Prospects of Dalitz Analysis on Charm Physics at Belle II

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On behalf of the Belle II Collaboration

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Outline

1. Belle experiment to Belle II experiment
   - Accelerator and Nano-beam
   - Detector and its highlights
   - Data set and Collaboration
2. Prospects of TDDA on charm at Belle II
   - D^0-$\overline{D^0}$ mixing and CP violation
   - Time-dependent Dalitz analysis
   - Prospect of TDDA in $D^0 \to K_S^0\pi^+\pi^-$
   - Prospect of TDDA in $D^0 \to K^+\pi^-\pi^0$
   - A new D^0-tag method: ROE method
3. Re-discoveries of Phase2 at Belle II
4. Summary

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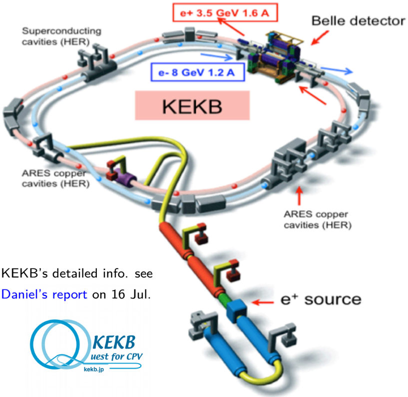
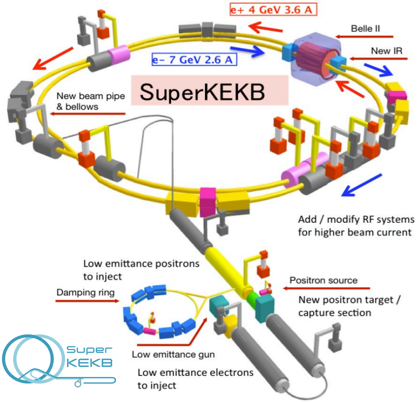
Accelerator: KEKB Vs. SuperKEKB

- As 1^{st} and 2^{nd} generation B-factory located at Tsukuba in Japan, KEKB and SuperKEKB have many similarities, along with more differences, such as
  - Damping ring: for a high-intensity e^{+} beam.
  - beam energy: admit lower asymmetry to mitigate Touschek effects.
  - beam current: ~ 2 improved to contribute to higher luminosity.

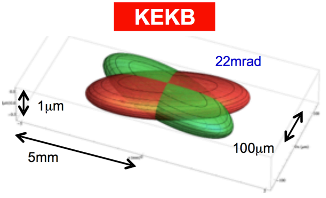


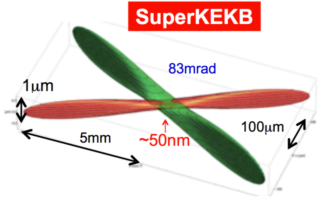
KEKB's detailed info. see Daniel's report on 16 Jul.



Nano-Beam Scheme

- The SuperKEKB upgrade is based on 'Nano-beam' scheme (first proposed for SuperB in Italy)
- Its basic idea is to squeeze the vertical beta function at the IP β_y^* by minimizing the longitudinal size of the overlap region of the two beams at the IP.





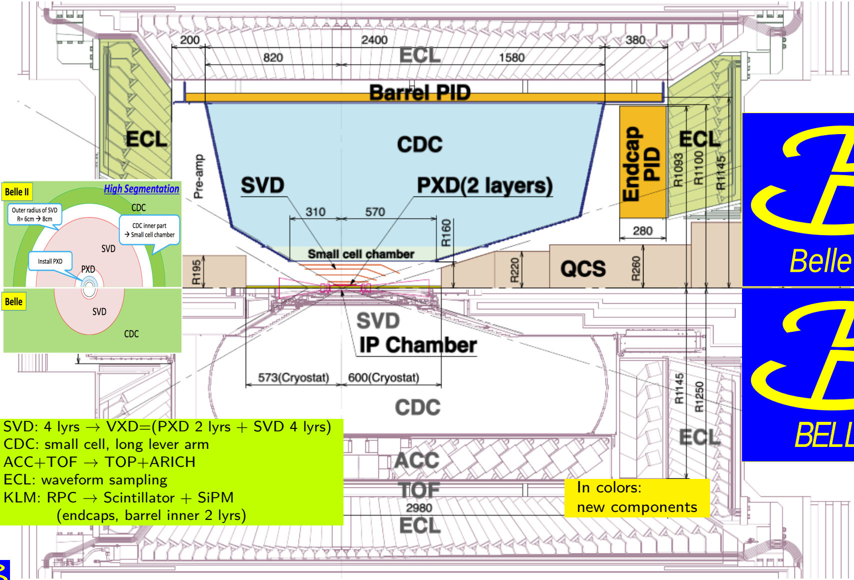
luminosity

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

beam size: σ^*, beam-beam par.: $\xi_\pm$, beam current: $I_\pm$, beta function: β^*

	$E_\pm$ (GeV) LER/HER	Cross Angle (mrad)	$I_\pm$ (A) LER/HER	β_y^* (mm) LER/HER	$\mathcal{L}$ $(cm^{-2}s^{-1})$
KEKB	3.5/8.0	22	1.64/1.19	5.9/5.9	2.1×10^{34}
SuperKEKB	4.0/7.0	83	3.60/2.60	0.27/0.31	80×10^{34}
	$\beta\gamma\sim 2/3$		$\times 2$	$\times 20$	$\times 40$

Detector: Belle Vs. Belle II

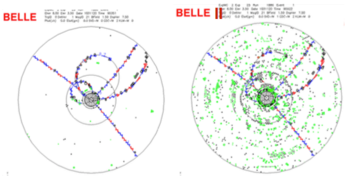


SVD: 4 lyrs → VXD=(PXD 2 lyrs + SVD 4 lyrs)
CDC: small cell, long lever arm
ACC+TOF → TOP+ARICH
ECL: waveform sampling
KLM: RPC → Scintillator + SiPM
(endcaps, barrel inner 2 lyrs)

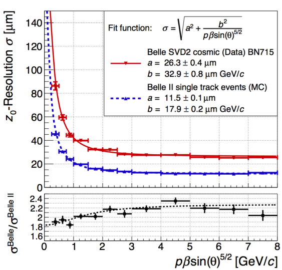
In colors:
new components

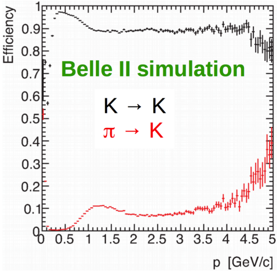
Detector highlights at Belle II

- Under higher luminosity($\times 50$), Belle II is fighting with
  (1) higher machine backgrounds ($\times 20$);
  (2) higher event rate ($\times 10$)
  (3) reduced energy asymmetry ($\beta\gamma$: 0.45$\rightarrow$0.28)



- A lot of improved performances, such as
  - improved L1 trigger: 500Hz (Belle) Vs. 30kHz (Belle II).
  - vertex detector(VXD): better spatial resolution (Belle II: $\sim$ 2 better than Belle)
  - VXD: $\sim$ 30% larger acceptance for K_S^0 reconstruction
  - higher tracking reconstruction efficiency
  - better particle identification: $K(\pi)$ eff.$>$ 90% with fake rate $<$ 10% for $p < 4$ GeV/c.



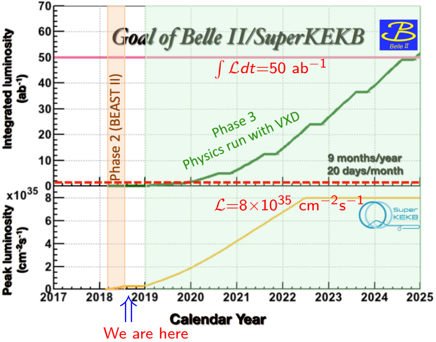


larger Data set at Belle II

- Each 1 ab^{-1} dataset at B-factory provides:
  - $\sim 1.1 \times 10^9$ $B\bar{B}$ $\Rightarrow$ a B-factory;
  - $\sim 1.3 \times 10^9$ $c\bar{c}$ $\Rightarrow$ a charm-factory;
  - $\sim 0.9 \times 10^9$ $\tau^+\tau^-$ $\Rightarrow$ a τ-factory;
  - wide region $E^{eff.}_{c.m}$=[0.5-10] GeV via ISR process.
- Available charm dataset at some experiments:

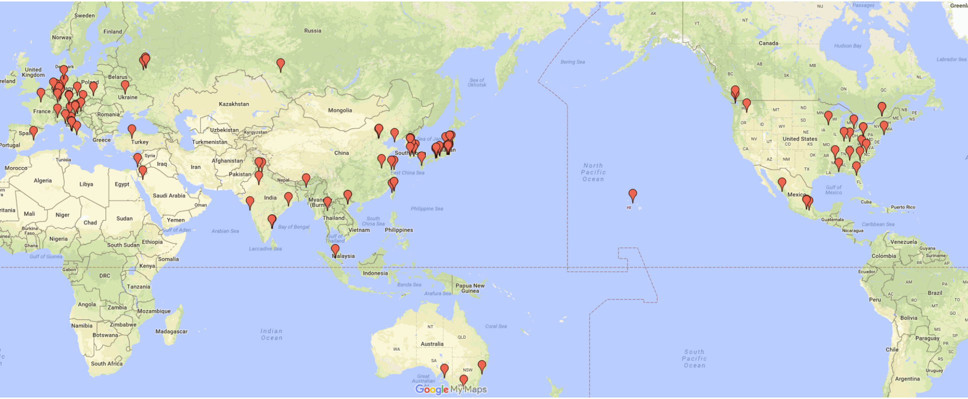
Experiment	Machine	C.M $\sqrt{s}$	Luminosity	charm sample	efficiency
CLEOc	CESR (e^+e^-)	3.77 GeV	0.8 fb^{-1}	$2.9 \times 10^6 (D^0)$ $2.3 \times 10^6 (D^+)$	$\sim$10-30%
		4.17 GeV	0.6 fb^{-1}	$0.6 \times 10^6 (D_s^+)$	
BESIII	BEPC-II (e^+e^-)	3.77 GeV	2.9 fb^{-1}	$10.5 \times 10^6 (D^0)$ $8.4 \times 10^6 (D^+)$	
		4.18 GeV	3.0 fb^{-1}	$3 \times 10^6 (D_s^+)$	
		4.6 GeV	0.6 fb^{-1}	$1 \times 10^5 (\Lambda_c^+)$	
				★	★★★
BELLE	KEKB (e^+e^-)	10.58 GeV	1 ab^{-1}	$1.3 \times 10^9 (D^0)$ $7.7 \times 10^8 (D^+)$ $2.5 \times 10^8 (D_s^+)$ $1.5 \times 10^8 (\Lambda_c^+)$	$\sim$5-10%
BaBar	PEP-II (e^+e^-)	10.58 GeV	0.5 ab^{-1}	$6.5 \times 10^8 (D^0)$ $3.8 \times 10^8 (D^+)$ $1.2 \times 10^8 (D_s^+)$ $0.7 \times 10^8 (\Lambda_c^+)$	
				★★	★★
CDF	Tevatron ($p\bar{p}$)	1.96 TeV	9.6 fb^{-1}	1.3×10^{11}	$<$0.5%
LHCb	LHC (pp)	7 TeV 8 TeV	1.0 fb^{-1} 2.0 fb^{-1}	5.0×10^{12}	
				★★★	★

- Belle II is back to the game.
  - Phase 2 has finished (Apr 26 - Jul 17)
  - Phase 3 (physics run) will start next spring.
  - $\mathcal{L}$(Belle+BaBar) will be reached in next year.
  - collect ~ 5 ab^{-1} by mid 2020.
  - collect 50 ab^{-1} before 2025.



- Belle II awards us a huge B/charm/τ sample.

A big family in Belle II Collaboration



- Belle Collaboration : 536 colleagues, 91 institutions, 20 countries/regions
- Belle II Collaboration: 822 colleagues, 110 institutions, 25 countries/regions
- Belle II has 7 inst. from China mainland (including two new inst. this Jun):
  - IHEP(14), USTC(6), Peking(3), BUAA(9), Fudan(7) + LNNU + Soochow.

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

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

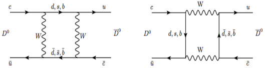
$$K^0 \Leftrightarrow \overline{K^0},\ B_d^0 \Leftrightarrow \overline{B_d^0},\ B_s^0 \Leftrightarrow \overline{B_s^0},\ D^0 \Leftrightarrow \overline{D^0}$$

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

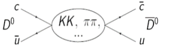
$$|D_{1,2}\rangle \equiv p|D^0\rangle \pm q|\overline{D^0}\rangle \text{ (CPT: } p^2+q^2=1)$$

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

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



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



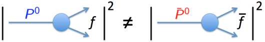
(2) long distance ($\sim 1\%$)

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

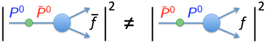
- Three types of Charged-conjugated-Parity combined symmetry Violation (CPV):

$$\boxed{A^f_{CP} = \frac{\Gamma(D\to f) - \Gamma(\bar{D}\to \bar{f})}{\Gamma(D\to f) + \Gamma(\bar{D}\to \bar{f})} = a^f_d + a^f_m + a^f_i}$$

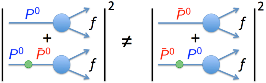
- a^f_d: (direct CPV) CPV in decay $|\bar{A}_{\bar{f}}/A_f| \neq 1$



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



- a^f_i: 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$\to$NP

Time evolution of D^0-$\overline{D^0}$ system

- Time evolution of D^0-$\overline{D^0}$ system:

$$i\frac{\partial}{\partial t}\begin{pmatrix} D^0(t) \\ \overline{D^0}(t) \end{pmatrix} = \left(M - \frac{i}{2}\Gamma\right)\begin{pmatrix} D^0(t) \\ \overline{D^0}(t) \end{pmatrix}$$

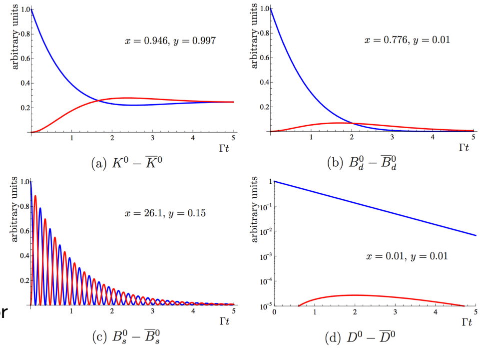
  diagonal: $D \to D$, non-diagonal: $D \to \bar{D}$.

- Measure D^0-$\overline{D^0}$ mixing (x,y) and CPV (q/p)

$$|D^0(t)\rangle = g_+(t)|D^0\rangle + \frac{q}{p}g_-(t)|\overline{D^0}\rangle$$
$$|\overline{D^0}(t)\rangle = \frac{p}{q}g_-(t)|D^0\rangle + g_+(t)|\overline{D^0}\rangle$$
$$g_+(t) = exp\left(-iMt - \frac{1}{2}\Gamma t\right)\cosh\left(-\frac{i\mathbf{x}+\mathbf{y}}{2}\Gamma t\right)$$
$$g_-(t) = exp\left(-iMt - \frac{1}{2}\Gamma t\right)\sinh\left(-\frac{i\mathbf{x}+\mathbf{y}}{2}\Gamma t\right)$$

- Probabilities of changed or unchanged D flavor at time t for an initial pure flavor state $|D^0\rangle$

$$|\langle D^0|D^0(t)\rangle|^2 = \frac{1}{2}e^{-\Gamma t}\left[\cosh(y\Gamma t) + \cos(x\Gamma t)\right]$$
$$|\langle D^0|\overline{D^0}(t)\rangle|^2 = \frac{1}{2}\left|\frac{q}{p}\right|^2 e^{-\Gamma t}\left[\cosh(y\Gamma t) - \cos(x\Gamma t)\right]$$



y effects lifetime in amplitude; x: brings a sine oscillating.

▶ D^0-$\overline{D^0}$ mixing measurement is most difficult.

Time-dependent Dalitz analyses in D^0 three-body decays

- Time-dependent Dalitz analysis(TDDA) provides an essential tool in studying D^0-$\overline{D^0}$ mixing.

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

- An unique method: sensitive to linear order for both mixing parameters.
- Status of D^0-$\overline{D^0}$ mixing and CP violation measurement in D^0 three-body decays:

Decay Type	Final State	BELLE		LHCb	CDF	CLEO	BESIII
DCS decay (WS)	$K^+\pi^-\pi^0$	✓[(a)]	☆			✓ A_{CP}	$\circ_\delta$
Self-conjugated CF decay	$K^0_S\pi^+\pi^-$	✓	✓	✓	✓ A_{CP}	✓	$\circ_\delta$
	$K^0_S K^+K^-$	✓[(b)]	✓	○			$\circ_\delta$
Self-conjugated SCS decay	$\pi^+\pi^-\pi^0$	✓ A_{CP}	✓ mixing A_{CP}	✓ A_{CP}			$\circ_\delta$
	$K^+K^-\pi^0$		✓ A_{CP}				$\circ_\delta$
SCS decay	$K^0_S K^+\pi^-$			✓ A_{CP}		✓ $_\delta$	$\circ_\delta$
	$K^0_S K^-\pi^+$			✓ A_{CP}		✓ $_\delta$	$\circ_\delta$

★ for observation ($> 5\sigma$); ☆ for evidence ($> 3\sigma$); ✓ for measurement published; ○ for analysis on going.

The related publishments are linked under their corresponding signs.

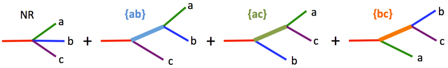
(a) Belle measured WS-to-RS ratio R_{WS} and A_{CP} in $D^0 \to K^\mp\pi^\pm\pi^0$ in PRL **95**, 231801 (2005).

(b) 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.

- A neutral particle exists in the FSPs of all above channels, this possibly makes them more promising at Belle II than LHCb.
  $\Rightarrow$ TDDA will be one of favourites of Belle II Charm WG to measure D^0-$\overline{D^0}$ mixing and CPV in such D^0 three-body decays.

Dalitz analysis with Isobar model

- $P \to P_a P_b P_c$ decay: d.o.f=2 (i.e. m^2_{ab}, m^2_{bc})
- Isobar describes $\mathcal{M}$: Phys. Rev. **123**, 333 (1961)



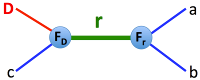
$$\mathcal{M}(m^2_{ab}, m^2_{bc}) = a_{NR} e^{i\phi_{NR}} + \sum_r a_r e^{i\phi_r} \mathcal{A}_r(m^2_{ab}, m^2_{bc})$$

here $a_r(\phi_r)$ is magnitude (phase) of resonance r

- T_r: dynamic function
  1) using relativistic Breit-Wigner (Γ depends on M)
  2) Special resonances description:
  - ✓ Flatté model, for mass threshold
    i.e. $f_0(980)(KK)/a_0(980)(KK/\eta'\pi)$ [PRD **95**, 032002 (2017)]
  - ✓ K-matrix model, for overlap resonances,
    i.e. $\pi\pi$ S-wave [EPJ **A16** (2003) 229-258]
  - ✓ Gounaris-Sakurai model:
    i.e. $\pi\pi$ P-wave ρ family [PRL **24**,244(1968)]
  - ✓ LASS model:
    i.e. $K\pi$ S-wave with $K^*_0(1430)$ [EPJ **C74** (2014): 3026]
  - ✓ non-resonance:
    i.e. const.(D decay) or exponential(B decay)

Also see Daniel's report on 16 July

- Matrix element $\mathcal{A}_r$ describes the dynamics of $D \to (r \to ab)c$ PRD **63**, 092001 (2001)



$$\boxed{\mathcal{A}_r(m^2_{ab}, m^2_{bc}) = F_D \times F_r \times T_r \times W_r}$$

- F_r, F_D form factor: [PR **D 63**, 092001 (2001)]
  ▶ using Blatt-Weisskopt Barrier parameterization, depends on angular quantum ℓ(here equals J):

$$F_{J=0} = 1$$
$$F_{J=1} = \frac{\sqrt{1+z_r}}{\sqrt{1+z_{ab}}}$$
$$F_{J=2} = \frac{\sqrt{(z_r-3)^2+9z_r}}{\sqrt{(z_{ab}-3)^2+9z_{ab}}}$$
$$F_{J=3} = \frac{\sqrt{z_r(z_r-15)^2+9(2z_r-5)}}{\sqrt{z_{ab}(z_{ab}-15)^2+9(2z_{ab}-5)}}$$

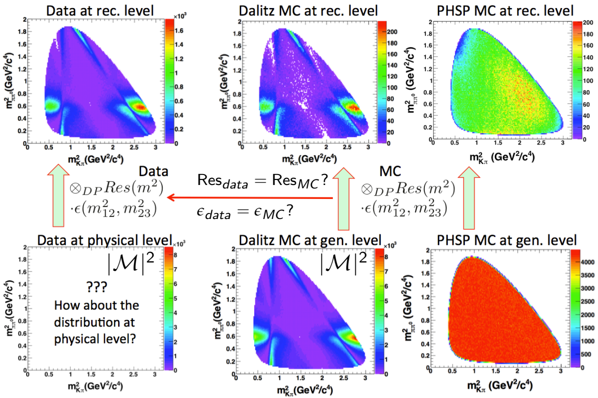
here $z = (R \cdot q)^2$, R is radius of D or resonance r

- W_r angular function:
  (1) Helicity form;
  (2) Zemach covariant tensor form

(time-integrated) Dalitz analysis method

- probability density function of (time-integrated) Dalitz analysis:
  - (1) efficiency plane $\epsilon(m^2_{12,i}, m^2_{23,i})$ to correct: obtained by a large signal MC produced at free PHSP.
  - (2) mass resolution $Res(m)$ effect: needed to check if need? how to consider the resolution?
  - (3) normalization: numerical integration on full DP region

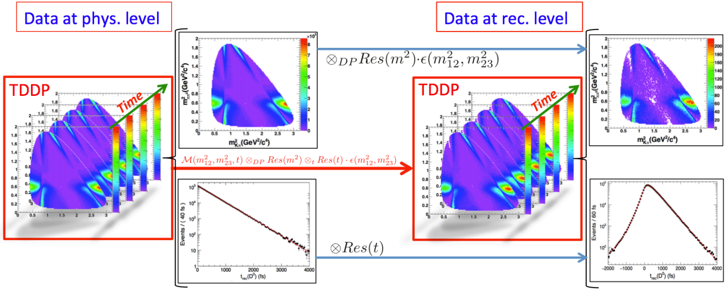
$$p_{\mathrm{sig}}(m^2_{12,i}, m^2_{23,i}) = \frac{|\mathcal{M}(m^2_{12,i}, m^2_{23,i})|^2 \otimes_m Res(m) \cdot \epsilon(m^2_{12,i}, m^2_{23,i})}{\iint_{DP} dm^2_{12}\, dm^2_{23}\ |\mathcal{M}(m^2_{12}, m^2_{23})|^2 \otimes_m Res(m) \cdot \epsilon(m^2_{12}, m^2_{23})}$$



Time-dependent Dalitz analysis

- p.d.f of signal for TDDA:
  (1) efficiency plane $\epsilon(m^2_{12,i}, m^2_{23,i})$ and mass resolution $Res(m)$, similar with TIDA.
  (2) time resolution $Res(t)$ effect: usually based on data.
  (3) normalization: numerical integration on full t-dept DP region.

$$p_{\rm sig}(m^2_{12,i}, m^2_{23,i}, t_i) = \frac{1}{N}\int dt' R_{\rm sig}(t_i - t', k\sigma^i_t)\,|\mathcal{M}(m^2_{12,i}, m^2_{23,i}, t')|^2 \otimes_m Res(m)\cdot\epsilon(m^2_{12,i}, m^2_{23,i})$$



- Method: Unbinned Maximum Likelihood (UML) and consideration of Punzi bias

$$2\ln\mathcal{L} = 2\sum_i^n\{\ln(f^i_{\rm sig}p_{\rm sig}(m^2_{12,i}, m^2_{23,i}, t_i, k\sigma^i_t; x, y, q/p)p^{nc}_{sig}(\sigma^i_t) + \sum_{x=bg} f^i_x p_x(m^2_{12,i}, m^2_{23,i}, t_i)p^{nc}_x(\sigma^i_t))\}$$

here $p^{nc}_x(\sigma^i_t)$ is a function of global time error function, independed on other variables

Self-conjugated decay $D^0 \to K^0_S\pi^+\pi^-$

- TDDA in D^0 self-conjugated decays:

  (1) direct measurement for x and y; (2) search for CPV: $q/p \neq 1$

  $$|\mathcal{M}(f,t)|^2 = \frac{e^{-\Gamma t}}{2}[(|\mathcal{A}_f|^2 + |\frac{q}{p}|^2|\mathcal{A}_{\bar{f}}|^2)\cosh(y\Gamma t) + (|\mathcal{A}_f|^2 - |\frac{q}{p}|^2|\mathcal{A}_{\bar{f}}|^2)\cos(x\Gamma t) + 2\,\mathrm{Re}[\frac{q}{p}\mathcal{A}_{\bar{f}}\mathcal{A}_f^*]\sinh(y\Gamma t) + 2\,\mathrm{Im}[\frac{q}{p}\mathcal{A}_{\bar{f}}\mathcal{A}_f^*]\sin(x\Gamma t)]$$

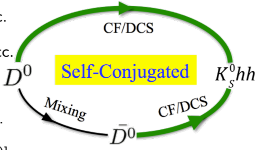
- $D^0 \to K^0_S\pi^+\pi^-$ with qusai-two-body decays with difference physics process:

  Right-Sign: $\mathcal{A}_f = \langle f|\mathcal{H}|D^0\rangle$; $\frac{q}{p}\frac{\bar{\mathcal{A}}_f}{\mathcal{A}_f} = \left|\frac{\bar{\mathcal{A}}_f}{\mathcal{A}_f}\right| \frac{1-\epsilon}{1+\epsilon} e^{i(\delta+\phi)}$; eg: $D^0 \to K^{*-}\pi^+$ etc.

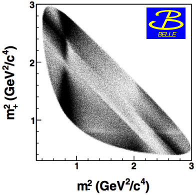
  Wrong-Sign: $\mathcal{A}_{\bar{f}} = \langle \bar{f}|\mathcal{H}|D^0\rangle$; $\frac{q}{p}\frac{\bar{\mathcal{A}}_{\bar{f}}}{\mathcal{A}_{\bar{f}}} = \left|\frac{\bar{\mathcal{A}}_{\bar{f}}}{\mathcal{A}_{\bar{f}}}\right| \frac{1-\epsilon}{1+\epsilon} e^{-i(\delta-\phi)}$; eg: $D^0 \to K^{*+}\pi^-$ etc.

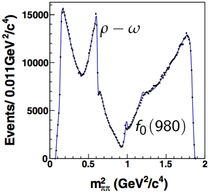
  CP-even: $\mathcal{A}_+ = \langle +|\mathcal{H}|D^0\rangle$ $\frac{q}{p}\frac{\bar{\mathcal{A}}_+}{\mathcal{A}_+} = +\frac{1-\epsilon}{1+\epsilon} e^{+i\phi}$; eg: $D^0 \to K^0_S f_0$ etc.

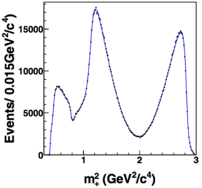
  CP-odd: $\mathcal{A}_- = \langle -|\mathcal{H}|D^0\rangle$ $\frac{q}{p}\frac{\bar{\mathcal{A}}_-}{\mathcal{A}_-} = -\frac{1-\epsilon}{1+\epsilon} e^{-i\phi}$; eg: $D^0 \to K^0_S\rho / K^0_S\omega$ etc.

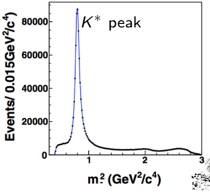


- Review of Belle's result of TDDA in this decay [PRD **89**, 091103(R) (2014)]
  - D^0 flavor is tagged via the charge of slow π_s from $D^{*+} \to D^0\pi_s^+$.
  - Dalitz variables $m_-^2 = m^2_{K^0_S\pi^-}$, $m_+^2 = m^2_{K^0_S\pi^+}$ for D^0, exchange for $\overline{D^0}$.
  - Dalitz Model: 12 RBW+K-matrix($\pi\pi$ S-wave)+LASS($K\pi$ S-wave).



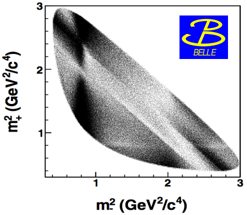


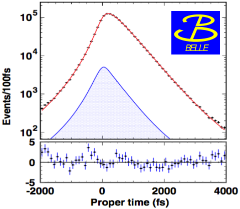


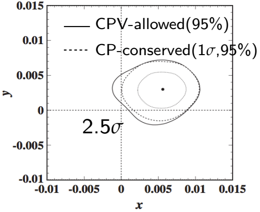


Dataset size effect on TDDA in $D^0 \to K_S^0\pi^+\pi^-$

- Results of TDDA based on 921 fb^{-1} of data at Belle [PRD **89**, 091103(R) (2014)]
  - a consistent determination of D^0-$\overline{D^0}$ mixing with significantly improve sensitivity.
  - the most accurate value of CPV parameters $|q/p|$ and $\arg(q/p)$.







- Prospects at Belle II with larger dataset: $\sigma_{Belle\ II} = \sqrt{(\sigma^2_{stat} + \sigma^2_{sys})\frac{\mathcal{L}_{Belle}}{50\ ab^{-1}} + \sigma^2_{irreducible}}$
- a significantly improved σ_{stat}; Dalitz model uncertainty will dominate the errors.
  $\Rightarrow$ model-indept. Dalitz analysis will be more promising in this channel.

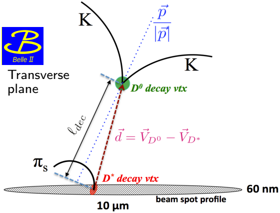
Fit type	Para.	Belle Fit result	Belle II prospect		model-indept.	LHCb
		921 fb^{-1}	5 ab^{-1}	50 ab^{-1}	100 M signals	50 fb^{-1}
No CPV	x(%)	$0.56 \pm 0.19^{+0.03+0.06}_{-0.09-0.09}$	$\pm 0.08 \pm 0.11$	$\pm 0.03 \pm 0.11$	± 0.017	
	y(%)	$0.30 \pm 0.15^{+0.04+0.03}_{-0.05-0.06}$	$\pm 0.06 \pm 0.05$	$\pm 0.02 \pm 0.04$	± 0.019	
indirect	x(%)	$0.56 \pm 0.19^{+0.04+0.06}_{-0.08-0.08}$	$\pm 0.08 \pm 0.11$	$\pm 0.03 \pm 0.11$		0.04
	y(%)	$0.30 \pm 0.15^{+0.04+0.03}_{-0.05-0.07}$	$\pm 0.06 \pm 0.05$	$\pm 0.02 \pm 0.04$		0.004
CPV	$\lvert q/p \rvert$	$0.90^{+0.16+0.05+0.06}_{-0.15-0.04-0.05}$	$\pm 0.069 \pm 0.073$	$\pm 0.022 \pm 0.069$		0.04
	$\arg(q/p)(^o)$	$-6 \pm 11 \pm 3^{+3}_{-4}$	$\pm 4.7 \pm 4.2$	$\pm 1.5 \pm 3.8$		3

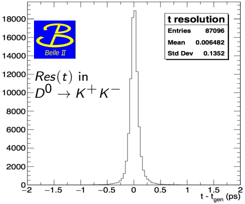
Improved D^0 lifetime resolution at Belle II

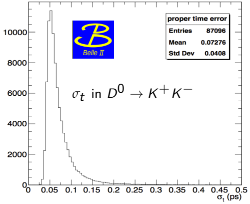
- Time resolution is essential in time-dependent measurements of D^0-$\overline{D^0}$ mixing and CPV.
  - such as the time-dependent amplitude of $D^0 \to f$ (here $t[\tau_{D^0}]$ and $\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}$):

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

- D^0 lifetime: $\boxed{t = \frac{\ell_{dec}}{c\beta\gamma} = \frac{m_D}{cp}\vec{d}\cdot\frac{\vec{p}}{p}}$ and σ_t by error matrix of vertex fits and momentum.







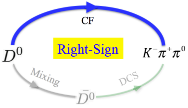
- Based on MC study, D^0 lifetime resolution Res(t)≈140 fs: half of BaBar's (270 fs)
- Time error σ_t: 1/3 of BaBar's; and RMS(σ_t) reduced by half.
  - resolution function $g(t) = Gauss(\mu, k\sigma_t)$, reduced RMS($\sigma_t$) (higher weight in the fit) results in an increased statistics

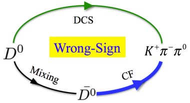
Time resolution effect on TDDA in $D^0 \to K^+\pi^-\pi^0$

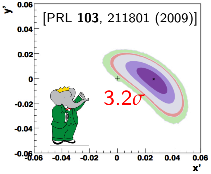
- TDDP fit on $D^0 \to K^+\pi^-\pi^0$ WS decays to extract mixing par. $(x''/r_0,\ y''/r_0)$

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

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

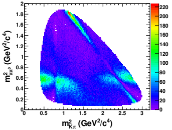


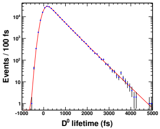


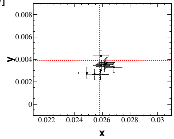


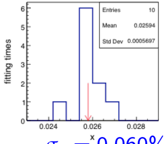
- BaBar performed TDDA with 384 fb^{-1}:
  $x'' = (2.61^{+0.57}_{-0.68} \pm 0.39)\%$, $y'' = (-0.06^{+0.55}_{-0.64} \pm 0.34)\%$
  $\Rightarrow$ the first evidence to veto the hypothesis of no D^0-$\overline{D^0}$ mixing in D^0 multi-body decays.
- ToyMC: smear exponential lifetime with Gauss(σ=140 fs) to consider the improved time resolution at Belle II; without considering backgroud effects.
- Sensitivity estimation: one order of magnitude improvement than BaBar

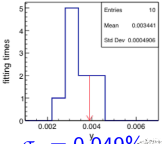
detailed info. see [Chin. Phys. C, **41**: 023001 (2017)]







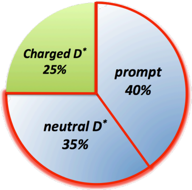




$\sigma_x = 0.060\%$, $\sigma_y = 0.049\%$

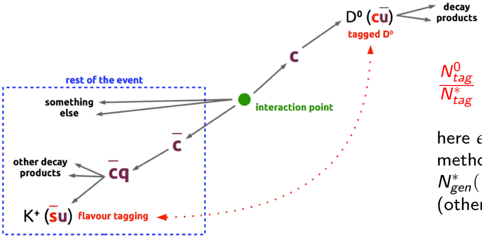
A new D^0-tag method at Belle II: ROE method

- To measure CPV, the flavor of D is needed to be determined efficiently.
- At B-factories, the charge of π_s from $D^{*+} \to D^0\pi_s^+$ is used to tag the flavor of D^0 and D^0 mesons from B decays are excluded.
  $\Rightarrow$ only D^0 from $D^{*\pm}$ in $c\bar{c}$ events (25%) were used.
- To utilize another charm meson decay is the essential idea of ROE.



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

- ROE method: select events with only one $K^\pm$ in the Rest Of Event;
- Using 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%($\leqslant$ 20%).
$N^*_{gen}(N^0_{gen})$: number of D^0 produced by a D^* (other $c\bar{c}$ event) with $N^*_{gen} : N^0_{gen} \simeq 1:3$

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

$\boxed{\text{an additional } D^0 \text{ sample via ROE method will be available and optimistic.}}$

Outline

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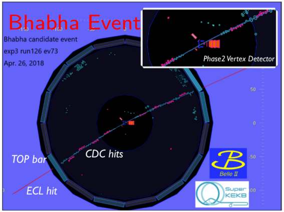
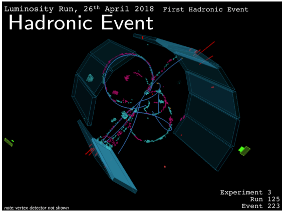
   - Time-dependent Dalitz analysis
   - Prospect of TDDA in $D^0 \to K_S^0 \pi^+ \pi^-$
   - Prospect of TDDA in $D^0 \to K^+ \pi^- \pi^0$
   - A new D^0-tag method: ROE method
3. Re-discoveries of Phase2 at Belle II
4. Summary

Some 'first' events and re-dicoveries with first data

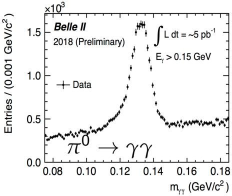
- First collision and 'First' events

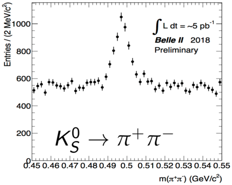
First collision at April 25, 2018

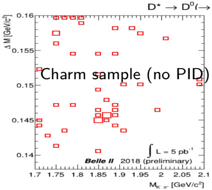


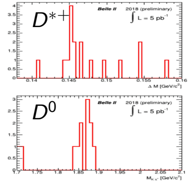


- First data (5 pb^{-1}) gave evidences of π^0/K_S^0/charm. Calibrations at a very early stage.



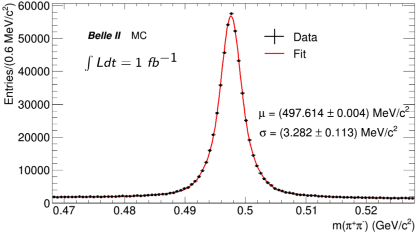


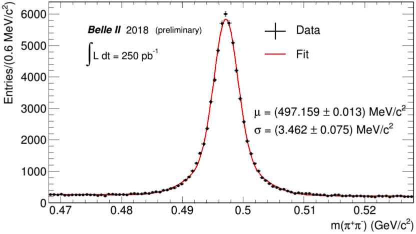




K_S^0 invariant Mass

- Belle II has already finished Phase 2 on Jul 17 with $\sim$xxx pb^{-1}(wait official statement).
- Some approval plots on up to 250 pb^{-1}: with requirement of at least tree tracks from the IP region, while rejecting beam included background, Bhabha events and other low multiplicity background sources.
- for example of $K_S^0 \to \pi^+\pi^-$ with partial Phase2 dataset.

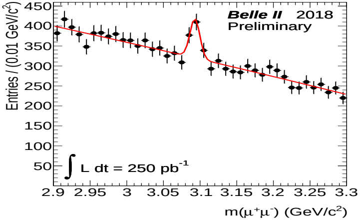


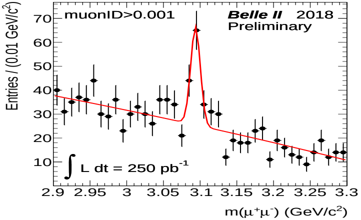


- K_S^0 mass resolutions within a few % of what expected by the simulation.
- Tracking efficiency measurements are ongoing.

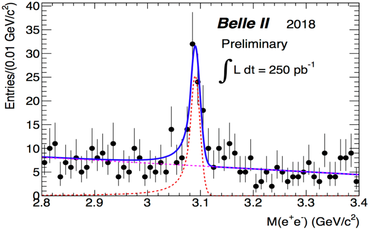
Re-discovery: November revolution in June

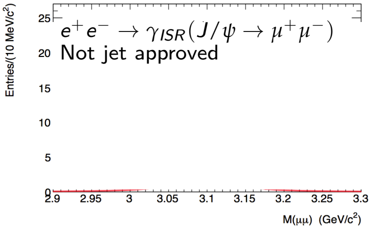
- re-discovery of $J/\psi \to \mu^+\mu^-$ in 250 pb^{-1} of Phase 2 data w/o and w/ muonID.





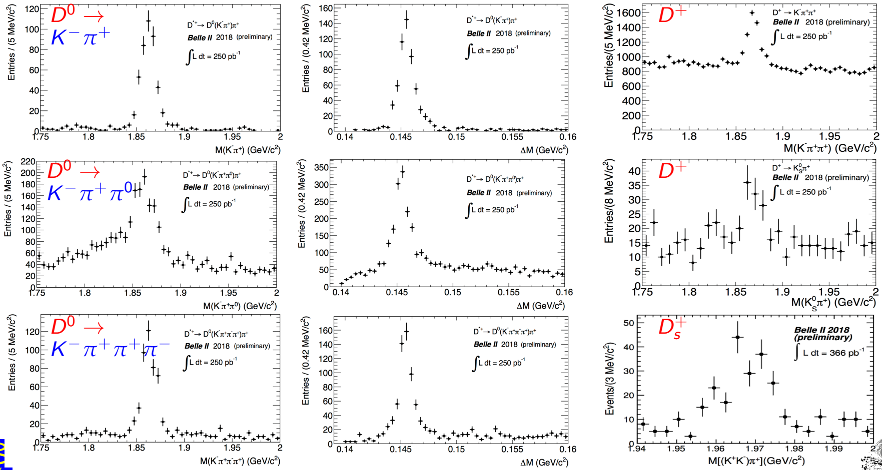
- other processes, like $J/\psi \to e^+e^-$ and ~~$e^+e^- \to \gamma_{ISR}(J/\psi \to \mu^+\mu^-)$~~.





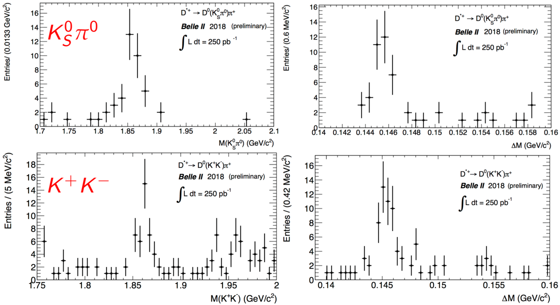
Re-discovery: charm sample with definite flavor

- Each $c\bar{c}$ event at B-factories has averaged $\bar{N}(D^0) = 1.119 \pm 0.007$, $\bar{N}(D^+) = 0.595 \pm 0.005$, $\bar{N}(D_s^+) = 0.195 \pm 0.003$.
- D^0 CF decays $K\pi$, $K\pi\pi^0$ and $K\pi\pi\pi$ with flavor tagged, and $D^+_{(s)}$ are observed.

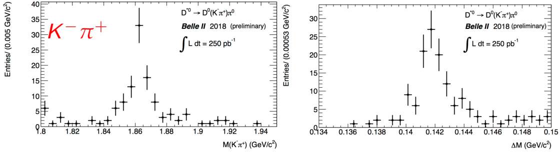


Re-discovery: D^0 sample in other channels

- in D^{*+} sample: CP eigenstate decays of $D^0 \to K_S^0\pi^0$(CF) and $D^0 \to K^+K^-$(SCS) are observed.

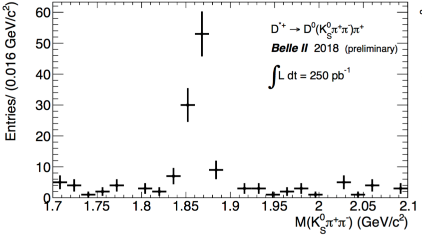


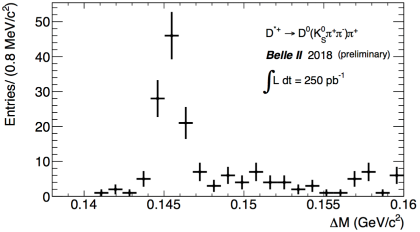
- In D^{*0} sample: $D^0 \to K^-\pi^+$ is observed.



Re-discovery: charm sample

- Golden channel $D^{*+} \to (D^0 \to K_S^0 \pi^+ \pi^-)\pi^+$ is observed with high purity





- what is the future with full Belle II dataset ($\times 40,000$) for this channel? most precise result on D^0-$\overline{D^0}$ mixing? observation CPV in charm?

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Summary

- Belle II is back to the game after eight year passed since Belle shut down.
- Belle II will have a rich charm physics program ahead. TDDA will become one of favourites of Belle II charm WG to study D^0-$\overline{D}^0$ mixing and CP violation in many multi-body decays.
- Considering 50 times dataset and half of D^0 lifetime resolution at Belle II, two sensitivity estimations in TDDA are presented:
  - Prospect in $D^0 \to K_S^0 \pi^+ \pi^-$: factor 3 improved, and Dalitz model will dominate the errors.
  - Prospect in $D^0 \to K^+ \pi^- \pi^0$: one order of magnitude improved w/o considering the bkg effects.
  - more decay channels will contribute D^0-$\overline{D}^0$ mixing and CPV via TDDA benefiting from improved performances and a large date set.
- ROE D^0 tagging method is presented: provides an additional tagged D^0 sample.
- Phase2 has finished, some re-discoveries with 250 pb^{-1} are shown, especially charm sample in many channels.
- Phase3 operation (physics run) with full Belle II detector will start next spring.
- Looking forward to charming news on charm physics via TDDA.

Back up

Thank you for your attention.

谢谢！

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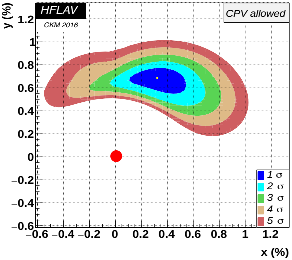
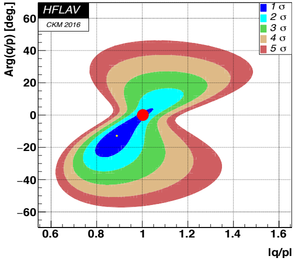
Status of D^0-$\overline{D^0}$ mixing and CP violation [mainly ref. charm physics at HFLAV]

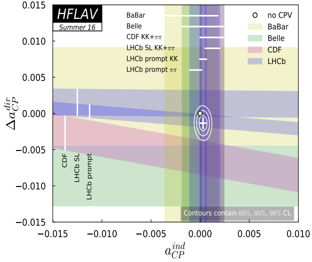
D^0-$\overline{D^0}$ mixing



indirect CP violation



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



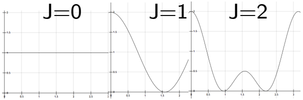
- $\gg 11.5\sigma$ to exclude no mixing (x,y)=(0,0) with CPV-allowed
- No hints for indirect CPV $\Leftarrow$ no direct CPV ($|q/p|,\phi$)=(1,0) at C.L=40%
- No clear evidence of direct CPV $\Leftarrow$ no CPV at C.L=9.3%

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

description of angular function W_r

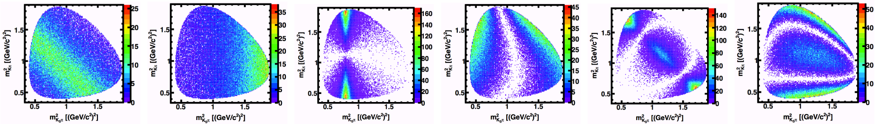
(1) Helicity form: [Phys. Rev. D **78**, 052001 (2008)]
easily understood, but need many Lorantz transform, take much time on calculation

$$\mathcal{A}_r = F_D \times F_r \times T_r \times \left(|p|^J |q|^J P_J(\cos\theta_H^r)\right)$$
$$W_r(J=0) = 1 \qquad \propto const.$$
$$W_r(J=1) = -2(\vec{p}\cdot\vec{q}) = -2|p||q|\cos\theta_H \qquad \propto \cos\theta_H$$
$$W_r(J=2) = \tfrac{16}{3}|p|^2|q|^2(3\cos^2\theta_H - 1) \qquad \propto \cos^2\theta_H$$



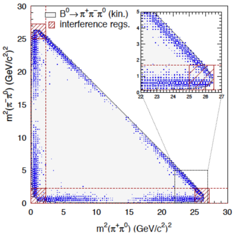
(2) Zemach covariant tensor form: [Phys. Rev. **133**, B1201 (1964), Phys. Rev. **140**, B109 (1965)]
difficult to understand, usually only used in spin-0 final state particles, but take less time in calculation

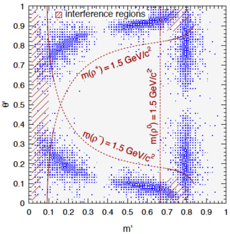
$$W_r(J=0) = 1$$
$$W_r(J=1) = m_{ac}^2 - m_{bc}^2 + \frac{(M_D^2 - M_c^2)(M_b^2 - M_a^2)}{M_r^2}$$
$$W_r(J=2) = \left[m_{bc}^2 - m_{ac}^2 + \frac{(M_D^2 - M_c^2)(M_a^2 - M_b^2)}{M_r^2}\right]^2 - \frac{1}{3}\left[m_{ab}^2 - 2M_D^2 - 2M_c^2 + \frac{(M_D^2 - M_c^2)^2}{M_r^2}\right] \times \left[m_{ab}^2 - 2M_a^2 - 2M_b^2 + \frac{(M_a^2 - M_b^2)^2}{M_r^2}\right]$$



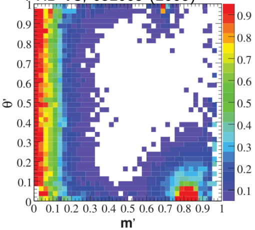
Square Dalitz Plot Method

- In Dalitz analyses od B meson decays, the cared interference region is usually concentrate on the marginal area (left figure).
- To avoid the variation of efficiency plane in one bin, a better Dalitz plot region with better resolution is needed.
- It can also efficiently describe efficiency plane or background distribution on Dalitz plot, such as misidentified background in $B \to K\pi\pi^0$(right figure)。
- Expanded Dalitz plot plane $[0,1] \times [0,1]$: square Dalitz Plot (SDP) [PRD **72**, 052002 (2005)]
  - $m' = \frac{1}{\pi} \arccos\left(2\frac{m_{ab} - m_{ab}^{min}}{m_{ab}^{max} - m_{ab}^{min}} - 1\right) \in [0,1] \qquad \theta' = \frac{1}{\pi}\theta_{ab} \in [0,1]$
  - where $m_{ab}^{max} = M_B - m_c$, $m_{ab}^{min} = m_a + m_b$, Jacobian determinant |J| meets: $dm_{12}^2 dm_{23}^2 = |J| dm' d\theta'$



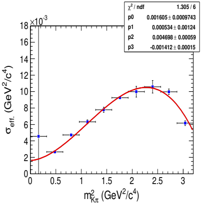


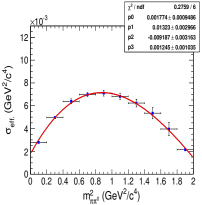
PRD **78**, 052005 (2008)



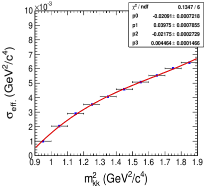
Mass resolution problem in Dalitz analysis

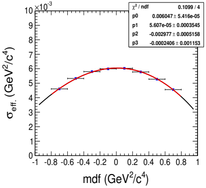
- In $D^0 \to K^+\pi^-\pi^0$, Dalitz resolution meets $\sigma(m^2) \ll 2m_r \cdot \Gamma_r$, but narrowest width of intermediate states is $\Gamma(K^*(892)^0) = 48.7\ MeV/c^2$





- In $D^0 \to K_S^0 K^+ K^-$, Dalitz resolution meets $\sigma(m^2) \sim 2m_r \cdot \Gamma_r$, but narrowest width of intermediate states is $\Gamma(\phi(1020))$=4.38 MeV/c^2.





here DP uses $m_{KK}^2 = C - (m_+^2 + m_-^2)$ and $mdf = m_+^2 - m_-^2$

- Strictly speaking, a convolution is needed on whole region of DP to consider the resolution effects: a time-consuming challenge for CPU.
- A discretization of convolution via a grid weight method: decide grid size by resolution, and use averaged value of around grid points with weight $W_{lj} = e^{-(l^2+j^2)/2}$, the normalized form is as follows:

$$pdf_{resol}(x,y) = \sum_{l=-3,j=-3}^{3,3} pdf(x + l\sigma_x, y + j\sigma_y) \cdot W_{lj} \ / \sum_{l=-3,j=-3}^{3,3} W_{lj}$$

Efficiency difference between data and MC

- To consider the difference of particle identification(PID) efficiency between data and MC, a data-driven efficiency plane is applied.
- Obtain a 2D table of the ratio of each charged particles' PID efficiency between data and MC, dependent on various particles' momentum and PID requirement.
- re-weight each event in reconstructed DP according its momentum, PID requirement and above ratio value, then obtain the data-driven efficiency plane by the ratio of corrected rec. DP plane to gen. DP plane.