$D_{S}^{*+} \rightarrow D_{S}^{+} e^{+} e^{-}$

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18 June 2009
The $D_{s}^{*+} \rightarrow D_{s}^{+}e^{+}e^{-}$ Process

If we write the decay of the $D_{s}^{*+}$ to a real photon in the form:

$$M = \varepsilon_{D_{s}^{*+}}^{\mu} \varepsilon_{\gamma}^{*\nu} T_{\mu\nu} (P, k)$$

Then we can write the decay to $e^{+}, e^{-}$ in the form:

$$M = \varepsilon_{D_{s}^{*+}}^{\mu} T_{\mu\nu} (P, k) \left( -\frac{ig_{\nu\sigma}}{k^2} \right) \bar{u}(p)ie\gamma_{\sigma}v(p')$$

Evaluating the spin-average of the invariant amplitudes and integrating over phase space, we predict the ratio of decay rates:

$$\frac{\Gamma(D_{s}^{*+} \rightarrow D_{s}^{+}e^{+}e^{-})}{\Gamma(D_{s}^{*+} \rightarrow D_{s}^{+}\gamma)} \approx 1.1\alpha$$
Dataset Used

- Use data collected at $E_{CM} = 4170$ MeV (dataset 47).
- CLEO-c has 602 pb$^{-1}$ of data at this energy.
  
  \[ D_s^{*-}D_s^{-} + D_s^{*-}D_s^{+} \]
  
  cross section is $\sim 1$ nb at this energy.
  
  Hence we expect $\sim 602,000$ $D_s^{*-}$ produced at this energy.
- So far, we have looked at 48.2 pb$^{-1}$ of data.
Right now we are reconstructing the $D_s^+$ from the $D_s^{*+}$ and decaying via the channel:

$$D_s^+ \rightarrow \phi \pi^+$$

$$\phi \rightarrow K^+ K^-$$

This is known to have a branching fraction of $2.18 \pm 0.33\%$
• Signal events with decay chain which we reconstruct:
  \[ D_s^{*+} \rightarrow D_s^+ e^+ e^- \]
  \[ D_s^+ \rightarrow \phi \pi^+ \]
  \[ \phi \rightarrow K^+ K^- \]

• predicted branching fraction = 94\% \ast (1.1\alpha) \ast 2.18\% \approx 0.017\%

• In 602 pb\(^{-1}\), this would mean \approx 100 produced events.

• For signal Monte Carlo, we force e\(^+\)e\(^-\) collisions to decay into \(\Psi(4160)\), and then that to decay into the abovementioned channel.

• We added an EVTGEN plug-in to generate vector (D\(_s^{*+}\)) to scalar (D\(_s^+\)), lepton (e\(^-\)), lepton (e\(^+\)) distributions with the invariant amplitude in consideration, apart from the invariant phase space factor.

• We refitted electrons to the electron hypothesis instead of the pion hypothesis.

  We expect soft electron tracks with pT < 70 MeV which the pion fit would not do justice to.

• We generated 9,988 signal MC events.
Background events are expected, largely, to be:

\[ D_s^{*+} \rightarrow D_s^+ \gamma \]
\[ D_s^+ \rightarrow \phi \pi^+ \]
\[ \phi \rightarrow K^+ K^- \]

where the photon converts in the beampipe material: \( \gamma \rightarrow e^+ e^- \)

- Without the photon conversion, the branching fraction = 94.2% * 2.18% ~ 2.05%
- In 602 pb\(^{-1}\), this would mean ~ 12,340 produced events which may yet undergo conversion.
- For background Monte Carlo, we force e\(^+\)e\(^-\) collisions to decay into \( \Psi(4160) \), and then that to decay into the abovementioned channel (without forcing the photon to convert in the beampipe).
- We refitted electrons to the electron hypothesis instead of the pion hypothesis.
- We generated 998,800 events.
Processor Level Cuts

• Kaon and pion tracks must pass track quality cuts:
  • 50 MeV < Track Momentum < 2.0 GeV
  • Number of hits / number expected > 0.5
  • chiSquared < 100,000
  • d0 < 5 mm, z0 < 5 cm
• Kaon and pion tracks’ dE/dx are fitted to 3.0 σ

• Reconstructed φ mass peak from K+, K− cut on | φ_{Mass_reco} − 1019.5 MeV | < 100 MeV

• Reconstructed $D_S^+$ mass peak from φ, π+ cut on | $D_S^{+ Mass}$ − 1968.49 MeV | < 100 MeV

• Electron tracks must pass track quality cuts:
  • 10 MeV < Track Momentum < 2.0 GeV
  • chiSquared < 100,000
  • d0 < 5 mm, z0 < 5 cm
• Electron track’s dE/dx is fitted to 3.0 σ

• All these cuts, and the reconstruction of a $D_s^{*+}$ were required for filling our n-tuples on which we applied subsequent cuts.
$\phi_{\text{Mass}}$ Cut

- Reconstructed $\phi_{\text{Mass}}$

- We cut on:
  \[ | \phi_{\text{Mass}} - 1019.5 \text{ MeV} | < 15 \text{ MeV} \]
**$D_{S}^{+}$ Mass Cut**

- **Reconstructed $D_{S}^{+}$ Mass**

- **We cut on**

  $$\left| D_{S}^{+} \text{Mass} - 1968.49 \text{ MeV} \right| < 20 \text{ MeV}$$
\[ \Delta E = E(K^+ K^- \pi^+ e^+ e^-) - E(D_s^{*+} beam) \]

- We cut on \(|\Delta E| < 0.016 \text{ GeV}\)
\( m_{BC} = \sqrt{E^2(D_0^{*+}\text{beam}) - P^2(K^+K^-\pi^+e^+e^-)} \)

- Will cut on \(| m_{BC} - 2.112 \text{ GeV} | < 0.005 \text{ GeV} |\)
\( \delta m \) Cut

\[
\delta m = M(K^+ K^- \pi^+ e^+ e^-) - M(K^+ K^- \pi^+)
\]

- We cut on \( |\delta m - 0.144 \text{ GeV}| < 0.005 \text{ GeV} \)
Impact Parameters of the Electron and Positron
• We require $d0_e - d0_p > -0.004$ m
diffD0 vs dΦ

![Graph showing the distribution of diffD0 vs dΦ.](image)
We require $d_{0e} - d_{0p} > -0.004$ m
\[ a_1 = r_1 + d_1 \]
\[ a_2 = r_2 + d_2 \]
\[ \theta = \Phi_1 - \Phi_2 \]
\[ R = \frac{a_1 a_2 \sin \theta}{\sqrt{a_1^2 + a_2^2 + 2a_1 a_2 \cos \theta}} \]
We have 678 signal events out of 99,880 and 26 background events out of 998,800.

In a sample of 602 pb\(^{-1}\), we should expect to see:

- \(602,000 \times 0.017\% \times \frac{678}{9,988} \approx 7.0\) signal events
- \(602,000 \times 2.05\% \times \frac{26}{998,800} \approx 0.3\) background events
## Performance of Cuts

<table>
<thead>
<tr>
<th>Selection Cut</th>
<th>Signal</th>
<th></th>
<th>Background</th>
<th></th>
<th>Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># of Events</td>
<td>Marginal Efficiency</td>
<td>Events in 48.2 pb⁻¹</td>
<td># of Events</td>
<td>Marginal Efficiency</td>
<td>Events in 48.2 pb⁻¹</td>
</tr>
<tr>
<td><strong>φ</strong>&lt;sub&gt;Mass&lt;/sub&gt;</td>
<td>4029</td>
<td>86.7%</td>
<td>3.3</td>
<td>43106</td>
<td>89.4%</td>
<td>42.6</td>
</tr>
<tr>
<td><strong>D</strong>&lt;sub&gt;S⁺&lt;/sub&gt; &lt;sub&gt;Mass&lt;/sub&gt;</td>
<td>3641</td>
<td>90.4%</td>
<td>3.0</td>
<td>39682</td>
<td>92.1%</td>
<td>39.3</td>
</tr>
<tr>
<td><strong>ΔE</strong></td>
<td>1330</td>
<td>36.5%</td>
<td>1.1</td>
<td>1202</td>
<td>3.0%</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>m</strong>&lt;sub&gt;BC&lt;/sub&gt;</td>
<td>1064</td>
<td>80%</td>
<td>0.9</td>
<td>542</td>
<td>45.1%</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>δm</strong></td>
<td>848</td>
<td>79.7%</td>
<td>0.7</td>
<td>370</td>
<td>68.3%</td>
<td>0.4</td>
</tr>
<tr>
<td>d₀ₐ – d₀ₚ</td>
<td>825</td>
<td>97.3%</td>
<td>0.7</td>
<td>214</td>
<td>57.8%</td>
<td>0.2</td>
</tr>
<tr>
<td>dΦ</td>
<td>678</td>
<td>82.2%</td>
<td>0.6</td>
<td>26</td>
<td>12.2%</td>
<td>0.03</td>
</tr>
</tbody>
</table>
• Optimize selection cuts
• Calculate predicted rate more accurately.
• Use the DTagging tools and use other decay modes:

\[ \begin{align*}
K^+ K^- \pi^- \\
K_S K^- \\
\eta \pi^-; \eta \rightarrow \gamma \gamma \\
\eta' \pi^-; \eta' \rightarrow \pi^+ \pi^- \eta, \eta \rightarrow \gamma \gamma \\
K+K^-\pi^-\pi^0 \\
\pi^+\pi^-\pi^- \\
K^*-K^{*0}; K^*\rightarrow K^0_S\pi^-, K^{*0} \rightarrow K^+\pi^- \\
\eta\rho^-; \eta \rightarrow \gamma \gamma, \rho^- \rightarrow \pi^-\pi^0 \\
\eta'\pi^-; \eta' \rightarrow \rho^0\gamma,
\end{align*}\]

• Reconstruct the *other* Ds (and cut on slightly different kinematic quantities)
• Electron-refit the data…