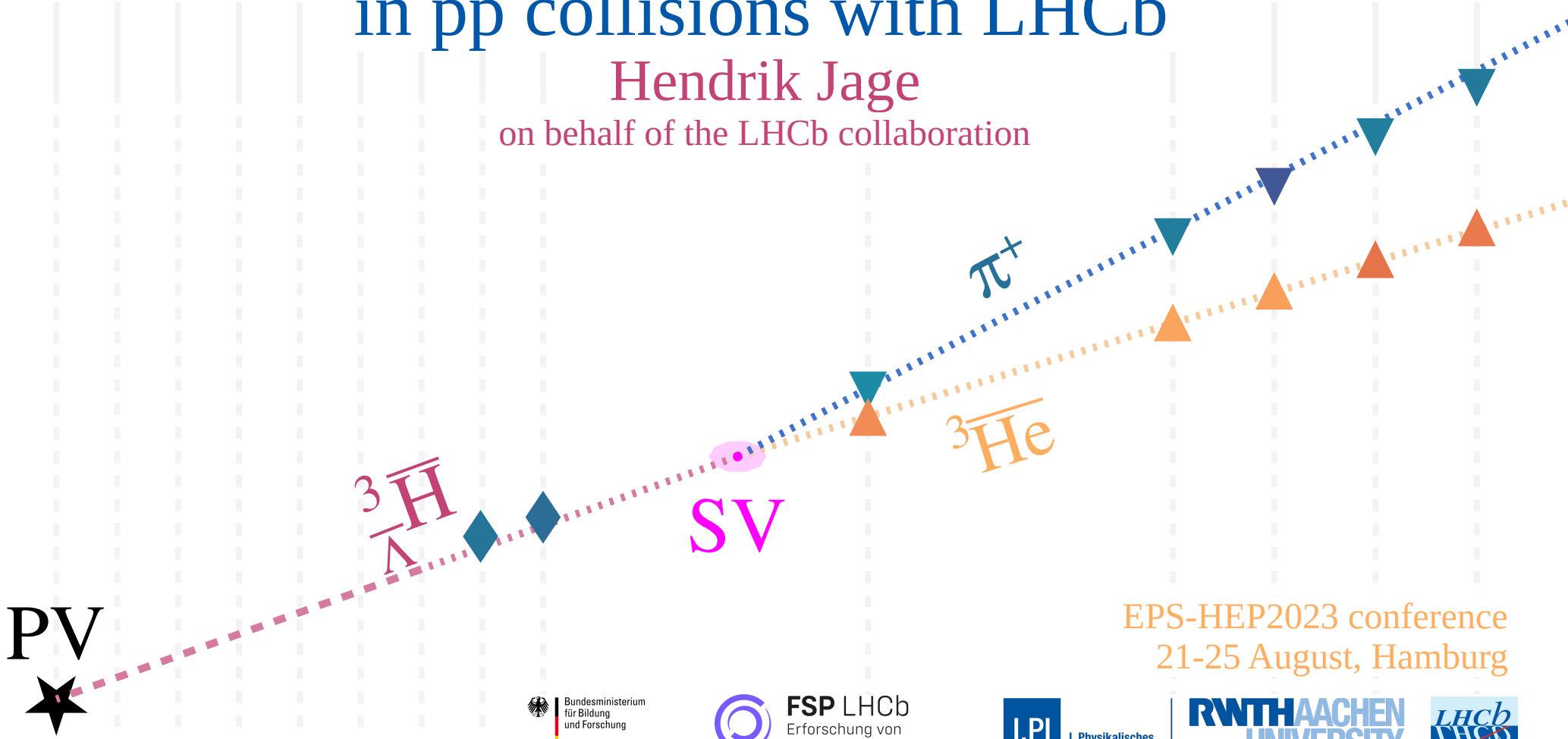
Observation of **antihelium** and **antihypertriton** in pp collisions with LHCb

Hendrik Jage
on behalf of the LHCb collaboration



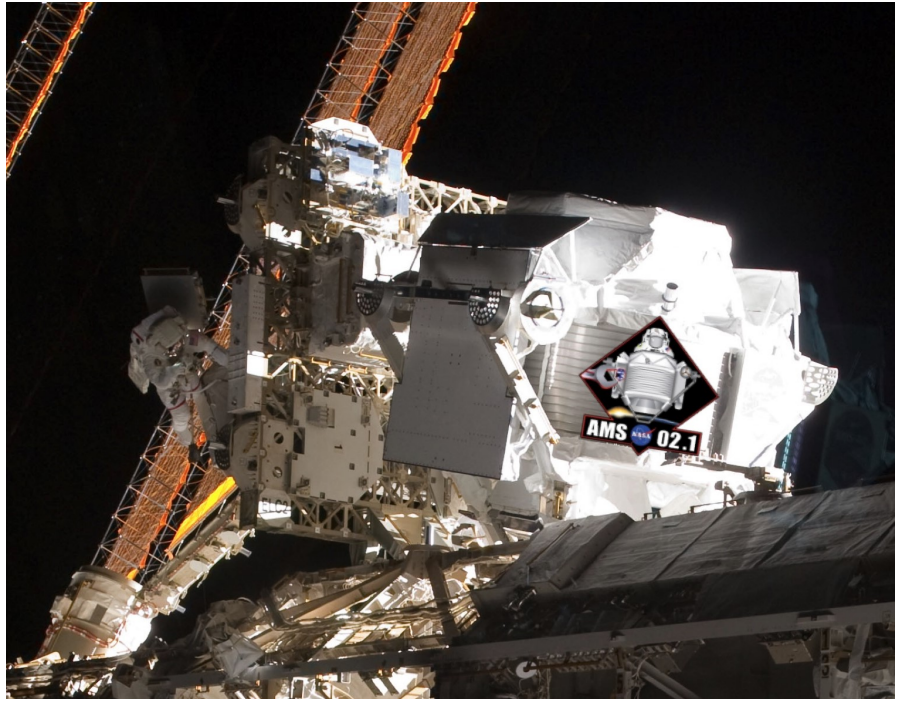
EPS-HEP2023 conference
21-25 August, Hamburg

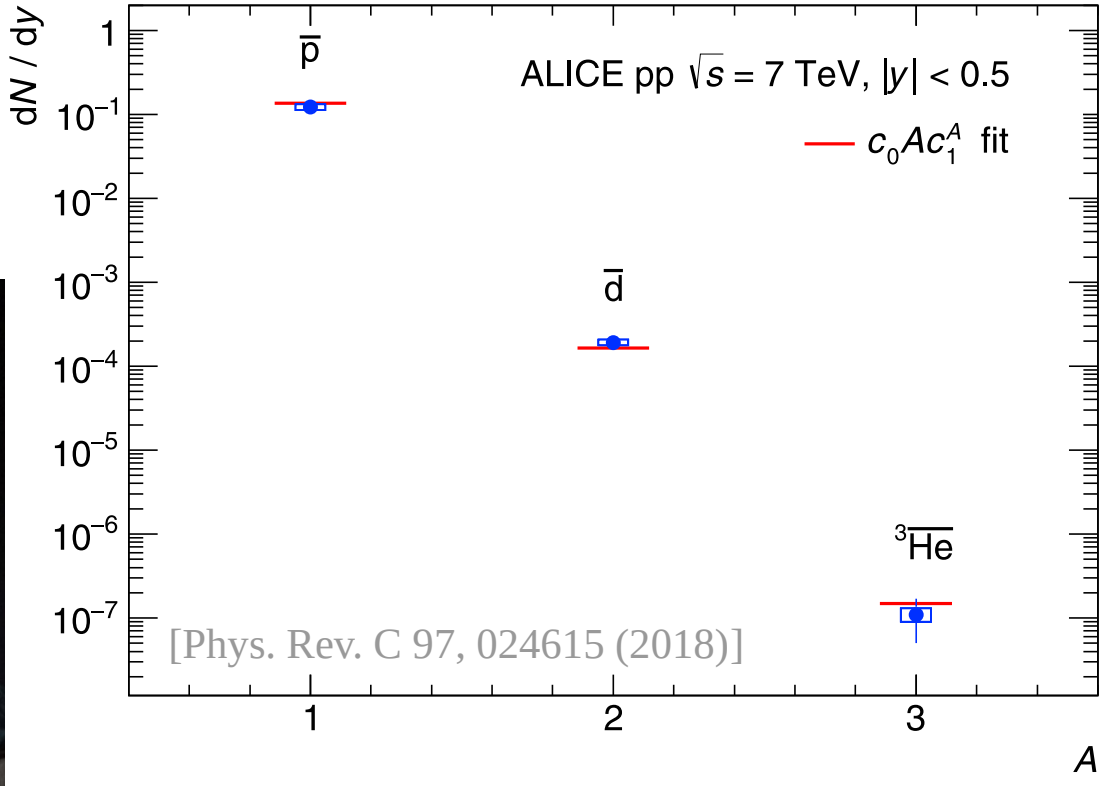
Bundesministerium für Bildung und Forschung
FSP LHCb Erforschung von Universum und Materie
I. Physikalisches Institut
RWTH AACHEN UNIVERSITY
LHCb

AMS-02: Antihelium in Space

[COSPAR 2022]

- Reported $\mathcal{O}(10)$ $\overline{\mathrm{He}}$ candidates in Cosmic Rays at conferences
- Origin is unclear:
  AMS never reported $\overline{\mathrm{d}}$ observation



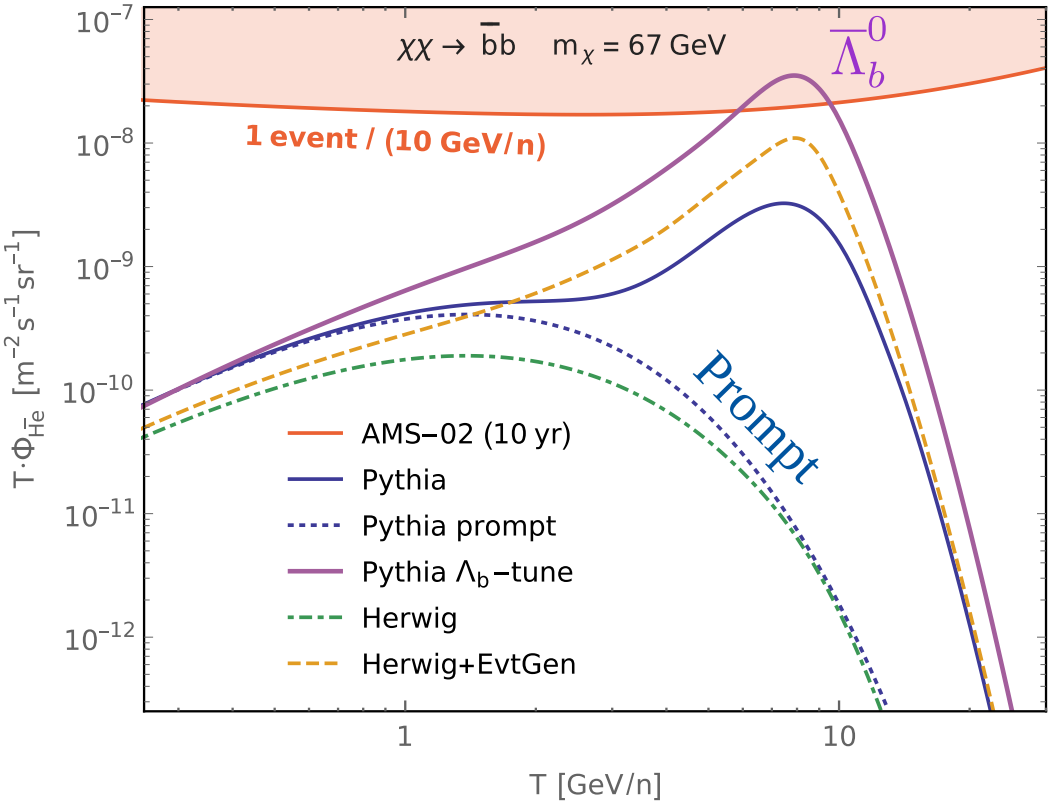


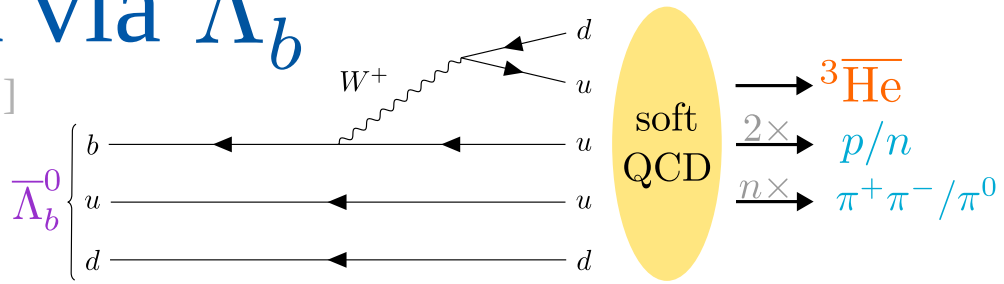
$\Rightarrow$ Expected $\overline{\mathrm{d}}/^3\overline{\mathrm{He}}$ ratio is 10^3

- If AMS-02 results are confirmed:
  New source of $\overline{\mathrm{He}}$ required

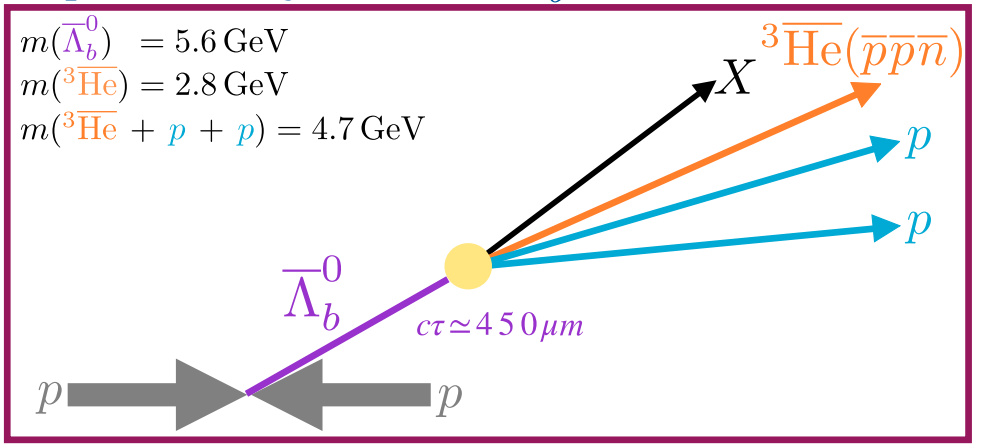
Antihelium-3 production via $\overline{\Lambda}_b^0$

M. W. Winkler and T. Linden [Phys. Rev. C 97, 024615 (2018)]





Experimentally cleanest: $\overline{\Lambda}_b^0 \to {}^3\overline{\mathrm{He}}\, p\, p + X$

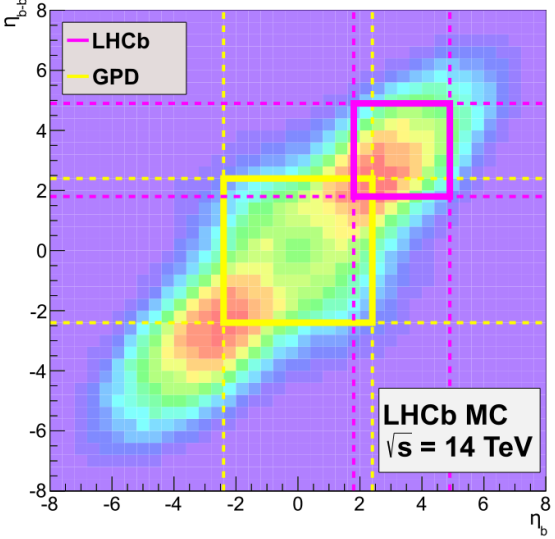


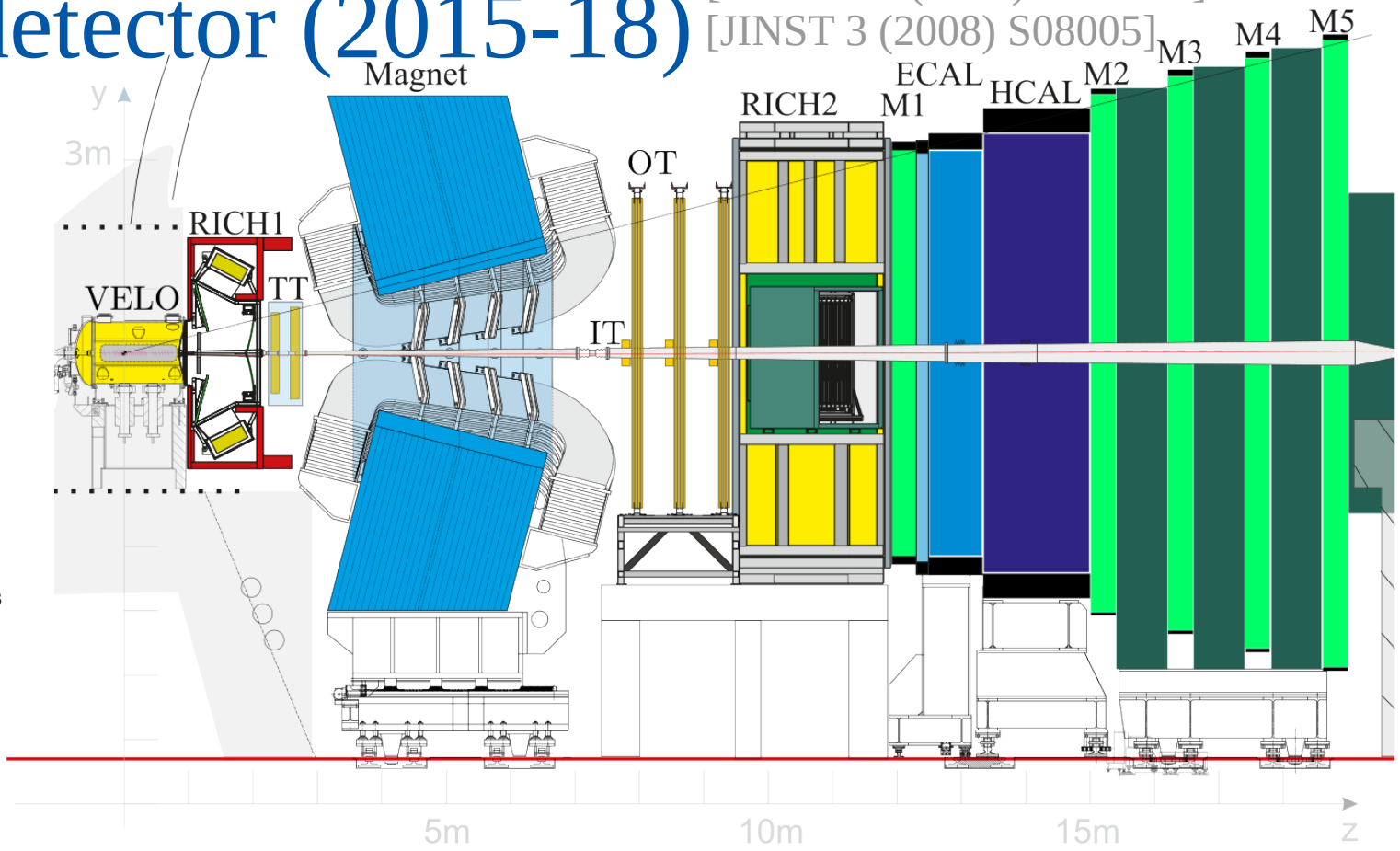
- $\overline{\Lambda}_b^0$ decays: $^3\overline{\mathrm{He}}$ production enhanced with respect to $\bar{\mathrm{d}}$

The LHCb detector (2015-18)

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

- Coverage: $2 < \eta < 5$





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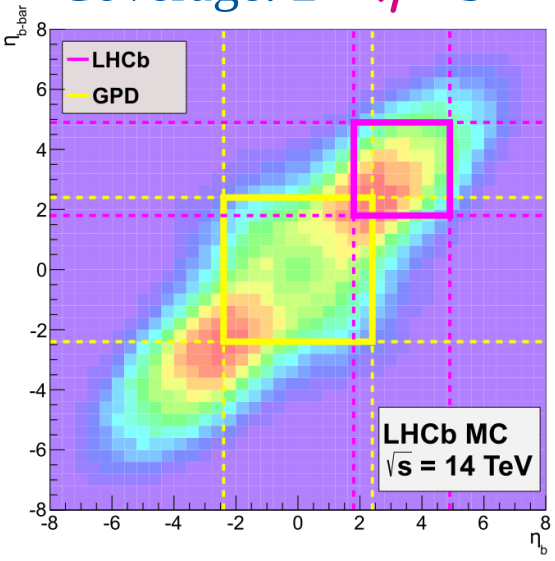
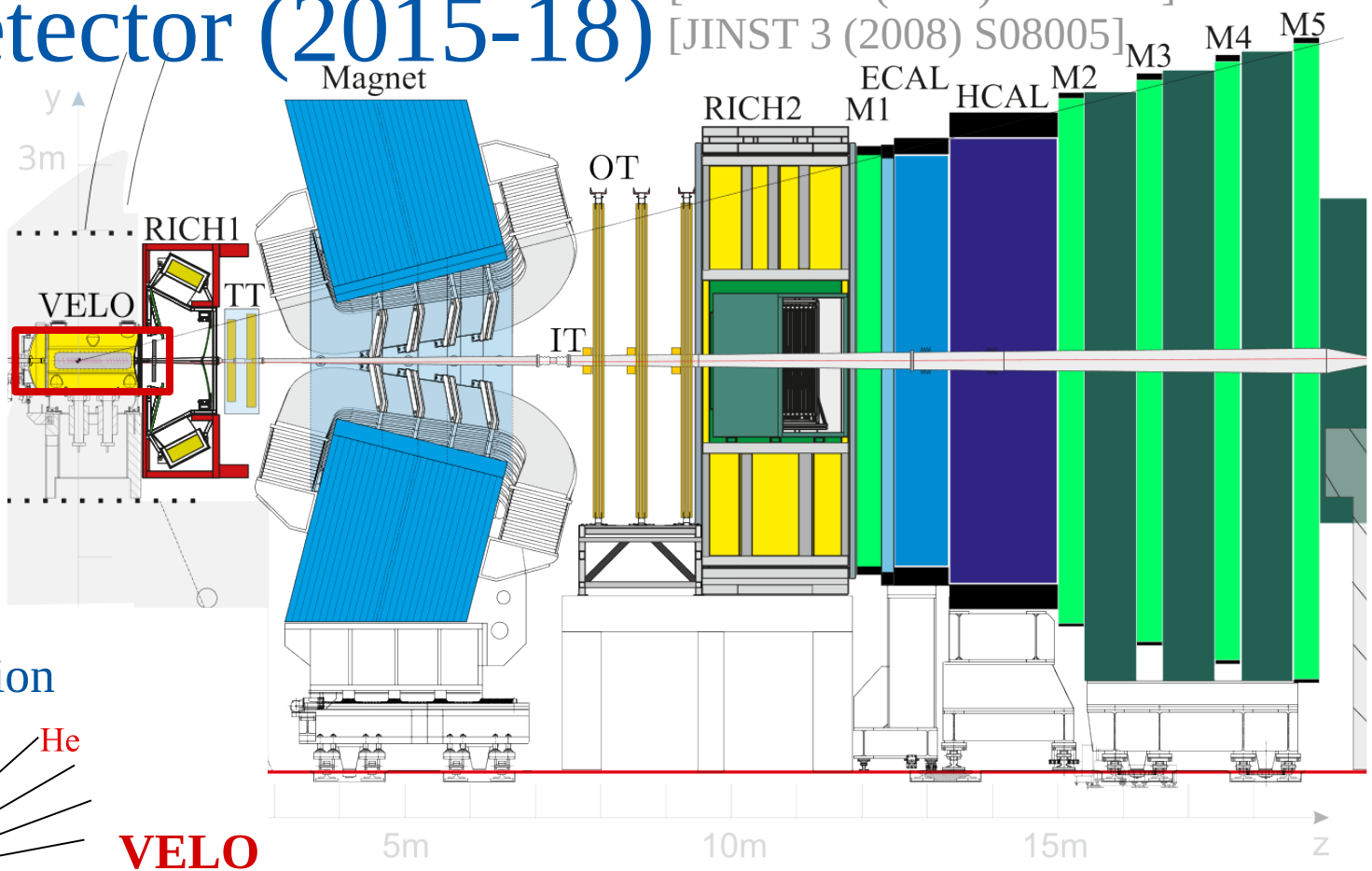
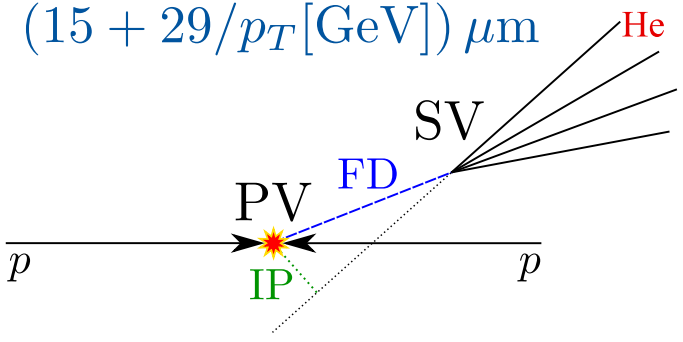
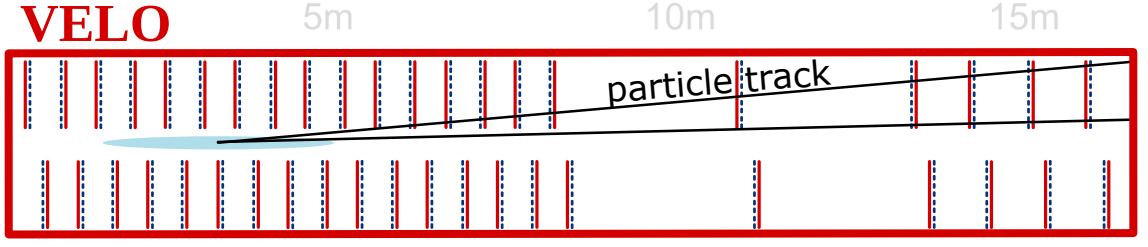




- **I**mpact **P**arameter resolution

$(15 + 29/p_T[\mathrm{GeV}])\ \mu\mathrm{m}$



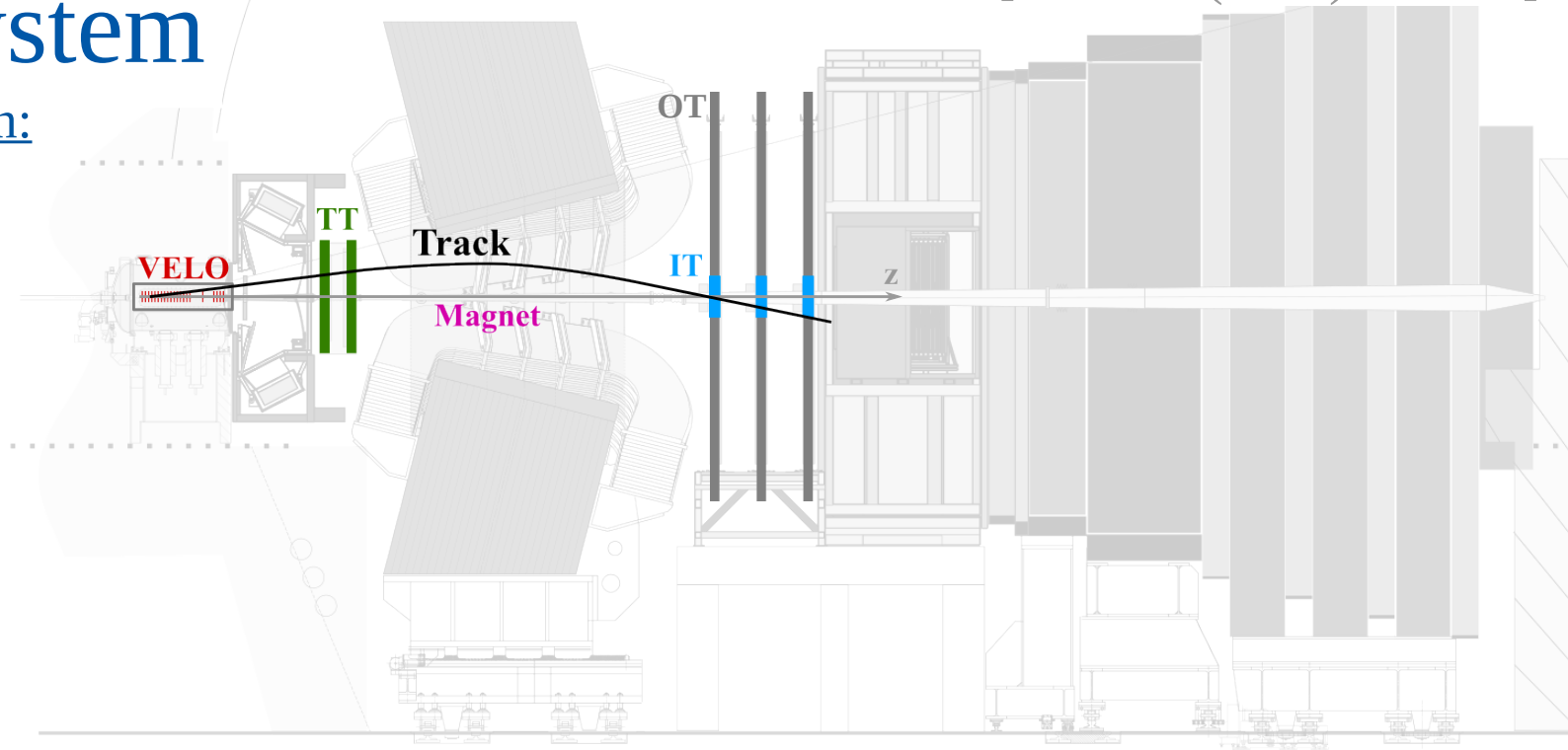


Tracking system

[JINST 3 (2008) S08005]

- Momentum resolution:

$$\frac{\Delta p}{p} = (0.5 - 1)\%$$



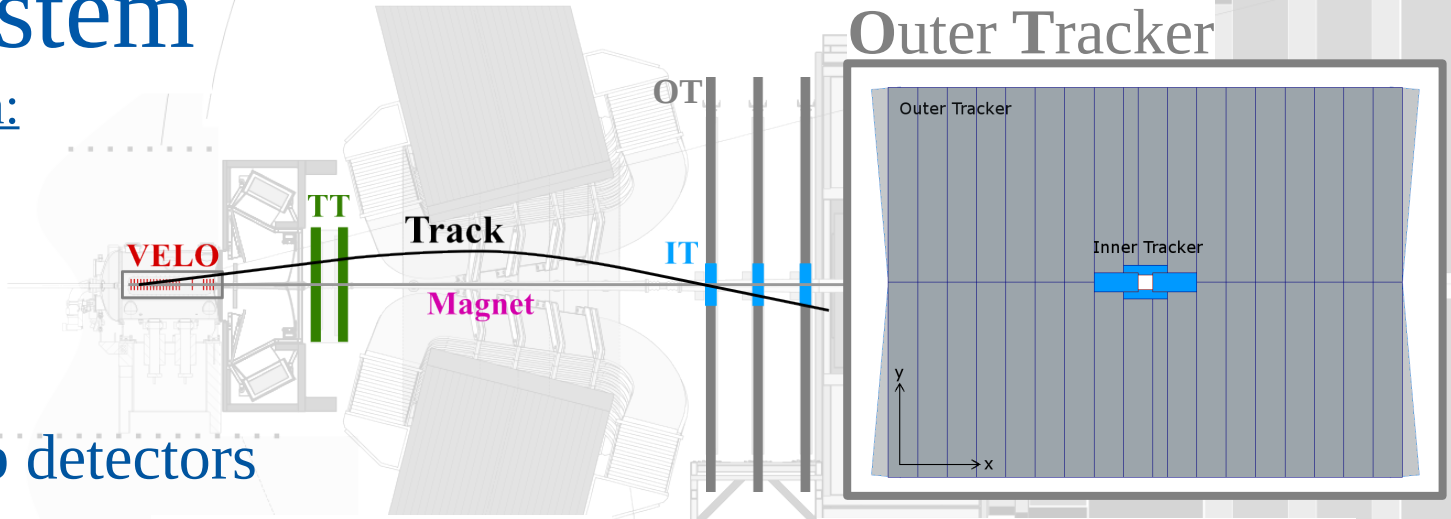
- LHCb **not designed** for helium identification
  $\Rightarrow$ Use information from the **tracking system**

[JINST 3 (2008) S08005]

Tracking system

- Momentum resolution:

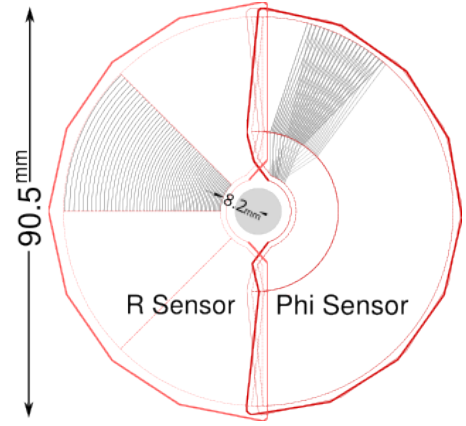
$$\frac{\Delta p}{p} = (0.5 - 1)\%$$



- Three **silicon strip** detectors

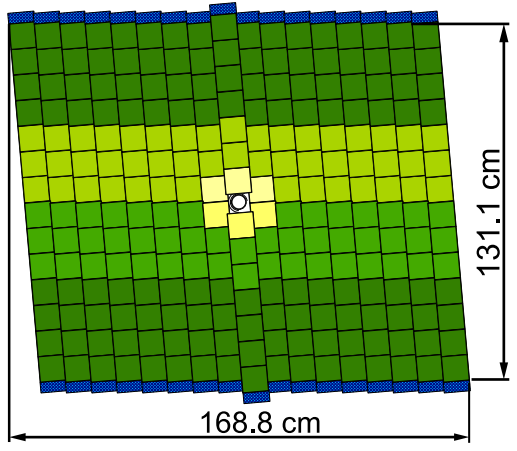
1. VErtex LOcator

2 x 21 Layers



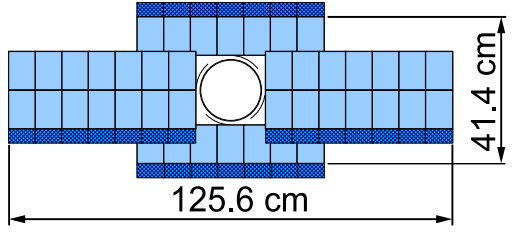
2. Tracker Turicensis

4 Layers



3. Inner Tracker

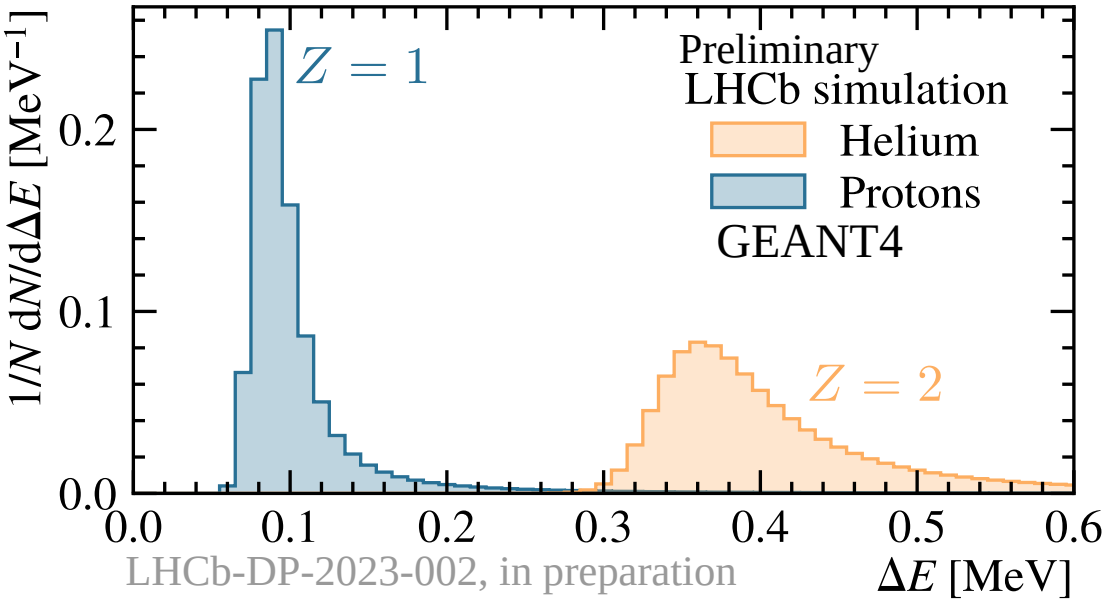
12 Layers



Acceptance:
20% of the tracks

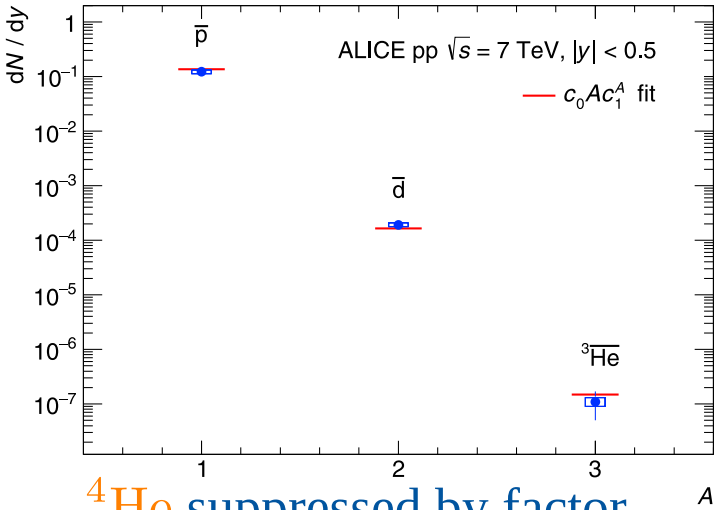
New helium identification strategy

- Based on ionisation losses in **silicon sensors**
- Exploit $\mathbf{Z^2}$ dependence in Bethe formula



LHCb-DP-2023-002, in preparation

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



^{4}He suppressed by factor 10^3 from **coalescence**

$\Rightarrow$ Assume all helium is ^{3}He

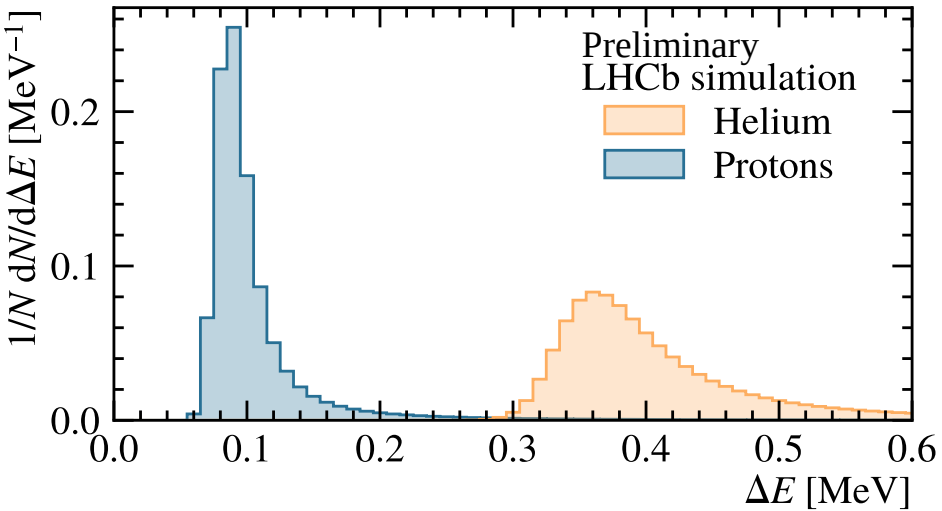
Dataset

- Proton-proton collisions
- Run2 data (2016-18, $\sqrt{s} = 13\,\mathrm{TeV}$)
- $\mathcal{L}_{\mathrm{int}} = 5.5\,\mathrm{fb}^{-1}$

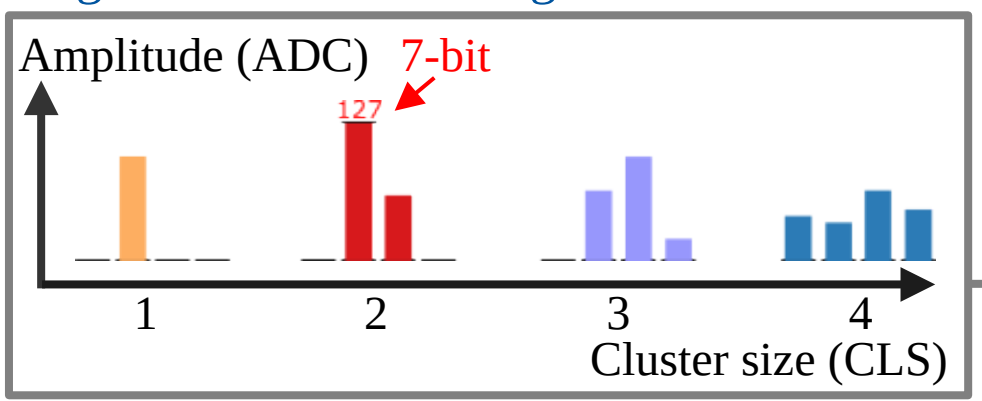
Preselection

- Combined output of **all trigger** lines
- "Prompt" tracks, compatible with PV (others: "secondary")
- Mild track-quality requirements

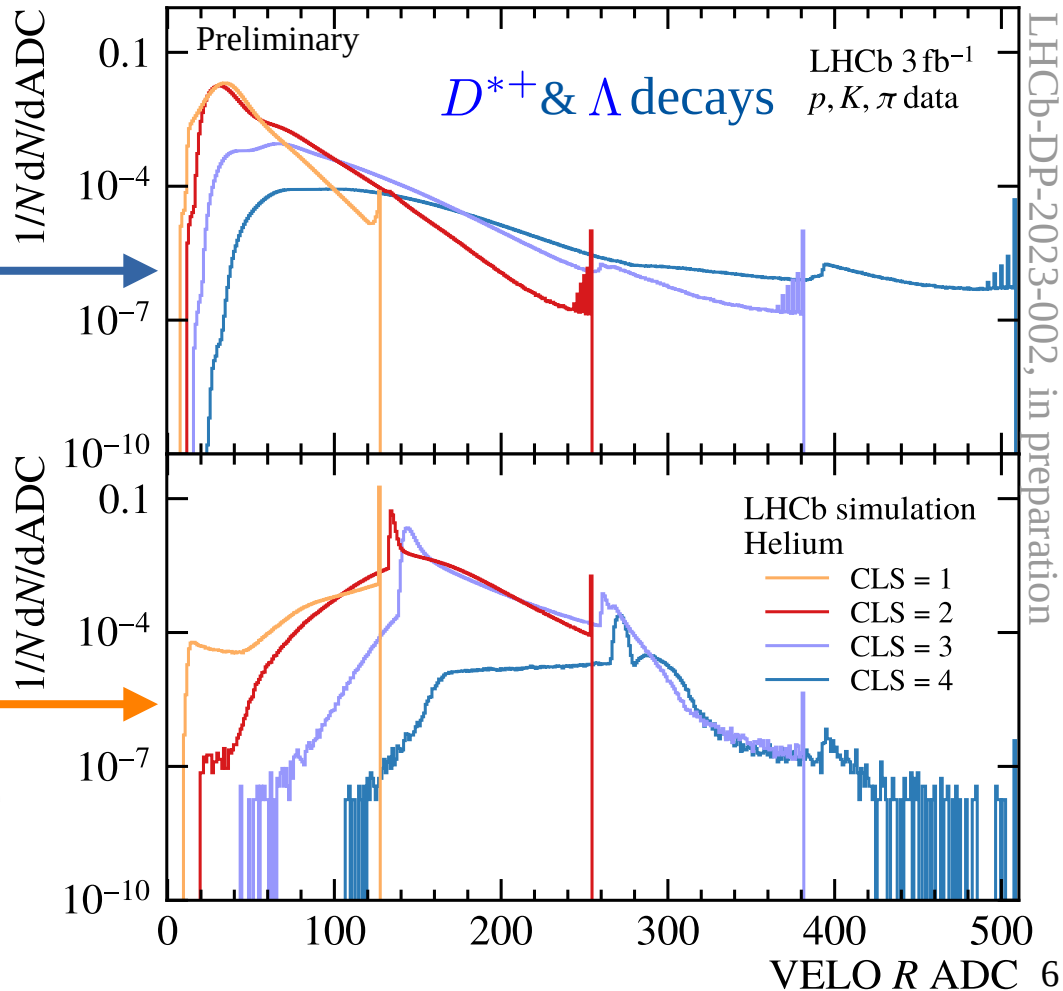
dE/dx measurements



- Digitization & clustering:



- Helium induces **higher ADC counts** and **wider clusters**



Likelihood Discriminators

- Combine n measurements:

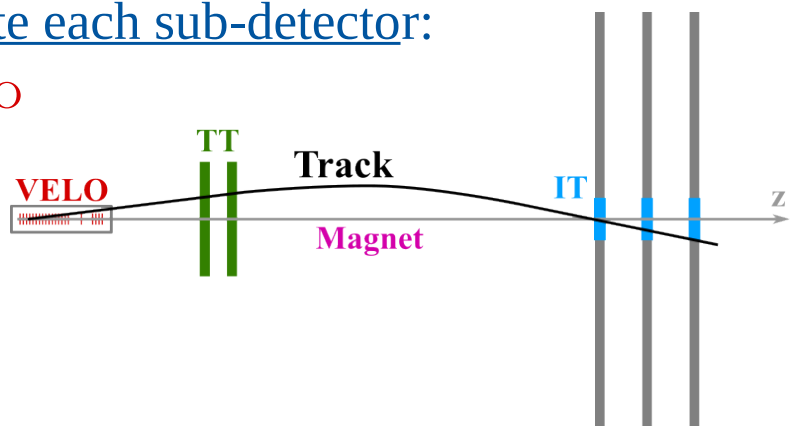
$$\mathcal{L}^X = \left(\prod_{i=1}^{n} \mathrm{PDD}_i^X(\mathrm{CLS}, \mathrm{ADC}) \right)^{\frac{1}{n}}$$

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

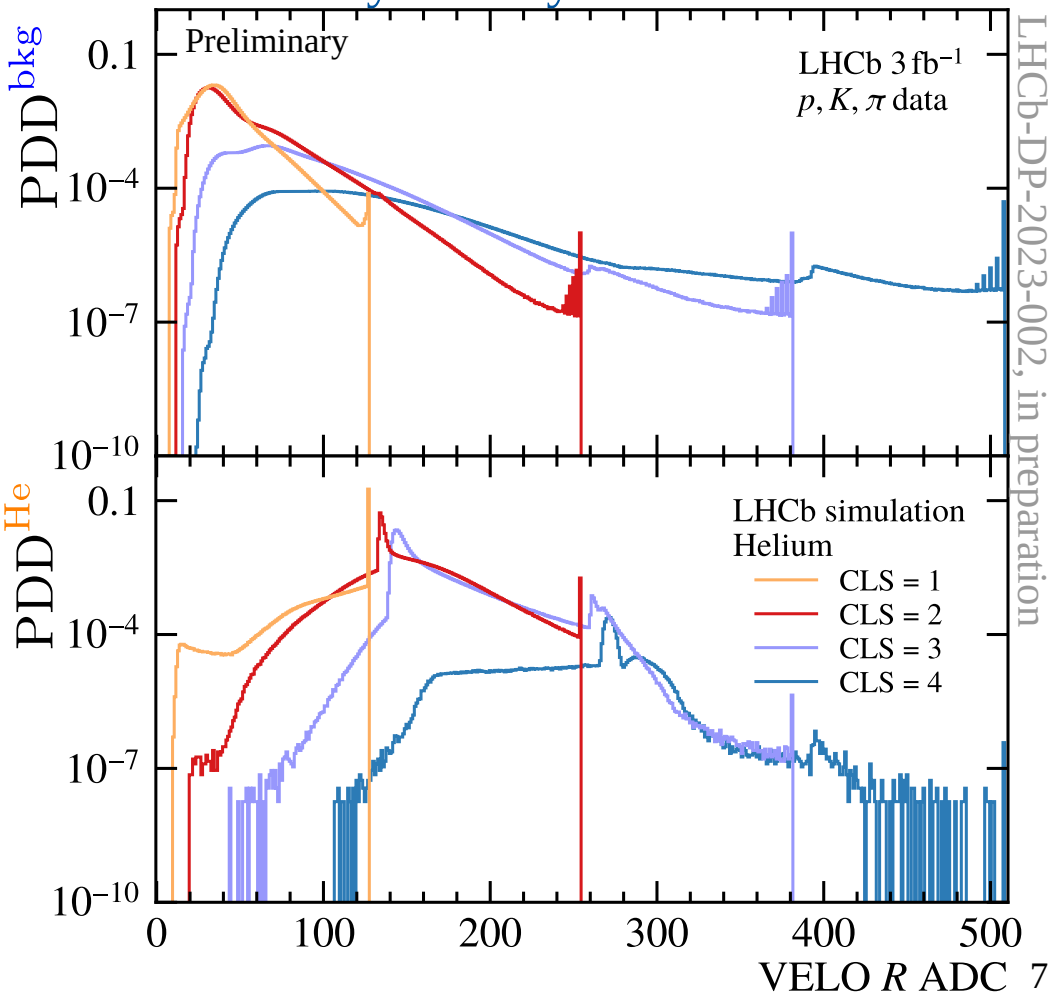
$$\boldsymbol{\Lambda_{\mathrm{LD}}} = \log \mathcal{L}^{\mathrm{He}} - \log \mathcal{L}^{\mathrm{bkg}}$$

- Separate each sub-detector:

1. $\Lambda_{\mathrm{LD}}^{\mathrm{VELO}}$
2. $\Lambda_{\mathrm{LD}}^{\mathrm{TT}}$
3. $\Lambda_{\mathrm{LD}}^{\mathrm{IT}}$

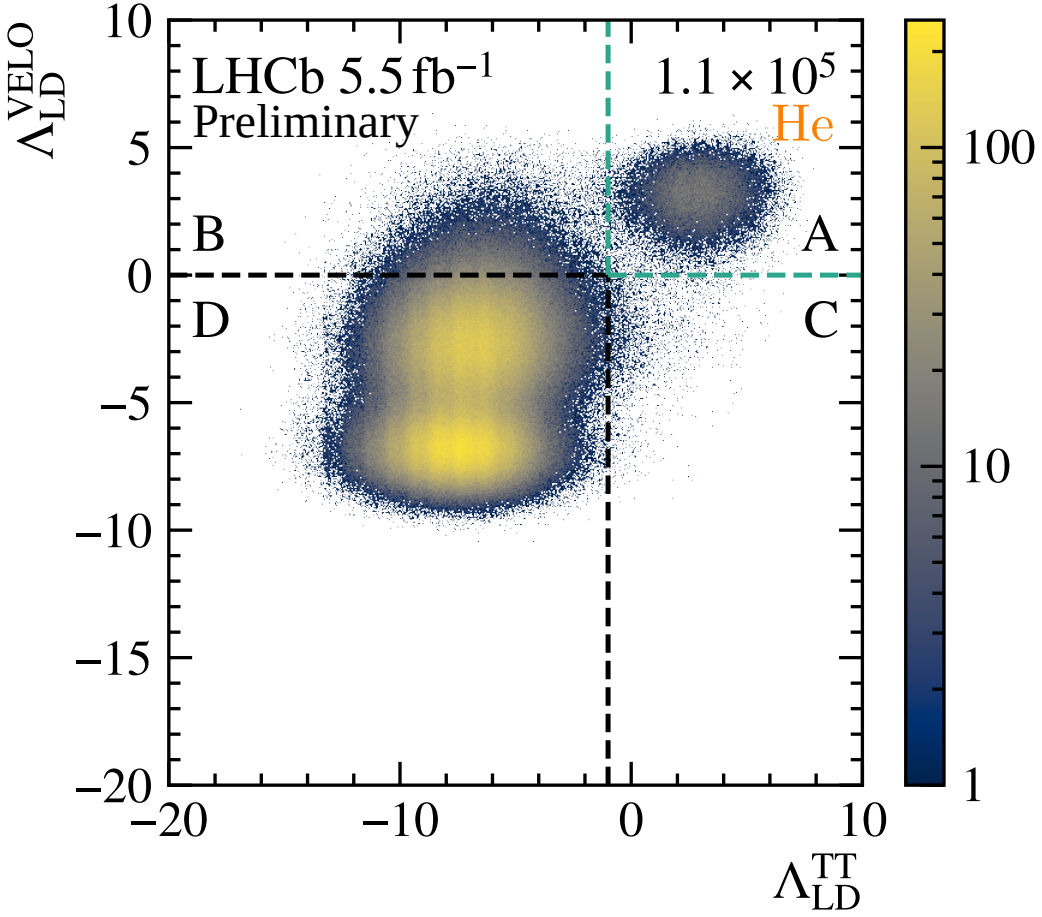


- Probability Density Distributions

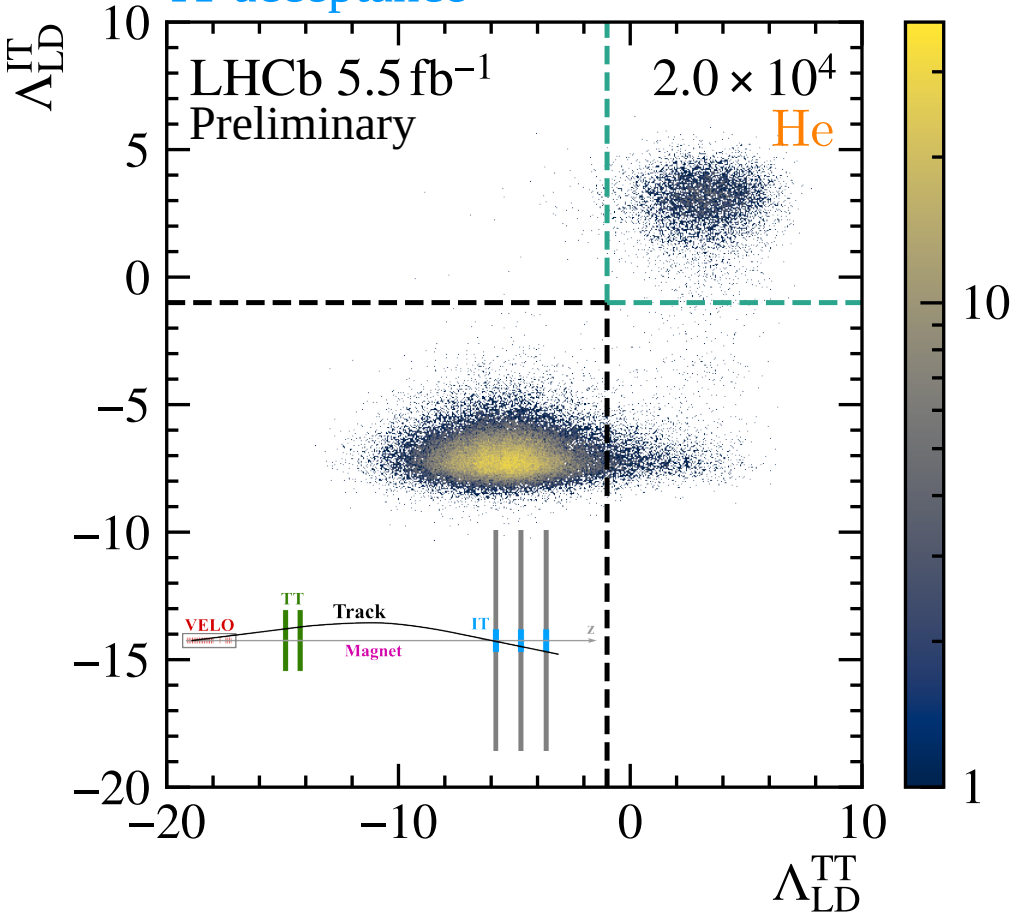


Prompt helium at LHCb

LHCb-DP-2023-002, in preparation

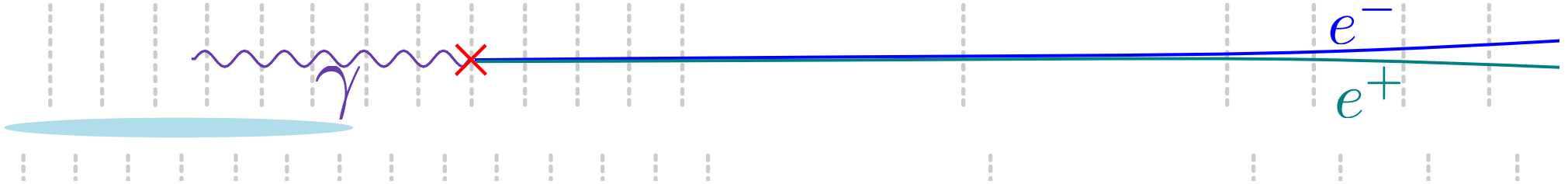


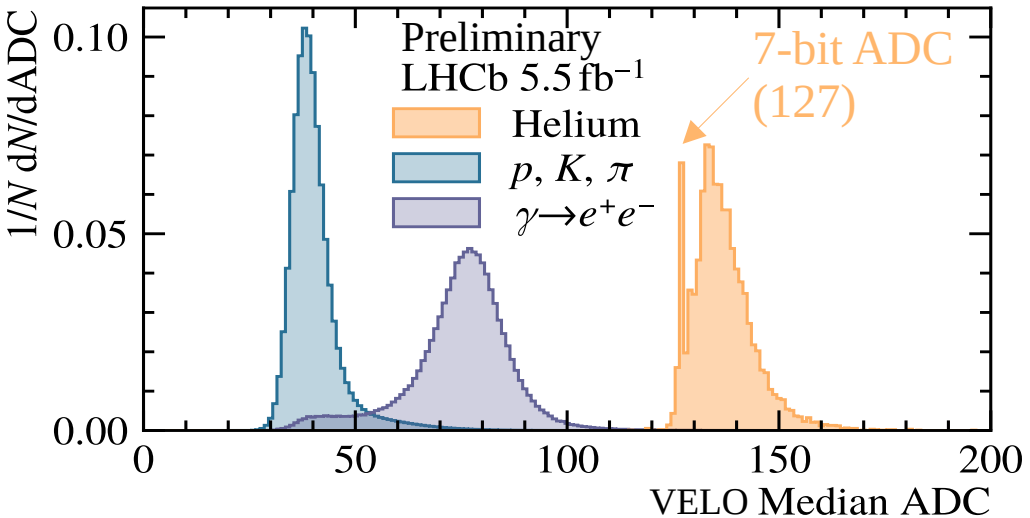
IT acceptance



First helium identification at LHCb!

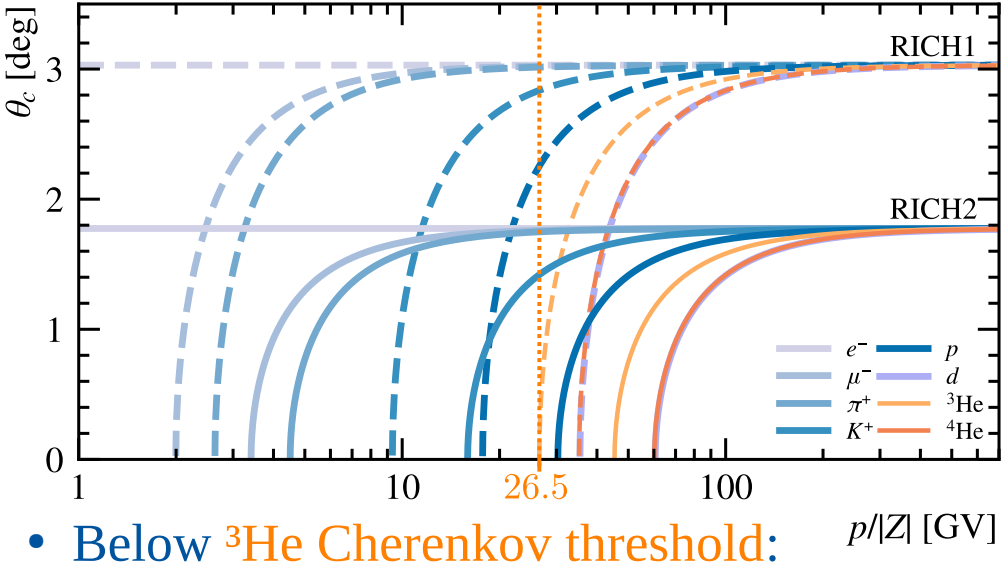
Converted photons





- Conversion signature:
  e^+ and e^- contribute to same cluster
  $\Rightarrow$ Closer to helium than $Z{=}1$ is

Ring Imaging CHerenkov detectors

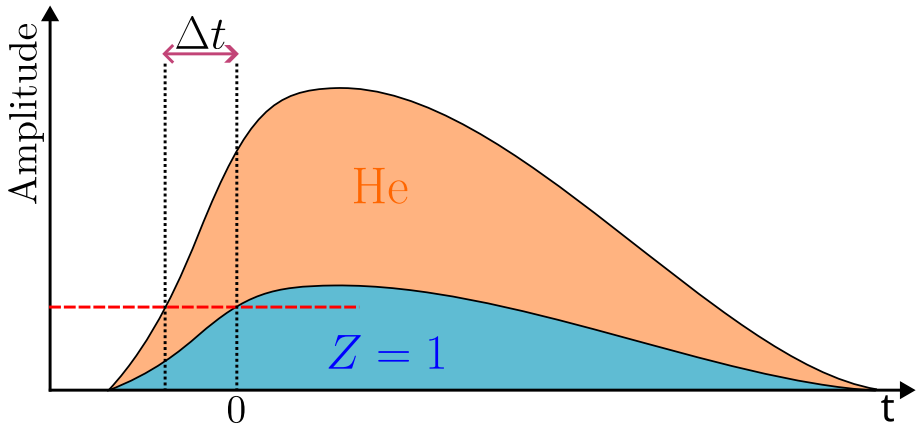


- Below ^{3}He Cherenkov threshold:
  Reject converted photons up to $\mathcal{O}(10^2)$
- Above threshold:
  Helium **identification** to be implemented

LHCb-DP-2023-002, in preparation

Timing information from Outer Tracker

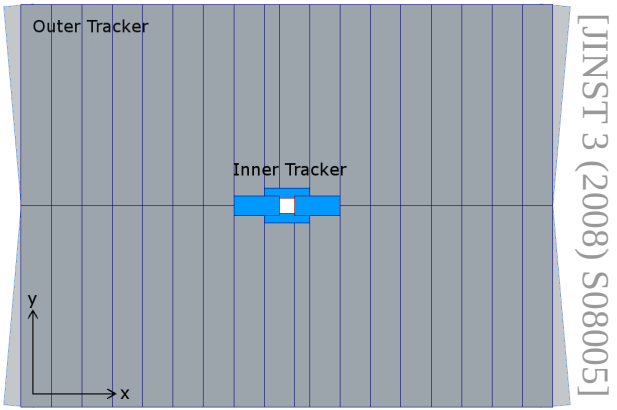
- **Straw drift tube** detector
- OT has a constant threshold
  ⇒ Does **not measure dE/dx** information
- But: Z=2 crosses threshold earlier



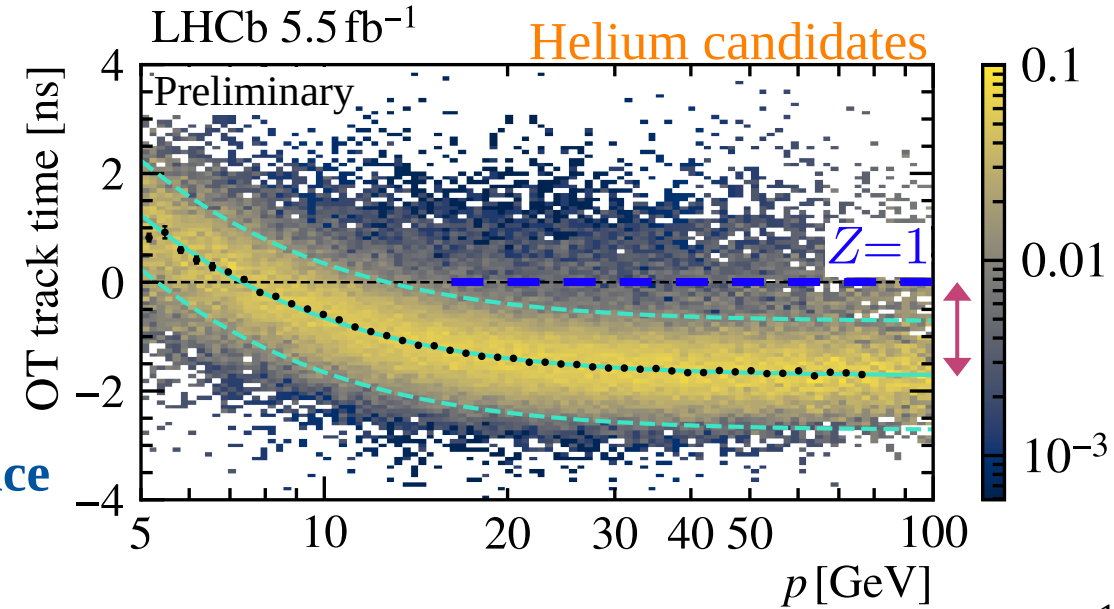
⇒ Identification power via "OT track time"

- Low momentum: **T**ime **O**f **F**light

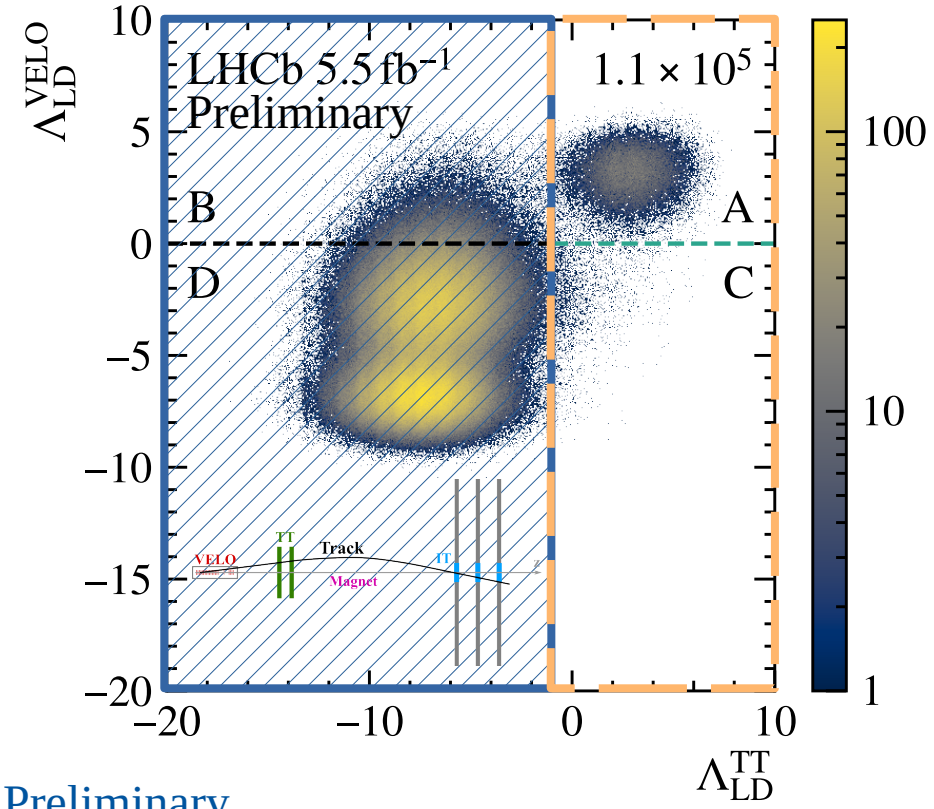
⇒ Helium ID after magnet in **full acceptance**



[JINST 3 (2008) S08005]



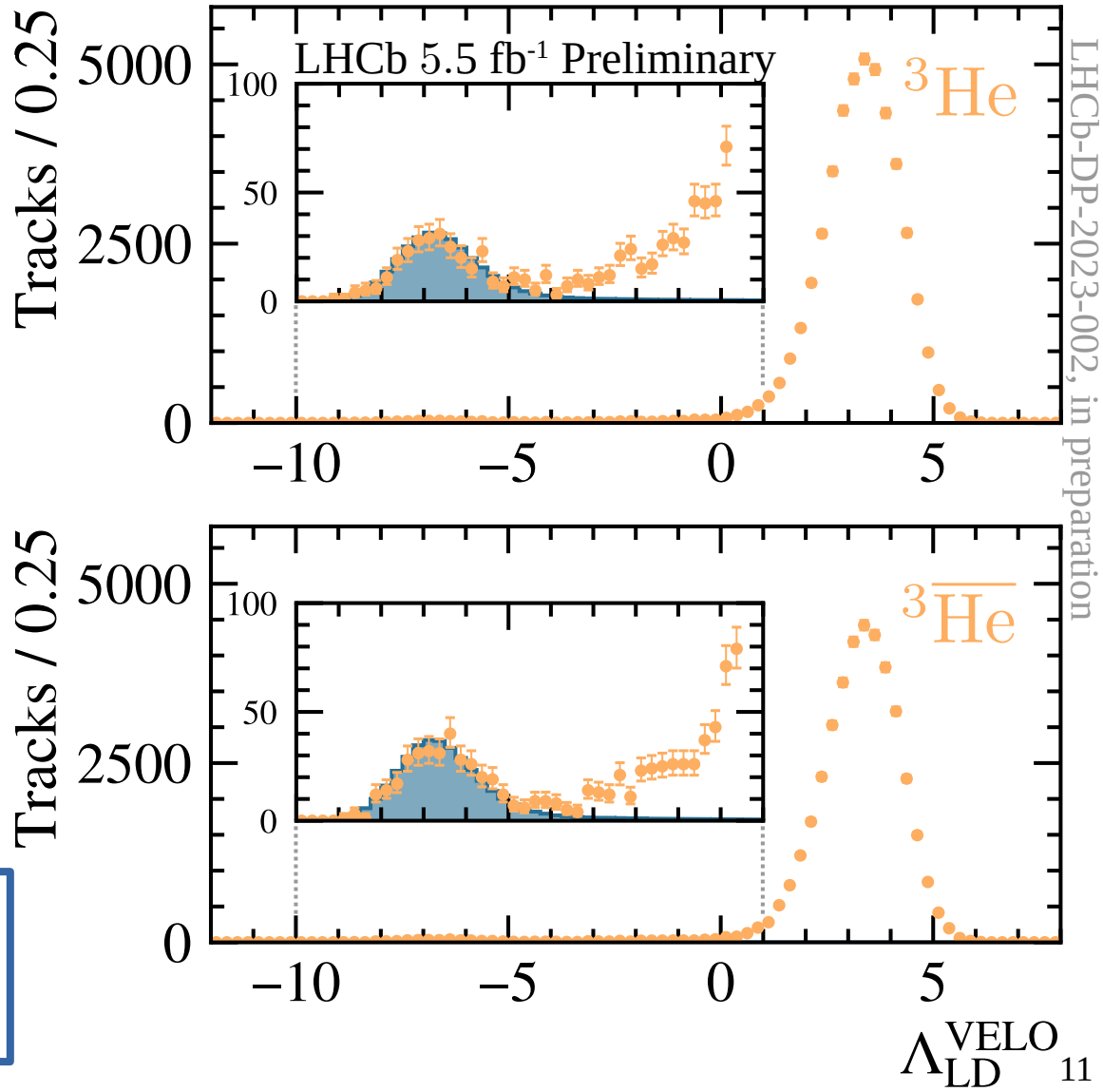
Separation power:



Preliminary

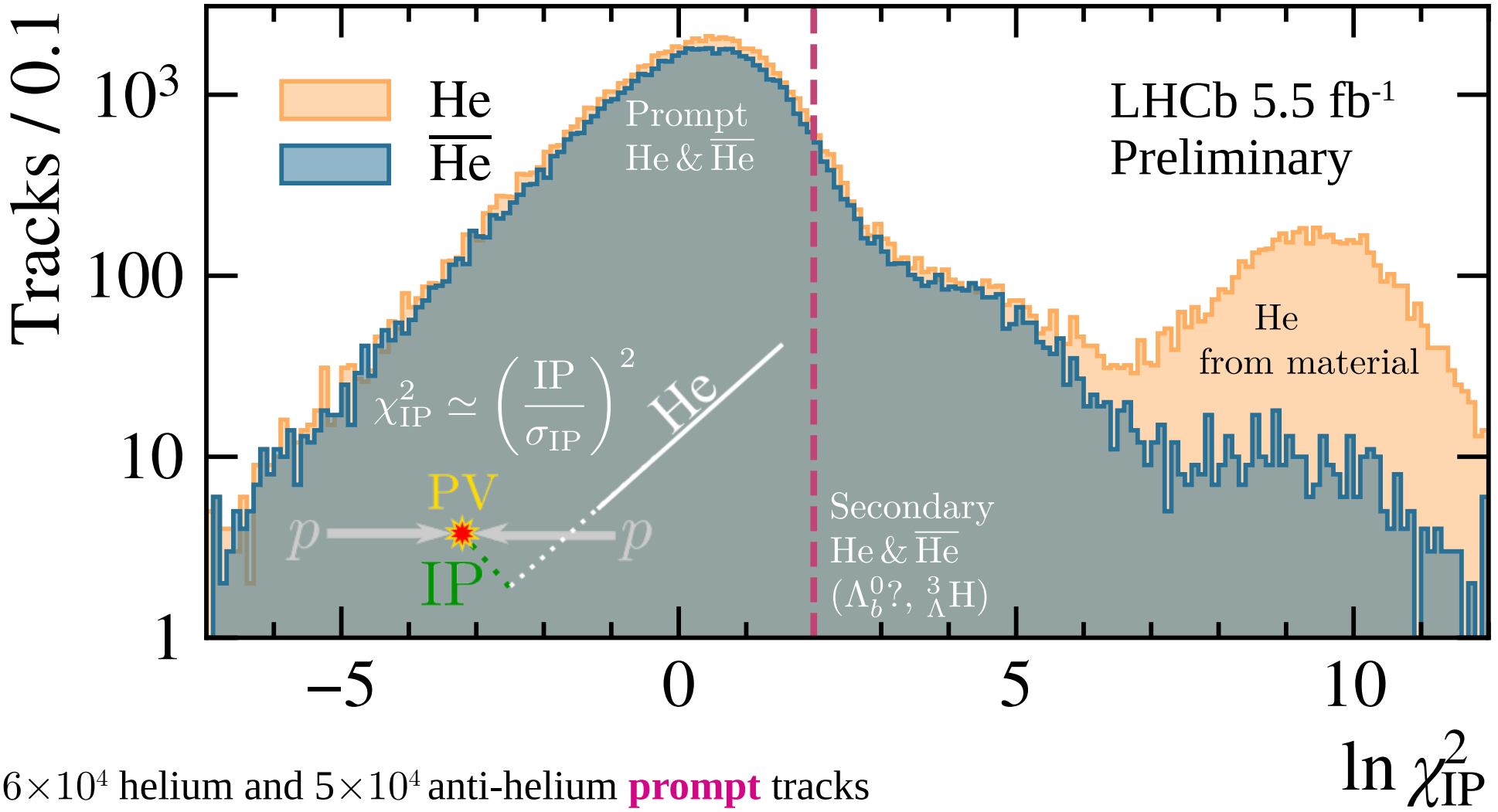
Performance for well-reconstructed tracks:

- Mis-ID probabiltiy (bkg $\rightarrow$ He): $\mathcal{O}(10^{-12})$
- Signal (He) efficieny: ~50%



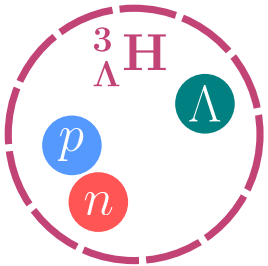
Sources of helium

LHCb-DP-2023-002, in preparation

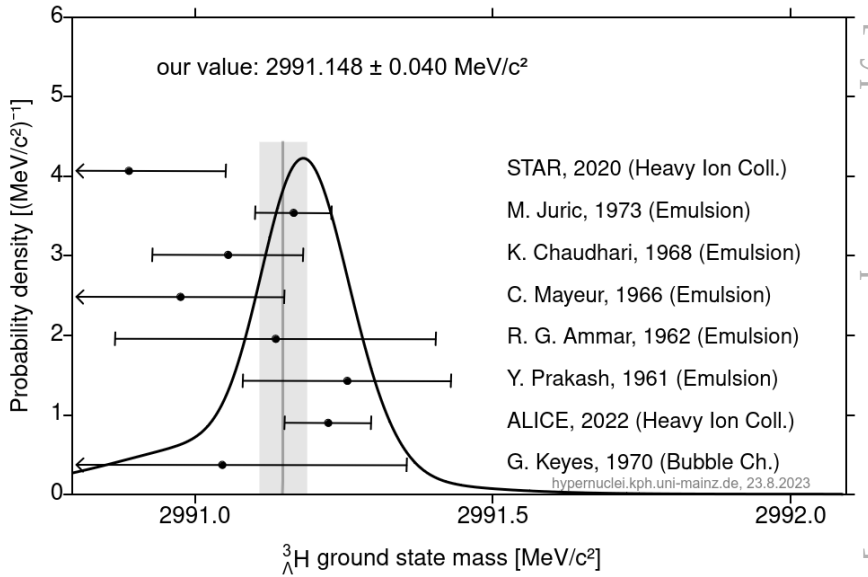


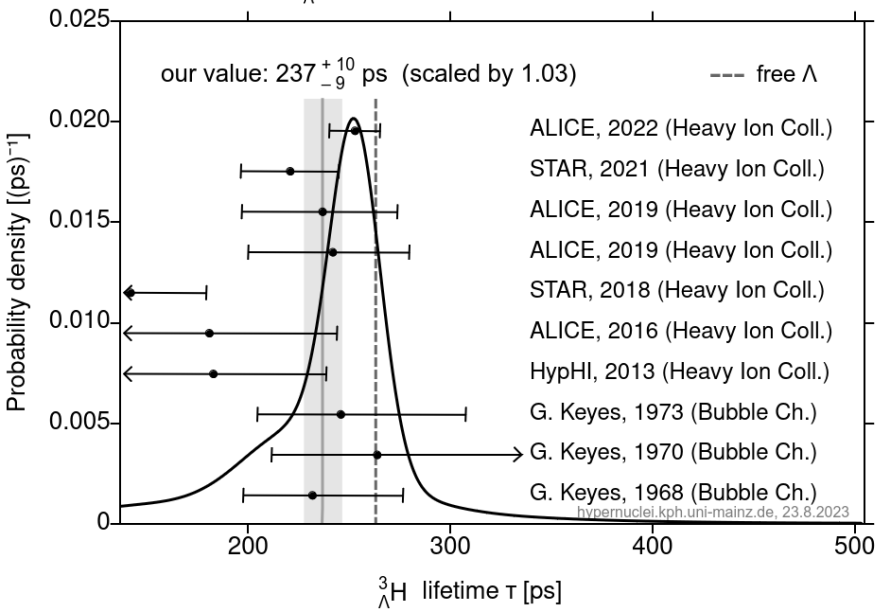
6×10^4 helium and 5×10^4 anti-helium **prompt** tracks

Hypertriton

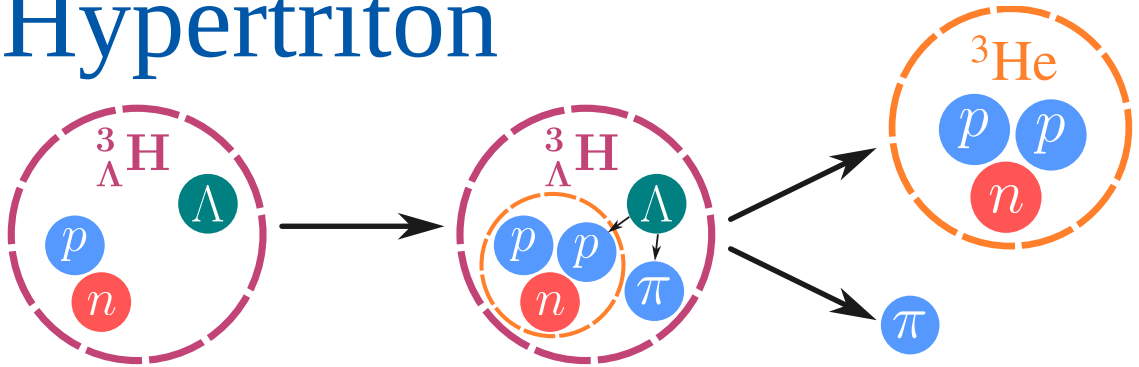


- Access to hyperon-nucleon interaction
  $\Rightarrow$ Implications for **neutron stars**
- Hypertriton “life-time puzzle”:
  - Tension between STAR and ALICE





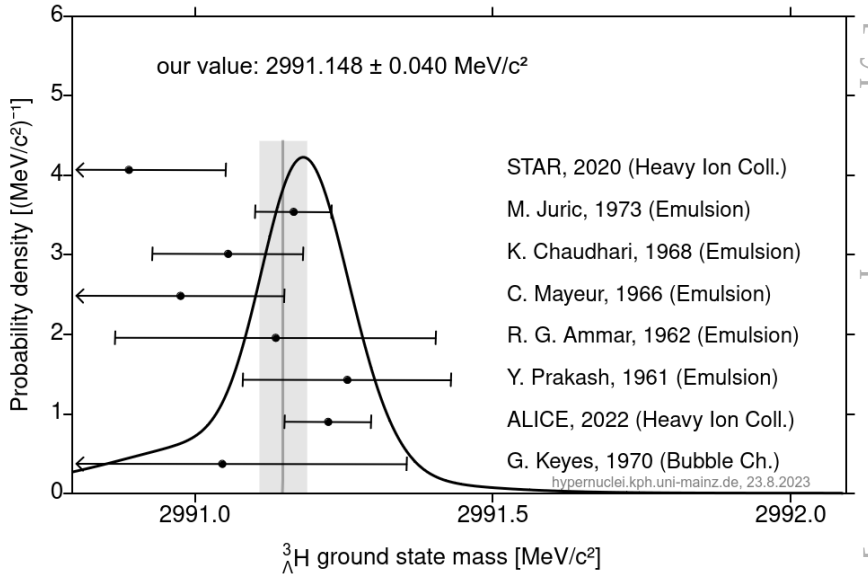
Hypertriton

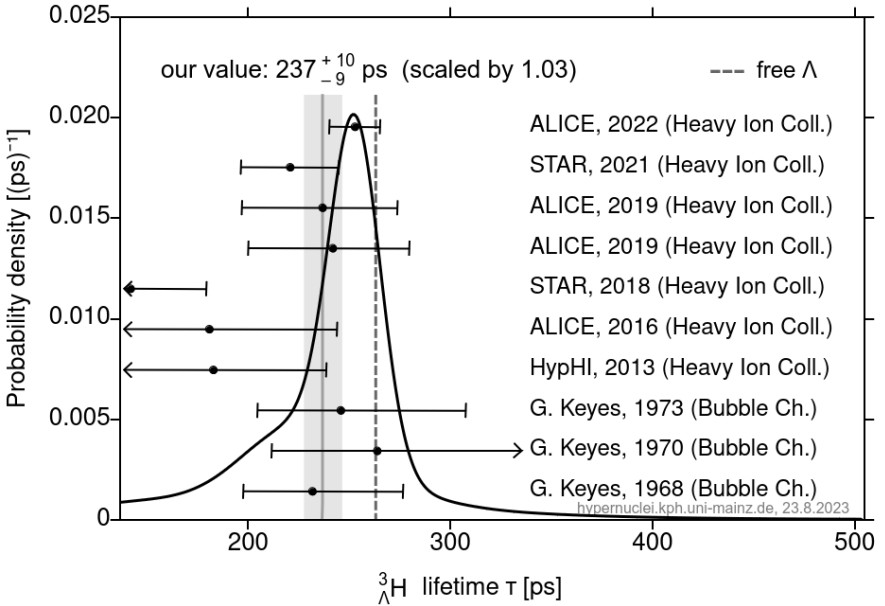


- Access to hyperon-nucleon interaction
  $\Rightarrow$ Implications for **neutron stars**
- Hypertriton "life-time puzzle":
  - Tension between STAR and ALICE

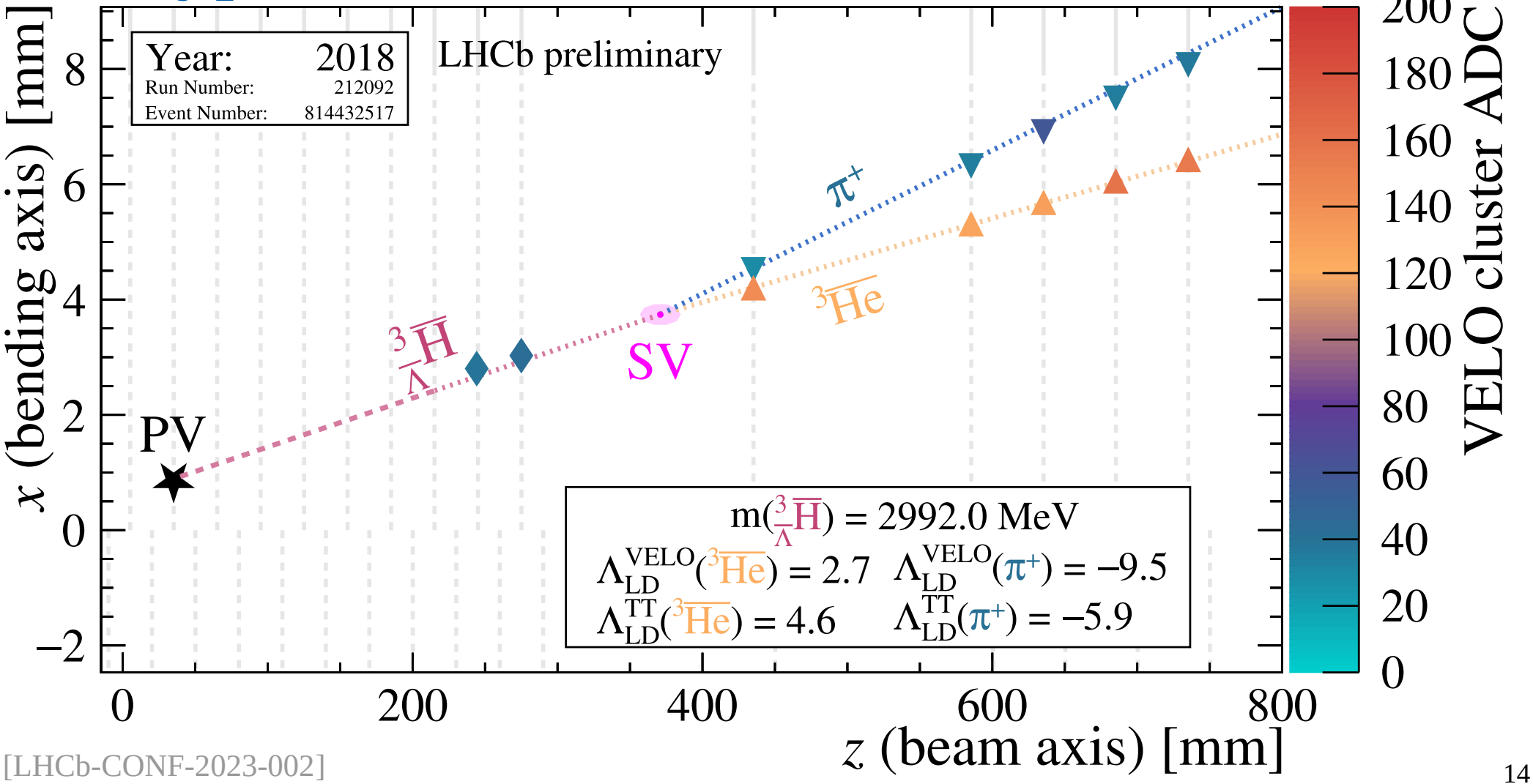
Selection

- 2-body decay into helium:
  $^3_\Lambda\mathrm{H} \rightarrow {}^3\mathrm{He}\,\pi^-$
- Secondary helium candidates (not from PV):
  $\ln \chi^2_{\mathrm{IP}}({}^3\mathrm{He}) > 2$
- Combine with charged pion
- Well reconstructed secondary vertex





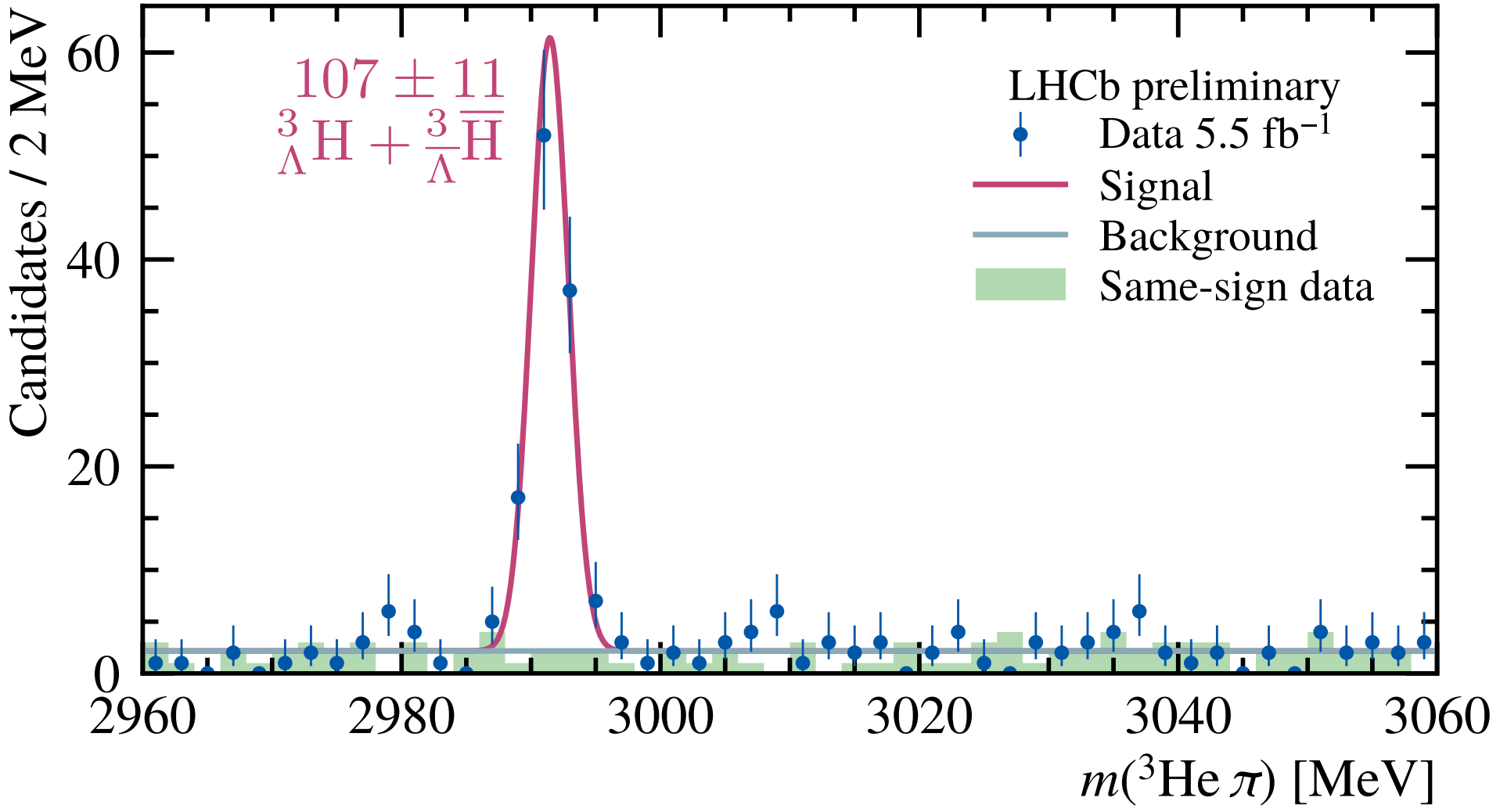
Antihypertriton candidate in VELO



[LHCb-CONF-2023-002]

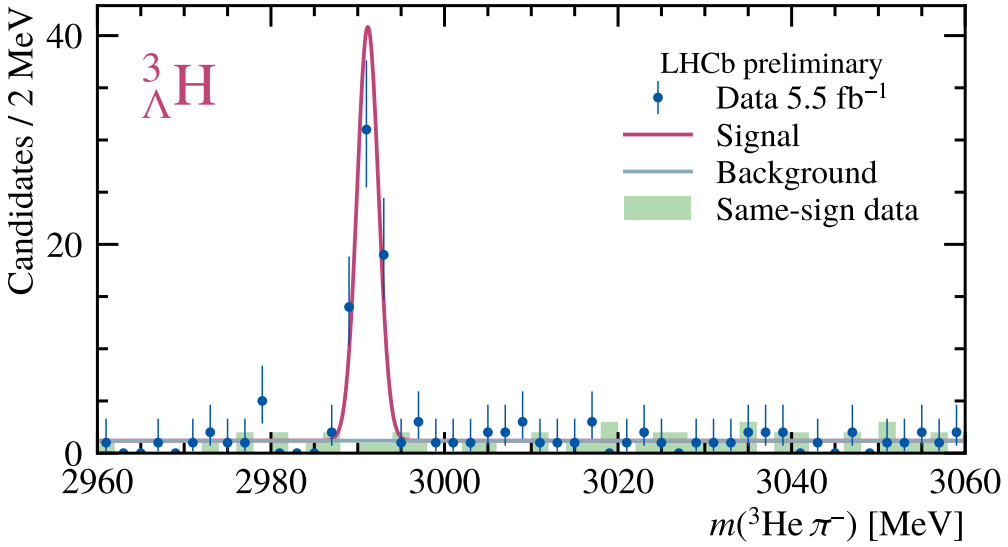
Observation of hypertriton

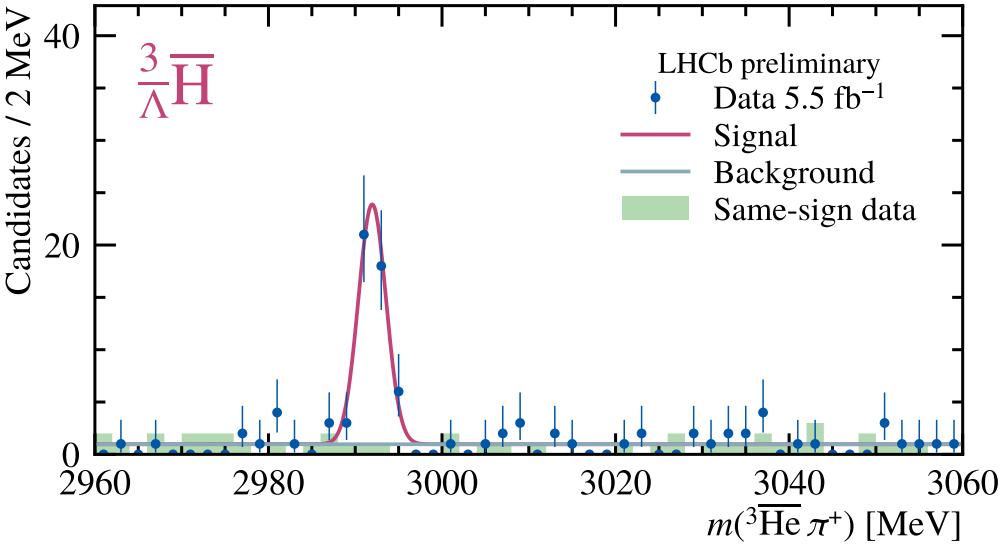
[LHCb-CONF-2023-002]



Observation of (anti)hypertriton

[LHCb-CONF-2023-002]



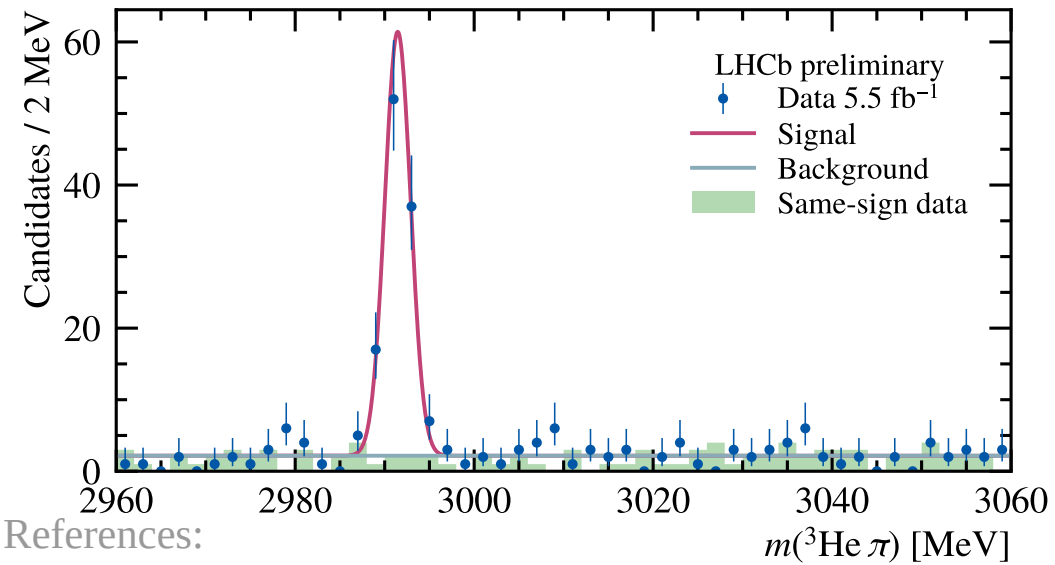


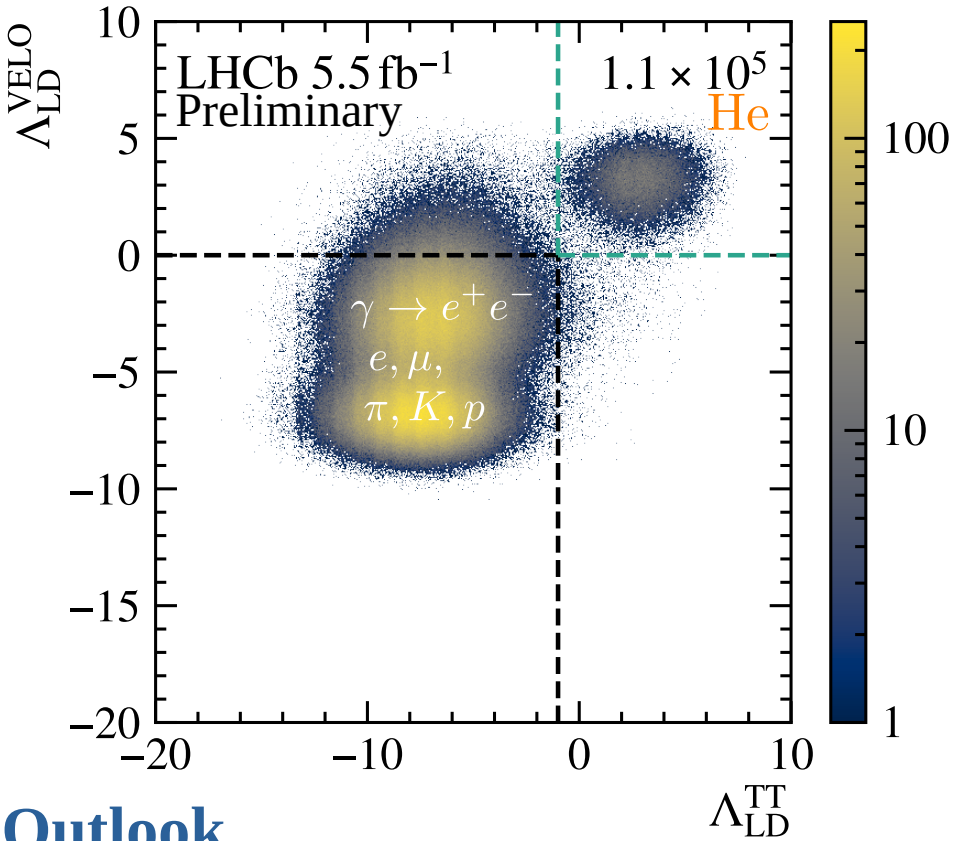
- **Fit results:**
  - Yields: Preliminary
    $N(^3_\Lambda\text{H}) = 61 \pm 8$
    $N(^3_\Lambda\overline{\text{H}}) = 46 \pm 7$
  - Statistical mass precision: $0.16\,\text{MeV}$

- **Under investigation:**
  - Systematic corrections on mass scale: Charge-sign dependent **energy-loss** and **tracking** corrections for $Z{=}2$
  - **Efficiency** and acceptance corrections

Summary

- LHCb is now able to identify helium in Run2
  - dE/dx, **timing** and **Cherenkov** based method
- 1.1×10^5 prompt (anti)helium in pp collisions
  - **Negligible background** contamination
  - In experimentally unexplored **forward region**
- 107 ± 11 (anti)hypertriton candidates





Outlook

- Measure properties of hypertriton
- Measure helium production from Λ_b^0

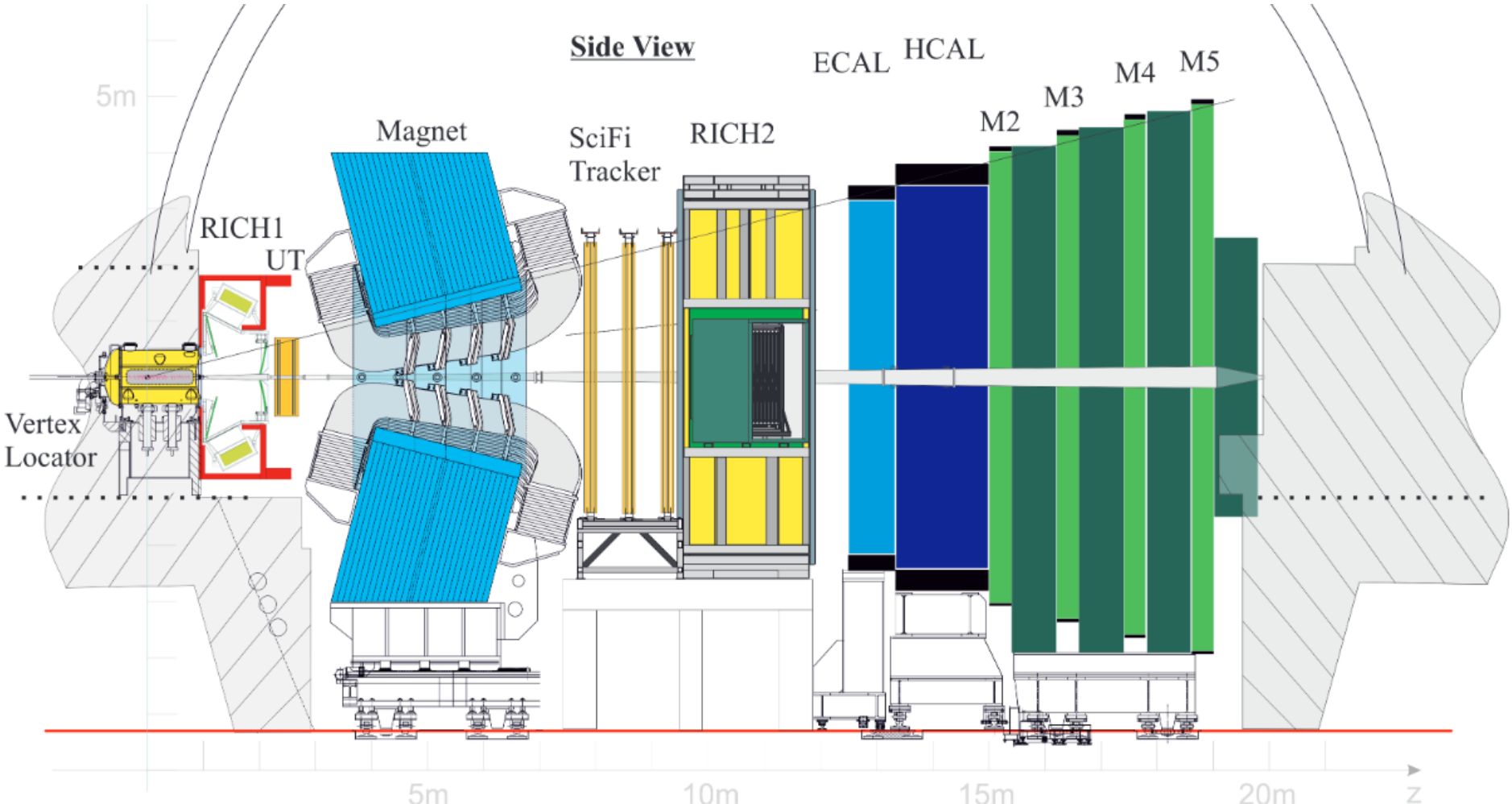
References:

- LHCb-DP-2023-002, in preparation
- LHCb-CONF-2023-002, on CDS

Backup

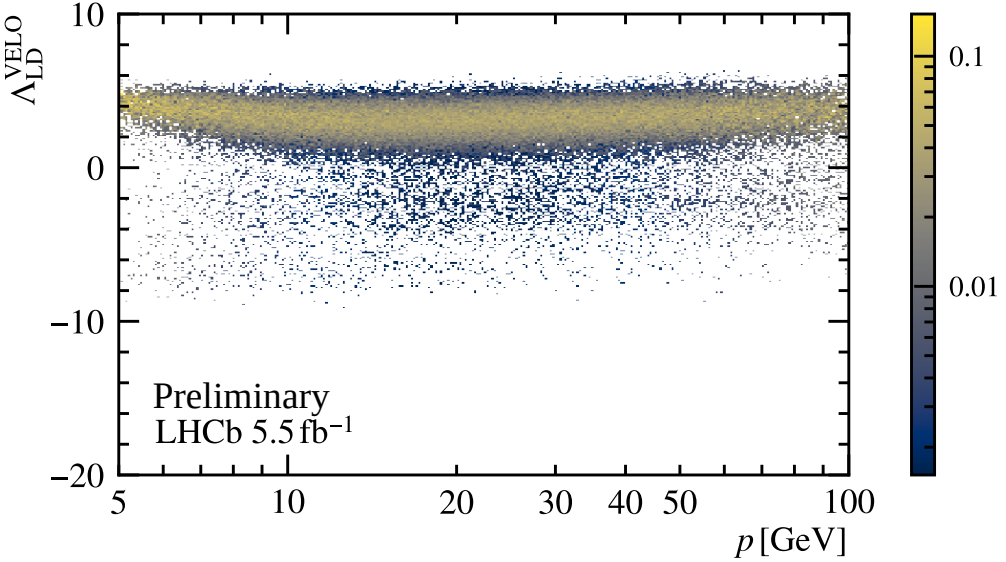
LHCb detector Run 3

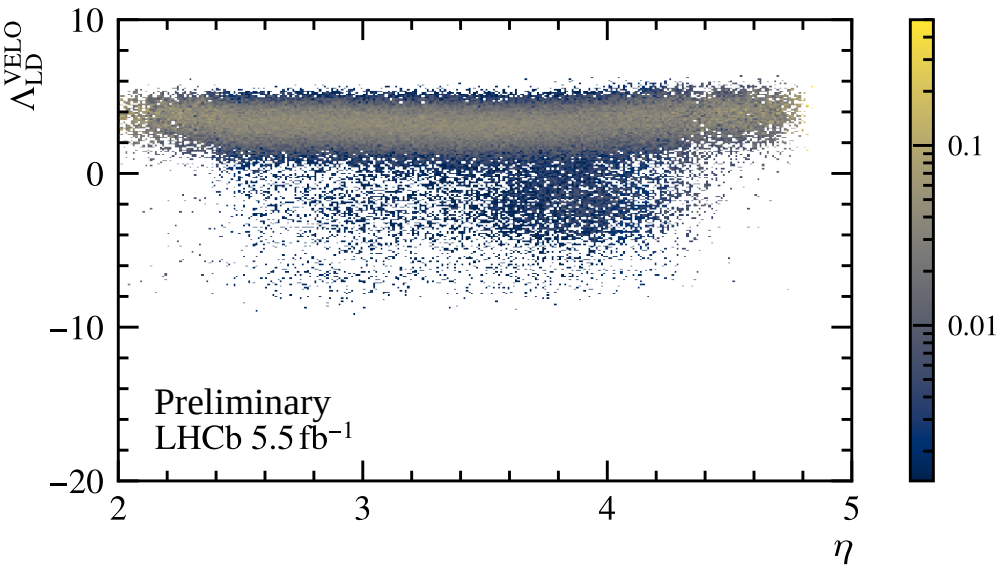
[CERN-LHCC-2014-001]



Less amplitude information available in Run3

Λ_{LD}: No strong dependence on kinematics





Prompt helium and antihelium

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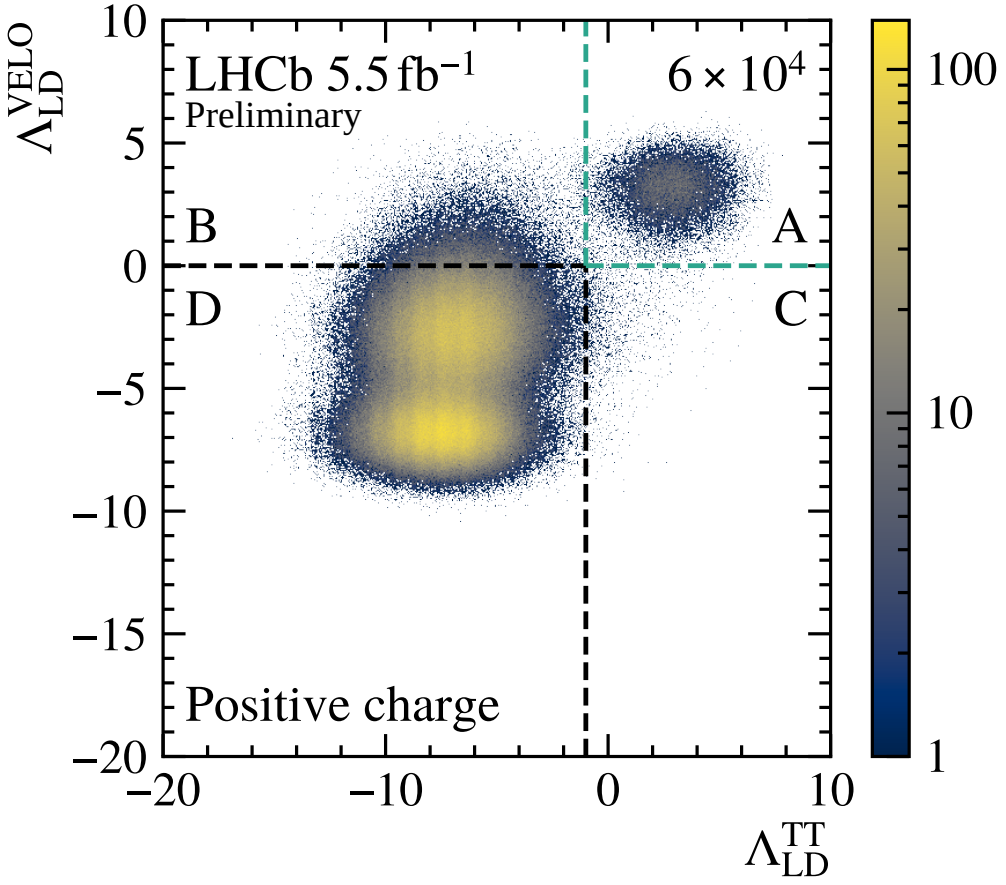
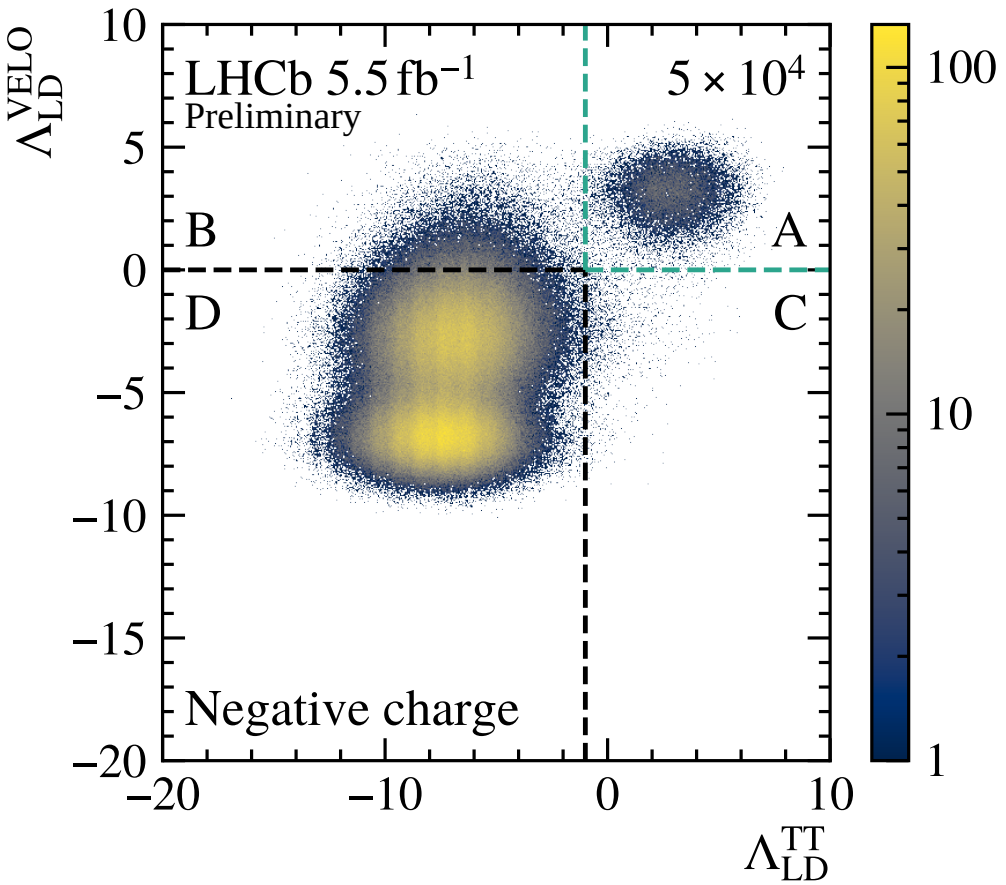
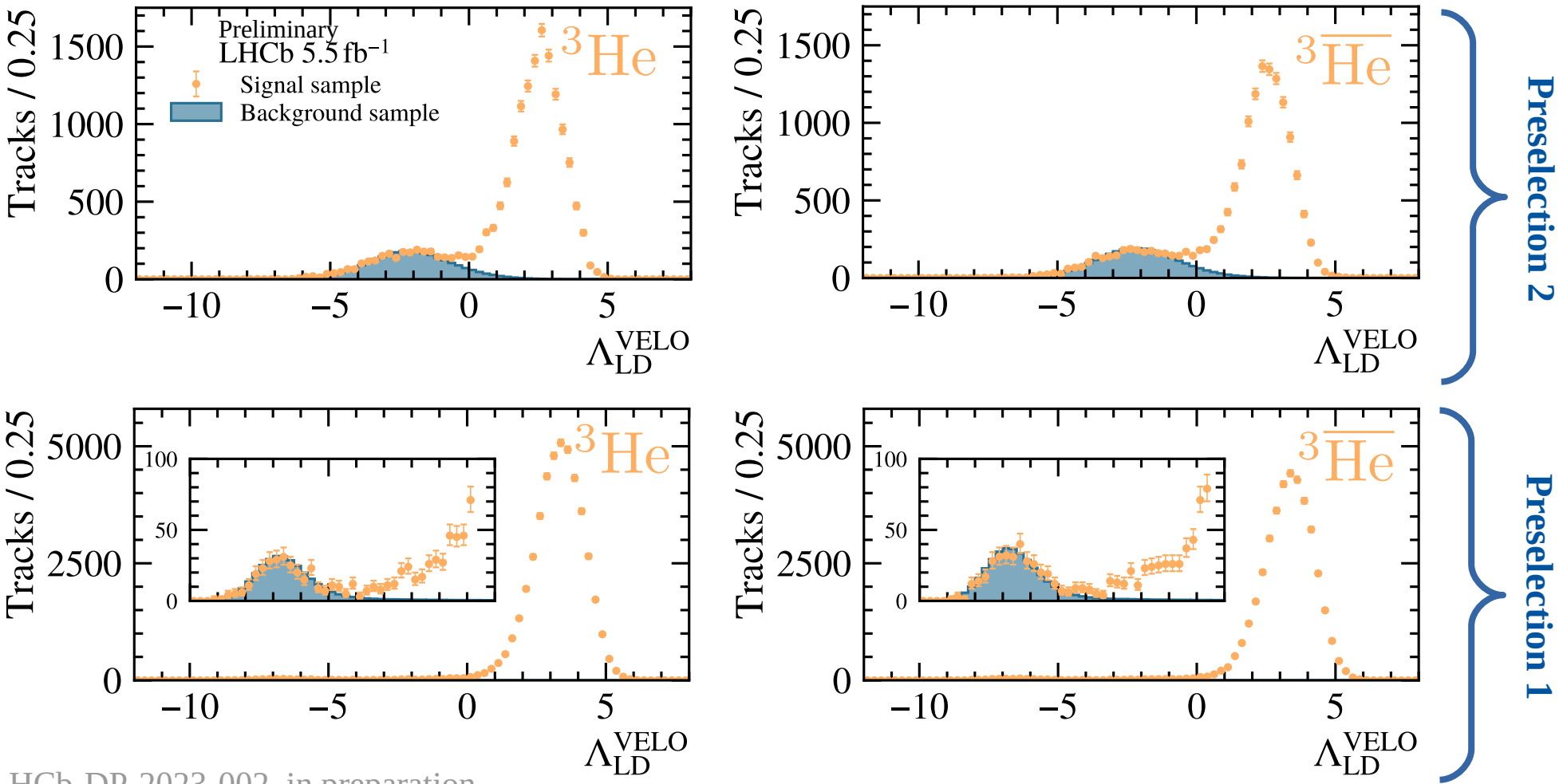




Λ_{LD}^{VELO} separated by charge and preselection



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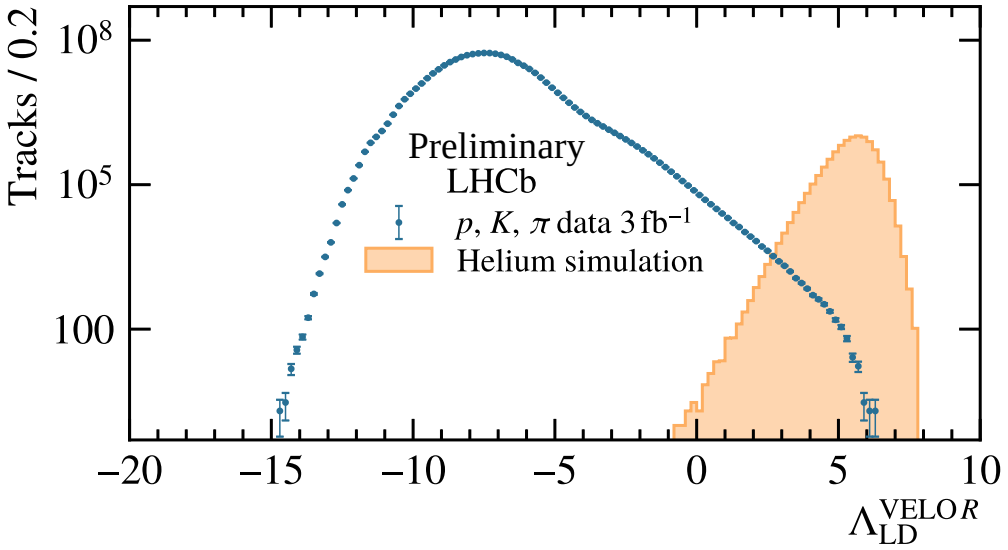
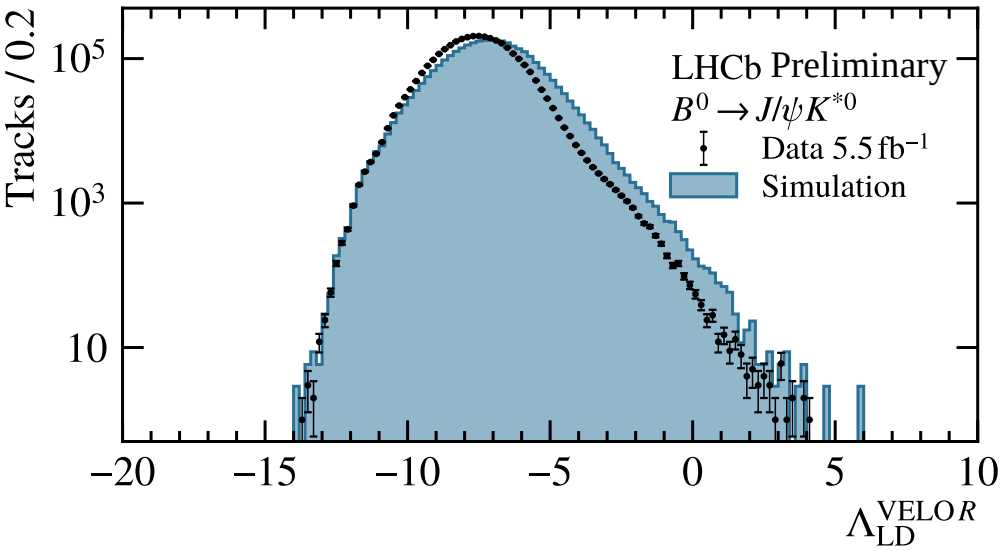
Data and simulation comparison





Helium in minimum bias data

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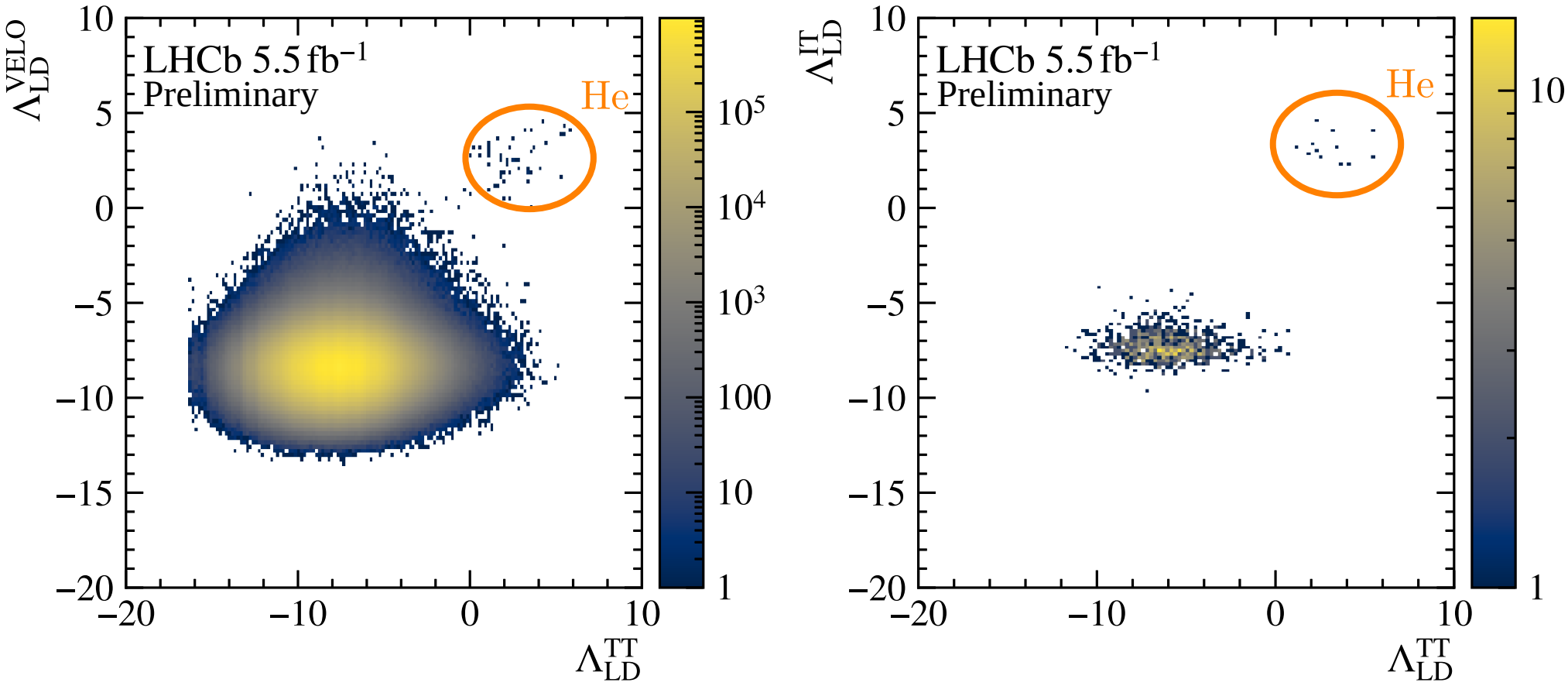
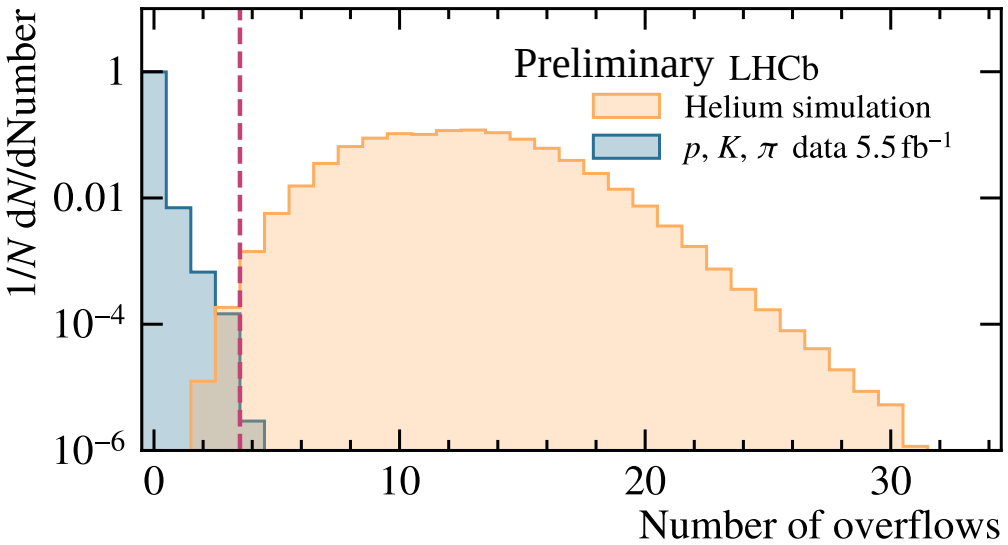


Observe in 2×10^9 tracks a displaced population of 54 at large Λ_{LD}

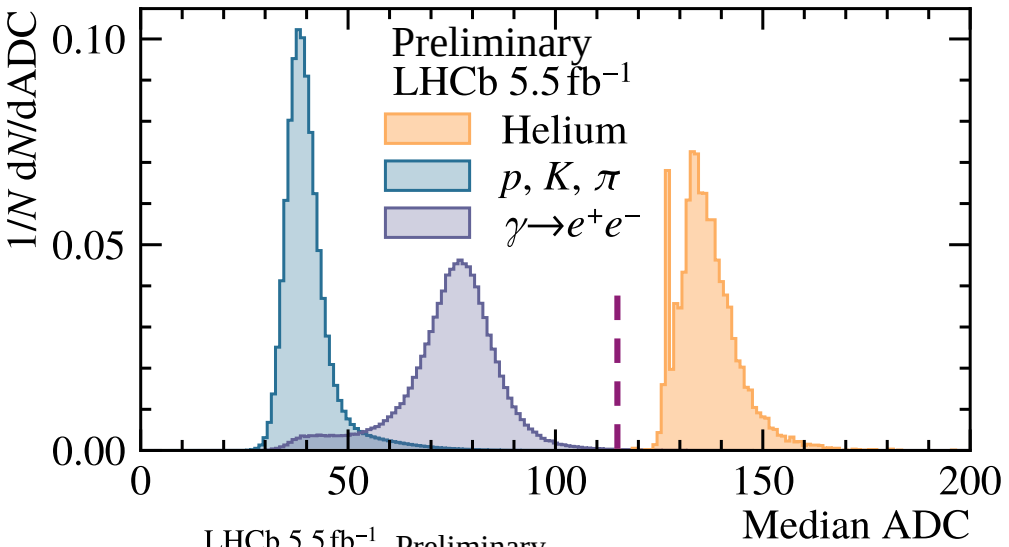
LHCb skimming stage

- Run2 pp data from two different preselections

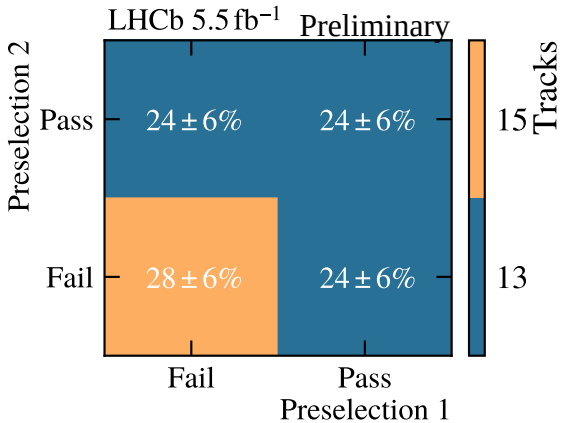
Preselection 1



Preselection 2



Efficiencies estimated from minimum bias candidates:



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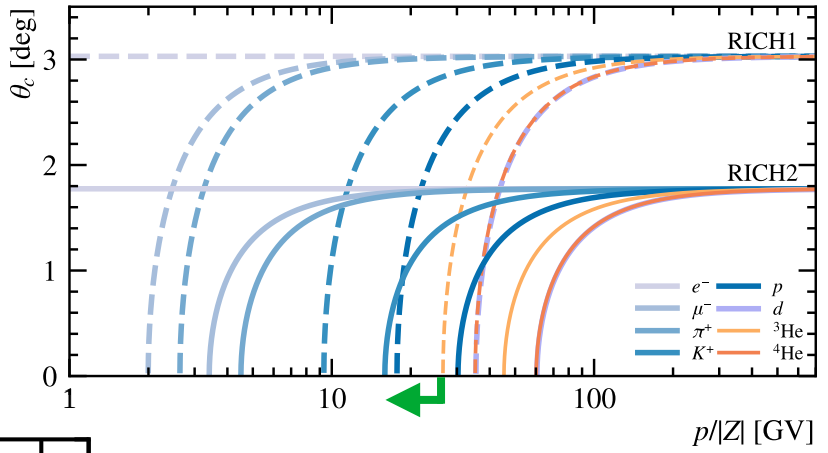
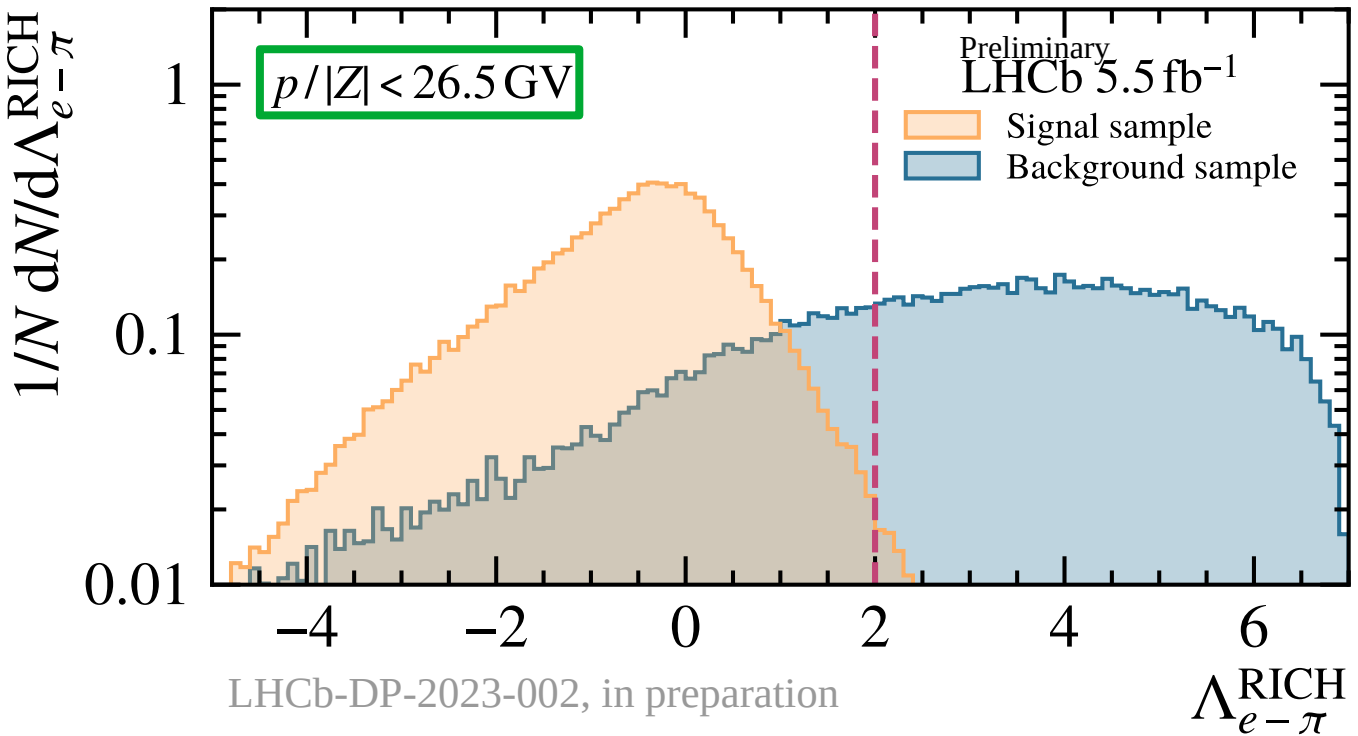
Rigidity dependence





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Positive identification above threshold possible, but not implemented up to now

[LHCb-CONF-2023-002]

Hypertriton selection