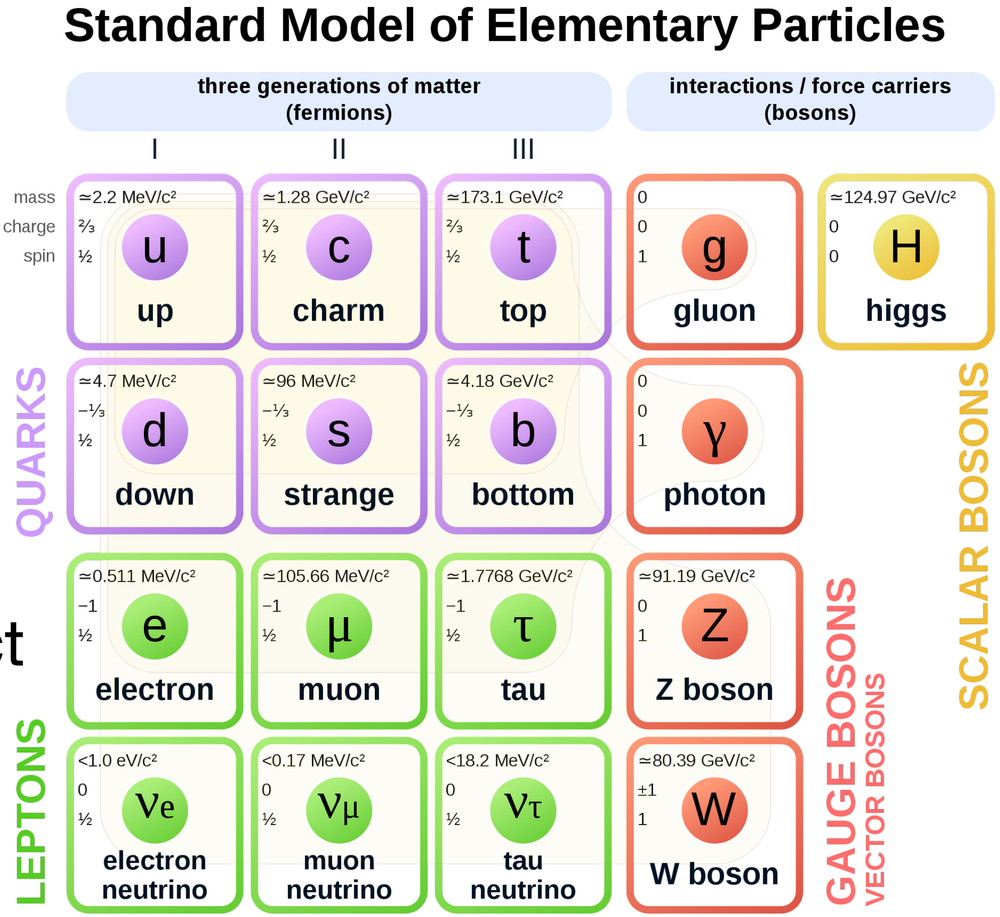
Lepton flavour and new physics

- Standard Model: leptons behave equally
- Recently, deviations between electrons, muons, tau are seen
  —> Lepton Flavour violation
  —> Lepton non-universality
- Explanation: LeptoQuarks?
- Challenge: electrons are difficult to reconstruct (Bremsstrahlung)



The LHCb detector

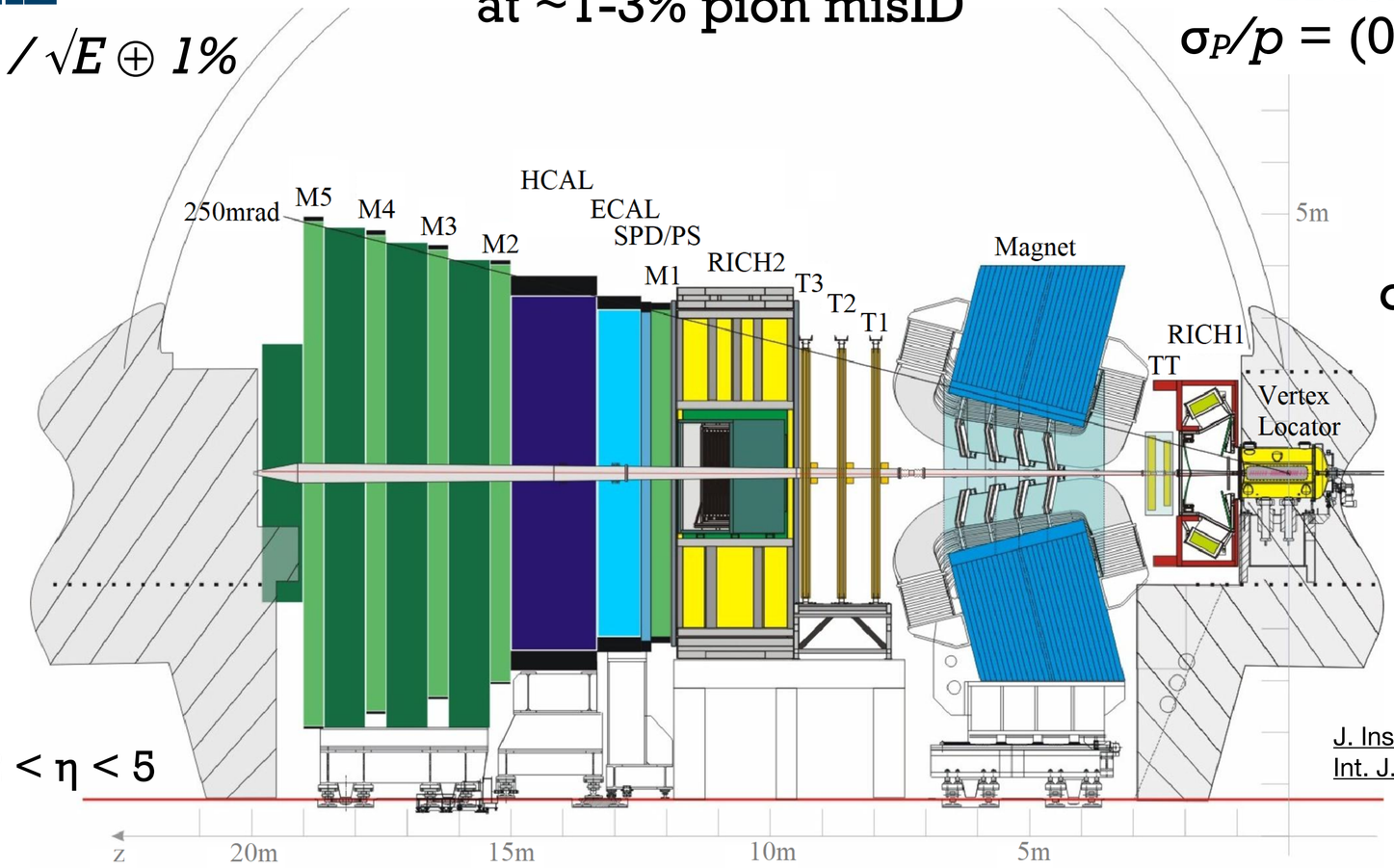
Particle ID
~97% lepton ID rate
at ~1-3% pion misID

ECAL
$\sigma_E/E \sim 10\% / \sqrt{E} \oplus 1\%$

Tracking
$\sigma_P/p = (0.4\text{-}0.6)\%$

MUON
trigger eff. > 90%
for $p_T > 5$ *GeV/c²*

VELO
$\sigma_{IP} = (15 + 29/p_T)\ \mu m$



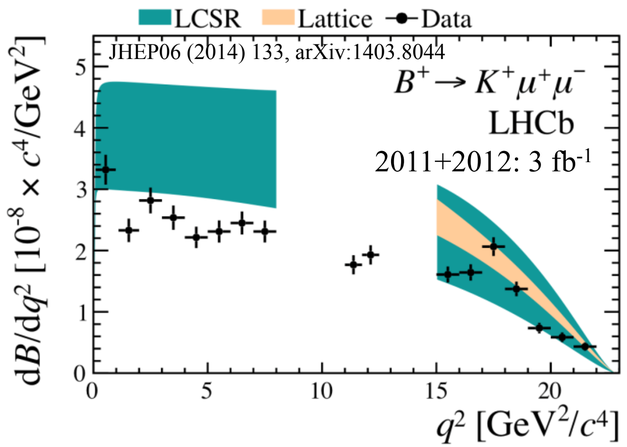
Acceptance $2 < \eta < 5$

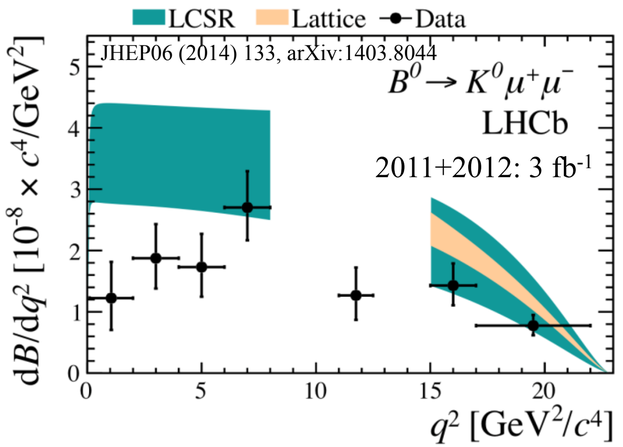
J. Instrum. 3 (2008) S08005
Int. J. Mod. Phys. A 30 (2015) 1530022

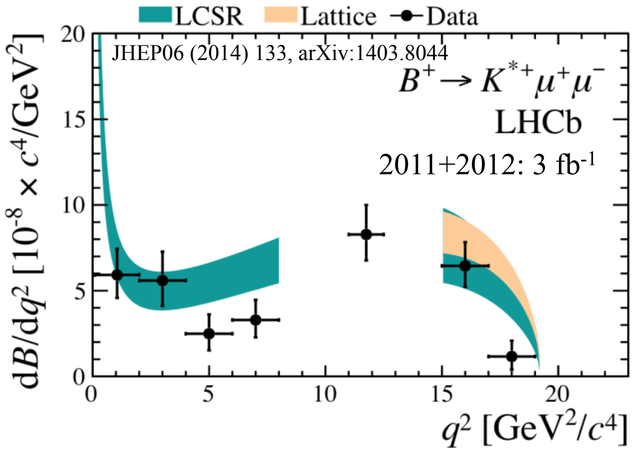
A wealth of results

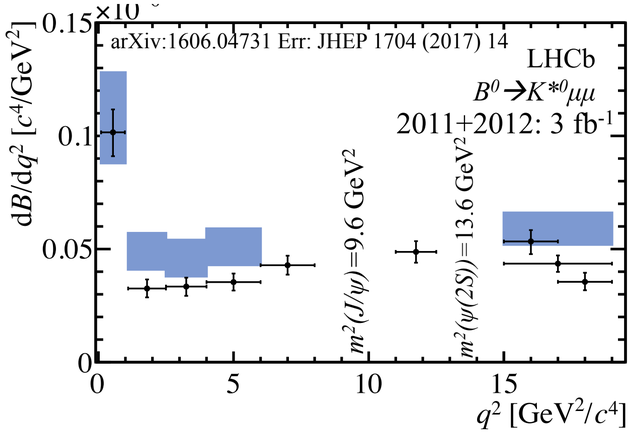
- Large amount of LHCb rare decays publications
- Decay rates are consistently low
- Should we get excited?

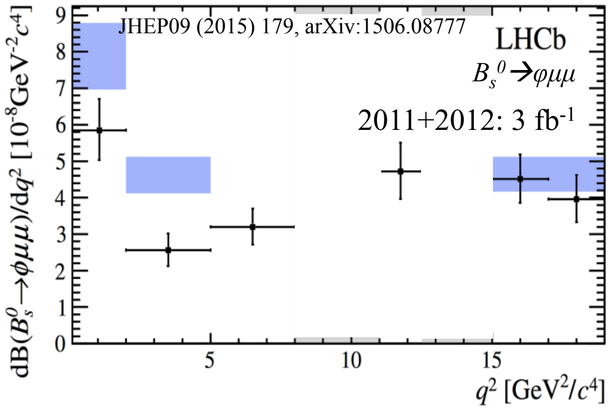
Niels Tuning, Nikhef Seminar, 8 May 2020

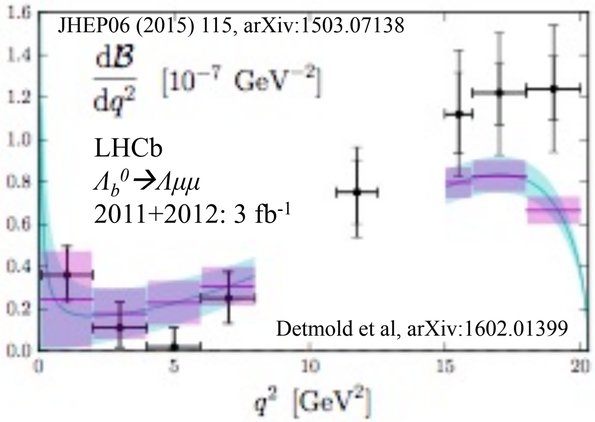












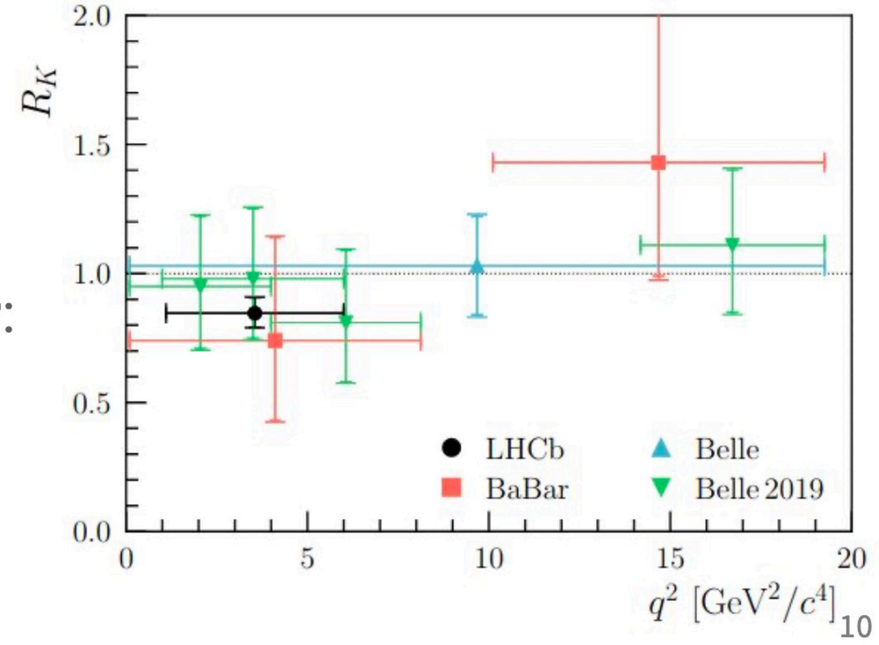
R(K)

[PRL 122 (2019) 191801]

- $X = K^+ \Longrightarrow B^+ \rightarrow K^+ e^+ e^-$, $B^+ \rightarrow K^+ \mu^+ \mu^-$
- One region of q^2: central ($1.1 < q^2 < 6.0$ GeV$^2/c^4$)
- Run 1 data (2011 - 2012) + Run 2 data (2015 - 2016)
  - Twice as many B^+'s as the previous measurement [PRL 113, 151601]
- Various cross-checks performed:
  - $r_{J/\psi}$ is flat for a number of reconstructed variables.
  - $r_{J/\psi} = 1.014 \pm 0.035(\text{stat} + \text{syst})$
  - $R_K^{\Psi(2S)} = 0.986 \pm 0.013(\text{stat} + \text{syst})$

➢ R(K) compatible with the SM expectation at **2.5σ**:

$$R_K = 0.846^{+0.060+0.016}_{-0.054-0.014}$$

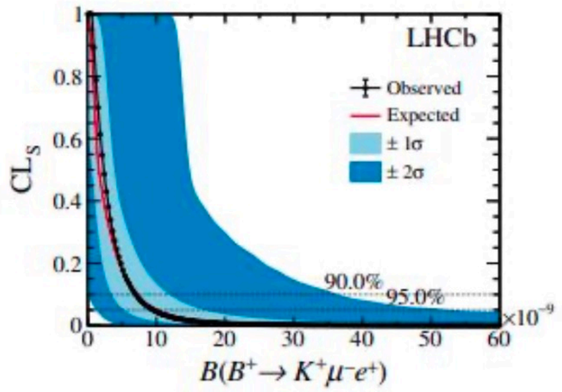


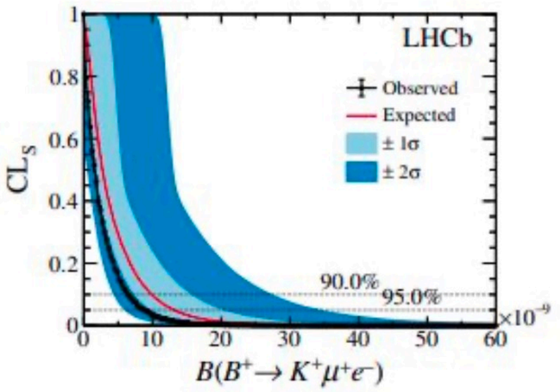
[PRD 86 (2012) 032012], [PRL 103 (2009) 171801], [arXiv:1908.01848]

$B^+ \to K^+ \mu^\pm e^\mp$ [PRL.123 (2019) 241802]

- Run 1 analysis, using $B^+ \to K^+ J/\psi(\to \mu^+\mu^-)$ as **normalization** & $B^+ \to K^+ J/\psi(\to e^+e^-)$ as **control** channels
  - Assumes a **uniform** distribution of signal events within the phase space
  - Most significant **background**: partially reconstructed B^+ decays (vetoed)
  - Two **BDTs** for combinatorial background & bkg from partially reconstructed b-hadron decays
- No signal excess found, upper limit @ 90% (95%) CL:

$$\mathcal{B}(B^+ \to K^+ \mu^- e^+) < 7.0(9.5) \times 10^{-9}$$
$$\mathcal{B}(B^+ \to K^+ \mu^+ e^-) < 6.4(8.8) \times 10^{-9}$$

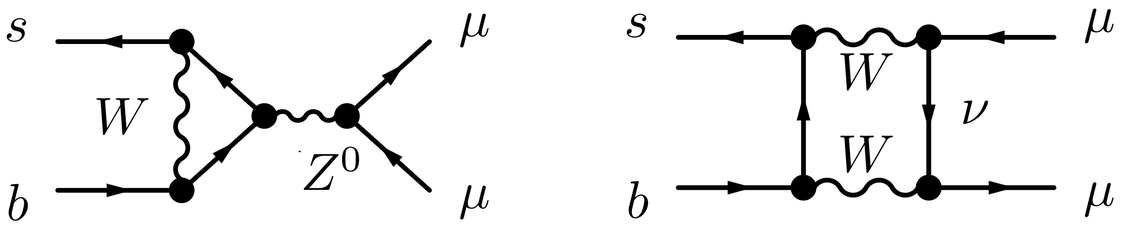




➢ 1 order of magnitude improvement

➢ Systematics dominated by simulation corrections

$B_{(s)} \rightarrow$ 2 leptons

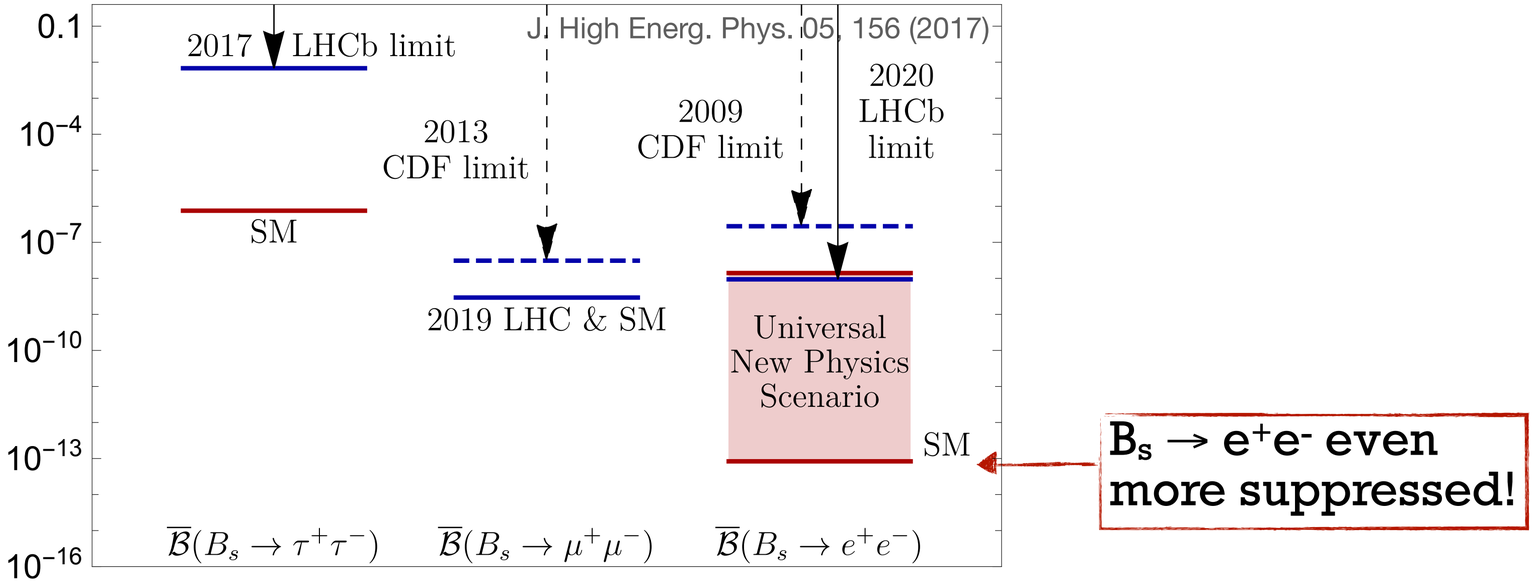


- b → sll transitions in two-body decays: extremely suppressed!

helicity suppression!

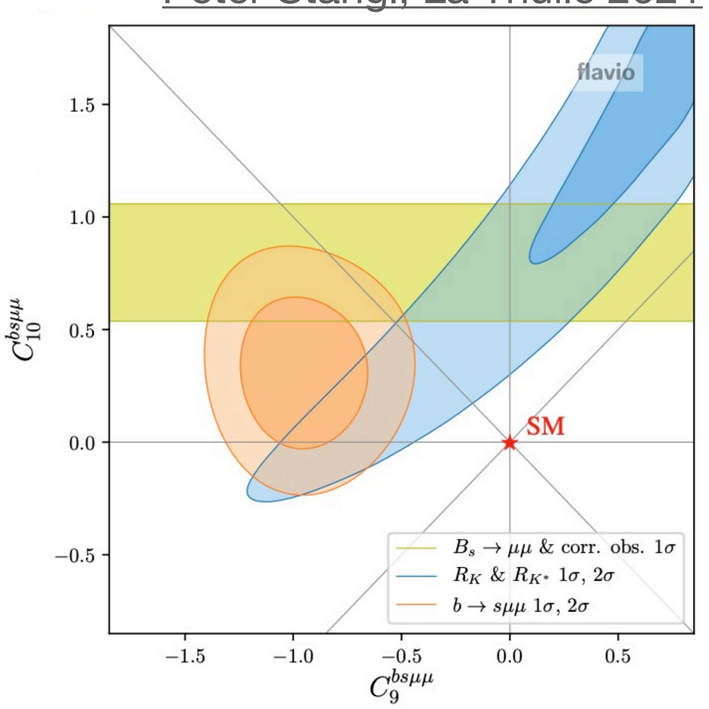
$$\mathcal{B} \propto |V_{tb}V_{tq}|^2 \left[(1 - \frac{4m_\mu^2}{M_B^2}) |C_S - C_S'|^2 + |(C_P - C_P') + \frac{2m_\mu}{M_B}(C_{10} - C_{10}')|^2 \right]$$

- Sensitive to (pseudo)scalar and axial vector (C_{10}) contributions



$B_s \rightarrow e^+e^-$ even more suppressed!

Peter Stangl, La Thuile 2021



B -> mu mu - latest results

- B-decays to two leptons are an ideal laboratory to search for new physics

- Full LHCb Run1+2 analysis of $B_{(s)} \to \mu^+\mu^-$ presented

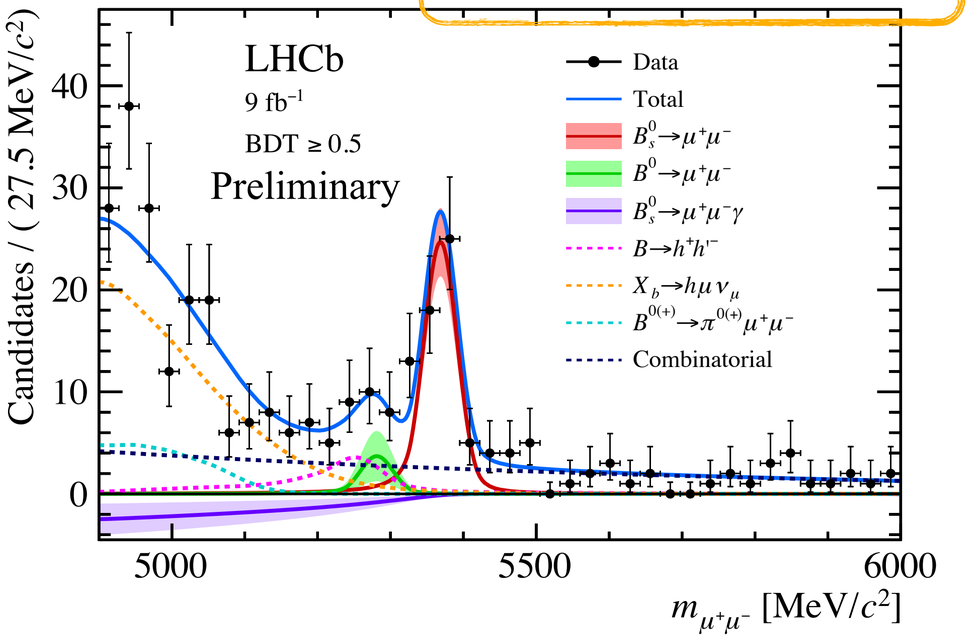
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(3.09\,^{+0.46}_{-0.43}\,^{+0.15}_{-0.11}\right) \times 10^{-9}$$

  - Strong limit on $B_d \to \mu^+\mu^-$
  - First search for $B_s \to \mu^+\mu^-\gamma$ (ISR)
  - Most precise measurement of $B_s \to \mu^+\mu^-$ effective lifetime

- Looking forward to CMS and Atlas full Run1+2 dataset results!

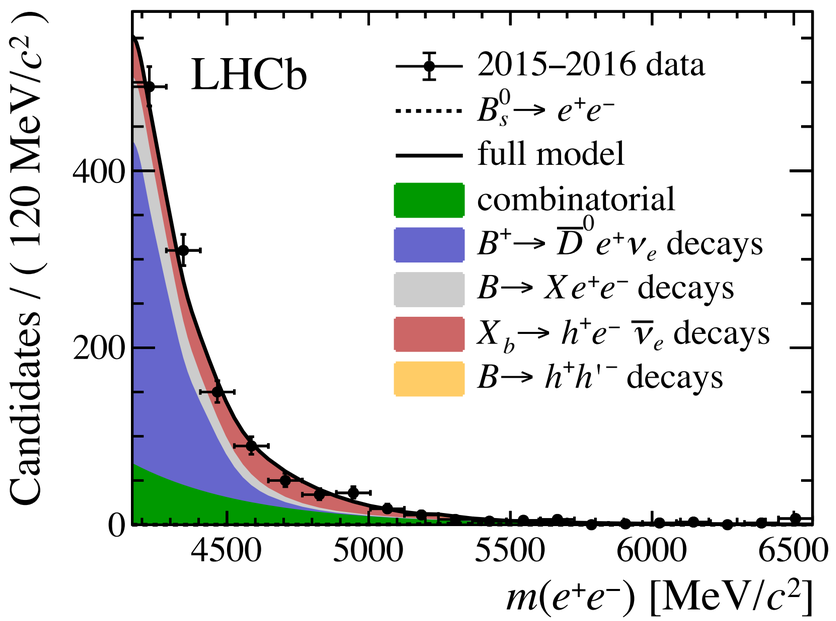
(in preparation)

LHCb-PAPER-2021-007
LHCb-PAPER-2021-008



$B_{(s)} \to e^+e^-$

Phys. Rev. Lett. 124, 211802 (2020)

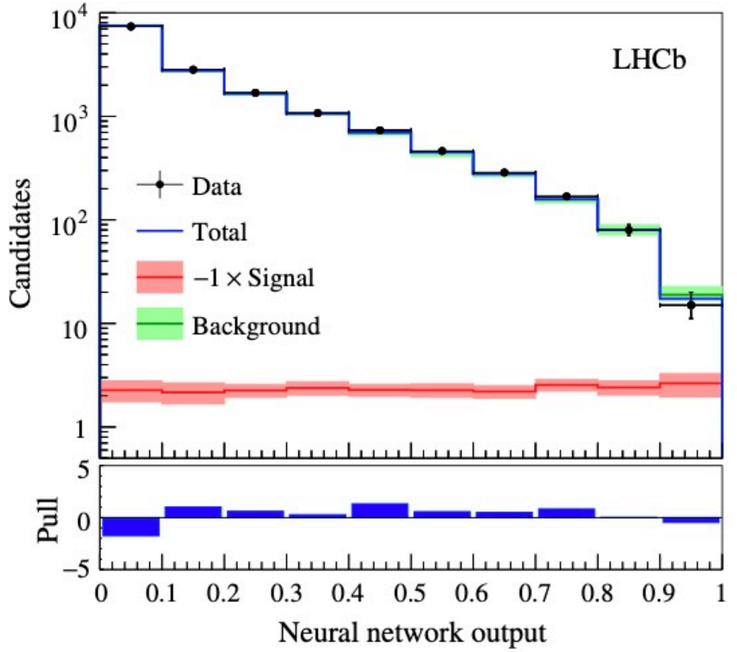


- 5.0 fb-1 dataset
- Main challenge: electron Bremsstrahlung

$$\mathcal{B}(B_s^0 \to e^+e^-) < 9.4\,(11.2) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to e^+e^-) < 2.5\,(3.0) \times 10^{-9}$$

$B_{(s)} \to \tau^+\tau^-$

Phys. Rev. Lett. 118, 251802 (2017)



- 3.0 fb-1 dataset
- Main challenge: Tau reconstruction (3π)

$$\mathcal{B}(B_s^0 \to \tau^+\tau^-) < 6.8 \times 10^{-3}$$
$$\mathcal{B}(B^0 \to \tau^+\tau^-) < 2.1 \times 10^{-3}$$

Combinations

Model independent fits to O(170) measurements

- C_9^{NP} deviates from 0 by > 4σ
- Many independent fits seem to favour C_9^{NP} = -1
- Vector Leptoquarks? Z'? —> Many models! (see e.g. talk by Geng CHEN, ICHEP 2018)