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The NESSiE concept for sterile neutrinos

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Summary. — The NESSiE (Neutrino Experiment with SpectrometerS in Europe) experimental proposal is a project to combine two liquid argon (LAr) image detectors (Time Projection Chambers, TPC) and two magnetic spectrometers; for the observation of electron and muon neutrino events at different distances. At the near (400 m) and far (1600 m) positions from the neutrino beam origin. The experiment aims to definitively clarify the present neutrino oscillation scenarios and to explore (or to refute) the possibility of the existence of sterile neutrinos. The main characteristics of the spectrometers are described here. Spectrometers will employ a bipolar magnetic field with iron slabs, and a new concept air-core magnet, to perform charge identification and muon momentum measurements in the energy range from $\sim 100\,\mathrm{MeV}$ to few GeV over a large transverse area ($> 50\,\mathrm{m}^2$). The performances of the spectrometers as stand-alone detectors are summarized in terms the ν_μ disappearance sensitivity plot for an exposure of two years with $\bar{\nu}_\mu$ plus one year with ν_μ.

PACS 13.15.+g – Neutrino Interactions.
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1. – Introduction

Neutrino physics is nowadays receiving more and more attention as a possible source of information for the long standing problem on new physics beyond the Standard Model. The recent measurements of the third mixing angle θ_{13} in the standard mixing oscillation scenario, encourage to pursue the still missing results on the leptonic CP violation and the so called mass hierarchy. On the other hand way several puzzling and not conclusive measurements are in place which may deserve an exhaustive evaluation and study to finally assess the three standard neutrino scenario. While the accomplishment of the study of 3-neutrino matrix is foreseen to be achieved via Long-Baseline (LBL) projects one possible way to disentangle the current tensions in the 3+n patterns is through Short-Baseline (SBL) experiments. In either way, the use of large multi-ton liquid argon (LAr) detectors has been identified as the optimal one in terms of needed total mass,

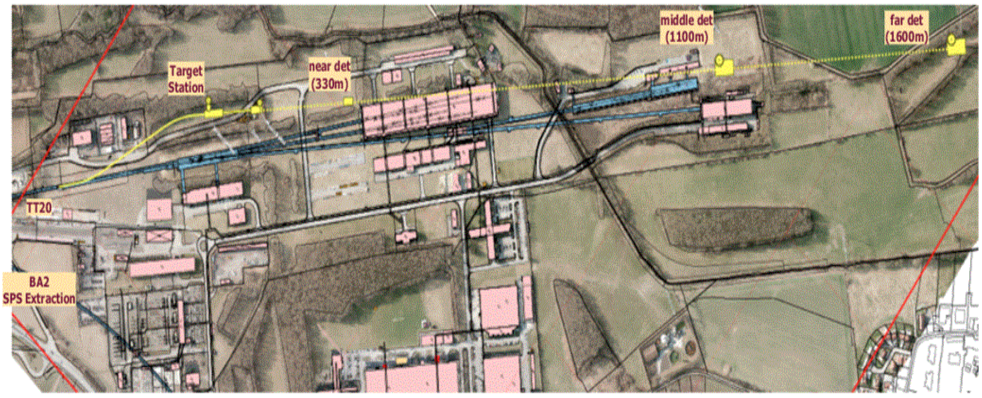

Fig. 1. – Preliminary SBL layout at CERN north area. In the figure the possible positions of the target station, near and far detectors sites are highlighted.

electron identification, background rejection, full measurement of the neutrino interaction. However the LAr is missing a clear and extended measurement of muon charge and momentum, on an event-by-event basis.

A proposal to couple a spectrometer with the multi-ton LAr ICARUS detector, was proposed by the NESSiE Collaboration, applying it to a possible SBL experiment to be built at CERN. Neither the needed neutrino beam nor the spectrometer have been approved and funded for the SBL proposal so far, but the interest is growing due to the recent conclusions of the European Strategy Planning Group and the relevant funding approved by USA for a LBL project for technology synergy between SBL and LBL, LAr and spectrometers.

The proposed site for the european SBL is the CERN North Area. A 100 GeV proton beam would be extracted from the CERN-SPS to provide an L/E oscillation path length which ensuring an appropriate matching to the $\Delta\, m^2$ window of the expected anomalies. The experimental program is based on two LAr TPCs followed by magnetized spectrometers, observing electron and muon neutrino events at the far and near positions 1600 and 400 m far from the proton target, respectively. In fig. 1 the possible SPS North Area neutrino beam layout is sketched.

The search for sterile neutrino ν_s will be mainly performed by looking for any difference in the event distribution at the two detector sites. Two main anomalies will be explored with both neutrino and anti-neutrino focused beams. According to the first anomally some of the $\nu_e(\bar{\nu}_e)$ and/or $\nu_\mu(\bar{\nu}_\mu)$ events might be converted into invisible (sterile) componentes, leading to observation of an oscillatory, distance dependent appearance rate. In a second anomally some distance dependent $\nu_\mu \to \nu_e$ oscillations must be observed as ν_e excess, specially in the anti-neutrino channel. Figure 2 shows the expected ν and $\bar{\nu}$ fluxes of charged current (CC) events, for both the electron (right) and muon (left) components at the near and far sites; the oscillated signal is expected below a neutrino energy of 6 GeV.

The proposed detector is composed of a LAr TPC, and imaging detector with the capability to clearly identify all kinds of interaction channels. Together with magnetic spectrometers able to accurately determinate, event by event, the muon charge and momentum in a wide range (about 0.5–8 GeV/c), with a mis-identification rate at the

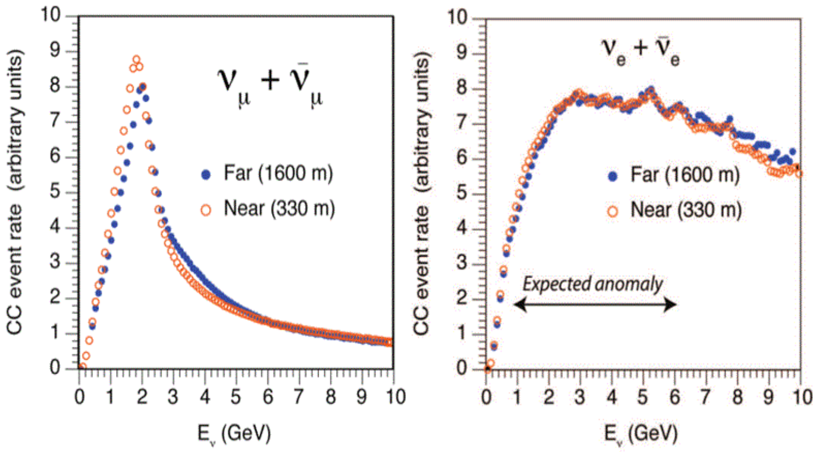

Fig. 2. – Expected charged current (CC) event rates at the near (red) and far (blue) detectors. Left: the neutrino ν_μ and anti-neutrino $\bar{\nu}_\mu$ muon components; Right: the ν_e and $\bar{\nu}_e$ components. The oscillation anomalies are expected bellow a neutrino energy of 6 GeV.

level of a few percent. This choice would provide a double benefit with respect to a LAr detector running in a stand-alone mode. To cover the required momentum range, each spectrometer, at each side, should use two different technologies.

The determination of the muon charge with the spectrometers allows the full separation of ν_μ and $\bar{\nu}_\mu$ and therefore controlling systematics from muon mis-identification largely at high momenta. The disentagling of ν_μ form $\bar{\nu}_\mu$ will allow to exploit the different possible oscillation scenarios, as well as the interplay between disappearance and appearance of different neutrino states and flavors. Moreover the NC/CC ratio will provide a neutrino oscillation signal by itself, and it will complement the normalization and the systematics studies [1].

2. – The NESSiE muon spectrometers

To measure the muon momenta over a large energy range, the thickness of a multi layer iron core magnet (ICM) placed downstream of an air-core magnet (ACM) was optimized. Low momentum muons, which do not cross a sufficient number of iron layers to determinate their curvature, are measured by the ACM. Figure 3 (right) shows the result for the charge identification over the whole energy range covered by the spectrometers described below.

2·1. *The iron core magnets, ICM.* – The two similar iron spectrometers placed at the near and far sites are basically build assembling iron slabs. For the far detector 294 slabs are needed with a total iron mass of 1515 tons. The magnet dimensions are: 500 cm (depth) ×900 cm (width) ×750 cm (height). Instead the near detector is composed of 210 iron slabs with a total iron mass of 840 tons; with dimentions: 500 cm (depth) ×600 cm (wide) ×500 cm (height). Figure 3 (left) shows a scheme of the ICM and ACM.

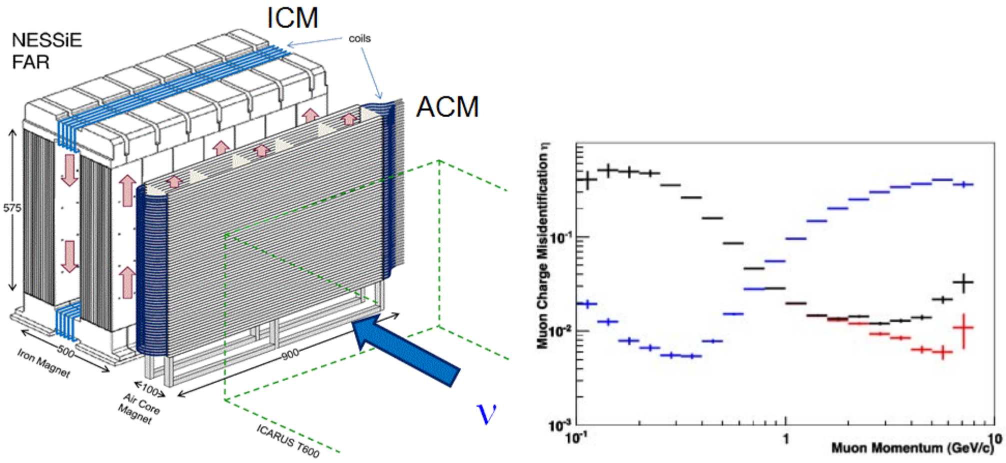

Fig. 3. – Left: Schematic view of the NESSiE far detector. Right: Charge mis-identification percentage, including the selection and efficiency of the NESSiE reconstruction. Black markers show the reconstruction considering the 1st arm of the ICM only; red markers considering both arms. Blue markers are the ACM results.

2·2. *The air-core magnets, ACM.* – For low momentum muons the effect of multiple scattering on air is comparable to the magnetic bending. For muon momentum less than 2 GeV/c the charge measurement can be then performed by means of the magnetic field in air. The coil design is made of aluminium and the complete magnet should be built using 80 coils 9 m long in the straight part plus two half-circular bending regions for the return of the conductors, outside of the beam region. The electrical and hydraulic (needed to cool the coils) connection services and controls are outside of the beam area. Conductors should be operated with a current density of 4.6 A/mm^2; the magnet total power consuption is 3.17 MW. In fig. 3 (left) the ACM is sketched.

3. – Expected results

There are needs to establish the leptonic CP violation level and to solve the Mass Hierarchy problem in the Neutrino Physics. Moreover there are some experimental results that might be due to the existence of one or more sterile neutrinos ν_s (not interacting through the $W^{\pm}$ or Z^0 exchange). Either case can be studied with neutrino beams and large mass detectors. The optimal detector seems to be the liquid argon one, coupled with a magnetic field for extended measurements of muon events. The NESSiE system allows a full disentangling by measuring CC and NC neutrino and anti-neutrino interactions in at least two different distances with respect to the proton target. For a forseen data taking period of two year run of $\bar{\nu}_\mu$ plus one year of ν_μ, NESSiE spectrometeres can measure the ν_μ disappearance in a wide energy range, exploring the possible anomalies over the hole parameter space considering sterile neutrino models. By measuring the muon charge NESSiE can separate neutrino from anti-neutrino events critical to detect the CP violation signal by observing any difference in the $\nu_\mu \to \nu_e$ and $\bar{\nu}_\mu \to \bar{\nu}_e$. Also measurements of the neutrino flux at the near detector in the full muon momentum range are relevant to keep the systematic errors at the lowest possible values.

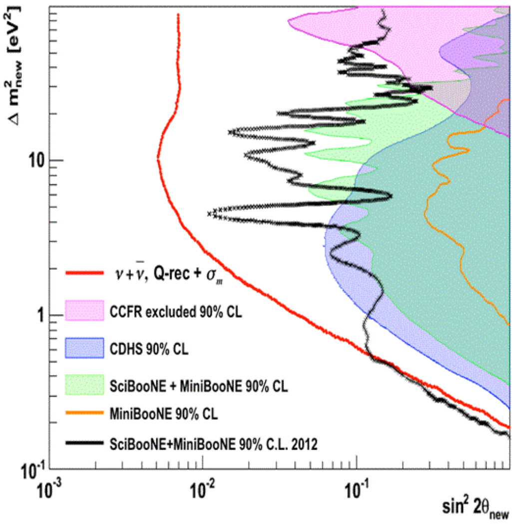

Fig. 4. – Sensitivity plot (at 90% C.L.) considering 2 years in anti-neutrino and 1 year in neutrino mode run of the CERN-SPS beam from CC events fully reconstructed in NESSiE+LAr. Red line: ν_μ exclusion limit. Exclusion limits on the ν_μ from CCFR [2], CDHS [3] and SciBooNE+MiniBooNE [4] experiments (at 90% C.L.) are also shown. Orange line: recent exclusion limits on ν_μ from MiniBooNE alone measurement [5].

Figure 4 shows the sensivity plot at 90% C.L. for ν_μ disappearance of NESSiE. This performance can be reached in a three years run (two years in anti-neutrino mode (negative focusing) plus one year in neutrino mode (positive focusing)) from CC events fully reconstructed in NESSiE plus LAr. In the plot the red line shows the ν_μ exclusion limit; the other filled areas represent exclusion limits on ν_μ of different experimens (at 90% C.L.).

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