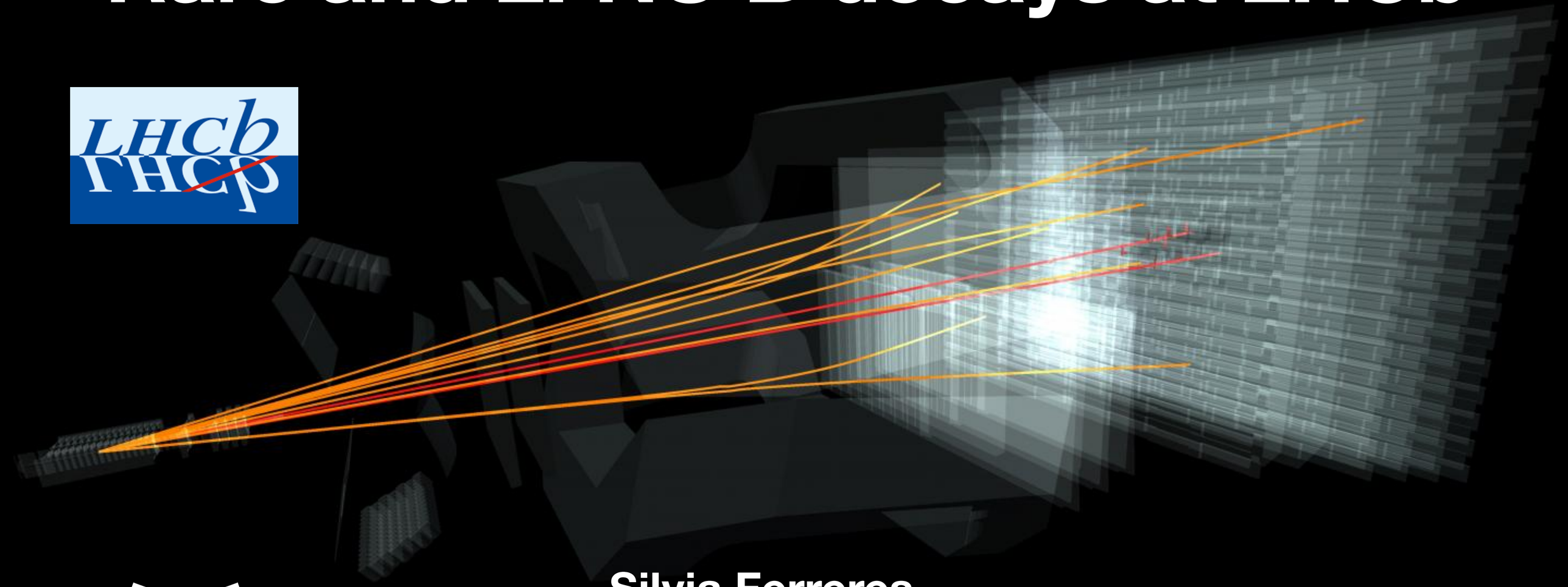
Rare and LFNU B decays at LHCb



Silvia Ferreres
on behalf of the LHCb Collaboration

Nikhef

Maastricht University

LHCb detector

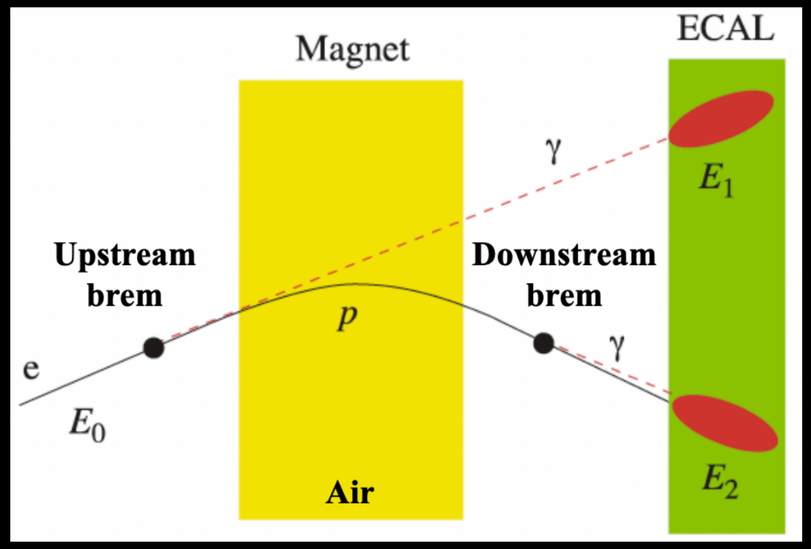
FORWARD SPECTROMETER

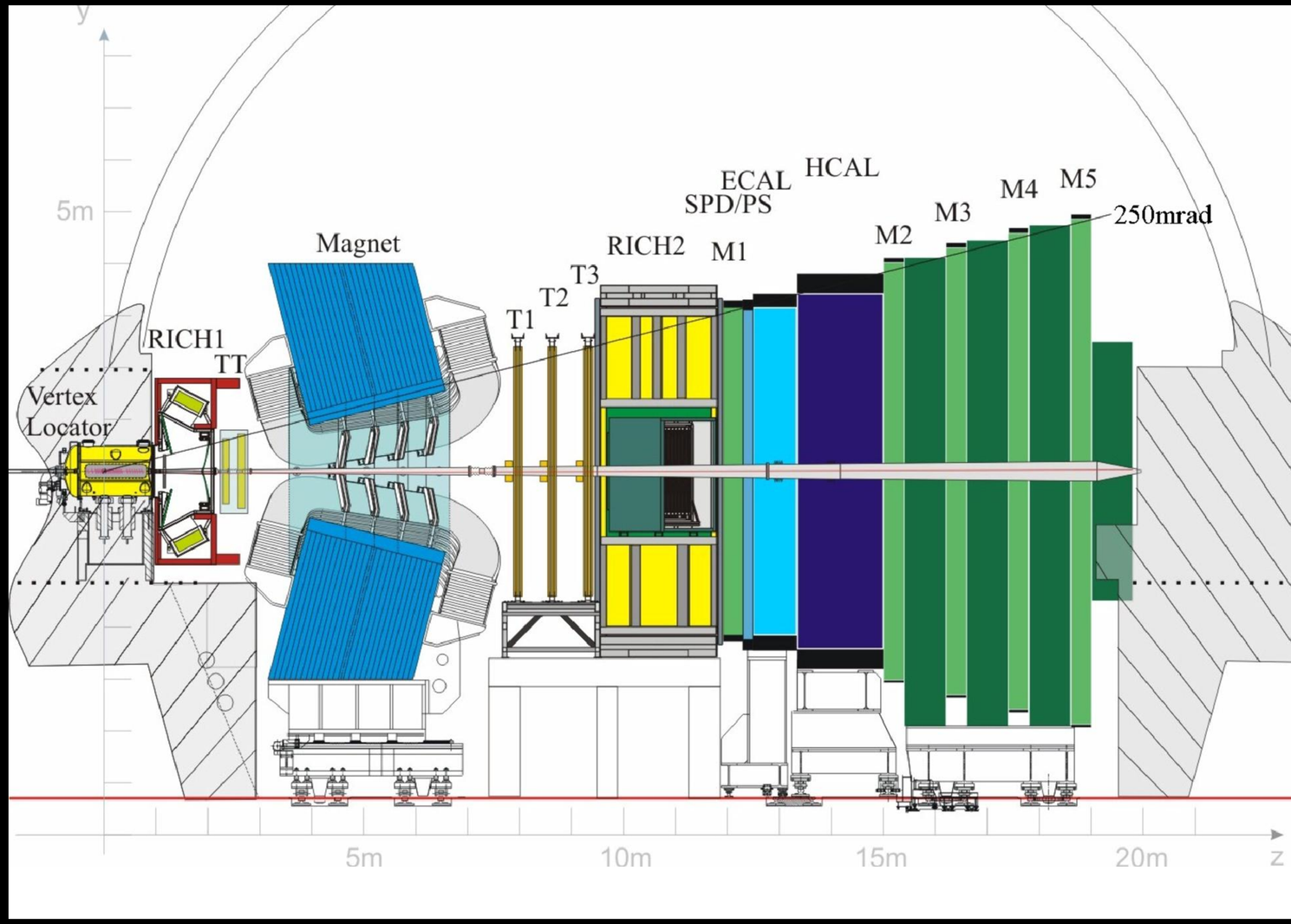
PRODUCTION OF B-HADRONS IN pp COLLISIONS

RUN 1 AND RUN 2 → 9 FB^{-1} INTEGRATED LUMINOSITY

TRIGGERING AND RECONSTRUCTING:

- GOOD AND EASY FOR MUONS
- DIFFICULT FOR ELECTRONS → BREMSSTRAHLUNG

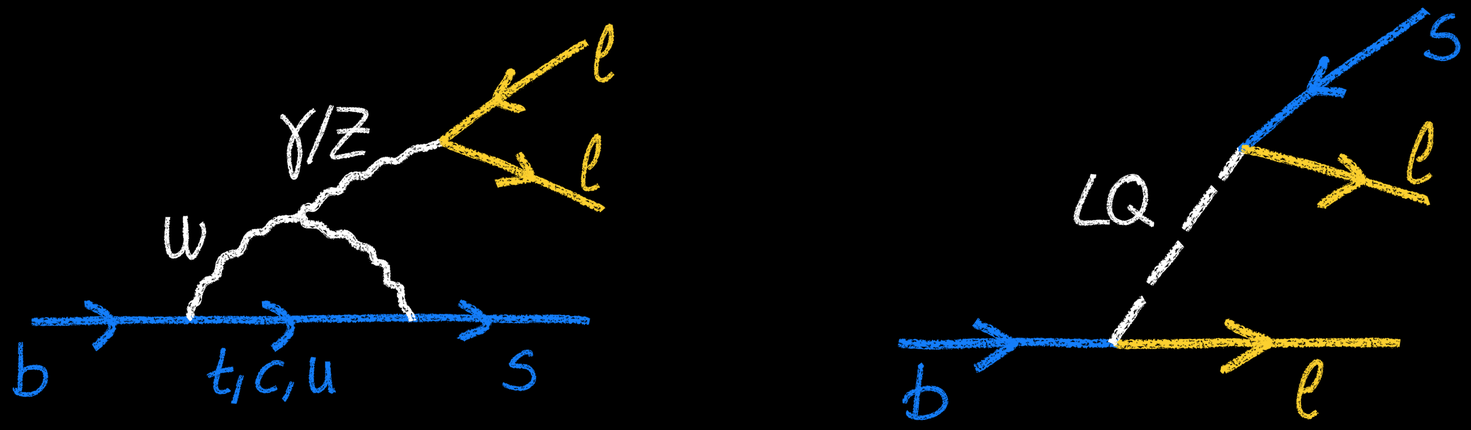




Rare decays

RARE DECAYS: ELECTROWEAK DECAYS WITH LOW BF OR FORBIDDEN IN SM

STUDY OF THE $b \to s\ell\ell$ TRANSITION



VERY SUPPRESSED IN THE SM:

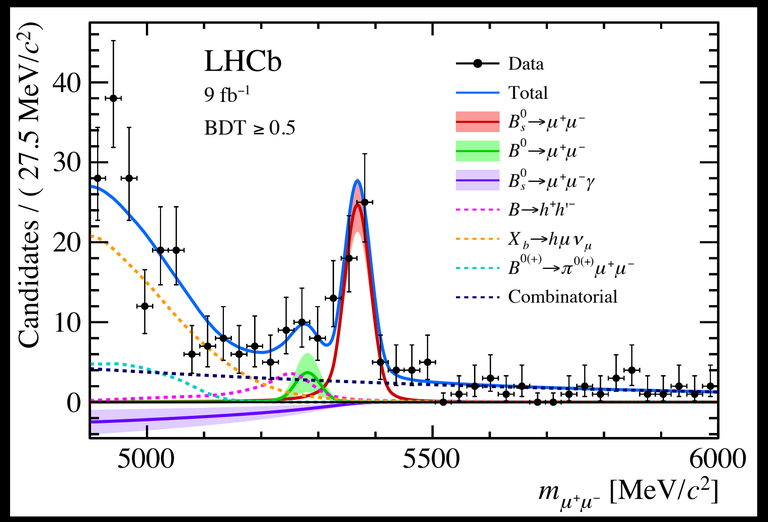
THEORETICALLY VERY CLEAN (QCD UNCERTAINTIES CANCEL)

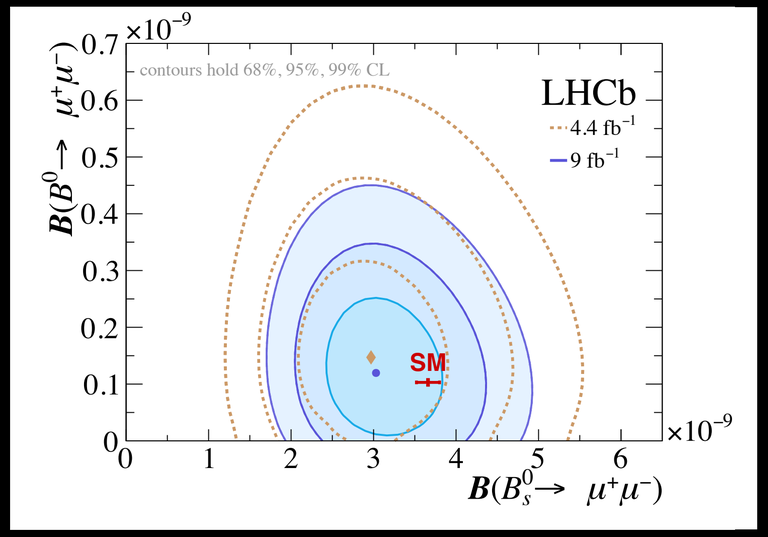
VERY SENSITIVE TO NEW PHYSICS

PRD105 (2022) 012010
PRL128 (2022) 041801

$B^0_{(s)} \to \mu^+\mu^-(\gamma)$

Run1+Run2 datasets





- $\mu^+\mu^-$ CANDIDATES FORMING A GOOD, DISPLACED VERTEX
- SIGNAL FROM FIT TO $m_{\mu^+\mu^-}$ IN BINS OF A BDT CLASSIFIER

$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.09^{+0.46+0.15}_{-0.43-0.11}) \times 10^{-9}$

MOST PRECISE TO DATE
IN AGREEMENT WITH SM

$\mathcal{B}(B^0 \to \mu^+\mu^-) < 2.6 \times 10^{-10}$ at 95% CL

TIGHTER UPPER LIMIT
AFFECTED BY $B \to h^+h'^-$

$\mathcal{B}(B^0_s \to \mu^+\mu^-\gamma)_{m_{\mu\mu}>4.9\ \text{GeV}/c^2} < 2.0 \times 10^{-9}$ at 95% CL

ONLY ISR INCLUDED
FIRST LIMIT EVER SET

PRD105 (2022) 012010
PRL128 (2022) 041801

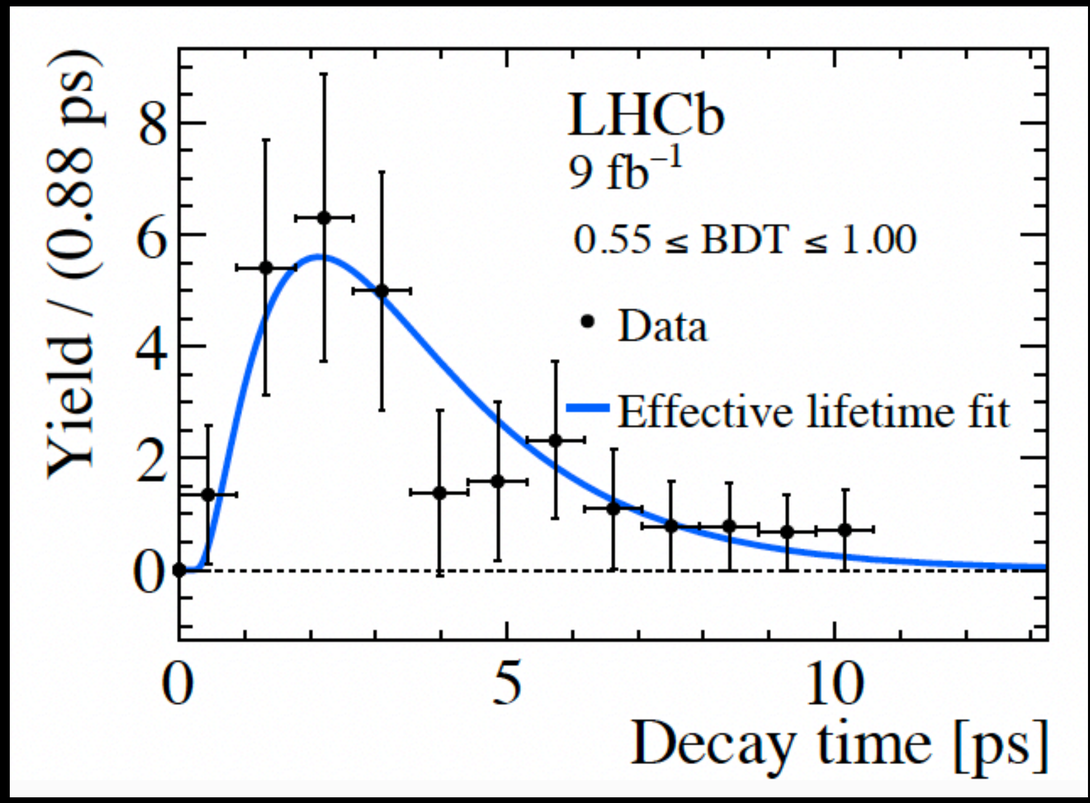
$B^0_{(s)} \to \mu^+\mu^-(\gamma)$

Run1+Run2 datasets

* EFFECTIVE LIFETIME: AVERAGE DECAY TIME OF DECAY CANDIDATES IN EXPERIMENT

$$\tau_{\mu\mu} = (2.07 \pm 0.29 \pm 0.03)\ \text{ps}$$

CONSISTENT WITH HEAVY MASS EIGENSTATE (SM) → 1.5 σ



Lepton Flavour Universality

- In SM electroweak coupling is universal for all leptons
- Only differences from masses → phase space
- Tested in many different decays

$$R_H = \frac{\mathcal{B}(X_b \to H\mu^+\mu^-)}{\mathcal{B}(X_b \to He^+e^-)} \sim 1$$

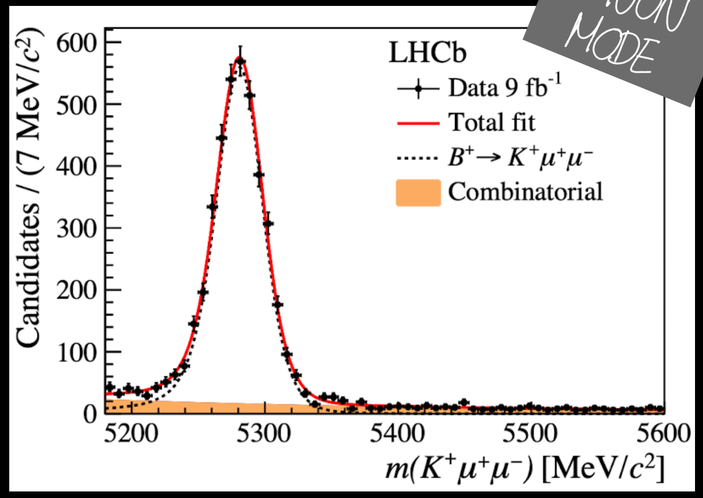
- Good way to search for new physics:
  - Some NP models do not have LFU
  - Well predicted → QCD uncertainties cancel

Nature Phys. 18 (2022) 3, 277-282

LFU: R_K

Run1+Run2 datasets

MUON MODE



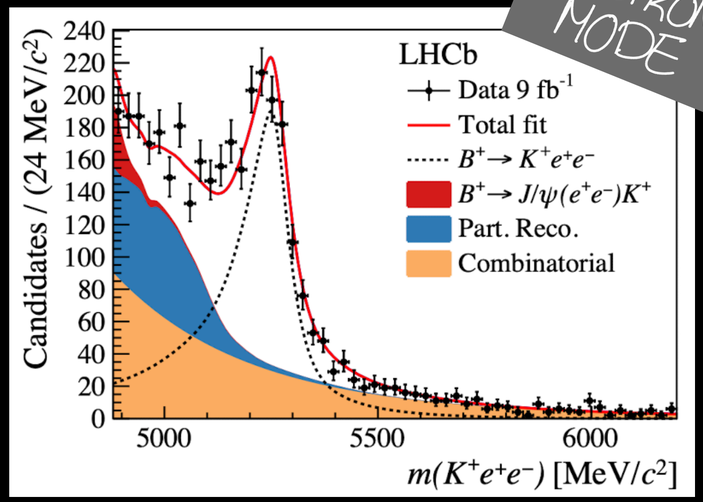
DOUBLE RATIO → CANCEL μ VS e DETECTION ASYMMETRIES

$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to J/\psi(\mu^+\mu^-)K^+)} \times \frac{\mathcal{B}(B^+ \to J/\psi(e^+e^-)K^+)}{\mathcal{B}(B^+ \to K^+e^+e^-)}$$

FOR RARE MODE ONLY $1.1 < q^2_{ll} < 6\ \text{GeV}^2/c^4$

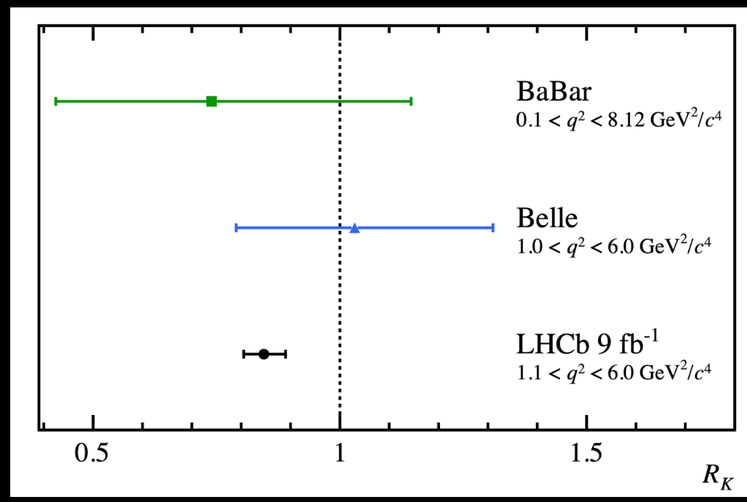
EFFICIENCIES VALIDATED WITH J/ψ RATIO → CONSISTENT WITH UNITY

ELECTRON MODE



$$R_K = 0.846\ ^{+0.042\ +0.013}_{-0.039\ -0.012}$$

TENSIONS WITH SM → 3.1σ

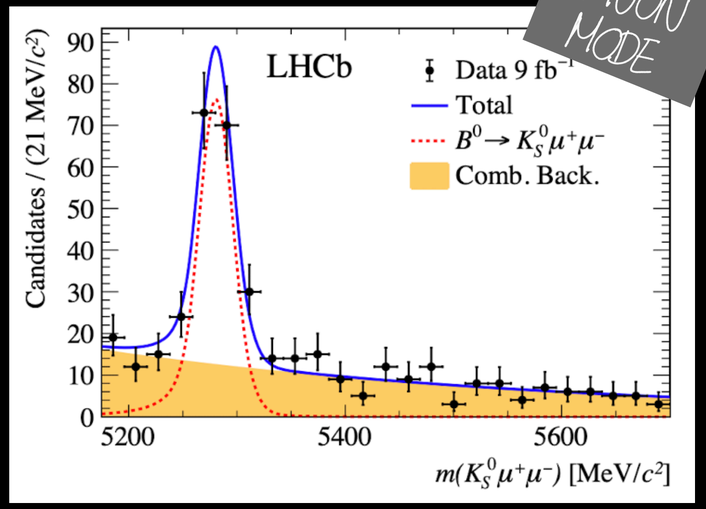


arXiv 2110.09501

LFU: $R_{K_S^0}$

Run1+Run2 datasets

MUON MODE

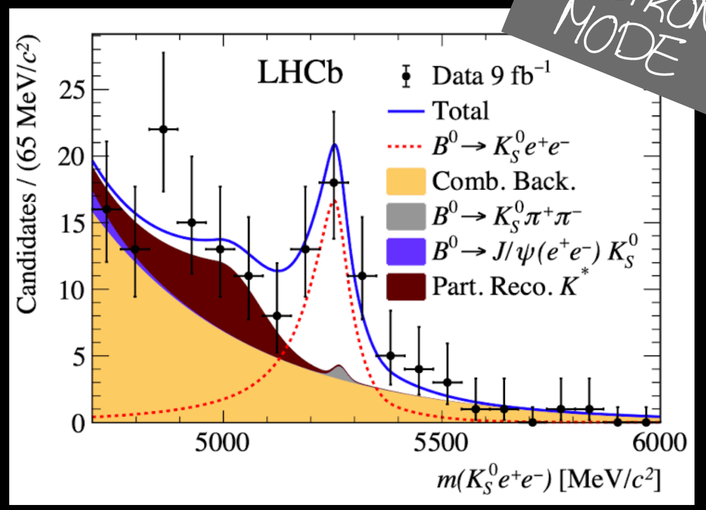


- ISOSPIN PARTNER. INVERSE DOUBLE RATIO

$$R_{K_S^0}^{-1} = \left(\frac{\mathcal{B}(B^0 \to K_S^0 \mu^+\mu^-)}{\mathcal{B}(B^0 \to J/\psi(\mu^+\mu^-)K_S^0)} \times \frac{\mathcal{B}(B^0 \to J/\psi(e^+e^-)K_S^0)}{\mathcal{B}(B^0 \to K_S^0 e^+e^-)} \right)^{-1}$$

FOR RARE MODE ONLY $1.1 < q^2_{ll} < 6\ \text{GeV}^2/c^4$

ELECTRON MODE



- K_S^0 RECONSTRUCTED AS $K_S^0 \to \pi^+\pi^-$ → LESS PRECISE

$$R_{K_S^0}^{-1} = 1.51^{+0.40+0.09}_{-0.35-0.04}$$

$$R_{K_S^0} = 0.66^{+0.20+0.02}_{-0.14-0.04}$$

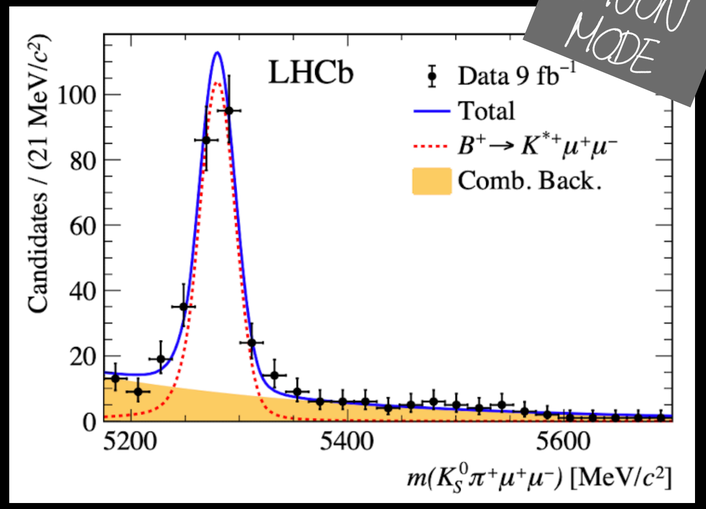
AGREES WITH SM → 1.5σ

arXiv 2110.09501

Run1+Run2 datasets

LFU: $R_{K^{*+}}$

MUON MODE

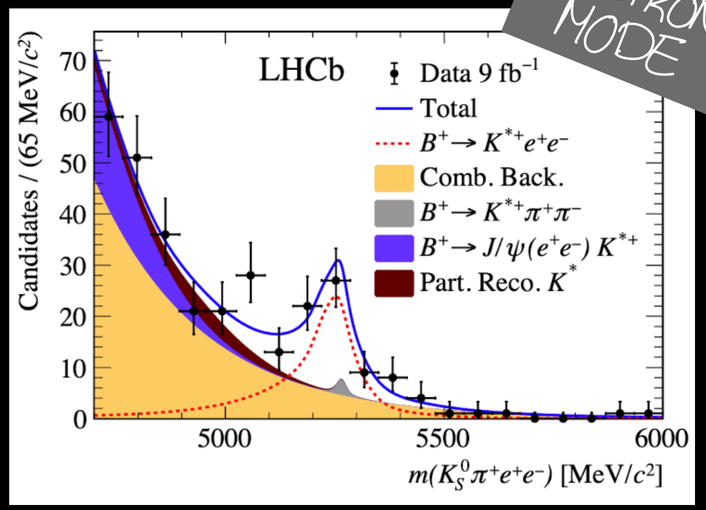


AND ALSO $B^+ \to K^{*+}\ell^+\ell^-$ WITH INVERSE DOUBLE RATIO

$$R^{-1}_{K^{*+}} = \left(\frac{\mathcal{B}(B^+ \to K^{*+}\mu^+\mu^-)}{\mathcal{B}(B^+ \to J/\psi(\mu^+\mu^-)K^{*+})} \times \frac{\mathcal{B}(B^+ \to J/\psi(e^+e^-)K^{*+})}{\mathcal{B}(B^+ \to K^{*+}e^+e^-)} \right)^{-1}$$

FOR RARE MODE ONLY $0.045 < q^2_{ll} < 6\ \text{GeV}^2/c^4$

ELECTRON MODE



K^{*+} RECONSTRUCTED AS $K^{*+} \to K^0_S\pi^+$

$$R^{-1}_{K^{*+}} = 1.44^{+0.32+0.09}_{-0.29-0.06}$$

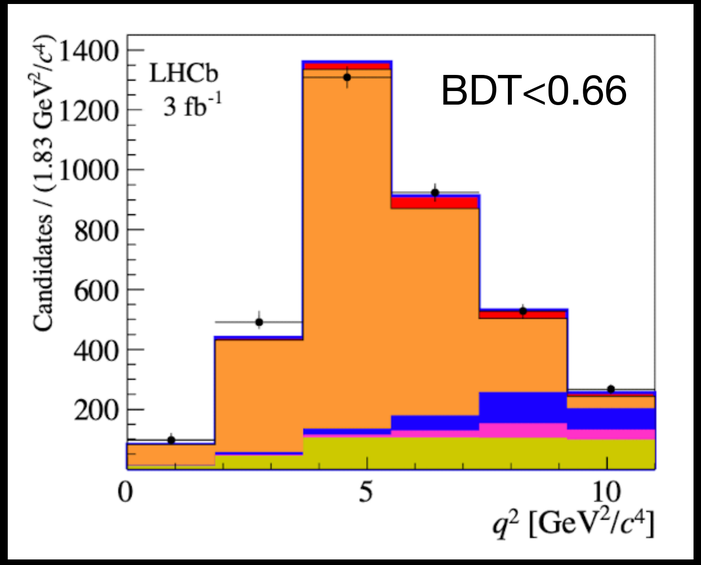
$$R_{K^{*+}} = 0.70^{+0.18+0.03}_{-0.13-0.04}$$

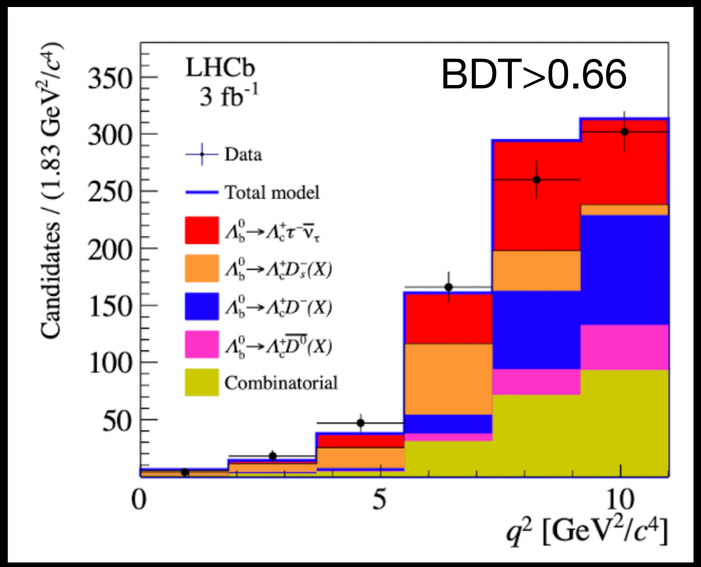
AGREES WITH SM $\to 1.4\sigma$

arXiv: 2201.03497

$\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau$ and $R_{\Lambda_c^+}$

Run1 datasets





COMPLEMENTARY: SPIN 1/2 AND DIFFERENT FORM-FACTORS

DECAY $\Lambda_b \to \Lambda_c^+ \tau^- \bar{\nu}_\tau$ WITH $\tau^- \to \pi^-\pi^+\pi^-(\pi^0)\nu_\tau$ AND $\Lambda_c^+ \to pK^-\pi^+$

3-D FIT TO BDT, PSEUDO DECAY-TIME OF τ AND q^2

USING DELPHI VALUE FOR $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \mu\nu) = 6.2 \pm 1.4\,\%$

$$R_{\Lambda_c^+} = 0.242 \pm 0.026\,(\text{stat}) \pm 0.040\,(\text{syst}) \pm 0.059\,(\text{ext BF})$$

POOR KNOWLEDGE OF BFs

Summary

- BRANCHING FRACTIONS AND LFU IN $b \to s\ell\ell$ TRANSITIONS
- R_K SHOWS TENSIONS WITH SM (3.1 σ)
- $R_{K_S^0}$ AND $R_{K^{*+}}$ ALSO SHOWING DEFICIT IN MUON MODE
- BARYONIC DECAYS LOOK PROMISING

STAY TUNED!

BACKUP

Displacement of the tau