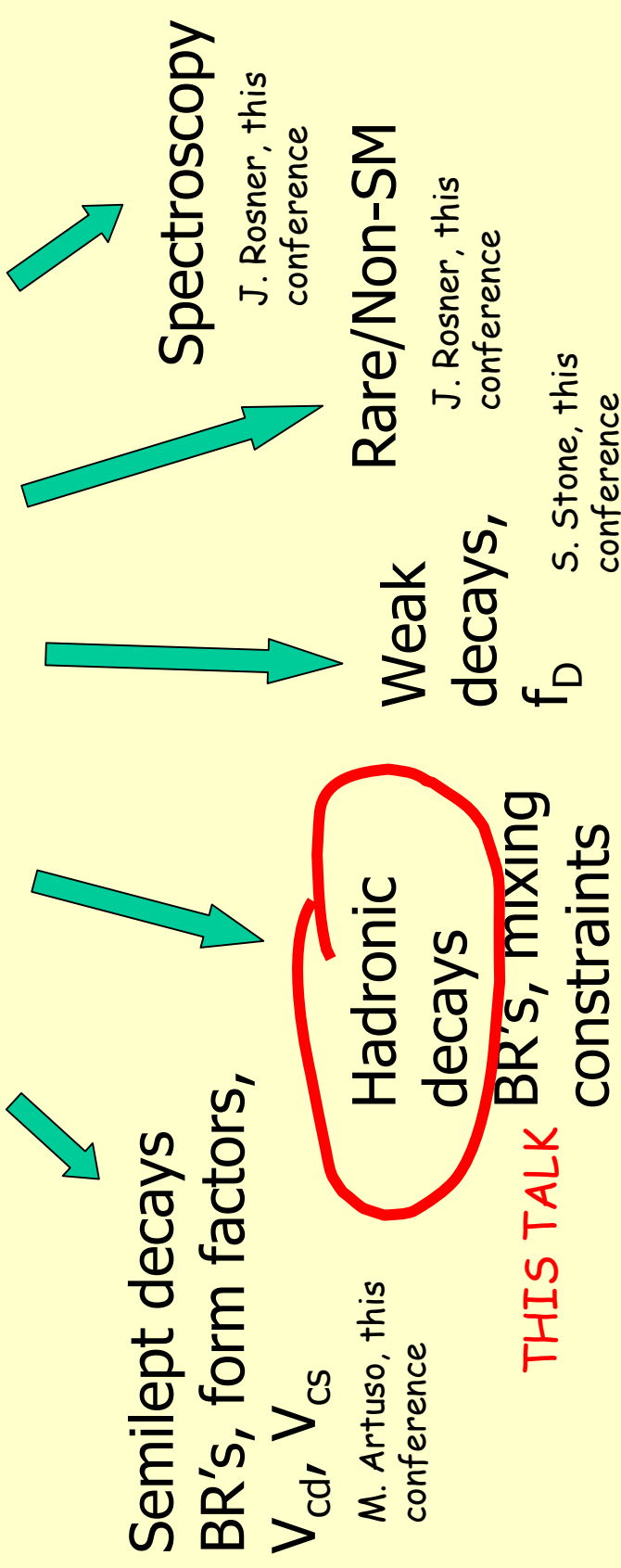


Measurement of absolute D hadronic branching fractions

Hanna Mahlke
Cornell University
for the
CLEO Collaboration

BEAUTY 2005, Assisi, Italy

CLEO-c: high precision, low energy



Improve upon current precision

Validation of LQCD tools

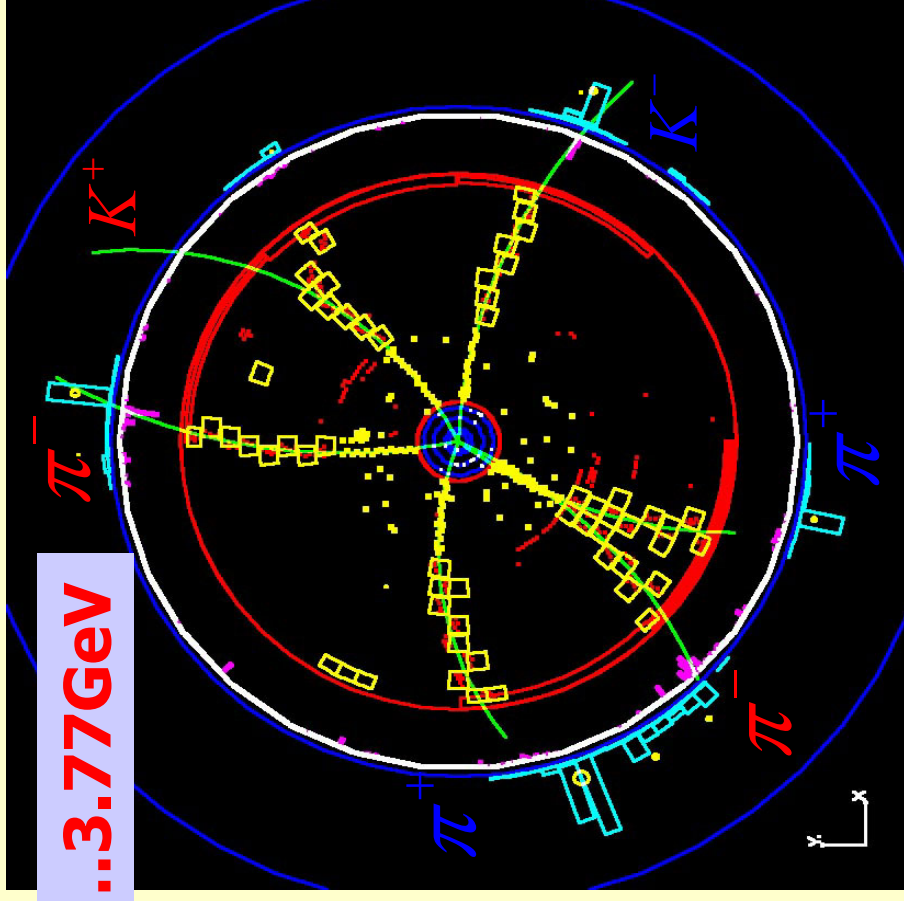
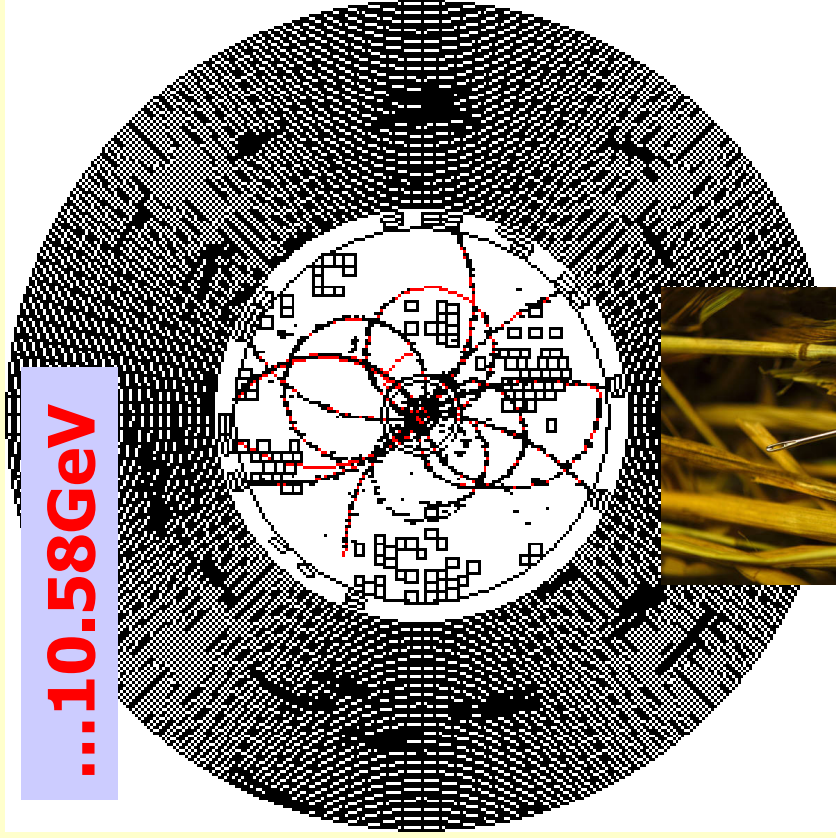
Reduced uncertainties in other measurements

Hadronic D Decays: Why?

- ❖ Many current measurements determined with respect to normalizing modes $D^0 \rightarrow K^- \pi^+$, $D^+ \rightarrow K^- \pi^+ \pi^+$
- ❖ Input to MANY measurements (*e.g.* V_{cb} from $B \rightarrow D^* l \nu$)
- ❖ CLEO-c will provide...
 - ❖ ... **absolute** measurements
 - ❖ ... **relative measurements at great precision** available already now
 - ❖ ... most precise measurement of D hadronic BRs; pick $h = \pi, K$ (including π^0 and K_S)
- ❖ Much easier to do at threshold and in pairs than at 10GeV!
- ❖ Byproduct: $D\bar{D}$ production cross sections
- ❖ First step toward improved constraints on D mixing parameters

These results: 60/pb “pilot run” (0.36M $D\bar{D}$ pairs)
CLEO Collab., Q. He et al., hep-ex/0504003, subm. to PRL

D Production at....

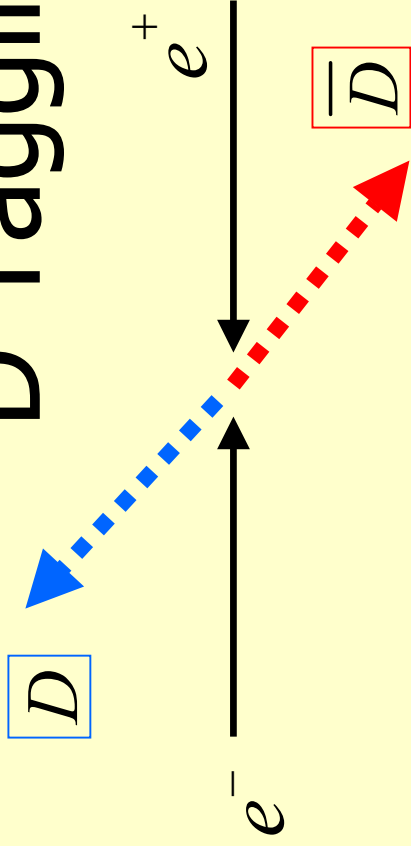


$$\psi(3770) \rightarrow D^+ D^-$$

$$D^+ \rightarrow K^- \pi^+ \pi^+, D^- \rightarrow K^+ \pi^- \pi^-$$

"D Tagging"

(AKA "The MarkIII Method")



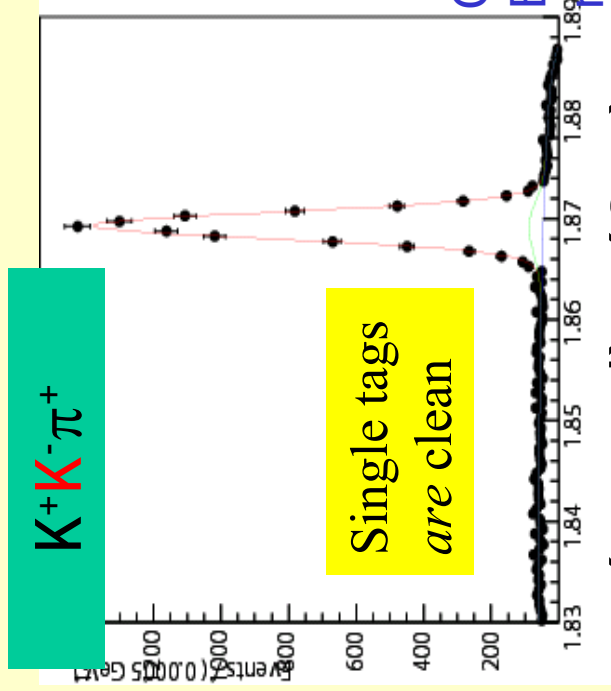
Basic Strategy (for most CLEO-c analyses):

- Full reconstruction of one D meson ("Tag D")
- Search remainder of event for signal D decay

$$e.g. B(D^+ \rightarrow K^- \pi^+ \pi^+) =$$

$$\frac{\#(K^- \pi^+ \pi^+) \text{ in tagged events}}{(\epsilon(K^- \pi^+ \pi^+) * \#tags)}$$

Continuum, τ pair, radiative return events suppressed significantly.

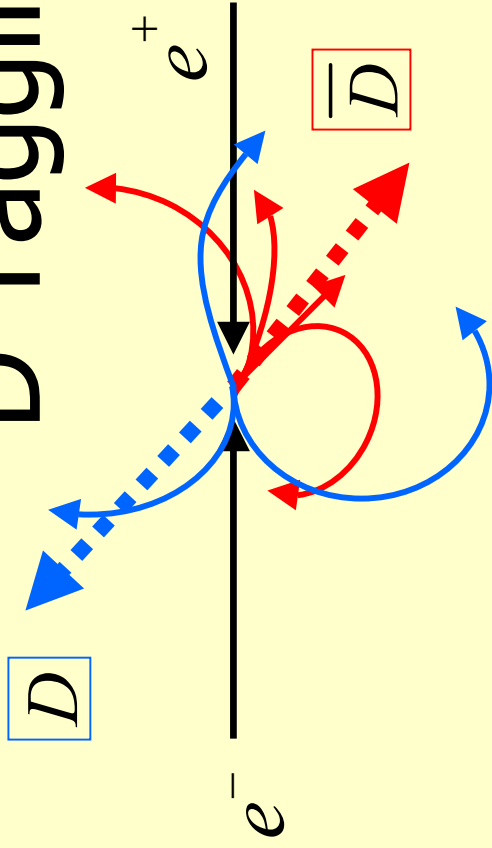


Compute $m(D)^{\text{rec}}$ with $E_D = E_{\text{beam}}$ and p_D from reconstructed decay products

$m(D \text{ cand})^{\text{rec}}$ (GeV)

"D Tagging"

(AKA "The MarkIII Method")



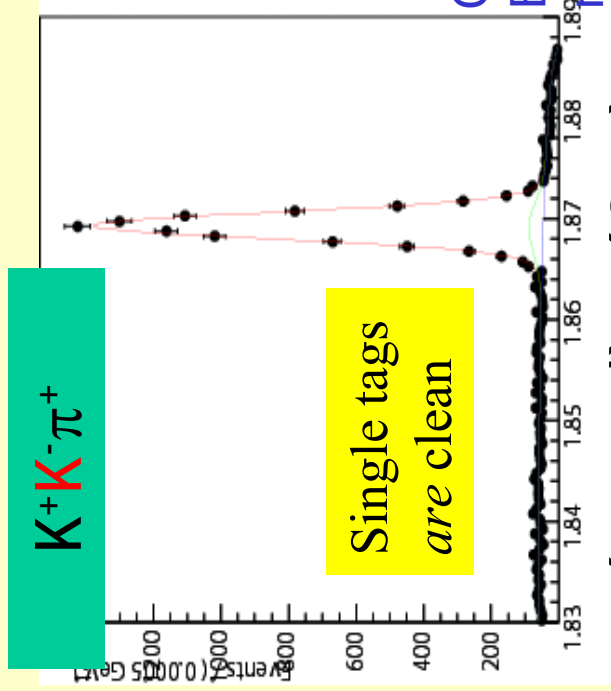
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$m(D \text{ cand})^{\text{rec}} \text{ (GeV)}$

The BR Fit

want
 "have" / know
 Single tags: $N_i = N_{DD} \mathcal{B}_i \varepsilon_i$
 Double tags: $N_{ij} = N_{DD} \mathcal{B}_i \mathcal{B}_j \varepsilon_{ij}$

$$B_i = \frac{N_{ij} \varepsilon_j}{N_j \varepsilon_{ij}}$$

$$N_{DD} = \frac{N_i N_j \varepsilon_{ij}}{N_{ij} \varepsilon_i \varepsilon_j}$$

Syst unc cancel

D and anti-D yields measured separately

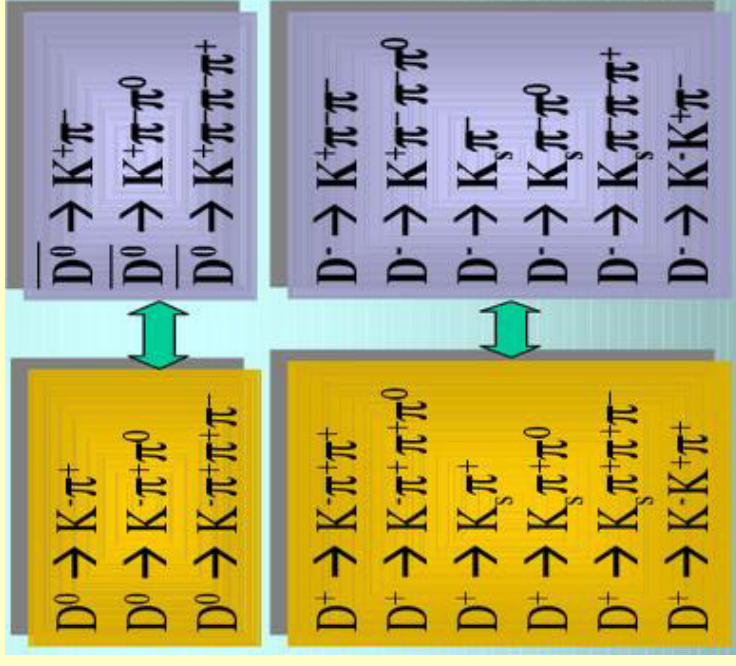
$\mathcal{B}_i \sim$ independent of tag modes and ε 's

The Plan:

1. Determine yields N_i, N_{ij}

2. Simultaneously fit for $N_{D^+D^-}, N_{D^0\bar{D}^0}$ (cross sections)
 and all $\mathcal{B}_i$ W. Sun, arXiv:physics/0503050,
 subm. to NIM A

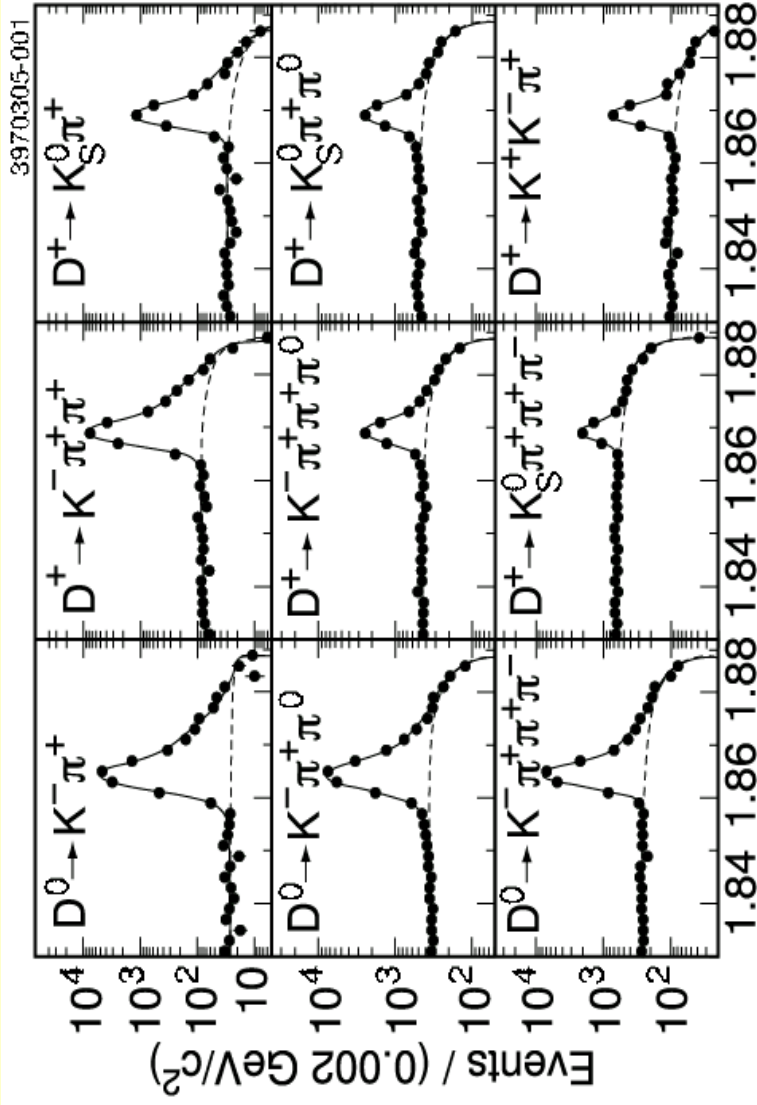
(All correlations and errors taken into account!)



BR Fit Input I: Single Tag Event Yields

D0

D+



(log scale)

$m(D \text{ cand.})^{\text{rec}}$ (GeV)

Yields vary between 0.6k and ~ 10 k events

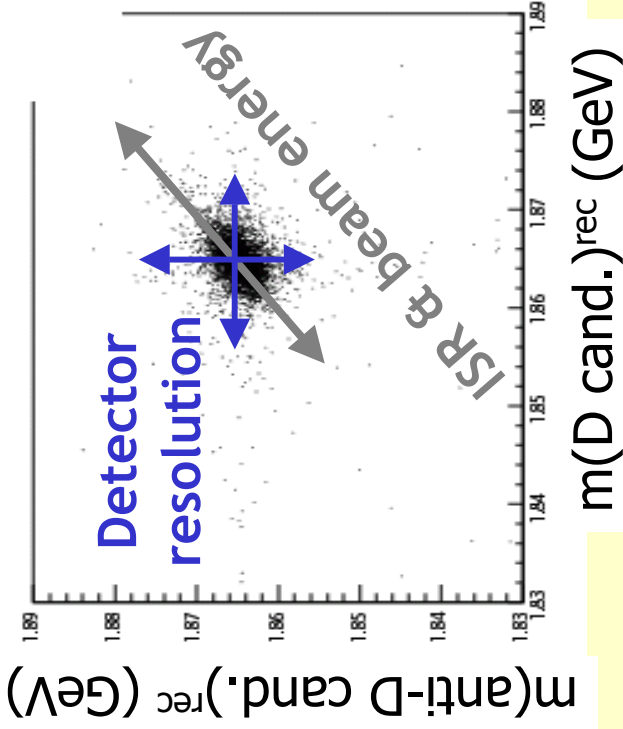
Determined separately for D, $\bar{D}$

Efficiencies 23-67%

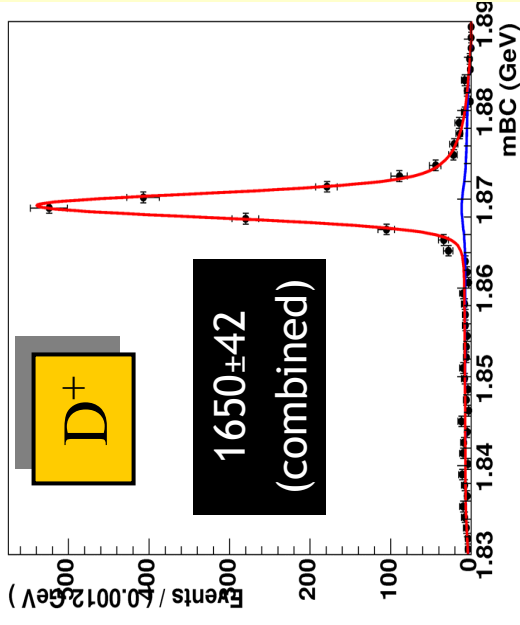
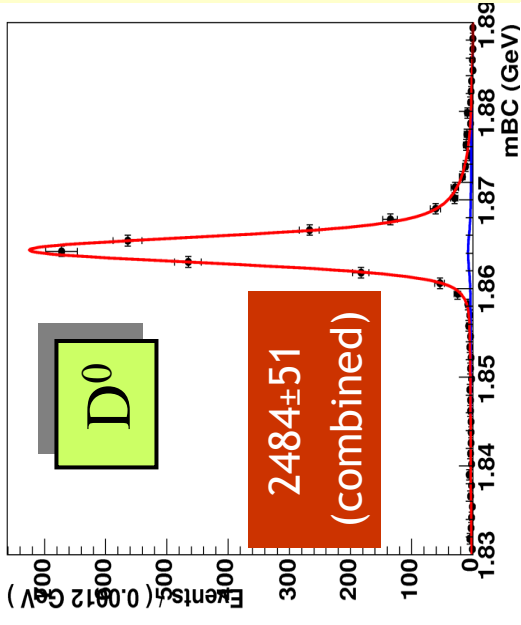
Signal shape: $\psi(3770)$ line shape,
ISR, beam energy spread
& momentum resolution
Background: ARGUS

This fit removes smooth background

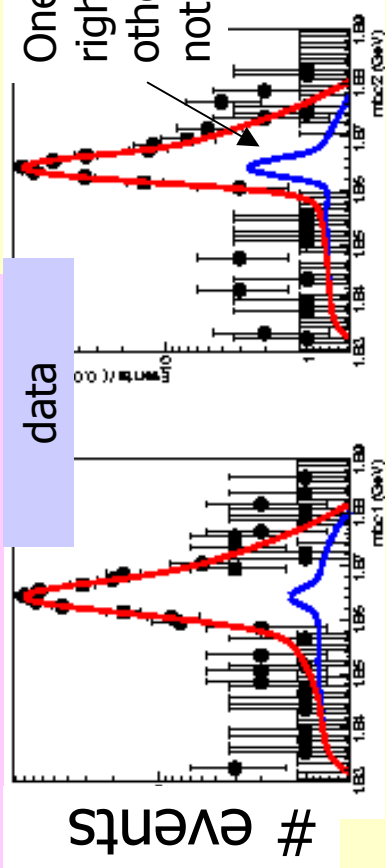
Efficiencies include FSR correction
(effect on BR: 0.2-2.2% downward)



BR Fit Input II: Double Tag Event Yields



$K\pi\pi\pi^0$ vs $K_S\pi\pi\pi$:



BR Fit Output: branching
fractions, N_{D+D^-} , $N_{D^0D^0\text{bar}}$

Tracking systematics:

high/low mom: For data & MC,
reconstruct $J/\psi + \pi$ from $\psi' \rightarrow J/\psi \pi^+ \pi^-$,
Plot recoiling mass. Peak at $m(\pi)$.
Intermediate mom: $D \rightarrow K\pi, K\pi\pi$

Same procedure for π^0

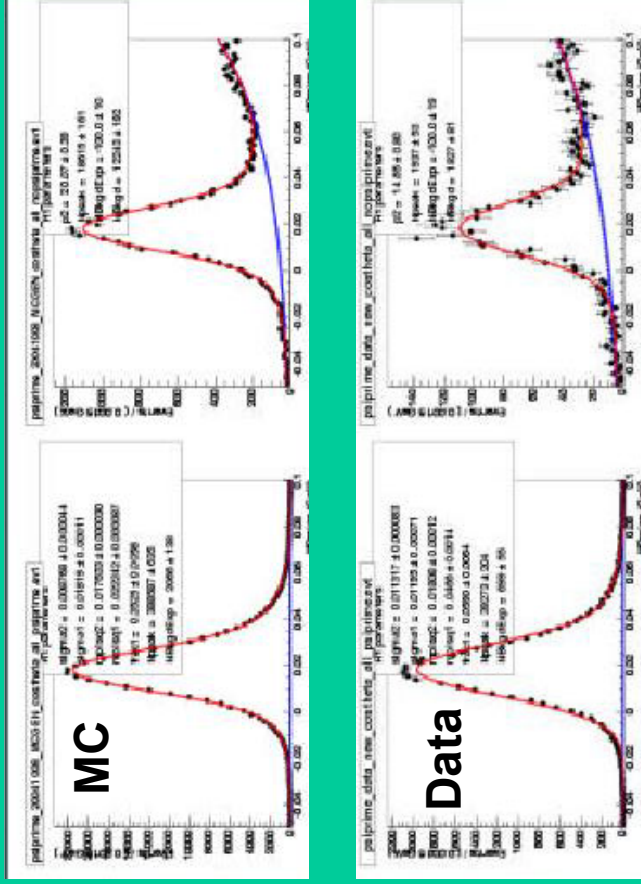
K_S from $D \rightarrow K_S \pi \pi$ “double tag” events

Systematics

Source	Value (%)
Tracking/ K_S/π^0	0.7/3.0/2.0
Particle ID	$0.3/\pi^+ \pi^-$, $1.3/K^+ \pi^-$
ΔE	1.0-2.5
$\Gamma_{\psi}(3770)$	0.6
Final State Radiation	0.5 ST / 1.0 DT
Resonant Substr.	0.4-1.5
DCSD Interference	0.8
Fit functions	0.5
Online/offline filtering	0.4
Multiplicity, det. noise	0.2-1.3

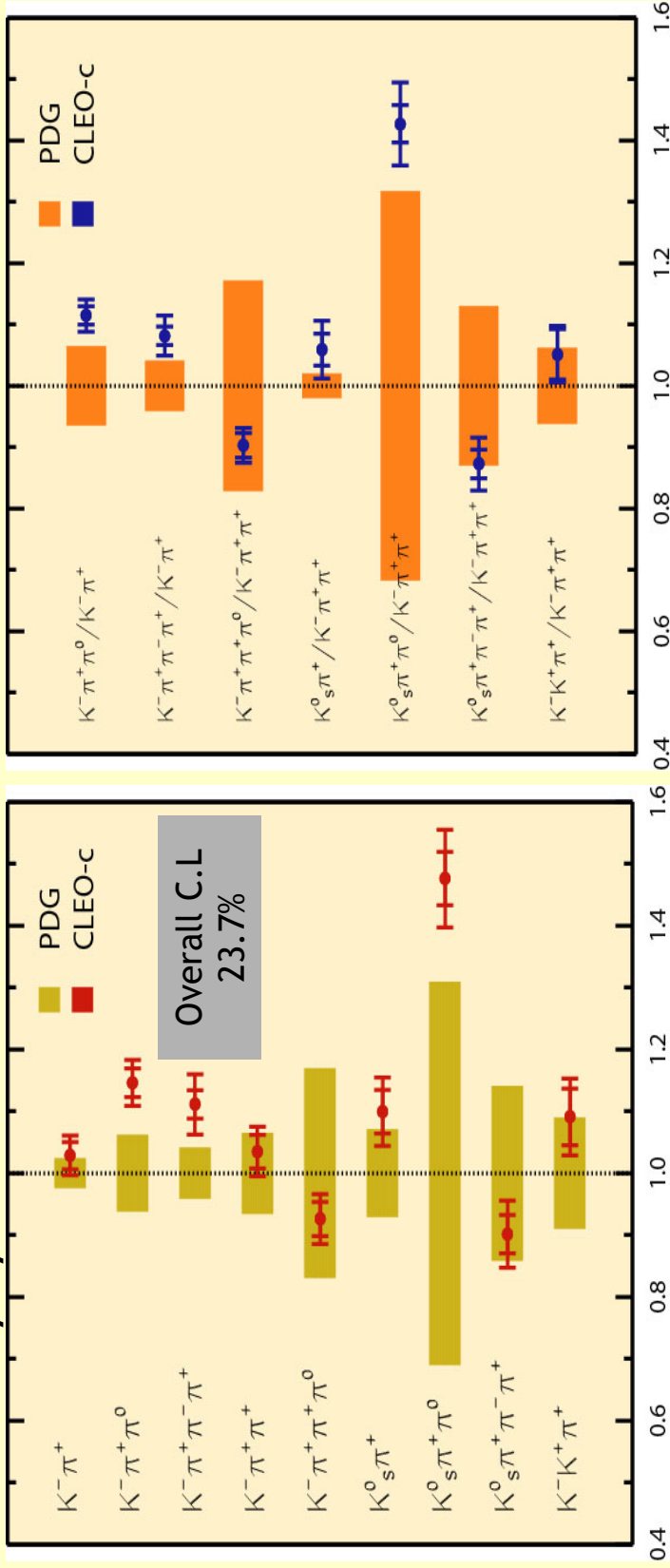
Pion found

Pion not found



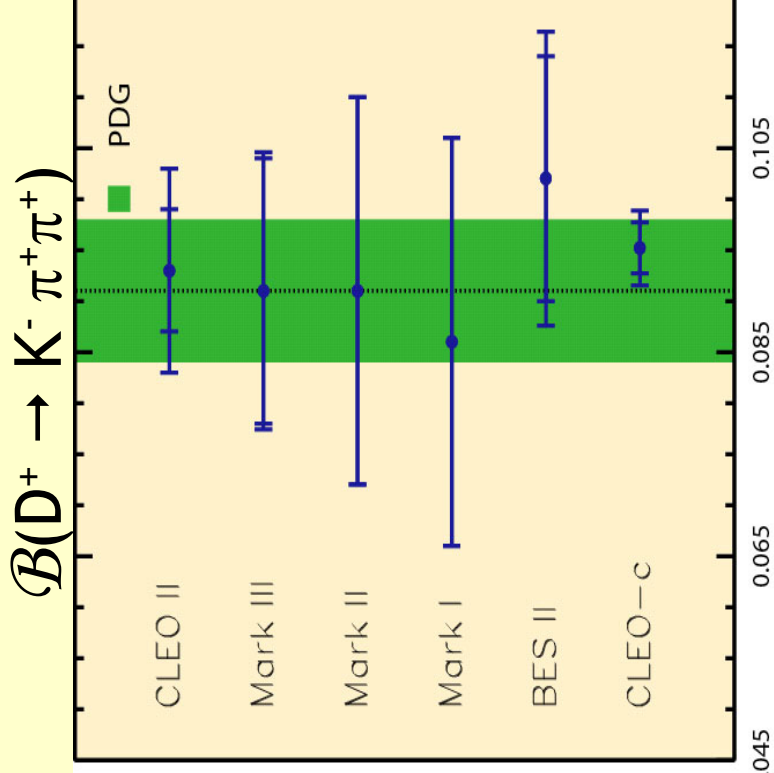
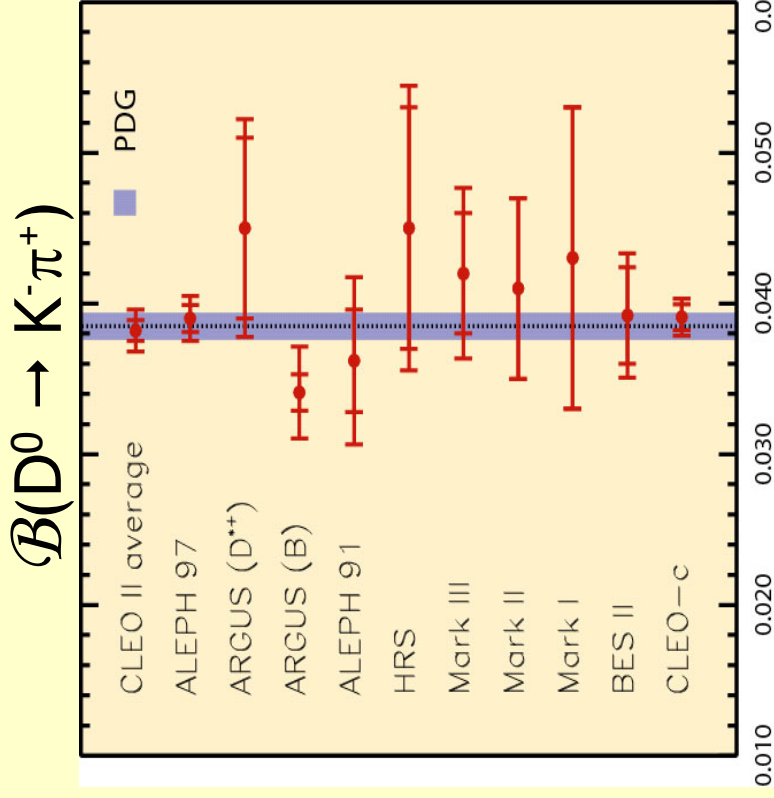
Comparison with PDG 2004 (I)

- Measurements and errors normalized to PDG value.
- PDG global fit includes ratios to $K^-\pi^+$ or $K^-\pi^+\pi^+$:
 - Correlations among charged modes and among neutral modes.
- Our measurements also correlated (stats and efficiency systs).
- Our efficiencies include FSR; those used by PDG do not.
- Already systematics limited in some channels



Comparison with PDG 2004 (II)

- Compare with other *direct* measurements in PDG.
- PDG band = average of direct meas., not global fit.



Cross Sections

Convert $N_{D\bar{D}}$'s to cross sections:

$$\begin{aligned}\sigma(e^+e^- \rightarrow D\bar{D}) &= (6.23 \pm 0.09 \pm 0.21) \text{ nb} \\ \sigma(e^+e^- \rightarrow D^0\bar{D}^0) &= (3.51 \pm 0.07 \pm 0.14) \text{ nb} \\ \sigma(e^+e^- \rightarrow D^+D^-) &= (2.72 \pm 0.07 \pm 0.09) \text{ nb}\end{aligned}$$

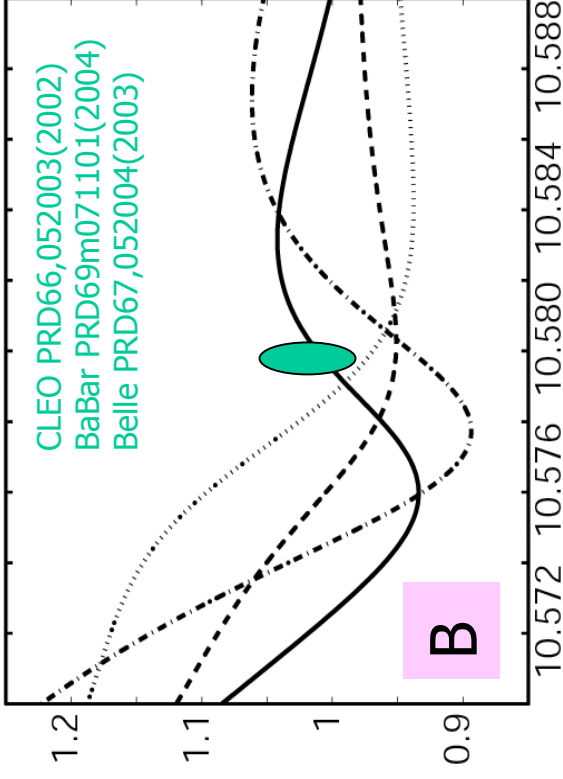
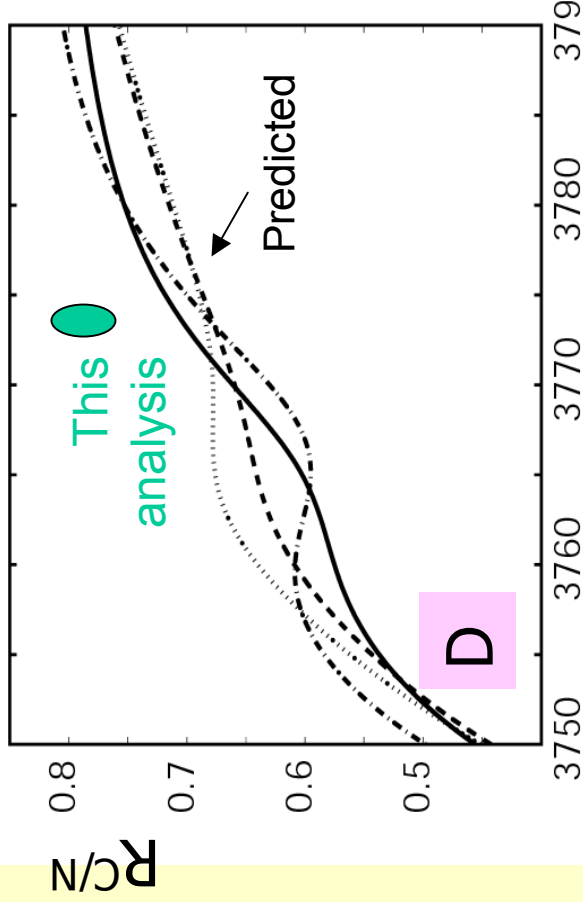
$$\begin{aligned}\text{BES PLB603,130(2004)} \\ (6.14 \pm 0.12 \pm 0.50) \text{ nb} \\ (3.58 \pm 0.09 \pm 0.31) \text{ nb} \\ (2.56 \pm 0.08 \pm 0.26) \text{ nb} \\ (17/\text{pb, single tag only})\end{aligned}$$

- most precise to date
- charged to neutral ratio
- non- $D\bar{D}$? (See J. Rosner's talk)

Charged to Neutral Ratio

$$R^{C/N} = \frac{\sigma(e^+e^+ \rightarrow D^+D^-)}{\sigma(e^+e^+ \rightarrow D^0\overline{D}^0)} = 0.78 \pm 0.02 \pm 0.02$$

Prediction:
M. Voloshin,
hep-ph/0402170



E_{CM} (GeV)

E_{CM} (GeV)

These (and other) data-theory discrepancies have prompted speculation of 4-quark component of $\psi(3770)$.

BEAUTY05, 06/23/05

H. Mahlke: CLEO D hadronic BR

M.V., hep-ph/0504197

Summary:

CLEO-c absolute hadronic D BR's

- First results, based on 60/pb
- 9 decay modes (incl $D^0 \rightarrow K^- \pi^+$, $D^+ \rightarrow K^- \pi^+ \pi^+$) double tagging method $\Rightarrow$ absolute BRs
- Agreement with PDG global fit; comparable or superior accuracy
- Already systematics limited in some modes, will be able to reduce some with more data
- Final state radiative corrections supplied
- $\sigma(\psi'' \rightarrow DD)$, $\sigma(\psi'' \rightarrow D^0 \bar{D}^0)$, $\sigma(\psi'' \rightarrow D^+ D^-)$, and $\sigma(\psi'' \rightarrow D^+ D^-) / \sigma(\psi'' \rightarrow D^0 \bar{D}^0)$

Outlook: Hadronic D Decays

- Will add more data to this analysis
 - 281pb⁻¹ as of this summer
 - Stat error $\Rightarrow \times 0.5$, syst error $\Rightarrow$ not as much
- Cabibbo suppressed hadronic D decays, esp. including π^0
- D mixing constraints
- Move on to D_s (esp. $D_s^+ \rightarrow \phi \pi^+$)

DONE

Non- $D\bar{D}$ ψ'' decays

$$\begin{aligned}\sigma(\psi'' \rightarrow D\bar{D}) &= (6.39 \pm 0.09 \pm 0.21) \text{ nb} \text{ OZI preferred} \\ \sigma(\psi'' \rightarrow \text{hadrons}) &\sim 8 \text{ nb} \text{ (see hep-ph/0411196 for an} \\ &\quad \text{average of older measurements)}\end{aligned}$$

Is there a deficit? Can this deficit be confirmed?
Two approaches:

CLEO precision measurement of

$\sigma(\psi'' \rightarrow \text{hadrons})$ underway [ISR correction](#)

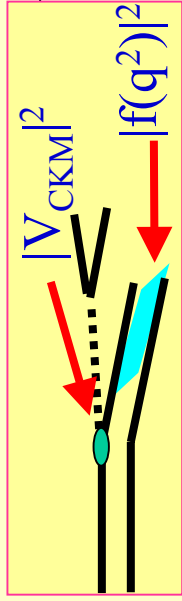
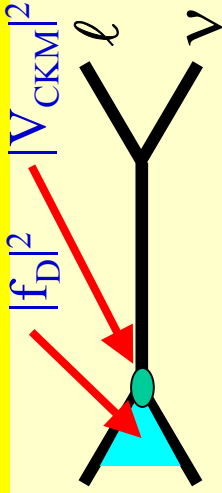
Search for exclusive decay modes like for any other charmonium state:

$\psi'' \rightarrow XJ/\psi$, two-body (VP), multibody, $\gamma\chi_{cJ}$

Status of Absolute Charm Branching Ratios

Poorly known $\xrightarrow{Br} \text{---} = \Gamma$

Measured very precisely $\xrightarrow{\tau}$



Key hadronic charm decay
modes used to normalize
B physics

	Mode	PDG04 (%)	Error (%)
D^+	$\mu\nu$	$0.08^{+0.17}_{-0.05}$	100
D_s^+	$\mu\nu$	0.60 ± 0.14	24
D^0	$\pi^- e^+ \nu$	$0.39^{+0.23}_{-0.11} \pm .04$	45
D^0	$K-\pi^+$	3.80 ± 0.09	2.4
D^+	$K-\pi^+ \pi^+$	9.2 ± 0.6	6.5
D_s^+	$\phi \pi^+$	3.6 ± 0.9	25
Λ_c	$p K-\pi^+$	5.0 ± 1.3	26
J/ψ	$\mu^+ \mu^-$	5.88 ± 0.10	1.7

Charm produced at B Factories/Tevatron or at dedicated FT experiments allows relative rate measurements but absolute rate measurements are hard because backgrounds are sizeable & because # D's produced is not well known.

Backgrounds are large.

#X Observed

$$Br(D \rightarrow X) = \frac{\text{efficiency} \times \#D\text{'s produced}}{\text{efficiency} \times \#D\text{'s produced}}$$

BEAUTY05, 06/23/05

H. Mahlke: CLEO D hadronic BR

#D's produced
is not well known.

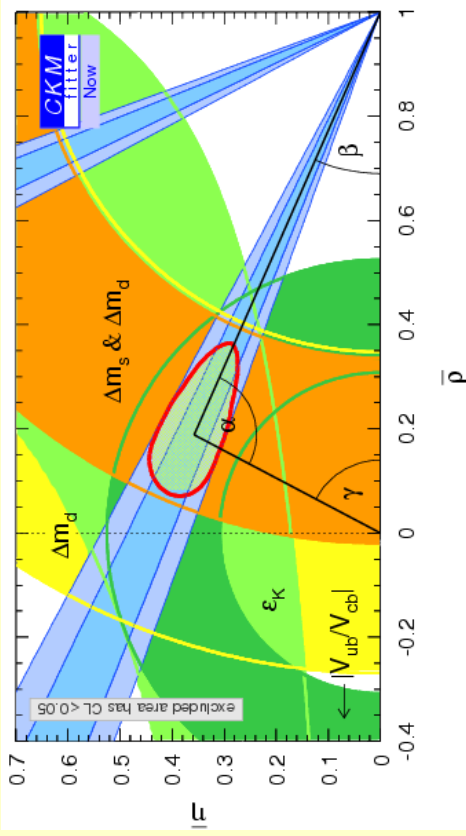
Branching Fraction Results

Parameter	Fitted Value (%)
$N(D^0\bar{D}^0)$	$(2.006 \pm 0.038 \pm 0.16) \times 10^5$
$\mathcal{B}(D^0 \rightarrow K^- \pi^+)$	$(3.91 \pm 0.08 \pm 0.09) \%$
$\mathcal{B}(D^0 \rightarrow K^- \pi^+ \pi^0)$	$(14.94 \pm 0.30 \pm 0.47) \%$
$\mathcal{B}(D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-)$	$(8.29 \pm 0.17 \pm 0.32) \%$

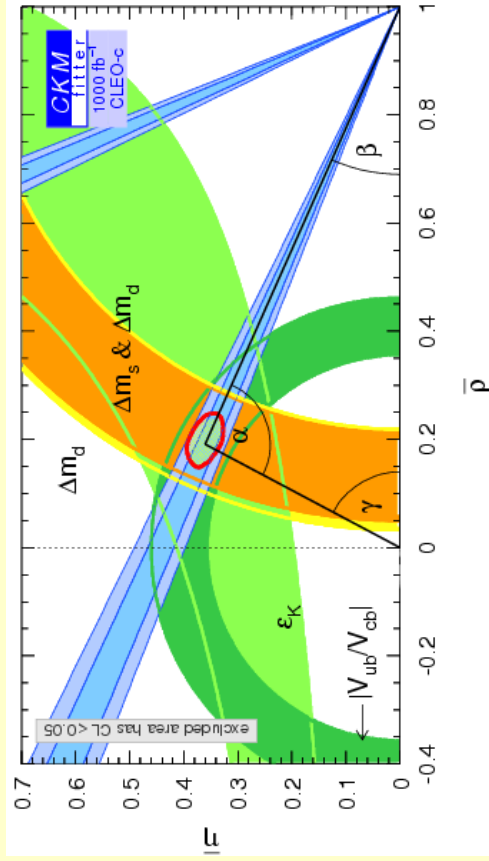
Parameter	Fitted Value (%)
$N(D^+ D^-)$	$(1.558 \pm 0.038 \pm 0.12) \times 10^5$
$\mathcal{B}(D^+ \rightarrow K^- \pi^+ \pi^+)$	$(9.52 \pm 0.25 \pm 0.27) \%$
$\mathcal{B}(D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0)$	$(6.04 \pm 0.18 \pm 0.22) \%$
$\mathcal{B}(D^+ \rightarrow K_s^- \pi^+)$	$(1.55 \pm 0.05 \pm 0.06) \%$
$\mathcal{B}(D^+ \rightarrow K_s^- \pi^+ \pi^0)$	$(7.17 \pm 0.21 \pm 0.38) \%$
$\mathcal{B}(D^+ \rightarrow K_s^- \pi^+ \pi^+ \pi^-)$	$(3.20 \pm 0.11 \pm 0.16) \%$
$\mathcal{B}(D^+ \rightarrow K^+ K^- \pi^+)$	$(0.97 \pm 0.04 \pm 0.04) \%$

Unitarity Constraints

Today



With 1000/pb from B factories and
CLEO-c lattice calibration



CLEO-c will allow B factory
measurements to reach full potential
by calibrating lattice QCD.

→ form factor measurements

→ D meson decay constant (f_D)

CLEO II/III analyses at $Y(4S)$ energies
continue to improve our knowledge
of CKM constraints...

D hadronic BR

Fit Inputs

Yield	$\mathbf{n} \ (n)$	$\mathbf{V_n} \ (n \times n)$
Background	$\mathbf{b} \ (b)$	$\mathbf{V_b} \ (b \times b)$
Signal efficiency	$\mathbf{E} \ (n \times n)$	$\mathbf{V_E} \ (n^2 \times n^2)$
Background efficiency	$\mathbf{F} \ (n \times b)$	$\mathbf{V_F} \ (nb \times nb)$

Errors on elements of $\mathbf{E}$, $\mathbf{F}$:

- Tracking, π^0 , K_S^0 systematics (correlateds all elements).
- Resonant substructure.
- Introduces correlations between D^0 and D^+ results.

Double tags subsets of single tags, so they are correlated.

Background sources:

- D modes not in fit (depends on free parameters N_{DD}).
- $e^+e^- \rightarrow \text{continuum}$, $\psi'\gamma$, $\tau^+\tau^-$ (correlated b/c of luminosity).
- Most Cabibbo-suppressed modes negligible (thanks to PID).

Efficiency matrices account for crossfeed.

The Algorithm

$$\mathbf{N} = \mathbf{E}^{-1} (\mathbf{n} - \mathbf{F}\mathbf{b})$$

- Correct measured yields:
- Equate with functions ($\mathbf{N}^*$) of $\mathbf{m}$:
 - $N_i^* = N_{DD}\mathcal{B}_i$, $N_{ij}^* = N_{DD}\mathcal{B}_i\mathcal{B}_j$, modulo factors of 2.
- Propagate stat. and syst. errors on $\mathbf{n}$, $\mathbf{b}$, $\mathbf{E}$, $\mathbf{F}$ to $\mathbf{V}_\mathbf{N}$:

$$\mathbf{V}_\mathbf{N} = \mathbf{E}^{-1} \left(\mathbf{V}_\mathbf{n} + \mathbf{F}\mathbf{V}_\mathbf{b}\mathbf{F}^T + \frac{\partial \mathbf{p}^T}{\partial \mathbf{E}} \mathbf{V}_\mathbf{E} \frac{\partial \mathbf{p}}{\partial \mathbf{E}} (\mathbf{E}^{-1})^T + \frac{\partial \mathbf{N}^T}{\partial \mathbf{F}} \mathbf{V}_\mathbf{F} \frac{\partial \mathbf{N}}{\partial \mathbf{F}} - 2 \left(\mathbf{E}^{-1} \frac{\partial \mathbf{p}^T}{\partial \mathbf{E}} \mathbf{C}_{\mathbf{EF}} \frac{\partial \mathbf{N}}{\partial \mathbf{F}} \right)^{sym} \right)$$

where $\mathbf{p} = \mathbf{n} - \mathbf{F}\mathbf{b}$ and $\mathbf{C}_{\mathbf{EF}}$ gives the $\mathbf{E}/\mathbf{F}$ correlations.

$$\chi^2 = (\mathbf{N} - \mathbf{N}^*)^T \mathbf{V}_\mathbf{N} (\mathbf{N} - \mathbf{N}^*)$$

- Minimize
- Input $\mathbf{b}$ depends on $\mathbf{m}$:
 - Update inputs between iterations.
 - Include $d\mathbf{b}/d\mathbf{m}$ in derivatives $d\chi^2/d\mathbf{m}$.