Charm physics prospects at the Belle II experiment

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Outline

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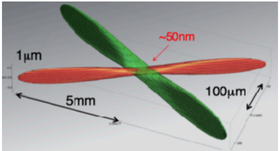
SuperKEKB

- KEKB ⇒ SuperKEKB (with "Nano-Beam" scheme)

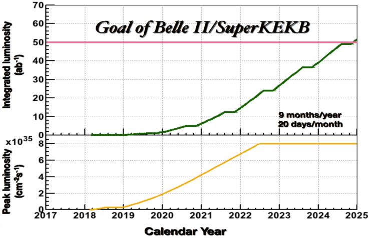
more info, see Jake's report on 3rd Sep



luminosity: $\mathcal{L} = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}\left(\frac{R_L}{R_{\xi_y}}\right)$

	E (GeV) LER/HER	I (A) LER/HER	β_y^* (mm) LER/HER	Lumin. ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	1.64/1.19	5.9/5.9	2.1×10^{34}
SuperKEKB	4.0/7.0	3.60/2.60	0.27/0.31	80×10^{34}
	$\beta\gamma\sim2/3$	$\times2$	$\times20$	$\times40$

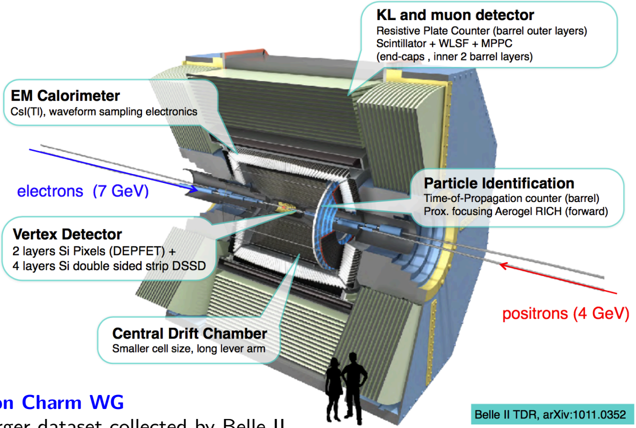
- Target integrated luminosity for Belle II at SuperKEKB: $\int_t \mathcal{L}dt = 50$ ab^{-1}



First physics run will start in 2018
Each 1 ab^{-1} experimental data provides

- $\sim 1.1\times10^9$ $B\bar{B}$ ⇒ a super B-factory;
- $\sim 1.3\times10^9$ $c\bar{c}$ ⇒ a super charm factory;
- $\sim 0.9\times10^9$ $\tau^+\tau^-$ ⇒ a super τ factory;
- wide effective $E_{c.m}$=[0.5-10] GeV via ISR process.

Belle II Detector



Impacts on Charm WG

- ☺ 50× larger dataset collected by Belle II
- ☺ Better D^0 proper time resolution (improved IP and secondary vertex resolution)
- ☺ Better reconstruction efficiency with improved tracking efficiency, eg: $D^{*+} \to D^0 \pi_s^+$ etc.
- ☺ Better particle identification capabilities, eg: $D^0 \to K^+ \pi^-$ etc.
- ☺ ...

Outline

Formalism of D^0-$\overline{D^0}$ mixing and CP violation

- Open-flavor neutral meson transforms to anti-meson:

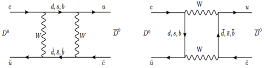
$$K^0 \Leftrightarrow \overline{K^0},\ B_d^0 \Leftrightarrow \overline{B_d^0},\ B_s^0 \Leftrightarrow \overline{B_s^0},\ D^0 \Leftrightarrow \overline{D^0}$$

- Flavor eigenstate ($|D^0\rangle$, $|\overline{D^0}\rangle$) $\neq$ mass eigenstate $|D_{1,2}\rangle$ with $M_{1,2}$ and $\Gamma_{1,2}$)

$$|D_{1,2}\rangle \equiv p|D^0\rangle \pm q|\overline{D^0}\rangle \ \text{(CPT: } p^2+q^2=1)$$

- Mixing parameters: $\mathbf{x} \equiv 2\frac{M_1 - M_2}{\Gamma_1 + \Gamma_2}, \quad \mathbf{y} \equiv \frac{\Gamma_1 - \Gamma_2}{\Gamma_1 + \Gamma_2}$

- Unique system: only up-type meson for mixing
- Standard Model(SM) predicts: $\sim \mathcal{O}(1\%)$



(1) short distance ($< 0.1\%$)

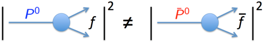
(2) long distance ($\sim 1\%$)

- Precise measurement of x, y: effectively limit the New Physics(NP) modes; and search for NP, eg: $|x| \gg |y|$

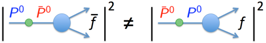
► Three types of Charged-conjugated-Parity combined symmetry Violation (CPV):

$$A_{CP}^f = \frac{\Gamma(D \to f) - \Gamma(\bar{D} \to \bar{f})}{\Gamma(D \to f) + \Gamma(\bar{D} \to \bar{f})} = a_d^f + a_m^f + a_i^f$$

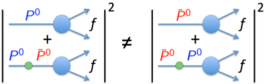
- a_d^f: (direct CPV) CPV in decay $|\bar{A}_{\bar{f}}/A_f| \neq 1$



- a_m^f: CPV in mixing with $r_m = |q/p| \neq 1$



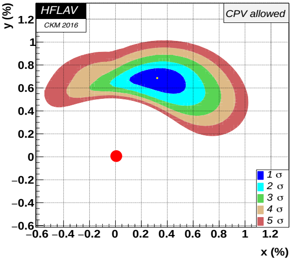
- a_i^f: CPV in interference with $\arg(q/p) \neq 0$



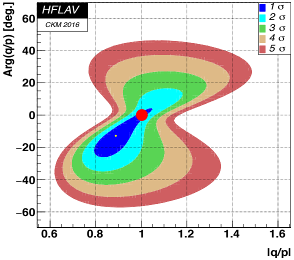
- SM with only a source: the phase in CKM
- in charm sector, it's predicted at $\sim \mathcal{O}(10^{-3})$
- $\sim 1\%$ exp. sensitivity to observe CPV→NP

Status of D^0-$\overline{D}^0$ mixing and CP violation [mainly ref. charm physics at HFAG]

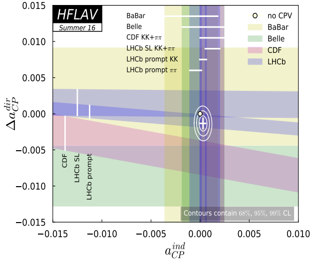
D^0-$\overline{D}^0$ mixing



indirect CP violation



CP violation in $D^0 \to KK/\pi\pi$



- $\gg 11.5\sigma$ to exclude no mixing (x,y)=(0,0) with CPV-allowed
- No hints for indirect CPV $\Leftarrow$ no direct CPV $(|q/p|,\phi)=(1,0)$ at C.L=40%
- No clear evidence of direct CPV $\Leftarrow$ no CPV at C.L=9.3%

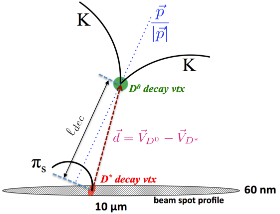
D^0-$\overline{D}^0$ mixing observation in more channels, and CPV searches are two of most important physical goals of Charm WG at the Belle II experiment.

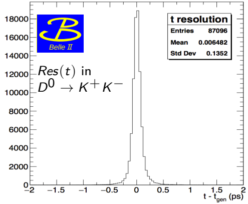
Improved D^0 proper time resolution at Belle II

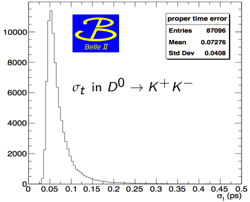
- Time-dependent amplitude of $D^0 \to f$ (here $t[\tau_{D^0}]$ and $\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}$):

$$\Gamma(D^0(t)\to f) \propto |\mathcal{A}_f|^2 e^{-t}\left(\frac{1+|\lambda_f|^2}{2}\cosh(yt) - \mathrm{Re}(\lambda_f)\sinh(yt)\frac{1-|\lambda_f|^2}{2}\cos(xt) + \mathrm{Im}(\lambda_f)\sin(xt)\right) \otimes_t Res(t)$$

- Time resolution $Res(t)$ is essential in t-dept. measurements of D^0-$\overline{D^0}$ mixing and CPV
- Determine D^0 proper time: $t = \frac{\ell_{dec}}{c\beta\gamma} = \frac{m_D}{cp}\vec{d}\cdot\frac{\vec{p}}{p}$ and its uncertainty σ_t







- Based on MC study, time resolution = 140 fs: 2× better than BaBar (270 fs)
- Time error σ_t: factor 3 improvement; and RMS(σ_t): reduced by a factor 2.
  - $Res = Gauss(\mu, k\sigma_t)$, so reduced RMS($\sigma_t$) (higher weight in the fit) results in an increased statistics

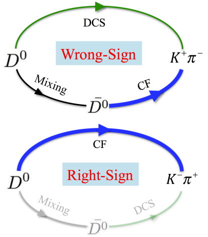
Hadronic wrong-sign decays $D^0 \to K^+\pi^-$

- Wrong-sign(WS) decay rates with D^0-$\overline{D}^0$ mixing or CPV-allowed:

$$\frac{N(D^0 \to f)}{dt} = e^{-\Gamma t}\left[R_D + \left|\frac{q}{p}\right|\sqrt{R_D}(y'\cos\phi - x'\sin\phi)(\Gamma t) + \left|\frac{q}{p}\right|^2 \frac{(x'^2 + y'^2)}{4}(\Gamma t)^2\right]$$

$$\frac{N(D^0 \to f)}{dt} = e^{-\Gamma t}\left[R_D + \sqrt{R_D}y'(\Gamma t) + \frac{(x'^2 + y'^2)}{4}(\Gamma t)^2\right] \text{ (no CPV)}$$

where $x' = x\cos\delta + y\sin\delta$, $y' = y\cos\delta - x\sin\delta$ with strong phase difference δ



- Belle: first observation (5.1σ) of D^0-$\overline{D}^0$ mixing in e^+e^- collisions
  [PRL 112, 111801 (2014)]
- Belle II sensitivity estimation based on ToyMC
  - Smear decay time with Gauss (σ =140 fs) for 1000 experiments
  - Obtain sensitivities by RMS of residuals distribution of parameters

Parameter		Belle	Belle II		
		976 /fb	5 /ab	20 /ab	50 /ab
no CPV	$\sigma(x'^2)(10^{-5})$	22	7.5	3.7	2.3
	$\sigma(y')(\%)$	0.34	0.11	0.056	0.035
CPV-allowed	$\sigma(x')(\%)$		0.37	0.23	0.15
	$\sigma(y')(\%)$		0.26	0.17	0.10
	$\sigma(\lvert q/p\rvert)$		0.197	0.089	0.051
	$\sigma(\phi)(^o)$		15.5	9.2	5.7

one order of magnitude better than Belle measurement

Time-dependent Dalitz analyses in D three-body decays

- Time-dependent Dalitz plot(TDDP) provides an essential tool in studying D^0-$\overline{D^0}$ mixing.
- Only method: sensitive to linear order in both mixing parameters, especially self-conjugated decays like $K^0_S hh$ (not rotated by an unknown δ)

- TDDP fit on $D^0 \to K^+\pi^-\pi^0$ WS decays to extract mixing par. $(x''/r_0,\ y''/r_0)$

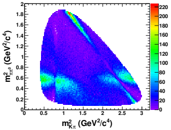
$$|\mathcal{A}_{\bar{f}}|^2 = \left[|\mathcal{A}^{DCS}_{\bar{f}}|^2 e^{-\Gamma t} + \frac{(x^2+y^2)}{4r_0^2}|\bar{\mathcal{A}}^{CF}_{\bar{f}}|^2(\Gamma t)^2 e^{-\Gamma t} + \left(\frac{y''}{r_0}\mathrm{Re}[\mathcal{A}^{DCS}_{\bar{f}}\bar{\mathcal{A}}^{*CF}_{\bar{f}}] + \frac{x''}{r_0}\mathrm{Im}[\mathcal{A}^{DCS}_{\bar{f}}\bar{\mathcal{A}}^{*CF}_{\bar{f}}]\right)(\Gamma t)e^{-\Gamma t}\right] \otimes_t Res(t)$$

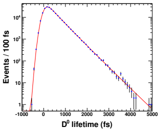
$$x'' = x\cos\delta_{K\rho} + y\sin\delta_{K\rho},\ y'' = y\cos\delta_{K\rho} - x\sin\delta_{K\rho},\ r_0 = |A^{CF}|/|A^{DCS}|$$

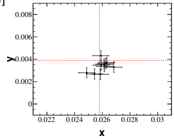
- BaBar: the evidence (3.2σ) with 384 fb^{-1}: $\sigma(x'', y'') = \left({}^{+0.57}_{-0.68}, {}^{+0.55}_{-0.64}\right)\%$ [PRL **103**, 211801 (2009)]

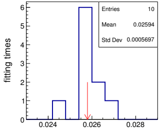
- ToyMC: smear lifetime with Gauss(σ=140 fs); without considering bkg effects.
- Sensitivity estimation: one order of magnitude improvement than BaBar

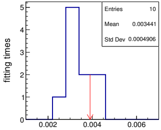
detailed info. see [Chin. Phys. C, **41**: 023001 (2017)]











$\sigma_x = 0.060\%$, $\sigma_y = 0.049\%$

- More t-dept. measurements, like $D^0 \to K^+K^-, \pi^+\pi^-$ (y_{CP}, A_Γ), $D^0 \to K^0_S\pi^+\pi^-$ (x,y,|q/p|,ϕ) etc. in backup.

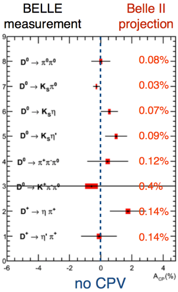
Time-integrated CP asymmetry in D decays

- Time-integrated CP asymmetries are measured based on partial decay rates:

$$A^f_{CP} = \frac{\Gamma(D \to f) - \Gamma(\bar{D} \to \bar{f})}{\Gamma(D \to f) + \Gamma(\bar{D} \to \bar{f})} = a^f_d + a^f_{ind}$$ e.g: in $D^0 \to K^0_S h^+$, measured asym.: $A_{raw} = A_{CP} + A_{FB} + A^{h^+}_{\epsilon} + A^{K^0}_{CP}$

- Several measurements are performed at Belle

Channel	Current measurement $\mathcal{L}(/\text{fb})$	value(%)	References	Belle II 50 ab^{-1}(%)	LHCb 50 fb^{-1}(%)
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	PoS ICHEP2012 (2013) 353	± 0.05	± 0.03
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	PoS ICHEP2012 (2013) 353	± 0.03	± 0.03
$D^0 \to \pi^0\pi^0$	966	$-0.03 \pm 0.64 \pm 0.10$	PRL **112**, 211601 (2014)	± 0.09	
$D^0 \to K^0_S K^0_S$	921	$-0.02 \pm 1.53 \pm 0.17$	arXiv:1705.05966	± 0.20	
$D^0 \to K^0_S \pi^0$	966	$-0.21 \pm 0.16 \pm 0.07$	PRL **112**, 211601 (2014)	± 0.03	
$D^0 \to K^0_S \eta$	791	$+0.54 \pm 0.51 \pm 0.16$	PRL **106**, 211801 (2011)	± 0.07	
$D^0 \to K^0_S \eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	PRL **106**, 211801 (2011)	± 0.09	
$D^0 \to \pi^+\pi^-\pi^0$	532	$+0.43 \pm 0.41 \pm 1.23$	PLB **662**, 102 (2008)	± 0.13	
$D^0 \to K^+\pi^-\pi^0$	281	-0.60 ± 5.30	PRL **95**, 231801 (2005)	± 0.40	
$D^0 \to K^+\pi^-\pi^+\pi^-$	281	$+0.43 \pm 1.30$	PRL **95**, 231801 (2005)	± 0.33	
$D^+ \to \pi^0\pi^+$	921	$+0.89 \pm 1.98 \pm 0.22$	Belle Preliminary	± 0.40	
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	PRL **108**, 071801 (2012)	± 0.04	
$D^+ \to \eta\pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	PRL **107**, 221801 (2011)	± 0.14	± 0.01
$D^+ \to \eta'\pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	PRL **107**, 221801 (2011)	± 0.14	
$D^+ \to K^0_S \pi^+$	977	$-0.363 \pm 0.094 \pm 0.067$	PRL **109**, 021601 (2012)	± 0.03	± 0.03
$D^+ \to K^0_S K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	JHEP **02** (2013) 098	± 0.05	
$D^+_s \to K^0_S \pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	PRL **104**, 181602 (2010)	± 0.29	± 0.03
$D^+_s \to K^0_S K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	PRL **104**, 181602 (2010)	± 0.05	

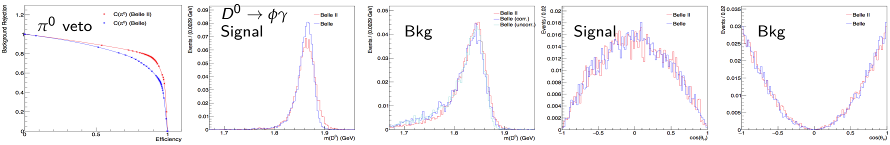


- Belle II: precision of $\mathcal{O}(0.01\%)$ (down to SM level). $\sigma_{Belle\ II} = \sqrt{(\sigma^2_{stat} + \sigma^2_{syst}) \cdot (\mathcal{L}_{Belle}/50\ \text{ab}^{-1}) + \sigma^2_{irred}}$
- With respect to LHCb, Belle II has advantages of excellent γ and π^0 reconstruction.
- There are some other important methods at Belle II, like T-odd asymmetry measurement with neutral particle in final states (see backup)

Outline

Rare radiative decays of $D^0 \to V\gamma$

- Radiative decays of $D^0 \to V\gamma$: dominated by long-range contribution ($\sim 10^{-5}$, whereas short-range at 10^{-8} level); direct CPV can be enhanced to exceed 1% in NP. [PRL 109,17801(2012)]
- BR measurement to test SM; observing $A_{CP}^{V\gamma} > 3\%$ is a signal of NP. [PRL 109,17801(2012)]
- Belle II sensitivity estimation for A_{CP} based on MC study:
  - similar performance of π^0 veto and resolution of signal or bkg
  - similar signal-to-bkg btw Belle and Belle II $\Rightarrow$ scaling luminosity



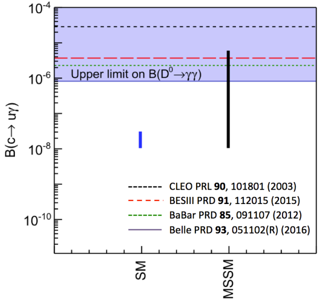
- Belle II: statistical $\sigma_{A_{CP}}$ at $1-2\%$ level with 50 ab^{-1}.

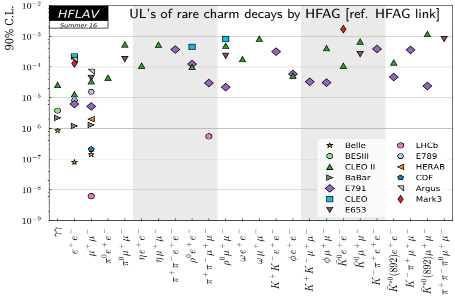
radiative decays	Belle A_{CP} results [1] 976 fb^{-1}	Belle II uncertainty 5 ab^{-1}	15 ab^{-1}	50 ab^{-1}
$D^0 \to \rho^0\gamma$	$+0.056 \pm 0.152 \pm 0.006$	±0.07	±0.04	±0.02
$D^0 \to \phi\gamma$	$-0.094 \pm 0.066 \pm 0.001$	±0.03	±0.02	±0.01
$D^0 \to \bar{K}^{*0}\gamma$	$-0.003 \pm 0.020 \pm 0.000$	±0.01	±0.005	±0.003

[1] T. Nanut *et al.*(Belle Collaboration), Phys. Rev. Lett. **118**, 051801 (2017)

Rare radiative decay of $D^0 \to \gamma\gamma$

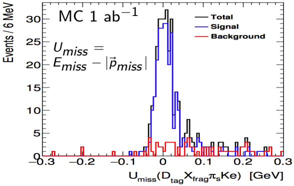
- FCNC process is forbidden at tree level in SM; but NP modes allow it and lead to significant enhancement on BR.
- $D^0 \to \gamma\gamma$: a sensitive probe for new physics.
- Belle: most restrictive limit (832 fb^{-1}): $BR < 8.5 \times 10^{-7}$ approaching SM prediction (10^{-8})
- This FCNC decay will be probed further at Belle II on 50 ab^{-1}: $\sim 10^{-7} - 10^{-8}$
- With respect to LHCb, there are still some rooms for semileptonic decays (neutrinos in final states) at Belle II.

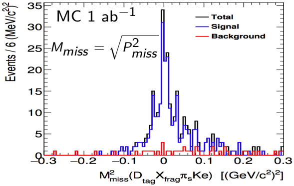




prospects for D (semi-) Leptonic decays

- (Semi-)Leptoinc charm decays involve both well-understood weak interactions physics and non-perturbative strong-interaction effects $\Rightarrow$ test lattice QCD or measure $|V_{cd}|$ and $|V_{cs}|$.
  - leptonic decays are used to extract $|V_{cd}|f_D$ or $|V_{cs}|f_{D_s}$
  - semileptonic decays are used to extract $|V_{cd}|f_+^{\pi}(q^2=0)$ or $|V_{cs}|f_+^K(q^2=0)$
- Study with missing energy from the neutrino in $c\bar{c} \to D_{\rm tag}^{0+} D^{*-} X_{\rm frag}^{-0} \ell(h)$ ($\ell = e/\mu$; $h = K/\pi$) with $P_{miss} = P_{e^+} + P_{e^-} - P_{\rm tag} - P_{\rm frag} - P_\ell(-P_h)$, define U_{miss} (better resol.) or M_{miss}





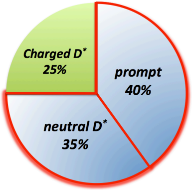
- Leptonic decays yields estimation at Belle II with 50 ab^{-1}

Mode	$D_s^- \to \mu^-\bar{\nu}$	$D^0 \to \nu\bar{\nu}$	$D^- \to \mu^-\bar{\nu}$	$D \to \pi\ell^+\nu$
Belle	0.91 ab^{-1} 492±26	0.92 ab^{-1} $(695 \pm 1) \times 10^3$		0.28 ab^{-1} 126±12
Belle II	27000	38×10^6	1250	7.0×10^5
Sensitivity	improve $|V_{cs}|_{best}$	$7\times$ better	$<2\%$ $|V_{cd}|$	comparable to BESIII

Outline

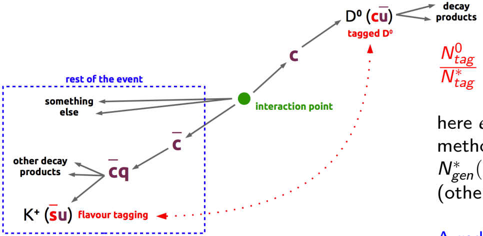
ROE: a new D^0 flavor tagging method

- To measure CPV, the flavor of D^0 is determined effectively.
- At B-factories, the charge of π_s from $D^{*+} \to D^0 \pi_s^+$ is used to tag the flavor of D^0; but D^0 mesons from B decays are excluded.
  $\Rightarrow$ only D^0 from $D^{*\pm}$ in $c\bar{c}$ events (25%) were used.



$c\bar{c} \to D^{*+}X,\ D^{*+} \to D^0\pi_s^+$
$c\bar{c} \to D^{*0}X,\ D^{*0} \to D^0\pi^0/D^0\gamma$
$c\bar{c} \to D^0 D^- X/D^0\bar{\Lambda}_c^- X$

- ROE method: select events with only one $K^\pm$ in the Rest Of Event;
- the charge of this $K^\pm$ in ROE to determine the flavor of D^0.



$$\frac{N^0_{tag}}{N^*_{tag}} = \frac{\epsilon^0_{tag}}{\epsilon^*_{tag}} \cdot \frac{N^0_{gen} + (1-\epsilon^*_{tag}) \cdot N^*_{gen}}{N^*_{gen}} \sim 1$$

here $\epsilon^*_{tag}(\epsilon^0_{tag})$: tagging efficieny of D^*(ROE) method with 80%($\lesssim$ 20%).
$N^*_{gen}(N^0_{gen})$: number of D^0 produced by a D^* (other $c\bar{c}$ event) with $N^0_{gen} : N^*_{gen} \simeq 3:1$

A reduction of $\sim$ 15% of $\sigma(stat)$ on A_{CP}

An additional D^0 sample from ROE for mixing and CPV measurements.

Outline

Summary

- Belle II at SuperKEKB which aims to achieve luminosity of 8.0×10^{35} cm^{-2}s^{-1}, will collect 50 ab^{-1} of dataset, which gives us a rich program for charm physics study.
- Many impacts on charm physics at Belle II with the large dataset are presented, benefiting from the improved tracking efficiency and vertex reconstruction,
  - D^0-$\overline{D^0}$ mixing and CP violation measurement with much more precision
  - more precise and exciting results for CP asymmetries
  - competitive in searches of several rare charm decays
- A new D^0 flavor tagging method, ROE, will increase an additional D^0 sample.
- Belle II will achieve more precise measurements (mostly one order of magnitude improvement) of charm observables in the next decade, improving our knowledge of charm physics and searching for new physics beyond the Standard Model.

Let's look forwards to the charming news of charm physics from Belle II.

Back up

Thank you for your attention.

谢谢!

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Status of D^0-$\overline{D}^0$ mixing and CP violation [mainly ref. charm physics at HFAG]

Decay Type	Final State	BELLE	BaBar	LHCb	CDF	CLEO	BESIII
WS 2-body decay	$K^+\pi^-$	★	☆	★	★	✓	✓ $_{\delta K\pi}$
CP-eigenstates	$K^+K^-/\pi^+\pi^-$	☆	☆	☆$^{(a)}$ A_{CP}	✓ A_{CP}	✓	
WS 3-body decay	$K^+\pi^-\pi^0$	○$^{(b)}$	☆			✓ A_{CP}	○$_\delta$
Self-conjugated 3-body decay	$K^0_S\pi^+\pi^-$	✓	✓	✓	✓ A_{CP}	✓	○$_\delta$
	$K^0_S K^+K^-$	○$^{(c)}$	✓	○			○$_\delta$
	$K^0_S\pi^0\pi^0$					✓ Dalitz	○$_{y_{CP}}$
Self-conjugated SCS 3-body decay	$\pi^+\pi^-\pi^0$	✓ A_{CP}	✓ mixing A_{CP}	✓ A_{CP}			○$_\delta$
	$K^+K^-\pi^0$		✓ A_{CP}				○$_\delta$
SCS 3-body	$K^0_S K^\pm\pi^\mp$			✓ A_{CP}		✓ δ	○$_\delta$
Semileptonic decay	$K^+\ell^-\nu_\ell$	✓	✓			✓	
Multi-body(n≥4)	$K^+\pi^-\pi^+\pi^-$	✓ R_{WS}	✓	★			○$_{\delta RS}$
	$\pi^+\pi^-\pi^+\pi^-$	○ A_{CP}		✓ A_{CP}			
	$K^+K^-\pi^+\pi^-$	○ A_T	✓ A_T	✓$^{(d)}$ A_{CP}		✓ A_{CP}	○
	$K^0_S\pi^+\pi^-\pi^0$	✓ A_T					
$\psi(3770)\to D^0\overline{D}^0$ via correlations						✓ $_{\delta K\pi}$	✓ y_{CP}

★ for observation ($> 5\sigma$); ☆ for evidence ($> 3\sigma$); ✓ for measurement published; ○ for analysis on going. A_T stands for measuring CP asymmetry using T-odd correlations.

The related publishments are linked under their corresponding signs.

(a) LHCb also give the measurement of indirect CP asymmetry in $D^0\to h^-h^+$ decay in PRL **112**, 041801 (2014).

(b) Belle measured WS-to-RS ratio R_{WS} and A_{CP} in $D^0\to K^\mp\pi^\pm\pi^0$ in PRL **95**, 231801 (2005).

(c) Belle measured y_{CP} in $D^0\to K^0_S\phi$ in PRD **80**, 052006 (2009), the amplitude analysis for mixing parameters is on going.

(d) LHCb also search for CP violation using T-odd correlations in $D^0\to K^+K^-\pi^+\pi^-$ decays in JHEP **10**(2014) 005.

Belle II detector upgrade

- Vertex detector:
  - 2 layers PXD (DEPFET) + 4 layers SVD (DSSD)
  - smaller inner radius, larger outer radius
    $\Rightarrow$ better vertex resolution
    $\Rightarrow$ improved efficiency for slow pion and K_S^0
- Central drift chamber
  - smaller cells, larger outer radius
    $\Rightarrow$ improved momentum resoluion and dE/dx
- Hadron Identification
  - TOP (barrel) and Aerogel RICH (forward): replace ACC+TOF
    $\Rightarrow$ less material in front of calorimeter
    $\Rightarrow$ improved hadron ID
- Electromagnetic calorimeter
  - waveform sampling technique to cope with increase background
- K_L^0 and muon detector
  - RPC's in endcaps and first two layers of barrel replaced with scintillator counters to cope with increased neutron background

D^0 Decays to CP eigenstates

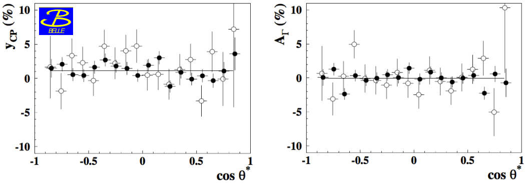
- Mixing and CPV: using CP eigenstates D^0 lifetime analysis relative to non-CP eigenstates (here h=K/π):

$$y_{cp} = \frac{\tau_{K\pi}}{<\tau_{hh}>} - 1 \qquad A_\Gamma = \frac{\tau(\bar{D}^0 \to hh) - \tau(D^0 \to hh)}{\tau(\bar{D}^0 \to hh) + \tau(D^0 \to hh)}$$

- if CP is conserved, $y_{CP} = y$;
- if direct CPV negligible, $y_{CP} = y\cos\phi - \frac{1}{2}A_M \sin\phi$, $A_\Gamma = \frac{1}{2}A_M y\cos\phi - x\sin\phi$
- Belle: the first evidence (540 fb^{-1}): $y_{CP} = (+1.31 \pm 0.32 \pm 0.25)\%$ [PRL **98**, 211801 (2007)]
- Belle updated result(976 fb^{-1}) [PLB **753**, 412 (2016)]

  y_{CP}=[1.11±0.22±0.09]%(4.7σ)
  A_Γ=[-0.03±0.20±0.07]%

- Belle II sensitivity (50 ab^{-1}):
  $\sigma_{y_{CP}} \approx 0.06\%$, $\sigma_{A_\Gamma} \approx 0.04\%$
  One order of magnitude improvement
- other CP-eigenstate decays: $K_S^0\phi$, $K_S^0\omega$, $K_S^0 a_0(980)$ etc.

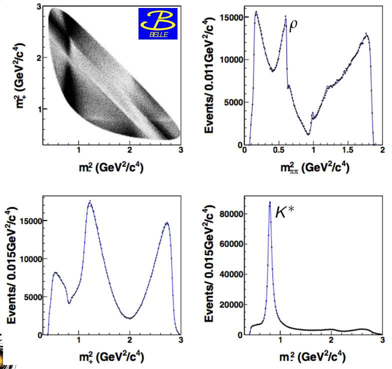


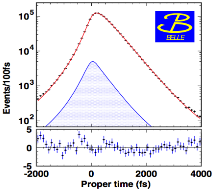
open(full) circles for 3(4)-layer SVD

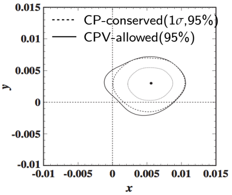
D^0 three-body self-conjugated decays $D^0 \to K_S^0 \pi\pi$

Belle $K_S^0\pi^+\pi^-$ by time-dependent Dalitz analysis [T. Peng *et al.* PRD **89**, 091103(R) (2014)]

- direct measure x and y; search for CPV: $q/p \neq 1$
- 921 fb^{-1} dataset: $\sim$1.23M signals with high purity 95.5%
- a sum of quasi-2-body amplitudes: CF/DCS/CP-eigenstate decays, like $K^{*\mp}\pi^{\pm}$, ρK_S^0 ...
- isobar model with form factor (Blatt-Weisskopt), angular dependence (Zemach tensor)





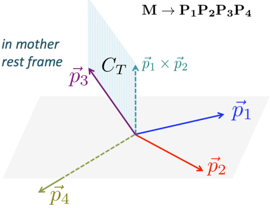


dataset	Belle 976 fb^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
x(%)	$0.56 \pm 0.19^{+0.03+0.06}_{-0.09-0.09}$	$\pm 0.08 \pm 0.11$	$\pm 0.03 \pm 0.11$
y(%)	$0.30 \pm 0.15^{+0.04+0.03}_{-0.05-0.06}$	$\pm 0.06 \pm 0.05$	$\pm 0.02 \pm 0.04$
$\lvert q/p \rvert$	$0.90^{+0.16+0.05+0.06}_{-0.15-0.04-0.05}$	$\pm 0.07 \pm 0.07$	$\pm 0.02 \pm 0.07$
$\arg(q/p)(^o)$	$-6 \pm 11 \pm 3^{+3}_{-4}$	$\pm 5 \pm 4$	$\pm 2 \pm 4$

T-odd asymmetry measurements in D four-body decays

- T-odd correlations provides a powerful tool to indirectly search for CP violation:
  (1) a triple product of momenta;   (2) assuming CPT symmetry conservation
- Parity-odd observable $C_T = (\vec{p}_1 \times \vec{p}_2) \cdot \vec{p}_3$ and its CP-conjugated observable $\overline{C}_T$

$$A_T = \frac{\Gamma(C_T > 0) - \Gamma(C_T < 0)}{\Gamma(C_T > 0) + \Gamma(C_T < 0)} \qquad \overline{A}_T = \frac{\Gamma(-\overline{C}_T > 0) - \Gamma(-\overline{C}_T < 0)}{\Gamma(-\overline{C}_T > 0) + \Gamma(-\overline{C}_T < 0)}$$



- T-odd asymmetry definition to veto FSI effects:

$$\boxed{a_{CP}^{\text{T-odd}} = \frac{1}{2}(A_T - \overline{A}_T)}$$ can be nonzero if CPV

- Observing a T-odd asymmetry would be a signal for processes beyond the SM.
- Status of T-odd asymmetries in charmed mesons decay-rates:

$D^0 \to K_S^0 \pi^+ \pi^- \pi^0$	$a_{CP}^{\text{T-odd}} = (-0.28 \pm 1.38^{+0.23}_{-0.76}) \times 10^{-3}$	Belle[1]
$D^0 \to K^+ K^- \pi^+ \pi^-$	$a_{CP}^{\text{T-odd}} = (+1.7 \pm 2.7) \times 10^{-3}$	LHCb[2], BaBar[3], Focus[4]
$D^+ \to K_S^0 K^+ \pi^+ \pi^-$	$a_{CP}^{\text{T-odd}} = (-1.10 \pm 1.09) \times 10^{-2}$	BaBar[5], Focus[4]
$D_s^+ \to K_S^0 K^+ \pi^+ \pi^-$	$a_{CP}^{\text{T-odd}} = (-1.39 \pm 0.84) \times 10^{-2}$	BaBar[5], Focus[4]

[1] K. Prasanth *et al.*(Belle Collab.), Phys. Rev. D **95**, 091101(R) (2017)
[2] R. Aaij *et al.*(LHCb Collab.), JHEP **10**, 5 (2014)
[3] P. del Amo Sanchez *et al.*(BaBar Collab.), Phys. Rev. D **81**, 111103(R) (2010)
[4] J.M. Link *et al.*(FOCUS Collab.), Phys. Lett. B **622**, 239 (2005)
[5] J.P. Lees *et al.*(BaBar Collab.), Phys. Rev. D **84**, 031103(R) (2011)

Belle II could improve these results with more precision benefited from the increased dataset.

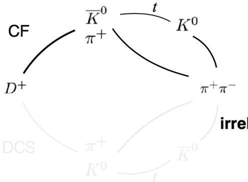
A_{CP} in charm decays into neutral kaons [ref. Fu-Sheng Yu et al., arXiv:1707.09297]

- A new CP violation effect in charm decays into neutral kaons, e.g: $D^+ \to K_S^0\pi^0$ with evidence for CP violation: $A_{CP} = (-0.363 \pm 0.094 \pm 0.067)\%$

Indirect CPV in kaon mixing

$$A_{CP}(t) \simeq \left[A_{CP}^{\overline{K}^0}(t) + A_{CP}^{dir}(t) + A_{CP}^{int}(t)\right]/D(t)$$

$$A_{CP}^{\overline{K}^0}(t) = 2e^{-t/\tau_S}\left[\mathcal{R}e(\epsilon) - e^{\Delta\Gamma t/2}\left(\mathcal{R}e(\epsilon)\cos(\Delta m t) + \mathcal{I}m(\epsilon)\sin(\Delta m t)\right)\right] \quad (10^{-3})$$



Dominant

but

irrelevant to charm

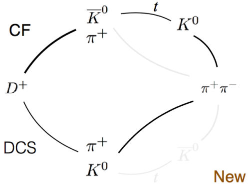
Report at Beihang Univ. at 22nd Jun. 2017

CPV in interference between kaon mixing and charm decays

$$A_{CP}(t) \simeq \left[A_{CP}^{\overline{K}^0}(t) + A_{CP}^{dir}(t) + A_{CP}^{int}(t)\right]/D(t)$$

$$A_{CP}^{int}(t) = e^{-t/\tau_S}\,4r_f\cos\phi\sin\delta_f\left[-\mathcal{I}m(\epsilon) + e^{\Delta\Gamma t/2}\left(\mathcal{I}m(\epsilon)\cos(\Delta m t) - \mathcal{R}e(\epsilon)\sin(\Delta m t)\right)\right]$$

$(10^{-4\sim-3})$



Non-negligible

and

important

New findings

ROE method impacts

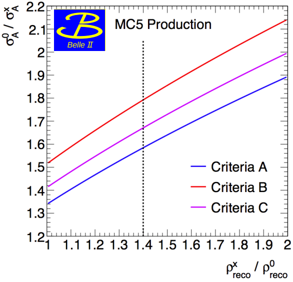
Impacts on measurements of CP asymmetries ref. [BELLE2-NOTE-PH-2017-001]

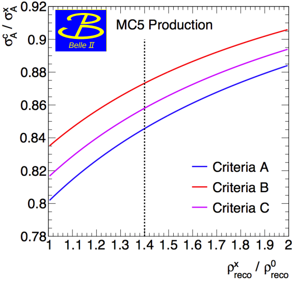
- Ratio $\frac{\sigma_A^0}{\sigma_A^*}$ of A_{CP} statistical sensitivity σ between ROE method and D^* method

$$\alpha = \frac{\sigma_A^0}{\sigma_A^*} = \sqrt{\frac{1}{3} \cdot \frac{Q^*}{Q^0} \cdot \frac{\rho^*_{rec}}{\rho^0_{rec}}}$$

  - effective tagging efficiency: $Q = \epsilon_{tag}(1-2\omega)^2$ with mistagging ratio ω;
  - ρ_{rec}: purity of reconstructed D.

- Combining ROE and D^* method: $\sigma_A^c = \frac{\alpha}{\sqrt{1+\alpha}} \simeq 0.85 \cdot \sigma_A^*$, with assuming $\rho^*_{rec}/\rho^0_{rec} = 1.4$





A reduction of $\sim 15\%$ of $\sigma(stat)$ on A_{CP}

Criteria A	basical (see ref. [BELLE2-NOTE-PH-2017-001])
Criteria B	veto rec.ed $K_S^0 \to \pi^+\pi^-$ in ROE; proper cut on $\cos\theta_{K^\pm D^0}$
Criteria C	veto all K_S^0/K_L^0 gen.ed in ROE same cut on $\cos\theta_{K^\pm D^0}$ as before