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Nikhef

Rare Decays at LHCb

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on behalf of the LHCb collaboration

CIPANP2018, Palm Springs, CA, USA, 29 May – 3 June 2018

Outline

Introduction

$B_{(s)} \to \mu\mu$: qFCNC

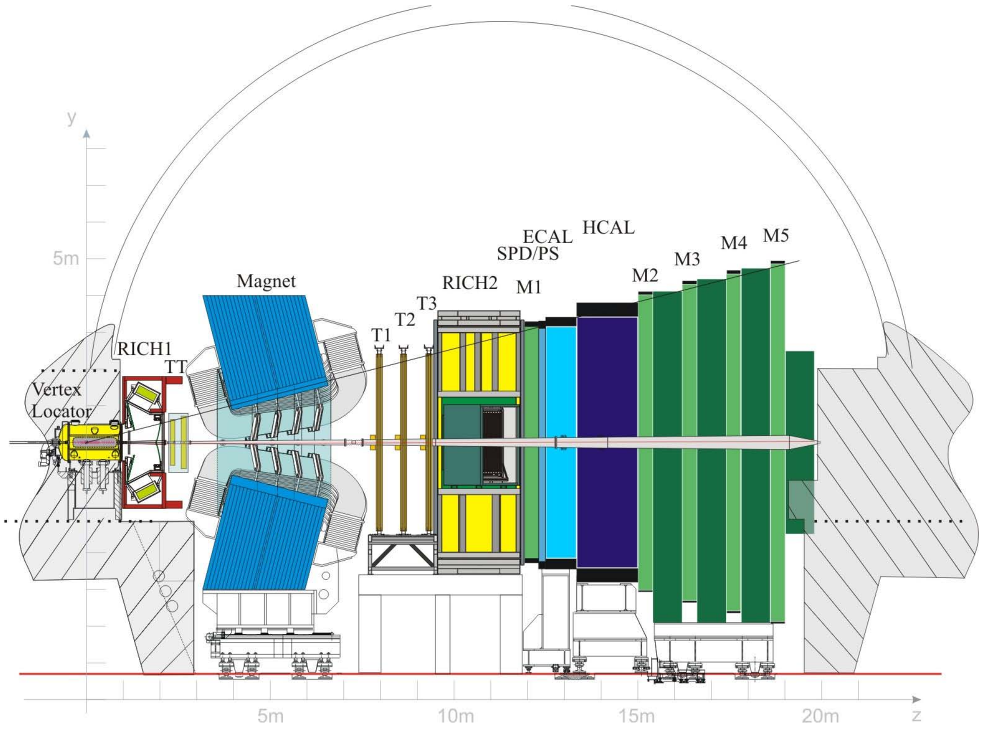
$B_{(s)} \to \tau\tau$: LNU

$B_{(s)} \to e\mu$: cLFV

$B^0 \to \overline{K}^{*0}\mu\mu$: q_{13}FCNC

$B^0 \to K^{*0}\mu\mu$: post-BR

Conclusion



Intro

Testing SM with rare decays

many processes forbidden at tree level b/c symmetry principle

e.g. B, L, $L_{e\mu\tau}$, V-A, LI, CPT, …

possible via SM loop contributions → strongly suppressed → **rare**

BSM may contribute → large deviation from SM prediction

If deviations observed → clear sign of New Physics

Complementary to direct searches

Can probe higher energy ranges through virtual particles

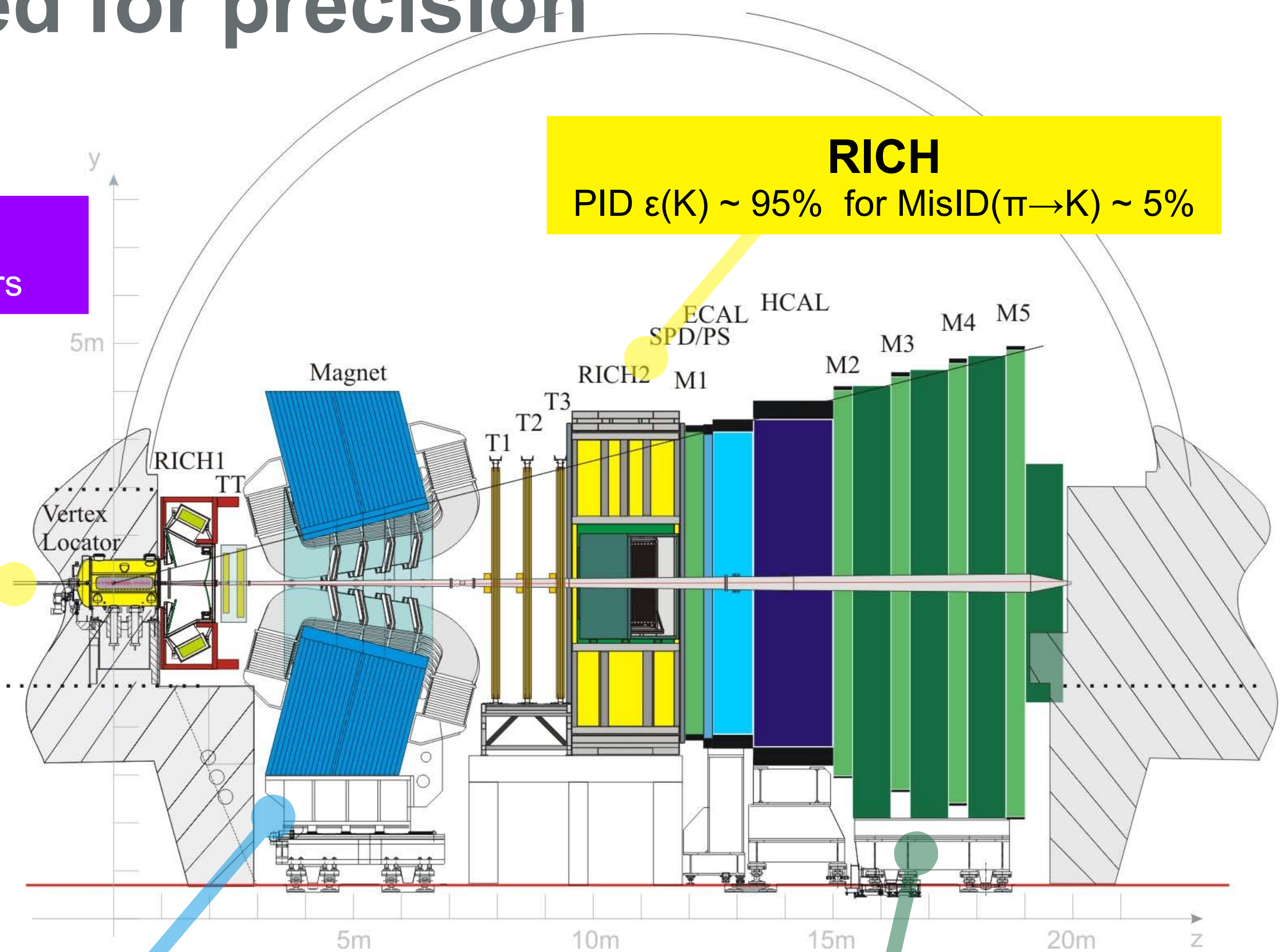
LHCb

LHCb : designed for precision

Trigger
high efficiency *esp.* muon triggers

RICH
PID ε(K) ~ 95% for MisID(π→K) ~ 5%

VELO
IP resolution 15+29/(p_T/GeV) µm

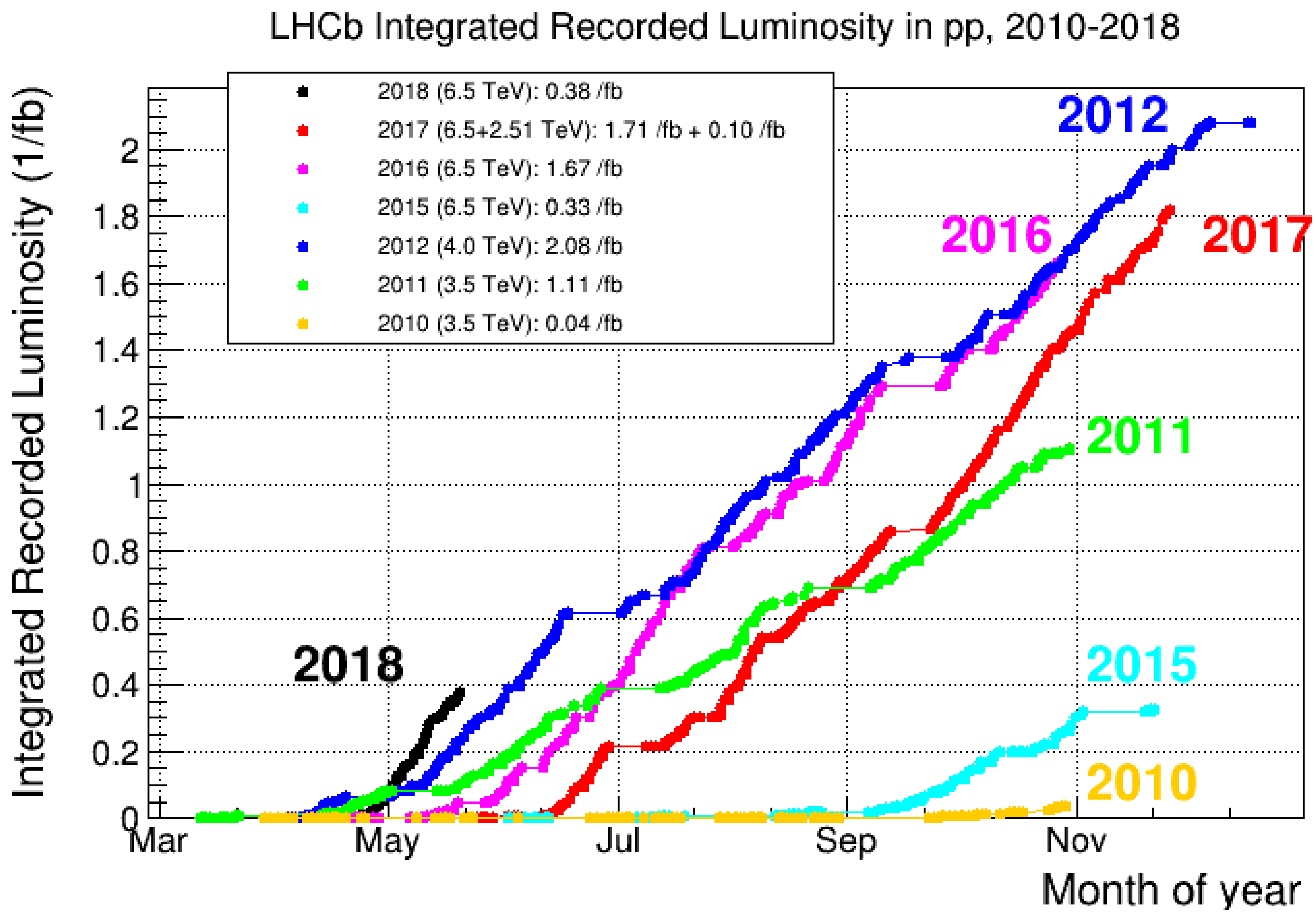


Tracking Δp/p
0.4% @ 5 GeV/*c* – 1.0% @ 200 GeV/*c*

Muon ID
identification ε ~ 97% misID ~ 2%

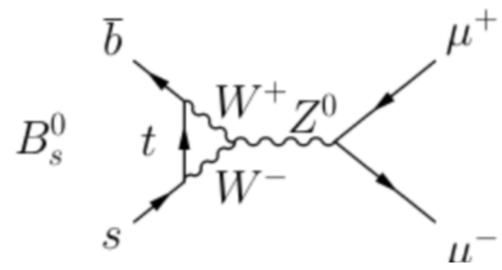
Int. J. Mod. Phys. A 30, 1530022 (2015)

Excellent data collection



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

Golden Channel

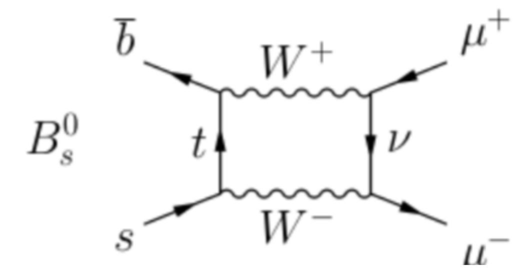


Very rare decay, heavily helicity suppressed

within SM only through loops

$Br_{SM}(B_S \to \mu^+\mu^-) = (3.66 \pm 0.23) \cdot 10^{-9}$

$Br_{SM}(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \cdot 10^{-10}$

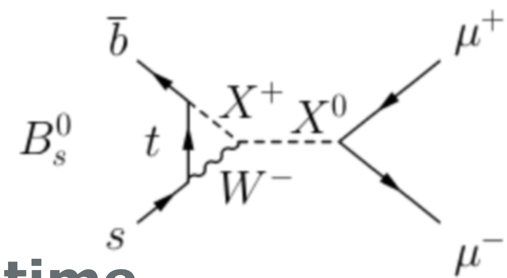


Previous measurement

LHCb + CMS, 2011 + 2012 data

$Br(B_S \to \mu^+\mu^-) = (2.8 \pm 0.7) \cdot 10^{-9}$

$Br(B^0 \to \mu^+\mu^-) = (3.9 \pm 1.6) \cdot 10^{-10}$

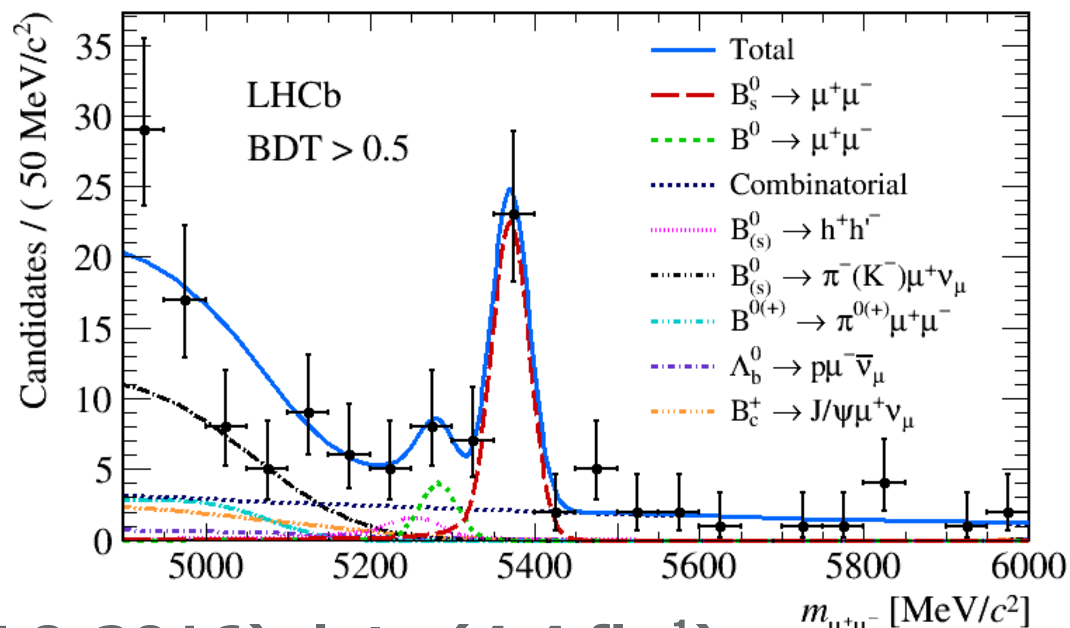


Complementary measurement of effective lifetime

can help disentangle B_S and $\bar{B}_S$ contributions

Theory: doi.org/10.1103/PhysRevLett.112.101801
LHCb + CMS: doi:10.1038/nature14474

Branching Fractions



Optimization

Better rejection of misidentified b-hadron decays

Improved separation of signal from combinatorial background

Run1 + part Run2 (2015 & 2016) data (4.4 fb^{-1})

Br($B_S \to \mu^+\mu^-$) = $(3.0\pm0.7)\cdot10^{-9}$ 7.8σ excess

Br($B^0 \to \mu^+\mu^-$) = $<3.4\cdot10^{-10}$ @ 95% C.L.

Results compatible with SM → stringent BSM constraint

doi.org/10.1103/PhysRevLett.118.191801

Effective Lifetime

Fit Details

Background-subtracted data

Reduced **μμ** mass window

Looser PID requirements for **μ**'s

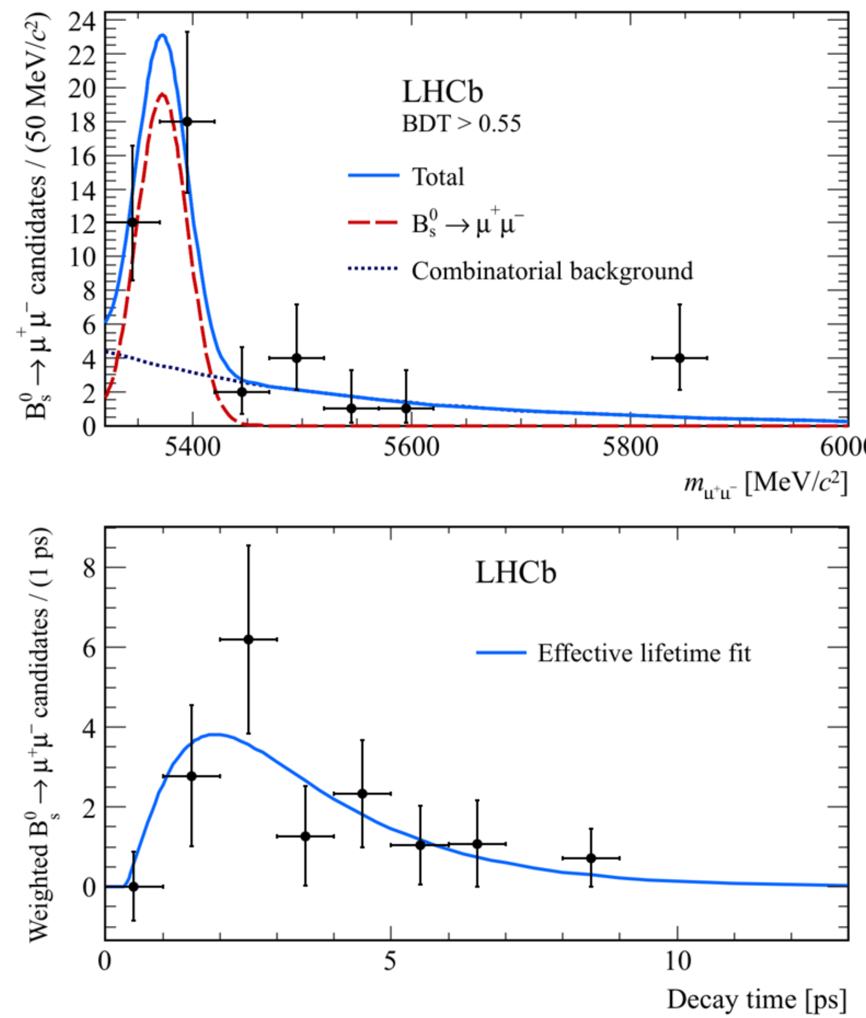
Cut excessively large times

Results

$\tau(B_s \to \mu^+\mu^-) = 2.04 \pm 0.44 \pm 0.05$ ps

Consistent with SM at 1.0σ

Convincing proof-of-principle



doi.org/10.1103/PhysRevLett.118.191801

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

Gold-plated channel

Less helicity suppressed, Universality test

$Br_{SM}(B_S \to \tau^+\tau^-) = (7.73 \pm 0.49) \cdot 10^{-7}$

$Br_{SM}(B^0 \to \tau^+\tau^-) = (2.22 \pm 0.19) \cdot 10^{-8}$

BSM explaining latest LNU → **enhance orders of magnitude**

Previous measurements

$Br(B_S \to \tau^+\tau^-) < 3 \cdot 10^{-2}$ Indirect @ 90% C.L.

$Br(B^0 \to \tau^+\tau^-) < 4 \cdot 10^{-3}$ Babar @ 90% C.L.

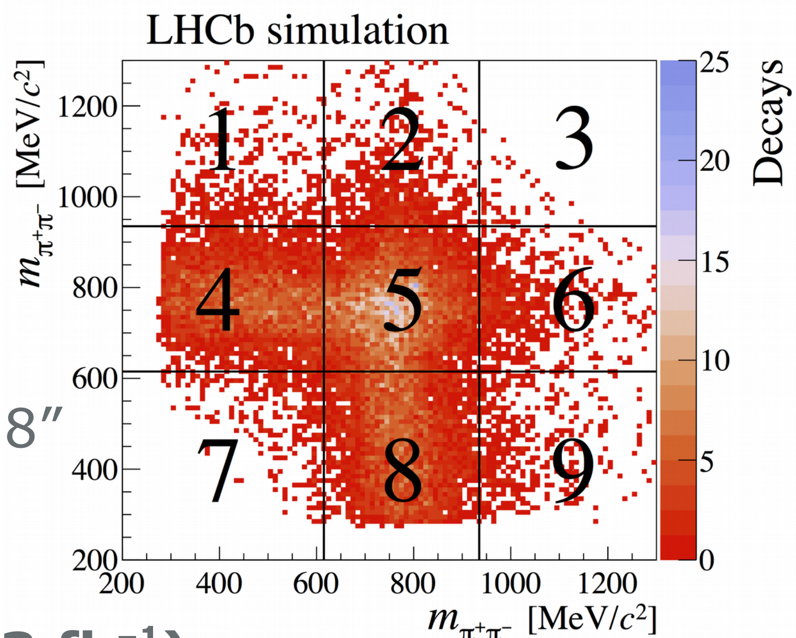
Tau reconstruction

use $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ via $\tau^- \to a_1 \nu_\tau$, $a_1 \to \rho^0 \pi^-$, $\rho^0 \to \pi^+ \pi^-$

final state neutrinos → cannot use $m_{\tau\tau}$ to distinguish B_S & B^0

Theory: doi.org/10.1103/PhysRevLett.112.101801
Babar: doi.org/10.1103/PhysRevLett.96.241802
Bs result: doi.org/10.1103/PhysRevD.82.031502

Signal Extraction



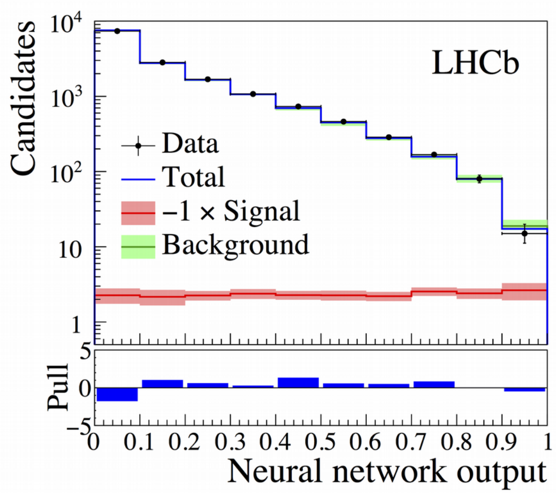
Exploit $\rho(770)^0$ resonance

Signal : both τ's in "5"

Signal-depleted : $\geq 1\tau$ in "1,3,7,9"

Control : 1τ in "4,5,8", 1τ in "4,8"

Fit to Neural Network



Run1 data (3 fb^{-1})

$Br(B_s \to \tau^+\tau^-) < 6.8 \cdot 10^{-3}$ @ 95% C.L.

(first direct limit)

$Br(B^0 \to \tau^+\tau^-) < 2.1 \cdot 10^{-3}$ @ 95% C.L.

(world's best limit)

Still far from SM prediction

doi.org/10.1103/PhysRevLett.118.251802

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

Lepton-Flavour Violating decay

Forbidden in SM → sensitive to new physics

allowed through neutrino mixing $Br_{SM}(B_S \to e\mu) = O(10^{-huge})$

large LFV expected in numerous BSM scenarios (SUSY, LQ, ...)

Previous measurements: LHCb 1 fb^{-1}

$Br(B_S \to e\mu) < 1.4 \cdot 10^{-8}$ @ 95% C.L.

$Br(B^0 \to e\mu) < 3.7 \cdot 10^{-9}$ @ 95% C.L.

Improvements

larger data sample

improved selection (multivariate classifier)

improved treatment of Bremsstrahlung

BSM: doi.org/10.1103/PhysRevD.92.054013
BSM: doi.org/10.1103/PhysRevD.94.115021
BSM: doi.org/10.1007/JHEP06(2015)072
LHCb:doi.org/10.1103/PhysRevLett.111.141801

Signal Extraction

Unbinned maximum likelihood fit to the $m_{e\mu}$ distributions

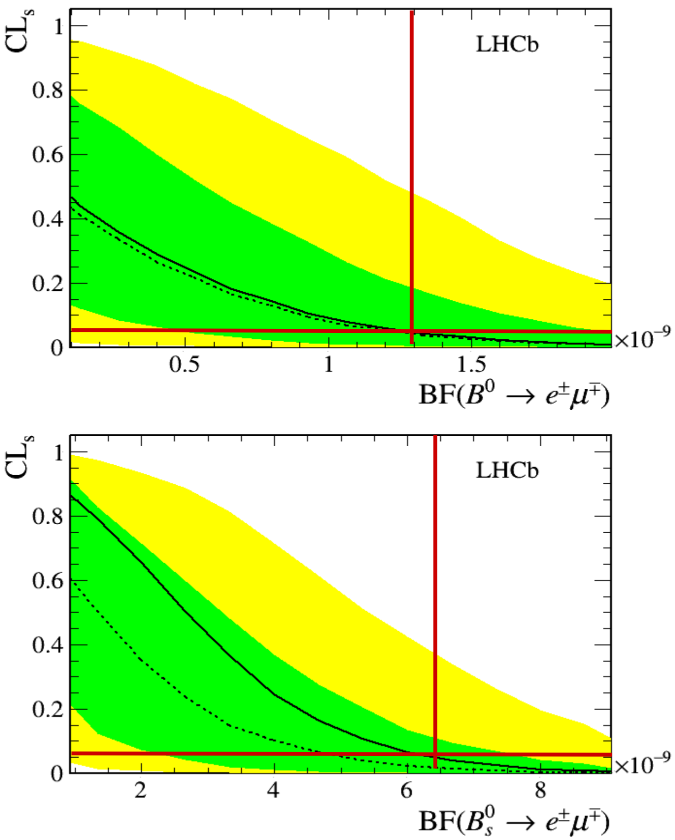
- 7 bins in BDT response
- **signal**: simulated $B_S \to$ **eμ**
- **background**: data with **eμ**

Run1 data (3 fb^{-1}, @ 95% C.L.)

- $Br(B^0 \to e\mu) < 1.3 \cdot 10^{-9}$
- $Br(B_S \to e\mu) < 6.3 \cdot 10^{-9}$

Strongest limit on these decays

- **consistent with background-only**



doi.org/10.1007/JHEP03(2018)078

$B_s^0 \to \overline{K}^{*0} \mu\mu$

Search for new channel

$b \to d$ Flavor-Changing Neutral Current

- $Br_{SM}(B_s \to \overline{K}^{*0}\mu\mu) \sim O(10^{-8})$ (CKM suppressed)
- complementary to $B^0 \to K^{*0}\mu\mu$
- can be used to calculate $|V_{td}/V_{ts}|$
- **never observed**

Unbinned maximum likelihood fit to $m(K^-\pi^+\mu^+\mu^-)$

- $m(K^-\pi^+)$ within ±70 MeV/c² of $\overline{K}^*(892)^0$
- Use $0.1 < q^2 = m^2_{\mu\mu} < 19$ GeV²/c⁴
  - $12.5 < q^2 < 15.0$ GeV²/c⁴ excluded, Ψ(2S)
  - $8.0 < q^2 < 11.0$ GeV²/c⁴ treated separately, J/Ψ

arXiv:1804.07167

Signal Extraction

Run1 + part Run2 (2015 + 2016) data (4.6 fb^{-1})

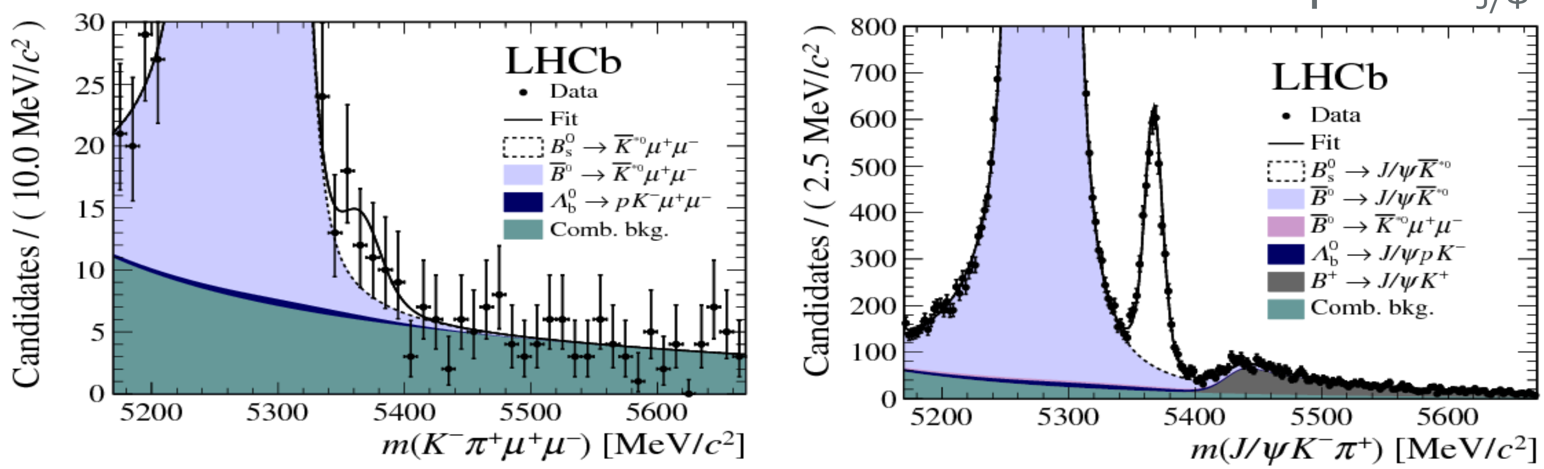
$N(B_s \to \overline{K}^{*0}\mu\mu) = 38 \pm 12$ 3.4σ above background

(first evidence)

$Br(B_s \to \overline{K}^{*0}\mu\mu) = [2.9 \pm 1.0(stat) \pm 0.2(sys) \pm 0.3(norm)] \cdot 10^{-8}$

(first measurement)

$q^2 = m^2_{J/\psi}$



arXiv:1804.07167

$B^0 \to K^{*0}\mu\mu$

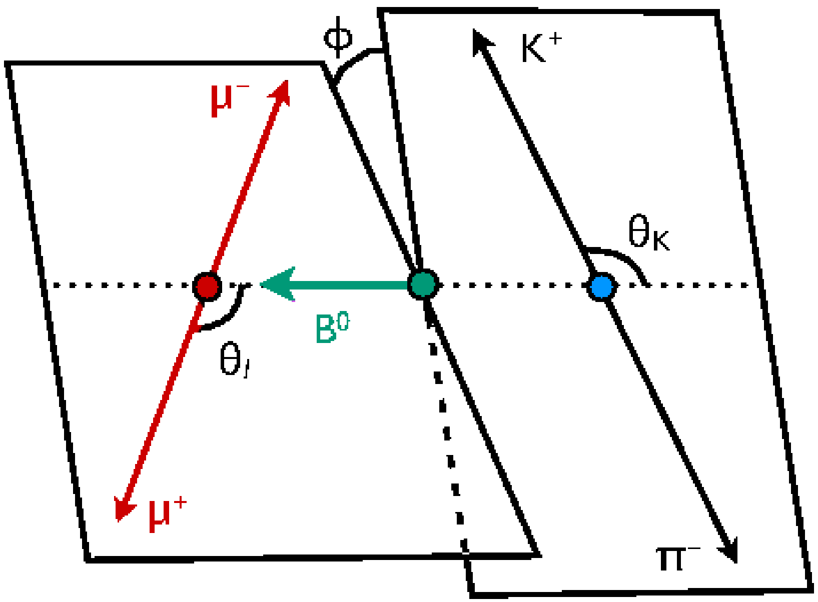
Enhancing sensitivity

b → s Flavor-Changing Neutral Current

- move beyond branching fractions → angular distribution
- **angular observables**: less affected by hadronic uncertainties than branching fraction measurements

Previous measurements

- by LHCb, Babar, Belle, CDF, CMS
- $K^*(892)^0 \to K^+\pi^-$
- final state characterized by
  - $(\theta_\ell, \theta_K, \varphi)$, $m(K^+\pi^-)$, $q^2(m^2_{\mu\mu})$



LHCb : doi.org/10.1103/PhysRevLett.111.191801
Babar : doi.org/10.1103/PhysRevD.73.092001
Belle : doi.org/10.1103/PhysRevLett.103.171801
CDF : doi.org/10.1103/PhysRevLett.108.081807
CMS : doi.org/10.1016/j.physletb.2013.10.017

Signal Extraction

$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi\, dq^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

Use of optimized observables

reduce theoretical uncertainties

$P_5' = S_5 / \sqrt{F_L(1-F_L)}$

Tension with SM prediction

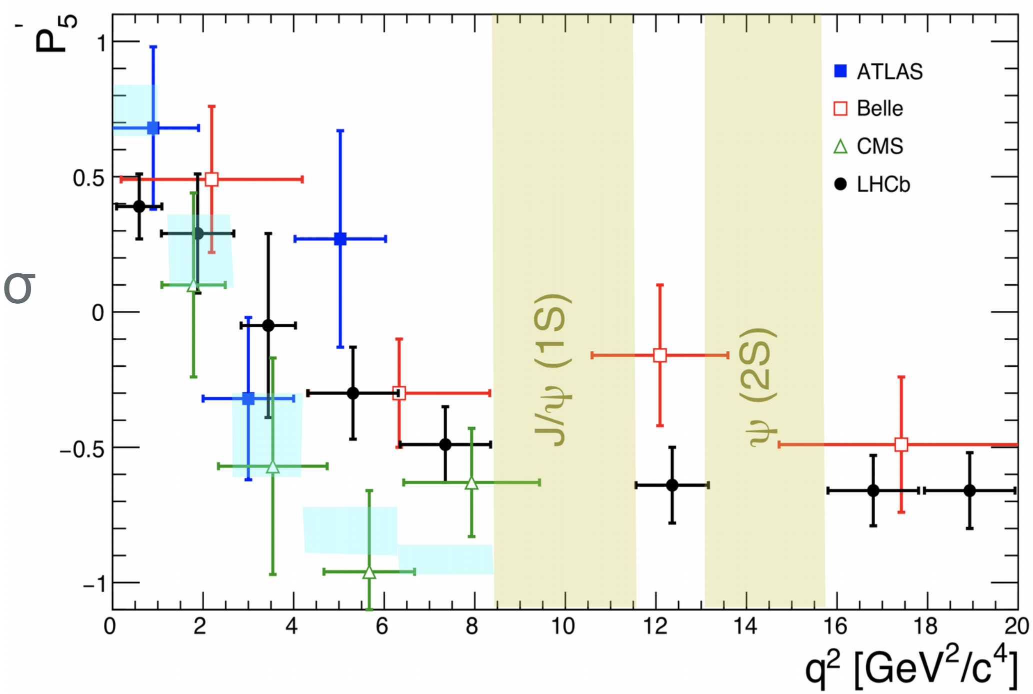
obvious in two q^2 bins of P_5'

combined $P_i^{(\prime)}$ significance 3.4σ

– **BSM** physics?

– **QCD** uncertainty?

Consistent with other data



doi.org/10.1007/JHEP02(2016)104
arXiv:1805.05399

Conclusion

Take away message

A lot of activity in rare decays @ LHCb

- $B_s \to \mu^+\mu^-$: first observation in single experiment + first measurement of effective lifetime
- Improved upper limits for $B_{(s)} \to \tau^+\tau^-$ and $B_{(s)} \to e\mu$
- First evidence of $B_s \to \overline{K}^{*0}\mu^+\mu^-$
- $B^0 \to K^{*0}\mu^+\mu^-$: tension with SM persists
- Many more results: FCNC, LFV, BNV, LNV, $qq\bar{q}q\bar{q}$, γ_{dark}, ν_{heavy}, …

Important constraints on New Physics

university of groningen
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Thank you for your attention!

LHCb

Nikhef