Charm Hadronic Decays and Quantum Correlations at CLEO-c

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(+ CLEO & BESIII)

International Workshop
On e^+e^- Collisions
From ϕ to ψ

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U.S. DEPARTMENT OF ENERGY

NSF

Outline

Introduction

Mapping $D_{(s)}$ Decays

- *Absolute D_s Branching Fractions with "tagging"*
- *D and D_s Dalitz plots (untagged)*

Correlations and Coherence

- *Quantum Correlations: The $K\pi$ strong phase*
- *The CKM angle γ: Coherence in $D^0 \to K2\pi$, $K3\pi$*

The Future…

Backup slides feature several other recent analyses:

$D_{(s)} \to PP$ (pseudoscalars)	$D \to K_S\pi$, $K_L\pi$	$D \to KK$
$D_s \to p\ n$	$D \to \eta X$, $\eta' X$ (excl.)	Charm cross-sections

Charm Threshold

D^+ & D^0 studies:*   818 pb^{-1} at 3770 MeV

$e^+e^- \rightarrow \psi(3770) \rightarrow D^+ D^-, D^0 \bar{D}^0$ [2.9 nb, 3.7 nb]

Resonance on top of ~16 nb of uds continuum

D_s studies:*   586 pb^{-1} at 4170 MeV

$e^+e^- \rightarrow D_s^{*+} D_s^-$ + c.c.   [0.9 nb]

$D_s^{*\pm} \rightarrow D_s^\pm \gamma$ (94%)

on top of ~13 nb of uds continuum

~ 9 nb of non-strange charm pairs (+ tiny $D_s^+ D_s^-$)

Both cases: ONLY charm mesons, no E_{cm} for extra pions !

Benefit from constrained kinematics.

*Note: a few analyses use only part of integrated luminosity

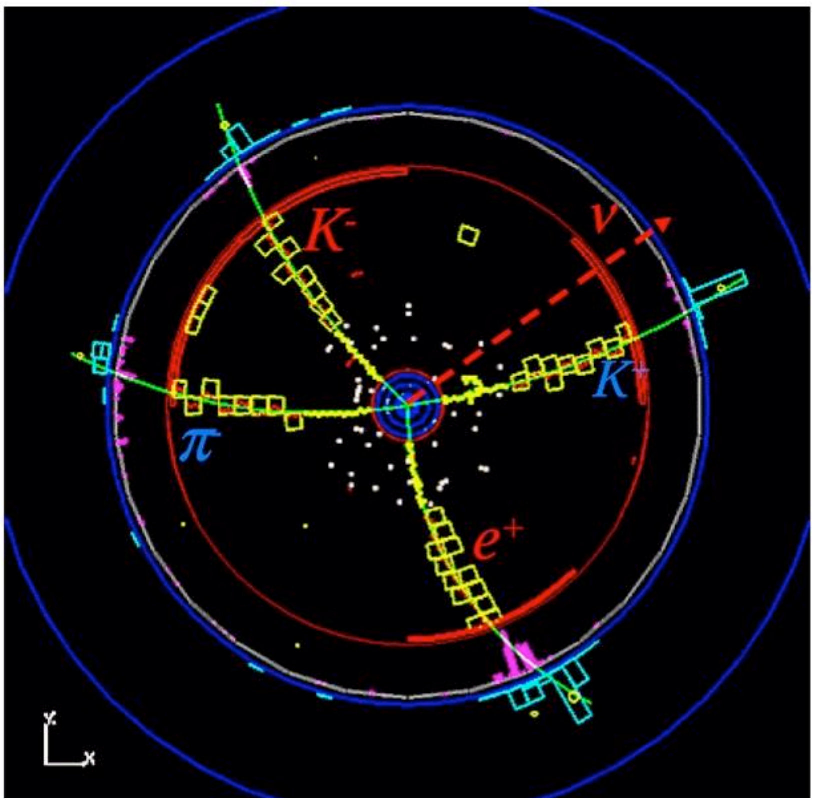
$D_{(s)}$ Tagged Events

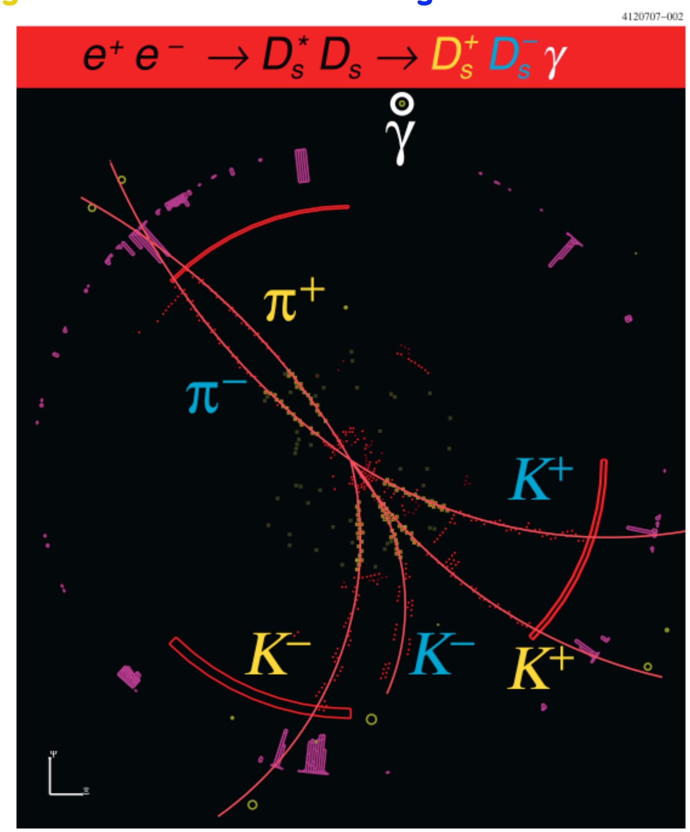
"Tag": fully-reconstructed $D_{(s)}$ meson

- *Eliminates uds continuum*
- *Further constrains the other $D_{(s)}$ [know direction]*

***Tag** can also have definite flavor, or be **a CP-eigenstate** !*

$\bar{D}^0 \to K^+ \pi^-$ $D^0 \to K^- e^+ \nu$ $D_s^+ \to K^- K^+ \pi^+$ $D_s^- \to K^- K^+ \pi^-$





Hadronic D_s Decays

Recent past:

> Overall 25% syst. on branching fraction scale
 [all referenced to $D_s \to \phi\pi$, measured with a complex technique]

> Smaller number of modes explored, compared to non-strange D

> Poor knowledge of inclusive rates

Now, big improvements from CLEO-c:

> Precise $D_s \to KK\pi$ absolute branching fraction + Dalitz analysis

> Other modes improved, first observations added, …

> Much-improved inclusive picture

> Very useful for Monte-Carlo simulations [LHC-b, BESIII, B factories…]

D_s Absolute Branching Fractions

PRL100, 161804
298 pb^{-1} (2008)

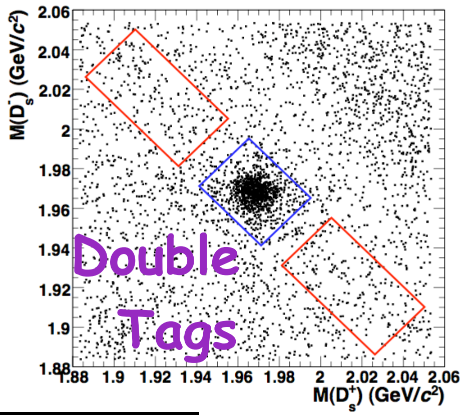
Global fit to single tag and double tag rates

- *Independent of # $D_s^*D_s$ pairs*
- *Each BF insensitive to efficiency of all other modes used as tags*

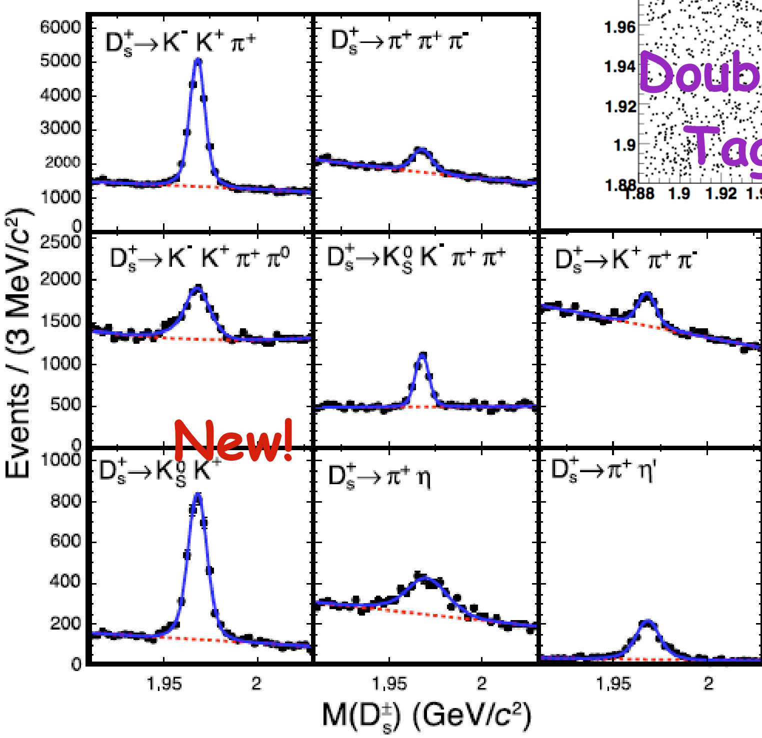
$B(D_s^+ \to K^+ K^- \pi^+) = (5.50 \pm 0.23 \pm 0.16)\%$

***plus* 7 other modes:**

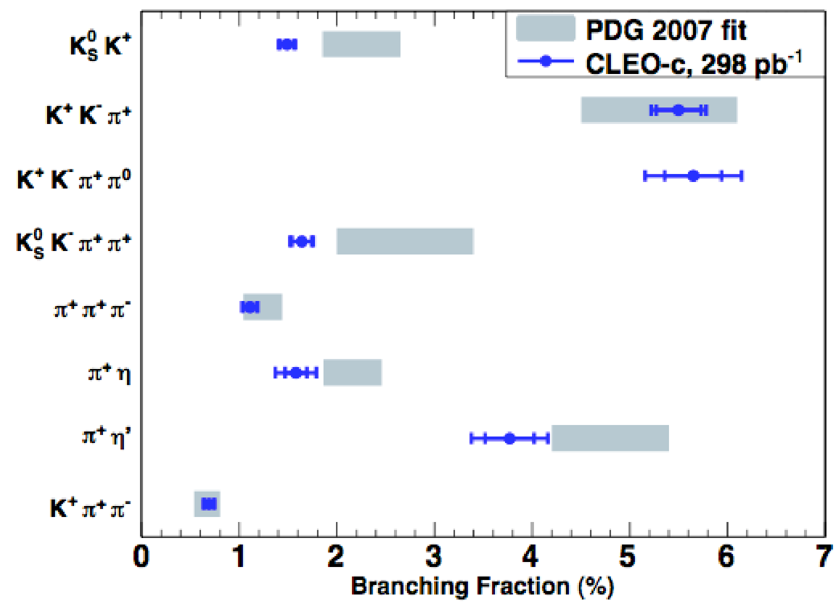
$K_s K^+$ $K^+K^-\pi^+\pi^0$ $K_s K^-\pi^+\pi^+$
$\pi^+\pi^+\pi^-$ $\pi^+\eta$ $\pi^+\eta'$ $K^+\pi^+\pi^-$



Single Tags



CLEO-c vs. PDG



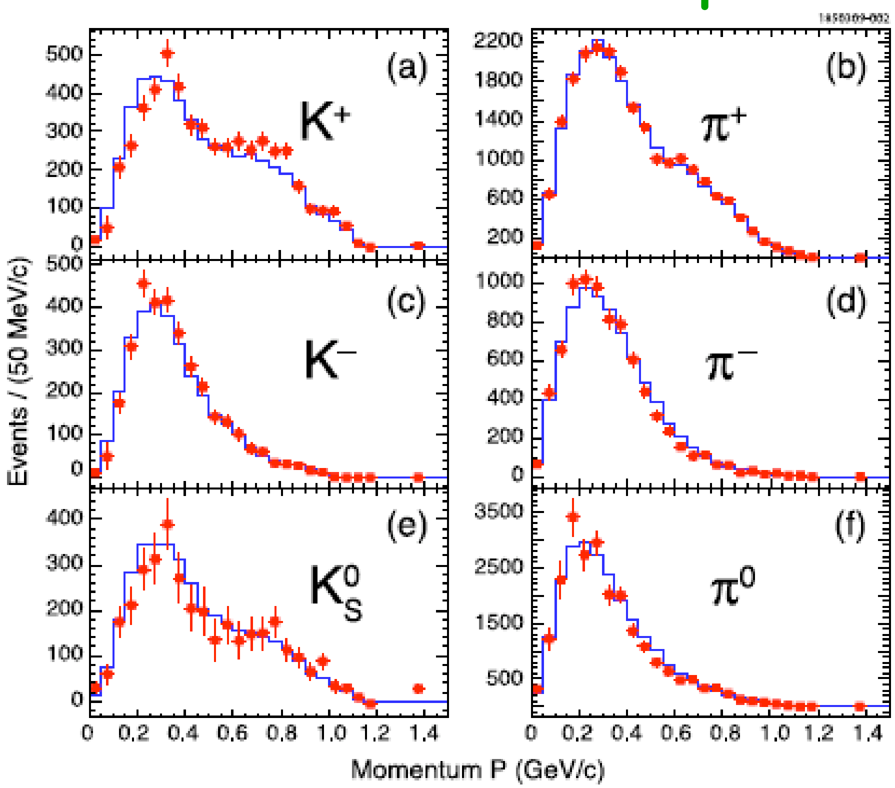
D_s Inclusive Hadrons

PRD 79, 112008
586 pb^{-1} (2009)

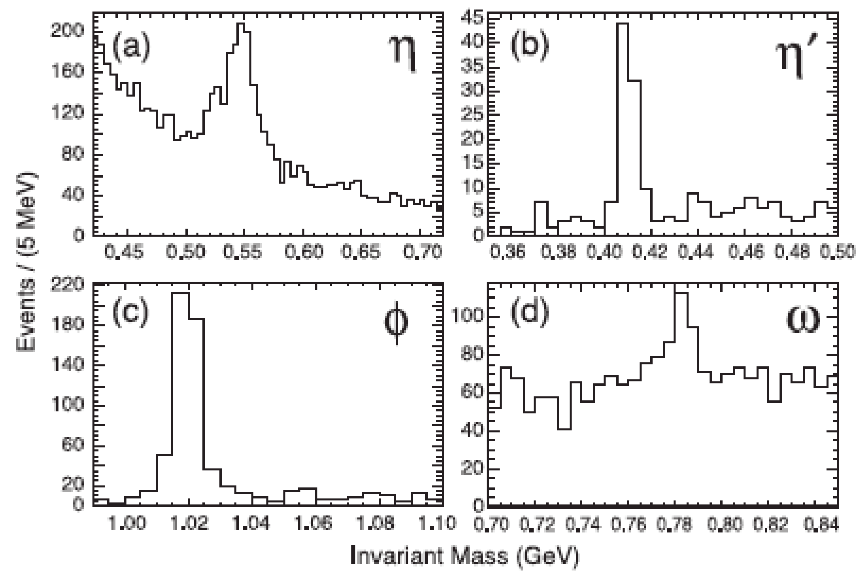
Use 3 best tag modes: $\phi\pi$ $K^{*0}K$ $K\,K$ [18600 tags]

- 94% of $D_s^*D_s$ leads to $D_s D_s \gamma$; here, we require γ
- cut on recoil masses against both (D_s) & ($D_s \gamma$) systems

Inclusive momentum spectra:



Inclusive mass peaks:



Also measure rates to KKX, for various kaon charge combinations…

D_s Inclusive Hadrons

PRD 79, 112008
586 pb^{-1} (2009)

TABLE I. D_s inclusive yield results. Uncertainties are statistical and systematic, respectively. The inclusive K_L^0 results are only used as a check for K_S^0. The $D_s^+ \to K_L^0 X$ yield requires a correction before comparing with the $D_s^+ \to K_S^0 X$ yield, as explained in the text. PDG [11] averages are shown in the last column, when available, for non-CLEO measurements.

Mode	Yield (%)	K_L^0 mode	Yield (%)	$\mathcal{B}$ (PDG) (%)
$D_s^+ \to \pi^+ X$	$119.3 \pm 1.2 \pm 0.7$			
$D_s^+ \to \pi^- X$	$43.2 \pm 0.9 \pm 0.3$			
$D_s^+ \to \pi^0 X$	$123.4 \pm 3.8 \pm 5.3$			
$D_s^+ \to K^+ X$	$28.9 \pm 0.6 \pm 0.3$			20^{+18}_{-14}
$D_s^+ \to K^- X$	$18.7 \pm 0.5 \pm 0.2$			13^{+14}_{-12}
$D_s^+ \to \eta X$	$29.9 \pm 2.2 \pm 1.7$			
$D_s^+ \to \eta' X$	$11.7 \pm 1.7 \pm 0.7$			
$D_s^+ \to \phi X$	$15.7 \pm 0.8 \pm 0.6$			
$D_s^+ \to \omega X$	$6.1 \pm 1.4 \pm 0.3$			
$D_s^+ \to f_0(980) X$, $f_0(980) \to \pi^+\pi^-$	$<1.3\%$ (90% C.L.)			
$D_s^+ \to K_S^0 X$	$19.0 \pm 1.0 \pm 0.4$	$D_s^+ \to K_L^0 X$	15.6 ± 2.0	20 ± 14
$D_s^+ \to K_S^0 K_S^0 X$	$1.7 \pm 0.3 \pm 0.1$	$D_s^+ \to K_L^0 K_S^0 X$	5.0 ± 1.0	
$D_s^+ \to K_S^0 K^+ X$	$5.8 \pm 0.5 \pm 0.1$	$D_s^+ \to K_L^0 K^+ X$	5.2 ± 0.7	
$D_s^+ \to K_S^0 K^- X$	$1.9 \pm 0.4 \pm 0.1$	$D_s^+ \to K_L^0 K^- X$	1.9 ± 0.3	
$D_s^+ \to K^+ K^- X$	$15.8 \pm 0.6 \pm 0.3$			
$D_s^+ \to K^+ K^+ X$	$<0.26\%$ (90% C.L.)			
$D_s^+ \to K^- K^- X$	$<0.06\%$ (90% C.L.)			

21 CLEO results

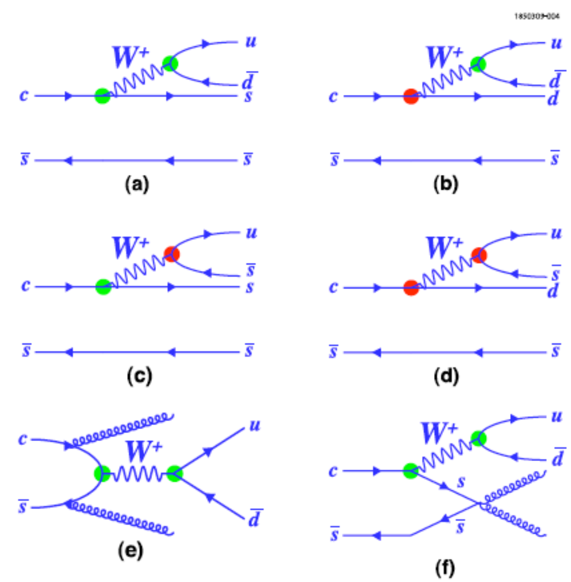
vs.

3 prior non-CLEO

KKX rates: use to help to untangle decay mechanisms shown in Feynman diagrams

In particular, we obtain lower limits on hadronic annihilation diagram contributions…

[diagrams (e) and (f) at right]



D_s: Exclusive ω modes

PRD 80, 051102
586 pb^{-1} (2009)

Motivated by previous inclusive ω yield:

$B(D_s^+ \to \omega X) = (6.1 \pm 1.4)\ \%$

SAME tagging technique used.

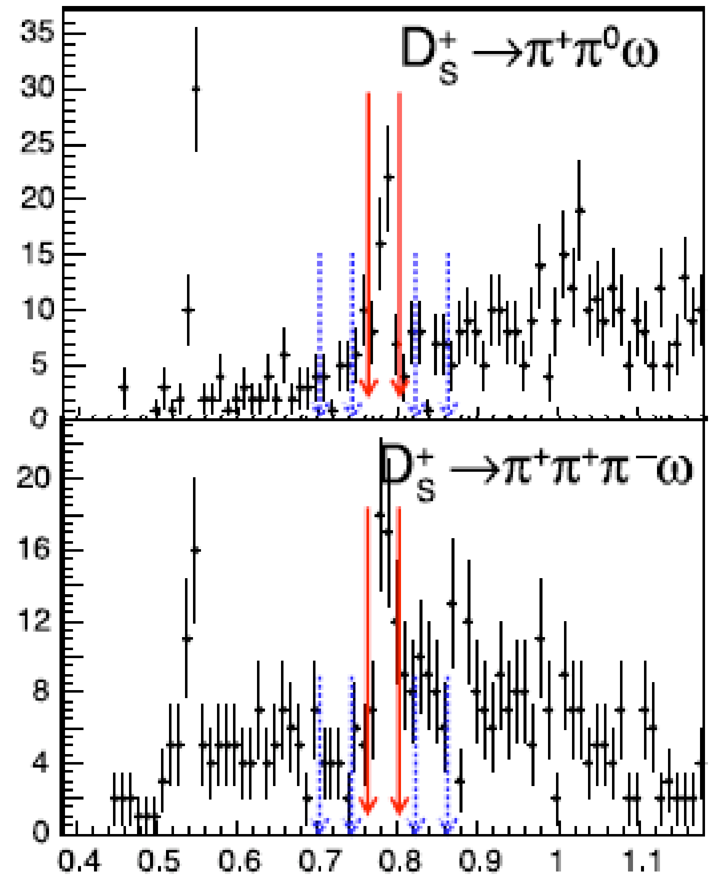
Mode	B (%)
$D_s^+ \to \pi^+ \omega$	$0.21 \pm 0.09 \pm 0.01$
$D_s^+ \to \pi^+ \pi^0 \omega$	$2.78 \pm 0.65 \pm 0.25$
$D_s^+ \to \pi^+ \pi^+ \pi^- \omega$	$1.58 \pm 0.45 \pm 0.09$

5 other modes with limits:

$\pi^+ \eta \omega$ $K^+ \eta \omega$

$K^+ \omega$ $K^+ \pi^0 \omega$ $K^+ \pi^+ \pi^- \omega$

Selected Mass Peaks:



Dalitz Analysis Overview

Use untagged analyses:

- Higher background, but also higher statistics
- Still statistics limited; can handle background systematics

Fits start with an "Isobar model" :

- Sum of interfering Breit-Wigners, with correct angular factors
- Many other subtleties; see papers

… and then add some extra features :

- Detailed S-wave treatments are tried [not just BW !]
- Flatte formalism for $f_0(980) \rightarrow K K$ [needed near threshold]

2 of 3 analyses: "golden modes" used for normalization

- Results can improve models so "users" get correct efficiency
- Subtleties are important for physics; models just need a good fit…

Dalitz 1: $D_s^+ \to K^+ K^- \pi^+$

PRD 79, 072008
586 pb^{-1} (2009)

>12000 signal events; 85% purity   Key D_s normalization mode

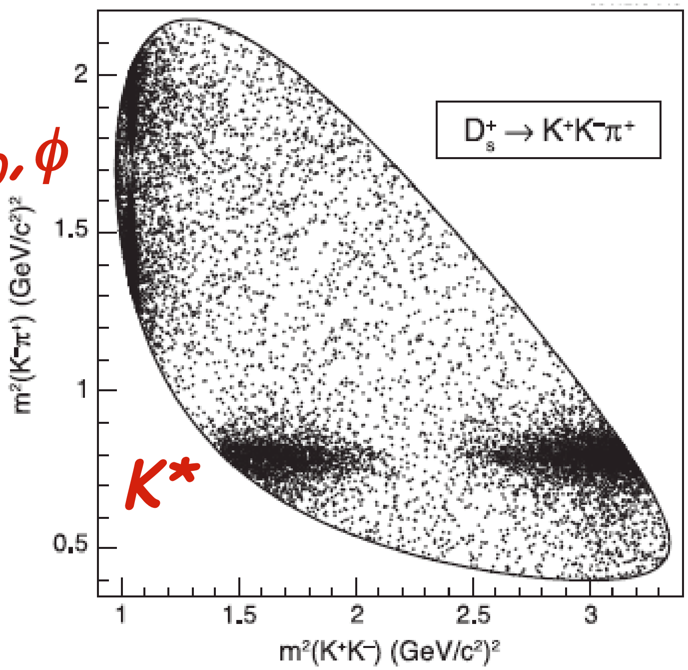
Resonant Sub-modes required: [= E687 + $f(1370)^0 \pi^+$]

$\phi(1020)\pi$ $K^*(892)^0 K^+$ $f_0(980)^0 \pi^+$ $K^*_0(1430)^0 K^+$ $f_0(1370)^0 \pi^+$ $f_0(1710)^0 \pi^+$

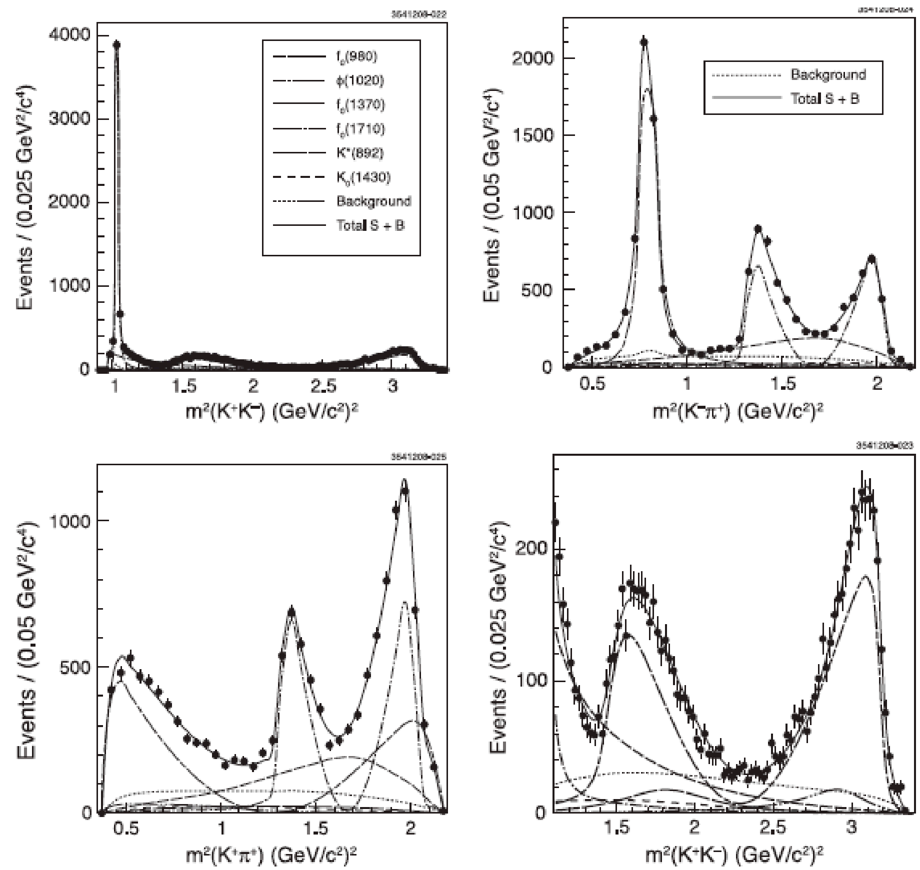
- Add f(1370) $\Delta\chi^2$ = -100   Fit χ^2: 178/117
- No need for κ $\Delta\chi^2$ = -5

  [= S-wave $K\pi$]

f_0, ϕ



K^*



Dalitz 2: $D^+ \to K^+ K^- \pi^+$

PRD 78, 072003
818 pb^{-1} (2008)

19500 <u>signal</u> events; 84% purity

Best fit: *Fit χ^2: 895/708*

$\phi(1020)\,\pi^+$ $K^*(892)^0\,K^+$ $K^*_0(1430)^0\,K^+$ $a_0(1450)^0\,\pi^+$ $K^*_2(1430)^0\,K^+$ $\phi(1680)^0\,\pi^+$

***plus**: $\kappa\ K^+$ (κ = S-wave $K\pi$)*

BUT non-resonant almost as good as κ: $\chi^2 = 898/708$

[LASS-inspired $K\pi$: $\chi^2 = 912/710$]

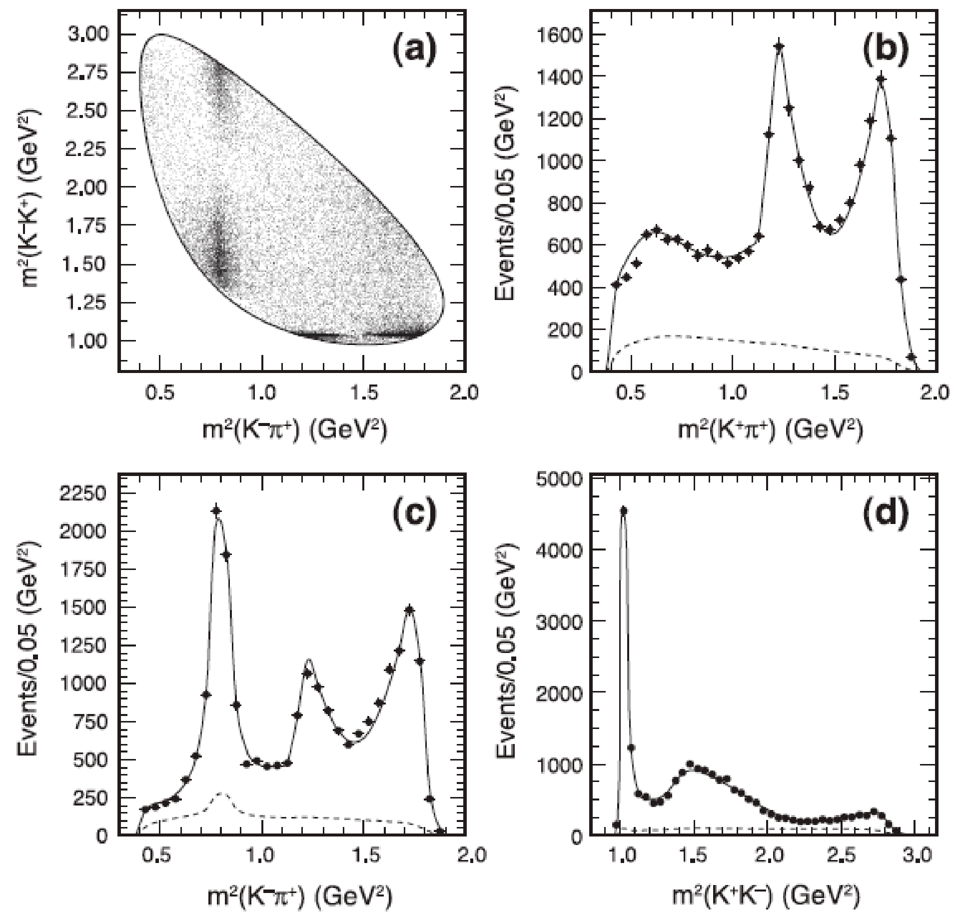
Also search for CP violation:

- Singly-Cabibbo suppressed
- Sensitive to new physics in penguins
- Not true of CF, DCSD…

Asymmetry:

(-0.03 ± 0.84 ± 0.29)%

Also have results by submode…



Dalitz 3: $D^+ \to K^- \pi^+ \pi^+$

PRD 78, 052001
572 pb^{-1} (2008)

>139000 signal events; 99% purity   Key D^+ normalization mode

Starting Fit [E791 model] :   *Fit χ^2: 531/391*

$K^*(892)^0 \pi^+$ $K^*_0(1410)^0 \pi^+$ $K^*_2(1430)^0 \pi^+$ $K^*(1680)^0 \pi^+$

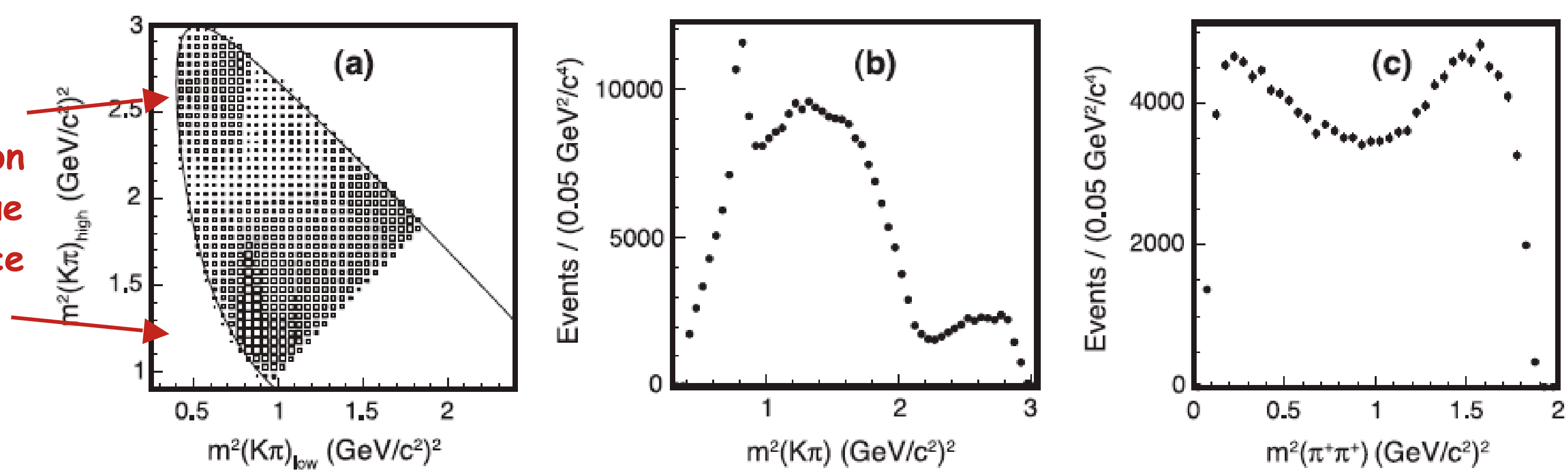
plus *non-resonant term & $\kappa\pi^+$ (κ = S-wave $K\pi$)*

κ is the dominant "fit fraction" -- But, fit can be improved ...

Improved by adding I=2 $\pi^+ \pi^+$ S-wave: *Fit χ^2: 416/385*

Also *replace κ*, non-res w/ binned S-wave $K\pi$:   *Fit χ^2: 359/347*

Note distortion of K* band due to interference

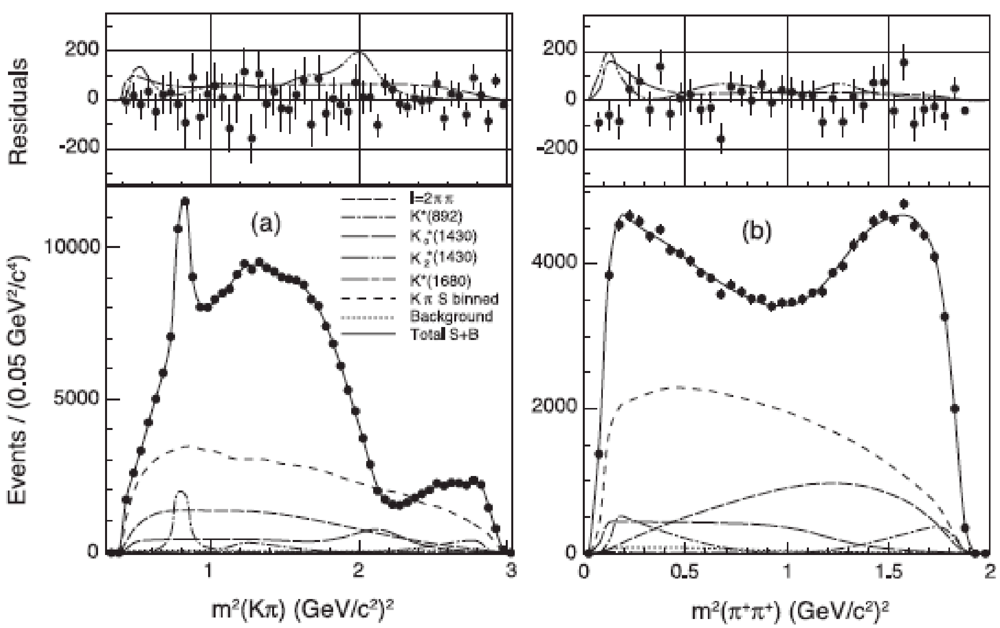


Dalitz 3: $D^+ \to K^- \pi^+ \pi^+$

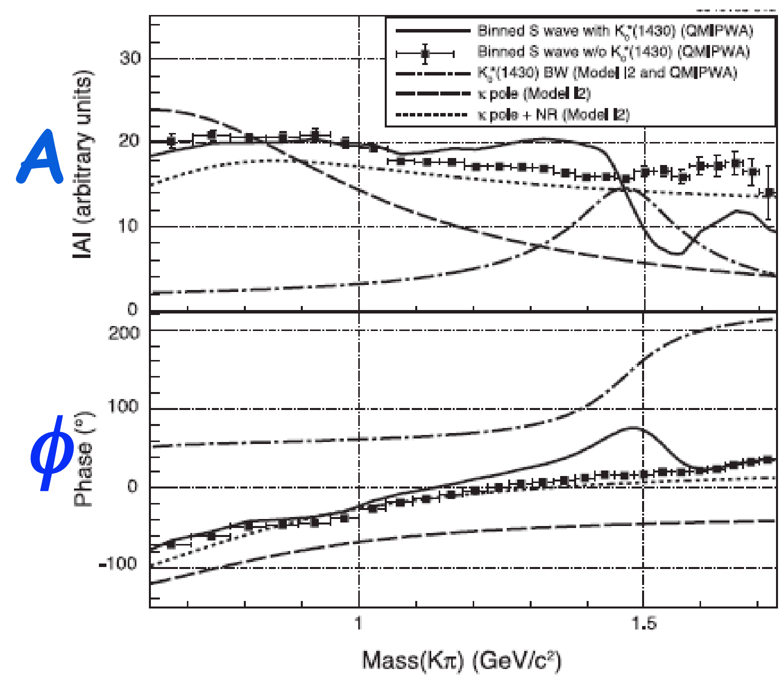
PRD 78, 052001
572 pb^{-1} (2008)

Results with binned S-wave Kπ

Fit to Dalitz Projections



Amplitude & Phase of S-wave



Black points above:

Ampl. & phase are quite smooth vs. mass; curves show other models

binned S-wave Kπ: idea from E791

Phase Information

Subtleties of D Tagging

- lepton flavor tags: a PURE tag of c vs. cbar
- hadronic "flavor" tags: pure for charged D^+, not for D^0

  contaminated with "DCSD": $D^0 \rightarrow K^+ \pi^-$ is 0.4% of $K^- \pi^+$

  contaminated by $D^0 D^{0bar}$ mixing
- CP-eigenstate tags: other D is ~ ($D^0 \pm D^{0bar}$)

Complicated… BUT: sensitivity to interesting parameters!

All phase measurements depend on interference

- CP-eigenstate decays to common (D^0, D^{0bar}) final states (e.g., $K^- K^+$)
- DCSD processes also provide common final states

Phases & interference are always interesting physics,
but these analyses are also useful inputs
to D mixing and flavor physics in the B sector…

D Physics & CKM γ

$B^- \to D^0 K^-$ & $D^{0bar} K^-$

- Interfere if D^0, D^{0bar} have common final states;
  Allows extraction of angle γ ("phase of V_{ub}")

$K\pi$ mode:

- Must know relative phase: from the $K\pi$ final-state interactions
- This phase is also relevant to proper use of
  D^0-D^{0bar} mixing results from this decay mode

Multibody modes:

- D^0-D^{0bar} interference is averaged over Dalitz plot
  Two body case: only phase Now: phase + reduction in magnitude
- Measure one global complex parameter, or do in "Dalitz bins"

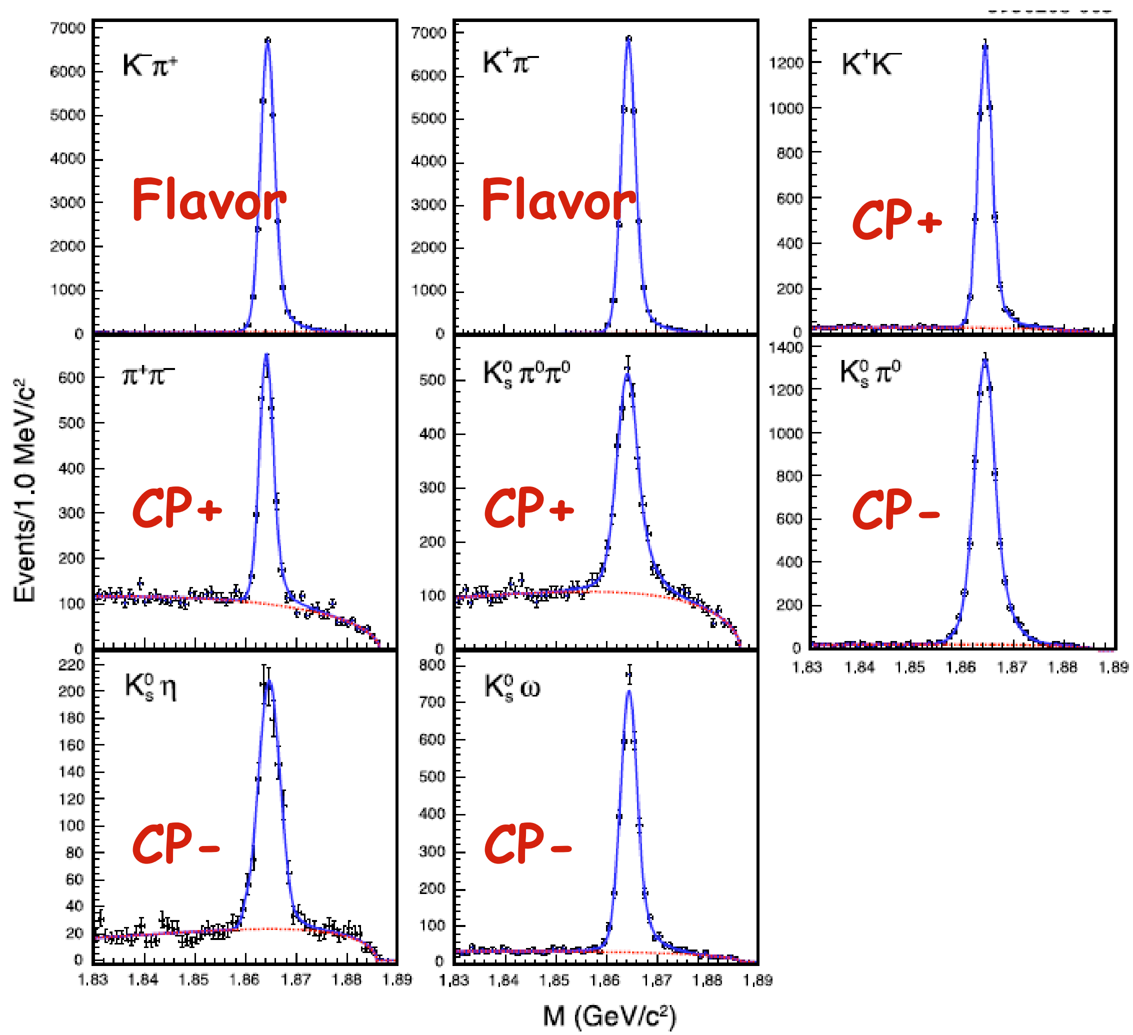
Quantum Correlation Analysis

PRD 78, 012001
PRL100, 221801
281 pb^{-1} (2008)

Familiar hadronic tags:
- Approximate flavor tags
- CP tags (both signs)

Hadronic tags with K_L:
- Can do, given kinematics
- Adds more CP tags

Semileptonic Tags
- Exact flavor tag



Quantum Correlation Analysis

PRD 78, 012001
PRL100, 221801
281 pb^{-1} (2008)

Correlated D pairs are produced at the $\psi(3770)$:
Produces a C = -1 initial state.

- *CP+CP+ & CP-CP- decays are forbidden*
- *CP+CP- are enhanced*

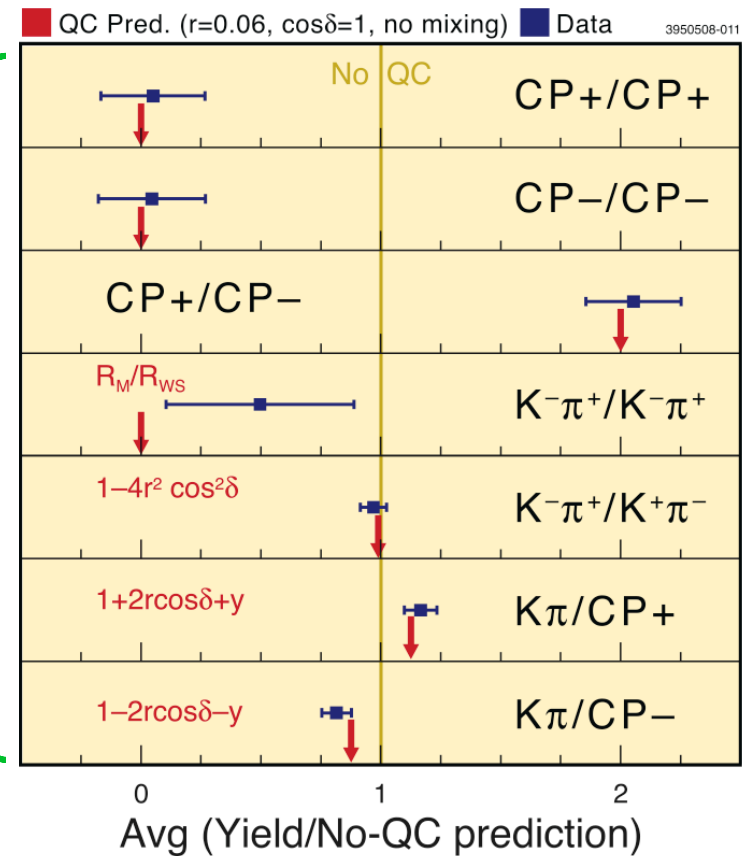
  etc.

Forbidden by CP conservation	CP+	CP+
	CP−	CP−
Maximal enhancement	CP+	CP−
Forbidden if no mixing	$K^-\pi^+$	$K^-\pi^+$
Interference of CF with DCS (gives cosδ)	$K^-\pi^+$	CP±
	CP±	$K^-\pi^+$
Single Tags Unaffected	CP± $K^-\pi^+$ SL	X

Useful reference

Nicely Confirmed!

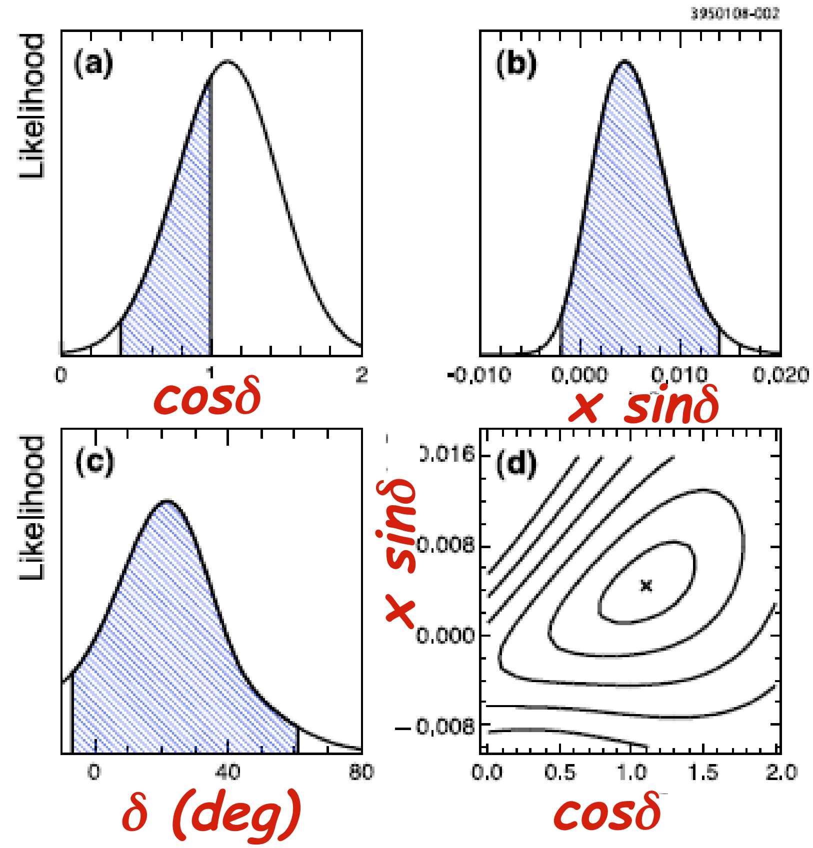
CLEO Results
vs. theory



Quantum Correlations & Kπ phase

PRD 78, 012001
PRL100, 221801
281 pb^{-1} (2008)

Allows a measurement of strong Kπ FSI phase,
[of great interest for D mixing results]



Simultaneous fit to:
hadronic & semilep modes
+ external mixing inputs:
(x, y, x'^{2}, y', r^2)

Shading: 90% CL
[physical region]

Results:

$\cos\delta = 1.10 \pm 0.35 \pm 0.07$

$\delta = (22\ ^{+11}_{-12}\ ^{+9}_{-11})^\circ$

Quantum Correlations Update

Large update in progress at CLEO-c

Improvements:

- More luminosity: 2.9 x
- Add semileptonic muons
- Use more modes K_L tags [+30%/+60% for CP+/CP- statistics]
- Use $K_{L/S}\pi$ in Dalitz bins
- Add $Ke\upsilon$ vs $K_L\pi^0$ [has two missing particles !!!]
- Switch from inclusive to exclusive semileptonic
- Use $K^- l^+ \upsilon$ vs. $K^- \pi^+$: unique parameter sensitivity

Expect to cut error on cosδ in half

Coherence Factors

Multi-body modes: $D^0 \to K^- \pi^+ \pi^0$ and $D^0 \to K^- \pi^+ \pi^+ \pi^-$

Measure actual "Dalitz-integrated" interference via R, δ

If D^0 and D^{0bar} decays were identical: R = 1, δ = 0

Variations across Dalitz "dilute" effect; roughly speaking:

The " 2 " in interference cross-term becomes " 2 R cosδ " *

Can write a formal expression… "x" is position in Dalitz plot

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

$$r_D^{K\pi\pi^0} = \frac{A_{K^+\pi^-\pi^0}}{A_{K^-\pi^+\pi^0}}.$$

Measure by using CP, hadronic, leptonic flavor tags

* Reality is just a bit more complicated, but this is the "spirit" of the math…

Coherence Factors

PRD 80, 031105
818 pb^{-1} (2009)

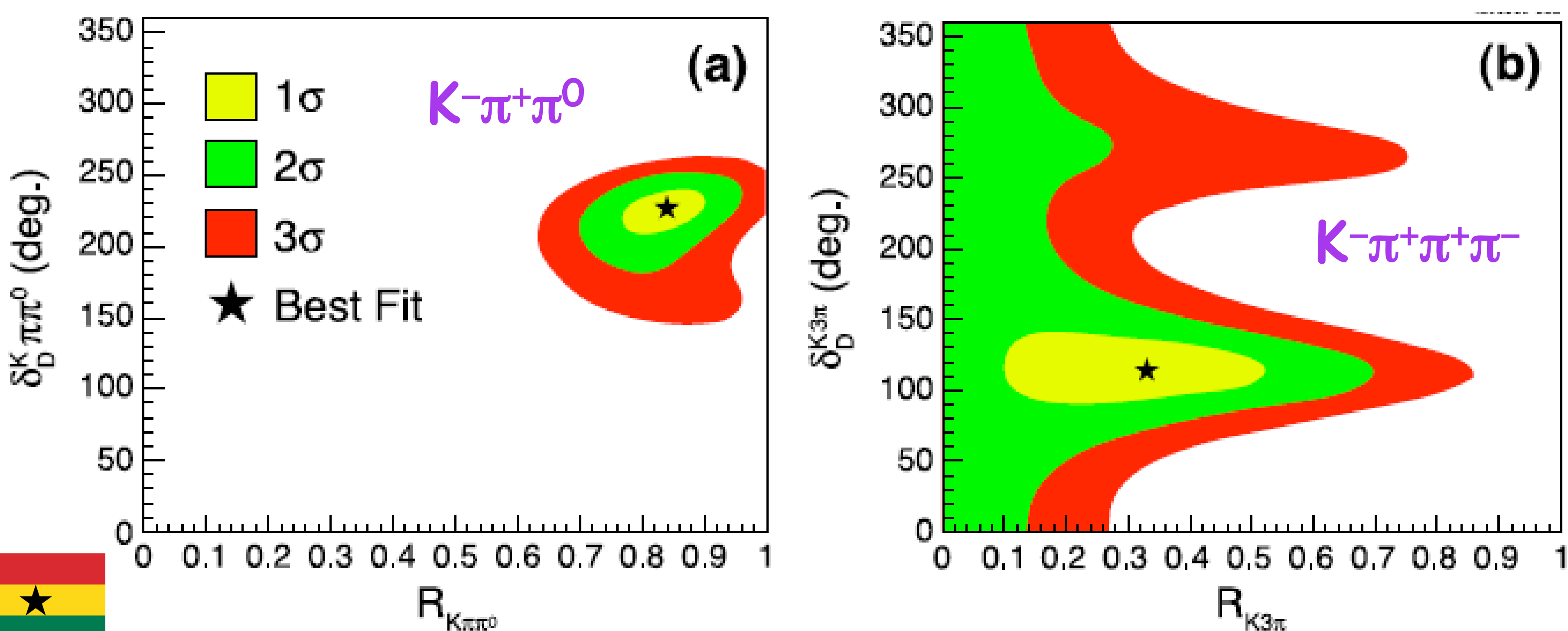
Measure for $D^0 \to K^-\pi^+\pi^0$ and $D^0 \to K^-\pi^+\pi^+\pi^-$ modes

$K^-\pi^+\pi^0$: ***Large R**, retain sensitivity even when integrating Dalitz plot*

$K^-\pi^+\pi^+\pi^-$: *More cancellation across Dalitz plot* [subtlety: likely good news, for other reasons…]

TABLE II. D final states reconstructed in this analysis.

Type	Final states
Flavored	$K^{\mp}\pi^{\pm}$, $K^{\mp}\pi^{\pm}\pi^{\pm}\pi^{\mp}$, $K^{\mp}\pi^{\pm}\pi^0$
CP-even	K^+K^-, $\pi^+\pi^-$, $K^0_S\pi^0\pi^0$, $K^0_L\pi^0$, $K^0_L\omega$
CP-odd	$K^0_S\pi^0$, $K^0_S\omega$, $K^0_S\phi$, $K^0_S\eta$, $K^0_S\eta'$



Coherence Factors

PRD 80, 032002
818 pb^{-1} (2009)

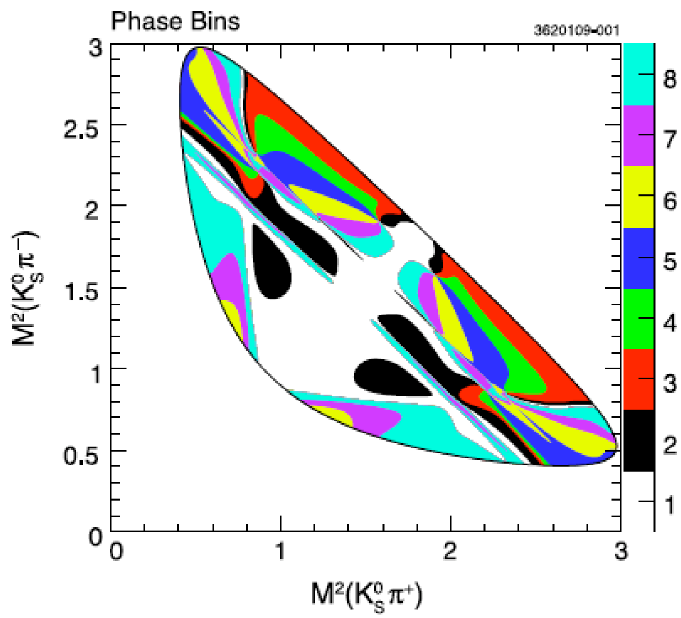
$D^0 \rightarrow K_S \pi^+ \pi^-$ mode

[Giri et al.; Bondar & Poluektov]

Same sort of physics as preceding analysis

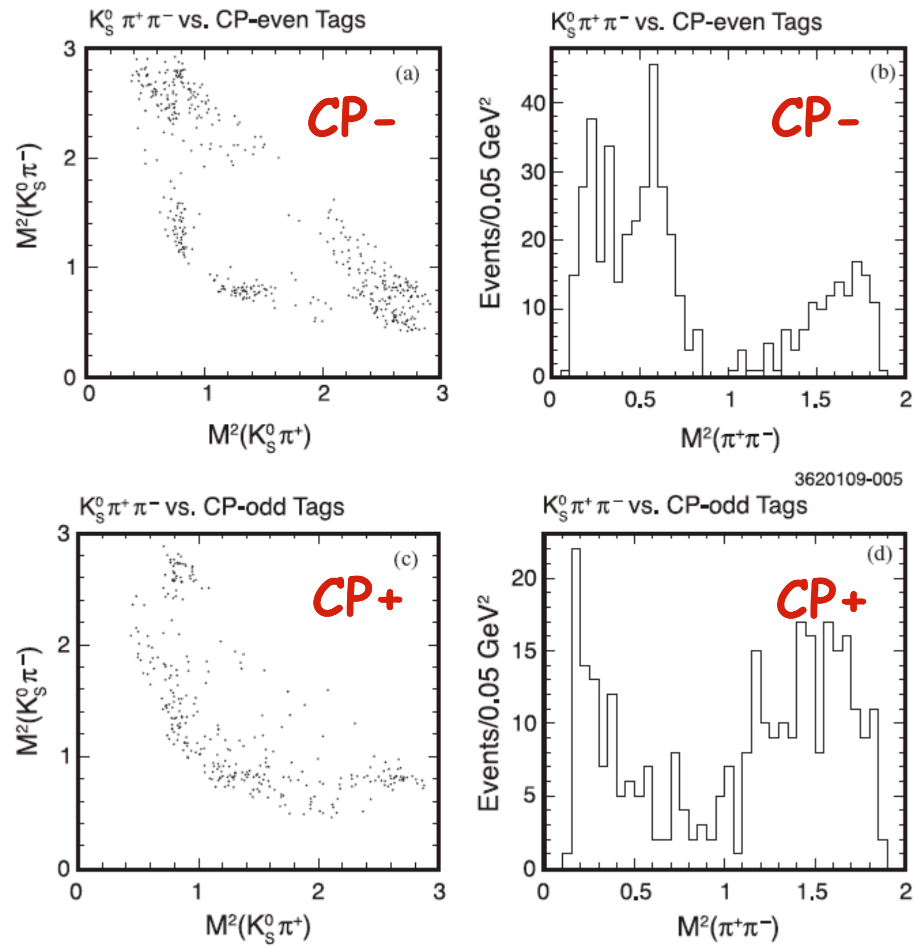
But, now done in bins of the Dalitz plot

(8 colored bins below)



Observe clear difference in Dalitz structure for CP-, CP+

(Tag & signal are opposite CP)



Coherence Factors

PRD 80, 032002
818 pb^{-1} (2009)

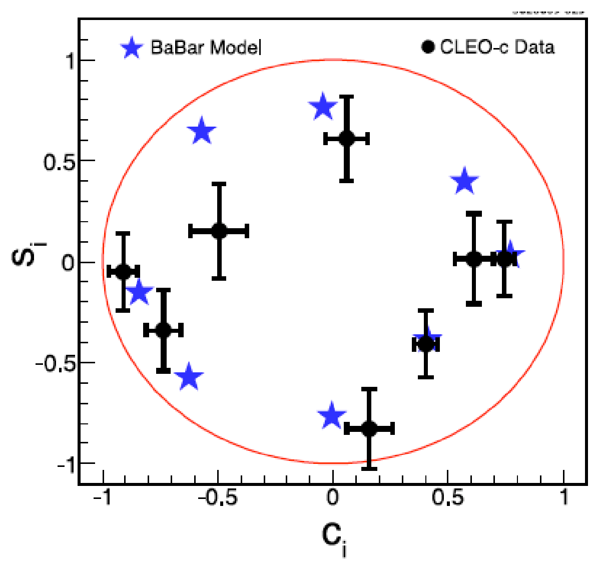
c_i and s_i: essentially bin-averaged $\langle R \cos \delta \rangle$ and $\langle R \sin \delta \rangle$

[a re-mapping of previous R, δ in each bin: $c_i^2 + s_i^2 = R_i^2$]

We try to optimize choice of binning based on model,

NOTE: any binning gives unbiased CKM γ; optimize for precision

Compare CLEO to BaBar model: Now we have *control* of uncertainties…



Flavor tags
$K^- \pi^+$
$K^- \pi^+ \pi^0$
$K^- \pi^+ \pi^+ \pi^-$
$K^- e^+ \nu$

CP-even tags
$K^+ K^-$
$\pi^+ \pi^-$
$K^0_S \pi^0 \pi^0$
$K^0_L \pi^0$

CP-odd tags
$K^0_S \pi^0$
$K^0_S \eta$
$K^0_S \omega$

$K^0_S \pi^+ \pi^-$ tags

High-statistics toy MC studies:

Reduces model uncertainty in CKM measurement using this D mode form about 7° to 1.7°

The Future

CLEO-c finished data taking in March, 2008:

- Many analyses here use full data samples.
- But others (e.g., Quantum Correlations) are being updated and improved in technique.
- Other analyses are also in progress.

BESIII turned on in July, 2008:

- New detector; second ring added to accelerator
- Peak luminosity: already ~4-5x CLEO-c at $\psi(3770)$
- So far, charmonium data [200 M J/ψ ; 100 M $\psi(2S)$]
- Open-charm data soon; ***will benefit from CLEO experience***

Super B Factories:

- High-statistics of continuum charm [D mixing !]
- Good for Dalitz analyses, for example [but NO CP-tagging…]
- Maybe run at charm threshold ?

New *dedicated* tau-charm machine ?

BACKUP SLIDES

Other recent hadronic analyses

- $D_s \to p\,\bar{n}$
- $D \to K_S\pi,\ K_L\pi$
- $D \to KK$
- $D \to \eta X,\ \eta' X$ [excl. modes]
- $D_{(s)} \to PP$ [P = pseudoscalars]
- Cross-sections

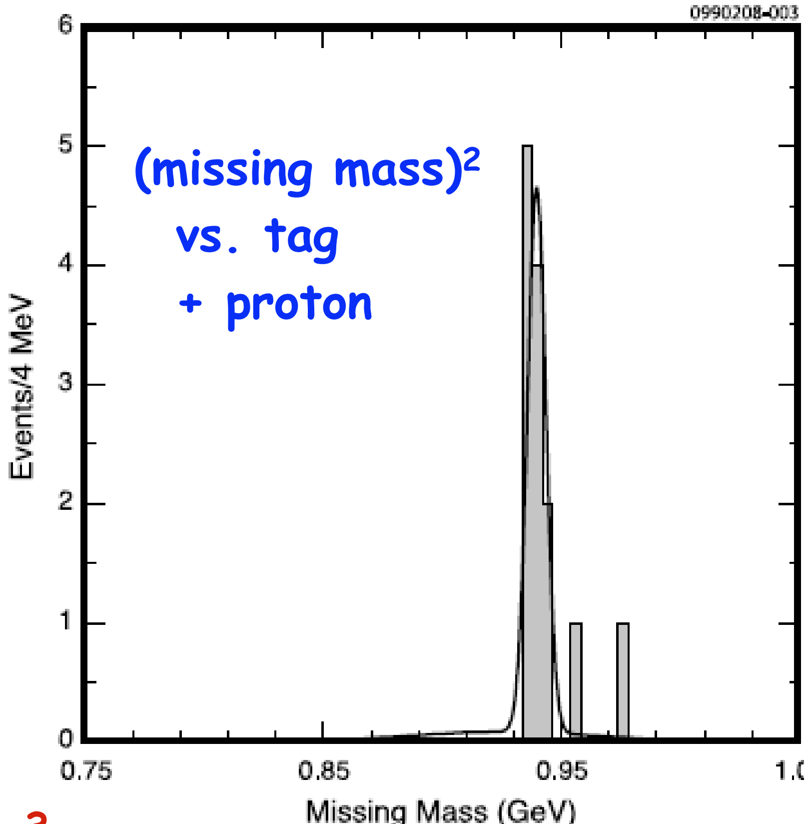
$D_s \to p\,\bar{n}$

PRL100, 181802
325 pb^{-1} (2008)

Missing neutron:
use tagging,
include γ from D_s^*

Only phase-space allowed baryonic decay among any of $D^0/D^+/D_s$

$B(D_s \to p\,\bar{n}) =$
$(1.30 \pm 0.36 +0.12 -0.16) \times 10^{-3}$



Interference in $K_L\,\pi$, $K_S\,\pi$

D Decay diagrams source both K^0 and K^0bar

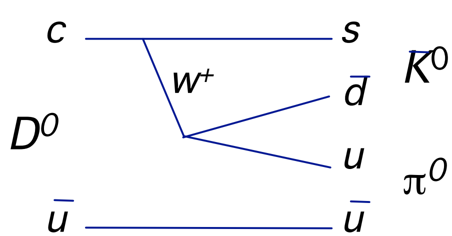
$\Rightarrow$ These interfere in physical K_L, K_S final states: K_S, K_L asymmetry

$$R(D) = [\,B(D \Rightarrow K_S\pi) - B(D \Rightarrow K_L\pi)\,] \,/\, [\,B(D \Rightarrow K_S\pi) + B(D \Rightarrow K_L\pi)\,]$$

Bigi & Yamamoto [PLB 349, 363 (1995)]

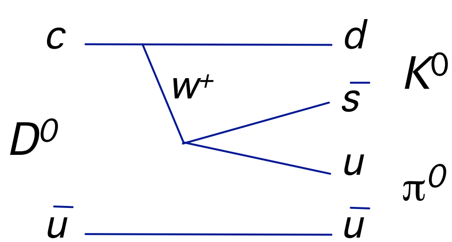
D^0 : expect BF asymmetry of: $R(D^0) = 2\tan^2\theta_C \sim 10\%$

D^+ : more diagrams to consider… $R(D+)$ see next page…



Cabibbo-favored

$$\bar{K}^0 = \frac{1}{\sqrt{2}}\left(K_S^0 - K_L^0\right)$$

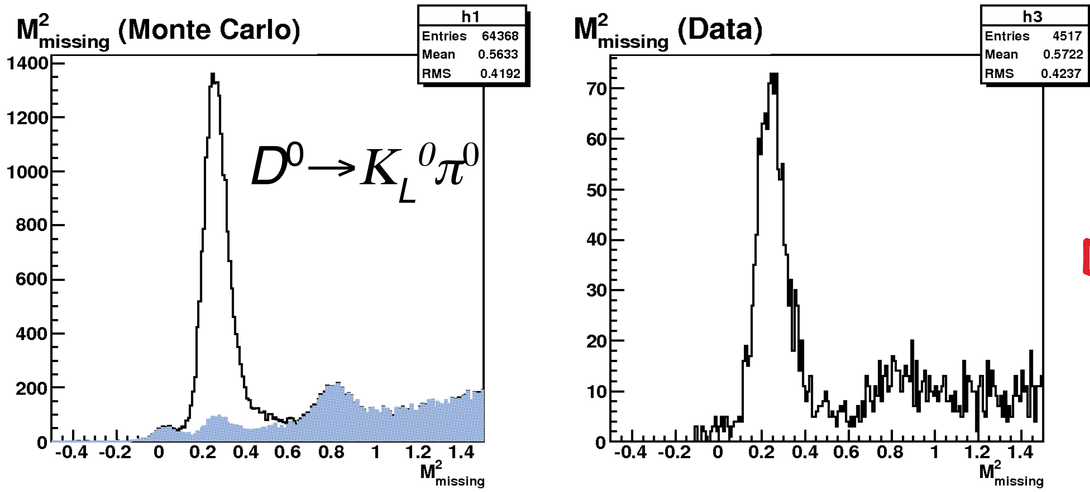


Cabibbo-suppressed

$$K^0 = \frac{1}{\sqrt{2}}\left(K_S^0 + K_L^0\right)$$

Interference in $K_L\pi$, $K_S\pi$

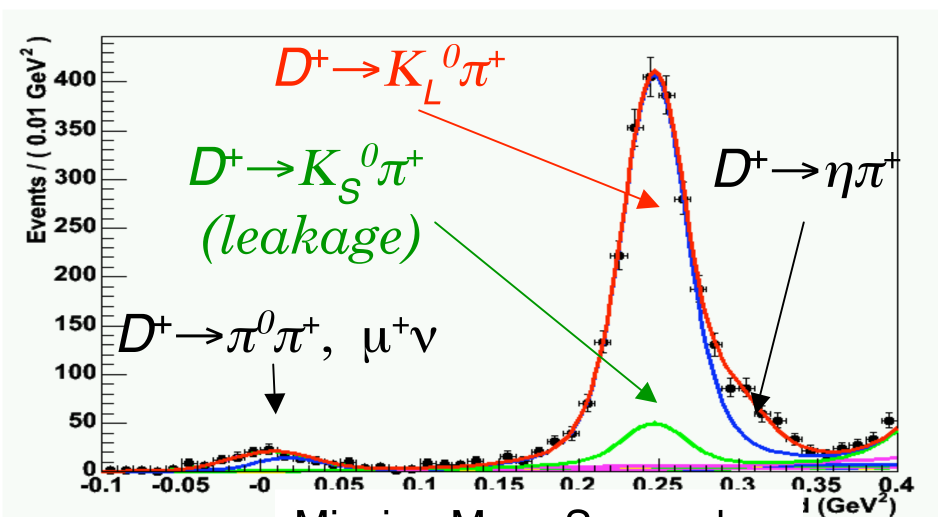
PRL100, 091801
281 pb^{-1} (2008)



Missing Mass Squared

D^0: R_D = 0.108 ± 0.025 ± 0.024

[consistent with 2 $\tan^2\theta_C$]



Missing Mass Squared

D$^+$: R_D = 0.022 ± 0.016 ± 0.018

Dao-Neng Gao predicts:

R(D$^+$) = 0.035 to 0.044

[PLB645, 59 (2007)]

Bhattacharya & Rosner:

R(D$^+$) = -0.01 ± 0.03

[PRD77, 114020 (2008)]

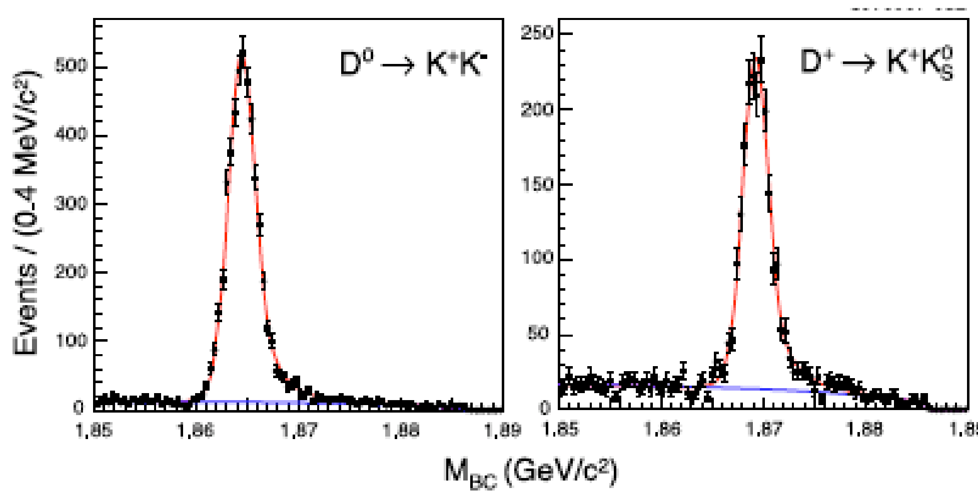
$D \to KK$

PRD 77, 091106
281 pb^{-1} (2008)

Interesting to study SU(3) breaking effects:

- Long known $K^+ K^-$ *is enhanced relative to* $\pi^+ \pi^-$
- $K_S K_S$: two diagrams cancel in SU(3) limit; but can have rescattering…

Mode	Br. Frac. (10^{-4})		
$K^+ K^-$	40.8	± 0.8	± 0.9
$K^+ K_S$	31.4	± 0.9	± 0.8
$K_S K_S$	1.46	± 0.32	± 0.09



Also measure SU(3)-breaking ratio:

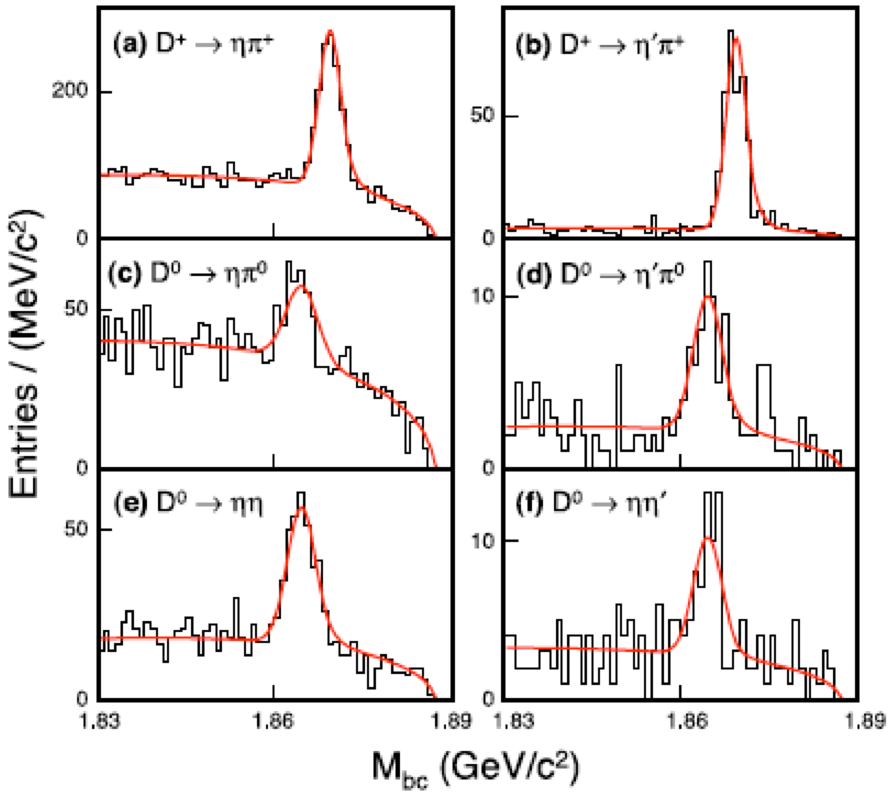
$B(D^0 \to K^+ K^-) / B(D^0 \to \pi^+ \pi^-)$

$= 2.89 \pm 0.05 \pm 0.06$

Exclusive $D \to \eta, \eta'$ modes

PRD 77, 092003
281 pb^{-1} (2008)

First observations of:	$\eta'\pi^0$	$\eta\eta$	$\eta\eta'$	$\eta\pi^+\pi^-$
Evidence for:	$\eta\pi^+\pi^0$	$\eta'\pi^+\pi^0$	$\eta'\pi^+\pi^-$	
Improved BF for:	$\eta\pi^0$	$\eta\pi^+$	$\eta'\pi^+$	



Mode	Yield	Branching Fraction (10^{-4})	PDG [16] (10^{-4})
$D^+ \to \eta\pi^+$	1033 ± 42	$34.3 \pm 1.4 \pm 1.7$	35.0 ± 3.2
$D^+ \to \eta'\pi^+$	352 ± 20	$44.2 \pm 2.5 \pm 2.9$	53 ± 11
$D^0 \to \eta\pi^0$	156 ± 24	$6.4 \pm 1.0 \pm 0.4$	5.6 ± 1.4
$D^0 \to \eta'\pi^0$	50 ± 9	$8.1 \pm 1.5 \pm 0.6$	—
$D^0 \to \eta\eta$	255 ± 22	$16.7 \pm 1.4 \pm 1.3$	—
$(\gamma\gamma)(\gamma\gamma)$	141 ± 17	15.3 ± 1.8 (stat.)	—
$(\gamma\gamma)(\pi^+\pi^-\pi^0)$	115 ± 13	19.0 ± 2.2 (stat.)	—
$D^0 \to \eta\eta'$	46 ± 9	$12.6 \pm 2.5 \pm 1.1$	—
$(\gamma\gamma)(\gamma\gamma)$	33 ± 8	14.8 ± 3.3 (stat.)	—
$(\gamma\gamma)(\pi^+\pi^-\pi^0)$	14 ± 5	10.5 ± 3.5 (stat.)	—
$D^0 \to \eta\pi^+\pi^-$	257 ± 32	$10.9 \pm 1.3 \pm 0.9$	<19
$D^+ \to \eta\pi^+\pi^0$	149 ± 34	$13.8 \pm 3.1 \pm 1.6$	—
$D^0 \to \eta'\pi^+\pi^-$	21 ± 8	$4.5 \pm 1.6 \pm 0.5$	—
$D^+ \to \eta'\pi^+\pi^0$	33 ± 9	$15.7 \pm 4.3 \pm 2.5$	—

Comprehensive $D_{(s)} \rightarrow P\ P$

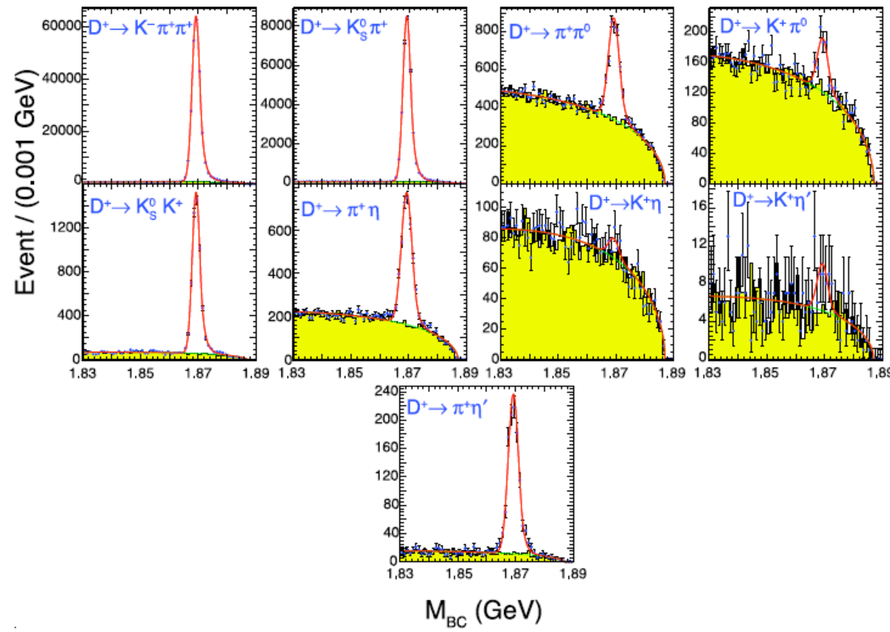
Sub. To PRD
818 + 586 pb^{-1}

Measure all modes to two pseudoscalars
[$K^{\pm}/K_S/\pi^{\pm}/\pi^0/\eta/\eta'$]

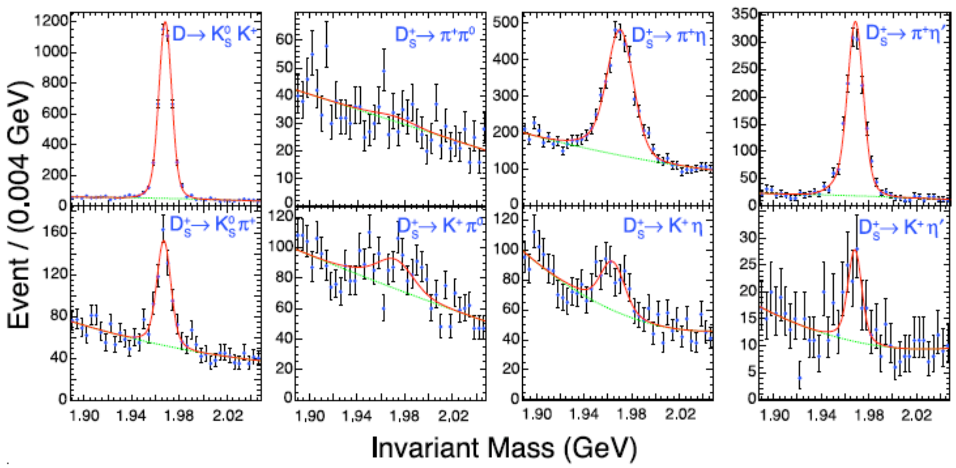
9+1 D^0 / 8+1 D^+ / 7+1 D_s^+ modes

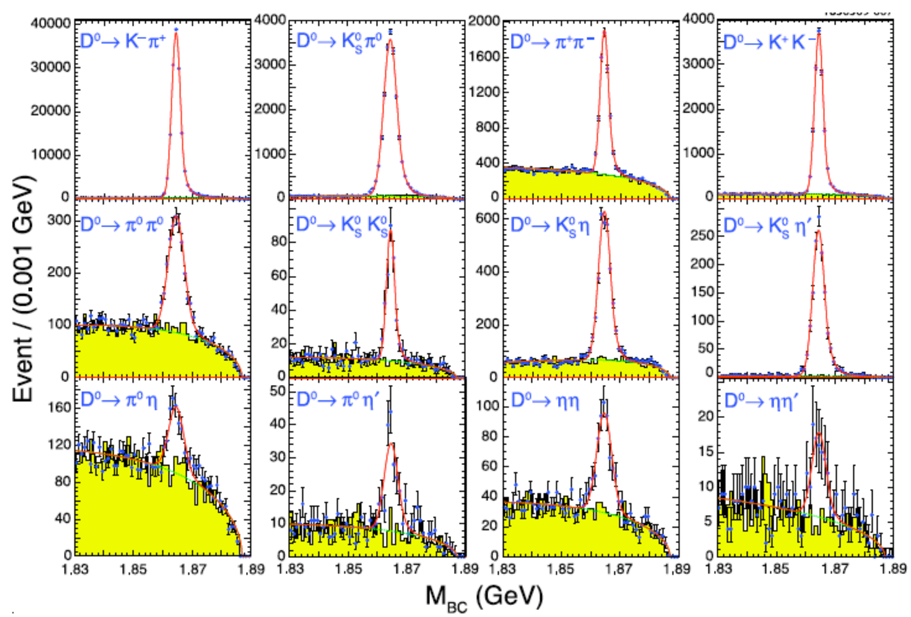
"+1" : Normalize to:

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



Also report CP asymmetries





Charm Threshold

PRD 80, 072001
E_{cm} Scan (2009)

Reconstruct one $D_{(s)}$ meson:

momentum can separate

DD, DD, DDπ, etc.*

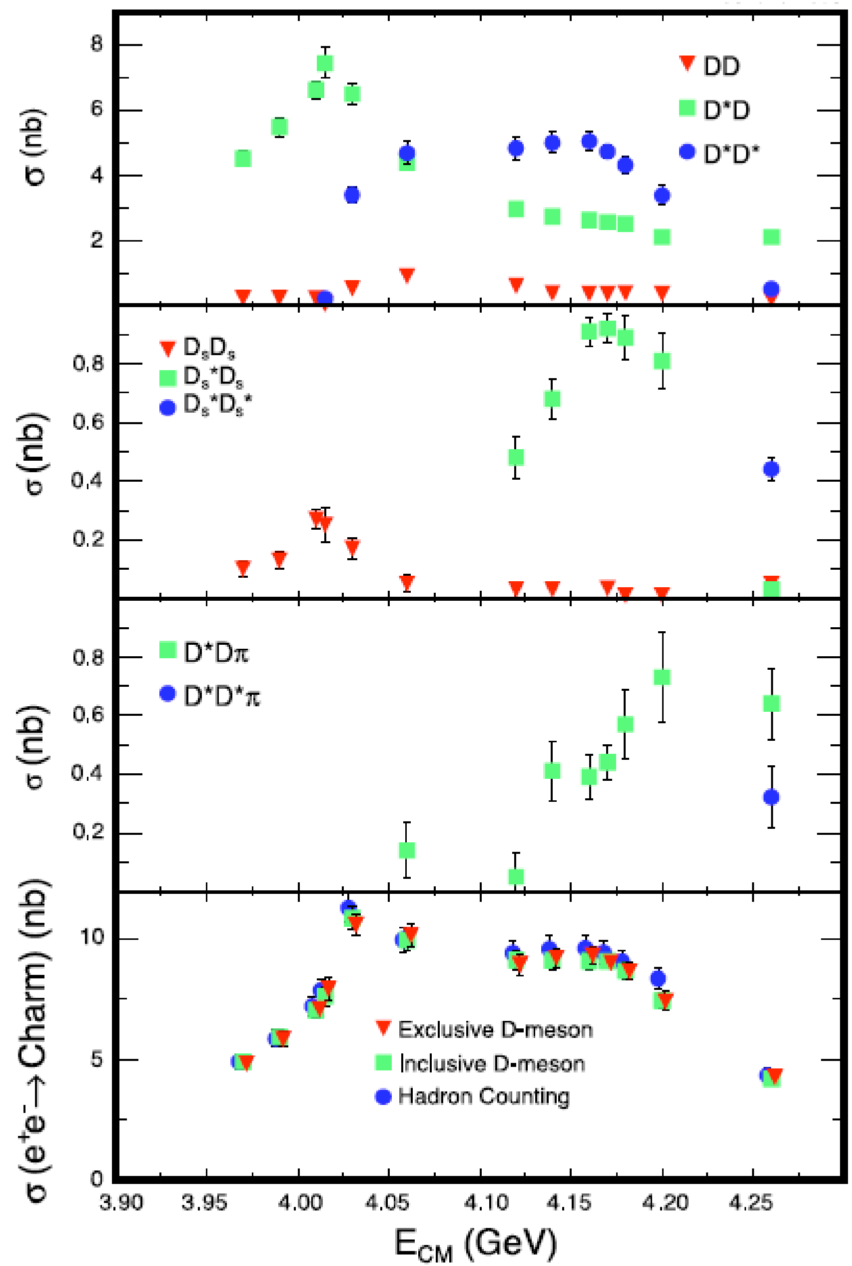
***Much** more detailed than*

previous results !

Used to choose CLEO CofM

energy for D_s physics

See a much richer structure in separated channels, compared to the total charm rate



What about $D_s \to \phi\, \pi^+$?

PRL 100, 161804 (2008) 298 pb^{-1}

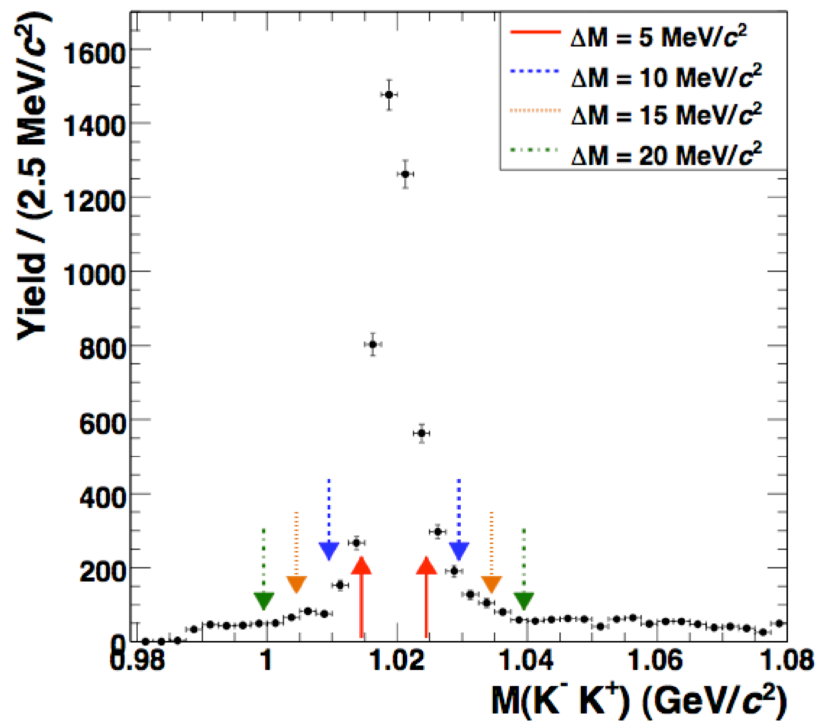
New key normalizing mode? :

B ($D_s \to K^+ K^- \pi^+$)

= (5.50 ± 0.23 ± 0.16) %

$\phi\, \pi^+$ "Branching fraction" ill-defined

$D_s \to K^+ K^- \pi^+$



Can also quote B $\mathcal{B}$($D_s \to K^+ K^- \pi^+$)

with various $M(K^+ K^-)$ windows:

$\mathcal{B}_{\Delta M}$ for mass within ± ΔM of ϕ

Value	This result $\mathcal{B}$ (%)
$\mathcal{B}_5$	$1.69 \pm 0.08 \pm 0.06$
$\mathcal{B}_{10}$	$1.99 \pm 0.10 \pm 0.05$
$\mathcal{B}_{15}$	$2.14 \pm 0.10 \pm 0.05$
$\mathcal{B}_{20}$	$2.24 \pm 0.11 \pm 0.06$