The nervous system of the LUX-ZEPLIN detector

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The LZ detector

The LZ (LUX-ZEPLIN) collaboration aims to detect Dark Matter in the form of cosmic Weakly Interacting Massive Particles (WIMPs).
The detector is a Time Projection Chamber (TPC) filled with 10 ton of Liquid Xenon (LXe), which will be the target for WIMP to baryonic matter interactions. The **LXe TPC** is surrounded by Gadolinium-loaded organic liquid scintillator (**GdLS**). The interactions observed in the GdLS by **Veto PMTs** help to identify background gamma and neutrons events. The whole assembly is placed inside a **Water Tank** which provides an extra shielding against the backgrounds. [1]

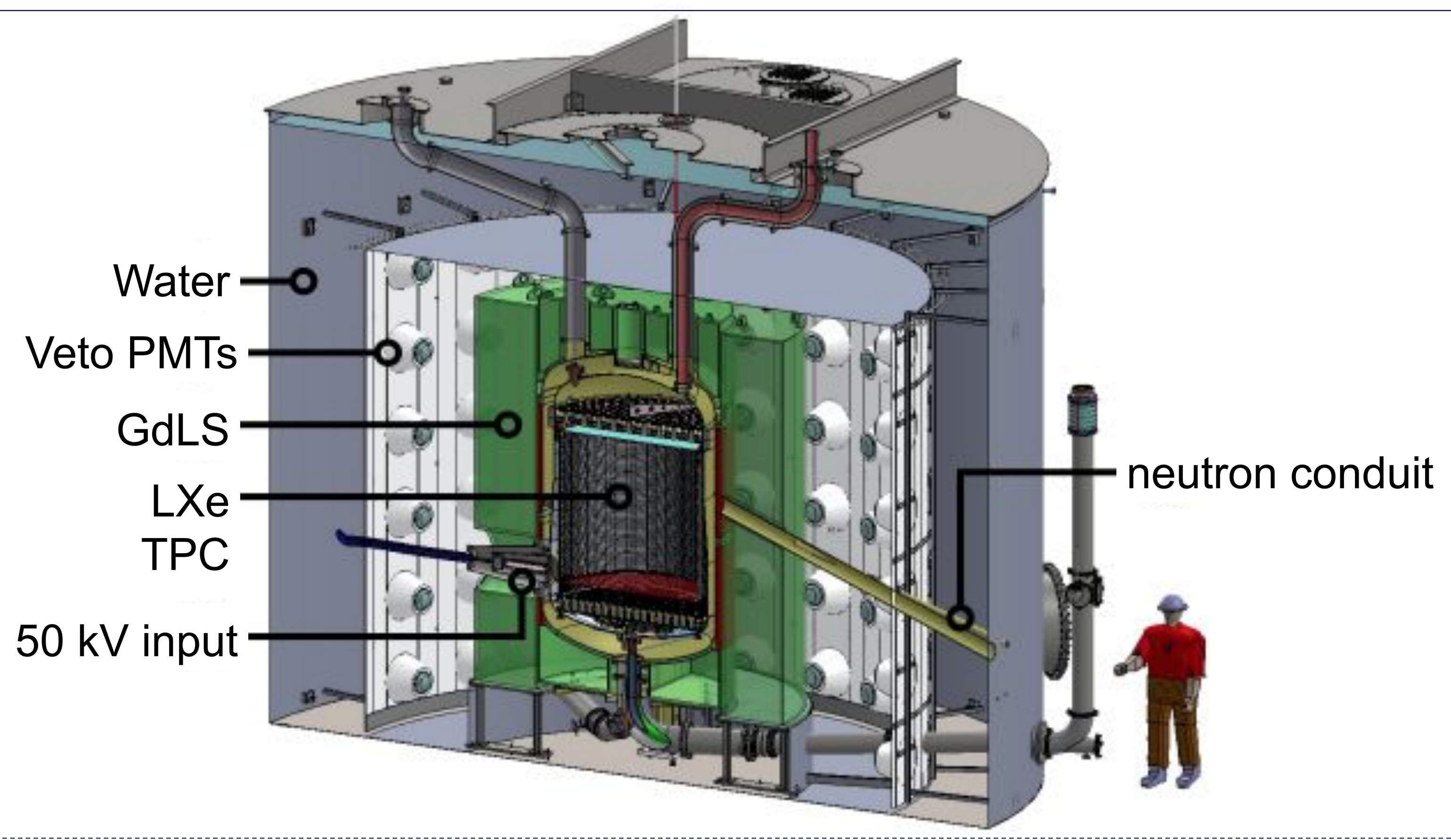

Figure 1 – The LUX-ZEPLIN detector

Particles scattering on xenon atoms create two light signals: prompt (S1) and delayed (S2) which are detected by two arrays of extremely sensitive light detectors – Photomultiplier Tubes (PMTs), located at the bottom and the top of the TPC, with 241 and 253 PMTs, respectively. In addition, 93 PMTs monitor xenon outside of the TPC to increase background rejection efficiency [2].
To guarantee the quality of the acquired data, the xenon inside the detector must be extremely pure and also kept very still, as the gas bubbles and ripples on the liquid surface would interfere with S1 and S2 signals. To maintain purity, xenon is continuously circulating through the purification system, with freshly purified liquid entering the detector from the bottom and slowly passing to the top to be removed for the next purification cycle. It takes approximately 2.4 days to pass all the 10 tons of xenon through the purifier. A sophisticated cryogenic system maintains the LXe inside the detector at constant temperature of -104°C to make sure that the liquid is always still and transparent.

The Experiment Control

The Experiment Control (EC) system of LZ behaves like the nervous system of the detector. Its role is to guarantee safety of the detector, support systems' hardware and xenon supply. This is accomplished by monitoring and controlling parameters related to LXe conditions (such as temperature, pressure and level), field cage properties and PMT HV. The LZ infrastructure is organized in different subsystems, listed below with the corresponding number of channels that are being reported to the EC.

Detector and Xe tower	290
Xe delivery and recovery	480
Xe circulation and purification	120
Cryogenics	335
Vacuum	284
Environment monitoring	8
Water Tank	30

Calibration	226
Purity monitor	15
Electronics Analog+Digital	2600+1500
Power distribution and UPS	78
PMT HV	5516
Total (SURF)	11404
Kr removal (SLAC)	1336

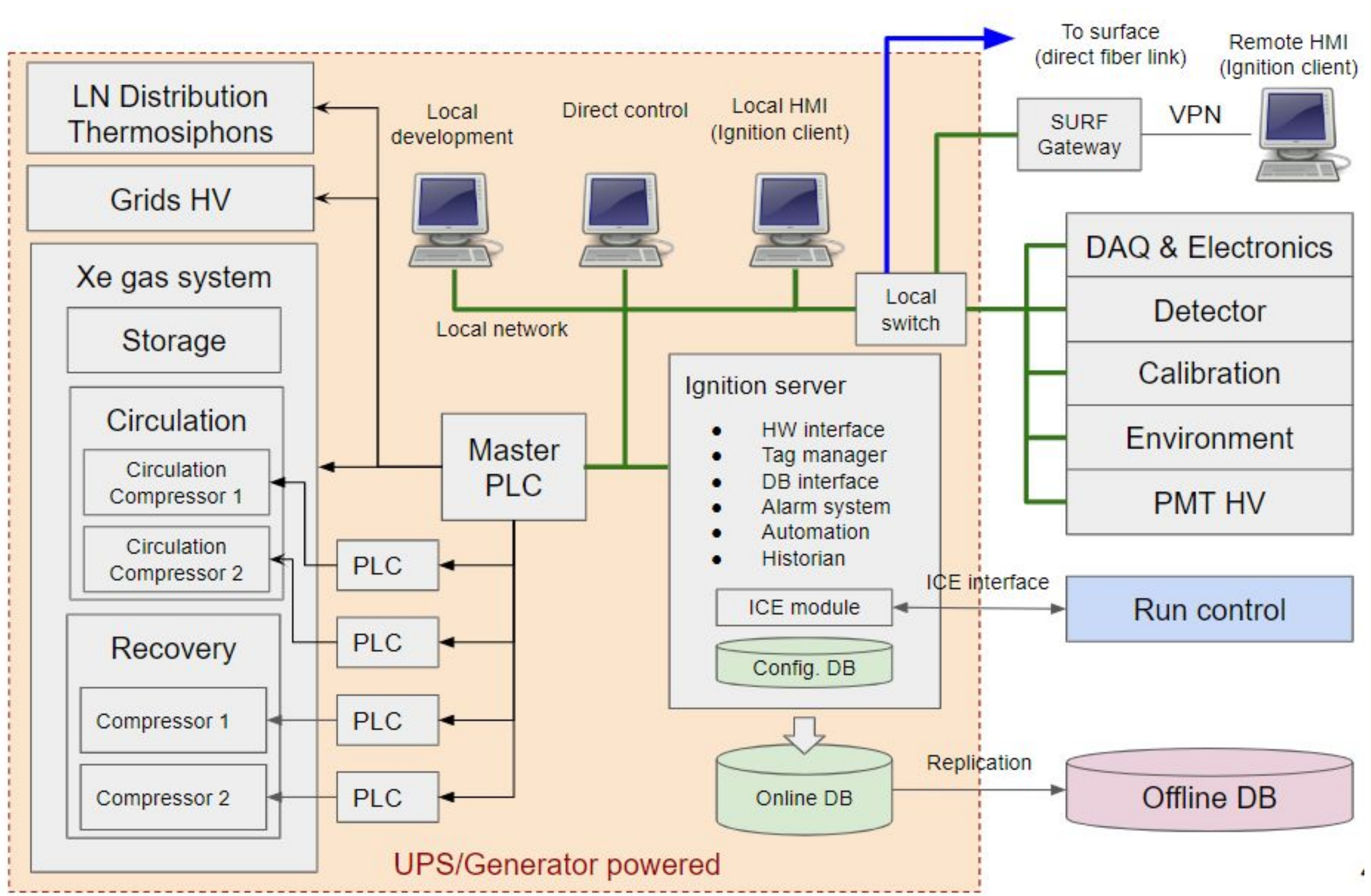

Figure 2 – Experiment Control functional chart, where the main elements are the PLC and the Ignition server

The key elements of the EC are the Programmable Logic Controller (PLC) and the Ignition server (Figure 2). In the LZ "nervous system", the PLC acts as a "reptilian brain" that always maintains the system in a safe state by means of preprogrammed interlocks (reflexes) and PID loops (homeostasis).
The Ignition server is a commercial software platform that permits to develop a robust SCADA system to unify all the LZ subsystems in a single remotely-accessible framework. A user connects to this Ignition server via a Graphical User Interface (GUI) to monitor and control thousands of channels involved in the LZ experiment. The history is saved in a database, so past behaviour of any sensor or control can be analysed. For each sensor, a range of acceptable values is defined and an alarm is raised is the reading goes out of this safety range.
To reduce risk of human error during detector operations, the Control system has a scripting engine that allows to automate complex tasks, especially those that require coordination between various subsystems.

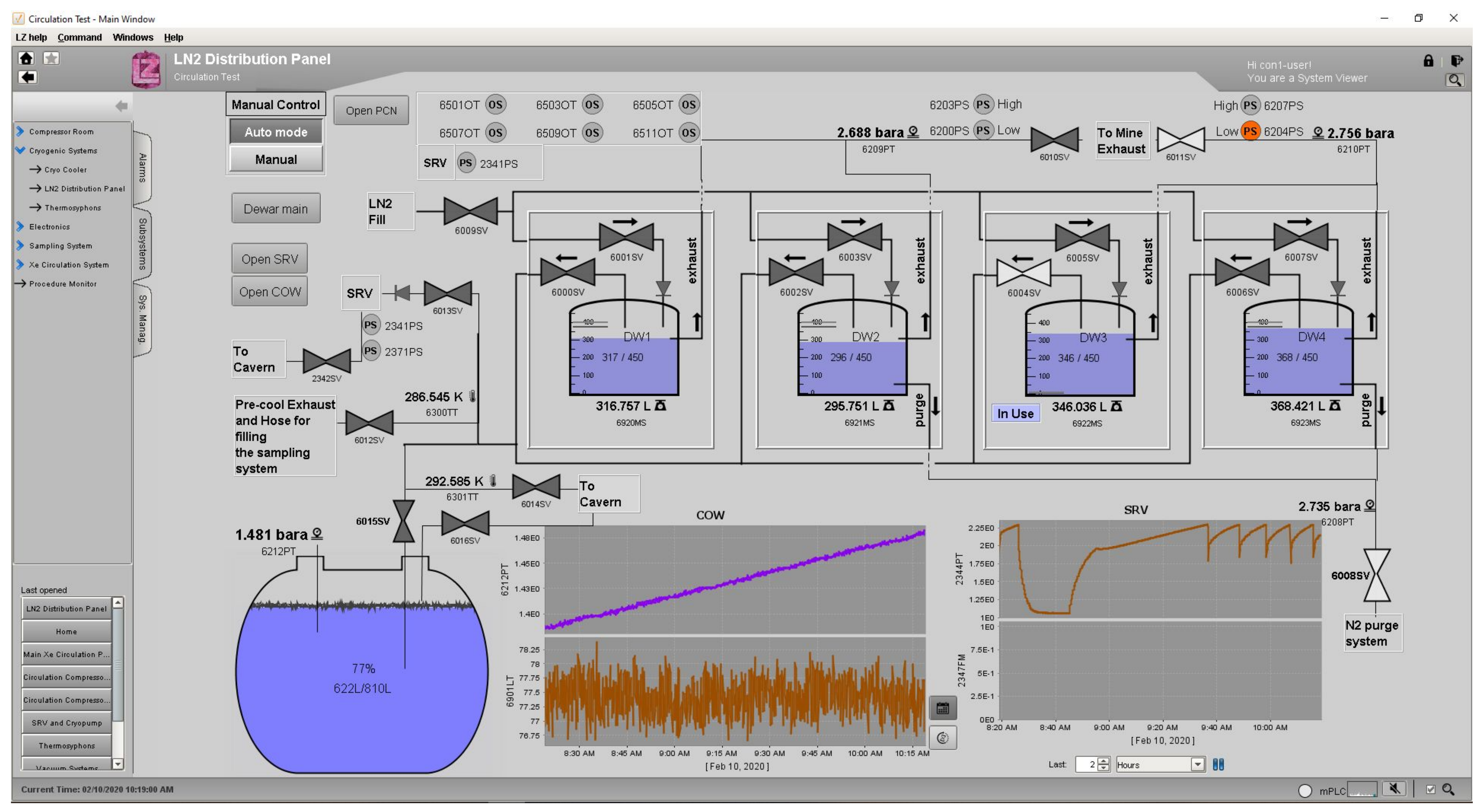

Figure 3 – Graphical user interface for the Liquid Nitrogen system was implemented following guidelines of High Performance Human Machine Interface

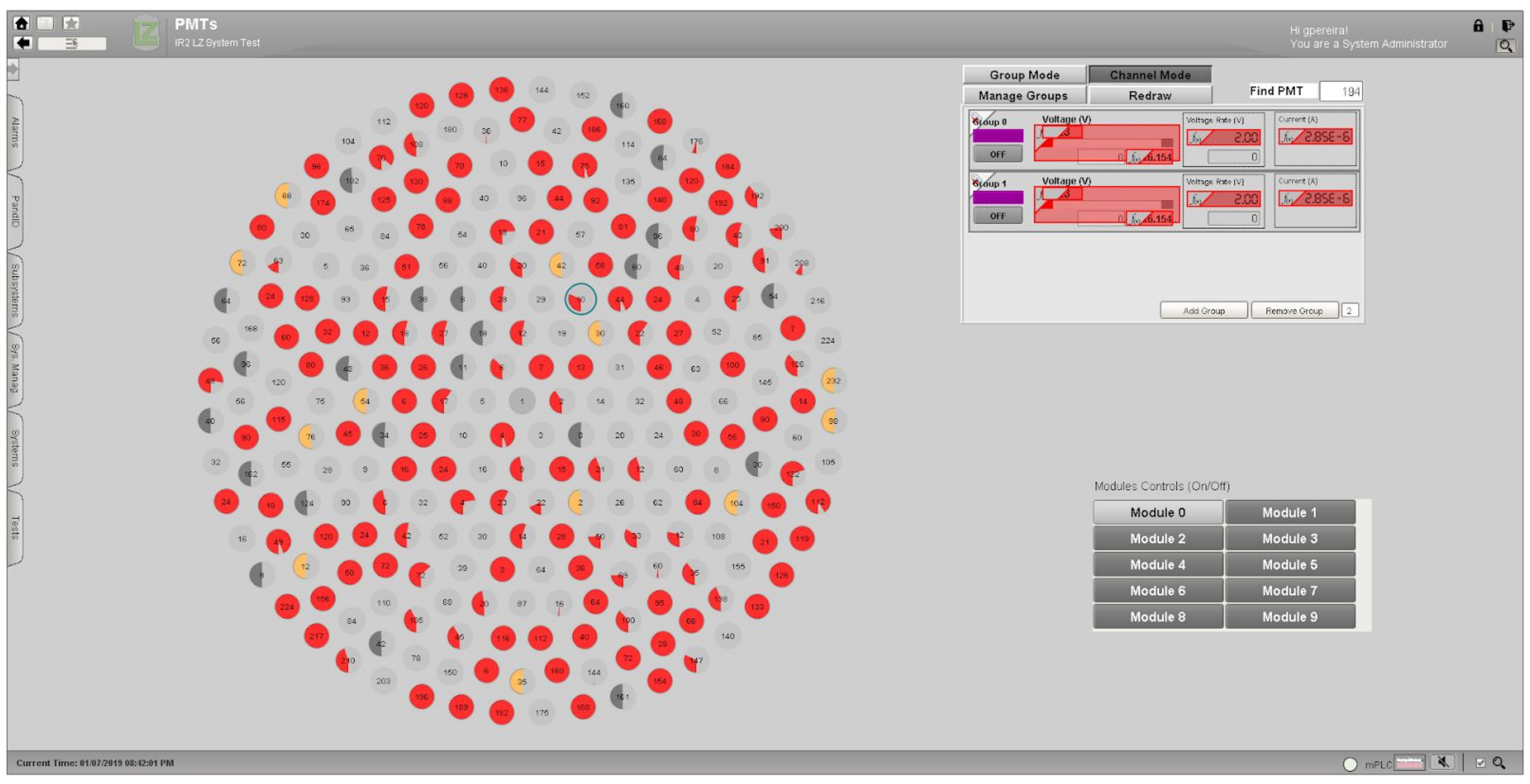

Figure 4 – Graphical user interface to monitor and control the PMT arrays

The LZ Experiment Control was designed as a high availability redundant system with automatic failover:

- PLC: Dual-CPU Siemens S7-400 model
- Ignition SCADA: redundant two-server configuration
- Compressors: 2 circulation + 2 recovery
- Database: continuously replicated to a mirror on surface
- Network: two physically separated 10 GB/s links
- Redundancy in all important controls and sensors

Conclusion

The LZ detector, currently in the final stage of development, is being assembled in the Davis Lab at SURF (Sanford Underground Research Facility, South Dakota, USA), at a depth of 1500m.
The Control group is one of the most vital groups for the LUX-ZEPLIN collaboration. Its mission is to ensure the safety of the detector and the LXe during operations. This group is also responsible for the operations of an independent circulation system, developed at San Francisco in SLAC, that is being used for removal of radioactive ^{85}Kr from LZ xenon.
The Dark Matter group at LIP is responsible for the Ignition development and maintenance (including online support for the underground team) as well as integration of non-critical subsystems into the experiment control.

References

[1] - Akerib, D. S., et al. "The LUX-ZEPLIN (LZ) experiment." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 953 (2020): 163047.

[2] - Akerib, D. S., et al. "Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment." arXiv preprint arXiv:1802.06039 (2018).