

# CP-violation and lifetime measurements in charm-hadron decays

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...symmetry?

...violation?

- > Particle - antiparticle oscillations
  - ▶  $K^0 - \bar{K}^0$
  - ▶  $B^0 - \bar{B}^0$
  - ▶  $D^0 - \bar{D}^0$  (*CP*-violation has not been observed yet)

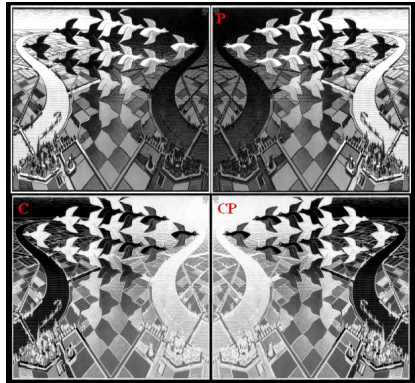
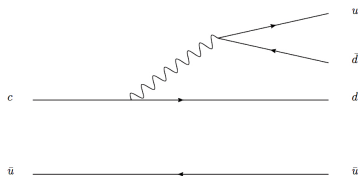


Figure: M.C. Escher, *Tessellation "Day and Night"* (1938).

# Why $D^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^-$ ?

- ▶  $D^0$  - the lightest meson containing  $c$  quark
- ▶ 4-body decay
  - ▶ Previous analyses for direct  $CP$  violation with 3- and 4- body decays  $\mathcal{O}(10^{-3})$
- ▶ Aims:
  - ▶ Cross-check a different decay mode
  - ▶ Add statistics to the world average

## Decay scheme



**Figure:** M. Coombes and J. Rademacker *A model-independent search for CP violation in  $D \rightarrow \pi^- \pi^+ \pi^+ \pi^-$  and  $D \rightarrow K^- K^+ \pi^- \pi^+$  decays* (2013).

# Channel properties

- ▶ Search for indirect  $CP$  violation
- ▶ 4-body decay
  - ▶ Previous analyses for direct  $CP$  violation with 3- and 4-body decays  $\mathcal{O}(10^{-3})$
- ▶ SCS **main** channel,  $D^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^-$
- ▶ CF **control** channel,  $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$
- ▶  $D^0$  flavour determined from a  $D^*$  (2010) decay:
  - ▶  $D^{*+}(2010) \rightarrow D^0 \pi^+$
  - ▶  $D^{*-}(2010) \rightarrow \bar{D}^0 \pi^-$
- ▶ Full run I dataset from LHCb

# Definitions

- ▶ Direct CPV

- ▶  $\Gamma(D^0 \rightarrow f) \neq \Gamma(\bar{D}^0 \rightarrow \bar{f})$  where  
 $f, \bar{f}$  - some final states  
 $\Gamma$  - decay width

- ▶ Indirect CPV

- ▶  $P(D^0 \rightarrow \bar{D}^0)(t) \neq P(\bar{D}^0 \rightarrow D^0)(t)$  for proper decay time  $t$   
( $D^0$  and  $\bar{D}^0$  mix at different rates)
- ▶ Interference between mixing and decay

## Parameter $A_r$

$$A_r \equiv \frac{\hat{\Gamma} - \hat{\bar{\Gamma}}}{\hat{\Gamma} + \hat{\bar{\Gamma}}} \approx \left[ \frac{1}{2}(A_m + A_d)y \cos \phi - x \sin \phi \right] \frac{\eta_{CP}}{1 + y_{CP}}$$
$$\approx \eta_{CP} \left[ \frac{1}{2}(A_m + A_d)y \cos \phi - x \sin \phi \right]$$

## Parameter $A_\Gamma$

$$A_\Gamma \equiv \frac{\hat{\Gamma} - \bar{\Gamma}}{\hat{\Gamma} + \bar{\Gamma}} \approx \left[ \frac{1}{2}(A_m + A_d)y \cos \phi - x \sin \phi \right] \frac{\eta_{CP}}{1 + y_{CP}}$$
$$\approx \eta_{CP} \left[ \frac{1}{2}(A_m + A_d)y \cos \phi - x \sin \phi \right]$$

## Rate asymmetry $A_{CP}$

$$A_{CP} \equiv \frac{\Gamma(D^0 \rightarrow \pi^+\pi^-\pi^+\pi^-) - \Gamma(\bar{D}^0 \rightarrow \pi^+\pi^-\pi^+\pi^-)}{\Gamma(D^0 \rightarrow \pi^+\pi^-\pi^+\pi^-) + \Gamma(\bar{D}^0 \rightarrow \pi^+\pi^-\pi^+\pi^-)}$$

# Signal separation from background I

Table: Fitting function shapes.

	$m_{D^0}$ shape	$\Delta m$ shape
Signal	Crystal Ball and Gaussian	Johnson
Random slow pion background	Gaussian	Background*
Combinatorial background	Exponential	Background*

\* Background function:

$$\left[ (\Delta m - \Delta m_0) + p_1 (\Delta m - \Delta m_0)^2 \right]^a$$



# Signal separation from background II

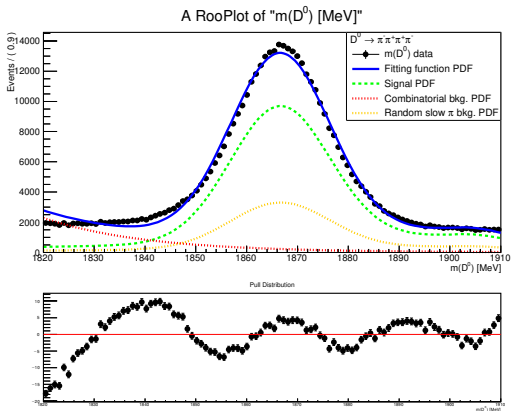
## Signal

- ▶ Gaussian pdf
- ▶ Crystal Ball pdf
- ▶ pdf

## Background

- ▶ Combinatorial
- ▶ Random slow pion

## $D^0$ mass distribution



# Results & conclusions

## Results

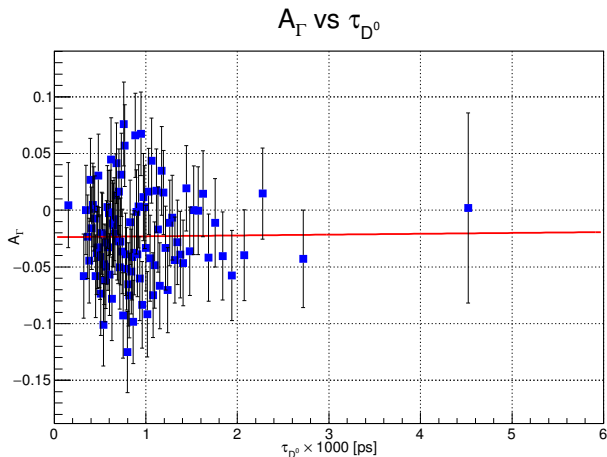


Figure:  $A_{\Gamma}$  estimation in the control channel,  $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$  (100 uniform-density bins, 500k entries).

# Conclusions

- ▶ Main channel currently blinded.
- ▶ Check with Run II data.

$$\mathcal{A}_\Gamma(K^-\pi^+\pi^-\pi^+) = -0.009967 \\ \pm 0.020307(\text{stat.}) \pm 0.0000723(\text{syst.}).$$

- ▶ Control channel performs as expected.