New test of Lepton Flavour Universality with rare $\Lambda_b^0 \to \Lambda \ell \ell$ decays at LHCb

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Conseil Européen pour la Recherche Nucléaire
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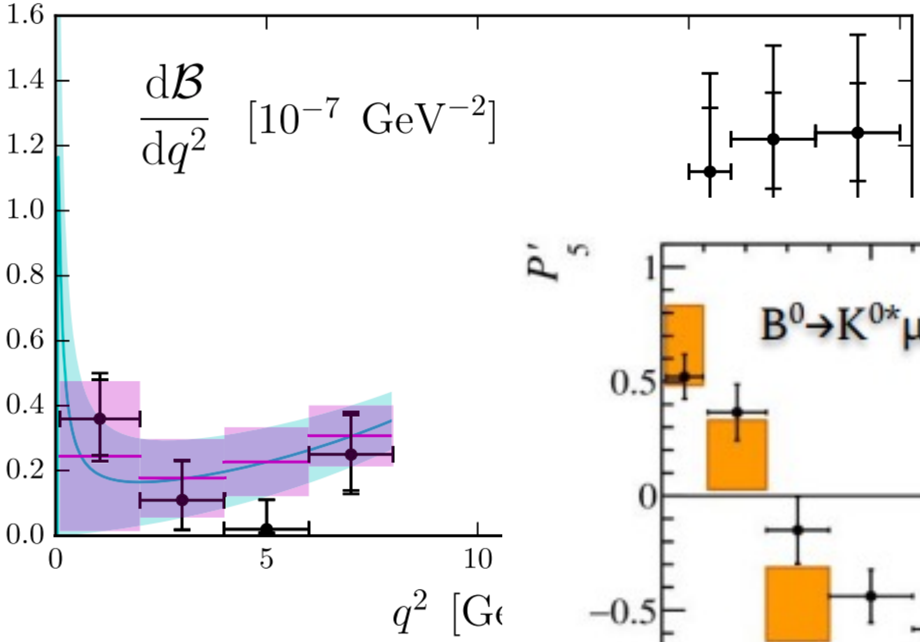
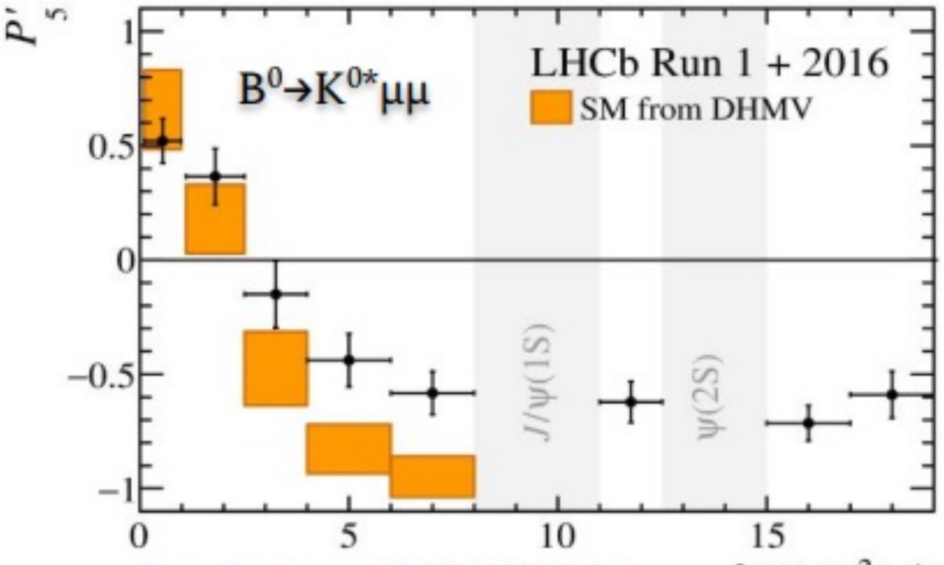
Anomalies at LHCb

Branching Fraction of $\Lambda_b^0 \to \Lambda\mu^+\mu^-$
PHYSICAL REVIEW D 93, 074501 (2016)



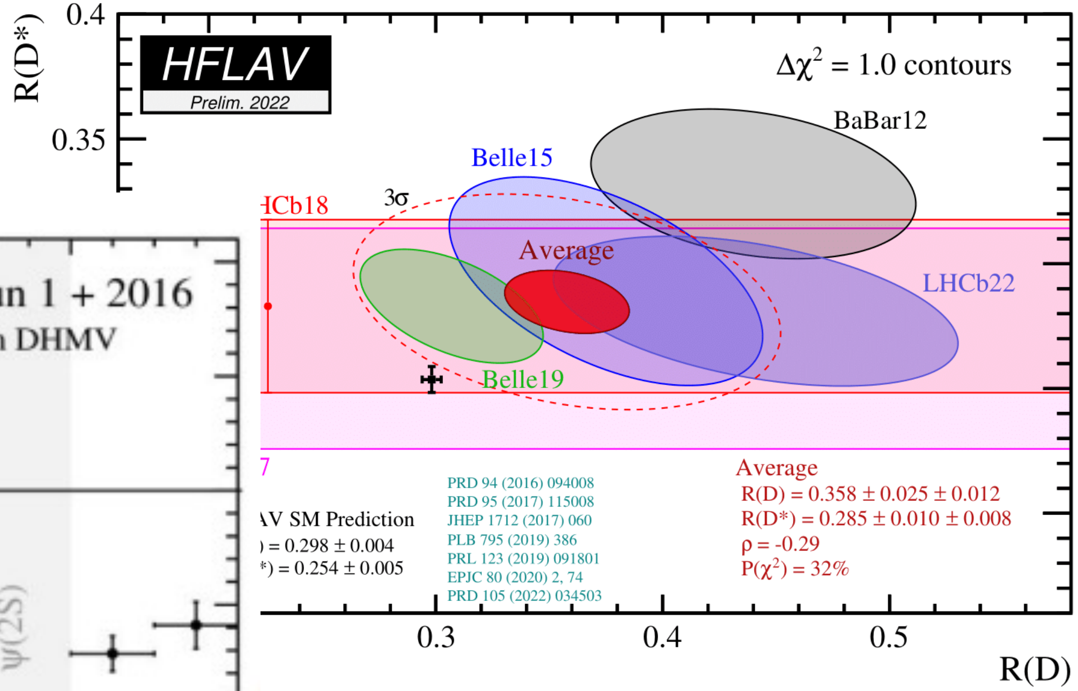


Phys. Rev. Lett. 125, 011802 (2020)

Angular Coefficients of $B^0 \to K^{0*}\mu^+\mu^-$

Semi-Leptonic decays: LHC seminar 18.10.22

First joint measurement of $R(D^*)$ and $R(D^0)$ at LHCb

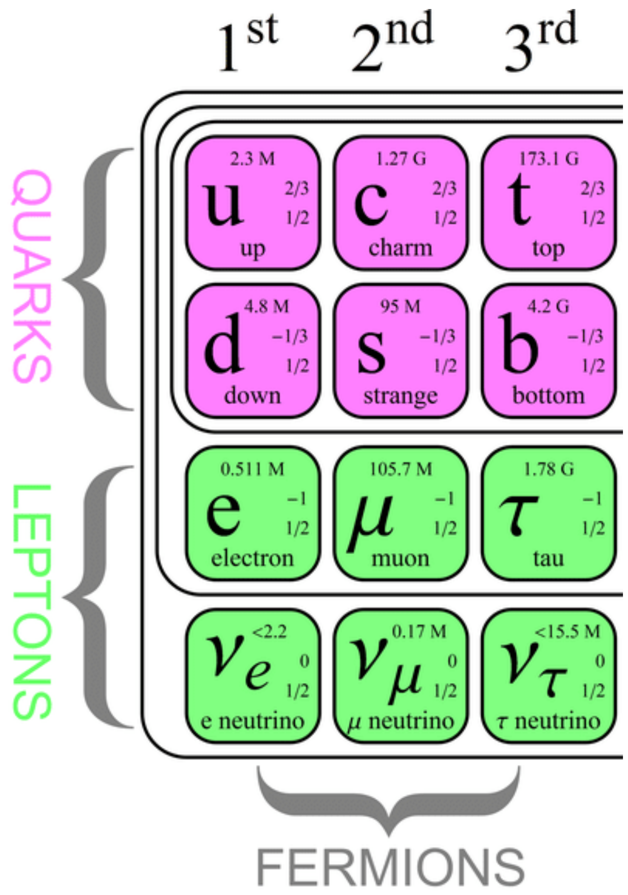


Our playground: the Standard Model

- Fermions (matter):
  - Why 3 generations of Quarks?
  - Why 3 generations of Leptons?

- Bosons (interactions):
  - Strong, Weak, and Electromagnetic forces all have identical couplings to the generations of fermions

  - Higgs field does distinguish among the generations of fermions



Lepton Flavour Universality (LFU)

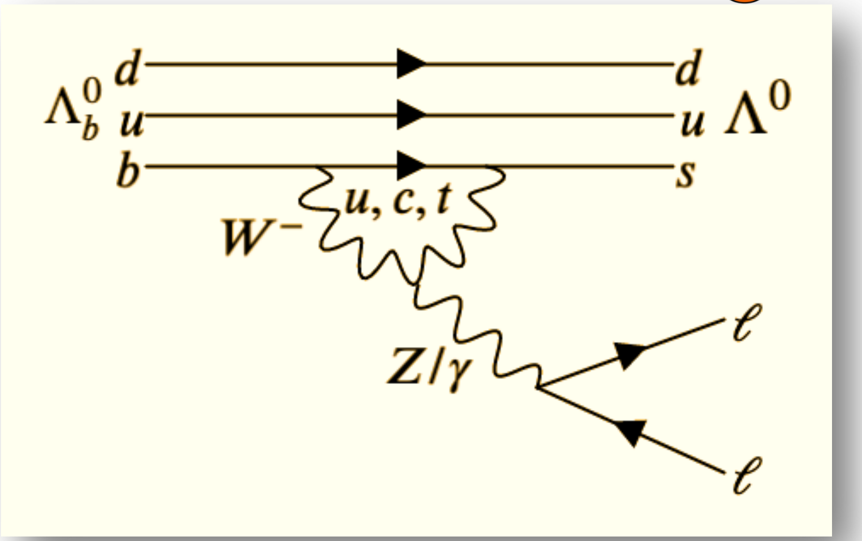
- Standard Model couplings of leptons to vector bosons are flavour-independent

- Precision measurements to:
  - Carefully examine LFU prediction by the Standard Model
  - Search for New Physics

- Experimentally measured as Ratio: counting μ/e decays

Why $b \to s\ell\ell$ transitions? (ℓ=lepton)

- Part of the anomalies!
- Electroweak
- Flavour Changing Neutral Current
- In SM forbidden at tree level, only possible via higher order diagrams and thus highly suppressed



Therefore, being a rare decay sensitive to new physics effects.

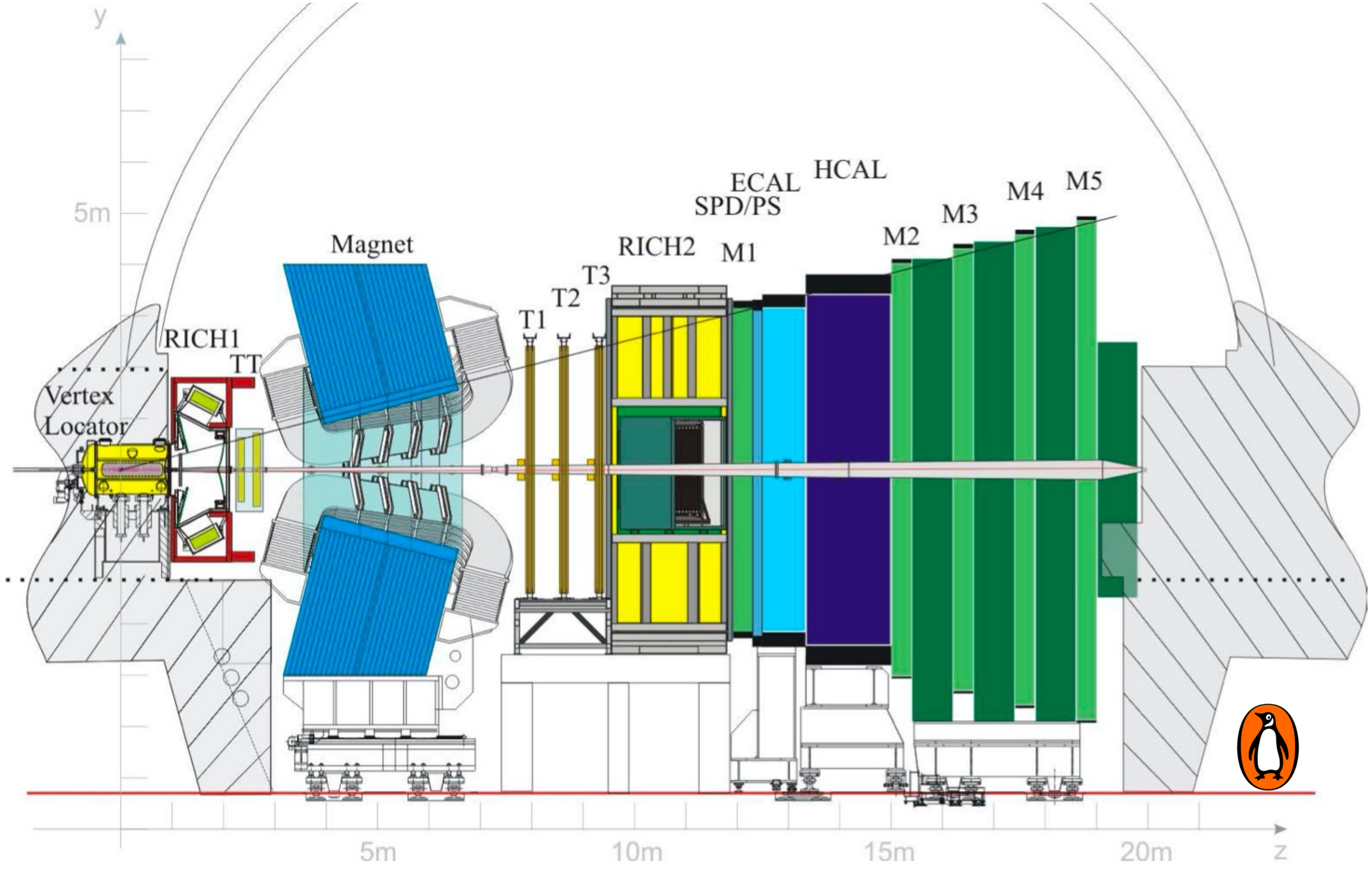
Motivation for using Λ_b^0 decays

- Baryonic decay to be measured:
  - complementary to mesons
  - different form factors
  - different spin structure
- Measured as a double ratio:

$$R_\Lambda = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda\mu^+\mu^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda e^+e^-)} \cdot \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda J/\psi(\to e^+e^-))}{\mathcal{B}(\Lambda_b^0 \to \Lambda J/\psi(\to \mu^+\mu^-))}$$

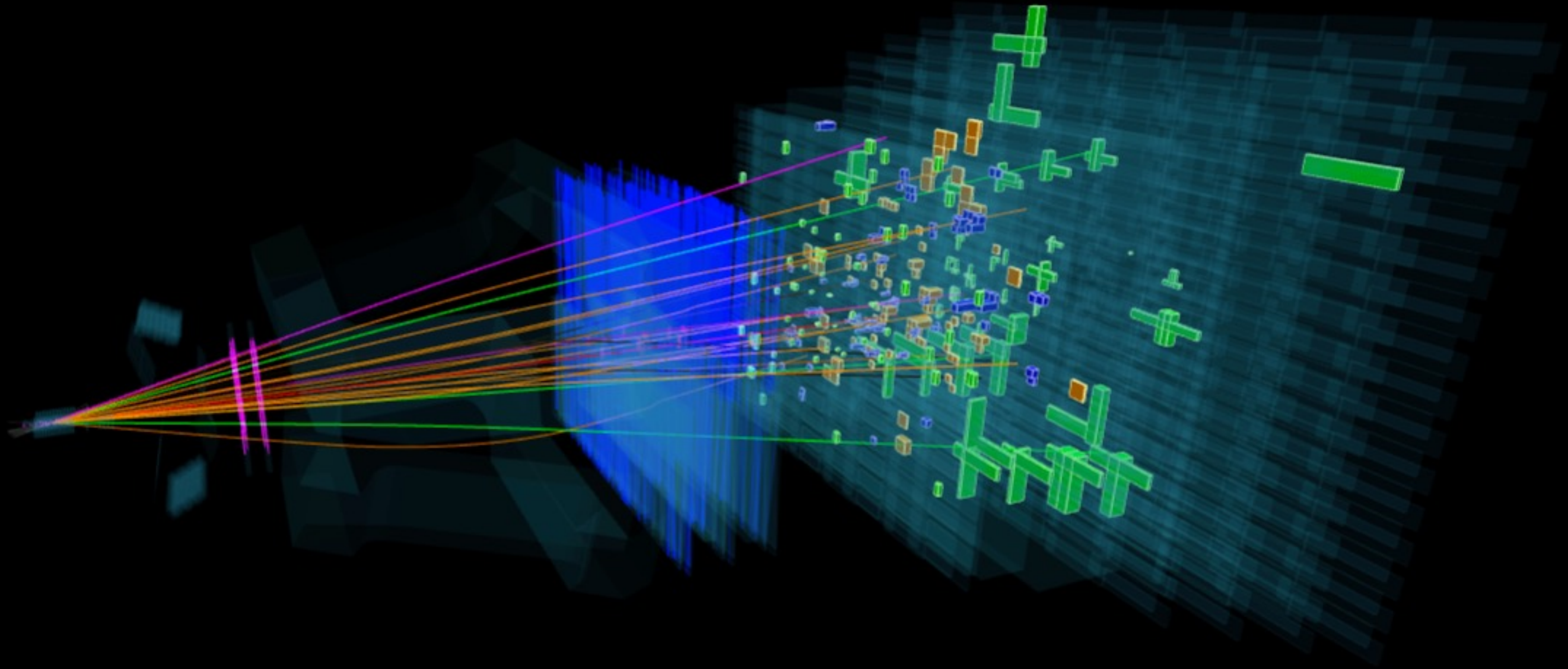
1 in SM!

The LHCb detector



LHCb

Event 291000117
Run 116803
Mon, 28 May 2012 07:23:2

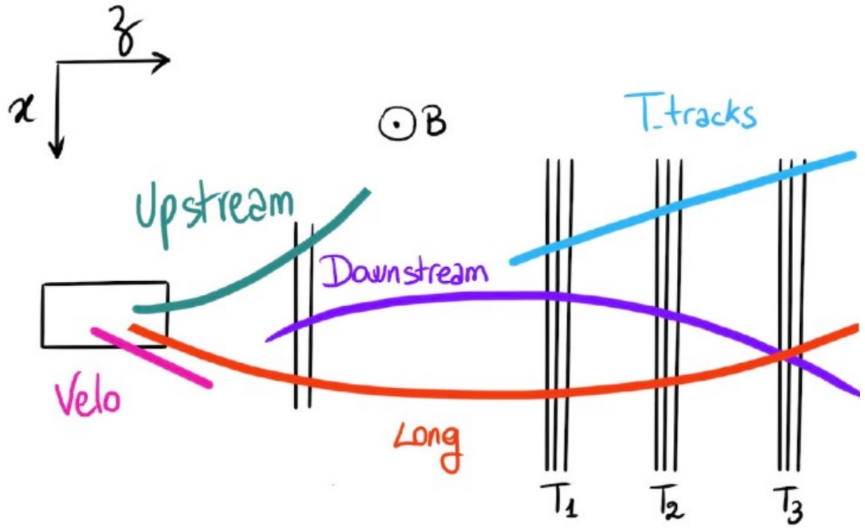


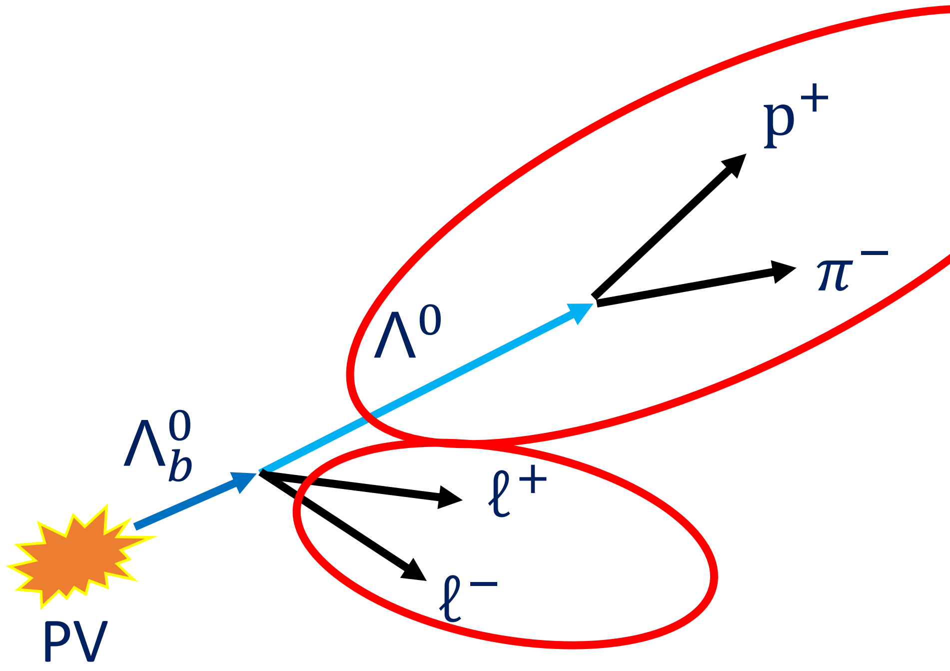
Event reconstruction

decay length ≈ 1 m   (γ=15-25)

- Λ is long lived, decays into $p^+\pi^-$
  - ➢ Reconstruction split into Downstream/Long tracks
  - ➢ Downstream comes with lower mass resolution but does increase statistics by a factor 3

- Lepton pair created:
  - ➢ Dilepton invariant mass (q^2) measured
  - ➢ Incl. two resonances: J/ψ and ψ(2S)





Samples

- $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ and $\Lambda_b^0 \to \Lambda e^+e^-$ decays

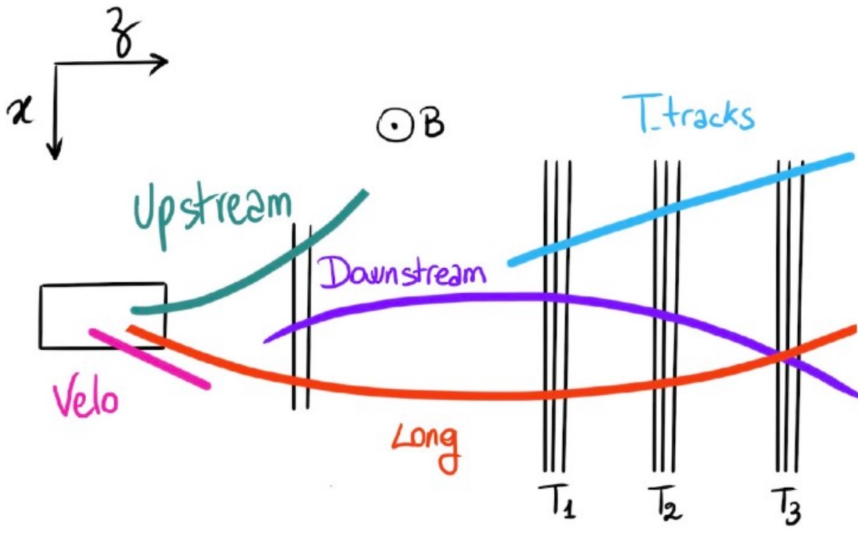
- Cross-checks via resonances:

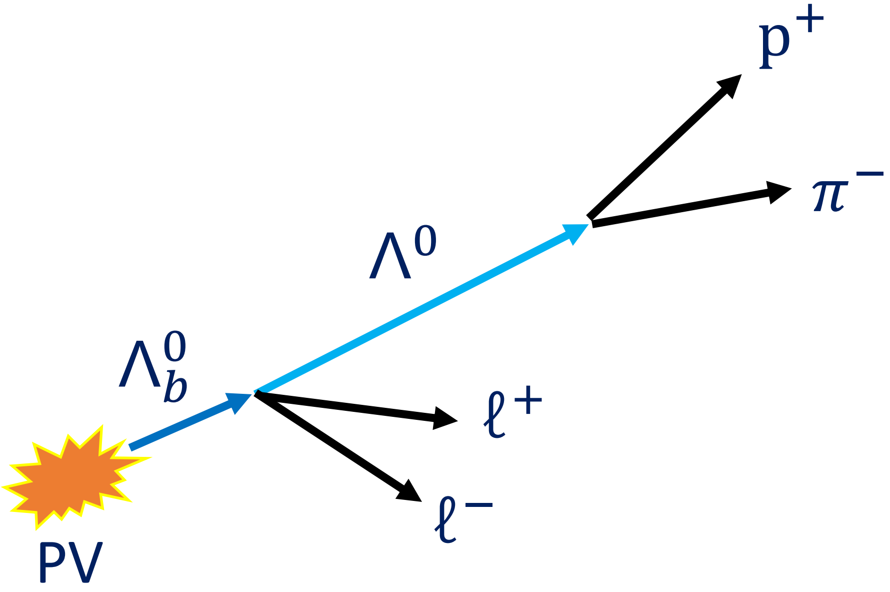
  $\Lambda_b^0 \to \Lambda J/\psi(\to\mu^+\mu^-)$ and $\Lambda_b^0 \to \Lambda\psi(2s)(\to\mu^+\mu^-)$

  $\Lambda_b^0 \to \Lambda J/\psi(\to e^+e^-)$ and $\Lambda_b^0 \to \Lambda\psi(2s)(\to e^+e^-)$

q^2-range:	J/ψ	$\psi(2S)$	Rare
Downstream	Cross-checks	Cross-checks	Blinded!
Long			

- Split over periods: LHC Run1, Run2





What about $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ decays?

- Lepton pair created:
  - ➢ Dilepton invariant mass (q^2) measured
  - ➢ Incl. two resonances: J/ψ and $\psi(2S)$

- Muon mode has been measured before

  $\mathcal{B}$ (J/ψ) also being re-measured

- Most signal expected at high q^2

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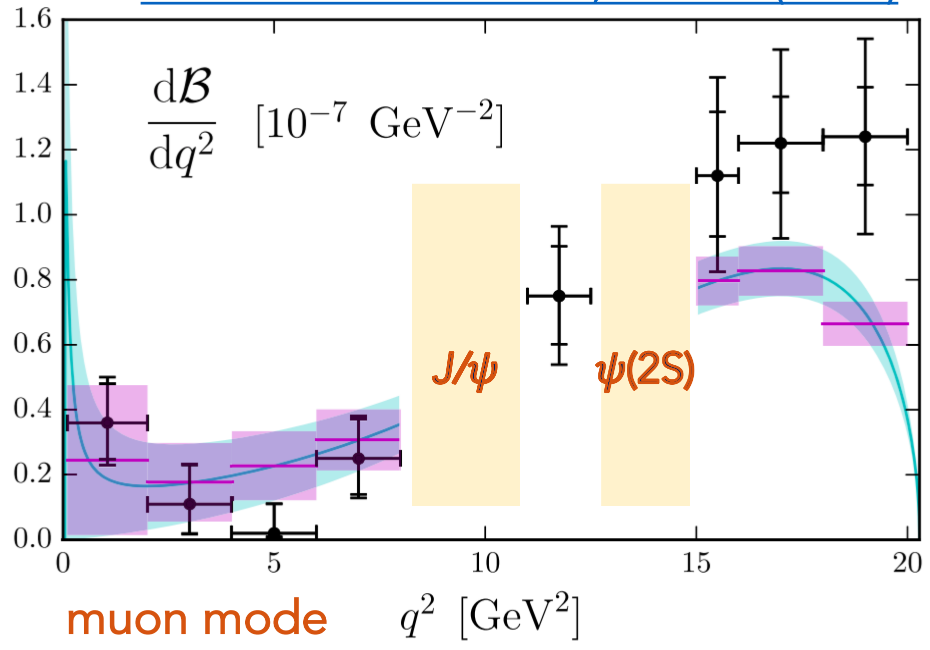
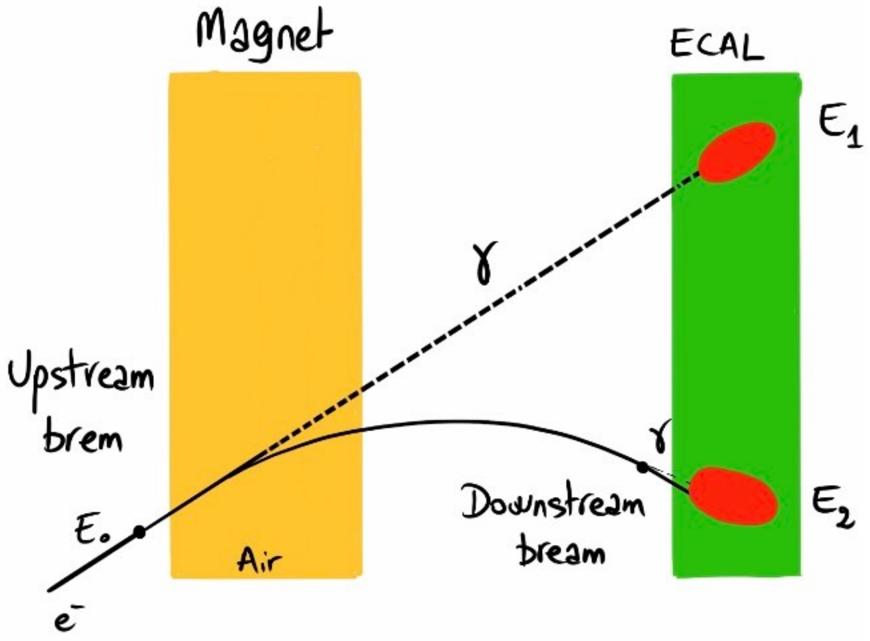


What about $\Lambda_b^0 \to \Lambda e^+ e^-$ decays?

- First measurement of $\Lambda_b^0 \to \Lambda\, e^+e^-$
- Electrons are challenging:
  - Bremsstrahlung
  - Lower mass resolution
  - Lower reconstruction efficiency



Lepton Flavour Universality in Λ_b decays

$$R_\Lambda = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda\mu^+\mu^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda e^+e^-)} \cdot \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda J/\psi(\to e^+e^-))}{\mathcal{B}(\Lambda_b^0 \to \Lambda J/\psi(\to \mu^+\mu^-))}$$

1 in SM!

- $J/\psi \to \ell^+\ell^-$ well understood and measured ($r_{J/\psi} = 1$)
- Double ratio to reduce systematic uncertainties:
  - μ and **e** modes have <u>different detector signatures</u>
  - double ratio <u>cancels</u> most of these <u>systematic uncertainties</u>

Cross-checks: J/ψ and ψ(2S)

- Two cross-checks before measuring R_Λ:
  1. single ratios $r_{J/\psi}$, $r_{\psi(2s)}$:

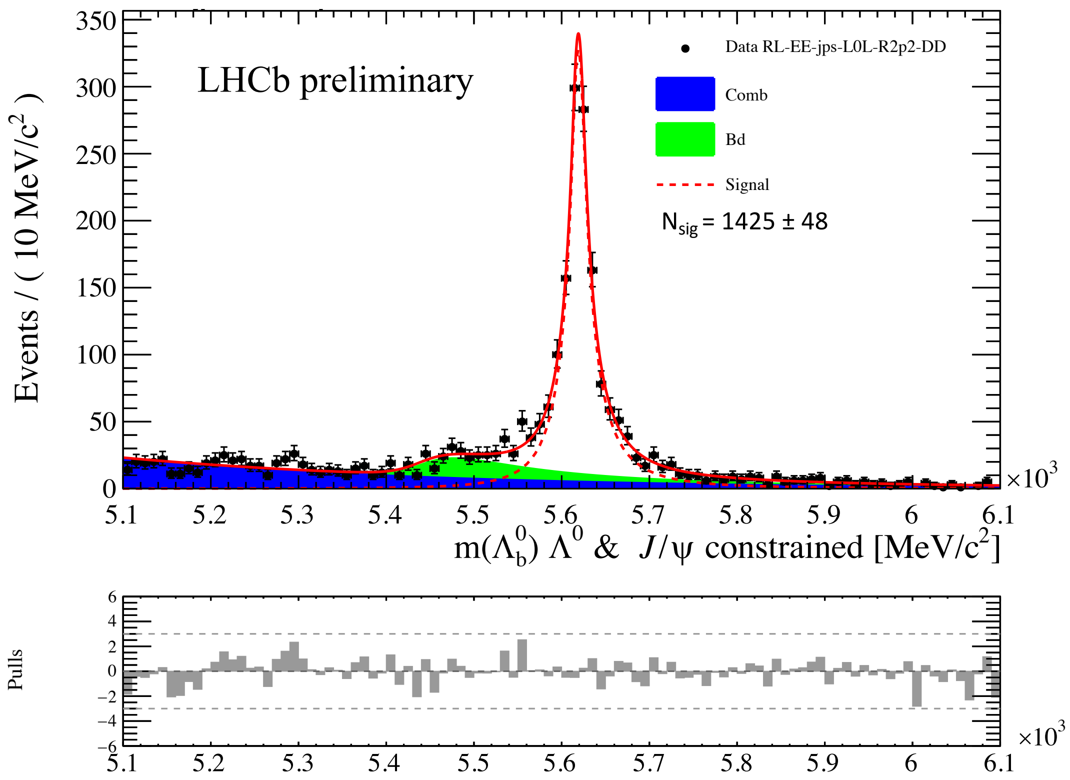
$$r_{J/\psi} = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda J/\psi(\to \mu^+\mu^-))}{\mathcal{B}(\Lambda_b^0 \to \Lambda J/\psi(\to e^+e^-))} = 1$$

$$r_{\psi(2s)} = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda \psi(2S)(\to \mu^+\mu-))}{\mathcal{B}(\Lambda_b^0 \to \Lambda \psi(2S)(\to e^+e-))} = 1$$

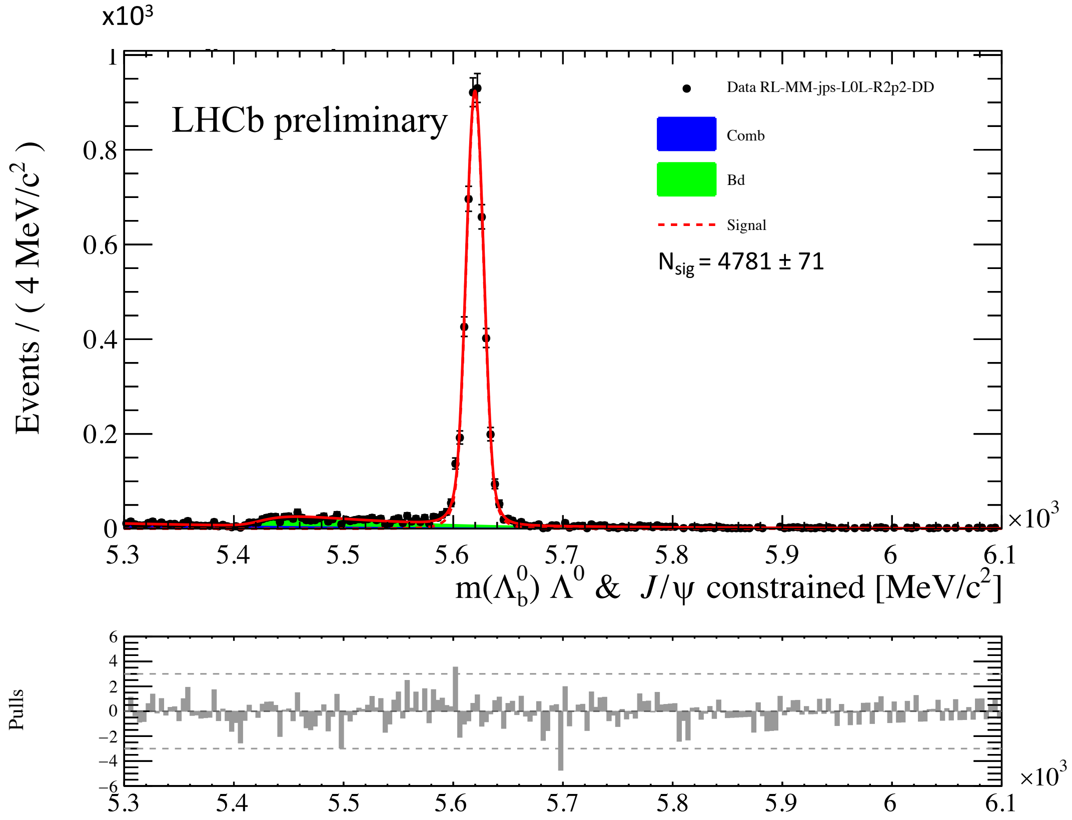
  2. double ratio $R_{\psi(2s)}$:

$$R_{\psi(2s)} = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda \psi(2S)(\to \mu^+\mu-))}{\mathcal{B}(\Lambda_b^0 \to \Lambda \psi(2S)(\to e^+e-))} \cdot \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda J/\psi(\to e^+e^-))}{\mathcal{B}(\Lambda_b^0 \to \Lambda J/\psi(\to \mu^+\mu^-))} = 1$$

Mass fits: $\Lambda_b^0 \to \Lambda J/\psi(\to \ell^+\ell^-)$

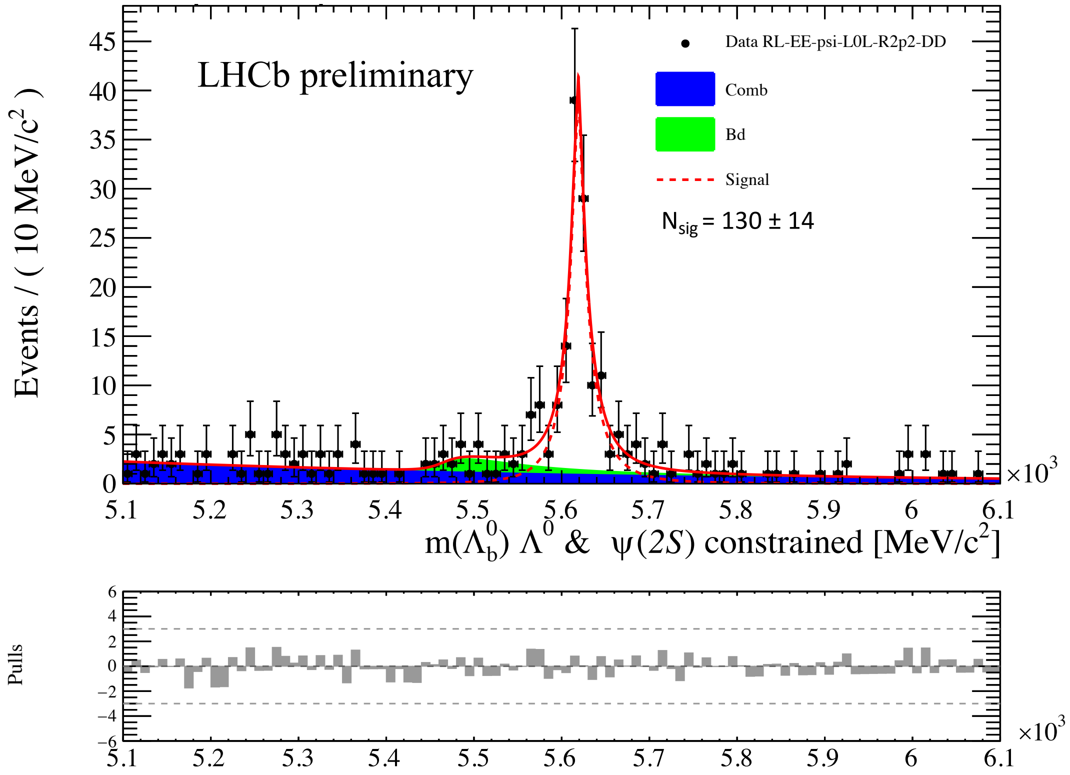


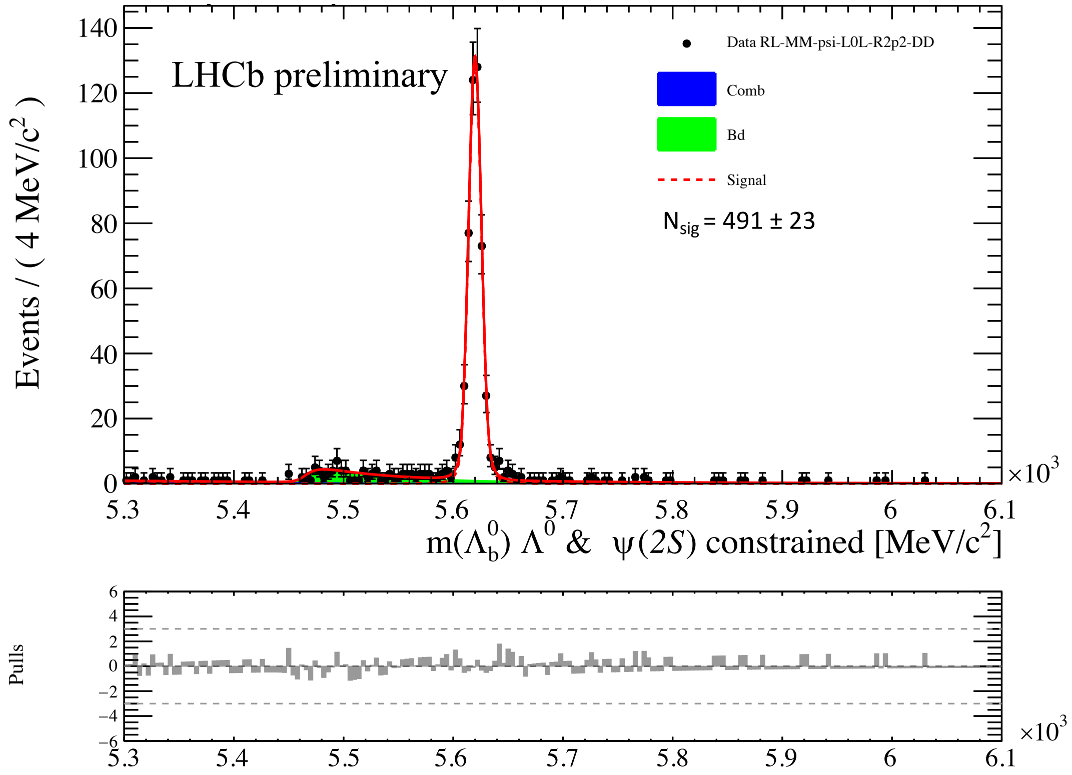
electron mode: $\Lambda_b^0 \to \Lambda J/\psi(\to e^+e^-)$



muon mode: $\Lambda_b^0 \to \Lambda J/\psi(\to \mu^+\mu^-)$

Mass fits: $\Lambda_b^0 \to \Lambda\psi(2S)(\to \ell^+\ell^-)$





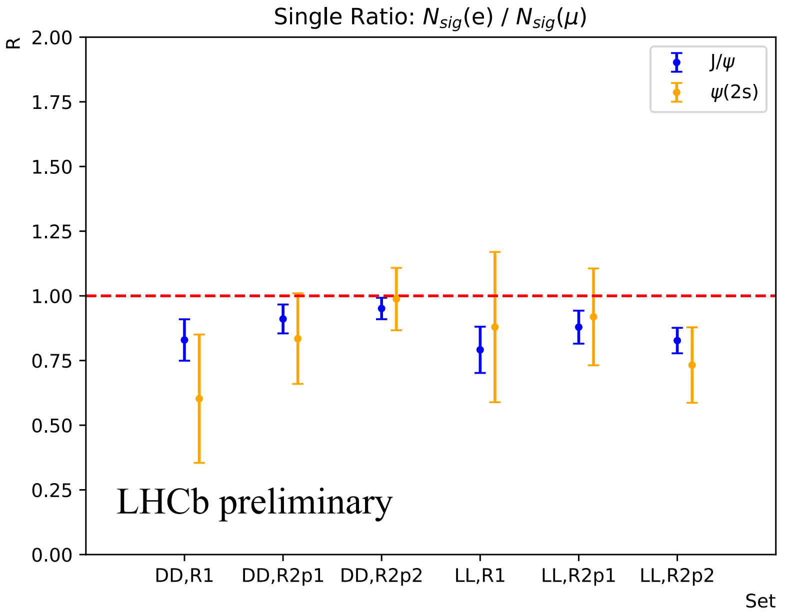
electron mode: $\Lambda_b^0 \to \Lambda\psi(2S)(\to e^+e^-)$

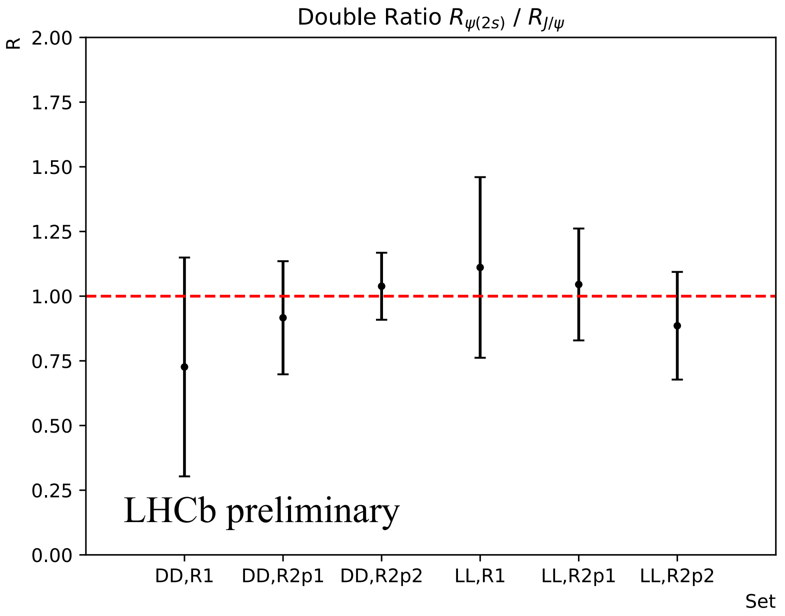
muon mode: $\Lambda_b^0 \to \Lambda\psi(2S)(\to \mu^+\mu^-)$

Ratio plots

- Single ratios
- Double ratio is a powerful method:
  → systematic biases cancel

- Work to be done on trigger efficiency
- Promising step for the analysis!



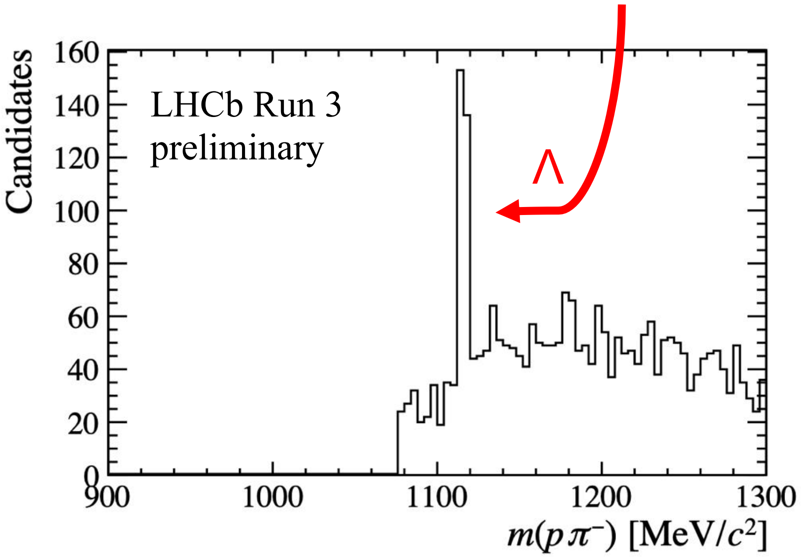


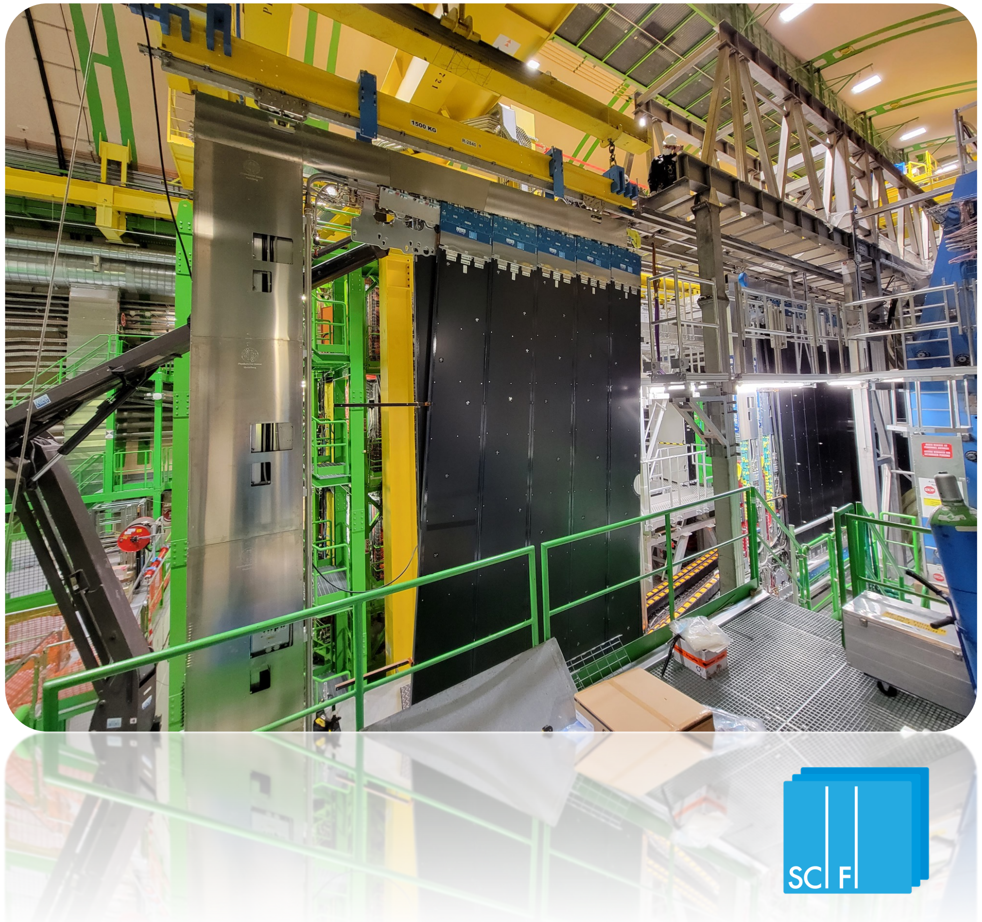
Final remarks

- Why uniformity among generations of fermions?
- $\Lambda_b^0 \to \Lambda \ell \ell$: new channel to measure LFU
- Intermediate results shown: single + double ratio

Bright future ahead for the experiment:

- Brand <u>new</u> LHCb detector installed!
- First Λ events in Run 3 data!!





Thank you for listening! Questions?