Electroweak penguin decays at LHCb

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Lake Louise Winter Institute
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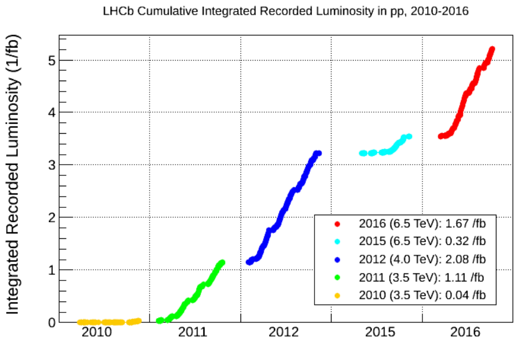
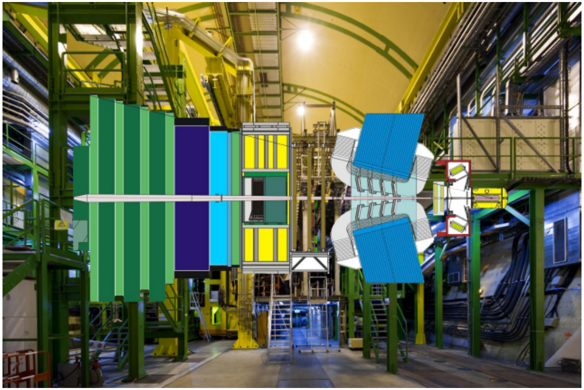
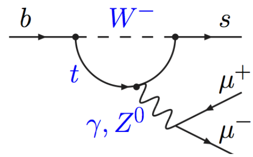


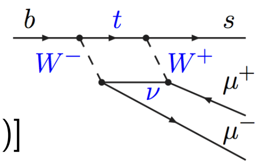
- Single arm forward spectrometer
- Dedicated to heavy flavour physics
- Looks for indirect evidence of new physics in CP violation and rare decays

Momentum resolution:
$\delta p/p = 0.4$ % at 5 GeV to 0.6 % at 100 GeV
Impact parameter resolution:
$\sigma_{IP} \sim 20\ \mu m$
Primary vertex resolution:
13 μm in x and y, and 71 μm in z
Decay time resolution:
$\sigma_{\tau} \sim 50$ fs
Excellent particle identification



Int. J. Mod. Phys. A 30, 1530022 (2015), JINST 3 (2008) S08005





- Mediated by electroweak Flavour Changing Neutral Current (FCNC) processes in the Standard Model (SM)
- They are suppressed in the SM, so more sensitive to New Physics
- There are many precise SM predictions

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i [C_i(\mu) O_i(\mu) + C_i'(\mu) O_i'(\mu)]$$

$i = 1, 2$	Tree	Wilson coefficients C_i : perturbative short-distance effects
$i = 3-6, 8$	Gluon penguin	Operators O_i : non-perturbative long-distance effects
$i = 7$	Photon penguin	
$i = 9, 10$	Electroweak penguin	
$i = S$	Higgs (scalar) penguin	
$i = P$	Pseudoscalar penguin	

- New particles in the loop level processes could significantly change observables
- The pattern of deviations can guide towards NP

Recent LHCb measurements

Branching fractions:

$\Lambda_b \to \pi p \mu^+ \mu^-$ arXiv:1701.08705
$B^0 \to K^{*0} \mu^+ \mu^-$ JHEP 1611 (2016) 047
$B^\pm \to \pi^\pm \mu^- \mu^+$ JHEP 10 (2015) 034
$B_s^0 \to \phi \mu^+ \mu^-$ JHEP 09 (2015) 179
$\Lambda_b \to \Lambda \mu^+ \mu^-$ JHEP 06 (2015) 115
$B_{(s)}^0 \to \pi^+ \pi^- \mu^+ \mu^-$ Phys.Lett B743 (2015) 46
$B^+ \to K^+ \pi^+ \pi^- \mu^+ \mu^-$ JHEP 10 (2014) 064
$B^+ \to \phi K^+ \mu^+ \mu^-$ JHEP 10 (2014) 064
$B^0 \to K^{*0} e^+ e^-$ JHEP 05 (2013) 159

CP asymmetry:

$B^\pm \to \pi^\pm \mu^- \mu^+$ JHEP 10 (2015) 034

Isospin asymmetry:

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

Phase difference:

$B^+ \to K^+ \mu^+ \mu^-$ JHEP 11 (2016) 047

Lepton Universality:

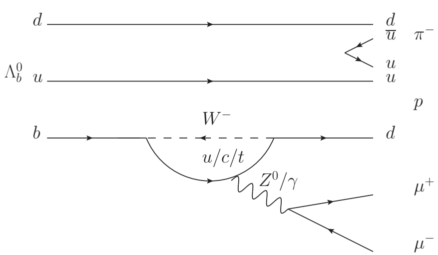
$B^\pm \to K^\pm l^- l^+$
Phys.Rev.Lett.113, 151601(2014)

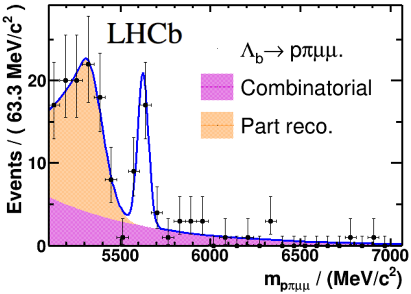
Angular:

$B^0 \to K^+ \pi^- \mu^+ \mu^-$ JHEP 12 (2016) 065
$B^0 \to K^{*0} \mu^- \mu^+$ JHEP 02 (2016) 104
$B_s^0 \to \phi \mu^+ \mu^-$ JHEP 09 (2015) 179
$\Lambda_b \to \Lambda \mu^+ \mu^-$ JHEP 06 (2015) 115
$B^0 \to K^{*0} e^- e^+$ JHEP 04 (2015) 064

- The first observation of the $\Lambda_b^0 \to \pi^- p \mu^+ \mu^-$ decay.
- Statistical significance corresponding to $5.5\ \sigma$.
- Normalized to $\Lambda_b^0 \to J/\psi \pi^- p$. Chin. Phys. C40 (2016) 011001
- The expected branching fraction is of $\mathcal{O}(10^{-8})$.
- This is the first observation of a $b \to d$ transition in a baryonic decay.

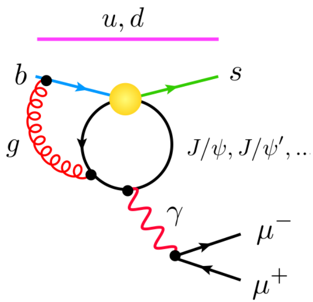
$$\mathcal{B}(\Lambda_b^0 \to \pi^- p \mu^+ \mu^-) = (6.9 \pm 1.9 \pm 1.1^{+1.3}_{-1.0}) \times 10^{-8}$$





arXiv:1701.08705

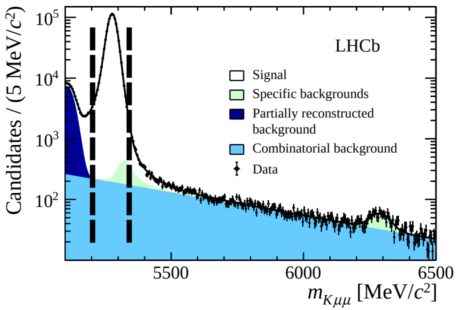
$B^+ \to K^+\mu^+\mu^-$ the phase difference



- Deviations from the SM in the $b \to sll$ transitions could be explained by the short-distance contributions from non-SM particles.
- They also could indicate a problem with SM predictions.
- Contributions from $B \to X_{c\bar{c}}(\to \mu\mu)K$ could mimic vector-like new physics effects.

Measurement of the phase difference between short-distance and long-distance amplitudes:

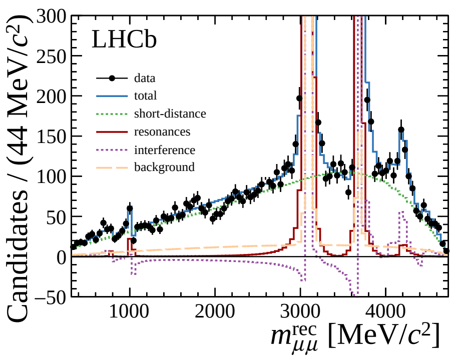
- the full di-muon mass spectrum, candidates with $40\ \mathrm{MeV}/c^2$ of B^+ mass,
- sum of relativistic Breit–Wigner amplitudes as a long-distance contributions,
- C_7 fixed to SM, hadronic form factors f_+ constrained Phys. Rev. D 93, 025026 (2016), magnitudes, phases, $\mathcal{C}_9$ and $\mathcal{C}_{10}$ floated.

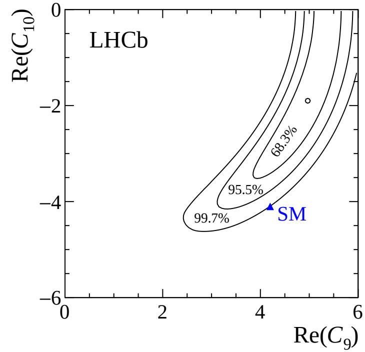


JHEP 11 (2016) 047

- J/ψ phase is compatible with $\pm\frac{\pi}{2}$, interference with short distance contribution far from pole is small.
- Fit to Wilson coefficients: $|\mathcal{C}_{10}| < |\mathcal{C}_{10}^{SM}|$ and $|\mathcal{C}_9| > |\mathcal{C}_9^{SM}|$, or if $|\mathcal{C}_{10}| = |\mathcal{C}_{10}^{SM}|$ then $|\mathcal{C}_9| < |\mathcal{C}_9^{SM}|$.
- The best $\mathcal{C}_9,\ \mathcal{C}_{10}$ fit-point deviates at the level of 3.0 σ from SM.
- These results are consistent with the results reported previously in global analyses.

$$\mathcal{B}(B^+ \to K^+\mu^+\mu^-) = (4.37 \pm 0.15(\text{stat}) \pm 0.23(\text{syst})) \times 10^{-7}$$



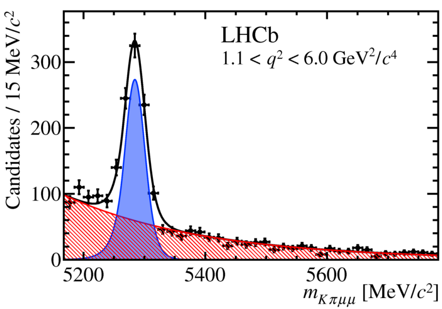


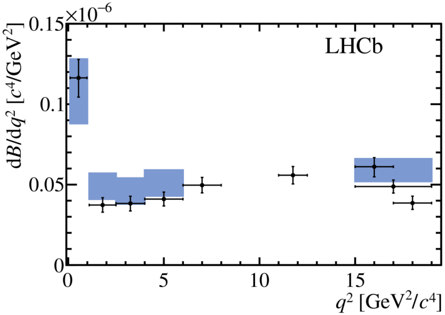
JHEP 11 (2016) 047

$B^0 \to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$ branching fraction

- First (P-wave only) measurement of the differential branching fraction of the $B^0 \to K^*(892)^0\mu^+\mu^-$ decay.
- Precise theoretical predictions in the $1.1 < q^2 < 6.0\ \mathrm{GeV}^2/c^4$.
- The first measurement of the S-wave fraction in the range $796 < m(K^+\pi^-) < 996\ \mathrm{MeV}/c^2$, $F_s = 0.101 \pm 0.017(\mathrm{stat}) \pm 0.009(\mathrm{syst})$
- The differencial branching fraction is determined to be $d\mathcal{B}/dq^2 = (0.392)^{+0.020}_{-0.019}(\mathrm{stat}) \pm 0.010(\mathrm{syst}) \pm 0.027(\mathrm{norm}) \times 10^{-7} c^4/\mathrm{GeV}^2$ - in agreement with SM predictions.

Phys. Rev. D89 (2014) 094501 arXiv:1503.05534.

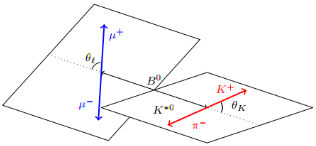




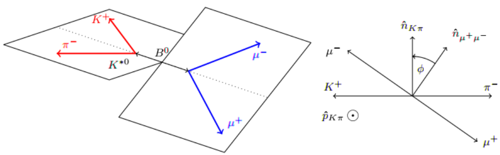
JHEP 1611 (2016) 047

$B^0 \to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$ angular

Described by:
- three helicity angles (θ_l, θ_K, ϕ),
- the di-lepton invariant mass squared q^2.



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



(b) ϕ definition for the B^0 decay

The CP-averaged angular decay distribution:

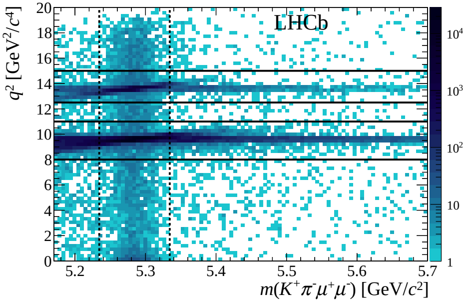
$$\frac{1}{d(\Gamma+\bar{\Gamma})/dq^2}\frac{d^4(\Gamma+\bar{\Gamma})}{dq^2\,d\vec{\Omega}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \tfrac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_l - F_L\cos^2\theta_K\cos 2\theta_l + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_l\cos\phi + S_5\sin 2\theta_K\sin\theta_l\cos\phi + \tfrac{4}{3}A_{FB}\sin^2\theta_K\cos\theta_l + S_7\sin 2\theta_K\sin\theta_l\sin\phi + S_8\sin 2\theta_K\sin 2\theta_l\sin\phi + S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big]$$

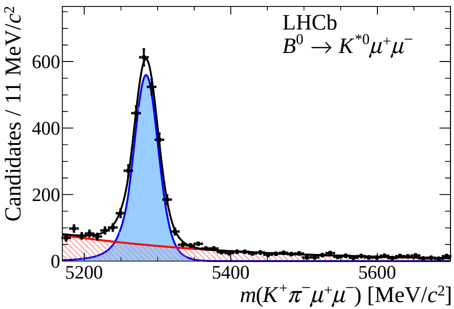
A_{FB}, F_L, S_j - functions of Wilson coefficients

Additional sets of observables, for which the leading form-factor uncertainties cancel, e.g.: JHEP 1305(2013)137

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

$B^0 \to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$ angular





Signal yield: 2398 ± 57

Signal candidates:
$5170 < \mathrm{m}(K^+\pi^-\mu^+\mu^-) < 5700\ \mathrm{MeV}/c^2$

K^{*0} candidates:
$796 < \mathrm{m}(K^+\pi^-) < 996\ \mathrm{MeV}/c^2$

Combinatorial background is reduced using a boosted decision tree:

- trained fully on data
  - $B^0 \to J/\psi K^{*0}$ as a signal
  - background sample: data
  $5350 < \mathrm{m}(K^+\pi^-\mu^+\mu^-) < 7000\ \mathrm{MeV}/c^2$
- variables used for training
  - PID - kinematics and geometric quantities - isolations

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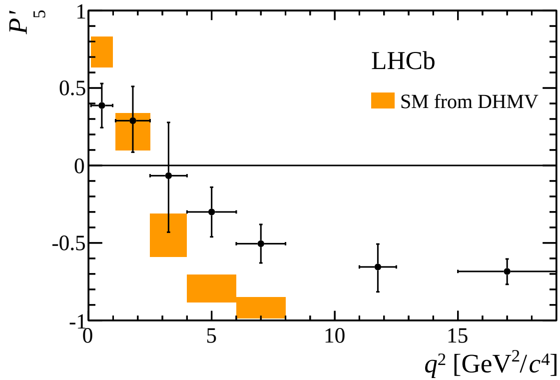
$B^0 \to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$ angular

The first full angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$ decay (Run 1):

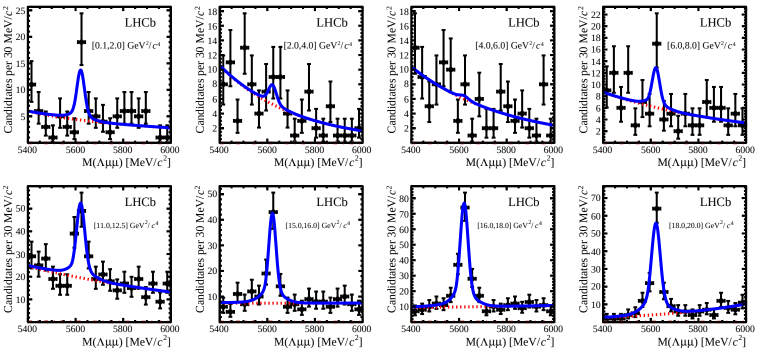
- tension in P'_5
- $3.4\,\sigma$ global deviations from the SM
- the SM central value for $\mathrm{Re}(C_9)$ is 4.27, best fit-point corresponds to the $\Delta\mathrm{Re}(C_9) = -1.04 \pm 0.25$

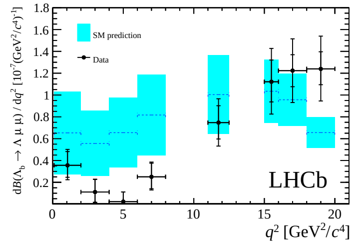


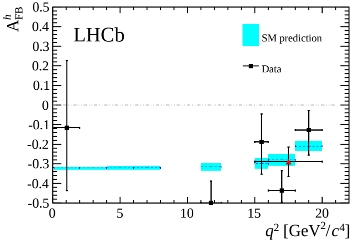
Phys. Rev. D 91, 114012 (2015), JHEP 02 (2016) 104

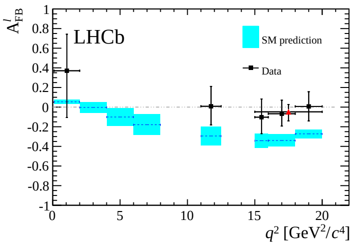
$\Lambda_b \to \Lambda(\to p\pi^-)\mu^+\mu^-$

- Normalized to $\Lambda_b \to \Lambda J/\psi$.
- No evidence for signal in $2 < q^2 < 8\ \mathrm{GeV}^2/c^4$.
- More statistics needed.





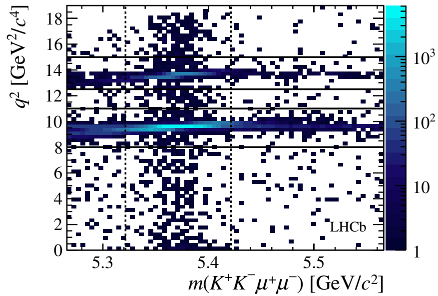


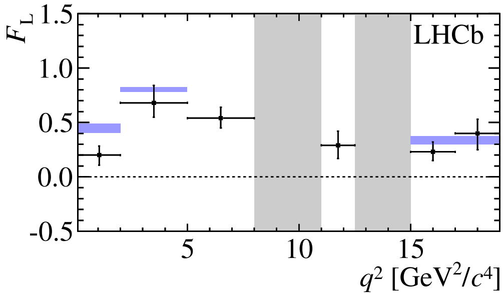


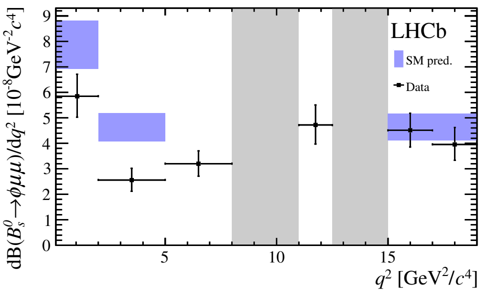
JHEP06(2015)115

$B_s^0 \to \phi(\to K^+K^-)\mu^+\mu^-$

- Similar to $B^0 \to K^{*0}\mu^+\mu^-$, experimentally very clean (narrow ϕ resonance).
- Final state not self-tagging - less observables are accessible.
  JHEP 0807 (2008) 106
- Angular distributions - good agreement with SM.
- Branching fraction - differs from SM by $3.3\ \sigma$ at low q^2



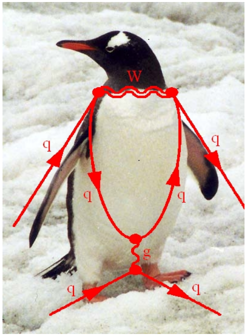




JHEP09(2015)179

Summary

- Rare decays are a powerful tool for searching for BSM effects.
- Intresting tensions with SM predictions emerged in the rare decays: $\mathrm{B}^0 \to \mathrm{K}^{*0}\mu^+\mu^-$ angular observables, $\mathrm{B}_s^0 \to \phi\mu^+\mu^-$ brancing fraction.
- Motivates further work both in theory and experiment.
- Many more analyses in the pipeline.



Thank you for your attention :)