Flavour Anomalies: Experimental status

- Introduction
- Penguins
- Lepton Universality
- More Lepton Universality

Since many theorists speak after me, I leave interpretation (mostly) aside and avoid Wilson coefficients.

29/03/2018 — VUB CrossTalk

Patrick Koppenburg

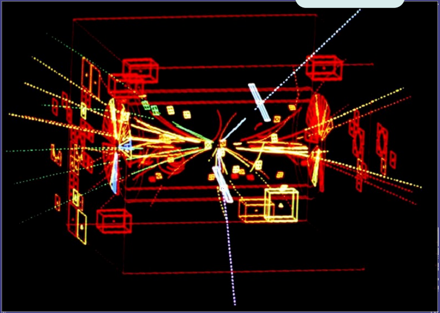
Nikhef

Precision Measurements


1973

Sensitive to "New" Physics effects off-shell

- When was the Z discovered?
  - 1973 from $\nu N \to \nu N$
  - 1983 at SpS collider?
- c quark needed to explain $K^0_{\mathrm{L}} \to \mu^+\mu^-$ (GIM)
- Third family (b,t) to explain CP violation (Kobayashi & Maskawa)

1983


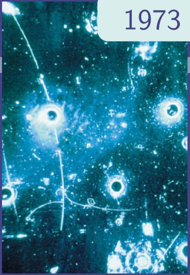
Generic New Physics Amplitude:

$$\mathcal{A} = \mathcal{A}_0 \left(\frac{C_{\mathrm{SM}}}{M_W^2} + \frac{C_{\mathrm{NP}}}{\Lambda^2} \right)$$

➜ Sensitive to very high NP scales Λ

Precision Measurements

1973



Sensitive to “New” Physics effects off-shell

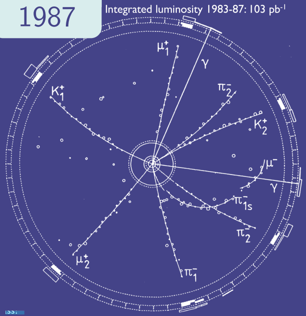
- When was the Z discovered?
  - 1973 from $\nu N \to \nu N$
  - 1983 at SpS collider?
- c quark needed to explain $K^0_{\mathrm{L}} \to \mu^+\mu^-$ (GIM)
- Third family (b,t) to explain CP violation (Kobayashi & Maskawa)

✔ Estimate masses
  - t quark from $B\overline{B}$ mixing
  - ✔ Much larger mass coverage than $\sqrt{s}$

✔ Get phases of couplings
  - Half of new parameters
  - Needed for a full understanding

- Look in lepton and **flavour** sectors
  - ➜ CP asymmetry in the Universe

1987



Precision Measurements

Where to look?

Need three ingredients:

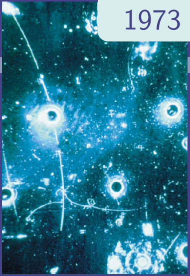
1. Precise SM prediction
2. (desirable) Precise beyond-SM predictions
3. Good experimental precision

Generic New Physics Amplitude:

$$\mathcal{A} = \mathcal{A}_0 \left(\frac{C_{\text{SM}}}{M_W^2} + \frac{C_{\text{NP}}}{\Lambda^2} \right)$$

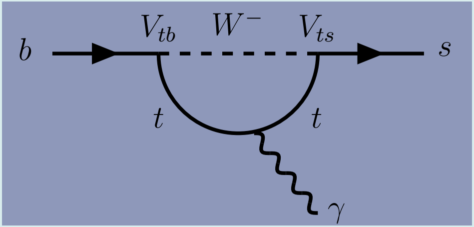
Check out my Scholarpedia article on Rare Decays. [Scholarpedia 32643]

1973



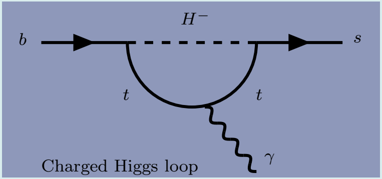
1987

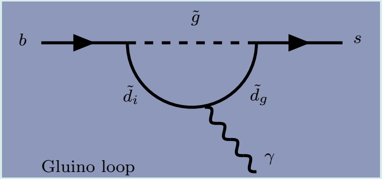
The mother of all penguins: $b \to s\gamma$

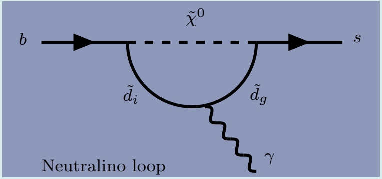


- No tree diagram ➜ suppressed
- First penguin ever observed (93)
- Experiment (WA): $\mathcal{B} = (3.49 \pm 0.19) \cdot 10^{-4}$
- SM: $\mathcal{B} = (3.36 \pm 0.23) \cdot 10^{-4}$
  [Misiak et al., PRL 114, 221801, arXiv:1503.01789]

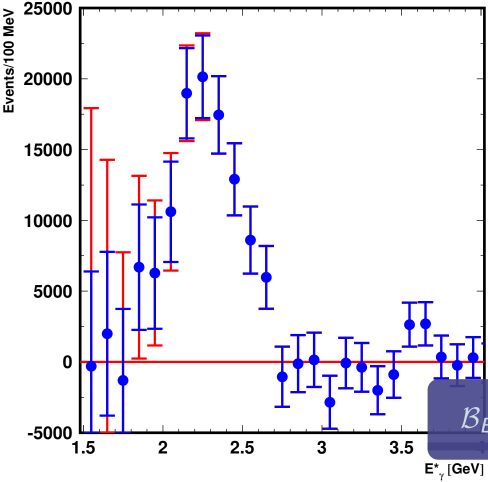
➜ Strong constraint on New Physics







PHOTON SPECTRUM IN $b \to s\gamma$



Efficiency-corrected spectrum

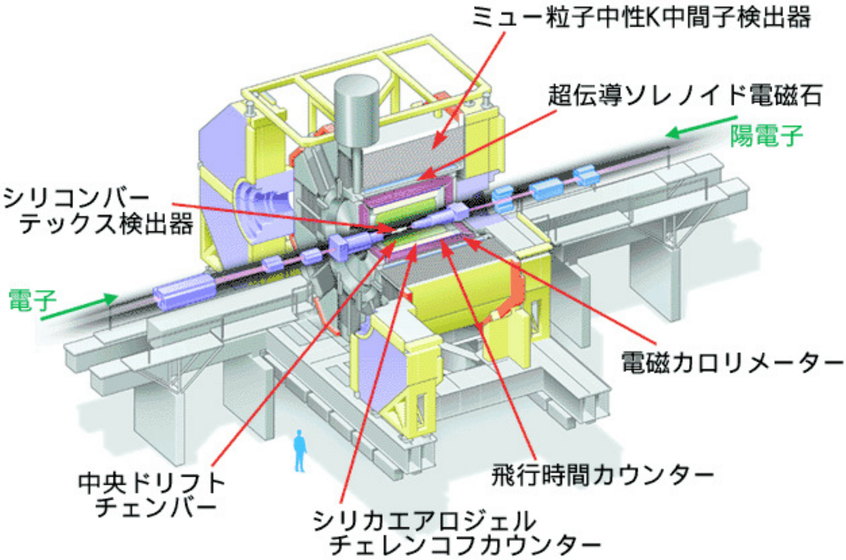
Fully inclusive $b \to s\gamma$ spectrum: The signal is just one photon

- π^0 and η backgrounds vetoed
- Non-$B\overline{B}$ subtracted from below-$\Upsilon(4S)$ data
- Remainder is $b \to s\gamma$ signal
  - ➜ efficiency-corrected

$$\mathcal{B}_{E_\gamma > 1.8} = 3.55 \pm 0.32\ {}^{+0.30}_{-0.31}\ {}^{+0.11}_{-0.07}$$

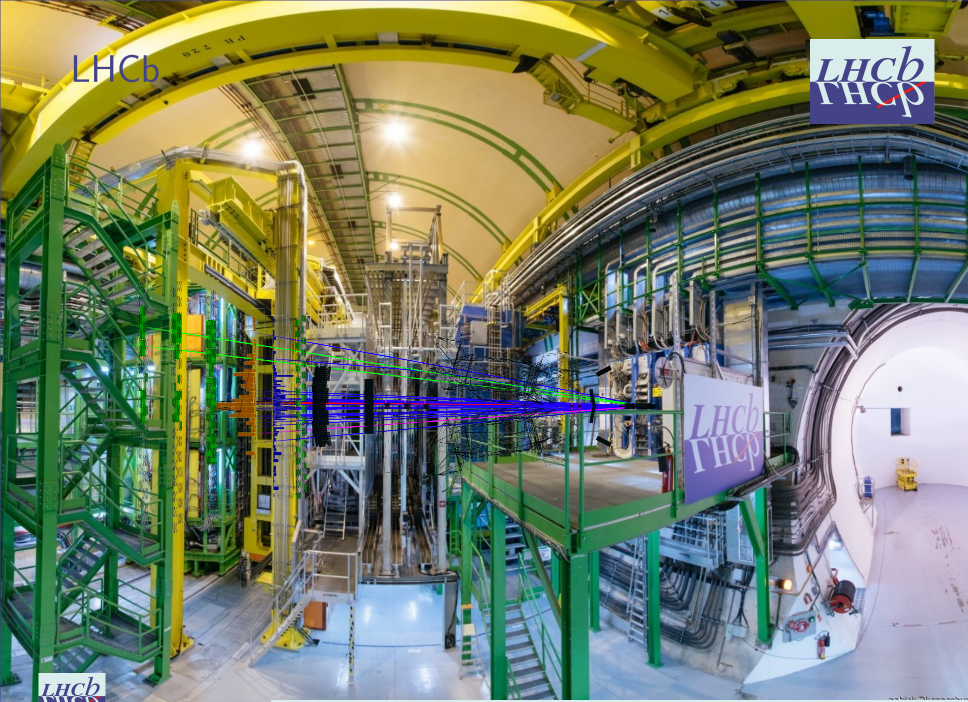
In the meantime superseded by [arXiv:1608.02344]

The Belle Experiment



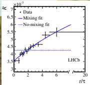
LHCb

LHCb

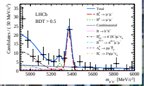


LHCb Physics Programme

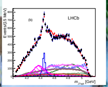
CKM and *CP* violation with *b* and *c* hadrons

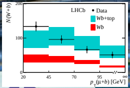


Rare decays of *b* hadrons and *c* hadrons

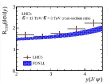


Spectroscopy in *pp* interactions and *B* decays

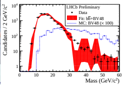




Electroweak and QCD measurements in the forward acceptance



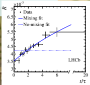
Heavy quark production



Exotica searches

LHCb Physics Programme

CKM and *CP* violation with *b* and *c* hadrons



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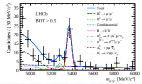

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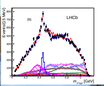

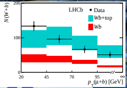

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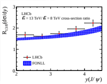

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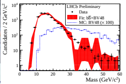
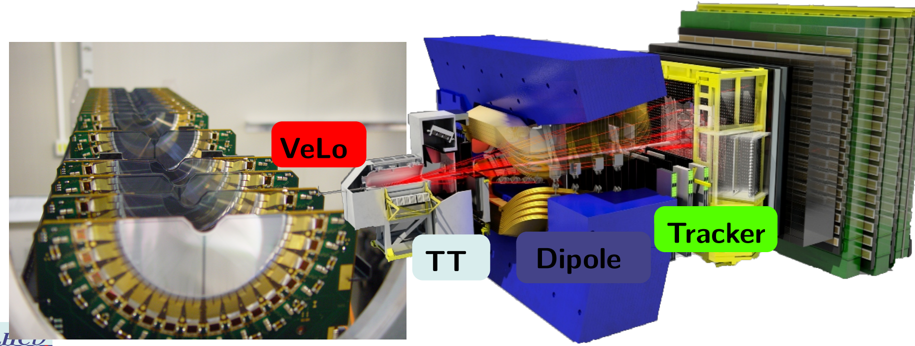


Exotica searches

LHCb Detector

Forward detector: many *b* hadrons produced forward at LHC, $(154.3 \pm 1.5 \pm 14.3)$ μb in acceptance at 13TeV [PRL 118 (2017) 052002]

- Warm dipole magnet. Polarity can be reversed
- ✔ Good momentum and position resolution
    - Vertex detector gets 8mm to the beam



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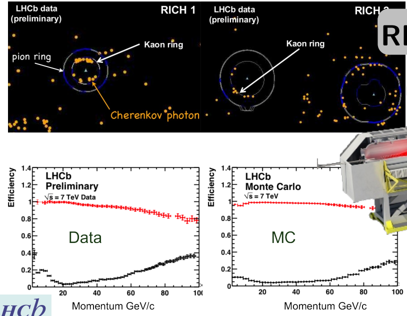
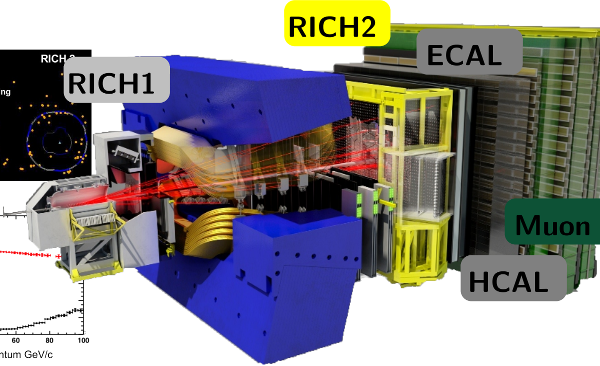
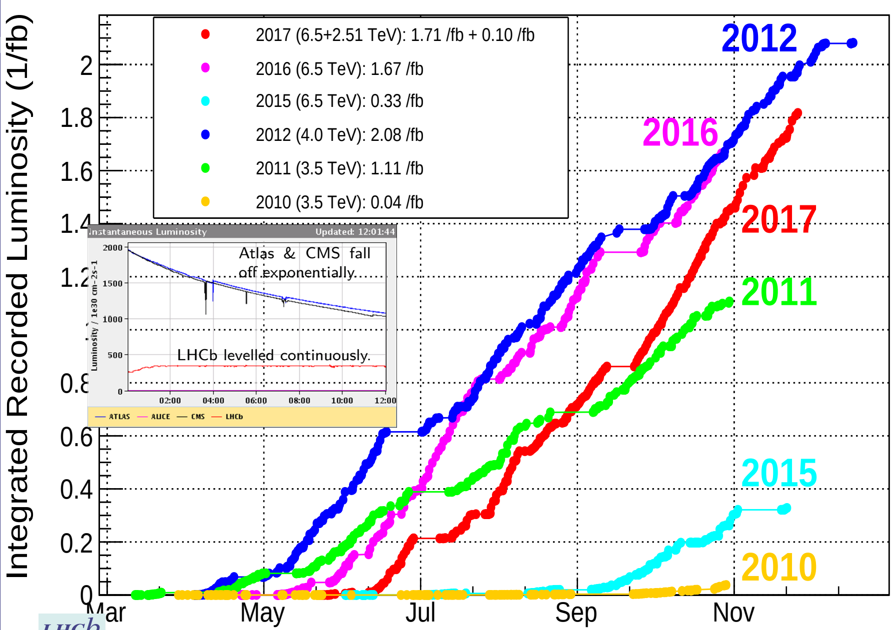
- Warm dipole magnet. Polarity can be reversed
- ✔ Good momentum and position resolution, high efficiency
- ✔ Excellent Particle ID



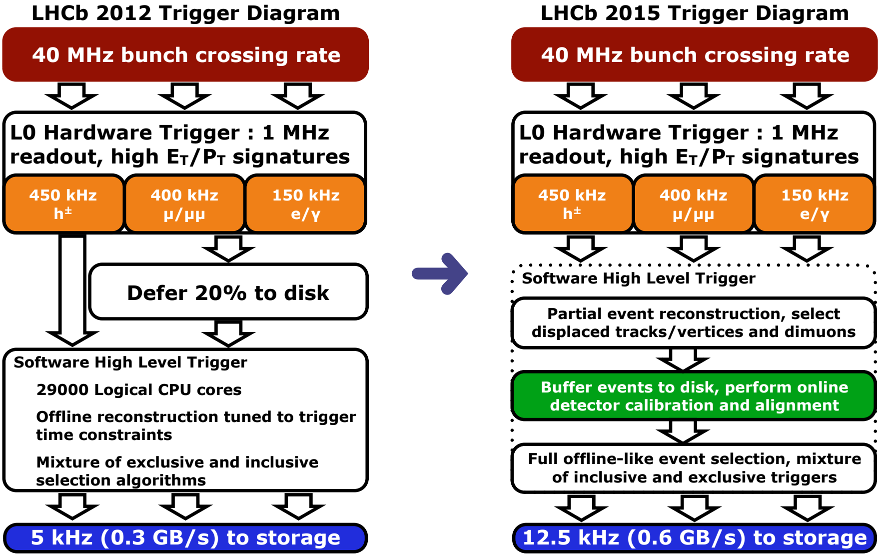


LHCb Integrated Recorded Luminosity in pp, 2010-2017

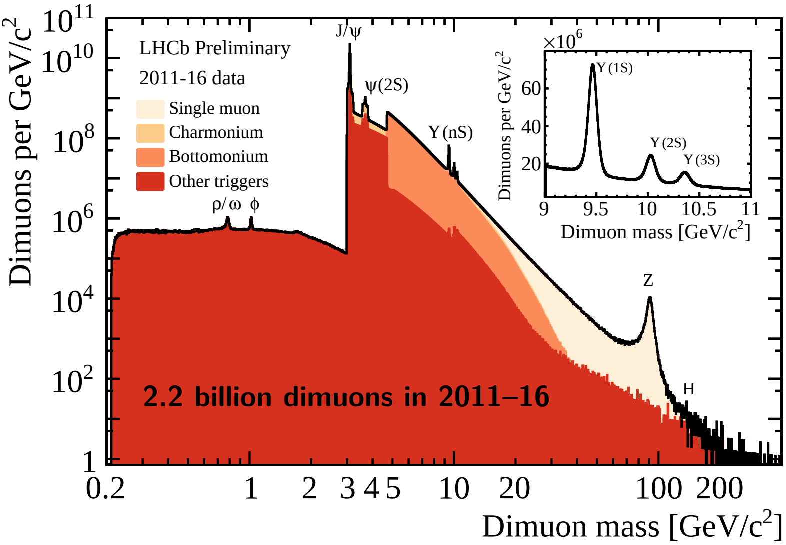
[Lumi Plots]



LHCb Trigger in Run 2



Dimuon mass distribution

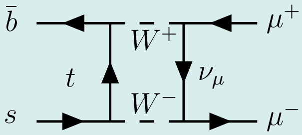


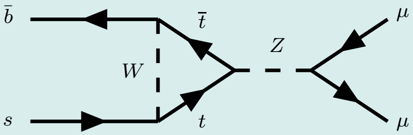
$B_s^0 \to \mu^+\mu^-$

Very rare decay, well described in the SM

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-)_{\text{SM}} = (3.57 \pm 0.17) \cdot 10^{-9}$$

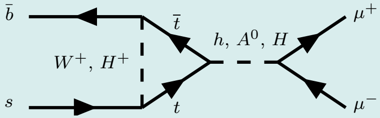
[Beneke, Bobeth, Szafron], [Bobeth, Gorbahn, Hermann, Misiak, Stamou, Steinhauser, PRL 112, 101801 (2014), arXiv:1311.0903], [De Bruyn, Fleischer, Knegjens, PK, Merk, Pellegrino, Tuning, PRL 109, 041801 (2012)] ...



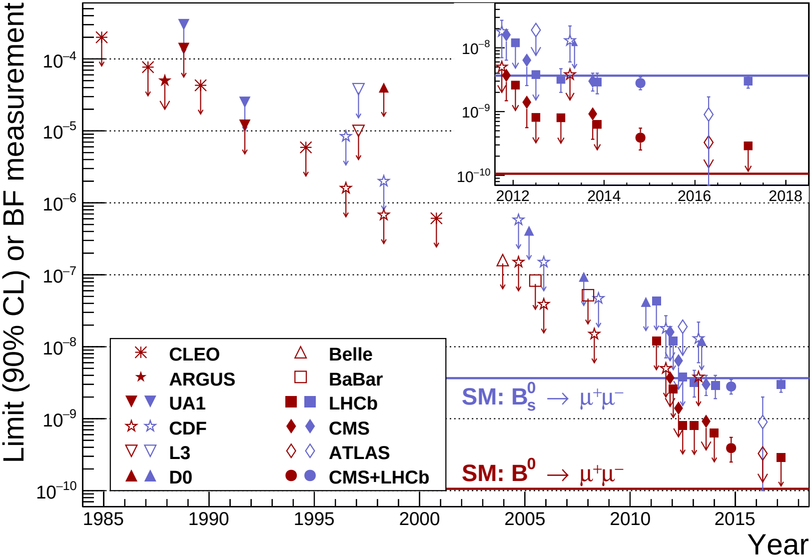


Very sensitive to NP, e.g. Minimal Susy Models:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-)_{\text{MSSM}} \propto \frac{m_b^2 m_\ell^2 \tan^6\beta}{m_A^4}$$



$B_s^0 \to \mu^+\mu^-$ Limits History



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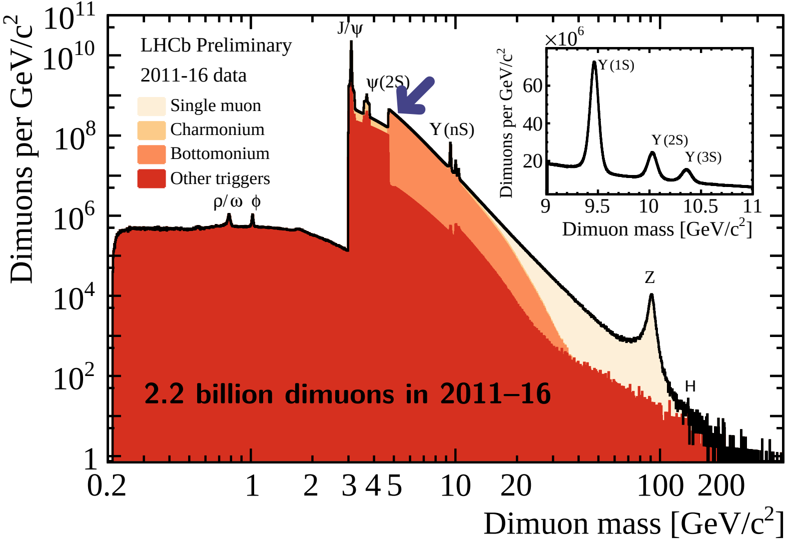
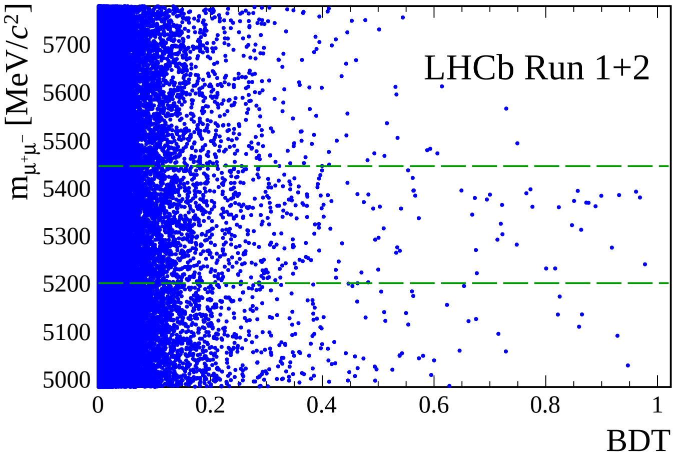
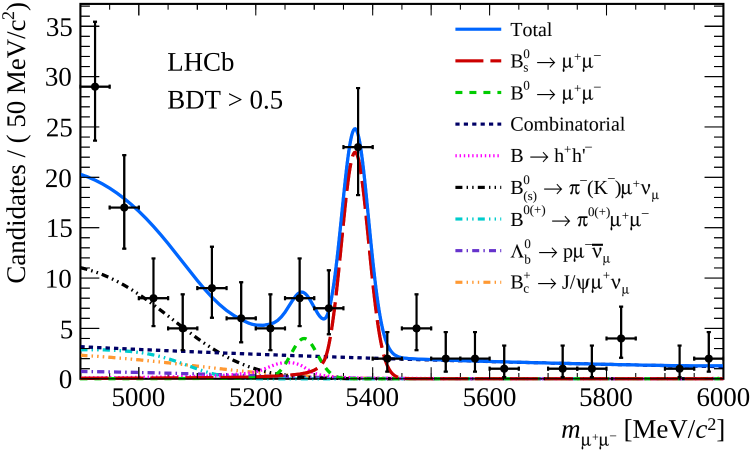


Observation of the decay $B_s^0 \to \mu^+\mu^-$



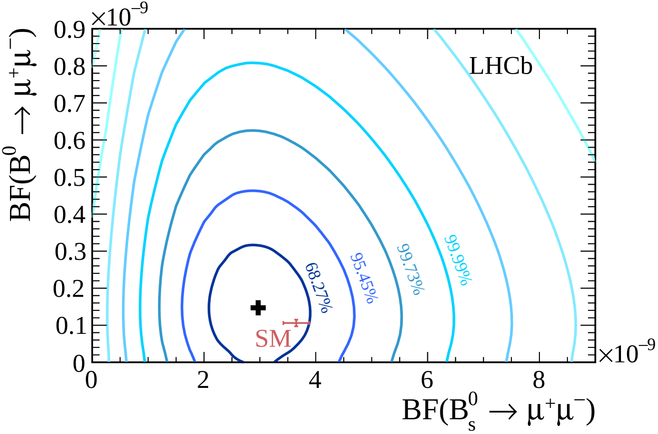
A $B \to \mu^+\mu^-$ search using 2011–2016 data is done with a mass fit in bins of BDT output.

Observation of the decay $B_s^0 \to \mu^+\mu^-$



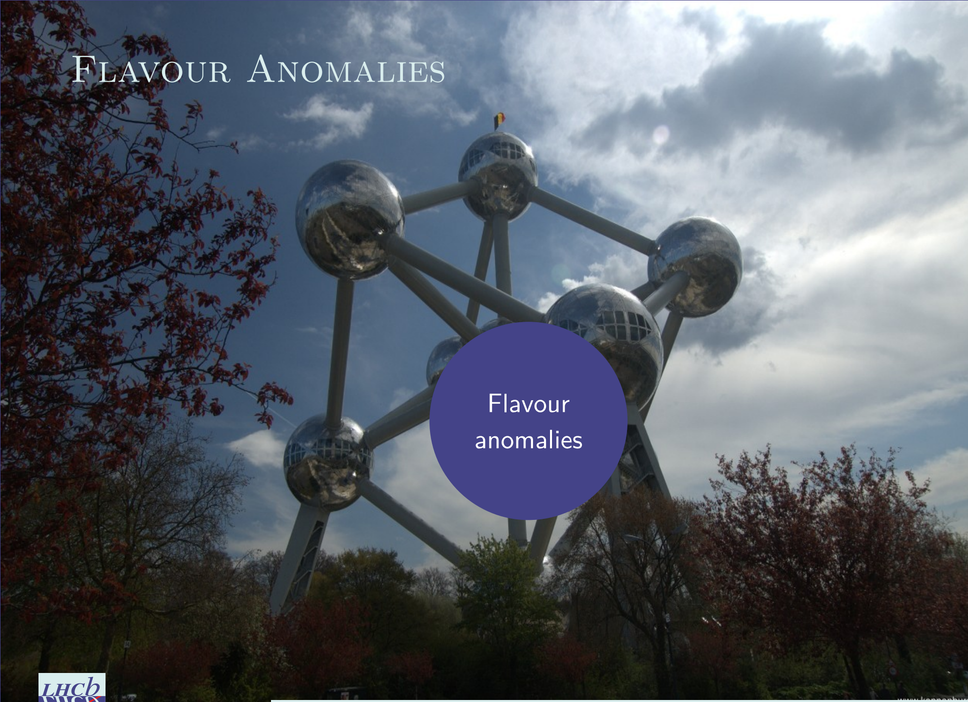
Fits are then added for better visualisation, here requiring BDT$>$ 0.5. The significances are 7.8σ for $B_s^0 \to \mu^+\mu^-$ and 1.6σ for $B^0 \to \mu^+\mu^-$.

Observation of the decay $B_s^0 \to \mu^+\mu^-$



The results $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.0 \pm 0.6\,^{+\,0.3}_{-\,0.2}) \times 10^{-9}$ and $\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.5\,^{+\,1.2}_{-\,1.0}\,^{+\,0.2}_{-\,0.1}) \times 10^{-10}$ are consistent with the SM.

Flavour Anomalies



Flavour anomalies

Flavour Anomalies

Angular (P_5')

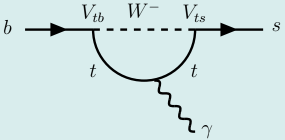
$b \to s\ell^+\ell^-$ FCNC

Flavour anomalies

BFs

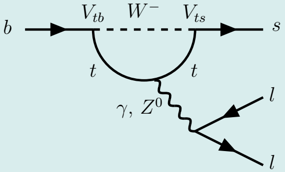
e–μ universality

$b \to s\ell^+\ell^-$



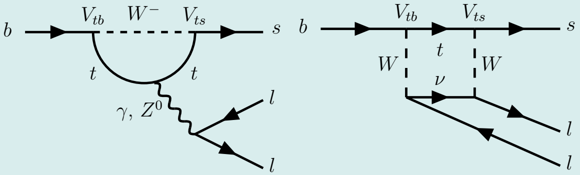
- Start with $b \to s\gamma$

$b \to s\ell^+\ell^-$



- Start with $b \to s\gamma$, pay a factor α_{EM}
  - ➜ Decay the γ into 2 leptons

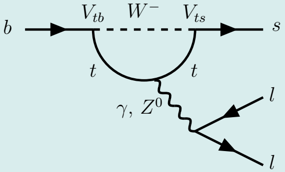
$b \to s\ell^+\ell^-$

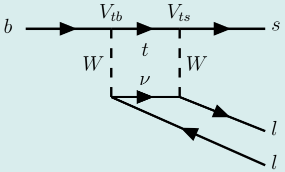


- Start with $b \to s\gamma$, pay a factor $\alpha_{\rm EM}$
  - ➜ Decay the γ into 2 leptons
  - Add an interfering box diagram
  - ➜ $b \to s\ell^+\ell^-$, very rare in the SM
    $\mathcal{B}(B \to K^*\ell^+\ell^-) = (1.8 \pm 0.2)\cdot 10^{-6}$

    [Huber et al., Nucl.Phys.B802:40-62,2008]

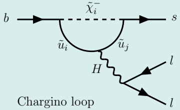
$b \to s\ell^+\ell^-$



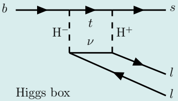


- Start with $b \to s\gamma$, pay a factor α_{EM}
  - ➜ Decay the γ into 2 leptons
  - Add an interfering box diagram
  - ➜ $b \to s\ell^+\ell^-$, very rare in the SM
- Sensitive to Supersymmetry, Any 2HDM, Fourth generation, Extra dimensions, Leptoquarks, Axions . . .

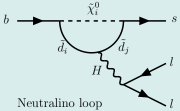
✔ Ideal place to look for new physics



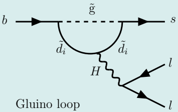
Chargino loop



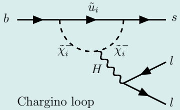
Higgs box



Neutralino loop

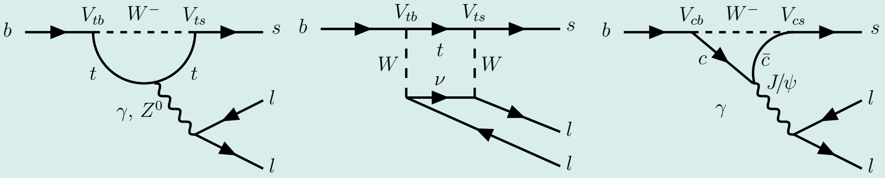


Gluino loop

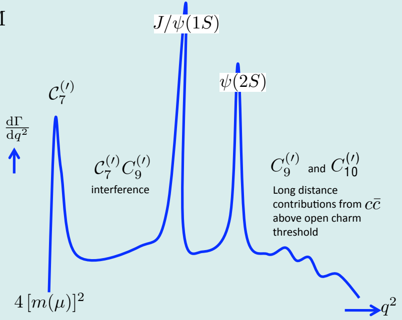


Chargino loop

$b \to s\ell^+\ell^-$



- Start with $b \to s\gamma$, pay a factor $\alpha_{\rm EM}$
  - ➜ Decay the γ into 2 leptons
  - Add an interfering box diagram
  - ➜ $b \to s\ell^+\ell^-$, very rare in the SM
- ✗ But beware of long-distance effects:
  - Tree $b \to c\bar{c}s$, $(c\bar{c}) \to \ell\ell$
  - ✔ Can be removed by mass cuts
  - ✗ ✔ Interferes elsewhere

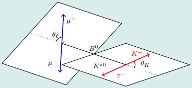


(c) Jaeger

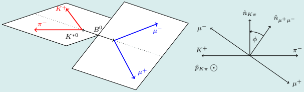
$B \to K^{*}\ell^{+}\ell^{-}$ Angular Distributions

A lot of information in the full θ_ℓ, θ_K and ϕ distributions

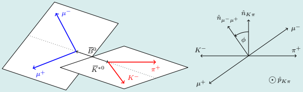
$$
\begin{aligned}
\frac{1}{\Gamma}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}\,\mathrm{d}q^2} = \frac{9}{32\pi}\Big[&\frac{3}{4}(1-F_{\mathrm{L}})\sin^2\theta_K + F_{\mathrm{L}}\cos^2\theta_K \\
&+\frac{1}{4}(1-F_{\mathrm{L}})\sin^2\theta_K\cos 2\theta_\ell - F_{\mathrm{L}}\cos^2\theta_K\cos 2\theta_\ell \\
&+ S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi \\
&+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi \\
&+ S_5\sin 2\theta_K\sin\theta_\ell\cos\phi \\
&+ S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi \\
&+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi \\
&+ S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]
\end{aligned}
$$



(a) θ_K and θ_ℓ definitions for the B^0 decay



(b) ϕ definition for the B^0 decay



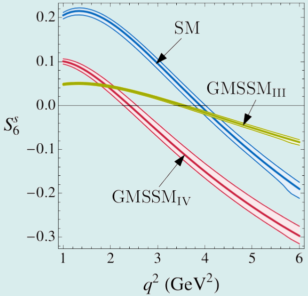
(c) ϕ definition for the $\overline{B}^0$ decay

➜ **Many observables depending on $q^2 = m_{\ell\ell}^2 c^4$**

$B \to K^* \ell^+ \ell^-$ Angular Distributions

A lot of information in the full θ_ℓ, θ_K and ϕ distributions

$$\frac{1}{\Gamma}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}\,\mathrm{d}q^2} = \frac{9}{32\pi}\left[\frac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K \right.$$
$$+\frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\cos 2\theta_\ell - F_\mathrm{L}\cos^2\theta_K\cos 2\theta_\ell$$
$$+ S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi$$
$$+ S_5\sin 2\theta_K\sin\theta_\ell\cos\phi$$
$$+ S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi$$
$$\left. + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\right]$$



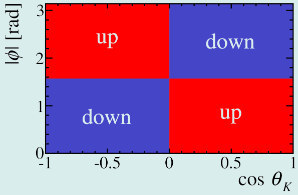
➜ **Forward-backward asymmetry**
$S_6 = \frac{4}{3}A_{\mathrm{FB}}$

[Altmannshofer et al., JHEP 0901:019,2009] [Krüger & Matias, Phys.Rev.D71:094009] [Egede et al., JHEP 0811:032,2008] [Ali et al., Phys.Rev.D61:074024]

$B \to K^*\ell^+\ell^-$ Angular Distributions

A lot of information in the full θ_ℓ, θ_K and ϕ distributions

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



$\to \quad P'_{4,5} = \dfrac{S_{4,5}}{\sqrt{F_L(1-F_L)}}$

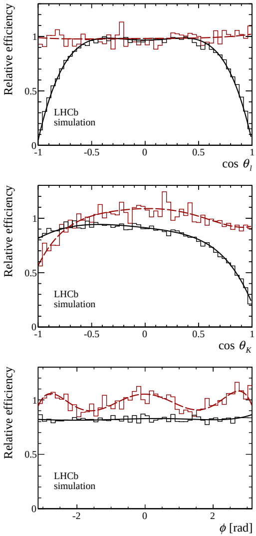
[Descotes-Genon et al., arXiv:1303.5794]

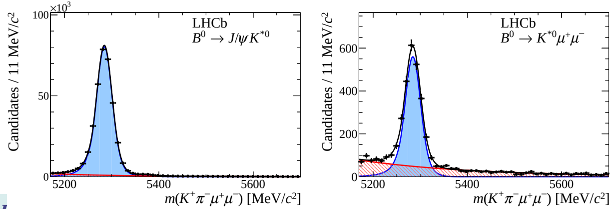
[Altmannshofer et al., JHEP 0901:019,2009] [Krüger & Matias, Phys.Rev.D71:094009] [Egede et al., JHEP 0811:032,2008] [Ali et al., Phys.Rev.D61:074024]

Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

Update of [JHEP 08 (2013) 131] and [PRL 111 (2013) 191801] to 3 fb^{-1}. S-wave is taken into account, we have finer bins, and no φ folding is needed.

- Angular acceptance obtained from MC and validated on $B^0 \to J/\psi K^*$ decays.

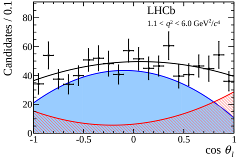


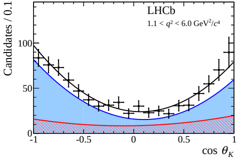


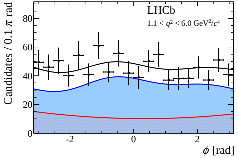
Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

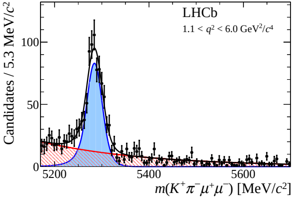
Update of [JHEP 08 (2013) 131] and [PRL 111 (2013) 191801] to 3 fb^{-1}. S-wave is taken into account, we have finer bins, and no φ folding is needed.

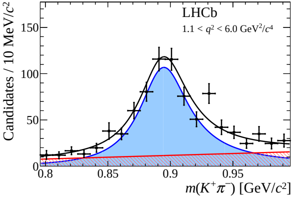
- Angular acceptance obtained from MC and validated on $B^0 \to J/\psi K^*$ decays.
- **Max Likelihood fit:** 4D fit to $m(K^+\pi^-)$ and three angles in bins of q^2.
  - Here $1.1 < q^2 < 6\ \text{GeV}^2/c^4$ is shown.
  - 2398 ± 57 decays found in total.







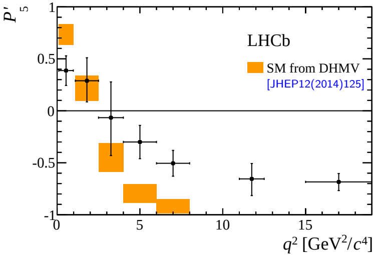


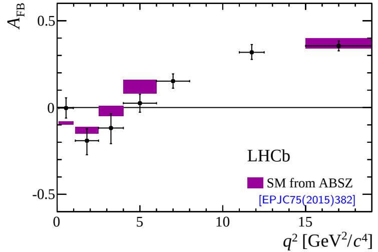


Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

Update of [JHEP 08 (2013) 131] and [PRL 111 (2013) 191801] to 3 fb^{-1}. S-wave is taken into account, we have finer bins, and no φ folding is needed.

- **Max Likelihood fit:** 4D fit to $m(K^+\pi^-)$ and three angles in bins of q^2.
- Observables consistent with SM, except S_5
- $P_5' = S_5/\sqrt{F_L(1-F_L)}$ has a local discrepancy in two bins
- $A_{\rm FB}$ seems to show a trend, but is consistent with SM





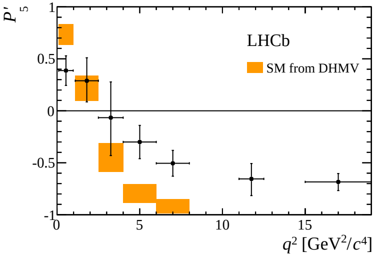
[LHCb, JHEP 02 (2016) 104, arXiv:1512.04442]

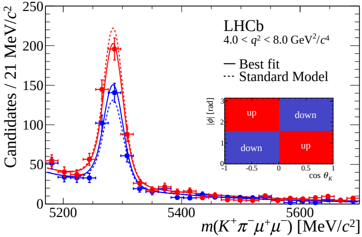
Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

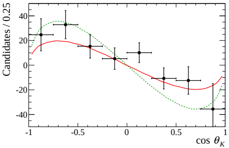
What is P_5'?

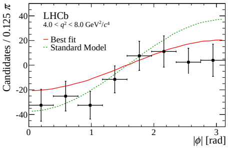
It is an asymmetry built with $\cos\theta_K$ and $|\phi|$, shown in the sketch. (integrating over one of the two gets zero).

The discrepancy with the SM prediction is visible in both angular distributions.







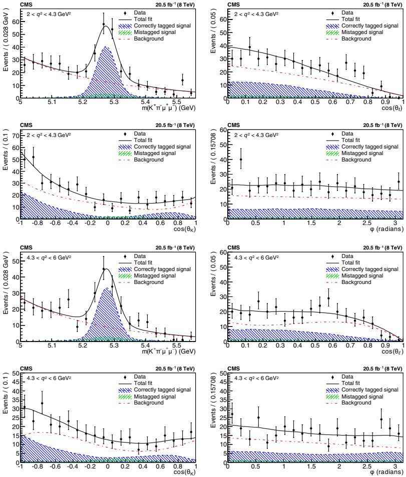


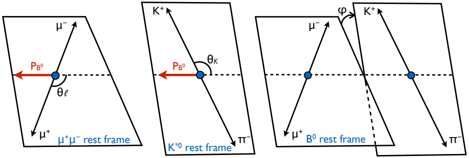
[CMS, arXiv:1710.02846]

$B^0 \to K^{*0}\mu^+\mu^-$ at CMS

CMS also study the P_5' variable using $20.5\,\text{fb}^{-1}$ at 8TeV.

- See 1400 decays
- B^0 flavour is obtained from $K^\pm\pi^\mp$ combination closest to $K^*(892)^0$ mass.

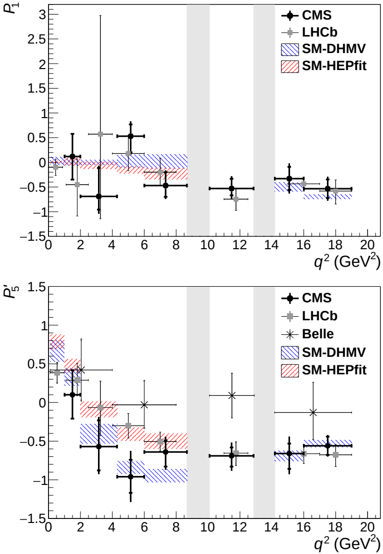




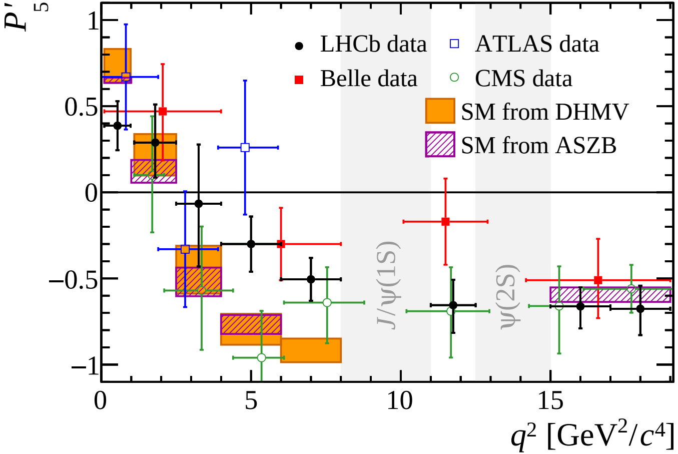
$B^0 \to K^{*0}\mu^+\mu^-$ at CMS

CMS also study the P_5' variable using $20.5\,\text{fb}^{-1}$ at 8TeV.

- See 1400 decays
- B^0 flavour is obtained from $K^\pm\pi^\mp$ combination closest to $K^*(892)^0$ mass.
- CMS measurement of P_5' is closer to the SM than LHCb and Belle
  - ✗ "SM-HEPfit" is not a prediction but a fit to the LHCb data [Ciuchini et al., JHEP 1606 (2016) 116]

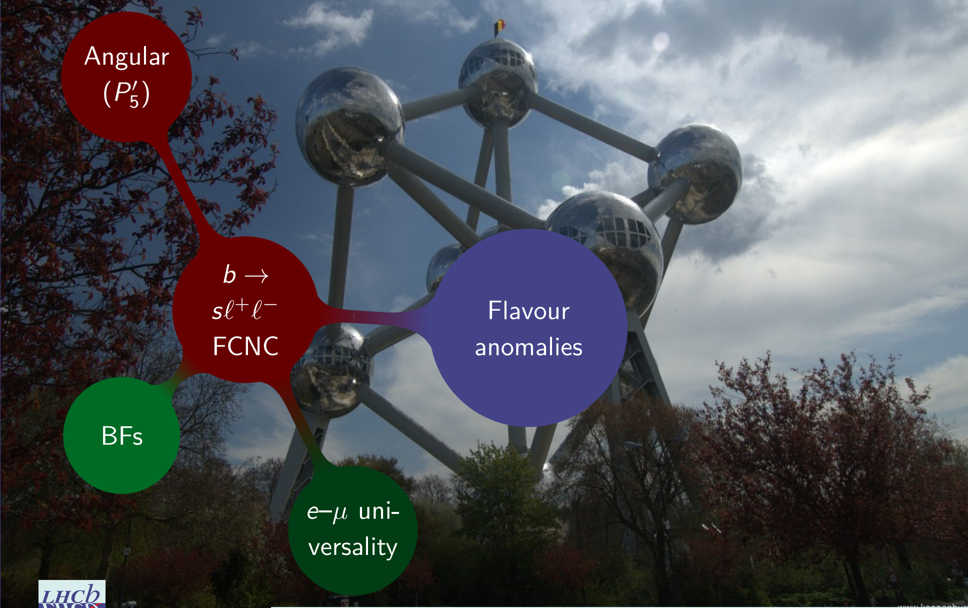


All P'_5 measurements



[LHCb, JHEP 02 (2016) 104, arXiv:1512.04442][Belle, PRL 118 (2017) 111801, arXiv:1604.04042] [CMS, arXiv:1710.02846] [ATLAS-CONF-2017-023]

Flavour Anomalies



$B \to K e^+ e^-$ Theory

$$R_X = \frac{\int_{4m_\mu^2}^{q^2_{\text{max}}} \mathrm{d}s \frac{d\Gamma\left(B \to X \mu^+ \mu^-\right)}{\mathrm{d}s}}{\int_{4m_\mu^2}^{q^2_{\text{max}}} \mathrm{d}s \frac{d\Gamma\left(B \to X e^+ e^-\right)}{\mathrm{d}s}} \overset{\text{SM}}{=} \begin{cases} 1.000 \pm 0.001 & X = K \\ 0.991 \pm 0.002 & X = K^* \end{cases}$$

[Hiller & Krüger, PRD69 (2004) 074020]

Corrections can be $\mathcal{O}(10\%)$ for instance with neutral Higgs boson exchanges.

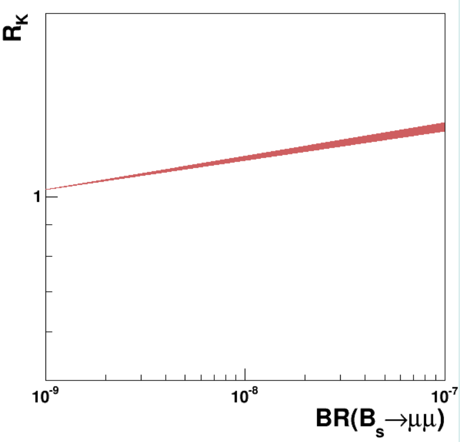
$B \to K e^+ e^-$ Theory

$$R_X = \frac{\int_{4m_\mu^2}^{q^2_{max}} \mathrm{d}s \frac{d\Gamma(B \to X \mu^+ \mu^-)}{\mathrm{d}s}}{\int_{4m_\mu^2}^{q^2_{max}} \mathrm{d}s \frac{d\Gamma(B \to X e^+ e^-)}{\mathrm{d}s}}$$

$$R_K - 1 \propto \mathcal{B}(B^0_s \to \mu^+ \mu^-)$$

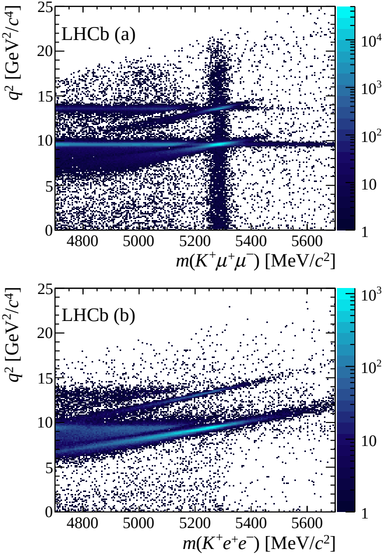
Assuming:

- Right-handed currents negligible
- (Pseudo-)scalar couplings $\propto m_l$,
- No CP phases beyond the SM



[Hiller & Krüger, PRD69 (2004) 074020]

Lepton universality with $B^+ \to K^+\ell^+\ell^-$

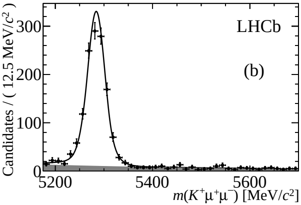


- Measure ratio R_K of $B^+ \to K^+\mu^+\mu^-$ to $B^+ \to K^+e^+e^-$ in $1 < q^2 < 6$ GeV^2

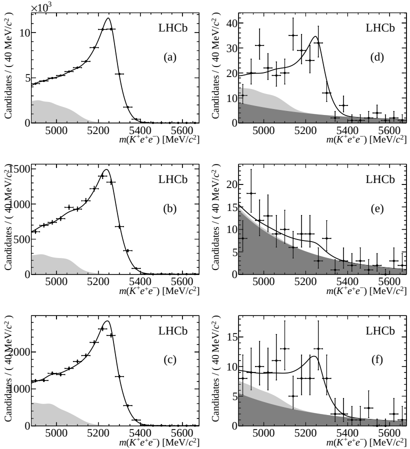
$$R_K \simeq \frac{|C_{9,10,\mathrm{SM}} + C^{\mu}_{9,10} + C'^{\mu}_{9,10}|^2}{|C_{9,10,\mathrm{SM}} + C^{e}_{9,10} + C'^{e}_{9,10}|^2}$$

[Hiller & Schmaltz, arXiv:1411.4773]

✔ Signal clearly visible in $K^+\mu^+\mu^-$



Lepton universality with $B^+ \to K^+\ell^+\ell^-$



- Measure ratio R_K of $B^+ \to K^+\mu^+\mu^-$ to $B^+ \to K^+e^+e^-$ in $1 < q^2 < 6\ \mathrm{GeV}^2$
  - ✔ Signal clearly visible in $K^+\mu^+\mu^-$
- Separate $K^+e^+e^-$ by electron, hadron and other L0 triggers
  - Use different mass pdf depending on the number of bremsstrahlung photons
- Build a double ratio $R_K =$

$$\left(\frac{\mathcal{N}_{K^+\mu^+\mu^-}}{\mathcal{N}_{K^+e^+e^-}}\right)\left(\frac{\mathcal{N}_{J/\psi(e^+e^-)K^+}}{\mathcal{N}_{J/\psi(\mu^+\mu^-)K^+}}\right)$$

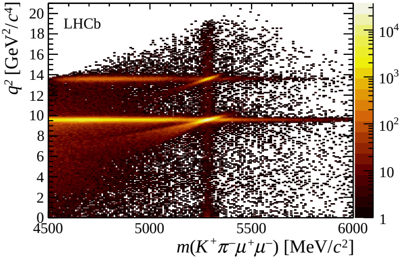
$$= 0.745\,^{+0.090}_{-0.074} \pm 0.036$$

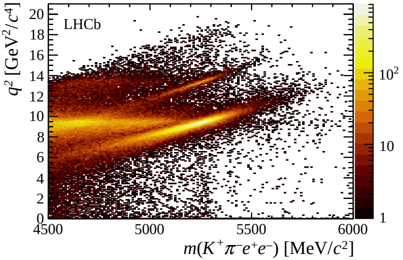
2.6σ from unity

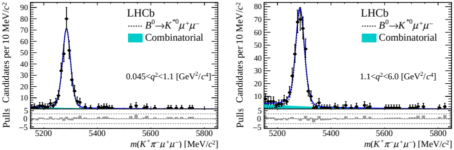
Lepton universality in $B^0 \to K^{*0}\ell^+\ell^-$

Measure ratio R_{K^*} of $B^0 \to K^{*0}\mu^+\mu^-$ to $B^0 \to K^{*0}e^+e^-$ in $0.045 < q^2 < 1.1$ and $1.1 < q^2 < 6$ GeV^2

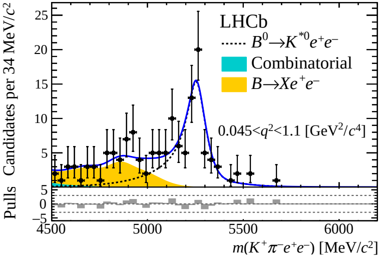
- ✔ Signal clearly visible in $K^{*0}\mu^+\mu^-$

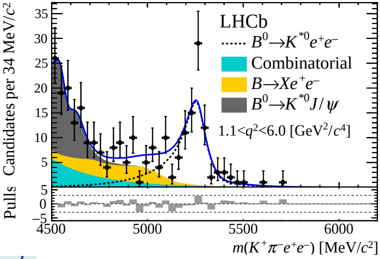






Lepton universality in $B^0 \to K^{*0}\ell^+\ell^-$

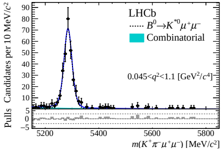


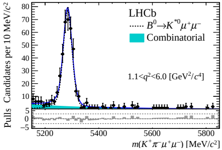


Measure ratio R_{K^*} of $B^0 \to K^{*0}\mu^+\mu^-$ to $B^0 \to K^{*0}e^+e^-$ in $0.045 < q^2 < 1.1$ and $1.1 < q^2 < 6$ GeV^2

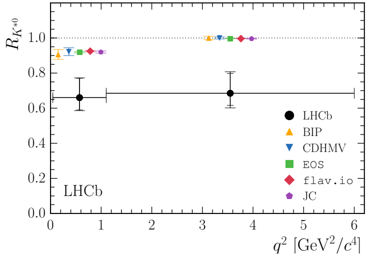
- ✔ Signal clearly visible in $K^{*0}\mu^+\mu^-$
- Separate $K^{*0}e^+e^-$ by electron, hadron and other L0 triggers

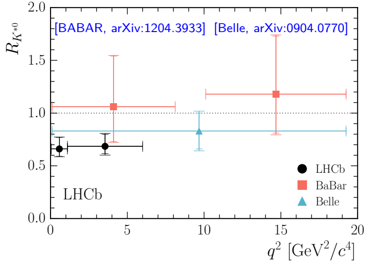
	$B^0 \to K^{*0}\ell^+\ell^-$		$B^0 \to K^{*0}J/\psi(\to \ell^+\ell^-)$
	low-q^2	central-q^2	
$\mu^+\mu^-$	$285\,^{+18}_{-18}$	$353\,^{+21}_{-21}$	$274416\,^{+602}_{-654}$
e^+e^- (L0E)	$55\,^{+9}_{-8}$	$67\,^{+10}_{-10}$	$43468\,^{+222}_{-221}$
e^+e^- (L0H)	$13\,^{+5}_{-5}$	$19\,^{+6}_{-5}$	$3388\,^{+62}_{-61}$
e^+e^- (L0I)	$21\,^{+5}_{-4}$	$25\,^{+7}_{-6}$	$11505\,^{+115}_{-114}$





Lepton universality in $B^0 \to K^{*0}\ell^+\ell^-$





Measure ratio R_{K^*} of $B^0 \to K^{*0}\mu^+\mu^-$ to $B^0 \to K^{*0}e^+e^-$ in $0.045 < q^2 < 1.1$ and $1.1 < q^2 < 6$ GeV^2

- ✔ Signal clearly visible in $K^{*0}\mu^+\mu^-$
- Separate $K^{*0}e^+e^-$ by electron, hadron and other L0 triggers

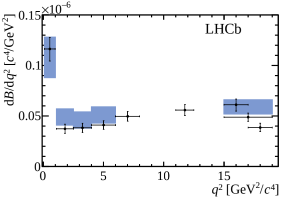
Build a double ratio $R_K =$

$$\left(\frac{\mathcal{N}_{K^{*0}\mu^+\mu^-}}{\mathcal{N}_{K^{*0}e^+e^-}}\right)\left(\frac{\mathcal{N}_{J/\psi(e^+e^-)K^{*0}}}{\mathcal{N}_{J/\psi(\mu^+\mu^-)K^{*0}}}\right)$$

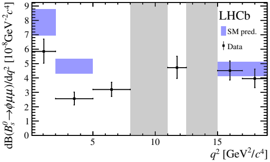
$$= \begin{cases} 0.66\,^{+0.11}_{-0.07} \pm 0.03 & 0.045 < q^2 < 1.1 \\ 0.69\,^{+0.11}_{-0.07} \pm 0.05 & 1.1 < q^2 < 6.0 \end{cases}$$

This about 2 to 2.5σ from the SM, depending on predictions. [BIP, EPJC 76 440] [CDHMV, JHEP04(2017)016] [EOS, PRD 95 035029] [flav.io, EPJC 77 377] [JC, PRD93 014028]

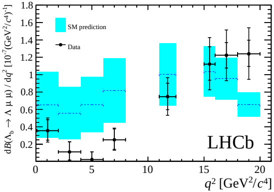
BFs too low in $b \to s\mu^+\mu^-$ decays?



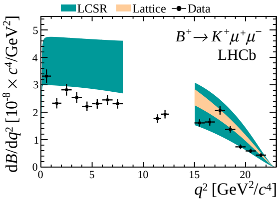
$B^0 \to K^{*0}\mu^+\mu^-$ [JHEP 11 (2016) 047]



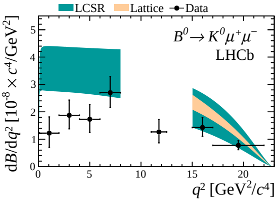
$B^0_s \to \phi\mu^+\mu^-$ [JHEP 09 (2015) 179]



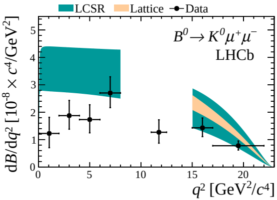
$\Lambda^0_b \to \Lambda\mu^+\mu^-$ [JHEP 06 (2015) 115]



$B^+ \to K^+\mu^+\mu^-$ [JHEP 06 (2014) 133]

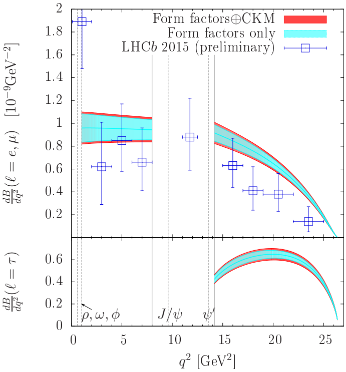


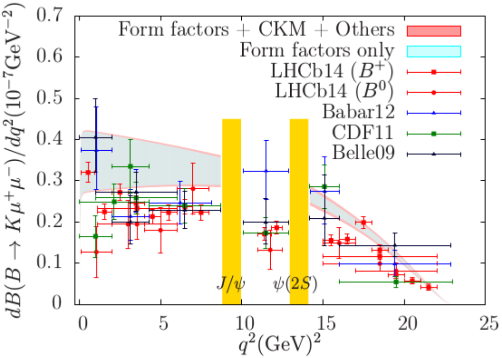
$B^0 \to K^0\mu^+\mu^-$ [JHEP 06 (2014) 133]



$B^+ \to K^{*+}\mu^+\mu^-$ [JHEP 06 (2014) 133]

$B \to h\ell^+\ell^-$ form factors from MILC



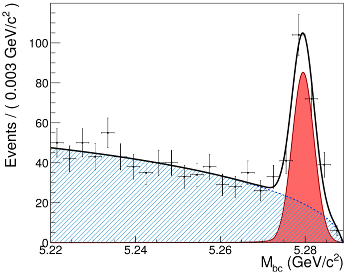


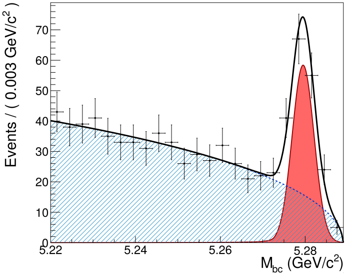
$B^+ \to \pi^+\ell^+\ell^-$ [JHEP 10 (2015) 034] and $B \to K\ell^+\ell^-$ [JHEP 06 (2014) 133] are all below the lattice computations.

$B^0 \to K^{*0}\ell^+\ell^-$ ANGULAR ANALYSIS

Belle do an angular analysis of $P'_{(4,5)}$ as LHCb [JHEP 02 (2016) 104]. A_{FB} and $\mathrm{d}\Gamma/\mathrm{d}q^2$ were published in [PRL 103 171801 (2009)]

- Split sample in muons (185 ± 17 decays) and electrons (127 ± 15)

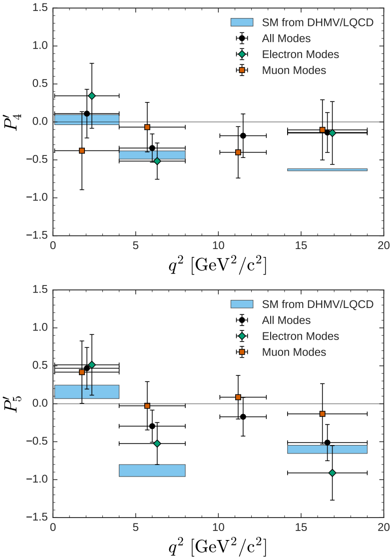




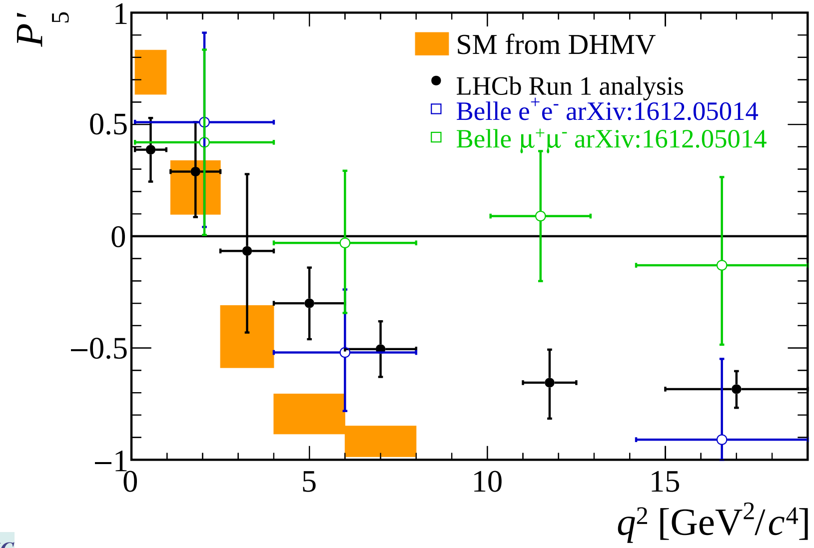
$B^0 \to K^{*0}\ell^+\ell^-$ ANGULAR ANALYSIS

Belle do an angular analysis of $P'_{(4,5)}$ as LHCb [JHEP 02 (2016) 104]. $A_{\rm FB}$ and $\mathrm{d}\Gamma/\mathrm{d}q^2$ were published in [PRL 103 171801 (2009)]

- Split sample in muons (185 ± 17 decays) and electrons (127 ± 15)
- Measure P'_4 and P'_5 and see a 2.6σ P'_5 tension for the muon modes in the $4 < q^2 < 8\,\mathrm{GeV}^2/c^4$ bin.
- Electrons are closer to the SM.



$B^0 \to K^{*0}\ell^+\ell^-$ ANGULAR ANALYSIS



First $K^+ \to \pi^+ \nu\overline{\nu}$ decay

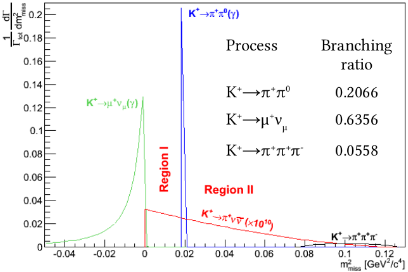
Search for $K^+ \to \pi^+ \nu\overline{\nu}$

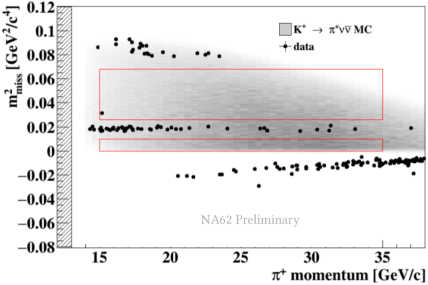
Signature is a π^+ with missing energy $m^2_{\text{miss}} = (p_{K^+} - p_{\pi^+})^2$

See one candidate in signal box
➜ Set 90% CL

$$\mathcal{B}(K^+ \to \pi^+ \nu\overline{\nu}) < 11 \times 10^{-10}$$

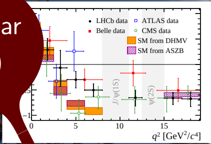
Consistent with SM expectation $(8.4{\pm}1.0){\pm}10^{-11}$ [Buras, Buttazzo, Girrbach, Knegjens, JHEP 1511 (2015) 033].





Flavour Anomalies

Angular (P_5')

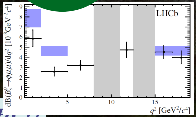


Global fits of $b \to s\ell^+\ell^-$ transitions indicate deviations from the SM of 3 to 6 σ, depending on treatment of QCD uncertainties.

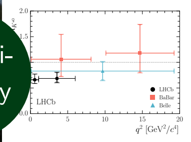
$b \to s\ell^+\ell^-$ FCNC

Flavour anomalies

BFs



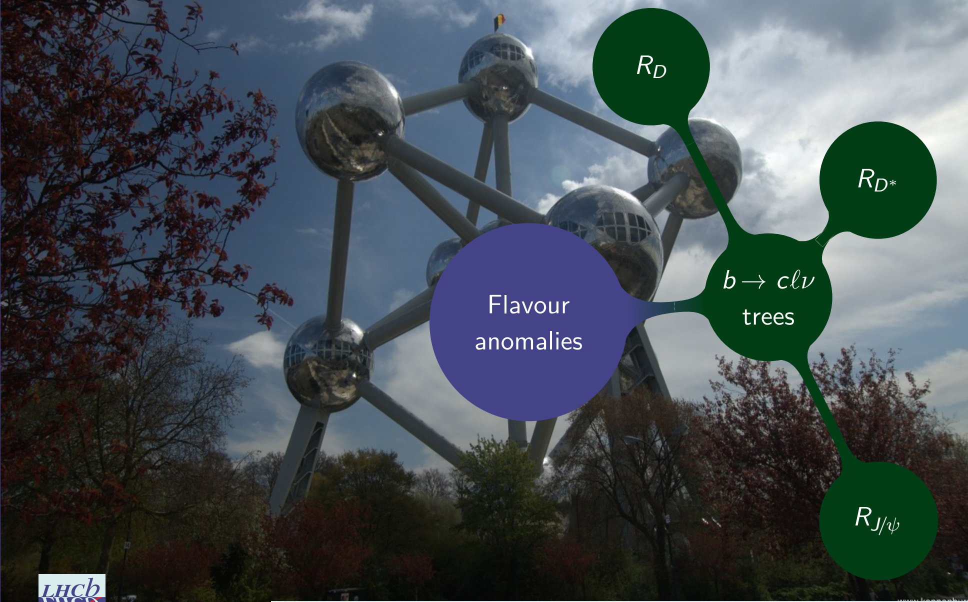
e–μ universality



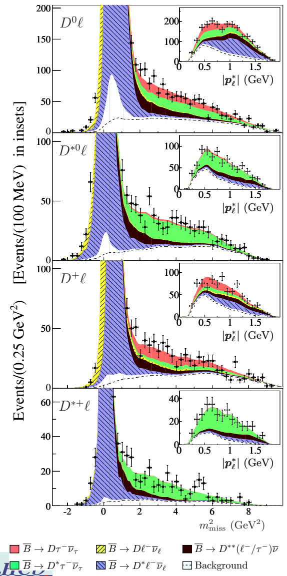
[JHEP 02 (2016) 104] [ATLAS-CONF-2017-023] [CMS, arXiv:1710.02846] [Belle, PRL118 111801] [JHEP 09 (2015) 179] [JHEP 06 (2014) 133] [JHEP 11 (2016) 047] [JHEP 06 (2015) 115] [JHEP 08 (2017) 055] [PRL 113 (2014) 151601]

[Geng et al., PRD96 093006] [Altmannshofer et al., PRD96 055008] [D'Amico et al., JHEP09(2017)010] [Ciuchini et al., EPJC77 688] [Capedevila et al, arXiv:1704.05340]

Flavour Anomalies

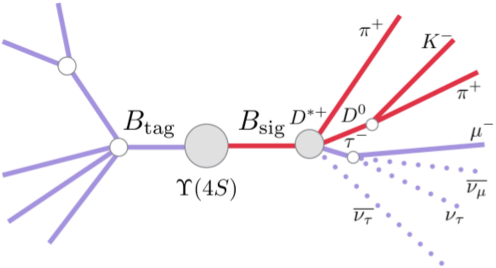


Evidence for a $B \to D^{(*)}\tau\nu$ excess

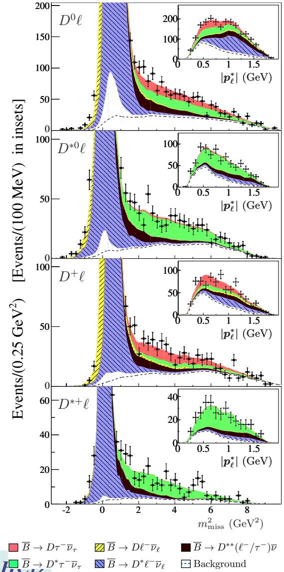


BaBar investigate $B^{0,+} \to D^{(*)}\tau\nu$ with $\tau \to \ell\nu\overline{\nu}$ and compare to $B^{0,+} \to D^{(*)}\ell\nu$

- Full sampe of 471 million $B\overline{B}$ pairs
- The other B meson is fully reconstructed in 1680 final states
- Signal combines a $\ell = e, \mu$ to a $D^{(*)}$



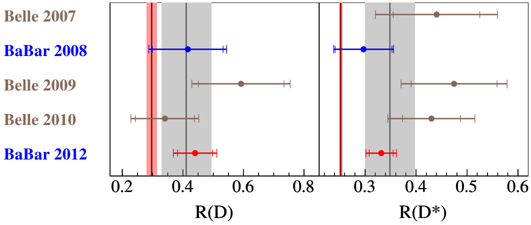
Evidence for a $B \to D^{(*)}\tau\nu$ excess



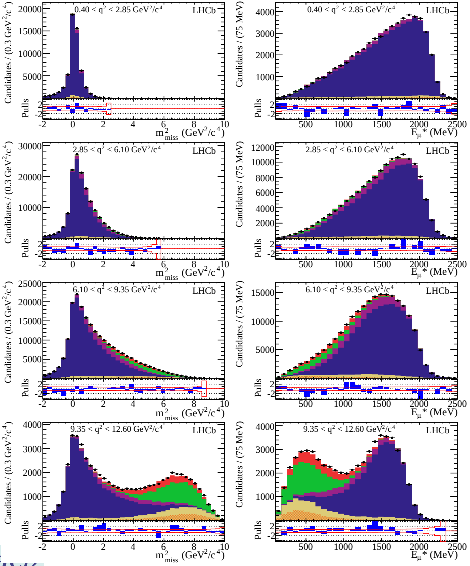
BaBar investigate $B^{0,+} \to D^{(*)}\tau\nu$ with $\tau \to \ell\nu\overline{\nu}$ and compare to $B^{0,+} \to D^{(*)}\ell\nu$

- Full sampe of 471 million $B\overline{B}$ pairs
- The other B meson is fully reconstructed in 1680 final states
- Signal combines a $\ell = e, \mu$ to a $D^{(*)}$

➜ Fit missing mass $m_{\rm miss}$ and momentum of lepton $|p^*_\ell|$



$\overline{B}^0 \rightarrow D^{*+}\tau\nu$ AT LHCb



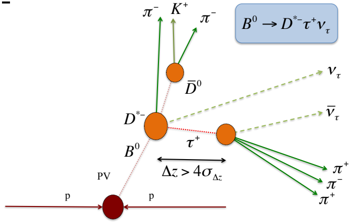
- $B^0 \rightarrow D^{*+}\tau^-\overline{\nu}$ with $\tau^- \rightarrow \mu^-\nu\overline{\nu}$ and $B^0 \rightarrow D^{*+}\mu^-\overline{\nu}$ have same final state.
- Disentangled by kinematical variables : q^2, E^*_μ, m^2_{miss}.
- A template fit in q^2 bins determines signal yields
- Get 36300 ± 1600 $B \rightarrow D^{*+}\mu^-\overline{\nu}$ decays and $R_{D^*} = 0.336 \pm 0.027 \pm 0.030$
  - Dominant systematics are MC stats and mis-ID μ shapes

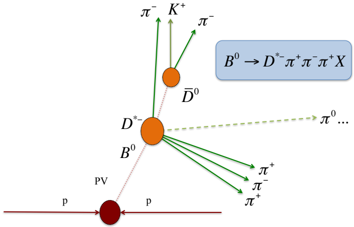
[LHCb, arXiv:1708.08856, submitted to Phys. Rev. Lett][LHCb, arXiv:1711.02505, submitted to Phys. Rev. D]

$B^0 \to D^{*-}\tau^+\nu_\tau$ WITH $\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\overline{\nu}_\tau$

The ratio $\mathcal{R}(D^*) = \frac{\mathcal{B}(B\to D^*\tau^+\nu_\tau)}{\mathcal{B}(B\to D^*\mu^+\nu_\mu)}$ is measured above the SM.

- So far all measurements used $\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$, which provides the same final state as $(B\to D^*\mu^+\nu_\mu$
- Here for the first time, $\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\overline{\nu}_\tau$ is used.
- The main background is $B^0 \to D^{*-}\pi^+\pi^-\pi^-$. The two are separated exploiting the τ^+ lifetime.
- A BDT is used for that purpose

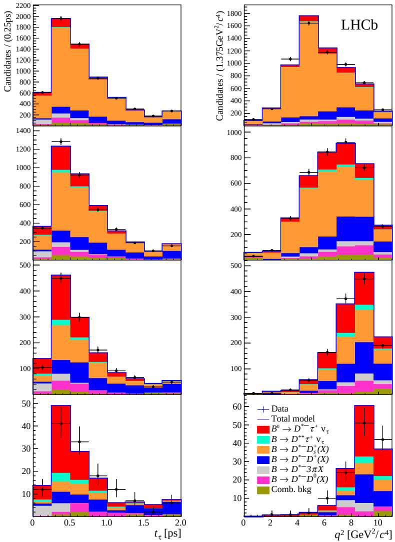




$B^0 \to D^{*-}\tau^+\nu_\tau$ WITH $\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\overline{\nu}_\tau$

Signal and backgrounds are determined by a three-dimensional binned fit to t_τ, q^2 and BDT output.

- signal yield: 1273 ± 85.

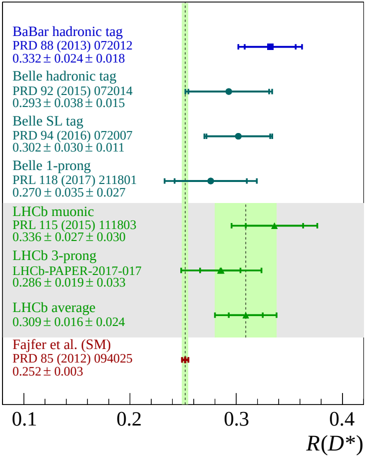


$B^0 \to D^{*-}\tau^+\nu_\tau$ WITH $\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\overline{\nu}_\tau$

Signal and backgrounds are determined by a three-dimensional binned fit to t_τ, q^2 and BDT output.

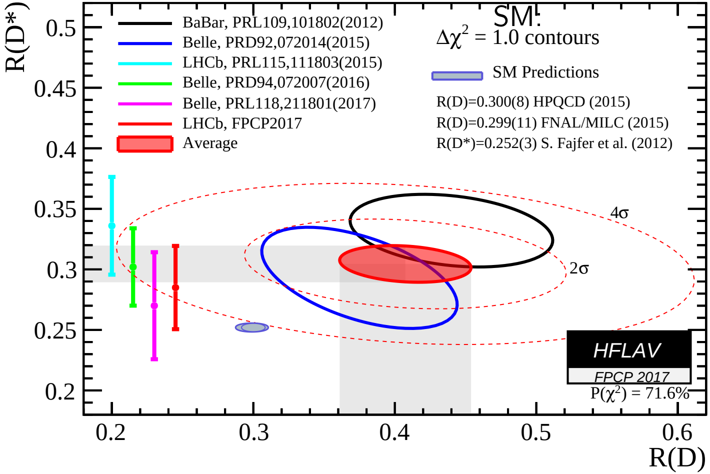
- signal yield: 1273 ± 85.
- Normalised to $B^0 \to D^{*-}\pi^+\pi^-\pi^+$ [PRD 87 (2013) 092001], yielding $\mathcal{B}(B \to D^*\tau^+\nu_\tau) = (1.40 \pm 0.09 \pm 0.12 \pm 0.10)\%$

$\mathcal{R}(D^*) = 0.286 \pm 0.019 \pm 0.025 \pm 0.021$, 1σ above the SM (0.252 ± 0.003 [Faijfer et al.]) and consistent with the world average.



The world average becomes $\mathcal{R}(D^*)^{\text{WA}} = 0.304 \pm 0.013 \pm 0.007$

$B \to D^{(*)}\tau\nu$ HFLAV average



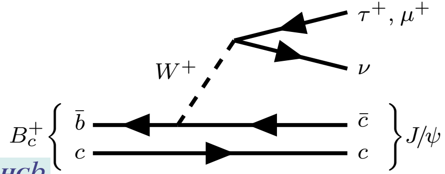
BABAR [PRL 109 101802 (2012)], [PRD 88 072012 (2013)] Belle [PRD 92 072014 (2015)] [Moriond EW, arXiv:1603.06711], LHCb [PRL 115 (2015) 111803] [arXiv:1708.08856].
Theory [Na et al., PRD 92 054410 (2015)], [Faijfer et al., PRD 85 094025 (2012)]

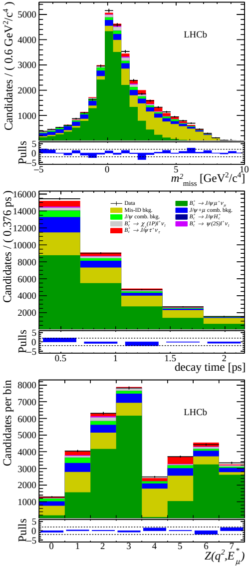
Study of $B_c^+ \to J/\psi \tau^+ \nu_\tau$

LHCb measured $R(D^{*+})$ with $\tau^+ \to \mu^+ \nu \overline{\nu}$ [PRL 115 (2015) 111803] and $\tau^+ \to \pi^+ \pi^- \pi^+$ [arXiv:1708.08856]

What about $B_c^+ \to J/\psi \tau^+ (\mu^+ \nu \overline{\nu}) \nu$?

- Three-dimensional template fit in missing mass (m_{miss}), decay time (τ) and coarse E^*, q^2 bins (Z)
- ✔ Surprising signal excess (3σ)
- Measure $R(J/\psi) = 0.71 \pm 0.17 \pm 0.18$, which is 2σ above the SM





τ DECAYS LEPTON UNIVERSALITY

$$\Gamma(L \to \nu_L \ell \overline{\nu}_\ell(\gamma)) = g_L^2 g_\ell^2 \times f\left(m_L, m_\ell, m_W\right)$$ [HFAG]

Using PDG BFs [PDG 2014, Chin. Phys. C38 090001]:

$$\left(\frac{g_\tau}{g_\mu}\right) = 1.0010 \pm 0.0015, \quad \left(\frac{g_\tau}{g_e}\right) = 1.0029 \pm 0.0015$$

$$\left(\frac{g_\mu}{g_e}\right) = 1.0019 \pm 0.0014$$

Similarly, using $\tau \to h\nu_\tau$ and $h \to \mu\overline{\nu}_\mu$ decays

$$\left(\frac{g_\tau}{g_\mu}\right)_\pi = 0.9961 \pm 0.0027, \quad \left(\frac{g_\tau}{g_\mu}\right)_K = 0.9860 \pm 0.0070$$

This is obviously work for electron machines, including BESIII.

Lepton-Universality in $D^{0,+} \to \pi^{0,+}\mu\nu$

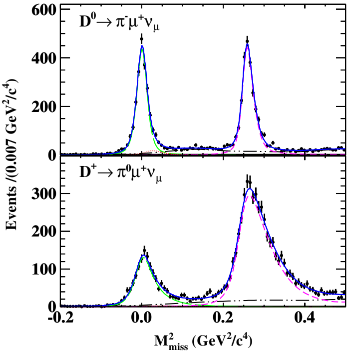
Using $2.93\,\text{fb}^{-1}$ data at $3.773\,\text{GeV}$ BESIII study $D^{0,+} \to \pi^{-,0}\mu^+\nu$

$$\mathcal{B}(D^0 \to \pi^-\mu^+\nu) = (0.267 \pm 0.007 \pm 0.007)\%$$
$$\mathcal{B}(D^+ \to \pi^0\mu^+\nu) = (0.342 \pm 0.011 \pm 0.010)\%$$

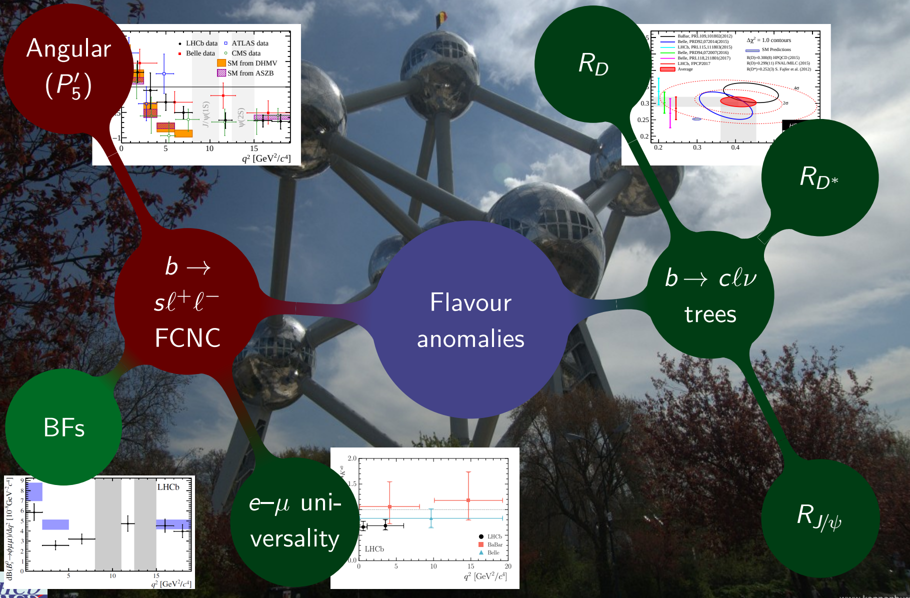
They combine with existing electronic BFs [CLEO, PRD80 (2009) 032005] [BESIII,PRD92 (2015) 072012] to get

$$\mathcal{R}(D^0 \to \pi^-\ell^+\nu) = 0.905 \pm 0.027 \pm 0.023$$
$$\mathcal{R}(D^+ \to \pi^0\ell^+\nu) = 0.942 \pm 0.037 \pm 0.027$$

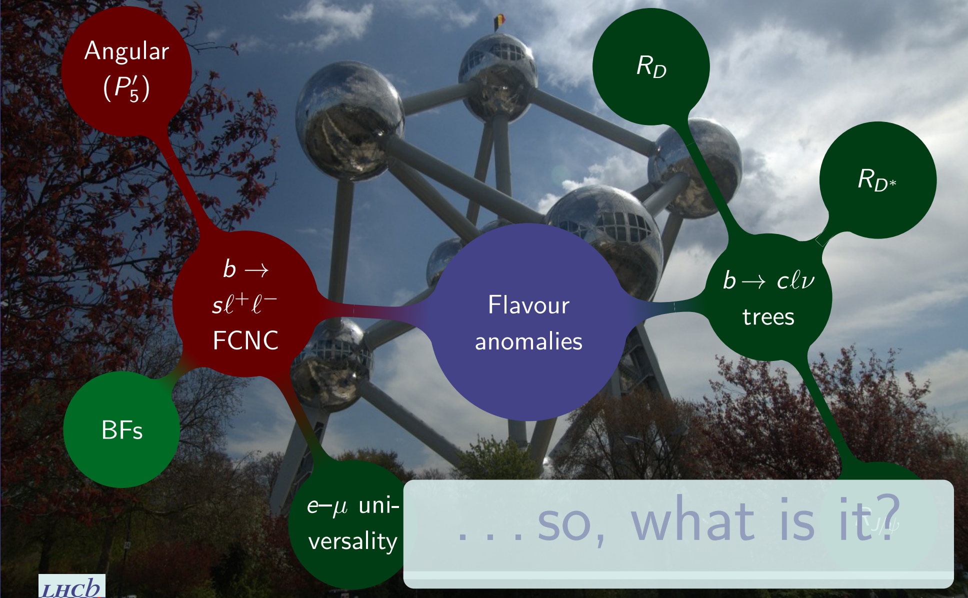
which are 1.9 and 0.6σ below the SM expectation of 0.97.



Flavour Anomalies



Flavour Anomalies



. . . so, what is it?

QCD and Statistics?


LIVE
breakyourownnews.com
Freya Blekman
BREAKING NEWS
NEW PHYSICS IN LEPTONS
16:23
THIS CHANGES HOW WE SEE THE UNIVERSE SAYS PROF. BLEKMAN

Flavour Anomalies

We need a better precision in QCD.

Flavour anomalies

QCD

Lattice

Sum rules

Flavour Anomalies

It could be new vector bosons (but beware of $B\overline{B}$ mixing)

Z', W'

Flavour anomalies

QCD

Lattice

Sum rules

Flavour Anomalies

It could be new vector bosons, or leptoquarks

Flavour anomalies

Z', W'

QCD

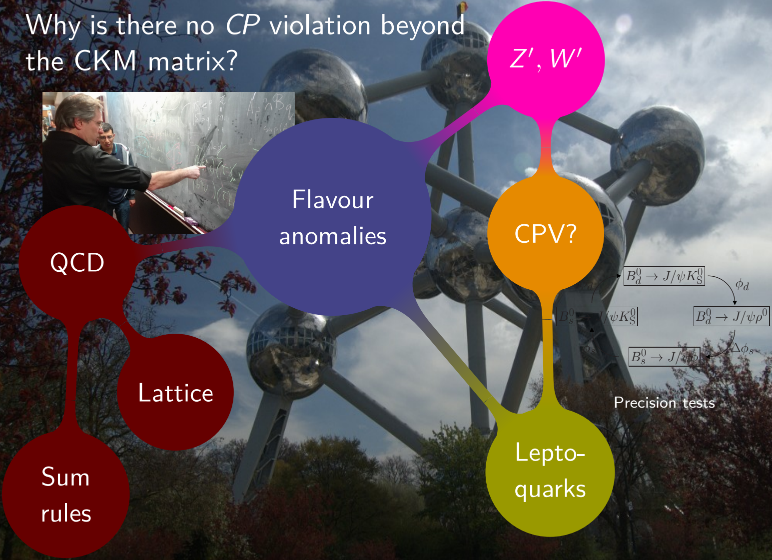
Lattice

Sum rules

Lepto-quarks

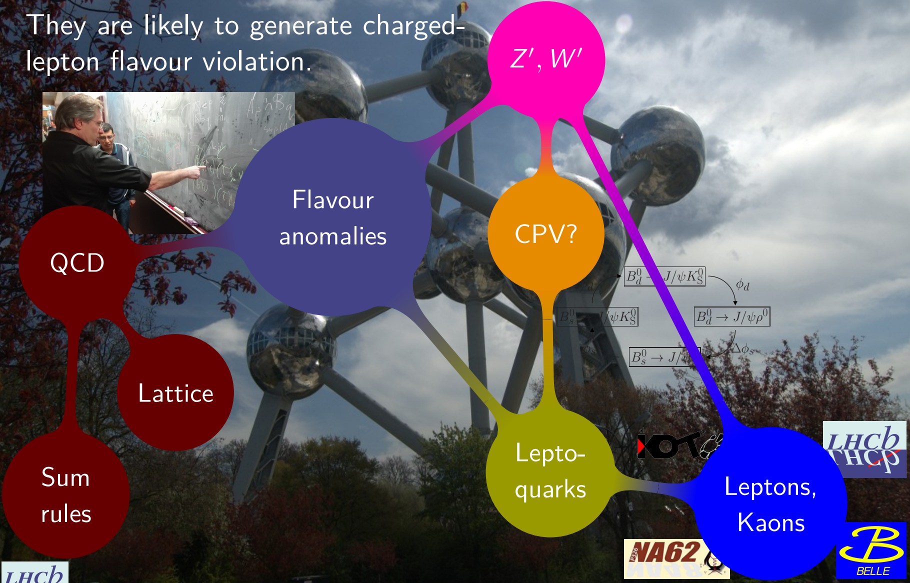
Flavour Anomalies

Why is there no *CP* violation beyond the CKM matrix?



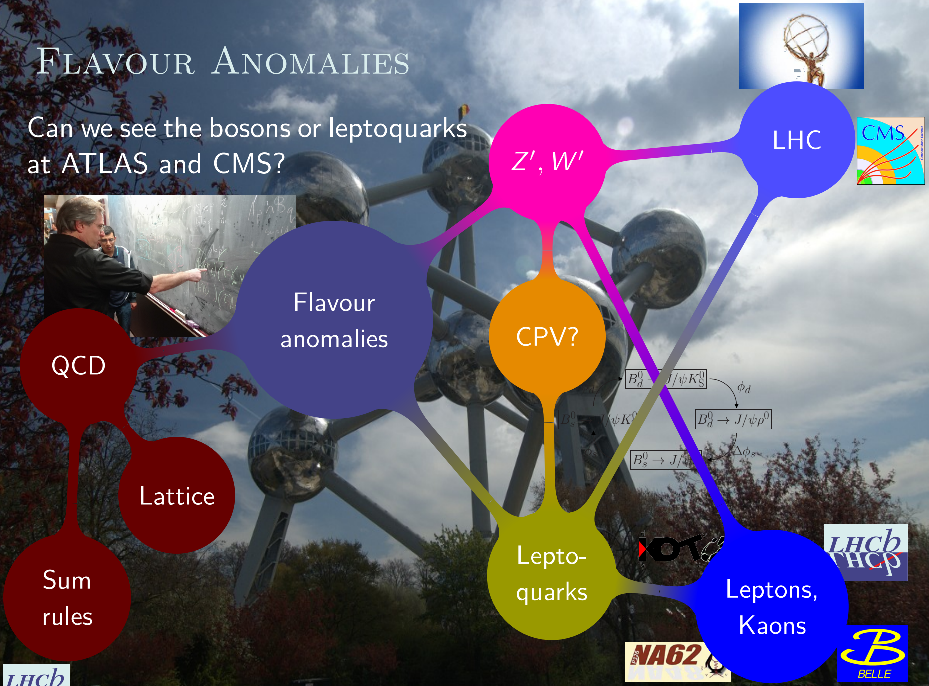
Flavour Anomalies

They are likely to generate charged-lepton flavour violation.



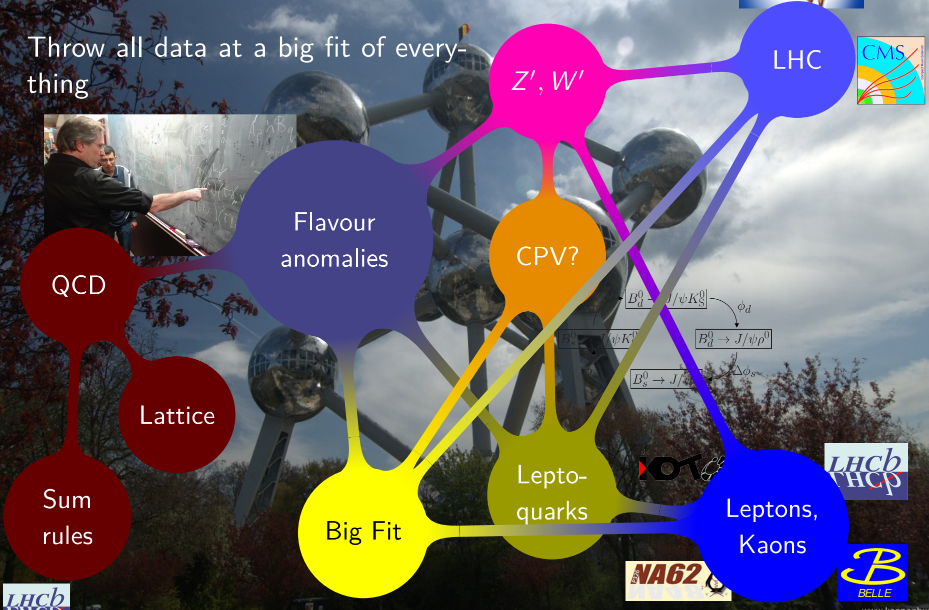
Flavour Anomalies

Can we see the bosons or leptoquarks at ATLAS and CMS?



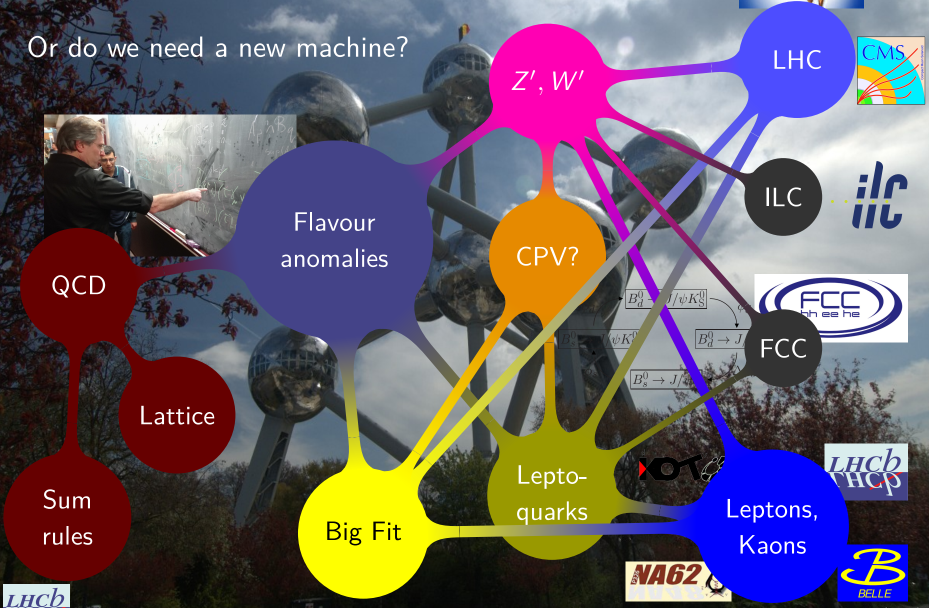
Flavour Anomalies

Throw all data at a big fit of everything



Flavour Anomalies

Or do we need a new machine?



Next

Next updates

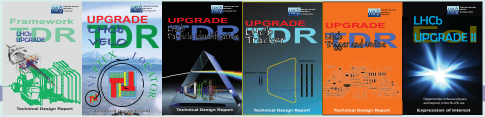
People are working on

- R_K with Run 2 data and improvements for Run 1 (mea culpa)
- $R(D)$, $R(\Lambda_c^+)$
- Run 2 updates of all what I have shown, but probably including 2018 data
- More

These measurements take time: See how much time ATLAS & CMS take

Things may speed up once we get competition from Belle II

LHCb Upgrade



$\mathcal{L} = 2{\cdot}10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ requires some new detectors and 40 MHz read-out clock new electronics

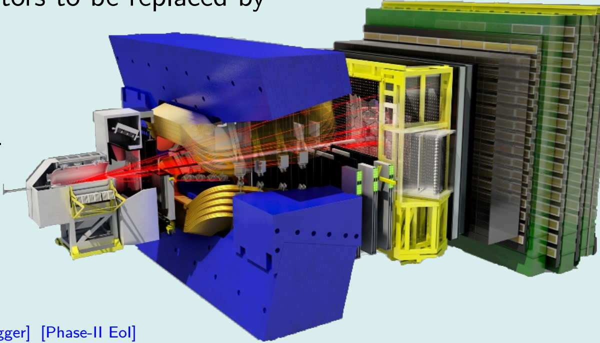
Velo: New pixel vertex detector

Trackers: New scintillating fibre tracker. The upstream tracker is also replaced

PID: Hybrid photodetectors to be replaced by multi-anode PMTs

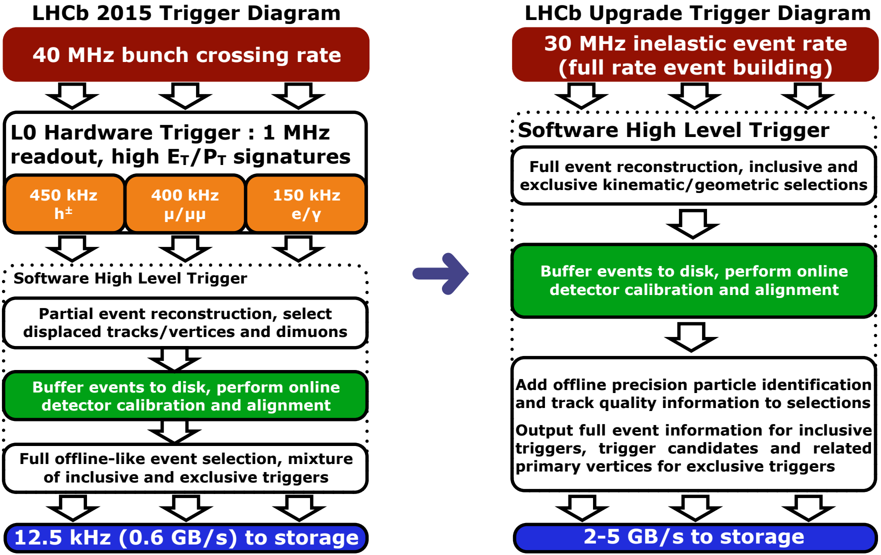
➜ 50 fb^{-1} by Run 4.

✔ We are preparing another upgrade for Run 5 ➜ 300 fb^{-1}

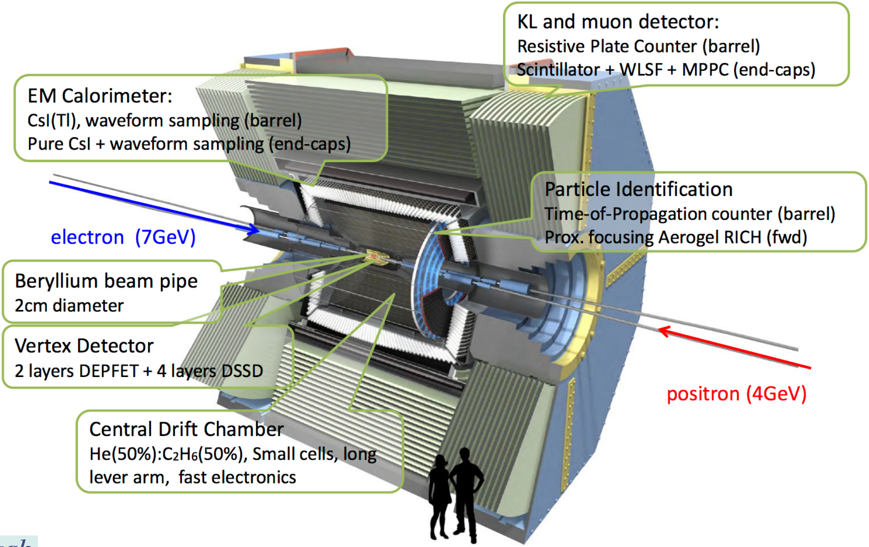


[Upgrade TDR] [Velo] [PID] [Sci-Fi] [Trigger] [Phase-II EoI]

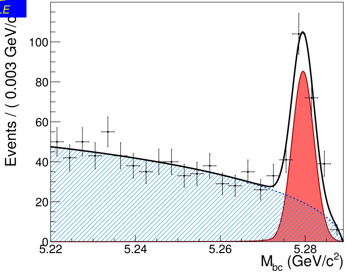
LHCb Trigger in Run 3

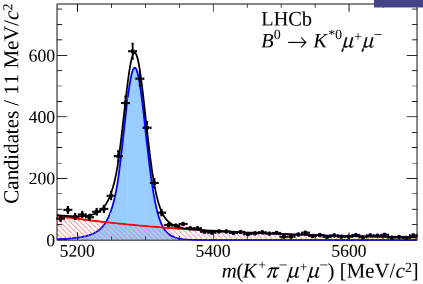


Belle II


KL and muon detector:
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps)
EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)
electron (7GeV)
Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)
Beryllium beam pipe
2cm diameter
Vertex Detector
2 layers DEPFET + 4 layers DSSD
positron (4GeV)
Central Drift Chamber
He(50%):C2H6(50%), Small cells, long
lever arm, fast electronics

Belle versus LHCb





Example: $B^0 \to K^{*0}\mu^+\mu^-$

✔ Two handles: B mass and B energy in $\Upsilon(4S)$ frame (ΔE)

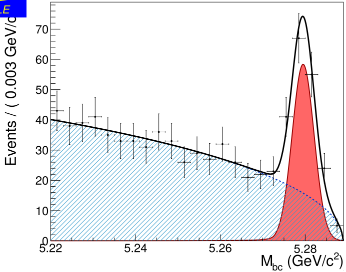
185 signal decays with 711 fb^{-1}

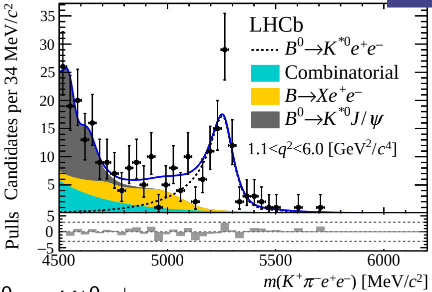
✔ Two handles: B mass and pointing to PV

2400 signal decays with 3 fb^{-1} at 7–8 TeV

Conversion factor: 5 ab^{-1} $\leftrightarrow$ 1 fb^{-1} (at 13 TeV)

Belle versus LHCb





Example: $B^0 \to K^{*0} e^+ e^-$

✔ Electron channels are as "easy" as muonic

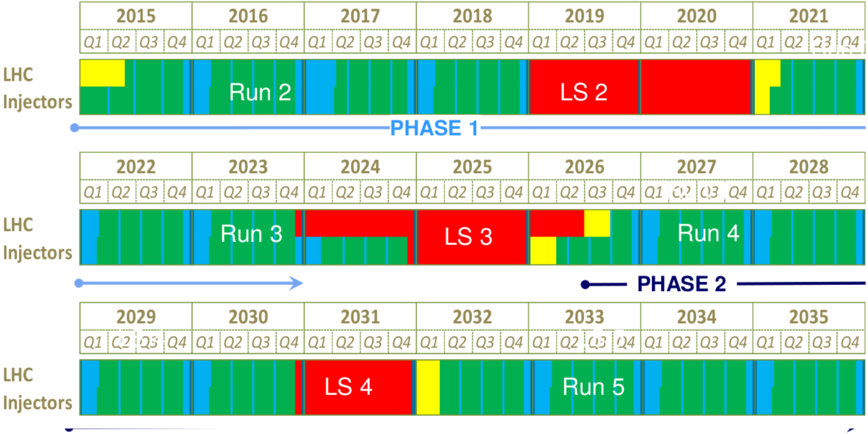
127 signal decays with $711\,\text{fb}^{-1}$

✗ Bremsstrahlung makes electrons much more difficult

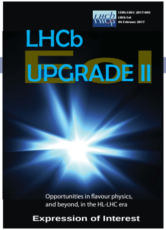
200 signal decays with $3\,\text{fb}^{-1}$ at 7–8 TeV

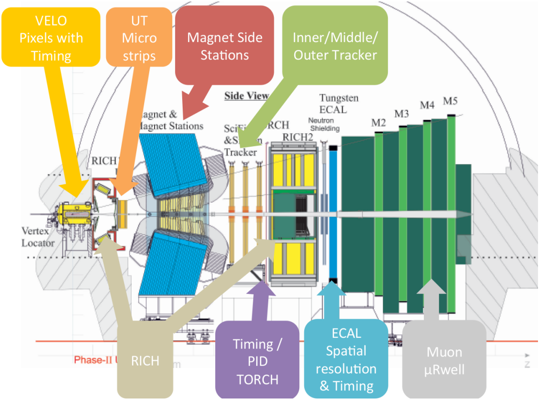
Conversion factor: $1\,\text{ab}^{-1} \leftrightarrow 1\,\text{fb}^{-1}$ (at 13 TeV, upgraded)

LHC SCHEDULE



EoI for Phase-II Upgrade

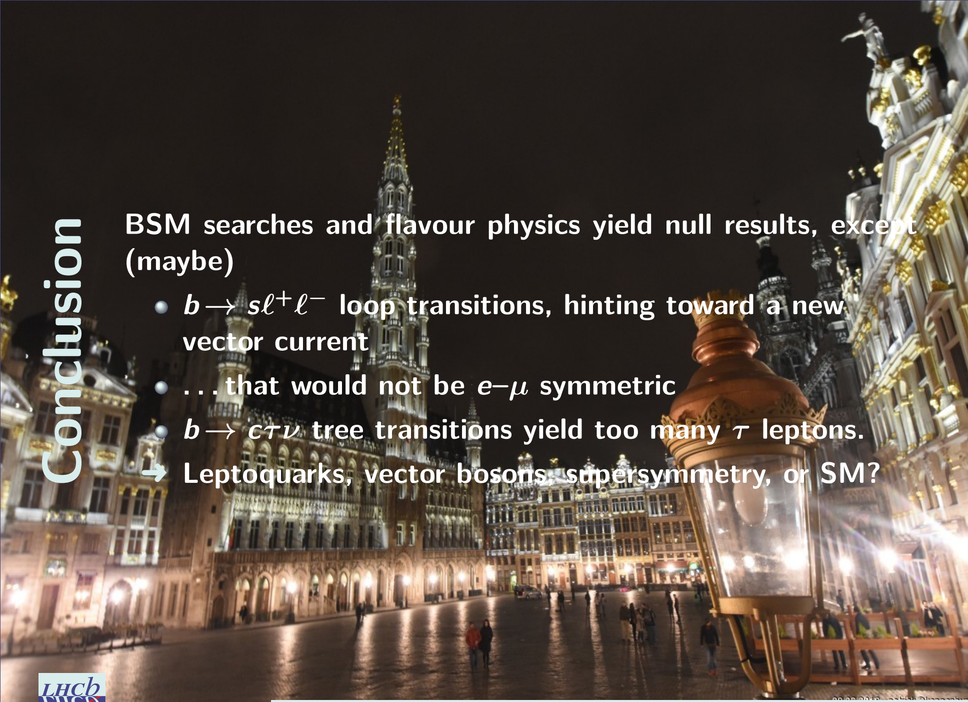




We have experessed an interest for a Phase-II upgrade [CERN-LHCC-2017-003] .

We are now writing the physics case.

Luminosity increments	Run 1 2010–12	Run 2 2015–18	Run 3 2021–24	Run 4 2026–30	Run 5 2032–35
$\Delta\mathcal{L}$ [fb^{-1}]	+3	+6	+14	+27	+250
Total $\mathcal{L}$ [fb^{-1}]	3	9	23	50	300



Conclusion

BSM searches and flavour physics yield null results, except (maybe)

- $b \to s\ell^+\ell^-$ loop transitions, hinting toward a new vector current
- . . . that would not be e–μ symmetric
- $b \to c\tau\nu$ tree transitions yield too many τ leptons.

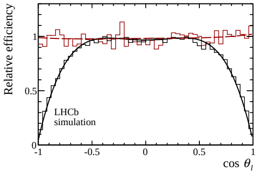
→ Leptoquarks, vector bosons, supersymmetry, or SM?

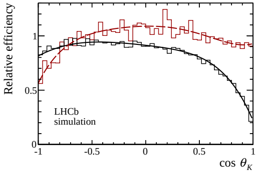
Backup

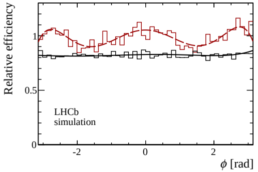
Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

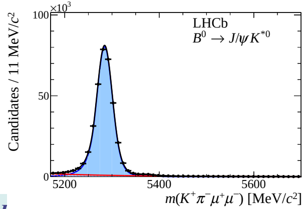
Update of [JHEP 08 (2013) 131] and [PRL 111 (2013) 191801] to 3 fb^{-1}. S-wave is taken into account, we have finer bins, and no φ folding is needed.

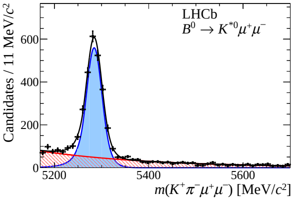
- Angular acceptance obtained from MC and validated on $B^0 \to J/\psi K^*$ decays.







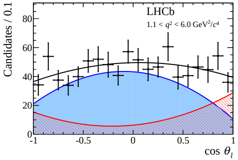


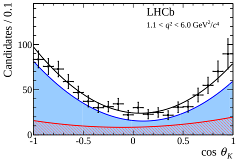


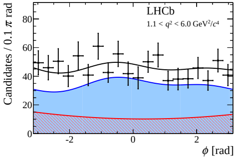
Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

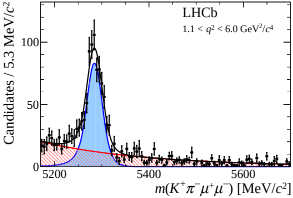
Update of [JHEP 08 (2013) 131] and [PRL 111 (2013) 191801] to 3 fb^{-1}. S-wave is taken into account, we have finer bins, and no φ folding is needed.

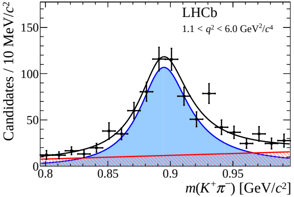
- Angular acceptance obtained from MC and validated on $B^0 \to J/\psi K^*$ decays.
- **Max Likelihood fit:** 4D fit to $m(K^+\pi^-)$ and three angles in bins of q^2.
    - Here $1.1 < q^2 < 6\ \text{GeV}^2/c^4$ is shown.
    - 2398 ± 57 decays found in total.











ANGULAR ANALYSIS OF $B^0 \to K^{*0}\mu^+\mu^-$

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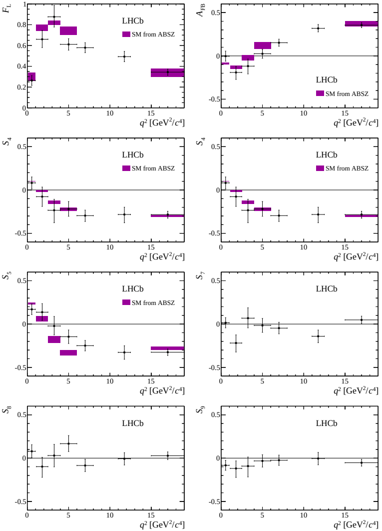
- Angular acceptance obtained from MC and validated on $B^0 \to J/\psi K^*$ decays.
- **Max Likelihood fit:** 4D fit to $m(K^+\pi^-)$ and three angles in bins of q^2.
- Observables consistent with SM, except S_5



Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

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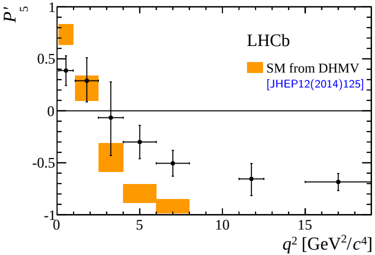
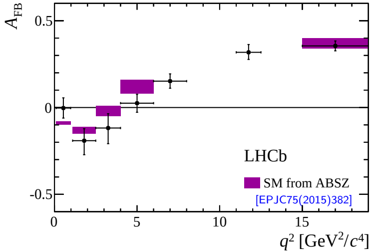
- **Max Likelihood fit:** 4D fit to $m(K^+\pi^-)$ and three angles in bins of q^2.
- Observables consistent with SM, except S_5
- $P_5' = S_5/\sqrt{F_L(1-F_L)}$ has a local discrepancy in two bins
- A_{FB} seems to show a trend, but is consistent with SM





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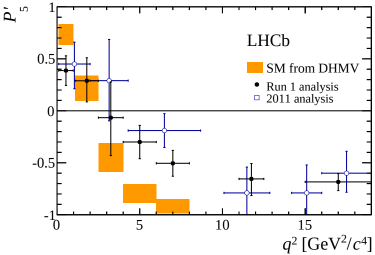


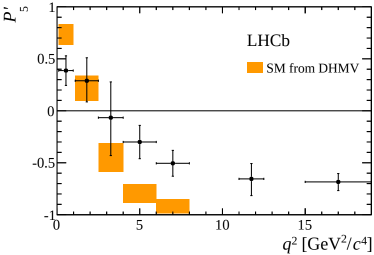
Comparison of P_5' between the 1 fb^{-1} analysis [PRL 111 (2013) 191801] and the 3 fb^{-1} update [JHEP 02 (2016) 104]

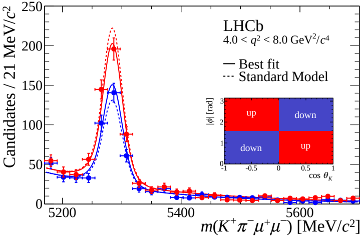
Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

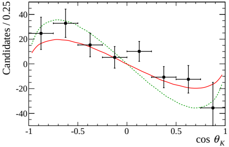
What is P_5'?

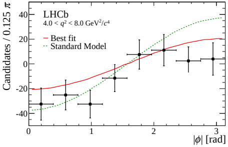
It is an asymmetry built with $\cos\theta_K$ and $|\phi|$, shown in the sketch. (integrating over one of the two gets zero).

The discrepancy with the SM prediction is visible in both angular distributions.







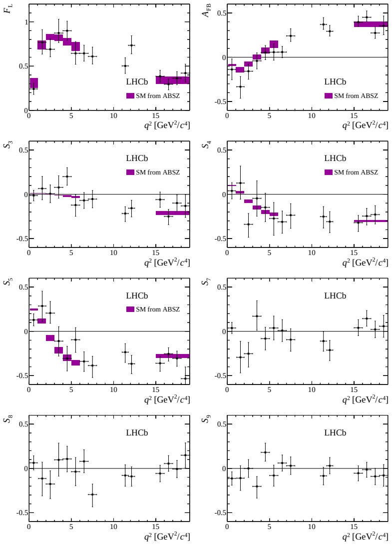


Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

On top of the maximum likelihood method, the paper adds two more methods

Method of moments: Counting method, less precise but more stable: Allows for 1 GeV^2/c^4 bins.

- Important test for QED corrections: They would generate tensor currents not affecting this method [Gratrex, Hopfer, Zwicky PRD93 054008].



ANGULAR ANALYSIS OF $B^0 \to K^{*0}\mu^+\mu^-$

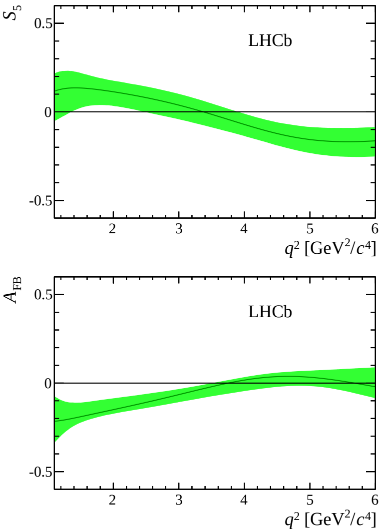
On top of the maximum likelihood method, the paper adds two more methods

METHOD OF MOMENTS: Counting method, less precise but more stable: Allows for 1 GeV^2/c^4 bins.

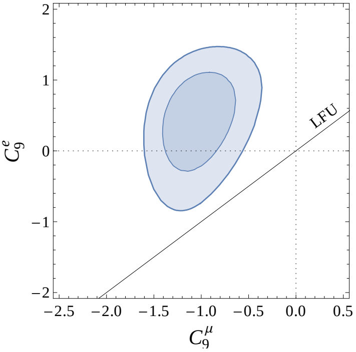
FIT TO DECAY AMPLITUDES: Modelling the q^2 dependence of the amplitudes one can fit for zero-crossing points more precisely

$$q_0^2(A_{\rm FB}) \in [3.40, 4.87]\,\mathrm{GeV}^2/c^4$$

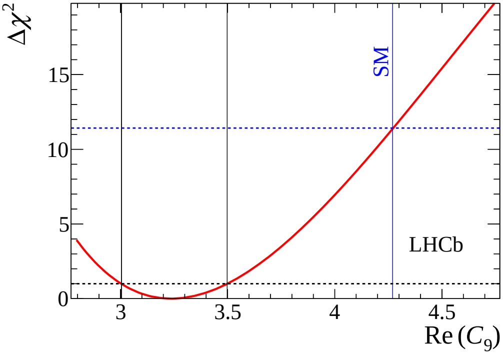
at 68% C.L.



ANGULAR ANALYSIS OF $B^0 \to K^{*0}\mu^+\mu^-$



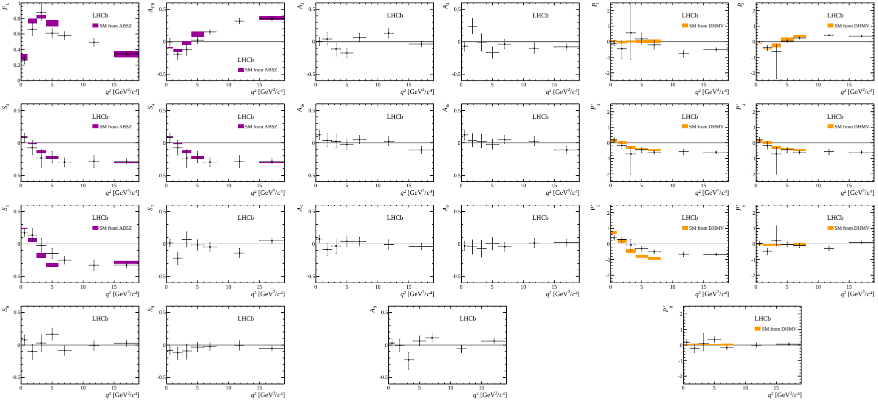
[Altmannshofer, Straub, EPJC 75 382 (2015)]



Using EOS software [Bobeth et al, JHEP 1007 098], we fit the likelihood fit results for a modified C_9 (vector coupling) Wilson coefficient and get

$$\Delta C_9 = -1.04 \pm 0.25 \quad (3.4\sigma)$$

Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$



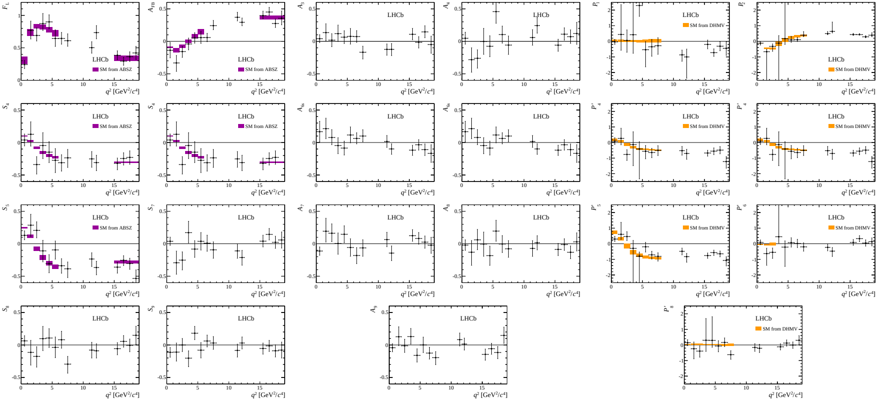
CP-averaged observables

CP-asymmetric observables

Optimised observables

All observables obtained from the maximum likelihood fit

Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

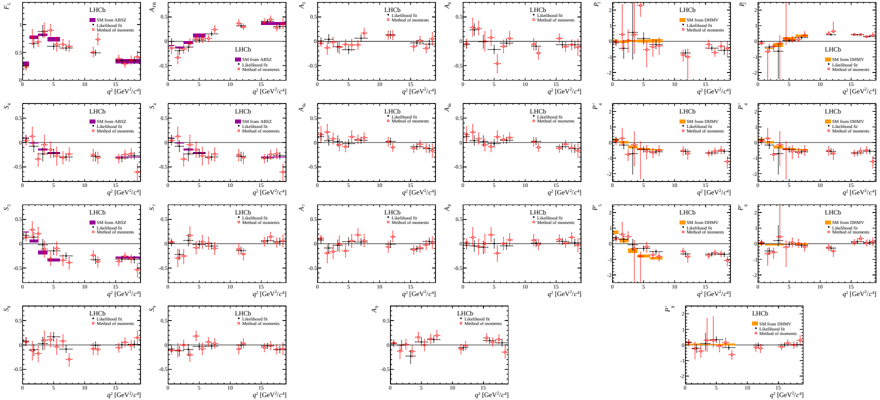


CP-averaged observables | *CP*-asymmetric observables | Optimised observables

All observables obtained from the moment analysis

[LHCb, JHEP 02 (2016) 104, arXiv:1512.04442]

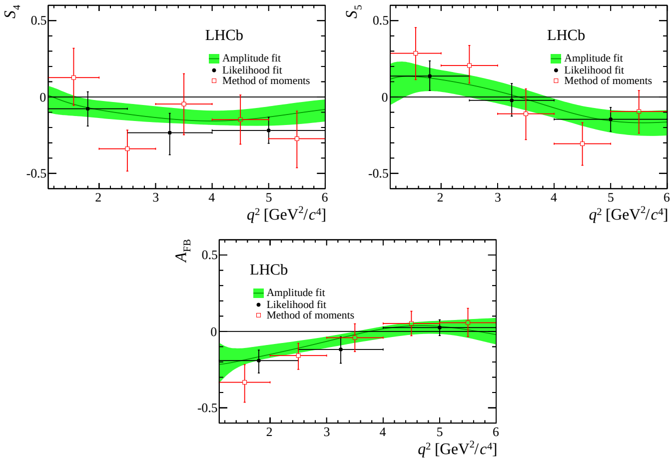
Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$



CP-averaged observables | *CP*-asymmetric observables | Optimised observables

Comparison of likelihood fit and moments

Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$



Observables determined by fitting the q^2-dependent amplitudes

[Belle, PRD 94 072007 (2016)]

$R(D^*)$ WITH $\tau \to \ell\nu\overline{\nu}$

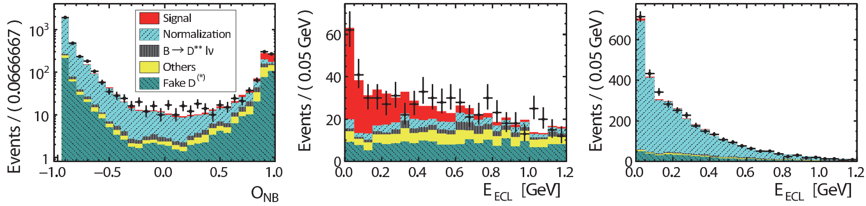
Using 772 million $B\overline{B}$ pairs, Belle compare $\overline{B}^0 \to D^{*+}\tau^-(\ell^-\nu_\tau\overline{\nu}_\ell)\overline{\nu}_\tau$ and $\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_\ell$

- $D^{*+} \to D^0\pi^+$ with 10 decay modes for D^0
- $D^{*+} \to D^+\pi^0$ with 5 decay modes for D^+

They measure

$$R(D^*) = 0.302 \pm 0.030 \pm 0.011$$

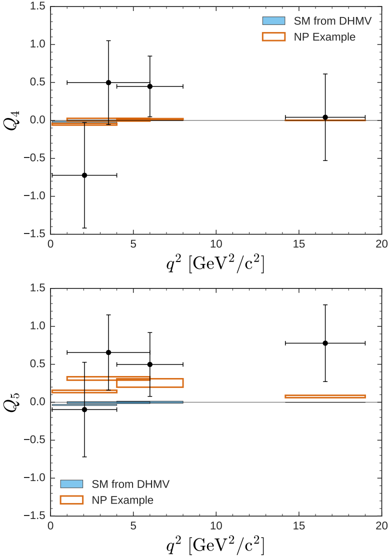
which is 1.6σ above the SM prediction.



$B^0 \to K^{*0}\ell^+\ell^-$ ANGULAR ANALYSIS

Belle do an angular analysis of $P'_{(4,5)}$ as LHCb [JHEP 02 (2016) 104]. $A_{\rm FB}$ and $\mathrm{d}\Gamma/\mathrm{d}q^2$ were published in [PRL 103 171801 (2009)]

- Split sample in muons (185 ± 17 decays) and electrons (127 ± 15)
- Measure P'_4 and P'_5 and see a 2.6σ P'_5 tension for the muon modes in the $4 < q^2 < 8\,\mathrm{GeV}^2/c^4$ bin.
- Electrons are closer to the SM.
- This can be shown as LFU-violating variables $Q_{4,5} = P^{\mu}_{4,5} - P^{e}_{4,5}$



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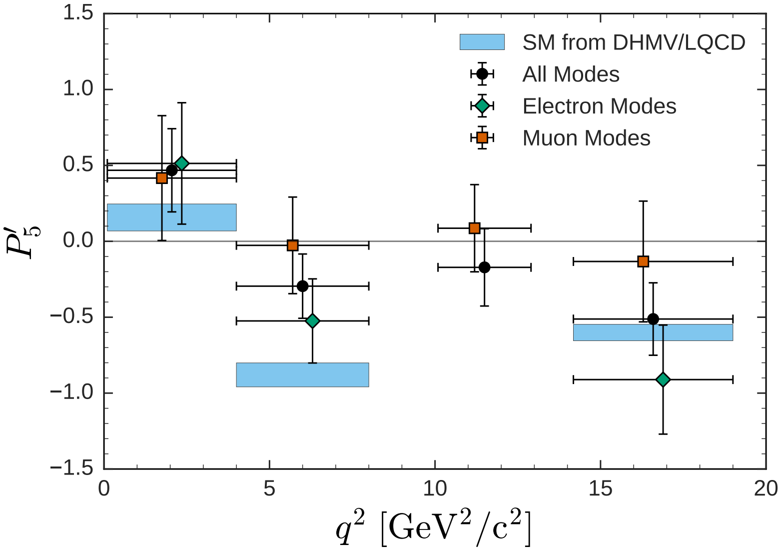

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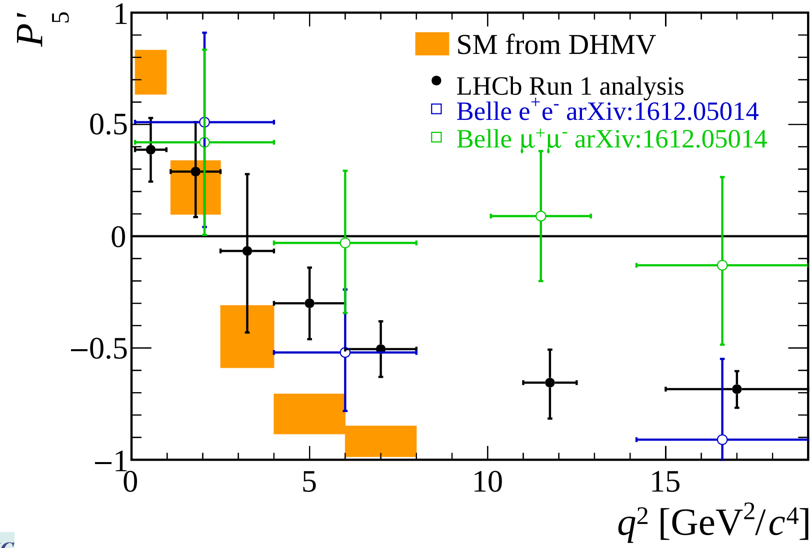
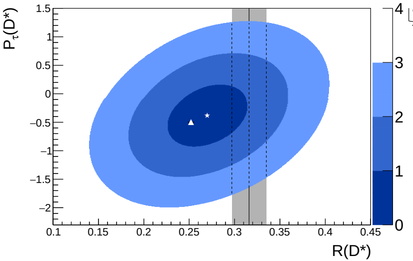


[Belle, PRD 97 012004 (2018), arXiv:1709.00129]

$R(D^*)$ with $\tau^+ \to (\pi^+, \rho^+)\overline{\nu}$

Using 772 million $B\overline{B}$ pairs, Belle compare $\overline{B}^0 \to D^{*+}\tau^-(\ell^-\nu_\tau\overline{\nu}_\ell)\overline{\nu}_\tau$ and $\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_\ell$

- 15 decay modes for D^0 and D^+
- 4 decay modes for D^{*+} and D^{*0}
- $\tau \to \pi^+\overline{\nu}$ and $\tau \to \rho^+\overline{\nu}$



They measure

$$R(D^*) = 0.270 \pm 0.035 \,^{+0.028}_{-0.025}$$

$$\tau \text{ polarisation:} \quad P_\tau = -0.38 \pm 0.51 \,^{+0.21}_{-0.16}$$

where the τ polarisation is the asymmetry of $\pm\frac{1}{2}$ helicities. The SM predicts [M. Tanaka, R. Watanabe, PRD82 034028]

$$P_\tau = -0.497 \pm 0.013$$

$B \to \mu^+\mu^-$ effective lifetime

The effective lifetime allows the extraction of

$$\mathcal{A}_{\Delta\Gamma}\, y_s = \frac{(1-y_s^2)\tau_{\mu^+\mu^-} - (1+y_s^2)\tau_{B_s^0}}{2\tau_{B_s^0} - (1-y_s^2)\tau_{\mu^+\mu^-}}$$

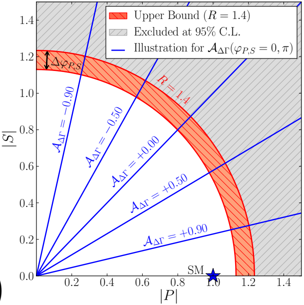
$$\text{with } y_s = \frac{1}{2}\tau_{B_s^0}\Delta\Gamma_s = 0.075 \pm 0.010 \quad \text{[HFAG]}$$

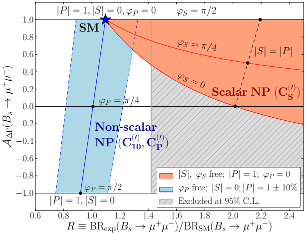
This gives sensitivity to the (pseudo-) scalar operators $\mathcal{O}_{P,S}$ with Wilson coefficients P and S ($= 1, 0$ in SM):

$$R \equiv \frac{\mathrm{BR}(B_s^0 \to \mu^+\mu^-)_{\mathrm{exp}}}{\mathrm{BR}(B_s^0 \to \mu^+\mu^-)_{\mathrm{SM}}} = \left[\frac{1+\mathcal{A}_{\Delta\Gamma} y_s}{1-y_s^2}\right]\left(|P|^2 + |S|^2\right)$$

$$= \left[\frac{1+y_s\cos 2\varphi_P}{1-y_s^2}\right]|P|^2 + \left[\frac{1-y_s\cos 2\varphi_S}{1-y_s^2}\right]|S|^2,$$

LHCb expects $\mathcal{O}(500)$ events with 50 fb^{-1}, as many as for $\tau_{\mathrm{eff}}(B_s^0 \to KK)$ [Phys.Lett. B707 (2012) 349-356, arXiv:1111.0521]

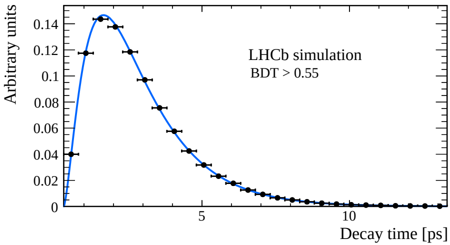


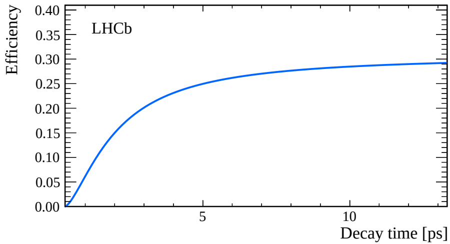


$B_s^0 \to \mu^+\mu^-$ EFFECTIVE LIFETIME

For the first time the effective lifetime of $B_s^0 \to \mu^+\mu^-$ is measured, as proposed by [De Bruyn, PK, et al., PRL 109, 041801 (2012)].

- Only candidates with BDT$>$ 0.55 are used.
- The time acceptance is taken from simulation.





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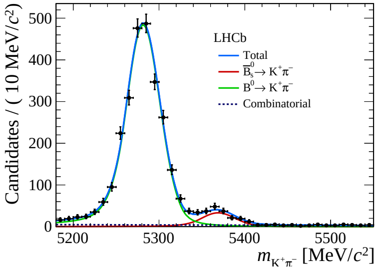
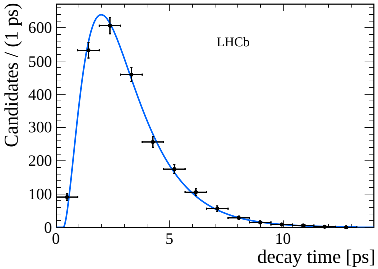
- The time acceptance is taken from simulation.
- The time acceptance is validated using $B^0 \to K^+\pi^-$, yielding $1.52 \pm 0.03\ \mathrm{ps}$, consistent with the B^0 lifetime.





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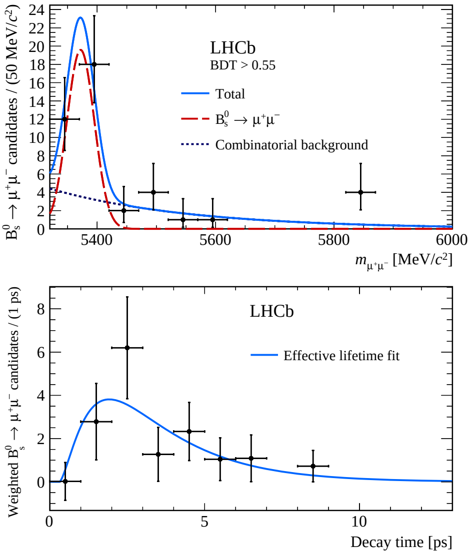
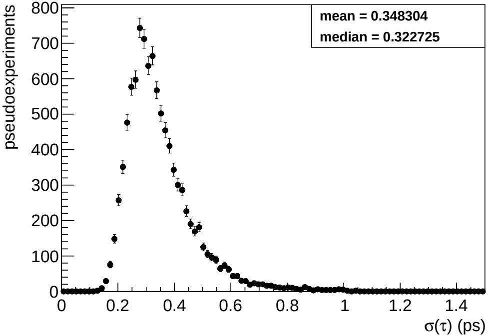
- Only candidates with BDT>0.55 are used.
- The time acceptance is taken from simulation.
- Using the sPlot technique: $\tau^{\text{eff}}_{B_s^0\to\mu^+\mu^-} = 2.04 \pm 0.44 \pm 0.5\ \text{ps}$

➜ Consistent with $A_{\Delta\Gamma}^{\mu^+\mu^-} = 1\,(-1)$ at 1σ (1.4σ) level



Expected sensitivity for lifetime



The expected sensitivity for this analysis was 0.32 ps but we got unlucky with 0.44 ps.

Extrapolating assuming an unchanged analysis we expect 0.079 ps for 50 fb^{-1} and 0.032 ps for 300 fb^{-1}.

This would allow disentangling the $B_{s\text{H}}$ anb $B_{s\text{L}}$ states by 6σ