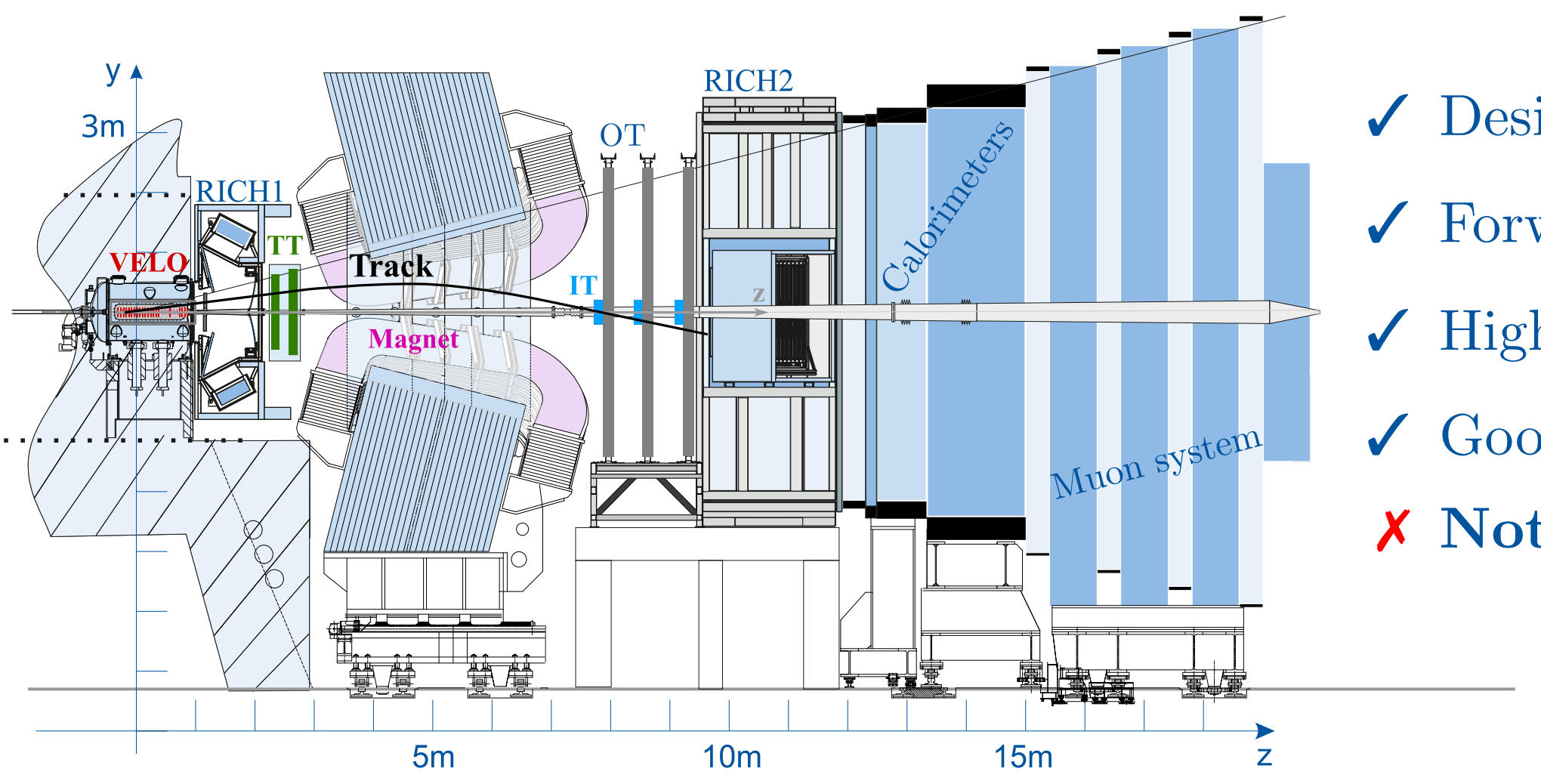
New helium identification technique at LHCb

Observation of (anti)helium and (anti)hypertriton in proton-proton collisions

Hendrik Jage, on behalf of the LHCb collaboration

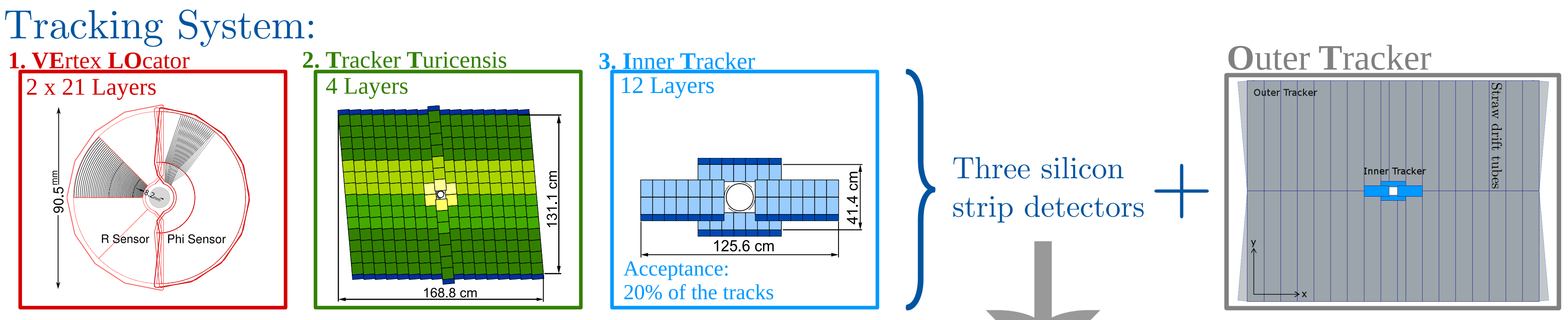
The LHCb detector (2015 - 18)

[IJMPA3 30 (2015) 1530022]
[JINST 3 (2008) S08005]



- ✓ Designed to study beauty hadrons
- ✓ Forward spectrometer ($2 < \eta < 5$)
- ✓ High-precision vertexing
- ✓ Good momentum resolution
- ✗ **Not designed** for helium identification

- Tracking System:

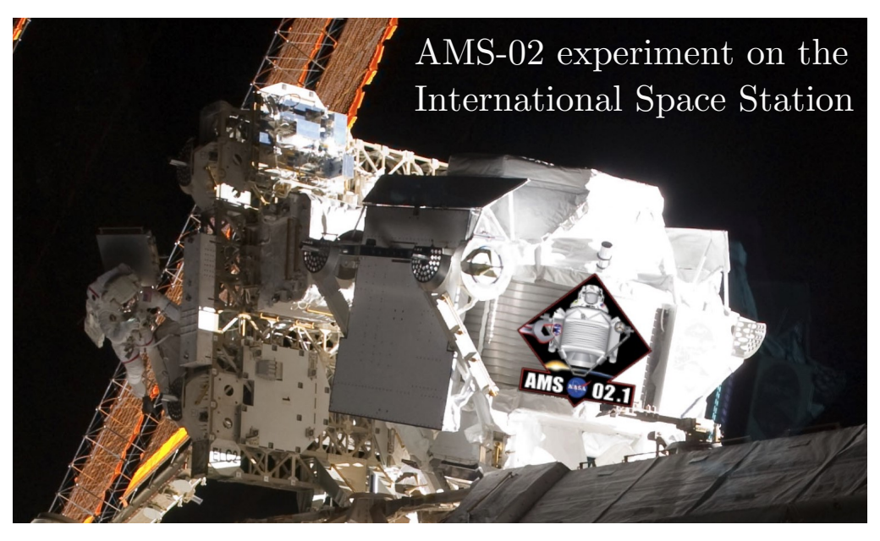


Three silicon strip detectors +

One motivation: Antihelium in Space

- **AMS-02** reported $\mathcal{O}(10)$ $\overline{\mathrm{He}}$ in Cosmic Rays at conferences [COSPAR 2022]
- Origin is completely unclear:
  - Antideuterons expected to be more abundant from **coalescence** and measurements
  - ✗ No $\overline{\mathrm{d}}$ observations reported by AMS-02

⇒ New antihelium source in Space needed



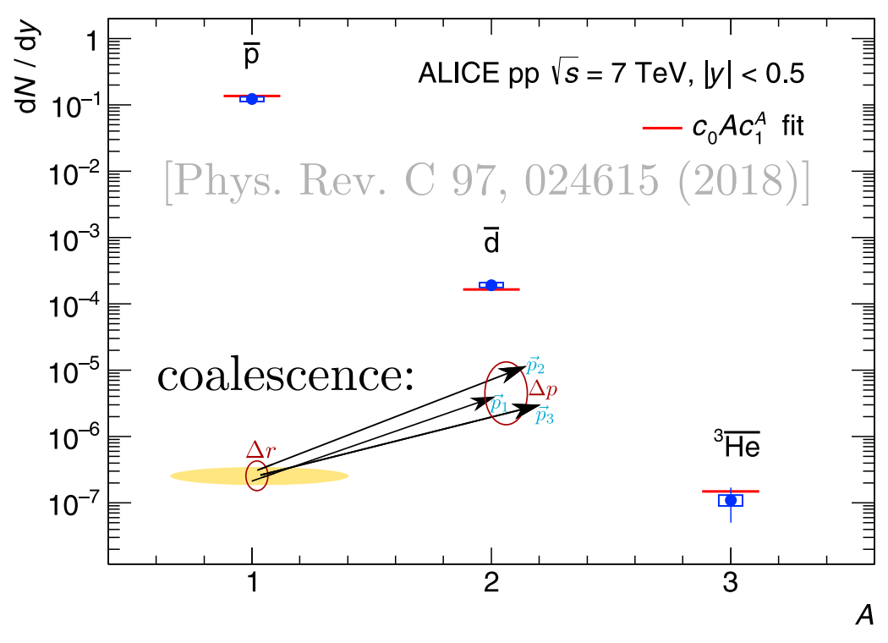
AMS-02 experiment on the International Space Station

Antihelium production via $\overline{\Lambda}_b^0$ decays

[Phys. Rev. Lett. 126 (2021) 101101]

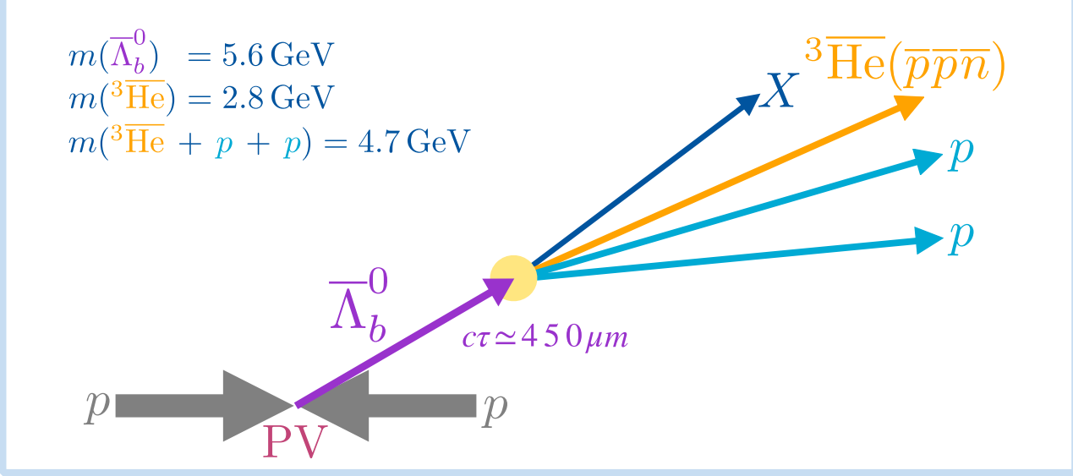
- Model: $\overline{\Lambda}_b^0$ from Dark Matter annihilation
- Most optimistic case predicts antihelium in AMS-02
- Theoretical predictions: large uncertainties from QCD

⇒ Direct measurements are needed

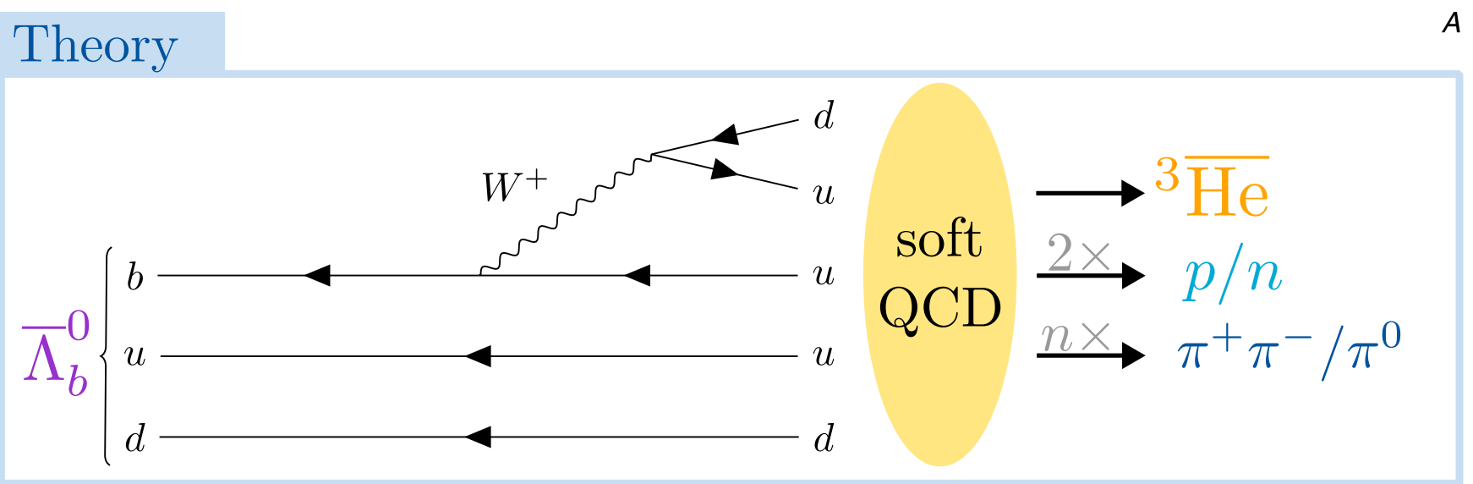


[Phys. Rev. C 97, 024615 (2018)]

Experimental signature



Theory

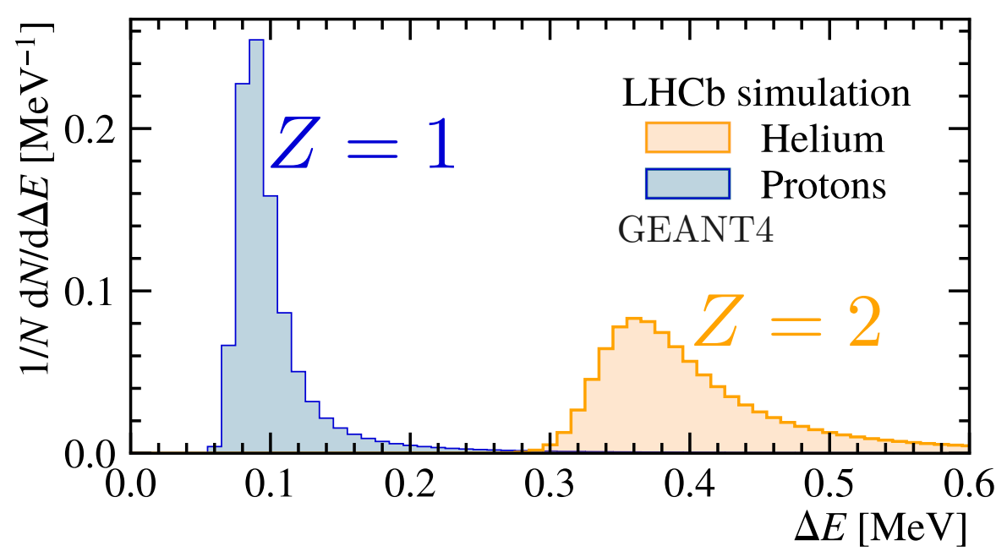


Identification strategy

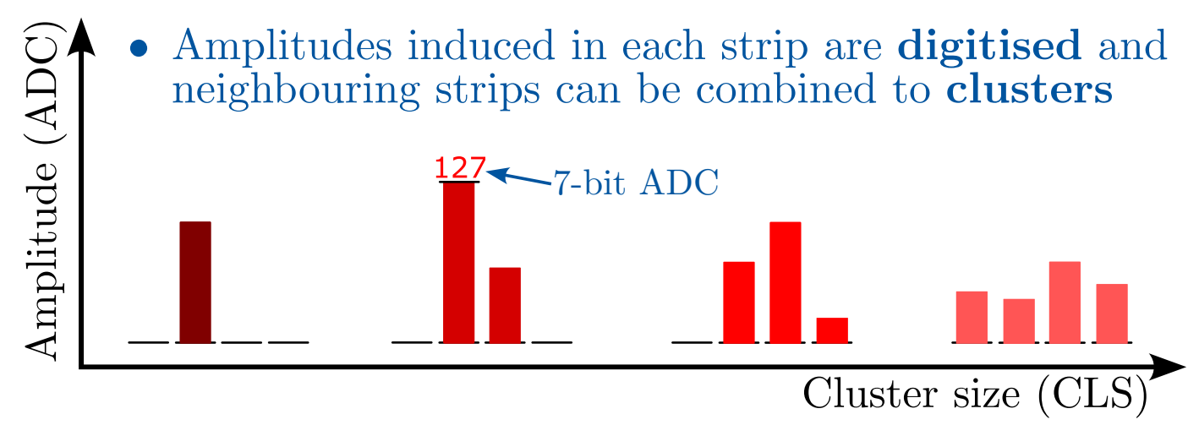
[arXiv:2310.05864]

- Based on **ionisation** losses in silicon tracking sensors

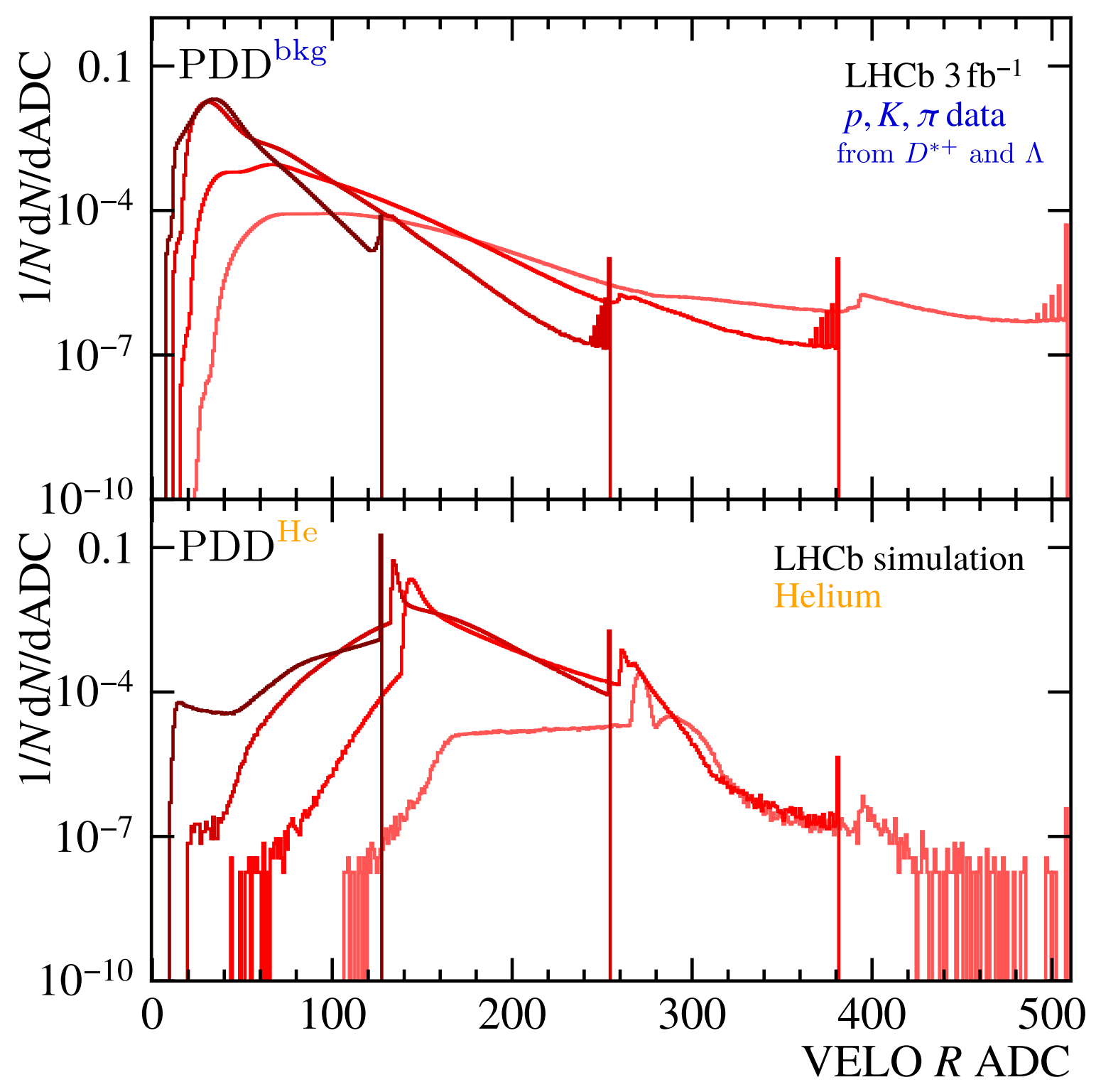
- Exploit $\boldsymbol{Z^2}$ dependence in Bethe formula



- Assume all doubly-charged tracks are ^{3}He:
  - Coalescence: ^{4}He suppressed by $\mathcal{O}(10^3)$



- Amplitudes induced in each strip are **digitised** and neighbouring strips can be combined to **clusters**



- Helium induces higher ADC counts and wider clusters
- Construct **P**robability **D**ensity **D**istributions (PDD):
  - Hypotheses: Signal (He) and $Z = 1$ background (bkg)
  - Separate for each silicon sensor type

Likelihood Discriminator

- Combine information from n clusters

$$\mathcal{L}^X = \left(\prod_{i=1}^{n} \mathrm{PDD}_i^X(\mathrm{CLS}, \mathrm{ADC})\right)^{\frac{1}{n}}$$

with $X = \{\mathrm{bkg}, \mathrm{He}\}$

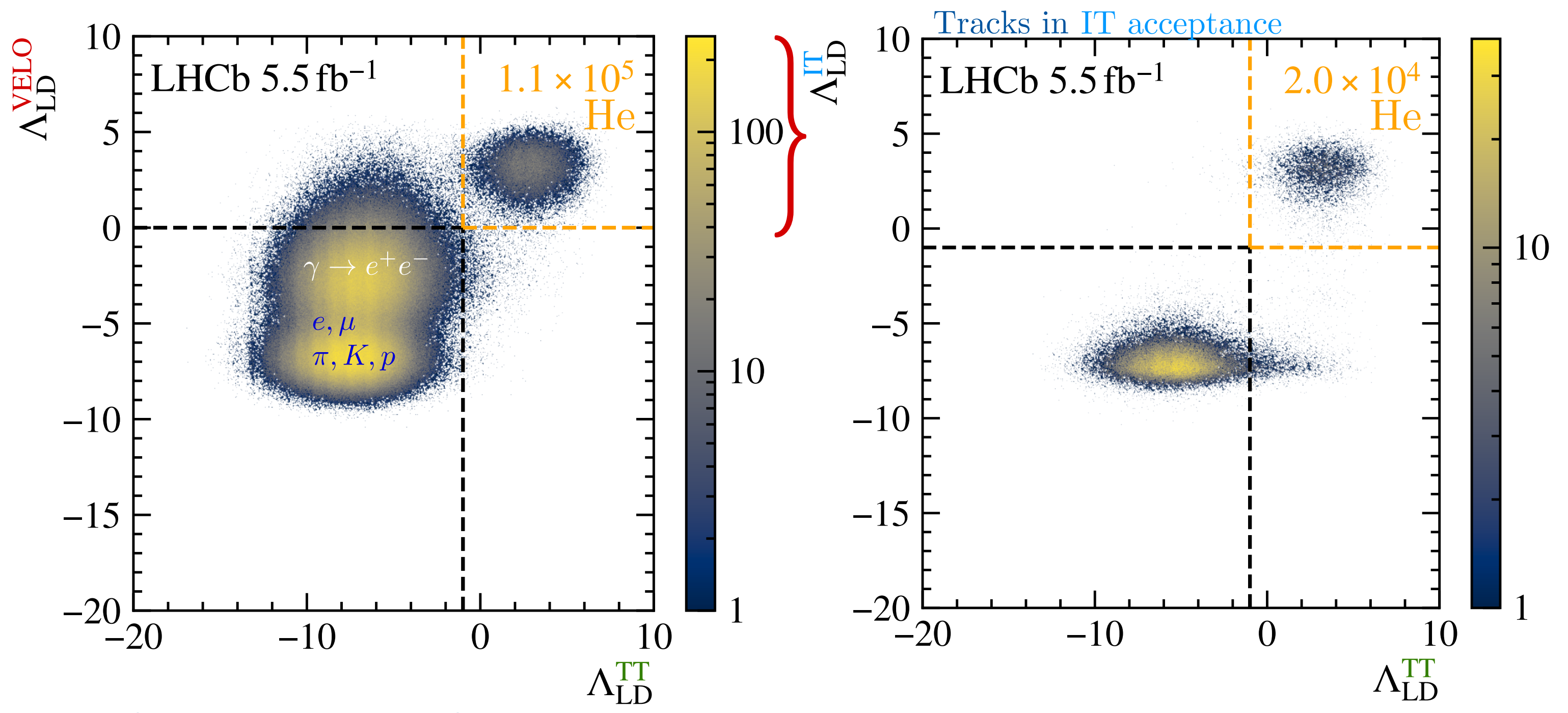
$$\boldsymbol{\Lambda_{\mathrm{LD}}} = \log \mathcal{L}^{\mathrm{He}} - \log \mathcal{L}^{\mathrm{bkg}}$$

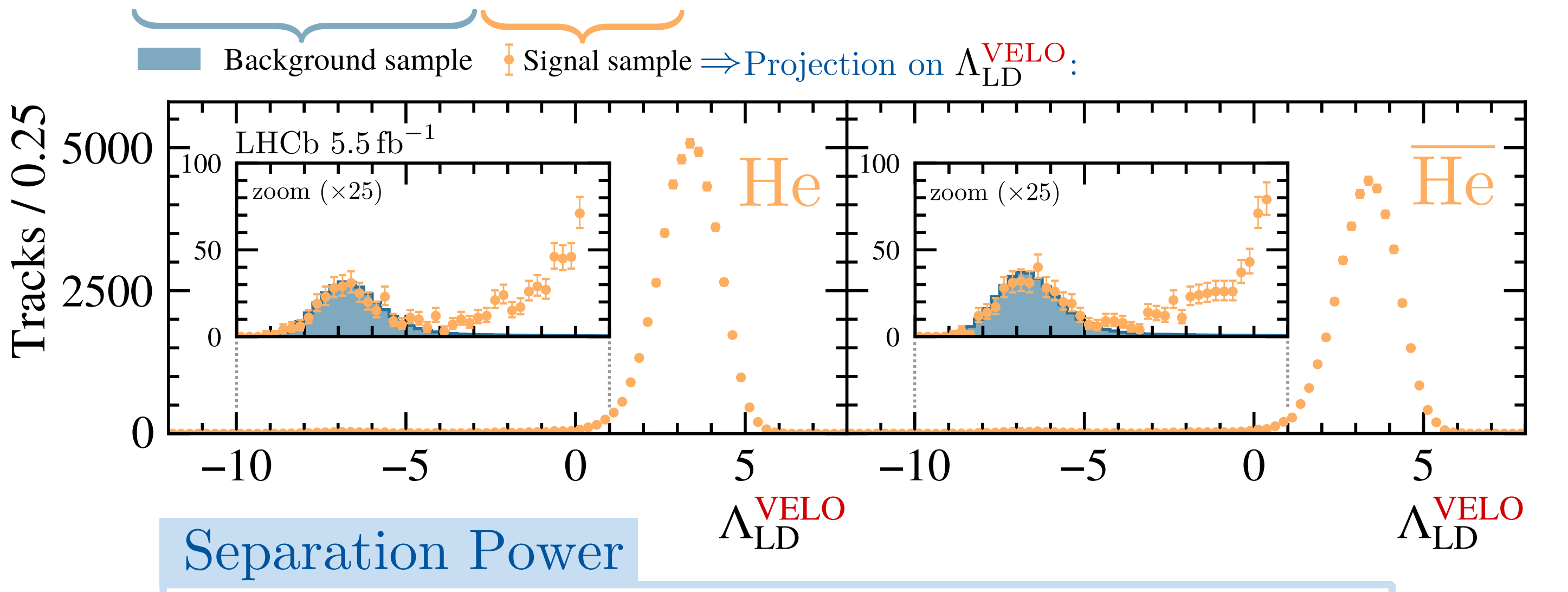
- Separate per silicon subdetector:
  1. $\Lambda_{\mathrm{LD}}^{\mathrm{VELO}}$
  2. $\Lambda_{\mathrm{LD}}^{\mathrm{TT}}$
  3. $\Lambda_{\mathrm{LD}}^{\mathrm{IT}}$

Observation of helium

[arXiv:2310.05864]

- Background suppression with **RICH** and **Outer Tracker**
- ✓ Separated population at large values of Λ_{LD}:





⇒ Projection on $\Lambda_{\mathrm{LD}}^{\mathrm{VELO}}$:

Separation Power

Performance for well-reconstructed tracks:
- Misidentification probability (bkg → He): $\mathcal{O}(10^{-12})$
- Helium signal efficiency: ∼ 50%

✓ **First** He and $\overline{\mathrm{He}}$ **identification** at LHCb!

Selection

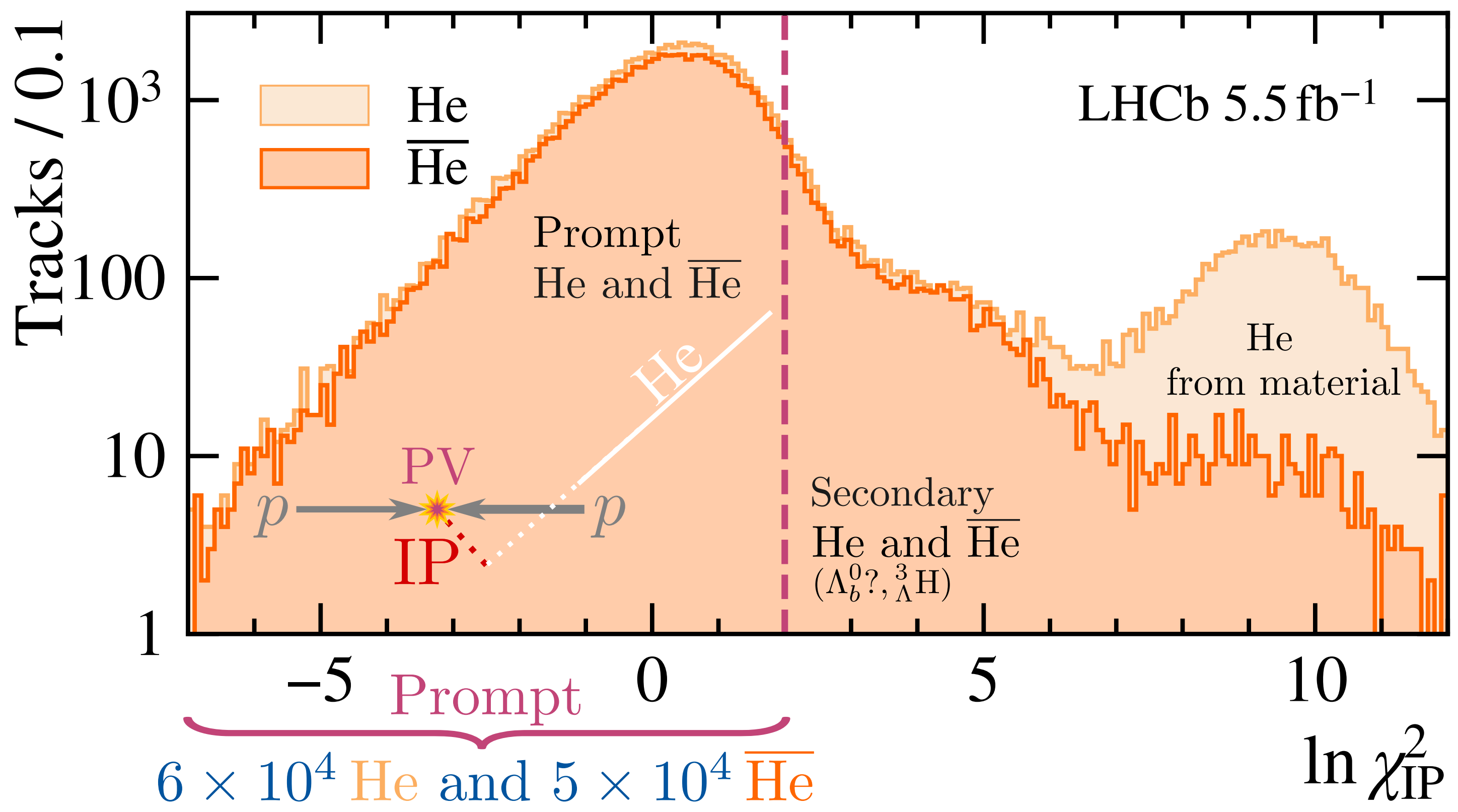
Dataset
- Proton-proton collisions
- Run 2 data (2016 – 2018, $\sqrt{s} = 13\,\mathrm{TeV}$)
- $\mathcal{L}_{\mathrm{int}} = 5.5\,\mathrm{fb}^{-1}$

Preselection
- Combined output of **all physics trigger** lines
- Prompt tracks, compatible with PV
- Mild track-quality requirements

Sources of helium

[arXiv:2310.05864]

- Determine **track origin** via impact parameter (IP):
  - Distance of closest approach of the extrapolated track to the primary vertex (PV)
  - χ^2_{IP}: χ^2 change of PV when reconstructed with or without the track $\simeq (\mathrm{IP}/\sigma_{\mathrm{IP}})^2$



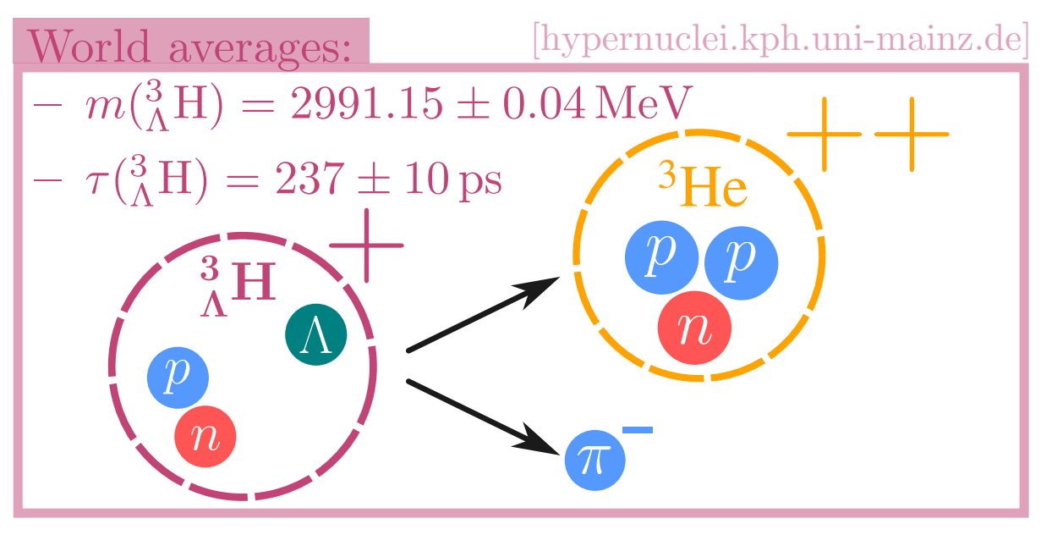
6×10^4 He and 5×10^4 $\overline{\mathrm{He}}$

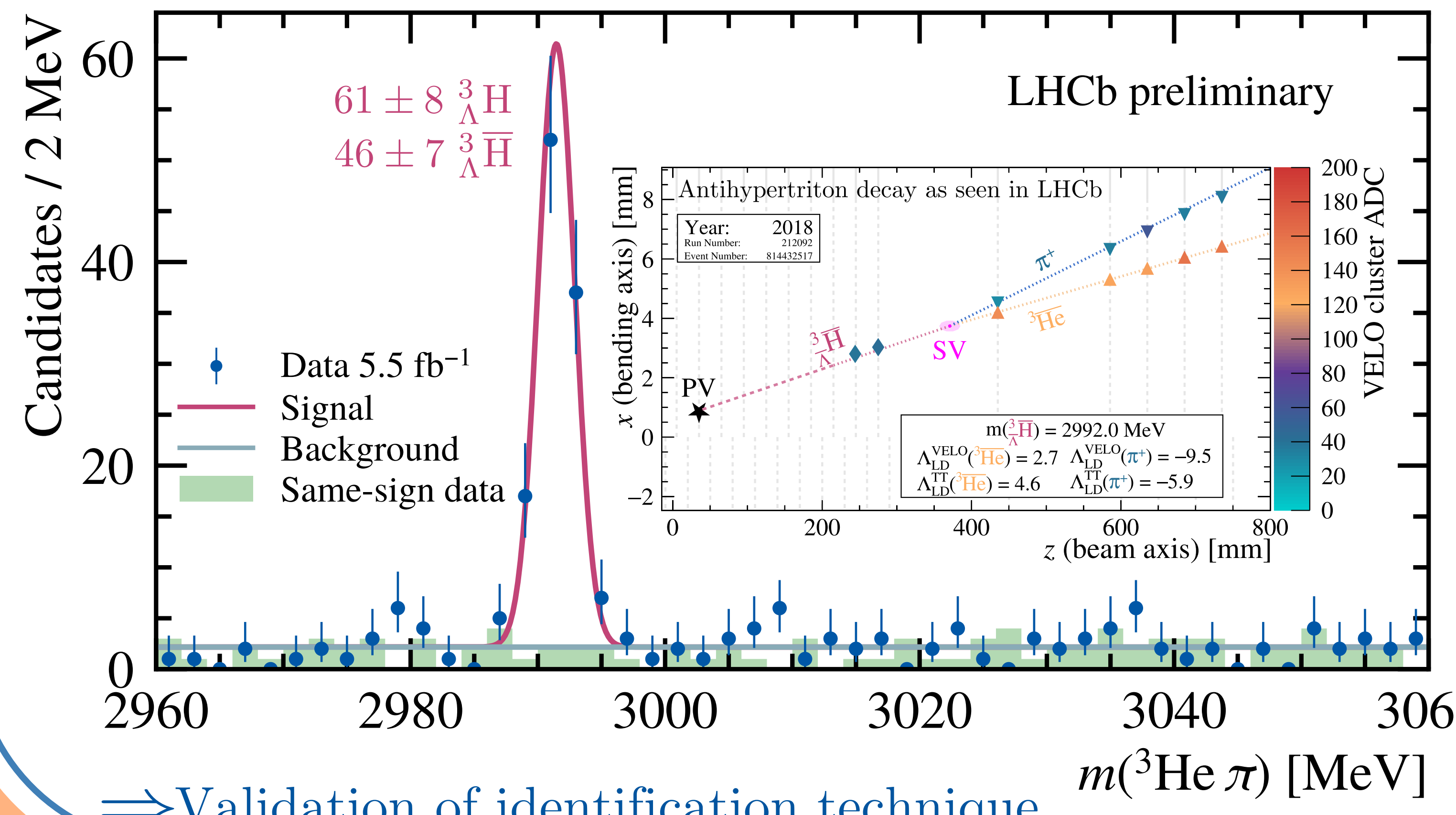
Observation of (anti)hypertriton

[LHCb-CONF-2023-002]

- p, n, Λ bound state
- Access to hyperon-nucleon interactions
  - ⇒ Implications for **neutron stars**
- Decay into ^{3}He and charged pion

World averages: [hypernuclei.kph.uni-mainz.de]
- $m(^3_\Lambda\mathrm{H}) = 2991.15 \pm 0.04\,\mathrm{MeV}$
- $\tau(^3_\Lambda\mathrm{H}) = 237 \pm 10\,\mathrm{ps}$





⇒ Validation of identification technique

This identification technique, innovative at the LHCb experiment, allows for a rich programme of measurements involving helium, of QCD and astrophysical interest!

156th LHCC Week
27th November 2023, CERN

References

Contact: hendrik.jage@cern.ch