D Meson Hadronic Decays at CLEO-c

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CLEO Collaboration

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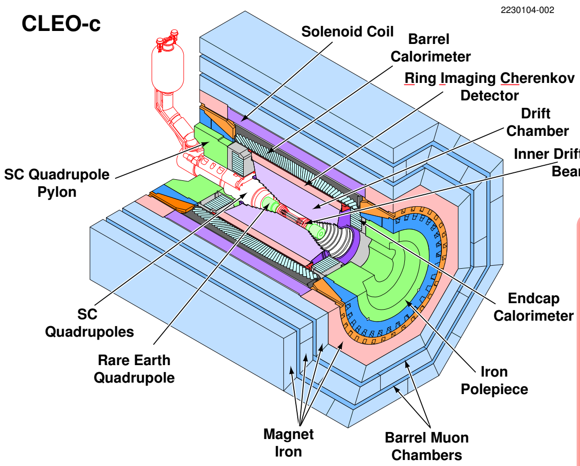
Outline

1. CLEO-c Experiment - detector and data sample
2. First Observations of Suppressed Decays of D_s^+ Mesons to Two Pseudoscalar Mesons
   - $K^+\eta$, $K^+\eta'$, $\pi^+K_S^0$, $K^+\pi^0$ & $\pi^+\pi^0$
3. Inclusive Branching Fractions for D_s^+ Decays
   - $K^+X, K^-X, K_S^0X, \pi^+X, \pi^-X, \pi^0X, f_0(980)X, \eta X, \eta' X, \phi X, \omega X$ & K-pair X
4. Branching Fraction for the Doubly Cabibbo Suppressed Decay - $D^+ \to K^+\pi^0$
5. Flavor Symmetry and Decays of Charmed Particles D^0, D^+, and D_s^+ to Pairs of Light Pseudoscalar Mesons P
   - Cabibbo-favored, singly-Cabibbo-suppressed and doubly-Cabibbo-suppressed
6. Absolute Branching Fractions of D^0, D^+, and D_s^+
   - Key modes

CLEO-c Detector



e^+e^- **Collisions at CESR-c**

- General-purpose symmetric detector
- 93% coverage (charged and neutral)
- Tracking: $\delta p/p = 0.6\%$ at 1 GeV
- Calorimeter: $\delta E/E \sim 5\%$ at 100 MeV, 2% at 1 GeV.
- Particle ID: dE/dx & Ring Imaging Cherenkov $\Rightarrow$ Great π/K separation.

Data Sample at CLEO-c

$D_s^\pm D_s^{*\mp}$ $E_{\rm cm} = 4.170$ GeV

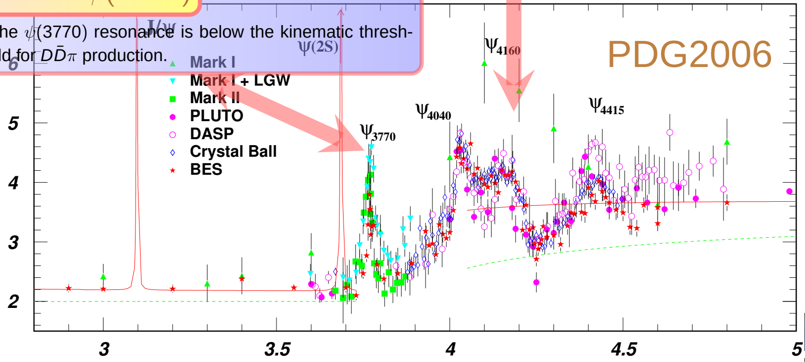
At 4.170 GeV energy (below the D_sDK threshold of 4.33 GeV), production of a $D_s^\pm$ meson in charm- and strangeness-conserving processes requires the production of a $D_s^\mp$ meson elsewhere in the event

$D\bar{D}$ At $\psi(3770)$

The $\psi(3770)$ resonance is below the kinematic threshold for $D\bar{D}\pi$ production.

$D\bar{D}$@3770 : 818 pb^{-1}

$D_s^\pm D_s^{*\mp}$@4170 : 602 pb^{-1}

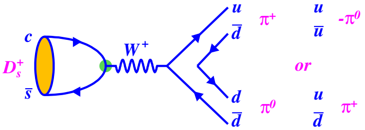


First Observations of Suppressed Decays of D_s^+ Mesons to Two Pseudoscalar Mesons

- DataSet: 298 pb^{-1} at $E_{\mathrm{cm}} = 4.170$ GeV
- Published in Phys. Rev. Lett. **99**, 191805 (2007)

Motivation

- Study D_s two-body final states with two pseudo scalars
  - Will have either: K^+ or π^+, and
  - one: of η, η', π^0, K_S^0
- This analysis studies the following modes:
  - Single-Cabibbo-suppressed modes: $D_s^+ \to K^+\eta$, $D_s^+ \to K^+\eta'$, $D_s^+ \to K^+\pi^0$ and $D_s^+ \to \pi^+K_S^0$
  - The isospin forbidden mode: $D_s^+ \to \pi^+\pi^0$



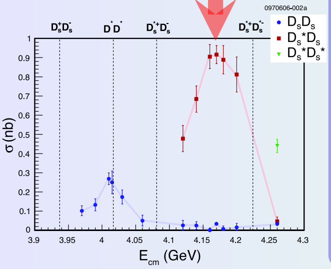
$$\pi^0 = \frac{1}{\sqrt{2}}(d\bar{d} - u\bar{u})$$

- Measure as ratios to the Cabibbo favored modes: $D_s^+ \to \pi^+\eta$, $D_s^+ \to \pi^+\eta'$, $D_s^+ \to K^+K_S^0$

Single Tag Method @ $E_{\rm cm} = 4.170$ GeV

$D_S^\pm D_S^{*\mp}$ 298 pb^{-1} @ 4170 MeV

- Dedicated scan to find optimal energy for D_s physics
- $\sigma(D_s^{*+} D_s^-) \sim 0.9$ nb



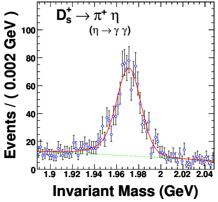
Background Suppression

- Require that the K_S^0 has traveled a measurable distance from the interaction point before decaying
- Slow track veto to eliminate the soft pions from $D^*\bar{D}^*$ decays (through $D^* \to \pi D$)
- For the modes with η or η', $\eta \to \gamma\gamma$, we reject the η candidate if either of the daughter photons is consistent with coming from $\pi^0 \to \gamma\gamma$ when paired with any other γ in the event.
- Define The recoil mass variable $M_{\rm recoil}(D_s + \gamma) = \sqrt{(\sqrt{s} - \sqrt{m_{D_s}^2 + \vec{p}_{D_s}^2} - E_\gamma)^2 - (\vec{p}_{\rm Lab} - \vec{p}_{D_s} - \vec{p}_\gamma)^2}$. We require $M_{\rm recoil}(D_s + \gamma)$ must be in the D_s mass region.

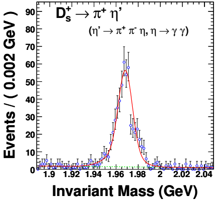
- Variable $M_{\rm recoil}(D_s) = \sqrt{(\sqrt{s} - \sqrt{m_{D_s}^2 + \vec{p}_{D_s}^{\,2}})^2 - (\vec{p}_{\rm Lab} - \vec{p}_{D_s})^2}$
- Extract yields in invariant mass after cutting on recoil mass

Cabibbo Favored Modes Data Yields

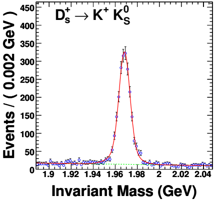
908 ± 43



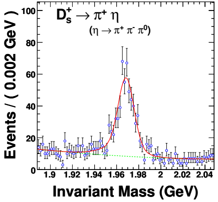
509 ± 25



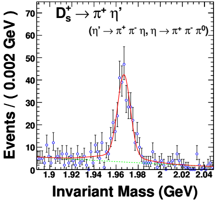
2174 ± 52



512 ± 31



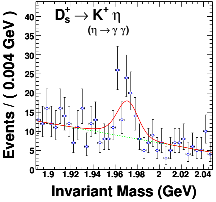
344 ± 24



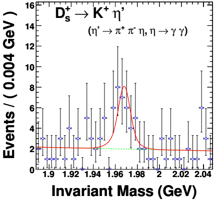
Normalization Mode Yields $298\ pb^{-1}$

Singly-Cabibbo-Suppressed Modes Data Yields

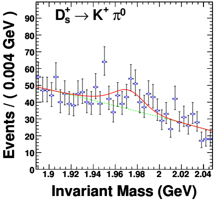
68 ± 13 ($5.8\ \sigma$)



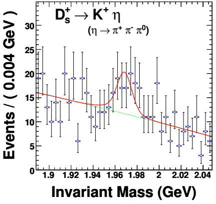
25 ± 7 ($5.0\ \sigma$)



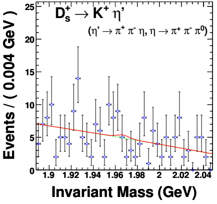
141 ± 34 ($4.3\ \sigma$)



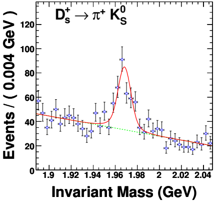
45 ± 13 ($4.0\ \sigma$)



3 ± 6 ($0.5\ \sigma$)

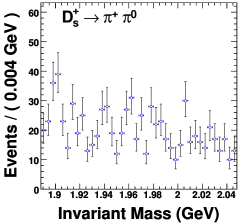


206 ± 22 ($11.1\ \sigma$)



Yields Summary

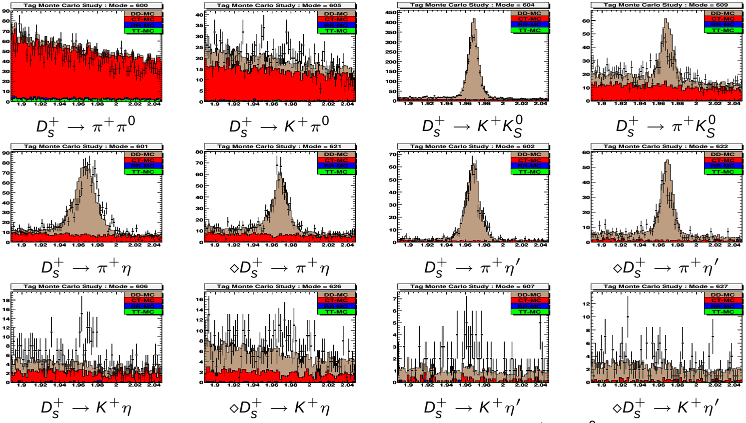
- Find no significant evidence for the isospin-forbidden decay $D_S^+ \to \pi^+\pi^0$, and therefore set an upper limit.
- Monte Carlo studies indicate that tightening the requirement on $M_{\text{recoil}}(D_s)$ to ± 10 MeV should improve the upper limit.
- Apply a sideband subtraction to the invariant mass distribution and obtain a yield of 17 ± 25 events.
- Phys. Rev. Lett. **99**, 191805 (2007).



Observed Yields From Data

D_s Mode	Sub-Mode Decay	Yield	Significance (σ)	Efficiency (%)
$D_S^+ \to \pi^+\eta$	$\eta \to \gamma\gamma$	908 ± 43		9.97 ± 0.05
$D_S^+ \to \pi^+\eta$	$\eta \to \pi^+\pi^-\pi^0$	512 ± 31		5.00 ± 0.03
$D_S^+ \to \pi^+\eta'$	$\eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$	509 ± 25		2.43 ± 0.02
$D_S^+ \to \pi^+\eta'$	$\eta' \to \pi^+\pi^-\eta, \eta \to \pi^+\pi^-\pi^0$	344 ± 24		1.80 ± 0.01
$D_S^+ \to K^+K_S^0$	$K_S^0 \to \pi^+\pi^-$	2174 ± 52		26.13 ± 0.14
$D_S^+ \to \pi^+K_S^0$	$K_S^0 \to \pi^+\pi^-$	206 ± 22	11.1	29.93 ± 0.15
$D_S^+ \to K^+\pi^0$	$\pi^0 \to \gamma\gamma$	141 ± 34	4.3	30.90 ± 0.14
$D_S^+ \to K^+\eta$	$\eta \to \gamma\gamma$	68 ± 13	5.8	8.93 ± 0.05
$D_S^+ \to K^+\eta$	$\eta \to \pi^+\pi^-\pi^0$	45 ± 13	4.0	4.39 ± 0.03
$D_S^+ \to K^+\eta'$	$\eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$	25 ± 7	5.0	2.10 ± 0.02
$D_S^+ \to K^+\eta'$	$\eta' \to \pi^+\pi^-\eta, \eta \to \pi^+\pi^-\pi^0$	3 ± 6	0.5	1.53 ± 0.01

Background Study Using Monte Carlo



$\diamond$: The modes with η, η was reconstructed in $\eta \to \pi^+\pi^-\pi^0$.

The points are obtained from real data, and the colorful shaded histograms are from normalized Monte Carlo samples (mcDD-mix (brown), continuum(red), radiative return to the psi2S(blue) and tau-pair(green))

Double Check Using Double Tag Method

- D_S-tag : either primary or secondary D_S.
- $M(D_S)$, $M_{\text{recoil}}(D_S)$ are defined as before.
- Recoil mass cut:

  $-55 \leq [M_{\text{recoil}}(D_S) - M_{D_S^*}] < +55$ MeV.

  - Signal region :
    $-20 \leq [M(D_S) - M_{D_S}] < +20$ MeV
  - Sideband region :
    $-55 \leq [M(D_S) - M_{D_S}] < -35$ MeV
    and $+35 \leq [M(D_S) - M_{D_S}] < +55$ MeV
- Tag set-1: three cleanest tag modes
- Tag set-2 : total 13 tag modes.
- Multiple tag candidates are allowed.

Double Tag Results

Consistent with our results from single tag method. But due to low statistics, have big errors.

Tag set 1 (Three cleanest tag modes)	
Mode#	Decay
400	$D_S^+ \to K^+K_S^0, K_S^0 \to \pi^+\pi^-$
4011	$D_S^+ \to \phi\pi^+, \phi \to K^+K^-$
4012	$D_S^+ \to K^+\bar{K}^\star(892)^0$, $\bar{K}^\star(892)^0 \to K^-\pi^+$

Tag set 2 (Total 13 tag modes)	
Mode#	Decay
400	$D_S^- \to K_S^0K^-$
401	$D_S^- \to K^+K^-\pi^-$
402	$D_S^- \to K_S^0K^-\pi^0$
403	$D_S^- \to K_S^0K_S^0\pi^-$
404	$D_S^- \to K^+K^-\pi^-\pi^0$
405	$D_S^- \to K_S^0K^-\pi^-\pi^+$
406	$D_S^- \to K_S^0K^+\pi^-\pi^-$
421	$D_S^- \to \pi^-\pi^-\pi^+$
440	$D_S^- \to \pi^-\eta\ (\eta \to \gamma\gamma)$
441	$D_S^- \to \pi^-\pi^0\eta\ (\eta \to \gamma\gamma)$
460	$D_S^- \to \pi^-\eta'$ $(\eta' \to \pi^+\pi^-\eta)$
461	$D_S^- \to \pi^-\pi^0\eta'$ $(\eta' \to \pi^+\pi^-\eta)$
480	$D_S^- \to \pi^-\eta'\ (\eta' \to \rho^0\gamma)$

Systematic Uncertainties

Main Systematic Uncertainties Summary

Source	Value (%)				
	$\frac{\mathcal{B}(D_s^+ \to K^+\eta)}{\mathcal{B}(D_s^+ \to \pi^+\eta)}$	$\frac{\mathcal{B}(D_s^+ \to K^+\eta')}{\mathcal{B}(D_s^+ \to \pi^+\eta')}$	$\frac{\mathcal{B}(D_s^+ \to \pi^+ K_S^0)}{\mathcal{B}(D_s^+ \to K^+ K_S^0)}$	$\frac{\mathcal{B}(D_s^+ \to K^+\pi^0)}{\mathcal{B}(D_s^+ \to K^+ K_S^0)}$	$\frac{\mathcal{B}(D_s^+ \to \pi^+\pi^0)}{\mathcal{B}(D_s^+ \to K^+ K_S^0)}$
$\pi^\pm$&$K^\pm$ Tracking	—	—	—	—	—
$K^\pm$ Tracking	0.6	0.6	0.6	—	0.6
K_S^0	—	—	—	1.8	1.8
K_S^0 F.S.	—	—	—	0.52	0.52
Track Veto	—	—	—	0.28	0.28
π^0, η, γ Rec.	—	—	—	4.2	4.2
$\pi^\pm$ PID	0.25	0.25	0.25	0.50	0.25
$K^\pm$ PID	0.30	0.30	0.30	—	0.30
π^0 Veto	—	—	—	—	—
Fitting	—	—	—	4.94	0.67
BG Shape	4.45	5.99	2.43	10.59	—
π^0 Tail	—	—	—	—	1.85
$\mathcal{B}_{\text{ref.}}$	—	—	—	—	—
Total	4.507	6.033	2.533	12.583	5.061

- In calculating the relative systematic uncertainties for the measured ratio of Cabibbo-suppressed mode branching fractions to Cabibbo-favored mode branching fractions ($\mathcal{B}_{\text{Suppressed}}/\mathcal{B}_{\text{Favored}}$), cancellation of uncertainties has been taken into account.

Published Results

- First observations of four Cabibbo-suppressed D_s decays
- Those ratios to be of order $|V_{cd}/V_{cs}|^2 \approx 1/20$
- Phys. Rev. Lett. **99**, 191805 (2007).

Mode	$\mathcal{B}_S/\mathcal{B}_F(10^{-2})$
$\mathcal{B}(D_s^+ \to K^+\eta)$ / $\mathcal{B}(D_s^+ \to \pi^+\eta)$	$8.9 \pm 1.5 \pm 0.4$
$\mathcal{B}(D_s^+ \to K^+\eta')$ / $\mathcal{B}(D_s^+ \to \pi^+\eta')$	$4.2 \pm 1.3 \pm 0.3$
$\mathcal{B}(D_s^+ \to \pi^+K_S^0)$ / $\mathcal{B}(D_s^+ \to K^+K_S^0)$	$8.2 \pm 0.9 \pm 0.2$
$\mathcal{B}(D_s^+ \to K^+\pi^0)$ / $\mathcal{B}(D_s^+ \to K^+K_S^0)$	$5.5 \pm 1.3 \pm 0.7$
$\mathcal{B}(D_s^+ \to \pi^+\pi^0)$ / $\mathcal{B}(D_s^+ \to K^+K_S^0)$	< 4.1 (90% CL)

Mode	$(\mathcal{B}_+ - \mathcal{B}_-)/(\mathcal{B}_+ + \mathcal{B}_-)(\%)$
$\mathcal{A}(D_s^+ \to K^+\eta)$	-20 ± 18
$\mathcal{A}(D_s^+ \to K^+\eta')$	-17 ± 37
$\mathcal{A}(D_s^+ \to \pi^+K_S^0)$	27 ± 11
$\mathcal{A}(D_s^+ \to K^+\pi^0)$	2 ± 29

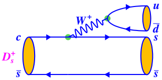
$\mathcal{A}_{CP} = \frac{\mathcal{B}_+ - \mathcal{B}_-}{\mathcal{B}_+ + \mathcal{B}_-}$

No significant CP asymmetry

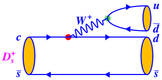
Inclusive Branching Fractions for D_s^+ Decays

- DataSet: 586 pb^{-1} at $E_{\mathrm{cm}} = 4.170$ GeV
- CLEO Preliminary

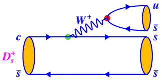
Motivation & Introduction of D_s^+ Decays



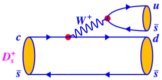
Favored Decay



SCS Decay(a)



SCS Decay(b)

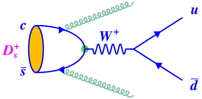


DCS Decay

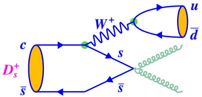
Classify Final States

- The D_s^+ meson, consisting of c and $\bar{s}$ quark, is the least extensively studied of the ground state charmed mesons. Inclusive study will be helpful to get a overview of D_s decays.
- Classify "quark-level" final states
- The Cabibbo-favored decays:
  $\mathcal{B}(s\bar{s}) = \mathcal{B}(\eta) + \mathcal{B}(\eta') + \mathcal{B}(\omega) + \mathcal{B}(\phi) + \mathcal{B}(K\bar{K})$
- The singly Cabibbo-suppressed decays (a): $\mathcal{B}(\bar{s})$.
- The singly Cabibbo-suppressed decays (b):
  $\mathcal{B}(s\bar{s}\bar{s}) = \mathcal{B}(\eta\bar{s}) + \mathcal{B}(\eta'\bar{s}) + \mathcal{B}(\omega\bar{s}) + \mathcal{B}(\phi\bar{s}) + \mathcal{B}(K\bar{K}\bar{s})$
- The doubly Cabibbo-suppressed decays: $\mathcal{B}(\bar{s}\bar{s})$
- The annihilation decays:
  $\mathcal{B}(\text{Annihi}) = \mathcal{B}(\text{Lep}) + \mathcal{B}(\text{Other Annihi})$

Get $\mathcal{B}(\text{Other Annihi})$ from the global fit

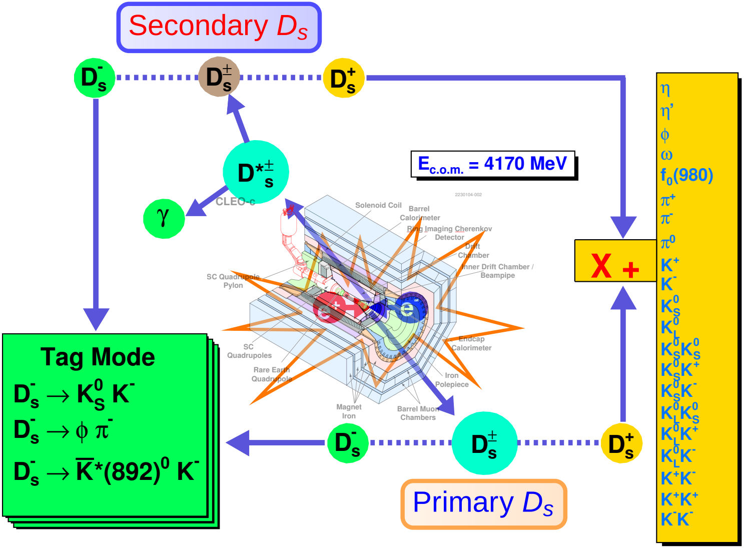


Annihilation(a)



Annihilation(b)

Double Tag Method @ $E_{cm} = 4.170$ GeV



D_s Tag Selection

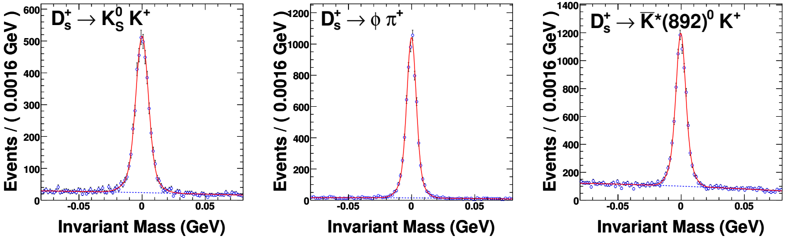
- Three cleanest tag modes:
  1. $D_S^+ \to K^+K_S^0, K_S^0 \to \pi^+\pi^-$
  2. $D_S^+ \to \phi\pi^+, \phi \to K^+K^-$
  3. $D_S^+ \to K^+\bar{K}^\star(892)^0, \bar{K}^\star(892)^0 \to K^-\pi^+$
- Either primary or secondary D_s.
- First recoil mass cut: $-55 \leq [M_{\text{recoil}}(D_s) - M_{D_s^*}] < +55$ MeV.
- Second recoil mass cut: $|M_{\text{recoil}}(D_s + \gamma) - m_{D_s}| < 30$ MeV.
- All charged particles must have momentum above 100 MeV/c to eliminate the soft pions from $D^*\bar{D}^*$ decays (through $D^* \to \pi D$).
- Tag invariant mass signal and sideband regions:
  - Signal region : $-20 \leq [M(D_s) - M_{D_s}] < +20$ MeV
  - Sideband region : $-55 \leq [M(D_s) - M_{D_s}] < -35$ MeV and $+35 \leq [M(D_s) - M_{D_s}] < +55$ MeV

$$M_{\text{recoil}}(D_s) = \sqrt{E_{\text{recoil}}^2 - \vec{p}_{\text{recoil}}^{\,2}} \quad (1)$$
$$= \sqrt{(\sqrt{s} - E_{D_s})^2 - (\vec{p}_{\text{Lab}} - \vec{p}_{D_s})^2} \quad (2)$$
$$= \sqrt{(\sqrt{s} - \sqrt{m_{D_s}^2 + \vec{p}_{D_s}^{\,2}})^2 - (\vec{p}_{\text{Lab}} - \vec{p}_{D_s})^2} \quad (3)$$

$$M_{\text{recoil}}(D_s + \gamma) = \sqrt{(\sqrt{s} - E_{D_s} - E_\gamma)^2 - (\vec{p}_{D_s} + \vec{p}_\gamma)^2} \quad (4)$$

D_s Tag Yield

18586 ± 163 D_s Tags



Fit the $\Delta M(D_s)$ distribution to the sum of signal (double Gaussian) plus background (second degree polynomial) functions to obtain the sideband scaling factor.

$$f(x) = A_1 \left(G_1(x; \mu_1, \sigma_1) + \frac{A_2}{A_1} \cdot G_2(x; \mu_2, \sigma_2) \right) + (p_0 + p_1 \cdot x + p_2 \cdot x^2), \quad (5)$$

where $G(x; \mu, \sigma) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$.

Signal Selection Criteria

Track Selection

- Good track fit quality.
- Momentum $p > 50$ MeV/c.
- Angles with respect to the beam line, $|\cos\theta| < 0.80$.
- Coming from the interaction point in three dimensions.

Particle Identification

- Pion and kaon candidates are required to have dE/dx measurements within three standard deviations (3σ) of the expected value.
- When $p > 700$ MeV/c, RICH information, if available, is combined with dE/dx.
- Candidate electron use in addition the ratio of calorimeter energy E to track momentum p.

π^0 and η

- Identify π^0 via $\pi^0 \to \gamma\gamma$.
- Form η by using $\eta \to \gamma\gamma$ decay.
- Photons must satisfy some good photon selection criteria.

K_S^0, $f_0(980)$, η', ω and ϕ

- $K_S^0 \to \pi^+\pi^-$. (These two pions have no PID requirements, and a vertex fit is done to allow for the K_S^0 flight distance.)
- $f_0(980) \to \pi^+\pi^-$.
- $\eta'(\omega) \to \eta(\pi^0)\pi^+\pi^-$, $\eta(\pi^0) \to \gamma\gamma$. The η (π^0) candidates within 3 r.m.s. widths of the η (π^0) mass.
- $\phi \to K^+K^-$.
- Pions and kaons are required to satisfy the track selection and PID requirements.

Background Estimation For Charged Kaon and Pion

Cross Fake among $e^\pm, K^\pm$ and $\pi^\pm$

Fake rates (from MC)

$$F_i^{a\to b} = \frac{\sum_j N_{i,j}^{a\to b}\ (\text{MC})}{\sum_j N_{i,j}^{\text{observed}-a}\ (\text{MC})}$$

Estimated background (in data)

$$N_{i,j}^{a\to b}\ (\text{Data}) = F_i^{a\to b} \times N_{i,j}^{\text{observed}-a}\ (\text{Data})$$

$\mu^\pm$ Fake to $K^\pm$ and $\pi^\pm$

- u^+ background (using e^+ to normalize)

$$N_{i,j}^{\mu^+\to K^+/\pi^+}\ (\text{Data}) = F_i^{\mu^+\to K^+/\pi^+} \times N_{i,j}^{\text{observed}-e^+}(\text{Data})$$

- u^- background (directly frome MC)

$$N_{i,j}^{\mu^-\to K^-/\pi^-}\ (\text{Data}) = N_{i,j}^{\mu^-\to K^-/\pi^-}\ (\text{MC}) \times \frac{N^{\text{Data}}_{D_S\text{Tag}}}{N^{\text{MC}}_{D_S\text{Tag}}}$$

$\pi^\pm$ from K_S^0 Decay

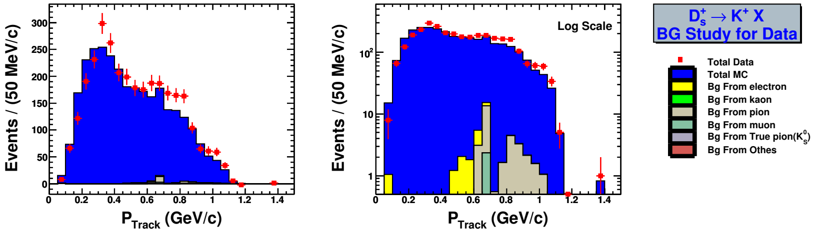
- Pion background from K_S^0 decay (using K_S^0 yield to normalize)

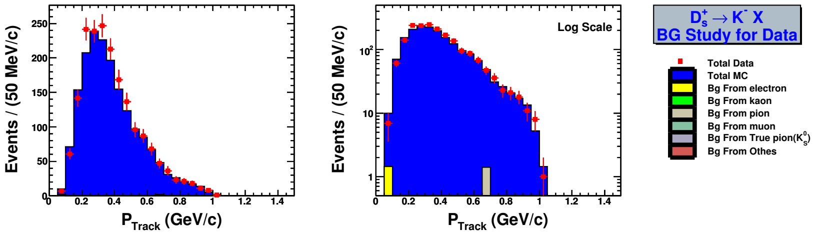
$$N_{i,j}^{\pi^\pm}\ \text{From } K_S^0\ (\text{Data}) = N_{i,j}^{\pi^\pm}\ \text{From } K_S^0\ (\text{MC}) \times \frac{N^{\text{Data}}_{K_S^0}}{N^{\text{MC}}_{K_S^0}}$$

Others

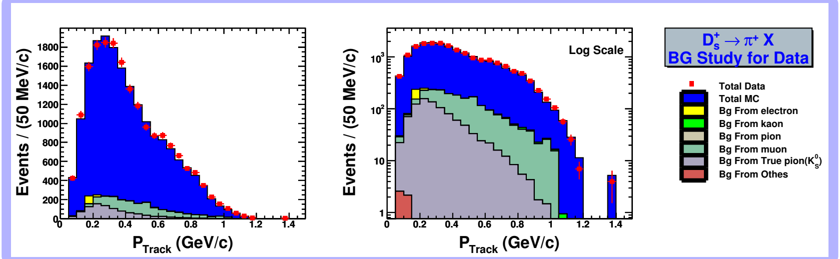
Monte Carlo study shows us there is a very tiny background contribution from other sources in addition to what we have considered upon. We directly subtract them based on the Monte Carlo simulation.

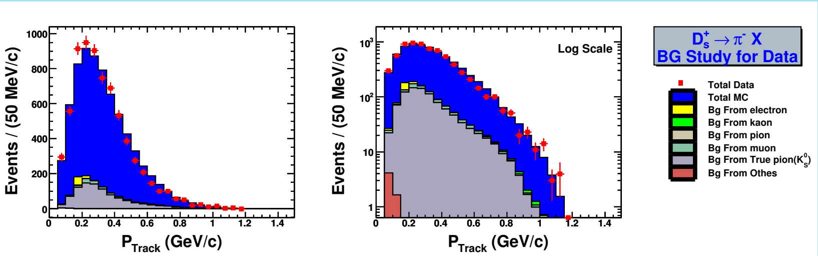
$K^\pm$ Background Study





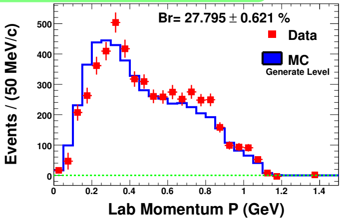
$\pi^{\pm}$ Background Study



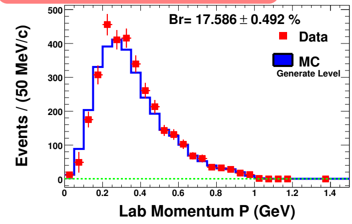


Kaon and Pion Momentum Spectra

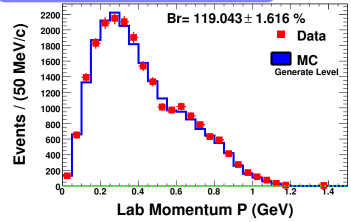
K^+ Momentum Spectrum



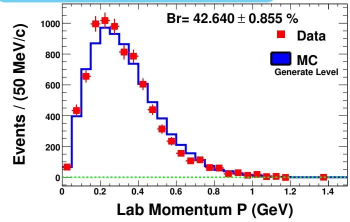
K^- Momentum Spectrum



π^+ Momentum Spectrum



π^- Momentum Spectrum



Systematic Uncertainties-General

Main Systematics

- D_S-tag
- MC statistics
- Tracking systematic
- PID
- K_S^0, π^0, η finding
- e, K, π production rates
- Cross fake rates
- Fit procedure
- Truncate point
- Effect from $D_S^{*+} \to D_S^+\pi^0$
- K^+K^+X MC Efficiency
- Single tag efficiency

D_S-Tag Systematics

- Many of the systematics from the D_s tag side cancel in the final inclusive branching fractions.
- The error in total D_s tag yield is 0.87%.

MC Statistics

- About 20 $\times$ mcDD-mix Monte Carlo samples are used to estimate the efficiencies. The expected uncertainties in efficiencies have been included in the statistical errors.

Tracking

- Assign 0.3% per charged particle. An additional 0.6% systematic uncertainty for each kaon track is added.

Systematics Uncertainties Summary

Main Systematic Uncertainties Summary

Mode	Value (%)									
	Tracking	$K^\pm$ Trk	$K^\pm$ ID	$\pi^\pm$ ID	K_S^0, π^0, f_0, η	Truncate	Tag Eff	Other	Total	C. F.
$f_0(980)X$	0.600	—	—	0.500	5.620	—	—	6.748	8.817	0.990
π^+X	0.300	—	—	0.250	—	0.295	0.352	—	0.603	0.998
π^-X	0.300	—	—	0.250	—	0.421	0.445	—	0.727	0.987
π^0X	—	—	—	—	4.000	—	0.374	1.466	4.276	0.988
K^+X	0.300	0.600	0.300	—	—	0.158	0.510	—	0.908	0.961
K^-X	0.300	0.600	0.300	—	—	0.186	0.618	—	0.978	0.941
K_S^0X	0.600	—	—	—	1.800	—	0.596	—	1.989	0.989
$K_S^0K_S^0X$	1.200	—	—	—	3.600	—	1.958	—	4.270	1.014
$K_S^0K^+X$	0.900	0.600	0.300	—	1.800	—	1.064	—	2.373	0.984
$K_S^0K^-X$	0.900	0.600	0.300	—	1.800	—	1.864	—	2.824	0.909
K^+K^-X	0.600	1.200	0.600	—	—	—	0.678	—	1.619	0.939
K^+K^+X	0.600	1.200	0.600	—	—	—	—	6.227	6.398	0.980
K^-K^-X	0.600	1.200	0.600	—	—	—	—	—	1.470	0.980
ηX	—	—	—	—	5.600	—	0.503	—	5.623	0.989
$\eta' X$	0.600	—	—	0.500	5.600	—	0.792	—	5.709	0.951
ϕX	0.600	1.200	0.600	—	—	3.653	0.634	—	3.988	0.980
ωX	0.600	—	—	0.500	4.000	—	3.325	—	5.260	0.867

Results-Preliminary

D_s Inclusive Branching Frations (586 pb^{-1} at $E_{cm} = 4.170$ GeV)

Mode	$\mathcal{B}$(%)	K_L^0 Mode	$\mathcal{B}$(%)	$\mathcal{B}$(PDG)(%)
$D_s^+ \to f_0(980)X$	$< 2.457\%$ (90% CL)			
$D_s^+ \to \pi^+ X$	$119.283 \pm 1.163 \pm 0.719$			
$D_s^+ \to \pi^- X$	$43.200 \pm 0.866 \pm 0.314$			
$D_s^+ \to \pi^0 X$	$123.411 \pm 3.801 \pm 5.278$			
$D_s^+ \to K^+ X$	$28.914 \pm 0.646 \pm 0.263$			20^{+18}_{-14}
$D_s^+ \to K^- X$	$18.679 \pm 0.523 \pm 0.183$			13^{+14}_{-12}
$D_s^+ \to K_S^0 X$	$19.017 \pm 0.969 \pm 0.378$	$D_s^+ \to K_L^0 X$	15.585 ± 1.984	20 ± 14
$D_s^+ \to K_S^0 K_S^0 X$	$1.716 \pm 0.329 \pm 0.073$	$D_s^+ \to K_L^0 K_S^0 X$	4.965 ± 0.985	
$D_s^+ \to K_S^0 K^+ X$	$5.846 \pm 0.456 \pm 0.139$	$D_s^+ \to K_L^0 K^+ X$	5.192 ± 0.707	
$D_s^+ \to K_S^0 K^- X$	$1.920 \pm 0.357 \pm 0.054$	$D_s^+ \to K_L^0 K^- X$	1.885 ± 0.303	
$D_s^+ \to K^+ K^- X$	$15.810 \pm 0.590 \pm 0.256$			
$D_s^+ \to K^+ K^+ X$	$< 0.259\%$ (90% CL)			
$D_s^+ \to K^- K^- X$	$< 0.064\%$ (90% CL)			
$D_s^+ \to \eta X$	$29.933 \pm 2.225 \pm 1.683$			
$D_s^+ \to \eta' X$	$11.667 \pm 1.682 \pm 0.666$			
$D_s^+ \to \phi X$	$15.714 \pm 0.816 \pm 0.627$			
$D_s^+ \to \omega X$	$6.090 \pm 1.401 \pm 0.320$			

PDG(2006)

K_L^0 Mode

Preliminary

- The first error is statistical error and the second one is systematic error. For upper limits, we conservatively increase the quoted upper limits by 1.28 times the systematic errors.

All Measurements List

All of our measurements

Value(%)	Mode
(28.914 ± 0.697)	(K^+X)
(18.679 ± 0.554)	(K^-X)
(19.017 ± 1.040)	(K_S^0X)
(19.017 ± 1.040)	($K_L^0X = K_S^0X$)
(85.627 ± 2.263)	$D_s^+ \to KX$

Value(%)	Mode
2 × (1.716 ± 0.337)	($K_S^0K_S^0X = K_L^0K_L^0X$)
2 × (5.846 ± 0.477)	($K_S^0K^+X = K_L^0K^+X$)
2 × (1.920 ± 0.361)	($K_S^0K^-X = K_L^0K^-X$)
(15.810 ± 0.643)	(K^+K^-X)
(0.130 ± 0.130)	(K^+K^+X)
(0.032 ± 0.032)	(K^-K^-X)
(4.965 ± 0.985)	($K_L^0K_S^0X$)
(39.901 ± 1.813)	$D_s^+ \to KKX$

Mode	Measurement	$\mathcal{B}$ (%)
$D_s^+ \to \tau^+\nu$	CLEO-c Measurment	6.470 ± 0.660
$D_s^+ \to \mu^+\nu$	CLEO-c Measurment	0.638 ± 0.067
$D_s^+ \to \eta X$		29.933 ± 2.790
$D_s^+ \to \eta' X$		11.667 ± 1.809
$D_s^+ \to \phi X$		15.714 ± 1.029
$D_s^+ \to \omega X$		6.090 ± 1.437
$D_s^+ \to KKX$	Sum of all kaon-pair Branching Fractions	39.901 ± 1.813
$D_s^+ \to KX$	Sum of all kaon Branching Fractions	85.627 ± 2.263
$D_s^+ \to (S)K^+X$	$K^+ - K^+K^- - 2 \times K_S^0K^+ - 2 \times K^+K^+$	1.152 ± 1.370
$D_s^+ \to (S)K^-X$	$K^- - K^+K^- - 2 \times K_S^0K^- - 2 \times K^-K^-$	-1.035 ± 1.116
$D_s^+ \to (S)K_S^0X$	$K_S^0 - K_S^0K^+ - K_S^0K^- - K_S^0K_L^0 - 2 \times K_S^0K_S^0$	2.854 ± 1.895

Global Fit On Inclusive Branching Fractions

We have performed a global fit to our measurements. For this, we write:

- $\mathcal{B}(s\bar{s}) = \mathcal{B}(\eta) + \mathcal{B}(\eta') + \mathcal{B}(\phi) + \mathcal{B}(K\bar{K})$,
- $\mathcal{B}(s\bar{s}\bar{s}) = \mathcal{B}(\eta\bar{s}) + \mathcal{B}(\eta'\bar{s}) + \mathcal{B}(\phi\bar{s}) + \mathcal{B}(K\bar{K}\bar{s})$,

We searched for $D_s^+ \to \eta\eta X$, $D_s^+ \to \eta\eta' X$ and $D_s^+ \to \eta\phi X$ modes, no clear signals were found. The $\mathcal{B}(\text{Extra } \eta)$ from data is about $(6.0 \pm 3.9)\%$.

Lower bound of $\mathcal{B}(D_s^+ \to \text{Other Annihilation})$
$(18.5 \pm 2.9 \pm 0.50 \pm 0.40 \pm 4.0)\%$

Global Fit Results

$\mathcal{B}(\text{E } \eta)$ (%)	Vary C_1, C_2 (%) (χ^2)				$\mathcal{B}(D_s^+ \to \text{Other Annihilation})$ (%)	
In Data	1.25	1.25	1.00	1.50	C_1	1.25
6.0 ± 3.9	0.50	1.00	0.75	0.75	C_2	0.75
6.00	18.15 (0.002)	18.90 (0.148)	19.02 (0.001)	18.05 (0.164)	$18.53 \pm 2.89 \pm 0.37 \pm 0.49$ (0.047)	

- The first error of the lower bound is statistical error, the second one is from C_1, the third one is from C_2 and the last one is from $\mathcal{B}(\text{Extra } \eta)$

Branching Fraction for the Doubly Cabibbo Suppressed Decay $D^+ \to K^+\pi^0$

- DataSet: 281 pb^{-1} at $\psi(3770)$
- Published in Phys. Rev. D **74**, 071102(R) (2006)

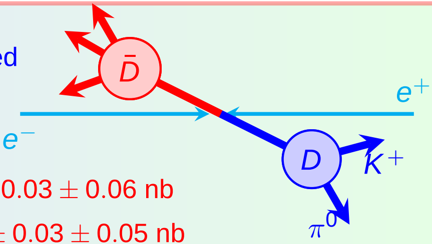
Motivation

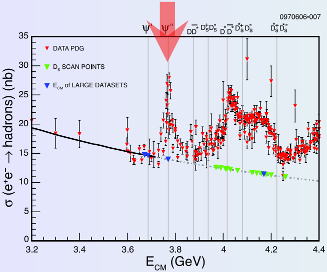
- The Cabibbo-favored hadronic decays of the c quark proceed through
  - $c \to sW_V^+$, $W_V^+ \to u\overline{d}$
  - Here W_V^+ is a virtual W^+ boson.
- The doubly-Cabibbo-suppressed decays proceed through
  - $c \to dW_V^+$, $W_V^+ \to u\overline{s}$
  - These are expected to be suppressed by a factor $|(V_{cd}V_{us})/(V_{cs}V_{ud})|^2 \approx 2.5 \times 10^{-3}$
- Measurements of DCS decays can provide insight into the decay mechanisms for $D \to K\pi$: the validity of SU(3), the roles of the annihilation, exchange, and color-suppressed spectator diagrams relative to the color-favored spectator diagram
  - $D^0 \to K^+\pi^-$ - First observation in 1994 at CLEO.
  - $D^+ \to K^+\pi^0$ - BaBar's result and this analysis.
  - $D^+ \to K^0\pi^+$ and $D^0 \to K^0\pi^0$ - Still Missing

Single Tag Method at $\psi(3770)$

$D\bar{D}$ 281 pb^{-1} @ $\psi(3770)$

- No additional pions produced
- Extremely clean event
- High tagging efficiency
- $\sigma(e^+e^- \to D^0\bar{D}^0) = 3.66 \pm 0.03 \pm 0.06$ nb
- $\sigma(e^+e^- \to D^+D^-) = 2.91 \pm 0.03 \pm 0.05$ nb





D Tag Reconstruction

- The $\psi(3770)$ resonance is below the kinematic threshold for $D\bar{D}\pi$ production, and so the events of interest, $e^+e^- \to \psi(3770) \to D\bar{D}$, have D mesons with energy equal to the beam energy.
- Two key variables in reconstruction of a D:
  - $M_{\mathrm{bc}} \equiv \sqrt{E_{\mathrm{beam}}^2 - |\sum_i \vec{P}_i|^2}$
  - $\Delta E \equiv \sum_i E_i - E_{\mathrm{beam}}$
- where E_i, $\vec{P}_i$ are the energy and momentum of each D decay product. For a correct combination of particles, ΔE will be consistent with zero, and the beam-constrained mass M_{bc} will be consistent with the D mass

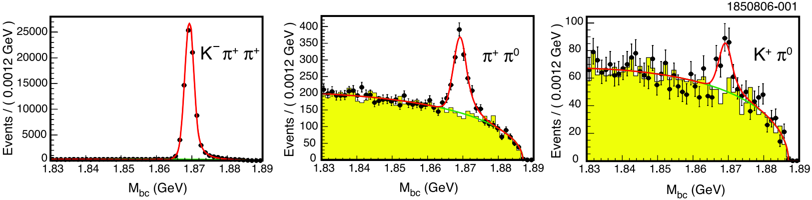
Fit Function

- We perform an unbinned maximum likelihood fit to extract signal yields from the $M_{\rm bc}$ distributions
  - For the signal, use a Crystal Ball line shape, which is a Gaussian with a high-side tail

    - Determined the line shape parameters (Gaussian peak location, Gaussian width, point at which high-side tail begins) from the high-rate decay mode $D^+ \to \pi^+\pi^0$ $M_{\rm bc}$ distribution, and used them in the fit to the $D^+ \to K^+\pi^0$ $M_{\rm bc}$ distribution
  - For the background, use an ARGUS function

    - With shape parameter determined from the ΔE sideband $M_{\rm bc}$ distribution, high-end cutoff given by $E_{\rm beam}$, and normalization determined from the fit to the ΔE signal region
- The branching fraction of $D^+ \to \pi^+\pi^0$ and $D^+ \to K^+\pi^0$:
  $\mathcal{B}(D^+ \to K^+(\pi^+)\pi^0) = \mathcal{B}_{ref} \times \frac{N(D^+\to K^+(\pi^+)\pi^0)}{N_{ref}} \times \frac{\epsilon_{ref}}{\epsilon_{D^+\to K^+(\pi^+)\pi^0}}$
- The Cabibbo-favored decay $D^+ \to K^-\pi^+\pi^+$, as a high-rate, low-background mode used for normalization

Data Yields



Mode	ϵ (%)	Signal yield	$\mathcal{B}$ (%)
$D^+ \to K^-\pi^+\pi^+$	52.16 $\pm$ 0.16	79612 $\pm$ 291	9.51 (Input)
$D^+ \to \pi^+\pi^0$	47.65 $\pm$ 0.15	964 $\pm$ 54	0.1326 $\pm$ 0.0075
$D^+ \to K^+\pi^0$	42.30 $\pm$ 0.14	148 $\pm$ 23	0.0228 $\pm$ 0.0036

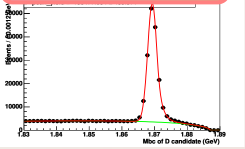
- The branching fraction for $D^+ \to \pi^+\pi^0$ is in good agreement with our previously-published branching fraction using the same data set, $(0.125 \pm 0.006 \pm 0.007 \pm 0.004)\%$
- Those branching fractions are obtained by measuring the respective efficiency-corrected yields relative to that for $D^+ \to K^-\pi^+\pi^+$, taking that branching fraction as $(9.51 \pm 0.34)\%$, which is taken from the PDG 2006

Double Check & Background Study

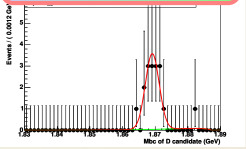
Double Check Using Double Tag Method

- $D^+ \to K^-\pi^+\pi^+$
- $D^+ \to K^-\pi^+\pi^+\pi^0$
- $D^+ \to K_S\pi^+$
- $D^+ \to K_S\pi^+\pi^0$
- $D^+ \to K_S\pi^+\pi^+\pi^-$
- $D^+ \to K^-K^+\pi^+$

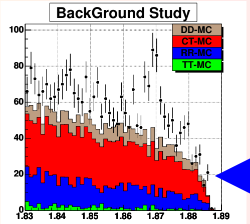
Six D Tag M_{bc} Distribution



$D \to K^+\pi^0$ M_{bc} Distribution



- Use six D tag modes
- Measure 15.6 ± 4.0 $D^+ \to K^+\pi^0$ events
- $\mathcal{B}(D^+ \to K^+\pi^0) = (2.3 \pm 0.6) \times 10^{-4}$, consistent with single tag result.



MC Background Study

- 11% from $D\overline{D}$ events, 8% from radiative return events
- 80% of the background comes from continuum events
- 8% from radiative return events
- 1% from τ-pair events

Systematic Uncertainties

Source		$D^+ \to K^+\pi^0$	$D^+ \to \pi^+\pi^0$
MC Efficiency		0.3%	0.3%
Tracking		0.7%	0.7%
π^0		4.2%	4.2%
Particle ID		1.3%	1.3%
FSR		0.5%	0.5%
Fitting	Argus BG	4.4%	1.3%
	CB-N	0.052%	0.036%
	CB-mean	0.15%	
	CB-σ CB-α	2.6%	
ΔE		0.44%	0.44%
Reference $\mathcal{B}$		3.2%	3.2%
Total		6.82%	4.70%

Published Results

Collaboration	$\mathcal{B}(D^+ \to K^+\pi^0)$
BaBar	$(2.52 \pm 0.47 \pm 0.25 \pm 0.08) \times 10^{-4}$
CLEO-c	$(2.28 \pm 0.36 \pm 0.15 \pm 0.08) \times 10^{-4}$

- First observation of $D^+ \to K^+\pi^0$ is from BaBar

Collaboration	$\mathcal{B}(D^+ \to \pi^+\pi^0)$
BaBar	$(1.25 \pm 0.10 \pm 0.09 \pm 0.04) \times 10^{-3}$
CLEO-c	$(1.25 \pm 0.06 \pm 0.07 \pm 0.04) \times 10^{-3}$

- The CLEO result for $D^+ \to \pi^+\pi^0$ is from the SCSD analysis

Collaboration	$\frac{\Gamma(D^+\to K^+\pi^0)}{\Gamma(D^0\to K^+\pi^-)} = \frac{\mathcal{B}(D^+\to K^+\pi^0)\times\tau_{D^0}}{\mathcal{B}(D^0\to K^+\pi^-)\times\tau_{D^+}}$
BaBar	0.71 ± 0.16
CLEO-c	0.63 ± 0.11

- Phys. Rev. D **74**, 071102(R) (2006)

Flavor Symmetry and Decays of Charmed Particles D^0, D^+, and D_s to Pairs of Light Pseudoscalar Mesons P

- DataSet-1: Full CLEO-c dataset (818 pb^{-1}) at $\psi(3770)$
- DataSet-2: Full CLEO-c dataset (586 pb^{-1}) at $E_{\mathrm{cm}} = 4.170$ GeV
- Working on progress (unofficial result!)

Motivation

- Our final goal of this analysis is measuring all branching fractions that D meson decay to pairs of light pseudoscalar mesons by using full CLEO-c datasets
  $\star$ 818 pb^{-1} at $\psi(3770)$ and 586 pb^{-1} at $E_{cm} = 4.170$ GeV
  - The D meson includes D^0, D^+ and D_s
  - The pseudoscalar meson can be any of π, K, η or η'
- This analysis will cover:
  - All of 8 Cabibbo-favored modes
  - All of 16 singly-Cabibbo-suppressed modes
  - Four doubly-cabibbo-suppressed and forbidden modes
- Use the corresponding reference modes to calculate branching fractions
  - $D^0 \to K^-\pi^+$ for D^0 modes.
  - $D^+ \to K^-\pi^+\pi^+$ for D^+ modes.
  - $D_S^+ \to K^+K_S^0$ for D_s modes.
- The relative ratios ($\mathcal{B}_{\text{mode}}/\mathcal{B}_{\text{ref}}$) will benefit from the cancellation of uncertainties.

Analysis Technique

Absolute Branching Fractions

- $$\mathcal{B}_{\text{mode}} = \mathcal{B}_{\text{ref}} \times \frac{N_{\text{mode}}}{N_{\text{ref}}} \times \frac{\epsilon_{\text{ref}}}{\epsilon_{\text{mode}}}$$

D^0 and D^+ Reconstructions

- $M_{\text{bc}} \equiv \sqrt{E_{\text{beam}}^2 - |\sum_i \vec{P}_i|^2}$
- $\Delta E \equiv \sum_i E_i - E_{\text{beam}}$
- Cut on ΔE, extract D^0 and D^+ yields from M_{bc} distributions.

D_s Reconstruction

- First recoil mass : $M_{\text{recoil}}(D_s)$
- Second recoil mass : $M_{\text{recoil}}(D_s + \gamma)$
- Cut on first and second recoil mass, extract D_s yields from invariant mass distribution.

Fit Function

- The D^0 and D^+ yields are extracted by fitting the M_{bc} distribution to a **Crystal Ball signal function**, to account for the high side tail and an **Argus background function**
- The D_s yields are extracted by fitting the invariant mass distribution to a **sum of two Gaussian signal function** and a **second degree polynomial background function**.

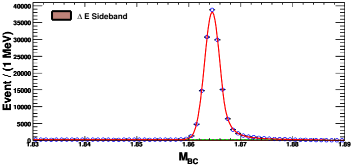
D^0 Mode Data Yields

$D^0 \to K^- \pi^+$

$Br(D^0 \to K^- \pi^+) =$
3.8910 ± 0.0141 %
$Br(D^0 \to K^- \pi^+)/Br(D^0 \to K^-\pi^+) =$
1.0000 ± 0.0036

Reference Mode : $D^0 \to K^-\pi^+$
Ref. Mode MC Eff. : 65.1099 ± 0.1507 %
Ref. Mode Yield : 150258.61 ± 419.74
Ref. Mode Br(Input) : 3.8910 ± 0.0000 %
Signal Mode : $D^0 \to K^- \pi^+$
Signal Mode Mc Eff : 65.1099 ± 0.1507 %
Signal Mode Yield : 150258.61 ± 419.74
Signal Mode Br : 3.8910 ± 0.0141 %

Fit Strategy : 0
CBall Mean : 1.8645051 ± 0.0000043
CBall Sigma : 0.0014769 ± 0.0000036
CBall Alpha : -1.4762040 ± 0.0090404
CBall n : 2.6932922 ± 0.0566800
Argus c : -13.5480663 ± 1.0322770

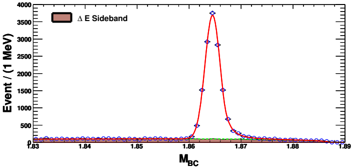


$D^0 \to K^+ K^-$

$Br(D^0 \to K^+ K^-) =$
0.4032 ± 0.0041 %
$Br(D^0 \to K^+ K^-)/Br(D^0 \to K^-\pi^+) =$
0.1036 ± 0.0011

Reference Mode : $D^0 \to K^-\pi^+$
Ref. Mode MC Eff. : 65.1099 ± 0.1507 %
Ref. Mode Yield : 150258.61 ± 419.74
Ref. Mode Br(Input) : 3.8910 ± 0.0000 %
Signal Mode : $D^0 \to K^+ K^-$
Signal Mode Mc Eff : 57.6383 ± 0.1558 %
Signal Mode Yield : 13782.34 ± 135.84
Signal Mode Br : 0.4032 ± 0.0041 %

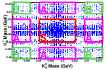
Fit Strategy : 0
CBall Mean : 1.8645127 ± 0.0000143
CBall Sigma : 0.0014537 ± 0.0000122
CBall Alpha : -1.5117120 ± 0.0360163
CBall n : 3.3734699 ± 0.4445596
Argus c : -13.4847540 ± 1.1827674



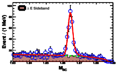
$D^0 \to K^0_S K^0_S$

$Br(D^0 \to K^0_S K^0_S) =$
0.0162 ± 0.0017 %
$Br(D^0 \to K^0_S K^0_S)/Br(D^0 \to K^-\pi^+) =$
0.0042 ± 0.0004

Reference Mode : $D^0 \to K^-\pi^+$
Ref. Mode MC Eff. : 65.1099 ± 0.1507 %
Ref. Mode Yield : 150258.61 ± 419.74
Ref. Mode Br(Input) : 3.8910 ± 0.0000 %
Signal Mode : $D^0 \to K^0_S K^0_S$
Signal Mode Mc Eff : 22.3926 ± 0.1319 %
Signal Mode Yield : 214.83 ± 22.65
Signal Mode Br : 0.0162 ± 0.0017 %

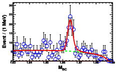


Signal Region



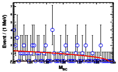
Fit Strategy : 1
CBall Mean : 1.8644920 ± 0.0000000
CBall Sigma : 0.0013856 ± 0.0000000
CBall Alpha : -1.3258279 ± 0.0000000
CBall n : 5.7479000 ± 0.0000000
Argus c : -7.2257195 ± 0.0000000
SG Yield : 283.96 ± 19.43
S.S. (S-A+B) : 214.83 ± 22.65
SB/SG : 24.3453 %

Sideband A Region



Fit Strategy : 2
CBall Mean : 1.8644920 ± 0.0000000
CBall Sigma : 0.0015366 ± 0.0002504
CBall Alpha : -1.3258279 ± 0.0000000
CBall n : 5.7479000 ± 0.0000000
Argus c : -10.5185513 ± 3.9079882
SG Yield : 283.96 ± 19.43
SB A Yield : 69.13 ± 11.62
SB/SG : 24.3453 %

Sideband B Region

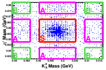


Fit Strategy : Fixed
CBall Mean : 1.8644920 ± 0.0000000
CBall Sigma : 0.0013856 ± 0.0000000
CBall Alpha : -1.3258279 ± 0.0000000
CBall n : 5.7479000 ± 0.0000000
Argus c : -0.0000000 ± 3.0933436
SG Yield : 283.96 ± 19.43
SB B Yield : 0.00 ± 0.75
SB/SG : 0.0000 %

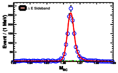
$D^0 \to K^0_S \eta'$

$Br(D^0 \to K^0_S \eta') =$
0.9043 ± 0.0298 %
$Br(D^0 \to K^0_S \eta')/Br(D^0 \to K^-\pi^+) =$
0.2324 ± 0.0077

Reference Mode : $D^0 \to K^-\pi^+$
Ref. Mode MC Eff. : 65.1099 ± 0.1507 %
Ref. Mode Yield : 150258.61 ± 419.74
Ref. Mode Br(Input) : 3.8910 ± 0.0000 %
Signal Mode : $D^0 \to K^0_S \eta'$
Signal Mode Mc Eff : 14.2768 ± 0.1106 %
Signal Mode Yield : 1320.58 ± 42.32
Signal Mode Br : 0.9043 ± 0.0298 %

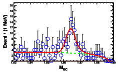


Signal Region



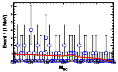
Fit Strategy : 0
CBall Mean : 1.8643880 ± 0.0000666
CBall Sigma : 0.0020082 ± 0.0000601
CBall Alpha : -1.2310181 ± 0.1118788
CBall n : 8.3760993 ± 5.4698020
Argus c : -12.5050595 ± 8.1409787
SG Yield : 1383.92 ± 39.99
S.S. (S-A+B) : 1320.58 ± 42.32
SB/SG : 4.5771 %

Sideband A Region



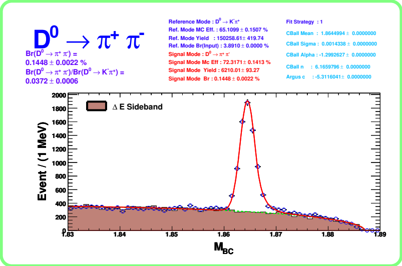
Fit Strategy : 2
CBall Mean : 1.8643880 ± 0.0000000
CBall Sigma : 0.0027868 ± 0.0006634
CBall Alpha : -1.2310181 ± 0.0000000
CBall n : 8.3760993 ± 0.0000000
Argus c : -10.5114531 ± 5.8066492
SG Yield : 1383.92 ± 39.99
SB A Yield : 64.50 ± 13.63
SB/SG : 4.6608 %

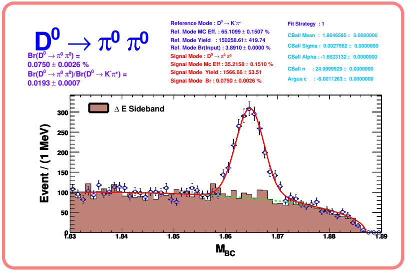
Sideband B Region

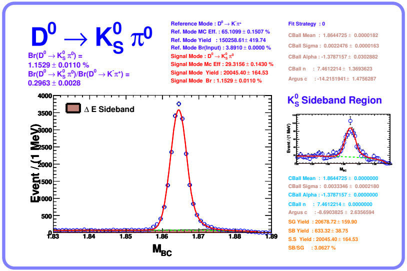


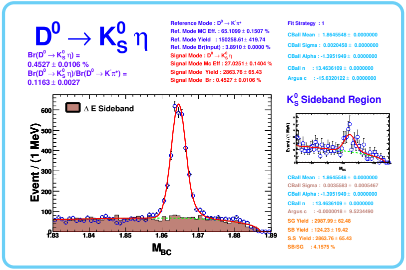
Fit Strategy : Fixed
CBall Mean : 1.8643880 ± 0.0000000
CBall Sigma : 0.0020082 ± 0.0000000
CBall Alpha : -1.2310181 ± 0.0000000
CBall n : 8.3760993 ± 0.0000000
Argus c : -0.0021976 ± 68.5667464
SG Yield : 1383.92 ± 39.99
SB B Yield : 1.16 ± 2.51
SB/SG : 0.0836 %

D^0 Mode Data Yields









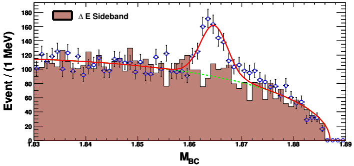
D^0 Mode Data Yields

$D^0 \to \pi^0 \eta$

$Br(D^0 \to \pi^0 \eta)$ =
0.0615 ± 0.0051 %
$Br(D^0 \to \pi^0 \eta)/Br(D^0 \to K^-\pi^+)$ =
0.0158 ± 0.0013

Reference Mode : $D^0 \to K^-\pi^+$
Ref. Mode MC Eff. : 65.1099 ± 0.1507 %
Ref. Mode Yield : 150258.61 ± 419.74
Ref. Mode Br(Input) : 3.8910 ± 0.0000 %
Signal Mode : $D^0 \to \pi^0 \eta$
Signal Mode Mc Eff : 33.4106 ± 0.1492 %
Signal Mode Yield : 480.96 ± 40.15
Signal Mode Br : 0.0615 ± 0.0051 %

Fit Strategy : 1
CBall Mean : 1.8646619 ± 0.0000000
CBall Sigma : 0.0026356 ± 0.0000000
CBall Alpha : -1.7126970 ± 0.0000000
CBall n : 19.1146181 ± 0.0000000
Argus c : -5.6762769 ± 0.0000000

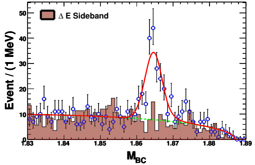


$D^0 \to \pi^0 \eta'$

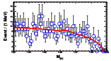
$Br(D^0 \to \pi^0 \eta')$ =
0.0828 ± 0.0099 %
$Br(D^0 \to \pi^0 \eta')/Br(D^0 \to K^-\pi^+)$ =
0.0213 ± 0.0025

Reference Mode : $D^0 \to K^-\pi^+$
Ref. Mode MC Eff. : 65.1099 ± 0.1507 %
Ref. Mode Yield : 150258.61 ± 419.74
Ref. Mode Br(Input) : 3.8910 ± 0.0000 %
Signal Mode : $D^0 \to \pi^0 \eta'$
Signal Mode Mc Eff : 18.7581 ± 0.1235 %
Signal Mode Yield : 158.83 ± 18.93
Signal Mode Br : 0.0828 ± 0.0099 %

Fit Strategy : 1
CBall Mean : 1.8646265 ± 0.0000000
CBall Sigma : 0.0023798 ± 0.0000000
CBall Alpha : -1.5243304 ± 0.0000000
CBall n : 19.3837500 ± 0.0000000
Argus c : -5.7142515 ± 0.0000000



η' Sideband Region



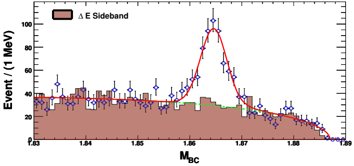
CBall Mean : 1.8646265 ± 0.0000000
CBall Sigma : 0.0023798 ± 0.0000000
CBall Alpha : -1.5243304 ± 0.0000000
CBall n : 19.3837500 ± 0.0000000
Argus c : -6.6265742 ± 3.1912506
SG Yield : 162.28 ± 16.30
SB Yield : 3.44 ± 9.62
S.S Yield : 158.83 ± 18.93
SB/SG : 2.1214 %

$D^0 \to \eta \eta$

$Br(D^0 \to \eta \eta)$ =
0.1467 ± 0.0098 %
$Br(D^0 \to \eta \eta)/Br(D^0 \to K^-\pi^+)$ =
0.0377 ± 0.0025

Reference Mode : $D^0 \to K^-\pi^+$
Ref. Mode MC Eff. : 65.1099 ± 0.1507 %
Ref. Mode Yield : 150258.61 ± 419.74
Ref. Mode Br(Input) : 3.8910 ± 0.0000 %
Signal Mode : $D^0 \to \eta \eta$
Signal Mode Mc Eff : 31.7462 ± 0.1472 %
Signal Mode Yield : 430.37 ± 28.67
Signal Mode Br : 0.1467 ± 0.0098 %

Fit Strategy : 1
CBall Mean : 1.8646104 ± 0.0000000
CBall Sigma : 0.0025475 ± 0.0000000
CBall Alpha : -1.7720349 ± 0.0000000
CBall n : 13.9079352 ± 0.0000000
Argus c : -6.3314150 ± 0.0000000

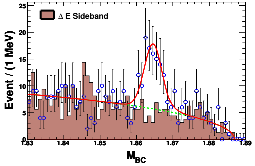


$D^0 \to \eta \eta'$

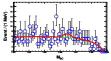
$Br(D^0 \to \eta \eta')$ =
0.0934 ± 0.0213 %
$Br(D^0 \to \eta \eta')/Br(D^0 \to K^-\pi^+)$ =
0.0240 ± 0.0055

Reference Mode : $D^0 \to K^-\pi^+$
Ref. Mode MC Eff. : 65.1099 ± 0.1507 %
Ref. Mode Yield : 150258.61 ± 419.74
Ref. Mode Br(Input) : 3.8910 ± 0.0000 %
Signal Mode : $D^0 \to \eta \eta'$
Signal Mode Mc Eff : 17.5163 ± 0.1202 %
Signal Mode Yield : 66.04 ± 15.07
Signal Mode Br : 0.0934 ± 0.0213 %

Fit Strategy : 1
CBall Mean : 1.8645603 ± 0.0000000
CBall Sigma : 0.0024234 ± 0.0000000
CBall Alpha : -1.5202078 ± 0.0000000
CBall n : 25.9808942 ± 0.0000000
Argus c : -1.4099401 ± 0.0000000

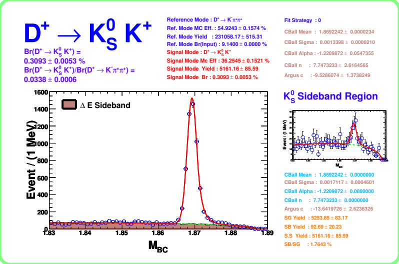


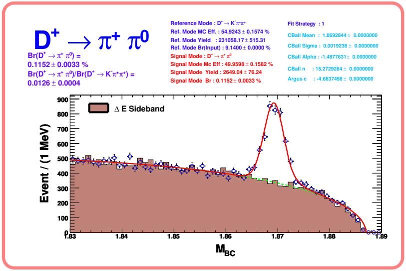
η' Sideband Region

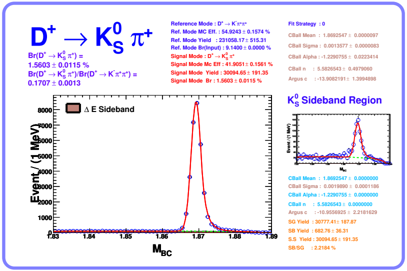


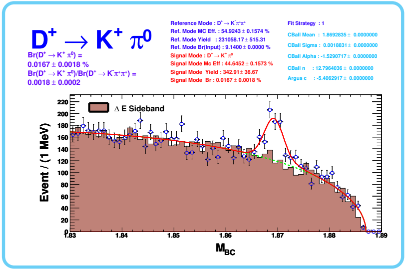
CBall Mean : 1.8645603 ± 0.0000000
CBall Sigma : 0.0024234 ± 0.0000000
CBall Alpha : -1.5202078 ± 0.0000000
CBall n : 25.9808942 ± 0.0000000
Argus c : $-11.2037535 \pm 3.8156007$
SG Yield : 75.11 ± 12.13
SB Yield : 9.07 ± 8.93
S.S Yield : 66.04 ± 15.07
SB/SG : 12.0753 %

D^+ Mode Data Yields

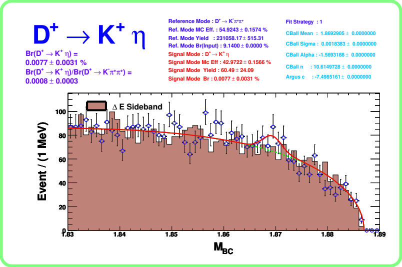


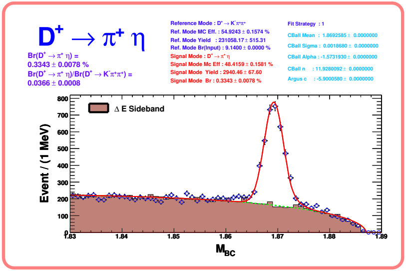


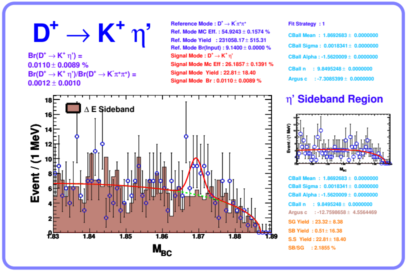


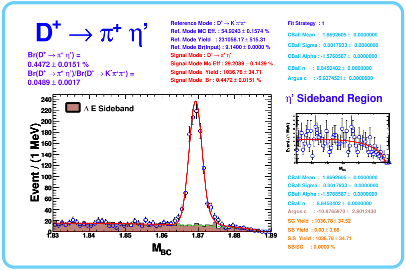


D^+ Mode Data Yields

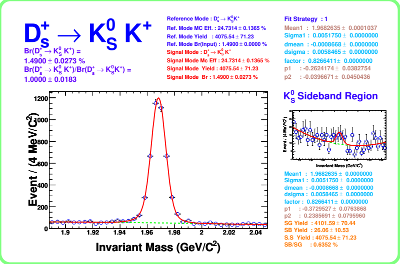


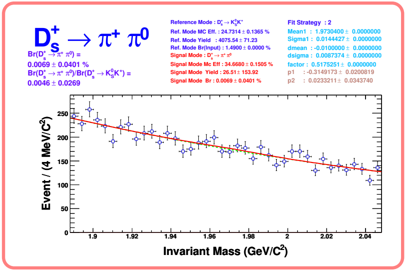


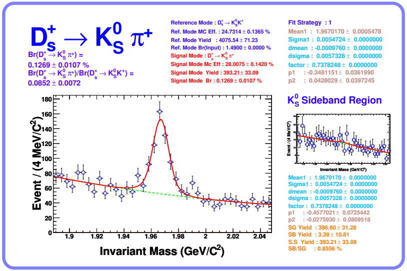


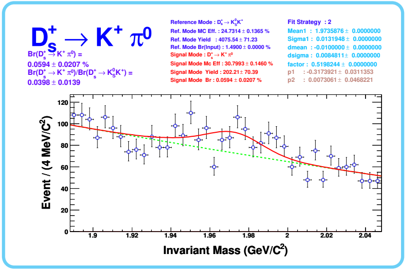


D_s Mode Data Yields

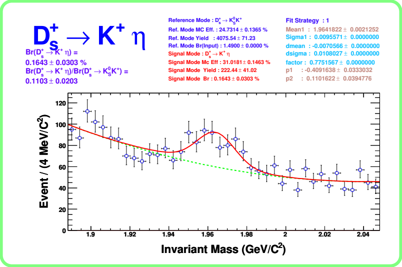


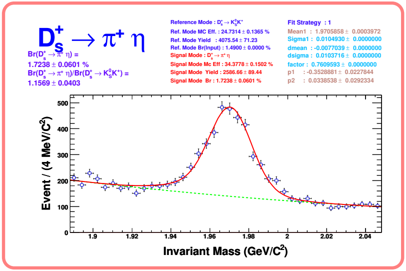


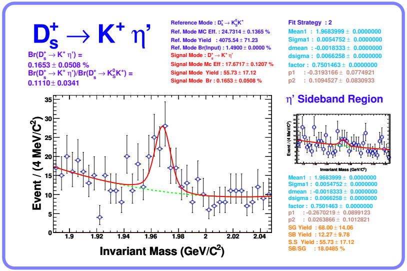


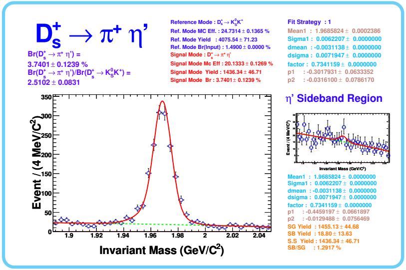


D_s Mode Data Yields









Systematic Uncertainties-General

Sources of Systematic Uncertainty

1. Tracking systematics
2. Additional Kaon track
3. π PID
4. K PID
5. π^0, K_S^0, η recon.
6. ΔE requirements
7. Background shape
8. Crystal Ball σ
9. Crystal Ball α
10. Crystal Ball n
11. ISR
12. FSR
13. Reference mode $\mathcal{B}$
14. Reference mode yield

Uncertainties and Correction Factors

Source	Uncer. (%)	C. F. (%)
Tracking finding	0.3	—
$K^{\pm}$ track	0.6	—
K_S^0 finding	1.9	—
π^0 finding	1.0	-6.0
η finding	4.0	-6.5
$\pi^{\pm}$ PID	0.3	-0.5
$K^{\pm}$ PID	0.3	-1.0

D^0 and D^+ Mode Systematics Uncertainties

D^0 Mode Main Systematic Uncertainties Summary

Mode	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Sum
$D^0 \to K^+K^-$	0.00	0.60	0.30	0.30	0.00	0.05	0.00	0.00	0.00	0.00	0.50	0.50	1.98	0.36	2.26
$D^0 \to K_S^0 K_S^0$	0.60	0.60	0.30	0.30	3.80	0.06	0.79	3.04	1.20	0.10	0.50	0.50	1.98	0.36	5.58
$D^0 \to \pi^+\pi^-$	0.00	0.60	0.30	0.30	0.00	0.07	0.25	1.44	1.30	0.91	0.50	0.50	1.98	0.36	3.12
$D^0 \to \pi^0\pi^0$	0.60	0.60	0.30	0.30	2.00	1.38	0.77	0.55	2.03	0.09	0.50	0.50	1.98	0.36	4.05
$D^0 \to K^-\pi^+$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	1.98	0.36	2.13
$D^0 \to K_S^0\pi^0$	0.00	0.60	0.30	0.30	2.15	0.04	0.00	0.00	0.00	0.00	0.50	0.50	1.98	0.36	3.11
$D^0 \to K_S^0\eta$	0.00	0.60	0.30	0.30	4.43	0.03	0.34	0.97	2.62	0.98	0.50	0.50	1.98	0.36	5.80
$D^0 \to \pi^0\eta$	0.60	0.60	0.30	0.30	4.12	0.38	2.10	1.55	3.04	0.50	0.50	0.50	1.98	0.36	6.23
$D^0 \to K_S^0\eta'$	0.60	0.60	0.30	0.30	4.43	0.48	0.00	0.00	0.00	0.00	0.50	0.50	1.98	0.36	5.03
$D^0 \to \pi^0\eta'$	0.00	0.60	0.30	0.30	4.12	0.74	1.81	2.32	3.43	0.79	0.50	0.50	1.98	0.36	6.61
$D^0 \to \eta\eta$	0.60	0.60	0.30	0.30	8.00	0.17	1.23	1.00	0.76	0.12	0.50	0.50	1.98	0.36	8.52
$D^0 \to \eta\eta'$	0.00	0.60	0.30	0.30	8.00	0.59	3.50	0.10	2.43	0.33	0.50	0.50	1.98	0.36	9.36

D^+ Mode Main Systematic Uncertainties Summary

Mode	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Sum
$D^+ \to K^-\pi^+\pi^+$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	2.16	0.36	2.30
$D^+ \to K_S^0 K^+$	0.00	0.00	0.60	0.00	1.90	0.11	0.00	0.00	0.00	0.00	0.50	0.50	2.16	0.36	3.04
$D^+ \to \pi^+\pi^0$	0.60	0.60	0.30	0.30	1.00	1.17	0.72	1.83	1.73	0.70	0.50	0.50	2.16	0.36	3.99
$D^+ \to K_S^0\pi^+$	0.00	0.60	0.30	0.30	1.90	0.06	0.00	0.00	0.00	0.00	0.50	0.50	2.16	0.36	3.07
$D^+ \to K^+\pi^0$	0.60	0.00	0.60	0.00	1.00	0.94	0.72	1.83	1.73	0.70	0.50	0.50	2.16	0.36	3.90
$D^+ \to K^+\eta$	0.60	0.00	0.60	0.00	4.00	1.00	0.41	2.01	1.66	0.46	0.50	0.50	2.16	0.36	5.49
$D^+ \to \pi^+\eta$	0.60	0.60	0.30	0.30	4.00	0.09	0.41	2.01	1.66	0.46	0.50	0.50	2.16	0.36	5.42
$D^+ \to K^+\eta'$	0.00	0.00	0.00	0.00	4.00	0.89	0.41	1.58	1.39	0.91	0.50	0.50	2.16	0.36	5.24
$D^+ \to \pi^+\eta'$	0.00	0.60	0.30	0.30	4.00	1.30	0.41	1.58	1.39	0.91	0.50	0.50	2.16	0.36	5.38

D_s Mode Systematics Uncertainties

D_s Mode Main Systematic Uncertainties Summary

Mode	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Sum
$D_s^+ \to K_S^0 K^+$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.50	0.50	5.77	1.83	6.15
$D_s^+ \to \pi^+\pi^0$	0.60	0.60	0.30	0.30	2.15	0.00	0.00	2.44	0.00	0.00	0.50	0.50	5.77	1.83	6.97
$D_s^+ \to K_S^0\pi^+$	0.00	0.60	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	5.77	1.83	6.14
$D_s^+ \to K^+\pi^0$	0.60	0.00	0.00	0.00	2.15	0.00	0.00	4.55	0.00	0.00	0.50	0.50	5.77	1.83	7.93
$D_s^+ \to K^+\eta$	0.60	0.00	0.00	0.00	4.43	0.00	0.00	1.05	0.00	0.00	0.50	0.50	5.77	1.83	7.63
$D_s^+ \to \pi^+\eta$	0.60	0.60	0.30	0.30	4.43	0.00	0.00	1.05	0.00	0.00	0.50	0.50	5.77	1.83	7.67
$D_s^+ \to K^+\eta'$	0.00	0.00	0.60	0.00	4.43	0.00	0.00	1.60	0.00	0.00	0.50	0.50	5.77	1.83	7.73
$D_s^+ \to \pi^+\eta'$	0.00	0.60	0.90	0.30	4.43	0.00	0.00	1.60	0.00	0.00	0.50	0.50	5.77	1.83	7.79
$\frac{D_s^+\to\pi^+\pi^0}{D_s^+\to K_S^0K^+}$	0.60	0.60	0.30	0.30	2.15	0.00	0.00	2.44	0.00	0.00	0.50	0.50	0.00	1.83	3.92
$\frac{D_s^+\to K^+\pi^0}{D_s^+\to K_S^0K^+}$	0.60	0.00	0.00	0.00	2.15	0.00	0.00	4.55	0.00	0.00	0.50	0.50	0.00	1.83	5.44
$\frac{D_s^+\to K_S^0\pi^+}{D_s^+\to K_S^0K^+}$	0.00	0.60	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	1.83	2.10
$\frac{D_s^+\to K^+\eta}{D_s^+\to\pi^+\eta}$	0.00	0.60	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	3.49	3.63
$\frac{D_s^+\to K^+\eta'}{D_s^+\to\pi^+\eta'}$	0.00	0.60	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	3.31	3.47

D^0 and D^+ Mode Results-Internal Results

D^0 Mode Branching Fractions Summary

Mode	C.F.	$\mathcal{B}_{\text{mode}}/\mathcal{B}_{\text{ref}}$ (%)	$\mathcal{B}_{\text{mode}}$ (%)	$\mathcal{B}(281\text{pb}^{-1})$(%)
$D^0 \to K^+K^-$	0.9950	10.4138 ± 0.1064 ± 0.1063	0.4052 ± 0.0041 ± 0.0041 ± 0.0082	0.4080 ± 0.0080 ± 0.0090
$D^0 \to K_S^0 K_S^0$	1.0152	0.4095 ± 0.0432 ± 0.0213	0.0159 ± 0.0017 ± 0.0008 ± 0.0003	0.0146 ± 0.0032 ± 0.0009
$D^0 \to \pi^+\pi^-$	1.0051	3.7023 ± 0.0561 ± 0.0883	0.1441 ± 0.0022 ± 0.0034 ± 0.0029	0.1390 ± 0.0040 ± 0.0050
$D^0 \to \pi^0\pi^0$	0.8970	2.1491 ± 0.0740 ± 0.0754	0.0836 ± 0.0029 ± 0.0029 ± 0.0017	0.0790 ± 0.0050 ± 0.0060
$D^0 \to K^-\pi^+$	—	—	—	3.8910 ± 0.0350 ± 0.0690
$D^0 \to K_S^0\pi^0$	0.9543	31.0495 ± 0.2964 ± 0.7382	1.2081 ± 0.0115 ± 0.0287 ± 0.0243	1.2400 ± 0.0170 ± 0.0560
$D^0 \to K_S^0\eta$	0.9492	12.2575 ± 0.2872 ± 0.6662	0.4769 ± 0.0112 ± 0.0259 ± 0.0096	0.4420 ± 0.0150 ± 0.0280
$D^0 \to \pi^0\eta$	0.8922	1.7714 ± 0.1481 ± 0.1045	0.0689 ± 0.0058 ± 0.0041 ± 0.0014	0.0620 ± 0.0140 ± 0.0050
$D^0 \to K_S^0\eta'$	0.9397	24.7307 ± 0.8154 ± 1.1398	0.9623 ± 0.0317 ± 0.0443 ± 0.0194	—
$D^0 \to \pi^0\eta'$	0.8833	2.4084 ± 0.2874 ± 0.1517	0.0937 ± 0.0112 ± 0.0059 ± 0.0019	0.0810 ± 0.0150 ± 0.0060
$D^0 \to \eta\eta$	0.8875	4.2495 ± 0.2838 ± 0.3518	0.1653 ± 0.0110 ± 0.0137 ± 0.0033	0.1670 ± 0.0140 ± 0.0130
$D^0 \to \eta\eta'$	0.8786	2.7318 ± 0.6235 ± 0.2498	0.1063 ± 0.0243 ± 0.0097 ± 0.0021	0.1260 ± 0.0250 ± 0.0110

D^+ Mode Branching Fractions Summary

Mode	C.F.	$\mathcal{B}_{\text{mode}}/\mathcal{B}_{\text{ref}}$ (%)	$\mathcal{B}_{\text{mode}}$ (%)	$\mathcal{B}(281\text{pb}^{-1})$(%)
$D^+ \to K^-\pi^+\pi^+$	—	—	—	9.1400 ± 0.1000 ± 0.1700
$D^+ \to K_S^0 K^+$	1.0101	3.3502 ± 0.0573 ± 0.0709	0.3062 ± 0.0052 ± 0.0065 ± 0.0067	0.3140 ± 0.0090 ± 0.0080
$D^+ \to \pi^+\pi^0$	0.9543	1.3208 ± 0.0382 ± 0.0441	0.1207 ± 0.0035 ± 0.0040 ± 0.0026	0.1250 ± 0.0060 ± 0.0080
$D^+ \to K_S^0\pi^+$	1.0152	16.8160 ± 0.1239 ± 0.3628	1.5370 ± 0.0113 ± 0.0332 ± 0.0336	1.5260 ± 0.0220 ± 0.0380
$D^+ \to K^+\pi^0$	0.9495	0.1923 ± 0.0206 ± 0.0062	0.0176 ± 0.0019 ± 0.0006 ± 0.0004	0.0228 ± 0.0036 ± 0.0017
$D^+ \to K^+\eta$	0.9444	0.0898 ± 0.0357 ± 0.0045	0.0082 ± 0.0033 ± 0.0004 ± 0.0002	—
$D^+ \to \pi^+\eta$	0.9492	3.8538 ± 0.0895 ± 0.1911	0.3522 ± 0.0082 ± 0.0175 ± 0.0077	0.3610 ± 0.0250 ± 0.0260
$D^+ \to K^+\eta'$	0.9350	0.1284 ± 0.1036 ± 0.0061	0.0117 ± 0.0095 ± 0.0006 ± 0.0003	—
$D^+ \to \pi^+\eta'$	0.9397	5.2061 ± 0.1762 ± 0.2558	0.4758 ± 0.0161 ± 0.0234 ± 0.0104	0.4420 ± 0.0250 ± 0.0290

D_s Mode Results-Internal Results

D_s Mode Branching Fractions Summary

Mode	C.F.	$\mathcal{B}_{\text{mode}}/\mathcal{B}_{\text{ref}}$ (%)	$\mathcal{B}_{\text{mode}}$ (%)	$\mathcal{B}(298\text{pb}^{-1})$(%)
$D_S^+ \to K_S^0K^+$	—	—	—	1.4900 ± 0.0700 ± 0.0500
$D_S^+ \to \pi^+\pi^0$	0.9447	0.4911 ± 2.8518 ± 0.0192	0.0073 ± 0.0425 ± 0.0003 ± 0.0004	RefBr
$D_S^+ \to K_S^0\pi^+$	1.0051	8.4766 ± 0.7147 ± 0.1778	0.1263 ± 0.0106 ± 0.0026 ± 0.0073	RefBr
$D_S^+ \to K^+\pi^0$	0.9400	4.2383 ± 1.4756 ± 0.2304	0.0632 ± 0.0220 ± 0.0034 ± 0.0036	RefBr
$D_S^+ \to K^+\eta$	0.9350	11.7933 ± 2.1753 ± 0.5888	0.1757 ± 0.0324 ± 0.0088 ± 0.0101	RefBr
$D_S^+ \to \pi^+\eta$	0.9397	123.1123 ± 4.2907 ± 6.2133	1.8344 ± 0.0639 ± 0.0926 ± 0.1059	1.5800 ± 0.1100 ± 0.1800
$D_S^+ \to K^+\eta'$	0.9257	11.9866 ± 3.6840 ± 0.6158	0.1786 ± 0.0549 ± 0.0092 ± 0.0103	RefBr
$D_S^+ \to \pi^+\eta'$	0.9303	269.8080 ± 8.9375 ± 14.0957	4.0201 ± 0.1332 ± 0.2100 ± 0.2320	3.7700 ± 0.2500 ± 0.3000
$\frac{D_S^+\to\pi^+\pi^0}{D_S^+\to K_S^0K^+}$	0.9447	0.4911 ± 2.8518 ± 0.0192	—	< 4.1000 (90% C.L.)
$\frac{D_S^+\to K^+\pi^0}{D_S^+\to K_S^0K^+}$	0.9400	4.2383 ± 1.4756 ± 0.2304	—	5.5000 ± 1.3000 ± 0.7000
$\frac{D_S^+\to K_S^0\pi^+}{D_S^+\to K_S^0K^+}$	1.0051	8.4766 ± 0.7147 ± 0.1778	—	8.2000 ± 0.9000 ± 0.2000
$\frac{D_S^+\to K^+\eta}{D_S^+\to\pi^+\eta}$	0.9950	9.5793 ± 1.7669 ± 0.3479	—	8.9000 ± 1.5000 ± 0.4000
$\frac{D_S^+\to K^+\eta'}{D_S^+\to\pi^+\eta'}$	0.9950	4.4426 ± 1.3654 ± 0.1540	—	4.2000 ± 1.3000 ± 0.3000

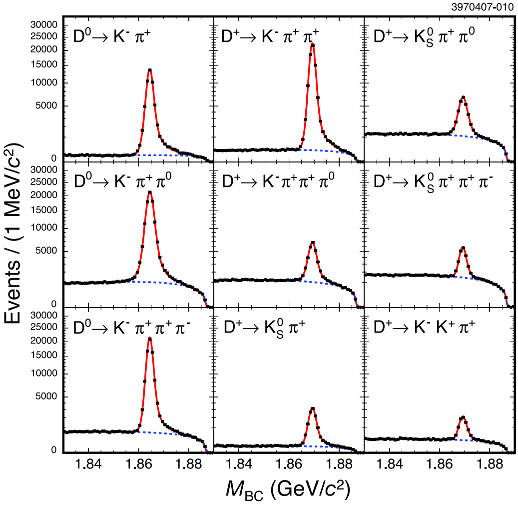
Absolute Branching Fractions for Key Hadronic Modes of D^0, D^+ and D_s Mesons

- DataSet: 281 pb^{-1} at $\psi(3770)$. Phys. Rev. D **76**, 112001 (2007)
- DataSet: 298 pb^{-1} at $E_{\mathrm{cm}} = 4.170$ GeV. Phys. Rev. Lett. **100**, 161804 (2008)
- Served in paper committee

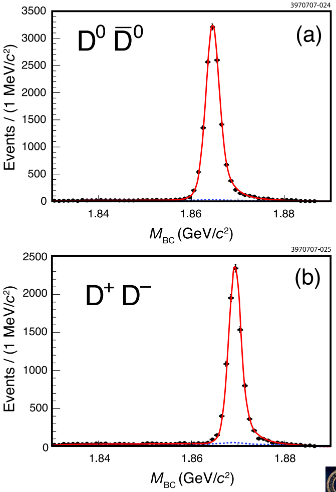
Double Tag Technique

- Use a "double tag" technique pioneered by the MARK III
  - $y_i = \epsilon_i \mathcal{B}_i N_{D\bar{D}}$ is single tag yields for $D \to i$ and $\bar{D} \to X$
  - $y_{\bar{j}} = \epsilon_{\bar{j}} \mathcal{B}_j N_{D\bar{D}}$ is single tag yields for $D \to X$ and $\bar{D} \to \bar{j}$
  - $y_{i\bar{j}} = \epsilon_{i\bar{j}} \mathcal{B}_i \mathcal{B}_j N_{D\bar{D}}$ is double tag yields for $D \to i$ and $\bar{D} \to \bar{j}$
  - $\mathcal{B}_i = \frac{y_{i\bar{j}}}{y_{\bar{j}}} \frac{\epsilon_{\bar{j}}}{\epsilon_{i\bar{j}}}$, $N_{D\bar{D}} = \frac{y_i y_{\bar{j}}}{y_{i\bar{j}}} \frac{\epsilon_{i\bar{j}}}{\epsilon_i \epsilon_{\bar{j}}}$, $\epsilon_{i\bar{j}} \approx \epsilon_i \epsilon_{\bar{j}}$
- Branching fractions independent of luminosity or $N_{D\bar{D}}$
- Measure 3 neutral and 6 charged D decay modes
  - D^0 : $K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^-\pi^+$
  - D^+ : $K^-\pi^+\pi^+$, $K^-\pi^+\pi^+\pi^0$, $K_S^0\pi^+$, $K_S^0\pi^+\pi^0$, $K_S^0\pi^+\pi^+\pi^-$, $K^+K^-\pi^+$
- Obtain ST and DT yields from fits to beam constrained mass distributions ($M_{\rm bc} \equiv \sqrt{E_{\rm beam}^2 - P_D^2}$)
- Do a combined χ^2 fit including all yields and errors to extract 9 branching fractions and $N_{D\bar{D}}$

D^0 and D^+ Data Yields



Single Tag



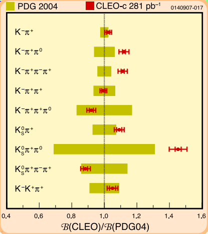
Double Tag

Absolute D^0 and D^+ Hadronic Branching Fractions

Parameter	Fitted Value	Fractional Error Stat.(%)	Fractional Error Syst.(%)	Δ_{FSR} (%)
$N_{D^0\bar{D}^0}$	$(1.031 \pm 0.008 \pm 0.013) \times 10^6$	0.8	1.3	+0.1
$\mathcal{B}(D^0 \to K^-\pi^+)$	$(3.891 \pm 0.035 \pm 0.059 \pm 0.035)\%$	0.9	1.8	−3.0
$\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$	$(14.57 \pm 0.12 \pm 0.38 \pm 0.05)\%$	0.8	2.7	−1.1
$\mathcal{B}(D^0 \to K^-\pi^+\pi^-\pi^+)$	$(8.30 \pm 0.07 \pm 0.19 \pm 0.07)\%$	0.9	2.4	−2.4
$N_{D^+D^-}$	$(0.819 \pm 0.008 \pm 0.010) \times 10^6$	1.0	1.2	+0.1
$\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$	$(9.14 \pm 0.10 \pm 0.16 \pm 0.07)\%$	1.1	1.9	−2.3
$\mathcal{B}(D^+ \to K^-\pi^+\pi^+\pi^0)$	$(5.98 \pm 0.08 \pm 0.16 \pm 0.02)\%$	1.3	2.8	−1.0
$\mathcal{B}(D^+ \to K_S^0\pi^+)$	$(1.526 \pm 0.022 \pm 0.037 \pm 0.009)\%$	1.4	2.5	−1.8
$\mathcal{B}(D^+ \to K_S^0\pi^+\pi^0)$	$(6.99 \pm 0.09 \pm 0.25 \pm 0.01)\%$	1.3	3.5	−0.4
$\mathcal{B}(D^+ \to K_S^0\pi^+\pi^+\pi^-)$	$(3.122 \pm 0.046 \pm 0.094 \pm 0.019)\%$	1.5	3.0	−1.9
$\mathcal{B}(D^+ \to K^+K^-\pi^+)$	$(0.935 \pm 0.017 \pm 0.024 \pm 0.003)\%$	1.8	2.6	−1.2

Fitted Branching Fractions and $D\bar{D}$ Pair Yields

Compair to PDG04

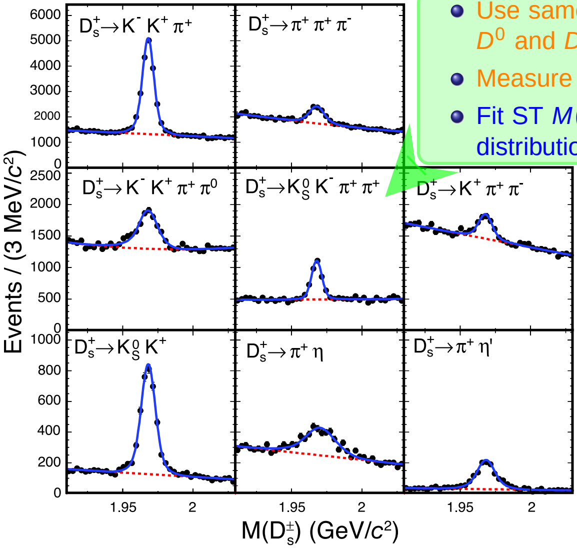


$\sigma(D^0\bar{D}^0) = 3.66 \pm 0.03 \pm 0.06$ nb
$\sigma(D^+D^-) = 2.91 \pm 0.03 \pm 0.05$ nb

Phys. Rev. D **76**, 112001 (2007)

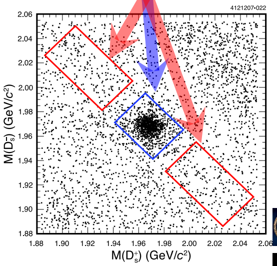
- Systematic errors dominate!
- Statistical errors is $\sim 1\%$ – mostly limited by DT yields
- Δ_{FSR}, is the relative shift in the fit results when FSR is not included in the Monte Carlo simulations used to determine efficiencies.

D_s Data Yields



- Use same technique as for the D^0 and D^+ branching fractions
- Measure ST and DT events
- Fit ST $M(D_s)$ invariant mass distribution

- Cut DT in $M(D_s^+)$ vs $M(D_s^-)$ plane
  - Blue box signal
  - Red boxes sidebands



Absolute D_s Hadronic Branching Fractions

Mode	This Result $\mathcal{B}$ (%)	PDG 2007 fit $\mathcal{B}$ (%)	$\mathcal{B}/\mathcal{B}(K^-K^+\pi^+)$	$\mathcal{A}_{CP}$ (%)
$K_S^0K^+$	$1.49 \pm 0.07 \pm 0.05$	2.2 ± 0.4	$0.270 \pm 0.009 \pm 0.008$	$+4.9 \pm 2.1 \pm 0.9$
$K^-K^+\pi^+$	$5.50 \pm 0.23 \pm 0.16$	5.3 ± 0.8	1	$+0.3 \pm 1.1 \pm 0.8$
$K^-K^+\pi^+\pi^0$	$5.65 \pm 0.29 \pm 0.40$	—	$1.03 \pm 0.05 \pm 0.08$	$-5.9 \pm 4.2 \pm 1.2$
$K_S^0K^-\pi^+\pi^+$	$1.64 \pm 0.10 \pm 0.07$	2.7 ± 0.7	$0.298 \pm 0.014 \pm 0.011$	$-0.7 \pm 3.6 \pm 1.1$
$\pi^+\pi^+\pi^-$	$1.11 \pm 0.07 \pm 0.04$	1.24 ± 0.20	$0.202 \pm 0.011 \pm 0.009$	$+2.0 \pm 4.6 \pm 0.7$
$\pi^+\eta$	$1.58 \pm 0.11 \pm 0.18$	2.16 ± 0.30	$0.288 \pm 0.018 \pm 0.033$	$-8.2 \pm 5.2 \pm 0.8$
$\pi^+\eta'$	$3.77 \pm 0.25 \pm 0.30$	4.8 ± 0.6	$0.69 \pm 0.04 \pm 0.06$	$-5.5 \pm 3.7 \pm 1.2$
$K^+\pi^+\pi^-$	$0.69 \pm 0.05 \pm 0.03$	0.67 ± 0.13	$0.125 \pm 0.009 \pm 0.005$	$+11.2 \pm 7.0 \pm 0.9$

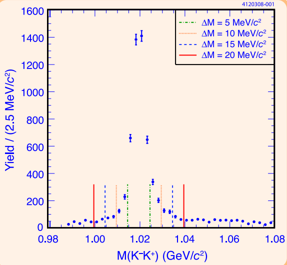
Branching Fraction Results

$$\mathcal{A}_{CP,i} = \frac{y_i/\epsilon_i - y_{\bar{i}}/\epsilon_{\bar{i}}}{y_i/\epsilon_i + y_{\bar{i}}/\epsilon_{\bar{i}}}$$

Phys. Rev. Lett. **100**, 161804 (2008)

Value	This Result $\mathcal{B}$ (%)
$\mathcal{B}_5$	$1.69 \pm 0.08 \pm 0.06$
$\mathcal{B}_{10}$	$1.99 \pm 0.10 \pm 0.05$
$\mathcal{B}_{15}$	$2.14 \pm 0.10 \pm 0.05$
$\mathcal{B}_{20}$	$2.24 \pm 0.11 \pm 0.06$

$\mathcal{B}_{\Delta M} \equiv \mathcal{B}(D_s^+ \to K^-K^+\pi^+)$ with $|M(K^+K^-) - M_\phi| < \Delta M$ MeV/c^2



- For the key mode $D_s^+ \to K^-K^+\pi^+$, the statistical and systematic uncertainties are comparable.
- $\mathcal{B}(D_s^+ \to \phi\pi^+)$ is not well defined and CLEO-c are not quoting it.
- Instead provide partial branching fractions for windows centered on the ϕ mass which do not assume a specific resonant composition of the decay.

Summary of Research Work at CLEO-c

Using the CLEO-c data ($D\bar{D}$ and $D_s^{\pm} D_s^{*\mp}$), we studied the hadronic decays of D^0, D^+ and D_s mesons. Precision measurements of these decays allow us to better constrain parameters of the standard model

Published Analysis Topics

- First Observations of Suppressed Decays of D_s^+ Mesons to Two Pseudoscalar Mesons - Phys. Rev. Lett. **99**, 191805 (2007)
- Branching Fraction for the Doubly Cabibbo Suppressed Decay $D^+ \to K^+\pi^0$ - Phys. Rev. D **74**, 071102(R) (2006)
- Absolute Measurement of Hadronic Branching Fractions of the D_s^+ Meson - Phys. Rev. Lett. **100**, 161804 (2008) (Worked in Paper Committee)

Current Analysis Topics - Thesis

- Inclusive Branching Fractions for D_s^+ Decays -Preliminary results are available, main analysis work has been finished. Working on the paper draft. (To be published soon)
- Flavor Symmetry and Decays of Charmed Particles D^0, D^+, and D_s to Pairs of Light Pseudoscalar Mesons P -Measurements of branching fractions have been finished. Working on theoretical interpretation and paper draft. (Will be published before my graduation)

Backup Slides

Inclusive Branching Fractions for D_s^+ Decays

- DataSet: 586 pb^{-1} at $E_{\mathrm{cm}} = 4.170$ GeV
- CLEO Preliminary

Charged Kaon and Pion Efficiencies

$K^\pm$ and $\pi^\pm$ PID Efficiencies

- The momentum-dependent PID efficiency is defined as:

$$\epsilon_i^{K^\pm/\pi^\pm} = \frac{\sum_j N_{i,j\ \text{Identify as}\ K^\pm/\pi^\pm}^{\text{MC Truth}}}{\sum_j N_{i,j\ \text{Detected}\ K^\pm/\pi^\pm}^{\text{MC Truth}}}$$

Tracking Efficiency

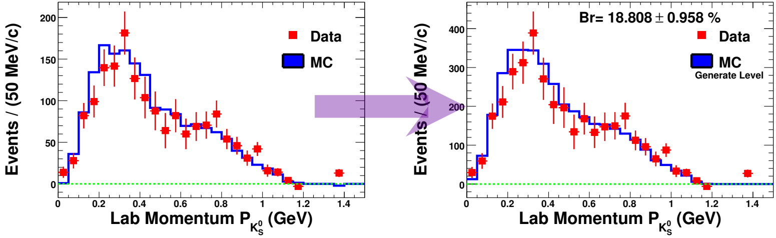
We include several items (listed as follow) into a total overall average efficiency called as tracking efficiency.

- track finding
- quality
- radiation feed-down (due to material bremsstrahlung)
- resolution effects
- geometrical acceptance ($|\cos\theta| < 0.80$) correction

$D_S^+ \to K_S^0 X$

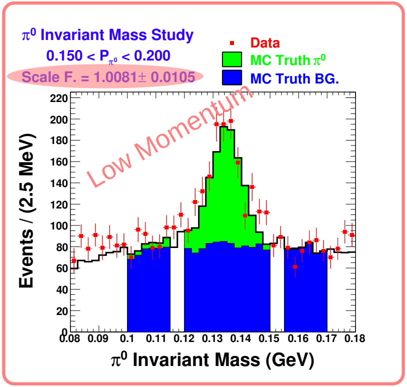
- The K_S^0 yield is extracted by defining a signal region and sideband regions in the invariant mass distribution of the pion pair.
- Apply the momentum-dependent efficiency correction to obtain the final K_S^0 momentum spectrum.

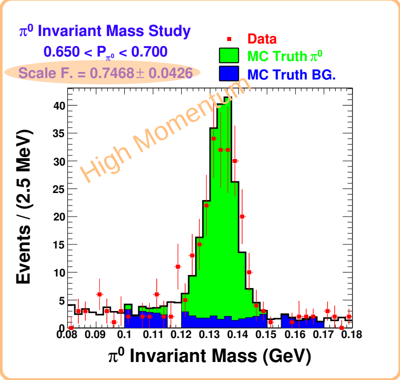
Before ⇒ Efficiency Correction (bin by bin) ⇒ After



π^0 Invariant Mass Study

- Apply sideband subtraction on π^0 invariant mass distribution to extract π^0 yield
- The background shapes of π^0 are different in each momentum bin (50 MeV/c).
- Utilize generic Monte Carlo samples to get the sideband scaling factor momentum bin by bin, and apply this scaling factor to data.

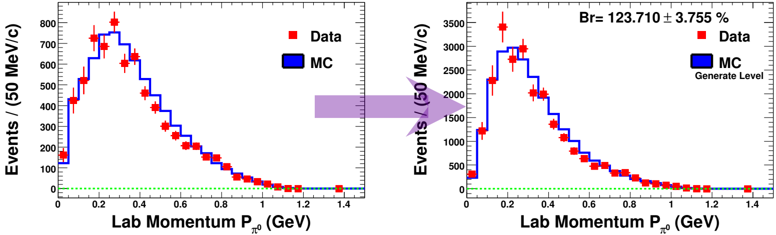




$D_s^+ \to \pi^0 X$

- We treat π^0 from K_S^0 decay as a background for the decay $D_s^+ \to \pi^0 X$ and subtract it based on K_S^0 yield.
- Apply the momentum-dependent efficiency correction to obtain the final π^0 momentum spectrum.

Before ⇒ Efficiency Correction (bin by bin) ⇒ After



η Yields

Separate the η sample into two momentum intervals

- The η efficiency is constant above 300 MeV/c and increase slowly below.
- To measure the inclusive branching fractions, we define two η momentum bins.
  - The low momentum bin is below 300 MeV/c
  - The other one is above 300 MeV/c.

Fit Function

The η yields are extracted by fitting the two-photon invariant mass distribution to a **Crystal Ball signal function**, to account for the low mass tail and a **second degree polynomial background function**.

The η yields from D_s tag signal region

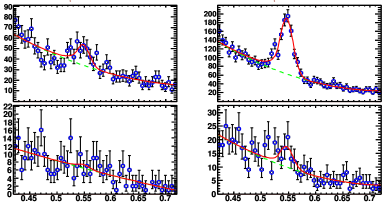
- The two tail part parameters of **Crystal Ball signal function** are fixed to the values obtained by Monte Carlo simulation,
- The mean and the width are allowed to float.

The η yields from D_s tag sideband region

- All of the signal shape parameters are fixed to the corresponding values from D_s tag signal region.

$D_s^+ \to \eta X$

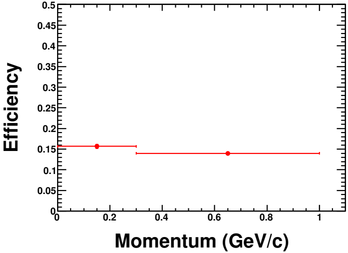
$P_\eta < 0.3$ $P_\eta > 0.3$

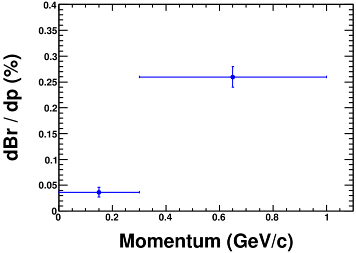


P (GeV/c)	$P_\eta < 0.3$	$P_\eta > 0.3$	Total
N_{sig}	111.9 ± 25.0	718.9 ± 49.6	830.8 ± 55.6
N_{bkg}	5.0 ± 9.7	42.9 ± 13.7	47.9 ± 16.7
N_η	106.9 ± 26.8	676.0 ± 51.5	782.9 ± 58.1
MC ϵ^i (%)	15.7 ± 0.5	14.0 ± 0.2	-
Br^i (%)	3.7 ± 0.9	26.0 ± 2.0	29.6 ± 2.2

$D_s^+ \to \eta X$

Br = (29.6 ± 2.2) %





η' Yields

The η' has constant efficiency with momentum

- So we don't need to separate the η' sample into different momentum intervals.

Fit Function

The η' yields are extracted by fitting the distributions of $\eta\pi^+\pi^- - \eta$ mass difference to a **Gaussian signal function** and a **second degree polynomial background function**.

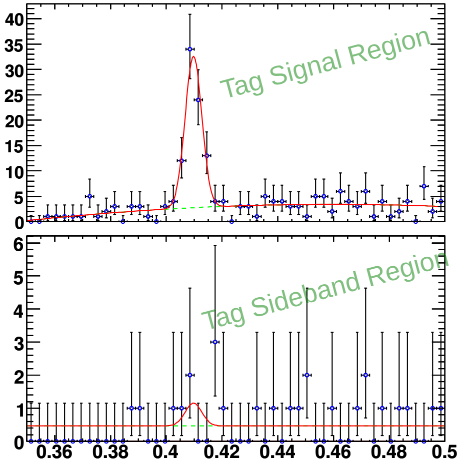
The η' yields from D_s tag signal region

- The signal shape parameters **(Gaussian peak location and width)** are allowed to float.

The η' yields from D_s tag sideband region

- All of the signal shape parameters are fixed to the corresponding values from D_s tag signal region.

$D_s^+ \to \eta' X$



N_{sig}	74.7 ± 9.8
N_{bkg}	1.7 ± 2.0
$N_{\eta'}$	73.0 ± 10.0
MC $\in$ (%)	3.52 ± 0.14
Br (%)	11.1 ± 1.6

$D_s^+ \to \eta' X$

Br = (11.1 ± 1.6) %

ϕ Yields

Separate the ϕ sample into several momentum regions

- The ϕ efficiency decreases drastically with decreasing momentum
- To measure the inclusive branching fractions, we separate the ϕ sample into 200 MeV/*c* momentum bins.
- As the ϕ becomes less energetic, it becomes more probable that it decays to slow kaons (with momentum below 0.2 Gev/*c*), and these particles have very low detection efficiencies as they have large energy losses in the beam pipe and detector.

Fit Function

The ϕ yields are extracted by fitting the the K^+K^- invariant mass distribution to a **Sum of two Gaussian signal function** and a **second degree polynomial background function**.

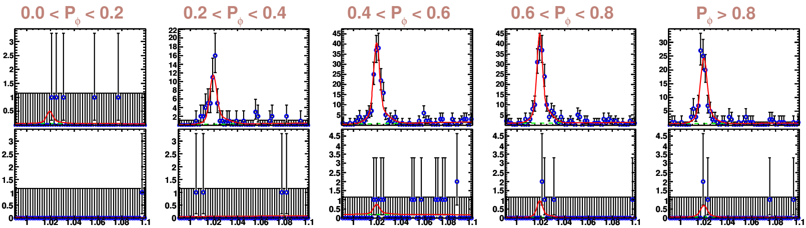
The ϕ yields from D_s tag signal region

- The shape parameters of **sum of two Gaussian signal function** are fixed to the values obtained by Monte Carlo simulation,

The ϕ yields from D_s tag sideband region

- All of the signal shape parameters are fixed to the corresponding values from D_s tag signal region.

$D_S^+ \to \phi X$

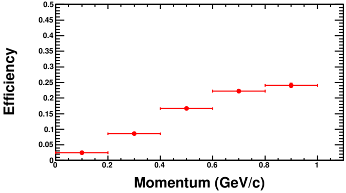


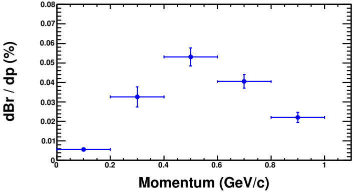
P (GeV/c)	0.0 - 0.2	0.2 - 0.4	0.4 - 0.6	0.6 - 0.8	> 0.8	Total
N_{sig}	1.8 ± 1.7	51.8 ± 7.9	166.4 ± 13.7	170.3 ± 14.0	101.4 ± 10.7	491.7 ± 23.7
N_{bkg}	0.0 ± 0.5	0.0 ± 0.6	2.3 ± 2.0	3.5 ± 2.0	2.7 ± 1.7	8.5 ± 3.4
N_ϕ	1.8 ± 1.8	51.8 ± 8.0	164.1 ± 13.9	166.8 ± 14.1	98.6 ± 10.9	483.2 ± 24.0
MC ϵ^i (%)	2.5 ± 0.5	8.6 ± 0.3	16.6 ± 0.3	22.2 ± 0.5	24.1 ± 0.7	-
Br^i (%)	0.4 ± 0.4	3.3 ± 0.5	5.3 ± 0.5	4.0 ± 0.4	2.2 ± 0.3	15.2 ± 0.9

Set Br (0.0 - 0.2) = (0.6 ± 0.0) %

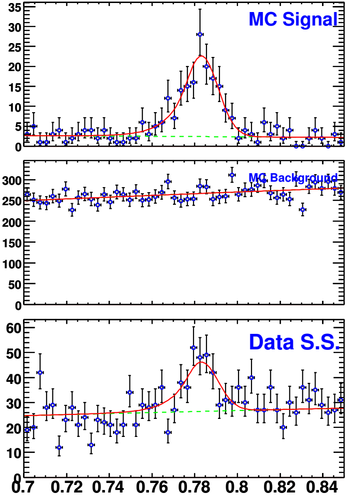
$D_s^+ \to \phi X$

Br = (15.4 ± 0.8) %





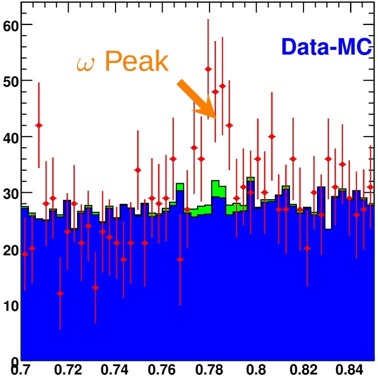
$D_s^+ \to \omega X$



$D_s^+ \to \omega X$

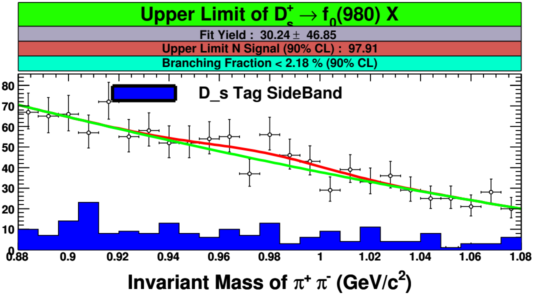
Br = (5.3 ± 1.2) %

N_{sig}	140.7 ± 30.5
MC ϵ (%)	14.34 ± 1.10
Br (%)	5.2788 ± 1.2139



$D_s^+ \to f_0(980)X$

- No significant evidence is found for the decay $D_s^+ \to f_0(980)X$, $f_0(980) \to \pi^+\pi^-$.
- Fit the invariant mass distribution of $\pi^+\pi^-$ pair to the **Gaussian signal** plus **second-degree polynomial background** functions to obtain a yield of 30 ± 47
- The upper limit is $\mathcal{B}(D_s^+ \to f_0(980)X) < 2.18\%$ (statistical only) and < 2.46 (including systematic errors) (90%CL).

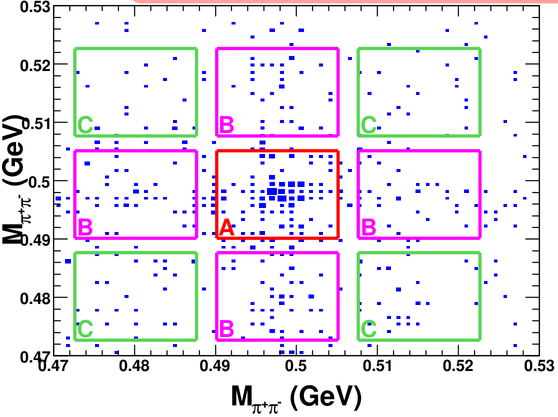


$$\frac{\int_0^{N_{Signal}+\mathcal{R}\cdot\delta N_{Signal}} G(N, N_{Signal}, \delta N_{Signal}) \cdot dN}{\int_0^{\infty} G(N, N_{Signal}, \delta N_{Signal}) \cdot dN} = 90\%(CL) \quad (6)$$

$$UL@90\%CL = \frac{N_{Signal} + \mathcal{R}\cdot\delta N_{Signal}}{N_{D_s}(\mathcal{L})\cdot\epsilon\cdot\mathcal{B}(f_0(980)\to\pi^+\pi^-)} \quad (7)$$

$D_s^+ \to K_S^0 K_S^0 X$

In order to account for $D_s^+ \to K_S^0\pi^+\pi^- X$ and any other events entering into the signal region of $D_s^+ \to K_S^0 K_S^0 X$, we perform a background subtraction which has two components.



Nss=Na-0.5*Nb+0.25*Nc

N Region A : 122.00 ± 11.05

N Region B : 136.00 ± 11.66

N Region C : 82.00 ± 9.06

N S.S. : 74.50 ± 12.69

N TagSB : 1.75 ± 5.09

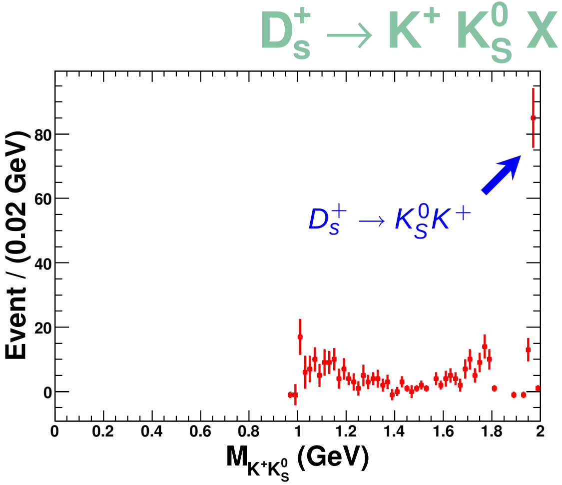
N Tag S.S. : 72.75 ± 13.68

MC Eff : 22.50 ± 0.81 %

DsTag : 18585.80 ± 162.55

Br : 1.7400 ± 0.3335 %

$D_s^+ \to K_S^0 K^+ X$



N Signal S.S. : 292.00 $\pm$ 20.78

Nbg(From MC) : 13.99 $\pm$ 2.90

N Signal : 278.01 $\pm$ 20.99

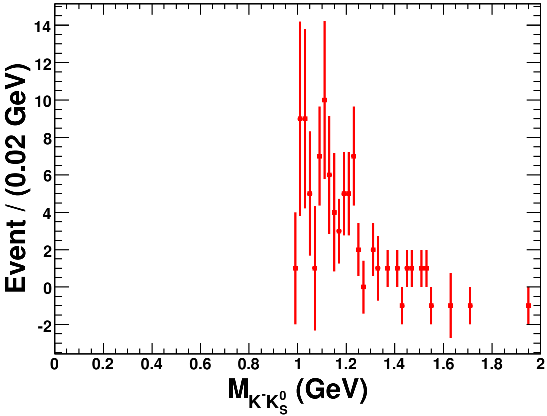
MC Eff : 26.00 $\pm$ 0.46 %

DsTag : 18585.80 $\pm$ 162.55

Br : 5.7527 $\pm$ 0.4486 %

$D_s^+ \to K_S^0 K^- X$

$D_s^+ \to K^- K_S^0 X$



N Signal S.S. : 78.00 ± 12.96

Nbg(From MC) : 5.66 ± 2.36

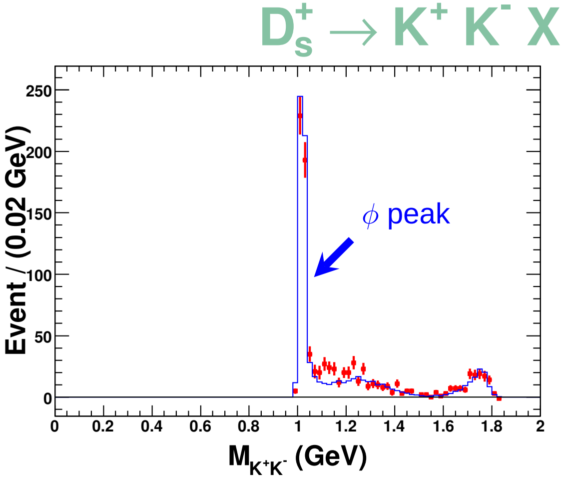
N Signal : 72.34 ± 13.17

MC Eff : 22.31 ± 0.76 %

DsTag : 18585.80 ± 162.55

Br : 1.7448 ± 0.3237 %

$D_s^+ \to K^+K^-X$



N Signal S.S. : 896.00 ± 31.43

Nbg(From MC) : 1.23 ± 0.36

N Signal : 894.77 ± 31.43

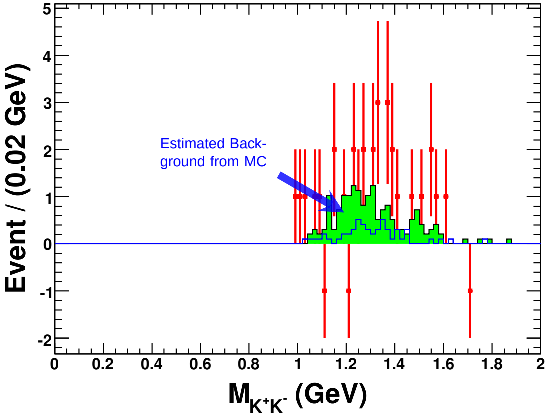
MC Eff : 32.43 ± 0.30 %

DsTag : 18585.80 ± 162.55

Br : 14.8430 ± 0.5542 %

$D_s^+ \to K^+K^+X$

$D_s^+ \to K^+ K^+ X$



N Signal S.S. : 27.00 ± 5.74

Nbg(From MC) : 17.18 ± 1.33

N Signal : 9.82 ± 5.90

MC Eff : 40.95 ± 0.44 %

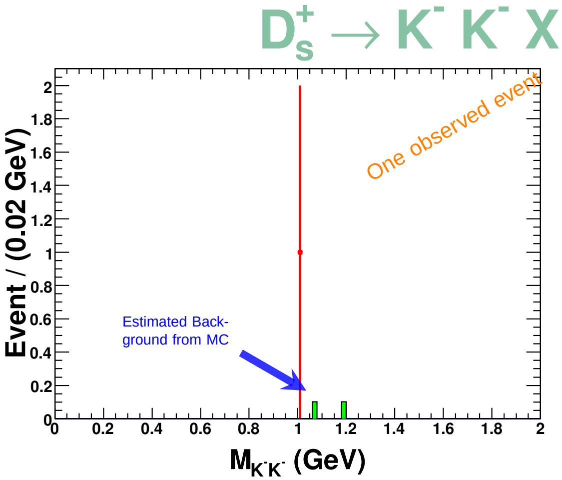
DsTag : 18585.80 ± 162.55

Br : 0.1290 ± 0.0775 %

UL N: 17.81

UL : < 0.2340 % @90%CL

$D_s^+ \to K^-K^-X$



N Signal S.S. : 1.00 ± 1.00

Nbg(From MC) : 0.21 ± 0.15

N Signal : 0.79 ± 1.01

MC Eff : 32.74 ± 0.43 %

DsTag : 18585.80 ± 162.55

Br : 0.0131 ± 0.0166 %

UL N: 3.71

UL : < 0.0609 % @90%CL

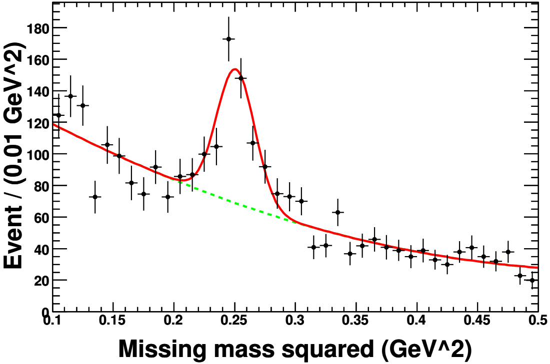
$D_S^+ \to K_L^0 X$

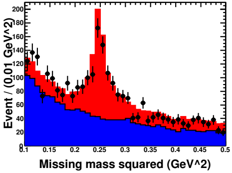
$D_s^+ \to K_L^0$ X

Tags :

- $D_s^+ \to K_S^0 K^+$
- $D_s^+ \to \phi \pi^+$
- $D_s^+ \to \overline{K}^*(892)^0 K^+$

Mode	$D_s^+ \to K_S^0 K^+$	$D_s^+ \to \phi \pi^+$	$D_s^+ \to \overline{K}^*(892)^0 K^+$	Fit Together
Signal Yield	99.78 ± 23.92	100.19 ± 21.43	178.34 ± 28.75	333.00 ± 41.97
D_s Tag	4204.52 ± 74.29	6786.49 ± 86.85	7594.83 ± 115.59	18585.84 ± 162.55
MC Eff	13.39 ± 0.42 %	9.09 ± 0.27 %	13.09 ± 0.30 %	11.70 ± 0.18 %
Gaussian Mean	0.25647 ± 0.00516	0.24592 ± 0.00341	0.25482 ± 0.00269	0.25095 ± 0.00175
Gaussian Sigma	0.02359 ± 0.00527	0.01574 ± 0.00346	0.01836 ± 0.00340	0.01572 ± 0.00248
BR	17.72 ± 4.30 %	16.24 ± 3.51 %	17.94 ± 2.93 %	15.32 ± 1.95 %





Signal : 333.00 ± 41.97

MC Eff : 11.70 ± 0.18 %

D_s Tag : 18585.84 ± 162.55

Fit BR : 15.32 ± 1.95 %

Com. BR : 17.34 ± 1.99 %

$D_s^+ \to K_L^0 K_S^0 X$

$D_s^+ \to K_S^0 K_L^0 X$

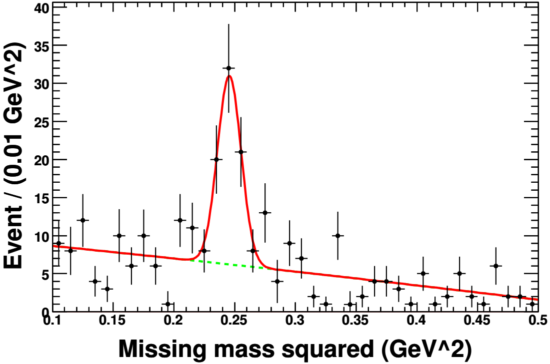
Tags :

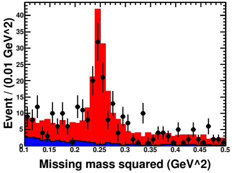
$D_s^+ \to K_S^0 K^+$

$D_s^+ \to \phi \pi^+$

$D_s^+ \to \overline{K}^*(892)^0 K^+$

Mode	$D_s^+ \to K_S^0 K^+$	$D_s^+ \to \phi \pi^+$	$D_s^+ \to \overline{K}^*(892)^0 K^+$	Fit Together
Signal Yield	22.10 ± 6.31	22.50 ± 8.37	30.19 ± 6.58	60.16 ± 11.83
D_s Tag	4204.52 ± 74.29	6786.49 ± 86.85	7594.83 ± 115.59	18585.84 ± 162.55
MC Eff	6.76 ± 0.44 %	5.37 ± 0.30 %	7.49 ± 0.34 %	6.55 ± 0.20 %
Gaussian Mean	0.25622 ± 0.00476	0.24061 ± 0.00676	0.24457 ± 0.00211	0.24559 ± 0.00186
Gaussian Sigma	0.01617 ± 0.00422	0.01959 ± 0.00754	0.00868 ± 0.00236	0.00974 ± 0.00281
BR	7.77 ± 2.28 %	6.17 ± 2.32 %	5.31 ± 1.18 %	4.94 ± 0.98 %





Signal : 60.16 ± 11.83

MC Eff : 6.55 ± 0.20 %

D_s Tag : 18585.84 ± 162.55

Fit BR : 4.94 ± 0.98 %

Com. BR : 5.89 ± 0.96 %

$D_S^+ \to K_L^0 K^+ X$

$D_s^+ \to K^+ K_L^0 X$

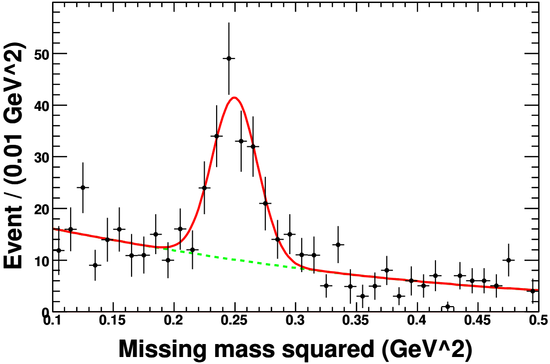
Tags :

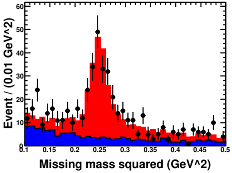
$D_s^+ \to K_S^0 K^+$

$D_s^+ \to \phi \pi^+$

$D_s^+ \to \overline{K}^*(892)^0 K^+$

Mode	$D_s^+ \to K_S^0 K^+$	$D_s^+ \to \phi \pi^+$	$D_s^+ \to \overline{K}^*(892)^0 K^+$	Fit Together
Signal Yield	30.00 ± 6.83	59.43 ± 11.40	57.00 ± 13.22	147.40 ± 19.74
D_s Tag	4204.52 ± 74.29	6786.49 ± 86.85	7594.83 ± 115.59	18585.84 ± 162.55
MC Eff	20.46 ± 0.90 %	11.82 ± 0.55 %	15.89 ± 0.60 %	15.44 ± 0.38 %
Gaussian Mean	0.24685 ± 0.00313	0.25263 ± 0.00421	0.24812 ± 0.00451	0.24990 ± 0.00243
Gaussian Sigma	0.01235 ± 0.00429	0.02079 ± 0.00380	0.01999 ± 0.00505	0.01879 ± 0.00285
BR	3.49 ± 0.81 %	7.41 ± 1.47 %	4.72 ± 1.11 %	5.14 ± 0.70 %





Signal : 147.40 ± 19.74

MC Eff : 15.44 ± 0.38 %

D_s Tag : 18585.84 ± 162.55

Fit BR : 5.14 ± 0.70 %

Com. BR : 4.50 ± 0.60 %

$D_S^+ \to K_L^0 K^- X$

$D_s^+ \to K^- K_L^0 X$

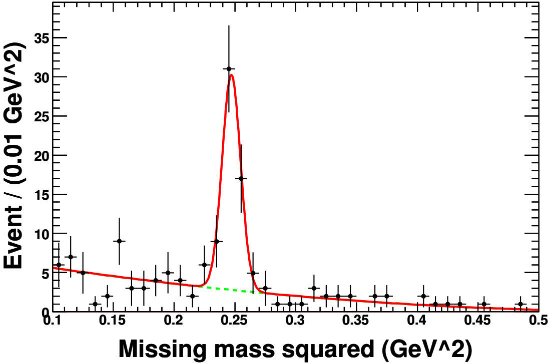
Tags :

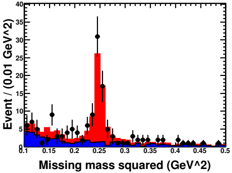
$D_s^+ \to K_S^0 K^+$

$D_s^+ \to \phi \pi^+$

$D_s^+ \to \overline{K}^*(892)^0 K^+$

Mode	$D_s^+ \to K_S^0 K^+$	$D_s^+ \to \phi \pi^+$	$D_s^+ \to \overline{K}^*(892)^0 K^+$	Fit Together
Signal Yield	11.53 ± 4.41	15.81 ± 4.52	20.04 ± 5.18	51.41 ± 8.43
D_s Tag	4204.52 ± 74.29	6786.49 ± 86.85	7594.83 ± 115.59	18585.84 ± 162.55
MC Eff	17.29 ± 1.54 %	13.78 ± 1.02 %	17.09 ± 1.07 %	15.93 ± 0.67 %
Gaussian Mean	0.24434 ± 0.00261	0.24841 ± 0.00176	0.24777 ± 0.00232	0.24709 ± 0.00133
Gaussian Sigma	0.00575 ± 0.01082	0.00602 ± 0.00128	0.00831 ± 0.00209	0.00758 ± 0.00145
BR	1.59 ± 0.62 %	1.69 ± 0.50 %	1.54 ± 0.41 %	1.74 ± 0.29 %





Signal : 51.41 ± 8.43

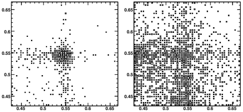
MC Eff : 15.93 ± 0.67 %

D_s Tag : 18585.84 ± 162.55

Fit BR : 1.74 ± 0.29 %

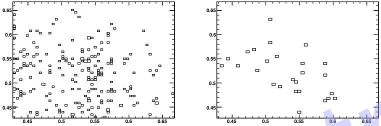
Com. BR : 1.60 ± 0.28 %

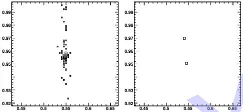
$D_S^+ \to \eta\eta X\,,\ \eta\eta' X\,,\ \eta\phi X\,,\ \eta\omega X$



$D_s^+ \to \eta\,\eta\,X$

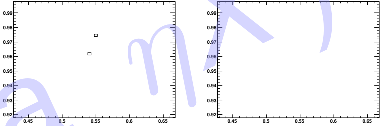
Yield : 11.0000 ± 7.5083
MCBG : -0.2829 ± 2.0764
Nsig : 11.2829 ± 7.7901
DsTag: 18585.8 ± 162.6
Eff : (1.4597 ± 0.0996) %
Br : (4.1588 ± 2.8856) %
ULN : (21.5787) %
UL@90C.L. < (7.9537) %

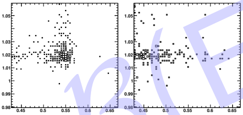




$D_s^+ \to \eta\,\eta'\,X$

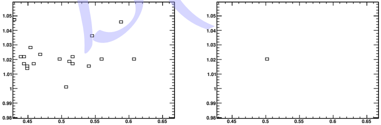
Yield : 0.5000 ± 1.1180
MCBG : 0.0514 ± 0.1150
Nsig : 0.4486 ± 1.1239
DsTag: 18585.8 ± 162.6
Eff : (0.2411 ± 0.0407) %
Br : (1.0010 ± 2.5138) %
ULN : (2.1355) %
UL@90C.L. < (4.7653) %

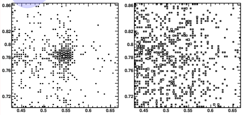




$D_s^+ \to \eta\,\phi\,X$

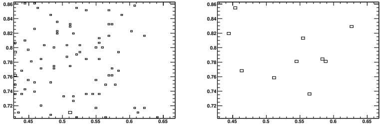
Yield : 0.0000 ± 1.9685
MCBG : -1.9805 ± 0.6274
Nsig : 1.9805 ± 2.0661
DsTag: 18585.8 ± 162.6
Eff : (1.2654 ± 0.0946) %
Br : (0.8421 ± 0.8808) %
ULN : (4.8346) %
UL@90C.L. < (2.0557) %





$D_s^+ \to \eta\,\omega\,X$

Yield : 4.0000 ± 3.8568
MCBG : -1.6718 ± 1.1990
Nsig : 5.6718 ± 4.0389
DsTag: 18585.8 ± 162.6
Eff : (1.2778 ± 0.0944) %
Br : (2.3883 ± 1.7099) %
ULN : (11.0261) %
UL@90C.L. < (4.6428) %



$\mathcal{B}$(Extra ηX)

Systematics-Fake Rate, PID

e, K, π production rates

- We define the following variable to estimate how big the difference of e, K, π production rate between data and Monte Carlo can effect the final inclusive branching fraction, and take the value of this variable as the systematic error for e, K, π production rate.

$$\delta_{a\to b} = \frac{N_a^{\text{Data}}}{N_b^{\text{Data}}} \times F^{a\to b} \times \left(1 - \frac{\epsilon^a + N_b^{\text{MC}}/N_a^{\text{MC}} \times F^{b\to a} + N_c^{\text{MC}}/N_a^{\text{MC}} \times F^{c\to a}}{\epsilon^a + N_b^{\text{Data}}/N_a^{\text{Data}} \times F^{b\to a} + N_c^{\text{Data}}/N_a^{\text{Data}} \times F^{c\to a}}\right)$$

- This systematic is very tiny. We can ignore them.

Particle ID

- 0.30% per kaon (Average).
- 0.25% per pion (Average).

K_S^0, π^0, η Finding

- We assign 1.8% as the systematic uncertainty for K_S^0, 4.0% for π^0, and 5.6% for η

Cross Fake Rate

- The PID efficiency systematic error not only can effect the signal particle yield, but also can effect the fake background through:

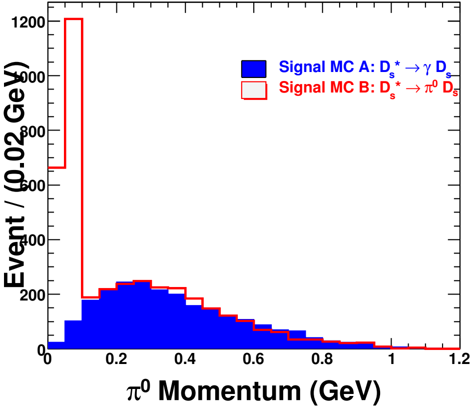
$$\delta_{a\to b} = \frac{N_a^{\text{Data}}}{N_b^{\text{Data}}} \times F^{a\to b} \times \delta_{\epsilon^a}$$

Systematics-π^0 from D_s^{*+}

The Effect from $D_s^{*+} \to D_s^+\pi^0$ Decay

Two Monte Carlo samples have been generated to study this systematics. One only contains $D_s^{*+} \to D_s^+\gamma$ and the other only contains $D_s^{*+} \to D_s^+\pi^0$.

Transition π^0 Systematic Study



$Br(D_s^* \to \pi^0 D_s)$ (PDG) : 5.8000 %

Tag Efficiency Ratio(B/A) : 0.4460

Tag from $\pi^0 D_s$ Ratio : 2.6728 %

N_{π^0} Per Tag A : 0.3597

N_{π^0} Per Tag B : 0.6300

π^0 Efficiency[0-50]MeV : 0.5204

π^0 Efficiency[50-100]MeV : 0.3365

Weighted Average π^0 Eff. : 0.4043

The Effect From $\pi^0 D_s$: 1.7870 %

Systematics-Truncate Point, Correction Factors

Systematics for Truncate Branching Fraction

- We estimate the number of signal track below 50 MeV/c by using Monte Carlo directly. We take a half of this number as the systematic uncertainty.
- For $D_s^+ \to \phi X$, we modeled the partial branching ratio in first momentum bin by taking the fraction of ϕ yield in the first momentum interval to ϕ yield in the rest of the momentum intervals in data to be equal to the same fraction from the Monte Carlo simulation, and assign systematic uncertainty equal to its value.

$D_s^+ \to K^+K^+X$ Monte Carlo Efficiency

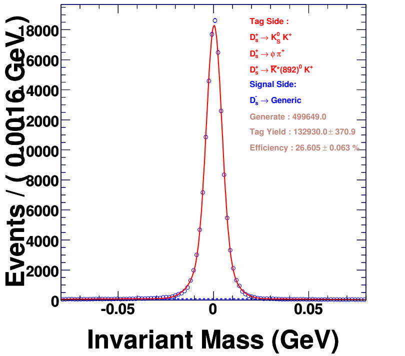
- For the $D_s^+ \to K^+K^+X$ mode, actually our generic Monte Carlo only contains $D_s^+ \to K^+K^+K^-$. There is another possible contribution to $D_s^+ \to K^+K^+X$ decay, it is $D_s^+ \to K^+K^+\pi^-$. We generate this sample to study the efficiency difference between these two possible modes and set this difference as the systematic.

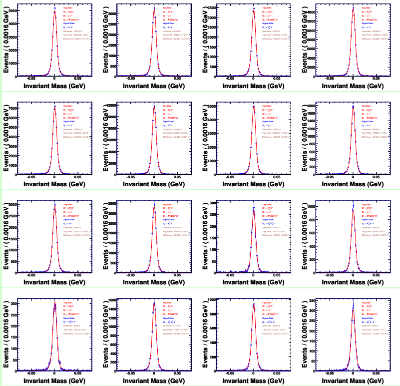
The Efficency Correction Factors

- We apply the correction factors for PID, π^0 finding and η finding. They are 0.5% for $\pi^\pm$ PID and 1% for $K^\pm$ PID. The correction factor for π^0 and η finding is 6%.

Systematics-Single Tag Efficiency

D_s Tag Invariant Mass Distributions





- Take the ratio between the single tagging efficiency in generic D_s meson decays (ϵ_{tag}) and the single tagging efficiency in inclusive decays (ϵ'_{tag}) as the single tag efficiency correction factor, and assign the systematic based on the error.

Systematics-Tag Bias Correction

The efficiencies and correction factors summary table

Mode	eff(%)	$\epsilon'_{tag}/\epsilon_{tag}$	Systematic (%)
$D_s^+ \to$ Generic	26.605 ± 0.063	—	—
$D_s^+ \to K^+X$	25.827 ± 0.117	0.971	0.510
$D_s^+ \to K^-X$	25.294 ± 0.145	0.951	0.618
$D_s^+ \to K_S^0X$	26.321 ± 0.144	0.989	0.596
$D_s^+ \to \pi^+X$	26.686 ± 0.070	1.003	0.352
$D_s^+ \to \pi^-X$	26.392 ± 0.100	0.992	0.445
$D_s^+ \to \pi^0X$	27.948 ± 0.081	1.051	0.374
$D_s^+ \to \eta X$	28.000 ± 0.125	1.052	0.503
$D_s^+ \to \eta' X$	27.219 ± 0.206	1.023	0.792
$D_s^+ \to \phi X$	26.601 ± 0.157	1.000	0.634
$D_s^+ \to \omega X$	24.787 ± 0.822	0.932	3.325
$D_s^+ \to K_L^0X$	26.148 ± 0.144	0.983	0.600
$D_s^+ \to K_S^0K_S^0X$	26.985 ± 0.525	1.014	1.958
$D_s^+ \to K_S^0K^+X$	26.456 ± 0.275	0.994	1.064
$D_s^+ \to K_S^0K^-X$	24.415 ± 0.452	0.918	1.864
$D_s^+ \to K^+K^-X$	25.500 ± 0.162	0.958	0.678
$D_s^+ \to K_L^0K_S^0X$	26.459 ± 0.216	0.995	0.849
$D_s^+ \to K_L^0K^+X$	26.341 ± 0.276	0.990	1.072
$D_s^+ \to K_L^0K^-X$	24.560 ± 0.453	0.923	1.860

Constraints on Branching Fractions

Singly-Cabbibo-suppressed (a) *vs* Cabbibo-favored

- $\mathcal{B}(\bar{s}) = C_1 \times |V_{cd}/V_{cs}|^2 \times \mathcal{B}(s\bar{s})$

Singly-Cabbibo-suppressed (b) *vs* Cabbibo-favored

- $\mathcal{B}(\eta\bar{s}) = C_2 \times |V_{cd}/V_{cs}|^2 \times \mathcal{B}(\eta)$
- $\mathcal{B}(\eta'\bar{s}) = C_2 \times |V_{cd}/V_{cs}|^2 \times \mathcal{B}(\eta')$
- $\mathcal{B}(\omega\bar{s}) = C_2 \times |V_{cd}/V_{cs}|^2 \times \mathcal{B}(\omega)$
- $\mathcal{B}(\phi\bar{s}) = C_2 \times |V_{cd}/V_{cs}|^2 \times \mathcal{B}(\phi)$
- $\mathcal{B}(K\bar{K}\bar{s}) = C_2 \times |V_{cd}/V_{cs}|^2 \times \mathcal{B}(K\bar{K})$

Doubly-Cabbibo-suppressed (a) *vs* Cabbibo-favored

- $\mathcal{B}(\bar{s}\bar{s}) = C_3 \times |V_{cd}/V_{cs}|^4 \times \mathcal{B}(s\bar{s})$

Total Branching Fraction $\mathcal{B}$

- $\mathcal{B}(s\bar{s}) + \mathcal{B}(s\bar{s}\bar{s}) + \mathcal{B}(\bar{s}) + \mathcal{B}(\bar{s}\bar{s}) + \mathcal{B}(\text{Annihi}) = 100\%$

χ^2 Formulas For Global Fit

We bulid χ^2 in the following way and do a global fit.

1. $$\left(\frac{\mathrm{M}_\eta - (\mathcal{B}(\eta)+\mathcal{B}(\eta\bar{s})+\mathcal{B}(\eta'\to\eta)\times(\mathcal{B}(\eta')+\mathcal{B}(\eta'\bar{s}))+\mathcal{B}(\text{Extra } \eta))}{\delta_{\mathrm{M}_\eta}}\right)^2$$
2. $$\left(\frac{\mathrm{M}_{\eta'} - (\mathcal{B}(\eta')+\mathcal{B}(\eta'\bar{s}))}{\delta_{\mathrm{M}_{\eta'}}}\right)^2$$
3. $$\left(\frac{\mathrm{M}_\omega - (\mathcal{B}(\omega)+\mathcal{B}(\omega\bar{s}))}{\delta_{\mathrm{M}_\omega}}\right)^2$$
4. $$\left(\frac{\mathrm{M}_\phi - (\mathcal{B}(\phi)+\mathcal{B}(\phi\bar{s}))}{\delta_{\mathrm{M}_\phi}}\right)^2$$
5. $$\left(\frac{\mathrm{M}_{KK} - (\mathcal{B}(K\bar{K})+\mathcal{B}(K\bar{K}\bar{s})+\mathcal{B}(\phi\to K\bar{K})\times(\mathcal{B}(\phi)+\mathcal{B}(\phi\bar{s}))+\mathcal{B}(\bar{s}\bar{s}))}{\delta_{\mathrm{M}_{KK}}}\right)^2$$
6. $$\left(\frac{\mathrm{M}_K - (2\times(\mathcal{B}(K\bar{K})+\mathcal{B}(K\bar{K}\bar{s}))+2\times\mathcal{B}(\phi\to K\bar{K})\times(\mathcal{B}(\phi)+\mathcal{B}(\phi\bar{s}))+\mathcal{B}(s\bar{s}\bar{s})+\mathcal{B}(\bar{s})+2\times\mathcal{B}(\bar{s}\bar{s}))}{\delta_{\mathrm{M}_K}}\right)^2$$

Where, M_i is the center value of the measurement, δ_{M_i} is the error of the measurement and $\mathcal{B}$ is the fit parameter. $\mathcal{B}(\eta' \to \eta)$ and $\mathcal{B}(\phi \to K\bar{K})$ are fixed to PDG(2006) during the fit.

Fit Case-A

We estimated the contribution from $s\bar{s} \to \omega$ by looking at semileptonic decays $D_s^+ \to \omega e^+\nu$ vs $D_s^+ \to \phi e^+\nu$. A reasonable approximation is

$$\frac{\mathcal{B}(D_s^+ \to s\bar{s} \to \omega)}{\mathcal{B}(D_s^+ \to s\bar{s} \to \phi)} = \frac{\mathcal{B}(D_s^+ \to \omega e^+\nu)}{\mathcal{B}(D_s^+ \to \phi e^+\nu)}. \quad (8)$$

A preliminary result for the second ratio is 10%. This predicts $\mathcal{B}(D_s^+ \to s\bar{s} \to \omega)$ is 1.6%.

Case-A Fit Results

$\mathcal{B}(E\ \eta)$ (%)	Vary C_1, C_2 (%) (χ^2)				$\mathcal{B}(D_s^+ \to$ Other Annihilation) (%)
In Data	1.25	1.25	1.00	1.50	C_1 1.25
6.0 ± 3.9	0.50	1.00	0.75	0.75	C_2 0.75
2.00	12.44 (0.022)	13.24 (0.269)	13.37 (0.017)	12.33 (0.292)	$12.85 \pm 2.89 \pm 0.40 \pm 0.52$ (0.113)
6.00	16.54 (0.005)	17.30 (0.179)	17.43 (0.003)	16.43 (0.197)	$16.92 \pm 2.89 \pm 0.38 \pm 0.50$ (0.062)
10.00	20.65 (0.000)	21.36 (0.107)	21.49 (0.000)	20.54 (0.120)	$21.01 \pm 2.89 \pm 0.36 \pm 0.47$ (0.027)

- The first error is statistical error, the second one is from C_2 and the third one is from C_1.

Fit Case-B

Take the contribution from ω into account. We treat all of the ω as coming from $s\bar{s}$ and write

- $\mathcal{B}(s\bar{s}) = \mathcal{B}(\eta) + \mathcal{B}(\eta') + \mathcal{B}(\phi) + \mathcal{B}(K\bar{K}) + \mathcal{B}(\omega)$,
- $\mathcal{B}(s\bar{s}\bar{s}) = \mathcal{B}(\eta\bar{s}) + \mathcal{B}(\eta'\bar{s}) + \mathcal{B}(\phi\bar{s}) + \mathcal{B}(K\bar{K}\bar{s}) + \mathcal{B}(\omega\bar{s})$.

In addition $D_s^+ \to \eta\eta X$, $D_s^+ \to \eta\eta' X$ and $D_s^+ \to \eta\phi X$ modes, we also search for $D_s^+ \to \eta\omega X$ mode, no clear signals were found. The $\mathcal{B}(\text{Extra }\eta)$ from data is about $(8.4 \pm 4.3)\%$. We vary the value of $\mathcal{B}(\text{Extra }\eta)$ from 0 to 15% and perform the fit for each value.

Case-B Fit Results

$\mathcal{B}$(E η) (%)	Vary C_1, C_2 (%) (χ^2)				$\mathcal{B}(D_s^+ \to$ Other Annihilation) (%)
In Data	1.25	1.25	1.00	1.50	C_1 1.25
8.4 ± 4.3	0.50	1.00	0.75	0.75	C_2 0.75
4.00	9.86 (0.039)	10.72 (0.335)	10.83 (0.032)	9.77 (0.361)	$10.29 \pm 3.18 \pm 0.43 \pm 0.53$ (0.153)
8.00	13.96 (0.014)	14.77 (0.233)	14.88 (0.011)	13.87 (0.254)	$14.37 \pm 3.18 \pm 0.40 \pm 0.50$ (0.093)
12.00	18.06 (0.002)	18.82 (0.150)	18.93 (0.001)	17.97 (0.166)	$18.45 \pm 3.18 \pm 0.38 \pm 0.48$ (0.047)

- The first error is statistical error, the second one is from C_2 and the third one is from C_1.

Mode	$\mathcal{B}$ (%)	Combination π^+	Combination π^-	Combination π^0	Decay π^+	Decay π^-	Decay π^0	Total π^+	Total π^-	Total π^0
$D_s^+ \to \eta X$	22.314	22.314	0.000	0.000	6.112	6.112	26.828	28.426	6.112	26.828
	Rate	100.000	0.000	0.000	27.390	27.390	120.230	127.390	27.390	120.230
$D_s^+ \to \eta' X$	11.667	11.667	0.000	0.000	11.030	11.030	14.414	22.697	11.030	14.414
	Rate	100.000	0.000	0.000	94.537	94.537	123.545	194.537	94.537	123.545
$D_s^+ \to \phi X$	15.714	15.714	0.000	0.000	2.460	2.460	2.650	18.174	2.460	2.650
	Rate	100.000	0.000	0.000	15.656	15.656	16.864	115.656	15.656	16.864
$D_s^+ \to K_S^0 K_S^0 (K_L^0 K_L^0) X$	3.432	3.432	0.000	0.000	0.000	0.000	0.000	3.432	0.000	0.000
	Rate	100.000	0.000	0.000	0.000	0.000	0.000	100.000	0.000	0.000
$D_s^+ \to K_S^0 K^+ (K_L^0 K^+) X$	11.692	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Rate	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$D_s^+ \to K_S^0 K^- (K_L^0 K^-) X$	3.840	7.680	0.000	0.000	0.000	0.000	0.000	7.680	0.000	0.000
	Rate	200.000	0.000	0.000	0.000	0.000	0.000	200.000	0.000	0.000
$D_s^+ \to K^+ K^- (-\phi) X$	8.079	8.079	0.000	0.000	0.000	0.000	0.000	8.079	0.000	0.000
	Rate	100.000	0.000	0.000	0.000	0.000	0.000	100.000	0.000	0.000
$D_s^+ \to K^+ K^+ X$	0.130	0.000	0.130	0.000	0.000	0.000	0.000	0.000	0.130	0.000
	Rate	0.000	100.000	0.000	0.000	0.000	0.000	0.000	100.000	0.000
$D_s^+ \to K^- K^- X$	0.032	0.096	0.000	0.000	0.000	0.000	0.000	0.096	0.000	0.000
	Rate	300.000	0.000	0.000	0.000	0.000	0.000	300.000	0.000	0.000
$D_s^+ \to K_S^0 K_L^0 (-\phi) X$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Rate	100.000	0.000	0.000	0.000	0.000	0.000	100.000	0.000	0.000
$D_s^+ \to \omega X$	6.090	6.090	0.000	0.000	5.530	5.530	5.968	11.620	5.530	5.968
	Rate	100.000	0.000	0.000	90.800	90.800	98.000	190.800	90.800	98.000
$D_s^+ \to e^+ (\mu^+) \eta, \eta', \phi$	10.740	-10.740	0.000	0.000	0.000	0.000	0.000	-10.740	0.000	0.000
	Rate	-100.000	0.000	0.000	0.000	0.000	0.000	-100.000	0.000	0.000
$D_s^+ \to \tau^+ \nu$	6.470	0.000	0.000	0.000	4.777	0.889	3.300	4.777	0.889	3.300
	Rate	0.000	0.000	0.000	73.828	13.734	51.010	73.828	13.734	51.010
$D_s^+ \to$ Extra ηX	8.000	-8.000	0.000	0.000	0.000	0.000	0.000	-8.000	0.000	0.000
	Rate	-100.000	0.000	0.000	0.000	0.000	0.000	-100.000	0.000	0.000
Total	108.200	56.332	0.130	0.000	29.908	26.020	53.161	86.240	26.150	53.161
Measure								119.283	43.200	123.411
Difference								33.043	17.050	70.250

Check Here!

Flavor Symmetry and Decays of Charmed Particles D^0, D^+, and D_s to Pairs of Light Pseudoscalar Mesons P

- DataSet-1: Full CLEO-c dataset (818 pb^{-1}) at $\psi(3770)$
- DataSet-2: Full CLEO-c dataset (586 pb^{-1}) at $E_{\mathrm{cm}} = 4.170$ GeV
- Working on progress (unofficial result!)

D^0 Mode Data Yields Summary

D^0 Mode Monte Carlo efficiencies and data yields

Mode	Efficiency (%)	Yield
$D^0 \to K^+K^-$	57.64 ± 0.16	13782.3 ± 135.8
$D^0 \to K_S^0 K_S^0$	22.39 ± 0.13	214.8 ± 22.7
$D^0 \to \pi^+\pi^-$	72.32 ± 0.14	6210.0 ± 93.3
$D^0 \to \pi^0\pi^0$	35.22 ± 0.15	1566.7 ± 53.5
$D^0 \to K^-\pi^+$	65.11 ± 0.15	150258.6 ± 419.7
$D^0 \to K_S^0\pi^0$	29.32 ± 0.14	20045.4 ± 164.5
$D^0 \to K_S^0\eta$	27.03 ± 0.14	2863.8 ± 65.4
$D^0 \to \pi^0\eta$	33.41 ± 0.15	481.0 ± 40.2
$D^0 \to K_S^0\eta'$	14.28 ± 0.11	1320.6 ± 42.3
$D^0 \to \pi^0\eta'$	18.76 ± 0.12	158.8 ± 18.9
$D^0 \to \eta\eta$	31.75 ± 0.15	430.4 ± 28.7
$D^0 \to \eta\eta'$	17.52 ± 0.12	66.0 ± 15.1

D^+ Mode Data Yields Summary

D^+ Mode Monte Carlo efficiencies and data yields

Mode	Efficiency (%)	Yield
$D^+ \to K^-\pi^+\pi^+$	54.92 ± 0.16	231058.2 ± 515.3
$D^+ \to K_S^0K^+$	36.25 ± 0.15	5161.2 ± 85.6
$D^+ \to \pi^+\pi^0$	49.96 ± 0.16	2649.0 ± 76.2
$D^+ \to K_S^0\pi^+$	41.91 ± 0.16	30094.7 ± 191.3
$D^+ \to K^+\pi^0$	44.65 ± 0.16	342.9 ± 36.7
$D^+ \to K^+\eta$	42.97 ± 0.16	60.5 ± 24.1
$D^+ \to \pi^+\eta$	48.42 ± 0.16	2940.5 ± 67.6
$D^+ \to K^+\eta'$	26.19 ± 0.14	22.8 ± 18.4
$D^+ \to \pi^+\eta'$	29.21 ± 0.14	1036.8 ± 34.7

D_s Mode Data Yields Summary

D_s Mode Monte Carlo efficiencies and data yields

Mode	Efficiency (%)	Yield
$D_s^+ \to K_S^0 K^+$	24.73 ± 0.14	4075.5 ± 71.2
$D_s^+ \to \pi^+\pi^0$	34.67 ± 0.15	26.5 ± 153.9
$D_s^+ \to K_S^0 \pi^+$	28.01 ± 0.14	393.2 ± 33.1
$D_s^+ \to K^+\pi^0$	30.80 ± 0.15	202.2 ± 70.4
$D_s^+ \to K^+\eta$	31.02 ± 0.15	222.4 ± 41.0
$D_s^+ \to \pi^+\eta$	34.38 ± 0.15	2586.7 ± 89.4
$D_s^+ \to K^+\eta'$	17.67 ± 0.12	55.7 ± 17.1
$D_s^+ \to \pi^+\eta'$	20.13 ± 0.13	1436.3 ± 46.7