Charm in the CHORUS emulsion

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IIHE (Brussels), 29 April 2002

- Charm in opposite-sign dimuons
- CHORUS detector & emulsion
- Automatic event location, ‘analysis-driven’ vertex analysis
- Net scan technique, ‘general’ vertex analysis
- Automatic reconstruction and charm selection
- Semi-leptonic branching fraction
- Outlook
Neutrino charm production

\[ |V_{cd}|^2, |V_{cs}|^2 \]

Beam knowledge

\[ d, s \]

Quark density functions, strange sea (\( \kappa \))

\[ c \]

Charm fragmentation
\[ D^0 : D^+ : D_s^+ : \Lambda_c^+ \]
\[ z = p_c / p_D \]

\[ B(c \rightarrow \mu) \]

\[ \nu \rightarrow \mu \]

\[ \mu \rightarrow h \]

\[ E_{\text{had}} \]

+ NLO effects

+ radiative gluon and self energy diagrams
Previous experiments

**CDHS (CERN WBB)**
- 9922 $\mu^-\mu^+$, 2123 $\mu^+\mu^-$ events

**CCFR (NuTeV)**
- 5044 $\mu^-\mu^+$, 1062 $\mu^+\mu^-$ events

**CHARMII (CERN WANF)**
- 4111 $\mu^-\mu^+$, 871 $\mu^+\mu^-$ events

**NOMAD (CERN WANF)**
- 2714 $\mu^-\mu^+$, 115 $\mu^+\mu^-$ events

**E531 (Fermilab, Nagoya)**
- 131 charm events in emulsion
- only measurement of $D^0 : D^+ : D_s^+ : \Lambda_c^+$
- $B(c \rightarrow \mu)$ crucial for other experiments
~ 800 kg active target
MIP : 30 ~ 40 grains / 100 μm
transverse resolution ~ 0.5 μm
depth of focus : 1 to 3 μm

Automatic Scanning

Tracks reconstructed by a hardware video processor frame to frame emulsion grains coincidence

tomographic image

microscope stroke

CCD camera

150x150 μm view

X50 magnification ~3μm focal depth

emulsion plate

350 μm (175 μm) emulsion sheet

90 μm plastic backing

350 μm (175 μm) emulsion sheet

## Microscope optics

### Objective
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>FOV</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>DOF</td>
<td>1.2 μm</td>
</tr>
<tr>
<td>FWD</td>
<td>1.2 mm</td>
</tr>
<tr>
<td>NA</td>
<td>1.05</td>
</tr>
<tr>
<td>M</td>
<td>40x (60x, 80x)</td>
</tr>
<tr>
<td>λ</td>
<td>436 nm</td>
</tr>
<tr>
<td>n (emulsion)</td>
<td>1.48-1.54</td>
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</table>

### Light source
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
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<td>FOV</td>
<td>&gt; 0.6 mm</td>
</tr>
<tr>
<td>NA</td>
<td>0.95</td>
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<tr>
<td>shutter/flash</td>
<td>up to 120 Hz</td>
</tr>
<tr>
<td>intensity range</td>
<td>1:30</td>
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</tbody>
</table>

350 x 350 μm/view
Digital filters

Concepts:
Chorus note 97/27

Number of layers hit out of 16 (tracks)

5 cycles/pixel
⇒ 2x40 Mpixel images/s

35 assembler instructions on C620 (VLIW)
Prediction tracking

- CCD image capture
- Byte reordering
- Digital filter (3-pole IIR)
- Zero suppression
- Clustering
- Predicted angle tracking

DSP C81
Assembler
5ms

DSP C620
Assembler
25ms
5ms

DMA transfer
20ms

Dual PII 333
C++
<1s (20 images)

Flow diagram

Scanback
- 25 images
- 100 micron thickness
- predicted angle

Vertex analysis
- 2 x 60 images
- 2 x 350 micron
- all angles up to 400 mrad
Tracking results

Neutrino vertex

Distance to vertex
- 0.03 µm
- 0.05 µm
- 0.19 µm

Zoom in of vertex

J. Uiterwijk et al., in preparation
**CHORUS Phase II: net scan**

All track segments ($\theta < 0.4$ rad) in

Fiducial volume: $1.5 \times 1.5 \ mm^2 \times 8$ plates

Offline analysis of emulsion data

- Track segments from 8 plates overlapped
- At least 2-segment connected tracks
- Eliminate passing-through tracks
- Reconstruct full vertex topology
Charm selection

- matching to electronic detectors
- track and vertex fitting (MCS)
- displaced vertex with at least one or more matched tracks OR
- isolated, matched track with large impact parameter
## High purity selection

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<th>tight</th>
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<tr>
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<td>291</td>
<td>261</td>
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<tr>
<td>charm</td>
<td>261</td>
<td>242</td>
<td>236</td>
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<tr>
<td>secondary</td>
<td>29</td>
<td>28</td>
<td>13</td>
</tr>
<tr>
<td>background</td>
<td>48</td>
<td>21</td>
<td>12</td>
</tr>
<tr>
<td>not checked</td>
<td>14</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>primary</td>
<td>13</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>e+e-</td>
<td>6</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>passing</td>
<td>8</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>fake vee</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>unrelated 2ry</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>
Outlook

• **D^0 production rate**
  Data taking ongoing: 25k CC → 200k CC
  Improved selection: purity 65% → 90%

  No need for manual?

• **Inclusive charm, including charged**
  ~ 4,000 neutrino-induced charm events
  Fragmentation fractions $D^0 : D^+ : D_s^+ : \Lambda_c^+ : B(c \rightarrow \mu), V_{cd}, s(x), ...$

• **Associated charm production**
  Background evaluation based on CHORUS data and FLUKA
  Improved selection: efficiency 1% → 25%

• **Exclusive channels**
  Proton identification
  MCS momentum measurement
  $\Sigma^\pm$ detection

  $\Lambda_c$ absolute BR, QE $\Lambda_c$ production, $D^{*+} \rightarrow D^0 \pi^+$
The CKM matrix

\[
\begin{pmatrix}
  d' \\
  s' \\
  b'
\end{pmatrix}
= \begin{pmatrix}
  V_{ud} & V_{us} & V_{ub} \\
  V_{cd} & V_{cs} & V_{cb} \\
  V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\begin{pmatrix}
  d \\
  s \\
  b
\end{pmatrix}
\]

- **V_{ud}**: 0.1% nuclear beta decay
- **V_{us}**: 1% $K_{e3}$ decay
- **V_{ub}**: 25% $b \rightarrow u \nu \nu$
- **V_{cd}**: 7% $\nu$ charm production
- **V_{cs}**: 15% $D_{e3}$ decay
- **V_{cb}**: 5% $B_{e3}$ decay
- **V_{td}**: $\nu$ charm production
- **V_{ts}**: $\nu$ charm production
- **V_{tb}**: 30% $t \rightarrow b \nu \nu$

Review of particle physics, 98 edition
Measuring $V_{cd}$

\[
\begin{align*}
\sigma_{V\mu CC}^{charm} & \sim \sigma_{V\mu CC}^{all} \\
\propto d(x) |V_{cd}|^2 + s(x) |V_{cs}|^2 \\
& \propto \frac{|V_{cd}|^2 + s|V_{cs}|^2}{1 + s/d} \\
& \propto |V_{cd}|^2 \\
\text{s} \to 0 \quad \text{for large } x_{\text{Bjorken}}
\end{align*}
\]

**Difficulties**

- No antineutrino data in emulsion (5% contamination in neutrino mode)
- No invariant mass reconstruction or particle ID (inclusive analysis)
- Biases in the sample of vertices located in Nagoya (CERN microscopes)
- Too low statistics for the time being (Phase II rescan of all events)
- Hadronic decays more interesting than muonic ones, but harder (Net scan both in Nagoya and at CERN)
A microscope view

Plates are orthogonal to the neutrino beam

An AgBr emulsion grain has about 0.5 mm diameter

Large angle nuclear fragments (if any) are seen as a ‘star’ of heavy ionizing ‘tracks’ in the vertex view

Interaction tracks are seen as the coincidence of a single grain from each view