Analisi angolare di $B^0 \to K^* \mu\mu$

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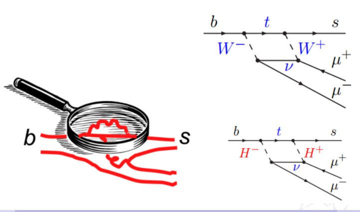
Introduction

Why measuring $\mathrm{B}_0 \to \mathrm{K}^{*0}\mu\mu$ angular distributions?

- In SM allows only the charged interactions to change flavour.
  - Other interactions are flavour conserving.
- One can escape this constrain and produce $b \to s$ (and $b \to d$) at loop level.
- Flavour Changing Neutral Current: FCNC
  - This kind of processes are suppressed in SM: Rare decays.
  - New Physics can enter in the loops.
- detailed study of yield ($B_s \to \mu\mu$), angular distributions ($\mathrm{B}_0 \to \mathrm{K}^{*0}\mu\mu$)[A. Ali, T. Mannel, and T. Morozumi(1991), U. Egede(2007)], etc



Theoretical framework

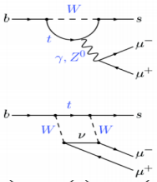
$$H_{eff} = -\frac{4G_f}{\sqrt{2}} VV'^{*} \sum_i \left[\underbrace{C_i(\mu)O_i(\mu)}_{\text{left-handed}} + \underbrace{C'_i(\mu)O'_i(\mu)}_{\text{right-handed}} \right] ,$$

i=1,2	Tree
i=3-6,8	Gluon penguin
i=7	Photon penguin
i=9.10	EW penguin
i=S	Scalar penguin
i=P	Pseudoscalar per

where C_i are the Wilson coefficients and O_i are the corresponding effective operators.

- Very active theoretical activity on the angular distribution of FCNC
- precision SM prediction are available
  - see eg S. Descotes-Genon presentation at KEK-FF2015 [S. Descotes-Genon et al(2013)]
  - with some alternative, and wildly discussed alternative (see A. Paul, M.Ciuchini ibidem)

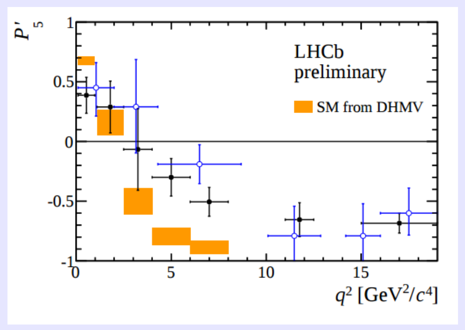
$$b \to s\ell^+\ell^-$$



$$C_7^{(\prime)}, C_9^{(\prime)}, C_{10}^{(\prime)}$$

Current status

- LHCb published [LHCb(2013)] a full angular analysis using 3 fb^{-1}
  - showing in particular a significant tension wrt SM prediction for one of the parameter of the angular distribution P'_5 (black dots);
  - confirming previous tension (blue dots 1 fb^{-1}).
- CMS published [CMS(2015)] a partial angular analysis with 20 fb^{-1}
  - Smaller overall statistics (1200 signal events vs 2400 LHCb)
  - No results on P'_5.



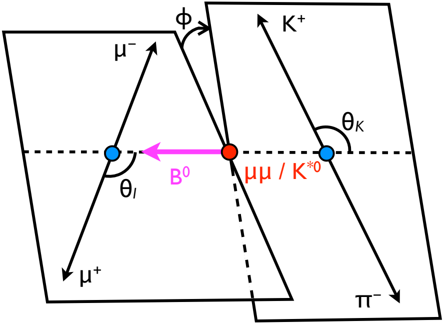
Discrepancy reported as 3.7σ for $4 < q^2 < 8$ GeV^2 for P'_5

Smaller tensions also for other observables.

- Task force setup $\sim 6/'15$ to update 2D analysis to include also P'_5

Coord	Mauro Dinardo (MiB): author of 2D analysis
Bejing	angular pdf fit;
Padova	efficiency computation.

- Three angles completely defines the decay;
  - θ_L, θ_K, ϕ
    - ★ dependence on P_5' only from ϕ: integrated in previous 2D analysis.
- studied in different bins of $q^2_{\mu\mu}$
  - including two *control regions*: $K^* J/\psi(\to \mu\mu)$ and $K^* \psi'(\to \mu\mu)$
- decay is self-tagging, provided K/π are told apart
  - LHCb had PID
  - CMS uses kinematic properties of decay
  - mis-tag probability $\sim 13\%$



- Data selection **identical** to 2D analysis: "just" perform 3D fit
  - requires 3D efficiency and more complex fit

Theoretical pdf quite complex: simplified by folding some of the angular variables. S-wave (non resonant $K\pi$)[T. Blake, U. Egede, and A. Shires(2013)] also present

$$\frac{1}{\Gamma_{full}}\frac{1}{dq^2 d\cos\theta_l d\cos\theta_k d\phi} = \frac{9}{8\pi}\left\{\frac{2}{3}\left[(Fs + As\cos\theta_k)\left(1-\cos^2\theta_l\right) + A_s^5\sqrt{1-\cos^2\theta_k}\sqrt{1-\cos^2\theta_l}\cos\phi\right]\right.$$
$$+ (1-Fs)\left[2F_L\cos^2\theta_k\left(1-\cos^2\theta_l\right) + \frac{1}{2}(1-F_L)\left(1-\cos^2\theta_k\right)\left(1+\cos^2\theta_l\right)\right.$$
$$+\frac{1}{2}P_1(1-F_L)(1-\cos^2\theta_k)(1-\cos^2\theta_l)\cos 2\phi$$
$$\left.\left.+2P5'\cos\theta_k\sqrt{F_L(1-F_L)}\sqrt{1-\cos^2\theta_k}\sqrt{1-\cos^2\theta_l}\cos\phi\right]\right\} \tag{9}$$

Including reconstruction efficiency, mis-tagged events, and background even worse:

$$\begin{aligned}\text{p.d.f.}(m,\cos\theta_K,\cos\theta_l,\phi) = {} & f_{Si}^R\cdot\left((1-f_i^M)S_i^R(m)\cdot S_i^a(\cos\theta_K,\cos\theta_l,\phi)\cdot\epsilon(\cos\theta_K,\cos\theta_l,\phi)\right.\\ & \left.+ f_i^M\cdot S_i^M(m)\cdot S_i^a(-\cos\theta_K,-\cos\theta_l,-\phi)\cdot\epsilon_i^M(-\cos\theta_l,-\cos\theta_k,-\phi)\right)\\ & + (1-f_{Si}^R)\cdot B_i^m(m)\cdot B_i^{\cos\theta_k}(\cos\theta_k)\cdot B_i^{\cos\theta_l}(\cos\theta_l)\cdot B_i^{\phi}(\phi).\end{aligned} \tag{1}$$

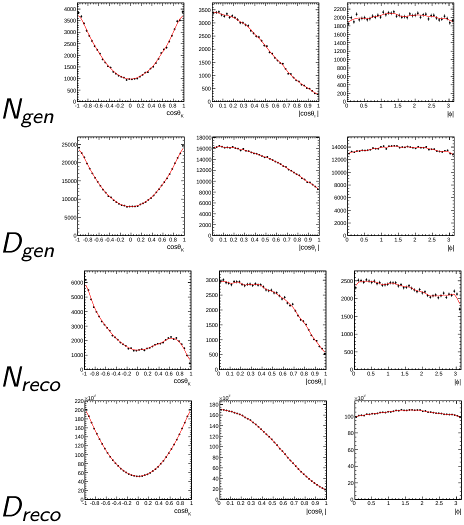
Efficiency

We decided to break down the 3D efficiency in two terms

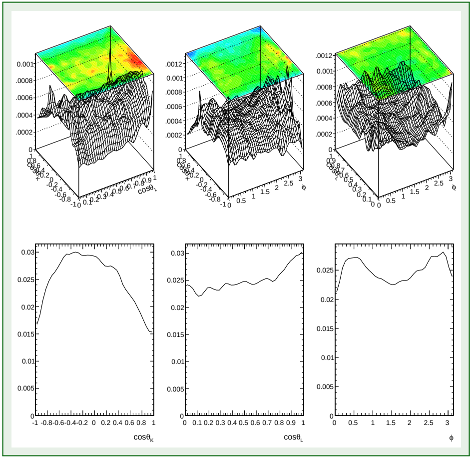
$$\epsilon(q^2, \theta_L, \theta_K, \phi) = \frac{N_{gen}}{D_{gen}} \times \frac{N_{reco}}{D_{gen}}$$

- describe each of the four terms via a non-parametric description using Kernel Density Estimator technique of the 3D distributions;
- basic idea is to describe any unbinned distribution as a superposition of N 3-dimensional gaussian kernels, each contributing to 1/N to the total pdf
- then build the double ratio and get the efficiency including all correlations

Example of KDE description



- Example for one q^2 bin;
- These are just 1D projections,
- the actual efficiency is fully 3-dimensional
- Done for all 9 bins,
- separately for right-tagged events and mis-tagged events;



Projection of the efficiency on two (upper row) and one variable (lower row), integrating over the other variable for q^2 bin 9

Closure tests

In order to validate the efficiency description, we tried to reproduce the MC reco distribution as:

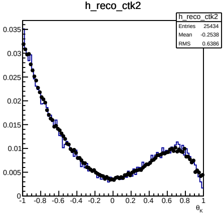
$$\texttt{pdf}(q^2,\theta_K,\theta_L,\phi)^{R/M}_{reco} = \texttt{pdf}(q^2,\theta_K,\theta_L,\phi)_{gen} \otimes \epsilon^{R/M}(q^2,\theta_L,\theta_K,\phi)$$

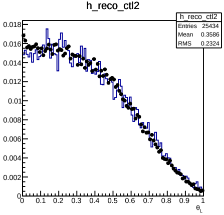
To guarantee statistical independence, we divided the MC in two orthogonal samples, using one for the efficiency determination, and the other one for the closure test

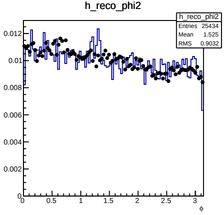
Performed closure test for all bins, separately for right and mis-tagged events, as well as for the two control samples

Some tuning needed for KDE to achieve good results

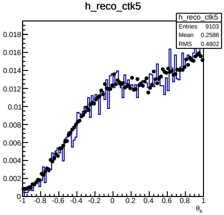
Closure test for the reconstructed angles using KDE, for q^2 bin 3

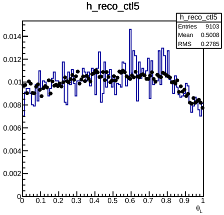


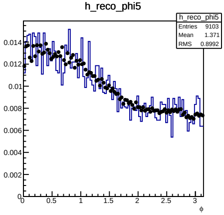




Closure test using KDE, for q^2 bin 6, for wrongly tagged events







Fit

- Efficiency task completed since october, with small additions/corrections since then.
- The fit is been developed, from the 2D analysis one, by the Bejing team (1 senior, 1 PhD);
  - Not an easy task, pdf is complex, progress has been slow;
  - lot of discussion to setup a fit procedure in order to validate the code using MC before moving to data;
- still not complete;
- non negligible communication issues with the Bejing team. . .
  - even trying to help is non trivial.
  - most pressing issue is the lack of a clear plan by the fit team
  - and the difficulty to follow one when provided by us/Mauro.

Fit sequence

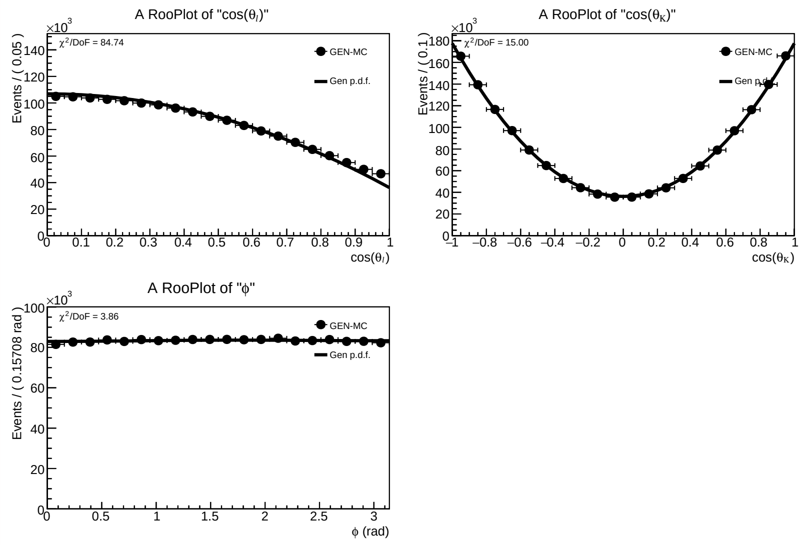
General steps

- Fit MC at GEN level, signal only; Done

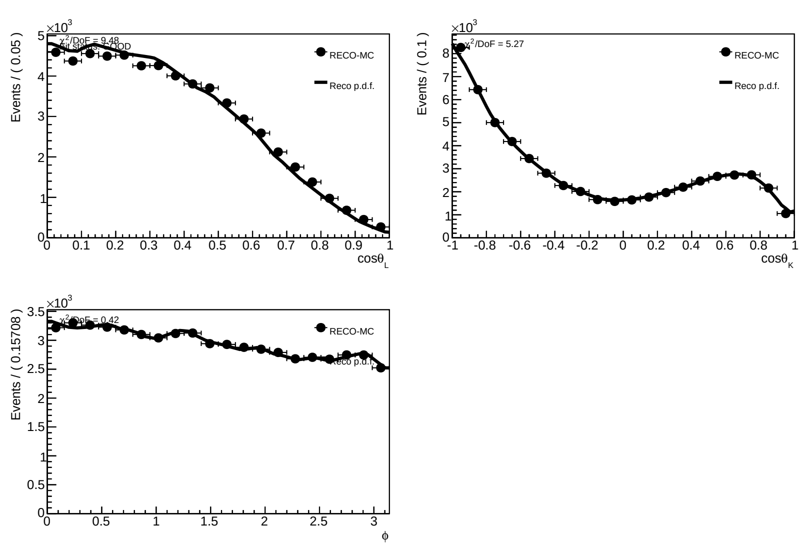
caveat S-wave not simulated in MC!

- Fit MC at RECO level, signal only; Done
  - using 3D efficiency
  - separately for right-tag, mis-tag, and both; Done
- parametrize background from M_B side bands on data Done(?)
  - no MC available;
  - create cocktail samples, with signal MC and background from toy with same size as data Done (PD)
  - try the fit on cocktail samples in progress
- Try the actual fit on control samples not yet there
- Perform the fit on data not yet there
- Systematics assessment In progress PD

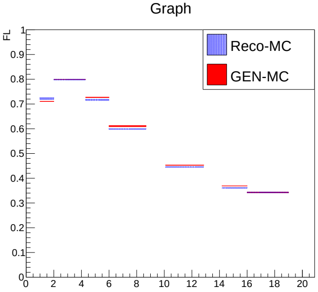
GEN level fit (projections)

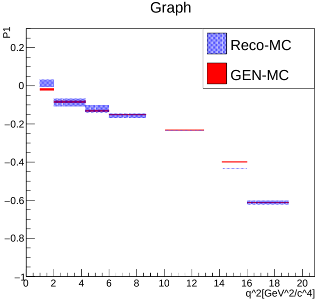


RECO level fit: right+mis-tag (projections)



GEN-RECO closure test for angular observables



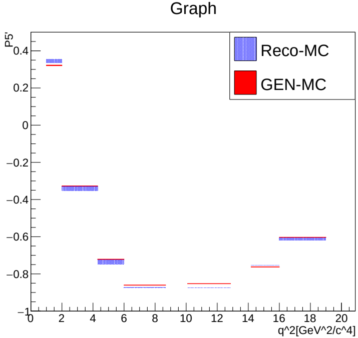


left-top F_L

left-bottom P_1

right P_5'

This closure will be used as systematics



Systematics

BPH conveneers ask for help for the systematics: we agreed.

List of systematics

Start identifing possible source of systematics and how to evaluate them:
Most of the systematics can be computed only when we have fit working

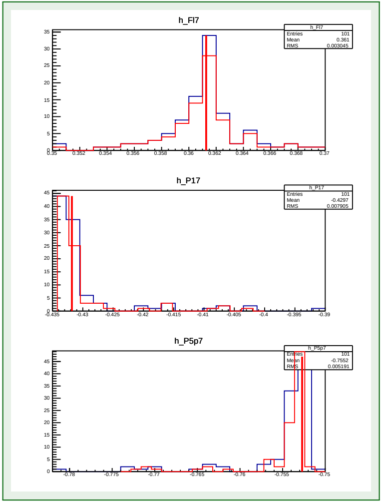
- limited amount of simulated events: PD working
- simulation mismodeling: compare GEN-RECO fit: done
- efficiency shape: control sample
- fitting bias: toy fitting
- wrong CP assignment: use control samples + toy
- background determination: as 2D analysis
- MC derived `pdf` component: ditto
- angular resolution: ditto: PD next task

Two methods

1. generate toys MC from KDE description of four terms of efficiency, run KDE on those, build 100 “toy” efficiency, use them in the fit and look at observables spread;

   first results →

2. split the MC in four samples, get 4 independent efficiency via KDE, use for the fit, look at spread/$\sqrt{4}$ in progress;



Future

- Still sizeable work to be done!
- our initial task (efficiency) completed since last fall;
- we helped with other, critical, tasks (and coordination)
- recent progress, and progress rate, is finally encouraging!
- still working at 8 TeV
  - at the very beginning we discussed to add also 7 TeV (for statistics), but never again since then
  - we have already our hands full with 8 TeV data!
- Discussion has started to extend the analysis at 13 TeV, where, in principle, we should collect more data than LHCb, and so still be competitive
- Can become Alessio's Phd thesis arguments

Additional stuff

Additional or backup slides

Bibliography I

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