Reactor neutrino detection experiment using Skipper CCDs

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NF Topical Groups: (check all that apply □/■)
□ (NF1) Neutrino oscillations
■ (NF2) Sterile neutrinos
■ (NF3) Beyond the Standard Model
□ (NF4) Neutrinos from natural sources
■ (NF5) Neutrino properties
■ (NF6) Neutrino cross sections
■ (NF7) Applications
□ (TF11) Theory of neutrino physics
■ (NF9) Artificial neutrino sources
■ (NF10) Neutrino detectors
■ (IF2) Instrumentation Frontier, Photon detectors.

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Abstract: With this letter of interest we aim for the construction of a short baseline neutrino program based on Skipper Charge Coupled Devices (Skipper-CCDs) at a nuclear reactor facility. The instrument will allow to access to unexplored neutrino interactions up to the electron-volt energy range at a very intense source of neutrinos. The technology is mature enough to develop a system of several kilograms that enables a very broad physic program.

I. INTRODUCTION

The development of the Skipper Charge Coupled Devices (Skipper-CCDs) has been a major technological breakthrough for sensing very weak ionizing particles [1]. Skipper-CCD allows to reach the ultimate sensitivity as a charge sensor by unambiguous determination of the number of carriers produced by an interaction in the silicon, even for single electron-hole pair creation. This unprecedented capability is mature enough to build multi-CCD systems [2] that expand the detection capability, as is used to set most stringiest dark matter limits in the SENSEI experiment [3] and aimed for future experiments like OSCURA [4]. The neutrino community can highly benefit from this technology by accessing to interactions up to the electron-volt energy scale (three orders of magnitude below current technologies with thresholds O(keV)). Very low energy sensors enable the observation of the entire neutrino flux from nuclear reactors [5], (which are the most intense source of neutrino in the earth) for both electron and nucleus reactions. This allows to set the best sensitivity to standard and non standard interactions.

Different experiments have proven a successful operation and background control operating at this kind of facilities [6, 7]. Moreover, recent observation of CEνNS (Coherent Elastic Neutrino-Nucleus Scattering) enhancement in accelerator facilities provides a new channel for testing new neutrino theories.

The first workshop dedicated to experiments based on Skipper CCD in nuclear reactor was held in Buenos Aires in December 2019. It covered the inclusion of Latin American nuclear power plants as available facilities for placing neutrino experiments. The two more suitable options are Atucha II, in Argentina, with $\sim$2 GW (thermal) with a possibility to set the experiment at 12 m/8 m of distance to the reactor core, and Angra II, in Brasil, with $\sim$4 GW (thermal) and a location at $\sim$30 m.

With this letter of interest we aim for the construction of a short baseline neutrino program based on a multi-kilogram array of Skipper CCDs at a nuclear reactor.

II. PHYSICS GOALS

CEνNS is a Standard Model (SM) process predicted more than 40 years ago [8] through which a neutrino interacts coherently with all nucleons present in an atomic nucleus. In this interaction, there is an enhancement of the scattering cross section, that is approximately proportional to the square of the number of neutrons that are present in the nucleus. However, despite its large cross section, this process took a long time to be observed due to the difficulty of measuring the low-energy nuclear recoils (O (eV)) produced by the neutrino-nucleus scattering events. Recently, (CEνNS) was detected by the COHERENT collaboration [9] thanks to the development of novel detectors and the unique neutrino beam facility of the Spallation Neutron Source (SNS) at the Oak Ridge National Laboratory.

The CEνNS signal has not been detected yet for the low energy reactor neutrinos. The potential for CEνNS as a tool to search for beyond the SM physics has been extensively discussed in the literature [10–21].

The capabilities for exploring new physics using standard CCD technology has been demonstrated by the CONNIE collaboration[6, 22]. Conservative studies carried out by our group, show a 95%-CL detection to CEνNS in 1.5 days for a 10-kg experiment based on Skipper-CCD in the Atucha II reactor at 8 m. This high sensitivity opens many opportunities for new science: high precision measurements of the standard model due to the large statistics and less nuclear uncertainties by small momentum transfer; a broad spectrum of non standard interactions including stronger limits on interesting properties like neutrino magnetic moment, dark sector exploration by dark photon mediated interactions, dark matter production in reactors, nuclear physics through the form factor in CEνNS interaction, setting bounds on solar neutrino floor background for new low threshold electron and nuclear recoil galactic dark matter searches; and sterile neutrino oscillations. The new energy scale that a Skipper-CCD can achieve, allows for a unique exploration of interactions mediated by low mass mediators or low momentum transfer, which is inaccessible for any other current technologies. Moreover, the neutrino flavor emitted by nuclear power reactors are complementary to those from the SNS experiments.

III. STATUS

There is a current collaboration called νIOLETA (Neutrino Interaction Observation with a Low Energy Threshold Array) that joins the R&D efforts for building a kg-scale experiment based on Skipper-CCDs. The first workshop was held in December 2019 in Buenos Aires [23]. The main lines identified were: new Skipper sensor design, new front-end electronics, new simulation framework for 1eV-500eV energy range, the construction of the first small array prototype of Skipper sensors, and the accessibility to nuclear reactor facilities. This effort also benefits from the current and future results obtained by the CONNIE experiment running an array of standard CCDs at Angra II power nuclear plant.

There is a background measurement campaign in Atucha II that is going to be done during the end of 2020 at some specific locations identified as candidates for placing a neutrino experiment: 8 m, 12 m and 18 m from the reactor core.

IV. PLANS

Background measurement campeign in 2020. Install the first Skipper prototype in a nuclear reactor during 2020-2021. Finish developing of a simulation framework and test it with first prototype at a reactor in 2021 and set world-leading limits for new physics with new prototype. In 2022, build 200 g experiment for CEνNS detection and reactor-background control.

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