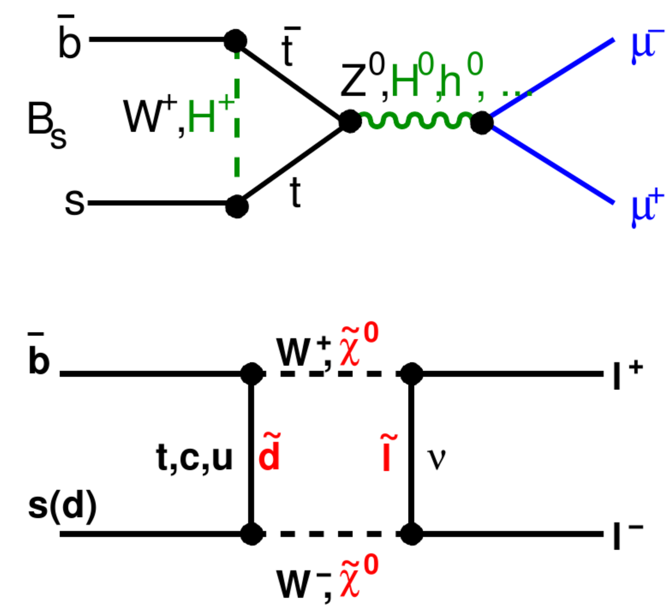
# $B^0_{s(d)} \to \mu\mu$ Search with 1.14 fb$^{-1}$ of CMS Data

## Motivation

- Highly suppressed in the Standard Model
  - flavor-changing neutral current: $b \to s(d)$
  - internal quark annihilation: $(f_B/m_B)^2 \approx 2{\times}10^{-3}$
  - helicity suppressed by factors of $m_\mu^2$
- Enhanced in many models of new physics (green and red contributions to the diagrams)
- $B_s^0 \to \mu\mu$ and $B^0 \to \mu\mu$ are enhanced separately in models containing lepto-quarks, SUSY with non-universal Higgs, and MSSM with large tanβ (proportional to $\tan^6\beta$)

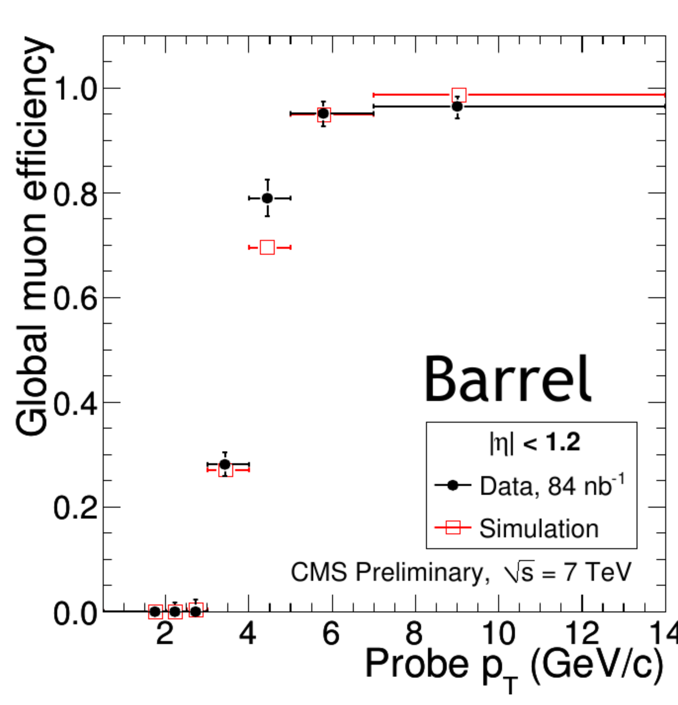



$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$$

(Buras 2010)

## Muon Reconstruction

- Large muon system
  - pseudorapidity coverage up to 2.4
  - 3–4 layers of muon chambers, each containing 6–12 measurement planes
- Two reconstruction algorithms: inside-out and outside-in (both required for this analysis)
- Well-understood efficiency and misidentification rates



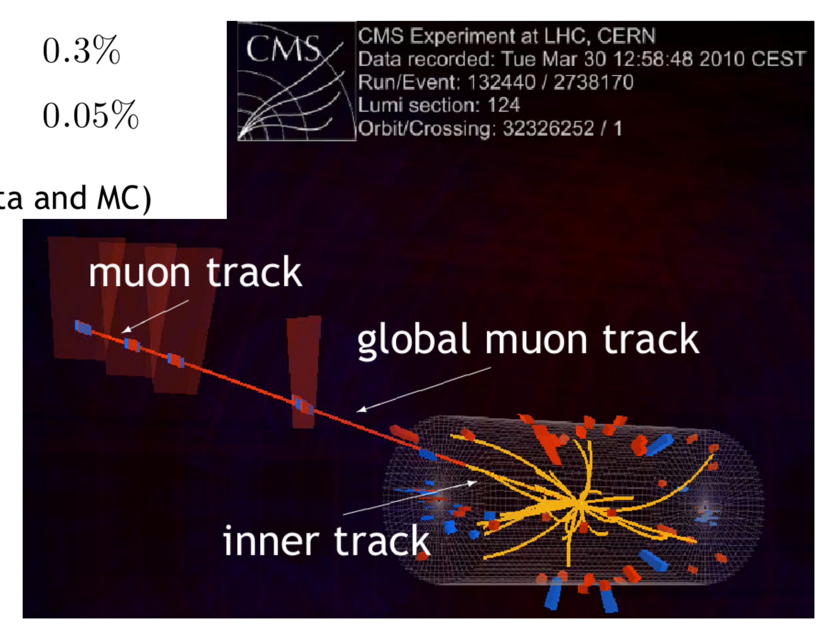

Muon misidentification

$\varepsilon(\mu|\pi) \leq 0.3\%$

$\varepsilon(\mu|K) \leq 0.3\%$

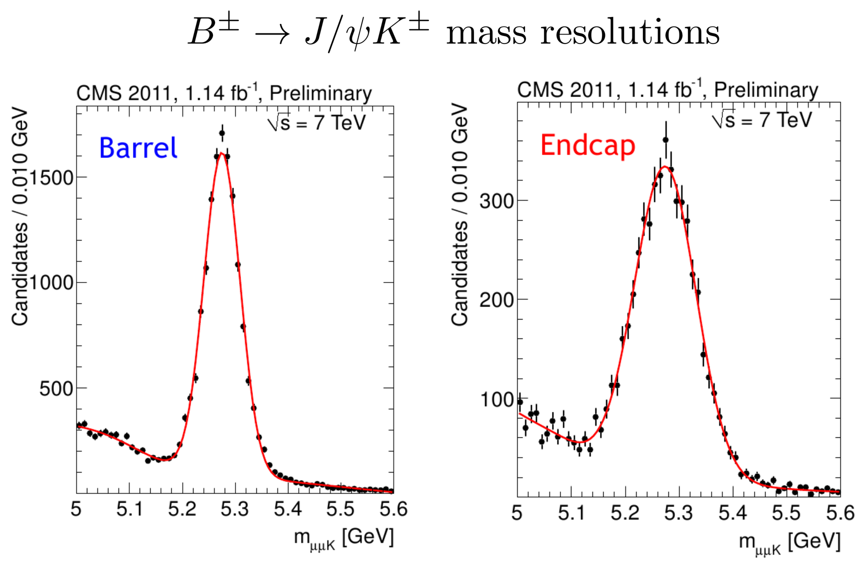
$\varepsilon(\mu|p) \leq 0.05\%$

(measured in data and MC)

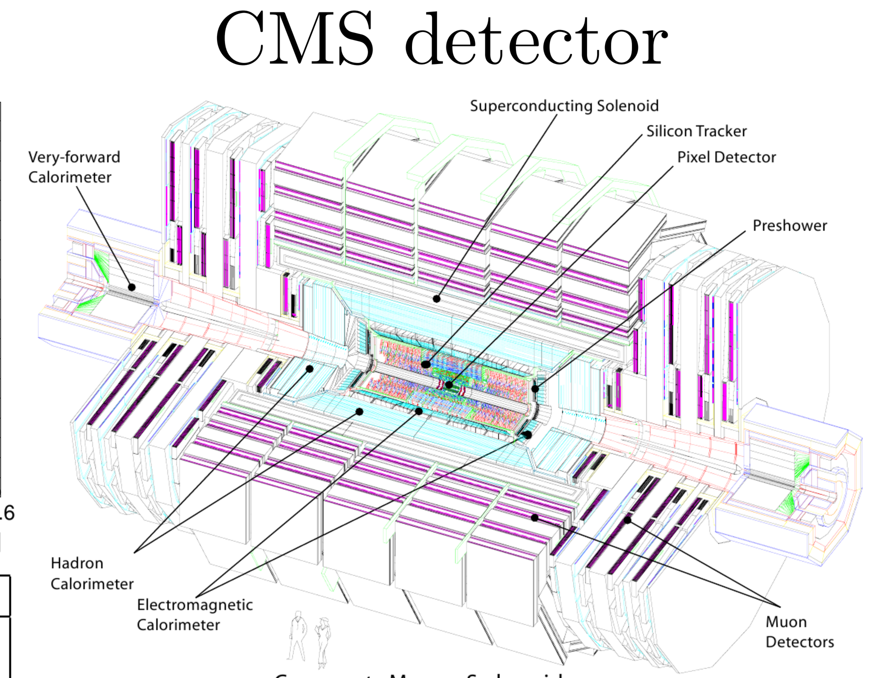



## Detector Resolution

$B^\pm \to J/\psi K^\pm$ mass resolutions



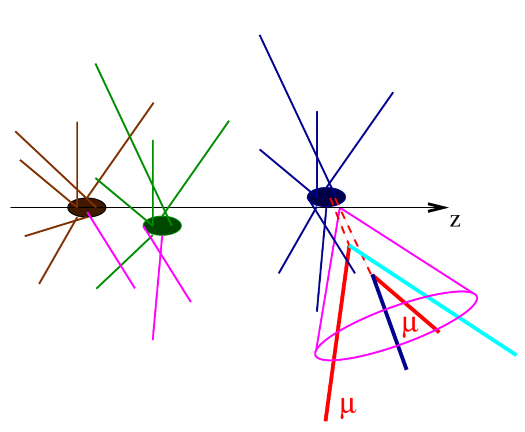

CMS detector



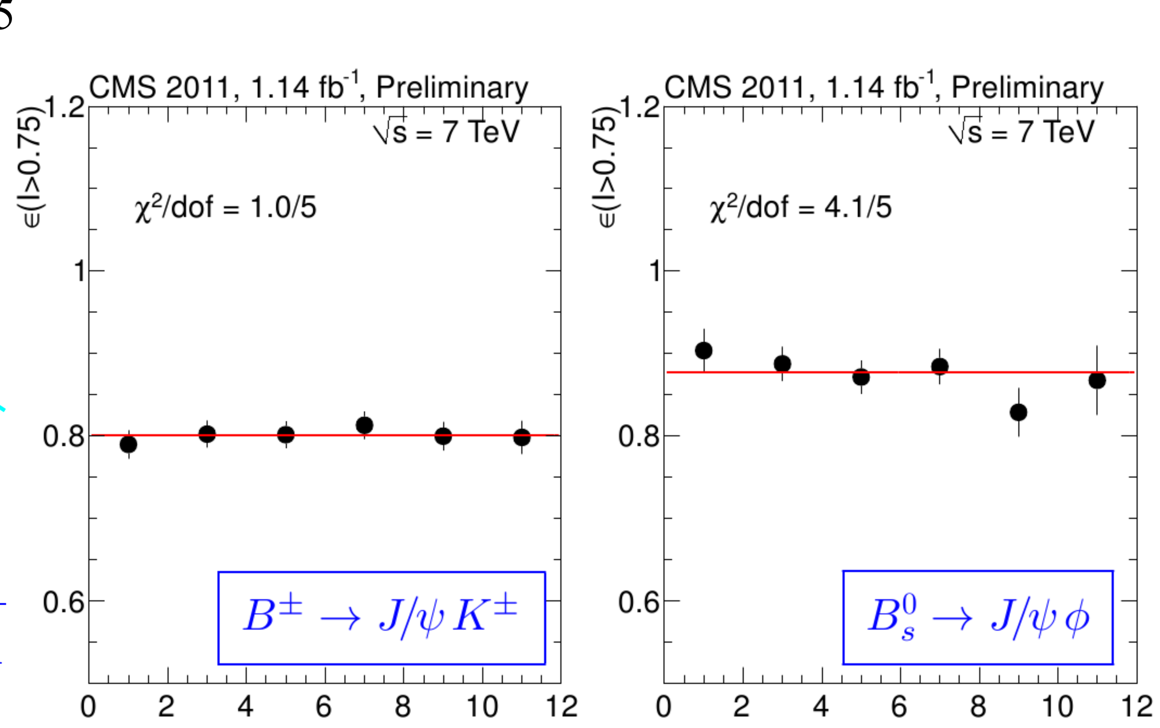

| Component | Characteristics | resolutions |
|---|---|---|
| Pixel | 3/2 Si layers | $\delta_z \approx 20\,\mu$m, $\delta_\phi \approx 10\,\mu$m |
| Tracker | 10/12 Si strips | $\delta(p_\perp)/p_\perp \approx 1\%$ |
| ECAL | $PbWO_4$ | $\delta E/E \approx 3\%/\sqrt{E} \oplus 0.5\%$ |
| HCAL (B) | Brass/Sc, $> 7.2\lambda$ | $\delta E/E \approx 100\sqrt{E}\%$ |
| HCAL (F) | Fe/Quartz | $\delta(\not{E}_T) \approx 0.98\sqrt{\sum E_T}$ |
| Magnet | 3.8 T solenoid | |
| Muons | DT/CSC + RPC | $\delta(p_\perp)/p_\perp \approx 10\%$ (STA) |

## (Lack of) Dependence on Pile-Up

- High-quality alignment and deterministic annealing reconstruction of primary vertices yields significant separation of collision centers
- Track-based quantities are restricted to the primary vertex responsible for the muon pair
- Independence of isolation and flight significance cuts tested with data up to $N_{PV} = 12$
- Current average $N_{PV} = 5.5$




$$I = \frac{p_\perp(\mu^+\mu^-)}{p_\perp(\mu^+\mu^-) + \sum\limits_{\Delta R<1} p_\perp}$$

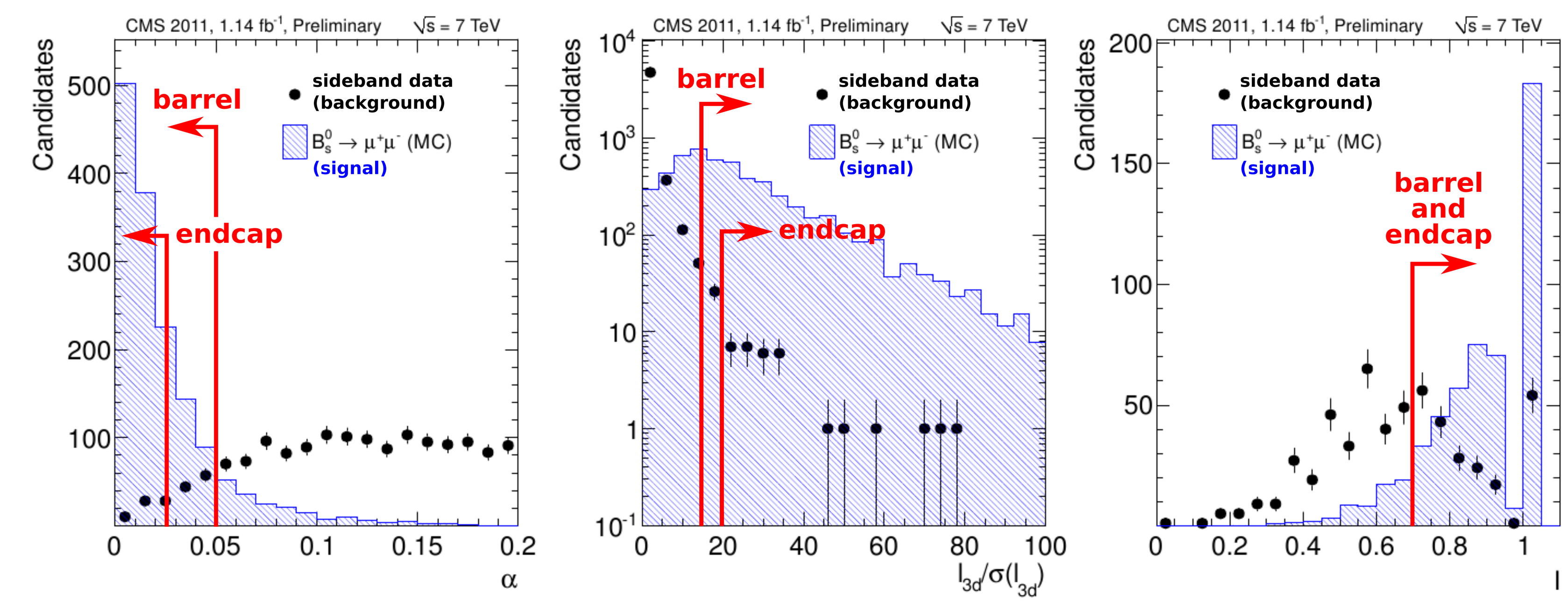



## Analysis

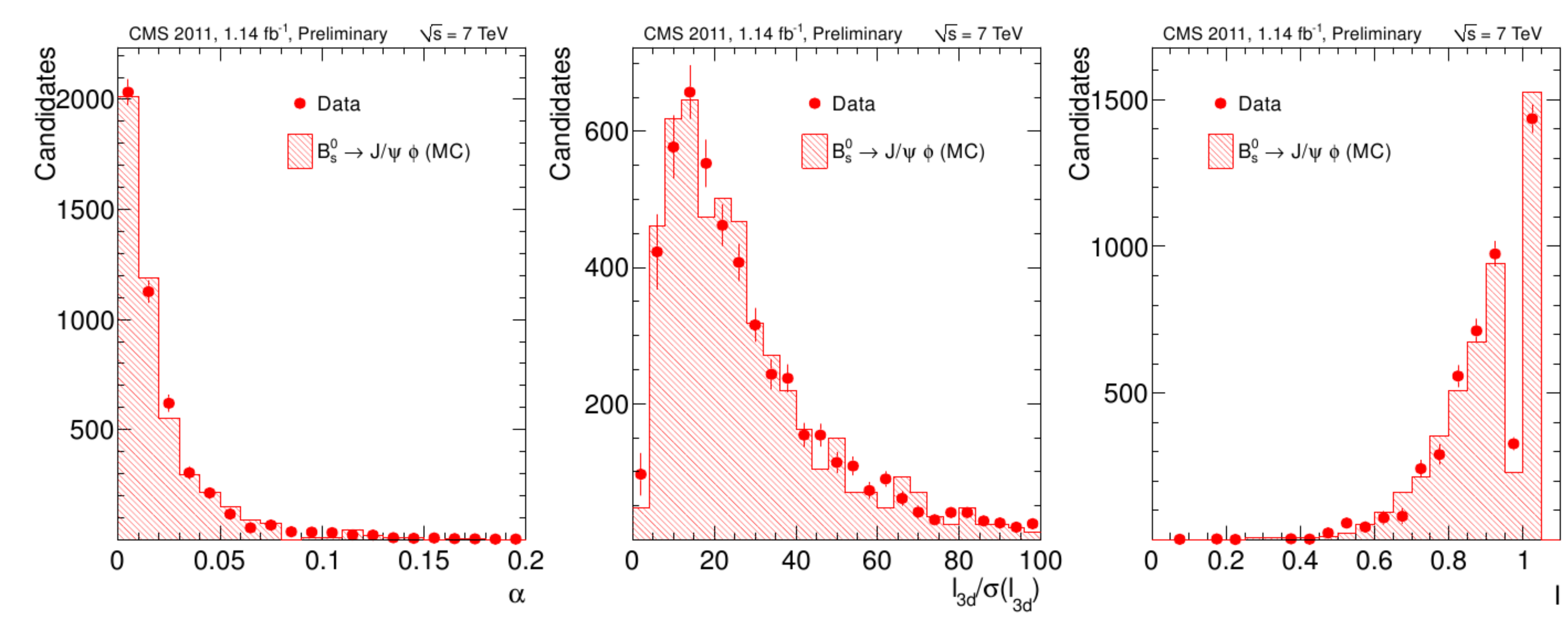
- Barrel (both muon |η| < 1.4) and endcap (at least one |η| ≥ 1.4) treated as separate channels
- Signal branching fractions measured relative to normalization samples

$$\mathcal{B}(B_s^0 \to \mu\mu) = \frac{N_S}{N_{\text{obs}}^{B\pm}} \frac{f_u}{f_s} \frac{\varepsilon_{\text{tot}}^{B\pm}}{\varepsilon_{\text{tot}}} \mathcal{B}(B^\pm \to J/\psi\, K^\pm)$$

- Event selection (grid-search optimized):
  - $p_T$ > 4.5 GeV/c (highest-pT muon), 4.0 (second muon), and 6.5 (vector sum)
  - track $\chi^2$ < 1.6
  - 3D pointing angle α, 3D flight significance ℓ/σ(ℓ), and isolation shown below
  - additional isolation for endcap: non-muon closest approach to B vertex > 150 μm

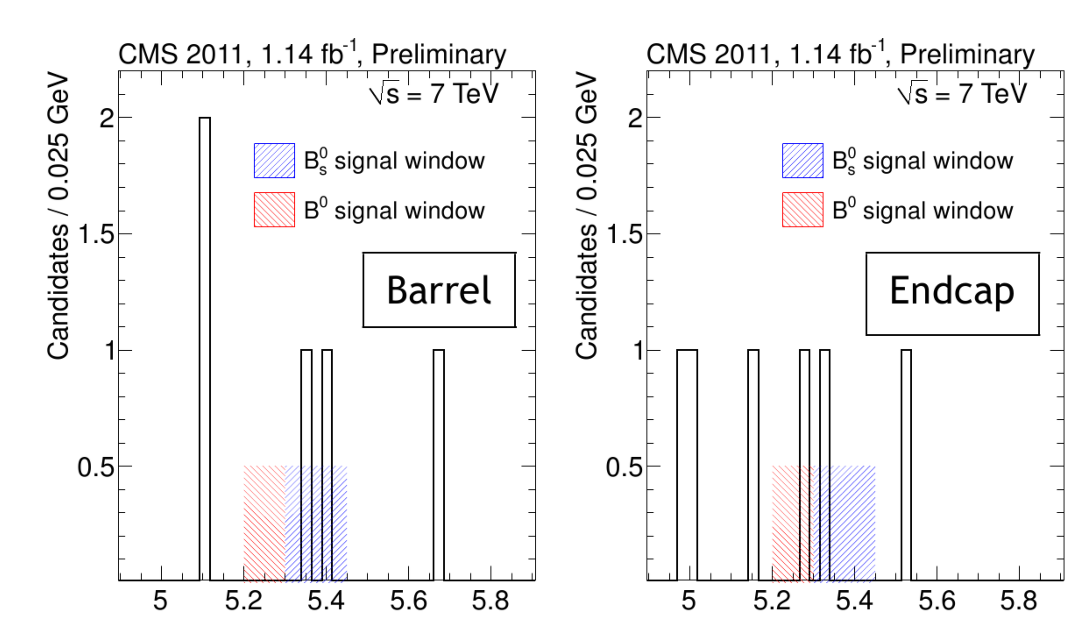



- Validate Monte Carlo by comparing $B_s^0 \to J/\psi\,\varphi$ data with simulation




## Results

- 17% systematic uncertainty (dominated by $f_u/f_s$ ratio)
- Most consistent with the sum of background and $B_{s(d)} \to \mu\mu$ observation
- Upper limits from $CL_S$
- Constrains new physics models (not shown here)




| | Barrel | | Endcap | |
|---|---|---|---|---|
| | $B^0 \to \mu^+\mu^-$ | $B_s^0 \to \mu^+\mu^-$ | $B^0 \to \mu^+\mu^-$ | $B_s^0 \to \mu^+\mu^-$ |
| Acceptance | $(24.62 \pm 0.99) \times 10^{-2}$ | $(24.72 \pm 0.99) \times 10^{-2}$ | $(22.61 \pm 0.91) \times 10^{-2}$ | $(23.14 \pm 0.93) \times 10^{-2}$ |
| $\varepsilon_{\text{analysis}}$ | $(2.23 \pm 0.19) \times 10^{-2}$ | $(2.22 \pm 0.19) \times 10^{-2}$ | $(1.16 \pm 0.10) \times 10^{-2}$ | $(1.24 \pm 0.11) \times 10^{-2}$ |
| $\varepsilon_{\text{tot}}$ | $(0.36 \pm 0.04) \times 10^{-2}$ | $(0.36 \pm 0.04) \times 10^{-2}$ | $(0.21 \pm 0.02) \times 10^{-2}$ | $(0.21 \pm 0.02) \times 10^{-2}$ |
| $N_{\text{signal}}^{\text{exp}}$ | $0.065 \pm 0.011$ | $0.80 \pm 0.16$ | $0.025 \pm 0.004$ | $0.36 \pm 0.07$ |
| $N_{\text{bg}}^{\text{exp}}$ | $0.40 \pm 0.23$ | $0.60 \pm 0.35$ | $0.53 \pm 0.27$ | $0.80 \pm 0.40$ |
| $N_{\text{peak}}^{\text{exp}}$ | $0.25 \pm 0.06$ | $0.07 \pm 0.02$ | $0.16 \pm 0.04$ | $0.04 \pm 0.01$ |
| $N_{\text{obs}}$ | 0 | 2 | 1 | 1 |

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 1.9 \times 10^{-8} \quad (95\%\ \text{C.L.})$$
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 1.6 \times 10^{-8} \quad (90\%\ \text{C.L.})$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 4.6 \times 10^{-9} \quad (95\%\ \text{C.L.})$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.7 \times 10^{-9} \quad (90\%\ \text{C.L.})$$

$p$ values for background-only hypothesis

$B_s^0 \to \mu^+\mu^-$: 0.11

$B^0 \to \mu^+\mu^-$: 0.40

$p$ value for $5.6 \times$ SM (cf. arXiv:1107.2304)

$B_s^0 \to \mu^+\mu^-$: 0.053


Poster prepared by Jim Pivarski on behalf of the CMS Collaboration


**see https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH for more**