Charm inputs for γ measurements

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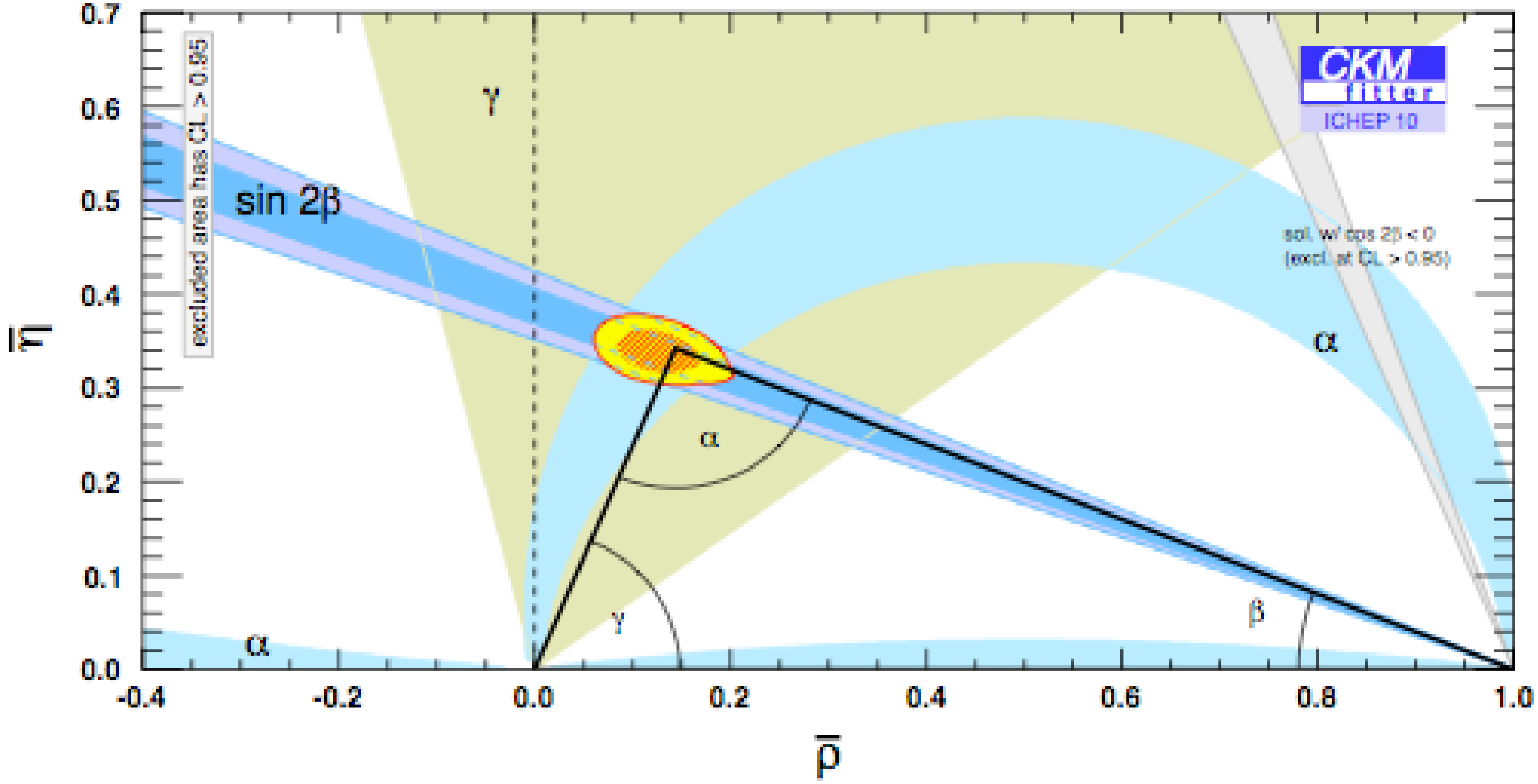
on behalf of the CLEO collaboration

Outline

- The status of tree level γ measurements
- Where measurements from quantum-correlated $D^0\overline{D^0}$ decays have an impact
- Measurements from CLEO-c
  - o D^0 --> $K_s\pi\pi$, K_sKK
  - o D^0 --> $K\pi$, $K\pi\pi\pi$, $K\pi\pi^0$, $K\pi K_S$

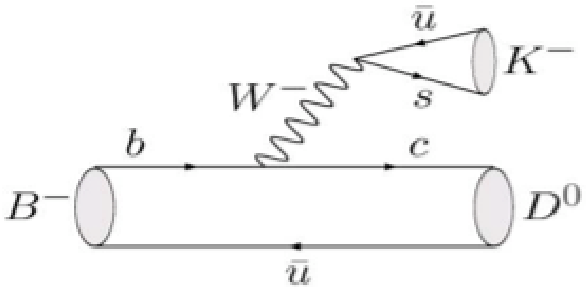
Status of direct determination of γ



γ is the least well known angle ~20°

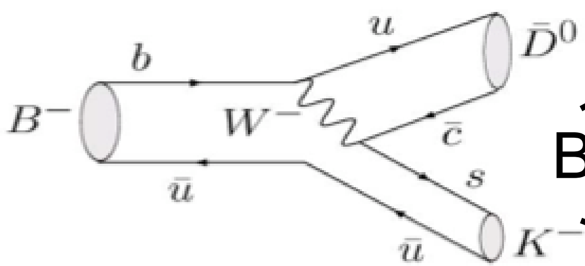
Comparison of γ from tree and loop processes -- sensitive to new physics

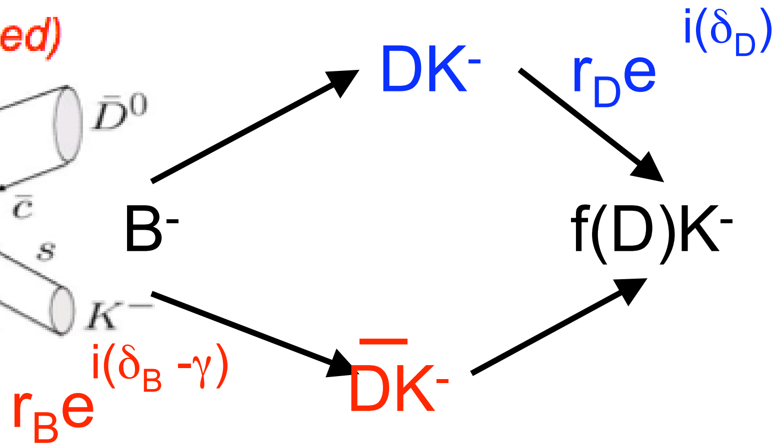
Using B→DK for γ measurements



b → c (favoured)

b → u (suppressed)





Sensitivity to γ from b→c and b→u interference

Require D^0 and $\overline{D^0}$ to decay to same final state

$$\frac{\langle B^- \to \overline{D^0} K^- \rangle}{\langle B^- \to D^0 K^- \rangle} = r_B e^{i(\delta_B - \gamma)}$$

Comparison of B^+ and B^- yields to determine γ

r_D and δ_D are like B-decay quantities, but in multibody decays, they vary over Dalitz space

Data from CLEO-c can be used to determine the average for the varying parameters

Measuring γ using $B \rightarrow DK$, $D \rightarrow K_s hh$

$Br[D \rightarrow K_S \pi\pi] = 2.99 \pm 0.17$ %

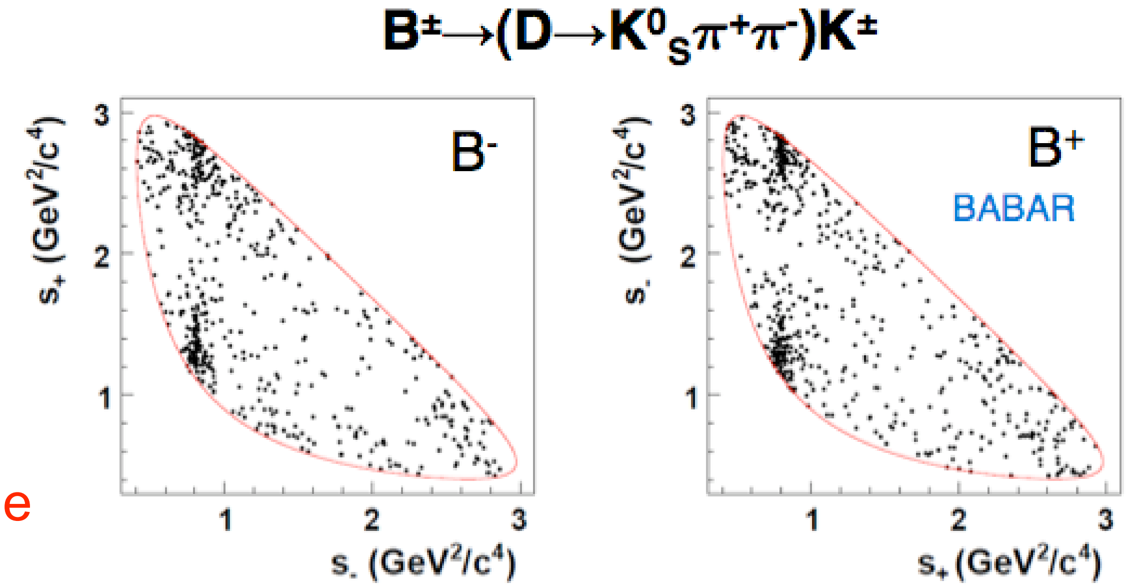
$Br[D \rightarrow K_S KK] = 0.47 \pm 0.03$ %

Studied at B factories

BABAR: PRL 105 121801(2010)

Belle: PRD 82 112002 (2010)

Necessary D information determined from the amplitude models of the decays



Amplitude models determined from $D^* \rightarrow D^0\pi$ decays

Amplitude models give rise to 3-9° uncertainty on γ

For LHCb and future experiments it will limiting.

Model independent approach possible using CLEO-c data

Binned model dependent fit

Proposed by Giri *et al.*[PRD 68 054018 (2003)], developed by Bondar and Poluektov [EPJ C 55 (2008) 51]

Relates number of B events in the dalitz plots to other quantities including γ.

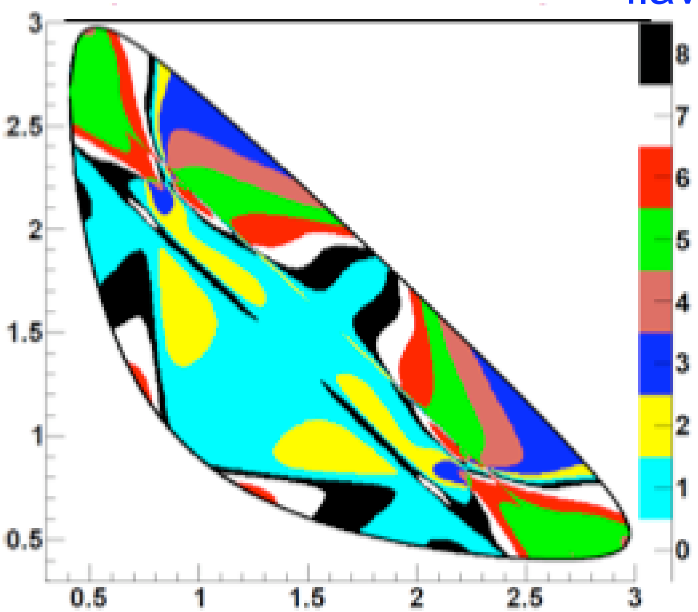
$$N^{\pm} = h\left(K_{\pm i} + r_B^2 K_{\mp i} + 2\sqrt{K_i K_{-i}}\left[x_{\pm} c_i \pm y_{\pm} s_i\right]\right)$$

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

Number of events for flavour tagged D sample

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

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



c_i and s_i - average of the cosine and sine of the strong phase difference over the bin.

Can be measured at CLEO-c

What binning? (see later)

CLEO-c and quantum coherence

Hermitic detector based at CESR e^+e^- collider

Operated at threshold energy

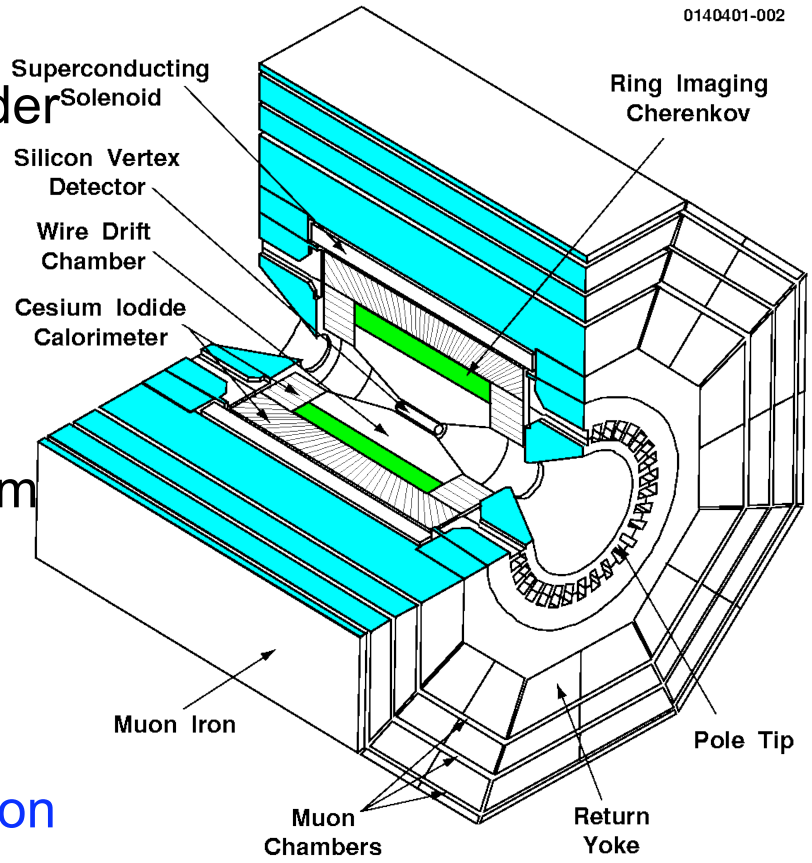
We study $\psi(3770) \rightarrow D^0\overline{D^0}$ decays

Key: C=-1 for $\psi(3770)$ at threshold

Hence the decays of D^0 and $\overline{D^0}$ are quantum correlated

Reconstruct decays of both D mesons

i.e. reconstructing one D meson decay to a CP eigenstate means that the other D meson decays has opposite CP



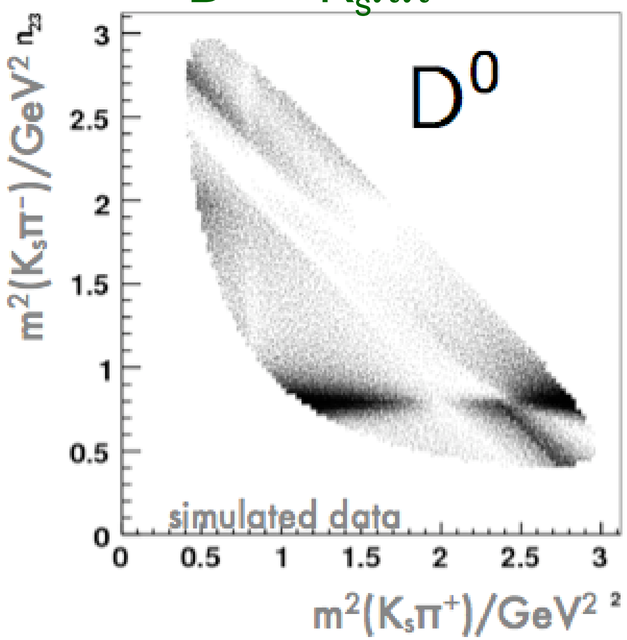
Strong phase differences from Q-C decays

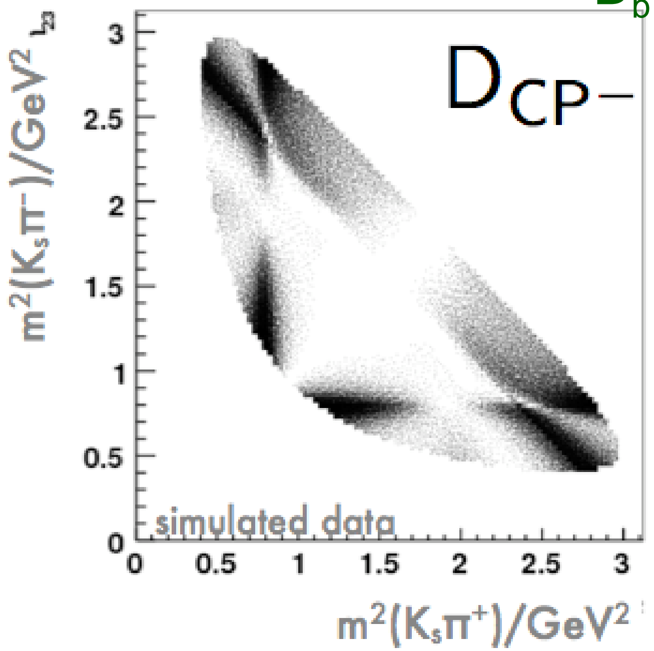
$D^{*+} \to D^0\pi$

$\psi(3770) \to D_a D_b \quad D_a \to CP$

$D^0 \to K_s\pi\pi$

$D_b \to K_s\pi\pi$





superposition of D^0 and $\overline{D^0}$

distribution $\propto |D^0|^2$

distribution $\propto |D^0|^2 + |\overline{D0}|^2 \pm 2|D0||\overline{D0}|\cos(\delta)$

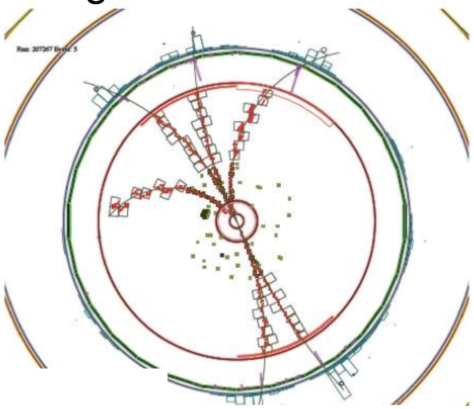
CP tags are just an example -- other hadronic decays can be used too.

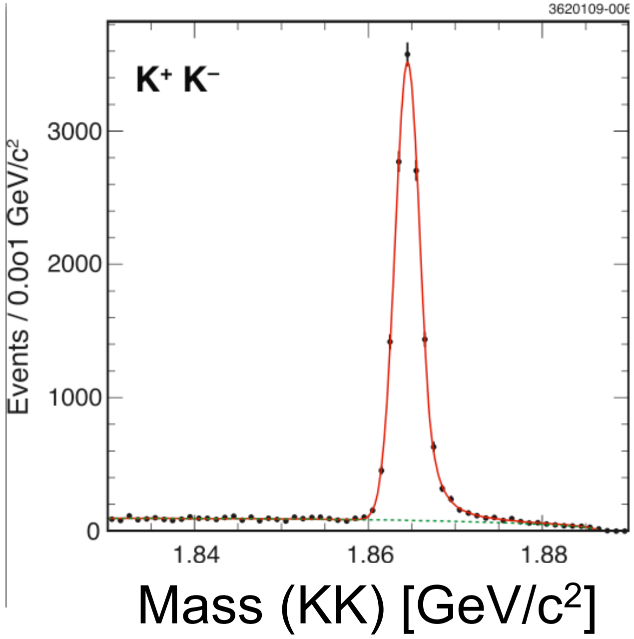
Strengths of the CLEO-c detector

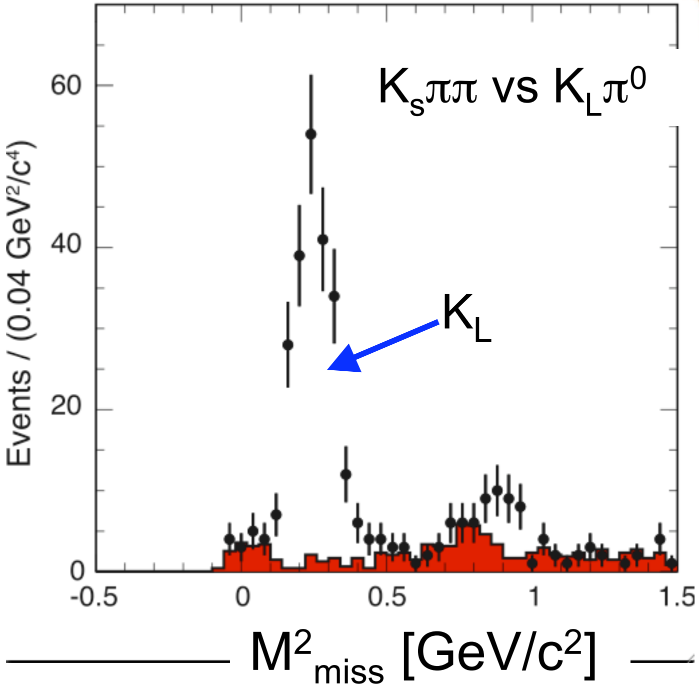
Very clean events

S/B ~ 10 -100

$K_s\pi\pi$ vs $K\pi$







Excellent E-M and hadron calorimetry and PID

K_L reconstruction possible through missing mass technique

Using CLEO-c data to measure c_i, s_i

1. Reconstruct double tag : $D_1 \to K_s\pi\pi$ $D_2 \to CP$

Ksππ flavour tagged yield in bin i

CP tagged Ksππ yield in bin i

$$M_i^{\pm} = h_{CP\pm}(K_i \pm 2c_i\sqrt{K_i K_{-i}} + K_{-i})$$

2. Reconstruct double tag : $D_1 \to K_s\pi\pi$ $D_2 \to K_s\pi\pi$

i and j are Dalitz plot bins for each $D \to K_s\pi\pi$ decay

$$M_{ij} = h_{\rm corr}(K_i K_{-j} + K_{-i} K_j - 2\sqrt{K_i K_{-j} K_{-i} K_j}(c_i c_j + s_i s_j))$$

3. Reconstruct double tag : $D_1 \to K_L\pi\pi$ $D_2 \to CP$

CP odd $K_s\pi\pi \approx$ CP even $K_L\pi\pi$

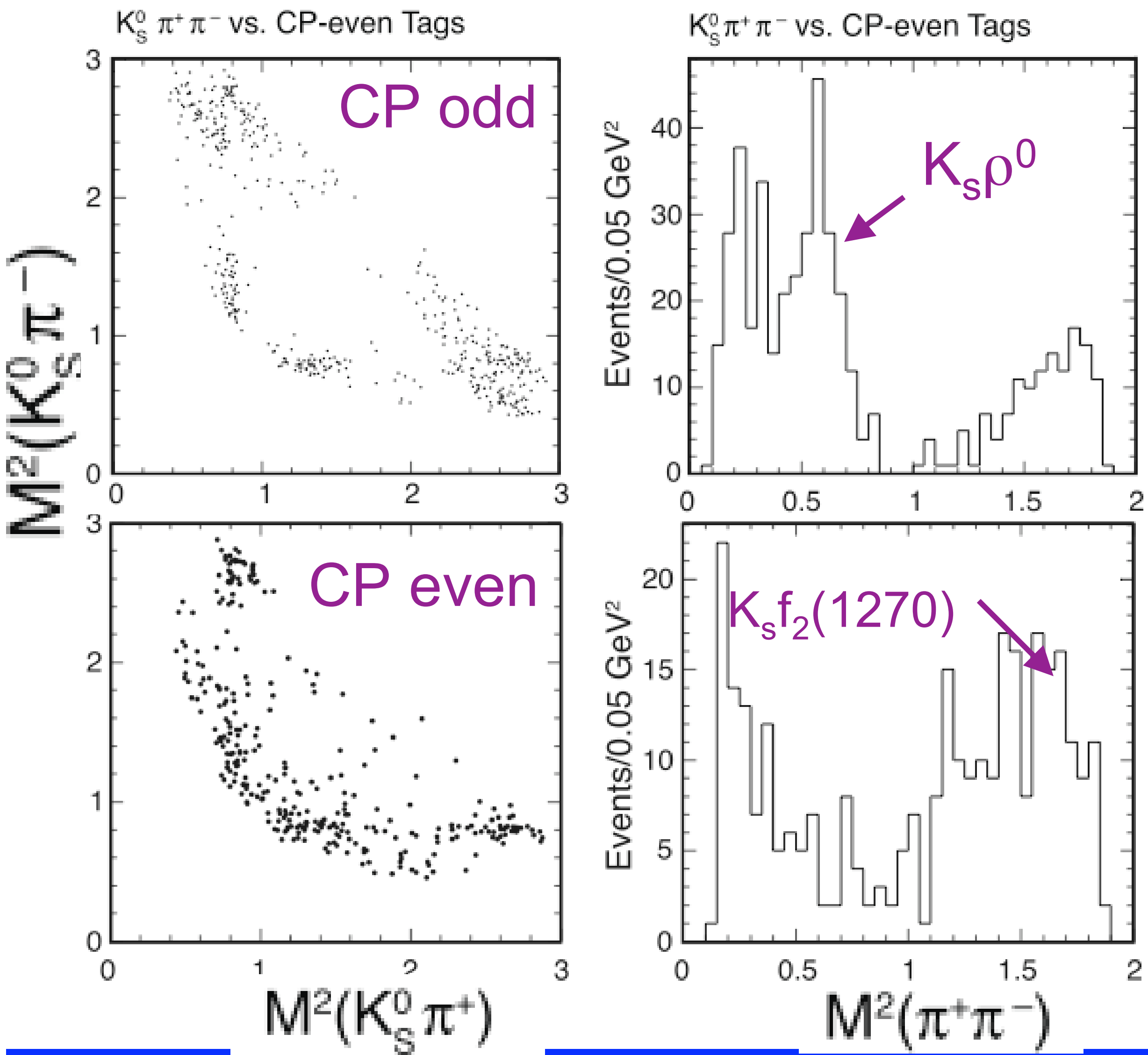
$$M_i'^{\pm} = h_{CP\pm}(K_i' \mp 2c_i'\sqrt{K_i' K_{-i}'} + K_{-i}')$$

4. Reconstruct double tag : $D_1 \to K_s\pi\pi$ $D_2 \to K_L\pi\pi$

$$M_{ij}' = h_{corr}(K_i K_{-j}' + K_{-i} K_j' + 2\sqrt{K_i K_{-j}' K_{-i} K_j'}(c_i c_j' + s_i s_j'))$$

Introduces weak model dependence as difference between c' and c is constrained by model prediction.

CP tagged Dalitz plots



As an example see the Dalitz plots for $D \to K_s\pi\pi$ where the other D decays to CP even or CP odd decay

Clear differences due to quantum coherence

Event yields:

$K_s\pi\pi$ vs CP ~ 1700

$K_s\pi\pi$ vs $K^0\pi\pi$ ~ 1700

PRD 80 032002 (2009)

What binning to use

Binning loses statistical sensitivity in comparison to the unbinned case.

This loss can be mitigated by “smarter” binning approaches

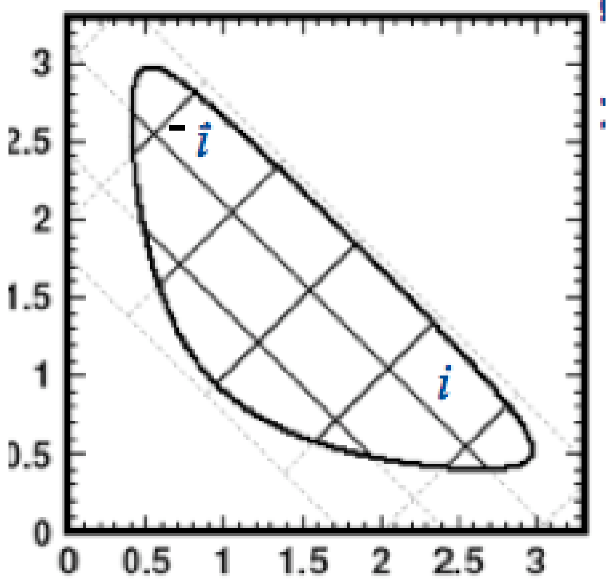
e.g choosing bins of *expected* similar strong phase

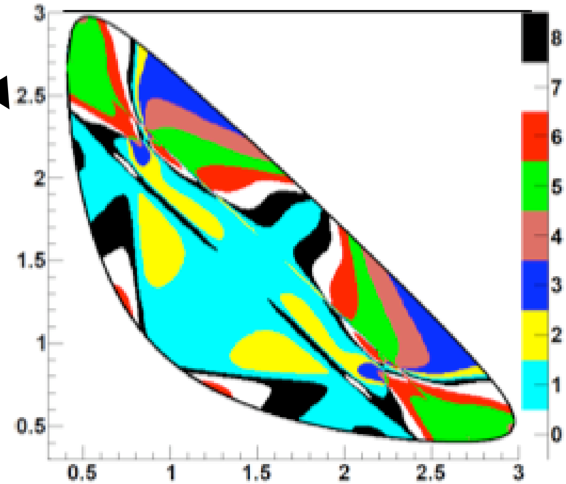
- lose 20% statistical sensitivity in comparison to the unbinned case. cf ~ 40% for rectangular bins. Worthwhile using an improved model

Using the *expected* B statistics distribution can optimize further

“optimal binning” gains ~10% if low background

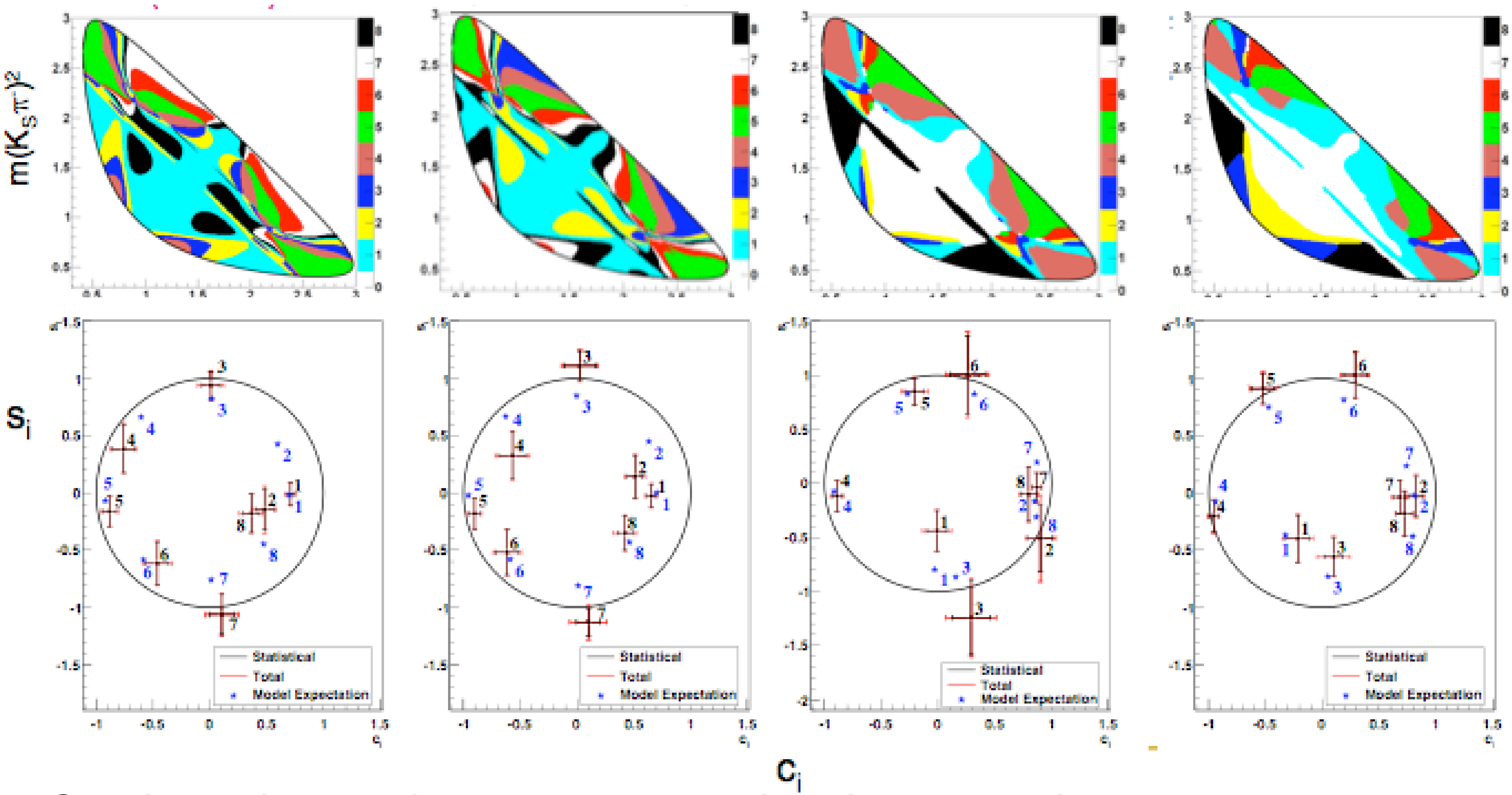
Modified optimal best for LHCb bkgs





Results with new binnings

Equal $\Delta\delta_D$ Belle | Equal $\Delta\delta_D$ Babar | Optimal | Modified Optimal



Good consistency between expected and measured.

Belle model binning allows for further crosschecks

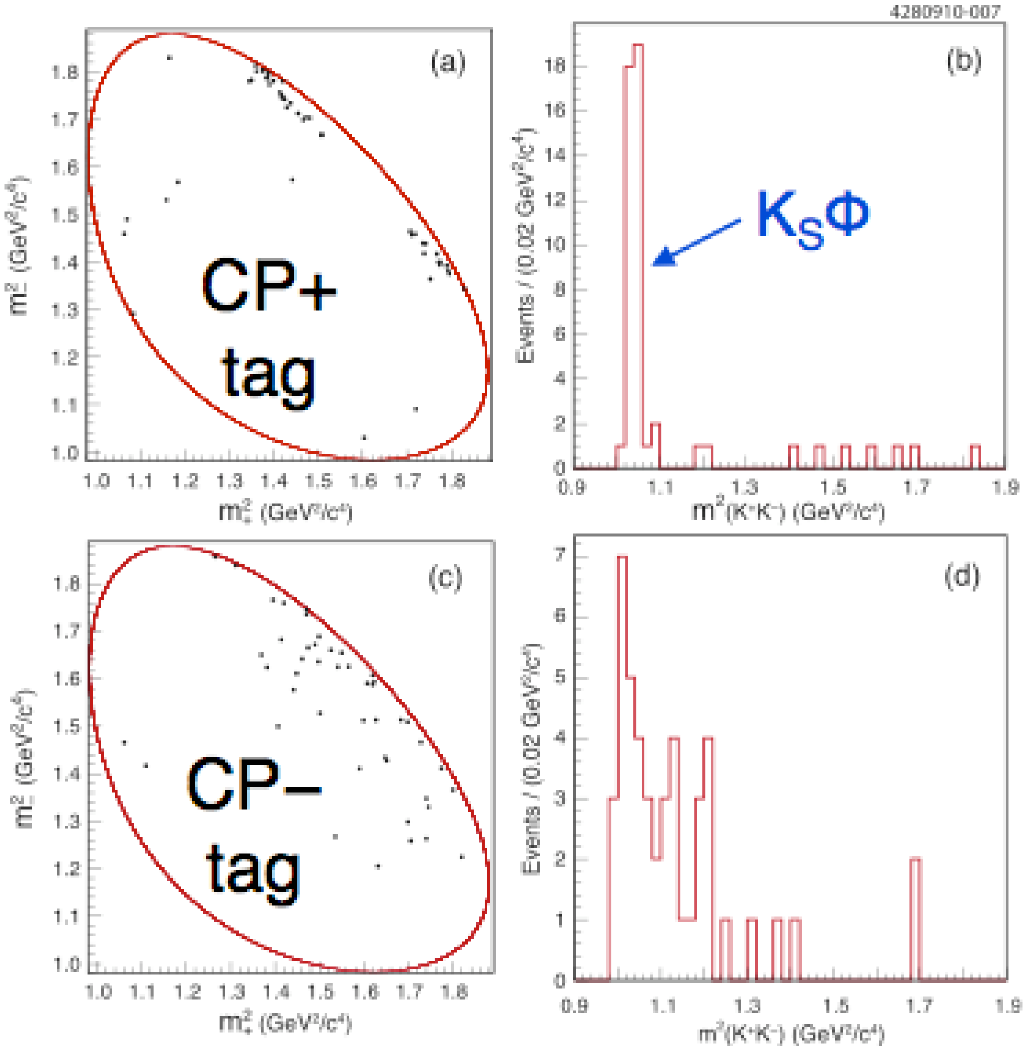
PRD 82, 112006 (2010)

Extension to KsKK

Similar analysis for KsKK

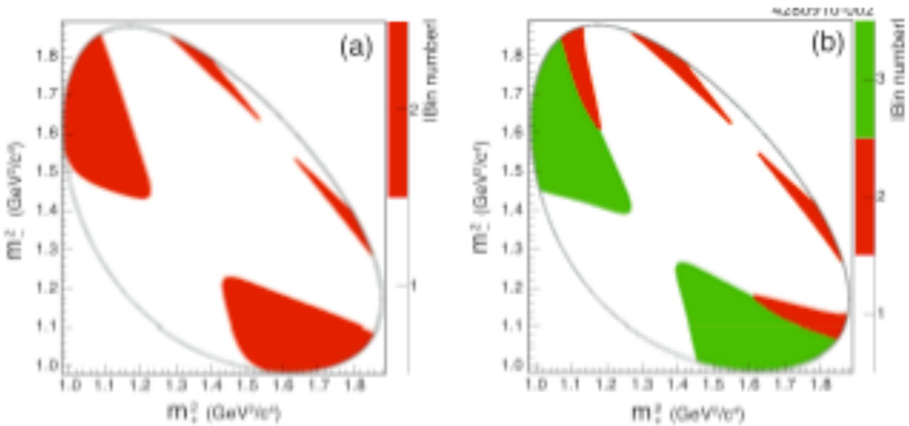
In addition can use double tags $D_1 \rightarrow KsKK$, $D_2 \rightarrow K^0\pi\pi$ with knowledge of c_i and s_i of $K_S\pi\pi$

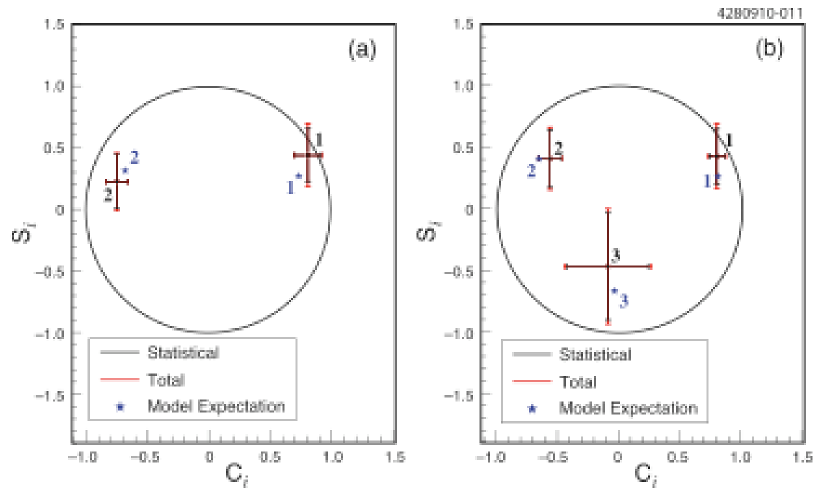
In total ~550 QC double tags

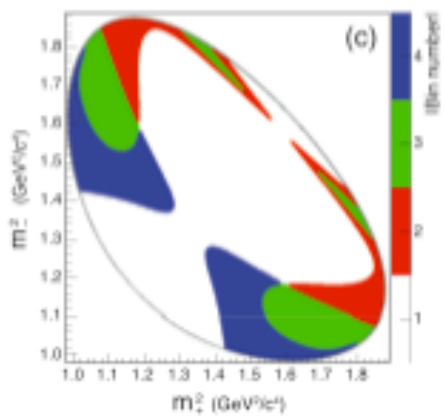


PRD 82, 112006 (2010)

Results for KsKK



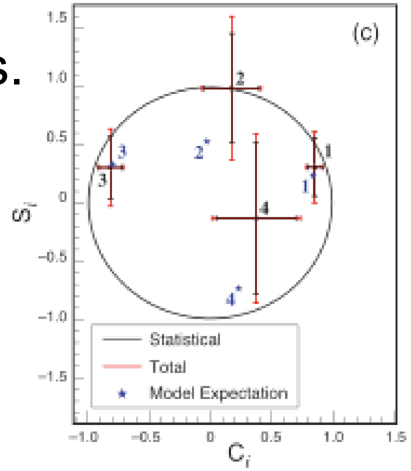




Results presented in 2, 3 & 4 bins.

Use only equal $\Delta\delta_D$ binnings from Babar 2010 model PRL 105, 121801 (2010)

Optimal binnings had negligible improvement



PRD 82, 112006 (2010)

Impact on γ

Uncertainties on c_i and s_i will lead to uncertainties on γ measurement.

In the limit of high statistics these are:

Preliminary result from Belle using this method

1.7--3.9° for $K_s\pi\pi$ (dependent on binning)

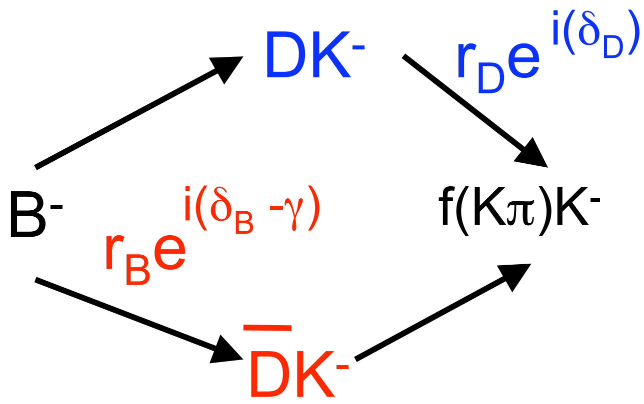
3.2--3.9° for K_sKK (dependent on binning)

- s_i statistical uncertainties dominate

Compare this to a model error of 3--9°

Similar uncertainty, however the model independent uncertainty arises from experimentally measured quantities only.

ADS analysis



$$\Gamma\left(B^+ \to D(K^+\pi^-)K^+\right) \propto 1 + \left(r_B r_D\right)^2 + 2 r_B r_D \cos\left(\delta_B + \gamma - \delta_D\right)$$

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

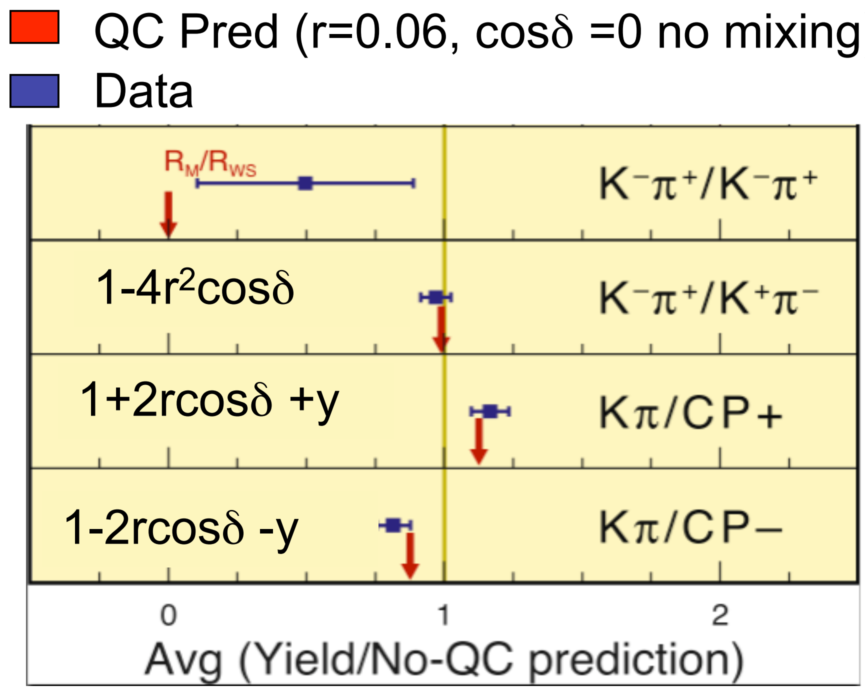
$Br[D^0 \to K^-\pi^+] = 3.89 \pm 0.05$ %

δ_D measured at CLEO

QC gives access to different D^0 $\overline{D^0}$ superposition

δ_D measurement uses many decays. Compares single tag yields (not affected by QC) to double tags (affected by QC)

Also sensitive to D mixing



Preliminary $\delta_{K\pi}$ results

First measurement using 281 pb^{-1}

Update with full 818 pb^{-1} on going adding many more decay channels

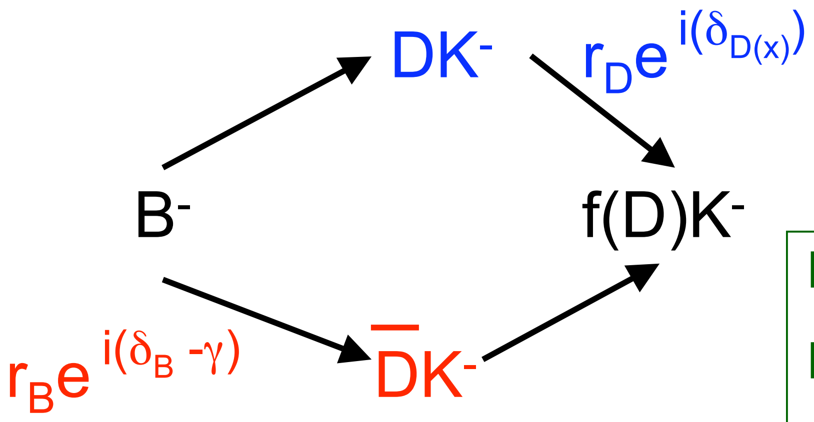
Parameter	Previous: PDG, HFAG, or CLEO	Fit: no ext. meas.	Fit: with ext. y, x, y'
y (10^{-2})	0.79 ± 0.13	$3.0 \pm 2.0 \pm 1.2$	0.635 ± 0.118
x^2 (10^{-3})	0.037 ± 0.024	$1.5 \pm 2.0 \pm 0.9$	0.022 ± 0.017
r^2 (10^{-3})	3.32 ± 0.08	$4.12 \pm 0.92 \pm 0.23$	3.32 ± 0.08
$\cos\delta$	1.10 ± 0.36	$0.98\ ^{+0.27}_{-0.20} \pm 0.08$	$1.15 \pm 0.16 \pm 0.12$
$\sin\delta$	---	$-0.04 \pm 0.49 \pm 0.08$	$0.55\ ^{+0.36}_{-0.40} \pm 0.08$
δ (°) [derived]	$22\ ^{+11}_{-12}\ ^{+9}_{-11}$	$0 \pm 22 \pm 6$	$15\ ^{+11}_{-17} \pm 7$

PRL 100, 221801 (2008)

PRD 78, 012001 (2008)

preliminary 818 pb^{-1} results

ADS - style analysis



$$R_F e^{-i\delta_D^F} = \frac{\int A_{D^0}(x) A_{\overline{D^0}}(x) dx}{A_{D^0} A_{\overline{D^0}}}$$

$Br[D^0 \to K^-\pi^+\pi\pi] = 8.1 \pm 0.2$ %
$Br[D^0 \to K^-\pi^+\pi^0] = 13.9 \pm 0.5$ %
$Br[D^0 \to K^-\pi^+K_s] = 0.35 \pm 0.05$ %

$$\Gamma_1(B^+ \to D(\to F^+)K^+) \propto 1 + (r_B r_D)^2 + 2 r_B r_D R_F \cos(\delta_B + \gamma - \delta_D),$$
$$\Gamma_2(B^+ \to D(\to F^-)K^+) \propto r_B^2 + r_D^2 + 2 r_B r_D R_F \cos(\delta_B + \gamma + \delta_D),$$

$F^\pm = K^\pm\pi\pi\pi$, $K^\pm\pi\pi^0$, $K^\pm K_s\pi$.

For $K\pi\pi\pi$ and $K\pi\pi^0$ r_D ~0.06. CF ($D^0 \to K^-\pi^+$) and DCS decays ($D^0 \to K^+\pi^-$)

However for $K\pi K_S$ r_D ~ 0.7 ➔Both $D^0 \to K^-\pi^+K_s$ and $D^0 \to K^+\pi^-K_s$ SCS decays.
Promising new channel despite lower branching fractions.

Double tags sensitive to the coherence factor

Senstivity to R_F and δ_F comes from counting various double tag yields.

$F^{\pm} = K^{\pm}\pi\pi\pi$, $K^{\pm}\pi\pi^0$, $K^{\pm}\pi K_S$.

Not used for $K^{\pm}\pi K_s$ as yield =0 → $F^{\pm}$ vs $F^{\pm}$

Double Tag	Sensitive to
$F^{\pm}$ vs $F^{\pm}$	$(R_F)^2$
$F^{\pm}$ vs CP	$R_F\cos(\delta_F)$
$F^{\pm}_1$ vs $K^{\pm}\pi$	$R_F\cos(\delta_F - \delta_{Kpi})$
$F^{\pm}_1$ vs $F^{\pm}_2$	$R_{F1}R_{F2}\cos(\delta_{F1} - \delta_{F2})$
$F^{\pm}$ vs $K^0\pi\pi$	$R_F\cos(\delta_F)$, $R_F\sin(\delta_F)$

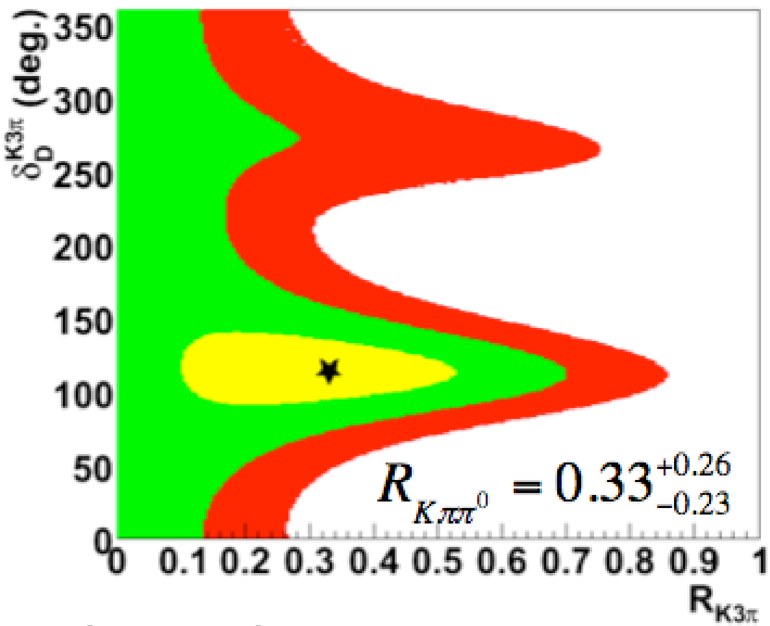
Additional information used for for $K^{\pm}\pi K_s$

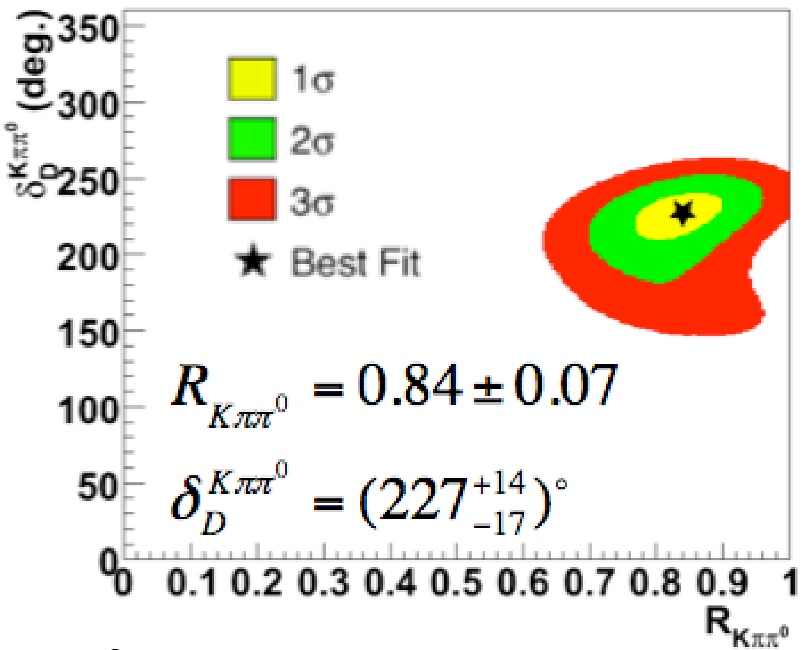
Relies on c_i and s_i measurements → $F^{\pm}$ vs $K^0\pi\pi$

Yield of CP tags (→ $F^{\pm}$ vs CP)

$K^{\pm}\pi\pi\pi$, ~3465 $K^{\pm}\pi\pi^0$ ~4774, $K^{\pm}\pi K_S$ ~122

Coherence factor results





$K^{\pm}\pi\pi\pi$: Low coherence

$\Gamma \propto r_B^2 + r_D^2 + 2 r_B r_D R_F \cos(\delta_D + \delta_B + \gamma)$ → 0

improves knowledge of r_B

$K^{\pm}\pi\pi^0$: High coherence

Useful in ADS γ measurement

PRD 80, 031105 (2009)

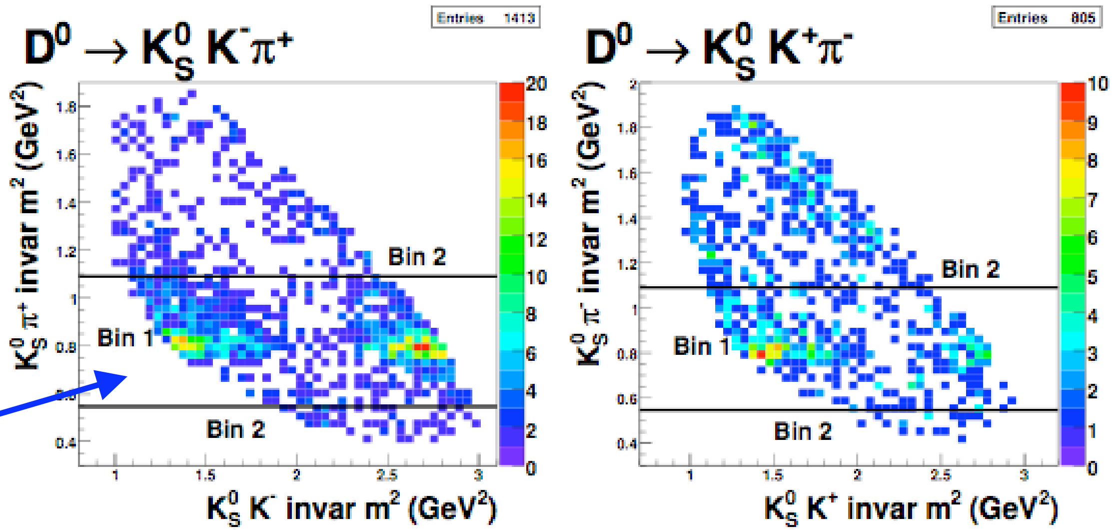
Preliminary coherence factor results

The coherence around a resonance is expected to be close to 1.

Good motivation to repeat measurement in a Dalitz plot bin around the K* resonance.

Bin is 2*(natural width) around the K* mass.

Analysis is repeated using data in this bin only.



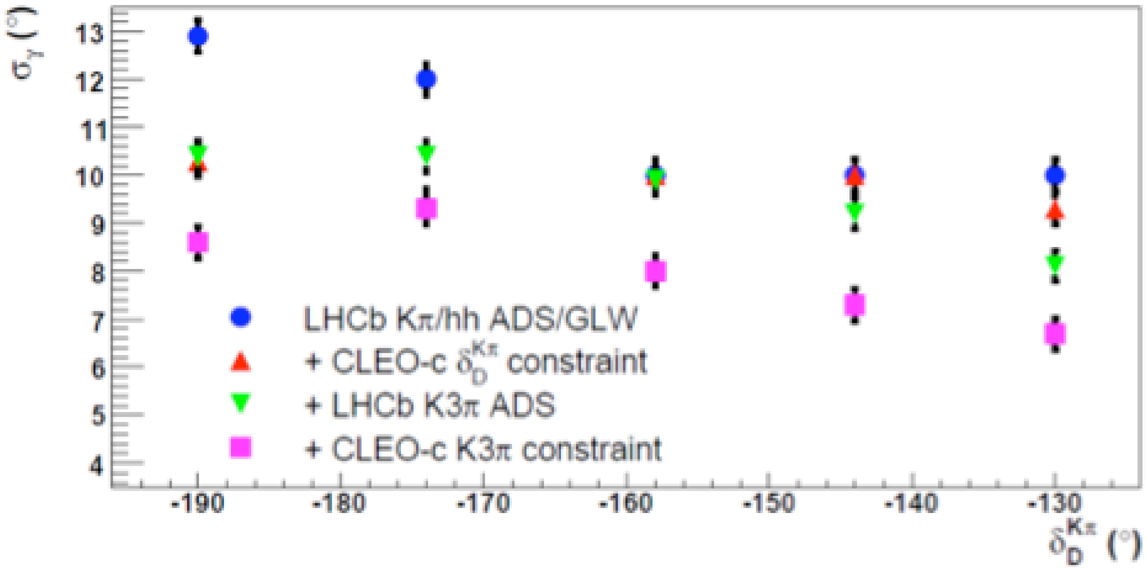
Preliminary CLEO-c Results:

Full Dalitz plot : $R_F = 0.73 \pm 0.09$ $\delta_D = 8.2 \pm 15.2°$

Bin 1 : $R_F = 0.961 \pm 0.171$, $\delta_D = 25.8 \pm 17.3$

Impact of these results on γ

Expected γ precision using ADS modes at LHCb 2fb^{-1}



Inclusion of $K\pi\pi^0$ assuming 1/2 yield of $K\pi\pi\pi$ with same background

$\sigma(\gamma) \sim 7.5°$

Knowledge of coherence factor for $D \rightarrow K\pi K_S$ means additional statistics of the decay $B \rightarrow D(K\pi K_S)K$ can also be used

Summary

- Quantum correlated decays give access to the strong phase difference
- Measurements can improve γ measurements in using $B \rightarrow DK$
- Allows for Dalitz model independent measurements
- Several measurements from CLEO-c
  - $D \rightarrow K_s\pi\pi$ and K_sKK
  - $\delta_{K\pi}$ measurement
  - Coherence factor and average strong phase measurements in $D \rightarrow K\pi\pi\pi$, $K\pi\pi^0$, $K\pi K_s$