CP-violating lifetime asymmetries of prompt two-body charm decays at LHCb

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1) Introduction

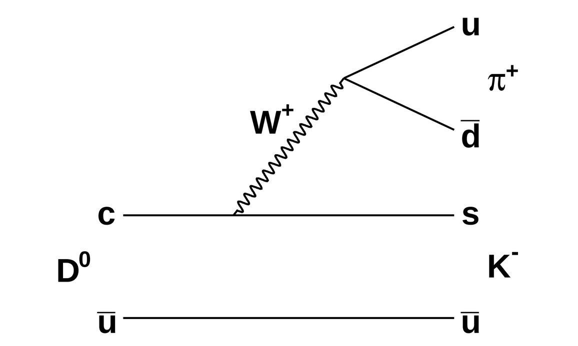
- Measurements of asymmetries in the behaviour of matter and anti-matter through the mechanism of CP-violation (CPV) are presented here.
- The standard Model predicts that CPV in the D^0 system will be very small.

The world's most accurate measurements of the CP violation observable A_Γ are presented here.

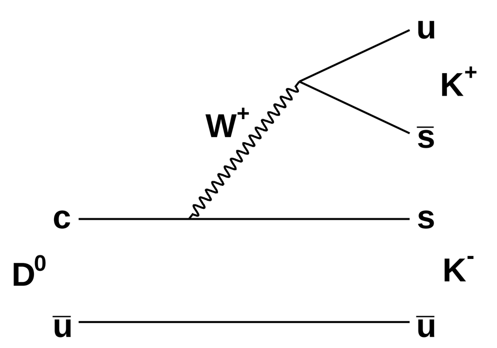
- Two methods are used. The first measures A_Γ as the yield asymmetry between D^0 and $\bar{D}^0$ in bins of decay time. The other method is described here.
- Both analyses use $D^{*+} \to (D^0 \to hh)\pi^+$ decays which have come directly from the primary vertex (*Prompt*), where h is π or K. *Secondary* events are those in which the D^* comes from a B or other long lived particle.

Theory

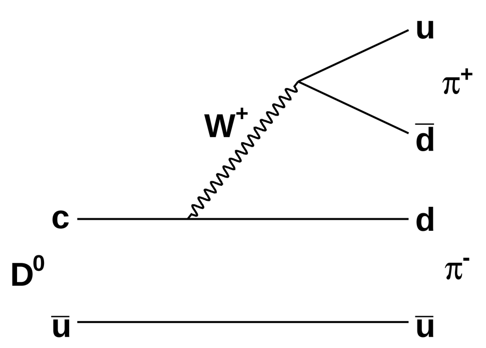
- Non-zero off diagonal elements of the CKM matrix allow for mixing between different quark generations.
- CPV can occur in the interference between decays to the same final state, with and without mixing.
- D^0 and $\bar{D}^0$ can both decay to CP-eigenstates.



Cabibbo Favoured(Control)



CP-eigenstate



CP-eigenstate

2) Effective Lifetime Measurements

- The observable of interest to this analysis is the asymmetry between the effective decay widths, $\hat{\Gamma}$ of D^0 and its anti-particle $\bar{D}^0$:

$$A_\Gamma = \frac{\hat{\Gamma}(D^0 \to f) - \hat{\Gamma}(\bar{D}^0 \to f)}{\hat{\Gamma}(D^0 \to f) + \hat{\Gamma}(\bar{D}^0 \to f)},$$

- $\hat{\Gamma}$ is related to the time dependent decay rate by $\Gamma(t; D^0 \to f) \propto \exp\left(-\hat{\Gamma}(D^0 \to f)t\right)$ and $\hat{\tau} = 1/\hat{\Gamma}(D^0 \to f)$ is the effective lifetime of the D^0 decay, which is measured here.

This observable has contributions from both CPV in Mixing, A_m, and direct CPV, A_d [1],where ϕ is the CP violating phase between mixing and decay,

$$A_\Gamma \approx \eta_{CP}\left\{\frac{1}{2}(A_m + A_d)y\cos\phi - x\sin\phi\right\}.$$

3) Lifetime Biases

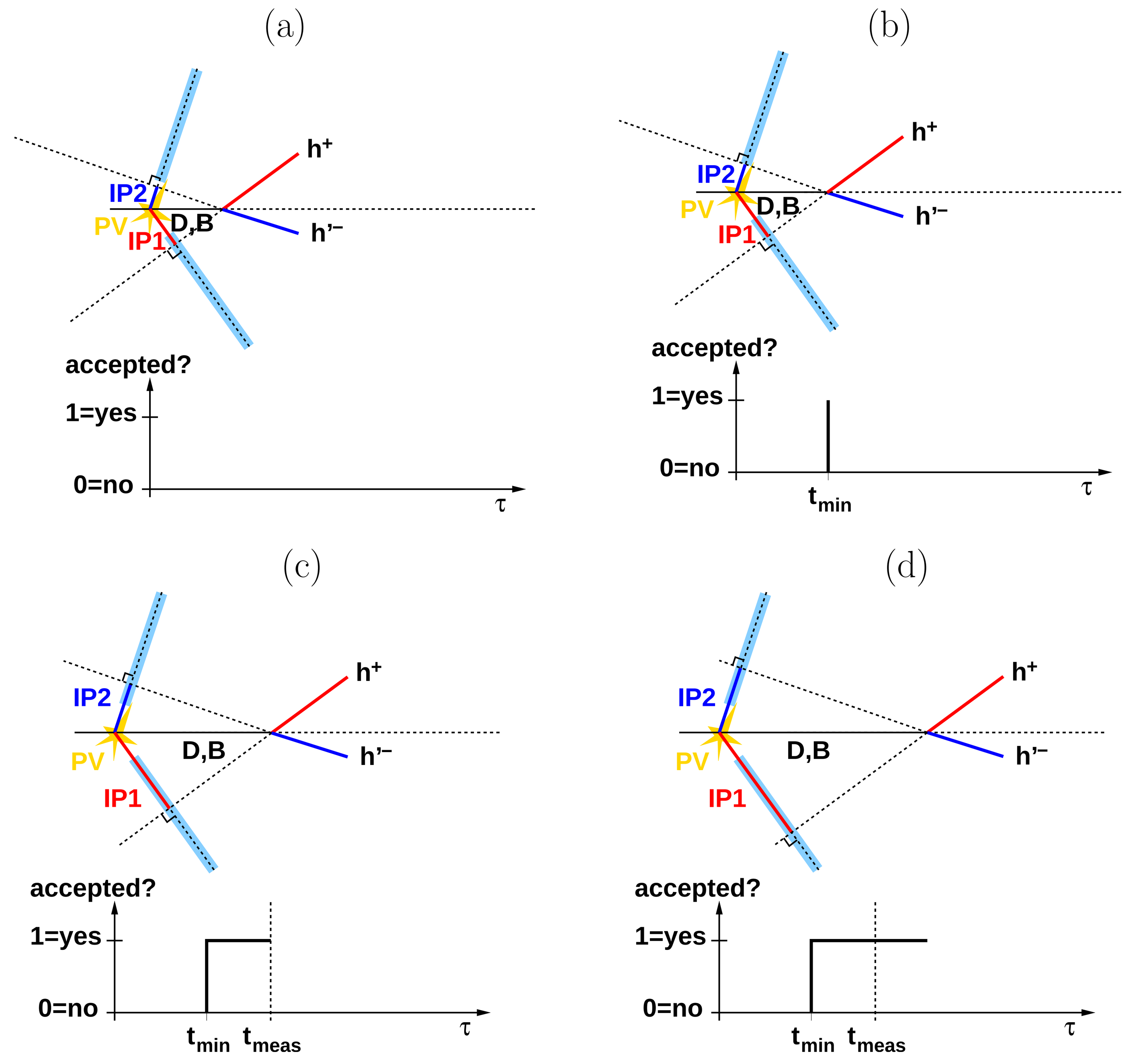
- The D^0 travels a few millimeters before decaying, thus the event selection searches for candidates with displaced vertices.
- A number of selection cuts create biases in the measured lifetimes:

1. **A cut on low Impact Parameter (IP) and low χ^2_{IP} candidates is made in the trigger to remove combinatoric backgrounds which do not have a displaced vertex. However this creates a bias in the lifetime as it removes short lived candidates which decay near the PV.**
2. An offline cut is made to the radial distance of flight of the D^0 candidates at $R > 4$ mm to reduce detector material interaction.
3. Many smaller biasing effects also. Ask Me!

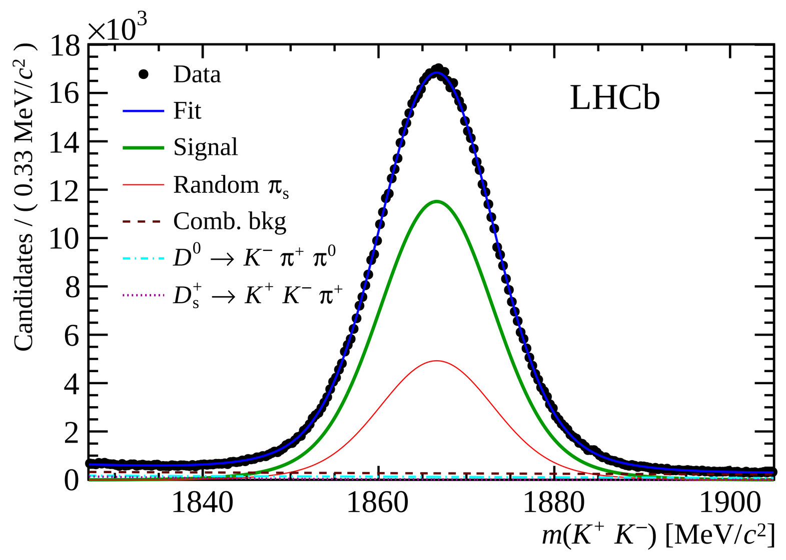
Swimming Algorithm

The swimming algorithm is a data driven method for measuring the per event lifetime acceptance caused by biases in selection criteria [2]

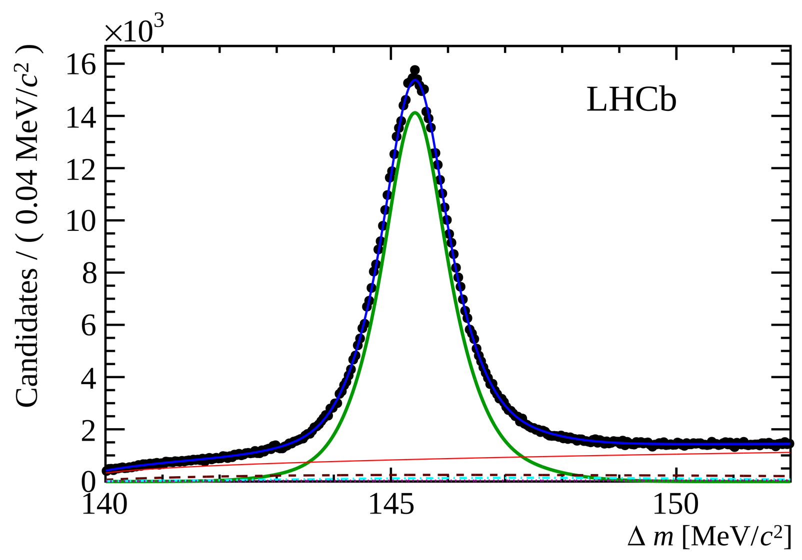
- The D^0 decay vertex is moved in steps along its momentum direction and the selection decision is recalculated at each of these discrete points.
- However, in practice it is easier to move the PV instead of the D^0 vertex.
- This results in a per event acceptance function which is a series of turn off and turn on points. The figures show how IP cuts affect the acceptance.
- The lifetime acceptance function used in the fit is the sum of the per event acceptance functions weighted by the probability of the event being signal or background.



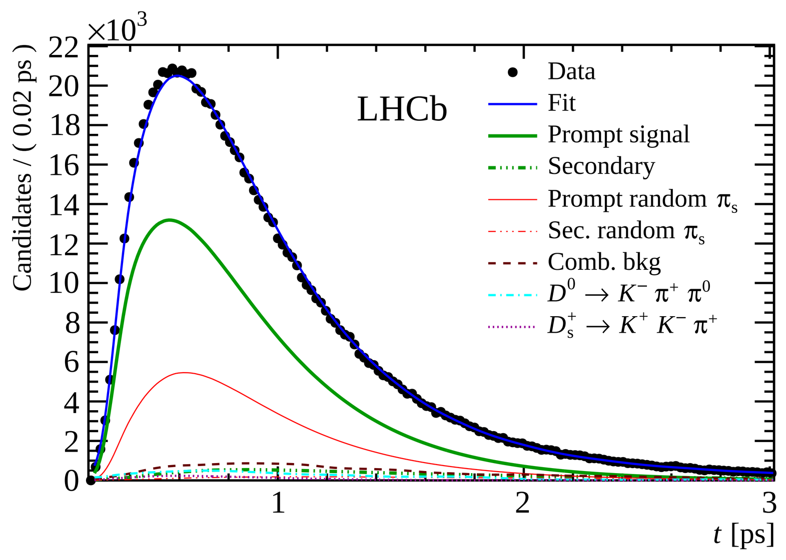
4) $D^0 \to K^+K^-$ Fit: One Sample



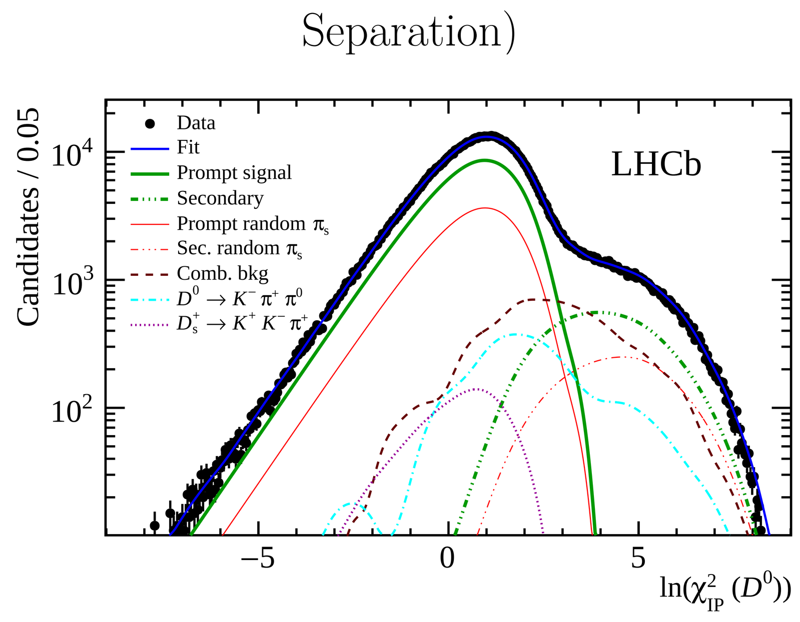
D^0 Mass (Combinatorial Separation)



D* Mass minus D^0 Mass (Mistagged Separation)



Lifetime



$\ln(\chi^2_{IP})$ (Secondary Separation)

5) Results [3]

A_Γ is found to be consistent with no CPV:

$$A_\Gamma(D^0 \to K^+K^-) = (-0.14 \pm 0.37 \pm 0.10) \times 10^{-3},$$
$$A_\Gamma(D^0 \to \pi^+\pi^-) = (\ \ 0.14 \pm 0.63 \pm 0.15) \times 10^{-3}.$$

Complimentary measurement with different analysis method:

$$A_\Gamma(D^0 \to K^+K^-) = (-0.30 \pm 0.32 \pm 0.10) \times 10^{-3},$$
$$A_\Gamma(D^0 \to \pi^+\pi^-) = (\ \ 0.46 \pm 0.58 \pm 0.12) \times 10^{-3}.$$

A difference between the final states indicates new physics, no difference is seen:

$$\Delta A_\Gamma = (-0.76 \pm 0.66 \pm 0.04) \times 10^{-3}.$$

Assuming the difference is zero, the average is:

$$A_\Gamma = (-0.13 \pm 0.28 \pm 0.10) \times 10^{-3}.$$

References

[1] M. Gersabeck and Others, "On the interplay of direct and indirect CP violation in the charm sector" *J.Phys.*, 2012.

[2] J. Rademacker, "Reduction of statistical power per event due to upper lifetime cuts in lifetime measurements" *Nucl.Instrum.Meth.*, vol. A570, pp. 525–528, 2007.

[3] R. Aaij *et al.*, "Measurement of the CP violation parameter A_Γ in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays" CERN-EP-2017-028 [Submitted to PRL].

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