Spin:1/2 Lifetime:~ 250ps
- Mesonic charged decay channels:

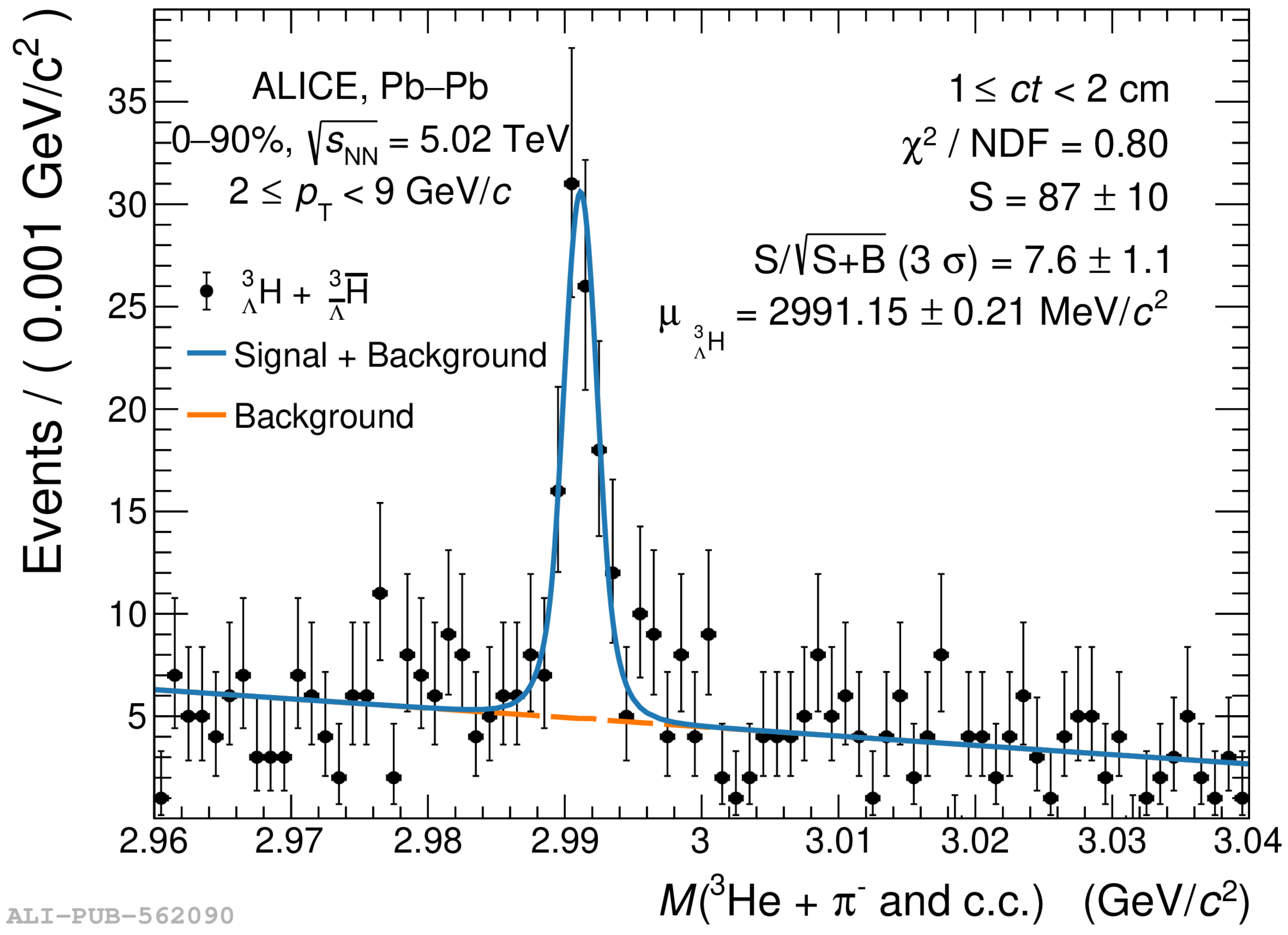
$$^3_\Lambda H \rightarrow ^3 He + \pi^- (B.R \approx 0.25)$$
$$^3_\Lambda H \rightarrow ^2 H + p + \pi^- (B.R \approx 0.40)$$

2 Hypertriton Measurement

(Anti)Hypertriton - the lightest known hypernucleus



Boost decision tree(BDT)

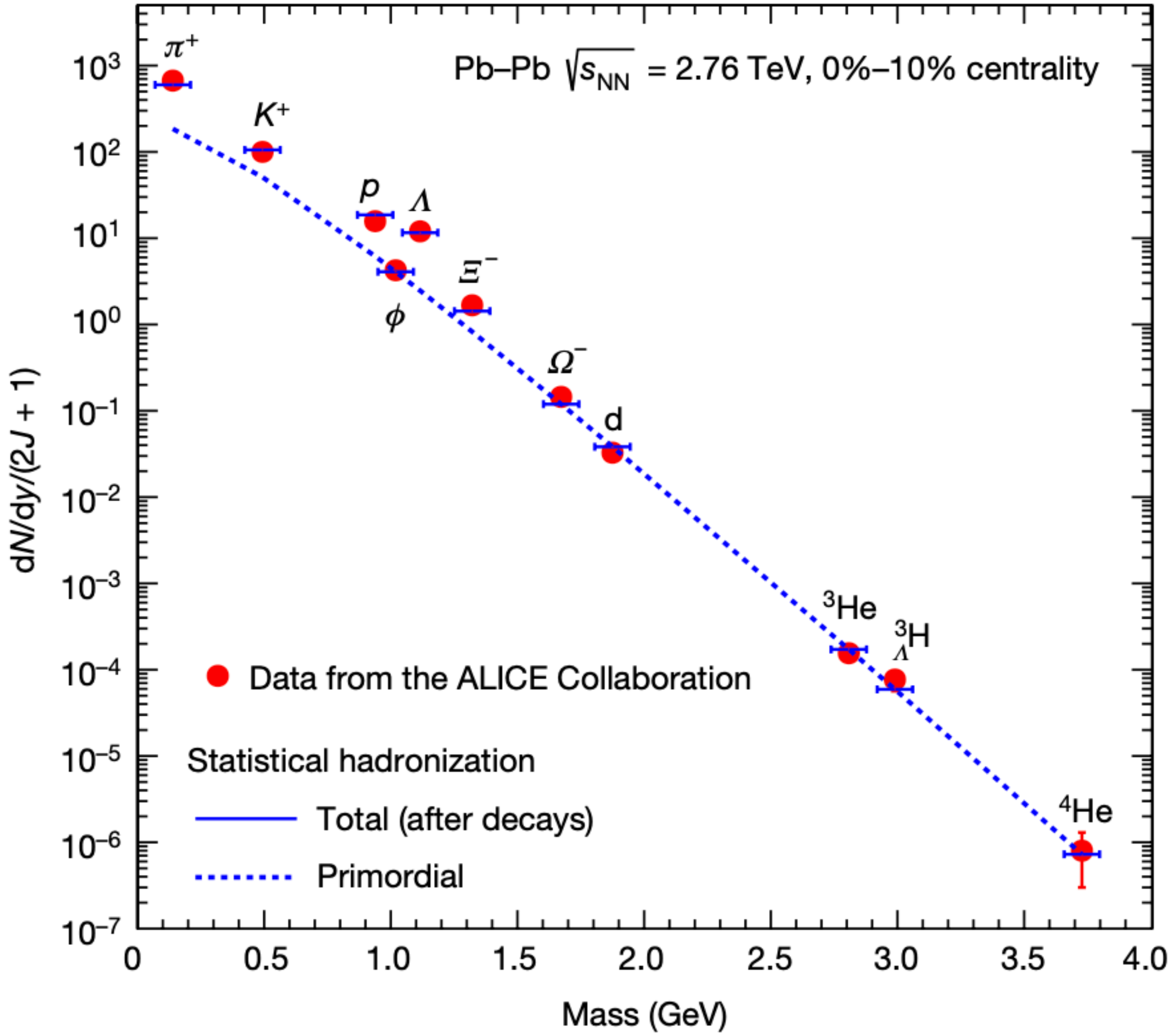


Bonetti et al., Il Nuovo Cimento 11.2, (1954)

2 Hypertriton Measurement

(Anti)Hypertriton as a test stone for (anti)nuclei production mechanism

- Statistical hadronization Model(SHM)
  - Hadrons emitted directly from the interaction region in statistical and chemical equilibrium at a limiting temperature T_{chem}
  - $dN/dy \propto exp(-m/T_{chem})$



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

2 Hypertriton Measurement

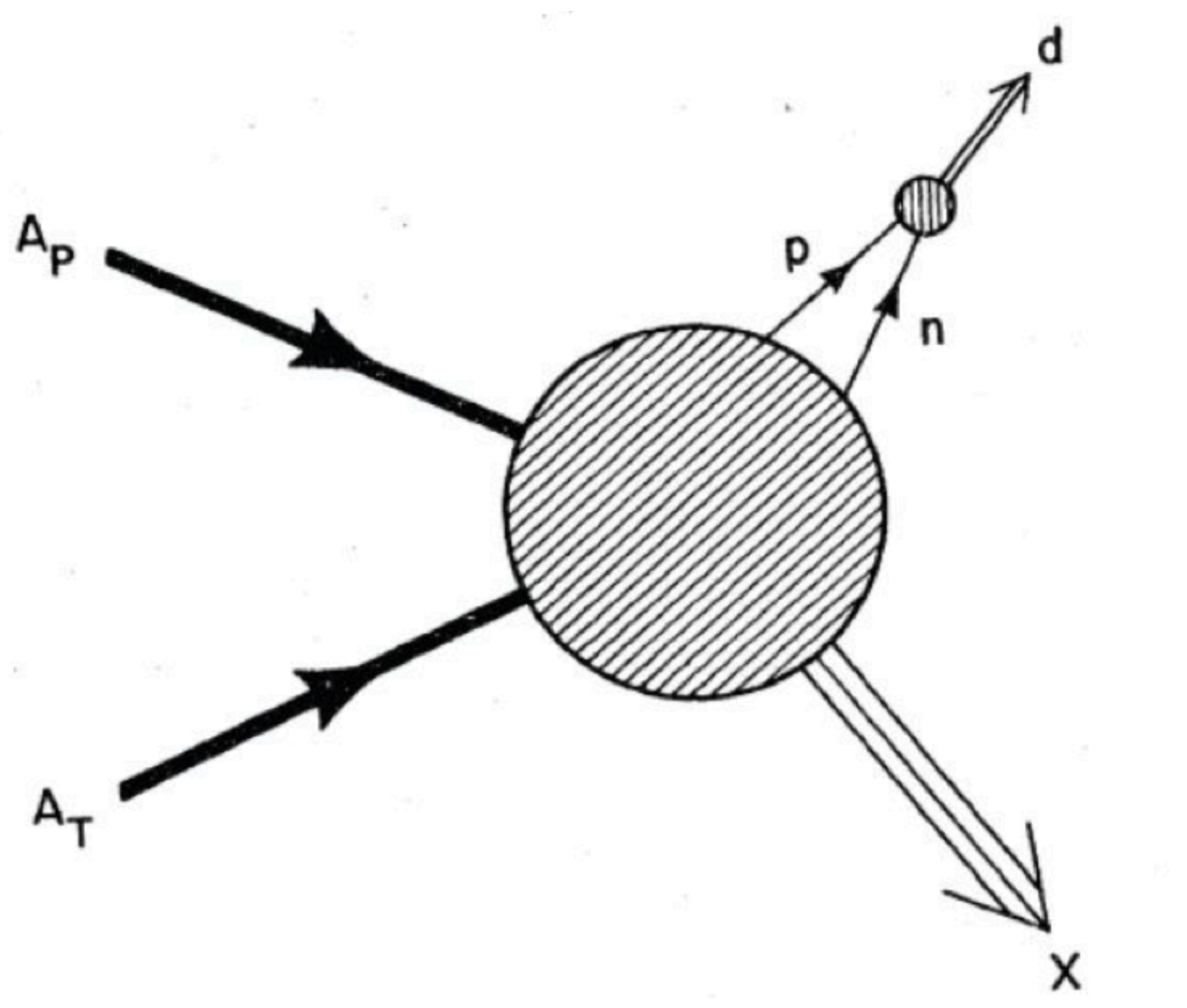
ALICE

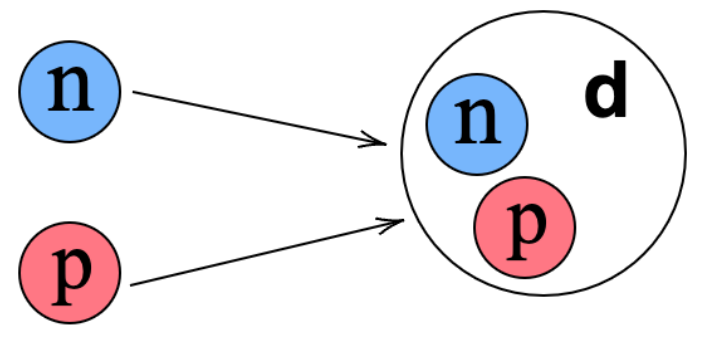
(Anti)Hypertriton as a test stone for (anti)nuclei production mechanism

- Coalescence Model
  - Baryons close enough in phase space can form a nucleus
  - $N_A = Tr(\hat{\rho}_s \hat{\rho}_A) = g_c \int d\Gamma \rho_s(\{x_i, p_i\}) \times W_A(\{x_i, p_i\})$

Emission source size

Target nucleus Wigner function



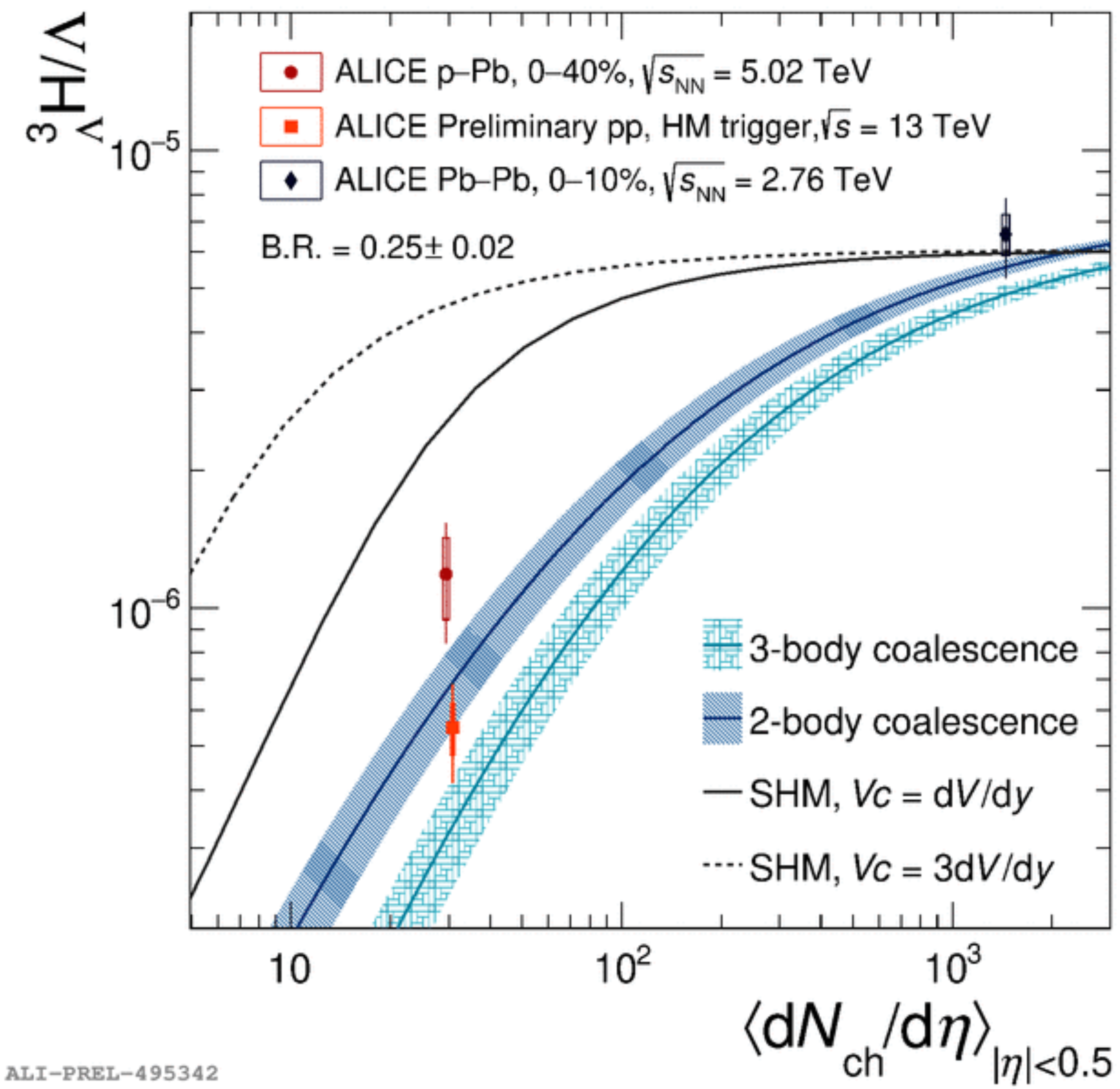


K. J. Sun et al., Phys.Lett.B 792 (2019), 132-137
D. N. Liu et al., arXiv:2404.02701

2 Hypertriton Measurement

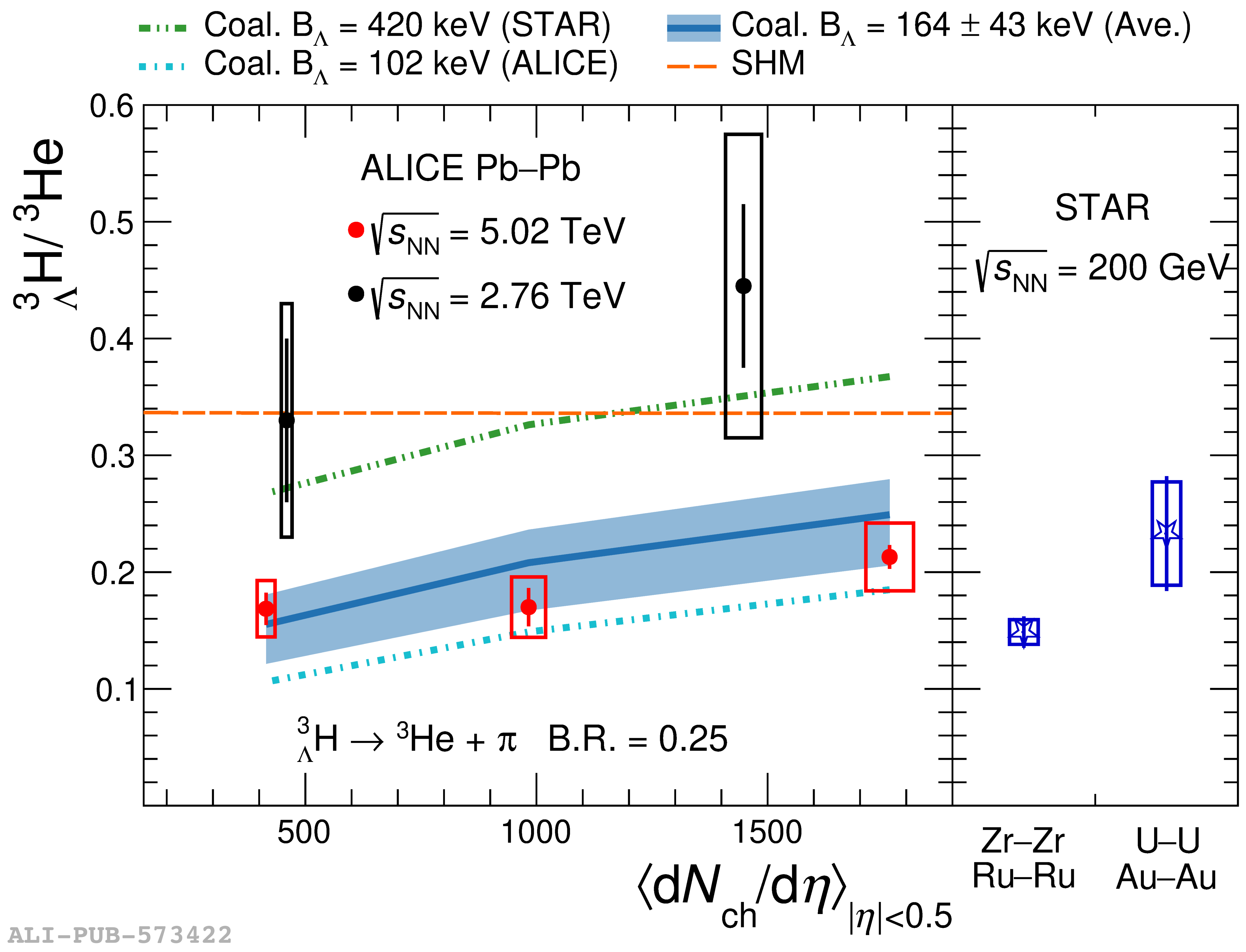
${}^{3}_{\Lambda}H/\Lambda$ ratio in different colliding system

- First measurement of ${}^{3}_{\Lambda}H/\Lambda$ in pp and pPb collisions
- Better agreement with 2-body coalescence model
- Further analysis required to figure out the system size dependence
- Measurements of the production of other hypernuclei is needed



2 Hypertriton Measurement

Multiplicity dependence for ${}^{3}_{\Lambda}H/{}^{3}He$ ratio(PbPb)

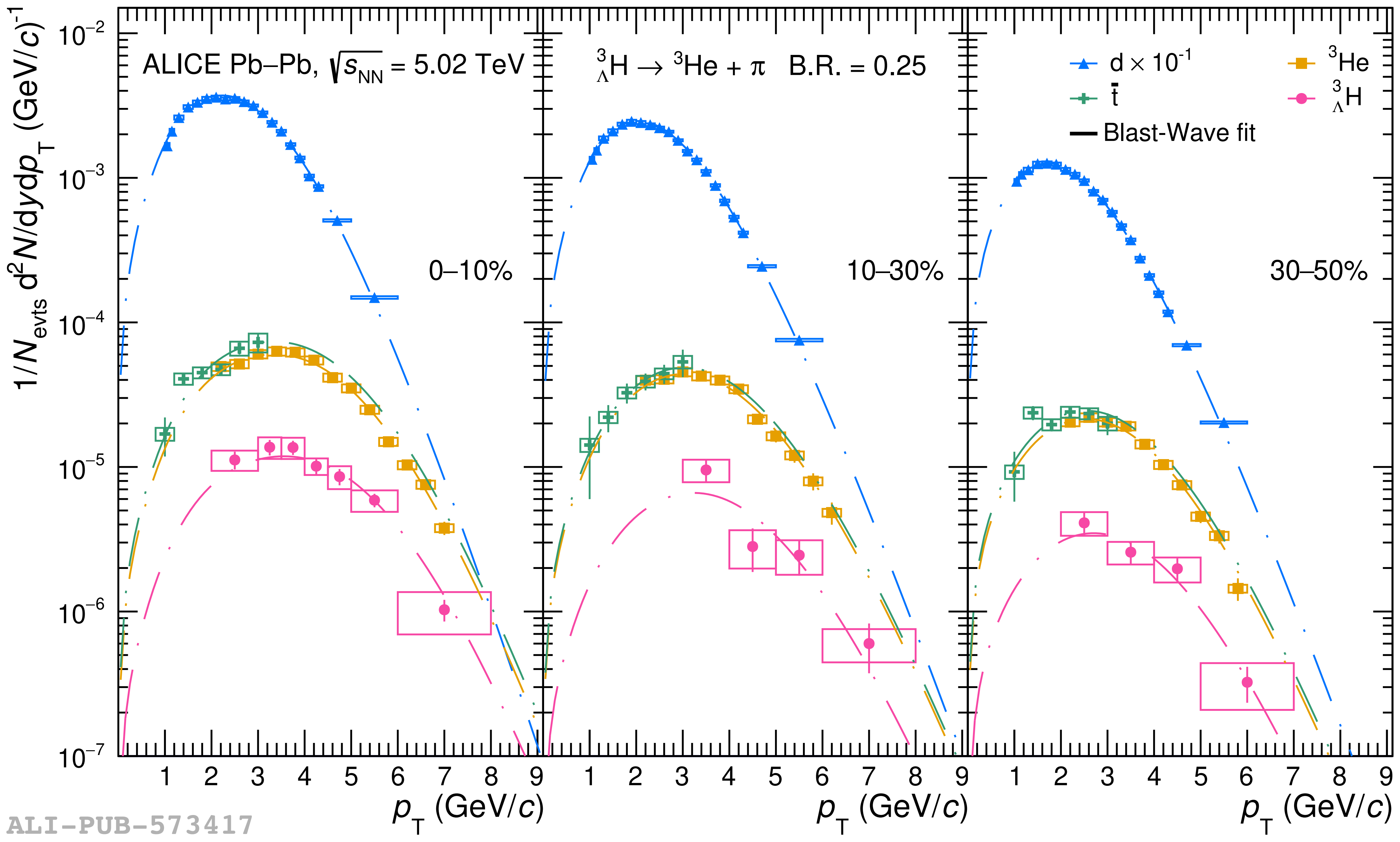


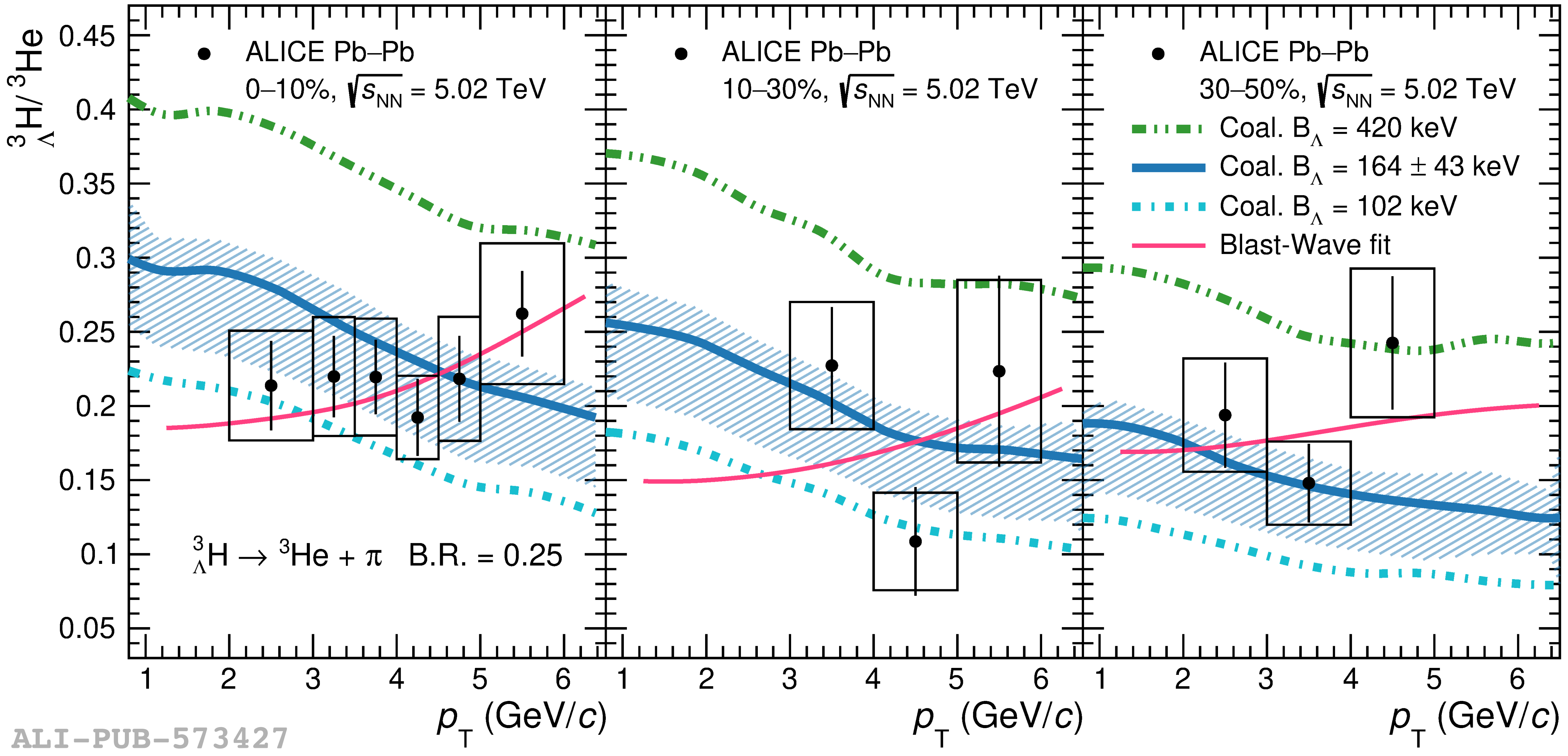
ALICE Collaboration, arXiv:2405.19839

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

2 Hypertriton Measurement

Hypertriton pt spectrum(PbPb)





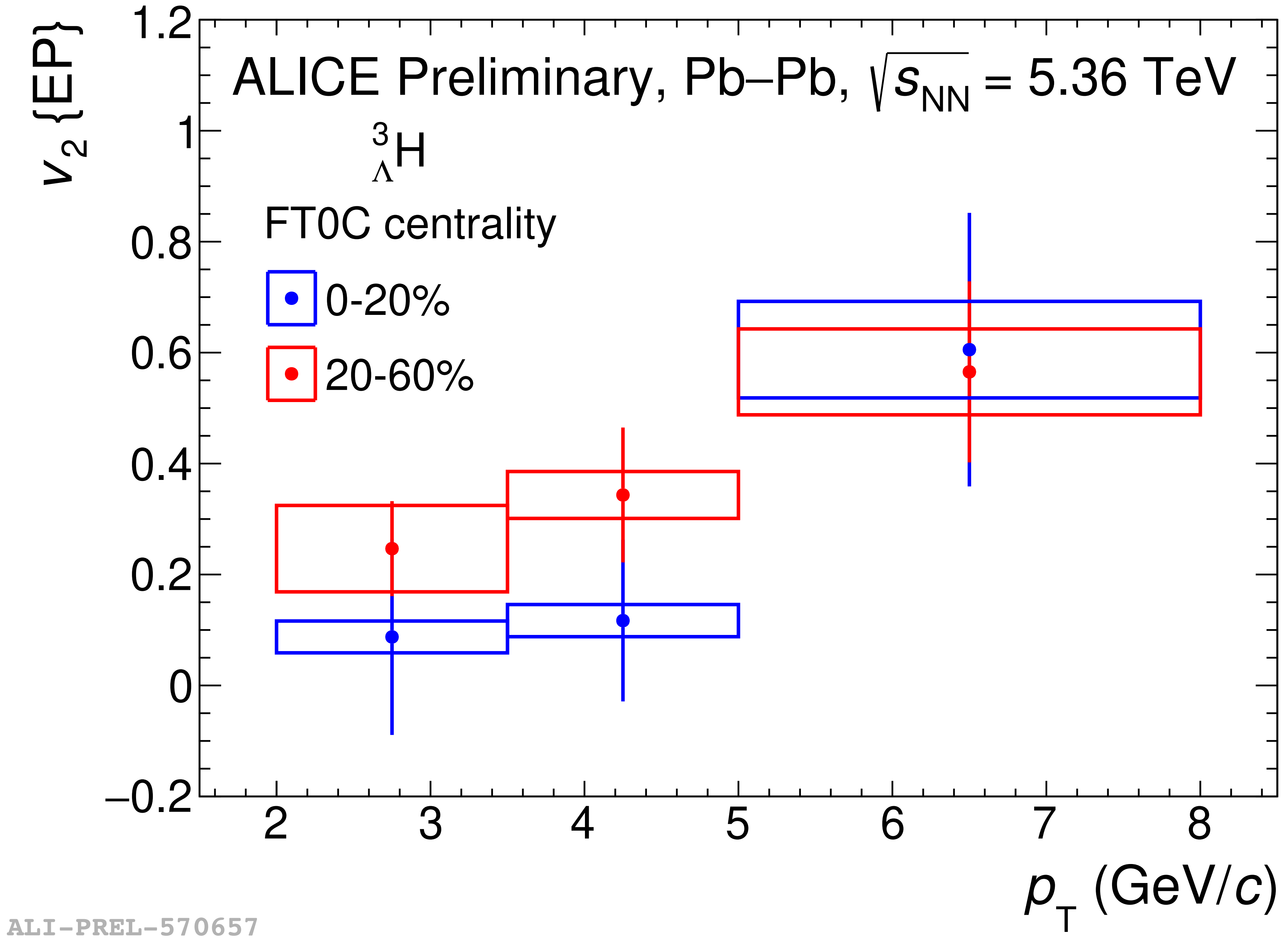
ALICE Collaboration, arXiv:2405.19839

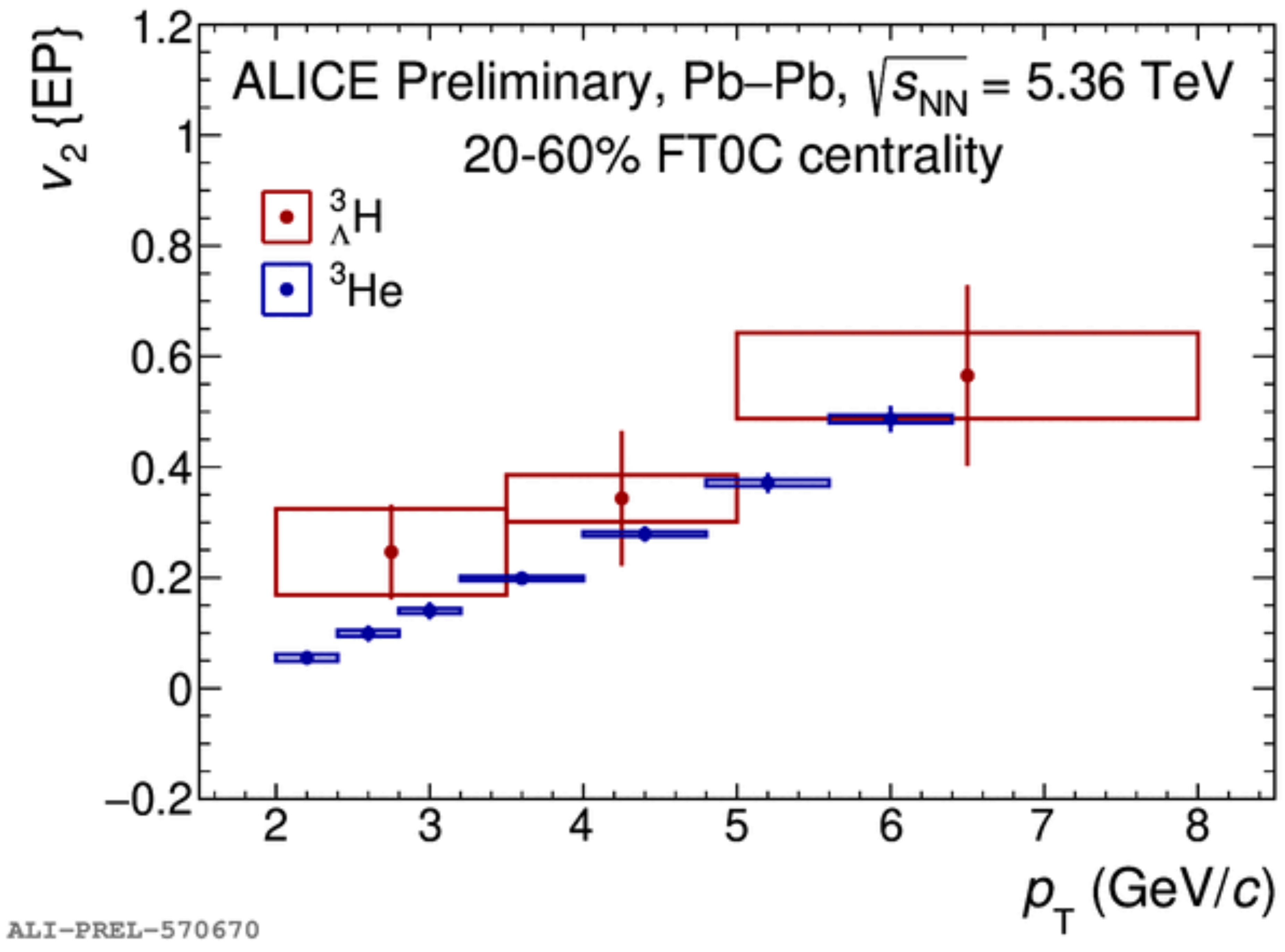
- Hypertriton shares the similar freeze out parameters as ordinary nuclei
- Pt dependence of ${}^{3}_{\Lambda}H/{}^{3}He$ ratio show different trend form Blast Wave extrapolation and coalescence prediction(large uncertainty hard to draw a conclusion)

2 Hypertriton Measurement

Hypertriton flow

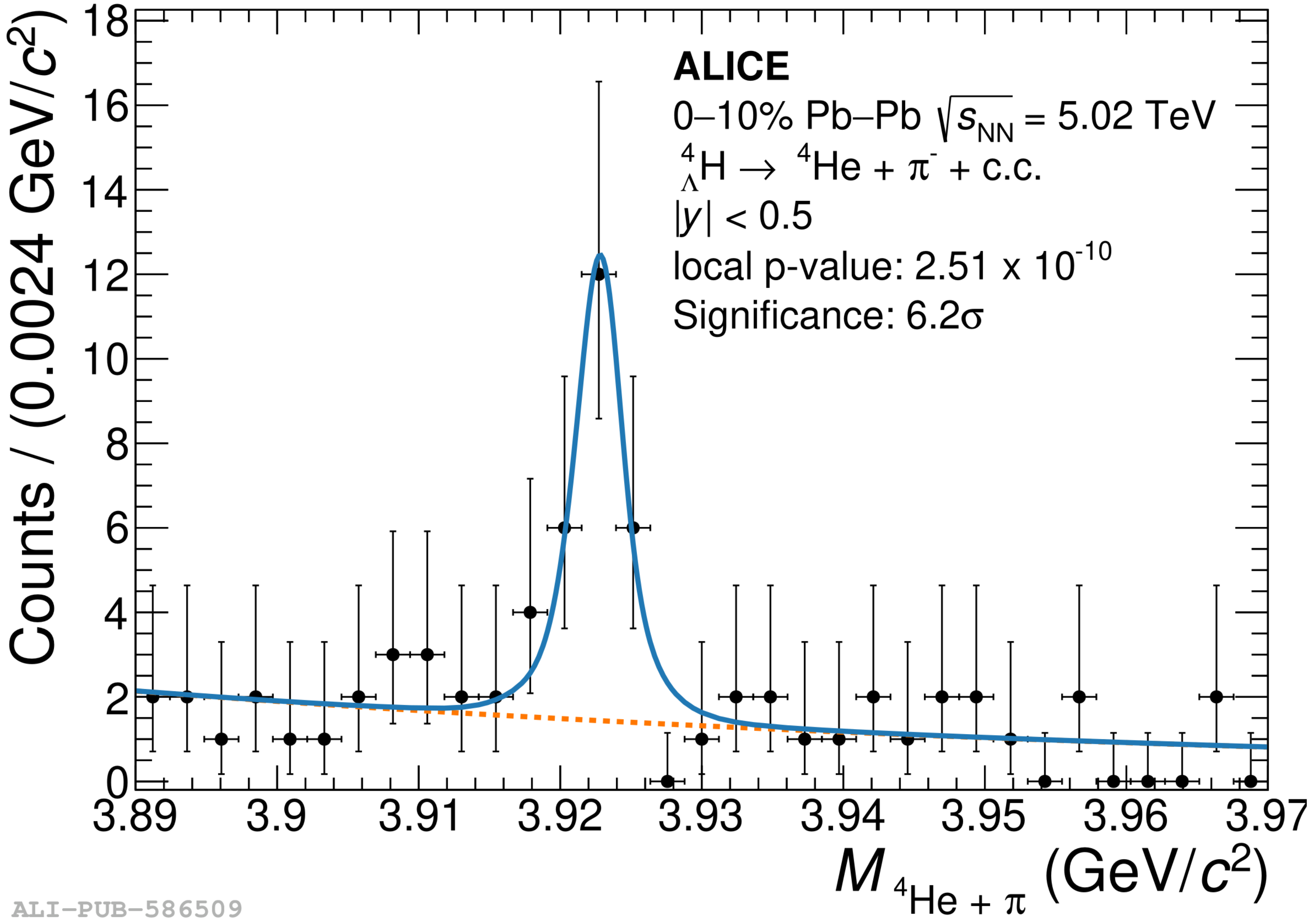
- First measurement of elliptic flow of ${}^{3}_{\Lambda}\mathrm{H}$ in ALICE
- v_2 increases with both centrality and p_T

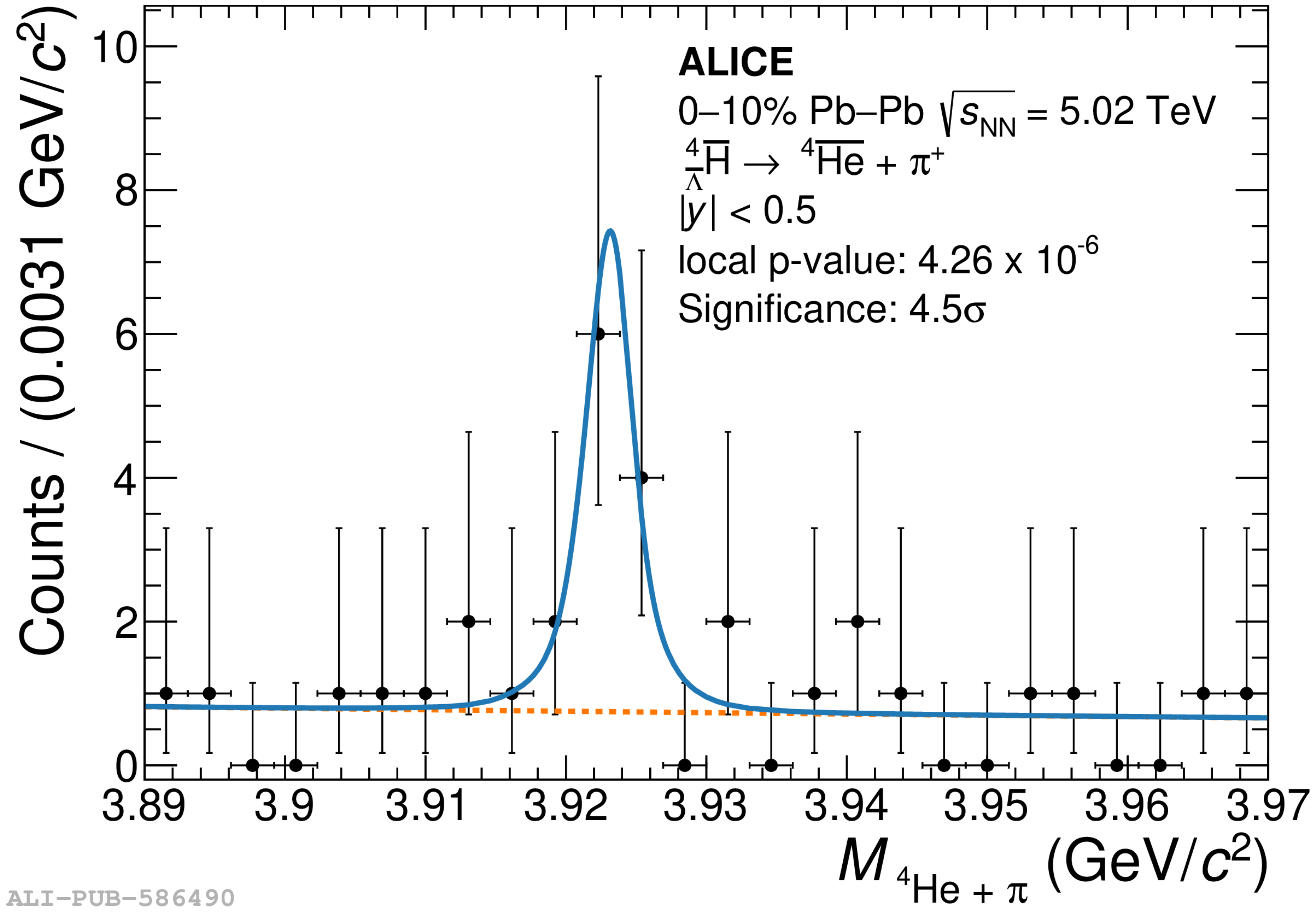




A=4 hypernuclei

- First signal of ${}^{4}_{\Lambda}H$ and ${}^{4}_{\bar{\Lambda}}\bar{H}$ in ALICE



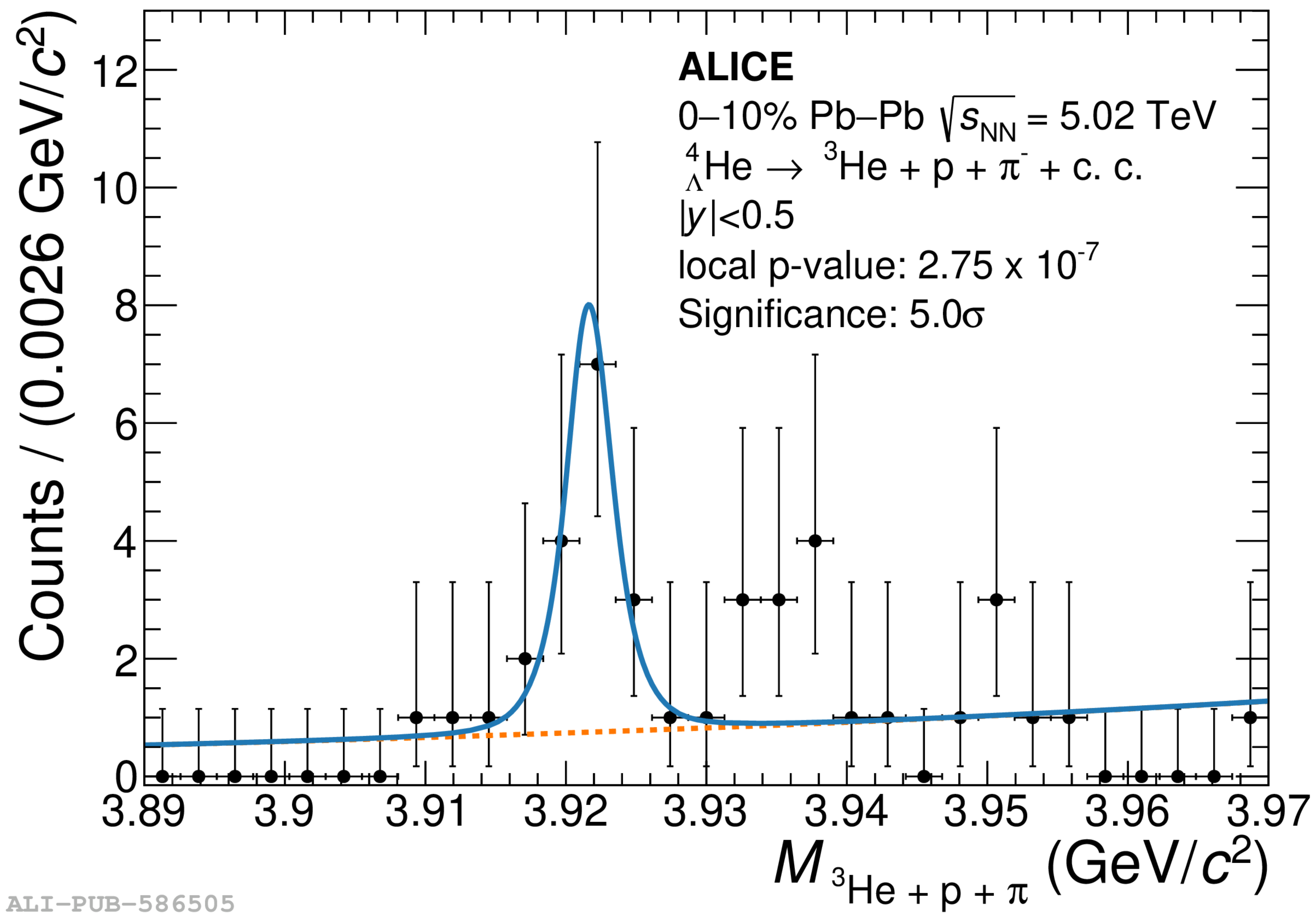


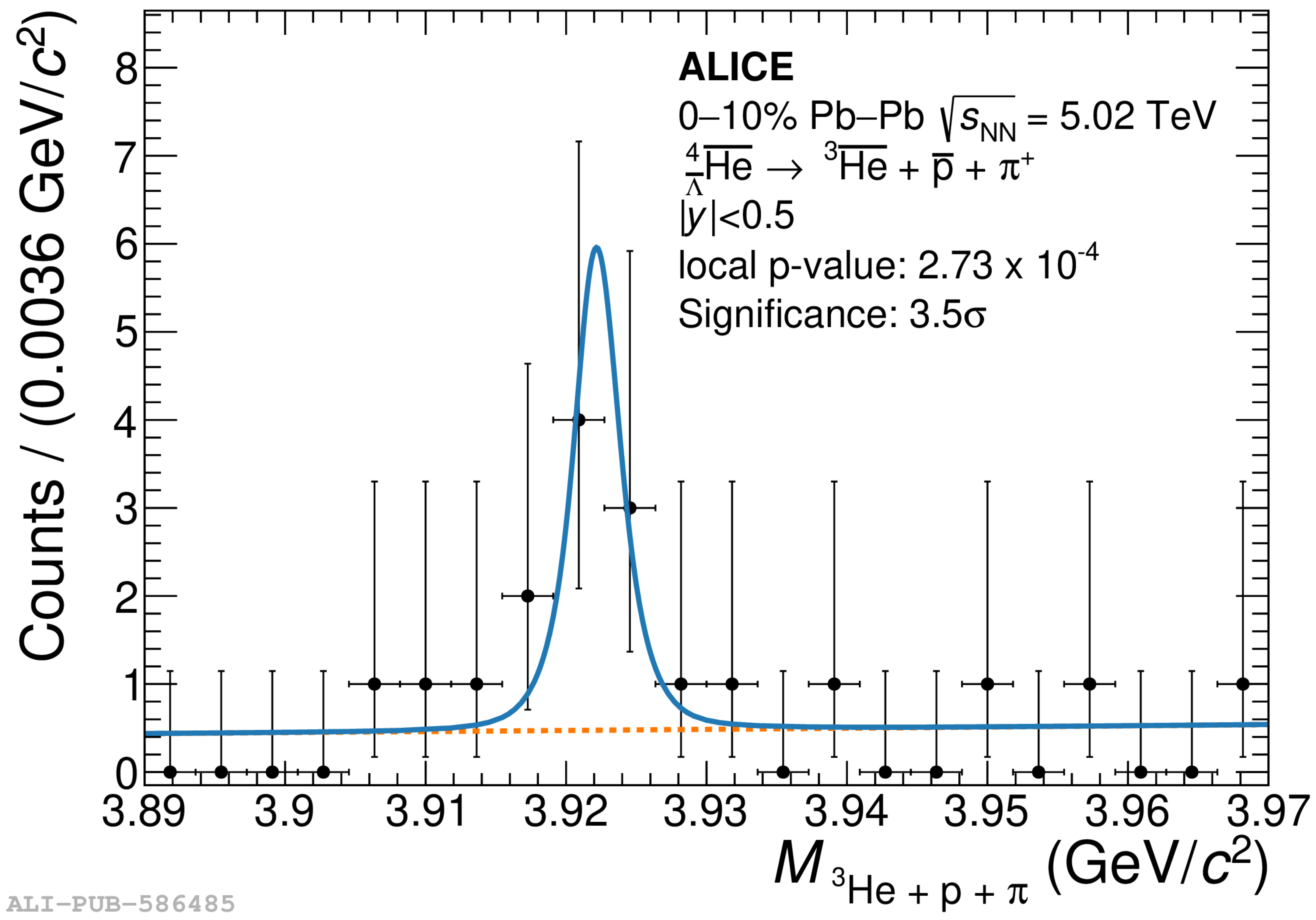
ALICE Collaboration, arXiv:2410.17769

Beyond Hypertriton

A=4 hypernuclei

- First signal of ${}^{4}_{\Lambda}He$ and ${}^{4}_{\bar{\Lambda}}\bar{He}$ in ALICE

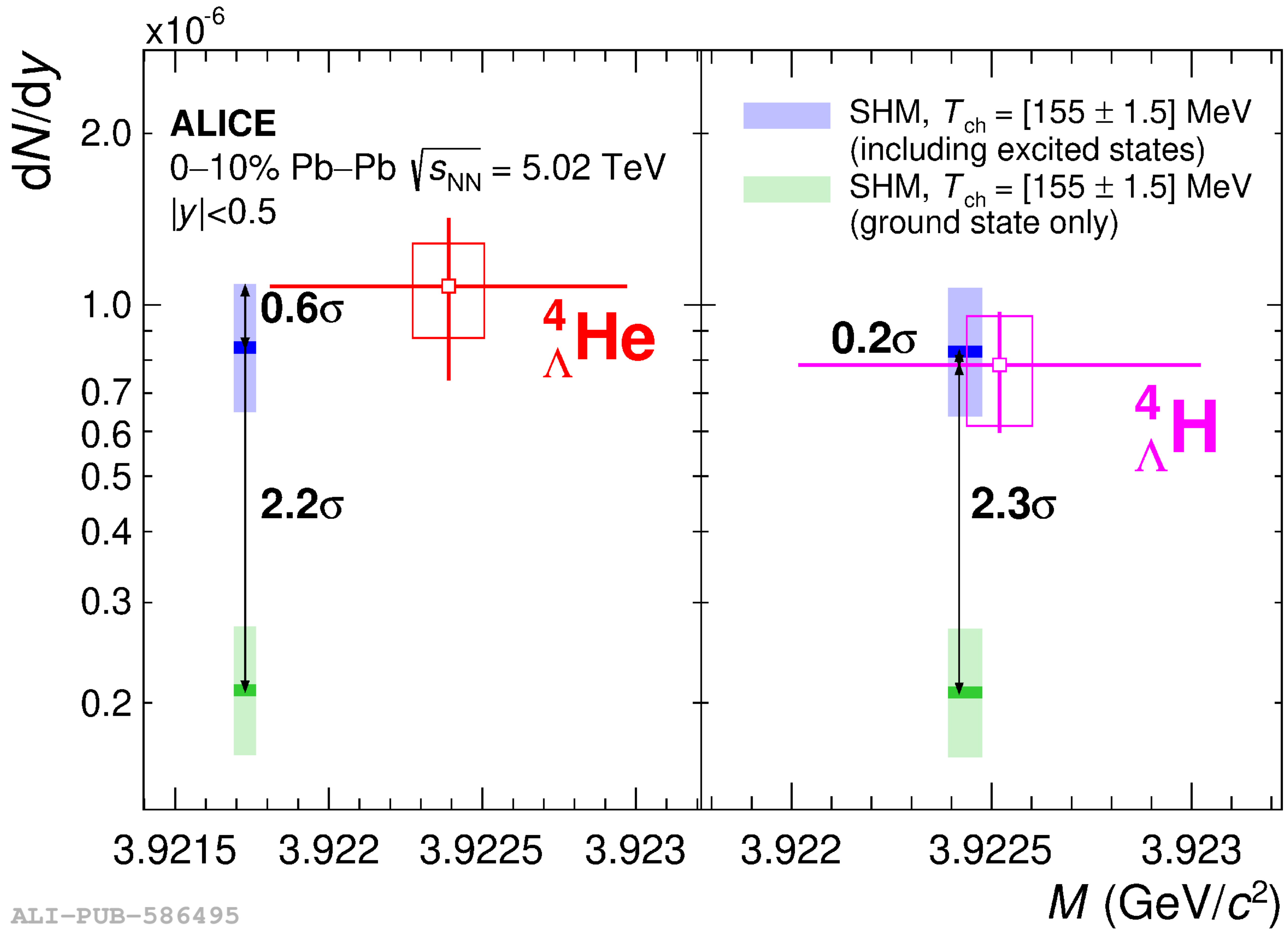




ALICE Collaboration, arXiv:2410.17769

Production of ${}^{4}_{\Lambda}H$ and ${}^{4}_{\Lambda}He$

- Mass are compatible with the world-average values
- Yield value agree with the excited states SHM



ALICE Collaboration, arXiv:2410.17769

3 Beyond Hypertriton

Other hypernuclei and exotica bound state

$$n\Lambda \rightarrow \pi^- + ^2H$$

$$nn\Lambda \rightarrow \pi^- + ^3He$$

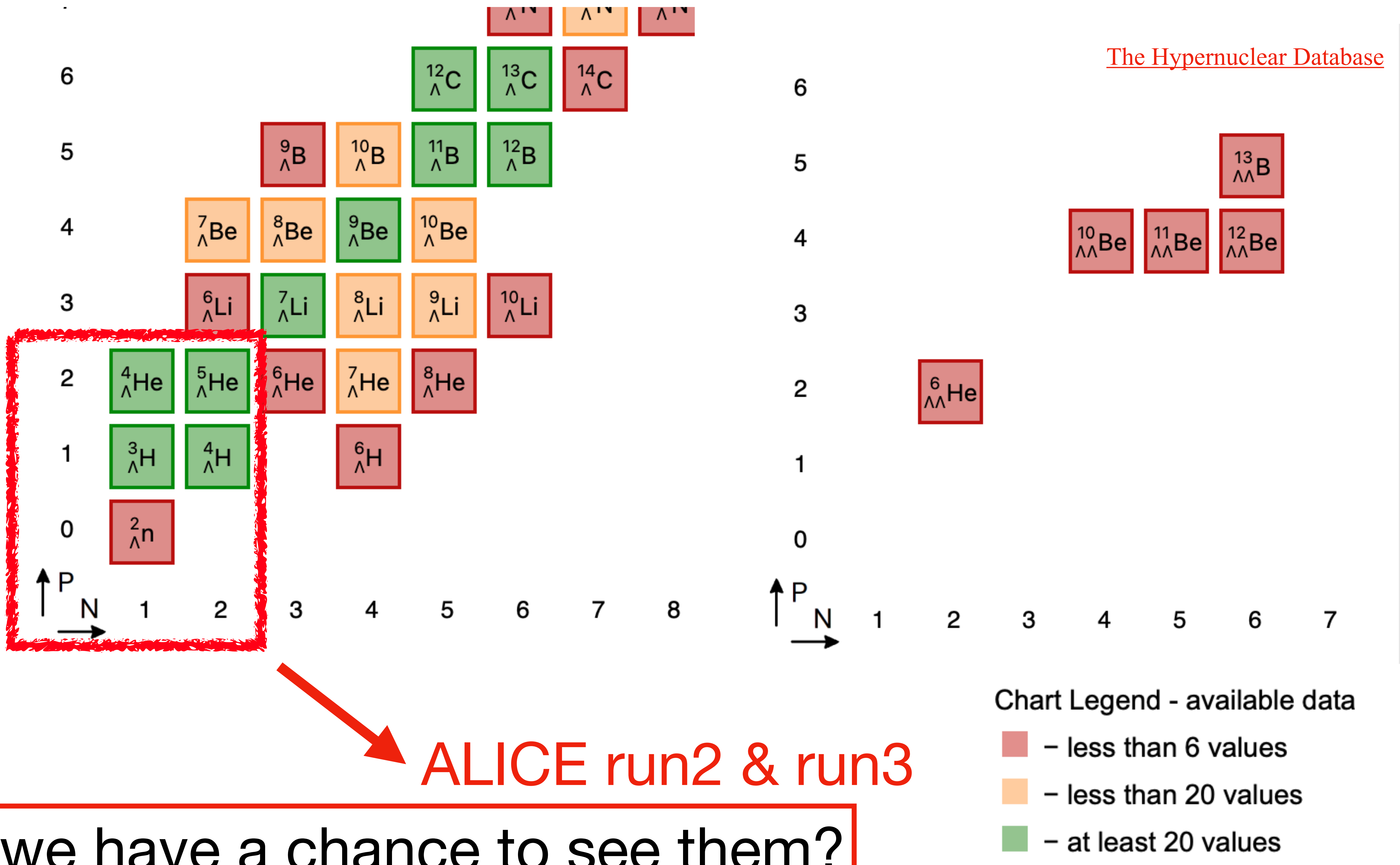
$$pn\Sigma^+ \rightarrow \pi^+ + ^3H$$

$$n\Omega^- \rightarrow \pi^- + K^- + ^2H$$

$$\Omega^-\Omega^- \rightarrow \Omega^- + \Lambda + K^-$$

$$^4_\Sigma He \rightarrow + n + \pi^+ + ^3H$$

……



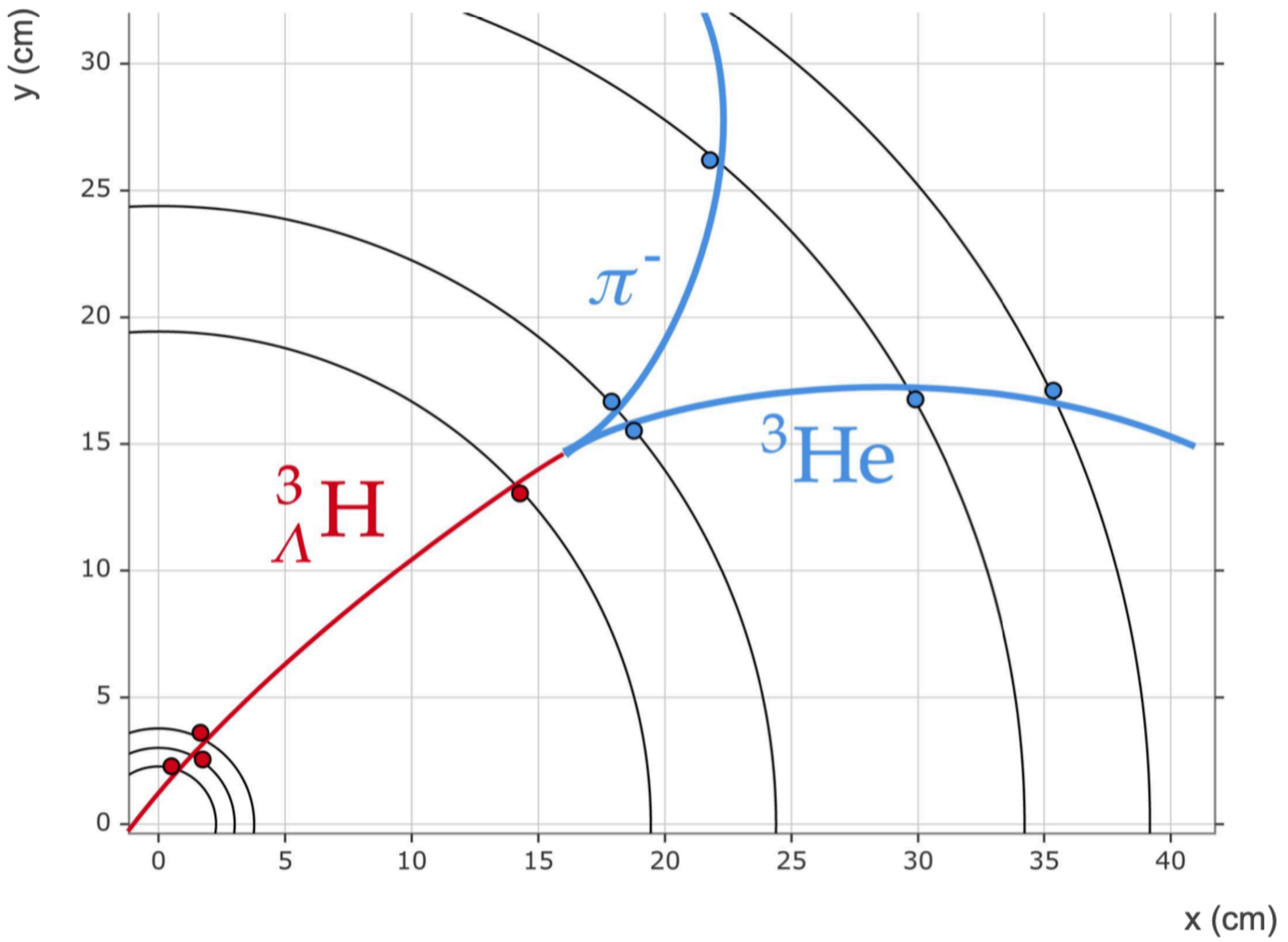
Do we have a chance to see them?

3 Beyond Hypertriton

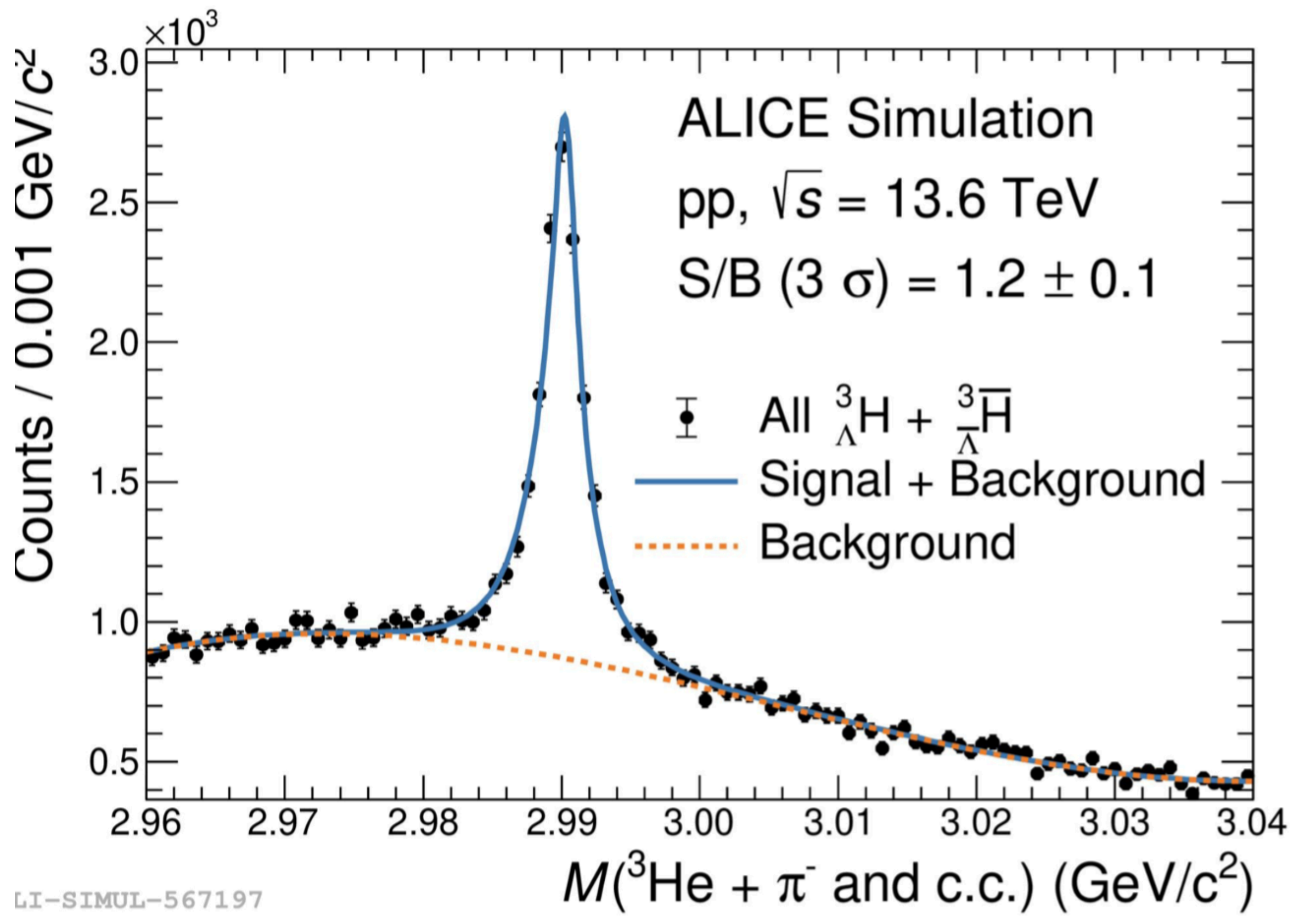
Using strangeness tracking algorithm in run3

1. Matches the ${}^{3}_{\Lambda}H$ track with the decay daughter tracks

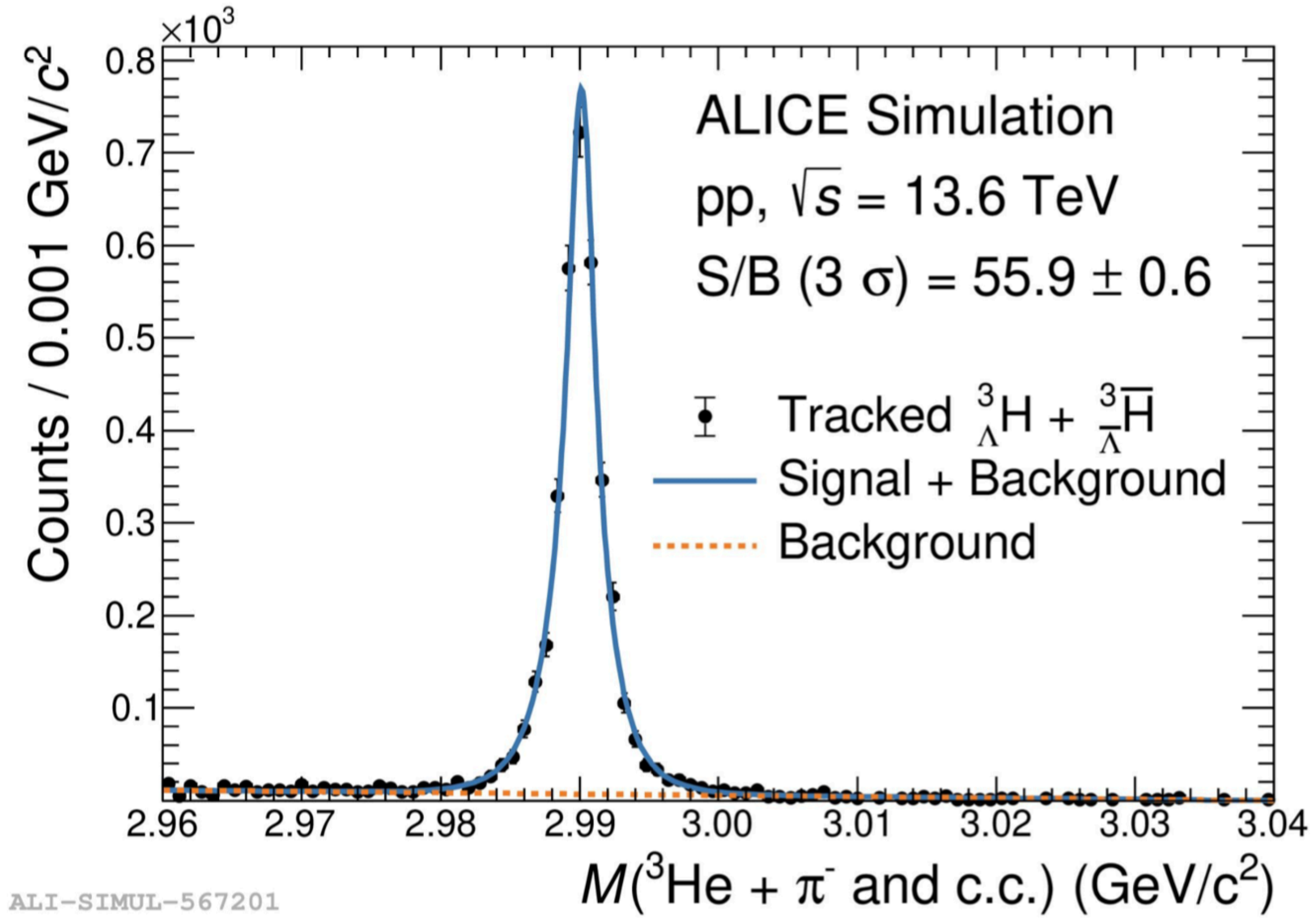
2. Final kinematic fit of the decay topology (WIP)



Before



After



4 Summary and prospects

ALICE

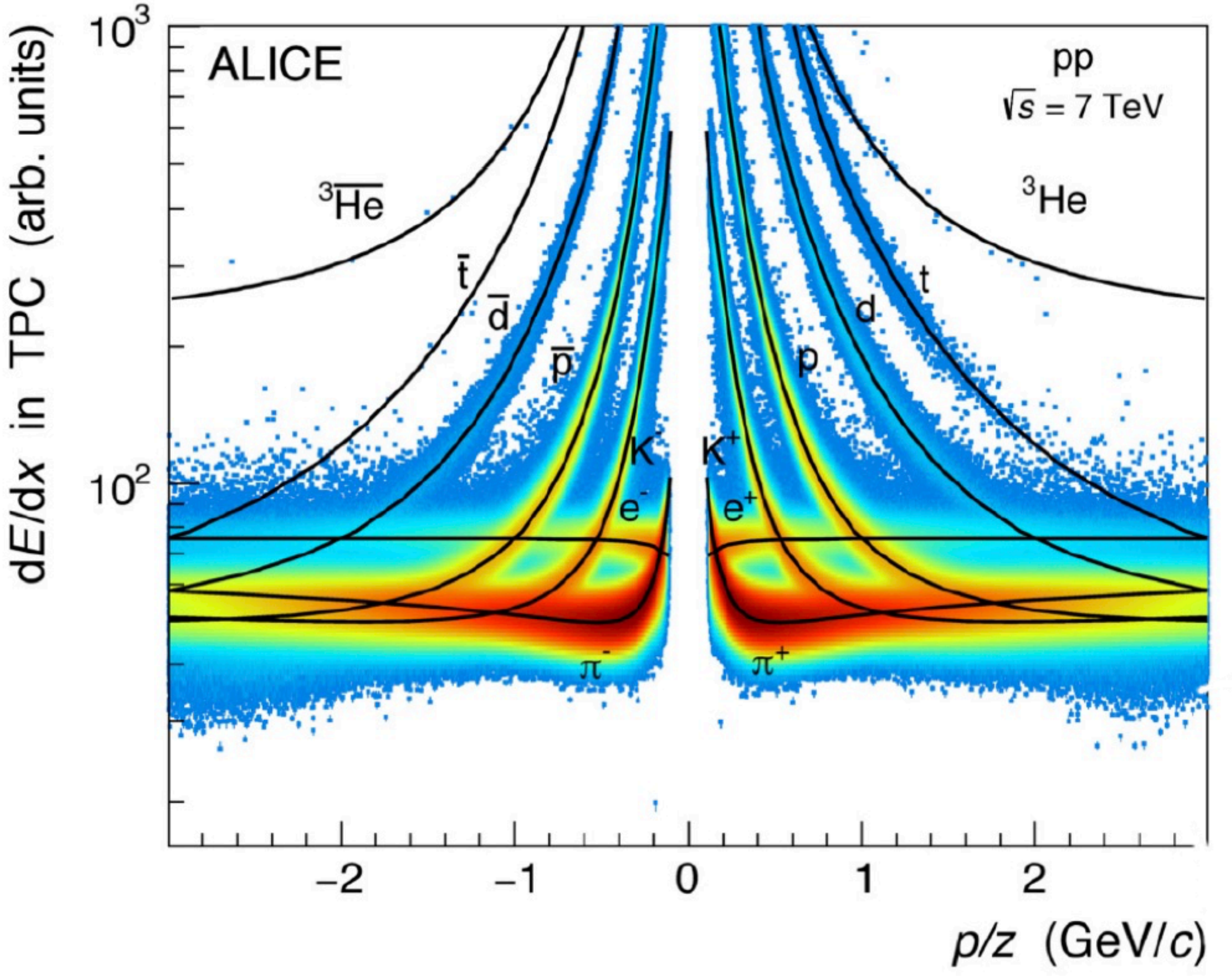
- Hypernuclei is the bound state of nucleons and hyperons
  - Measuring the hypernuclei is of grate importance for studying both the N-Y and Y-Y interaction might help solve the hyperon puzzle in neutron stars equation state
- Hypertriton is now the most measured hypernuclei in ALICE
  - ALICE measured serval properties of hypertriton in p-p p-Pb Pb-Pb system using run2 and run3 data and it favors the coalescence mechanism for nucleosynthesis
- Observation of A = 4 hypernuclei with ALICE Run 2 data
  - Yield value for both ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{He}$ agree with the excited states SHM
- Run3 and future prospects
  - Hypertriton reconstruction through the three body decay channel
  - Hypertriton properties measurement with the run3 PbPb data
  - Hypertriton flow and polarization
  - More efforts for non-Λ hypernuclei and exotica using strangeness tracking

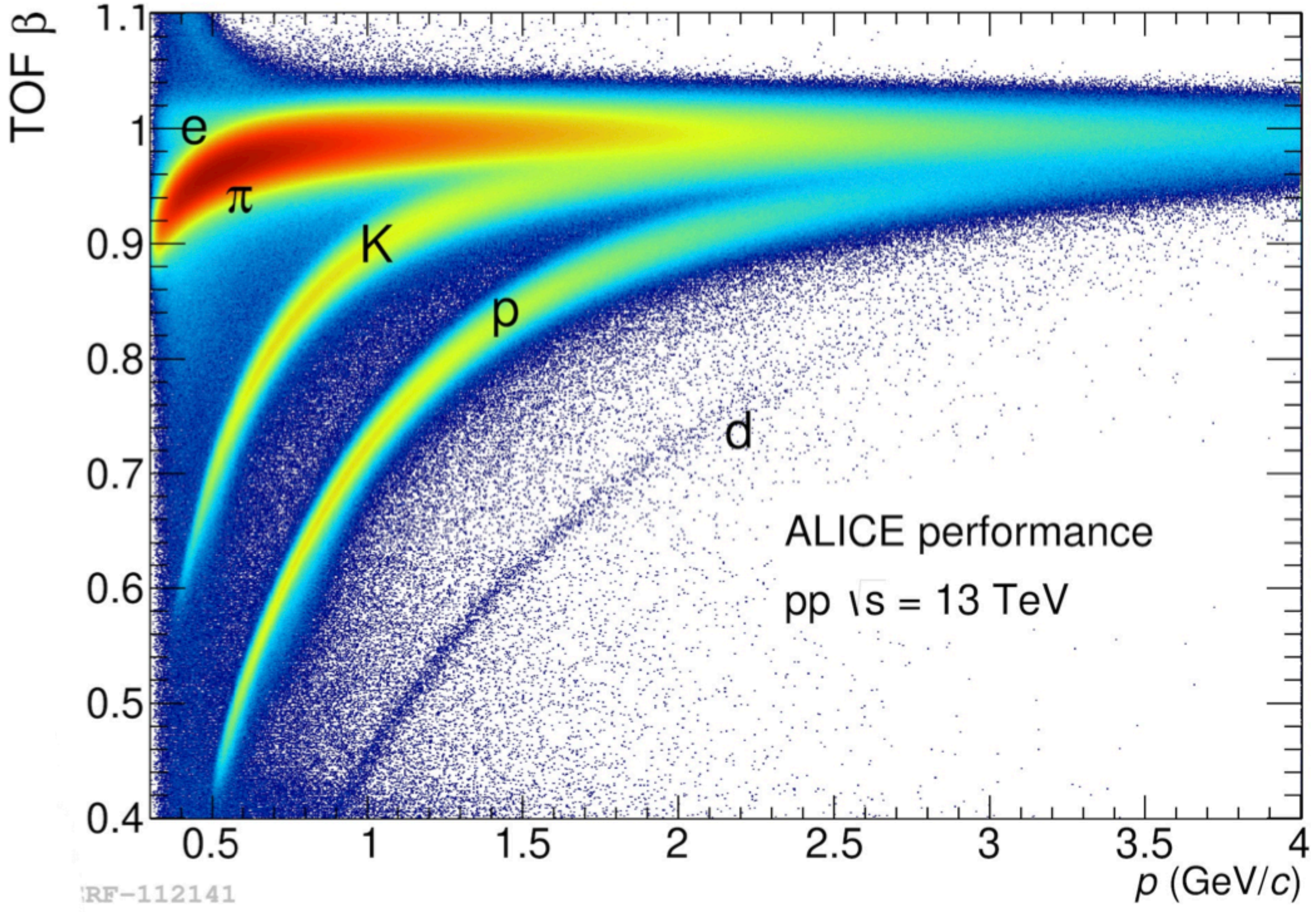
Thanks for your attention

Back Up

5 Back Up Slides

PID figures (TPC & TOF)





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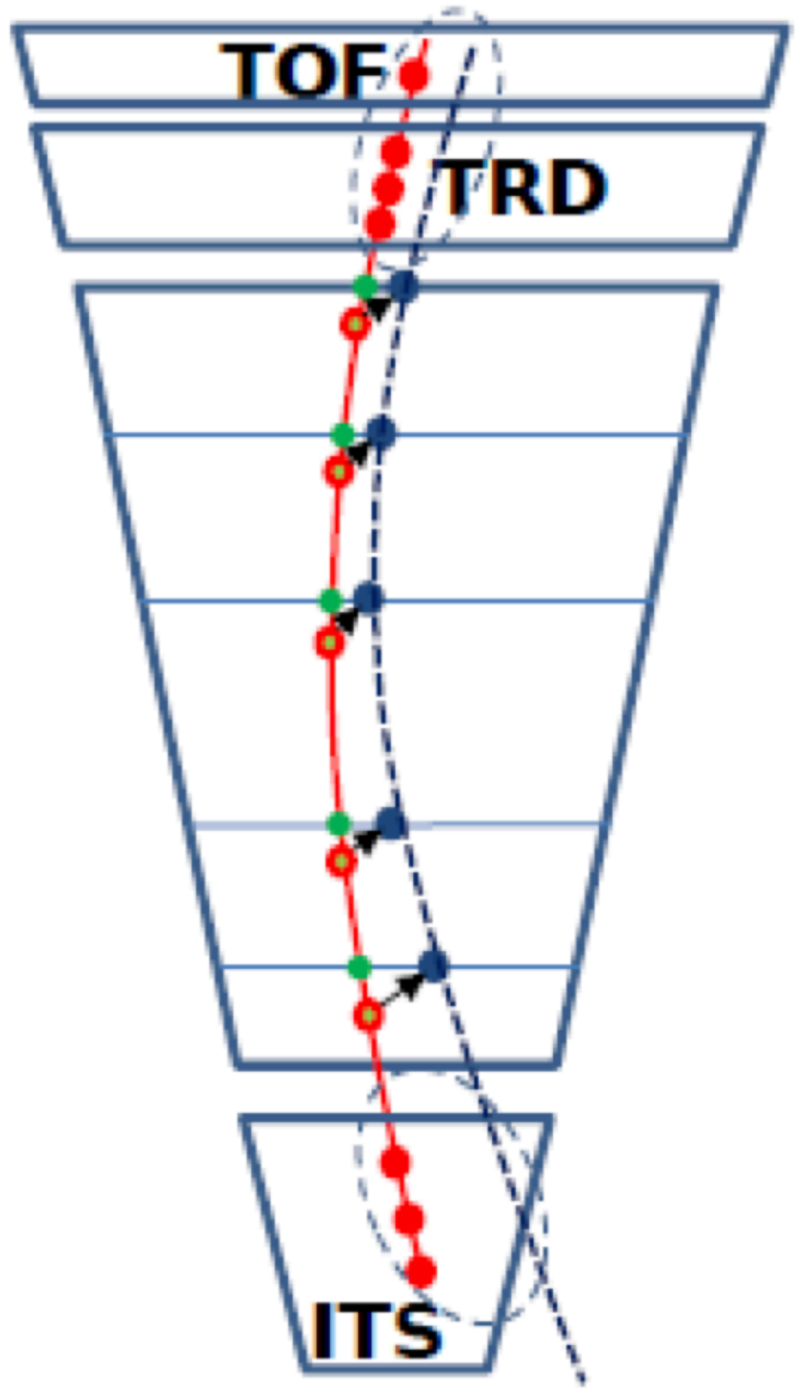
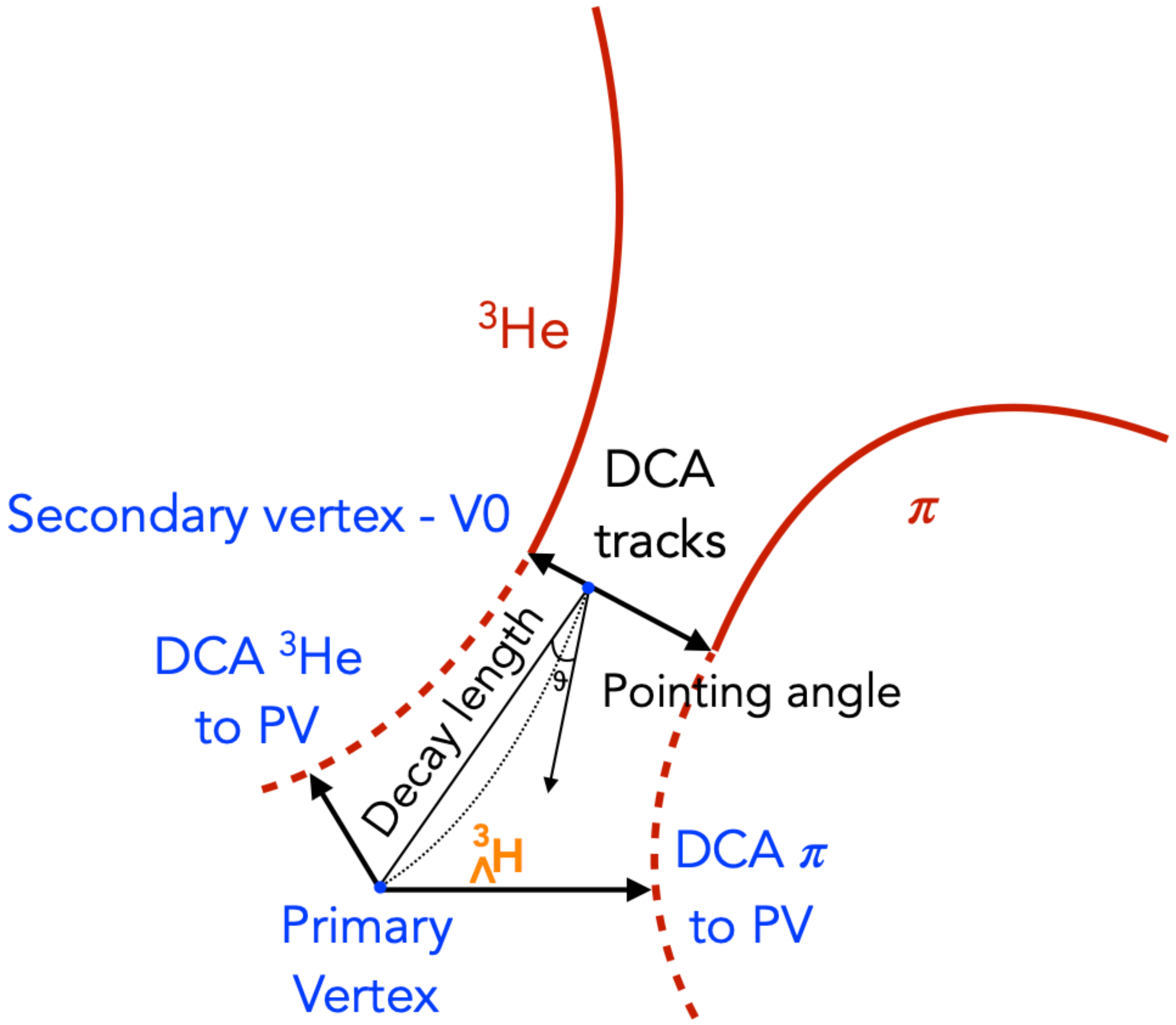
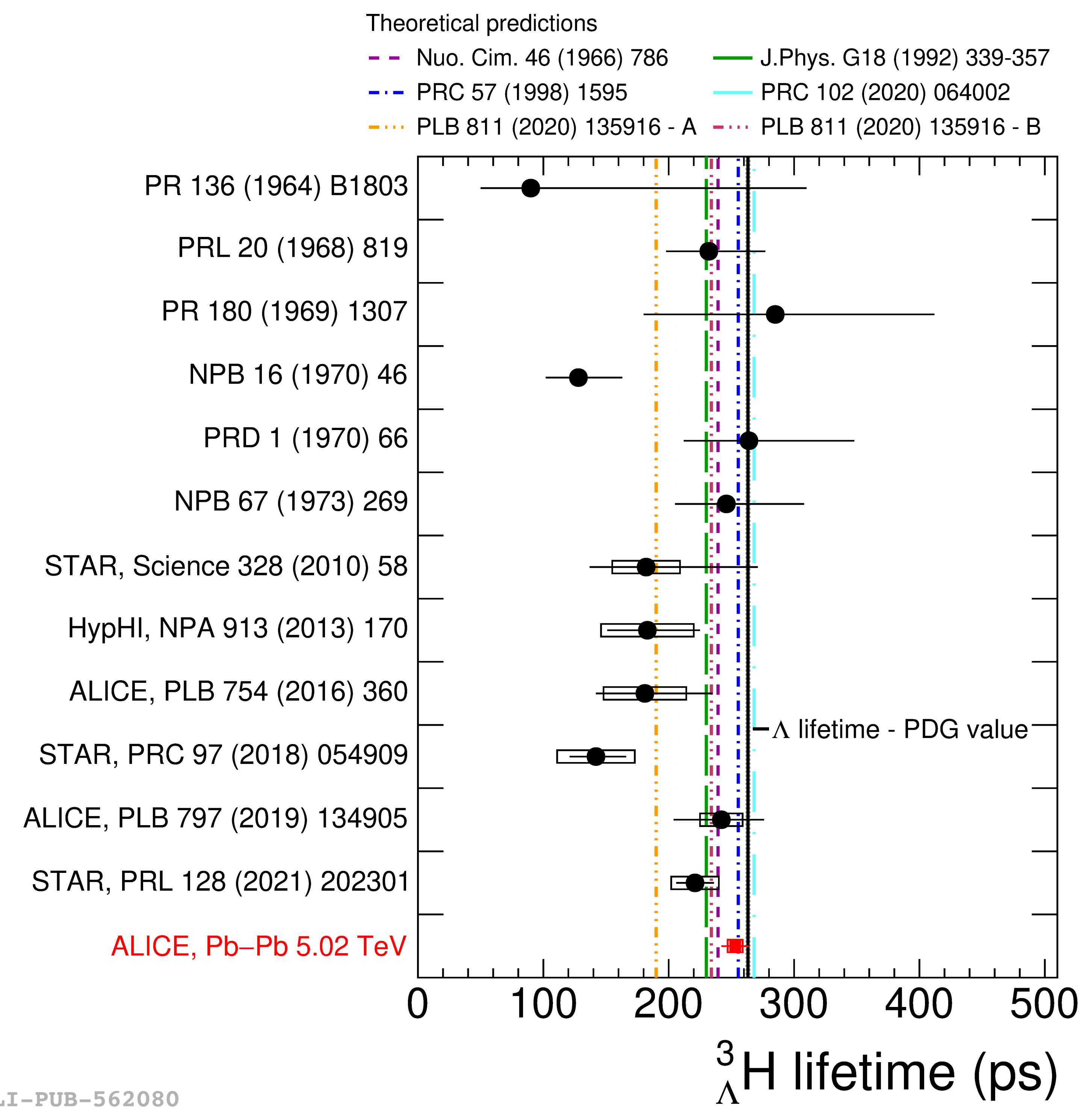
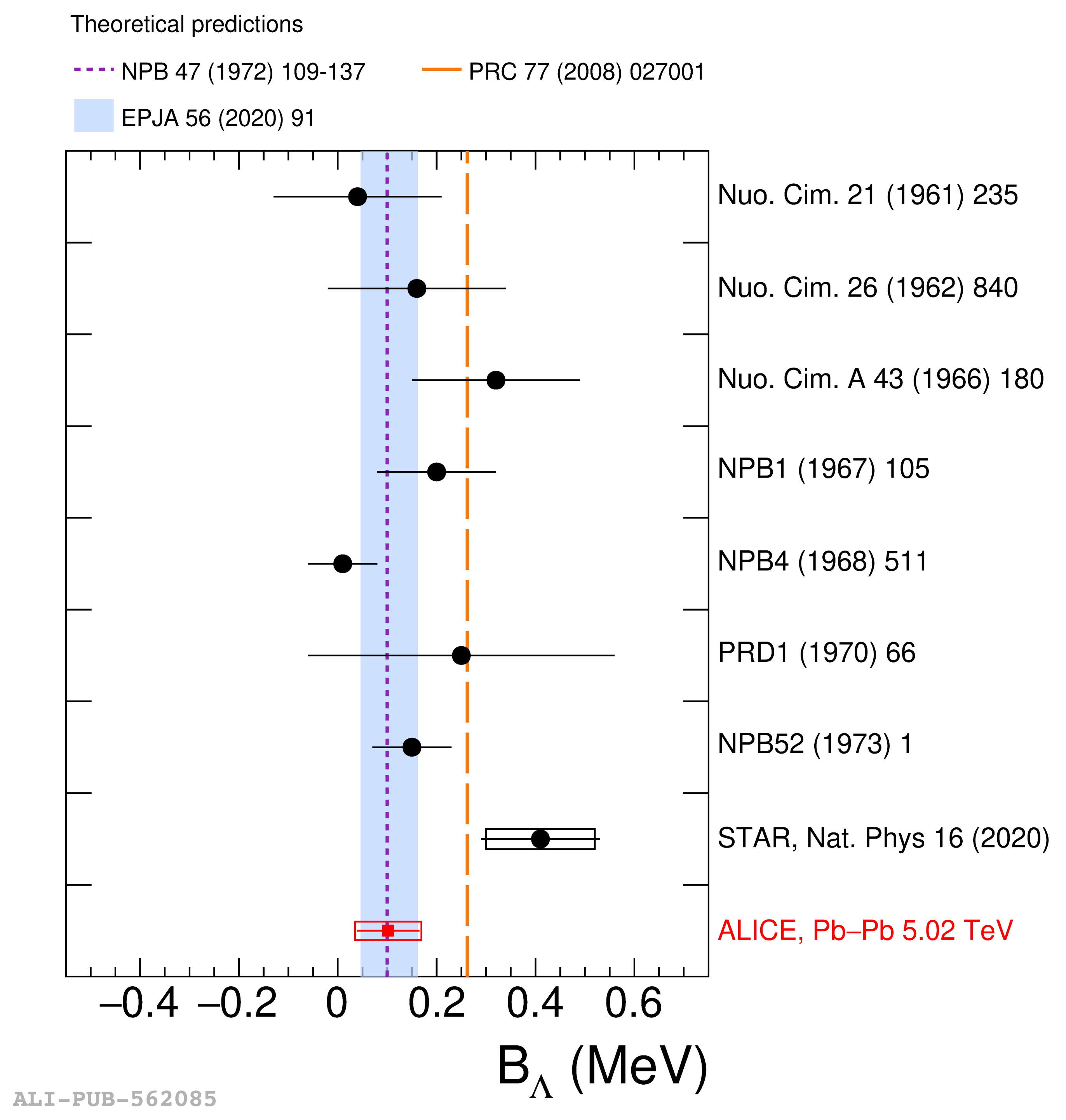
ALICE tracking and hypertriton decay topology

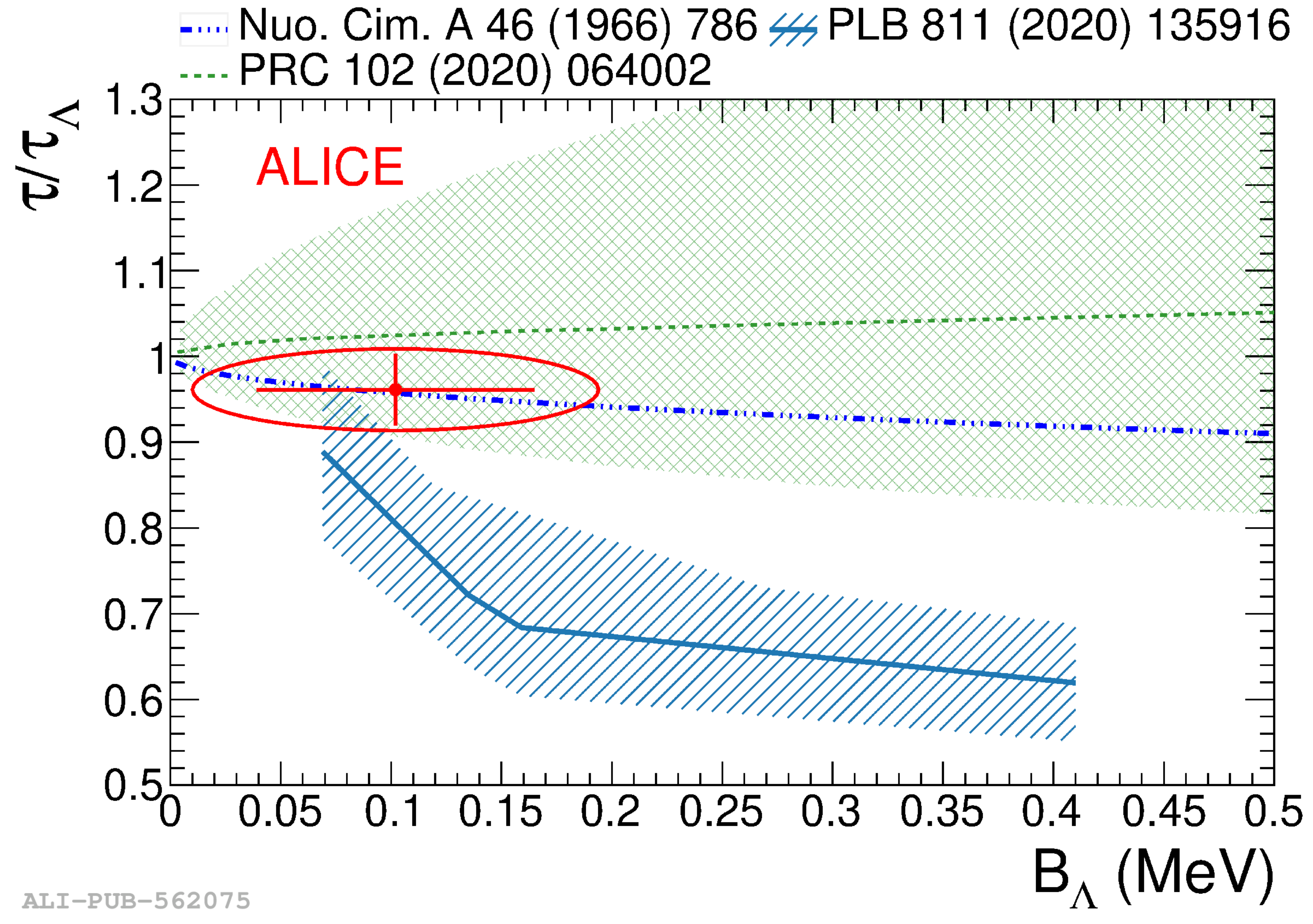




Hypertriton properties(life time and B_Λ)

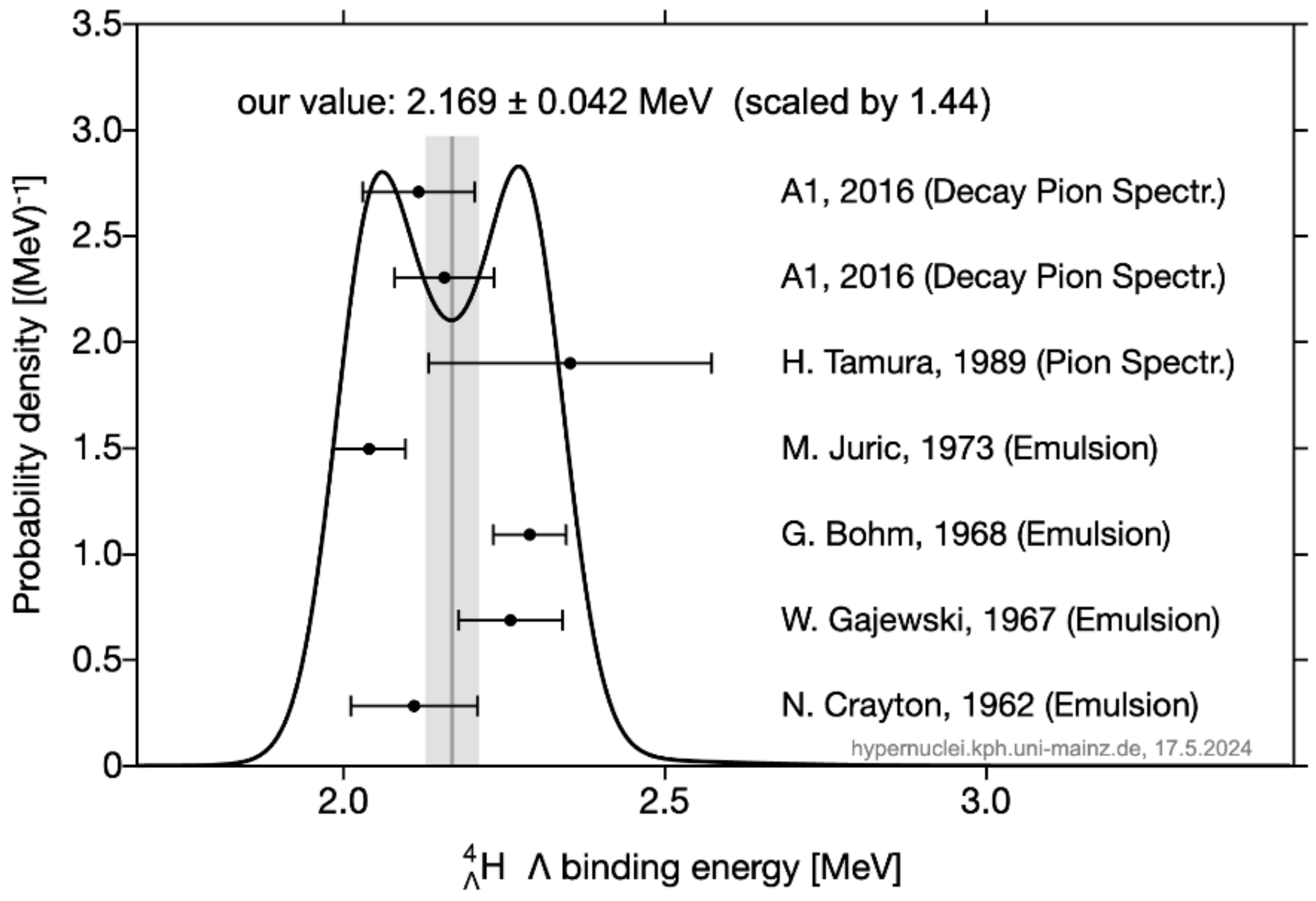


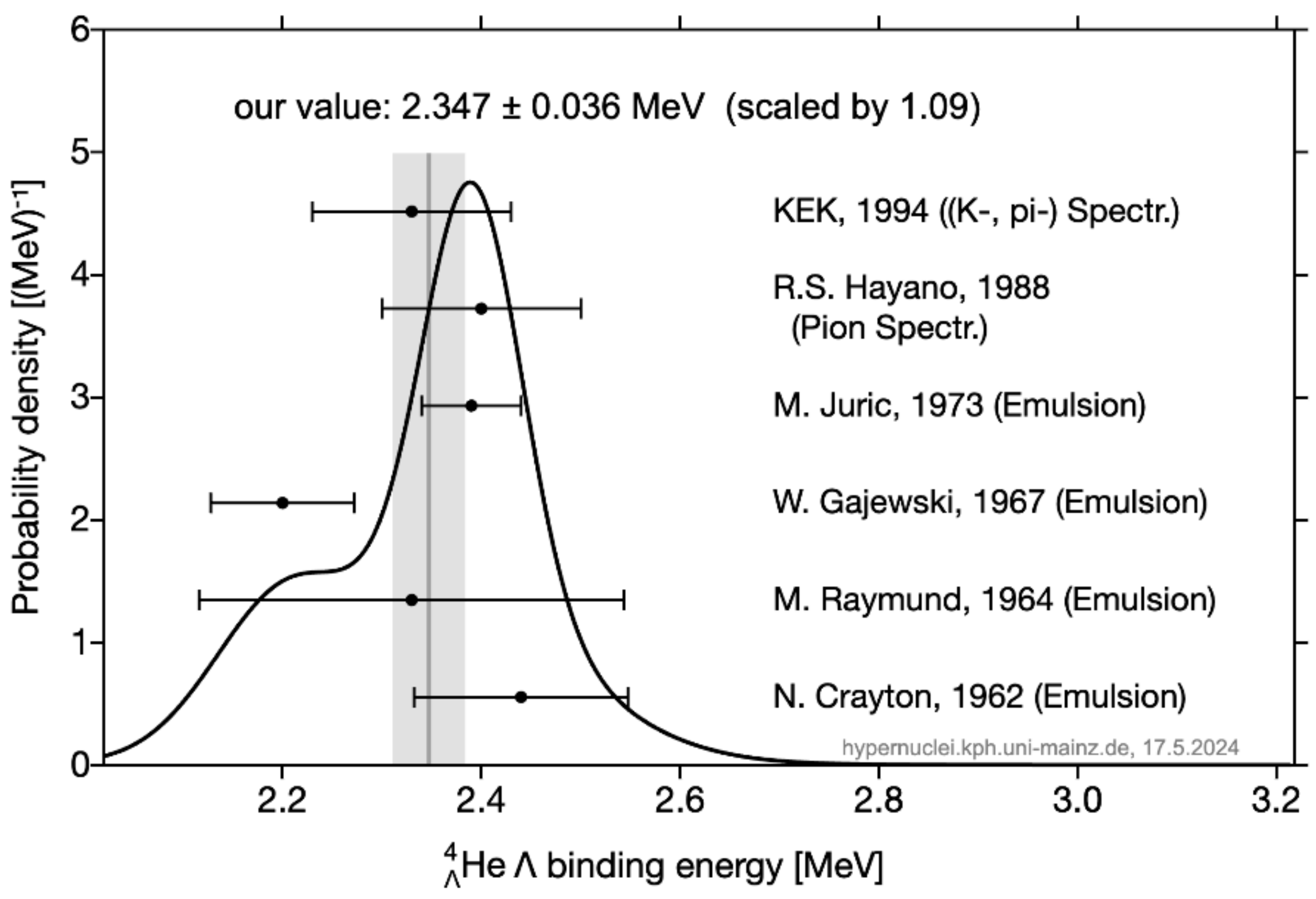




5 Back Up Slides

($^{4}_{\Lambda}$H, $^{4}_{\Lambda}$He) properties



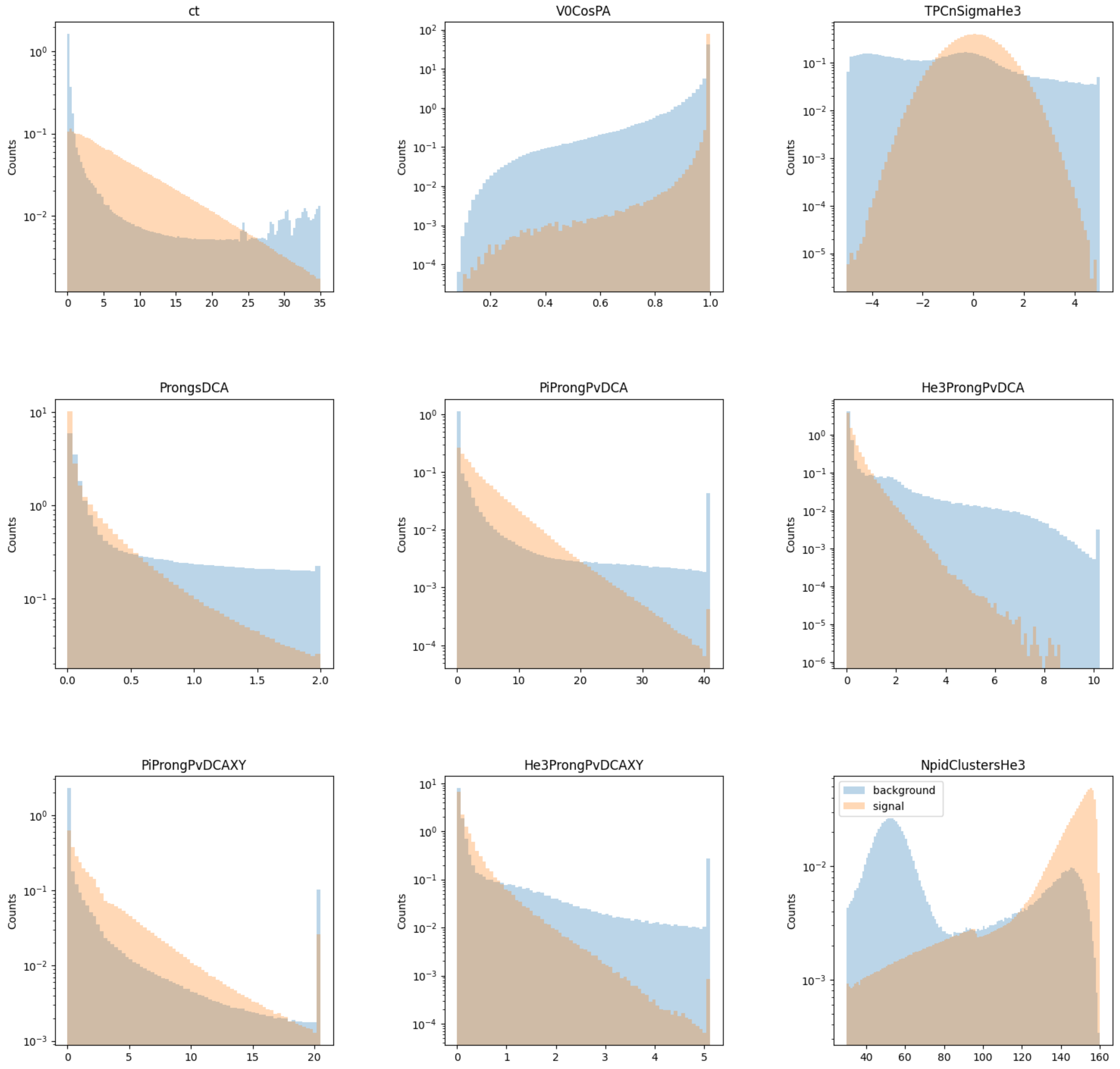


5 Back Up Slides

About the Boost Decision Tree(BDT)

Track selections	
Kink daughters	rejected
TPC clusters	> 50
χ^2 per TPC clusters	< 4
|DCA|	< 8 cm
p_{T} ^{3}He track	> 1.2 GeV/c
TPC nσ	< 5

Table 1: Track selections applied for generating the Training Set.



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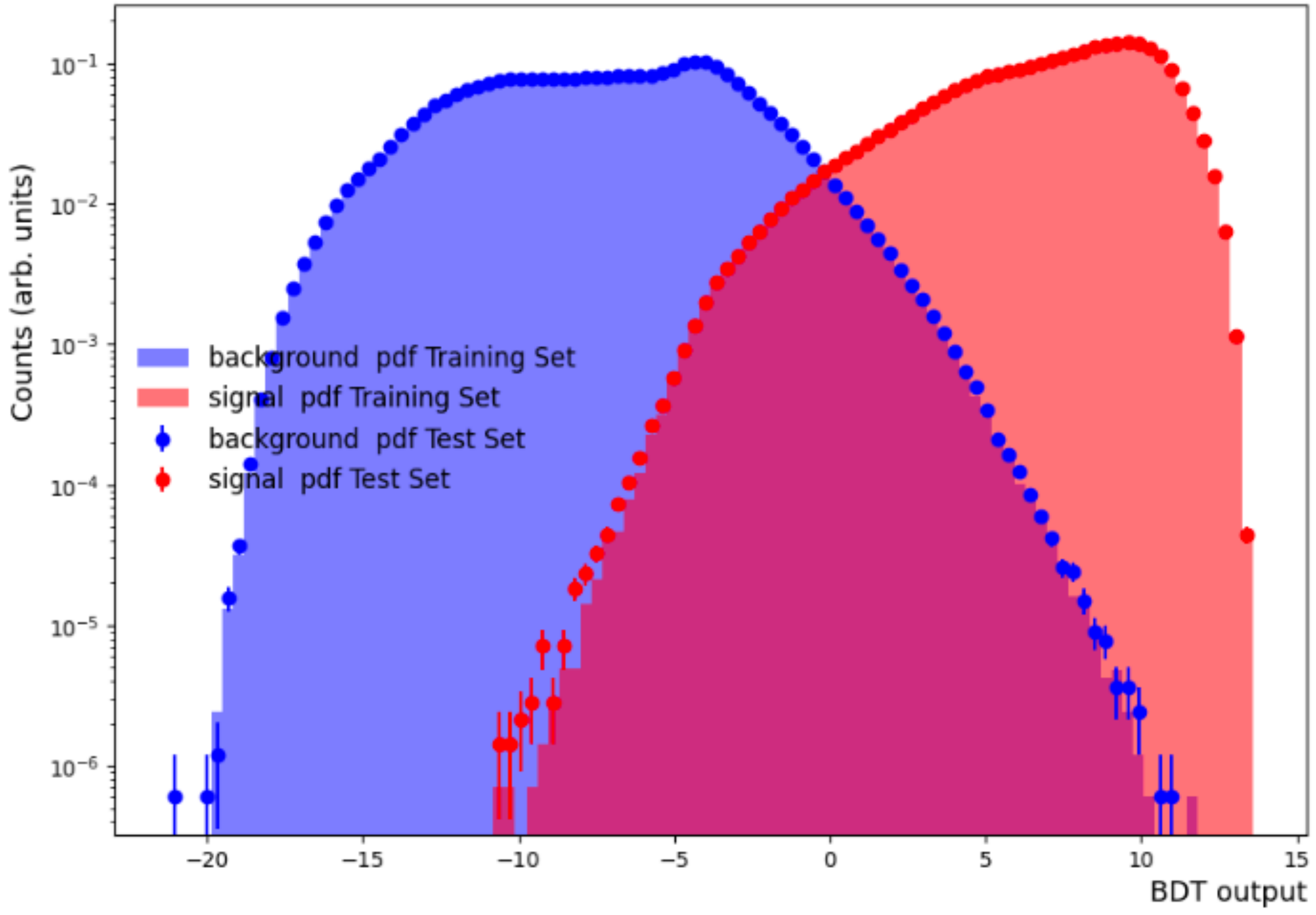
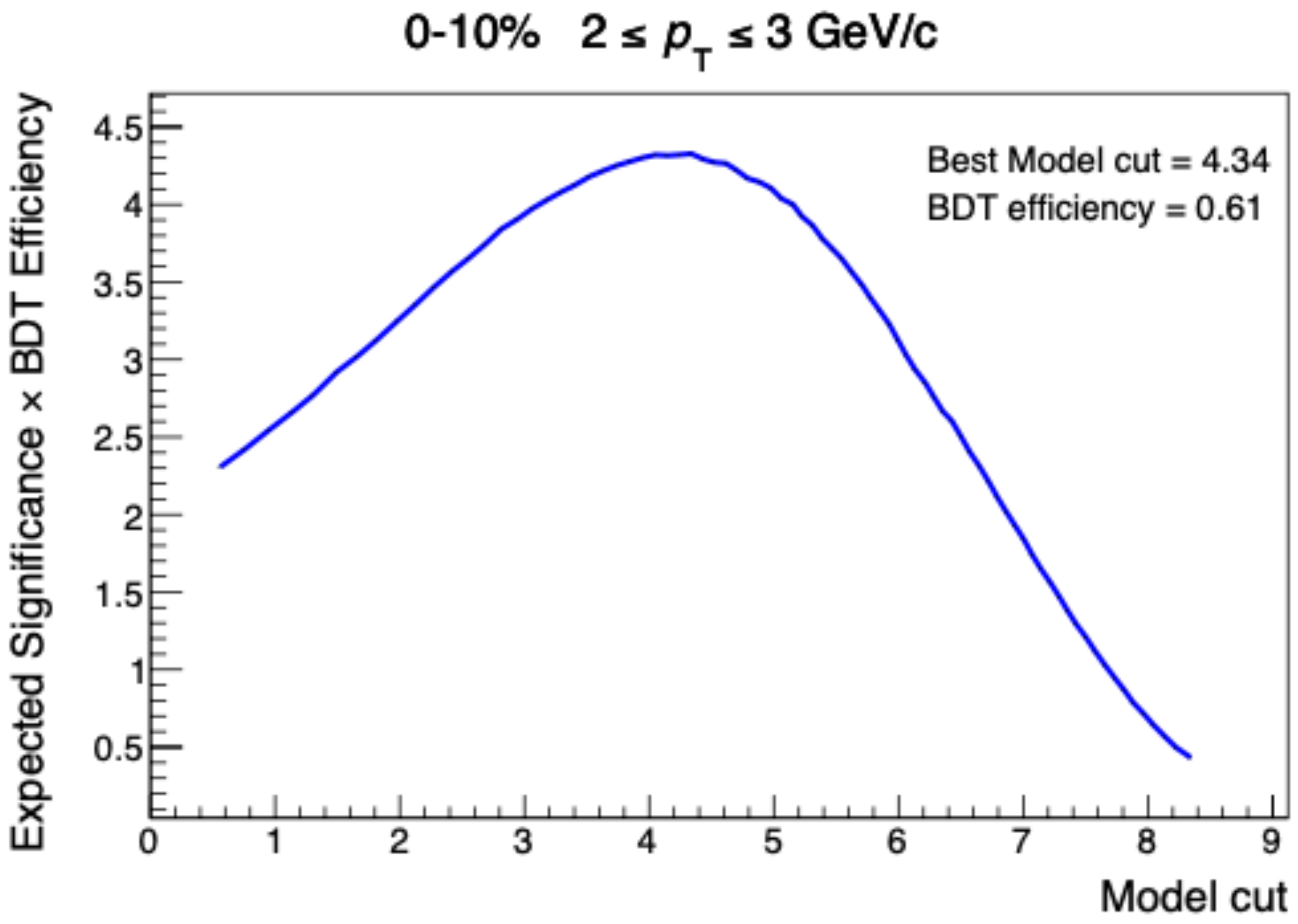
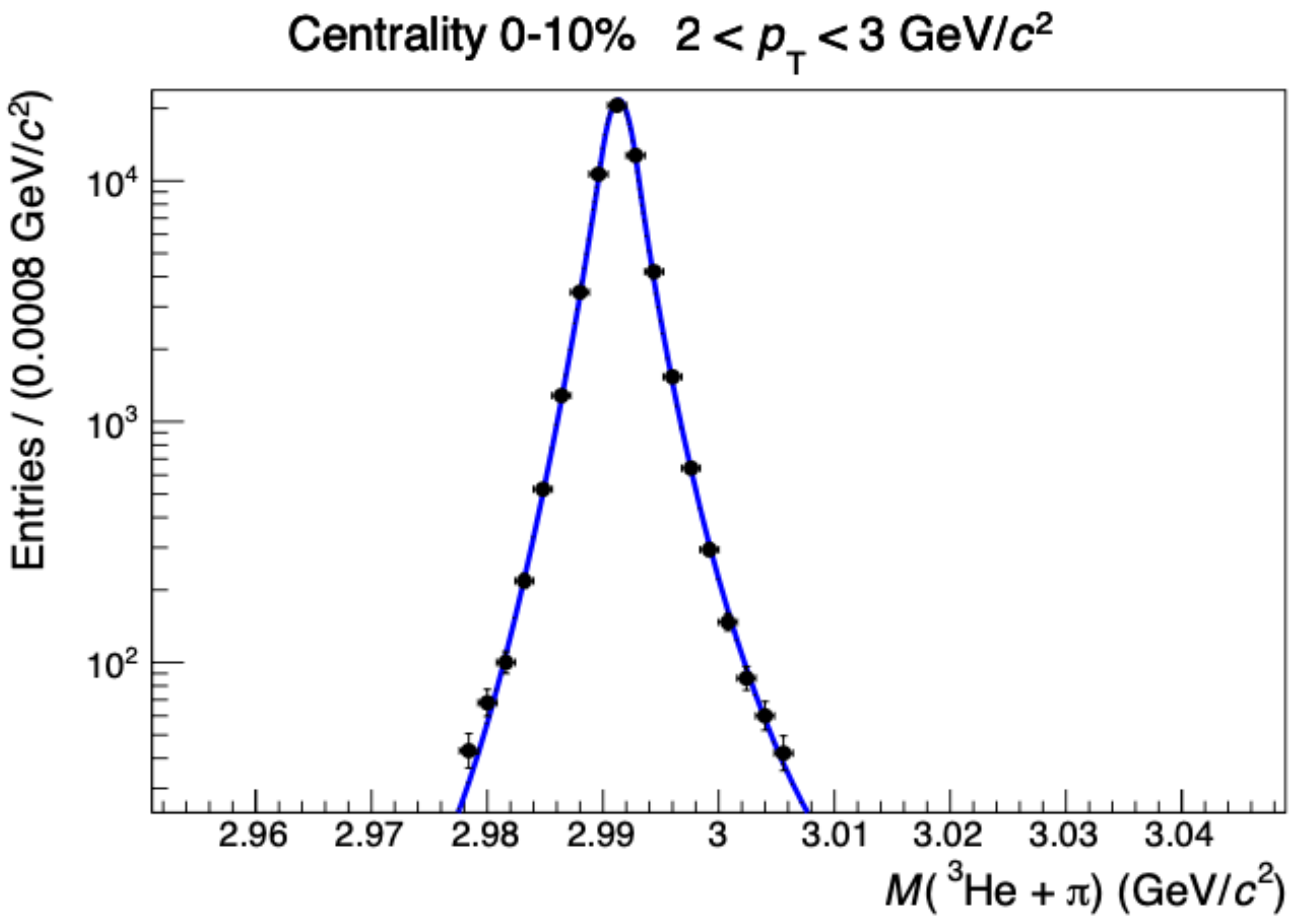
About the Boost Decision Tree(BDT)



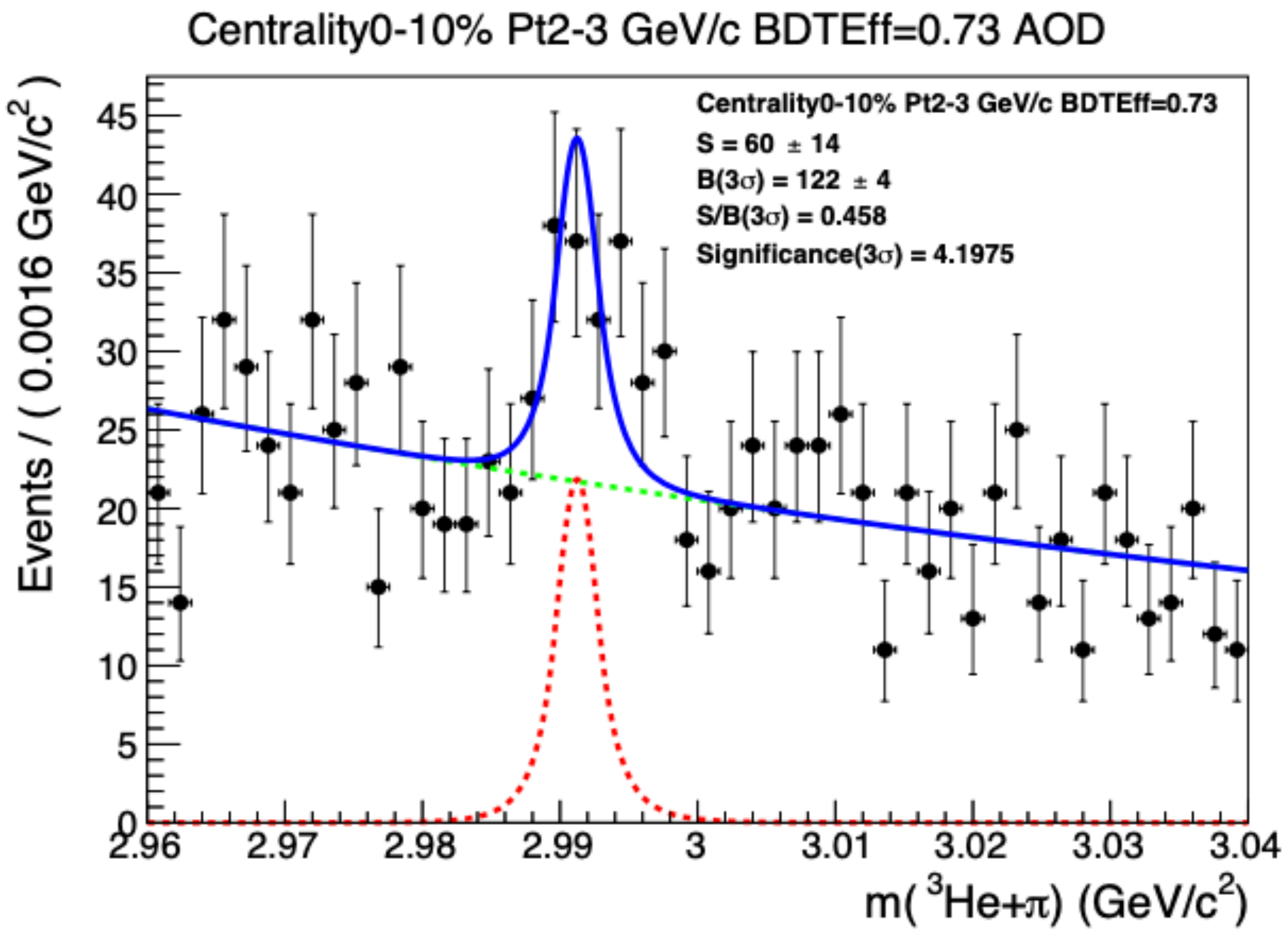


About the Boost Decision Tree(BDT)

MC input fix the dscb tails

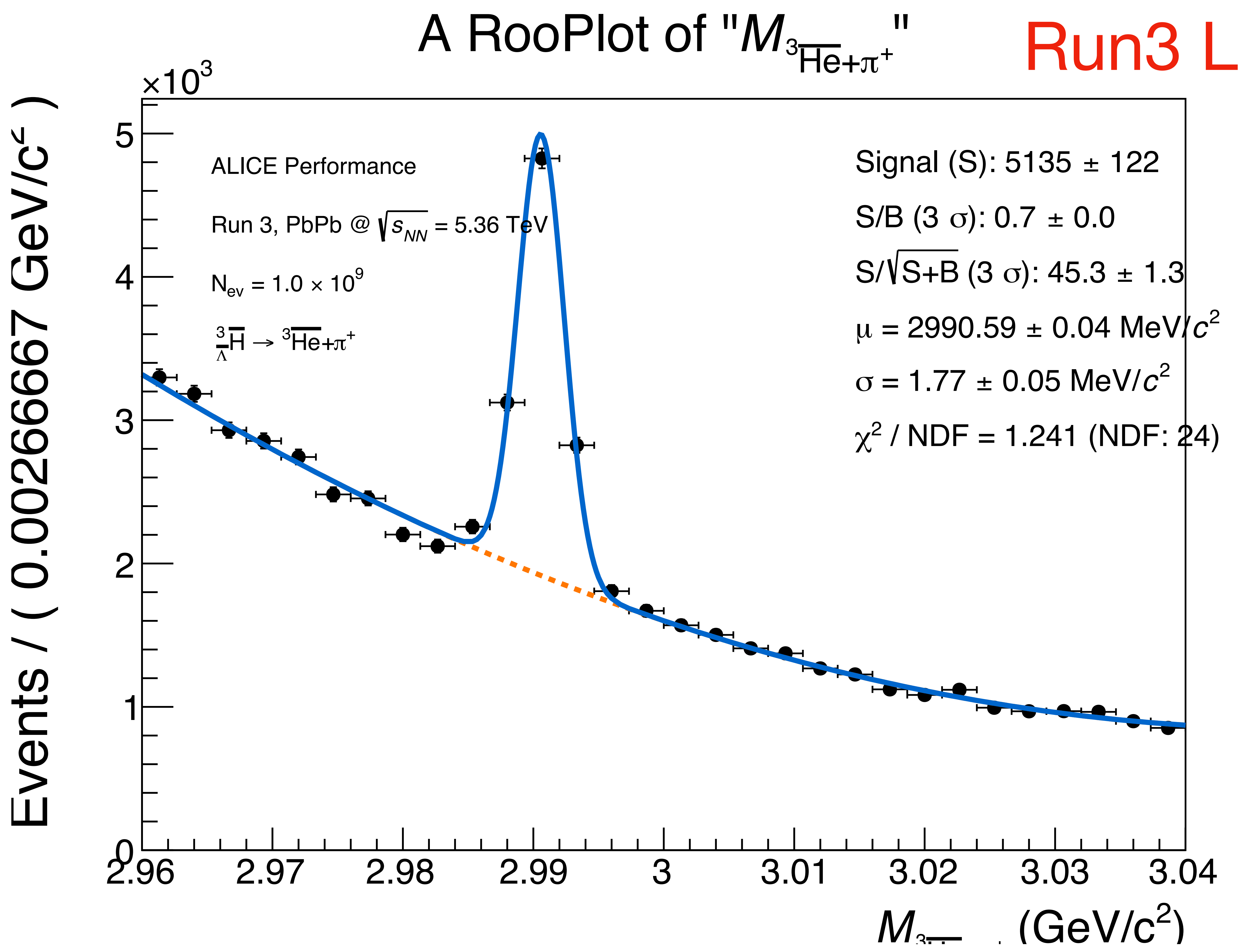


Centrality 0-10% 4 < p_T < 4.5 GeV/c^2



5 Back Up Slides

Run3 PbPb pass4 data test result and yield correction steps



Run3 LHC23_pbpb_pass4

Efficiency correction

Absorption correction

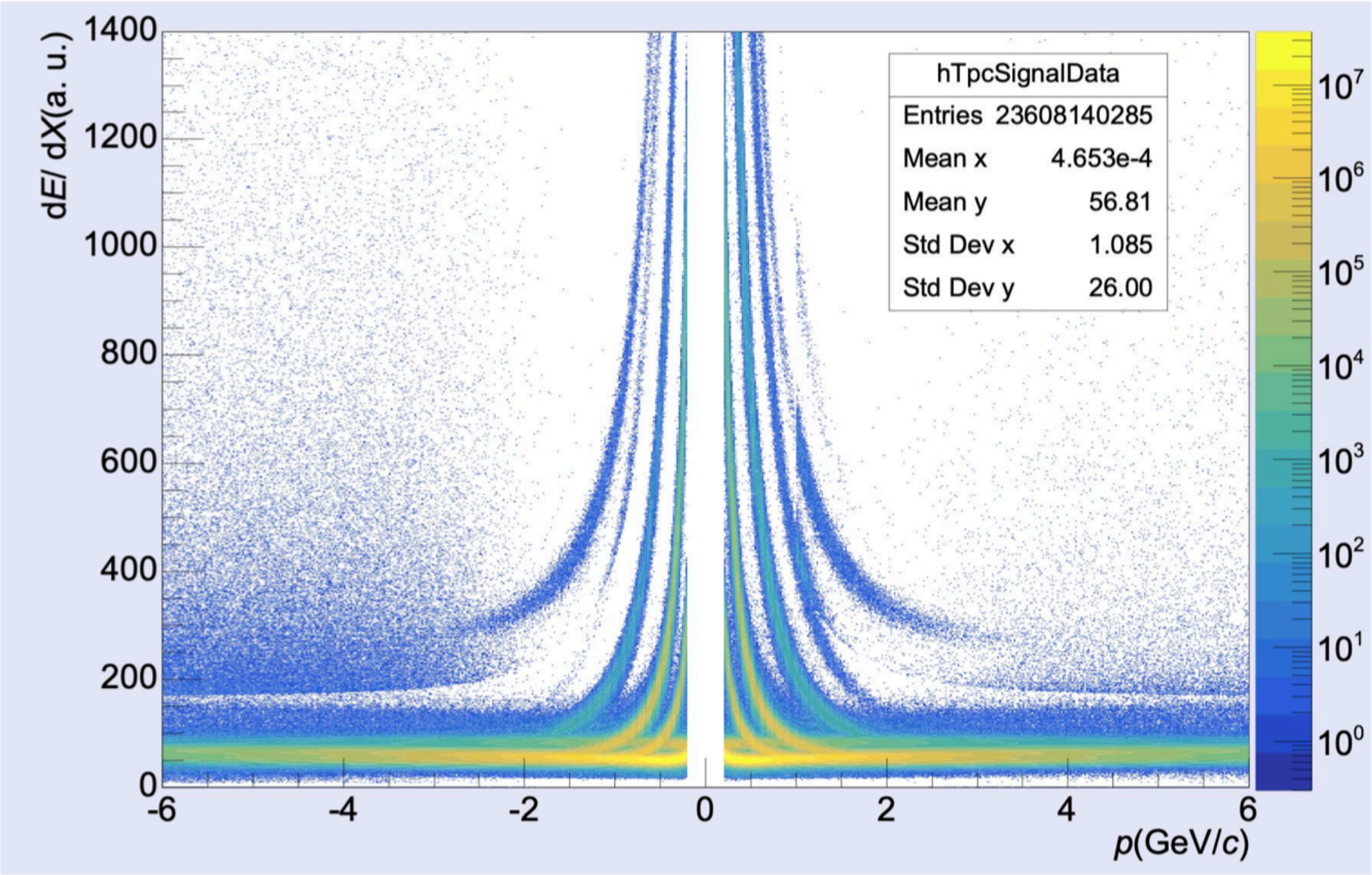
Branch ratio correction

Run3 data challenges

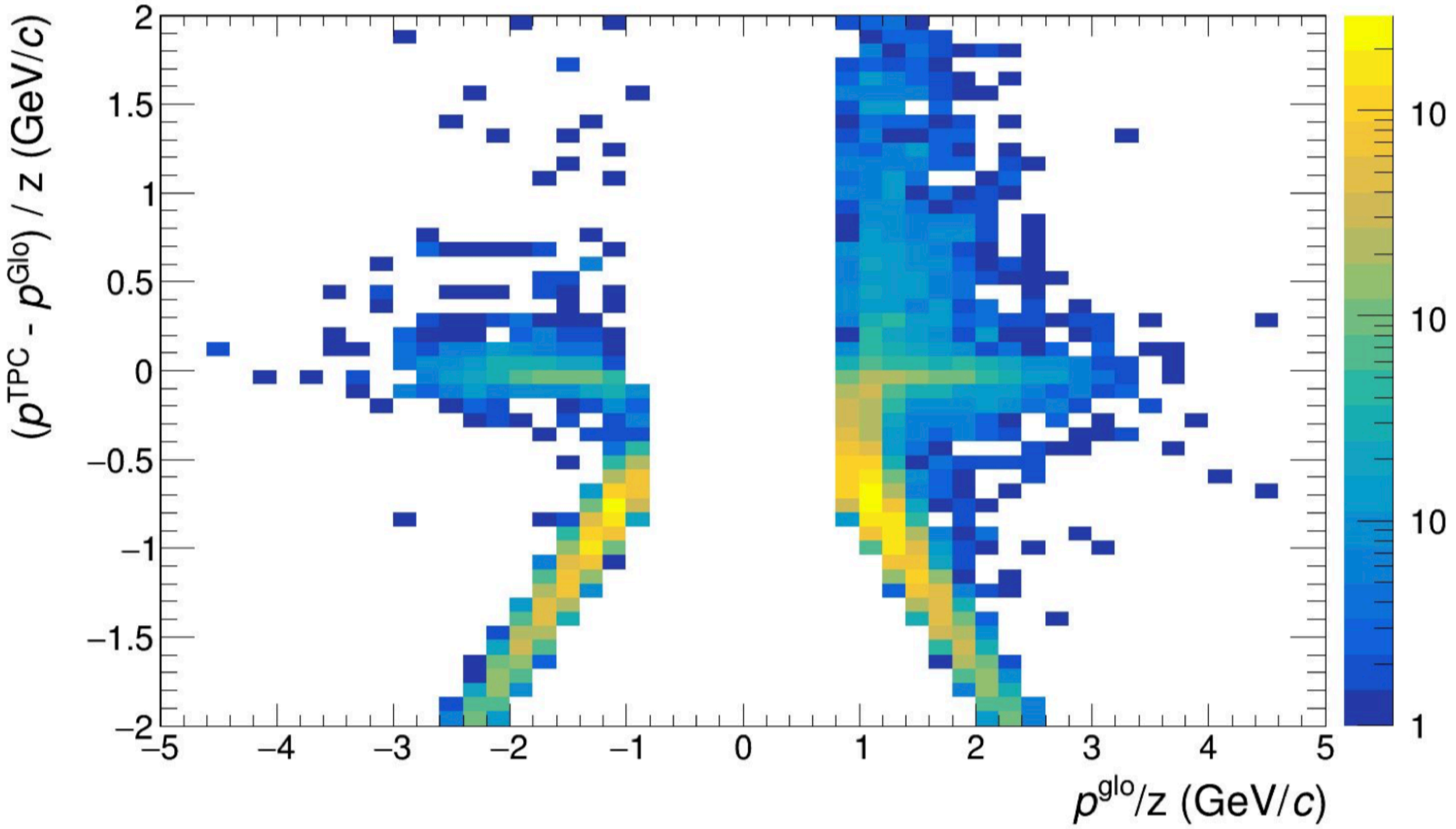
New detectors, continuous readout, new software, data deletion

➢ Lower efficiencies, reconstruction artifacts

pp2024, contamination at high *p*



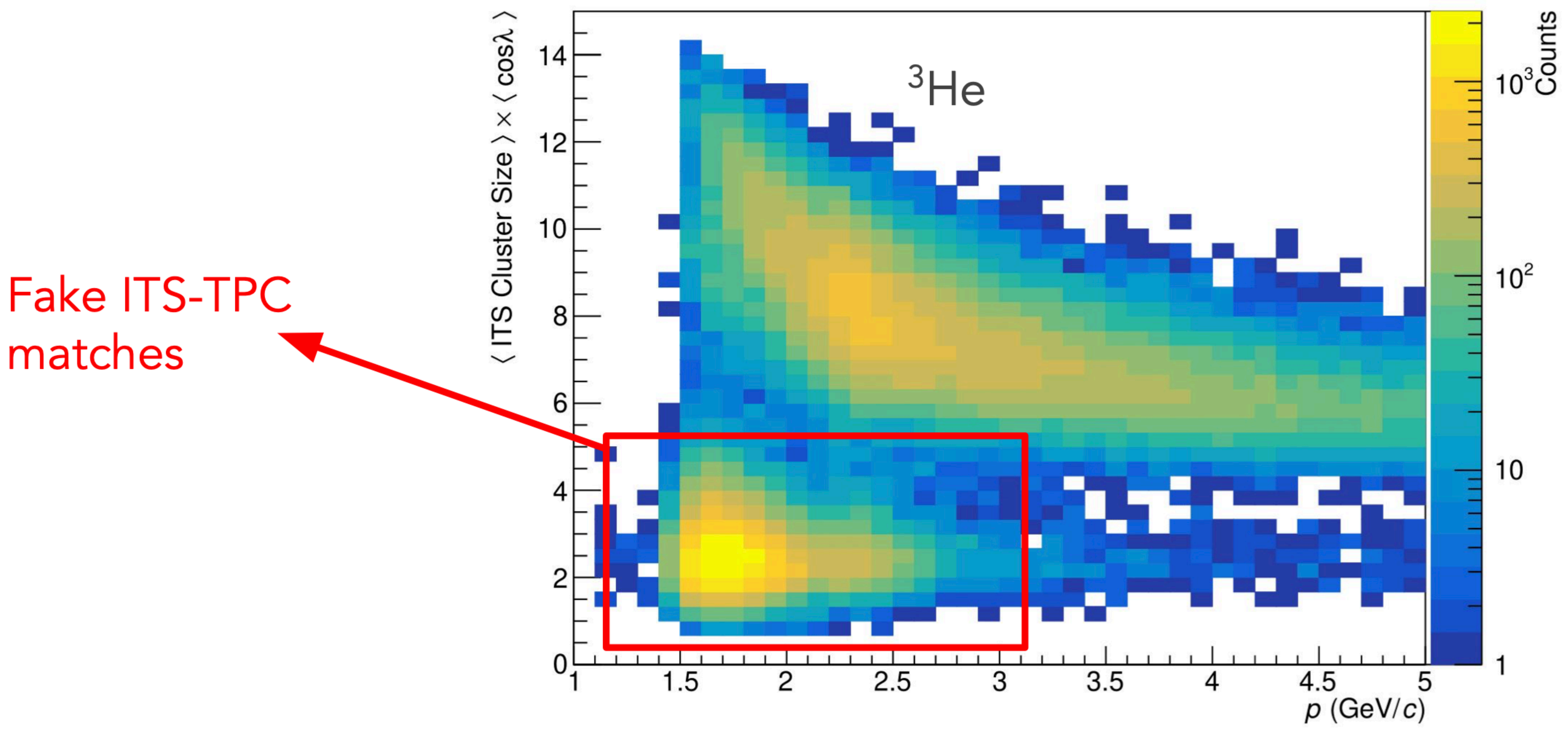
$^{3}He \leftarrow ^{3}_{\Lambda}H$



Pb–Pb 2023, apass2: Fake ITS-TPC matchings, partially mitigated with new reco passes

Run3 data challenges

- Use of ITS cluster size to tag ^{3}He daughter track and reduce ITS-TPC fake matchings



ITS2 upgrades in run3

- ITS2: 7 layers based on Monolithic Active Pixel Sensors (MAPS)
- 24120 chips, 12.5 Gpixes
- Largest MAPS-based detector in High-Energy Physics
- Reduced material budget and higher spatial resolution: ($r\varphi$, z) = 5x5 μm2