Study of a new kinematic weighting algorithm for the measurement of CP asymmetries in charm decays

LHCb Collaboration

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Abstract

We investigate the asymmetries that occur in charm decays at the LHCb, specifically we study $D^{\star+} \to D^0\pi^+$ and $\bar{D}^{\star-} \to D^0\pi^-$ where $D^0 \to K^-K^+$ or $D^0 \to \pi^-\pi^+$. We study the effect of CP and detection asymmetries on MC samples generated via RapidSim and implement a new kinematic weighting function which allows us to keep events that are otherwise discarded from LHCb data, since they are associated with large detection asymmetries.

1 Introduction

We investigate charm decays and specifically the $D^\star$ meson. By studying the differences between $D^{\star+}$ and $D^{\star-}$ decays shown in Fig. 1 we can estimate the CP asymmetry in charm decays.

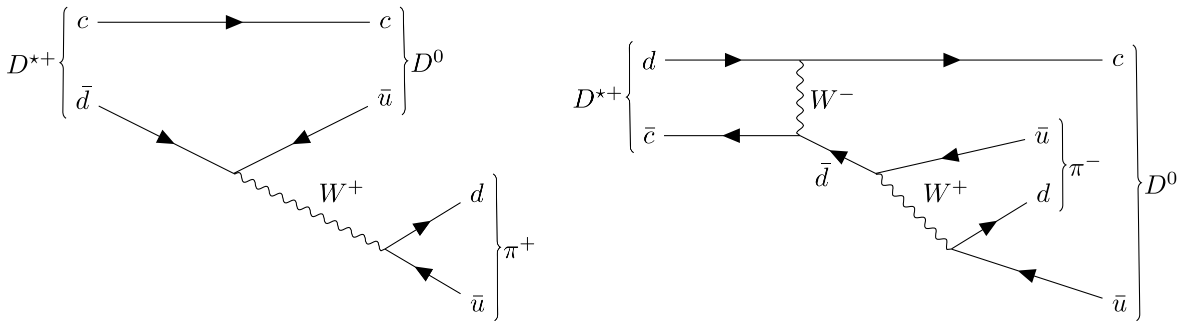

Figure 1: Feynman diagram showing $D^{\star\pm} \to D^0\pi^\pm$ decays.

The total asymmetry one observes at an experiment is a combination of multiple asymmetries. Namely, the total asymmetry consists of a *CP asymmetry* and a *detection asymmetry*. The former is associated with the difference between matter and anti-matter, while the latter is associated with the differences while detecting the soft pion (π_s) that is produced during the decay.

The total asymmetry can be estimated using

$$A_{\text{total}} = \frac{A_{CP} + A_{\text{D}}}{1 + A_C A_{\text{D}}} \tag{1}$$

where A_{CP} and A_{D} are the CP and *integrated detection asymmetries*. The latter can be calculated through

$$A_{\text{D}} = \frac{\int \mathrm{d}\vec{p} N(\vec{p}) A_{\text{D}}(\vec{p})}{\int dd\vec{p} N(\vec{p})} \tag{2}$$

At the LHCb one observes large pion detection asymmetries that are associated with specific kinematic regions, which so far have been discarded, thus reducing the statistics. We can, however, introduce a *weighting function* that allows us to keep events associated with large asymmetries. Such a weighting function can be expressed as the following ratio

$$Q(\vec{p}_{D^\star}, \vec{p}_{\pi_s}) \simeq \frac{\Gamma^{\pi\pi}_{D^0}(\vec{p}_{D^\star} - \vec{p}_{\pi_s}) + \Gamma^{\pi\pi}_{\bar{D}^0}(\vec{p}_{D^\star} - \vec{p}_{\pi_s})}{\Gamma^{KK}_{D^0}(\vec{p}_{D^\star} - \vec{p}_{\pi_s}) + \Gamma^{KK}_{\bar{D}^0}(\vec{p}_{D^\star} - \vec{p}_{\pi_s})} \tag{3}$$

where $\Gamma^{\pi\pi/KK}_{D^0/\bar{D}^0}$ are the normalized distributions of D^0 candidates. Unfortunately in Run-2 such candidates were discarded, thus, we do not have a large enough sample to accurately calculate the weighting function and we resort to Monte Carlo simulations.

2 Analysis

2.1 RapidSim

For the analysis we make use of the RapidSim simulation [1] to generate $D^{\star\pm} \to D^0\pi^\pm$ events where D^0 subsequently decays into K^-K^+ or $\pi^-\pi^+$. We present the RapiDSim parameters in Tab. 1

	Parameter	Value
Center of mass energy	`energy`	`13`
Detector geometry	`geometry`	`LHCb`
Acceptance region	`acceptance`	`AllIn`
Smearing on produced particles	`smear`	`LHCbGeneric`

Table 1: RapidSim parameters used to generate our data.

2.2 Calculation of the Q function

As previously discussed, the weighting function Eq. 3 allows us to keep more events from LHCb to more accurate results, thus, the calculation of the weighting function needs to be done correctly and with enough precision.

We generate separate samples for calculating the weighting function Q and analyzing our data to eliminate correlations between the two. Both samples start with 10 million events, to have high enough statistics and then events are discarded due to the selections we applied in Tab. 1.

We calculate the weighting function twice, once with detection asymmetry and once without, and compare the results. We present the weighting function distributions for before and after the detection asymmetry in Fig. 2. It is obvious that the introduction of the detection asymmetry

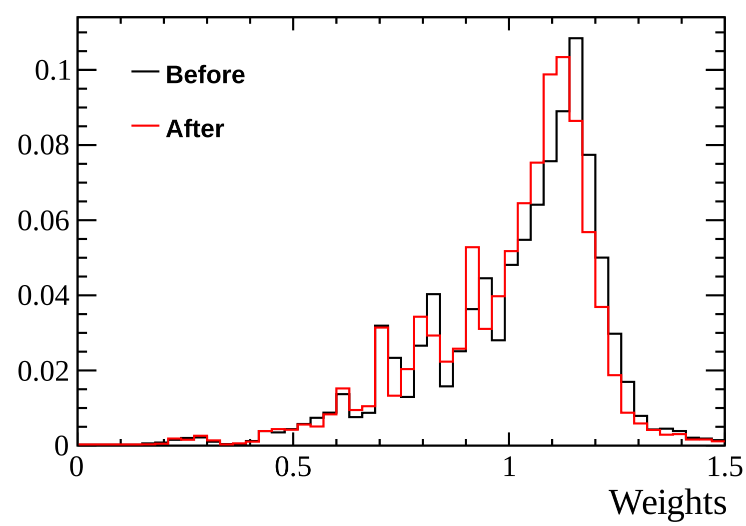

Figure 2: Distribution of weighting function values before and after the detection asymmetry.

slightly affects the weighting function distribution.

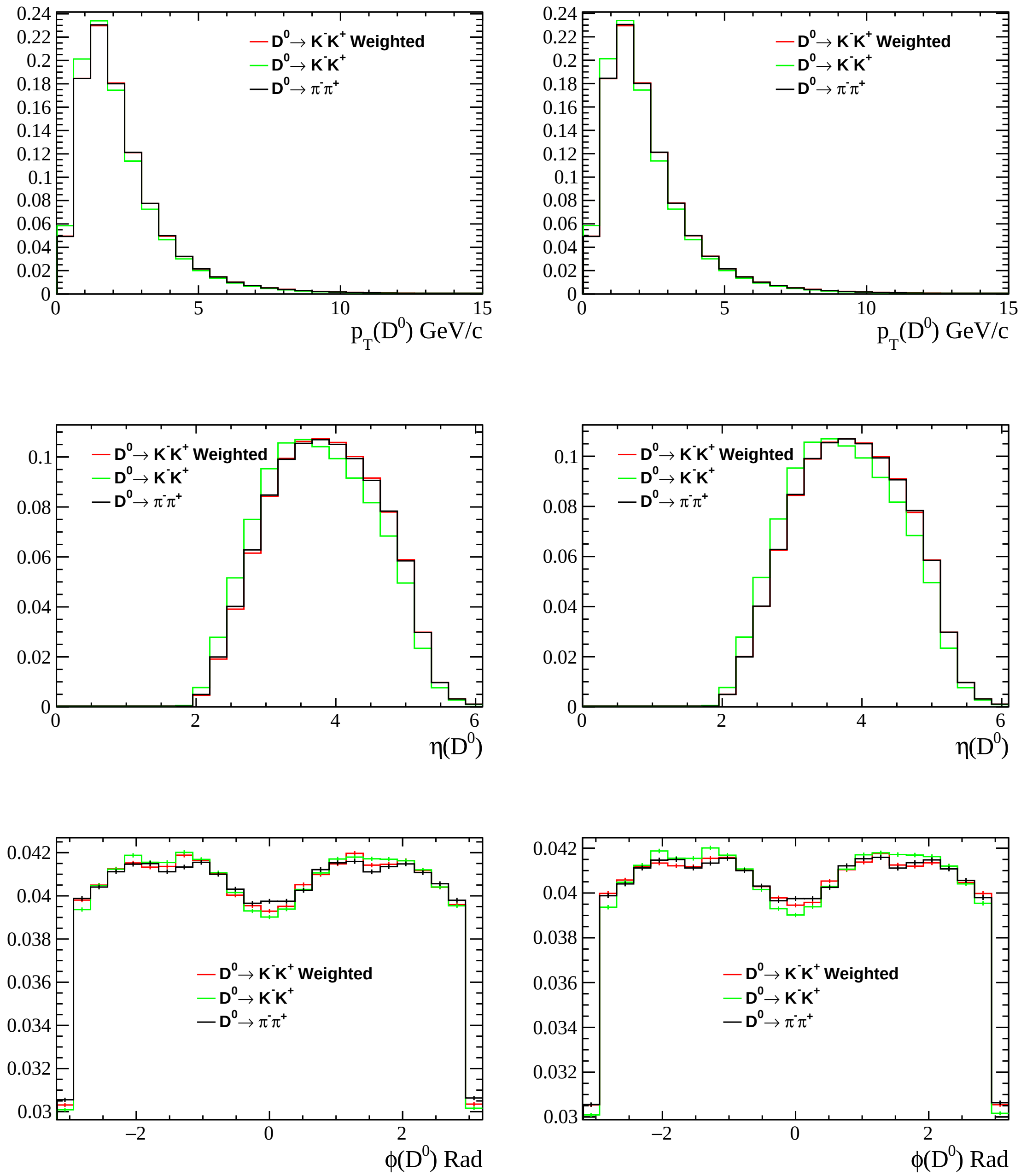

Figure 3: Comparison of D^0 kinematics with and without weighting. On the left and right columns we present the weighting before and after the introduction of the detection asymmetry respectively.

2.3 Asymmetry calculation

Using the weighting function we can calculate the total asymmetry for $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ samples and compare to the unweighted result. The total asymmetry can be calculated using

$$A_{\text{total}} = \frac{N_+ - N_-}{N_+ + N_-} \tag{4}$$

where

$$N_\pm = \sum_i w_i^\pm, \text{ and } \sigma N_\pm = \sqrt{\sum_i (w_i^\pm)^2} \tag{5}$$

and using propagation of uncertainties we can calculate the total asymmetry error

$$\sigma A_{\text{total}}^2 = \left(\frac{\partial A_{\text{total}}}{\partial N^+}\sigma N^+\right)^2 + \left(\frac{\partial A_{\text{total}}}{\partial N^-}\sigma N^-\right)^2 \tag{6}$$

For the case of the unweighted total asymmetry, $N_\pm$ is the number of events with positive and negative soft pions.

We present the calculated asymmetries for the $D^0 \to K^-K^+$ sample in Tab. 2

	Weighted	Unweighted
Before	0.14726 ± 0.00066	0.16268 ± 0.00064
After	0.14994 ± 0.00066	

Table 2: A_{total} for the $D^0 \to K^-K^+$ sample with and without weighting.

and for the $D^0 \to \pi^-\pi^+$ sample we get

$$A_{\text{total}} = 0.24571 \pm 0.00067 \tag{7}$$

We calculate the difference between the total asymmetries of the two samples

$$\Delta A_{\text{total}} = A_{\text{total}}^{KK} - A_{\text{total}}^{\pi\pi} \tag{8}$$

We introduce $A_{CP}^{KK} = 0.1$ and $A_{CP}^{\pi\pi} = 0.2$, thus, the estimated total asymmetry difference is $\Delta A_{\text{total}} = -0.1$. We present the results of the total asymmetry difference in Tab. 3 as well as the deviation from the expected value.

		Weighted	Unweighted
Before	ΔA_{total}	-0.09578 ± 0.00094	-0.08304 ± 0.00092
	Deviation (σ)	4.49	4.59
After	ΔA_{total}	-0.09845 ± 0.00094	-0.08304 ± 0.00092
	Deviation (σ)	1.64	4.59

Table 3: Total asymmetry difference with and without weights. We present both weighting procedures, before and after the detection asymmetry.

2.4 Particle Gun analysis

ADD PLOTS FOR DETECTION ASYMMETRY IN THE ANALYSIS AS WELL AS IN THE PARTICLE GUN SECTION.

References

[1] G. A. Cowan, D. C. Craik, and M. D. Needham. "RapidSim: an application for the fast simulation of heavy-quark hadron decays". In: *Comput. Phys. Commun.* 214 (2017), pp. 239–246. DOI: `10.1016/j.cpc.2017.01.029`. arXiv: `1612.07489 [hep-ex]`.

[2] Roel Aaij et al. "LHCb Detector Performance". In: *Int. J. Mod. Phys. A* 30.07 (2015), p. 1530022. DOI: `10.1142/S0217751X15300227`. arXiv: `1412.6352 [hep-ex]`.

[3] Roel Aaij et al. "Observation of CP Violation in Charm Decays". In: *Phys. Rev. Lett.* 122.21 (2019), p. 211803. DOI: `10.1103/PhysRevLett.122.211803`. arXiv: `1903.08726 [hep-ex]`.

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