D Decays at CLEO-c

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For the CLEO Collaboration

- **Absolute D^0 and D^+ Branching Fractions**
- **Absolute D_s Branching Fractions**
- **Summary and Conclusions**

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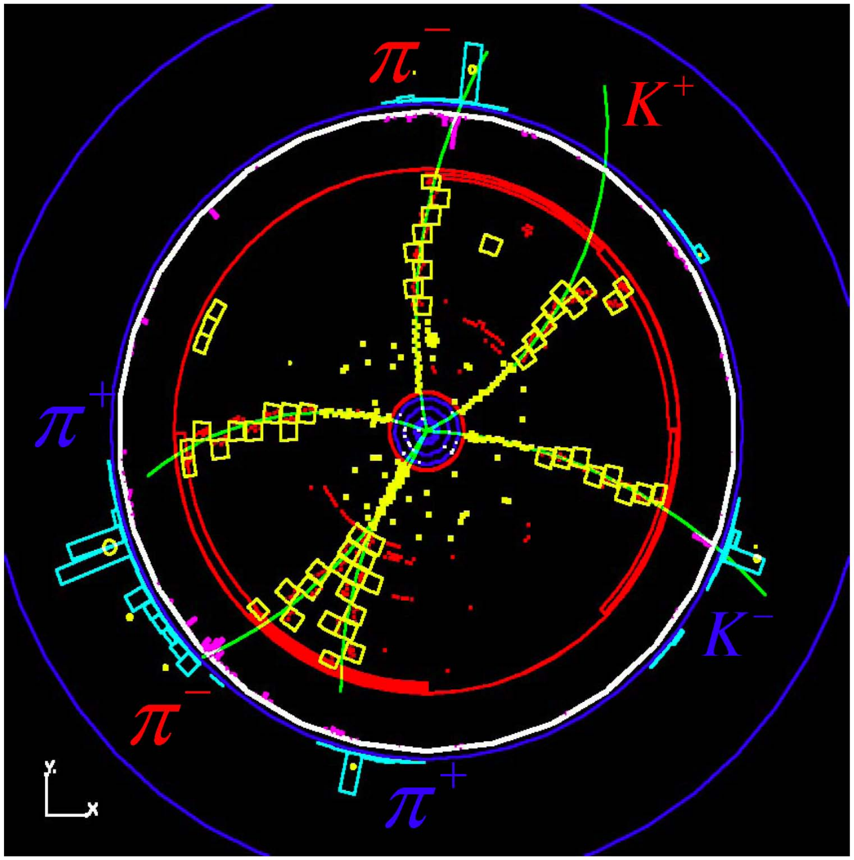
$e^+e^- \to \psi(3770) \to D\bar{D}$ Events and Analyses

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

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



- CLEO-c uses D^+ and D^0 decays from $e^+e^- \to \psi(3770) \to D^+D^-$ or $D^0\bar{D}^0$
  - No additional pions produced
  - Extremely clean events
- Leptonic, semileptonic, and key hadronic branching fractions measured with a double tagging technique
  - Other branching fractions measured relative to a reference mode, usually $D^0 \to K^-\pi^+$ or $D^+ \to K^-\pi^+\pi^+$
- Absolute branching fractions for key Cabibbo Favored hadronic modes were published with 56 $pb^{-1}$of data.
  - Preliminary update with 281 pb^{-1}.
- Some other branching ratios utilizing 281 pb^{-1} already published or submitted for publication

Absolute D^0 and D^+ Hadronic Branching Fractions

Utilize technique pioneered by MARK III

- Single Tag (ST) Yields $D \to i$ and $\bar{D} \to X$ $N_i = N_{D\bar{D}}\,\mathcal{B}_i\,\epsilon_i$
- Double Tag (DT) Yields $D \to i$ and $\bar{D} \to \bar{j}$ $N_{i\bar{j}} = N_{D\bar{D}}\,\mathcal{B}_i\,\mathcal{B}_{\bar{j}}\,\epsilon_{i\bar{j}}$
  - Obtain ST and DT yields from fits to beam constrained mass distributions
  - Compute branching fractions and $N_{D\bar{D}}$

    $$\mathcal{B}_i = \frac{N_{i\bar{j}}}{N_{\bar{j}}}\,\frac{\epsilon_{\bar{j}}}{\epsilon_{i\bar{j}}} \quad \text{and} \quad N_{D\bar{D}} = \frac{N_i N_{\bar{j}}}{N_{i\bar{j}}}\,\frac{\epsilon_{i\bar{j}}}{\epsilon_i \epsilon_{\bar{j}}}$$

  - $\epsilon_{i\bar{j}} \approx \epsilon_i \epsilon_{\bar{j}}$ so $\mathcal{B}_i$ is nearly independent of efficiencies for $\bar{j}$.
  - Branching fraction values independent of luminosity or $N_{D\bar{D}}$ measurements.
  - Do a χ^2 fit including all yields and all errors – correlated and uncorrelated.
  - Input N_i and $N_{\bar{i}}$ separately, but constrain $\mathcal{B}_i = \mathcal{B}_{\bar{i}}$

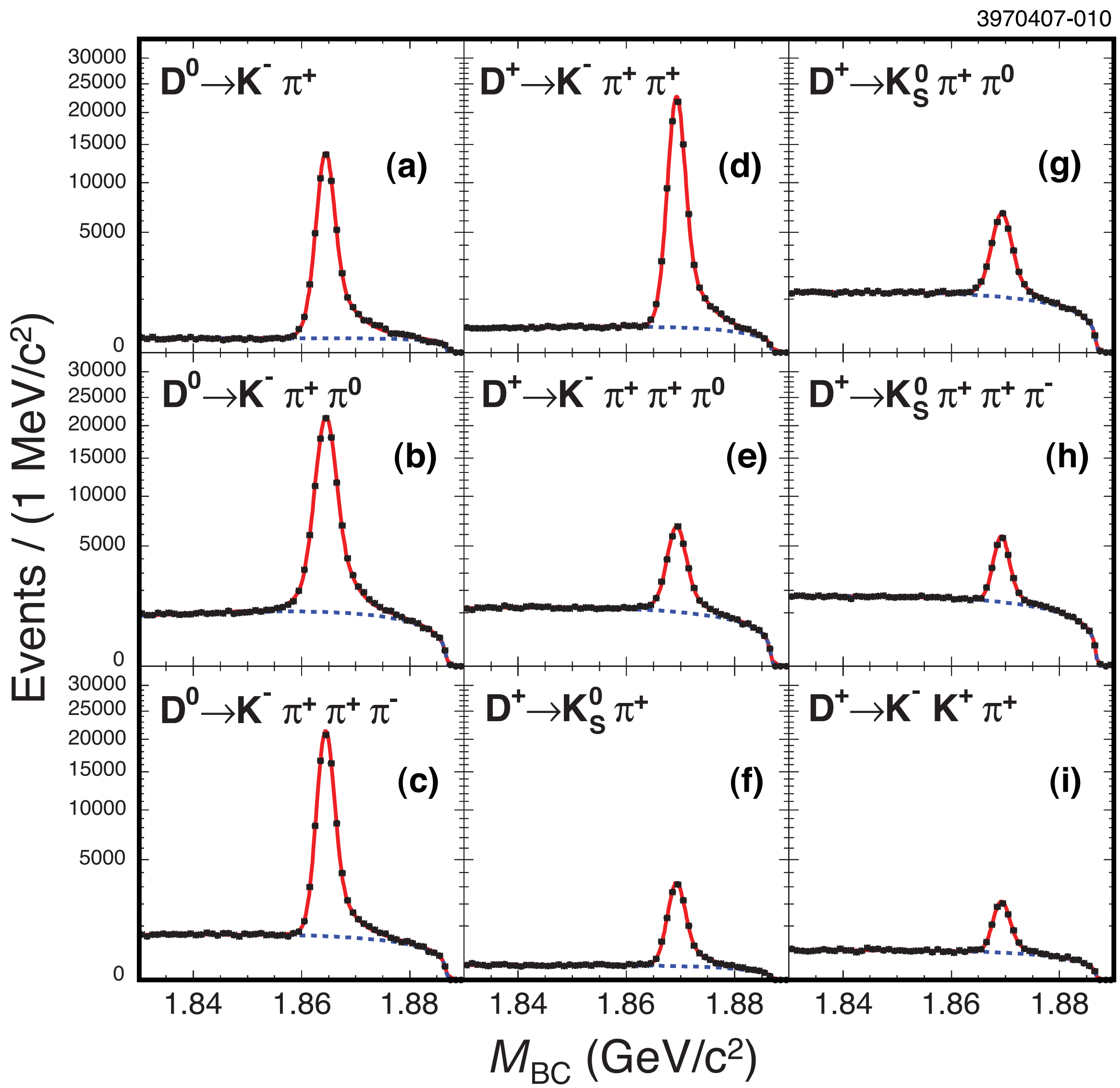
Yields from 281 pb^{-1}

- ST all modes: 230,225 $D^0/\bar{D}^0$ 167,086 D^+/D^-
- DT all modes: $13,575 \pm 120$ $D^0\bar{D}^0$ $8,867 \pm 97$ D^+D^-

Single Tag and Double Tag Yields

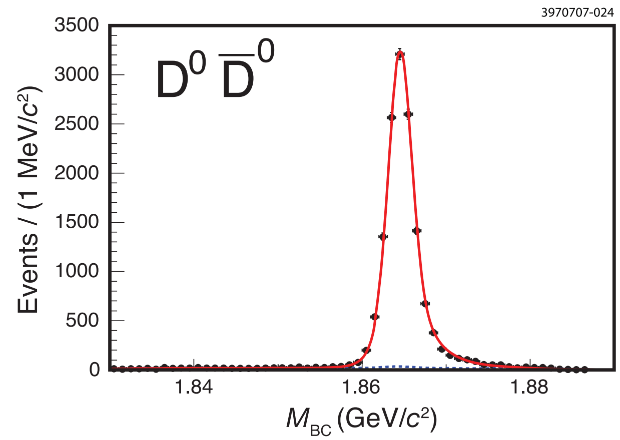
Single Tag Yields and Fits

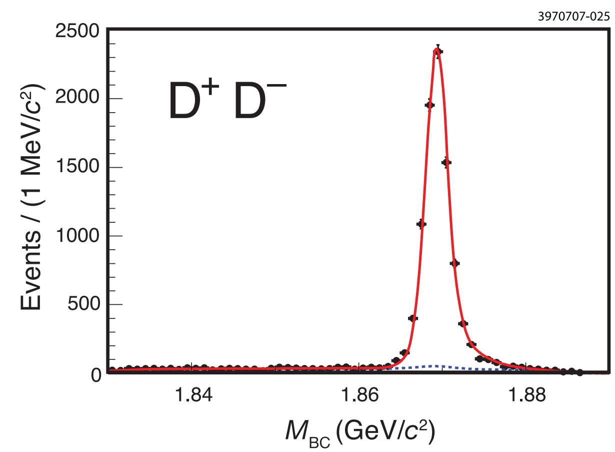
Square Root Scale



Double Tag Yields and Fits

Linear Scale



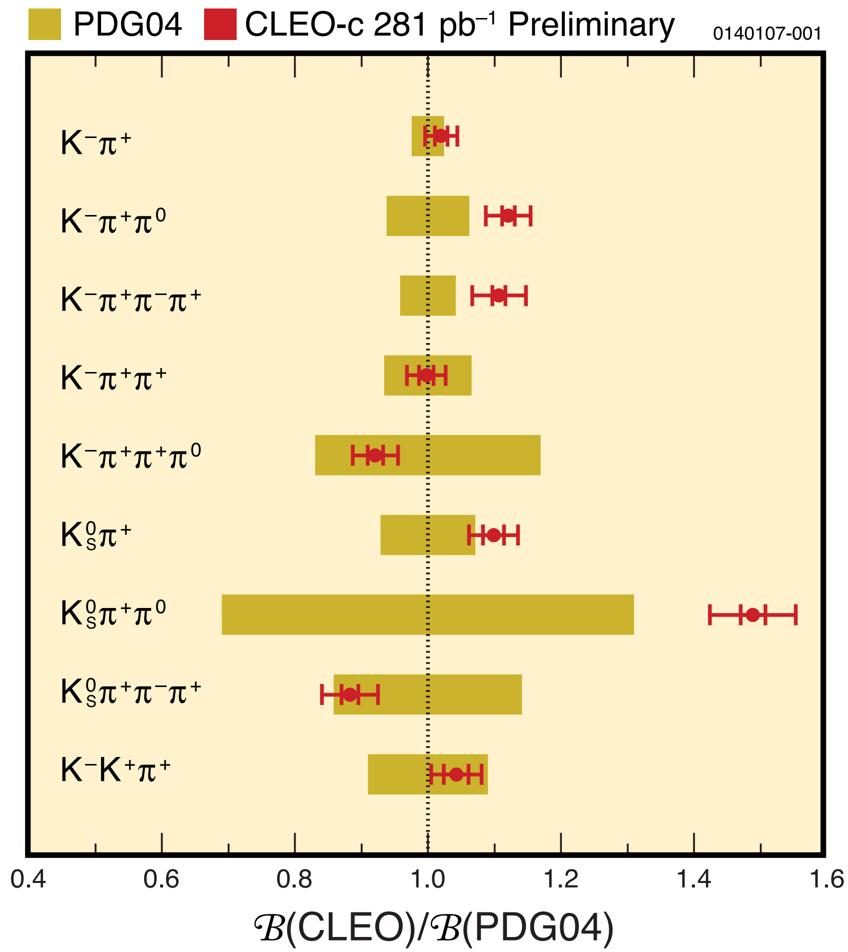


Absolute Hadronic D^0 and D^+ Branching Fractions

CLEO-c 281 pb^{-1} **Preliminary**

Mode	$\mathcal{B}$ (%)
$D^0 \to K^-\pi^+$	$3.87 \pm 0.04 \pm 0.08$
$D^0 \to K^-\pi^+\pi^0$	$14.6 \pm 0.1 \pm 0.4$
$D^0 \to K^-\pi^+\pi^+\pi^-$	$8.3 \pm 0.1 \pm 0.3$
$D^+ \to K^-\pi^+\pi^+$	$9.2 \pm 0.1 \pm 0.2$
$D^+ \to K^-\pi^+\pi^+\pi^0$	$6.0 \pm 0.1 \pm 0.2$
$D^+ \to K^0_S\pi^+$	$1.55 \pm 0.02 \pm 0.05$
$D^+ \to K^0_S\pi^+\pi^0$	$7.2 \pm 0.1 \pm 0.3$
$D^+ \to K^0_S\pi^+\pi^+\pi^-$	$3.13 \pm 0.05 \pm 0.14$
$D^+ \to K^+K^-\pi^+$	$0.93 \pm 0.02 \pm 0.03$

- Systematic errors dominate!
- Final State Radiation is significant $\sim 2\% - 3\%$
  - Ignoring FSR decreases $\mathcal{B}$'s



Compare to PDG04 because PDG06 includes CLEO-c 56 pb^{-1} in averages

Comparison of $D \to K^0_S\pi$ and $D \to K^0_L\pi$ Decay Rates

Cabibbo-Favored and Doubly-Cabibbo-Suppressed amplitudes for $D \to K^0\pi$.

- Observed final states are K^0_S and K^0_L
- Interference between CF and DCS amplitudes can lead to different rates for $D \to K^0_S\pi$ and $D \to K^0_L\pi$ (Bigi and Yamamoto)
- Reconstruct $D \to K^0_L\pi$ from missing mass

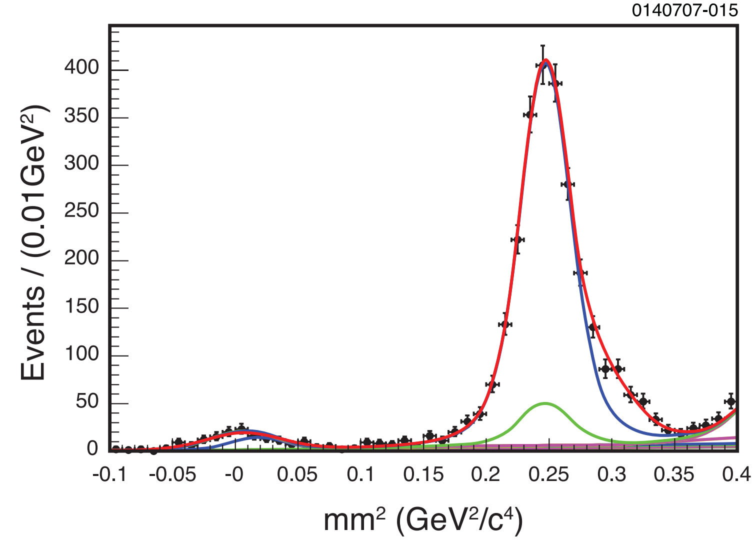
$$R(D) \equiv \frac{\mathcal{B}(D \to K^0_S\pi) - \mathcal{B}(D \to K^0_L\pi)}{\mathcal{B}(D \to K^0_S\pi) + \mathcal{B}(D \to K^0_L\pi)}$$

CLEO-c Preliminary

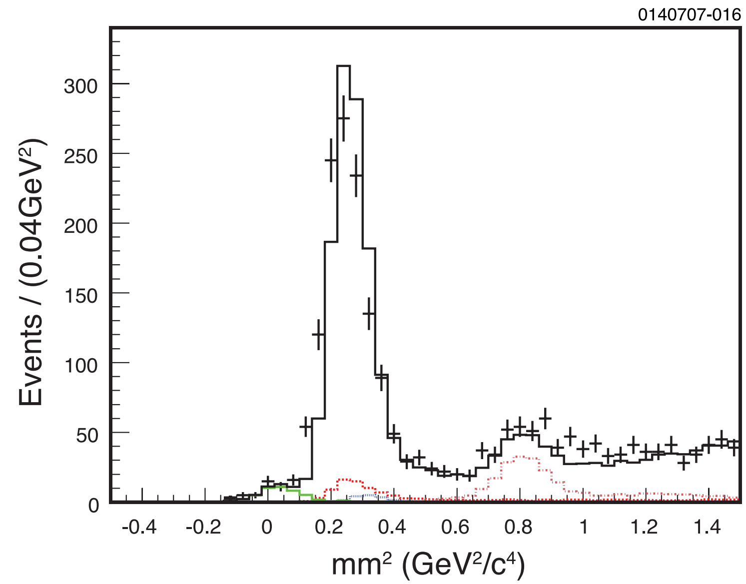
$R(D^+)$	$0.030 \pm 0.023 \pm 0.025$
$R(D^0)$	$0.122 \pm 0.024 \pm 0.030$

- U-spin and SU(3) predict $R(D^0) = 2\tan^2(\theta_c)$ which gives $R(D^0) = 0.109 \pm 0.001$
- $R(D^+)$ not so simple:
  $D^+ \to \bar{K}^0\pi^+$ external & internal spectator
  $D^+ \to K^0\pi^+$ internal spectator & annihilation

$D^+ \to X\pi^+$

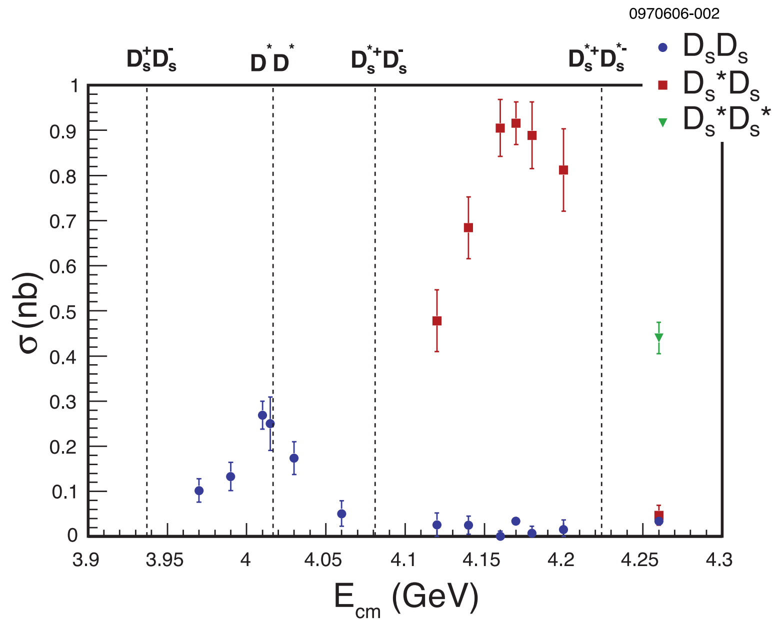


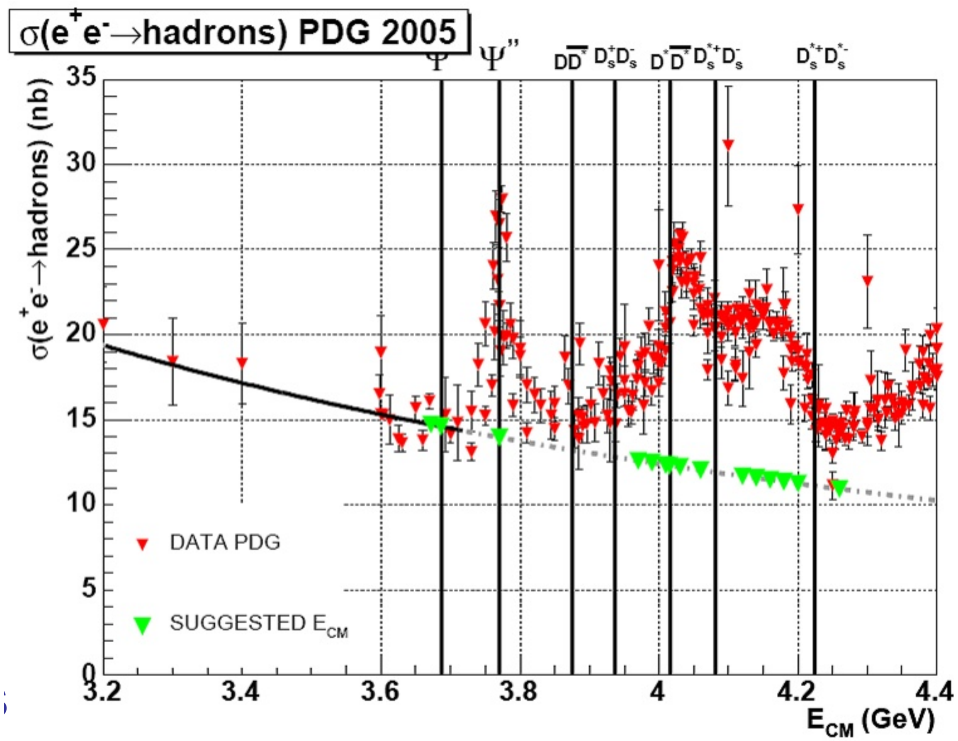
$D^0 \to X\pi^0$

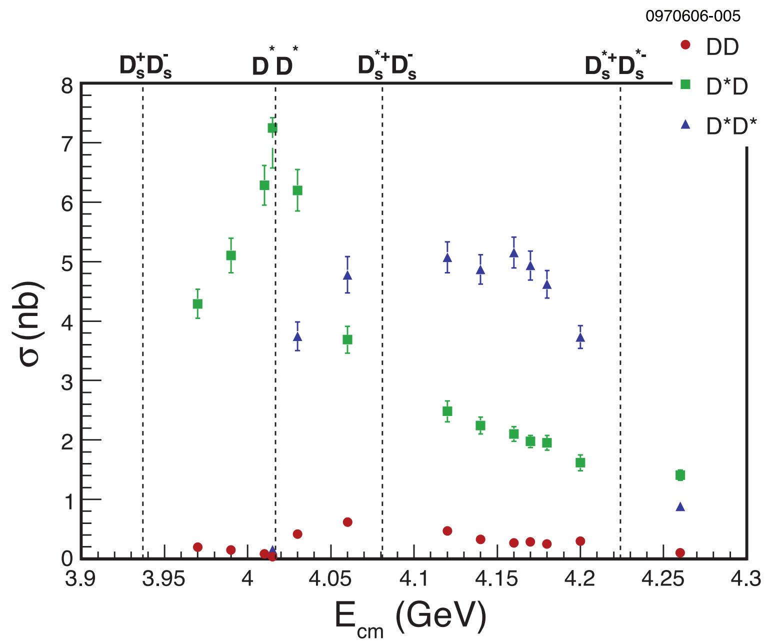


D_s Production Cross Section

- Little was know about the composition of $\sigma(e^+e^-)$ above $E_{cm} = 3.8$ GeV.
- CLEO scan with ~ 5 pb^{-1} per point with fast turnaround and feedback
- More luminosity in the region around $E_{cm} = 4.17$ GeV where $D_s^{\pm}D_s^{*\mp}$ peaks
  - $\sigma(e^+e^- \to D_s^{\pm}D_s^{*\mp}) \approx 0.9$ nb





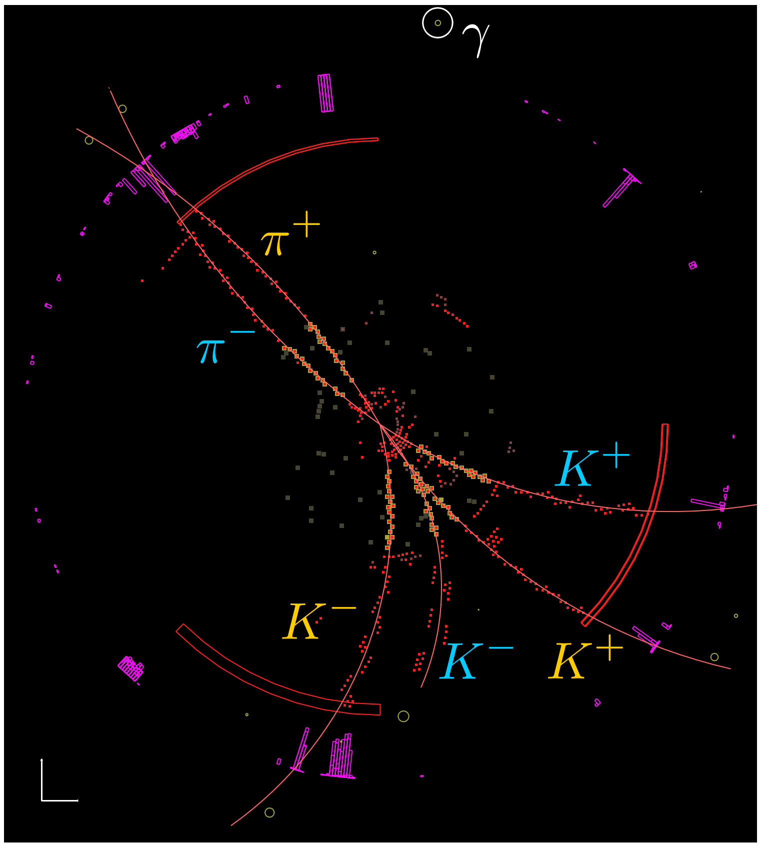


Selecting $D_s^{\pm} D_s^{*\mp}$ Events

DT event

$D_s^+ \to K^+ K^- \pi^+ / D_s^- \to K^+ K^- \pi^-$

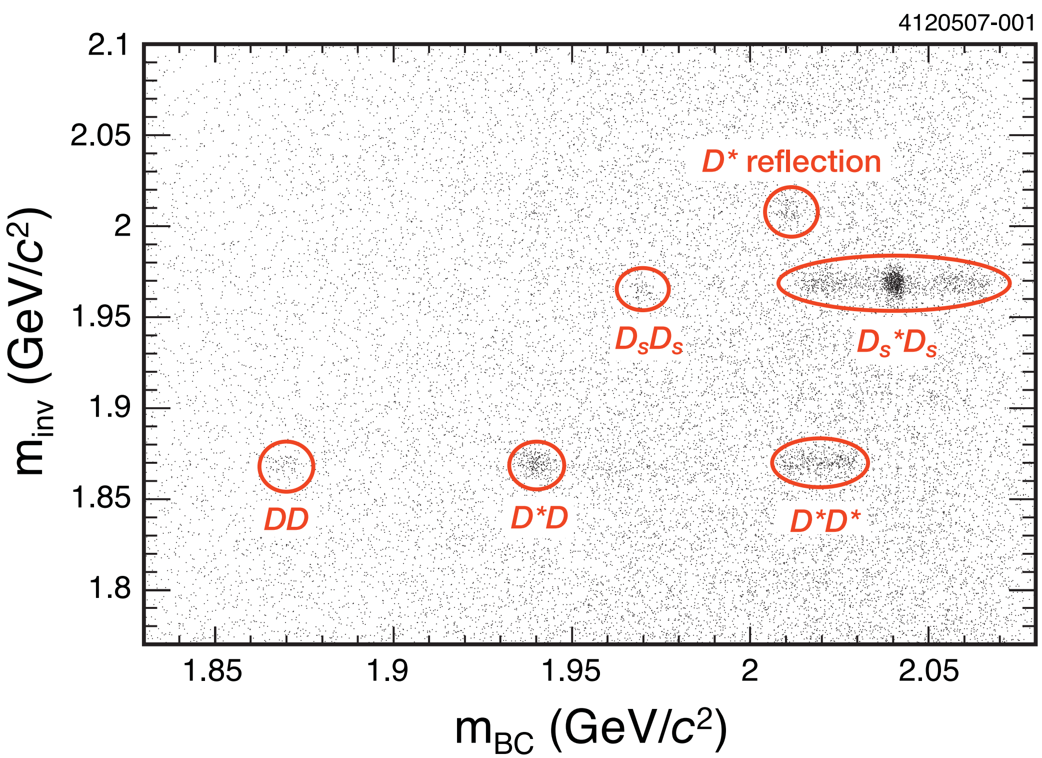
$e^+e^- \to D_s^* D_s \to D_s^+ D_s^- \gamma$



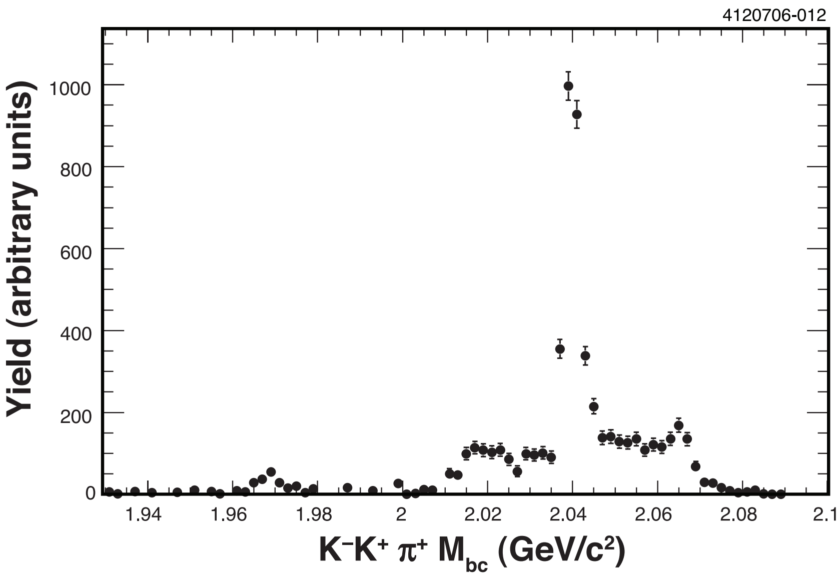
Ignore the γ or π^0 from D_s^* decay

Select $D_s^{\pm} D_s^{*\mp}$ events using:

- m_{inv}, the candidate invariant mass
- $m_{BC} \equiv [E_{\text{beam}}^2 - p^2(D_s)]^{\frac{1}{2}}$
  - m_{BC} is a proxy for momentum
  - m_{BC} distribution is narrow for D_s
  - m_{BC} distribution is wide for D_s^*

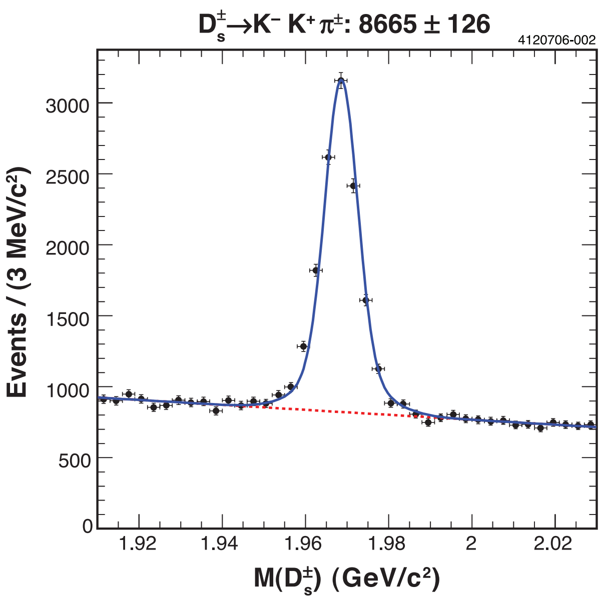


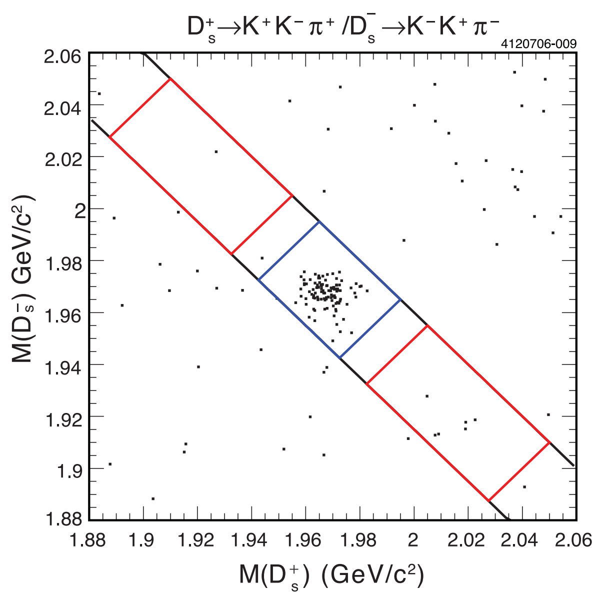
Analyzing $D_s^{\pm} D_s^{*\mp}$ Events

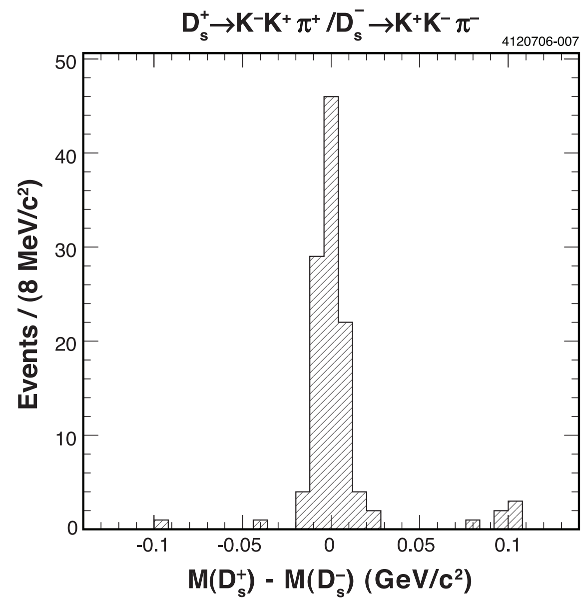


Measuring ST and DT events:

- Require $M_{bc} > 2.01$ GeV
- Fit ST $M(D_s)$ candidate invariant mass distribution
- Cut DT in $M(D_s^-)$ vs $M(D_s^+)$ plane
  - Blue box signal
  - Red boxes sidebands







Absolute Hadronic D_s Branching Fractions

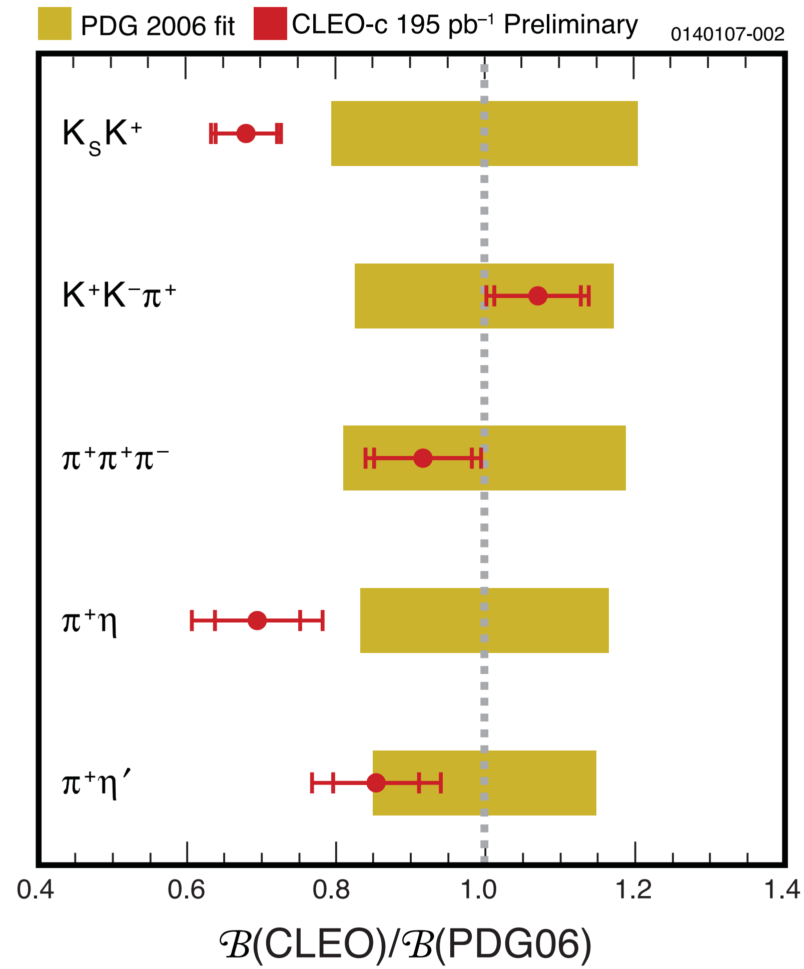
CLEO-c Preliminary

195 pb^{-1} of data

D_s^+ Mode	$\mathcal{B}$ (%)
$K_S K^+$	$1.50 \pm 0.09 \pm 0.05$
$K^- K^+ \pi^+$	$5.57 \pm 0.30 \pm 0.19$
$K^- K^+ \pi^+ \pi^0$	$5.62 \pm 0.33 \pm 0.51$
$\pi^+ \pi^+ \pi^-$	$1.12 \pm 0.08 \pm 0.05$
$\pi^+ \eta$	$1.47 \pm 0.12 \pm 0.14$
$\pi^+ \eta'$	$4.02 \pm 0.27 \pm 0.30$

Additional 105 pb^{-1} to be analyzed

Comparison with PDG 2006



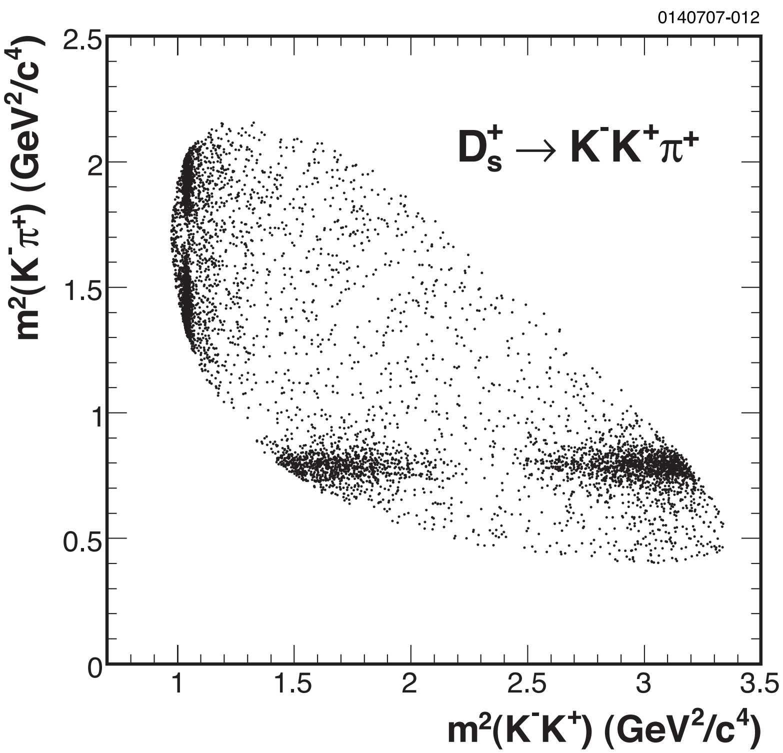
Belle measures $\mathcal{B}(D_s^+ \to K^- K^+ \pi^+)$ utilizing a partial reconstruction technique for $e^+ e^- \to D_{s1} D_s^*$ events hep-ex/0701053

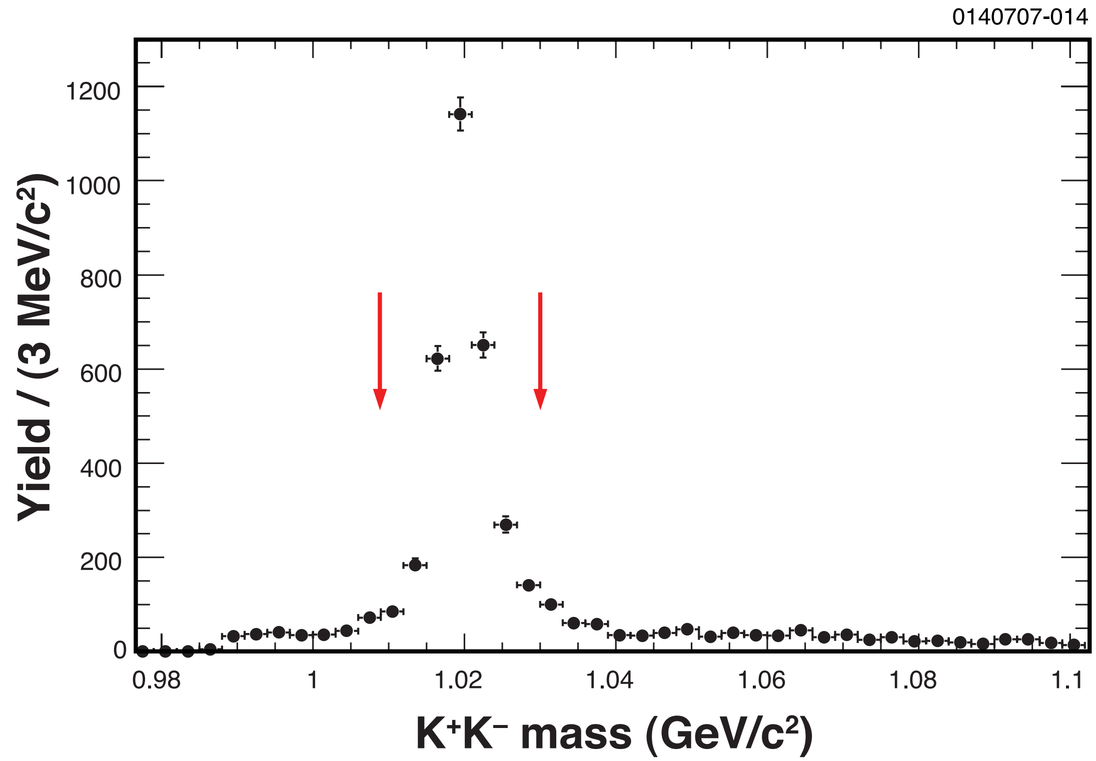
		$\mathcal{B}(D_s^+ \to K^- K^+ \pi^+)$ (%)
CLEO	Preliminary	$5.57 \pm 0.30 \pm 0.19$
Belle	Preliminary	$4.0 \pm 0.4 \pm 0.4$

Partial $D_s^+ \to K^-K^+\pi^+$ Branching Fractions and $D_s^+ \to \phi\pi^+$

$\mathcal{B}(D_s^+ \to \phi\pi^+ \to K^-K^+\pi^+)$ is one of the largest D_s branching fractions

- A branching fraction called $\mathcal{B}(D_s^+ \to \phi\pi^+)$ has often been used as a reference branching fraction for D_s decays.
  - Derived from a fairly narrow mass cut (typically near ± 10 MeV$/c^2$) around the ϕ peak in the $M(K^+K^-)$ distribution in $D_s^+ \to K^-K^+\pi^+$ events.
- E687 and FOCUS report significant contributions from $f_0(980)$ (or $a_0(980)$) in the $\phi\pi$ region of the $D_s^+ \to K^-K^+\pi^+$ Dalitz plot.





Partial $D_s^+ \to K^-K^+\pi^+$ Branching Fractions and $D_s^+ \to \phi\pi^+$

With a mass cut of approximately ± 10 MeV$/c^2$:

- The scalar contribution under the ϕ peak in $M(K^+K^-)$ is $\sim 6\%$.
  - Hence about 6% of the quoted $\mathcal{B}(D_s^+ \to \phi\pi^+)$ is due to other processes.
  - This contribution is comparable to current CLEO-c errors for partial $D_s^+ \to K^-K^+\pi^+$ branching fractions
  - CLEO now quotes $\mathcal{B}_{\Delta M} \equiv \mathcal{B}(D_s^+ \to K^-K^+\pi^+)$ with $|M(K^-K^+) - M_\phi| < \Delta M$ MeV$/c^2$.
  - This could become the reference branching fraction for D_s^+ decays!

CLEO-c Preliminary

	$\mathcal{B}_{\Delta M}$ (%)
$\mathcal{B}_{10}$	$1.98 \pm 0.12 \pm 0.09$
$\mathcal{B}_{20}$	$2.25 \pm 0.13 \pm 0.12$
PDG 07	2.2 ± 0.2

The PDG 07 value is $\mathcal{B}(D_s^+ \to \phi\pi^+) \times \mathcal{B}(\phi \to K^-K^+)$

$\mathcal{B}(D_s^+ \to \phi\pi^+)$ values used for PDG 07

Experiment	$\mathcal{B}(D_s^+ \to \phi\pi^+)$ (%)	ΔM MeV$/c^2$
CLEO 96	$3.59 \pm 0.77 \pm 0.48$	± 8
BaBar 05	$4.81 \pm 0.52 \pm 0.38$	-11.5 $+15.5$
BaBar 06	$4.62 \pm 0.36 \pm 0.51$	± 15
PDG 07	4.5 ± 0.4	

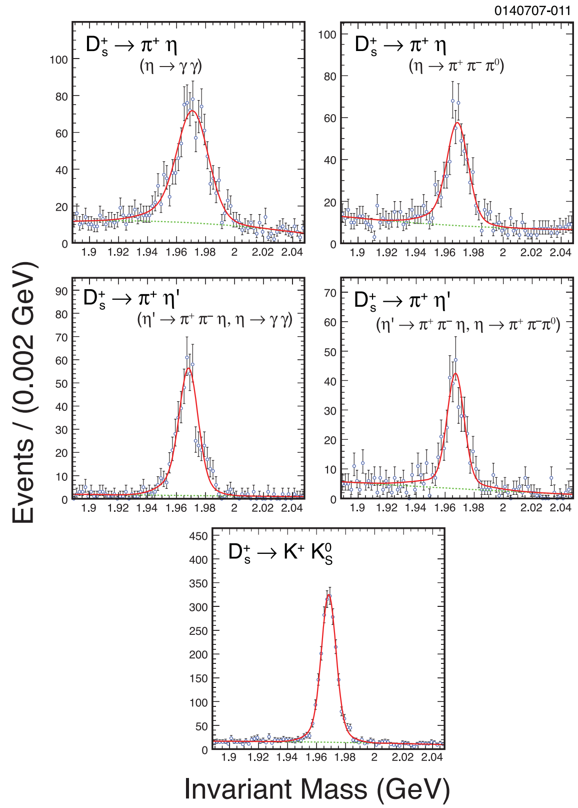
Cabibbo Suppressed D_s^+ Decays to Two Pseudoscalars

Analogous D_s^+ Decays

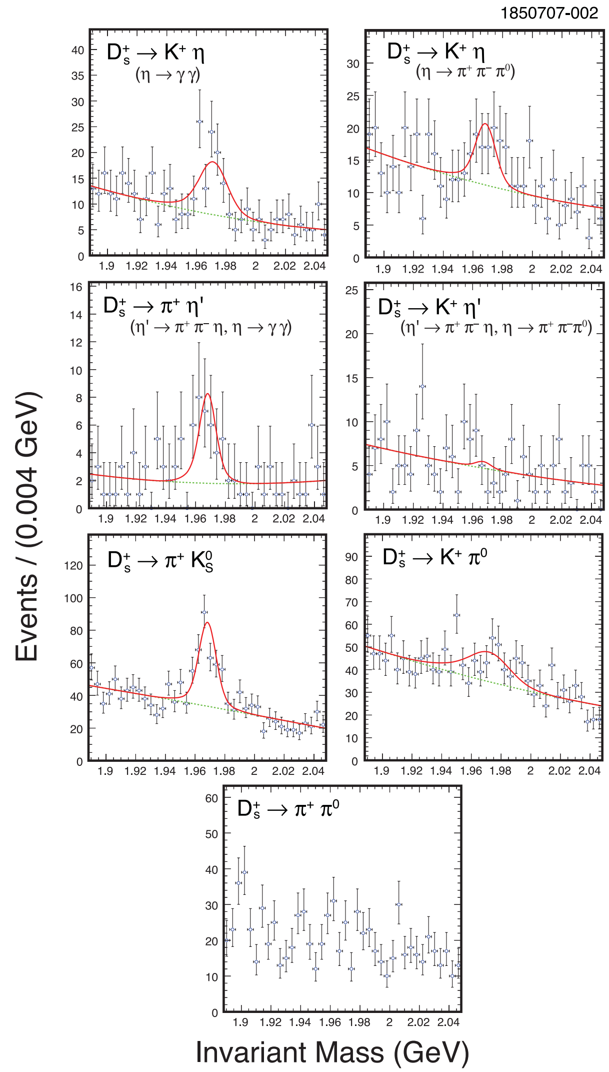
Favored	Suppressed
$\pi^+\eta$	$K^+\eta$
$\pi^+\eta'$	$K^+\eta'$
$K^+K_S^0$	$K_S^0\pi^+$
$K^+K_S^0$	$K^+\pi^0$
$K^+K_S^0$	$\pi^+\pi^0$ †

† Isospin Forbidden

Cabibbo Favored



Cabibbo Suppressed



Analysis technique:

- Measure single tag yields of Cabibbo favored and suppressed D_s^+ decays.
- Determine ratios of branching fractions from ratios of yields and efficiencies.

Cabibbo Suppressed D_s^+ Decays to Two Pseudoscalars

Preliminary Results

Ratio of Branching Fractions	Value
$\mathcal{B}(D_s^+ \to K^+\eta)/\mathcal{B}(D_s^+ \to \pi^+\eta)$	$(8.0 \pm 1.5)\%$
$\mathcal{B}(D_s^+ \to K^+\eta')/\mathcal{B}(D_s^+ \to \pi^+\eta')$	$(3.9 \pm 1.3)\%$
$\mathcal{B}(D_s^+ \to \pi^+K_S^0)/\mathcal{B}(D_s^+ \to K^+K_S^0)$	$(8.3 \pm 0.9)\%$
$\mathcal{B}(D_s^+ \to K^+\pi^0)/\mathcal{B}(D_s^+ \to K^+K_S^0)$	$(4.2 \pm 1.2)\%$
$\mathcal{B}(D_s^+ \to \pi^+\pi^0)/\mathcal{B}(D_s^+ \to K^+K_S^0)$	$(< 4.0)\%$

Consistent with $\tan^2\theta_C = 5\%$

Summary and Conclusions

CLEO is providing precision measurements of absolute D hadronic branching fractions using the CLEO-c detector in the charm threshold region

- Events are very clean with little background
- 281 pb^{-1} Preliminary results for D^0 and D^+ limited by systematic errors
  - Cabibbo Favored decay errors $\lesssim 3\%$
  - Final results coming soon
  - Some improvement with more data may be possible
  - Now Final State Radiation must be considered – effects $\sim 2\% - 3\%$
    - This is an interesting problem for the PDG
- 195 pb^{-1} Preliminary results for D_s limited by statistics
  - Cabibbo Favored decay errors as low as $\lesssim 10\%$
  - Results with more data coming soon
  - Scalar K^+K^- contribution becoming significant in measurements of $\mathcal{B}(D_s \to K^-K^+\pi^+)$ with $M(K^+K^-)$ cuts around the ϕ peak
    - Hence, the branching fraction conventionally quoted as $\mathcal{B}(D_s \to \phi\pi^+)$ has significant contributions from other processes
    - Need to define a new reference branching fraction for D_s decays
    - CLEO provides $\mathcal{B}_{\Delta M} \equiv \mathcal{B}(D_s^+ \to K^-K^+\pi^+)$ with $|M(K^-K^+) - M_\phi| < \Delta M$ MeV$/c^2$.