Antihelium Identification and Antihypertriton Observation with LHCb

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On behalf of the LHCb Collaboration

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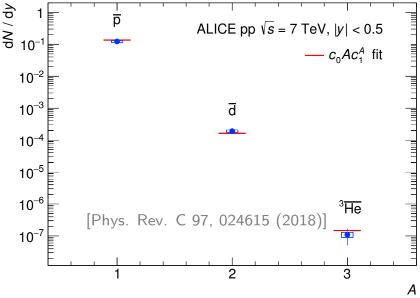
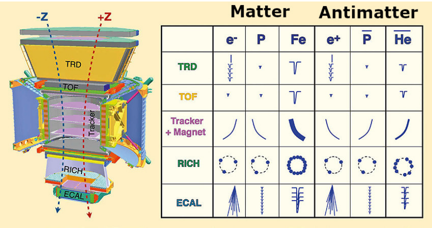
Cosmic Motivation: AMS-02 Result

[CERN Seminar by Prof. Samuel Ting]

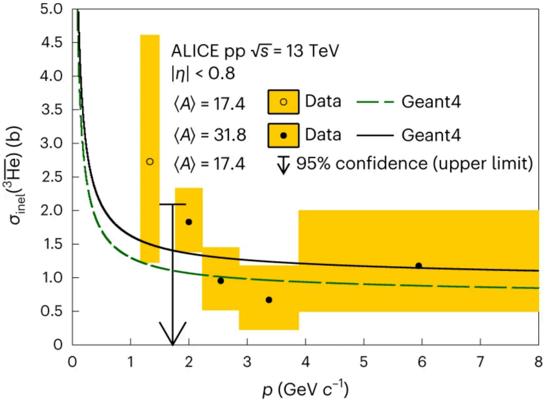
- Observation of $\mathcal{O}(10)$ $\overline{\mathrm{He}}$ candidates by AMS-02 [COSPAR 2022]
- Observe 1 $\overline{\mathrm{He}}$ for every 10^8 He
- Origin of antihelium events unclear
- No $\overline{\mathrm{d}}$ events reported at conferences
- New Source for helium required

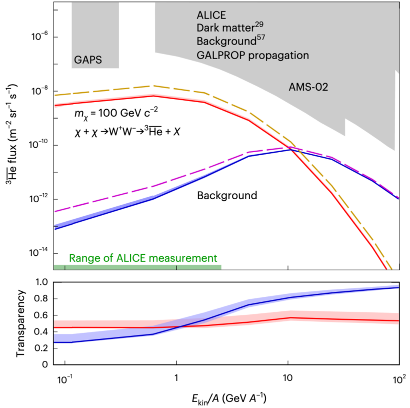




Recent ALICE Results on $^{3}\overline{\mathrm{He}}$ [Nat. Phys. 19, 61–71 (2023)]

Measurement of anti-^{3}He nuclei absorption in matter and impact on their propagation in the Galaxy

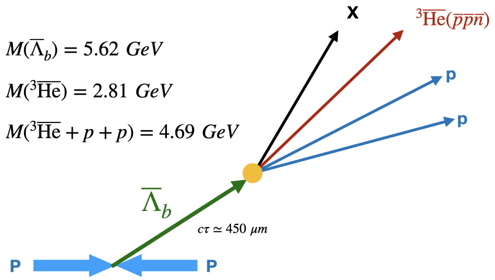


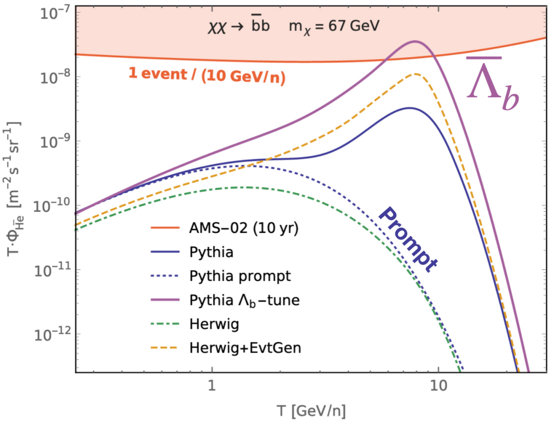


Theory Proposal: $^3\overline{\mathrm{He}}$ from $\overline{\Lambda}_b$ Decays

[Phys. Rev. Lett. 126, 101101]

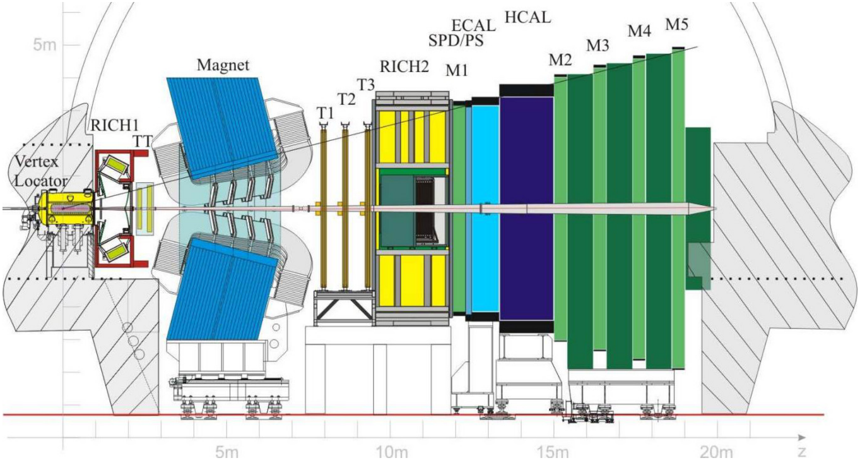
- Estimated $^3\overline{\mathrm{He}}$ production via $\overline{\Lambda}_b$:
  $\mathcal{B}(\overline{\Lambda}_b \to {}^3\overline{\mathrm{He}} + X) \simeq 3 \times 10^{-6}$
- **Coalescence** enhanced by small $\overline{\Lambda}_b$ phase-space
- A special tuning of Pythia gives $^3\mathrm{He}$ rate consistent with AMS observation (Λ_b-tune)
- Large uncertainties in non-perturb. QCD





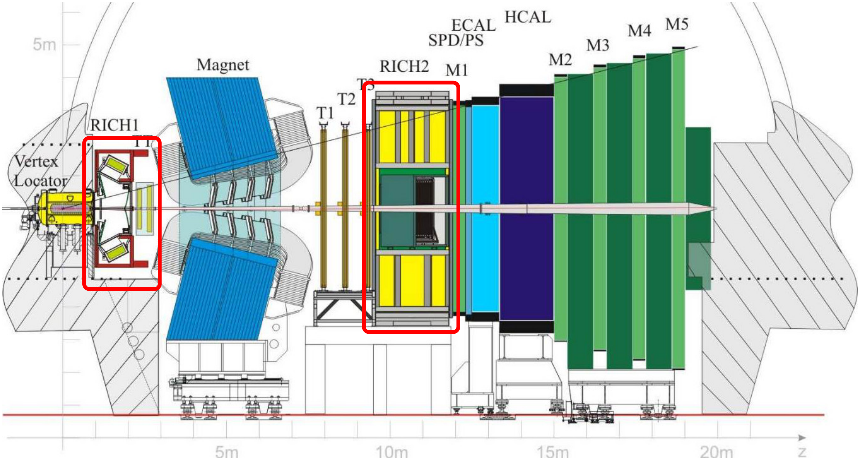
The LHCb Detector (2015-2018)

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

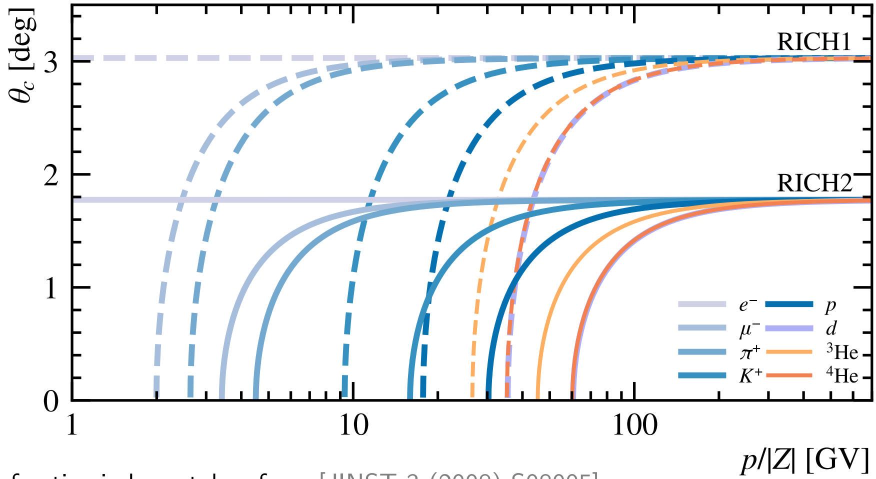


PID at LHCb: RICH

p/K misID $< 5\%$ [Eur. Phys. J. C 73, 2431 (2013)]



LHCb is Not Designed for Helium Identification



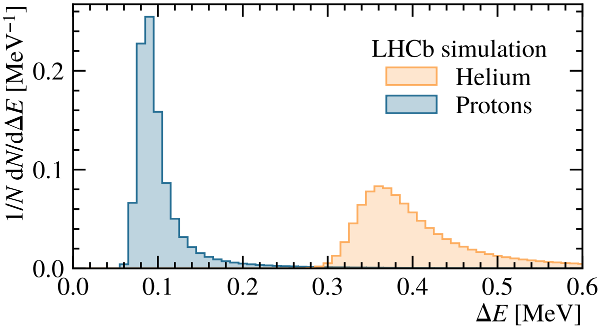
Refractive indeces taken from [JINST 3 (2008) S08005]

New PID Strategy: Exploit Z=2 of Helium

[R. Aaij et al 2024 JINST **19** P02010]

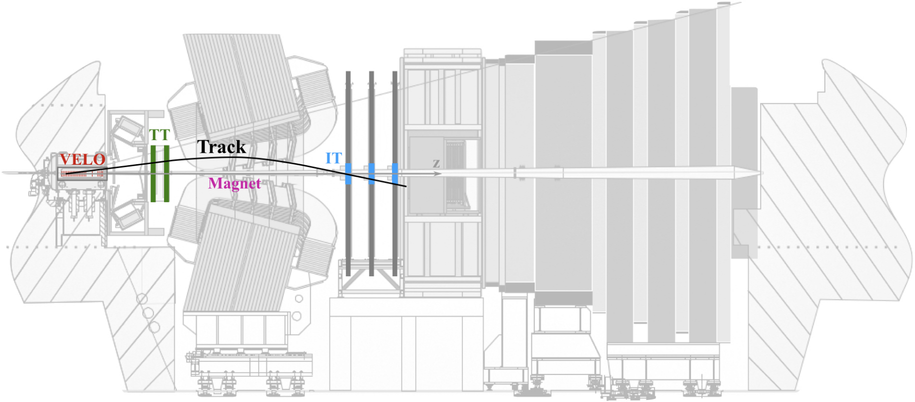
- Ionisation losses in **Silicon Trackers**
- Proportional to Z^2 by Bethe formula

- **Dataset**:
  - proton-proton collisions
  - Run 2 (2016-2018, $\sqrt{s} = 13\ \mathrm{TeV}$)
  - $\mathcal{L}_{int} = 5.5\ \mathrm{fb}^{-1}$
- **Preselection**:
  - Combined output of all trigger lines
  - Loose track-quality requirements
  - Prompt tracks from PV



LHCb Silicon Trackers

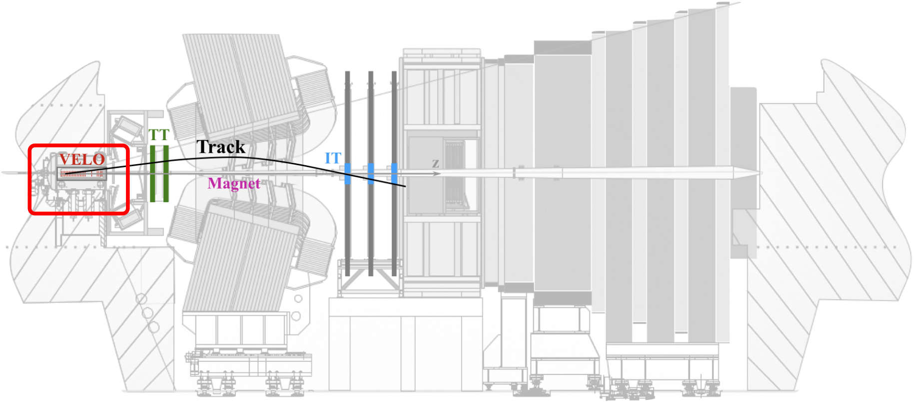
[JINST 9 (2014) P09007] [Phys.Procedia 37 (2012) 851-858] [2014 JINST 9 P01002]



$\Delta p/p = 0.5\%$, VTX Res. 8 (45)μm x and y (z) axis, IP Res. (15 +29/pT[GeV])μm, τ Res. $\sim$ 45fs

LHCb Silicon Trackers

[JINST 9 (2014) P09007] [Phys.Procedia 37 (2012) 851-858] [2014 JINST 9 P01002]



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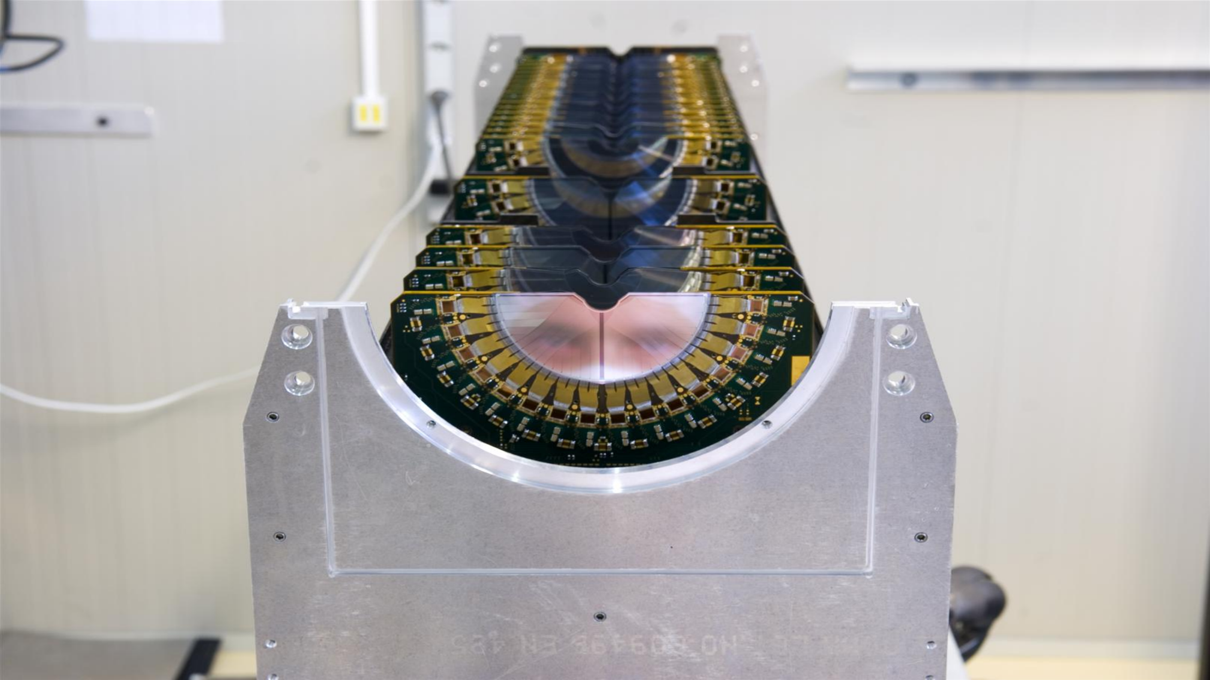
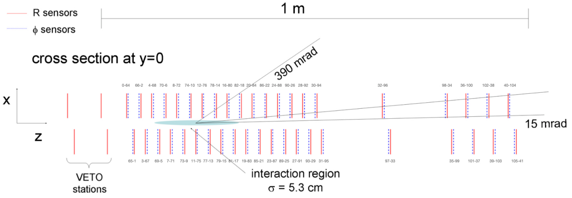
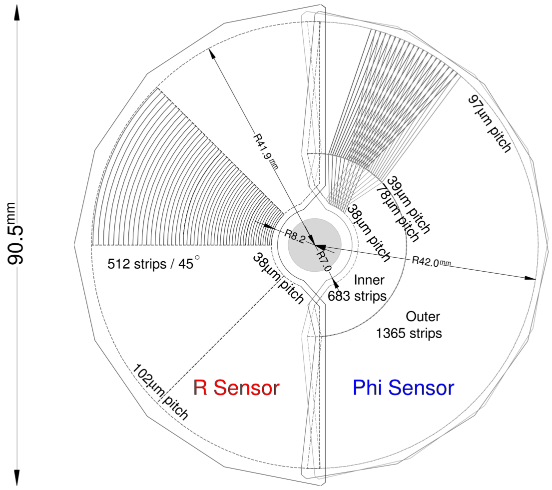


VELO Summary

- Charge is digitised as **7-bit** ADC
- Two types of sensors R and Φ
- Average of 13 VELO hits per track
- Clusters formed from up to **4** strips



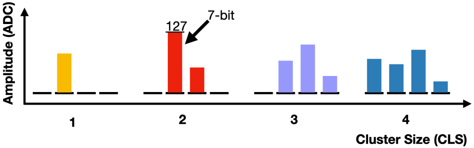
[JINST 9 (2014) P09007]

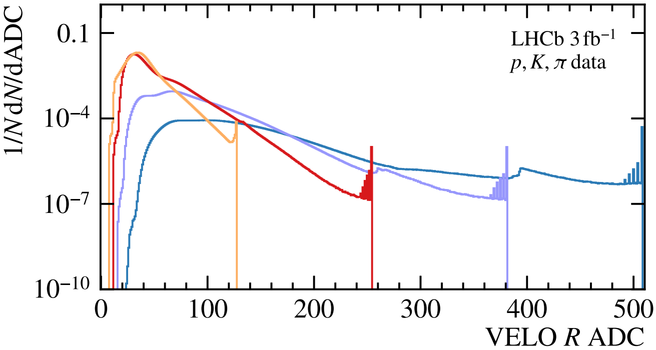


VELO Response for Z=1 Particles

[R. Aaij et al 2024 JINST **19** P02010]

- 4 different cluster sizes (CLS)
- Visible saturation peaks (digitisation)
- Amplitude peaks at $\sim$ 40 ADC
- Z=1 data from D^{+*} and Λ decays
- Separate for R and Φ sensors

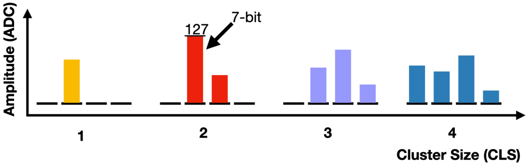


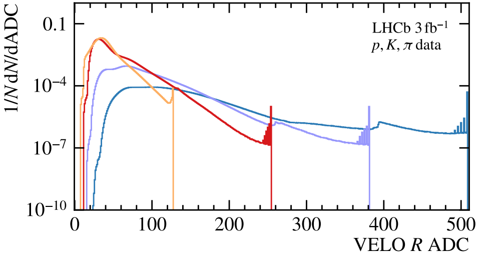


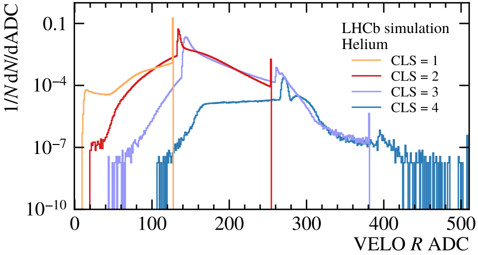
Helium Simulation VELO Response

[R. Aaij et al 2024 JINST **19** P02010]

- Helium induces higher ADC counts
- Helium tends to have larger size clusters
- Helium has more saturated strips
- Can be used for discrimination







Constructing Likelihood Discriminator

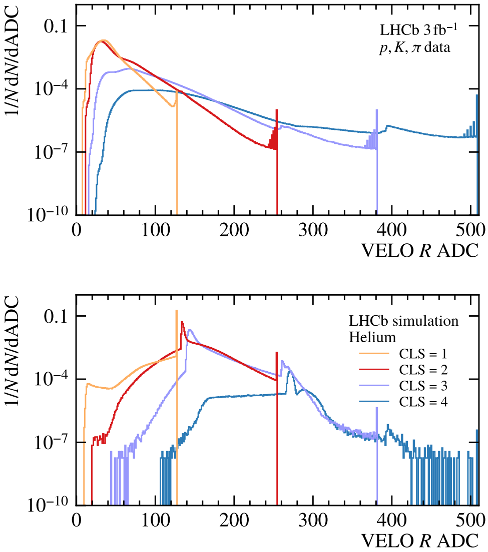
[R. Aaij et al 2024 JINST **19** P02010]

1. Use ADC distributions as PDDs
2. Derive a bkg/^{3}He probability for each cluster
3. Combine the probabilities to likelihoods
4. Define a likelihood discriminator for the whole track

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

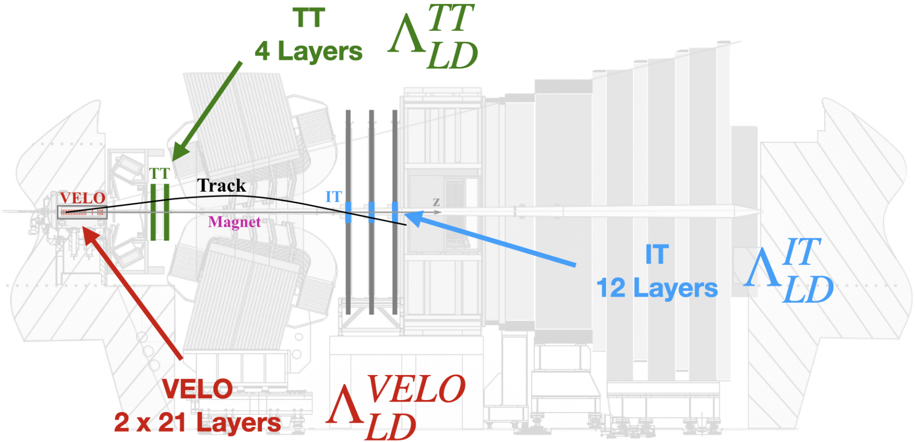
with X = {bkg, He}

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



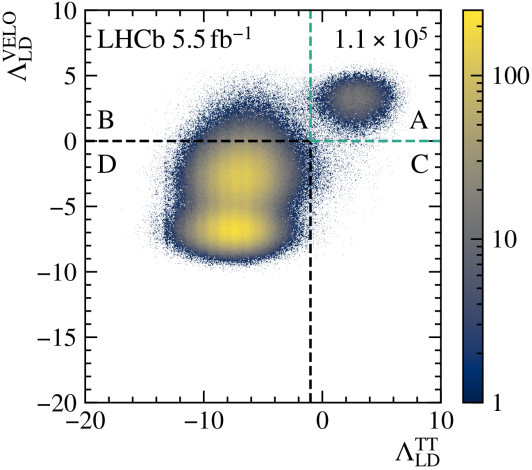
Combining the Full Power of LHCb Tracking System

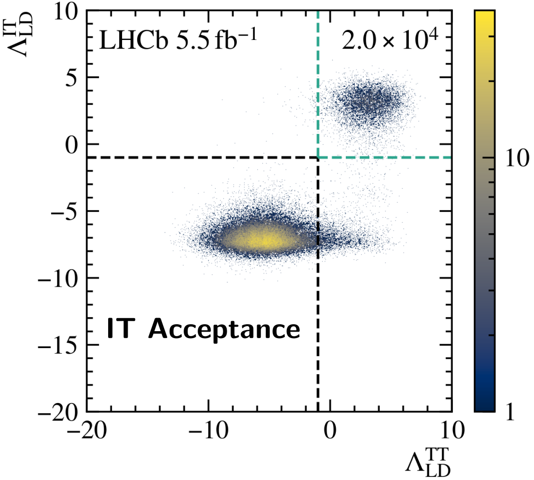
[JINST 9 (2014) P09007] [Phys.Procedia 37 (2012) 851-858] [2014 JINST 9 P01002]



$\varepsilon_{LongTrack} \sim 96\%$

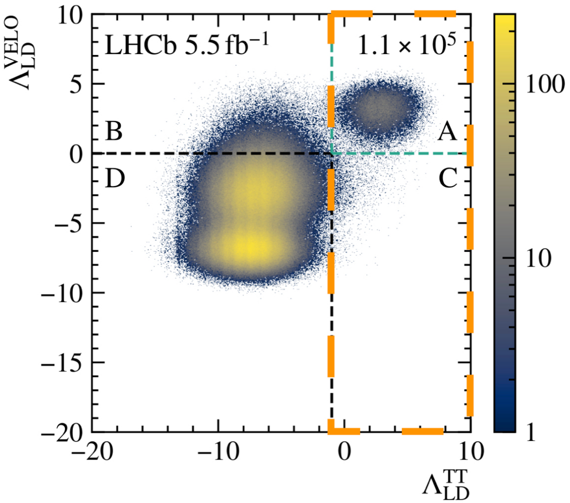
The First Observation of Prompt Helium at LHCb [R. Aaij et al 2024 JINST **19** P02010]

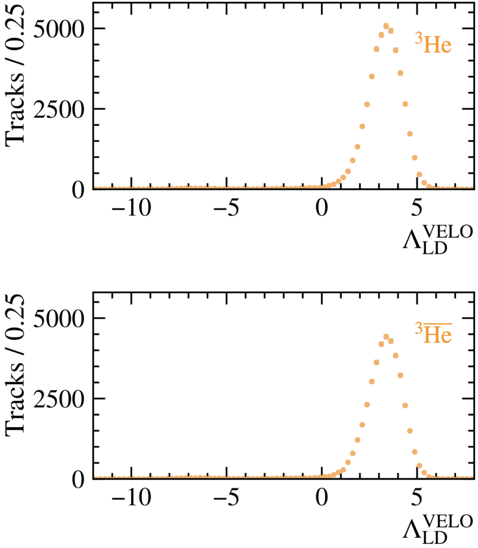




Separation Power

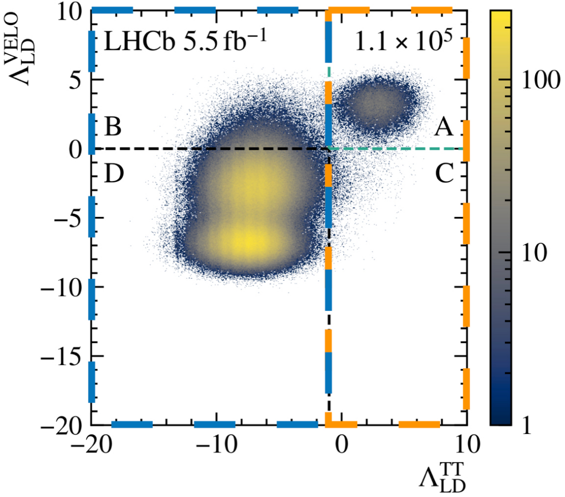
[R. Aaij et al 2024 JINST **19** P02010]

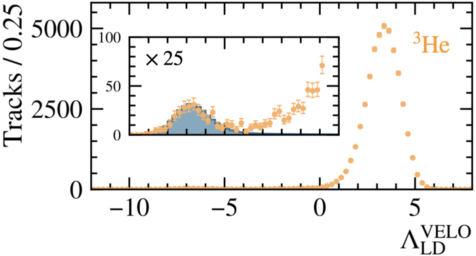


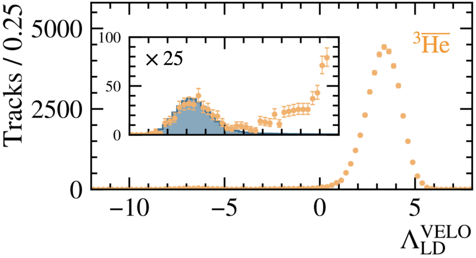


Separation Power: $\mathcal{O}(10^{-12})$ with Signal Efficiency $\sim 50\%$

[R. Aaij et al 2024 JINST **19** P02010]

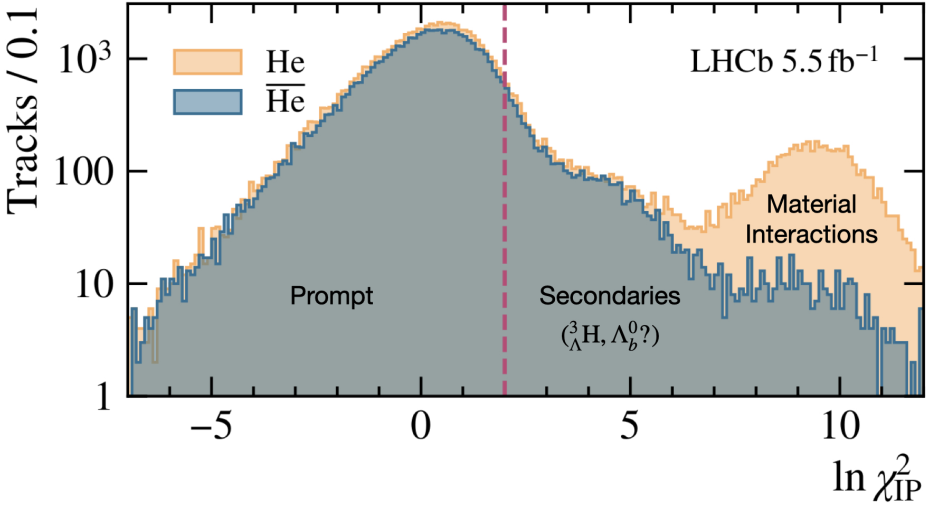






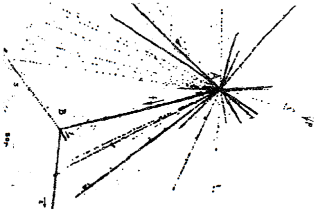
Sources of Helium

[R. Aaij et al 2024 JINST **19** P02010]

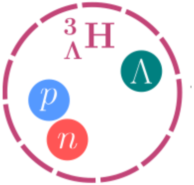


A Brief History of Hypermatter

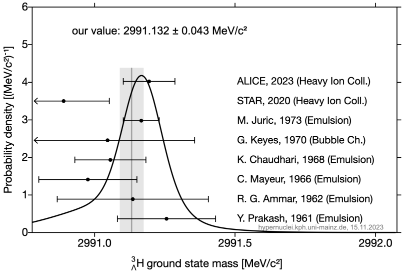
- First *hyperfragments* discovered in 1952
- Can access hyperon-nucleon interaction
  $\Rightarrow$ Relevant for neutron stars
- Hypertriton - ${}^{3}_{\Lambda}\mathrm{H}$ is the lightest hypernucleus
- Hypertriton "Lifetime Puzzle"

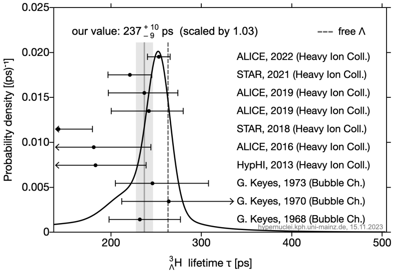


[1953 Philos. Mag., 44:348]



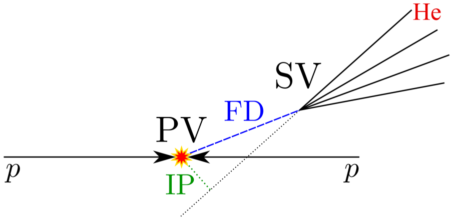
[hypernuclei.kph.uni-mainz.de]

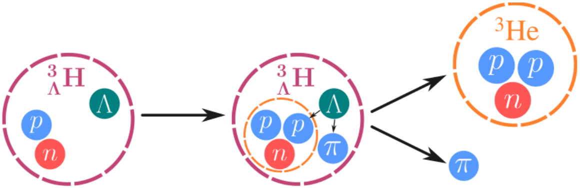




Hypertriton Reconstruction with LHCb

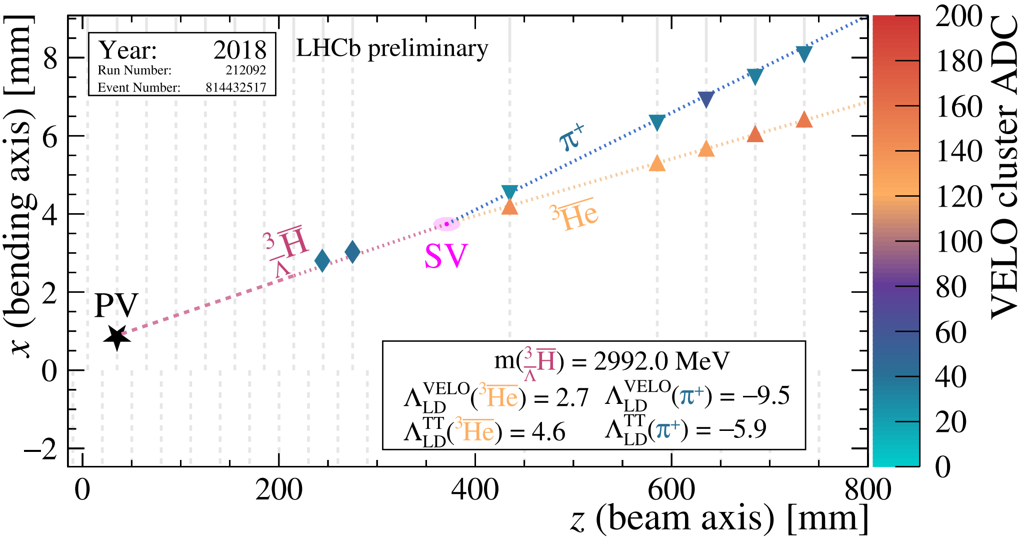
- Unambiguous $^{3}\mathrm{He}$ Signature
- 2-body decay into helium: ${}^{3}_{\Lambda}\mathrm{H} \to {}^{3}\mathrm{He}\pi^{-}$
- Secondary helium candidates: $\ln\chi^2_{IP}({}^{3}\mathrm{He}) > 2$
- Form 2-body vertex with charged pion
- Apply vertex quality requirements





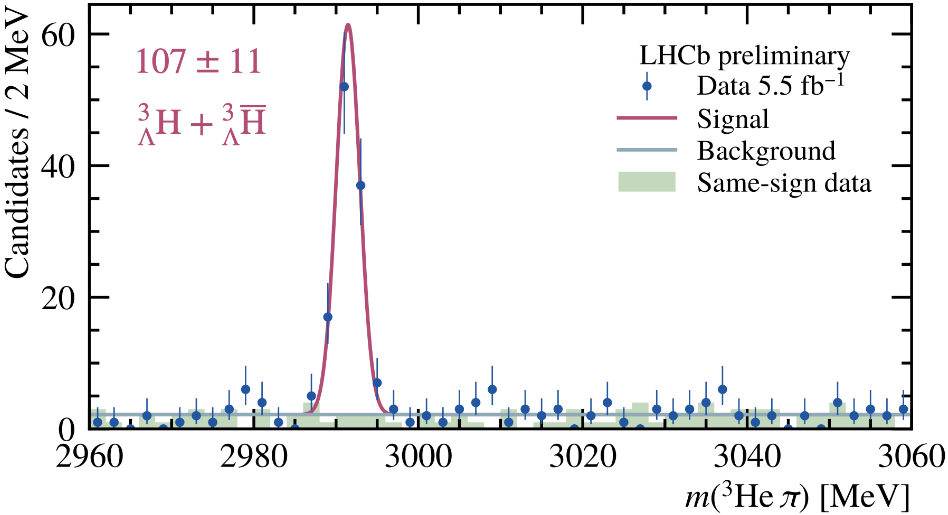
Antihypertriton Candidate in VELO

[CERN-LHCb-CONF-2023-002]



Observation of Hypertriton at LHCb

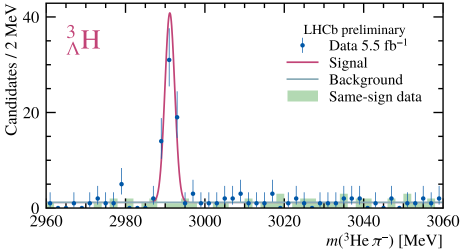
[CERN-LHCb-CONF-2023-002]

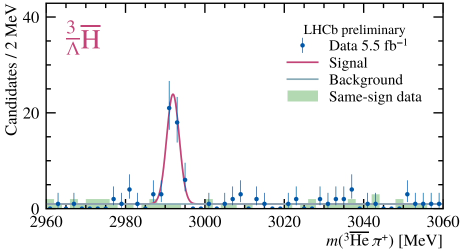


Observation of (Anti)hypertriton at LHCb

[CERN-LHCb-CONF-2023-002]

- **Preliminary fit results:**
  - $N({}^{3}_{\Lambda}\mathrm{H} = 61 \pm 8)$
  - $N({}^{3}_{\Lambda}\overline{\mathrm{H}} = 46 \pm 7)$
- Statistical mass precision: 0.16 MeV
- **Under investigation**:
  - Charge-sign dependent energy-loss corrections
  - Tracking corrections for Z=2
  - Efficiency and acceptance corrections

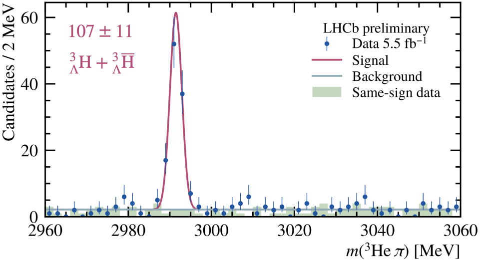


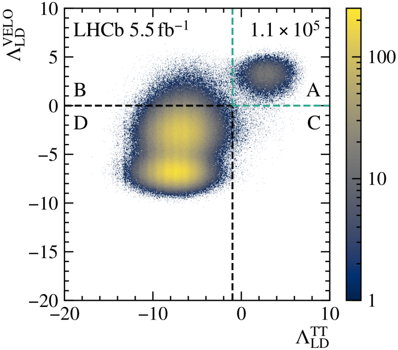


Summary

[R. Aaij et al 2024 JINST **19** P02010] [CERN-LHCb-CONF-2023-002]

- First observation of helium in LHCb
- Using **dE/dx, timing, RICH** information on Run 2 data
- 1.1×10^5 prompt (anti)helium
- Negligible background
- 107 ± 11 (anti)hypertriton reconstructed





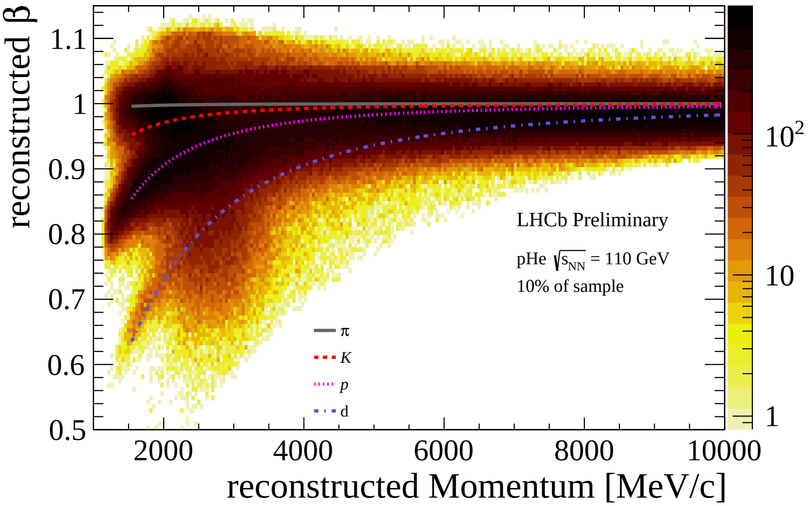
Outlook:

- More physics to come from light nuclei
- Determine properties of hypertriton
- Measure helium production from Λ_b^0

BACKUP

Light Nuclei Identification at LHCb - Deuterons

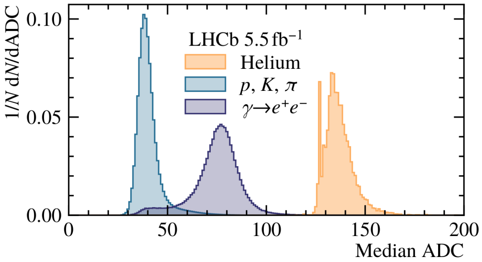
[LHCB-FIGURE-2023-017]

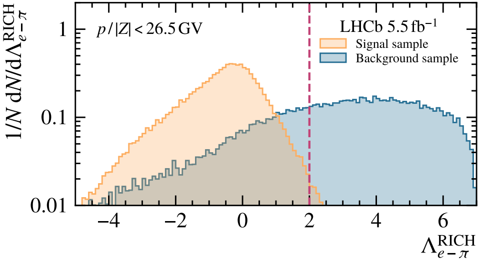


Refinements: Photon Conversions

[R. Aaij et al 2024 JINST **19** P02010]

- e^- and e^+ pair from photon conversion flies almost co-linearly
- Energy deposited on the same clusters
- Can be rejected by applying RICH cut
- Rejection up to $\mathcal{O}(10^2)$





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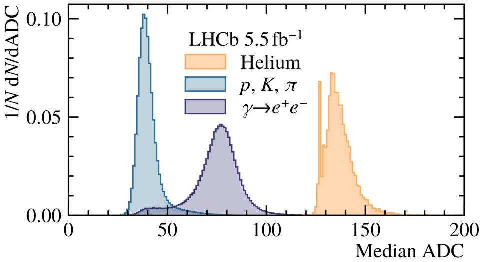
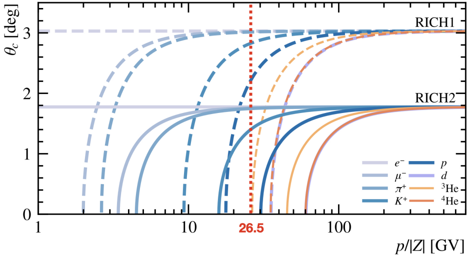
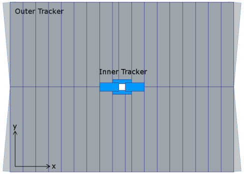
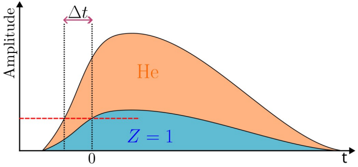


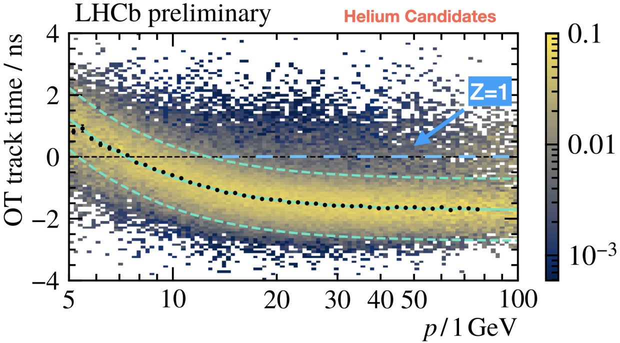


Refinements: Outer Tracker Timing Information [R. Aaij et al 2024 JINST **19** P02010]



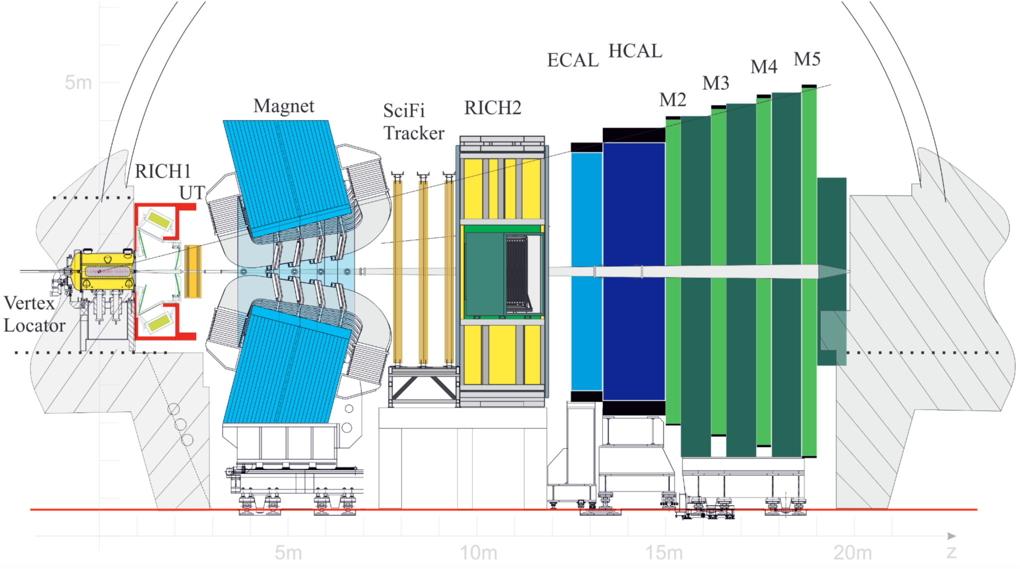


- Outer Tracker (OT) - Straw Drift Tube detector
- OT has constant threshold (no dE/dx information)
- Helium crosses the threshold earlier
- PID power via "*OT track time*"



Backup: LHCb Detector Upgrade - Run 3

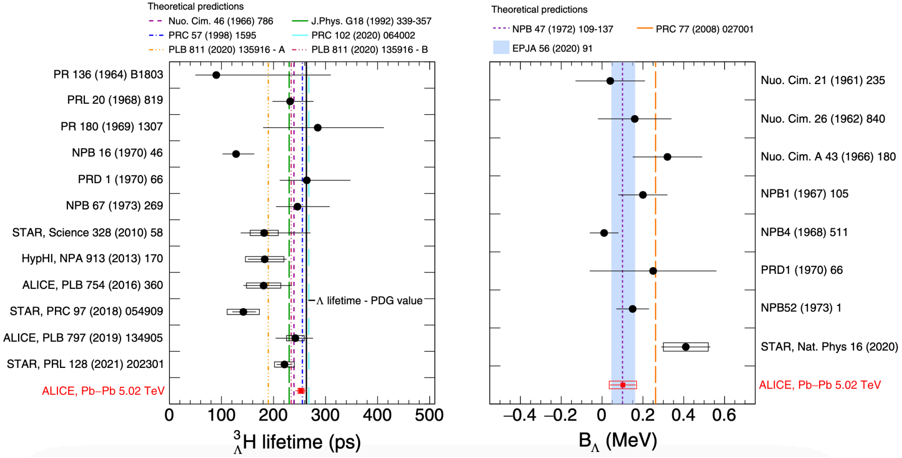
[CERN-LHCC-2014-001]



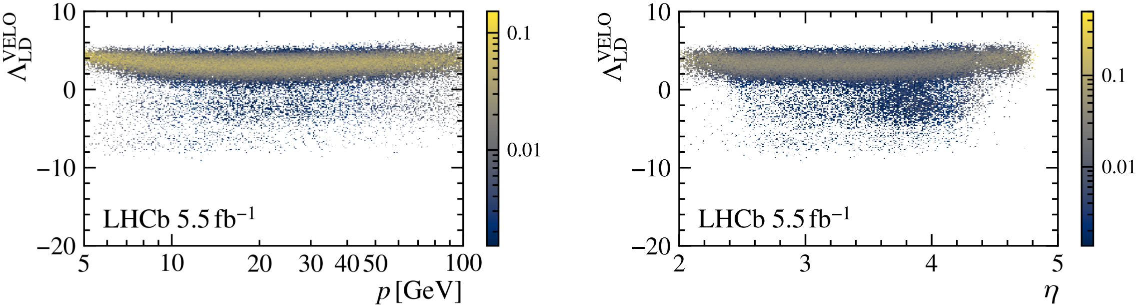
Backup: ALICE Results on Hypertriton

[Phys. Rev. Lett. 131, 102302]

Measurement of the Lifetime and Λ Separation Energy of ${}^{3}_{\Lambda}\mathrm{H}$

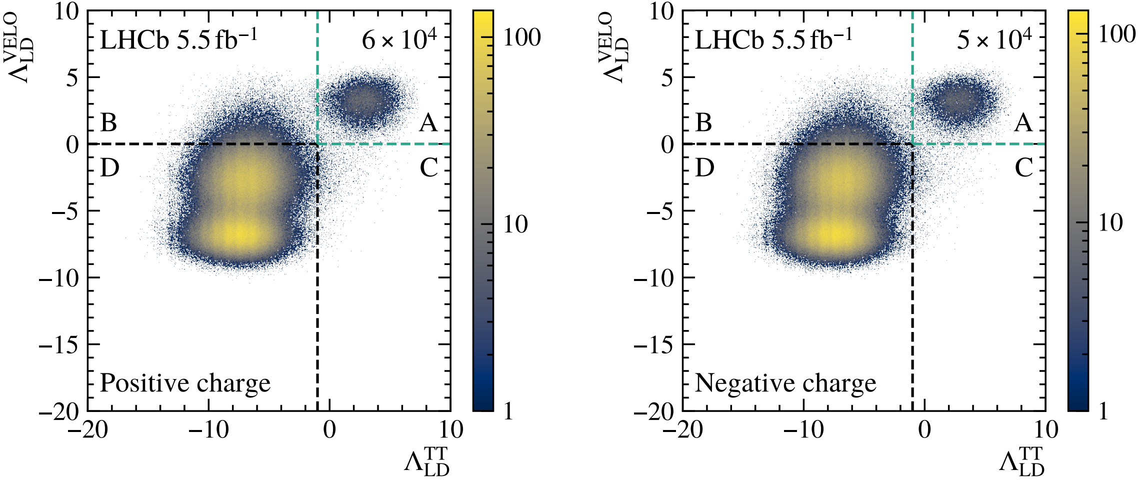


Backup: No Strong Λ_{LD}^{VELO} Dependence on Kinematics [R. Aaij et al 2024 JINST **19** P02010]



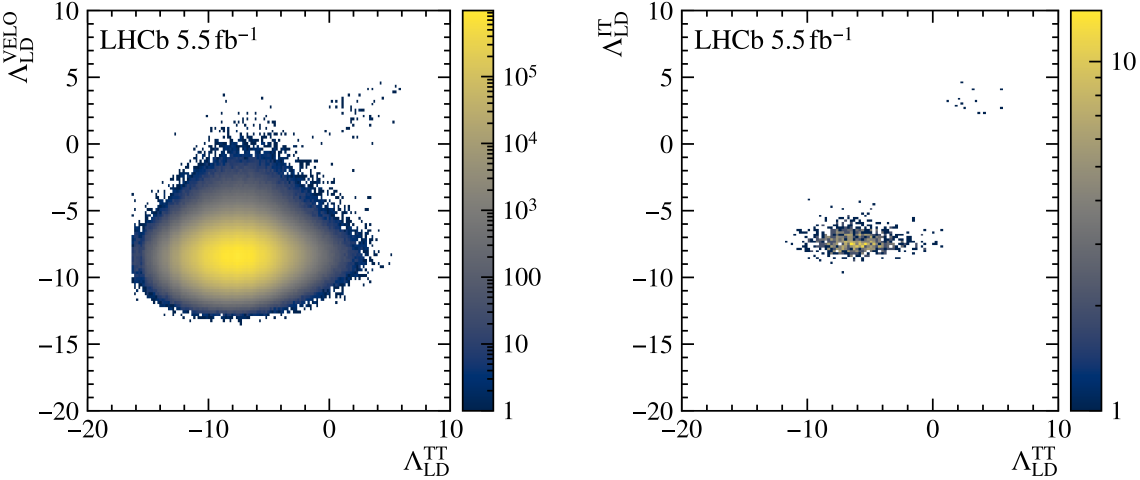
Backup: Prompt Helium Split by Charge

[R. Aaij et al 2024 JINST **19** P02010]

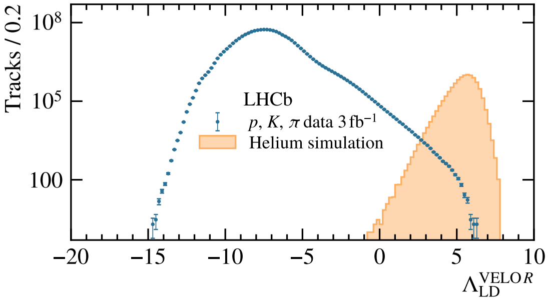


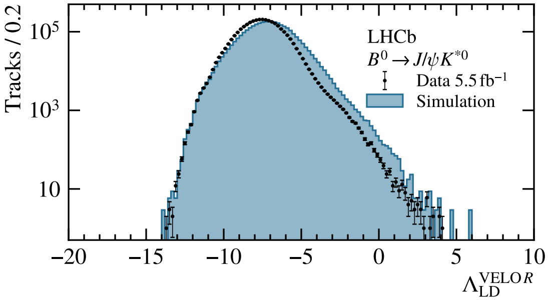
Backup: Prompt Helium in Minbias

[R. Aaij et al 2024 JINST **19** P02010]



Backup: Data and Simulation Comparison

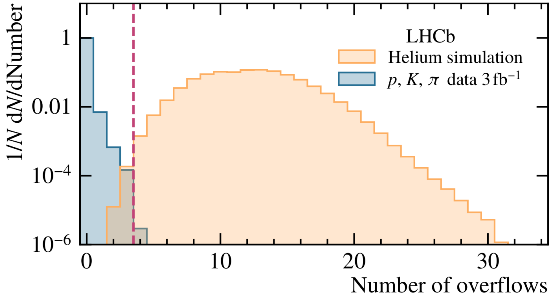




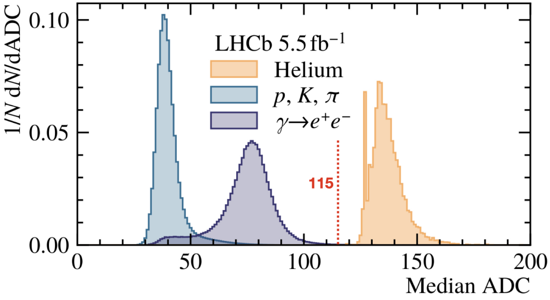
Backup: Different Preselections

[R. Aaij et al 2024 JINST **19** P02010]

Preselection 1

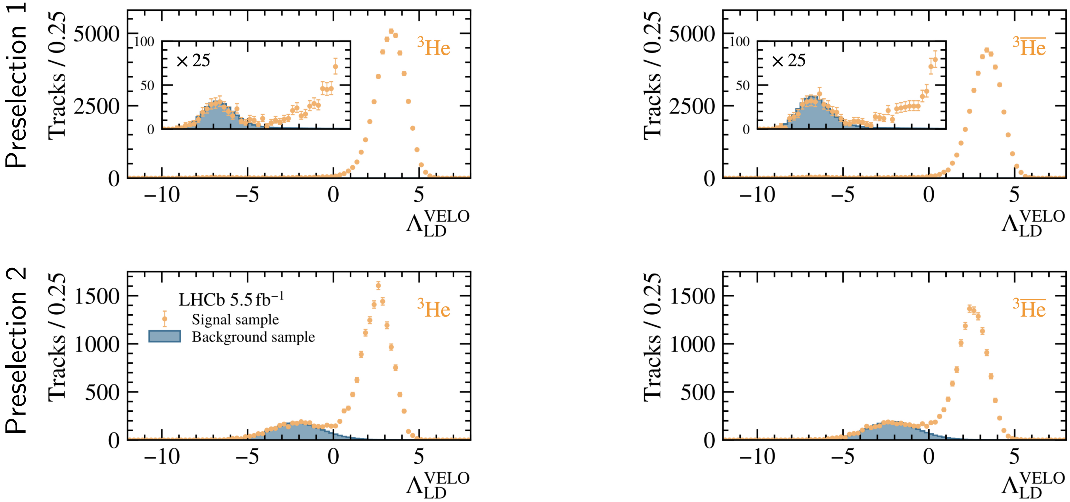


Preselection 2



Backup: Different Preselections

[R. Aaij et al 2024 JINST **19** P02010]



Backup: Hypertriton Selection

[CERN-LHCb-CONF-2023-002]