

Searching for Dark Matter with the LZ Experiment

Despite accounting for 85% of the mass of the Universe, the nature of dark matter remains a mystery. The LZ experiment is at the forefront in the quest to observe galactic dark matter, having recently published world-leading limits on dark matter interactions from its engineering run. LZ is now probing uncharted electroweak parameter space, with the ability to discover or provide constraints on the foremost dark matter theories.

UCL is one of the founding members of LZ, and played significant roles in the design and construction of the project. We have since led significant areas of data exploitation. Dr. Cottle is an expert in background modelling and is presently in charge of the main dark matter analysis; Prof. Ghag has led the UCL Dark Matter group in HEP for over a decade, and is an expert in direct dark matter searches, liquid noble detectors and low-background technologies. The group has overseen a number of CDT and non-CDT students who have employed a range of data intensive methods in their work, pushing LZ analysis to new frontiers. Most recently, a UCL student pioneered the development of a statistical framework that has potential to be adopted by the wider dark matter community (see <https://arxiv.org/abs/2204.13621>).

For this studentship, the successful applicant will be working at the cutting edge of LZ's flagship dark matter search, currently being led by the UCL group. There is wide scope to innovate our physics analyses, with discovery potential not only for dark matter, but also for a range of exotic neutrino and other beyond the Standard Model physics. With LZ set to take science data for the next two plus years, a wealth of prospective data will be available to explore over the timescale of the PhD.

Projects will centre on applying advanced data science and machine learning techniques to LZ data, and will involve the extensive use of Monte Carlo simulations and statistical inference methods. Potential areas of focus could include:

- The characterisation of background sources, including the identification of so-called "accidental" events, formed by random coincidences of light and charge signals that are dangerous in mimicking the signatures of dark matter interactions.
- The advancement of pulse classification algorithms to supersede those in our existing event reconstruction. Examples of possible applications include the extraction of low energy events close to our noise baseline, dramatically increasing our signal efficiency in this region of interest for light dark matter models; the improved discrimination of multiple scatter interactions from single scatter ones, vastly enhancing our sensitivity to neutrinoless double beta decay processes.
- Multi-dimensional statistical analysis, involving the creation of background and signal probability distribution functions in various parameter spaces. This will lead to further development of the aforementioned statistical framework that evaluates likelihoods on an event-by-event basis, using analytic probability elements convolved together into a single TensorFlow multiplication.

If the student wishes, they can also participate in hardware activities on-site, with the potential to travel to assist in the operation of the LZ detector. Finally, there is the chance to engage with R&D efforts towards a future global xenon-based rare event search observatory under the new XLZD consortium, formed by the LZ, XENON and DARWIN collaborations, who collectively developed the world-leading xenon TPC technology. In particular, there is the opportunity to undertake sensitivity studies for XLZD, which will impact the design of the next-generation experiment. In short, the studentship aligns well with the foreseen data-taking and science output of LZ, ensuring the candidate plays an active role in the discovery of new physics, or the establishment of new world-leading model constraints with LZ, as well as the planning phase of XLZD, seen as the ultimate xenon instrument for dark matter searches.