Mixing and Coherence in D Mesons

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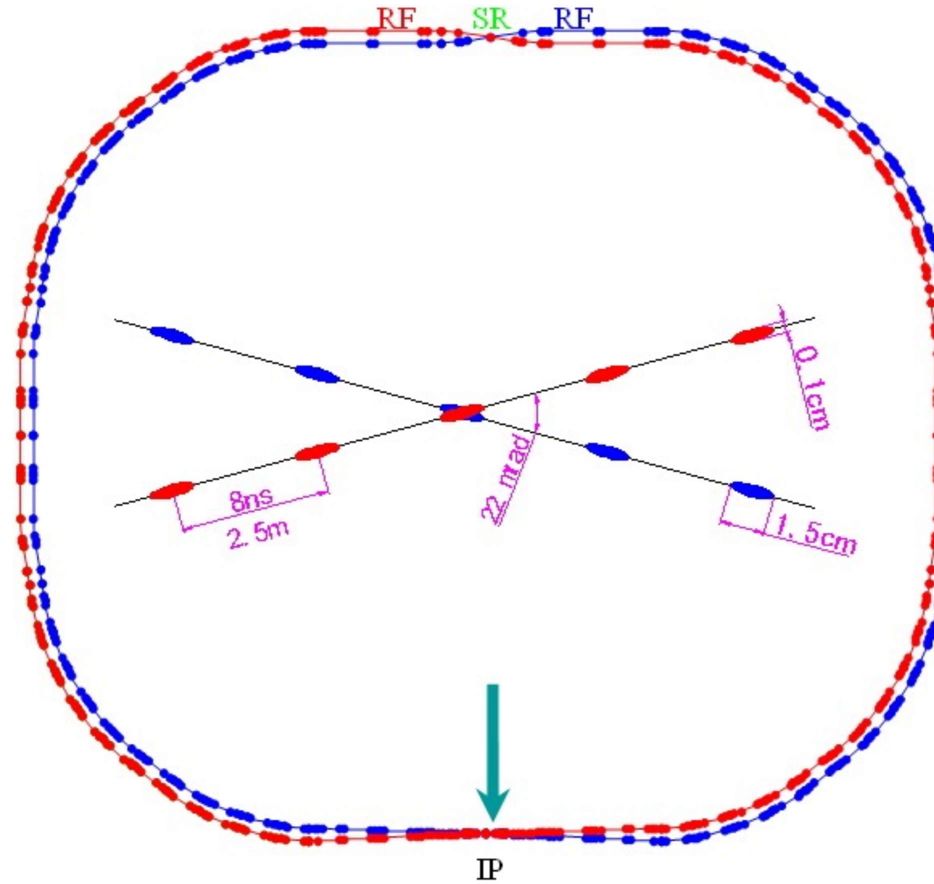
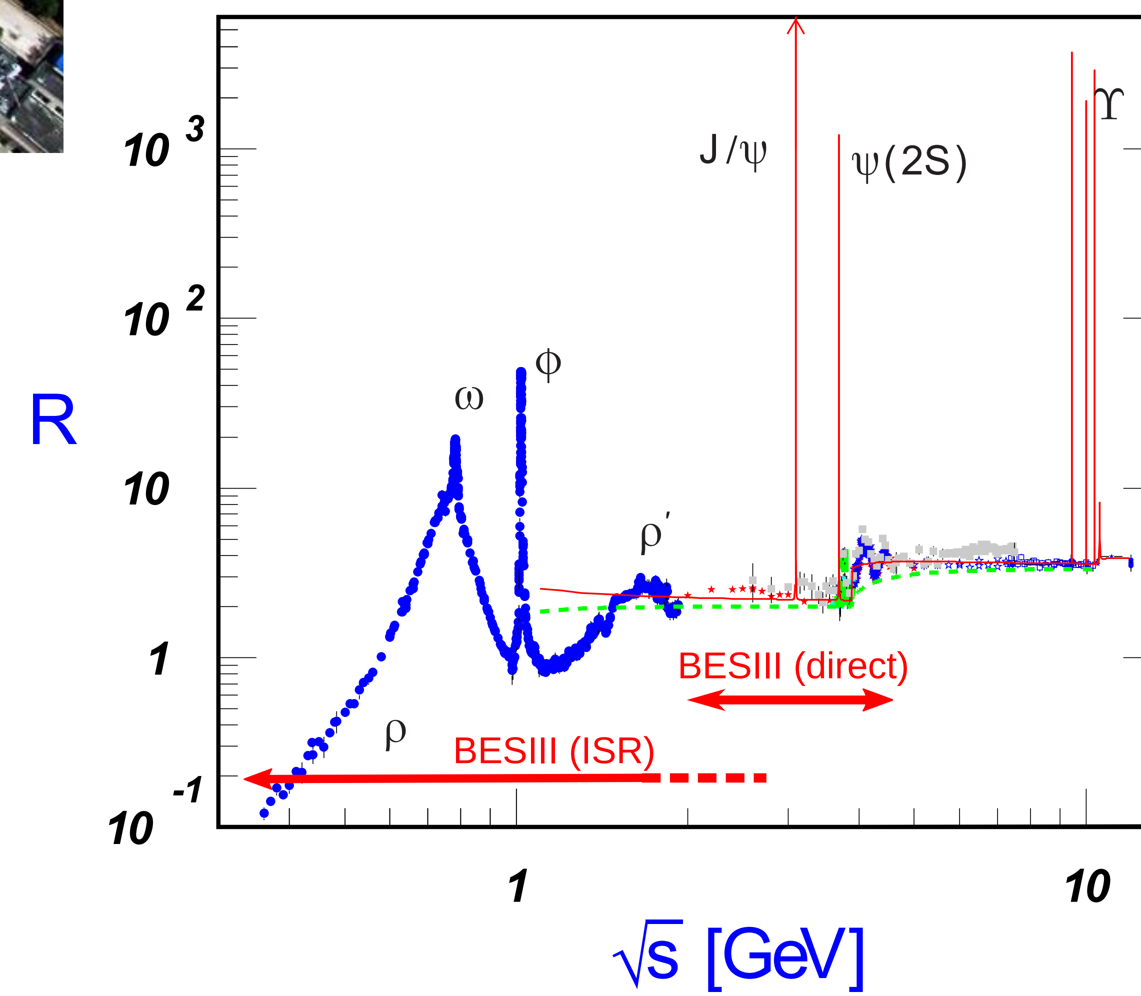
BEPC II Storage ring

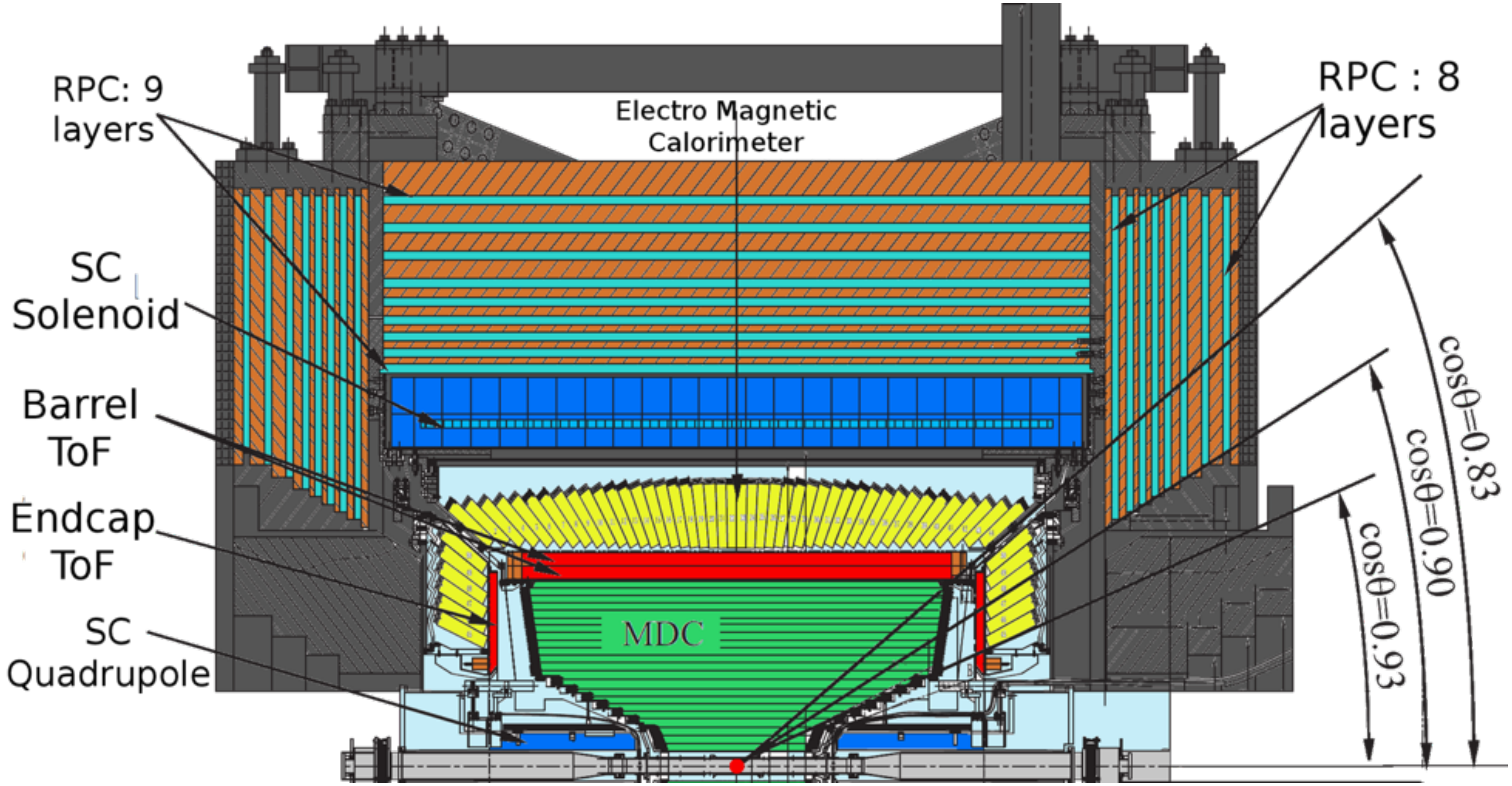
Institute of High Energy Physics (IHEP) campus
Beijing, China

Beam energy: 1.0 - 2.3 GeV
Energy spread: 5×10^{-4}
L_{peak}: $0.7\times10^{33}/cm^2s$

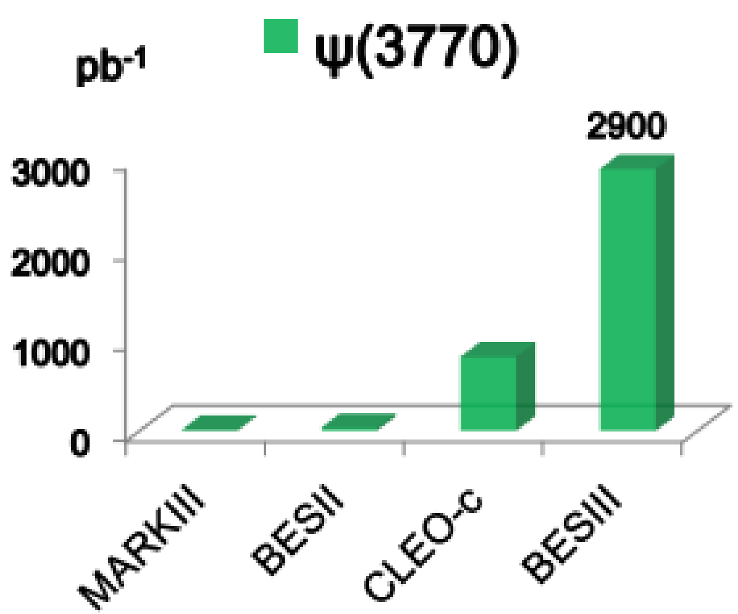


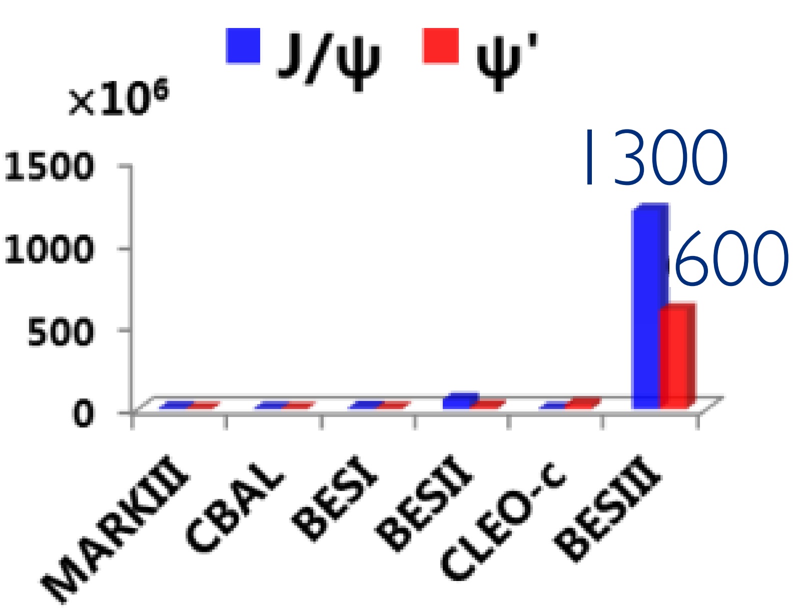


BESIII Detector



Beijing Electron Spectrometer



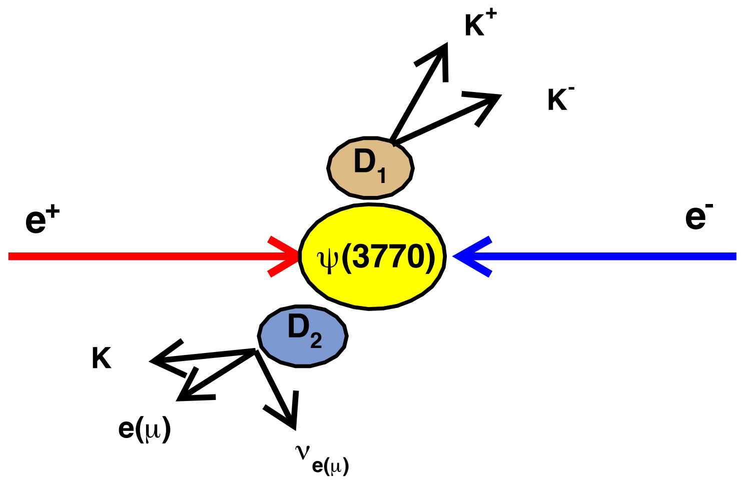


Outline

- **D Tagging**
- Measurement of y_{CP} in D^0-$\bar{D}^0$ oscillation
- GGSZ Analysis of $D^0 \to K^0 \pi^+ \pi^-$

D Tagging

$D\bar{D}$ pairs are produced while running at 3.773 GeV ~93% the time



D Tagging is used for selecting events.

Single Tag, Fully reconstruct one D decay

Double Tag, when the partner $\bar{D}$ is also reconstructed.

Single Tag (ST):

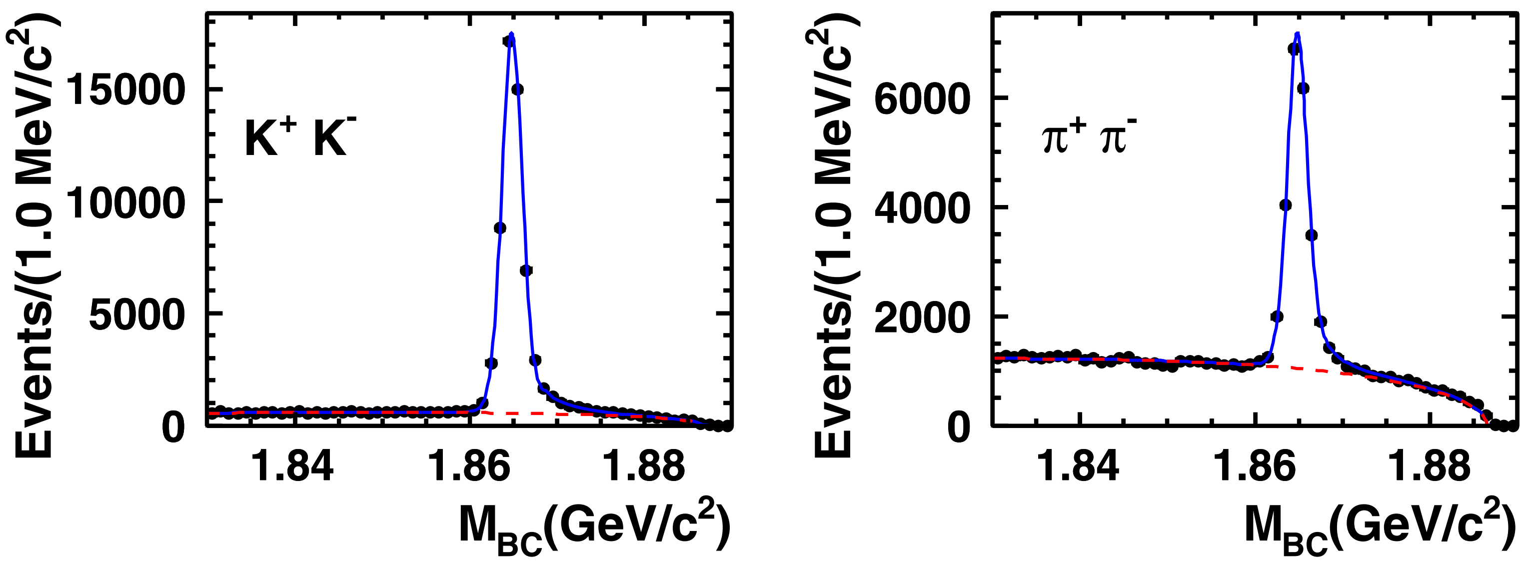
Tag modes are reconstructed requiring a certain window for the **Δ**E variable.

$$\Delta E \equiv E_D - E_{\text{beam}}$$

M_{BC} distribution is fit to calculate tag yields.

$$M_{\text{BC}} \equiv \sqrt{E_{\text{beam}}^2/c^4 - |\vec{p}_D|^2/c^2}$$

Example fits



Double Tag (DT):

Depending on the D decay that is being studied, M_{BC} or some other variable will be used to calculate double tag yields.

Both analyses that I will be talking about use D Tagging.

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Measurement of y_{CP} in D^0-$\overline{D}^0$ oscillation

Oscillations in D^0-$\overline{D}^0$ system are characterized by

$$x = \Delta m / \Gamma$$

$$y = \Delta\Gamma / 2\Gamma$$

mass and the width differences between two mass eigenstates

$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle$$

$$\phi = \arg(q/p)$$

rewrite

$$|D_{CP-}\rangle \equiv \frac{|D^0\rangle - |\overline{D}^0\rangle}{\sqrt{2}}$$

allowing small indirect CPV

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

in the absence of CPV y_{CP} reduces to

y with $|q/p| = 1$ and $\phi = 0$

At BESIII we are capable of producing $D^0\overline{D}^0$ pairs at threshold with a definite $C = -1$ state.

D mesons will have opposite CP.

Semileptonic decays of D^0 are used for probing the mixing parameter.

$$\Gamma_{CP\pm} = \Gamma(1 \pm y_{CP})$$

Branching fraction of a semileptonic decay becomes:

$$\mathcal{B}_{D_{CP\pm}\to l} \approx \mathcal{B}_{D\to l}(1 \mp y_{CP})$$

$$\rightarrow \quad y_{CP} \approx \frac{1}{4}\left(\frac{\mathcal{B}_{D_{CP-}\to l}}{\mathcal{B}_{D_{CP+}\to l}} - \frac{\mathcal{B}_{D_{CP+}\to l}}{\mathcal{B}_{D_{CP-}\to l}}\right)$$

use $D^0\overline{D}^0$

CP eigenstate | Semileptonic

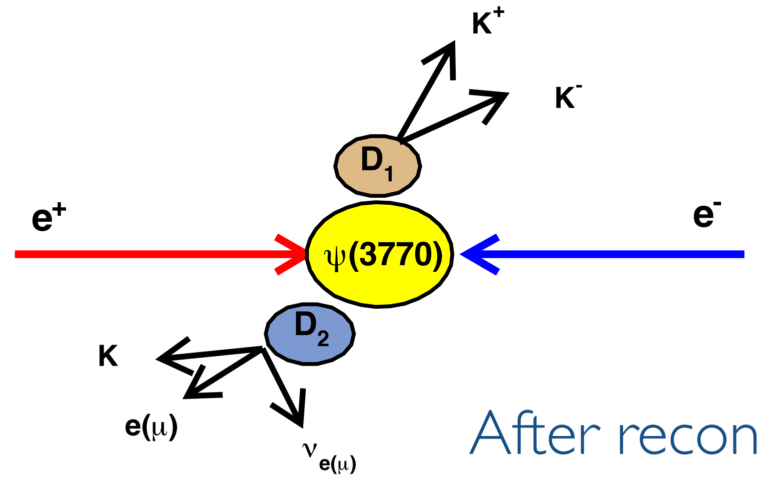
or opposite

$$\mathcal{B}_{D_{CP\mp}\to l} = \frac{N_{CP\pm;l}}{N_{CP\pm}} \cdot \frac{\varepsilon_{CP\pm}}{\varepsilon_{CP\pm;l}}$$

Measurement of y_{CP} in D^0-$\bar{D}^0$ oscillation

Decays used in the analysis

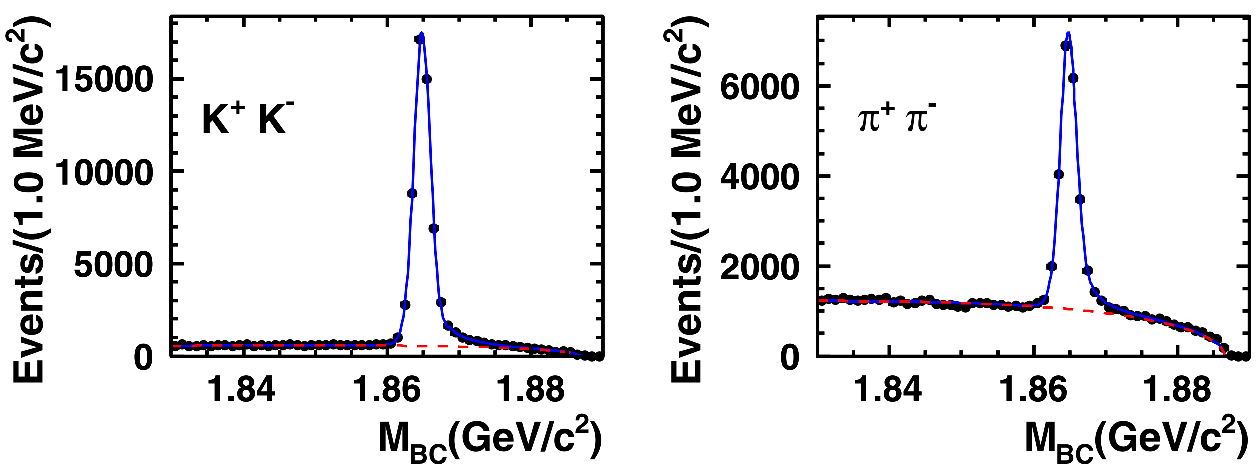
$CP+$	K^+K^-, $\pi^+\pi^-$, $K_S^0\pi^0\pi^0$
$CP-$	$K_S^0\pi^0$, $K_S^0\omega$, $K_S^0\eta$
Semileptonic	$K^\mp e^\pm\nu$, $K^\mp\mu^\pm\nu$



Single Tag (ST):

CP tag modes are reconstructed as single tags.

Example fits



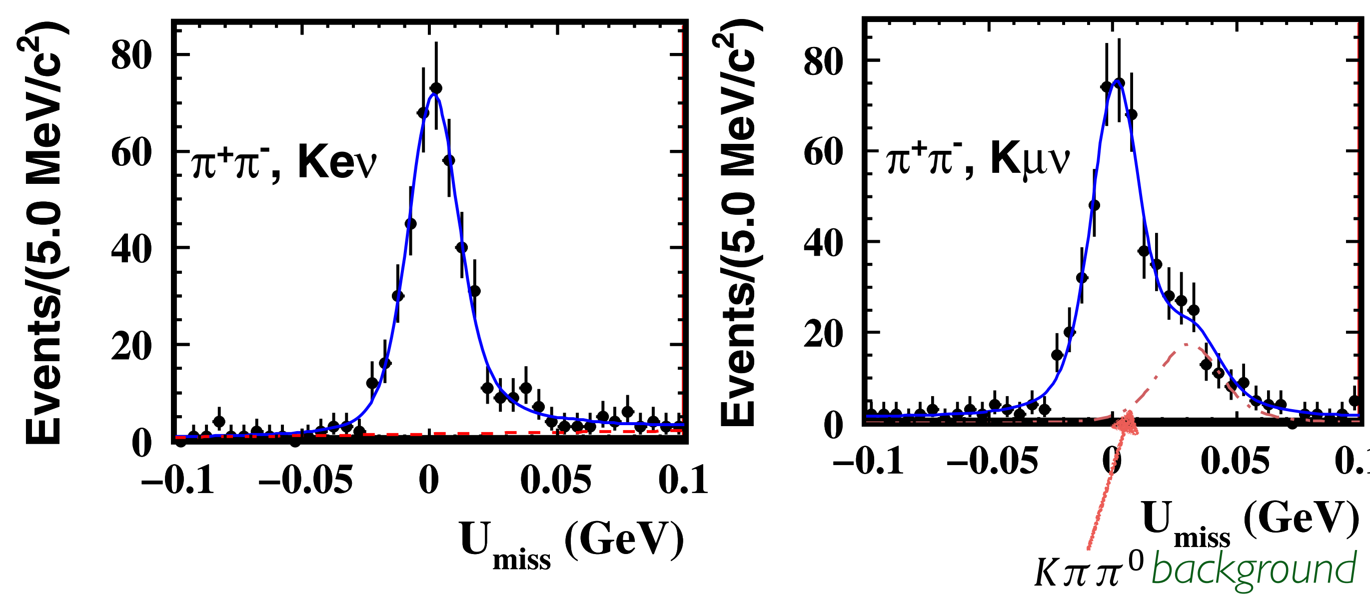
Double Tag (DT):

After reconstructing the CP tag, semileptonic decay of the pair D meson is reconstructed The U_{miss} distribution is fit to calculate the DT yields.

$$U_{\rm miss} \equiv E_{\rm miss} - c|\vec{p}_{\rm miss}|$$

$$E_{\rm miss} \equiv E_{\rm beam} - E_K - E_l$$

$$\vec{p}_{\rm miss} \equiv -\left[\vec{p}_K + \vec{p}_l + \hat{p}_{\rm ST}\sqrt{E_{\rm beam}^2/c^2 - c^2 m_D^2}\right]$$



Quite clean after the analysis requirements, U_{miss} provides better resolution compared to M^2_{miss}

Measurement of y_{CP} in D^0-$\bar{D}^0$ oscillation - Results

Yields are then used to calculate the branching ratio, with the efficiency measured using the MC sample

$$\mathcal{B}_{D_{CP\mp}\to l} = \frac{N_{CP\pm;l}}{N_{CP\pm}} \cdot \frac{\varepsilon_{CP\pm}}{\varepsilon_{CP\pm;l}}$$

Branching ratios of $K e \nu$ and $K \mu \nu$ are summed to calculate $\mathcal{B}_{CP\pm\to\ell}$

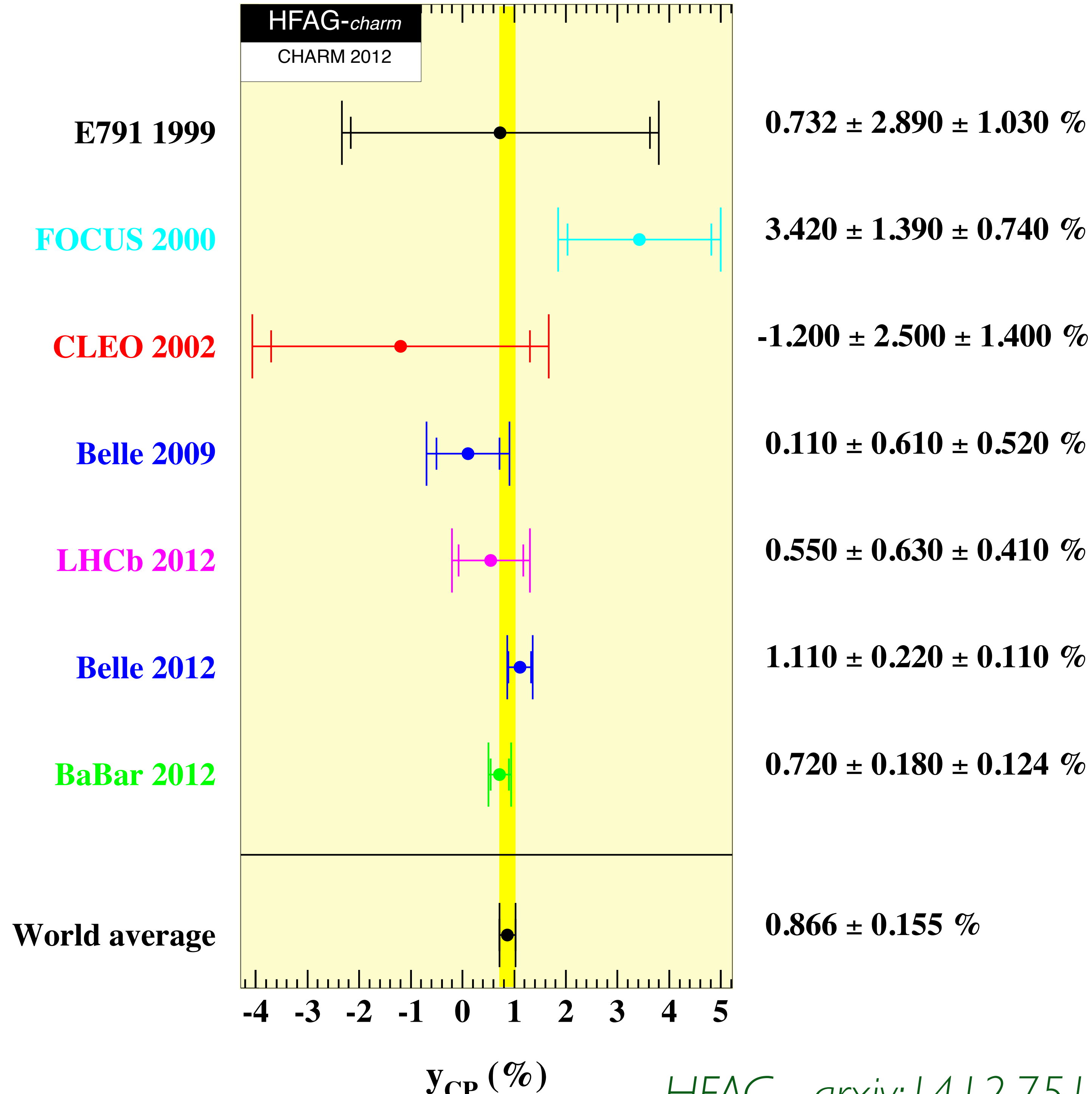
Results are then combined for different CP modes using the standard weighted least-square method, minimizing,

$$\chi^2 = \sum_{\alpha} \frac{\left(\tilde{\mathcal{B}}_{D_{CP\pm}\to l} - \mathcal{B}^{\alpha}_{D_{CP\pm}\to l}\right)^2}{(\sigma^{\alpha}_{CP\pm})^2}$$

Result:

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

Phys.Lett. B 744 (2015) 339-346



HFAG - arxiv:1412.7515

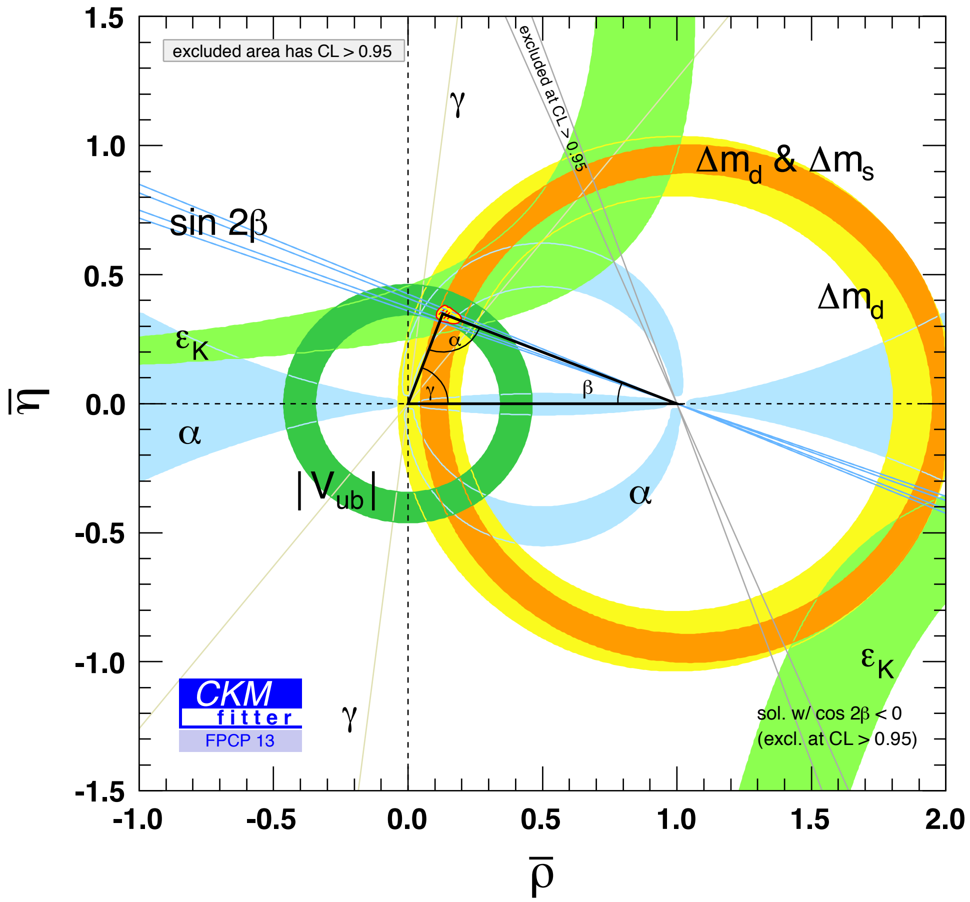
Outline

- D Tagging
- Measurement of y_{CP} in D^0-$\overline{D}^0$ oscillation
- **GGSZ Analysis of $D^0 \to K^0 \pi^+ \pi^-$**

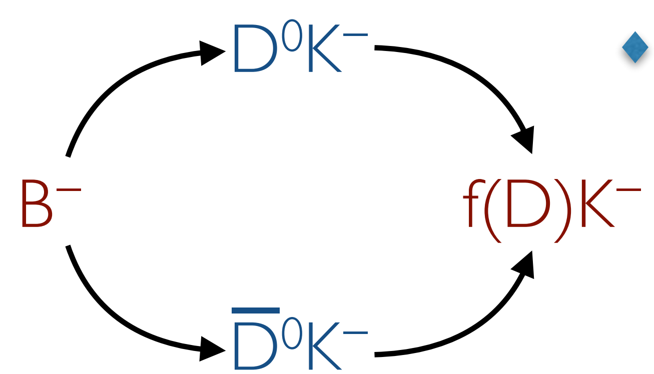
Strong Phase Difference b/w D^0 and $\bar{D}^0 \rightarrow K^0\pi^+\pi^-$

Motivated by the quest to increase the precision of the angle γ measurement in $B^- \rightarrow DK^-$ decay.

$$\gamma = \arg(-V_{ud}V^*_{ub}/V_{cd}V^*_{cb})$$



Determine γ through the interference between $b \rightarrow c$ and $b \rightarrow u$ transitions when D^0 and $\bar{D}^0$ both decay to the same final state f(D).



- $\mathcal{A}\,(B^{\pm} \to K^{\pm}\tilde{D}^0, \tilde{D}^0 \to K^0_S\pi^+\pi^-(x,y))$ $\propto f_D(x,y) + r_B e^{i\theta_{\pm}} f_{\bar{D}}(x,y).$
- $\theta_{\pm} \equiv \delta_B \pm \gamma$
- $x \equiv m^2_{K^0_S\pi^+},\ y \equiv m^2_{K^0_S\pi^-}$
- $\Delta\delta_D \equiv \delta_D(x,y) - \delta_D(y,x)$

BESIII can help reducing the systematics on this important measurement with providing more information on the

$D^0 \rightarrow K^0\pi^+\pi^-$ decay.

With the amount of data LHCb collecting, γ measurement soon will be systematically limited.

We will use the GGSZ* method to investigate the decay

Final states are three body, self-conjugate modes

eg: K_sKK, $K_s\pi\pi$

- Binning regions of Dalitz plot where δ_D is similar
- Model independent, there is no incorrect binning.
- Optimization for binning for increased sensitivity.

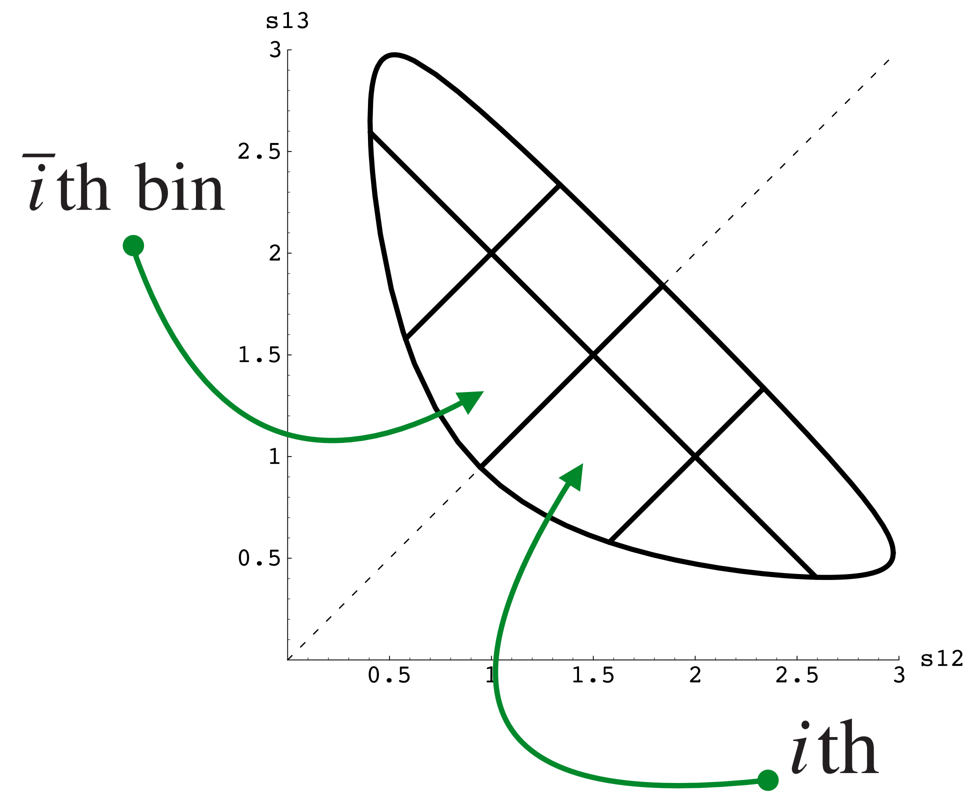
*Giri, Grossman, Soffer, Zupan (**GGSZ**)
Phys. Rev. D 68 (2003) 054018

Strong Phase Difference b/w D^0 and $\bar{D}^0 \to K^0\pi^+\pi^-$

- T_i : measured in flavor decays
- r_B : color suppression ~0.1
- δ_B : strong phase of B
- c_i,s_i : weighted average of cos($\Delta\delta_D$) and sin($\Delta\delta_D$), phase difference between Ds given by $\Delta\delta_D$.

  All but c_i,s_i variables will be measured in B factories.

Dalitz Plot



$c_{\bar{i}}$ = c_i and $s_{\bar{i}}$ = -s_i

Belle model independent γ measurement

$$77.3^{+15.1}_{-14.9}(stat) \pm 4.2(syst) \pm 4.3(c_i/s_i)$$

c_i,s_i error dominates

Phys. Rev. D 85, 112014 (2012)

$$\Gamma_i^{\pm} \equiv \int_i d\Gamma(B^{\pm} \to (K_S^0\pi^-\pi^+)_D K^{\pm})$$
$$= T_i + r_B^2 T_{\bar{i}} \pm 2r_B\sqrt{T_i T_{\bar{i}}}[\cos(\delta_B+\gamma)c_i - \sin(\delta_B+\gamma)s_i]$$

Strong Phase Difference b/w D^0 and $\bar{D}^0 \rightarrow K^0\pi^+\pi^-$

c_i,s_i can be measured using the Double Tags:

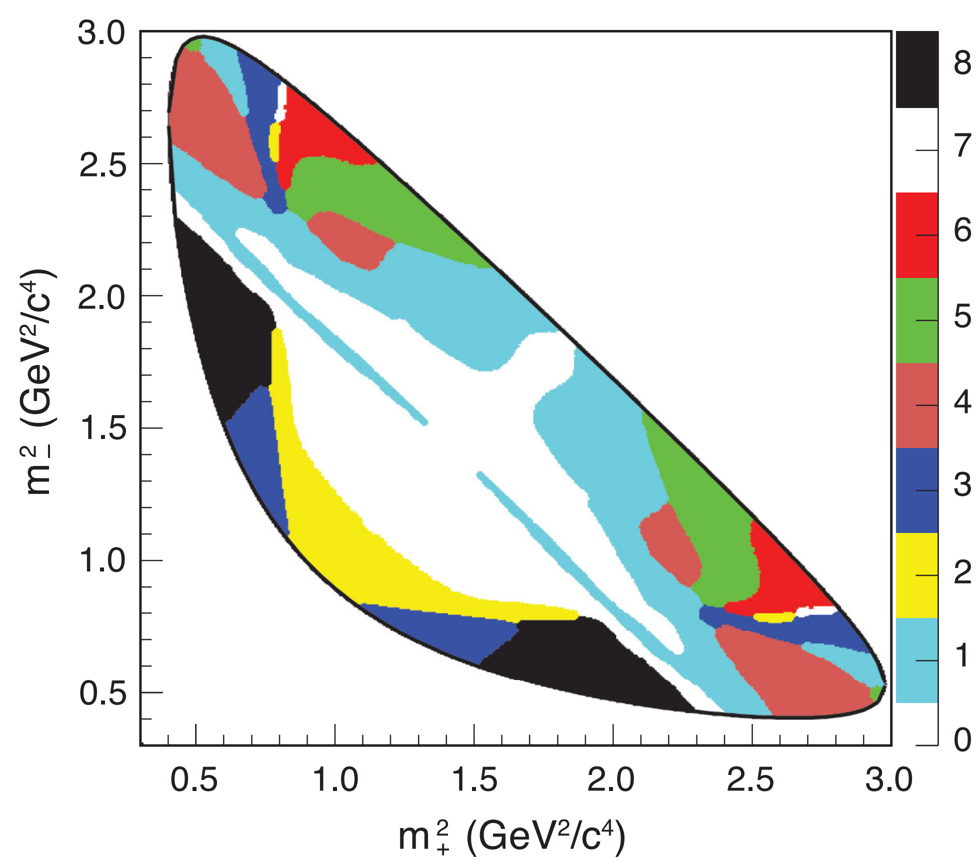
$D^0 \rightarrow K_s\pi^+\pi^-$ vs ($K_{S/L}\pi^+\pi^-$ or CP tags)

c_i and s_i *c'_i and s'_i*

[$K_s\pi^+\pi^-$ vs CP tags] [$K_L\pi^+\pi^-$ vs CP tags]

[$K_S\pi^+\pi^-$ vs $K_S\pi^+\pi^-$] [$K_L\pi^+\pi^-$ vs $K_S\pi^+\pi^-$]

Use both (c_i,s_i) and (c'_i,s'_i) to further constrain the results (c_i,s_i)



Babar optimized Binning Scheme 2008:

Optimized to increase sensitivity to γ, and smooths the bins to account for the regions that are smaller than the detector resolution.

Strong Phase Difference b/w D^0 and $\bar{D}^0 \to K^0\pi^+\pi^-$

Measured using the worlds largest $\psi(3770)$ data sample taken at the threshold.

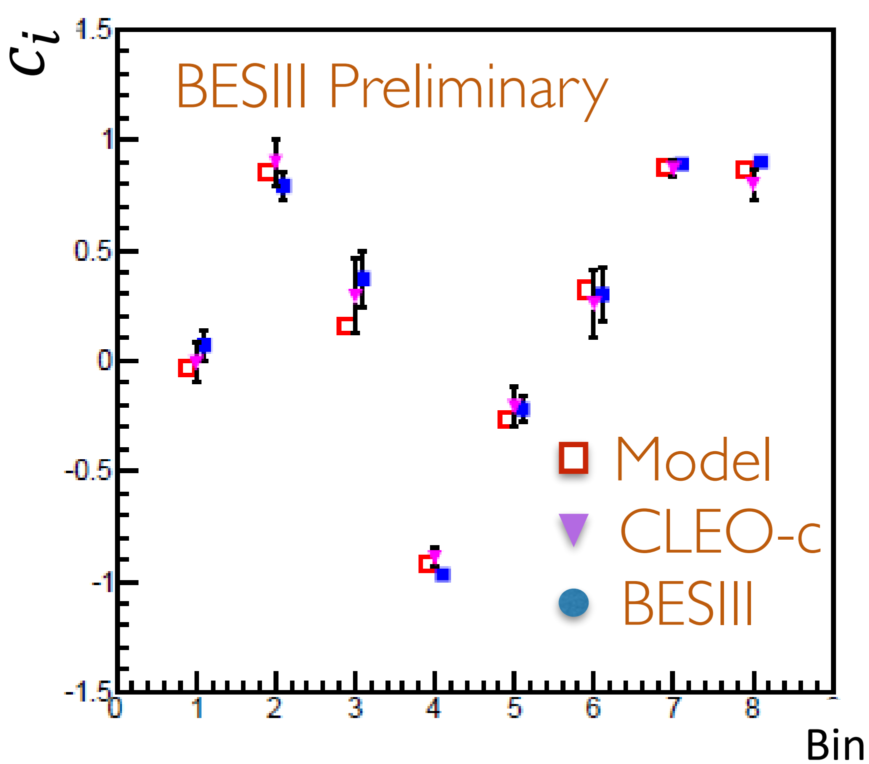
Results consistent with the CLEO-c with superior statistical uncertainties.

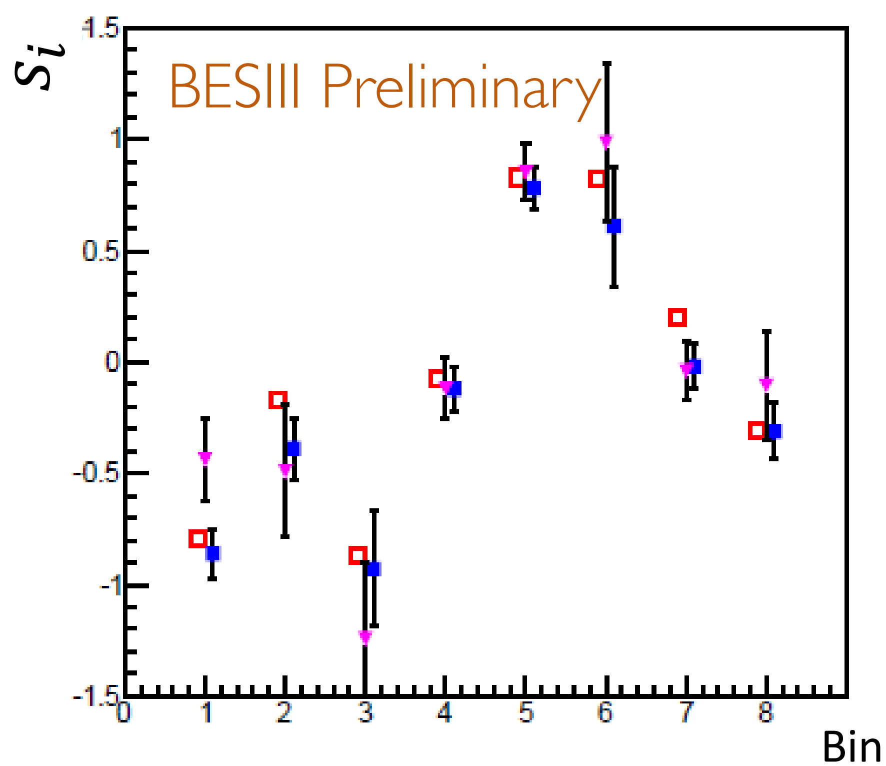
Contribution to the uncertainty in gamma of ±2.1° using optimal binning, compared to Belle's current measurement of ±4.3° from CLEO-c's results.

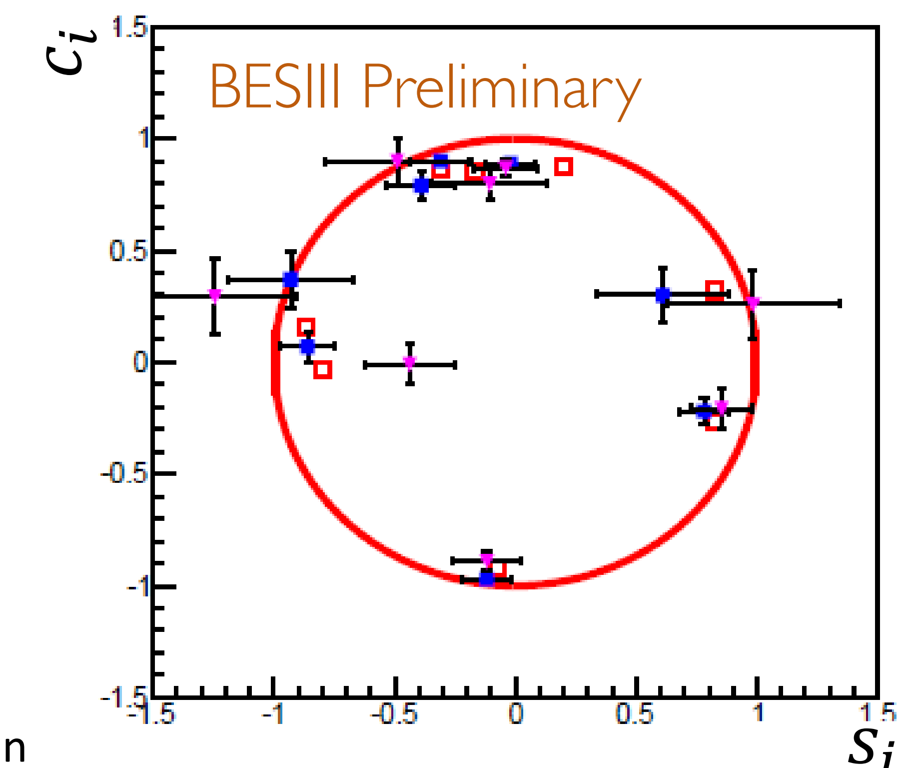
BESIII Preliminary

	c_i		s_i	
Bins	BES-III	CLEO-c	BES-III	CLEO-c
1	0.066 ± 0.066	-0.009 ± 0.088	-0.843 ± 0.119	-0.438 ± 0.184
2	0.796 ± 0.061	0.900 ± 0.106	-0.357 ± 0.148	-0.490 ± 0.295
3	0.361 ± 0.125	0.292 ± 0.168	-0.962 ± 0.258	-1.243 ± 0.341
4	-0.985 ± 0.017	-0.890 ± 0.041	-0.090 ± 0.093	-0.119 ± 0.141
5	-0.278 ± 0.056	-0.208 ± 0.085	0.778 ± 0.092	0.853 ± 0.123
6	0.267 ± 0.119	0.258 ± 0.155	0.635 ± 0.293	0.984 ± 0.357
7	0.902 ± 0.017	0.869 ± 0.034	-0.018 ± 0.103	-0.041 ± 0.132
8	0.888 ± 0.036	0.798 ± 0.070	-0.301 ± 0.140	-0.107 ± 0.240

CLEO-c result: Phys. Rev. D 82, 112006







Summary and Outlook

- y_{cp} measurement online. *Phys.Lett. B 744 (2015) 339-346*
- Finalizing the $D^0 \rightarrow K^0\pi^+\pi^-$ model independent measurement.
- More quantum coherence papers are in the works.

Thank you!