university of groningen / faculty of science and engineering / van swinderen institute for particle physics and gravity

Nikhef

cLFV @ LHCb

Status & Prospects

Gerco Onderwater

on behalf of the LHCb collaboration

cLFV2016, Fukuoka, Japan, 17-19 June 2019

Outline

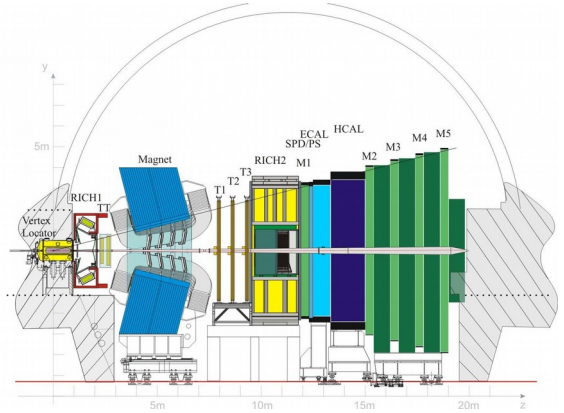
Intro

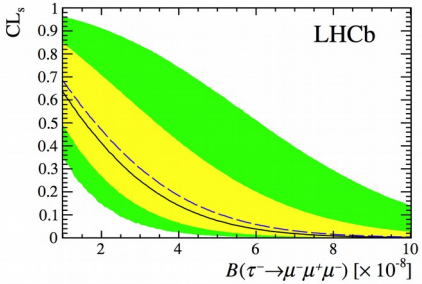
LHCb Experiment

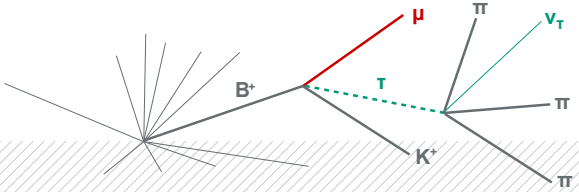
LFV with electrons : $B^0 \to e\mu$

LFV with taus : $B^0 \to \mu\tau$

Conclusion



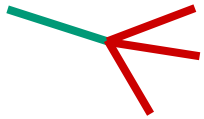




Intro

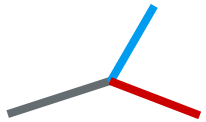
Towards studying (c)LFV

Decay $\mu \to e\gamma$, $\mu \to eee$, $\tau \to \mu\mu\mu$, $\tau \to \mu hh$, ...



Conversion $\mu A \to eA$

Production $B_s \to e\mu$, $B \to Ke\mu$, $h^0 \to \mu\tau$, ...



Oscillation $\nu_e \leftrightarrow \nu_\mu \leftrightarrow \nu_\tau$, $M(\mu^+e^-) \leftrightarrow \overline{M}(\mu^-e^+)$

Number violation $0\nu2\beta$, $B^- \to \pi^+\mu^-\mu^-$, ...

Non-Universality $\overline{B}^0 \to D^{*+}\tau^-\overline{\nu}_\tau$ *vs* $\overline{B}^0 \to D^{*+}\mu^-\overline{\nu}_\mu$, ...

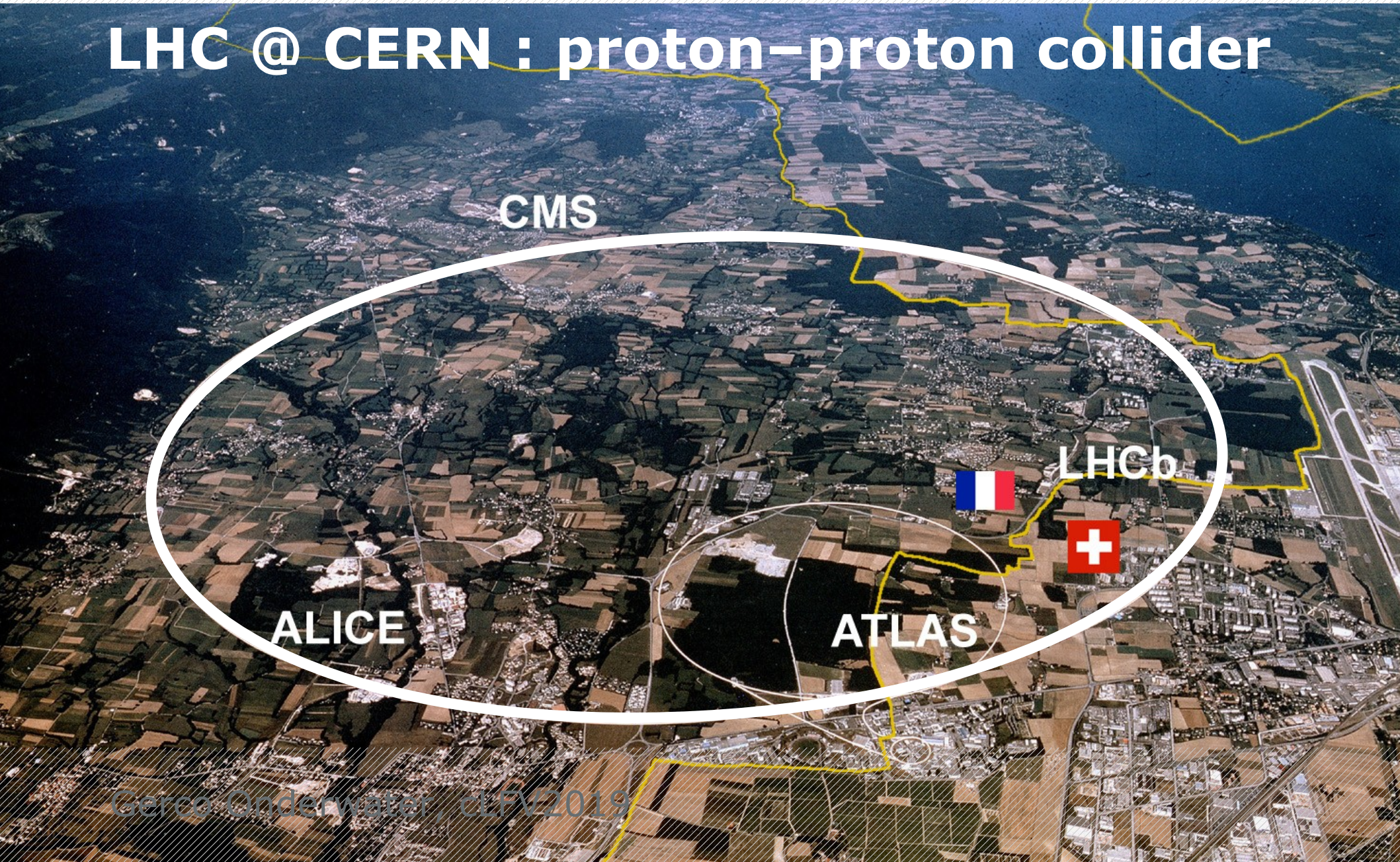
Charges dropped, unless relevant

LHCb results since cLFV2016

$B^0_{(s)} \to \tau\mu$	arXiv:1905.06614 (PRL)	**LFV**	⟸
$h^0 \to \tau\mu$	EPJ C78 (2018) 1008	**LFV**	
$B^0_{(s)} \to e\mu$	JHEP 03 (2018) 043	**LFV**	⟸
$B^+_{(s)} \to K^+\mu\mu$ / ee	PRL 122, 191801 (2019)	LNU	
$Z^0 \to \tau\tau$ / ee	JHEP 09 (2018) 159	LNU	
$B_c^+ \to J/\psi\, e\bar{\nu}_e$ / $\mu\bar{\nu}_\mu$	PRL 120, 121801 (2018)	LNU	
$\bar{B}^0 \to K^{*0}\mu\mu$ / ee	JHEP 08 (2017) 055	LNU	
$\bar{B}^0 \to D^{*+}\tau\bar{\nu}_\tau$ / $\mu\bar{\nu}_\mu$	PRL 120, 171802 (2017)	LNU	

LHCb

LHC @ CERN : proton–proton collider

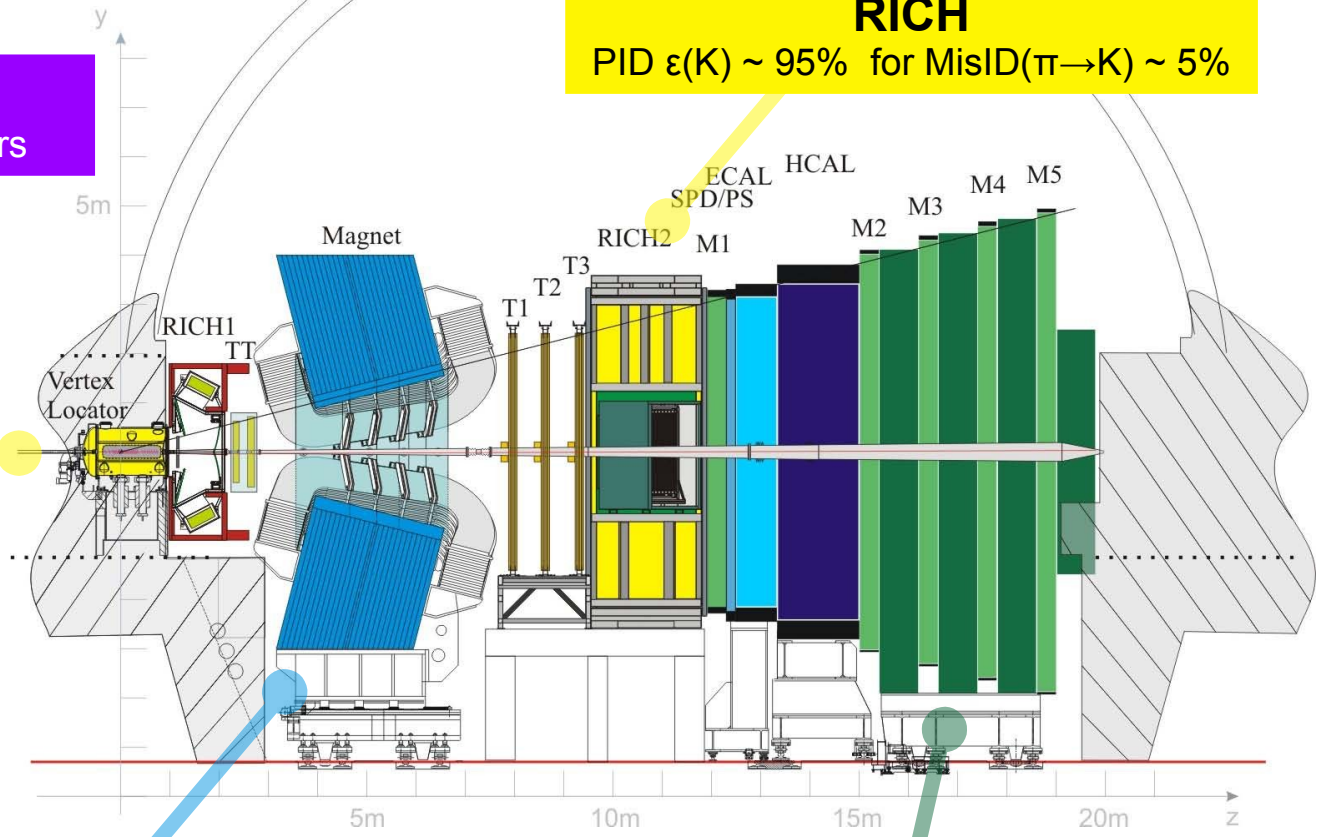


LHCb detector

LHCb : precision measurement

Trigger
high efficiency *esp.* muon triggers

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



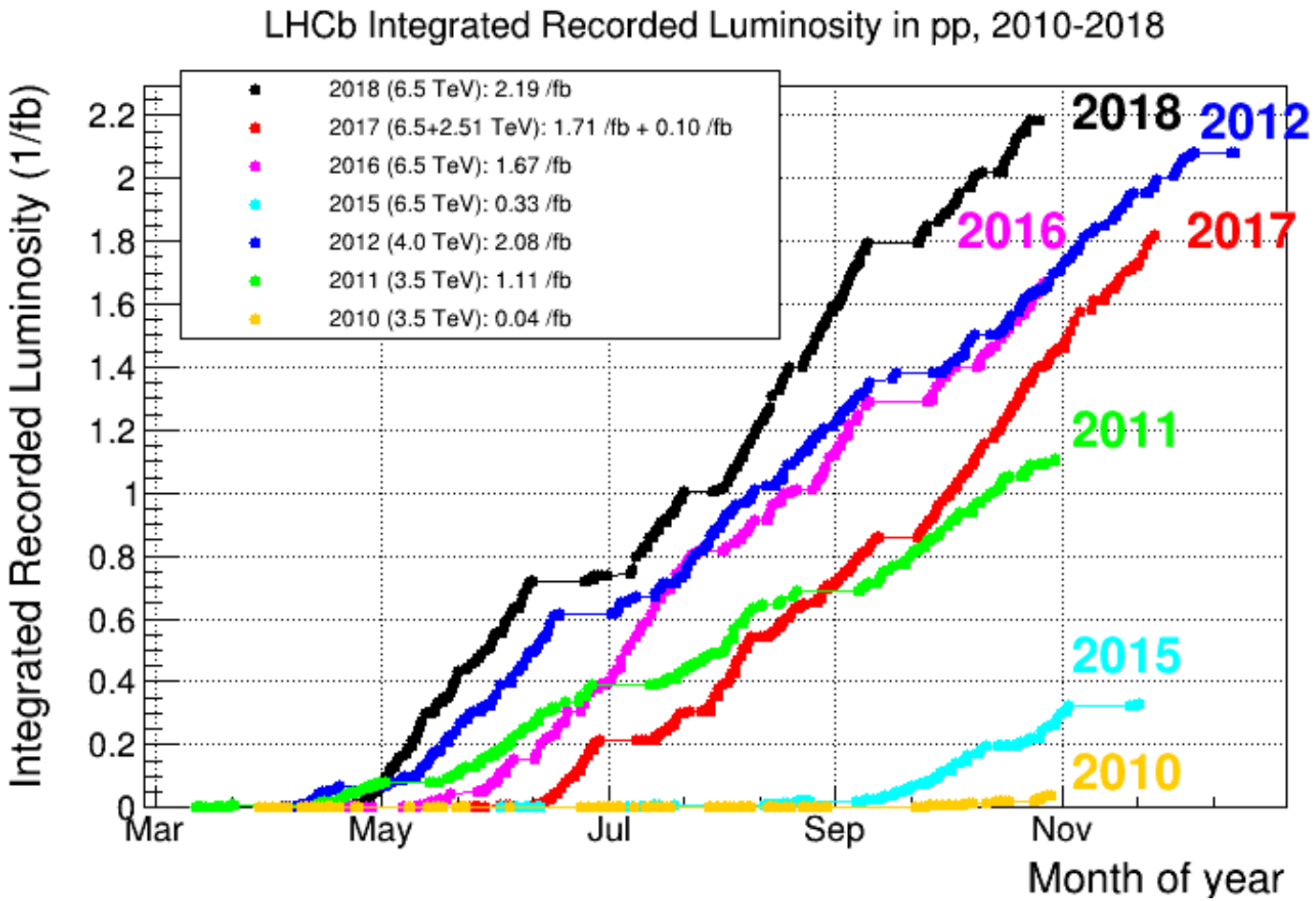
VELO
~20μm IP resolution for p_T > 2 GeV

Tracking Δp/p
0.4% @ 5 GeV/*c* – 0.6% @ 100 GeV/*c*

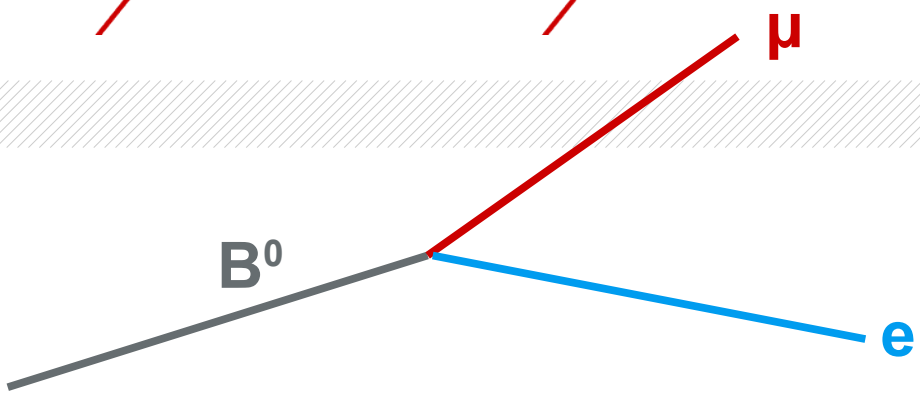
Muon ID
identification ε ~ 97% misID ~ 2%

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

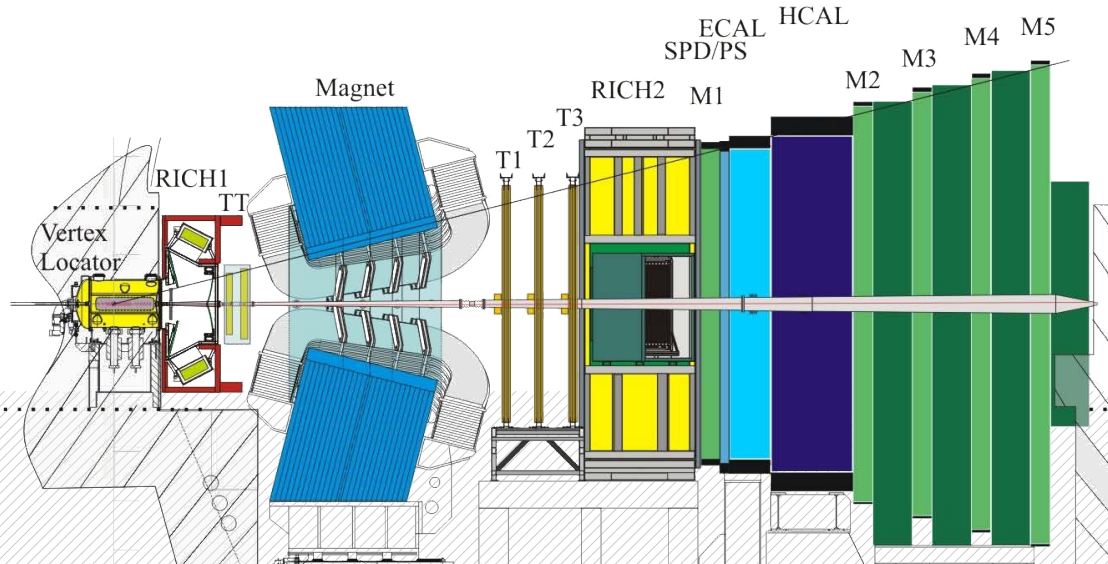
LHCb Data Taking



Results


μ
B⁰
e

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


Magnet
RICH1
TT
Vertex Locator
T1
T2
T3
RICH2
M1
ECAL
SPD/PS
HCAL
M2
M3
M4
M5

Context

Hints for LNU effects in semi-leptonic decays and b→sℓℓ

Models explaining LNU may enhance LFV(eμ) → O(10^{-11})

New gauge boson Z'
Leptoquarks
…

LHCb @ 1 fb^{-1} (2013)

$Br(B^0 \to e\mu) < 3.7 \times 10^{-9}$ (95% CL)
$Br(B_s^0 \to e\mu) < 1.4 \times 10^{-8}$ (95% CL)

More data available

2011 + 2012: 3 fb^{-1} ← result discussed
Up to now: ~9 fb^{-1} ← to be analyzed

JHEP 03 (2018) 078

Selection

Pair of tracks with

good secondary vertex

clearly separated from primary vertex (15x uncertainty)

B-candidate

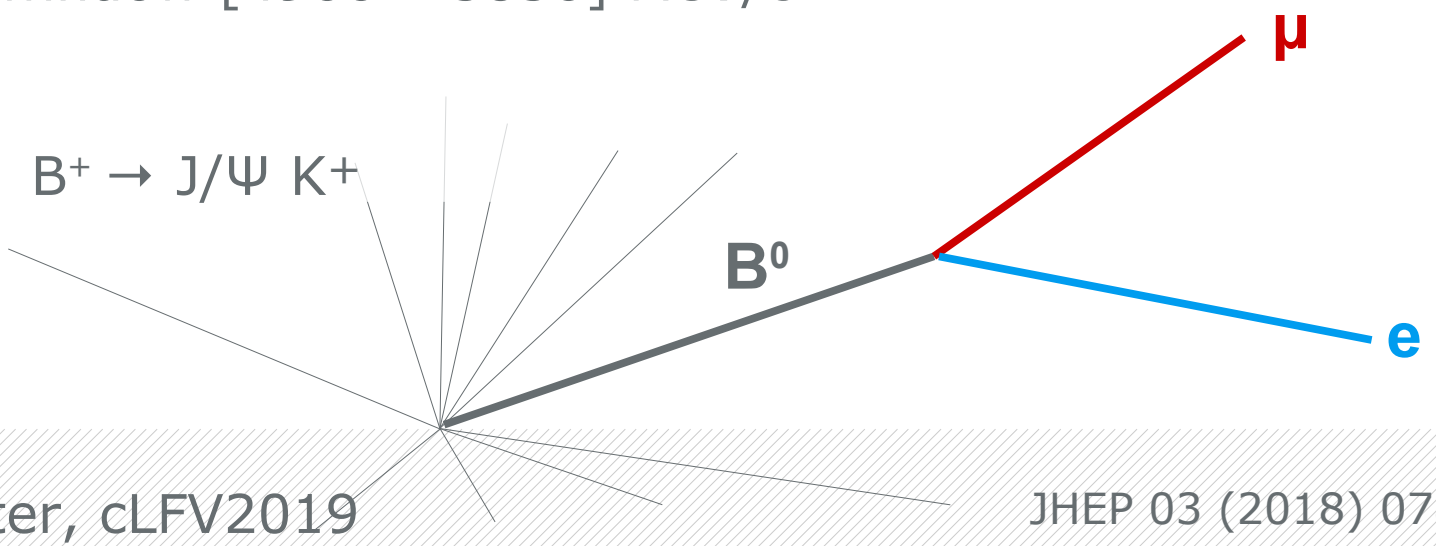
transverse momentum > 0.5 GeV/*c*

originating from primary vertex

invariant mass window [4900 – 5850] MeV/c²

Normalization

$B^0 \to K^+\pi^-$ and $B^+ \to J/\Psi\, K^+$



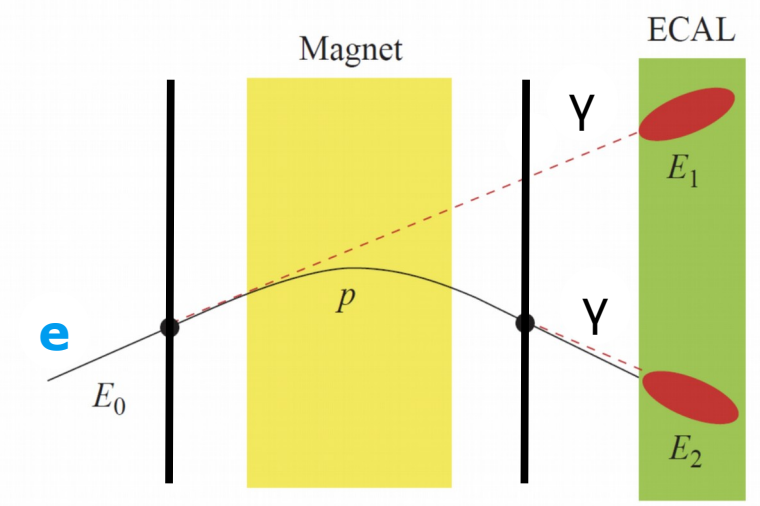
JHEP 03 (2018) 078

Bremsstrahlung

Charged particles deflected by nuclei emit radiation
especially important for **electrons** ($\sim\gamma^6$)
photons emitted predominantly along direction of motion

Main effect
change in *magnitude* of momentum, less so in *direction*
broadened invariant mass spectrum

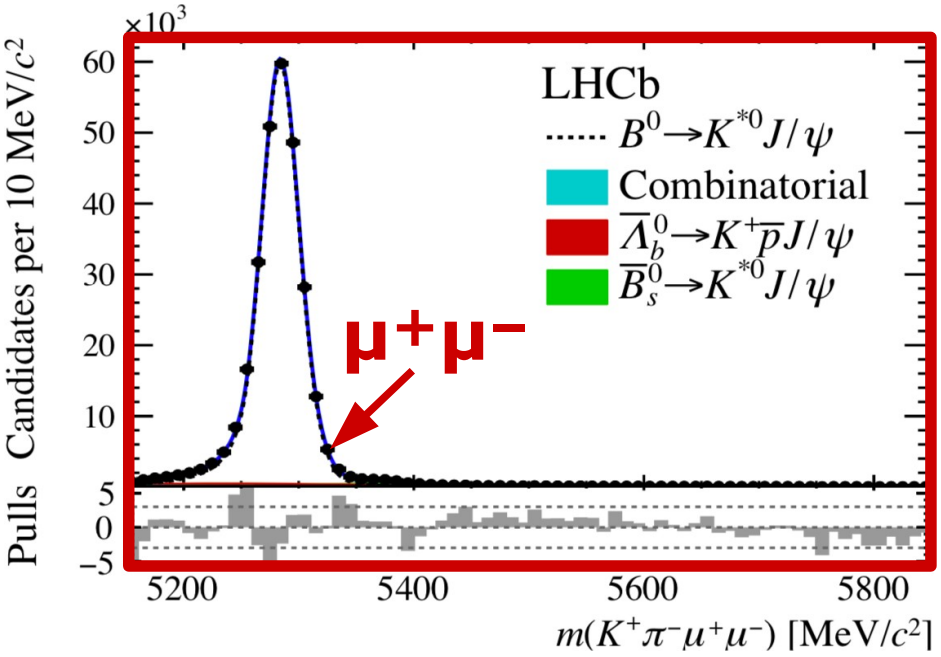
Remedy: Photon recovery
in part automatic
in part to be done by-hand

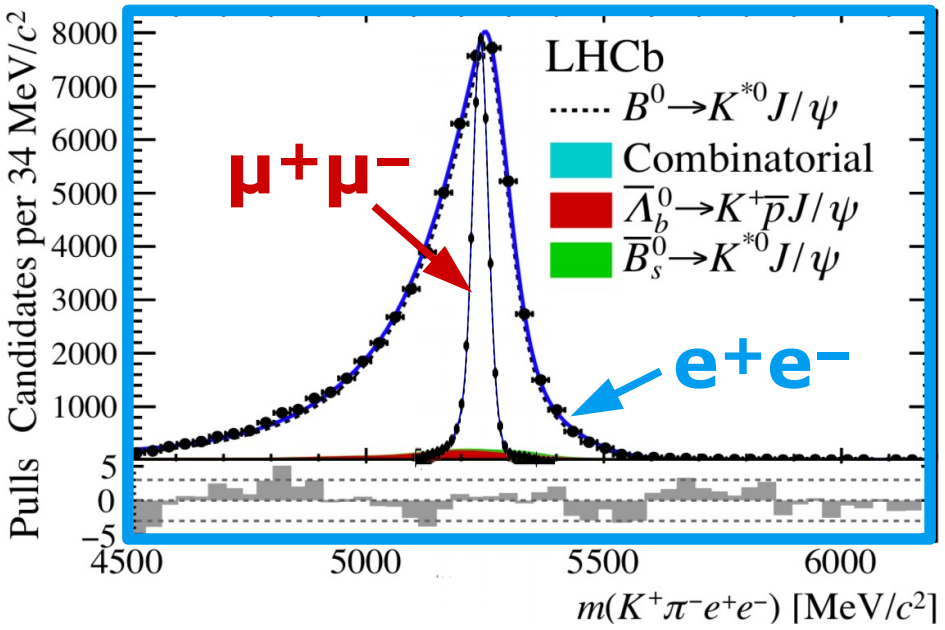


JHEP 03 (2018) 078

Bremsstrahlung

$B^0 \rightarrow K^{*0}(\rightarrow K^+\pi^-)\, J/\psi(\rightarrow \ell^+\ell^-)$



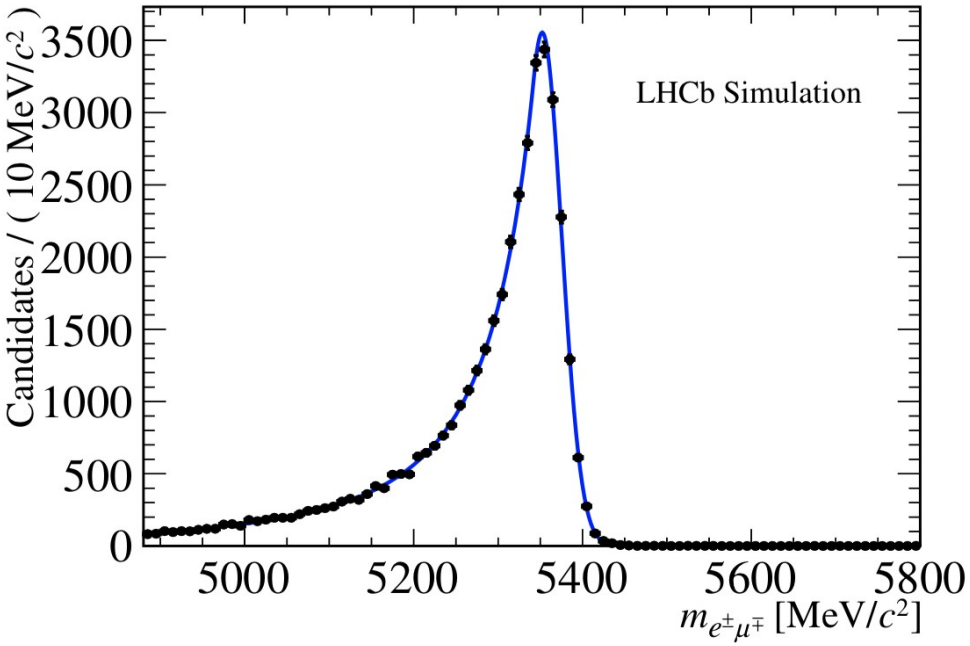


JHEP 08 (2017) 055

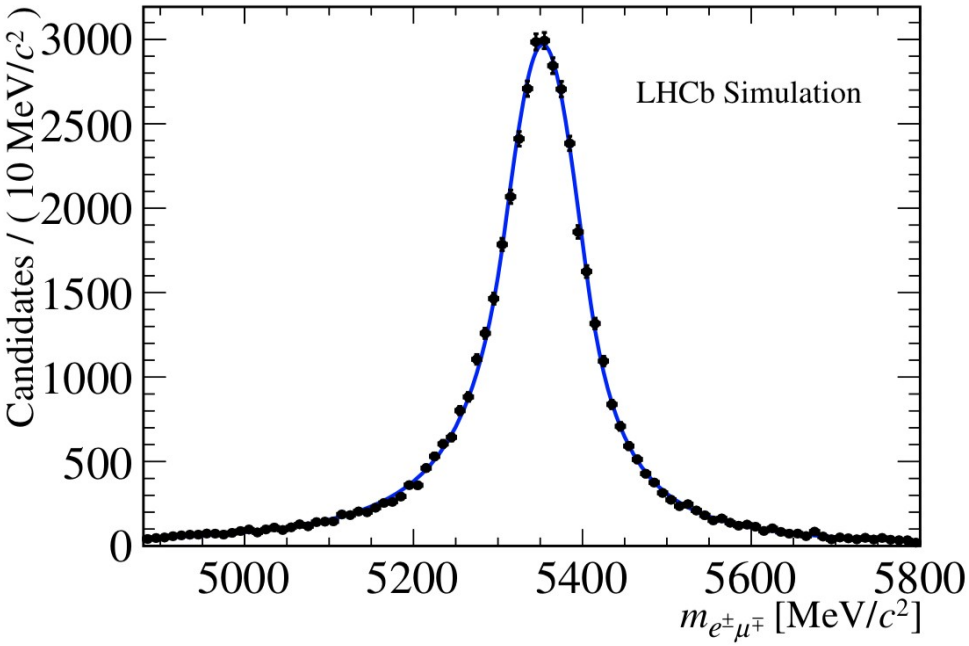
Photon recovery

Simulation of $B_s^0 \to e\mu$

without photon recovery



with photon recovery



JHEP 03 (2018) 078

Background suppression

BDT to separate signal from combinatorial background

simulated signal sample for $B_s^0 \to e\mu$

same sign candidates $e^{\pm}\mu^{\pm}$ as background proxy

Input variables

decay time of B-candidate

impact parameter of leptons and B w.r.t. primary vertex

closest approach of lepton tracks

...

Calibration

BDT uses only kinematic info

can use $B^0 \to K\pi$

JHEP 03 (2018) 078

Normalisation

In terms of similar SM-allowed channels

$B^0 \to K^+\pi^-$ and $B^+ \to J/\psi\, K^+$

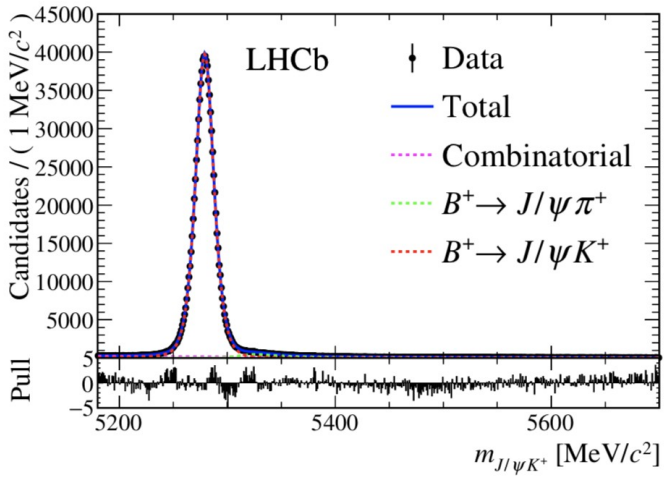
$$\mathcal{B}(B^0_{(s)} \to e^\pm\mu^\mp) = \sum_i w^i \frac{\mathcal{B}^i_{\rm norm}}{N^i_{\rm norm}} \frac{\varepsilon^i_{\rm norm}}{\varepsilon_{\rm sig}} \frac{f_q}{f_{d(s)}} \frac{\mathcal{L}^i_{\rm norm}}{\mathcal{L}_{\rm sig}} \times N_{B^0_{(s)}\to e^\pm\mu^\mp}$$

$$= \alpha_{B^0_{(s)}} \times N_{B^0_{(s)}\to e^\pm\mu^\mp},$$

Obtained normalisation factors

$B^0 \to e\mu$: (6.16 ± 0.23) x 10^{-11}

$B_s^0 \to e\mu$: (2.48 ± 0.17) x 10^{-10}



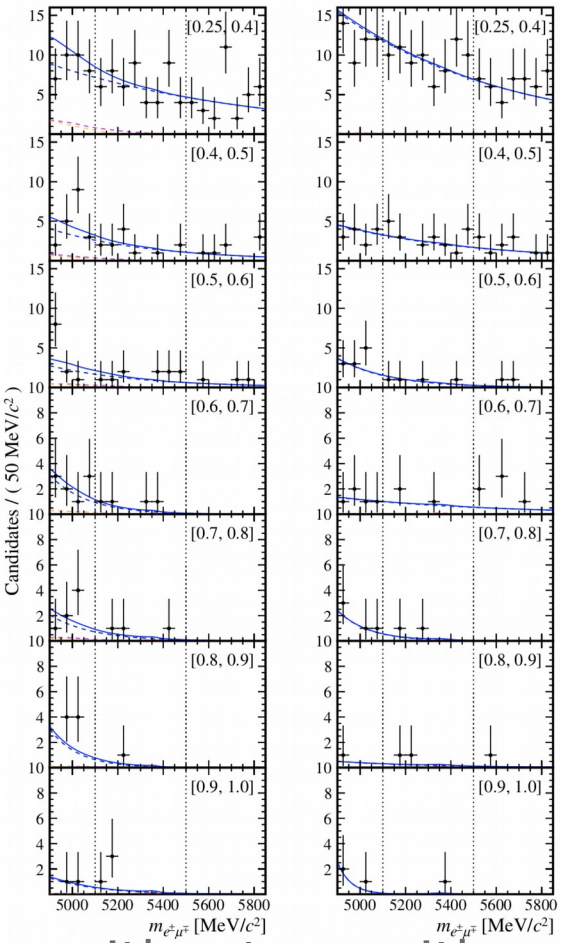
JHEP 03 (2018) 078

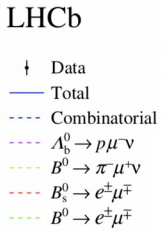
Unbinned simultaneous fits

BKGD-like

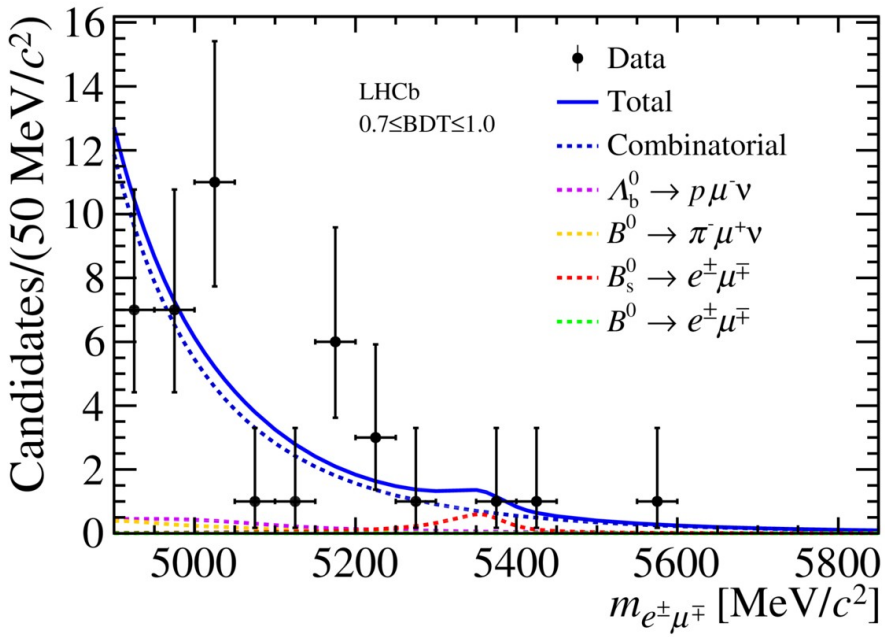
intermediate

Signal-like





photon recovery: without with



JHEP 03 (2018) 078

Result

- robust analysis method
- statistics limited
- no significant evidence for excess of events

$B(B^0 \to e\mu) < 1.0(1.3) \times 10^{-9}$

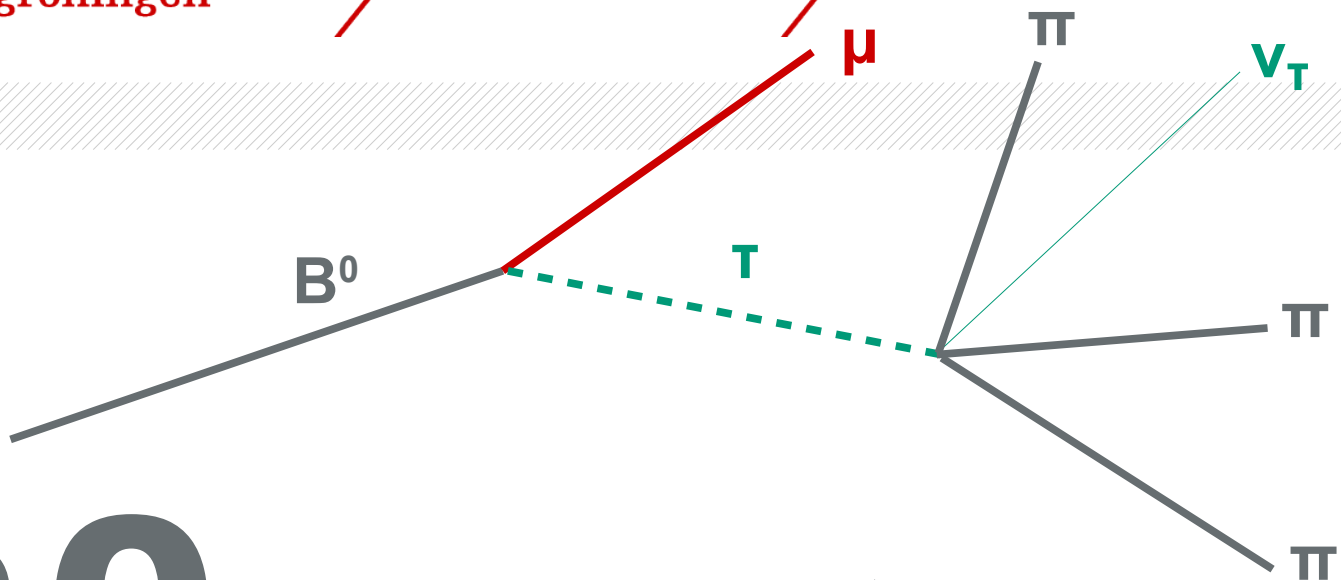
$B(B_s^0 \to e\mu) < 5.4(6.3) \times 10^{-9}$*

@ 90%(95%) C.L.

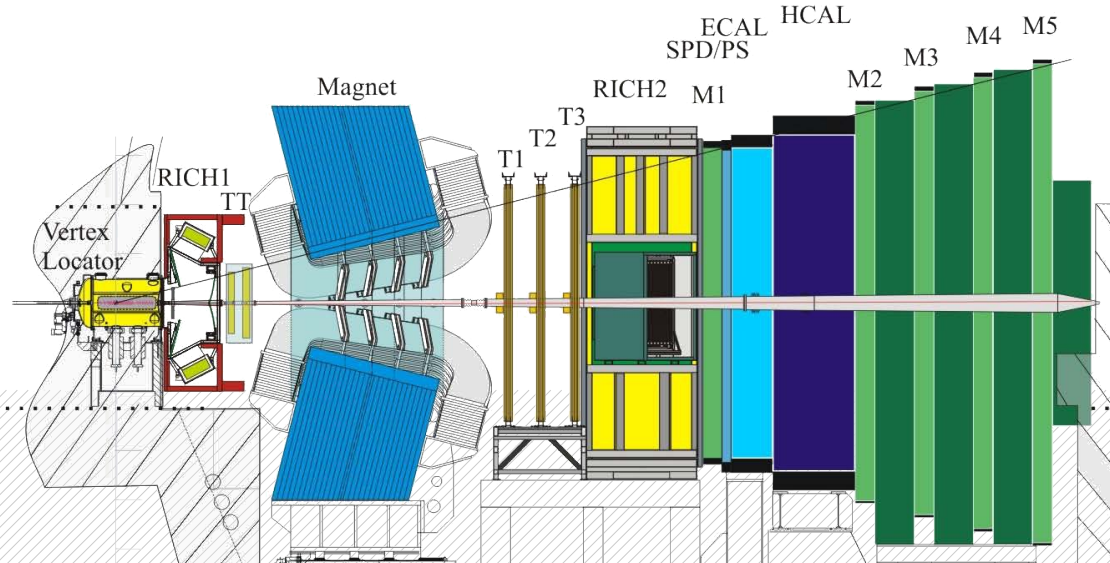
2–3x improvement over previous result

*heavy eigenstate only

JHEP 03 (2018) 078



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



Context

Models explaining LNU may enhance LFV(τμ) → O(10^{-5})

New gauge boson Z'

Leptoquarks

…

Existing limits

Br($B^0 \to \tau\mu$) < 2.2×10^{-5} (90% CL) BaBar*

Br($B_s^0 \to \tau\mu$) no experimental results

More data available

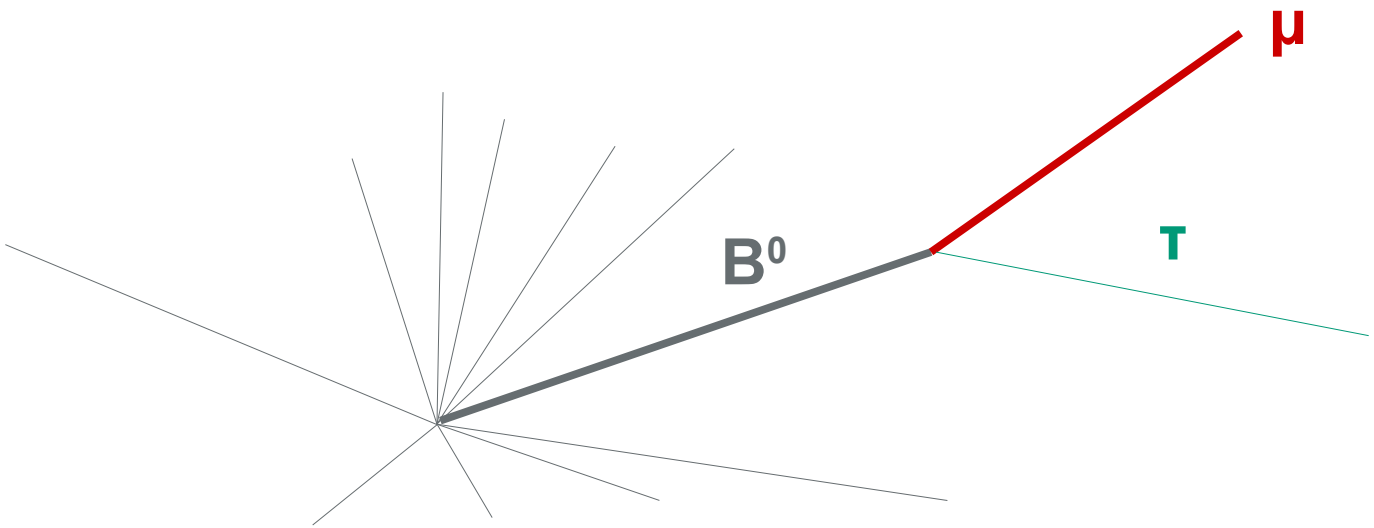
2011 + 2012: 3 fb^{-1} ← result discussed

Up to now: ~9 fb^{-1} ← to be analyzed

*PRD 77 (2008) 091104

Reconstruction

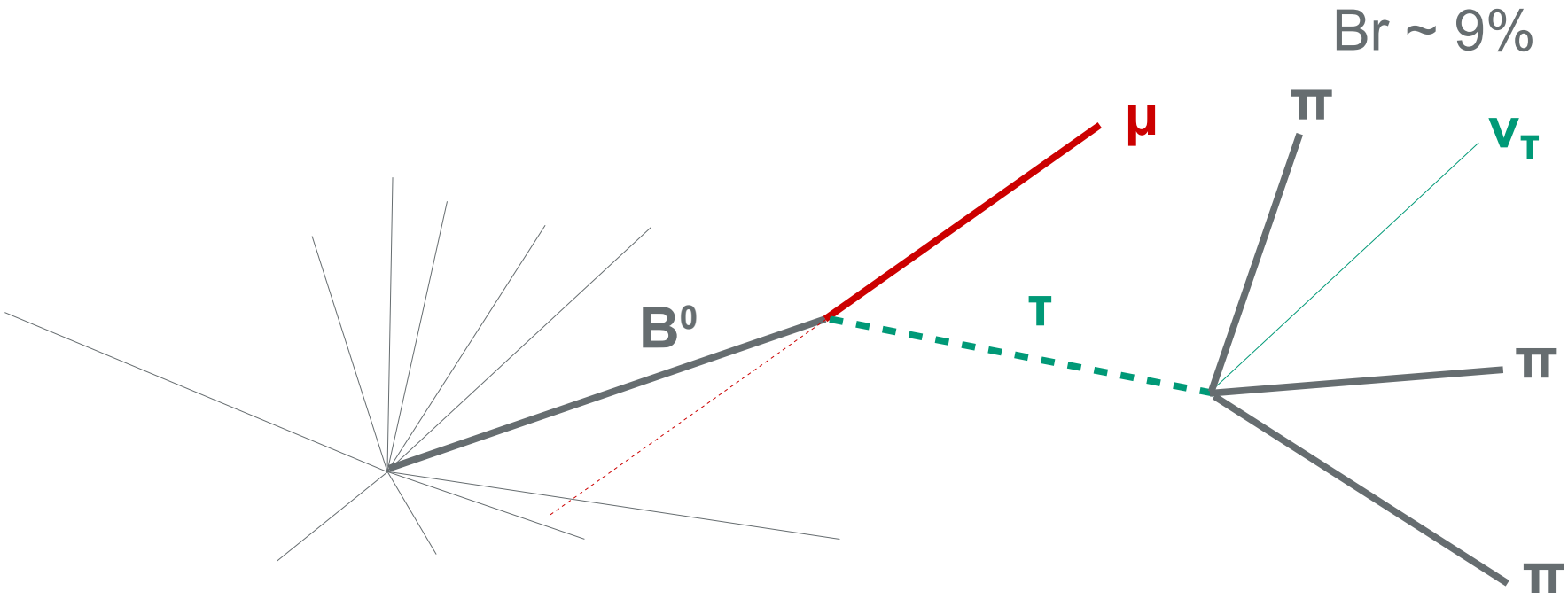
Short lifetime prohibits direct detection



arXiv:1905.06614

Reconstruction via $\tau \to \pi^-\pi^+\pi^-\,\nu_\tau$

Fixes τ decay vertex
Can reconstruct if τ (or B) mass assumed → 2-fold ambiguity
Hadronic τ decay structure helps in signal selection



arXiv:1905.06614

Background suppression

Reconstruction ambiguity

use solution with largest signal and background separation

3-pion structure

Mainly via intermediate state $a_1(1260)^-$ and $\rho(770)^0$

Discard events with $M(\pi^-\pi^+)<550$ MeV/c²

Discard events with $M(\pi^-\pi^+\pi^-)>1.8$ GeV/c²

Topology

isolation in detector, esp. neutral particles

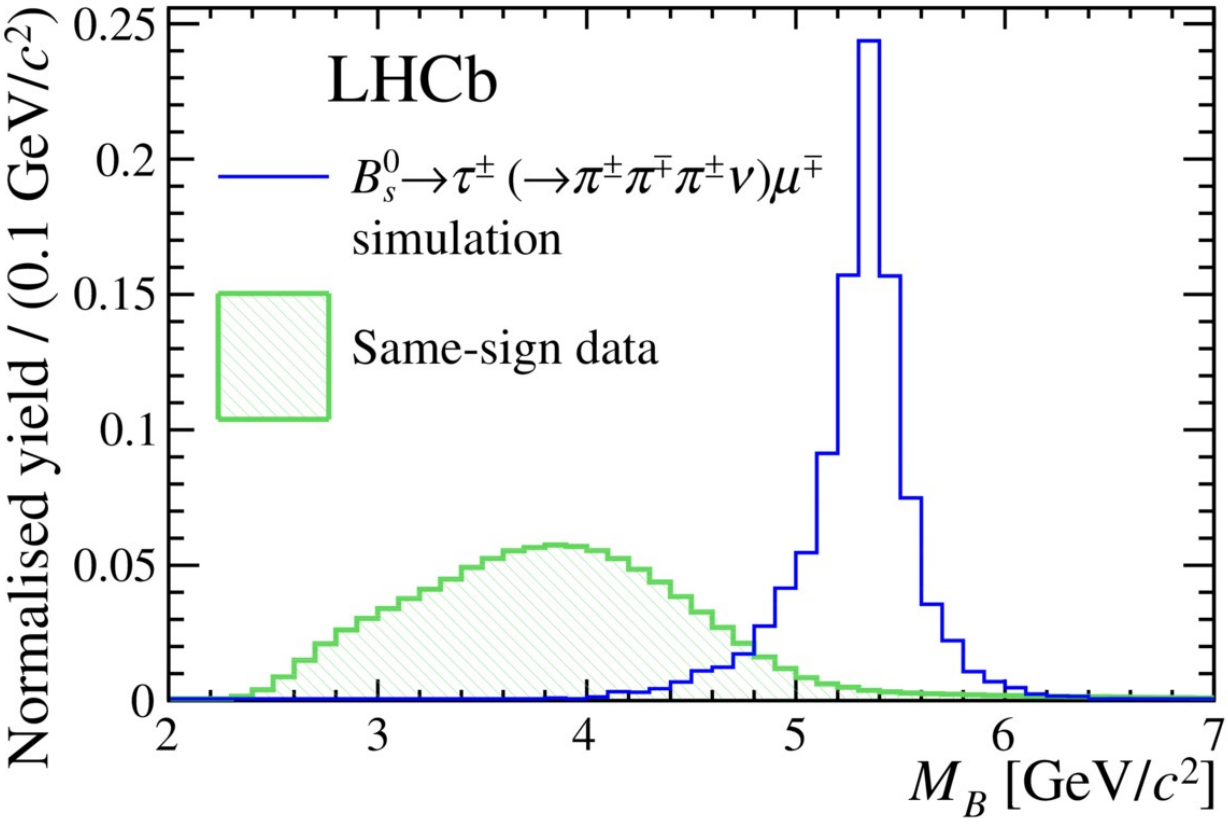
additional tracks from vertices

Train BDT to distinguish signal and background

arXiv:1905.06614

Invariant mass distribution

BDT training data



arXiv:1905.06614

Normalisation: $B^0 \to D^-(\to K^+\pi^-\pi^-)\pi^+$

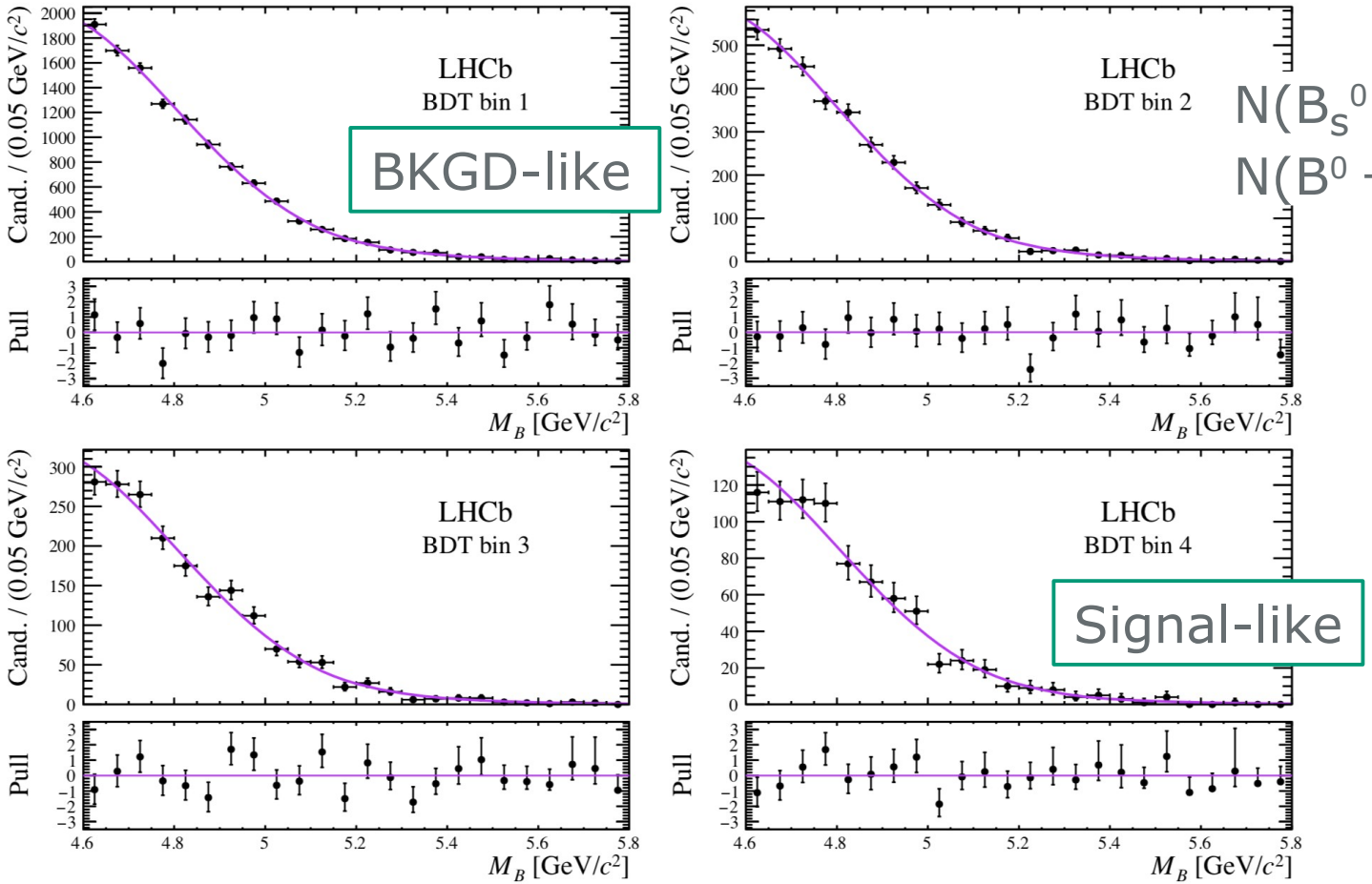
$$\mathcal{B}\left(B^0_{(s)} \to \tau^{\pm}\mu^{\mp}\right) = \alpha^{\text{norm}}_{(s)} \cdot N^{\text{sig}}_{(s)},$$

$$\alpha^{\text{norm}}_{(s)} = \frac{f_{B^0}}{f_{B^0_{(s)}}} \cdot \frac{\mathcal{B}\left(B^0 \to D^-(\to K^+\pi^-\pi^-)\pi^+\right)}{\mathcal{B}\left(\tau^- \to \pi^-\pi^+\pi^-\nu_\tau\right)} \cdot \frac{\epsilon_{B\to D\pi}}{\epsilon_{B_{(s)}\to\tau\mu}} \cdot \frac{1}{N^{\text{norm}}},$$

$$\alpha^{\text{norm}}_s = (4.32 \pm 0.19 \pm 0.45 \pm 0.36) \times 10^{-7} \text{ and}$$
$$\alpha^{\text{norm}} = (1.25 \pm 0.06 \pm 0.13 \pm 0.08) \times 10^{-7},$$

arXiv:1905.06614

Unbinned simultaneous fits



$N(B_s^0 \to \tau\mu) = -16 \pm 38$

$N(B^0 \to \tau\mu) = -65 \pm 58$

arXiv:1905.06614

Result

- robust analysis method
- statistics limited
- no significant evidence for excess of events

$B(B^0 \to \tau\mu) < 1.2(1.4) \times 10^{-5}$

$B(B_s^0 \to \tau\mu) < 3.4(4.2) \times 10^{-5}$

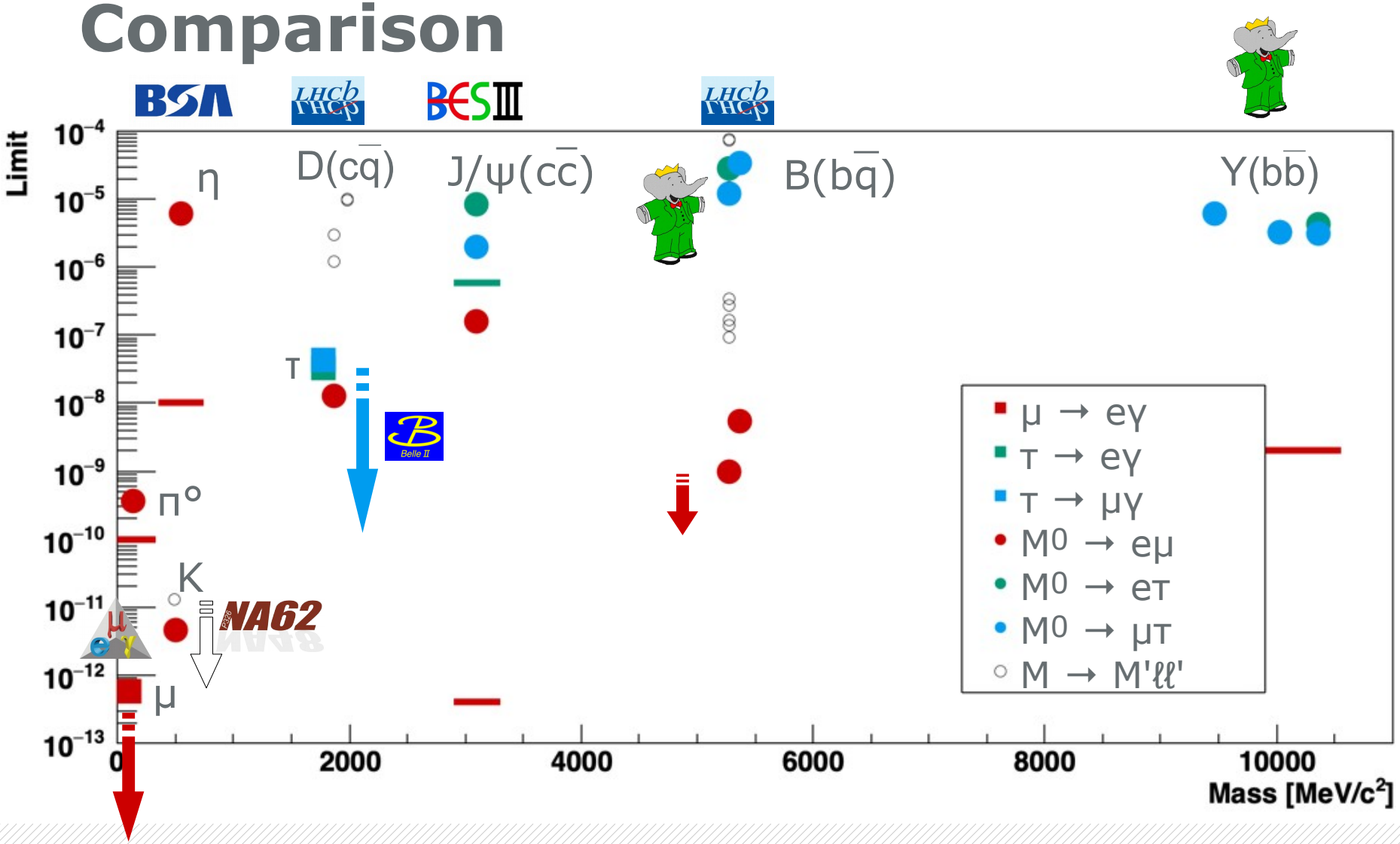
@ 90%(95%) C.L.

B^0 : 2x improvement over previous result

B_s^0 : first measurement

arXiv:1905.06614

Comparison



Original pubs, PRD63 (2001) 016003

Conclusion

Take away message

LHCb : study flavor physics with all three lepton generations

With LHC **Run-I** data **LHCb** sharpened limits for many LFV, LNV, and BNV channels

No significant deviations from **SM** seen

Demonstrated sensitive **BSM** searches @ hadron collider

Many additional channels available

lots of additional data to be analyzed from **Run-II** (just completed) & expected from **Run-III**

Thank you for your attention!