Direct $\mathcal{CP}$-violation using prompt 2-body charm decays at LHCb

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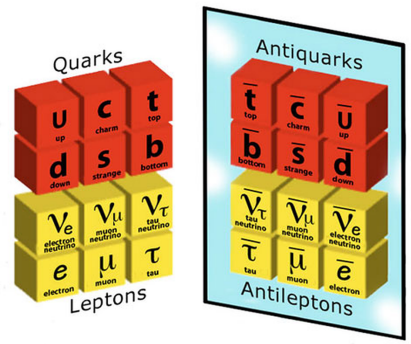
$\mathcal{CP}$-violation in the Standard Model vs observation

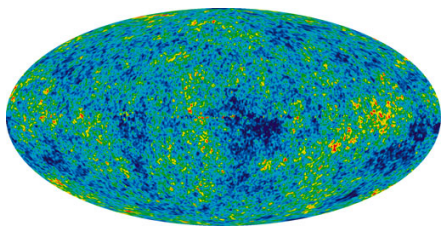
$\mathcal{CP}$-violation in the SM:

$$\eta \approx \mathcal{O}(10^{-20})$$



$\mathcal{CP}$-violation in the universe:

$$\eta = (6.21 \pm 0.16) \times 10^{-10}$$



Direct $\mathcal{CP}$-violation:

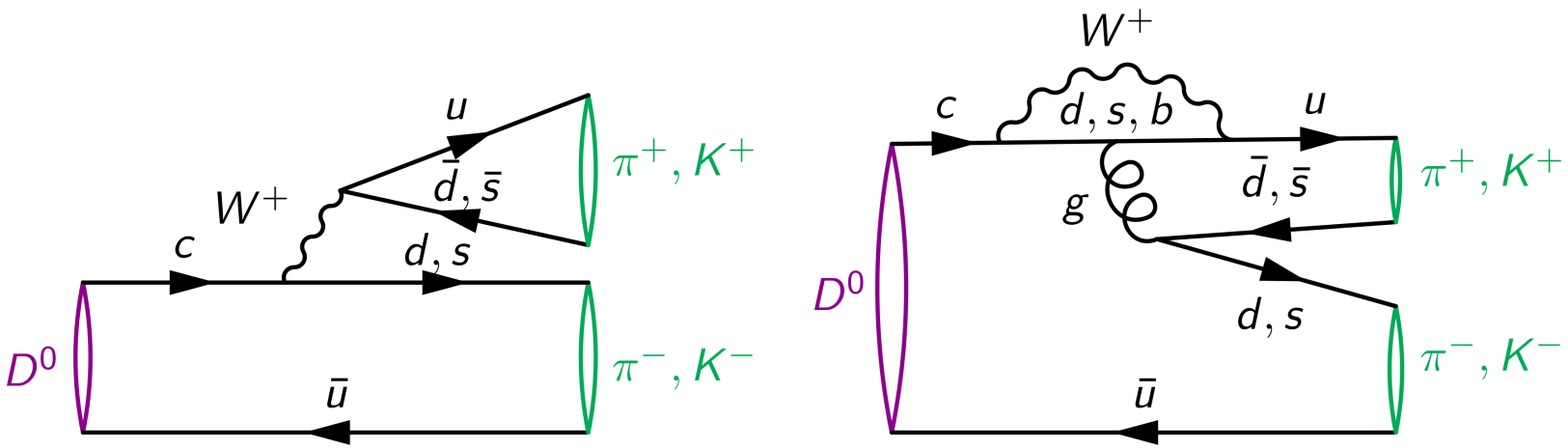
$A \to B \neq \bar{A} \to \bar{B}$

indirect $\mathcal{CP}$-violation:

$A \to \bar{A} \neq \bar{A} \to A$

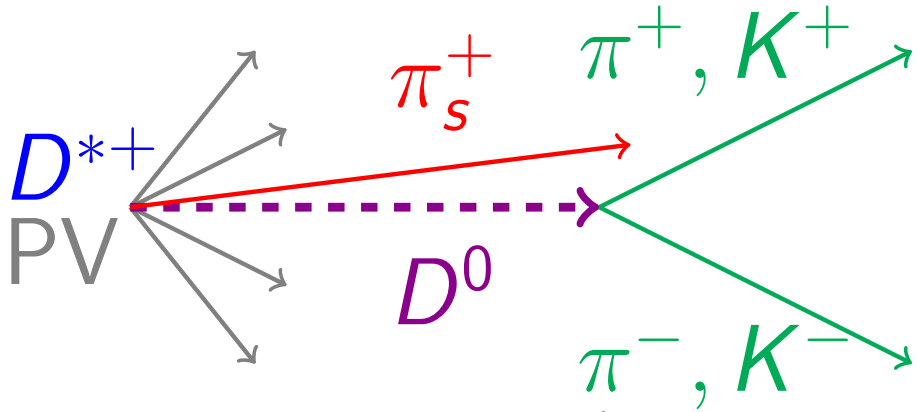
Introduction

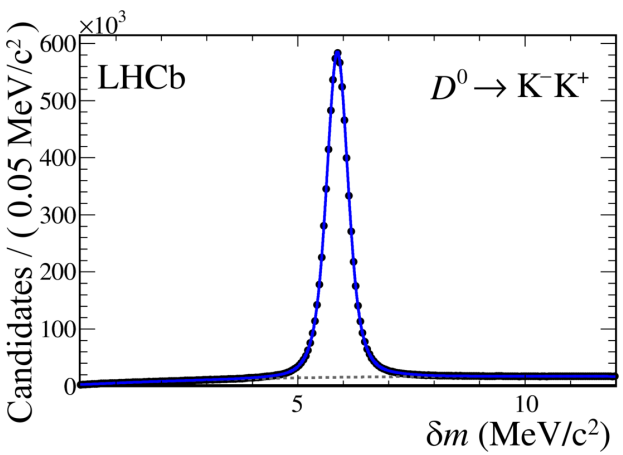
Use the $\mathcal{CP}$-even decays $D^0 \to K^- K^+$ and $D^0 \to \pi^+ \pi^-$ to study direct $\mathcal{CP}$-violation

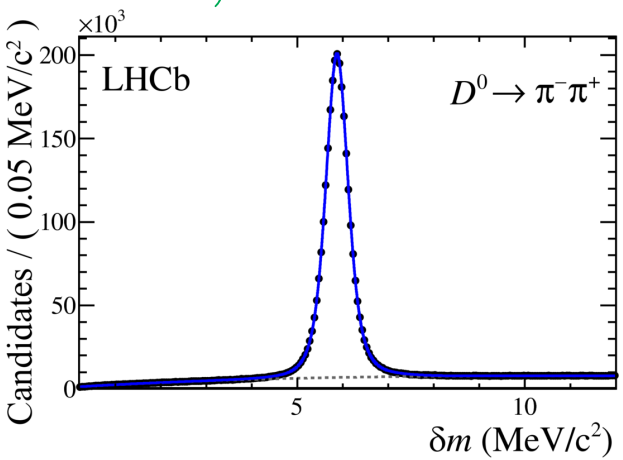


Prompt tagging

Initial flavour: charge of the π_s in prompt $D^{*\pm} \to D^0 \pi_s^+$ and $D^{*-} \to \overline{D}^0 \pi_s^-$ decays







arXiv:1602.03160

Experimental complications

We want to measure the $\mathcal{CP}$-asymmetry:

$$A_{CP}(f) = \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D}^0 \to \overline{f})}{\Gamma(D^0 \to f) + \Gamma(\overline{D}^0 \to \overline{f})}$$

We measure the number of signal candidates:

$$A_{raw}(f) = \frac{N_{signal}(D^{*+}) - N_{signal}(D^{*-})}{N_{signal}^{total}}$$

$$A_{raw}(f) \approx A_{CP}(f) + A_D(f) + A_D(\pi_s) + A_P(D^*)$$

$A_D(f)$: Detection asymmetry of the final state K^-K^+

$A_D(\pi_s)$: Detection asymmetry of the tagging π_s

$A_P(D^*)$: Production asymmetry of the D^*

Experimental complications

How do we get rid of the nuisance asymmetries? We use both the $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays:

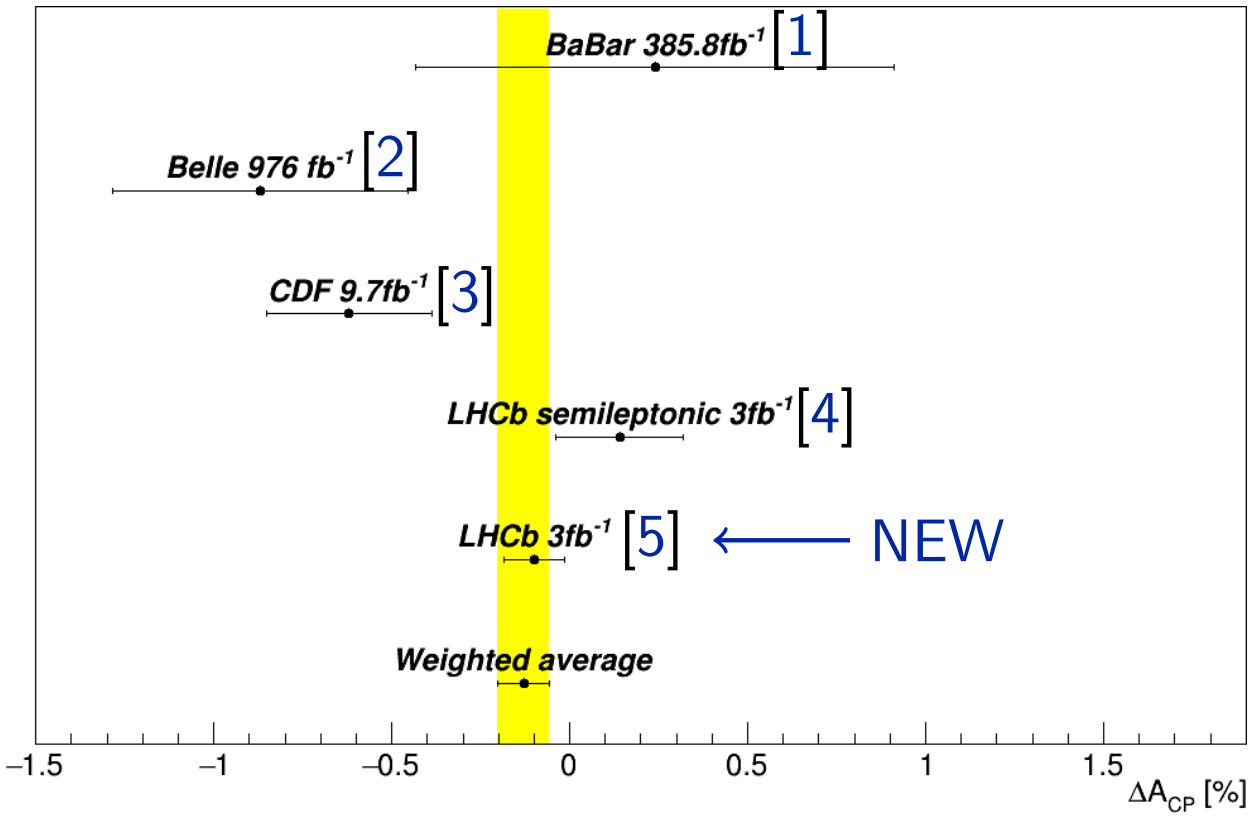
$$A_{raw}(K^-K^+) \approx A_{CP}(K^-K^+) + A_D(K^-K^+) + A_D(\pi_s) + A_P(D^*)$$

$$A_{raw}(\pi^-\pi^+) \approx A_{CP}(\pi^-\pi^+) + A_D(\pi^-\pi^+) + A_D(\pi_s) + A_P(D^*)$$

and measure:

$$\begin{aligned}\Delta A_{CP} &= A_{raw}(K^-K^+) - A_{raw}(\pi^-\pi^+) \\ &= A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+)\end{aligned}$$

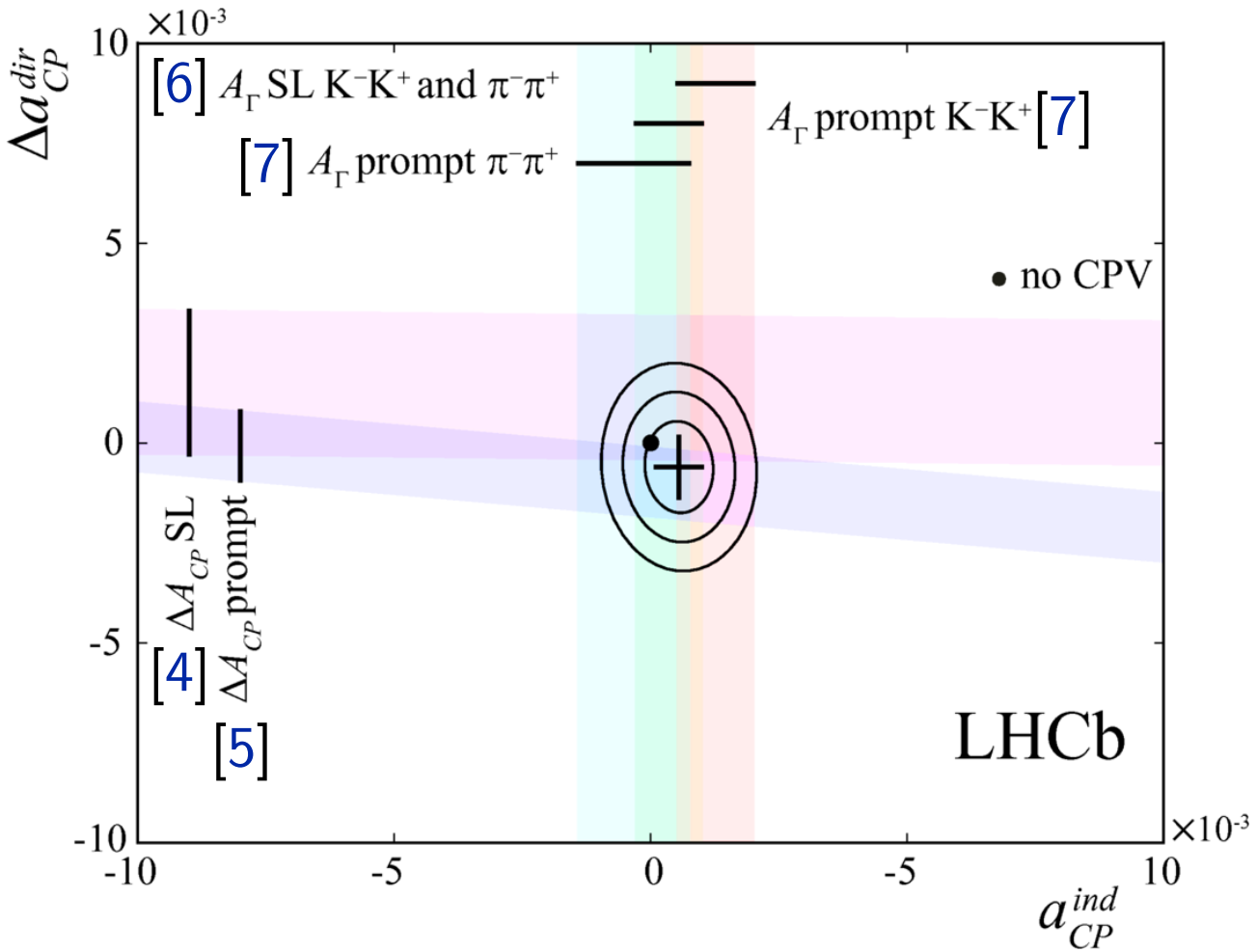
Results



$$\Delta A_{CP} = (-0.10 \pm 0.08 \pm 0.03)\% \quad \text{arxiv:1602.03160}$$

Theory predictions: $\Delta A_{CP} \approx \mathcal{O}(10^{-3})$

Status of $\mathcal{CP}$-violation in 2-body charm decays



arXiv:1602.03160

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Appendix

References I

[1] **BaBar Collaboration** , B. Aubert *et al.*, "Search for CP violation in the decays $D^0 \to K^- K^+$ and $D^0 \to \pi^- \pi^+$," *Phys.Rev.Lett.* **100** (2008) 061803, arXiv:0709.2715 [hep-ex].

[2] **Belle Collaboration** , B. R. Ko, "CP violation and mixing in the charm sector at Belle, and current HFAG averages," arXiv:1212.5320 [hep-ex].

[3] **CDF Collaboration** , T. Aaltonen *et al.*, "Measurement of the difference of CP–violating asymmetries in $D^0 \to K^+ K^-$ and $D^0 \to \pi^+ \pi^-$ decays at CDF," *Phys.Rev.Lett.* **109** (2012) 111801, arXiv:1207.2158 [hep-ex].

References II

[4] **LHCb Collaboration** , R. Aaij *et al.*, "Measurement of *CP* asymmetry in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays," *JHEP* **07** (2014) 041, arXiv:1405.2797 [hep-ex].

[5] **LHCb Collaboration** , R. Aaij *et al.*, "Measurement of the difference of time-integrated CP asymmetries in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays," arXiv:1602.03160 [hep-ex].

[6] **LHCb Collaboration** , R. Aaij *et al.*, "Measurement of indirect *CP* asymmetries in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays using semileptonic B decays," *JHEP* **04** (2015) 043, arXiv:1501.06777 [hep-ex].

References III

[7] **LHCb** , R. Aaij *et al.*, "Measurements of indirect CP asymmetries in $D^0 \to K^- K^+$ and $D^0 \to \pi^- \pi^+$ decays," *Phys. Rev. Lett.* **112** no. 4, (2014) 041801, arXiv:1310.7201 [hep-ex].

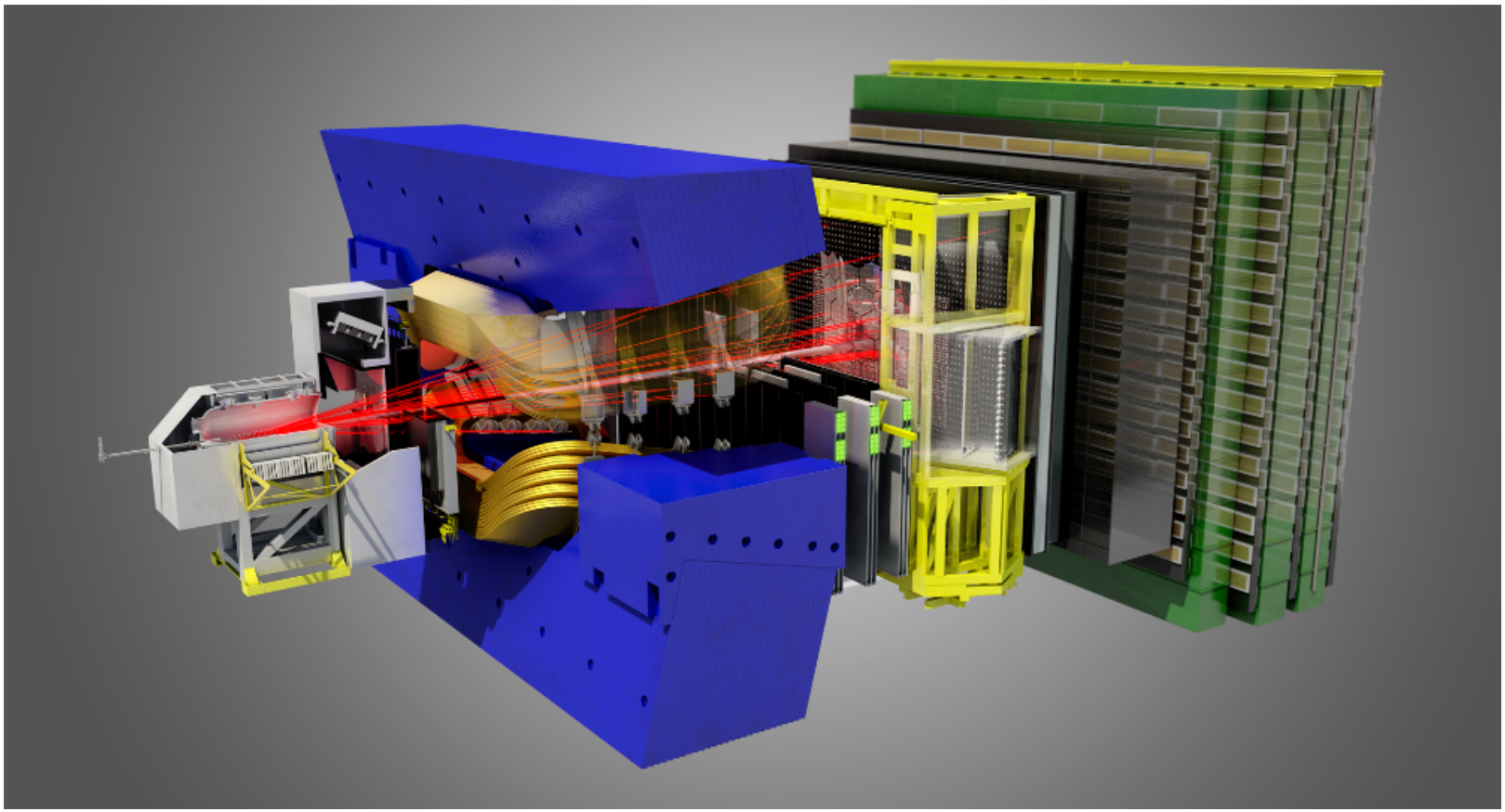
Measuring direct $\mathcal{CP}$-violation

$$A_{CP}(f) = \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\overline{D}^0 \to f)} \approx a_{CP}^{dir}(f) - A_\Gamma \frac{\langle t \rangle}{\tau}$$

Measure the difference of $\mathcal{CP}$-asymmetries in the two decays:

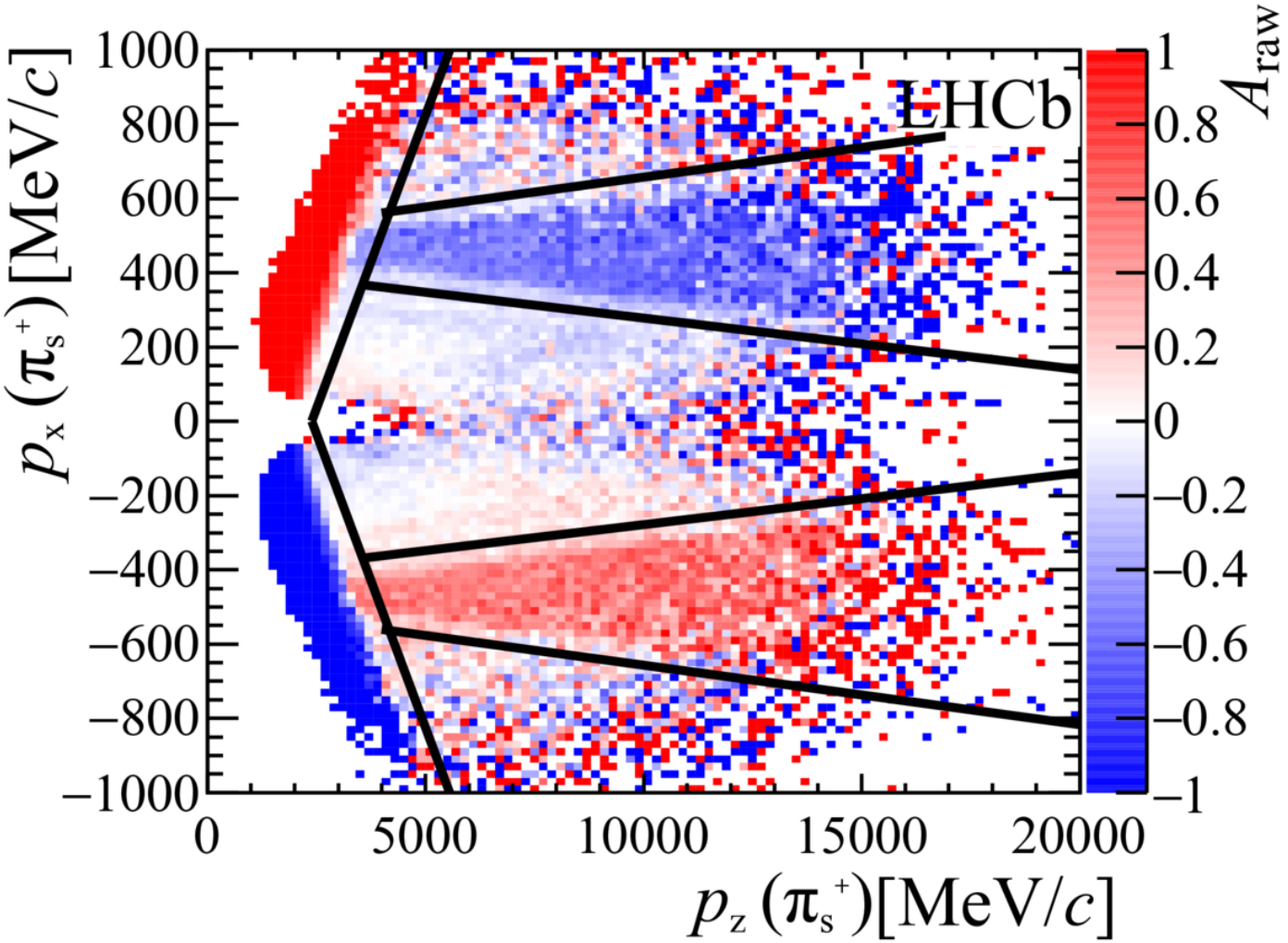
$$\begin{aligned} \Delta A_{CP} &\equiv A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+) \\ &\approx \left(1 + \frac{\overline{\langle t \rangle}}{\tau} \cdot y_{CP}\right) \cdot \Delta a_{CP}^{dir} - \frac{\Delta\langle t \rangle}{\tau} \cdot \overline{A}_\Gamma \end{aligned}$$

The LHCb detector



Excellent tracking, good PID to distinguish $D^0 \to K^- K^+$ and $D^0 \to \pi^- \pi^+$ decays.

Fiducial requirements



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Fit model

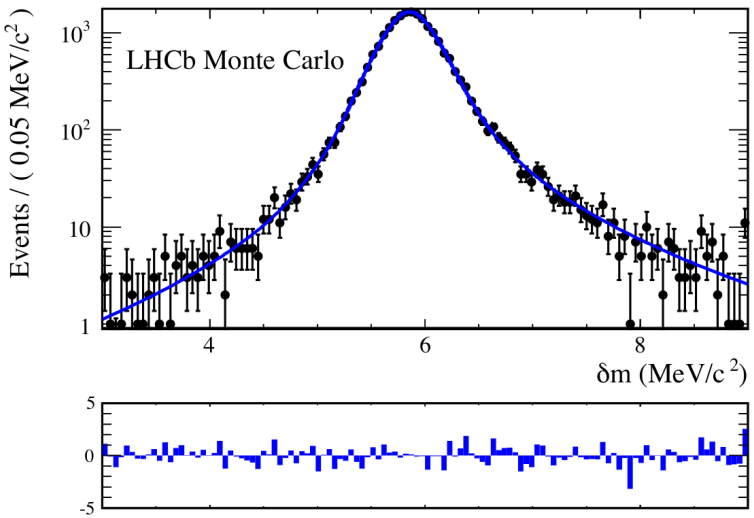
Describe data in
$\delta m = m(D^*) - m(D^0) - m(\pi_s) = m(hh\pi_s) - m(hh) - m(\pi_s)$**:**

– **Signal:** Sum of two Gaussians with Johnson function:

$$J(\delta m; \mu, \sigma_J, \delta, \gamma) = \frac{\delta}{\sigma_J \sqrt{2\pi}\sqrt{1+z^2}} \exp\left[-\frac{1}{2}\left(\gamma + \delta \cdot \sinh^{-1} z\right)^2\right],$$

with $z = \left(\frac{\delta m - \mu}{\sigma_f}\right)$

Allow a difference between the means and width between $D^{*+}$and D^{*-}decays. Validated on MC.



– **Background:** Empirical random pion background function:

$$\mathcal{P}_{\rm bg}(\delta m; B, C, \delta m_0) = \left[1 - \exp\left(-\frac{\delta m - \delta m_0}{C}\right)\right] + B\left(\frac{\delta m}{\delta m_0} - 1\right).$$

Results in subsamples

polarity	trigger	$\sqrt{s}$ [TeV]	ΔA_{C_P} [%]
up	TOS	7	-0.40 ± 0.35
up	nTOS	7	-0.19 ± 0.29
down	TOS	7	-0.31 ± 0.29
down	nTOS	7	-0.06 ± 0.24
up	TOS	8	-0.11 ± 0.21
up	nTOS	8	-0.22 ± 0.17
down	TOS	8	-0.22 ± 0.21
down	nTOS	8	$+0.24 \pm 0.17$
average			-0.10 ± 0.08

arXiv:1602.03160

HFAG results for direct and indirect $\mathcal{CP}$-violation