Rare Radiative decays at LHCb

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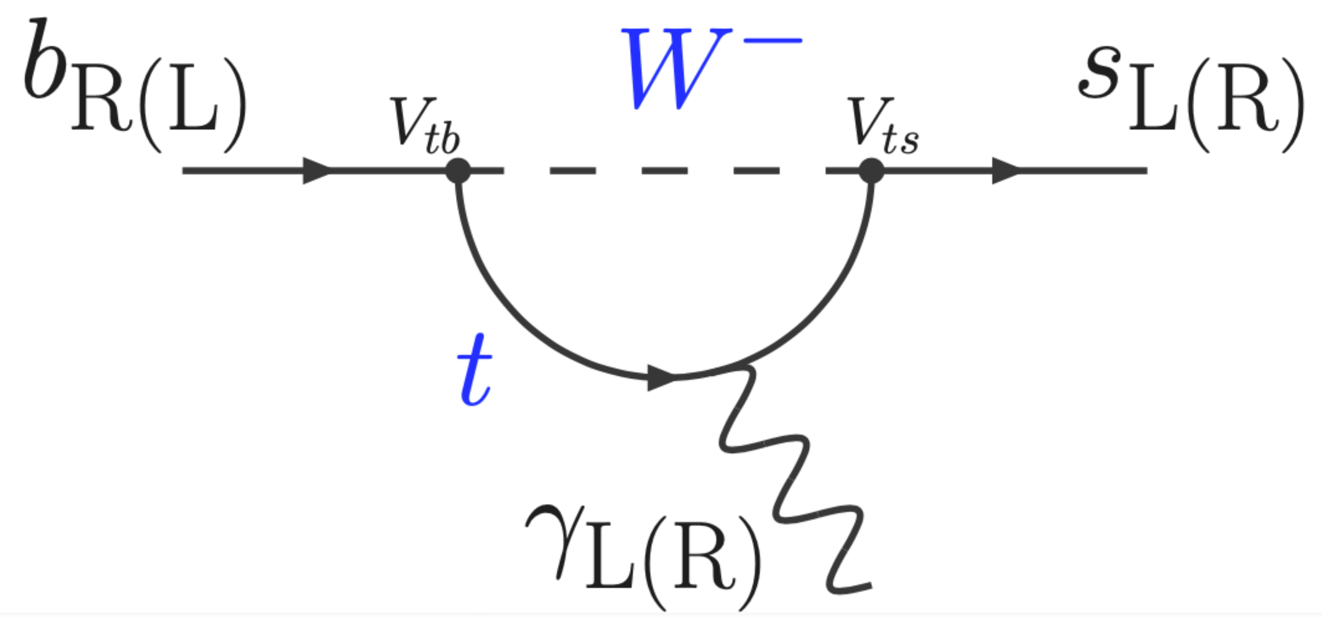
Radiative decays

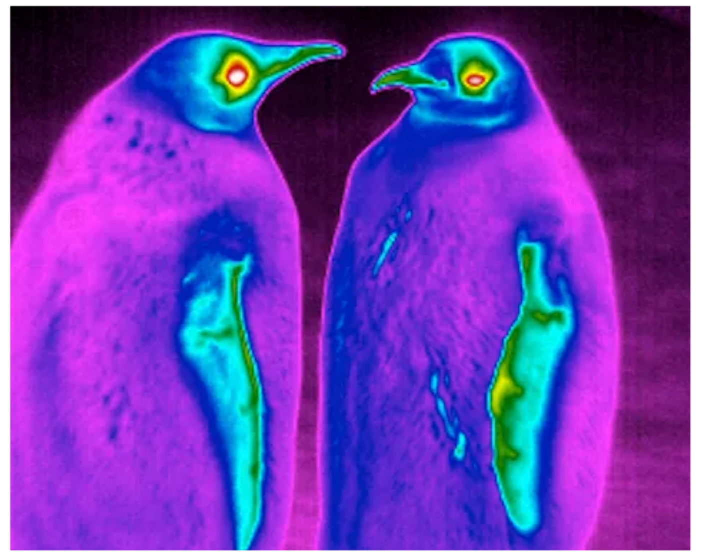
- **Flavour Changing Neutral Current** →proceeds via loops in the Standard Model (SM)
  - There is **no restriction to which particles run in the loop**!
  - Access to much **larger mass scales** than direct searches
- **Plenty of observables to study**
  - $\mathscr{H}_{eff} \propto V_{ts}^{*} V_{tb} (C_7 O_7 + C_7' O_7')$
  - $O_7^{(\prime)}$ are the left(right)-handed electromagnetic dipole operators and $C_7^{(\prime)}$ the Wilson coefficients
  - Right-handed currents / C_7' very suppressed in the SM



$\cancel{CP} \rightarrow \ Im(C_7^{(\prime)})$

$\mathscr{B} \rightarrow (|C_7|^2 + |C_7'|^2)$

$\gamma_{(L/R)} \rightarrow |C_7'/C_7|$



Brief history of LHCb's triggers used for radiatives

- **Run 1:**
  - Exclusive $B^0 \to K^*\gamma$ and $B_s^0 \to \phi\gamma$
  - Focus on hadronic part (topological lines)
  - Inclusive High Level Trigger (HLT) selection optimised for 2 hadrons + γ

- **Run 3** (similar structure as for Run 2):
  - Better knowledge and increased statistics of the training samples for the MVA based triggers
  - Much improved case for converted photons (less material)
  - Better understanding of the partially reconstructed backgrounds with π^0 and η
  - Larger dynamic range of the ECAL, saturation shifted to 20GeV (instead of 10GeV)

- **Run 2:**
  - Exclusive lines kept to maximise statistics
  - New topologies included in exclusive lines (baryons, di-photon,…) also with displaced secondary vertices
  - Significant rates with converted photons ($\gamma \to e^+e^-$)
  - Dedicated 2 and $3h$ combinations, matched with a high energy γ
    - Looser requirements on the hadronic part
    - MVA selection replaces rectangular cuts
    - Good performance on $4h + \gamma$ modes too

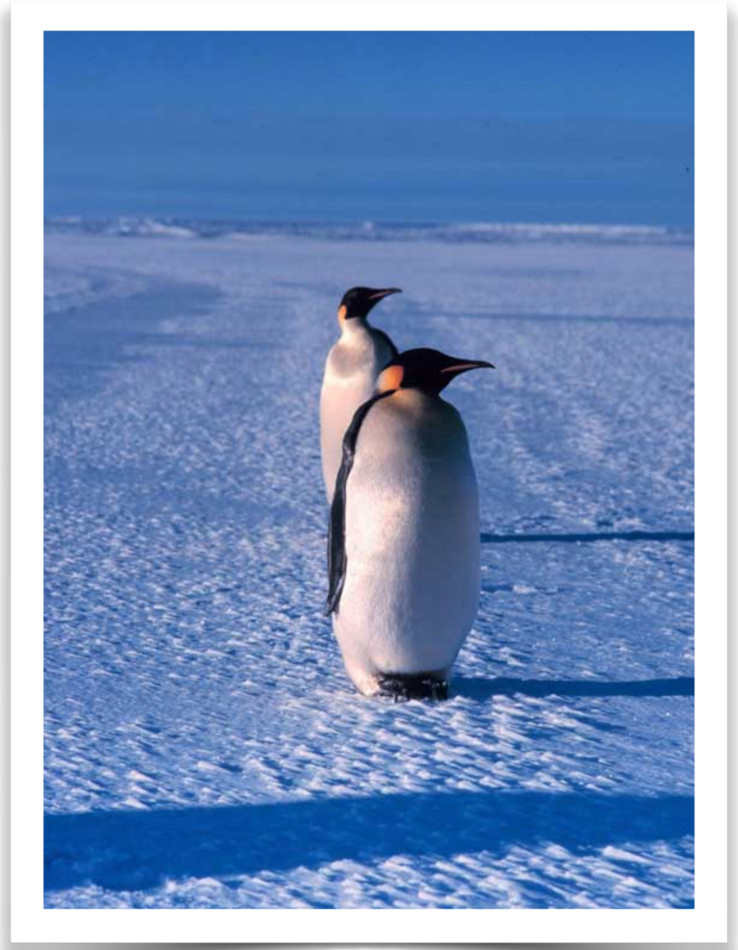
Brief history of LHCb's triggers used for radiatives

- **Run 1:**
  - Exclusive $B^0 \to K^*\gamma$ and $B_s^0 \to \phi\gamma$
  - Im(C7'), BR and TD analyses

- **Run 3** (similar structure as for Run 2):
  - Better knowledge and increased statistics of the training samples for the MVA based triggers
  - Much improved case for converted photons (less material)
  - Better understanding of the partially reconstructed backgrounds with π^0 and η
  - Larger dynamic range of the ECAL, saturation shifted to 20GeV (instead of 10GeV)

- **Run 2:**
  - Improved Time-Dependent analyses for with $B_{(s)} \to hh\gamma$
  - First results with baryonic decays
  - Angular analysis in $B^0 \to K^{*0}e^+e^-$ at low q^2 [JHEP 12 (2020) 081]
  - Search for rare modes $(|C_7|^2 + |C_7'|^2)$, including $b \to d\gamma$
  - Amplitude analyses (also with Time-Dependent CPV sensitivity) $(|C_7'/C_7|)$

LHCb's latest results on Radiative decays



Known penguins?

Rare penguins?

No penguins?

- News since ICHEP20:
  - ***Measurement of the photon polarisation in $\Lambda_b^0 \to \Lambda\gamma$ decays*** [Phys. Rev. D105 (2022) L051104]
  - ***Search for the radiative $\Xi_b^- \to \Xi^-\gamma$ decay*** [JHEP 01 (2022) 069]
  - [Bonus, short title] "… ***and search for the $B_s^0 \to \mu\mu\gamma$ decay***" [PHYS. REV. D105 (2022) 012010] and [Phys. Rev. Lett. 128, (2022) 041801]

See M. Van Veghel's talk, today@15h07

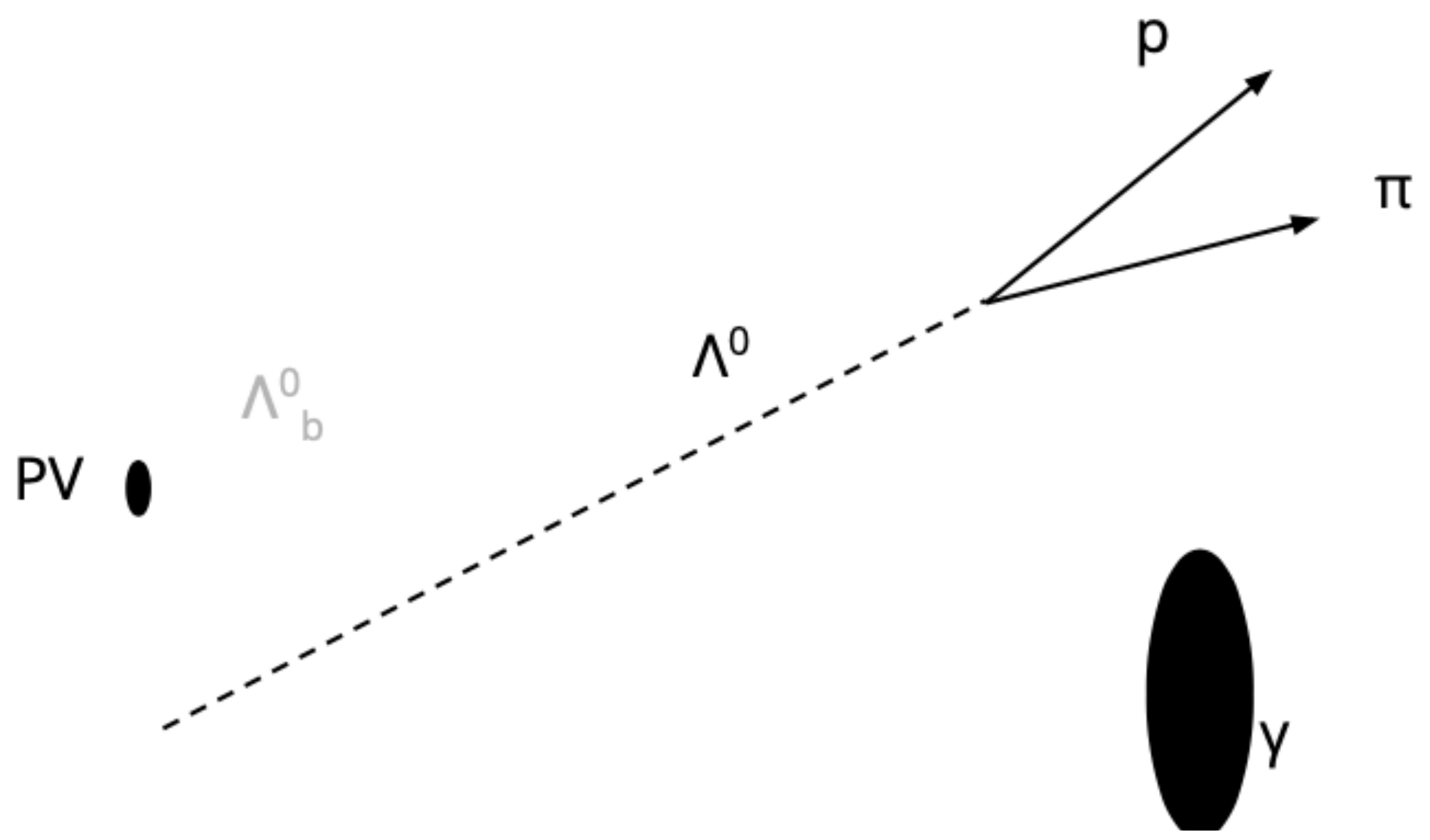
Measurement of the photon polarisation in $\Lambda_b^0 \to \Lambda\gamma$ decays

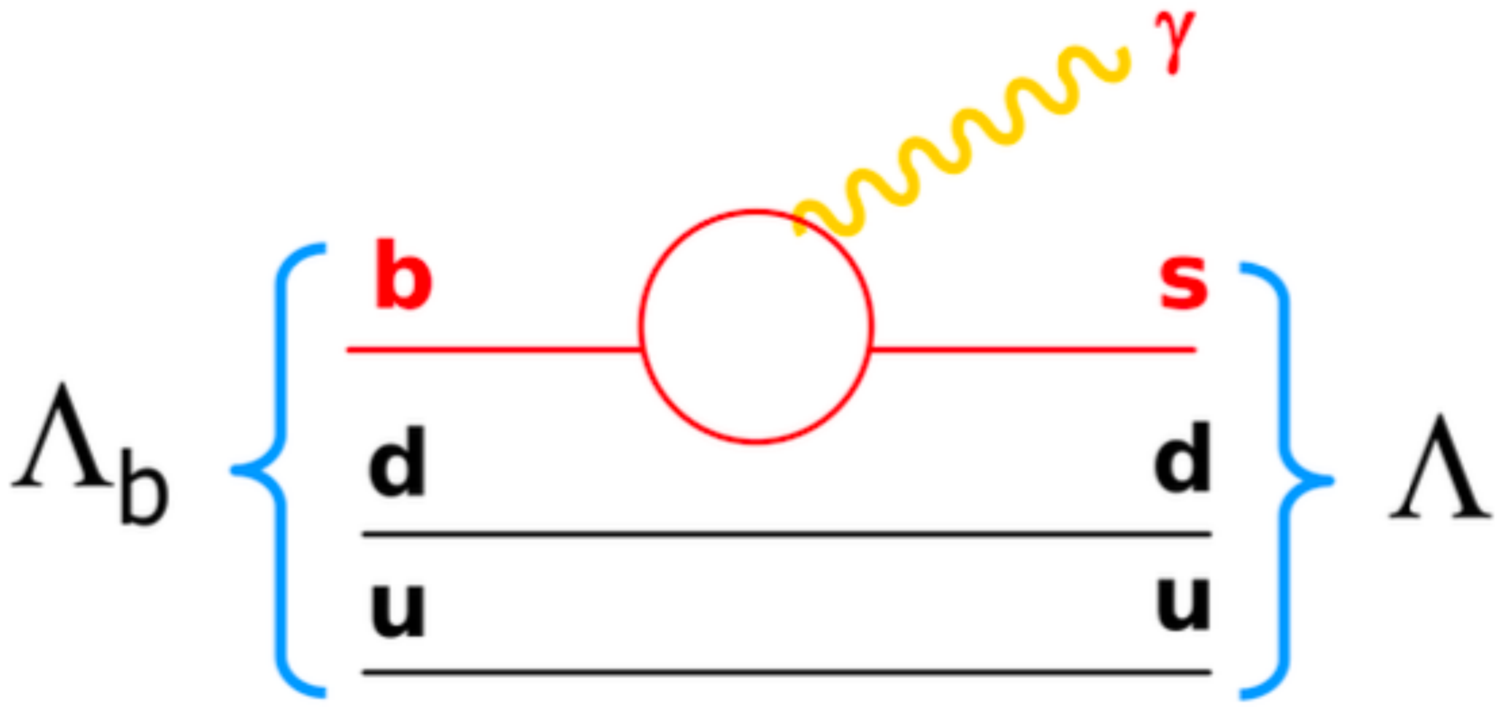
[Phys. Rev. D105 (2022) L051104]

- First observation by LHCb [PRL 123 031801 (2019)] using 1.6 fb^{-1}

$$\mathscr{B}(\Lambda_b^0 \to \Lambda\gamma) = (7.1 \pm 1.5 \pm 0.6 \pm 0.7) \times 10^{-6}$$

- **Very challenging topology**:
  - Long-lived secondary particle + photon (no track, no direction from the ECAL cluster)
  - Combinatorial background controlled with efficient MVA
  - Dedicated exclusive trigger line for Run 2
- **Now**: first **angular analysis** of radiative b-baryon decays using 6 fb^{-1} collected by LHCb in Run 2
  - Optimised selection





Measurement of the photon polarisation in $\Lambda_b^0 \to \Lambda\gamma$ decays

[Phys. Rev. D105 (2022) L051104]

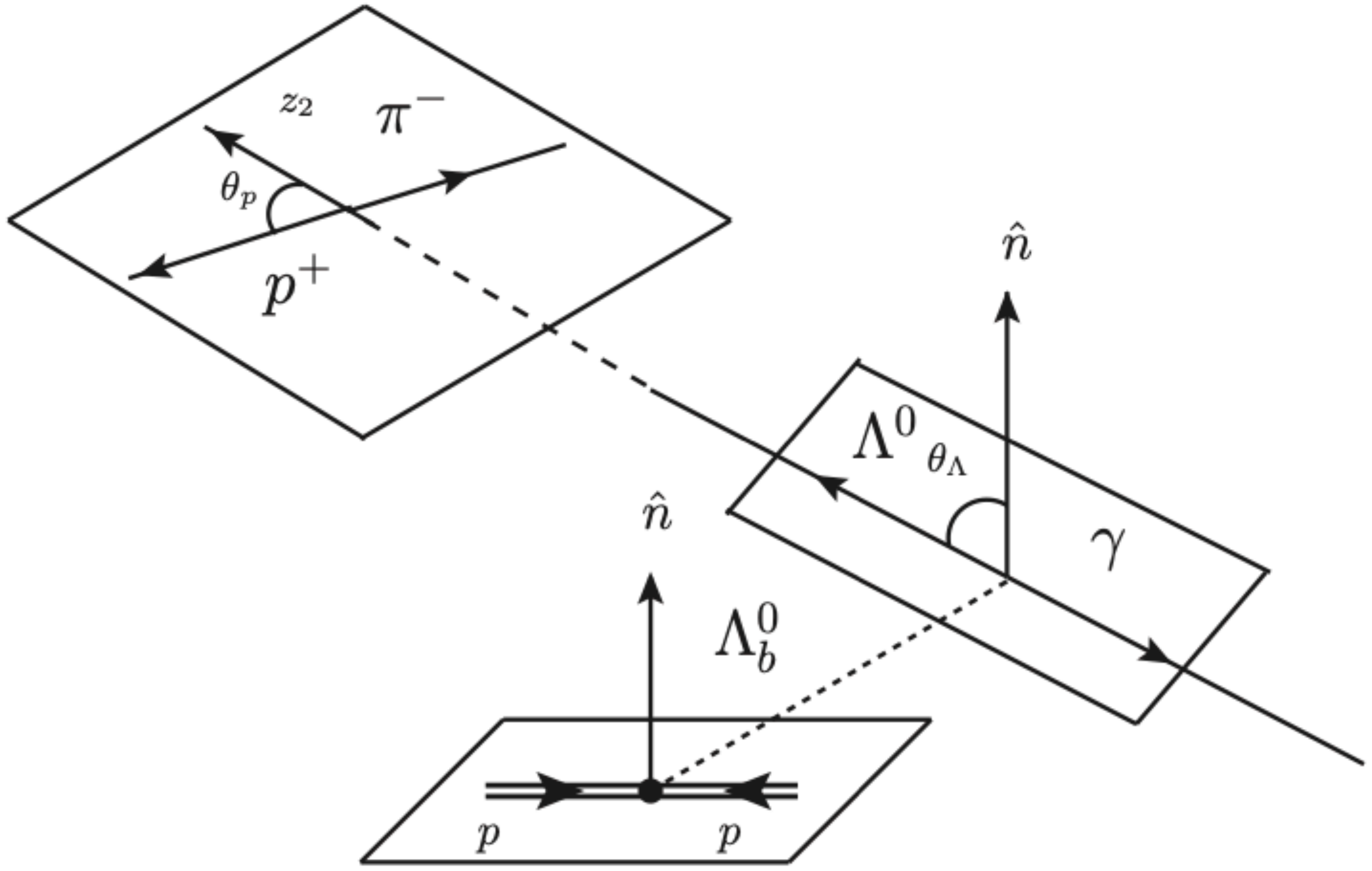
- **Weak decay of b-baryon** (non-zero spin): **sensitivity to photon polarisation** [Phys.Lett. B355 (1995) 579-583]
- Angular dependence

$$dW(\theta_p, \theta_\Lambda) \propto 1 - \alpha_\Lambda P_{\Lambda_b} \cos\theta_p \cos\theta_\Lambda - \alpha_\gamma \left(\alpha_\Lambda \cos\theta_p - P_{\Lambda_b} \cos\theta_\Lambda\right)$$

- Integrating over $cos(\theta_\Lambda)$

$$dW(\theta_p) \propto 1 - \alpha_\gamma \alpha_\Lambda \cos\theta_p$$

- Sensitivity to α_γ using α_Λ (Λ weak decay parameter) fixed to the average of the values measured by BESIII in Λ and $\overline{\Lambda}$ decays, $\alpha_\Lambda = 0.754 \pm 0.004$ [Nature Phys. 15 (2019) 631]



$$\alpha_\gamma = \frac{P(\gamma_L) - P(\gamma_R)}{P(\gamma_L) + P(\gamma_R)}$$

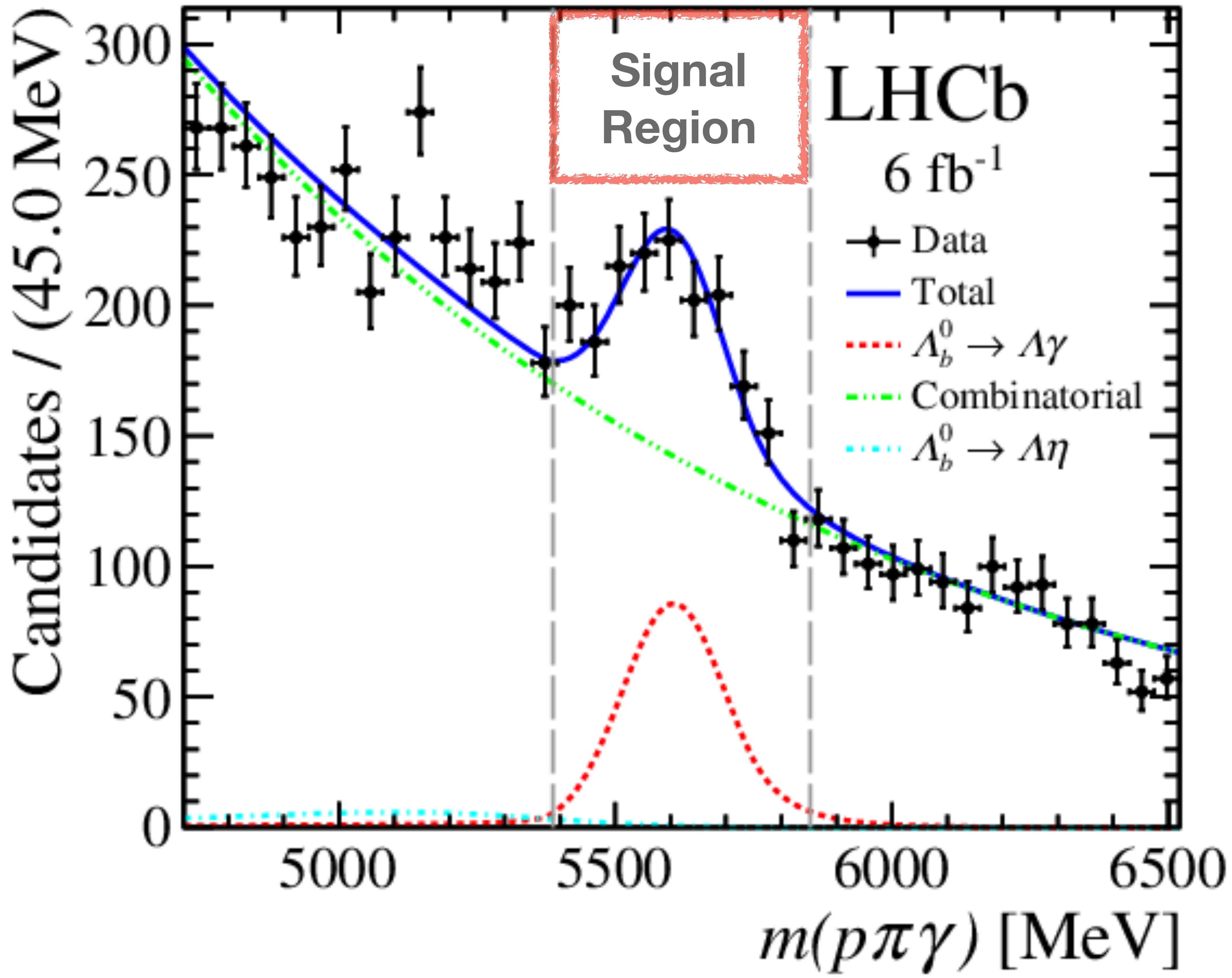
$$\alpha_\gamma = \frac{1-|r|^2}{1+|r|^2}$$

$$r^{LO} = \frac{C_7'}{C_7} \sim \frac{m_s}{m_b} \text{ in SM}$$

Measurement of the photon polarisation in $\Lambda_b^0 \to \Lambda\gamma$ decays

[Phys. Rev. D105 (2022) L051104]

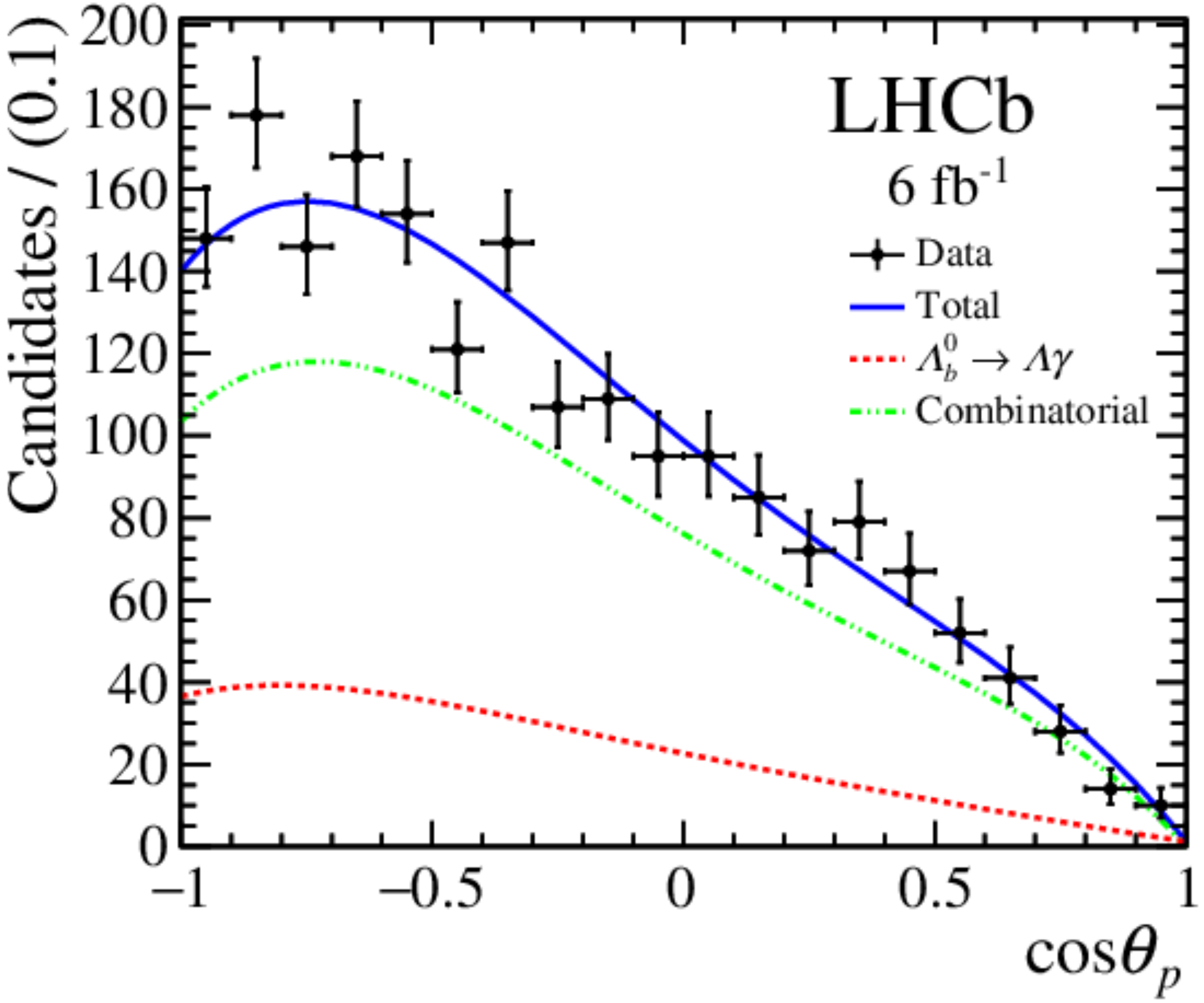
- Analysis strategy: fit the $cos(\theta_p)$ distribution using $m(p\pi\gamma)$ to define signal region and fix signal/background yields



- Mass fit with three components: Combinatorial, Signal, Partially reconstructed $\Lambda_b^0 \to \Lambda\eta(\to \gamma\gamma)$
  - Signal yield in signal region: 440 ± 40 events
- Background shape for angular fit taken from the sidebands

Measurement of the photon polarisation in $\Lambda_b^0 \to \Lambda\gamma$ decays

[Phys. Rev. D105 (2022) L051104]



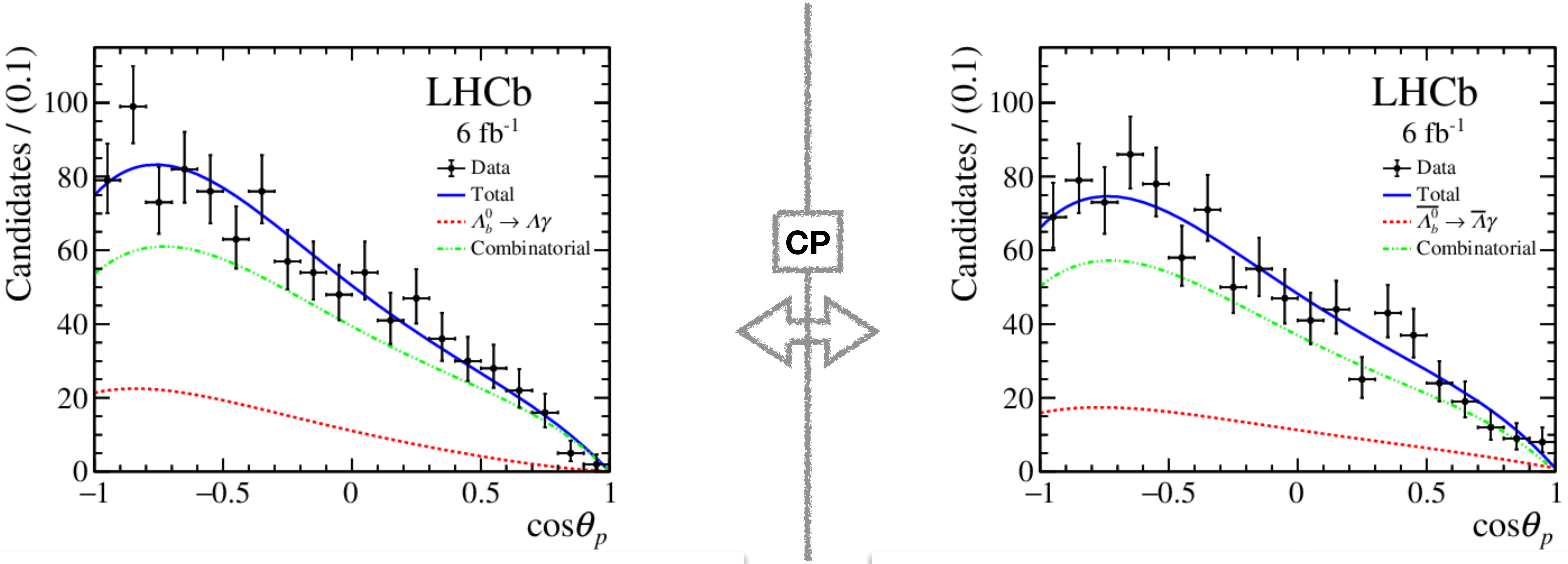
- Acceptance shape taken from simulation
  - Validated with simulation and data from $\Lambda_b^0 \to \Lambda J/\psi$ decay (same final state hadrons)
- Combinatorial shape accounts for the partially reconstructed $\Lambda_b^0 \to \Lambda\eta(\to\gamma\gamma)$
- Result **allows to rule-out previous 2-fold ambiguity** in the $Re(C_7^{\prime NP})\,|\,Re(C_7^{NP})$ plane
- **First direct measurement** of the photon polarisation!

$$\alpha_\gamma = 0.82^{+0.17}_{-0.26}\,(stat.)^{+0.04}_{-0.13}\,(syst.)$$

Measurement of the photon polarisation in $\Lambda_b^0 \to \Lambda\gamma$ decays

[Phys. Rev. D105 (2022) L051104]

- Sensitivity to **CP-violation**: self-tagged decay, allows to split the sample depending to the charge of the final state hadrons



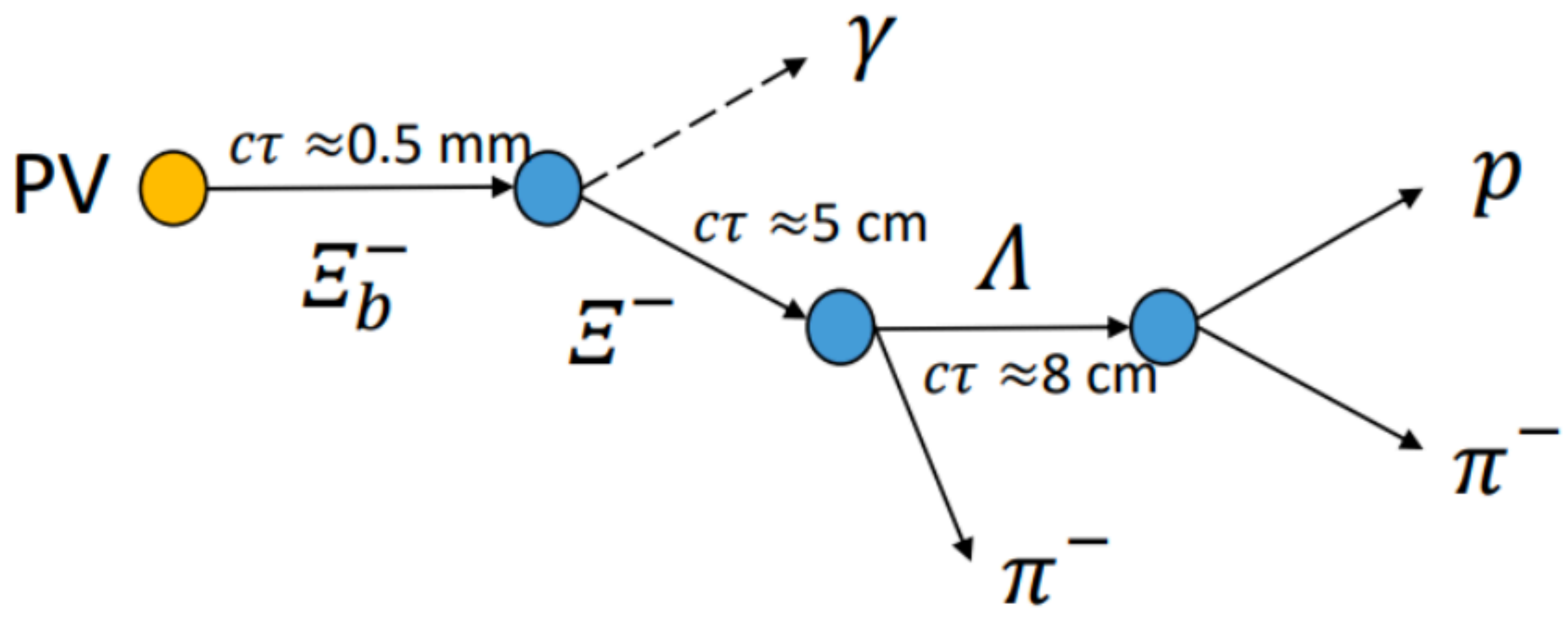
$\alpha_\gamma^- > 0.56\ (0.44)$ at 90% (95%) CL

$\alpha_\gamma^+ = -0.56^{+0.36}_{-0.33}\,(stat.)^{+0.16}_{-0.09}\,(syst.)$

Search for the radiative $\Xi_b^- \to \Xi^-\gamma$ decay

[JHEP 01 (2022) 069]

- **First attempt at this search!**
- Very challenging topology at LHCb, only 5% decay in the vertex locator

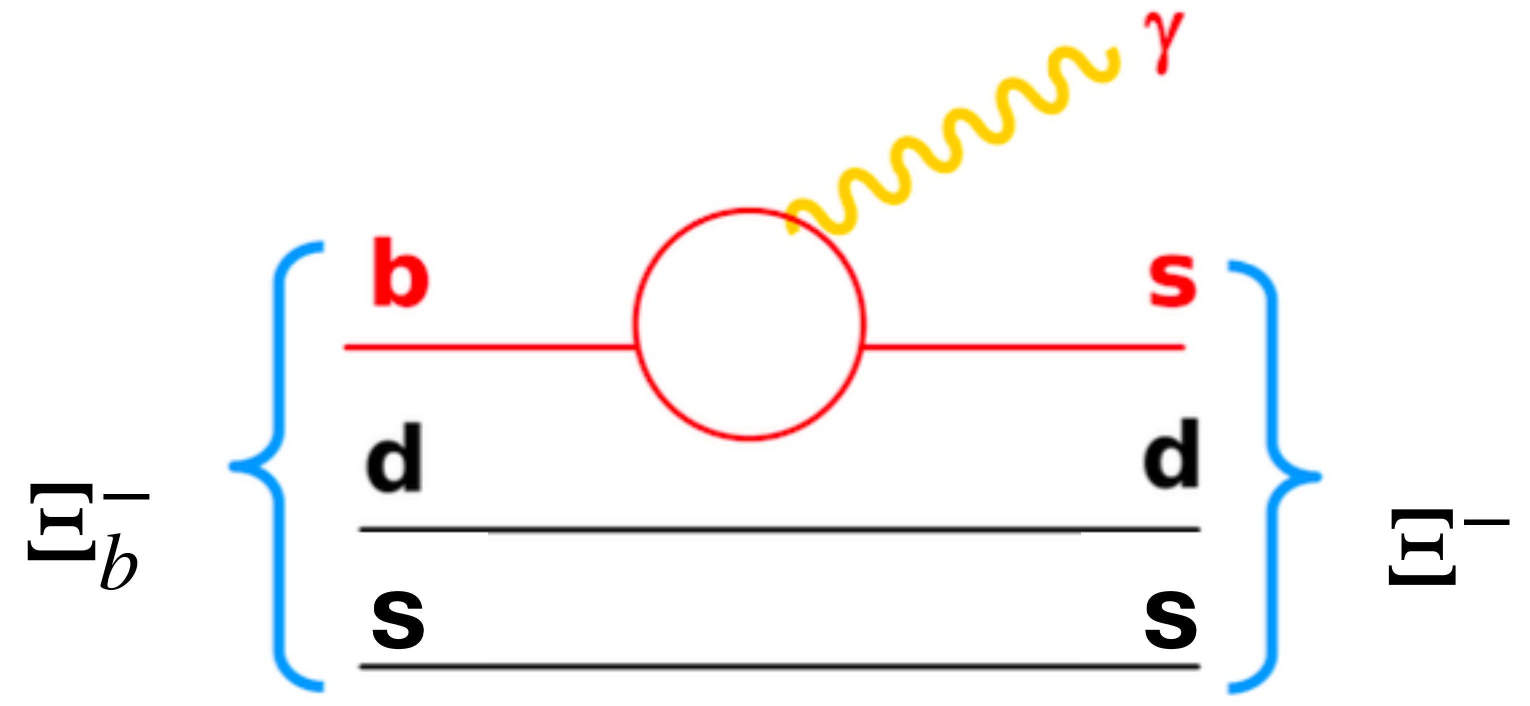


- Several theoretical predictions for $\mathscr{B}_{SM}(\Xi_b^- \to \Xi^-\gamma)$
  - Phys. Rev. D 83, 054007

    $\to (3.03 \pm 0.10) \times 10^{-4}$
  - arXiv:2008.06624v1

    $\to (1.23 \pm 0.64) \times 10^{-5}$
  - arXiv:2202.06179

    $\to (1.1 \pm 0.1) \times 10^{-5}$

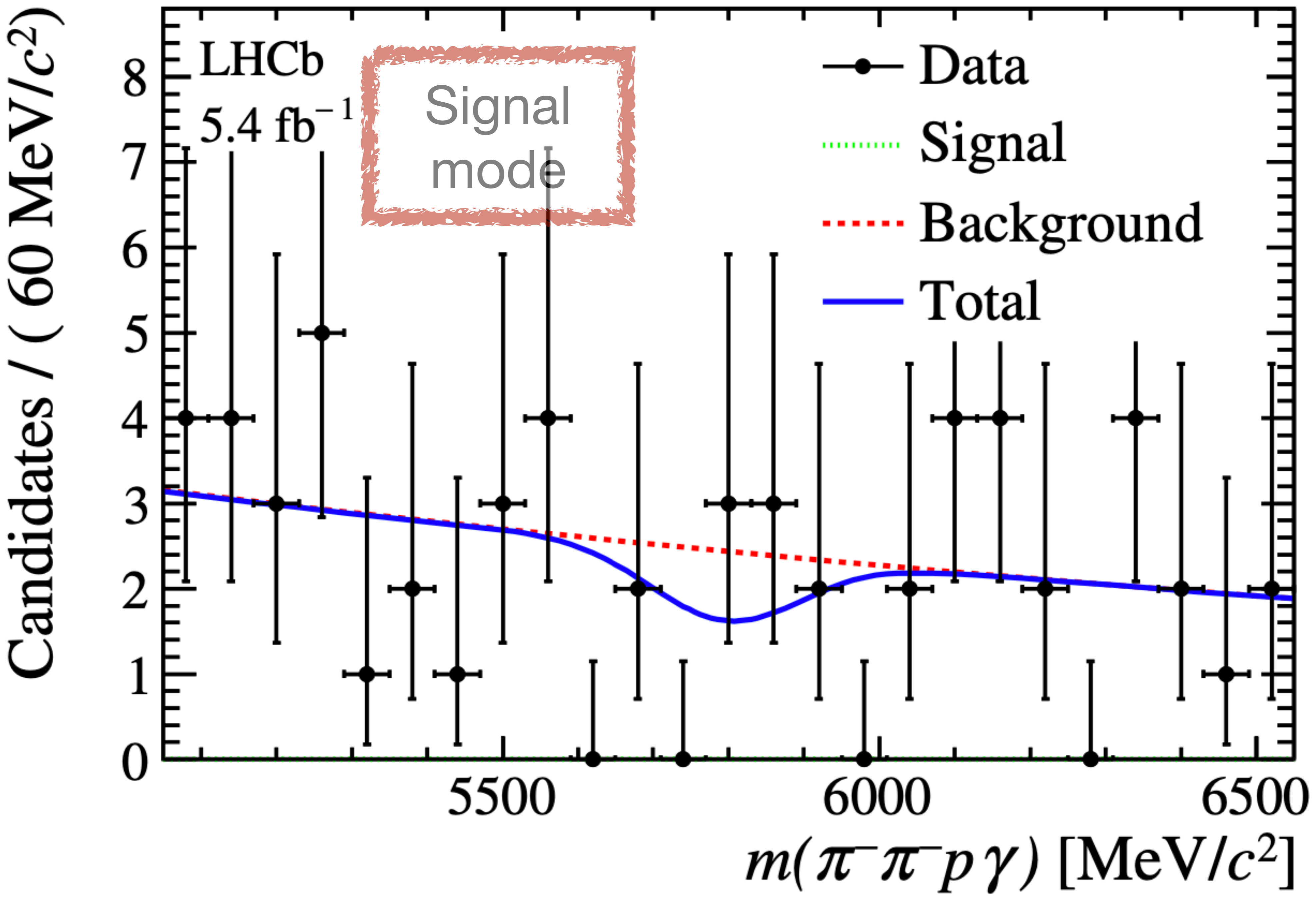


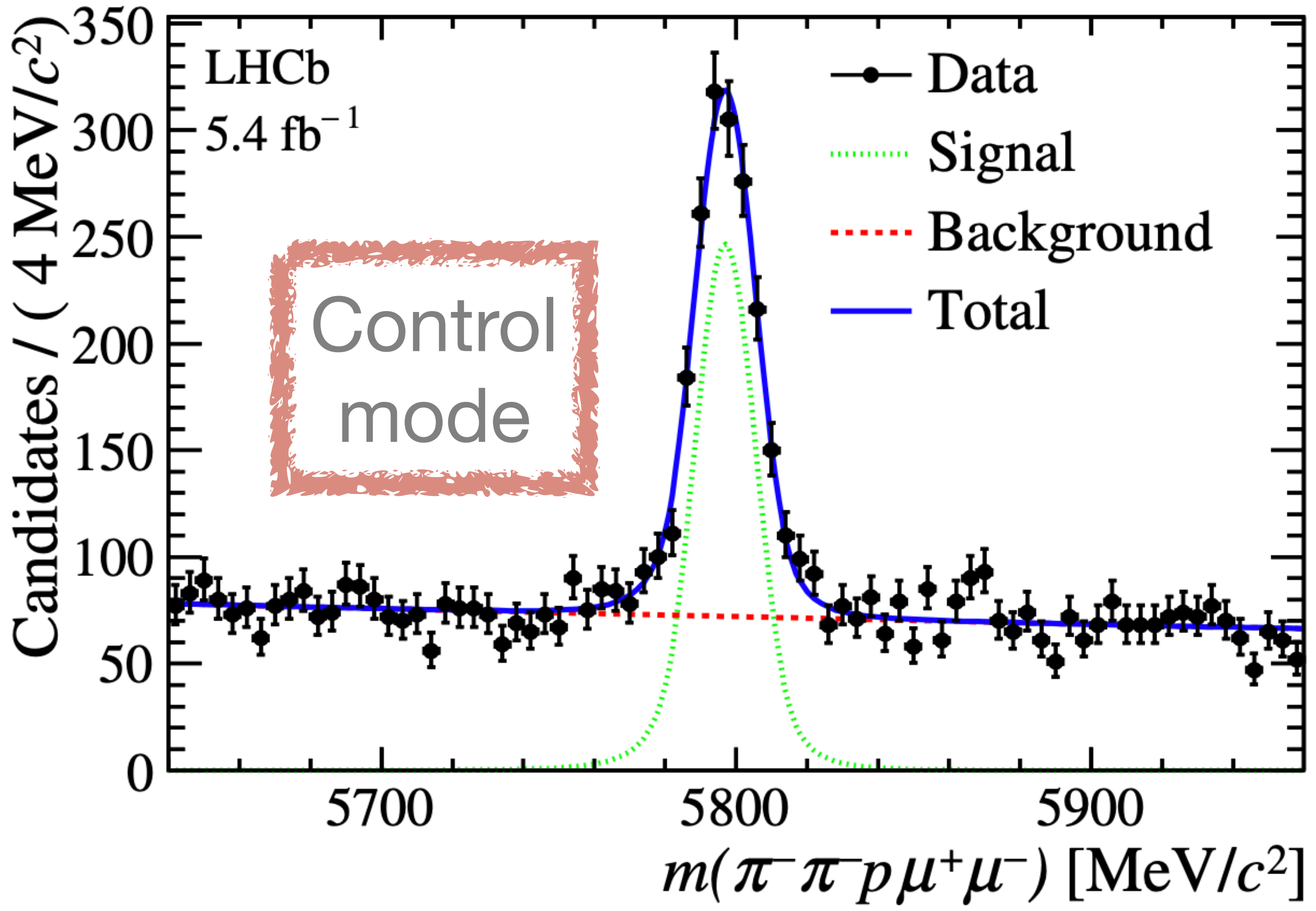
Search for the radiative $\Xi_b^- \to \Xi^-\gamma$ decay

- **Three displaced vertices**:
  - Restrict analysis to cases where all resonances decay inside the VELO (existing trigger line)
- **Selection based** on **mass windows** around the Λ, Ξ^- and the Ξ_b^- and **multivariate discriminator** against combinatorial background
- Simultaneous fit to signal candidates + control mode ($\Xi_b^- \to \Xi^- J/\psi$, with same hadronic content in the final state), sharing the $m_{\Xi_b^-}$ parameter
- No signal found, **limit placed** using Feldman-Cousins method

$\mathcal{B}(\Xi_b^- \to \Xi^-\gamma) < 1.3(0.6) \times 10^{-4}$ at 95%(90%) level

[JHEP 01 (2022) 069]





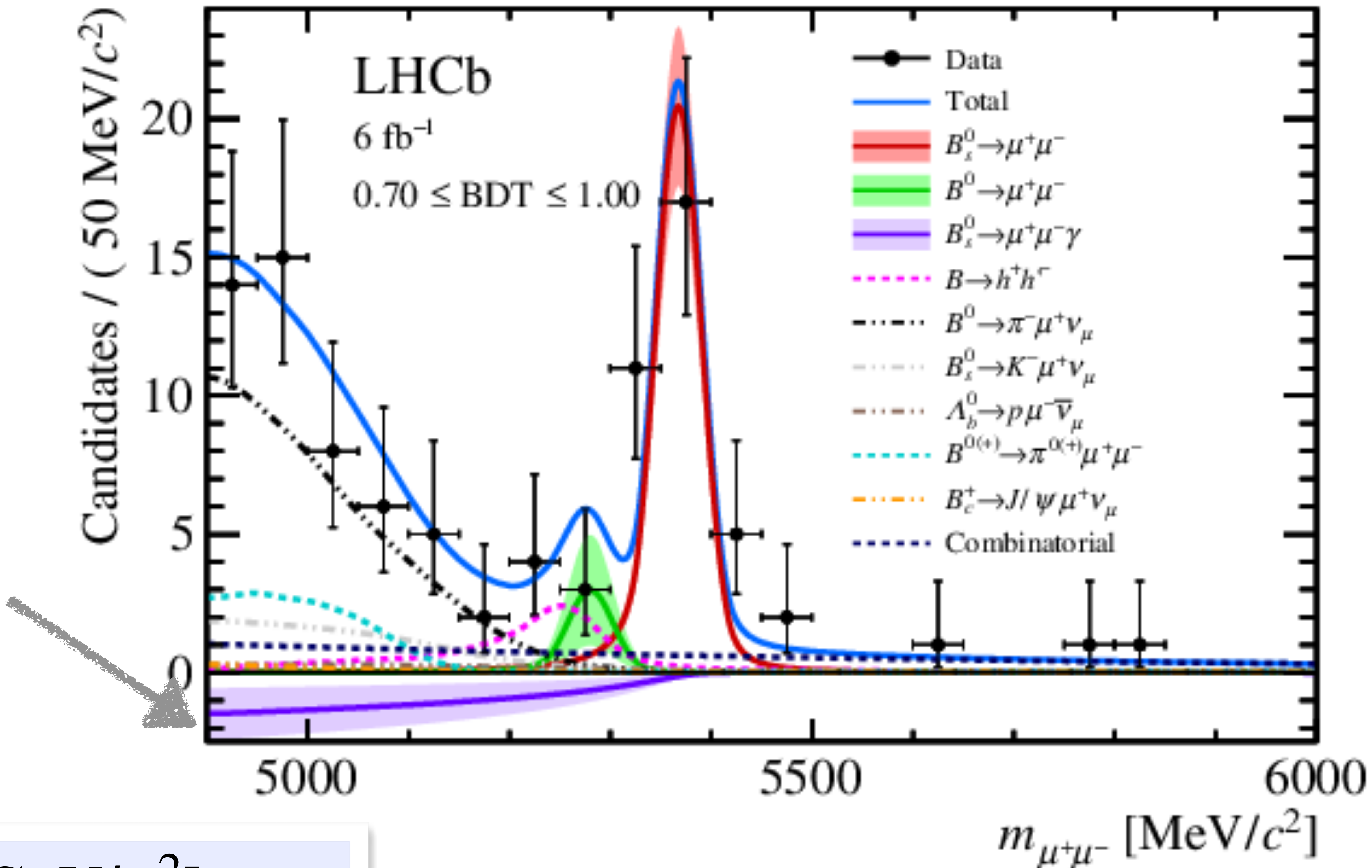
Added bonus in the $B_s^0 \to \mu^+\mu^-$ analysis!

[Phys. Rev. D105 (2022) 012010]

[Phys. Rev. Lett. 128, (2022) 041801]

today@15h07

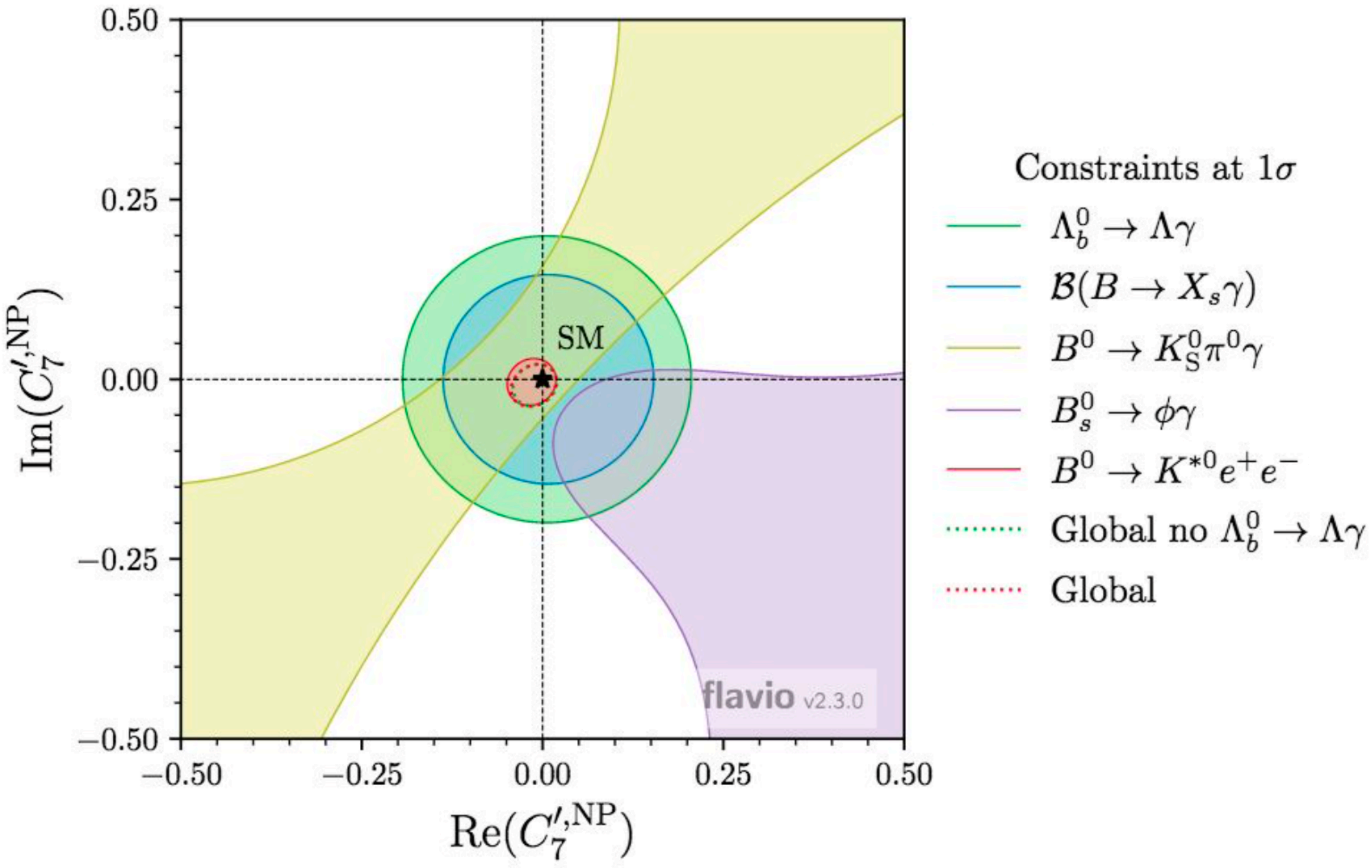
- See Maarten's talk for details
  - Use $B_s^0 \to \mu^+\mu^-$ data sample and analysis strategy to search for $B_s^0 \to \mu^+\mu^-\gamma$, without explicitly reconstructing the photon
  - No evidence found for $B_s^0 \to \mu^+\mu^-\gamma$ (1.5σ), limit set using CLs method:



$$\mathscr{B}(B_s^0 \to \mu^+\mu^-\gamma) < 1.5(2.0) \times 10^{-9}, [m_{\mu\mu} > 4.9 GeV/c^2]$$

Conclusions

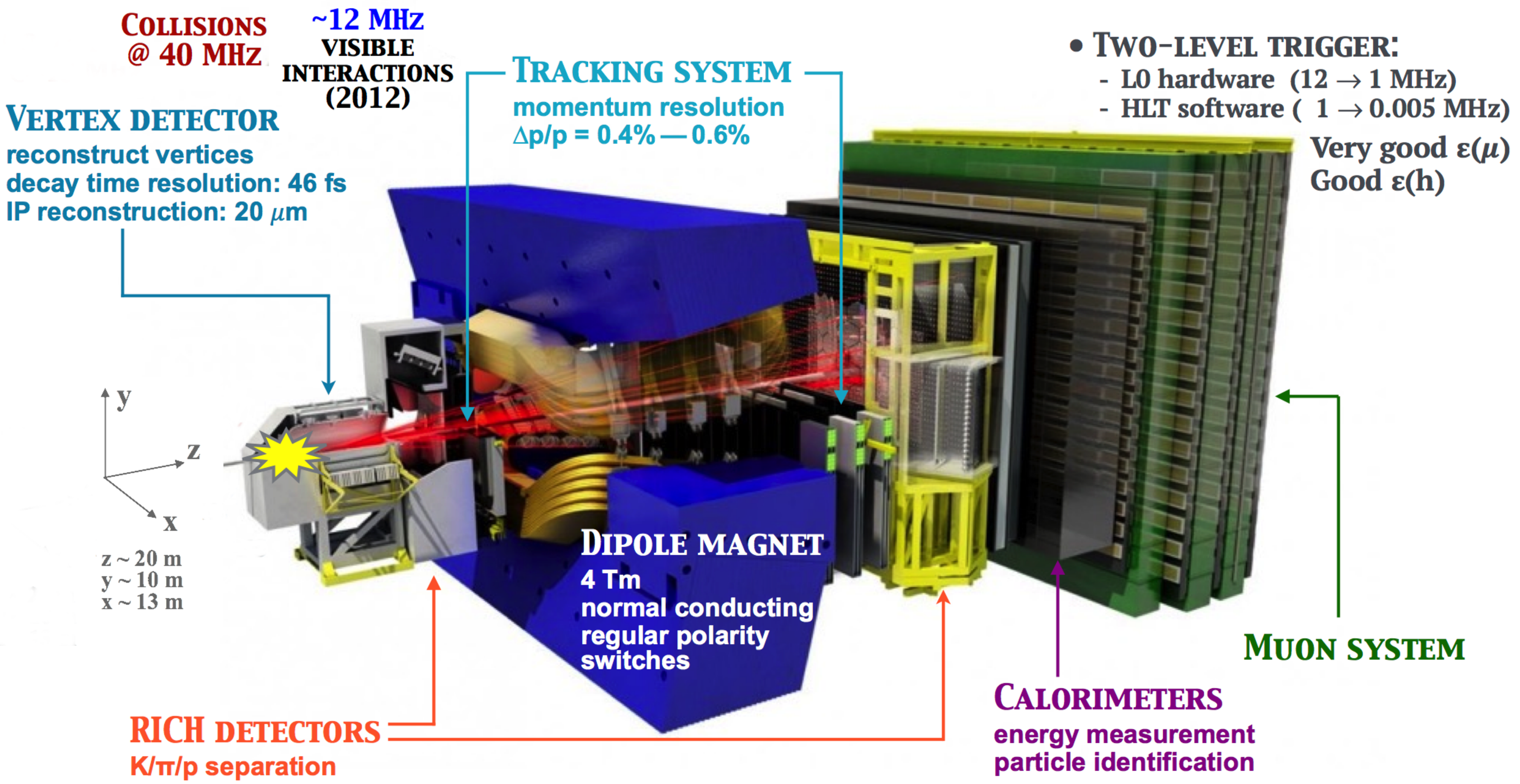
- $b \to s(d)\gamma$ transitions are **sensitive to New Physics phenomena**
- **LHCb** has unique **opportunities** to explore radiative decays of **all hadron species with large data samples**!
  - Achieved world-best constraint on photon polarisation with $B^0 \to K^{*0}e^+e^-$
  - First direct measurement of photon polarisation in $\Lambda_b^0 \to \Lambda\gamma$
- Several analysis with Run 2 data on the pipe line
- **Run 3 is around the corner!**



A. Paul and D. M. Straub, JHEP 04 (2017) 027 D. M. Straub, "flavio", arXiv:1810.08132


DETAILS

The LHCb detector (Runs 1 and 2)

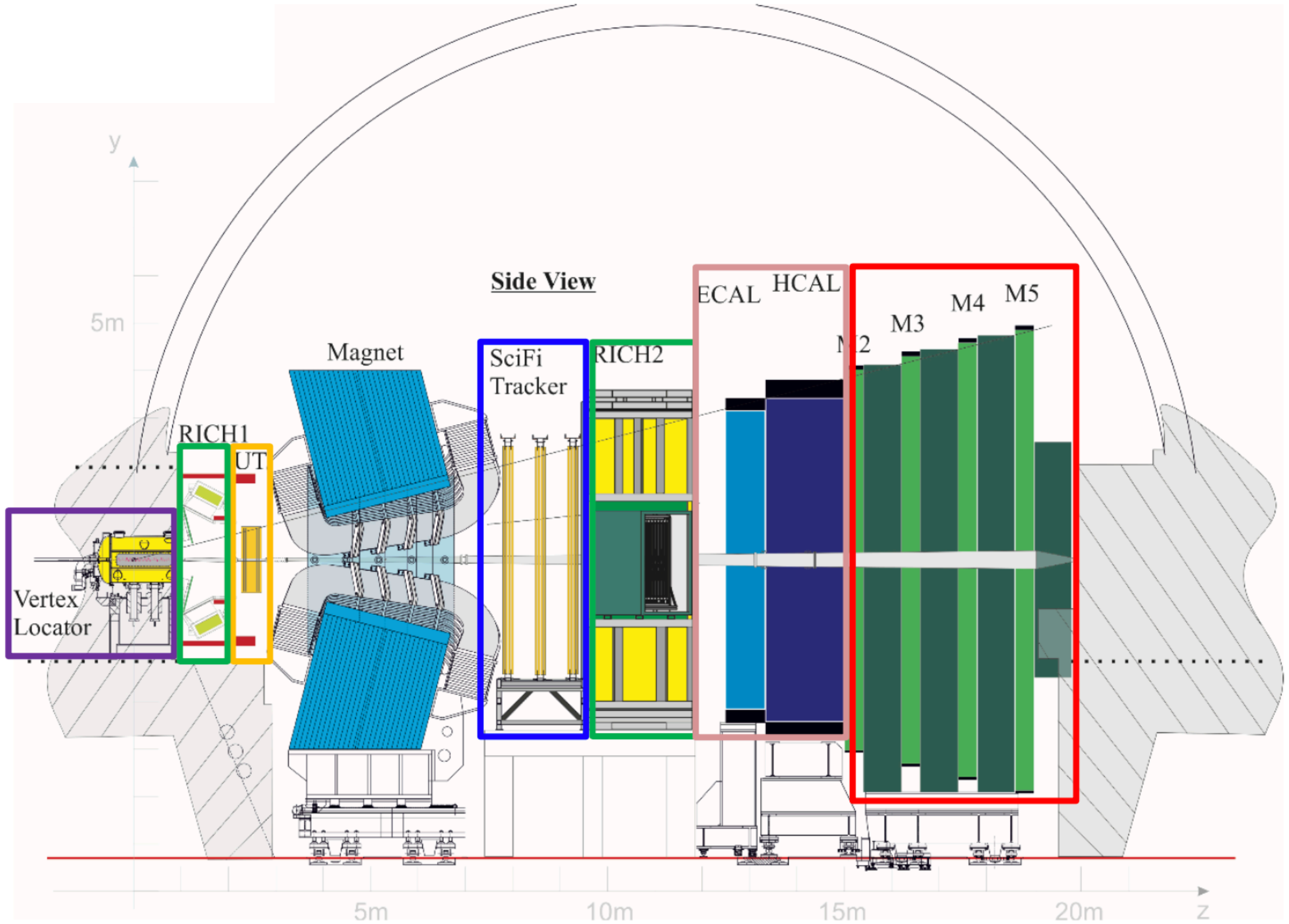


$$\Delta E/E_{ECAL} = 1\% + 10\,\%/\sqrt{(E[GeV])}$$

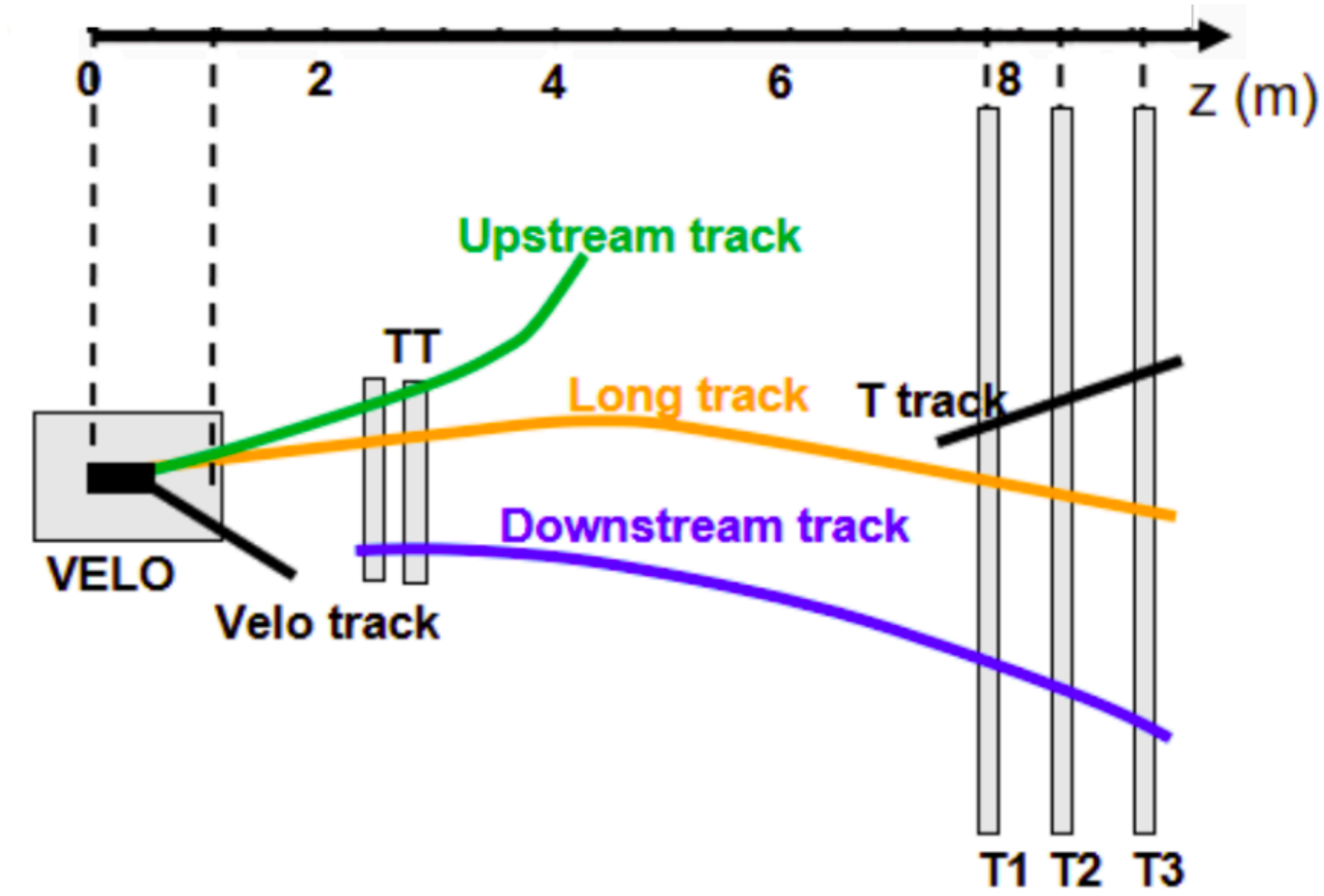
LHCb Detector Performance
International Journal of Modern Physics A
Vol. 30, No. 7 (2015) 1530022

LHCb detector upgrade (Run 3)

- Installation of the upgrade during LHC Long Shutdown 2 (2019-2022)
- Main changes in operation:
  - Instantaneous luminosity $2 \cdot 10^{33} cm^{-2} s^{-1}$ (x5 Run2)
  - 40 MHz trigger-less read-out
  - Full software trigger
- Main changes in the detector:
  - New tracking detectors: VELO, UT, SciFi
  - Upgraded photodetectors and electronics for both RICH systems
  - Upgrade of readout electronics for the calorimeters and the muon system

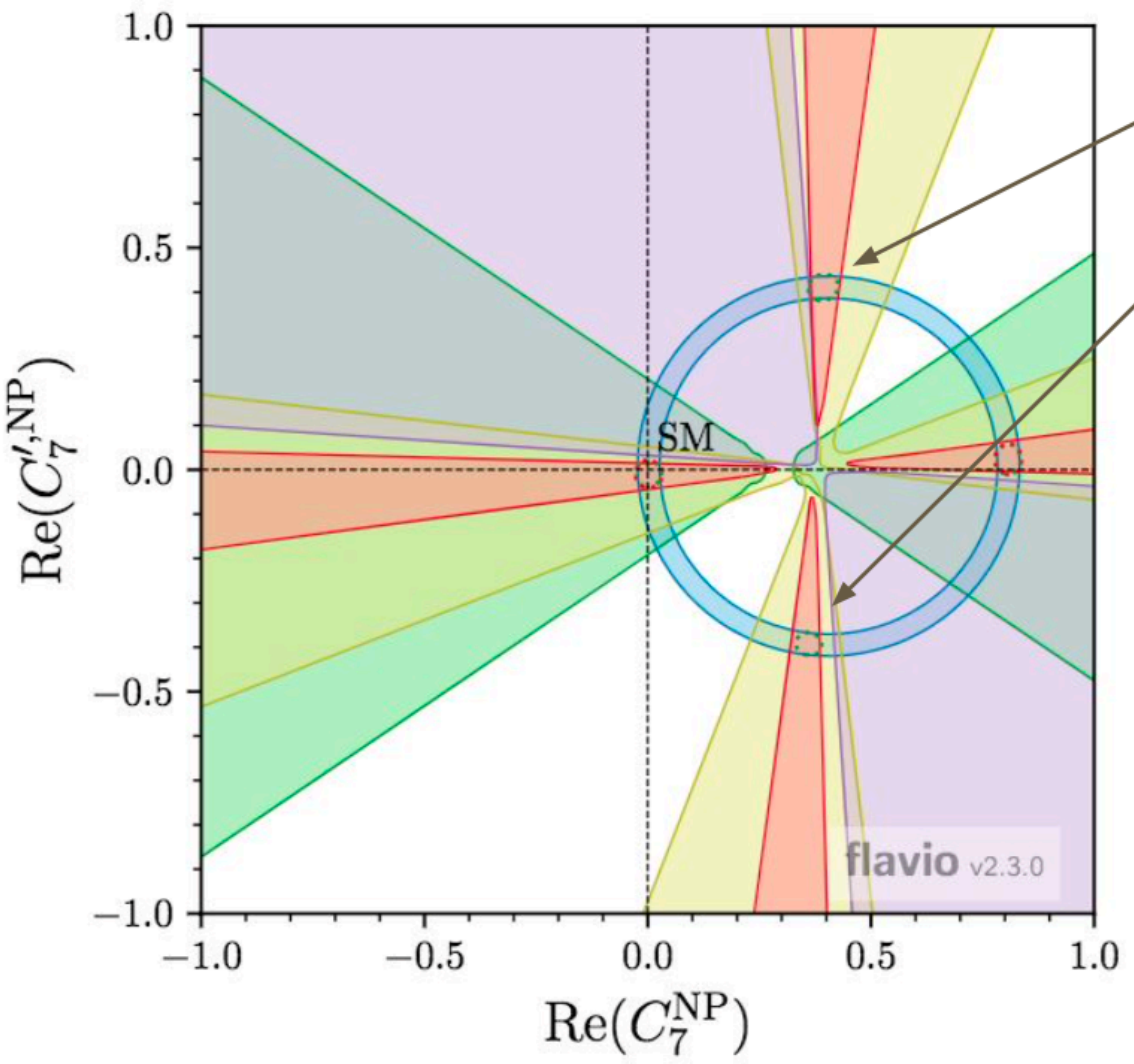


Track types in LHCb



Measurement of the photon polarisation in $\Lambda_b^0 \to \Lambda\gamma$ decays

[Phys. Rev. D105 (2022) L051104]



Result **allows to rule-out previous 2-fold ambiguity** in the $Re(C_7^{\prime NP})\,|\,Re(C_7^{NP})$ plane

New input from $\Lambda_b^0 \to \Lambda\gamma$