Rare heavy flavour decays

Standard Model at the LHC 2022

11- 14 April 2022 – CERN, Geneva

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Outline

- Search for $B^0_{(s)} \rightarrow \mu^+\mu^-$ decays   ATLAS   CMS   LHCb
  - + combination of results @LHC
  - + updated results from LHCb

- Search for $B^0_{(s)} \rightarrow e^+e^-$ and $B^0_{(s)} \rightarrow \tau^+\tau^-$ decays   LHCb

- Search for $B^0_{(s)} \rightarrow \mu^+\mu^-\mu^+\mu^-$ decays   LHCb

- Some of last results from direct LFV searches
  - $\tau \rightarrow 3\mu$ ATLAS   CMS   LHCb
  - $B^0_{(s)} \longrightarrow \tau\mu$ LHCb
  - $B^0_{(s)} \longrightarrow e\mu$ LHCb

Search for $B^0_{(s)} \to \mu\mu$ decays

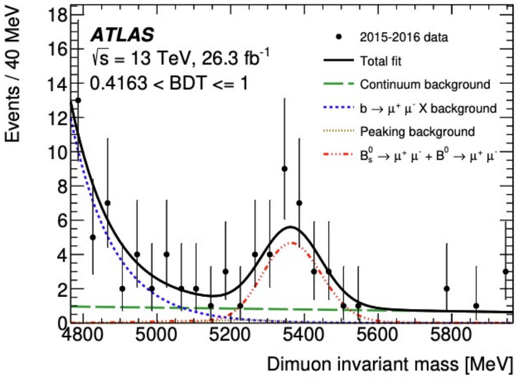
- Very rare in SM (only proceed via quantum-loop transitions)
- In addition, they are helicity and CKM suppressed

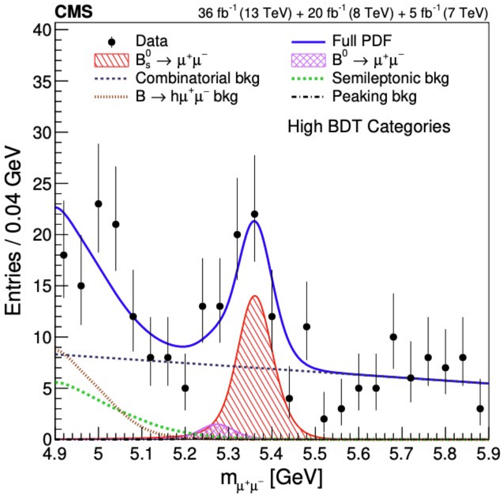
⇒ SM predictions of their time-integrated BR have small uncertainties
  - ***precise measurements*** *may reveal* ***discrepancies*** *with expected values!*

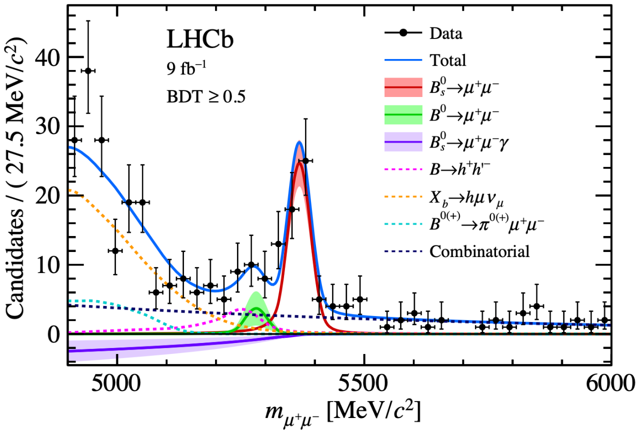
Significant deviations from SM predictions could arise in models involving **non-SM heavy particles**, such as in

- **Minimal Supersymmetric Standard Model**
- **Minimal Flavour Violation**,
- **TwoHiggs-Doublet Models**, ...

- In the $B^0_s - \overline{B^0_s}$ system, **light and heavy mass eigenstates** are characterized by a sizable difference between their **decay widths**, $\Delta\Gamma = 0.082 \pm 0.007\ \mathrm{ps}^{-1}$.
- In SM, **only heavy state decays to $\mu^+\mu^-$** (CP odd), but *this does not necessarily hold in BSM scenarios*
  - contributions from the 2 states can be disentangled by measuring $B^0_s \to \mu^+\mu^-$ **effective lifetime**, which, in the search for physics BSM, is a ***complementary probe to BR measurement***







Search for $B^0_{(s)} \to \mu\mu$ decays

ATLAS CMS LHCb

Search for $B^0_{(s)} \to \mu\mu$ decays

ATLAS

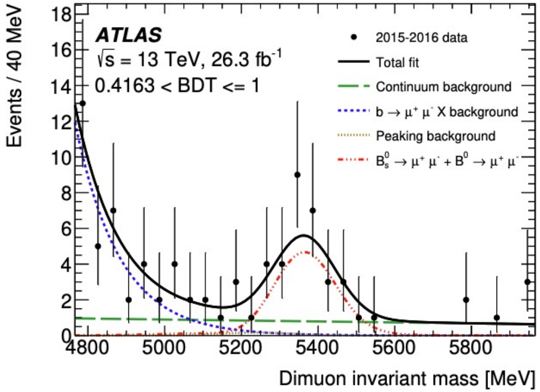
JHEP 04, (2019) 098

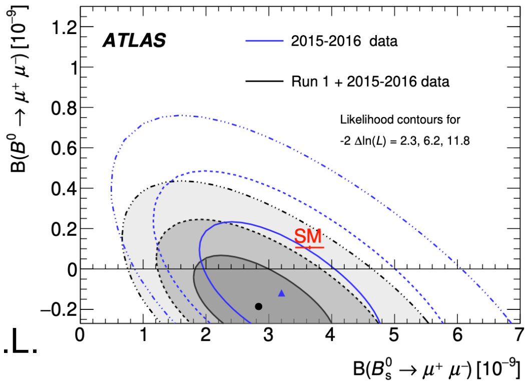
- $B^0_{(s)} \to \mu^+\mu^-$ BR measured relative to $B^+ \to J/\psi(\mu^+\mu^-)K^+$
  - this reference decay mode is abundant, has a very well-measured BR and allows for the reduction of several systematic uncertainties
- The **detector resolution** in $\mu^+\mu^-$ invariant mass is comparable to B^0_s- B^0 **mass difference**
  - a single fit determines the signal yields for both decay modes
- BR extracted from data using un **unbinned extended max-likelihood fit** on dimuon invariant mass distributions
  - result of the fit parametrized with the total yield of $B^0_s \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ events
- The values of BR obtained from the statistical analysis involving the **Neyman construction**, are:

$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.2^{+1.1}_{-1.0}) \cdot 10^{-9}$ $\quad$ $\mathcal{B}(B^0 \to \mu^+\mu^-) < 4.3 \cdot 10^{-10}$ at 95% C.L.

- After combination with **Run 1** results:

$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (2.8^{+0.8}_{-0.7}) \cdot 10^{-9}$ $\quad$ $\mathcal{B}(B^0 \to \mu^+\mu^-) < 2.1 \cdot 10^{-10}$ at 95% C.L.





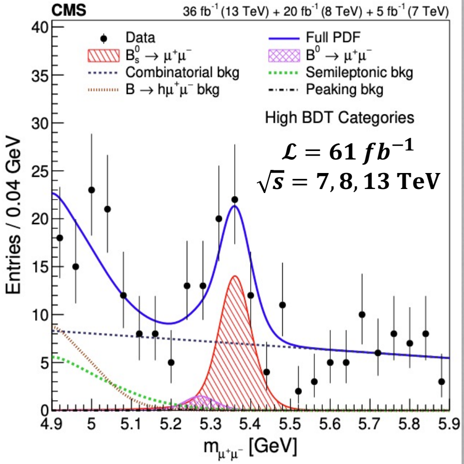
Consistent with SM predictions within 2.4 σ in the $\mathcal{B}(B^0 \to \mu^+\mu^-) - \mathcal{B}(B^0_s \to \mu^+\mu^-)$ plane

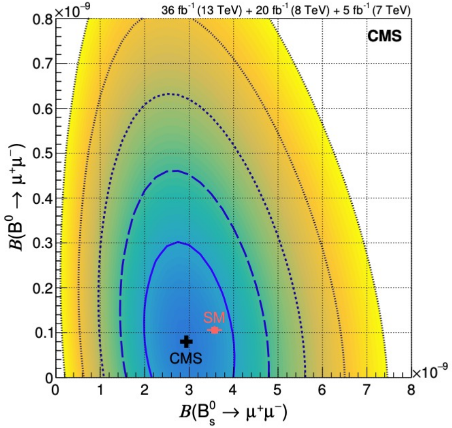
Search for $B^0_{(s)} \to \mu\mu$ decays

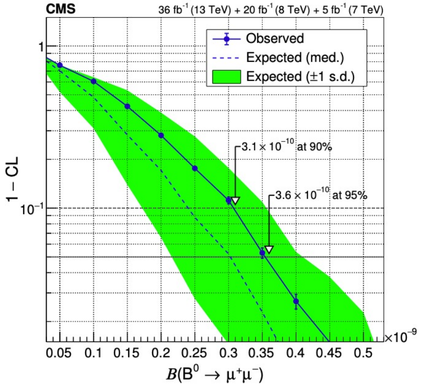
CMS

JHEP 04, (2020) 188

- BR determined by measuring event yields relative to $B^+ \to J/\psi\, K^+$ decays
- Main improvements in this analysis w.r.t. previous BR measured (only Run 1):
  - **greater statistical precision** of the larger data sample,
  - improved **muon identification algorithm** (newly developed BDT),
  - **better constraints against background contamination** in the search for $B^0 \to \mu^+\mu^-$.
- BR of $B^0_{(s)} \to \mu^+\mu^-$ determined with a **3D extended UML fit** to:
  - **binary distribution of dimuon pairing configuration** C, with $C = +1\ (-1)$ when the 2 muons bend towards (away from) each other in the magnetic field
  - $m_{\mu^+\mu^-}$ distribution,
  - **relative mass resolution** $\sigma(m_{\mu^+\mu^-})/m_{\mu^+\mu^-}$,







- $B^0_s \to \mu^+\mu^-$ decay observed with **5.6 σ** significance

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (\mathbf{2.9} \pm 0.7\ (\text{exp}) \pm 0.2(\text{frag})) \cdot \mathbf{10^{-9}}$$

$$\tau\,(B^0_s \to \mu^+\mu^-) = \mathbf{1.70^{+0.61}_{-0.44}\ ps}$$

- No significant excess is observed for $B^0 \to \mu^+\mu^-$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < \mathbf{3.6 \cdot 10^{-10}} \text{ at 95\% C.L.}$$

Search for $B^0_{(s)} \to \mu\mu$ decays

LHCb

PRL 118, (2017) 191801

- **Multivariate classifiers** employed at various stages of the analysis to select the signal:
  - loose preselection based on a multivariate discriminator
  - $B^0_{(s)} \to \mu^+\mu^-$ candidates classified according to their dimuon mass and the output variable of a multivariate classifier based on a BDT (used to separate signal and combinatorial bkg)

- **Signal yield** determined from fit to dimuon mass distribution of candidates
  - converted into a BR using as normalization modes the decays $B^0 \to K^+\pi^-$ and $B^+ \to J/\psi(\mu^+\mu^-)K^+$

- $B^0_s \to \mu^+\mu^-$ decay observed with $7.8\,\sigma$ significance

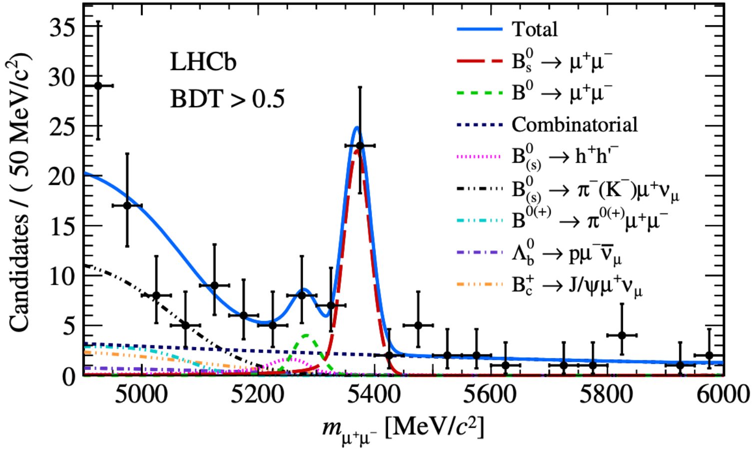
$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.0 \pm 0.6^{+0.3}_{-0.2}) \cdot 10^{-9}$$

$$\tau\,(B^0_s \to \mu^+\mu^-) = 2.04 \pm 0.44 \pm 0.05\ \text{ps}$$

first measurement!

$\mathcal{L} = 4.4\ fb^{-1}$

$\sqrt{s} = 7, 8, 13$ TeV



- No significant excess is observed for $B^0 \to \mu^+\mu^-$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.4 \cdot 10^{-10} \text{ at 95\% C.L.}$$

All results in agreement with SM expectations

Combination of results for $B^0_{(s)} \to \mu\mu$ searches @LHC

CMS-PAS-BPH-20-003

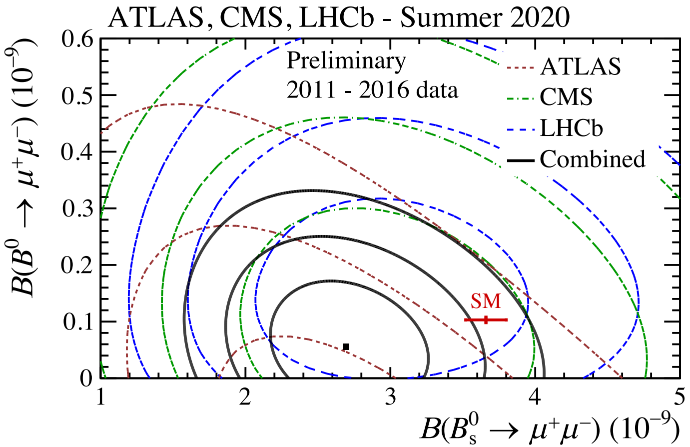
- Most up-to-date SM predictions for the $B^0_{(s)} \to \mu^+\mu^-$ BR JHEP 10 (2019) 232

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.66 \pm 0.14) \cdot 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.03 \pm 0.15) \cdot 10^{-10}$$

$$\mathcal{R} = \frac{\mathcal{B}(B^0 \to \mu^+\mu^-)}{\mathcal{B}(B^0_s \to \mu^+\mu^-)} = 0.00281 \pm 0.0016$$

$\mathcal{R}$ prediction has smaller uncertainty than individual BR, owing to the cancellation of several common factors

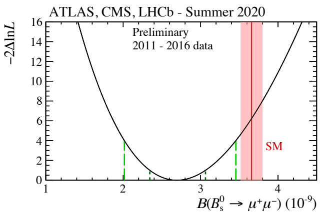
- Combination of data collected @LHC between 2011 and 2016 performed using **2D profile likelihoods** obtained by each experiment from their fit to the **dimuon invariant mass distributions**
  - each likelihood assumes the lifetime for $B^0_s \to \mu^+\mu^-$ to be the SM one

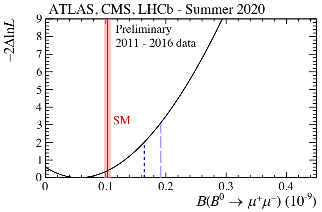


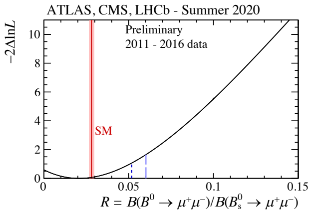
- **Results** obtained from **the combination**:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (2.69^{+0.37}_{-0.35}) \cdot 10^{-9}$$
$$\tau(B^0_s \to \mu^+\mu^-) = 1.91^{+0.37}_{-0.35}\ \text{ps}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.9 \cdot 10^{-10} \text{ at 95\% C.L.}$$

$\mathcal{R} < 0.060$ at 95% C.L.







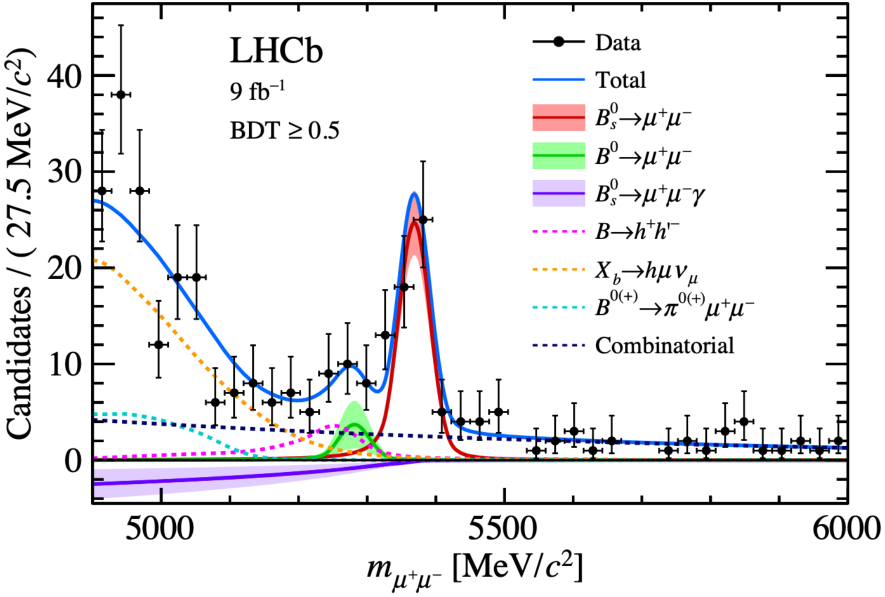
*Results compatible with SM predictions within **2.1 σ** in the 2D plane of the BR*

Search for $B^0_{(s)} \to \mu\mu$ decays

updated!

LHCb

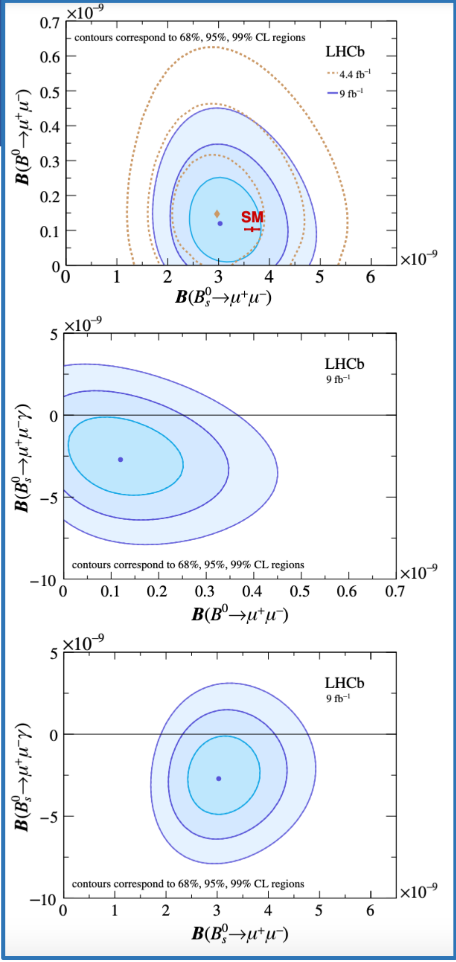
- Improved measurements of $B^0_{(s)} \to \mu^+\mu^-$ time-integrated BR and of the $\tau\left(B^0_s \to \mu^+\mu^-\right)$, superseding previous LHCb results + first search for $B^0_s \to \mu^+\mu^-\gamma$ decays



$\mathcal{L} = 9\, fb^{-1}$

$\sqrt{s} = 7, 8, 13$ TeV

PRL 128, (2022) 041801



The contribution from $B^0 \to \mu^+\mu^-\gamma$ decays negligible compared to that from $B^0_s \to \mu^+\mu^-$ because of the additional CKM suppression

Search for $B^0_{(s)} \to \mu\mu$ decays - Results

LHCb

[PRL 128, (2022) 041801]

- $B^0_s \to \mu^+\mu^-$ decay observed with $\sim$ **11 σ** significance

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

$$\tau(B^0_s \to \mu^+\mu^-) = 2.07 \pm 0.29 \pm 0.03 \text{ ps}$$

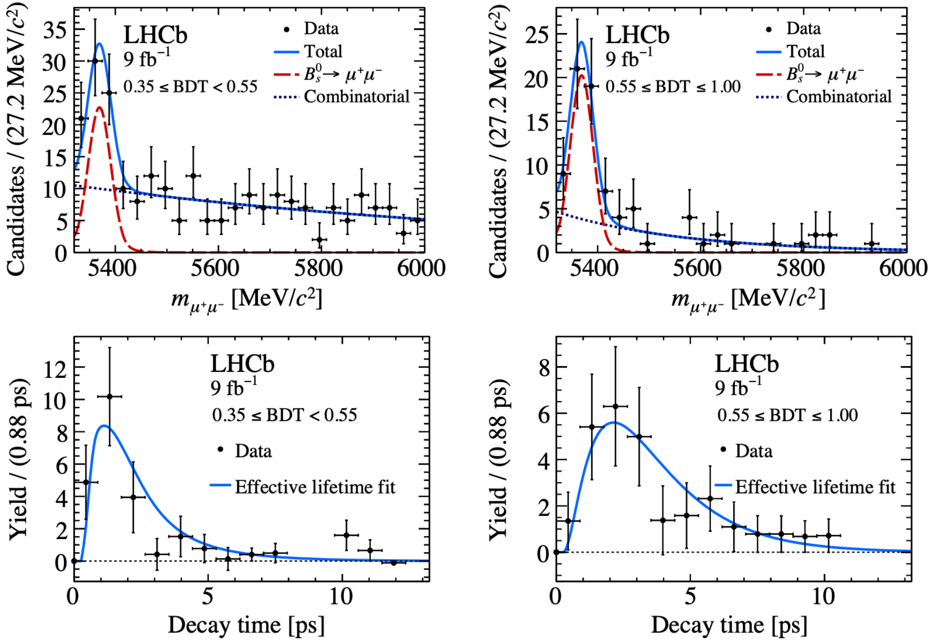
- **No significant signal** for $B^0 \to \mu^+\mu^-$ and $B^0_s \to \mu^+\mu^-\gamma$ is found

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 2.6 \cdot 10^{-10} \text{ at 95\% C.L.}$$

$$\mathcal{B}(B^0_s \to \mu^+\mu^-\gamma) < 2.0 \cdot 10^{-9} \text{ at 95\% C.L.}$$

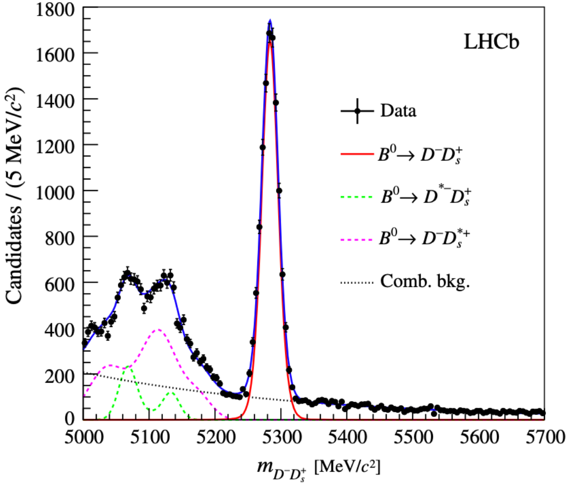
Limited to the range $m_{\mu\mu} > 4.9\ \text{GeV}/c^2$

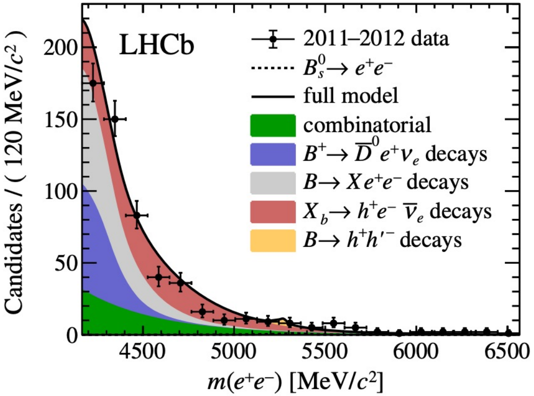
Results in agreement with SM predictions

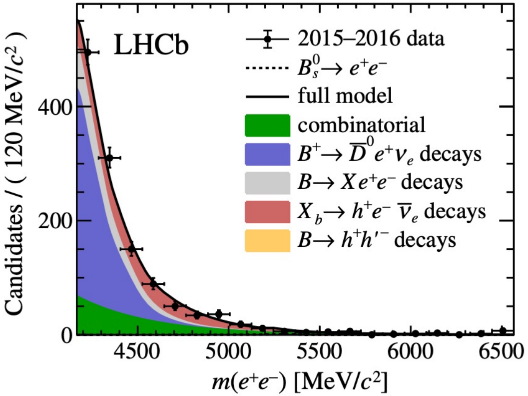


Search dominated by *statistical* uncertainty

10% precision expected with ATLAS/CMS Run 2







Search for $B^0_{(s)} \to ee$ and $B^0_{(s)} \to \tau\tau$ decays

Search for $B^0_{(s)} \to ee$ decays

LHCb

[PRL 124 (2020) 211802]

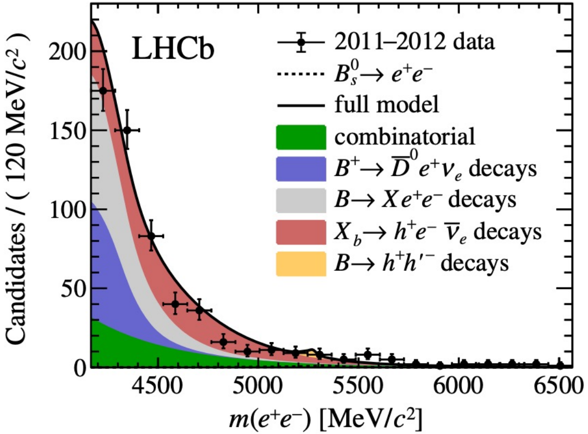
- This search provides an independent test of Lepton Flavor Universality (LFU)
- According to SM predictions:

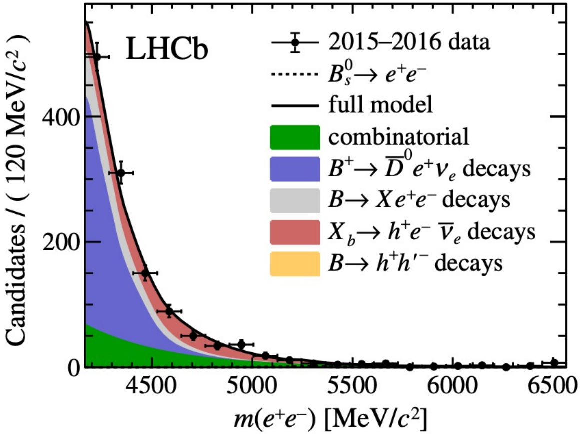
$$\mathcal{B}(B^0_s \to e^+e^-) = (8.60 \pm 0.36) \cdot 10^{-14}$$
$$\mathcal{B}(B^0 \to e^+e^-) = (2.41 \pm 0.13) \cdot 10^{-15}$$

- With BSM contributions:

$$\mathcal{B}(B^0_s \to e^+e^-) = \mathcal{O}(10^{-8})$$
$$\mathcal{B}(B^0 \to e^+e^-) = \mathcal{O}(10^{-10})$$

- **Signal yields** determined from **fit to data** and **normalized to** $B^+ \to J/\psi(e^+e^-)\,K^+$
- **BDT** used to separate $B^0_{(s)} \to e^+e^-$ signal from combinatorial bkg





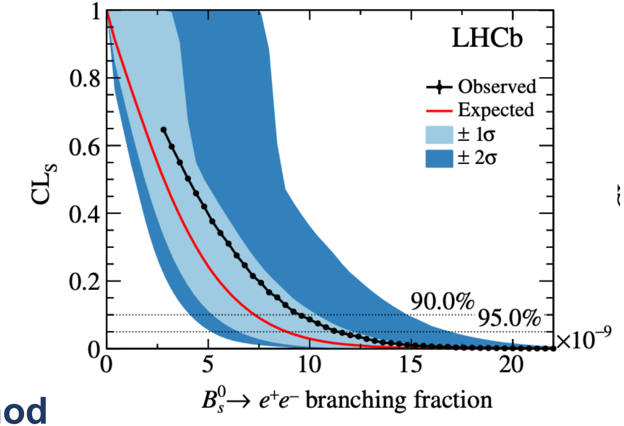
$\mathcal{L} = 5\ fb^{-1}$
$\sqrt{s} = 7, 8, 13$ TeV

Search for $B^0_{(s)} \to ee$ decays

LHCb

PRL 124 (2020) 211802

- Due to **limited mass resolution** (due to imperfect bremsstrahlung recovery), line shapes of $B_s^0 \to e^+e^-$ and $B^0 \to e^+e^-$ are overlapping
- $\mathcal{B}(B_s^0 \to e^+e^-)$ obtained by performing a **simultaneous fit** to the dielectron invariant mass distribution while neglecting the contribution from $B^0 \to e^+e^-$, and viceversa.



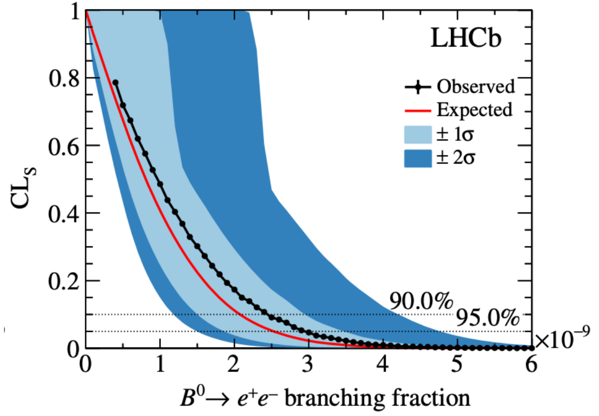
- **No evidence** found; upper limits on BR set using the **CLs method**

$$\mathcal{B}(B_s^0 \to e^+e^-) < 11.2 \cdot 10^{-9} \text{ at 95\% C.L.}$$

assuming no contribution from $B^0 \to e^+e^-$

$$\mathcal{B}(B^0 \to e^+e^-) < 3.0 \cdot 10^{-9} \text{ at 95\% C.L.}$$

assuming no contribution from $B_s^0 \to e^+e^-$

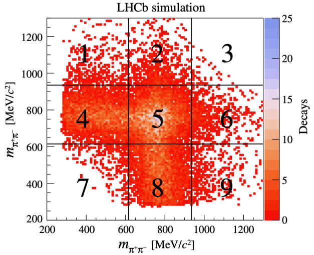


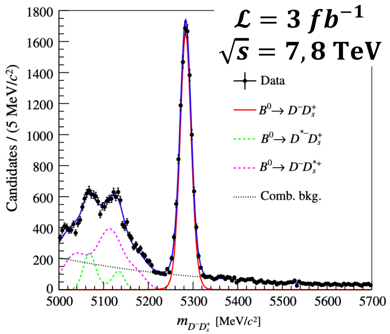
Search for $B^0_{(s)} \rightarrow \tau\tau$ decays

LHCb

PRL 118 (2017) 251802

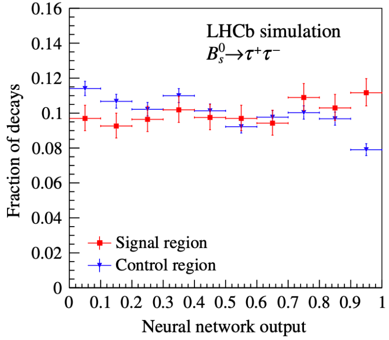
- The τ leptons are reconstructed through the decay $\tau^- \rightarrow \pi^-\pi^+\pi^-\upsilon_\tau$
  - proceeds predominantly through decay chain: $\tau^- \rightarrow a_1(1260)^- \upsilon_\tau,\ a_1(1260)^- \rightarrow \rho(770)^0\pi^-$
  - $\mathcal{B}(\tau^- \rightarrow \pi^-\pi^+\pi^-\upsilon_\tau) = (9.31 \pm 0.05)\%$
  - normalization channel: $B^0 \rightarrow D^-D_s^+$, $D^- \rightarrow K^+\pi^-\pi^-$ and $D_s^+ \rightarrow K^-K^+\pi^+$





- For each τ candidate, 2D distribution $m_{\pi^+\pi^-}$ divided in 9 sectors
  - **signal** region: **both** τ candidates in **sector 5**
  - **control** regions: **one** τ in sectors **4, 5 or 8** and other in sectors **4 or 8**

- **NN** trained to discriminate signal from bkg
  - **7** input variables**:** $\tau^\pm$ masses and decay times, **charged track isolation** variable for **pions**, **neutral isolation** variable for ***B***, one variable from the analytic reconstruction method



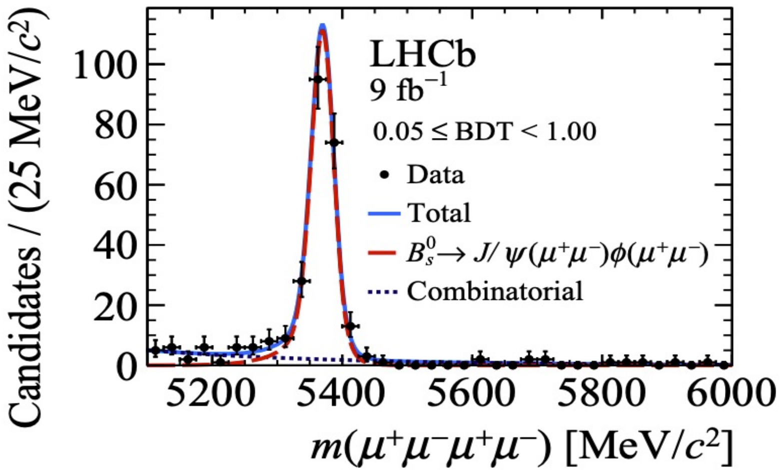
- **Binned max likelihood fit** performed on **output of** a second **NN** to determine the signal yield
- **No evidence** found; upper limits on BR set using the **CLs method**

$\mathcal{B}(B_s^0 \rightarrow \tau^+\tau^-) < 6.8 \cdot 10^{-3}$ at 95% C.L.

assuming no contribution from $B^0 \rightarrow \tau^+\tau^-$

$\mathcal{B}(B^0 \rightarrow \tau^+\tau^-) < 2.1 \cdot 10^{-3}$ at 95% C.L.

assuming no contribution from $B_s^0 \rightarrow \tau^+\tau^-$



Search for $B^0_{(s)} \to 4\mu$ decays

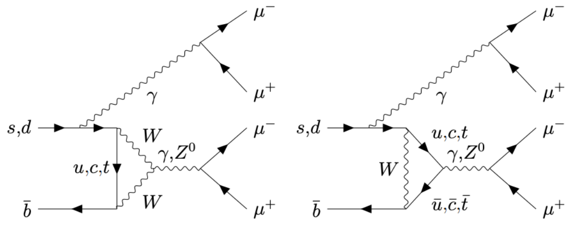
LHCb

Search for $B^0_{(s)} \to 4\mu$ decays

LHCb

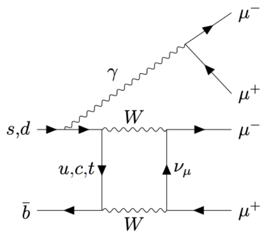
JHEP 03 (2022) 109

- Decays of B^0_s and B^0 into 4μ, that are not mediated by intermediate resonances, proceed through $b \to s$ and $b \to d$ quark FCNC transitions



- In the SM, these decays proceed by EW loops, due to the absence of tree-level FCNCs (so, highly suppressed!)
  - $\mathcal{B}(B^0_s \to \mu^+\mu^-\mu^+\mu^-) = (0.9 - 1.0) \cdot 10^{-10}$
  - $\mathcal{B}(B^0 \to \mu^+\mu^-\mu^+\mu^-) = (0.4 - 4.0) \cdot 10^{-12}$

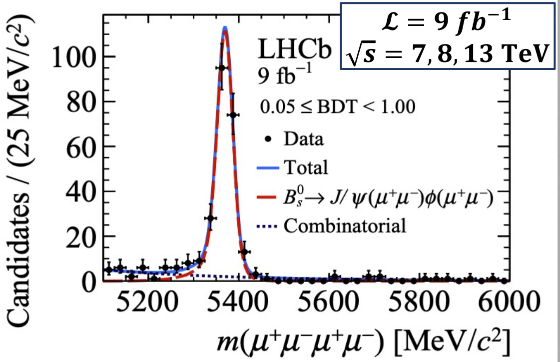
New particles BSM may significantly enhance these BR



- In extension of SM with new strongly interacting sector, we can have:

$$B^0_{(s)} \to a(\mu^+\mu^-)\, a(\mu^+\mu^-), \text{ with } m_a \sim 1\ \mathrm{GeV/c^2}$$

- **Direct** decays and decays **via light scalar** (a) and J/ψ **resonances** ($B^0_{(s)} \to J/\psi(\mu^+\mu^-)\,\mu^+\mu^-$) are considered
  - $B^0_s \to J/\psi(\mu^+\mu^-)\,\phi(\mu^+\mu^-)$ used as **normalisation** channel (BR ~ $1.74 \cdot 10^{-8}$)
  - Combinatorial bkg suppressed using a BDT
  - Hadronic background suppressed using tight PID requirements



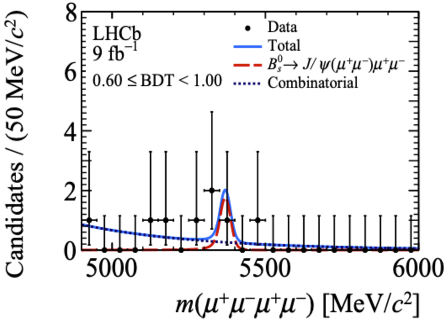
Search for $B^0_{(s)} \to 4\mu$ decays: results

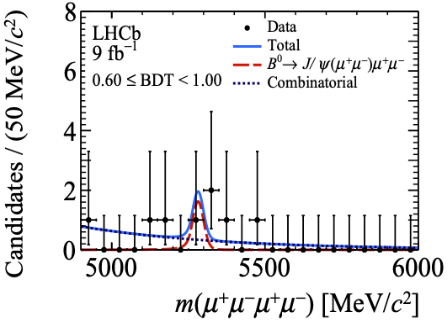
[JHEP 03 (2022) 109]

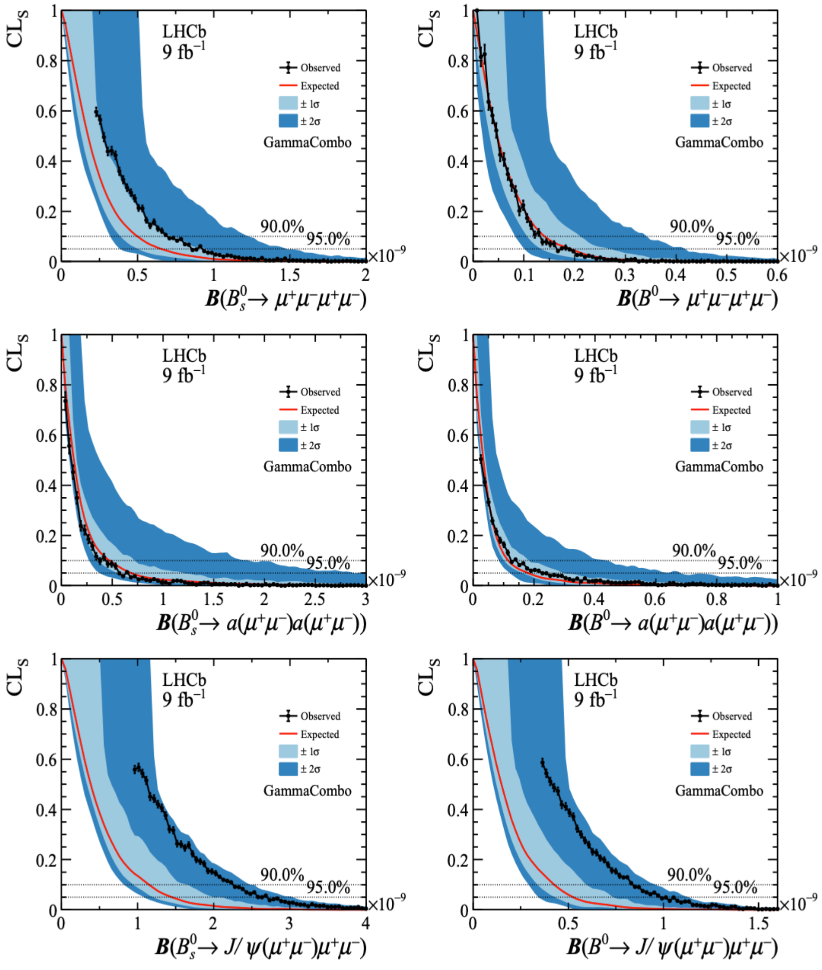
➢ **No evidence** found for the **6 decays** searched for

$$\mathcal{B}\left(B^0_s \to \mu^+\mu^-\mu^+\mu^-\right) < 8.6 \times 10^{-10},$$
$$\mathcal{B}\left(B^0 \to \mu^+\mu^-\mu^+\mu^-\right) < 1.8 \times 10^{-10},$$
$$\mathcal{B}\left(B^0_s \to a\left(\mu^+\mu^-\right) a\left(\mu^+\mu^-\right)\right) < 5.8 \times 10^{-10},$$
$$\mathcal{B}\left(B^0 \to a\left(\mu^+\mu^-\right) a\left(\mu^+\mu^-\right)\right) < 2.3 \times 10^{-10},$$
$$\mathcal{B}\left(B^0_s \to J/\psi\left(\mu^+\mu^-\right) \mu^+\mu^-\right) < 2.6 \times 10^{-9},$$
$$\mathcal{B}\left(B^0 \to J/\psi\left(\mu^+\mu^-\right) \mu^+\mu^-\right) < 1.0 \times 10^{-9}.$$

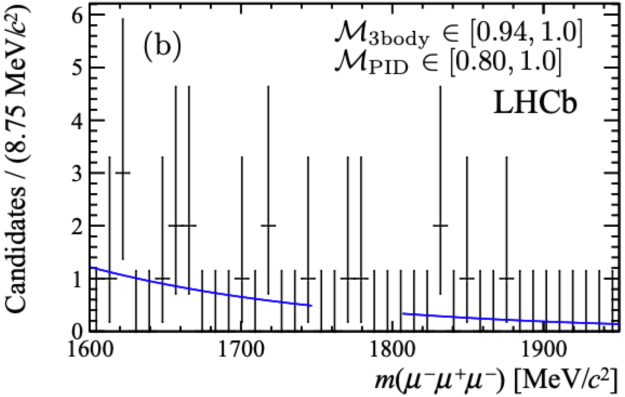
Presently, the most stringent limits set at ***95% CL***







$$\tau \longrightarrow 3\mu$$

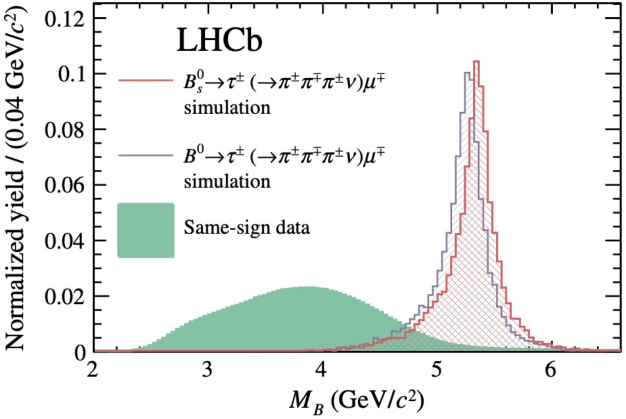


ATLAS CMS LHCb

$$B^0_{(s)} \longrightarrow \tau\mu$$

$$B^0_{(s)} \longrightarrow e\mu$$

LHCb

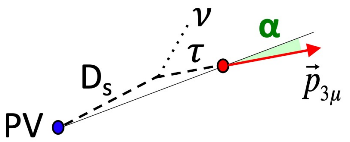


Some of last results from direct LFV searches

Search for $\tau \rightarrow 3\mu$ decays

ATLAS [Eur. Phys. J. C 76 (2016) 232]
CMS [JHEP 01 (2021) 163]
LHCb [JHEP 02 (2015) 121]

- **At LHC, two** main **channels** for this search (depending on the **source** of τ leptons):
  - **Heavy Flavor**: abundant (especially $D_s \rightarrow \tau\upsilon$) but challenging because of very low p_T forward muons
  - **W**: 10^4 time less abundant, but with clear signature

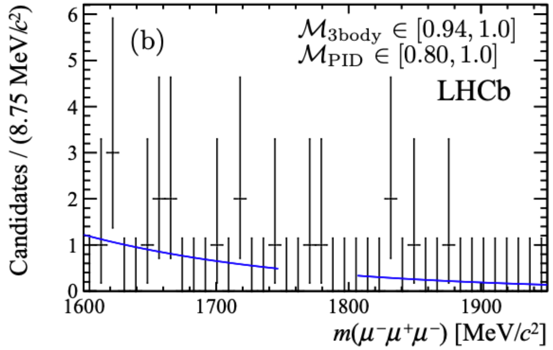


- **Results from search @LHC:** **No evidence** found

  - **LHCb**: **HF** channel, $\mathcal{L} = 3\ fb^{-1}$ — $\mathcal{B}(\tau \rightarrow 3\mu) < 4.6 \cdot 10^{-8}$ at **95% C.L.**
  - **ATLAS**: **W** channel, $\mathcal{L} = 20\ fb^{-1}$ — $\mathcal{B}(\tau \rightarrow 3\mu) < 3.8 \cdot 10^{-7}$ at **95% C.L.**
  - **CMS**: Both **HF and W** channels, $\mathcal{L} = 33\ fb^{-1}$ — $\mathcal{B}(\tau \rightarrow 3\mu) < 8.0 \cdot 10^{-8}$ at **95% C.L.**

Best UL set by the **Belle** experiment: $\mathcal{B}(\tau \rightarrow 3\mu) < 2.1 \cdot 10^{-8}$ at **95% C.L.**

Searches with the full Run 2 datasets are ongoing



- **HL-LHC projections**
  - **ATLAS:** ATL-PHYS-PUB-2018-032
  - **CMS:** Phase 2 Muon Upgrade TDR, CMS-TDR-016 (2017)

Sensitivity improvement expected to scale better than $1/\sqrt{\mathcal{L}}$ because of trigger/detector upgrades

Search for $B^0_{(s)} \longrightarrow \tau\mu$ decays

LHCb

PRL 123 (2019) 211801

- LFV decays of mesons with *b* quarks are extremely suppressed in SM
  - SM: BR $\mathcal{O}(10^{-54})$, because of quantum loops + neutrino oscillations
  - BSM: BR $\mathcal{O}(10^{-4}\text{-}\ 10^{-8})$
- τ leptons are reconstructed through the decay $\tau^- \rightarrow \pi^-\pi^+\pi^-\upsilon_\tau$
- **neutrino momentum** determined from position of PV and τ, $\vec{p}_\mu$, $\vec{p}_{3\pi}$
- **BDT** trained on same-sign candidates and simulated $B^0_s \rightarrow \tau^\pm\mu^\mp$ decays
- **signal yield** determined by performing an **unbinned max likelihood fit** to the reconstructed *B* invariant mass in range [4.6-5.8] GeV/c^2
  - $B^0_s \rightarrow D^-(\rightarrow K^+\pi^-\pi^+)\pi^+$ used as normalization channel

As the separation btw $B^0_s \rightarrow \tau^\pm\mu^\mp$ and $B^0 \rightarrow \tau^\pm\mu^\mp$ is limited, ***2 independent fits*** *are performed while* ***assuming the contribution*** *of* ***either*** *the* ***B^0_s or the B^0 signal only***

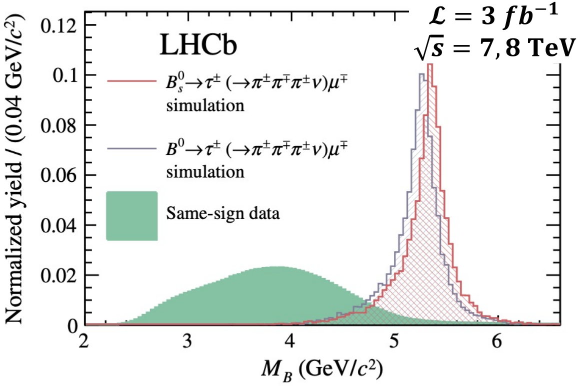
- **No evidence** found

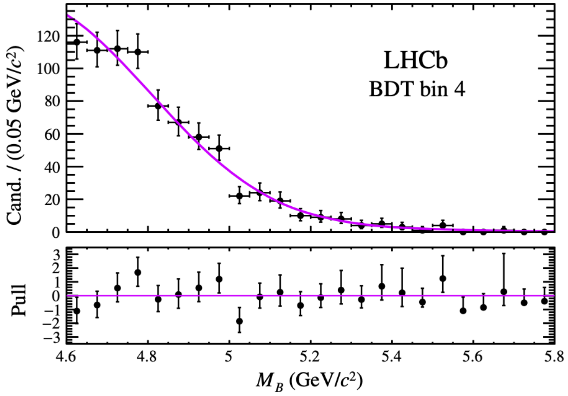
$\mathcal{B}(B^0_s \rightarrow \tau^\pm\mu^\mp) < 4.2 \cdot 10^{-5}$ — *assuming no contribution from $B^0 \rightarrow \tau^\pm\mu^\mp$*

$\mathcal{B}(B^0 \rightarrow \tau^\pm\mu^\mp) < 1.4 \cdot 10^{-5}$ @95% C.L. — *assuming no contribution from $B^0_s \rightarrow \tau^\pm\mu^\mp$*

$\mathcal{L} = 3\ fb^{-1}$

$\sqrt{s} = 7, 8$ TeV





Fit in B^0_s signal only hypothesis

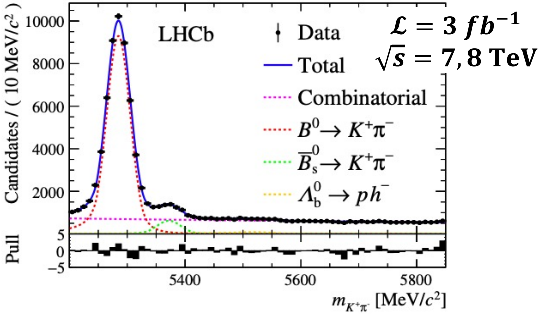
Search for $B^0_{(s)} \longrightarrow e\mu$ decays

LHCb

[JHEP 03 (2018) 078]

- BSM scenarios like models with a new gauge Z' boson or leptoquarks predict $\mathcal{B}(B^0_{(s)} \to e^\pm\mu^\mp) \sim \mathcal{O}(10^{-11})$

- In this analysis, two **normalization channels** are used:
  - $B^0 \to K^+\pi^-$ topology similar to signal one
  - $B^0 \to J/\psi(\mu^+\mu^-)\, K^+$ abundant yield, similar purity and trigger selection



- A **BDT** is used to separate signal from combinatorial bkg
  - trained using MC for signal and data with same-sign $e^\pm\mu^\pm$ for the combinatorial bkg

- **Signal yields** obtained from an **unbinned extended max likelihood fit** to $m_{e^\pm\mu^\mp}$

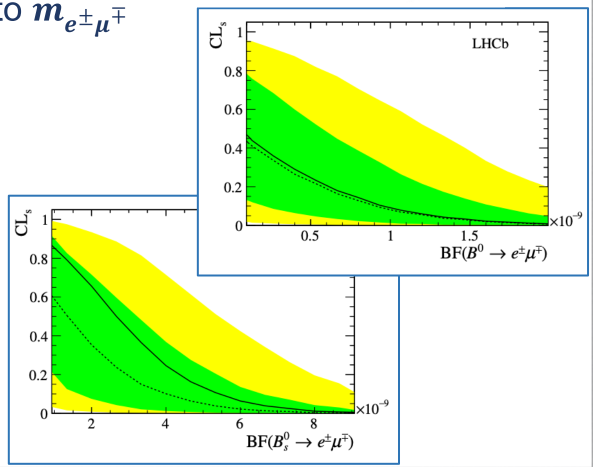
- **No evidence** found
  - The two B^0_s mass eigenstates are characterized by large lifetime difference
  - UL for $B^0_s \to e^\pm\mu^\mp$ evaluated both in hp of **amplitude completely dominated** by **heavy** eigenstate and by **light eigenstate**

$$\mathcal{B}(B^0_s \to e^\pm\mu^\mp) < 6.3 \cdot 10^{-9} \text{ @95\% C.L.}$$
$$\mathcal{B}(B^0_s \to e^\pm\mu^\mp) < 7.2 \cdot 10^{-9} \text{ @95\% C.L.}$$

assuming no contribution from $B^0 \to e^\pm\mu^\mp$

$$\mathcal{B}(B^0 \to e^\pm\mu^\mp) < 1.3 \cdot 10^{-9} \text{ @95\% C.L.}$$

assuming no contribution from $B^0_s \to e^\pm\mu^\mp$



Summary

- **Rare decays provide a very clean way of probing the SM**
  - in particular, purely leptonic decays have small bkg and predictions of their BR are very precise

- **In the context of $B^0_{(s)} \to l^+ l^-$ decays:**
  - $B^0_s \to \mu^+\mu^-$ is the only one observed so far
  - UL on the BR of the other decays are set, constraining the phase space of BSM theories

- **LFV searches are a complementary way to test BSM theories predicting LFU violation**
  - They are further suppressed in the SM due to the neutrino oscillation
  - No observation of charged LFV so far

- **Analysis on full Run 2 data, as well as detector and trigger upgrades** to enhance the sensitivity of these searches @LHC**, are *ongoing***

Exciting time for (B)physics is coming soon, stay tuned!

Backup slides

Search for $B^0_{(s)} \to \mu\mu$ decays - normalisation

- Yield of $B^0_s \to \mu^+\mu^-$ candidates converted into its BR by normalising to $B^+ \to J/\psi\, K^+$ decay

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = \frac{f_d}{f_s} \frac{\varepsilon_{B^+\to J/\psi\, K^+}}{\varepsilon_{B^0_s \to \mu^+\mu^-}} \frac{N_{B^0_s \to \mu^+\mu^-}}{N_{B^+\to J/\psi\, K^+}} \mathcal{B}(B^+ \to J/\psi\, K^+)$$

known with limited precision, largest systematic uncertainty on $\mathcal{B}(B^0_s \to \mu^+\mu^-)$

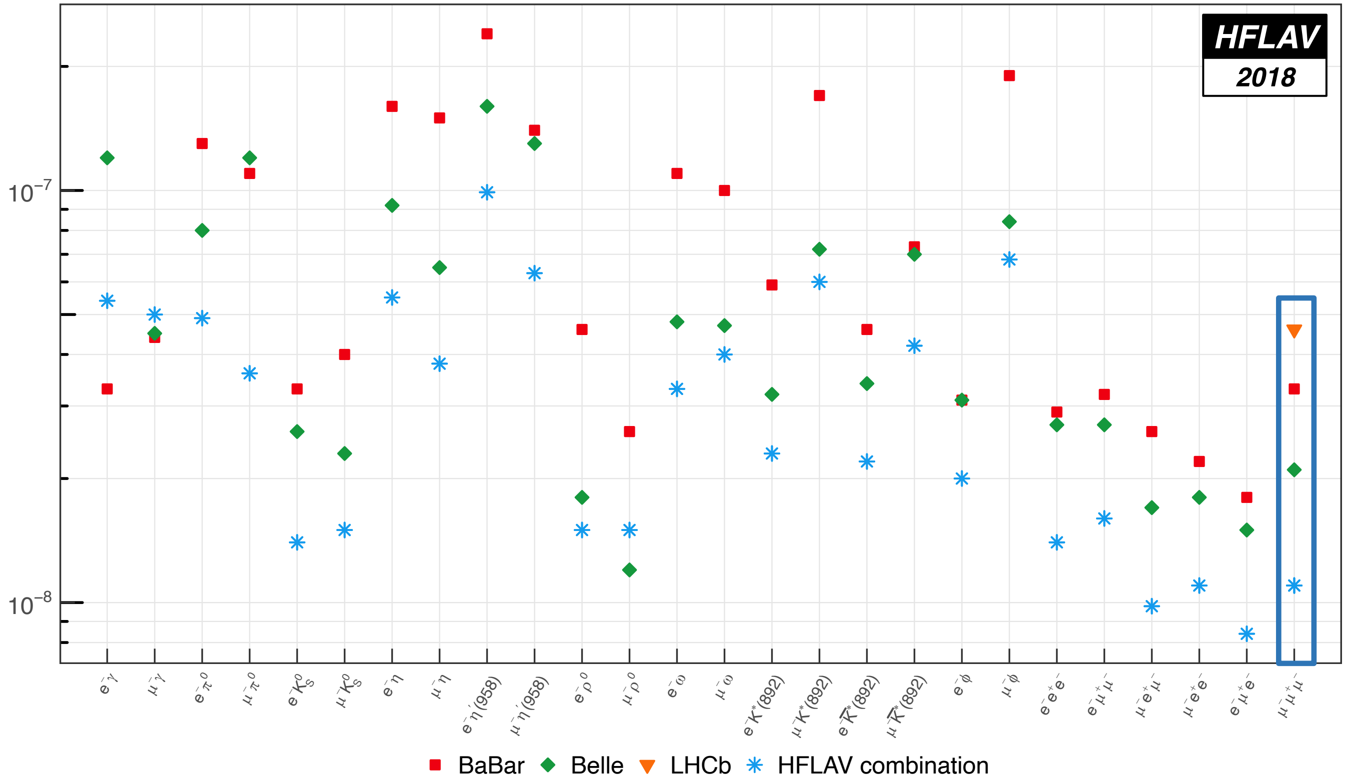
- N : yield
- ε : efficiency (determined using simulation and corrected with data-driven methods)
- f_d : fragmentation fraction of a *b* quark to a B^0 meson
- f_s : fragmentation fraction of a *b* quark to a B^0_s meson

- Normalisation of B^0 is similar but without $\frac{f_d}{f_s}$ term

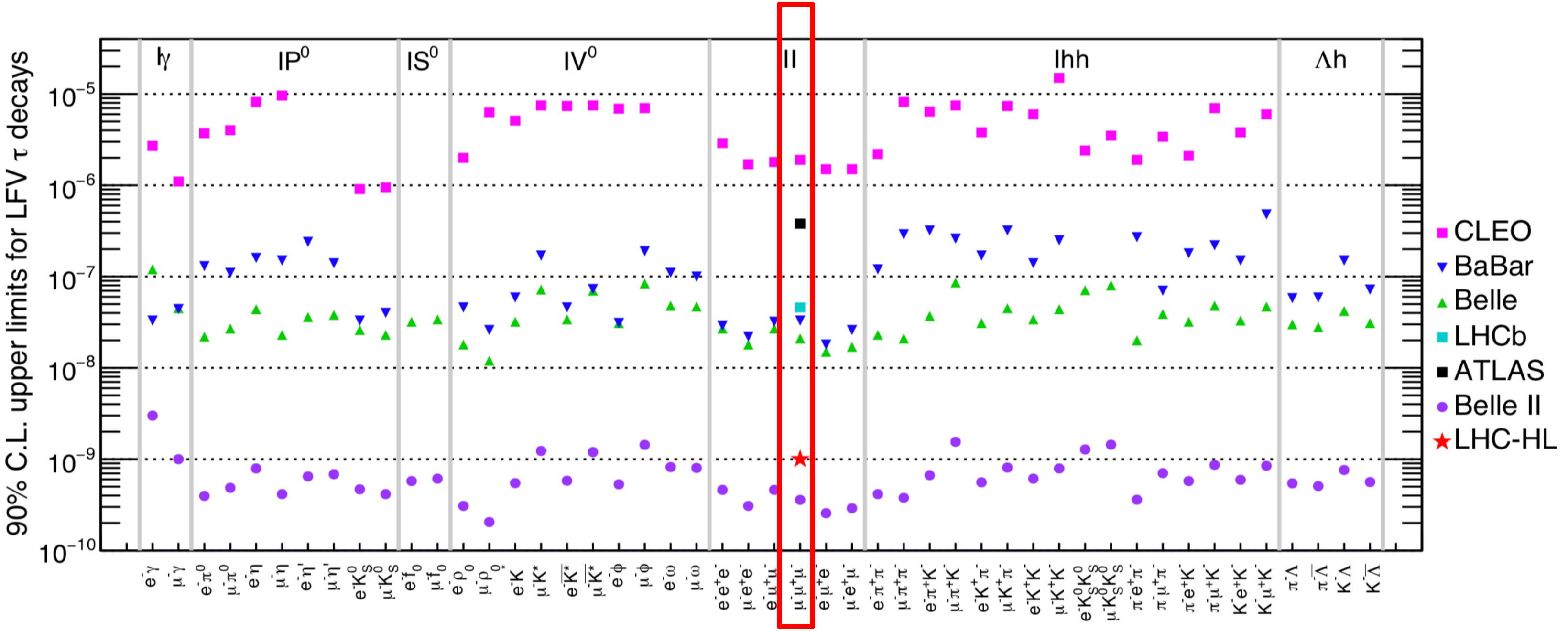
It's assumed that the fragmentation fractions of B^0 and B^+ mesons are equal due to isospin symmetry to a good accuracy

Future perspectives for LFV search in τ decays

90% CL upper limits on τ LFV decays



Future perspectives for LFV search in τ decays



Bounds on Tau Lepton Flavour Data from the existing experiments are compiled by HFLAV; projections of the Belle-II bounds were performed by the Belle-II collaboration assuming 50 ab^{-1} of integrated luminosity.

arXiv:1812.07638

Search for τ → 3μ @ATLAS during HL-LHC

Summary of inputs to the limit calculation for each scenario as well as the expected 90% CLs UL on the LFV BR for an assumed lumi of **3000 fb⁻¹**

W channel

Scenario	$\mathcal{A} \times \epsilon$ [%]	$N_{\text{bkg}}^{\text{exp}}$	90% CL UL on BR($\tau \to 3\mu$) [10^{-9}]
Run 1 result	2.31	0.19	276
Non-improved	2.31	50.71	13.52
Intermediate	5.01	50.71	6.23
Improved	5.01	40.06	5.36

1. **Non-improved scenario**: Most conservative approach: no analysis or detector improvements are considered and the sensitivity is extrapolated scaling for the integrated lumi. Bkg yield of the Run 1 is scaled by a factor **260**, while A × ε considered the same as in Run 1.

2. **Intermediate scenario**: Improvements in triggering and reco of low pT muons estimated from Run 2 MC included in the projection, while no effects on further impacts of the ML selection or better resolution are considered. The net effect is an increase of a factor **2.2** in the signal yield relative to Run 1 + applied extrapolation factor of **260** accounting for the increased cross-section and integrated lumi.

3. **Improved scenario**: Signal search window is tightened, taking into account expected improvements in mass resolution. The combined fit has a **width 20% smaller than the Run 1** counterpart. This reflects in a **25% improvement** in the **S/B ratio** which is applied to the projection. Improvements of previous scenarios are applicable as well.

HF channel

Scenario	$\mathcal{A} \times \epsilon$ [%]	$N_{\text{bkg}}^{\text{exp}}$	90% CL UL on BR($\tau \to 3\mu$) [10^{-9}]
High background	0.88	507.05	6.40
Medium background	0.88	152.12	2.31
Low background	0.88	50.71	1.03

1. **High background scenario**: Most conservative approach taking the bkg level one order of magnitude larger than in the Run 1 W-channel analysis. The bkg estimated in the Run 1 analysis is scaled by the increase in luminosity and data and an additional penalty factor of **10** is applied on top.

2. **Medium background scenario**: Bkg level in HF channel considered is a factor of 3 larger than in the W one. The scaling according to the increase in luminosity is applied.

3. **Low background scenario**: Most aggressive scenario: bkg level assumed to be the same as in the W-channel, still taking into account the increase in luminosity. This scenario provides a reference for the effect of potential analysis improvements.

Search for $\tau \to 3\mu$ @CMS during HL-LHC

	Category 1	Category 2
Number of background events	2.4×10^6	2.6×10^6
Number of signal events	4580	3640
Trimuon mass resolution	18 MeV	31 MeV
$\mathcal{B}(\tau \to 3\mu)$ limit per event category	4.3×10^{-9}	7.0×10^{-9}
$\mathcal{B}(\tau \to 3\mu)$ 90% C.L. limit	3.7×10^{-9}	
$\mathcal{B}(\tau \to 3\mu)$ for 3-σ evidence	6.7×10^{-9}	
$\mathcal{B}(\tau \to 3\mu)$ for 5-σ observation	1.1×10^{-8}	

(Top) The expected numbers of signal and background events in the mass window 1.55 -2.0 GeV for CMS. An integrated luminosity of **3000 fb^{-1}** and a signal $B(\tau \to 3\mu) = 2 \times 10^{-8}$ is assumed.

(Bottom) The search sensitivities for the combined categories.

- **Category 1** for events with all three muons reconstructed only with the Phase-1 detectors, and
- **Category 2** for events with at least one muon reconstructed by the new triple Gas Electron Multiplier (GEM) detectors.