SORBONNE UNIVERSITÉ

CHINA SCHOLARSHIP COUNCIL

Appel à projets
Campagne 2022
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Title of the research project :

Search for two neutrino double electron capture in 124Xe with XENONnT

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Research Unit

Name : LPNHE

Code *(ex. UMR xxxx)* : UMR7585

Doctorate School

Thesis supervisor's doctorate school (candidate's futur doctoral school) : STEP'UP (ED 560)

PhD student currently supervised by the thesis supervisor (number, year of the first inscription) :

1 (2019)

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Number of PhD student currently supervised :2

Description of the project

Astronomical and cosmological observations reveal that the vast majority of the matter and energy content of our universe is invisible – or dark – and interacts neither strongly nor electromagnetically with ordinary matter. About 27% of the overall energy budget is composed of dark matter (DM), a yet-undetected form of matter whose presence is needed to explain the observed large-scale structures and galaxies. Because the Standard Model of particle physics does not accommodate dark matter, the observationally-driven need for its existence is one of the strongest indications for physics beyond the Standard Model. The direct detection and subsequent characterization of dark matter particles are, therefore, one of the major experimental challenges of modern particle and astroparticle physics [1].

One of the most promising candidates for dark matter is given by Weakly Interacting Massive Particles (WIMPs), which arise naturally in several models of physics beyond the Standard Model. Worldwide, more than a dozen experimental collaborations are prepared to observe low-energy nuclear recoils induced by galactic WIMPs in ultra-sensitive, low-background detectors. One of the leading technologies today is dual-phase liquid xenon (LXe) Time Projection Chambers (TPCs). LXe is intrinsically extremely radio-pure. The simultaneous detection of both ionization and scintillation signals down to a few keV enables dual-phase TPCs to be sensitive to low-energy depositions, the likely signature of a DM particle scattering off a xenon atom. Particularly attractive is the scalability of a LXe TPC to contain a homogeneous target of several tons, that allows the sensitivity of the detector to the WIMP search to be increased dramatically.

XENON1T [2] was the first experiment of this generation to use more than 1 ton of active noble element scintillating liquid and its upgrade, XENONnT, that is employing 10 tons of LXe, started its first scientific run in spring 2021. It is located at Gran Sasso National Laboratory (LNGS), an underground laboratory built below the Apennine Mountains in Italy. At the present time, XENON1T has set the most stringent, world-leading result on WIMP interactions with ordinary matter [3]. The accumulated data, thanks to an incredibly low radioactive background and an unprecedented detector size, represented a unique opportunity to explore dark matter models beyond WIMP as well, but also to search for extremely rare nuclear processes. XENON1T thus observed for the first time two-neutrino double electron capture in Xe^124 [4]. With a half-life of the order of 10^22 years, greater than the age of the universe by several orders of magnitude, it is the rarest decay ever observed.

In parallel to dark matter, the nature of the neutrino is another one of the major unanswered questions about the universe and its fondamental constituents. It is still not known if, in contrast to all other fermions, neutrinos are of Majorana type, i.e. if they are their own antiparticles, or not. The observation of a new type of nuclear decay, called neutrinoless double beta decay, which would be the proof of the Majorana nature of the neutrino, is therefore an intense field of activity in and one of the most important scientific goals of experimental particle physics. Detecting its standard model equivalent, the two-neutrino double electron capture, is a very important step towards this goal. The measurement of this process for Xe^124 already helps to constrain nuclear models used to calculate rates of double beta decay, which in turn will allow predictions for neutrinoless double beta decay to be refined. With a 3-fold increase in active xenon mass, the XENONnT detector will allow the two-neutrino double electron capture in Xe^124 to be measured with unprecedented precision. This is the subject of the proposed research project.

The successful candidate for this project will be carrying out PhD work at LPNHE laboratory in Sorbonne University, Paris (France) with possible travels to the experimental site of XENONnT at LNGS laboratory, Gran Sasso (Italy). The LPNHE laboratory is devoted to research in particle and astroparticle physics, and cosmology. It has three main axes of research, first on the fundamental constituents (ATLAS), second on matter-antimatter asymmetry (LHCb, T2K), third on high-energy processes in the universe and the search for dark matter and dark energy (HESS, LSST, XENON). The XENON experiment, which looks mainly for dark matter but can also perform measurements on neutrinos, is thus at the core of the activity of LPNHE.

As most of the work will be based on data analysis in the context of an international collaboration, the candidate should show a strong interest in experimental particle physics, the ability to work and communicate easily in English as well as good programming skills, preferrably in Python language.

The project will be supervised by Dr. Luca SCOTTO LAVINA, PI (Principal Investigator) for LPNHE group and Coordinator for Computing in the XENON collaboration. Dr. SCOTTO LAVINA has a strong expertise on analyses based on the sole detection of ionisation signal (S2-only), which is one of the key ingredients in two-neutrino double electron capture in Xe^124 process.

The project will be co-supervised by Pr. Fei GAO, PI for Tsinghua University group in the XENON collaboration. As a former Analysis Coordinator for XENON1T experiment, Pr. GAO was one of the main responsibles for the two-neutrino double electron capture in Xe124 first measurement.

Both Dr. SCOTTO LAVINA and Pr. GAO are authors and important contributors of articles [2][3][4] already cited.

Bibliography

[1] M. Schumann, Direct detection of WIMP dark matter: concepts and status, J. Phys. G: Nucl. Part. Phys. 46 103003, arXiv:1903.03026

[2] E. Aprile et al. (XENON Collaboration), The XENON1T Dark Matter Experiment, Eur. Phys. J. C (2017) 77: 881, arXiv:1708.07051

[3] E. Aprile et al. (XENON Collaboration), Dark Matter Search Results from a One Ton×Year Exposure of XENON1T, Phys. Rev. Lett. 121, 111302, arXiv: 1805.12562

[4] E. Aprile et al. (XENON Collaboration), Observation of two-neutrino double electron capture in Xe^124 with XENON1T, Nature 568, 532 (2019)