LLAMA - A novel system for in-situ monitoring of optical parameters in liquid argon

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Motivation

Monitoring liquid argon

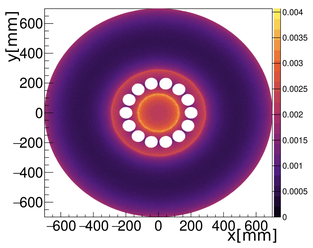
- Various particle physics experiments use Liquid Argon (LAr) as primary detection medium
⇨ Readout of LAr scintillation light (emission wavelength: 128 nm)
- Impurity concentrations at ppm (parts per million) levels alter optical properties of LAr:
  - Light yield
  - Lifetime of triplet state
  - Attenuation length λ @ 128 nm
- Knowledge of these parameters for modeling large volume detectors
- Potential contamination events during data taking require constant monitoring of LAr quality rather than single measurement

LLAMA for LEGEND

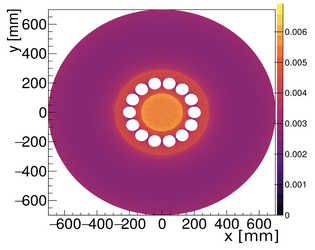
- The next-generation neutrinoless double-beta decay experiment LEGEND employs the LAr technology as active veto system
- Knowledge of light yield and attenuation length required for modeling LAr veto performance

Photon detection probabilities for different values for λ:

λ = 20 cm



λ = 1 m



⇨ Developing **LLAMA**, the LEGEND Liquid Argon Monitoring Apparatus as permanent in-situ monitor for LEGEND-200, the first stage of LEGEND

Key Features of LLAMA

- Permanent in-situ operation in LAr volume
- Copper as main structural material: reduced reflections and high radiopurity
- Use of triggered scintillation light source (4)
- Using HAMAMATSU VUV4 SiPMs exclusively (5):
  - directly sensitive to 128 nm photons
  - no wavelength shifter used in the setup ⇨ no visible photons

Peripheral light detection

- 13 VUV4 SiPMs in distances from 15 to 75 cm from light source

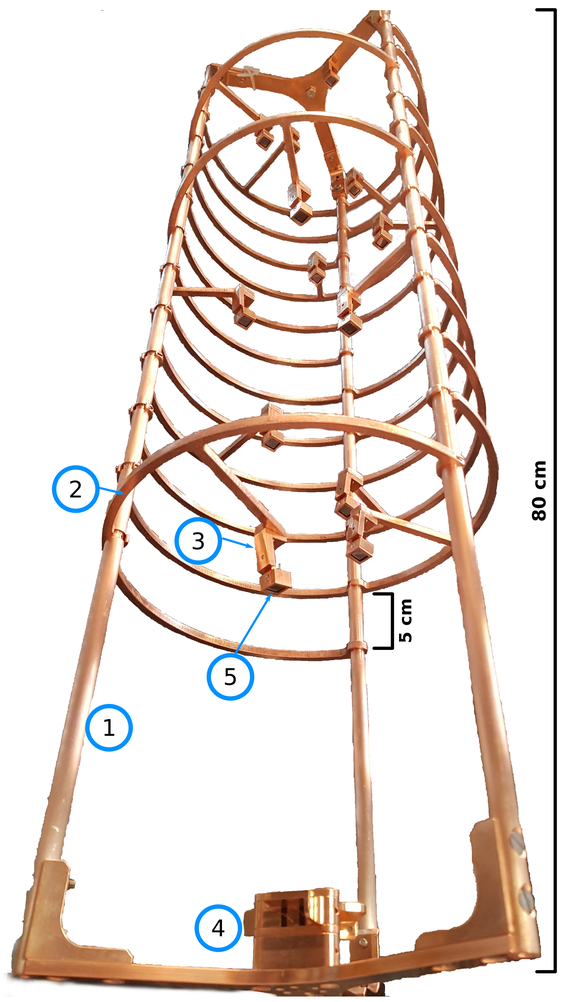
⇨ 13 data points for attenuation length measurements

- Individual holders align SiPMs to face the light source directly (3)
- Light levels for peripheral SiPMs very low

⇨ Probability of photon detection in given SiPM per scintillation event much less than one

⇨ Counting analysis applied (see Analysis section)

LLAMA Setup

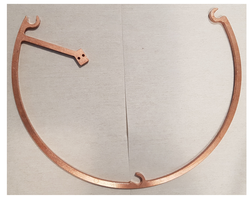


1 Copper Rods

- Three copper rods spanning between top and bottom of setup
- Grooves in regular distances for attaching rings

2 Copper Rings

- 12 individually shaped copper rings
- SiPM holders mounted on rings



3 SiPM Holders

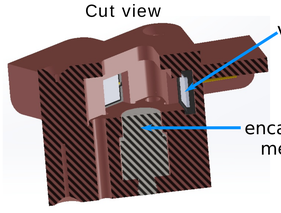
- 13 holders with individual angles

⇨ SiPMs face light source directly

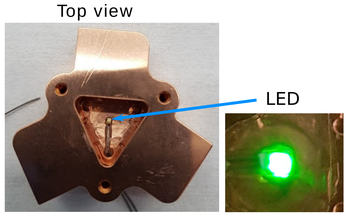
4 Light Source

- Triangular copper light source filled with LAr
- 60 keV gammas from ^{241}Am create scintillation light events: 128 nm photons
  - Energy below Čerenkov threshold: no visible photons produced
  - Metal shield against α radiation of ^{241}Am
- Three VUV4 SiPMs watch central volume for primary event information
  - Trigger time position, total energy information and spatial resolution
- Additionally: green LED for SiPM calibration

Cut view



Top view



5 SiPMs

- HAMAMATSU VUV4

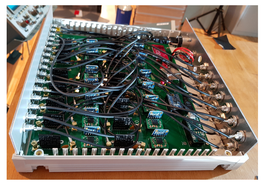
⇨ directly sensitive to 128 nm photons

⇨ LAr in-situ operation possible

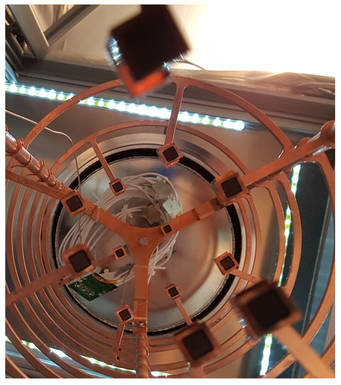
3 SiPMs in light source
+ 13 peripheral SiPMs
= 16 total readout channels

Electronics

- Custom electronics box housing preamplifiers and power supply for 16 SiPM channels
- SiPM voltages individually adjustable
- Digitization of signals using SIS-3316 FADC (250 MHz, 14 bit)



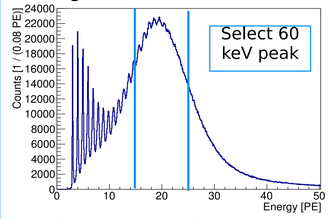
Look upwards: free line of sight for SiPMs



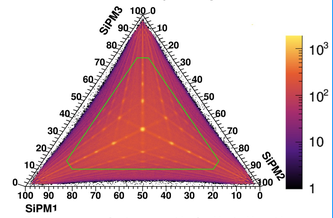
Analysis

Light source SiPMs

- Using events in the three source SiPMs for data quality cuts:



Total energy deposition in source.
Extract **light yield**.



Ternary plot: spatial distribution.
Select central events.

Peripheral SiPMs

- Probability to detect a photon per trigger in the light source (pulse per trigger, PPT) < 2.5 %

⇨ Sub-poisson statistics, perform photon counting analysis:

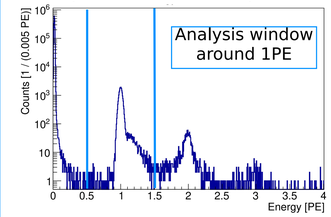
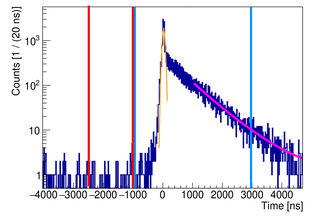


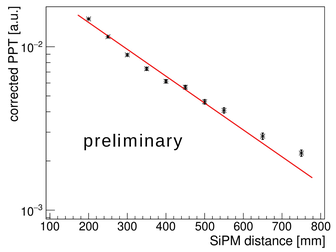
Photo-Electron spectrum for a peripheral SiPM.



Time spectrum for SiPM.
Extract **triplet lifetime**.
Count signal & background

Calculation of attenuation length

- Using net PPT values (statistical subtraction of accidental background)
- Correcting for SiPM quantum efficiency deviations, obtained from separate LED calibration run
- Obtain λ = (264 ± 4) mm for test Cryostat with poor LAr quality



Conclusion and Outlook

- LLAMA monitors optical properties of LAr continuously & in-situ
- Triggered scintillation light source:
  - 3 VUV4 SiPMs for primary event information
  - 60 keV gammas from ^{241}Am for 128 nm photon production
- 13 peripheral VUV4 SiPMs in distances from 15 to 75 cm for attenuation length measurements
- Plan to study effects of changing imputity levels & Xe-doping
- Single measurement of LAr in GERDA experiment forseen
- Installation in LEGEND-200 as monitor for LAr quality

Acknowledgements

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