Search for sterile neutrinos at a new Short-Baseline CERN neutrino beam

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INFN - LNF

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Outline

1. Why sterile neutrinos?
2. The physics case
   - SBL anomalies
   - Reactor and Gallium anomalies
3. The ultimate experiment
   - Detector concept
   - NESSiE
4. Conclusions

The 3 neutrino oscillation paradigm

- The discovery of neutrino oscillations established the first piece of physics BSM: neutrinos have mass!
- Decades of experiments have drawn a picture consistent with the mixing of three active neutrinos, formalized by the PMNS unitary matrix

BUT

- a certain number of *anomalies* shows a tension with the 3 flavor framework, pointing towards a new parameter region $\Delta m^2 \sim eV^2$
- however, the Z invisible decay width measured at LEP bound $N_{active} = 3$ (active neutrinos with $m_\nu \lesssim M_Z/2$)
- the extraordinary consequence of a possible sterile neutrino discovery calls for a conclusive experimental search

Sterile neutrino

What is a sterile neutrino?

A **sterile neutrino** is a neutral lepton which does NOT couple to W/Z
Sterile neutrino is a "natural" consequence of neutrinos having non-zero mass, we do NOT need exotic particles!

SM naturally provides inactive $\mathrm{SU}(2)_L$ singlets, with no "a priori" mass scale, that can mix with the active doublets

- minimal extensions of the SM introduce right-handed sterile ν_R with CP-conjugate ν_L^c
- no need to assume other New Physics BSM

To cope with experimental "anomalies", the new mass term should be small: $O(\mathrm{eV}) \rightarrow$ light steriles!

Experimental tensions

Experimental tensions arise between the well established 3ν scenario and the recently observed "anomalies":

1. $\bar{\nu}_e$ appearance signals
   - excess of $\bar{\nu}_e$ originated by initial $\bar{\nu}_\mu$: LSND/MiniBooNE but no ν_e excess signal from $\nu_\mu \to \nu_e$
2. $\bar{\nu}_e/\nu_e$ disappearance signals
   - deficit in the $\bar{\nu}_e$ fluxes from nuclear reactors
   - reduced ν_e event rate from MCi calibration sources in Gallium experiments

Also cosmological data (CMB and LSS observations) favor the existence of a 4^{th} light degree of freedom

$$N_{eff} \sim 4 \longrightarrow \text{preference for one light sterile neutrino}$$

All these anomalies point towards the possible existence of (at least) one sterile neutrino driving oscillations in the $\Delta m^2 \sim 1\ \text{eV}^2$ range

SBL anomalies

Appearance signals

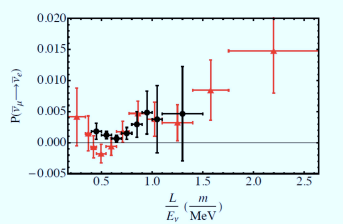
LSND: first piece of evidence in favor of *beyond 3ν* oscillations (3.8σ)

- appearance of $\bar{\nu}_e$ from $\bar{\nu}_\mu$, interpreted as oscillation with $\Delta m^2 \sim 1$ eV^2

MiniBooNE tested LSND parameter region

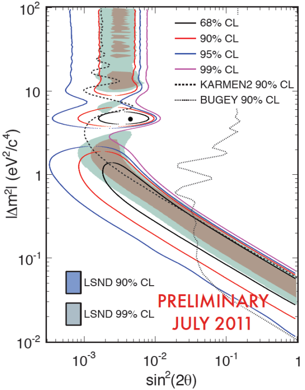
- (ν-mode) result: incompatible
- ($\bar{\nu}$-mode) result: compatible

$\bar{\nu}_\mu \to \bar{\nu}_e$ probability



Black: LSND; Red: MiniBooNE

Allowed parameter space



Reactor and Gallium anomalies

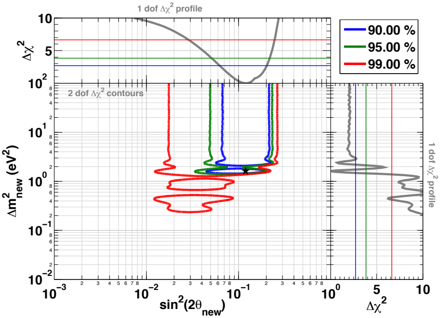
Disappearance signals

- $\sim$6% deficit in the $\bar{\nu}_e$ reactor rates, given the recent and carefully recomputed fluxes (3.0σ)
- 5-20% deficit in the ν_e rates from intense calibration source in Gallium experiments (2.7σ)

Combining Gallium and reactor anomalies: compatible phase space regions

$\Delta m^2_{new} \approx \text{eV}^2$,
$\sin^2(2\theta_{new}) \approx 0.1$

arXiv:1101.2755v4



The ultimate experiment

Compelling question arised from the experimental hints:
is there one (or more) sterile neutrino(s)?
The experiment which may disentangle all the "anomalies"

Measure at L/E corresponding at $\Delta m^2 \sim 1\ eV^2$

with ≥ 2 sites

ν_μ AND $\bar{\nu}_\mu$

in Apppearance (ν_e)

AND

in Disappearance (ν_μ)

2^3 combs

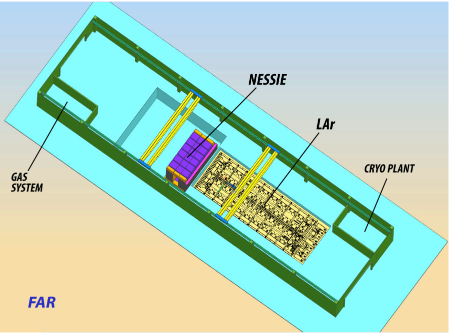
L.Stanco©

A new approach to sterile oscillations at CERN/SPS

A direct and unambiguous measurement of an oscillatory pattern requires necessarily the (simultaneous) observation at several different distances: the only way to identify both Δm^2 and $\sin^2(2\theta)$

ICARUS
Imaging detector capable to identify unambiguously ALL reaction channels with a LAr-TPC

NESSiE
Magnetic spectrometers to determine muon charge and momentum



$\longrightarrow$ Two LAr-TPC's followed by magnetized spectrometers in NEAR (300 m) and FAR (1600 m) positions

Detector concept

NESSiE (**N**eutrino **E**xperiment with **S**pectrometer**S** in **E**urope)

Charge and momentum measurements in CC neutrino interactions

- **Fundamental**:
  - measure precisely ν_μ disappearance in a wide energy range, a key (so far unknown) effect
  - separate ν_μ from $\bar{\nu}_\mu$ in order to address CPV issues, especially in the $\bar{\nu}_\mu$ beam (thus reducing the data taking period)
  - measure the neutrino flux at the Near detector, to keep systematics as low as possible
  - normalize NC/CC rates
- **Challenging**:
  - find best compromise between active and passive materials

A new neutrino beam from the CERN-SPS

A new neutrino facility in the CERN North Area

- synergy between Short and Long Baseline projects

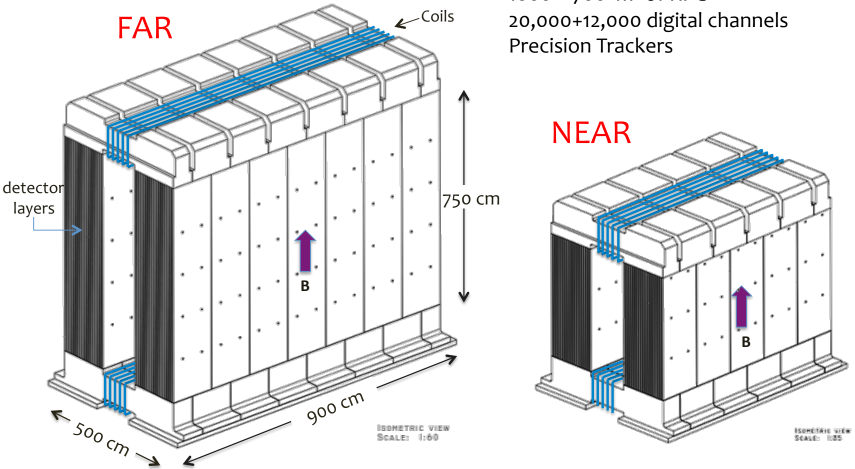
Primary beam: 100 GeV protons
from SPS

ν-beam energy: $\sim$ 2 GeV
ν-beam angle: pointing upwards
$\sim$ 5 mrad slope

NESSiE iron dipolar magnets

B = 1.5 T

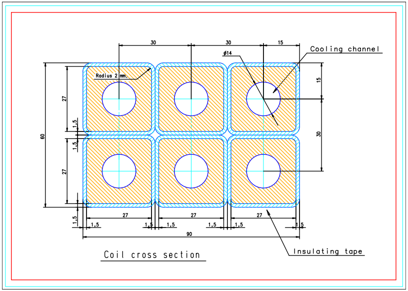
1800 + 700 m² of RPC
20,000+12,000 digital channels
Precision Trackers

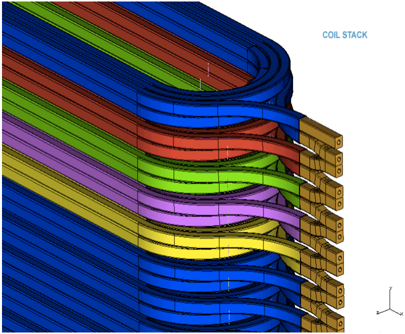


NESSiE air magnet

Fully new concept of a 40 m^2 transverse area magnetic field in air (**B = 0.25 T**)

The air magnet single coil structure





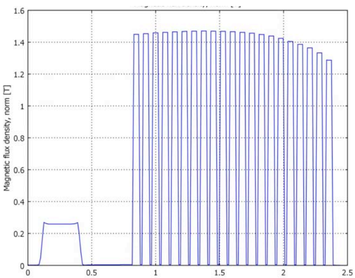
The air magnet coil structure (“pancake”)

Reconstruction capabilities with NESSiE

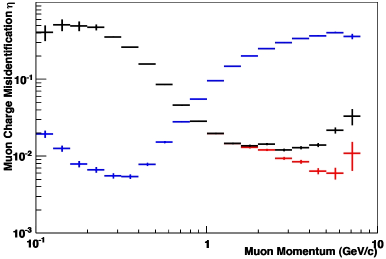
Demanding task: measure both charge and momentum over a large energy range

Complementarity of NESSiE spectrometers in the low (<1 GeV) and high energy domains

Transverse profile of the global magnetic field (air plus iron)



Charge misidentification percentage
including selection, efficiency and reconstruction procedures

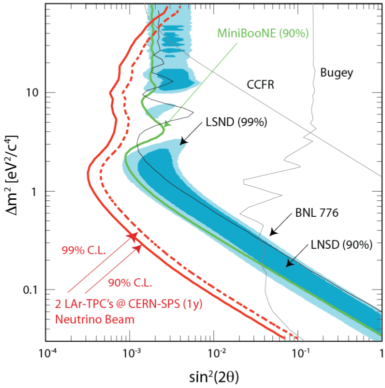


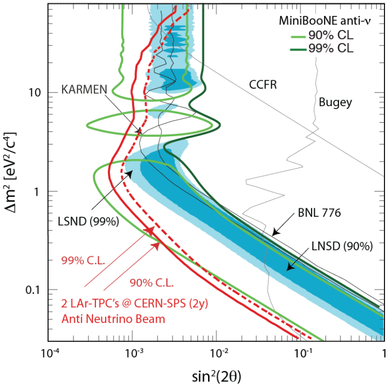
Air magnet
Two iron magnet arms (one iron magnet arm)

Physics reach: sensitivities to appearance anomalies

Expected sensitivity for the proposed experiment: ν_μ beam (left) and $\bar{\nu}_\mu$ beam (right) for 4.5×10^{19} p.o.t. (1 year) and 9.0×10^{19} p.o.t. (2 years) respectively

2 LAr-TPC's at CERN-SPS



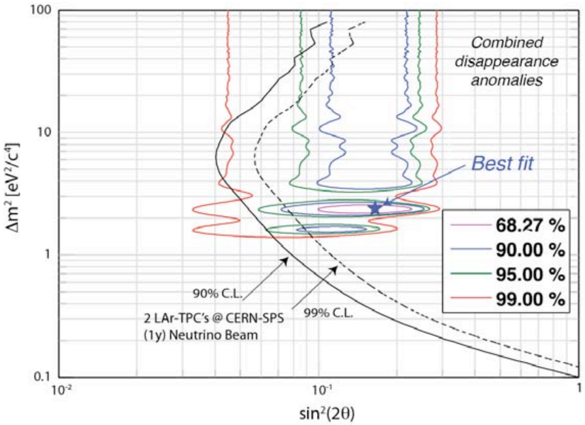


LSND allowed region is fully explored in both cases

Physics reach: sensitivities to disappearance anomalies

Expected sensitivity for 1 year ν_μ beam (4.5×10^{19} p.o.t.)

2 LAr-TPC's at CERN-SPS



Reactor and Gallium allowed region is fully explored

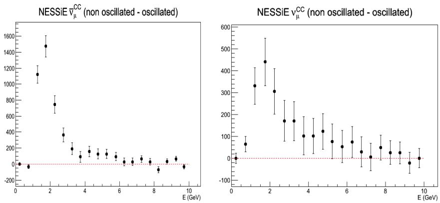
Sensitivity to ν_μ disappearance

NESSiE can disentangle ν_μ and $\bar{\nu}_\mu$

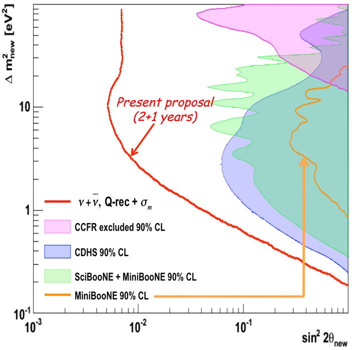
$\nu_\mu/\bar{\nu}_\mu$ disappearance for 1 year $\bar{\nu}_\mu$ beam

Non oscillated-Oscillated in the NESSiE Far Detector

Example of oscillation signal for $\Delta m^2 \sim 2$ eV^2



90% C.L. sensitivity for 2 years $\bar{\nu}_\mu$ beam and 1 year ν_μ beam



Conclusions

- A number of experimental results appear anomalous in the context of the standard 3 neutrino framework, and can be explained by a sterile neutrino with mass around 1 eV
- The data collected to date present an incomplete, perhaps even contradictory picture
- A conclusive and complete test appear to be mandatory in order to confirm or refute the light sterile neutrino hypothesis: **the ultimate experiment**!
- The NESSiE spectrometers, complementing a LAr target experiment, will offer remarkable discovery potentialities, collecting a very large number of unbiased events both in the ν and $\bar{\nu}$ channels
- Definitive clarification of the physics issue:

bring anomalies to evidence or get rid of them

Thank you for your attention!