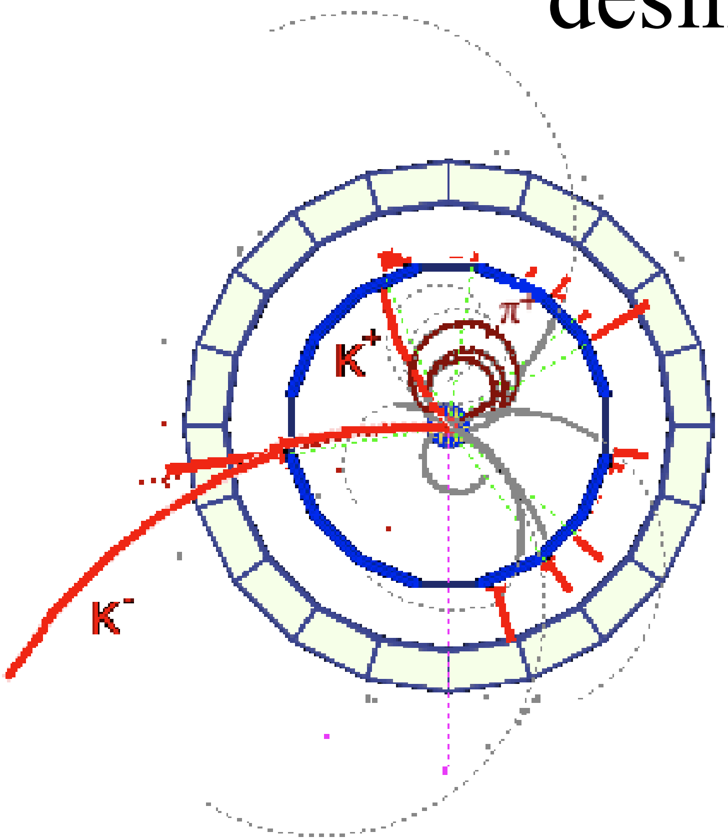
Belle II

Recherche de nouvelle physique dans les désintégrations des mésons D^0 à Belle II



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Institut Pluridisciplinaire Hubert Curien Strasbourg

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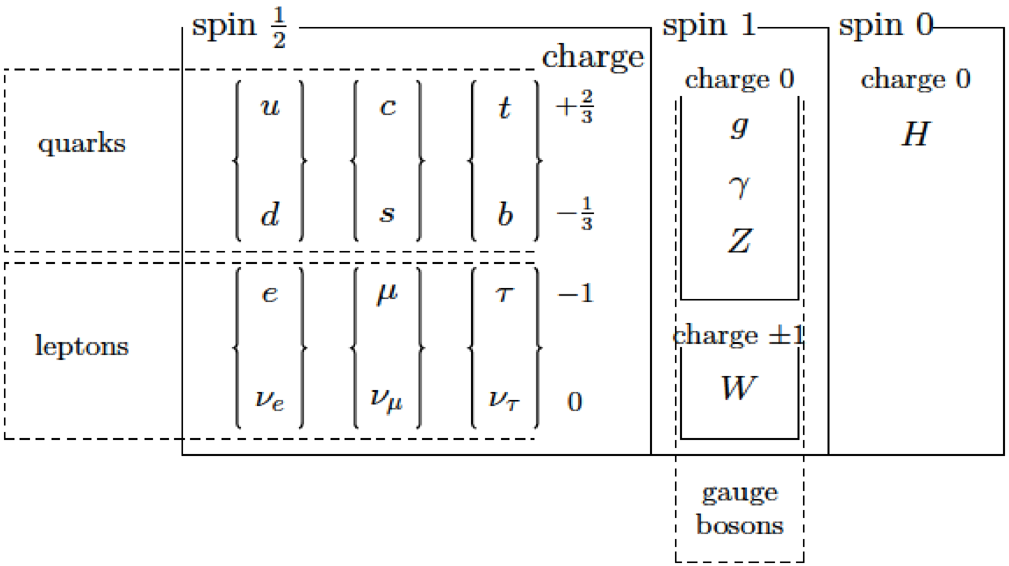
Elementary particles of the standard model



- Mesons ⇨ 2 quarks, ex: D^0 $(c\bar{u})$, B^0 $(d\bar{b})$

Several arguments imply that it is an effective theory, not valid at very high energies

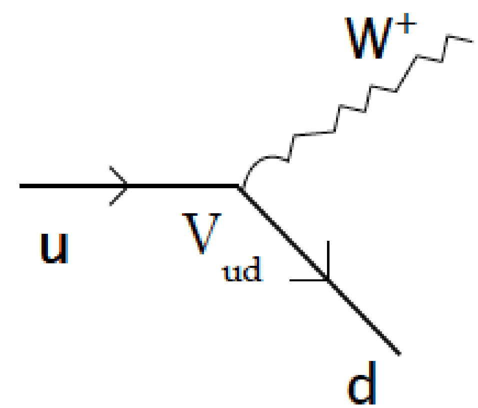
The argument we are interested in:

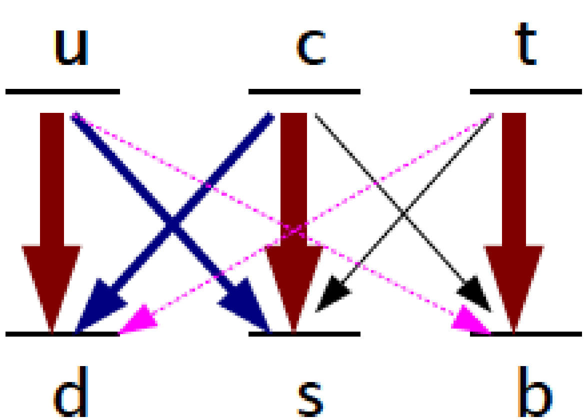
- If the observed baryon number is a dynamically generated quantity ⇨ CP violation required
- But the SM mechanism for CP violation mechanism is not enough
- Additional sources of CP violation are needed

CP violation in the Standard Model for the quark sector:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}_{weak} = \underbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}_{\text{Cabibbo-Kobayashi-Maskawa matrix}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{mass}$$

Flavour changing





Described with 4 independent parameters:

- 3 rotation angles (real)
- 1 phase (complex)

CP violation responsible

The SM CP asymmetry (within the CKM matrix) can not explain the dominance of matter in Universe!

Search for new physics

1) Energy frontier
Direct production of new particles (LHC at 13 TeV)

May 2015

2) Intensity frontier
Quantum manifestation of new particles (Belle II, LHCb Run 3, nEDM)

October 2018 | 2021

3) Neutrino sector
Additional source of CPV?

>2025

CPV in D^0 decays is a good benchmark to search for new physics

- Expected to be very small, 10^{-4} - 10^{-3}
- Could be enhanced by new physics

LHCb measurements (time integrated)

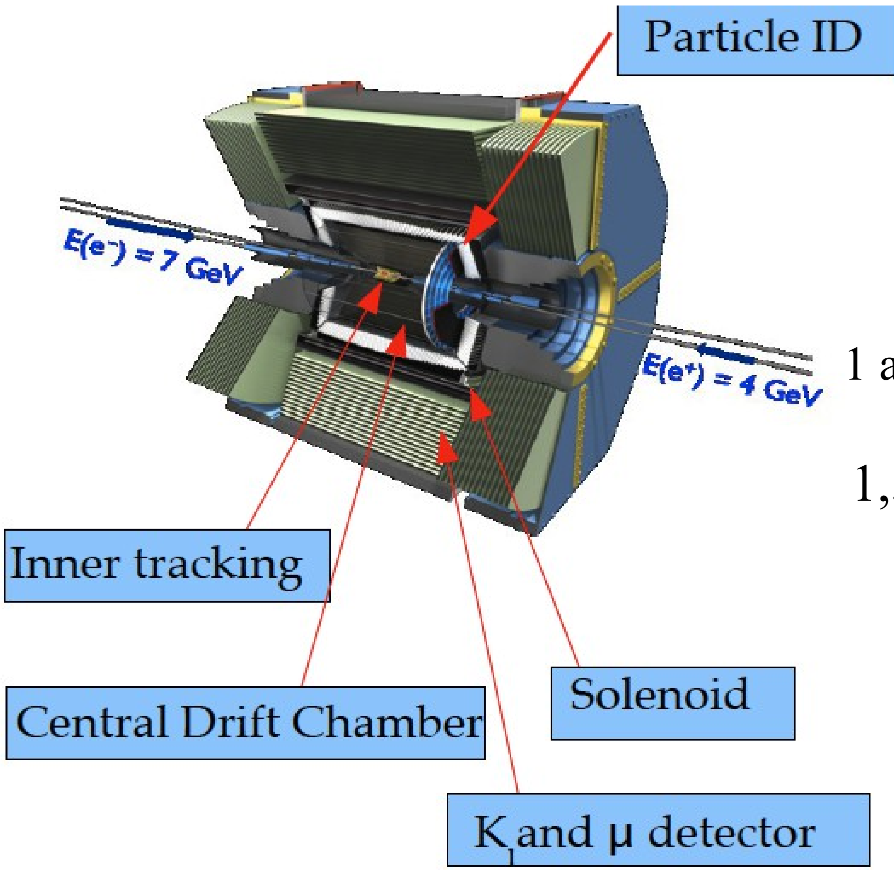
$D^0 \rightarrow K^+K^-$
$D^0 \rightarrow \pi^+\pi^-$

$\Delta A_{CP} = (-0.82 \pm 0.21\ (stat) \pm 0.11\ (syst))\ \%$ In 2012

$\Delta A_{CP} = (+0.14 \pm 0.16\ (stat) \pm 0.08\ (syst))\ \%$ In 2015

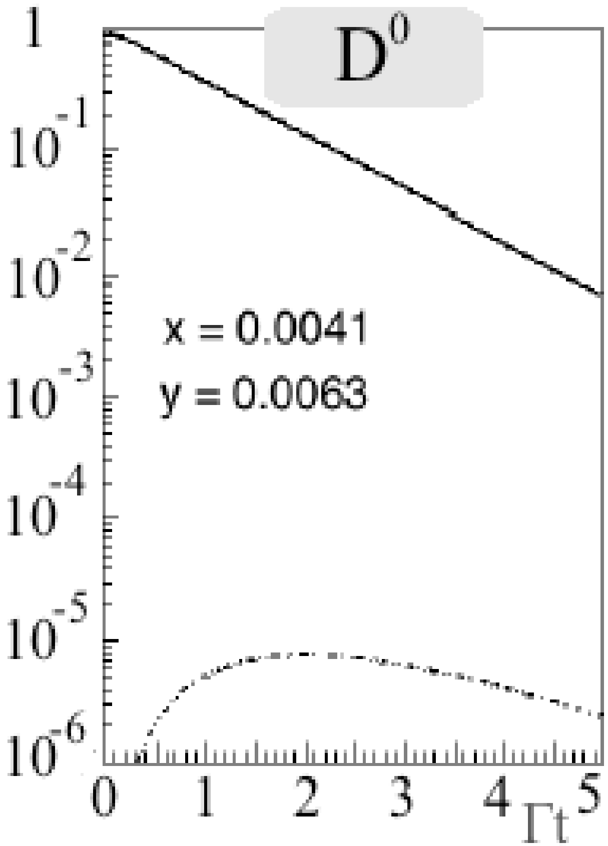
Need new measurement to conclude

More statistics is needed → Belle II experiment at SuperKEKB e^+e^- collider

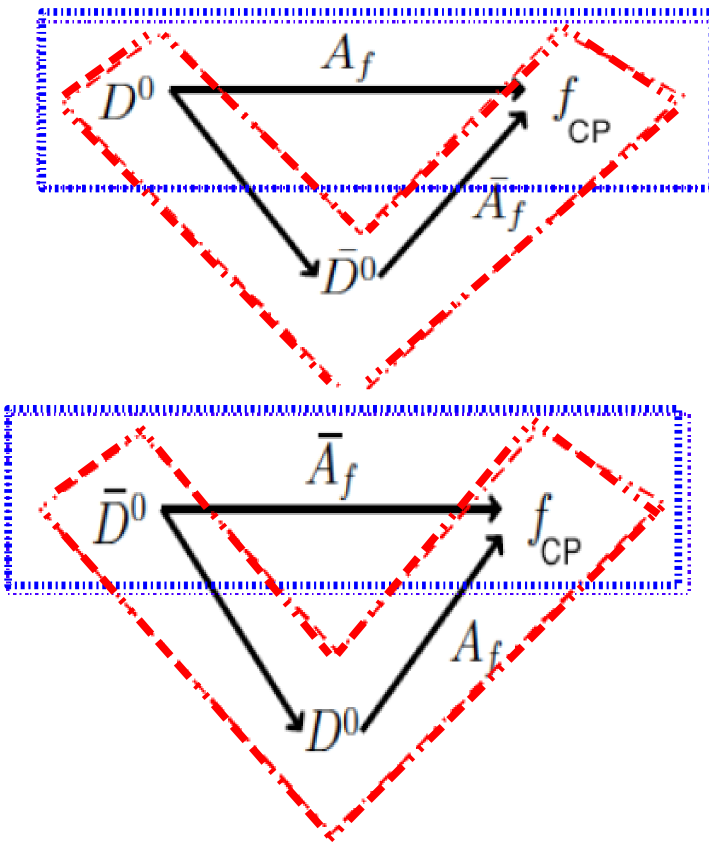


Belle experiment	Belle II experiment
Crab scheme	Nano-beam scheme
1 ab^{-1} integrated luminosity	**50 ab^{-1} ~ 5 years of run**
1,5 cm beam pipe radius	1 cm beam pipe radius
$\beta\gamma = 0.425$	$\beta\gamma = 0.28$

D^0 ⇨ smallest D^0-$\bar{D}^0$ mixing probability:



Types of CP violation measurements in $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$



If blue squares are different ⇨ CPV in decays (direct)

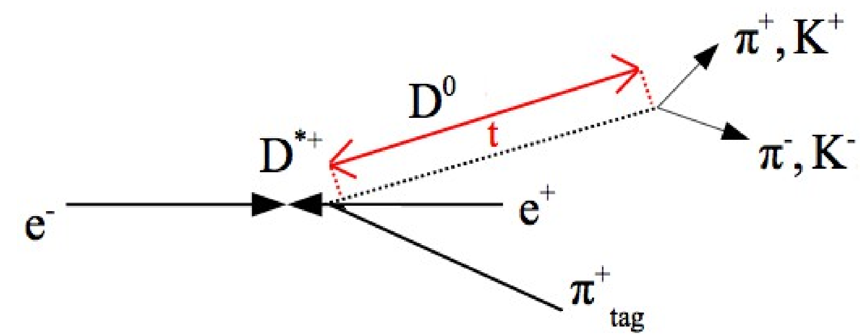
If red V's are different ⇨ CPV in mixing (indirect)

If triangles are different ⇨ CPV in interference between mixing and decay (indirect)

Measurement of the time-dependent CP asymmetry:

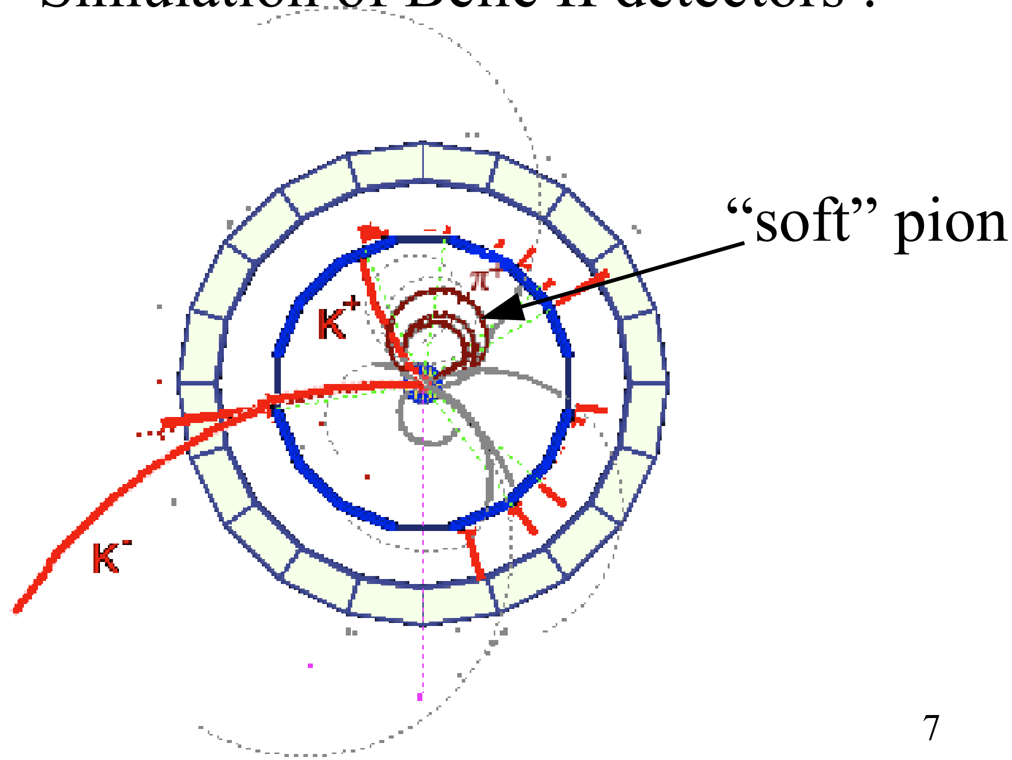
the time-dependent asymmetry

$$A_{CP}(t) = \frac{\bar{\Gamma}(t) - \Gamma(t)}{\bar{\Gamma}(t) + \Gamma(t)}$$



Important to know *t* and the flavour of D

Simulation of Belle II detectors :



The charge of the soft pion gives the flavour of the D meson: $e^+e^- \rightarrow D^{*\pm} X$

$\downarrow$

$D^0\pi^\pm$

$\pi^+ \rightarrow D^0$

$\pi^- \rightarrow \bar{D}^0$

Simulation and measurement of the time-dependent CP asymmetry:

Expected statistics for Belle II:

$5 \cdot 10^6$	$D^0 \rightarrow \pi^+\pi^-$
$12 \cdot 10^6$	$D^0 \rightarrow K^+K^-$

(c.c. included)

D^0 time evolution given by:

$$\Gamma(t)(D^0 \to f) \quad = e^{-t/\tau}\left[cosh(\tfrac{\Delta\Gamma t}{2}) - \tfrac{2Re(\lambda_f)}{1+|\lambda_f|^2} sinh(\tfrac{\Delta\Gamma t}{2}) + \tfrac{1-|\lambda_f|^2}{1+|\lambda_f|^2} cos(\Delta M t) - \tfrac{Im(\lambda_f)}{1+|\lambda_f|^2} sin(\Delta M t)\right]$$

$$\bar{\Gamma}(t)(\overline{D}^0 \to f) \quad = e^{-t/\tau}\left[cosh(\tfrac{\Delta\Gamma t}{2}) - \tfrac{2Re(\lambda_f)}{1+|\lambda_f|^2} sinh(\tfrac{\Delta\Gamma t}{2}) - \tfrac{1-|\lambda_f|^2}{1+|\lambda_f|^2} cos(\Delta M t) + \tfrac{Im(\lambda_f)}{1+|\lambda_f|^2} sin(\Delta M t)\right]$$

Used to generate D^0 and $\overline{D}^0$

Depends on: ΔM, $\Delta\Gamma$ (D^0 is a weak eigenstate)

$$\lambda_f = \left|\frac{q}{p}\right| \left|\frac{\overline{A}}{A}\right| e^{i\varphi}$$

CP violation in interference

Direct CP violation

CP violation in mixing

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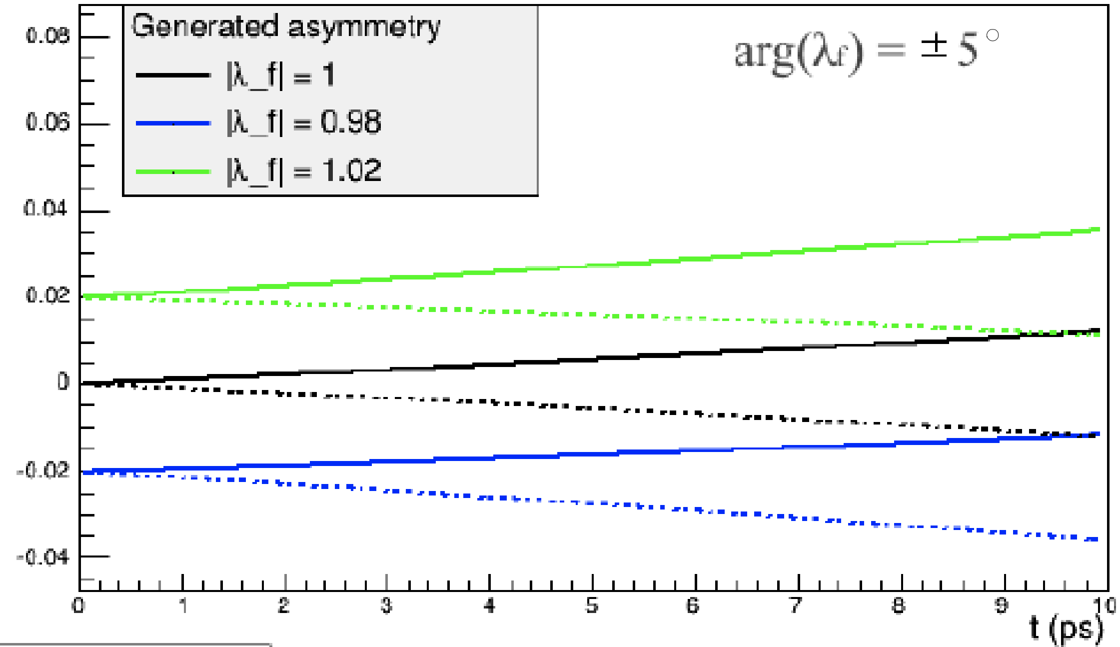
Difficulties in reconstructing the asymmetry

The shape of the asymmetry depends on the direct and indirect CPV contributions →

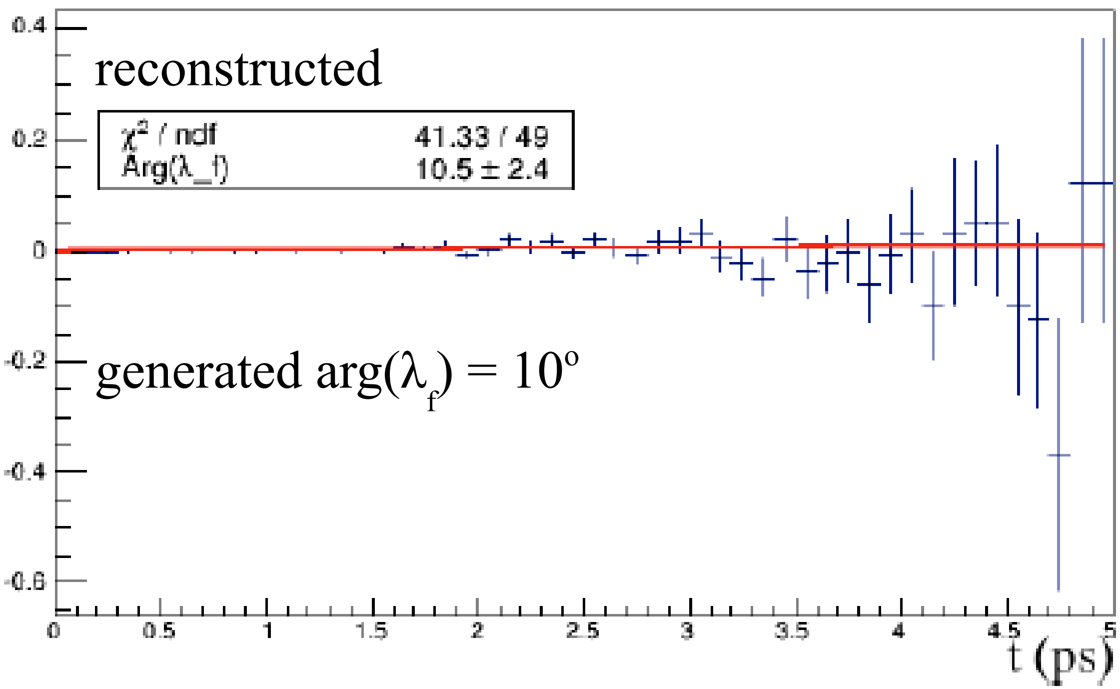


$|\lambda_f| = 1$

Measurement of $\arg(\lambda_f)$

↓

Interference: direct CPV and CPV in mixing

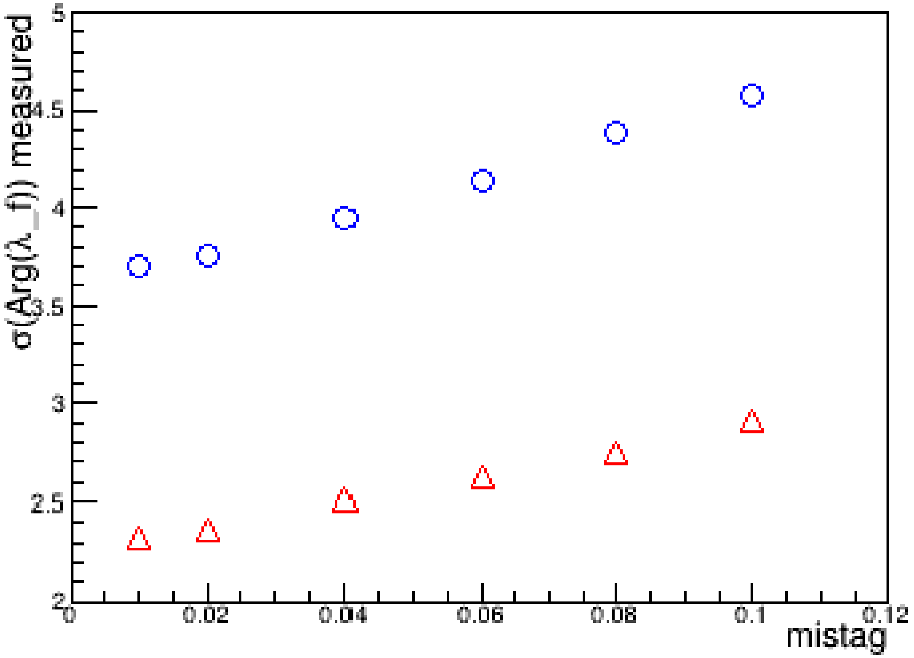


An example of reconstructed asymmetry, with a perfect detector

Measurement: binned likelihood fit of the reconstructed asymmetry as a function of time.

Systematics

Mistag:



○ $D^0 \longrightarrow K^+K^-$

△ $D^0 \longrightarrow \pi^+\pi^-$

Mixing parameters:

$$x = \frac{\Delta M}{\Gamma} \qquad y = \frac{\Delta\Gamma}{2\Gamma}$$

Source of uncertainty	$D^0 \to K^+K^-$	$D^0 \to \pi^+\pi^-$
mixing parameter x (degrees)	+0.0025 -0.0347	0.03 -0.014
mixing parameter y (degrees)	+0.0137 -0.0004	0.0003 -0.00275

Conclusions:

We estimate an uncertainty on $\arg(\lambda_f)$:

$D^0 \longrightarrow \pi^+\pi^-$ →	$\arg(\lambda_f) = \varphi_{mix} + 2\beta_{c,eff}$	← SM prediction: 0.035° can be enhanced by NP
$D^0 \longrightarrow K^+K^-$ →	$\arg(\lambda_f) = \varphi_{mix}$	← Not well known

We can measure $\beta_{c,eff}$ and compare to SM predictions

Belle II estimations:

$\sigma_{\arg(\lambda f)} = 3.6^o$ with $D^0 \longrightarrow \pi^+\pi^-$

$\sigma_{\arg(\lambda f)} = 2.4^o$ with $D^0 \longrightarrow K^+K^-$

⇨ 2.2° uncertainty on $\beta_{c,eff}$

$\sigma_{stat} >> \sigma_{syst}$

The statistics is a key factor of this measurement.

Thank your for your attention

Backup slides

Mixing probability for neutral mesons