University of Zurich[UZH]

Physik-Insitut

GERDA

elusives
neutrinos, dark matter & dark energy physics

# Studies of a PMT with magnesium fluoride window for direct detection of liquid argon scintillation light

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# Use of LAr scintillation light

- Neutrino and dark matter experiments increasingly exploiting scintillation of liquid argon
- e.g. time projection chambers (TPC), veto

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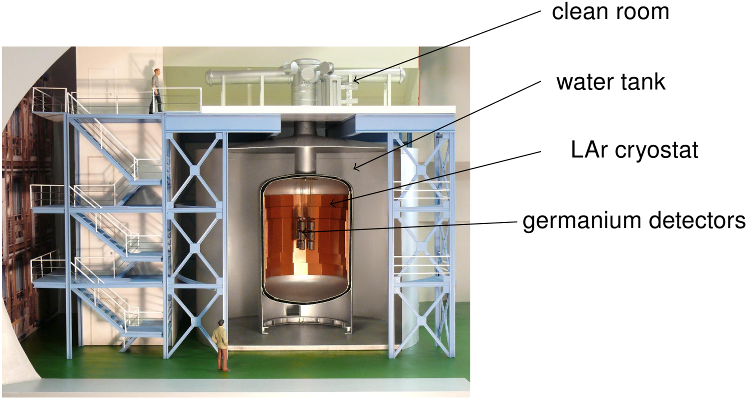
- Detectors working at low-energy spectrum require very low backgrounds due to materials

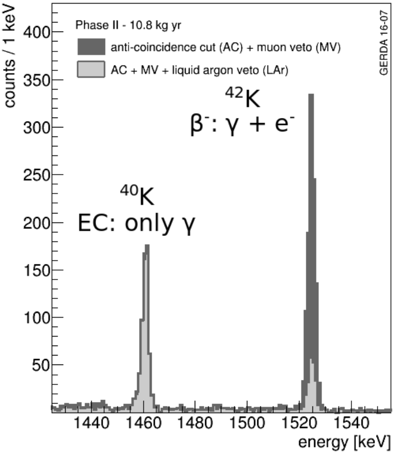
# GERDA

- GERDA searches for $0\nu\beta\beta$ decay of $^{76}$Ge at LNGS
- Current half limit = $8.0 \cdot 10^{25}$yr
  (preliminary, see R. Hiller talk yesterday)
- Employs enriched germanium detectors in liquid argon
- Active shielding: liquid argon veto



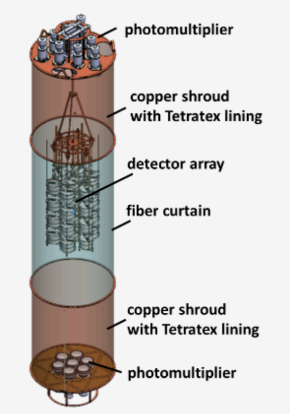
# GERDA

- Active shielding: liquid argon veto
- Energy deposit in liquid argon produces scintillation light

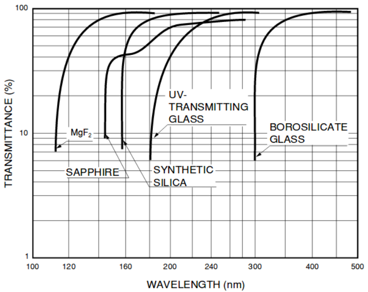


# Liquid argon (LAr) active shielding

- Argon scintillation light emitted at 128nm
- Current PMTs opaque at this wavelength $\rightarrow$ wavelength shifters required




The LAr veto system




Transmittance of various Hamamatsu PMT window materials [Hamamatsu PMT handbook]

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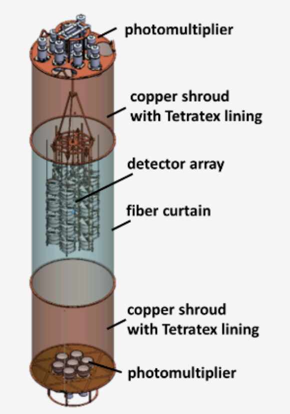
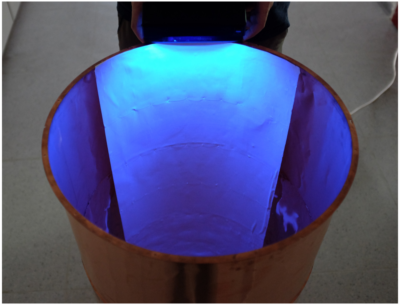
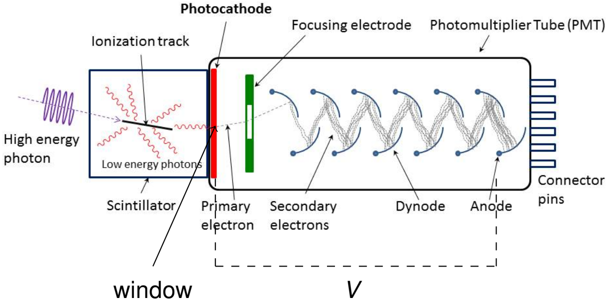


The LAr veto system

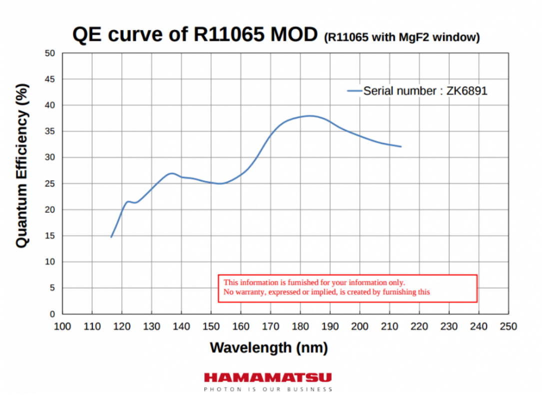
# Operation of a PMT

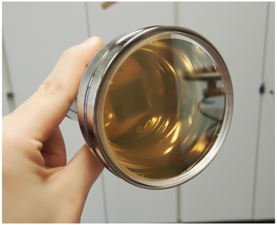



Schematic of PMT [https://commons.wikimedia.org/w/index.php?curid=38349029]

# $MgF_2$ PMT

- $MgF_2$ is transparent at 128nm
- PMT with $MgF_2$ window could form part of liquid argon setup without use of wavelength shifters → reduction in material

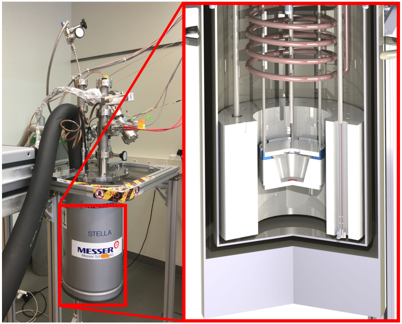


The Hamamatsu R11065 with a $MgF_2$ window

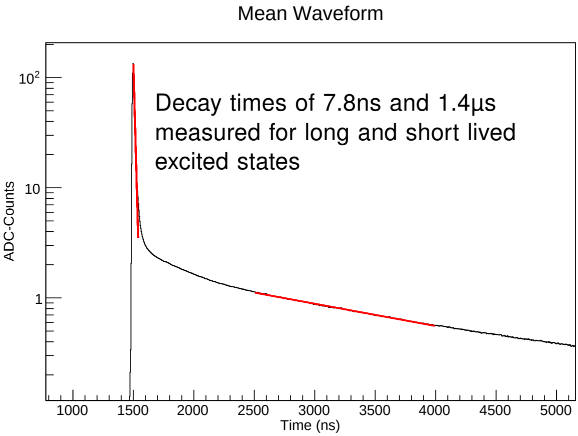
# The Liquid Argon Setup (LArS) and Sandbox

- LArS: chamber for testing PMTs and SiPM arrays during operation in liquid argon or nitrogen, at UZH
- Sandbox: Light-tight black box with enclosed LED



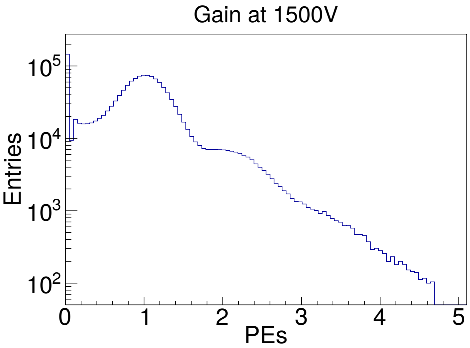

# Observation of LAr light

- Scintillation light stimulated by $^{241}$Am alpha-source in LArS
- Average waveform shows fast and slow component decays

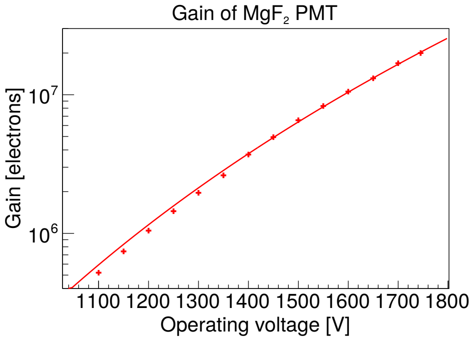


# Gain measurements

Gain: Amplification of PMT, collected charge in units of electron charge per initial photoelectron
Room temperature measurements, in Sandbox.




Area of trigger events in units of photoelectrons

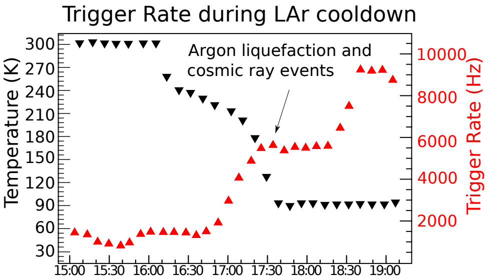


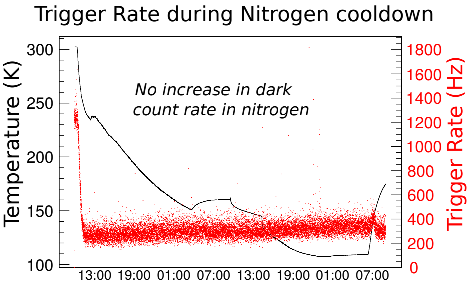

Gain of MgF2 PMT with voltage.
First data set, in Sandbox

Gain is $6.5 \times 10^6$ at nominal operating voltage of 1500V.

# Dark count rate measurements

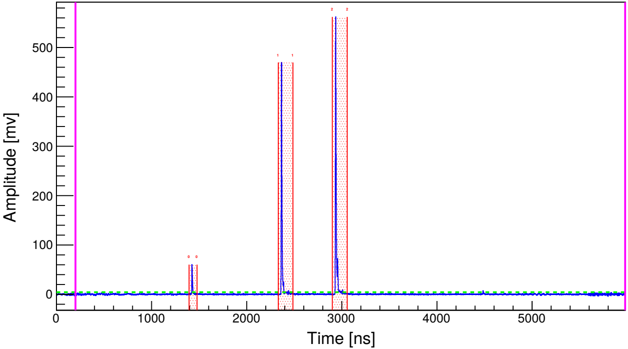
Dark count rate: rate of events above defined threshold in the absence of external signal



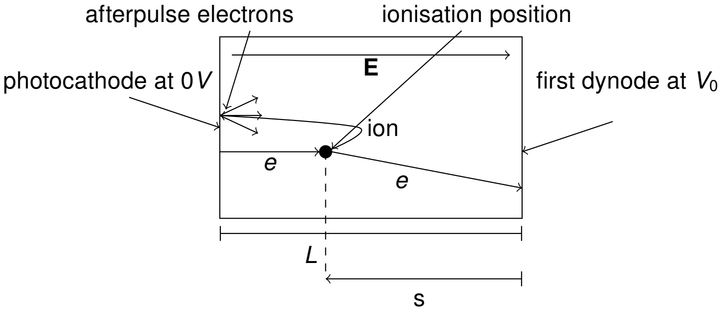

Increase in trigger rate in liquid argon environment but not nitrogen environment suggests that liquid argon scintillation light is being observed as expected.

# Afterpulses




Example afterpulse waveform

# Afterpulses model



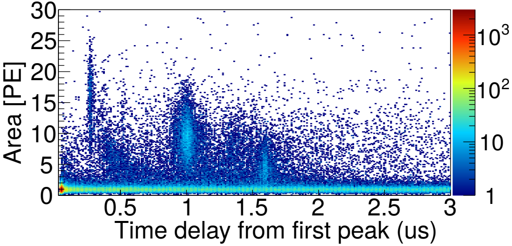

Model parameters

$$V(s) = V_0 \left(1 - \frac{s}{L}\right)^2 \qquad (1)$$

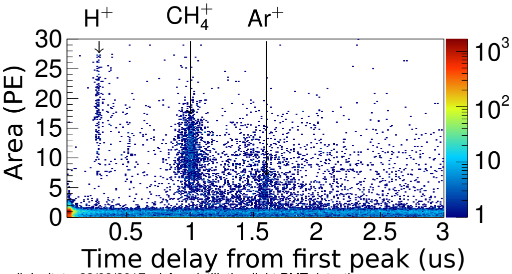
$$t = \frac{L\pi}{2}\sqrt{\frac{m_I}{2q_I V_0}} \qquad (2)$$

# Size and delay of afterpulses

Afterpulses from end 2015 ($2 \times 10^7$ waveforms, no amplifier)




Afterpulses from end 2016 ($4.5 \times 10^6$ waveforms, with amplifier)



# Afterpulse rates

Afterpulses > 3 PEs: remove time-uniform pedestal not due to ionisations.

| | All afterpulses | |
|---|---|---|
| | 2015 | 2016 |
| Afterpulse events per trigger event | 0.38% | 0.42% |
| Afterpulse events per trigger PE | **0.37%** | **0.35%** |

Comparable results, no large increase in afterpulses signifying no degradation of vacuum.

# Plans and conclusions

- Intend to now look at long-term performance of PMT in liquid argon
- Period in liquid argon bounded by period in nitrogen, to study dark rate stability (ongoing)
- PMT observed by SiPM array to look for light emission from PMT itself

- MgF2 PMT is sensitive to LAr light
- No increase in afterpulses indicates no degradation of vacuum.
- May procure further MgF2 PMTs for further studies.
- Currently taking long-term measurements in nitrogen, to be followed by liquid argon

Thank you for your attention

# Backup slides

# Afterpulses model

$$t = \int_{s_0}^{L} \frac{1}{v}\,\mathrm{d}s \tag{3}$$

$$\mathrm{K.E} = \frac{1}{2} m_l v^2 = e\,[V(s_0) - V(s)]$$

$$v = \sqrt{\frac{2q_l}{m_l}}\,\frac{\sqrt{V_0[(L-s_0)^2 - (L-s)^2]}}{L}$$

$$t = \frac{L\pi}{2}\sqrt{\frac{m_l}{2q_l V_0}} \tag{4}$$

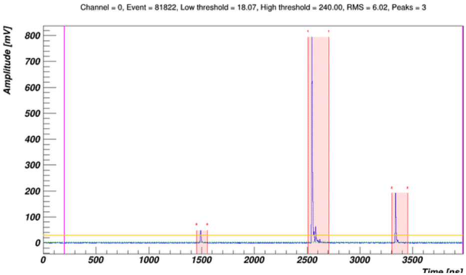
$$\frac{M}{Q} = \frac{8\,V_0}{(\pi L)^2}\,\frac{q_p}{m_p}(\Delta t)^2$$

$$= C_0 \cdot (\Delta t)^2 \tag{5}$$

$$C_0 = \frac{8\,V_0}{(\pi L)^2}\,\frac{q_p}{m_p} \tag{6}$$

# Selection of afterpulse events

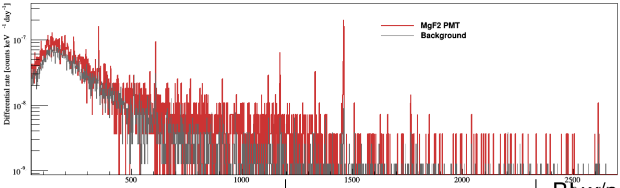
- RMS cut to ensure correct identification of peaks and calculation of area.
- Original signal pulse position in trigger window.
- Original signal pulse area between 0 and 3 photoelectrons.
- Afterpulses appear after the trigger window.
- Afterpulses have area greater than zero.




Waveform with afterpulse example

# Screening

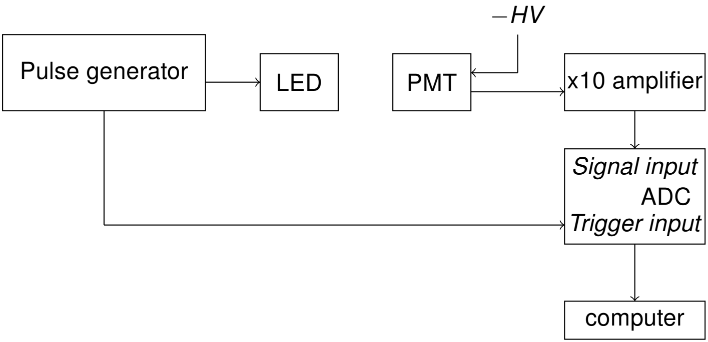
16 days screening of second MgF2 PMT in Gator facility.




| Background Source | | Activity (mBq / PMT) | BI w/o LAr veto (estimated for MgF2) |
|---|---|---|---|
| Current GERDA LAr PMTs | Th228 | <2.44 | $<3.1(1)\times10^{-4}$ |
| | Ra226 | <2.84 | $<5.5(2)\times10^{-5}$ |
| MgF2 PMT | Th228 | <3.36 | $<4.3\times10^{-4}$ |
| | Ra226 | $3.8 \pm 1.3$ | $7.4\times10^{-5}$ |

Similar results as for current PMTs, within a factor or two.

# Electronics setup




This year's electronics arrangement