Appel à projet – campagne 2024
Proposition de projet de recherche doctoral (PRD)
Initiative Physique des Infinis

Acronym of the Project : XENONnT
Title of the Project : Light dark matter search in XENONnT experiment and the challenge of single electron background
Supervisor (with HDR) : Luca Scotto Lavina, Directeur de Recherche CNRS/IN2P3
Unit : LPNHE (UMR7585)
Doctoral school : ED564 PIF
Co-supervisor : Prof. Elisabetta Barberio, University of Melbourne

Shedding light on the nature of **Dark Matter** is one of the main priority of modern particle and astroparticle physics today. Direct detection experiments aim to scope the particle dark matter models where this mysterious particle, travelling through our galaxy, might scatter off targets of ultra-sensitive, low-background detectors in Earth. One of the leading technologies today are the dual-phase liquid xenon Time Projection Chambers (LXe TPC). **The XENON Project [1][2][3] is leading this field worldwide** since more than a decade, also publishing papers on other fields at high ranking levels [4]. The size of the detectors that we are currently operating (XENONnT detector, currently taking data) is so large that a new background is challenging our capability to detect light dark matter, composed by isolated electrons or small electron clusters. This background is currently under study and we expect that for the next-generation detector, called DARWIN [5][6], it would be even larger, despite our efforts on xenon purification and a careful choice of detector materials. With this project, we aim to take in charge two challenges for XENONnT and DARWIN: from hardware side, we are developing novel electrodes that will be tested in our newborn small-scale TPC installed at LPNHE (this is the only facility existing in France), named XeLab. We plan to characterize this background source, eventually by generating it by purpose inside XeLab [7], with the goal of measuring the relevant physical parameters required to develop a strong background model. From the **data analysis** side, we intend to develop a series of cuts that will improve the suppression of those electrons, by improving the current sensitivity of XENONnT to dark matter. The candidate will have therefore the unique chance to work on the analysis of three years of XENONnT data and at the same time will **operate our local Liquid Xenon TPC XeLab**.

Both XENONnT and XeLab are **Master Projects** funded by IN2P3, both of them internationally known. XENONnT has been built by a collaboration now composed by 180 members from 13 countries, in four continents. XeLab, led by Luca Scotto Lavina and entirely located at LPNHE, has been built in collaboration with Subatech Laboratory (Nantes) and had recently attracted the interest of Elisabetta Barberio, Professor of the University of Melbourne and Director of the ARC Centre of Excellence for Dark Matter Particle Physics. An **International Research Project** (IRP) has been created this year by CNRS by federating the LPNHE (PI Luca Scotto Lavina, he/him), Subatech (PI Sara Diglio CR/CNRS, she/her), The University of Melbourne (Prof. Elisabetta Barberio, she/her) and the University of Sydney (Céline Bœhm, she/her). The main goal of this IRP is focused exactly on this specific thesis subject, with the goal of fostering the R&D in view of building the next

generation DARWIN detector, which is internationally recognised as the ultimate Dark Matter detector.

The candidate of this thesis is encouraged to start an M2 internship in our group by working on XENONnT data analysis and by extracting the first information on single electrons background. He/she will participate in the test of a new algorithm that classifies tiny ionization signals, with the goal to characterise and eventually separate the different background components. On top of that, he/she will have the chance to participat to the commissioning of XeLab, which is a great occasion to see a TPC starting detecting its first light.

The thesis work can be declined into three phases:

- **1st year.** Advancing on the analysis of single electrons, by deriving a background model by using uniquely the data from XENONnT. In parallel working on the commissioning of the XeLab TPC. During this year, we will profit of the help of Prof. Elisabetta Barberio who plans to spend a period in France, together with another PhD student and a postdoc. She is an expert on DAQ and Photo-Multipliers Tubes (PMTs) characterizations and her role will be crucial for the scientific goals of the experiment. We foresee to publish the first technical paper of XeLab including its performances on cryogenics and PMTs response.
- **2nd year.** With first data collected by XeLab, we will be able to derive some crucial parameters (delayed extraction times of electrons, dependency on the target purity) that are the ingredients necessary to complete the background model. The interplay between XENONnT and XeLab is the major novelty of this exciting research. Luca Scotto Lavina is worldwide recognised as an expert on light dark matter and its background, having a leading role on several papers on this subject [1][2][3][8].
- **3rd year.** The candidate will work on finalizing the publication of a XENONnT paper on light dark matter search and on the first science paper of XeLab. With this material, he/she will finally focus on the redaction of the thesis manuscript.

This work is mainly supported by four networks: 1) the **CNRS IRP** as detailed above; 2) the International Research Laboratory (IRL) CNRS-Helmoltz Foundation **DMLab** (the student will be allowed to spend few weeks at Karlsruhe to share knowledge on LXe TPC); 3) he/she will be member of the **XENON Collaboration**, also spending two weeks per year by contributing to the operations of XENONnT detector; 4) finally, the student will present his/her results to the Groupement de Recherche (GDR) **Deep Underground Physics** (DUPhy), funded by IN2P3 four years ago, for which Luca Scotto Lavina is member of the organising committee.

Non exhaustive list of relevant publications of Luca Scotto Lavina:

[1] **Search for New Physics in Electronic Recoil Data from XENONnT**, Phys. Rev. Lett. 129, 161805 (2022), arXiv:2207.11330

[2] **First Dark Matter Search with Nuclear Recoils from the XENONnT Experiment**, Phys. Rev. Lett. 131, 041003, arXiv:2303.14729

[3] **Light dark matter search with ionization signals in XENON1T**, Phys. Rev. Lett. 123, 251801 (2019), arXiv:1907.11485

[4] **First detection of two neutrino double electron capture in 124Xe - the longest half-life ever observed directly**, *Nature 568, 532 (2019)*, *arXiv:1904.11002*

[5] **DARWIN: towards the ultimate dark matter detector**, JCAP 1611 (2016) 017, arXiv:1606.07001

[6] **A next-generation liquid xenon observatory for dark matter and neutrino physics**, J. Phys. G: Nucl. Part. Phys. 50 013001, arXiv:2203.02309

[7] **XeLab: a test platform for xenon TPC instrumentation**, PoS ICRC2023 (2023) 1420

[8] **Observation and applications of single-electron charge signals in the XENON100 experiment**, *J. Phys. G: Nucl. Part. Phys. 41 (2014) 035201*, *arXiv:1311.1088*