Measuring charm mixing parameters using a model-independent technique in $D0 \rightarrow K_S h^+ h^-$

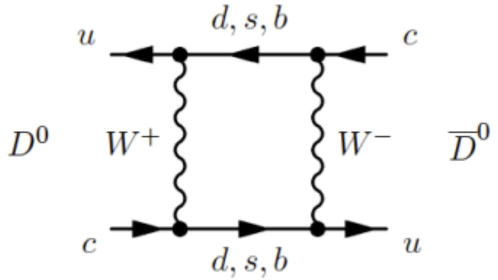
Tomáš Pilař on behalf of the LHCb Collaboration

Mixing overview

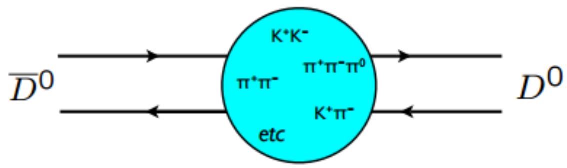
First evidence by BaBar and Belle in 2007

[Phys.Rev.Lett. 98 (2007) 211802,Phys.Rev.Lett. 98 (2007) 211803]

Can be short or long range:



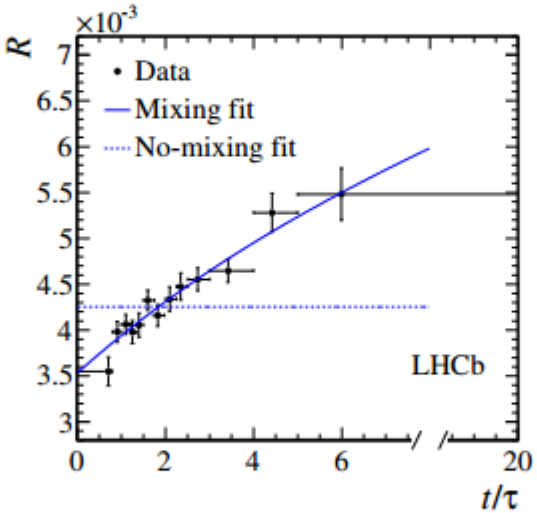
Mixing via box-diagram

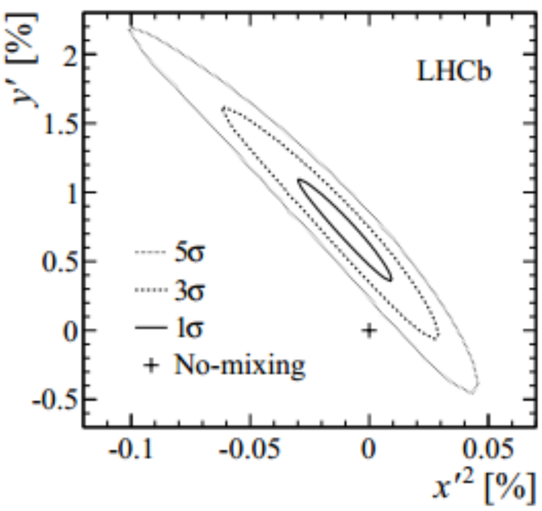


Mixing via hadronic intermediate states

New result from LHCb with 9σ

Phys.Rev.Lett. 110, 101802 (2013)





Mixing theory

Mixing arises from the off-diagonal elements of the mass and gamma matrix of the D^0 evolution equation.

$$i\frac{\partial}{\partial t}\begin{pmatrix} D^0(t) \\ \bar{D}^0(t) \end{pmatrix} = (\mathbf{M} - \frac{i}{2}\mathbf{\Gamma})\begin{pmatrix} D^0(t) \\ \bar{D}^0(t) \end{pmatrix}$$

$$M_{11} \equiv M_{22}, \Gamma_{11} \equiv \Gamma_{22}$$

Can express mass eigenstates in terms of flavour eigenstates as follows:

$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$$

$$|p|^2 + |q|^2 \equiv 1$$

$$\left(\frac{q}{p}\right)^2 = \frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}$$

Corresponding eigenvalues depend solely on the masses and widths of $D_{1,2}$ thus we can express the mixing using dimensionless parameters x and y.

$$\boxed{x \equiv \frac{(m_1 - m_2)}{\Gamma} = \frac{\Delta m}{\Gamma}}$$

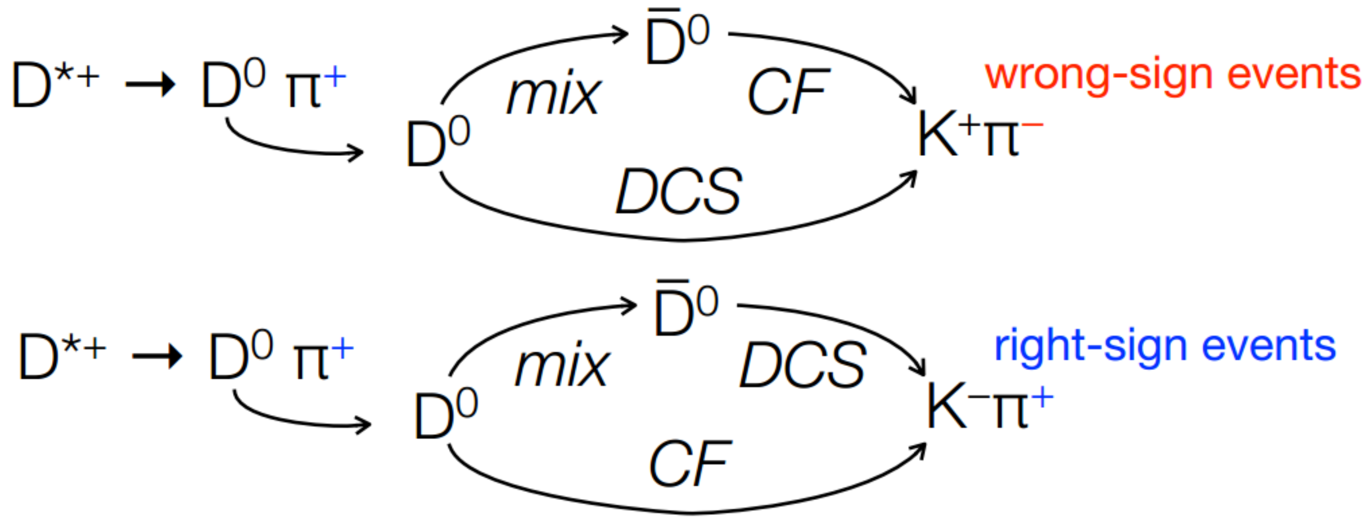
$$\boxed{y \equiv \frac{(\Gamma_1 - \Gamma_2)}{2\Gamma} = \frac{\Delta\Gamma}{2\Gamma}}$$

If CP is conserved then q and p are real and q/p = 1

One should note that |x|,|y| << 1 which makes this a much different game compared to B or K systems.

Mixing theory

Common ways of extracting mixing exploit interference between Cabibbo favoured and Cabibbo suppressed decays into the same final state.



This allows for extractions of variables transformed by the strong phase δ:

$$R(t) = \frac{N_{WS}(t)}{N_{RS}(t)} = R_D + \sqrt{R_D}\,y't + \frac{x'^2 + y'^2}{4}t^2 \qquad \boxed{\begin{aligned} x' &= x\cos\delta + y\sin\delta \\ y' &= y\cos\delta - x\sin\delta \end{aligned}}$$

Outline and Motivation

Extraction of charm mixing parameters x and y using prompt $D^0 \to K_S h^+ h^-$ decays (specifically ππ and KK). Some sensitivity to indirect CP violation.

- Sensitivity to relative sign of x and y
- Complementary other mixing analyses
- Large number of $D^0 \to K_S h^+ h^-$ events in the LHCb dataset
- Major analysis for the LHCb upgrade program
- Access to indirect CP violation
- Implementation and validation of lifetime bias correction
- Field test of analysis techniques (see Nick Torr's slides)

Current situation:

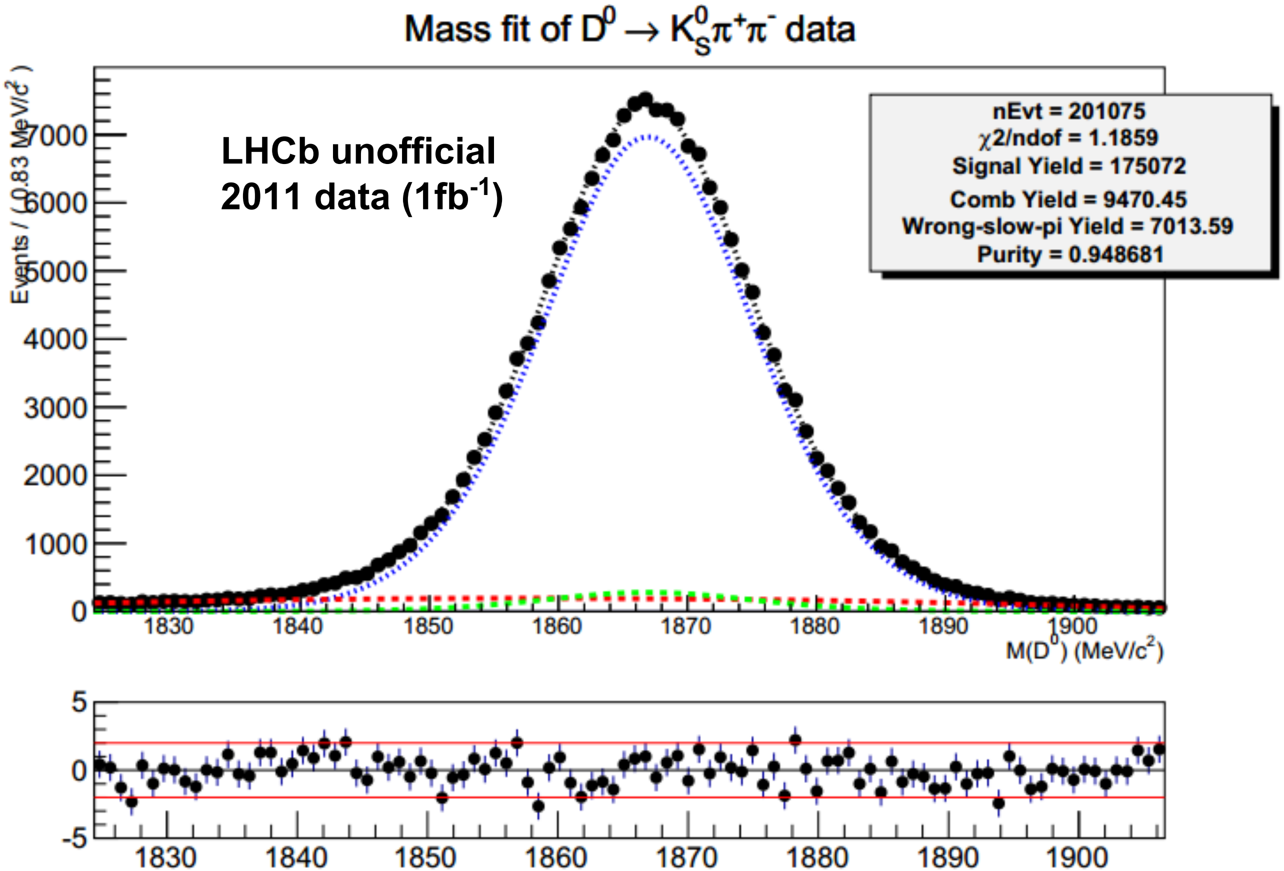
- Working on the 2011 dataset for now (reduced statistics cf. 2012)
- Multiple approaches to analysis (various dependence on models)

Dataset

Currently working on the 2011 dataset (1 fb^{-1}), using only well reconstructed K_S due to trigger limitation (decayed in VELO -> fd_{Ks} < 60cm)

Very good purity out of stripping (92% in the mass window 43.8 MeV/c^2)

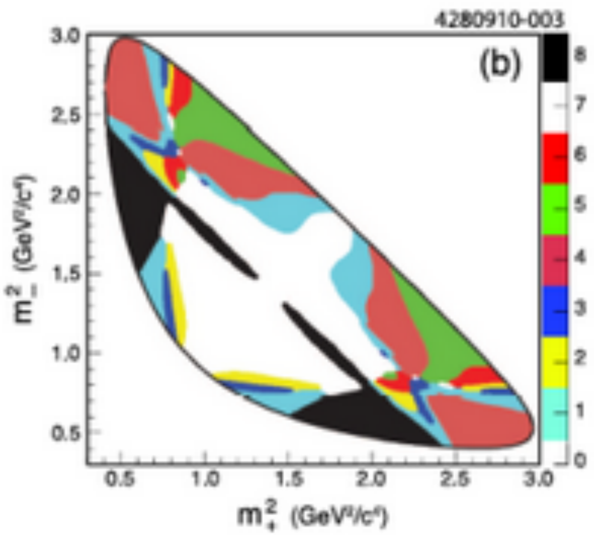
Simple rectangular cut based selection.

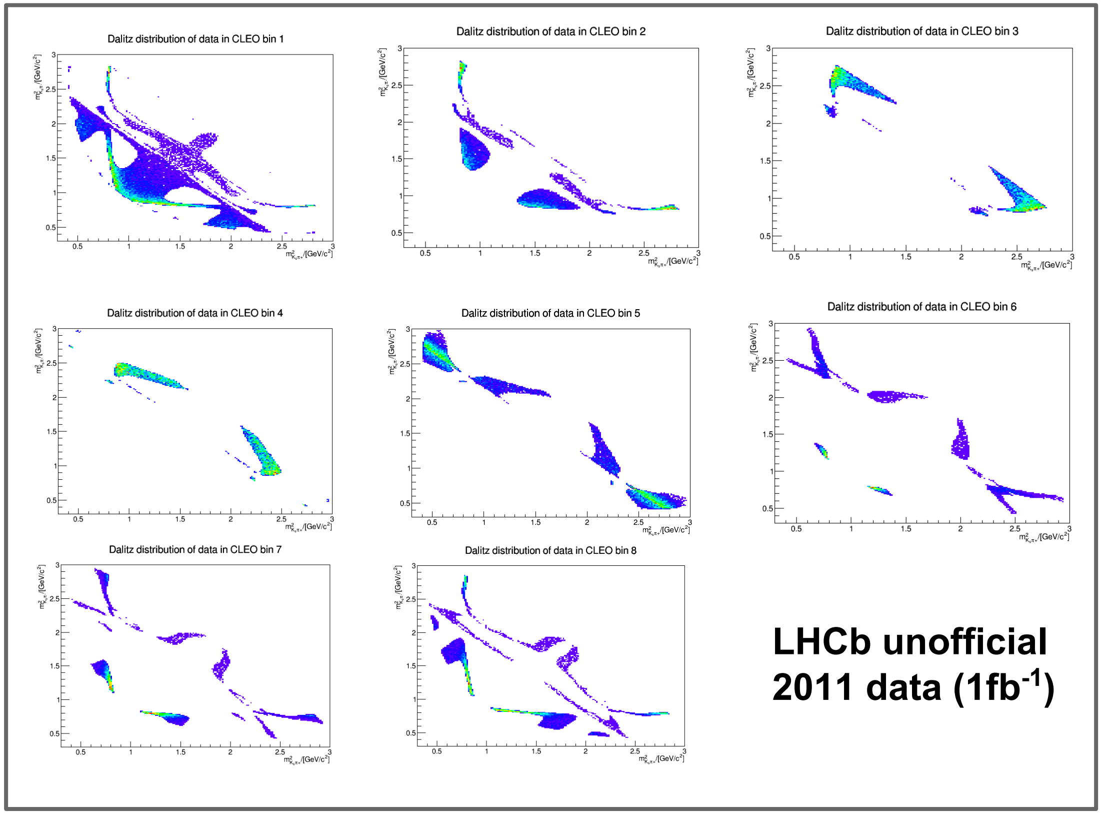


Model independent approach

Eliminate the Dalitz amplitude model from the analysis - eliminate the model systematic uncertainty
The approach uses binning in the Dalitz space to average the strong phase information. This removes the model from the equation requires us to know the strong phase content in each bin.

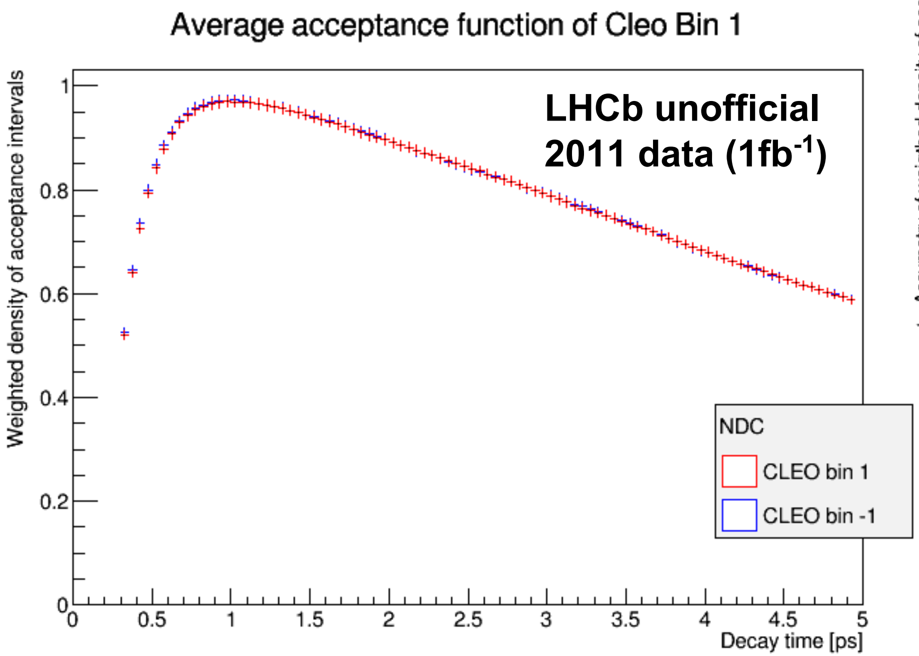
Fortunately, CLEO already measured this using quantum correlated **Ψ(3770)** decays. We are looking at two different binning schemes: equal-Δδ (crosscheck) and optimal (analysis)

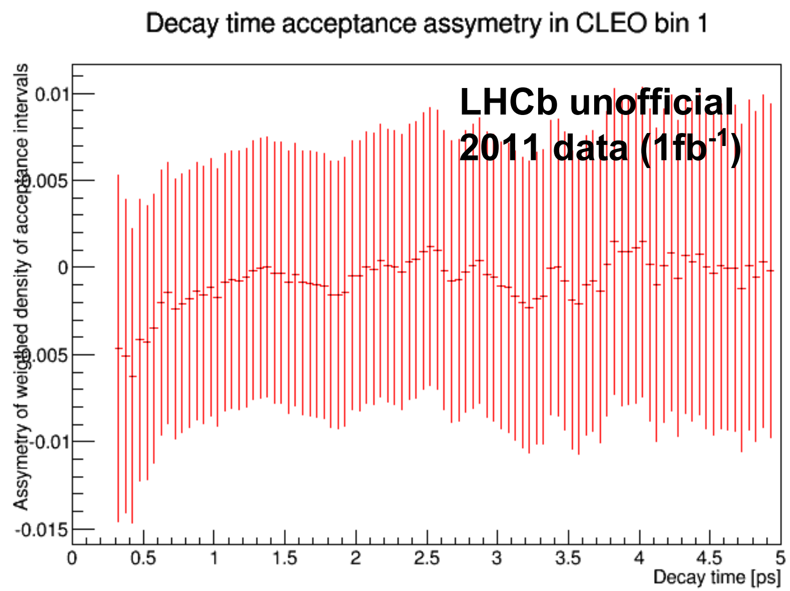




Swimming

Technique to account for lifetime bias due to trigger, stripping and selection cuts on the data.
Consists of sampling the respective decisions while moving the primary vertex along the D^0 flight direction along the entire VELO and weighting each event with this acceptance function.





Model independent approach

Required CLEO information:
(http://arxiv.org/abs/1010.2817)
:

$$\boxed{T_i = \int_i a_{12,13}^2 \mathrm{d}m_{12}^2 \mathrm{d}m_{13}^2}$$

Expected number of evens in bin i

$$c_i = \frac{1}{\sqrt{T_i T_{-i}}} \int_i a_{12,13} a_{13,12} \cos(\delta_{12,13} - \delta_{13,12}) \mathrm{d}m_{12}^2 \mathrm{d}m_{13}^2$$

$$s_i = \frac{1}{\sqrt{T_i T_{-i}}} \int_i a_{12,13} a_{13,12} \sin(\delta_{12,13} - \delta_{13,12}) \mathrm{d}m_{12}^2 \mathrm{d}m_{13}^2$$

Integrated strong phase information in bin i

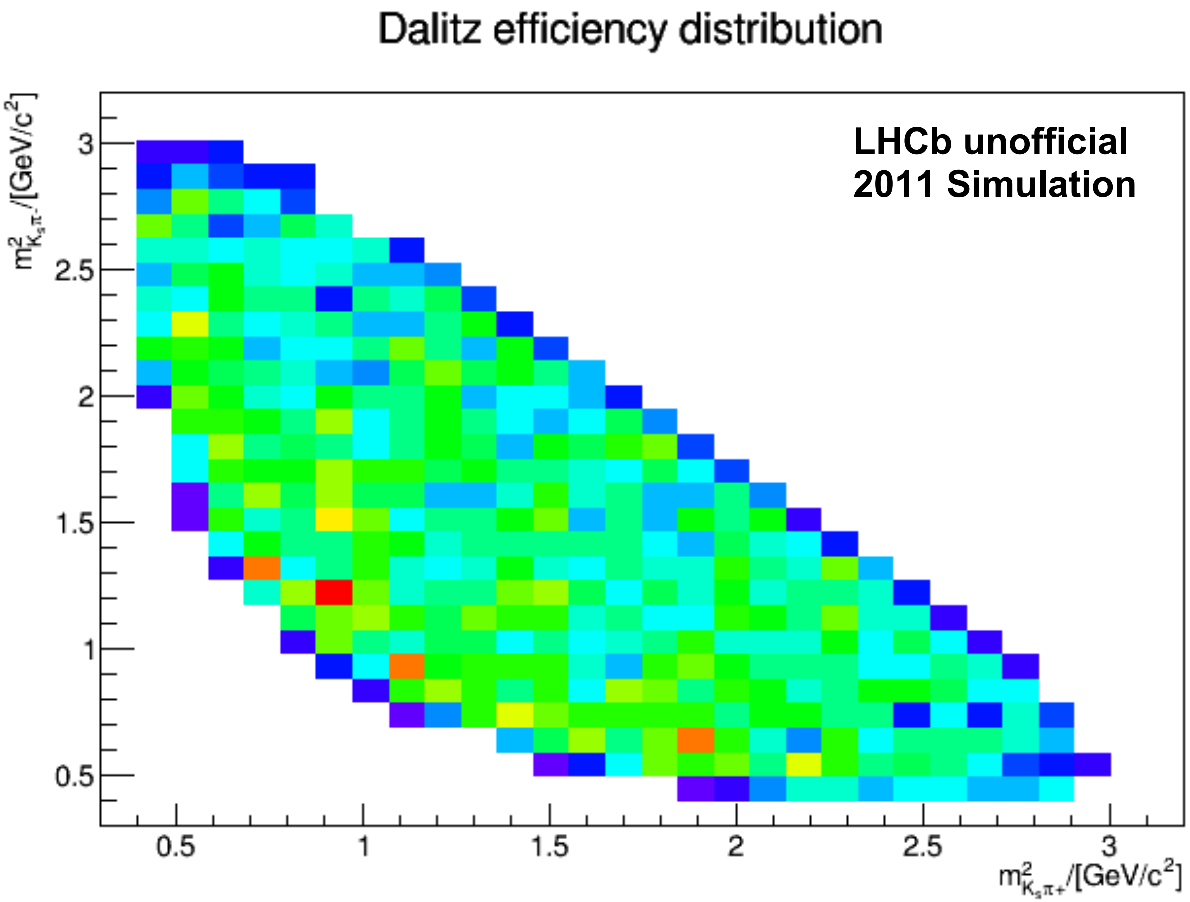
This introduces 32 ($c_i = c_{-i}$ and $s_i = -s_{-i}$) parameters that are floated in the fit.

Also, a systematic limitation depending on our current knowledge of these parameters. BES-III should be able to improve these measurements (maybe some potential futur echarm factories as well)

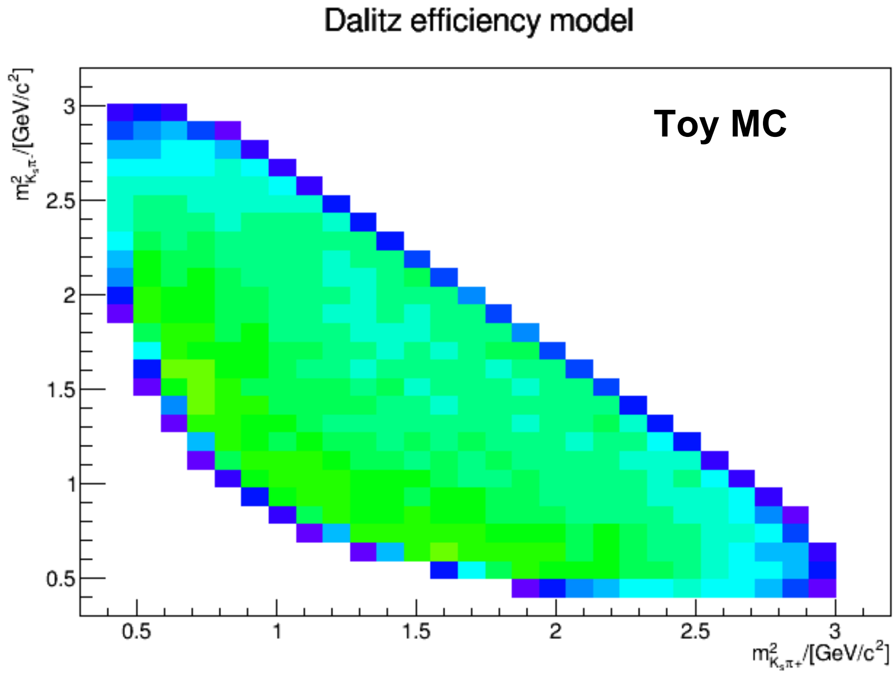
Model independent approach

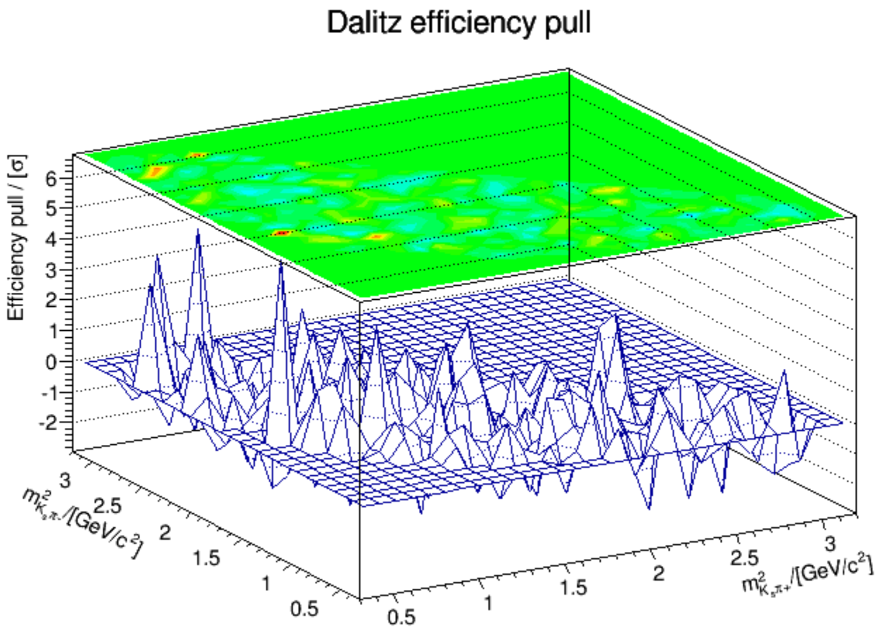
Another issue is efficiency variation across the Dalitz plot. In model dependent approach this is absorbed in the fit, but with binning we need to know the variation of efficiency across each bin.

Efficiency was extracted using phase-space flat MC passed through trigger, stripping and selection and then fitted with a custom symmetric model.



Model independent approach





$$\epsilon(m^2_{K_s\pi^+}, m^2_{K_s\pi^-}) = au^3 + bu^2 + cu^2v + du + euv + fv + gv^2 + hv^3$$

$$u = (m^2_{K_s\pi^+} + m^2_{K_s\pi^-}), v = |m^2_{K_s\pi^+} - m^2_{K_s\pi^-}|$$

This parametrisation gave the best fit result (χ/ndf ~ 343/321 ~ 1.07).

Conclusion

To sum up:

- The model independent approach provides an alternative approach to a full amplitude analysis with its own benefits and drawbacks
- This dataset should already give us a handle on relative sign of x and y
- The current CLEO strong phase measurements should be sufficient for the 2011 dataset, future charm factories should improve these
- We are ready to start fitting with 2011 data (paper in summer)

Future:

- The LHCb now has 3.5 (fb^{-1}) corresponding to 3.5M events for us
- Much better sensitivity to mixing and CPV parameters
- Inclusion of D^0 from semileptonic B decays