# NeSSiE and sterile neutrinos

P. Bernardini[1 2] G. Mancarella[1 2], G.Marsella[1 2], and A. Surdo[2]

[1]Dipartimento di Matematica e Fisica "E. De Giorgi", Università del Salento, Italy

[2]Istituto Nazionale di Fisica Nucleare, Sezione di Lecce, Italy

## 1. The *sterile* issue at 1 eV mass scale

The recent LHC discoveries confirm once more the great success of the Standard Model (SM). In this rapidly emerging picture, neutrino mixing and masses represent a first evidence of physics Beyond the Standard Model. Being the neutrinos the only elementary Fermions whose basic properties are largely unknown, it is natural to put priority for more research in this field. The mixing parameters and the small masses differentiate neutrinos from all other known Fermions. A unique and appropriate theoretical framework, which accomodate all this, would significantly drive particle physics forward. The recent results by T2K [1], MINOS [2], RENO [3] and Daya Bay [4] showing that all 3 mixing angles are non-vanishing and are large, opens a new spectrum of intriguing possibilities. A precise investigation of the oscillation probabilities as a function of energy and a comparison of neutrino and antineutrino behaviours is becoming mandatory. Such measurements will also yield a definitive resolution of the neutrino mass hierarchy and a significant exploration of CP-violation in the neutrino sector. The physics case raised by the NESSiE collaboration that proposes a short baseline neutrino experiment for the search of a new type of neutrinos, the sterile one, is also a fundamental milestone that needs to be adressed with priority. The proposal is to construct and operate a short baseline experiment, with two sets of neutrino detectors placed at 2 different distances from the production target (far and near detectors). In the two positions, the radial and energy spectra of the $\nu_\mu$ beams are well correlated. Moreover comparing the two detectors, in absence of oscillations, all cross sections and experimental biases cancel out. Therefore the two experimentally observed event distributions are a relevant source of information. Any difference of the foreseen event distributions at the locations of the two detectors might be attributed to the possible existence of $\nu$-oscillations, presumably due to additional neutrinos with a small mixing angle $sin^2 2\theta_{new}$ and a larger mass difference $\Delta m^2_{new}$. There are a number of anomalies that, if experimentally confirmed, could be hinting at the presence of additional, larger squared mass differences in the framework of neutrinos with mixing or of other unknown effects. The possible existence of some additional sterile neutrinos was originally proposed by B. Pontecorvo, in [5] he considered the existence of right-handed $\nu_s$, the lepton number violation and the $0\nu\beta\beta$ decay. There are actually other questions that dominated neutrino physics up to now, but sofar without conclusion. Two distinct classes of anomalies have been reported, although not in an entirely conclusive level:

- Apparent disappearance signals: (1) the $\bar{\nu}_e$ events detected from near-by nuclear reactors and (2) from the Mega-Curie k-capture calibration sources in the solar-$\nu_e$ Gallium experiments;
- Observation for excess signals of $\nu_e$ electrons from neutrinos from particle accelerators (LNSD, MiniBooNE).

At present the LSND [6] experiment and the MiniBooNe [7] experiment both claim an independent 3.8 $\sigma$ effect from standard neutrino physics. The recent Mini-BooNe result, confirming the LNSD result, indicates a neutrino oscillation signal both in neutrino and antineutrino with $\Delta m^2_{new}$ from $\sim$ 0.01 to 1.0 $eV^2$. These experiments may all point to the possible existence of additional non standard $\nu$-states driving oscillations at small distances, with relatively small mixing angle. The existence of a $4^{th}$ $\nu$-state may be also hinted, or at least not excluded, by cosmological data [8]. These two distinct classes of anomalies will be explored with both neutrino and antineutrino focused beams. According to the first anomaly some of the $\nu_e$ ($\bar{\nu}_e$) and/or of the $\nu_\mu$ ($\bar{\nu}_\mu$) events might be converted into invisible (sterile) components, leading to observation of oscillatory, distance dependent disappearance rates. In a second anomaly (following LSND and MiniBooNE observations) some distance dependent $\nu_e/\nu_\mu$ oscillations may be observed as $\nu_e$ excess, especially

| conf | LN (m) | LF (m) | yN (m) | yF (m) | sN (m) | sF (m) |
|---|---|---|---|---|---|---|
| 1 | 110 | 710 | 0 | 0 | 4 | 8 |
| 2 | 110 | 710 | 0 | 0 | 1.25 | 8 |
| 3 | 110 | 710 | 1.4 | 11 | 4 | 8 |
| 4 | 110 | 710 | 1.4 | 11 | 1.25 | 8 |
| 5 | 460 | 710 | 7 | 11 | 4 | 8 |
| 6 | 460 | 710 | 6.5 | 10 | 4 | 6 |

Table 1
Near-Far detectors configurations. LN(F) is the distance of the near (far) detector from the target. yN(F) is the vertical coordinate of the center of the near (far) detector with respect to the beam axis which lies at about -7 m from the ground surface. sN(F) is the dimension of the near (far) detector.

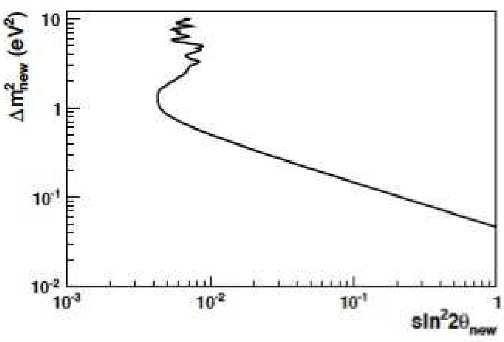


Figure 1. The sensitivity plot obtained by computing the modified raster-scan method, in a CLS framework, by using the reconstructed muon momentum as estimator, and a 1% uncorrelated systematic error. A conservative cut was applied ($p_{\mu,rec} \geq 500\ MeV$).

in the antineutrino channel. The disentangling of $\nu_\mu$ from $\bar{\nu}_\mu$ will allow to exploit the interplay of the different possible oscillation scenario, as well as the interplay between disappearance and appearance of different neutrino states and flavors.

## 2. The FNAL proposal

Motivated by the present scenario a detailed study of the physics case for the FNAL-Booster beam was performed and a proposal has been presented at FNAL [9]. The study follows the similar analysis developed for the CERN-PS and CERN-SPS cases [11,12] and the study in [13]. We pondered many detector configurations investigating experimental aspects not fully addressed by the LAr detection. This includes the measurements of the muon energy over a wide range and its charge on event-by-event basis. Indeed, muons from Charged Current (CC) neutrino interactions play an important role in disentangling different phenomenological scenarios provided their energy is well measured in the full possible interval, not forgetting the determination of their charge state. Also, the study of muon appearance/disappearance can benefit from the large statistics of muonic-CC events from the primary neutrino beam. In the FNAL-Booster beam the antineutrino contribution is rather small and it then becomes a systematic effect to be taken into account.

Results of our study are reported in detail in the full NESSiE proposal [9]. We aim to design, construct and install two spectrometers at two sites, $Near$ (at 110 m, on-axis) and $Far$ (at 710 m, on surface), in line with the FNAL-Booster, fully compatible with the proposed LAr detectors.

Profiting of the large mass of the two spectrometer systems, their stand-alone performances are exploited for the disappearance study. Besides, complementary measurements with LAr can be undertaken to increase their control of systematic errors. Using the constraints from HARP-E910 [10] data, we have estimated the uncertainties associated to hadroproduction, the FNR being of order $1-2\%$ for a configuration with the far detector at surface and a near detector with a similar off-axis angle and a

fiducial volume tailored to match the acceptance of the far detector (configuration 4 of Tab. 1). Given also the high available statistics and the large lever-arm for oscillation studies we consider such a layout with baselines of 110 m and 710 m as a viable choice. We developed sophisticated analyses to determine the sensitivity region that can be explored with an exposure of $6.6 \times 10^{20}$ p.o.t., corresponding to 3 years of data collection at FNAL-Booster beam. Our guidelines have been the maximal extension at small values of the mixing angle parameter, as well as its dependence on systematic effects. To this aim the sensitivity of the experiment has been evaluated using three different analyses implementing different techniques and approximations. In Fig. 1 the expected best sensitivity result that our experiment can achieve if the systematics can be limited to 1% level, as we are confident in.

## 3. The CERN neutrino platform

The CERN neutrino platform has been planned to be operative between 2016 and 2018 [14]). The intent is to provide the neutrino community with a device for testing the solution for future experiments either to be developed in Europe or in USA. The NESSiE collaboration has presented a proposal for testing new spectrometers to be placed downstream LAr detectors. The main purpose is to provide charge identification and momentum reconstruction of the muons produced in the neutrino interactions. In order to perform the measurement with high precision in a wide energy range, from sub-GeV to multi-GeV, a wide iron-core dipole magnet (ICM) is coupled to an air-core magnet (ACM) in front of it. Low momentum muons will be measured by the ACM. The goal is to provide a charge misidentification probability as low as 1% over a momentum range extending from 0.1 to 10 GeV. The ACM is a new device, today under design. Two hypothesis are under evaluation. The first possibility is to build the air core magnet using 80 coils 9 meters long in the straight parts plus two half circular bending regions for the return of the conductors, outside the beam region. Aluminum is the material of choice, both for the conducting cable and the supporting structure. All coils are connected electrically and hydraulically in series. This solution would allow to generate magnetic field of the order of 0.1 T. The second possibility is to use superconductor materials which would allow to reach higher magnetic fields (0.5 T - 2 T). The design would be different as the idea is to use superconducting coils to build a toroid with a uniform magnetic field. Various materials could be used: NbTi has been proven to be a successful technology operating at 4 K, but exploring new materials, such as MgB2 operating at 20 K, would allow to work at higher temperature. Long term R&D are required for cabled conductor development, coil winding technology, realization of demonstration coils and the qualification of coil operation. For both solutions, planes of high-precision tracker will be allocated in the ACM with a resolution of about 1 mm.

## REFERENCES


1. K. Abe et al. (T2K Coll.), Phys. Rev. Lett. 112 (2014) 181801, arXiv:1311.4750
2. P. Adamson et al. (MINOS Coll.), "Search for sterile neutrino mixing in the MINOS long-baseline experiment", Phys. Rev. D 81 (2010) 052004, arXiv:1001.0336
3. J. Ahn et al. (RENO Coll.), "Observation of Reactor Electron Antineutrino Disappearance in the RENO Experiment", Phys. Rev. Lett. 108 (2012) 191802, arXiv:1204.0626; S.H. Seo et al., Proceedings of Neutrino2014, (Boston, 2014), arXiv:1410.798
4. F. Anet et al. (DAYA-BAY Coll.), Phys. Rev. Lett. 112 (2014) 061801, arXiv:1310.0732
5. B. Pontecorvo, Sov. Phys. JETP 26 (1968) 984
6. A. Aguilar et al. (LNSD Coll.), Phys. Rev. D 64 (2001) 112007
7. , A.A. Aguilar-Arevalo et al. (MiniBooNE Coll.), "A search for muon neutrino and antineutrino disappearance in MiniBooNE", Phys. Rev. Lett. 103 (2009) 061802, arXiv:0903.2465; K.B.M. Mahn et al. (MiniBooNE and SciBooNE Coll.s), "Dual baseline search for muon neutrino disappearance at 0.5 $eV^2 < \Delta m^2 < 40\ eV^2$", Phys. Rev. D 85 (2012) 032007, arXiv:1106.5685; G. Cheng et al. (MiniBooNE and SciBooNE Coll.s), "Dual base-line search for muon antineutrino disappearance at 0.1 $eV^2 < \Delta m^2 < 100\ eV^2$", Phys. Rev. D 86 (2012) 052009, arXiv:1208.0322
8. Planck Coll., A&A A1 (2011) 536; P.A.R. Ade et al. (Planck Coll.), arXiv:1303.5076
9. A. Anokhina at al. (NESSiE Coll.), FNAL-P-768 1057, arXiv:1404.2521; A. Anokhina et al. (NESSiE Coll.), "Search for sterile neutrinos in the $\nu_\mu$ disappearance mode at FNAL", submitted to Phys. Rev. D.
10. A.A. Aguilar-Arevalo et al. (MiniBooNE Coll.), Phys. Rev. D 79 (2009) 072002, arXiv:hep-ex/0601022v1
11. P. Bernardini et al. (NESSiE Coll.), "Prospect for Charge Current Neutrino Interactions Measurements at the CERN-PS", SPSC-P-343 (2011), arXiv:1111.2242
12. M. Antonello et al. (ICARUS and NESSiE Coll.s), "Search for anomalies from neutrino and anti-neutrino oscillations at $\Delta m^2 \sim 1\ eV^2$ with muon spectrometers and large LArTPC imaging detectors", SPSC-P-347 (2012), arXiv:1203.3432
13. L. Stanco et al., "An Appraisal of Muon Neutrino Disappearance at Short Baseline", AHEP 2013 (2013) 948626, arXiv:1306.3455v2
14. M. Nessi et al., "Letter of Intent for the new CERN Neutrino Facility (CENF)", https://edms.cern.ch/nav/P:CERN-0000077383:V0/P:CERN-0000096728:V0/TAB3