Status and Prospects for Mixing & CPV Using Charm at Threshold

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Outline

Pros and Cons of Threshold

CPV ? Mixing ? (both tough @ threshold)

What remains: Phases !

Outlook & Conclusions

"Anyone who has played with these invariances knows that it is an orgy of relative phases."
-- Abraham Pais, Inward Bound

There are lots of experts in the audience who know much more than me on any given topic; I assure you that any errors I may make are intentional and meant to stimulate discussion

Pros and Cons of Threshold

PRO :

Unique features: Coherent $D^0\,D^{0bar}$ pairs, CP+ & CP- tags

Low background, constrained kinematics

CON :

Low statistics

statistics (↓)	**BESIII (now)**	**20 million D pairs**	(↑) **cleaner,**
	Belle	**1 billion**	**more modes**
	LHCb	**many billions**	**accessible**

Especially for hadronic modes, non-threshold is often clean enough…

Low statistics are bad for both mixing and CPV

But the unique features can be extremely interesting !

CPV at Threshold

Generally, one does better elsewhere using higher statistics.
But can we leverage the quantum coherence ?

Some work exists, focusing on D^0 D^{0bar} $\rightarrow$ VV, V $K\pi$

PHYSICAL REVIEW D 81, 054032 (2010)

Extracting *CP* violation and strong phase in *D* decays by using quantum correlations in $\psi(3770) \to D^0 \bar{D}^0 \to (V_1 V_2)(V_3 V_4)$ and $\psi(3770) \to D^0 \bar{D}^0 \to (V_1 V_2)(K\pi)$

Jérome Charles,[2] Sebastien Descotes-Genon,[3] Xian-Wei Kang,[1,4] Hai-Bo Li,[1] and Gong-Ru Lu[4]

Shows sensitivity to strong phase and CPV; but does need high statistics

Other ideas?
Look for exceptions to CP+ vs. CP- ?   (probably small)

D^0 Mixing @ $\psi(3770)$

There's a very nice well-known D^0 mixing signature at ψ (3770)

No DCSD: cancels with these correlated D pairs

Like-sign $K^-\pi^+$ pairs (+ c.c.) are pure mixing !

But it's HARD in practice :

#events = $N_{DD}\, B_{K\pi}^2\, \varepsilon_{K\pi}^2\, (x^2 + y^2)$

$N_{DD} = 3.7 \times 10^6$ /fb^{-1} $\quad B_{K\pi}^2 = 1.5 \times 10^{-3}$

$\varepsilon_{K\pi}^2 = 0.4$ $\quad (x^2 + y^2) = 1 \times 10^{-4}$

Result: #events = 0.2 / fb^{-1}

The only number we have control over is the efficiency, $\varepsilon_{K\pi}$

But PID needs to be ~tight, to avoid background from $K\pi$ swaps …

Of course, this is not the only way to access mixing at threshold,

but it does roughly set the scale.

Our Remaining Portfolio

Already discussed at this workshop

Charm Mixing at Threshold (Quantum Correlations) at CLEO

Werner Sun WG VIII Yesterday

"TQCA": The Quantum Correlation Analysis (261 rates !)

strong $K\pi$ phase $\delta_{K\pi}$; mixing parameters

Quantum-Correlated Measurements at CLEO and BESIII

Jim Libby WG V This morning

$K2\pi$, $K3\pi$, $K_SK\pi$ global "coherence factors"

$K_S2\pi$ binned "coherence factors"

However…

These speakers were burdened with ***actual results***…

I have more freedom to discuss the big picture

TQCA: Kπ Strong Phase

In my younger days, I learned :

No strong FSI: $\overline{A} = A^*$ With FSI: $\overline{A} = A^* e^{i\delta}$ (in a convenient phase convention)

weak phase is "inside A" and flips sign; strong phase doesn't

Here, A & $\overline{A}$ are charge-conjugate amplitudes

Almost this simple for us today, except :

We are looking at relative phase between
a Cabibbo-favored and a DCSD amplitude

Can vary across a Dalitz plot

Two-body case:

Trivial phase space → one phase parameter

(beware varying definitions, however…)

Kπ Mixing results: measure x', y' ; we need to rotate to get x,y

From W. Sun's talk:

$\cos\delta_{K\pi} = 0.81\,^{+0.22}_{-0.18}\,^{+0.07}_{-0.05}$ **CLEO-c only**

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

Multi-Body Mixing Analyses

Dalitz model: Use N amplitudes for both CF and DCSD:

2N parameters each flavor: N amplitudes, N-1 relative phases

Concentrate on Phases

2(N-1) relative phase parameters in 2 separate Dalitz plot fits

But there are 2N - 1 = 2(N-1) + 1 physical phase parameters

Need threshold to get relative CF-to-DCSD phase for $Kn\pi$

Relevant current case:

$K\pi\pi^0$ mixing analysis from BaBar; extracts x'', y''

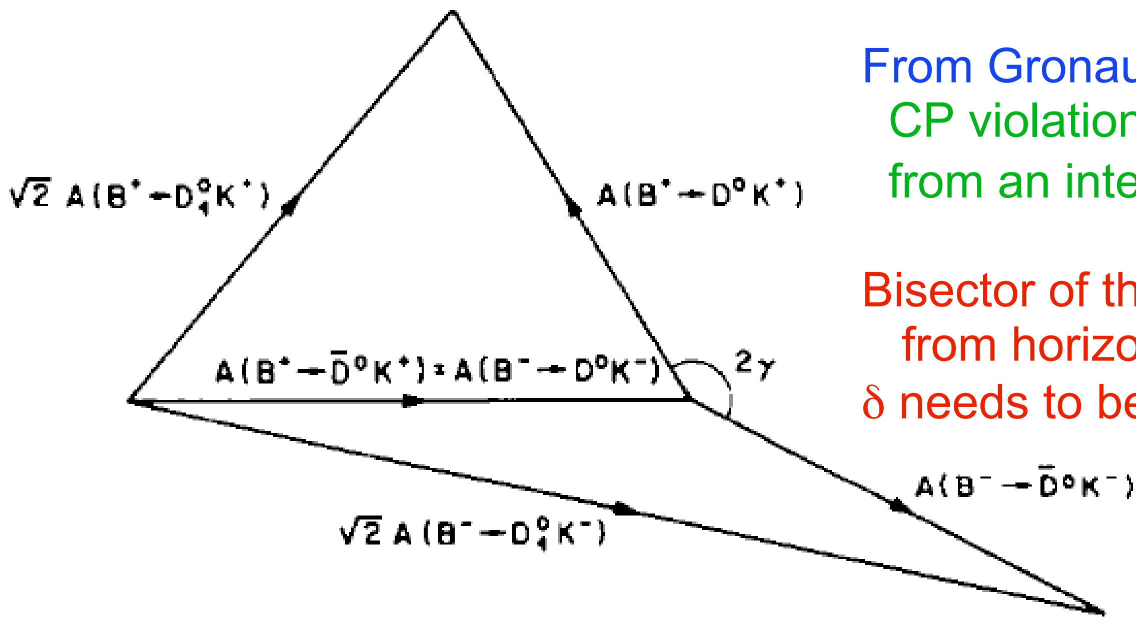
Relative CF-DCSD phase for $K\rho$ isobar amplitude unknown

We can measure this at threshold !

but… we haven't, we measured something else instead (more later)

The point is that we can help these mixing analyses…

"Alphabet Techniques" for ϕ_3/γ: GLW / ADS / GGSZ *



From Gronau & Wyler '91:
CP violation in $B^\pm \to D^0_1 K^\pm$
from an interplay of strong and weak phases

Bisector of this angle* is rotated
from horizontal by strong phase δ_B
δ needs to be non-zero for direct CPV

Our interest is ϕ_3/γ; we don't
really care about strong phase --
just need to be able to eliminate it…

Triangle relation shown here is used to deal with a priori unknown strong phase
Other methods are similar in spirit; interference of common final states
CP eigenstates are replaced by CF & DCSD, or special cases like $K_S\pi\pi$
$\Rightarrow$ Measure more observables than unknowns to constrain phases.

*MANY talk in WG V on these !

*For simplicity, we're ignoring discrete ambiguities…

Dealing with Strong Phases

The GLW / ADS / GGSZ methods are all designed to help us deal with a priori unknown strong phases

But, different cases have different nuances

KK, $\pi\pi$, etc. :

GLW doesn't need external phase input; in fact it only has a strong B phase
Strong D phase is known for CP eignestates : 0 or π

K$n\pi$:

ADS involves a strong D phase between CF and DCSD amplitudes
Could live without threshold input, but it's much nicer to add it in

$K_S\pi\pi$:

In GGSZ, we have a mixed-CP mode (messy), but it is still self-conjugate (nice):
both flavors are together in one Dalitz plot
Thus, one can measure strong phase without threshold data,
but it has been pointed out that threshold can still help a lot
Probably the most famous/popular/topical use of threshold phase information
⇒ **threshold data leads to model-independent results**

Multi-Body "Coherence Factors"

Coherence Factors

2-body Interfering Amplitudes: cross-term has a "2" & a relative phase

3-body generalization?

If we integrate over Dalitz plot: can write non-int. terms using averaged amplitudes, BUT we need an extra $Re^{-i\delta}$ "fudge factor" in the interference term…

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

Multi body $\int dDalitz\ | A_1 + A_2|^2 = | \mathbf{A}_1{}^2 + \mathbf{A}_2{}^2 + 2 R e^{-i\delta} \mathbf{A}_1 \mathbf{A}_2 |$

The bold **A** are real averaged amplitudes.

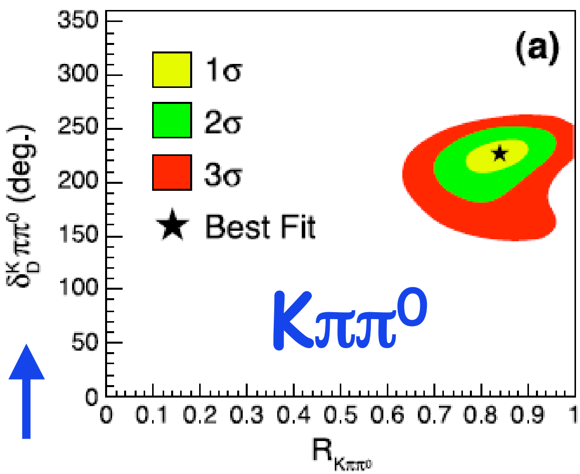
But in interference term, the relative phase matters, AND changes across Dalitz plot:

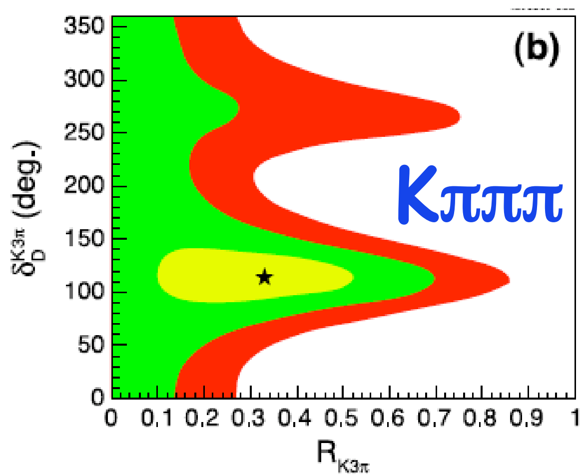
Define: $R\ e^{-i\delta}$ = (actual intergrated cross-term) / (naïve $\mathbf{A}_1 \mathbf{A}_2$)

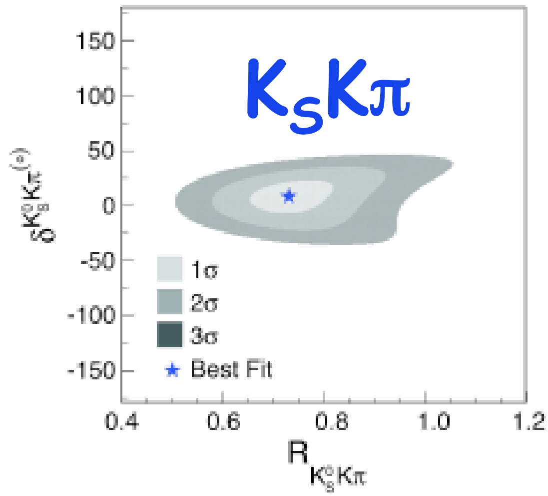
$$A^2_{K^\pm\pi^\mp\pi^0} = \int |\mathcal{A}_{K^\pm\pi^\mp\pi^0}(\mathbf{x})|^2 d\mathbf{x}$$

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

CLEO Coherence Factors



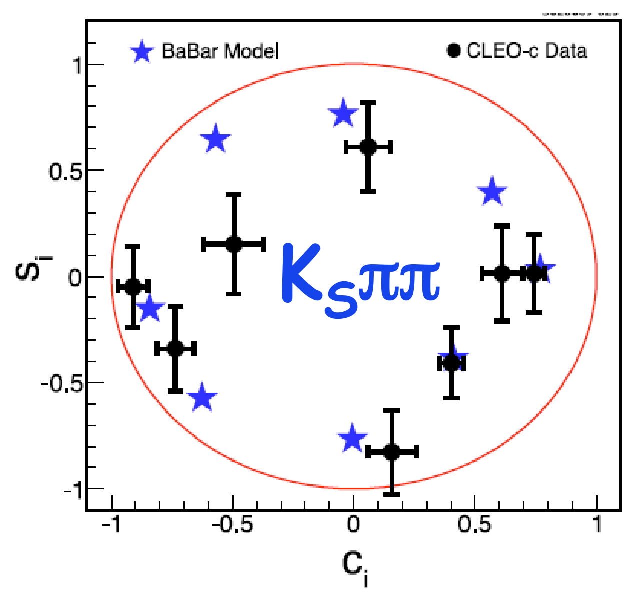




Note: this is an average phase, not the one needed in BaBar's mixing analysis…

Or, we could bin across Dalitz plot

c_i and s_i: bin-averaged $\langle R \cos\delta \rangle$ and $\langle R \sin\delta \rangle$



More details: see J. Libby, Mon AM

BESIII Ongoing Analyses

CLEO-c: 818 pb^{-1} @ $\psi(3770)$

TQCA now final; perhaps more to come on phases?

BESIII: 2900 pb^{-1} (toward 10 fb^{-1} in a few years: 2015-6 ?)

Now 3.5x CLEO-c

"TQCA" Analysis

Correlations with $K\pi$, flavor, CP tags ($\delta_{K\pi}$, y, …)

perhaps fewer modes than CLEO-c at first, but 3.5x data

CKM γ-related Analyses

$K_S\pi\pi$ tagged Dalitz analysis (c_i, s_i)

$K\pi\pi^0$ coherence factor (R, δ)

More will be added… (suggestions welcome!)

Future Directions I

Consider $D \to K_S\pi\pi\pi^0$

5-dimensional Dalitz space: a bit daunting…

Impractical to bin in this space!

But a totally-integrated coherence factor risks averaging out effects (c.f. $K\pi\pi\pi$)

But… in both of these 4-body modes, threshold exp'ts can look for regions of high coherence

We need to avoid bias of hunting till we find a large result…

Obvious places to check: guided by resonance structure

What about CP- pairs from $D^0 D^{0bar} \gamma$?

Is this only "more of the same", or is there a new twist?

Future Directions II

Many pioneering current B factory analyses,
but more precision to come from LHCb & BelleII + SuperB

Fortunately, charm will advance as well

Prospects for a leap ahead in charm threshold statistics:
~100x a final BESIII dataset of 10 fb^{-1} (?)

Dedicated Novosibirsk tau-charm factory !
SuperB: charm threshold running is in the plan
(for both: see plenary talk by M. Roney)

A large increase like this can support new ideas…

Conclusion

Threshold charm lags B factories and hadron colliders in statistics

But unique features exist at threshold !

For us, the main ones are:

- Coherent D^0 D^0 pairs
- CP and other tags to access phases

We contribute indirectly to mixing, and to other areas (CKM angle)

BESIII welcomes input on these types of analysis:
priorities, packaging of results, …

New machines will keep this area very active for years to come

Acknowledgements

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Selected Theory References

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