Absolute $D_s$ Hadronic Branching Fractions

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Why absolute $D_s$ branching fractions?

- Measurements of decays to $c$ quarks depend on reconstructing $D_{(s)}$ decays
- Branching fraction measurements can be limiting systematics
  - Since $b \to c$ is a dominant decay mode, $B$ measurements often rely on knowing various $D_{(s)}$ BFs
  - Affects precision measurements of $Z \to c\bar{c}$, $H \to c\bar{c}$, 
  - Reference modes ($D^0 \to K^−\pi^+$, $D^+ \to K^−\pi^+\pi^+$, $D^+_s \to \phi\pi^+$) normalize virtually all other $D$ branching fractions
- CLEO-c has published results for $D^0$, $D^+$ (talk by Steve Stroiney); is now able to investigate $D_s$
The classic reference decay has been the exclusive mode
\[ D_s^+ \rightarrow \phi \pi^+ \rightarrow K^- K^+ \pi^+ \]

Essentially all other decays have branching ratios to this mode

This causes problems since \( \phi \) signal is ambiguous given the precision we will soon achieve

We instead measure inclusive branching fractions. No \( \phi \pi^+ \) result will be presented in this talk.

### Modes used

<table>
<thead>
<tr>
<th>Decay</th>
<th>PDG 2004 BF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D_s^+ \rightarrow K_S K^+ )</td>
<td>1.8 ± 0.55</td>
</tr>
<tr>
<td>( D_s^+ \rightarrow K^- K^+ \pi^+ )</td>
<td>4.3 ± 1.2</td>
</tr>
<tr>
<td>( D_s^+ \rightarrow K^- K^+ \pi^+ \pi^0 )</td>
<td>—</td>
</tr>
<tr>
<td>( D_s^+ \rightarrow \pi^+ \pi^+ \pi^- )</td>
<td>1.00 ± 0.28</td>
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</table>

Relative uncertainties are roughly 25–30%, limited by the \( \phi \pi^+ \) BF in PDG 2004. BaBar has a \( \phi \pi^+ \) measurement with smaller errors.
Dataset and Landscape

- Use 76 pb\(^{-1}\) of data collected at \(E_{cm} \sim 4170\) MeV as part of the CLEO-c \(D_s\) energy scan and data run
  - See next talk by Brian Lang
  - Chose running point for maximal \(D_s\) production
- Dominant \(D_s\) production channel in this region is \(D_s^* D_s\), \(\approx 1\) nb
- \(D^0, D^+\) events produced at \(\approx 7\) nb, are the major background

![Graph showing the distribution of \(J/\psi\) and \(\psi(2S)\) with a marked operating point and \(D_s^* D_s\) threshold.](image-url)
We use events with the topology \( e^+ e^- \rightarrow D_s^* \pm D_s^\mp \rightarrow D_s^+ D_s^- (\gamma, \pi^0) \).
We do not reconstruct the \( \gamma \) or \( \pi^0 \).
We use the momentum of the \( D_s \) candidates to select for events with an intermediate \( D_s^* \). (The quantity \( m_{BC} = \sqrt{E_{\text{beam}}^2 - \vec{p}_D^2} \) is a proxy for momentum.)
We can use a loose cut to include the daughters of \( D_s^* \), or a tight cut for the directly produced \( D_s \).
Analysis Method

- Similar to $D^0/D^+$ analysis
- Uses both **single tags** (one $D_s$ reconstructed) and **double tags** (both $D_s$ reconstructed)
  - Recall: we don’t reconstruct the entire event, just the $D_s^+D_s^-$ component, but kinematic cuts force the event to have been $D_s^*D_s$
- We do a binned maximum likelihood fit for all the observed yields (utilizing Poisson statistics for double tags)
- Method maximizes statistical power from a smaller dataset
  - Dominant statistical uncertainty on every branching fraction is $\approx \sqrt{N(\text{total double tags})}$, so every double tag mode helps every BF
  - Example: The $KK\pi$ mode is 62% of all single tags, but $KK\pi/KK\pi$ is only 26% of the double tag yield
  - Important given relatively low $D_s$ cross-section
Crossfeed between $D_s$ modes from $K_S \leftrightarrow \pi^+\pi^-$ is Cabibbo-suppressed

- Use vetoes and sidebands

Peaking structure can arise from reflections: for example, the decay chain $D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-K^+\pi^+$ has correct $m_{BC}$, peaks at 2.06 GeV.

- We veto certain mass regions; e.g. for $KK\pi$ we reject events consistent with $D^0 \rightarrow KK$.
- This doesn’t affect signal but makes the background easier to model
Yield extraction

**DATA: KKπ Single Tags**

- Fit single tag signals with double Gaussian or Crystal Ball function (parameters fixed from Monte Carlo) plus a linear background
  - Each charge done separately

**DATA: KKπ⁺/KKπ⁻ Double Tag**

- In double tags, count events in signal and sideband boxes
  - Combinatoric background is flat in \( m(D_s^+) - m(D_s^-) \), has structure in \( m(D_s^+) + m(D_s^-) \)
Data Results

\begin{align*}
\text{m(D}_{s}^{0}, D_{s}^{*}\rightarrow K_{s} K^{+}) & \quad 788 \pm 34 \\
\text{m(D}_{s}^{0}, D_{s}^{*}\rightarrow K^{-} K^{+} \pi^{0}) & \quad 709 \pm 54 \\
\text{m(D}_{s}^{0}, D_{s}^{*}\rightarrow \pi^{+} \pi^{+} \pi^{0}) & \quad 539 \pm 41 \\
\text{m(D}_{s}^{0}, D_{s}^{*}\rightarrow K^{-} K^{+} \pi^{+} \pi^{-}) & \quad 3344 \pm 77
\end{align*}
## Systematic uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>Fractional uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking/(K_S/\pi^0)</td>
<td>0.35/1.1/5.0 per particle</td>
</tr>
<tr>
<td>Particle ID</td>
<td>0.3–1.4 correlated by decay</td>
</tr>
<tr>
<td>Resonant substructure</td>
<td>0–6.0 correlated by decay</td>
</tr>
<tr>
<td>Fit procedure</td>
<td>3.5 in fit result</td>
</tr>
<tr>
<td>Event environment</td>
<td>3.5 in (KK\pi\pi^0)</td>
</tr>
<tr>
<td>Initial state radiation correction</td>
<td>0–5 per single tag</td>
</tr>
<tr>
<td>(\mathcal{B}(D_s^{*+} \rightarrow \pi^0 D_s^+))</td>
<td>0.7 in (KK\pi\pi^0, \pi\pi\pi)</td>
</tr>
</tbody>
</table>
### Preliminary Results

<table>
<thead>
<tr>
<th>Mode</th>
<th>Fit (%)</th>
<th>PDG 2004 fit (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{B}(K_S K^+)$</td>
<td>$1.28^{+0.13}_{-0.12} \pm 0.07$</td>
<td>$1.8 \pm 0.55$</td>
</tr>
<tr>
<td>$\mathcal{B}(K^- K^+ \pi^+)$</td>
<td>$4.54^{+0.44}_{-0.42} \pm 0.25$</td>
<td>$4.3 \pm 1.2$</td>
</tr>
<tr>
<td>$\mathcal{B}(K^- K^+ \pi^+ \pi^0)$</td>
<td>$4.83^{+0.49}_{-0.47} \pm 0.46$</td>
<td>—</td>
</tr>
<tr>
<td>$\mathcal{B}(\pi^+ \pi^+ \pi^-)$</td>
<td>$1.02^{+0.11}_{-0.10} \pm 0.05$</td>
<td>$1.00 \pm 0.28$</td>
</tr>
</tbody>
</table>

The graphs show the branching fraction distributions for various decay modes, compared to the PDG 2004 fit. The data points represent CLEO preliminary results based on 76 pb$^{-1}$ of data.
With 76 pb$^{-1}$ of CLEO-c data, we have extracted preliminary absolute branching fractions for four $D_s$ decay modes.

- Precision about 11% for all-charged modes
- Inclusive $K^- K^+ \pi^+ \pi^0$ is a first measurement

The measured BFs are consistent with the PDG 2004 fit.

We are actively working on adding more modes (especially decays with $\eta$, $\eta'$).

We are aiming for < 4% uncertainties with full CLEO-c dataset.

Already have more than xxx pb$^{-1}$ additional data on tape!
Backup Slides
Comparison with BaBar $\phi\pi^+$

Can we compare with the BaBar $\mathcal{B}(D_s^+ \rightarrow \phi\pi^+)$ result?

▶ We can use the PDG fit branching ratios...

We are more consistent with 3.6% than 4.8%
The $\phi\pi^+$ problem

Expect $(f_0(980) \to K^- K^+)\pi^+$ to contribute to any $\phi$ mass region, with badly controlled parameters. Correction might be on the order of 5% — but depends on mass window, resolution, angular distribution requirements!

Looking at low-mass $KK$ pairs ($m(KK) < 1.005$ GeV) we see evidence for scalar production by looking at helicity angle.
Our Monte Carlo has some reasonable mixture of intermediate resonances.

Our efficiencies depend on the intermediate state.

We reweight the expected efficiencies by comparing data yields with MC expectations.

- Size of correction is largest systematic for $K^- K^+ \pi^+ \pi^0$

The correction for a given mode affects that mode’s BF only.