Model-independent measurement of the CKM angle γ through decays with LHCb and CLEO-c

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Second year report

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Contents

Second year report

1.1 Introduction

The work done in the first part of the second year of this phd program consisted of a determination of the CP-even fraction of the decay of the D meson into 4 pions. The CP-even fraction of the decay was determined using correlated D meson pairs produced at the lepton collider CESR and reconstructed by the CLEO-c detector. The results of this analysis have been published are now used by the Oxford group to measure the CKM gamma angle using LHCb data.
The last month of work was used towards producing an alignment for the RICH detectors in the LHCb experiment for RunII.

Unless otherwise stated all activities described in this report were performed by the author.

1.2 Determining the CP-even fraction of $D \to 4\pi$

1.2.1 Short theory

The simplest way of determining the CP-even fraction of a decay using correlated pairs is by measuring the rate of events against decays with definitive CP-eigenstates. This part of the analysis was performed by the Oxford group.
Another way of determining the CP-even fraction is by reconstructing it against a decay which strong phase difference in different bins of phasespace has been determined previously. The decay used here is $D \to K_S^0 \pi\pi$ and $D \to K_L^0 \pi\pi$.
The CP-even fraction $F_+^{4\pi}$ of 4π can be determined through the evaluation of

$$M_i^{K_S^0\pi\pi} = h_{K_S^0\pi\pi}(T_i^{K_S^0\pi\pi} + T_{-i}^{K_S^0\pi\pi} - 2\,c_i\sqrt{T_i^{K_S^0\pi\pi}T_{-i}^{K_S^0\pi\pi}}\,(2F_+^{4\pi} - 1)) \qquad (1.1)$$

and

$$M_i^{K_L^0\pi\pi} = h_{K_L^0\pi\pi}(T_i^{K_L^0\pi\pi} + T_{-i}^{K_L^0\pi\pi} + 2\,c_i'\sqrt{T_i^{K_L^0\pi\pi}T_{-i}^{K_L^0\pi\pi}}\,(2F_+^{4\pi} - 1)) \qquad (1.2)$$

where the M_i denote the number of events in bin i of the $K_S^0\pi\pi$/ $K_L^0\pi\pi$ Dalitz-Plot tagged against 4π, the T_i the relative amount of events in bin i of flavour-tagged $K_S^0\pi\pi$/ $K_L^0\pi\pi$ Dalitz-Plot and the h are normalisation factors.
By summing over the bins i and $-i$ these expressions become

$$MM_i^{K_S^0\pi\pi} = M_i^{K_S^0\pi\pi} + M_i^{K_S^0\pi\pi} = 2 \cdot h_{K_S^0\pi\pi}(T_i^{K_S^0\pi\pi} + T_{-i}^{K_S^0\pi\pi} - 2\,c_i\sqrt{T_i^{K_S^0\pi\pi}T_{-i}^{K_S^0\pi\pi}}\,(2F_+^{4\pi} - 1))$$
$$(1.3)$$

and

$$MM_i^{K_L^0 \pi\pi} = M_i^{K_L^0 \pi\pi} + M_{-i}^{K_L^0 \pi\pi} = 2 \cdot h_{K_L^0 \pi\pi} (T_i^{K_L^0 \pi\pi} + T_{-i}^{K_L^0 \pi\pi} + 2\, c_i' \sqrt{T_i^{K_L^0 \pi\pi} T_{-i}^{K_L^0 \pi\pi}} \, (2F_+^{4\pi} - 1)) \tag{1.4}$$

The following report summarised how the values for $MM_i^{K_S^0 \pi\pi}$ and $MM_i^{K_L^0 \pi\pi}$ are determined.

1.2.2   Binned $K_S^0 \pi\pi$ / $K_L^0 \pi\pi$ vs 4π yields

The values for $MM_i(K_S^0 \pi\pi)$ are obtained by counting the number of $K_S^0 \pi\pi$ / $K_L^0 \pi\pi$ vs. 4π events, subtracting the bkg in the sample and then correcting for different signal reconstruction and selection efficiencies in the different bins of the $K_S^0 \pi\pi$ / $K_L^0 \pi\pi$ Dalitz-Plot. The contributions to the yields for the $K_S^0 \pi\pi$ tag are listed below:

$$MM_i^{K_S^0 \pi\pi} = (N_i^{meas} - B_i^{peak} - B_i^{flat})/\epsilon_i \tag{1.5}$$

- $MM_i^{K_S^0 \pi\pi}$: absolute number of 4π vs $K_S^0 \pi\pi$ events in bin i. This is the quantity that enters the fit for F_+.

- N_i^{meas} : total number of reconstructed and selected events in bin i.

- B_i^{peak} : number of reconstructed and selected peaking bkg. events in bin i. The only peaking bkg. expected is $K_S^0 \pi\pi$ vs $K_S^0 \pi\pi$ where on of the $K_S^0 \pi\pi$ decays is reconstructed as a 4π.

- B_i^{flat} : number of reconstructed and selected flat bkg. events in bin i.

- ϵ_i : reconstruction and selection efficiency for 4π vs $K_S^0 \pi\pi$ events in bin i.

The values for $MM_i^{K_L^0 \pi\pi}$ are obtained using:

$$MM_i^{K_L^0 \pi\pi} = (N_i^{meas} - B_i^{peak} - B_i^{flat} - B_i^{cont})/\epsilon_i \tag{1.6}$$

- $MM_i^{K_L^0 \pi\pi}$: absolute number of 4π vs $K_L^0 \pi\pi$ events in bin i. This is the quantity that enters the fit for F_+.

- N_i^{meas} : total number of reconstructed and selected events in bin i.

- B_i^{peak} : number of reconstructed and selected peaking bkg. events in bin i. The two peaking bkgs considered in this case are $K_L^0 \pi\pi$ vs $K_S^0 \pi\pi$ where the $K_S^0 \pi\pi$ is reconstructed as 4π (8% of the events in the signal window) and $K_S^0 \pi\pi$ vs 4π where the K_S^0 is not reconstructed (1.9% of the events in the signal window).

- B_i^{flat} : number of reconstructed and selected flat bkg. events in bin i.

- B_i^{cont} : number of reconstructed and selected continuum bkg. events in bin i.

- ϵ_i : reconstruction and selection efficiency for 4π vs $K_L^0\pi\pi$ events in bin i.

The contributions for the $K_L^0\pi\pi$ tag have another component, which is the continuum bkg. This bkg does not appear in the $K_S^0\pi\pi$ tag because in this tag requires 4 pions to be reconstructed while in the $K_L^0\pi\pi$ case only 2 pions are reconstructed.
The distribution of reconstructed $K_S^0\pi\pi$/ $K_L^0\pi\pi$ vs 4π events in the phasespace of the tag can be seen in Figure 1.1.
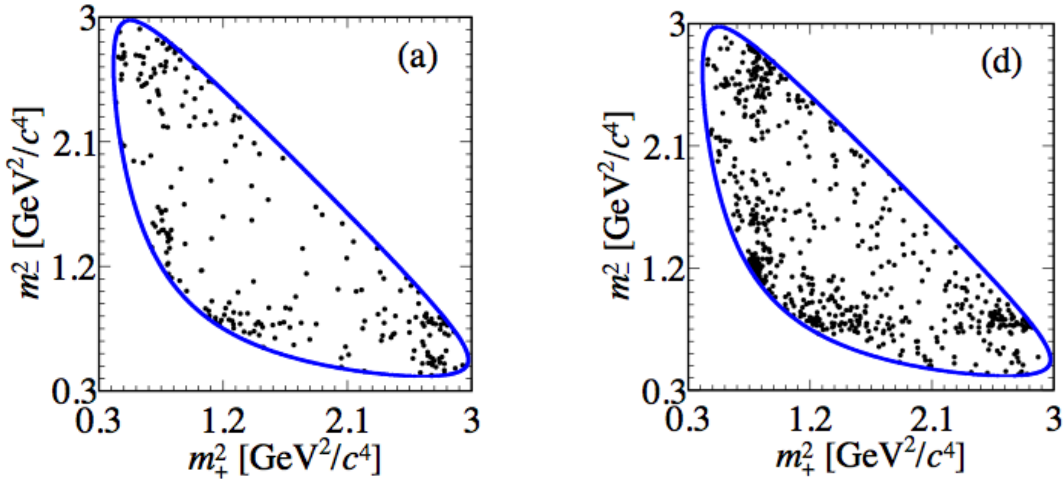
Figure 1.1: *Dalitz-plot distributions for $K_S^0\pi\pi$ (left) and $K_L^0\pi\pi$ (right) reconstructed against 4i.*

1.2.2.1 Determination of number of flat and continuum background events

The total number of flat bkg events is determined using a combination of sidebands and extrapolated to the signal region. As the name suggest, the flat background is distributed evenly over the $K_S^0\pi\pi$ phasespace. Therefore the distribution across the different $K_S^0\pi\pi$ bins is used according to the area of each bin.
The same is true for the continuum bkg, only that the total number of continuum bkg events was determined using the continuum MC sample produced by CLEO-c and scaling according to the luminosity of the data sample.

1.2.2.2 Determination of peaking bkg events

The total number of peaking bkg events was determined by scaling their contribution in the generic MC sample to the data sample. The distribution of those events over the bins of the $K_S^0\pi\pi$/ $K_L^0\pi\pi$ phasespace was determined using a combination of data-driven and MC-driven techniques.

1.2.2.3   Determination of the signal efficiency

The signal efficiency of both the $K_{\mathrm{S}}^0\pi\pi$ and the $K_{\mathrm{L}}^0\pi\pi$ tags were determined using a signal MC sample of 250k events.

1.2.3   Fit for $F_+(4\pi)$

1.2.3.1   Input from former analyses

The given values for K_i' obtained from Table 1 of `arXiv:1210.939` contain effects from charm-mixing that cancel in our case. The factors T_i without mixing are archived by numerically solving the system of equations:

$$K_i' = T_i + \sqrt{T_i T_{-i}}(yc_i + xs_i) \tag{1.7}$$

where x and y charm-mixing parameters. The fit also takes into account that the sum over the T_i should be one by fixing $T_1 = 1 - \sum_{i\neq 1} T_i$. The values for x and y are take from the latest HFAG results ($x = (0.63 \pm 0.19)\%$, $y = (0.75 \pm 0.12)\%$) and the values for c_i and s_i are taken from `arXiv:1010.2817`. In the fit all input variables are Gaussian constraint and the correlation between c_i and s_i are taken into account.

The fractional flavour-tagged $K_{\mathrm{L}}^0\pi\pi$ yields are taken from Sean Brisbane's thesis (Section 3., Table 3.14).

1.2.3.2   Results F_+

A fit for F_+ is performed for the default signal results, for the results with stat. error only.

In order to determine the effect of the systematic uncertainties - most of which come for the estimation of bkg events - the each systematic uncertainty is separately added to the statistic uncertainty and the fit is performed again.

Listing the statistical error and the systematic error from the Dalitz plot acceptance separately this results in $F_+ = 0.737 \pm 0.049 \pm 0.024$ where the first error is statistical and the second one systematic. These results are in very good agreement with the result from the CP-eigenstate analysis which yielded a value of $F_+ = 0.754 \pm 0.031 \pm 0.021$.
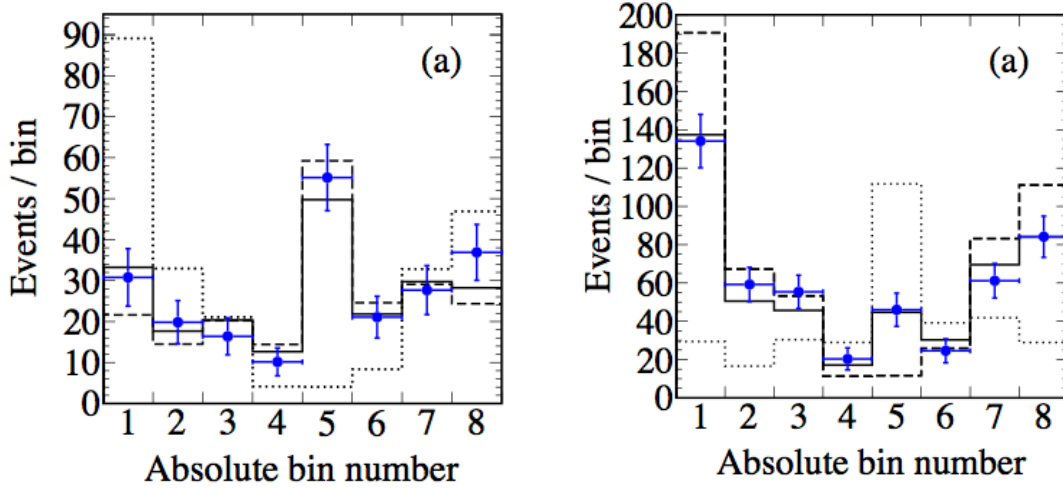
Figure 1.2: *Distribution of signal yields per bin for $K^0_S\pi\pi$ (left) and $K^0_L\pi\pi$ (right). Red: data, solid line: fit results, dotted line: values for F_+=0, dashed line: values for F_+=1.0.*

1.3   RICH alignment

The work on the RICH alignment for the LHCb detector consists mostly of making the existing alignment code work and producing an alignment on the data taken in the last days.

Additionally work on the ONLINE RICH alignment is ongoing which - amongst other things - consists of rewriting the existing alignment script in a way that is compatible with the Finite State Machine system under which the entire online framework operates.

1.4   Future work

The work for the next year includes the following steps

- finalize the work on the RICH alignment by producing a functioning and hopefully stable online alignment

- perform a c_i and s_i measurement for $D \to 4\pi$ on CLEO-c data and publish this

- if there is still time left in the year start working on the γ measurement at LHCb