RESULTS from the
CHORUS EXPERIMENT

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OVERVIEW

- Physics Goals
- The Detector
- Data Selection and Analysis
- Results:
  - Oscillation Limit
  - Ds Observation
- Outlook and Conclusions
$\nu_\mu \rightarrow \nu_\tau$ Oscillations

- If $m_\nu > 0$ and mixing of family

- If $m_\nu \sim 10$eV (see-saw models)

$\nu_\tau$ it's a good candidate as hot dark matter!

It's important study process involving $\nu_\tau$

- $\text{Prob}(\nu_\mu \rightarrow \nu_\tau) = \sin^2(2\theta) \sin^2(\frac{\Delta m^2 L}{4E})$

- The previous limit for $\nu_\mu \rightarrow \nu_\tau$ oscillation (E531) was $\sin^2(2\theta) < 5 \times 10^{-3}$

Explore mixing angles down to $\sin^2(2\theta) \sim 10^{-4}$

- Charm Physics

- 3 -
CERN Wide Band $\nu$ Beam

High Intensity: $> 2 \times 10^{13}$ protons/cycle

High Energy: $< E_{\nu_\mu} > \approx 27$ GeV

Low Contamination: $\frac{N_{\nu_e}}{N_{\nu_\mu}} \sim 3 \times 10^{-6}$

Two 6 ms bursts/ 14.4 s

$L \approx 600$ m
CHORUS is...

- A classic "appearance experiment"....

- Aim:

CHORUS looks for:

identification of $\nu_\tau$ EVENT by EVENT

detecting both $\nu_\tau$ interaction and $\tau$ decay vertices

- In particular

We should isolate "few" signal events

CC interaction: $\nu_\tau N \rightarrow \tau^- X$

$\rightarrow \mu^- \nu \nu$ 18%

$\rightarrow h^- \nu + n\pi^0$ 50%

$\rightarrow h^- h^- h^+ + n\pi^0$ 14%

- From the large background of

- $\nu_\mu N \rightarrow \mu^- X$ (CC)

- $\nu_\mu N \rightarrow \nu_\mu X$ (NC)
The Chorus Idea

- Use a "big" active target (800 kg) of Nuclear Emulsions
  \((\sim 1.\mu m \text{ of resolution})\)
  
  \(\tau^- \text{ has lifetime } c\tau=90 \mu m \Rightarrow \sim 1.5 \text{ mm flight path}\)
  
  with:

- Automatic Scanning facilities
  (Reduce the Scanning Time)

- High resolution tracking devices
  (Reduce the Scanning Area)

- Electronic Detectors with good \(E, P, \theta\) resolution
  (Scanning Sample Reduction and Kinematical Reconstruction)
The CHORUS Detector

Calorimeter
\[ E_{\text{had}}, \Theta_{\text{had}} \]
\[ \Delta E/E \sim 0.35 / \sqrt{E} \]

Magnet Spectrometer
\[ q_{\text{had}}, p_{\text{had}} \]
\[ \Delta p/p \sim 0.25 @ 5 \text{ GeV/c} \]

Muon Spectrometer
\[ p_\mu, q_\mu \]
\[ \Delta p/p \sim 10 - 20 \]
(for \( p < 100 \text{ GeV} \))

Emulsion Target and Target Tracker

T2
T1

G. Cates, SS11998
Target Tracker resolution

- Obtained by comparing reconstructed tracks with tracks scanned in emulsion
- Resolution: 200 $\mu m$, 3 mrad
Automatic Scanning

Automatic microscope

CCD

TOMOGRAPHIC IMAGE

TO VIDEO PROCESSOR

reconstruction by hardware video processor (1–3 sec/event)

emulsion

× 50
focal depth 5μm
(one view
512 × 512 pixels
120 × 150μm²)

frame (formed by adjacent views)

track (● matching grains)
**μ⁻ Channel**

**Flightlength:** \[20 \mu m \leq \gamma c \tau \leq 5 \text{ mm}\]

...to reject K decays

**Conditions for Daughter-Track:**

\[\tau \rightarrow \mu \bar{\nu}_\mu \nu_\tau\]

- Track to follow: negatively charged muon

\[P_T \geq 250 \text{ MeV/c}\]

\[P_{\mu^-} \leq 30 \text{ GeV/c}\]

- Main BG Source:

\[\bar{\nu}_\mu N \rightarrow \mu^+ X D^-\]

escapes identification \[\rightarrow \mu^- \bar{\nu}_\mu K^0\]

\[\frac{10^{-7}}{N_{\nu_\mu}^{\text{obs}}}\]
$\tau \rightarrow 50\% \nu_\tau h^- (n\pi^0)$

- Track to follow: negatively charged hadron

- Kinematical Cut:

  $1 \text{GeV/c} \leq P_{h^-} \leq 20 \text{GeV/c}$

  $P_T \geq 250 \text{MeV/c}$

- Main BG Source:

  $\bar{\nu}_\mu N \rightarrow \mu^+ X D^-$

  escapes identification ...

  $h^- + \text{neutr.} \approx \frac{10^7}{N_{\nu_\mu}}$

  $h^- N \rightarrow h^- N$

  (WK) without visible recoil ...

  $\approx \frac{10^6}{N_{\nu_\mu}}$
Vertex Kinematics: Transverse Plane

**Signal:** $\tau^-$

$\nu_\tau N \rightarrow \tau^- X$

$\Theta \sim 180^\circ$

$\pi^-$ (or other $\tau^-$ daughters)

**Background:**

"White Kink"

$\nu_\mu N \rightarrow \nu_\mu \pi X$

$\Theta$ small

Charm ($D^-$) Decays

$\bar{\nu}_\mu N \rightarrow \mu^+ D^- X$

$\Theta \equiv$ Transverse Angle between Kink Parent and Hadron Shower
Vertex location

vertex plate

Location efficiency

Vertex location procedure
Detection Strategy

○ SHORT DECAY (1 plate) [30%]

Impact Parameter Methode
\[ \nu_\mu \rightarrow IP \sim 0 \]
\[ \nu_\tau \rightarrow IP > 0 \]

○ LONG DECAY, LARGE ANGLE [60%]

Video Image Analysis
Tracking through CCD pixel clusters from 96 emulsion slices

+ 1995:

Parent Track Search
Connection of parent with muon by IP
BG track suppression

○ LONG DECAY, SMALL ANGLE [10%]

\[ P_T = \frac{P_\mu}{P_\nu} \cdot |\phi_\mu - \phi_\nu| \geq 250 \text{ MeV/c} \]
"Short" Decay (27\%)}

vertex and decay in same plate

VERTEX PLATE
800 \( \mu \)m

NOM ZERO IMPACT PARAMETER

\( \nu_{\tau} \)

ZERO IMPACT PARAMETER

\( \nu_\mu \)

SB \( \mu^- \)

tracker predictions

SB \( \mu^- \)

tracker predictions

measured track segment

impact parameter cut

Data

to eye scan

\( \nu_{\tau}.MC \)

arbitrary units

Impact par. [\( \mu \)m]
**Vertex Properties**

<table>
<thead>
<tr>
<th>Nuclear Fragments:</th>
<th>Shower particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 200 grains/ 100 ( \mu m )</td>
<td>30 – 40 grains/100 ( \mu m )</td>
</tr>
<tr>
<td>( \sim ) 5.3 tracks/ event</td>
<td>( \sim ) 3.6 tracks/event</td>
</tr>
</tbody>
</table>

*From University of Bari*
\[ \nu N \rightarrow D^+ \mu^- X \]

Dimuon Event in the Emulsion

160 units
Video image of vertex reconstruction in Emulsion at Nagoya

Video image of tracks reconstruction at the vertex in two projections
# Data
(data taking finished in 1997)

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pot/10^{19}</td>
<td>0.81</td>
<td>1.20</td>
<td>1.38</td>
<td>1.67</td>
<td>5.06</td>
</tr>
<tr>
<td>Chorus efficiency</td>
<td>0.77</td>
<td>0.88</td>
<td>0.94</td>
<td>0.94</td>
<td>0.90</td>
</tr>
<tr>
<td>Potato/10^{19} *)</td>
<td>0.62</td>
<td>1.06</td>
<td>1.30</td>
<td>1.76</td>
<td>4.74</td>
</tr>
<tr>
<td>Deadtime</td>
<td>0.10</td>
<td>0.10</td>
<td>0.13</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Main triggers</td>
<td>388 k</td>
<td>547 k</td>
<td>617 k</td>
<td>719 k</td>
<td>2271K</td>
</tr>
<tr>
<td>CC per main trigger</td>
<td>0.30</td>
<td>0.37</td>
<td>0.38</td>
<td>0.40</td>
<td>0.37</td>
</tr>
<tr>
<td>1\mu events</td>
<td>66911</td>
<td>110916</td>
<td>129669</td>
<td>151105</td>
<td>360K</td>
</tr>
<tr>
<td>0\mu events</td>
<td>17731</td>
<td>27841</td>
<td>32548</td>
<td>37929</td>
<td>120K</td>
</tr>
<tr>
<td>1\mu scanned so far</td>
<td>63%</td>
<td>45%</td>
<td>56%</td>
<td>0%</td>
<td>36%</td>
</tr>
<tr>
<td>0\mu scanned so far</td>
<td>50%</td>
<td>30%</td>
<td>0%</td>
<td>0%</td>
<td>15%</td>
</tr>
<tr>
<td>1\mu located so far</td>
<td>18286</td>
<td>20642</td>
<td>30128</td>
<td>0</td>
<td>68156</td>
</tr>
<tr>
<td>0\mu located so far</td>
<td>3401</td>
<td>3805</td>
<td>0</td>
<td>0</td>
<td>7206</td>
</tr>
</tbody>
</table>

*) Protons On Target And Tape On
Results

36182N_{1\mu} + 6844N_{0\mu} \Rightarrow \text{Accepted for publication on Phys. Lett. B (CERN - EP/98 - 73)}

New data: 31974N_{i\mu} + 362N_{0\mu} \text{ events have been analysed}

No \nu_{\tau} candidate has been found!

@ 90\% C.L. \quad P_{\mu\tau} \leq \frac{2.38 \cdot r_\sigma \cdot r_A}{BR_{\mu} \cdot <\varepsilon_{\tau\mu}> \cdot [N_{\mu} + N^{eq}_{\mu}]} = 6.0 \cdot 10^{-4}

where \quad N^{eq}_{\mu} = (N_{\mu})_{0-\mu} \cdot \sum_{i=2}^{4} \frac{<A_i>}{<A_{\tau\mu}>} \cdot \frac{<\varepsilon_i>}{<\varepsilon_{\tau\mu}>} \cdot \frac{BR_i}{BR_{\mu}}

if i=4 the \mu is not identified
The exclusion plot (@ 90% C.L.)
A special event

\[ D_s^* + N \rightarrow D_s^+ + \gamma \]

\[ \nu_\mu N \rightarrow \mu^- \]

Parallel session 5 July 25th talk given by O. Melzer
INTERPRETATION

- Two Decays within 215 μm

⇒ CHARM Decay

- Double KinK:

\[ D^+ \rightarrow K^+ \rightarrow \mu^+ \quad \text{Prob: } 9 \times 10^{-4} \]
\[ D_s^+ \rightarrow K^+ \rightarrow \mu^+ \quad \text{Prob: } 2 \times 10^{-4} \]
\[ D_s^+ \rightarrow \omega K \rightarrow \mu^+ \quad \text{Prob: } 3 \times 10^{-3} \]
\[ D_s^+ \rightarrow K^+ \rightarrow \mu^+ \quad \text{Prob: } 0.96 \]

- \(\gamma\) Conversion

\[ D_s^* \rightarrow D_s \gamma \]

- neutral particle interaction in calorimeter

⇒ Signal of a neutron
INTERPRETATION-2

- ...Small $Q^2$ ... Small $t$

$$Q^2 = (0.8 \pm 0.1) \text{ GeV}^2/c^2$$

$$t = (1.1 \pm 0.4) \text{ GeV}/c^2/c^2$$

- ...no nuclear break-up at the primary vertex

DIFFRACTIVE PRODUCTION of $D_s^*$
OUTLOOK and CONCLUSIONS

- The Electronic Detector Data Taking finished successfully in 1997 and the Emulsion Scanning is goin on

- The Automatic Vertex location is realible and fast

- The Automatic Kink finding procedure works and is improving in speed and efficency

- When we will complete the scanning of the whole statistic we will gain:
  - a factor 3.0 for the 1 $\mu$ sample
  - a factor 6.7 for the 0 $\mu$ sample

If no $\tau$ candidate will be found:

\[ \sin^2(2\theta) \sim 2 \times 10^{-4} \]