Charm physics at B-factories

Longke LI (李龙科)
(On behalf of the Belle Collaboration)

Institute of High Energy Physics, CAS, China (IHEP)

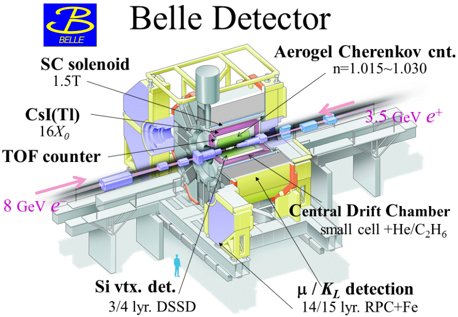
the 17th International Conference on B-physics at Frontier Machines
Beauty 2018, May 6-11, La Biodola, Italy

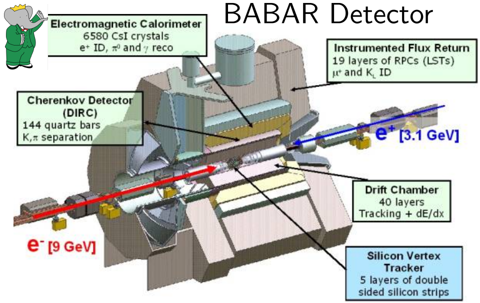
Outline

Outline

Belle@KEKB and BABAR@PEPII

Also see Saurabh's report on 10 May





- KEKB and PEPII: asymmetric-energy e^+e^- collider, running near $\Upsilon(4S)$ mass peak, with high peak luminosity $2.1(1.2) \times 10^{34}\ cm^{-2}s^{-1}$
- Excellent vertexing and particle identification with Vertex detector, Cerenkov detector, etc.
- Final state with $\gamma/K_S^0/\pi^0$ can be well reconstructed that are difficult/impractical to reconstruct at hadron machine
- Low background, high trigger/rec. efficiencies, minimal decay time bias

Available Charm Samples from Charm factories, B-factories, hadron colliders

Experiment	Machine	C.M	Lumin.	N(D)	efficiency	☺advantage/☹disadvantage
CLEO	CESR (e^+e^-)	3.77 GeV 4.17 GeV	0.8 fb^{-1} 0.6 fb^{-1}	2.9×10^6 $2.3\times10^6(D^\pm)$ 0.6×10^6	~10-30%	☺ extremely clean enviroment ☺ pure D-beam, almost no bkg ☺ quantum coherence ☹ no CM boost, no T-dep analyses
BESIII	BEPC-II (e^+e^-)	3.77 GeV 4.18 GeV 4.6 GeV	2.92 fb^{-1} 3 fb^{-1} 0.567 fb^{-1}	10.5×10^6 8.4×10^6 $(D^\pm)$ $3\times10^6(D_s^+)$ $1\times10^5(\Lambda_c^+)$ ★	★★★	
BELLE	KEKB (e^+e^-)	10.58 GeV	1 ab^{-1}	1.3×10^9 $1.5\times10^8(\Lambda_c^+)$	~5-10%	☺ clear event environment ☺ high trigger efficiency ☺ high-efficiency detection of neutrals ☺ many high-statistics control samples ☺ time-dependent analysis ☹ smaller cross-section than pp collid.
BaBar	PEP-II (e^+e^-)	10.58 GeV	0.5 ab^{-1}	6.5×10^8 ★★	★★	
CDF II	Tevatron ($p\bar{p}$)	1.96 TeV	9.6 fb^{-1}	1.3×10^{11}	<0.5%	☺ large production cross-section ☺ large boost ☺excellent time resolution ☹ dedicated trigger required ☹ hard to do with neutrals/neutrinos
LHCb	LHC (pp)	7 TeV 8 TeV	1.0 fb^{-1} 2.0 fb^{-1}	5.0×10^{12} ★★★	★	

Here cross section $\sigma(D^0\bar{D}^0@3.77\ GeV)$=3.61 nb, $\sigma(D^+D^-@3.77\ GeV)$=2.88 nb, $\sigma(D^*D_s@4.17\ GeV)$=0.967 nb, $\sigma(c\bar{c}@10.58\ GeV)$=1.3 nb, $\sigma(D^0@LHCb)$=1.661 nb are used. This table mainly refers to Int. J. Mod. Phys. A **29**, 1430051 (2014) and G. Casarosa's report at SLAC experimental seminar 2016.

► Above N(Λ_c^+) does not include charmed hadrons from B decays at B-factories. Large charm sample from B meson sample via $b\to c$ transition is available to study charm physics.

Outline

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

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

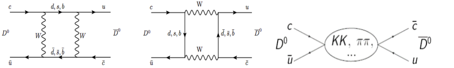
$$K^0 \Leftrightarrow \overline{K^0},\ B^0_d \Leftrightarrow \overline{B^0_d},\ B^0_s \Leftrightarrow \overline{B^0_s},\ D^0 \Leftrightarrow \overline{D^0}$$

- 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: $\sim \mathcal{O}(1\%)$



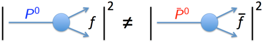
(1) short distance ($< 0.1\%$) (2) long distance ($\sim 1\%$)

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

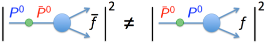
▶ Three types of Charged-conjugated-Parity combined symmetry Violation (CPV):

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

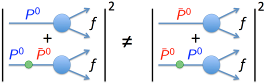
- a^f_d: (direct CPV) CPV in decay $|\bar{A}_{\bar{f}}/A_f| \neq 1$



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



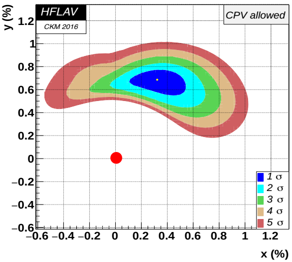
- a^f_i: CPV in interference with $\arg(q/p) \neq 0$



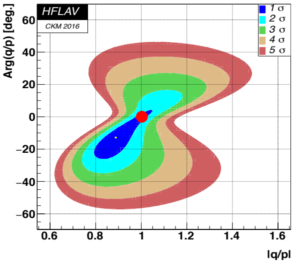
- SM with only a source: the phase in CKM
- in charm sector, it's predicted at $\sim \mathcal{O}(10^{-3})$
- $\sim 1\%$ exp. sensitivity to observe CPV→NP

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

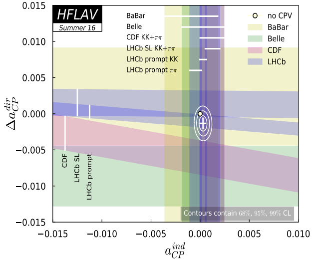
D^0-$\overline{D}^0$ mixing



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 B-factories.

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

Decay Type	Final State	BELLE		LHCb	CDF	CLEO	BESIII
DCS 2-body(WS)	$K^+\pi^-$	★	☆	★$^{(a)}$	★	✓	✓ $_{\delta K\pi}$
DCS 3-body(WS)	$K^+\pi^-\pi^0$	○$^{(c)}$	☆			✓ A_{CP}	○ $_\delta$
CP-eigenstate	(even) h^+h^-	☆	☆	☆$^{(b)}$ A_{CP}	✓ A_{CP}	✓	
	(odd) $K_S^0\phi$	✓					
Self-conj. 3-body decay	$K_S^0\pi^+\pi^-$	✓	✓	✓	✓ A_{CP}	✓	○ $_\delta$
	$K_S^0K^+K^-$	○	✓	○			○ $_\delta$
	$K_S^0\pi^0\pi^0$					✓ Dalitz	○ y_{CP}
Self-conj. 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	$K_S^0K^\pm\pi^\mp$			✓ A_{CP}		✓ $_\delta$	○ $_\delta$
Semileptonic decay	$K^+\ell^-\nu_\ell$	✓	✓			✓	
Multi-body(n≥4)	$K^+\pi^-\pi^+\pi^-$	✓ R_{WS}	✓	★			○ $_{\delta RS}$
	$\pi^+\pi^-\pi^+\pi^-$	○ A_{CP}		✓$^{(d)}$ A_{CP}			
	$K^+K^-\pi^+\pi^-$	○ A_T	✓ A_T	✓$^{(e)}$ A_{CP}		✓ A_{CP}	○
	$K_S^0\pi^+\pi^-\pi^0$	✓ A_T					
$\psi(3770)\to D^0\overline{D^0}$ via correlations						✓ $_{\delta K\pi}$	✓ y_{CP}

In D^0-$\overline{D^0}$ mixing measurements: ★ 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.

(a) LHCb gave the measurements in PRL **111**, 251801 (2013) and PRD **95**, 052004 (2017).

(b) LHCb gave the measurements of CP violation in $D^0\to h^-h^+$ decay in PRL **112**, 041801 (2014) and PRL **118**, 261803 (2017).

(c) 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).

(d) LHCb also searched for CP violation in phase space of $D^0\to\pi^+\pi^-\pi^+\pi^-$ decays in PLB **769**(2017) 345.

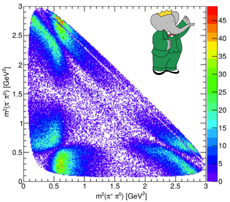
(e) LHCb also searched for CP violation using T-odd correlations in $D^0\to K^+K^-\pi^+\pi^-$ decays in JHEP **10**(2014)005.

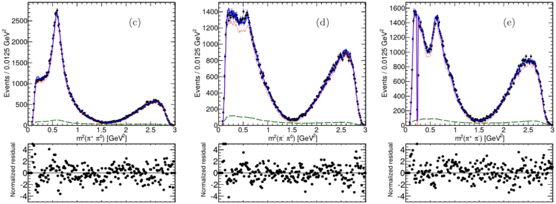
recent measurement: mixing in $D^0 \to \pi^+\pi^-\pi^0$ via TDDA [PRD **93**, 112014 (2016)]

- Time-dependent Dalitz Analysis(TDDA) provides an essential tool to study D^0-$\overline{D^0}$ mixing, used for $D^0 \to K_S^0\pi^+\pi^-$ (and $K_S^0K^+K^-$) with high statistics (Belle, BaBar, LHCb).
- Only method of sensitive to linear order in both mixing parameters, especially self-conjugated decays like K_S^0hh (not rotated by an unknown δ)
- TDDP fit on (m_-^2, m_+^2, t) to extract mixing/CPV par. (x,y) and $\frac{q}{p}$ (if no CPV, $\frac{q}{p}=1$)

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

- Dalitz model is determined from a t-integrated Dalitz fit to an Isobar Model.
- Based on $\mathcal{L} = 468.1\ fb^{-1}$, BaBar achieves first measurement on D^0-$\overline{D^0}$ mixing using TDDA of $D^0 \to \pi^+\pi^-\pi^0$: $x = (1.5 \pm 1.2 \pm 0.6)\%$, $y = (0.2 \pm 0.9 \pm 0.5)\%$.

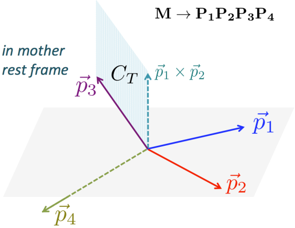




T-odd asymmetry measurements in D four-body decays

- 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 $\overline{C}_T$

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



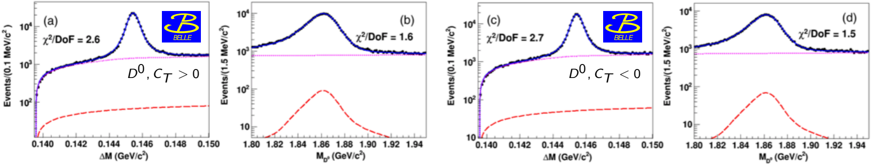
- T-odd asymmetry definition to veto FSI effects:

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

- In SM, CF decay: no effect is expected; CS decay: effect could be $\sim 0.1\%$ [PRD **51**, 3478 (1995)]
- Observing a T-odd asymmetry would be a signal for processes beyond the SM.

First measurement of $a^{\text{T-odd}}$ in $D^0 \to K^0_S \pi^+ \pi^- \pi^0$ at Belle [PRD **95**, 091101(R) (2017)]

- using full data set with $\mathcal{L} = 966\ fb^{-1}$; perform 2D fit ($M_{D^0}$, ΔM) for signal yields,
- simultaneously fit to four samples: D^0, $\overline{D^0}$, $C_T < 0$ and $C_T > 0$.



► Result Vs. others measurements in charmed mesons decay-rates:

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

- perform $a_{CP}^{\text{T-odd}}$ measurement in different PHSP ⇒ consistent with no CP violation.

[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)

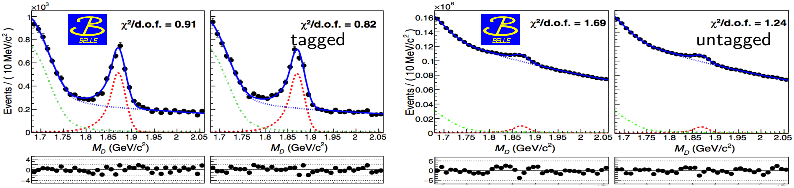
Belle II could improve these results with more precision benefited from the increased dataset.

CP violation in $D^+ \to \pi^+\pi^0$ at Belle [PRD **97**, 011101(R) (2018)]

- Singly Cabibbo-suppressed decay: excellent candidates to probe CPV in charm sector.
- Any *CP* asymmetry found in these channels point to New Physics [PRD 85,114036(2012)]
- Based on 921 fb^{-1}, *CP* asymmetries are measured from a simultaneous fit to M_D:

$$A^{\pi\pi}_{raw} = \frac{N(D^+ \to \pi^+\pi^0) - N(D^- \to \pi^-\pi^0)}{N(D^+ \to \pi^+\pi^0) - N(D^- \to \pi^-\pi^0)} = A_{CP} + A_{FB} + A^{\pi^\pm}_{\epsilon}$$

- tagged: $A^{\pi\pi}_{raw} = (+0.52 \pm 1.92)\%$; untagged: $A^{\pi\pi}_{raw} = (+3.77 \pm 1.60)\%$.



- normalization $D^+ \to K^0_S\pi^+$ with $A^{K\pi}_{CP} = (-0.363 \pm 0.094 \pm 0.067)\%$[PRL **109**, 021601 (2012)]
  $A^{K\pi}_{raw} = (-0.29 \pm 0.44)\%$ (tagged); $A^{K\pi}_{raw} = (-0.25 \pm 0.17)\%$.
- A combination: $A_{raw} = (+2.67 \pm 1.24 \pm 0.20)\%$ [EPJC**75**,453(2015)]
- Leads to $A^{\pi\pi}_{CP} = A^{K\pi}_{CP} + \Delta A_{raw}$, thus $A_{CP}(D^+ \to \pi^+\pi^0) = (+2.31 \pm 1.24 \pm 0.23)\%$.

Time-integrated *CP* asymmetry in D decays

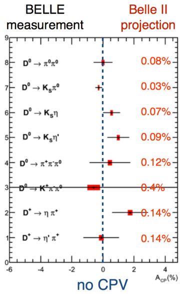
- Time-integrated *CP* asymmetries are measured based on partial decay rates:

$$A^f_{CP} = \frac{\Gamma(D \to f) - \Gamma(\overline{D} \to \overline{f})}{\Gamma(D \to f) + \Gamma(\overline{D} \to \overline{f})} = a^f_d + a^f_{ind}$$

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			Belle II	LHCb
	$\mathcal{L}$(/fb)	value(%)	References	50 ab^{-1}(%)	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	$-0.02 \pm 1.53 \pm 0.17$	PRL **119**, 171801 (2017)	± 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	$+2.31 \pm 1.24 \pm 0.23$	PRD **97**, 011101(R) (2018)	± 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	

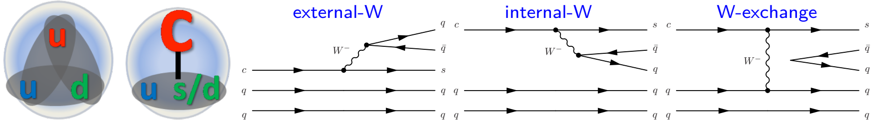


- Belle II: precision of $\mathcal{O}(0.01\%)$ (down to SM level). $\sigma_{Belle\ II} = \sqrt{(\sigma^2_{stat} + \sigma^2_{syst}) \cdot (\mathcal{L}_{Belle}/50\ \text{ab}^{-1}) + \sigma^2_{irred}}$
- With respect to LHCb, Belle II has advantages of excellent γ and π^0 reconstruction.

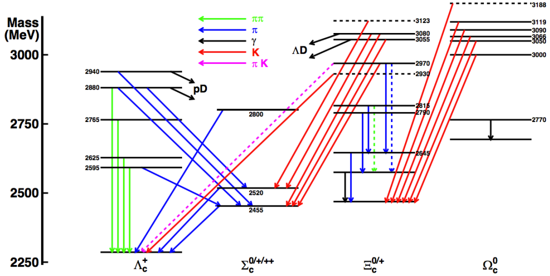
Outline

Physics of Charmed Baryons

- Character: $M_c \gg M_q$ (q=u,d,s); Di-quark structure in light quarks in charmed bargyons
- Charmed baryon weak decay is not understood well: three diagrams contribute in the tree level, but the strength of each is not known.

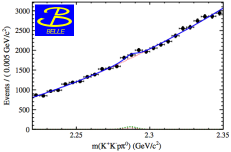


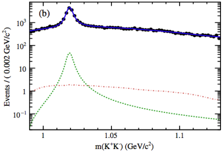
- Gound state charmed baryons: Λ_c, Σ_c, Ξ_c, Ω_c; and their excited states (spectroscopy)
  - ▶ a good laboratory to study strange baryons as decay proceed via $c \to s$ transition.

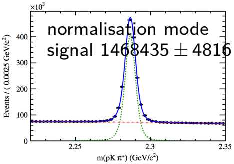


Search for hidden-strange pentaquark P_s in $\Lambda_c^+ \to \phi p \pi^0$ [PRD **96**, 051102(R) (2017)]

- Search for P_s in $\Lambda_c^+ \to \phi p \pi^0$: motivated by $P_c^+(4380, 4450)$ in $\Lambda_b \to J/\psi p K^-$(LHCb).
- Determine signal yields 148 ± 62 by 2D fit to M($K^+K^-p\pi^0$) and M(K^+K^-)

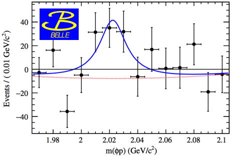


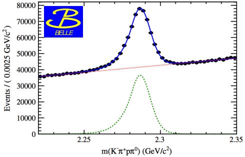




- To search for P_s, perform 2D fits in bins of M(ϕp): $N(P_s \to \phi p) = 78 \pm 28$
  - No significant P_s^+ signal observed.

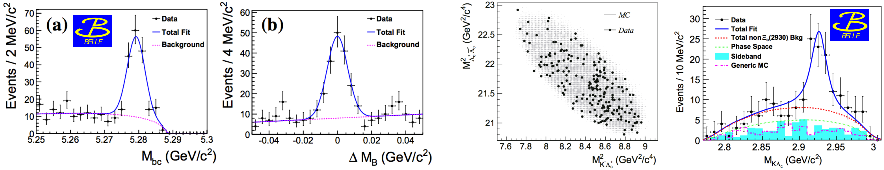
  $M(P_s) = 2.025 \pm 0.005\ GeV/c^2$ and $\Gamma(P_s) = 22 \pm 12$ MeV.
- Measured $BR(\Lambda_c \to K^-\pi^+p\pi^0) = (4.42 \pm 0.05 \pm 0.12 \pm 0.16)\%$: most precise measurement and consistent with recent BESIII result $BR = (4.53 \pm 0.23 \pm 0.30)\%$ [PRL116,052001(2016)]





Observation of $\Xi_c(2930)^0$ in $B^+ \to K^-\Lambda_c^+\bar{\Lambda}_c^-$ [EPJC (2018) 78:252]

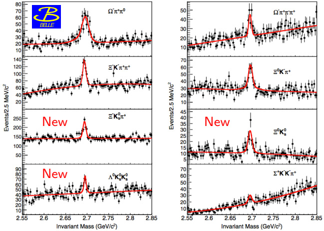
- Based on full $\Upsilon(4S)$ data set (772 M $B\bar{B}$ pairs) at Belle.
- Five Λ_c decay channels: $\Lambda_c^+ \to pK^-\pi^+$, pK_S^0, $\Lambda\pi^+$, $pK_S^0\pi^+\pi^-$ and $\Lambda\pi^+\pi^+\pi^-$.
- B candidates via beam-energy constraint M_{bc} and ΔM_B.



- fit result ($> 5\sigma$): $M_{\Xi_c(2930)} = (2928.9 \pm 3.0^{+0.9}_{-12.0})$ MeV$/c^2$, $\Gamma_{\Xi_c(2930)} = (19.5 \pm 8.4^{+5.9}_{-7.9})$ MeV.
- measured $\mathcal{B}(B^- \to K^-\Lambda_c^+\bar{\Lambda}_c^-) = (4.80 \pm 0.43 \pm 0.60) \times 10^{-4}$ [W.A. $(6.9 \pm 2.2) \times 10^{-4}$]
- measured $\mathcal{B}(B^- \to \Xi_c(2930)\bar{\Lambda}_c^-)\mathcal{B}(\Xi_c(2930) \to K^-\Lambda_c^+) = (1.73 \pm 0.45 \pm 0.21) \times 10^{-4}$.
- No significant signals seen in the $\Lambda_c^+\bar{\Lambda}_c^-$ mass spectrum. Upper limits for $Y(4600)$:
  $\mathcal{B}(B^- \to K^-Y(4660))\mathcal{B}(Y(4600) \to \Lambda_c^+\bar{\Lambda}_c^-) < 1.2 \times 10^{-4}$.

BR of Ω_c hadronic decays at Belle [PRD **97**, 032001 (2018)]

- Ω_c is only has same flavor light quarks (ss), constructive interf. is though to be origin of this short lifetime: $[\tau(\Lambda_c^+/\Xi_c^0/\Xi_c^+/\Omega_c) = (200\pm 6)/(112^{+13}_{-10})/(442\pm 26)/(69\pm 12)$ ps]
- Precise measurements will shed light on the dynamics of baryon weak decays.
- Based on full Belle data sets with $\mathcal{L} = 980\ fb^{-1}$; 8 decay modes are measured relative to nominal mode $\Omega^-\pi^+$.
- Precision improved by $\sim$factor 2 for already measured modes.

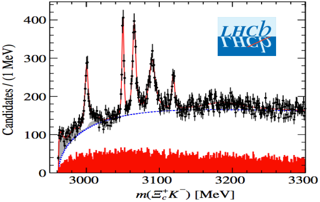


Mode	Branching ratio with respect to $\Omega^-\pi^+$	Substructure	Previous measurement
$\Omega^-\pi^+$	1		
$\Omega^-\pi^+\pi^0$	$2.00\pm0.17\pm0.11$		$1.27\pm0.3\pm0.11$ [4]
$\Omega^-\rho^+$		$>71\%$	
$\Omega^-\pi^+\pi^-\pi^+$	$0.32\pm0.05\pm0.02$		$0.28\pm0.09\pm0.01$ [4]
$\Xi^-K^-\pi^+\pi^+$	$0.68\pm0.07\pm0.03$		$0.46\pm0.13\pm0.03$ [4]
$\Xi^0(1530)K^-\pi^+$		$(33\pm9)\%$	
$\Xi^-\bar{K}^{*0}\pi^+$		$(55\pm16)\%$	
$\Xi^0K^-\pi^+$	$1.20\pm0.16\pm0.08$		$4.0\pm2.5\pm0.4$ [2]
$\Xi^0\bar{K}^{*0}$		$(57\pm10)\%$	
$\Xi^-\bar{K}^0\pi^+$	$2.12\pm0.24\pm0.14$ First observ.		
$\Xi^0\bar{K}^0$	$1.64\pm0.26\pm0.12$ First observ.		
$\Lambda\bar{K}^0\bar{K}^0$	$1.72\pm0.32\pm0.14$ First observ.		
$\Sigma^+K^-K^-\pi^+$	<0.32 (90% CL)		

- Intermediate resonances are studied for first time in 3 decays: dominant contributions.

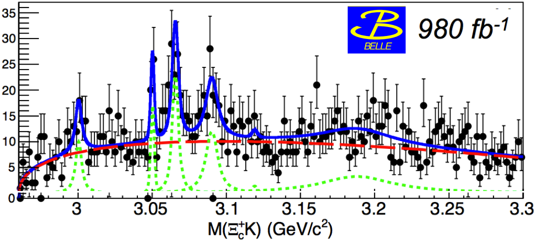
Confirm of excited $\Omega_c^0 \to \Xi_c^+ K^-$ [PRD **97**, 051102(R) (2018)]

- LHCb: dramatic observation of five excited Ω_c based on 3.3 fb^{-1} [PRL 118, 182001 (2017)]
  - Reconstruct $\Xi_c^+ \to p K^- \pi^+$ (1.0×10^6), five peaks appear in $\Xi_c^+ K^-$:



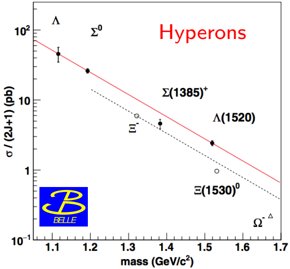
Resonance	Mass (MeV)	Γ (MeV)	Yield	N_σ
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$	$1300 \pm 100 \pm 80$	20.4
$\Omega_c(3050)^0$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$ <1.2 MeV, 95% C.L.	$970 \pm 60 \pm 20$	20.4
$\Omega_c(3066)^0$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$	$1740 \pm 100 \pm 50$	23.9
$\Omega_c(3090)^0$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$	$2000 \pm 140 \pm 130$	21.1
$\Omega_c(3119)^0$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$ <2.6 MeV, 95% C.L.	$480 \pm 70 \pm 30$	10.4
$\Omega_c(3188)^0$	$3188 \pm 5 \pm 13$	$60 \pm 15 \pm 11$	$1670 \pm 450 \pm 360$	
$\Omega_c(3066)^0_{\rm fd}$			$700 \pm 40 \pm 140$	
$\Omega_c(3090)^0_{\rm fd}$			$220 \pm 60 \pm 90$	
$\Omega_c(3119)^0_{\rm fd}$			$190 \pm 70 \pm 20$	

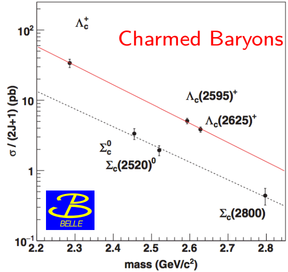
- Belle: using full data sets, confirm four of five narrow states reported by LHCb.
  - $\Omega_c(300)(3.9\sigma)$, $\Omega_c(3050)(4.6\sigma)$, $\Omega_c(3066)(7.2\sigma)$, $\Omega_c(3090)(5.7\sigma)$



Production rate of various baryons @10.52 GeV [PRD **97**, 072005 (2018)]

- Inclusive cross section of hyperons and charmed baryons using a 800 fb^{-1} near $\Upsilon(4S)$.
- Scaled direct production cross section as a function of mass of hyperons and charmed baryons.





- Lie on one common exponential function of mass. Explained by string fragment model
- A factor three suppression of Σ_c is observed:
  - ▶ If charmed baryon production proceeds via diquark-anti-diquark pair production, the mass difference of spin-0 diquark (Λ_c) and spin-1 diquark (Σ_c) can explain this.
  - ▶ Suggesting a diquark structure in the charmed baryon.

Outline

Summary

- Belle and BaBar have achieved fruitful production on charm physics at B-factories, based on an integrated luminosity of $\sim 1.5\ ab^{-1}$ data sets.
- Measure D^0-$\overline{D^0}$ mixing and CP violation in many channels at Belle and BaBar.
  - First measurement of mixing in $D^0 \to \pi^+\pi^-\pi^0$ at BaBar: $x = (1.5 \pm 1.2 \pm 0.6)\%$, $y = (0.2 \pm 0.9 \pm 0.5)\%$
  - CP asymmetries via T-odd moments in $D^0 \to K_S^0\pi^+\pi^-\pi^0$ at Belle: $a_{CP}^{\text{T-odd}} = (-0.28 \pm 1.38^{+0.23}_{-0.76}) \times 10^{-3}$
- Actively working on the charmed baryons at Belle:
  - Search of hidden-strange pentaquark in $\Lambda_c^+ \to \phi p \pi^0$.
  - Observation of $\Xi_c(2930)^0$ in $B^+ \to K^-\Lambda_c^+\bar{\Lambda}_c^-$.
  - Branching fractions of Ω_c hadronic decays; confirm excited $\Omega_c^0 \to \Xi_c^+ K^-$
  - production rate of hyperons and charmed baryons.

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

Back up

Thank you for your attention.

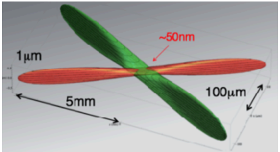
谢谢！

Longke LI (李龙科)
Room A519, 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

SuperKEKB

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

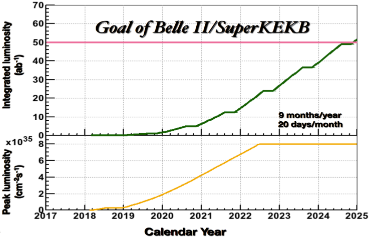
more info, see Mario's report on 10 May



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}
	$\beta\gamma \sim 2/3$	$\times 2$	$\times 20$	$\times 40$

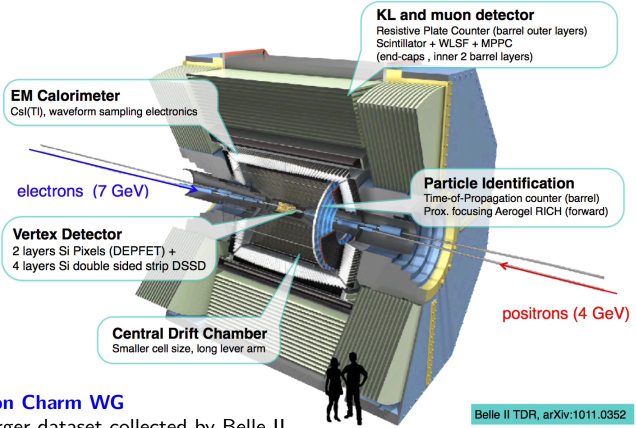
- Target integrated luminosity for Belle II at SuperKEKB: $\int_t \mathcal{L}dt = 50\ \text{ab}^{-1}$



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

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

Belle II Detector



Impacts on Charm WG

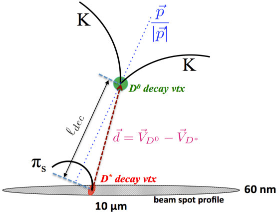
- ☺ 50× larger dataset collected by Belle II
- ☺ Better D^0 proper time resolution (improved IP and secondary vertex resolution)
- ☺ Better reconstruction efficiency with improved tracking efficiency, eg: $D^{*+} \to D^0 \pi_s^+$ etc.
- ☺ Better particle identification capabilities, eg: $D^0 \to K^+\pi^-$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

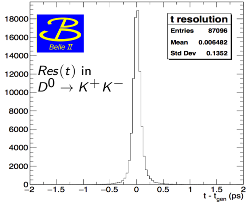
Improved D^0 proper time resolution at Belle II

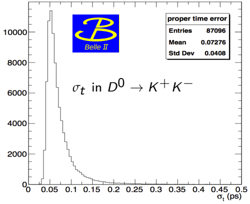
- Time-dependent amplitude of $D^0 \to f$ (here $t[\tau_{D^0}]$ and $\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}$):

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

- 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



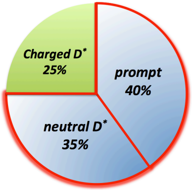




- Based on MC study, time resolution = 140 fs: 2× better than BaBar (270 fs)
- Time error σ_t: factor 3 improvement; and RMS(σ_t): reduced by a factor 2.
  - $Res = Gauss(\mu, k\sigma_t)$, so reduced RMS($\sigma_t$) (higher weight in the fit) results in an increased statistics

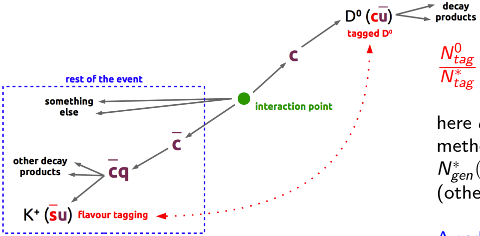
ROE: a new D^0 flavor tagging method

- 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%($\leqslant$ 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.

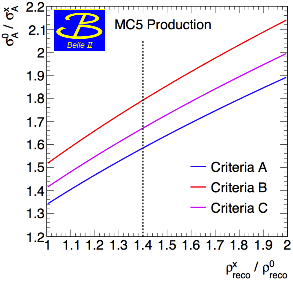
Impacts on measurements of *CP* asymmetries ref. [BELLE2-NOTE-PH-2017-001]

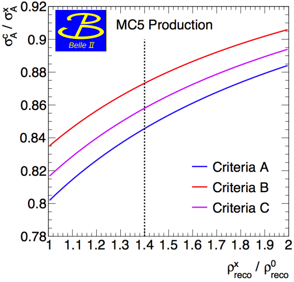
- Ratio $\frac{\sigma_A^0}{\sigma_A^*}$ of A_{CP} statistical sensitivity σ between ROE method and D^* method

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

  - 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 $\rho_{rec}^*/\rho_{rec}^0 = 1.4$





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