Rare decays from LHCb and CMS

Michael McCann
On behalf of the LHCb collaboration

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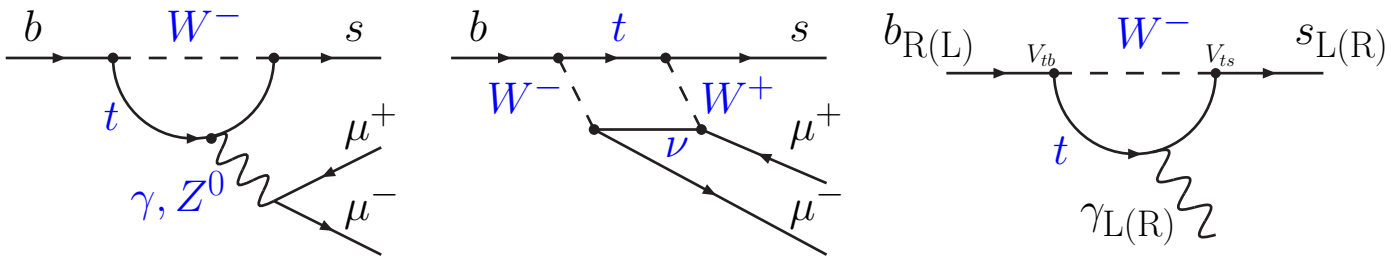
LHC Days – Split, Croatia

Rare decays – What and why?

- Processes through loop diagrams or CKM suppressed
  - Typically $\mathcal{B} < \mathcal{O}(10^{-6})$
- Indirect new physics searches
  - The lower SM BF allow BSM contributions to stand out
- Typical loop topologies
  - Flavour-changing neutral currents (penguin/box diagrams)



- Will focus on rare decays of b quarks

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

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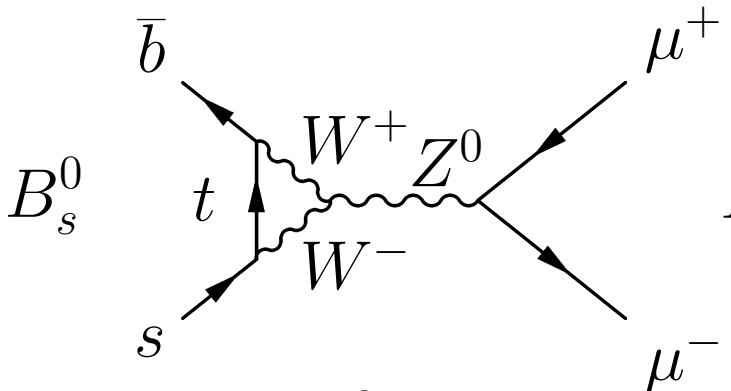
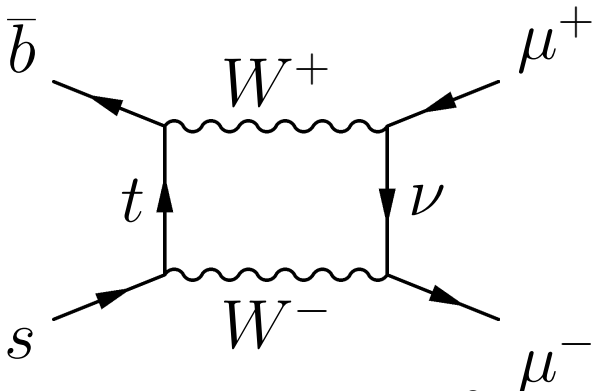
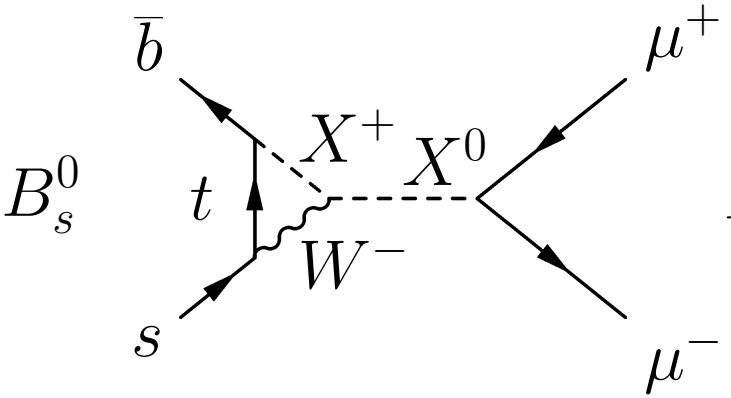
Precise SM prediction

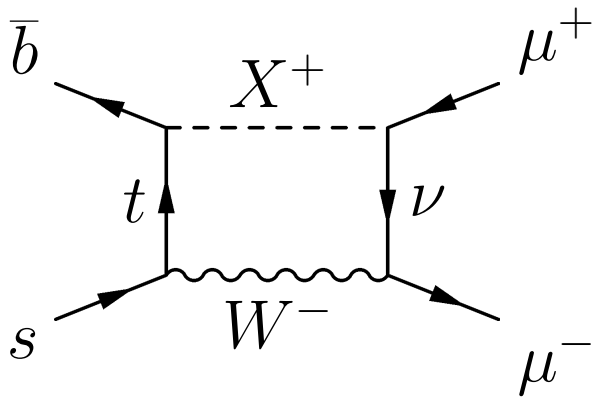




$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.66 \pm 0.23) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$$

Sensitive to new physics





Two muons → Experimentally clean

$B^0_{(s)} \to \mu^+\mu^-$ – LHCb and CMS

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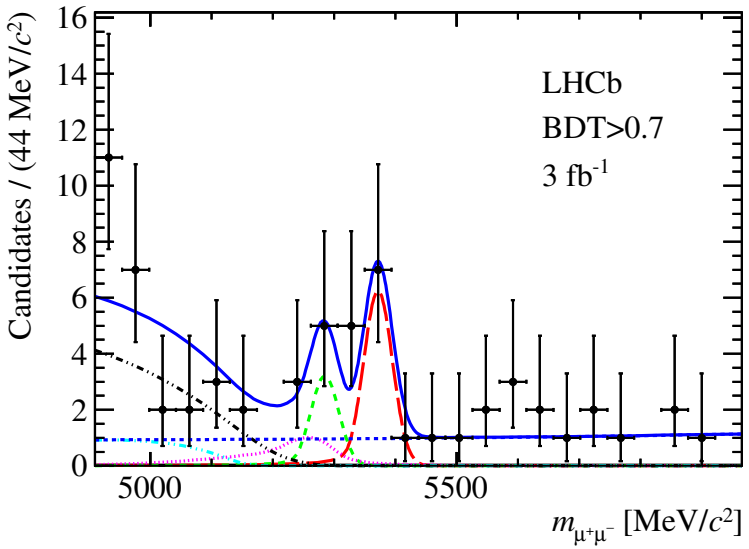
LHCb

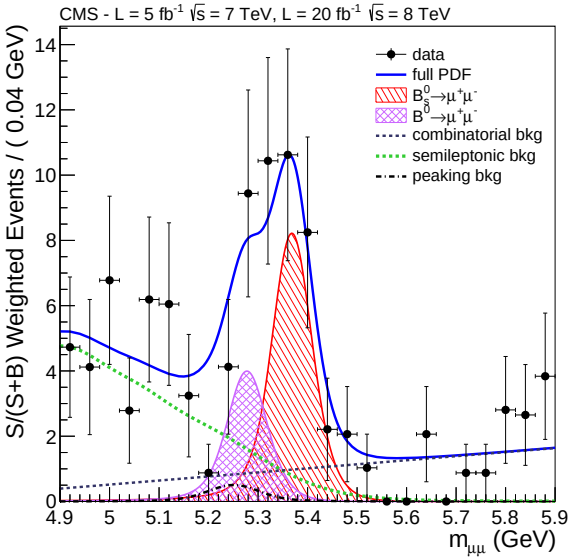


$$\mathcal{B}(B^0_s) = (2.9^{+1.1}_{-1.0}) \times 10^{-9} (4.0\sigma)$$

$$\mathcal{B}(B^0) < 7.4 \times 10^{-10}\,(95\,\%)$$

Phys. Rev. Lett. 111, 101805 (2013)

CMS



$$\mathcal{B}(B^0_s) = (3.1^{+1.0}_{-0.9}) \times 10^{-9} (4.3\sigma)$$

$$\mathcal{B}(B^0) < \ 1.1 \times 10^{-9}\,(95\,\%)$$

Phys. Rev. Lett. 111 (2013) 101804

What if the data were combined?

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

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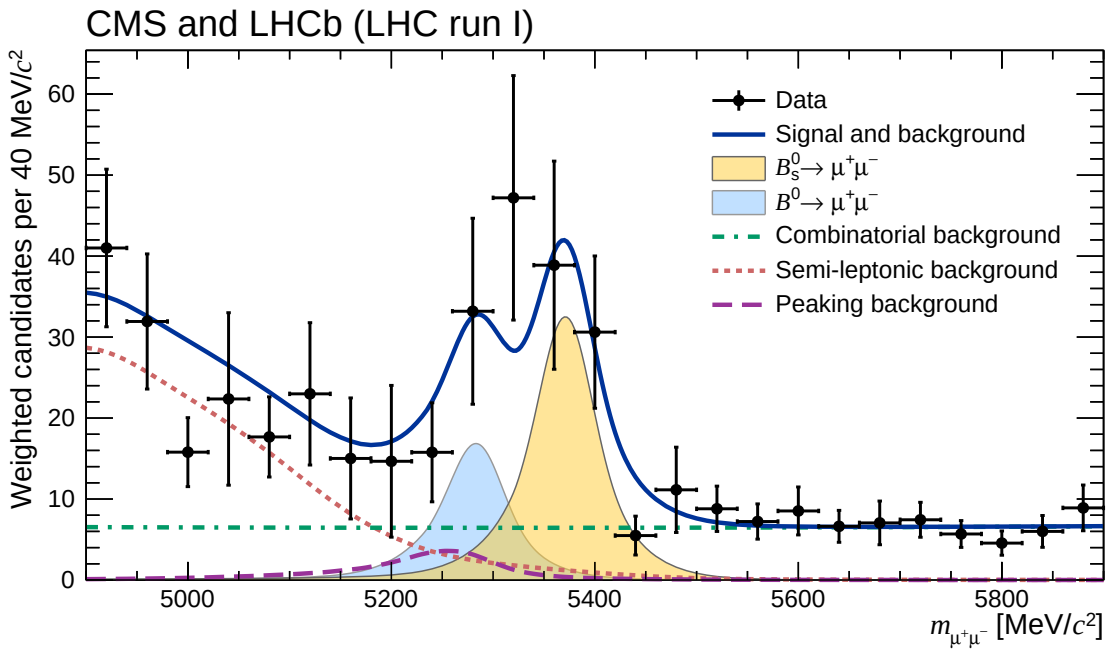
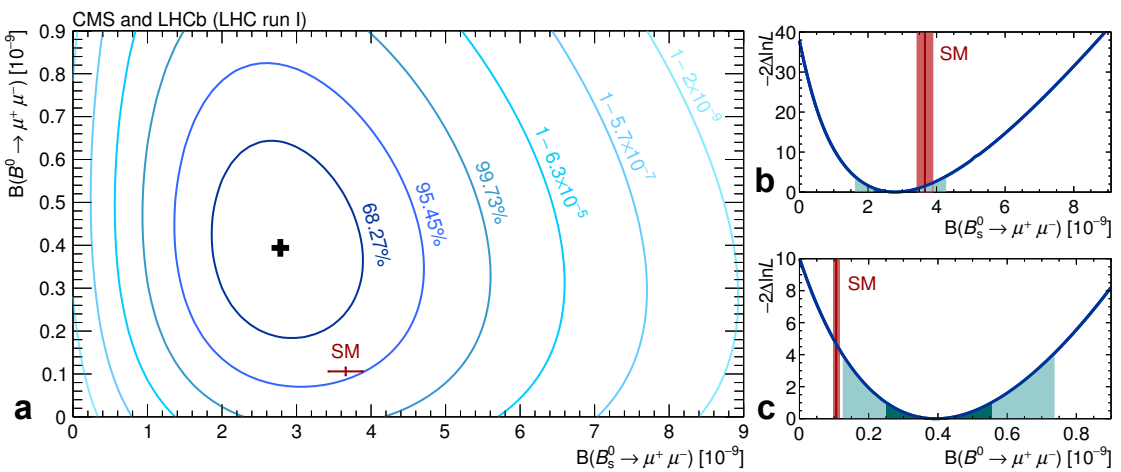
$$\mathcal{B}(B^0_s) = (2.8^{+0.7}_{-0.6}) \times 10^{-9}$$

$$\mathcal{B}(B^0) = (3.9^{+1.6}_{-1.4}) \times 10^{-9}$$

- Combined:
  B^0_s fit $> 6.2\sigma$
  B^0 fit $> 3.2\sigma$
- $\sim 2\sigma$ from SM
- Great advert for combined effort





Nature 522 (2015) 68

$B^0_{(s)} \to J/\psi\gamma$ at LHCb

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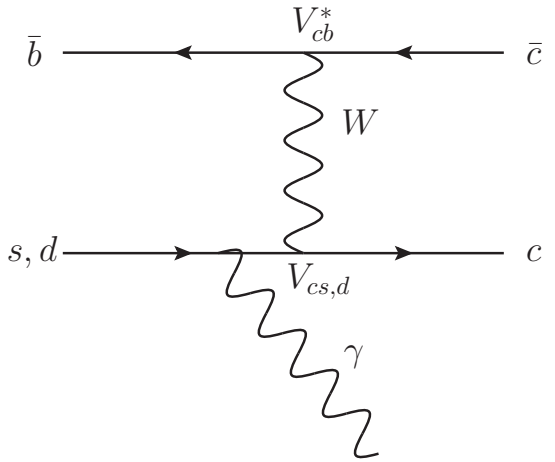
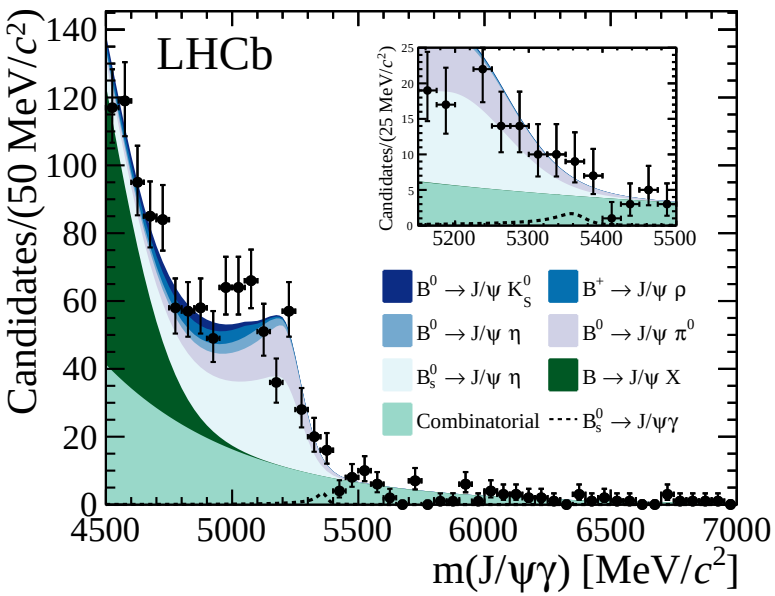
- Radiative decay of $B^0_{(s)}$
- SM predictions vary wildly
  - $\mathcal{B} \sim 2\times10^{-7}$—$5\times10^{-6}$
  - Highly sensitive to QCD effects
  - Tests QCD factorisation
- Sensitive to **New Physics**
  - Particularly RH currents
- Limits set (90% conf):

$$\mathcal{B}(B^0_s) < 1.5\times10^{-6}$$
$$\mathcal{B}(B^0) < 7.3\times10^{-6}$$





Phys. Rev. D92 (2015) 112002

$B_s^0 \to \phi\gamma$ – photon polarisation at LHCb

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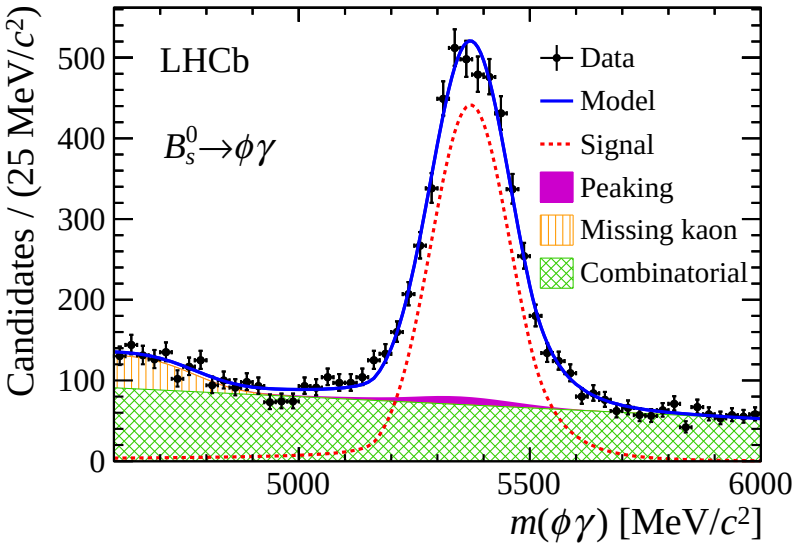
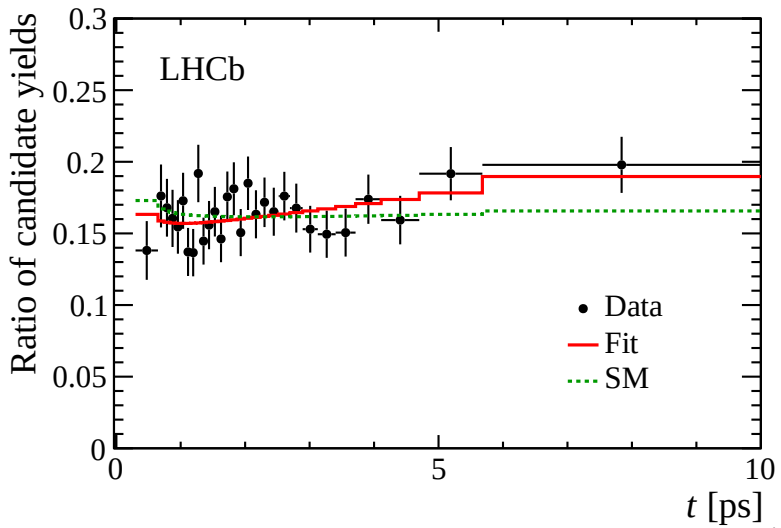
- SM $b \to s\gamma \sim$ left-handed
  - Small right-handed component ($m_s \neq 0$)
  - $\mathcal{A}^{\Delta}_{\mathrm{SM}} = 0.047^{+0.029}_{-0.025}$
- Time dependent analysis

$$\mathcal{P}(t) \sim e^{-\Gamma_s t} \times \{\cosh(\Delta\Gamma_s t/2) - \mathcal{A}^{\Delta}\sinh(\Delta\Gamma_s t/2)\}$$

- In ratio with $B^0 \to K^{*0}\gamma$
- $\mathcal{A}^{\Delta} = -0.98^{+0.46+0.23}_{-0.52-0.20}$





arXiv:1609.02032

$B^0 \to K^*(892)^0\mu^+\mu^-$ angular analysis

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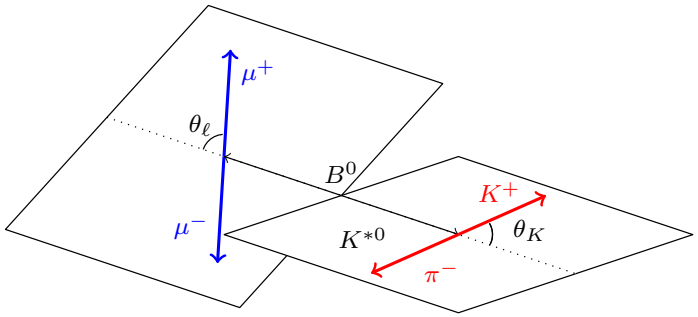
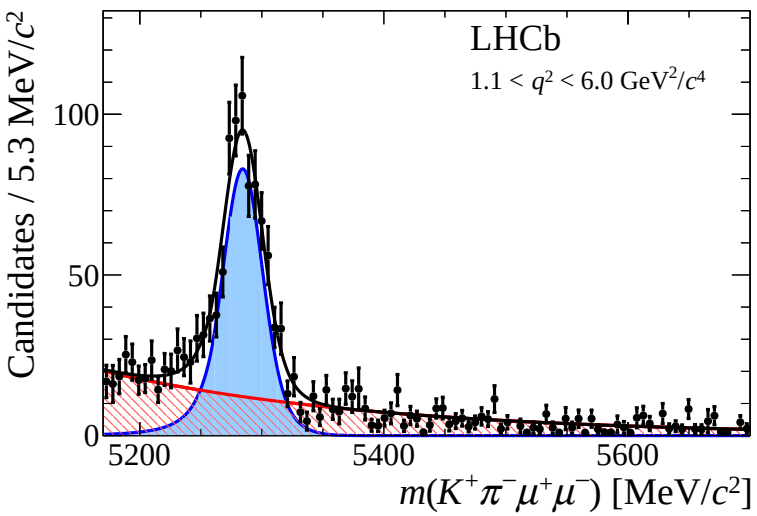
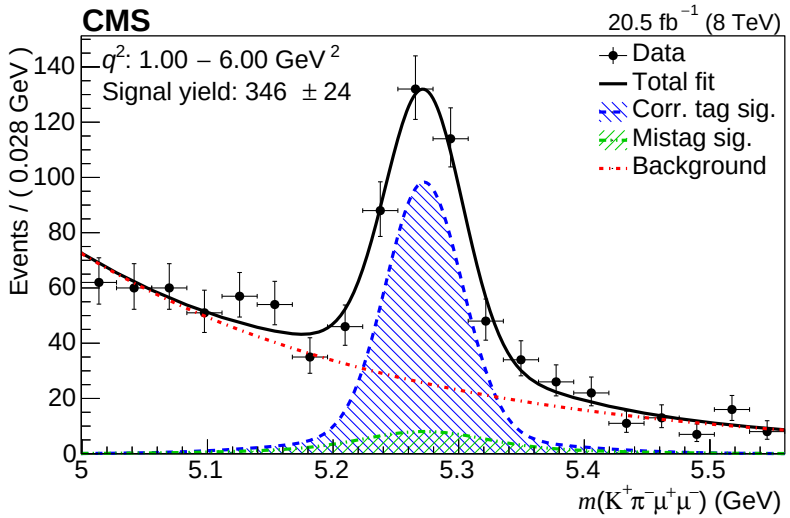
- FCNC process
- Angular variables less susceptible to hadronic FF
- Sensitive to Wilson coeffs C_9 and C_{10} (& others) (vector and axial-vector)



Three angles and q^2



JHEP 02 (2016) 104



Phys. Lett. B 753 (2016) 424

$B^0 \to K^*(892)^0\mu^+\mu^-$ angular analysis

- Angular dependence from 6 amplitudes (+ 2 for S-Wave)
  - Helicity and spin components
  - $\mathcal{A}^{L,R}_{0,\parallel,\perp}$ ($\mathcal{A}^{L,R}_{S}$)
- Many observables formed from amplitudes, e.g

$$F_L = \frac{|\mathcal{A}^L_0|^2 + |\mathcal{A}^R_0|^2}{|\mathcal{A}^L_0|^2 + |\mathcal{A}^R_0|^2 + |\mathcal{A}^L_\parallel|^2 + |\mathcal{A}^R_\parallel|^2 + |\mathcal{A}^L_\perp|^2 + |\mathcal{A}^R_\perp|^2}$$

$$A_{\mathrm{FB}} = \frac{3\mathrm{Re}(\mathcal{A}^L_\parallel \mathcal{A}^{L*}_\perp + \mathcal{A}^R_\parallel \mathcal{A}^{R*}_\perp)/2}{|\mathcal{A}^L_0|^2 + |\mathcal{A}^R_0|^2 + |\mathcal{A}^L_\parallel|^2 + |\mathcal{A}^R_\parallel|^2 + |\mathcal{A}^L_\perp|^2 + |\mathcal{A}^R_\perp|^2}$$

$$P'_5 = \frac{\sqrt{2}\mathrm{Re}(\mathcal{A}^L_0 \mathcal{A}^{L*}_\perp + \mathcal{A}^R_0 \mathcal{A}^{R*}_\perp)}{\sqrt{F_L(1-F_L)}}$$

- Some have physical meaning
  - F_L: Fraction of the longitudinal component of K^{*0}
  - A_{FB}: Dimuon forward-backward asymmetry

$B^0 \to K^{*0}\mu^+\mu^-$ angular analysis – LHCb and CMS

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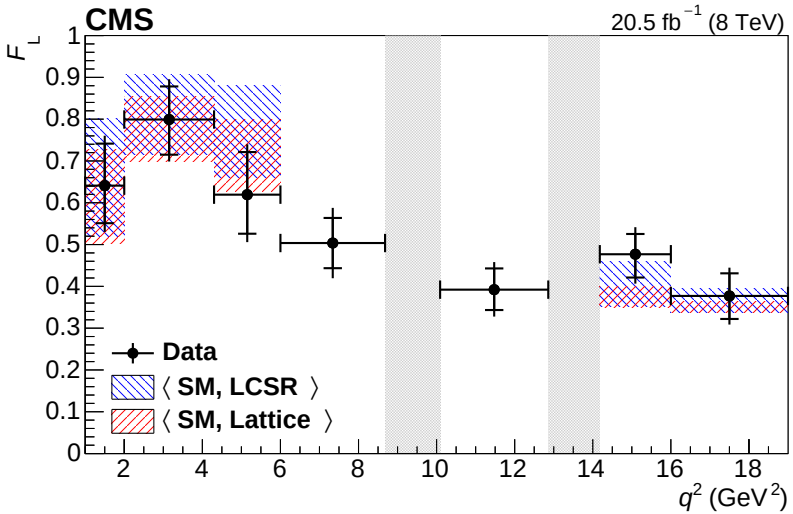
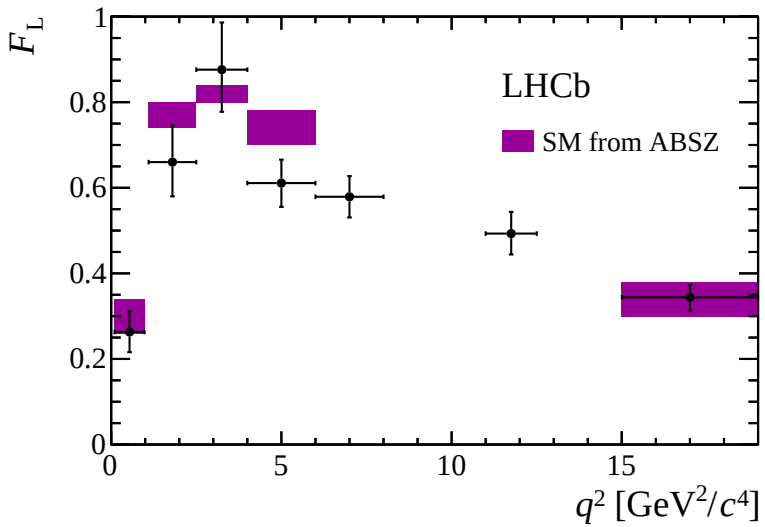
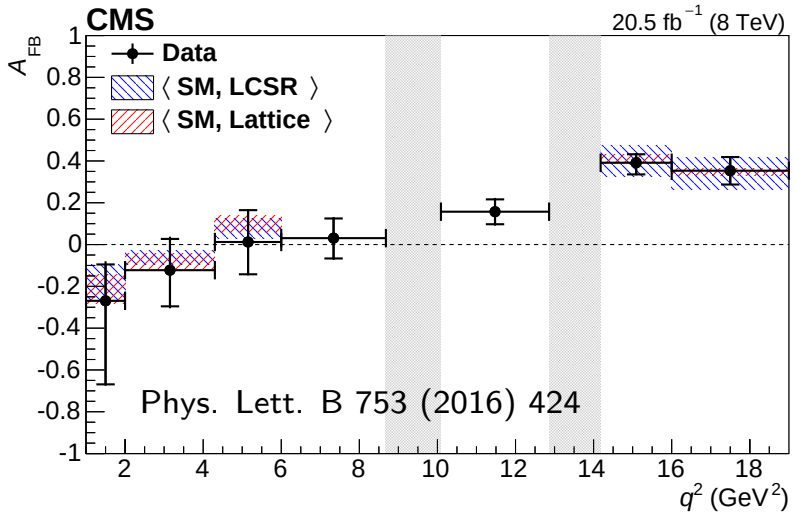
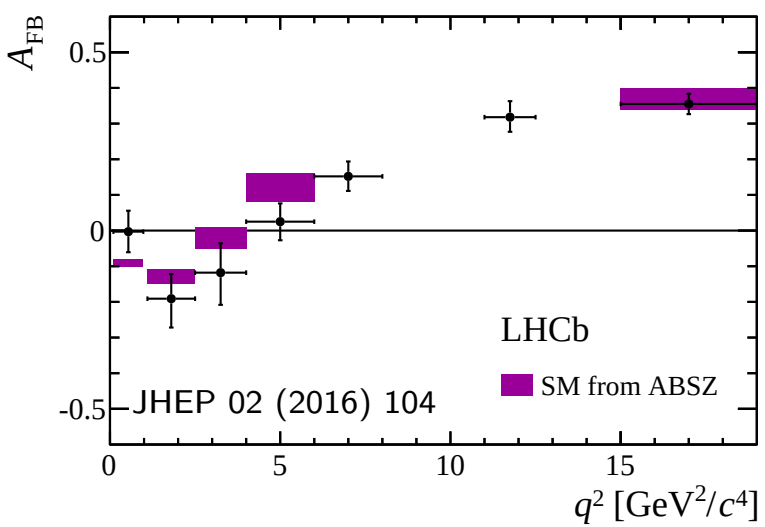
Longitudinal K^{*0} fraction





Forward-backward asymmetry





$B^0 \to K^{*0}\mu^+\mu^-$ angular analysis – LHCb

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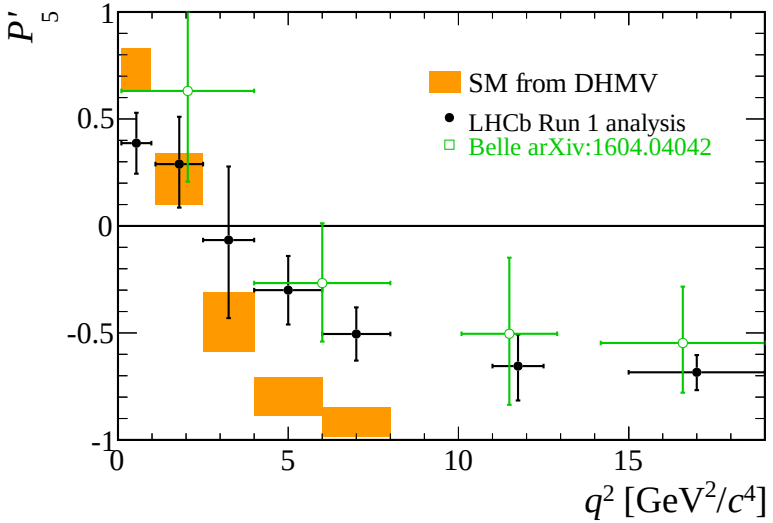
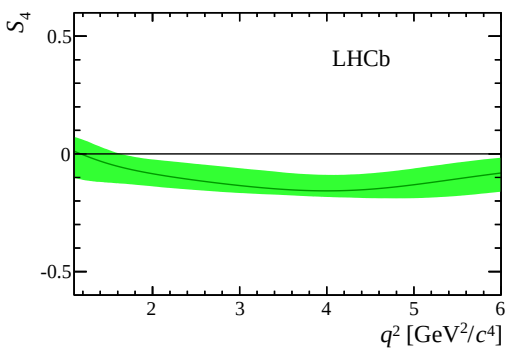
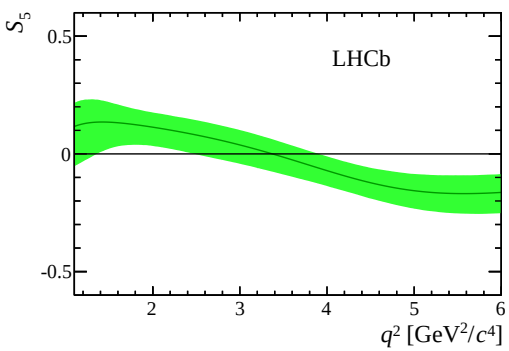
JHEP 02 (2016) 104

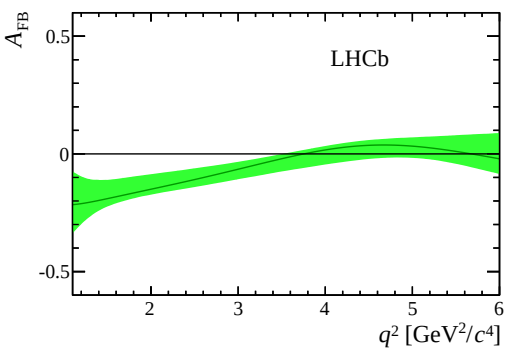
- Local $\sim 3\sigma$ deviations
- $\Delta\mathrm{Re}(C_9) = -1.0 \pm 0.3$
  - Consistent with new vector particle
  - QCD effects (charm)?



Amplitudes fitted with low q^2 ansatz, $(a + bq^2 + c/q^2)$







$q_0^2(A_{\mathrm{FB}}) = [3.40, 4.80]\mathrm{GeV}^2$ (SM $4.36^{+0.33}_{-0.31}$ Eur.Phys.J.C41:173-188,2005)

$B^0 \to K^+\pi^-\mu^+\mu^-$ and $B^0 \to K^*(892)^0\mu^+\mu^-$

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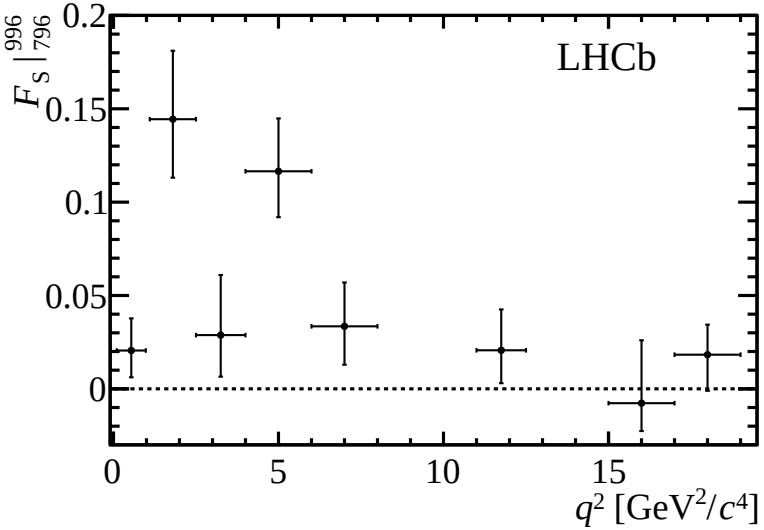
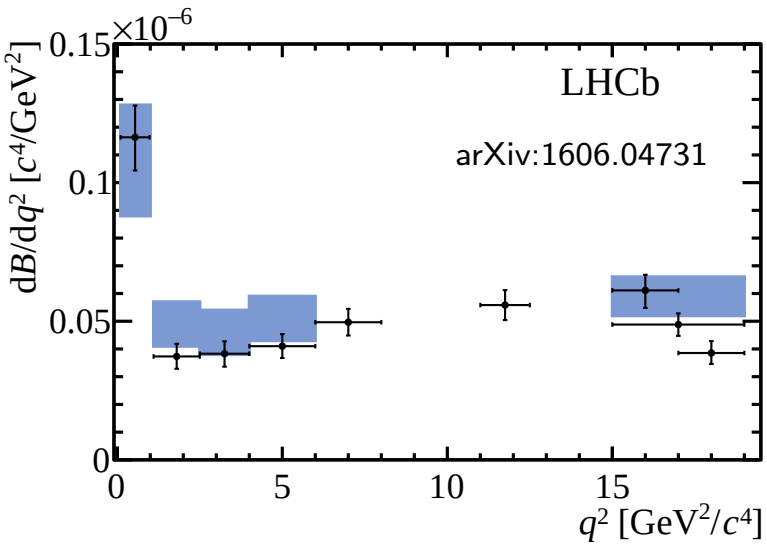
- $K^+\pi^-$ system in S- and P-wave
- SM predictions for P-wave only
- Need S-wave fraction to extract BF measurement
- Ratio of spin states S- & P-wave important for understanding hadronic effects





$$F_S = 0.101 \pm 0.017(\text{stat}) \pm 0.009(\text{syst}) \quad [1.1 \leq q^2 < 6.0\,\text{GeV}^2]$$

$$\frac{d\mathcal{B}}{dq^2} = (0.392^{+0.020}_{-0.019}(\text{stat}) \pm 0.010(\text{syst}) \pm 0.027(\text{norm})) \times 10^{-7}\,\text{GeV}^{-2}$$

$B^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$ differential BF and $\mathcal{A}_{CP}$ at LHCb

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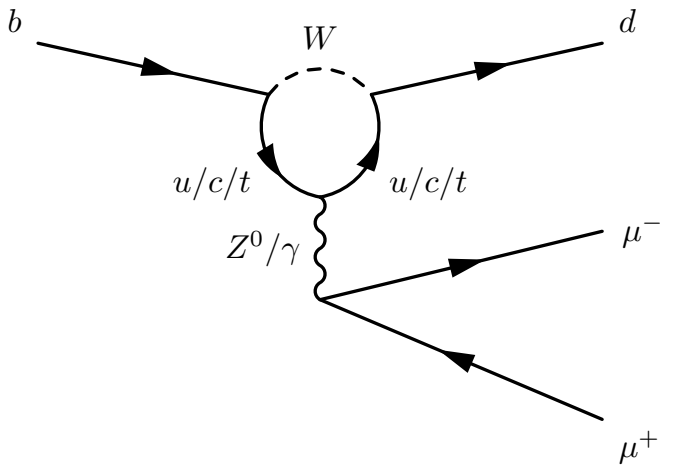
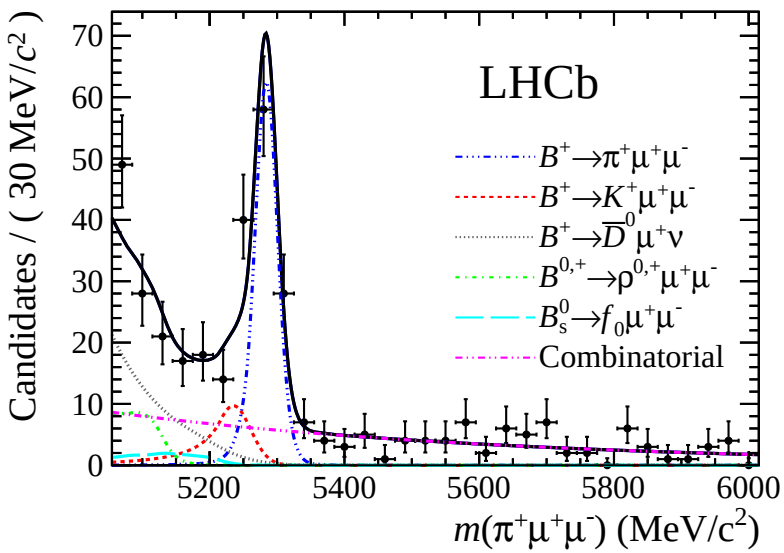
- $b \to dll$ transition
  - More suppressed than $b \to sll$
- Access to CKM element $|V_{td}|$
  - $|V_{td}/V_{ts}|$ with $K^{+}\mu\mu$
- Not exclusively a top loop
  - CP asymmetry non-zero

JHEP 10 (2015) 034





$B^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$ differential BF and $\mathcal{A}_{CP}$

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$$\mathcal{A}_{CP} = -0.11 \pm 0.12 \pm 0.01$$

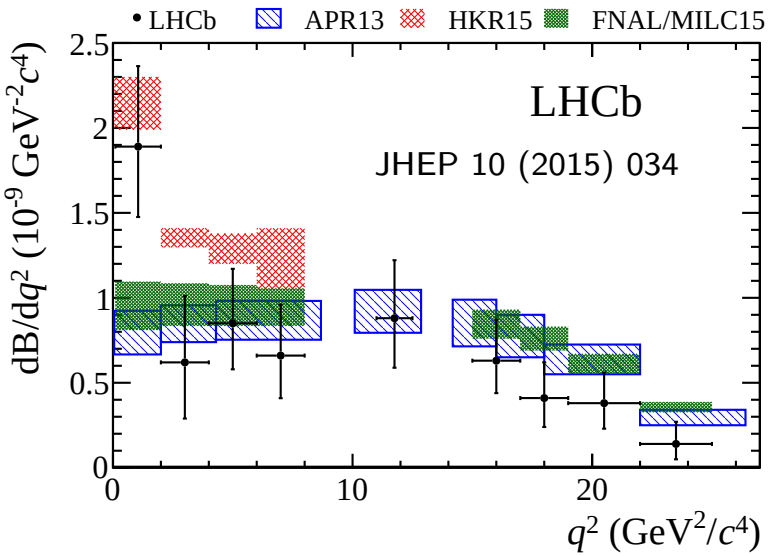
$$|V_{td}| = 7.2^{+0.9}_{-0.8} \times 10^{-3}$$

$$|V_{ts}| = 3.2^{+0.4}_{-0.4} \times 10^{-2}$$

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.24^{+0.05}_{-0.04}$$

$$(= 0.20 \pm 0.02)$$

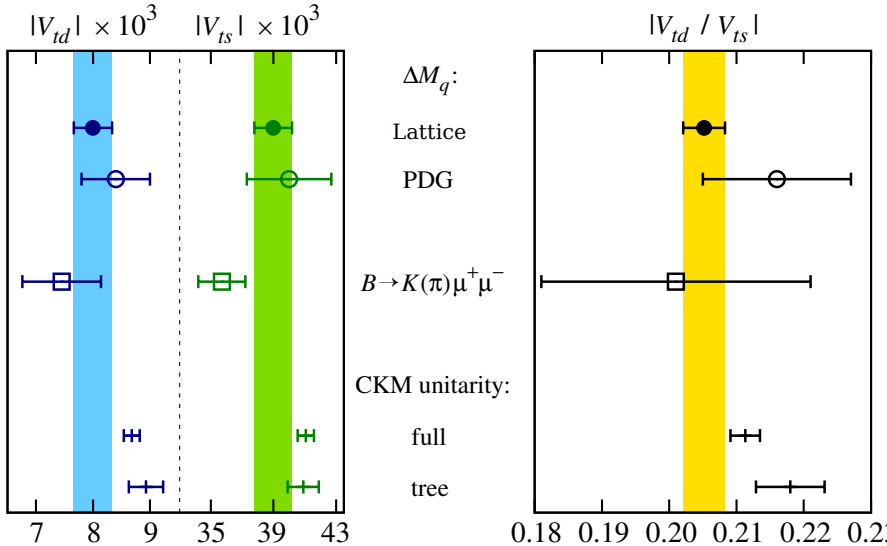
Phys. Rev. D 93, 034005 (2016)



CKM tests important

- RD CKM competitive with $B^0_{(s)}$ mixing
- $1-3\sigma$ deviations of global (tree) fits to measurements

arXiv:1602.03560



Other recent rare decays at LHCb

Can only give a taste of the full rare decays program: Recent

- Ratio BF $B^+ \to K^+\mu^+\mu^-/B^+ \to K^+e^+e^-$
  - $R(K) = 0.74 \pm 0.10$, 2.6σ deviation from SM.
- Search for Hidden bosons in $B^0 \to K^{*0}\mu^+\mu^-$
- $B_s^0 \to \phi\mu^+\mu^-$ diff. BF and angular
- $\Lambda_b^0 \to \Lambda^0\mu^+\mu^-$ diff. BF and angular
- $B^0 \to K^{*0}e^+e^-$ angular analysis
- $B^0_{(s)} \to \pi^+\pi^-\mu^+\mu^-$ BF
- Search for $\tau^- \to \mu^-\mu^+\mu^-$
- Ratio BF $B^+ \to K^+\mu^+\mu^-/B^+ \to K^+e^+e^-$

Many more in the works

Conclusions

- A rich and varied rare decays programme at the LHC
- Rare decays a speciality of LHCb
  - GPDs can contribute
- Collaboration between the experiments yield valuable
- Interesting hints at departures from the SM
- More to come with LHC Run II data

Backup

LHCb and CMS

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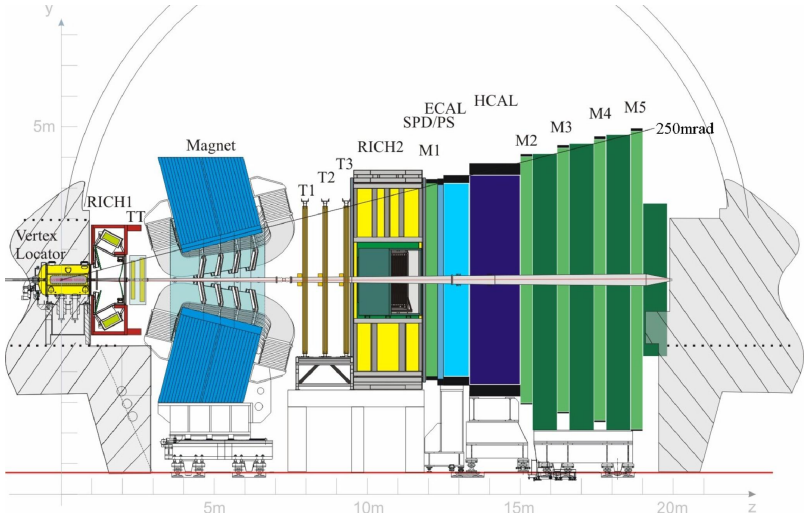
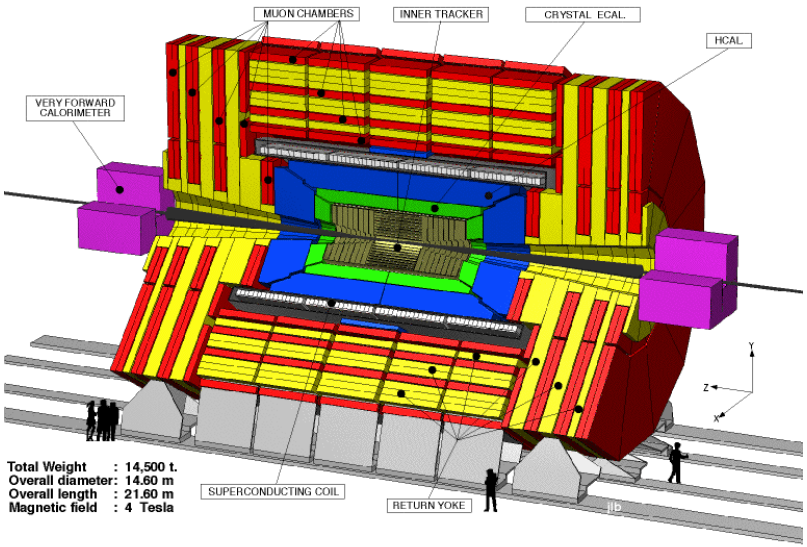
LHCb



- Excellent momentum resolution
- Excellent PID
- Excellent vertexing

CMS



- Excellent energy resolution
- Full acceptance
- Vast integrated luminosity