LAr Time Projection Chamber R&D at UCL

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Outline

• Why LAr R&D
• LAr R&D areas
• Recent results
• Conclusions
Why LAr R&D

Several experiments for dark matter searches and studying neutrinos use noble gas dual-phase TPC technology (later).

- **One-phase LAr TPC** with charge readout and minimal light readout for the signal trigger for studies of neutrinos from CNGS beam.

- **EXO-200**
  For 0νββ decay in the Xe-136.

- **DUNE**
  The full-scope DUNE far detector is LAr TPC of fiducial mass 34 kt.

- **Dual-phase LXe TPC** @ Sanford Underground Laboratory at the Homestake mine, South Dakota (US).

- **Dual-phase LAr TPC** @ LNGS.

- **Dual-phase LXe TPC** @ China-Jin Ping underground Laboratory (CJPL) in south west China.
Figure 2. Illustration of the operation principle of a double-phase electroluminescence detector. The number of electrodes may vary: some detectors do not feature a grid under the liquid surface; additional grids are often placed in front of the photomultipliers in order to shield them from the external electric field. Only one array of photomultipliers is used in some chambers: either immersed into the liquid and looking upwards, or placed in the gas phase viewing downward.

The interaction of a dark matter particle with the detector takes place in the bulk of the liquefied xenon or argon. The particle scatters elastically off an atomic nucleus transferring to it part of its kinetic energy. In the energy range considered (\(\sim 1–100\) keV) the initial velocity of the nuclear recoil is comparable to that of the atomic electrons, so that the recoiling atom conserves most of its electrons and moves through the liquid as a positive ion with low effective charge (or even as a neutral atom). The moving ion continuously exchanges electrons with other atoms along its way and its average charge in xenon is \(\sim 0.1\) e at 1 keV and \(\sim 1\) e for 100 keV (for argon and neon these values are approximately twice as large). As the medium consists of atoms of the same species, the primary recoil can transfer a significant fraction of its kinetic energy in each collision, thus losing rapidly its 'projectile' identity and producing a cascade of secondary recoils of comparable energy which interact with the medium in the same way.

The interaction mechanism of nuclear recoils with matter differs from that of electrons, as besides the energy loss to atomic electrons it involves energy transfer to atomic nuclei (essentially generating heat, which does not contribute to the observed signal in these detectors). Consequently, the track structure is different for electrons and nuclear recoils and one can expect that the charge recombination along the particle track also behaves differently. This is indeed verified.

LAr R&D areas

- Single-phase TPC (vs double phase TPC)
  - no high voltage handling in gas (HV might lead to discharge due to lower breakdown voltage in gases)
  - no need of a precise control of the liquid-gas interface level
  - no total internal reflections suffered by S1 at the liquid-gas interface, i.e. higher light collection efficiency for S1
  - main challenge is then to build up a S2 signal with sufficient gain
LAr R&D areas

- Replace extraction grid by thick gaseous multipliers (ThGEMs)
- Test SiPMs
  - better resolution, higher QE and more robust than PMTs
- Test HV feedthrough
What has been done.

- Comparison of SiPM performance at room temperature to standard PMT

- Waveform analyser - LArView

- First tests of SiPM at cold temperature (-40°C)

- Completed construction of ThGEMs (started preliminary tests at room temperature)
What has been done lately.

- vacuum pump
- flow meter
- PG1
- PG2
- filters
- by pass line
- connection to pump
- SAFETY PROTOCOLS
- RGA
- Ar bottle
- connection to pump
- getter
- BPR
- ft cap sensor & PT100 ladder
- extraction fan
- dirty LAr container
1. **PT100 ladder:**
   - It consists of a PTFE rod mounted on a blank.
   - Holes along the rod host the PT100s.
   - PT100 are platinum sensors, whose operating principle lies on the correlating the resistance of the platinum element with temperature (highly repeatable, very linear T vs R relationship)
   - A PTFE holder has been designed to avoid breaking the PT100 legs which are very fragile.
2. Capacitive sensor

- It exploits the pullability of quartz crystals to work as a level sensor.

**In theory**

A quartz behaves like a RLC circuit, with a precise res. freq.

$$\omega_r = \frac{1}{L_m C_m}$$

By adding a load capacitance in series with the crystal, the res. freq. changes.

$$\omega_L = \omega_r \sqrt{1 + \frac{C_m}{C_s + C_L}}$$

The pullability tells how much the res. freq. changes as a function of a load capacitance.

**In practice**

Quartz with nominal res. freq. of 11.0592MHz

A custom made SS cylindrical capacitor.

By immersing the sensor in LAr the capacitance increases, while the res. freq. decreases.

9 identical quartz in parallel
Level sensor

2. Capacitive sensor

- VNA to scan over frequencies and find the resonant one.
- When more than one quartz is used, multiple resonance frequencies appear.
- We chose to monitor two: 30MHz and 92MHz, which showed the greatest pullability.
LAr test (17/03/2015)
Calibration

- The tests we carried out at room temperature outside the chamber showed a linear relation between resonance frequency and level of LAr.

- The relation we found using the information on PT100s location inside the vessel and on the bottom and top points of the capacitive sensor is a polynomial of order 2.

Source of error in the calibration:
- not know precisely when the change in the frequency trend occurs

Liquid level touches sensor (point A at 10.2 mm from bottom)

Liquid level beyond sensor (point B, at 430.2 mm from bottom)
LAr level
Conclusions

• We have successfully liquified a whole chamber of LAr

• Developed good safety protocols

• LAr-1ND HV feedthrough sealing tests

• We are now working on evaluating all the data, optimising running procedures and optimising the sensors

• Passive cooling with the dirty LAr jacket works. We’ll now look at active control to liquify argon.

• Design/build of the TPC on going...
TPC technology

S1 provides a trigger signal
z position: electron drift velocity \times drift time
xy position: \( (x, y) = \frac{\sum_{i=1}^{N_{\text{top}}} (x, y)_i \cdot S_2_i}{\sum_{i=1}^{N_{\text{top}}} S_2_i} \)

Two scintillation mechanisms

**Excitation**
- \( \chi + R \rightarrow R^* + \chi \)  \( \text{impact excitation} \)
- \( R^* + R \rightarrow R^*_2 ; \nu' \)  \( \text{excimer formation} \)
- \( R^*_2 ; \nu' + R \rightarrow R^*_2 + R \)  \( \text{relaxation} \)
- \( R^*_2 \rightarrow R + R + h\nu \)  \( \text{VUV emission} \)

**Ionisation**
- \( \chi + R \rightarrow R^+ + e^- +\chi \)  \( \text{ionisation} \)
- \( R^+ + R + R \rightarrow R^+_2 + R \)  \( \text{recombination} \)
- \( e^- + R^+_2 \rightarrow R^{**} + R \)  \( \text{recombination} \)
- \( R^{**} + R \rightarrow R^* + R + \text{heat} \)  \( \text{recombination} \)
- \( R^* + R + R \rightarrow R^*_2 + R + \text{heat} \)  \( \text{recombination} \)
- \( R^*_2 \rightarrow R + R + h\nu \)  \( \text{VUV emission} \)
Argon: phase diagram

Heavy lines show the boundaries between liquid and gas (TC) and between liquid and solid (TM). Curve PQRS describes a path from a typically liquid state (P) to a typically gaseous state (S).

Working pressure inside the chamber to guarantee argon in form of liquid

Dirty liquid argon 87.8K at 1 bar.
92MHz res. freq. corrected

Error on frequency
~0.2MHz
Source of error in the calibration:
• not very clear when PT100s are being touched by the liquid