Hadronic D Decays at CLEO-c

David Cinabro, Wayne State

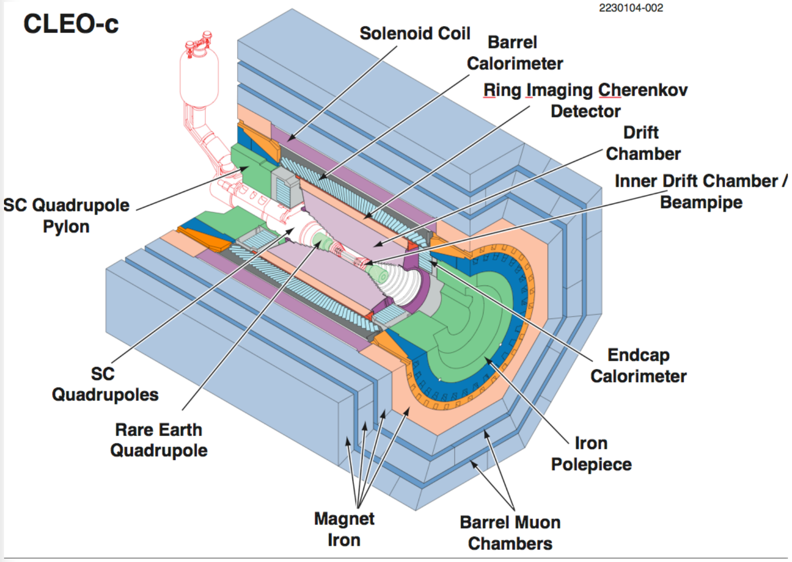
for

the CLEO Collaboration

Outline

- New since the winter conferences
- Support of CKM angle γ measures (Strong phase and coherence factor in $D \rightarrow K3\pi$ and $D \rightarrow K\pi\pi^0$, preliminary binned analysis for strong phase in $D \rightarrow K^0\pi\pi$)
- D_S inclusive hadron yields, exclusive ω modes, $KK\pi$ Dalitz
- D to two pseudoscalars

CLEO-c: The Experiment



Detector is a classic:

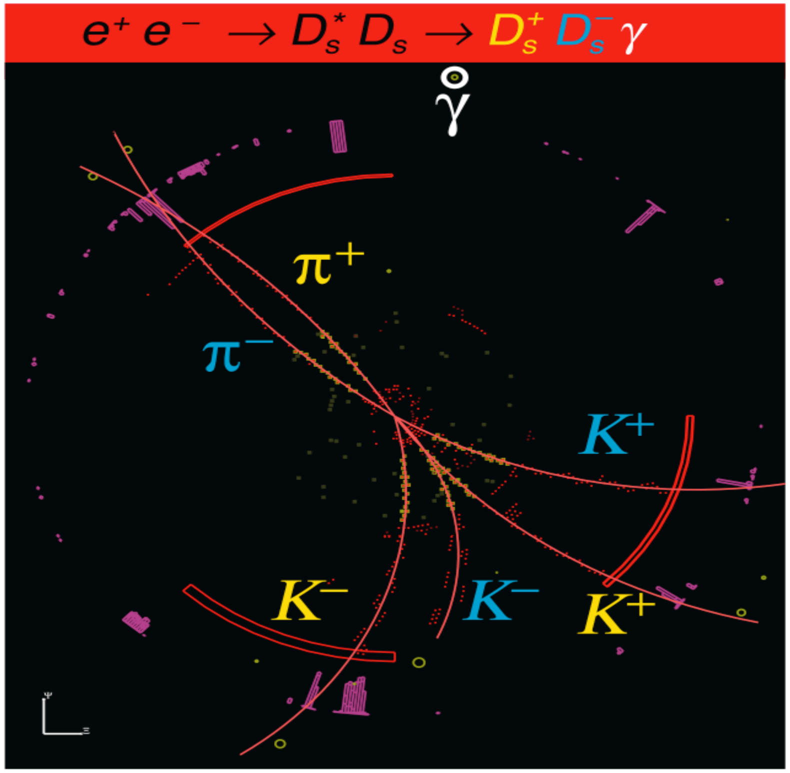
Tracking in two drift chambers

Photons in CsI

818/pb $e^+e^- \rightarrow \Psi(3770) \rightarrow DD$, coherent production

586/pb $e^+e^- \rightarrow D_s\, D_s^*$ at 4770 MeV

Threshold and near threshold production yields clean, efficient reconstruction

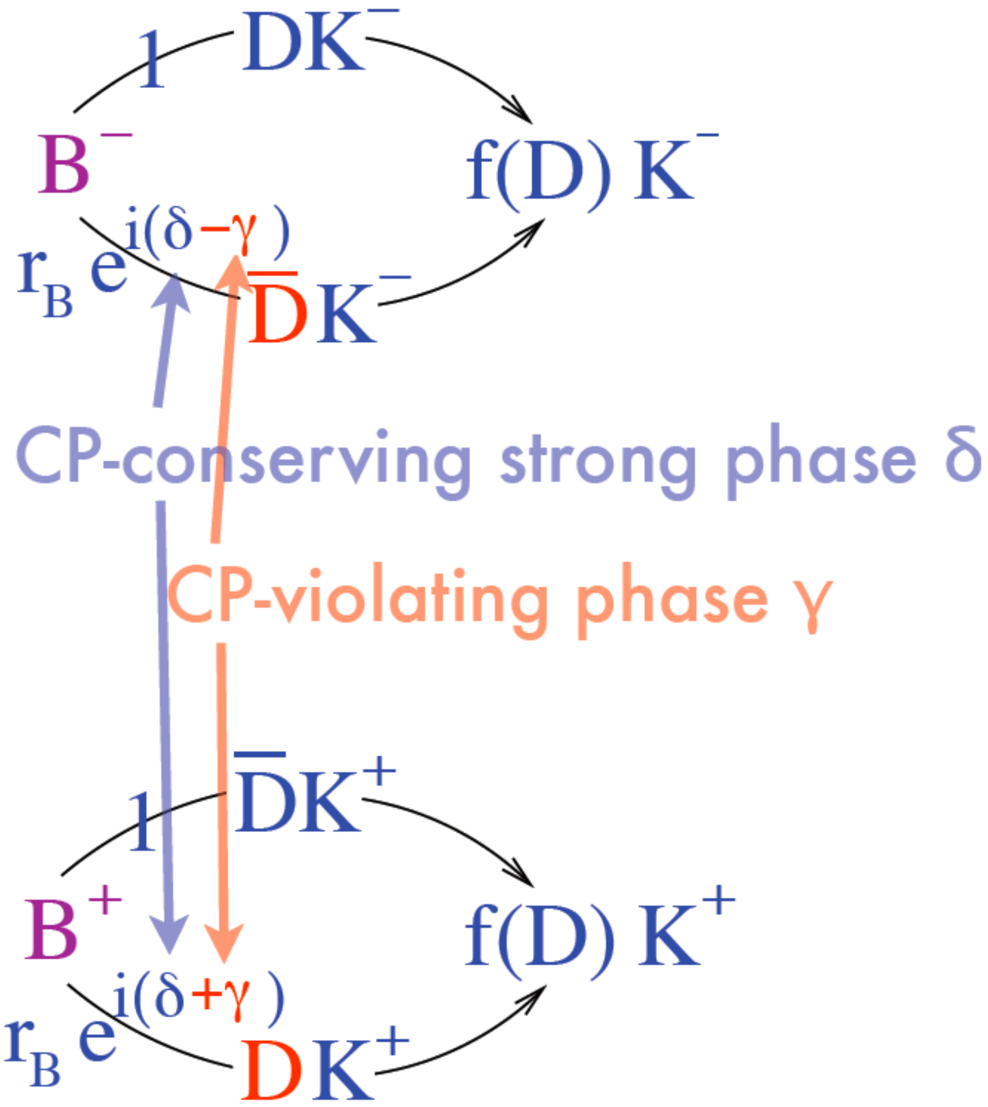


Support for CKM γ

Interference in B→DK sensitive to γ, but need to know the strong phase in the D decay.

Leads to ±7-9° on γ which will dominate at LHCb and SuperB.

At CLEO-c take advantage of the Quantum Coherence of the initial DD.



Coherence Factor in $D \rightarrow K3\pi$

Idea from Atwood and Soni (PRD 68 033003 (2003)

Treat the decay like a two-body decay with a single effective strong phase, $\delta_D^{K3\pi}$. Must introduce a new parameter, $R_{K3\pi}$, the coherence factor, which is near 1 if the decay is dominated by a single mode and near 0 if many modes contribute.

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

At CLEO-c take advantage of coherent production.

Double Tag Rate	Sensitive To
$K3\pi$ vs. $K3\pi$	$(R_{K3\pi})^2$
$K3\pi$ vs. CP	$R_{K3\pi}\cos(\delta_D^{K3\pi})$
$K3\pi$ vs. $K\pi$	$R_{K3\pi}\cos(\delta_D^{K\pi}-\delta_D^{K3\pi})$

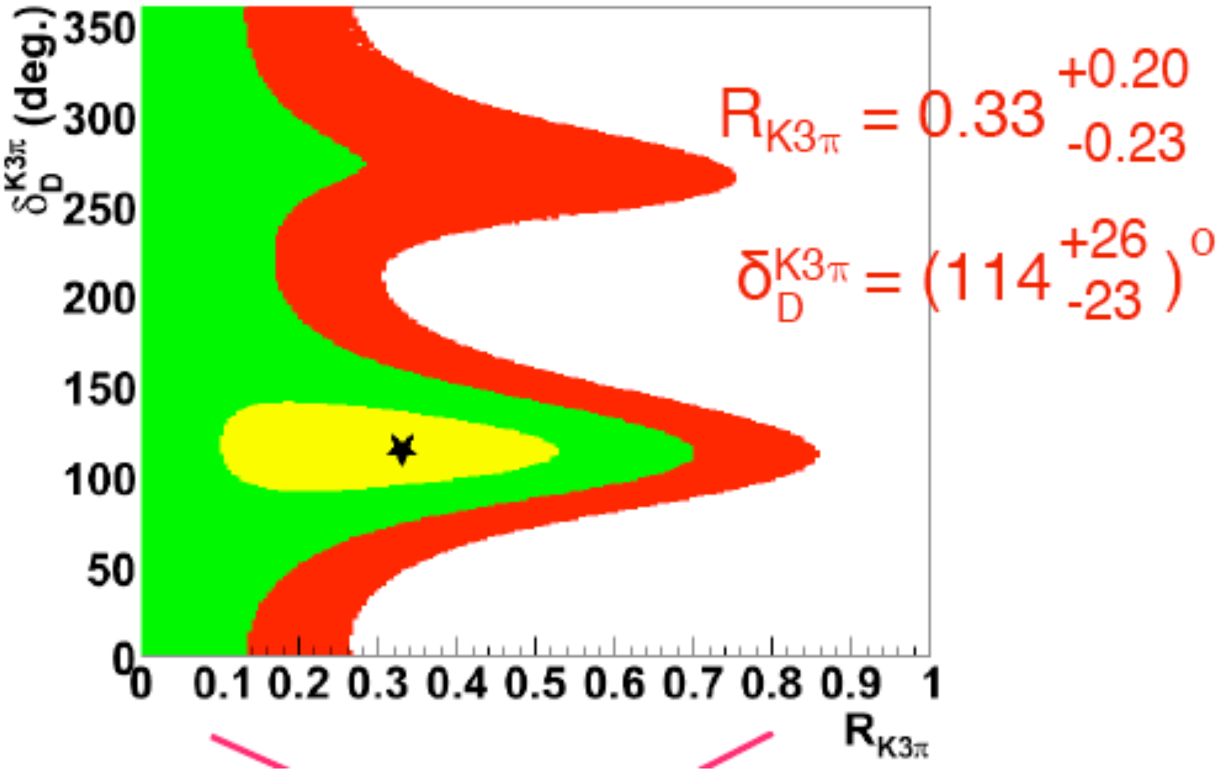
hep-ex/0903.4853

Coherence Factor in D→K3π

This mode is not very coherent.

Not much sensitivity to CKM γ. Maybe better in a coherent region of the Dalitz plot?

LHCb (1 year) σ(γ) goes from 9.5° to 7.9° with this input.



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

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

Coherence Factor in D→$K\pi\pi^0$

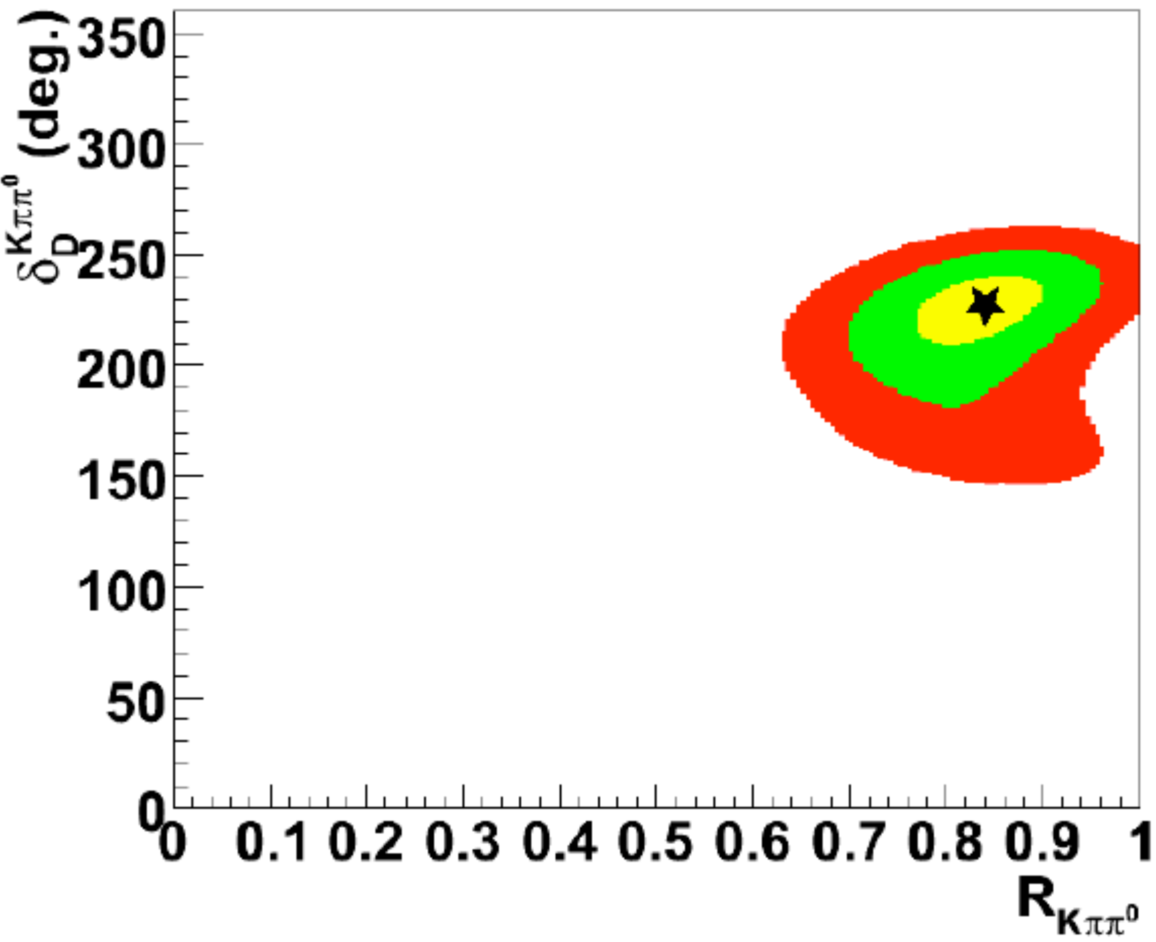
Combined analysis with previous mode.

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

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

Very coherent!

Need to evaluate impact on $\sigma(\delta)$ at LHCb and SuperB



Strong Phase in $D \rightarrow K^0 KK$

Similar analysis to $D \rightarrow K^0 \pi\pi$ hep-ex/0903.1681

B-Factory analyses get $\sigma(\gamma)$ of 5-9° using these two modes

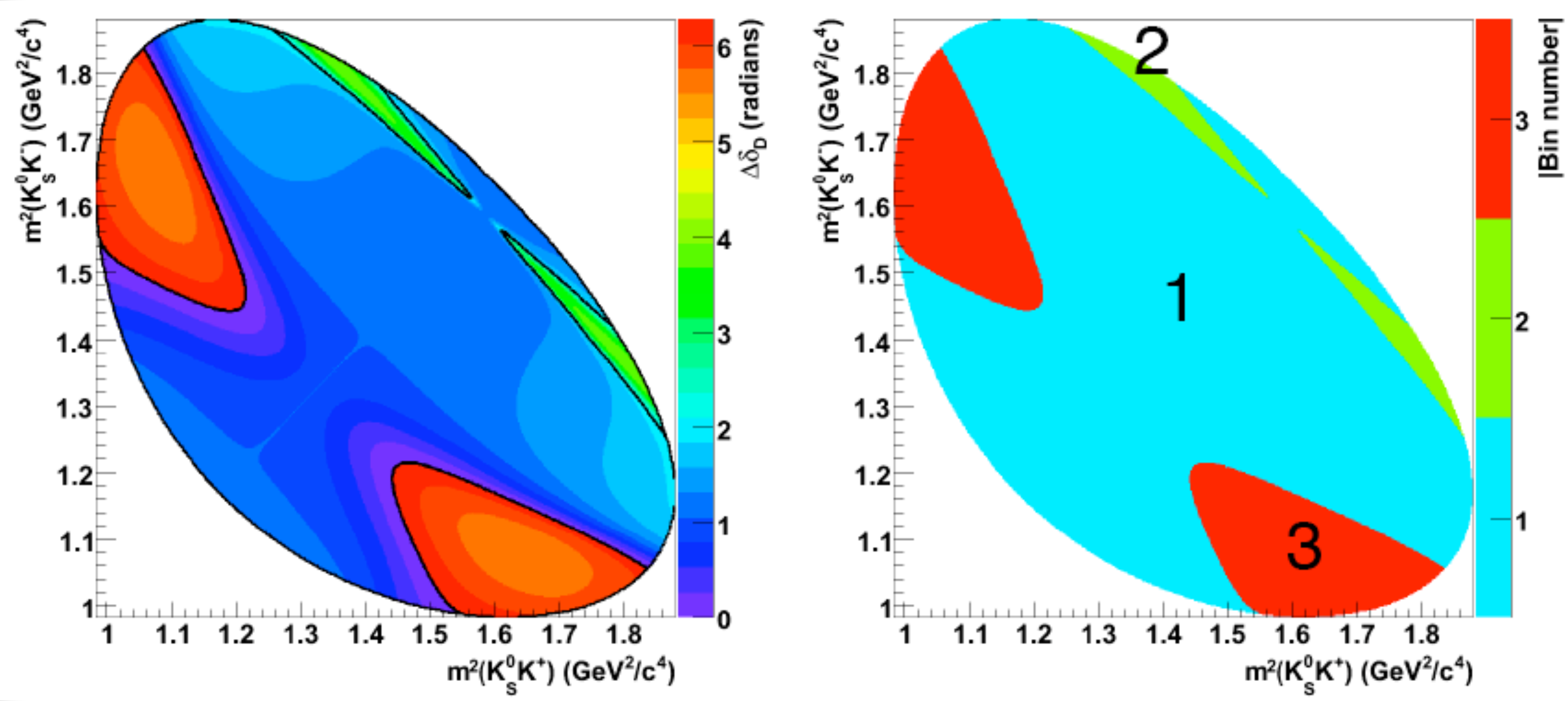
Idea from Bondar and Poluektov (Eur.Phys.J.C47:347(2006)

Measure cos and sin of strong phase difference in bins across the Dalitz plot. Most sensitive if bins are equally spaced in $\Delta\delta_D$

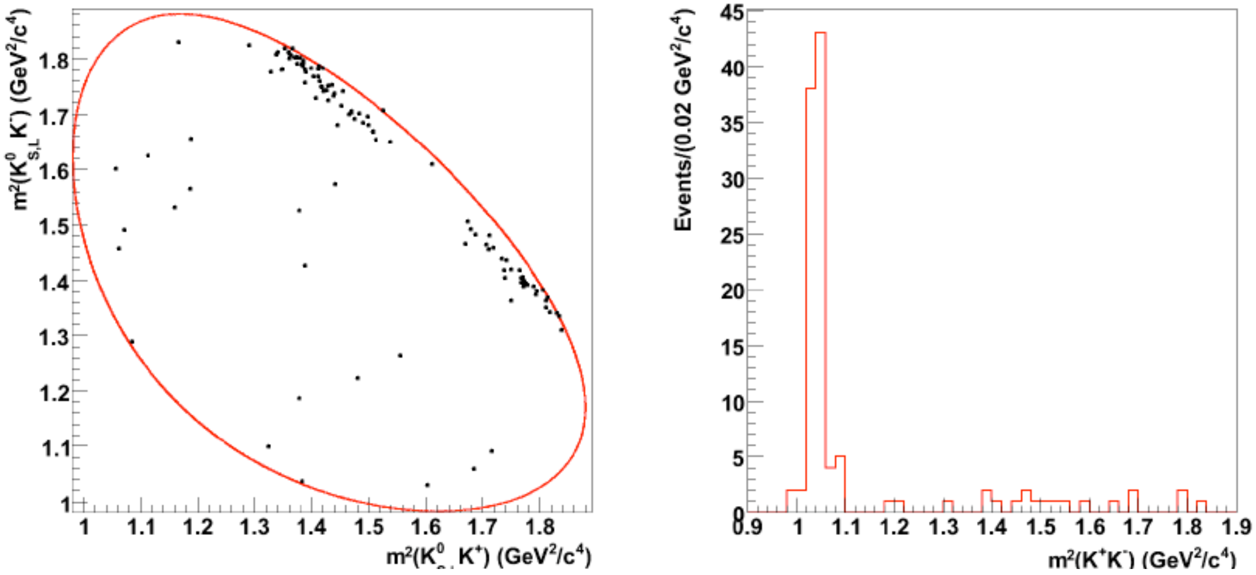
Difficult to quantify error from uncorrelated analysis replaced by CLEO-c statistical error. Preliminary!

Strong Phase in D→K^{0}KK

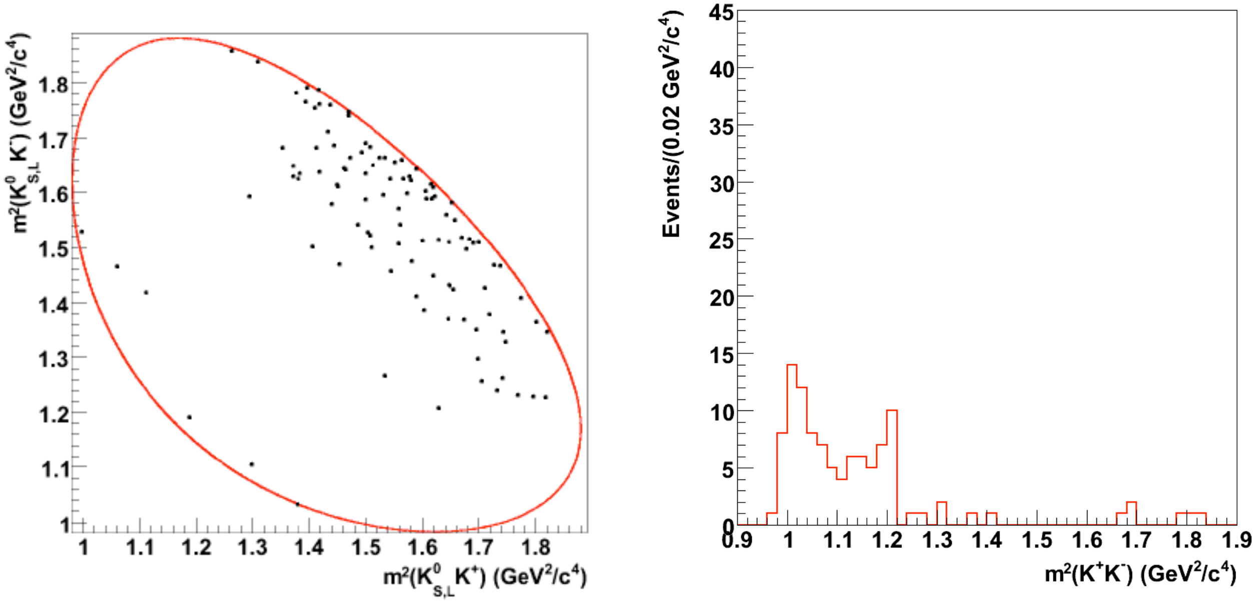
Use Babar Dalitz analysis to define bins (PRD 78, 032023 (2008))



- **$K_S KK$ vs CP+ & $K_L KK$ vs CP-**



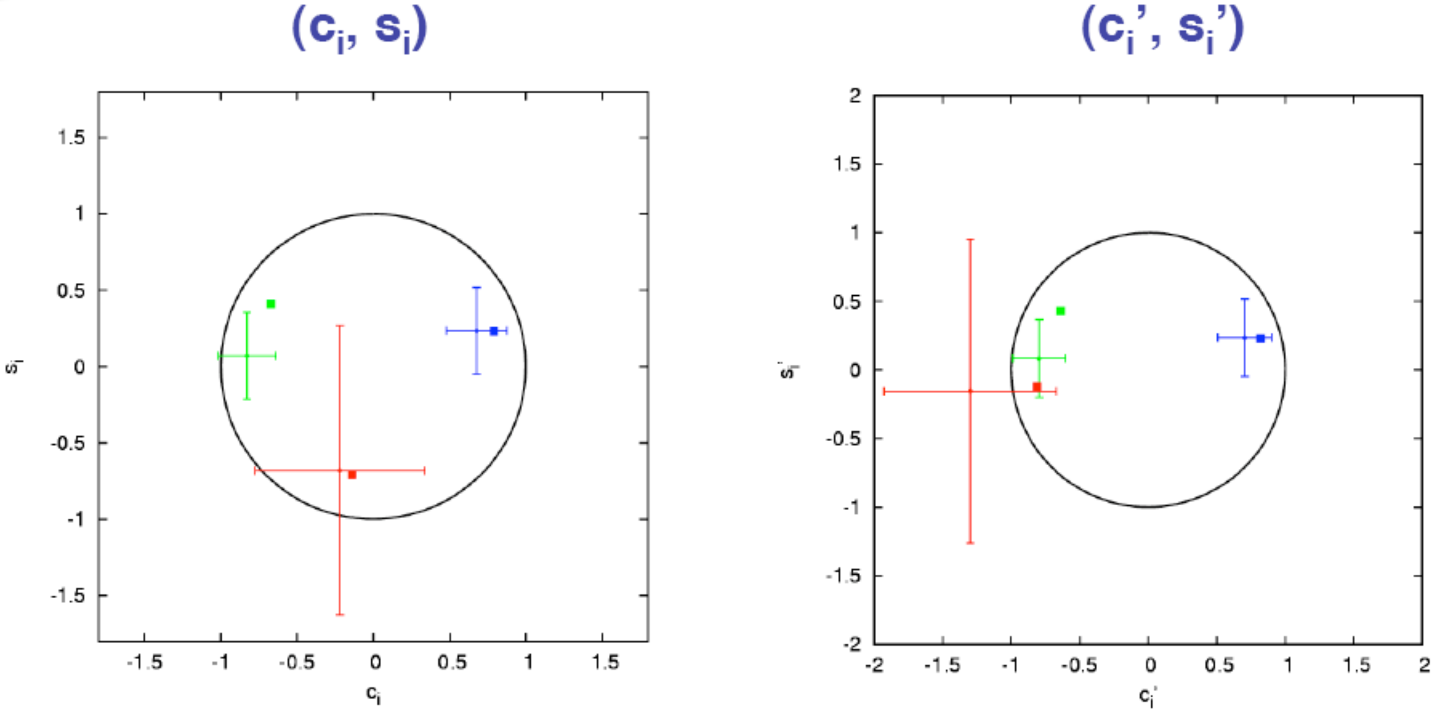
- **$K_S KK$ vs CP- & $K_L KK$ vs CP+**



Also K^0KK vs. a $K\pi$ flavor tag is used for normalization

Strong Phase in D→K^0KK

Preliminary CLEO-c measure of c_i,s_i,c_i’,s_i’ (‘ for K_L),



(c_i, s_i)

(c_i’, s_i’)

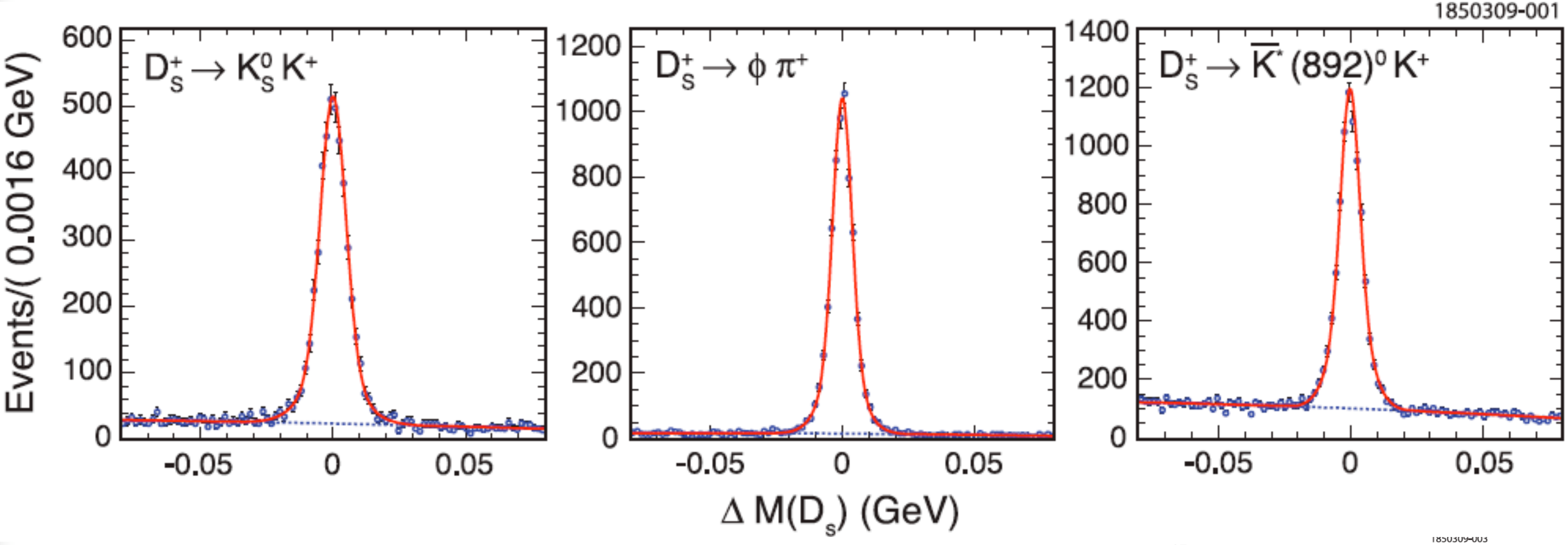
Bin 1 Bin 2 Bin 3

■Babar Model +CLEO-c Preliminary (errors are stat only)

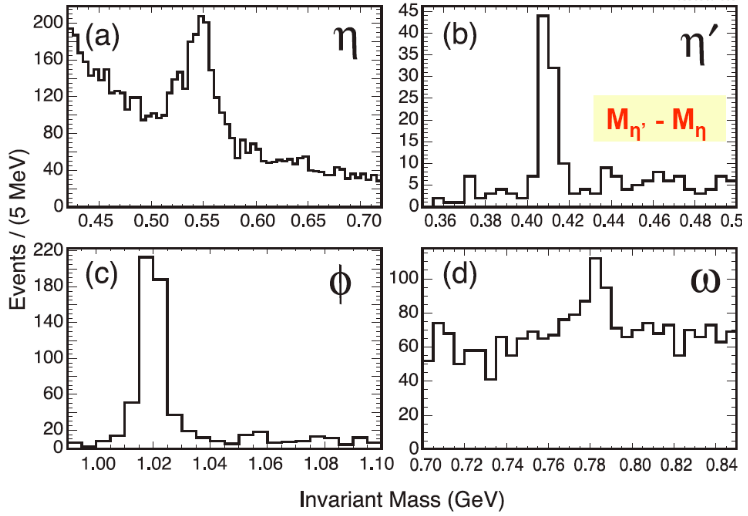
Gives σ(γ) of 5.5º

D_s Inclusive Hadron Yields

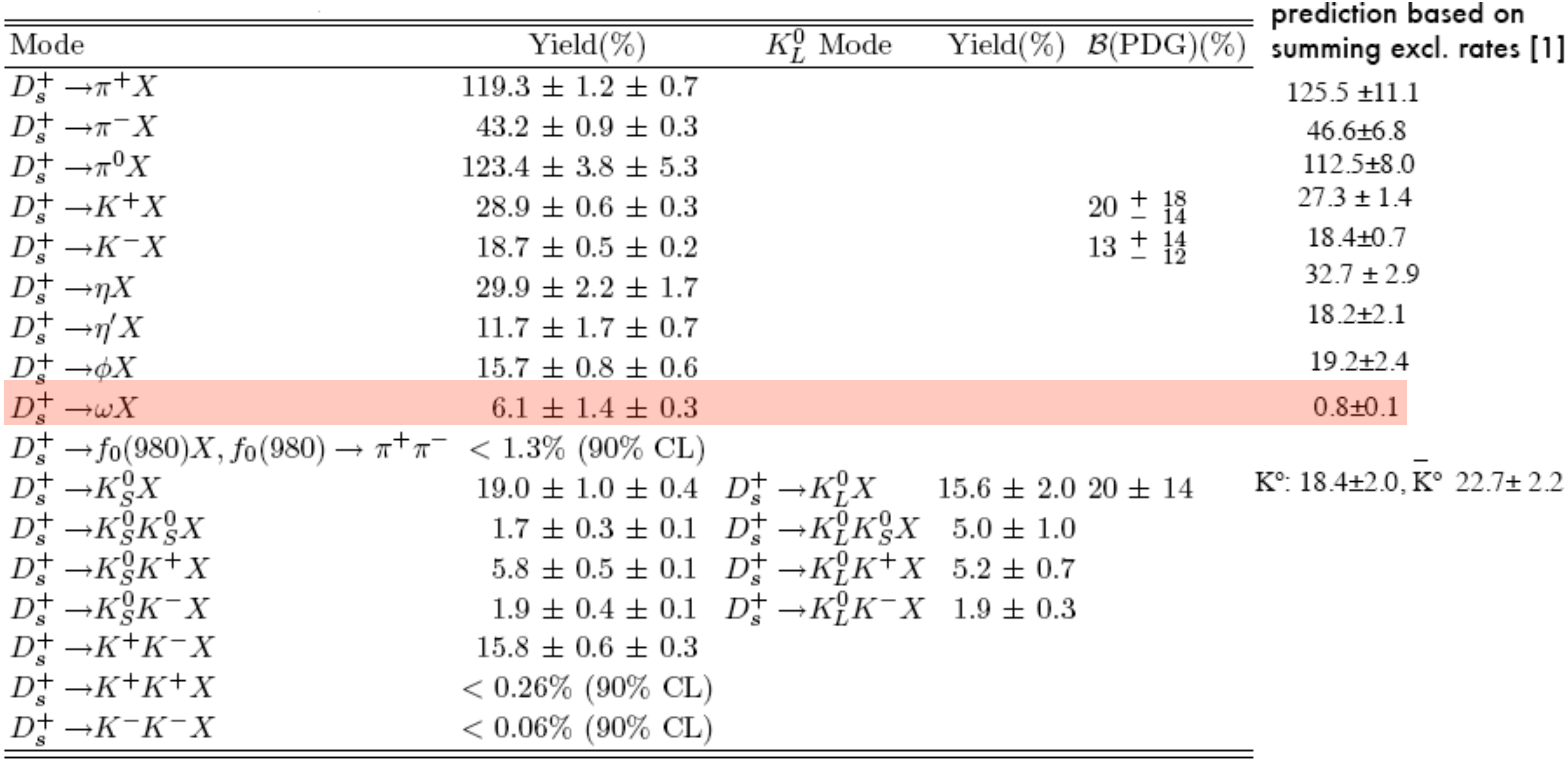
hep-ex/00094.2417. Look opposite tags (18586±163):



Then observe all else in event for π, K, etc. or reconstruct others:



D_s Inclusive Hadron Yields



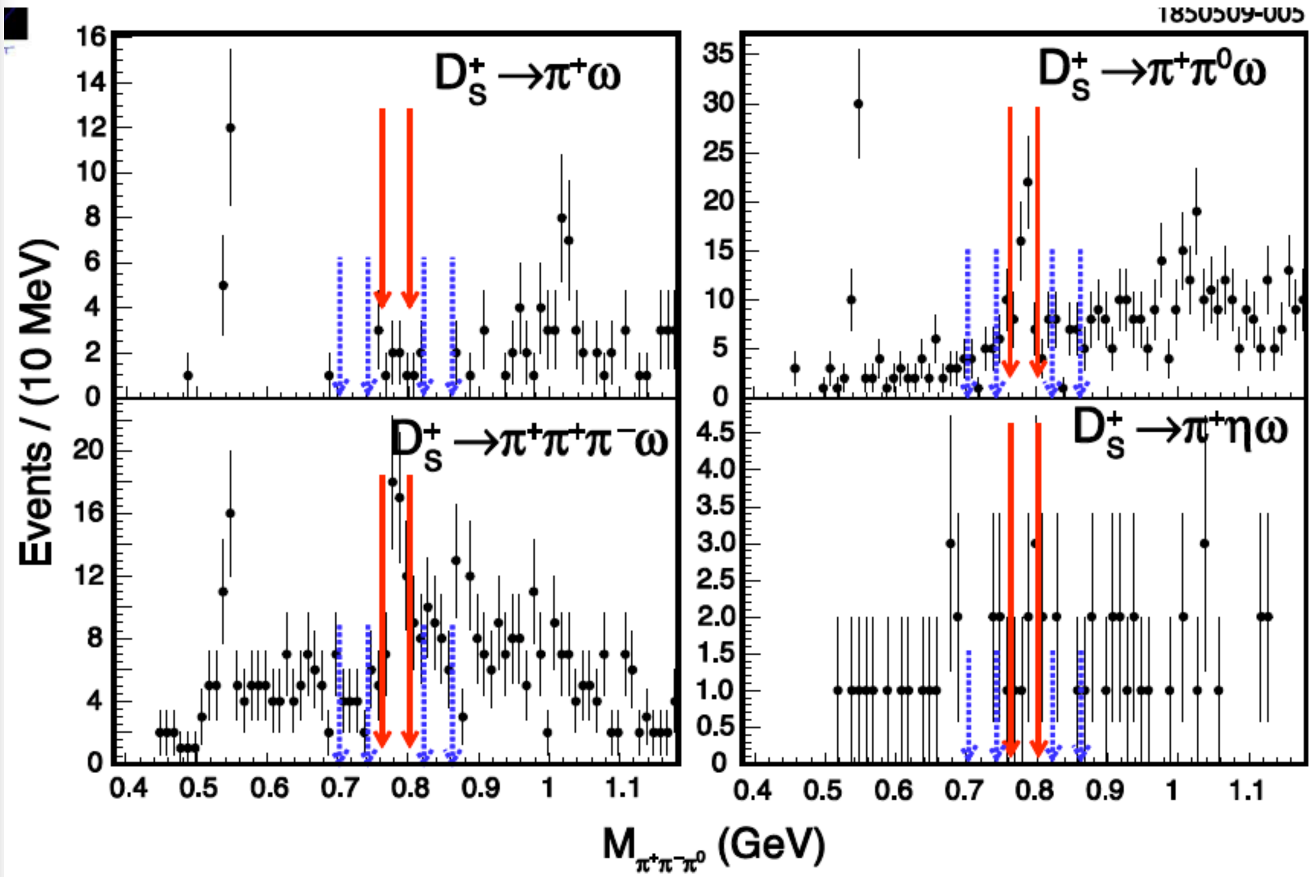
Mode	Yield(%)	K_L^0 Mode	Yield(%)	$\mathcal{B}$(PDG)(%)	prediction based on summing excl. rates [1]
$D_s^+ \to \pi^+ X$	$119.3 \pm 1.2 \pm 0.7$				125.5 ± 11.1
$D_s^+ \to \pi^- X$	$43.2 \pm 0.9 \pm 0.3$				46.6 ± 6.8
$D_s^+ \to \pi^0 X$	$123.4 \pm 3.8 \pm 5.3$				112.5 ± 8.0
$D_s^+ \to K^+ X$	$28.9 \pm 0.6 \pm 0.3$			$20\ ^{+18}_{-14}$	27.3 ± 1.4
$D_s^+ \to K^- X$	$18.7 \pm 0.5 \pm 0.2$			$13\ ^{+14}_{-12}$	18.4 ± 0.7
$D_s^+ \to \eta X$	$29.9 \pm 2.2 \pm 1.7$				32.7 ± 2.9
$D_s^+ \to \eta' X$	$11.7 \pm 1.7 \pm 0.7$				18.2 ± 2.1
$D_s^+ \to \phi X$	$15.7 \pm 0.8 \pm 0.6$				19.2 ± 2.4
$D_s^+ \to \omega X$	$6.1 \pm 1.4 \pm 0.3$				0.8 ± 0.1
$D_s^+ \to f_0(980)X, f_0(980) \to \pi^+\pi^-$	$< 1.3\%$ (90% CL)				
$D_s^+ \to K_S^0 X$	$19.0 \pm 1.0 \pm 0.4$	$D_s^+ \to K_L^0 X$	15.6 ± 2.0	20 ± 14	K^0: 18.4 ± 2.0, $\bar{K}^0$ 22.7 ± 2.2
$D_s^+ \to K_S^0 K_S^0 X$	$1.7 \pm 0.3 \pm 0.1$	$D_s^+ \to K_L^0 K_S^0 X$	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% CL)				
$D_s^+ \to K^- K^- X$	$< 0.06\%$ (90% CL)				

Compare with prediction of Gronau and Rosner (hep-ph/0903.2287)

Why is ω so large?

D_s Exclusive ω Modes

hep-ex/0906.2138 Look opposite tags:

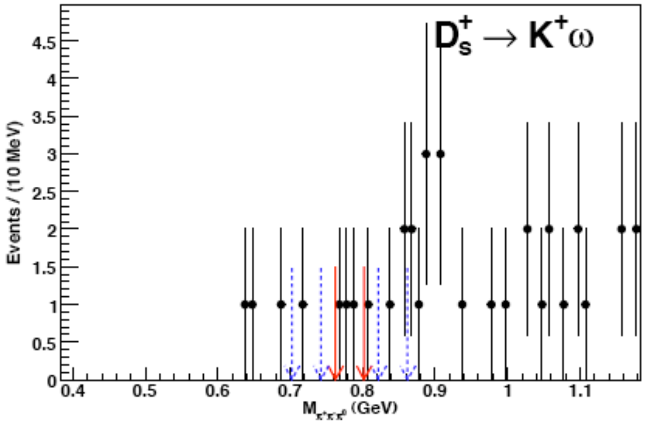


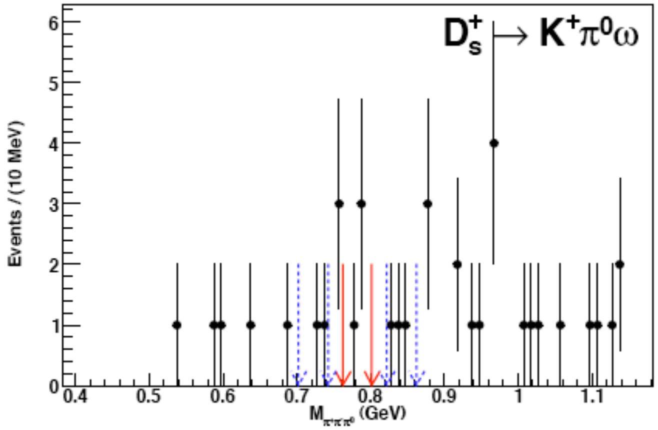
Red is ω signal region

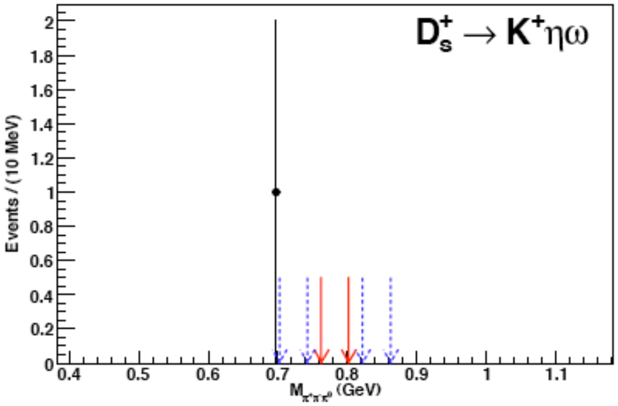
Blue are sidebands

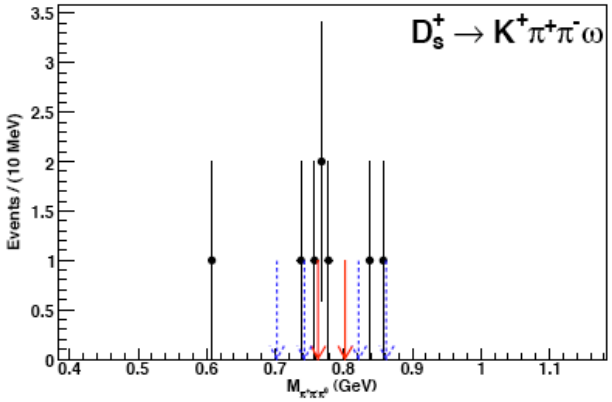
Clear signals in 3 modes

D_s Exclusive ω Modes







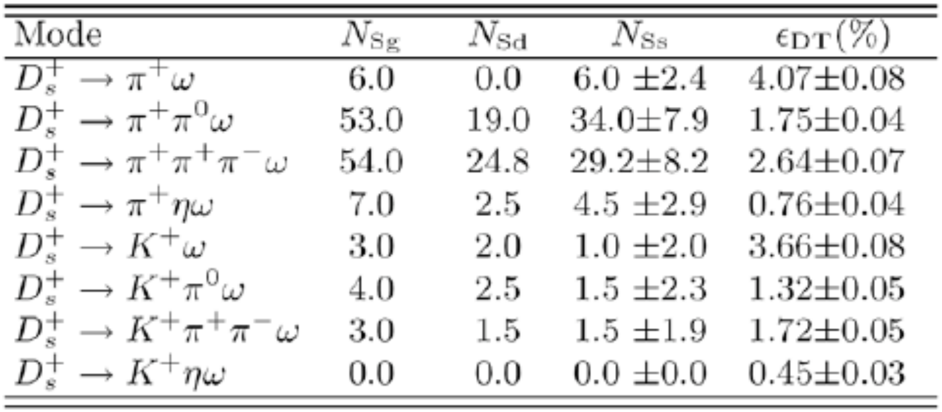


Red is ω signal region

Blue are sidebands

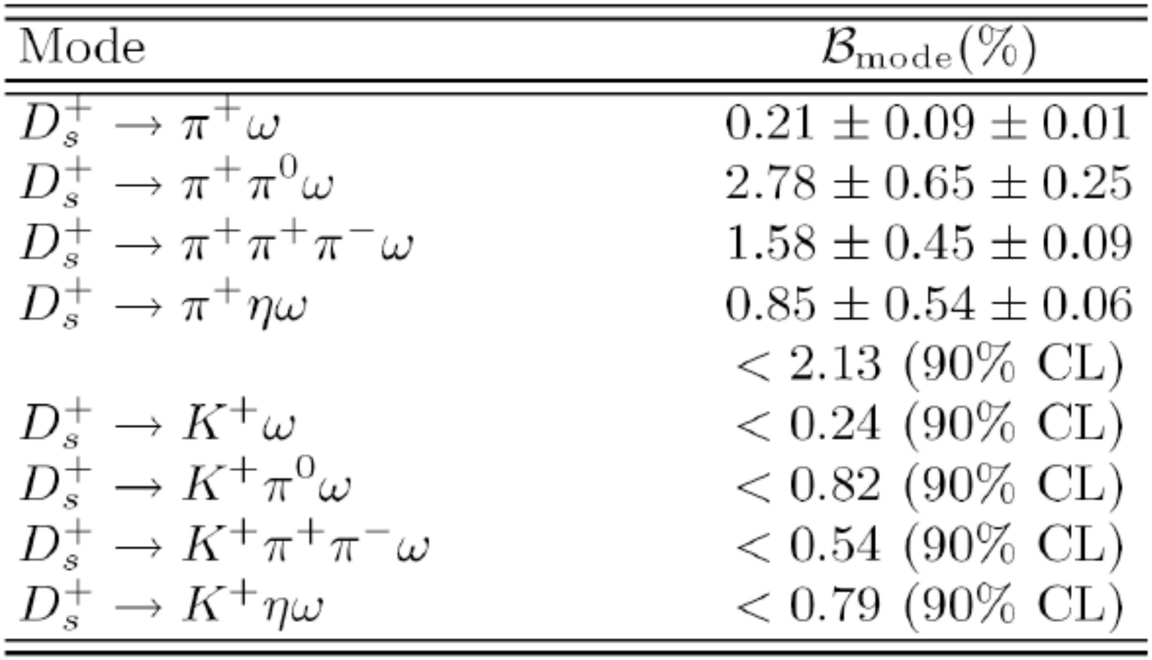
No clear signal in 5 modes

D_s Exclusive ω Modes



Mode	$N_{\rm Sg}$	$N_{\rm Sd}$	$N_{\rm Ss}$	$\epsilon_{\rm DT}(\%)$
$D_s^+ \to \pi^+\omega$	6.0	0.0	6.0 ±2.4	4.07±0.08
$D_s^+ \to \pi^+\pi^0\omega$	53.0	19.0	34.0±7.9	1.75±0.04
$D_s^+ \to \pi^+\pi^+\pi^-\omega$	54.0	24.8	29.2±8.2	2.64±0.07
$D_s^+ \to \pi^+\eta\omega$	7.0	2.5	4.5 ±2.9	0.76±0.04
$D_s^+ \to K^+\omega$	3.0	2.0	1.0 ±2.0	3.66±0.08
$D_s^+ \to K^+\pi^0\omega$	4.0	2.5	1.5 ±2.3	1.32±0.05
$D_s^+ \to K^+\pi^+\pi^-\omega$	3.0	1.5	1.5 ±1.9	1.72±0.05
$D_s^+ \to K^+\eta\omega$	0.0	0.0	0.0 ±0.0	0.45±0.03

Note that 0.52±0.30 of $\pi\pi^0$ goes via ρ from fitting the $\pi\pi^0$ mass.



Mode	$\mathcal{B}_{\rm mode}(\%)$
$D_s^+ \to \pi^+\omega$	$0.21 \pm 0.09 \pm 0.01$
$D_s^+ \to \pi^+\pi^0\omega$	$2.78 \pm 0.65 \pm 0.25$
$D_s^+ \to \pi^+\pi^+\pi^-\omega$	$1.58 \pm 0.45 \pm 0.09$
$D_s^+ \to \pi^+\eta\omega$	$0.85 \pm 0.54 \pm 0.06$ < 2.13 (90% CL)
$D_s^+ \to K^+\omega$	< 0.24 (90% CL)
$D_s^+ \to K^+\pi^0\omega$	< 0.82 (90% CL)
$D_s^+ \to K^+\pi^+\pi^-\omega$	< 0.54 (90% CL)
$D_s^+ \to K^+\eta\omega$	< 0.79 (90% CL)

Sum of exclusive consistent with inclusive (~6%).

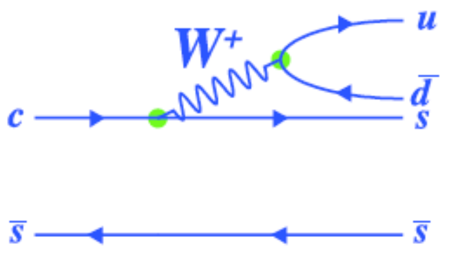
D_s likes to go to ω?

D_s Inclusive Hadron Yields

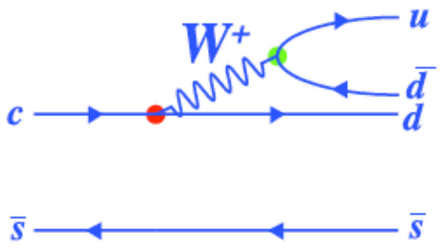
Can use the inclusive yields to measure the amplitudes of all the diagrams that contribute to D_s decay.

See paper for results.

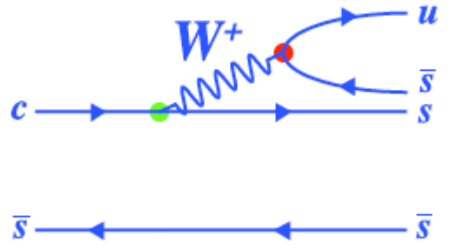
Still not clear why the D_s likes to decay to ω?



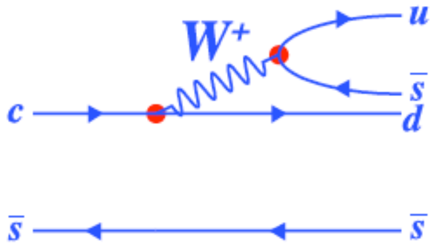
(a)



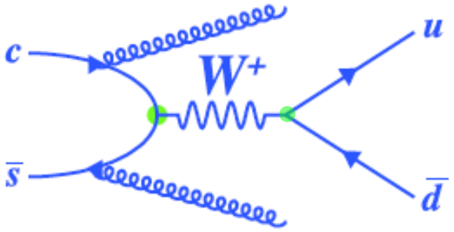
(b)



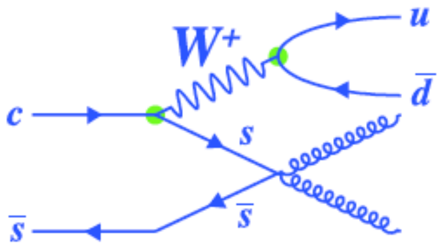
(c)



(d)



(e)



(f)

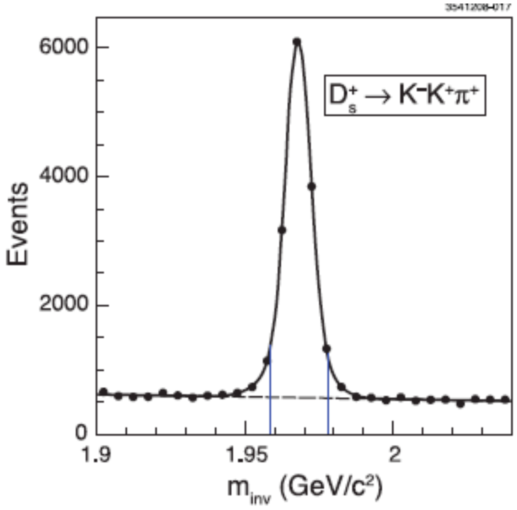
$D_s \rightarrow KK\pi$ Dalitz

PRD 79, 072008(2009)

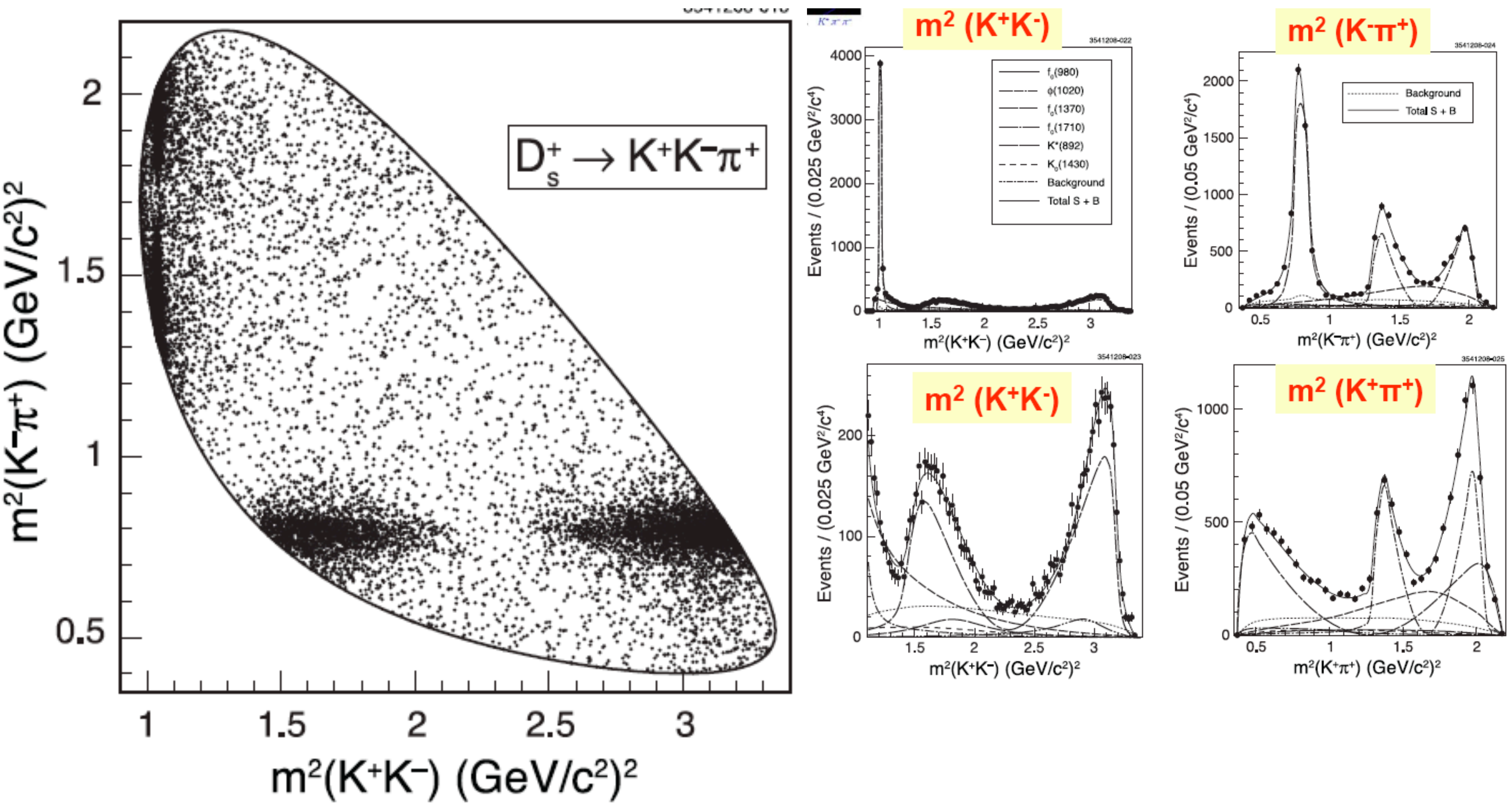
$D_s \rightarrow \phi\pi$ is a common normalization mode.

E687 (700 signal PLB 351, 591(1995)) finds substantial (~10%) contribution from $f_0(980)$ in the $KK\pi$ Dalitz plot which leads to unacceptable dependence on exactly how one defines the ϕ in $D_s \rightarrow \phi\pi$ when used for normalization.

Untagged:

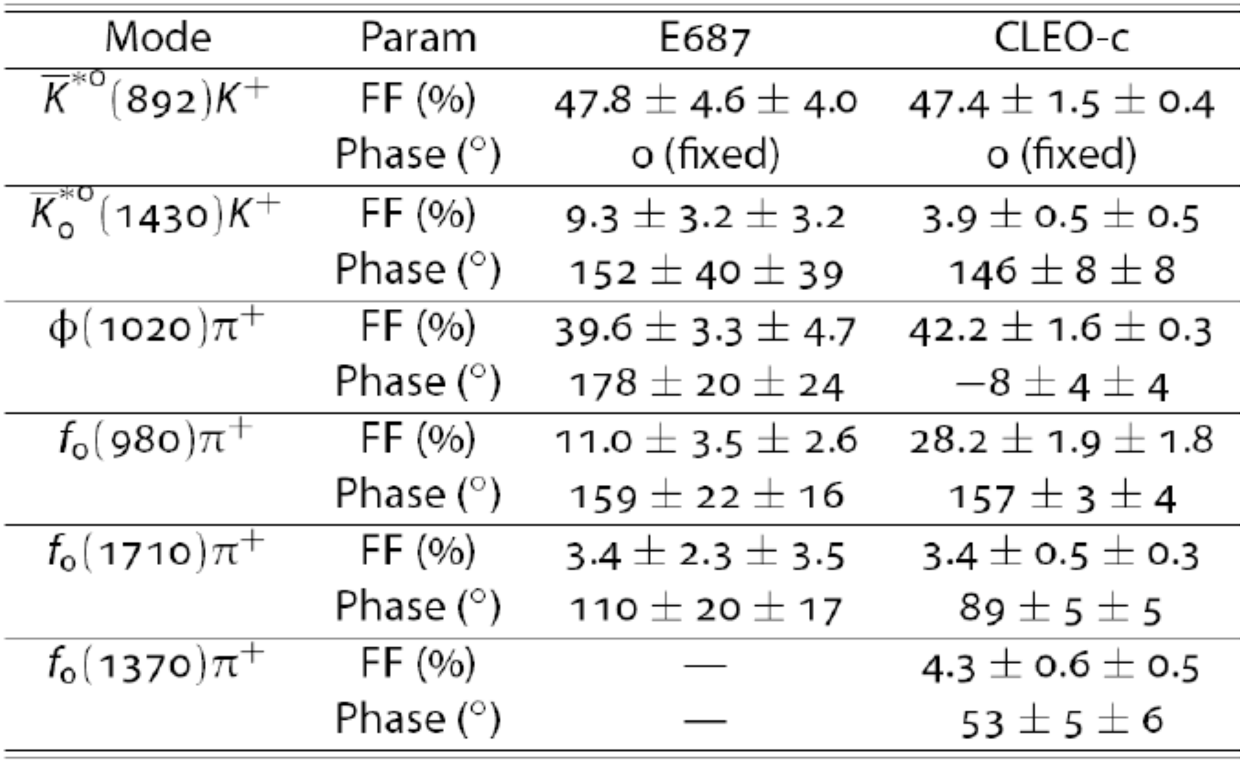


14400 candidates with background ~15%



Dalitz plot fit with the isobar model.
Consider 7 Kπ and 11 KK resonances.

$D_s \to KK\pi$ Dalitz

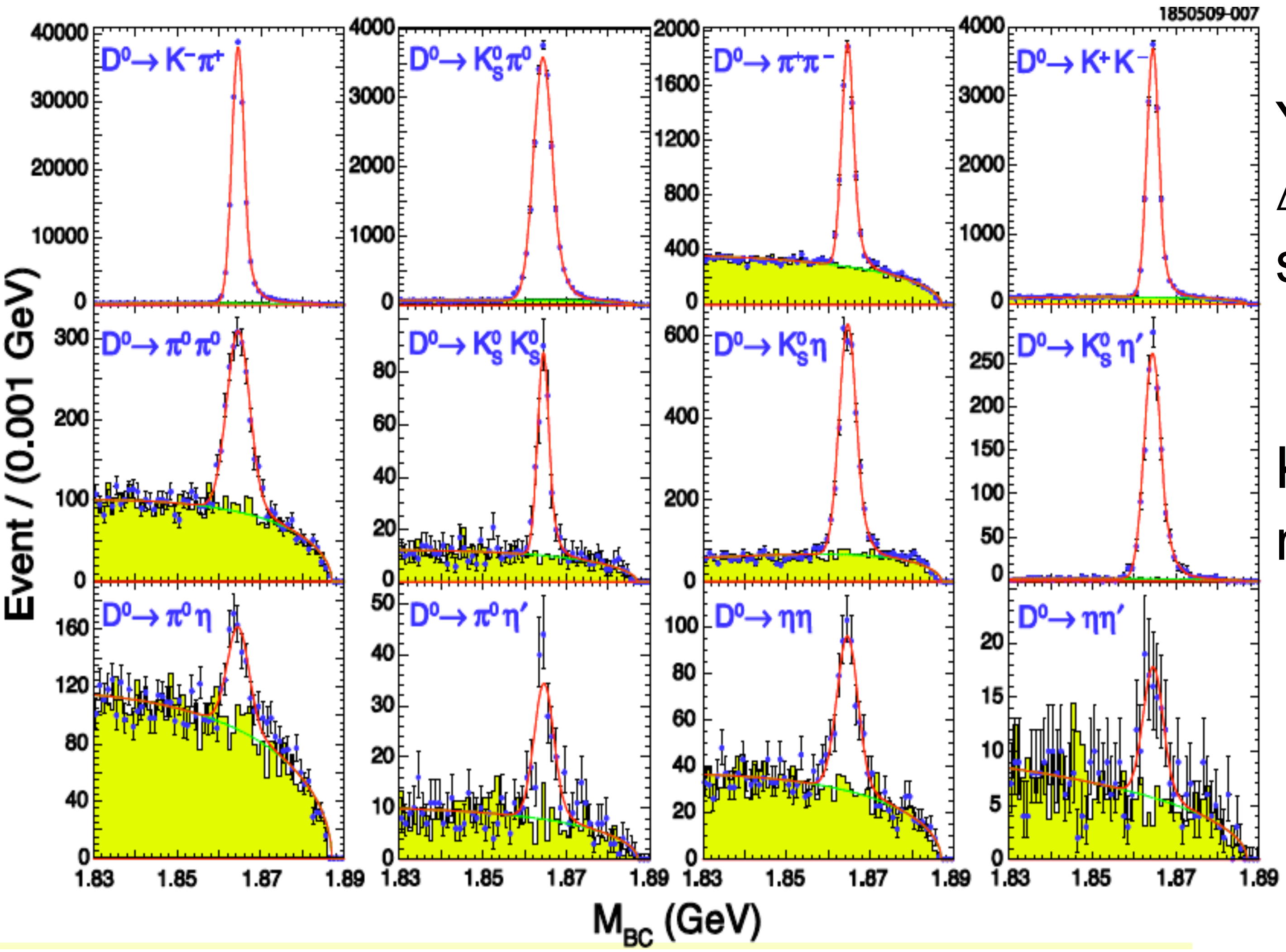


Mode	Param	E687	CLEO-c
$\overline{K}^{*0}(892)K^+$	FF (%)	$47.8 \pm 4.6 \pm 4.0$	$47.4 \pm 1.5 \pm 0.4$
	Phase (°)	0 (fixed)	0 (fixed)
$\overline{K}_0^{*0}(1430)K^+$	FF (%)	$9.3 \pm 3.2 \pm 3.2$	$3.9 \pm 0.5 \pm 0.5$
	Phase (°)	$152 \pm 40 \pm 39$	$146 \pm 8 \pm 8$
$\phi(1020)\pi^+$	FF (%)	$39.6 \pm 3.3 \pm 4.7$	$42.2 \pm 1.6 \pm 0.3$
	Phase (°)	$178 \pm 20 \pm 24$	$-8 \pm 4 \pm 4$
$f_0(980)\pi^+$	FF (%)	$11.0 \pm 3.5 \pm 2.6$	$28.2 \pm 1.9 \pm 1.8$
	Phase (°)	$159 \pm 22 \pm 16$	$157 \pm 3 \pm 4$
$f_0(1710)\pi^+$	FF (%)	$3.4 \pm 2.3 \pm 3.5$	$3.4 \pm 0.5 \pm 0.3$
	Phase (°)	$110 \pm 20 \pm 17$	$89 \pm 5 \pm 5$
$f_0(1370)\pi^+$	FF (%)	—	$4.3 \pm 0.6 \pm 0.5$
	Phase (°)	—	$53 \pm 5 \pm 6$

Much more precise than previous result, see $f_0(980)$ at the ~30% level, and need an $f_0(1370)$ contribution to get good agreement with the data. Limits on 12 unobserved.

D to Two Pseudoscalars

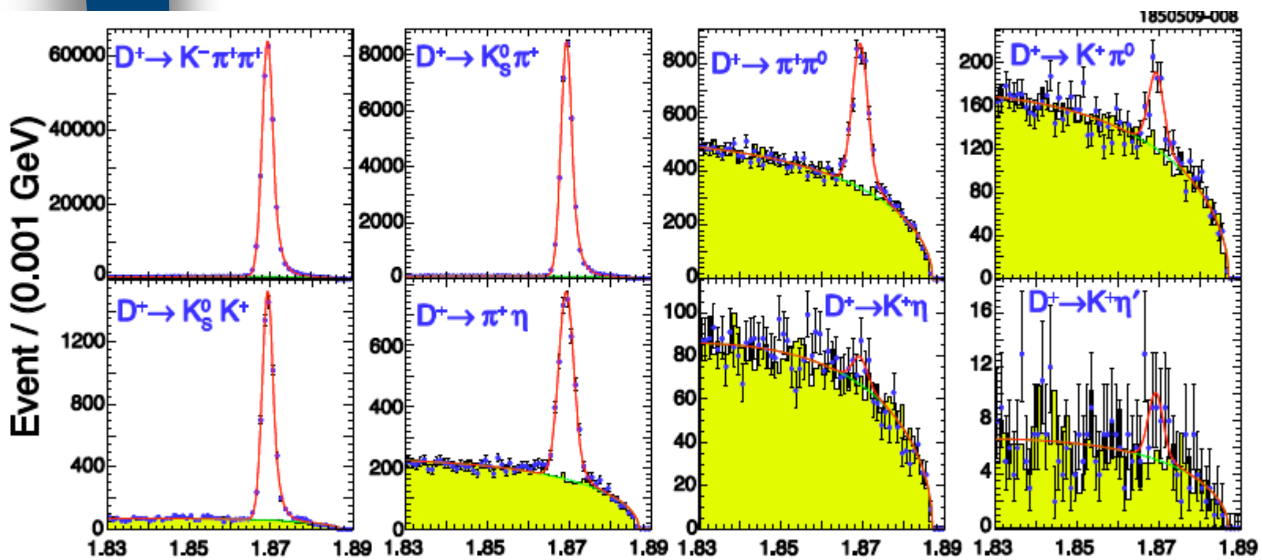
hep-ex/0906.3198, untagged, beam constraint for D^0 and D^+

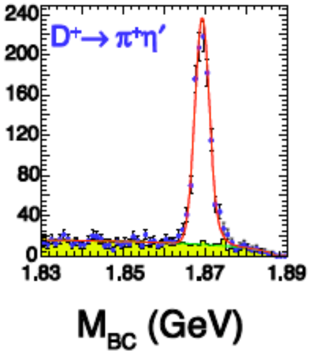


Yellow is ΔE sideband

$K\pi$ for norm

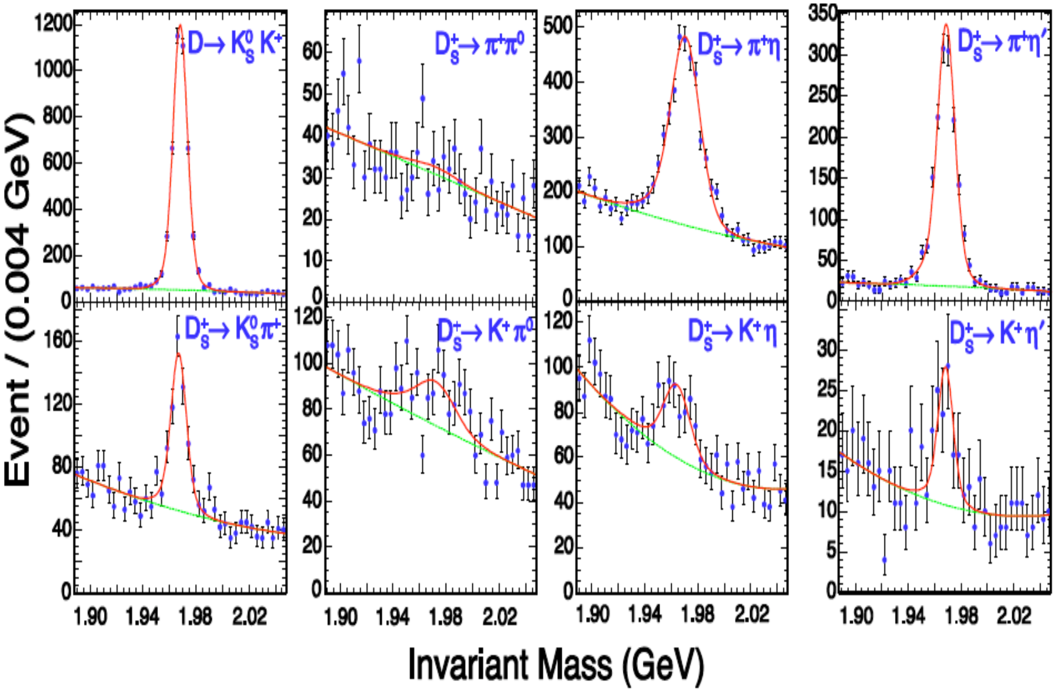
D to Two Pseudoscalars





For D^+ use $K\pi\pi$ for normalization

Yellow is ΔE sideband



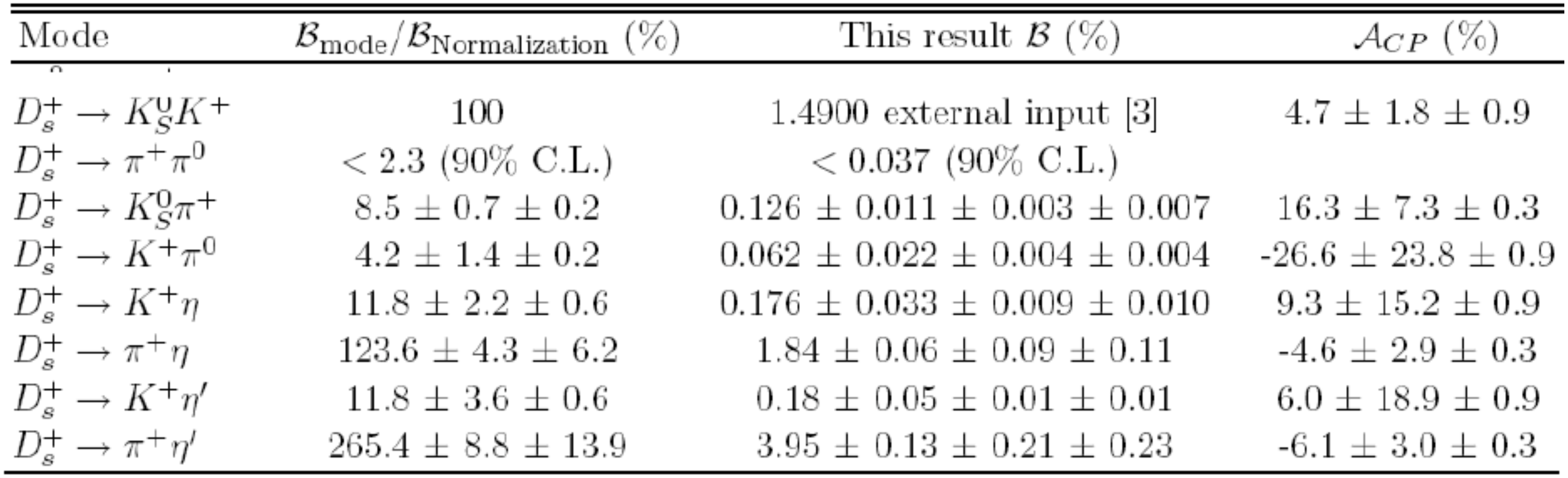
D_S uses recoil mass.
$K_S K$ for normalization

D to Two Pseudoscalars

Mode	$\mathcal{B}_{\text{mode}}/\mathcal{B}_{\text{Normalization}}$ (%)	This result $\mathcal{B}$ (%)	$\mathcal{A}_{CP}$ (%)
$D^0 \to K^+K^-$	$10.41 \pm 0.11 \pm 0.11$	$0.407 \pm 0.004 \pm 0.004 \pm 0.008$	
$D^0 \to K^0_S K^0_S$	$0.41 \pm 0.04 \pm 0.02$	$0.0160 \pm 0.0017 \pm 0.0008 \pm 0.0003$	
$D^0 \to \pi^+\pi^-$	$3.70 \pm 0.06 \pm 0.09$	$0.145 \pm 0.002 \pm 0.004 \pm 0.003$	
$D^0 \to \pi^0\pi^0$	$2.06 \pm 0.07 \pm 0.10$	$0.081 \pm 0.003 \pm 0.004 \pm 0.002$	
$D^0 \to K^-\pi^+$	100	3.9058 external input [2]	$0.5 \pm 0.4 \pm 0.9$
$D^0 \to K^0_S\pi^0$	$30.4 \pm 0.3 \pm 0.9$	$1.19 \pm 0.01 \pm 0.04 \pm 0.02$	
$D^0 \to K^0_S\eta$	$12.3 \pm 0.3 \pm 0.7$	$0.481 \pm 0.011 \pm 0.026 \pm 0.010$	
$D^0 \to \pi^0\eta$	$1.74 \pm 0.15 \pm 0.11$	$0.068 \pm 0.006 \pm 0.004 \pm 0.001$	
$D^0 \to K^0_S\eta'$	$24.3 \pm 0.8 \pm 1.1$	$0.95 \pm 0.03 \pm 0.04 \pm 0.02$	
$D^0 \to \pi^0\eta'$	$2.3 \pm 0.3 \pm 0.2$	$0.091 \pm 0.011 \pm 0.006 \pm 0.002$	
$D^0 \to \eta\eta$	$4.3 \pm 0.3 \pm 0.4$	$0.167 \pm 0.011 \pm 0.014 \pm 0.003$	
$D^0 \to \eta\eta'$	$2.7 \pm 0.6 \pm 0.3$	$0.105 \pm 0.024 \pm 0.010 \pm 0.002$	

Mode	$\mathcal{B}_{\text{mode}}/\mathcal{B}_{\text{Normalization}}$ (%)	This result $\mathcal{B}$ (%)	$\mathcal{A}_{CP}$ (%)
$D^+ \to K^-\pi^+\pi^+$	100	9.1400 external input [2]	-0.1 ± 0.4 ± 0.9
$D^+ \to K^0_S K^+$	$3.35 \pm 0.06 \pm 0.07$	$0.306 \pm 0.005 \pm 0.007 \pm 0.007$	-0.2 ± 1.5 ± 0.9
$D^+ \to \pi^+\pi^0$	$1.29 \pm 0.04 \pm 0.05$	$0.118 \pm 0.003 \pm 0.005 \pm 0.003$	2.9 ± 2.9 ± 0.3
$D^+ \to K^0_S\pi^+$	$16.82 \pm 0.12 \pm 0.37$	$1.537 \pm 0.011 \pm 0.034 \pm 0.033$	-1.3 ± 0.7 ± 0.3
$D^+ \to K^+\pi^0$	$0.19 \pm 0.02 \pm 0.01$	$0.0172 \pm 0.0018 \pm 0.0006 \pm 0.0004$	-3.5 ± 10.7 ± 0.9
$D^+ \to K^+\eta$	< 0.14 (90% C.L.)	< 0.013 (90% C.L.)	
$D^+ \to \pi^+\eta$	$3.87 \pm 0.09 \pm 0.19$	$0.354 \pm 0.008 \pm 0.018 \pm 0.008$	-2.0 ± 2.3 ± 0.3
$D^+ \to K^+\eta'$	< 0.20 (90% C.L.)	< 0.018 (90% C.L.)	
$D^+ \to \pi^+\eta'$	$5.12 \pm 0.17 \pm 0.25$	$0.468 \pm 0.016 \pm 0.023 \pm 0.010$	-4.0 ± 3.4 ± 0.3

D to Two Pseudoscalars



Mode	$\mathcal{B}_{\text{mode}}/\mathcal{B}_{\text{Normalization}}$ (%)	This result $\mathcal{B}$ (%)	$\mathcal{A}_{CP}$ (%)
$D_s^+ \to K_S^0 K^+$	100	1.4900 external input [3]	4.7 ± 1.8 ± 0.9
$D_s^+ \to \pi^+ \pi^0$	< 2.3 (90% C.L.)	< 0.037 (90% C.L.)	
$D_s^+ \to K_S^0 \pi^+$	8.5 ± 0.7 ± 0.2	0.126 ± 0.011 ± 0.003 ± 0.007	16.3 ± 7.3 ± 0.3
$D_s^+ \to K^+ \pi^0$	4.2 ± 1.4 ± 0.2	0.062 ± 0.022 ± 0.004 ± 0.004	-26.6 ± 23.8 ± 0.9
$D_s^+ \to K^+ \eta$	11.8 ± 2.2 ± 0.6	0.176 ± 0.033 ± 0.009 ± 0.010	9.3 ± 15.2 ± 0.9
$D_s^+ \to \pi^+ \eta$	123.6 ± 4.3 ± 6.2	1.84 ± 0.06 ± 0.09 ± 0.11	-4.6 ± 2.9 ± 0.3
$D_s^+ \to K^+ \eta'$	11.8 ± 3.6 ± 0.6	0.18 ± 0.05 ± 0.01 ± 0.01	6.0 ± 18.9 ± 0.9
$D_s^+ \to \pi^+ \eta'$	265.4 ± 8.8 ± 13.9	3.95 ± 0.13 ± 0.21 ± 0.23	-6.1 ± 3.0 ± 0.3

Uncertainties are statistics, systematics, and branching of the normalizing mode. Much improved and many new branchings.

No evidence of CP Asymmetry at the % level in D^0 and D^+ or the 10% level in D_S.

Summary

- CLEO-c measures of D strong phases improves CKM γ results
- Much more complete picture of D_S decay pattern
- The D_S likes to go to ω?
- Much improved $D_S \to KK\pi$ Dalitz
- No evidence for CP asymmetries in D decays