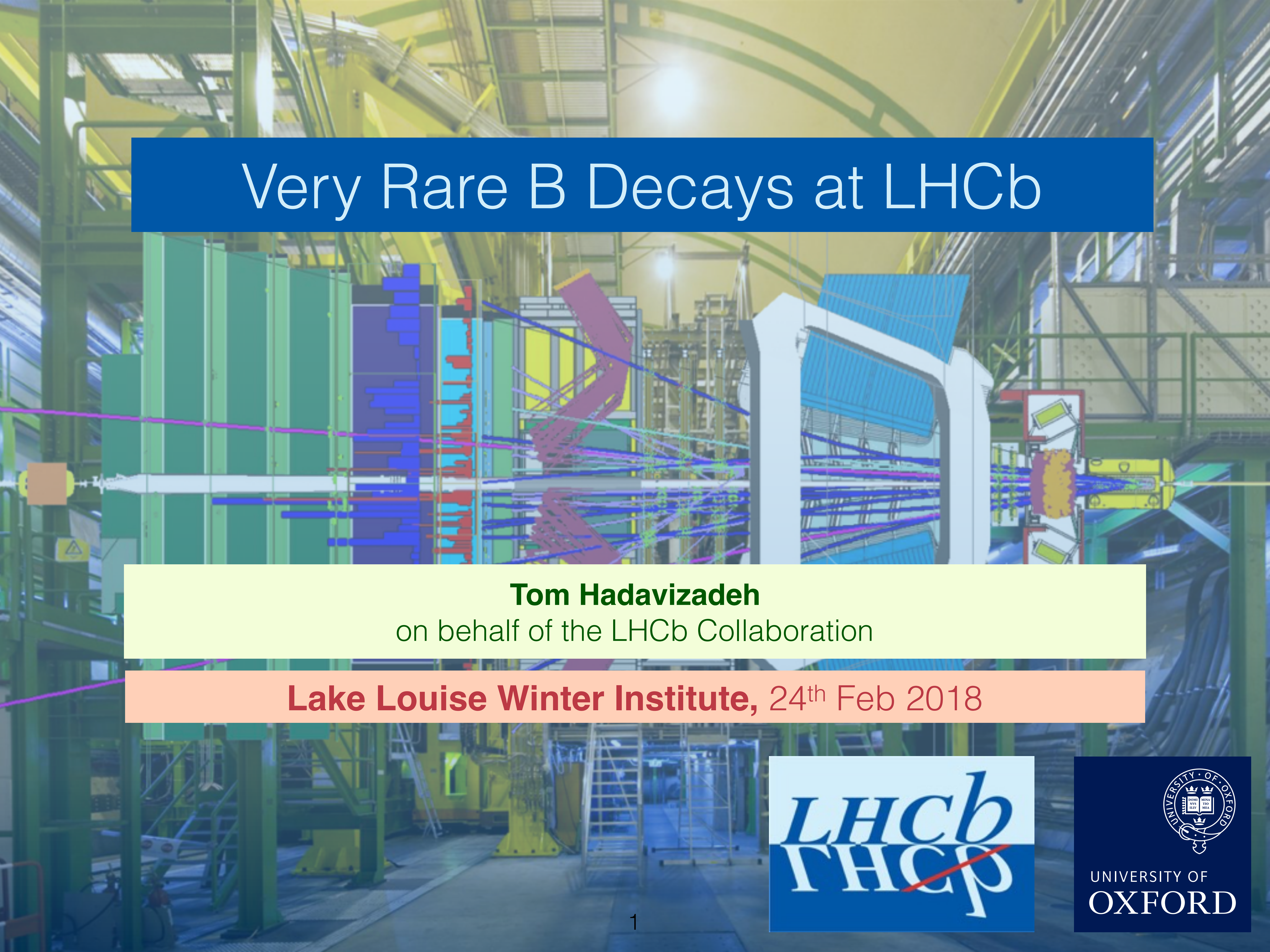

Very Rare B Decays at LHCb

Tom Hadavizadeh
on behalf of the LHCb Collaboration

Lake Louise Winter Institute, 24th Feb 2018

LHCb

UNIVERSITY OF OXFORD

Why study rare decays?

- When the **Standard Model** is highly suppressed, **New Physics** contributions could become apparent
- Sensitive to contributions from **new mediators**
    - Even if masses are **inaccessible** by direct production

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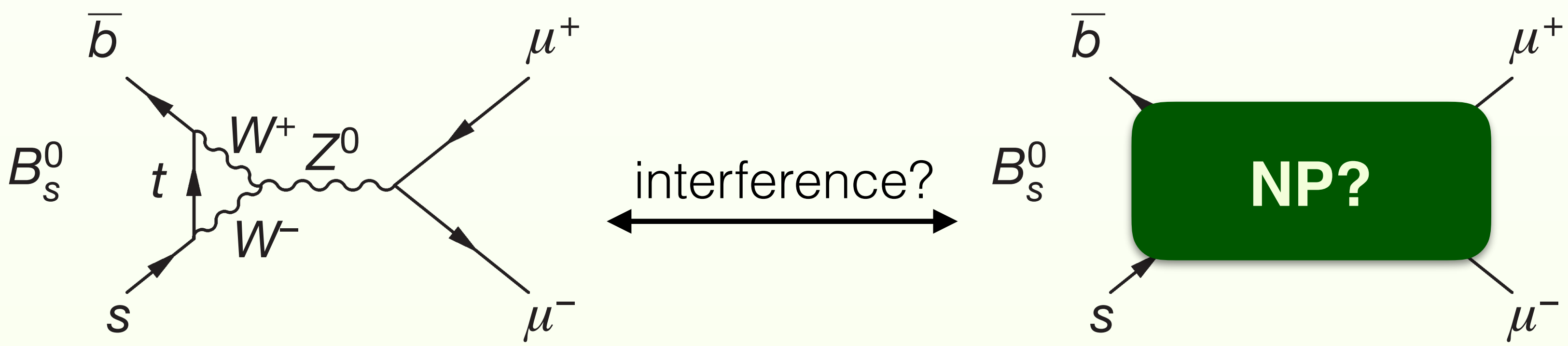

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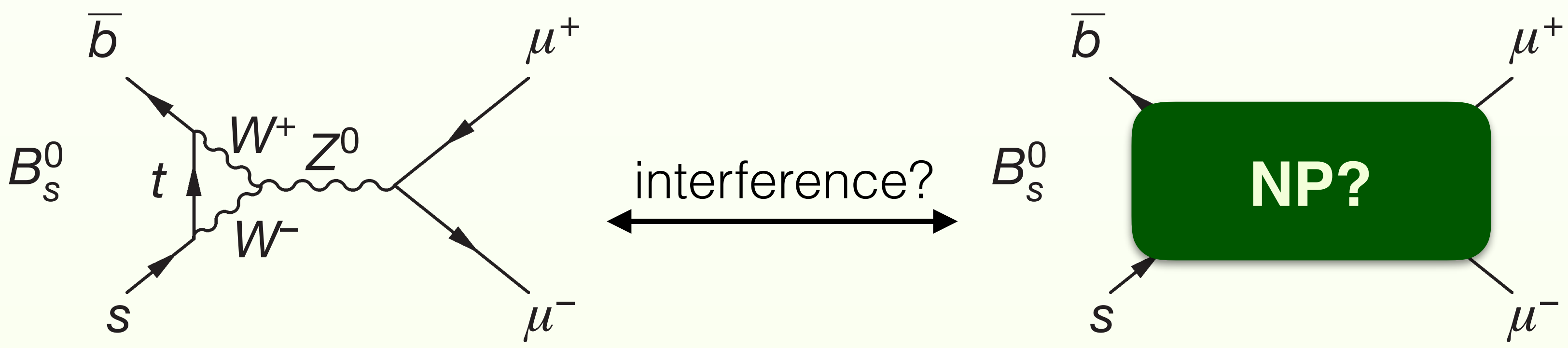


- **Large samples** of B mesons at LHCb make it a suitable place to search
    - High precision **vertex** reconstruction
    - Good **mass resolution**: $\sigma(\mu^+\mu^-)$ ~24 MeV
    - Efficient **particle identification**

Today's outline

Rare Leptonic B decays

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

$$B^0_{(s)} \to \tau^+\tau^-$$

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

+ Theoretically clean

Rare Hadronic B decays

$$B^0 \to p\bar{p}$$

$$B^+ \to D_s^+\phi$$

+ Varied and abundant
- Only sensitive to NP quark couplings

For Semi-tauonic B decays:
Victor Renaudin's **talk** (Friday 10:45)

For more on b->sll decays:
Violaine Bellee's **talk** (Friday 11:00)

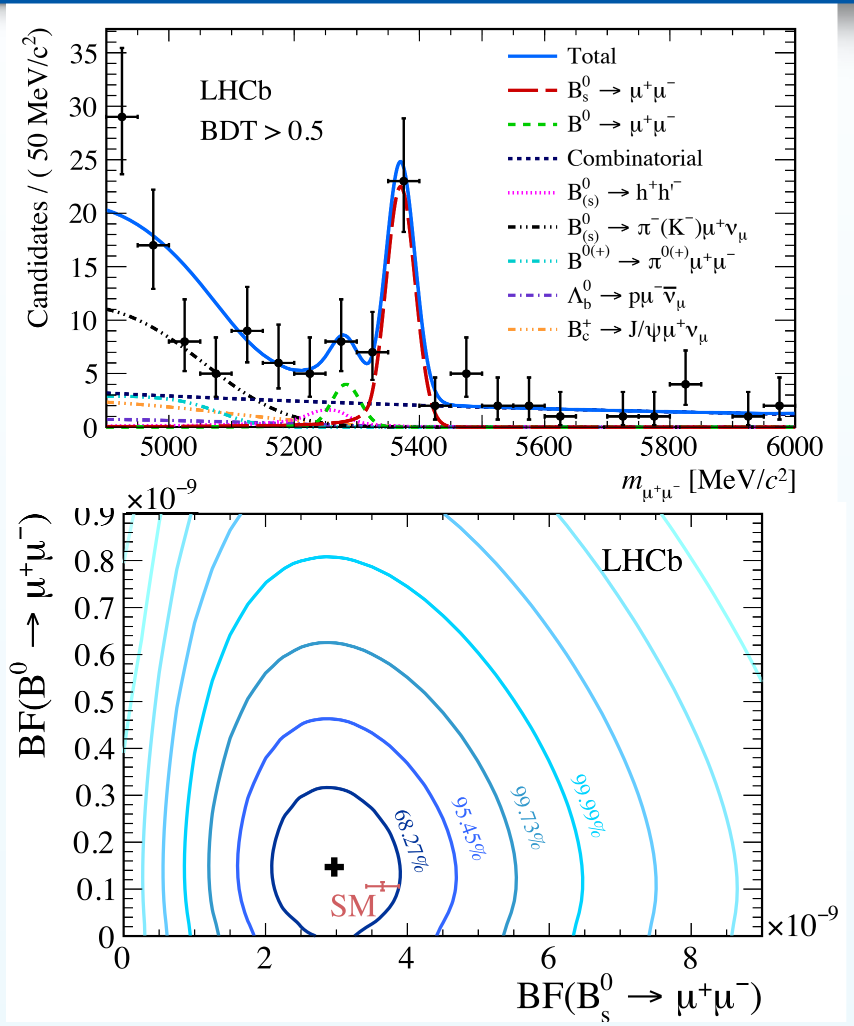
Very rare leptonic decays

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

- Search performed using **Run I** and some **Run II** data (4.4 fb^{-1})
- First observation of B_s^0 decay in a **single experiment**

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$$
(stat.) (sys.)

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



Phys. Rev. Lett. 118 (2017), 191801
Published: **May 2017**

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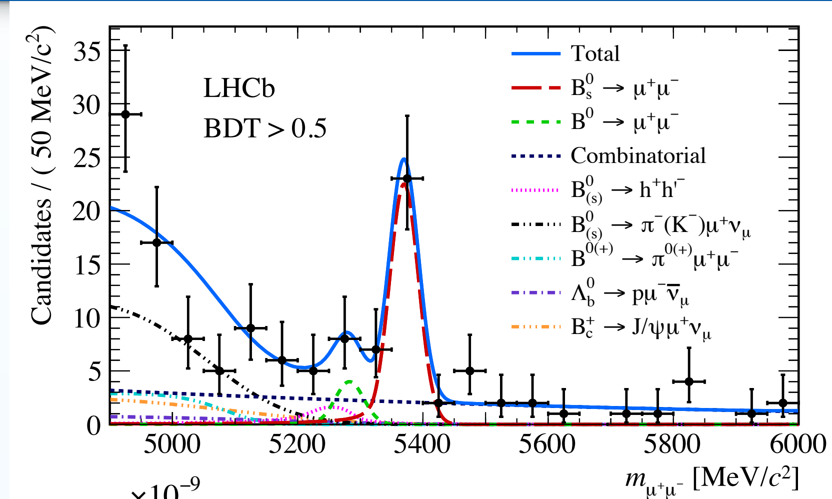
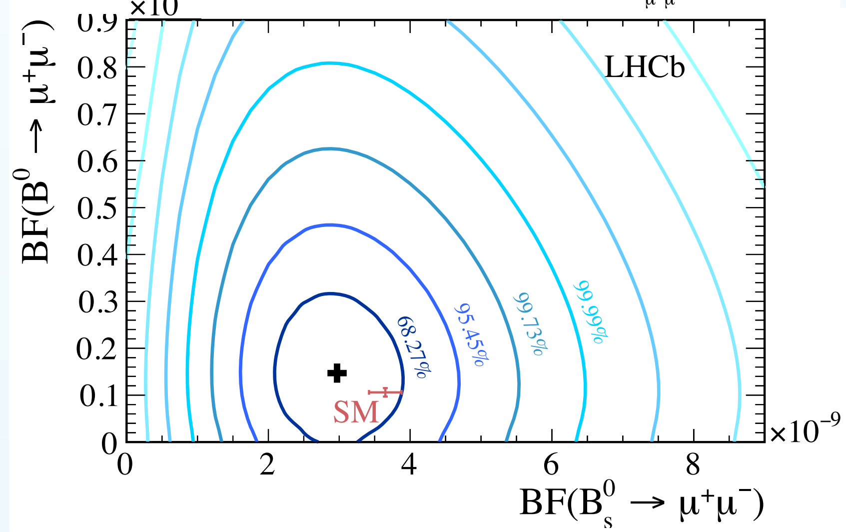
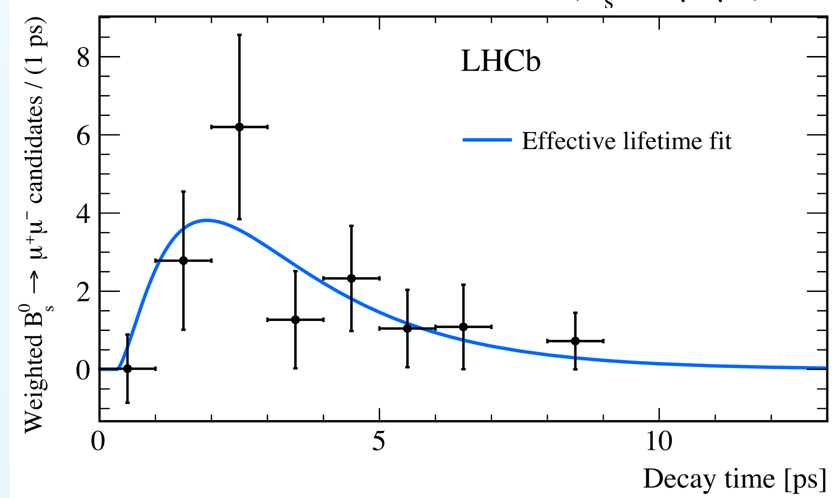
- First measurement of **effective lifetime**
  - Can be sensitive to NP, even if BF isn't
  - Only heavy B_s^0 mass eigenstate decays to $\mu\mu$ in SM

$$\tau(B_s^0 \to \mu^+\mu^-) = 2.04 \pm \underset{(stat.)}{0.44} \pm \underset{(sys.)}{0.05}\,\mathrm{ps}$$

  - Consistent with SM (1σ) and most extreme NP (1.4σ)





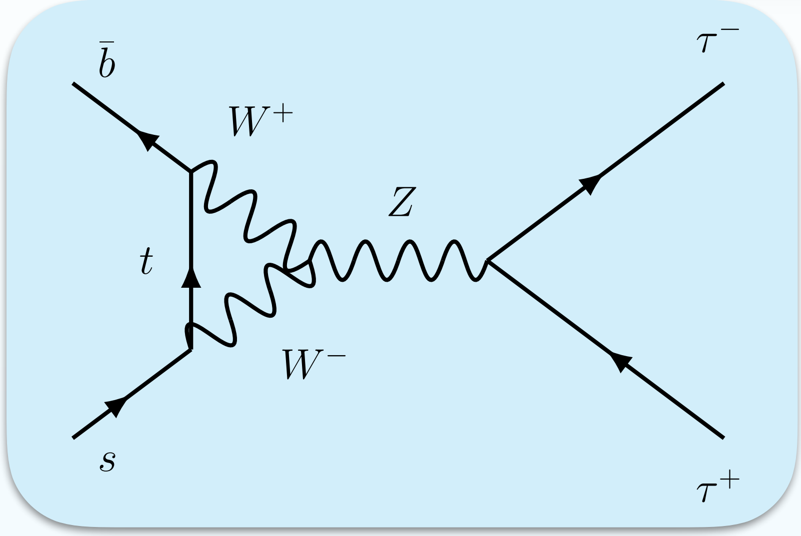


Phys. Rev. Lett. 118 (2017), 191801

Published: **May 2017**

$B^0_{(s)} \to \tau^+\tau^-$

- Complementary **tauonic** Run I search
  - More abundant: less helicity suppressed
  - As theoretically **clean**
  - More experimentally **challenging**



Phys. Rev. Lett. 118 (2017), 251802
Published: **June 2017**

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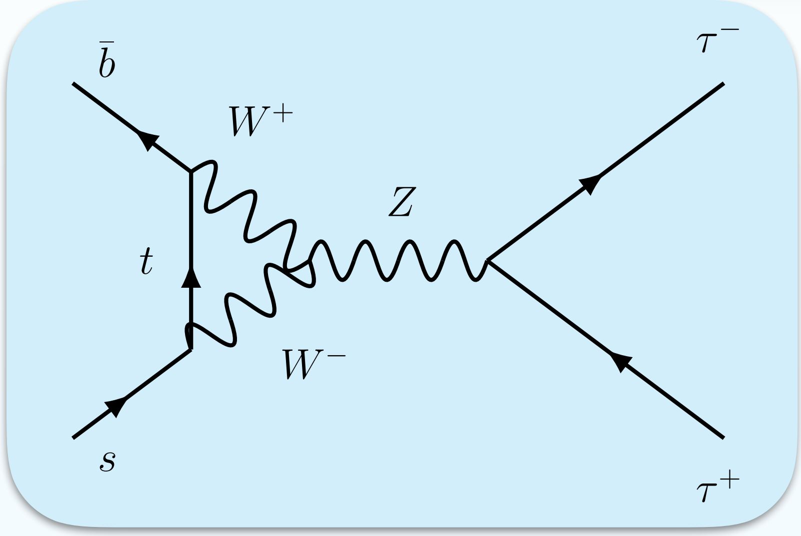
- Reconstruct **3-pronged hadronic** tau decays

$$\mathcal{B}(\tau^- \to \pi^-\pi^+\pi^-\nu_\tau) = (9.31 \pm 0.05)\%$$



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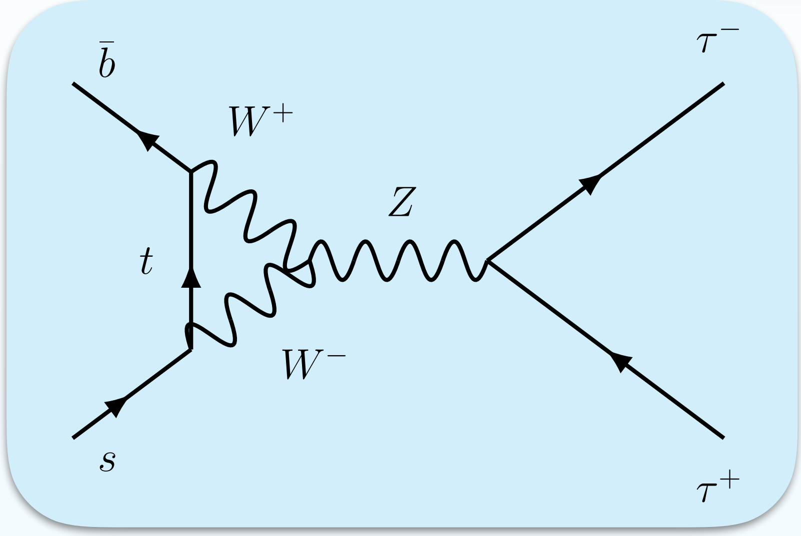
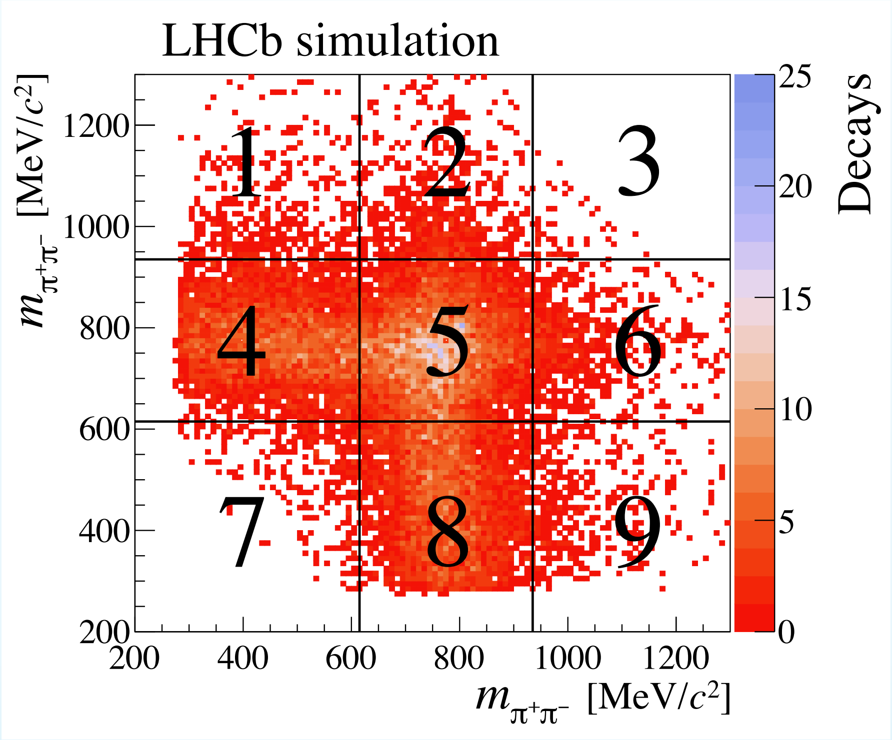


- Reconstruct **3-pronged hadronic** tau decays

$$\mathcal{B}(\tau^- \to \pi^-\pi^+\pi^-\nu_\tau) = (9.31 \pm 0.05)\%$$

- Exploit predominant decay to define **signal**, **control** and **signal-depleted** regions



$\tau^- \to a_1(1260)^-\nu_\tau$
$\quad\hookrightarrow \rho(770)^0\pi^-$
$\qquad\hookrightarrow \pi^+\pi^-$

- **Signal:** Used to determine signal yield
- **Control:** Background model for fit
- **Signal-depleted:** Background in Neural Net training

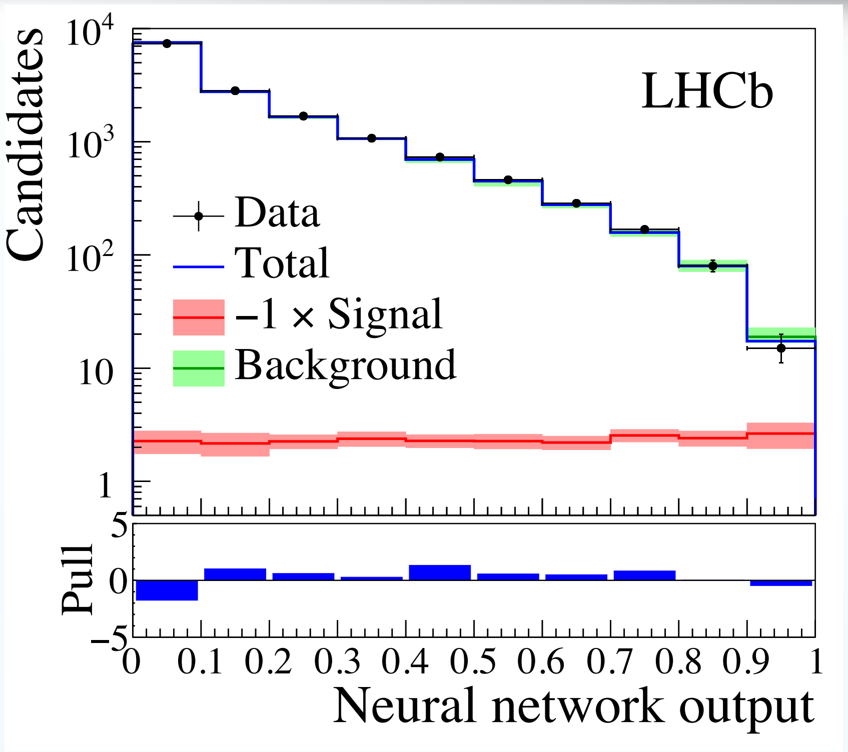
Phys. Rev. Lett. 118 (2017), 251802

Published: **June 2017**

$B^0_{(s)} \to \tau^+\tau^-$

- **Missed neutrinos** make $m(\tau^+\tau^-)$ not discriminating enough variable

- Instead perform binned fit to a second **Neutral Network classifier**
  - Signal PDF from **simulation samples**
  - Background PDF from **control regions**



Phys. Rev. Lett. 118 (2017), 251802

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$B^0_{(s)} \to \tau^+\tau^-$

- **Missed neutrinos** make m($\tau^+\tau^-$) not discriminating enough variable
- Instead perform binned fit to a second **Neutral Network classifier**
  - Signal PDF from **simulation samples**
  - Background PDF from **control regions**
- Both B^0 and B_s^0 consistent with no signal
- **Worlds best limits** set:

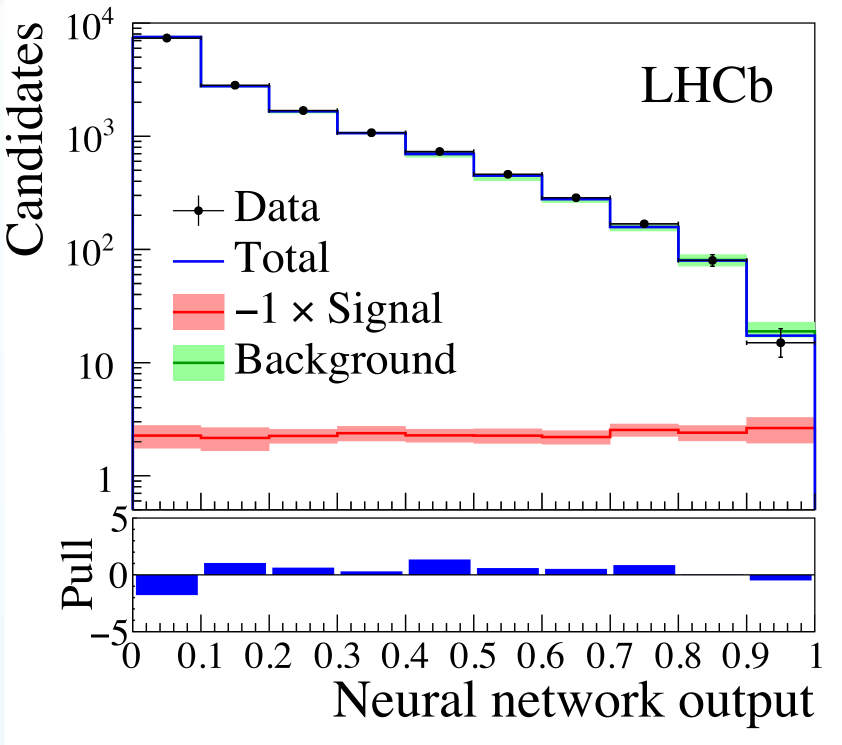
$$\mathcal{B}(B_s^0 \to \tau^+\tau^-) < 6.8 \times 10^{-3} \quad (95\%\ \mathrm{CL})$$

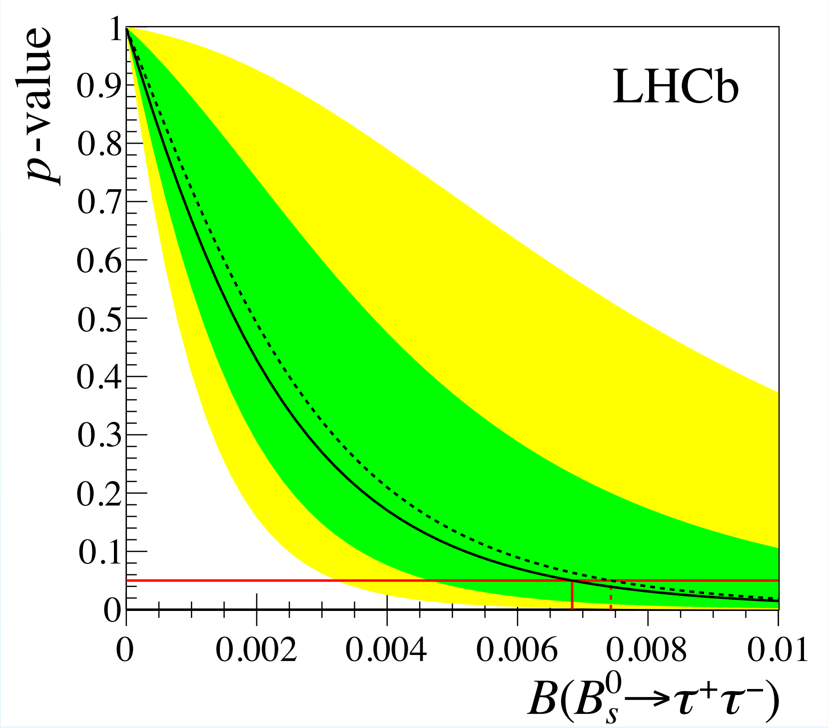
$$\mathcal{B}(B^0 \to \tau^+\tau^-) < 2.1 \times 10^{-3} \quad (95\%\ \mathrm{CL})$$

assuming no contribution from the other

SM predictions PRL 112 (2014) 101801

$$\mathcal{B}(B_s^0 \to \tau^+\tau^-)_{\mathrm{SM}} = (7.73 \pm 0.49) \times 10^{-7}$$
$$\mathcal{B}(B^0 \to \tau^+\tau^-)_{\mathrm{SM}} = (2.22 \pm 0.19) \times 10^{-8}$$





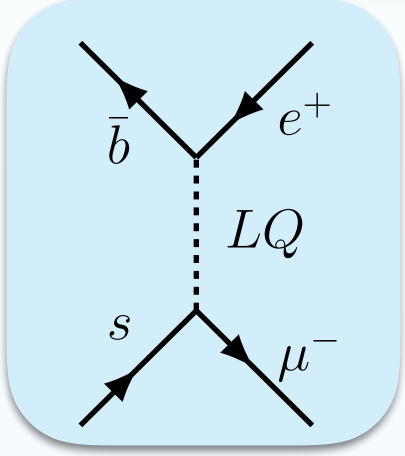
Phys. Rev. Lett. 118 (2017), 251802

Published: **June 2017**

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

- Lepton-flavour violating decay
  - Forbidden in the **SM**
  - Enhanced in **lepton non-universality** scenarios $\mathcal{O}(10^{-11})$

JHEP 06 (2015) 072

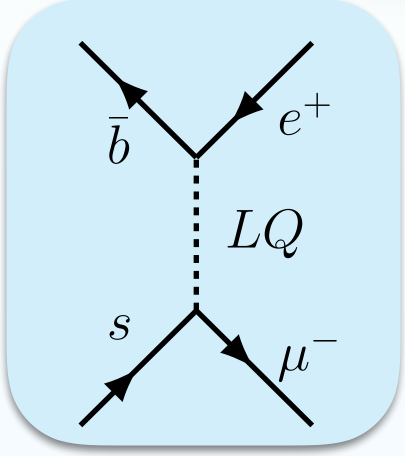


- Search performed with full **Run I** sample (3 fb^{-1})
  - Previous limits set by LHCb using 1 fb^{-1} sample

Phys. Rev. Lett. 111, 141801

arXiv:1710.04111
LHCB-PAPER-2017-031
Submitted: **JHEP**

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



- Lepton-flavour violating decay
  - Forbidden in the **SM**
  - Enhanced in **lepton non-universality** scenarios $\mathcal{O}(10^{-11})$

    JHEP 06 (2015) 072
- Search performed with full **Run I** sample (3 fb^{-1})
  - Previous limits set by LHCb using 1 fb^{-1} sample

    Phys. Rev. Lett. 111, 141801
- Candidates selected with an improved BDT
  - Trained on **signal simulations**
  - **Same sign** $e^\pm\mu^\pm$ data as background
- Branching fractions determined with two **normalisation channels**

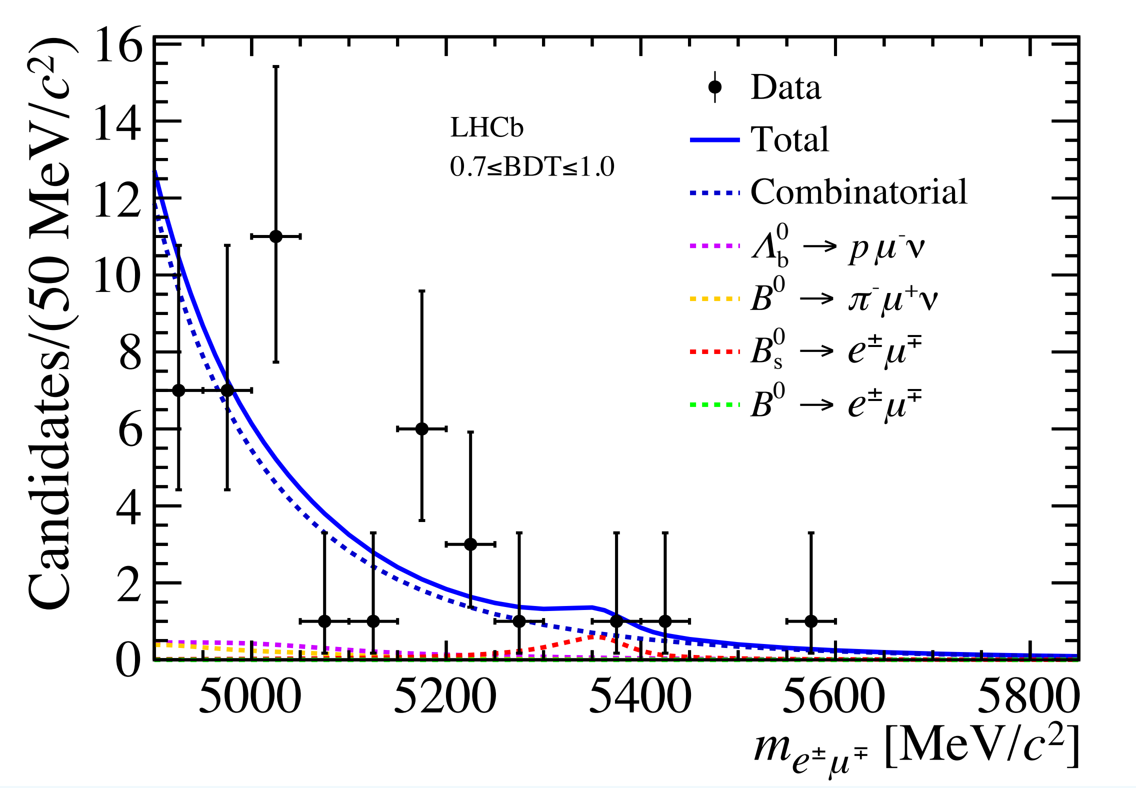
$$B^+ \to J/\psi K^+ \qquad B^0 \to K^+\pi^-$$

arXiv:1710.04111
LHCB-PAPER-2017-031
Submitted: **JHEP**

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

- Electrons are **experimentally challenging**
  - Candidates split by number of **Bremsstrahlung** photons

- Candidates fitted simultaneously in **seven** bins of MVA classifier output



arXiv:1710.04111
LHCB-PAPER-2017-031
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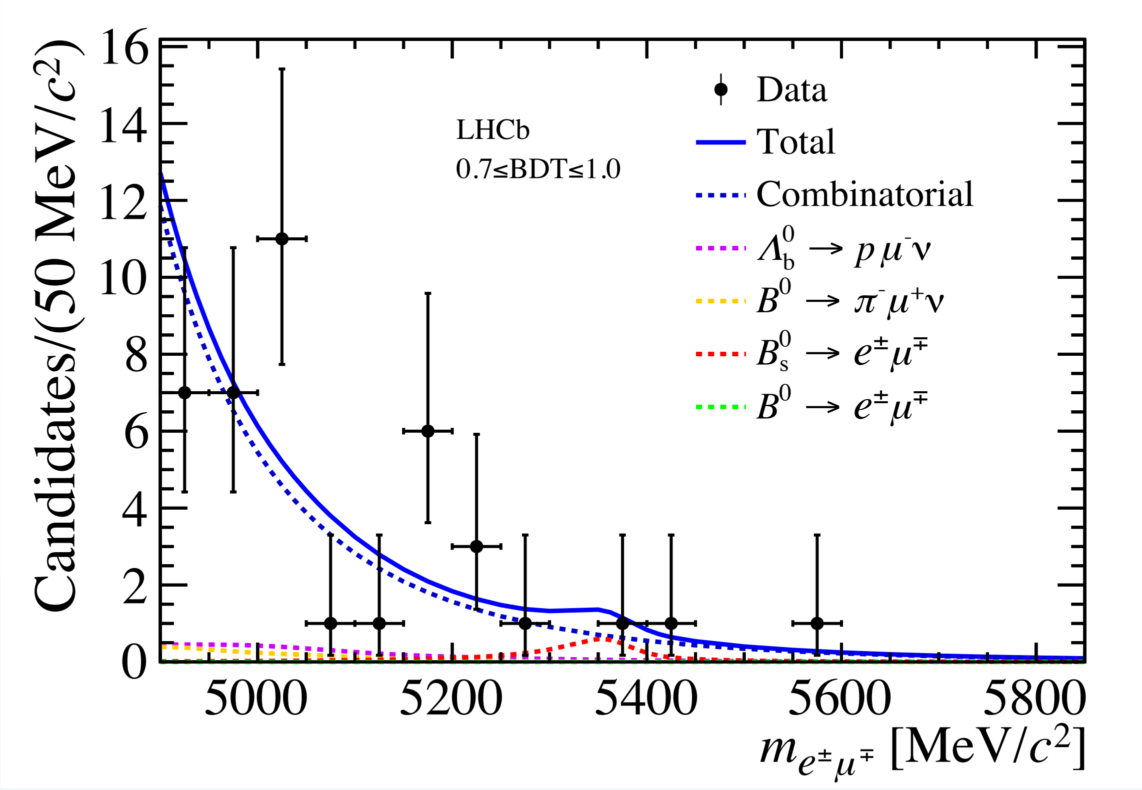


- Candidates fitted simultaneously in **seven** bins of MVA classifier output

- No yield observed, therefore limits calculated assuming only **heavy B_s mass eigenstate** contributes
  - **Worlds best limits** set:

$$\mathcal{B}(B_s^0 \to e^{\pm}\mu^{\mp}) < 6.3 \times 10^{-9} \quad (95\%\ \mathrm{CL})$$

$$\mathcal{B}(B^0 \to e^{\pm}\mu^{\mp}) < 1.3 \times 10^{-9} \quad (95\%\ \mathrm{CL})$$

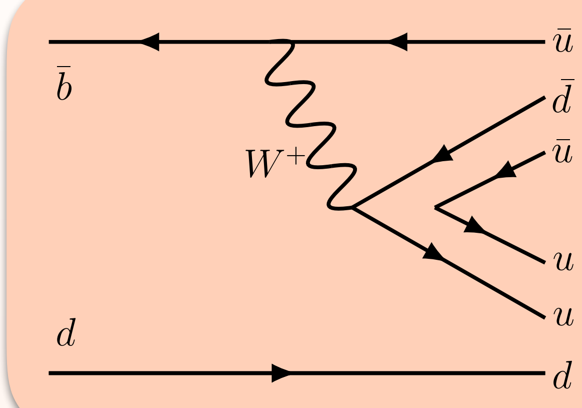
B_s^0 limit also calculated assuming only light mass eigenstate contributes

arXiv:1710.04111
LHCB-PAPER-2017-031
Submitted: **JHEP**

Very rare hadronic decays

$B^0 \to p\bar{p}$

- Search for a **purely baryonic** final state
  - **2-body** baryonic decays are fairly suppressed in SM
  - It can provide information about **tree level** and **penguin** amplitudes when combining BF info with $B^+ \to p\bar{\Lambda}$



[Phys. Rev. Lett. 119 (2017), 232001](#)

Published: **Dec 2017**

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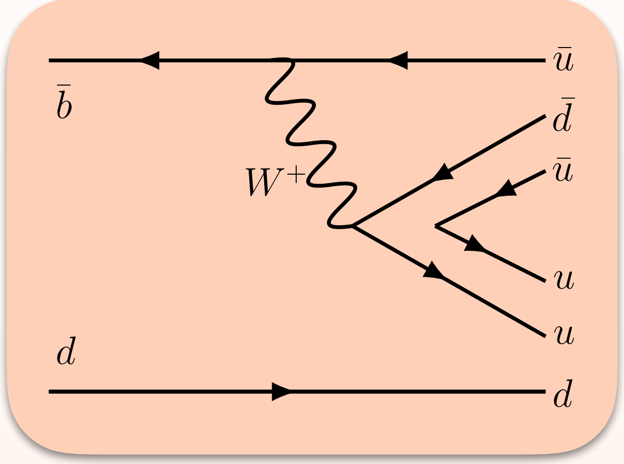

- Search performed on full **Run I** sample (3 fb^{-1})
  - Previous evidence reported by LHCb using 1 fb^{-1} sample

JHEP 10 (2013) 005

Phys. Rev. Lett. 119 (2017), 232001
Published: **Dec 2017**

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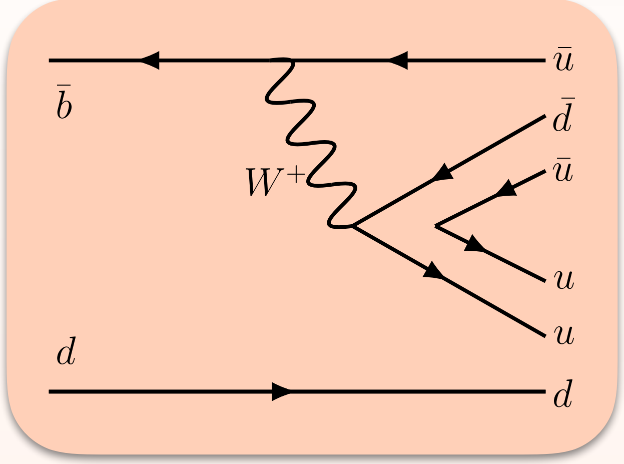


- Search performed on full **Run I** sample (3 fb^{-1})
  - Previous evidence reported by LHCb using 1 fb^{-1} sample — JHEP 10 (2013) 005
- Candidates selected with **tight PID** and **MVA** requirements
  - Multilayer perceptron classifier trained on simulation and data sidebands
- Various **backgrounds** studied
  - Partially reconstructed
  - Misidentified hadrons

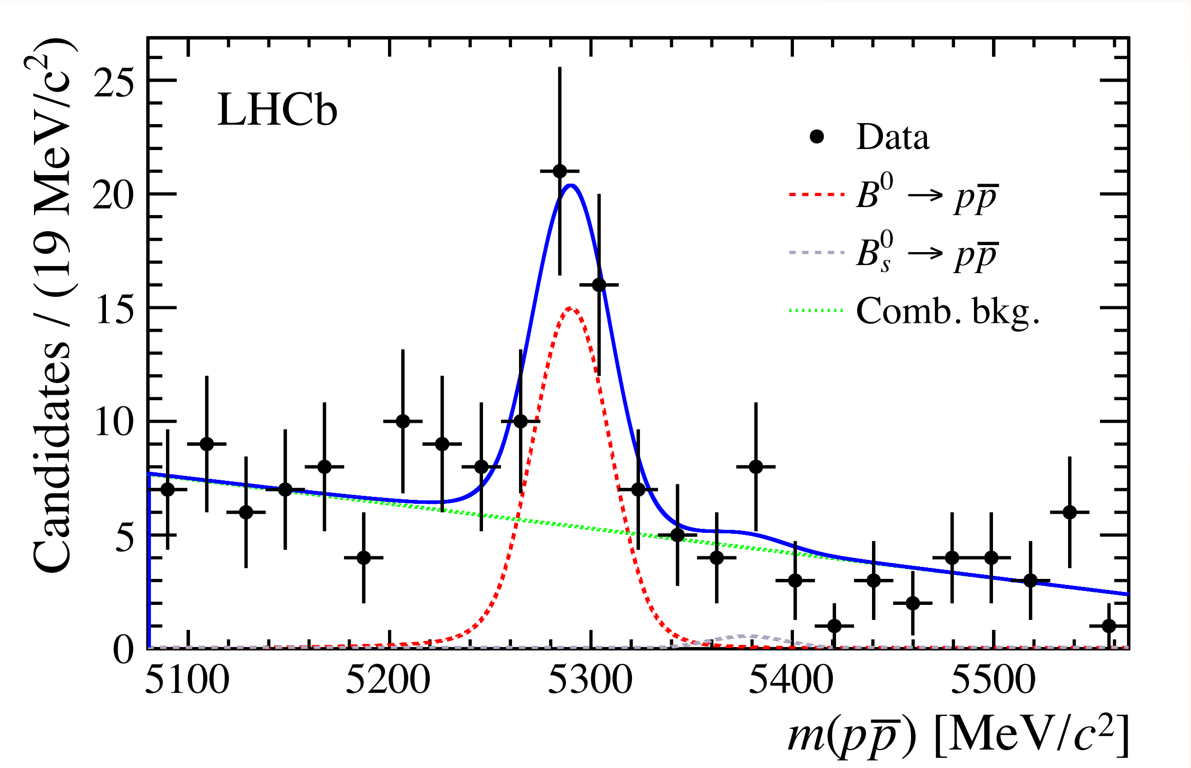
  } Found to not peak in m(B^0)

Phys. Rev. Lett. 119 (2017), 232001
Published: **Dec 2017**

$B^0 \to p\bar{p}$

- Clear B⁰ peak
  - **5.3σ** significance (inc. systematics)

- Branching fraction determined relative to **Normalisation** mode $B^0 \to K^+\pi^-$
  - Selected with same MVA



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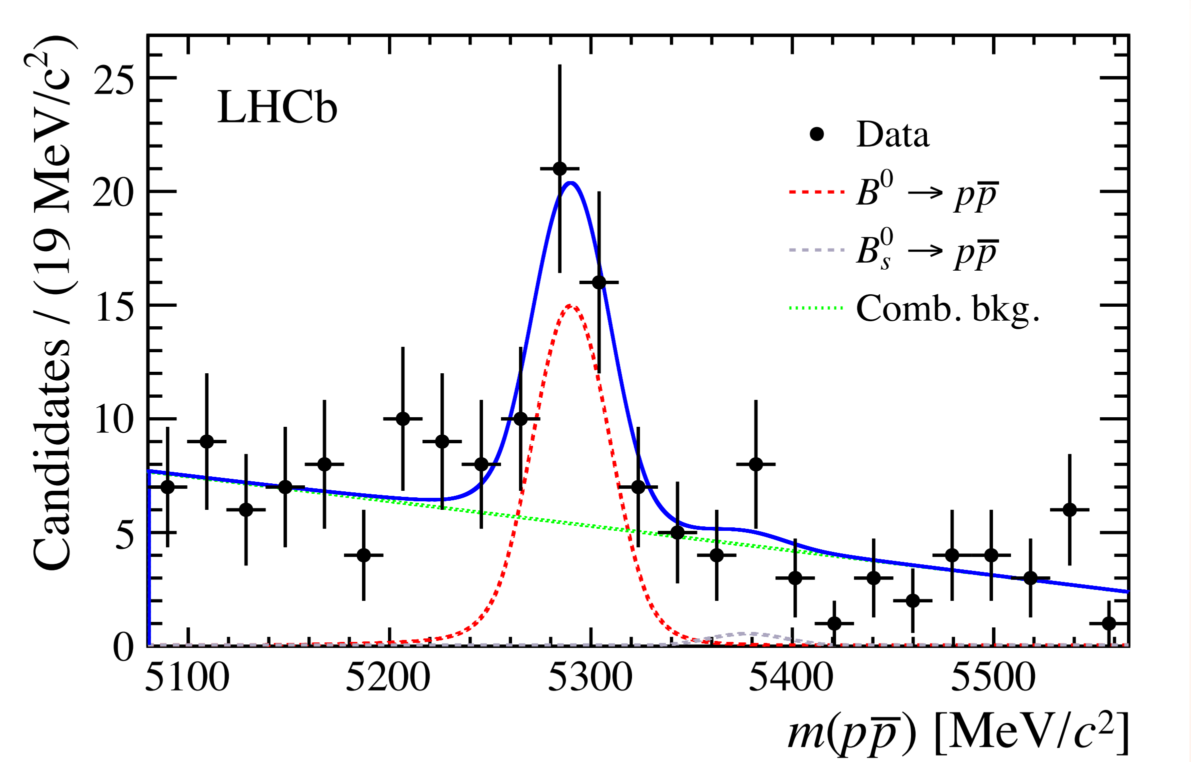


- Branching fraction determined relative to **Normalisation** mode $B^0 \to K^+\pi^-$
  - Selected with same MVA

- **First observation** of purely baryonic B^0 decay
  - **Rarest** B^0 decay ever observed
  - Limit set on B_s^0 decay

$$\mathcal{B}(B^0 \to p\bar{p}) = (1.25 \pm \underset{(stat.)}{0.27} \pm \underset{(sys.)}{0.18}) \times 10^{-8}$$

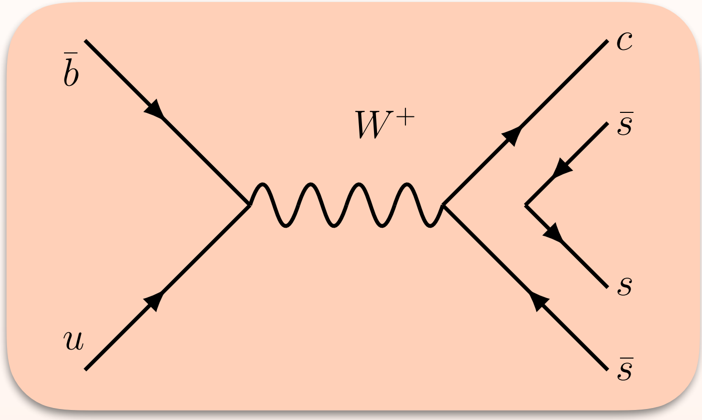
$$\mathcal{B}(B_s^0 \to p\bar{p}) < 1.5 \times 10^{-8} \qquad (90\%\ \text{CL})$$

Phys. Rev. Lett. 119 (2017), 232001
Published: **Dec 2017**

$B^+ \to D_s^+ \phi$

New

- Search for **pure annihilation** decay



JHEP 01 (2018) 131

Published: **Jan 2018**

$B^+ \to D_s^+ \phi$

New

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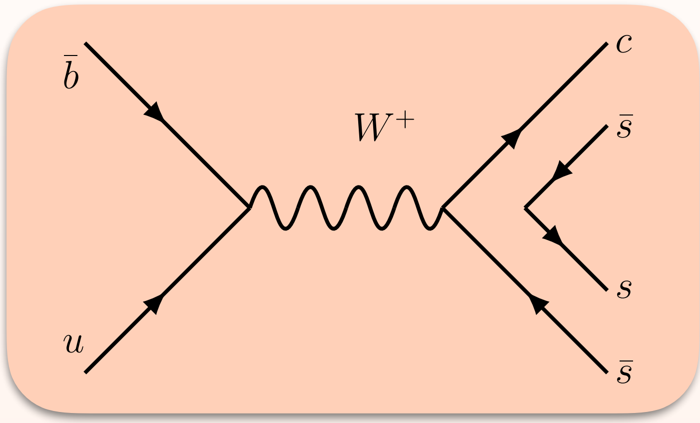


- Previous evidence reported by LHCb using 1 fb^{-1} sample

$$\mathcal{B}(B^+ \to D_s \phi) = (1.87^{+1.25}_{-0.73}\,\text{(stat.)} \pm 0.19\,\text{(sys.)} \pm 0.32\,\text{(norm.)}) \times 10^{-6}$$

JHEP 1302 (2013) 043

- Large branching fraction or CP violation possible in BSM scenarios

SM: $(1-7) \times 10^{-7}$

NP: $\mathcal{O}(10^{-5})$

Phys.Lett.B540:241-246,2002

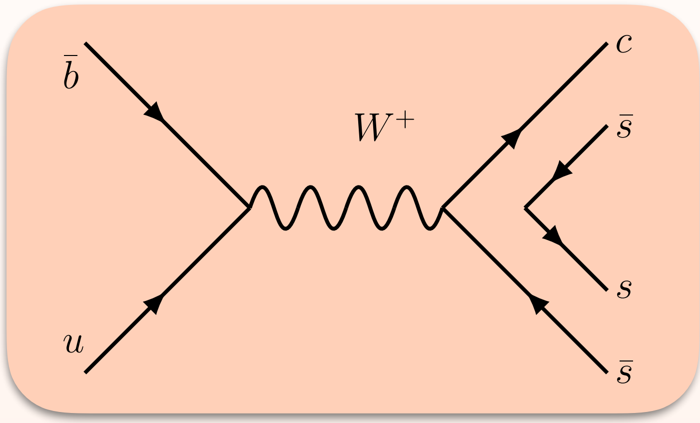
JHEP 01 (2018) 131

Published: **Jan 2018**

$B^+ \to D_s^+ \phi$

New

- Search for **pure annihilation** decay



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JHEP 01 (2018) 131

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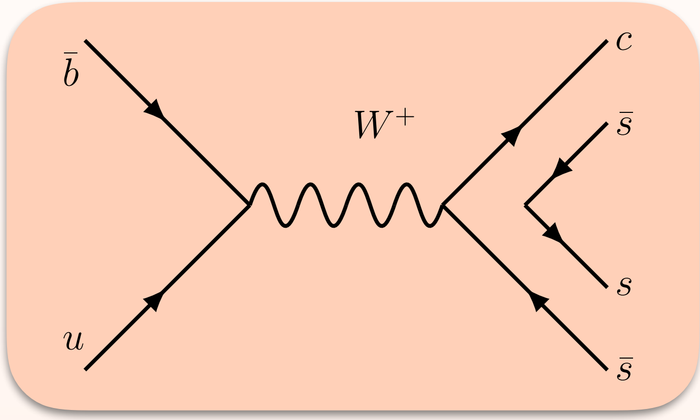

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Phys.Lett.B540:241-246,2002

- Updated with **Run I** and **Run II** dataset (4.8 fb^{-1})

- Analysis **split** into searches for both

$B^+ \to D_s^+ K^+ K^-$ and $B^+ \to D_s^+ \phi$

- Candidates selected with **data-driven** BDTs
  - Trained using large samples of high purity D_s and ϕ mesons in data

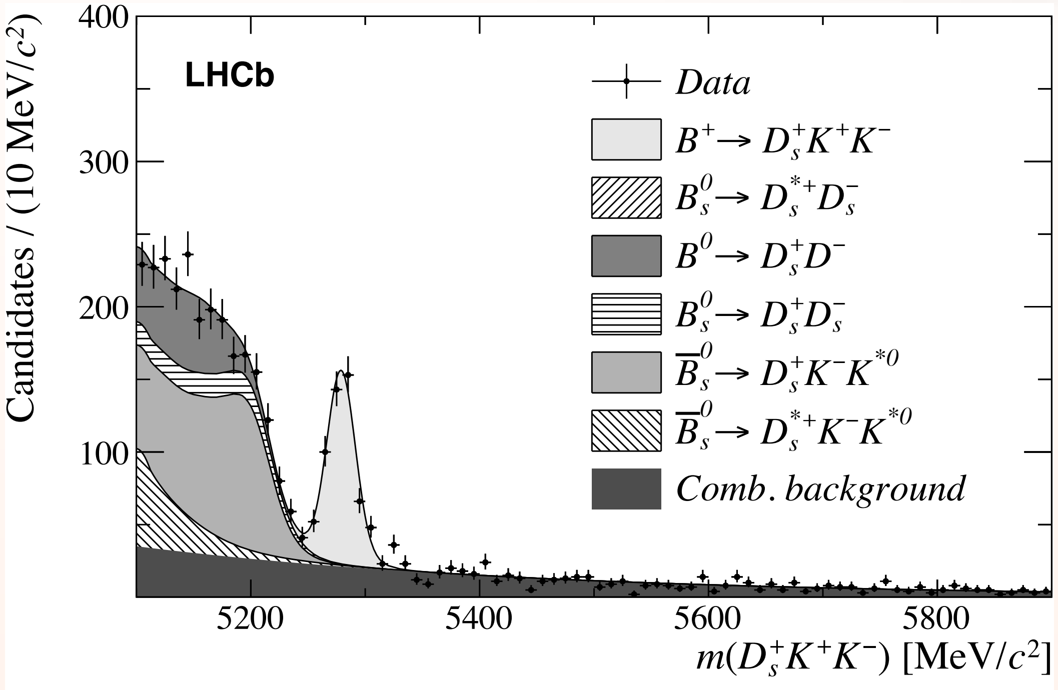
JHEP 01 (2018) 131

Published: **Jan 2018**

$B^+ \to D_s^+ \phi$

New

- Large peak for whole K^+K^- mass range
  - including ϕ mass range
- Branching fraction determined relative to **normalisation** mode $B^+ \to D_s^+ \overline{D}^0$



$$\mathcal{B}(B^+ \to D_s^+ K^+ K^-) = (7.1 \pm 0.5 \pm 0.6 \pm 0.7) \times 10^{-6}$$
(stat.) (sys.) (norm.)

JHEP 01 (2018) 131
Published: **Jan 2018**

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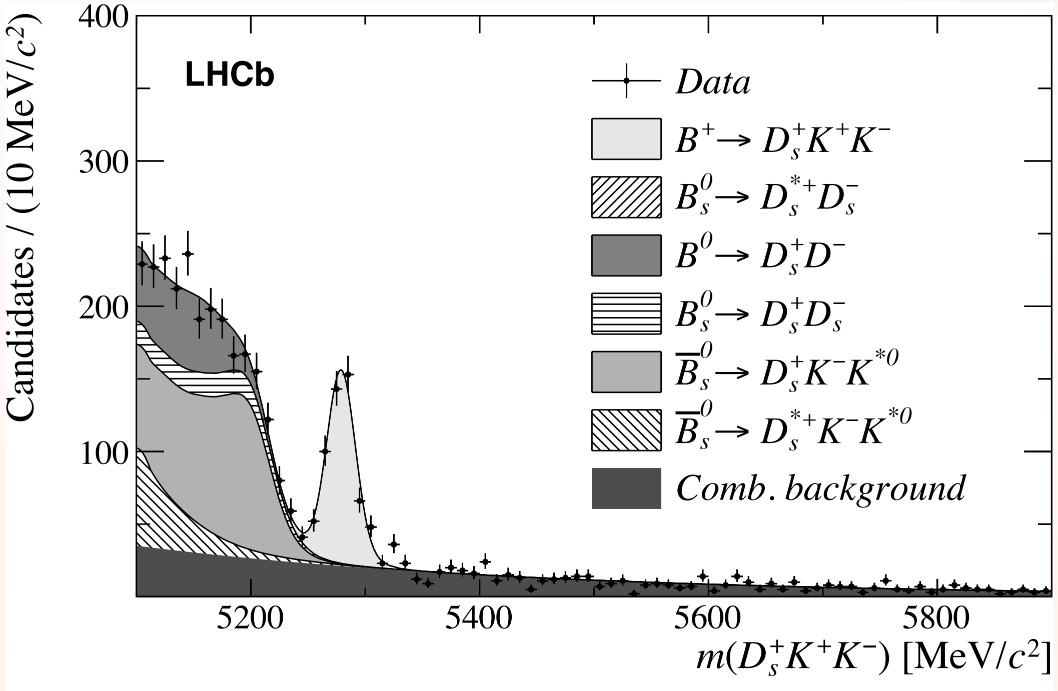

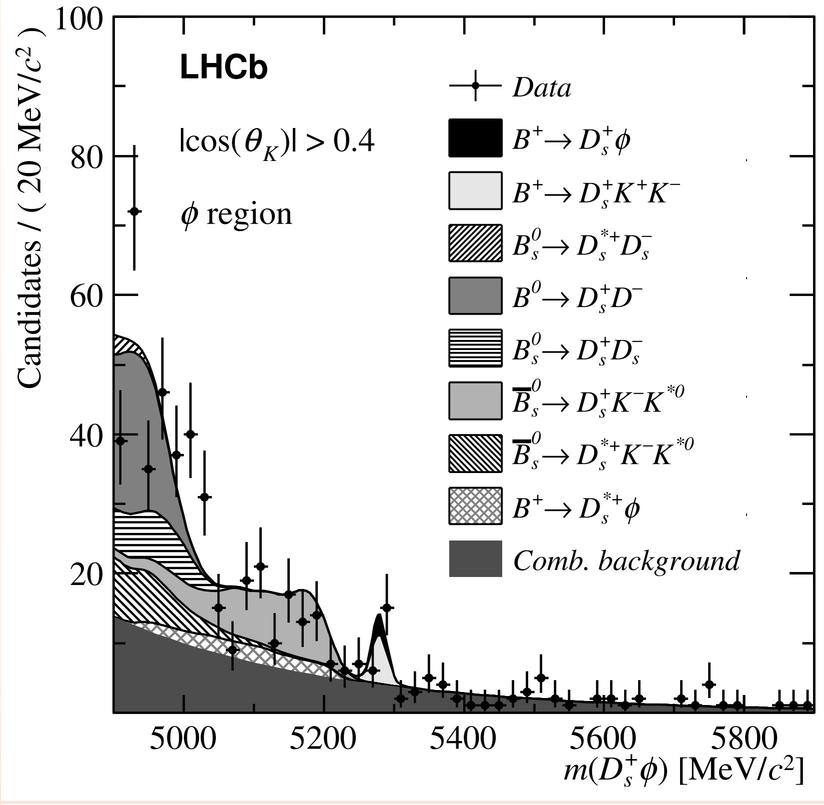

- Candidates fitted in **narrow region** around ϕ mass
  - ϕ meson isolated via **helicity** and **mass** distribution
- **New limit** set

$$\mathcal{B}(B^+ \to D_s^+ \phi) < 4.9 \times 10^{-7} \quad (95\%\ \text{CL})$$

supersedes previous result

NB: small peak is peaking background

JHEP 01 (2018) 131

Published: **Jan 2018**

Summary

- LHCb reports **many developments** for rare B decays…

$B^0_{(s)} \to \mu^+\mu^-$	**Single experiment** BF measurement, first measurement of **effective lifetime**
$B^0_{(s)} \to \tau^+\tau^-$	Worlds best **tauonic** limits set
$B^0_{(s)} \to e^\pm\mu^\mp$	Worlds best **LFV** limits set

$B^0 \to p\bar{p}$	**Rarest** B^0 decay ever observed
$B^+ \to D_s^+\phi$	**Updated limit** on pure annihilation decay, now sits in SM range

- Expect all results to be updated with **full LHCb dataset**
    - Approx **2-4** times effective statistics, depending on the mode

Tom Hadavizadeh

Back up slides

LHCb Detector