Highlight of Charm Physics at BESIII

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Meson 2014, May 29-June 03, Cracow, Poland

Outline

- Introduction to BESIII
- BESIII data sets
- Open charm physics
- Summary

Beijing Electron Positron Collider-II (BEPCII)

The BEPCII Collider

Beam energy: 1.0 − 2.3 GeV

Peak Luminosity:

- ***Design:*** **1×10^{33} cm^{-2}s^{-1}**
- ***Achieved:*** **$0.7\text{x}10^{33}$cm^{-2}s^{-1}@3770 MeV**

Optimum energy: 1.89 GeV

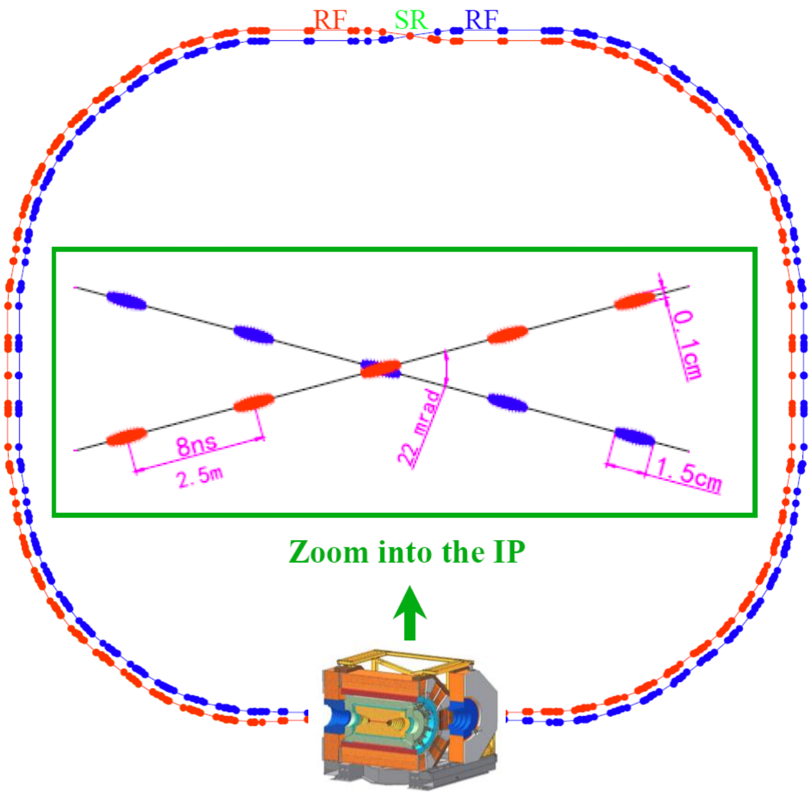
Energy spread: $5.16\ \times10^{-4}$

No. of bunches: 93

Bunch length: 1.5 cm

Total current: 0.91 A

Circumference: 237 m



BESIII

Beam energy measurement: **Using Compton backscattering technique. accuracy up to $5\cdot10^{-5}$**

The BESIII detector

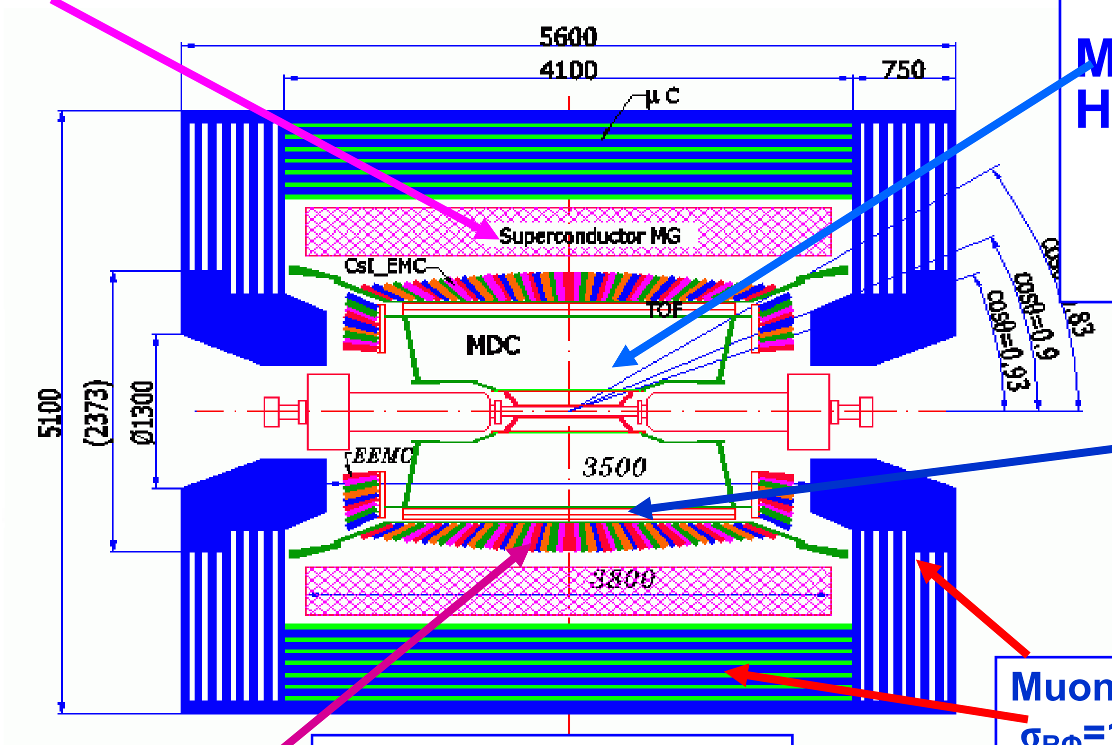
Solenoid Magnet: 1 T Super conducting

MDC: small cell & He gas

σ_{xy}=130 μm

$\delta p/p$ = 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.

The BESIII Collaboration

US (6)

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

Europe (13)

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

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

China(29)

IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ., Beihang Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.

~350 members
52 institutions from 11 countries

Data samples at BESIII

	Previous data	BESIII now	Goal
J/ψ	*BESII: 58 M*	*1.2 B 20*BESII*	*10 B*
ψ(3686)	CLEO: 28 M	0.5 B 20*CLEO	3 B
ψ(3770)	*CLEO: 0.8 /fb*	*2.9 /fb 3.5*CLEO*	*20 /fb*
Above open charm threshold	CLEO: 0.6/fb @4160MeV	2011: 0.5 /fb @ 4.009 GeV 2013: 1.9 /fb @ 4.26 GeV, 0.5 /fb @ 4.36 GeV 2014: 0.6 /fb @ 4.6 GeV 1.0 /fb @ 4.42 GeV and data for line shape	5-10 /fb
R Scan	*BESII*	2012: R @2.23,2.4,2.8,3.4GeV 25/pb tau threshold 2014: 0.8 /fb @ 3.85—4.59 GeV	

- **world's largest samples of on-threshold *ψ(3770)* data and keep increasing in the future**
- **the aim is to have 20 /fb data**

D physics @ $\psi(3770)$

At $\psi(3770)$ peak : $\sigma(e^+e^- \to DDbar) \approx 6.6$ nb

Only D pairs: no phase space for even one extra pion

Reconstruction one D in a set of hadronic "tag" modes:

Reduce backgrounds,

Find the other D's direction: produce a "tagged D beam"

→ can be used to reconstruct a neutrino 4-vector

Tag variables: conservation of momentum and energy:

$$M_{bc} = \sqrt{E_{beam}^2 - p_{cand}^2} \qquad \Delta E = E_{cand} - E_{beam}$$

Absolute BR measurement:

Tag-side efficiency mostly cancels;

tag systematics cancel.

$$BR = \frac{N_{tag+signal}\varepsilon_{tag}}{N_{tag}\varepsilon_{tag+signal}} \approx \frac{N_{tag+signal}}{N_{tag}\varepsilon_{signal}}$$

BESIII

Flavor Physics Connection

Tests of Lattice QCD and SM

Leptonic : decay constant f_D

indirectly access $|V_{td}|$, via x_B and f_D/f_B

Semi-leptonic : form factors $f(q^2)$

directly access to $|V_{cs/d}|$

Strong Phases

Accessible due to quantum-correlations

Affect CKM gamma/ϕ_3 extraction

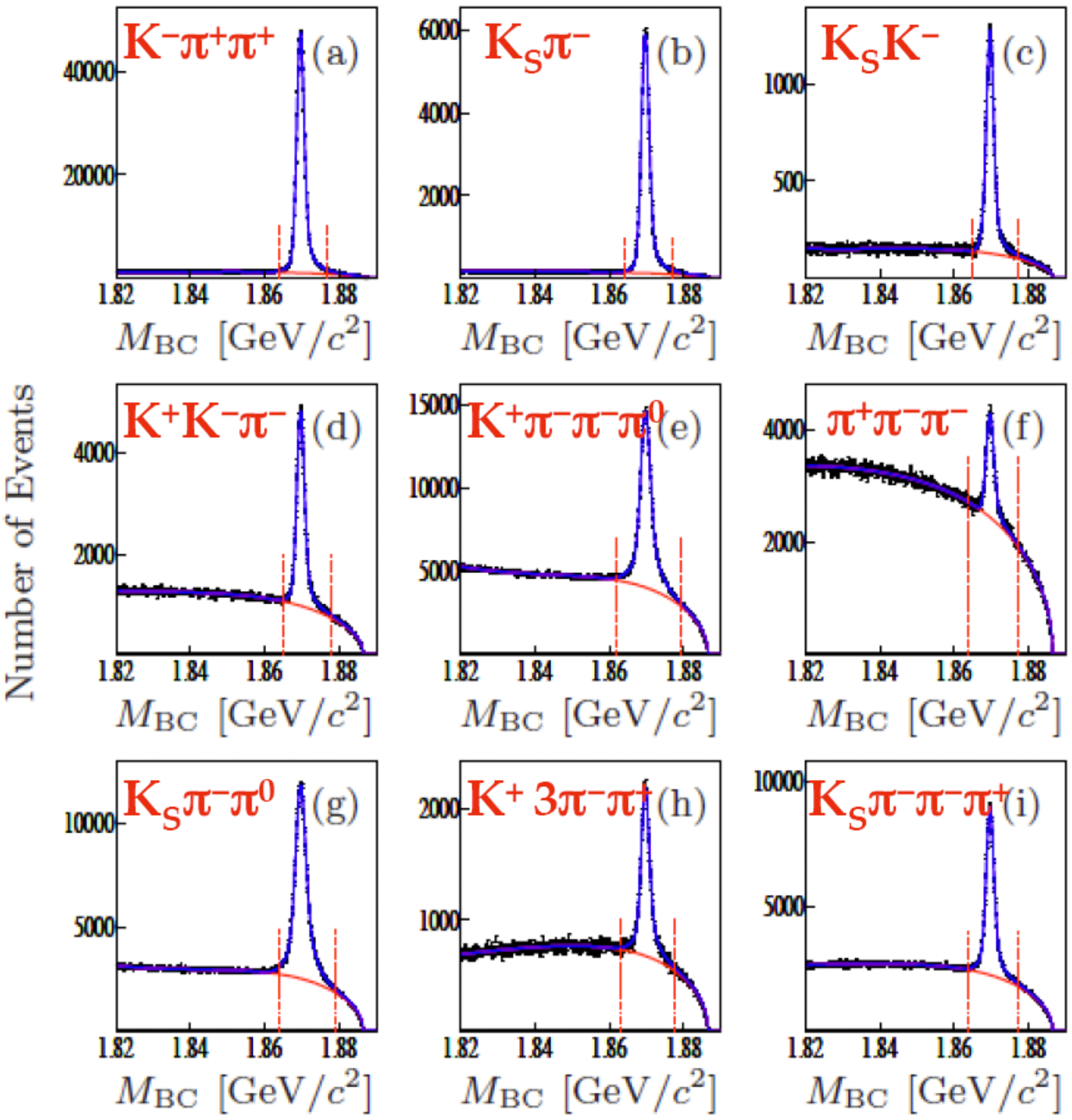
D^0 D^+ D_s^+ golden mode BF

Normalize heavy flavor physics

Systematics limited after CLEO-c; lower priority to check…

$D^+ \rightarrow \mu^+\nu$

PRD89, 051104(R)（2014）
BESIII: 2.9 fb^{-1}



Uses 9 tag modes

Signal side: ONE track !

Veto on extra tracks,
and un-matched showers
with E > 300 MeV

Reconstruct " MM² "
= (missing-mass)²

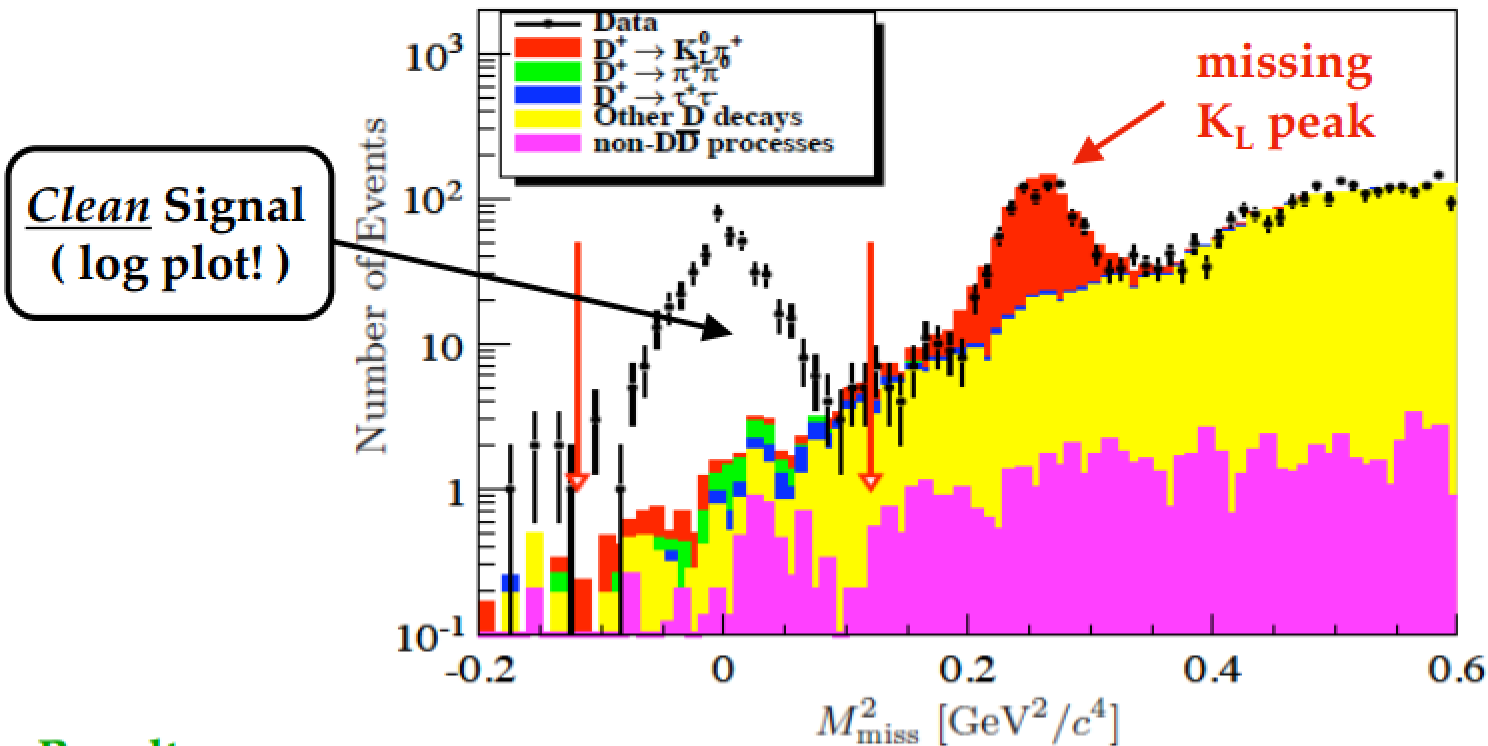
presumably just a neutrino:
signal peaks at 0

BESIII

$D^+ \to \mu^+\nu$

PRD89, 051104(R) (2014)

BESIII: 2.9 fb^{-1}



Result:

377.3 ± 20.6 ± 2.6 events above background

$B(D^+ \to \mu\nu) = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}$

Combining with V_{cd}, G_F, τ_D, m_D :

$f_D = 203.2 \pm 2.6\%(\text{stat.}) \pm 0.9\%(\text{sys.})$ MeV

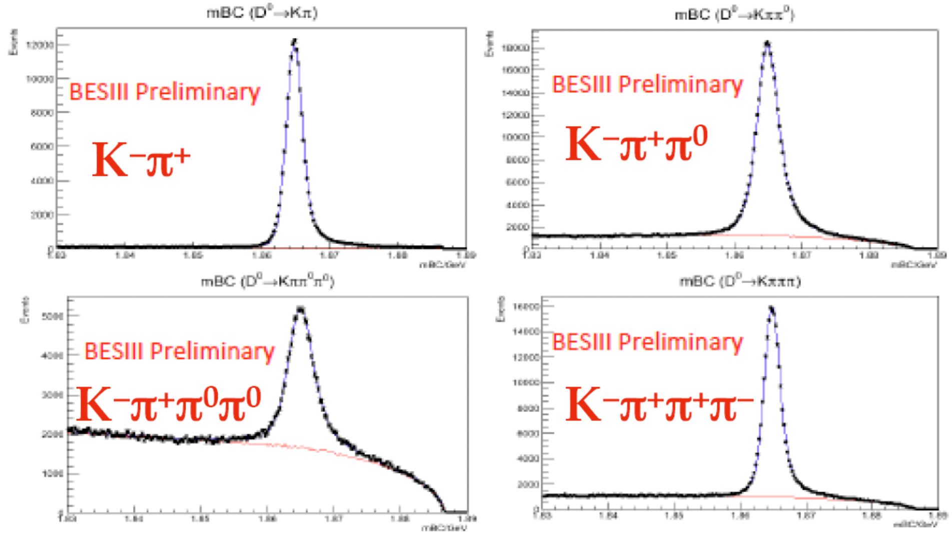
most precise !

Previous best : CLEO-c: 205.8 ± 4.1%(stat.)± 1.2%(sys.) MeV

$D^0 \to Ke\nu$, $\pi e\nu$

BESIII: 0.9 fb^{-1}

Use 4 hadronic tag modes



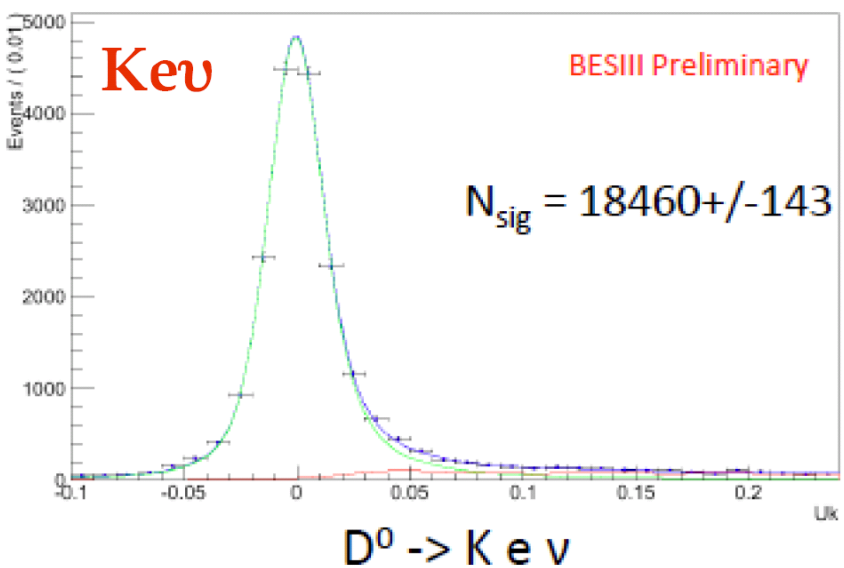
Signal side:

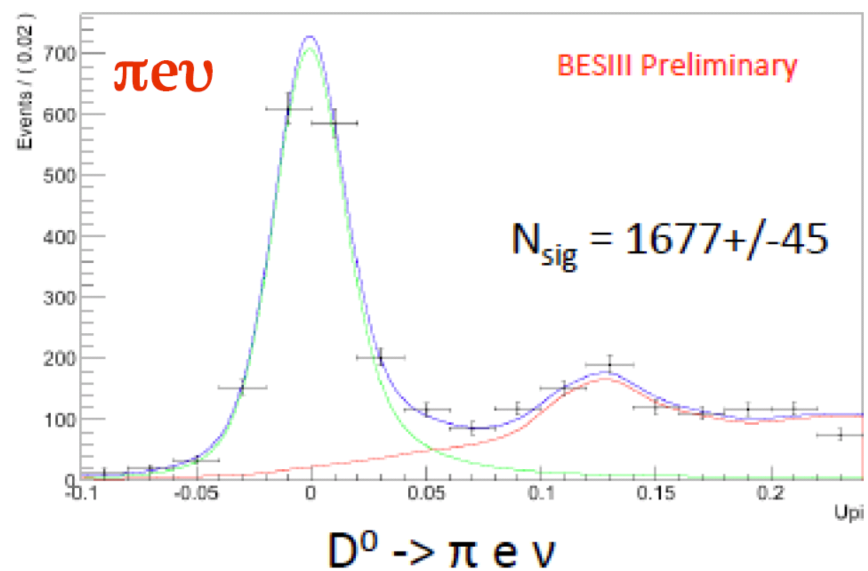
two tracks, e & K/π

Signal variable:

$U = E_{miss} - p_{miss}$

(peaks @ zero, similar to MM^2)

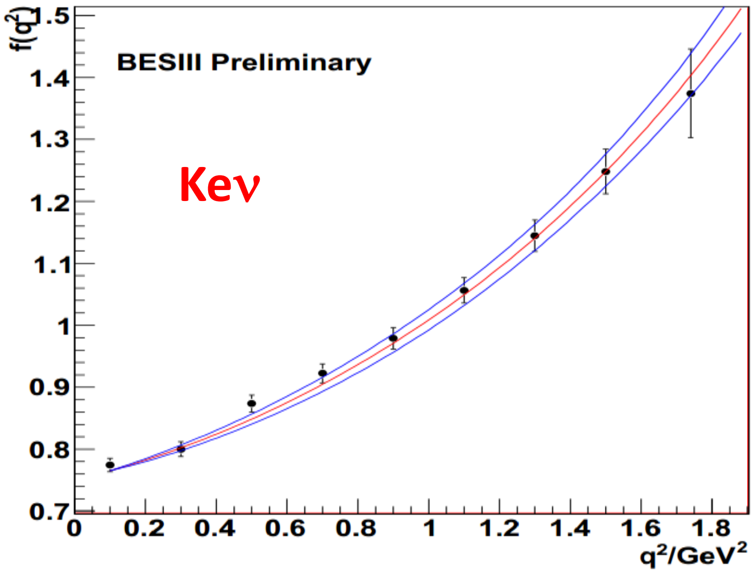




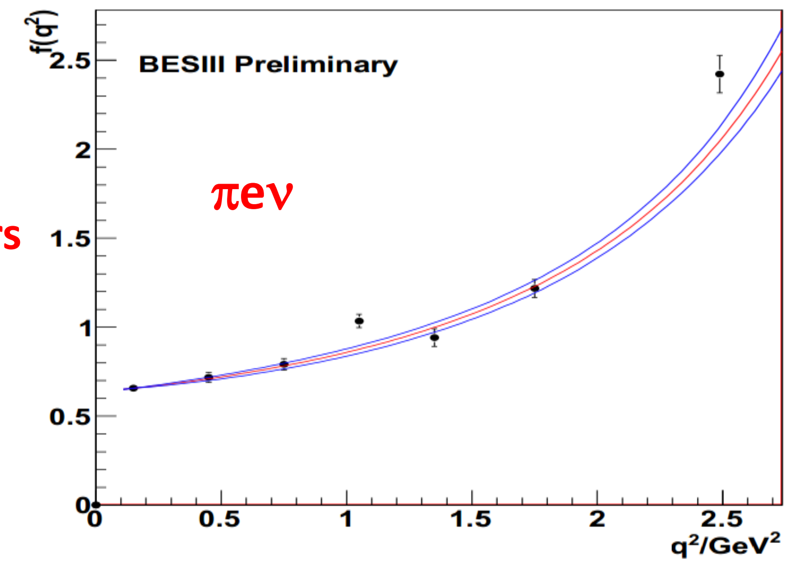
$D^0 \to Ke\nu$, $\pi e\nu$

BESIII: 0.9 fb^{-1}

- Points: data with stat. error only
- Curves: from Fermilab-MILC within one stat. error, preliminary, **arXiv:1111.5471** (XXIX International Symposium on Lattice Field Theory);
- Other theoretical work: HPQCD, arXiv:1111.0225
- Comparing shape only here ($f_+(0)$ not known)



Form Factors $f(q^2)$



$D^0 \to K e \nu$, $\pi e \nu$

BESIII: 0.9 fb^{-1}

BESIII preliminary

mode	Measurement(%)	PDG value (%)	CLEO-c value (%)
$\overline{D}^0 \to K^+ e^- \overline{\nu}$	3.542±0.030±0.067	3.55±0.04	3.50±0.03±0.04
$\overline{D}^0 \to \pi^+ e^- \overline{\nu}$	0.288±0.008±0.005	0.289±0.008	0.288±0.008±0.003

BESIII preliminary

Simple Pole	$f_+(0)\|V_{cd(s)}\|$	m_{pole}	
$\overline{D}^0 \to K^+ e^- \nu$	0.729±0.005±0.007	1.943±0.025±0.003	
$\overline{D}^0 \to \pi^+ e^- \nu$	0.142±0.003±0.001	1.876±0.023±0.004	
Modified Pole	$f_+(0)\|V_{cd(s)}\|$	α	
$\overline{D}^0 \to K^+ e^- \nu$	0.725±0.006±0.007	0.265±0.045±0.006	
$\overline{D}^0 \to \pi^+ e^- \nu$	0.140±0.003±0.002	0.315±0.071±0.012	
2 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	
$\overline{D}^0 \to K^+ e^- \nu$	0.726±0.006±0.007	-2.034±0.196±0.022	
$\overline{D}^0 \to \pi^+ e^- \nu$	0.140±0.004±0.002	-2.117±0.163±0.027	
3 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	r_2
$\overline{D}^0 \to K^+ e^- \nu$	0.729±0.008±0.007	-2.179±0.355±0.053	4.539±8.927±1.103
$\overline{D}^0 \to \pi^+ e^- \nu$	0.144±0.005±0.002	-2.728±0.482±0.076	4.194±3.122±0.448

Strong phase $\delta_{K\pi}$

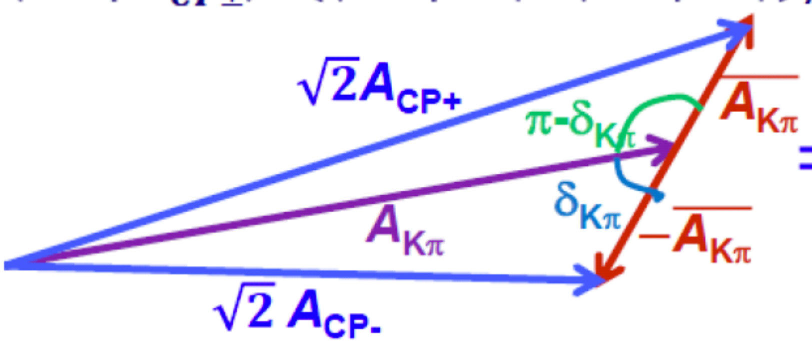
arXiv:1404.4691
Accepted by PLB

BESIII: 2.9 fb^{-1}

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

Quantum correlation → Interference → access strong phase!

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



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

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

- **Measuring $\delta_{K\pi}$ from rate differences if using external $r_{K\pi}$**
- **Reconstructed modes:**
  - **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):** $K^0_S\pi^0$, $K^0_S\eta$, $K^0_S\omega$

arXiv:1404.4691
Accepted by PLB

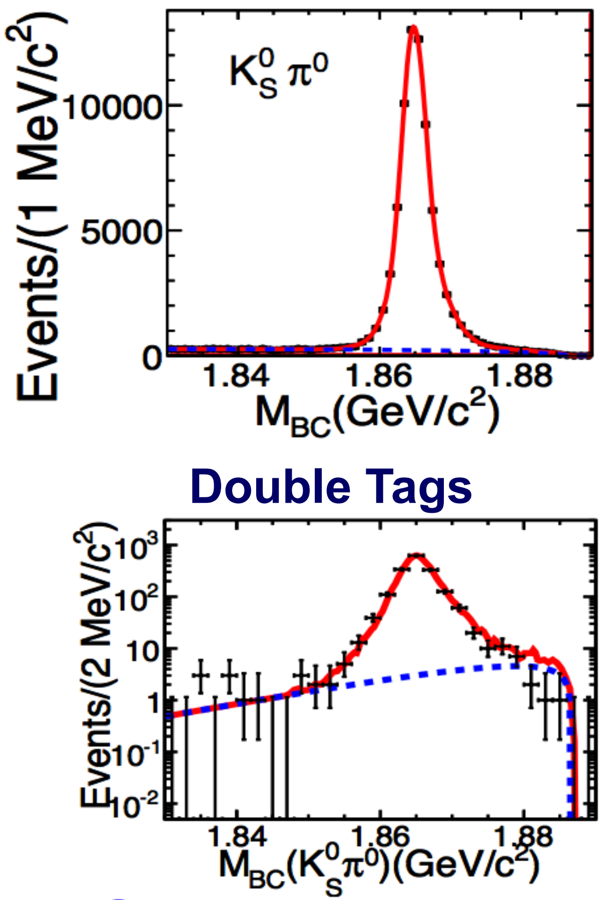
Strong phase $\delta_{K\pi}$

BESIII: 2.9 fb^{-1}

- **Signal reconstruction:**
  - **Single Tag (ST): CP tags**
  - **Double Tag (DT) : $K\pi$ + CP Tag**
  - **Kinematic variable: Beam Constrained Mass (M_{BC})**
  - **Singal shape: $\sigma\otimes$MC-truth**
  - **Background shape: ARGUS function**
- $$Br(D_{CP\pm} \to K\pi) = \frac{n_{K\pi,CP\pm}}{n_{CP\pm}} \cdot \frac{\varepsilon_{CP\pm}}{\varepsilon_{K\pi,CP\pm}}$$
  - **$n_{K\pi,CP\pm}$ and $n_{CP\pm}$ are event yields for DT and ST from M_{BC} fit**
  - **$\varepsilon_{K\pi,CP\pm}$ and $\varepsilon_{CP\pm}$ are detection efficiencies of DT and ST from MC simulation**
  - **Most systematics cancelled for ratio $\varepsilon_{CP\pm}/\ \varepsilon_{K\pi,CP\pm}$**

Single Tags

Double Tags



BESIII results:

$$\mathcal{A}_{CP\to K\pi} = (12.7 \pm 1.3 \pm 0.7) \times 10^{-2}$$

Strong phase $\delta_{K\pi}$

arXiv:1404.4691
Accepted by PLB

BESIII: 2.9 fb^{-1}

- If we don't ignore the mixing effect
- $2r_{K\pi}\cos\delta_{K\pi} + y = (1 + R_{WS}) \cdot A_{CP\to K\pi}$
  - $R_{WS} \equiv \frac{\Gamma(D^0\to K^+\pi^-)}{\Gamma(D^0\to K^-\pi^+)} = r^2_{K\pi} + r_{K\pi}y' + \frac{(x^2+y^2)}{2}$
- External inputs from HFAG2013 and PDG
  - $r^2_{K\pi} = 0.347 \pm 0.006\%$,
  - $y = 0.66 \pm 0.09\%$,
  - $R_{WS} = 0.380 \pm 0.005\%$

BESIII results:

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

- Uncertainty is dominated by the statistical error
- The third error is due to the input parameters
- World best precision

Other Quantum Correlation work

Coherence factors: feed into CKM γ/ϕ_3 with B's

$K_S \pi^+ \pi^-$ most advanced: binned analysis ("CLEO-style")

$$\left.\begin{array}{l} K^- \pi^+ \pi^0 \\ \pi^+ \pi^- \pi^0 \end{array}\right\}$$ likely to pursue both model-ind't analyses, and also detailed Dalitz analyses

+ other modes e.g., $K^-\pi^+\pi^+\pi^-$ & $K_S K^+\pi^-$ have been done by CLEO-c)

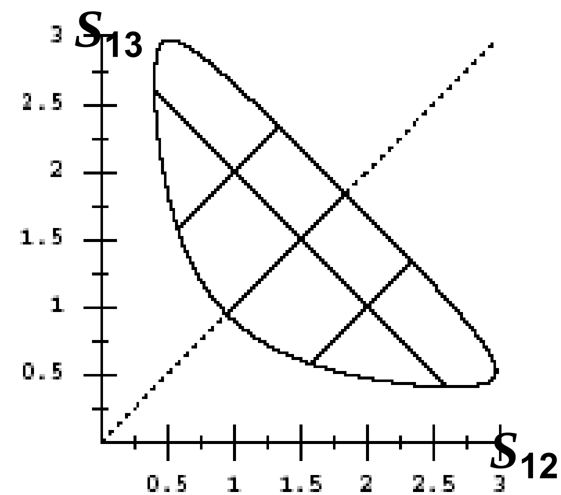
Mixing analyes: statistics-limited at $\psi(3770)$

Luminosity x cross-section much higher @ B factories, LHCb

But… We do have a y_{CP} analysis in the works

c_i, s_i for γ/ϕ_3 measurements

- GGSZ (Dalitz) method in $B \rightarrow D^0 K$
  - Most powerful method nowadays
  - D^0 to 3-body decays $K_S\pi^+\pi^-$, $K_S K^+ K^-$,…
  - Partition the Dalitz plot to 2k bins
  - B Signal yields in i[th] Dalitz bin



$B^\pm \rightarrow DK^\pm$ yields

from flav.-tagged $D \rightarrow K_S\pi\pi$

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

QC measurements from Charm factories

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

$$s_{12} \equiv m^2_{K_s\pi^-},\ s_{13} \equiv m^2_{K_s\pi^+}$$

$$\boxed{\begin{aligned} x_\pm &= \cos(\delta_B \pm \gamma) \\ y_\pm &= \sin(\delta_B \pm \gamma) \end{aligned}}$$

- Averaged phases in each bin: c_i, s_i (Giri et. al. **PRD68, 054018 (2003)**)

$$A_D(s_{12}, s_{13}) \equiv A_{12,13} e^{i\delta_{12,13}} \equiv A(D^0 \rightarrow K_s^0(p_1)\pi^-(p_2)\pi^+(p_3))$$

$$= A(\overline{D^0} \rightarrow K_s^0(p_1)\pi^+(p_2)\pi^-(p_3))$$

$$c_i \equiv \int_i dp A_{12,13} A_{13,12} \cos(\delta_{12,13} - \delta_{13,12})$$

$$s_i \equiv \int_i dp A_{12,13} A_{13,12} \sin(\delta_{12,13} - \delta_{13,12})$$

$$T_i \equiv \int_i dp A_{12,13}^2$$

c_i, s_i : weighted average of $\cos(\Delta\delta_D)$ and $\sin(\Delta\delta_D)$ respectively where $\Delta\delta_D$ is the difference between phase of D^0 and $\overline{D}^0$

Model independent approach

Modified optimal binning: 8 bins

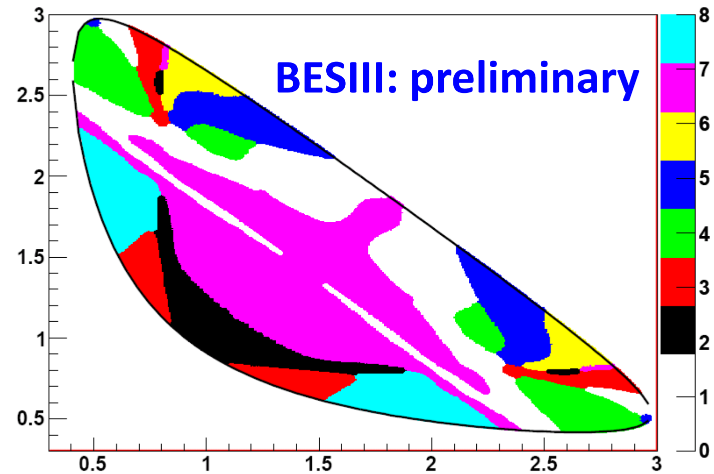
CLEO-c: 0.818 fb^{-1}

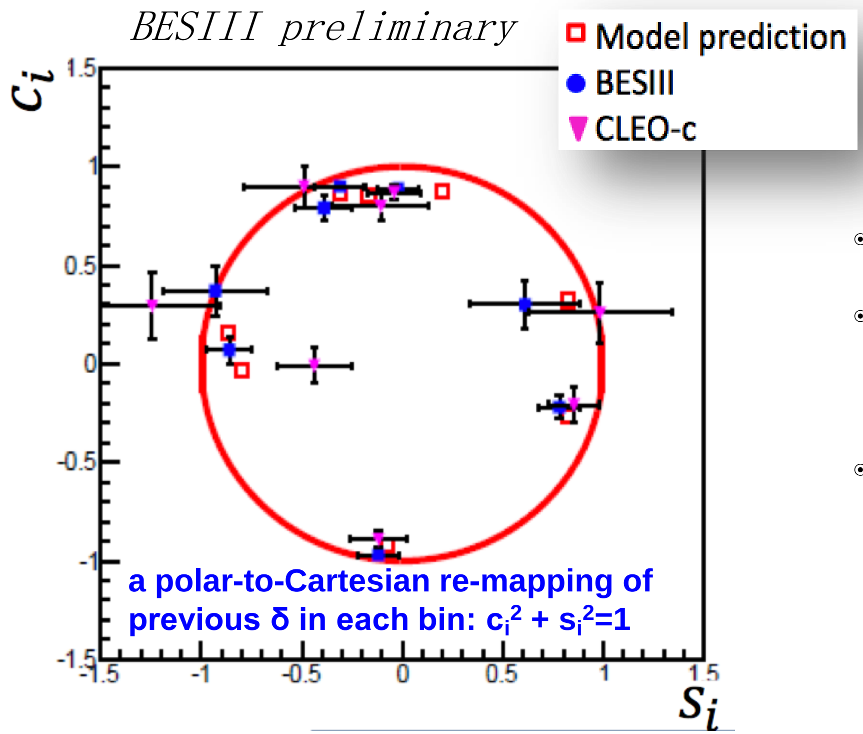
uncertainty on γ reduced to 1.7° to 3.9°

BESIII: 2.9fb^{-1}

Uncertainty on γ reduced to 0.9° to 2.0°

depend on the binning methods.





- **Still statistical limited.**
- **Only statistical errors are listed.**
- **Consistent agreement with CLEO-c measurements, but superior in statistical errors**

Summary

BESIII has started to be involved in the world campaign on identifying the $D\underline{D}$ oscillation, searching for the *CPV* in charm and over-constraining the CKM unitarity triangles.

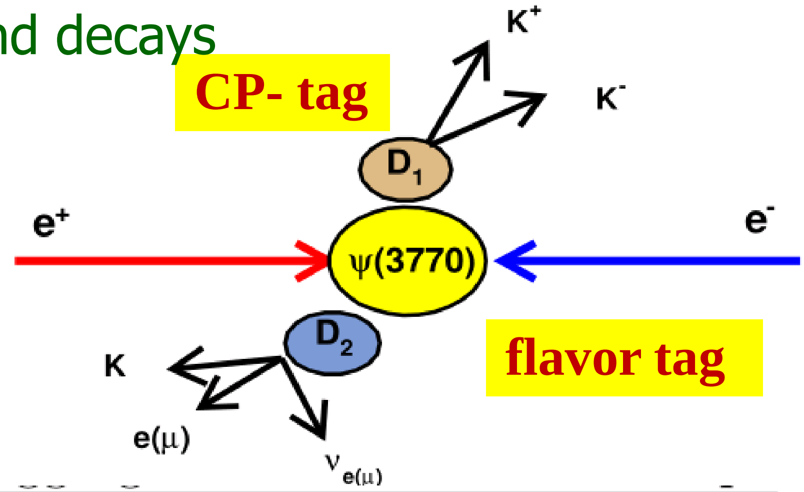
- We provide unique data on strong phases.
- Many more QC analyses are undergoing
- Purely and semi leptonic decays were studied
  - test LQCD
  - make precise measurements of CKM elements, to improve the accuracy of CKM unitarity tests.

Thanks

Backup

y_{CP}: CP tagged semileptonic D decays

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



Type	Modes
CP^+	K^+K^-, $\pi^+\pi^-$, $K_S\pi^0\pi^0$
CP^-	$K_S^0\pi^0$, $K_S^0\omega$, $K_S^0\eta$
$l^\pm$	$Ke\nu$, $K\mu\nu$

For D decay to CP eigenstates:

$$R_{CP\pm} \propto |A_{CP\pm}|^2(1 \mp y_{CP})$$

$$y_{CP} = \frac{1}{2}[y\cos\phi(|\frac{q}{p}| + |\frac{p}{q}|) - x\sin\phi(|\frac{q}{p}| - |\frac{p}{q}|)]$$

For CP tagged semileptonic D decays:

$$R_{l,CP\pm} \propto |A_l|^2|A_{CP\pm}|^2$$

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

Modes	N_{tag}	$N_{tag,Ke\nu}$	$N_{tag,K\mu\nu}$
K^+K^-	54307 ± 252	1216 ± 40	1093 ± 37
$\pi^+\pi^-$	19996 ± 177	427 ± 23	400 ± 23
$K_S^0\pi^0\pi^0$	24369 ± 231	560 ± 28	558 ± 28
$K_S^0\pi^0$	71419 ± 286	1699 ± 47	1475 ± 43
$K_S^0\omega$	21249 ± 157	473 ± 25	501 ± 26
$K_S^0\eta$	9843 ± 117	242 ± 17	237 ± 18

preliminary

$$\boxed{y_{CP} = -1.6\% \pm 1.3\%(\text{stat.}) \pm 0.6\%(\text{syst.})}$$

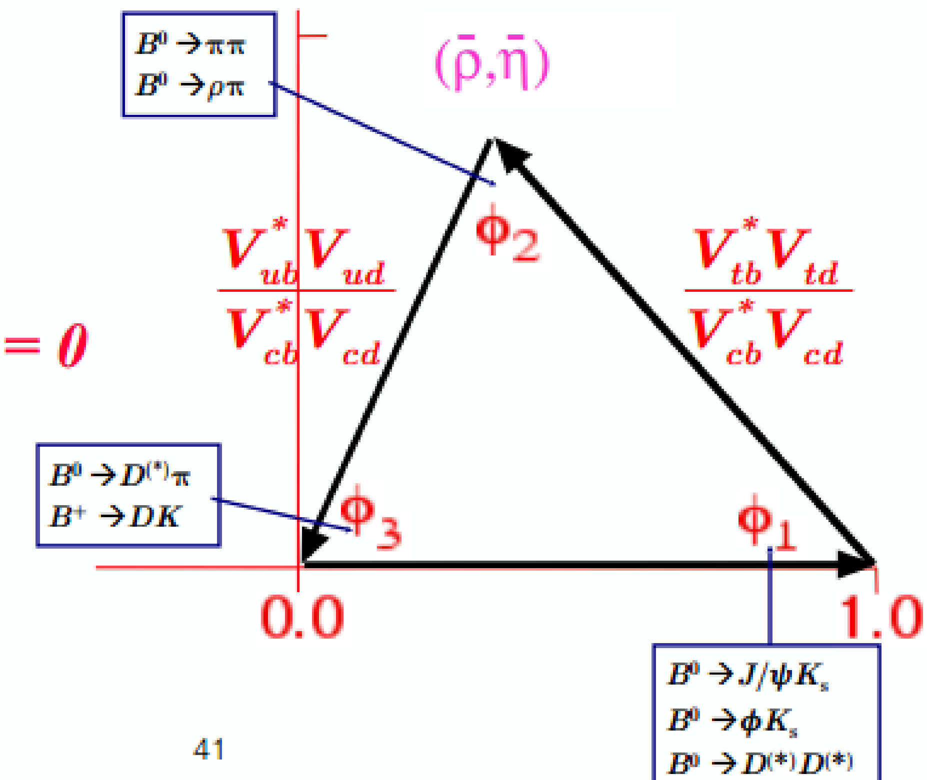
CLEOc ***[PRD 86 (2012) 112001]:***
y_{CP}=(4.2±2.0 ±1.0)%

Unitarity Triangle

$$V^{+}V = I \Rightarrow \begin{pmatrix} V_{ud}^{*} & V_{cd}^{*} & V_{td}^{*} \\ V_{us}^{*} & V_{cs}^{*} & V_{ts}^{*} \\ V_{ub}^{*} & V_{cb}^{*} & V_{tb}^{*} \end{pmatrix} \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$V_{ub}^{*}V_{ud} + V_{cb}^{*}V_{cd} + V_{tb}^{*}V_{td} = 0$$

(B system)



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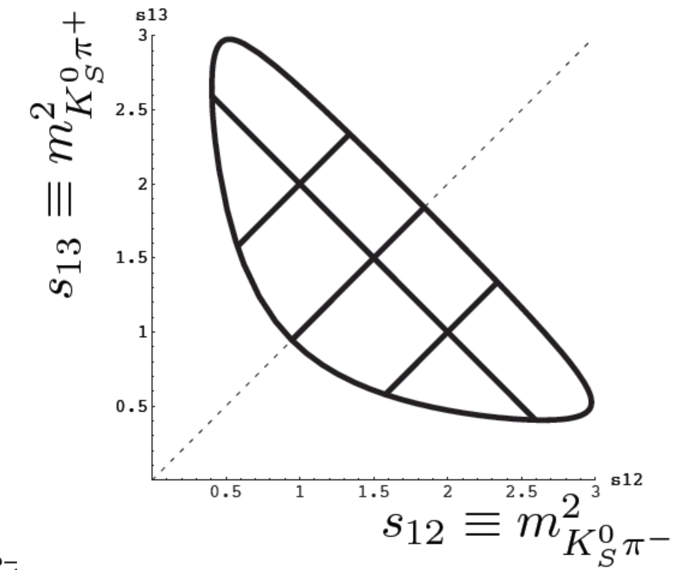
DP model independent approach

- **Initially proposed for γ measurement in $B^+ \to DK^+$**

- **Divide DP into symmetrical bins:**



$$c_i \equiv \int_i dp\, A_{12,13}\, A_{13,12}\, \cos(\delta_{12,13} - \delta_{13,12}),$$

$$s_i \equiv \int_i dp\, A_{12,13}\, A_{13,12} \sin(\delta_{12,13} - \delta_{13,12}),$$

$$T_i \equiv \int_i dp\, A^2_{12,13},$$

$$A_{1j,1k} \equiv A(s_{1j}, s_{1k})$$
$$\delta_{1j,1k} \equiv \delta(s_{1j}, s_{1k})$$

For mirror bins, i and $\bar{i}$: $c_i = c_{\bar{i}}$, $s_i = -s_{\bar{i}}$.

- **With mixing, the number of events in bin i at time t is:**

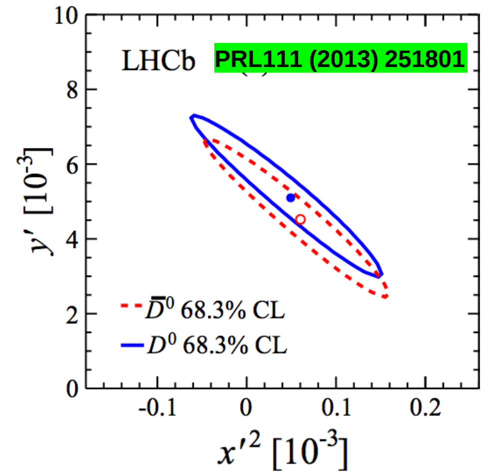
$$T'_i(t) \propto e^{-\Gamma t}[T_i + \sqrt{T_i T_{\bar{i}}}(c_i y_D + s_i x_D)\Gamma t + \mathcal{O}((x_D^2 + y_D^2)(\Gamma t)^2)]$$

[Bondar et al, PRD82, 034033 (2010)]

- **One can fit all bins simultaneously to extract (x_D, y_D), if s_i, c_i are: Known**

D oscillation and strong phase

- short distance is highly suppressed by the GIM mechanism and by the CKM matrix elements withi $x \sim \mathcal{O}(10^{-5}),\ y \sim \mathcal{O}(10^{-7})$
  - NP might manifest in the loop, such as FCNC processes with up-type quark, complementary to those with down quarks (K or B mesons, already studied with observed CPV)
- long distance is dominant: $x\ ,\ y \sim \mathcal{O}(10^{-3})$
  - but theoretical uncertainty is large
- Observation of D$\underline{\text{D}}$ oscillation by CDF and LHCb



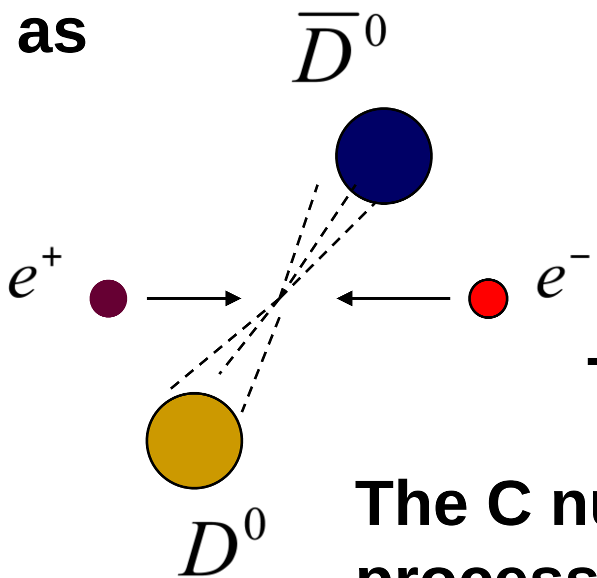
$$y' \equiv y \cos\delta_{K\pi} - x \sin\delta_{K\pi}$$

$$x' \equiv x \cos\delta_{K\pi} + y \sin\delta_{K\pi}$$

- Improving the constraints on the charm mixing parameters is important for testing the SM, such as long-distance effect
- In addition, strong phase is an important ingredient for
  - (over-)constraining the CKM unitarity triangle, which is crucial for searching for new physics
  - extract the mixing parameter (x,y) from (x', y')

The decay rate of a correlated state

For a physical process producing $\overline{D}^0$ D^0 such as $e^+e^- \to \psi'' \to D^0\overline{D}^0$



The D^0 $\overline{D}^0$ pair will be a quantum-correlated state.

The quantum number of ψ'' is $J^{PC} = 1^{--}$

The C number of $\overline{D}^0$ D^0 pair in this process is $C = -$

Taking advantage the quantum coherence of D<u>D</u> pairs, BESIII can study the charm physics in an unique way

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

Strong phase δ and γ/ϕ_3 in the CKM unitarity triangle

- 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 $\Rightarrow$ $y' = y\cos\delta_{K\pi} - x\sin\delta_{K\pi} = (4.8 \pm 1.0) \times 10^{-3}$ (LHCb2013)
  - $\delta_{K\pi}$: QC measurements from Charm factory
- γ/ϕ_3 measurements from $B \to D^0 K$
  - b→u : $\gamma/\phi_3 = \arg V^*_{ub}$
  - most sensitive method to constrain γ/ϕ_3 at present
  - GLW method (Gronau & London, PLB253, 483 (1991); Gronau & Wyler, PLB265, 172 (1991))
  - ADS method (Atwood, Dunetz & Soni, PRL78, 3257 (1997); PRD63, 036005 (2001))
  - GGSZ (Dalitz) method (Giri, Grossman, Soffer & Zupan, PRD68, 054018 (2003))
- GLW and ADS methods in $B \to D^0 K$
  - D^0 to doubly Cabibbo suppressed decays $K^+\pi^-$, $K^+\pi^-\pi^0$
  - Decay rates:

$$\Gamma\left(B^\pm \to (f)_D K^\pm\right) \propto r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B + \delta_D \pm \phi_3)$$

  - r_D, δ_D : QC measurements from Charm factory
  - (r_B, δ_B, ϕ_3) 3 unknowns, 4 measurements □

e^+e^- for τ-charm: physics goals

✓Hadron spectroscopy and test of QCD at low energy:
Light meson and baryon
Glueball: direct test of QCD at low energy
Hybrid/exotics states/multiquark states/molecular states…
Charmonium(-like) spectroscopy and decays / Charmed baryon decays

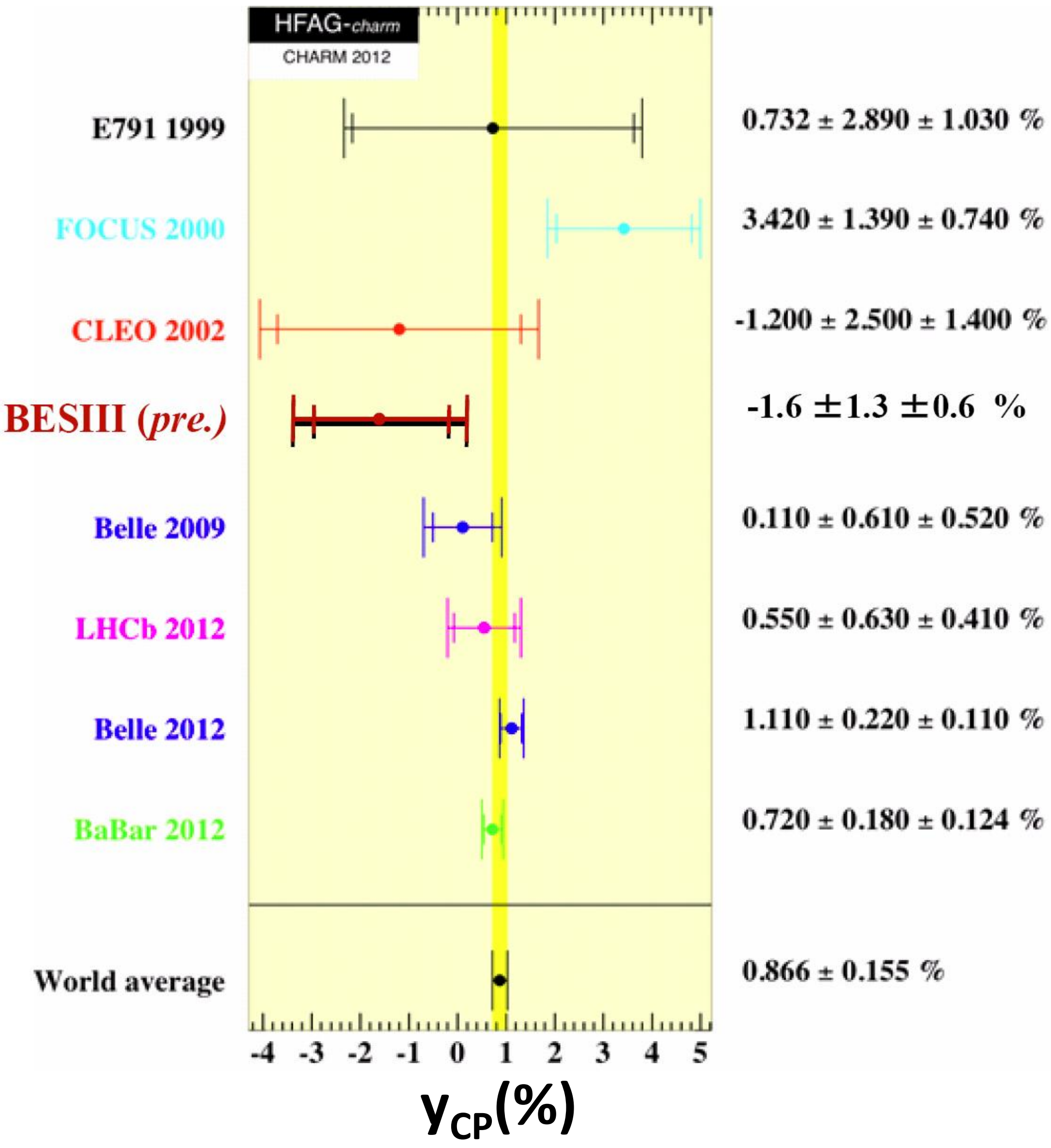
✓Precise test of the Standard Model:
R values, tau mass and tau decays, CKM matrix, lepton universality test…
Decay constants and form factors (in D meson decays)

✓ New physics searches at low energy (tiny/forbidden in SM):
Rare charmonium decays: weak decays, LFV, LNV, BNV …
Rare charm and tau decays: FCNC, LFV, LNV, invisible decays
Rare light meson decays: $\eta/\eta'/\omega/\phi$ rare decays
Neutral D mixing
CP violation in tau and charm: tiny in SM
CP violation in baryon /charmed baryon weak decays

✓ Exotic physics:
Light dark matter candidates, Dark photon, light Higgs boson(a_0),
New interactions…

BESIII is statistical limited

Comparison with world measurement

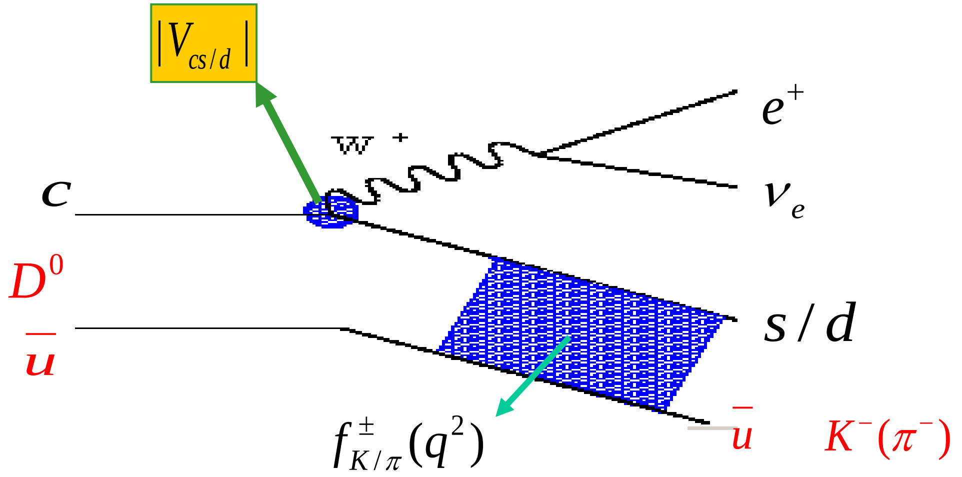


compatible with world average results

CLEOc 2012:
[PRD 86 (2012) 112001]
$y_{CP}=(4.2\pm2.0\pm1.0)\%$

best precision in Charm factory

$D^0 \rightarrow K/\pi^- e^+ \nu$ and form factor $f^+_{K/\pi}(q^2)$



$$\frac{\Delta\Gamma(D^0 \to K/\pi^- e^+ \upsilon_e)}{dq^2} = \frac{G_F^2 |V_{cs(d)}|^2}{24\pi^3} p^3 \left| f_+^2(q^2) \right|^2$$

- The strong interaction effect between the two quarks within the final state meson is simply factorized into the form factor $f^+_{K/\pi}(q^2)$.
- $|V_{cs/d}|$ parameterizes the mixing between the quark mass eigenstates and the two weak eigenstates.

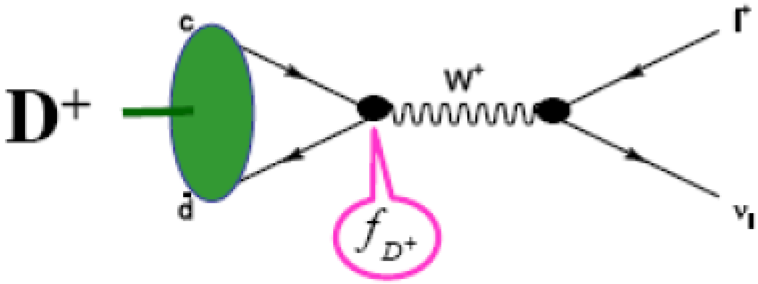
$f^{+}_{K/\pi}(q^2)$ and $|V_{cs/d}|$ from D semileptonic decay

- **In experiment, studies of $D^0 \rightarrow K/\pi^- e^+ \nu$ can provide**
  - **form factors of hadronic current $f^{+}_{K/\pi}(q^2)$**
    - **Single pole form**
    - **Modified pole model**
    - **ISGW2 model**
    - **Series expansion model**
  - **CKM matrix elements $|V_{cs}|$ and $|V_{cd}|$**

- **The improved $f^{+}_{K/\pi}(q^2)$ can be used to validate the LQCD calculations on $f^{+}_{K/\pi}(q^2)$**

- **More accurate measurements of $|V_{cs}|$ and $|V_{cd}|$ can more precisely test the SM.**

$D^+ \to \mu\nu$



$$\Gamma(D^+ \to \mu^+ \upsilon_\mu) = \frac{G_F^2}{8\pi} f_{D^+}^2 \, |V_{cd}|^2 \, m_l^2 \left(1 - \frac{m_l^2}{m_{D^+}^2}\right) m_{D^+}$$

- **f_{D+}: All strong interaction effects between the two initial-state quarks are absorbed into this decay constant**
- **To validate LQCD calculations of f_{D+}**

- **To produce a precise prediction of f_{B+}**
  - **In current LQCD calculations, the ratio f_{D+}/f_{B+} has a significantly better precision than their individual values**
- **To determine $|V_{td}|$**
  - **The well-measured $B^0 - \overline{B^0}$ mixing parameter x_B is related to $|V_{td}|^2$ and f_B ($f_B = f_{B^0} = f_{B^+}$ due to isospin symmetry)**
- **To test the unitarity of CKM matrix, and test the SM**

$|V_{cd}|$ measured via $D^+ \rightarrow \mu^+ \nu$

- In history, $|V_{cd}|$ was usually measured by
  - D meson decay $D \rightarrow \pi e^+ \nu$, which suffers 11% uncertainty of theoretical calculation of form factor;
  - neutrino and anti-neutrino interaction, which suffers 4.8% uncertainty.
- A recent un-quenched LQCD of f_{D+} reaches ~2% precision, thus provides an opportunity to accurately measure $|V_{cd}|$ by $D^+ \rightarrow \mu^+ \nu$.
- More accurate measurements of $|V_{cd}|$ and $|V_{td}|$ will improve the stringency of unitarity constraints on CKM matrix and provide improved test on the Standard Model.

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

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

from flav.-tagged $D \to K_S\pi\pi$

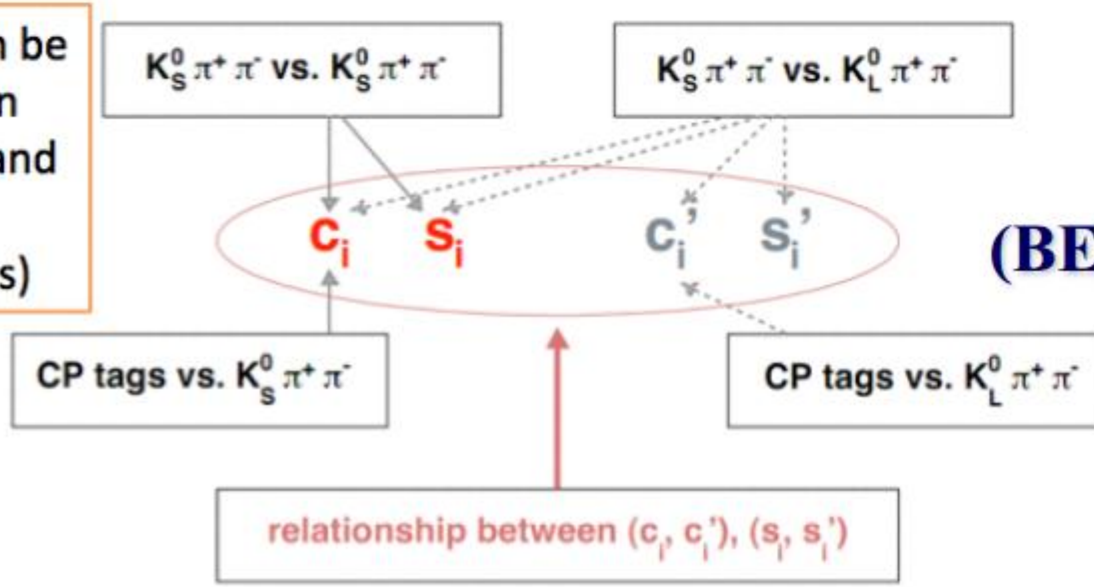
extracted from fit to the $B^\pm$ yields

measured by CLEO [PRD82, 112006 (2010)]

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

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)



(BESIII: 2.9 fb

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.

Calculation of c_i, c'_i, s_i, s'_i

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

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

$$M_i = \frac{S_\pm}{2S_f}(K_i \pm 2c_i\sqrt{K_iK_{\bar{i}}} + K_{\bar{i}}) \quad (CP, K_S^0\pi^+\pi^-)$$

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

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

$$M_{i,j} = \frac{N_{D,\overline{D}}}{2S_f^2}(K_iK_{\bar{j}} + K_{\bar{i}}K_j - 2\sqrt{K_iK_{\bar{j}}K_{\bar{i}}K_j}(c_ic_j + s_is_j)) \quad (K_S^0\pi^+\pi^-, K_S^0\pi^+\pi^-)$$

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

$M_{i,j}$ yields in each i[th] bin of the first Dalitz plot and the j[th] 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.

Running: Now & Later

So far this run (2014) :

About 100 points for R values "scan":

3.85-4.59 GeV, 5 or 10 MeV steps, $\sim 6 - 8$ pb^{-1} per point

500 pb^{-1} @ 4.60 GeV for XYZ states;

Future runs (no particular order)

- **Ds data @ 4.170 GeV**
- **more $\psi(3770)$ for D physics**
- **More "XYZ", J/ψ, ψ'**

Easy to fill MANY years !

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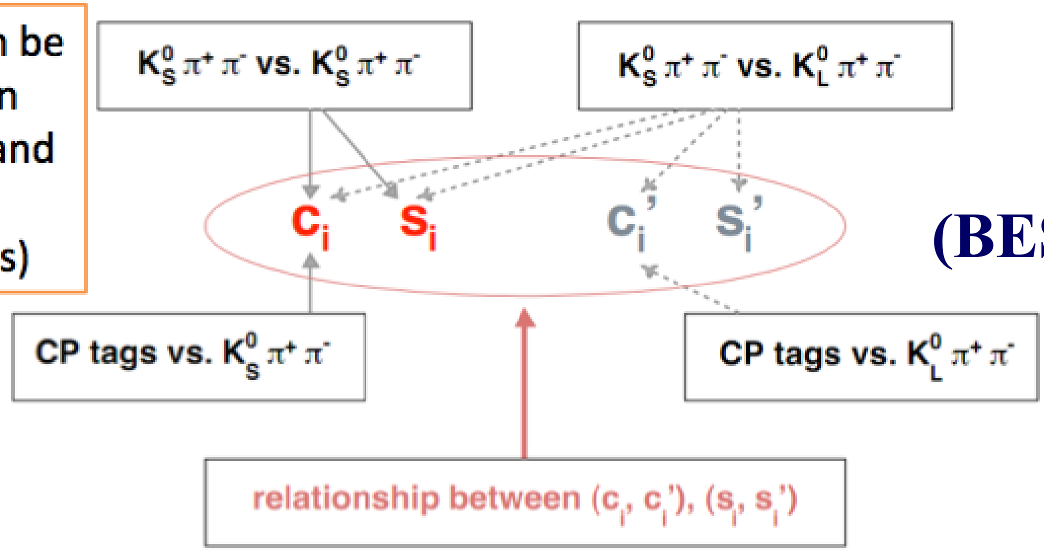

(BESIII: 2.9 fb^{-1})

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