Angular Analysis of $B^+ \to K^+ ee$ Decays at the LHCb Experiment

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Introduction I

Precision measurements using electroweak penguins

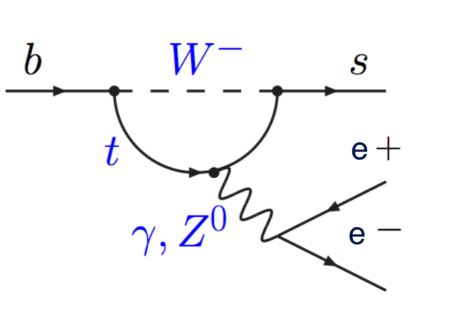
- $b \rightarrow sll$ forms a family of rare decays
- Look at the observables where:
  - SM contribution is small
  - The measurement can be made to a high precision
  - Predicted to a high precision
- Flavour changing neutral currents in SM

→ Loop level

→ GIM suppressed

→ Left handed chirality

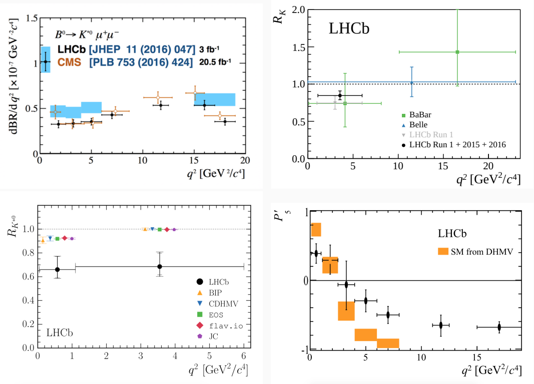
- NP could violate any of these



Introduction II

The anomalies in the $b \to sll$ sector persist and are not understood

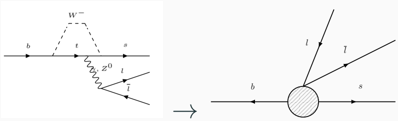
- $b \to sll$ is a rare decay - so NP contributions could enter on a comparable level
- Three key areas:
  1. Lepton flavour universality tests in decay rates of $B^{(*)+} \to K^{(*)+} l^+ l^-$
  2. Measured decay rates in $B^{(*)} \to K^{(*)} \mu^+ \mu^-$ and $B_s \to \phi \mu^+ \mu^-$
  3. Angular analyses of $B^{(*)} \to K^{(*)} \mu^+ \mu^-$ and $B_s \to \phi \mu^+ \mu^-$
- Now more than ever we need precision measurements.



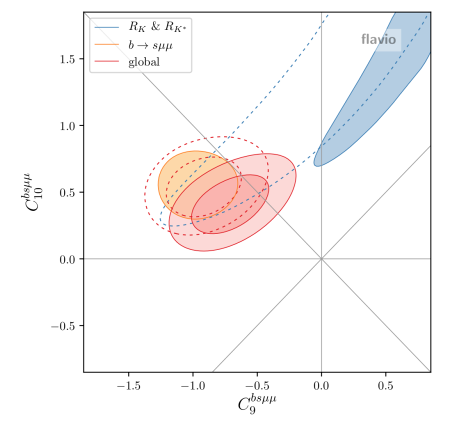
Introduction III

How do we interpret the anomalies?

- Model using effective field theories



  - C_7, C_9, C_{10}, C_P, C_S, C_T - photon, vector, axial-vector, (pseudo-)scalar, tensor
- Global fits point towards a shift in Wilson Coefficient C_9 (vector)
- Hints at potential lepton flavour universality violating effects in C_9



Real C_9 and C_{10} global fits showing the shift in favour of C_9 - (SM on crosshair) - Morimond 2019

Introduction IV: Where does an angular analysis come in?

Prompted to reconsider assumptions about lepton universality in other currents.
The $B^+ \to K^+\ell^+\ell^-$ decays have a very simple angular structure in terms of these parameters:

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

Quadratic in $cos\theta_l$, cosine of the opening angle between the l^+ and K^+

- For $q^2 \gg m_\ell^2$, F_H and A_{FB} ONLY sensitive to (pseudo-)scalar and tensor couplings ($C_{S,P,T}$).
- Thus electron final state not sensitive to C_9 and C_{10} in majority of q^2 distribution

  $\to$ Excellent sensitivity to (pseudo-)scalar and tensor Wilson coefficients $C_{S,P}$ and C_T

  $\to$ Alternatively validation of electron reconstruction and thus $R_{K^{(*)}}$ measurements

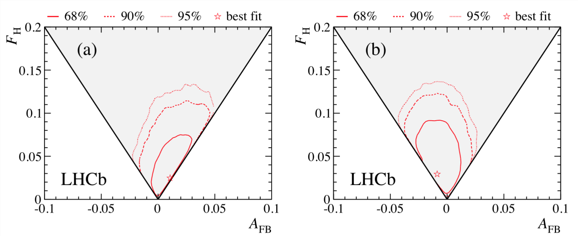
Introduction V: Previous Work

What does the measurement look like?

- The run 1 Angular fit in A_{FB}, F_H space of $B^+ \to K^+\mu\mu$ is in agreement with the SM

→ The allowed angular distribution lies in a triangle in A_{FB} and F_H space.

→ Physical region takes this shape by requiring angular PDF to be positive definite for all $cos\theta_l$



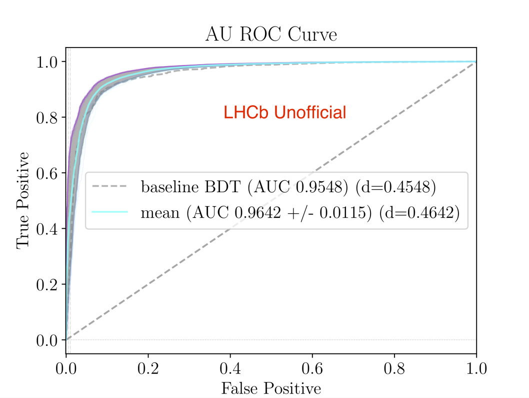
Angular fit in A_{fb}, F_H space for two q^2 regions (a) 1.1 - 6 GeV, (b) 15 - 20 GeV JHEP 1405 (2014) 082

Selection

Analysis conducted with 2011+2012 (Run1) and 2015+2016 (Run2) dataset

- Key backgrounds: combinatorial, partially-reconstructed ($B \to K^* ee$), cascading semi leptonic decays ($B \to D^0(\to Ke\nu)e\nu$)
- Selection utilises a series of neural networks to supress backgrounds
- And focused selections on particle mass hypotheses for mis-ID
- Simulation calibrated using data control channels

→ Calibrate: B^+ kinematics, Tracking, Particle ID, Trigger, Resolution



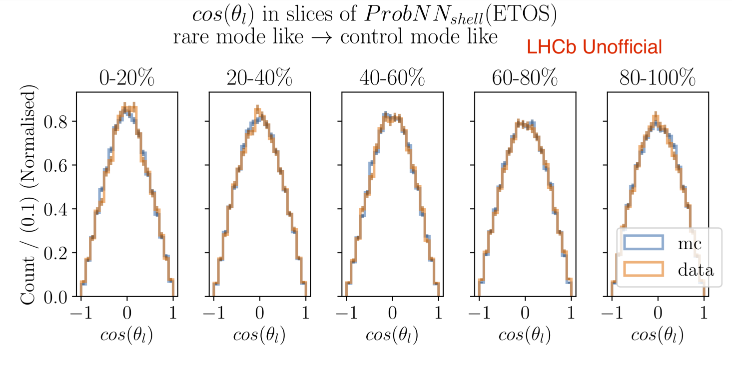
ROC curve from combinatorial neural network

Validating the control mode

Angular distribution of $B^+ \to K^+ J/\Psi(\to ee)$ well known - use as control mode

It will be a different q^2 region, different decay, different kinematics, etc...

- Need a way to approximate the rare mode
- Built a classifier (TF NN) to separate $B \to Kee$ and $B \to J/\Psi K$ MC. lepton and kaon opening angles, and high + low electron P_T
- Compare angular distribution of data/mc $B \to J/\Psi K$ in slices of this classifier



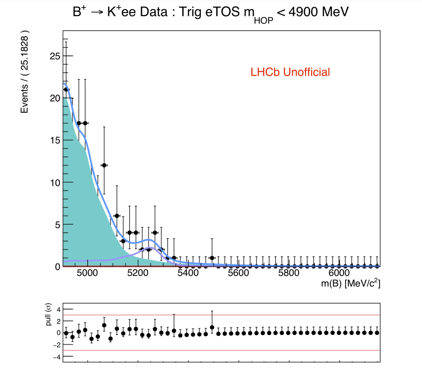
→ MC and data in agreement over this variable

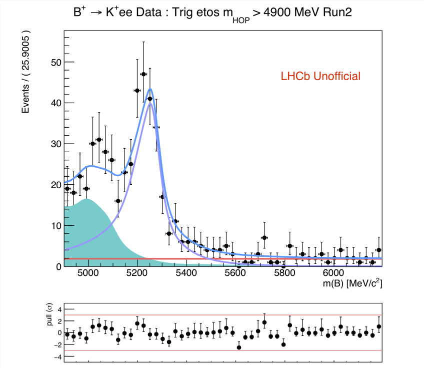
→ Allows us to validate our corrections in proxy variable for q^2

→ Given the inherent difficulty in justifying corrections from one region onto another, provides valuable validation information

Mass Fits

- Mass fitting strategy uses partially-reconstructed enriched + depleted regions as constraint
- 6 part simultaneous fit to three trigger categories for two part-reco regions



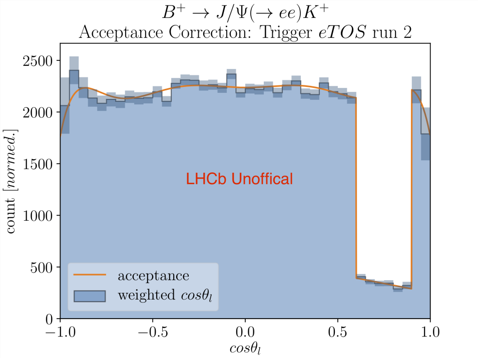


Yields consistent with those published in [arXiv:1903.09252]

Acceptance Corrections

To account for all sculpting of angular distribution

- Correction accounts for all selections in the pipeline, as well as detector / trigger level effects
- Model the difference of final selection to generator level MC
- Describe using Legendre Polynomial
- The step comes from focused selections against cascading semi leptonic backgrounds in the rare mode



$B^+ \to D^0(\to Ke\nu)e\nu$ peaks in $0.6 < cos\theta_l < 0.9$

Angular Fit I: $B \to J/\Psi(\to ee)K^+$ simultaneous fit

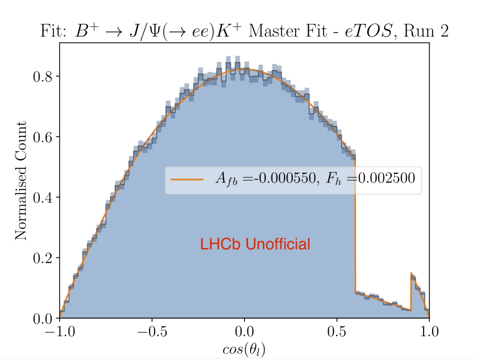
Fit function for the angular distribution is just a quadratic

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

SM parameters for $B^+ \to K^+ J/\Psi(\to ee)$:

$$A_{FB}, F_H = 0, 0$$

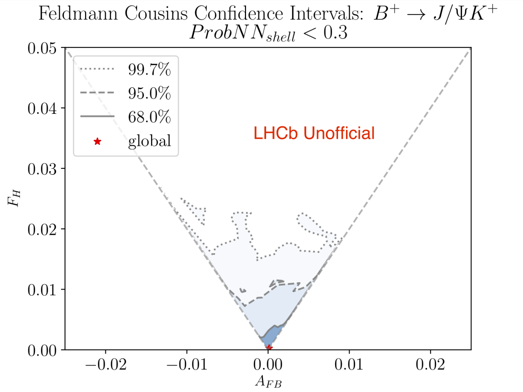
- Global fit is a 6 part simultaneous (3x exclusive trigger categories, 2x runs)
- Binned ML fit to $cos\theta_l$ in 20 bins, limited by mc statistics to understand q^2 migrations



Angular Fit II: $B^+ \to K^+ee$ like $B^+ \to K^+J/\Psi(\to ee)$ Data

Angular fit to the most $B^+ \to K^+ee$ like $B^+ \to K^+J/\Psi(\to ee)$ data to approximate rare mode

- Use a cut on $ProbNN_{shell} < 0.3$ to select the most *Kee* like $B^+ \to K^+ee$ like $B^+ \to K^+J/\Psi(\to ee)$ data
- This is the closest we can get with the control mode data to being confident about the propagation into the rare mode
- Full 2D Feldmann Cousins method to quantify systematic uncertainties - due to unphysical regions



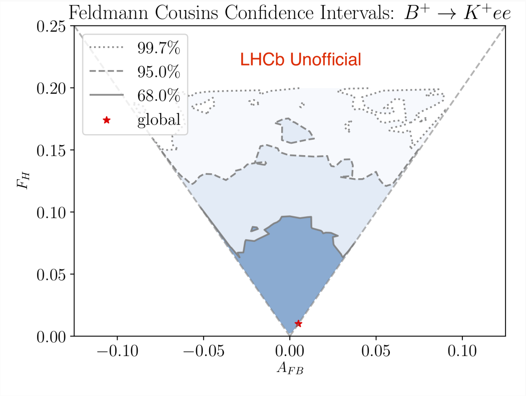
Feldmann Cousins confidence interval for *Kee* like $B^+ \to K^+J/\Psi(\to ee)$ data, to approximate rare mode. Uncertainties estimated with full Feldmann Cousins

Angular Fit III: $B^+ \to K^+ ee$ Expected Precision

What kind of confidence interval can we expect from our final result?

- Generate toy samples with specified A_{FB}, F_H - yields taken from mass fits to Run1 + Run2 data
- same six part simultaneous fit as in the $B^+ \to K^+ J/\Psi(\to ee)$ mode
- The results of the full Feldmann Cousins scan give an uncertainty on the order of 0.075 in F_h
- Uncertainty is statistically dominanted

→ Key systematics understood - background subtraction, and acceptance correction



Feldmann Cousins confidence intervals from toy studies, showing realistic uncertainty constraints

Conclusions

Nearing the end of this analysis.

- Validated our corrections and fit procedure
- Main systematic uncertainties have been evaluated
- Results should provide the most stringent constraints in C_S, C_P and C_T couplings to electrons

Questions / Comments?