Prospects of Dalitz Analysis on Charm Physics at Belle II

Longke LI[1] (李龙科)
On behalf of the Belle II Collaboration
[1]Institute of High Energy Physics, CAS, China (IHEP)

Belle II

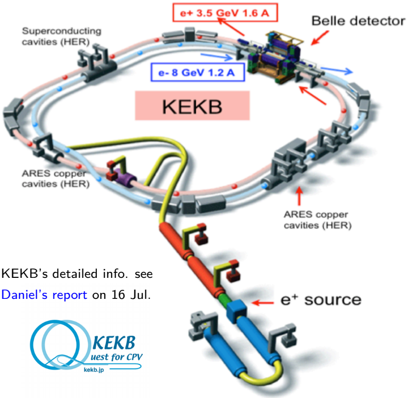
PWA 10/ATHOS 5, July 16th-20th, 2018, Beijing

Outline

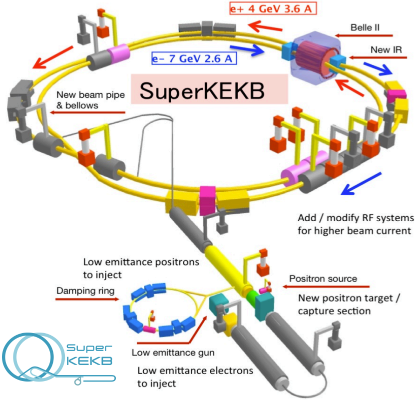
Outline

Accelerator: KEKB Vs. SuperKEKB

- As 1st and 2nd 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.

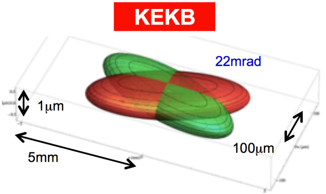


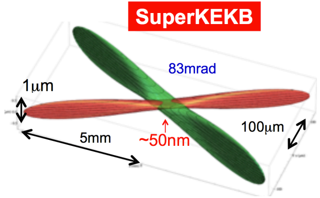
KEKB's detailed info. see Daniel's report on 16 Jul.



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.





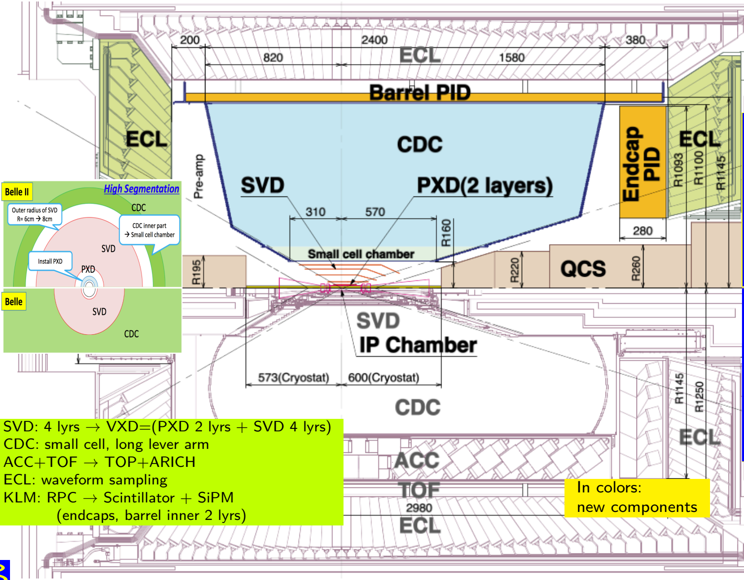
luminosity

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

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}
	$\beta\gamma\sim 2/3$		$\times2$	$\times20$	$\times40$

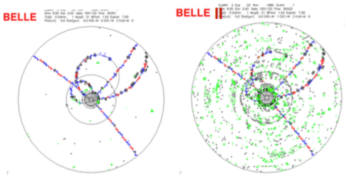
Detector: Belle Vs. Belle II



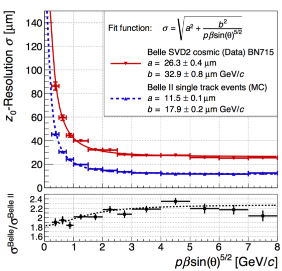
SVD: 4 lyrs → VXD=(PXD 2 lyrs + SVD 4 lyrs)
CDC: small cell, long lever arm
ACC+TOF → TOP+ARICH
ECL: waveform sampling
KLM: RPC → Scintillator + SiPM
(endcaps, barrel inner 2 lyrs)

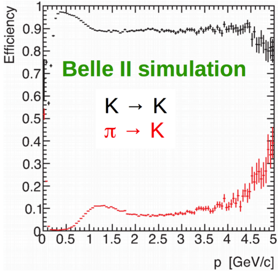
In colors:
new components

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$\to$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$/c$.



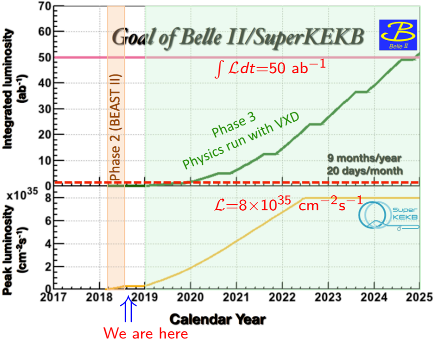


larger Data set at Belle II

- 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:

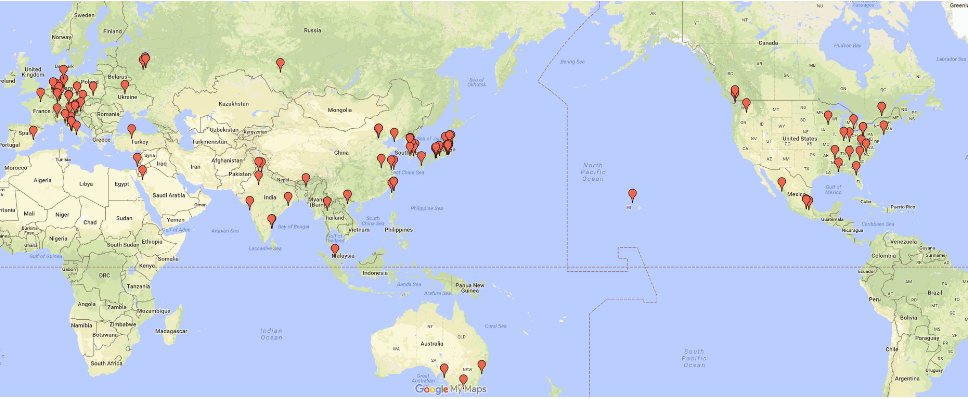
Experiment	Machine	C.M $\sqrt{s}$	Luminosity	charm sample	efficiency
CLEOc	CESR (e^+e^-)	3.77 GeV 4.17 GeV	0.8 fb^{-1} 0.6 fb^{-1}	$2.9 \times 10^6(D^0)$ $2.3 \times 10^6(D^+)$ $0.6 \times 10^6(D_s^+)$	~10-30%
BESIII	BEPC-II (e^+e^-)	3.77 GeV 4.18 GeV 4.6 GeV	2.9 fb^{-1} 3.0 fb^{-1} 0.6 fb^{-1}	$10.5 \times 10^6(D^0)$ $8.4 \times 10^6(D^+)$ $3 \times 10^6(D_s^+)$ $1 \times 10^5(\Lambda_c^+)$ ★	★★★
BELLE	KEKB (e^+e^-)	10.58 GeV	1 ab^{-1}	$1.3 \times 10^9(D^0)$ $7.7 \times 10^8(D^+)$ $2.5 \times 10^8(D_s^+)$ $1.5 \times 10^8(\Lambda_c^+)$	~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.

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

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

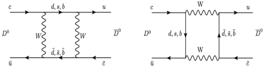
- Open-flavor neutral meson transforms to anti-meson:

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

- 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: $\mathbf{x} \equiv 2\dfrac{M_1 - M_2}{\Gamma_1 + \Gamma_2}, \quad \mathbf{y} \equiv \dfrac{\Gamma_1 - \Gamma_2}{\Gamma_1 + \Gamma_2}$
- Unique system: only up-type meson for mixing
- Standard Model(SM) predicts: $\sim \mathcal{O}(1\%)$



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

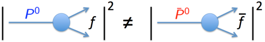
(2) long distance ($\sim 1\%$)

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

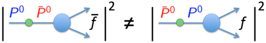
► Three types of Charged-conjugated-Parity combined symmetry Violation (CPV):

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

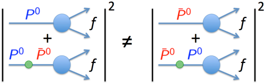
- a_d^f: (direct CPV) CPV in decay $|\bar{A}_{\bar{f}}/A_f| \neq 1$



- 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

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

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

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

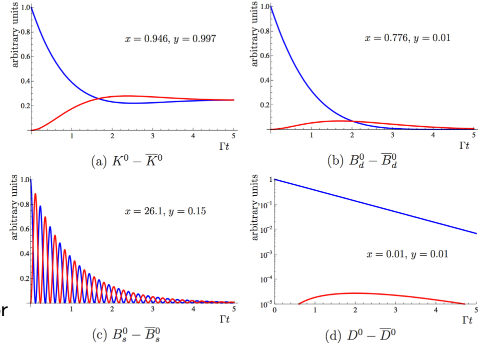
diagonal: $D \to D$,non-diagonal: $D \to \bar{D}$.

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

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

- 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}		✓ δ	$\circ_\delta$
	$K^0_S K^-\pi^+$			✓ A_{CP}		✓ δ	$\circ_\delta$

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

The related publishments are linked under their corresponding signs.

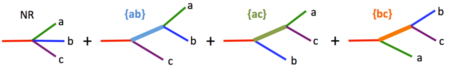
(a) Belle measured WS-to-RS ratio R_{WS} and A_{CP} in $D^0 \to K^\mp\pi^\pm\pi^0$ in PRL **95**, 231801 (2005).

(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)



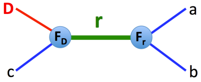
$$\mathcal{M}(m^2_{ab}, m^2_{bc}) = a_{NR} e^{i\phi_{NR}} + \sum_r a_r e^{i\phi_r} \mathcal{A}_r(m^2_{ab}, m^2_{bc})$$

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)



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

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

  $F_{J=0} = 1$

  $F_{J=1} = \frac{\sqrt{1+z_r}}{\sqrt{1+z_{ab}}}$

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

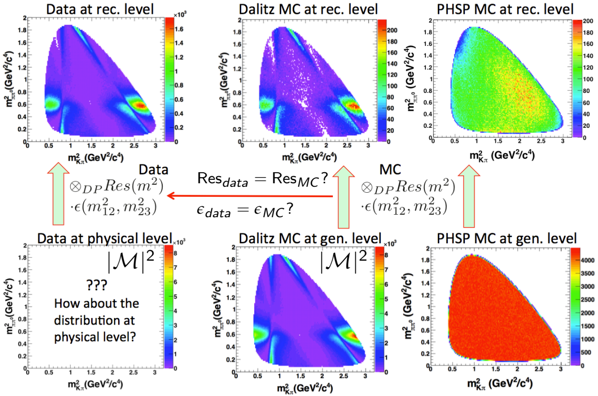
  $F_{J=3} = \frac{\sqrt{z_r(z_r-15)^2+9(2z_r-5)}}{\sqrt{z_{ab}(z_{ab}-15)^2+9(2z_{ab}-5)}}$

  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

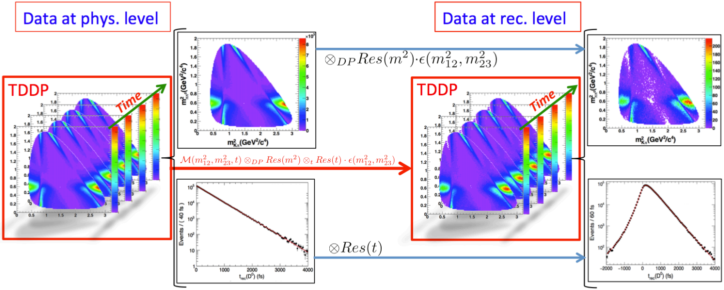
$$p_{\rm sig}(m^2_{12,i}, m^2_{23,i}) = \frac{|\mathcal{M}(m^2_{12,i}, m^2_{23,i})|^2 \otimes_m Res(m) \cdot \epsilon(m^2_{12,i}, m^2_{23,i})}{\iint_{DP} dm^2_{12} dm^2_{23} \; |\mathcal{M}(m^2_{12}, m^2_{23})|^2 \otimes_m Res(m) \cdot \epsilon(m^2_{12}, m^2_{23})}$$



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.

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



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

- TDDA in D^0 self-conjugated decays:

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

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

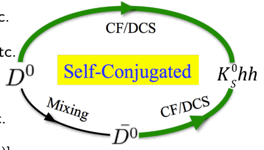
- $D^0 \to K_S^0\pi^+\pi^-$ with qusai-two-body decays with difference physics process:

  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.

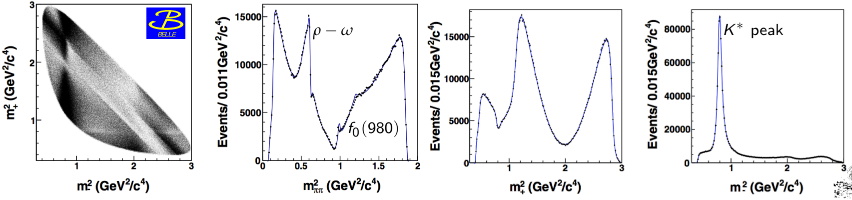
  Wrong-Sign: $\mathcal{A}_{\bar f} = \langle \bar f|\mathcal{H}|D^0\rangle$; $\frac{q}{p}\frac{\bar{\mathcal{A}}_{\bar f}}{\mathcal{A}_{\bar f}} = \left|\frac{\bar{\mathcal{A}}_{\bar f}}{\mathcal{A}_{\bar f}}\right|\frac{1-\epsilon}{1+\epsilon}e^{-i(\delta-\phi)}$; eg: $D^0 \to K^{*+}\pi^-$ etc.

  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: $D^0 \to K_S^0 f_0$ 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: $D^0 \to K_S^0\rho / K_S^0\omega$ etc.

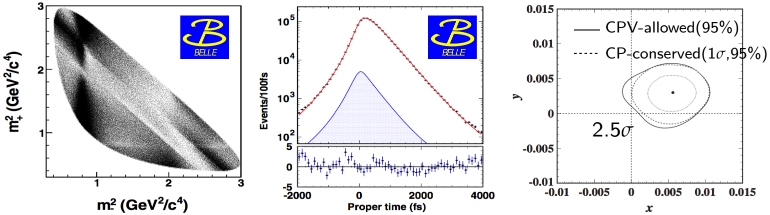


- Review of Belle's result of TDDA in this decay [PRD **89**, 091103(R) (2014)]
  - D^0 flavor is tagged via the charge of slow π_s from $D^{*+} \to D^0\pi_s^+$.
  - Dalitz variables $m_-^2 = m^2_{K_S^0\pi^-}$, $m_+^2 = m^2_{K_S^0\pi^+}$ for D^0, exchange for $\overline{D^0}$.
  - Dalitz Model: 12 RBW+K-matrix($\pi\pi$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



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

- 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.

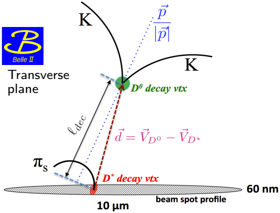
Fit type	Para.	Belle Fit result 921 fb^{-1}	Belle II prospect 5 ab^{-1}	Belle II prospect 50 ab^{-1}	model-indept. 100 M signals	LHCb 50 fb^{-1}
No CPV	x(%)	$0.56 \pm 0.19^{+0.03+0.06}_{-0.09-0.09}$	$\pm0.08 \pm 0.11$	$\pm0.03 \pm 0.11$	±0.017	
	y(%)	$0.30 \pm 0.15^{+0.04+0.03}_{-0.05-0.06}$	$\pm0.06 \pm 0.05$	$\pm0.02 \pm 0.04$	±0.019	
indirect	x(%)	$0.56 \pm 0.19^{+0.04+0.06}_{-0.08-0.08}$	$\pm0.08 \pm 0.11$	$\pm0.03 \pm 0.11$		0.04
	y(%)	$0.30 \pm 0.15^{+0.04+0.03}_{-0.05-0.07}$	$\pm0.06 \pm 0.05$	$\pm0.02 \pm 0.04$		0.004
CPV	$\|q/p\|$	$0.90^{+0.16+0.05+0.06}_{-0.15-0.04-0.05}$	$\pm0.069 \pm 0.073$	$\pm0.022 \pm 0.069$		0.04
	$\arg(q/p)(^o)$	$-6 \pm 11 \pm 3^{+3}_{-4}$	$\pm4.7 \pm 4.2$	$\pm1.5 \pm 3.8$		3

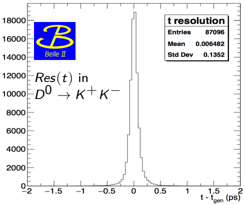
Improved D^0 lifetime resolution at Belle II

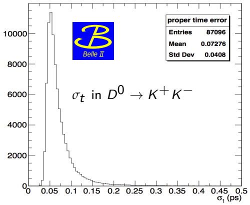
- Time resolution is essential in time-dependent measurements of D^0-$\overline{D^0}$ mixing and CPV.
  - such as the time-dependent amplitude of $D^0 \to f$ (here $t[\tau_{D^0}]$ and $\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}$):

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

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







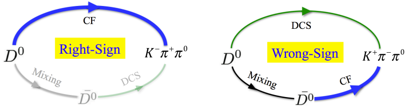
- Based on MC study, D^0 lifetime resolution Res(t)≈140 fs: half of BaBar's (270 fs)
- Time error σ_t: 1/3 of BaBar's; and RMS(σ_t) reduced by half.
  - resolution function $g(t) = Gauss(\mu, k\sigma_t)$, reduced RMS($\sigma_t$) (higher weight in the fit) results in an increased statistics

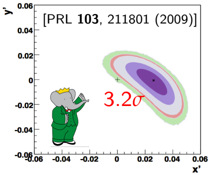
Time resolution effect on TDDA in $D^0 \to K^+\pi^-\pi^0$

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

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

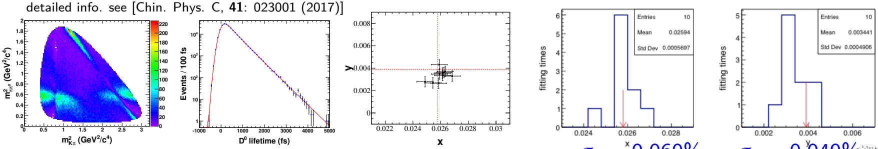
where $x'' = x\cos\delta_{K\rho} + y\sin\delta_{K\rho}$, $y'' = y\cos\delta_{K\rho} - x\sin\delta_{K\rho}$, $r_0 = |A^{CF}|/|A^{DCS}|$.





- 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

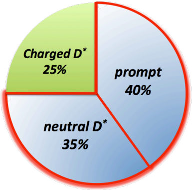
detailed info. see [Chin. Phys. C, **41**: 023001 (2017)]



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

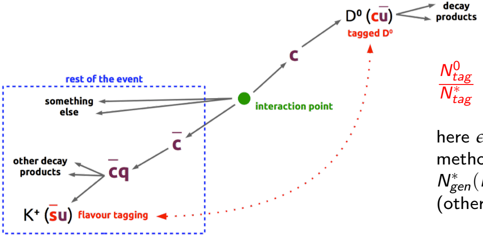
A new D^0-tag method at Belle II: ROE method

- 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.



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

- 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}

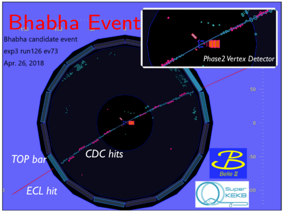
an additional D^0 sample via ROE method will be available and optimistic.

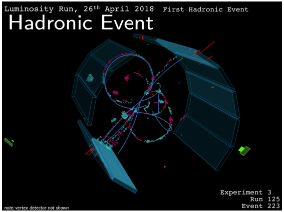
Outline

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

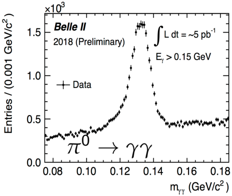
- First collision and 'First' events

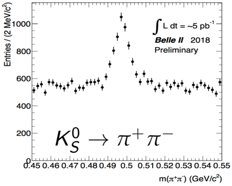
First collision at April 25, 2018

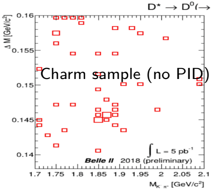


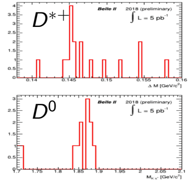


- First data (5 pb^{-1}) gave evidences of π^0/K_S^0/charm. Calibrations at a very early stage.



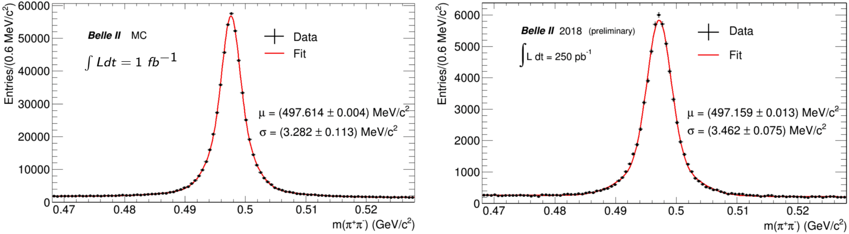






K_S^0 invariant Mass

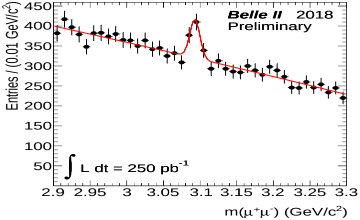
- Belle II has already finished Phase 2 on Jul 17 with ∼xxx pb^{-1}(wait official statement).
- Some approval plots on up to 250 pb^{-1}: with requirement of at least tree tracks from the IP region, while rejecting beam included background, Bhabha events and other low multiplicity background sources.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

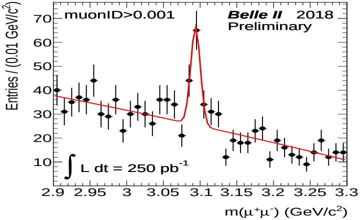


- K_S^0 mass resolutions within a few % of what expected by the simulation.
- Tracking efficiency measurements are ongoing.

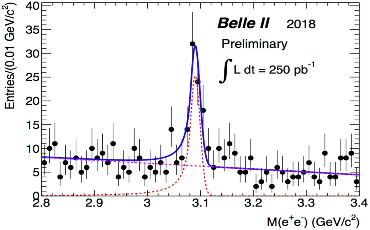
Re-discovery: November revolution in June

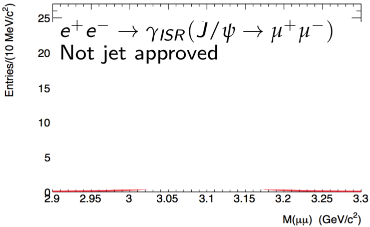
- re-discovery of $J/\psi \to \mu^+\mu^-$ in 250 pb^{-1} of Phase 2 data w/o and w/ muonID.





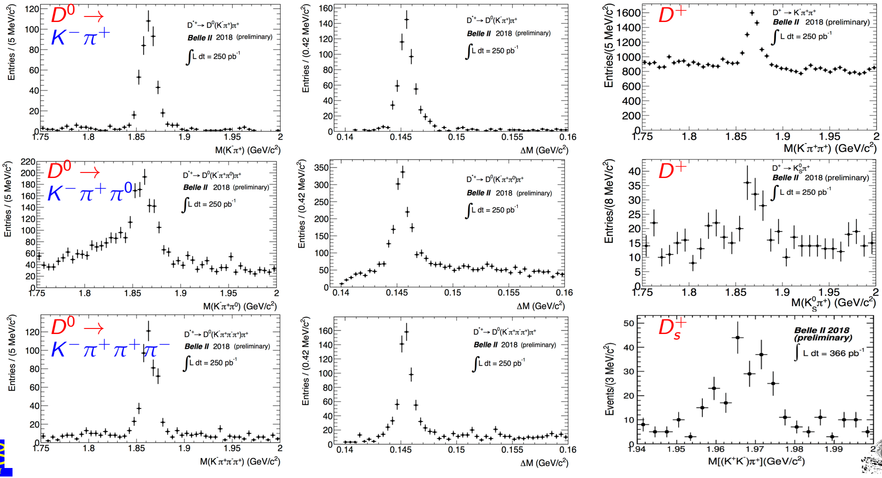
- other processes, like $J/\psi \to e^+e^-$ and ~~$e^+e^- \to \gamma_{ISR}(J/\psi \to \mu^+\mu^-)$~~.





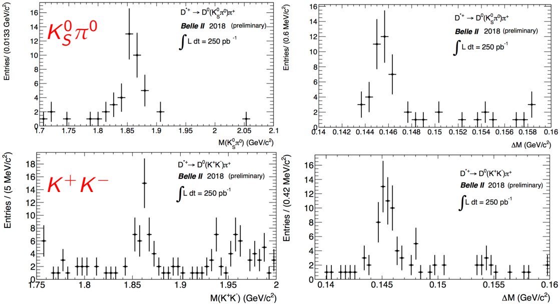
Re-discovery: charm sample with definite flavor

- 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.

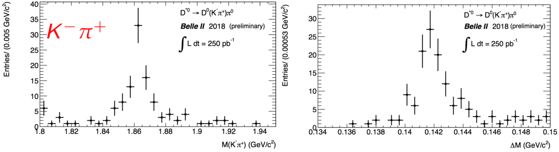


Re-discovery: D^0 sample in other channels

- 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.

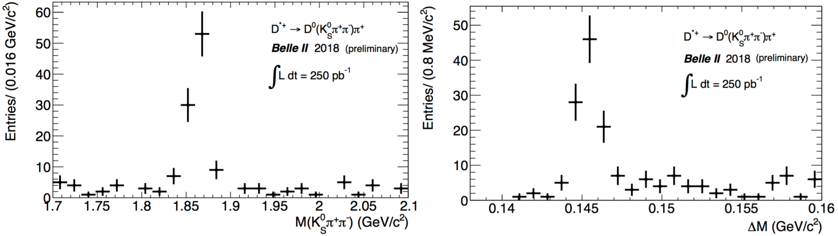


- In D^{*0} sample: $D^0 \to K^-\pi^+$ is observed.



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?

Outline

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

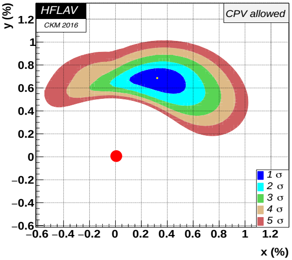
Thank you for your attention.

谢谢！

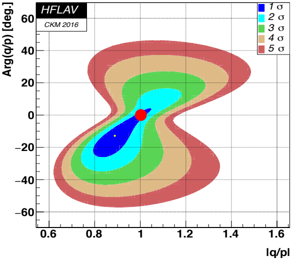
Longke LI (李龙科)
Room B413, Main Building
Institute of High Energy Physics, CAS (IHEP)
19B, Yuquan Road, Shijingshan District
Beijing City, 100049, P. R. China
(+86)-159-5693-4447
lilongke_ustc
lilongke@ihep.ac.cn

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

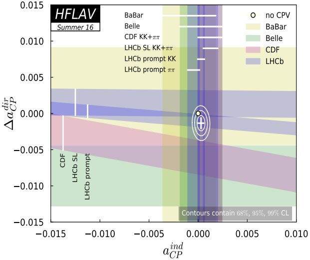
D^0-$\overline{D^0}$ mixing



indirect CP violation



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



- $\gg$ 11.5σ 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)]

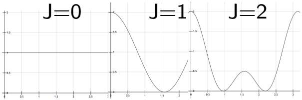
easily understood, but need many Lorantz transform, take much time on calculation

$$\mathcal{A}_r = F_D \times F_r \times T_r \times \left(|p|^J |q|^J P_J(\cos\theta_H^r)\right)$$

$$W_r(J=0) = 1 \qquad \propto const.$$

$$W_r(J=1) = -2(\vec{p}\cdot\vec{q}) = -2|p||q|\cos\theta_H \qquad \propto \cos\theta_H$$

$$W_r(J=2) = \frac{16}{3}|p|^2|q|^2(3\cos^2\theta_H - 1) \qquad \propto \cos^2\theta_H$$



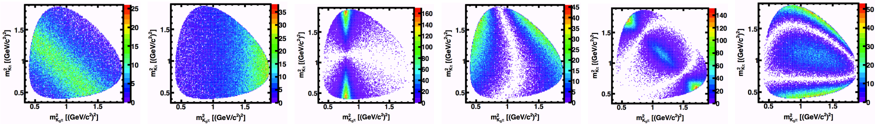
(2) Zemach covariant tensor form: [Phys. Rev. **133**, B1201 (1964), Phys. Rev. **140**, B109 (1965)]

difficult to understand, usually only used in spin-0 final state particles, but take less time in calculation

$$W_r(J=0) = 1$$

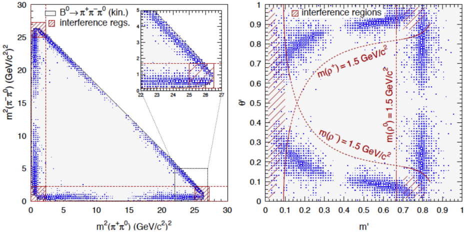
$$W_r(J=1) = m_{ac}^2 - m_{bc}^2 + \frac{(M_D^2 - M_c^2)(M_b^2 - M_a^2)}{M_r^2}$$

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

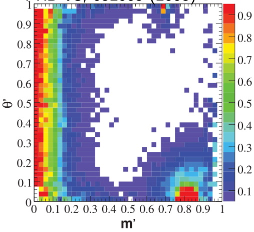


Square Dalitz Plot Method

- 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: $dm_{12}^2 dm_{23}^2 = |J| dm' d\theta'$

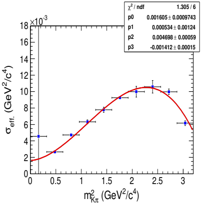


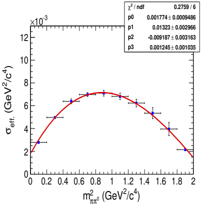
PRD **78**, 052005 (2008)



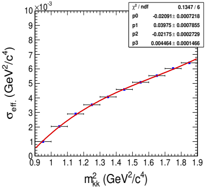
Mass resolution problem in Dalitz analysis

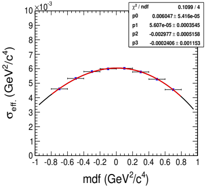
- In $D^0 \to K^+\pi^-\pi^0$, Dalitz resolution meets $\sigma(m^2) \ll 2m_r \cdot \Gamma_r$, but narrowest width of intermediate states is $\Gamma(K^*(892)^0) = 48.7\ MeV/c^2$





- 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.