Configuration of the tau neutrino detector

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New Muon Shield Configuration

Hans presentation yesterday

μ flux

0 1.8 1.8 29.5 1458
New sizes for the $\nu$ detector

Maximum possible sizes of the neutrino detector in the transverse plane at the beginning of our region, at the $z$ of the first drift tube assuming it at the same distance as in TP and at the beginning of the decay volume.

<table>
<thead>
<tr>
<th>$\Delta z$ from target (m)</th>
<th>$z$ (m)</th>
<th>$\Delta x$ (m)</th>
<th>$\Delta y$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.1</td>
<td>-35</td>
<td>1.7</td>
<td>3.32</td>
</tr>
<tr>
<td>40.1</td>
<td>-30</td>
<td>1.9</td>
<td>3.8</td>
</tr>
<tr>
<td>45.1</td>
<td>-25</td>
<td>2.1</td>
<td>4.2</td>
</tr>
</tbody>
</table>

$z$(Target) = -7010 cm

$z$ = -3500 cm  
Start of $\nu$ target region

$z$ = -3000 cm  
1$^{st}$ Drift Tube

$z$ = -2500 cm  
End of $\nu$ target region

$z$(TT4) = 3540 cm
Sizes for $\nu$ detector in the transverse plane

By taking a look at the transverse plane at the beginning of the neutrino detector region, assuming a $\nu$ target of $0.8 \times 1.6 \text{ m}^2$:

- In these 80 cm, there should be placed:
  - Read-out electronics of Target Tracker planes
  - Cooling system
  - Magnet coils
  - Return field

Goliath magnet would not fit anymore.
New magnet project to be done
New Magnet Layout

Different options under study

By D. Tommasini

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak field in the aperture [T]</td>
<td>1.0</td>
</tr>
<tr>
<td>Free aperture HxV [mm x mm]</td>
<td>1000 x 1500</td>
</tr>
<tr>
<td>Coil weight [t]</td>
<td>25</td>
</tr>
<tr>
<td>Yoke weight [t]</td>
<td>95</td>
</tr>
<tr>
<td>Coils cost [kCHF]</td>
<td>750</td>
</tr>
<tr>
<td>Yoke cost [kCHF]</td>
<td>250</td>
</tr>
<tr>
<td>Power consumption [MW]</td>
<td>about 1</td>
</tr>
</tbody>
</table>

- Dimensions similar to those required for this new configuration
- Not easy to perform target extraction for the target replacement
New Magnet Layout

Different options under study

- Magnet field 1.2T
- Magnet gap height 1m
- Radius of coil center = distance of coil centers 1.45m
- Coil cross section 0.4m x 0.4m
- Current 3570A
- Total power 0.57MW
- Cover plate 4.5m 4.5m 0.5m
- Column cross section 1.1x1.1m² - 0.6x0.6m²
- Outer flux return 2.3m x 0.5m x 0.25m
- Total magnet size 4.5m x 4.5m x 3m

Still to be optimized

By Walter Schmidt-Parzefall

- Horizontal magnetic field
- Allows extraction of the target from the top
New detector layout

Implementation in Geant4 performed by A. Di Crescenzo

Started from Walter idea: shrunked the x/y dimensions so to fit in the allowed region

Opening allowing the extraction of the target
New detector layout

Implementation in Geant4 performed by A. Di Crescenzo

Target extraction from the top

Neutrino target

Magnetic spectrometer

Incoming $\nu$ flux

3.2 m

4.5 m

3.8 m

10 m
Neutrino target

- 6 columns (along x direction)
- 12 rows (along y direction)
- 11 walls (along z direction)
- 12 layers of Target Trackers (upstream layer acting as veto)

Total dimensions: 0.8x1.6x2 m³
Fluxes of incoming neutrinos

Neutrino spectra produced by Thomas and extrapolated at z of the neutrino target

<table>
<thead>
<tr>
<th></th>
<th>New Config</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flux</td>
<td>&lt;E&gt; (GeV)</td>
</tr>
<tr>
<td>$\nu_\mu$</td>
<td>9.6x10$^{16}$</td>
<td>6.7</td>
</tr>
<tr>
<td>$\nu_e$</td>
<td>6.6x10$^{15}$</td>
<td>18.8</td>
</tr>
<tr>
<td>$\nu_\tau$</td>
<td>3.1x10$^{14}$</td>
<td>24.6</td>
</tr>
<tr>
<td>$\nu_\mu$-bar</td>
<td>7.8x10$^{16}$</td>
<td>6.3</td>
</tr>
<tr>
<td>$\nu_e$-bar</td>
<td>4.5x10$^{15}$</td>
<td>29.2</td>
</tr>
<tr>
<td>$\nu_\tau$-bar</td>
<td>3.1x10$^{14}$</td>
<td>23.6</td>
</tr>
</tbody>
</table>

With respect to TP
- Gain on incoming $\nu_\tau$ flux of $\approx$ factor 2 partially compensated by lower mean energy
Fluxes of CC interacting neutrinos

<table>
<thead>
<tr>
<th>Interacting ν on target</th>
<th>New Config</th>
<th>TP</th>
</tr>
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<tbody>
<tr>
<td>Flux</td>
<td>&lt;E&gt; (GeV)</td>
<td>Flux</td>
</tr>
<tr>
<td>ν$_{\mu}$</td>
<td>1.9x10$^6$</td>
<td>26.1</td>
</tr>
<tr>
<td>ν$_{e}$</td>
<td>3.4x10$^5$</td>
<td>49.8</td>
</tr>
<tr>
<td>ν$_{\tau}$</td>
<td>9.1x10$^3$</td>
<td>55.3</td>
</tr>
<tr>
<td>ν$_{\mu}$-bar</td>
<td>6.8x10$^5$</td>
<td>20.7</td>
</tr>
<tr>
<td>ν$_{e}$-bar</td>
<td>1.6x10$^5$</td>
<td>57.2</td>
</tr>
<tr>
<td>ν$_{\tau}$-bar</td>
<td>4.5x10$^3$</td>
<td>55.3</td>
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With respect to TP
- ≃ 1.2 the number of CC interactions from ν$_{\tau}$ and anti-ν$_{\tau}$
- Neutrino interactions for the following studies have been performed with NuAge - tuned version with NOMAD neutrino data (A. Chukanov)
DETECTOR
PERFOMANCES
Background sources

The main background source in $\nu_\tau$ and anti-$\nu_\tau$ searches is the charm production in anti-$\nu_\mu$ CC ($\nu_\mu$ CC) and anti-$\nu_e$ CC ($\nu_e$ CC) interactions, when the primary lepton is not identified.

### Expected v-induced charm fraction and yield in 5 years run (NEW CONFIG)

<table>
<thead>
<tr>
<th></th>
<th>Flux</th>
<th>$&lt;E&gt;$ (GeV)</th>
<th>charm/CC (%)</th>
</tr>
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<tbody>
<tr>
<td>$\nu_\mu$</td>
<td>$6.6x10^4$</td>
<td>46.5</td>
<td>3.5</td>
</tr>
<tr>
<td>$\nu_e$</td>
<td>$2.1x10^4$</td>
<td>60.2</td>
<td>6.2</td>
</tr>
<tr>
<td>$\nu_\mu$-bar</td>
<td>$2.0x10^4$</td>
<td>39.5</td>
<td>3.0</td>
</tr>
<tr>
<td>$\nu_e$-bar</td>
<td>$1.1x10^4$</td>
<td>66.3</td>
<td>6.6</td>
</tr>
</tbody>
</table>

### (TP CONFIG)

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<td>4.1</td>
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<td>$1.5x10^4$</td>
<td>57.0</td>
<td>6.0</td>
</tr>
<tr>
<td>$\nu_\mu$-bar</td>
<td>$2.7x10^4$</td>
<td>43.4</td>
<td>4.1</td>
</tr>
<tr>
<td>$\nu_e$-bar</td>
<td>$5.4x10^3$</td>
<td>56.7</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Muon Identification

Muons produced in $\nu_\mu$ CC interactions with charm production in the target
• 73% reach the Spectrometer without entering the target Magnet (A)
• 1% stop in the neutrino target
• 3% exit laterally from the neutrino target
• 23% enter in the David Magnet
  • 1% absorbed in the David Iron (B)
  • 22% exit from David
    • 17% reach the first DTT plane
    • 5% don’t reach the first DTT plane
Muons produced in $\nu_\mu$ CC interactions with charm production in the target

- 73% reach the Spectrometer without entering the target Magnet (A)
- 1% stop in the neutrino target
- 3% exit laterally from the neutrino target
- 23% enter in the David Magnet
  - 1% absorbed in the David Iron (B)
  - 22% exit from David
    - 17% reach the first DTT plane
    - 5% don’t reach the first DTT plane
Requirements:
1. track crossing 3 RPC layers in the ARM1 of the Magnetic Spectrometer
2. track crossing the Goliath Iron and reaching at least the first DTT plane

The usage of the Drift Tube Tracker plane for the muon identification in case 2. increases the muon identification efficiency of about 2%

\[ \mu^+ \text{ in anti-} \nu_\mu^{cc} \text{ charm} \]

\[ \tau^- \rightarrow \mu^- \]

Primary muon identification efficiency
\[ \varepsilon^{1\text{ry}}_{\mu\text{ID}} = 90\% \]

Decay muon identification efficiency
\[ \varepsilon^{2\text{ry}}_{\mu\text{ID}} = 89\% \quad (90\%) \]

\( ( ) = \text{values from TP} \)
Signal and Background expectation

Only topological selection considered (primary lepton identification and charge measurement)

**Example:** evaluation of signal and background in the $\tau^- \rightarrow \mu^-$ decay channel

$$N_{signal}^{\tau^- \rightarrow \mu^-} = N_{\nu_{\tau}} \times Br(\tau \rightarrow \mu) \times \varepsilon_{\mu ID}^{2r_y} \times \varepsilon_{charge}^\mu$$

$$N_{bkg}^{\tau^- \rightarrow \mu^-} = N_{bkg}(\nu_{\mu CC}) + N_{bkg}(\nu_{eCC}) + N_{bkg}(\bar{\nu}_{eCC}) + N_{bkg}(\bar{\nu}_{\mu CC})$$

$$N_{bkg}(\nu_{\mu CC}) = N_{\nu_{\mu}} \times \frac{\sigma_{charm}}{\sigma_{\nu_{\mu} CC}} \times f_{C^+} \times Br(C \rightarrow \mu) \times (1 - \varepsilon_{\mu ID}^{1r_y}) \times \omega_{charge}^\mu$$

<table>
<thead>
<tr>
<th></th>
<th>SIGNAL EVENTS</th>
<th>CHARM BKG</th>
<th>S/B RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau^- \rightarrow \mu^-$</td>
<td>774</td>
<td>59</td>
<td>13.2</td>
</tr>
<tr>
<td>$\tau^- \rightarrow h^-$</td>
<td>1326</td>
<td>151</td>
<td>8.8</td>
</tr>
<tr>
<td>$\tau^- \rightarrow 3h^-$</td>
<td>313</td>
<td>66</td>
<td>4.8</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2413</td>
<td>275</td>
<td>8.8</td>
</tr>
</tbody>
</table>

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<tr>
<td>$\tau^- \rightarrow \mu^-$</td>
<td>570</td>
<td>30</td>
<td>19</td>
</tr>
<tr>
<td>$\tau^- \rightarrow h^-$</td>
<td>990</td>
<td>80</td>
<td>12</td>
</tr>
<tr>
<td>$\tau^- \rightarrow 3h^-$</td>
<td>210</td>
<td>30</td>
<td>7</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1770</td>
<td>140</td>
<td>13</td>
</tr>
</tbody>
</table>
Conclusions

Started studies to understand implications of muon shield optimization on the tau neutrino detector side.

\textit{x and y dimensions of the space cleared from the muon flux smaller wrt TP}

- Not possible to use the Goliath Magnet anymore
  - Layouts suggested by D. Tommasini and W. Schmidt-Parzefall
  - Optimization still to be done
    - Realistic but not refined implementation in Geant4
- Neutrino target layout optimized so to have \(~\) the same number of neutrino interactions as those quoted in the TP

\textbf{NEXT STEPS}

- More neutrino statistic needed to perform a more accurate estimate of incoming neutrino flux
- Implementation in FairSHIP
BACKUP
Charge Measurement

Performed with the Magnetic Spectrometer and the Compact Emulsion Spectrometer

**Hadrons**: *Measured mainly in CES*

Efficiencies for correct charge assignment

\[ \varepsilon_{\text{charge}}^{h} = 68\% \quad (70\%) \]
\[ \varepsilon_{\text{charge}}^{3h} = 45\% \quad (49\%) \]

Misidentification probabilities

\[ \omega_{\text{charge}}^{h} = 0.5\% \]
\[ \omega_{\text{charge}}^{3h} = 1\% \]

**Muons**: *Measured mainly in the Magnetic Spectrometer*

Efficiency for correct charge assignment

\[ \varepsilon_{\text{charge}}^{\mu} = 93\% \quad (94\%) \]

Misidentification probability

\[ \omega_{\text{charge}}^{\mu} = 1.5\% \]

\( () = \text{values from TP} \)
Identification of $\nu_\tau$ and $\nu_\tau$ interactions requires, as a first step, the detection of both the neutrino interaction and the $\tau$ decay vertices.

**Event Location**

Procedure aiming at reconstruction of the neutrino interaction vertex.

- $\Rightarrow$ Vertex 1 mm far from the transverse edges and 5 mm from the downstream edge of the brick
- $\Rightarrow$ Presence of least one track with a momentum larger than 1 GeV/c attached to the primary vertex, with a slope $\tan \theta < 1$

**Decay search**

Procedure aiming at the detection of the $\tau$ decay vertex.

- $\Rightarrow$ Kink angle $> 20$ mrad
- $\Rightarrow$ Impact parameter $> 10$ $\mu$m
Identification of $\nu_\tau$ and $\nu_\tau$ interactions requires, as a first step, the detection of both the neutrino interaction and the $\tau$ decay vertices.

**Geometrical efficiency $\nu_\tau$ CC:** 96 %

**Location efficiency $\nu_\tau$ CC:** 85.7 % (87 %)

**Decay Search efficiencies $\nu_\tau$ CC:**
- $\tau$ -> $\mu$: 73.4 % (72%)
- $\tau$ ->1h: 74.4 % (74%)
- $\tau$ ->3h: 89.7 % (76%)
- $\tau$ ->e: 71.8 % (67%)

**Total efficiencies $\nu_\tau$ CC:** $\varepsilon_{\text{Tot}} = \varepsilon_{\text{Geom}} \times \varepsilon_{\text{Loc}} \times \varepsilon_{\text{DS}}$
- $\tau$ -> $\mu$: 60.4 % (60%)
- $\tau$ ->1h: 61.2 % (62%)
- $\tau$ ->3h: 73.8 % (63%)
- $\tau$ ->e: 59.0 % (56%)

$(\cdot)$ = values from TP