Bundesministerium für Bildung und Forschung

FSP LHCb Erforschung von Universum und Materie

RWTH AACHEN UNIVERSITY

LHCb

Study of antihelium production at LHCb

Dan Moise,

on behalf of the LHCb collaboration

ICHEP Prague

18th July 2024

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

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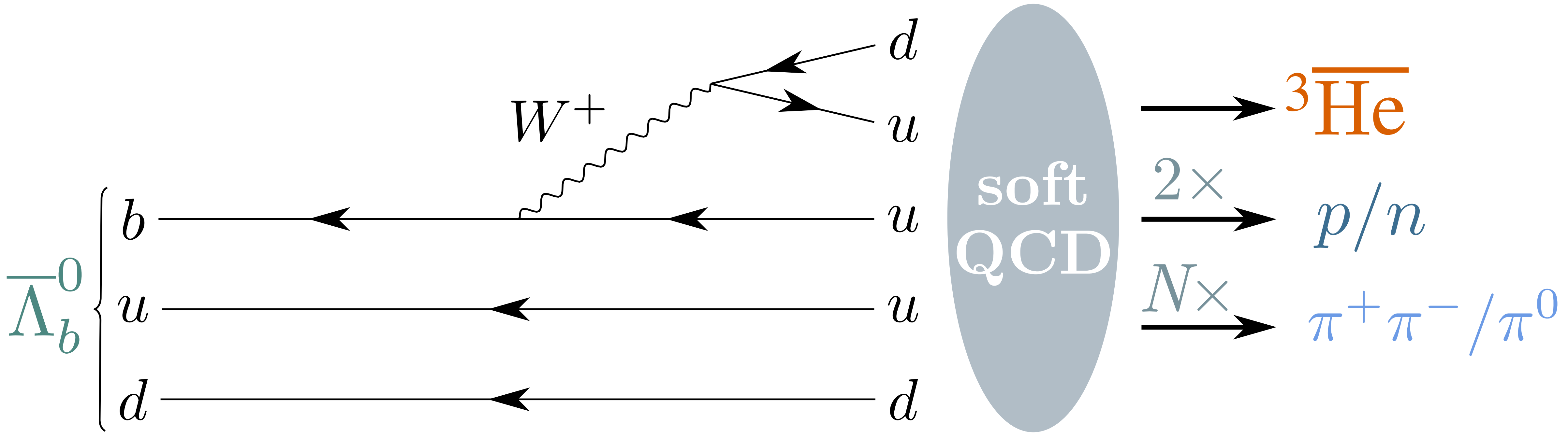
18th July 2024

S. Ting CERN colloquium

Dark Matter Annihilation Can Produce a Detectable Antihelium Flux through $\bar{\Lambda}_b$ Decays

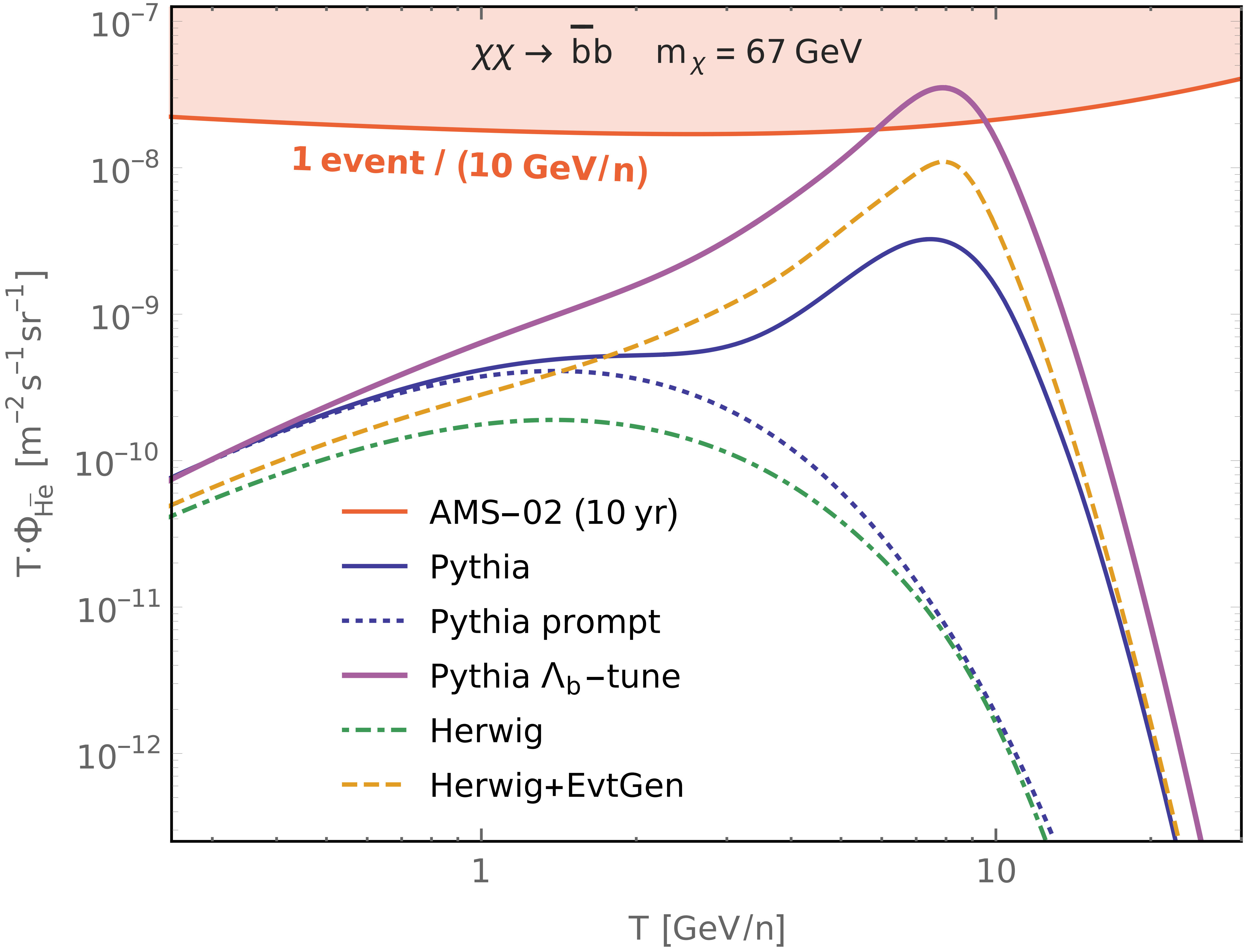
Martin Wolfgang Winkler[1,*] and Tim Linden[1,†]
[1]Stockholm University and The Oskar Klein Centre for Cosmoparticle Physics, Alba Nova, 10691 Stockholm, Sweden

PRL 126(2021)101101



$\mathcal{B}(\overline{\Lambda}_b^0 \to {}^3\overline{\mathrm{He}}X)$ predicted as high as 3×10^{-6} (modified Pythia 8.2)

well within reach of LHCb



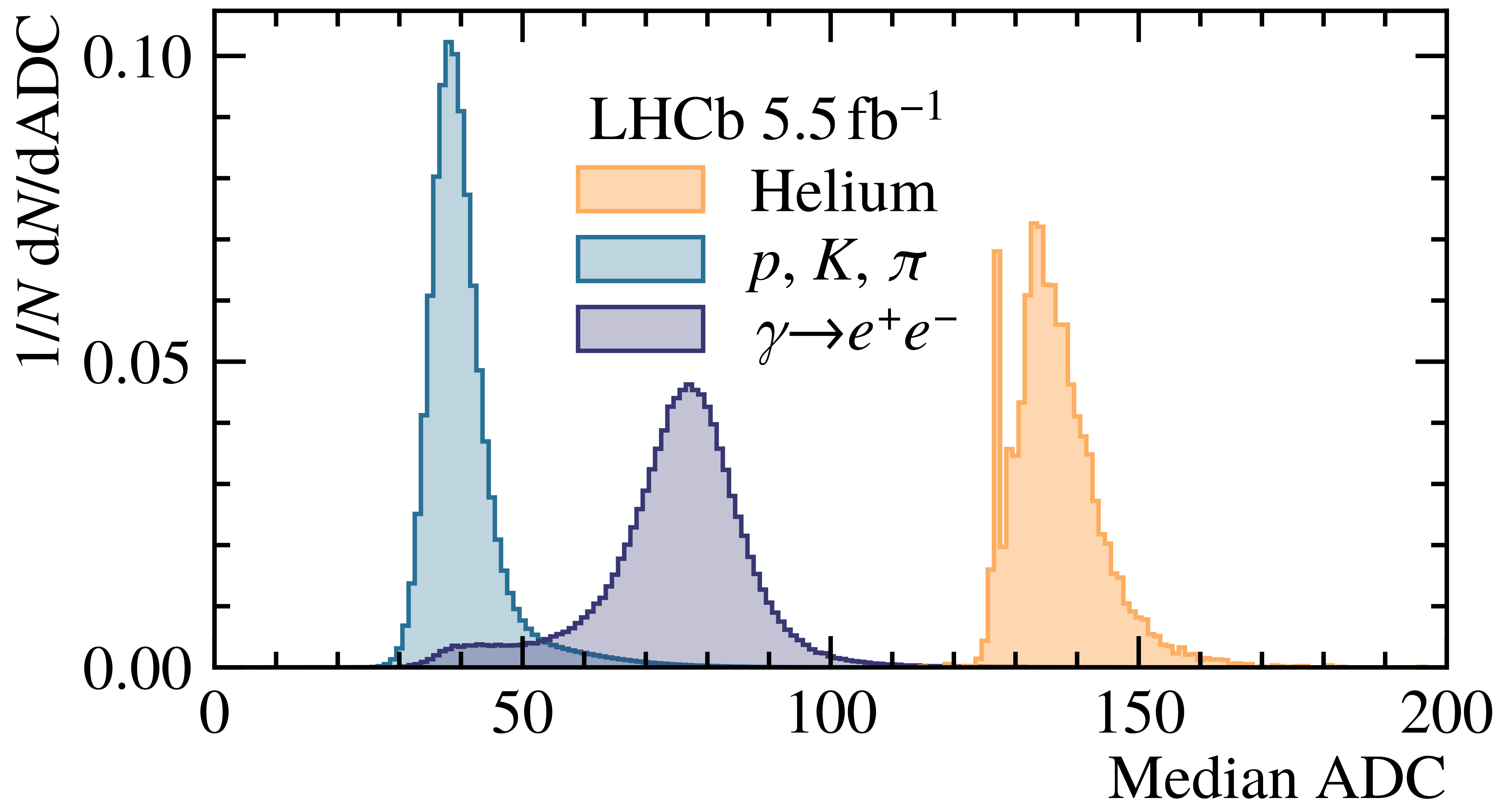
NB: discussion ongoing, e.g. PRC 1018(2023) 024903

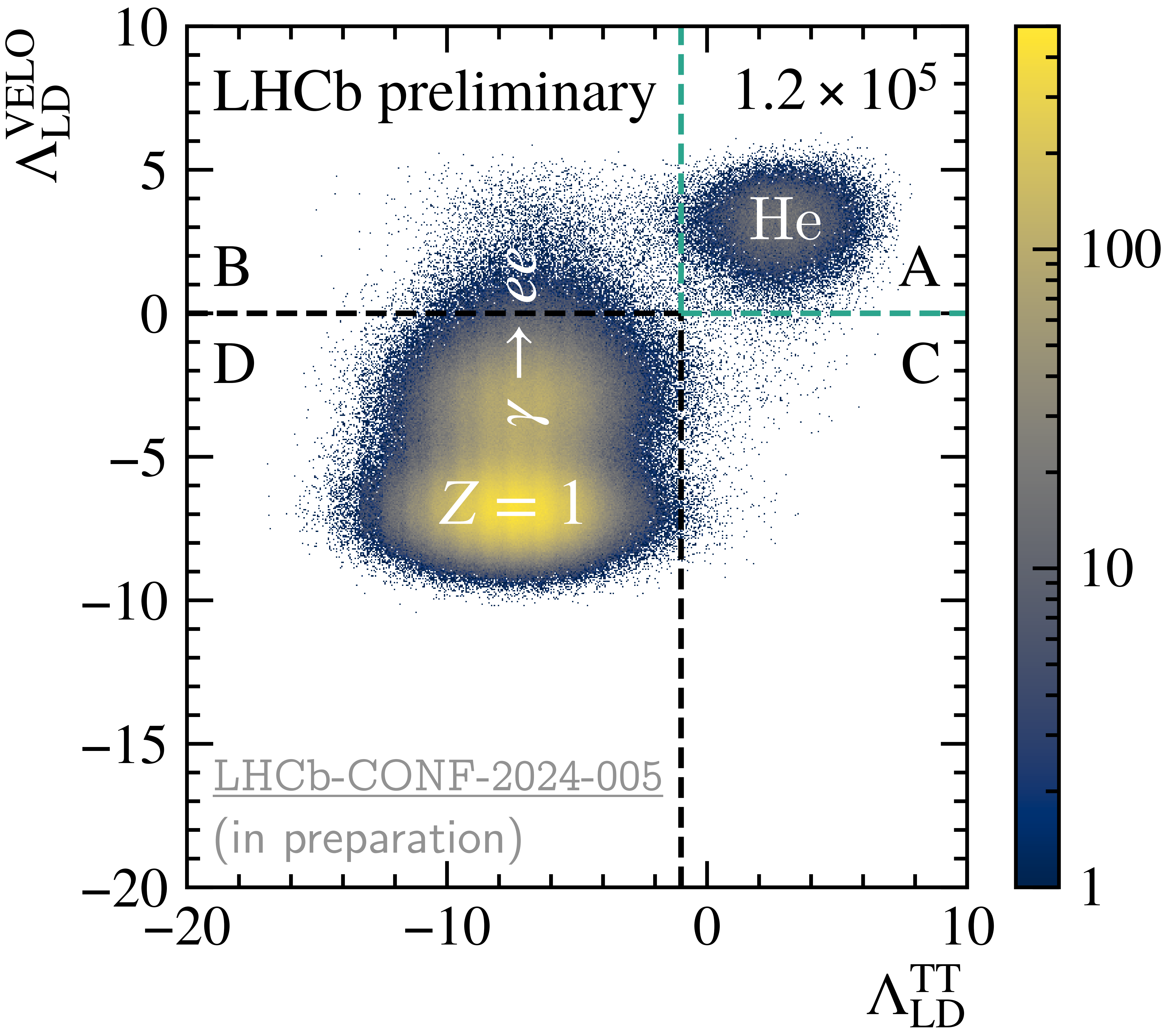
Helium selection: dE/dx

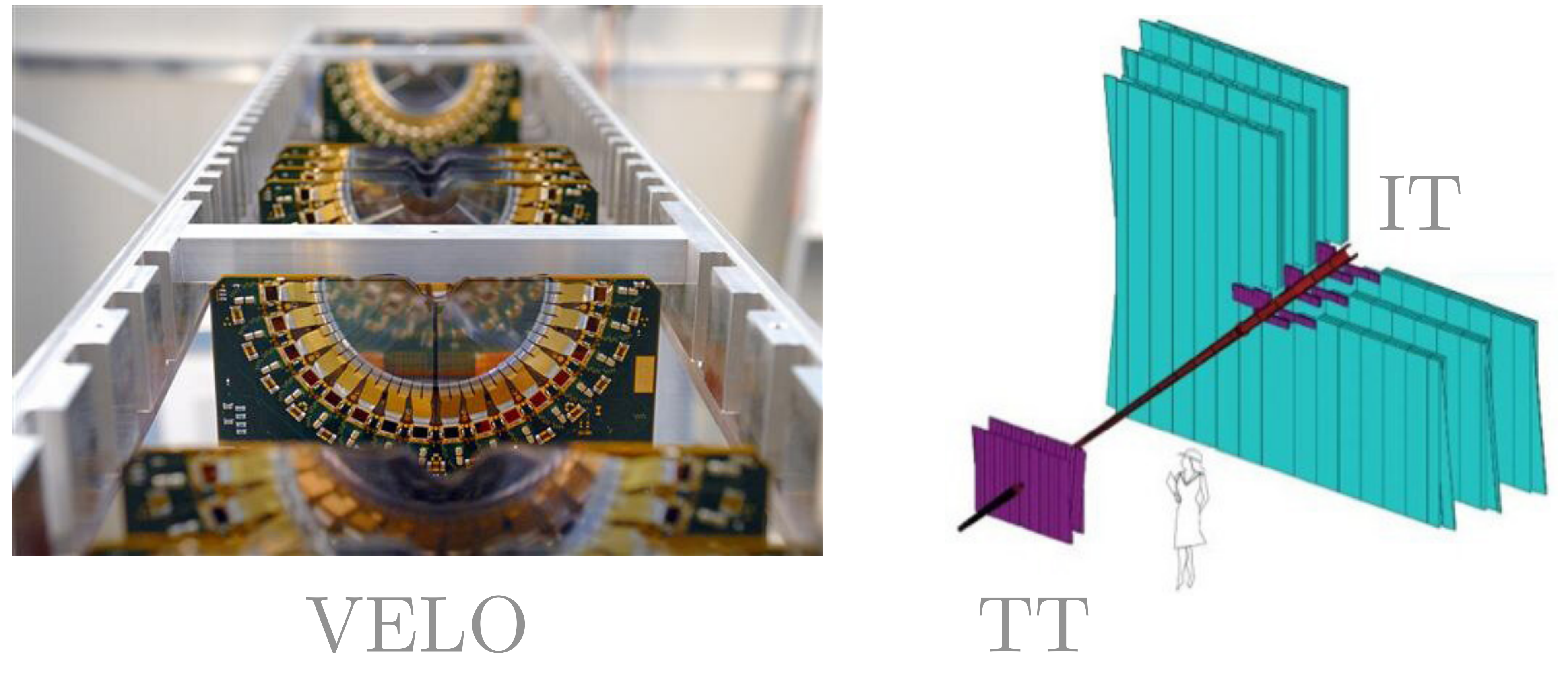
- energy-loss information in VELO, TT, and IT encoded into log-likelihood estimators (Λ_{LD})

$\Rightarrow$ excellent separation between helium and $Z = 1$ particles, $\mathcal{O}(10^{12})$ background rejection rate

JINST 19 (2024)270 P02010

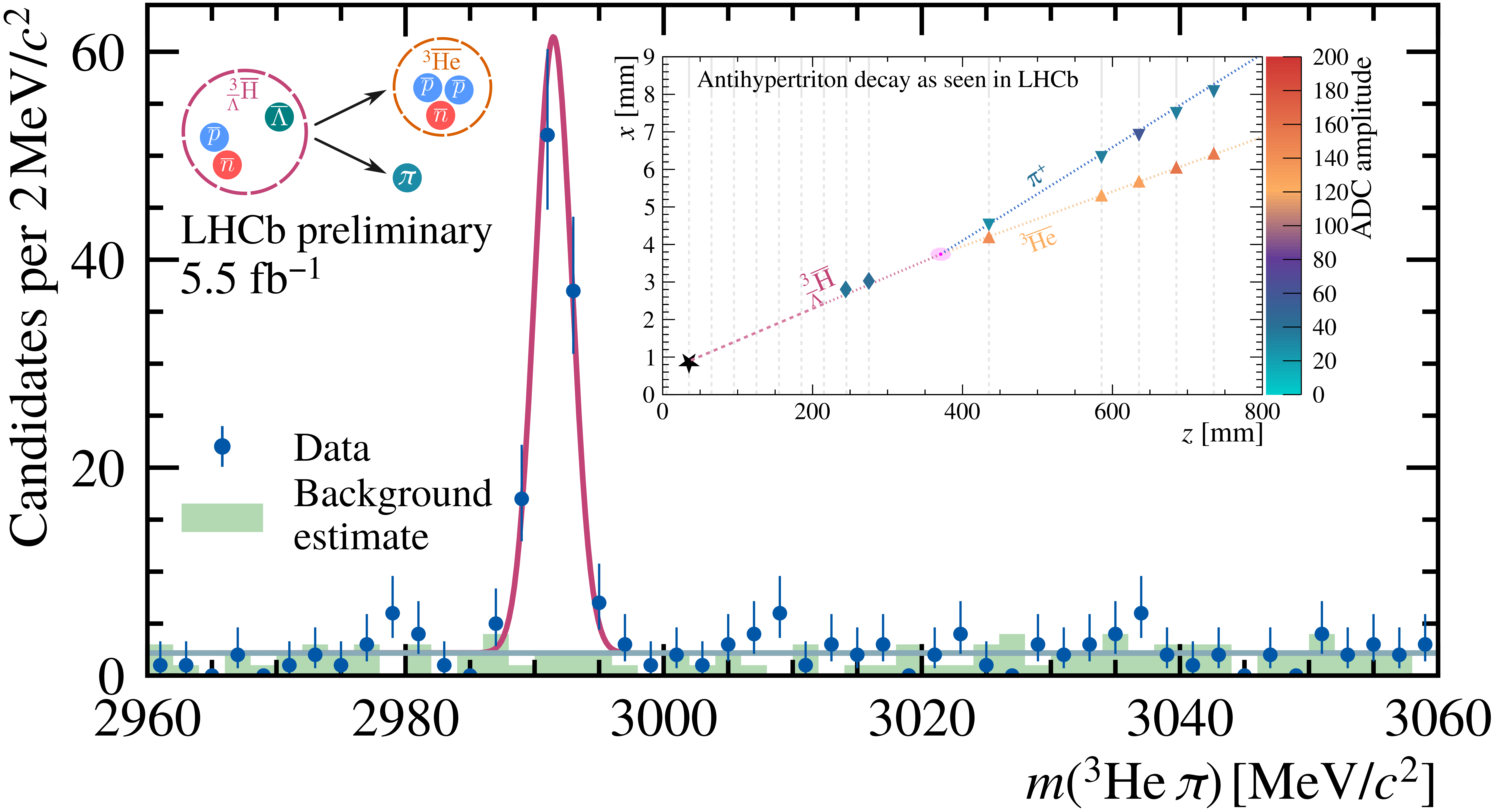




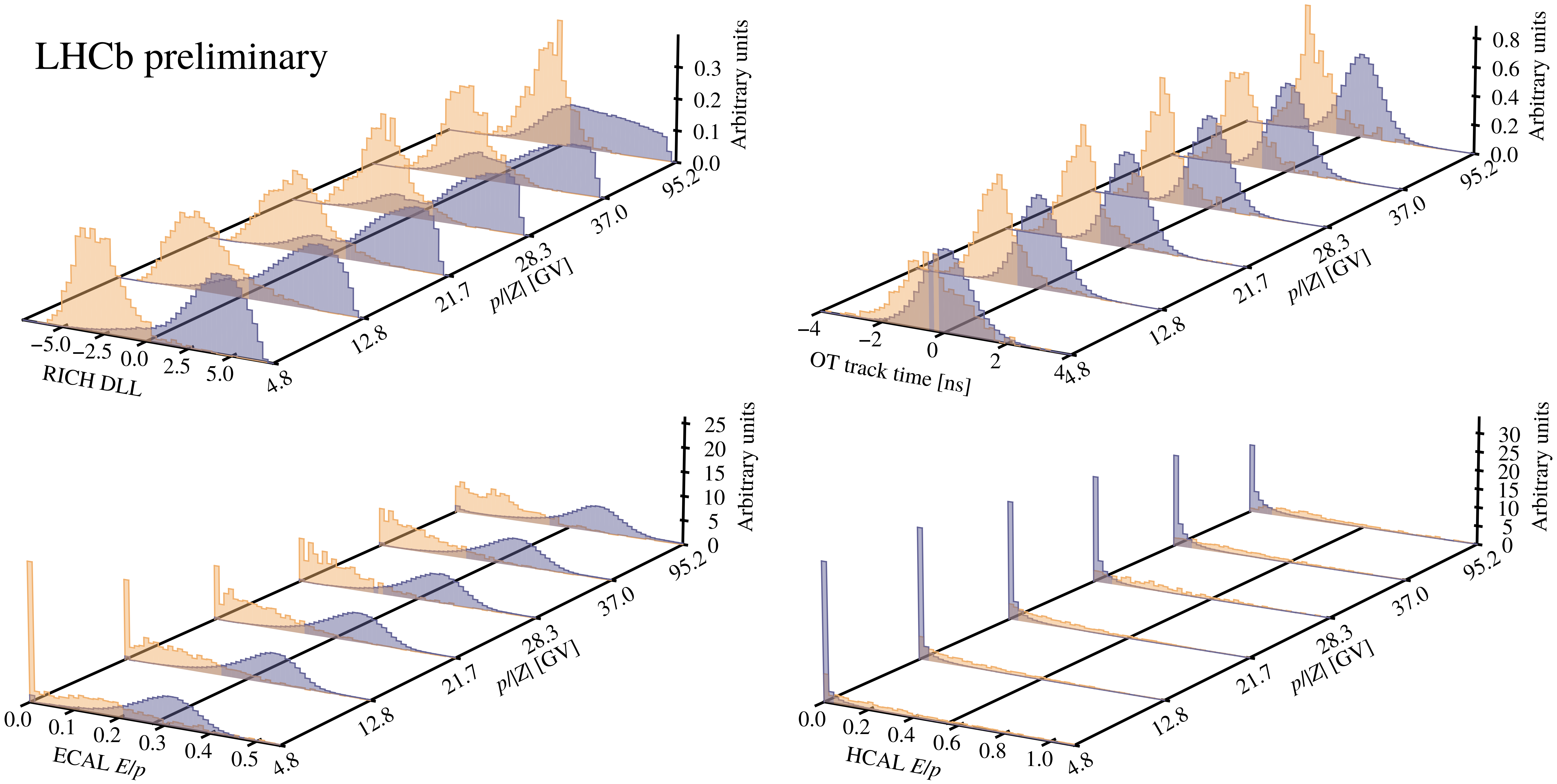


Observation of hypertriton at LHCb

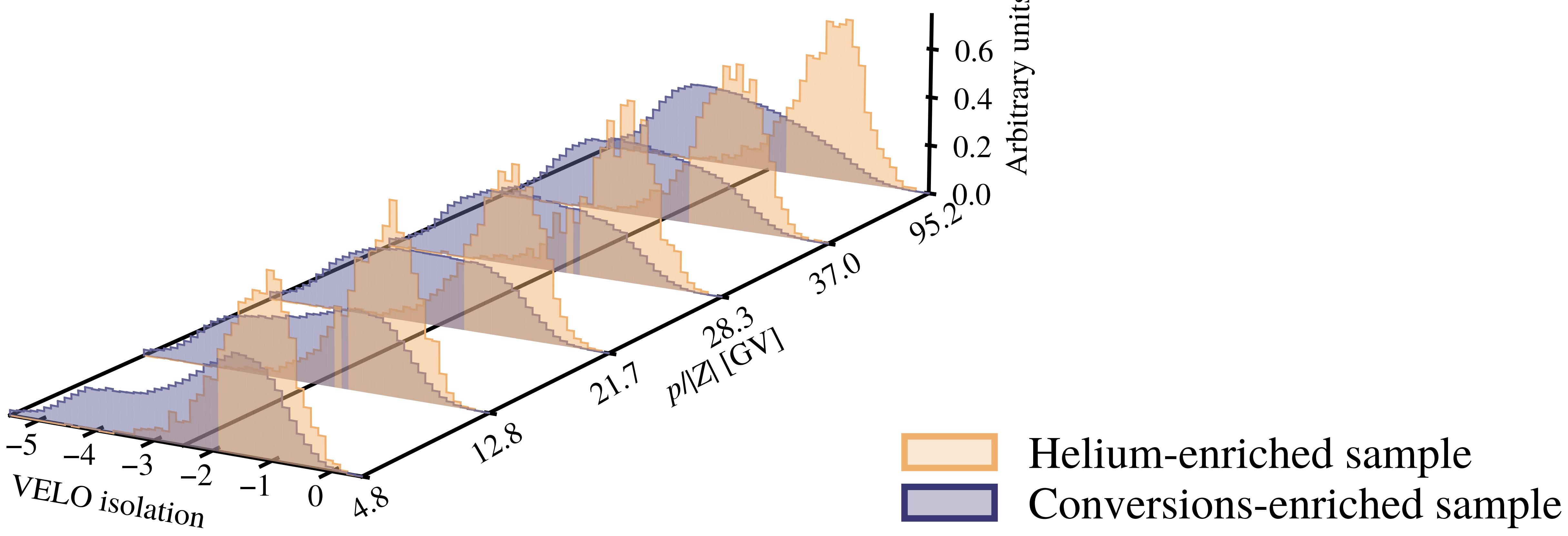
LHCb-CONF-2023-002
PoS EPS-HEP2023 (2024) 254



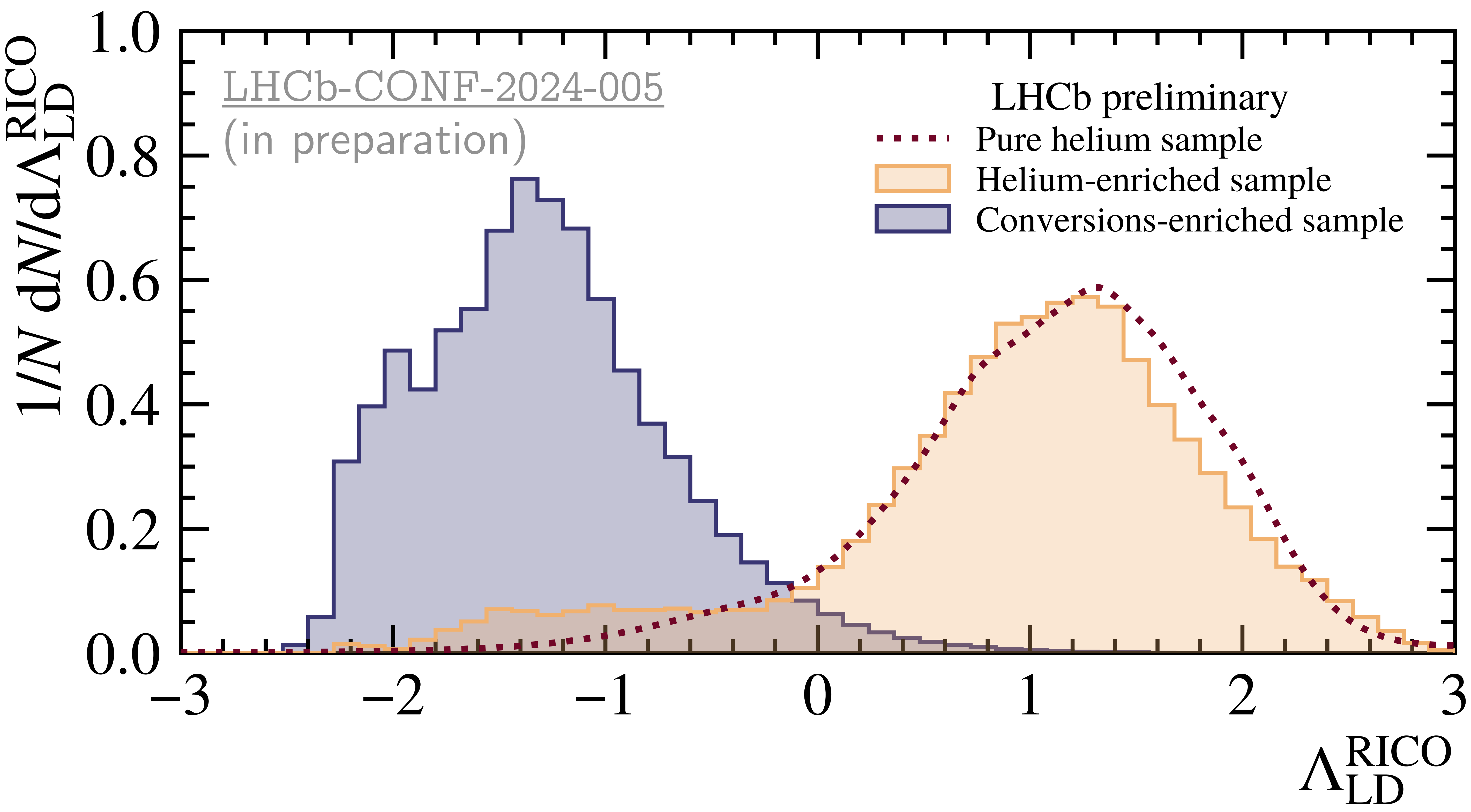
Helium selection: conversion rejection



LHCb-CONF-2024-005
(in preparation)



Helium selection: conversion rejection

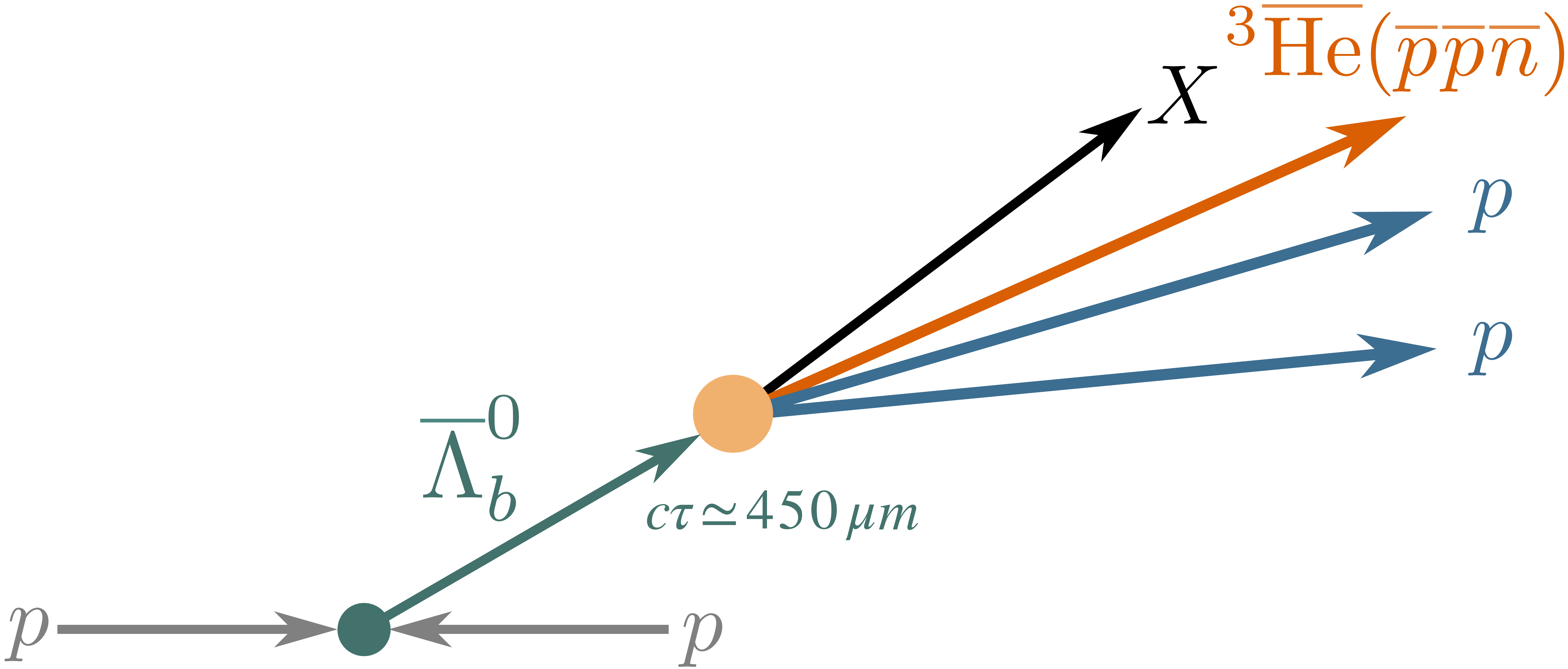


- **R**ICH, **I**solation, **C**alorimetry, and **O**T information combined into additional log-likelihood estimator: Λ^{RICO}_{LD}

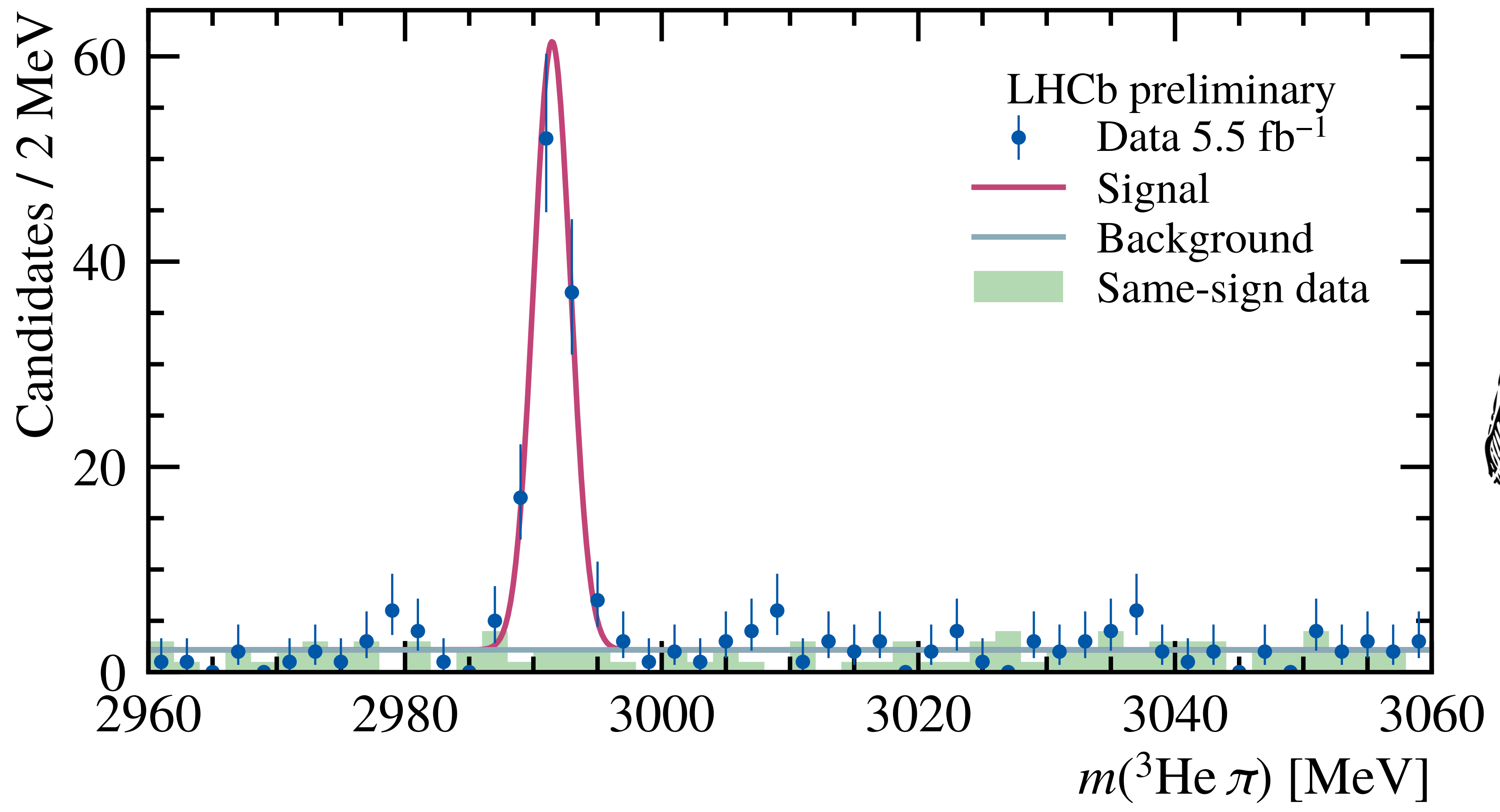
⇒ removes residual background from conversions

⇒ signal ↗ 10%, background ↘ 3x *cf.* previous publications

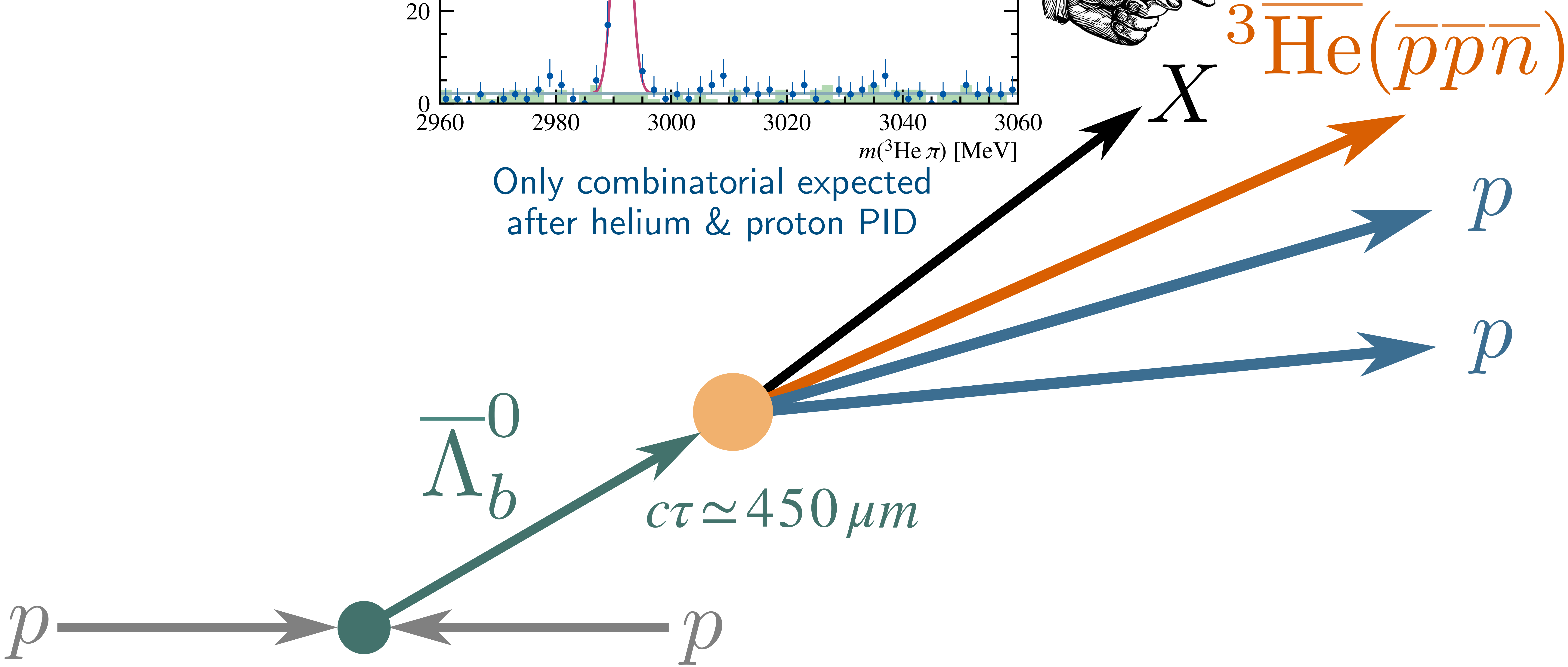
Topology & kinematics



Topology & kinematics



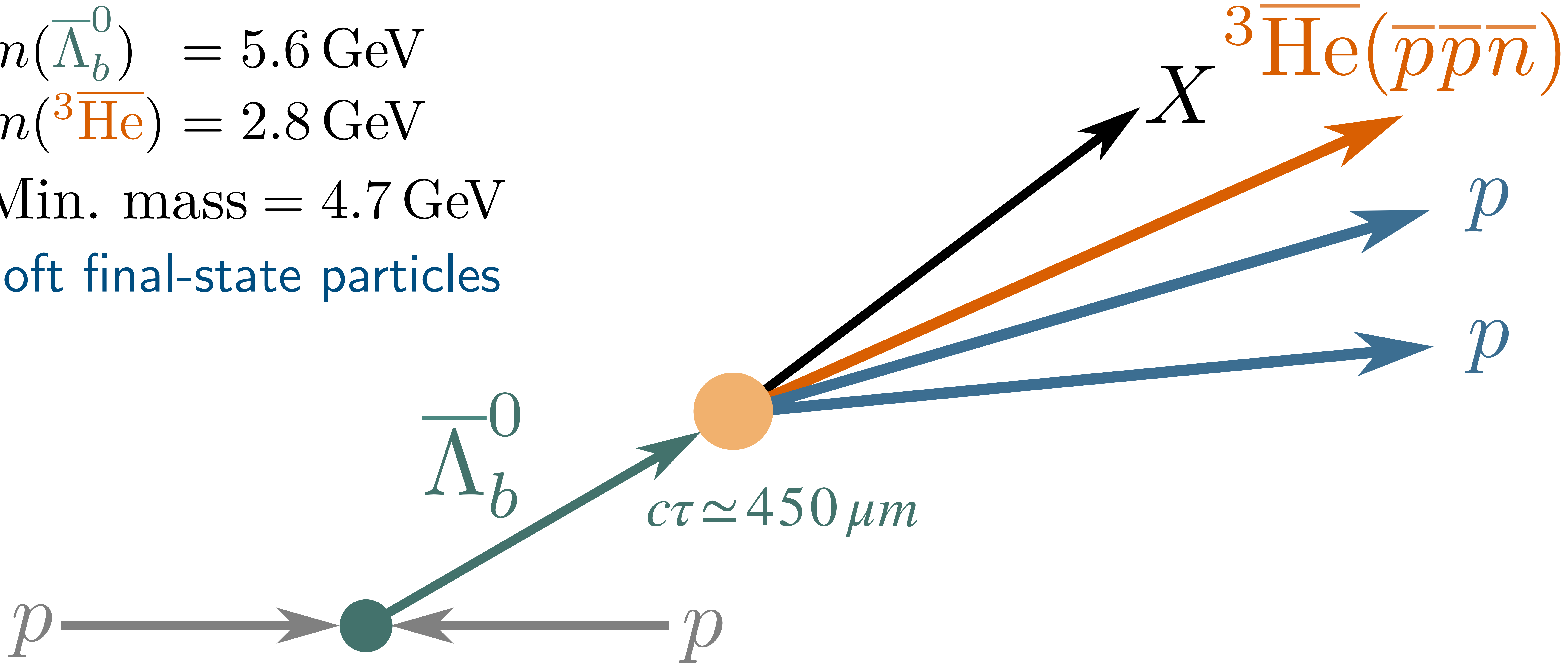
Only combinatorial expected
after helium & proton PID



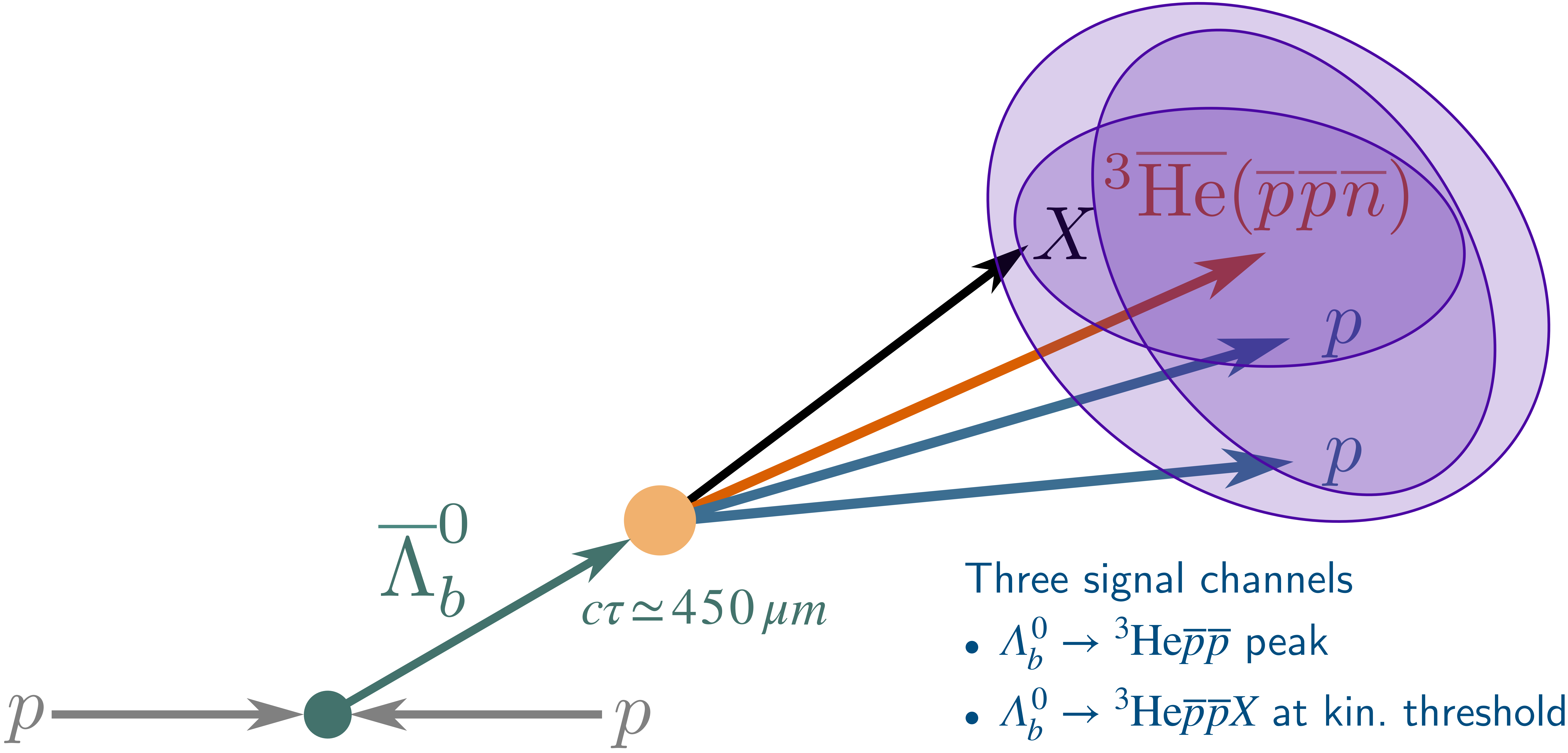
Topology & kinematics

$m(\overline{\Lambda}_b^0) = 5.6\,\mathrm{GeV}$
$m(^3\overline{\mathrm{He}}) = 2.8\,\mathrm{GeV}$
$\mathrm{Min.\ mass} = 4.7\,\mathrm{GeV}$

Soft final-state particles



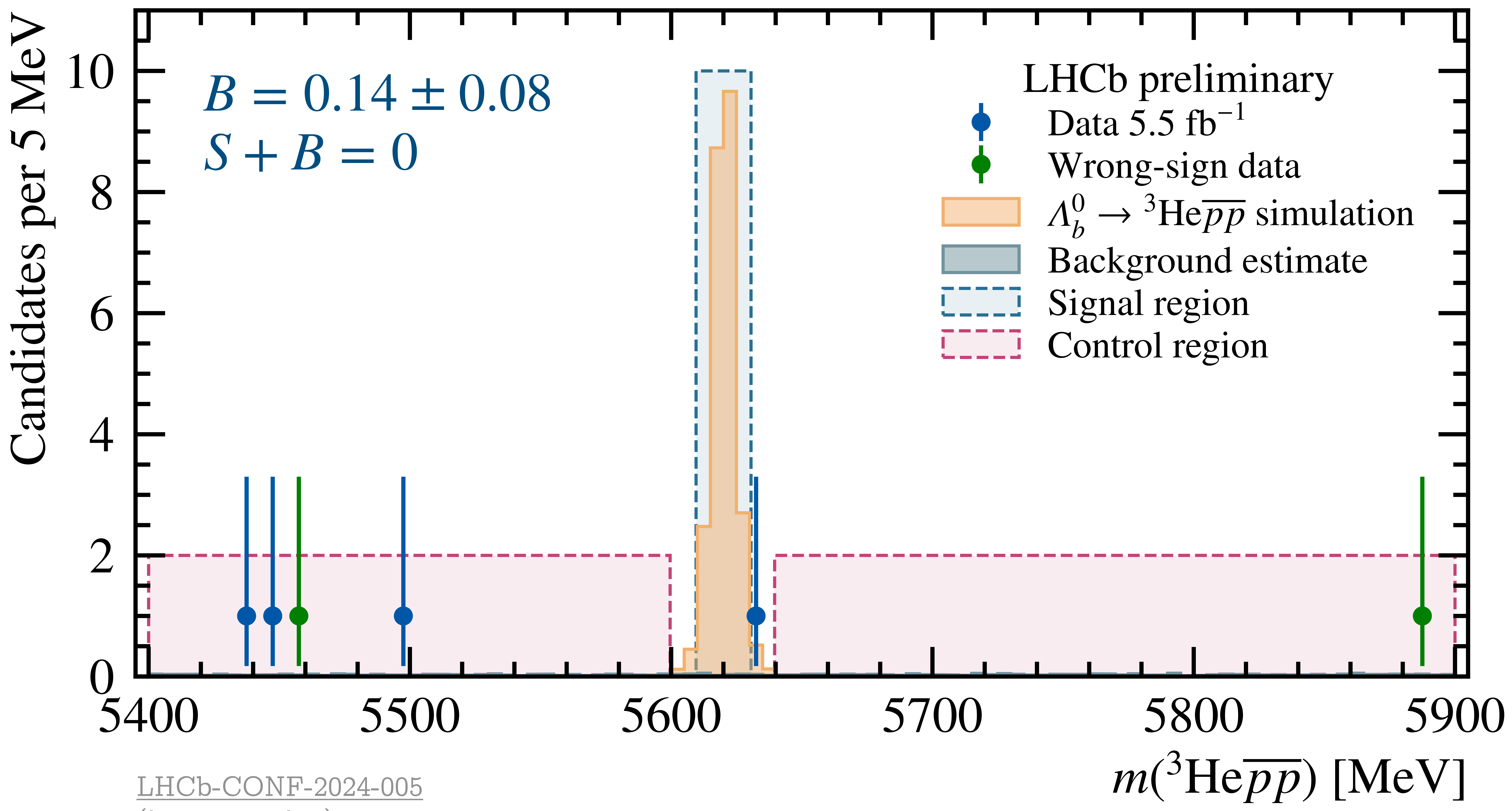
Topology & kinematics



Three signal channels

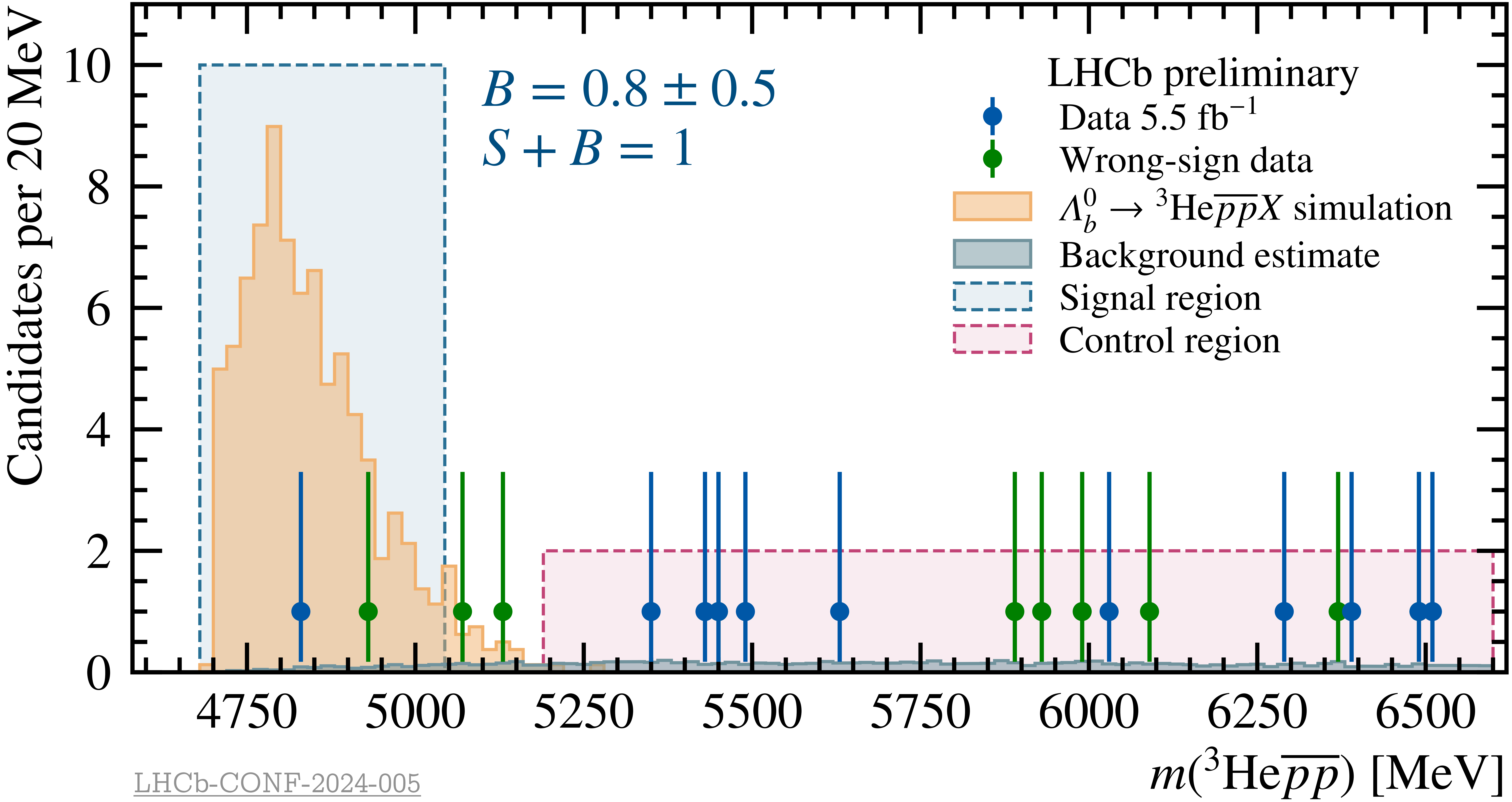
- $\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}$ peak
- $\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}X$ at kin. threshold
- $\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}X$ at kin. threshold

$\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}$ data



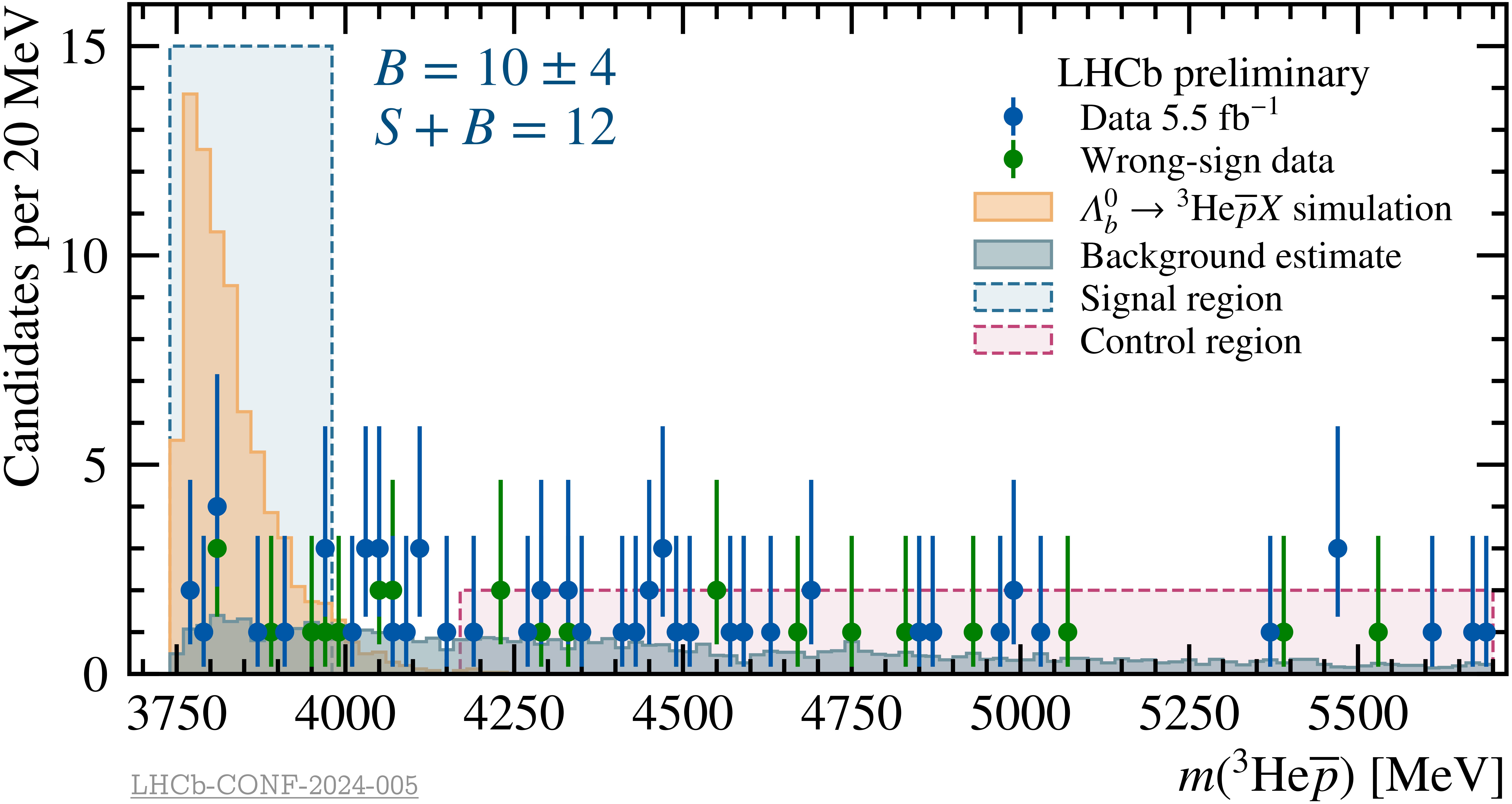
LHCb-CONF-2024-005
(in preparation)

$\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}X$ data



LHCb-CONF-2024-005
(in preparation)

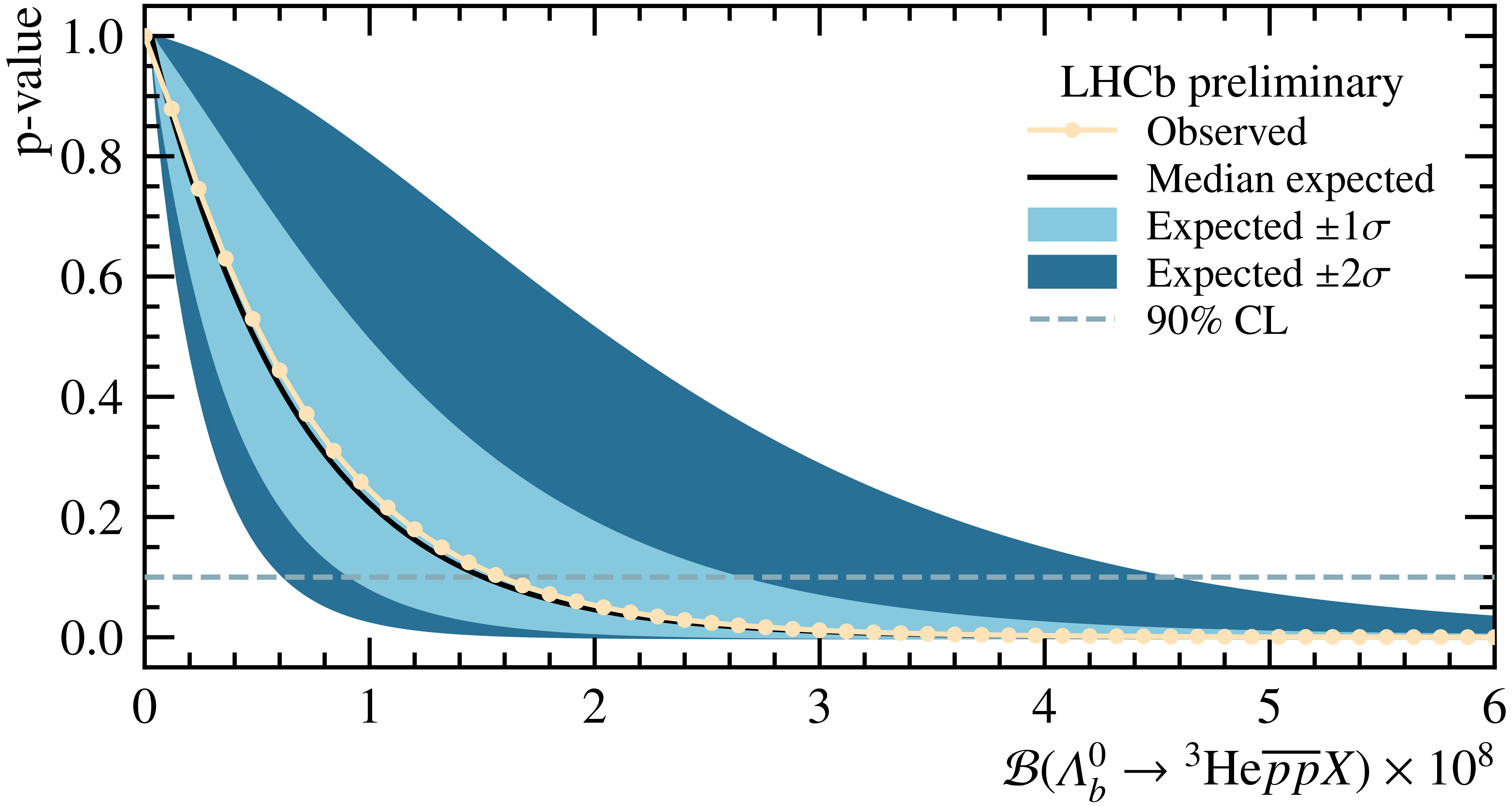
$\Lambda_b^0 \to {}^3\text{He}\bar{p}X$ data



LHCb-CONF-2024-005
(in preparation)

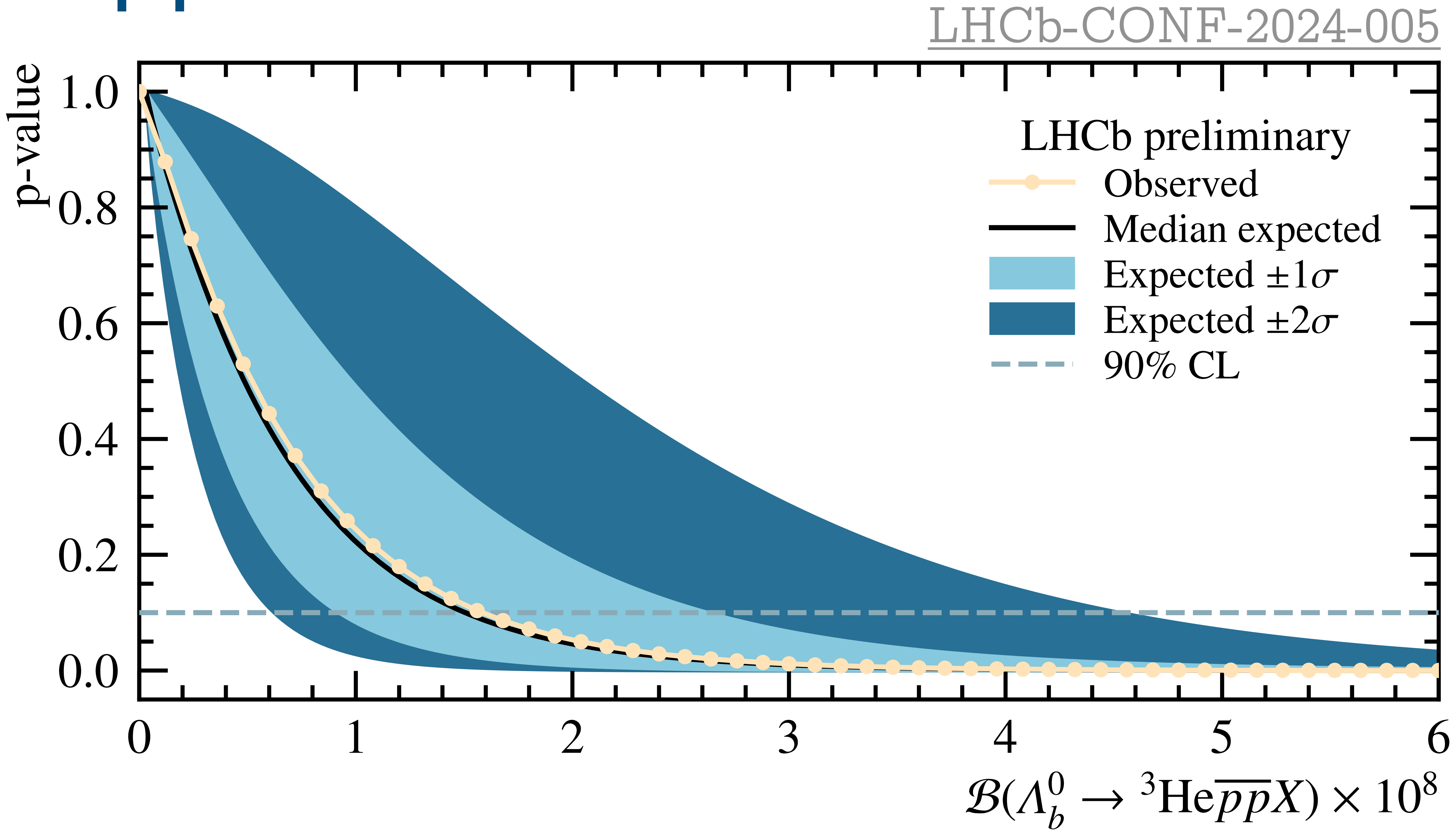
Upper limits

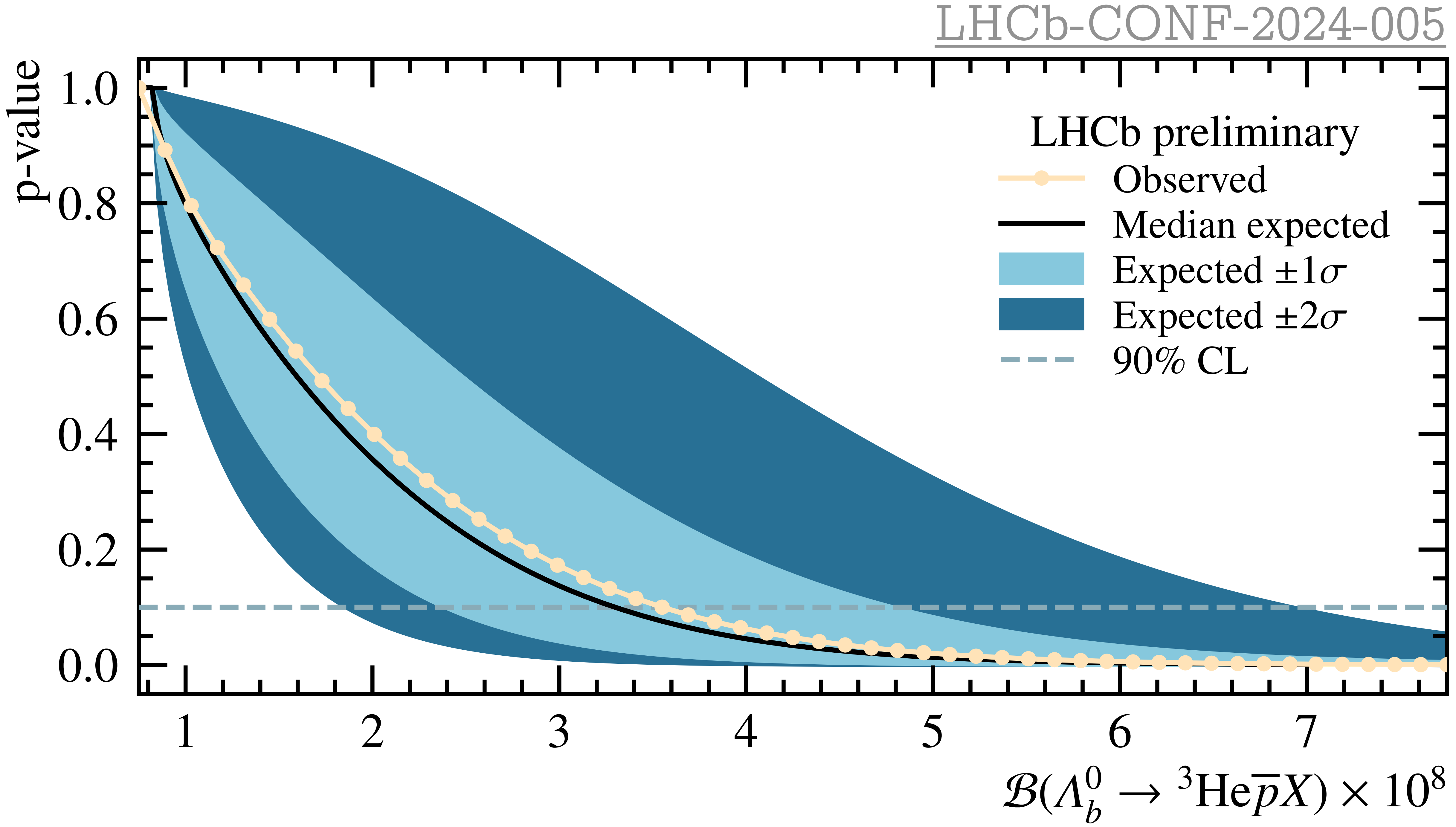
LHCb-CONF-2024-005



$$\mathcal{B}(\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}X) < 1.6 \times 10^{-8}$$

Upper limits



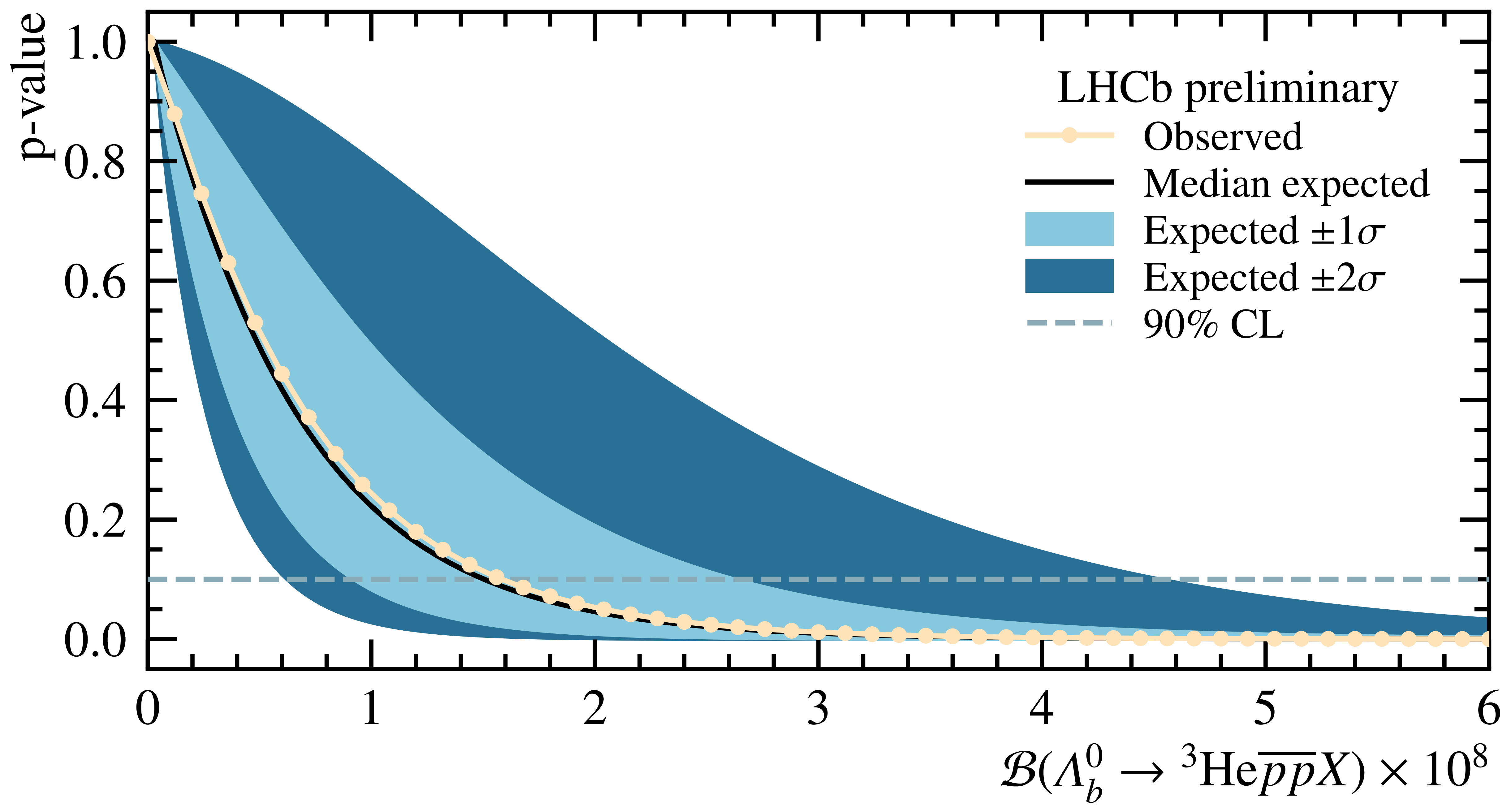


$\mathcal{B}(\Lambda_b^0 \to {}^3\text{He}\overline{p}\overline{p}X) < 1.6 \times 10^{-8}$

$\mathcal{B}(\Lambda_b^0 \to {}^3\text{He}\overline{p}X) < 3.6 \times 10^{-8}$

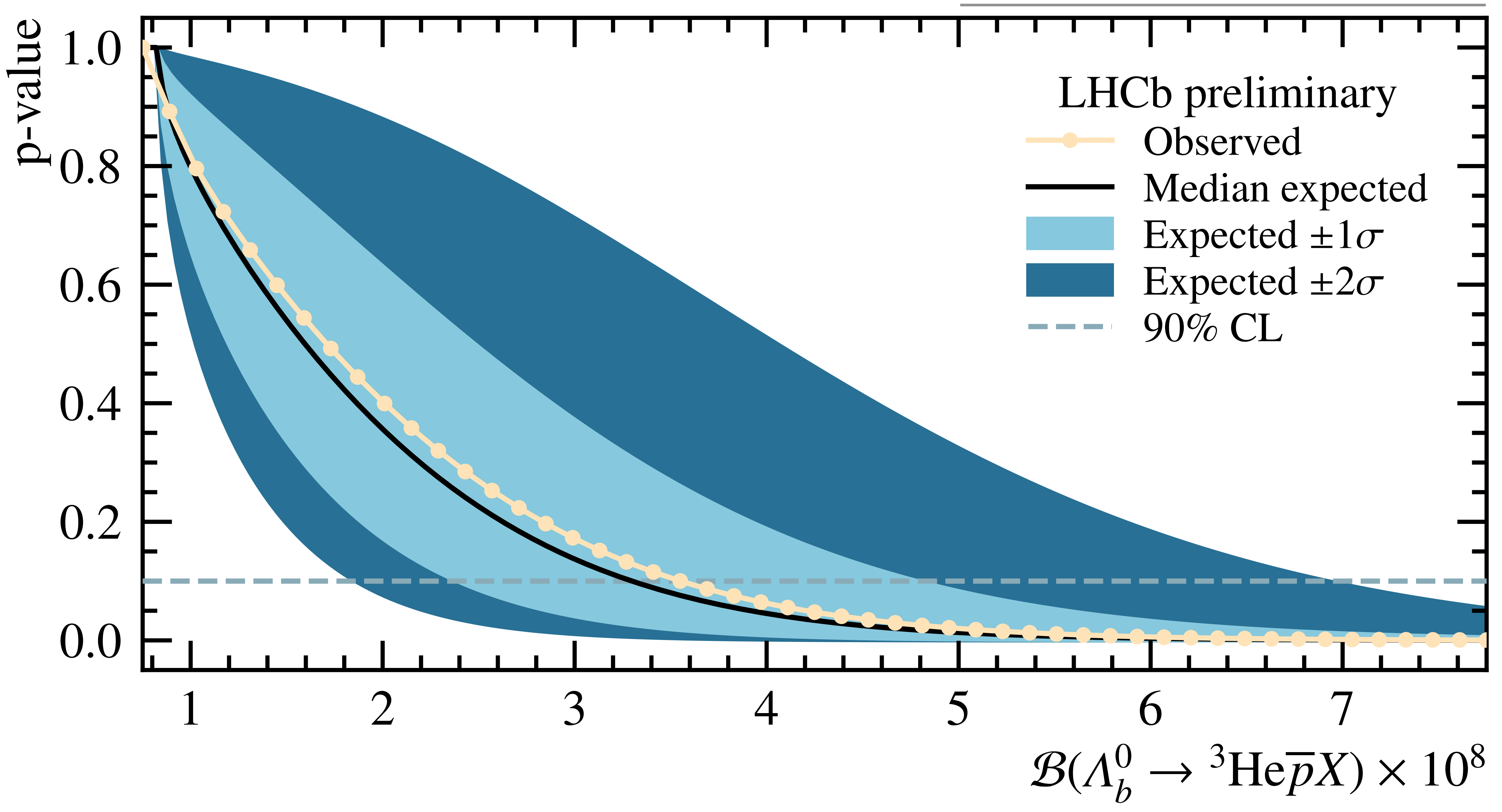
Upper limits

LHCb-CONF-2024-005



$$\mathcal{B}(\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}X) < 1.6 \times 10^{-8}$$

LHCb-CONF-2024-005



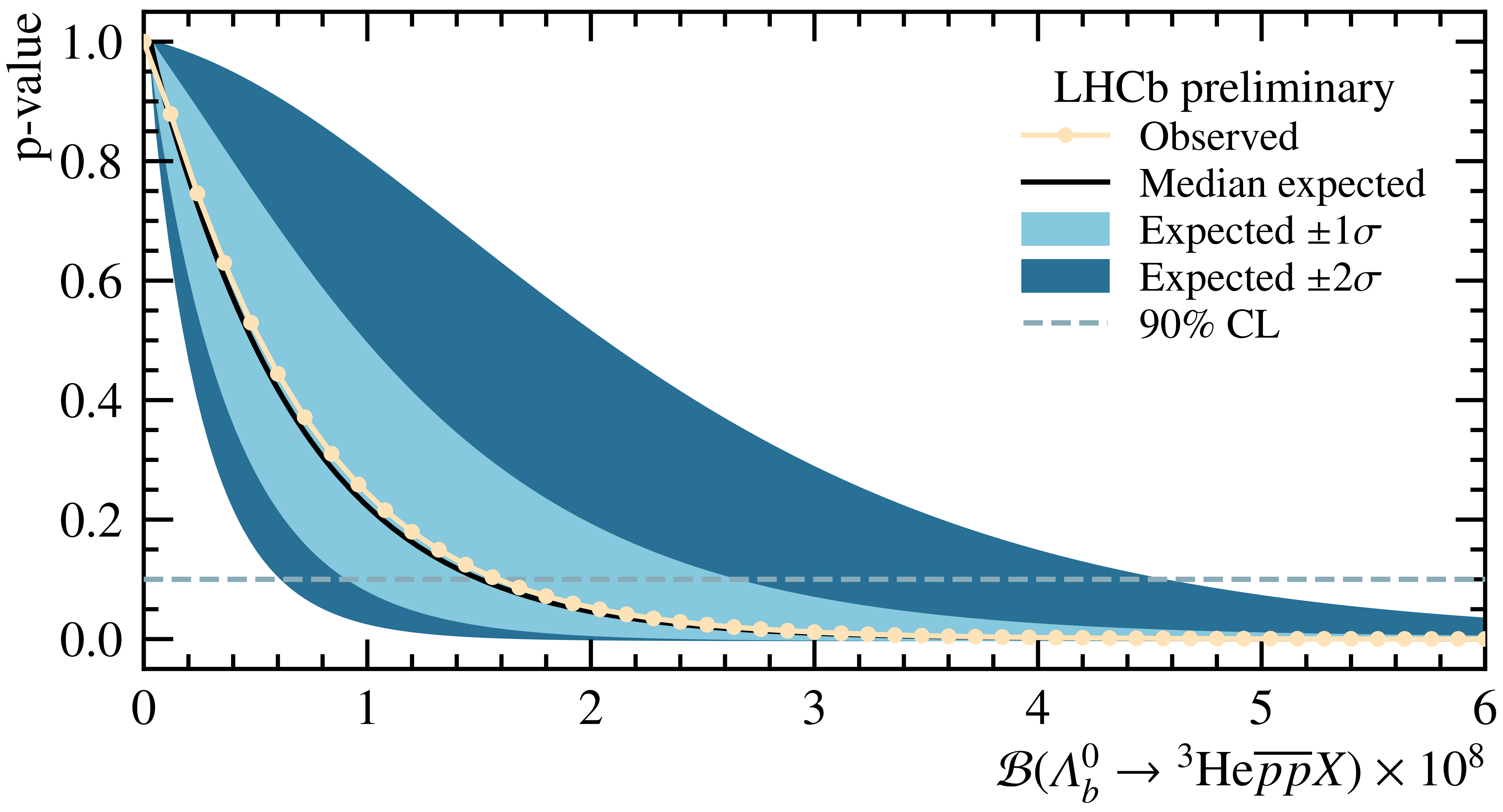
$$\mathcal{B}(\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}X) < 3.6 \times 10^{-8}$$

$$\mathcal{B}(\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}) < 1.9 \times 10^{-9}$$

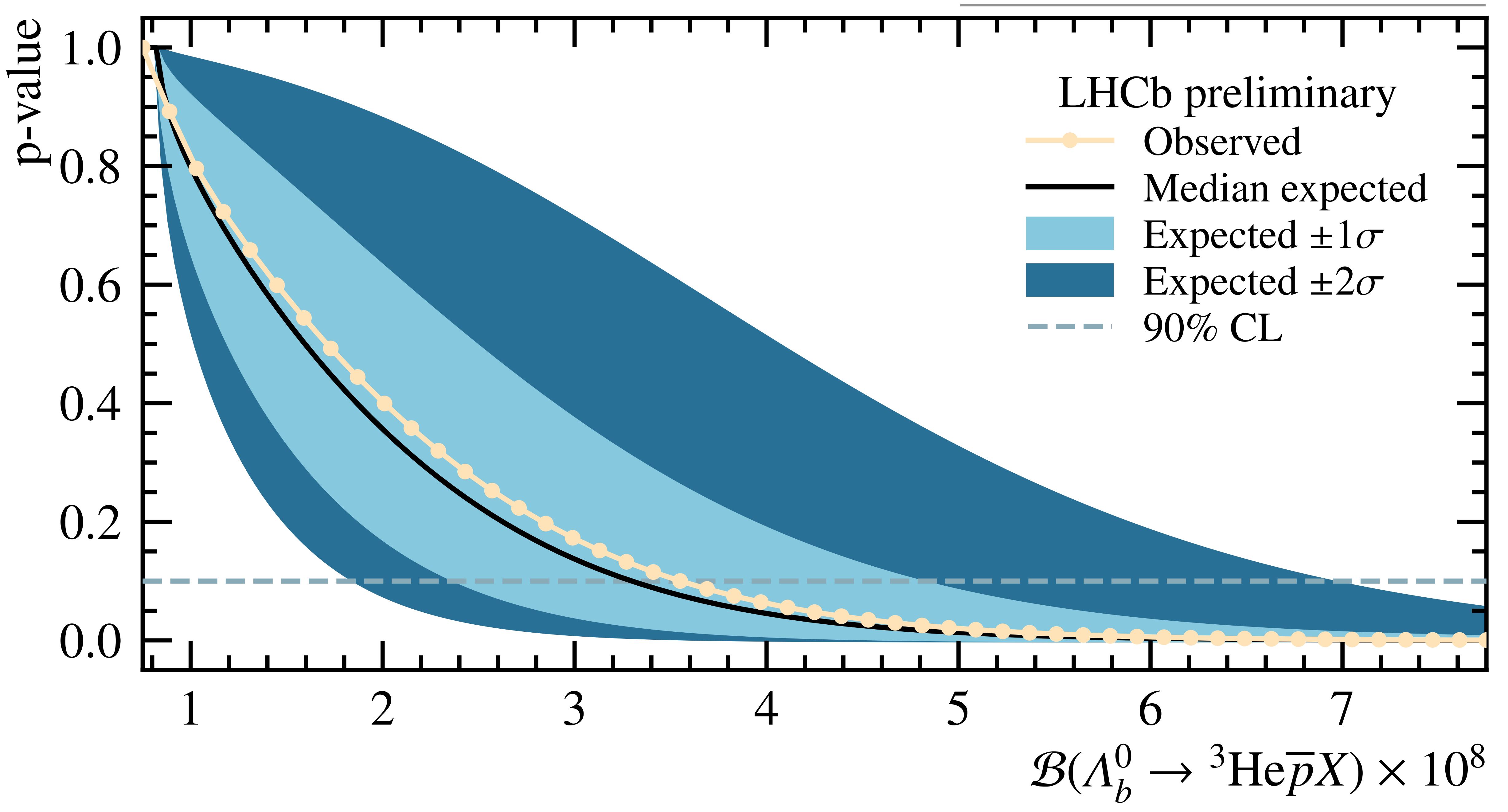
profile likelihood NIMA458(2001)745-758

Upper limits

LHCb-CONF-2024-005



LHCb-CONF-2024-005



$\mathcal{B}(\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}X) < 1.6 \times 10^{-8}$

$\mathcal{B}(\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}X) < 3.6 \times 10^{-8}$

isospin

$\overline{p}\overline{p}$: 25% $\overline{p}\overline{n}$: 25%

$\overline{n}\overline{p}$: 25% $\overline{n}\overline{n}$: 25%

(Pythia: $\overline{p}\overline{p} \sim 40\%$)

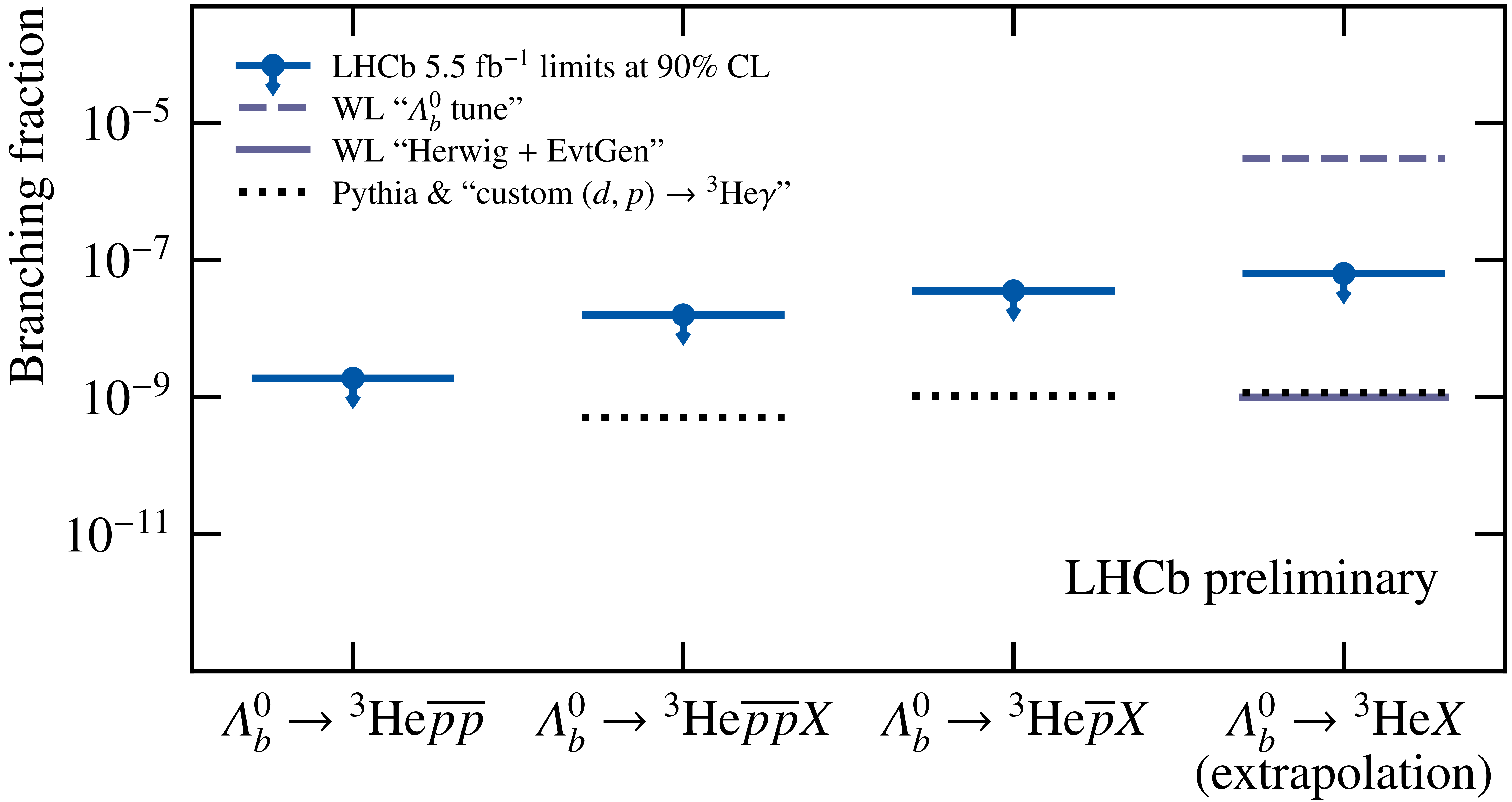
$$\mathcal{B}(\Lambda_b^0 \to {}^3\mathrm{He}X) < 6.3 \times 10^{-8}$$

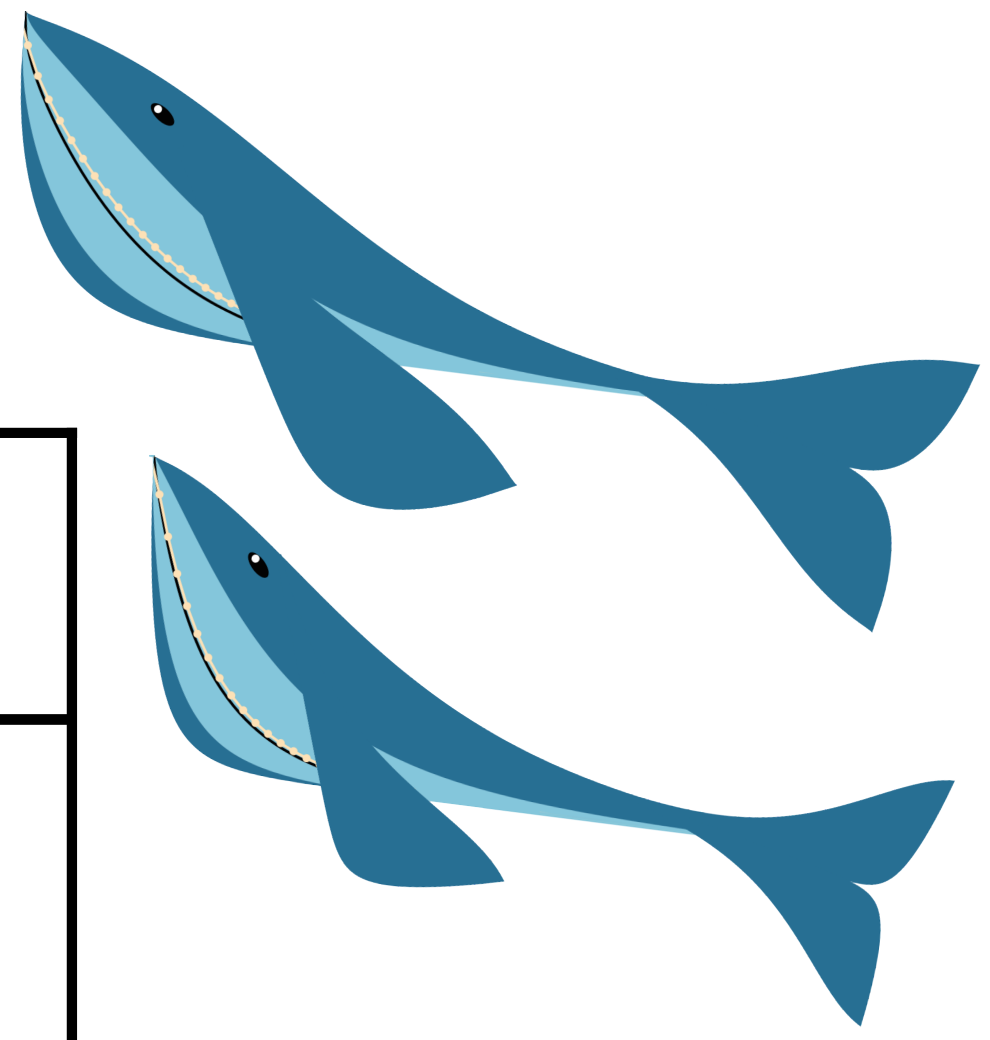
$\mathcal{B}(\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}) < 1.9 \times 10^{-9}$

profile likelihood NIMA458(2001)745-758

Summary

LHCb-CONF-2024-005 (in preparation)



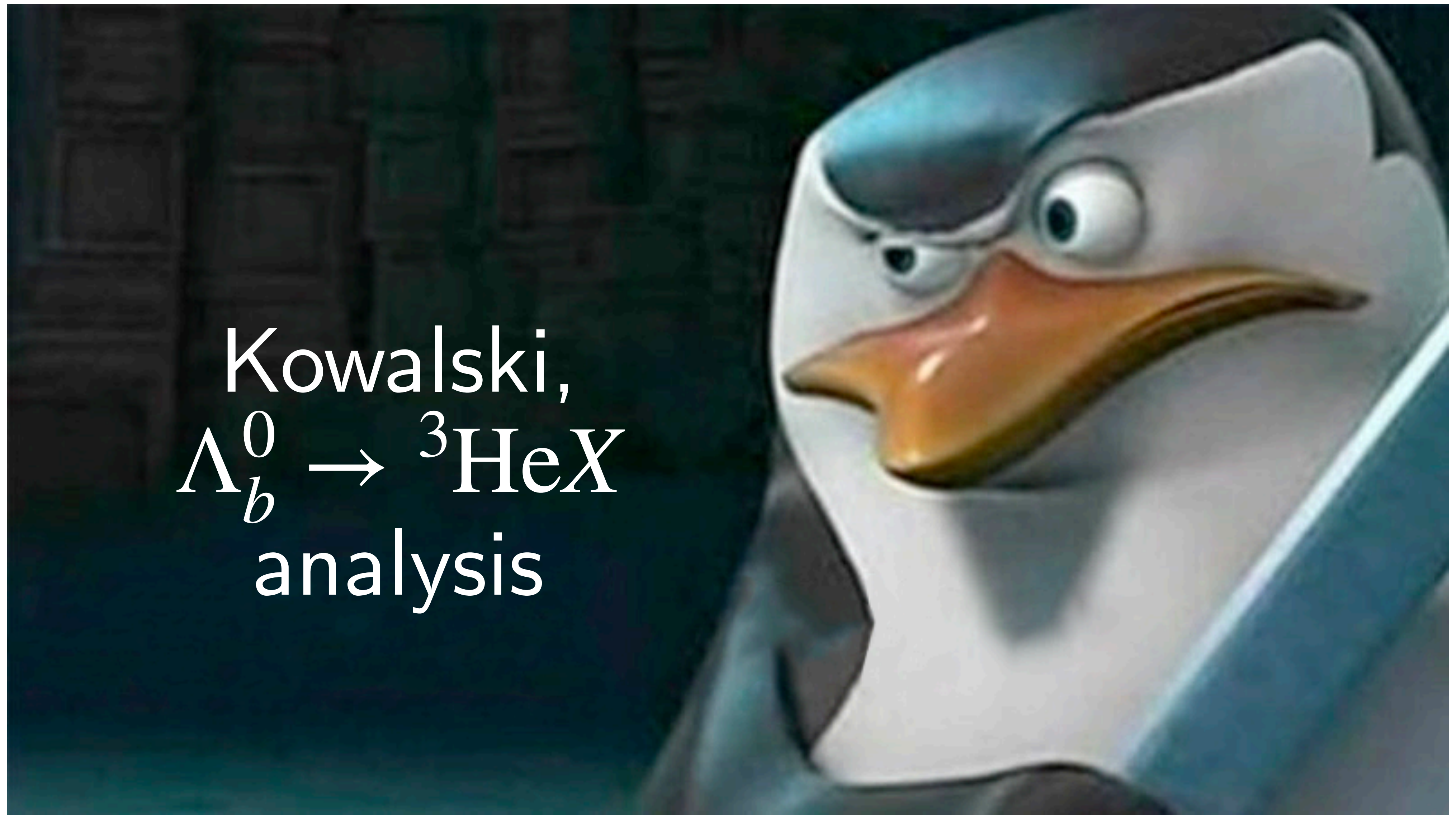


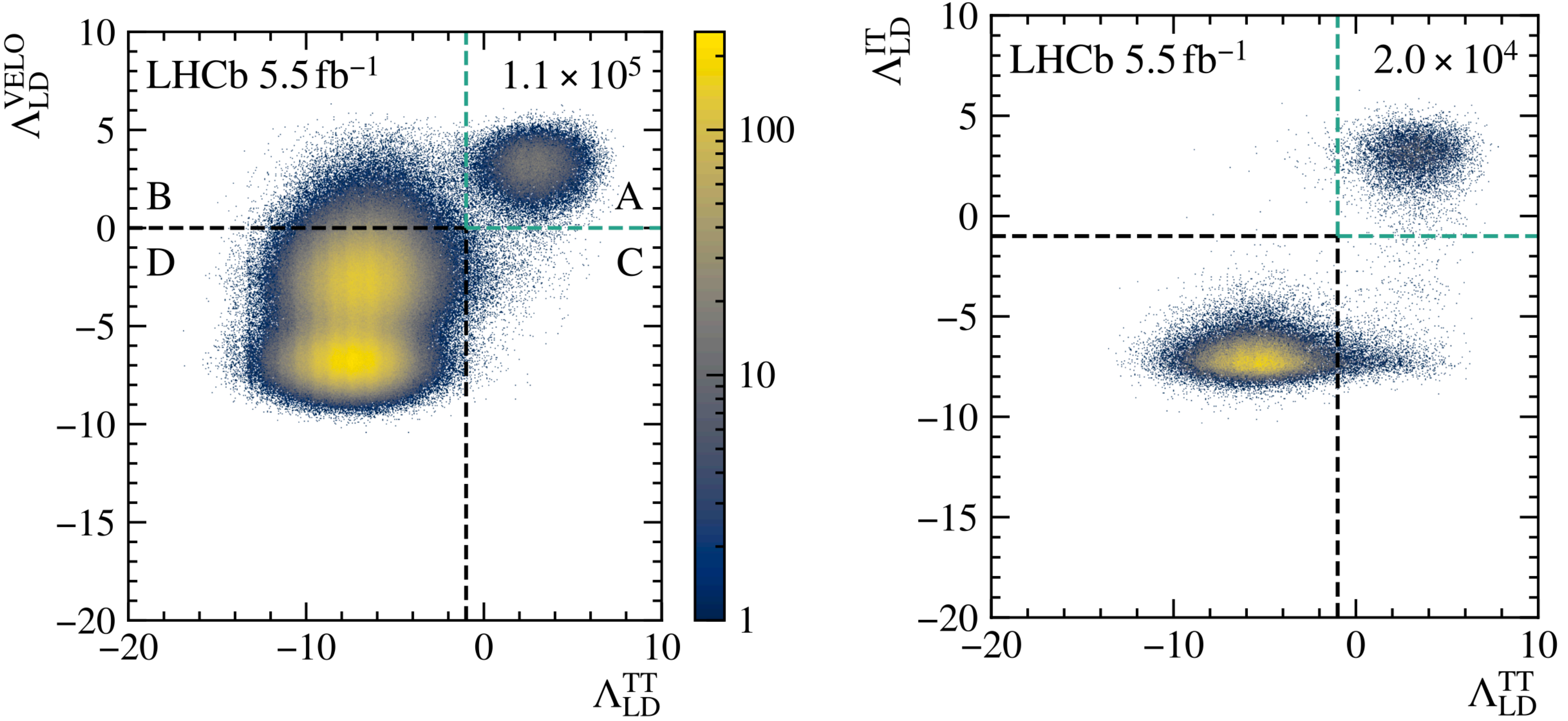
These are the first results on (anti)helium production in (anti)Λ_b decays.

They significantly restrict abundance of ${}^3\overline{\text{He}}$ in cosmic rays.

LHCb Upgrade II offers the potential to cover current estimates.

BACKUP





LHCb 5.5 fb^{-1}
1.1×10^5
Λ_{LD}^{VELO}
Λ_{LD}^{TT}
A
B
C
D
LHCb 5.5 fb^{-1}
2.0×10^4
Λ_{LD}^{IT}
Λ_{LD}^{TT}

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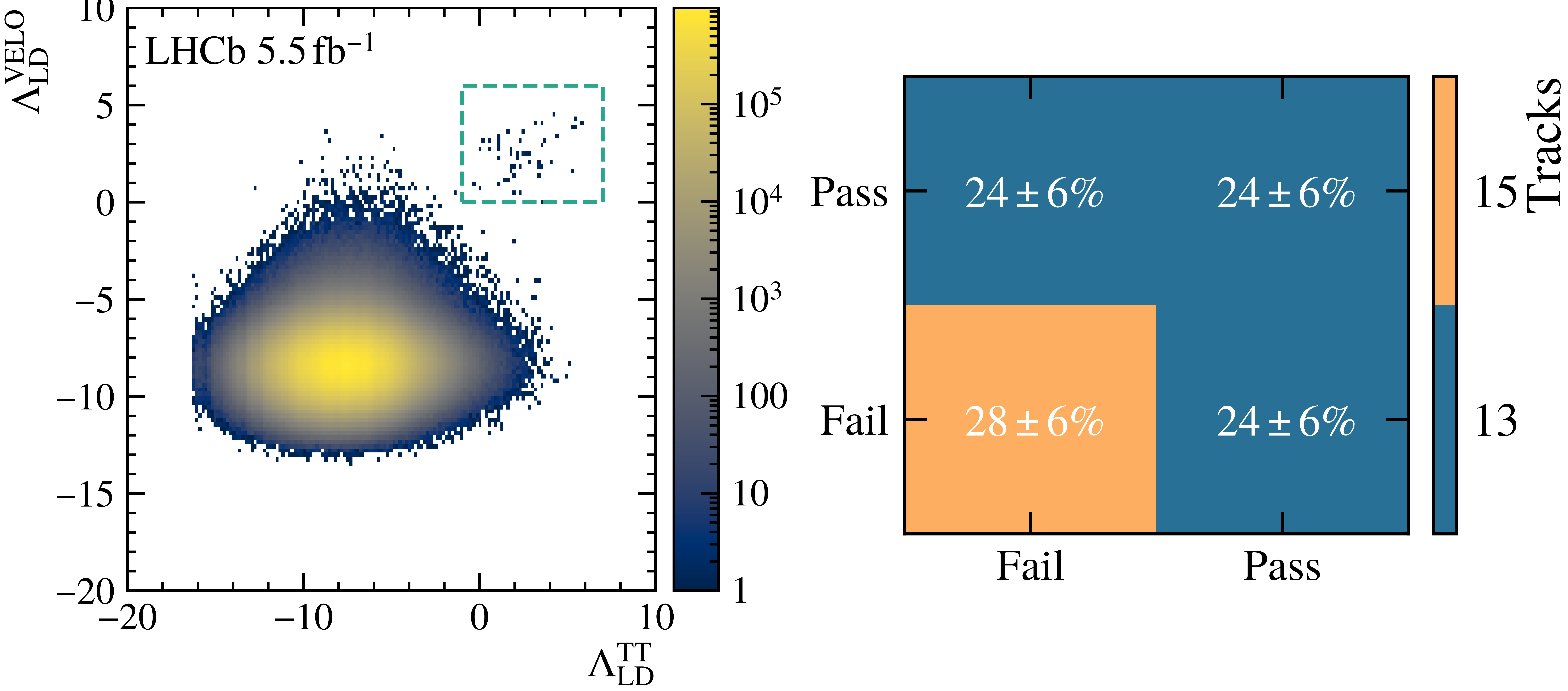
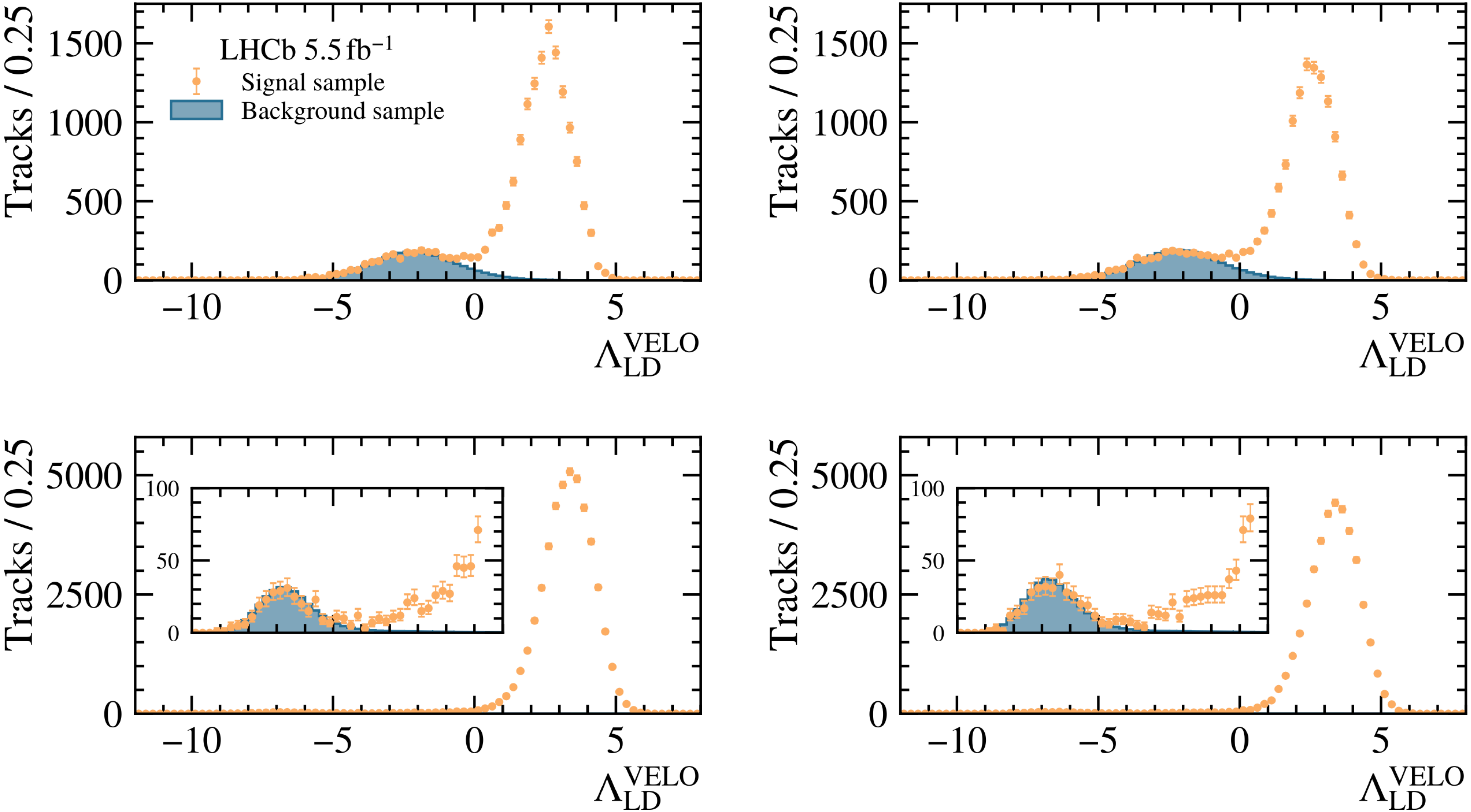
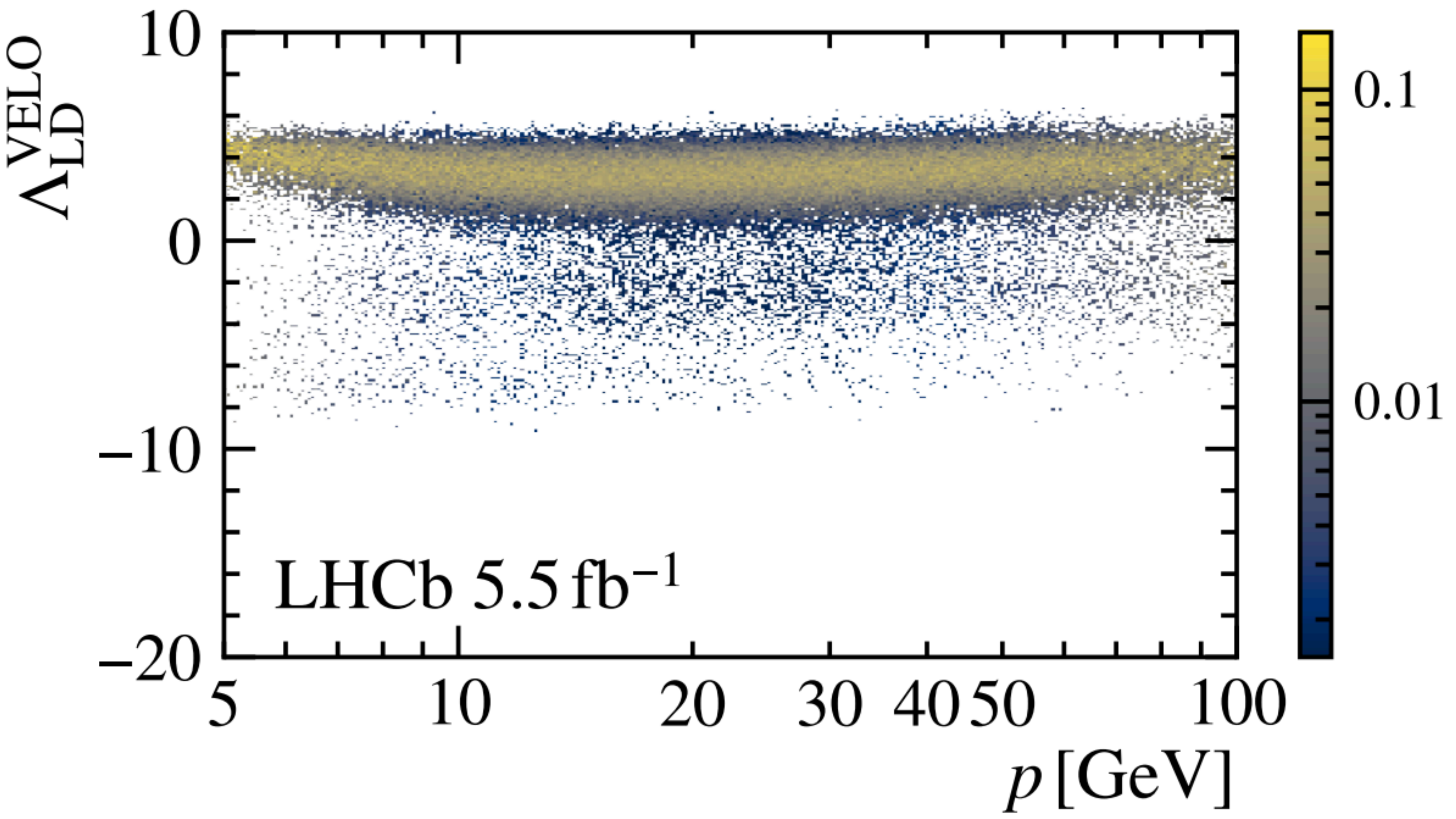
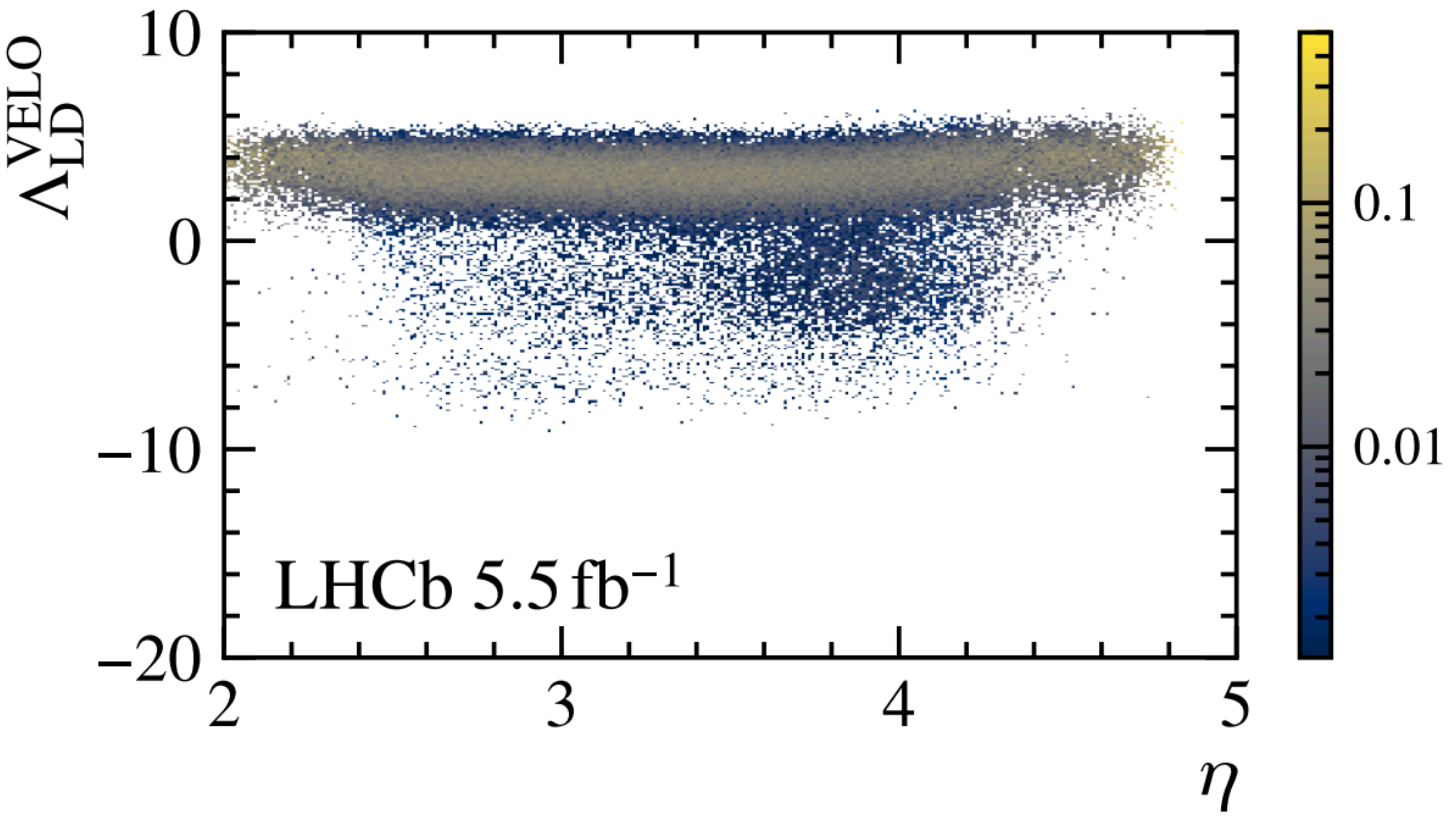


Background estimation

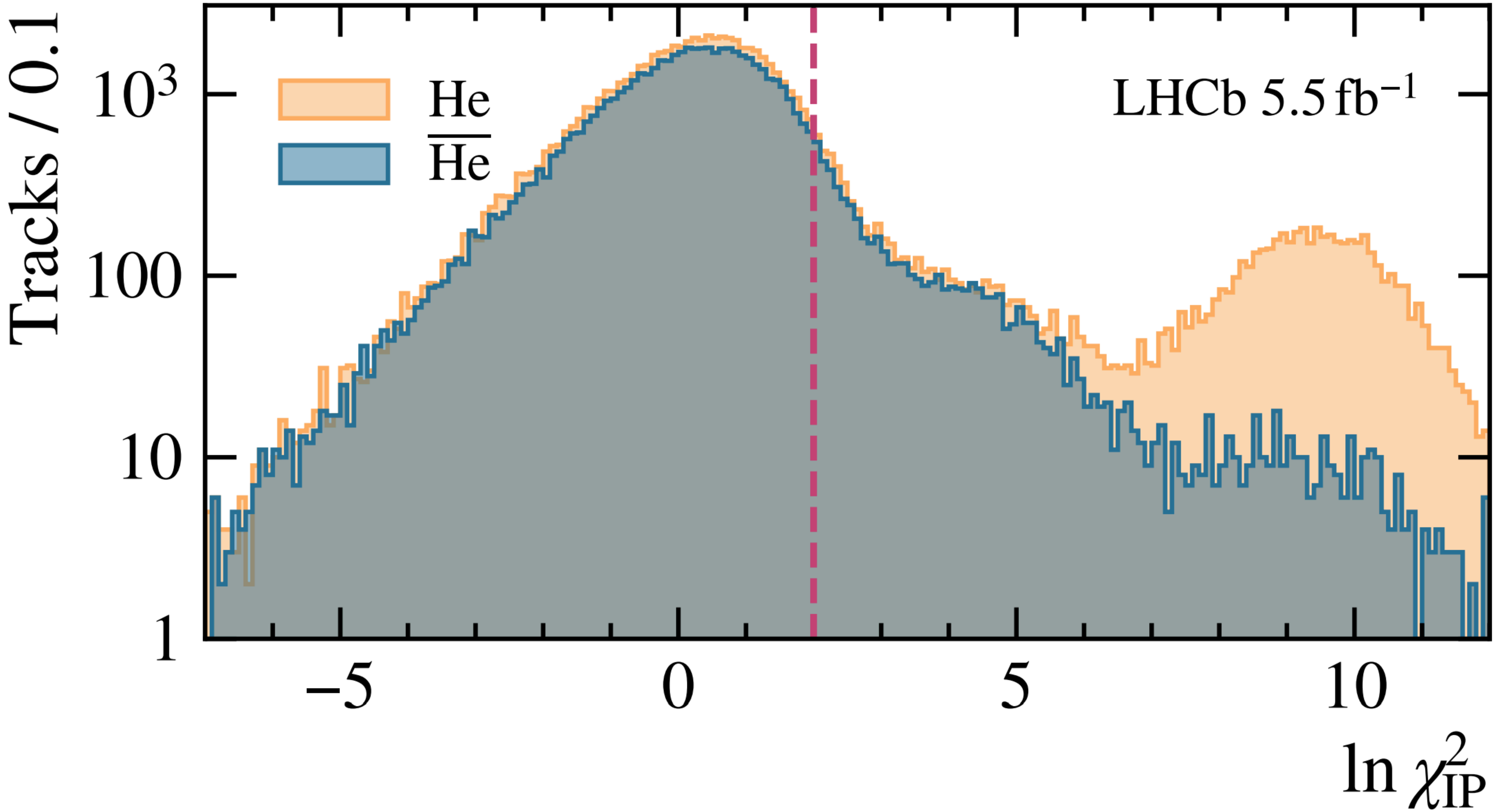


Performance flat in kinematics

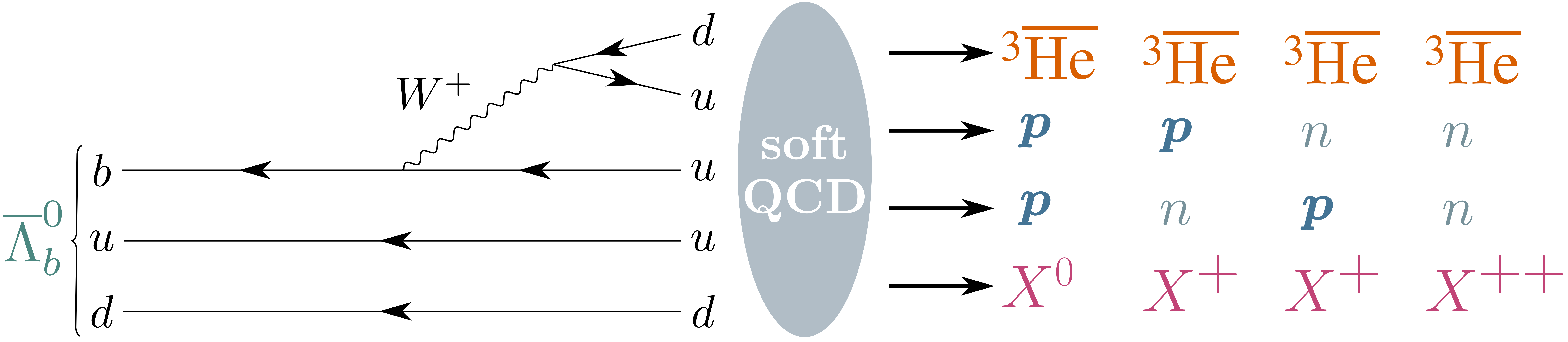




Prompt and displaced helium

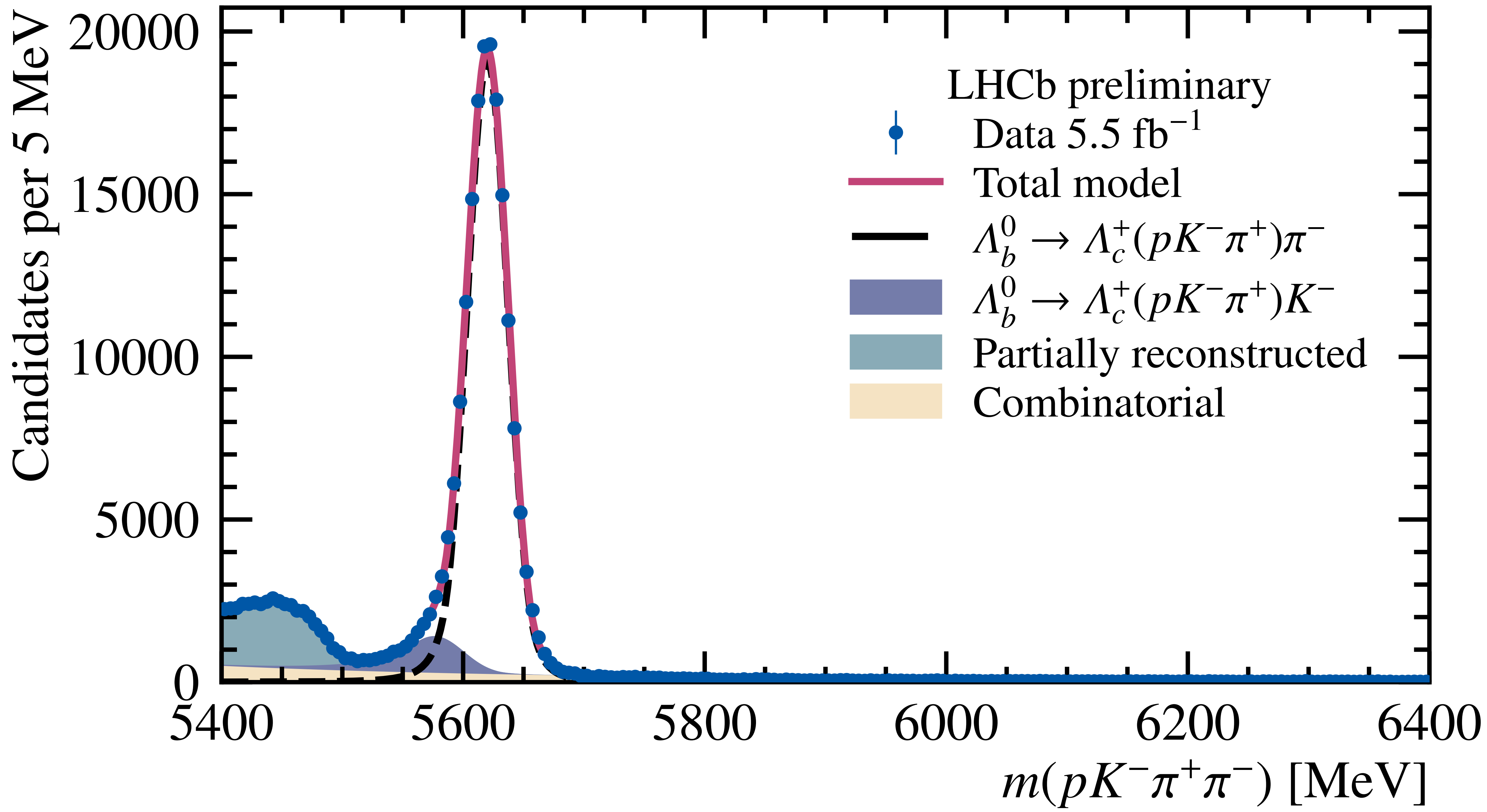


Extrapolation to $\mathcal{B}(\Lambda_b^0 \to {}^3\mathrm{He}X)$



Normalisation data

- $\Lambda_b^0 \to \Lambda_c^+(pK^-\pi^+)\pi^-$ used often in LHCb, BF $\mathcal{O}(10^{-4})$ JHEP 08 (2014) 143
- aiming for purity: tight vertex and PID
- extended unbinned ML fit with shapes taken from MC
- 3 PID working points:
  - loose PID ($\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}(X)$ norm.)
  - tight PID ($\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}X$ norm.)
  - no PID (kinematic weights)



Upper limits

values & uncertainties of normalisation & expected bkg.

$$\mathcal{L}(\mathcal{B}_{\rm sig}, c_{\rm norm}, B) = \mathcal{P}(\mathcal{B}_{\rm sig}/c_{\rm norm} + B) \cdot \mathcal{G}(c_{\rm norm}|\mu_{\rm norm}, \sigma_{\rm norm}) \cdot \mathcal{G}(B|\mu_B, \sigma_B)$$

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- CLs method based on Poisson likelihood

Upper limits

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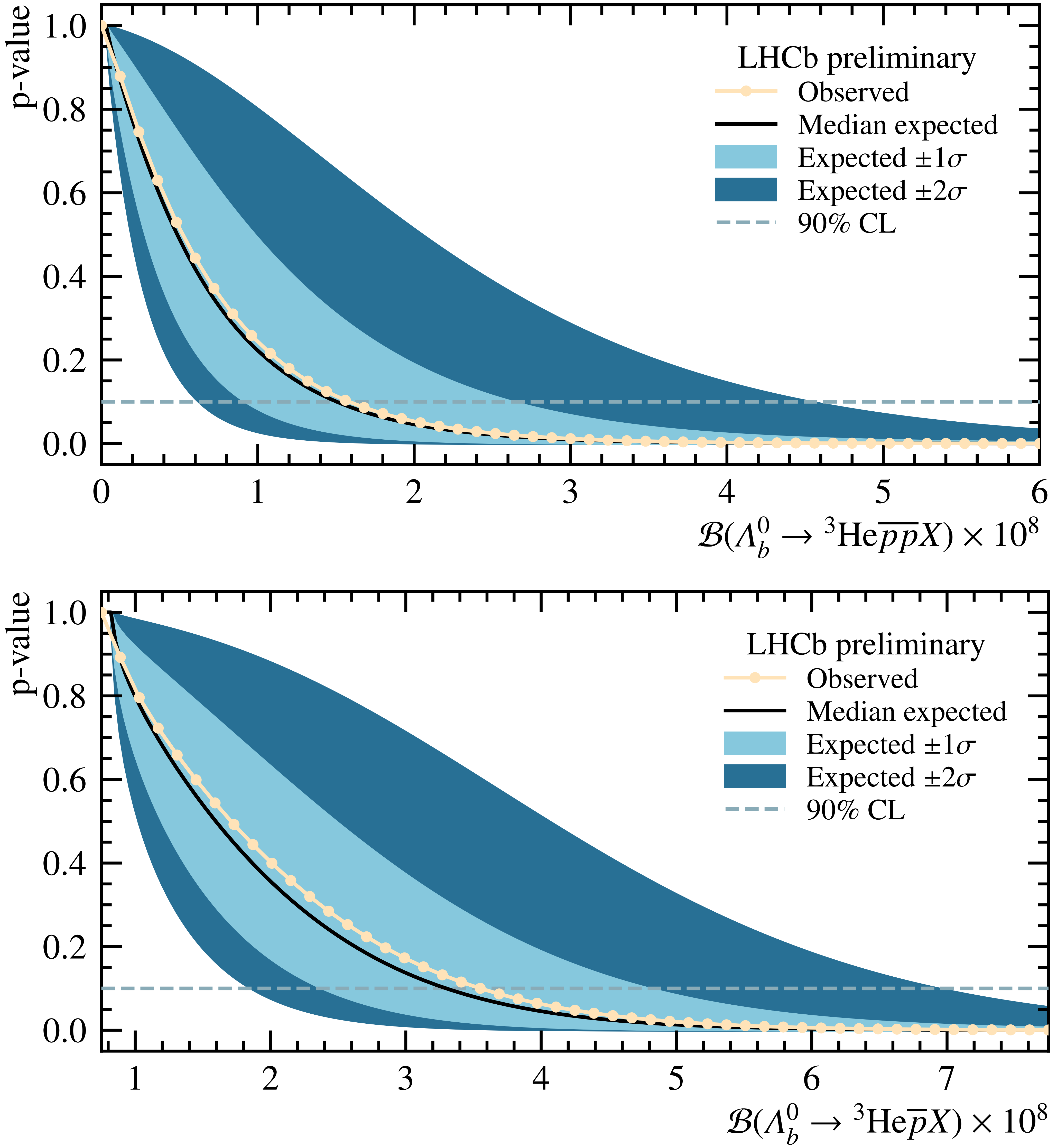
$$\mathcal{L}(\mathcal{B}_{\text{sig}}, c_{\text{norm}}, B) = \mathcal{P}(\mathcal{B}_{\text{sig}}/c_{\text{norm}} + B) \cdot \mathcal{G}(c_{\text{norm}}|\mu_{\text{norm}}, \sigma_{\text{norm}}) \cdot \mathcal{G}(B|\mu_B, \sigma_B)$$

- CLs method based on Poisson likelihood
  - $\mathcal{B}(\Lambda_b^0 \to {}^3\text{He}\overline{p}\overline{p}X) < 1.6 \times 10^{-8}$
  - $\mathcal{B}(\Lambda_b^0 \to {}^3\text{He}\overline{p}X) < 3.6 \times 10^{-8}$



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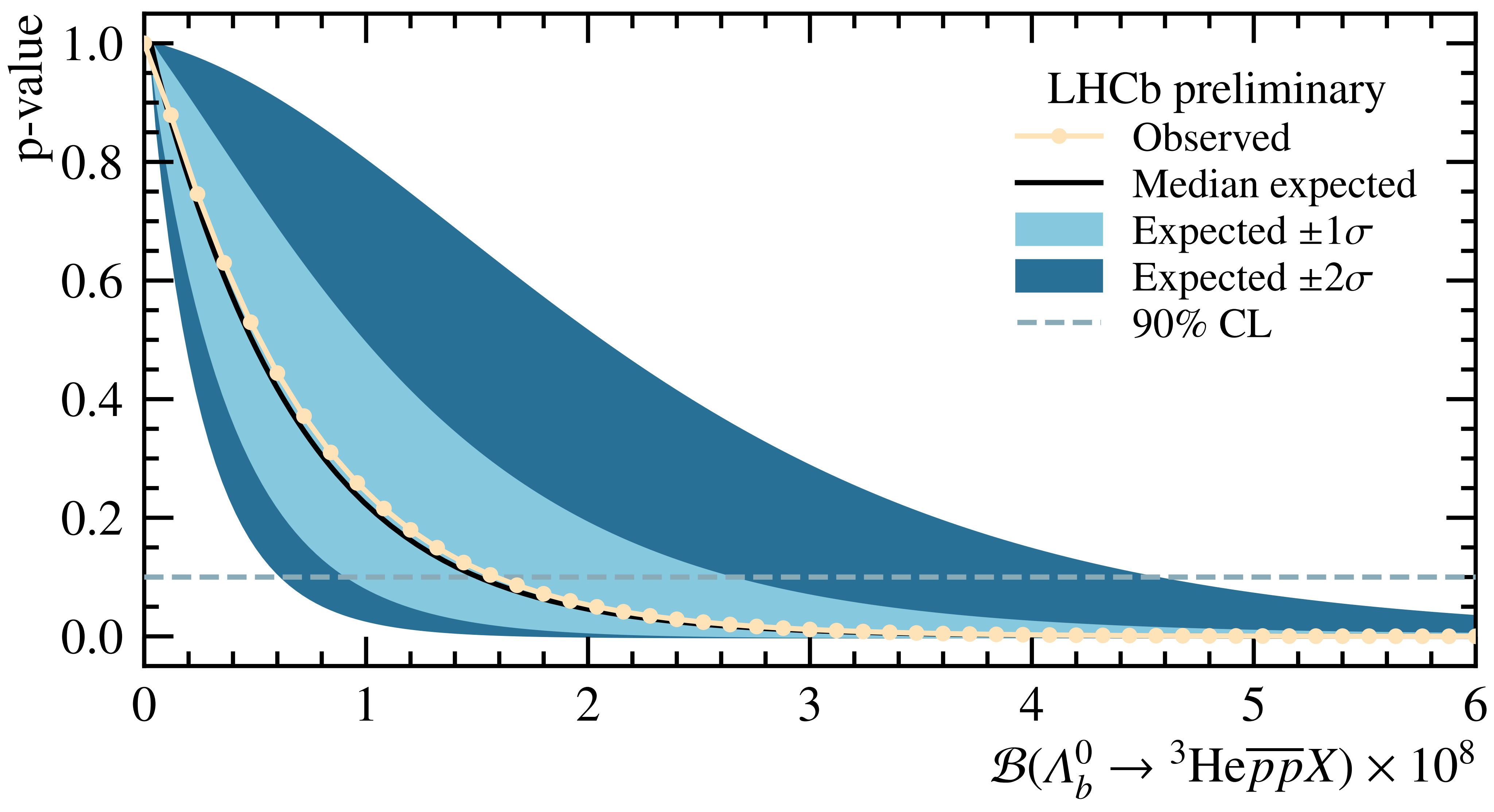
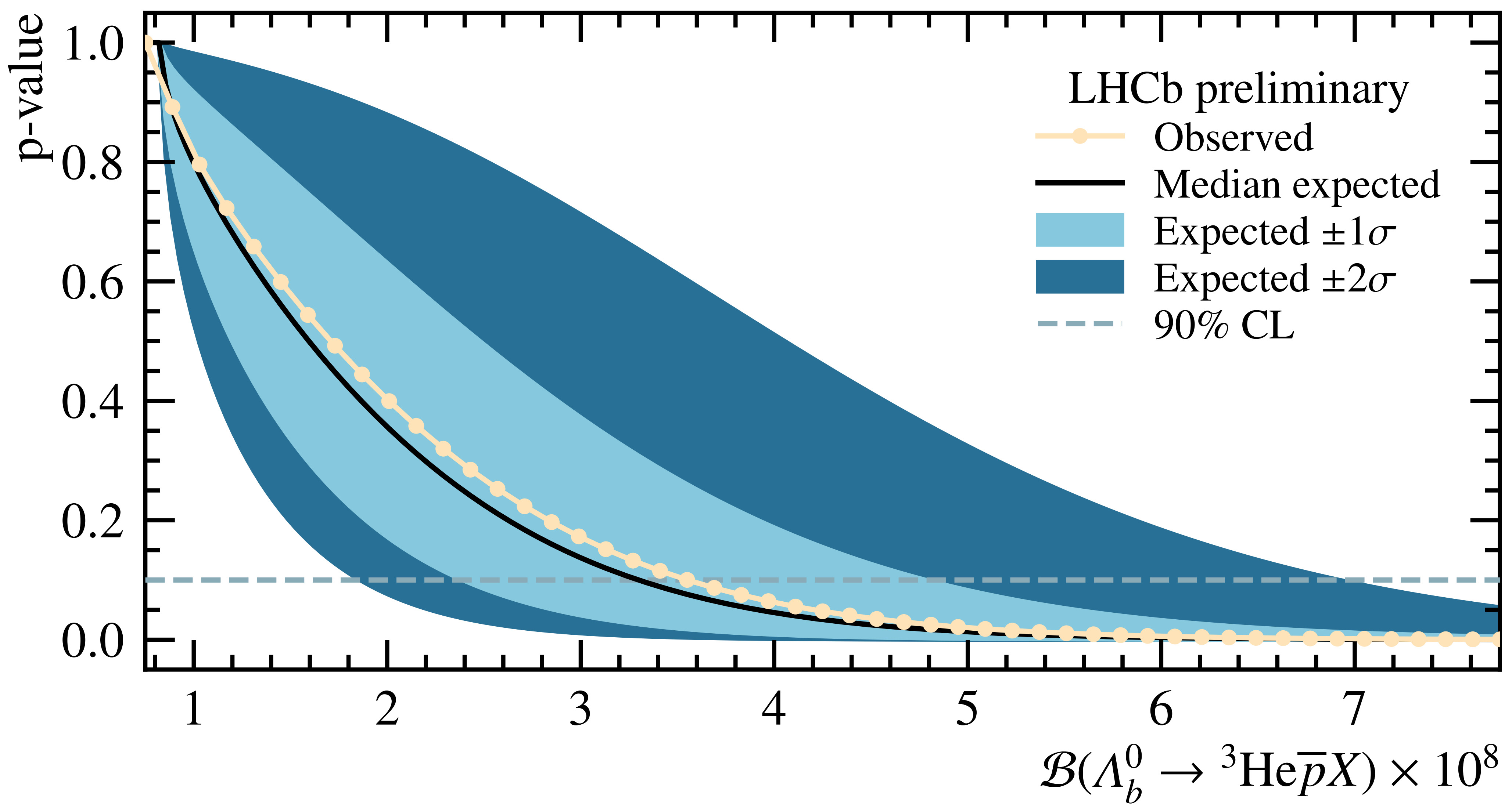
- similar results from invariant-mass fit, and from the Rolke method NIMA458(2001)745-758





Upper limits

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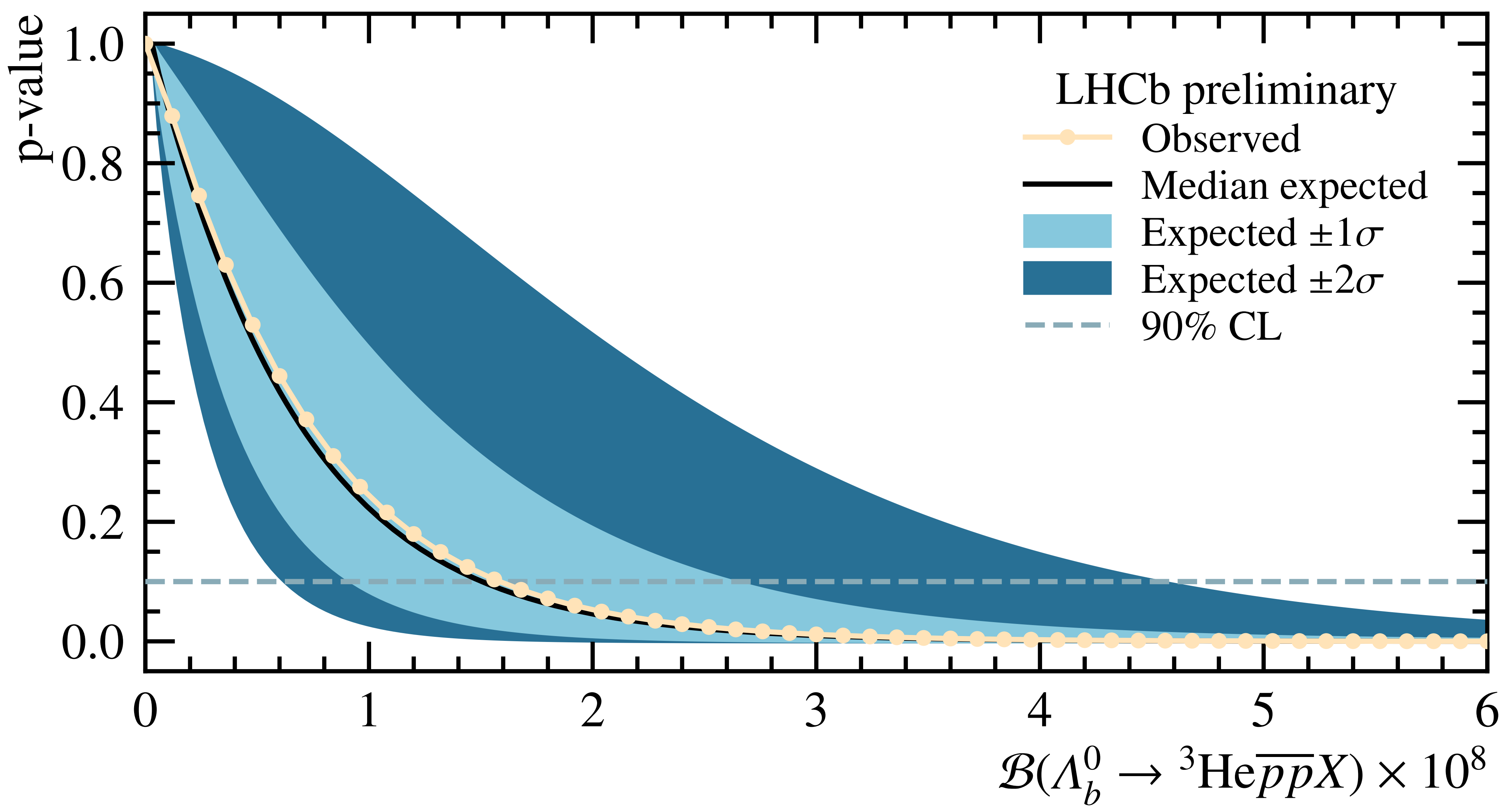
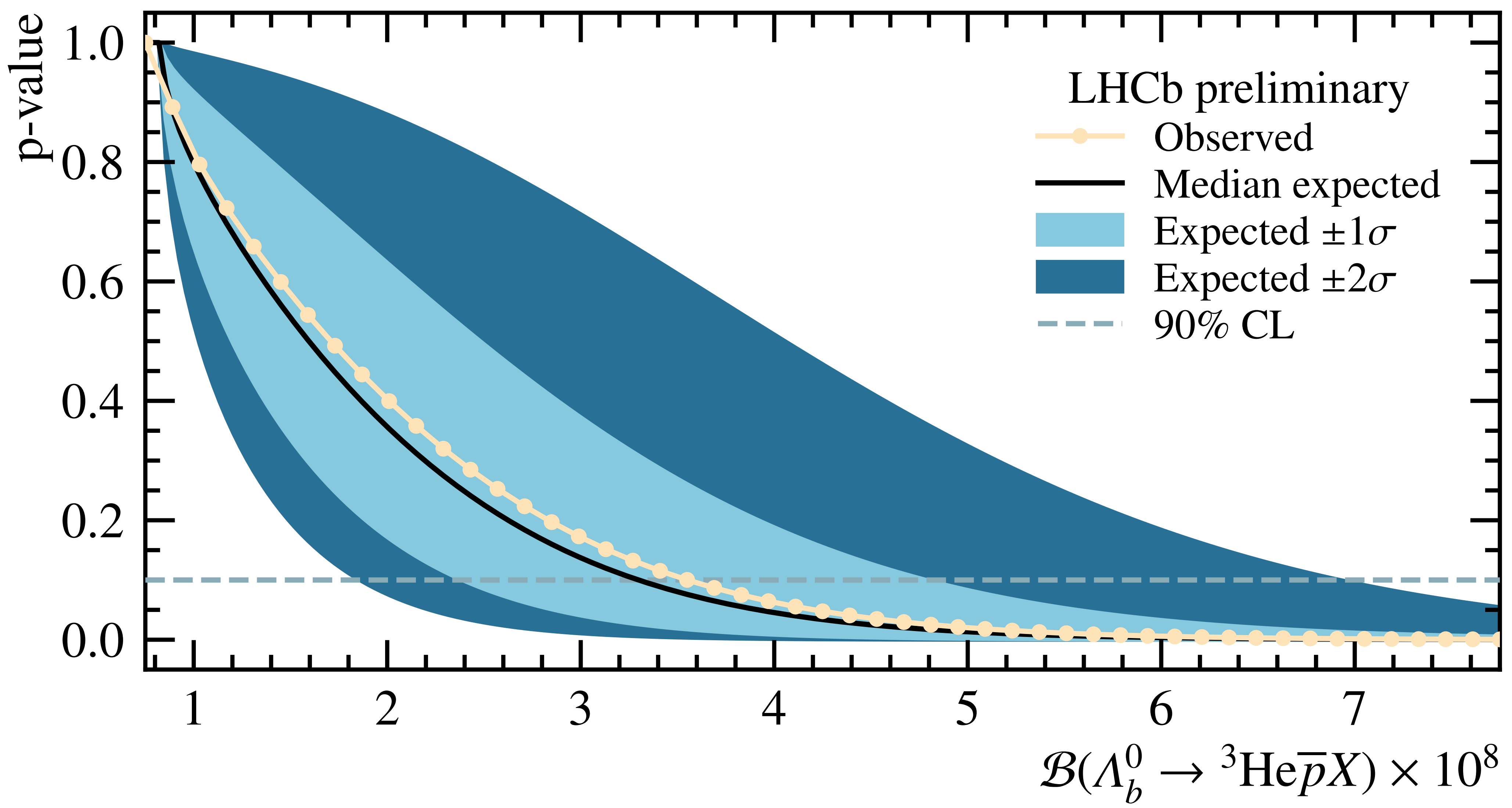
- similar results from invariant-mass fit, and from the Rolke method NIMA458(2001)745-758
- fit impractical for exclusive mode, Rolke used
  - $\mathcal{B}(\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}) < 1.9 \times 10^{-9}$





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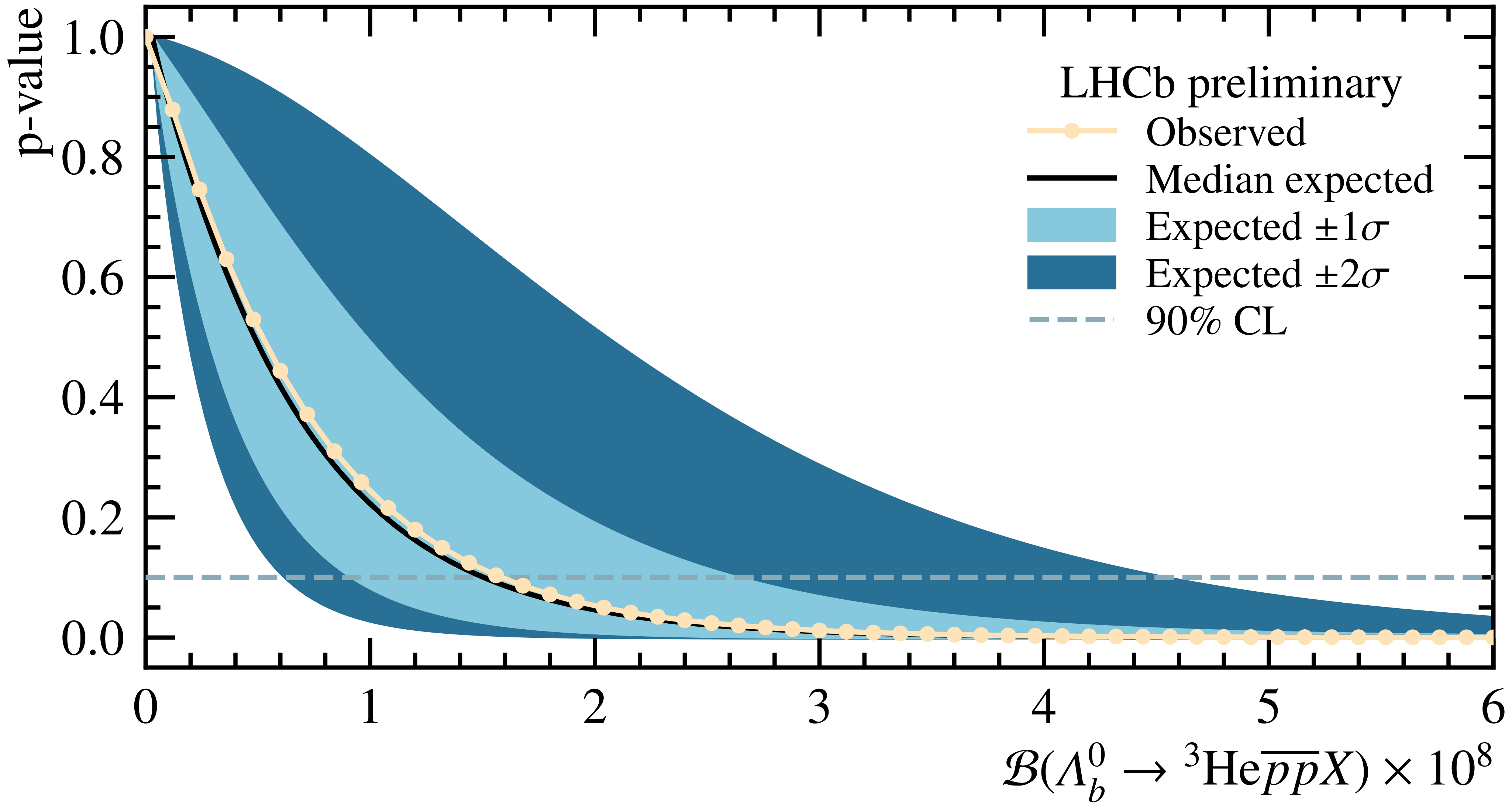
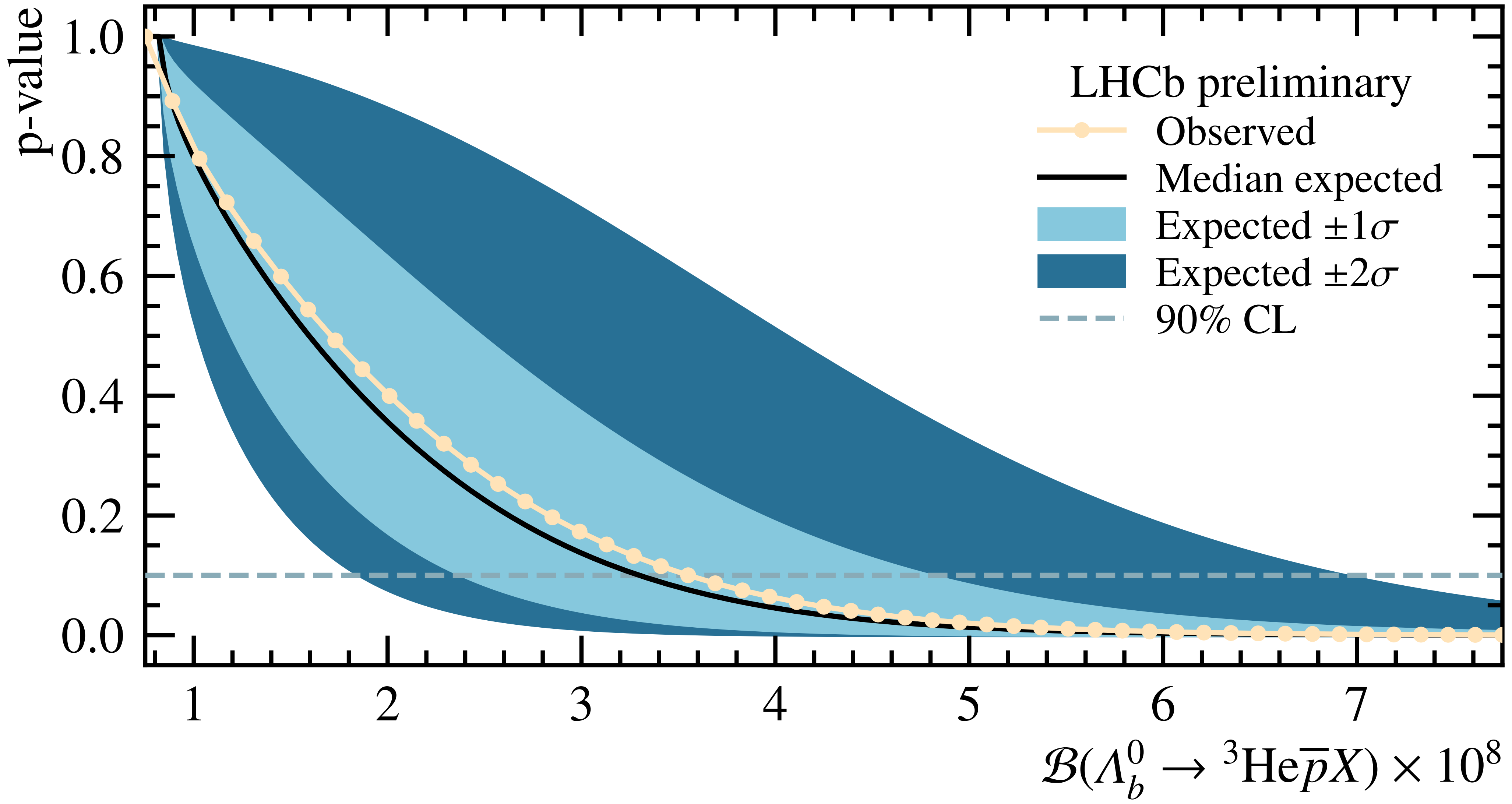
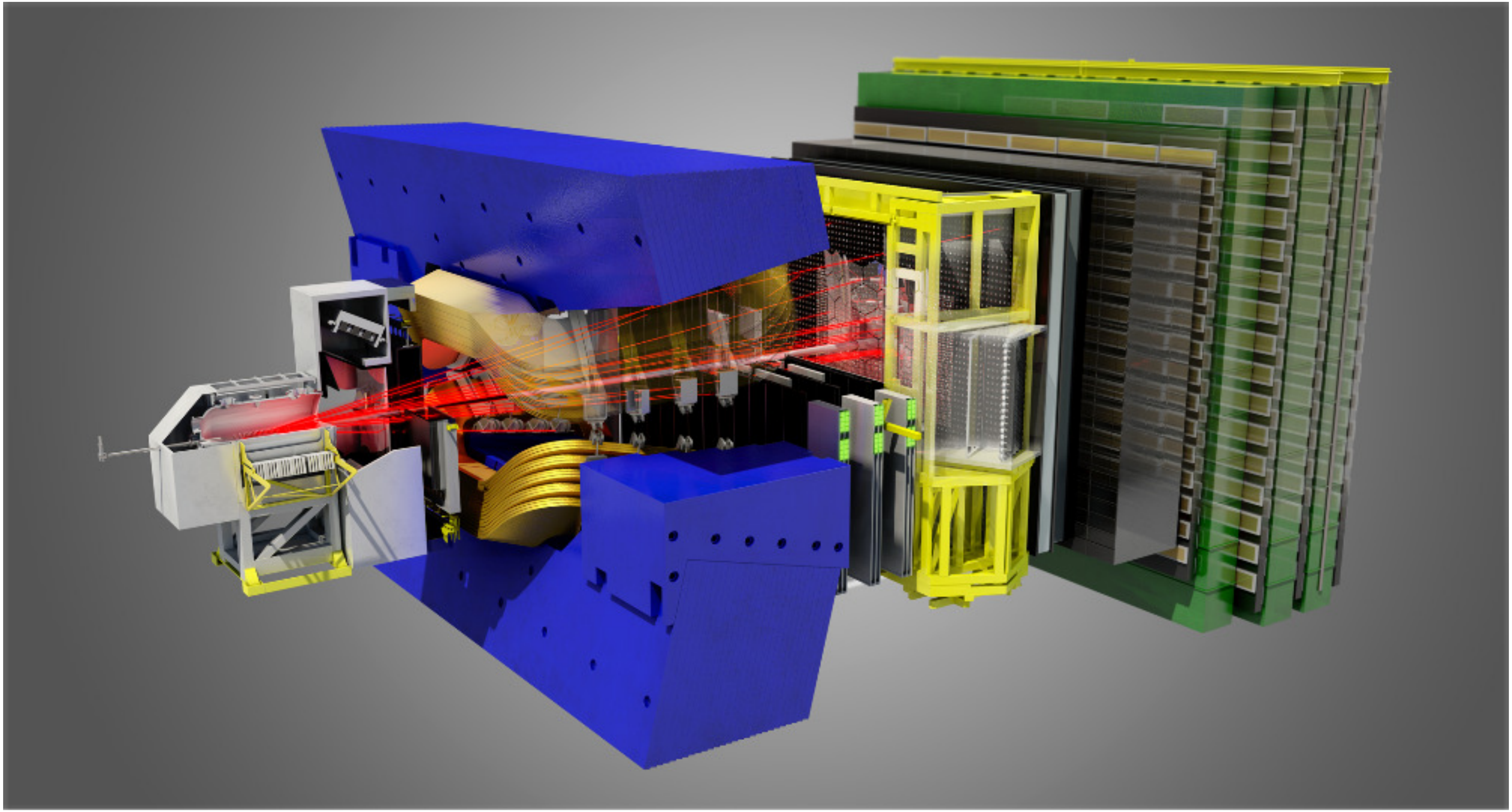
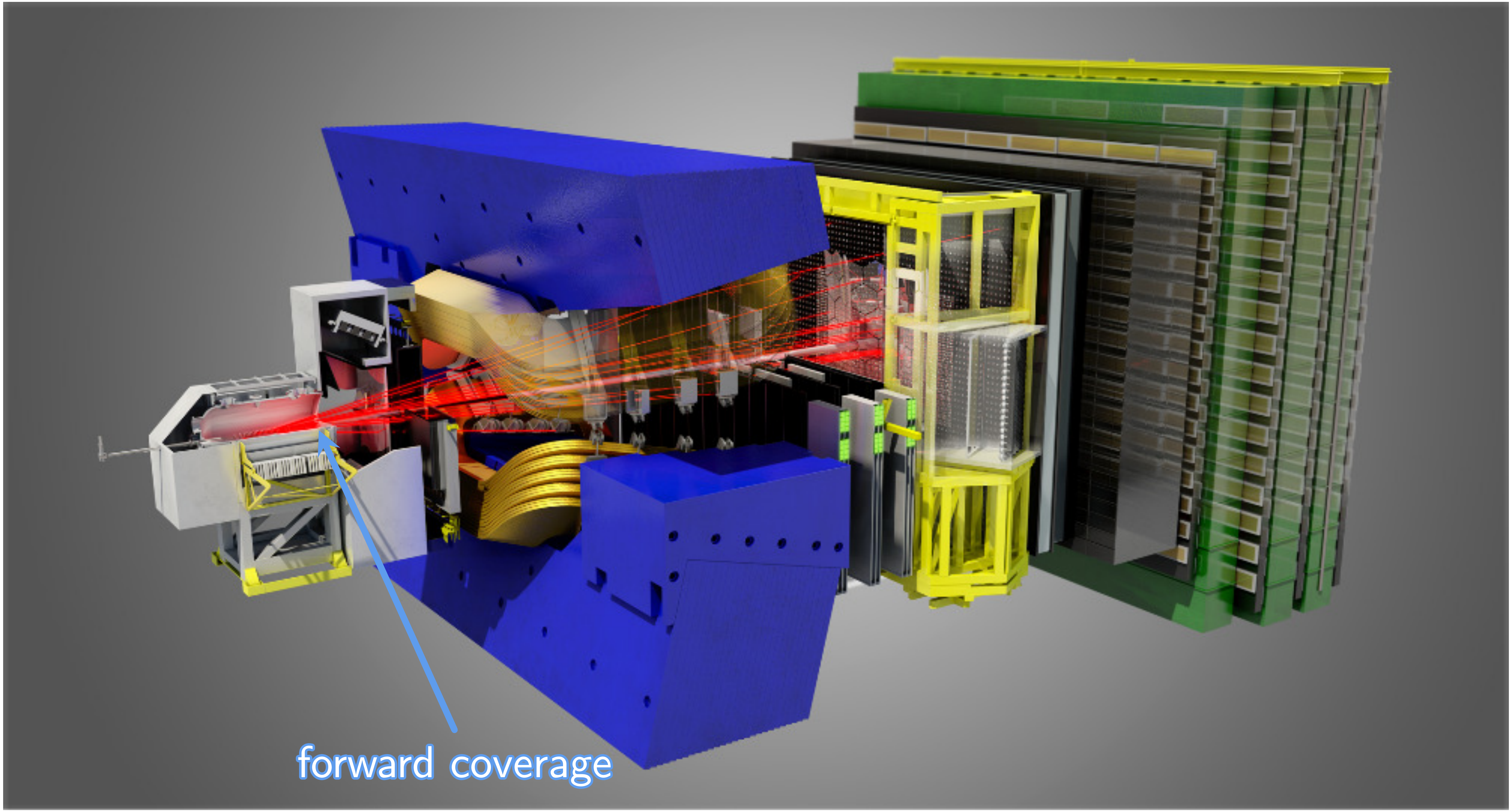
- fit impractical for exclusive mode, Rolke used
  - $\mathcal{B}(\Lambda_b^0 \to {}^3\text{He}\overline{p}\overline{p}) < 1.9 \times 10^{-9}$
- conservative extrapolation assuming isospin:

$\Rightarrow \mathcal{B}(\Lambda_b^0 \to {}^3\text{He}X) < 6.3 \times 10^{-8}$

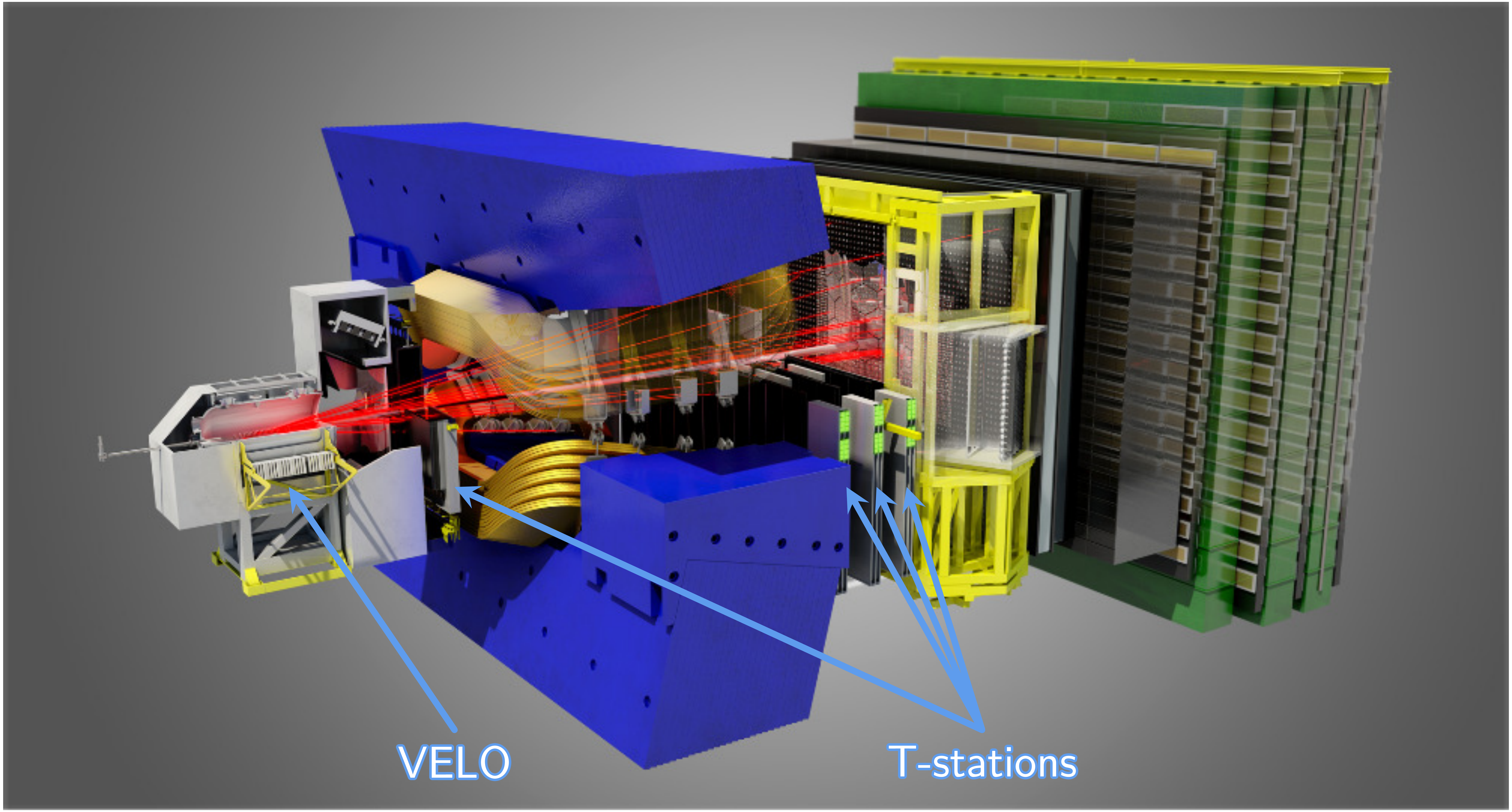




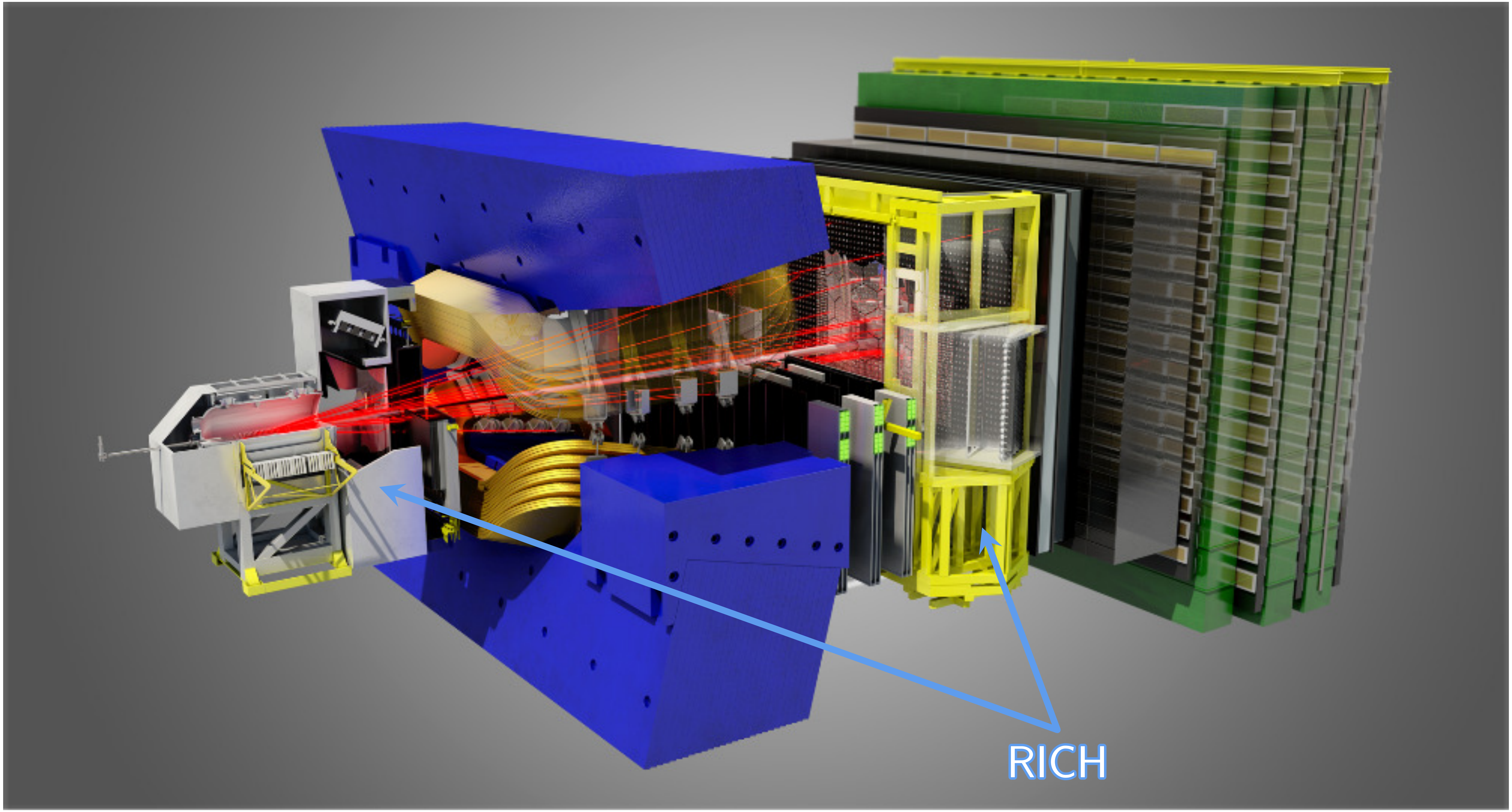




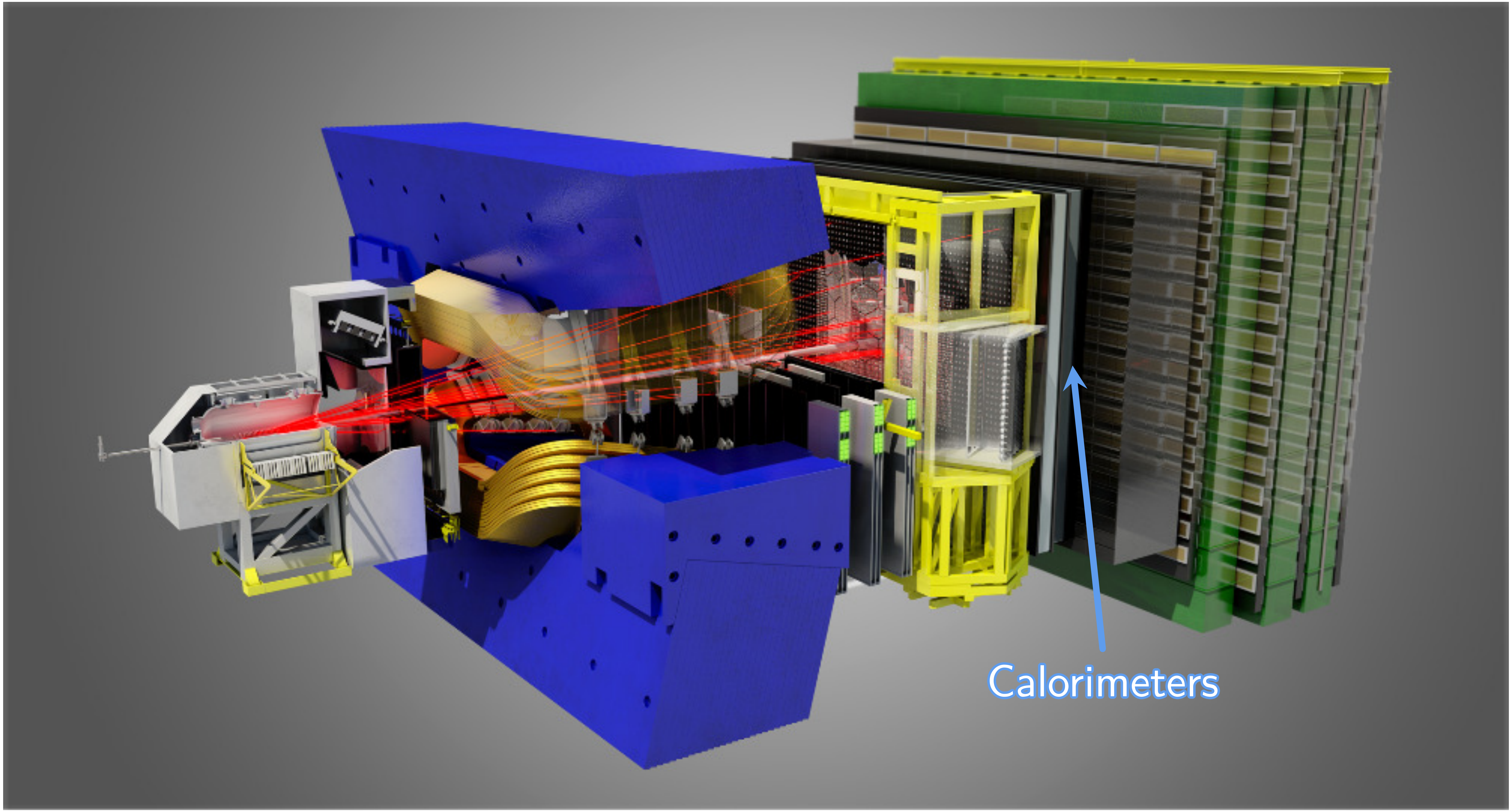
$\sigma_{b\bar{b}}$ up to $\sim$ 500 μb



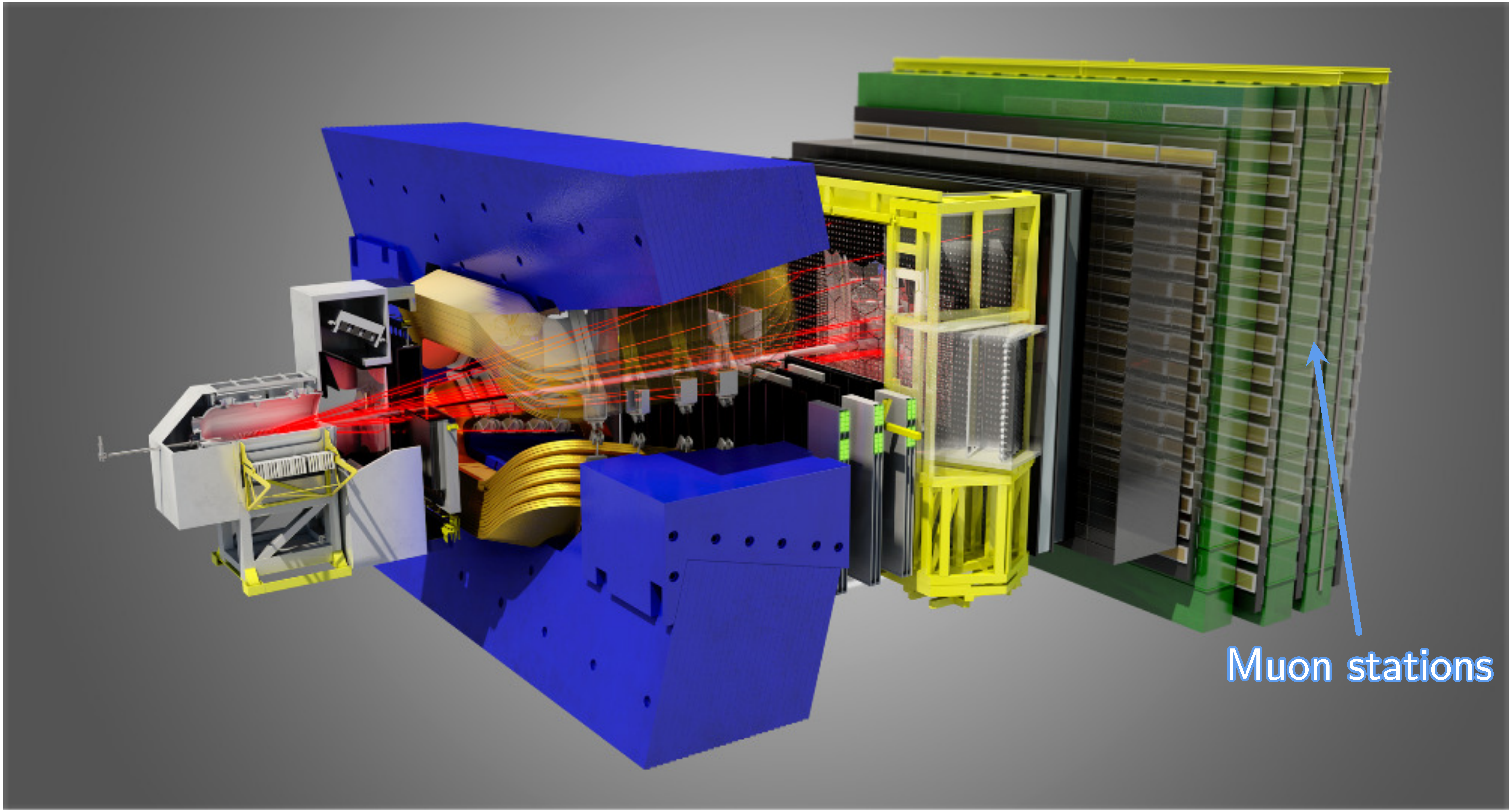
$\sigma_{\mathrm{IP}} = (15 \pm 29/p_{\mathrm{T}})$ µm $\quad \sigma_p/p \in [0.5\%,\ 1\%]$



$$\varepsilon_{K\to K} \sim 95\%,\ \varepsilon_{\pi\to K} \sim 5\%$$



$$\sigma_E/E = 1\% + 10\%/\sqrt{E}$$



$$\varepsilon_{\mu\to\mu} \sim 97\%,\ \varepsilon_{\pi\to\mu} \sim 1-3\%$$