CP asymmetries in $B \to K^{(*)}\mu^+\mu^-$ decays

IOP HEPP meeting 2014

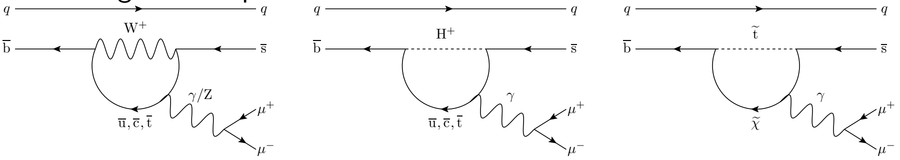
Simon Wright

University of Cambridge

Tuesday, April 8th, 2014

Electroweak penguins

- Study of flavour changing neutral current decays that have no tree-level Feynman diagrams.
- Hence proceed via loop and box diagrams, and New Physics can enter through the loops.



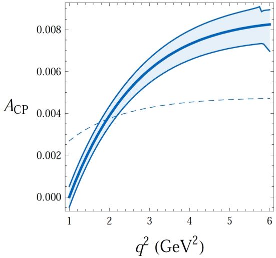
- Theoretical framework via an effective Hamiltonian:
  - Wilson coefficients (C_i), describing short-distance interactions
  - Operators, ($\mathcal{O}_i$), describing long-distance interactions

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} (C_i^{SM} + \Delta C_i^{NP}) \mathcal{O}_i$$

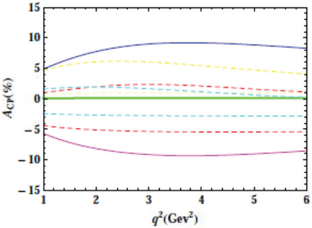
- Standard Model predictions for rate observables (sensitive to C_7, C_9 and C_{10}) are subject to large form-factor uncertainties.
- CP asymmetry measurements cancel these at leading order by taking a ratio:

$$\mathcal{A}_{CP}(q^2) = \frac{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\mu^+\mu^-) - \Gamma(B^0 \to K^{*0}\mu^+\mu^-)}{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\mu^+\mu^-) + \Gamma(B^0 \to K^{*0}\mu^+\mu^-)}$$

where $q^2 = m^2_{\mu^+\mu^-}$.



$\mathcal{A}_{CP}$ is predicted to be of order 10^{-3} in the SM...(JHEP 01(2009) 019)



...but can be significantly enhanced with physics beyond the SM. (arXiv:1103.5344)

Method

- Due to detection and production asymmetries, we do not measure $\mathcal{A}_{CP}$ directly, but instead a raw asymmetry

$$\mathcal{A}_{RAW} \simeq \mathcal{A}_{CP} + \kappa\mathcal{A}_P + \mathcal{A}_D$$

where $\mathcal{A}_{CP}$ is the CP asymmetry

$\mathcal{A}_P$ is the $B^0/\overline{B}^0$ production asymmetry.

$\mathcal{A}_D$ is the detection asymmetry.

- The detection asymmetry further subdivides

$$\mathcal{A}_D \equiv \frac{\epsilon(\bar{f}) - \epsilon(f)}{\epsilon(\bar{f}) + \epsilon(f)} = \mathcal{A}_I + \mathcal{A}_R$$

where $\mathcal{A}_I$ is the asymmetry due to the different interaction cross-sections of the final states with the detector material and $\mathcal{A}_R$ arises from a difference in detection efficiency between the left and right side of the detector.

- $\mathcal{A}_R$ can be ameliorated by taking an average of the results with the different magnet polarities.

Method

- Can use the control mode $B^0 \to J/\psi K^{*0}$, which has the same final state particles and similar kinematics, to get a handle on the unwanted asymmetries:

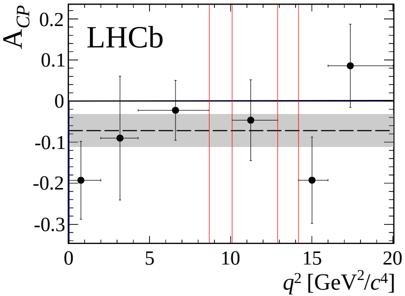
$$\mathcal{A}_{RAW}(J/\psi K^*) = \mathcal{A}_{CP}(J/\psi K^*) + \kappa \mathcal{A}_P(B^0) + \mathcal{A}_D(J/\psi K^*),$$

where $\mathcal{A}_{CP}(J/\psi K^*) \approx \mathcal{A}_{CP}(J/\psi K) = (1 \pm 7) \times 10^{-3}$.

- As the detector and production asymmetries cancel to first order (differences due to kinematics are considered as a systematic uncertainty), we can write

$$\mathcal{A}_{CP}(K^*\mu\mu) = \mathcal{A}_{RAW}(K^*\mu\mu) - \mathcal{A}_{RAW}(J/\psi K^*) + \mathcal{A}_{CP}(J/\psi K).$$

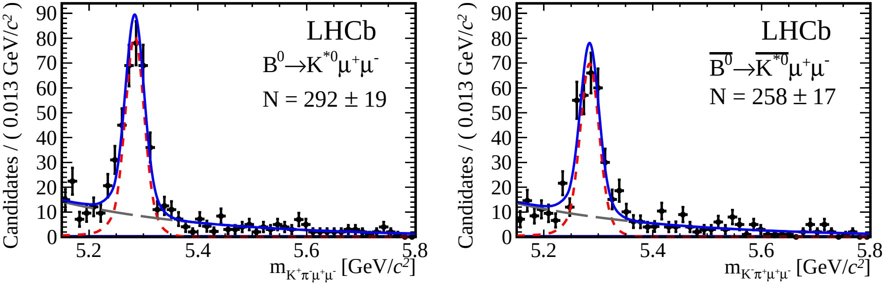
- CP asymmetry extracted from simultaneous unbinned likelihood fit of $B^0 \to J/\psi K^{*0}$ and $B^0 \to K^{*0}\mu^+\mu^-$ $m_{K\pi\mu\mu}$ distributions in bins of q^2, split by magnet polarity.



$\mathcal{A}_{CP} =$
$-0.072 \pm 0.040(\text{stat.}) \pm 0.005(\text{syst.})$

Consistent with the SM
World's most precise measurement

Mass distributions below for one magnet polarity:

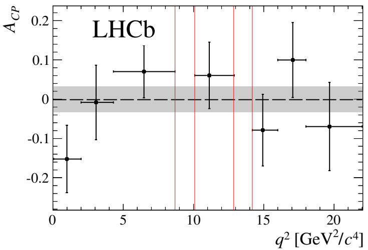


CP asymmetry in $B^+ \to K^+\mu^+\mu^-$

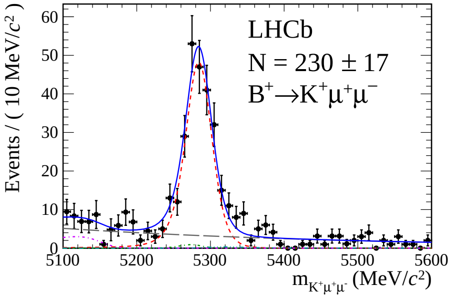
$$\mathcal{A}_{CP}(q^2) = \frac{\Gamma(B^- \to K^-\mu^+\mu^-) - \Gamma(B^+ \to K^+\mu^+\mu^-)}{\Gamma(B^- \to K^-\mu^+\mu^-) + \Gamma(B^+ \to K^+\mu^+\mu^-)}$$

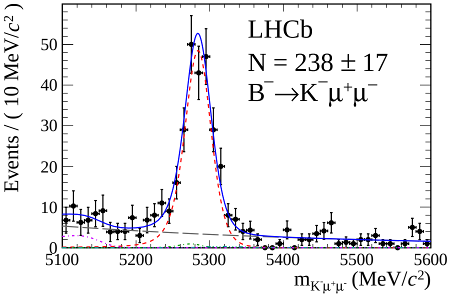
- Assuming that New Physics contributions to $\mathcal{A}_{CP}$ come from the loop in the penguin diagrams, $\mathcal{A}_{CP}$ $(B^+ \to K^+\mu^+\mu^-)$ and $\mathcal{A}_{CP}$ $(B^0 \to K^{*0}\mu^+\mu^-)$ should be very similar as the diagrams only differ by the spectator quark.
- $\mathcal{A}_{CP} \sim 10^{-4}$ in the Standard Model.
- Analysis performed using 2011 LHCb data set $(1.0\,\text{fb}^{-1})$ proceeding as for $B^0 \to K^{*0}\mu^+\mu^-$.
- Use $B^+ \to J/\psi K^+$ as a control channel to account for production and detection asymmetries:

$$\mathcal{A}_{CP}(K\mu\mu) = \mathcal{A}_{RAW}(K\mu\mu) - \mathcal{A}_{RAW}(J/\psi K) + \mathcal{A}_{CP}(J/\psi K).$$

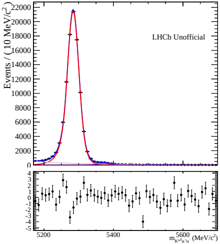


- $\mathcal{A}_{CP}$ over the full q^2 range is the average of each q^2 bin weighted by signal yield and efficiency.
- $\mathcal{A}_{CP} = 0.000 \pm 0.033(\text{stat.}) \pm 0.005(\text{syst.}) \pm 0.007(J/\psi K)$.
- World's best measurement by a factor of 4, and consistent with both SM and $B^0 \to K^{*0}\mu^+\mu^-$ measurement.
- Mass fits for one polarity below:



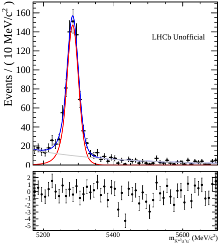


- The mass fits used are the same as for the 2011 $B^0 \to K^{*0}\mu^+\mu^-$ analysis - a sum of two Crystal Ball functions for the signal, and an exponential for the background.



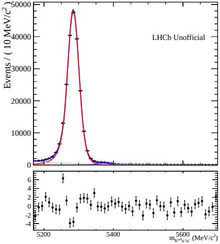
$B^0 \to J/\psi K^{*0}$

2011
Yield $= 96836 \pm 375$

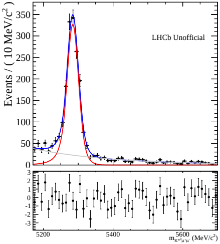


$B^0 \to K^{*0}\mu^+\mu^-$

2011
Yield $= 664 \pm 29$



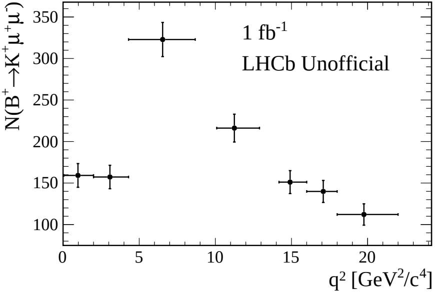
2012
Yield $= 216903 \pm 580$

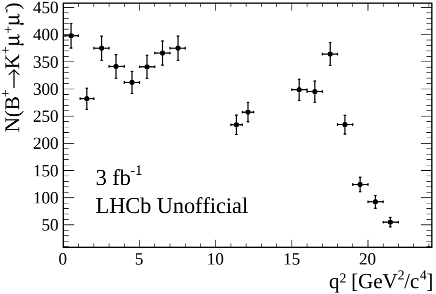


2012
Yield$= 1479 \pm 44$

2012 update - q^2 binning

- Have approximately 2.5 times more $B^0 \to K^{*0}\mu^+\mu^-$ events, and 4 times more $B^+ \to K^+\mu^+\mu^-$ events, than for the 2011 analysis.
- This drives down the statistical uncertainties on the $\mathcal{A}_{CP}$ measurements.
- It also enables a finer binning in q^2, using 14 bins for $B^0 \to K^{*0}\mu^+\mu^-$ and 17 for $B^+ \to K^+\mu^+\mu^-$ compared to 6 (7) is 2011.

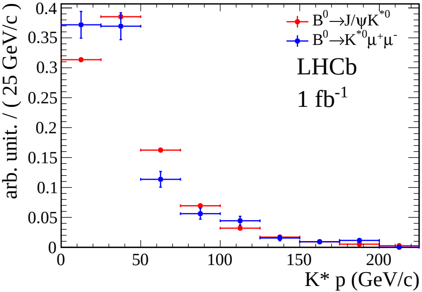




2012 update - Systematic uncertainties

- Main systematic is due to kinematic differences between $B^0 \to J/\psi K^{*0}$ and $B^0 \to K^{*0}\mu^+\mu^-$.
- If there are large differences in kinematic variables between the modes, and the raw asymmetry varies as a function of these, $\mathcal{A}_{CP} = \mathcal{A}_{RAW}(K^*\mu\mu) - \mathcal{A}_{RAW}(J/\psi K^*) + \mathcal{A}_{CP}(J/\psi K^*)$ may not be an accurate assumption.

- Calculate systematic by reweighting $B^0 \to J/\psi K^{*0}$ kinematic distributions to match $B^0 \to K^{*0}\mu^+\mu^-$ and recalculating $\mathcal{A}_{RAW}$.
- Take difference of the two as a systematic - $< 5\%$ of statistical.



- Other uncertainties arise from mass fitting and resolution effects.
- However, all turn out to be much smaller than the statistical uncertainity.

Summary

- Measurements of $\mathcal{A}_{CP}$ in electroweak penguin modes provide a complementary analysis to measurements of rate and angular observables.
- World's best values already measured at LHCb using the 2011 data set.

$$\mathcal{A}_{CP}(B^0 \to K^{*0}\mu^+\mu^-) = -0.072 \pm 0.040(\text{stat.}) \pm 0.005(\text{syst.})$$

$$\mathcal{A}_{CP}(B^+ \to K^+\mu^+\mu^-) = 0.000 \pm 0.033(\text{stat.}) \pm 0.005(\text{syst.}) \pm 0.007(J/\psi K).$$

- Analysis of the 2012 data well advanced, with much smaller uncertainties than the 2011 analysis.