il cucchiaio

Measurement of absolute D hadronic branching fractions

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Cornell University
for the
CLEO Collaboration

BEAUTY 2005, Assisi, Italy

la forchetta

il coltello

CLEO-c: high precision, low energy

Semilept decays BR's, form factors, V_{cd}, V_{cs}

M. Artuso, this conference

Hadronic decays BR's, mixing constraints

THIS TALK

Weak decays, f_D

S. Stone, this conference

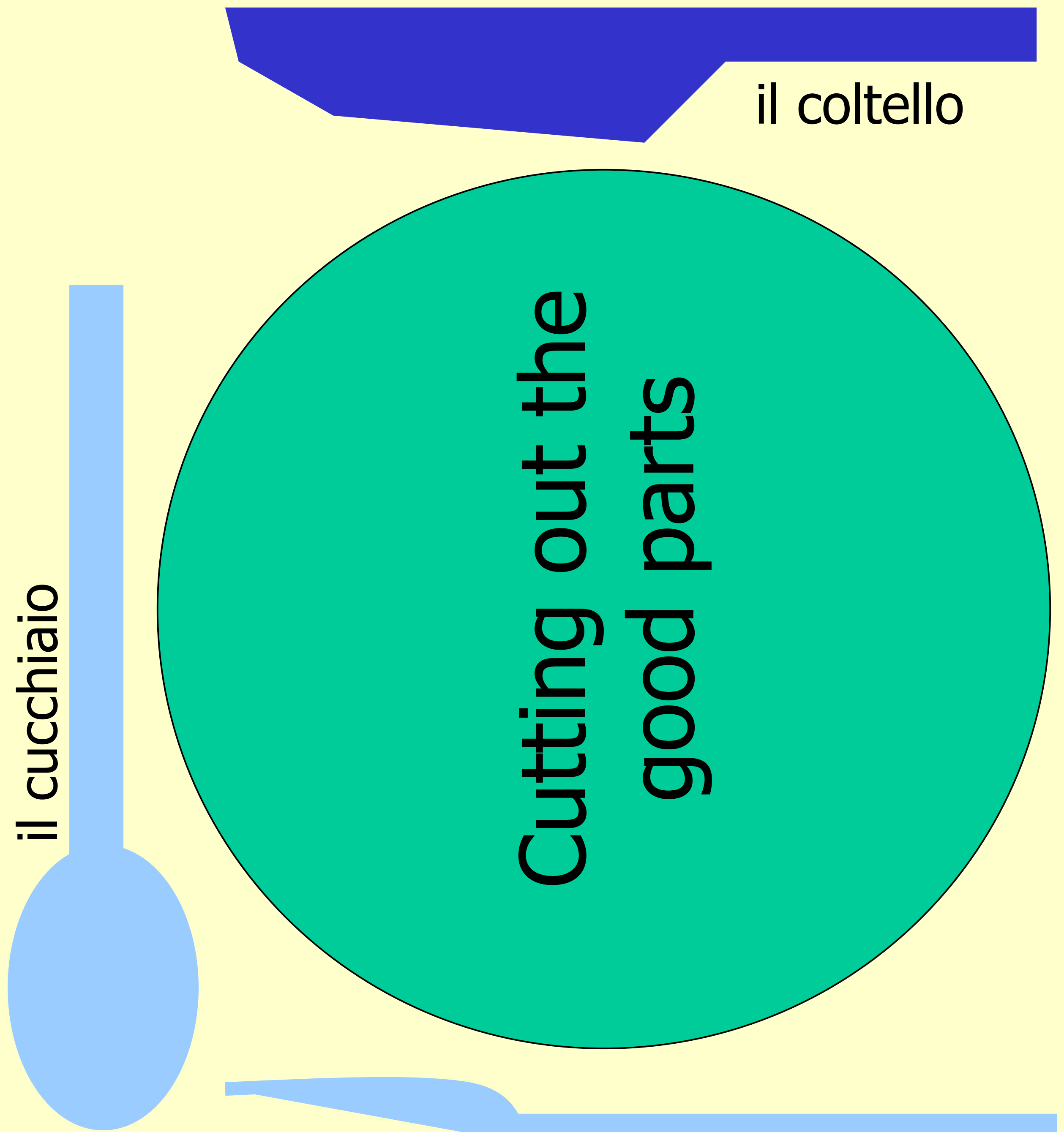
Rare/Non-SM

J. Rosner, this conference

Spectroscopy

J. Rosner, this conference

Improve upon current precision
Validation of LQCD tools
Reduced uncertainties in other measurements



il coltello
Cutting out the good parts
il cucchiaio
la forchetta

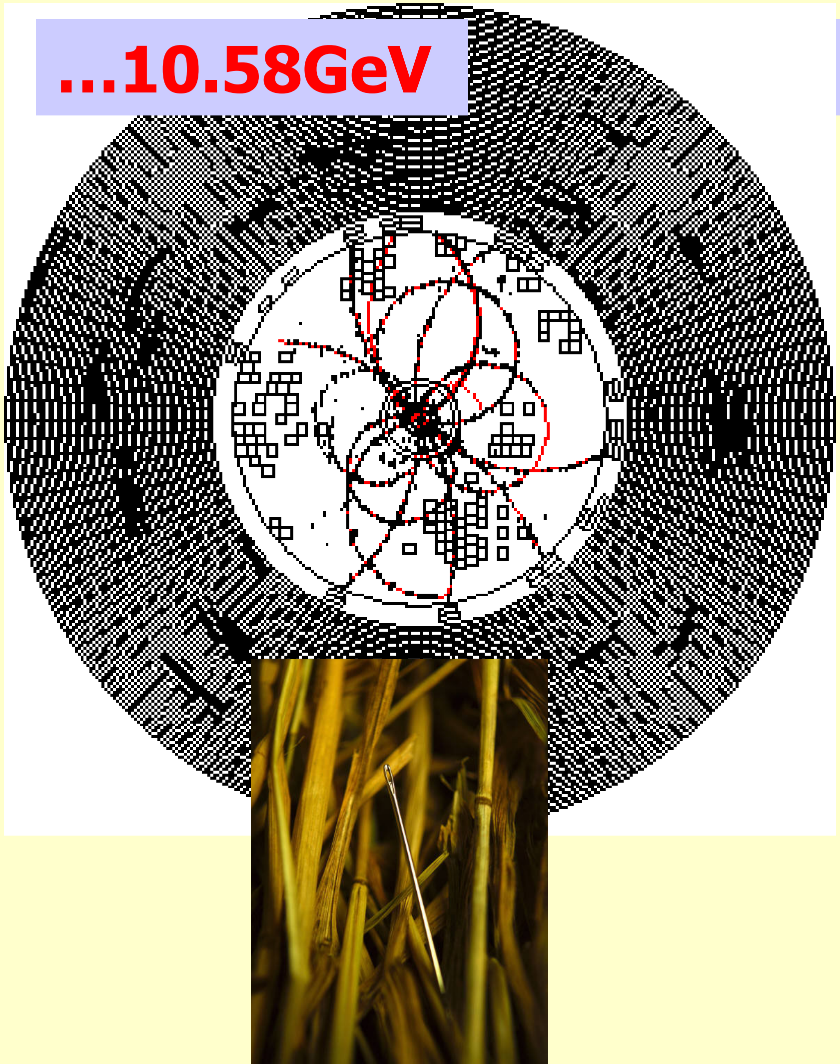
Hadronic D Decays: Why?

- Many current measurements determined with respect to normalizing modes $D^0 \to K^- \pi^+$, $D^+ \to K^- \pi^+ \pi^+$
- Input to MANY measurements (*e.g.* V_{cb} from $B \to D^* l \nu$)
- 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

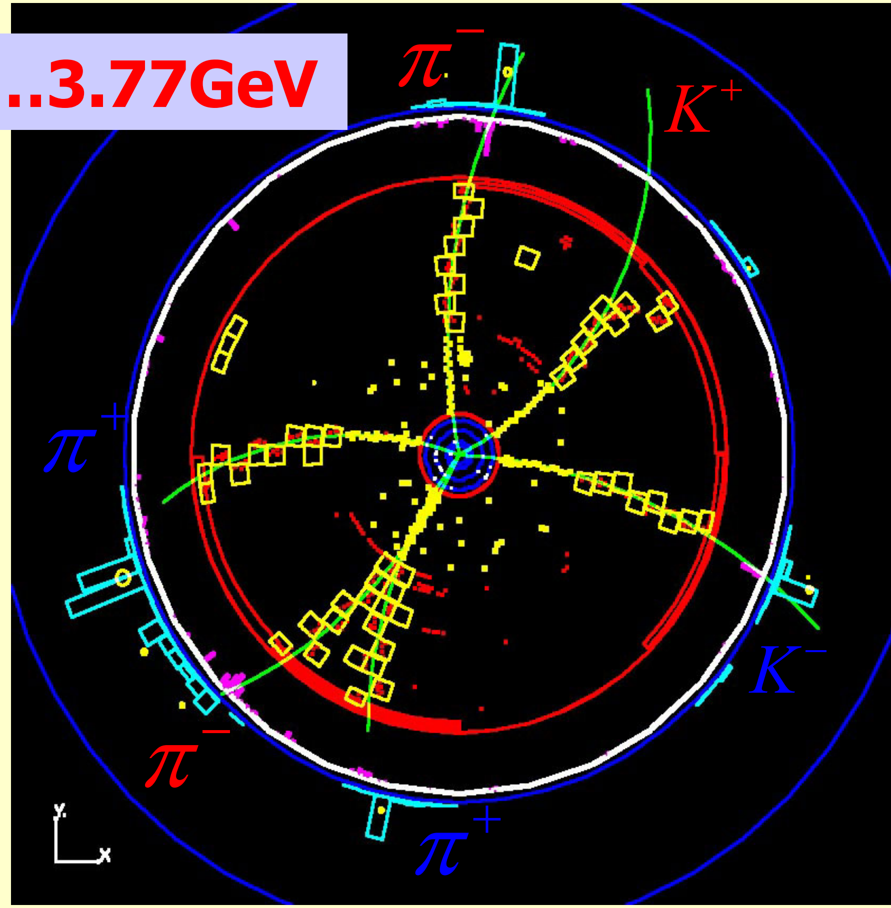
These results: 60/pb "pilot run" (0.36M $D\bar{D}$ pairs)
CLEO Collab., Q. He et al., hep-ex/0504003, subm. to PRL

D Production at...

...10.58GeV



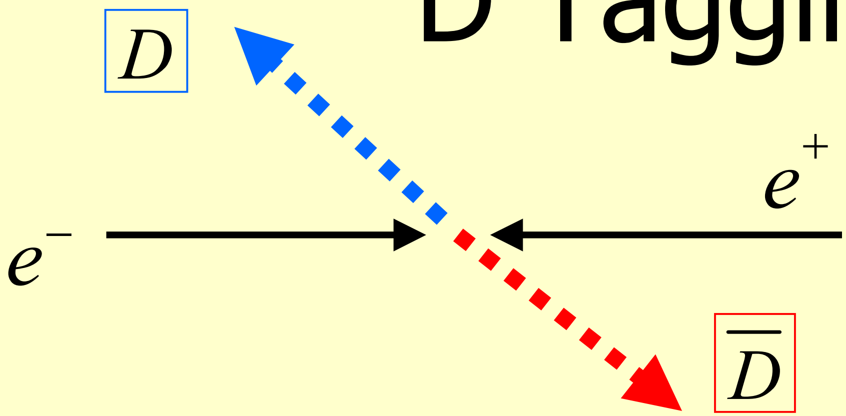
...3.77GeV



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

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

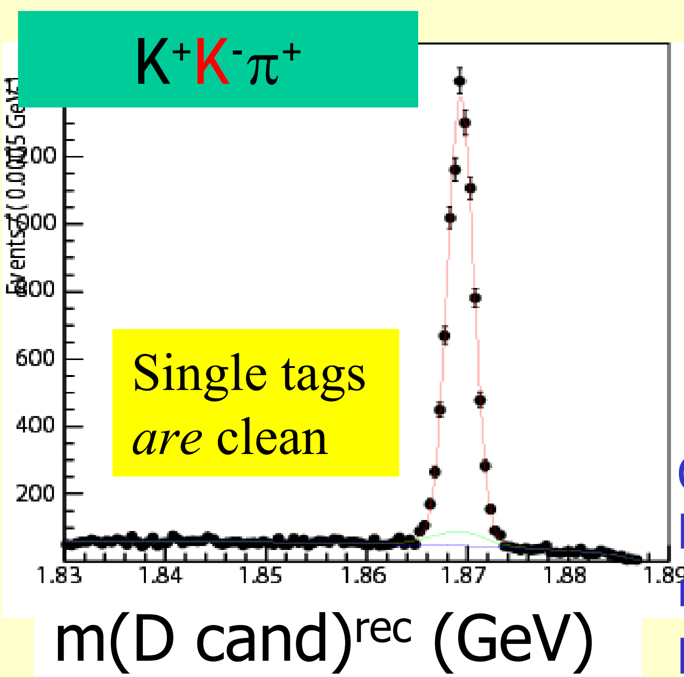
"D Tagging" (AKA "The MarkIII Method")



Basic Strategy (for most CLEO-c analyses):

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

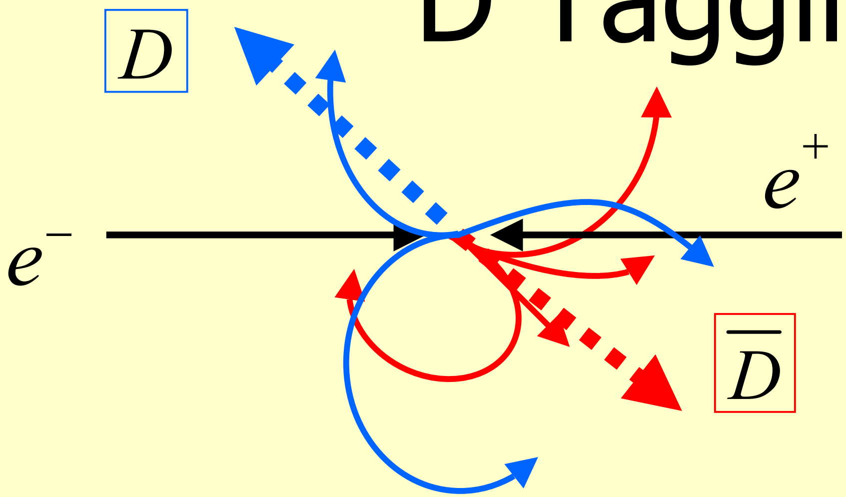
e.g. $B(D^+ \to K^-\pi^+\pi^+) = \dfrac{\#(K^-\pi^+\pi^+) \text{ in tagged events}}{(\varepsilon(K^-\pi^+\pi^+) * \#tags)}$



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

Continuum, τ pair, radiative return events suppressed significantly.

"D Tagging" (AKA "The MarkIII Method")



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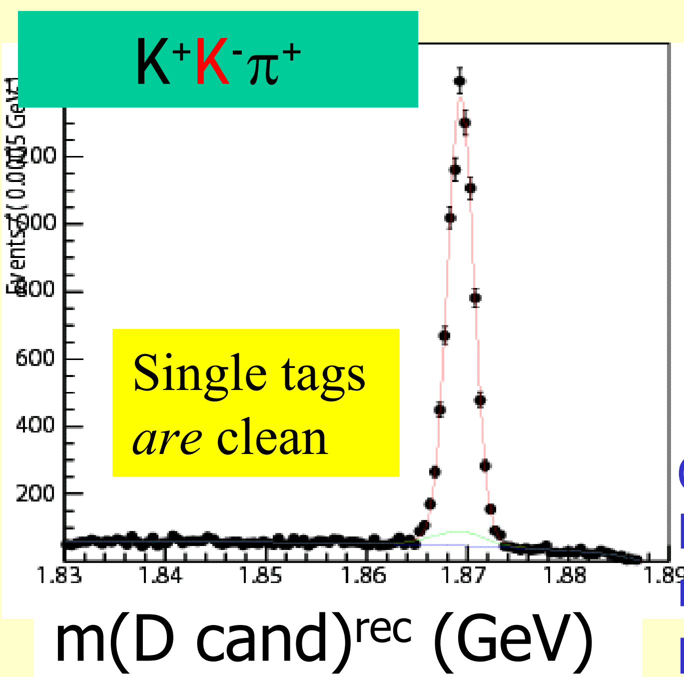

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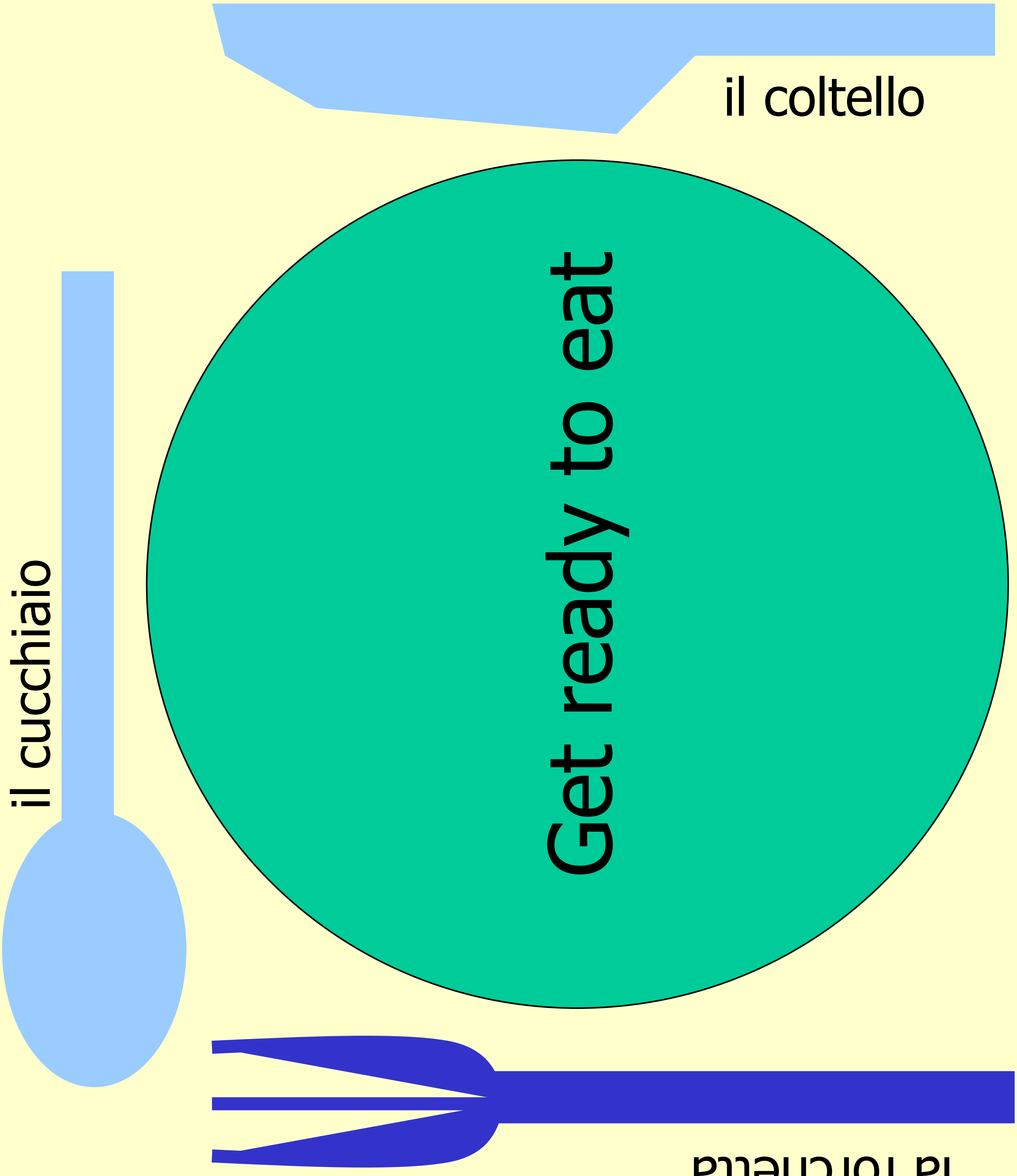
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Get ready to eat
il cucchiaio
la forchetta

The BR Fit

"have" — want — 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

$D^0 \to K^-\pi^+$	⟷	$\overline{D}^0 \to K^+\pi^-$
$D^0 \to K^-\pi^+\pi^0$		$\overline{D}^0 \to K^+\pi^-\pi^0$
$D^0 \to K^-\pi^+\pi^+\pi^-$		$\overline{D}^0 \to K^+\pi^-\pi^-\pi^+$
$D^+ \to K^-\pi^+\pi^+$	⟷	$D^- \to K^+\pi^-\pi^-$
$D^+ \to K^-\pi^+\pi^+\pi^0$		$D^- \to K^+\pi^-\pi^-\pi^0$
$D^+ \to K_s\pi^+$		$D^- \to K_s\pi^-$
$D^+ \to K_s\pi^+\pi^0$		$D^- \to K_s\pi^-\pi^0$
$D^+ \to K_s\pi^+\pi^+\pi^-$		$D^- \to K_s\pi^-\pi^-\pi^+$
$D^+ \to K^-K^+\pi^+$		$D^- \to K^-K^+\pi^-$

D and anti-D yields measured separately

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

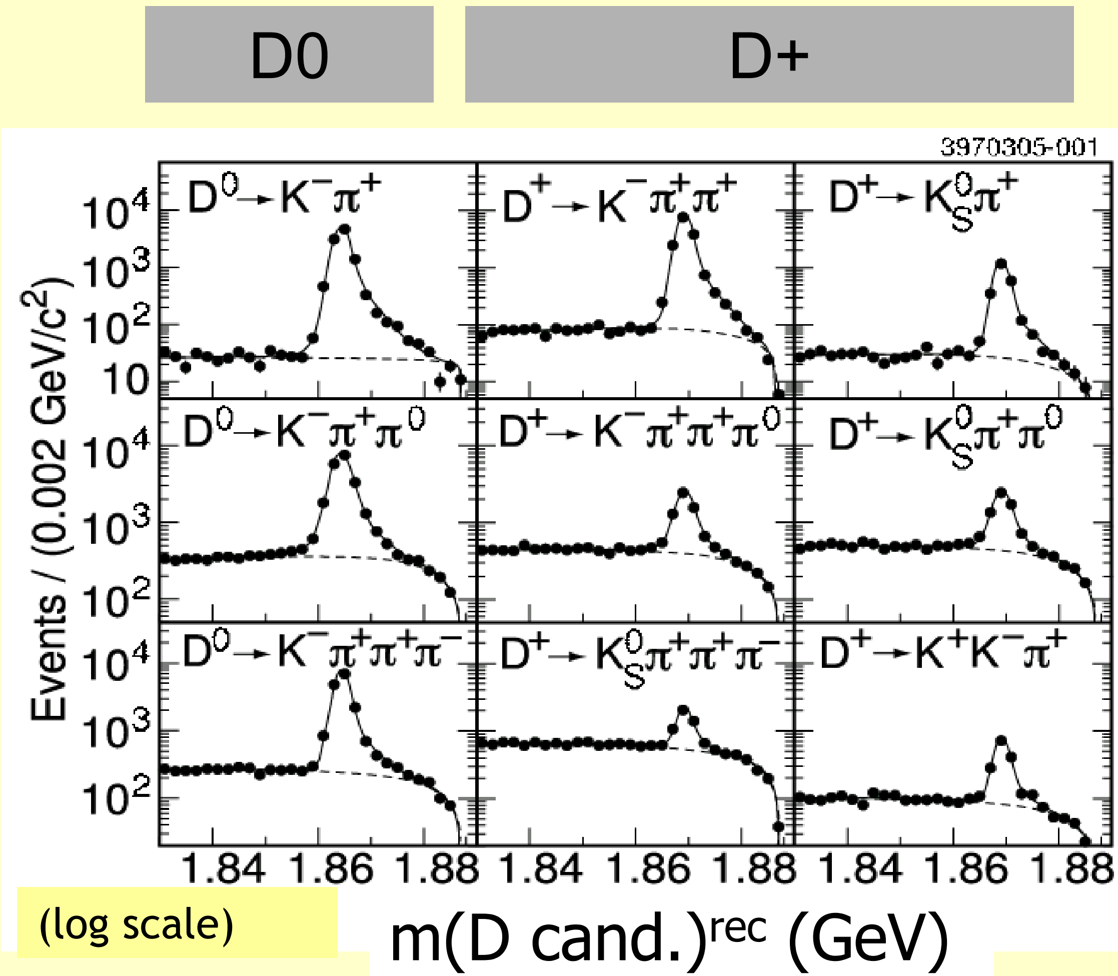
The Plan:

1. Determine yields N_i, N_{ij}
2. Simultaneously fit for N_{D+D-}, $N_{D0D0bar}$ ($\int \mathcal{L} \to$ 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



Yields vary between 0.6k and ~10k events

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

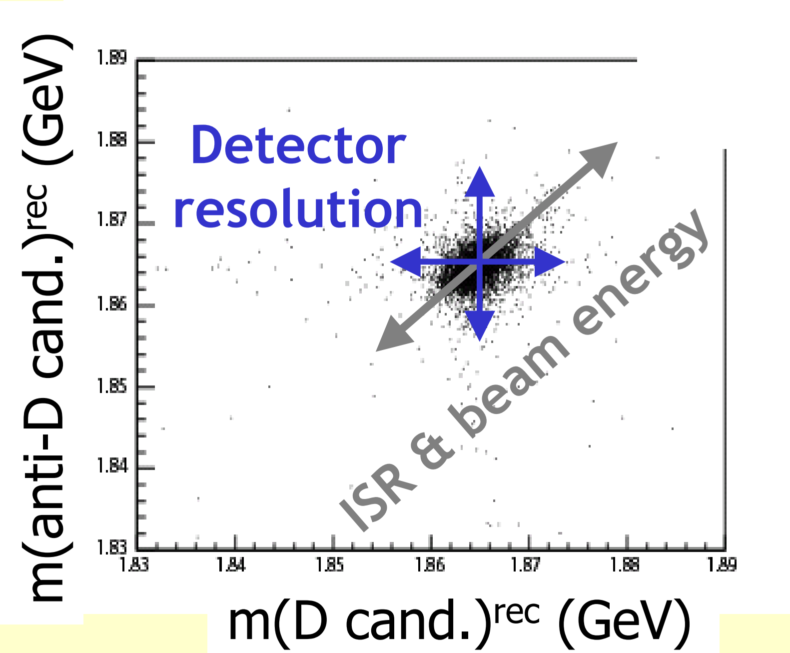
Efficiencies 23-67%

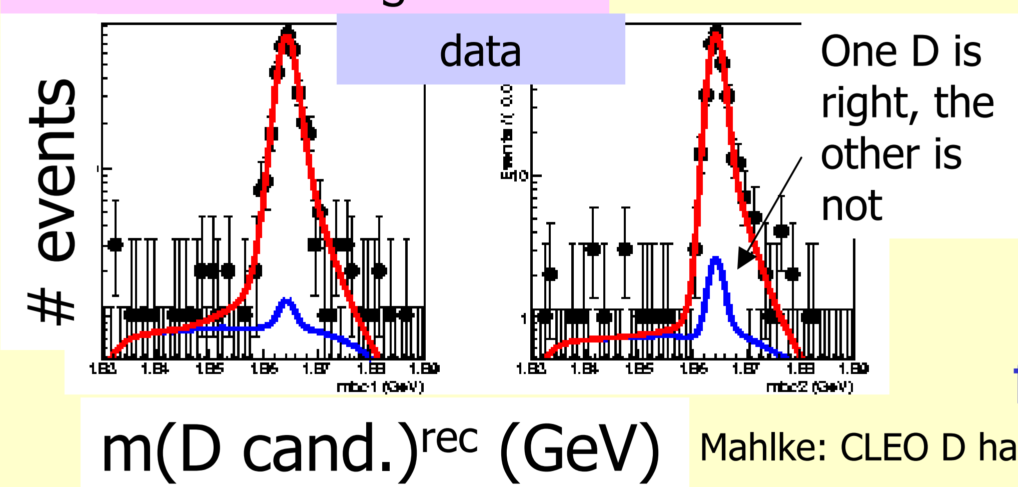
Signal shape: $\psi(3770)$ line shape, ISR, beam energy spread & momentum resolution
Background: ARGUS

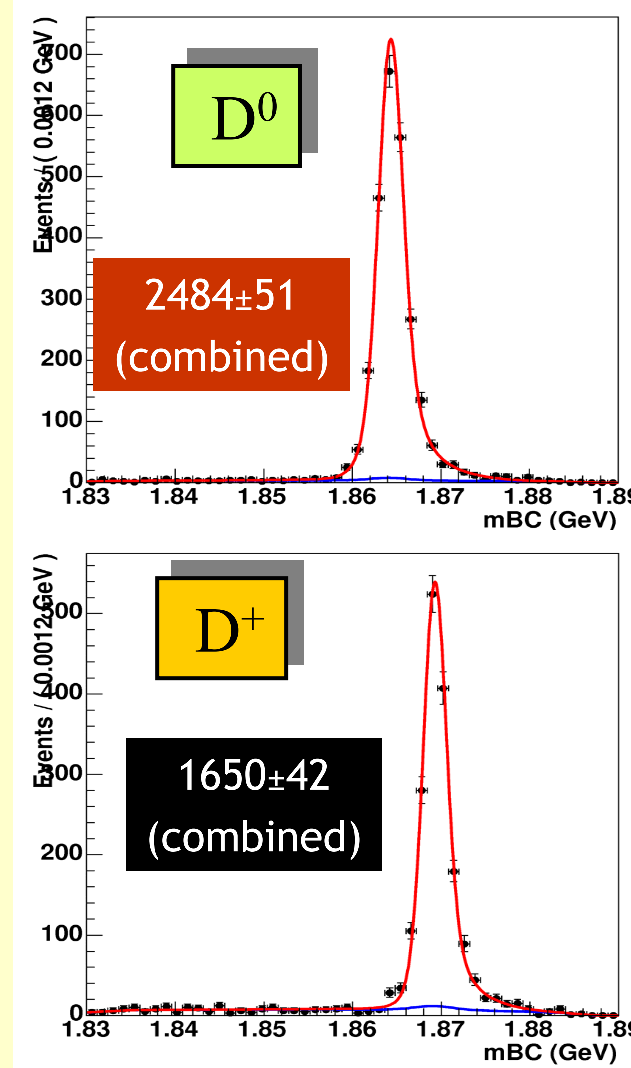
This fit removes smooth background

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

BR Fit Input II: Double Tag Event Yields







BR Fit Output: branching fractions, N_{D+D-}, $N_{D0D0bar}$

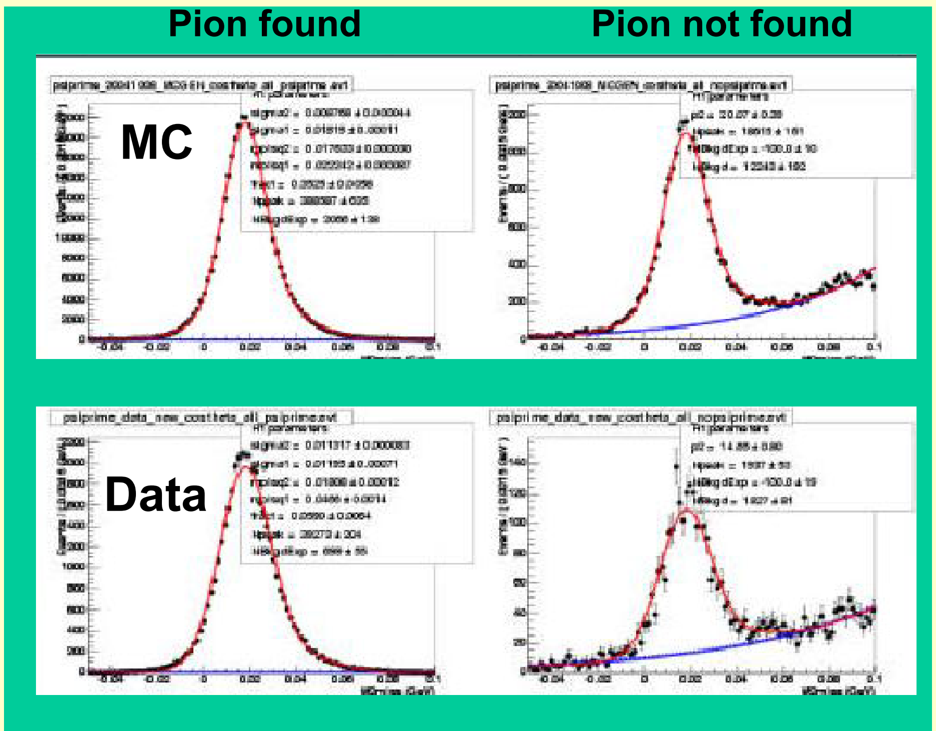
Systematics

Tracking systematics:

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

Same procedure for π^0

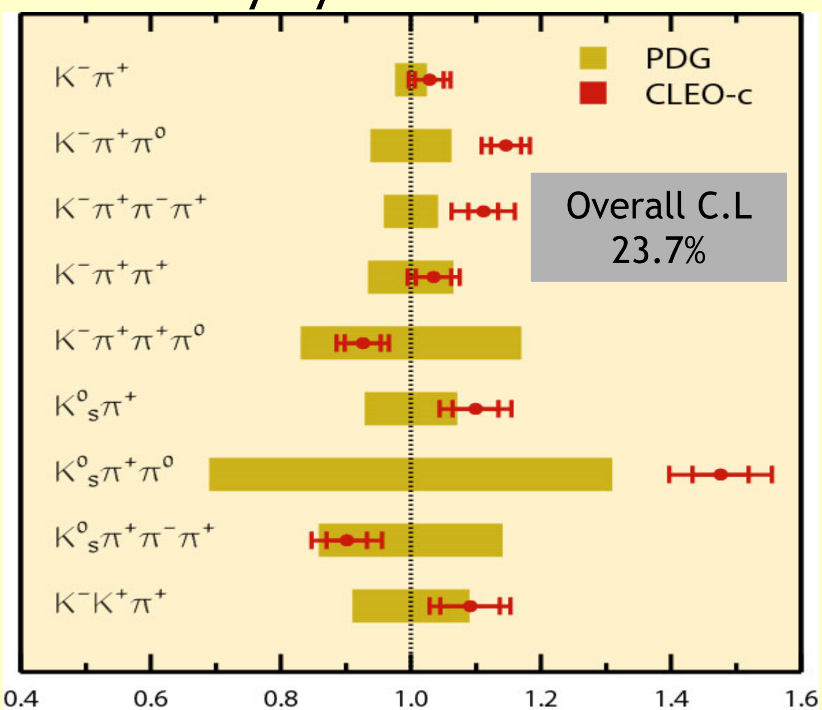
K_S from $D \to K_S\pi\pi$ "double tag" events

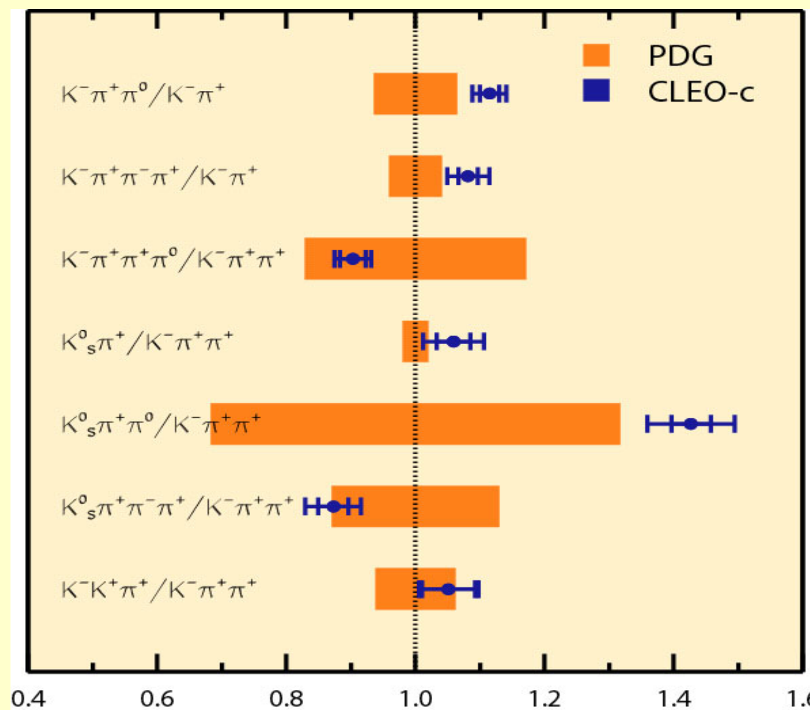


Source	Value (%)
Tracking/K_s/π^0	0.7/3.0/2.0
Particle ID	0.3/$\pi^{+,-}$, 1.3/$K^{+,-}$
ΔE	1.0-2.5
$\Gamma_{\psi(3770)}$	0.6
Final State Radiation	0.5 ST / 1.0 DT
Resonant Substr.	0.4-1.5
DCSD Interference	0.8
Fit functions	0.5
Online/offline filtering	0.4
Multiplicity, det. noise	0.2-1.3

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

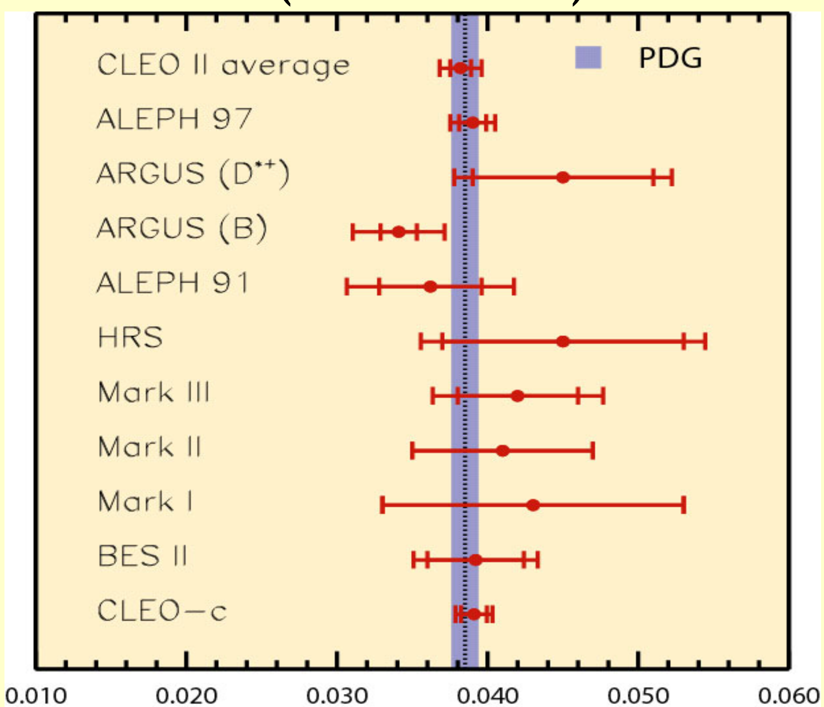




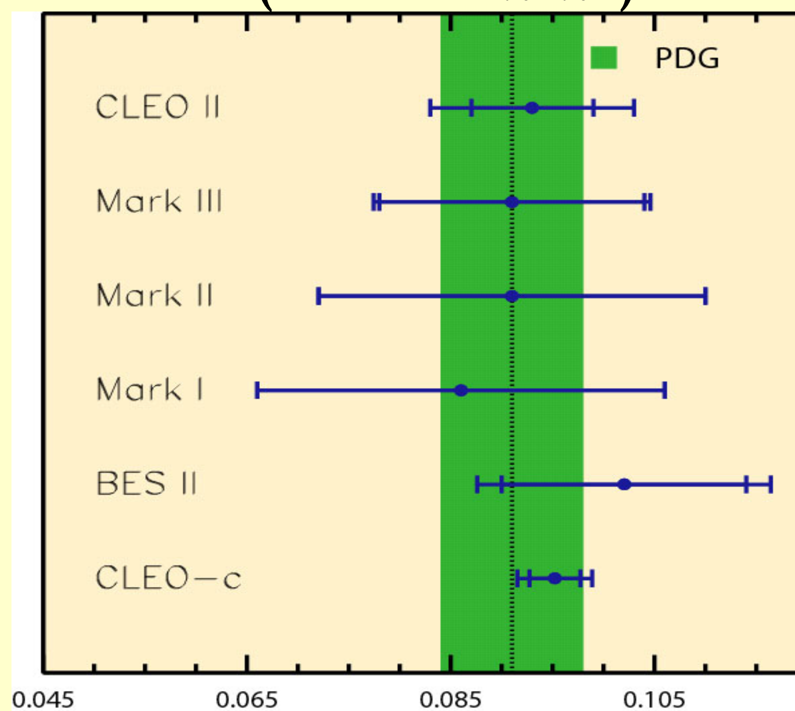
Comparison with PDG 2004 (II)

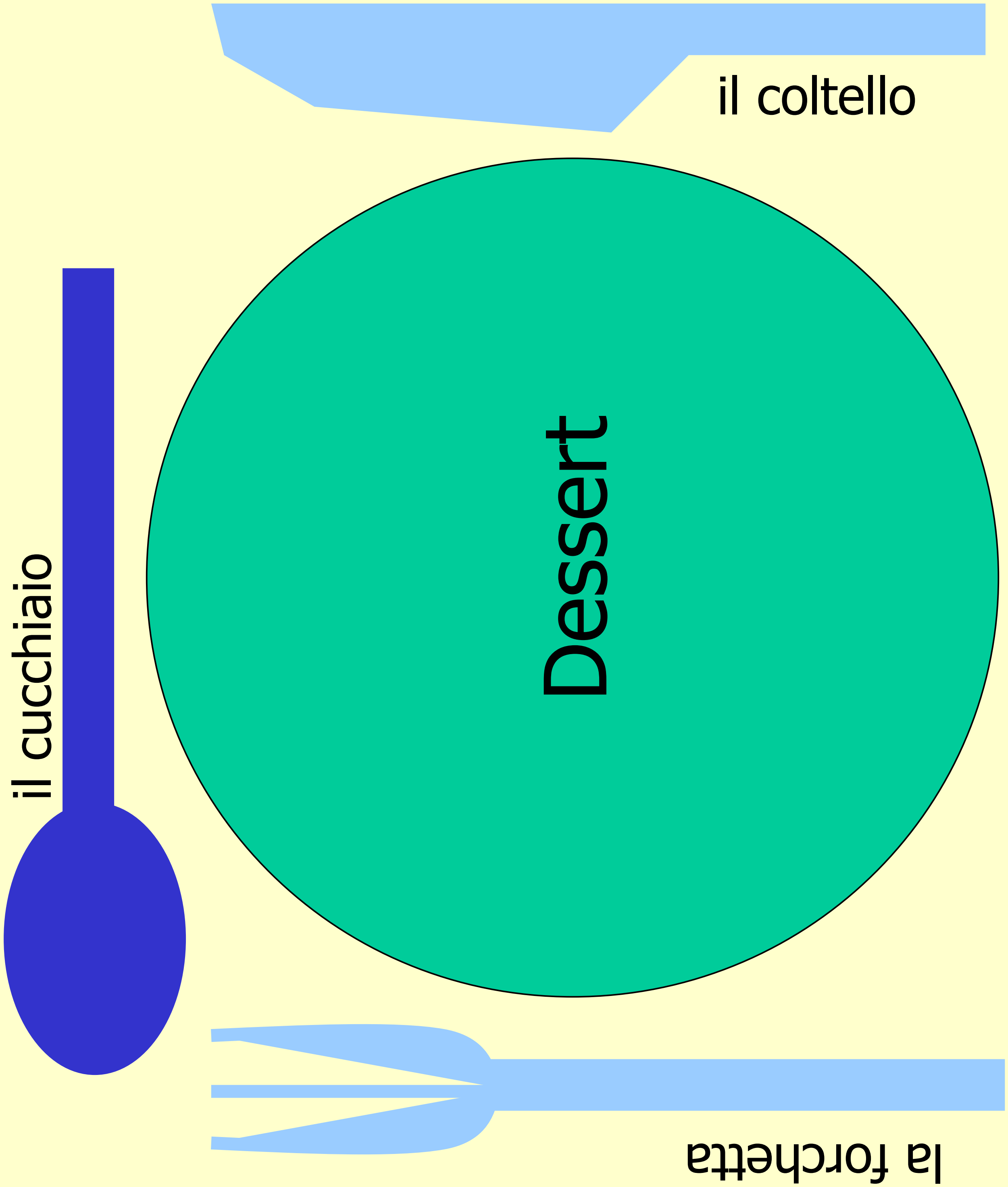
- Compare with other *direct* measurements in PDG.
- PDG band = average of direct meas., not global fit.

$\mathcal{B}(D^0 \to K^-\pi^+)$



$\mathcal{B}(D^+ \to K^- \pi^+\pi^+)$

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Dessert
il cucchiaio
la forchetta

Cross Sections

Convert N_{DD}'s to cross sections:

$$\sigma(e^+e^- \to D\bar{D}) = (6.23 \pm 0.09 \pm 0.21)\ nb$$
$$\sigma(e^+e^- \to D^0\overline{D^0}) = (3.51 \pm 0.07 \pm 0.14)\ nb$$
$$\sigma(e^+e^- \to D^+D^-) = (2.72 \pm 0.07 \pm 0.09)\ nb$$

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

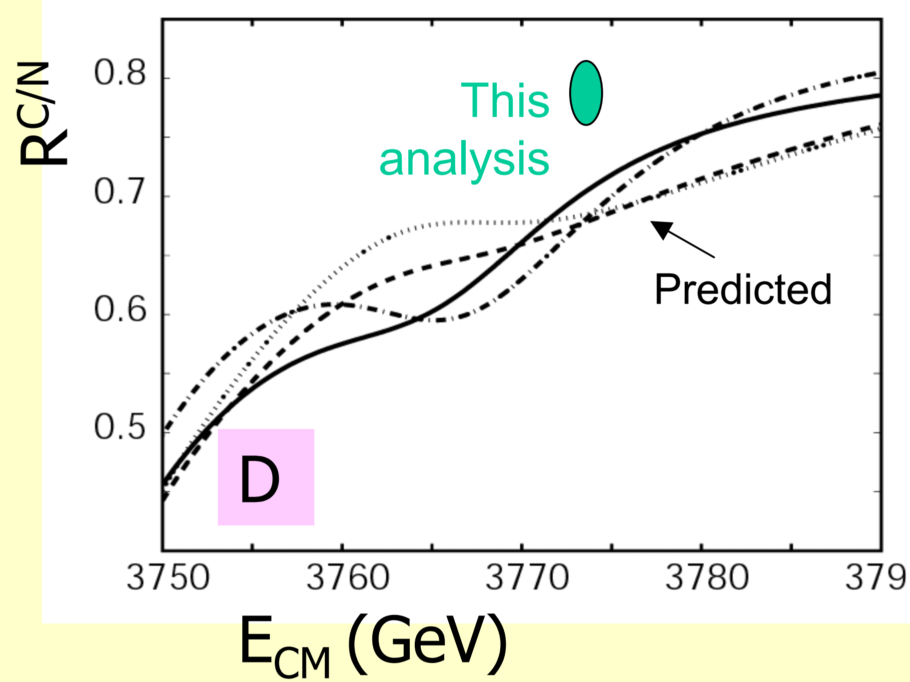
BES PLB603,130(2004)
(6.14±0.12±0.50)nb
(3.58±0.09±0.31)nb
(2.56±0.08±0.26)nb

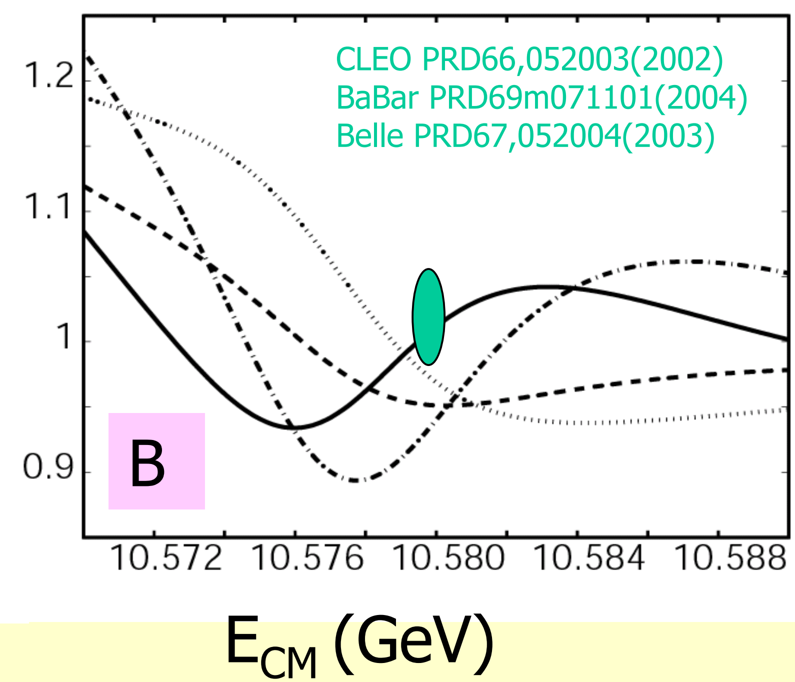
(17/pb, single tag only)

Charged to Neutral Ratio

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

Prediction:
M. Voloshin,
hep-ph/0402170





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

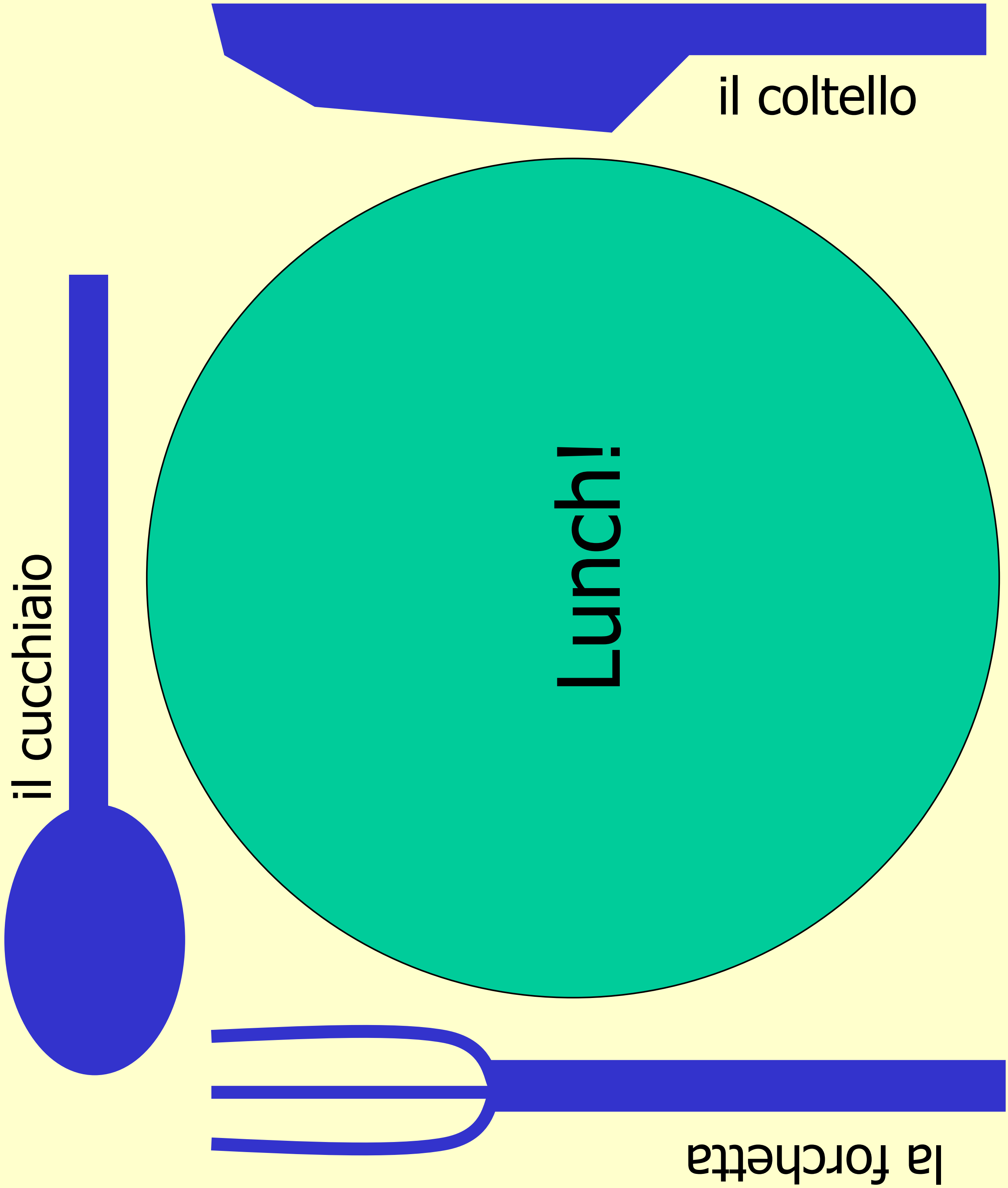
M.V., hep-ph/0504197

Summary: CLEO-c absolute hadronic D BR's

- First results, based on 60/pb
- 9 decay modes (incl $D^0 \to K^- \pi^+$, $D^+ \to K^- \pi^+ \pi^+$) 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
- $\sigma(\psi'' \to DD)$, $\sigma(\psi'' \to D^0 \overline{D}^0)$, $\sigma(\psi'' \to D^+ D^-)$, and $\sigma(\psi'' \to D^+ D^-)/\sigma(\psi'' \to D^0 \overline{D}^0)$

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. $D_s^+ \to \phi\pi^+$)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Lunch!
il cucchiaio
la forchetta

DONE

Non-$D\bar{D}$ ψ'' decays

$\sigma(\psi'' \to D\bar{D}) = (6.39 \pm 0.09 \pm 0.21)$ nb OZI preferred

$\sigma(\psi'' \to \text{hadrons}) \sim 8$ nb (see hep-ph/0411196 for an average of older measurements)

Is there a deficit? Can this deficit be confirmed?

Two approaches:

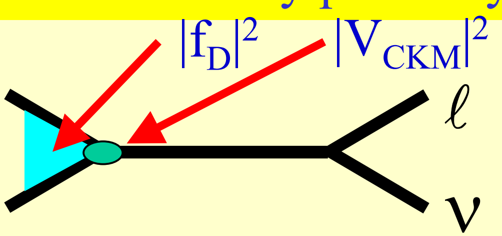
- CLEO precision measurement of $\sigma(\psi'' \to \text{hadrons})$ underway ISR correction
- Search for exclusive decay modes like for any other charmonium state: $\psi'' \to XJ/\psi$, two-body (VP), multibody, $\gamma\chi_{CJ}$

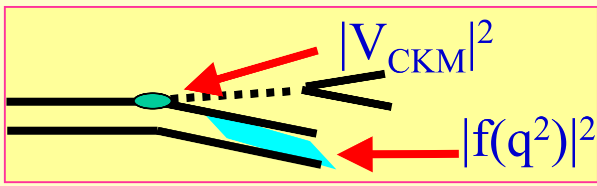
Status of Absolute Charm Branching Ratios

Poorly known → Br

Measured very precisely → τ

$$\frac{Br}{\tau} = \Gamma$$





	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^o	$K^-\pi^+$	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	$pK^-\pi^+$	5.0 ± 1.3	26
J/ψ	$\mu^+\mu^-$	5.88 ± 0.10	1.7

Key hadronic charm decay modes used to normalize B physics

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.

$$Br(D \to X) = \frac{\#X\ \text{Observed}}{\text{efficiency x \#D's produced}}$$

Backgrounds are large.

#D's produced is not well known.

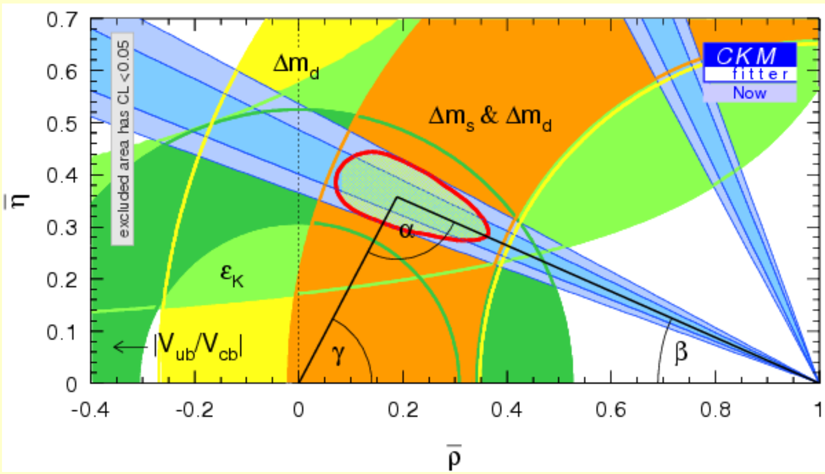
Branching Fraction Results

Parameter	Fitted Value (%)
$N(D^0\overline{D}^0)$	$(2.006\pm0.038\pm016)\times10^5$
$\mathcal{B}(D^0\rightarrow K^-\pi^+)$	$(3.91\pm0.08\pm0.09)$ %
$\mathcal{B}(D^0\rightarrow K^-\pi^+\pi^0)$	$(14.94\pm0.30\pm0.47)$ %
$\mathcal{B}(D^0\rightarrow K^-\pi^+\pi^+\pi^-)$	$(8.29\pm0.17\pm0.32)$ %

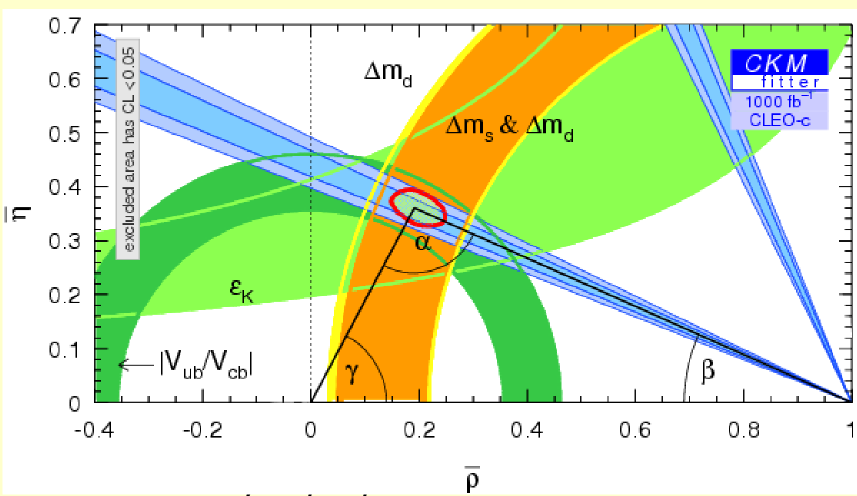
Parameter	Fitted Value (%)
$N(D^+D^-)$	$(1.558\pm0.038\pm012)\times10^5$
$\mathcal{B}(D^+\rightarrow K^-\pi^+\pi^+)$	$(9.52\pm0.25\pm0.27)$ %
$\mathcal{B}(D^+\rightarrow K^-\pi^+\pi^+\pi^0)$	$(6.04\pm0.18\pm0.22)$ %
$\mathcal{B}(D^+\rightarrow K_s\pi^+)$	$(1.55\pm0.05\pm0.06)$ %
$\mathcal{B}(D^+\rightarrow K_s\pi^+\pi^0)$	$(7.17\pm0.21\pm0.38)$ %
$\mathcal{B}(D^+\rightarrow K_s\pi^+\pi^+\pi^-)$	$(3.20\pm0.11\pm0.16)$ %
$\mathcal{B}(D^+\rightarrow K^+K^-\pi^+)$	$(0.97\pm0.04\pm0.04)$ %

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/IIV analyses at Y(4S) energies continue to improve our knowledge of CKM constraints…

Fit Inputs

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

Errors on elements of **E**, **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}).
- $e^+e^- \to$ 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

- Correct measured yields: $\mathbf{N} = \mathbf{E}^{-1}(\mathbf{n} - \mathbf{F}\mathbf{b})$
- 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 **n**, **b**, **E**, **F** to $\mathbf{V_N}$:

$$\mathbf{V_N} = \mathbf{E}^{-1}\left(\mathbf{V_n} + \mathbf{F}\mathbf{V_b}\mathbf{F}^T + \frac{\partial \mathbf{p}}{\partial \mathbf{E}}^T \mathbf{V_E} \frac{\partial \mathbf{p}}{\partial \mathbf{E}}\right)\left(\mathbf{E}^{-1}\right)^T + \frac{\partial \mathbf{N}}{\partial \mathbf{F}}^T \mathbf{V_F} \frac{\partial \mathbf{N}}{\partial \mathbf{F}} - 2\left(\mathbf{E}^{-1} \frac{\partial \mathbf{p}}{\partial \mathbf{E}}^T \mathbf{C_{EF}} \frac{\partial \mathbf{N}}{\partial \mathbf{F}}\right)_{sym}$$

  where $\mathbf{p} = \mathbf{n} - \mathbf{F}\mathbf{b}$ and $\mathbf{C_{EF}}$ gives the **E**/**F** correlations.
- Minimize $\chi^2 = (\mathbf{N} - \mathbf{N}^*)^T \mathbf{V_N} (\mathbf{N} - \mathbf{N}^*)$
- Input **b** depends on **m**:
  - Update inputs between iterations.
  - Include $d\mathbf{b}/d\mathbf{m}$ in derivatives $d\chi^2/d\mathbf{m}$.