Charm physics prospects at the Belle II experiment

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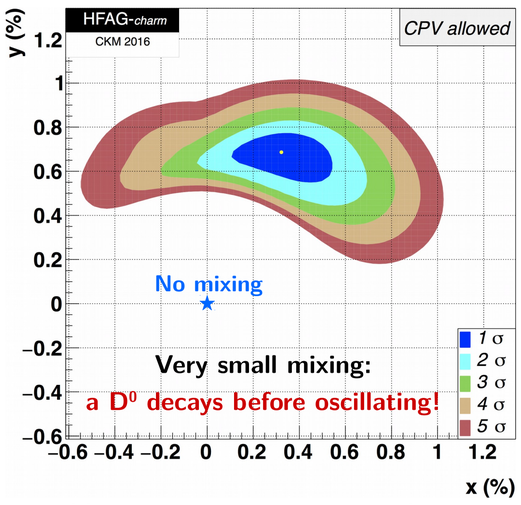
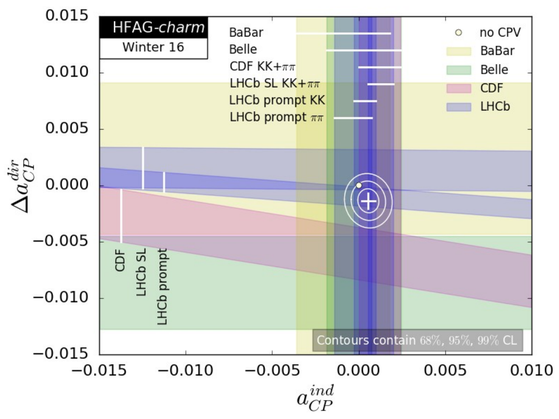
Charm physics: the state of the art





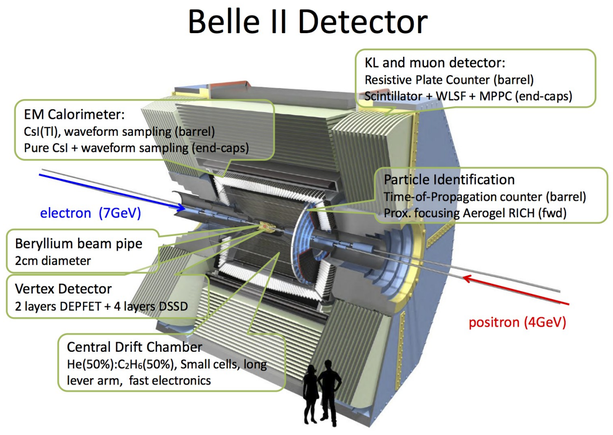
No CPV at 6.5% CL

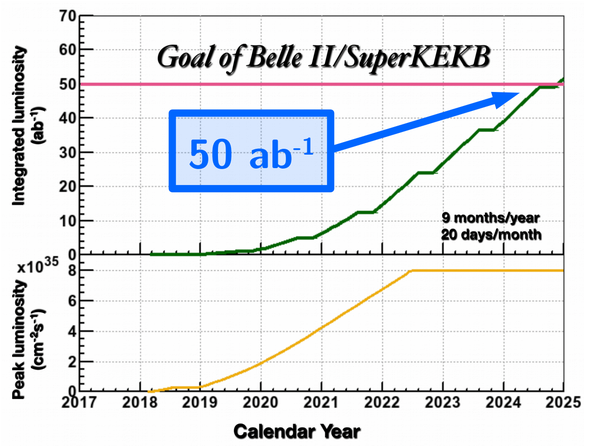
Unique system to study mixing and CPV in the **up-quark** sector

Measurements are achieving a **sub-percentage level** of precision

Difficult to make theoretical predictions (**non-perturbative effects**)

Belle II experiment @ SuperKEKB





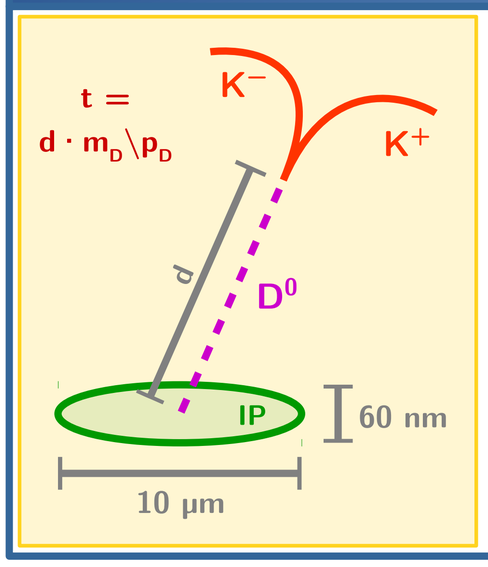
Innermost layer of the vertex detector is **2 times closer** to the IP w.r.t. Belle

Great performances expected in the reconstruction of

final states with neutrals and **missing energy**

First data taking (without vertex detector) will start in **2018**

Proper time resolution and error



Proper time resolution:

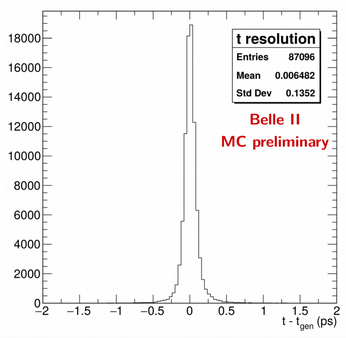
2 times better

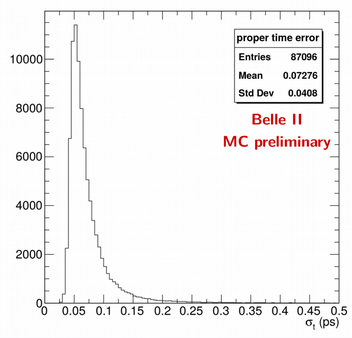
w.r.t. BaBar: **14 ps**

Proper time error:

3 times smaller

w.r.t. BaBar: **73 fs**



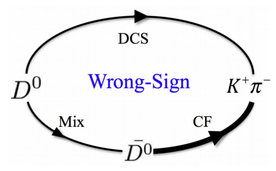


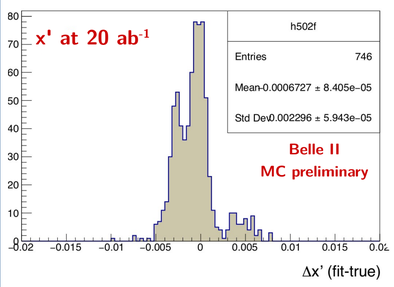
Impact on D⁰-$\overline{D}^0$ mixing and CPV

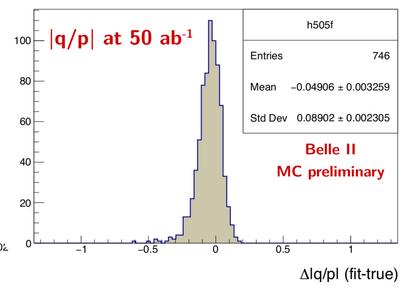
Toy MC study for the WS decay $D^0 \to K^+\pi^-$

(almost **background free** at the B-factories)

$$D^0(t) \propto e^{-\overline{\Gamma}t}\left[R_D + \left|\frac{q}{p}\right|\sqrt{R_D}(y'\cos\varphi - x'\sin\varphi)(\overline{\Gamma}t) + \left|\frac{q}{p}\right|^2\frac{(x'^2+y'^2)}{4}(\overline{\Gamma}t)^2\right]$$







|q/p| and φ are the CPV parameters;

x' and y' are defined as:

$$x' = x\cos\delta + y\sin\delta$$

$$y' = y\cos\delta - x\sin\delta$$

where δ is the strong phase between $D^0 \to K^+\pi^-$ and $D^0 \to K^-\pi^+$

The expected sensitivity at 50 ab^{-1} is:

δx' = 0.15% **δy' = 0.10%** **δ|q/p| = 0.05%** **δφ = 5.7°**

~ **1 order of magnitude better** than Belle ~ **1.6 times better** than the world average

Competitive with the upgrade of LHCb!

Impact on time-integrated CPV measurements

Current results from Belle for:

$$A_{CP} = \frac{\Gamma(D^0 \to X) - \Gamma(\overline{D}^0 \to \overline{X})}{\Gamma(D^0 \to X) + \Gamma(\overline{D}^0 \to \overline{X})}$$

Only correlations and sum rules

between A_{CP} for different final states

can be predicted precisely

(absolute values of A_{CP} have large uncertainties)

Golden channels at Belle II:

$D^0 \to K_S K_S$

(CPV is enhanced in the SM predictions; limited by statistics at Belle)

$D^+ \to \pi^0\pi^+$

(No CPV in the SM: possible enhancement from NP)

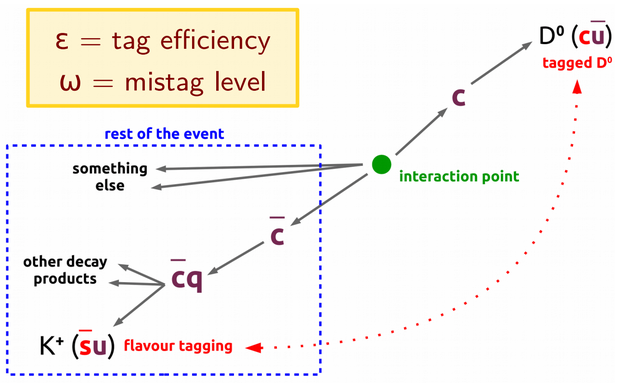
Channel	$\mathcal{L}$ (fb^{-1})	Current measurement value (%)	Scaled 50 ab^{-1}
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	± 0.03
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	± 0.05
$D^0 \to \pi^0\pi^0$	966	$-0.03 \pm 0.64 \pm 0.10$	± 0.09
$D^0 \to K^0_S\pi^0$	966	$-0.21 \pm 0.16 \pm 0.07$	± 0.03
$D^0 \to K^0_S\eta$	791	$+0.54 \pm 0.51 \pm 0.16$	± 0.07
$D^0 \to K^0_S\eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	± 0.09
$D^0 \to K^0_S K^0_S$	921	$-0.02 \pm 1.53 \pm 0.17$	± 0.02
$D^0 \to \pi^+\pi^-\pi^0$	532	$+0.43 \pm 1.30$	± 0.13
$D^0 \to K^+\pi^-\pi^0$	281	-0.60 ± 5.30	± 0.40
$D^0 \to K^+\pi^-\pi^+\pi^-$	281	-1.80 ± 4.40	± 0.33
$D^0 \to \rho^0\gamma$	976	$+0.056 \pm 0.152 \pm 0.006$	± 0.02
$D^0 \to \phi\gamma$	976	$-0.094 \pm 0.066 \pm 0.001$	± 0.01
$D^0 \to \overline{K}^{*0}\gamma$	976	$-0.003 \pm 0.020 \pm 0.000$	± 0.003
$D^+ \to \pi^0\pi^+$		ongoing analysis	± 0.04
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	± 0.04
$D^+ \to \eta\pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	± 0.14
$D^+ \to \eta'\pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	± 0.14
$D^+ \to K^0_S\pi^+$	977	$-0.36 \pm 0.09 \pm 0.07$	± 0.03
$D^+ \to K^0_S K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.05
$D^+_s \to K^0_S\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D^+_s \to K^0_S K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

$$\sigma_{\text{Belle II}} = \sqrt{(\sigma^2_{\text{stat}} + \sigma^2_{\text{syst}}) \cdot (\mathcal{L}_{\text{Belle}}/50\ \text{ab}^{-1}) + \sigma^2_{\text{irred}}}$$

Flavour tagging: the ROE method

A new method: selecting events **with only 1 $K^\pm$ in the ROE**

to tag the flavour of D^0 at production



Expected perfomances:

ε ~ 27% ω ~ 13%

$Q^0 = \varepsilon \cdot (1 - 2\omega)^2 \sim$ **20%**

(different selection criteria → different performances)

Performances for D^{*+} tag:

$Q^* = 0.8 \cdot (1 - 2 \cdot 0.02)^2 \sim$ **80%**

but only **25% of D^0 are from D^{*+}**

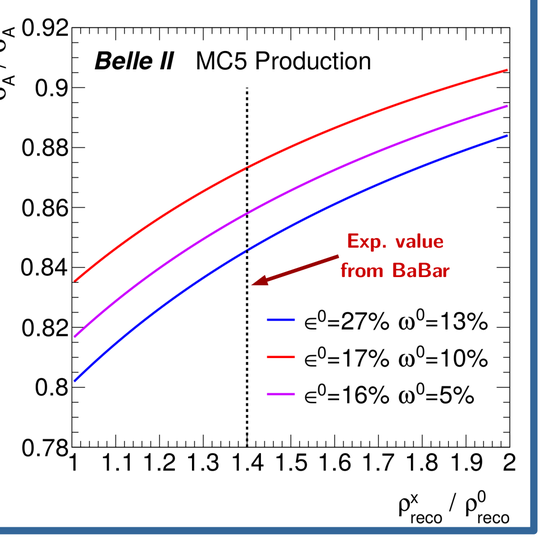
A fraction of D^0 can be doubly tagged: **measurement of Q^0 (ε, ω) on data**

15% reduction on statistical uncertainty of **$A_{CP}(D^0 \to K^-\pi^+)$** combining the D^{*+} and ROE methods:

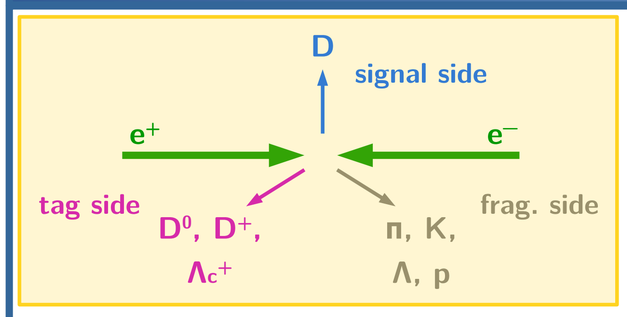
$$\frac{\sigma^c_{A_{CP}}}{\sigma^*_{A_{CP}}} = \frac{\alpha}{\sqrt{1+\alpha^2}}\ ; \quad \alpha \equiv \sqrt{\frac{1}{3}\cdot\frac{Q^*}{Q^0}\cdot\frac{\rho^*_{\text{reco}}}{\rho^0_{\text{reco}}}}$$

(where ρ^0 is the purity of the reconstructed D^0 tagged with the ROE method and ρ^* is the purity with the D^{*+} tag)

Enhancement of the effective luminosity by **35%** adding the ROE method



Leptonic and semileptonic decays



To study the (semi)leptonic decays, we look for configurations with **missing energy from the neutrino**:

$$P_{\text{miss}} = \sqrt{s} - P_{\text{tag}} - P_{\text{frag}} - P_l\ (-P_h)$$

M^2_{miss} peaks at 0 for the signal

Leptonic decays (**$D_{(s)}^+ \to \mu^+\nu$**)

Extracting $f_{D_q}|V_{cq}|^2$, the goals are:

- improve the most precise measurement of **$|V_{cs}|$** (from Belle)
- measure **$|V_{cd}|$** with **2%** of precision

Possibility to search for $D^0 \to$ invisibles

Semileptonic decays (**$D \to h l^+\nu$**)

MC with 1 ab^{-1}

Signal:

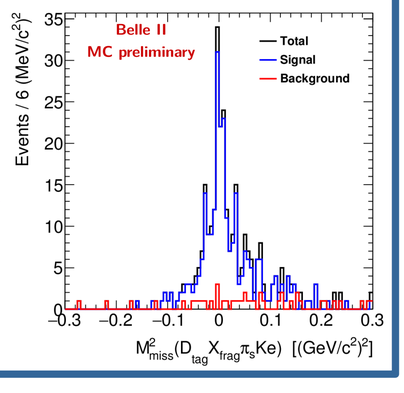
l = μ, e ; h = K, π

D^0 from D^{*+}

Tag: $D^0 \to K^-\pi^+$

Frag.: π^-

No background from continuum!



References

Belle II Theory Interface Platform (B2TiP) Report

(to be published on *Progress of Theoretical and Experimental Physics*)

XVI edition of Incontri di Fisica delle Alte Energie

19-21 April 2017 @ Trieste (TS), Italy