Purification of large volume of liquid argon for LEGEND-200

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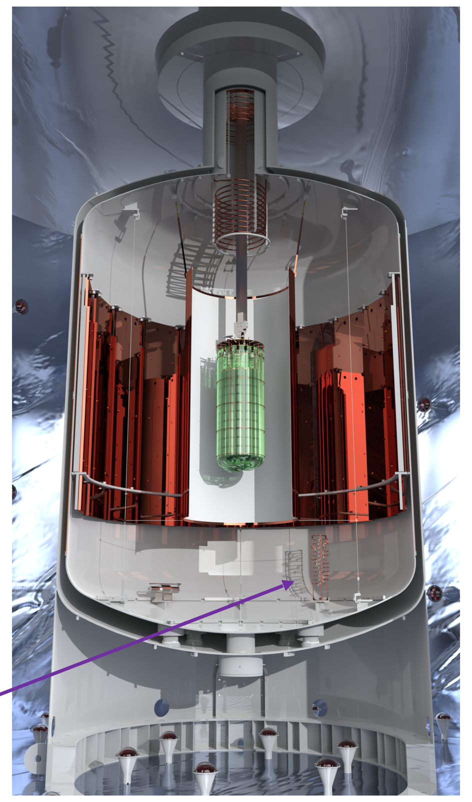
Large Enriched Germanium Experiment for Neutrinoless ββ Decay

Quasi-background-free search for 0νββ decay in ^{76}Ge

LEGEND-200 (L-200) combines technologies developed in GERDA (e.g. Liquid Argon veto) and MAJORANA DEMONSTRATOR (e.g. underground formed copper), as well as from other groups to:

- deploy 200 kg HPGe detectors in the GERDA infrastructure in the underground laboratory LNGS in Italy.
- achieve a background index below $2x10^{-4}$ cts/(keV kg yr).
- obtain a discovery sensitivity for a half-life of 10^{27} yr after 5 years of operation.
- liquid argon LAr (90 t) serves as coolant, passive and active shield.
- keep high LAr purity inside LEGEND-200 cryostat during data taking. LAr circulation and purification possible if needed.
- **LLAMA** (LAr Monitoring Apparatus), 13 SiPMs at various distances to radioactive source, measuring LAr triplet lifetime, light yield and attenuation length.



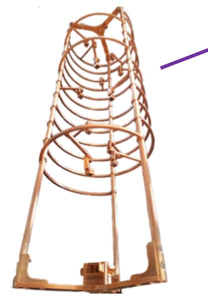
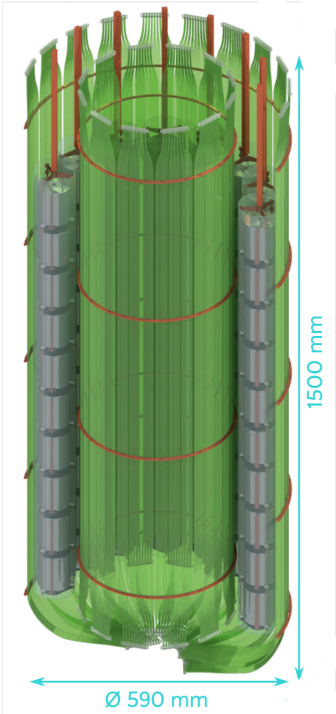
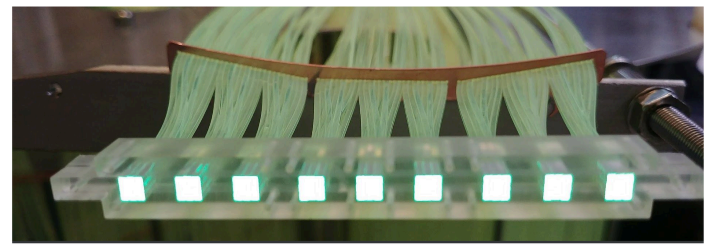


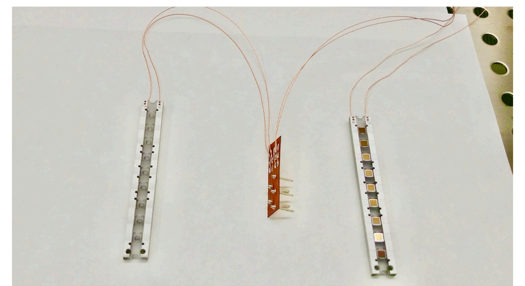
Fig 1. Legend-200 cryostat with instrumentation inside the water tank. LLAMA apparatus - purple arrow.

It has been already shown in **GERDA** experiment that the **LAr veto** is a very powerful tool for the background rejection [1].

L-200 LAr instrumentation is composed of low-background wavelenght shifting light guiding fibres connected to SiPMs detecting 128nm(VUV) scintillation light of argon.







SiPM arrays, before being connected to the light guiding fibres

The scintillation properties of LAr (light yield, attenuation length, effective triplet lifetime τ_3) are worsened by the presence in the liquid of electronegative impurities such as oxygen, water and nitrogen due to quenching and absorption processes. Consequently, the efficiency of the LAr veto will be impacted.

LAr purity goal: τ_3 > 1.2 μs inside LEGEND-200 cryostat during operation.

While the certified LAr (LEGEND-200 specification) from Linde delivered to LNGS contains: O_2 < 0.95 ppm, N_2 < 0.5 ppm, H_2O < 0.9 ppm => τ_3 **~ 0.9 μs**

References:

1. Gerda Collaboration, Phys. Rev. Lett., 125 (2020) 252502
2. LEGEND Collaboration, AIP Conf. ,Proccedings 1894(2017)

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Legend LAr Purification System - LLArS

Designed to remove O_2 and H_2O (N_2) from LAr while filling the Legend cryostat. The absorbent mass sufficient to process at least 8 ton i.e., the capacity of the storage tank. LLArS is integrated with the argon filling line and placed between the storage tank and the Legend-200 cryostat.

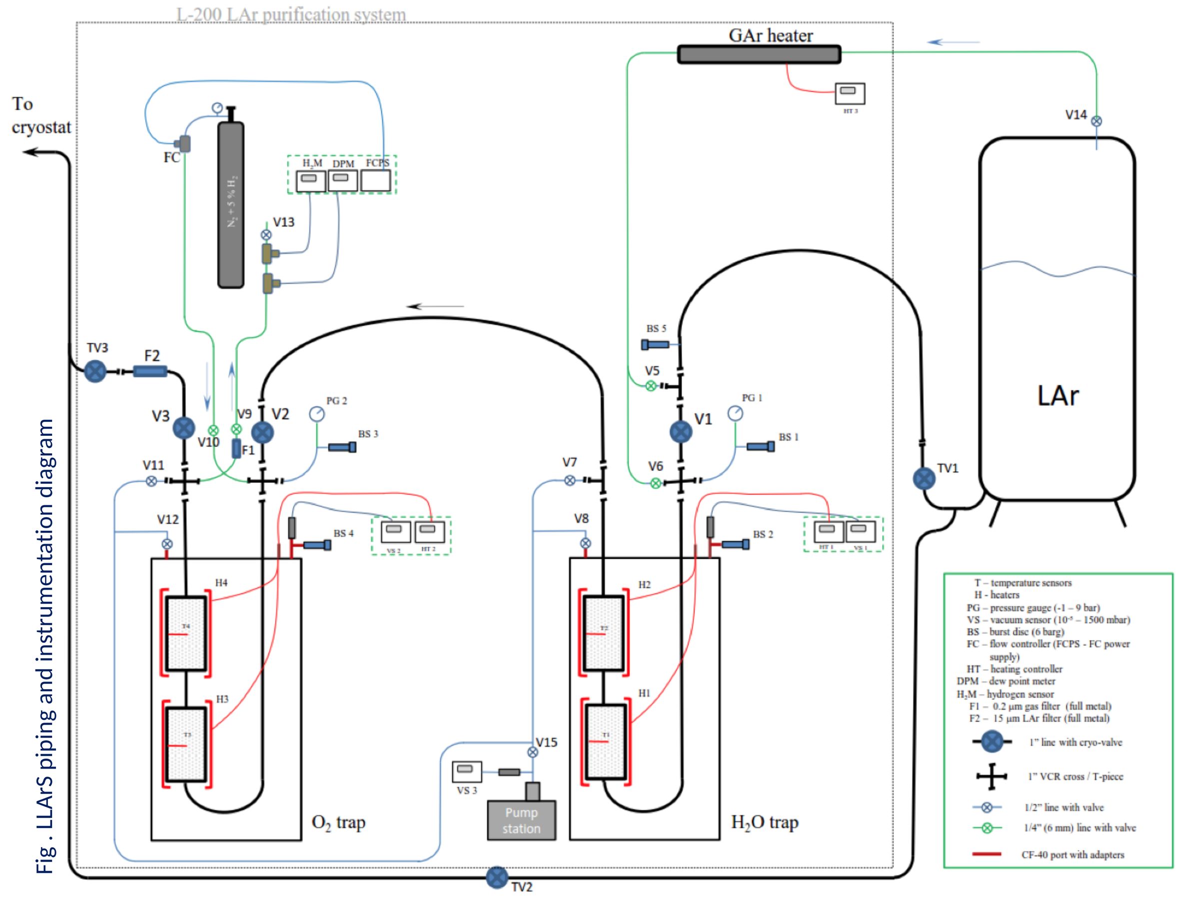


Fig . LLArS piping and instrumentation diagram

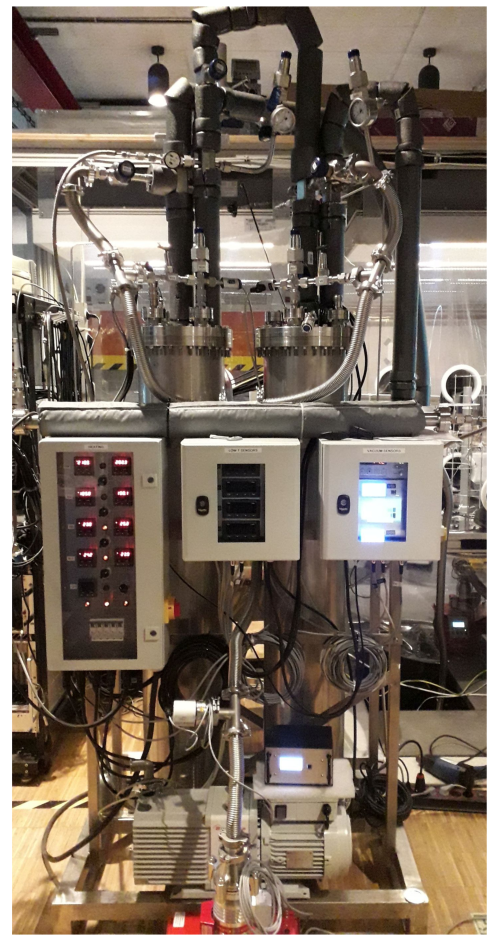


Fig 3. Assembled LLArS at TUM

Fig 4. Single trap equipped with heater. Test at JU.

Two units, each consist of 2 traps placed in vacuum insulation. The traps are equipped with heaters and temperature sensors. Water removal module: 2 × 5 kg of Molecular Sieve 4Å, oxygen removal module: 2 × 5 kg of copper cathalyst (Cu-0266 S®).

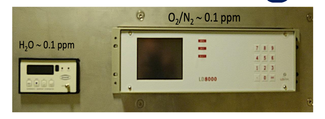
Regeneration procedure:

- O_2 traps: heating up to 250 °C and flushing with a mixture of 5% H_2 in N_2 for reduction of CuO while monitoring level of released water and hydrogen gas at the exit. After about 800 volumes of the traps have been exchanged H_2/N_2 is pumped out together with residual water to high vacuum (< 10^{-5} mbar).
- H_2O traps: heating up to 250 °C and pumping for several hours to reach high vacuum.

Verification of Liquid Argon purity by two systems:

- outside the LEGEND cryostat

Impurity Analyzer (IA) - H_20, N_2, O_2 at 0.1 ppm level - continuous monitoring



Scintillation Analyzer (SA) - LAr triplet lifetime measurement τ_3

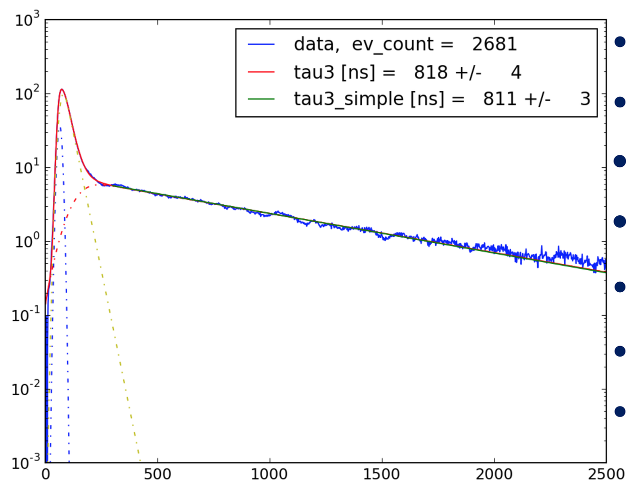
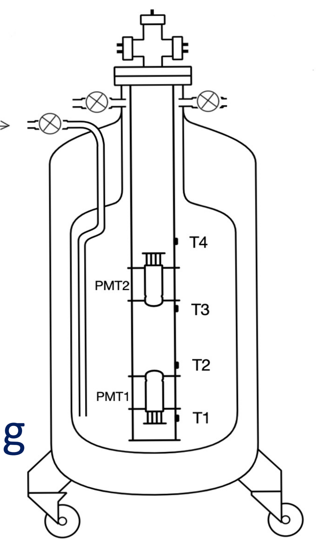


Fig 5. Scintillation light measurement of unpurified LAr sample (SA).

- 60L metal-sealed dewar, CF-160top flange
- LAr viewed by two 2" TPB-coated PMTs
- PMT's signal readout with linear amplifiers
- PMT's HV supply
- Temperature sensors – LAr level monitor
- DAQ unit: PC with 14 bit, 400MHz digitizer
- Pulse shape analysis determinig long component - triplet state lifetime τ_3



Initial tests at the Jagiellonian University (JU) in Kraków

80L of LAr 5.0 purified in a single trap filled with 5 kg of copper catalyst (see Fig. 4)

Argon scintillation light quality measured by SA before and after purification

before purification τ_3 **= 0.80 μs (SA)** => after purification τ_3 **= 1.25 μs (SA)**

Integrationgration test performed at Technische Universität München (TUM)

LLArS was fully assembled (Fig.3). Regeneration and operational procedures defined.

The system was tested by purifying **~1 ton** of certified LAr 5.0 containing:

2.3 ppm O_2, 3.7 ppm N_2 and 0.3 ppm H_2O (impurity level confirmed onsite with IA).

before purification τ_3 **= 0.65 μs (SA)** => after purification τ_3 **= 1.30 μs (LLAMA** in SCARF)

Commissioning test: in May 2021 LLArS was moved to LNGS.

The aim of the test was to proof the elaborated filling procedure and check the entire cryogenic system by purifying several tons of LAr and sending it to the cryostat.

4.3 ton of LAr (O_2 = 0.2 ppm, N_2 = 0.2 ppm, H_2O = 0.17 ppm) was processed. The τ_3 SA measurement was performed for unpurified and purified (several times) LAr.

before purification τ_3 **= 0.85 μs (SA)** => after purification τ_3 **= 1.25 μs (SA,** after 3.9 t)

Filling the LEGEND-200 cryostat in summer 2021

Cooling phase: cooling of the cryostat with low flow (~150 kg/h) of purified L-200 LAr to reduce the temperature of the walls avoiding large temperature gradients. Cooling phase used to determine the break through time (volume) of the purification system (monitoring of the triplet life time as a function of the volume of the processed LAr). After purifying 12 t of LAr the triplet life time dropped to about 1.1 μs and the system needs to be regenerated. We have also confirmed that regeneration of the water traps only does not recover the system fully.

Filling phase:

- LAr flow:~350 kg/h
- Continuous operation
- IA, SA and LLAMA: monitoring τ_3 and light yield levels
- LLArS performing as expected

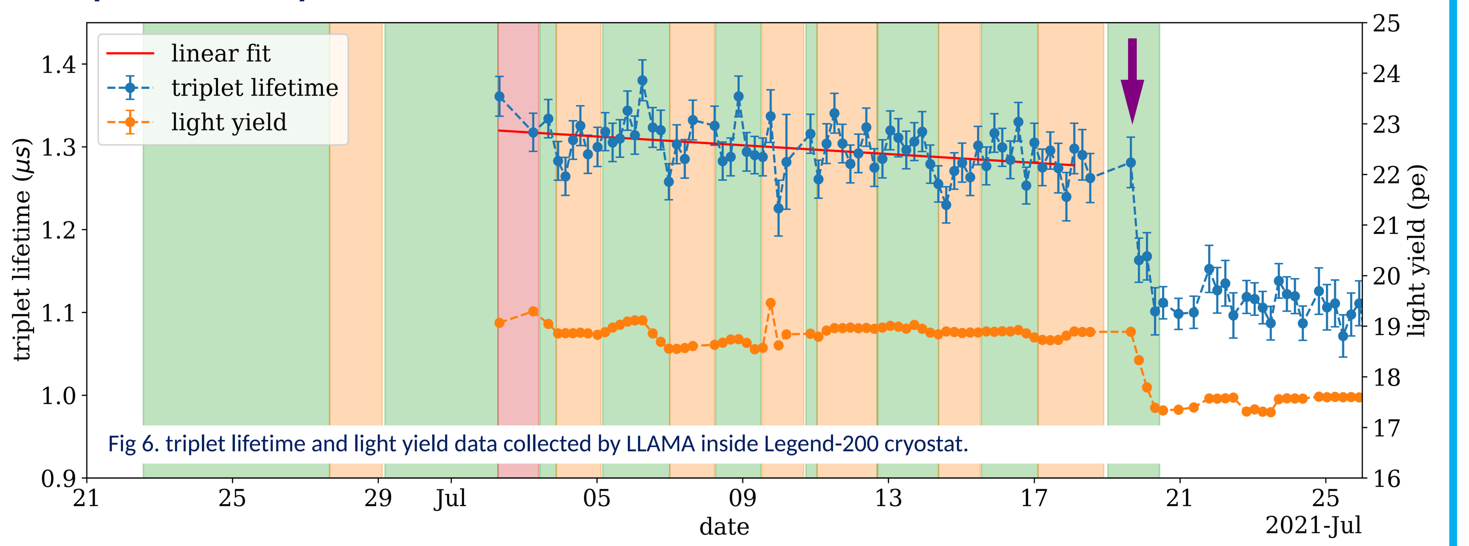


Fig 6. triplet lifetime and light yield data collected by LLAMA inside Legend-200 cryostat.

- Fig. 6 displays the filling/regeneration phases of the LLArS system as well as the triplet life time and LY measured by LLAMA for LAr filled into the cryostat.

mean value τ_3 = 1.29 μs was achieved for three weeks of filling!

- Purple arrow indicates a drop of τ_3 (to 1.1 μs) in the late filling phase (cryostat full in 77 %). The process was **stopped** and later investigations showed a high level of N_2 (10 ppm) in delivered LAr (although the delivery was certified for L-200 quality). LLArS was not able to reduce it enough. The problem of argon quality was discussed with Linde, appropriate measures have been taken to avoid similar issues in the future.
- Filling the missing ~25 t with high purity argon (September 2021) should improve τ_3 to about 1.16 μs.
- Additional purification of LAr with LLArS in the loop mode is possible thanks to a dedicated cryogenic pump installed already in the cryostat.