γ/φ_3 Impact from CLEO-c Using CP-Tagged $D \to K_{S,L}\pi\pi$ Decays

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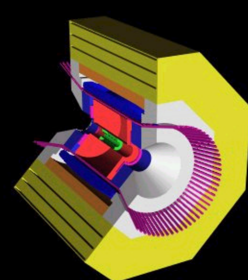
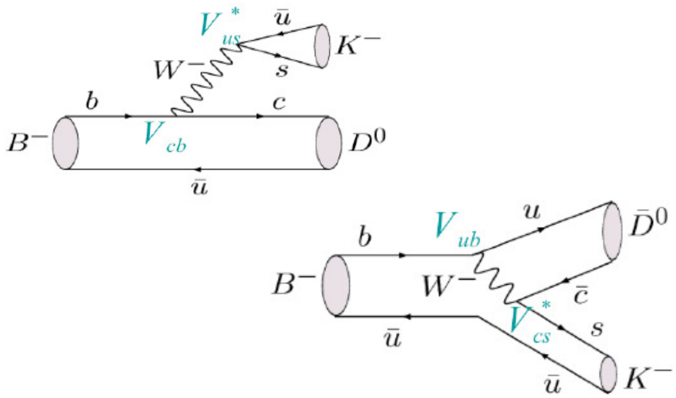
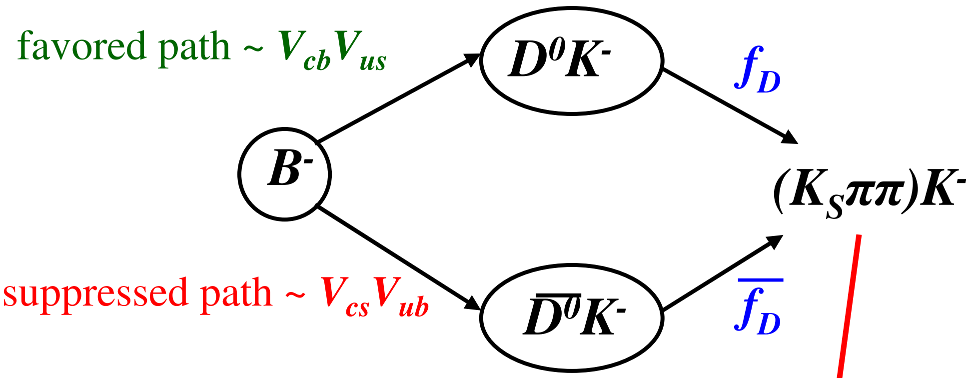
Charm 07



Path to Measuring γ/φ_3

- Use $B^{\pm}\rightarrow DK^{\pm}$ decays, followed by Dalitz plot analysis of $D\rightarrow K_s\pi^+\pi^-$.
- Developed by Giri, Grossman, Soffer, Zupan (GGSZ)[1] / Belle [2] -- exploit interference between D^0 and $\overline{D^0}$ channels

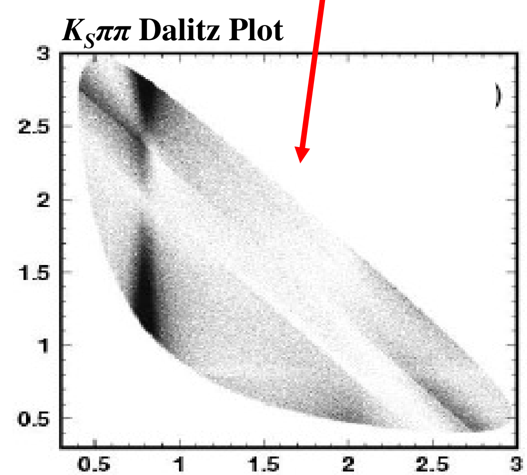




Additional unknowns due to D^0-$\overline{D^0}$ interference

$$N \sim |f_D|^2 + r_B^2|\overline{f_D}|^2 + 2|f_D||\overline{f_D}|r_B[\cos(\delta_D)\sin(\delta_B-\gamma) - \sin(\delta_D)\cos(\delta_B-\gamma)]$$

5 parameters: r_B, δ_B, γ, $\cos(\delta_D)$, $\sin(\delta_D)$ ← Measure at CLEO-c



[1] Giri et al. Phys. Rev. D 68, 054018 (2003)

[2] A.Bondar, Proceedings of Belle Special Analysis Meeting on Dalitz Analysis, 24-26 Sept. 2002, BINP, Novosibirsk (unpub.

Current γ/φ_3 Measurements

BaBar: $92^o \pm 41^o$(stat) $\pm 11^o$(syst) $\pm 12^o$(model) (211 fb^{-1})

BaBar Collaboration, B. Aubert *et al*. hep-ex/0607104

Belle: $53^o \pm 17^o$(stat) $\pm 3^o$(syst) $\pm 9^o$(model) (357 fb^{-1})

Belle Collaboration, A. Poluektov *et al*. Phys. Rev. D73 (2006)

Statistical uncertainty will go down to about ~ 6^o with projected 2 ab^{-1} ($r_B = 0.16$)

(LHCb projects ~ 3^o-5^o uncertainty after 5 years…)

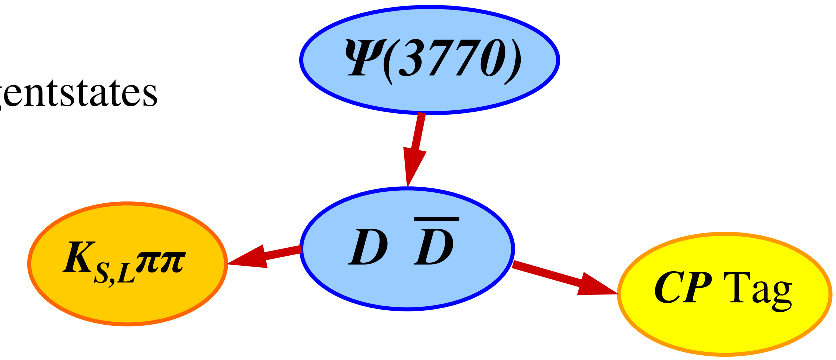
10^o model uncertainty will dominate → CLEO-c can help lower this number

Measuring c_i with *CP*-tagged $K_S\pi\pi$ Dalitz Plots

Correlated $D\bar{D}$ pairs ($C = -1$) are produced at CLEO-c

We **tag** the $K_S\pi\pi$ sample by reconstructing $D\rightarrow CP\pm$ eigentstates

$$D_{CP\pm} = \frac{D^0 \pm \overline{D^0}}{\sqrt{2}}$$



For *CP*-tagged Dalitz plots, number of events in Dalitz plot is

$$M \sim |f_D|^2 + |\overline{f_D}|^2 \pm 2|f_D||\overline{f_D}| \cos(\delta_D)$$

Divide the $(K_S\pi\pi)D$ Dalitz plot in to bins, symmetric under interchange of $\pi^+ \leftrightarrow \pi^-$ interchange.

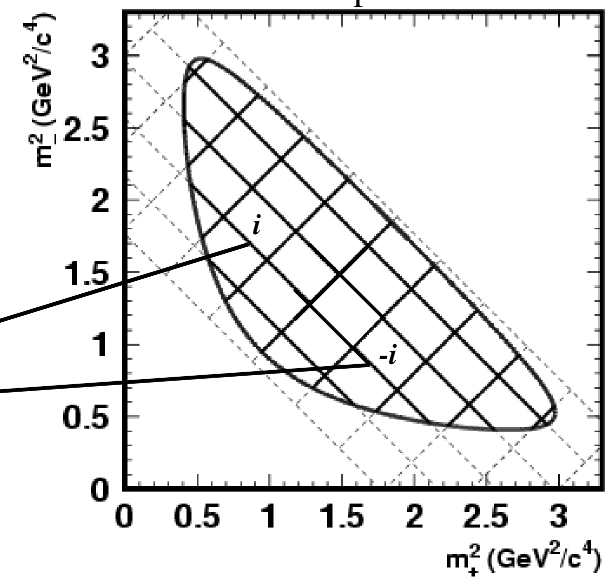
Define $\rightarrow$ $c_i = \langle\cos(\delta_D)\rangle_i$

c_i can be determined by counting *CP*-tagged bins

$$c_i = \frac{1}{2}\frac{(\overline{M}_i^- - \overline{M}_i^+)}{(\overline{M}_i^- + \overline{M}_i^+)}\frac{(K_i + K_{-i})}{\sqrt{K_i K_{-i}}}$$

CP-tagged flavor-tagged

Binned Dalitz plot



Tagged $K_S\pi^+\pi^-$ Data from CLEO-c

We use 398 pb^{-1} of correlated $\Psi(3770)\to D\bar{D}$ decays

Flavor-tagging modes: $D^0\to K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^-\pi^+$ (plus charge-conjugate)

Event selection cuts

$|\Delta E| < 30$ (MeV)

$|K_S \text{ mass}| < 3\sigma$

$|M_{bc} - M_D| < 4.2$ (MeV)

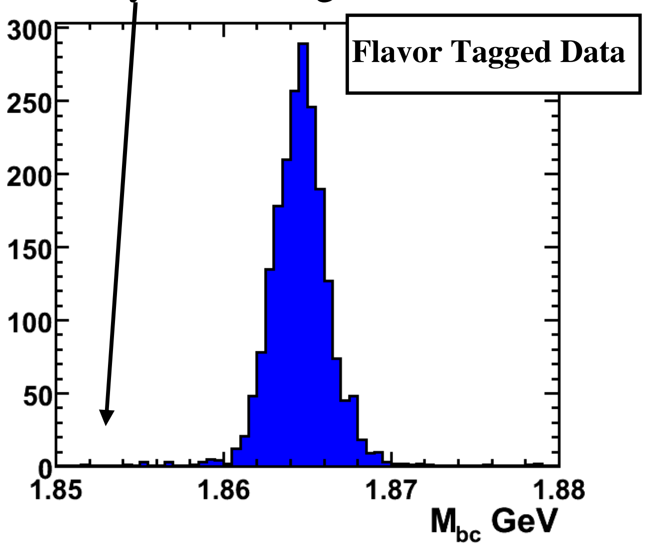
$(M_{bc} \equiv \sqrt{((E_{beam})^2 - (p_D)^2)}$

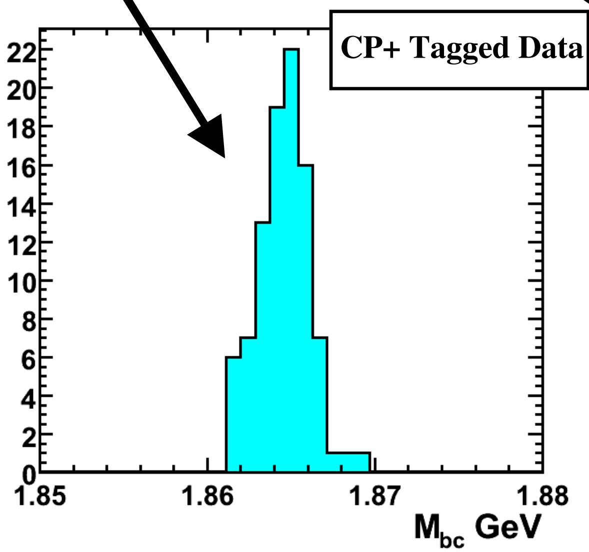
Only two-body *CP* tags are used – provide clean signal with very little background

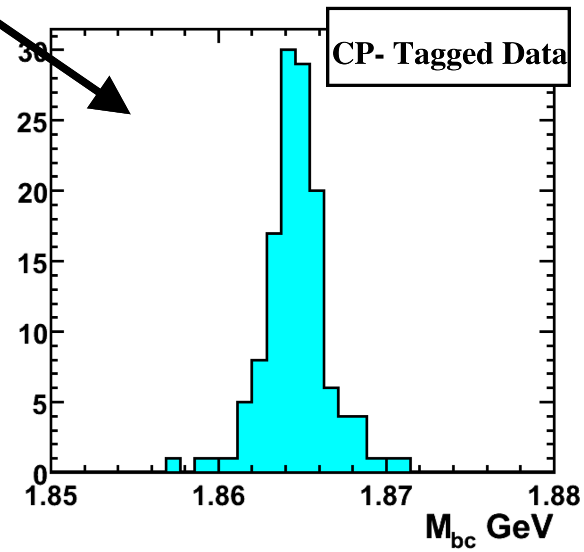
CP+ tags:	*CP*- tags:
K^+K^-	$K_S\pi^0$
$\pi^+\pi^-$	$K_S\eta$

Mode	Yield
K^+K^-	61
$\pi^+\pi^-$	33
$K_S\pi^0$	108
$K_S\eta$	29

Very low background







What about $K_L\pi\pi$?

- Why not use $K_L\pi\pi$?
- Similar structure, opposite ***CP***
- More than doubles overall statistics

Tagged $K_L\pi^+\pi^-$ Data

Use same flavor and *CP* tag modes as $K_S\pi\pi$, with same basic event selection

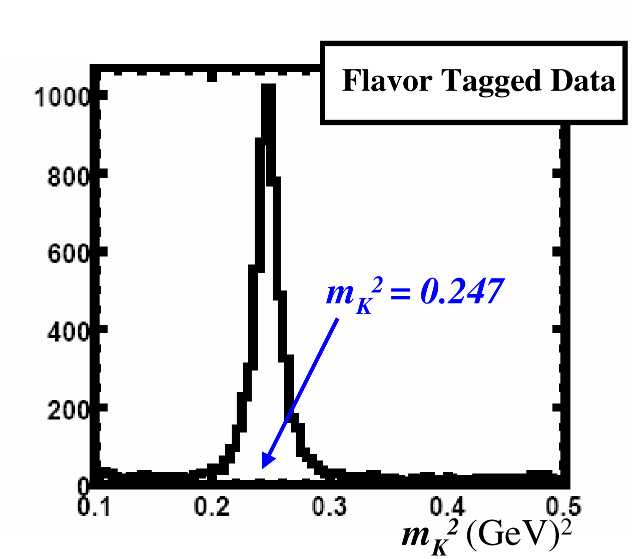
$K_L\pi\pi$ events are reconstructed using "missing mass" technique

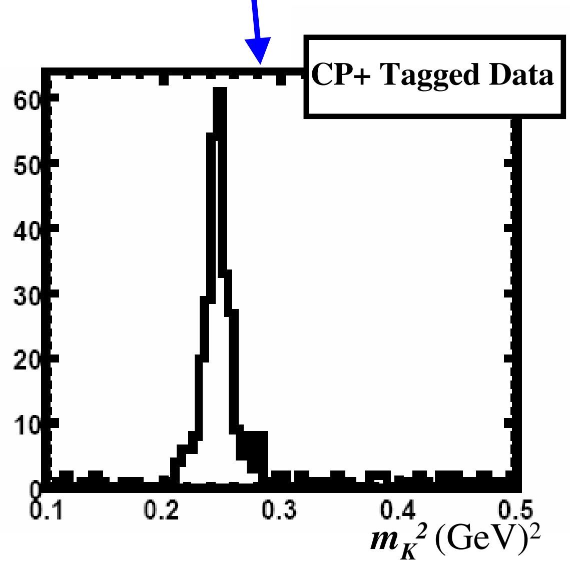
Require additional π^0, η veto

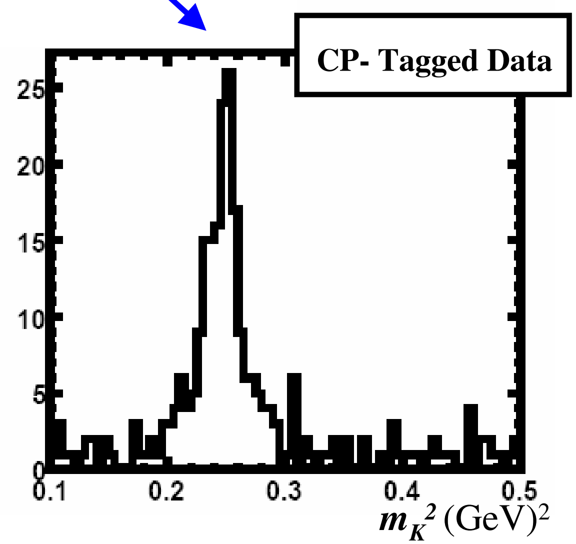
Same two-body CP tags are used as $K_S\pi\pi$:

CP+ tags:	*CP*- tags:
K^+K^-	$K_S\pi^0$
$\pi^+\pi^-$	$K_S\eta$

Mode	Yield
K^+K^-	194
$\pi^+\pi^-$	90
$K_S\pi^0$	263
$K_S\eta$	21







$K_L\pi^0$ vs. $K_S\pi\pi$

Additionally, we use $K_L\pi^0$ as *CP*-even tag for $K_S\pi\pi$ mode

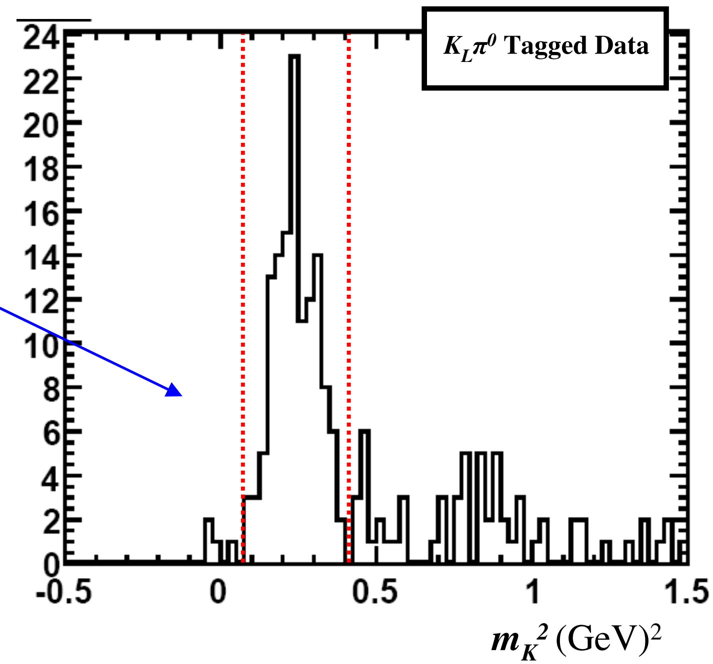
Similar event selection, with additional cuts:

- Require zero tracks
- 3σ cut on π^0 mass
- Additional π^0s vetoed

Reconstruct missing mass of K_L

Doubles number of *CP*-even tags

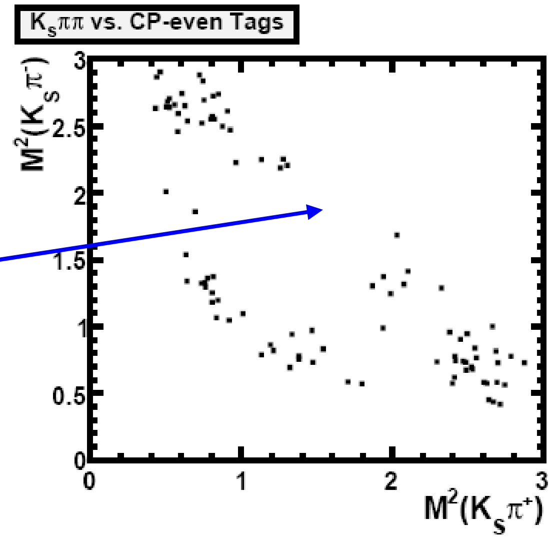
Yield: 190 events

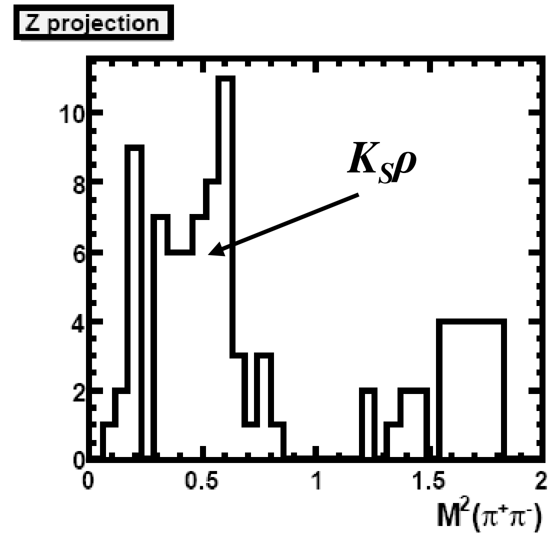


This mode contains highest background level ~ 5%

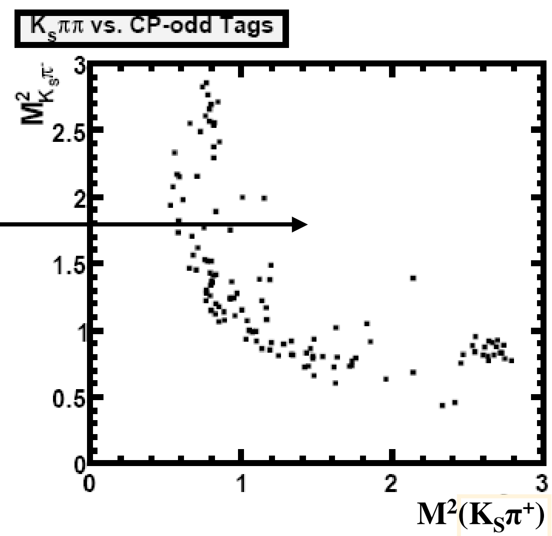
CP-tagged $K_S\pi^+\pi^-$ Dalitz Plots

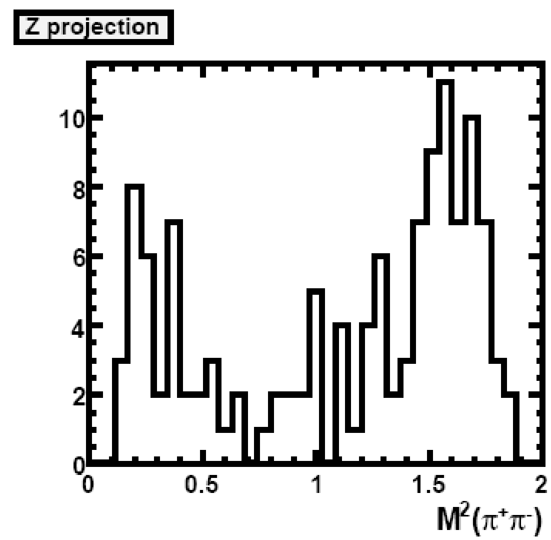
$K_S\rho^0$ resonance enhanced in CP-odd Dalitz plot





CP-odd $K_S\rho^0$ resonance absent in CP-even Dalitz plot

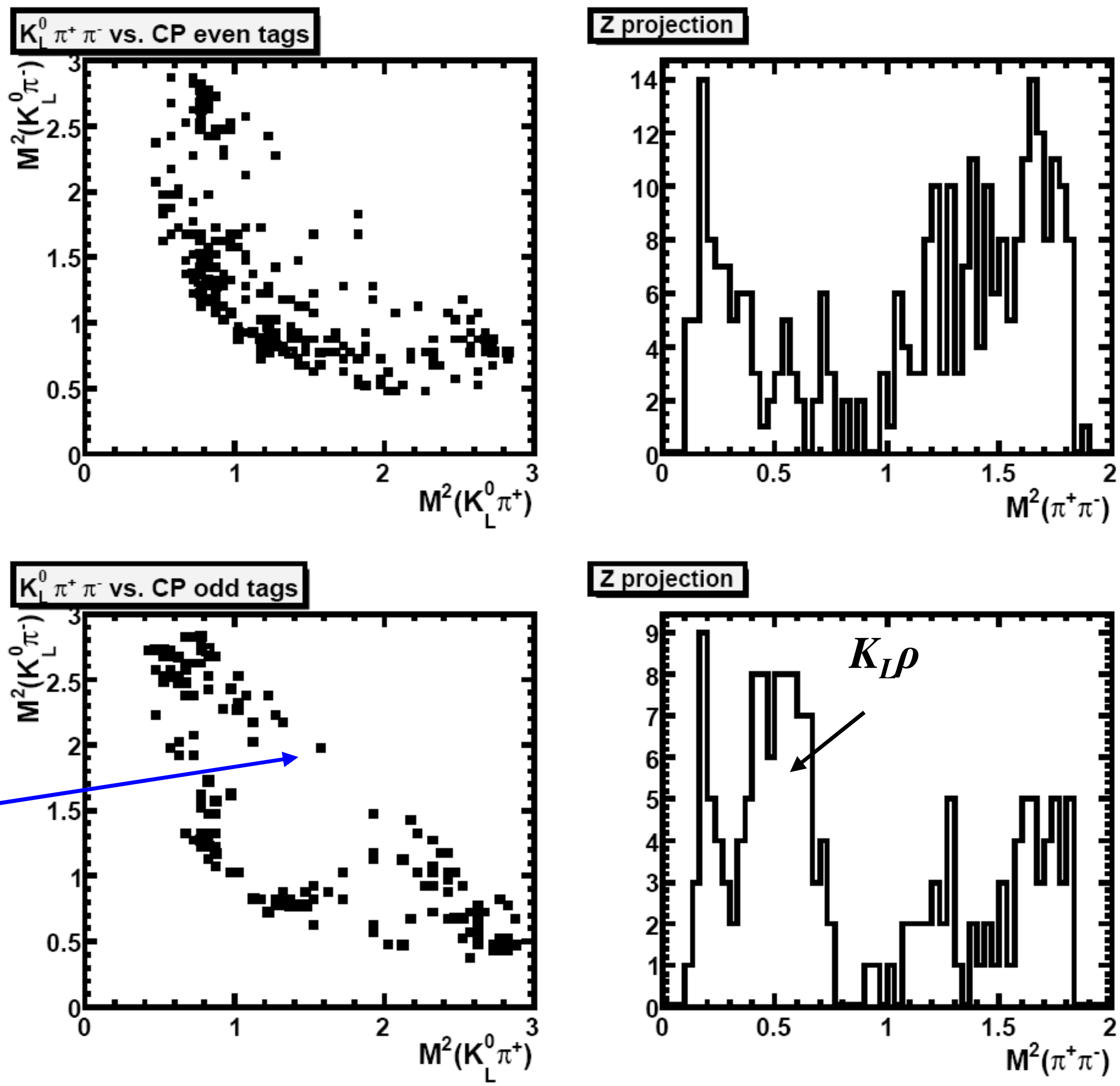




CP-tagged $K_L\pi^+\pi^-$ Dalitz Plots

Since CP of K_L is opposite to K_S, $K_L\pi\pi$ Dalitz plot contains opposite CP structure to that of $K_S\pi\pi$

$K_L\rho^0$ resonance enhanced in CP-even Dalitz plot

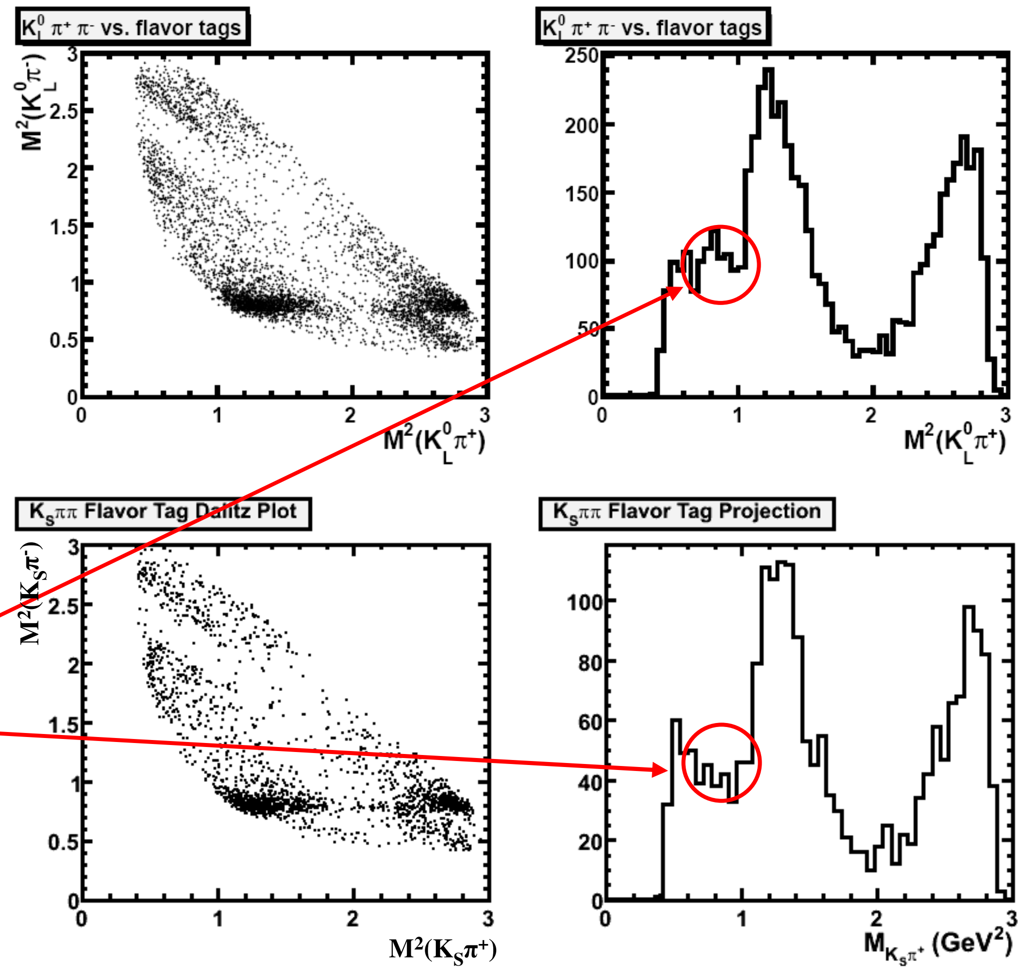


Flavor-tagged $K_{S,L}\pi^+\pi^-$ Dalitz Plots

The $K_{S,L}\pi\pi$ Dalitz plots are not exactly equal

There is a clear difference in the DCS K^{*+} peak

Appears constructively in $K_L\pi\pi$, and destructively in $K_S\pi\pi$



Must take this into account before combining c_i measurements for $K_L\pi\pi$ and $K_S\pi\pi$ samples

Combining c_i from $K_S\pi\pi$ and $K_L\pi\pi$

K_S and K_L can be expressed:

CF DCS

$$A(D^0 \to K^0_S\pi^+\pi^-) = \frac{1}{\sqrt{2}}[A(D^0 \to \bar{K}^0\pi^+\pi^-) + A(D^0 \to K^0\pi^+\pi^-)]$$

$$A(D^0 \to K^0_L\pi^+\pi^-) = \frac{1}{\sqrt{2}}[A(D^0 \to \bar{K}^0\pi^+\pi^-) - A(D^0 \to K^0\pi^+\pi^-)]$$

Define r as the magnitude of DCS/CF ratio

r is small (~ 0.06), but is the phase known?

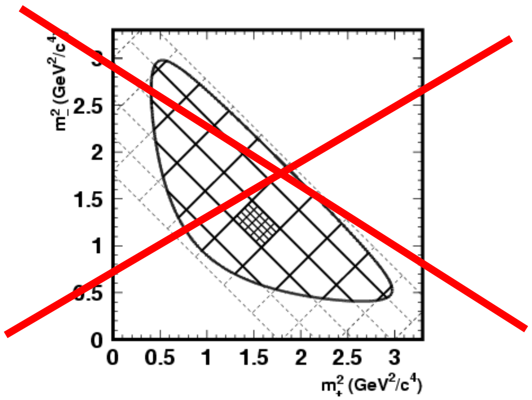
$$A(D^0 \to K_S\pi\pi) = K^{*-}(CF) + K^{*+}(DCS) + f_0 + \rho^0 + \ldots$$

$$A(D^0 \to K_L\pi\pi) = K^{*-}(CF) - K^{*+}(DCS) + (1\text{-}2re^{i?})f_0 + (1\text{-}2re^{i?})\rho^0 + \ldots$$

Value of c_i is in general different for $K_L\pi\pi$ and $K_S\pi\pi$, but can be related through U-spin symmetry

By varying each unknown phase and recalculating c_i, we can determine a measure of the systematic uncertainty for $K_L\pi\pi$

Binned Analysis

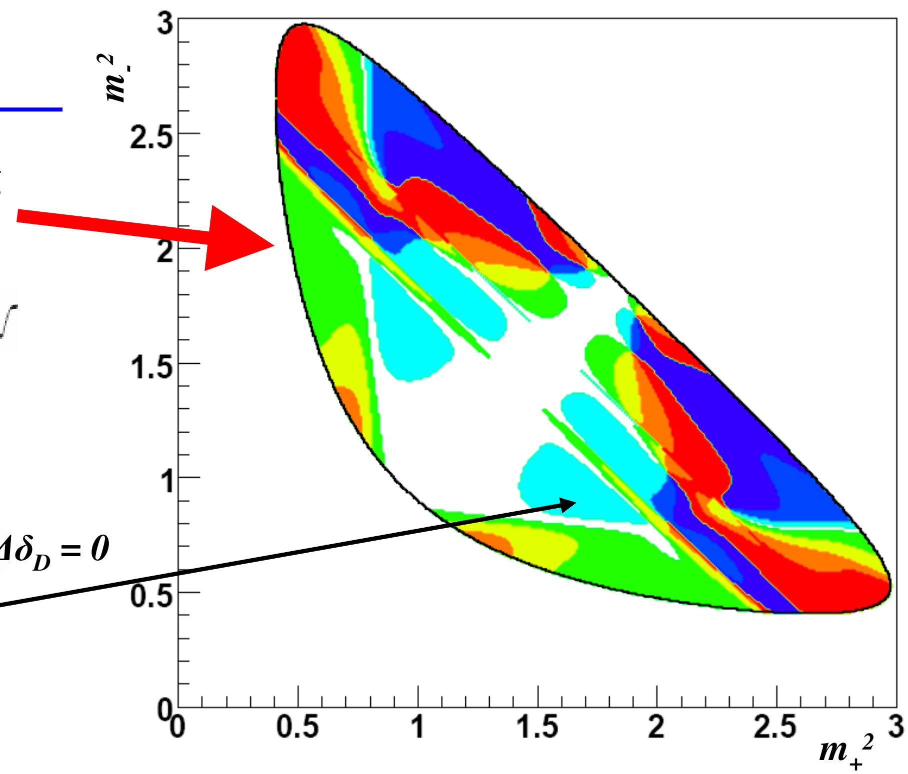


s_i can be determined from $c_i \rightarrow \quad s_i = \pm\sqrt{1 - c_i^2}$

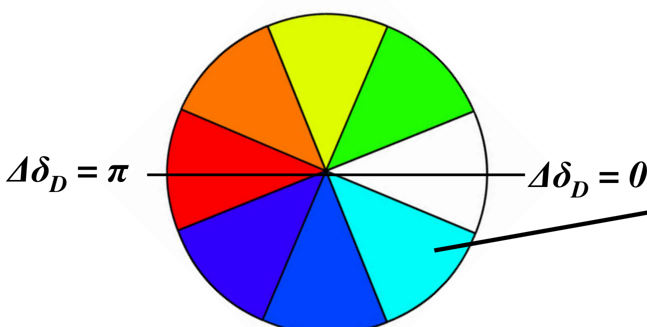
Provided fluctuations of phase difference δ_D across bins are small

Variation of δ_D phase can be minimized by choosing a more intelligent, model-inspired binning:

$$2\pi(i-1/2)/\mathcal{N} < \Delta\delta_D(m_+^2, m_-^2) < 2\pi(i+1/2)/\mathcal{N}$$



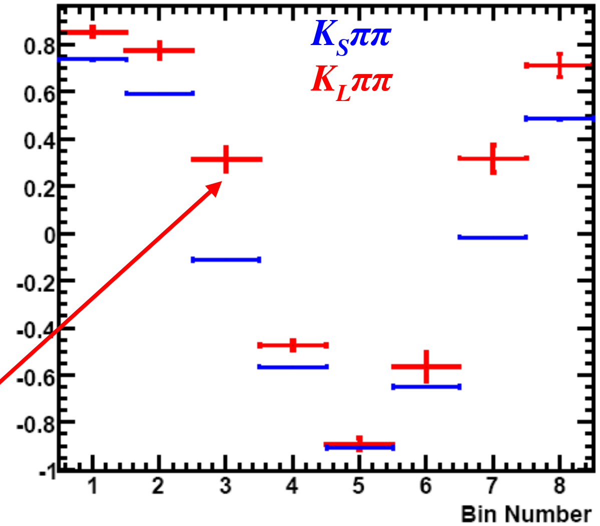
We use $N = 8$ bins in this analysis



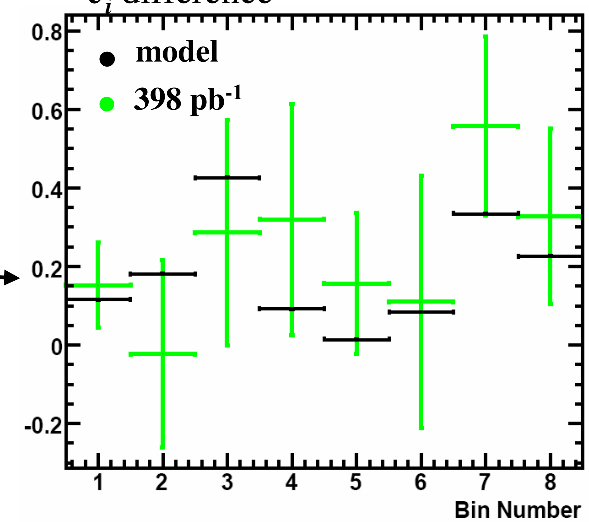
Bondar, Poluektov hep-ph/0703267v1 (2007)
Belle Collaboration, A. Poluektov *et al*. Phys. Rev. **D73**, 112009 (2006)

Comparing c_i for $K_{S,L}\pi^+\pi^-$

- Obtain $K_L\pi\pi$ model by changing sign of DCS terms → $K^{*+}(892)$, $K^{*+}(1410)$…
- Calculate c_i from $K_S\pi\pi$ and $K_L\pi\pi$ models
- Vary phase for each resonance, keep largest difference in c_i



- Systematic uncertainty from $K_L\pi\pi$ is small compared to c_i difference
- Good agreement of c_i difference in data

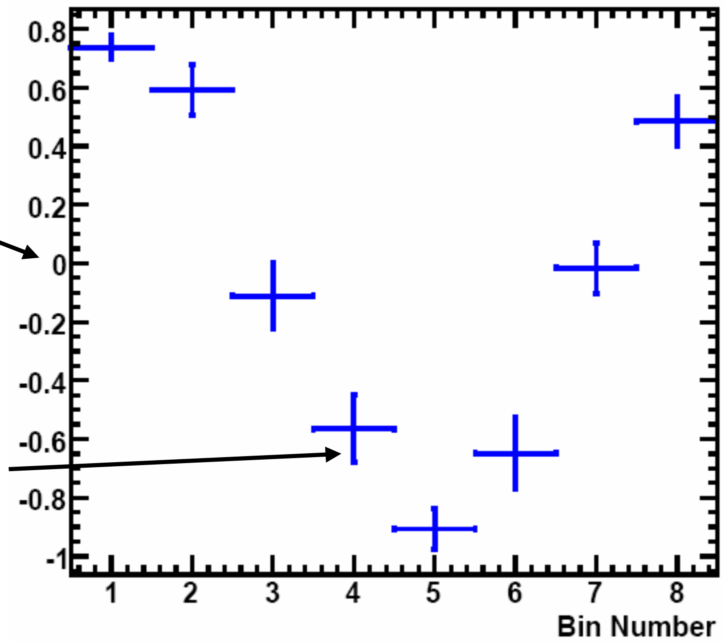


Sensitivity to c_i

- We combine $K_L\pi\pi$, $K_S\pi\pi$ Dalitz plots into an improved overall measurement of c_i
- Scale statistical uncertainty up to full 750 pb^{-1}
- Combine with $K_L\pi\pi$ systematic uncertainty to determine overall expected sensitivity from CLEO-c measurement

Error bars represent <u>expected</u> uncertainty, as projected from current data sample

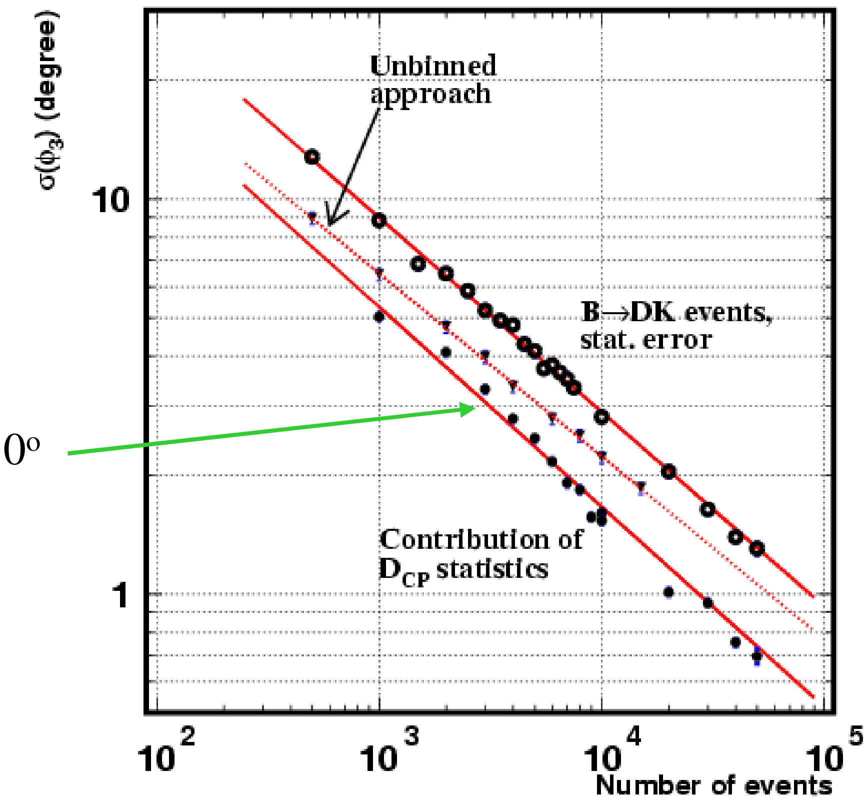
c_i calculated from model



Conclusion

- $K_L\pi\pi$, $K_S\pi\pi$ samples can be combined
- Good sensitivity to c_i
- Total D_{CP} expected to be ~ 1,530 for 750 pb^{-1}
- Combined BaBar/Belle (2 ab^{-1}) statistical uncertainty → ±6°
- CLEO-c can reduce model uncertainty from ±10° down to ± 4° in γ/φ_3 measurement

[1] Bondar, Poluektov [hep-ph/0510246]



Back up

Following modes will also be used to measure c_i and s_i

$K_S\pi\pi$ vs. $K_S\pi\pi$ (~ 480)
$K_S\pi\pi$ vs. $K_L\pi\pi$ (~ 1240)

} Expected yields (750 pb^{-1})