Quantum Coherence and Charm

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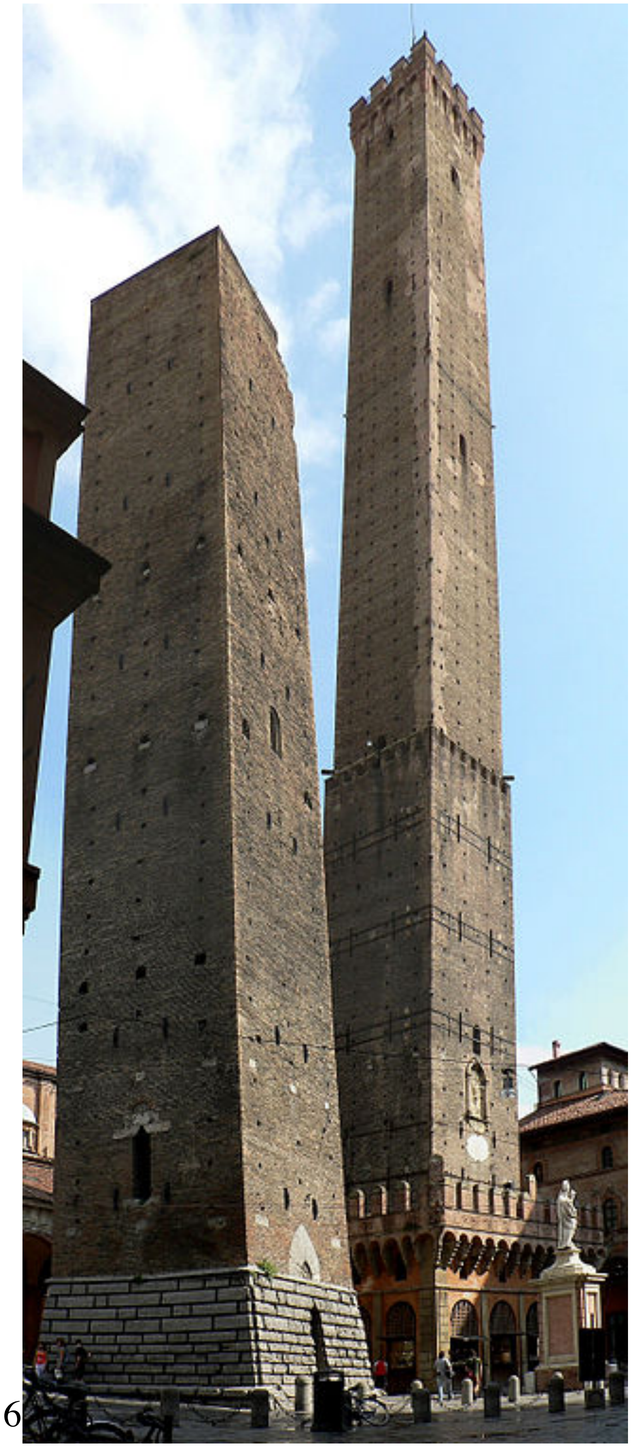
*Full disclosure: member of CLEO-c / BESIII / Belle II



Quantum coherence analyses allow us to form a more solid foundation for our studies in flavor physics…

They gives us unique access to strong phases, and it's fun to work with EPR-entangled states in an HEP context !

→ It takes TWO amplitudes to have a relative phase…

Of course, our goal is to find some flaw in the structure of the Standard Model…

We always seem to have a few *hints* of failure; the Standard Model bends yet does not break ! (thus far…)

→ Phases are angles…

Outline

Introduction: Essentials

Overview of Older Results

Survey of Recent Results

Selected Issues Going Forward

Conclusion

relative strong phases

Model Independence

For a written overview, see my CKM2014 proceedings : arXiV:1411.7327

The Big Picture: Phase Inputs

Places where relative D^0, D^{0bar} phases can show up:

1) Quantum-correlated ("EPR") D pairs @ threshold: **ψ (3770)**
2) D^0 - D^{0bar} mixing
3) B → DX , with common D^0, D^{0bar} final states [re: CKM γ]

Generally, 1) is viewed as a source of information to be input for use by 2) & 3) **[more on this later…]**

The relevant datasets are CLEO-c and BESIII :

→ **Access to relative D^0, D^{0bar} *strong phase differences***

→ **Can obtain *model-independent results***

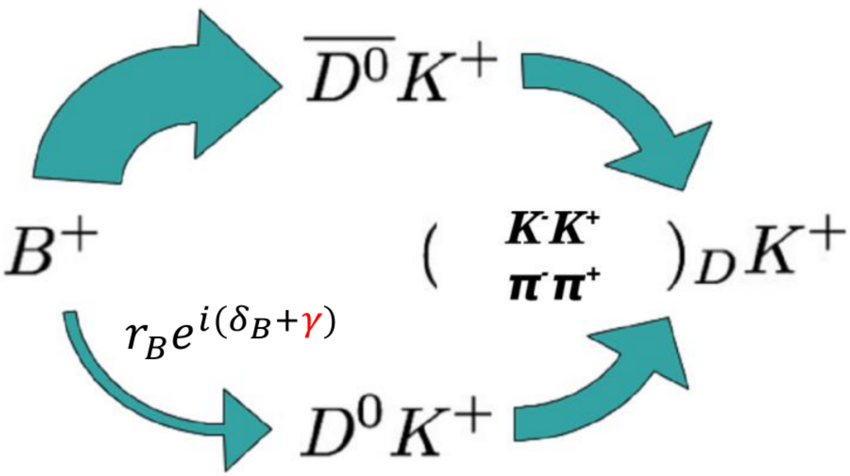
For 2) Rotate measured Kπ mode x',y' parameters to get x, y

For 3) Reduce model-dep. of CKM γ from $B \rightarrow D^{(*)} K^{(*)}$, $D^{(*)} \pi$

Main Customer: CKM γ Extraction

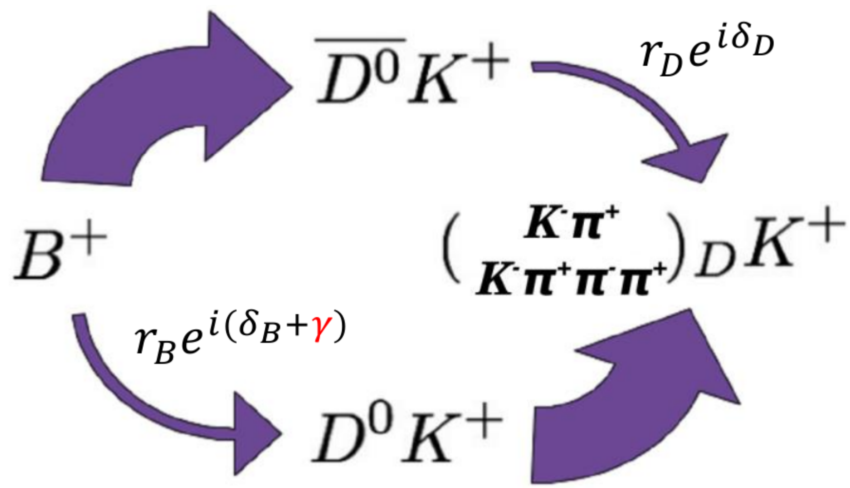
CKM Angle γ Measurement

✦ *Gronau, London, Wyler (**GLW**)*



Final states are CP eigenstates. Interference is O(10%)

✦ *Atwood, Dunietz, Soni (**ADS**)*



Final states are flavor modes (Kπ, K3π). CF and DCSD decays. Interference is large.

Borrowed from C. Wallace (LHC-b), talk @ Pheno 2014

Using The ψ (3770)

Threshold production of charm with $e^+e^- \rightarrow \psi(3770)$

The ψ (3770) decays to *coherent* pair of D mesons

$$\psi(3770) \rightarrow \frac{1}{\sqrt{2}}\left[\, D^0(+z)\overline{D}^0(-z) \; - \; \overline{D}^0(+z)D^0(-z) \,\right]$$

$$\psi(3770) \rightarrow \frac{1}{\sqrt{2}}\left[\, D_{CP-}(+z)D_{CP+}(-z) \; - \; D_{CP+}(+z)D_{CP-}(-z) \,\right]$$

CP eigen-states: $D_{CP\pm} = [D^0 \pm \overline{D}^0]/\sqrt{2}$

Measure various combination of rates for:

- **one decay mode only → "single tags"**
- **two decay modes → "double tags"**

Easiest way to see access to relative phases:

→ Reconstruct one meson in a CP eigenstate: a "**CP tag**"

→ Projects 2^{nd} meson into a D^0, D^{0bar} superposition (Eq 2)

→ So, D^0, D^{0bar} amplitudes to common final state interfere

Also can change the sign of interference ! *Use CP+ or CP- tag*

Decay Mode Jargon

Flavored

Flavored semileptonic	$K^- e^+ \nu$, $K^- \mu^+ \nu$	Pure CF
Flavored hadronic	$K^- \pi^+$, $K^- \pi^+ \pi^0$, $K^- \pi^+ \pi^+ \pi$-	CF + DCSD

Self-Conjugate

2-body CP eigenstate	$K^- K^+$, $\pi^+ \pi^-$, ...	SCS
2-body CP eigenstate	$K_S \pi^0$, ...	CF + DCSD
Multi body	$K^+ K^- \pi^+ \pi^-$, $\pi^+ \pi^- \pi^0$	SCS
Multi body	$K_S h^+ h^-$, $K_L h^+ h^-$	CF + DCSD

Neither $K_S K^- \pi^+$ SCS

[Note: "Both" is not possible !]

Blue modes: used for γ **Green : future?** **Black: tag only**

(? out-of-date now ?)

Shorthand: hadron "h" = K, π

CF : Cabibbo-Favored **right-sign Kaon: D → K^{bar} X + c.c.**

SCS : Singly-Cabibbo-Suppressed

DCSD : Double-Cabibbo-Suppressed (Decay) **wrong-sign Kaon: D → K X + c.c.**

Multi-Body "Coherence Factors"

Simplified Two body:

$| A_1 + A_2 |^2 = | A_1{}^2 + A_2{}^2 + 2 A_1 A_2 e^{-i\delta} |$ 1, 2 = CF, DCSD

Generalization → Atwood-Soni :

Integrate over Dalitz plot; define real average amplitudes

[$\mathcal{A}$ → A below]

BUT this requires a "fudge factor" of $Re^{-i\delta}$ for interference term

Simplified Multi body:

$\int d\, Dalitz\ | \mathcal{A}_1 + \mathcal{A}_2 |^2 = | A_1{}^2 + A_2{}^2 + 2\, R\, e^{-i\delta} A_1 A_2 |$

Define: $R\ e^{-i\delta}$ = (true cross-term) / (naïve = $A_1 A_2$)

Note: R < 1 due to two reasons: varying phase & " | r(x) | ≠ 1"

$r = A_2 / A_1$

$$A^2_{K^\pm \pi^\mp \pi^0} = \int |\mathcal{A}_{K^\pm \pi^\mp \pi^0}(\mathbf{x})|^2 d\mathbf{x}$$

$$R_{K\pi\pi^0} e^{-i\delta_D^{K\pi\pi^0}} = \frac{\int \mathcal{A}_{K^- \pi^+ \pi^0}(\mathbf{x}) \mathcal{A}_{K^+ \pi^- \pi^0}(\mathbf{x}) d\mathbf{x}}{A_{K^- \pi^+ \pi^0} A_{K^+ \pi^- \pi^0}}$$

From Tags to Physics

CP+ & CP- tags:

Switch of +- flips sign of interference term

Also used directly for γ, but *phases are trivial* [GLW]

Semileptonic flavor tags:

No interference; clean normalization [but pesky ν…]

Hadronic flavor tags:

Normalization, modulo DCSD [easier than semilep for exp.]

Also modes we want to study for γ [ADS]

Multi-body self-conjugate

Modes we want to under study for γ [GGSZ]

Different analyses use different numbers of tag modes

CLEO $K^-\pi^+$ & CLEO-c, BESIII $K_S\pi^+\pi^-$ use ***many*** tags

BESIII $K^-\pi^+$ analysis uses only signal and CP tags

Experimental Output

K^-K^+, $\pi^+\pi^-$	GLW	$\delta = 0, \pi$	
$K^-\pi^+$	ADS	δ (R=1)	get from threshold charm…
$K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$, $K_SK^-\pi^+$	ADS+	R, δ	
$K_S\pi^+\pi^-$, $K_SK^+K^-$	GGSZ	c_i, s_i	

R, δ are Atwood-Soni coherence factors for ADS modes

→ ***No relative D^0-D^{0bar} phase*** in separate D^0, D^{0bar} Dalitz fits

e.g., if one fits N amplitudes to D^0, D^{0bar} separately: [D*-tagged @ B factory]

only gets 2(N-1) = 2N-2 out of 2N-1 relative phases

→ Also ***avoid Dalitz models***

c_i, s_i are "Cartesian R, δ in Dalitz bins" for GGSZ modes

→ Here, relative D^0-D^{0bar} phase is trivial

(distinction due to self-conjugate modes, not changing basis to c_i, s_i !)

→ But we still ***avoid Dalitz models***

QC for Pedestrians I - SKIP -

Simplest effect:

$\psi(3770) \rightarrow [\, D_{CP+} D_{CP-} - D_{CP-} D_{CP+} \,] / \sqrt{2}$

***Like CP* (++, --) :** cancels ***Unlike CP* (+-, -+) :** doubled

My favorite general form: * Ignore mixing for now *

$$\Gamma_{FG} / A_F^2 A_G^2 = [\, r_F^2 + r_G^2 + 2\, r_F\, r_G\, R_F\, R_G \cos(\delta_G - \delta_F) \,]$$

or $1 + r_F^2 r_G^2 + \ldots$: factor out A_i such that $r < 1$

→ $r_{F,G}$ (averaged) amplitude ratios : ~ $A(D^{0bar} \rightarrow F,G) / A(D^0 \rightarrow F,G)$

1 for CP eigenstates

$\sim\tan^2(\theta_C)$ for hadronic K^- modes [DCSD / CF]

0 for semileptonic → no interference

→ R, δ: Atwood-Soni coherence factors

R=1; $\delta = 0, \pi$ for CP eigenstates;

R=1; $\delta = ?$ for $K^- \pi^+$

Both non-trivial for multi-body hadronic

QC for Pedestrians II - SKIP -

Need some double-tag rate with two "non-trivial" modes to fully separate parameters

→ If not, get only $\mathrm{Re}[R\, e^{-i\delta}] = R \cos\delta$, not separate (R, δ)

[Or, only c_i, not both c_i, s_i]

The reason that having two works is simple trigonometry:

$$\cos(\delta_2 - \delta_1) = \cos\delta_1 \cos\delta_2 - \sin\delta_1 \sin\delta_2$$

With this, one has enough observables to separate (can still use modes where one $\delta_i = 0$)

Two "non-trivial" modes ?

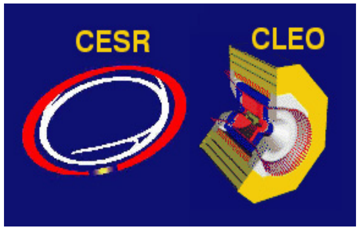
→ Can be different values of n in $K^-(n\pi)^+$ analyses

→ Can even be different bins (i) in $K_S\pi^+\pi^-$ c_i, s_i analyses

CLEO-c Results

CLEO-c Data : 0.8 fb^{-1} @ $\Psi(3770)$ & 0.6 fb^{-1} @ 4170 MeV 2003 - 08

$K^-\pi^+$	**281 pb^{-1}** (updated below)	**PRL 100, 221801 (2008); PRD, 78, 012001 (2008) [= more details]**
$K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$	**818 pb^{-1}**	**PRD 80, 031105(R) (2009)**
$K_S\pi^+\pi^-$	**818 pb^{-1}**	**PRD 80, 032002 (2009)**
$K_{S,L}h^+h^-$	**818 pb^{-1}**	**PRD 82, 112006 (2010)**
$K_SK^+\pi^-$	**818 pb^{-1}** *	**PRD 85, 092016 (2012)**
$K^-\pi^+$	→ **818 pb^{-1}**	**PRD 86, 112001 (2012)**
$K^+K^-\pi^+\pi^-$	**818 pb^{-1}** **	**PRD 85, 122002 (2012)** { **isobar analysis; but *first* D, D^{bar}**



also use high-E continuum {
- * + **15 fb^{-1} ~10 GeV**
- ** + **24 fb^{-1} ~10 GeV & 600 pb^{-1} 4.17 GeV**

Today's Main Topics

BESIII Results

Dataset : 2.92 fb^{-1} 2010 - 11 (1 ⅔ years) → 3.5x CLEO-c
Future ability : ~ 4 fb^{-1} / running year [note: $\mathcal{L}_{2011} >> \mathcal{L}_{2010}$]

BESIII

$K^-\pi^+$	**2.92 fb^{-1}**	**PLB 734, 227 (2014)**
$K_S\pi^+\pi^-$	**2.92 fb^{-1}**	**Preliminary @ APS, Apr 2014**

[Will use first as an example; second analysis is in backup slides…]

CLEO-c "Legacy" Results

$K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$	**818 pb^{-1}**	**PLB 731, 197 (2014)**
$\pi^+\pi^-\pi^0$, $K^+K^-\pi^0$	**818 pb^{-1}**	**PLB 740, 1 (2015)**
$\pi^+\pi^+\pi^-\pi^-$, $\pi^+\pi^-\pi^0$, $K^+K^-\pi^0$	**818 pb^{-1}**	**PLB 747, 9 (2015)**

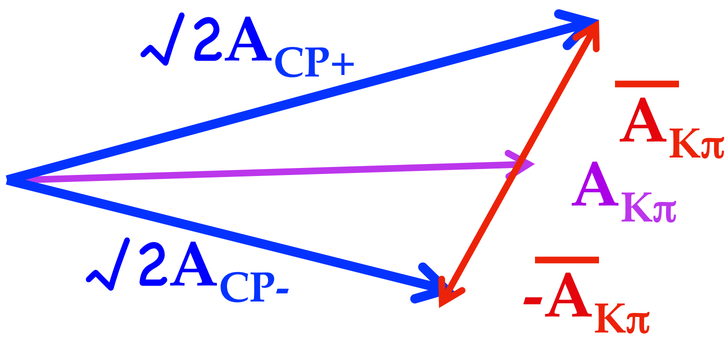
[CLEO-c data analyzed by past members, after collaboration disbanded]

Also: 2016 joint analysis of CLEO-c Legacy = LHC-b for $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$

Strong Phase $\delta_{K\pi}$

BESIII 2.9 fb^{-1}
PLB 734, 227 (2014)

Simplified Picture: (simple = no mixing)



Amplitude triangle:

$CP_{\pm}$ = CF ± DCSD

[DCSD enhanced for visibility !]

Complex ratio DCSD/CF amplitude

$$\frac{\langle K^-\pi^+|\overline{D}^0\rangle}{\langle K^-\pi^+|D^0\rangle} = -re^{-i\delta_{K\pi}}$$

Flip CP of tag: reverses interference term

CP-tagged rate asymmetry (essentially) measures r cos δ

$$\mathcal{A}_{CP} = [\,|A_{CP-}|^2 - |A_{CP+}|^2\,] \,/\, [\,|A_{CP-}|^2 + |A_{CP+}|^2\,]$$ ← **measure**

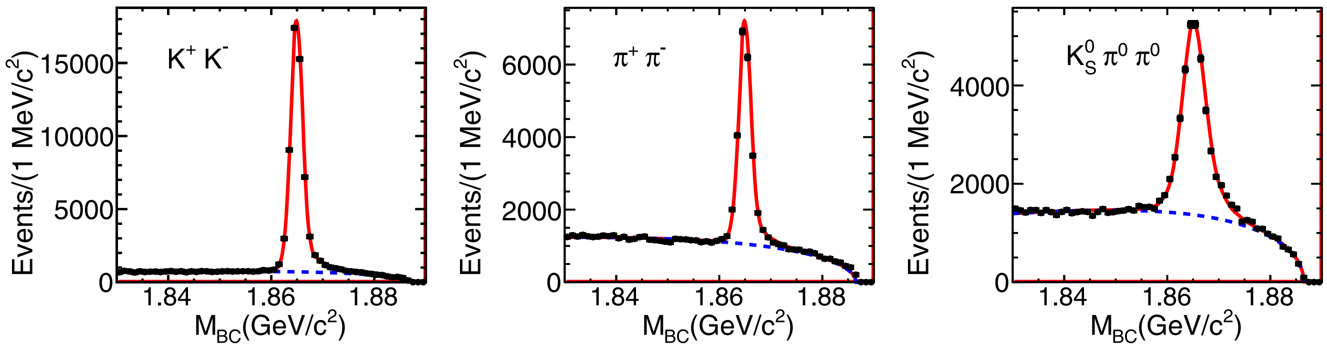
$$= r\cos\delta$$ (+ D mixing corrections: y, R_{WS}) ← **extract**

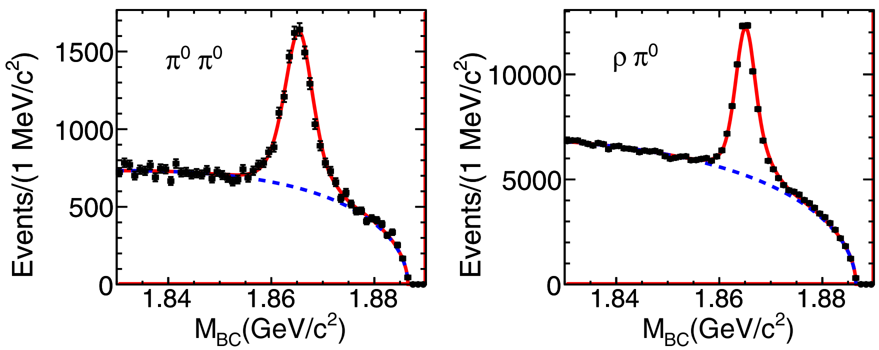
BESIII

Strong Phase $\delta_{K\pi}$

BESIII 2.9 fb^{-1}
PLB 734, 227 (2014)

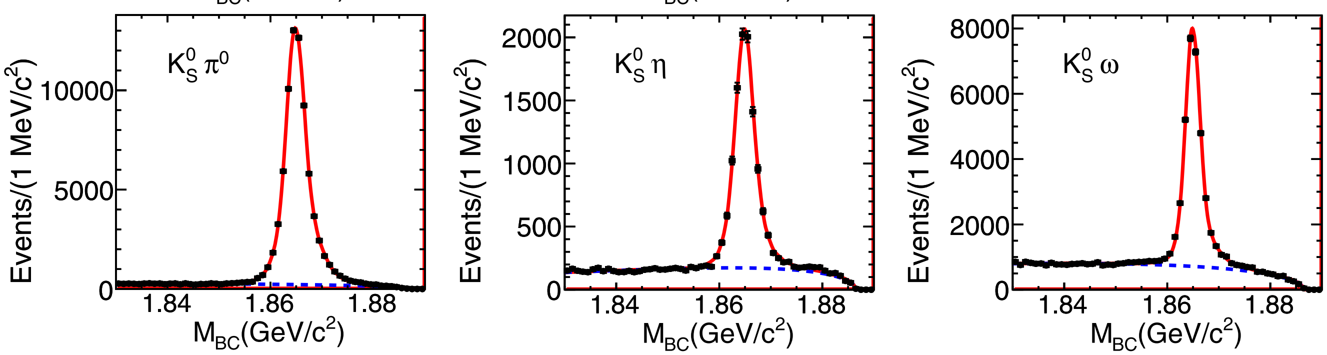
First BESIII Quantum Coherence result : *straightforward analysis*





Tags Used: 5 CP+, 3 CP-

$S+$	$K^+K^-, \pi^+\pi^-, K^0_S\pi^0\pi^0, \pi^0\pi^0, \rho^0\pi^0$
$S-$	$K^0_S\pi^0, K^0_S\eta, K^0_S\omega$



Strong Phase $\delta_{K\pi}$

BESIII 2.9 fb^{-1}
PLB 734, 227 (2014)

$$\mathcal{A}^{CP}_{K\pi} \equiv \frac{\mathcal{B}_{D^{S-}\to K^-\pi^+} - \mathcal{B}_{D^{S+}\to K^-\pi^+}}{\mathcal{B}_{D^{S-}\to K^-\pi^+} + \mathcal{B}_{D^{S+}\to K^-\pi^+}}$$

$S+$ $(S-)$ denotes the CP-even (CP-odd) eigenstate.

Direct result : *

$\mathcal{A}_{CP}$ **= (12.7 ± 1.3 ± 0.7)%**

$$2r\cos\delta_{K\pi} + y = (1 + R_{WS}) \cdot \mathcal{A}^{CP}_{K\pi}$$

Using external inputs for $r_{K\pi}$, R_{WS}, y, we extract :

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

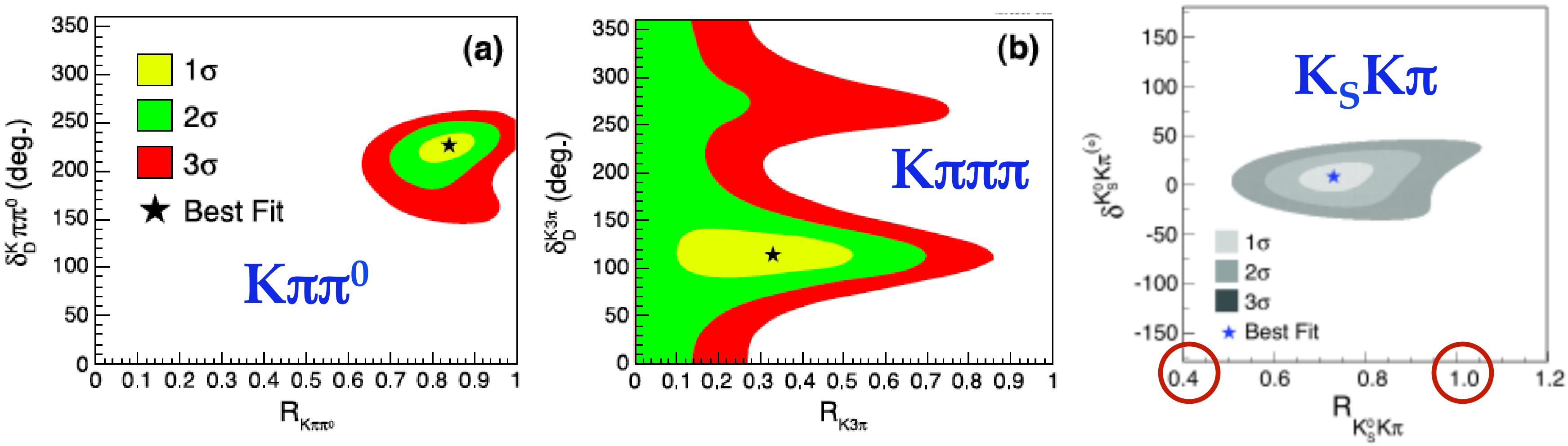
Compare to CLEO-c:

$\cos\delta_{K\pi} = 0.81\,^{+0.22}_{-0.18}\,^{+0.07}_{-0.06}$ (no external inputs)

$\cos\delta_{K\pi} = 1.15\,^{+0.19}_{-0.17}\,^{+0.00}_{-0.08}$ (w/ external inputs)

* **HFAG can use this, I believe: they now omit final $\delta_{K\pi}$ due to external inputs …**

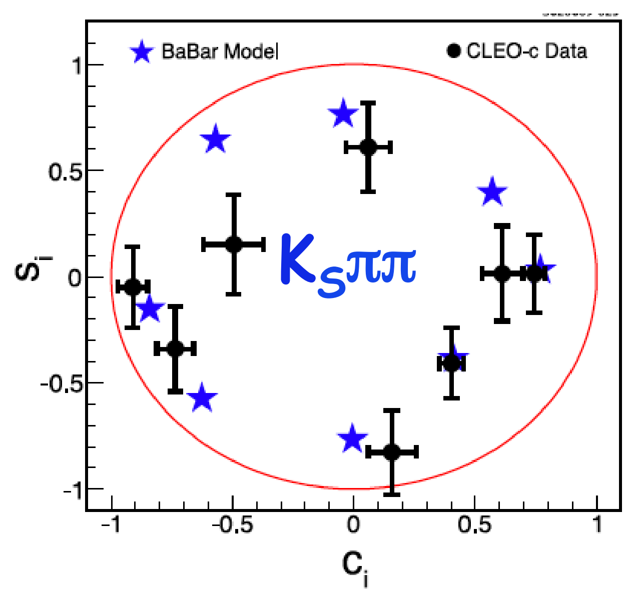
Original CLEO-c Coherence Factors



Small R for $K\pi\pi\pi$: still useful for r_B !

Or, we could bin across Dalitz plot

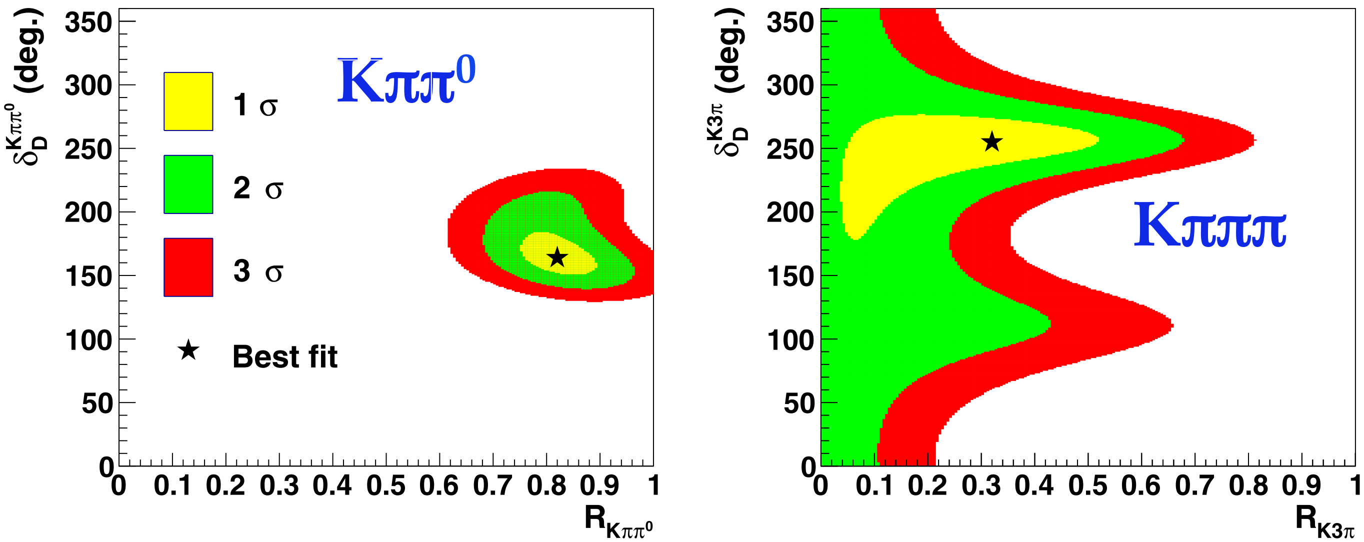
c_i and s_i: bin-averaged
<R cos δ> and <R sin δ>



$K^- (n\pi)^+$ Update

PLB 731, 197 (2014) 818 pb^{-1}

CLEO-c "Legacy data" publication → not a collaboration result
(but I personally believe it to be of equal quality)



Note:
Kπππ best fit now in other lobe…

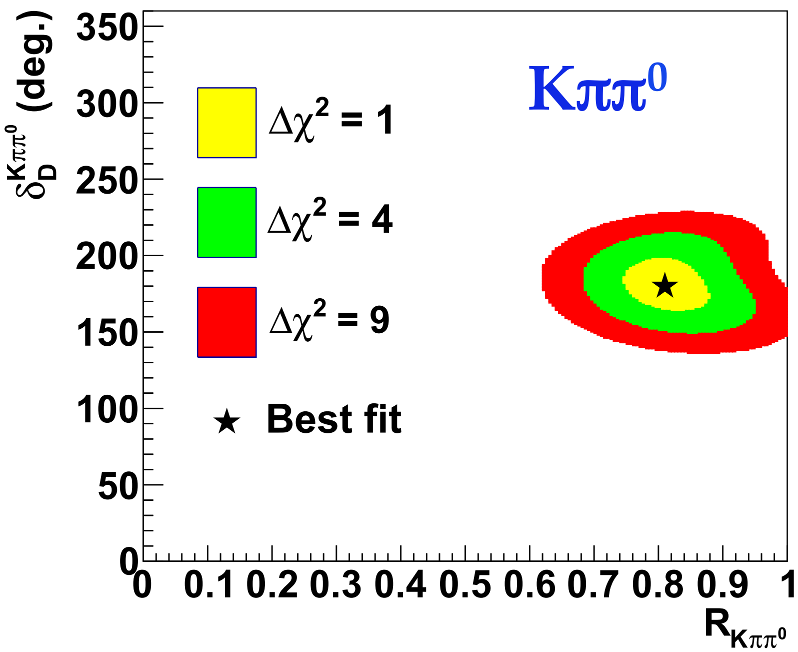
→ Now includes $K_S\pi^+\pi^-$ tags
→ Updated external inputs (BF, mixing, Kπ)

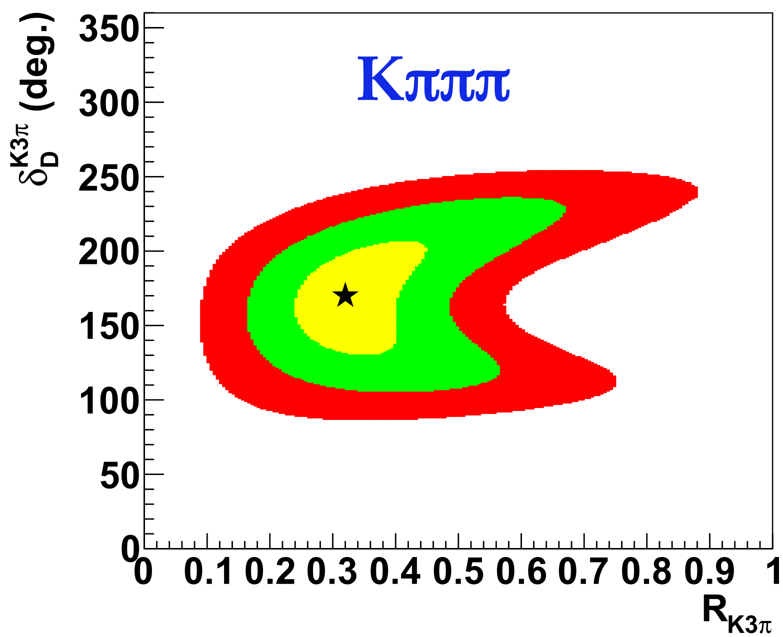
Kπππ updated again in
PLB 757, 520
(2016) Now including LHCb data…

$K^-(n\pi)^+$ Update II

PLB 757, 520 (2016) 818 pb^{-1} + LHCb data

Combined fit to: CLEO-c "Legacy data" + LHC-b data for D mixing





Note: now $K\pi\pi\pi$ "lobes" are almost gone…

$\pi^+\pi^-\pi^0$ & $K^+K^-\pi^0$ CP Fractions

PLB 740, 1 (2015) 818 pb^{-1}

More CLEO-c "Legacy data" results

CP fraction for a mixed-CP final state:

$$F_+ = N(CP+) / [\, N(CP+) + N(CP-) \,]$$

These states act similar to CP eigenstates, but suffer from a statistical "Dilution factor" of $w = (2F^+ - 1)$

If the CP-content is nearly pure (F_+ is near 1 or 0), then the loss is small

Results:

$\pi^+\pi^-\pi^0$: $F_+ = 0.968 \pm 0.017 \pm 0.006$

$K^+K^-\pi^0$: $F_+ = 0.731 \pm 0.058 \pm 0.021$

The three-pion mode is nearly pure: acts *almost* like a CP-eigenstate

$\pi^+\pi^-\pi^+\pi^-$ CP Fraction & More

PLB 747, 9 (2015) 818 pb^{-1}

These CLEO-c "Legacy data" results also imake use of more comlpex non-CP-eigenstate $K_S\pi^+\pi^-$ & $K_L\pi^+\pi^-$ tags

Results:

$\pi^+\pi^-\pi^+\pi^-$: $F_+ = 0.737 \pm 0.028$

The new tags can be used to update the previous modes

New $\pi^+\pi^-\pi^0$: $F_+ = 1.014 \pm 0.045 \pm 0.022$

Combined : $F_+ = 0.973 \pm 0.017$

New $K^+K^-\pi^0$: $F_+ = 0.734 \pm 0.106 \pm 0.054$

Combined : $F_+ = 0.732 \pm 0.055$

$K_S X$ vs. $K_L X$ Rate Asymmetries

Another somewhat related topic, also involving phases

Study rate asymmetries for specific mode pairs of the form :

$K_S n\pi$ & $K_L n\pi$

The K_S & K_L wave-functions lead to net amplitudes that are sums and differences of the CF and DCSD amplitudes

➔ up to 10% effects, depending on a relative phase

Some results from CLEO-c ; many more in progress @ BESIII

Selected Issues I

Places to make progress on existing ideas:

→ Use data to un-rotate mixing results for multi-body modes !
e.g., $K\pi\pi^0$: "Atwood-Soni for mixing" [Bondar et al. 2010]

→ Explore suggestion to use Charm mixing as a ***SOURCE*** of strong phase information [Harnew & Rademacker 2014, 2015]

And, of course:

Maintain a lively D ←→ B interchange & forge ahead !

Selected Issues II

Places to Be Careful…

→ Efficiencies vary across D Dalitz plots
Charm and B factories differ; we traffic in corrected variables
Current methods accurate ? Need Dalitz models to do well ?
So, take care if using A-S coherence factors or CP fractions !

→ Are studies of D mixing, D CPV, K_S CPV effects complete ?
[Probably; see excellent review by Matteo Rama, CKM14, Vienna]

→ Assumptions of SM re: CPV could be more explicit
e.g., GGSZ assumes no *weak phase* between CF & DCSD (?)

→ Take care with Kaon regeneration and Kaon interactions !

Everything is a Special Case !
(almost)

So if you were confused, you're probably not alone…

$K^-\pi^+$ **$K^-\pi^+\pi^0$** **$K^-\pi^+\pi^+\pi^-$** **$K_S K^+\pi$**

K^+K^- **$\pi^+\pi^-$** **$K^+K^-\pi^+\pi^-$** **$K_S\pi^+\pi^-$** **$\pi^+\pi^-\pi^0$**

$K^-\pi^+$ only δ ; $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$ have both R & δ

Multi-body Self-conjugate modes:
If no CPV, only 2(n-1) isobar phases, not 2n-1
Need threshold data only to avoid model dependence;
there is no "essential" D^0-D^{0bar} phase

4-body: more complicated angular momenta than 3-body

K_S modes: CF and DCSD give K^0, K^{0bar}, not K_S directly

Conclusions

Unique access to strong phases & ability to extract model-independent results with charm at threshold

- Started with many CLEO-c Results, added "legacy" results
- Perhaps a tiny bit more activity with CLEO-c "legacy data" ?
- Now, the 3.5x larger BESIII dataset is producing results

Many modes in progress…stay tuned!

Interest of B physics users remains high

- LHCb is a ***huge*** addition to older B-factory data
- But… e^+e^- will return soon with Belle II [beams stored !]
- Important to keep active interaction between B & D

Future prospects are bright

- More precision, new modes, new variables !
- Need to maintain threshold analysis manpower

Selected Theory References: Insights, Old & New

Quantum Correlations

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Gronau, Grossman & Rosner, Phys.Lett. B508, 37 (2001)
Atwood & Petrov, Phys. Rev. D71, 054032 (2005) [2002 eprint: hep-ph/0207165]
Asner & Sun, Phys. Rev. D73, 034024 (2006); E: ibid, D77, 019901 (2008)

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Bigi & Sanda, Phys. Lett. B171, 320 (1986) [see Ref. 5 for other contributors…]

"Attention PDG" : $K_S \neq 1/2$ of K^0 or K^{0bar}

Bigi & Yamamoto, Phys. Lett. B349, 363 (1995)

D^0 Mixing with $K_S K\pi$

Malde & Wilkinson, Phys. Lett. B701, 353 (2011)

D^0 Mixing as the Source of Phase Info for CKM Υ with "DK" modes

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B physics: CKM Υ with "DK" modes

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Grossman, Ligeti & Soffer PRD 67, 071301 (2003) **"GLS"**: non-eigenstate SCS

Bondar & Gershon Phys. Rev. D 70, 091503 (2004) $B \to D^{*0}K$, with $D^{*0} \to D^0\pi^0$, $D^0\gamma$

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Early Explorations of D Mixing

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Rama Phys. Rev. D 89, 014021 (2014)

D Direct CPV and CKM ϒ from B -> DK

Martone & Zupan, Phys. Rev. D 87, 034005 (2013)

Bhattacharya ,Gronau, London & Rosner Phys. Rev. D 87, 074002 (2013)

Wang Phys. Rev. Lett. 110, 061802 (2013)

CPV in K_S & CKM ϒ

Grossman & Savastio JHEP 03, 008 (2014)

K_S decay time acceptance and CPV in tau, D

Bigi & Sanda Phys. Lett. B 625, 47 (2005)

Grossman & Nir JHEP 04, 002 (2012)

K_S detector interactions & B, D CPV

Ko, Won, Golob, Pakhlov Phys. Rev. D 84, 111501(R) (2011)

BESIII Preliminary $K_S\pi^+\pi^-$ Results

Classic "GGSZ mode"; better precision than CLEO-c
Preliminary results presented @ APS meeting, Apr 2014

$K_S\pi^+\pi^-$ is the main topic: extract c_i, s_i
$K_L\pi^+\pi^-$ is also used: extract c'_i, s'_I
relate to c_i, s_i with model corrections.

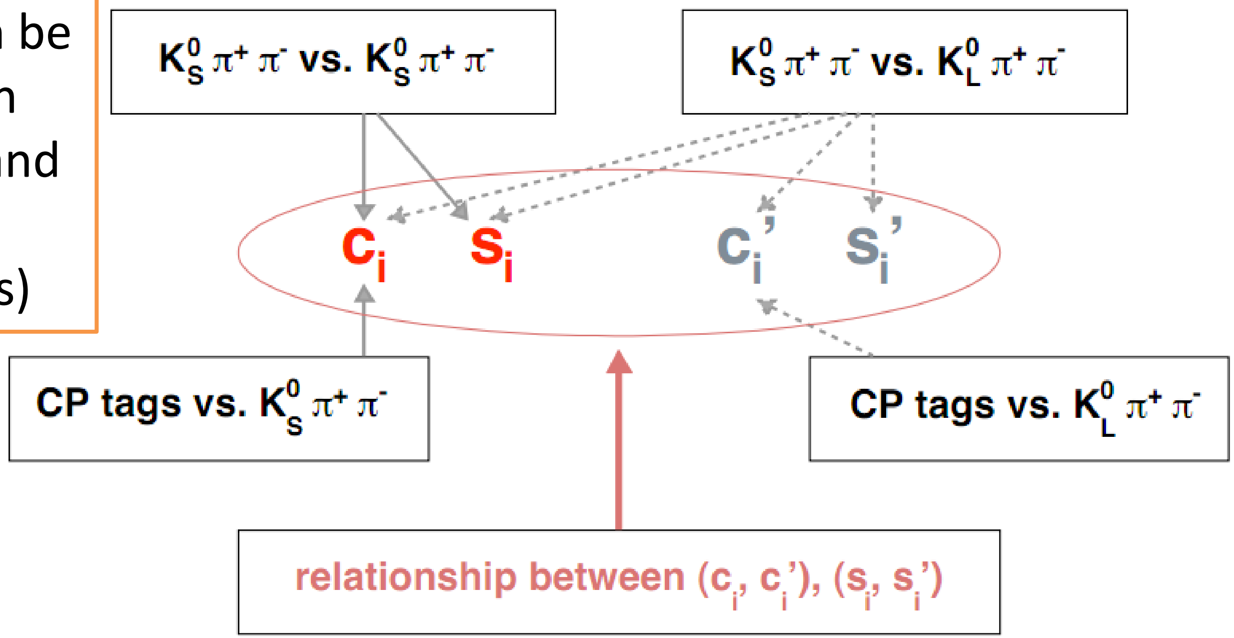
Aggressive use of tags, including partial reconstruction

All results preliminary; as presented at April 2014 AP meeting

Preliminary $K_S\pi^+\pi^-$ Results

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

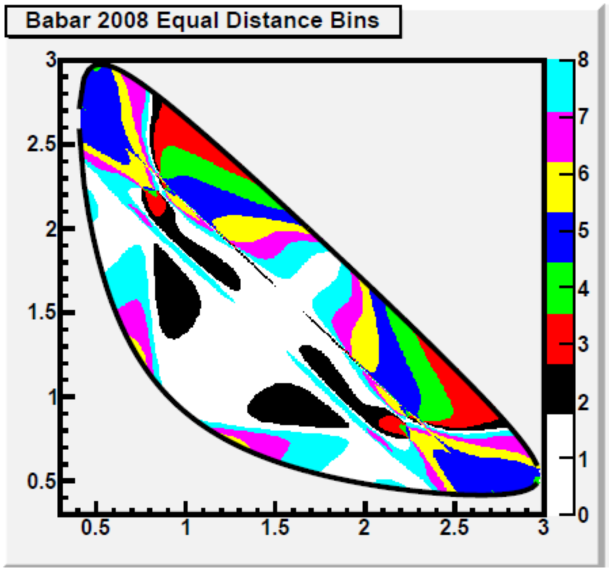
A relationship can be shown between Dalitz bin yields and c_i and s_i (in backup slides)

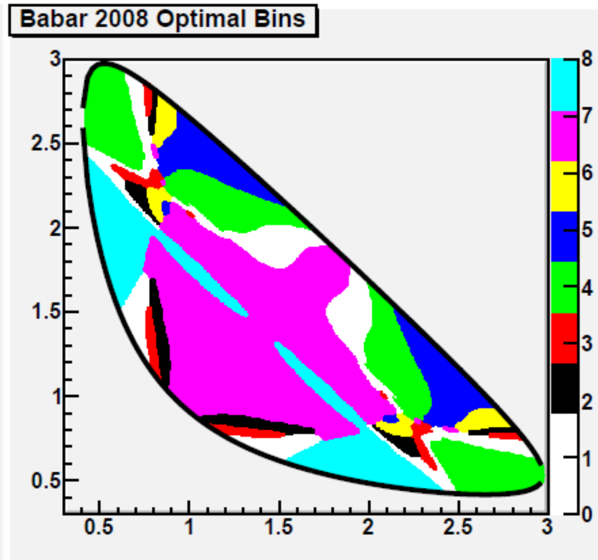


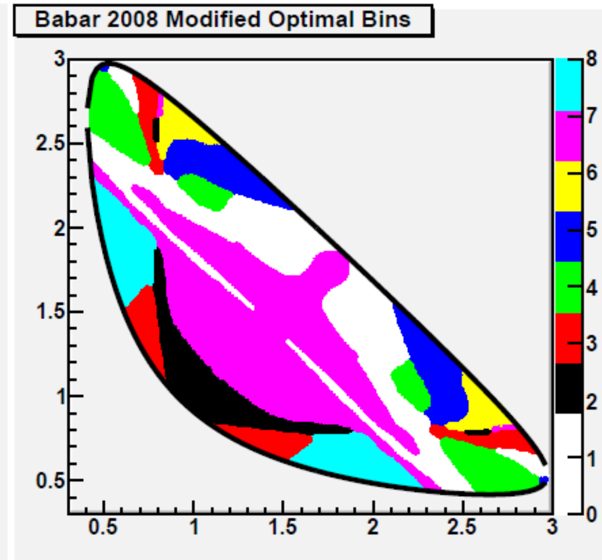
Only c_i, s_i from $K_s\pi^+\pi^-$ is used to calculate γ.
However adding in $D^0 \rightarrow K_L\pi^+\pi^-$ we can calculate c'_i, s'_i and use how they relate to c_i, s_i to further constrain our results in a Global fit.

Slide from Dan Ambrose, APS 2014

Preliminary $K_S\pi^+\pi^-$ Results







Result of splitting the Dalitz phase space into 8 equally spaced phase bins based on the BaBar 2008 Model.

Starting with the equally spaced bins, bins are adjusted to optimize the sensitivity to γ. A secondary adjustment smooths binned areas smaller than detector resolution.

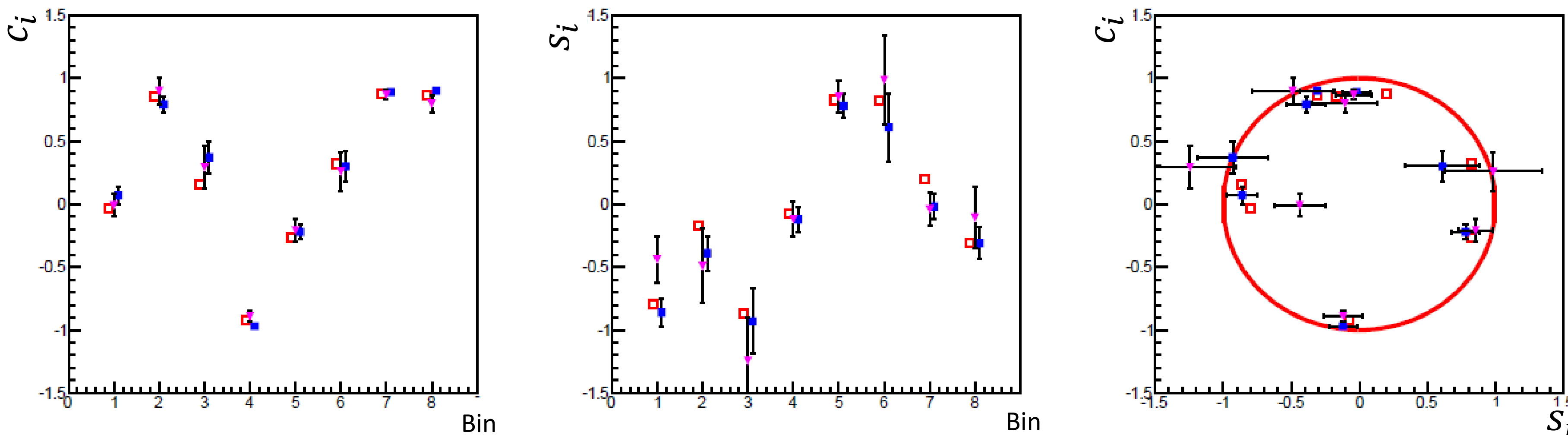
Similar to the "optimal binning" except the expected background is taken into account before optimizing for γ sensitivity.

Source: CLEO Collaboration, Physical Review D, vol 82., pp. 112006 - 112035

Slide from Dan Ambrose, APS 2014

Preliminary $K_S\pi^+\pi^-$ Results

c_i s_i $c_i\ s_i$



Bins	c_i BES-III	c_i CLEO-c	s_i BES-III	s_i 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

***Only statistical uncertainty is listed

BESIII Preliminary

Model prediction
BESIII
CLEO-c

Consistent agreement with CLEO-c measurements.

Source: CLEO Collaboration, Physical Review D, vol 82., pp. 112006 - 112035

Improved errors w.r.t. CLEO-c

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