Measurement of the $D\bar{D}$ Cross Sections

and

D^0/D^+ Hadronic Branching Fractions

Guang-Pei Chen

(representing the CLEO Collaboration)

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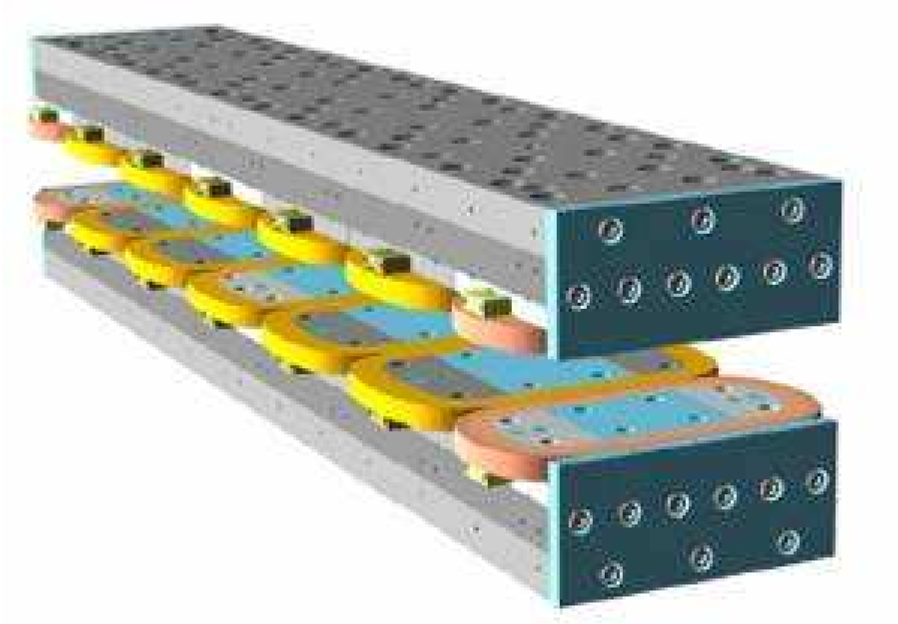
Introduction

- New preliminary results from CLEO-c.
  - $D\bar{D}$ Cross Sections at $\sqrt{s} = 3.77$ GeV.
  - Absolute D Meson Branching Fractions.
    $\mathcal{B}(D^0 \to K^-\pi^+)$ and $\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$ are two reference branching fractions.
    - → Determine other branching fractions.
    - → Reduce systematics when extracting some CKM matrix elements.
- Based on “double tag” technique pioneered by MARK III.
  Running at $\sqrt{s} = 3.77$ GeV:
  - No additional hadrons accompany the $D\bar{D}$ pair: clean.
  - Reconstruction of one D meson serves to tag the event as $D\bar{D}$ (single tag).
  - Reconstruction of the other D (double tag) determines the D branching fractions independent of luminosity.

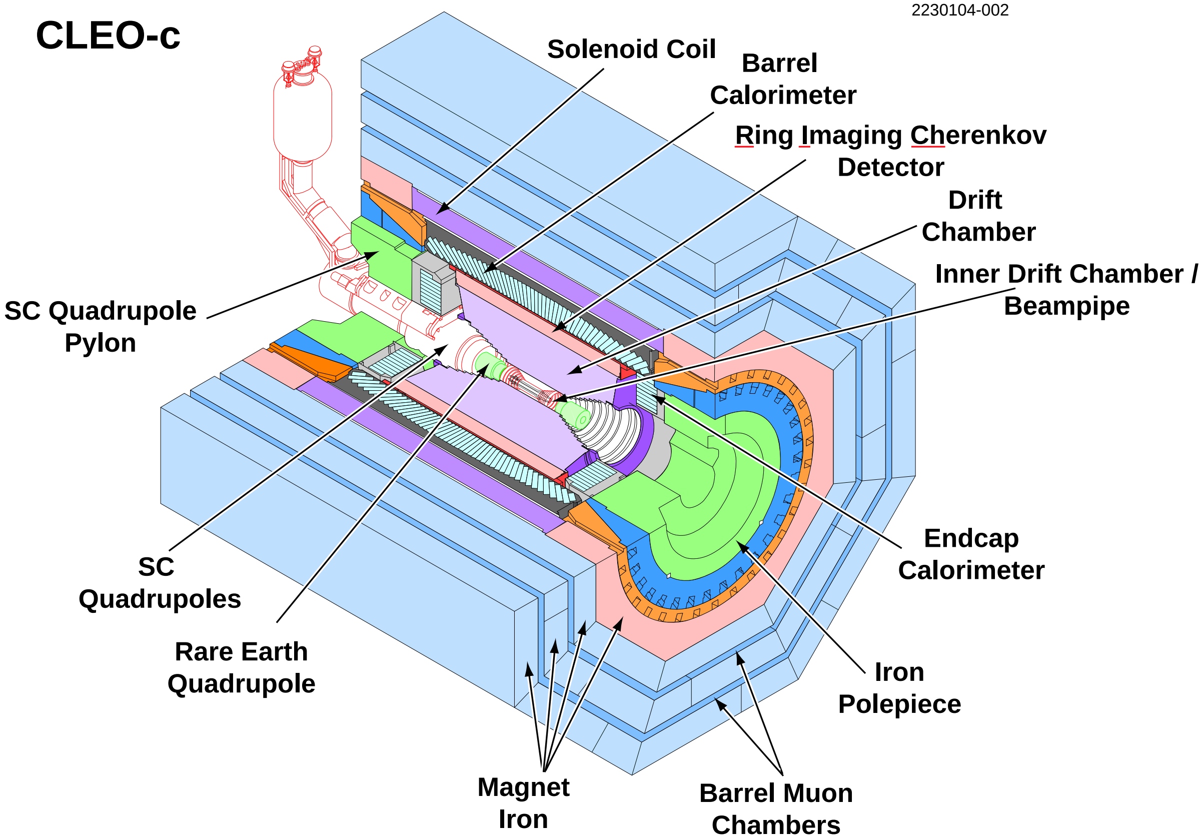
CESR-c

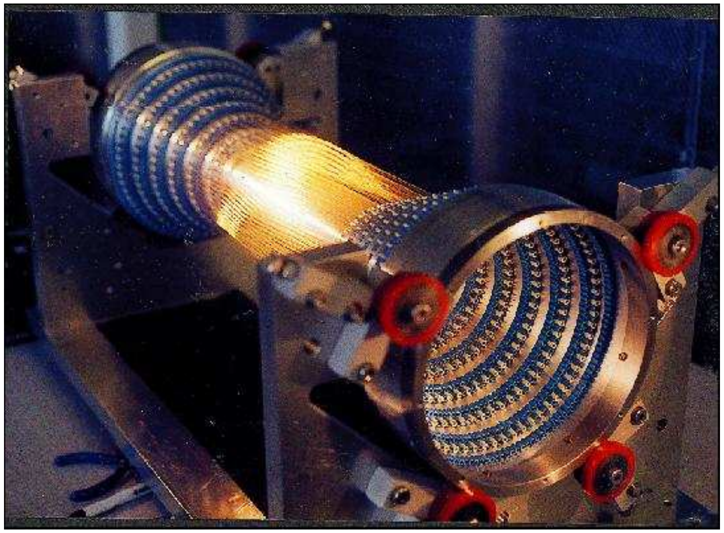


- $\mathbf{6}$ of $\mathbf{12}$ Wiggler magnets installed last year.
- A pilot run Dec.'03 through Mar.'04.
- $\mathbf{57.2}$ pb^{-1} data at $\sqrt{s} = \mathbf{3.770}$ GeV.

  This talk is based on.
- Final 6 magnets installed this summer.
- Resume run this fall.

CLEO-c

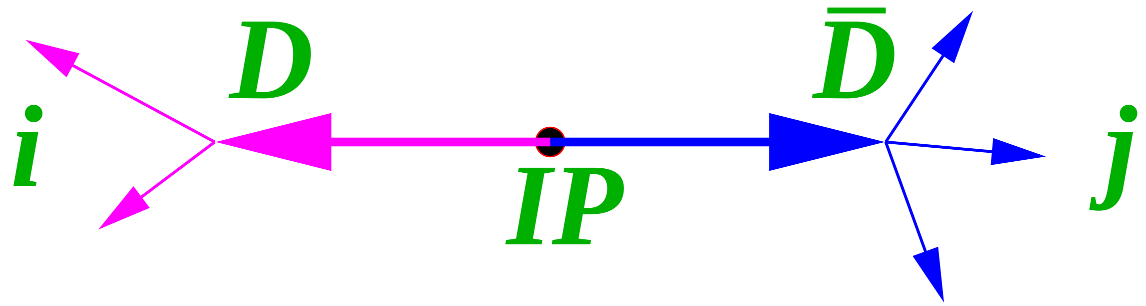




- New inner drift chamber
- 1 T B-field.

Method of Tagging

Cross section needs the number of $D\bar{D}$ events, BF's don't.



$$\begin{cases} N_i = 2\epsilon_i \mathcal{B}_i N_{D\bar{D}}, & \text{Single Tag,} \\ N_{ij} = (2-\delta_{ij})\epsilon_{ij}\mathcal{B}_i\mathcal{B}_j N_{D\bar{D}}, & \text{Double Tag.} \end{cases}$$

therefore,

$$\mathcal{B}_j = \frac{2\epsilon_i}{(2-\delta_{ij})\epsilon_{ij}} \cdot \frac{N_{ij}}{N_i},$$

$$N_{D\bar{D}} = \frac{(2-\delta_{ij})\epsilon_{ij}}{4\epsilon_i\epsilon_j} \cdot \frac{N_i N_j}{N_{ij}}.$$

$$(\epsilon_{ij} \approx \epsilon_i\epsilon_j)$$

Strategy

- Use the following modes for now:
  - $3\ D^0$ modes: $K^-\pi^+,\ \ K^-\pi^+\pi^0,\ \ K^-\pi^+\pi^+\pi^-$.
  - $2\ D^+$ modes: $K^-\pi^+\pi^+,\ \ K^0_S\pi^+$.
- Count D and $\bar{D}$ in a given mode separately,
  - 10 single tag yields: N_i.
  - $13 = 3^2 + 2^2$ double tag yields: N_{ij}.
- Determine ϵ_i and ϵ_{ij} with signal Monte Carlo.
- A combined χ^2 fit to extract:
  - $D\bar{D}$ yields: $N_{D^0\bar{D}^0},\ \ N_{D^+D^-}$.
  - 5 branching fractions: $\mathcal{B}_j$.
- Many systematic errors cancel in $D\bar{D}$ yields.

Reconstructing D Mesons

- Two important observables for a D candidate:
  - Beam-constrained mass

$$M_{BC} = \sqrt{E_{\text{beam}}^2 - \vec{p}_D^{\,2}}.$$

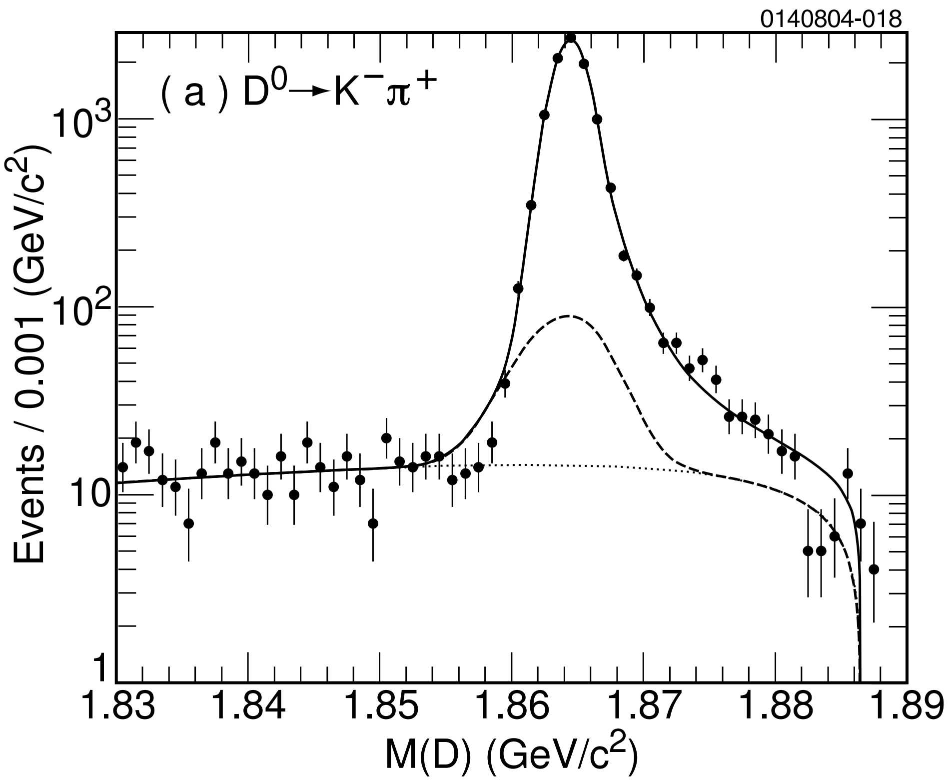
  - Energy difference

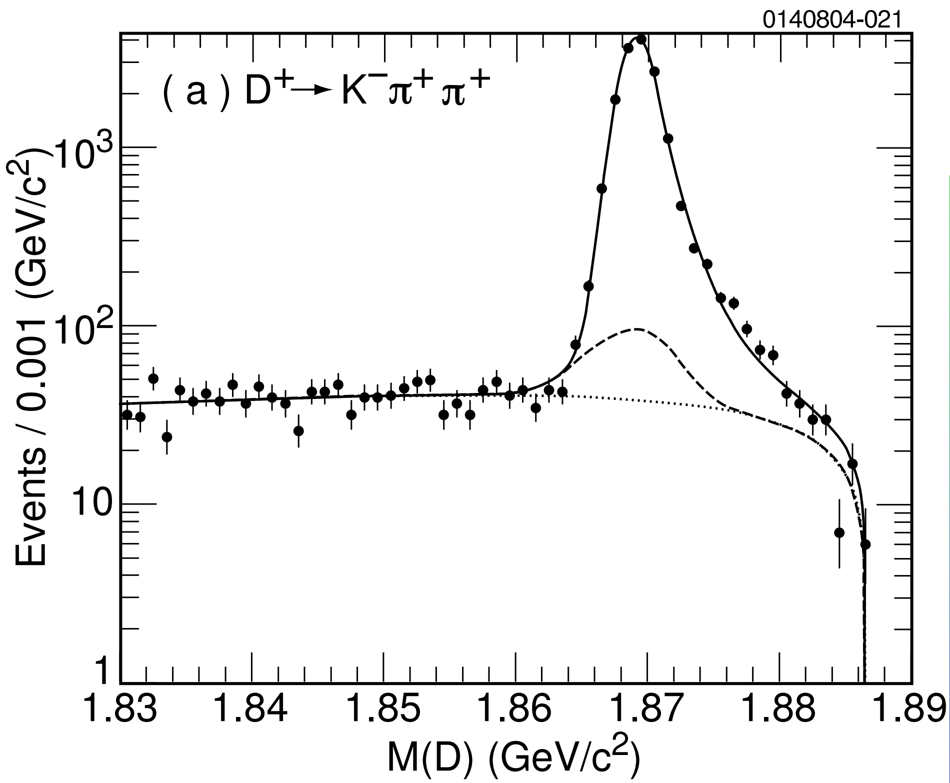
$$\Delta E = E_D - E_{\text{beam}}.$$

- Event selection
  - Track: track quality, particle identification.
  - π^0: π^0 mass cut, a kinematic fit is applied.
  - K_S^0: a constrained vertex fit to apply K_S^0 mass cut.
  - D: ΔE cut. Smallest $|\Delta E|$ candidate is chosen/mode/event.

Single Tag Yields

- Binned likelihood fits to extract N_i:
  - An inverted Crystal Ball function accounting for core Gaussian with ISR tail.
  - A bifurcated Gaussian modeling signal and tails.
  - An ARGUS function representing backgrounds.





Single Tag Yields–Continued

☞ Single Tag Yields

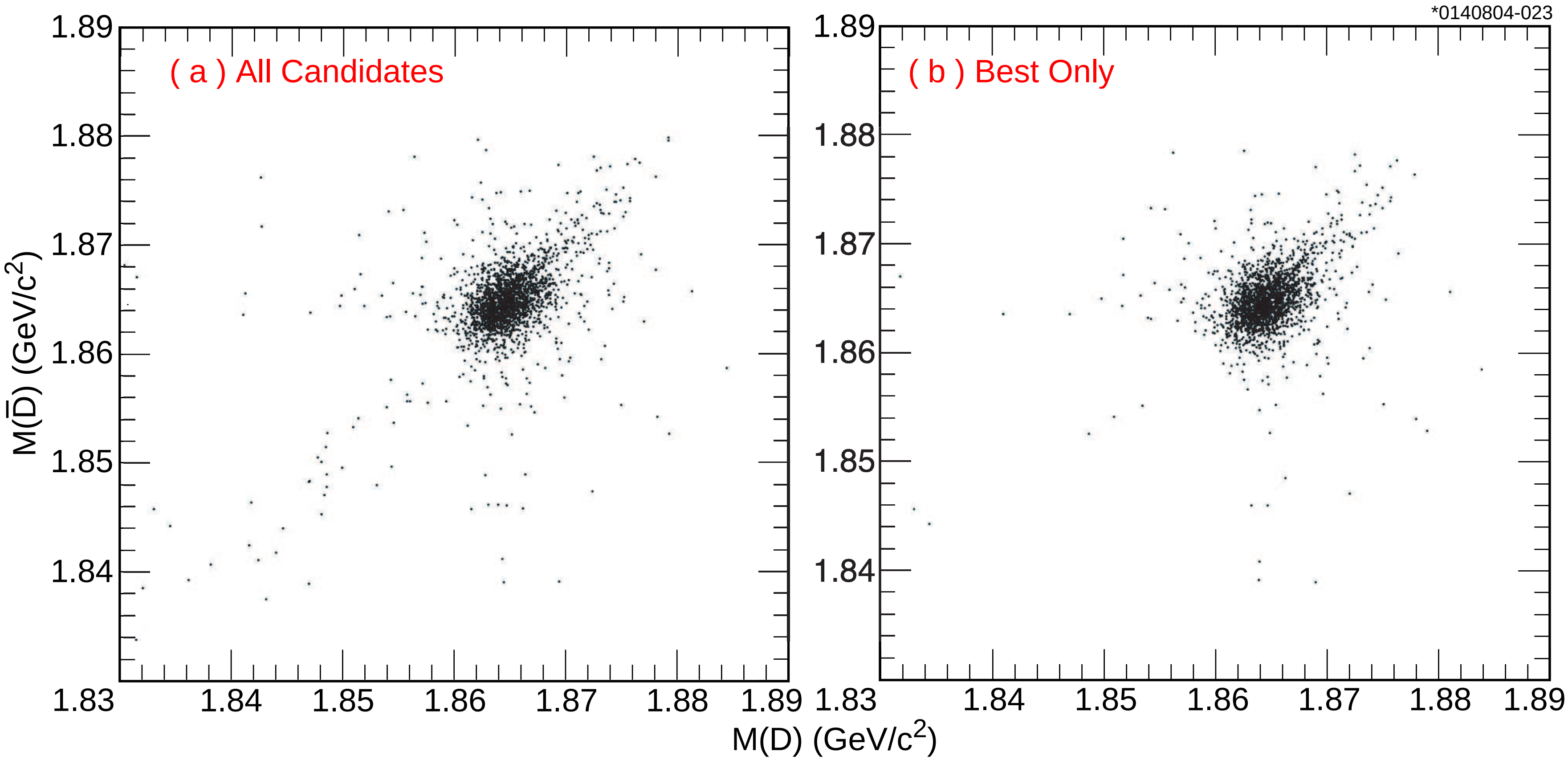
D or $\bar{D}$ Mode	Yield (10^3)	Efficiency (%)
$D^0 \to K^-\pi^+$	5.14 ± 0.07	65.1 ± 0.6
$\bar{D}^0 \to K^+\pi^-$	5.16 ± 0.08	66.3 ± 0.6
$D^0 \to K^-\pi^+\pi^0$	9.62 ± 0.12	33.6 ± 0.4
$\bar{D}^0 \to K^+\pi^-\pi^0$	9.58 ± 0.12	34.0 ± 0.4
$D^0 \to K^-\pi^+\pi^+\pi^-$	7.39 ± 0.10	45.1 ± 0.5
$\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$	7.39 ± 0.10	45.5 ± 0.5
$D^+ \to K^-\pi^+\pi^+$	7.58 ± 0.09	52.2 ± 0.5
$D^- \to K^+\pi^-\pi^-$	7.57 ± 0.09	51.9 ± 0.5
$D^+ \to K^0_S\pi^+$	1.09 ± 0.04	45.6 ± 0.5
$D^- \to K^0_S\pi^-$	1.12 ± 0.04	45.9 ± 0.5

Double Tag Yields

☞ $D\bar{D}$ selection

Choose candidate with $\hat{M}_{BC} \equiv \frac{M_{BC}^{D} + M_{BC}^{\bar{D}}}{2}$ nearest to M_{D^0} or M_{D^+}.

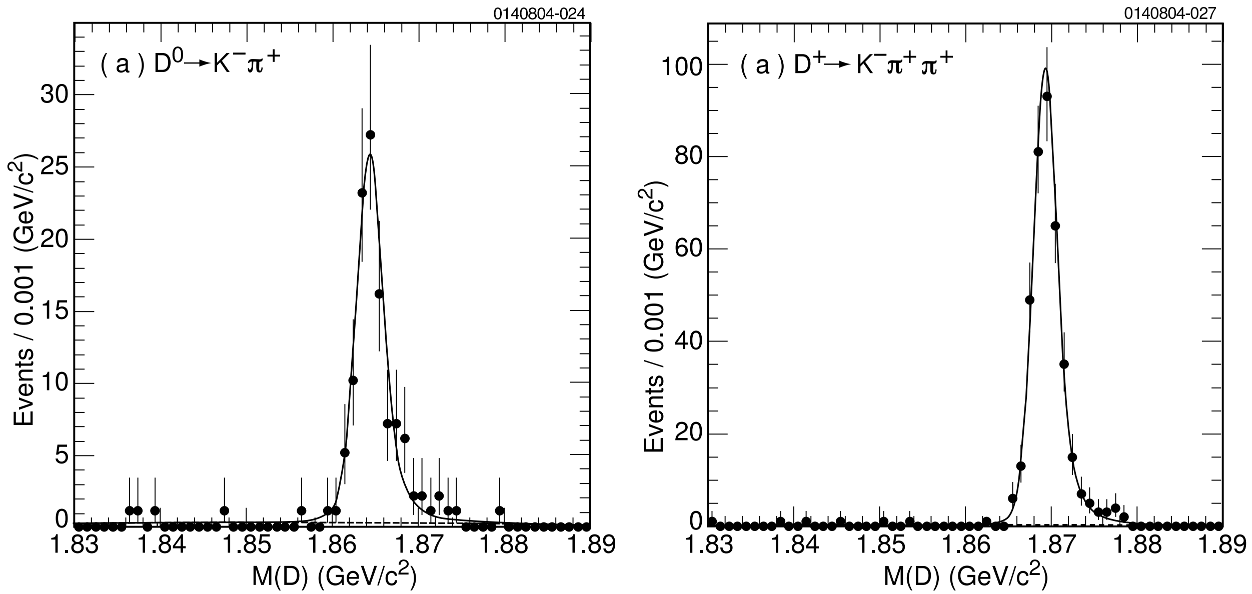
Monte Carlo studies show no peaking background.



Double Tag Yields–Continued

☞ Binned 2-D likelihood fi t to extract N_{ij}

- A Crystal Ball function of $\hat{M}_{BC}$ and a Gaussian function of $\delta M_{BC} \equiv \dfrac{M_{BC}^{D} - M_{BC}^{\bar{D}}}{2}$.
- A product of two bifurcated Gaussian functions for M_{BC}^{D} and $M_{BC}^{\bar{D}}$ accounting for signal and tails.
- A product of an ARGUS function of $\hat{M}_{BC}$ and a Gaussian function of δM_{BC} for mispartitioning and continuum backgrounds.
- A product of an ARGUS function of M_{BC}^{D} and a Gaussian function of $M_{BC}^{\bar{D}}$ for the horizontal band; a similar product for the vertical band.



Double Tag Yields–Continued

- Double tag yields

D Mode	$\bar{D}$ Mode	Yield	Efficiency (%)
$D^0 \to K^-\pi^+$	$\bar{D}^0 \to K^+\pi^-$	109 ± 11	42.6 ± 0.5
$D^0 \to K^-\pi^+\pi^0$	$\bar{D}^0 \to K^+\pi^-\pi^0$	484 ± 23	12.1 ± 0.3
$D^0 \to K^-\pi^+\pi^+\pi^-$	$\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$	280 ± 17	20.8 ± 0.4
$D^0 \to K^-\pi^+$	$\bar{D}^0 \to K^+\pi^-\pi^0$	245 ± 16	23.2 ± 0.4
$D^0 \to K^-\pi^+\pi^0$	$\bar{D}^0 \to K^+\pi^-$	262 ± 16	22.6 ± 0.4
$D^0 \to K^-\pi^+$	$\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$	205 ± 14	29.6 ± 0.4
$D^0 \to K^-\pi^+\pi^+\pi^-$	$\bar{D}^0 \to K^+\pi^-$	197 ± 14	29.6 ± 0.4
$D^0 \to K^-\pi^+\pi^0$	$\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$	359 ± 20	15.2 ± 0.3
$D^0 \to K^-\pi^+\pi^+\pi^-$	$\bar{D}^0 \to K^+\pi^-\pi^0$	340 ± 19	15.5 ± 0.3
$D^+ \to K^-\pi^+\pi^+$	$D^- \to K^+\pi^-\pi^-$	379 ± 20	26.7 ± 0.4
$D^+ \to K^0_S\pi^+$	$D^- \to K^0_S\pi^-$	9 ± 3	20.6 ± 0.4
$D^+ \to K^-\pi^+\pi^+$	$D^- \to K^0_S\pi^-$	61 ± 8	23.7 ± 0.4
$D^+ \to K^0_S\pi^+$	$D^- \to K^+\pi^-\pi^-$	53 ± 7	23.9 ± 0.4

Systematics

Source	Uncertainty (%)	Quantity
Data processing	0.3	All yields
Yield fit functions	0.1–2.9	All yields
Background bias	2.5	Double tag yields
Double DCSD interference	0.8	Neutral double tag yields
Detector simulation	3.0	Tracking efficiencies
	3.0	K^0_S efficiencies
	4.4	π^0 efficiencies
	0.3	$\pi^\pm$ PID efficiencies
	1.0	$K^\pm$ PID efficiencies
Trigger simulation	0.3	Trigger efficiencies
Final state radiation	0.5	D efficiencies
$\lvert\Delta E\rvert$ requirement	1.0	D efficiencies, correlated by decay
Resonant substructure	3.0	$D^0 \to K^-\pi^+\pi^+\pi^-$ efficiencies

- Tracking efficiencies dominate

  Conservative 3%/track tracking efficiency: working to reduce it.

- Most systematics will be improved with more data.

Combined χ^2 Fitter

- Fits simultaneously $N_{D^0\bar{D}^0}$, $N_{D^+D^-}$, and all $\mathcal{B}_j$'s.
- Takes into account:
  - Correlation of N_{ij} and N_i.
  - Correlation of different tagging modes when measuring $\mathcal{B}_j$.
  - All correlations introduced by systematics.
- Tested with generic Monte Carlo sample:

	$N_{D^0\bar{D}^0}$	$K^-\pi^+$	$K^-\pi^+\pi^0$	$K^-\pi^+\pi^+\pi^-$	$N_{D^+D^-}$	$K^-\pi^+\pi^+$	$K^0_S\pi^+$
In	2.04 M	3.83%	13.90%	7.90%	1.52 M	9.00%	1.45%
Out	2.08 M	3.77%	13.73%	7.86%	1.55 M	9.02%	1.47%
σ	0.02 M	0.04%	0.13%	0.08%	0.03 M	0.17%	0.03%
$\frac{\Delta}{\sigma}$	$+1.6$	-1.4	-1.3	-0.5	$+1.1$	$+0.1$	$+0.6$

Results–Cross Sections

Parameter	Fitted Value
$N_{D^0\bar{D}^0}$	$(1.98 \pm 0.04 \pm 0.03) \times 10^5$
$N_{D^+D^-}$	$(1.48 \pm 0.06 \pm 0.04) \times 10^5$

- Using $\mathcal{L} = 57.2 \pm 1.7$ pb^{-1}, we get:

$$\begin{cases} \sigma(e^+e^- \to D^0\bar{D}^0) = (3.47 \pm 0.07 \pm 0.15)\ \text{nb}, \\ \sigma(e^+e^- \to D^+D^-) = (2.59 \pm 0.11 \pm 0.11)\ \text{nb}, \\ \sigma(e^+e^- \to D\bar{D}) = (6.06 \pm 0.13 \pm 0.22)\ \text{nb}, \\ \dfrac{\sigma(e^+e^- \to D^+D^-)}{\sigma(e^+e^- \to D^0\bar{D}^0)} = 0.75 \pm 0.04 \pm 0.02. \end{cases}$$

- Results from other experiments (BES uses PDG BF's):

Exp.	$\sigma(D^0\bar{D}^0)$	$\sigma(D^+D^-)$	Reference
MARK III	$(5.8 \pm 0.5 \pm 0.6)/2$	$(4.2 \pm 0.6 \pm 0.3)/2$	PRL **60**, 89(1988)
BES	$3.26 \pm 0.09 \pm 0.25$	$2.52 \pm 0.07 \pm 0.24$	hep-ex/0406027

Results–Branching Fractions

Parameter	Fitted Value	PDG 2004
$\mathcal{B}(D^0 \to K^-\pi^+)$	$0.0392 \pm 0.0008 \pm 0.0023$	0.0380 ± 0.0009
$\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$	$0.143 \pm 0.003 \pm 0.010$	0.1300 ± 0.0080
$\mathcal{B}(D^0 \to K^-\pi^+\pi^+\pi^-)$	$0.081 \pm 0.002 \pm 0.009$	0.0746 ± 0.0031
$\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$	$0.098 \pm 0.004 \pm 0.008$	0.092 ± 0.006
$\mathcal{B}(D^+ \to K^0_S\pi^+)$	$0.0161 \pm 0.0008 \pm 0.0015$	0.0282 ± 0.0019
$\frac{\mathcal{B}(D^0 \to K^-\pi^+\pi^0)}{\mathcal{B}(D^0 \to K^-\pi^+)}$	$3.64 \pm 0.05 \pm 0.17$	3.42 ± 0.22
$\frac{\mathcal{B}(D^0 \to K^-\pi^+\pi^+\pi^-)}{\mathcal{B}(D^0 \to K^-\pi^+)}$	$2.05 \pm 0.03 \pm 0.14$	1.96 ± 0.06
$\frac{\mathcal{B}(D^+ \to K^0_S\pi^+)}{\mathcal{B}(D^+ \to K^-\pi^+\pi^+)}$	$0.164 \pm 0.004 \pm 0.006$	0.153 ± 0.003

☞ FSR included in MC efficiencies, PDG values don't include this effect.

Conclusions

- CESR-c pilot run accumulated 57.2 pb^{-1} data at $\sqrt{s} = 3.77$ GeV.
- Using these data, we obtained preliminary results:
  - $D\bar{D}$ cross sections at $\sqrt{s} = 3.77$ GeV:

$$
\begin{aligned}
\sigma(e^+e^- \to D^0\bar{D}^0) &= (3.47 \pm 0.07 \pm 0.15)\ \text{nb}, \\
\sigma(e^+e^- \to D^+D^-) &= (2.59 \pm 0.11 \pm 0.11)\ \text{nb}, \\
\sigma(e^+e^- \to D\bar{D}) &= (6.06 \pm 0.13 \pm 0.22)\ \text{nb}.
\end{aligned}
$$

Preliminary

  - 5 branching fractions:

$$
\begin{aligned}
\mathcal{B}(D^0 \to K^-\pi^+) &= 0.0392 \pm 0.0008 \pm 0.0023, \\
\mathcal{B}(D^0 \to K^-\pi^+\pi^0) &= 0.143 \pm 0.003 \pm 0.010, \\
\mathcal{B}(D^0 \to K^-\pi^+\pi^+\pi^-) &= 0.081 \pm 0.002 \pm 0.009, \\
\mathcal{B}(D^+ \to K^-\pi^+\pi^+) &= 0.098 \pm 0.004 \pm 0.008, \\
\mathcal{B}(D^+ \to K^0_S\pi^+) &= 0.0161 \pm 0.0008 \pm 0.0015.
\end{aligned}
$$

- More info available from ICHEP '04 conference paper.
- Full equipped CESR-c ready for run, more results from CLEO-c soon.