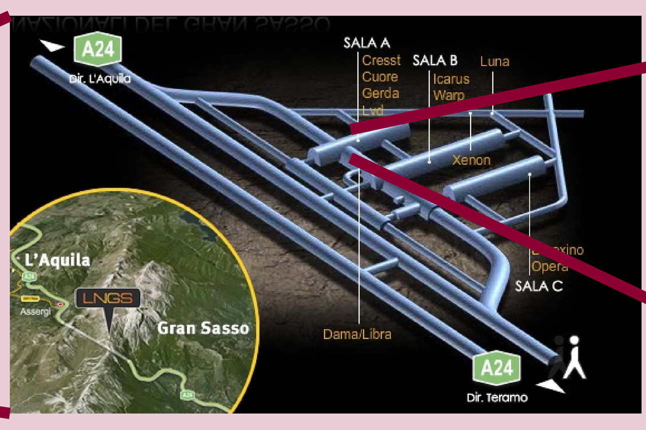
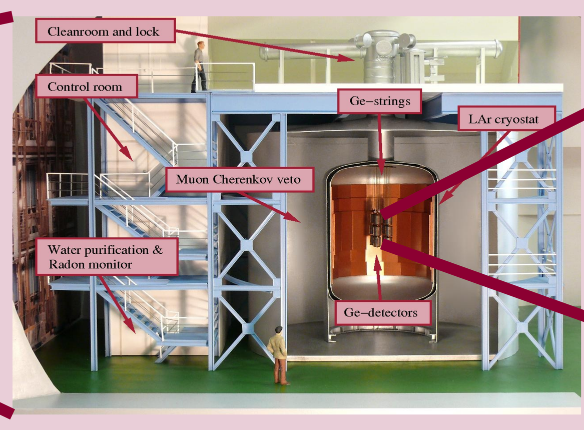
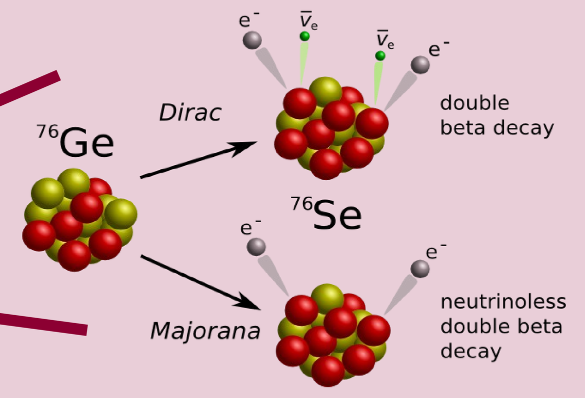
The Muon Veto

of the GERDA 0νββ Experiment

Kai Freund for the GERDA Collaboration
freund@pit.pysik.uni-tuebingen.de



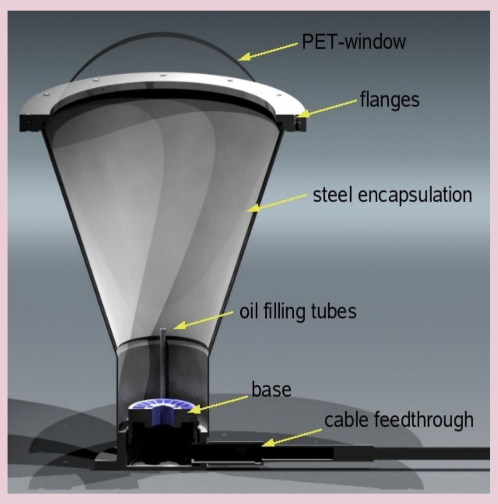



The GERDA (**Ger**manium **D**etector **A**rray) collaboration searches for the neutrinoless double beta decay (0νββ) of ^{76}Ge. The existence of this decay would strongly support the assumption that the neutrino is a Majorana particle, i.e. its own antiparticle. A measured half-life could be used to determine the effective neutrino mass and hence resolve the neutrino mass hierarchy problem.

Germanium diodes, isotopically enriched in ^{76}Ge, are used as both source and detector. Due to the low rate of this decay ($T_{1/2}>10^{25}$ yr), the experimental background must be reduced to a level of 10^{-2} counts/(kg yr keV) or better in the region around $Q_{\beta\beta}$.

To minimize background from cosmogenically produced secondary particles, a low Z shielding is employed. The naked diodes are operated in a liquid argon cryostat, which is surrounded by a water tank acting as both passive shield and active muon Cherenkov veto. In addition, the 3500 m.w.e. of rock overburden reduce the flux of muons by ~10^6.

Photomultiplier and Encapsulation



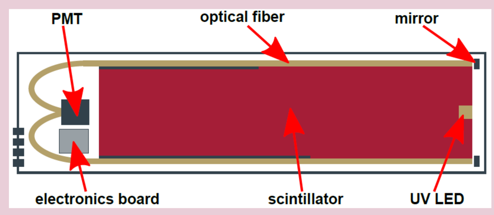
Technical details:
- PMT: 8" ETL 9350KB / ETL 9354KB
- 30% @ 350 nm q.e.
- 66 encapsulated PMTs
- Solid steel capsule, PET window
- μ-metal by ETL
- Filled with spectroscopy mineral oil
- Sealed with polyurethane, silicon gel, masterbond
- RG213/U underwater cable
- Encapsulated since 2008
- PMTs show constant response

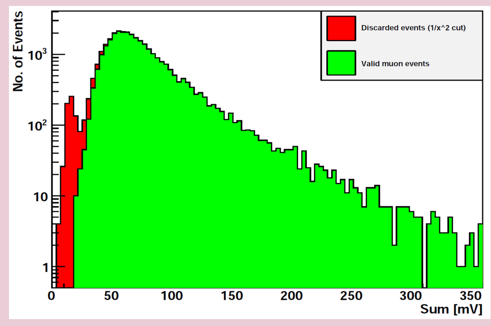
The Cherenkov effect is recorded with encapsulated photomultipliers (PMTs). The capsule protects the PMT and its electronics from the water and minimizes the danger of implosion. The design is based on the Borexino capsules. All materials used in the encapsulation are screened for radio-impurities. The low-activity 9354 PMTs are those next to the cryostat. The mineral oil inside the capsule smoothes the optical transition between the glass of the PMT and the PET window.

Plastic Scintillator Veto

Muons may pass through the neck of the LAr cryostat and may travel only a short distance in the water tank. In order to maintain a high veto power against this class of muons, a plastic veto was installed on top of the GERDA cleanroom. It is read out by the muon DAQ and its signal can be used to identify true muon events in the water tank. The panels are positioned in a triple layer stack which strongly suppresses coincident gamma events even with a low threshold. The remaining non-muon events are discarded with a $1/x^2$ cut (red area, plot to the right).

Technical details:
- 200x50x3 cm plastic scintillator
- PMT: PMT-085 / HM-6780
- Electronics board with two discriminators (low thr / high thr)
- 36 panels in a 3 layer stack
- Semi-pixilated arrangement: 32 50x50cm and 4 200x50 cm pixel
- Rate: ~2.8×10^{-3} cts/(s m^2)
- 6.5% of all veto events have a panel contribution
- In operation since summer 2011





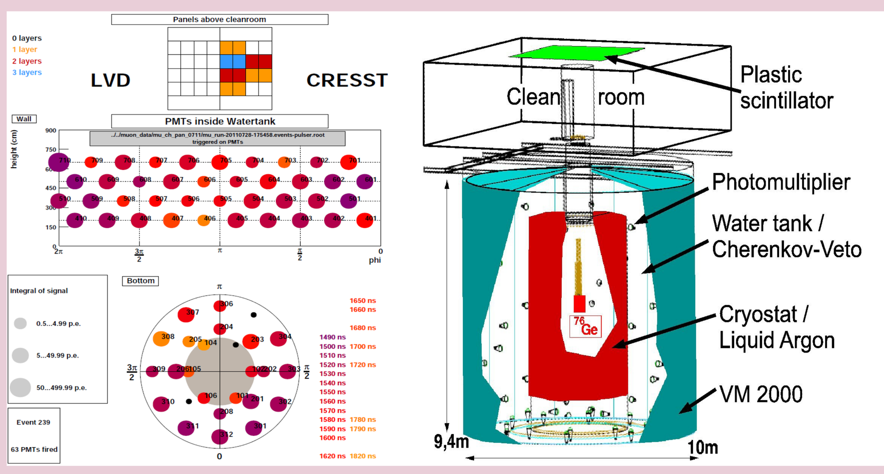
Cherenkov Muon Veto Setup

The GERDA muon Cherenkov veto is installed in the water tank (height 9 m, Ø 10 m, 580 m^3 high-purity water) surrounding the LAr cryostat. 66 encapsulated PMTs are detecting the Cherenkov light produced by passing muons. The PMTs are homogeneously distributed in two rings on the floor, four rings on the wall and the volume under the cryostat. In order to increase the light yield, the entire tank is clad with the reflective VM2000 foil. This foil not only has a reflectivity of >99%, it also acts as a wavelength shifter from UV to visible light, where the PMTs are most sensitive.

The veto is periodically calibrated with the aid of five diffusor balls in the water tank. These balls are filled with a mixture of glass beads and silicon. An optical fiber connects them to a set of LEDs outside the tank. These LEDs can be pulsed, so that the entire water tank is illuminated homogeneously and that all PMTs give a single photon-electron (PE) response.

The DAQ system is located in a control room in the GERDA superstructure.

Technical Details DAQ:
- 14 Struck SIS 3301 14 bit 8 channel FADC
- VME CPU and an MPIC housekeeping module
- CAEN HV 6*12 channel crate
- 66 pass filter as signal/HV splitter
- 5 LED boxes driven by a DAC
- Trigger condition: 5 PMT, 60ns, 0.5 PE threshold
- Trigger rate: ~0.04/s



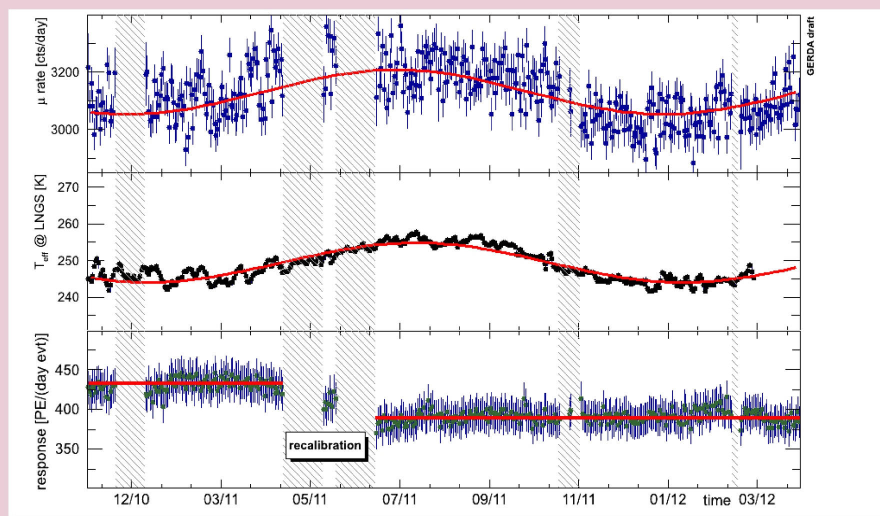

Long Term Stability

The muon veto is in operation since fall 2009. Of major interest to the performance of the system is the stability of its response. However, there are expected modulations in the detector response.

The muon rate is subject to annual changes. The atmosphere's temperature determines the mean free path of secondary mesons produced by interaction of the atmosphere with cosmic particles. This directly correlates to the number of produced and detectable muons since only the most energetic muons will be able to penetrate the rock overburden of the LNGS.

The ECMWF (European Centre for Medium-Range Weather Forecast) supplies world-wide temperature data and this service was used to determine the effective temparature (T_{eff}) weighted over different atmospheric depths at the LNGS. Both muon rate and T_{eff} show an annual modulation peaking 15-20 July with an amplitude of 2.4 %.

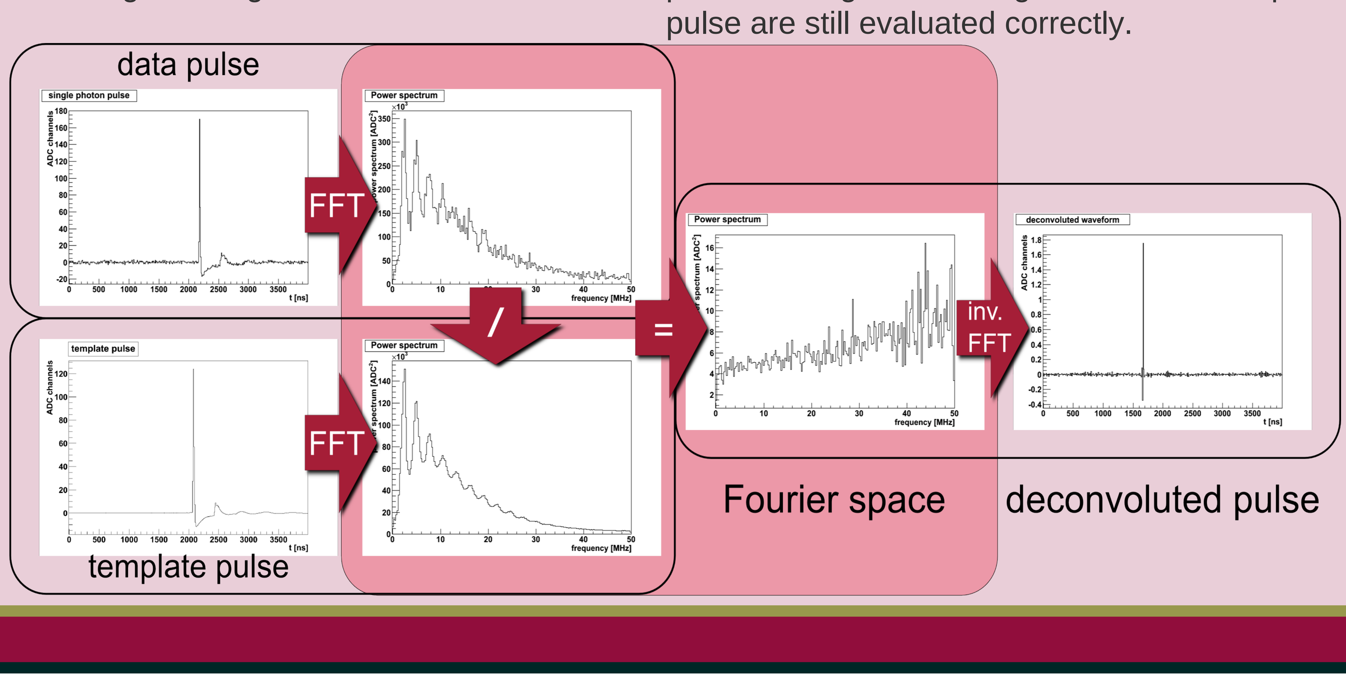
In spring 2011, the veto response was recalibrated. Prior, the PMTs were set to a 2×10^7 gain. However, in order to better suit the DAQ capabilities, the single photon responses of the PMTs were set to a fixed value. Apart from this, the individual PMTs as well as the entire muon veto is operating stable since the beginning.



Pulse Form Deconvolution

The signal of the used PMT type has a large negative overshoot part. The integral of the waveform as a measure of the detected light is thus not entirely reliable for small signals. The pulse height of a recorded signal serves well for small signals. But brighter signals, that might even include reflections, are not accurately represented by the pulse height. To circumvent this problem, a template pulse is constructed out of single PE signals.

The measured waveform is deconvoluted with this template pulse, i.e. their Fourier spectra are being divided in Fourier space and transformed back in the time domain. The resulting waveform represents the original signal, thus photon(s) being detected, unfolding the response of the PMT. This method provides the number of detected photo electrons over the whole range of the PMTs. Subsequent pulses sitting in the negative overshoot part of the first pulse are still evaluated correctly.



Muon Detection Efficiency

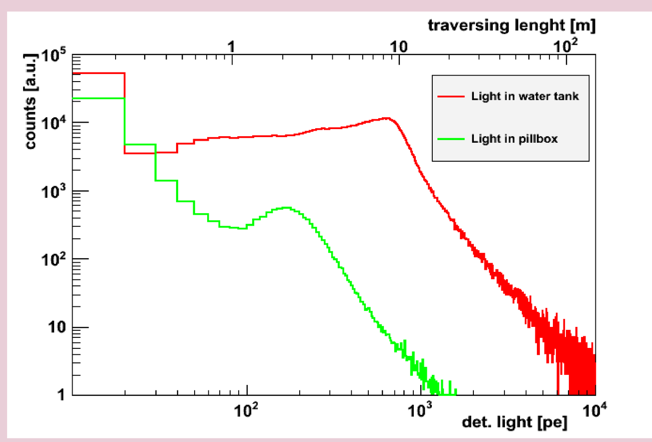
The Cherenkov light detected by the system and hence its detectability is dependent on the length of the muon track in the water. The PMT distribution in the tank and the trigger filter are additional factors. From the signals of the two volumes, the pillbox (volume under the cryostat) and the water tank, the amount of light per muon is estimated to (90±30) PE/m.

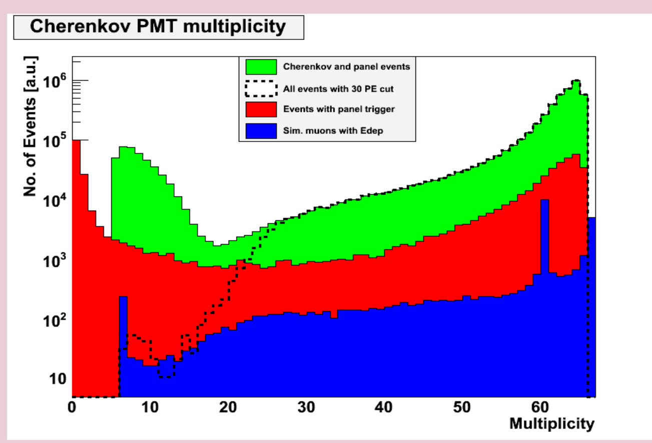
However, an abundance of events in the low PE/multiplicity region is visible caused by scintillation of the VM2000 foil. As expected, these events do not show if "true" muon events selected by the panels are studied. A 30 PE cut discards this low multiplicity bump (dotted line, plot on the lower right hand side).

From MC simulations, muon tracks can be selected that would not survive this cut. Applying this to data, a detection efficiency can be assumed. In addition, the combinatorical factors for triggering the veto have to be taken into account. One arrives at a detection efficiency of:

$$\varepsilon_{MDE} = (97.17\pm0.27)\%$$

The detection efficiency for simulated events with energy deposition in the germanium is higher ε_{edep} = (99.56±0.42)%, since these are "full hits" of the water tank (required track length of 60 cm). However, this is only a small subset of all muon events .





Kai Freund, Peter Grabmayr, Josef Jochum,
Christopher Schmitt, Katharina von Sturm

Auf der Morgenstelle 14
72076 Tuebingen, Germany
freund@pit.physik.uni-tuebingen.de

[1] I.Abt et.al., *GERDA:The GERmanium Detector Array*, Letter of Intent to LNGS, 2004
[2] M.Knapp, *Design, Simulation und Aufbau des GERDA-Myonvetos*, PhD thesis, U. Tübingen, 2009
[3] F.Ritter, *Analysis of the GERDA Muon Veto,* PhD thesis, U. Tübingen, 2011
[4] Bellini et.al., arXiv: 1202.6403v2, 2012
[5] European Centre for Medium-Range Weather Forecast www.ecwmf.int

This work is in part supported by the german BMBF (05A11VT3).