

# Hunting hypertritons in heavy ion collisions with the ALICE experiment using a Machine Learning approach

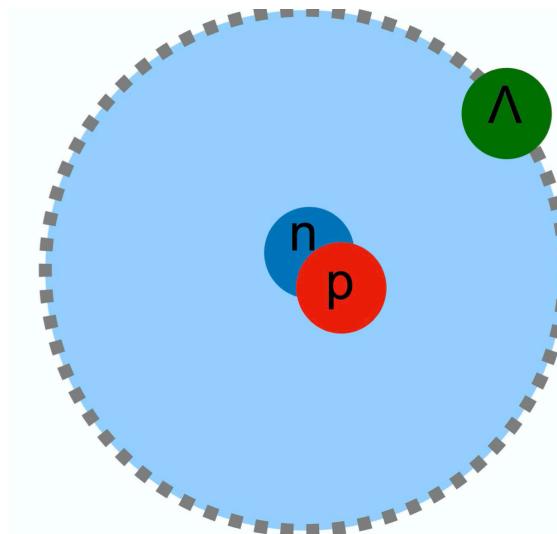
Pietro Fecchio on behalf of the ALICE Collaboration  
Politecnico di Torino e INFN Torino

106° Congresso Nazionale della Società Italiana di Fisica



# Hypertriton

- Lightest known hypernucleus
  - bound state of p, n and  $\Lambda$
  - mass:  $2.99116 \pm 0.00005$  GeV/c<sup>2</sup> [1]
- $\Lambda$  hyperons can explore the nuclear structure **without being affected by the Pauli principle**.
- The measured  $\Lambda$  separation energy  $E_\Lambda$  is only  $130 \pm 50$  keV [2]
  - hypertriton could be approximated as a bound state of a deuteron and a  $\Lambda$
- Decay channels reconstructed by ALICE:
  - ${}^3_{\Lambda}\text{H} \rightarrow {}^3\text{He} + \pi$  (B.R. 0.23)
  - ${}^3_{\Lambda}\text{H} \rightarrow d + p + \pi$  (B.R. 0.40)



[1] D.H. Davis., Nucl. Phys. A 754 (2005) 3-13

[2] M. Jurić et al., Nucl. Phys. B, 52 (1973), p. 1

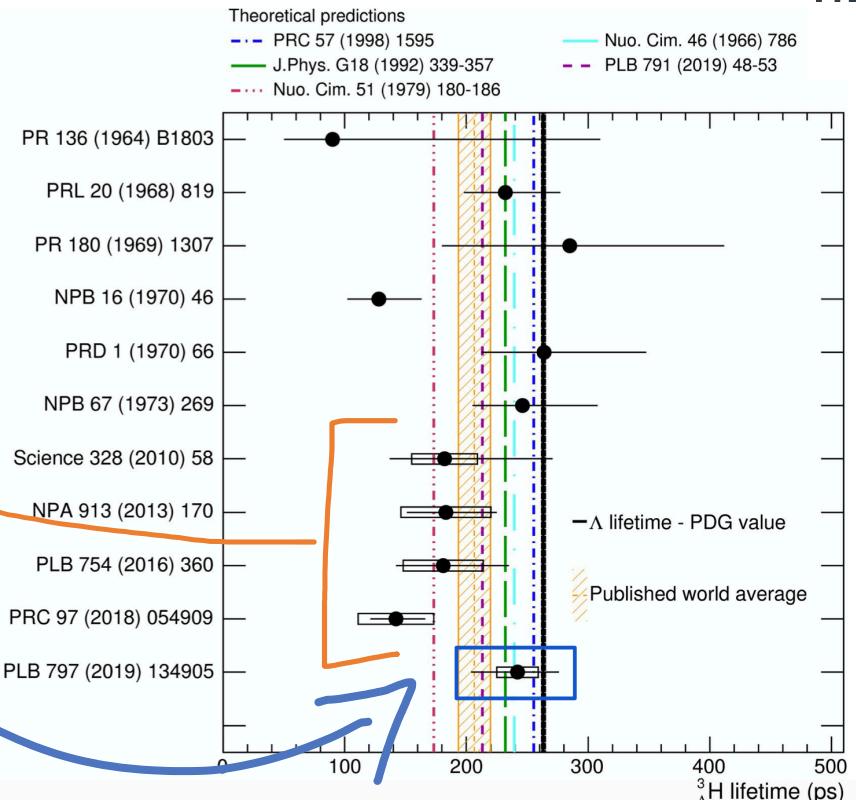
# The lifetime puzzle

- Expected lifetime close to free  $\Lambda$  one due to low  $\Lambda$  separation energy

$$\bullet \tau_\Lambda = 263.2 \pm 2.0 \text{ ps}^{[3]}$$

- Recent measurements<sup>[4]</sup> lower than predictions

- Latest ALICE published result<sup>[5]</sup> compatible within  $1\sigma$  with most of the theoretical models



[3] Kamada et al., Physical Rev.C 57.4, p. 1595 (1998)

[4] STAR Collaboration Phys. Rev. C 97, 5, 054909 (2018)

[5] ALICE Collaboration Phys. Lett. B 797, 134905 (2019)

# The lifetime puzzle

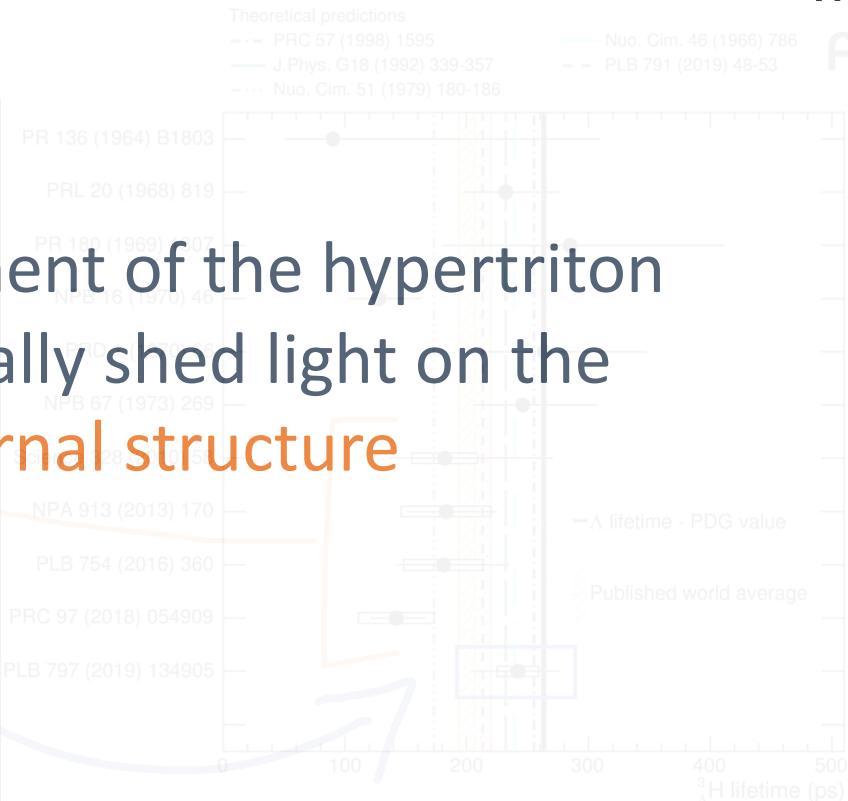


- Expected lifetime close to free  $\Lambda$  one due to low  $\Lambda$  separation energy

$\tau = 263.2 \pm 2.0$  ps<sup>[3]</sup>

## A new precise measurement of the hypertriton lifetime is crucial to finally shed light on the hypertriton internal structure

- Recent measurements lower than predictions
- Latest ALICE published result<sup>[5]</sup> compatible within  $1\sigma$  with most of the theoretical models



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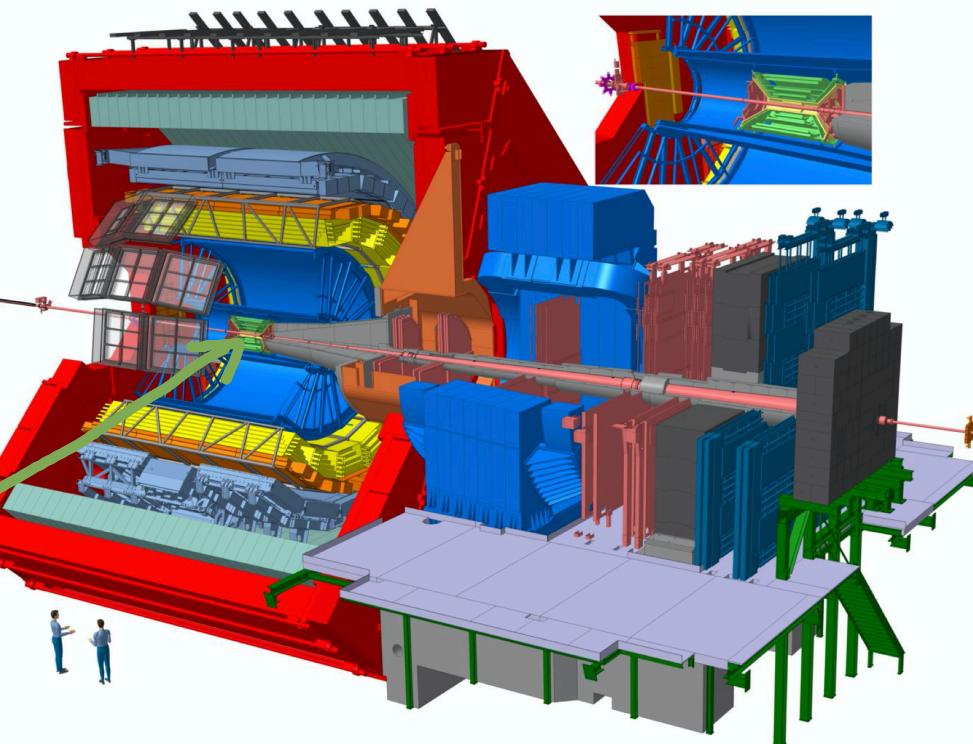
# The ALICE detector



- Hypertriton decay products identified exploiting the excellent **particle identification (PID)** capabilities of the ALICE apparatus

**Inner Tracking System**

- Track reconstruction
- Primary and secondary vertex reconstruction
- PID of low momentum particles



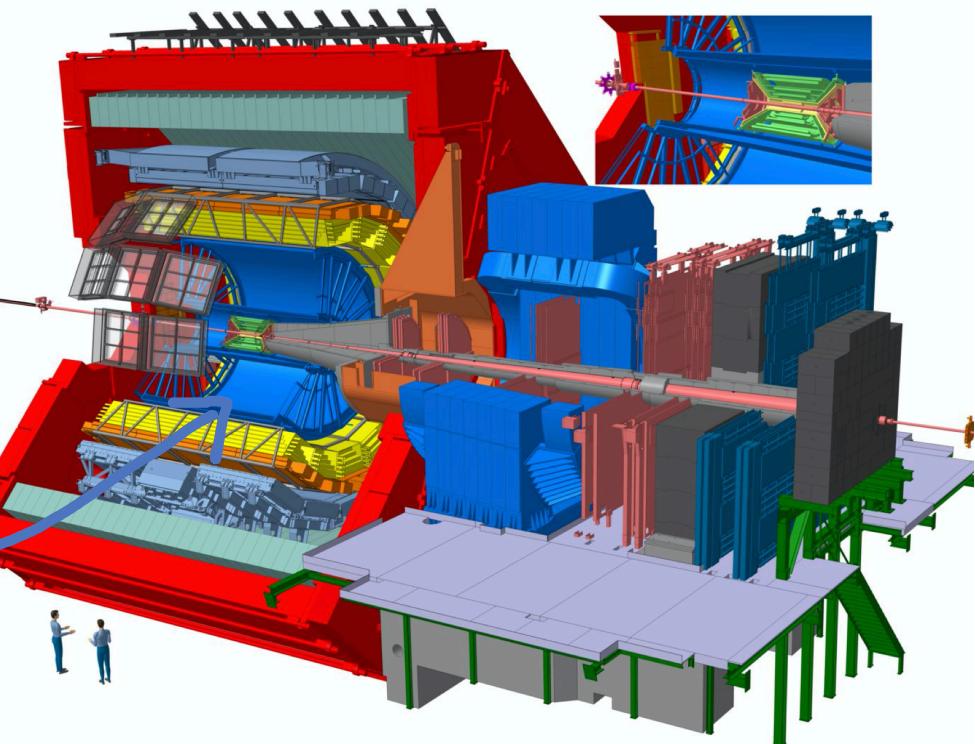
# The ALICE detector



- Hypertriton decay products identified exploiting the excellent **particle identification (PID)** capabilities of the ALICE apparatus

## Time Projection Chamber

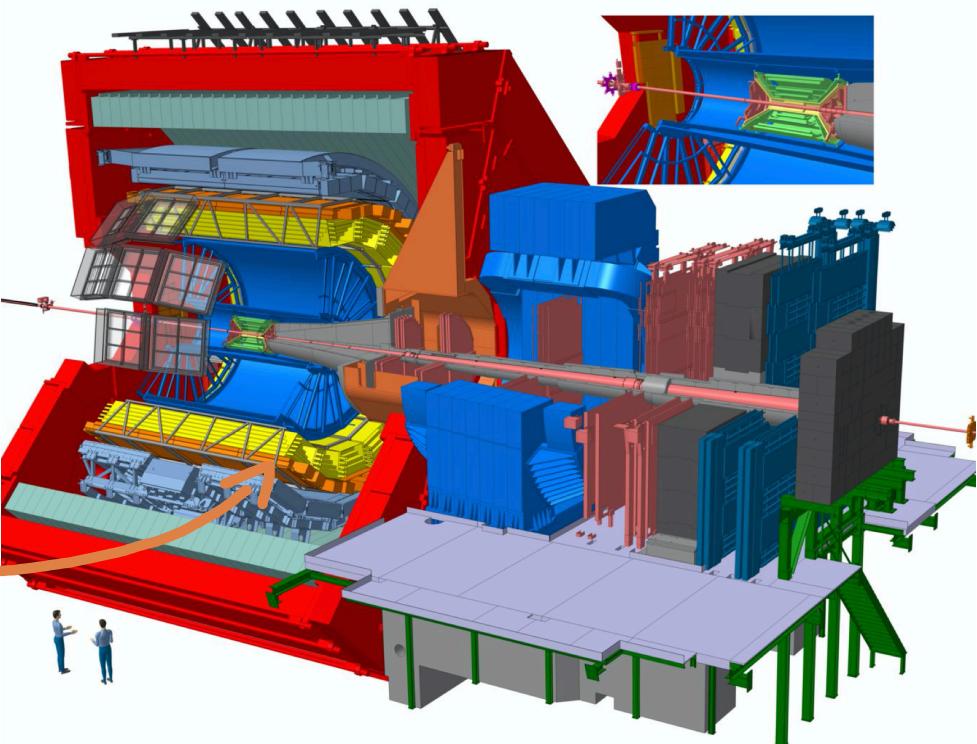
- Tracking
- PID via specific energy loss



# The ALICE detector



- Hypertriton decay products identified exploiting the excellent **particle identification (PID)** capabilities of the ALICE apparatus

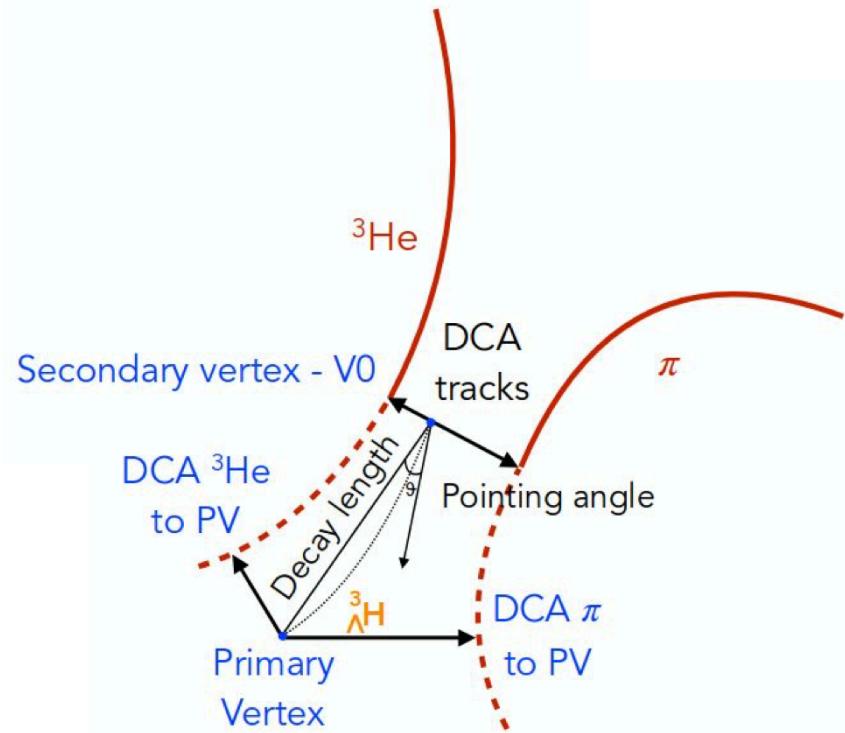


## Time Of Flight detector

- PID via particle time of flight

# Reconstruction of the 2 body decay

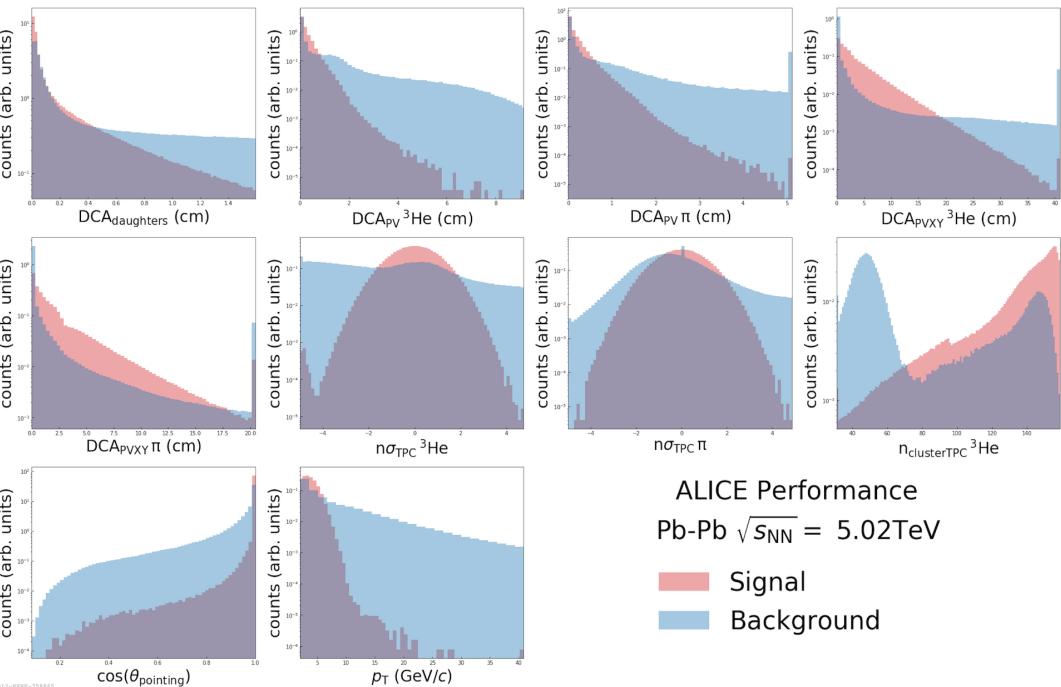
- Analyzed data sample: Pb-Pb collisions at  $\sqrt{S_{NN}} = 5.02 \text{ TeV}$  collected by ALICE in 2018
- Hypertriton candidates  $\rightarrow {}^3\text{He} + \pi^-$  pairs and related charge conjugates
- Secondary vertex reconstruction:
  - matching of  ${}^3\text{He} + \pi^-$  coming from a **common vertex**



# A Machine Learning approach for hypertriton identification



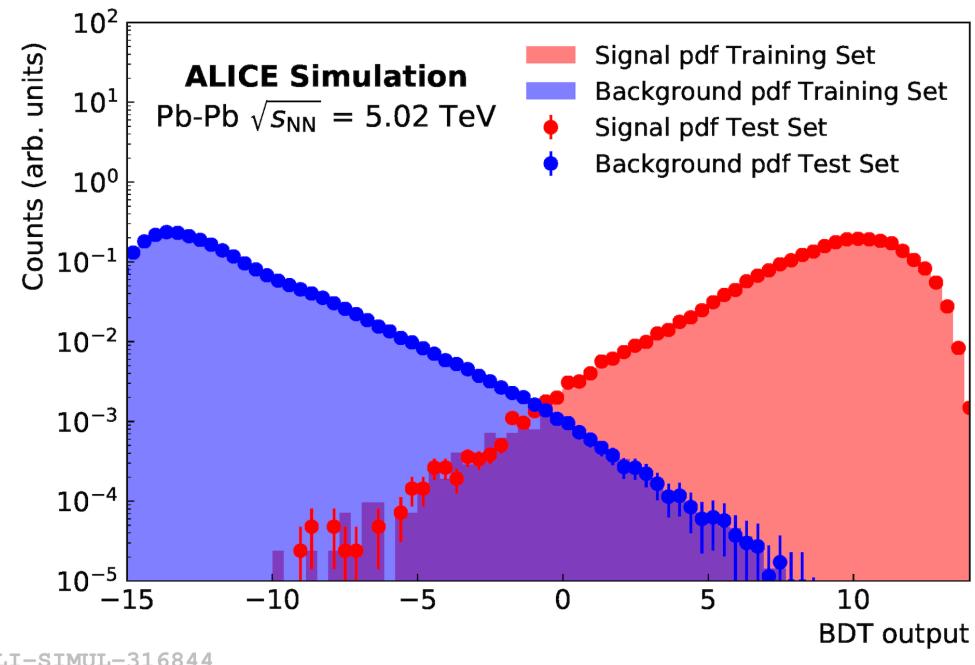
- **Boosted Decision Trees (BDT)**  
classifier to discriminate between signal and background candidates
- BDT training and testing on a dedicated sample containing labelled signal and background candidates
  - Signal taken from **Monte Carlo**
  - Background taken from **like-sign** pairs  ${}^3\text{He} + \pi^+$



# Hypertriton selection with BDTs



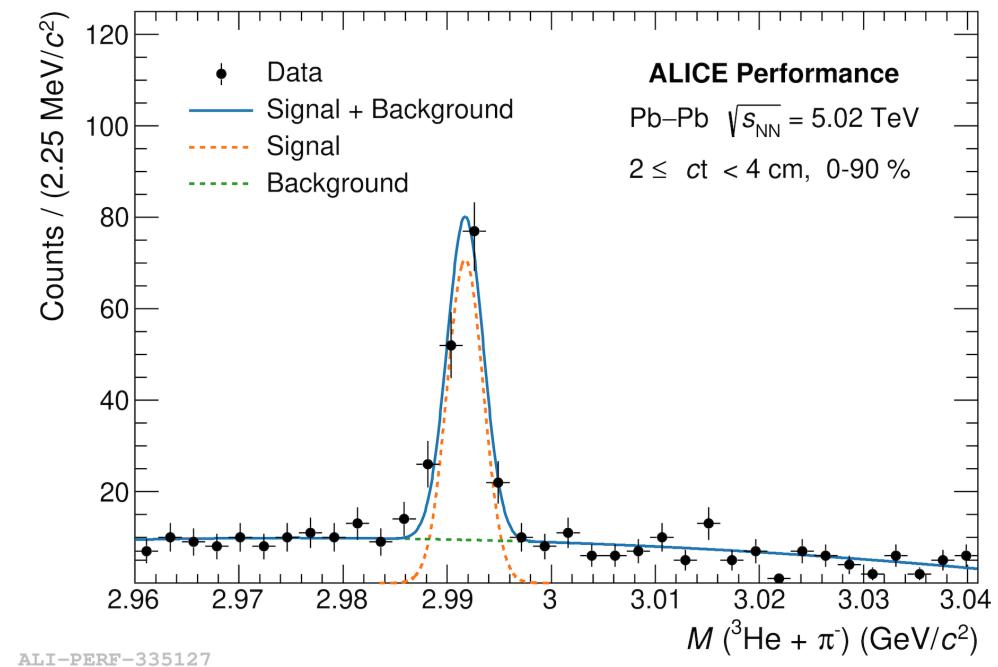
- Independent training for each  $ct$  bins
- BDT output  $\rightarrow$  a **score** related to the probability of the candidate to be signal
- High discrimination power and **no overfitting**



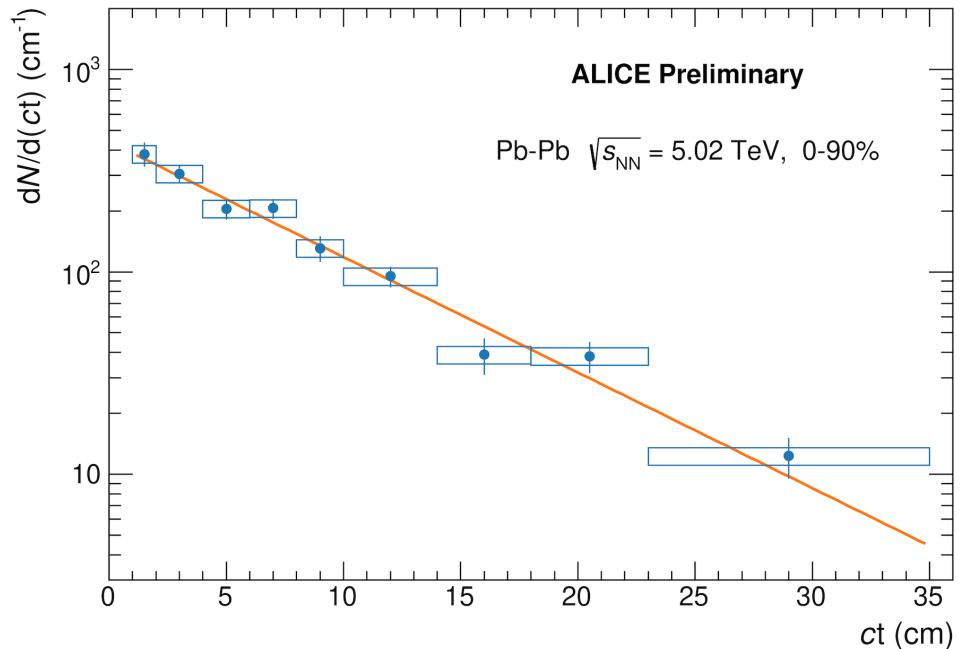
ALI-SIMUL-316844

# Signal extraction

- Fit to the invariant mass spectrum of the selected candidates
  - Background-> **polynomial**
  - Signal-> **Gaussian**
- Signal extracted in 9 ct bins from 1 to 35 cm



# Lifetime measurement



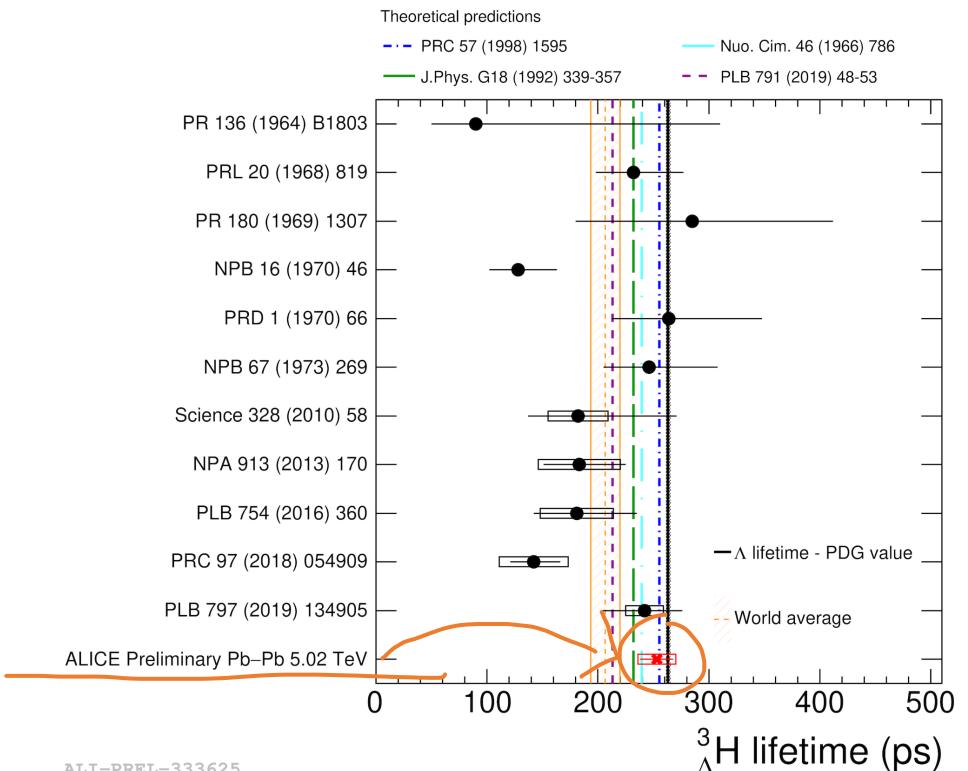
- Corrected  $ct$  spectrum fitted with exponential function
- Lifetime value from the fit
  - $254 \pm 15 \text{ (stat.)} \pm 17 \text{ (syst.)} \text{ ps}$
- Statistical uncertainty  $\sim 6\%$
- Systematic uncertainty (boxes)  $\sim 6.7\%$

ALI-PREL-334667

# Lifetime - discussion



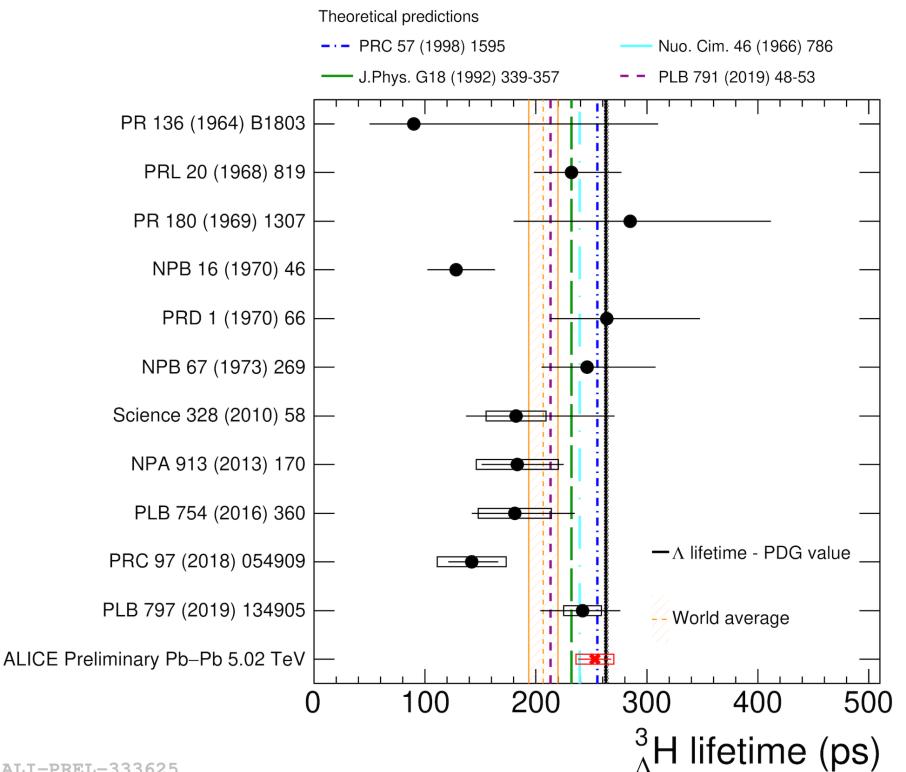
- Most precise measurement in the world
- Statistical uncertainty lower than the published world average uncertainty
- Measurement compatible with former **ALICE** results



# Lifetime - discussion



- Models predicting lifetime near to the free  $\Lambda$  are favoured
- Models assuming compact hypertriton are disfavoured ( $3.6\sigma$  far from)
- Hypertriton **weakly bound nature** seems to be confirmed



ALI-PREL-333625

# Summary

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- ALICE has performed a **new measurement** of the hypertriton lifetime in the 2-body decay channel in Pb-Pb collisions at  $\sqrt{S_{NN}} = 5.02$  TeV using a machine learning approach for the signal selection
  - higher precision with respect to all the previous measurements
  - lifetime value confirms that hypertriton is a weakly bound state of deuteron and  $\Lambda$