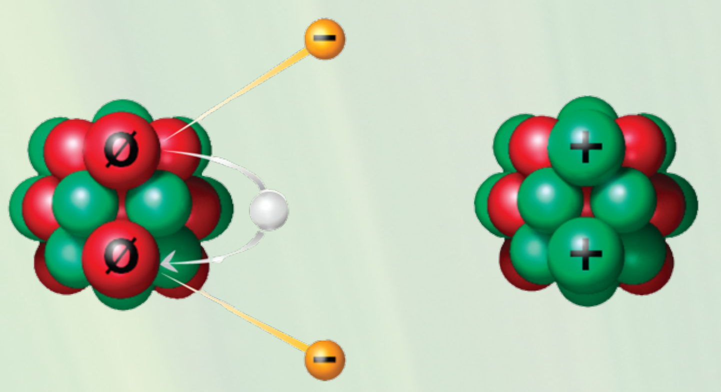
The LEGEND-200 LAr instrumentation in the search of neutrinoless double beta decay

Nina Burlac on behalf of LEGEND Collaboration

1. LEGEND-200 experiment

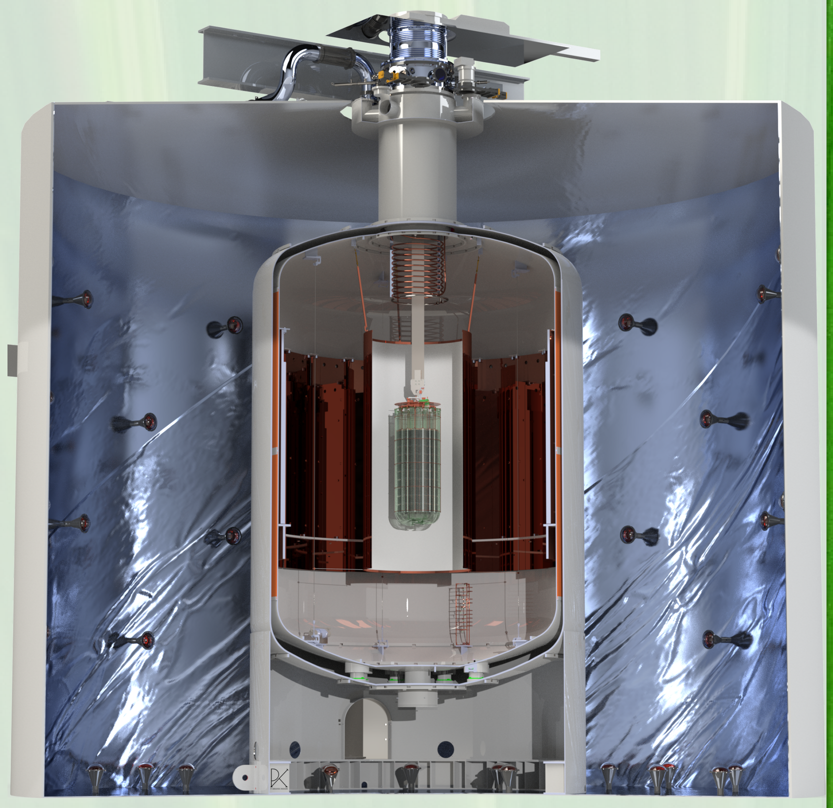
The LEGEND Collaboration works to develop the largest ^{76}Ge neutrinoless double-beta ($0\nu\beta\beta$) decay experiment in history [1];

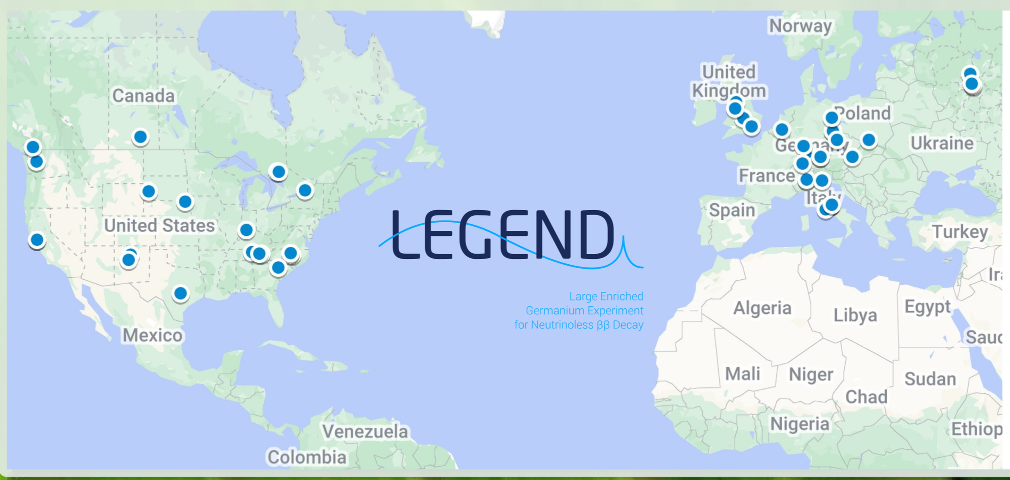


- the $0\nu\beta\beta$ decay is a nuclear transition in which two neutrons are simultaneously converted into two protons with the emission of two electrons and no anti-neutrinos;
- thus, the $0\nu\beta\beta$ decay violates the law of lepton number conservation and requires the exchange of massive Majorana neutrinos.

The first stage of the project, called LEGEND-200, already started at LNGS:

- the experiment aims to reach a sensitivity on the half-life of $0\nu\beta\beta$ decay up to 10^{27} yr;
- $\sim$200 kg of high-purity germanium (HPGe) detectors will be used;
- the HPGe detectors will operate in a cryostat filled with ultrapure Liquid Argon (LAr), which acts as cooling medium and shielding against background radiation;
- the LAr cryostat is placed inside a tank with purified water, which shields from neutron and gamma backgrounds, and also works as a muon veto;
- LEGEND-200 will start data taking in summer of 2022.





SNOLAB	Simon Fraser Univ.	Joint Res. Centre, Geel
Roma Tre	Univ. New Mexico	Lawrence Berkeley Natl. Lab.
Duke Univ.	Univ. Texas, Austin	Univ. California, Berkeley
Univ. Zurich	Univ. Washington	Polymer Research Dresden
Queens Univ.	Univ. Tuebingen	Leibniz Inst. Crystal Growth
Padova Univ.	Tech. Univ. Munich	Max Planck Inst., Munich
INFN Padova	Oak Ridge Natl. Lab.	Czech Tech. Univ. Prague
Laurentian Univ.	Univ. South Dakota	North Carolina State Univ.
Univ. Tennessee	South Dakota Mines	Joint Inst. Nucl. Res. Inst.
Univ. of Indiana	Univ. of North Carolina	Lab. Exper. Nucl. Phy. MEPhI
Comenius Univ.	Univ. of South Carolina	INFN Milano Bicocca
Lancaster Univ.	L'Aquila Univ. and INFN	Milano Univ. and INFN
Univ. of Regina	Gran Sasso Science Inst.	Triangle Univ. Nuclear. Lab.
Univ. Liverpool	Lab. Naz. Gran Sasso	Max Planck Inst., Heidelberg
Tennessee Tech	Univ. College London	Inst. Nucl. Res. Russ. Acad. Sci.
Univ. of Warwick.	Los Alamos Natl. Lab.	Natl. Res. Center Kurchatov Inst.
Jagiellonian Univ.	Tech. Univ. Dresden	

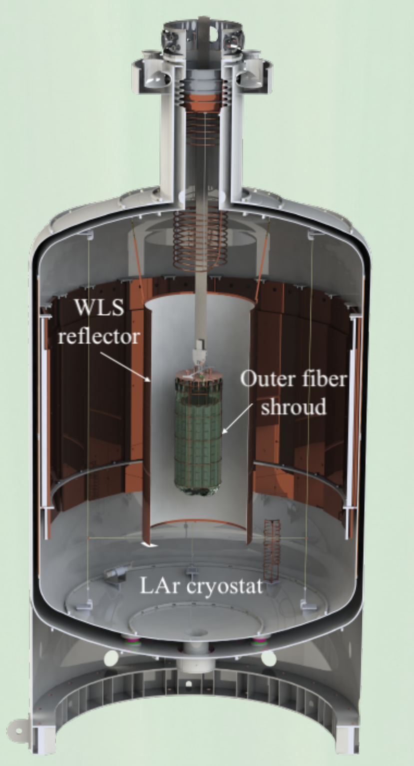
2. LAr instrumentation of LEGEND-200

The LAr instrumentation is an essential part of the LEGEND-200 experiment:

- designed to actively suppress background events;
- successfully tested in GERDA;
- improved version with greater coverage area adopted in LEGEND-200;
- made of materials with minimal background contribution.

The LAr instrumentation consists of:

- two concentric curtains of TetraPhenyl Butadiene (TPB) coated, double-cladded WaveLenght Shifting (WLS) fibers coupled to SiPMs;
- transparent TPB coated nylon mini-shrouds (NMS);
- TPB coated WLS Reflector (WLSR) cylinder.

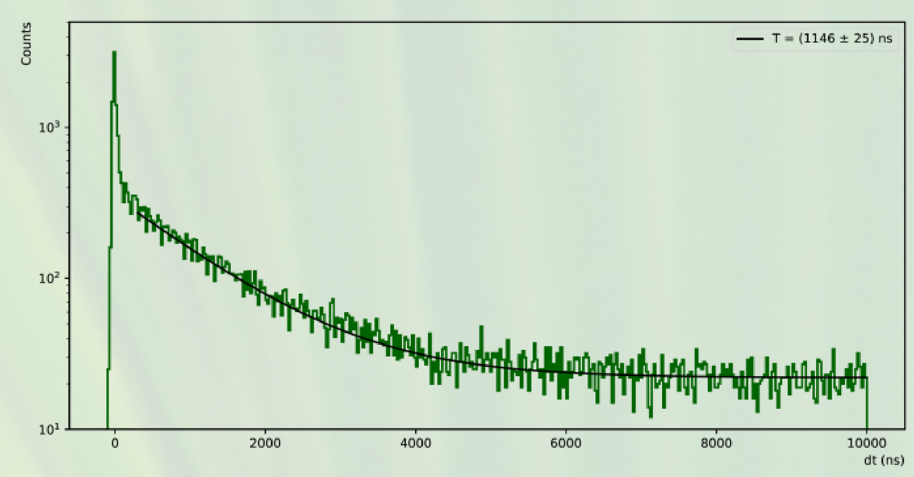


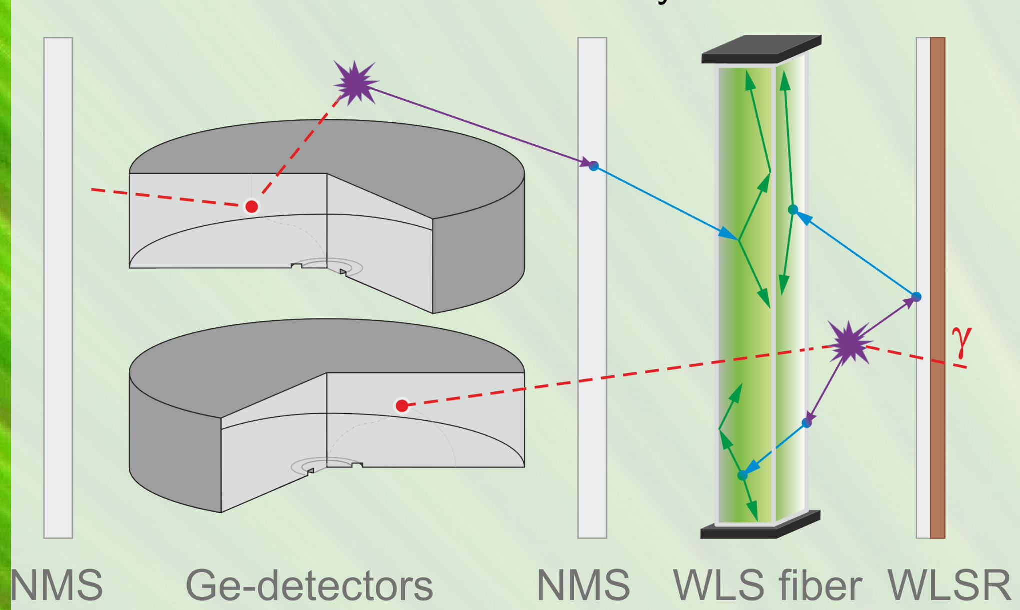
3. Liquid argon scintillation

There are predominantly two scintillation pathways:

- a fast component of 6 ns (singlet state);
- a slow component of 1450 ns (triplet state).

Decreasing of the triplet life-time reflects level of impurities in LAr.
The current triplet lifetime in LEGEND-200 is around 1150 ns and it's continuously monitored.





- Upon the interaction with ionizing radiation liquid argon emits 128 nm VUV light;
- TPB allows to shift the VUV light to blue light;
- optical WLS fibers shift the blue light to green, which is read out by SiPMs.

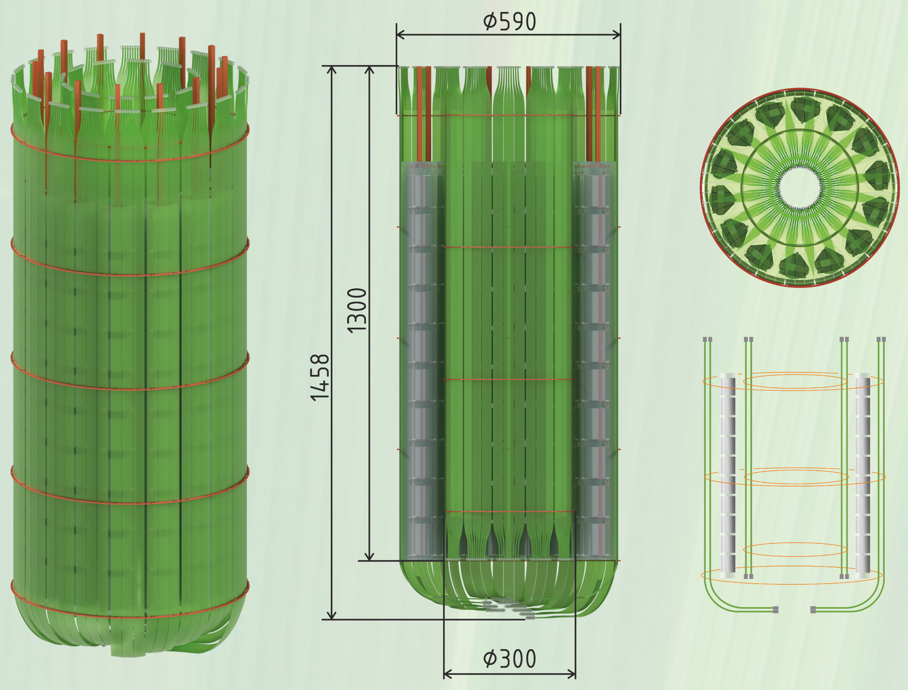
- The LAr instrumentation detects the Ar scintillation light created by energy depositions in the LAr that accompanies energy depositions in the HPGe detectors;
- such background events originate from α, β, γ or neutron interactions, originating from primordial, anthropogenic radioisotopes or cosmogenic produced unstable isotopes;
- they must be discriminated from $0\nu\beta\beta$ decay signals, which have energy deposition inside the HPGe detectors and no energy deposition in the LAr.

References

[1] LEGEND website: http://legend-exp.org/

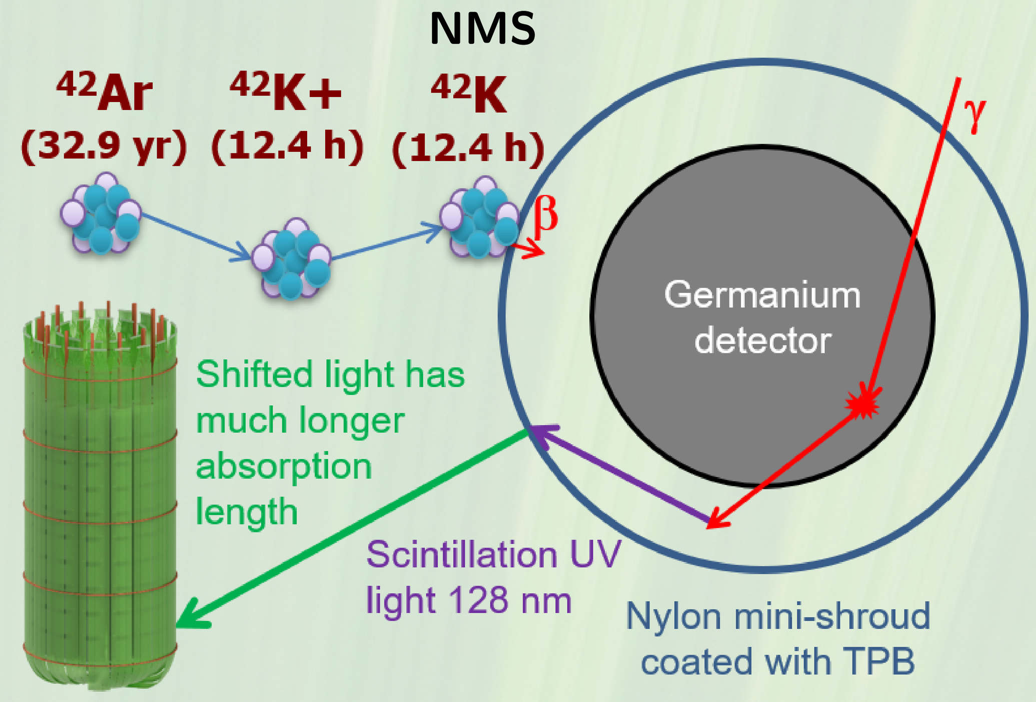
4. WLS fiber curtains, NMS and WLSR details

WLS fibers



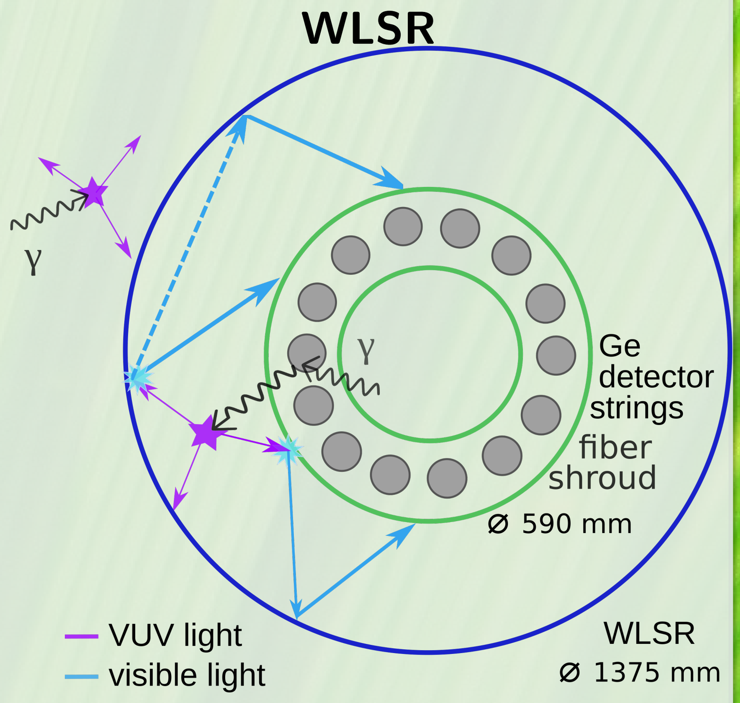
- 81 WLS fibers separated into 9 groups are glued into acrylic adapter and form one module;
- 1 μm of TPB is applied on modules by evaporation;
- SiPMs are coupled optically to the fiber modules on both ends;
- fiber modules with SiPMs are mounted on low radioactive copper barrels:
  - 9 fiber modules for the Inner barrel;
  - 20 fiber modules for the Outer barrel;

NMS



- transparent for LAr scintillation light due to WLS TPB coating;
- effective suppression of ^{42}K background (ion drift barrier).

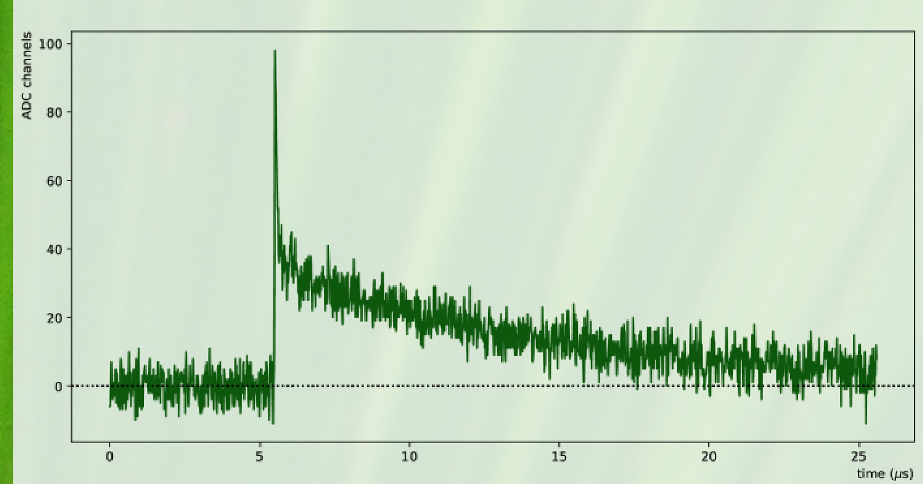
WLSR



- WLSR shifts VUV light and reflects visible light;
- the γ reflected from the WLSR can reach the fibers without attenuation in LAr;

5. Commissioning at LNGS

- The differential signals from SiPMs are driven via a 10 m long Kapton flat band to the outside of the LAr cryostat;
- then via 6 m long cat6A cables to the Front-End (FE) electronics which consist of:
  - 5 NIM FE boards:
    - 12 receivers and V differential amplifiers each;
    - 12 SiPM V_{bias} regulators each;
  - 1 controller board to set and monitor the main SiPM parameters (V_{bias} and I).
- the operation voltage of each SiPM is optimized to achieve uniform rates across all channels ($\sim$2-5 kHz due to ^{39}Ar);
- the analog pulses are digitized by FlashCam, a 16-bit 62.5 MHz flash ADC converter;
- data are acquired for characterization in terms of SPE resolution;
- the digital signal processing of the traces is performed within a dedicated software.

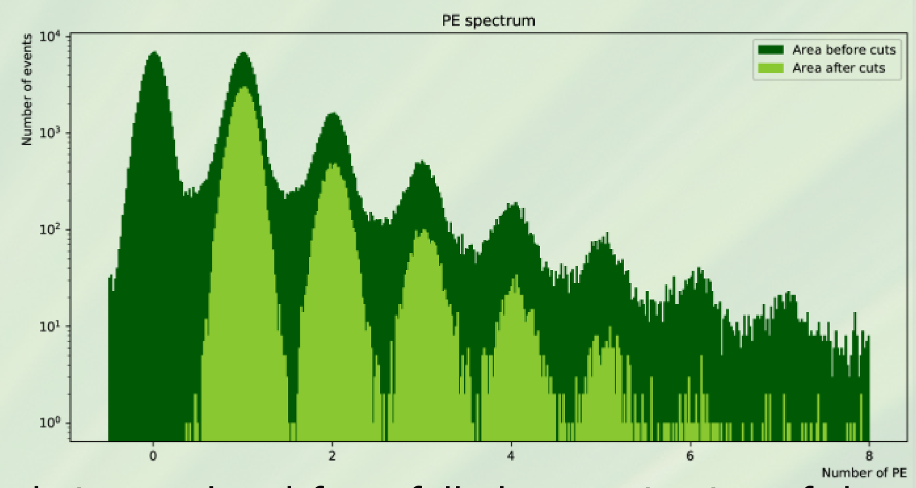


Typical signal

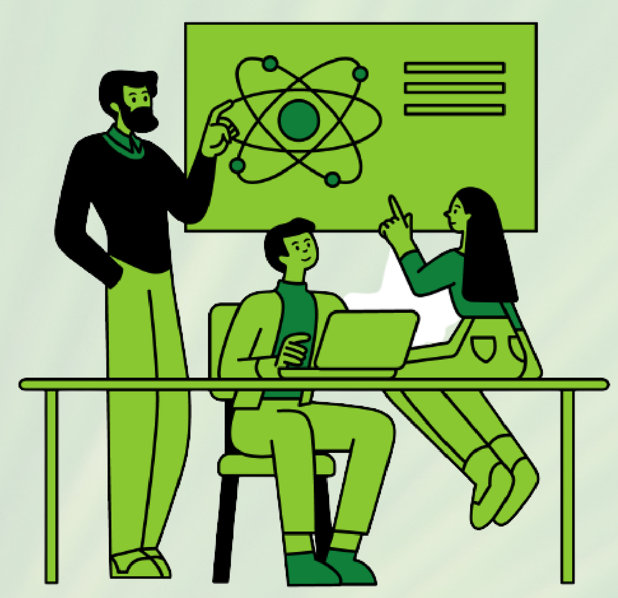
- signal with 2 decay components:
  - "fast" component ($\sim$0.2 μs): parasitic capacitance spike;
  - "slow" component ($\sim$5 μs): recharge of the microcell of SiPM;
- low noise level ($\sim$0.2 mV);

Example of SPE spectrum

- nice Single Photo-Electron (SPE) resolution (dark-green spectrum) obtained by signal integration;
- improved SPE resolution after quality cuts (yellow-green spectrum).



Several runs of data were recently acquired and are being analysed for a full characterization of the LAr instrumentation:



- ^{39}Ar runs
  - low energy calibration of the SiPMs;
- coincidence runs
  - rate coincidence between fiber modules;
- ultra high energy events (i.e Muons)
  - high energy calibration of the SiPMs;
- time coincidence of ^{214}Bi β and ^{214}Po α decays
  - rate measurements of ^{222}Ra contamination;
- data taking with ^{228}Th and ^{226}Ra sources
  - energy calibration of light detection spectra.