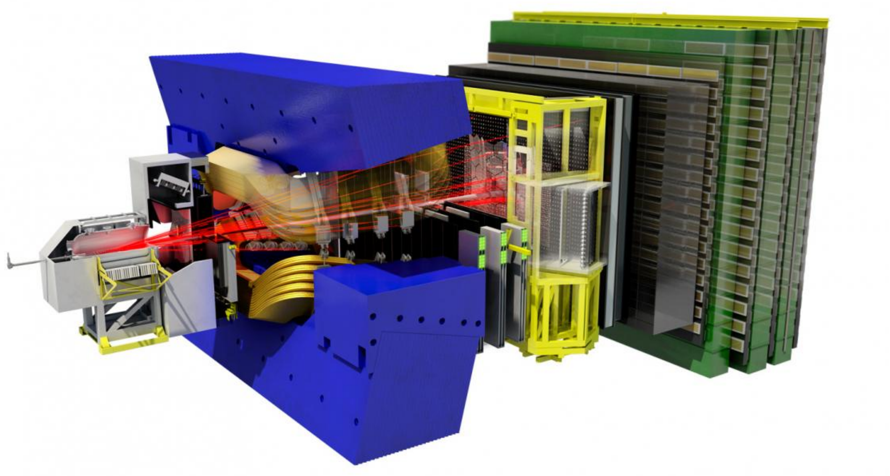
Measurement of D^0 mixing and *CP* violation in $D^0 \to K^+\pi^-$ decay at LHCb



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Mixing and *CP* Violation

The mass eigenstates of a charmed neutral meson can be written as linear combinations of flavour eigenstates $|D_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle$, hence it follows the D^0-$\overline{D}^0$ oscillation.

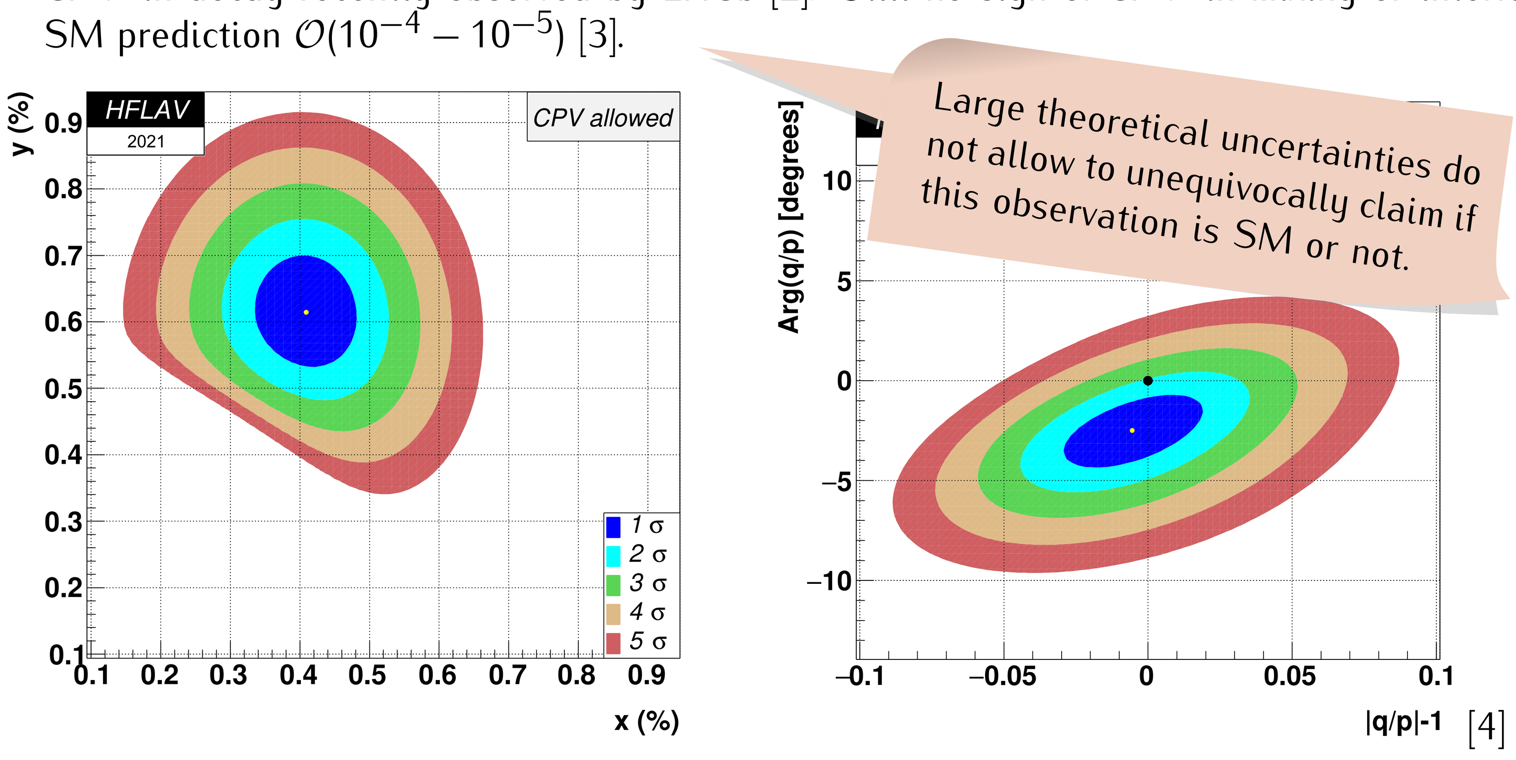
Three different *CP* violation (*CPV*) phenomenologies can be observed:

- *CPV* in decay $|\mathcal{A}_f| \neq |\overline{\mathcal{A}}_{\bar{f}}|$;
- *CPV* in mixing $|q| \neq |p|$;
- *CPV* in interference between decay and mixing $\arg(q\overline{\mathcal{A}}_f/p\mathcal{A}_f) \neq -\arg(q\overline{\mathcal{A}}_{\bar{f}}/p\mathcal{A}_{\bar{f}})$.
  In charmed mesons, with good approximation, this is equivalent to $\phi \equiv \arg\left(\frac{q}{p}\right) \neq 0$.

In the limit of *CP* symmetry, mixing is characterized only by the difference in mass and in decay width between mass eigenstates, conveniently expressed in terms of dimensionless mixing parameters $x \equiv \Delta m/\Gamma$ and $y \equiv \Delta\Gamma/2\Gamma$.

Motivation

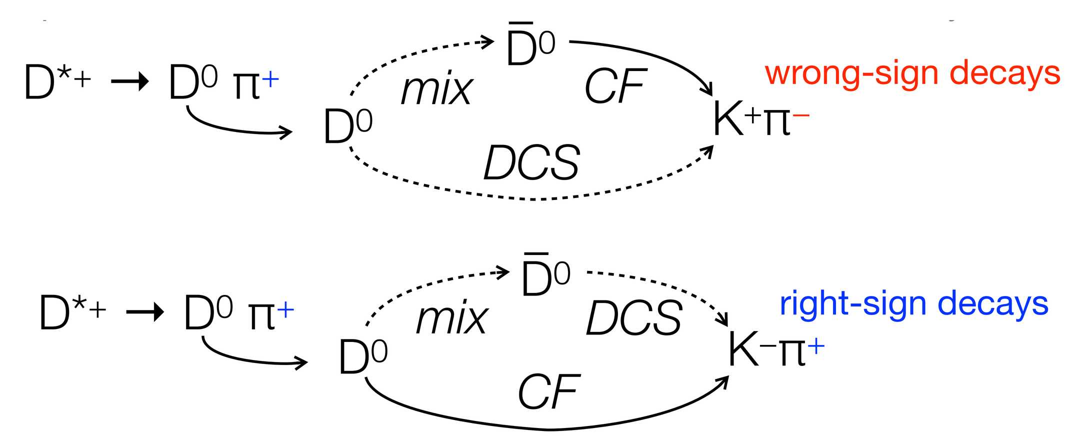
- **Charm is the only up-type quark where *CPV* can be observed.**
- Mixing in D^0-$\overline{D}^0$ well established, non null x value observed recently by LHCb [1].
- *CPV* in decay recently observed by LHCb [2]. Still no sign of *CPV* in mixing or interference, SM prediction $\mathcal{O}(10^{-4} - 10^{-5})$ [3].



[4]

Analysis detail

The aim is to measure time dependence of WS-to-RS ratio:



that is predicted to be $R(t) \simeq R_D + \sqrt{R_D}y'\Gamma t + (x'^2 + y'^2)/4 \cdot (\Gamma t)^2$, where x' and y' are a rotation of the mixing parameters x and y by the strong phase δ, (measured by CLEO and BESIII):

$$x' = x\cos\delta + y\sin\delta, \qquad y' = y\cos\delta - x\sin\delta.$$

Repeating the measurement independently for D^{*+} and D^{*-} samples provides two sets of parameters: $(R_D^{\pm}, x'^{2\pm}, y'^{\pm})$, allowing to access *CPV* parameters:

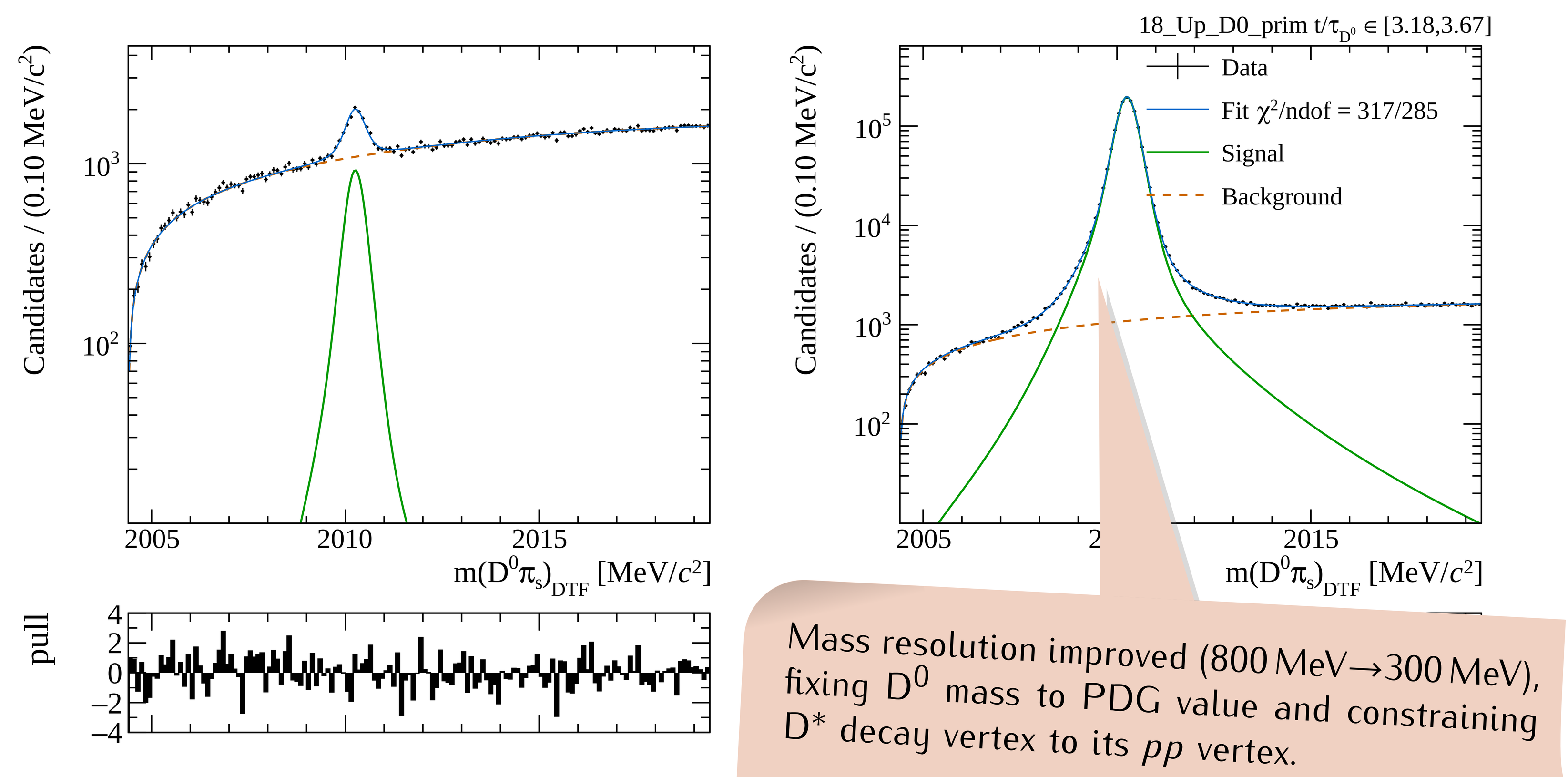
$$A_D = \frac{R_D^+ - R_D^-}{R_D^+ + R_D^-}, \quad x'^{\pm} = \left|\frac{q}{p}\right|^{\pm 1}(x'\cos\phi \pm y'\sin\phi), \quad y'^{\pm} = \left|\frac{q}{p}\right|^{\pm 1}(y'\cos\phi \mp x'\sin\phi)$$

The data sample is full Run 1 (2011-12, 3 fb^{-1} @ $\sqrt{s}$ = 7,8 TeV) and Run 2 (2015-18, 6 fb^{-1} @ $\sqrt{s}$ = 13 TeV) collected at the LHCb experiment, for a total of about 500k WS candidates and 2M RS candidates. This is an update of the previous LHCb measurement (data up to 2016) [5].

Yield determination

The sample is divided in 30 equally populated D^0 decay-time bins in the range $[0.4\tau_{D^0}, 8\tau_{D^0}]$.

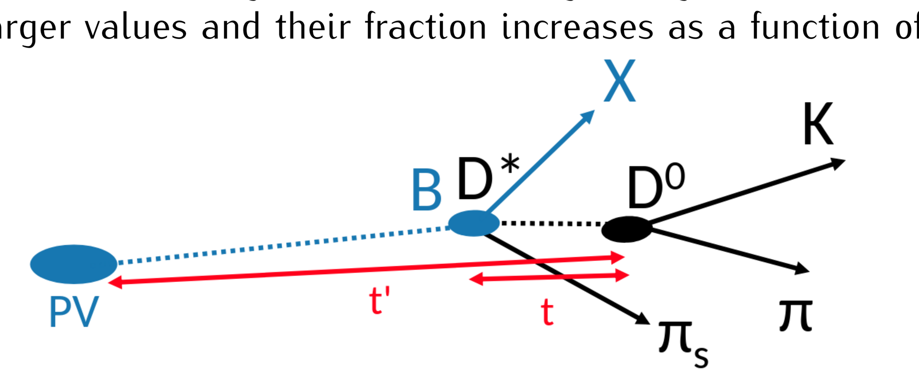
The number of WS (left) and RS (right) candidates is determined in each bin, separating signal from combinatorial background, by a χ^2 binned fit to the D^* mass distribution with empirical models.

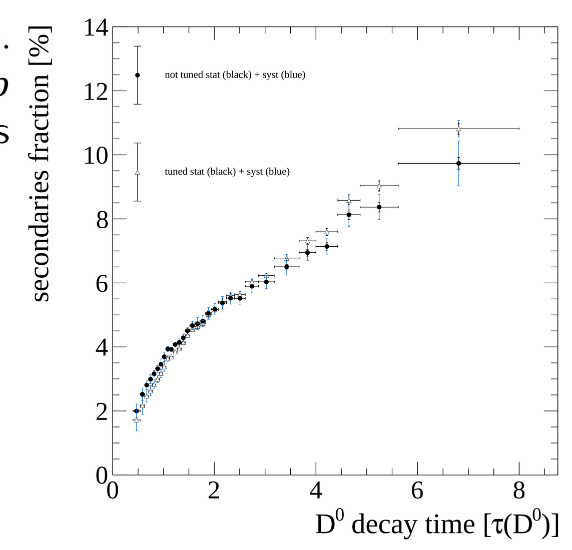


WS and RS are fitted simultaneously with shared signal shapes. Each decay-time bin, data-taking year, magnet polarity and D^0 flavour sample is independently fitted. Then the raw ratio $\widetilde{R}_i$ is computed for each decay-time bin i.

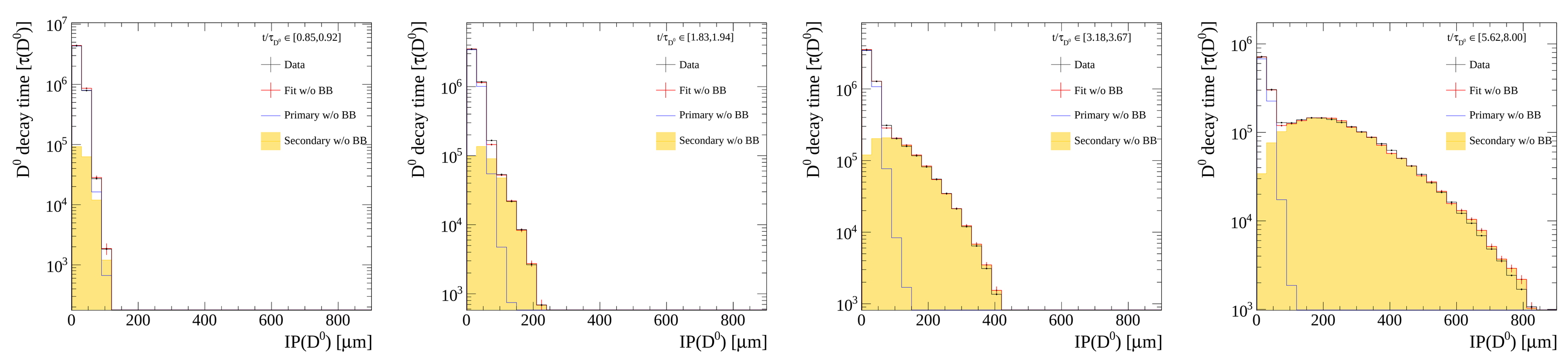
Secondary D^{*+} decays

They are D^{*+} mesons produced in the decay of a b hadron. Since the flight distance of the D^0 is measured from the pp vertex, the decay time of secondary decays is biased towards larger values and their fraction increases as a function of time.





This dilute the mixing effect, biasing $\widetilde{R}$: $\widetilde{R}_i = R_i \cdot \left(1 - f_i^B\right) + R_i^B \cdot f_i^B$, where R is the ratio of prompt candidates, R^B is the ratio of secondary candidates and f^B their fraction.



Other minor background

- Detection asymmetry: different reconstruction efficiency in WS and RS decays may emulate a physical *CPV*: $\widetilde{R}^{\pm} = R^{\pm}\frac{\epsilon(K^{\pm}\pi^{\mp})\epsilon(\pi_s^{\pm})(1 \pm A_p)}{\epsilon(K^{\mp}\pi^{\pm})\epsilon(\pi_s^{\pm})(1 \pm A_p)} = R^{\pm}\frac{\epsilon(K^{\pm}\pi^{\mp})}{\epsilon(K^{\mp}\pi^{\pm})}$, $A_D(K^-\pi^+) \simeq (1 \pm 0.1)\%$
- Peaking background: doubly-misidentified RS decays produce a narrow enhancement in the mass distribution biasing the measurement. PID requirement are tight and and the contamination of such background is estimated to be very small: $p \simeq (1 \pm 0.3) \times 10^{-3}$.
- Ghost pions background: soft pion tracks made by segments of different particles, peak at m value. They can make RS decays (much more common) looking like WS decays. The effect is small but not negligible, $\mathcal{O}(10^{-2} - 10^{-3})$.

Result and conclusions

Uncertainties on mixing parameters is expected to improve by a factor 1.4 (adding 2017 and 2018 data) and relevant biased of past analysis strategy has been removed.

References

[1] R. Aaij *et al.* [LHCb collaboration, arXiv:2106.03744, submitted to Phys. Rev. Lett.

[2] R. Aaij *et al.* [LHCb collaboration], *Phys. Rev. Lett.* **122**, 211803 (2019).

[3] A. L. Kagan and L. Silvestrini,, *Phys. Rev.* D **103**, 053008 (2021).

[4] Y. Amhis *et al.* [HFLAV collaboration], *Eur. Phys. J.* C **81**, 226 (2021).

[5] R. Aaij *et al.* [LHCb collaboration], *Phys. Rev.* D **97**, 031101 (2018).