CP-tagged charm decays: relevance, status and prospects

Introduction: quantum-correlated decays at the ψ(3770)

Quantum-correlated studies of $D \rightarrow K_S \pi^+ \pi^-$ and $K_S KK$ and impact on the γ determination

Quantum-correlated studies of $D \rightarrow K\pi$, $K\pi\pi\pi$ and $K\pi\pi^0$, and impact on the γ determination

Summary and Prospects

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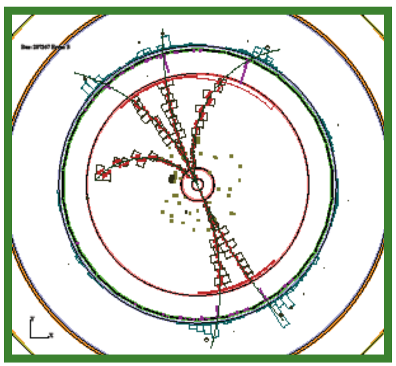
On behalf of the CLEO-c collaboration

CP-tagging at the $\psi(3770)$

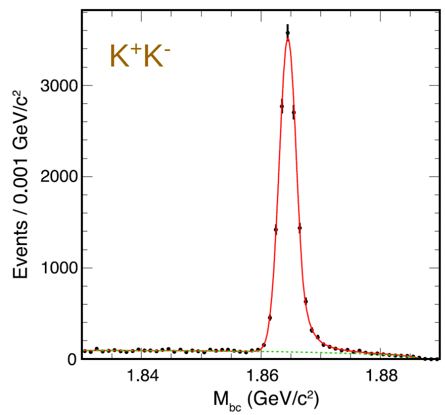
Best environment for CP-tagging is $e^+e^- \rightarrow \psi(3770) \rightarrow D^0\overline{D}^0$. Reconstruct one meson in mode of interest, eg. $K_S\pi^+\pi^-$, & other in CP-eigenstate, eg. K^+K^- (CP+).
Knowing that the $\psi(3770)$ is C=-1 allows us to infer the signal decay is CP-.

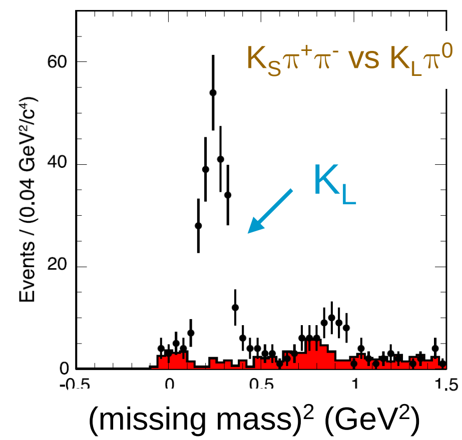
Threshold running has other practical advantages
(all examples CLEO-c: hermetic detector with excellent EM and hadron PID):

- Very clean – no fragmentation particles.



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





- Unseen particle reconstruction through kinematic constraints

CLEO-c accumulated 818 pb^{-1} at $\psi(3770)$. Prospects for more at BES-III

CP-tagged D-decays: the essential idea

Dalitz plots of CP-tagged decays at the Ψ'' provide orthogonal info to flavour tagged events accessible in, eg., D* decays. They provide direct access to the cosine of strong phase difference between the D^0 & $\overline{D}^0$ (cosδ)

$D^{*+} \rightarrow D^0 \pi^+$

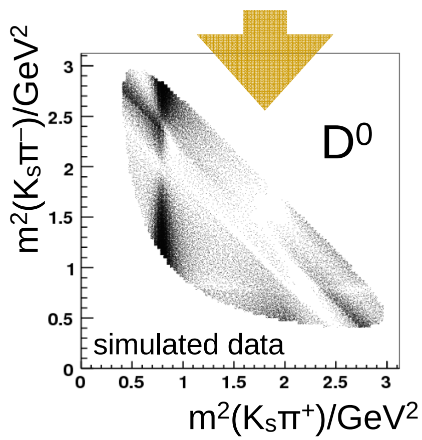
$D^0 \rightarrow K_S \pi^+ \pi^-$

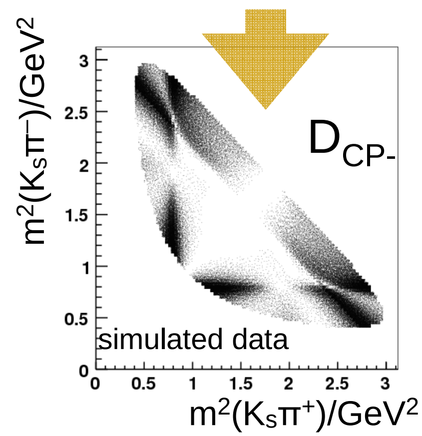
$\psi'' \rightarrow D_a D_b$

$D_a \rightarrow KK$ eg. CP+

$D_b \rightarrow K_S \pi^+ \pi^-$

Flavour tagged distribution $\propto$ $|D^0|^2$ or $|\overline{D}^0|^2$





CP-tagged $\propto$ $|D^0|^2 + |\overline{D}^0|^2 \pm 2\, D^0 \overline{D}^0 \cos\delta$

In given bin of Dalitz space suitable combination of flavour & CP-tagged info allows cosδ to be extracted. In fact, quantum-coherence means *other* hadronic decays, not only CP-eigenstates, can be used to extract useful information on δ, & more…

CP-tagged D-decays: applications

The strong phase information provided by quantum-correlated D-$\bar{D}$ events
Is important for three main reasons:

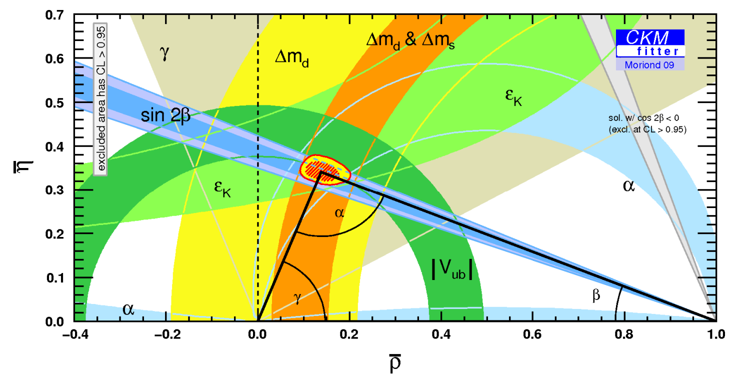
1) Interesting in itself for understanding D-decay dynamics and resulting light-quark mesons produced

2) Strong phases appear in measurements of D-mixing parameters, eg. studies of 'wrong sign' $D^0 \rightarrow K^+\pi^-$ events

Want to know: $x = \Delta m/\Gamma$, $y = \Delta\Gamma/2\Gamma$ Measure: $x' = x\cos\delta_{K\pi} + y\sin\delta_{K\pi}$, $y' = -x\sin\delta_{K\pi} + y\cos\delta_{K\pi}$ So need info on: $\delta_{K\pi}$

3) Invaluable for measurements of CKM angle γ in $B \rightarrow DK$ decays (main focus of talk)

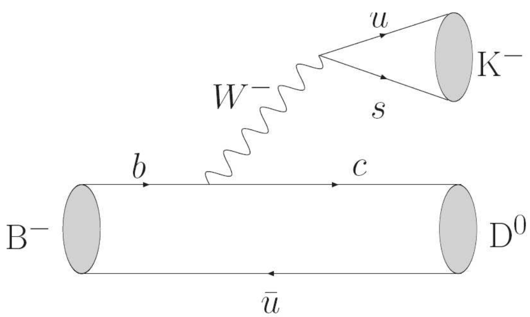
Present direct measurements give $\gamma = (70\,^{+27}_{-30})^{o}$ (CKMfitter)



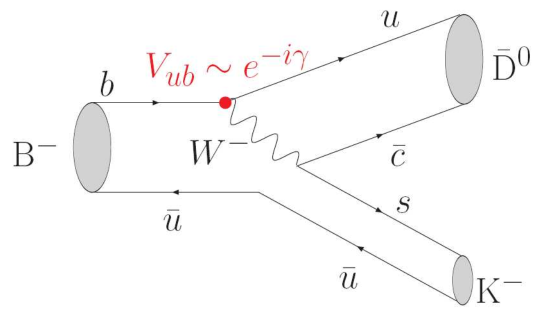
Quantum-correlated D-decays will play crucial role as B-decay statistical uncertainty decreases

γ from $B^{\pm} \rightarrow DK^{\pm}$

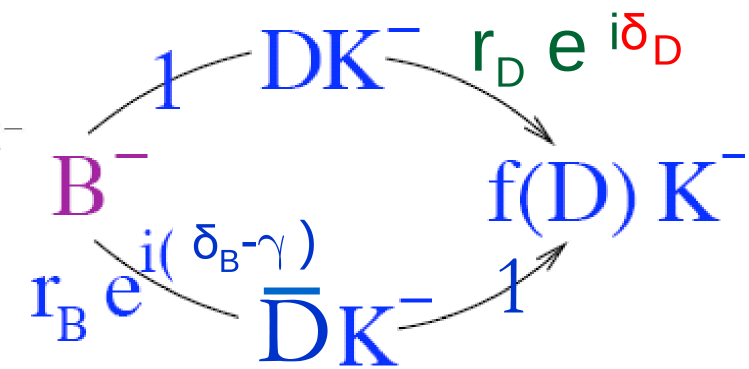
$B^- \longrightarrow D^0 K^-$



$B^- \longrightarrow \overline{D}^0 K^-$



$$\frac{< B^- \longrightarrow \overline{D}^0 K^- >}{< B^- \longrightarrow D^0 K^- >} = r_B e^{i(\delta_B - \gamma)}$$



- Extraction through interference between $b \rightarrow u$ and $b \rightarrow c$ transitions

- Require D^0 and $\overline{D}^0$ decay to a common final state, f(D). Some examples:

  $K^0_S hh$; $K\pi$; $K\pi\pi\pi$; $K\pi\pi^0$

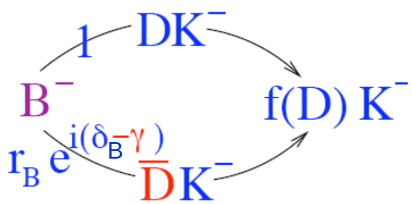
- Comparison of B^- and B^+ rates allow γ to be extracted. But other parameters in game. In particular invaluable to have constraint on δ_D – the very quantity we can access in quantum-correlated D-decays !

r_D & δ_D analogous to B-decay quantities. For 3, 4-… body decays, these parameters vary over Dalitz space

Study of $D \rightarrow K_{S,L}\pi^+\pi^-$ and $D \rightarrow K_{S,L}K^+K^-$ Dalitz Plots in Quantum-correlated Decays

- Motivation: B-factory $B \rightarrow D(K_S\pi^+\pi^-)K$ model dependent analyses
- The binned model independent $B \rightarrow D(K_S\pi^+\pi^-)K$ analysis
- CLEO-c quantum-correlated study of $D \rightarrow K_{S,L}\pi^+\pi^-$
- Impact on the γ measurement
- CLEO-c prospects for $D \rightarrow K_{S,L}KK$

B-factory $B \to D(K_S\pi^+\pi^-)K$ Dalitz Plots for γ

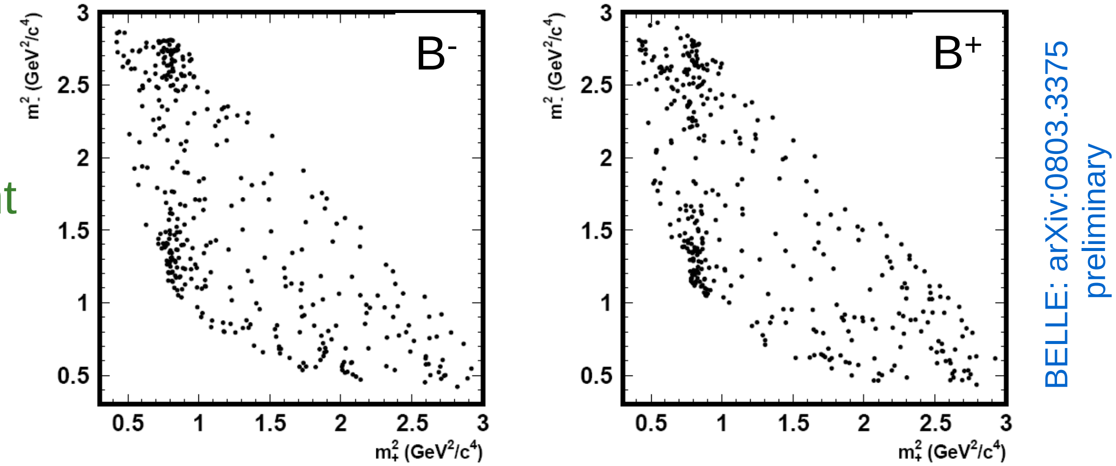


A powerful (and at *present*, only statistically useful) choice of common state f(D) is $K_s\pi^+\pi^-$. Rich resonant substructure.

Differences between B^- and B^+ Dalitz plots allow γ to be extracted in unbinned fit…

…need to understand different amplitudes from D^0 and $\bar{D}^0$ decay across Dalitz space, esp. variation in strong phase

Need a D decay model !



BaBar (383M BB) $\gamma = 76^\circ \pm 22^\circ(\text{stat}) \pm 5^\circ(\text{sys}) \pm 5^\circ(\text{model})$ r_B=0.09±0.09

BELLE (657M BB) $\gamma = 76^{\circ}{}^{+12^\circ}_{-13^\circ}(\text{stat}) \pm 4^\circ(\text{sys}) \pm 9^\circ(\text{model})$ r_B=0.16±0.04

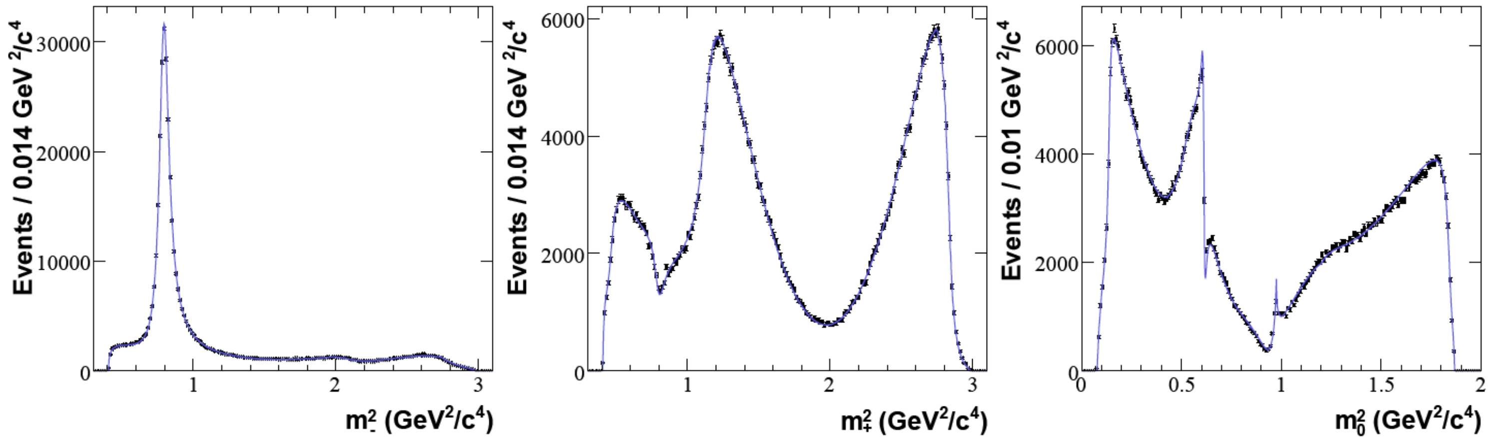
LHCb with 10 fb^{-1} can approach 3^o statistical error

(NB sensitivity scales with r_B. All B→DK data suggest ~0.10)

Modelling the $K_s\pi^+\pi^-$ decay

Unbinned fit of Dalitz space in $B \to D(K_s\pi^+\pi^-)K$ decays requires reliable model of D decay. Model developed on flavour tagged D* decays.

State of the art – BaBar model fitted from 487k decays:



BaBar, PRD 78 (2008) 034023

Ingredients – 10 resonances described with isobar model. S-wave $\pi\pi$ and $K\pi$ treated with K-matrix approach and LASS parametrisation respectively

(χ^2 / ndf = 1.11 to be compared with 1.20 for pure isobar model)

Impressive work – error on γ estimated to be 7^o.* But model systematic, even this small, uncomfortable for future very high stats measurements eg. LHCb.

* 5^o error on previous page includes K_SKK in combination

Binned Model-Independent Fit

Binned fit proposed by Giri *et al.* [PRD 68 (2003) 054018] and developed by Bondar & Poluektov [EPJ C 55 (2008) 51; EPJ C47 (2006) 347] removes model dependence by relating events in bin i of Dalitz plot to *experimental observables.*

$B^\pm$ events in bin i of Dalitz plot

Number of events for flavour-tagged D sample

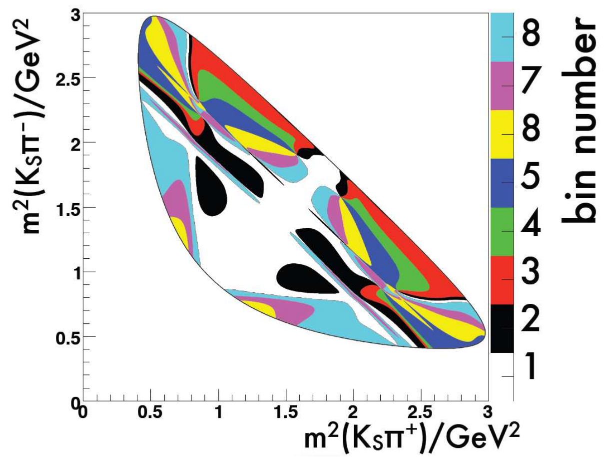
$x_\pm = r_B \cos(\delta_B \pm \gamma)$

$y_\pm = r_B \sin(\delta_B \pm \gamma)$

$$N_i^\pm = h(K_{\pm i} + r_B^2 K_{\mp i} + 2\sqrt{K_i K_{-i}}(x_\pm c_i \pm y_\pm s_i))$$

c_i, s_i : average in bin of cosine, sine of strong phase difference

Can be measured *directly* in quantum correlated decays at ψ(3770)!



Choosing bins of *expected* similar strong Phase difference maximises statistical precision

We will assume 8 bins of equal size in $\Delta\delta_D$ (and reference model will be: BaBar, PRL 95 (2005) 121802)

Small loss in statistical sensitivity w.r.t. unbinned result… but no model error!

CLEO-c Quantum-Correlated $K_{S,L}\pi^+\pi^-$ Analysis

Use 818 pb^{-1} of ψ(3770) data

- Flavour tags: ~20k double-tags
- CP-tags: ~1600 double-tags
  - → needed for c_i extraction
- $K^0\pi^+\pi^-$ vs $K^0\pi^+\pi^-$ events: ~1300
  - → needed for s_i and c_i extraction
- Also note that $K_L\pi^+\pi^-$ events are used – more on these later !

Signal to background 10-100 depending on tag mode

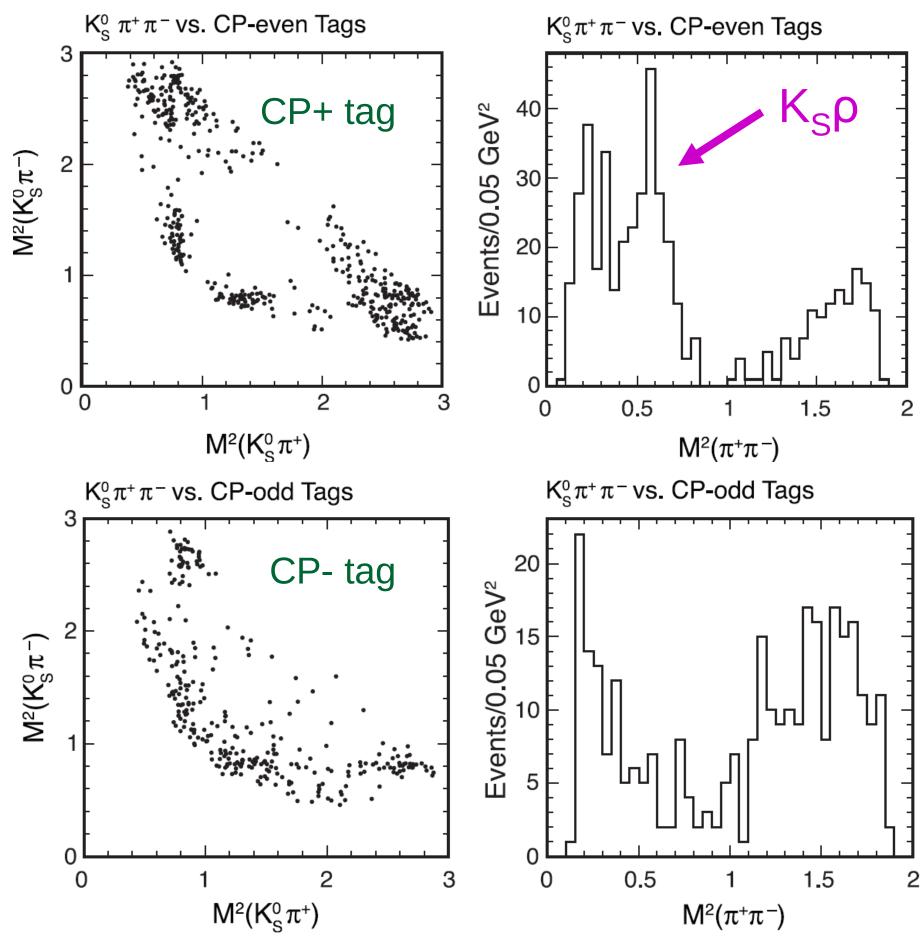
arXiv:0903.1681 [hep-ex] ; submitted to PRD

Mode	ST Yield	$K_S^0\pi^+\pi^-$ yield	$K_L^0\pi^+\pi^-$ yield
Flavor Tags			
$K^-\pi^+$	144563 ± 403	1447	2858
$K^-\pi^+\pi^0$	258938 ± 581	2776	5130
$K^-\pi^+\pi^+\pi^-$	220831 ± 541	2250	4110
$K^-e^+\nu$	123412 ± 4591	1356	-
CP-Even Tags			
K^+K^-	12867 ± 126	124	345
$\pi^+\pi^-$	5950 ± 112	62	172
$K_S^0\pi^0\pi^0$	6562 ± 131	56	-
$K_L^0\pi^0$	27955 ± 2013	229	-
CP-Odd Tags			
$K_S^0\pi^0$	19059 ± 150	189	281
$K_S^0\eta$	2793 ± 69	39	41
$K_S^0\omega$	8512 ± 107	83	-
$K_S^0\pi^+\pi^-$	-	475	867

CP-tagged $K_s\pi^+\pi^-$ Dalitz plots

Clear differences seen between CP-odd and CP-even:

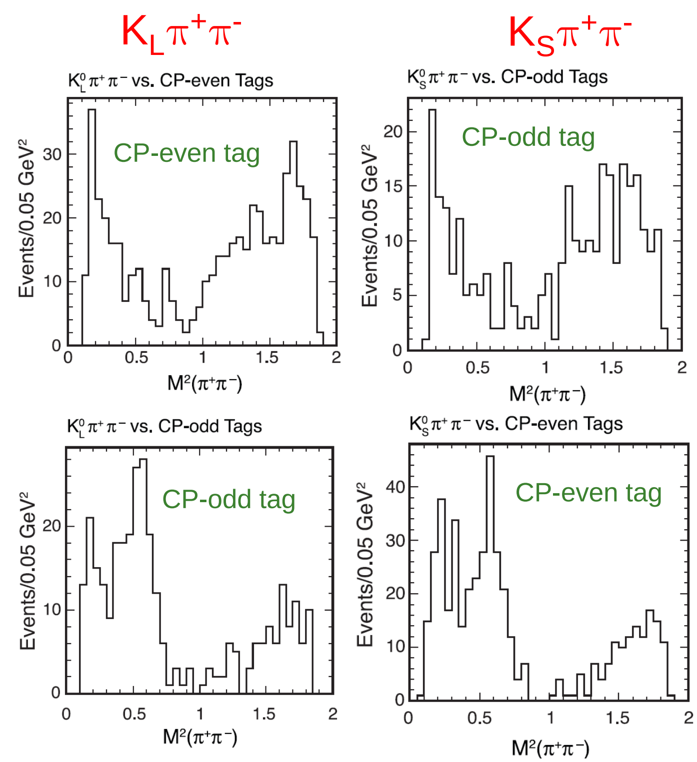
CLEO-c, arXiv:0903.1681 [hep-ex]



A Word on $K_L\pi^+\pi^-$ in CLEO-c Analysis

CP-odd $K_S\pi^+\pi^-$ ≈ CP-even $K_L\pi^+\pi^-$ & so latter can be used to increase statistics

This approximate equality is seen in data



There is however a correction term:

$$-A\left(D^0 \to K^0_L\pi^+\pi^-\right) =$$

$$A\left(D^0 \to K^0_S\pi^+\pi^-\right) - \sqrt{2}A\left(D^0 \to K^0_{\text{flavour}}\pi^+\pi^-\right)$$

CF+DCS — DCS

Correction order $\tan^2\theta_c$ – accounting for this introduces small model dependence

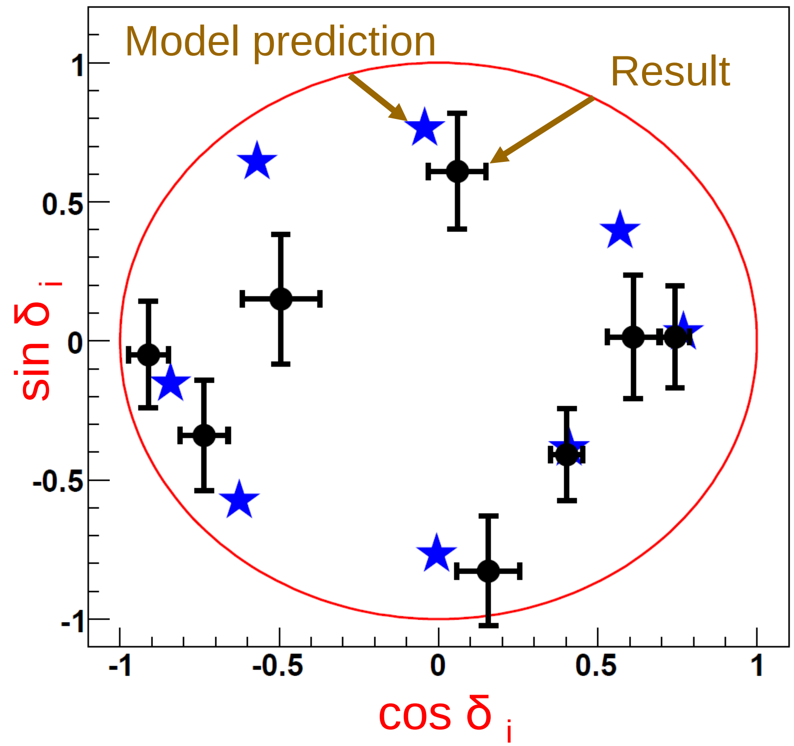
In analysis we measure separate c_i', s_i' for $K_L\pi^+\pi^-$, which differ from c_i, s_i by offsets which are floated in fit, but constrained with conservative uncertainties

CLEO-c Results on c_i and s_i

Result ± stat ± syst ± ($K_L\pi\pi \leftrightarrow K_S\pi\pi$ syst)

i	c_i	s_i
0	$0.743 \pm 0.037 \pm 0.022 \pm 0.013$	$0.014 \pm 0.160 \pm 0.077 \pm 0.045$
1	$0.611 \pm 0.071 \pm 0.037 \pm 0.009$	$0.014 \pm 0.215 \pm 0.055 \pm 0.017$
2	$0.059 \pm 0.063 \pm 0.031 \pm 0.057$	$0.609 \pm 0.190 \pm 0.076 \pm 0.037$
3	$-0.495 \pm 0.101 \pm 0.052 \pm 0.045$	$0.151 \pm 0.217 \pm 0.069 \pm 0.048$
4	$-0.911 \pm 0.049 \pm 0.032 \pm 0.021$	$-0.050 \pm 0.183 \pm 0.045 \pm 0.036$
5	$-0.736 \pm 0.066 \pm 0.030 \pm 0.018$	$-0.340 \pm 0.187 \pm 0.052 \pm 0.047$
6	$0.157 \pm 0.074 \pm 0.042 \pm 0.051$	$-0.827 \pm 0.185 \pm 0.060 \pm 0.036$
7	$0.403 \pm 0.046 \pm 0.021 \pm 0.002$	$-0.409 \pm 0.158 \pm 0.050 \pm 0.002$

- Statistical uncertainties dominant
- c_i better determined than s_i
- Results also available for c_i' and s_i'



Broad agreement with predictions

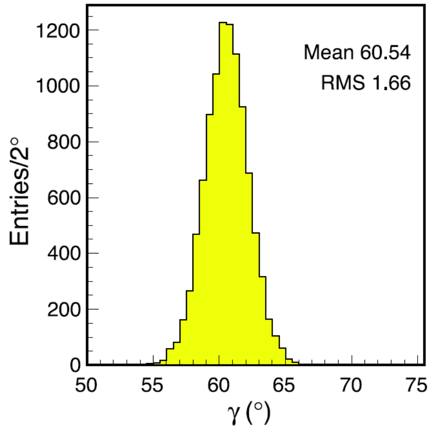
(model = BaBar PRL 95 (2005) 121802)

Impact on γ Measurement

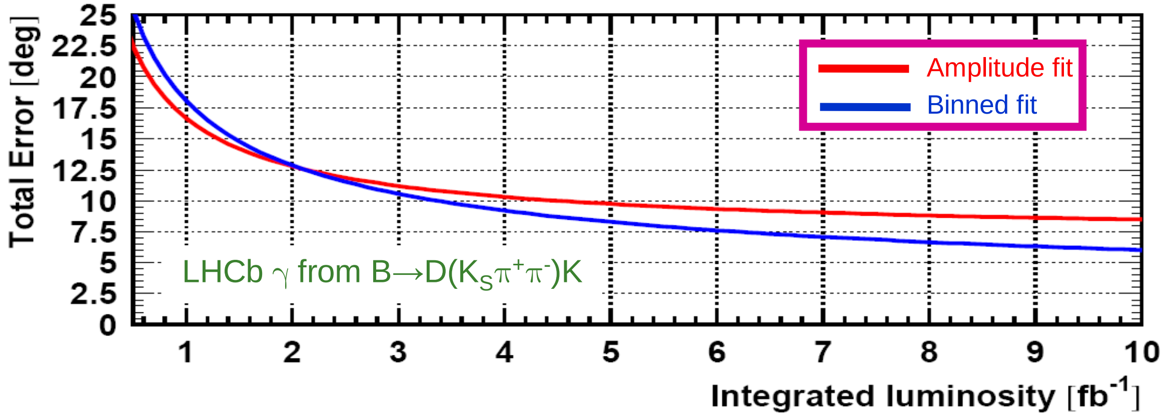
CLEO-c analysis has eliminated model error, but there is a residual uncertainty on γ arising from finite knowledge of c_i and s_i.

This has been estimated with a 'toy MC' with many simulated $B \to D(K_S\pi^+\pi^-)K$ experiments.

Error of 1.7° (recall model error = 7°)



With this result the reduced (~20%) statistical precision of binned analysis w.r.t. unbinned fit will soon be overcome at LHCb, with statistics dominating uncertainty



γ error after 10 fb^{-1}

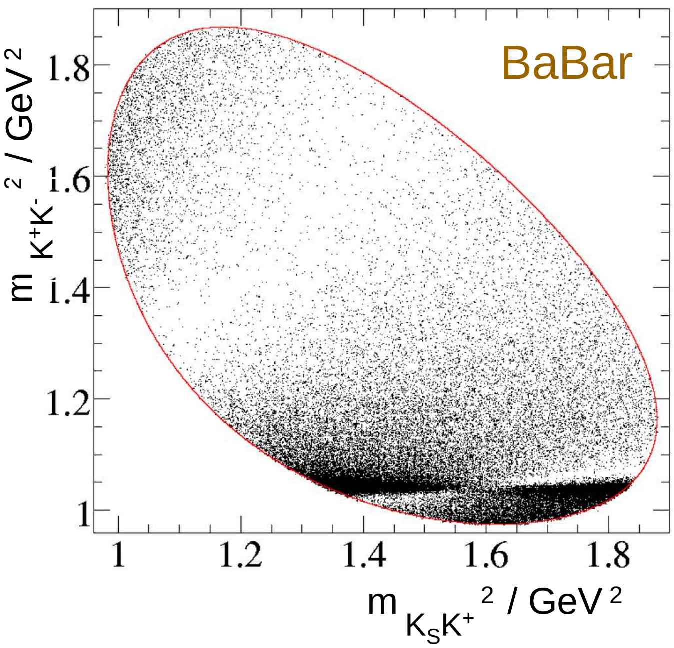
Amplitude fit: 8.5°

Binned fit: 6.0°

Extending to K_SKK

Dalitz γ analysis can be extended to $B \rightarrow D(K_SKK)K$. Pioneered by BaBar [PRD 78 (2008) 034023] who have built an amplitude model with flavour tagged decays

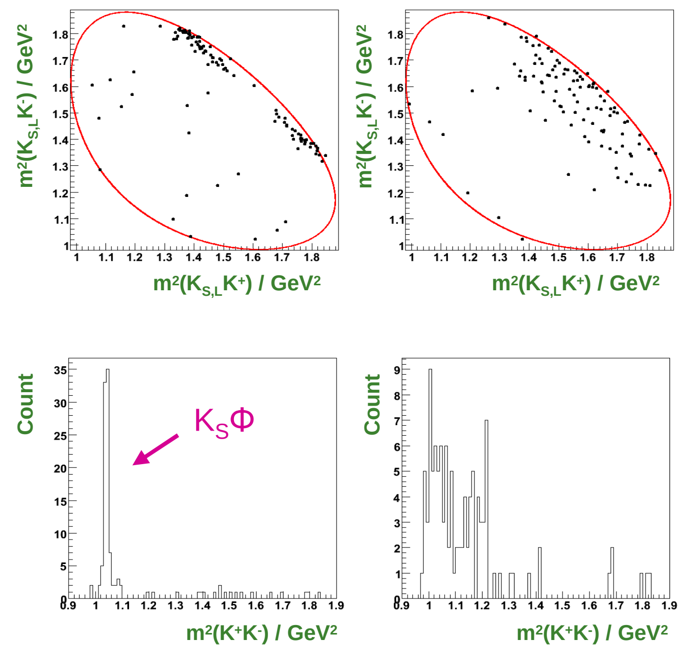
Flavour tagged K_SKK decays



Measurement of c_i's and s_i's underway at CLEO-c using ~550 quantum-correlated double-tags

CP+ tag vs K_SKK
CP- tag vs K_LKK

CP- tag vs K_SKK
CP+ tag vs K_LKK



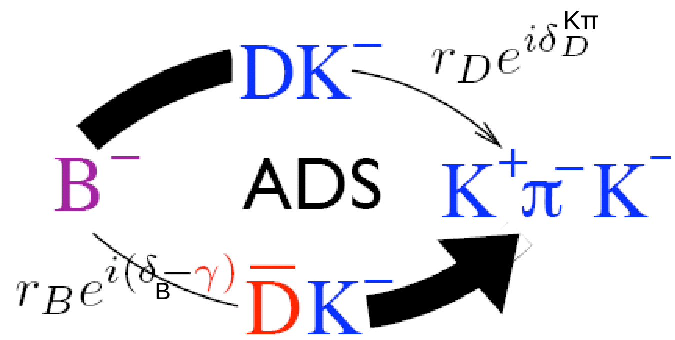
CLEO-c preliminary

‘ADS’ B→DK Measurements and the impact of quantum-correlated decays

- The ADS B→DK measurement
- CLEO-c analysis of D→Kπ strong phase
- CLEO-c coherence factor analysis of D→K$\pi\pi\pi$, K$\pi\pi^0$

Atwood-Dunietz-Soni (ADS) Method

Low interference scale of B→DK method (r_B~0.1) can be enhanced by exploiting Doubly Cabibbo Suppressed modes eg. $D^0 \rightarrow K^+\pi^-$



This introduces two new parameters:

$$\frac{< D^0 \longrightarrow K^+\pi^- >}{< \overline{D}^0 \longrightarrow K^+\pi^- >} = r_D^{K\pi} e^{i\delta_D^{K\pi}}$$

$r_D^{K\pi}$ known well, $\delta_D^{K\pi}$ unknown

~0.06, ie. similar in magnitude to r_B

4 possible final states, for 2 of which there can be a big CP-asymmetry:

$$\Gamma(B^- \rightarrow (K^+\pi^-)_D K^-) \propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cdot \cos(\delta_B + \delta_D^{K\pi} - \gamma)$$
$$\Gamma(B^+ \rightarrow (K^-\pi^+)_D K^+) \propto r_B^2 + (r_D^{K\pi})^2 + 2 r_B r_D^{K\pi} \cdot \cos(\delta_B + \delta_D^{K\pi} + \gamma)$$

these interference terms are 1st order

A powerful way to constrain γ, but need to know $\delta_D^{K\pi}$

Can be measured in quantum correlated D decays !

Measuring $\delta_D^{K\pi}$ in Quantum Correlated D Decays

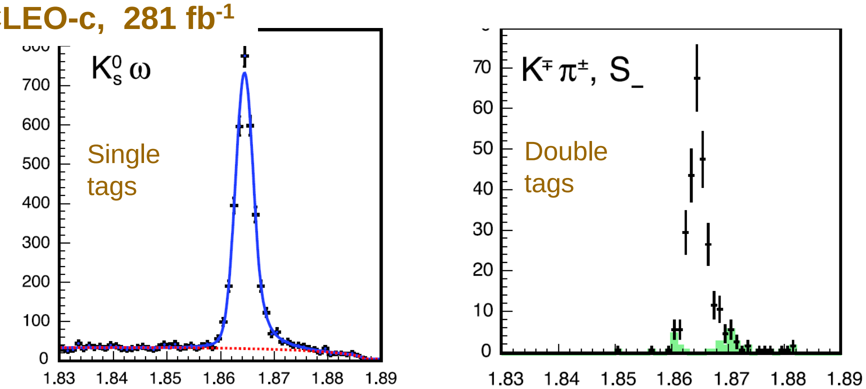
Usual idea: tag one D in CP eigenstate, other side is mixture of $\bar{D}^0$ and D^0, hence:

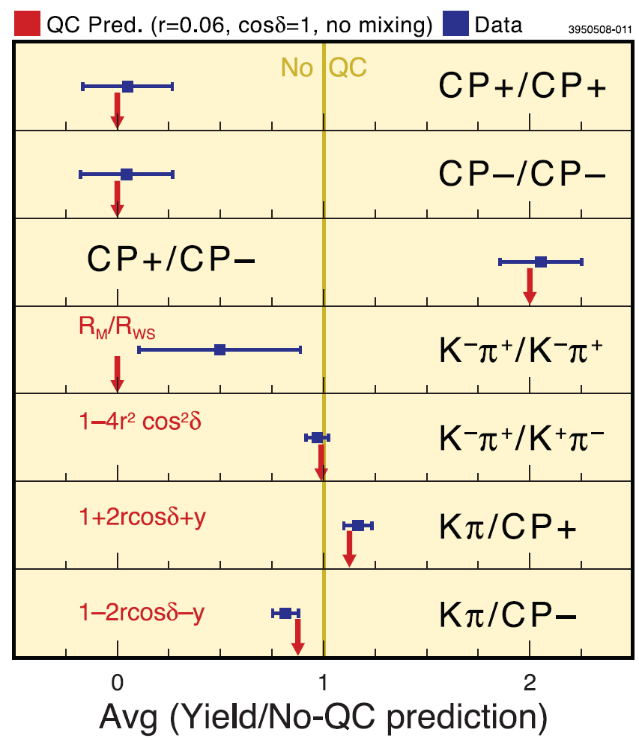
$$\text{Rate} \sim \; B_{CP+}\, B_{K\pi}\, (1 + \; 2r_D^{K\pi} \cos \delta_D^{K\pi})$$

Approximate - full expression has additional dependence on mixing parameters x & y…

Analysis: measure set of single & double tag rates, with Kπ vs CP tags, & flavour tags

CLEO-c, 281 fb^{-1}





CLEO-c: PRL 100 (2008) 221801; PRD 78 (2008) 012001

Extract $\delta_D^{K\pi}$, plus results on other parameters, including branching ratios.

Quantum correlations clearly seen !

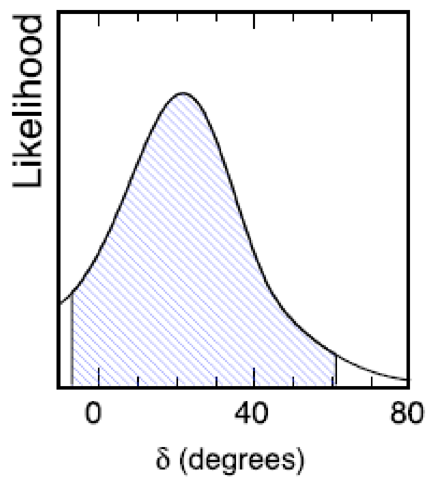
CLEO-c 281 pb^{-1} Results for $\delta_D^{K\pi}$

Result also important for charm mixing (x', y' measured in 'wrong sign' $K\pi\pi$ analysis related to x, y through:

$x' = x \cos \delta_D^{K\pi} + y \sin \delta_D^{K\pi}$)

Most precise result on $\delta_D^{K\pi}$ obtained with mixing results used as external constraint:

$$\delta_D^{K\pi} = \left(22^{+11+9}_{-12-11}\right)^\circ$$



Fit results with all external constraints

Parameter	Extended Fit
$\mathcal{N}$ (10^6)	$1.042 \pm 0.021 \pm 0.010$
y (10^{-3})	$6.5 \pm 0.2 \pm 2.1$
r^2 (10^{-3})	$3.44 \pm 0.01 \pm 0.09$
$\cos\delta$	$1.10 \pm 0.35 \pm 0.07$
x^2 (10^{-3})	$0.06 \pm 0.01 \pm 0.05$
$x \sin\delta$ (10^{-3})	$4.4 \pm 2.4 \pm 2.9$
$K^-\pi^+$ (%)	$3.78 \pm 0.05 \pm 0.05$
K^-K^+ (10^{-3})	$3.88 \pm 0.06 \pm 0.06$
$\pi^-\pi^+$ (10^{-3})	$1.36 \pm 0.02 \pm 0.03$
$K^0_S\pi^0\pi^0$ (10^{-3})	$8.35 \pm 0.44 \pm 0.42$
$K^0_S\pi^0$ (%)	$1.14 \pm 0.03 \pm 0.03$
$K^0_S\eta$ (10^{-3})	$4.42 \pm 0.15 \pm 0.28$
$K^0_S\omega$ (%)	$1.12 \pm 0.04 \pm 0.05$
$X^-e^+\nu_e$ (%)	$6.59 \pm 0.16 \pm 0.16$
$K^0_L\pi^0$ (%)	$1.01 \pm 0.03 \pm 0.02$
$\chi^2_{\rm fit}/{\rm ndof}$	$55.3/57$

Result will improve with full 818 fb^{-1} data set and inclusion of additional tags

see Paras Naik talk

Extending ADS to Multi-body D Decays

ADS method can be extended to other decays with $D \to K + n\pi$, eg. $K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$

Only difference: intermediate resonances such as $D \to K^{*}\rho$, $K^{-}a_{1}(1260)^{+}$,etc mean that many amplitudes contribute, each with their own strong phase

If we make no attempt to isolate a particular resonance, then interference term is diluted by a 'coherence factor' $R_{K3\pi}$

$$\Gamma(B^{-} \to (K^{+}\pi^{-}\pi^{-}\pi^{+})_{D} K^{-}) \propto r_B^2 + (r_D^{K3\pi})^2 + 2 r_B r_D^{K3\pi} R_{K3\pi} \cos(\delta_B + \delta_D^{K3\pi} - \gamma)$$

This is not present in $K\pi$ case

$R_{K3\pi}$ can take value between 0 (incoherent) and 1 (2 body, single amplitude limit)

$\delta_{K3\pi}$ is now the average strong phase difference over Dalitz space

$R_{K3\pi}$ and $\delta_D^{K3\pi}$ can also be measured at ψ'' [Atwood, Soni, PRD 68 (2003) 033003]
Analogous parameters exist in related channels, eg. $K\pi\pi^0$. CLEO-c has measured coherence factor and strong phase in $K\pi\pi\pi$ and $K\pi\pi^0$.

CLEO-c $K\pi\pi\pi$ & $K\pi\pi^0$ Coherence Factor Analysis

(arXiv:0903.4853 [hep-ex] submitted to journal)

Sensitivity to the $K\pi\pi\pi$ coherence factor and average strong phase difference comes from counting the following classes of double-tagged events:

Double tag Rate	Sensitive to
$K^\pm\pi^\mp\pi^+\pi^-$ vs $K^\pm\pi^\mp\pi^+\pi^-$	$(R_{K3\pi})^2$
$K^\pm\pi^\mp\pi^0$ vs $K^\pm\pi^\mp\pi^0$	$(R_{K\pi\pi^0})^2$
$K^\pm\pi^\mp\pi^+\pi^-$ vs CP	$R_{K3\pi}\cos(\delta^{K3\pi})$
$K^\pm\pi^\mp\pi^0$ vs CP	$R_{K\pi\pi^0}\cos(\delta^{K\pi\pi^0})$
$K^\pm\pi^\mp\pi^+\pi^-$ vs $K^\pm\pi^\mp$	$R_{K3\pi}\cos(\delta^{K3\pi} - \delta^{K\pi})$
$K^\pm\pi^\mp\pi^0$ vs $K^\pm\pi^\mp$	$R_{K\pi\pi^0}\cos(\delta^{K\pi\pi^0} - \delta^{K\pi})$
$K^\pm\pi^\mp\pi^+\pi^-$ vs $K^\pm\pi^\mp\pi^0$	$R_{K3\pi}R_{K\pi\pi^0}\cos(\delta^{K3\pi} - \delta^{K\pi\pi^0})$

Coherence Factor Analysis Event Yields

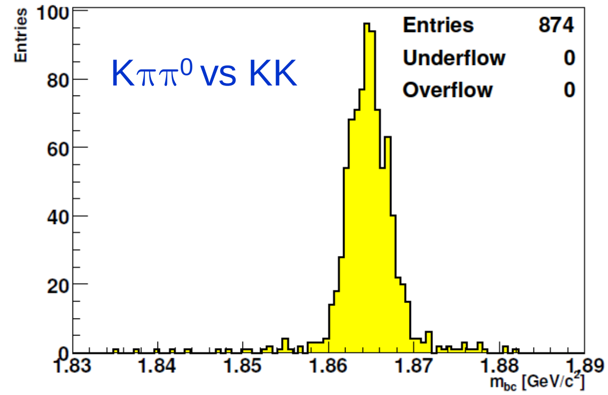
Analysis based on full 818 pb^{-1} ψ(3770) CLEO-c dataset

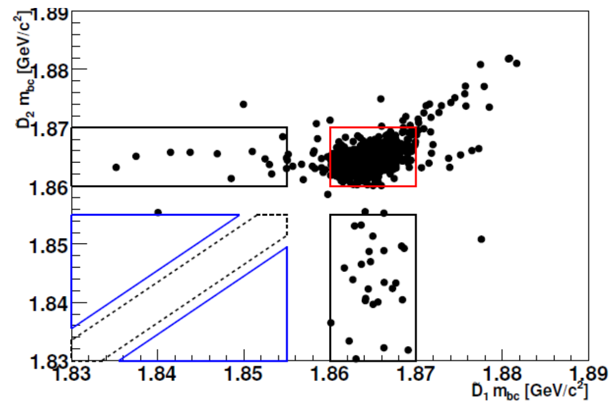
Use 10 separate CP-tags:

CP Tag	K3π yield	$K\pi\pi^0$ yield
KK, ππ	782	1100
$K_S\pi^0$	705	891
$K_S\omega(\pi^+\pi^-\pi^0)$	319	389
$K_S\pi^0\pi^0$	283	406
$K_S\phi(K^+K^-)$	53	91
$K_S\eta(\{\gamma\gamma, \pi^+\pi^-\pi^0\})$	164	153
$K_S\eta'(\pi^+\pi^-\eta)$	36	61
$K_L\pi^0$	695	1234
$K_L\omega(\pi^+\pi^-\pi^0)$	296	449
Total	**3465**	**4774**

CP = 1, *CP* = -1

Flat background assessed from m_{bc} space; peaking from MC



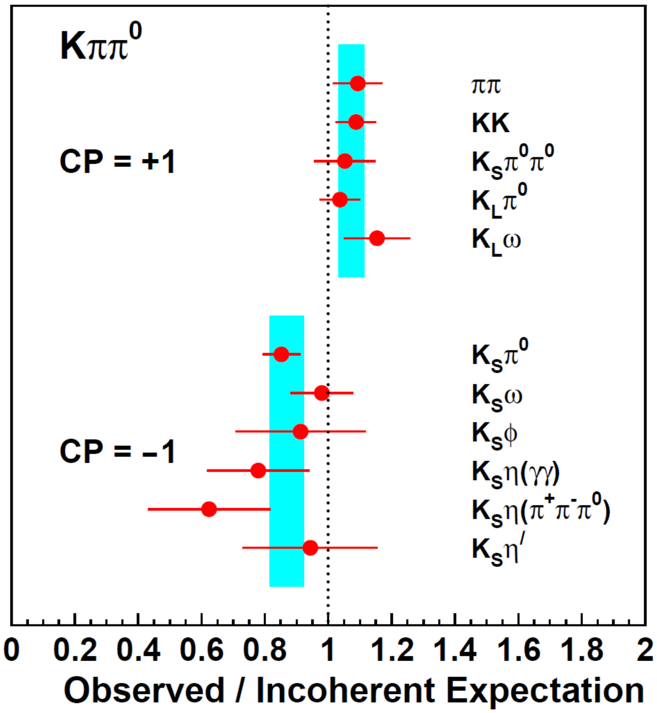


Other classes of double tags are suppressed (but generally very sensitive to physics parameters) so yields low: eg. 29 $K^\pm\pi\pi\pi$ vs $K^\pm\pi\pi\pi$ events

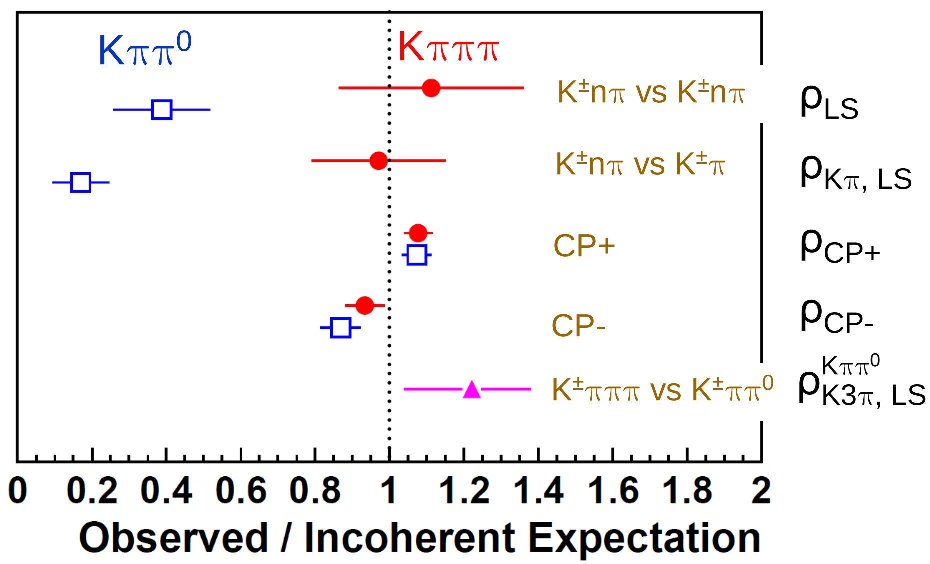
Results for observables

Calculate ratio of observed number of events, ρ, to expected number with zero coherence (≡ no quantum-correlations being present)

CP-tag results internally consistent



Results for all observables



$K\pi\pi^0$ looks very coherent; $K\pi\pi\pi$ does not (note that expected sign of shift for given parameter value varies between observables)

Results for Observables & Parameter Extraction

Observable	Value ± stat ± syst
$\rho^{K3\pi}_{CP+}$	$1.077 \pm 0.024 \pm 0.029$
$\rho^{K3\pi}_{CP-}$	$0.933 \pm 0.027 \pm 0.046$
$\rho^{K3\pi}_{LS}$	$1.112 \pm 0.226 \pm 0.102$
$\rho^{K3\pi}_{K\pi,LS}$	$0.971 \pm 0.169 \pm 0.062$
$\rho^{K\pi\pi^0}_{CP+}$	$1.073 \pm 0.020 \pm 0.035$
$\rho^{K\pi\pi^0}_{CP-}$	$0.868 \pm 0.023 \pm 0.049$
$\rho^{K\pi\pi^0}_{LS}$	$0.388 \pm 0.127 \pm 0.026$
$\rho^{K\pi\pi^0}_{K\pi,LS}$	$0.170 \pm 0.072 \pm 0.027$
$\rho^{K\pi\pi^0}_{K3\pi,LS}$	$1.221 \pm 0.169 \pm 0.080$

- Systematic for ρ_{CP} dominated by an internal uncertainty associated with normalisation, which is statistical in nature
- Systematics for other observables are small, and dominated by knowledge of BRs

Observables depend on R and δ, as well as ratio of DCS to CF amplitudes, r_D, and the D mixing parameters x and y.

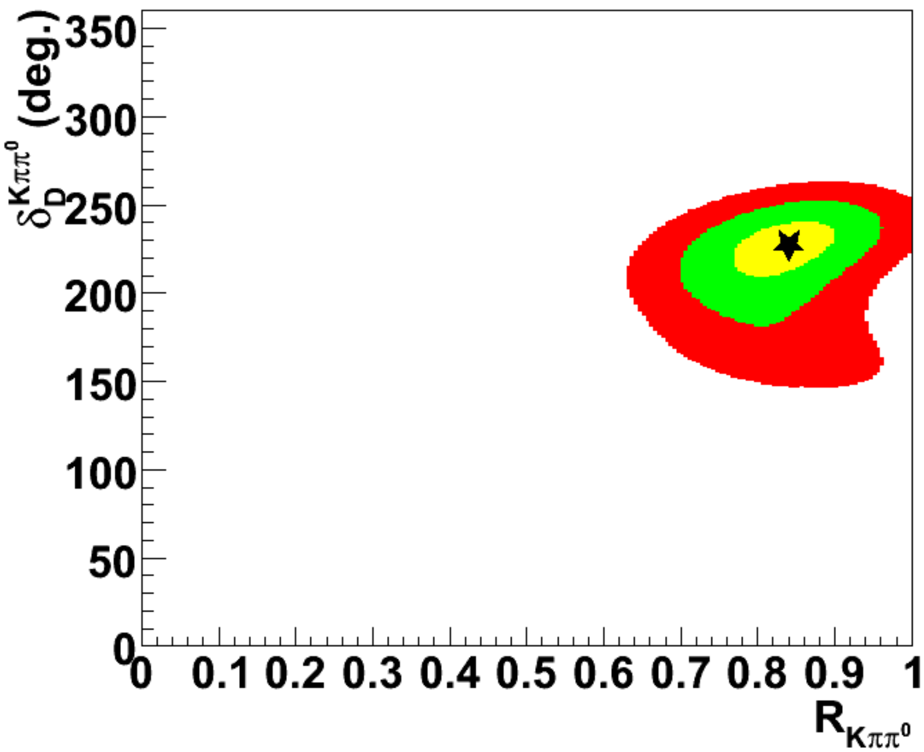
$$\rho^{K3\pi}_{LS} \cong \frac{1 - R^2_{K3\pi}}{1 + \frac{x^2+y^2}{2\left(r_D^{K3\pi}\right)^2} - \frac{R_{K3\pi}}{r_D^{K3\pi}}\left(y\cos\delta_D^{K3\pi} - x\sin\delta_D^{K3\pi}\right)}$$

$$\rho^{K3\pi}_{K\pi,LS} \propto \frac{1 + \left(\frac{r_D^{K3\pi}}{r_D^{K\pi}}\right)^2 - 2\frac{r_D^{K3\pi}}{r_D^{K\pi}} R_{K3\pi}\cos\delta_D^{K3\pi}}{1 + \frac{x^2+y^2}{2\left(r_D^{K\pi}\right)^2} - \frac{1}{r_D^{K\pi}}\left(y\cos\delta_D^{K\pi} - x\sin\delta_D^{K\pi}\right)}$$

$$\rho^{K3\pi}_{CP\pm} \cong 1 \pm \Delta^{K3\pi}_{CP} \text{ where } \Delta^{K3\pi}_{CP} = y - r_D^{K3\pi} R_{K3\pi}\cos\delta_D^{K3\pi}$$

Perform fit to extract R and δ , using external constraints on other parameters

CLEO-c Results for $R_{K\pi\pi^0}$ and $\delta_D^{K\pi\pi^0}$



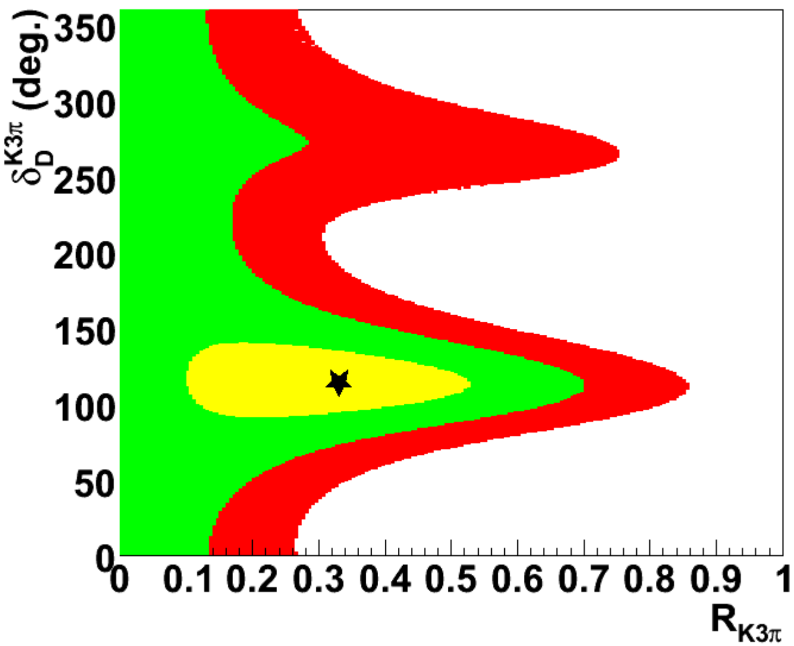
$R_{K\pi\pi^0} = 0.84 \pm 0.07$

$\delta^{K\pi\pi^0} = (227^{+14}_{-17})^o$

Very coherent
(almost at 'two body' limit!)

This is good news for γ measurement as ADS interference term will be large.

CLEO-c Results for $R_{K3\pi}$ and $\delta_D^{K3\pi}$



$R_{K3\pi} = 0.33^{+0.20}_{-0.23}$

$\delta_D^{K3\pi} = (114^{+26}_{-23})^o$

Low coherence preferred

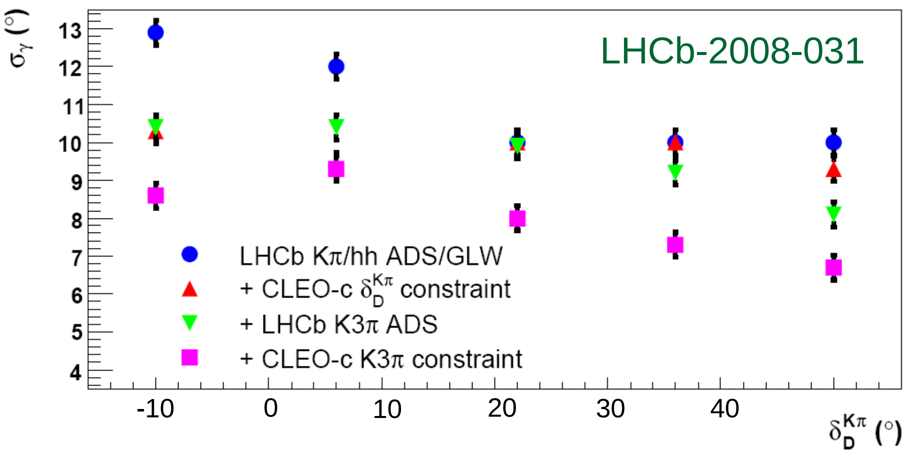
$R_{K3\pi}$ being low means interference term → 0, giving rates high sensitivity to r_B, which is very valuable constraint for sister B→DK analyses !

$$\Gamma(B^- \to (K^+\pi^-\pi^-\pi^+)_D K^-) \propto r_B^2 + (r_D^{K3\pi})^2 + 2 r_B r_D^{K3\pi} R_{K3\pi} \cos(\delta_B + \delta_D^{K3\pi} - \gamma)$$

badly known

Impact of CLEO-c on LHCb γ Measurement

Expected γ precision at LHCb with 2 fb^{-1} of data (one year) for ADS modes alone:



Improvements in going from $K\pi$ ADS (+KK,$\pi\pi$) to $K\pi\pi\pi$ ADS & adding constraints from CLEO-c

(no LHCb study of $K\pi\pi^0$ yet)

Add other measurements, especially $B \to D(K_S\pi^+\pi^-)K$, & extrapolate to 10 fb^{-1}

σ_γ = 1.9 - 2.7°

…in which $B \to DK$ methods have a weight of ~70%
(variation in number depends on values of phases)

Understanding of D decay properties central to precise measurement of γ !

Conclusions and Outlook

CLEO-c results available for D decays in several quantum-correlated analyses:

- $D \to K_{S(L)}\pi^+\pi^-$: $c_i^{(\prime)}$ and $s_i^{(\prime)}$ in 8 bins of equal width in $\Delta\delta$
- $D \to K\pi\pi\pi$, $K\pi\pi^0$: coherence factor & average strong phase difference

} All $\psi(3770)$ data used

- $D \to K\pi$: strong phase difference — ~1/3 $\psi(3770)$ data used

These results provide invaluable input in the γ measurement !

Other studies underway:

- $D \to K_{S(L)}KK$: $c_i^{(\prime)}$ and $s_i^{(\prime)}$ measurements – results soon
- $D \to K_{S(L)}\pi^+\pi^-$: other binnings being explored
- $D \to K\pi$: full statistics

And possibilities exist for analysis of other channels, eg. $D \to K_S\pi^+\pi^-\pi^0$

BES-III should be able to repeat and extend these studies with higher statistics. First $\psi(3770)$ running may occur next year. Estimated production is 5 fb^{-1} / year.

Backups