Studies of the nu_tau/LDM target with and without magnetic field

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A short summary

Layout of the SHiP detector as presented in last collaboration meeting

**Neutrino/LDM Target**
- Dimensions: 0.8 x 2 x 1.6 m$^3$
- Number of ECC bricks: 924
- Total mass: ~7 tons
- Horizontal magnetic field

*Optimisation still ongoing*
Light DM searches

- Generated in the beam-dump, e.g. via light dark photon mediators ($V$)
- Main production modes:
  1) direct production
  2) decay in flight
  3) resonant vector meson mixing

- Detected when scattering on atomic electrons of the target
Detector optimization for Light DM searches

- Improvement of SHiP sensitivity in LDM search requires a dedicated optimization of the emulsion detector, concerning:

1) **Data analysis tools:**
   - electromagnetic shower identification
   - electron energy measurement

2) **Detector layout:**
   - increase the detector mass
   - structure and material of ECC
   - Remove the magnet surrounding the neutrino detector
   - Explore different segmentations of passive material
   - Explore use of W rather than Pb
Detector optimization for Light DM searches

MASS INCREASE

Pros

1) increase in the LDM sensitivity
2) increase in neutrino statistics
3) CES not needed anymore: simplification of the target, further increase in target mass
4) Avoid multiple scattering in magnet iron

Contra

1) CES not needed anymore: charge measurement of hadrons not possible
2) only muonic tau channel (Br 17%) used for $\nu_\tau$/anti-$\nu_\tau$ separation
3) momentum measurement for hadron rely only on MCS in the brick

TARGET MAGNETIZATION

Pros

1) hadronic (Br 65%) and muonic (Br 17%) tau decay channels used for $\nu_\tau$/anti-$\nu_\tau$ separation
2) momentum measurement for hadrons performed with MCS algo in the brick and with sagitta method in CES

Contra

1) lower sensitivity in LDM search
2) target volume limited by the magnetized region
3) Multiple scattering in magnet iron
New neutrino/LDM target layout implemented

Optimisation still ongoing
New neutrino/LDM target layout

**Neutrino Target**
- 9 columns (along x direction)
- 20 rows (along y direction)
- 20 walls (along z direction)

**Total number of bricks: 3600**
(increase $\approx x4$ in the target mass)

**Magnetic Spectrometer**
- Reduced transversal dimension so to completely fit in the free muon background region

*Optimisation still ongoing*
# Expected CC Neutrino Interactions

## WITH MAGNET

<table>
<thead>
<tr>
<th>Neutrino Type</th>
<th>Flux</th>
<th>&lt;E&gt; (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_\mu$</td>
<td>$2.3 \times 10^6$</td>
<td>31</td>
</tr>
<tr>
<td>$\nu_e$</td>
<td>$6.3 \times 10^5$</td>
<td>50</td>
</tr>
<tr>
<td>$\nu_\tau$</td>
<td>$2.6 \times 10^4$</td>
<td>45</td>
</tr>
<tr>
<td>$\bar{\nu}_\mu$</td>
<td>$8.6 \times 10^5$</td>
<td>26</td>
</tr>
<tr>
<td>$\bar{\nu}_e$</td>
<td>$2.2 \times 10^5$</td>
<td>38</td>
</tr>
<tr>
<td>$\bar{\nu}_\tau$</td>
<td>$1.9 \times 10^4$</td>
<td>58</td>
</tr>
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</table>

## WITHOUT MAGNET

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<td>$1.7 \times 10^5$</td>
<td>45</td>
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<tr>
<td>$\nu_\tau$</td>
<td>$7.5 \times 10^4$</td>
<td>43</td>
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</tr>
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<td>36</td>
</tr>
<tr>
<td>$\bar{\nu}_\tau$</td>
<td>$4.7 \times 10^4$</td>
<td>54</td>
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Expected Neutrino-induced charm events

**WITH MAGNET**

<table>
<thead>
<tr>
<th></th>
<th>Flux</th>
<th>&lt;E&gt; (GeV)</th>
<th>charm/CC (%)</th>
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</thead>
<tbody>
<tr>
<td>$\nu_\mu$</td>
<td>$1.0 \times 10^5$</td>
<td>48</td>
<td>4.3</td>
</tr>
<tr>
<td>$\nu_e$</td>
<td>$3.9 \times 10^4$</td>
<td>59</td>
<td>6.3</td>
</tr>
<tr>
<td>$\bar{\nu}_\mu$</td>
<td>$3.6 \times 10^4$</td>
<td>41</td>
<td>3.8</td>
</tr>
<tr>
<td>$\bar{\nu}_e$</td>
<td>$1.2 \times 10^4$</td>
<td>49</td>
<td>5.3</td>
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**WITHOUT MAGNET**

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<tr>
<td>$\bar{\nu}_e$</td>
<td>$3.2 \times 10^4$</td>
<td>46</td>
<td>4.9</td>
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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.
Implementation of neutrino interactions with Genie

- Neutrino interactions generated in Genie on Pb (1.4% $^{204}\text{Pb}$, 24.1% $^{206}\text{Pb}$, 22.1% $^{207}\text{Pb}$, 52.4% $^{208}\text{Pb}$)

$R = \sqrt{x^2 + y^2}$

Example with $\nu_\tau\text{CC}$ in config. with magnet

NB: Interactions not scaled to one spill!
Spectra of generated neutrino interactions

WITH MAGNET

\( \nu_\tau \text{ CC} \)

Mean 49.45 ± 0.7757

\( \bar{\nu}_\tau \text{ CC} \)

Mean 64.13 ± 0.688

WITHOUT MAGNET

\( \nu_\tau \text{ CC} \)

Mean 46.4 ± 0.5745

\( \bar{\nu}_\tau \text{ CC} \)

Mean 58.54 ± 0.56
Location and Decay Search efficiencies (signal)

<table>
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<tr>
<th>τ → µ</th>
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<th>WITHOUT MAGNET</th>
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</thead>
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<tr>
<td></td>
<td>ε_{LOC} (%)</td>
<td>ε_{DS} (%)</td>
</tr>
<tr>
<td>τ → µ</td>
<td>78</td>
<td>79</td>
</tr>
<tr>
<td>τ → e</td>
<td>76</td>
<td>73</td>
</tr>
<tr>
<td>τ → h</td>
<td>74</td>
<td>75</td>
</tr>
<tr>
<td>τ → 3h</td>
<td>77</td>
<td>86</td>
</tr>
</tbody>
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- To locate a neutrino interaction:
  - at least 2 visible tracks at ν interaction vtx
  - at least one track of ν interaction vtx with p>1GeV
- Criteria used to select τ candidates (Decay Search):
  - kink angle>20 mrad
  - IP daugther w.r.t ν interaction vtx >10 μm

**Visible tracks**
- charged
- p>100 MeV/c
- $\text{tg } \theta_x$ and $\text{tg } \theta_y < 1$ rad
Energy spectra of located events

**WITH MAGNET**

- $\nu_\tau$ CC
- $\overline{\nu}_\mu$-bar CC charm

**WITHOUT MAGNET**

- $\nu_\tau$ CC
- $\overline{\nu}_\mu$-bar CC charm
Impact parameter and kink angle distributions

$\tau \rightarrow h$

![Graph of impact parameter and kink angle distributions](image-url)
Kinematical Variables

- Help in discriminating $\tau$ vs Charm events
- Different according to the different decay channel
- For TP used loose cuts:
  - $\tau \rightarrow e$
    - $p_e > 1$ GeV
    - $p_T > 100$ MeV
  - $\tau \rightarrow \mu$
    - $p_\mu > 1$ GeV
    - $p_T > 250$ MeV
  - $\tau \rightarrow 1h$
    - $p_h > 1$ GeV
    - $p_T > 100$ MeV
    - $\Phi_{\text{mod}} > \pi/2$
  - $\tau \rightarrow 3h$
    - $p_{3h} > 3$ GeV
    - $\Phi_{\text{mod}} > \pi/2$

- **Next step:** MVA to perform optimal S vs B discrimination

![Diagram showing kinematical variables and discriminating angles](image-url)
Required at least 3 hits in the RPCs of the downstream Muon Magnetic Spectrometer

**WITH MAGNET**

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</tr>
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<td>$\nu_\mu$-bar charm</td>
<td>64</td>
</tr>
<tr>
<td>$\nu_\tau$-bar</td>
<td>91</td>
</tr>
<tr>
<td>$\nu_\mu$ charm</td>
<td>63</td>
</tr>
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</table>

- Differences between charm and $\tau$ due to:
  - Lower mean energy of muon produced from charm decay
  - Wider angular distribution of muon produced from charm decay
Checks on Muon Identification Efficiency ($\tau$/charm)

- Average energy of muons from $\tau$: 9.2 GeV
- Average energy identified muons: 11.3 GeV
- Average energy not identified muons: 2.5 GeV

- Average energy of muons from charm: 4 GeV
- Average energy identified muons: 5.5 GeV
- Average energy not identified muons: 1.1 GeV
Checks on Muon Identification Efficiency ($\tau$/charm)

- RMS of slope distribution for identified muons $\sim85\text{ mrad}$
- RMS of slope distribution for not identified muons $\sim300\text{ mrad}$

RMS of slope distribution for identified muons $\sim85\text{ mrad}$
RMS of slope distribution for not identified muons $\sim350\text{ mrad}$
Muon Identification Efficiency

Required at least 3 hits in the RPCs of the downstream Muon Magnetic Spectrometer

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- Differences between the two configurations given by:
  - Lower mean energy of anti-$\nu_\tau$ in no magnet configuration option
  - Slightly lower energy of $\nu$-charm events in no magnet configuration option -> slightly lower average energy of muon from charm
  - NB: Statistics still very limited
Conclusions

• Evaluation of the performances of the emulsion detector in the two options: with/without magnet
  • Neutrino interactions produced with Genie
  • Used GenieGenerator for propagation in the detector
  • Evaluation of location and decay search efficiencies for $\nu_\tau$ interactions
  • Evaluation of muon identification efficiency for signal and charm background

• Next steps:
  • Further optimisation of the two configurations
  • Reproduce all TP studies in both configurations

• Results of these studies will be the subject of a paper