Hadronic Charm Decays: Experimental Review

Featuring results from

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ICHEP, 1 Aug 2008

What Can We Learn?

Hadronic charm decays are relevant in many ways:

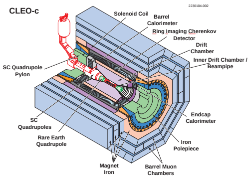
- Easy to reconstruct and large rate so they **normalize** many measurements in b and c systems
- In measurements of D mixing and when using CP eigenstates for B interferometry[1], long-distance physics introduces **phases** that must be measured
- A complete picture of decay rates tells us about **QCD in weak decays**
- Amplitude analysis gives access to **light meson spectroscopy**

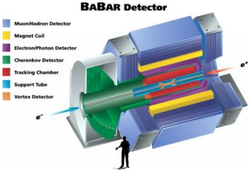
Brief glimpse of these topics in the next 12 minutes...

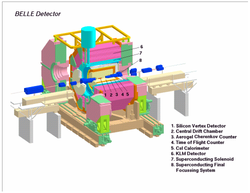
= New results for this conference!

[1]See talks by Meadows, Naik, Asner

Dramatis Personae







CLEO-c

- Symmetric charm facility
- Threshold operation:
  - Simple initial state
  - Generally very clean signals
  - *CP* correlation allows unique measurements

BaBar, Belle

- Asymmetric *B*-factories
- Huge luminosity and statistics
- Boost allows time-dependent measurements

Absolute Branching Fractions

Important normalizing modes:

- $D^0 \to K^-\pi^+$
- $D^+ \to K^-\pi^+\pi^+$
- $D_s^+ \to K^-K^+\pi^+$ (historically "$\phi\pi^+$")

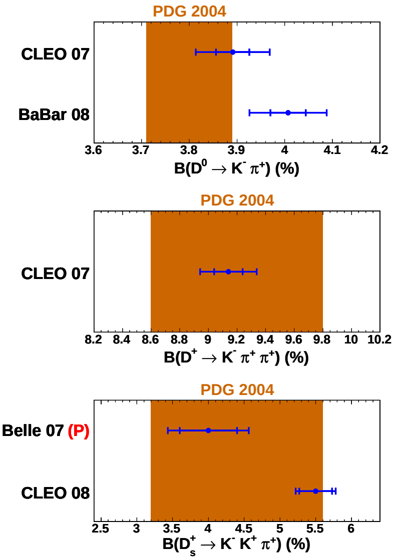
Charm branching fraction uncertainties affect e.g.

- exclusive $|V_{cb}|$
- $\mathcal{B}(B_s \to D_s^{(*)} D_s^{(*)})$

Great improvement in our knowledge in the last few years

$\to$ Replace $D_s^+ \to \phi\pi^+$ by $D_s^+ \to K^-K^+\pi^+$!

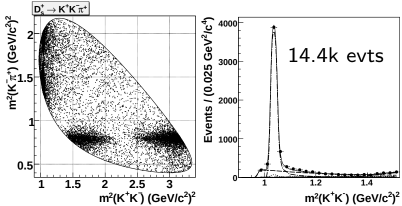
Belle 07: hep-ex/0701053 (Prel.) [552 fb^{-1}]
CLEO 07: PRD 76, 112001 [281 pb^{-1}]
BaBar 08: PRL 100, 051802 [210 fb^{-1}]
CLEO 08: PRL 100, 161804 [298 pb^{-1}]



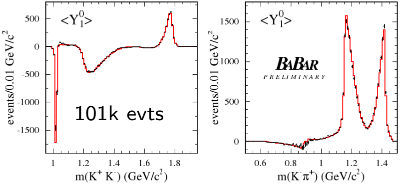
$D_s^+ \to K^-K^+\pi^+$ Dalitz Analyses

- $D_s^+ \to K^-K^+\pi^+$ dominated by resonances: eliminate background by rejecting most of phase space
- However much easier to define the full $\mathcal{B}(K^-K^+\pi^+)$
- Reconcile with good Dalitz analyses...

CLEO 586 pb^{-1} Preliminary NEW!



BaBar Preliminary arxiv:0711.4769



	$K^{*0}(892)K^+$	$K_0^*(1430)^0K^+$	$K_2^*(1430)K^+$	$f_0(980)\pi^+$	$\phi\pi^+$	$f_0(1370)\pi^+$	$f_0(1710)\pi^+$	$f_2(1270)\pi^+$
CLEO (± stat)	47.4 ± 1.5	3.9 ± 0.5	—	28.2 ± 1.9	42.2 ± 1.6	4.3 ± 0.6	3.4 ± 0.5	—
BaBar (± syst)	48.7 ± 1.6	2.0 ± 3.3	0.17 ± 0.3	35 ± 14	37.9 ± 1.8	6.3 ± 4.8	2.0 ± 1.0	0.18 ± 0.4

$K^-\pi^+$ Strong Phase

D^0 mixing parametrized in terms of

$$x \equiv \frac{\Delta m}{\Gamma}, \quad y \equiv \frac{\Delta\Gamma}{2\Gamma}$$

When mixing is measured in time-dependent $D^0 \to K^-\pi^+$, one obtains instead

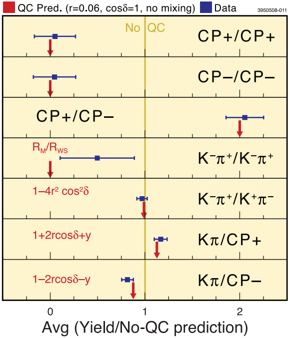
$$x' \equiv x\cos\delta + y\sin\delta, \quad y' \equiv y\cos\delta - x\sin\delta$$

if there is a non-trivial phase δ between $D^0 \to K^-\pi^+$ and $D^0 \to K^+\pi^-$.

Relating (x', y') to (x, y) requires external input on δ.

The Quantum Correlation Analysis

- Change basis to $\psi(3770) \to D_1 D_2$
- *CP* structure of initial state modifies production rates for double tag events; factors depend on x, y, δ, DCSD decay rate
- Use external inputs for weakly-measured parameters



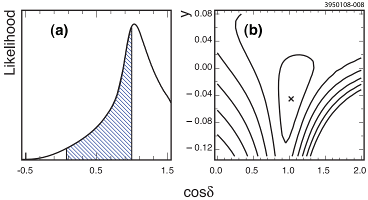
DT rates relative to uncorrelated decays

PRL 100, 221801

CLEO-c 281 pb^{-1}

Standard fit (external $\mathcal{B}$, R_M, R_{WS} only)

95% C.L.: $|\delta| < 75^\circ$



Also Extended fit (standard + external mixing)

95% C.L.: $\delta \in [-7^\circ, +61^\circ]$

$x \sin\delta \in [0.002, 0.014]$

Open Questions in D Decays

Open charm is an interesting system for looking at strong interactions in weak decays

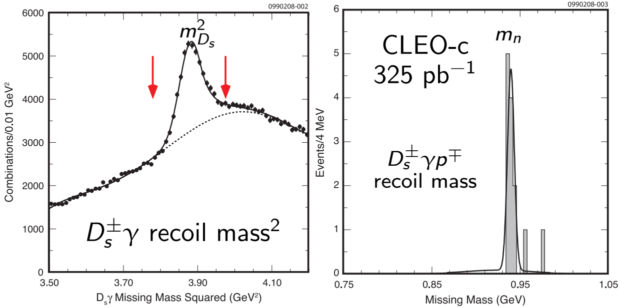
- **Long distance interactions** are important: many resonances in region of interest
- D mass is not far above K mass (e.g. $D^0 \rightarrow 4K$ is impossible, while 4π has lots of phase space): **SU(3) breaking** effects are significant
- **Factorization** assumptions can fail

Experimentally,

- D decays are low multiplicity, and e.g. $D \rightarrow PP$ decays have large branching ratios compared to the B system

$D_s^+ \to p\bar{n}$

- *Only* kinematically allowed baryonic decay of a D meson
- Unambiguous quark annihilation topology — first such D_s^+ hadronic decay
- Probes long distance effects (Pham, PRL 45, 1663; Bediaga & Predazzi, PLB 275, 161; Chen *et al.*, PLB 663, 326)

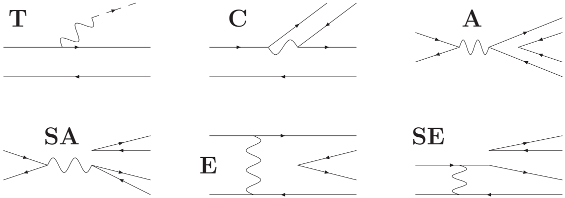


Result: $\mathcal{B}(D_s^+ \to p\bar{n}) = (1.30 \pm 0.36^{+0.12}_{-0.10}) \times 10^{-3}$

PRL 100, 181802

Decay Analysis

Can analyze hadronic decays in flavor-topology terms, extracting amplitudes for various terms:



By exploiting SU(3), one can relate different decays and search for a consistent picture.

Some interesting things to look at:

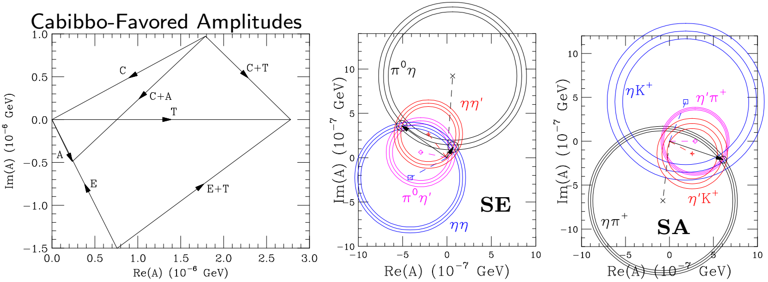
- **SU(3):** $|\mathcal{A}(D^0 \to K^-K^+)| = |\mathcal{A}(D^0 \to \pi^+\pi^-)|$
- **SU(3) + GIM:** $\mathcal{B}(D^0 \to K^0_S K^0_S)$ should be *zero*
- How large are disconnected graphs $\mathbf{SA}$ and $\mathbf{SE}$?

$D \to PP$

CLEO-c has assembled a complete picture of CF and SCS $D \to PP$ branching fractions — many are first observations

(PRD 77, 091106; PRL 99, 191805; PRD 77, 092003: + Absolute $\mathcal{B}$ measurements)

Analysis by Bhattacharya & Rosner (PRD 77, 114020):



- $|\mathcal{A}(K^-K^+)|/|\mathcal{A}(\pi^+\pi^-)| = 1.83 \pm 0.03 \neq 1$
- $\mathcal{B}(D^0 \to K^0_S K^0_S) = (1.46 \pm 0.32 \pm 0.09) \times 10^{-4} \neq 0$
- C, T, E similar magnitudes, large relative phases; $A \sim -0.3E$
- $|SA| \sim |A|$??

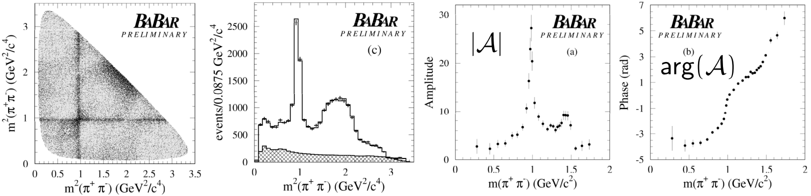
Dalitz Analysis

- D decays provide access to light hadrons complementary to e.g. J/ψ decay, hadroproduction
  - $P \to 3P$ has highly constrained partial waves
  - Interferometry for free
  - Difficult to go beyond three-body final states
- Controversies in the scalar sector can be addressed:
  - What states *are* there? (Does e.g. $f_0(1370)$ exist?)
  - What is up with the low mass S-wave? (σ and κ?)
  - How do the $f_0(980)$ and $a_0(980)$ interact? (Coupling constants, lineshape?)
- Recent high-statistics samples are pointing out the failures of the isobar model with simple resonances

$D_s^+ \to \pi^+\pi^+\pi^-$ Dalitz Analysis

- $D_s^+ \to \pi^+\pi^+\pi^-$ is dominated by $\pi^+\pi^-$ S-wave; interesting lab for probing scalar sector
- Also for D_s^+ decays: large $\mathcal{B}$ where $s\bar{s}$ is not manifest. Short-distance annihilation? Long-distance $s\bar{s} \to n\bar{n}$?
- Large statistics: explicitly obtain amplitudes and phases for one component instead of assuming Breit-Wigner/Flatté/... shapes: "(Quasi) Model Independent PWA" pioneered by E791
- Preliminary BaBar result on 384 fb^{-1} NEW!

S-wave



	$f_2(1270)\pi^+$	$\rho(770)\pi^+$	$\rho(1450)\pi^+$	S-wave
FF (%)	10.1 ± 1.5	1.8 ± 0.5	2.3 ± 0.8	83.0 ± 0.9

Clear $f_0(980)$, activity in 1400 MeV region, not much at low mass

Summary

- Hadronic decays of charm are linked to many other topics
- Interesting in their own right
- Recent large datasets have enabled a new era of precision, discovery
  - Some reference branching fractions 2–3$\times$ better than previous world average
  - First measurements being made of strong phases between *different* decays
  - First observation of baryonic decay
  - Access to decay mechanism information via comprehensive overview of decay modes
  - Studies of low-mass hadron interactions
  - (And D^0 mixing was first observed in hadronic decays. . .)
- Look forward to future results from current experiments, BES-III, LHCb!

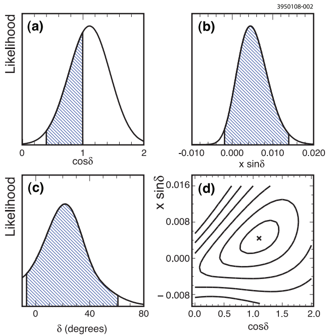
The End

TQCA Fits

Mode	Correlated	Uncorr.
$K^-\pi^+$	$1+R_{\rm WS}$	$1+R_{\rm WS}$
$S_\pm$	2	2
$K^-\pi^+, K^-\pi^+$	$R_{\rm M}$	$R_{\rm WS}$
$K^-\pi^+, K^+\pi^-$	$(1+R_{\rm WS})^2 - 4r\cos\delta(r\cos\delta + y)$	$1+R_{\rm WS}^2$
$K^-\pi^+, S_\pm$	$1+R_{\rm WS} \pm 2r\cos\delta \pm y$	$1+R_{\rm WS}$
$K^-\pi^+, e^-$	$1 - ry\cos\delta - rx\sin\delta$	1
$S_\pm, S_\pm$	0	1
S_+, S_-	4	2
$S_\pm, e^-$	$1\pm y$	1

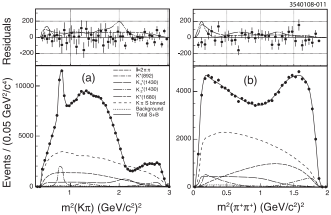
Standard fit uses external measurements of $\mathcal{B}$, $R_{\rm M}$, $R_{\rm WS}$

Extended fit in addition uses y, x, r^2, y', x'^2



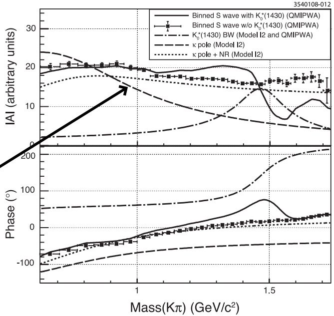
Likelihood contours from extended fit

- $D^+ \to K^-\pi^+\pi^+$ has dominant contribution from $K^-\pi^+$ S-wave
  - Can parametrize with κ and nonresonant, but can also derive quasi-model-independently through interference with P, D-waves (pioneered by E791)
- Need fairly sizable $\pi^+\pi^+$ S-wave (fit fraction 10–15%)



κ + NR match observed $|A|$ and phase, but only via large interference; κ by itself fails

$I = 2$ amplitude is nontrivial



arXiv:0802.4214, submitted to PRD