# The branching fraction and effective lifetime of $B^0_{(s)} \to \mu^+\mu^-$ at LHCb with Run 1+2 data

Mick Mulder on behalf of the LHCb Collaboration

52nd Rencontres de Moriond 2017

Electroweak Interactions and Unified Theories Session

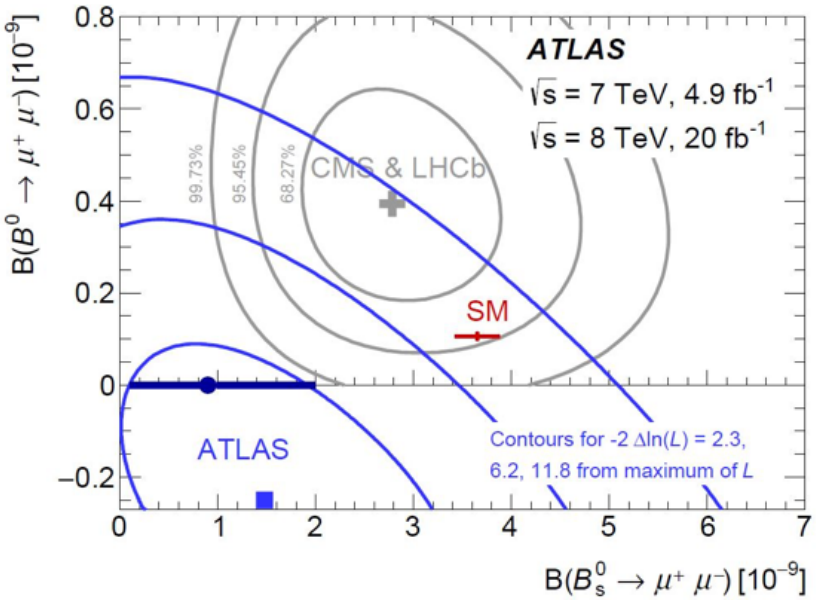
March 24 2017


# Branching fraction

## Motivation for branching fraction measurement

- In **SM**, $B^0_{(s)} \to \mu^+\mu^-$ only via higher order FCNC processes, with precise estimate of BF [PRL 112, 101801 (2014)]:
  $\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$,
  $\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.66 \pm 0.23) \times 10^{-9}$
- Very sensitive to New Physics!

- Latest result from **LHCb + CMS** (Nature 522, 68, 2015)
- Latest result from **ATLAS** (arXiv:1604.04263)
- Slight tension with current results

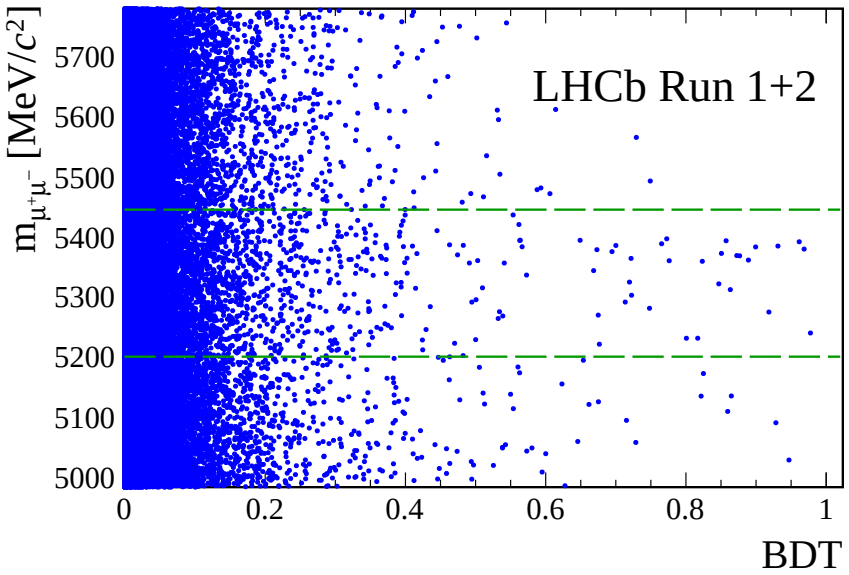



**Investigating with Run 1 + Run 2 data: 1.75 × Run 1 data!**

# Branching fraction
## Strategy

arXiv:1703.05747

- Candidates: $\mu^+\mu^-$ with
  1. $m_{\mu^+\mu^-} \in [4900, 6000]$ MeV
  2. Good, displaced vertex
- Separate signal from **background** by fitting $m_{\mu^+\mu^-}$ in bins of multivariate classifier (BDT)




- Reduce backgrounds with Particle Identification (PID) information
- Reoptimised BDT, PID (for $B^0 \to \mu^+\mu^-$): $\sim 25\%$ more sensitive!
- Data-driven calibration of signal (**BDT**, mass shape)
- **Normalisation** with $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$ and $B^0 \to K^+\pi^-$

# Branching fraction
## Normalisation

- Two normalisation channels with well known branching fractions:

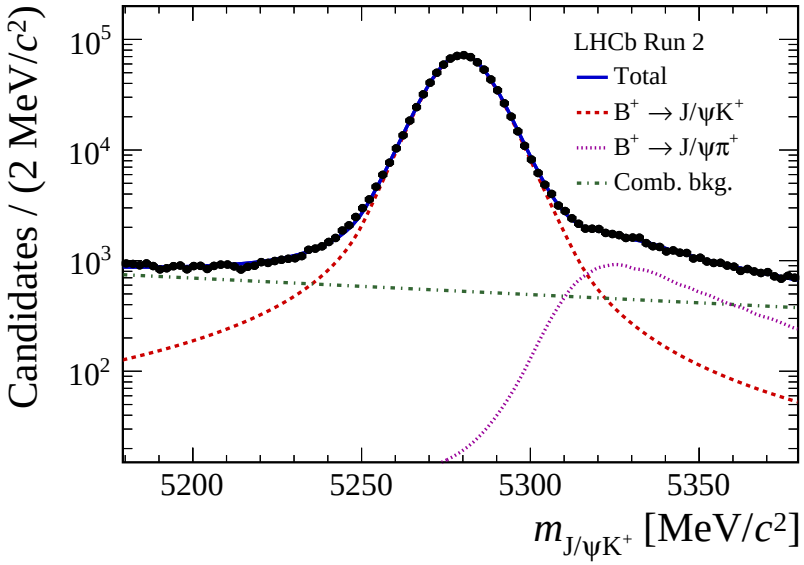
$$\mathcal{B}(B^0_{(s)} \to \mu^+\mu^-) = \frac{\epsilon_{norm}}{\epsilon_{B^0_{(s)}\to\mu^+\mu^-}} \frac{N_{B^0_{(s)}\to\mu^+\mu^-}}{N_{norm}} \frac{f_{norm}}{f_{d(s)}} \mathcal{B}_{norm}$$ (arXiv:1703.05747)

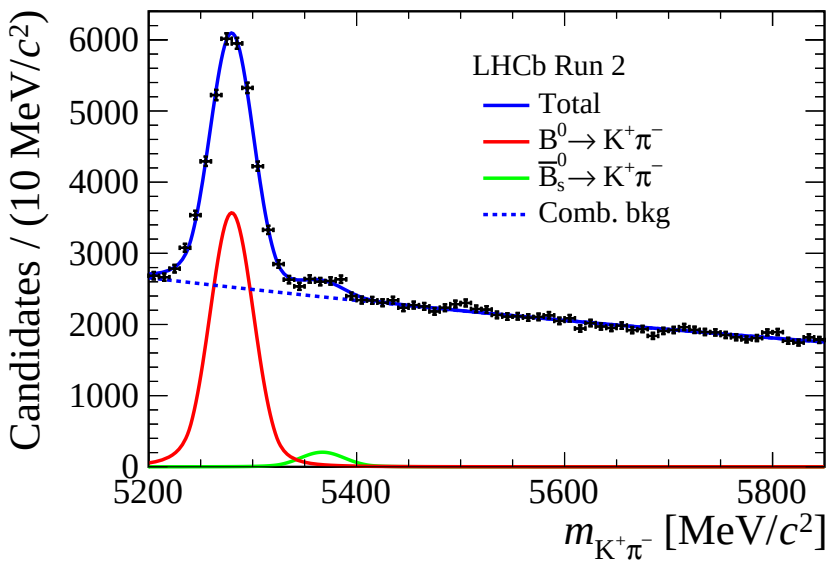
$B^+ \to J/\psi(\to \mu^+\mu^-)K^+$:

- Similar trigger, PID efficiency
- Correct for extra track

$B^0 \to K^+\pi^-$:

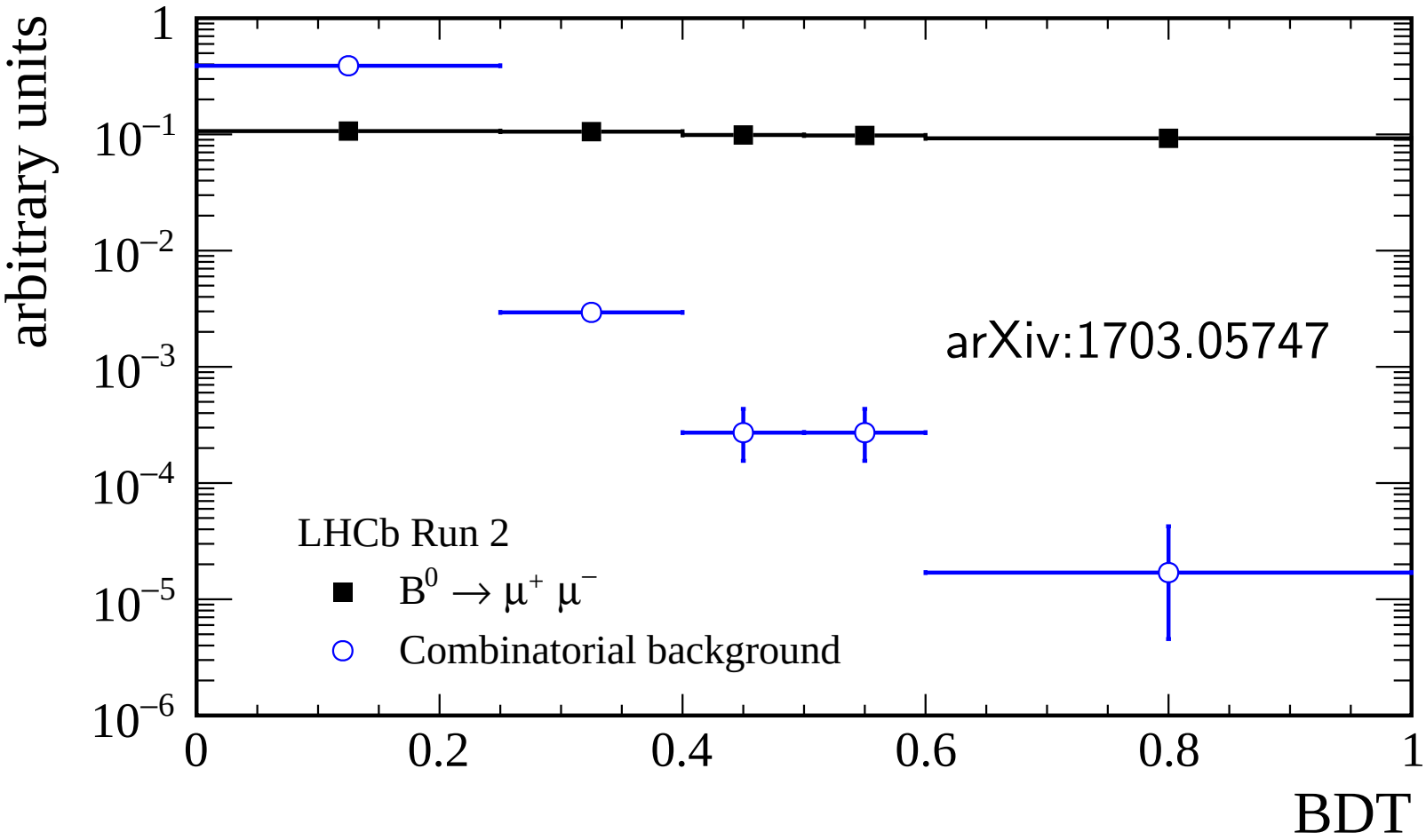
- Similar kinematics
- Correct for trigger, PID



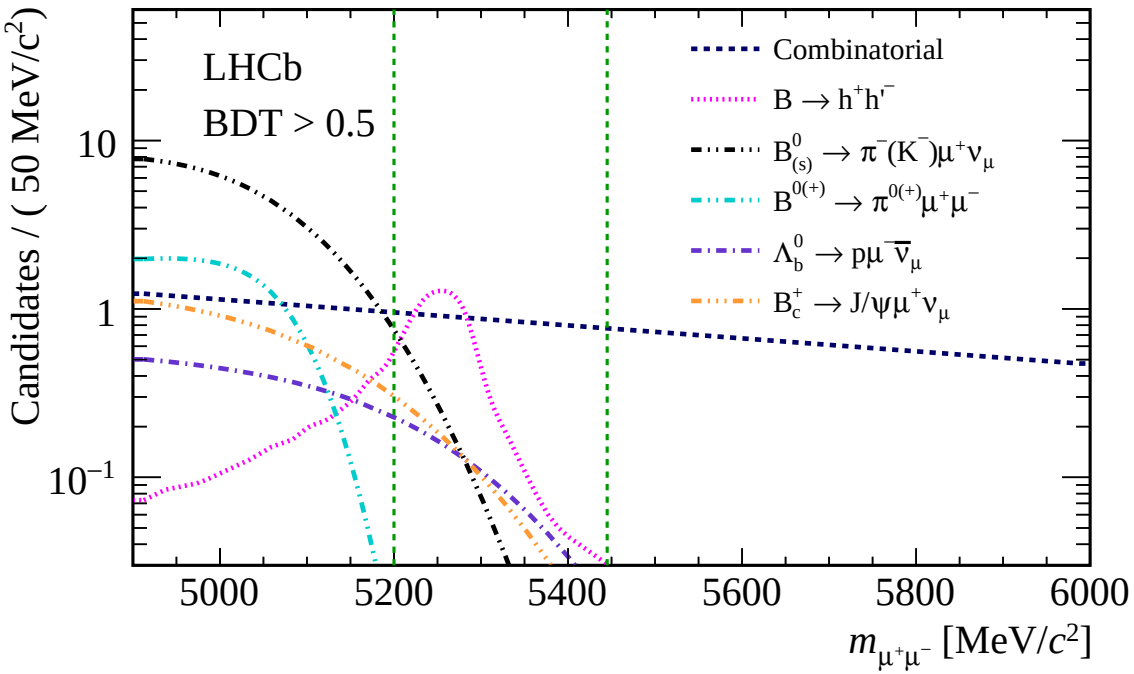



# Branching fraction
## BDT calibration

- Signal distribution in BDT bins calibrated on $B^0 \to K^+\pi^-$ data
- Fit to get $B^0 \to K^+\pi^-$ yield in each BDT bin
- Correct for trigger and PID to obtain $B^0_{(s)} \to \mu^+\mu^-$ distribution

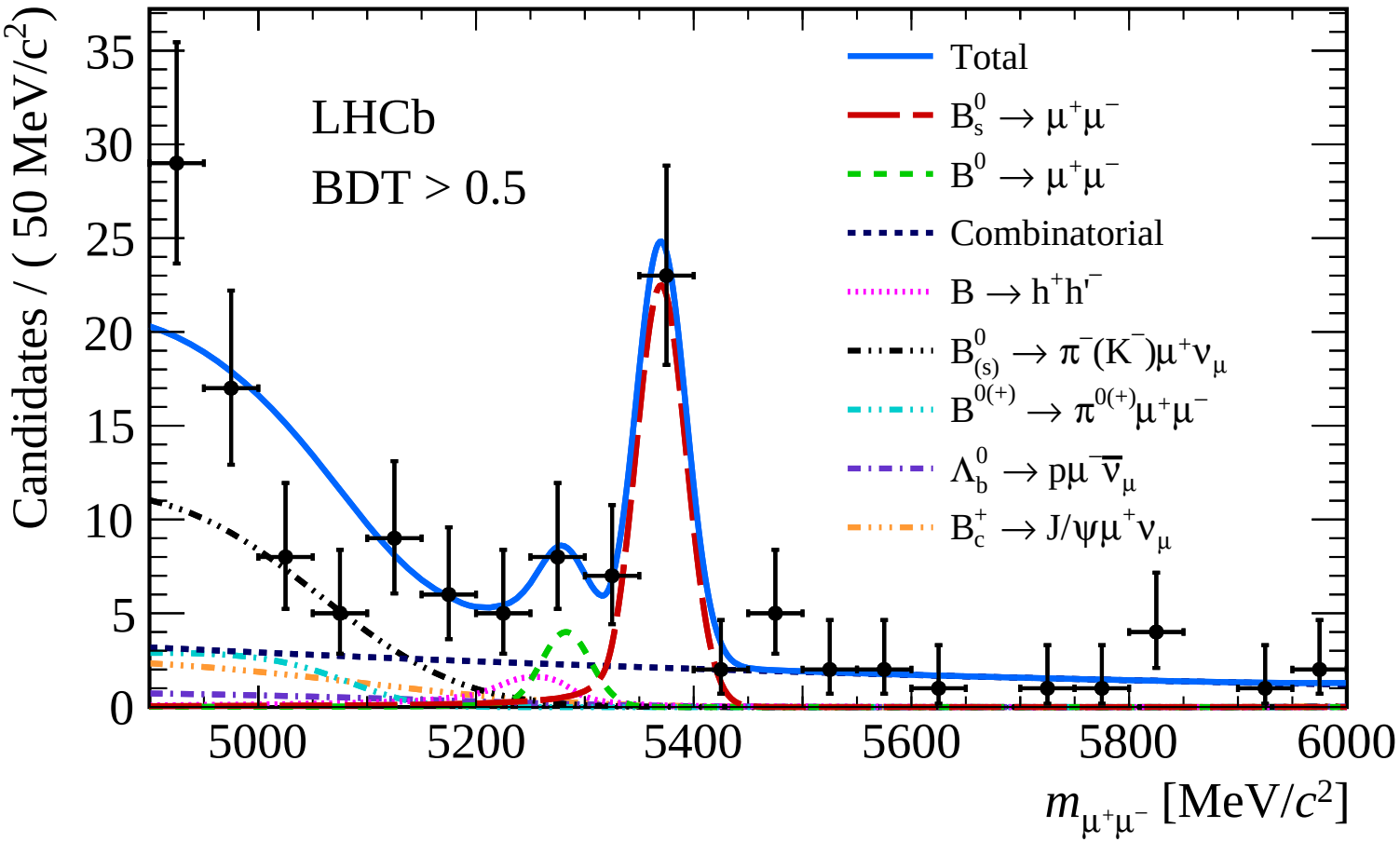


- Multiple backgrounds contaminate signal region:
  - Combinatorial background: non peaking, free in fit
  - Doubly misidentified $B^0_{(s)} \to h^+h^-$ decays
  - Semileptonic backgrounds with misidentification of single hadron
  - Semileptonic backgrounds with two muons
- Data-driven check of background contributions ($h\mu$ fit)
- Background-only plot (arXiv:1703.05747)



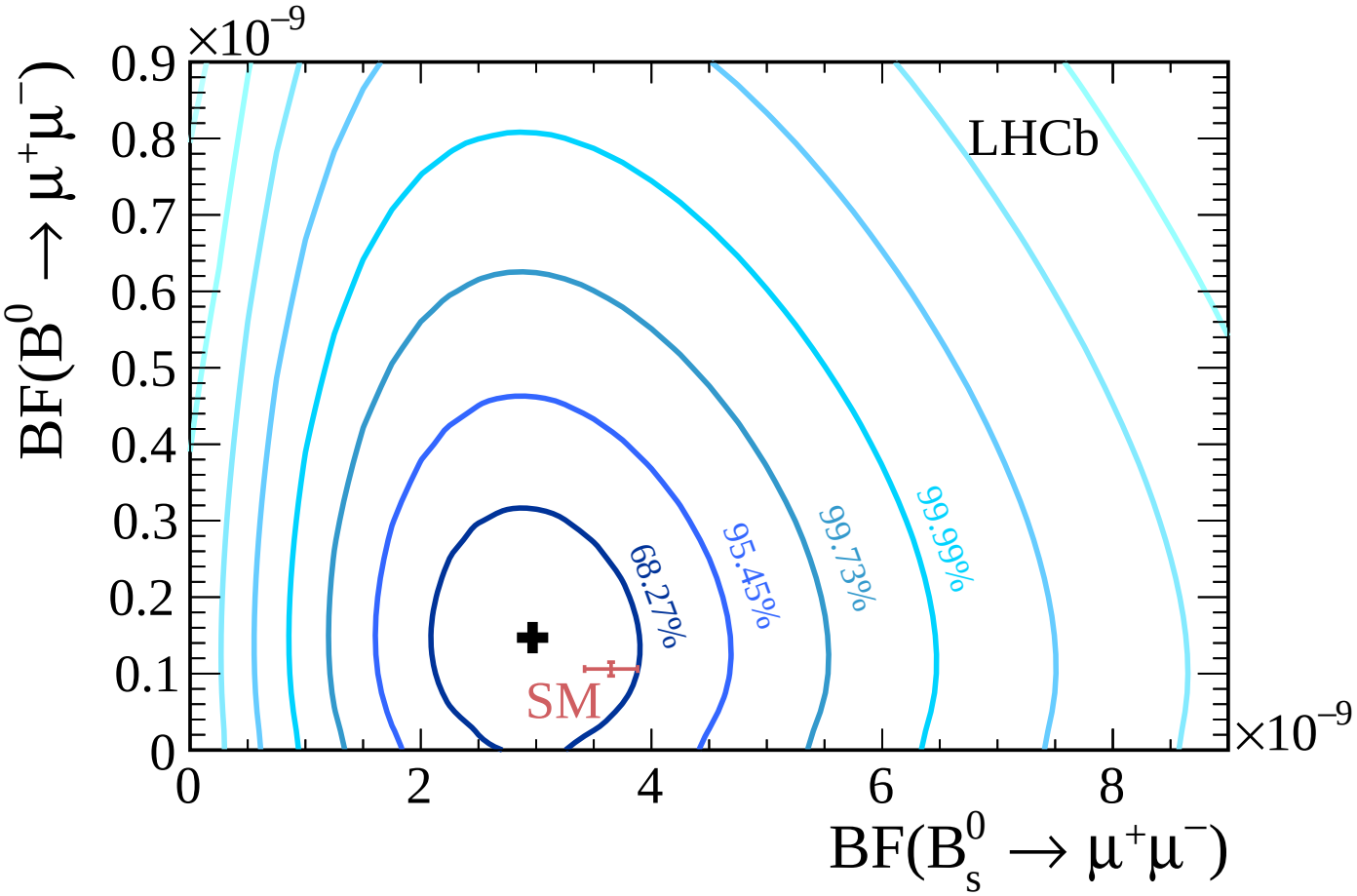
# Branching fraction
## Results

- Simultaneous fit to 8 BDT bins, 4 most sensitive below (arXiv:1703.05747)
- $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.0 \pm 0.6(\text{stat.})^{+0.3}_{-0.2}(\text{syst.})) \times 10^{-9}$ ($S = 7.8\sigma$)
- $\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10}$ at 95% CL



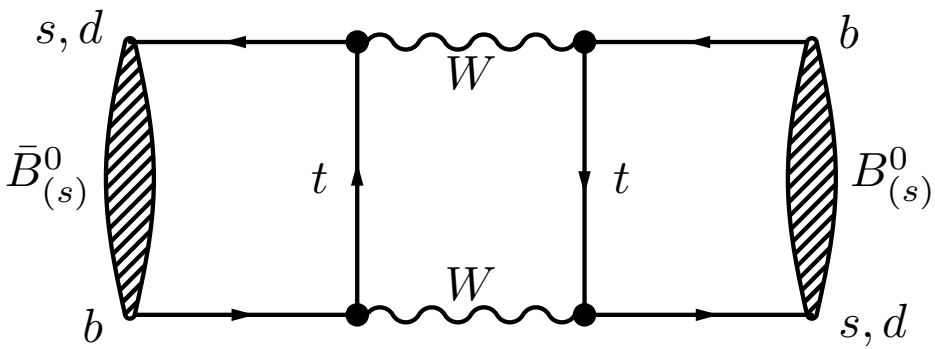
# Branching fraction
## Results

- Consistent with Standard Model (arXiv:1703.05747):
- $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.0 \pm 0.6(\text{stat.})^{+0.3}_{-0.2}(\text{syst.})) \times 10^{-9}$ $(S = 7.8\sigma)$
- $\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10}$ at 95% CL



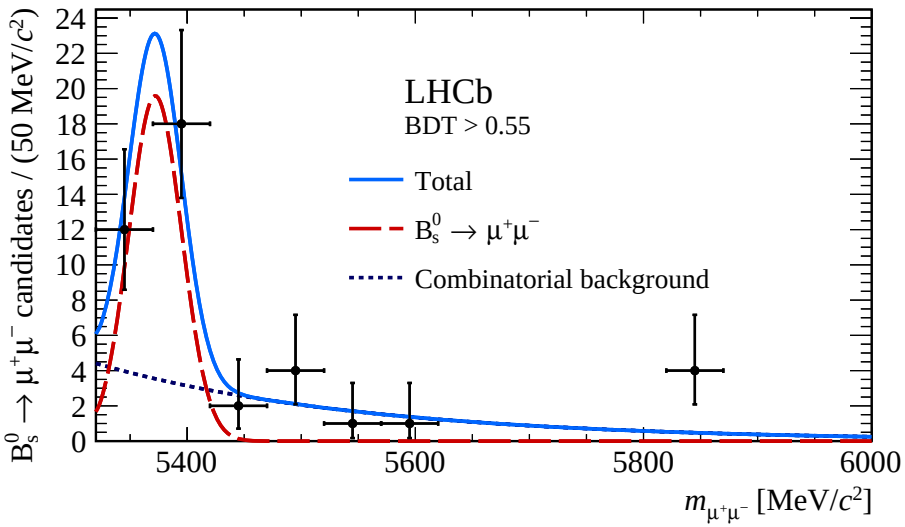
- $B^0_{(s)}$ mesons mix with anti-mesons, forming CP eigenstates
- **What is the CP state of $B^0_{(s)} \to \mu^+\mu^-$?**
- In SM, only CP-odd state decays to $\mu^+\mu^-$
- The $B^0_s$ CP states have a different lifetime: $\tau = 1.510$ ps, $\Delta\tau/\tau \sim 0.12$
- Measure lifetime to probe CP state $B^0_s \to \mu^+\mu^-$
- Never measured before!

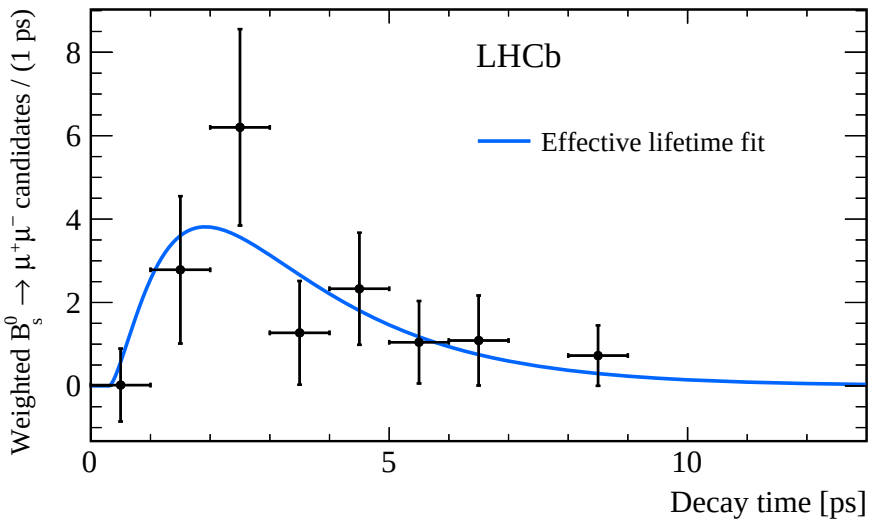
B mixing diagram



# Effective lifetime
## Results

- Effective lifetime analysis optimised for $B_s^0 \to \mu^+\mu^-$
- Looser PID selection, cut on mass window and BDT
- Mass fit: $B_s^0 \to \mu^+\mu^-$ and combinatorial
- Background-subtracted decay-time fit (acceptance included)




- $\tau(B_s^0 \to \mu^+\mu^-) = \mathbf{2.04 \pm 0.44 \pm 0.05}$ **ps** (arXiv:1703.05747)
- Consistent with odd/SM (even/NP) lifetime at $1(1.4)\sigma$ level

# Conclusions

- $B^0_{(s)} \to \mu^+\mu^-$ is important probe for New Physics
- First single experiment observation of $B^0_s \to \mu^+\mu^-$ decay:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.0^{+0.7}_{-0.6}) \times 10^{-9} \ (S = 7.8\sigma)$$

- No evidence for $B^0 \to \mu^+\mu^-$, stringent limit set:

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10} \text{ at } 95\% \text{ CL}$$

- First measurement of effective lifetime

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

- Strong constraints on New Physics!

# Backup slides

Backups are often required