SPECTROSCOPY OF ORBITTALY EXCITED CHARM MESONS

Outline
1. Excited charm states
2. Focus spectrometer
3. Event reconstruction
4. $D\pi$ combinations $D_2^*$
5. $J^P$ of $D_1$ and $D_2^*$
6. $c\bar{s}$ excited mesons
7. Summary

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Orbitally excited charm mesons (L=1)

In the heavy-quark limit the heavy-quark spin $S_Q$ and the total angular momentum of the light-quark $j_q = L + S_q$ are conserved.
Successor to E687. Designed to study charm particles produced by ~200 GeV photons using a fixed target spectrometer with upgraded Vertexing, Cerenkov, E+M Calorimetry, and Muon id capabilities. Includes groups from USA, Italy, Brazil, Mexico, Korea

1 million charm particles reconstructed into $D \rightarrow K\pi$, $K2\pi$, $K3\pi$
**FOCUS: Event reconstruction for excited D states**

D$_2^{*0}$ → D$^+\pi^-$  
K$^-$ 2$\pi$

γ → D$^+$  
K → D$^+\pi^-$

Primary vertex  
Required to be inside matter

Secondary vertex  
Required to be out of matter

Requirements on particle ID, vertex quality, primary and secondary vertex separation leave E831 with a very high statistics sample of very clean ground states!

> 1/3 Million D candidates with S/Background > 7

D candidates are now combined with pions in the primary vertex satisfying the particle ID and vertex quality criteria.
**Dπ mass distribution**

**Left panel:**
- Plot of $D^*_2 \rightarrow D^0 \pi^+$ with a shaded region indicating events.
- Arrow pointing to a peak labeled with the mass distribution.
- Text: "Feed down from $D^*_2, D_1$ partial reconstruction."
- Wrong sign indicated below the plot.

**Right panel:**
- Plot of $D^*_2^0 \rightarrow D^+ \pi^-$ with a shaded region indicating events.
- Arrow pointing to a peak labeled with the mass distribution.
- Text: "Feed down from $D^*_2, D_1$ partial reconstruction."
- Wrong sign indicated below the plot.

**Equations:**
- $D^*_2 \rightarrow D^0 \pi^+$
- $D^*_2^0 \rightarrow D^+ \pi^-$

**Axes:**
- **Y-axis:** Events / 10 MeV/c^2
- **X-axis:** $M(D^0 \pi^+)-M(D^0)+1.8646$ GeV/c^2
**D^*_2 Background**

Wrong sign, side band and right sign in the mass range beyond the signal region all show an exponential shape.
$D_2 \rightarrow D\,\pi$ Exponential Background Subtracted

Feed down from $D_1$ and $D_2^*$

Entries / 10 MeV/c^2

$M(D^*\pi^0) - M(D^+) + 1.8546$ GeV/c^2

Feed down from $D_1$ and $D_2^*$

Entries / 10 MeV/c^2

$M(D^*\pi^-) - M(D^+) + 1.8593$ GeV/c^2
Feed down line shapes from MonteCarlo

\[ D_1^+ \rightarrow D^*\pi^0, D^0 \pi, D^0 \gamma \]

\[ D_2^{*+} \rightarrow D^{*0}\pi^-, D^0 \pi, D^0 \gamma \]

\[ D_1\text{ and } D_2 \text{ feed downs summed with polynomial background} \]

\[ D^{*+}_2 \rightarrow D^0 \pi^+ \]
$D_{2}^{*+} \rightarrow D^{0}\pi^{+}$: Fitting the mass distribution

Fit: Extrapolated exponential from region 2.8 - 4.5 GeV/c$^2$ + D-wave relativistic BW convoluted with 7 MeV/c$^2$ mass resolution + $D_1$, $D_2$ feed downs from Monte Carlo

$\Gamma_{PDG}(D_{2}^{*+}) = 25^{+8}_{-7}$ MeV/c$^2$

$\chi^2$/ndf = 3.1

$M = 2468.2 \pm 1.5$ MeV/c$^2$

$\Gamma = 28.6 \pm 1.3$ MeV/c$^2$

$\Gamma_{PDG}(D_{2}^{*+}) = 25^{+8}_{-7}$ MeV/c$^2$

$\chi^2$/ndf = 1.8

$M = 2419 \pm 10$

$\Gamma = 185 \pm 18$
Reducing background from soft pions from $D^{*+}$ decays

$D^{*+} \rightarrow D^0 \pi^+$

Requiring Pion momentum to be greater than 10 GeV/c

$D_2^{*+} \rightarrow D^0 \pi^+$

Pion momentum (GeV/c)

$M = 2468.5 \pm 2.1$ MeV/c$^2$
$\Gamma = 30.3 \pm 3.6$ MeV/c$^2$

$M = 2425 \pm 8$ MeV/c$^2$
$\Gamma = 209 \pm 16$ MeV/c$^2$
$D^{*0}_2 \rightarrow D^+\pi^-$ : Fitting the mass distribution

$\chi^2/ndf = 0.9$

$M = 2463.5 \pm 1.5 \text{ MeV}/c^2$
$\Gamma = 30.5 \pm 1.9 \text{ MeV}/c^2$

$\chi^2/ndf = 2$

$\Gamma_{PDG}(D^{*0}_2) = 23 \pm 5 \text{ MeV}/c^2$
$M = 2415 \pm 13 \text{ MeV}/c^2$
$\Gamma = 187 \pm 19 \text{ MeV}/c^2$

Fit: Extrapolated exponential from region $2.8 - 4.5 \text{ GeV}/c^2$
+ D-wave relativistic BW convoluted with $7 \text{ MeV}/c^2$ mass resolution + $D_1, D_2$ feed downs from Monte Carlo

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**D**$^*_2$ Mass and width systematics

**D**$^{**+}$ Mass

**D**$^{**+}$ Width

**D**$^*_2$ FOCUS new measurements

PRELIMINARY

<table>
<thead>
<tr>
<th></th>
<th>Mass</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^*_2$</td>
<td>2468.2±1.5±1.4 MeV/c$^2$</td>
<td>28.6±1.3±3.8 MeV/c$^2$</td>
</tr>
<tr>
<td>$D^*_2$</td>
<td>2463.5±1.5±1.5 MeV/c$^2$</td>
<td>30.5±1.9±3.8 MeV/c$^2$</td>
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</tbody>
</table>

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$D^{*+} \pi^-$ Mass distribution

$D_2^{*0}, D_1^0 \rightarrow D^{*+} \pi^-$

$D_0 \rightarrow D^{0} \pi^+$

$K^- \pi^+$

$K^- 3\pi$

Yield $\approx 70 K$

$S/B \approx 5$

$D_1^0$ Yield $= 889 \pm 92$

$D_2^{*0}$ Yield $= 977 \pm 101$

Wrong sign
$D_1^0 (J^P=1^+)$ and $D_2^{*0} (J^P=2^+)$ disentangling using helicity angle

$D_1^0$ is relatively enhanced while helicity angle approaches zero.
$D_1^0, D_2^{*0}: J^P$ assignment

Background

\[ G_1 \{ a_1 + b_1 \mid \cos^2 \Theta_H \} \]
\[ + \]
\[ G_1 \{ a_2 + b_2 \mid \cos^2 \Theta_H \} \]

\[ a_1 = 0.84 \pm 0.25, \quad b_1 = 3.58 \pm 0.48 \]
\[ a_2 = 0.92 \pm 0.09, \quad b_2 = -0.66 \pm 0.29 \]

$1 \quad 3$  $\quad J^P = 1^+$

$1 \quad -1$  $\quad J^P = 2^+$

No acceptance corrections yet!

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FOCUS excited \( c\bar{c} \) mesons sample

PDG →
\( D_{sJ}^+ \) Mass = 2573.5 ± 1.7 MeV/c²
Width = 15±5-4 MeV/c²

PDG →
\( D_{s1}^+ \) Mass = 2535.35 ± 0.34 MeV/c²
Width < 2.3 MeV/c²

\( D_{sJ}^+ \) FOCUS PRELIMINARY (stat errors only)
Yield = 744±99
Mass = 2568.1 ± 1.6 MeV/c²
rms = 10±1 MeV/c²

\( D_{s1}^+ \) FOCUS PRELIMINARY (stat errors only)
Yield = 41 ± 6
Mass = 2535.2 ± 0.4 MeV/c²
rms = 1.3 ± 0.1 MeV/c²

\( D_{sJ}^+ \rightarrow D^0 K^+ \)

\( D_{s1}^+ \rightarrow D^{*+} K_s \)

Wrong sign
Summary

☑ **FOCUS** has collected about
10⁶ charm meson states  5000 excited charm decays
The study of Dπ mass spectrum gives new preliminary values of the masses and widths for
the D₂* meson:

<table>
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<td><strong>FOCUS</strong>:</td>
<td><strong>PDG</strong>:</td>
</tr>
<tr>
<td>2468.2±1.5±1.4 MeV/c²</td>
<td>2459±4 MeV/c²</td>
</tr>
<tr>
<td>28.6±1.3±3.8 MeV/c²</td>
<td>25±8 MeV/c²</td>
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<tr>
<td><strong>FOCUS</strong>:</td>
<td><strong>PDG</strong>:</td>
</tr>
<tr>
<td>2463.5±1.5±1.5 MeV/c²</td>
<td>2458.9±2.0 MeV/c²</td>
</tr>
<tr>
<td>30.5±1.9±3.8 MeV/c²</td>
<td>23±5 MeV/c²</td>
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☑ The Dπ mass spectrum shows an excess of events centered around 2420 MeV/c² and
about 185 MeV/c² wide.

☑ A broad (100≈200 MeV/c²) state (the D₀*) is predicted by Heavy Quark Symmetry at
about 2350 MeV/c². The observed excess could be due to this state, or a feed down from
another broad state, such as the D₁(j½=1/2). Work is in progress to verify such hypothesis.

☑ More FOCUS results to come.