$D^{*+}$ reconstruction in C-C collisions at 25A GeV in the CBM experiment

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September 21, 2011
Open charm production

$D$ mesons are produced in the early stages of nucleus-nucleus collisions. Multiplicity at FAIR energies ($E_{\text{kin}} = 25\text{A GeV}$) is very low.

<table>
<thead>
<tr>
<th>Meson</th>
<th>Mass [GeV]</th>
<th>Multiplicity (by HSD model)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C-C</td>
</tr>
<tr>
<td>$D^0$</td>
<td>1.864</td>
<td>$4.1 \cdot 10^{-7}$</td>
</tr>
<tr>
<td>$\bar{D}^0$</td>
<td>1.864</td>
<td>$11.6 \cdot 10^{-7}$</td>
</tr>
<tr>
<td>$D^+$</td>
<td>1.869</td>
<td>$4.26 \cdot 10^{-7}$</td>
</tr>
<tr>
<td>$D^-$</td>
<td>1.869</td>
<td>$9.68 \cdot 10^{-7}$</td>
</tr>
<tr>
<td>$D^{*0}$</td>
<td>2.007</td>
<td>$6.26 \cdot 10^{-7}$</td>
</tr>
<tr>
<td>$\bar{D}^{*0}$</td>
<td>2.007</td>
<td>$34.9 \cdot 10^{-7}$</td>
</tr>
<tr>
<td>$D^*$</td>
<td>2.010</td>
<td>$7.51 \cdot 10^{-7}$</td>
</tr>
<tr>
<td>$D^{*-}$</td>
<td>2.010</td>
<td>$19.4 \cdot 10^{-7}$</td>
</tr>
</tbody>
</table>
Event simulation and reconstruction with CBMROOT

- Event generator UrQMD plus $D^{*+}$ source
- Transport code GEANT 3

UrQMD central C-C, 25 A GeV
~ 24 tracks reconstructed with Cellular Automation and Kalman Filter algorithms

Micro Vertex Detector
- Monolithic pixel detectors
- Two vertex stations in vacuum vessel
- Vertex resolution 50 µm

Silicon Tracking System
- Silicon microstrip detectors
- Eight tracking stations
- Momentum resolution $\Delta p/p \approx 1\%$
**D mesons reconstruction**

Decay modes

$D^{∗+}$ and $D^0$ are reconstructed via hadronic decays:

$D^{∗+}$:  
$D^{∗+} \rightarrow D^0\pi^+ \ (c\tau \sim 10^{-12} \text{ m}, \text{branching ratio } 67.7\%)$

$D^0$:  
$D^0 \rightarrow K^-\pi^+ \ (c\tau = 123 \ \mu\text{m}, \text{branching ratio } 3.87\%)$

Main challenges

- Low multiplicity
- Low branching ratio
- A lot of background
$D^0$ reconstruction

$D^0$ is reconstructed via $K^-\pi^+$ decay. All reconstructed negative tracks are assigned kaon mass, and all positive ones – pion mass, and then combined.

Cuts used to distinguish $D^0$ signal from background

- $\chi^2_{\text{prim}} > \chi^2_{\text{primcut}}$ ($\chi^2_{\text{primcut}} = 4 – 7$) and $b < 1$ mm cuts on daughter tracks impact parameter in the target plane.
- $\chi^2_{\text{geo}} < 3$ cut on distance of minimum approach between daughter tracks.
- $\chi^2_{\text{topo}} < 3$ cut on $D^0$ impact parameter in the target plane.
- $z > 350$ µm cut on $D^0$ decay vertex $z$-coordinate.
**Signal calculation algorithm**

1. $10^5$ UrQMD events with embedded $D^{*+}$ meson, decaying into $D^0$, are simulated and reconstructed.

2. $D^0$ is reconstructed using all the cuts and Monte Carlo verification to obtain signal.

3. Result is renormalized for $10^{12}$ C-C collisions using multiplicities of D mesons.

**Background calculation algorithm**

1. 5000 UrQMD events without $D$ mesons are simulated and reconstructed.

2. Tracks, satisfying $\chi^2_{prim}$ cut are identified as $D^0$ daughter candidates.

3. They are combined with each other to construct background for effectively $2.5 \cdot 10^7$ events and then renormalized for $10^{12}$ events.
$D^0$ invariant mass distribution

$\chi^2_{\text{primcut}} = 7$, $S/B = 2.1$, $\text{eff} = 5.64\%$

$10^{12}$ central C-C collisions

<table>
<thead>
<tr>
<th>$\chi^2_{\text{primcut}}$</th>
<th>Signal</th>
<th>Efficiency</th>
<th>S/B (2σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>6167</td>
<td>10.46%</td>
<td>0.33</td>
</tr>
<tr>
<td>5</td>
<td>5075</td>
<td>8.60%</td>
<td>0.83</td>
</tr>
<tr>
<td>6</td>
<td>4120</td>
<td>6.97%</td>
<td>1.54</td>
</tr>
<tr>
<td>7</td>
<td>3331</td>
<td>5.64%</td>
<td>2.06</td>
</tr>
</tbody>
</table>
$D^{*+}$ detection

$D^{*+}$ is reconstructed via decay into $D^0$ and $\pi^+$.  

Algorithm

1. $10^5$ events with $D^{*+}$ are simulated and reconstructed.

2. $D^0$ daughter tracks are identified using above cuts and constraint $1.84 < M_{D^0} (\text{GeV}) < 1.89$.

3. $D^0$ is combined with all positive tracks which are assigned pion mass and satisfy $\chi^2_{\text{prim}} < 3$ cut.

4. $D^{*+}$ signal and background is obtained using Monte Carlo verification.

5. $D^{*+}$ background is renormalized to include contribution from events without $D^{*+}$. 
Reconstructed $D^{*+}$ mass is corrected:

$$M_{D^{*+}} = \tilde{M}_{D^{*+}} - M^{\text{rec}}_{D^0} + M^{mc}_{D^0}.$$ 

- Allows to effectively exclude error from $D^0$ mass determination.
- Essential to distinguish signal from background!
$D^{*+}$ invariant mass distribution

$\chi^2_{\text{primcut}} = 7$, S/B = 3.2, eff = 3.82 %

$10^{12}$ central C-C events

<table>
<thead>
<tr>
<th>$\chi^2_{\text{primcut}}$</th>
<th>Signal</th>
<th>Efficiency</th>
<th>S/B (2$\sigma$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1283</td>
<td>7.11%</td>
<td>1.08</td>
</tr>
<tr>
<td>5</td>
<td>1054</td>
<td>5.83%</td>
<td>2.06</td>
</tr>
<tr>
<td>6</td>
<td>852</td>
<td>4.71%</td>
<td>2.81</td>
</tr>
<tr>
<td>7</td>
<td>692</td>
<td>3.82%</td>
<td>3.19</td>
</tr>
</tbody>
</table>
1. Algorithm to detect $D^{*+}$ signal in central C-C collisions was developed.

2. Reconstruction method allows to collect about 3300 $D^0$ mesons (with signal to background ratio $S/B_{2\sigma} = 2.1$ and efficiency $\epsilon = 5.64\%$) and about 700 $D^{*+}$ mesons ($S/B_{2\sigma} = 3.2$, $\epsilon = 3.82\%$) per $10^{12}$ central C-C events.

3. $\chi^2_{primcut}$ values of 6-7 for a cut on $D^0$ daughter tracks’s impact parameter were found to be optimal for $D^0$ and $D^{*+}$ detection.
Thanks for your attention!