Charm physics prospects at the Belle II experiment

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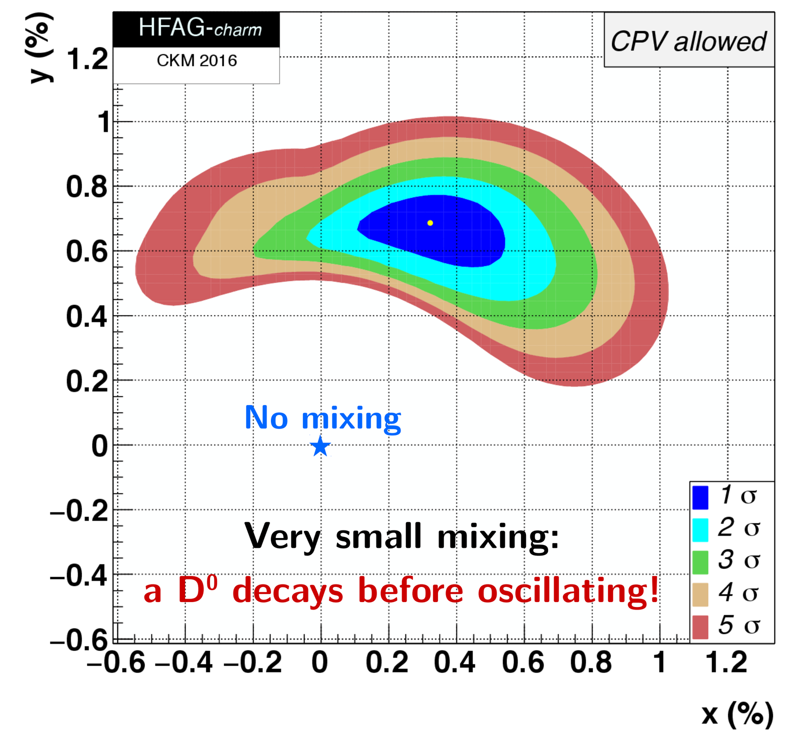
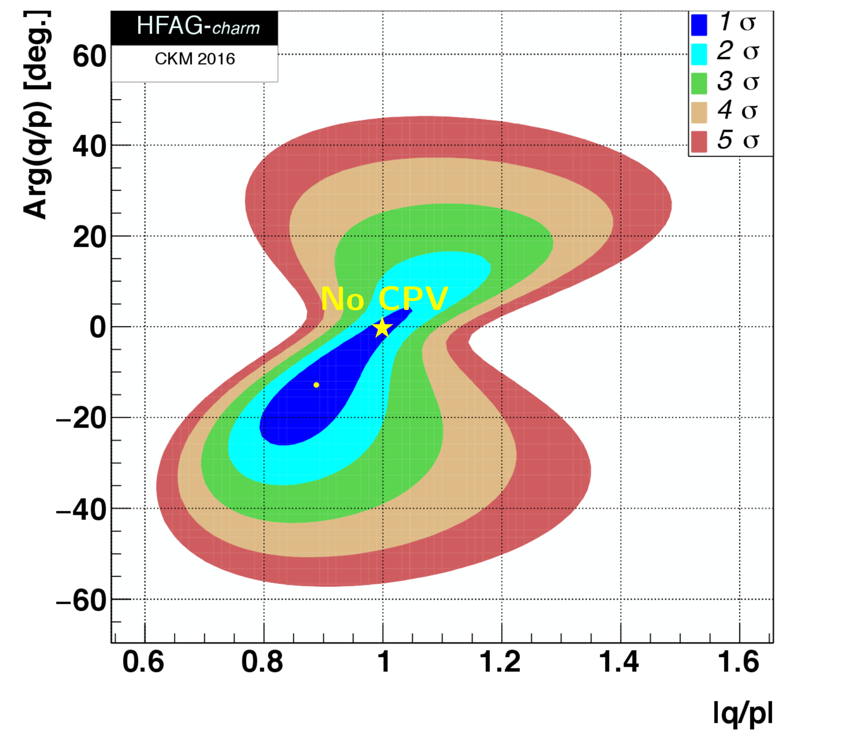
Charm physics: the state of the art



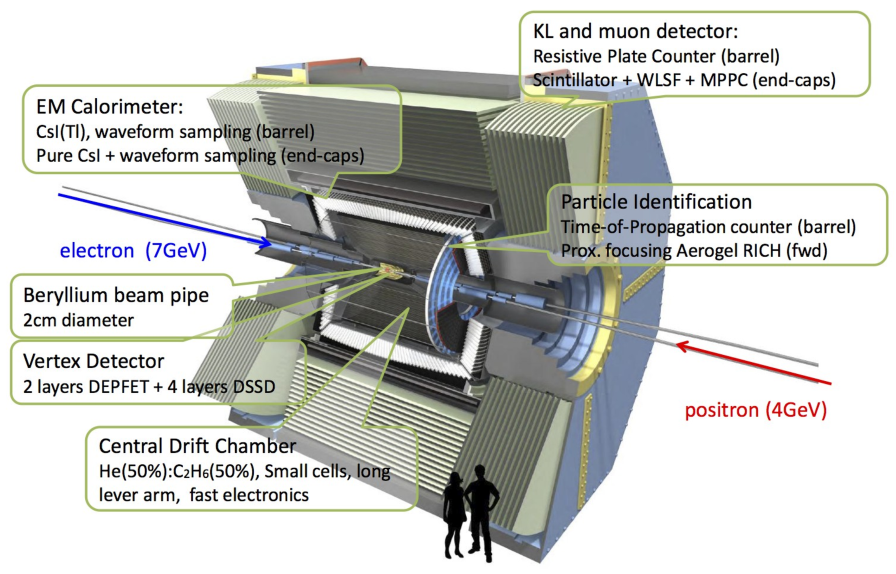


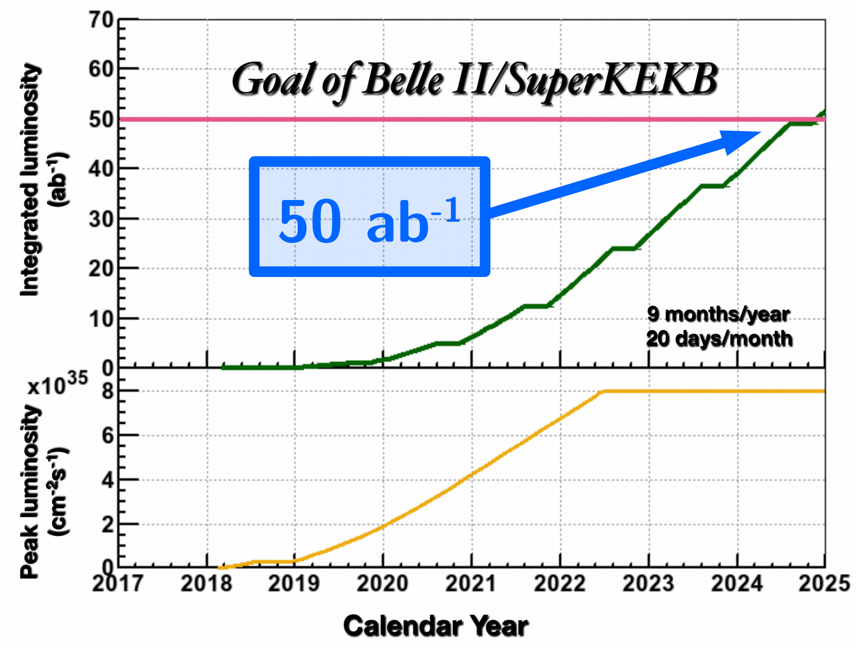
Unique system to study mixing and CPV in the **up-quark** sector

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

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

Belle II experiment @ SuperKEKB





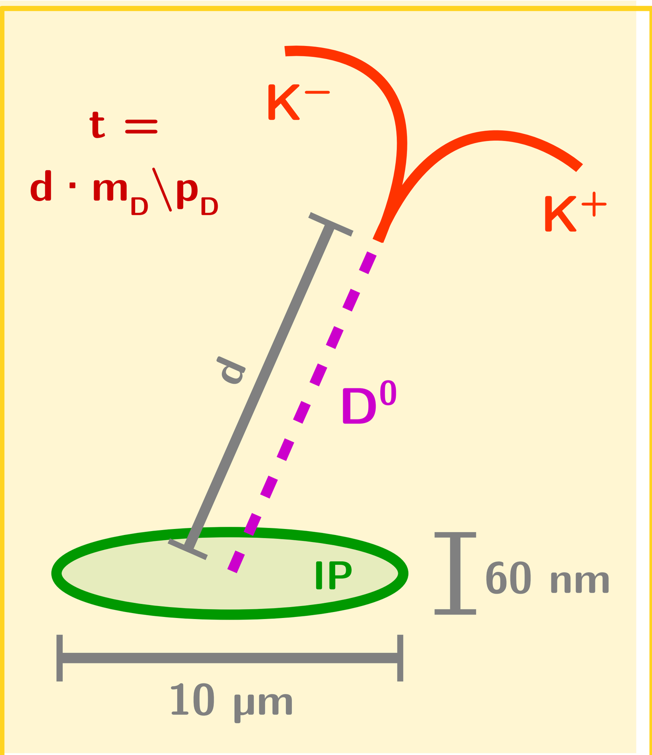
Innermost layer of the vertex detector is **2 times closer** to the IP w.r.t. Belle

Great performances expected in the reconstruction of

final states with neutrals and **missing energy**

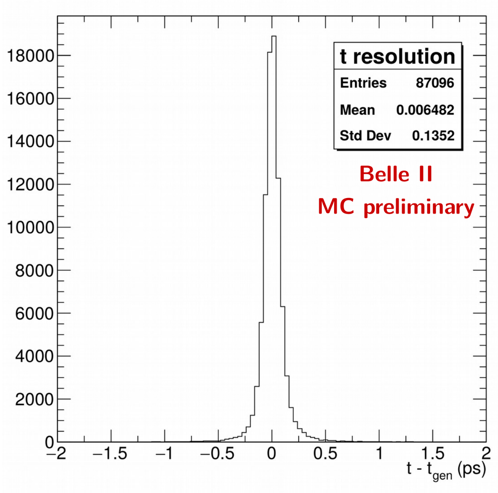
First data taking (without vertex detector) will start in **2018**

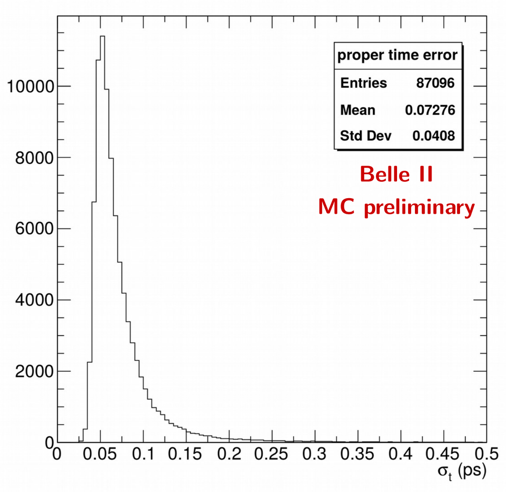
Proper time resolution and error



Proper time resolution: **2 times better** w.r.t. BaBar: **14 ps**

Proper time error: **3 times smaller** w.r.t. BaBar: **73 fs**



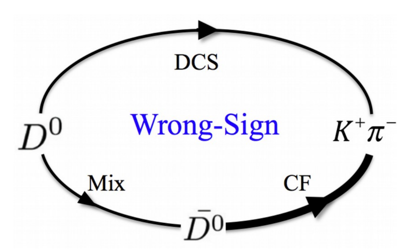


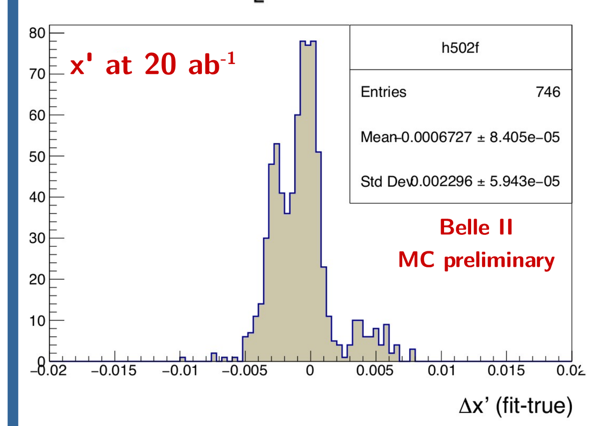
Impact on D^0-$\overline{D}^0$ mixing and CPV

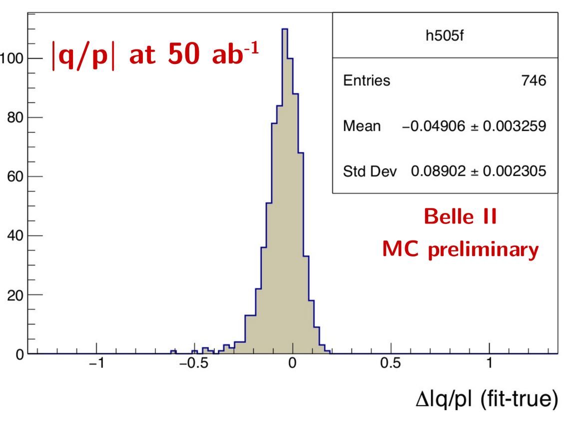
Toy MC study for the WS decay **$D^0 \to K^+\pi^-$**

(using **only D^{*+} tagging**; almost **background free** at 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:

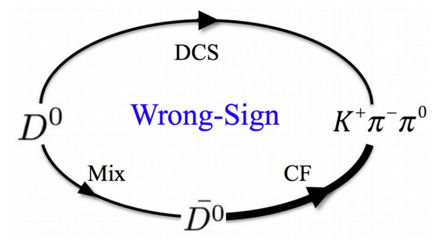
$\sigma(x') = 0.15\%$ **$\sigma(y') = 0.10\%$** **$\sigma(|q/p|) = 0.05\%$** **$\sigma(\varphi) = 5.7°$**

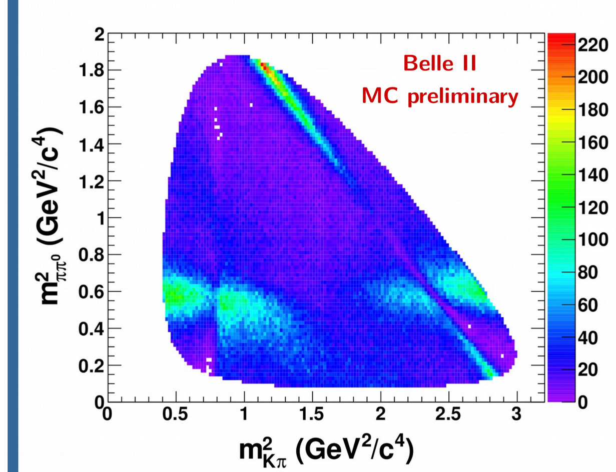
~ **1 order of magnitude better** than Belle ~ **1.6 times better** than the world average

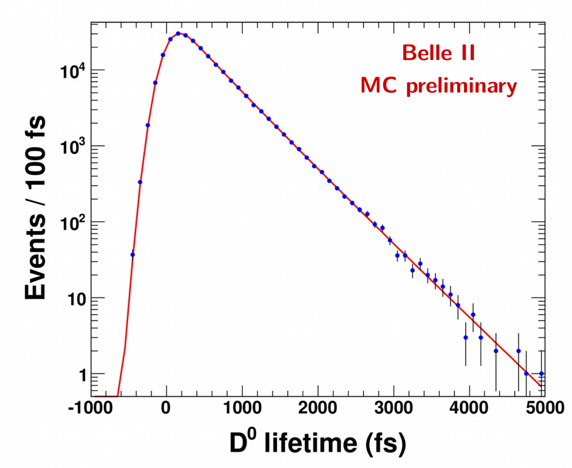
Toy MC study for the WS decay **$D^0 \to K^+\pi^-\pi^0$**

(using **only D^{*+} tagging**; **not considering the background**)

$$|\mathcal{M}(\bar{f},t)|^2 = e^{-\overline{\Gamma}t}\left\{r_0^2\left|\mathcal{A}_{\bar{f}}^{DCS}\right|^2 - r_0\left[Ay'' + Bx''\right](\overline{\Gamma}t) + \frac{(x''^2+y''^2)}{4}\left|\bar{\mathcal{A}}_{\bar{f}}^{CF}\right|^2(\overline{\Gamma}t)^2\right\}$$







CPV has been neglected; r_0 is defined as

$$r_0^2 = \frac{\int |\mathcal{A}_{\bar{f}}|^2 dm_{12}^2\, dm_{23}^2}{\int |\bar{\mathcal{A}}_{\bar{f}}|^2 dm_{12}^2\, dm_{23}^2}$$

The values $1/r_0 = 13.8$ and $\delta = 10°$ have been used as inputs

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

$\sigma(x) = 0.057\%$ **$\sigma(y) = 0.049\%$**

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 theoretically predicted

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

Typical golden channels at Belle II:

$D^0 \to K_S K_S$ (CPV is enhanced in the SM predictions; limited by statistics at Belle)

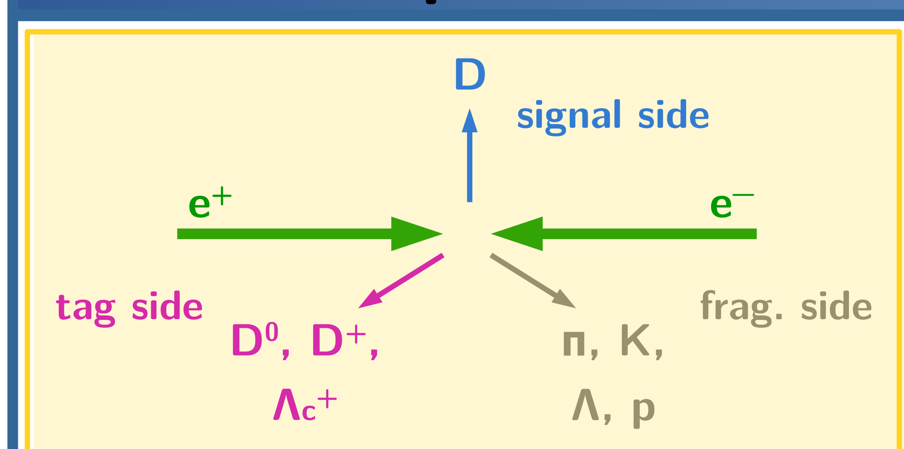
$D^+ \to \pi^0\pi^+$ (No CPV in the SM: possible enhancement from NP)

Assuming only D^{*+} tagging

Channel	Current measurement $\mathcal{L}$ (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
$D^0 \to K_S^0\pi^0$	966	$-0.21 \pm 0.16 \pm 0.07$	± 0.03
$D^0 \to K_S^0\eta$	791	$+0.54 \pm 0.51 \pm 0.16$	± 0.07
$D^0 \to K_S^0\eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	± 0.09
$D^0 \to K_S^0 K_S^0$	921	$-0.02 \pm 1.53 \pm 0.17$	± 0.20
$D^0 \to \pi^+\pi^-\pi^0$	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		± 0.40
$D^+ \to \phi\pi^+$	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
$D^+ \to K_S^0\pi^+$	977	$-0.36 \pm 0.09 \pm 0.07$	± 0.03
$D^+ \to K_S^0 K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.05
$D_s^+ \to K_S^0\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D_s^+ \to K_S^0 K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

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

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

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

Extracting $f_{D_q}|V_{cq}|$, 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 (**$D \to h l^+\nu$**)

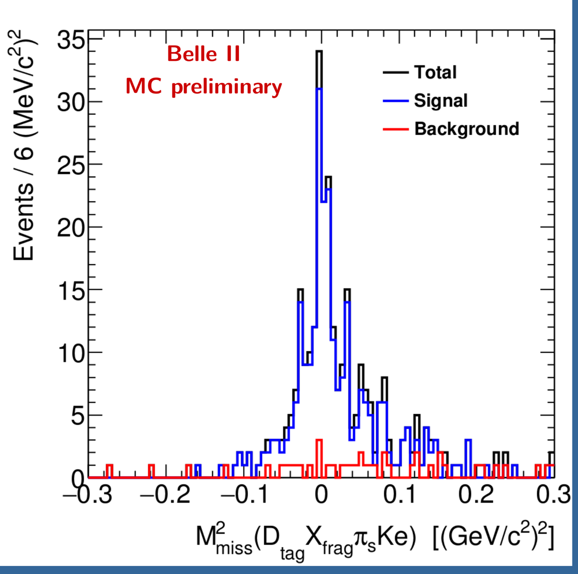
MC with 1 ab^{-1}

Signal: $l = \mu, e$; $h = K, \pi$; **D^0 from D^{*+}**

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

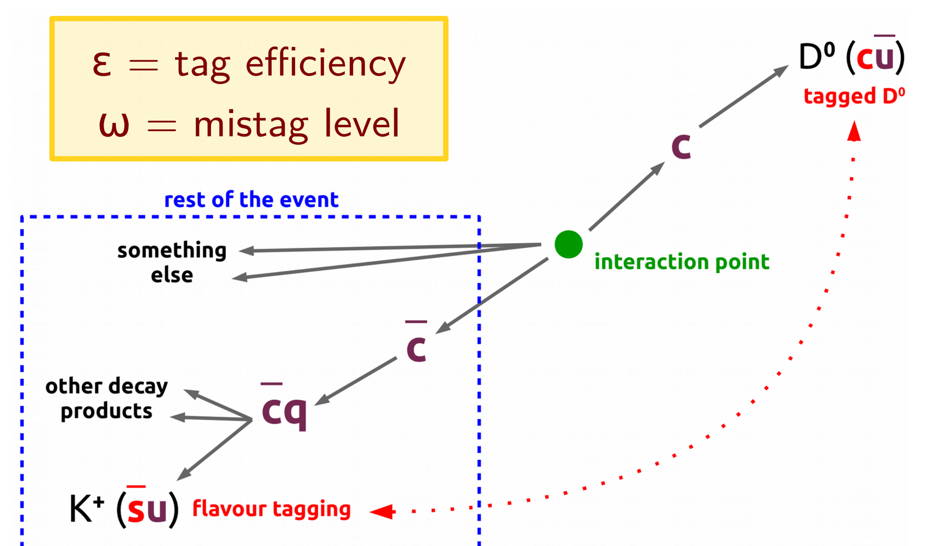
Frag.: π^-

No background from continuum!



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 the production time



Expected perfomances:

$\varepsilon \sim 27\%$ $\omega \sim 13\%$

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

Performances for D^{*+} tagging:

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

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

15% reduction on stat. uncertainty of **$A_{CP}(D^0 \to K^-\pi^+)$** combining both methods

References

Belle II Collaboration & B2TiP Theory Community, **The Physics Prospects for Belle II** (to be published on *Progress of Theoretical and Experimental Physics*)

ROMA TRE UNIVERSITÀ DEGLI STUDI

INFN Istituto Nazionale di Fisica Nucleare

EPS Conference on High Energy Physics 2017

5-12 July 2017 at Venice, Italy