Status and prospects of *D* mixing and CPV at BESIII

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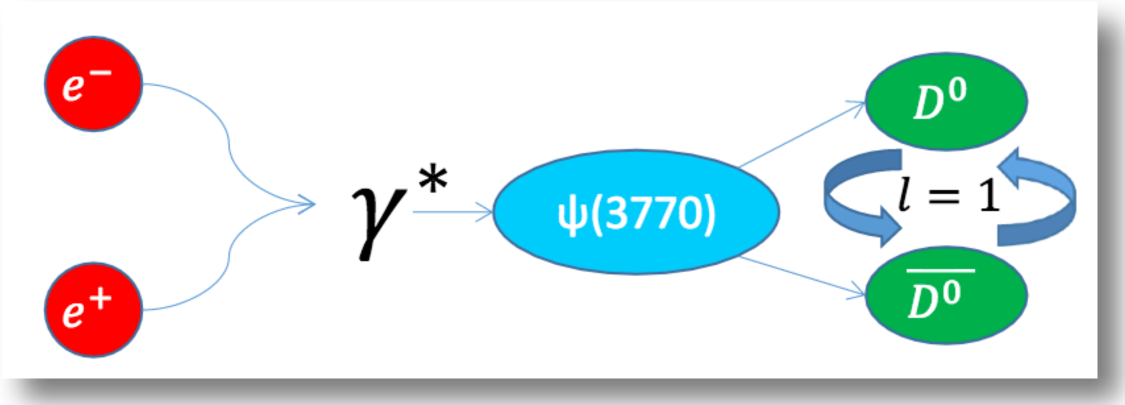
Image: https://en.wikipedia.org/wiki/Bandra-Worli_Sea_Link
Designed by Saurabh Sandilya

Outline

- Introduction and BESIII
- Recent results on D mixing and CPV
- Future plan & physics prospects
- Summary

Quantum correlated (QC) neutral *D* state near threshold

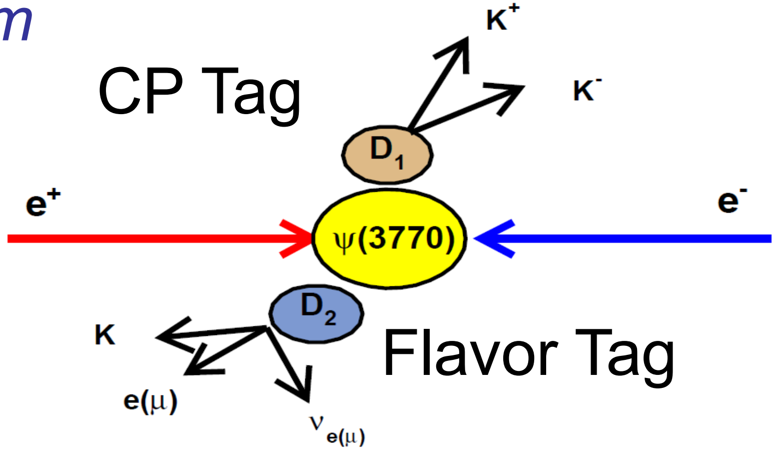


If D^0 in CP eigenstate, $\overline{D^0}$ must be in opposite CP eigenstate

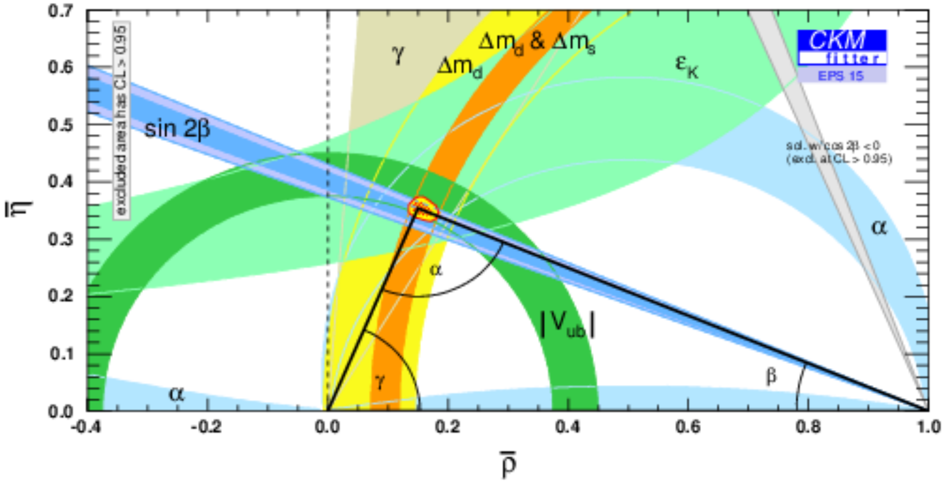
Quantum Correlations (QC) and CP-tagging are unique

Taking advantage the quantum coherence of D$\underline{\text{D}}$ pairs, BESIII can study the charm physics in an unique way

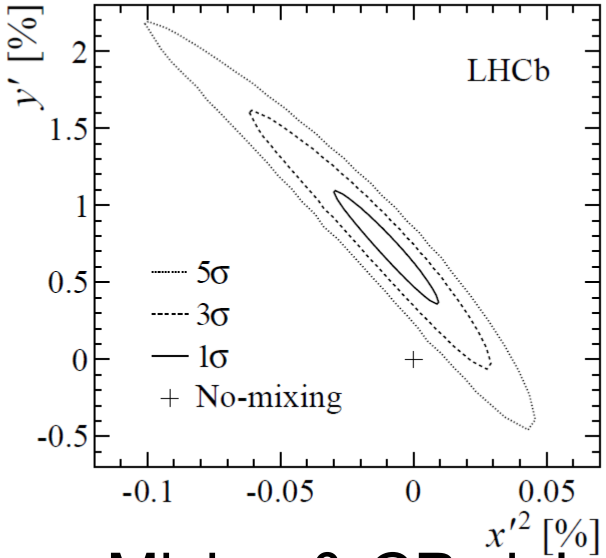
- *strong phase in D decays*
- *D mixing parameters*
- *direct CP violation*
- *…*



QC inputs for Charm Physics



Precision CKM test



Charm Mixing & CP violation

- **inputs from Quantum Correlated (QC) $\psi(3770) \to D\bar{D}$ decays**
  - **(Averaged)Strong phase difference: δ_D**
  - **Coherent factors: R_D**
  - **(Averaged)Strong phase in Dalitz bins: c_i, s_i**
- ***B* factories, LHCb, Super *B* factories are the customers**

δ and γ/ϕ₃ input

- *D* hadronic parameters for a final state

$$f: \ \frac{A(\bar{D}^0 \to f)}{A(D^0 \to f)} \equiv -r_D e^{-i\delta_D}$$

- Charm mixing parameters: $x = \frac{\Delta M}{\Gamma}$, $y = \frac{\Delta\Gamma}{2\Gamma}$
  - Time-dependent WS $D^0 \to K^+\pi^-$ rate ⇒

    $y' = y\cos\delta_{K\pi} - x\sin\delta_{K\pi}$ (LHCb)
  - $\delta_{K\pi}$: QC measurements from Charm factory
- γ/ϕ_3 measurements from $B \to D^0 K$
  - $b \to u$: $\gamma/\phi_3 = \arg V^*_{ub}$
    - most sensitive method to constrain γ/ϕ_3 at present
  - GLW, ADS method
    - r_D, δ_D : QC measurements from Charm factory
  - GGSZ method
    - c_i, s_i : QC measurements from Charm factory

Time-integrated decay rates

- **No time dependent information at Charm threshold**
- **Anti-symmetric wavefuction:**
  $\Gamma^2_{ij} = \left|\langle i|D^0\rangle\langle j|\bar{D}^0\rangle - \langle j|D^0\rangle\langle i|\bar{D}^0\rangle\right|^2$
- **Double tag rates:**
  $A_i^2 A_j^2\left[1 + r_i^2 r_j^2 - 2 r_i r_j \cos(\delta_i+\delta_j)\right]$
  - **CP tag: r=1, δ=0 or π; $l^{\pm}$ tag: r=0**
- **Single and Double tag rates**
  - $z_f \equiv 2\cos\delta_f, r_f \equiv \frac{A_{DCS}}{A_{CF}}, R_M \approx \frac{x^2+y^2}{2}$

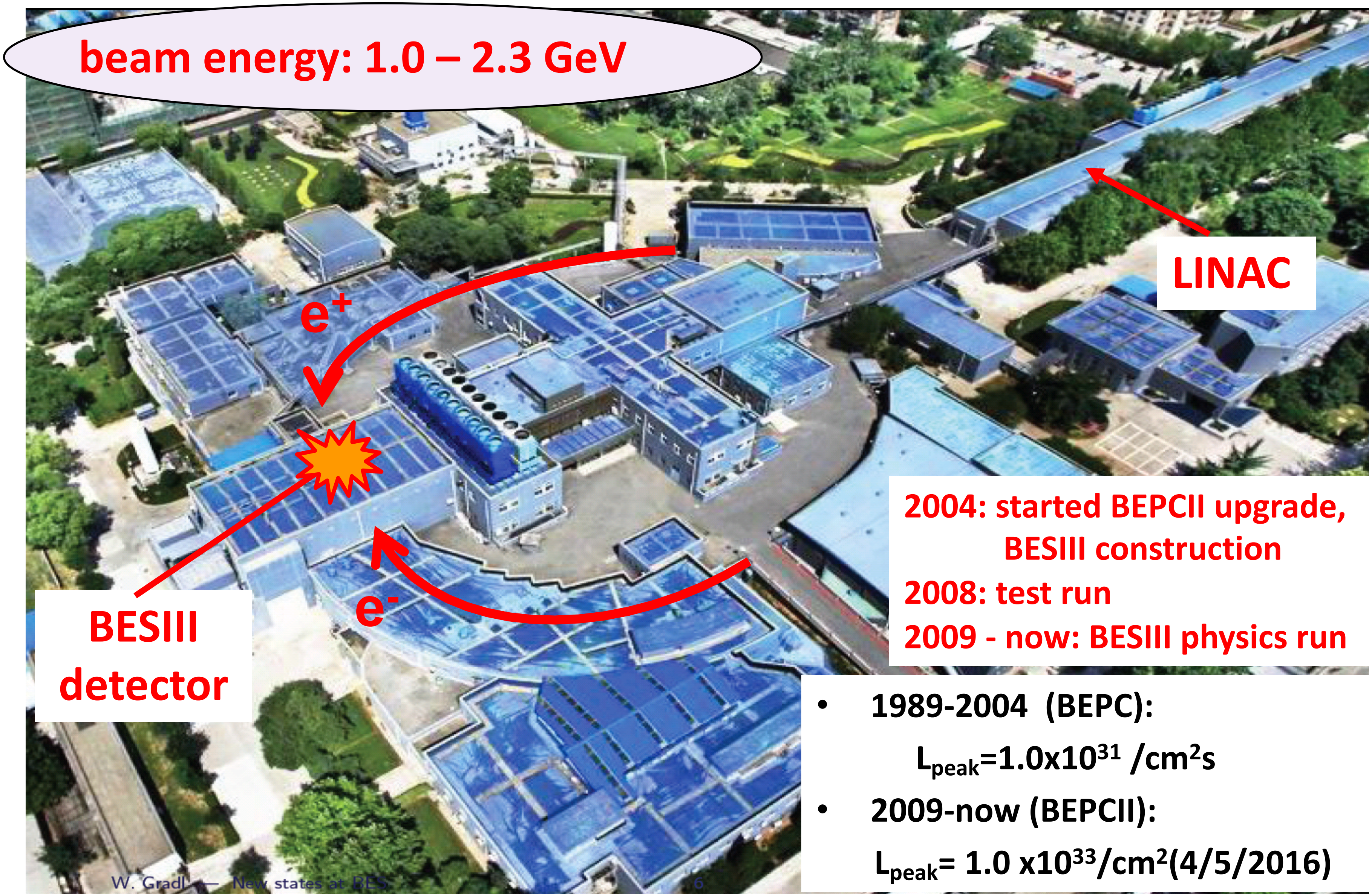
$$\psi(3770) \to [D^0\bar{D}^0 - \bar{D}^0 D^0]/\sqrt{2}$$

$$= -[D_{CP+}D_{CP-} - D_{CP-}D_{CP+}]/\sqrt{2}$$

$$D_{CP\pm} = [D^0 \pm \bar{D}^0]/\sqrt{2}$$

C-odd	***f***	$\bar{f}$	l^+	l^-	***CP+***	***CP-***
f	$R_M[1 + r_f^2(2 - z_f^2) + r_f^4]$					
$\bar{f}$	$1 + r_f^2(2 - z_f^2) + r_f^4$	$R_M[1 + r_f^2(2 - z_f^2) + r_f^4]$				
l^+	r_f^2	1	R_M			
l^-	1	r_f^2	1	R_M		
$CP+$	$1 + r_f(r_f + z_f)$	$1 + r_f(r_f + z_f)$	1	1	0	
$CP-$	$1 + r_f(r_f - z_f)$	$1 + r_f(r_f - z_f)$	1	1	4	0
Single Tag	$1 + r_f^2 - r_f z_f(A - y)$		1		$2[1 \pm (A - y)]$	

Beijing Electron Positron Collider (BEPC)



beam energy: 1.0 – 2.3 GeV

LINAC

BESIII detector

2004: started BEPCII upgrade, BESIII construction

2008: test run

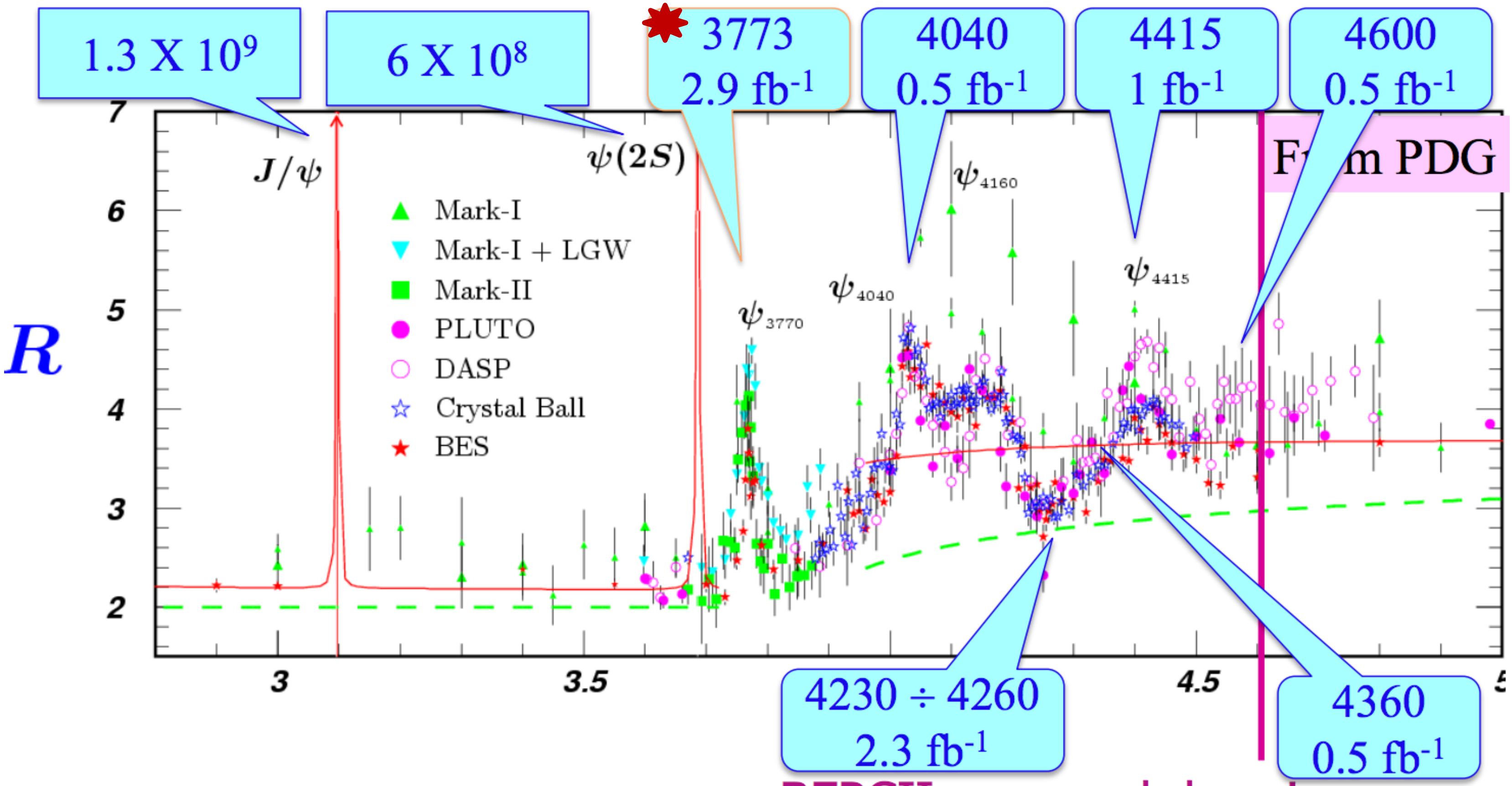
2009 - now: BESIII physics run

- 1989-2004 (BEPC):

  L_{peak}=1.0x10^{31} /cm^{2}s
- 2009-now (BEPCII):

  L_{peak}= 1.0 x10^{33}/cm^2(4/5/2016)

BESIII data samples



1.3×10^9

6×10^8

3773 $2.9\ fb^{-1}$

4040 $0.5\ fb^{-1}$

4415 $1\ fb^{-1}$

4600 $0.5\ fb^{-1}$

4230 ÷ 4260 $2.3\ fb^{-1}$

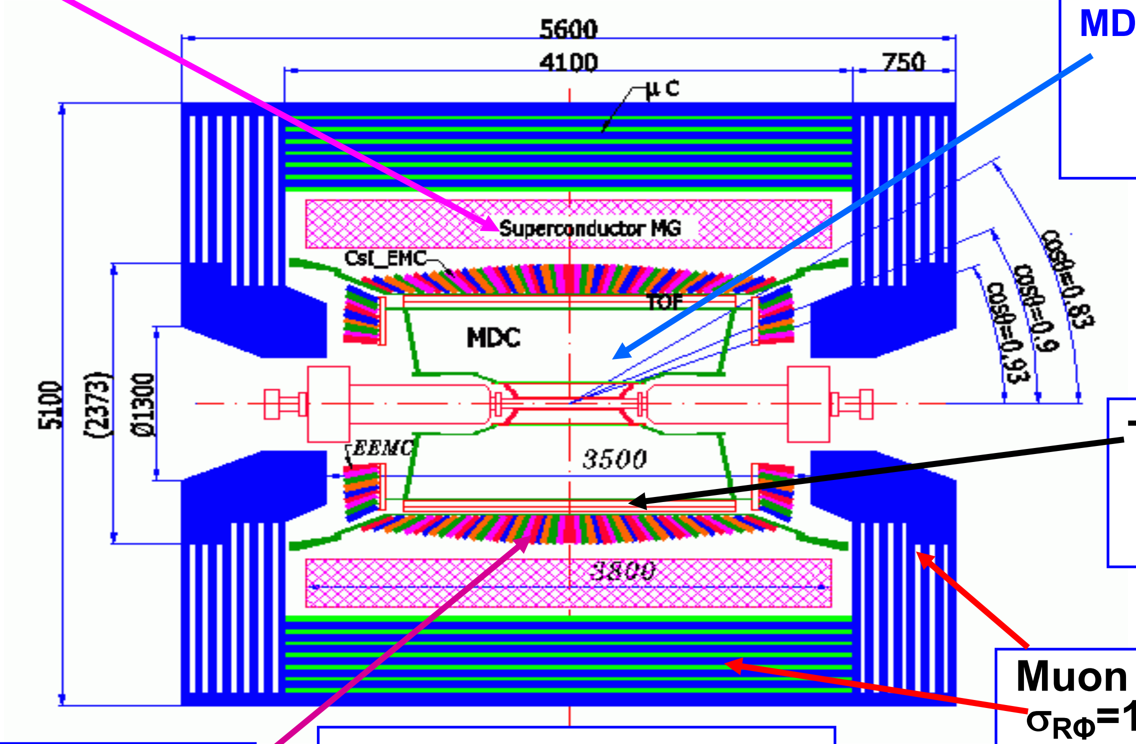
4360 $0.5\ fb^{-1}$

BEPCII can reach here!

- 4100~4400 MeV: 0.5/fb coarse scan
- 3850~4590 MeV: 0.5/fb fine scan
- In 2015, we finished energy scan at 2000~3000 MeV
- In 2016, we took 3/fb Ds data about 4180 MeV for Ds physics (*about 5 times of CLEO-c data*)

The BESIII Detector

NIM A614, 345 (2010)



Magnet: 1 T Super conducting

MDC: small cell & He gas
σ_{xy}=130 μm
δ_p/p = 0.5% @1GeV
dE/dx=6%

TOF:
σ_T = 90 ps Barrel
110 ps Endcap

Muon ID: 8~9 layer RPC
$\sigma_{R\Phi}$=1.4 cm~1.7 cm

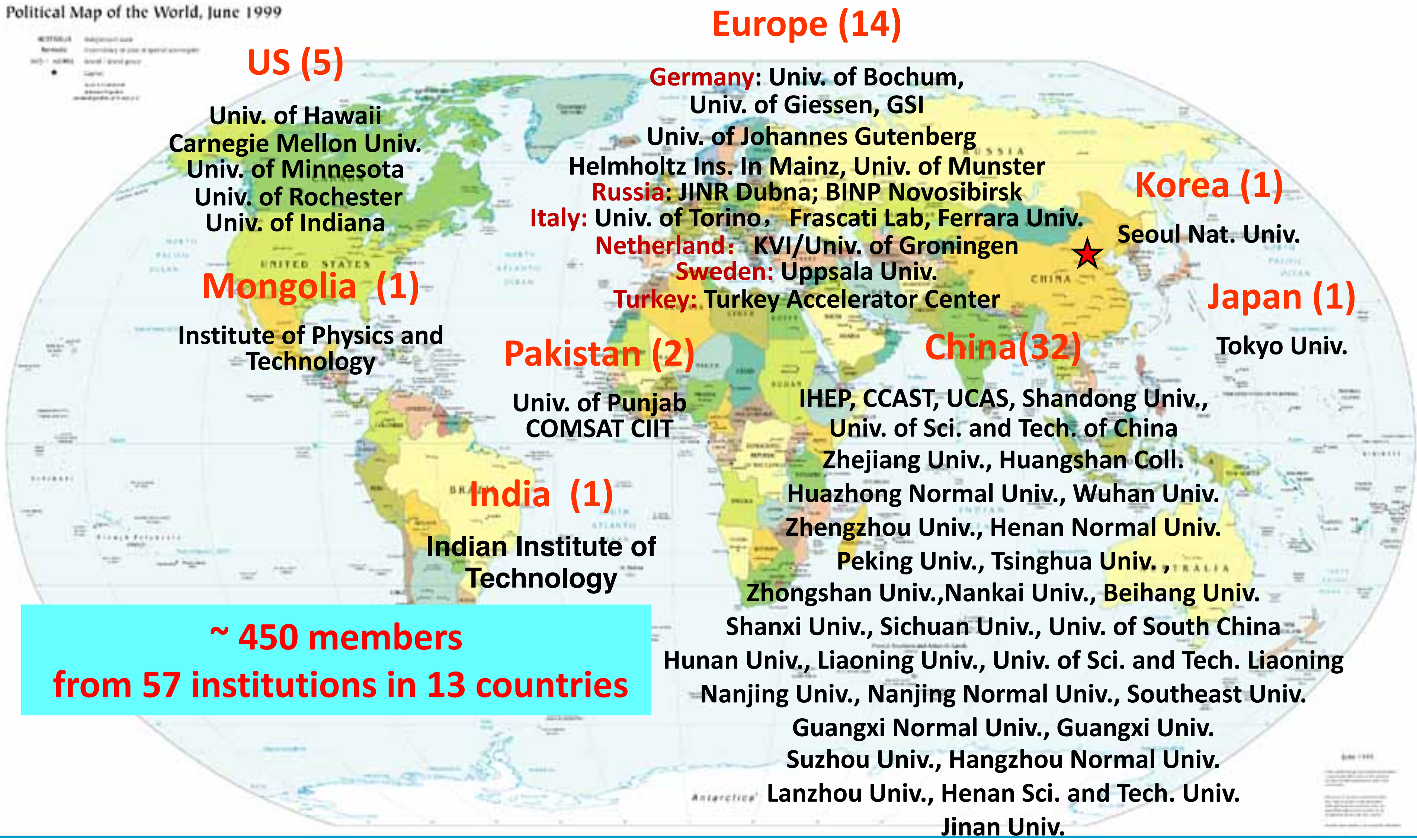
EMCAL: CsI crystal
$\Delta E/E$ = 2.5% @1 GeV
$\sigma_{\varphi,z}$ = 0.5~0.7 cm/$\sqrt{E}$

Data Acquisition:
Event rate = 3 kHz
Throughput ~ 50 MB/s

Trigger: Tracks & Showers
Pipelined; Latency = 6.4 μs

The new BESIII detector is hermetic for neutral and charged particle with excellent resolution, PID, and large coverage.

BESIII Collaboration



US (5)

Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Europe (14)

Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz, Univ. of Munster
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino， Frascati Lab, Ferrara Univ.
Netherland: KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Mongolia (1)

Institute of Physics and Technology

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

India (1)

Indian Institute of Technology

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Nanjing Univ., Nanjing Normal Univ., Southeast Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Jinan Univ.

~ 450 members
from 57 institutions in 13 countries

Charm facilities

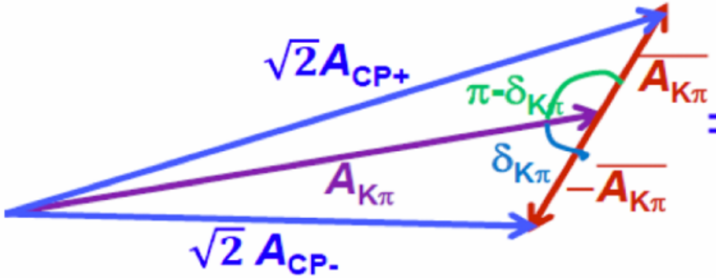
- Hadron colliders (huge cross-section, energy boost)
  - Tevetron (CDF, D0)
  - LHC (**LHCb**, CMS, ATLAS)
- e^+e^- Colliders (more kinematic constrains, clean environment, ~100% trigger efficiency)
  - B-factories (Belle(-II), BaBar)
  - Threshold production (CLEOc, BESIII)
    - Can not compete in statistics with Hadron colliders & B-factories!!!
    - Quantum Correlations (QC) and CP-tagging are unique
    - Only D meson pairs, no extra CM Energy for pions
    - Systematic uncertainties cancellations while applying double tag technique

Strong Phase $\delta_{K\pi}$

2.93 fb^{-1} @3.773GeV

Quantum correlation → Interference → access strong phase!

$$\langle K\pi|D_{CP\pm}\rangle = (\langle K\pi|D^0\rangle \pm \langle K\pi|\overline{D^0}\rangle)/\sqrt{2} \Rightarrow \sqrt{2}A_{CP\pm} = A_{K\pi} \pm \overline{A_{K\pi}}$$

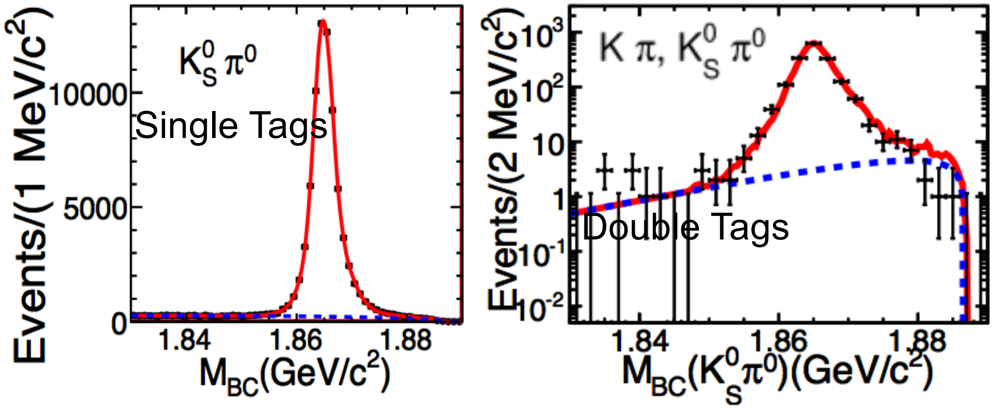


$$\Rightarrow 2r_{K\pi}\cdot\cos\delta_{K\pi} \approx A_{CP\to K\pi} \equiv \frac{|A_{CP-}|^2-|A_{CP+}|^2}{|A_{CP-}|^2+|A_{CP+}|^2}$$

$$= \frac{Br(D_{CP-}\to K\pi)-Br(D_{CP+}\to K\pi)}{Br(D_{CP-}\to K\pi)+Br(D_{CP+}\to K\pi)}$$

Strong phase: $\frac{\langle K^-\pi^+|\overline{D^0}\rangle^{DCS}}{\langle K^-\pi^+|D^0\rangle^{CF}} \equiv -r_{K\pi}e^{-i\delta_{K\pi}}$

- **Flavor tags:** $K^-\pi^+$, $K^+\pi^-$
- **CP+ tags (5 modes):** K^-K^+, $\pi^+\pi^-$, $K^0_S\pi^0\pi^0$, $\pi^0\pi^0$, $\rho^0\pi^0$
- **CP- tags (3 modes):** $K^0_S\pi^0$, $K^0_S\eta$, $K^0_S\omega$



PLB 734, 227 (2014)

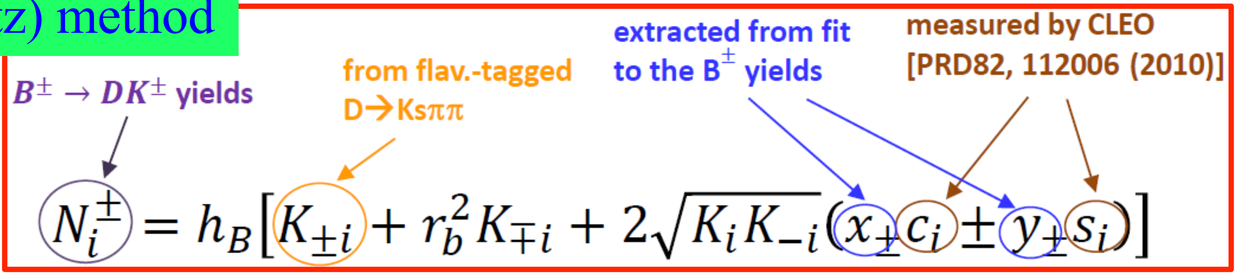
BESIII results:

$$\cos\delta_{K\pi} = 1.02 \pm 0.11 \pm 0.06 \pm 0.01$$

- **The third error is due to the input parameters**
- **World best precision**
- **In 10 /fb BESIII data, precision of cos$\delta_{K\pi}$ will reach ~0.07**

(c_i, s_i) in $D^0 \to K_{S,L}\pi^+\pi^-$ Dalitz analysis

GGSZ (Dalitz) method



$B^\pm \to DK^\pm$ yields

from flav.-tagged D→$K_S\pi\pi$

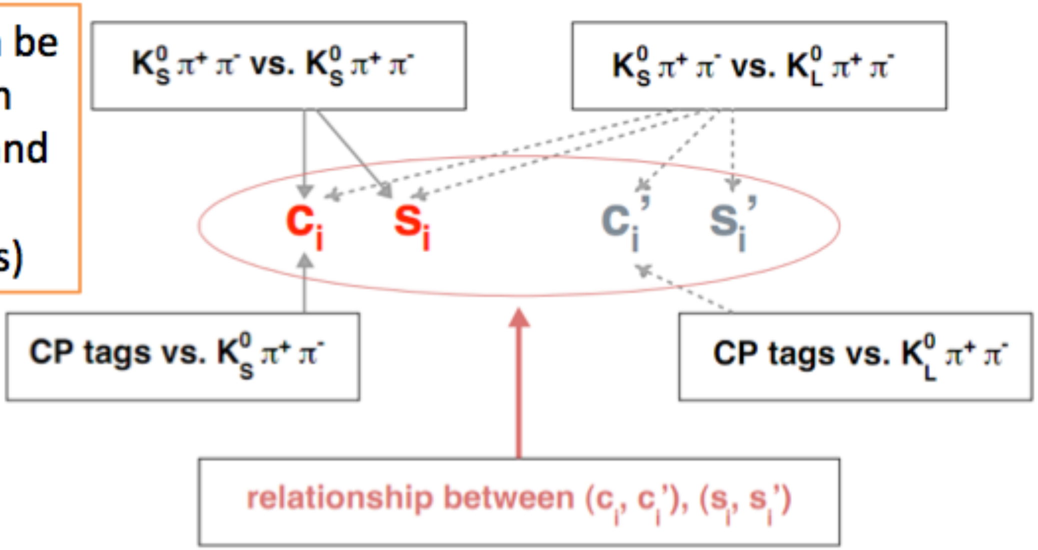
extracted from fit to the $B^\pm$ yields

measured by CLEO [PRD82, 112006 (2010)]

$$N_i^{\pm} = h_B\left[K_{\pm i} + r_b^2 K_{\mp i} + 2\sqrt{K_i K_{-i}}\left(x_\pm c_i \pm y_\pm s_i\right)\right]$$

We can calculate c_i and s_i from double tags of $D^0 \to K_S\pi^+\pi^-$ vs $D^0 \to (K_{S,L}\pi^+\pi^-$ or CP eigenstates)

A relationship can be shown between Dalitz bin yields and c_i and s_i (in backup slides)



$K^0_S\pi^+\pi^-$ vs. $K^0_S\pi^+\pi^-$

$K^0_S\pi^+\pi^-$ vs. $K^0_L\pi^+\pi^-$

c_i s_i c_i' s_i'

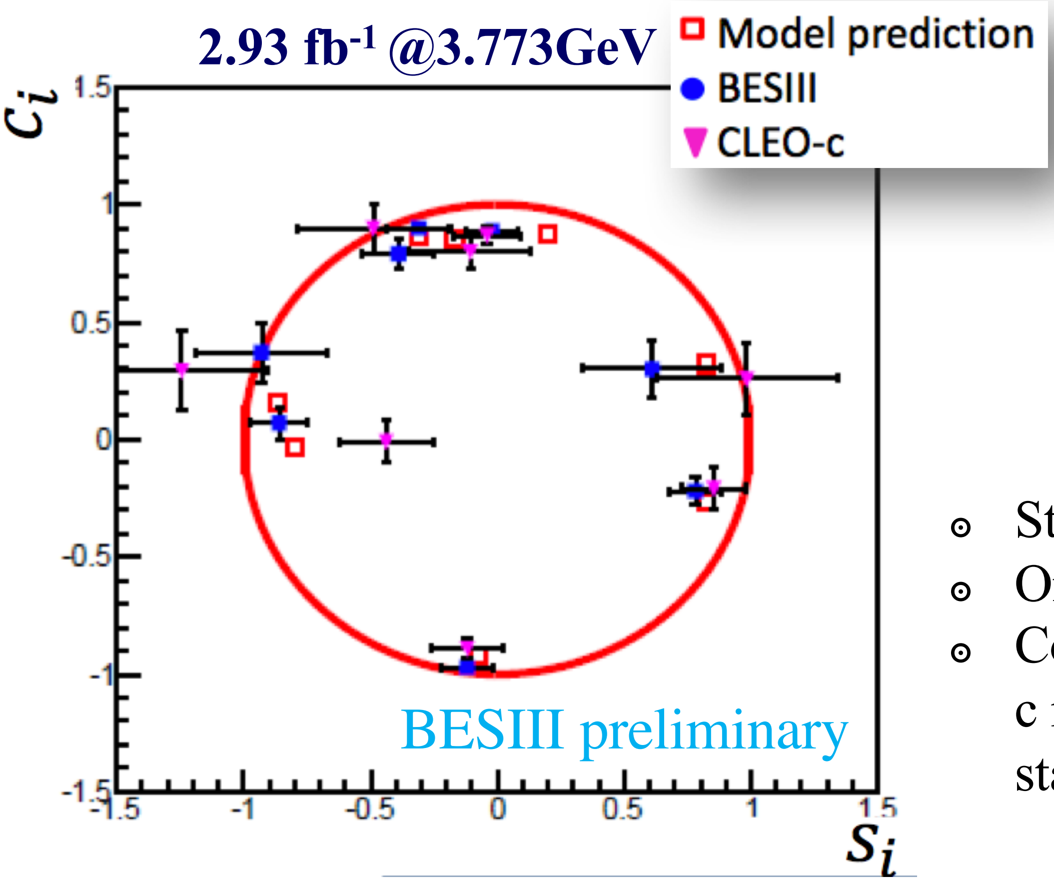
CP tags vs. $K^0_S\pi^+\pi^-$

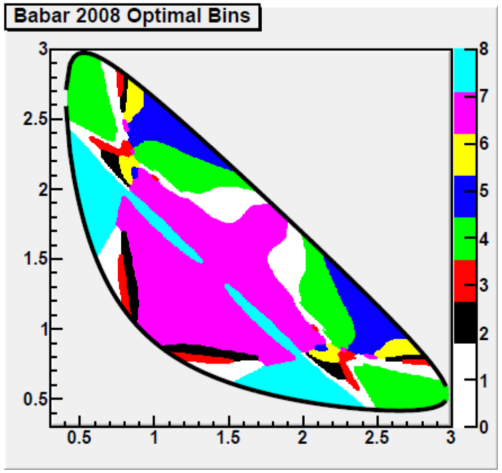
CP tags vs. $K^0_L\pi^+\pi^-$

relationship between (c_i, c_i'), (s_i, s_i')

Only c_i, s_i from $K_S\pi^+\pi^-$ is used to calculate γ.
However adding in $D^0 \to K_L\pi^+\pi^-$ we can calculate c'_i, s'_i and use how they relate to c_i, s_i to further constrain our results in a Global fit.

Preliminary Data Results





- Still statistical limited.
- Only statistical errors for BESIII
- Consistent agreement with CLEO-c measurements, but superior in statistical errors

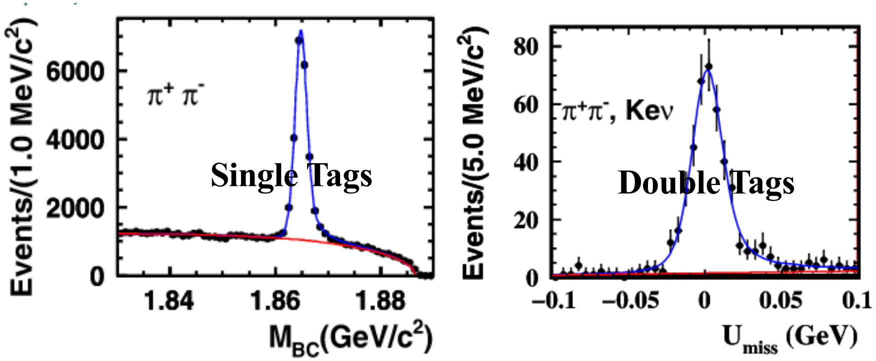
- Based on the BESIII results, we expect a reduction in the (c_i, s_i) contribution to the uncertainty in γ/ϕ_3 of ~40%.
- Crucial inputs for the future analysis carried out in the LHCb and BelleII experiment.

y_{CP} measurement

$2.93\ \mathrm{fb}^{-1}$ @3.773GeV

We measure the y_{CP} using CP-tagged semi-leptonic D decays, which allows to access CP asymmetry in mixing and decays.

- **Reconstructed modes:**
  - **Flavor tags: $Ke\nu_e$, $K\mu\nu_\mu$**
  - **CP+ tags (3 modes): K^-K^+, $\pi^+\pi^-$, $K^0_S\pi^0\pi^0$,**
  - **CP- tags (3 modes): $K^0_S\pi^0$, $K^0_S\eta$, $K^0_S\omega$**

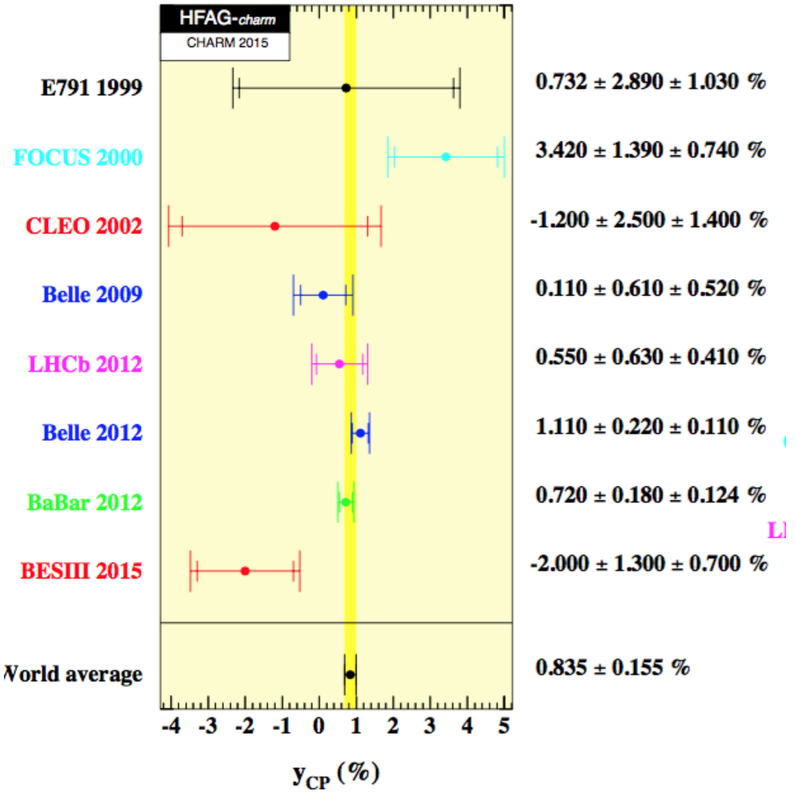


PLB 744, 339 (2015)

BESIII result:

$$y_{CP} = (-2.0 \pm 1.3 \pm 0.7)\%$$

$$y_{CP} \approx \frac{1}{4}\left(\frac{\Gamma_{l;CP+}\Gamma_{CP-}}{\Gamma_{l;CP-}\Gamma_{CP+}} - \frac{\Gamma_{l;CP-}\Gamma_{CP+}}{\Gamma_{l;CP+}\Gamma_{CP-}}\right)$$



- **Most precise measurement with QC charm mesons**
- **In the limit of no CP violation: $y_{CP} = y$**

$$\mathcal{R}(D \to K^0_{S,L}\pi^0(\pi^0)) = \frac{\mathcal{B}(D \to K^0_S\pi^0(\pi^0)) - \mathcal{B}(D \to K^0_L\pi^0(\pi^0))}{\mathcal{B}(D \to K^0_S\pi^0(\pi^0)) + \mathcal{B}(D \to K^0_L\pi^0(\pi^0))}$$

- **interference of the CF component D → $K^0\pi$'s with the DCS D → $\underline{K}^0\pi$'s component. $|K^0_L\rangle \approx 1/\sqrt{2}\,(|K^0\rangle - |\underline{K}^0\rangle)$ and $|K^0_S\rangle \approx 1/\sqrt{2}\,(|K^0\rangle + |\underline{K}^0\rangle)$. The sign of this interference of K^0 with $\underline{K}^0$ is opposite for K^0_L and K^0_S,**

Single tag:
- ✓ CP+: KK, $\pi\pi$;
- ✓ CP-: $K_S\pi^0$;
- ✓ Cabibbo Favored (CF): $K\pi$, $K\pi\pi\pi$, $K\pi\pi^0$;

Double tag:
- ✓ CP+ (KK, $\pi\pi$, $K_L\pi^0$, $K_S\pi^0\pi^0$) VS CF ($K\pi$, $K\pi\pi\pi$, $K\pi\pi^0$);
- ✓ CP- ($K_S\pi^0$, $K_L\pi^0\pi^0$) VS CF ($K\pi$, $K\pi\pi\pi$, $K\pi\pi^0$);

$$\begin{aligned} N_{\mathrm{ST}(CF)} =& (1+r^2)\cdot 2N_{D^0\bar{D}^0}\cdot \mathcal{B}_{CF}\cdot \epsilon_{\mathrm{ST}(CF)} \\ N_{\mathrm{ST}(CP\pm)} =& 2N_{D^0\bar{D}^0}\cdot \mathcal{B}_{CP\pm}\cdot \epsilon_{\mathrm{ST}(CP\pm)} \\ N_{\mathrm{DT}(CF,CP\pm)} =& (1+r^2 \mp 2r\cos\delta)\cdot 2N_{D^0\bar{D}^0} \\ & \cdot \mathcal{B}_{CF}\cdot \mathcal{B}_{CP\pm}\cdot \epsilon_{\mathrm{DT}(CF,CP\pm)}, \end{aligned}$$

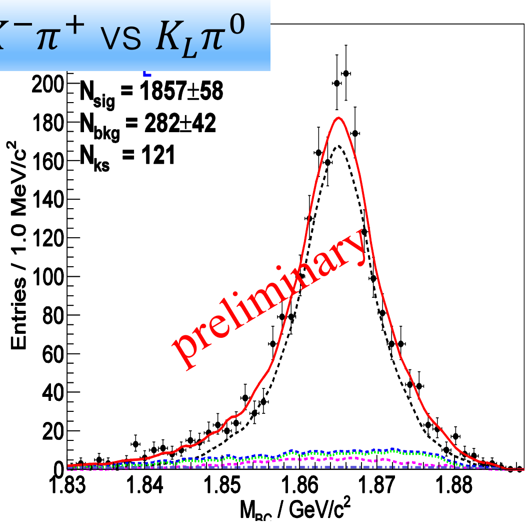
$$C_f = \frac{\frac{N_{CP-,CF}/\epsilon_{CP-,CF}}{N_{CP-}/\epsilon_{CP-}} - \frac{N_{CP+,CF}/\epsilon_{CP+,CF}}{N_{CP+}/\epsilon_{CP+}}}{\frac{N_{CP-,CF}/\epsilon_{CP-,CF}}{N_{CP-}/\epsilon_{CP-}} + \frac{N_{CP+,CF}/\epsilon_{CP+,CF}}{N_{CP+}/\epsilon_{CP+}}}$$

We can have

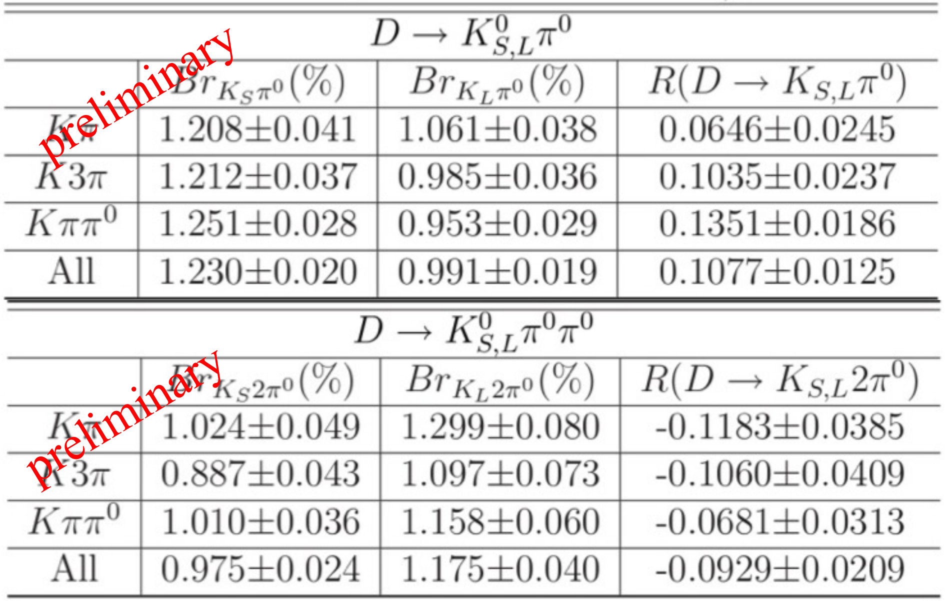
$$\mathcal{B}_{\mathrm{sig}(CP\pm)} = \frac{1}{1 \mp C_f}\,\frac{N_{CF,CP\pm}/\epsilon}{N_{CF}}, \quad \left(C_f \equiv \frac{2r\cos\delta}{1+r^2}\right)$$

K_L reconstruction and DT yields

- K_L interact with EMC and deposit part of energy, thus giving position information.
- After reconstructing all other particles, K_L can be inferred from its position information and the constraint ΔE = 0.



Statistical only



$D \to K^0_{S,L}\pi^0$			
	$Br_{K_S\pi^0}(\%)$	$Br_{K_L\pi^0}(\%)$	$R(D \to K_{S,L}\pi^0)$
$K\pi$	1.208±0.041	1.061±0.038	0.0646±0.0245
$K3\pi$	1.212±0.037	0.985±0.036	0.1035±0.0237
$K\pi\pi^0$	1.251±0.028	0.953±0.029	0.1351±0.0186
All	1.230±0.020	0.991±0.019	0.1077±0.0125

$D \to K^0_{S,L}\pi^0\pi^0$			
	$Br_{K_S2\pi^0}(\%)$	$Br_{K_L2\pi^0}(\%)$	$R(D \to K_{S,L}2\pi^0)$
$K\pi$	1.024±0.049	1.299±0.080	-0.1183±0.0385
$K3\pi$	0.887±0.043	1.097±0.073	-0.1060±0.0409
$K\pi\pi^0$	1.010±0.036	1.158±0.060	-0.0681±0.0313
All	0.975±0.024	1.175±0.040	-0.0929±0.0209

CLEO: $R(K_{S,L}\pi^0) = (10.8 \pm 2.5 \pm 2.4)\%$

- Consistent with PDG values
- $K_{S,L}\pi^0$ agrees with U-spin symmetry
- $K_L 2\pi^0$ is the first measurement

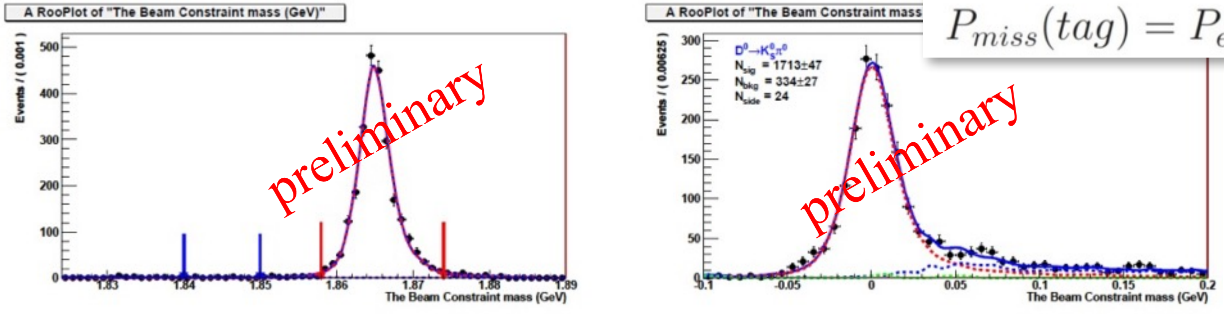
first measurement

$Ke\nu$ vs CP± ($K_S^0\pi^0$, $K_L^0\pi^0$) and y_{CP}

Single-tag yields can be got from $K_S\pi^0$, $K_L\pi^0$ branching fraction measurement results. Double-Tag yields are from U_{miss} fit.

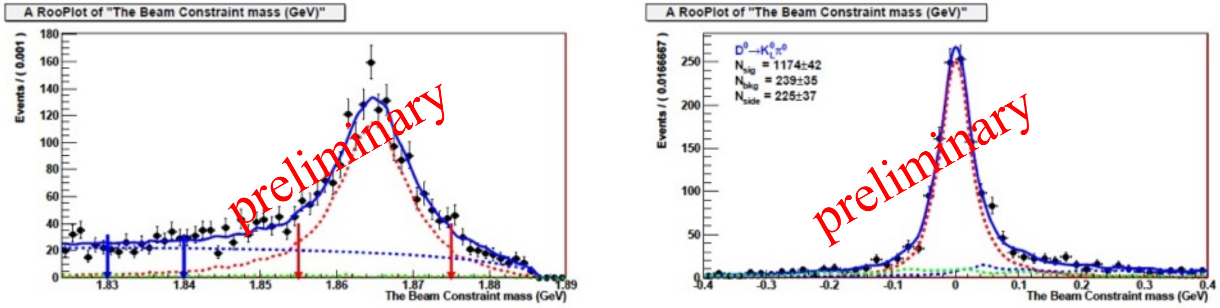
$$U_{miss}(tag) = E_{miss}(tag) - p_{miss}(tag)$$

$$P_{miss}(tag) = P_{e^+e^-} - P_{signal} - P_{tagtrack},$$



(a) $K_S^0\pi^0$ VS $Ke\nu$ tag-side

(b) $K_S^0\pi^0$ VS $Ke\nu$ signal-side



(c) $K_L^0\pi^0$ VS $Ke\nu$ tag-side

(d) $K_L^0\pi^0$ VS $Ke\nu$ signal-side

This work gives: y_{CP} = (0.980 ± 2.429)% (preliminary) *Statistical only*

Consistent with the published BESIII result: $y_{CP} = (-2.0 \pm 1.3 \pm 0.7)\%$

CPV in charm factory

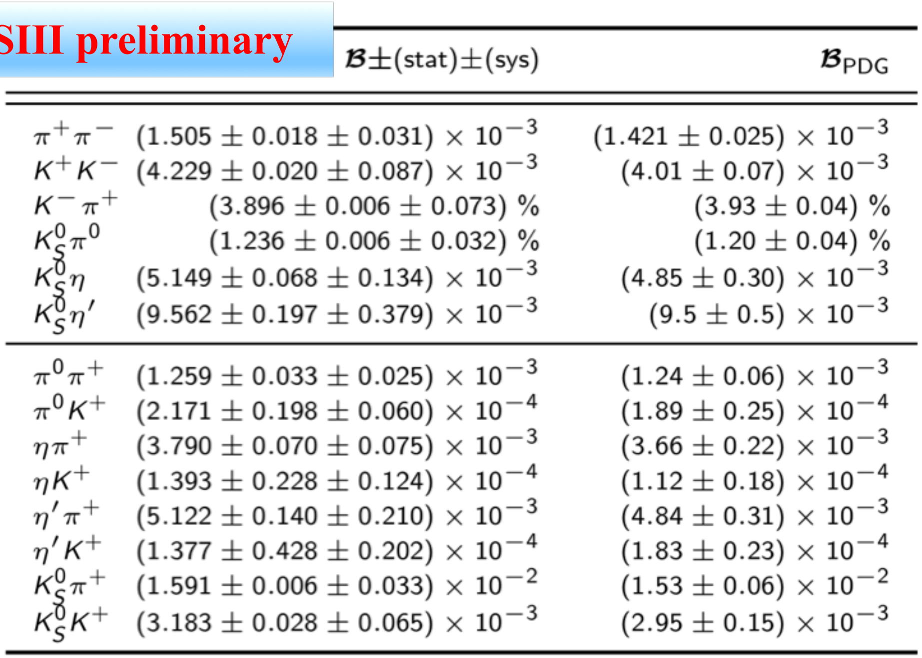
CP asymmetry: $A_{CP}(f) = \dfrac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})}$

- ★ CPV in charm:
  - ✤ SM: <= a few %
  - ✤ NP: >~ 1%
- ★ World precision: ~ 0.1%
- ★ CLEO-c measured Acp based on single tag events PRD89, 072002 (2014)
  - ✤ at the order 1% for all modes
  - ✤ no evidence of CPV
  - ✤ systematics dominant

In future charm factory, it is important to reduce the systematic uncertainty by using a large *D* threshold sample

Data: 2.93 fb^{-1} taken at 3.773 GeV;
Decays of interests:
$D^0 \to \pi^+\pi^-, K^+K^-, K^-\pi^+,$
$K_S^0\pi^0, K_S^0\eta, K_S^0\eta'$
$D^+ \to \pi^0\pi^+, \pi^0K^+, \eta\pi^+, \eta K^+,$
$\eta'\pi^+, \eta'K^+, K_S^0\pi^+, K_S^0K^+$

BESIII preliminary



	$\mathcal{B}\pm$(stat)$\pm$(sys)	$\mathcal{B}_{\rm PDG}$
$\pi^+\pi^-$	$(1.505 \pm 0.018 \pm 0.031) \times 10^{-3}$	$(1.421 \pm 0.025) \times 10^{-3}$
K^+K^-	$(4.229 \pm 0.020 \pm 0.087) \times 10^{-3}$	$(4.01 \pm 0.07) \times 10^{-3}$
$K^-\pi^+$	$(3.896 \pm 0.006 \pm 0.073)$ %	(3.93 ± 0.04) %
$K_S^0\pi^0$	$(1.236 \pm 0.006 \pm 0.032)$ %	(1.20 ± 0.04) %
$K_S^0\eta$	$(5.149 \pm 0.068 \pm 0.134) \times 10^{-3}$	$(4.85 \pm 0.30) \times 10^{-3}$
$K_S^0\eta'$	$(9.562 \pm 0.197 \pm 0.379) \times 10^{-3}$	$(9.5 \pm 0.5) \times 10^{-3}$
$\pi^0\pi^+$	$(1.259 \pm 0.033 \pm 0.025) \times 10^{-3}$	$(1.24 \pm 0.06) \times 10^{-3}$
π^0K^+	$(2.171 \pm 0.198 \pm 0.060) \times 10^{-4}$	$(1.89 \pm 0.25) \times 10^{-4}$
$\eta\pi^+$	$(3.790 \pm 0.070 \pm 0.075) \times 10^{-3}$	$(3.66 \pm 0.22) \times 10^{-3}$
ηK^+	$(1.393 \pm 0.228 \pm 0.124) \times 10^{-4}$	$(1.12 \pm 0.18) \times 10^{-4}$
$\eta'\pi^+$	$(5.122 \pm 0.140 \pm 0.210) \times 10^{-3}$	$(4.84 \pm 0.31) \times 10^{-3}$
$\eta'K^+$	$(1.377 \pm 0.428 \pm 0.202) \times 10^{-4}$	$(1.83 \pm 0.23) \times 10^{-4}$
$K_S^0\pi^+$	$(1.591 \pm 0.006 \pm 0.033) \times 10^{-2}$	$(1.53 \pm 0.06) \times 10^{-2}$
$K_S^0K^+$	$(3.183 \pm 0.028 \pm 0.065) \times 10^{-3}$	$(2.95 \pm 0.15) \times 10^{-3}$

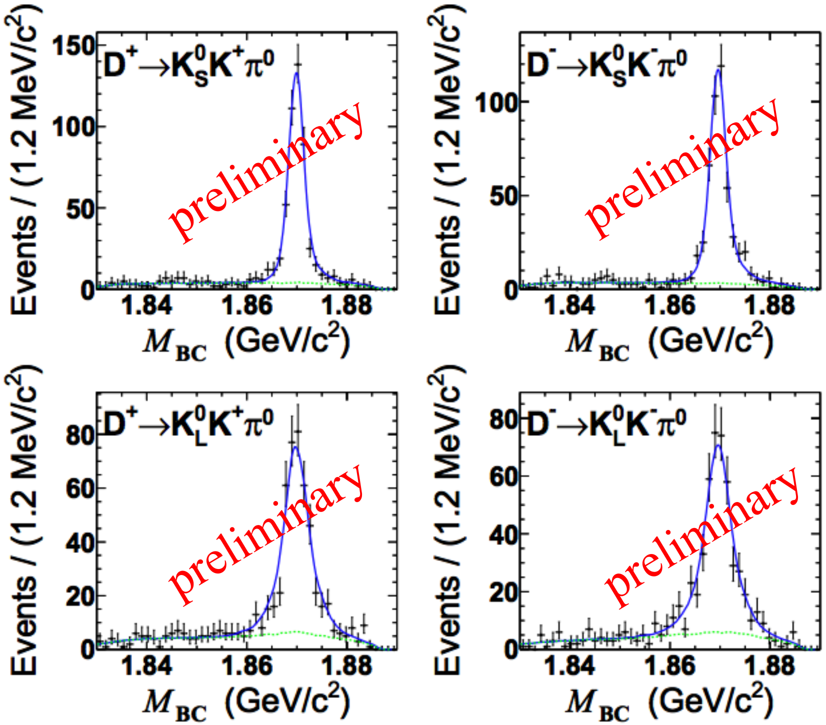
- BESIII has good potential to explore CPV
- Many channels have best precisions

BFs and CPV in SCS decays

$D^+ \rightarrow K_S K^+$, $K_s K^+ \pi^0$, $K_L K^+$ and $K_L K^+ \pi^0$

- The singly Cabibbo-suppressed (SCS) decay mode $D^+ \rightarrow K^0 K^+$ is useful for the estimation of SU(3) violating effects in the *D* meson system.
- Direct CP violation in SCS D^+ decays could arise from the interference between tree-level and penguin decay processes.

  - 6 CF ST modes v.s. DT signal modes; KL is inferred by EMC shower and the constraint $\Delta E = 0$
  - Two dimensional fits to M_{BC}(tag) versus M_{BC}(signal)



BESIII preliminary

Mode	$\overline{\mathcal{B}}$ $(\times 10^{-3})$	$\mathcal{A}_{CP}$ (%)
$K_S^0 K^\pm$	$3.06 \pm 0.09 \pm 0.10$	$-1.5 \pm 2.8 \pm 1.6$
$K_S^0 K^\pm \pi^0$	$5.16 \pm 0.21 \pm 0.23$	$1.4 \pm 4.0 \pm 2.4$
$K_L^0 K^\pm$	$3.23 \pm 0.11 \pm 0.13$	$-3.0 \pm 3.2 \pm 1.2$
$K_L^0 K^\pm \pi^0$	$5.22 \pm 0.22 \pm 0.21$	$-0.9 \pm 4.1 \pm 1.6$

- $B(D^+ \rightarrow K_s K^+)$ agrees with the CLEO's
- BFs of $D^+ \rightarrow K_s K^+ \pi^0$, $K_L K^+$ and $K_L K^+ \pi^0$ are measured for the first time
- No evidence for CPV

Prospects of data taking at BESIII

- **BESIII collected world's largest samples of J/ψ, $\psi(2S)$, $\psi(3770)$, $Y(4260)$, … from e^+e^- production.**
- **It will continue to run a few years.**

	BESIII	**Goal**
J/ψ	$1.3*10^9$ 21x BESII	$10*10^9$
ψ'	$0.6*10^9$ 24x CLEO-c	$3*10^9$
$\psi(3770)$	2.93 fb^{-1} 21x CLEO-c	15~20 fb^{-1}
Above open charm threshold	0.5 fb^{-1}@$\psi(4040)$, 1.9 fb^{-1} @~4260, 0.5 fb^{-1}@4360, 1.0 fb^{-1} @4420, 0.5 fb^{-1} @4600, **scan data @4.19~4.30GeV in 2017.**	>15 fb^{-1}
R scan and tau	3.8-4.6 GeV at 105 energy points 2.0-3.1 GeV at 20 energy points	
Y(2175)	100 pb^{-1} (2015)	
ψ(4170)	3 fb^{-1} (2016)	

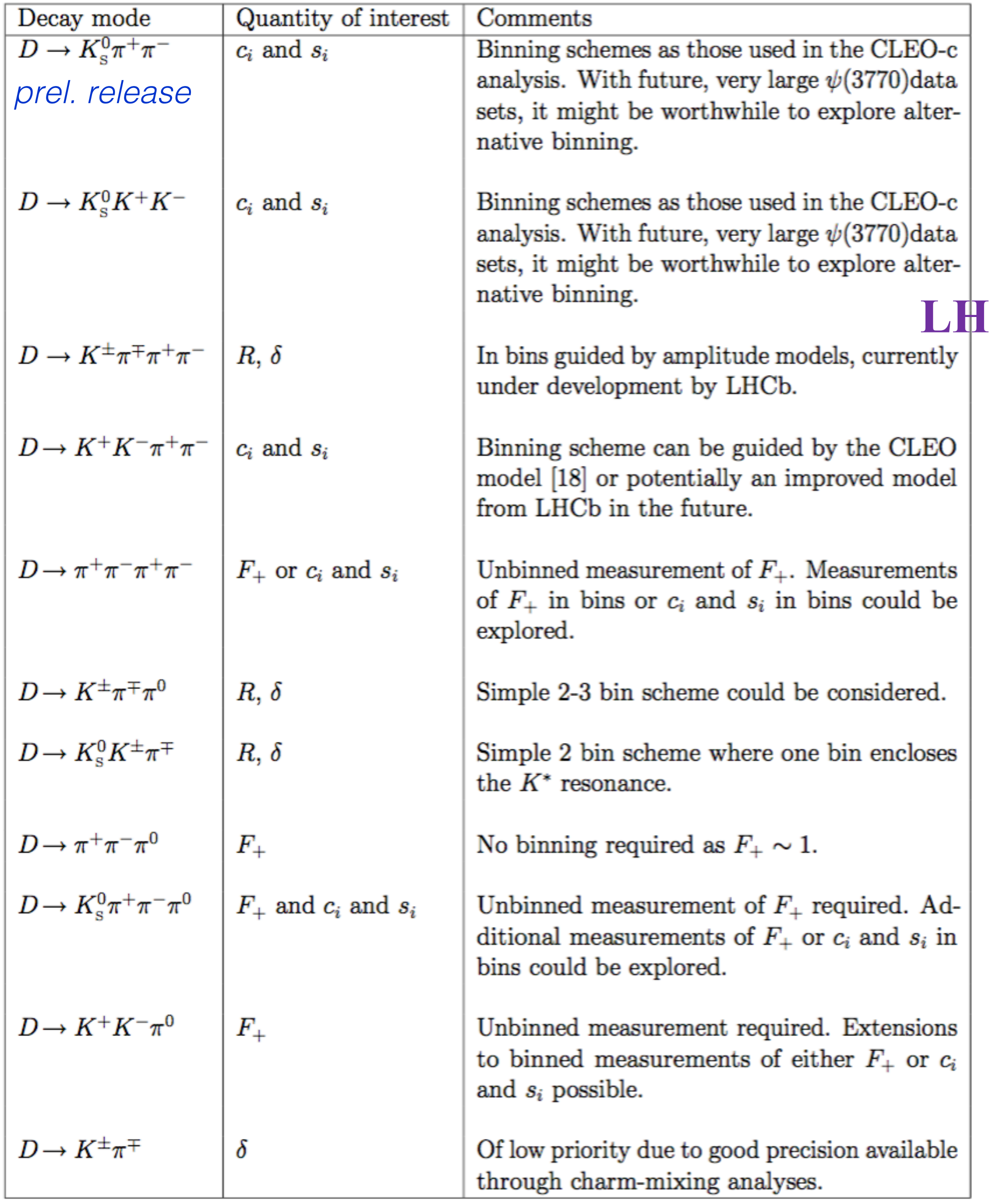
Opportunities for precise determination of strong phase and D mixing

Prospects of charmed hadron decays

Data at 3.773, 4.18 GeV and 4.63GeV

	Systematic	Statistical	
		~3 fb^{-1}	+10 fb^{-1}
$\Delta f_{D+}/f_{D+}$	~0.9%^{BESIII}	2.6%	1.3%
$\Delta f_{Ds+}/f_{Ds+}(\mu+\tau)$	~1.4%$^{CLEO\text{-}c}$	~1.5%	~0.7%
$\Delta f_{D\to K}/f_{D\to K}$	~0.5%^{BESIII}	0.4%	0.2%
$\Delta f_{D\to\pi}/f_{D\to\pi}$	~0.7%^{BESIII}	1.3%	0.6%
$\lvert V_{cs}\rvert^{Ds+\to l+v}(\mu+\tau)$	~1.4%$^{CLEO\text{-}c}$	~1.4%	~0.7%
$\lvert V_{cs}\rvert^{D0\to K\text{-}e+v}$	2.5%^{BESIII}(2.4%^{LQCD})	0.4%	0.2%
$\lvert V_{cd}\rvert^{D+\to\mu+v}$	2.1%^{BESIII}(1.9→0.5%^{LQCD})	2.6%	1.3%
$\lvert V_{cd}\rvert^{D0\to\pi\text{-}e+v}$	4.5%^{BESIII}(4.4%^{LQCD})	1.3%	0.6%
(c_i,s_i) in $D^0\to K^0\pi^+\pi^-$	Uncertianty for γ/ϕ_3	1%	0.5% ⬅
$\Lambda_c^+\to pK^-\pi^+$		4.8% (0.6fb^{-1}@4.6)	~2% (3fb^{-1}@4.6X)

Strong phases in D hadronic decays



	Decay mode	Quantity of interest	Comments
➢	$D \to K_S^0\pi^+\pi^-$ *prel. release*	c_i and s_i	Binning schemes as those used in the CLEO-c analysis. With future, very large $\psi(3770)$data sets, it might be worthwhile to explore alternative binning.
➢	$D \to K_S^0K^+K^-$	c_i and s_i	Binning schemes as those used in the CLEO-c analysis. With future, very large $\psi(3770)$data sets, it might be worthwhile to explore alternative binning.
➢	$D \to K^\pm\pi^\mp\pi^+\pi^-$	R, δ	In bins guided by amplitude models, currently under development by LHCb.
➪	$D \to K^+K^-\pi^+\pi^-$	c_i and s_i	Binning scheme can be guided by the CLEO model [18] or potentially an improved model from LHCb in the future.
➪	$D \to \pi^+\pi^-\pi^+\pi^-$	F_+ or c_i and s_i	Unbinned measurement of F_+. Measurements of F_+ in bins or c_i and s_i in bins could be explored.
➢	$D \to K^\pm\pi^\mp\pi^0$	R, δ	Simple 2-3 bin scheme could be considered.
➪	$D \to K_S^0K^\pm\pi^\mp$	R, δ	Simple 2 bin scheme where one bin encloses the K^* resonance.
➢	$D \to \pi^+\pi^-\pi^0$	F_+	No binning required as $F_+ \sim 1$.
➪	$D \to K_S^0\pi^+\pi^-\pi^0$	F_+ and c_i and s_i	Unbinned measurement of F_+ required. Additional measurements of F_+ or c_i and s_i in bins could be explored.
➢	$D \to K^+K^-\pi^0$	F_+	Unbinned measurement required. Extensions to binned measurements of either F_+ or c_i and s_i possible.
➡	$D \to K^\pm\pi^\mp$	δ	Of low priority due to good precision available through charm-mixing analyses.

LHCb-PUB-2016-025

Status at BESIII
- ➡ published
- ➢ under study
- ➪ in plan

Summary

- Unique access to strong phases & ability to extract model-independent results with charm at threshold
- BESIII is successfully operating since 2008
  - Collected large data samples in the τ-charm mass region
- BESIII will continue to run 6 – 8 years.
- BESIII team has learned and developed technology for charm mixing and CPV at threshold.
  - 2nd generation of QC analyses, while CLEO-c activity is declining.
  - more precision, new modes, new variables
  - some challenges on the systematics
- Future goals

  >15 /fb ψ(3770) data, and roughly 50M D^0, 50M D^+ , 1M Λ_c , 15M Ds, produced near threshold

Many works are ongoing; Stay tuned!

Thank you!

谢谢！

Connections of c_i, s_i and c'_i s'_i

’ indicates numbers from $K_L\pi^+\pi^-$ decays

From the CP tag modes, we are able to find c_i and c'_i

$M_i = \frac{S_\pm}{2S_f}(K_i \pm 2c_i\sqrt{K_iK_{\bar{i}}} + K_{\bar{i}})$	$(CP, K_S^0\pi^+\pi^-)$
$M'_i = \frac{S_\pm}{2S_f}(K'_i \mp 2c'_i\sqrt{K'_iK'_{\bar{i}}} + K'_{\bar{i}})$	$(CP, K_L^0\pi^+\pi^-)$

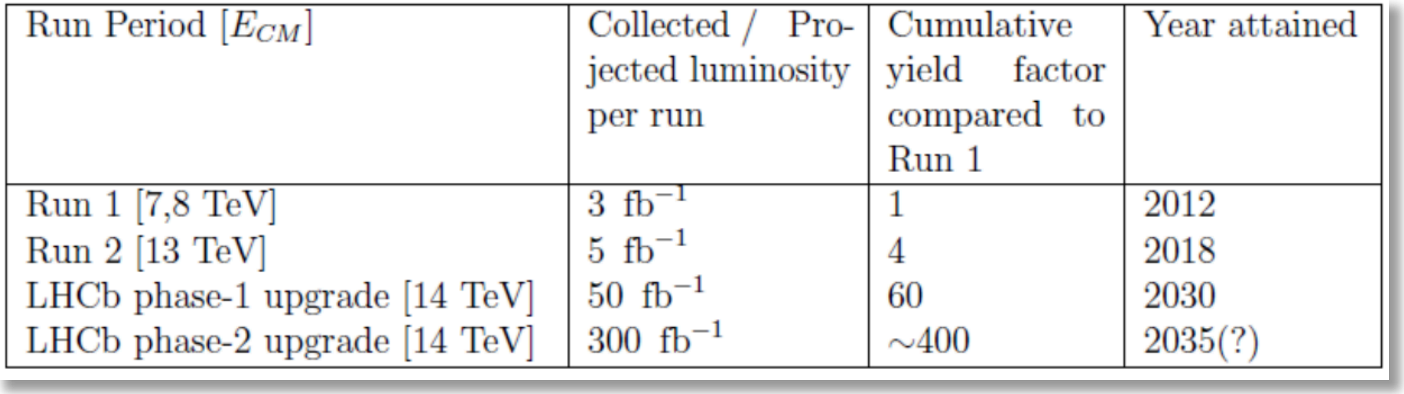
M_i yields in each bin of Dalitz plot for CP even(odd) modes.
$S_+(S_-)$, number of single tags for CP even(odd) modes.
$K_i(K_{\bar{i}})$, yields in each bin of Dalitz plot in flavor modes.

From the Double Dalitz modes, we are able to find c_i, c'_i, s_i, s'_i

$M_{i,j} = \frac{N_{D,\overline{D}}}{2S_f^2}(K_iK_{\bar{j}} + K_{\bar{i}}K_j - 2\sqrt{K_iK_{\bar{j}}K_{\bar{i}}K_j}(c_ic_j + s_is_j))$	$(K_S^0\pi^+\pi^-, K_S^0\pi^+\pi^-)$
$M'_{i,j} = \frac{N_{D,\overline{D}}}{2S_f}(K_iK'_{\bar{j}} + K_{\bar{i}}K'_j + 2\sqrt{K_iK'_{\bar{j}}K_{\bar{i}}K'_j}(c_ic'_j + s_is'_j))$	$(K_S^0\pi^+\pi^-, K_L^0\pi^+\pi^-)$

$M_{i,j}$ yields in each ith bin of the first Dalitz plot and the jth bin for the second Dalitz plot.
S_f, number of single tags for flavor modes.
$K_i(K_{\bar{i}})$, yields in each bin of Dalitz plot in flavor modes.

Impacts in LHCb γ/ϕ_3 measurement



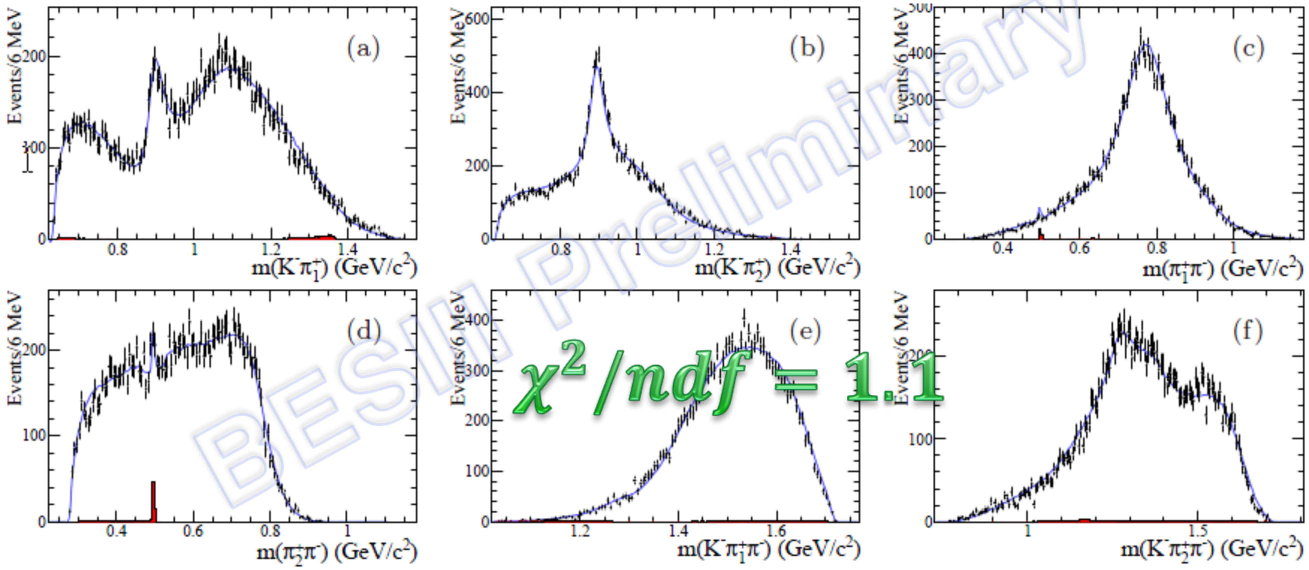
Run Period $[E_{CM}]$	Collected / Projected luminosity per run	Cumulative yield factor compared to Run 1	Year attained
Run 1 [7,8 TeV]	3 fb^{-1}	1	2012
Run 2 [13 TeV]	5 fb^{-1}	4	2018
LHCb phase-1 upgrade [14 TeV]	50 fb^{-1}	60	2030
LHCb phase-2 upgrade [14 TeV]	300 fb^{-1}	$\sim$400	2035(?)

- By considering the evolution of the LHCb measurements, which may differing among modes, this strong phase uncertainty is
  - 1.7 to 2.2° at the end of Run 2
  - 1.8 to 2.5° at the end of the phase 1 upgrade
- So now compared to the total precision an γ from LHCb expected
  - Run I – σ(γ) = 7° - limited impact of strong phase measurements
  - Run II - σ(γ) = 3.5° - becomes significant
  - **Upgrade phase I σ(γ) ~ strong phase uncertainty**

Amplitude analysis of $D^0 \to K^- \pi^+ \pi^+ \pi^-$

- ◆ This decay is one of three golden decay mode of D^0
- ◆ The knowledge of intermediate process can be widely used in many measurements, such as to study branching fraction and strong phase used in CKM unitary triangle γ measurement
- ◆ Construct coherent sum of 23 amplitudes and fit to data (double-tag (DT) 15912 events with purity of 99.4%)

2.93 fb^{-1} @3.773GeV



$\chi^2/ndf = 1.1$

- Improvements over the existing results!
- Strong phase extraction is under studies

Amplitudes of fitted components

With the fit fractions (FF) of every components and the branching ratio of $D^0 \to K^-\pi^+\pi^+\pi^-$, we calculate the branching ratios of the components with

$$Br(Component) = FF(Componet)Br(D^0 \to K^-\pi^+\pi^+\pi^-).$$

The results are listed in the table below :

Component	Branching fraction (%)	PDG value (%)
$D^0 \to \bar{K}^{*0}\rho^0$	$0.99 \pm 0.04 \pm 0.04 \pm 0.03$	1.05 ± 0.23
$D^0 \to K^- a_1^+(1260)(\rho^0\pi^+)$	$4.41 \pm 0.22 \pm 0.30 \pm 0.13$	3.6 ± 0.6
$D^0 \to K_1^-(1270)(\bar{K}^{*0}\pi^-)\pi^+$	$0.07 \pm 0.01 \pm 0.02 \pm 0.00$	0.29 ± 0.03
$D^0 \to K_1^-(1270)(K^-\rho^0)\pi^+$	$0.27 \pm 0.02 \pm 0.02 \pm 0.01$	
$D^0 \to K^-\pi^+\rho^0$	$0.68 \pm 0.09 \pm 0.18 \pm 0.02$	0.51 ± 0.23
$D^0 \to \bar{K}^{*0}\pi^+\pi^-$	$0.57 \pm 0.03 \pm 0.03 \pm 0.02$	0.99 ± 0.23
$D^0 \to K^-\pi^+\pi^+\pi^-$	$1.77 \pm 0.05 \pm 0.04 \pm 0.05$	1.88 ± 0.26

In the table, the first and second uncertainties of the branching ratios are statistical and systematic uncertainties from the fit fractions, the third errors is the uncertainties related to $Br(D^0 \to K^-\pi^+\pi^+\pi^-)$ in PDG.