$D^0 - \overline{D}^0$ mixing and CPV at BES-III

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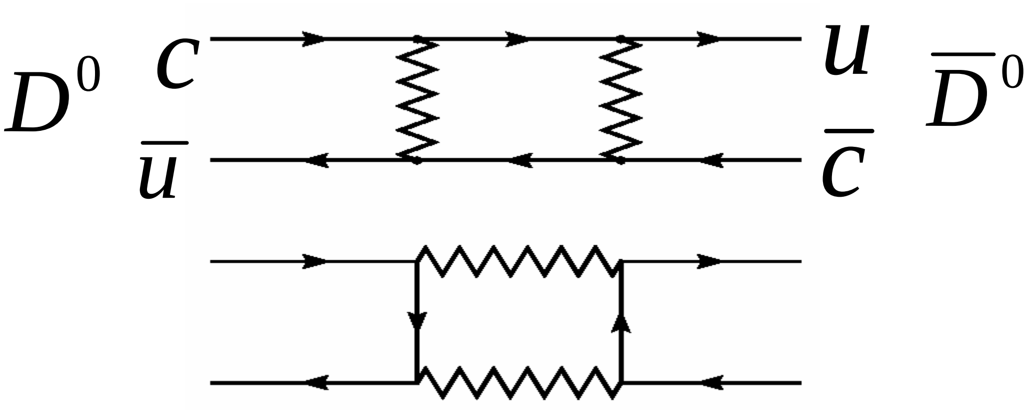
Outline

- A brief review
- Mixing and strong phase at BES-III
- Sensitivity to CPV at BES-III
- CPV in angular correlation
- Rare and forbidden charm decays
- Summary

Neutral D mixing --general definitions

D^0 and $\overline{D}^0$ can transform into each other under weak interaction



The weak eigenstates are

$$|D_1\rangle = p|D^0\rangle + q|\overline{D}^0\rangle$$

$$|D_2\rangle = p|D^0\rangle - q|\overline{D}^0\rangle$$

With eigenvalues

$$\mu_1 = m_1 - \frac{i}{2}\Gamma_1$$

$$\mu_2 = m_2 - \frac{i}{2}\Gamma_2$$

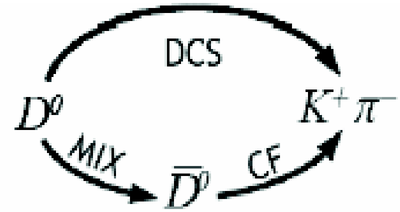
$$m \equiv \frac{m_1 + m_2}{2}, \qquad \Delta m \equiv m_2 - m_1$$

$$\Gamma \equiv \frac{\Gamma_1 + \Gamma_2}{2}, \qquad \Delta\Gamma \equiv \Gamma_2 - \Gamma_1$$

$$x \equiv \frac{\Delta m}{\Gamma}, \qquad y \equiv \frac{\Delta\Gamma}{2\Gamma}$$

Weak interaction, long-distance strong interaction make an observable mixing rate. While new physics favor x>>y .

D mixing at B factories



- Two ways to reach same final state:
  → interference
- Distinguish doubly Cabibbo-suppressed (DCS) from mixing using proper time evolution
  - DCS: exponential proper time distribution
  - Mixed decays only occur after some time

- Time evolution: $(|x| << 1,\ |y| << 1)$, CP-conserving

$$T_{\mathrm{WS}}(t) = e^{-\Gamma t}\left(\underbrace{R_{\mathrm{D}}}_{\text{DCS}} + \underbrace{\sqrt{R_{\mathrm{D}}}y'\,\Gamma t}_{\text{interference}} + \underbrace{\frac{x'^2 + y'^2}{4}(\Gamma t)^2}_{\text{mixing}}\right) \quad (1)$$

- strong phase: $x' = x\cos\delta_{K\pi} + y\sin\delta_{K\pi}, \qquad y' = -x\sin\delta_{K\pi} + y\cos\delta_{K\pi}$
  $\delta_{K\pi}$ is the strong phase between DCS and CF amplitudes

Combined results from HFAG

Semileptonic and hadronic D decays

$$R_M = \frac{x^2 + y^2}{2} = \frac{x'^2 + y'^2}{2}$$

$$R_M = (2.1 \pm 1.1) \times 10^{-4}$$

Averaged WS $K\pi$ mixing results (time-dependent):

$$x'^2 = (-0.1 \pm 2.0) \times 10^{-4}$$

$$y' = (0.55^{+0.28}_{-0.37})\%$$

$$R_D = (0.330^{+0.014}_{-0.012})\%$$

Averaged mixing results (time-dependent):

$$x = (0.87^{+0.30}_{-0.34})\%$$

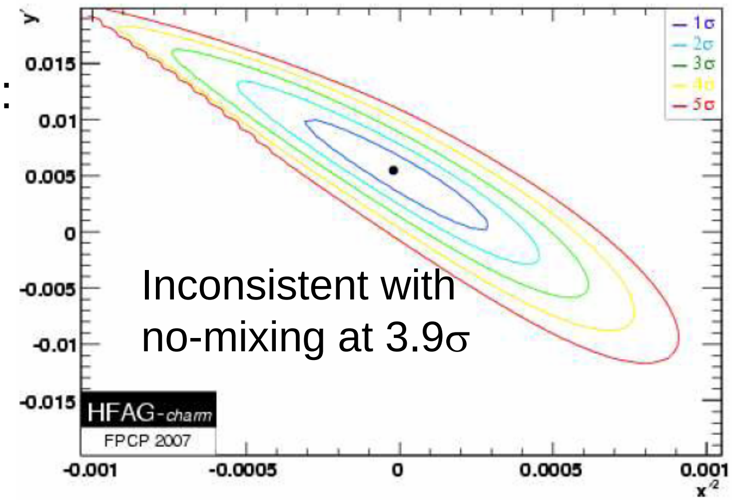
$$y = (0.66 \pm 0.21)\%$$

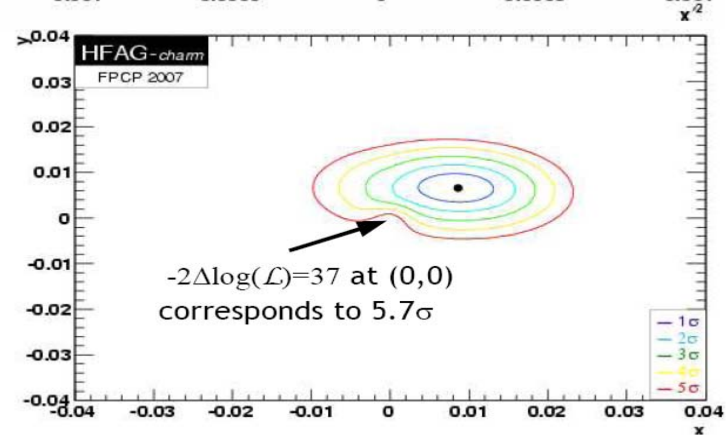
This average include preliminary CLEO-c measurement of $\cos\delta_{K\pi} = 1.09 \pm 0.66$

Averaged y_{CP} from KK, $\pi\pi$ lifetime ratio

$$y_{CP} = (1.12 \pm 0.32)\% \quad (3.9\ \sigma)$$

Combined contour in (x'^2, y'):



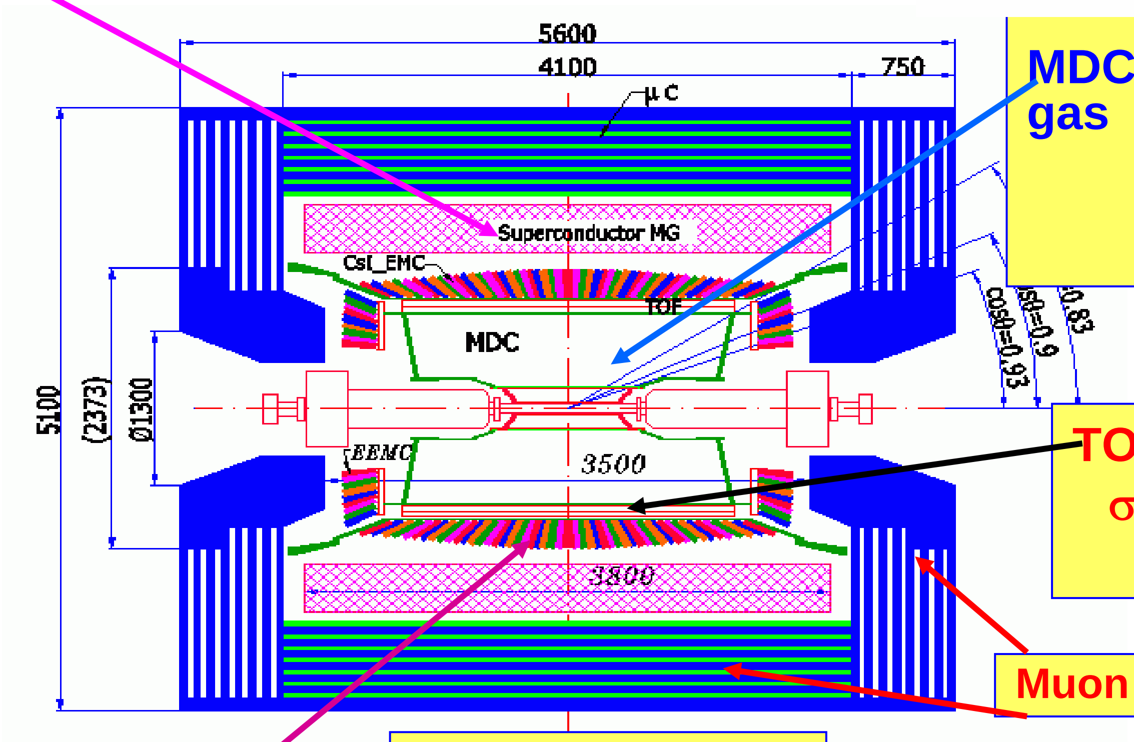


BES-III

BESIII detector: all new !

CsI calorimeter
Precision tracking
Time-of-flight + dE/dx PID

Magnet: 1 T Super conducting



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

TOF:
σ_T = 100 ps Barrel
110 ps Endcap

Muon ID: 9 layer RPC

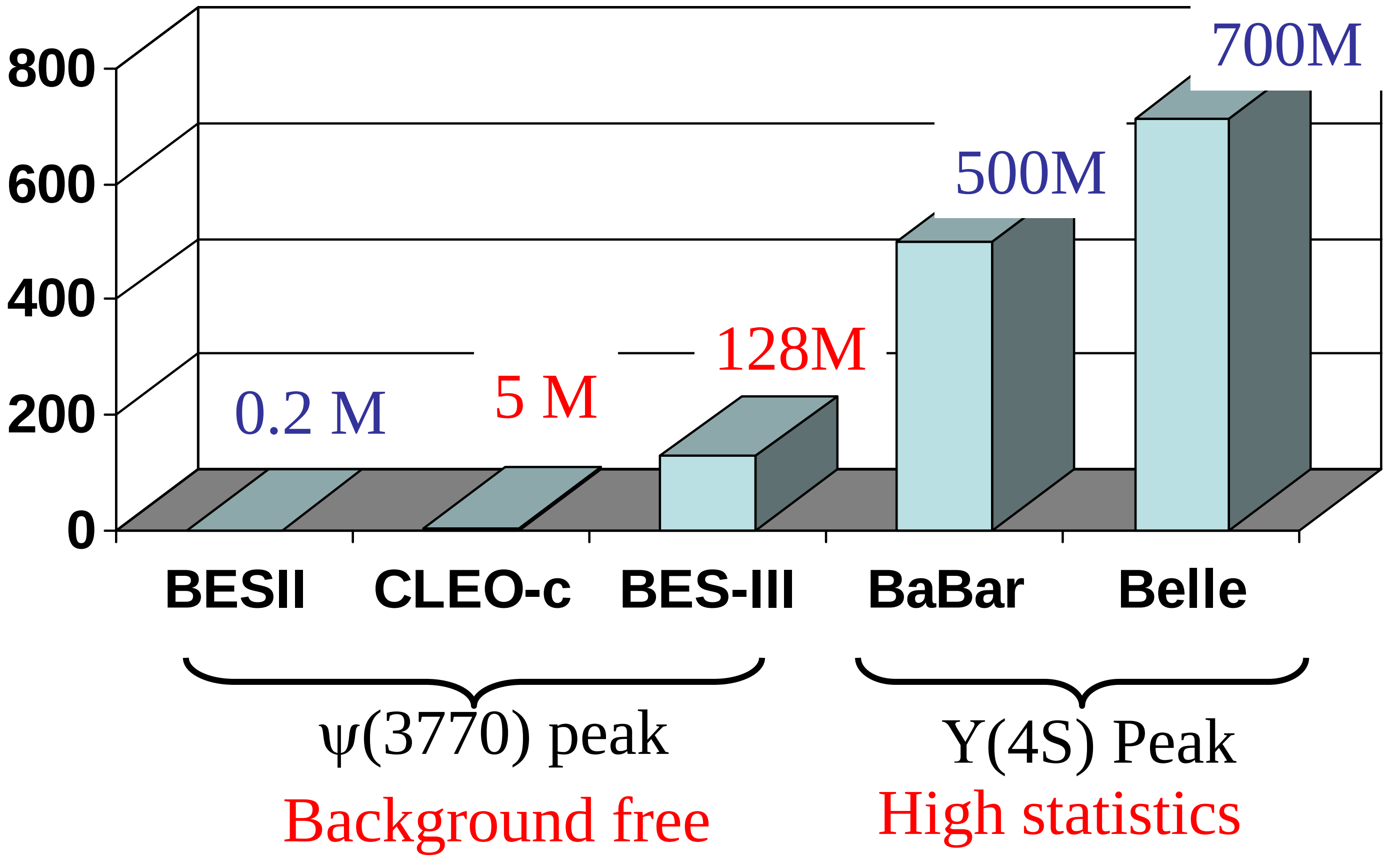
EMC: CsI crystal
ΔE/E = 2.5% @1 GeV
σz = 0.6 cm/√E

Data Acquisition:
Event rate = 4 kHz
Thruput ~ 50 MB/s

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

$D\bar{D}$ Pairs from different experiments

128 M are expected at BES-III with 4 years' luminosity@ψ(3770).
5 M are expected at CLEO-c until 2008@ψ(3770).



Quantum Correlation

At BES-III:

$D\overline{D}$ pair with L =1 must be in anti-asymmetric state

$$|D^0\overline{D}^0\rangle^{C=-1} = \frac{1}{\sqrt{2}}\left[|D^0\rangle|\overline{D}^0\rangle - |\overline{D}^0\rangle|D^0\rangle\right]$$

the interference comes for free:

$$M_{ij}^2 = \left|\langle i|D^0\rangle\langle j|\overline{D^0}\rangle - \langle j|D^0\rangle\langle i|\overline{D^0}\rangle\right|^2$$

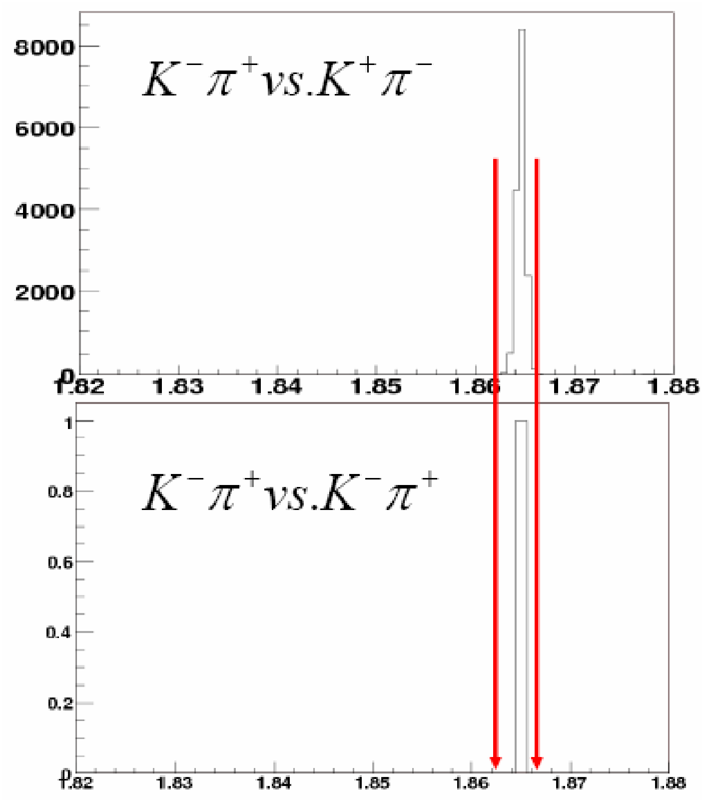
PRD 73, 034024 (2006)
Asner and Sun
I.I.Bigi SLAC report-33, 1989 page 169

(C=–1) $e^+e^- \to \psi(3770) \to$	D	$\overline{D}$
Forbidden if no mixing	$K^-\pi^+$	$K^-\pi^+$
Forbidden if no mixing	$K^-l^+\nu$	$K^-l^+\nu$
Forbidden by CP conservation	CP+	CP+
Forbidden by CP Conservation	CP–	CP–
Interference of CF with DCS	$K^-\pi^+$	CP±

The mixing rate R_M can be measured at the first order
Strong phase $\delta_{K\pi}$ is from CP tagged $D \to K\pi$
CP violation is measured in a production rate.

Mixing rate R_M from $\psi(3770)\to D^0\bar{D}^0\to(K^-\pi^+)(K^-\pi^+)$

Sensitivity in 20 fb^{-1} data at BES-III:



Beam constraint mass

$$m_{BC}=\sqrt{E_{beam}^2-P_D^2}$$

Background estimate:

$K^+K^- vs. K^+K^-$	1078	0
$\pi^+\pi^- vs. \pi^+\pi^-$	136	0
$K^+\pi^- vs. K^+K^-$	21057	0
$K^+\pi^- vs. \pi^+\pi^-$	7470	0
$K^+K^- vs. \pi^+\pi^-$	765	0
$K^+\pi^- vs. K^-\pi^+$	150000	2

2 events in the signal region due to mis-ID. (the mis-ID rate for pi as a Kaon is 1%).

RM < 1.5×10^{-4}

Challenge to PID in mixing rate measurements

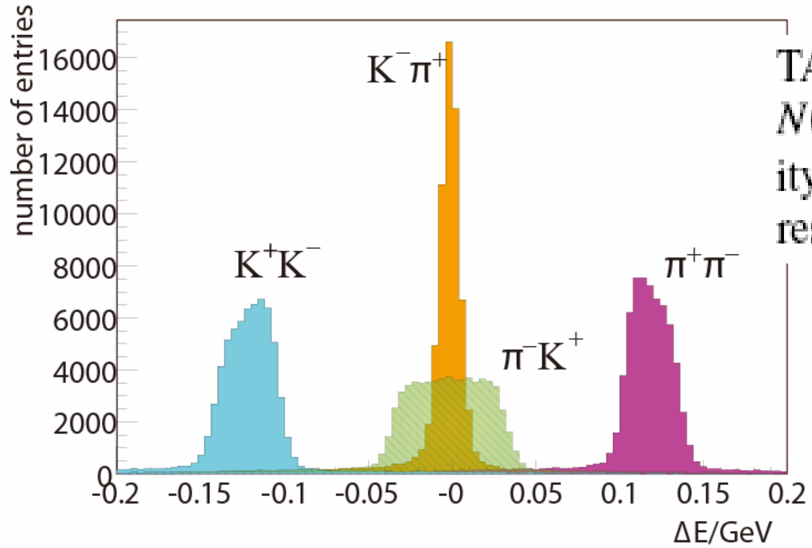
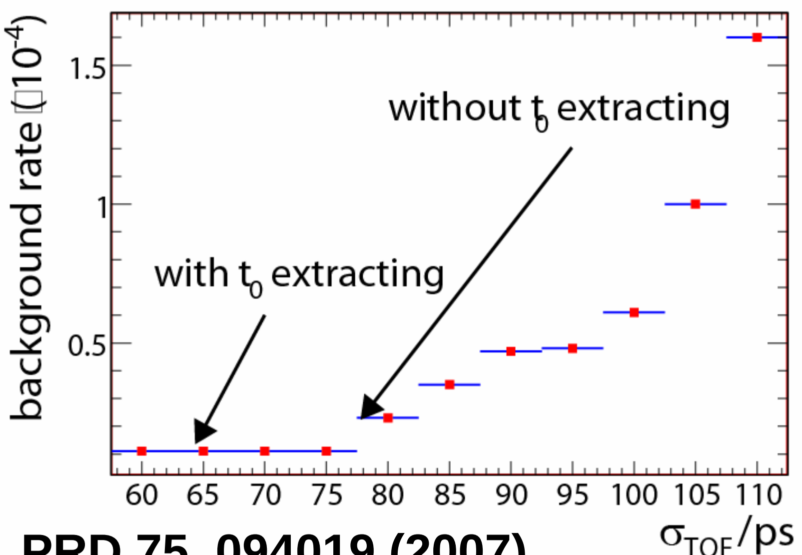


TABLE III. The expected mixing signal for $N_{sig} = N(K^{\pm}\pi^{\mp})(K^{\pm}\pi^{\mp})$, background N_{bkg}, and the Poisson probability $P(n)$ in 10 fb^{-1} and 20 fb^{-1} at BES-III at $\psi(3770)$ peak, respectively. Here, we take the mixing rate $R_M = 1.18 \times 10^{-4}$.

	10 fb^{-1} ($\psi(3770)$) 36×10^6 $D^0\bar{D}^0$	20 fb^{-1} ($\psi(3770)$) 72×10^6 $D^0\bar{D}^0$
N_{sig}	1.5	3.0
N_{bkg}	0.3	0.6
$P(n=0)$	15.7%	2.5%
$P(n=1)$	29.1%	9.1%
$P(n=2)$	26.9%	16.9%
$P(n=3)$	16.6%	20.9%
$P(n=4)$	7.7%	19.3%
$P(n=5)$	2.8%	14.3%
$P(n=6)$	0.9%	8.8%
$P(n=7)$	0.2%	4.7%
$P(n=8)$	0.1%	2.2%
$P(n=9)$	0.01%	0.9%



PRD 75, 094019 (2007)
Cheng, He, Li and Wang

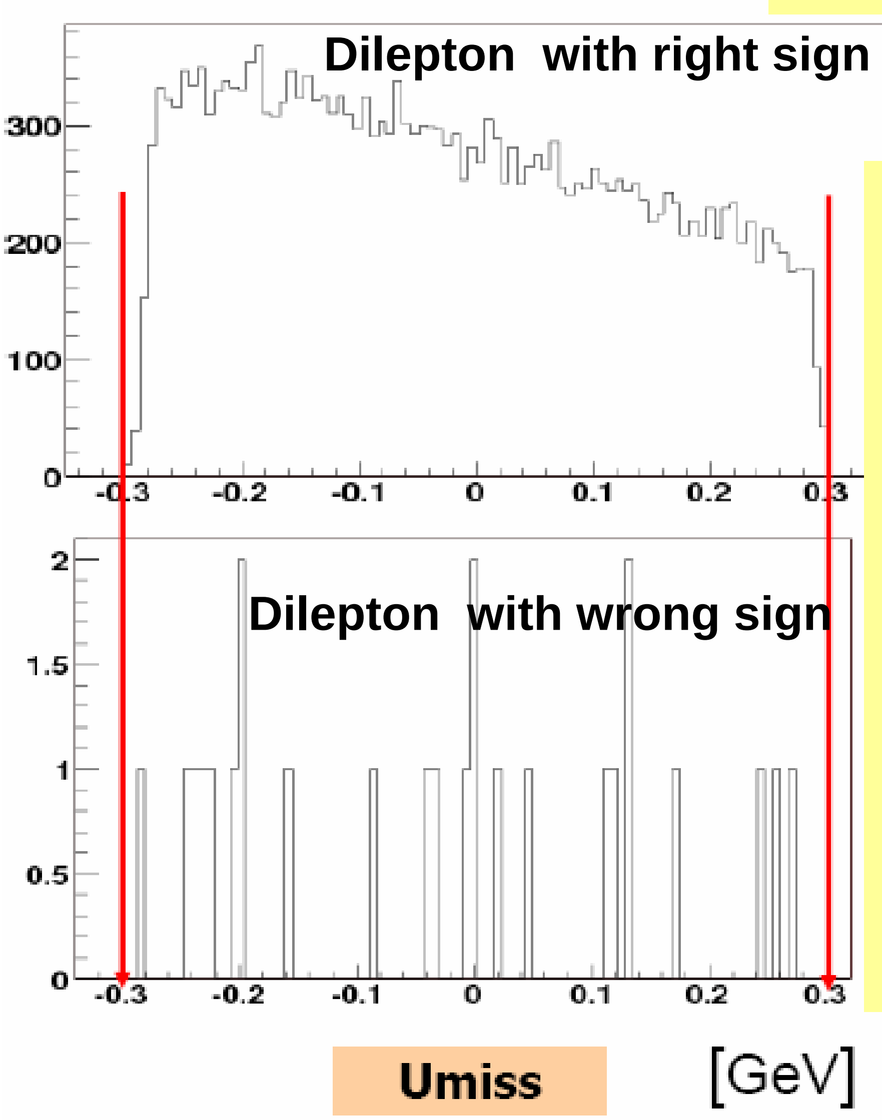
HEP & NP 31(05), 2007 Sun Y. Z. et al

$R_M < 1.5 \times 10^{-4}$ @ 95% C.L. with 20 fb^{-1} data at BES-III.

Mixing rate from semileptonic mode

20 fb^{-1} data at BES-III:

$$e^+e^- \to \gamma^* \xrightarrow{\psi(3770)} D\bar{D} \to (K^- l^+ \nu)(K^- l^+ \nu)$$



Dilepton with the same sign is the signal for "mixing" in SM.

The background is high and the sensitivity is about 1×10^{-3}, which is "second order effect".

Of course, since the time-evolution is not measured, observation of this reaction would indicate the violation of the selection rule relating the change in charm to the change in leptonic charge: it is true in SM, but new physics may make it without need of mixing.

I.I.Bigi SLAC report-33, 1989 page 169

Sensitivity to y and y_{CP} at BES-III

The y can be probed at the first order sensitivity:

- ✓ **Reconstruct *K+K-* (*CP*+) decay → other side must be D_1 (*CP*-)**
- ✓ **Inclusive *K+K-* rate probes *y*:**

$$n_{KK} = 2B_{KK}\Gamma_1 = 2B_{KK}(1-\eta y)\Gamma \quad \text{where } \eta = \pm 1 \text{ for CP} = \pm$$

$$1 - y = \frac{n_{KK}}{2N_{DD}}\frac{1}{B_{KK}}$$

✓**y_{CP} in semileptonic tag + CP tags:**

PRD 75, 094019 (2007)
Cheng, He, Li and Wang

$$y_{CP} = \frac{\Gamma(CP+) - \Gamma(CP-)}{\Gamma(CP+) + \Gamma(CP-)} = y\cos\phi + x\cdot\Delta\sin\phi$$

No CPV in mixing →

$$y_{CP} \approx y\cos\phi$$

With 20 fb $^{-1}$ data at BES-III,
and the CP tag rate is 1.1%,
thus the sensitivity to y_{CP} is
0.003, which could be 4.3 σ if the
world average hold up.

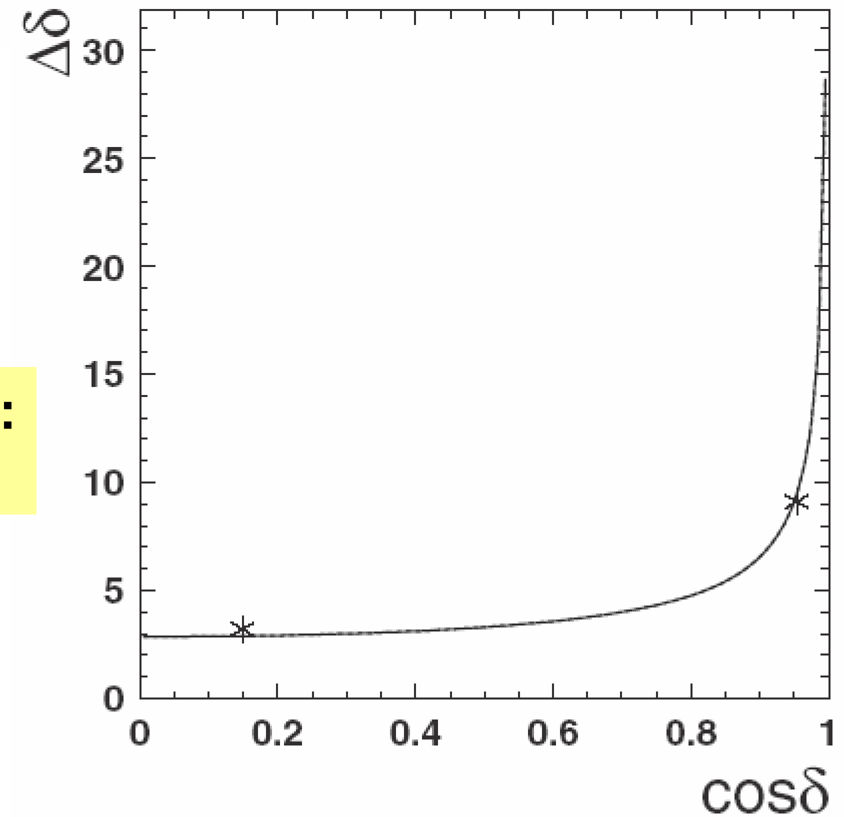
$$\Delta(y) = \frac{\pm 26}{\sqrt{N(D^0\bar{D}^0)}} = \pm 0.003.$$

The first order sensitivity to strong phase

$$\mathcal{A} \equiv \frac{\Gamma_{K\pi,f_+} - \Gamma_{K\pi;f_-}}{\Gamma_{K\pi,f_+} + \Gamma_{K\pi;f_-}}, = 2\sqrt{R_D}\cos\delta.$$

$$\Delta(\cos\delta) \approx \frac{1}{2\sqrt{R_D}\sqrt{N_{K^-\pi^+}}}.$$

At BES-III, 20 fb-1 data, the sensitivity:
δ (cosδ) = 0.04



CLEO PRELIMINARY is hold on:

cosδ = 1.03 $\pm$ 0.19 (stat) $\pm$ 0.08 (syst)

BESIII will pin down [-25^o – 25^o]

The model independent strong phase determination is useful for γ/ϕ_3
See A. Poluektov's talk.

Estimation of TQCA scaled from CLEO-c

parameter	value	CLEO-c ($3\times10^6 D^0\bar{D}^0$)		BESIII($20fb^{-1}$)	
		C=-1	C=+1	C=-1	C=+1
y	0	±0.01	±0.007	±0.003	±0.002
x^2	0	±0.0006	±0.0003	±0.00013	±0.0001
$\cos\delta_{K\pi}$	1	±0.15	±0.13	±0.035	±0.04
$x\sin\delta_{K\pi}$	0	—	±0.03	—	±0.003

From Sun's talk from CLEO-c at Charm2007

CPV in D system at BES-III

1. A_D — CP violation in decay

$$D^0 \to f \iff \overline{D}^0 \to \bar{f}$$

2. A_M — CP violation in mixing

$$D^0 \to \overline{D}^0 \to f$$

$$\Updownarrow$$

$$\overline{D}^0 \to D^0 \to \bar{f}$$

New physics favor:
x>>y
CP violation

3. ϕ — CP violation in the interference between decays with and without mixing

$$D^0 \longrightarrow f$$

$$D^0 \to \overline{D}^0 \to f$$

CP violation in D system

- CP violation in D decays is a clean way to probe new physics since the SM predicts an unobservable asymmetry: 10^{-4}
- CPV in SCS decay is sensitive to New physics since it is the only one to probe the gluonic penguin operators in the loop.
- CPV-in-mixing is the real new physics signal.
- In SM, no direct CP asymmetry in CF and DCS charm decay modes. Sensitive to new physics.
- 1% level CPV likely indicates new physics!

CPV in D decays is the next big thing in charm physics, but one has to think about the systematic effect, which should be controlled under 10^{-3} level. It is really a challenge to experiments.

CP violation at BES-III

- Quantum correlation
  - $\psi(3770) \rightarrow$ D(CP+)D(CP+), D(CP–)D(CP–)
- CP asymmetry in D^+ and Ds decays
- CP asymmetry in D^0 decays
  - Have to pay price for tag
  - Flavor tag with semileptonic mode at $\psi(3770)$
  - Flavor tag with $D^+ \rightarrow K^- \pi^+ \pi^+$ modes above DD* threshold (4.03GeV / 4.17 GeV)

$$e^+e^- \rightarrow D^+\bar{D}^{*-} \rightarrow D^+(\bar{D}^0\pi^-_{soft})$$

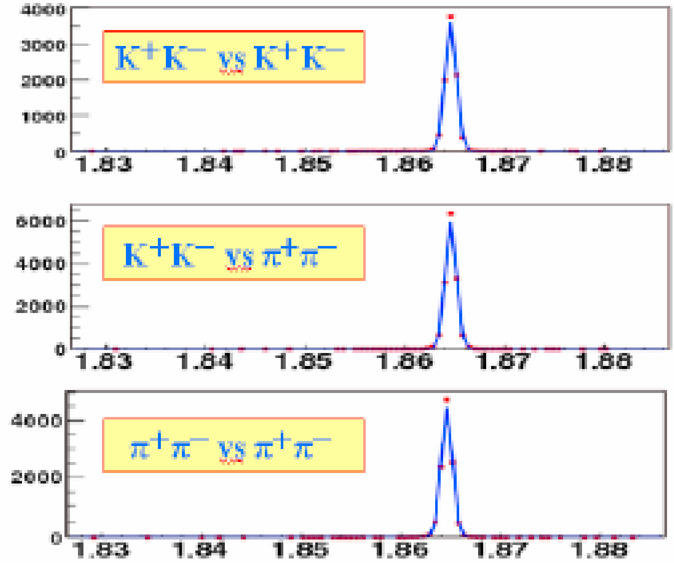
CP violation

Expected event numbers of the double tag modes in 20 fb^{-1} $\Psi(3770)$ data → $N_{D0D0} = 7.1224 \cdot 10^7$

Mode	Exp. number (if totally CPV)
K^+K^- vs K^+K^- (signal)	1078
K^+K^- vs $\pi^+\pi^-$ (signal)	765
$\pi^+\pi^-$ vs $\pi^+\pi^-$ (signal)	136
K^+K^- vs $K^-\pi^+$ (background)	21056
$\pi^+\pi^-$ vs $K^-\pi^+$ (background)	7470
$K^-\pi^+$ vs $K^+\pi^-$ (background)	102847

Efficiencies of signal channels

BOSS 6.0.2

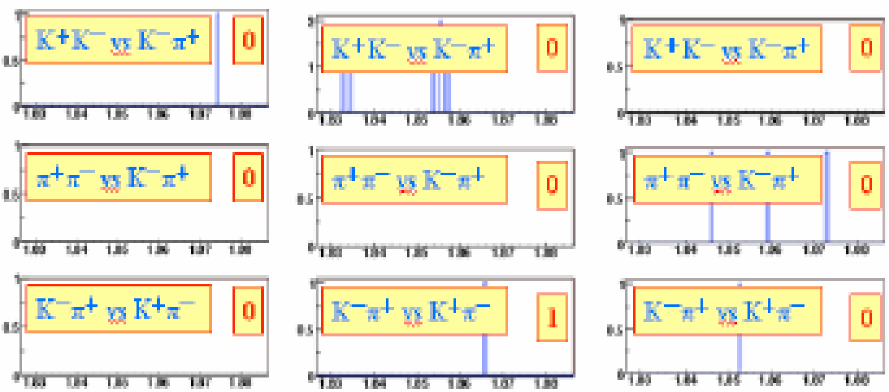


→ $\varepsilon = 43.8\ \%$

→ $\varepsilon = 47.2\ \%$

→ $\varepsilon = 53.3\ \%$

Mode	ε (%)	Tot CPV	Main background	
K^+K^- vs K^+K^-	43.8	440	K^+K^- vs $K^-\pi^+$	0
			$\pi^+\pi^-$ vs $K^-\pi^+$	0
			$K^-\pi^+$ vs $K^+\pi^-$	0
K^+K^- vs $\pi^+\pi^-$	47.2	340	K^+K^- vs $K^-\pi^+$	0
			$\pi^+\pi^-$ vs $K^-\pi^+$	0
			$K^-\pi^+$ vs $K^+\pi^-$	1
$\pi^+\pi^-$ vs $\pi^+\pi^-$	53.3	66	K^+K^- vs $K^-\pi^+$	0
			$\pi^+\pi^-$ vs $K^-\pi^+$	0
			$K^-\pi^+$ vs $K^+\pi^-$	0



K^+K^- vs K^+K^- | K^+K^- vs $\pi^+\pi^-$ | $\pi^+\pi^-$ vs $\pi^+\pi^-$

The sensitivity is about : $A_{CP} \sim 5 \cdot 10^{-3}$ @ 90% C.L.

CPV in angular analyses
a proposal

Poor data for $D \rightarrow V_1 V_2$ in PDG

D^0 decay

Large branching ratios!

$\overline{K}^*(892)^0 \rho^0$	(1.50 ± 0.33) %	
$\overline{K}^*(892)^0 \rho^0$ transverse	(1.6 ± 0.5) %	
$\overline{K}^*(892)^0 \rho^0$ S-wave	(2.9 ± 0.6) %	
$\overline{K}^*(892)^0 \rho^0$ S-wave long.	< 3 $\times 10^{-3}$	CL=90%
$\overline{K}^*(892)^0 \rho^0$ P-wave	< 3 $\times 10^{-3}$	CL=90%
$\overline{K}^*(892)^0 \rho^0$ D-wave	(2.0 ± 0.6) %	
$K^*(892)^- \rho^+$	(6.4 ± 2.5) %	
$K^*(892)^- \rho^+$ longitudinal	(3.1 ± 1.2) %	
$K^*(892)^- \rho^+$ transverse	(3.4 ± 2.0) %	
$K^*(892)^- \rho^+$ P-wave	< 1.5 %	CL=90%

Missing modes

ρρ

ρω

ωω

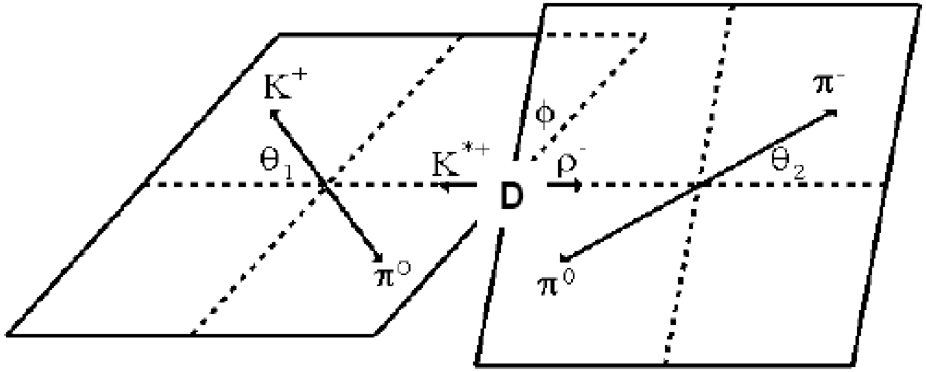
D^+ decay

$\overline{K}^*(892)^0 \rho^+$ total	[ss]	(1.8 ±1.4) %	
$\overline{K}^*(892)^0 \rho^+$ S-wave	[ss]	(1.4 ±1.5) %	
$\overline{K}^*(892)^0 \rho^+$ P-wave		< 1 $\times 10^{-3}$	CL=90%
$\overline{K}^*(892)^0 \rho^+$ D-wave		(8 ±7) $\times 10^{-3}$	
$\overline{K}^*(892)^0 \rho^+$ D-wave longitudinal		< 7 $\times 10^{-3}$	CL=90%
$K^*(892)^+ \overline{K}^*(892)^0$		(2.6 ±1.1) %	

Angular measurement in D → V_1V_2

- Basic quantum mechanics

BaBar: B→ φK*
A. Gritsan at ICHEP04



$$
\begin{aligned}
CP\text{-even longitudinal} &: A_0 = -\tfrac{1}{\sqrt{3}}S + \sqrt{\tfrac{2}{3}}D \\
CP\text{-even transverse} &: A_{\|} = \sqrt{\tfrac{2}{3}}S + \tfrac{1}{\sqrt{3}}D \\
CP\text{-odd transverse} &: A_{\perp} = P
\end{aligned}
$$

- Amplitudes from angular dependence for (V→ PP')

Longitudinal

Transverse

$\mathcal{H}_1 = \cos(\theta_1)$; $\mathcal{H}_2 = \cos(\theta_2)$

$$
\begin{aligned}
\frac{8\pi}{9\Gamma}\frac{d^3\Gamma}{d\mathcal{H}_1 d\mathcal{H}_2 d\Phi} = \frac{1}{|A_0|^2+|A_{\|}|^2+|A_{\perp}|^2} \times \{ \\
|A_0|^2\mathcal{H}_1^2\mathcal{H}_2^2 + \frac{1}{4}(|A_{\|}|^2+|A_{\perp}|^2)(1-\mathcal{H}_1^2)(1-\mathcal{H}_2^2) \\
+\frac{1}{4}(|A_{\|}|^2-|A_{\perp}|^2)(1-\mathcal{H}_1^2)(1-\mathcal{H}_2^2)\cos 2\Phi \\
-\mathcal{I}\mathrm{m}(A_{\perp}A_{\|}^*)(1-\mathcal{H}_1^2)(1-\mathcal{H}_2^2)\sin 2\Phi \\
+\sqrt{2}\mathcal{R}\mathrm{e}(A_{\|}A_0^*)\mathcal{H}_1\mathcal{H}_2\sqrt{1-\mathcal{H}_1^2}\sqrt{1-\mathcal{H}_2^2}\cos\Phi \\
-\sqrt{2}\mathcal{I}\mathrm{m}(A_{\perp}A_0^*)\mathcal{H}_1\mathcal{H}_2\sqrt{1-\mathcal{H}_1^2}\sqrt{1-\mathcal{H}_2^2}\sin\Phi \}.
\end{aligned}
$$

- 10 parameters for D^0 and $\overline{D}^0$:

$\lvert A_{\text{total}}\rvert$:	n_{sig} and $\mathcal{A}_{CP}$
$\lvert A_0\rvert$:	f_L and $\mathcal{A}_{CP}^0$
$\lvert A_{\perp}\rvert$:	$f_{\perp}$ and $\mathcal{A}_{CP}^{\perp}$
$\arg(A_{\|})$:	$\phi_{\|}$ and $\Delta\phi_{\|}$
$\arg(A_{\perp})$:	$\phi_{\perp}$ and $\Delta\phi_{\perp}$

CP asymmetry and T odd correlation in D→ V_1V_2

A. Gritsan at ICHEP04

- CP from New Physics interference: $\Delta\delta_{weak} \neq 0$;
- Direct asymmetry $\propto \sin(\Delta\delta_{weak}) \bullet \sin(\Delta\delta_{strong})$

$$|A_0|^2 \neq |\bar{A}_0|^2$$
$$|A_\parallel|^2 \neq |\bar{A}_\parallel|^2$$
$$|A_\perp|^2 \neq |\bar{A}_\perp|^2$$

- Triple-product:

Asymmetry in phases (define $\Delta\phi_\parallel = \arg(\bar{A}_\parallel/\bar{A}_0) - \arg(A_\parallel/A_0)\ldots$)

$$\mathrm{Im}(A_\perp A_0^*) \neq -\mathrm{Im}(\bar{A}_\perp \bar{A}_0^*)$$

$\propto \sin\Delta\delta_{\mathrm{weak}} \; \cos\Delta\delta_{\mathrm{strong}}$

$$\mathrm{Im}(A_\perp A_\parallel^*) \neq -\mathrm{Im}(\bar{A}_\perp \bar{A}_\parallel^*)$$

Maximum Likelihood Method

Estimate parameters (e.g. N_{sig}) with D → V_1V_2

$$\vec{x}_j = (m_{ES}, \Delta E, m_{V_1}, m_{V_2}, \theta_1, \theta_2, \Phi, \varepsilon, Q_{tag})$$

Max: $$\mathscr{L} = \exp\left(-\sum_{i,k} n_{ik}\right)\prod_{j=1}^{N}\exp\left(\ln\left(n_{ik}PDF(\vec{x}_j \vec{\alpha})\right)\right)$$

PDF: $$PDF_{i,k}(\vec{x}_j) = P_{i1}(m_{ES}) \bullet P_{i2}(\Delta E) \bullet P_{i3}(\varepsilon) \bullet$$

$$P_{i4}(m_{V_1}) \bullet P_{i5}(m_{V_2}) \bullet P_{i,k}^{hel}(\theta_1, \theta_2, \Phi, f_L, f_{\perp}, \phi_{\perp}, \phi_{\|})$$

$$f_L = \frac{|A_0|^2}{\sum |A_\lambda|^2}, \quad f_\perp = \frac{|A_\perp|^2}{\sum |A_\lambda|^2}$$

Measure:

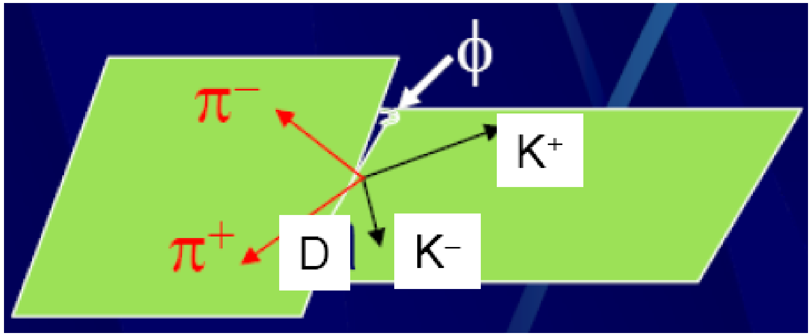
$$\phi_\| = \arg\left(\frac{A_\|}{A_0}\right), \quad \phi_\perp = \arg\left(\frac{A_\perp}{A_0}\right).$$

Search for T-odd correlation by I. I. Bigi

I. Bigi: I Know She Invented Fire, But What Has She Done Recently?" – On The Future Of Charm Physics, hep-ph/0608073

Consider the Cabibbo suppressed decay

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



□ Compute the angle ϕ between the K^+K^- and $\pi^+\pi^-$ decay planes for $D^0 \to K^+K^-\pi^+\pi^-$. Then one has:

$$\frac{d\Gamma}{d\phi}(D^0 \to K^+K^-\pi^+\pi^-) = \Gamma_1 cos^2\phi + \Gamma_2 sin^2\phi + \Gamma_3 cos\phi sin\phi$$

$$\frac{d\Gamma}{d\phi}(\overline{D^0} \to K^+K^-\pi^+\pi^-) = \bar{\Gamma}_1 cos^2\phi + \bar{\Gamma}_2 sin^2\phi + \bar{\Gamma}_3 cos\phi sin\phi$$

$$\Gamma_3 \neq \bar{\Gamma}_3 \to CP \quad violation$$

This is also applied to charged D 4-body decays!

Angular correlation

At BES-III:

$D\overline{D}$ pair with L =1 must be in anti-asymmetric state

$$|D^0\overline{D}^0\rangle^{C=-1} = \frac{1}{\sqrt{2}}\left[|D^0\rangle|\overline{D}^0\rangle - |\overline{D}^0\rangle|D^0\rangle\right]$$

the interference comes for free:

$$M_{ij}^2 = \left|\langle i|D^0\rangle\langle j|\overline{D^0}\rangle - \langle j|D^0\rangle\langle i|\overline{D^0}\rangle\right|^2$$

CP-even longitudinal	: A_0	=	$-\frac{1}{\sqrt{3}}S$	$+\sqrt{\frac{2}{3}}D$
CP-even transverse	: $A_{\|}$	=	$\sqrt{\frac{2}{3}}S$	$+\frac{1}{\sqrt{3}}D$
CP-odd transverse	: $A_{\perp}$	=	P	

$$\psi(3770) \to D\overline{D} \to (V_1V_2)(\overline{V}_1\overline{V}_2)$$

$$\mathrm{CP}(V_1V_2) = CP(\overline{V}_1\overline{V}_2) \Rightarrow \mathrm{CPV}$$

Fully reconstruct both D decay to VV, if you see:

$f_L^1 \neq 0$, and $f_L^2 \neq 0$

or

S (D) wave .vs. S (D) wave

P wave .vs. P wave

} **CPV**

Without CPV:

only S .vs. P, D .vs. P, S+D .vs. P allowed

- **Few dilution from mis-ID.**
- **Rich FSI and extended LH fit with multi-variables can improve the sensitivity.**

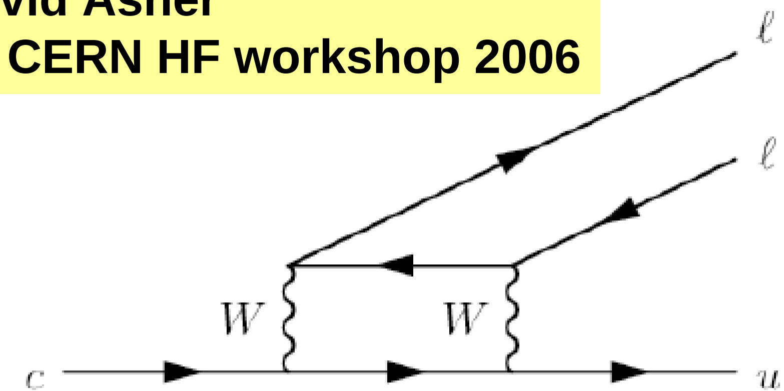
Full angular analysis:
Jerome Charles
Sebastien Descotes-Genon
Hai-bo Li

Rare and forbidden Charm Decays

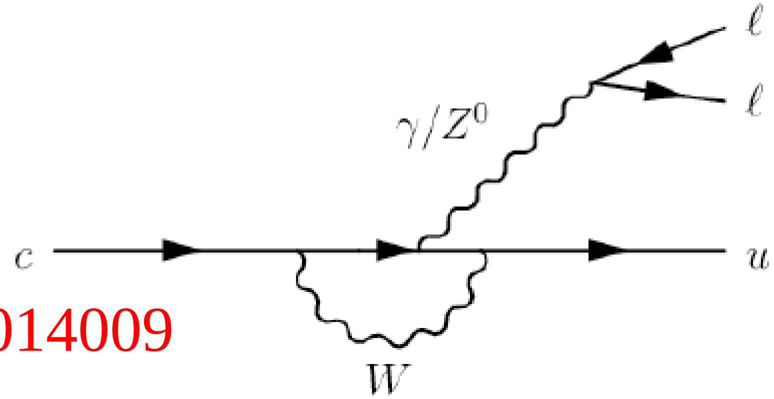
Charm FCNC decays heavily GIM suppressed in SM:

David Asner
at CERN HF workshop 2006

$BF(c \to ull) \sim 10^{-8}$



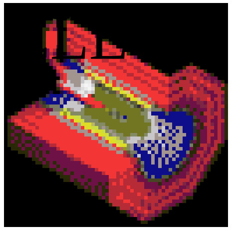
Burdman et. al., PRD66(2002)014009



New Physics can contribute in loop, which is different from the cases in B and Kaon mesons.

Lepton decays: $D^0 \to l^+l^-$ ($l = e,\mu$);
GIM suppressed decays: $D^{0(\pm)} \to M^{0(\pm)} l^+l^-$ (M is meson allowed);
LFV decays: $D^0 \to e^+\mu^-$, $D^{0(\pm)} \to M^{0(\pm)} e^+\mu^-$;
LNV decays: $D^{\pm} \to M^{\pm} l^+ l^+$ ($l = e, \mu$; the same signed-di-lepton) ;

Limits from CLEO-c



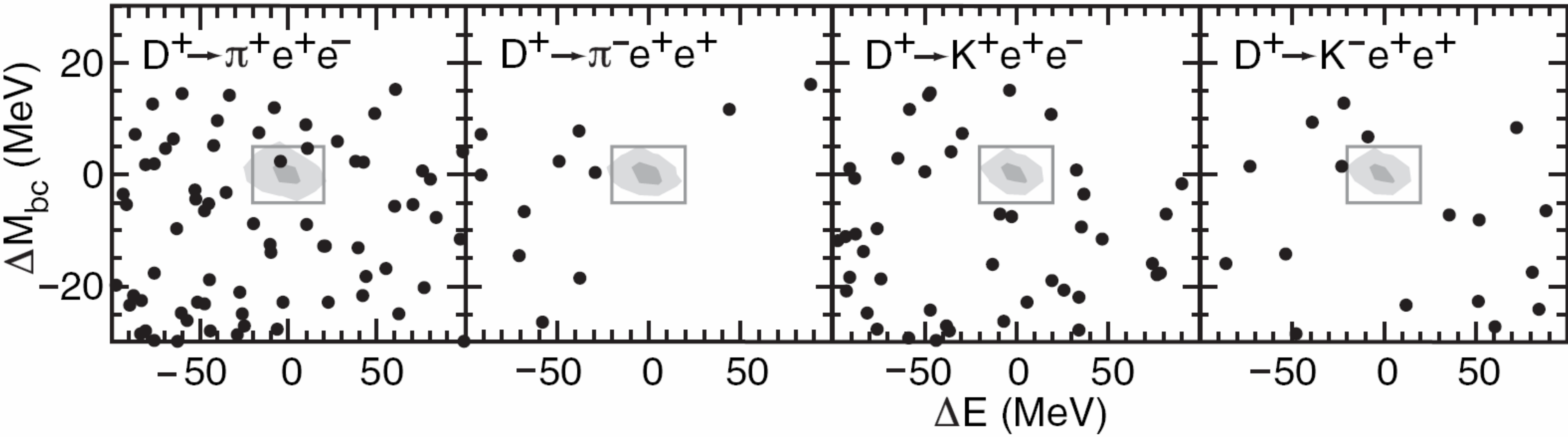
Branching-fraction UL values are all at 90% C.L.

0.8×10^{6} $D\bar{D}$ pairs

Mode	ϵ (%)	N	n	σ_{syst} (%)	$\mathcal{B}$ (10^{-6})
$\pi^+e^+e^-$	36.41	1.99	2	8.7	<7.4
$\pi^-e^+e^+$	43.85	0.48	0	7.1	<3.6
$K^+e^+e^-$	26.18	1.47	0	10.0	<6.2
$K^-e^+e^+$	35.44	0.50	0	7.2	<4.5
$\pi^+\phi(e^+e^-)$	46.22	0.04	2	7.4	$2.7^{+3.6}_{-1.8}\pm0.2$

$$\mathrm{UL} = \frac{C(n;N)}{\epsilon(2\sigma_{D^+D^-}\mathcal{L})},$$

N : expected backgrounds
n : observed events
C(n;N) : upper limit on signal in the presence of backgrounds

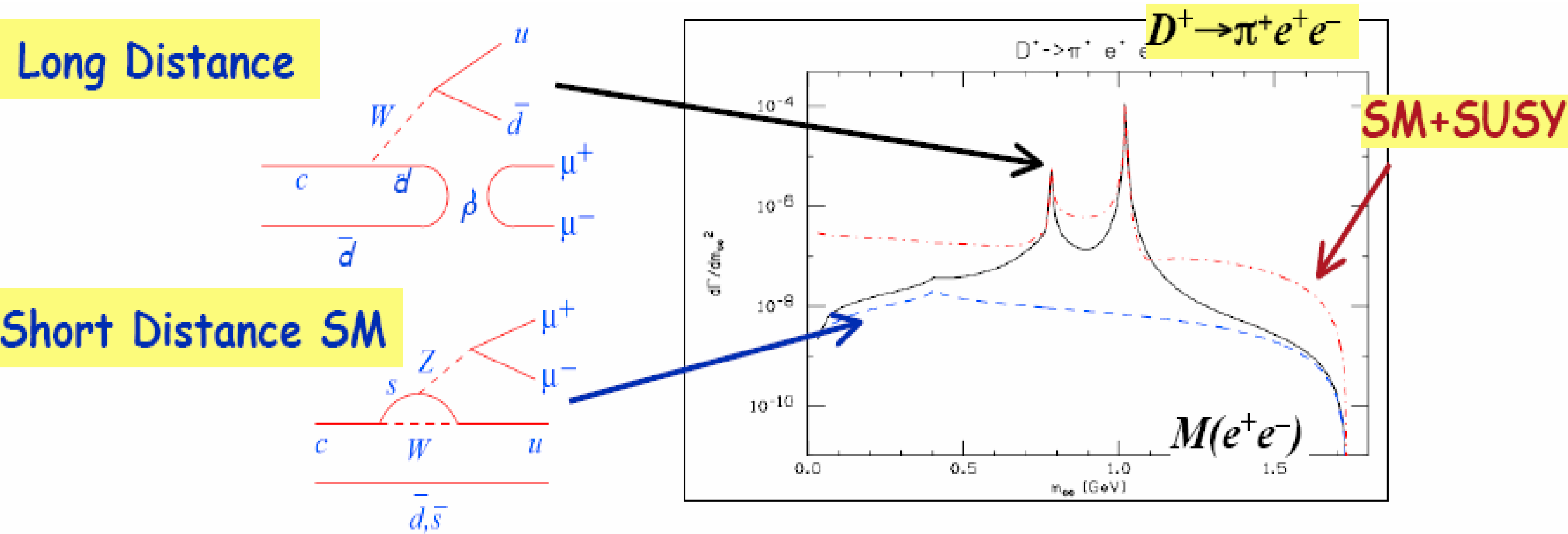


Signal region: -20 <Δ E < 20 MeV; -5<Δ M_{bc} < 5 MeV

PRL 95 (2005) 221802

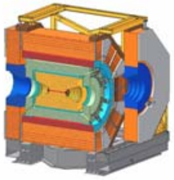
Rare D Decays

Ian Shipshey



Although the New Physics contributions are diluted by large uncertainty of long-distance contribution, the $m(e^+e^-)$ distribution may be distinct. Burdman et. al., PRD66(2002)014009

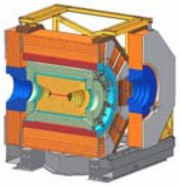
Rare (GIM suppressed) D Decays



PRD66(2002)014009 90%CL

	SM ($\times10^{-6}$)	RPV ($\times10^{-6}$)	Current limit ($\times10^{-6}$)	BESIII 10^{-8}
$D^+\to K^+\mu^-\mu^+$	-	-	9.2 (FOCUS)	10.5
$D^+\to\pi^+\mu^-\mu^+$	1.9	15	8.8 (FOCUS)	8.7
$D^+\to\rho^+\mu^-\mu^+$	-	-	560 (E653)	24.0
$D^0\to\pi^0\mu^-\mu^+$	-	-	180 (E653)	12.3
$D^0\to\rho^0\mu^-\mu^+$	1.8	8.7	22 (E791)	13.7
$D^0\to\overline{K}^0\mu^-\mu^+$	-	-	260 (E653)	10.6
$D^+\to K^+e^-e^+$	-	-	6.2 (CLEO-c)	6.7
$D^+\to\pi^+e^-e^+$	2.0	2.3	7.4 (CLEO-c)	5.6
$D^+\to\rho^+e^-e^+$	-	-	--	15.4
$D^0\to\pi^0e^-e^+$	-		45 (CLEO-II)	7.9
$D^0\to\rho^0e^-e^+$	1.8	5.1	100 (CLEO-II)	10.3
$D^0\to\overline{K}^0e^-e^+$	-	-	110 (CLEO-II)	7.5

LFV and LNV D Decays



PRD66(2002)014009

90%CL

		SM 10^{-6}	RPV 10^{-6}	Current limit 10^{-6}	BESIII 10^{-8}
LNV	$D^+ \to K^- \mu^+ \mu^+$	0	--	13 (653)	10.4
	$D^+ \to \pi^- \mu^+ \mu^+$	0	-	4.8 (FOCUS)	8.7
	$D^+ \to \rho^- \mu^+ \mu^+$	0	-	56 (E653)	19.4
	$D^+ \to K^- e^+ e^+$	0	-	4.5 (CLEO-c)	6.7
	$D^+ \to \pi^- e^+ e^+$	0	-	3.6 (CLEO-c)	5.6
	$D^+ \to \rho^- e^+ e^+$	0	-	-	12.4
LFV	$D^+ \to K^+ e^- \mu^+$	0	-	68 (E791)	8.3
	$D^+ \to \pi^+ e^- \mu^+$	0	30	34 (E791)	5.9
	$D^+ \to \rho^+ e^- \mu^+$	0	-	-	15.5
	$D^0 \to \pi^0 e^- \mu^+$	0	-	86 (CLEO-II)	9.7
	$D^0 \to \rho^0 e^- \mu^+$	0	14	49 (CLEO-II)	11.0
	$D^0 \to \bar{K}^0 e^- \mu^+$	0	-	100 (CLEO-II)	9.6

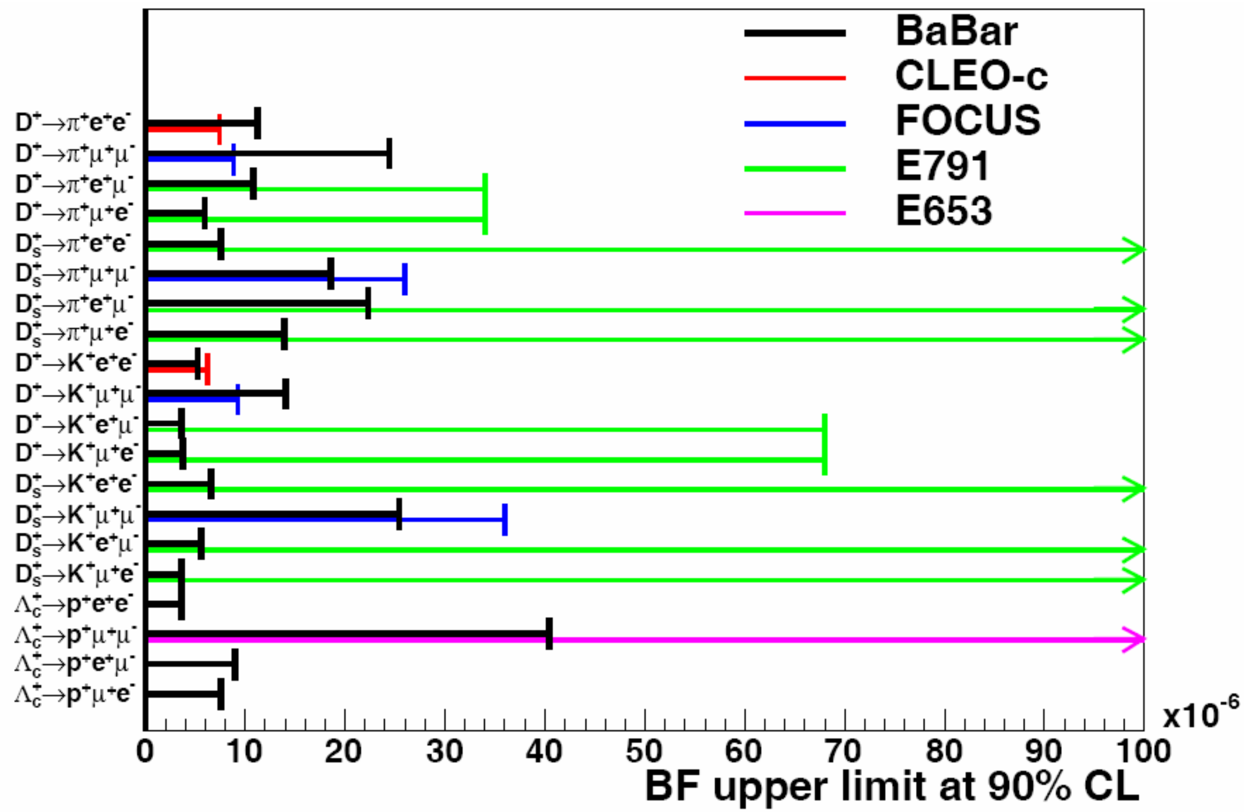
$D \to h l^+ l^-$ Like Rare Decays

BaBar Input
ICHEP06
288 fb^{-1} @$\Upsilon(4S)$

CLEO-c
0.8 M (0.281 fb^{-1})

$$\frac{L_{BaBar}}{L_{CLEO-c}} = \frac{288}{0.3} = 960$$

Background free at a tau charm factory @3770 peak!



Rare Leptonic Decays

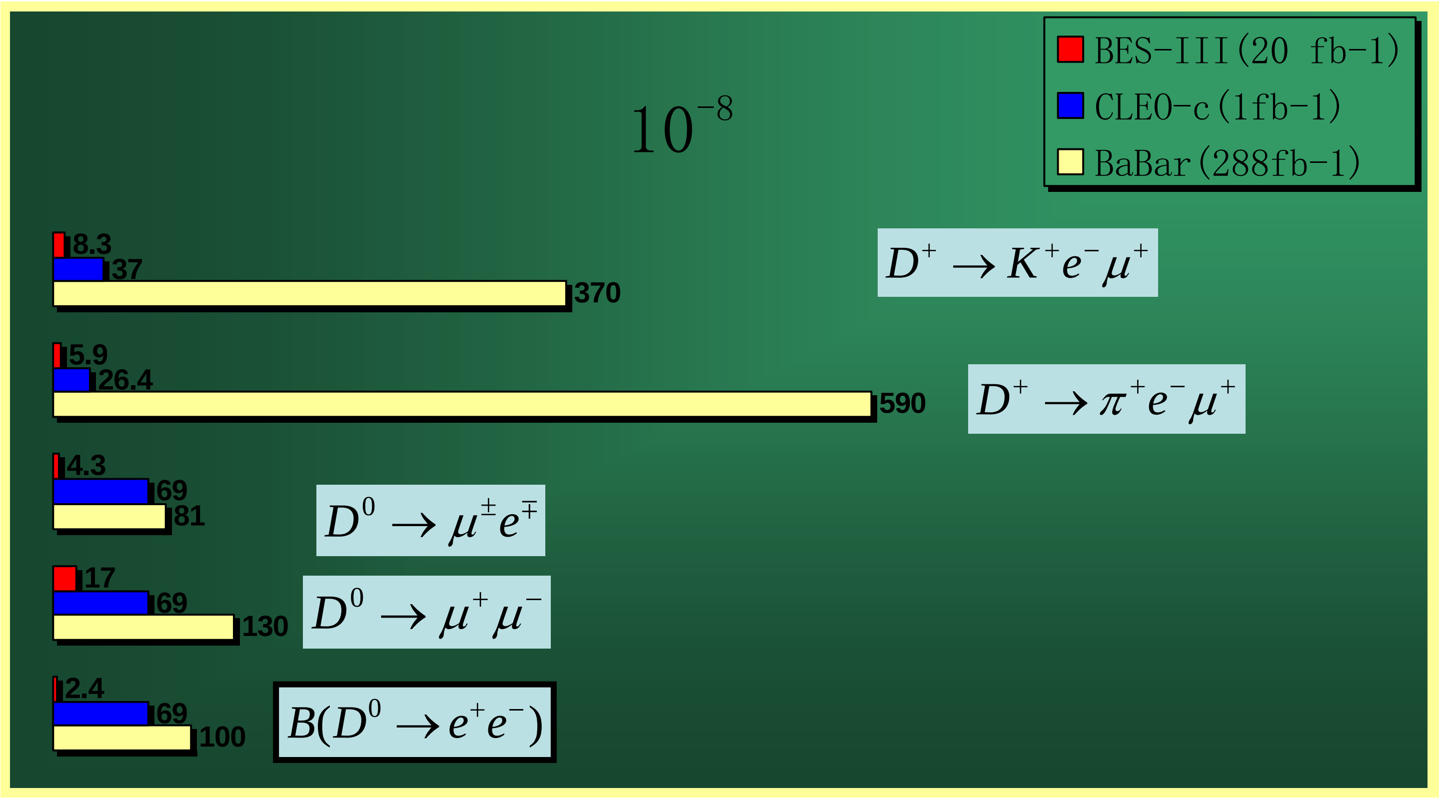
Burdman et. al., PRD66(2002)014009

	SM	RPV	Current Limit	CLEO-c	BESIII
$D^0 \to e^+e^-$	10^{-23}	1.0×10^{-10}	1.0×10^{-6} (BaBar)	6.9×10^{-7}	2.4×10^{-8}
$D^0 \to \mu^+\mu^-$	10^{-13}	3.5×10^{-6}	1.3×10^{-6} (BaBar)	--	1.7×10^{-7} (dilution from $D^0 \to \pi^+\pi^-$)
$D^0 \to e^\pm\mu^{-+}$	0	1.0×10^{-6}	8.1×10^{-7} (BaBar)	-	4.3×10^{-8}

The efficiency is about 70% at BES-III.

The mis-ID rate for π misidentified as a μ is about 5% below 1.0GeV.

Sensitivity to LFV



LFV and LNV are "smoking gun" , any indication of deviation from zero will indicate new physics.

Summary

- y_{CP} (y) and strong phase measured at BES-III by considering QC.
- CP violation from QC
- CP violation from angular correlation
  (QC+Partial Wave Analysis)

The 1th order sensitivities to mixing and CPV at BES-III:
$\delta(y) \sim 0.003$, $\delta(\cos(\delta)) \sim 0.04$, CPV: 10^{-3}

More complicated analyses: Dalitz plot, D→ VV angular correlation.
TQCA (Input from CLEO-c).

谢谢！