PROCEEDINGS OF SCIENCE

XeLab: a test platform for xenon TPC instrumentation

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Xenon double-phase TPCs have shown the best sensitivities for dark matter direct searches over a large parameter space. However, difficulties in the construction of large-scale TPCs have already arisen in the currently operated detectors and will be even more challenging in the next generation ones. Of critical importance are the construction of meter-scale electrodes with negligible sagging and high optical transparency but also the control of instrumental background such as single electron emission. XeLab is a system equipped with a small double-phase xenon TPC cooled with liquid nitrogen and a xenon recuperation module. The setup is primarily designed to test the innovative concept of floating electrodes but will also serve as a platform to develop instrumentation for xenon-based TPCs. We present the design and realisation of XeLab and the baseline of electrodes that we plan to test.

38th International Cosmic Ray Conference (ICRC2023)
26 July - 3 August, 2023
Nagoya, Japan

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PoS(ICRC2023)1420

1. Motivation

Searches for dark matter with liquid noble gases such as xenon were shown to be very effective for several reasons. These include the high scintillation light yield, the low ionization energy (~ 10 eV), large self shielding, the possibility to purify on line the active volume. Double phase liquid xenon TPC (Time Projection Chamber) for instance detect the light of primary scintillation S1 upon the interaction of a particle within the target material (liquid xenon) but also a secondary scintillation after the drifted electron are accelerated at the liquid gas interface by a large field. This large field is obtained thanks to two electrodes a few millimeters apart polarized with a large potential. Double phase LXE TPC have reached the best sensitivity in a large part of the spectrum for WIMP searches by always increasing the target mass. Current generation detector [1, 2] hold more than 8 tons of xenon in a cylindrical vessel of 1.3 meter diameter and 1.5 meter height. The next generation XLZD [3] is expected to have more than 50 tons be as large as 2.6 meter diameter. If the technique of the double phase TPC stays the same, the constraints due to the scale, in particular of the electrodes, leads to many developments in that area. The groups at LPNHE and Subatech have developed a facility XeLab to host the first xenon double phase TPC in France in order to address some of the opened questions. The first study will be dedicated to the design of electrodes for the next generation experiment.

2. Overall description of the cryogenic system

XeLab is a cryogenic facility that can host a double-phase TPC. The P&ID (Piping and Instrumentation Diagram) of the setup is shown in figure 1. It can be split into six sections connected to each other:

1. the outer and inner vessels: the outer vessel is maintained at high vacuum for thermal insulation. The inner vessel is cooled-down by the cooling system and contains the liquified and gaseous xenon. The nominal volume is 3L of liquid xenon.

2. the TPC is in its design phase and can be installed and accessed from the top flange.

3. the cooling system: LN_2 and GN_2 are used to cool down the inner vessel. The xenon liquefaction is carried out with a heat exchanger (see section 2.1).

4. the purification system: allows for the purification of xenon. Note that the first R&D that will be conducted with XeLab will not require a purity level as stringent as for dark matter searches. The current purification system comprises a getter (SAES Microtorr - GPUS-200FEX04R00CA) that remove electronegative impurities yielding impurity concentrations lower that the ppb level.

5. the recuperation system (mReStox): it is a custom-made and allows for the controlled recuperation and storage of xenon.

6. the pressure relief system: passively used only in case of emergency, it can hold the pressure of the 10 kg of xenon at ambient temperature and pressure. It is not yet included in the system.

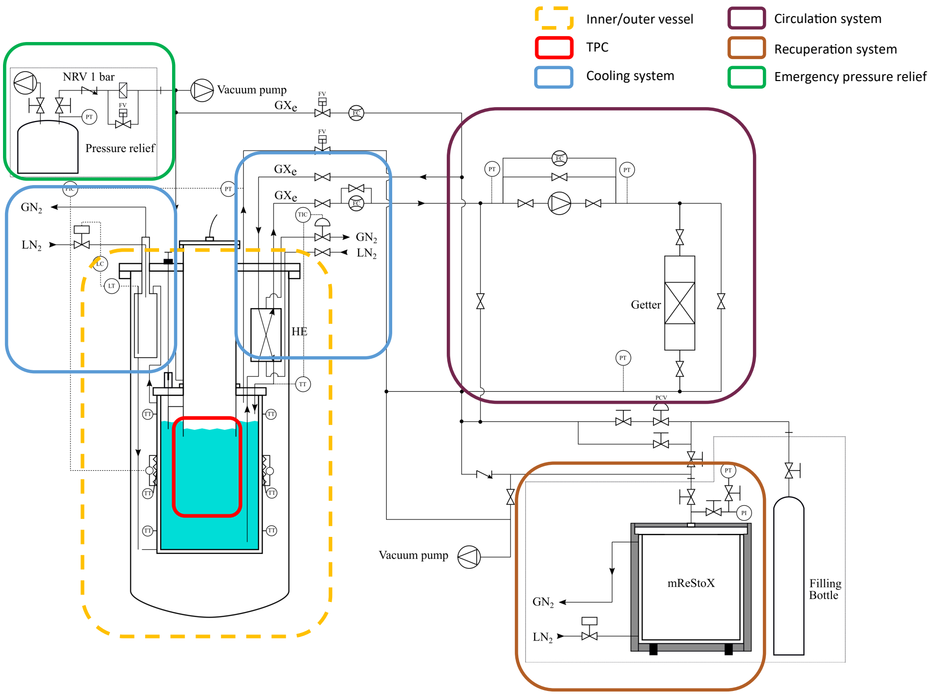

Figure 1: P&ID of XeLab facility

2.1 Cooling system

The cooling of the inner vessel is based on LN_2 boil-off. The laboratory building is supplied with a direct line of LN_2 from a 15 000 liters tank operated by the "Low Temperature Service" of Sorbonne Université. The LN_2 is used to cool down a copper belt surrounding the inner vessel. The cooling power is controlled with heating resistors placed directly in contact with the vessel. A heat exchanger based on the energy exchange between liquid and gaseous xenon is used to condense the xenon to the inner vessel. The small thermal losses during the process are compensated by an intake of LN_2.

2.2 Recuperation systems

mReStoX recuperation system was designed to recover xenon from the inner vessel when operations with the TPC are stopped. When LN_2 is accumulated in the mReStoX, xenon will be cryopumped and will solidify in several hours. When the recuperation is finished, the xenon can be warmed up to room temperature as mReStox is rated for pressures of 75 bar.

Figure 2: Left: rendering of the TPC under design. Right: The recovery system mReStoX.

2.3 The TPC

The current design of the TPC is shown in figure 2 it will be cylindrical with 50 mm height and 50 mm diameter. It will be composed of 5 electrodes namely the cathode, the gate, the anode and two field compensation electrodes in front of the PMTs (Photo Multiplier Tubes) placed on a Polytetrafluoroethylene (PTFE) frame. The light signals will be collected with an array of 4 PMTs (Hamamatsu R8520-406) at the top and with a single PMT (Hamamatsu R12699-406M4) at the bottom[1].

3. System control and DAQ

The first goal of the system control system is to ensure safety of people and goods, this implies to build a robust system to handle cryogenic fluids. Valve control is directly fed with a temperature sensors with no logic in between for the most crucial parts of the system. A second step of control is carried out by a PLC (Programmable Logic Controller). It comprises digital and analog inputs which can be read out and trigger some action on the outputs. After the logic is defined it can be operated independently of a computer. The PLC used is an RevPi Connect S with one analog and one digital module. It is programmed with standard Codesys software and complies with industry standards while allowing some customization offered by the open source design of the Rasberry Pi. Lastly, the monitoring is handled thanks to the "astro slow control" software suite [4] which allows for the communication with instrumentation devices such as the high voltage, the temperature and pressure sensors and allows for the monitoring of several parameters as well as their display and allows for alarms setting on them.
The digitisation of the PMT signals is done with a CAEN V1720 (8 channels, 12 bits 250MS/s ADC board). The software used, based on the XenoDAQ [5] code, allows for the configuration of the ADC board and the data acquisition with options such as a graphical interface and a zero length encoding to decrease the data throughput.

[1]this PMT is made of 4 cells whose signal can be separated in a later stage of the experiments if needed

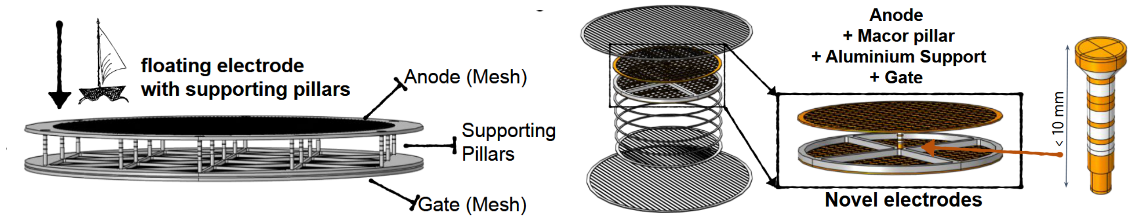

Figure 3: Left: New design of gate and anode electrodes, bound together with the supporting pillars. Right: TPC electrodes as designed for testing in XeLab and close up on one pillar with alternating layer of conductive and isolating material.

4. The floating electrodes

Concept The electrodes of current double-phase TPCs such as XENONnT are built with thin wires (typically 200 µm diameter). The gate electrode which ensures electron extraction from the liquid to the gas phase is placed only at a few millimeters from the liquid interface and the anode a few millimeters above. They are subjected to electrostatic and gravitational forces which can lead to sagging and in turn can affect the energy resolution. Furthermore, the tension on those wire is applied at room temperature while the actual operation of the TPC happens at the temperature of the liquid xenon (178 K) which can produce unexpected mechanical effects. To cope with such constraints, we propose a new electrode design with a rigid structure onto which a mesh is sitting. The gate to anode distance is kept fixed with isolating pillars. The material of the pole needs to be well chosen to minimize the Archimedes force. The electrode structure will also be fixed to the sides of the TPC (hence the electrode are not completely floating). The illustration of this design is shown in figure 3 (left).

Implementation The design of the electrodes that will be tested in the XeLab TPC will contain only a single pole as shown in figure 3(right). The electric field of the TPC was simulated using the COMSOL software to verify its uniformity. The mesh considered are stainless steel woven mesh of around 200µm in diameter wires with optical transparency between 70% and 75% from the Gantois [6] company. The pillar material will be subjected to high electric fields at low temperature. Several studies already in the literature have shown that specific ceramics such as Fe_2O_3/YSZ (Yttria Stabilized Zirconia) [7] but also High Density PolyEthylene (HDPE) [8] can comply with the requirements. The cryogenic system is expected to be commissioned in the fall 2023 to begin with electrode test in early 2024.

References

[1] Aprile, E. *et al* Projected WIMP sensitivity of the XENONnT dark matter experiment. *Journal Of Cosmology And Astroparticle Physics*. **2020**, 031-031 (2020,11), https://doi.org/10.1088

[2] Linehan, R. *et al* Design and production of the high voltage electrode grids and electron extraction region for the LZ dual-phase xenon time projection chamber. *Nuclear Instruments And Methods In Physics Research Section A: Accelerators, Spectrometers, Detectors And Associated Equipment*. **1031** pp. 165955 (2022,5), https://doi.org/10.1016

[3] Aalbers, J. A next-generation liquid xenon observatory for dark matter and neutrino physics. *Journal Of Physics G: Nuclear And Particle Physics*. **50**, 013001 (2022,12), https://doi.org/10.1088

[4] Nikkel, J, Yale University, https://bitbucket.org/jnikkel/astro-slow-control/src/master/

[5] Girard, F, University of Zurich, https://github.com/Physik-Institut-UZH/XenoDAQ/

[6] https://www.gantois.com/

[7] Olano-Vegas, L. Development of Fe2O3/YSZ ceramic plates for cryogenic operation of resistive-protected gaseous detectors. arxiv:2305.12899 [physics.ins-det]

[8] L. Rogers *et al* 2018 JINST 13 P10002