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

Jan de Boer
NNV Annual Meeting
4 November 2022

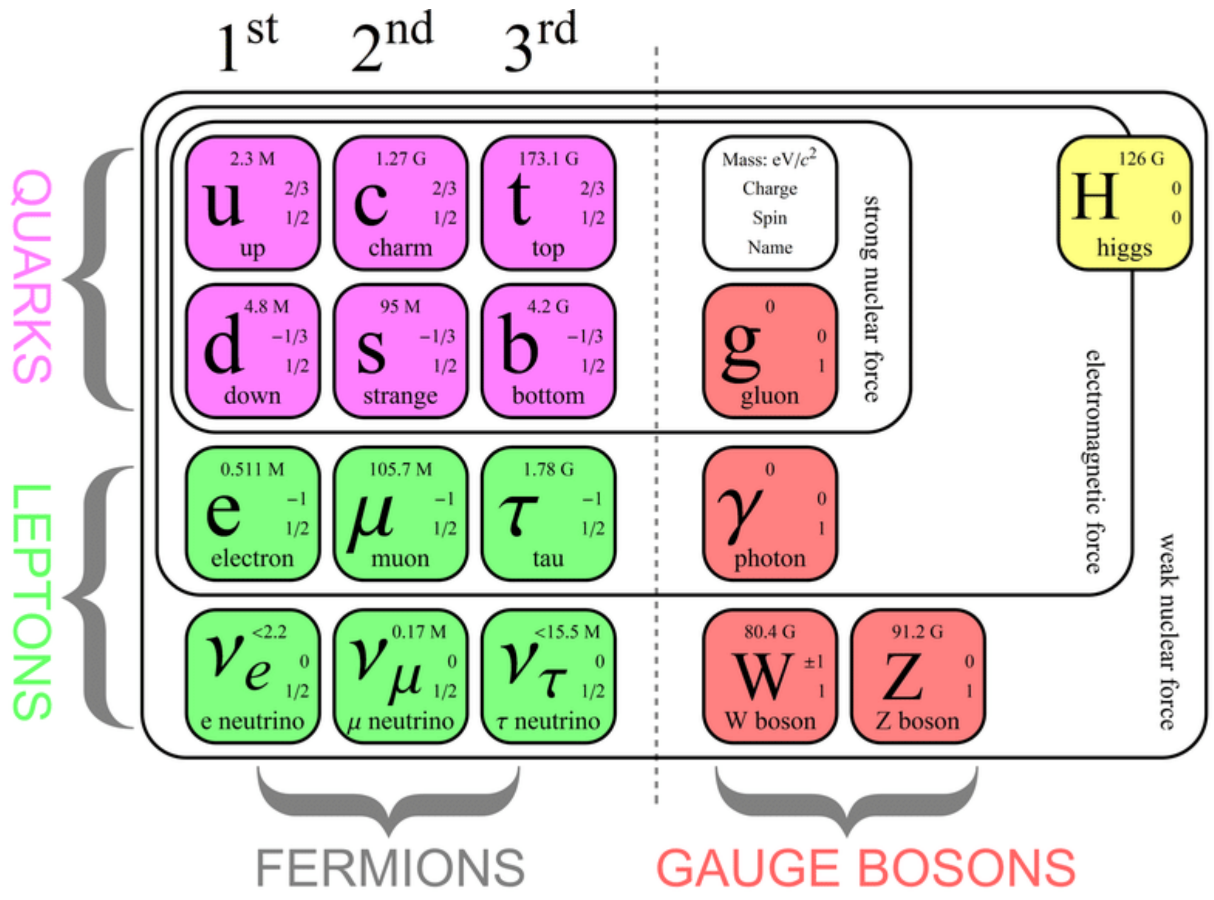
Conseil Européen pour la Recherche Nucléaire
University of Groningen
National Institute for Subatomic Physics

# Our playground: the Standard Model

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

- Bosons (interactions):
  - Strong, Weak, Electromagnetic forces have identical coupling constants to the generations of fermions

  - Higgs field introduces distinction among the generations of fermions



# Lepton Flavour Universality (LFU)

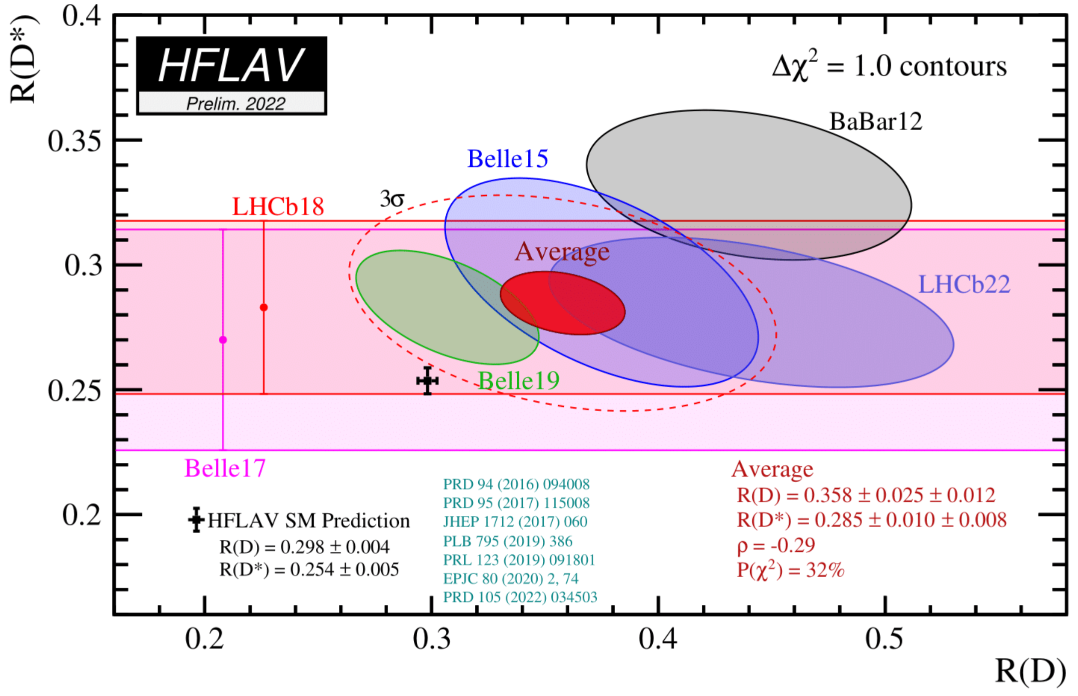
- Standard Model couplings of leptons to vector bosons are flavour-independent


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

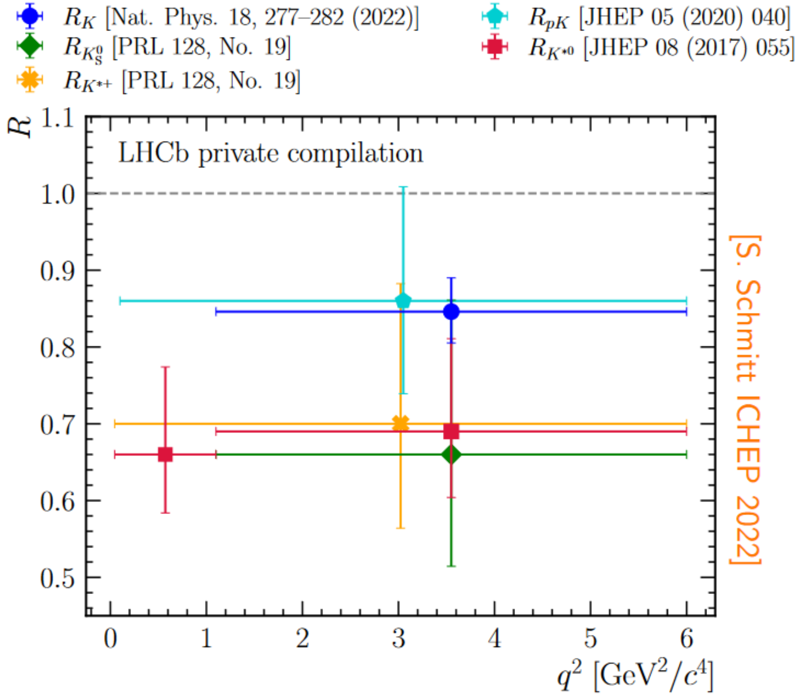
- Experimentally measured as Ratio: counting μ/e decays

# Anomalies in LFU tests at LHCb

## $b \to c \ell \nu$ decays:



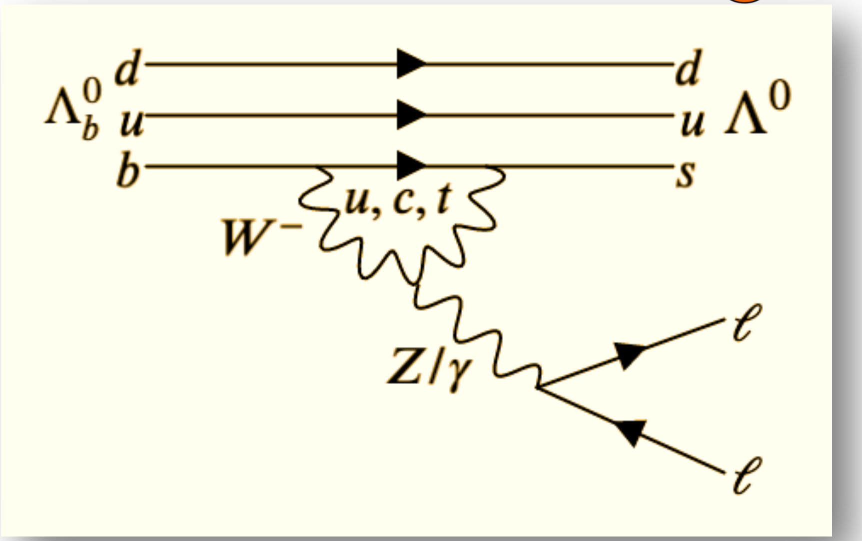

## $b \to s \ell \ell$ decays:




[S. Schmitt ICHEP 2022]

# b→sℓℓ 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




A rare decay that is sensitive to new physics effects.

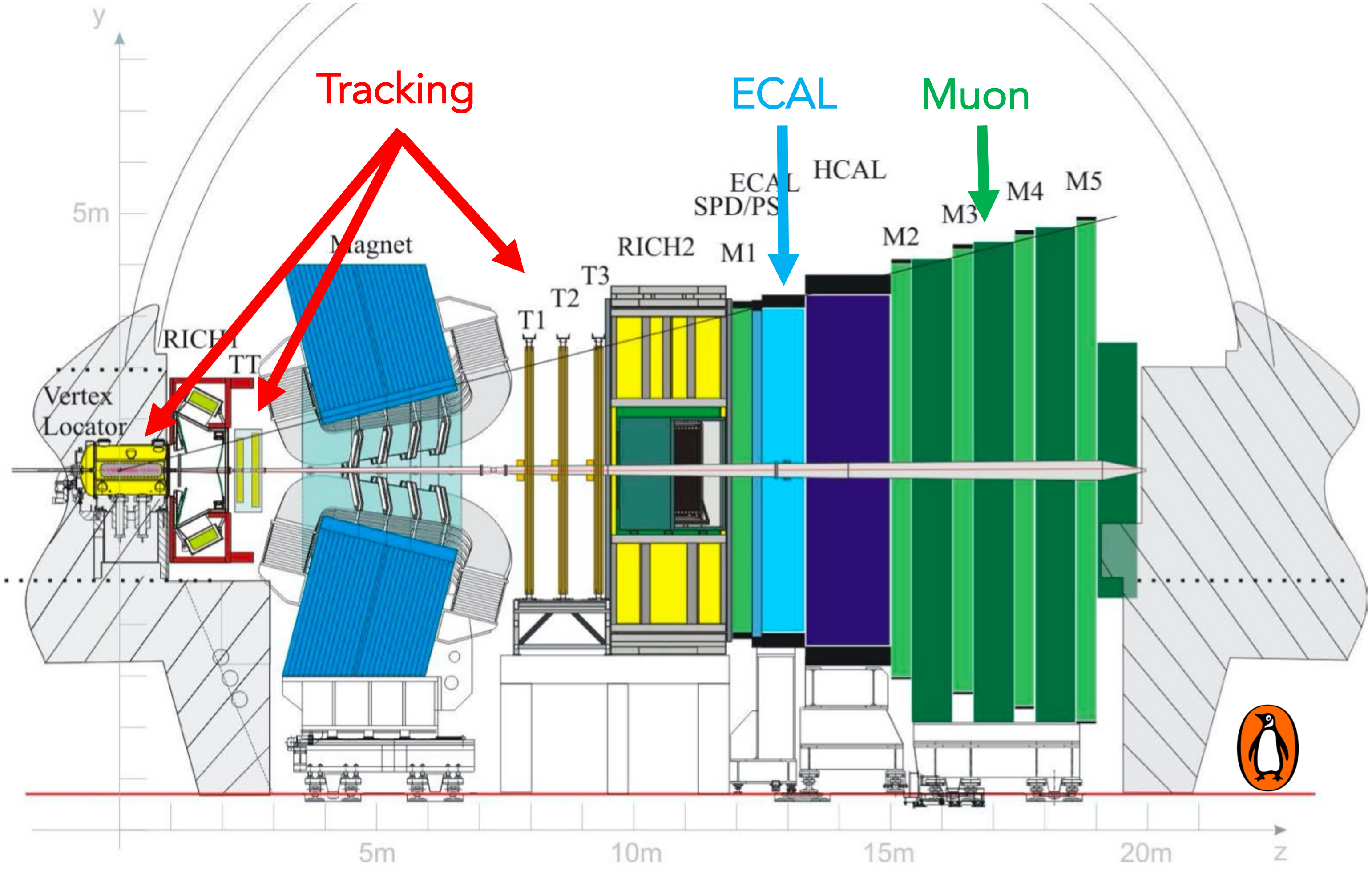
# Motivation for using $\Lambda_b^0$ decays

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

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

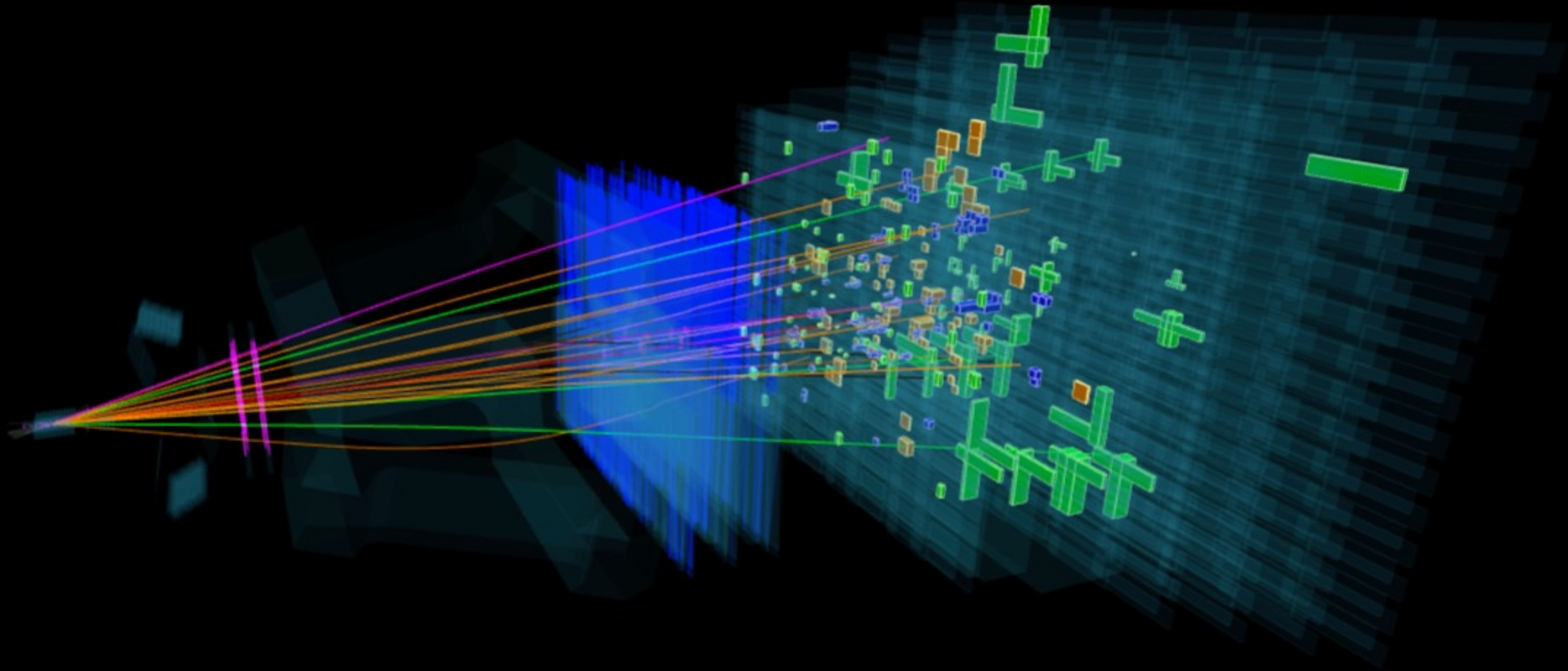
1 in SM!

# ~~The LHCb detector~~ ☠️ 2018



LHCb

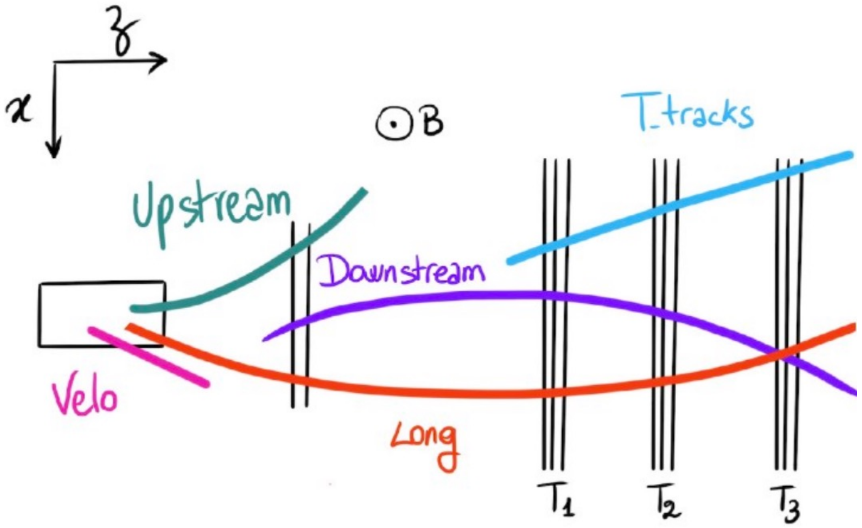
Event 291000117
Run 116803
Mon, 28 May 2012 07:23:28



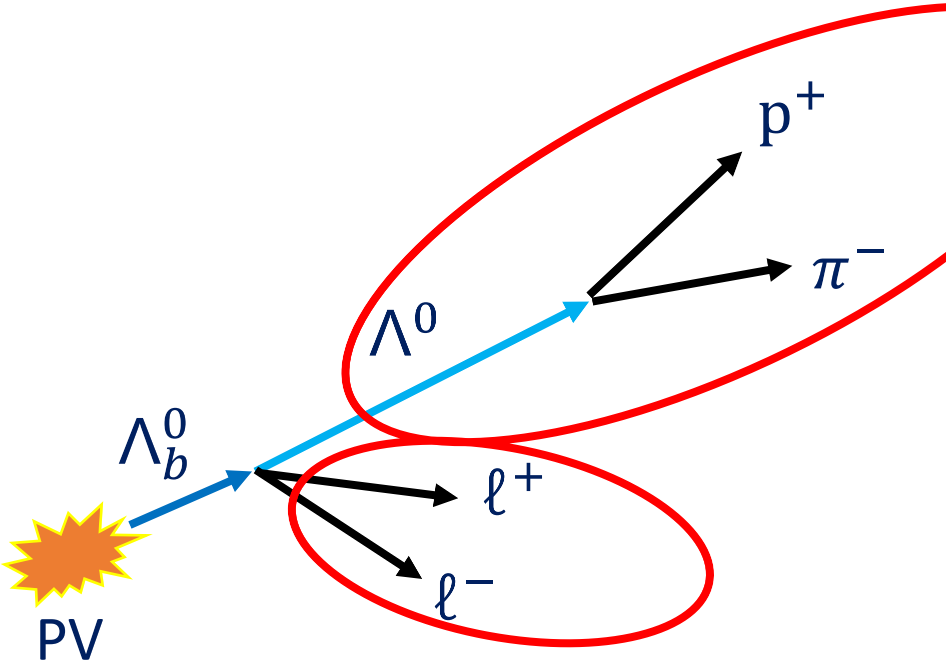
# Event reconstruction

decay length ≈ 1 m     ($\gamma$=15-25)

- $\Lambda$ 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: $J/\psi$ and $\psi(2S)$



# Samples

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

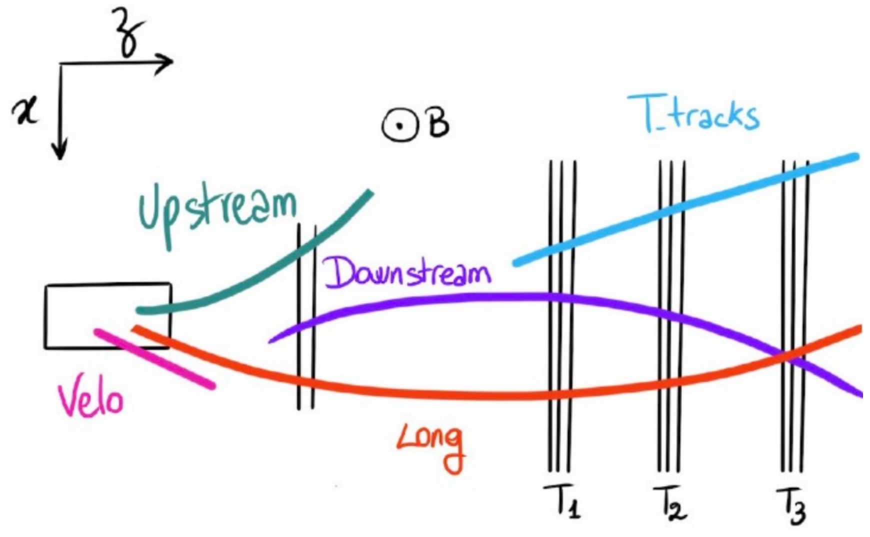
- Cross-checks via resonances:

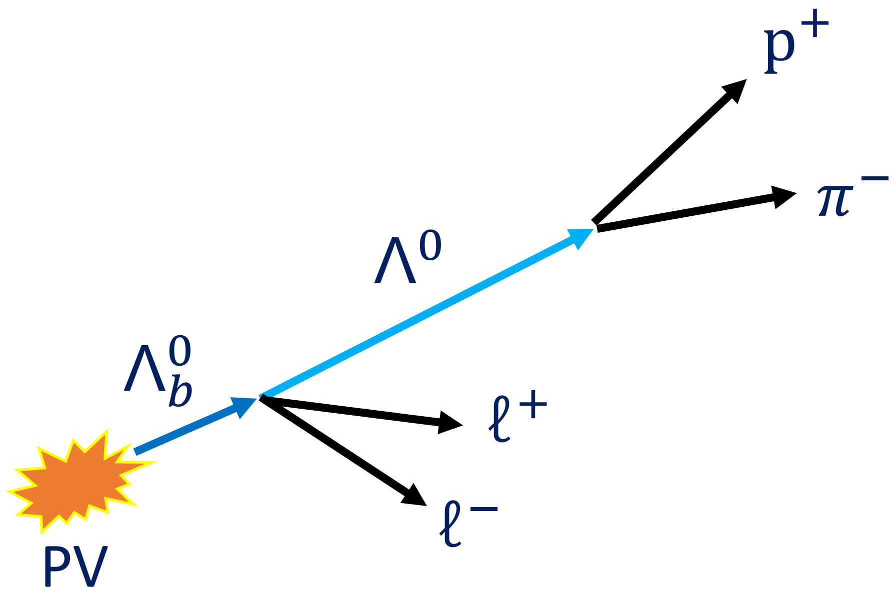
  $\Lambda_b^0 \to \Lambda J/\psi(\to\mu^+\mu^-)$ and $\Lambda_b^0 \to \Lambda\psi(2s)(\to\mu^+\mu^-)$

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

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

- Split over periods: LHC Run1, Run2



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

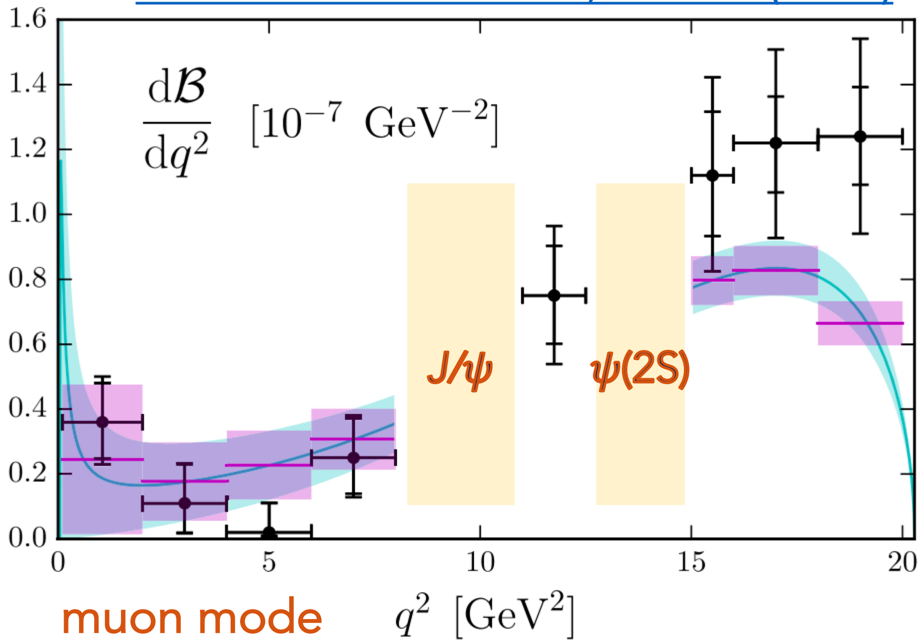
- Lepton pair created:
  - ➢ Dilepton invariant mass ($q^2$) measured
  - ➢ Incl. two resonances: $J/\psi$ and $\psi(2S)$

- Muon mode has been measured before

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

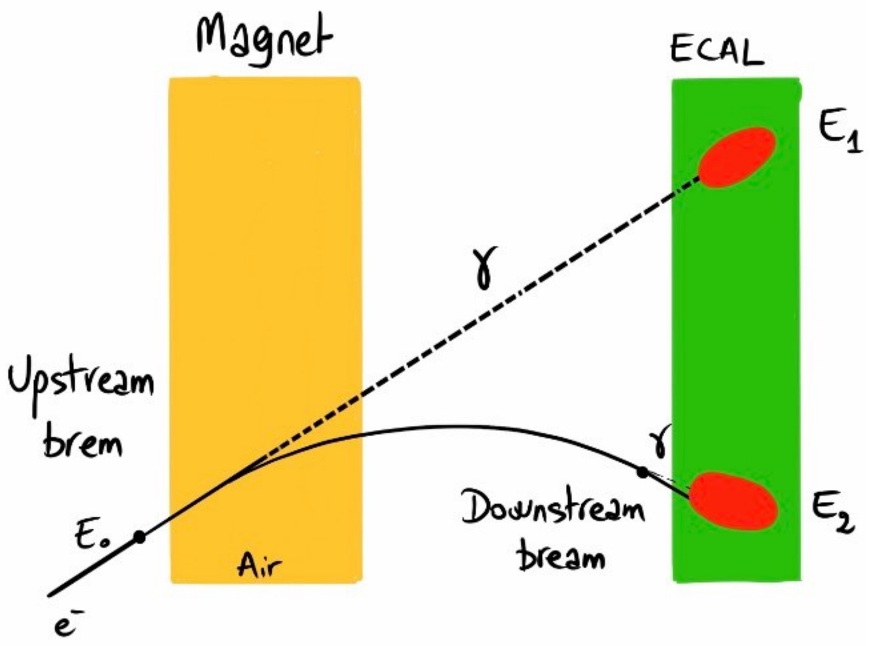
- Most signal expected at high $q^2$

PHYSICAL REVIEW D 93, 074501 (2016)



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

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



# Lepton Flavour Universality in $\Lambda_b$ 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 different detector signatures
  - -double ratio cancels most of these systematic uncertainties

# Cross-checks: J/$\psi$ and $\psi$(2S)

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

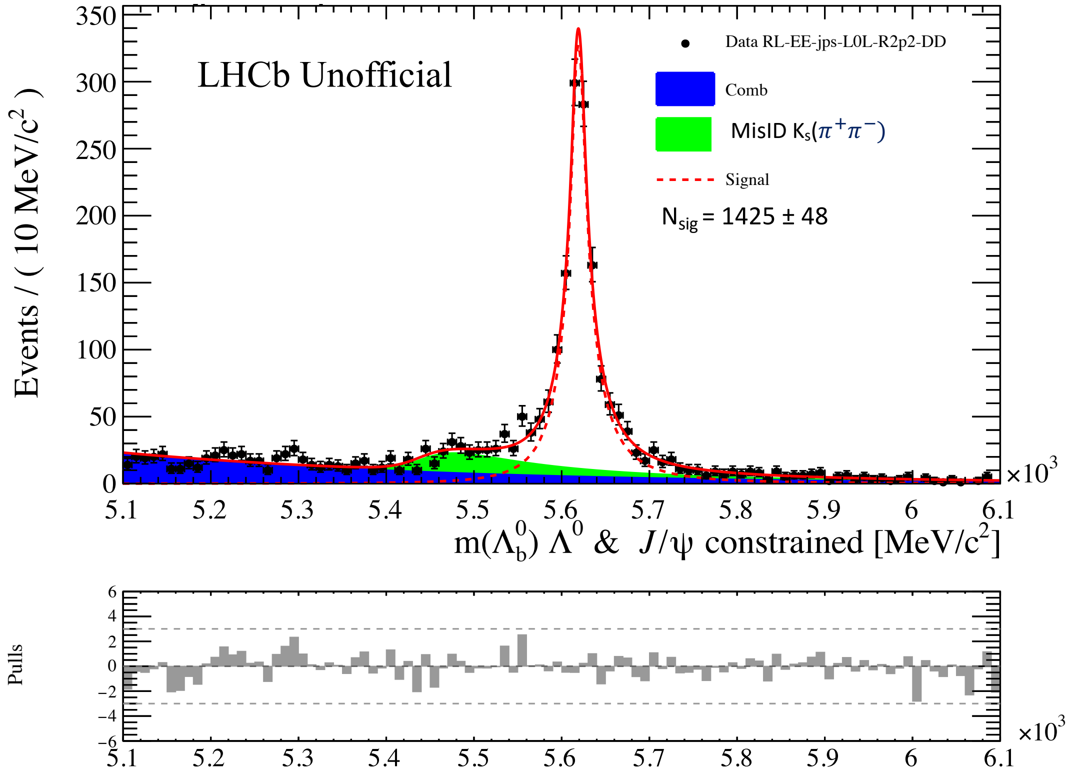
$$r_{J/\psi} = \frac{\mathscr{B}(\Lambda_b^0 \to \Lambda J/\psi(\to \mu^+\mu^-))}{\mathscr{B}(\Lambda_b^0 \to \Lambda J/\psi(\to e^+e^-))} = 1$$

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

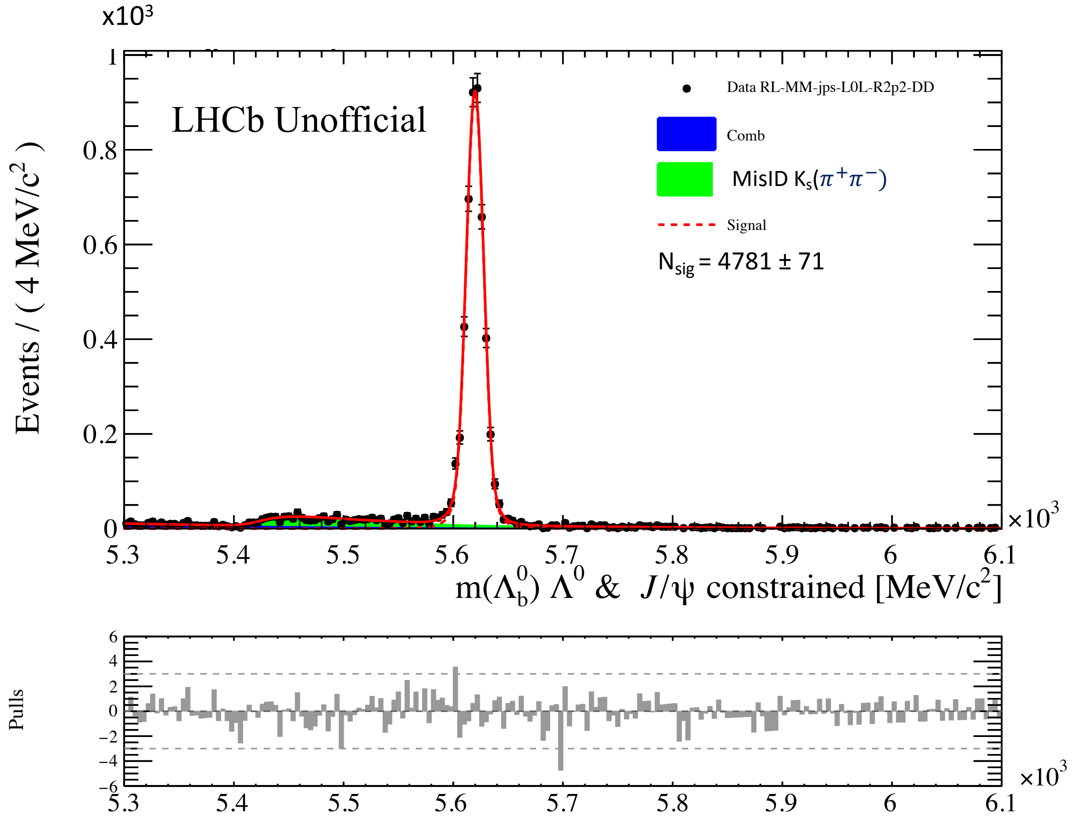
  2. double ratio $R_{\psi(2s)}$:

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

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

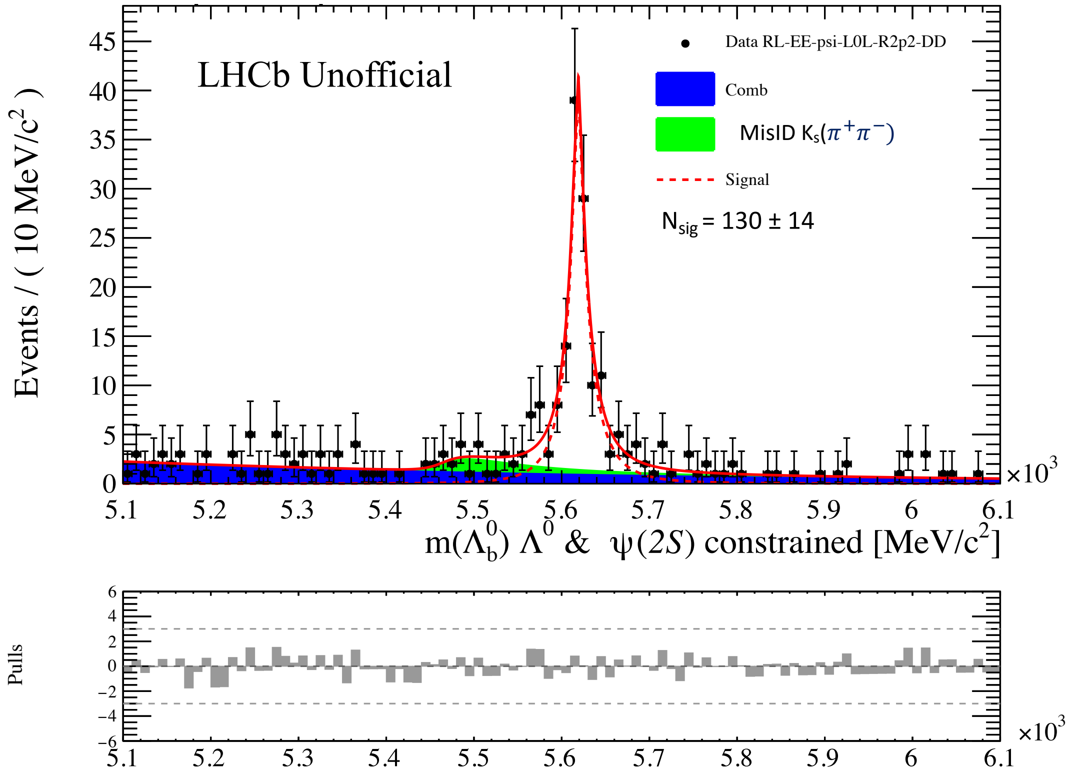



electron mode: $\Lambda_b^0 \rightarrow \Lambda J/\psi(\rightarrow e^+ e^-)$

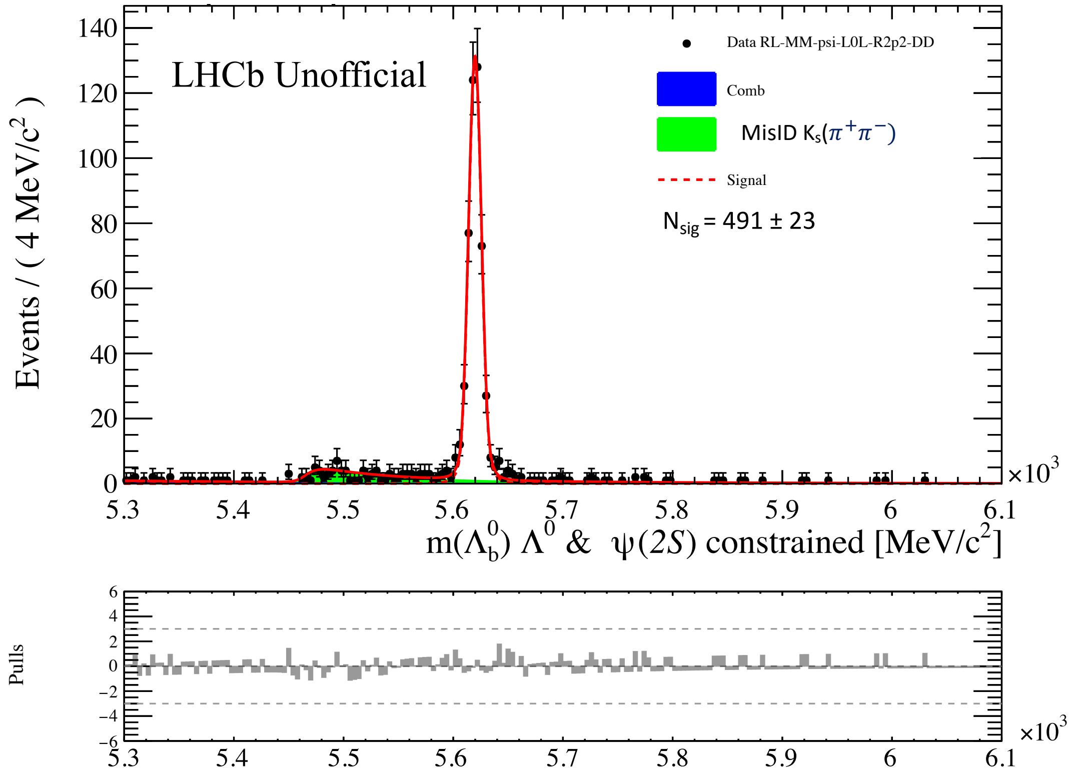



muon mode: $\Lambda_b^0 \rightarrow \Lambda J/\psi(\rightarrow \mu^+ \mu^-)$

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




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



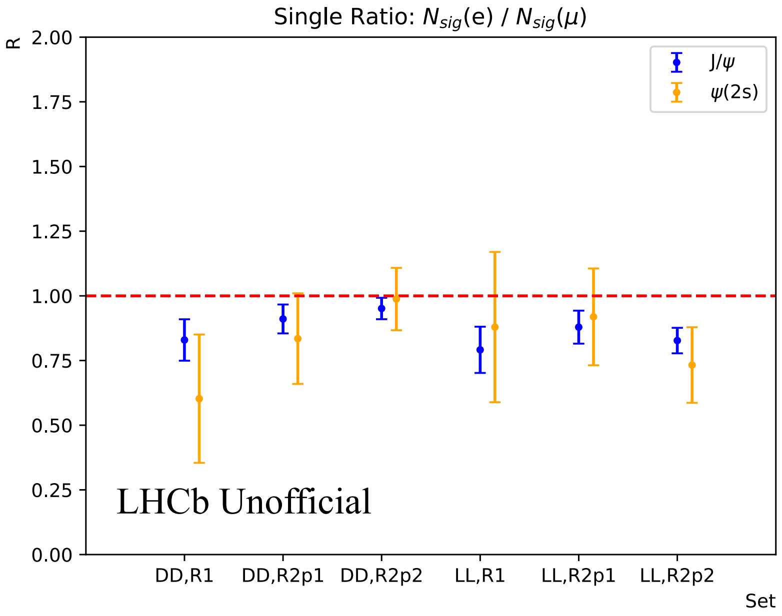

muon mode: $\Lambda_b^0 \to \Lambda\psi(2S)(\to \mu^+\mu^-)$

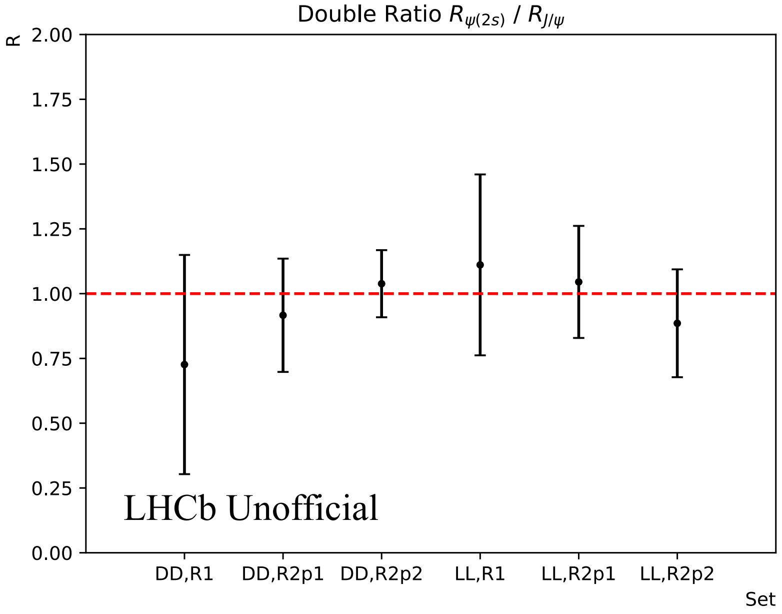
# Ratio plots

- Single ratios
- Double ratio is a powerful method:

  → systematic biases cancel

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



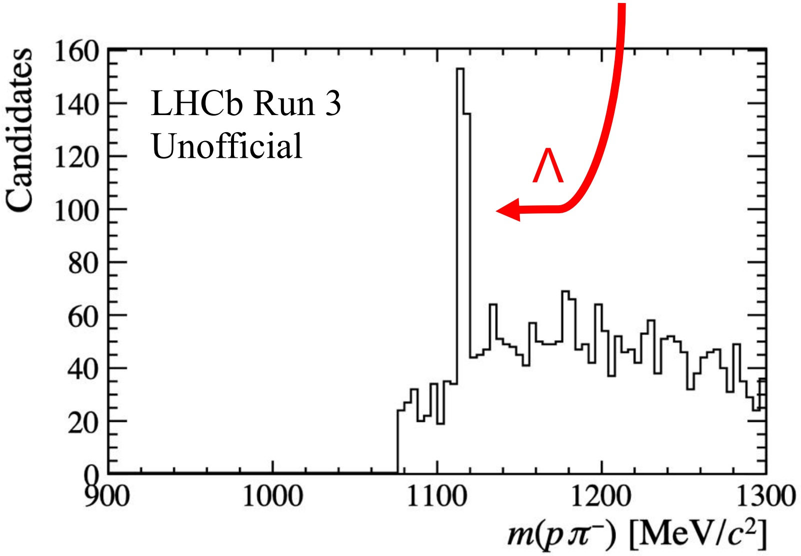



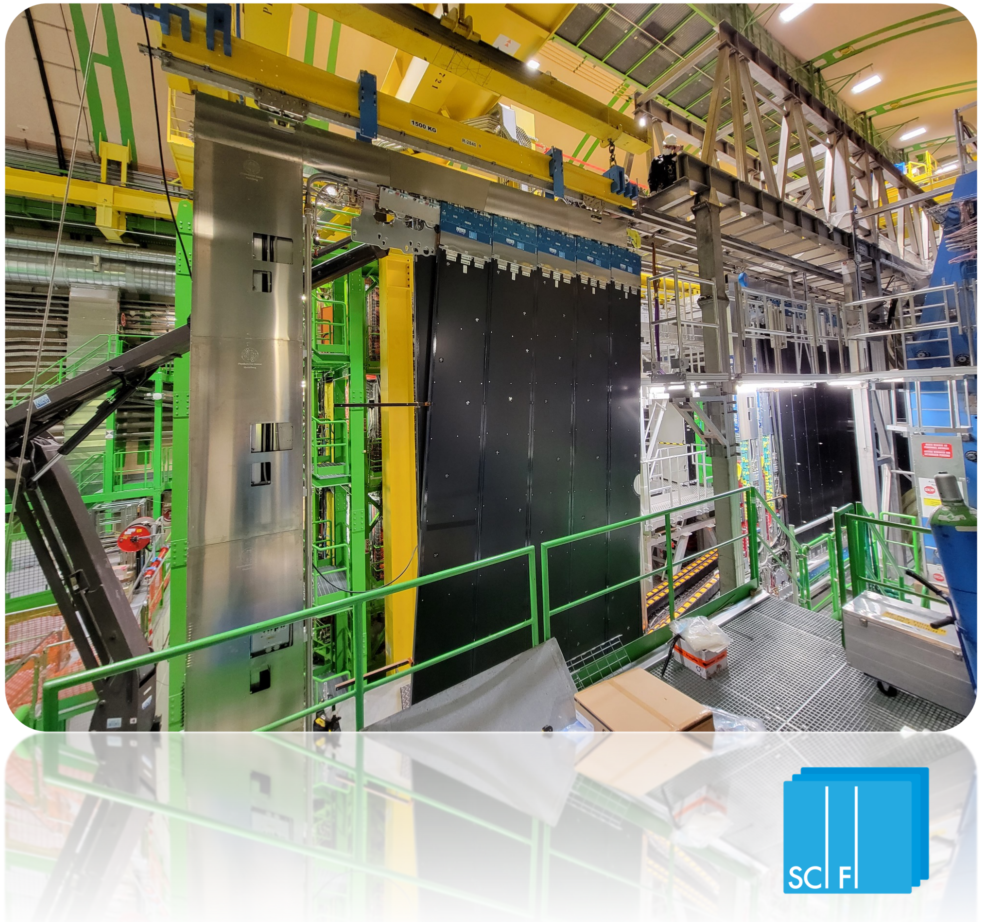
# Final remarks

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

Bright future ahead for the experiment:

- Brand new LHCb detector installed!
- First $\Lambda$ events in Run 3 data!!



# Thank you for listening! Questions?