Search for *CP* violation in $D_s^+ \to K_S\pi^+$, $D^+ \to K_S K^+$ and $D^+ \to \phi\pi^+$ decays

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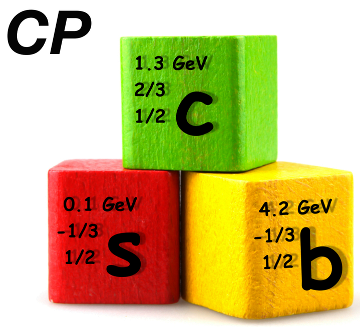
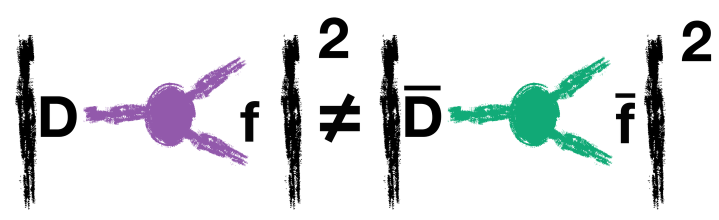
Motivations

- If new physics (NP) exists it could violate ***CP***
- **Up-type** quark: unique probe of NP
- In *charm*, *CP* violation (CPV):
  - has not yet been observed
  - is suppressed in the SM and predictions are hard

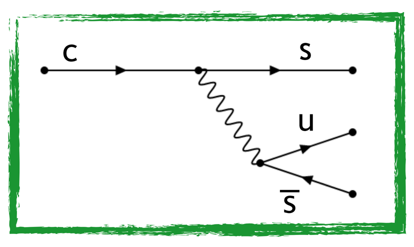


- Direct CPV corresponds to

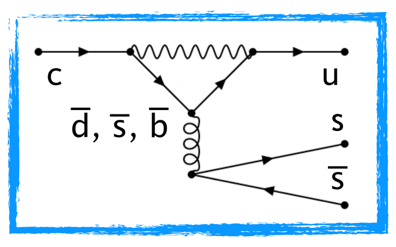
$$\mathcal{A}_{CP} = \frac{|A_f|^2 - |\bar{A}_{\bar{f}}|^2}{|A_f|^2 + |\bar{A}_{\bar{f}}|^2} \neq 0$$



- Most promising channels are **Cabibbo-suppressed** decays:

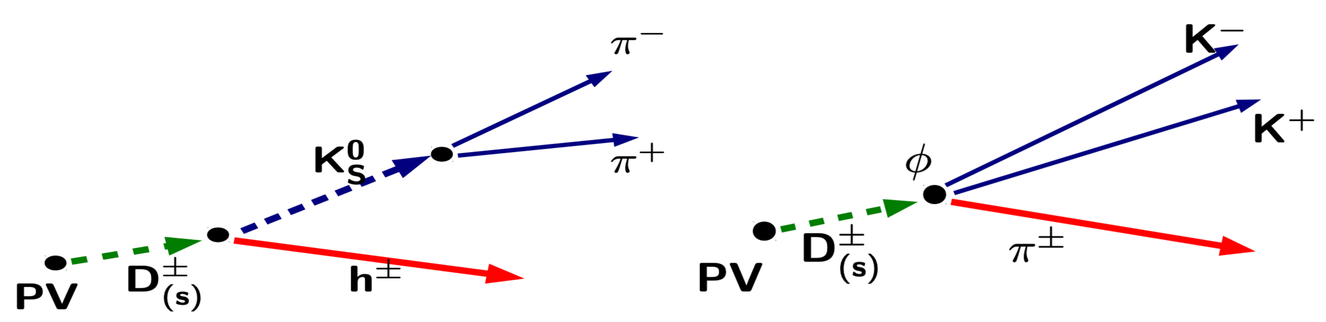


VS



CPV may arise from *interference* between **tree** and **penguin** amplitude

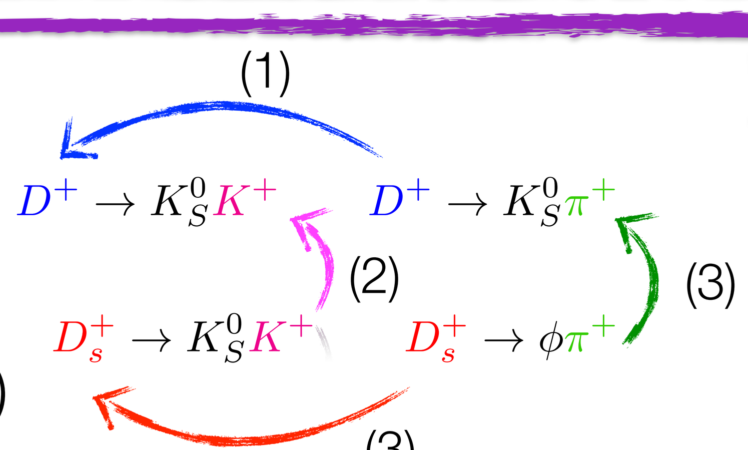
- ***$D_s^+ \to K_S\pi^+$, $D^+ \to K_S K^+$ and $D^+ \to \phi\pi^+$*** decays are easy-to-reconstruct and high-statistics channels



- Best measurements to date are from LHCb Run-1 [1, 2]
- Here, updated results using 3.8/fb of **Run-2** data collected during 2015-2017

Kinematic weighting

For example, let's consider $A_{CP}(D^+ \to K_S K^+)$



Production and ***detection*** asymmetries cancel out

Systematics [3]

Table 1: Summary of the systematic uncertainties (in units of 10^{-3}) on the measured quantities. The total is the sum in quadrature of the different sources.

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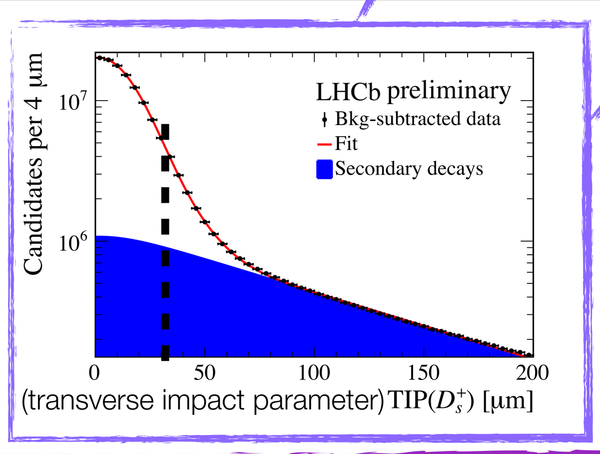
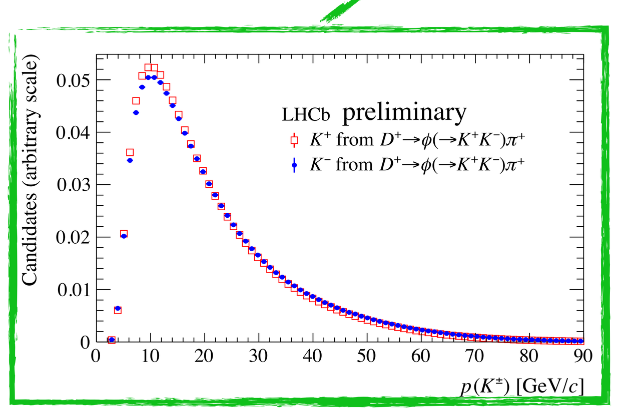
Source	$A_{CP}(D_s^+ \to K_S^0\pi^+)$	$A_{CP}(D^+ \to K_S^0 K^+)$	$A_{CP}(D^+ \to \phi\pi^+)$
Fit model	0.39	0.44	0.24
Secondary decays	0.30	0.12	0.03
Kinematic diff.	0.09	0.09	0.04
Neutral kaon asym.	0.05	0.05	0.04
Charged kaon asym.	0.08	0.09	0.15
Total	0.51	0.48	0.29





References

[1] = LHCb collaboration, Search for *CP* violation in $D^+ \to \phi\pi^+$ and $D_s^+ \to K_S\pi^+$ decays JHEP 06 (2013) 112

[2] = LHCb collaboration, Search for *CP* violation in $D^+ \to K_S K^+$ and $D_s^+ \to K_S\pi^+$ decays JHEP 1410 (2014) 025

[3] = LHCb collaboration, LHCB-PAPER-2019-002 (in preparation)

Strategy

- *Raw asymmetry* ***A*** between the observed yields has contributions other than A_{CP}:

Production asymmetry
different production cross-section in *pp* collisions

$$A_P(D) = \frac{\sigma(D) - \sigma(\bar{D})}{\sigma(D) + \sigma(\bar{D})}$$

Detection asymmetry
different cross-section when interacting with detector material

$$A_D(f) = \frac{\epsilon(f) - \epsilon(\bar{f})}{\epsilon(f) + \epsilon(\bar{f})}$$

- Correct *A* using kinematically weighted samples of Cabibbo-favored $D_{(s)}^+$ decays (where CPV can be neglected)

$$A_{CP}(D_s^+ \to K_S^0\pi^+) = [A(D_s^+ \to K_S^0\pi^+) - A_D(K^0)] - A(D_s^+ \to \phi\pi^+)$$

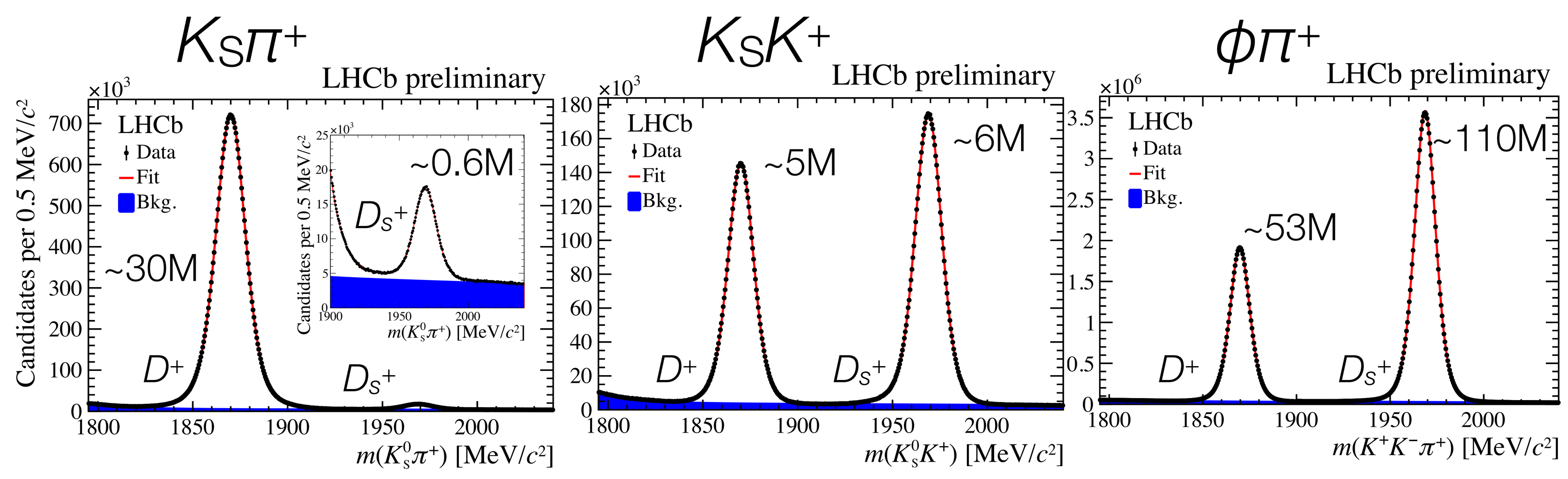
$$A_{CP}(D^+ \to K_S^0 K^+) = [A(D^+ \to K_S^0 K^+) - A_D(\bar{K}^0)] - [A(D^+ \to K_S^0\pi^+) - A_D(\bar{K}^0)] - [A(D_s^+ \to K_S^0 K^+) - A_D(\bar{K}^0)] + A(D_s^+ \to \phi\pi^+)$$

$$A_{CP}(D^+ \to \phi\pi^+) = A(D^+ \to \phi\pi^+) - [A(D^+ \to K_S^0\pi^+) - A_D(\bar{K}^0)]$$

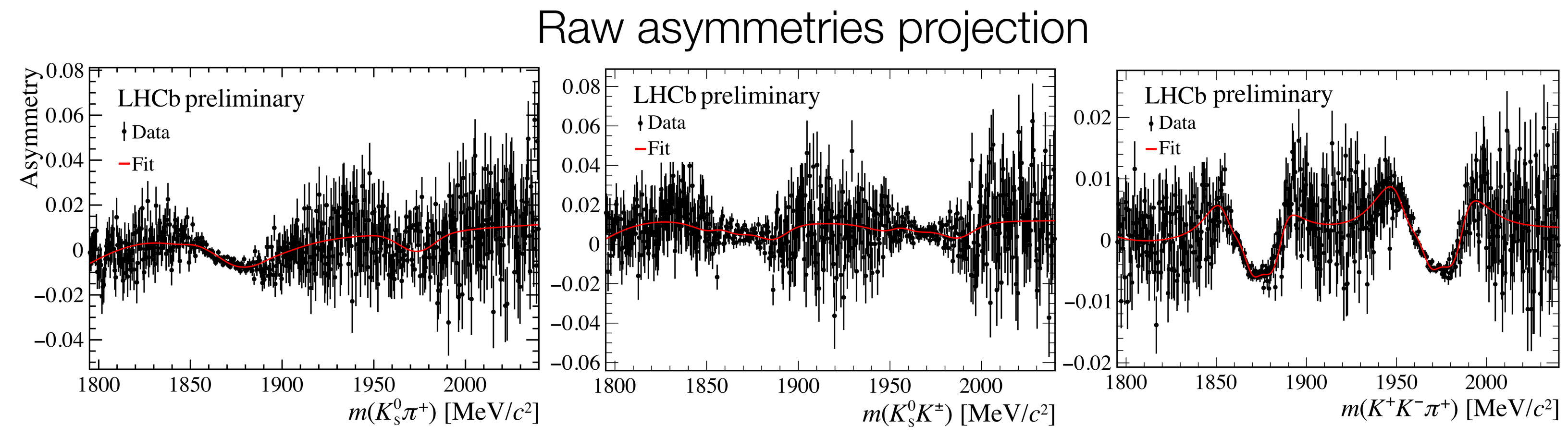
where $K_S \to \pi^+\pi^-$ and $A_D(K^0) = -A_D(\bar{K}^0)$ is the detection asymmetry of neutral kaons, which includes mixing and CPV effects

Determination of raw asymmetries [3]

Simultaneous fit to the $D_{(s)}^+$ and $D_{(s)}^-$ invariant-mass distributions



Raw asymmetries projection



Results [3]

most precise A_{CP} in charm hadrons!

No evidence of CPV

- *CP* asymmetries:

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$$\mathcal{A}_{CP}(D_s^+ \to K_S^0\pi^+) = (\ \ 1.3 \ \pm 1.9\ (\text{stat}) \pm 0.5\ (\text{syst})) \times 10^{-3},$$
$$\mathcal{A}_{CP}(D^+ \to K_S^0 K^+) = (-0.09 \pm 0.65\,(\text{stat}) \pm 0.48\,(\text{syst})) \times 10^{-3},$$
$$\mathcal{A}_{CP}(D^+ \to \phi\pi^+) = (\ \ 0.05 \pm 0.42\,(\text{stat}) \pm 0.29\,(\text{syst})) \times 10^{-3}.$$

- When averaged with previous LHCb measurements they yield

$$\mathcal{A}_{CP}(D_s^+ \to K_S^0\pi^+) = (\ \ 1.6 \ \pm 1.7\ (\text{stat}) \pm 0.5\ (\text{syst})) \times 10^{-3},$$
$$\mathcal{A}_{CP}(D^+ \to K_S^0 K^+) = (-0.04 \pm 0.61\,(\text{stat}) \pm 0.45\,(\text{syst})) \times 10^{-3},$$
$$\mathcal{A}_{CP}(D^+ \to \phi\pi^+) = (\ \ 0.03 \pm 0.40\,(\text{stat}) \pm 0.29\,(\text{syst})) \times 10^{-3}.$$