Short baseline neutrino and anti-neutrino oscillation studies at the CERN-SPS

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36th ICHEP, Melbourne, July 4-11, 2012
Outline

- Theoretical motivation
- Experimental motivation
- A conclusive experiment
  - Where: CERN
  - How: LAr + spectrometers
  - When: now!
- Conclusions
State of the art of (standard) neutrino physics (btw, beyond the SM!)

- There are 3 species of (light) neutrinos, with $m \leq m_Z/2$ (from LEP)
- They oscillate, so they have mass and mix (flavor basis ≠ mass basis)

We know

- 3 mixing angles $\theta_{12}$, $\theta_{23}$, $\theta_{13}$
- 2 mass square differences $\Delta m^2_{12}$, $\Delta m^2_{23} \sim \Delta m^2_{13}$

We do not know

- Mass hierarchy
- $\delta$ phase (CPV)
- Mass absolute values
- Neutrino nature (Dirac vs Majorana)

Theoretical motivations
Theoretical motivations

- Besides this solid scenario the quest for sterile neutrinos never stopped.
- A sterile neutrino is a neutral lepton without direct EW coupling (only through mixing with active states).
- A sterile neutrino is nothing but an exotic particle.
  - SM automatically introduces sterile neutrino states through mass generation.
  - See-saw mechanism introduces “adjustable” neutrino-mass scale.

![Graph showing the relationship between active-sterile mixing and right-handed neutrino mass](image.png)

*Active-sterile mixing as a function of the right-handed neutrino mass $M_R$ for different values of active neutrino masses $m_\nu$.***
In the last decade a set of experimental results challenged the 3 ν framework → no one conclusive, but all pointing toward the same direction
A conclusive experiment

A coupled system of LAr detector + muon spectrometer for

- Observation of all reaction channels ($\nu_\mu$, $\nu_e$; CC, NC) through the unique LAr-TPC imaging capabilities
- Charge separation and muon momentum extension with a magnetized iron spectrometer
- Different sites near (300 m) + far (1600 m)
Where: CERN North Area

- 100 GeV primary beam fast extracted from SPS
- Target station next to TCC2
- Decay pipe: $L = 100$ m, $\phi = 3$ m
- Beam dump: 15 m of Fe with graphite core, followed by $\mu$ stations
- Neutrino beam angle: pointing upwards, at -3m in the far detector, $\sim 5$ mrad slope
The new SPS neutrino beam

- 100 GeV protons, on-axis, fast extraction (10.5 μs), CNGS intensity (conservative)
- Sharing scenario: 2 years of $\bar{\nu}$-bar followed by 1 year of $\nu$

![CC muons](image1)

![CC electrons](image2)

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Lar-TPC imaging detectors

- **Near location:** T150 (basic structure of T600 already operating at LNGS)
- **Far location:** T600 (transportation from LNGS)

*T600 inside new insulation*

LAr performance shown for a particular testpoint

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NESSiE (Neutrino Experiment with Spectrometers in Europe)

- **Goal:**
  - Allow charge separation and momentum measurement of as many muons as possible escaping from LAr
    (large statistics $\leftrightarrow$ low $\sin^22\theta$)
  - Go as low as possible in muon momentum
    (low momenta $\leftrightarrow$ low $\Delta m^2$)
  - Possibility to also study (NESSiE) internal events
    (coarser resolution w.r.t. LAr)

- **Solution:**
  - Air-core magnets for low momentum muons escaping from LAr
    ($E_\mu < 0.5$ GeV/$c$ in NESSiE $\leftrightarrow$ $\langle E_\nu \rangle < 1$ GeV in LAr)
  - Downstream massive iron dipolar magnets for higher momenta extension
Air-core magnet

- New concept for a large transverse area magnetic field in air (~40 m²)
- \( B = 0.15 \) T
- Power < 2 MW
- To be coupled to a mm detector (different possibilities under study)
NESSiE iron dipolar magnets

$B = 1.5 \text{ T}$

1800 + 700 m$^2$ of RPC
20000 + 12000 digital channels
Detector configuration (far position)

Charge mis-reconstruction at few percent level in all dynamical range of interest (full simulation including selection, efficiency and reconstruction)

Picture credits: G. Sirri
## Expected signal rates

<table>
<thead>
<tr>
<th>Produced</th>
<th>NEAR (neg. foc.)</th>
<th>NEAR (pos. foc.)</th>
<th>FAR (neg. foc.)</th>
<th>FAR (pos. foc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_e + \bar{\nu}_e$ (LAr)</td>
<td>35 K</td>
<td>54 K</td>
<td>4.2 K</td>
<td>6.4 K</td>
</tr>
<tr>
<td>$\nu_\mu + \bar{\nu}_\mu$ (LAr)</td>
<td>2030 K</td>
<td>5250 K</td>
<td>270 K</td>
<td>670 K</td>
</tr>
<tr>
<td>Appear. test point</td>
<td>590</td>
<td>1900</td>
<td>360</td>
<td>914</td>
</tr>
<tr>
<td>$\nu_\mu$ (LAr+NESSiE)</td>
<td>230 K</td>
<td>1200 K</td>
<td>21 K</td>
<td>110 K</td>
</tr>
<tr>
<td>$\bar{\nu}_\mu$ (NESSiE)</td>
<td>1150 K</td>
<td>3600 K</td>
<td>94 K</td>
<td>280 K</td>
</tr>
<tr>
<td>$\bar{\nu}_\mu$ (LAr+NESSiE)</td>
<td>370 K</td>
<td>56 K</td>
<td>33 K</td>
<td>6.9 K</td>
</tr>
<tr>
<td>$\bar{\nu}_\mu$ (NESSiE)</td>
<td>1100 k</td>
<td>300 K</td>
<td>89 K</td>
<td>22 K</td>
</tr>
<tr>
<td>Disappear. test point</td>
<td>1840</td>
<td>4700</td>
<td>1700</td>
<td>5000</td>
</tr>
</tbody>
</table>

**NOTE:** $\nu$ "contamination" in anti-$\nu$ negative polarity beam

- Expected rates for near and far detectors given for $4.5 \times 10^{19}$ pot
- Signal test point fixed at 2 eV$^2$ shown as example
Physics reach of the project

- $\nu_e$ appearance and disappearance signals may share the same $\Delta m^2_{\text{new}}$ and different mixing angles in a 3+1 scenario.
- A two year run with $\nu$-bar would to address CPV in one shot with NESSiE.

$\nu_e$ appearance (2 + $\bar{1}$ years sharing)

$\nu_e$ disappearance (1 year of $\nu_\mu$)

$\nu_\mu$ disappearance ($\bar{2} + 1$)

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NESSiE time schedule

- In the meanwhile:
  - Request to switch PS ↔ SPS
- Joint technical proposal submitted to SPSC in March 2012 [arXiv:1203.3432]
- From green-light, we expect 3 years of prototyping and construction → run in 2016
Conclusions

- The search for sterile neutrino states has profound theoretical and experimental motivations

- We need an ultimate experiment to
  - Finally get rid of several long-standing anomalies OR
  - Discover the existence of a light sterile neutrino state \( \rightarrow \) enormous consequences for our understanding of physics BSM

- We are proposing an high-luminosity experiment
  - On a short time-scale if compared to other proposals
  - Ancillary to other LBL neutrino experimental proposals

- The NESSiE spectrometers would complement a LAr target experiment
  - To extend \( p_\mu \) range and to address charge separation
  - To better assess the role of systematics in the \( \nu_\mu \) disappearance channel