Electroweak penguins at LHCb

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(on behalf of the LHCb collaboration)

CERN

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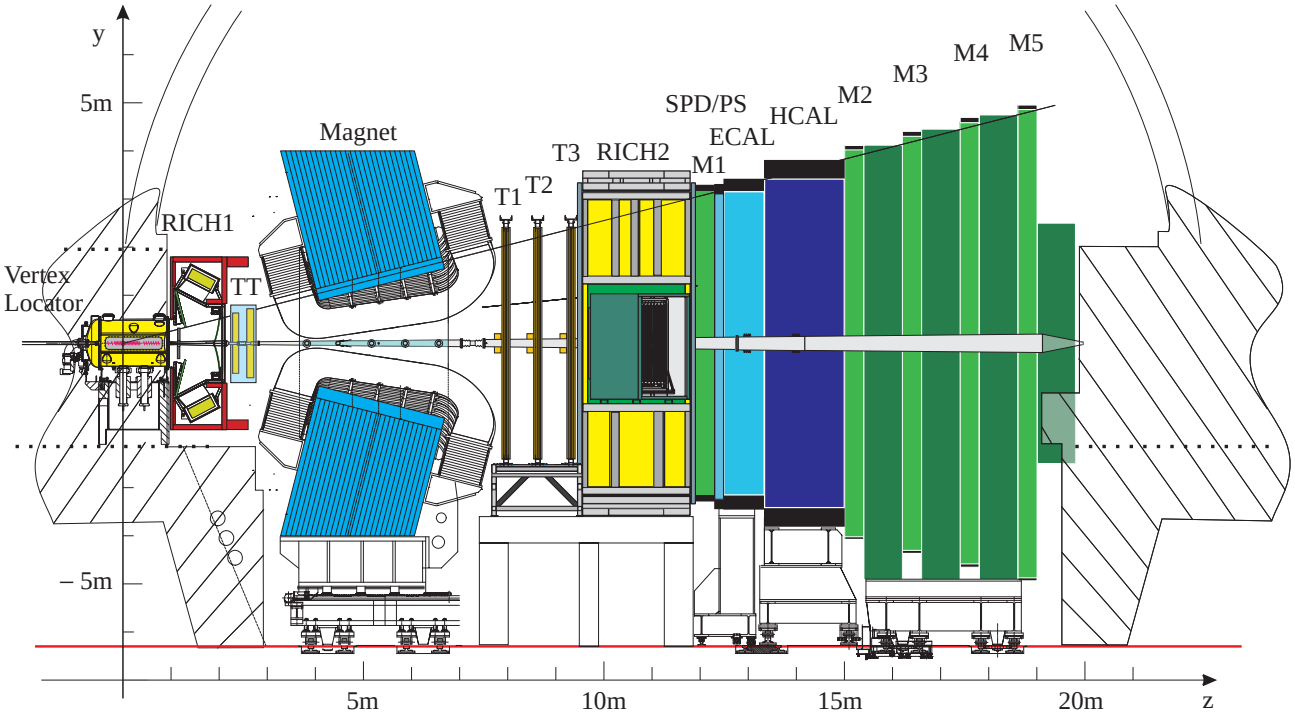
The LHCb detector

[JINST 3 (2008) S08005]

- Acceptance $2<\eta<5$, with excellent vertexing, tracking, PID
- $\mathcal{L}_{\rm int} = 1$ fb^{-1} @ 7 TeV in 2011, & 2 fb^{-1} @ 8 TeV in 2012



Vertex Locator	$\sigma_{\rm PV,x/y} \sim 10$ μm, $\sigma_{\rm PV,z} \sim 60$ μm
Tracking (TT, T1-T3)	$\Delta p/p$: 0.4% at 5 GeV/c, to 0.6% at 100 GeV/c
RICHs	$\varepsilon(K \to K) \sim 95\%$, mis-ID rate $(\pi \to K) \sim 5\%$
Muon system (M1-M5)	$\varepsilon(\mu \to \mu) \sim 97\%$, mis-ID rate $(\pi \to \mu) = 1-3\%$
ECAL	$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\%$ (E in GeV)
HCAL	$\sigma_E/E \sim 70\%/\sqrt{E} \oplus 10\%$ (E in GeV)

One way of indirect searches for NP at LHCb

- Measure FCNC transitions, where New Physics (NP) is more likely to emerge, and compare to predictions
  - E.g., Operator product expansion for $b \to s$ transitions

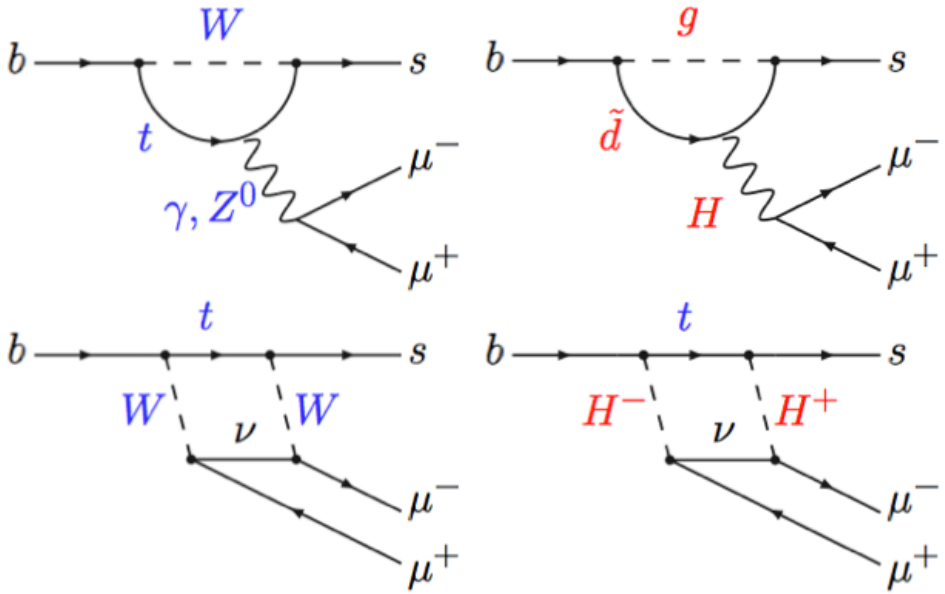
$$\mathcal{H}_{\text{eff}} = -\frac{4\,G_F}{\sqrt{2}}\,V_{tb}\,V_{ts}^{*}\,\frac{e^2}{16\pi^2}\sum_{i=1\ldots10,S,P}\left(C_i\,O_i + C_i'\,O_i'\right) + \text{h.c.}$$

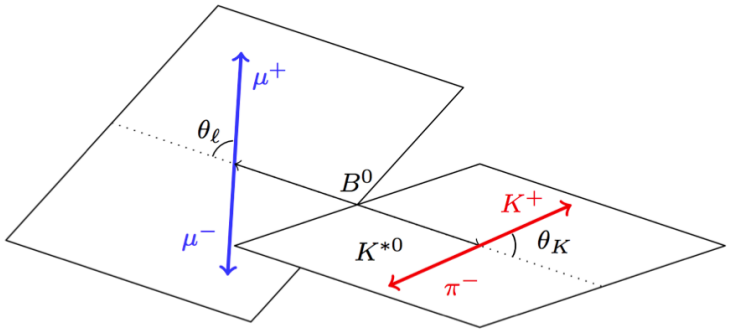
  - New Physics may
    - ★ modify short-distance Wilson coefficients $C^{(\prime)}$
    - ★ add new operators $\sum_j C_j^{\text{NP}}\,O_j^{\text{NP}}$

    and change the decay rates, angular distributions, etc
- Focus on EW penguins in this talk, other rare decays are discussed in J. Albrecht's talk [link]

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

- $b \to s\ell^+\ell^-$ processes governed by FCNCs, rates and angular distributions sensitive to NP





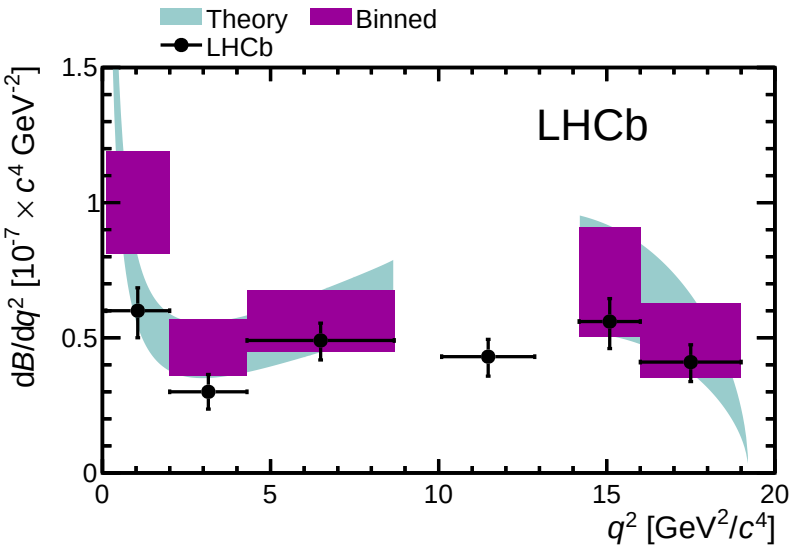
- $B^0 \to K^{*0}\ell^+\ell^-$, described by $q^2 = M^2(\ell^+\ell^-)$ and $(\theta_\ell, \theta_K, \phi)$

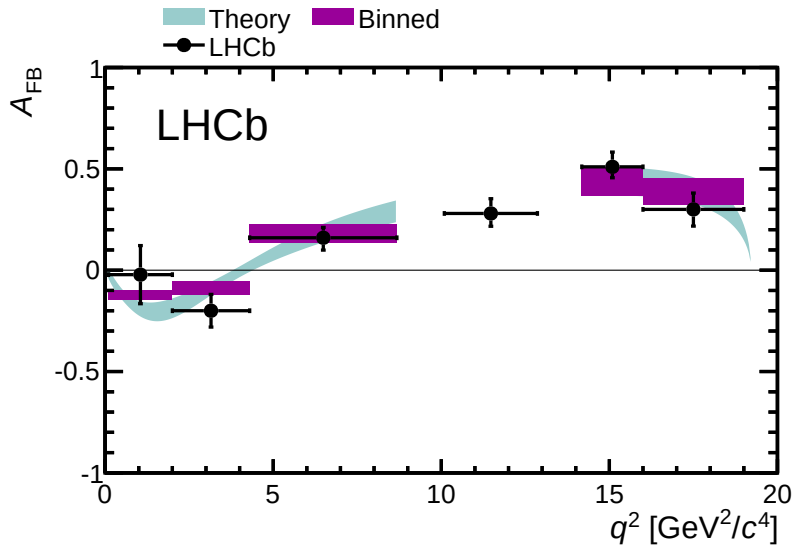
$$\frac{1}{\mathrm{d}\Gamma/dq^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\cos 2\theta_\ell$$
$$-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

$B^0 \to K^{*0}\mu^+\mu^-$, decay rates and $\mathcal{A}_{\rm FB}$

[JHEP 1308 (2013) 131]

- $d\mathcal{B}/dq^2$, differential branching fraction
- $\mathcal{A}_{\rm FB}(=\frac{3}{4}S_6)$, the forward-backward asymmetry of the dimuon system. In SM, it changes sign at q_0^2.
- First measurement of zero crossing point, $q_0^2 = 4.9 \pm 0.9$ GeV$^2/c^4$, consistent with SM predictions $3.9 - 4.4$ GeV$^2/c^4$





- Theory uncertainties are dominated by knowledge of $B \to K^*$ form factors

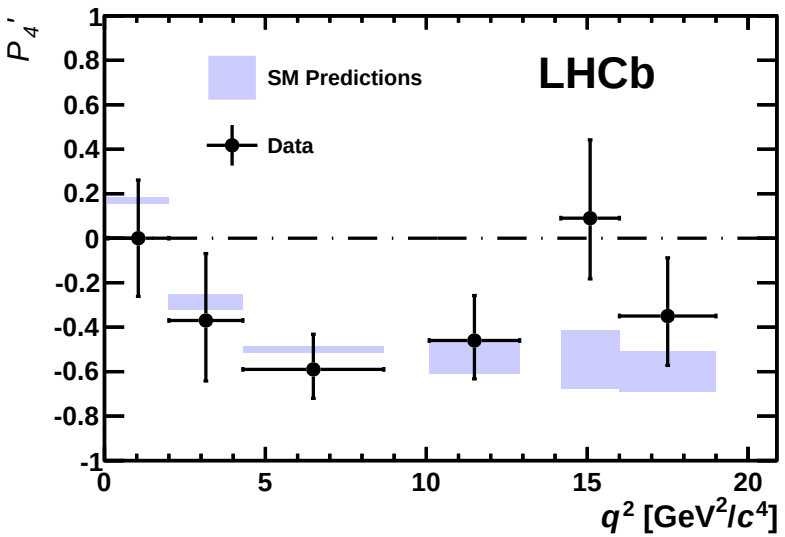
$B^0 \to K^{*0}\mu^+\mu^-$, form-factor-independent observables

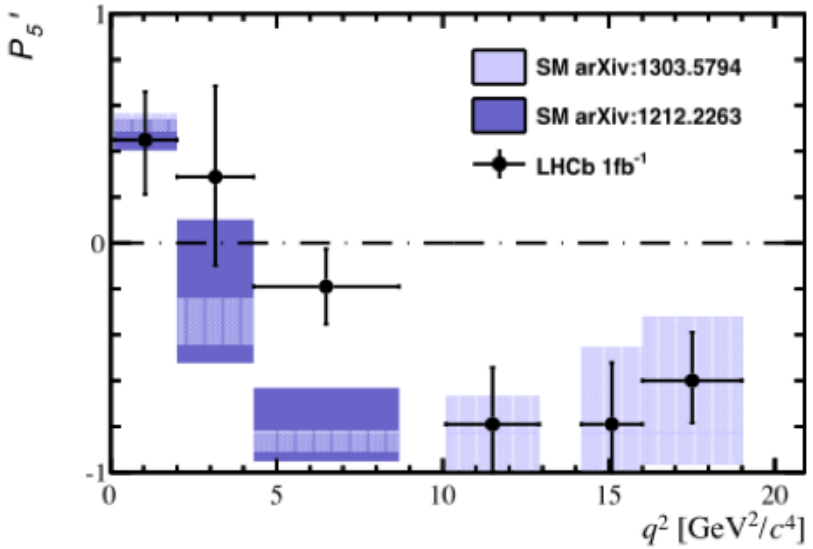
[PRL 111 (2013) 191801]

- New basis of observables, less dependent on form factors

$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$ [Descotes-Genon et al., arXiv:1303.5794]

- P'_5 shows deviation from "SM" in one q^2 bin $(4.30 - 8.68\ \mathrm{GeV}^2/c^4)$, how significant depends on theoretical predictions...

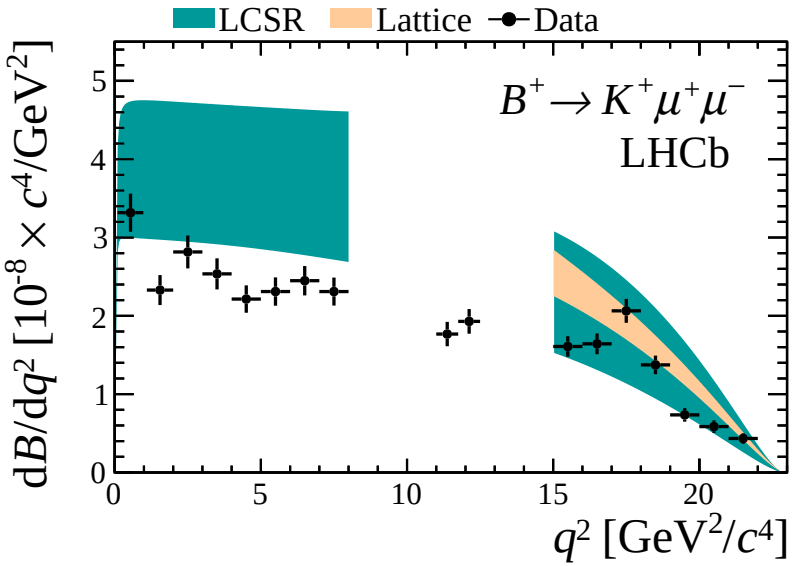


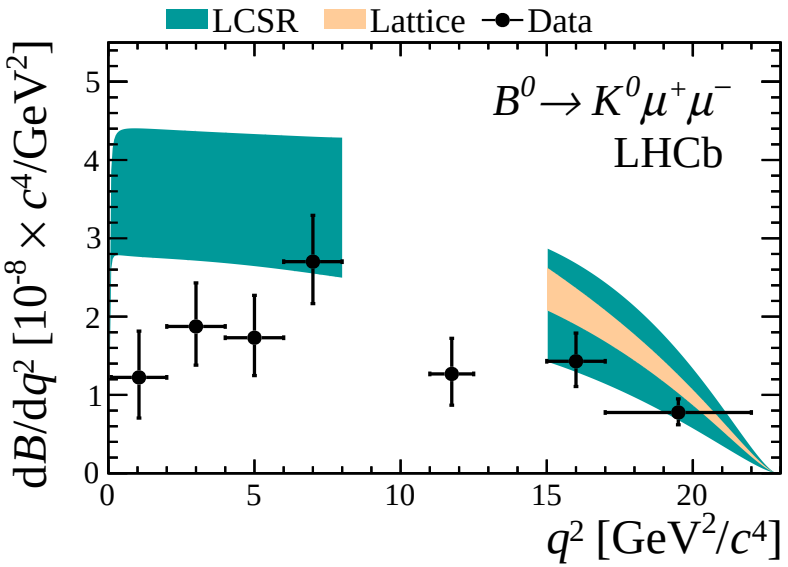


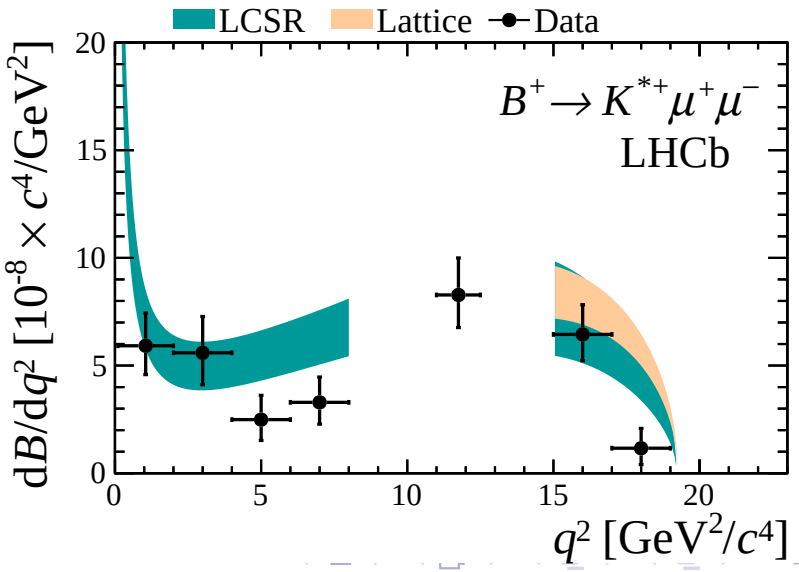
$B \to K^{(*)}\mu^+\mu^-$, differential branching fraction

[JHEP 06 (2014) 133]

- $\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)$ highly sensitive to contributions from (axial)-vector like particle beyond the SM
- Some discrepancy at the q^2 region?



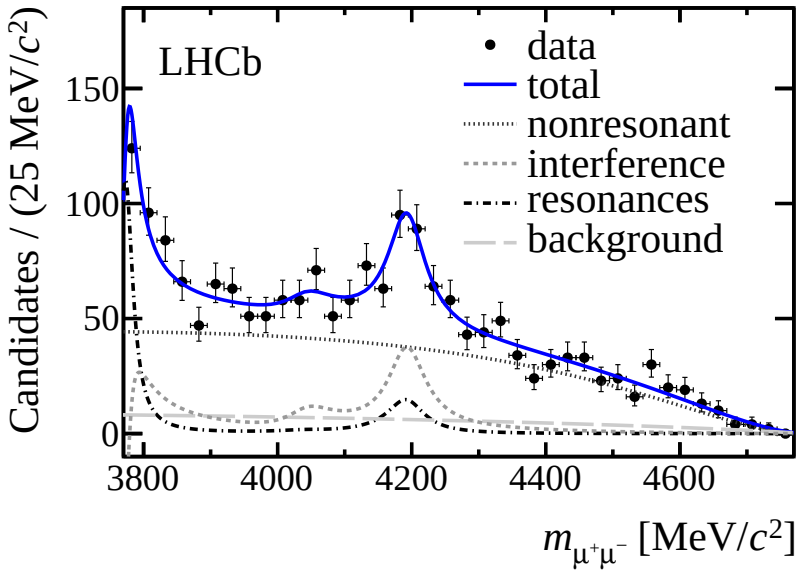




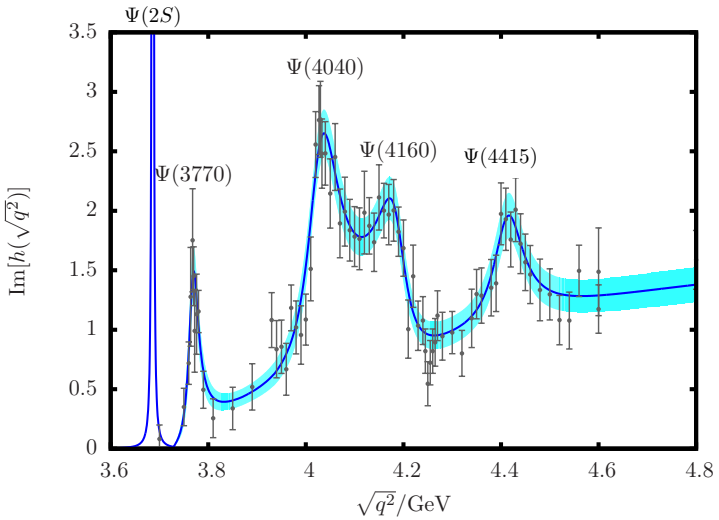
Control charmonium effects?

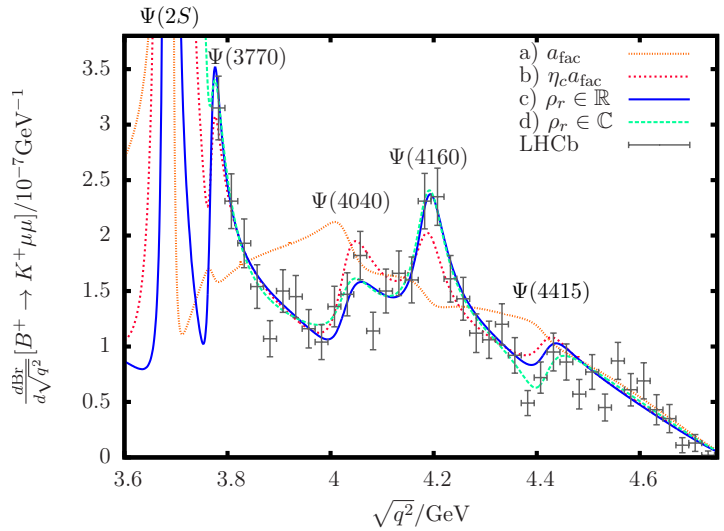
- $B^+ \to (\psi(4160) \to \mu^+\mu^-)K^+$
  first observation
  - Another ψ to exclude?
  - Interference to consider?

[PRL 111 (2013) 112003]



- QCD or New Physics?
  [Lyon, Zwicky, arXiv:1406.0566]
  - Large non-factorisable effects (or NP) required to have consistent picture between BESII $e^+e^- \to$ hadrons data and the LHCb result

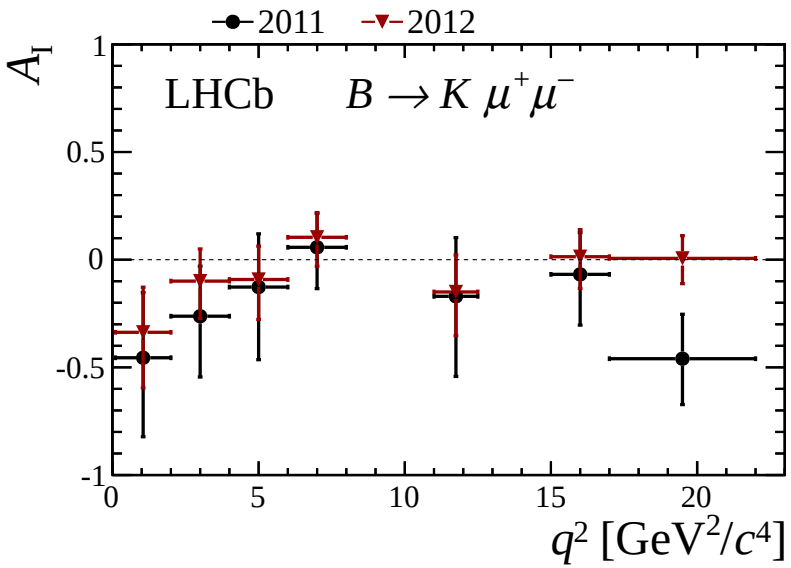


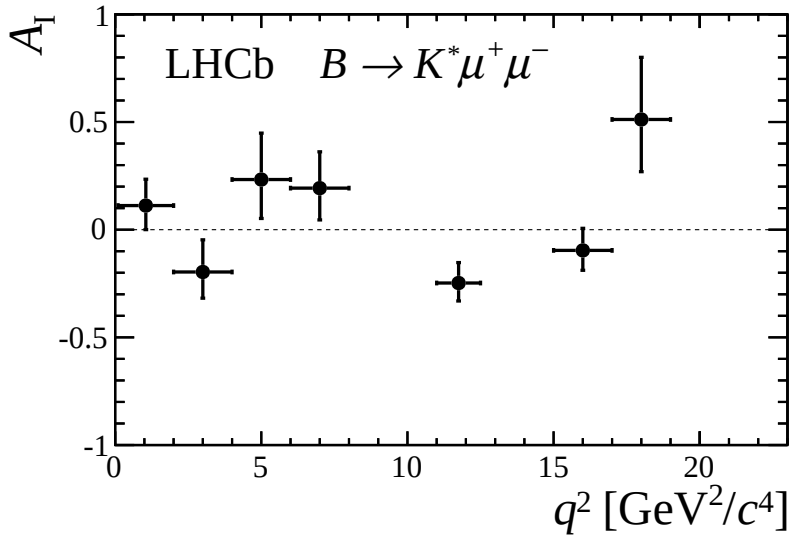


$B \to K^{(*)}\mu^+\mu^-$, isospin asymmetry

[JHEP 06 (2014) 133]

- Asymmetry in charged and neutral $B \to K^{(*)}\mu^+\mu^-$ decays
  $\mathcal{A}_I = \frac{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) - \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) + \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}$
- $\mathcal{A}_I$ predicted to be zero in the SM for both $B \to K\mu^+\mu^-$ and $B \to K^*\mu^+\mu^-$ decays [Lyon, Zwicky, arXiv:1305.4797]
- Deviation from SM observed for $B \to K\mu^+\mu^-$ decay with 2011 data (1 fb^{-1}), tension much reduced with full dataset (3 fb^{-1})



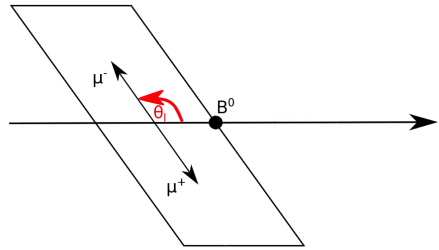


$B \to K\mu^+\mu^-$, angular analysis

[JHEP 05 (2014) 082]

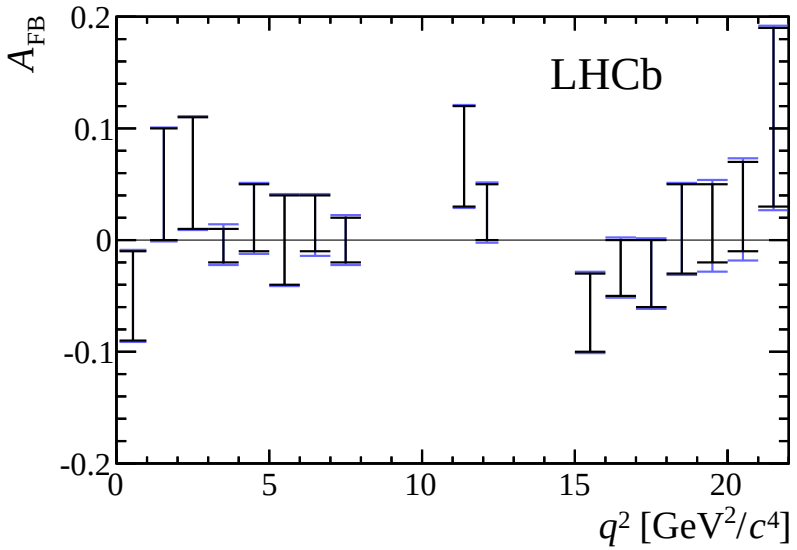
- Angular distribution

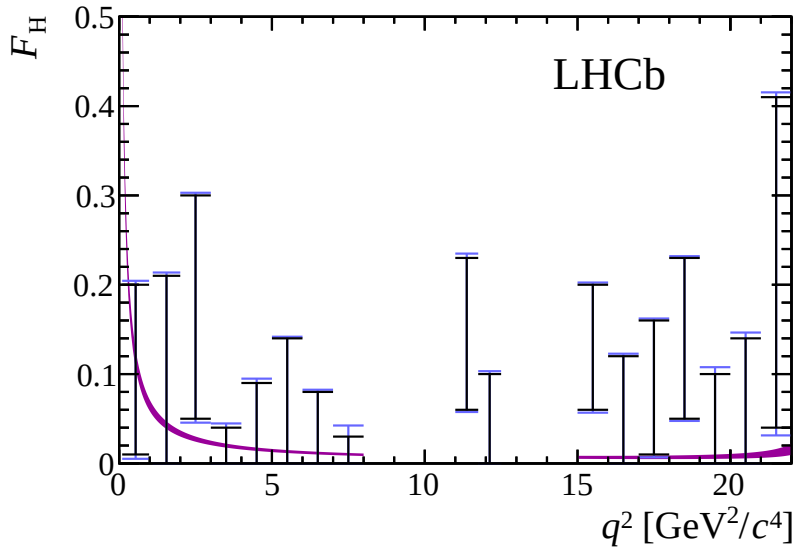
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4}(1-\mathcal{F}_H)(1-\cos^2\theta_\ell) + \frac{1}{2}\mathcal{F}_H + \mathcal{A}_{FB}\cos\theta_\ell$$



  - $\mathcal{A}_{FB}$ is almost zero in SM
  - "Flat term" $\mathcal{F}_H$
    - ★ Fractional contribution of (pseudo)scalar and tensor
    - ★ Non-zero but small in the SM, due to finite muon mass

- $B^+ \to K^+\mu^+\mu^-$, consistent with SM





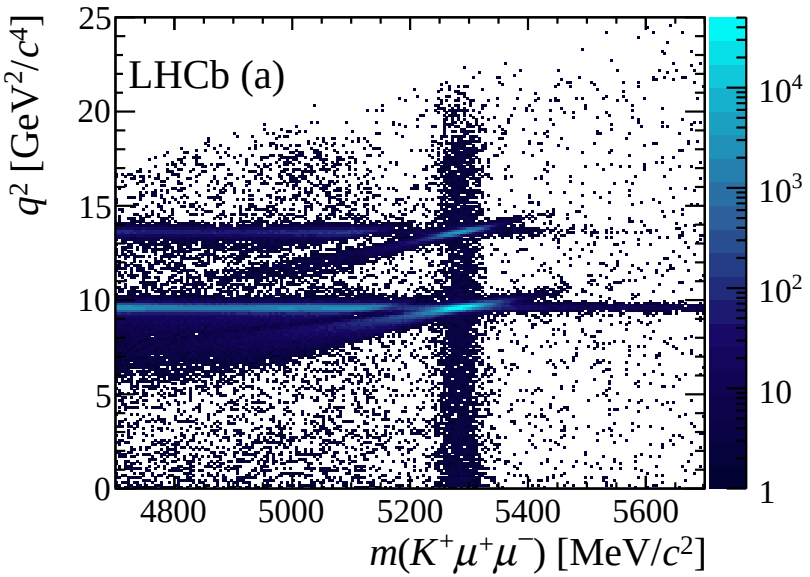
- The same for $B^0 \to K^0_S\mu^+\mu^-$

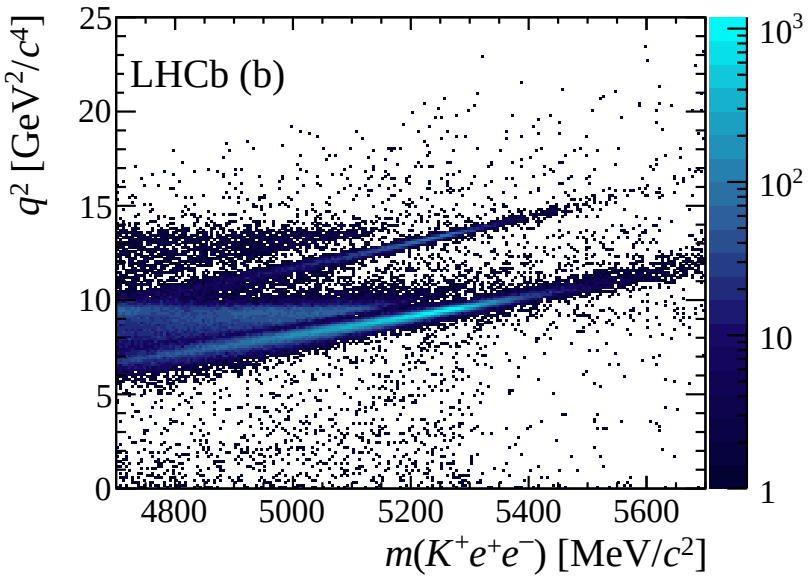
Test of lepton universality using $B^+ \to K^+\ell^+\ell^-$

[arXiv:1406.6482]

- $\mathcal{R}_K = \frac{\mathcal{B}(B^+\to K^+\mu^+\mu^-)}{\mathcal{B}(B^+\to K^+e^+e^-)} = 1 \pm \mathcal{O}(10^{-3})$ in the SM
  - Small corrections due to phase space & Higgs penguin diagrams
  - Up to 10% deviation from SM by new (pseudo)scalar operators
- Double ratio used to cancel systematic uncertainties

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



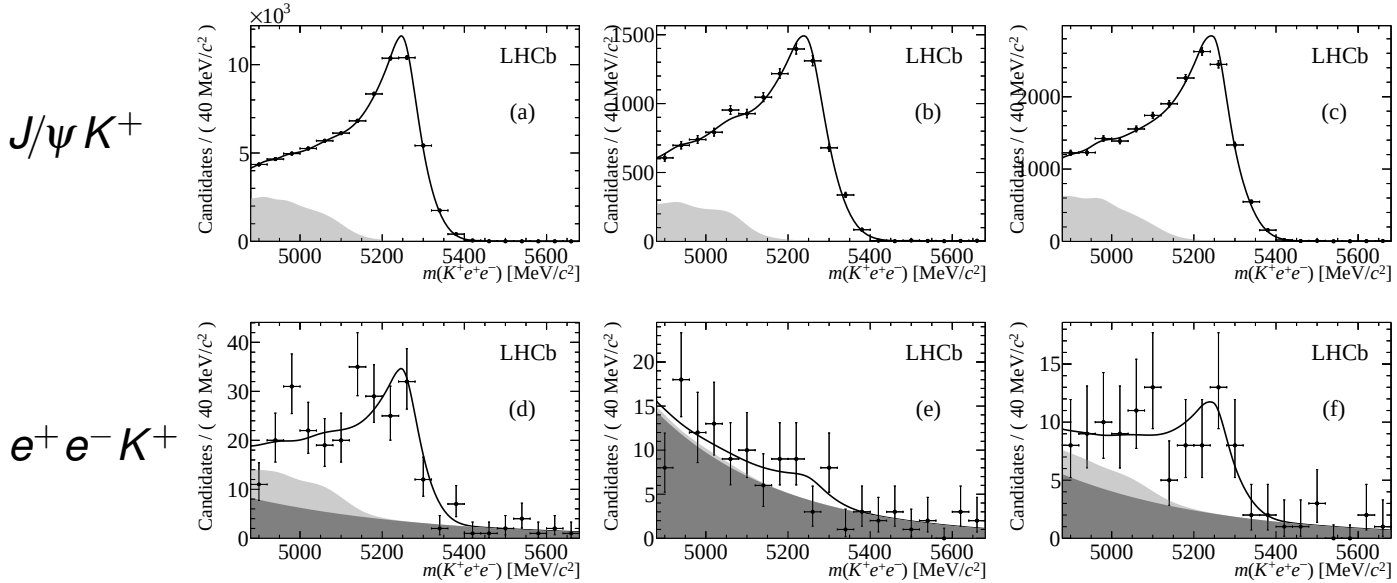


- Analysis done in the experimentally and theoretically favoured region $1 < q^2 < 6\ \mathrm{GeV}^2/c^4$

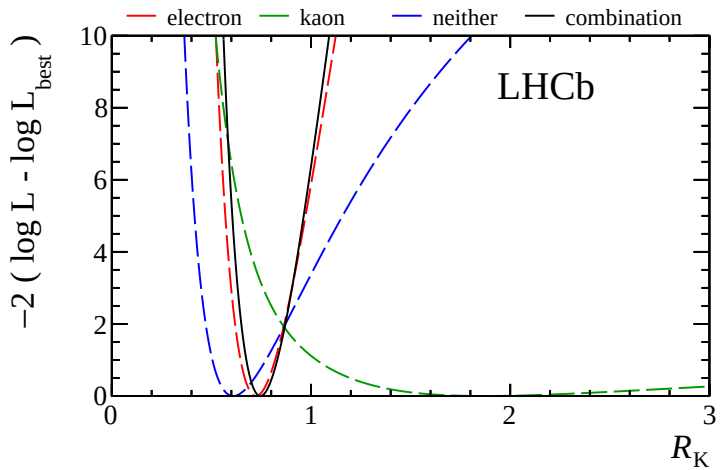
Test of lepton universality using $B^+ \to K^+\ell^+\ell^-$ (cont.)

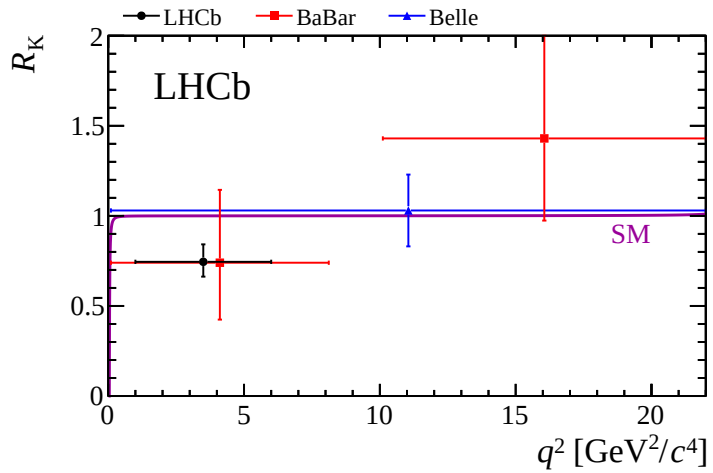
[arXiv:1406.6482]

- $B^+ \to K^+e^+e^-$ split by the way how the signal is triggered



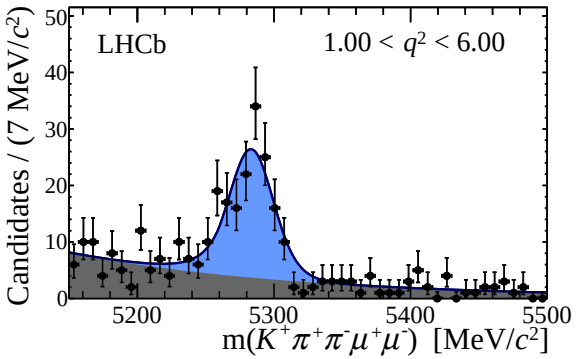
- $R_K = 0.745^{+0.090}_{-0.074} \pm 0.036$, compatible with SM within 2.6σ

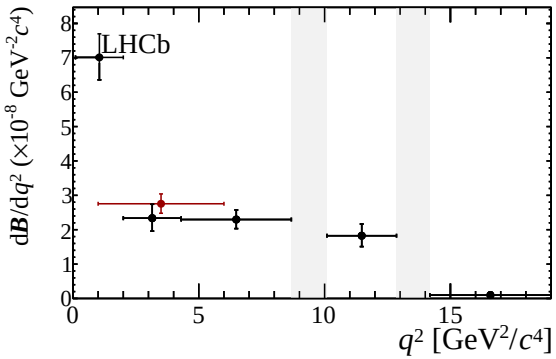


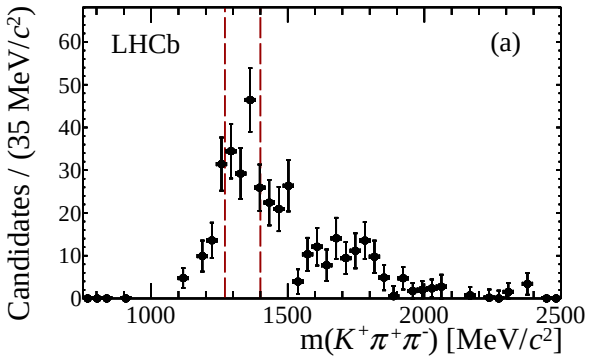


$B^+ \to K^+\pi^+\pi^-\{\phi K^+\}\mu^+\mu^-$, observations

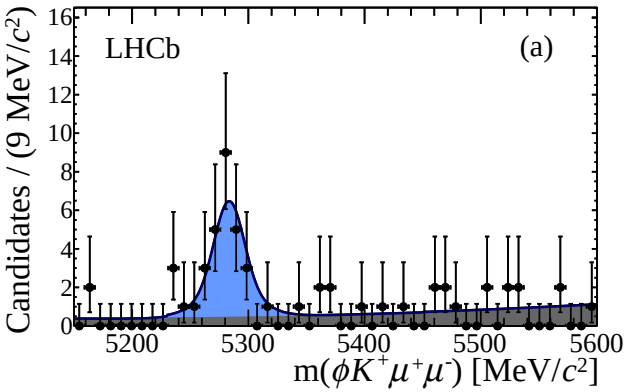
- $B^+ \to K^+\pi^+\pi^-\mu^+\mu^-$, first observation [LHCb-Paper-2014-030]
  - Differential branching fraction $d\mathcal{B}/dq^2$ measured
  - $K^+\pi^+\pi^-$ structure, integrated the overall q^2 range, consistent with several broad, overlapping resonances
  - $\mathcal{B} = \left(4.36\,^{+0.29}_{-0.27}\,(\text{stat}) \pm 0.20\,(\text{syst}) \pm 0.18\,(\text{norm})\right) \times 10^{-7}$







- $B^+ \to \phi K^+\mu^+\mu^-$, first observation
  - $\mathcal{B} = \left(8.22\,^{+1.88}_{-1.67}\,(\text{stat}) \pm 0.35\,(\text{syst}) \pm 2.74\,(\text{norm})\right) \times 10^{-8}$



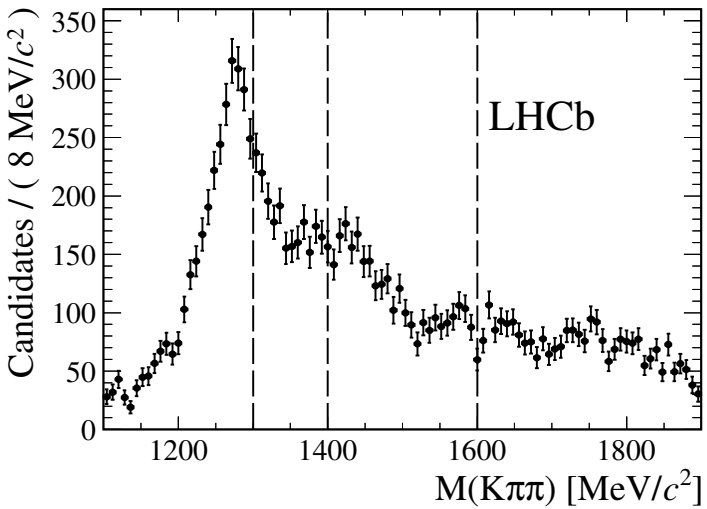
Photon polarization in $b \to s\gamma$

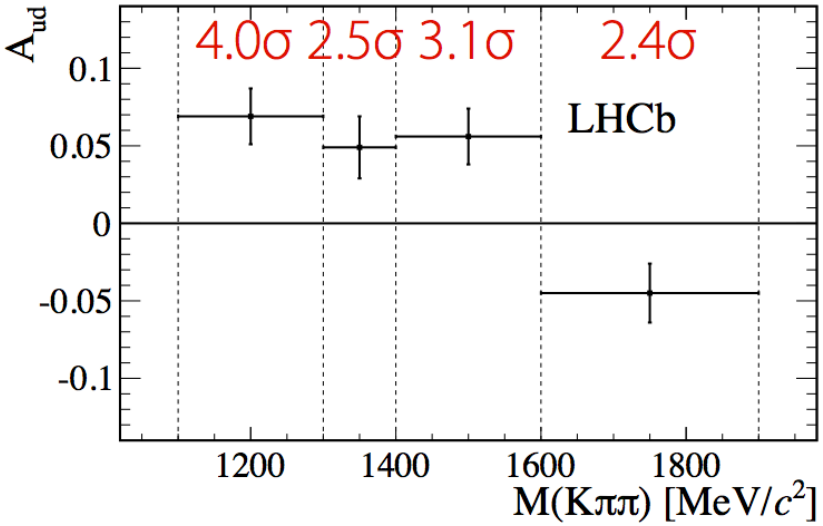
[PRL 112 (2014) 161801]

- Photon in $b \to s\gamma$ mostly left-handed in SM, correction at $\mathcal{O}(\frac{m_s}{m_b})$
- $B^+ \to K^+\pi^+\pi^-\gamma$, up-down asymmetry, $\propto$ photon polarization λ_γ

$$\mathcal{A}_{\rm ud} \equiv \frac{\int_0^1 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta} - \int_{-1}^0 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta}}{\int_{-1}^1 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta}} \propto \lambda_\gamma$$

- Four bins in $m(K^+\pi^+\pi^-)$, combined significance 5.2σ, first observation of photon polarization





Summary

- The LHC(b) is the new Flavour factory
- The SM tested thoroughly with the EW penguins at LHCb
  - Decay rates
  - Angular distributions
- The SM works so well, but some tensions observed, and awaiting theory explanations, and confirmations with more data
  - The P_5' puzzle in $B^0 \to K^{*0}\mu^+\mu^-$
- The photon in $b \to s\gamma$ transitions observed to be polarized
- More will come, stay tuned
  - $B^0 \to K^{*0}\mu^+\mu^-$ analysis with 3 fb^{-1}
  - Photon polarization measurements with, e.g., $B^0 \to K^{*0}e^+e^-$
  - ...