D Hadronic Branching Fractions and $D\overline{D}$ Cross Section at $\psi''(3770)$ from CLEO–c

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Hadron 05

Outline

Outline

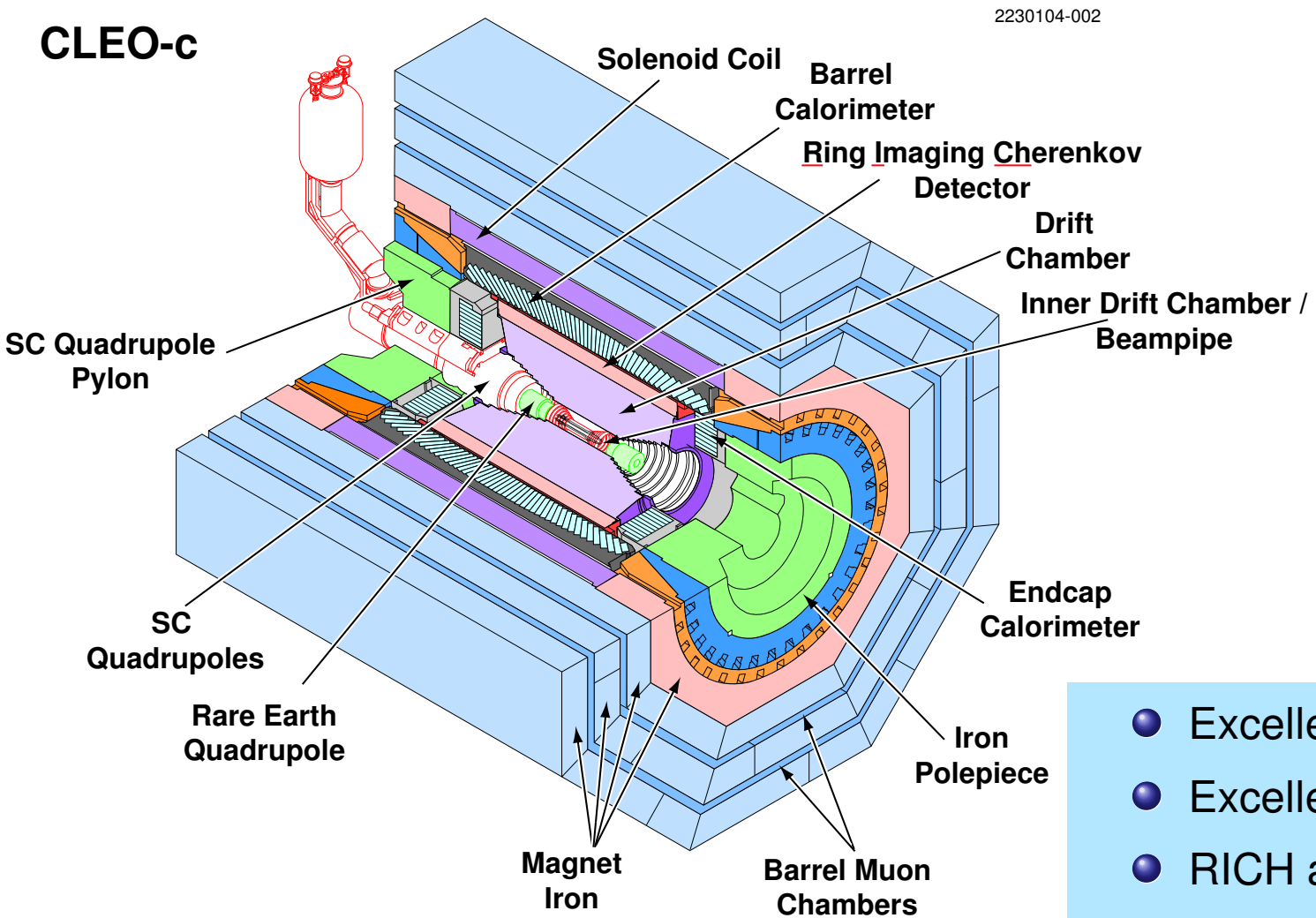
$e^+e^- \rightarrow \psi''(3770)$ at Cornell

$$\boxed{E_{\text{beam}} = (1.5 - 5.6)\ \text{GeV}}$$

$$\Rightarrow \sqrt{s} = (3.0 - 11.2)\ \text{GeV}$$

CESR–c collides e^+ e^- in order to produce the $\psi''(3770)$

Outline



- Excellent Calorimeter
- Excellent Tracking
- RICH and dE/dx for PID
- Muon Chambers

+ A Great Accelerator Team

Outline

Hadronic D Decays

- Measurements of hadronic charm meson branching fractions play central role in study of weak interaction
  - Serve to normalize many D and B meson branching fractions (normalizing modes: $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$)
  - Used to determine Cabibbo–Kobayashi–Maskawa (CKM) matrix elements (e.g. $|V_{cb}|$ from $B \to D^* l \nu$ requires D meson BF)
- CLEO–c will provide most precise measurements of D hadronic branching fractions
  - Also, determination of $D\overline{D}$ production cross sections
  - First step towards improved constraints on D mixing parameters

First results: 55.8 pb^{-1} (0.36 M $D\overline{D}$ pairs)
CLEO Collaboration (Q. He *et al.*), hep–ex/0504003, accepted by PRL

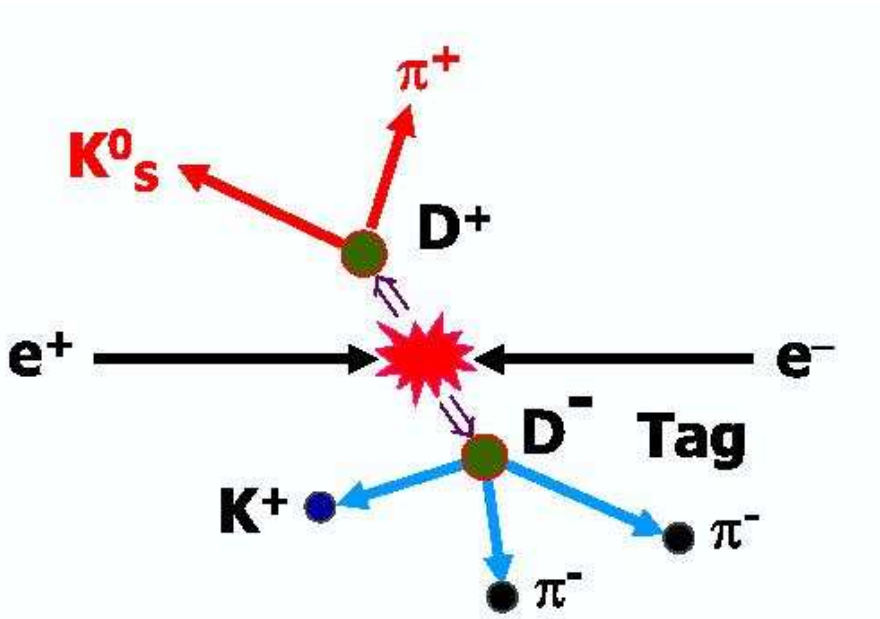
Outline

D Tagging and the Mark III Method

Identification of D meson candidates using beam–constrained mass:

$$\Delta E = E_D - E_{\text{beam}}$$

$$M_{\text{bc}} = \sqrt{E^2_{\text{beam}} - |p_D|^2}$$



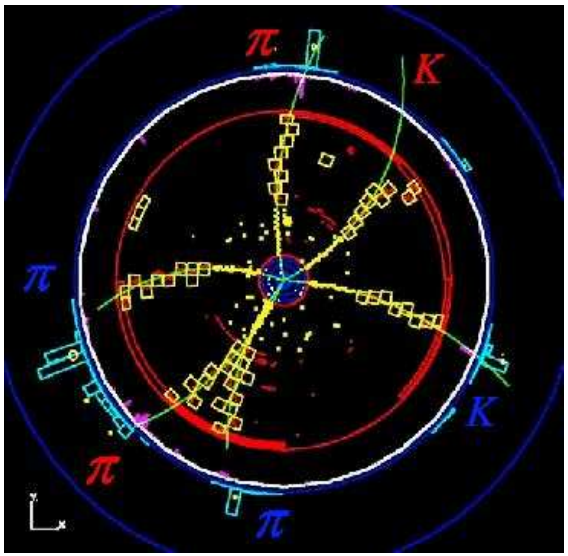
Basic strategy
(for most CLEO–c analyses)

- Full reconstruction of one D meson (*the tag*)
- Search for 2nd D meson in the remainder of the event

Reconstruction

- Charged tracks: Track fit quality and originate from interaction point
- π / K separation by dE/dx and RICH
- $\mathrm{K_S} \to \pi^+\pi^-$ and π^0 reconstruction
- 3σ cut on $\Delta E \equiv E_{\mathrm{D}} - E_0$

Single Tags and Double Tags



Measurement of single tags and double tags

Known

Measured

$$N_i = N_{D\overline{D}}\,\mathcal{B}_i\,\epsilon_i$$
$$N_{ij} = N_{D\overline{D}}\,\mathcal{B}_i\mathcal{B}_j\,\epsilon_{ij}$$

⇓ Wanted

Determination of Branching Fractions

- Determine yields N_i and N_{ij}
- Simultaneously fit for $N_{D^+D^-}$, $N_{D^0\overline{D^0}}$, and all $\mathcal{B}_i$

$$B_i = \frac{N_{ij}\,\epsilon_j}{N_j\,\epsilon_{ij}}$$
$$N_{D\overline{D}} = \frac{N_i\,N_j\,\epsilon_{ij}}{N_{ij}\,\epsilon_i\,\epsilon_j}$$

Outline

Fitting Technique (I)

Simultaneous fit for all $\mathcal{BR}$ & cross sections is performed

$\Rightarrow$ All correlations and errors properly taken into account

- Charged and neutral modes fit simultaneously
- D and $\overline{\mathrm{D}}$ yields measured separately

W.M. Sun
arXiv:physics/0503050
accepted by NIM A

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

$\mathrm{D}^+ \to \mathrm{K}^-\pi^+\pi^+$	$\mathrm{D}^- \to \mathrm{K}^+\pi^-\pi^-$
$\mathrm{D}^+ \to \mathrm{K}^-\pi^+\pi^+\pi^0$	$\mathrm{D}^- \to \mathrm{K}^+\pi^-\pi^-\pi^0$
$\mathrm{D}^+ \to \mathrm{K_S}\pi^+$	$\mathrm{D}^- \to \mathrm{K_S}\pi^-$
$\mathrm{D}^+ \to \mathrm{K_S}\pi^+\pi^0$	$\mathrm{D}^- \to \mathrm{K_S}\pi^-\pi^0$
$\mathrm{D}^+ \to \mathrm{K_S}\pi^+\pi^+\pi^-$	$\mathrm{D}^- \to \mathrm{K_S}\pi^-\pi^-\pi^+$
$\mathrm{D}^+ \to \mathrm{K}^-\mathrm{K}^+\pi^+$	$\mathrm{D}^- \to \mathrm{K}^+\mathrm{K}^-\pi^-$

Fitting Technique (II)

Background sources:

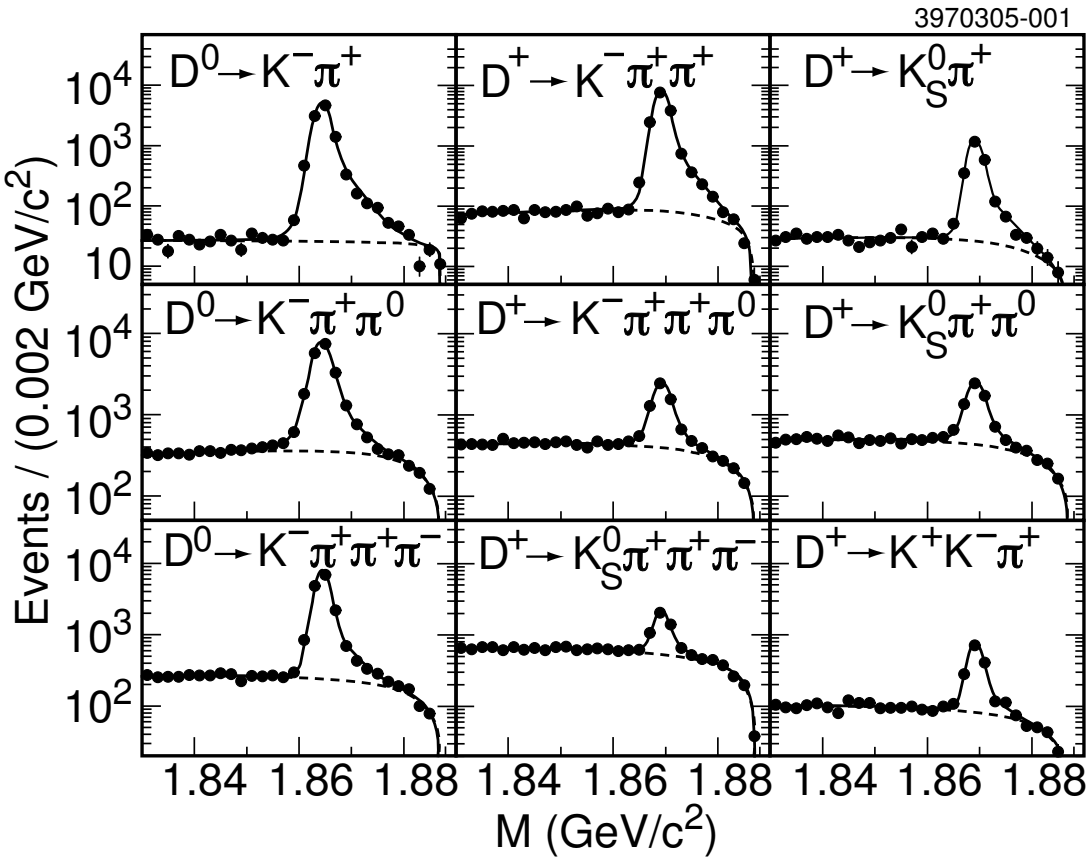
- D modes not in the fit
- $e^+e^- \rightarrow$ continuum
- Most Cabibbo-suppressed modes small

Errors on signals and background:

- Tracking, π^0, K_S systematics (correlates all elements)
- Resonant substructure
- Correlations between D^0 and D^+

Analysis technique validated by studying simulated $D\overline{D}$ events

Single–Tag Event Yields

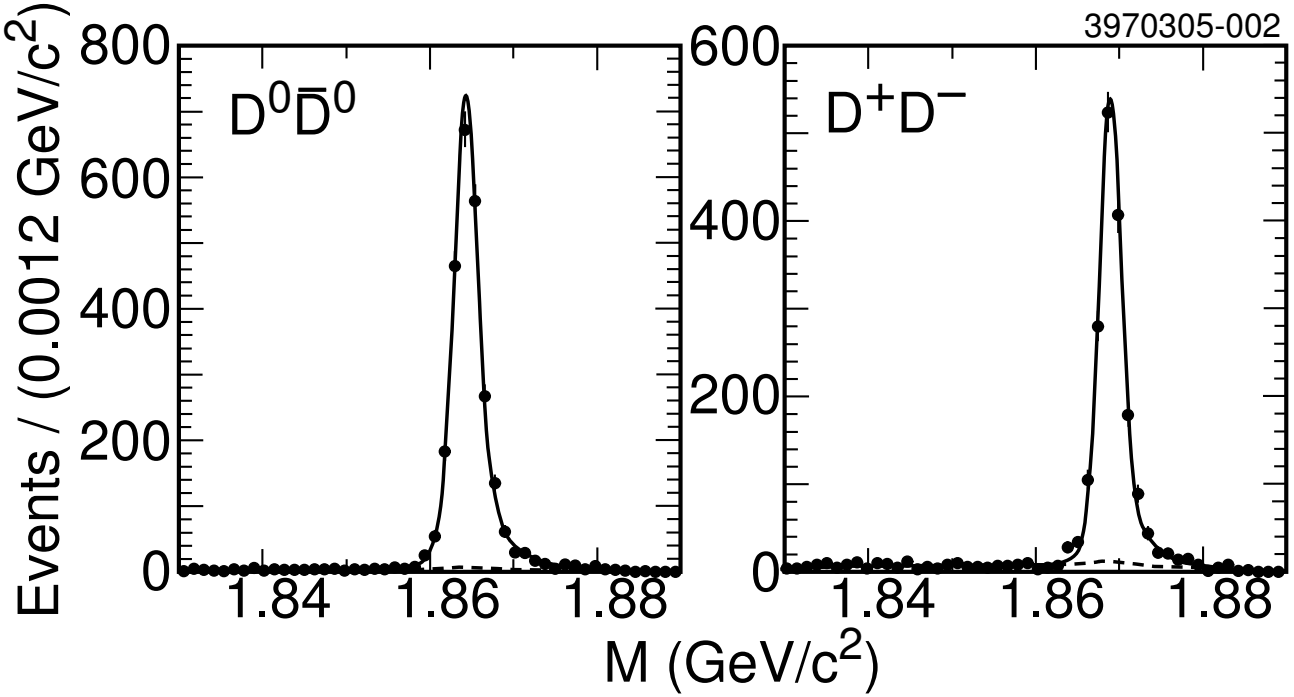


Note: log scale for single tags !

Yields vary between 0.6 k and ≈10 k events

- Signal shape:
  $\psi(3770)$ lineshape + ISR
  + beam–energy smearing,
  + reconstruction resolution
- Background shape:
  ARGUS function

Double–Tag Event Yields



Mass of D for all modes combined

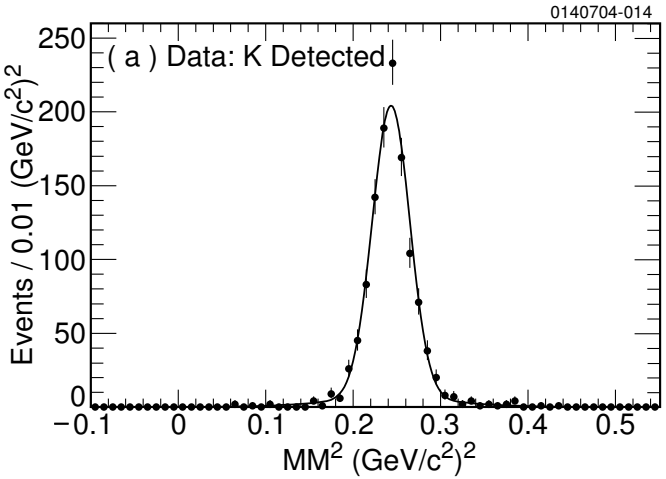
DT Yields

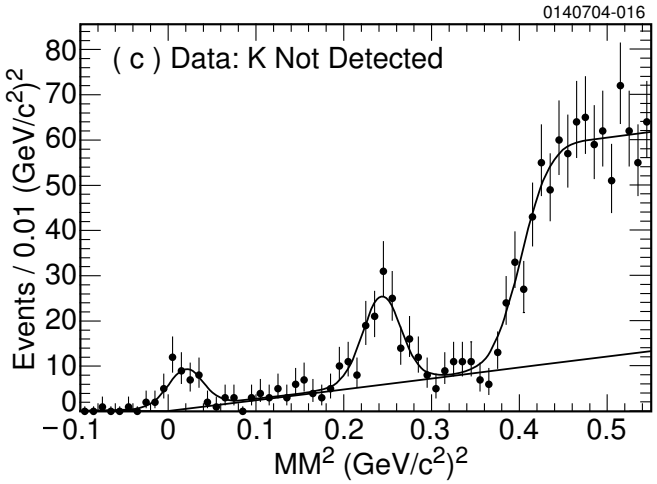
- 2484 ± 51 for D^0
- 1650 ± 42 for D^+

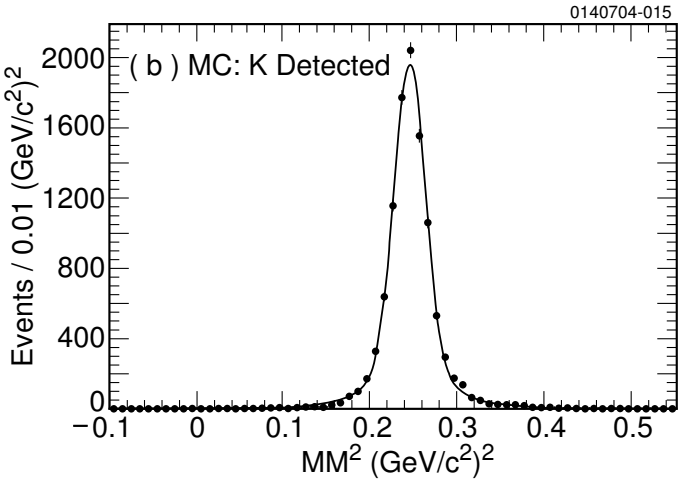
Double–tag modes clean

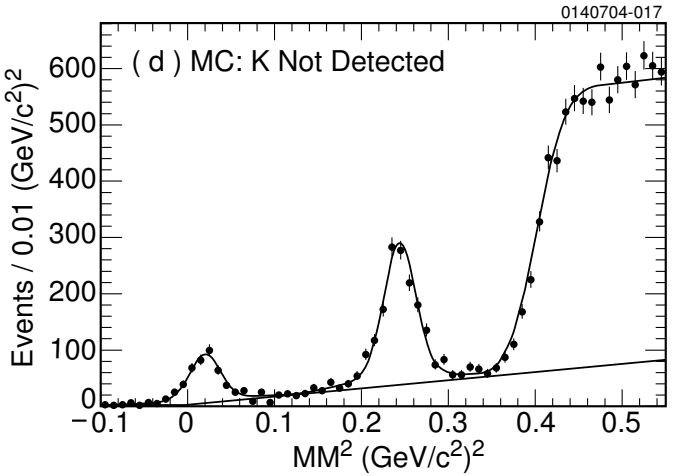
$\Rightarrow$ Statistical yield uncertainties close to $\sqrt{N_{ij}}$

Example: Tracking Systematics









Procedure

Example:
Reaction $D^0 \to K^- \pi^+$

- Leaving out K
  $\Rightarrow$ MM peaks at mass of omitted K
- Efficiency: Ratio of (a) and (c)
- Comparison between Data and MC

Systematics

Tracking Systematics

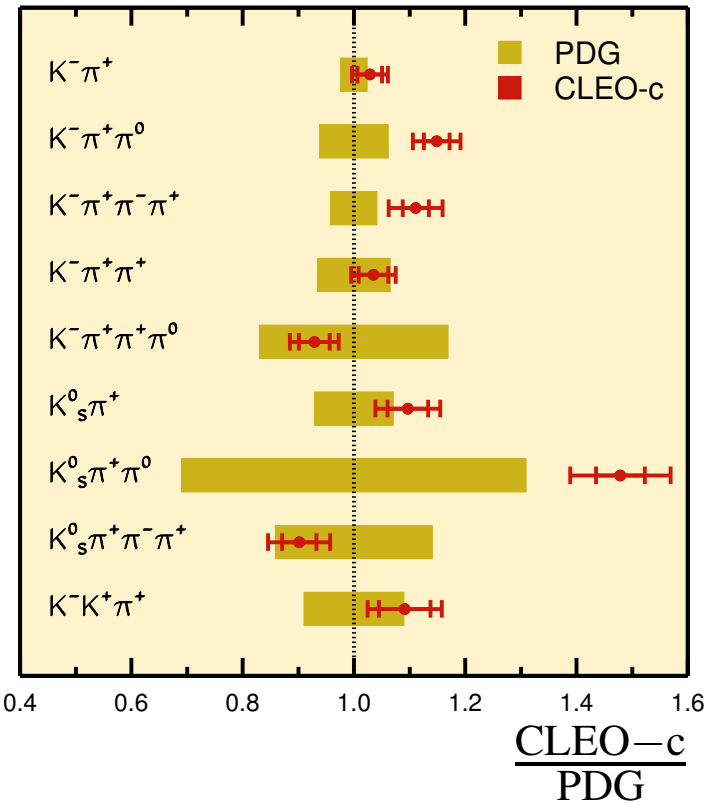
- $\psi(2S) \to J/\psi\,\pi^+\pi^-$

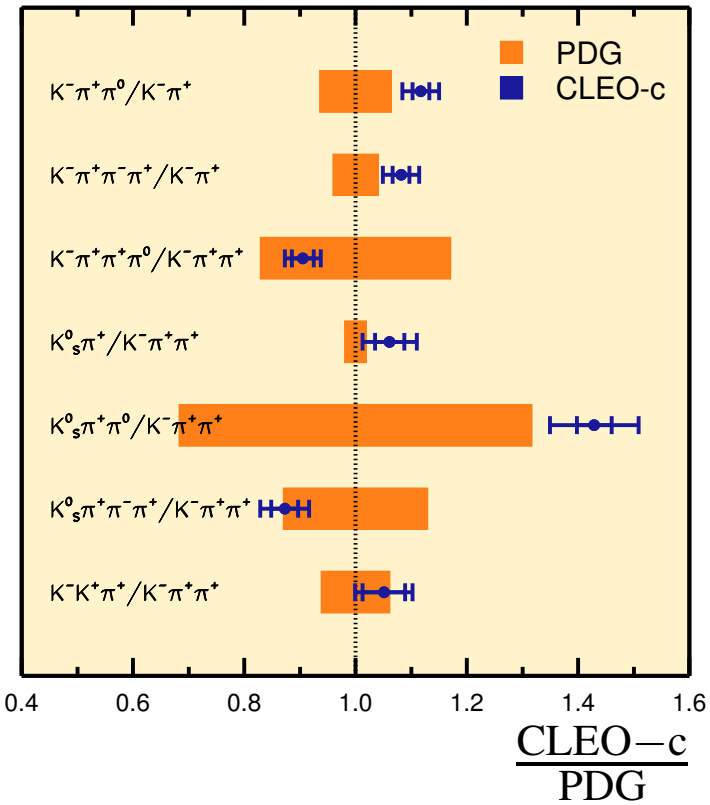
also:

- $\psi(2S) \to J/\psi\,\pi^0\pi^0$
- 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/$\pi^\pm$ 1.3/$K^\pm$
ΔE	1.0 – 2.5
$\Gamma_{\psi(3770)}$	0.6
Final State Radiation	0.5 ST / 1.0 DT
Resonant Substructure	0.4 / 1.5
DCSD Interference	0.8
Fit Functions	0.5
Online/Offline Filtering	0.4
Multiplicity	0.2 – 1.3
Detector Noise	

Comparison with PDG

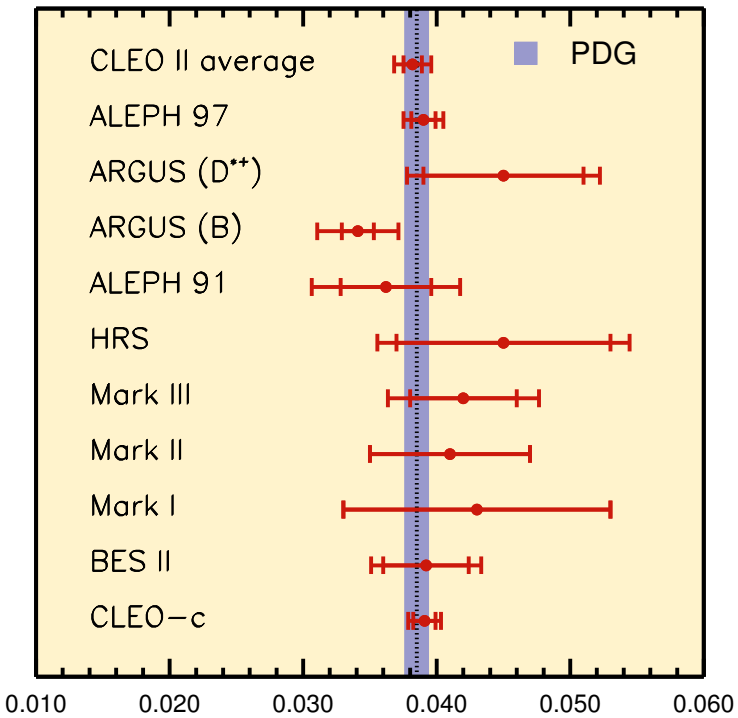




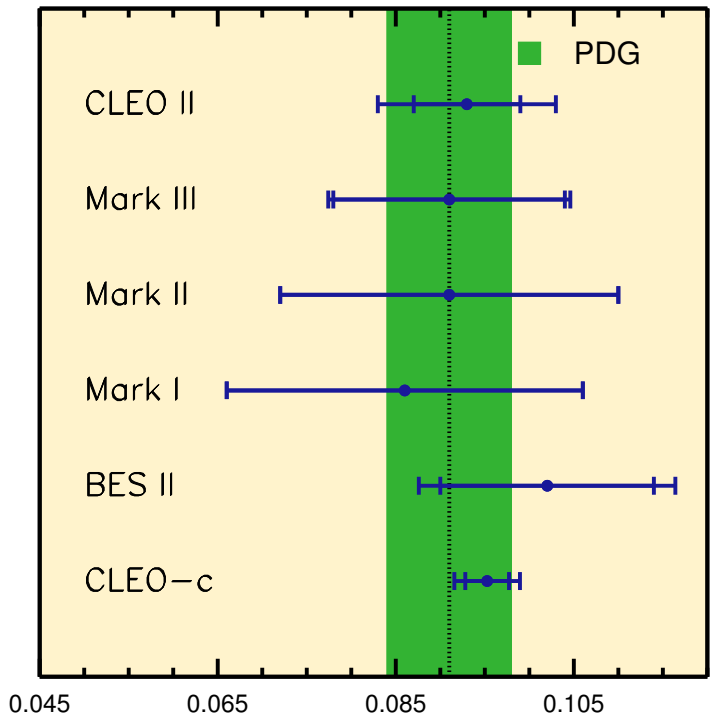
- CLEO efficiencies include **F**inal **S**tate **R**adiation (FSR)
- In some channels, systematics is already the limiting factor

Comparison with other direct measurements in PDG

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



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



PDG band corresponds to the average of all direct measurements

$\Rightarrow$ Not a global fit !

Cross Sections and Absolute Branching Fractions

Determination of cross sections

(scaling $N_{D\overline{D}}$ by the luminosity)

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

- Currently, most precise data
- Determination of charged to neutral ratio (→ next slide)

Comparison with BES

(PLB **603**, 130 (2004))

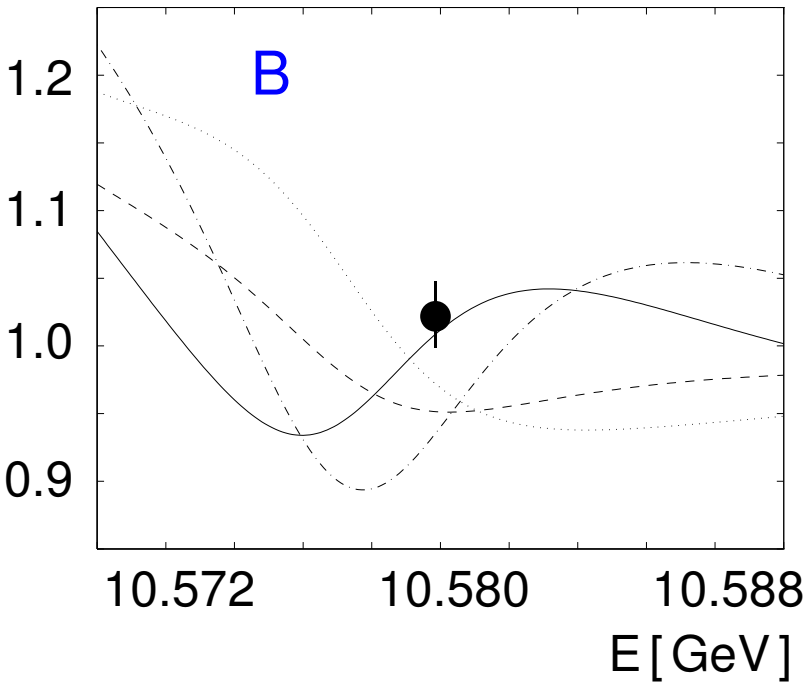
$$(6.14 \pm 0.12 \pm 0.50)\,\text{nb}$$
$$(3.58 \pm 0.09 \pm 0.31)\,\text{nb}$$
$$(2.56 \pm 0.08 \pm 0.26)\,\text{nb}$$

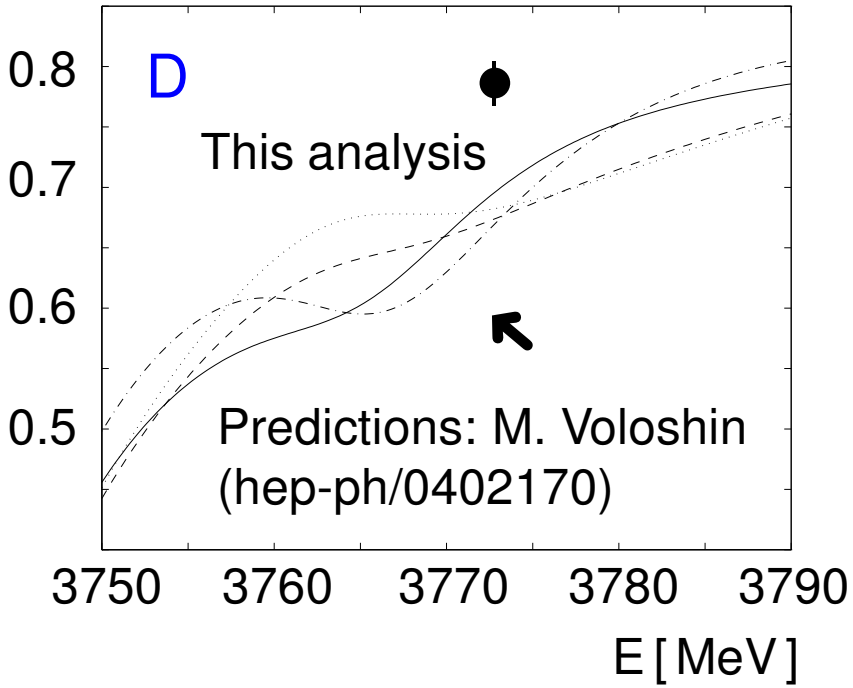
$\Rightarrow$ much larger

↓

Values higher than those of MARK III

Charged to Neutral Ratio





$$R^{\frac{\text{charged}}{\text{neutral}}} = \frac{\sigma(e^+e^- \to D^+D^-)}{\sigma(e^+e^- \to D^0\overline{D^0})} = 0.78 \pm 0.02 \pm 0.02$$

Discrepancies $\Rightarrow$ Speculation of 4–quark component of $\psi(3770)$
(M.V., hep-ph/0504197)

CLEO–c Absolute Hadronic BF: Summary

- First results based on (arXiv:hep–ex/0504003)
  - 55.8 pb^{-1} of e$^+$e$^-$ colllisions
  - 9 decay modes
    - $\Rightarrow$ Including reference branching fractions
      $\mathcal{B}(\mathrm{D}^0 \to \mathrm{K}^- \pi^+) = (3.91 \pm 0.08 \pm 0.09)$ %
      $\mathcal{B}(\mathrm{D}^+ \to \mathrm{K}^- \pi^+\pi^+) = (9.5 \pm 0.2 \pm 0.3)$ %
- Comparison with PDG: Branching fractions a little bit higher
  $\Rightarrow$ CLEO measurements corrected for FSR
- Already systematics limited in some modes
  $\Rightarrow$ New data will reduce statistical errors even more
- Cross sections:
  $\sigma(\psi'' \to \mathrm{D}\overline{\mathrm{D}})$, $\sigma(\psi'' \to \mathrm{D}^0\overline{\mathrm{D}^0})$, $\sigma(\psi'' \to \mathrm{D}^+\mathrm{D}^-)$, and $\mathrm{R}\,\frac{\text{charged}}{\text{neutral}}$

Hadronic D Decays: Outlook

- There will be more data available for this analysis
  - $281\,\mathrm{pb}^{-1}$ as of this summer
  - Statistical error will be reduced by a factor of 2
- Addition of Cabibbo–suppressed hadronic D decays
  $\Rightarrow$ including π^0
- D mixing constraints
  (hep–ph/0507238, submitted to PRD)