New kinematic weighting algorithm for CP asymmetries in charm decays

Georgios Christou
Supervisors: Dr. Federico Betti and Prof. Angelo Carbone

LHCb Collaboration

August 29, 2023

1 Introduction

- Asymmetries at the LHCb

2 Analysis

- RapidSim
- Particle Gun

3 Conclusions

Asymmetries at the LHCb

We study CP asymmetries in the following charm decays

$$D^{\star+} \to D^0\pi^+ \text{ and } D^{\star-} \to \bar{D}^0\pi^-,$$
$$D^0 \to K^-K^+ \text{ and } D^0 \to \pi^-\pi^+$$

At LHCb we observe:

- CP asymmetry $\to$Differences in matter and anti-matter decays
- Production asymmetry A_{CP} $\to$Differences in $D^{\star\pm}$ production
- Detection asymmetry A_D $\to$Differences in $\pi_s^\pm$ detection

$\to$We mainly focus on CP and detection asymmetries throughout this project

Asymmetries at the LHCb

$\rightarrow$At an experiment our physical observable is the total asymmetry

$$A_{\text{total}} = \frac{A_{CP}+A_D}{1+A_{CP}A_D} \approx A_{CP} + A_D + \mathcal{O}(10^{-6}),$$

$$A_D = \frac{\int \mathrm{d}\vec{p}N(\vec{p})A(\vec{p})}{\int \mathrm{d}\vec{p}N(\vec{p})} \rightarrow \text{ Integrated detection asymmetry}$$

- $N(\vec{p})$ $\rightarrow$Momentum dependent number of π_s
- $A(\vec{p})$ $\rightarrow$Momentum dependent detection asymmetry

$\rightarrow$We can measure the total asymmetry through

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

Asymmetries at the LHCb

→We define the total asymmetry difference

$$\Delta A_{\text{total}} = A^{KK}_{\text{total}} - A^{\pi\pi}_{\text{total}} = \Delta A_{CP} + \Delta A_D$$

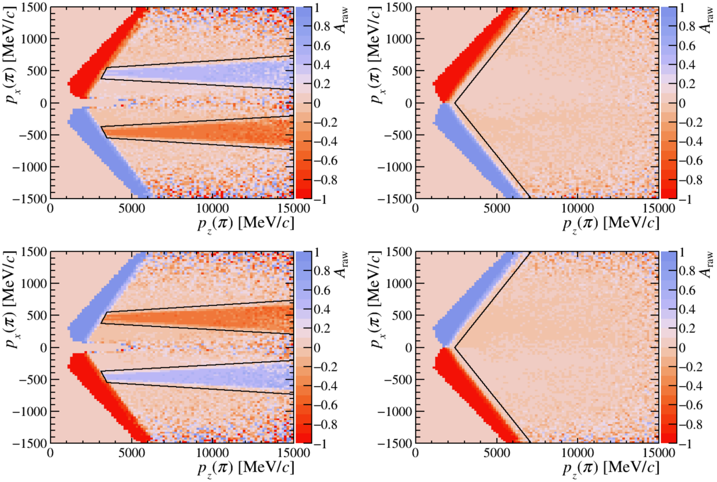
→$\Delta A_D = 0$ if $N(\vec{p})$ is equal between the two decay modes
How can we obtain ΔA_{CP}?

- We can equalize D^0 kinematic distributions for $D^0 \to K^- K^+$ and $D^0 \to \pi^- \pi^+$ decay modes
- The following weighting function allows us to do that

$$Q(\vec{p}_{D^\star}, \vec{p}_{\pi_s}) \simeq \frac{\Gamma^{\pi\pi}_{D^0}(\vec{p}_{D^\star} - \vec{p}_{\pi_s}) + \Gamma^{\pi\pi}_{\bar{D}^0}(\vec{p}_{D^\star} - \vec{p}_{\pi_s})}{\Gamma^{KK}_{D^0}(\vec{p}_{D^\star} - \vec{p}_{\pi_s}) + \Gamma^{KK}_{\bar{D}^0}(\vec{p}_{D^\star} - \vec{p}_{\pi_s})},$$ Ref: [1, 2]

→This weighting function works if $A_D(\vec{p}) < 0.2$, thus we apply fiducial cuts to regions associated with larger detection asymmetries ($\sim 30\%$ of data sample)

Asymmetries at the LHCb



Asymmetries at the LHCb

$\rightarrow$We introduce a new weighting technique Ref: [1, 2]

$$Q(\vec{p}_{D^0}) \simeq \frac{\Gamma^{\pi\pi}_{D^0}(\vec{p}_{D^0}) + \Gamma^{\pi\pi}_{\bar{D}^0}(\vec{p}_{D^0})}{\Gamma^{KK}_{D^0}(\vec{p}_{D^0}) + \Gamma^{KK}_{\bar{D}^0}(\vec{p}_{D^0})} \rightarrow \text{Not affected by } A_D$$

$\rightarrow\Gamma^{\pi\pi/KK}_{D^0/\bar{D}^0}(\vec{p}_{D^0/\bar{D}^0})$ for untagged D^0 candidates
$\rightarrow$Even if high $A_D(\vec{p})$ regions present $\Delta A_D = 0$

$\rightarrow$Now we can use the sample that was previously removed by fiducial cuts$\Rightarrow$**More statistics!**

$$\boxed{\Delta A_{\text{total}} = \Delta A_{CP}}$$

However:

- The untagged D^0 candidates were not kept in Run-2
- The untagged D^0 candidates are kept in Run-3, but we do not have enough statistics

$\rightarrow$We use MC samples to test the new weighting technique

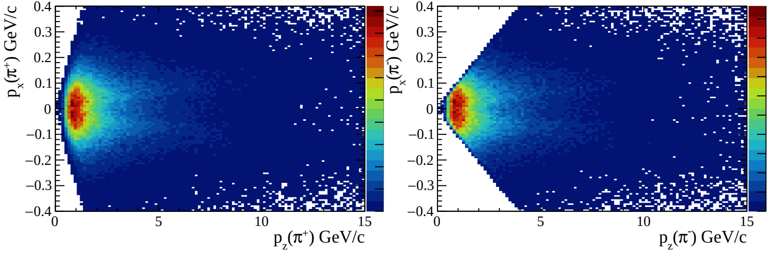
RapidSim

→We generate data using RapidSim and introduce:

- Different CP asymmetries for $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decay modes $\left(A_{CP}^{KK} = 0.1,\ A_{CP}^{\pi\pi} = 0.2,\ \to \Delta A_{\text{total}} = -0.1\right)$
- The same $A_D(\vec{p}) = 100\%$ in specified regions*

  →The integrated detection asymmetries are different for the two samples because the kinematic distributions differ

→We have around 4.8 (K^-K^+ mode) and 4.2 ($\pi^-\pi^+$ mode) million events



* This is an extreme case which is different from what we observe with real data

RapidSim

$\rightarrow$We calculate the weighting function before and after the introduction of the detection asymmetry

- Before: Emulates D^0 not associated with π_s $\Rightarrow$New weighting technique
- After: Emulates D^0 associated with π_s $\Rightarrow$We introduce bias

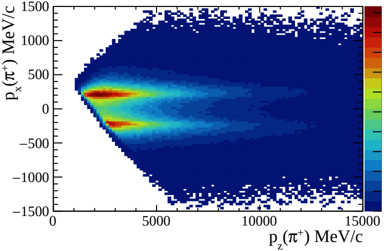
Technique		Weighted	Unweighted
Not associated	ΔA_{total}	-0.09845 ± 0.00073	-0.08303 ± 0.00072
	Deviation (σ)	2.12	23.6
Associated with π_s	ΔA_{total}	-0.09578 ± 0.00073	
	Deviation (σ)	5.78	

- The unweighted calculation is biased as expected $\rightarrow \Delta A_D \neq 0$
- The weighting function with π_s association yields a biased result
- The new weighting technique (not affected by large $A_D(\vec{p})$) allows us to keep events associated with large $A_D(\vec{p})$ $\Rightarrow$**More statistics!**

Particle Gun

→We use Particle Gun data for a more realistic scenario.

- We do not introduce CP asymmetry $\Delta A_{CP} = 0$
- The detection asymmetry is the one expected in data



→The new weighting technique should yield $\Delta A_{\text{total}} = 0$

Particle Gun

Technique		Weighted	Unweighted
Not associated	ΔA_{total}	-0.000084 ± 0.000262	-0.000015 ± 0.000262
	Deviation (σ)	0.32	0.057
Associated with π_s	ΔA_{total}	-0.000036 ± 0.000262	
	Deviation (σ)	0.14	

- The effect of A_D is small
- The weighting technique needs to be investigated further

Conclusions

RapidSim:

- The old weighting function reduces the deviation of ΔA_{total}, however it still introduces bias to our results
- The new weighting technique reduces the deviation of ΔA_{total} and allows us to keep all events, thus using higher statistics$\Rightarrow$**More effective**

Particle Gun:

- The effect of ΔA_D is small
- With this statistics, we do not seen any significant improvement

Thank you for your attention!
Questions?