Studies of the electroweak penguin transitions and radiative decays at LHCb

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Overview

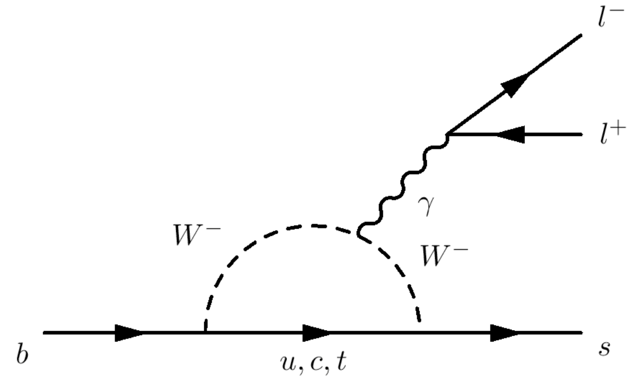
- Flavour changing neutral current (FCNC) decays can only proceed via loop-diagrams in the SM
- New Physics can enter at the same level as SM physics

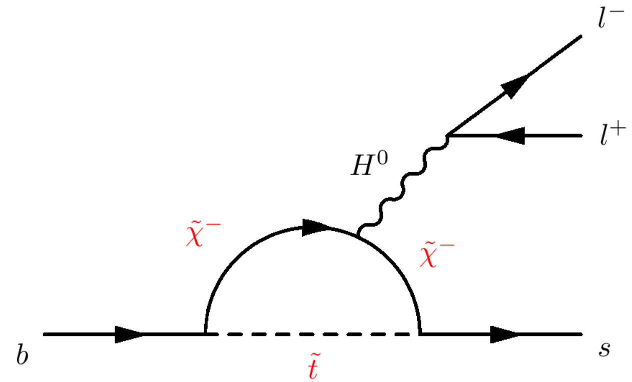
$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b \left(\bar{s}\sigma^{\mu\nu} P_R b\right) F_{\mu\nu}$$

$$\mathcal{O}_9 = \frac{e^2}{16\pi^2} (\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \ell)$$

$$\mathcal{O}_{10} = \frac{e^2}{16\pi^2} (\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \gamma_5 \ell)$$

Operators in SM





arXiv:1304.6325 ($1fb^{-1}$)

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

- $B^0 \to K^*\mu\mu$ is a FCNC process mediated by penguin and W-box diagrams in the SM
- Its angular distribution is described by three angles (θ_l, θ_k, ϕ) and the dimuon invariant mass squared (q^2)
- Observables F_L and S_i are functions of the Wilson coefficients and form-factors

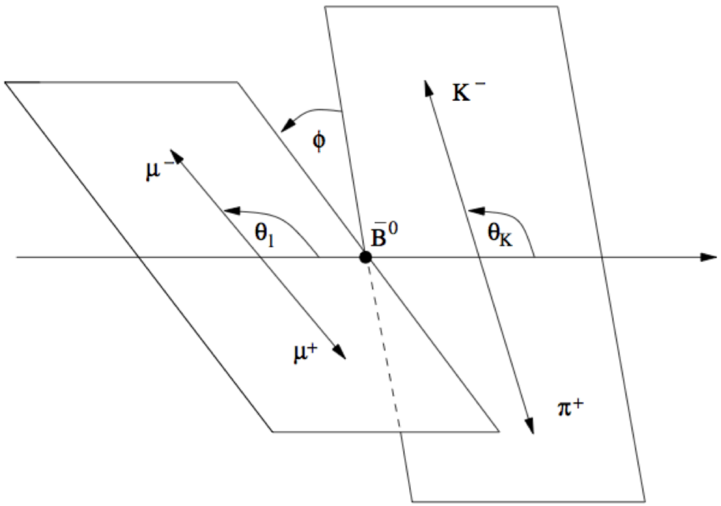
$$\frac{1}{\Gamma}\frac{d^3(\Gamma+\bar{\Gamma})}{d\cos\theta_\ell \, d\cos\theta_K \, d\phi} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos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

arXiv:1304.6325 (1fb^{-1})

Folding

- Performing the folding $\phi \to \phi+\pi$ ($\phi<0$) leads to:

$$\frac{1}{\Gamma}\frac{d^3(\Gamma+\bar{\Gamma})}{d\cos\theta_\ell\, d\cos\theta_K\, d\hat{\phi}} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_{\rm L})\sin^2\theta_K + F_{\rm L}\cos^2\theta_K + \frac{1}{4}(1-F_{\rm L})\sin^2\theta_K\cos 2\theta_\ell - F_{\rm L}\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\hat{\phi} + \frac{4}{3}A_{FB}\sin^2\theta_K\cos\theta_\ell + 2\theta_K\sin 2\theta_\ell\sin\hat{\phi} + A_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\hat{\phi}\Big]$$

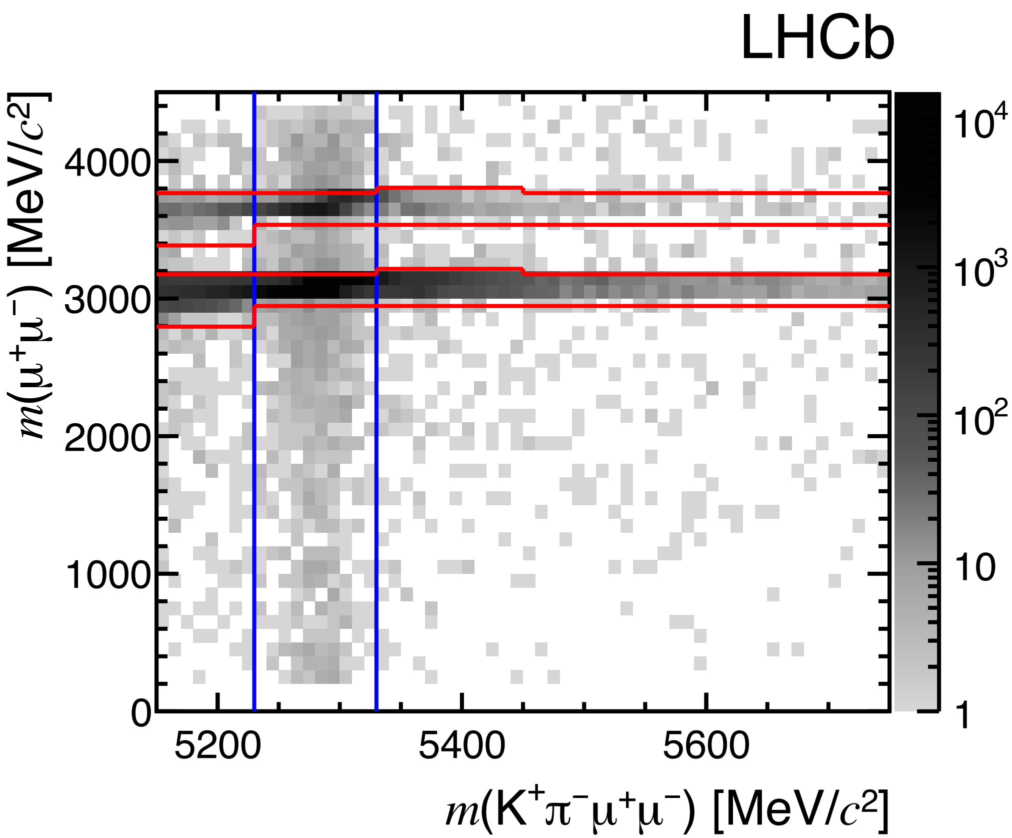


- Theoretically cleaner observables (reduced form-factor uncertainties) can be calculated from existing ones

$$A_T^{\rm Re} = \frac{\frac{4}{3}A_{\rm FB}}{(1-F_{\rm L})} \quad A_T^2 = \frac{2S_3}{(1-F_{\rm L})}$$

arXiv:1304.6325 (1fb^{-1})

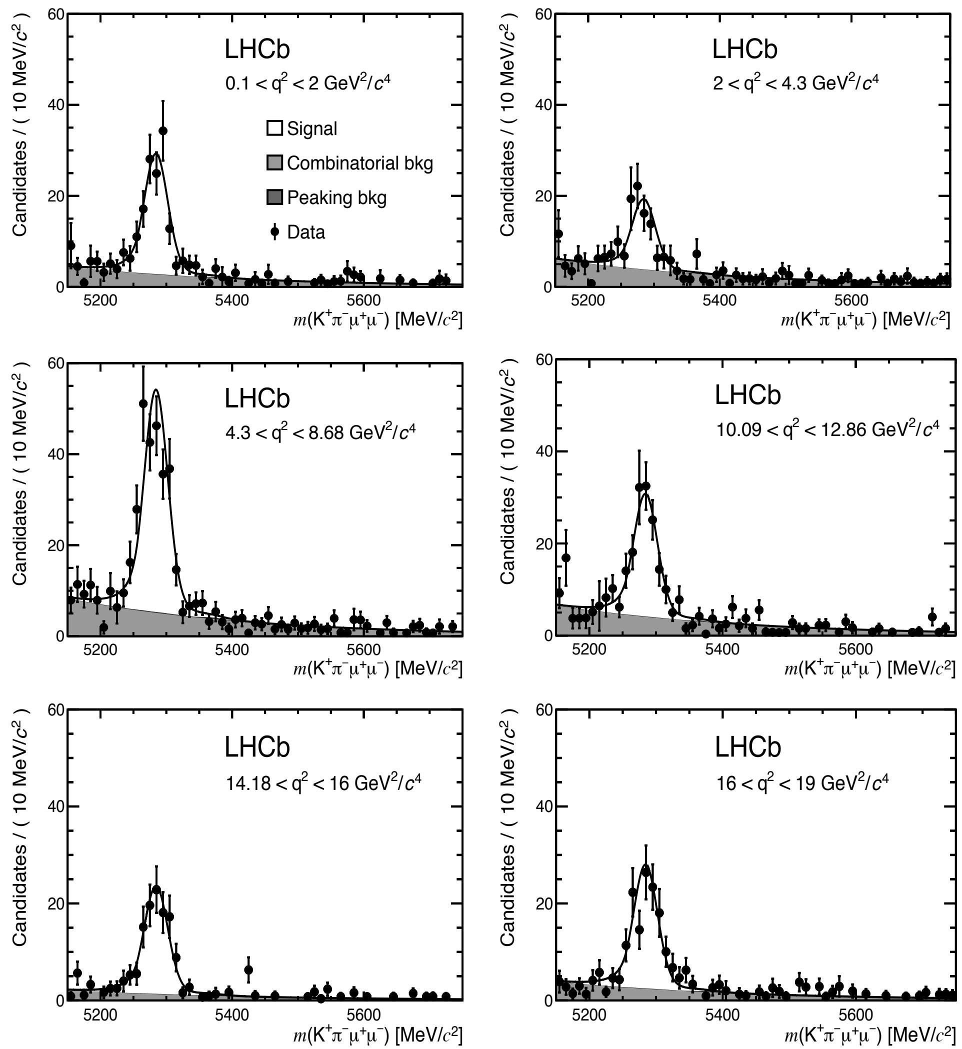
Candidate selection



- Candidates selected using a BDT
- (Tree-level) Charmonium resonances vetoed
- Exclusive and partially reconstructed background investigated and reduced to negligible level

arXiv:1304.6325 (1fb^{-1})

Candidate selection

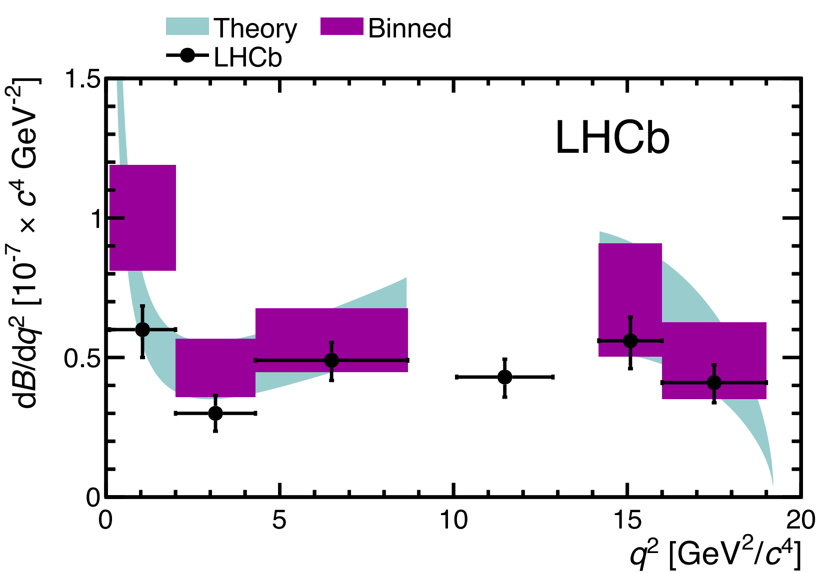


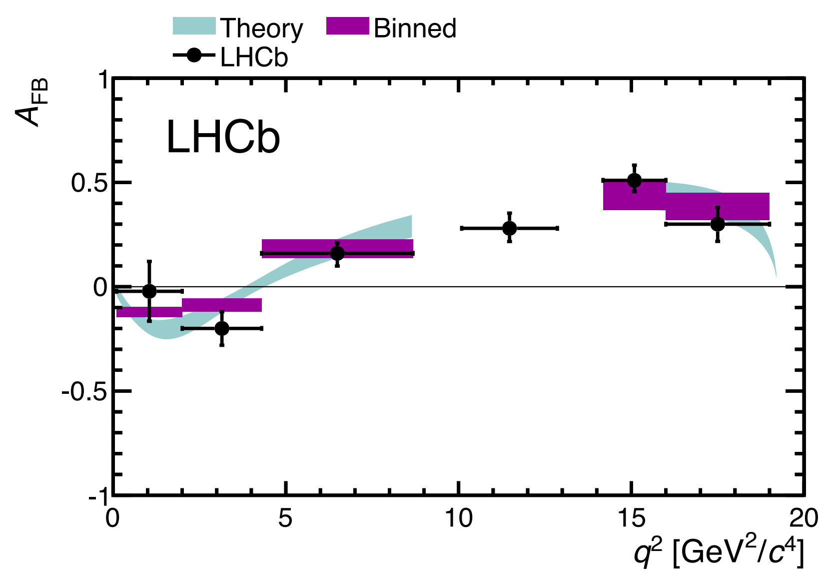
- Data/MC agreement calibrated using control modes e.g. $B^0 \to J/\psi K^*$, $D^* \to D(\to K\pi)\pi_s$
- Acceptance correction accounted for by weighting candidates with inverse of efficiency determined from simulation
- Total yield of 883 ± 34 signal candidates
- Analysis performed in 6 bins of q^2 ($m_{\mu\mu}^2$) and theoretically clean $1<q^2<6$ GeV$^2/c^4$

Results

- Results accord with the SM predictions (Bobeth et al., JHEP 01 (2012) 107)
- First measurement of the zero-crossing point of A_{FB} (error is stat+sys) (SM predictions in range 3.9-4.4 GeV²/c⁴)

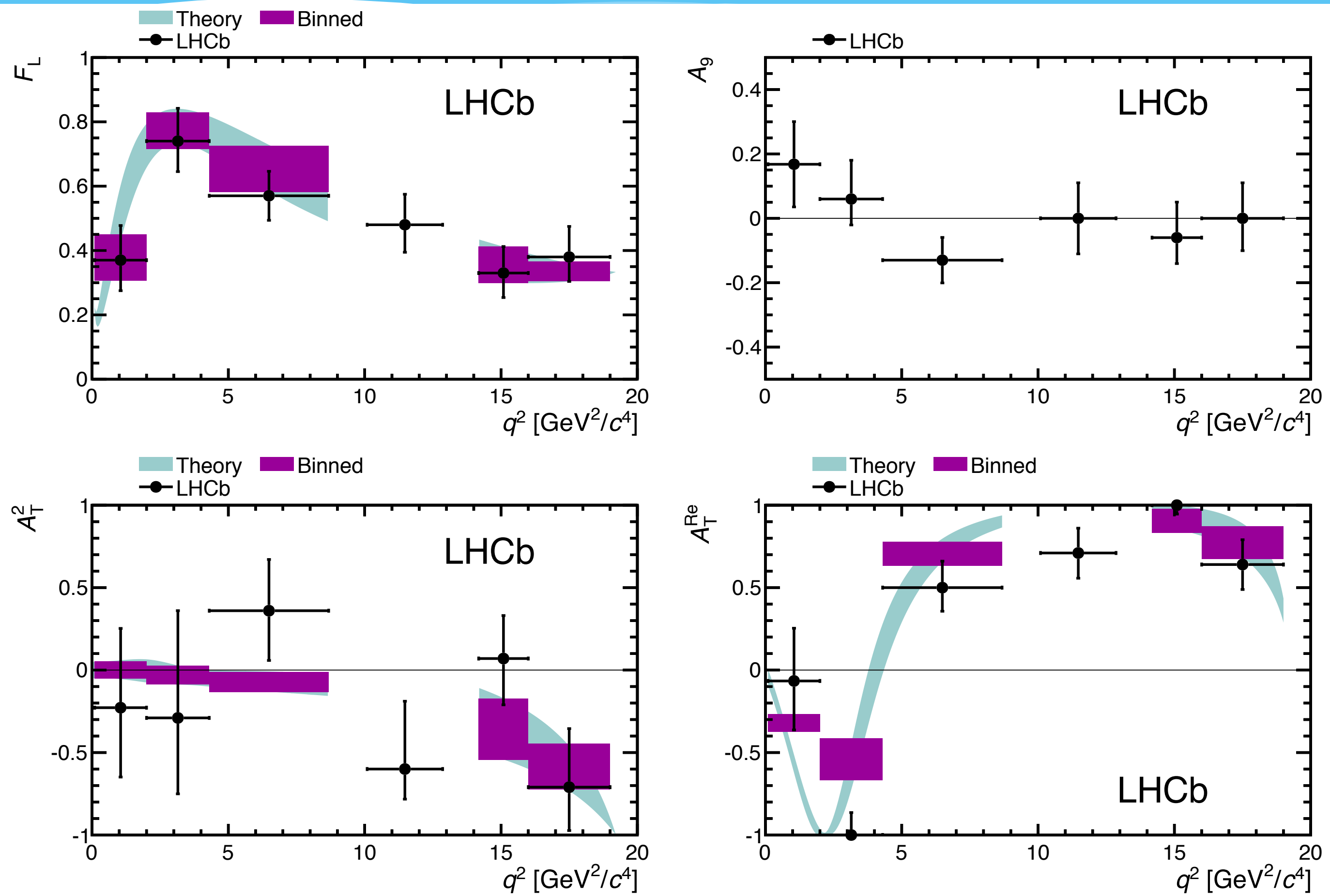
$$q_0^2 = 4.9 \pm 0.9\,\mathrm{GeV}^2/c^4$$





arXiv:1304.6325 ($1fb^{-1}$)

Results



- Consistent with SM predictions (Bobeth et al., JHEP 01 (2012) 107)

arXiv:1308.1707 (1fb^{-1})

New observables

- In low q^2 limit, observables denoted as P_4', P_5', P_6', P_8' are predicted to be largely free from form-factor uncertainties (J. Mathias et al., JHEP 05 (2013) 137)

$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_\mathrm{L}(1-F_\mathrm{L})}}$$

Here a 2D folding is used, for example:

$$P'_5,\ S_5\colon \begin{cases} \phi \to -\phi & \text{for } \phi < 0 \\ \theta_\ell \to \pi - \theta_\ell & \text{for } \theta_\ell > \pi/2 \end{cases}$$

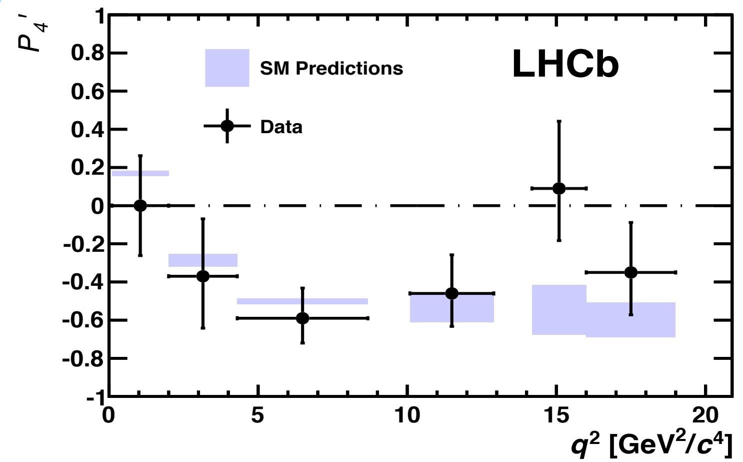
- Each folding preserves the first 5 terms in the differential angular distribution and the corresponding S_i term

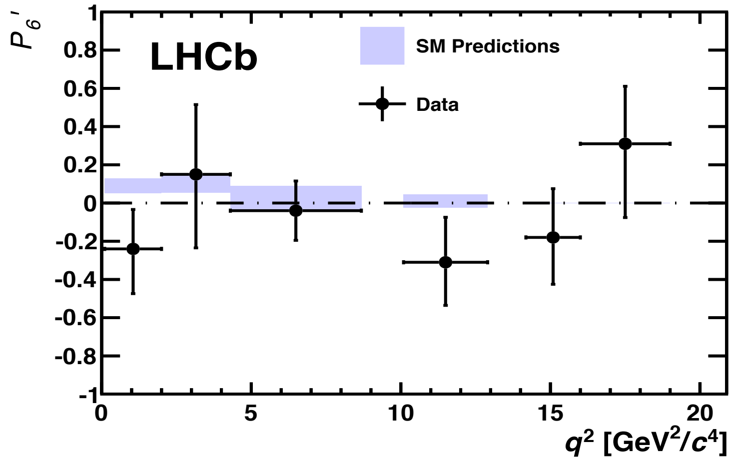
arXiv:1308.1707 (1fb^{-1})

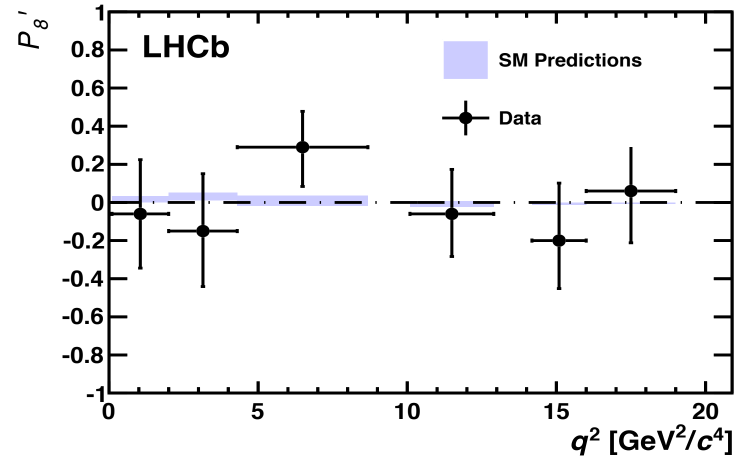
Results

First measurement of new observables

- Results accord with SM predictions (J. Mathias et al., JHEP 05 (2013) 137)



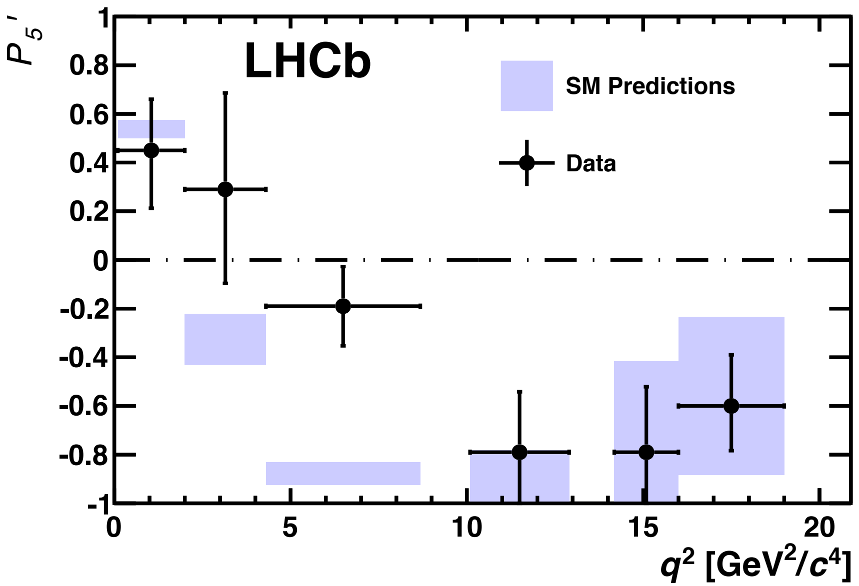


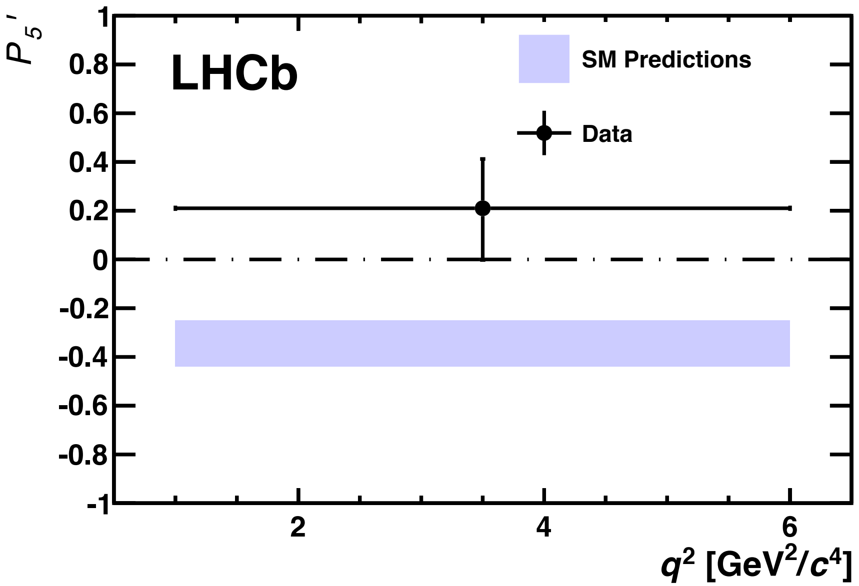


Results

First measurement of new observables

- Local discrepancy of 3.7σ in 3rd bin of P_5' (wrt J. Mathias et al., JHEP 05 (2013) 137)
- 2.5σ discrepancy in theoretically clean $1<q^2<6$ GeV^2/c^4 bin
- 0.5% probability to observe 3.7σ deviation in 24 independent measurements

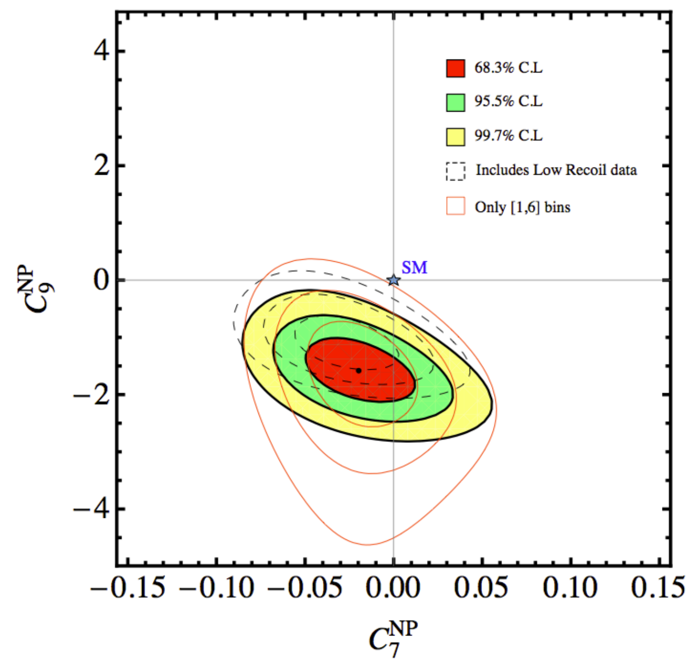




arXiv:1308.1707 (1fb^{-1})

Results

- Descotes-Genon et al. (arXiv:1307.5683) explain the discrepancy in P_5' and other smaller deviations through a large New Physics contribution to the Wilson coefficient of the semileptonic operator O_9

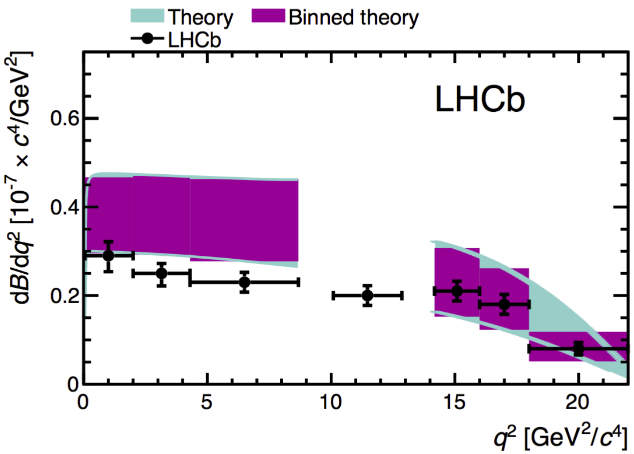


- Predictions for the first two bins and $1<q^2<6$ GeV^2/c^4 are also given by Jäger et al. (JHEP 05 (2013) 043)
- Leads to a larger theoretical uncertainty wrt J. Mathias et al.

- Measurements with higher statistics and further theoretical studies are necessary to draw more definitive conclusions

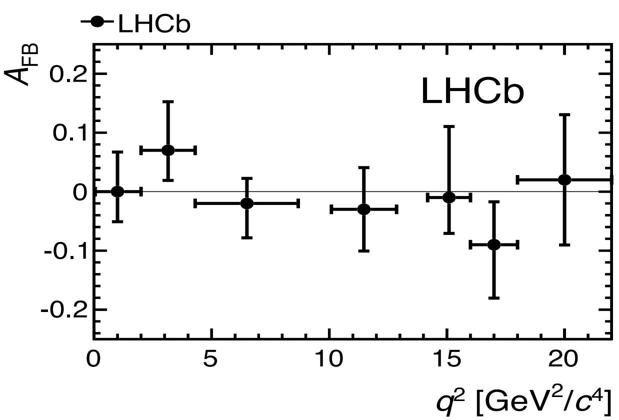
JHEP 02 (2013) 105 ($1 fb^{-1}$)

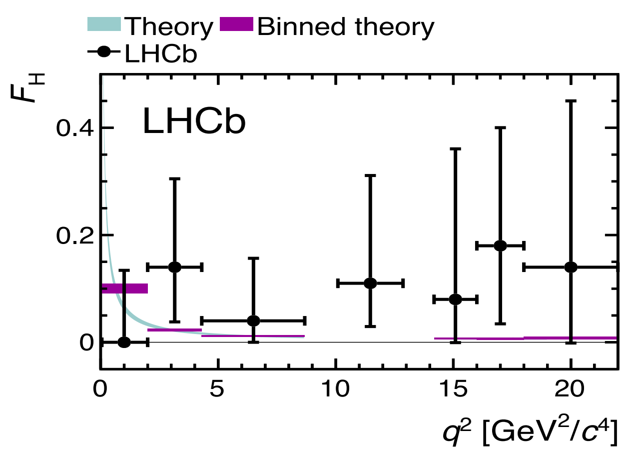
$B^+ \to K^+\mu\mu$



- Differential angular distribution described by single angle θ_l
- A_{FB} and F_H consistent with SM prediction of zero

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma[B^+ \to K^+\mu^+\mu^-]}{\mathrm{d}\cos\theta_l} = \frac{3}{4}(1-F_{\mathrm{H}})(1-\cos^2\theta_l) + \frac{1}{2}F_{\mathrm{H}} + A_{\mathrm{FB}}\cos\theta_l$$



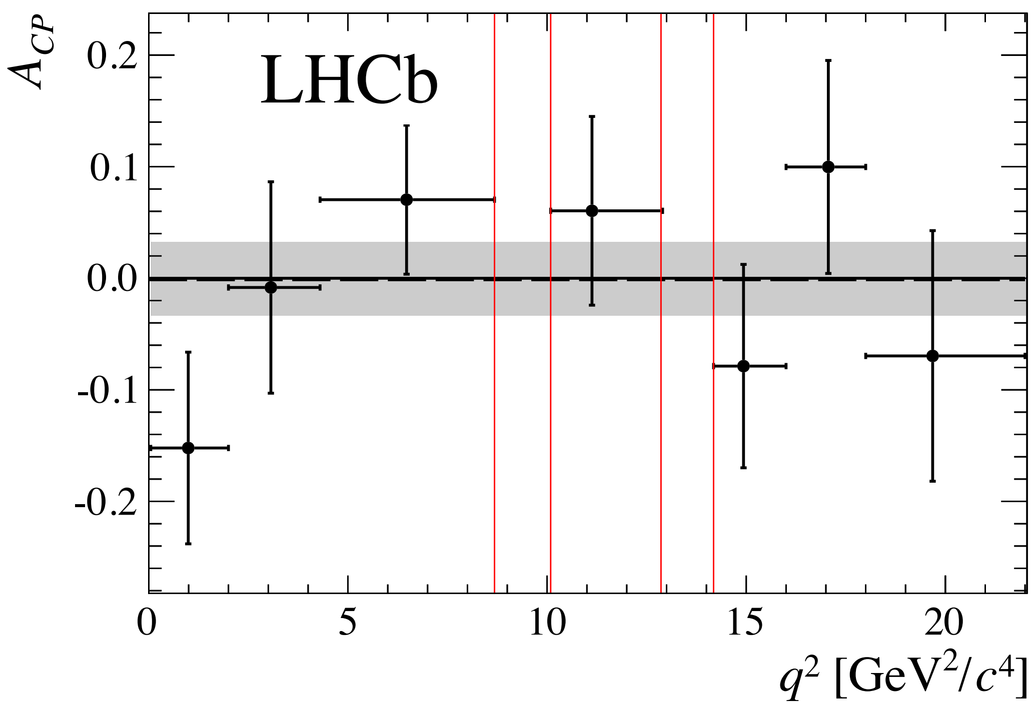


arXiv:1308.1340 (1fb^{-1})

A_{CP} in $B^+ \to K^+\mu\mu$

$$\mathcal{A}_{CP} = \frac{\Gamma(B^- \to K^-\mu^+\mu^-) - \Gamma(B^+ \to K^+\mu^+\mu^-)}{\Gamma(B^- \to K^-\mu^+\mu^-) + \Gamma(B^+ \to K^+\mu^+\mu^-)} = -0.0004 \pm 0.033 \pm 0.005 \pm 0.007$$

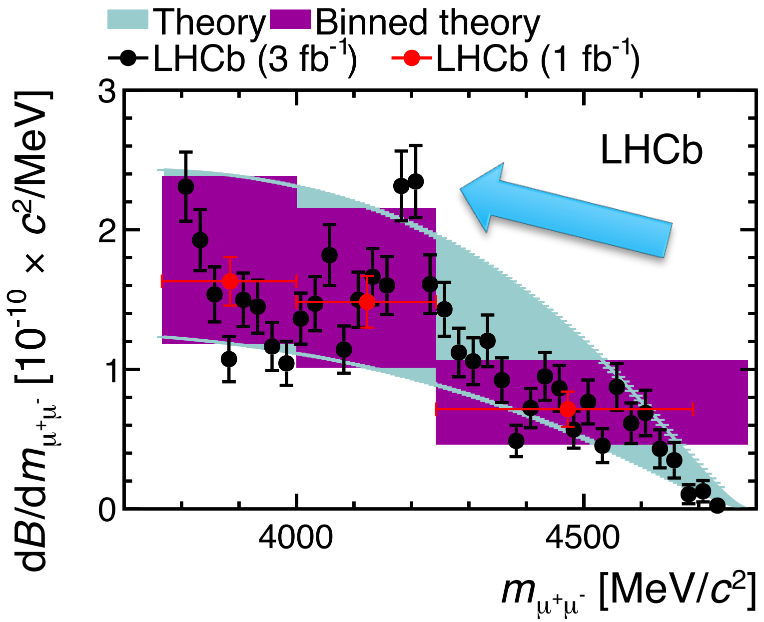
- Control channel $B^+ \to J/\psi K^+$ used to account for production and detection asymmetries
- Left-Right asymmetry accounted for by averaging magnet polarity
- Result consistent with SM prediction

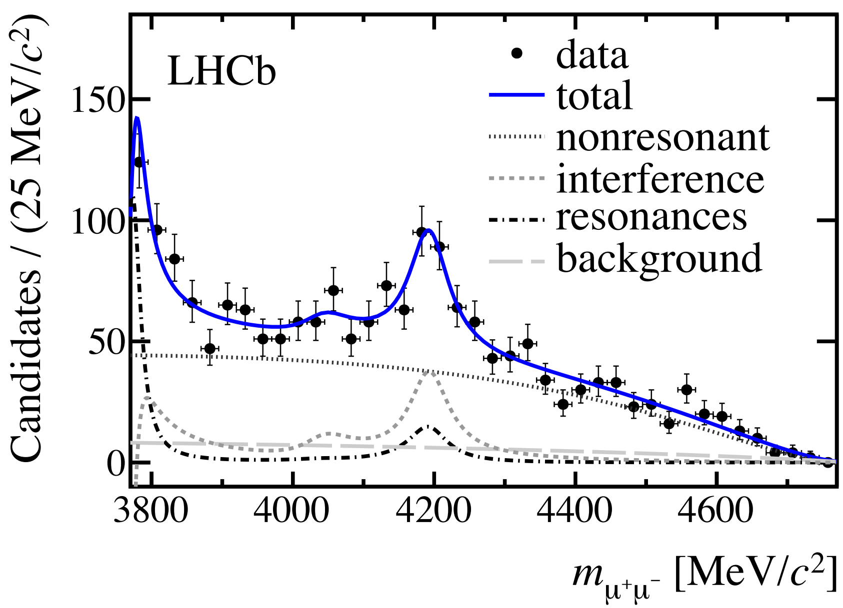


arXiv:1307.7595 ($1 fb^{-1}$)

New resonance at in $B^+ \to K^+\mu\mu$ at high q^2

- Resonance compatible with the ψ(4160) meson
- Larger than theoretical estimates
- First observation of both $B^+ \to \psi(4160)K^+$ and $\psi(4160) \to \mu^+\mu^-$
- Could complicate further $b \to s\mu^+\mu^-$ measurements at high q^2

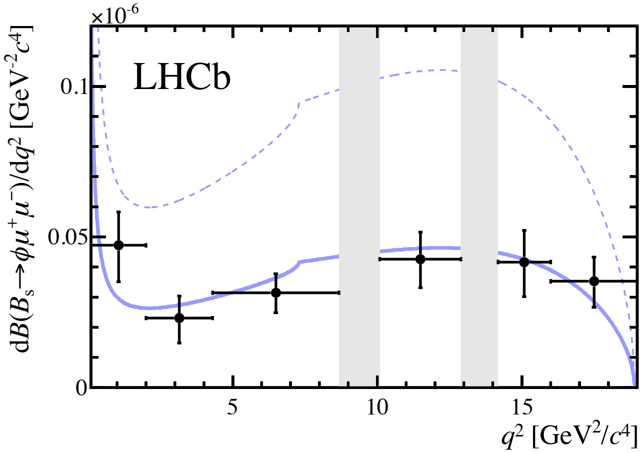


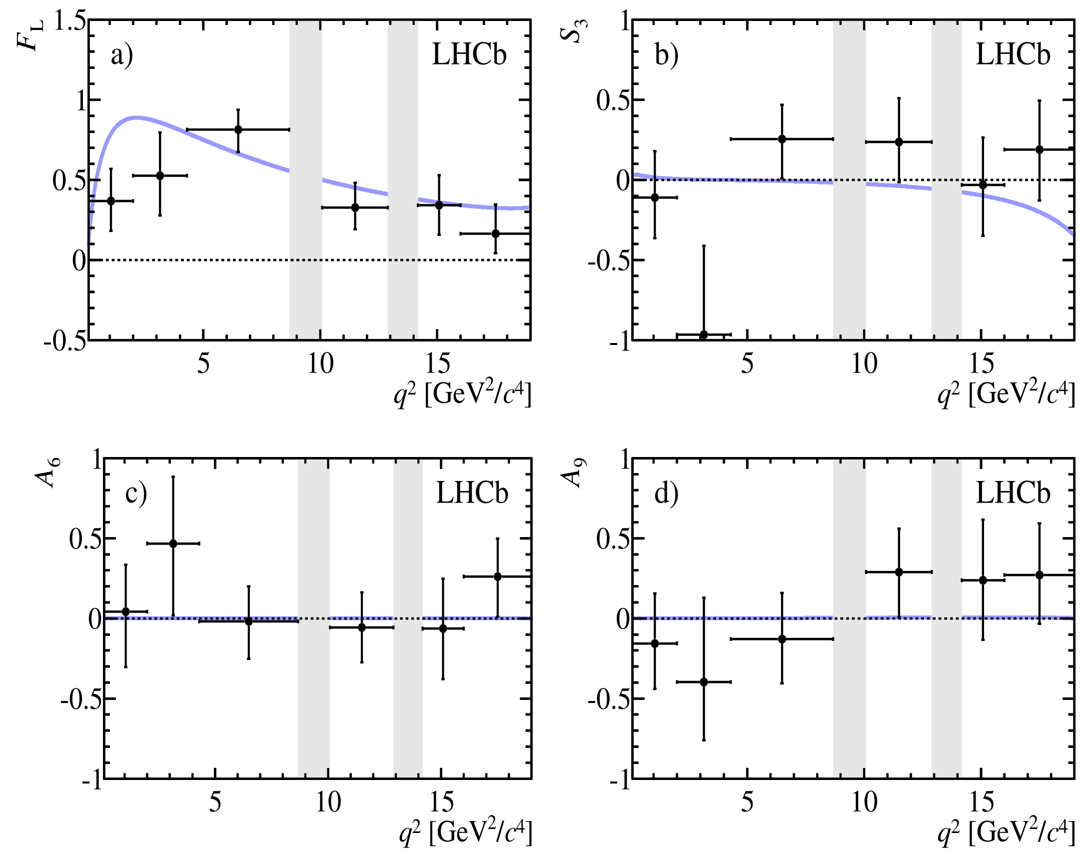


arXiv:1305.2168 ($1fb^{-1}$)

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

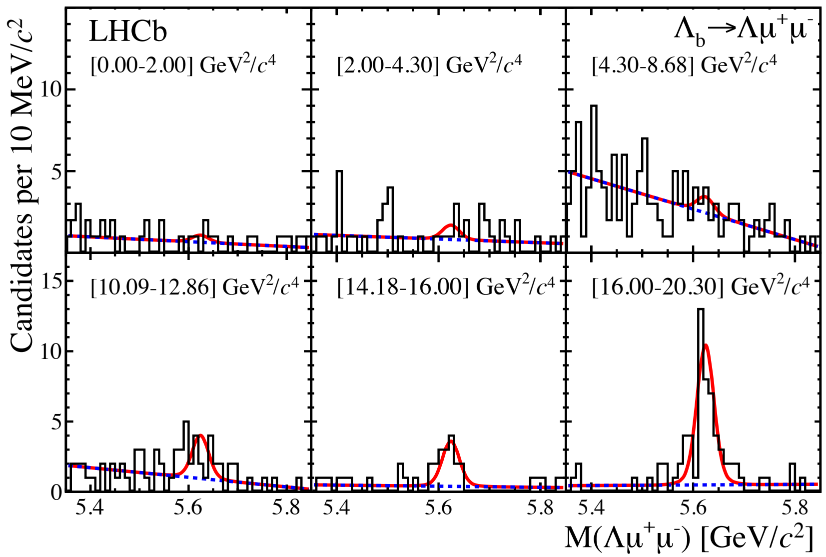
- Branching fraction lower than SM theory predictions (blue dotted line)
- First angular analysis of $B_s^0 \to \phi\mu^+\mu^-$
- All observables are consistent with SM expectation

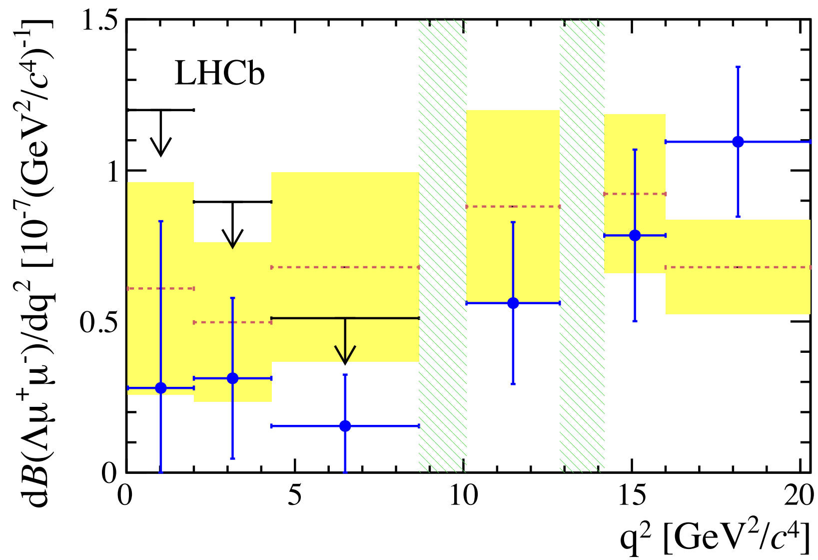




$\Lambda_b \to \Lambda\mu\mu$

- Baryon decays more theoretically complex
- Yield of 78±12 $\Lambda_b \to \Lambda\mu^+\mu^-$ decays observed, mostly in q^2 regions above J/ψ mass
- $\Lambda_b \to J/\psi\Lambda$ normalization mode



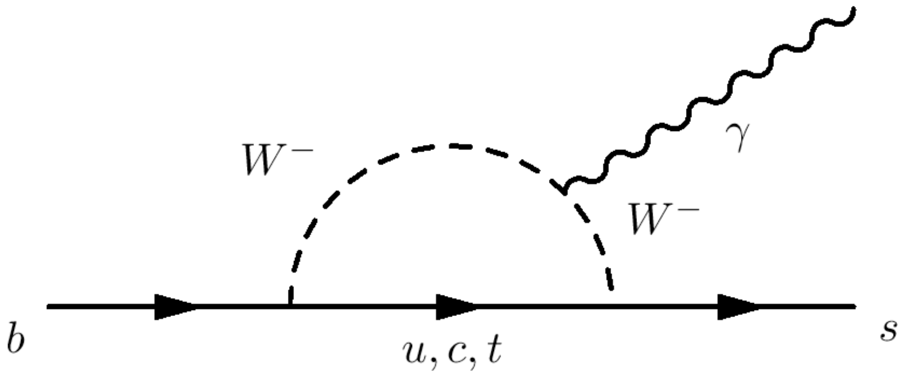


- Limits set at low q^2
- Good agreement with SM expectation

(Detmold et al., Phys.Rev. D87 (2013) 074502)

Radiative B decays

- b->sγ is a FCNC process
- In SM emitted photons in such decays are predicted to be predominately left handed since the recoil s quark that couples to the W boson if left handed



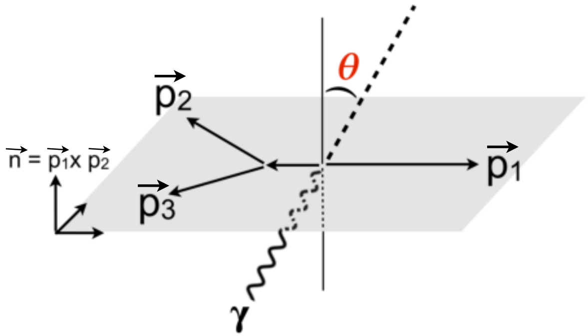
The photon polarization is defined as:

$$\lambda_\gamma \equiv \frac{|c_R|^2 - |c_L|^2}{|c_R|^2 + |c_L|^2}$$

LHCb-CONF-2013-017 ($2\,\mathrm{fb}^{-1}$)

B->$K_{res}\gamma$->$K\pi\pi\gamma$

- For decays of the type B->$K_{res}\gamma$->$K\pi\pi\gamma$, the photon polarization can be studied through the angular correlations of the daughters of the K_{res}
- For a single resonance, A_{ud} is proportional to λ_γ
- If the helicity amplitude J is known, λ_γ can be determined from a measurement of A_{ud}



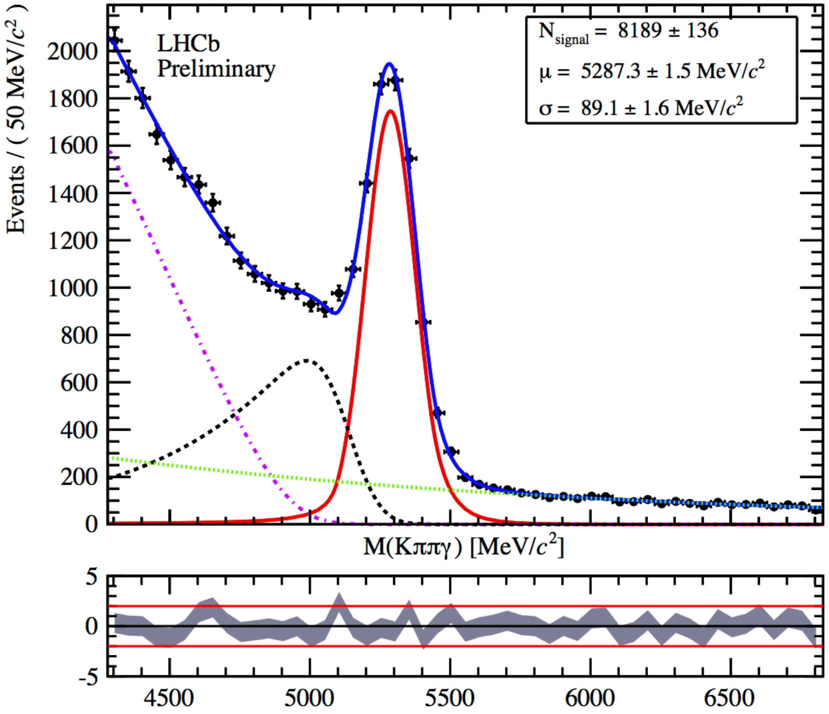
$$\mathcal{A}_{ud} \equiv \frac{\int_0^1 \mathrm{dcos}\,\tilde{\theta}\frac{\mathrm{d}\Gamma}{\mathrm{dcos}\,\tilde{\theta}} - \int_{-1}^0 \mathrm{dcos}\,\tilde{\theta}\frac{\mathrm{d}\Gamma}{\mathrm{dcos}\,\tilde{\theta}}}{\int_{-1}^1 \mathrm{dcos}\,\tilde{\theta}\frac{\mathrm{d}\Gamma}{\mathrm{dcos}\,\tilde{\theta}}} = \frac{3}{4}\lambda_\gamma \frac{\int \mathrm{d}s\,\mathrm{d}s_{13}\,\mathrm{d}s_{23}\mathrm{Im}\left[\vec{n}\cdot(\vec{\mathcal{J}}\times\vec{\mathcal{J}}^*)\right]}{\int \mathrm{d}s\,\mathrm{d}s_{13}\,\mathrm{d}s_{23}|\mathcal{J}|^2}$$

Theory input needed!

LHCb-CONF-2013-017 (2fb^{-1})

B->$K^+\pi^-\pi^+\gamma$

- Inclusive CP asymmetry measured for first time
- A_{CP} compatible with zero
- A_{ud} measured for the first time
- Result 4.5σ from zero
- Evidence of photon polarization in b->sγ decays
- If theoretical predictions existed, first measurement of λ_γ possible



$$\mathcal{A}_{CP} = -0.007 \pm 0.015\,(\text{stat})^{+0.012}_{-0.011}\,(\text{syst}) \quad \mathcal{A}_{\text{ud}} = -0.085 \pm 0.019\,(\text{stat}) \pm 0.004\,(\text{syst})$$

Summary

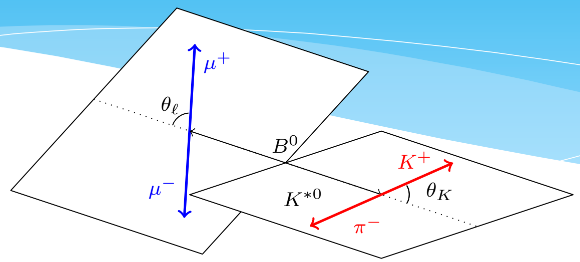
- LHCb has many recent precision measurements in electroweak penguin and radiative decay modes

  - New angular observables measured in $B^0 \to K^* \mu\mu$
  - First measurement of zero crossing point of A_{FB} in $B^0 \to K^* \mu\mu$
  - New resonance observed at high q^2 in $B^+ \to K^+ \mu\mu$
  - First angular analysis of $B_s^0 \to \phi\mu\mu$
  - First measurements of A_{CP} and A_{ud} in $B \to K\pi\pi\gamma$

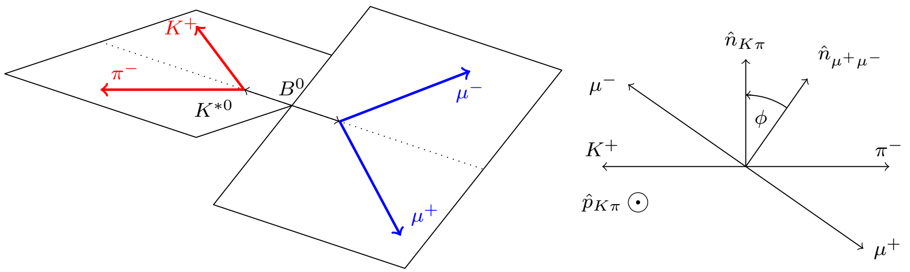
- In general, there is good agreement between results and SM predictions except for a deviation in low q^2 region of P_5' in $B^0 \to K^* \mu\mu$
- Many results shown only using 1 fb^{-1}, updates with full 3 fb^{-1} to follow!

Backup

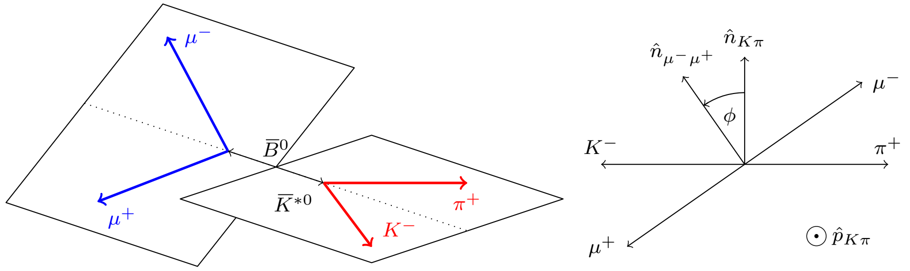
Angles in B⁰->K*μμ



(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

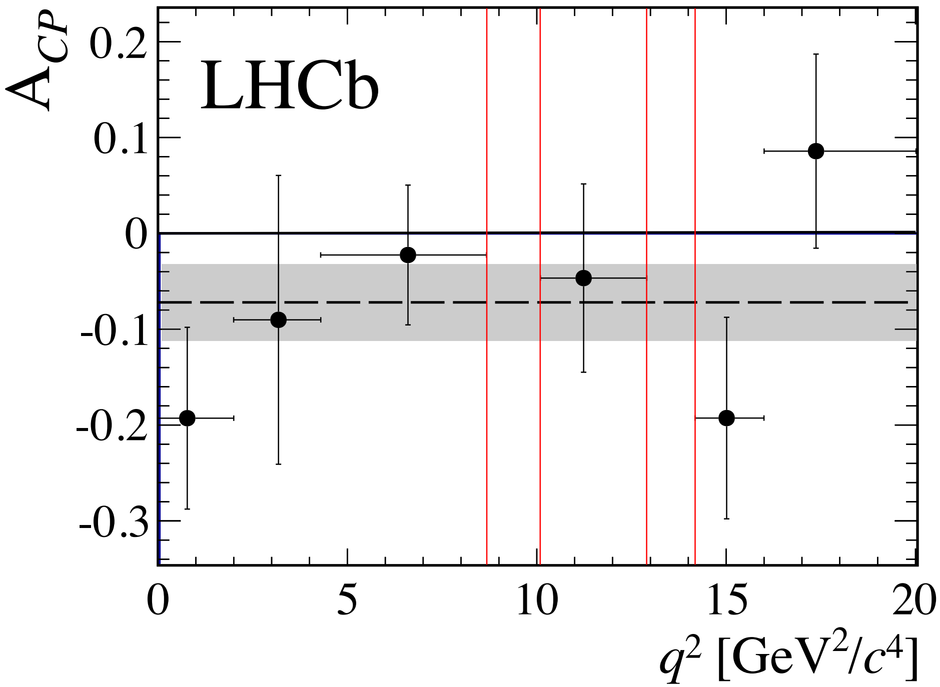
Phys. Rev. Lett. 110,031801 (2013) ($1 fb^{-1}$)

A_{CP} in $B^0 \rightarrow K^*\mu\mu$

$$\mathcal{A}_{CP} = \frac{\Gamma(B^- \to K^-\mu^+\mu^-) - \Gamma(B^+ \to K^+\mu^+\mu^-)}{\Gamma(B^- \to K^-\mu^+\mu^-) + \Gamma(B^+ \to K^+\mu^+\mu^-)}$$

$$-0.072 \pm 0.040\,(\mathrm{stat.}) \pm 0.005\,(\mathrm{syst.})$$

- Control channel $B^+ \rightarrow J/\psi K^+$ used to account for production and detection asymmetries
- Left-Right asymmetry accounted for by averaging magnet polarity
- Result consistent with SM prediction



New observables in B⁰->K*μμ

GeV^2/c^4	P'_4	P'_5	P'_6	P'_8
0.10 – 2.00	$0.00^{+0.26}_{-0.26} \pm 0.03$	$0.45^{+0.19}_{-0.22} \pm 0.09$	$-0.24^{+0.19}_{-0.22} \pm 0.05$	$-0.06^{+0.28}_{-0.28} \pm 0.02$
2.00 – 4.30	$-0.37^{+0.29}_{-0.26} \pm 0.08$	$0.29^{+0.39}_{-0.38} \pm 0.07$	$0.15^{+0.36}_{-038} \pm 0.05$	$-0.15^{+0.29}_{-0.28} \pm 0.07$
4.30 – 8.68	$-0.59^{+0.15}_{-0.12} \pm 0.05$	$-0.19^{+0.16}_{-0.16} \pm 0.03$	$-0.04^{+0.15}_{-0.15} \pm 0.05$	$0.29^{+0.17}_{-0.19} \pm 0.03$
10.09 – 12.90	$-0.46^{+0.20}_{-0.17} \pm 0.03$	$-0.79^{+0.16}_{-0.19} \pm 0.19$	$-0.31^{+023}_{-0.22} \pm 0.05$	$-0.06^{+0.23}_{-0.22} \pm 0.02$
14.18 – 16.00	$0.09^{+0.35}_{-0.27} \pm 0.04$	$-0.79^{+0.20}_{-0.13} \pm 0.18$	$-0.18^{+0.25}_{-0.24} \pm 0.03$	$-0.20^{+0.30}_{-0.25} \pm 0.03$
16.00 – 19.00	$-0.35^{+0.26}_{-0.22} \pm 0.03$	$-0.60^{+0.19}_{-0.16} \pm 0.09$	$0.31^{+0.38}_{-0.37} \pm 0.10$	$0.06^{+0.26}_{-0.27} \pm 0.03$
1.00 – 6.00	$-0.29^{+0.18}_{-0.16} \pm 0.03$	$0.21^{+0.20}_{-0.21} \pm 0.03$	$0.18^{+0.21}_{-0.21} \pm 0.03$	$0.23^{+0.18}_{-0.19} \pm 0.02$

	S_4	S_5	S_7	S_8
0.10 – 2.00	$-0.01^{+0.12}_{-0.12} \pm 0.03$	$0.22^{+0.09}_{-0.10} \pm 0.04$	$-0.12^{+0.11}_{-0.11} \pm 0.03$	$-0.04^{+0.12}_{-0.12} \pm 0.01$
2.00 – 4.30	$-0.14^{+0.13}_{-0.12} \pm 0.03$	$0.11^{+0.14}_{-0.13} \pm 0.03$	$0.06^{+0.15}_{-0.15} \pm 0.02$	$-0.05^{+0.12}_{-0.12} \pm 0.02$
4.30 – 8.68	$-0.29^{+0.06}_{-0.06} \pm 0.02$	$-0.09^{+0.08}_{-0.08} \pm 0.01$	$-0.03^{+0.07}_{-0.08} \pm 0.04$	$0.13^{+0.08}_{-0.08} \pm 0.01$
10.09 – 12.90	$-0.22^{+0.09}_{-0.08} \pm 0.02$	$-0.40^{+0.08}_{-0.10} \pm 0.10$	$-0.17^{+0.11}_{-0.11} \pm 0.03$	$-0.03^{+0.10}_{-0.10} \pm 0.01$
14.18 – 16.00	$0.05^{+0.14}_{-0.08} \pm 0.01$	$-0.38^{+0.10}_{-0.09} \pm 0.09$	$-0.08^{+0.13}_{-0.14} \pm 0.01$	$-0.10^{+0.13}_{-0.12} \pm 0.02$
16.00 – 19.00	$-0.16^{+0.11}_{-0.09} \pm 0.01$	$-0.29^{+0.09}_{-0.08} \pm 0.04$	$0.15^{+0.16}_{-0.15} \pm 0.03$	$0.03^{+0.12}_{-0.12} \pm 0.02$