Electroweak penguin decays at LHCb

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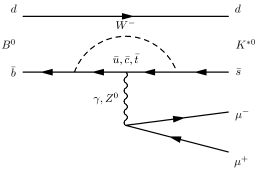
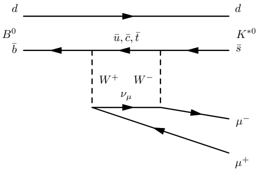
2nd June 2014

Michel De Cian, University of Heidelberg
on behalf of the LHCb collaboration

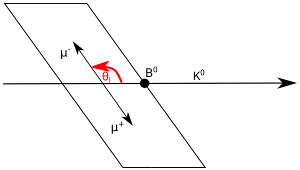
Electroweak penguin decays at LHCb





- FCNCs only occur via penguin or box diagrams in the SM.
- New particles can enter in the loop, altering the branching fraction or the angular distribution.
- Will only talk about $b \rightarrow s\ell\ell$ transitions. See talk by Tom Blake on Thursday about other EW penguins.
- Allows constraints on Wilson coefficients $\mathcal{C}_7^{(\prime)}, \mathcal{C}_9^{(\prime)}, \mathcal{C}_{10}^{(\prime)}$.
- Quantities of interest depend on dimuon invariant mass (squared), q^2.

Angular analysis of $B \rightarrow K\mu^+\mu^-$ (I)



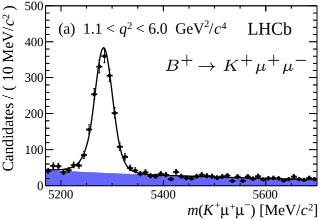
- Rare decay with $\mathcal{B} \approx 4.5 \cdot 10^{-7}$
- Sensitive to (pseudo)-scalar or tensor contributions.
- Angular distribution given by:

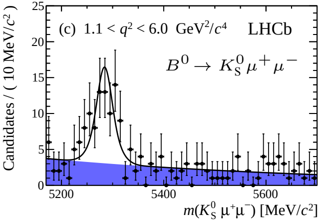
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4}(1 - F_H)\sin^2\theta_\ell + \frac{1}{2}F_H + A_{FB}\cos\theta_\ell$$

- Two parameters, both zero or very small in SM.
  - A_{FB}: Forward-backward asymmetry
  - F_H: Fractional contribution to decay width from (pseudo)-scalar or tensor amplitudes (know as "flat term")

{ arXiv:1403.8045 }

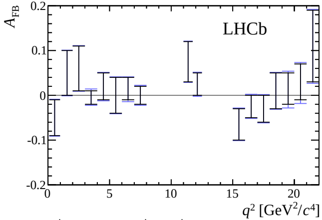
Angular analysis of $B \to K\mu^+\mu^-$ (II)

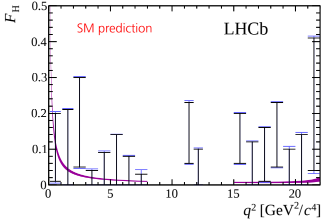




- Use full 2011+2012 dataset (3 fb^{-1})
- $B^+ \to K^+\mu^+\mu^-$
  - Large sample, 4761 ± 81 candidates, can separate B^+ and B^-.
- $B^0 \to K^0_s(\to \pi^-\pi^+)\mu^+\mu^-$
  - Smaller sample, 176 ± 17 candidates: Only 50% decay to K^0_s, one additional particle to reconstruct, ...
  - Cannot distinguish B^0 and $\overline{B}^0$, measure $|\cos\theta_\ell|$, only access to F_H.
- Correct for distortion of angular acceptance using simulation / exclude $B \to \psi(nS)K$ decays / veto MisID background

Angular analysis of $B \to K\mu^+\mu^-$ (III)

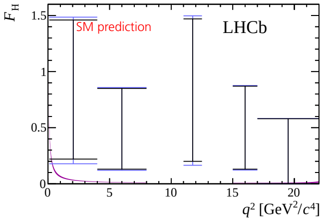




stat. only

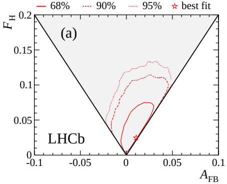
including systematics

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



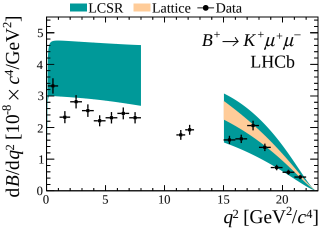
- $B^0 \to K^0_S(\to \pi^-\pi^+)\mu^+\mu^-$

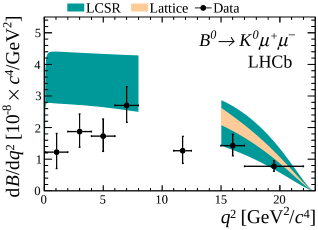
Uncertainties calculated using Feldman-Cousins technique



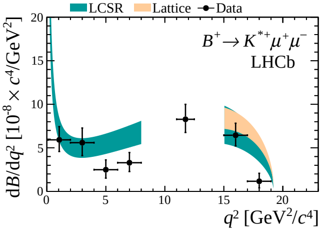
Theoretical predictions from JHEP 01(2012) 107

Branching fractions of $B \to K^{(*)}\mu^+\mu^-$ decays (I)



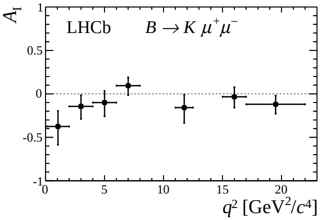


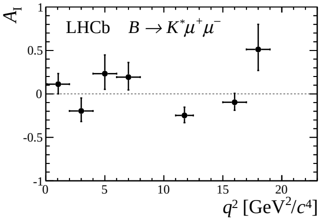
- Measure branching fraction of $B^+ \to K^+\mu^+\mu^-$ $B^0 \to K^0\mu^+\mu^-$ and $B^+ \to K^{*+}\mu^+\mu^-$ (all 3 fb^{-1}).
- Use the resonant channels $B \to J/\psi K^{(*)}$ as normalisation.



LCSR predictions from JHEP 01(2012) 107, JHEP 07(2011) 067
Lattice predictions from arXiv:1310.3207

Isospin asymmetry and $B \to K\mu^+\mu^-$ decays (I)

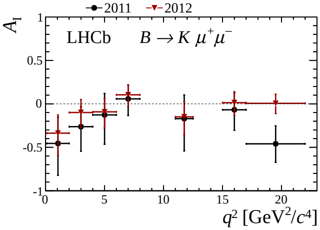




- Can also measure isospin asymmetry for $B \to K^*\mu^+\mu^-$ and $B \to K\mu^+\mu^-$ decays.
- $$A_I = \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - \frac{\tau_0}{\tau_+}\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + \frac{\tau_0}{\tau_+}\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}$$
- Compatible with theoretical predictions (zero).
- With 1 fb^{-1} a large discrepancy was observed...

Predictions from Phys. Rev. D 88 094004, JHEP 07(2011) 067

Isospin asymmetry of $B \to K\mu^+\mu^-$ decays (II)



- What changed in the meantime?
  - LHCb added another 2 fb^{-1} of data.
  - Previously assumption that equal amounts of B^+ and B^0 are produced at $\Upsilon(4S)$. Now assume isospin symmetry for $B \to J/\psi K^{(*)}$.
  - Reanalysis of 2011 data with identical selection for 2011 and 2012.
  - All these effects reduce the discrepancy.

{ preliminary }

Lepton universality using $B \to K\ell\ell$ decays (I)

New

- In the SM, coupling to all leptons is the same.
-
$$R_K = \frac{\Gamma(B^+ \to K^+\mu^+\mu^-)}{\Gamma(B^+ \to K^+e^+e^-)}$$
- Expect $R_K^{SM} = 1 + \mathcal{O}(\frac{m_\mu^2}{m_b^2})$, small corrections due to phase space and Higgs penguin diagrams.
- New (pseudo)scalar operators might distinguish electrons and muons in models with an extended Higgs sector, deviation up to 10% wrt to SM.
- $\frac{(R_K-1)}{\mathcal{B}(B_s^0 \to \mu^+\mu^-)} \sim 2 \cdot 10^{-5}$ for such models.
- R_K previously measured by BaBar and Belle with very limited statistics.
- First analysis by LHCb, uses 3 fb^{-1}.

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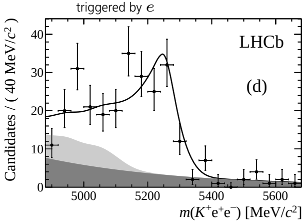
{ preliminary }

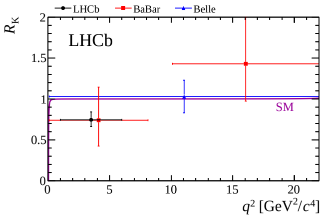
Lepton universality in $B \to K\ell\ell$ decays (II)

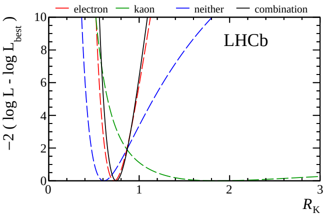


- Relative branching fraction measurement, using $B^+ \to J/\psi\, K^+$, with $J/\psi \to \mu^+\mu^-$, $J/\psi \to e^+e^-$ as normalisation channels.
- $B^+ \to K^+e^+e^-$ challenging:
  - Recover loss by Bremsstrahlung by adding ECAL cluster energy (> 75 MeV).
  - Signal shape strongly depends on number of Bremsstrahlung photons, $p_{\rm T}$ and occupancy of the event $\to$ split analysis in 3 trigger categories.
  - $B^0 \to K^*e^+e^-$ largest contribution to part. background.
  - About 5$\times$ less signal than in $B \to K\mu^+\mu^-$, mainly due to low trigger and reconstruction efficiency.

{ preliminary }

Lepton universality in $B \to K\ell\ell$ decays (III)





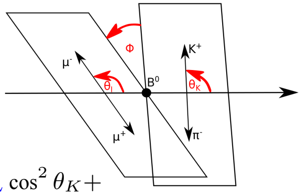
- Form double ratio with $B^+ \to J/\psi\, K^+$ to cancel systematics.
- Largest remaining systematics are fit model and trigger efficiency.
- Only consider 1 $\mathrm{GeV}^2/c^4 < q^2 < 6\ \mathrm{GeV}^2/c^4$. Theoretically well predicted: No charm loop contributions, not charm resonances.
- Most precise measurement to date:

$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{sys})$$

- Compatible with SM prediction within 2.5σ.

{ JHEP 08(2013) 131, PRL 111 191801 (2013) }

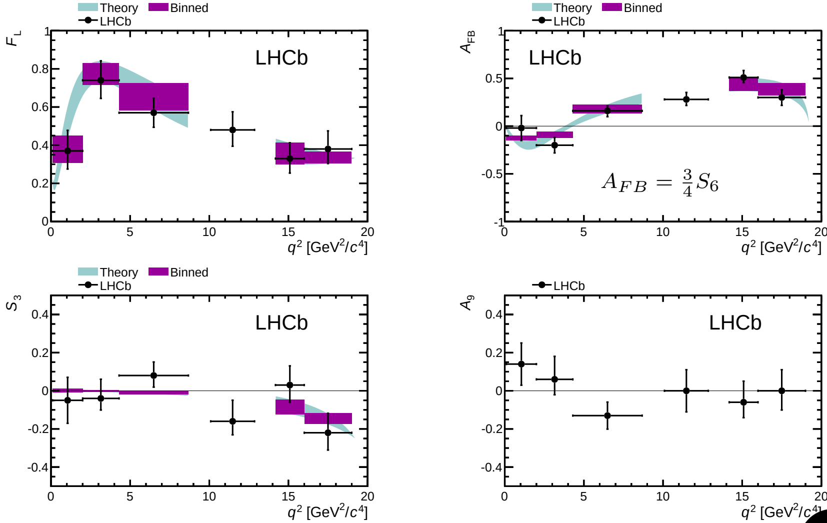
Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$



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

- Neglect lepton masses, average B^0 and $\overline{B}^0$.
- Can measure all coefficients of the angular terms in bins of q^2.
- Use different foldings to reduce number of coefficients.
- Only analysed 1 fb^{-1} so far.

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

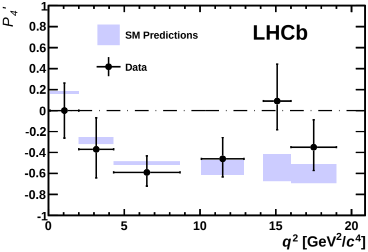


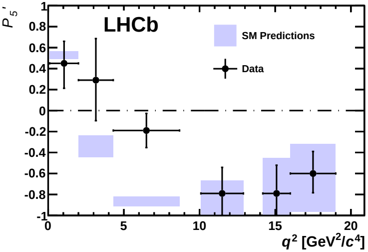
- All results compatible with the SM predictions.

Predictions from JHEP 07(2011) 067 and references therein

{PRL 111 191801 (2013) }

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

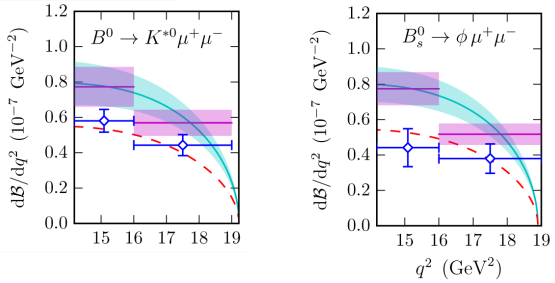




- Measure coefficients with reduced form-factor uncertainties:
  $$P'_{4,5} = \frac{S_{4,5}}{\sqrt{F_L(1-F_L)}}$$
- P'_5 deviates from SM prediction by $\approx 4\sigma$, probability is 0.5% to have one bin (out of 24) fluctuating by at least that much.
- Uncertainties on theoretical predictions are a much discussed topic.
- Analysis on 3 fb^{-1} needed to confirm experimental result.

Predictions from JHEP 05 (2013) 137

Deviation in $\mathcal{C}_9$?



$\mathcal{C}_9^{NP}$ = -1.0, $\mathcal{C}_9'$ = 1.2

- All branching fractions presented in this talk are below the theoretical predictions.
- The P_5' discrepancy can be reduced when allowing for a lower value of $\mathcal{C}_9$.
- As a consequence the diff. BRs for high q^2 are more compatible with the predictions.
- $\longrightarrow$ See Tom Blake's talk for a more detailed discussion, different views and possible interpretations on Thursday.

Summary

- Electroweak penguin decays are an ideal laboratory to look for physics effects beyond the Standard Model.
- LHCb has analysed a great variety of $b \to s\ell\ell$ transitions.
    - Measured for the first time R_K, testing lepton universality.
- All measured differential branching fractions tend to have a lower value than theoretically predicted.
- P_5' anomaly still waits an explanation - does the Wilson coefficient $\mathcal{C}_9$ deviate from the SM prediction?
    - Will the future reveal the truth?

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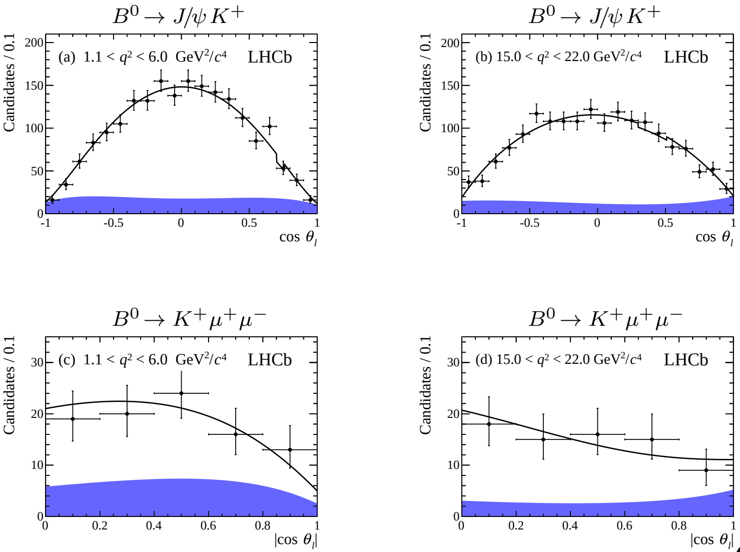
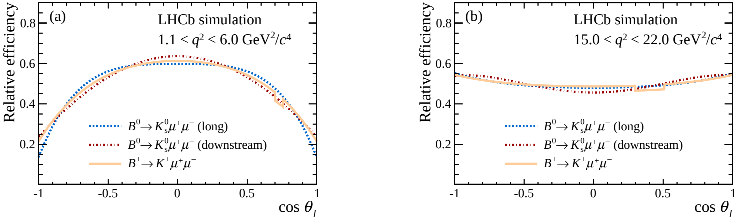
Backup

Angular fits for $B \to K\mu^+\mu^-$



Acceptance correction for $B \to K\mu^+\mu^-$



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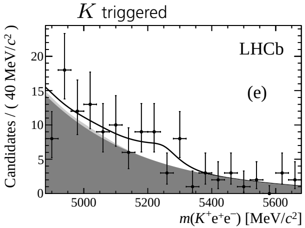
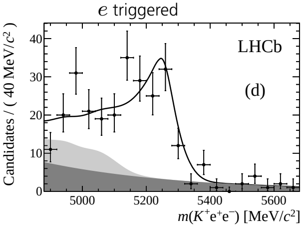
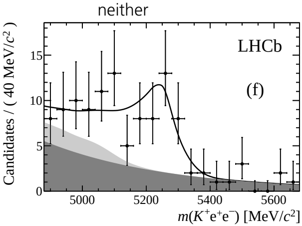
Mass distribution for $B^0 \to K^+ e^+ e^-$ (I)



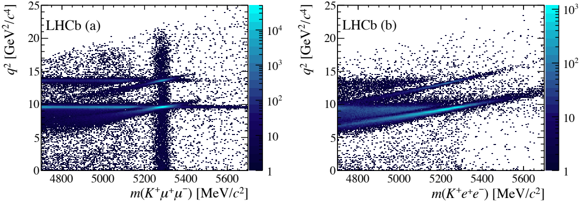


- Individual yields:
  - e triggered: 172^{+20}_{-19}
  - K triggered: 20^{+16}_{-14}
  - neither: 62 ± 13

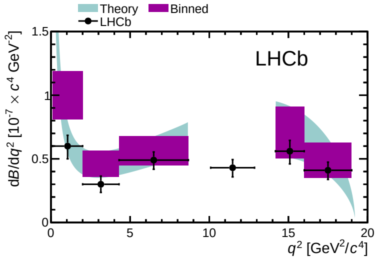


triggered = triggered in the hardware trigger

Mass distribution for $B^0 \to K^+e^+e^-$ (II)



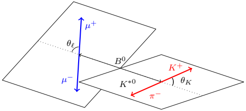
Branching fraction of $B^0 \to K^{*0}\mu^+\mu^-$



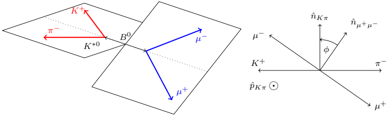
- Use $B^0 \to J/\psi\, K^*$ to normalise the branching fraction.

Predictions from JHEP 07(2011) 067 and references therein

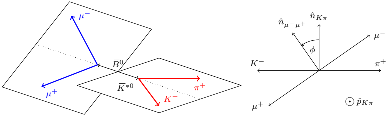
Angular definitions in $B^0 \to K^{*0}\mu^+\mu^-$



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

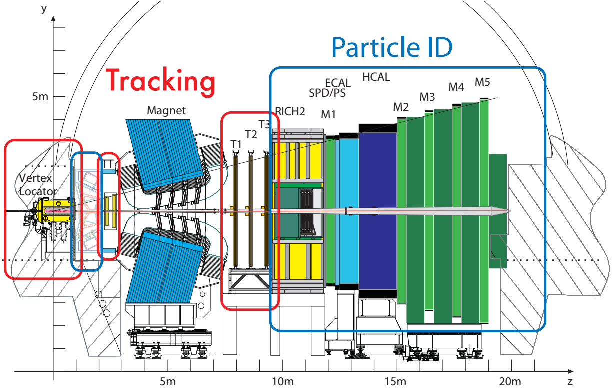


(b) ϕ definition for the B^0 decay



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

The LHCb detector



- LHCb covers a pseudorapidity $\eta = 2 - 5$.
- Excellent momentum resolution: $\Delta p/p = 0.4\% - 0.6\%$ in $5 - 140\,\mathrm{GeV}/c$.
- $K - \pi$ separation up to 100 GeV/c.

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