$D_{(s)}$ Branching Fractions

Jonas Rademacker on behalf of CLEO-c

21 May 2009, non-leptonic decays
session, Charm 2009, Leimen

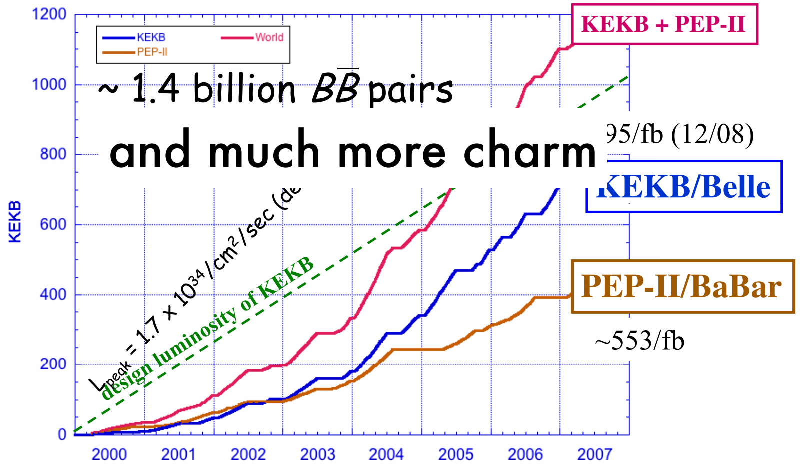
Charm Branching Fractions

- Test approximate symmetries: $SU(3)_F$, U-spin, Isospin
- Long-distance hadronic interactions - hard to calculate, even more important to get data.
- Still provide surprises - it is an experiment-led field.
- Input to B physics: U-spin tests, absolute charm B.F. for extracting B-rates from excl. B→DX decays.
- Search for direct CP violation and thus test the SM.
- Need to be measured because they are there.

Since last time

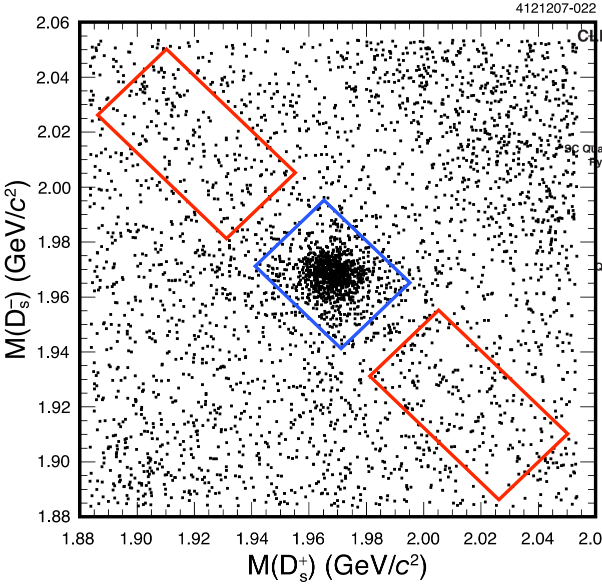
Data since Charm2007

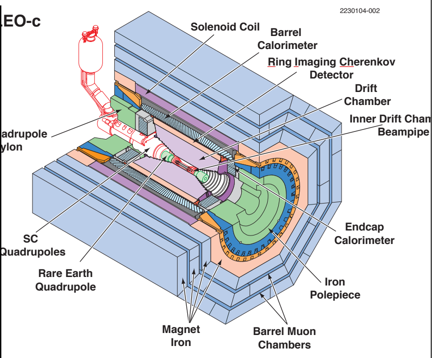
- New data from the B factories - used for wonderful charm analyses (including B.R.).
- New data and results from dedicated charm experiments FOCUS, CLEO-c.
- In particular a new large data sample of D_s mesons from CLEO-c running at $e^+e^- \rightarrow \psi(4170) \rightarrow D_S^{+*} D_S^-$



~ 1.4 billion $B\bar{B}$ pairs

and much more charm





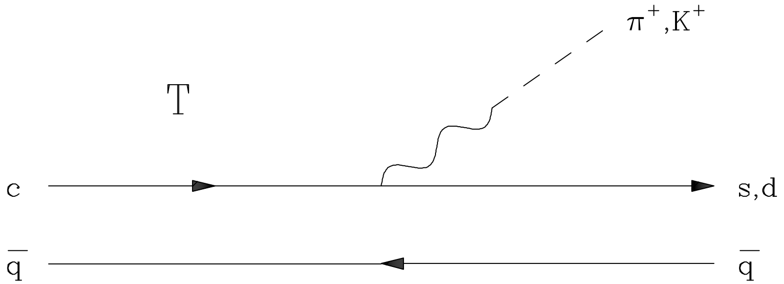
Outline

- The topological approach and symmetry tests
  - D→PP, D→Vη
- Radiative charm decays and long-distance effects
- Baryonic decay of charm
- Absolute branching fractions, golden modes.
- Inclusive D_S Branching Fractions
- Direct CP violation.

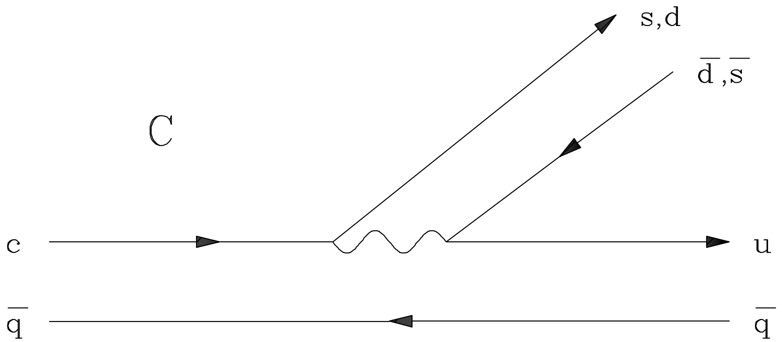
Topologies

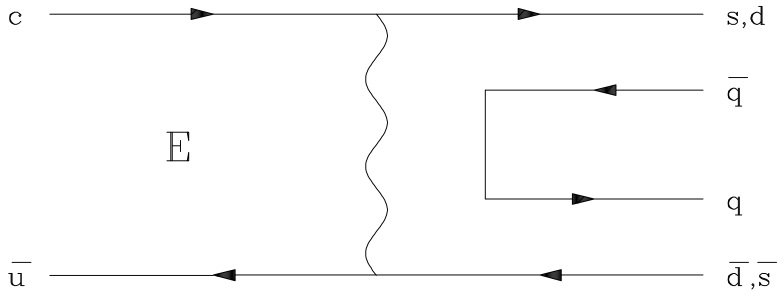
Topological Approach to Hadronic Decays

T=Colour-favoured Tree

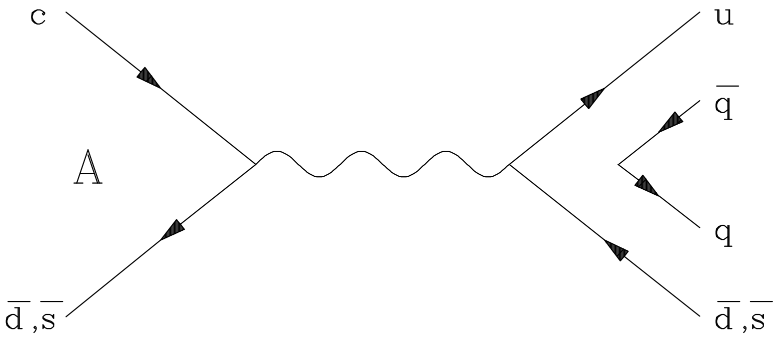


C=Colour-suppressed Tree





E=Exchange

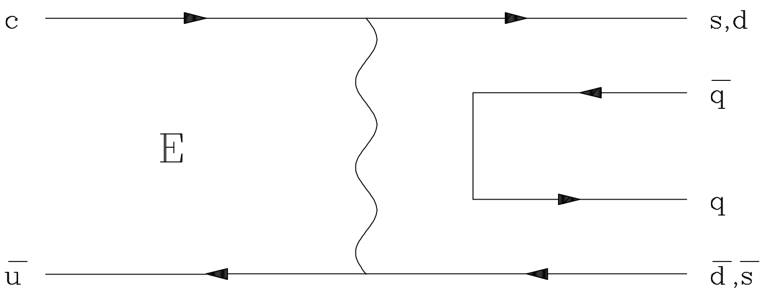


A=Annihilation

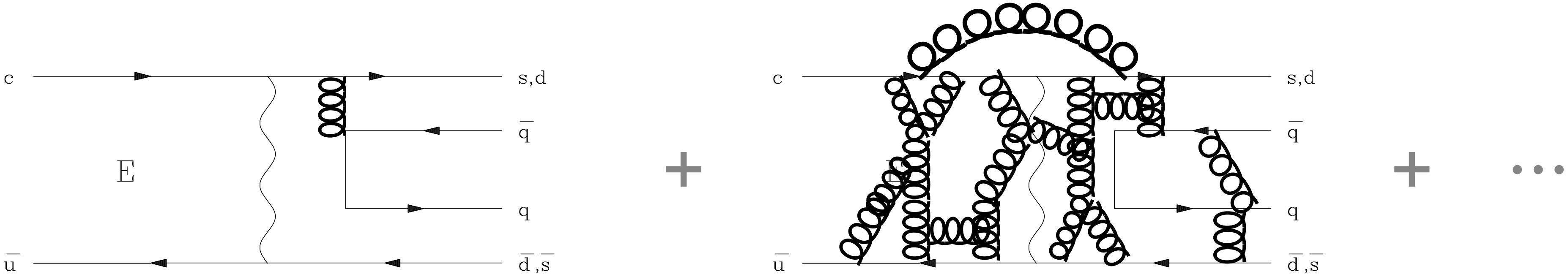
Topologies

Topological Approach to Hadronic Decays

- Topological diagram:



- Includes all hadronic effects to all orders.

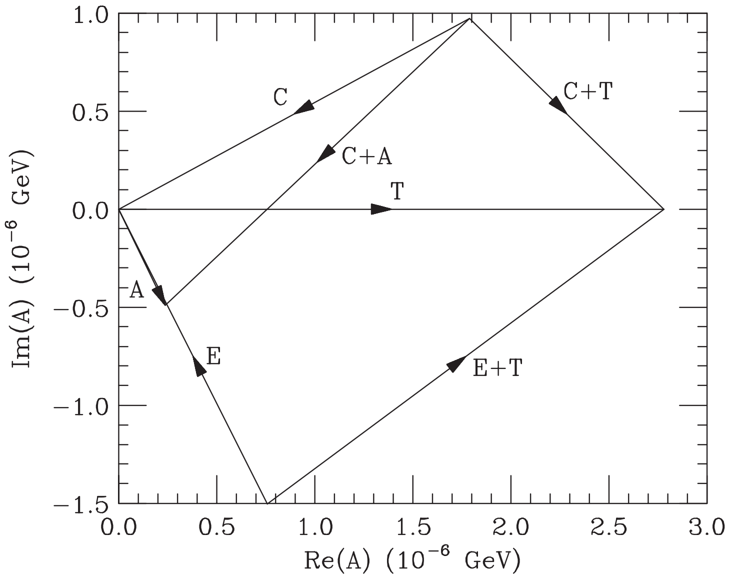


- Relies on SU(3)-flavour symmetry

CF decay rates in terms of topology amplitudes.

Meson	Decay mode	$\mathcal{B}$ (%)	Rep.
D^0	$K^-\pi^+$	3.89±0.08	$T+E$
	$\overline{K}^0\pi^0$	2.24±0.11	$(C-E)/\sqrt{2}$
	$\overline{K}^0\eta$	0.76±0.11	$C/\sqrt{3}$
	$\overline{K}^0\eta'$	1.87±0.28	$-(C+3E)/\sqrt{6}$
D^+	$\overline{K}^0\pi^+$	2.99±0.07	$C+T$
D_s^+	$\overline{K}^0K^+$	2.98±0.27	$C+A$
	$\pi^+\eta$	1.58±0.21	$(T-2A)/\sqrt{3}$
	$\pi^+\eta'$	3.77±0.39	$2(T+A)/\sqrt{6}$

Ds: CLEO Phys.Rev.Lett.99:191805,2007
Dº, D+: CLEO: Phys. Rev. Lett. 100, 161804 (2008)

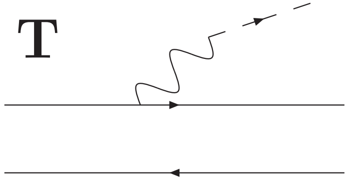


B. Bhattacharya and J. L. Rosner
Phys. Rev. D 77, 114020 (2008)

Can construct complex topological amplitudes by relating (real) decay rates

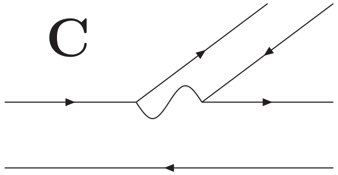
CF decay rates and amplitudes

T



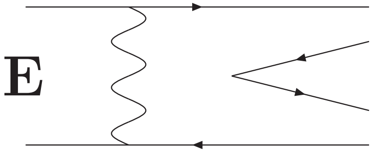
$T=2.78$

C



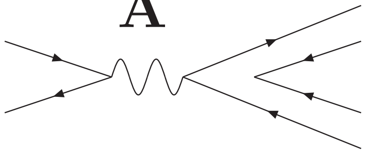
$C=(2.04 \pm 0.71)$
$\times \exp(i[-151.5° \pm 1.7°)]$

E



$E= (1.68 \pm 0.12)$
$\times \exp(i[116.7° \pm 3.6°)]$

A



$A=(0.55 \pm 0.39)$
$\times \exp(i[-64°^{+32°}_{-8°})]$

in units of 10^{-7} GeV

Previously: (Charm2007)[1]: $A \approx -E$, in contrast to expectation $A \approx -0.4E$[2].

Latest data gives $A \approx -0.3E$[3]

[1] B. Bhattacharya and J. L. Rosner, eConf C070805 [2] D.-N. Gao, Phys. Lett. B 645, 59 (2007)

[3] B. Bhattacharya and J. L. Rosner Phys. Rev. D 77, 114020 (2008)

SCS

- Same topological SU(3)-based approach as for CF
- Notation: SCS amplitudes get prime, i.e. T′, S′, E′ etc
- By SU(3) SCS amplitude = λ CF, i.e. T′ = λT etc
- By and large successful, but with some noticeable SU(3)-breaking effect:

SCS

Meson	Decay mode	$\mathcal{B}$ (10^{-3})	Rep.
D^0	$\pi^+\pi^-$	1.37±0.03	$-(T'+E')$
	$\pi^0\pi^0$	0.79±0.08	$-(C'-E')/\sqrt{2}$
	K^+K^-	3.93±0.07	$(T'+E')$
	$K^0\overline{K}^0$	0.37±0.06	0
D^+	$\pi^+\pi^0$	1.28±0.08	$-(T'+C')/\sqrt{2}$
	$K^+\overline{K}^0$	6.17±0.20	$T'-A'$
D_s^+	π^+K^0	2.44±0.30	$-(T'-A')$
	π^0K^+	0.75±0.28	$-(C'+A')/\sqrt{2}$

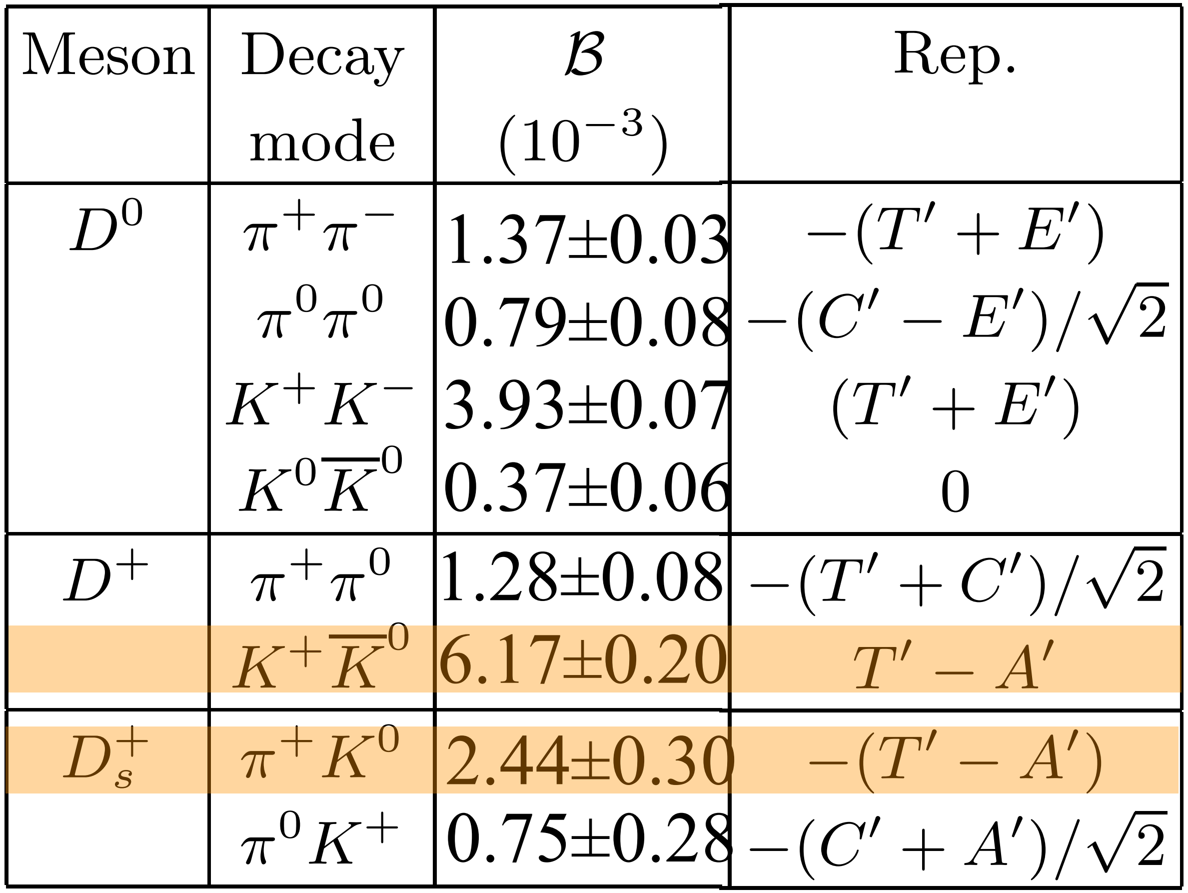
Table by: B. Bhattacharya and J. L. Rosner Phys. Rev. D 77, 114020 (2008) (modifed)

Expect from SU(3):
$A(D^0 \to \overline{K}^0 K^0) = 0$

D+ and D°: combine PDG 08 averages with new CLEO results:
Phys. Rev. D 77, 091106 (2008)

Ds results: CLEO
Phys. Rev. Lett. 100, 161804 (2008)
Phys. Rev. Lett. 99, 191805 (2007)

SCS



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	$\pi^0\pi^0$	0.79±0.08	$-(C'-E')/\sqrt{2}$
	K^+K^-	3.93±0.07	$(T'+E')$
	$K^0\overline{K}^0$	0.37±0.06	0
D^+	$\pi^+\pi^0$	1.28±0.08	$-(T'+C')/\sqrt{2}$
	$K^+\overline{K}^0$	6.17±0.20	$T'-A'$
D_s^+	π^+K^0	2.44±0.30	$-(T'-A')$
	π^0K^+	0.75±0.28	$-(C'+A')/\sqrt{2}$

Expect from SU(3):
$A(D^0 \to K^+\overline{K}^0) =$
$A(D_s^+ \to \pi^+K^0)$.

SCS D°→PP overview

Meson	Decay mode	$\mathcal{B}$ (10^{-3})	Rep.	Predicted $\mathcal{B}$ (10^{-3})
D^0	$\pi^+\pi^-$	$1.37 \pm 0.03^{\mathrm{a}}$	$-(T' + E')$	2.23
	$\pi^0\pi^0$	$0.79 \pm 0.08^{\mathrm{a}}$	$-(C' - E')/\sqrt{2}$	1.27
	K^+K^-	$3.93 \pm 0.07^{\mathrm{b}}$	$(T' + E')$	1.92
	$K^0\bar{K}^0$	$0.37 \pm 0.06^{\mathrm{b}}$	0	0
D^+	$\pi^+\pi^0$	$1.28 \pm 0.08^{\mathrm{a}}$	$-(T' + C')/\sqrt{2}$	0.87
	$K^+\bar{K}^0$	$6.17 \pm 0.20^{\mathrm{b}}$	$T' - A'$	5.12
D_s^+	π^+K^0	$2.44 \pm 0.30^{\mathrm{c}}$	$-(T' - A')$	2.56
	π^0K^+	$0.75 \pm 0.28^{\mathrm{c}}$	$-(C' + A')/\sqrt{2}$	0.87

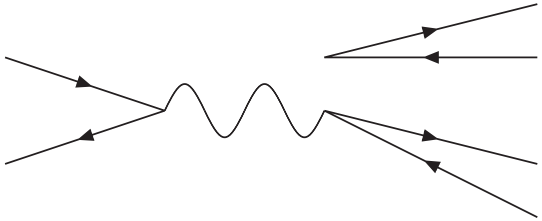
Table by: B. Bhattacharya and J. L. Rosner Phys. Rev. D 77, 114020 (2008)

D+ and D°: combine PDG 08 averages with new CLEO results:
Phys. Rev. D 77, 091106 (2008)

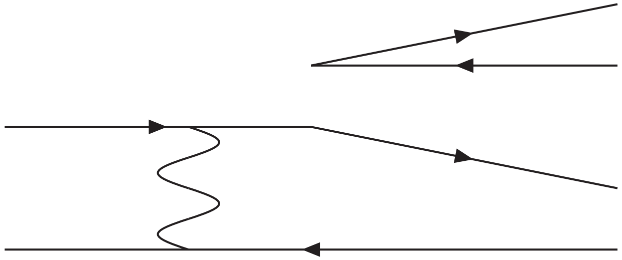
Ds results: CLEO
Phys. Rev. Lett. 100, 161804 (2008)
Phys. Rev. Lett. 99, 191805 (2007)

SCS decays with $\eta^{(\prime)}$

- Do we need additional (OZI-suppressed) Singlet Amplitudes?



Singlet-Annihilation (S-A)



Singlet-Exchange (S-E)

SCS decays with $\eta^{(\prime)}$

- Decays of D^o to $\eta^{(\prime)}$ in term of SU(3) topological amplitudes:

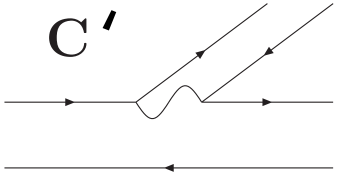
$$-\sqrt{6}\mathcal{A}(D^0\to\pi^0\eta')=2E'-C'+SE',$$

$$\frac{\sqrt{3}}{2}\mathcal{A}(D^0\to\pi^0\eta')=\frac{1}{2}(C'+E')+SE',$$

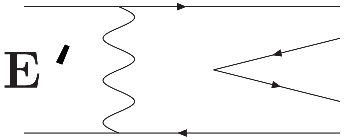
$$\frac{3}{2\sqrt{2}}\mathcal{A}(D^0\to\eta\eta)=C'+SE',$$

$$-\frac{3\sqrt{2}}{7}\mathcal{A}(D^0\to\eta\eta')=\frac{1}{7}(C'+6E')+SE'$$

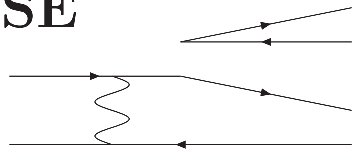
C′



E′



SE′

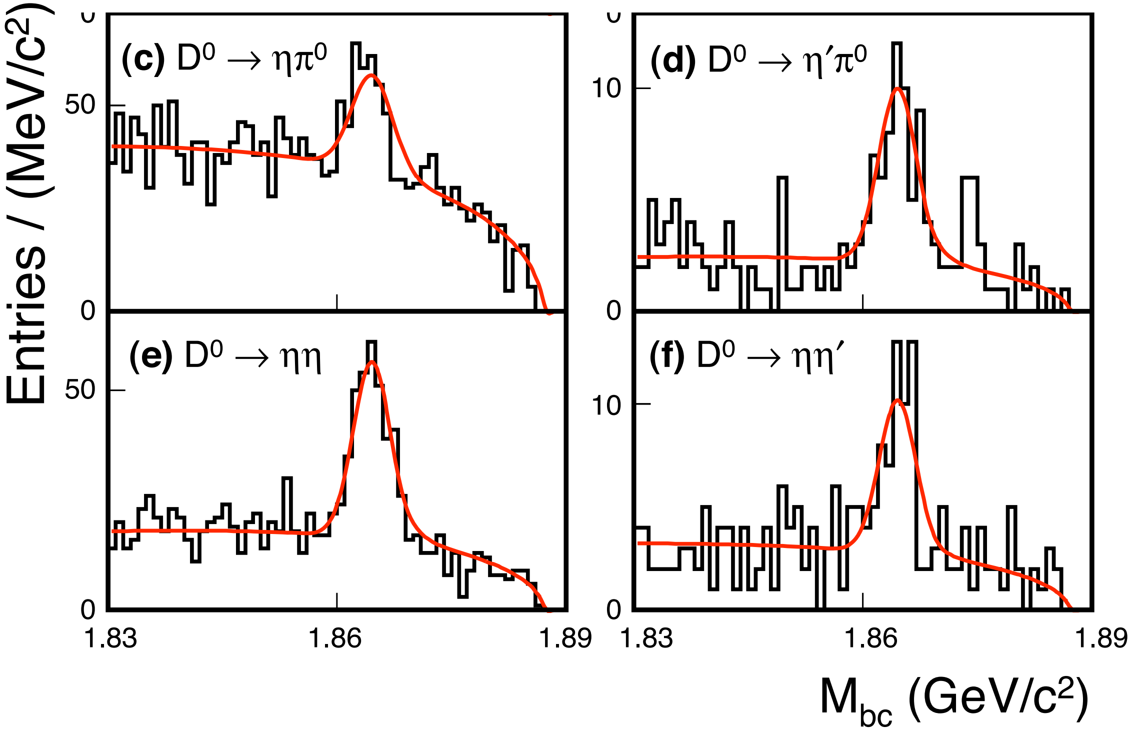


(the prime in C′, E′, SE′ indicates the SCS amplitude)

SCS decays with $\eta^{(\prime)}$ at CLEO-c

- Measured SCS B.R.:

Mode	$\mathcal{B}_{\mathrm{exp}}$ (10^{-4})
$D^0 \to \eta\pi^0$	6.4 ± 1.1
$D^0 \to \eta'\pi^0$	8.1 ± 1.6
$D^0 \to \eta\eta$	16.7 ± 1.9
$D^0 \to \eta\eta'$	12.6 ± 2.7



CLEO: Phys.Rev.D77:092003,2008

SCS decays with η$^{(\prime)}$

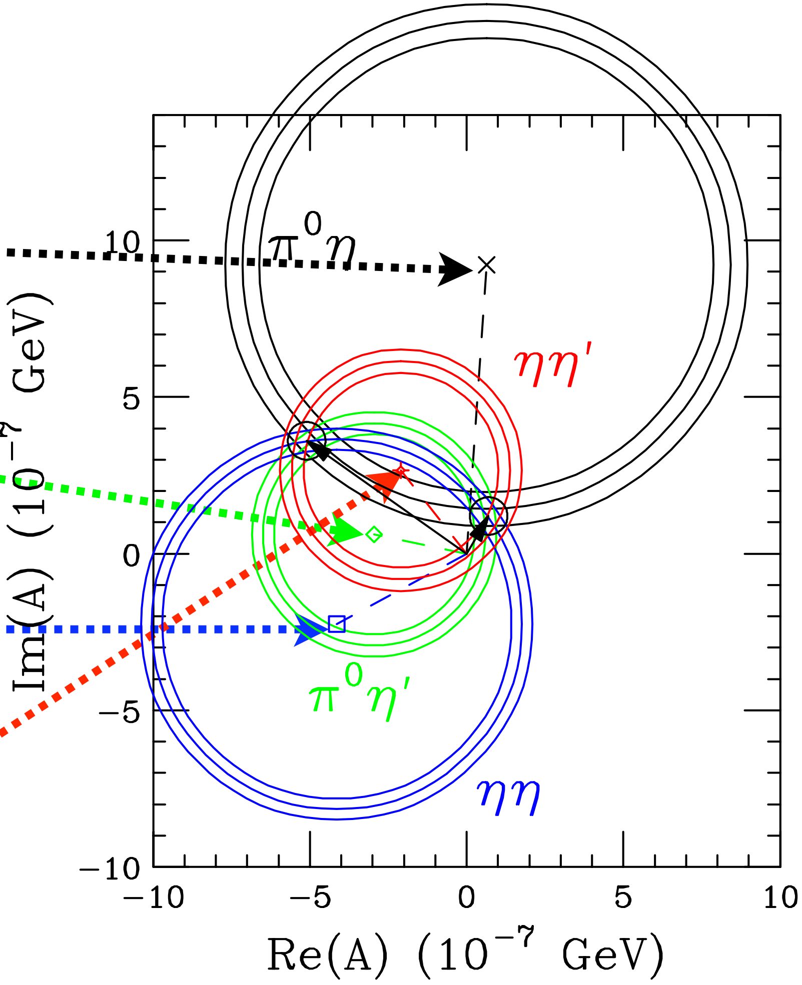
- Allowing for non-zero SE′

$$-\sqrt{6}\mathcal{A}(D^0\to\pi^0\eta')=\underline{2E'-C'+SE'},$$

$$\frac{\sqrt{3}}{2}\mathcal{A}(D^0\to\pi^0\eta')=\frac{1}{2}(C'+E')+SE',$$

$$\frac{3}{2\sqrt{2}}\mathcal{A}(D^0\to\eta\eta)=C'+SE',$$

$$-\frac{3\sqrt{2}}{7}\mathcal{A}(D^0\to\eta\eta')=\frac{1}{7}(C'+6E')+SE'$$



Plot: B. Bhattacharya and J. L. Rosner Phys. Rev. D 77, 114020 (2008), Results from CLEO: Phys.Rev.D77:092003,2008

SCS decays with $\eta^{(\prime)}$

- Measuring SE′
- Two solutions (units: 10^{-7} GeV):

SE′ = (5.3±0.5) + i(3.5±0.5)

or

SE′ = (-0.7±0.4) + i(1.0±0.6)

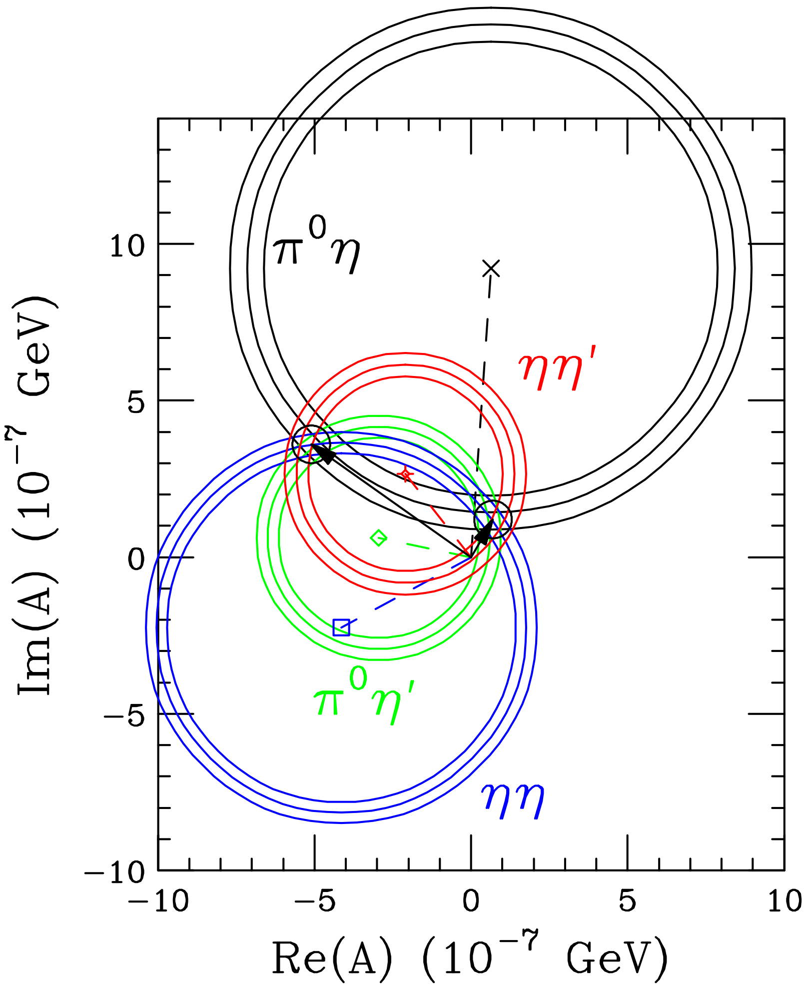
for comparison (obtained by scaling CF amplitudes)

$T' = 6.44;$

$C' = -4.15 - 2.25i;$

$E' = -1.76 + 3.48i;$

$A' = 0.55 - 1.14i.$

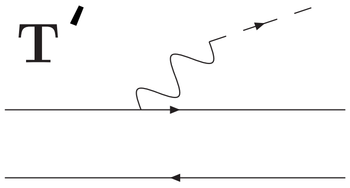


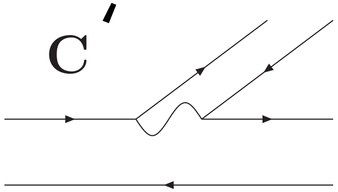
Plot: B. Bhattacharya and J. L. Rosner Phys. Rev. D 77, 114020 (2008), Results from CLEO: Phys.Rev.D77:092003,2008

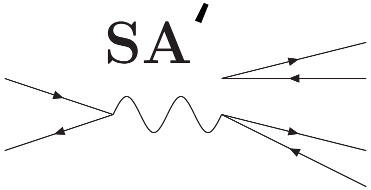
SCS decays with η(′)

- Decay of $D^+_{(s)}$ to $\eta^{(\prime)}$ in term of SU(3) topological amplitudes:

$$\begin{array}{lc}
\sqrt{3}\mathcal{A}(D^+ \to \pi^+\eta) & T' + 2C' + 2A' + SA' \\
-\frac{\sqrt{6}}{4}\mathcal{A}(D^+ \to \pi^+\eta') & \frac{1}{4}(T' - C' + 2A') + SA' \\
-\sqrt{3}\mathcal{A}(D_s^+ \to \eta K^+) & -(T' + 2C') + SA' \\
\frac{\sqrt{6}}{4}\mathcal{A}(D_s^+ \to \eta' K^+) & \frac{1}{4}(2T' + C' + 3A') + SA'
\end{array}$$







mode		BR / 10^{-4}
D^+	$\pi^+\eta$	$34.3 \pm 2.1^{\mathrm{a}}$
	$\pi^+\eta'$	$45.2 \pm 3.6^{\mathrm{a}}$
D_s^+	$K^+\eta$	$14.1 \pm 3.1^{\mathrm{c}}$
	$K^+\eta'$	$15.8 \pm 5.3^{\mathrm{c}}$

(the prime in T′, C′, SA′ indicate the SCS amplitude)

SCS decays with $\eta^{(\prime)}$

- Measuring SA′ using the same approach as previously
- Solution (units: 10^{-7} GeV)

  SA′ ≈ –6.1 + 2.1 i
- No zero solution.
- No OZI suppression for SA′?

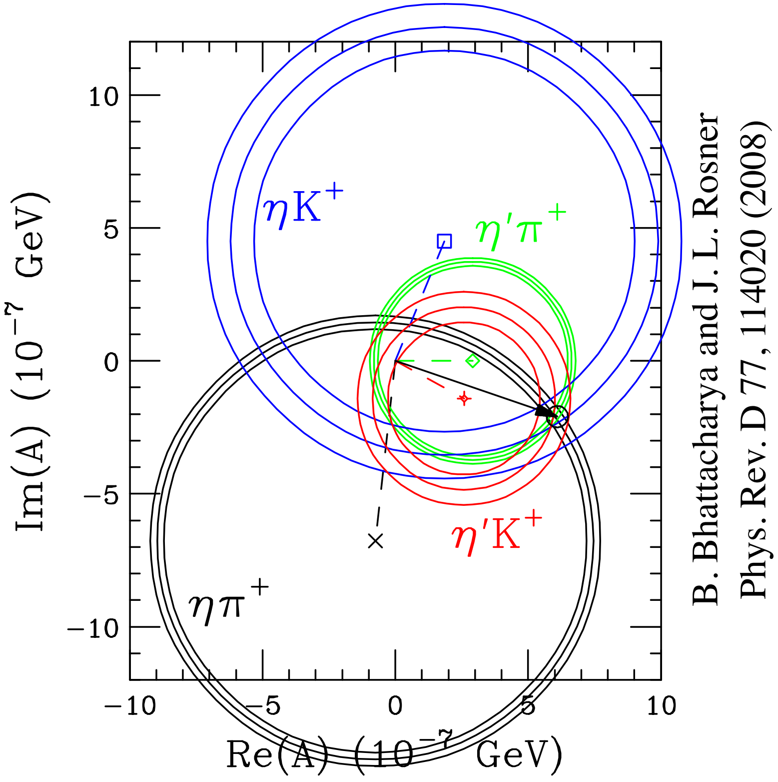
for comparison (obtained by scaling CF amplitudes)

$$T' = 6.44;$$

$$C' = -4.15 - 2.25i;$$

$$E' = -1.76 + 3.48i;$$

$$A' = 0.55 - 1.14i.$$



B. Bhattacharya and J. L. Rosner Phys. Rev. D 77, 114020 (2008)

SU(3)$_F$ and η sum rules

- Expect from SU(3)$_F$

$$8|\mathcal{A}(D^0 \to \pi^0\eta')|^2 + 16|\mathcal{A}(D^0 \to \pi^0\pi^0)|^2$$

$$= 16|\mathcal{A}(D^0 \to \pi^0\eta)|^2 + 9|\mathcal{A}(D^0 \to \eta\eta)|^2$$

- Find

$$8|\mathcal{A}(D^0 \to \pi^0\eta')|^2 + 16|\mathcal{A}(D^0 \to \pi^0\pi^0)|^2 = 325 \pm 33$$

$$16|\mathcal{A}(D^0 \to \pi^0\eta)|^2 + 9|\mathcal{A}(D^0 \to \eta\eta)|^2 = 440 \pm 39$$

- ca 2σ off

U-spin and $D^\circ \rightarrow K_{S,L}\pi^\circ$

- Naively, might expect $\Gamma(D^o \rightarrow K_S\pi^o) = \Gamma(D^o \rightarrow K_L\pi^o)$.
- But in these decays CF $A(D^o \rightarrow K^o\pi^o)$ and the DCS $A(\overline{D}^o \rightarrow K^o\pi^o)$ interfere with a different relative sign.[1]
- $D^o \rightarrow K_{L,S}\pi^o$ asymmetry allow a test of U-spin symmetry.[1]
- U-spin, s↔d, expected to be better than full $SU(3)_f$
- Important for certain strategies for extracting the CKM angle γ in decays with tree and penguin contributions, such as $B \rightarrow \pi\pi \leftrightarrow Bs \rightarrow KK$.

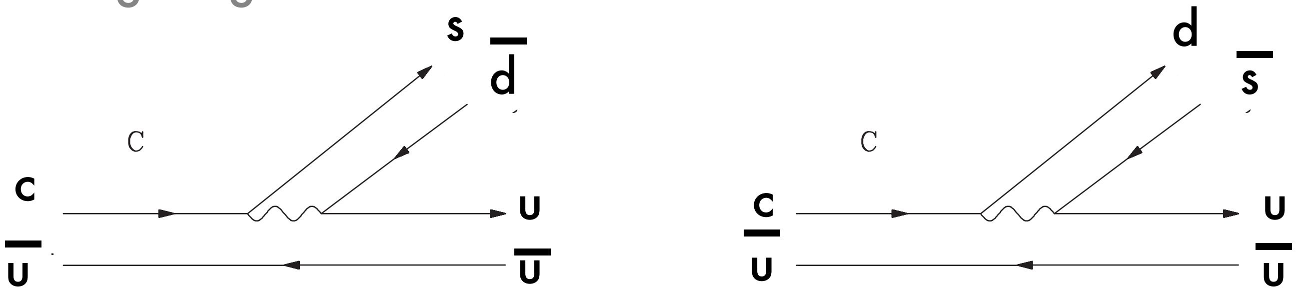
[1] I. Bigi and H. Yamamoto, Physics Letters 349 (1995) 363-366

U-spin and $D^\circ \to K_{S,L}\pi^\circ$

- $D \to \overline{K}^\circ \pi^\circ$ $D \to K^\circ \pi^\circ$

CF **DCS**

leading diagram:



U-spin prediction

- $A(D \to K_S\pi^\circ) = A_{CF} - A_{DCS}$, $A(D \to K_L\pi^\circ) = A_{CF} + A_{DCS}$
- $$\frac{\Gamma\left(D^0 \to K_S\pi^0\right) - \Gamma\left(D^0 \to K_L\pi^0\right)}{\Gamma\left(D^0 \to K_S\pi^0\right) + \Gamma\left(D^0 \to K_L\pi^0\right)} = -2\frac{A_{DCS}}{A_{CF}} = 2\tan^2\theta_C$$

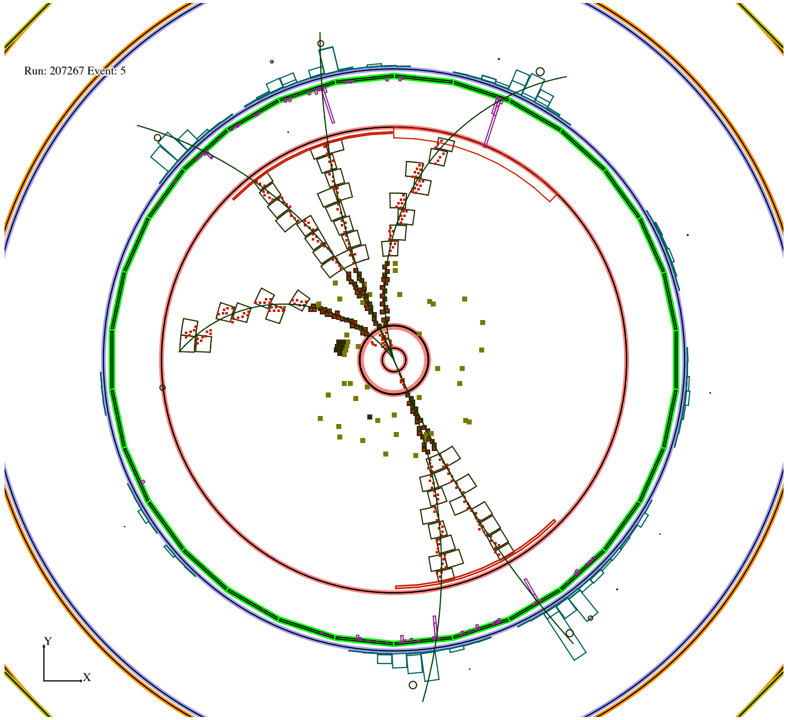
I. Bigi and H. Yamamoto, Physics Letters 349 (1995) 363-366

$D^0 \to K_{L,S}\pi^0$ $D^+ \to K_{L,S}\pi^+$ experimentally

- Challenging: Invisible K_L, difficult π^o.
- CLEO-c:
  - e+ e– → ψ(3770)→DD

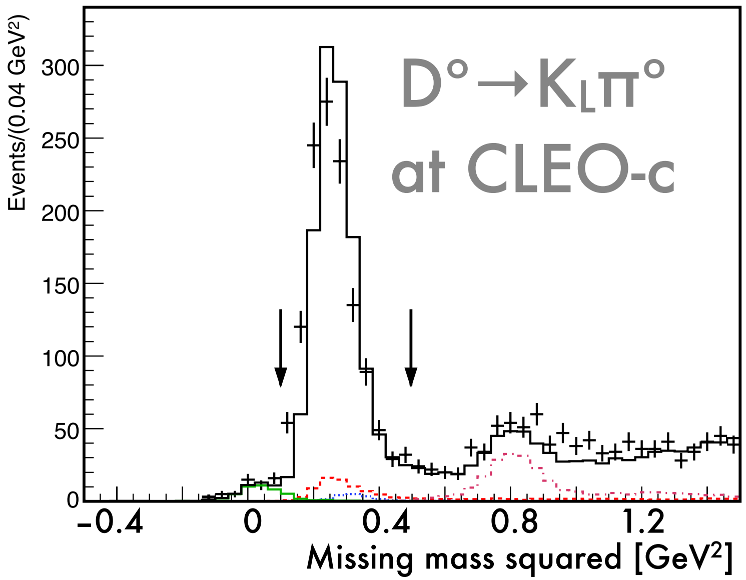
    100% of beam energy converted to DD pair ⇒ kinematic constraints.
  - Extremely clean environment, good calorimeter

CLEAN-c



$\psi(3770) \to D^0(K_S\pi^+\pi^-)\bar{D}^0(K^+\pi^-)$

D° → $K_{L,S}\pi^0$, at CLEO-c



- Clean missing mass-squared peak at $m_{K^o}{}^2 = 0.28\,\mathrm{GeV}^2$
- Lines: MC simulation. Crosses: Data.
- Result

$$\frac{\Gamma\left(D^0 \to K_S\pi^0\right) - \Gamma\left(D^0 \to K_L\pi^0\right)}{\Gamma\left(D^0 \to K_S\pi^0\right) + \Gamma\left(D^0 \to K_L\pi^0\right)} = 0.108 \pm 0.025 \pm 0.024$$

- In good agreement with U-spin prediction of $2\tan^2\theta = 0.109$

CLEO: PRL **100,** 091801 (2008)

$D^+ \to K_{L,S}\pi^+$ at CLEO-c

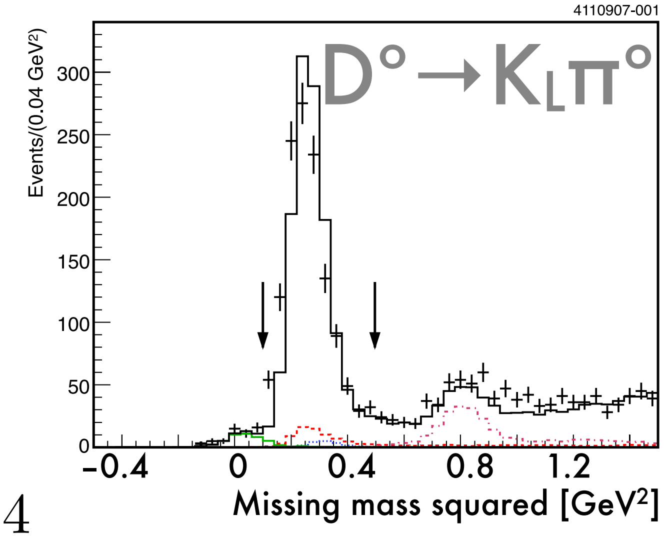
- Similar logic as for D°, but no U-spin symmetry.
- Still, prediction based on topology and SU(3) flavour possible, expect

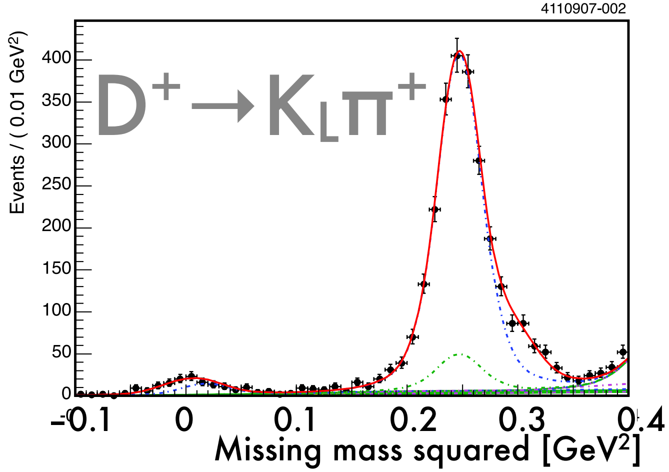
$$\frac{\Gamma\left(D^+ \to K_S\pi^+\right) - \Gamma\left(D^+ \to K_L\pi^+\right)}{\Gamma\left(D^+ \to K_S\pi^+\right) + \Gamma\left(D^+ \to K_L\pi^+\right)} \approx 0.04$$

D.-N. Gao, Phys. Lett. B **645**, 59 (2007)

- Result

$$\frac{\Gamma\left(D^+ \to K_S\pi^+\right) - \Gamma\left(D^+ \to K_L\pi^+\right)}{\Gamma\left(D^+ \to K_S\pi^+\right) + \Gamma\left(D^+ \to K_L\pi^+\right)} = 0.022 \pm 0.016 \pm 0.018$$

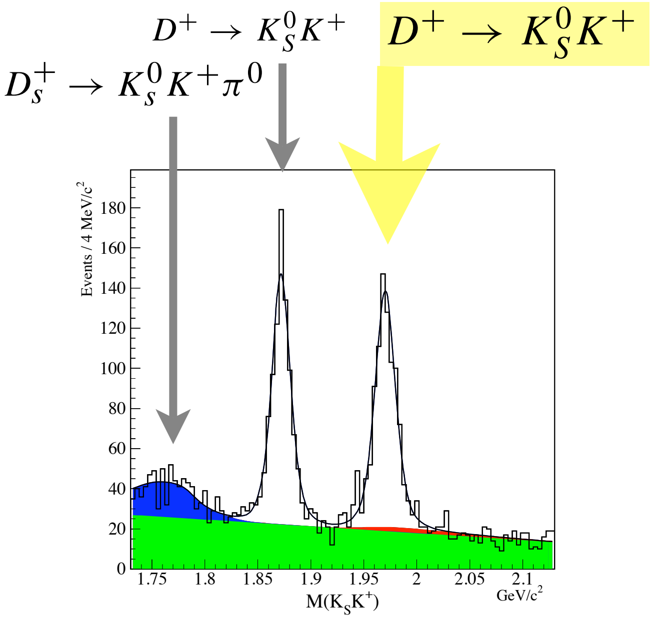


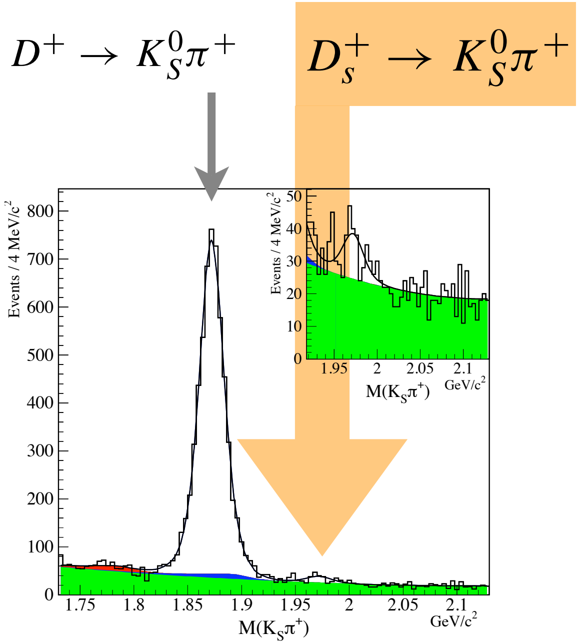


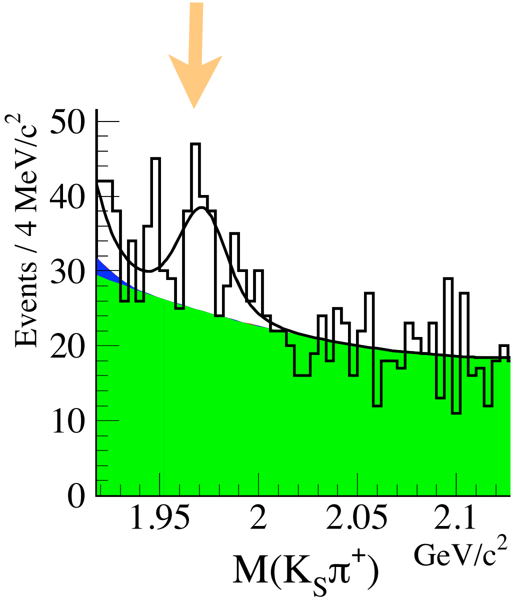
CLEO: PRL **100,** 091801 (2008)

Discovery of $D_S^+ \rightarrow K_S \pi^+ (\pi^- \pi^+)$ at FOCUS

Decay Mode	Ratio of Events	Efficiency Ratio	Branching Ratio
$\frac{\Gamma(D_s^+ \rightarrow K_S^0 \pi^- \pi^+ \pi^+)}{\Gamma(D_s^+ \rightarrow K_S^0 K^- \pi^+ \pi^+)}$	$\frac{179 \pm 36}{763 \pm 32}$	1.34	$0.18 \pm 0.04 \pm 0.05$
$\frac{\Gamma(D_s^+ \rightarrow K_S^0 \pi^+)}{\Gamma(D_s^+ \rightarrow K_S^0 K^+)}$	$\frac{113 \pm 26}{777 \pm 36}$	1.39	$0.104 \pm 0.024 \pm 0.013$







FOCUS: Phys.Lett.B660:147-153,2008

$D^o \rightarrow V\eta$

Predictions

- For $D^o \rightarrow VP$, use same topological approach as for $D^o \rightarrow PP$. Ignore Zweig-suppressed “singlet” topology (which was needed for $D^+_{(s)} \rightarrow P\eta$).
- Predict SCS B.R. based on CF rates.
- Global fit to topological amplitudes gives two solutions.

Mode	**Theory B.F. /10^{-3}** B. Bhattacharya, J. L. Rosner, arXiv:0812.3167v1 [hep-ph] (2008)	
	Sol A	Sol B
$D^o \rightarrow \phi\eta$	0.93 ± 0.09	1.4 ± 0.1
$D^o \rightarrow \omega\eta$	1.4 ± 0.09	1.27 ± 0.09
$D^o \rightarrow K^{*o}\ \eta$	0.038 ± 0.004	0.037 ± 0.004

$D^o \to V\eta$

Status until March

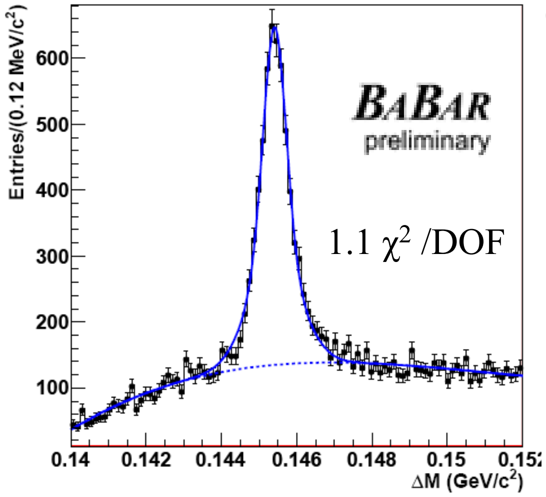
Mode	Theory B.F. /10^{-3} B. Bhattacharya, J. L. Rosner, arXiv:0812.3167v1 [hep-ph] (2008)		Experiment until recently
	Sol A	Sol B	
$D^o \to \phi\eta$	0.93 ± 0.09	1.4 ± 0.1	0.14 ± 0.04 (BELLE) [1]
$D^o \to \omega\eta$	1.4 ± 0.09	1.27 ± 0.09	
$D^o \to K^{*o}\,\eta$	0.038 ± 0.004	0.037 ± 0.004	

[1] Phys.Rev.Lett.92:101803,2004 [2] Caitlin Malone on behalf of the BaBar Collaboration at APS April Meeting 2009

D°→Vη

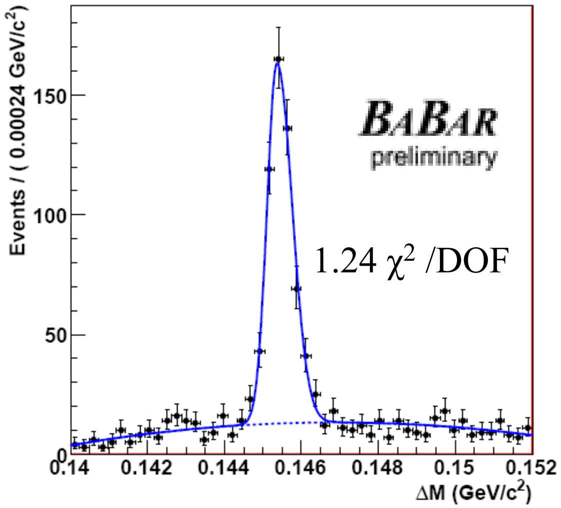
- BaBar analysed 467 fb^{-1} data (on and off resonance)
- About 1 billion D mesons in sample
- Preliminary result shown in April 2009 APS Meeting*:

$D^0 \to \omega\eta$



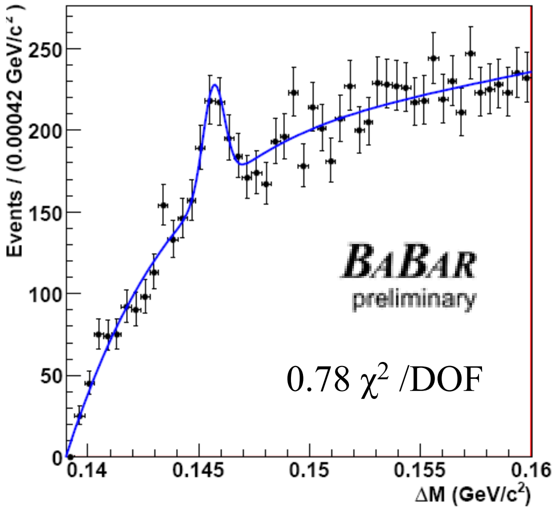
N = 4450 ± 103

$D^0 \to \varphi\eta$



N = 513 ± 26

$D^0 \to K^{*0}\eta$



N=117 ± 37

*) Caitlin Malone on behalf of the BaBar Collaboration at APS April Meeting 2009

$D^{o} \rightarrow V\eta$

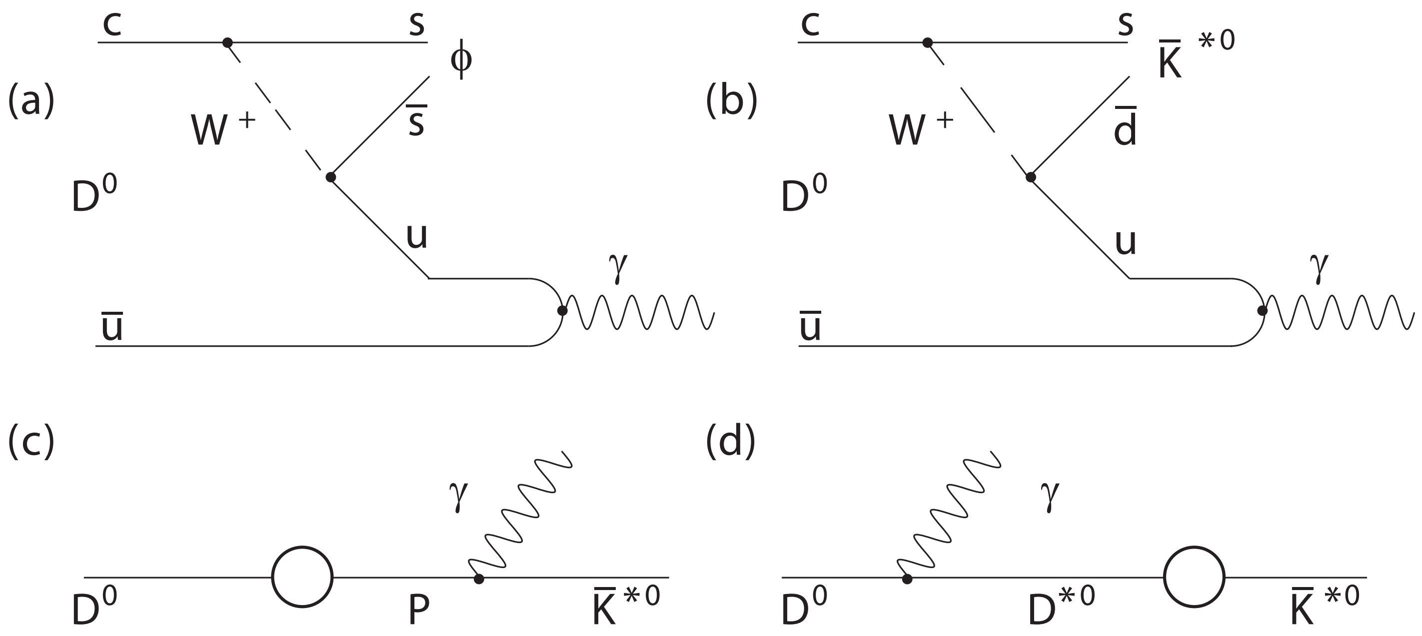
Mode	**Theory B.F. /10^{-3}** B. Bhattacharya, J. L. Rosner, arXiv: 0812.3167v1 [hep-ph] (2008)		Experiment until recently	BaBar Results (preliminary) April 08 [2]	
	Sol A	Sol B		BF	yield
$D^{o} \rightarrow \phi\eta$	0.93 ± 0.09	1.4 ± 0.1	0.14 ± 0.04 [1]	$0.21 \pm 0.01 \pm 0.02$	513 ± 26
$D^{o} \rightarrow \omega\eta$	1.4 ± 0.09	1.27 ± 0.09		$2.21 \pm 0.08 \pm 0.22$	4450 ± 103
$D^{o} \rightarrow K^{*o}\,\eta$	0.038 ± 0.004	0.037 ± 0.004		$0.048 \pm 0.010 \pm 0.004$	117 ± 37

[1] BELLE: Phys.Rev.Lett.92:101803,2004

[2] Caitlin Malone on behalf of the BaBar Collaboration at APS April Meeting 2009

Radiative Charm Decays

- In contrast to radiative B decays, radiative charm decays are dominated by long-distance contribution



- Rich laboratory for QCD

diagrams from BaBar, Phys. Rev. D 78, 071101 (2008)

Radiative Charm Decays

- Status until recently:

Mode	Experimental B.F. $(\times 10^{-5})$	Theoretical[3, 4, 5, 6, 7, 8, B.F. $(\times 10^{-5})$
$D^0 \to \phi\gamma$	$(2.43^{+0.66}_{-0.57}(stat.)^{+0.12}_{-0.14}(sys.)$ [10]	$0.1 - 3.4$
$D^0 \to \bar{K}^{*0}\gamma$	< 76 (90% C.L.) [11]	$7 - 80$
$D^0 \to \rho^0\gamma$	< 24 (90% C.L.) [11]	$0.1 - 6.3$
$D^0 \to \omega\gamma$	< 24 (90% C.L.) [11]	$0.1 - 0.9$

This table: BaBar, Phys. Rev. D 78, 071101 (2008)

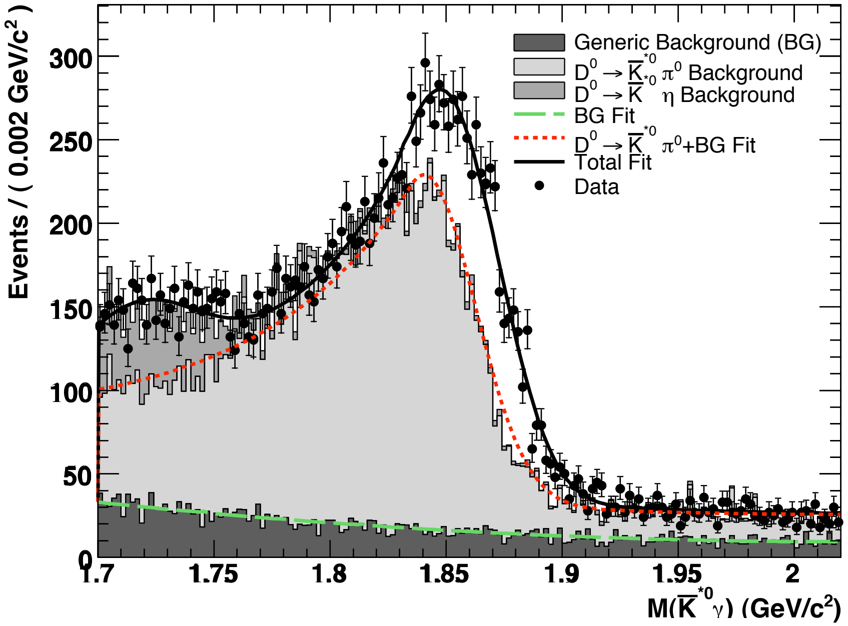
[3] B. Bajc, S. Fajfer, and R. J. Oakes, Phys. Rev. D51, 2230 (1995).
[4] B. Bajc, S. Fajfer, and R. J. Oakes, Phys. Rev. D54, 5883 (1996).
[5] G. Burdman, E. Golowich, J. L. Hewett, and S. Pakvasa, Phys. Rev. D52, 6383 (1995).
[6] H.-Y. Cheng et al., Phys. Rev. D51, 1199 (1995).
[7] S. Fajfer, A. Prapotnik, S. Prelovsek, P. Singer, and J. Zupan, Nucl. Phys. Proc. Suppl. 115, 93 (2003).
[8] S. Fajfer and P. Singer, Phys. Rev. D56, 4302 (1997).
[9] S. Fajfer, S. Prelovsek, and P. Singer, Eur. Phys. J. C6, 471 (1999).

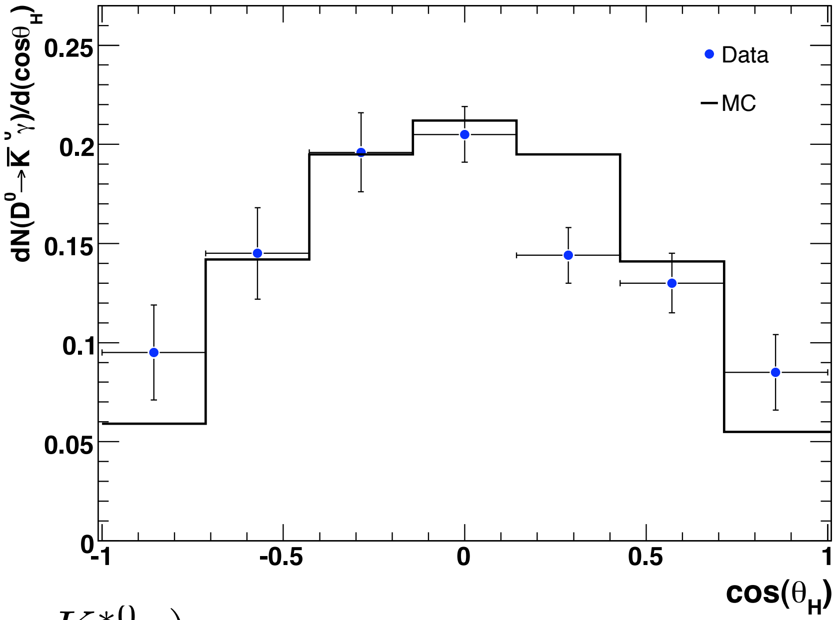
[10] K. Abe et al., Phys. Rev. Lett. 92, 101803 (2004), the published result has been rescaled using 07 PDG [15].
[11] D. M. Asner et al., Phys. Rev. D58, 092001 (1998)
[15] W.-M. Yao et al. (Particle Data Group), J. Phys. G33, 1 (2006), and 2007 partial update for the 2008 edition

D°→K*°γ at BaBar

mass

helicity angle





- ▆ Generic Background (BG)
- ▒ $D^0 \to \overline{K}^{*0}_{*0}\ \pi^0$ Background
- ▓ $D^0 \to \overline{K}\ \eta$ Background
- ‒ ‒ BG Fit
- ⋯ $D^0 \to \overline{K}^{*0}\ \pi^0$+BG Fit
- ― Total Fit
- ● Data

$$\frac{\mathcal{B}(D^0 \to K^{*0}\gamma)}{\mathcal{B}(D^0 \to K^-\pi^+)} = (8.43 \pm 0.51 \pm 0.70) \times 10^{-3}$$

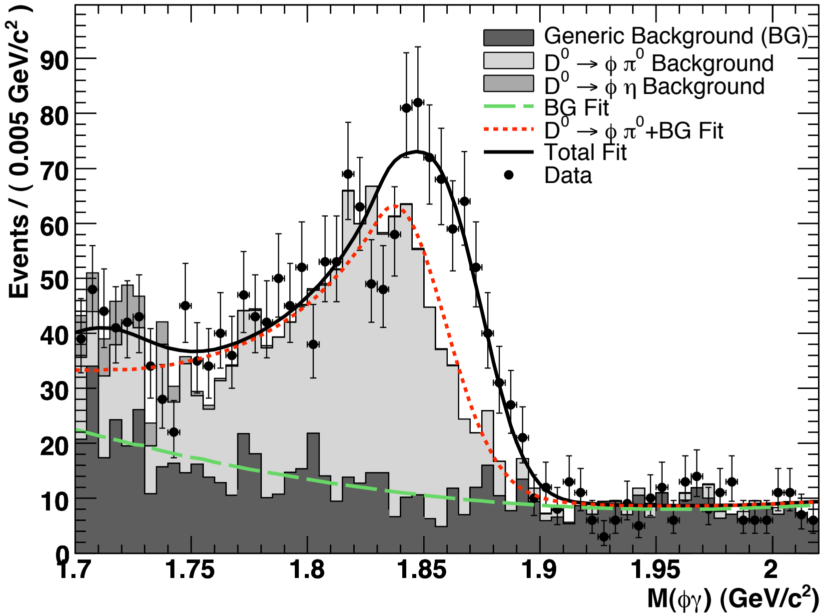
$$\mathcal{B}(D^0 \to \bar{K}^{*0}\gamma) = (3.22 \pm 0.20 \pm 0.27) \times 10^{-4}$$

First Observation of D°→K*°γ

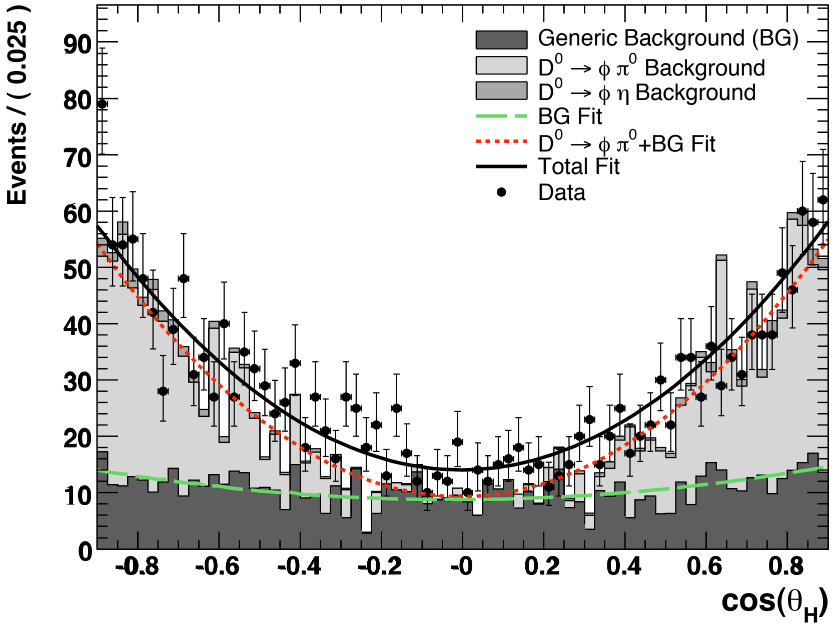
BaBar, Phys. Rev. D 78, 071101 (2008)

D°→φγ at BaBar

mass



helicity angle



$$\frac{\mathcal{B}(D^0 \to \phi\gamma)}{\mathcal{B}(D^0 \to K^-\pi^+)} = (7.15 \pm 0.78 \pm 0.69) \times 10^{-4}$$

$$\mathcal{B}(D^0 \to \phi\gamma) = (2.73 \pm 0.30 \pm 0.26) \times 10^{-5}$$

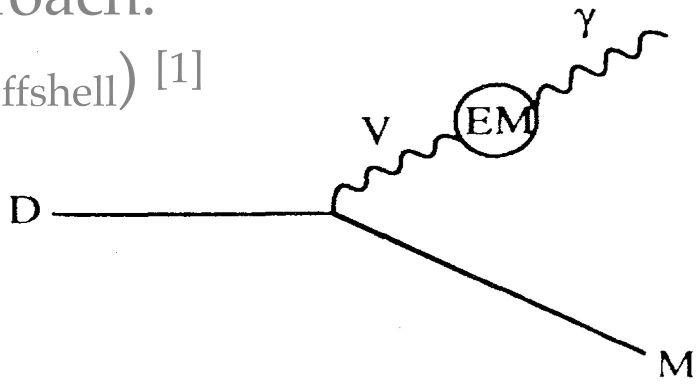
■ Generic Background (BG)
□ $D^0 \to \phi\,\pi^0$ Background
▨ $D^0 \to \phi\,\eta$ Background
— — BG Fit
········ $D^0 \to \phi\,\pi^0$+BG Fit
—— Total Fit
● Data

ca 1/2 the stat error, 2× sys error relative to 2004 BELLE measurement

BaBar, Phys. Rev. D 78, 071101 (2008)

VMD, D°→Vγ and D°→Vρ°

- Vector-Meson-Dominance approach:
  $A(D^o \to M\gamma) = (e/f_\rho)\, A(D \to M\rho^o_{\text{offshell}})$ [1]



- Predicts

$$\frac{\mathcal{B}(D^0 \to \phi\gamma)}{\mathcal{B}(D^0 \to \bar{K}^{*0}\gamma)} = \frac{\mathcal{B}(D^0 \to \phi\rho^0)}{\mathcal{B}(D^0 \to \bar{K}^{*0}\rho^0)}$$

- Find

$$\frac{\mathcal{B}(D^0 \to \phi\gamma)}{\mathcal{B}(D^0 \to \bar{K}^{*0}\gamma)} = (6.27 \pm 0.71 \pm 0.79) \times 10^{-2}$$

BaBar 08

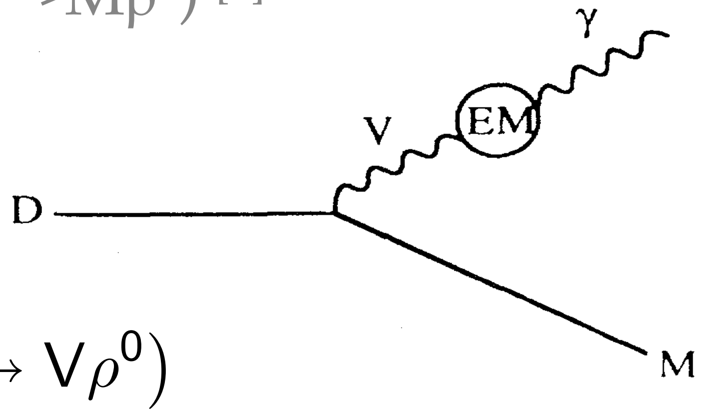
$$\frac{\mathcal{B}(D^0 \to \phi\rho^0)}{\mathcal{B}(D^0 \to \bar{K}^{*0}\rho^0)} = (6.7 \pm 1.6) \times 10^{-2}$$

PDG 07

[1] G. Burdman, E. Golowich, J. L. Hewett, and S. Pakvasa, Phys. Rev. , 6383 (1995)

VMD, $D^\circ \to V\gamma$ and $D^\circ \to V\rho^\circ$

- VMD: $A(D^o \to M\gamma) \approx (e/f_\rho)\, A(D \to M\rho^o)$ [1]



- Using $(e/f_\rho) = 0.06$ [2], expect:
  $$\mathcal{B}\left(D^0 \to V\gamma\right) \approx \underline{0.0036} \cdot \mathcal{B}\left(D^0 \to V\rho^0\right)$$

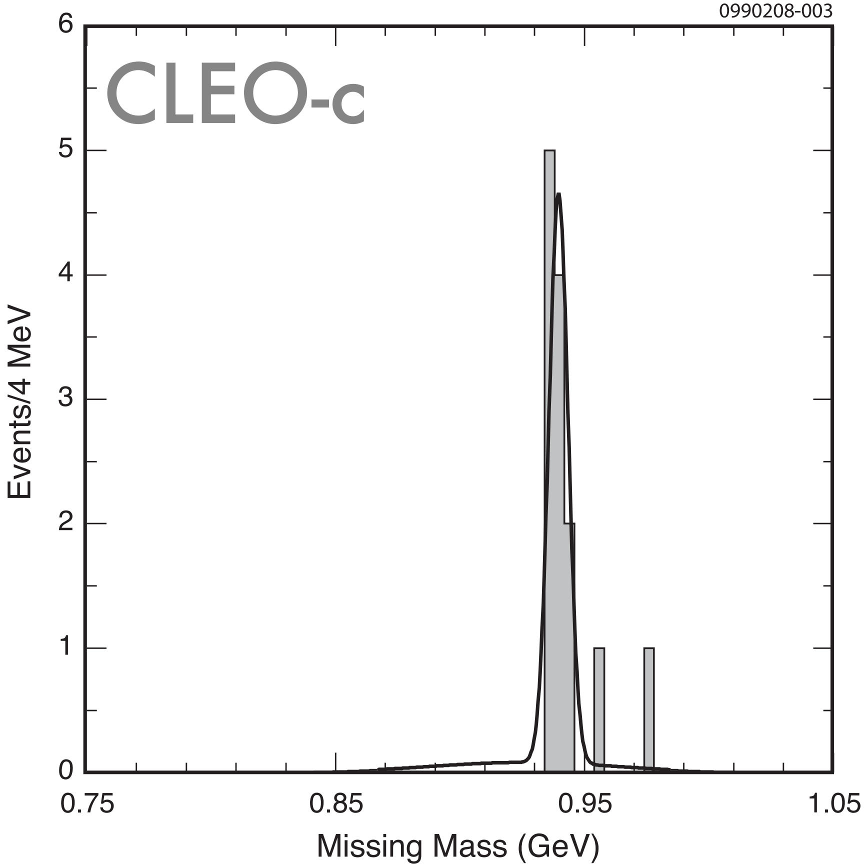
- Find
  $$\begin{aligned} \mathcal{B}(D^0 \to \bar{K}^{*0}\gamma) &= \underline{(0.021 \pm 0.005}) \, \mathcal{B}(D^0 \to \bar{K}^{*0}\rho^0) \\ \mathcal{B}(D^0 \to \phi\gamma) &= \underline{(0.020 \pm 0.003}) \, \mathcal{B}(D^0 \to \phi\rho^0) \end{aligned}$$

  i.e. $\mathcal{B}(D^o \to V\gamma) \approx 6\,(e/f_\rho)^2\, \mathcal{B}(D^o \to V\rho^o)$

- Suggests other processes might be important.

[1] G. Burdman, E. Golowich, J. L. Hewett, and S. Pakvasa, Phys. Rev. , 6383 (1995) [2] E. Golowich and S. Pakvasa, Phys. Rev. D 51, 1215 - 1223 (1995)

First Observation of $D_s^+ \to p\bar{n}$

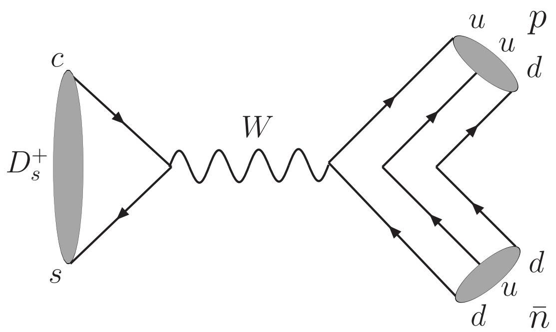


CLEO-c: Phys. Rev. Lett. 100, 181802 (2008)

- Only baryonic state kinematically accessible to D^0 D^+ D_s^+
- Virtually background-free reconstruction at CLEO-c
- First observation of meson → 2 baryons plus nothing else.

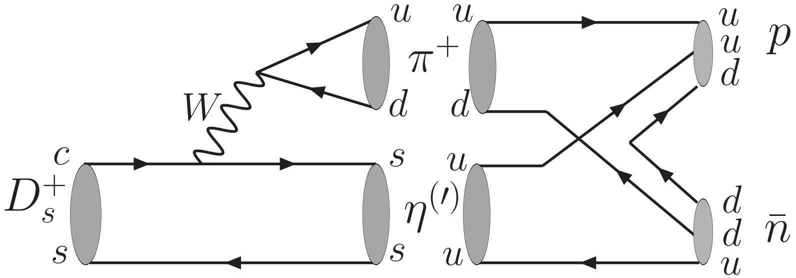
$$\mathcal{B}(D_s^+ \to p\bar{n}) = (1.30 \pm 0.36^{+0.12}_{-0.16}) \times 10^{-3}$$

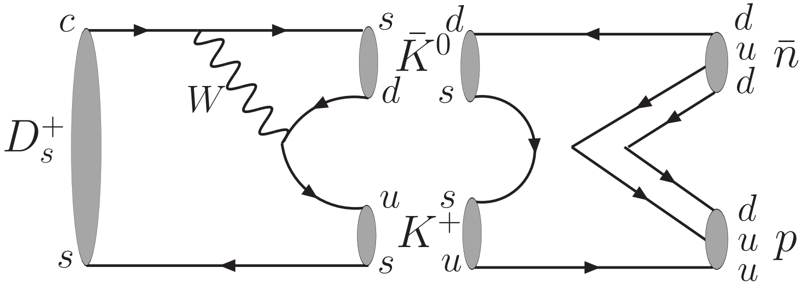
Theory of $D_s^+ \rightarrow p\bar{n}$



- Short Distance:

$$\mathcal{B}(D_s^+ \to p\bar{n})_{\mathrm{SD}} = (0.4^{+1.1}_{-0.3}) \times 10^{-6}$$





- Long Distance $\mathcal{B}(D_s^+ \to p\bar{n}) \approx \left(0.8^{+2.4}_{-0.6}\right) \times 10^{-3}$
- Measured $\mathcal{B}(D_s^+ \to p\bar{n}) = (1.30 \pm 0.36^{+0.12}_{-0.16}) \times 10^{-3}$

Chen, Cheng, Hsiao: Phys.Lett.B663:326-329,2008

Absolute BF

- Important normalising modes: $D^0 \to K^-\pi^+$

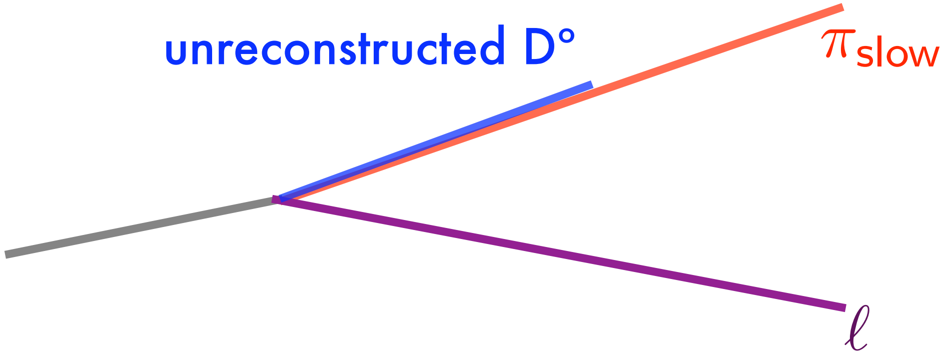
  $D^+ \to K^-\pi^+\pi^+$

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

  (historically "$\phi\pi^+$")

- Methods - need to know there is a D before reconstructing it
  - BaBar: partial reconstruction of $D^* \to D\pi$, using only the π (and the rest of the event, but not the D)
  - BELLE: $e^+e^- \to D_s^{*+}D_{s1}^-(\to \overline{D}^{*0}K^-)$
  - CLEO-c: $e^+e^- \to \psi \to \overline{D}\,D$

BaBar absolute BF D°→K⁻π⁺



- Partial reconstruction of

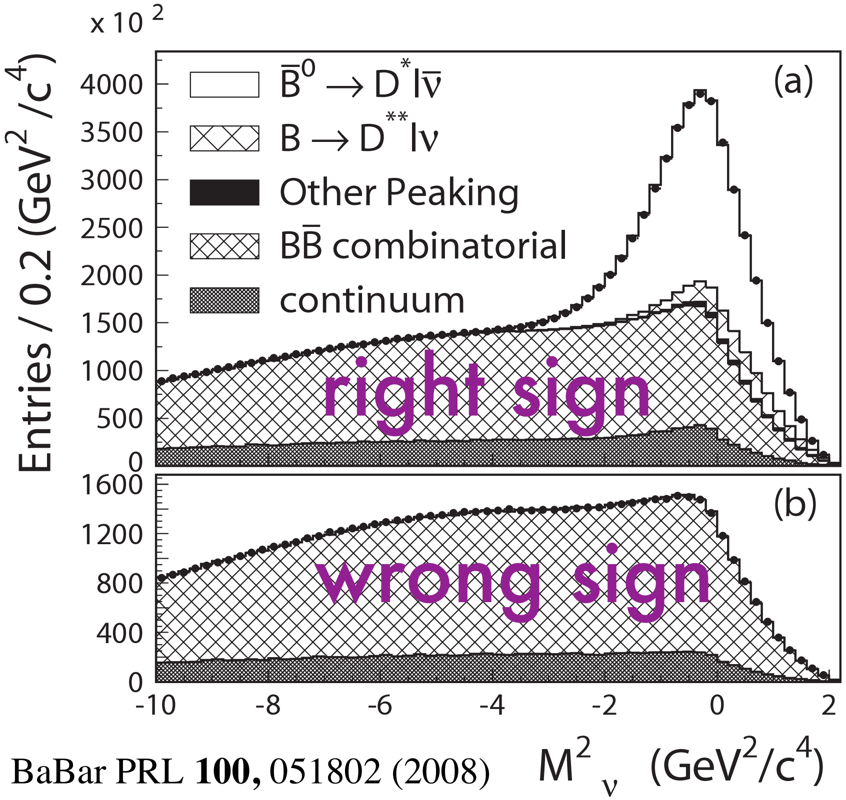
$$\bar{B}^0 \rightarrow D^{*+}(X)\ell^-\bar{\nu}_\ell$$

$$D^{*+} \rightarrow D^0\pi_{\text{slow}}$$

- Because of near-zero momentum of π_{slow} in D* restframe, D° direction ≈ π_{slow} direction.
- Together with beam constraints, enough information to reconstruct full decay w/o reconstructing D°
- This inclusive reconstruction provides normalisation.

BaBar absolute BF $D^{\circ}\to K^-\pi^+$

Reconstructed ν mass in $\bar{B}^0 \to D^{*+}(X)\ell^-\bar{\nu}_\ell$.



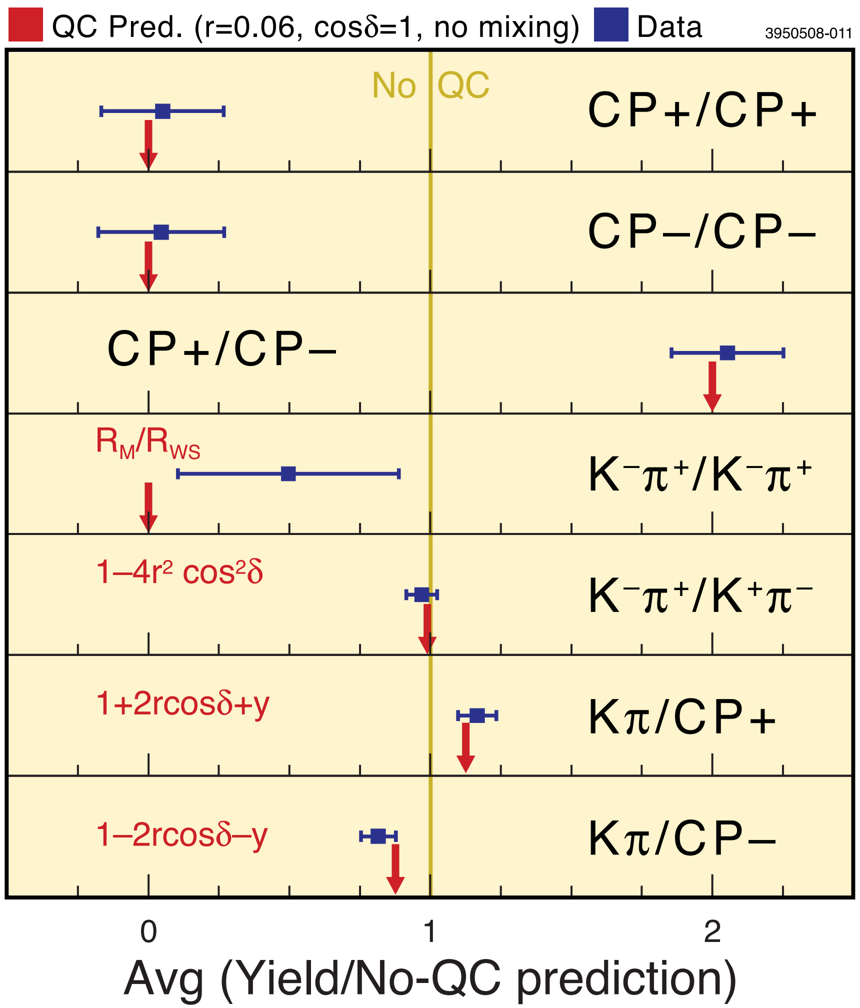
BaBar PRL **100,** 051802 (2008)

- $BR(D^{\circ}\to K^-\pi^+) = (4.007 \pm 0.037 \pm 0.072)\%$

Absolute BF at CLEO-c

- CLEO-c produces DD pairs:
  - $e^+e^- \to \psi(3770) \to D^+ D^-$
  - $e^+e^- \to \psi(3770) \to D^o \overline{D}^o$
  - $e^+e^- \to \psi(4170) \to D_S{}^{+*} D_S{}^-$
- Reconstruct both D mesons. One D (in decays to various high-yield modes) normalises the BF of the other to a specific final state.
- Some interesting and insightful complications arise for $\psi(3770) \to D^o \overline{D}^o$...

Exploiting Quantum Correlations at CLEO-c



PRL 100, 221801 (2008), PRD 78, 012001 (2008)

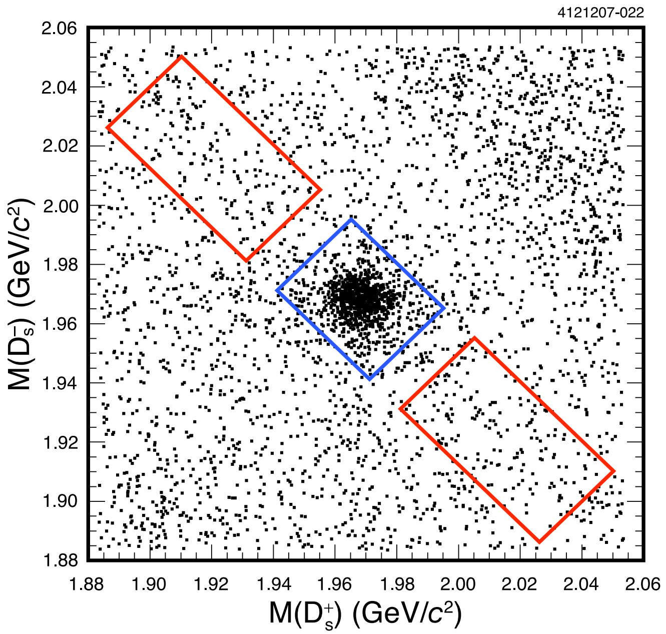
- $e^+e^- \to \psi(3770) \to D^o\, D^o$ is CP-odd and flavour neutral
- Quantum correlations allow the extraction of phases, including the phase δ between $A(D^o \to K^-\pi^+)$, $A(D^o \to K^+\pi^-)$ needed in D-mixing measurements:

$$\delta_D^{K\pi} = 22^{o}{}^{+11^o}_{-12^o}{}^{+9^o}_{-11^o}$$

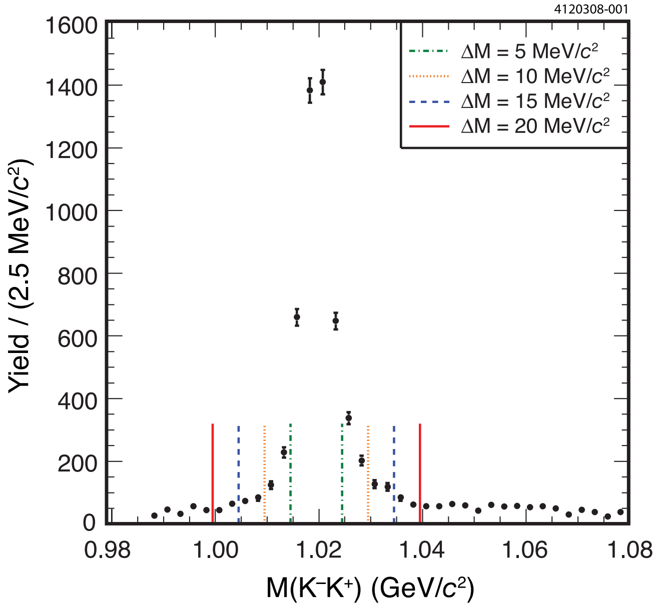
See Guy Wilkinson's talk yesterday and Paras Naik's talk earlier today.

Absolute Ds→KKπ BF at CLEO-c

$M(D_s^-)$ vs $M(D_s^+)$



KK pair mass - full phase space (not just φ) included in analysis



additionally the BF was calculated for various subsections of phase space indicated by the lines.

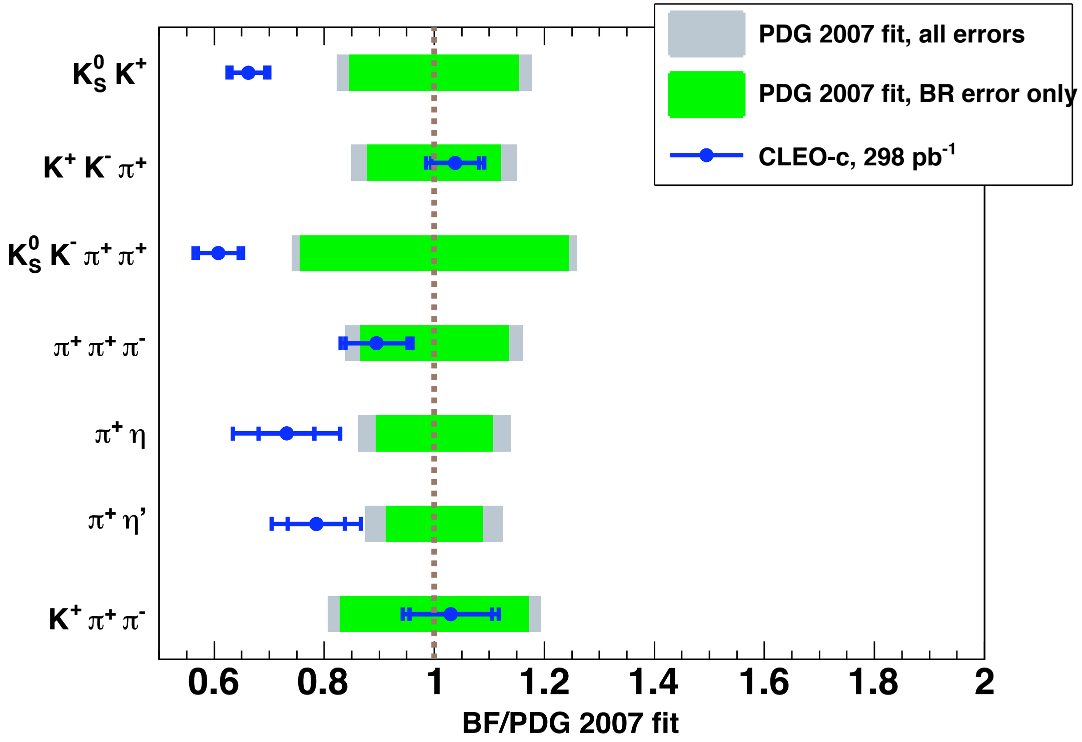
298 /pb of CLEO-c data at E_{cm} = 4.17 GeV

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

Phys.Rev.Lett.100:161804,2008 (arxiv)

More absolute Ds BF at CLEO-c

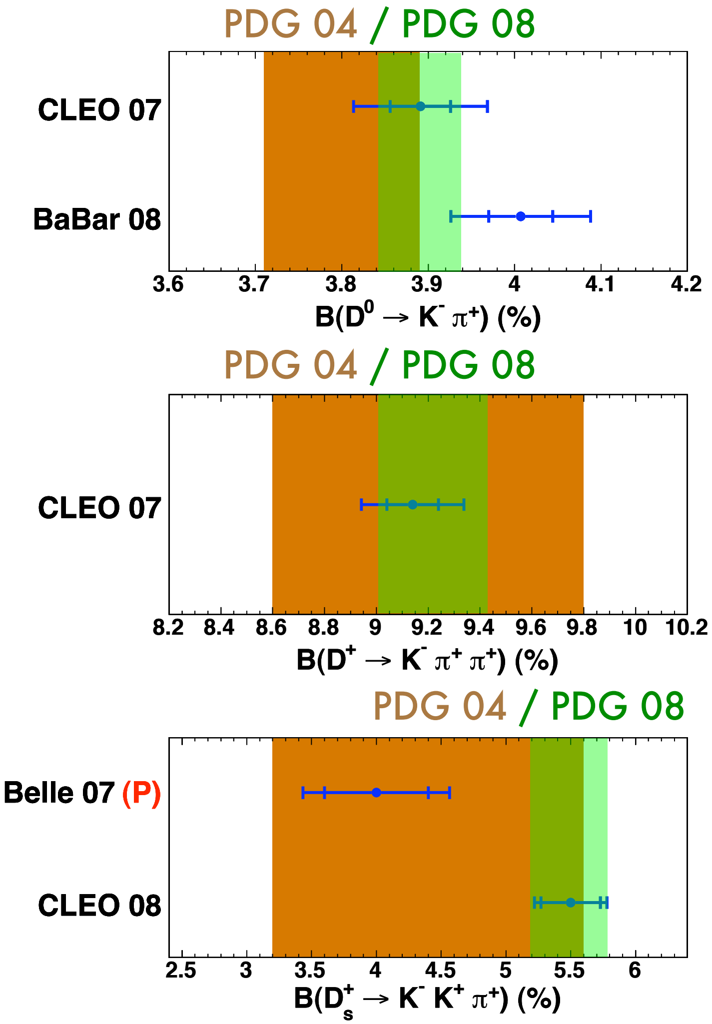
Mode	This result $\mathcal{B}$ (%)
$K_S^0 K^+$	$1.49 \pm 0.07 \pm 0.05$
$K^- K^+ \pi^+$	$5.50 \pm 0.23 \pm 0.16$
$K^- K^+ \pi^+ \pi^0$	$5.65 \pm 0.29 \pm 0.40$
$K_S^0 K^- \pi^+ \pi^+$	$1.64 \pm 0.10 \pm 0.07$
$\pi^+ \pi^+ \pi^-$	$1.11 \pm 0.07 \pm 0.04$
$\pi^+ \eta$	$1.58 \pm 0.11 \pm 0.18$
$\pi^+ \eta'$	$3.77 \pm 0.25 \pm 0.30$
$K^+ \pi^+ \pi^-$	$0.69 \pm 0.05 \pm 0.03$



Phys.Rev.Lett.100:161804,2008 (arxiv)

Absolute BF summary

- Progress in key reference modes
- Important for Ds: replace Ds→φπ (with uncertainties in interference effects etc) with Ds→KKπ

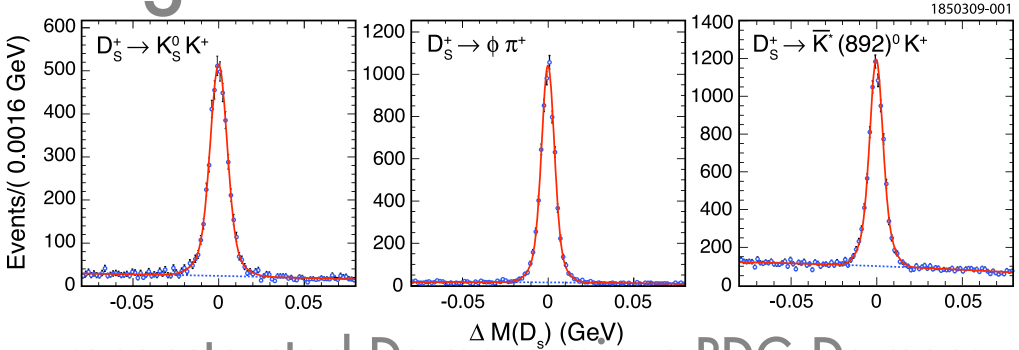


Belle 07: hep-ex/0701053 (Prel.) [552 fb^{-1}]
CLEO 07: PRD 76, 112001 [281 pb^{-1}]
BaBar 08: PRL 100, 051802 [210 fb^{-1}]
CLEO 08: PRL 100, 161804 [298 pb^{-1}]

Inclusive Ds BF

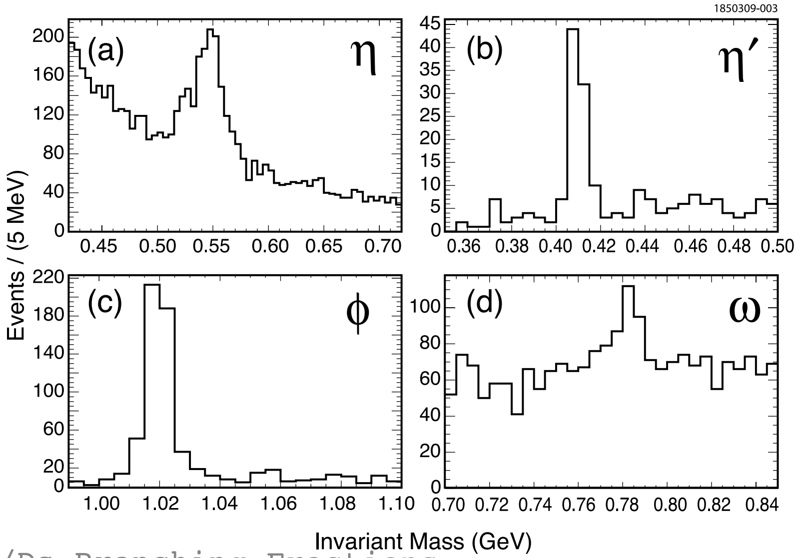
- $e^+e^- \to \psi(4170) \to D_S^{+*} D_S^-$
- Fully reconstruct one Ds as tag
- Reconstruction of desired decay product on other side gives absolute, inclusive BF.

Tag:



reconstructed Ds mass minus PDG Ds mass

Inclusive reconstruction:



CLEO: arXiv:0904.2417 [hep-ex], submitted to PRD

Inclusive Ds BF Results

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^o: 18.4±2.0, $\bar{K}^o$ 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)				

[1] Prediction: Gronau, Rosner , arXiv:0903.2287, Mar 2009, Submitted to Phys.Rev.D

CLEO result: arXiv:0904.2417 [hep-ex], submitted to PRD

Inclusive Ds BF Results

Mode	Yield(%)	K^0_L 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
$D_s^+ \to K^- X$	$18.7 \pm 0.5 \pm 0.2$			$13\ _{-\ 12}$	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
$D_s^+ \to \omega X$	[illegible]				0.8±0.1
$D_s^+ \to f_0(980) X, f_0(980) \to \pi^+\pi^-$	$< 1.3\%$ (90% CL)				
$D_s^+ \to K^0_S X$	$19.0 \pm 1.0 \pm 0.4$	$D_s^+ \to K^0_L X$	15.6 ± 2.0	20 ± 14	K°: 18.4±2.0, $\bar{\text{K}}$° 22.7± 2.2
$D_s^+ \to K^0_S K^0_S X$	$1.7 \pm 0.3 \pm 0.1$	$D_s^+ \to K^0_L K^0_S X$	5.0 ± 1.0		
$D_s^+ \to K^0_S K^+ X$	$5.8 \pm 0.5 \pm 0.1$	$D_s^+ \to K^0_L K^+ X$	5.2 ± 0.7		
$D_s^+ \to K^0_S K^- X$	$1.9 \pm 0.4 \pm 0.1$	$D_s^+ \to K^0_L K^- X$	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)				

$$D_s^+ \to \eta' X \quad 11.7 \pm 1.7 \pm 0.7 \qquad 18.2 \pm 2.1$$

[1] Prediction: Gronau, Rosner , arXiv:0903.2287, Mar 2009, Submitted to Phys.Rev.D

CLEO result (2009): arXiv:0904.2417 [hep-ex], submitted to PRD

Inclusive Ds BF Results

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
$D_s^+ \to \eta' X$	[illegible]				18.2±2.1
$D_s^+ \to \phi X$	$15.7 \pm 0.8 \pm 0.6$				19.2±2
$D_s^+ \to \omega X$	$6.1 \pm 1.4 \pm 0.3$				0.8±0.1
$D_s^+ \to f_0(980)X, f_0(980) \to \pi^+\pi^-$	$< 1.3\%$ (90% CL)				
$D_s^+ \to K_S^0 X$	[illegible]	$D_s^+ \to K_L^0 X$	[illegible]		[illegible] K⁰ 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		
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[1] Prediction: Gronau, Rosner , arXiv:0903.2287, Mar 2009, Submitted to Phys.Rev.D

CLEO result (2009): arXiv:0904.2417 [hep-ex], submitted to PRD

Direct CP Violation

- CP violation in charm provides one of the most powerful tests of the SM. See earlier sessions today
- Main focus there: time-dependent studies
- Here: compare time-integrated decay rates:

$$A_{CP} = \frac{\Gamma(\mathrm{D} \to \mathrm{f}) - \Gamma\left(\bar{\mathrm{D}} \to \bar{\mathrm{f}}\right)}{\Gamma(\mathrm{D} \to \mathrm{f}) + \Gamma\left(\bar{\mathrm{D}} \to \bar{\mathrm{f}}\right)}$$

- Not hopeless, but in 2-body modes “probably need to aim for accuracy of 10^{-3}” (Ikaros Bigi this morning).

Direct CPV in D°, D+

- Plenty of results from BaBar, BELLE, CDF, CLEO, E791, FOCUS, averaged by HFAG
- Table shows averages for those results that received updates in 2007 or 2008.
- Plenty more modes
- Reaching per-mil precision.

	Mode	A_{CP}(%) Charm09	A_{CP}(%) Charm07
D^o	K^+K^-	-0.16±0.23	1.36±1.2
	$\pi^+\pi^-$	0.22 ± 0.37	1.27±1.25
	$\pi^+\pi^-\pi^o$	-0.23±0.42	1.0±9.0
	$K^-\pi^+\pi^o$	0.16±0.89	3.1±8.6
	$K^-K^+\pi^o$	0.16 ± 0.89	-
D^+	$K^-K^+\pi^+$	0.39 ± 0.61	0.7±0.8
	$K_S\pi^+$	-0.86 ± 0.90	-1.6±1.7
	$K_S\pi^+\pi^o$	0.3 ± 0.9 ± 0.3	-
	$K^-\pi^+\pi^+\pi^o$	1.0 ± 0.9 ± 0.9	-

Direct CPV in Ds

- CLEO-c's Ds data allowed for the first time a precise test of direct CP in the Ds system
- Plenty of modes, all results new since Charm 2007
- Many results at the few % level.

Mode	A_{CP}(%)
$\pi^+\eta$	-8.2 ± 5.2 ± 0.8
$\pi^+\eta'$	-5.5 ± 3.7 ± 1.2
$K_S\pi^+$	27 ± 11
$K_S\pi^o$	2 ± 29
$K^+\eta$	-20 ± 18
$K^+\eta'$	-17 ± 37
K^+K_S	4.9 ± 2.1 ± 0.9
$\pi^+\pi^-\pi^+$	2.0 ± 4.6 ± 0.7
$K^+\pi^+\pi^-$	11.2 ± 7.0 ± 0.9
$K_SK^-\pi^+\pi^+$	-0.7 ± 3.6 ± 1.1
$K^+K^-\pi^+\pi^0$	-5.9 ± 4.2 ± 1.2

Prospects for direct CPV

- Example: $D^o \rightarrow K^+\overline{K}^-$
  - BaBar 2008: +0.0000 ± 0.0034 ± 0.0013
  - BELLE 2008: -0.0043 ± 0.0030 ± 0.0011
  - World average (HFAG): +0.0022 ± 0.0037
- CDF has obtained its result of +0.020 ± 0.012 ± 0.006 with only 2% of its current data set. CDF could beat world stat precision now.
- LHCb, due to start this year, expects stat precision of 0.004% in 10/fb (ca 5 years, using charm from B decays, including prompt charm will improve this further).

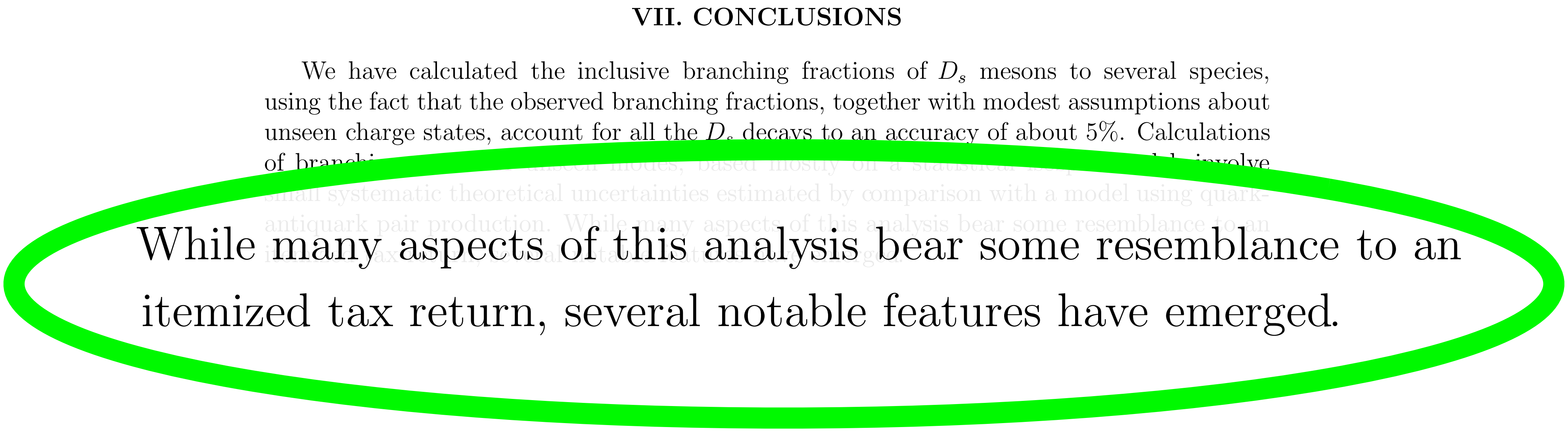
Summary

- Lots of new precise D branching fractions - inclusive, exclusive, relative and absolute. A lot of new Ds results.
- $SU(3)_F$ topological approach describes data reasonably well except, it seems, when $\eta^{(\prime)}$ or ω are involved. Why?
- $D^o \to K_S \pi^o \neq D^o \to K_L \pi^o$, asymmetry as expected by U-spin.
- Do we understand $D^o \to V\gamma$, $D^o \to V\rho^o$ (ratio too large)?
- New modes incl. $D^o \to \phi\eta$, $D^o \to \omega\eta$, with surprising BF's, and the first meson→2 baryon decay: $D_s^+ \to p\bar{n}$
- Increase in direct CPV sensitivity from percent to permil since Charm 2007

Backup

Inclusive BF prediction from exclusive rates

Gronau, Rosner, "Ds Inclusive Decays" arXiv:0903.2287, Mar 2009, Submitted to Phys.Rev.D



VII. CONCLUSIONS

We have calculated the inclusive branching fractions of D_s mesons to several species, using the fact that the observed branching fractions, together with modest assumptions about unseen charge states, account for all the D_s decays to an accuracy of about 5%. Calculations of branchi [illegible] unseen modes, based mostly on a statistical [illegible] involve small systematic theoretical uncertainties estimated by comparison with a model using quark-antiquark pair production. While many aspects of this analysis bear some resemblance to an itemized tax return, several notable features have emerged.

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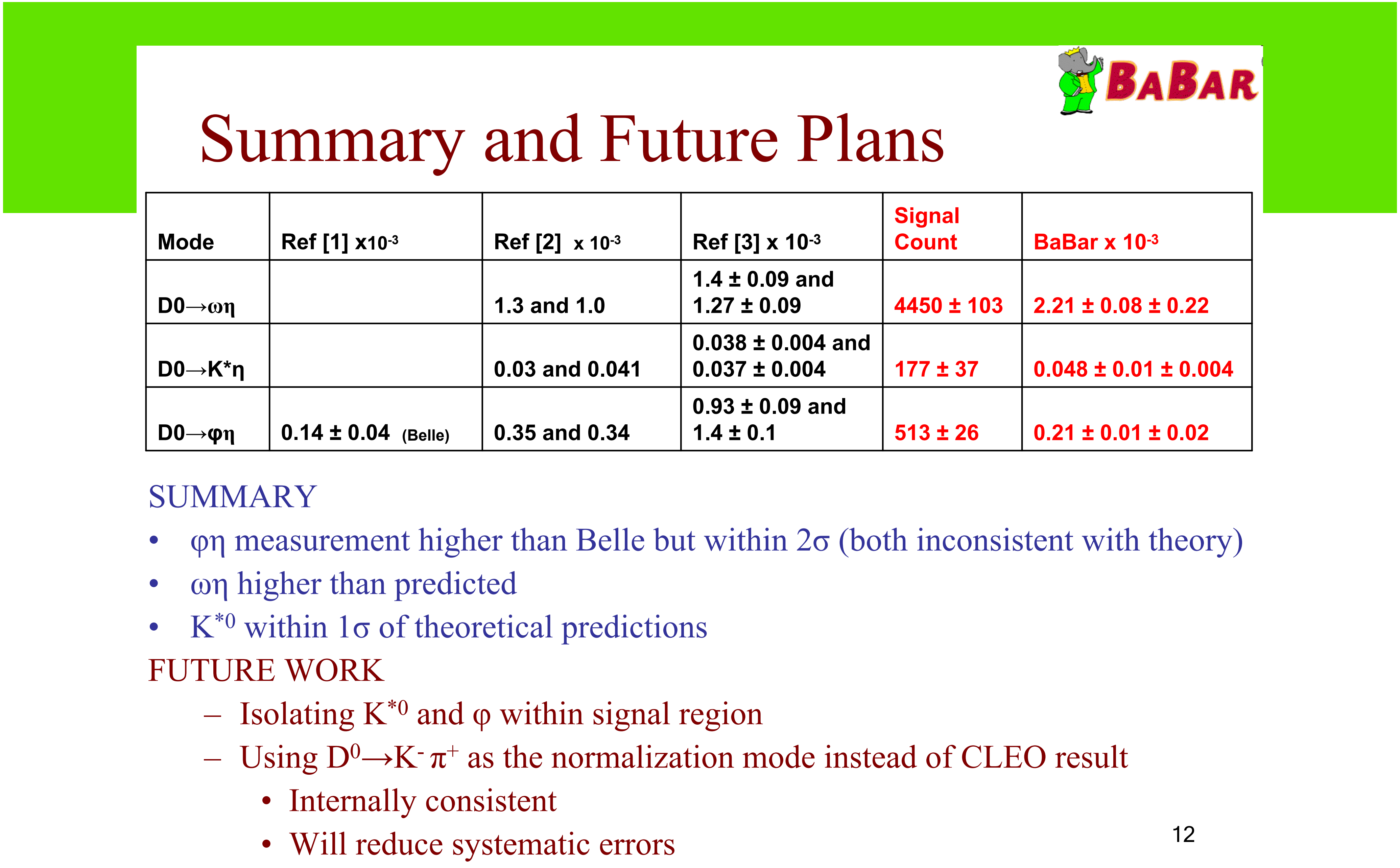


Summary and Future Plans

Mode	Ref [1] x10^{-3}	Ref [2] x 10^{-3}	Ref [3] x 10^{-3}	Signal Count	BaBar x 10^{-3}
$D0\to\omega\eta$		1.3 and 1.0	1.4 ± 0.09 and 1.27 ± 0.09	4450 ± 103	2.21 ± 0.08 ± 0.22
$D0\to K^*\eta$		0.03 and 0.041	0.038 ± 0.004 and 0.037 ± 0.004	177 ± 37	0.048 ± 0.01 ± 0.004
$D0\to\varphi\eta$	0.14 ± 0.04 (Belle)	0.35 and 0.34	0.93 ± 0.09 and 1.4 ± 0.1	513 ± 26	0.21 ± 0.01 ± 0.02

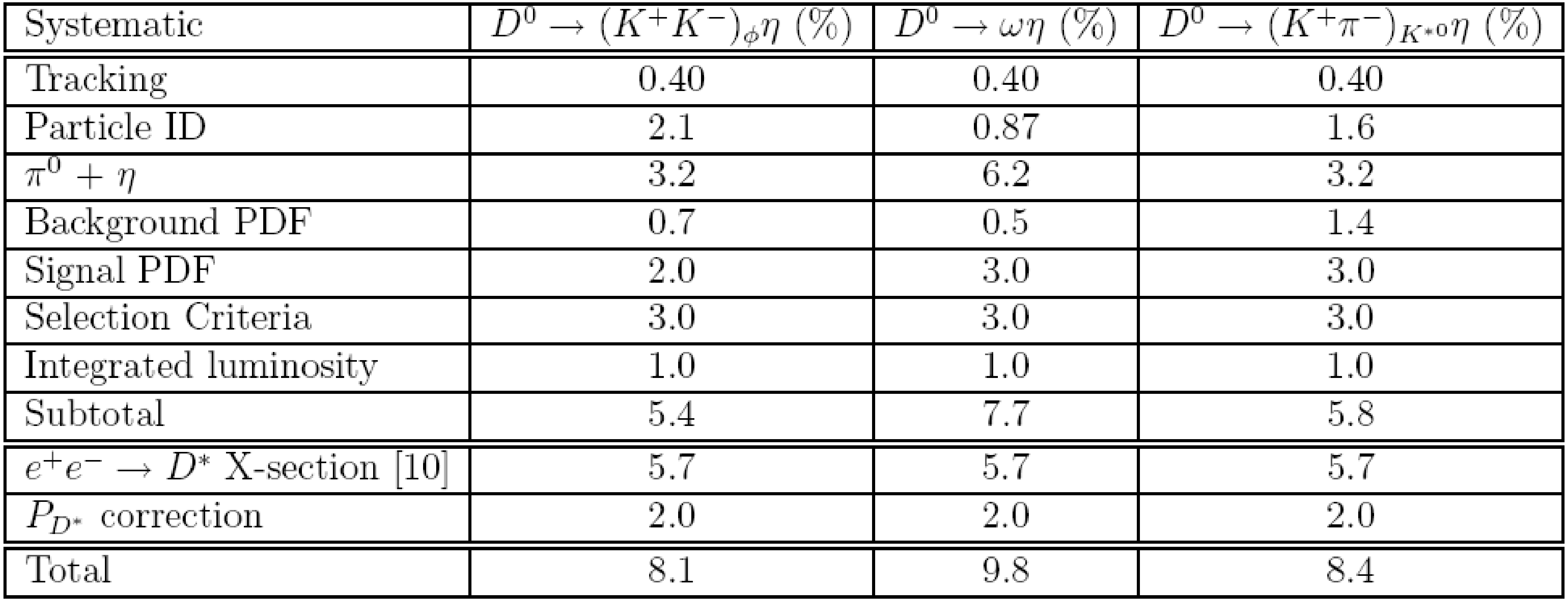
SUMMARY

- $\varphi\eta$ measurement higher than Belle but within 2σ (both inconsistent with theory)
- $\omega\eta$ higher than predicted
- K^{*0} within 1σ of theoretical predictions

FUTURE WORK

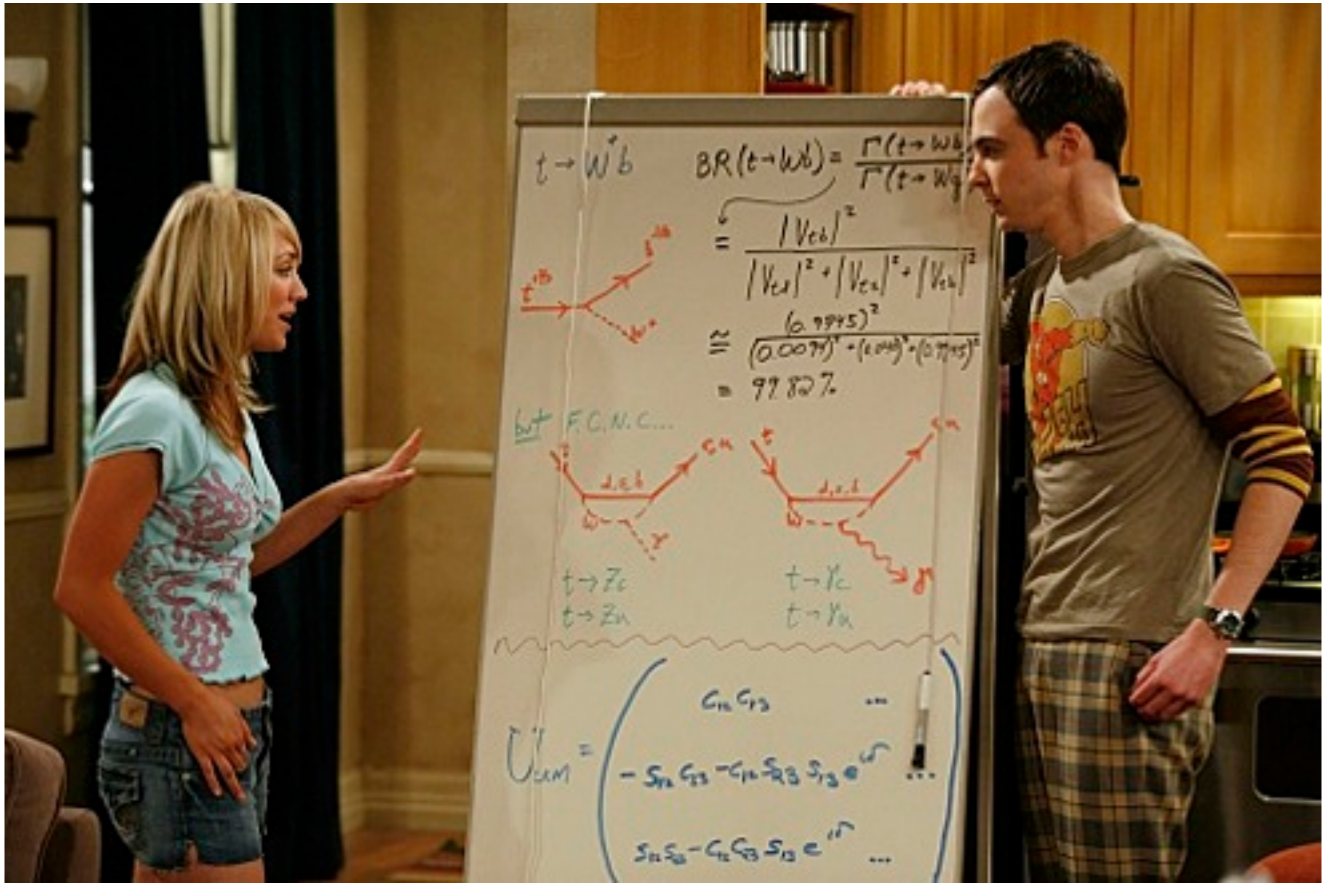
- Isolating K^{*0} and φ within signal region
- Using $D^0\to K^-\pi^+$ as the normalization mode instead of CLEO result
  - Internally consistent
  - Will reduce systematic errors

slide by: Caitlin Malone on behalf of the BaBar Collaboration at APS April Meeting 2009



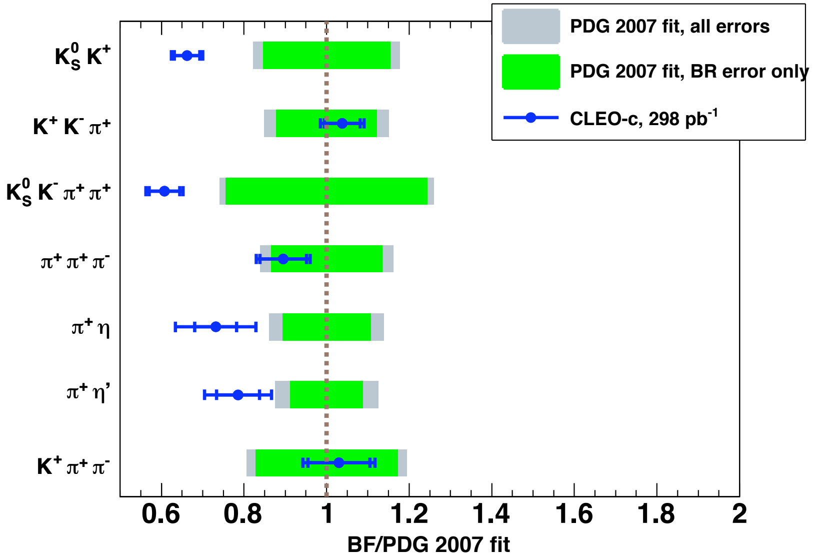
Systematic	$D^0 \to (K^+K^-)_\phi \eta$ (%)	$D^0 \to \omega\eta$ (%)	$D^0 \to (K^+\pi^-)_{K^{*0}} \eta$ (%)
Tracking	0.40	0.40	0.40
Particle ID	2.1	0.87	1.6
$\pi^0 + \eta$	3.2	6.2	3.2
Background PDF	0.7	0.5	1.4
Signal PDF	2.0	3.0	3.0
Selection Criteria	3.0	3.0	3.0
Integrated luminosity	1.0	1.0	1.0
Subtotal	5.4	7.7	5.8
$e^+e^- \to D^*$ X-section [10]	5.7	5.7	5.7
P_{D^*} correction	2.0	2.0	2.0
Total	8.1	9.8	8.4

slide by: Caitlin Malone on behalf of the BaBar Collaboration at APS April Meeting 2009


t → W b
BR(t→Wb) = Γ(t→Wb) / Γ(t→Wq)
= |Vtb|² / (|Vtd|² + |Vts|² + |Vtb|²)
≅ (0.9945)² / ((0.0074)² + (0.040)² + (0.9945)²)
= 99.82%
but F.C.N.C...
d,s,b
W
γ
t→Zc
t→Zu
t→γc
t→γu
U_CKM =
c12 c13 ...
−s12 c23 − c12 s23 s13 e^{iδ} ...
s12 s23 − c12 c23 s13 e^{iδ} ...

Absolute Ds BR

Mode	This result $\mathcal{B}$ (%)	PDG 2007 fit $\mathcal{B}$ (%)	$\mathcal{B}/\mathcal{B}(K^-K^+\pi^+)$	$\mathcal{A}_{CP}$ (%)
$K^0_S K^+$	$1.49 \pm 0.07 \pm 0.05$	2.2 ± 0.4	$0.270 \pm 0.009 \pm 0.008$	$+4.9 \pm 2.1 \pm 0.9$
$K^- K^+ \pi^+$	$5.50 \pm 0.23 \pm 0.16$	5.3 ± 0.8	1	$+0.3 \pm 1.1 \pm 0.8$
$K^- K^+ \pi^+ \pi^0$	$5.65 \pm 0.29 \pm 0.40$	$\cdots$	$1.03 \pm 0.05 \pm 0.08$	$-5.9 \pm 4.2 \pm 1.2$
$K^0_S K^- \pi^+ \pi^+$	$1.64 \pm 0.10 \pm 0.07$	2.7 ± 0.7	$0.298 \pm 0.014 \pm 0.011$	$-0.7 \pm 3.6 \pm 1.1$
$\pi^+ \pi^+ \pi^-$	$1.11 \pm 0.07 \pm 0.04$	1.24 ± 0.20	$0.202 \pm 0.011 \pm 0.009$	$+2.0 \pm 4.6 \pm 0.7$
$\pi^+ \eta$	$1.58 \pm 0.11 \pm 0.18$	2.16 ± 0.30	$0.288 \pm 0.018 \pm 0.033$	$-8.2 \pm 5.2 \pm 0.8$
$\pi^+ \eta'$	$3.77 \pm 0.25 \pm 0.30$	4.8 ± 0.6	$0.69 \pm 0.04 \pm 0.06$	$-5.5 \pm 3.7 \pm 1.2$
$K^+ \pi^+ \pi^-$	$0.69 \pm 0.05 \pm 0.03$	0.67 ± 0.13	$0.125 \pm 0.009 \pm 0.005$	$+11.2 \pm 7.0 \pm 0.9$

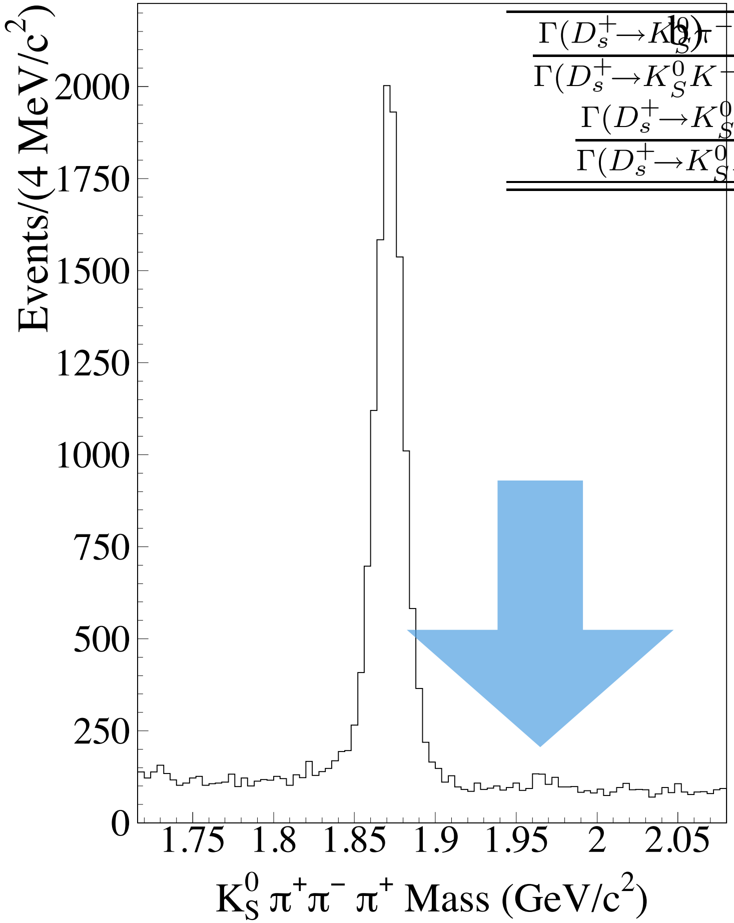


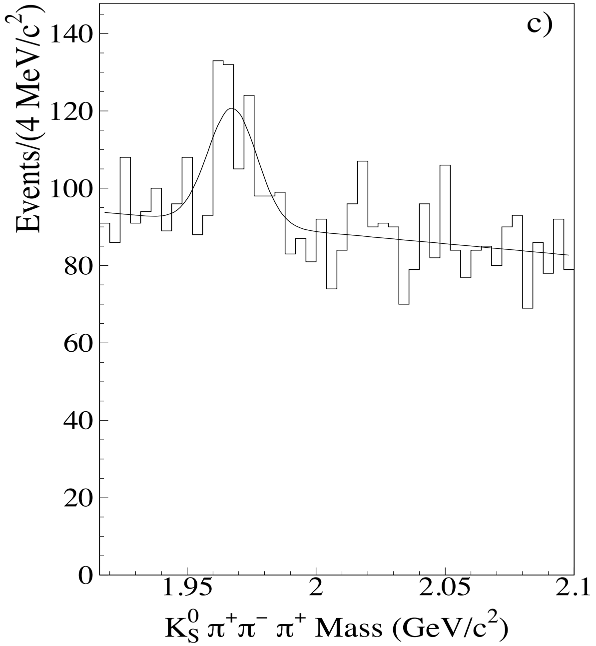
Phys.Rev.Lett.100:161804,2008 (arxiv)

Using 298 /pb , Ecm = 4.17 GeV, B(D_s -> K- K + pi+) = (5.50 +- 0.23 +- 0.16)%

New Modes at FOCUS

Decay Mode	Ratio of Events	Efficiency Ratio	Branching Ratio
$\frac{\Gamma(D_s^+\to K_S^0\pi^-\pi^+\pi^+)}{\Gamma(D_s^+\to K_S^0K^-\pi^+\pi^+)}$	$\frac{179\pm36}{763\pm32}$	1.34	$0.18 \pm 0.04 \pm 0.05$
$\frac{\Gamma(D_s^+\to K_S^0\pi^+)}{\Gamma(D_s^+\to K_S^0K^+)}$	$\frac{113\pm26}{777\pm36}$	1.39	$0.104 \pm 0.024 \pm 0.013$





FOCUS: Phys.Lett.B660:147-153,2008

A_{CP} in $D^o \rightarrow \pi^+\pi^-$

- $[\Gamma(D^o \rightarrow \pi^+\pi^-) - \Gamma(\bar{D}^o \rightarrow \pi^+\pi^-)] \; / \; [\Gamma(D^o \rightarrow \pi^+\pi^-) + \Gamma(D^o \rightarrow \pi^+\pi^-)]$
  - BaBar 2008: -0.0024 ± 0.0052 ± 0.0022
  - BELLE 2008: +0.0043 ± 0.0052 ± 0.0012
  - World average (HFAG): +0.0022 ± 0.0037
- Hadron machines: CDF has obtained its result of +0.010 ± 0.013 ± 0.006 with only 2% of its current data set.

T-odd moments

Experiement: FOCUS, Phys.Lett.B622:239-248,2005
Theory: I.I. Bigi, in Proceedings of KAON2001 (hep-ph/0107102)

- Form triple vector products that are odd under T (v could be a momentum or spin):

$$\vec{v_1} \cdot (\vec{v_2} \times \vec{v_3})$$

- Form the asymmetry of these triple products

$$A_T \equiv \frac{\Gamma(\vec{v_1} \cdot (\vec{v_2} \times \vec{v_3}) > 0) - \Gamma(\vec{v_1} \cdot (\vec{v_2} \times \vec{v_3}) < 0)}{\Gamma(\vec{v_1} \cdot (\vec{v_2} \times \vec{v_3}) > 0) + \Gamma(\vec{v_1} \cdot (\vec{v_2} \times \vec{v_3}) < 0)}$$

in this expression, it turns out that strong phases can produce a non-zero A_T in the absence of T violation.

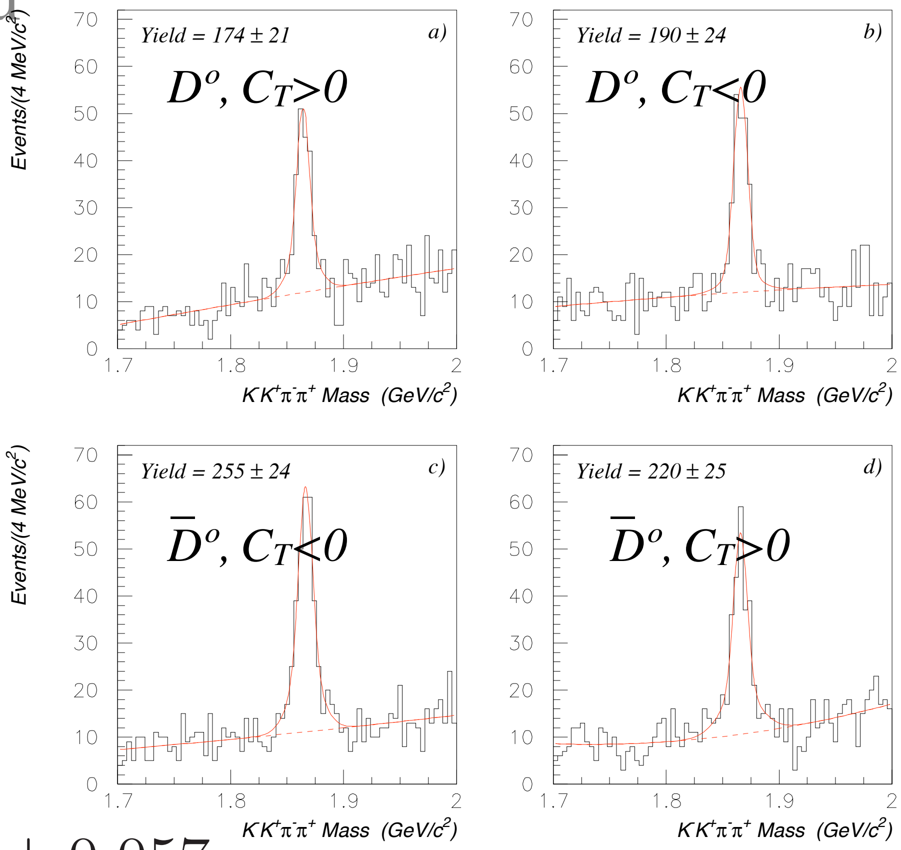
- Form the difference of CP-conjugate A_T asymmetries - truly T violating: $$A_{\mathrm{Tviol}} \equiv \frac{1}{2}(A_T - \overline{A_T})$$

T-odd moments at FOCUS

Experiement: FOCUS, Phys.Lett.B622:239-248,2005
Theory: I.I. Bigi, in Proceedings of KAON2001 (hep-ph/0107102)

- Analyse $D^o \rightarrow K^+K^-\pi^+\pi^-$ and base analysis on the following T-odd product:

$$C_T = \vec{p}_{K^+} \cdot (\vec{p}_{\pi^+} \times \vec{p}_{\pi^-})$$

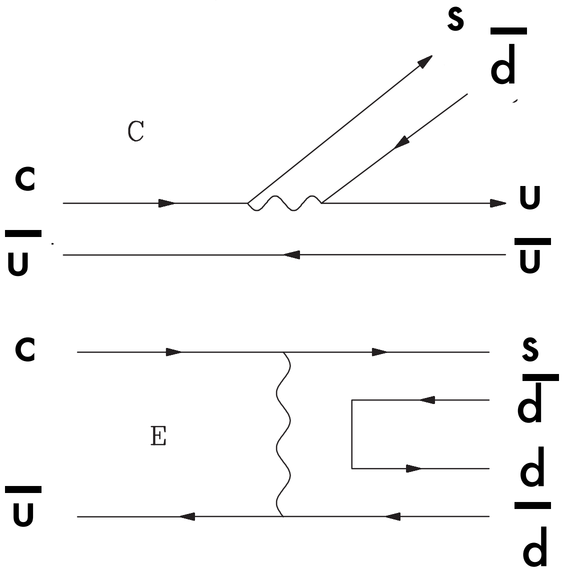


- Result

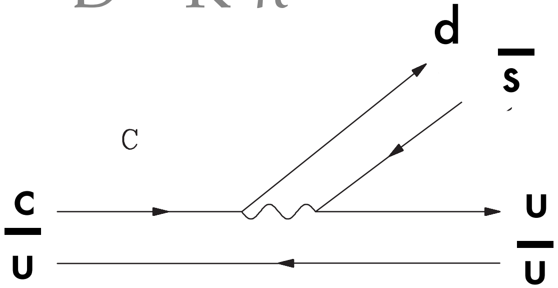
$$A_{\mathrm{Tviol}} = \frac{1}{2}(A_T - \overline{A_T}) = 0.010 \pm 0.057$$

U-spin symmetry and D→$K^0\pi^0$, $\overline{K}^0\pi^0$ interference

- D→$\overline{K}^o\pi^o$



D→$K^o\pi^o$



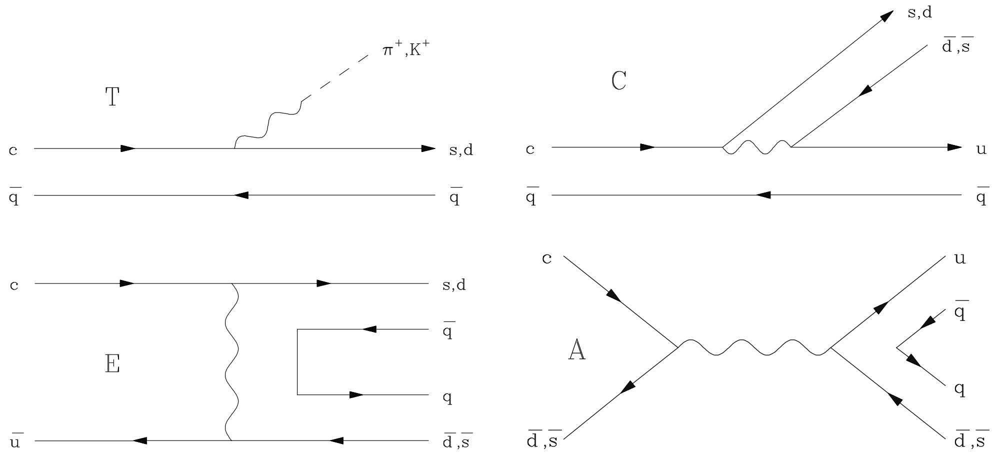
U-spin prediction

- $A(D\rightarrow K_S\pi^o) = A_{CF} - A_{DCS}$, $A(D\rightarrow K_L\pi^o) = A_{CF} + A_{DCS}$

- $$\frac{\Gamma\left(D^0 \to K_S\pi^0\right) - \Gamma\left(D^0 \to K_L\pi^0\right)}{\Gamma\left(D^0 \to K_S\pi^0\right) + \Gamma\left(D^0 \to K_L\pi^0\right)} = -2\frac{A_{DCS}}{A_{CF}} = 2\tan^2\theta_C$$

I. Bigi and H. Yamamoto, Physics Letters 349 (1995) 363-366

CF decay rates in terms of topology amplitudes.



$u\bar{u}$: $(1/\sqrt{2})\pi^0 + (1/\sqrt{6})\eta_0 + (1/\sqrt{3})\chi^0$

$d\bar{d}$: $-(1/\sqrt{2})\pi^0 + (1/\sqrt{6})\eta_0 + (1/\sqrt{3})\chi^0$

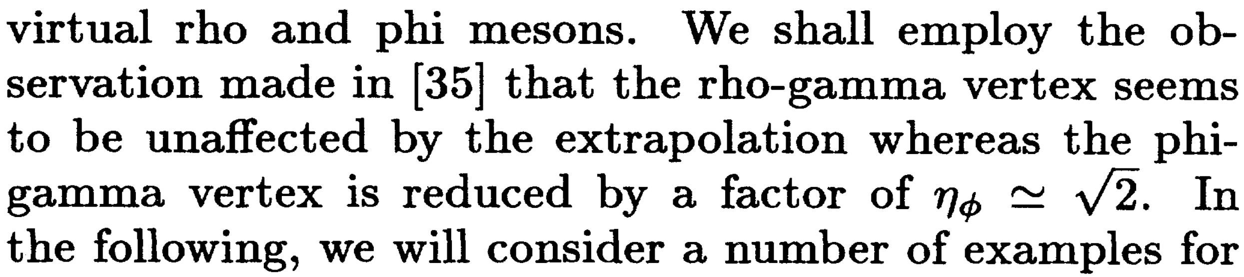
$s\bar{s}$: $-(\sqrt{2}/\sqrt{3})\eta_0 + (1/\sqrt{3})\chi^0$

$u\bar{d}$: π^+ , $d\bar{u}$: π^-

$u\bar{s}$: K^+ , $d\bar{s}$: K^0 ,

$s\bar{d}$: $\bar{K}^0$, $s\bar{u}$: K^-

Meson	Decay mode	Rep.
D^0	$K^-\pi^+$	$T+E$
	$\overline{K}^0\pi^0$	$(C-E)/\sqrt{2}$
	$\overline{K}^0\eta$	$C/\sqrt{3}$
	$\overline{K}^0\eta'$	$-(C+3E)/\sqrt{6}$
D^+	$\overline{K}^0\pi^+$	$C+T$
D_s^+	$\overline{K}^0K^+$	$C+A$
	$\pi^+\eta$	$(T-2A)/\sqrt{3}$
	$\pi^+\eta'$	$2(T+A)/\sqrt{6}$



virtual rho and phi mesons. We shall employ the observation made in [35] that the rho-gamma vertex seems to be unaffected by the extrapolation whereas the phi-gamma vertex is reduced by a factor of $\eta_\phi \simeq \sqrt{2}$. In the following, we will consider a number of examples for

Coefficients in radiative decays

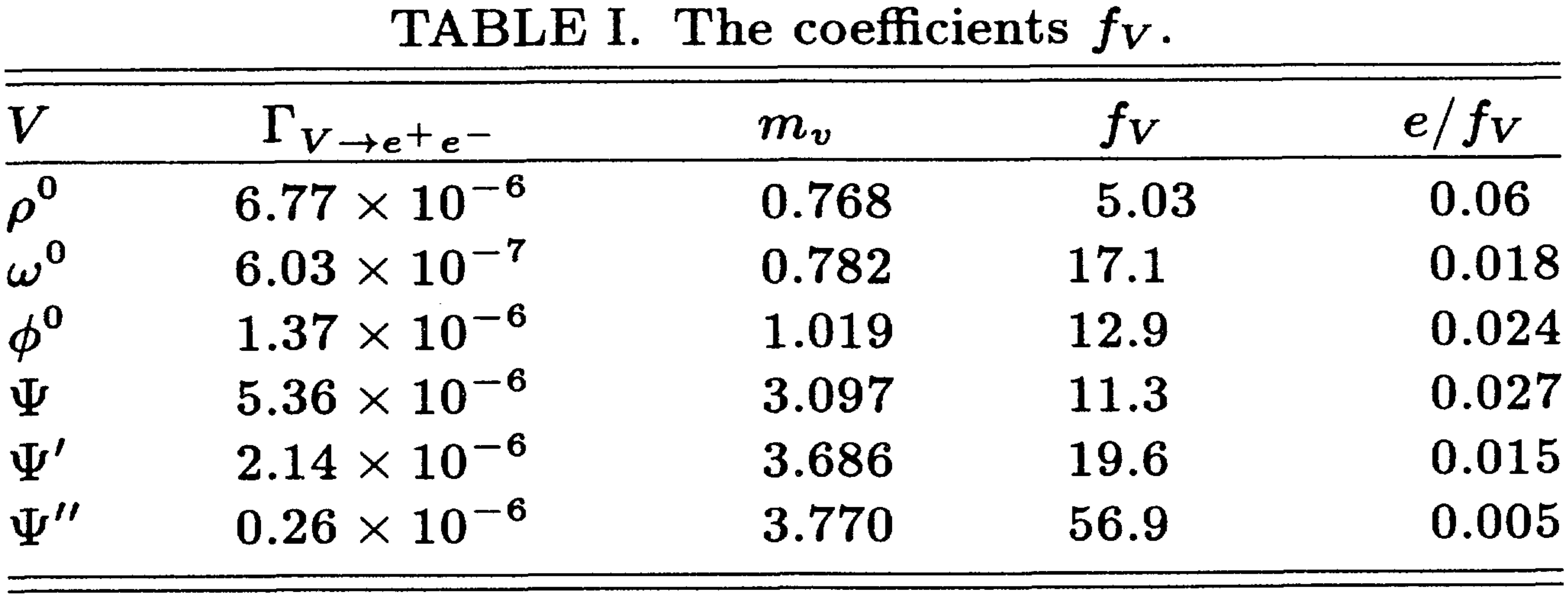
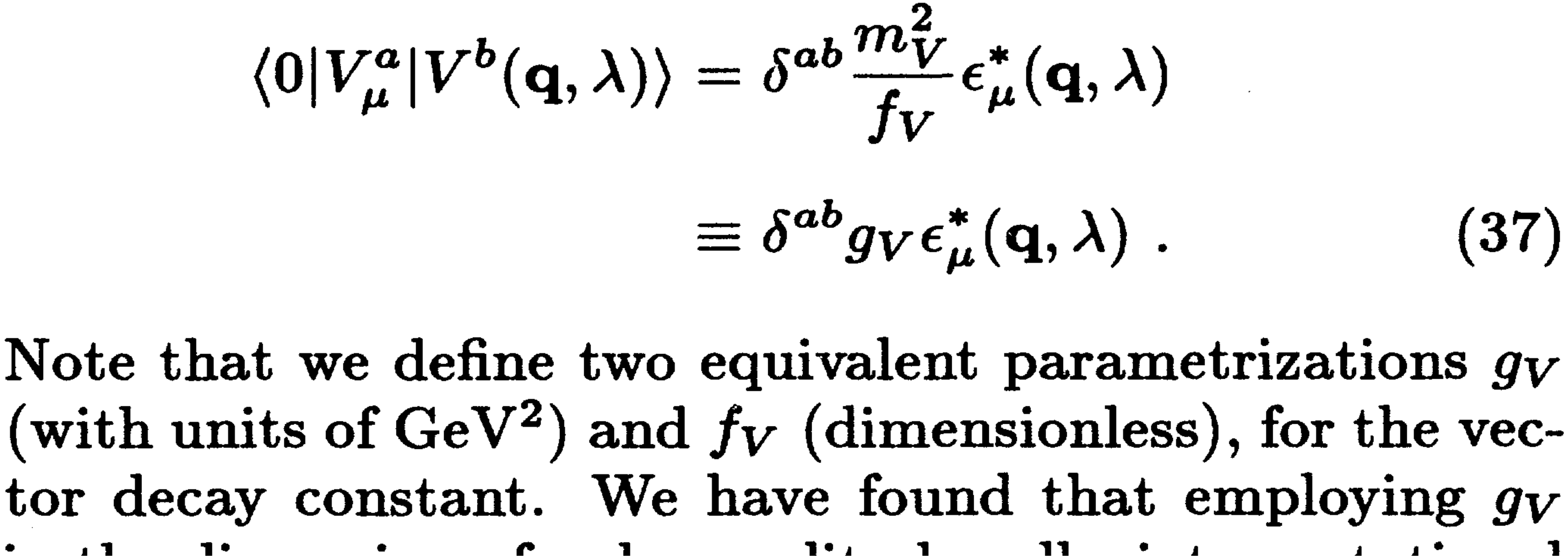


TABLE I. The coefficients f_V.

V	$\Gamma_{V\to e^+e^-}$	m_v	f_V	e/f_V
ρ^0	6.77×10^{-6}	0.768	5.03	0.06
ω^0	6.03×10^{-7}	0.782	17.1	0.018
ϕ^0	1.37×10^{-6}	1.019	12.9	0.024
Ψ	5.36×10^{-6}	3.097	11.3	0.027
Ψ'	2.14×10^{-6}	3.686	19.6	0.015
Ψ''	0.26×10^{-6}	3.770	56.9	0.005

E. Golowich and S. Pakvasa, Phys. Rev. D 51, 1215 - 1223 (1995)

Definition of f_V



$$\langle 0|V^a_\mu|V^b(\mathbf{q},\lambda)\rangle = \delta^{ab}\frac{m_V^2}{f_V}\epsilon^*_\mu(\mathbf{q},\lambda)$$

$$\equiv \delta^{ab} g_V \epsilon^*_\mu(\mathbf{q},\lambda)\ . \qquad (37)$$

Note that we define two equivalent parametrizations g_V (with units of GeV^2) and f_V (dimensionless), for the vector decay constant. We have found that employing g_V

G. Burdman, E. Golowich, J. L. Hewett, and S. Pakvasa, Phys. Rev. , 6383 (1995)