R&Ds in LEGEND

Large Enriched Germanium Experiment for Neutrinoless ββ Decay

HPGe semiconductor detectors

- **New detector concepts.** Explore new detector geometries, contact solutions, or electrode segmentation to maximise the sensitivity of LEGEND-1000 and beyond
- **Larger-volume long-collection-time detectors.** R&D on detector manufacturing processes (e.g. crystal pulling, annealing, electrode production) focusing on their connection with the final crystal properties and impact on charge trapping, charge cloud dynamics, surface currents, slow pulses, etc.
- **Mass production facilities**. Prepare test-stands and procedures to accept and characterise hundreds of detectors, assessing their spectroscopic and pulse-shape discrimination performance, active volume, uniformity of the surface response, depletion voltage, etc.
- **Advanced characterisation.** Design, build and exploit advanced detector characterisation test-stands to map the detector response, both in the bulk of the detector and on its surface. Examples are Compton coincidence scanning stations or vacuum cryostat containing both the detector and movable collimated alpha/beta/gamma sources.
- **High-precision measurements of charge carrier mobilities in Ge.** Set up an R&D program to measure the relation between electric field and charge carrier velocities in the Ge material used to produce the LEGEND detectors, including its dependence on crystallographic axis, impurity concentration, crystal annealing cycles and growing history.

Electronics and DAQ

- **DAQ.** Design, assemble, test and install the DAQ system, including the FADCs, triggering logic, firmware, and online data reduction.
- **HPGe detector read-out electronics.** Design and deliver ultra-low background front-end electronics and subsequent amplification stage usable at cryogenic temperature, fulfilling challenging background/bandwidth/cross-talk/noise specs
- **LAr light sensor read-out electronics.** Design and deliver fast low-background cryogenic read-out solutions for the LAr light sensors
- **Slow control.** Develop slow control system, network and protocols, integrate sensors used to monitor the experimental infrastructure, alarm system, automatic emergency operations.

Liquid argon detector

- **Light sensors.** Explore new light sensor technologies, including R&D with SiPM, and prepare characterization/testing capabilities for mass production.
- **LAr optical properties**. Measure liquid Ar optical properties (i.e. light yield, attenuation length, triplet lifetime) as a function of Ar purity and specific contaminants. Design/build monitoring systems for the standard and underground Ar of LEGEND-1000.
- **Light read-out.** Explore and optimise the LAr scintillation light read-out strategy, including fibres scheme and potential scintillating materials, with the optical and MC simulations.

Materials and Assay

- **Material screening and assay.** Improve/assemble new screening stations capable of detecting contaminants at the level of fractions of micro Bq.
- **Material selection and procurement**. Identify the most radiopure materials, producers and supply chain.
- **Novel materials**. Explore new materials (e.g. transparent plastics to construct the detector holders maximising the read-out efficiency of the liquid argon scintillation light) or material production systems (e.g. electroformed copper), exploiting synergies with ongoing efforts in the UK dark-matter community.
- **Techniques and materials for encapsulating HPGe detectors.** Explore solutions to surround each HPGe detector with a layer of material separating the Ge surface from LAr and reducing background due to Ar-42 beta-decays.

Infrastructure, Cryostat, Assembly, and Installation

- **Cryogenic and LAr infrastructure.** Design and construct challenging infrastructure, including pumping systems, LAr circulation and purification facilities, solutions to handle underground Ar including the re-entrant vessels in the cryostat, emergency systems and monitoring tools.
- **Lock-system and clean room.** Design, build and install the hardware infrastructure needed to mount and lower the detector array into the cryostat, including vacuum feedthroughs.
- **Detector Array.** Integrate and assemble the components of the detector arrays, including LAr/HPGe detectors, holding systems, contacting, cabling, and read-out electronic chain

Analysis, Simulations, and Computing

- **Software and hardware infrastructure**. Design and install computer infrastructure, including the above and underground networks, servers, and storage. Develop computing control interfaces, databases, web tools and automatic data flow managers. Design software solutions for distributed high-performance computing resources (e.g., NERSC) and GPUs. Design and implement analysis and simulation software frameworks.
- **Machine learning and advanced analysis techniques**. Develop techniques for event tagging and reconstruction (e.g. convolutional networks for data quality or MLP for pulse shape discrimination) and advanced digital signal processing (e.g. denoising and optimal filters in time and frequency domains).
- **Simulation models.** Develop and tune models for HPGe detectors (including their surface response and charge cloud deformations), LAr scintillation and light sensor (including optical simulations), and cosmic rays.
- **Background Analysis Tools and Methods.** Build multivariate fitting frameworks and procedures. Apply them to investigate background contributions in LEGEND-200, evaluate the impact on LEGEND-1000's background budget, and guide the experimental design.
- **Statistical tools and physics analysis.** Build frequentist and Bayesian methods to extract a single which can potentially be composed of just a few events over the entire duration of the experiment, tracking the operational performance of each of the hundreds of HPGe detectors deployed in LEGEND.