The GERDA Muon Veto Cherenkov Detector

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The GERmanium Detector Array, GERDA, is a new experiment designed to examine the neutrinoless double beta decay $0\nu\beta\beta$ of ^{76}Ge which has a lifetime of at least 10^{26} years and a single energy deposition of 2039 keV. To reach the goal of 10^{-3} background events/(keV·kg·y), several background reduction techniques like anti-coincidence and pulse shape analysis will be used. Cosmic muons can produce background in form of particles and radioactivity. To reject them, two independent detector systems will be integrated in GERDA. One of these is a Cherenkov muon veto detector, that uses the water tank around the cryostat in which the crystals will be operated. It is equipped with 66 eight inch photomultipliers (PMT).
The PMT distribution was found via extensive Monte Carlo studies to reach the highest efficiencies for dangerous muons (these are muons that cause an energy deposition of around 2 MeV in the germanium detectors), even though the PMTs cover less than 0.1 % of the water tank surface.
High efficiencies depend strongly on the amount of detected photons. For this, as many surfaces as possible will be covered with a highly reflective foil from 3M. This VM2000 has a high reflectivity in a wide range of wavelength and it also shifts photons from the UV into the optical range. It, more or less, doubles the amount of detectable photons, because the photomultipliers used, have an detection maximum between 370 and 400 nm. Thus, a detection efficiency of 98% should be easily achieved.

1. Introduction

The GERmanium Detector Array (GERDA) [1] experiment aims to examine the neutrinoless double beta decay $0\nu\beta\beta$ of ^{76}Ge, which has a lifetime in the order of 10^{26} years and a single energy deposition of 2039 keV. In the final phase of the GERDA experiment around 100 kg·y of data will be accumulated leading to a lower limit of $T_{1/2} > 1.35 \cdot 10^{26}$, depending on the background of the experiment. It is currently built up at the Laboratori Nazionali del Gran Sasso (LNGS) of the INFN.
A sketch of the GERDA setup can be seen in Fig. 1. The bare crystals are operated in a liquid argon cryostat, that is two meter in radius. This cryostat is surrounded by a water tank, of five meters in radius, acting as passive gamma and neutron shield and as active muon veto (see section 2). On top of the water tank will be a cleanroom and a helium leaktight lock with the mechanics for lowering the crystals into the cryostat. The last but not least part of the shielding are the mountains of Gran Sasso, providing an overburden of around 1400 m of rock, corresponding to a minimum of 3100 m of water equivalent shielding.
The background in such an underground laboratory is dominated by intrinsic sources, like radioactivity of the used materials or induced by cosmic ray muons in the surrounding materials. Due to this, GERDA uses low Z materials instead of the standard lead shielding, thus reducing the background induced by interaction of cosmic ray muons with e.g. lead. Nevertheless, the final goal, to reach a background level of less than 10^{-3} background events/(keV·kg·y), can only be achieved using different techniques like anticoincidence between the segments of the crystal detectors, pulse shape analysis and a muon veto.
The muons reaching Hall A of the Gran Sasso lab-

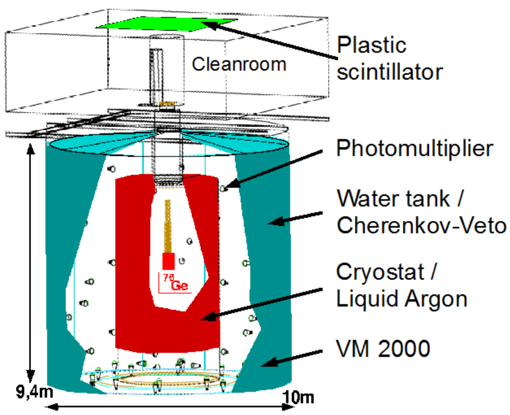

Figure 1. Sketch of the GERDA experiment

oratory have an average energy of 270 GeV [2]. The angular distribution has been measured by the MACRO experiment [3]; it is shaped by the profile of the Gran Sasso Mountains above the LNGS. This distribution has been used for extensive simulations to investigate the muon veto (see chapter 3).

2. The Cherenkov muon veto detector

The muon veto will consist of three independant detector systems. The first is a layer of plastic scintillator panels above the cleanroom, to detect in particular muons coming from the top and passing through the setup without hitting or only 'scratching' the water tank. The main bulk of the water tank constitutes the second system acting as an active Cherenkov veto. It is equipped with 60 photomultipliers. Four rings, each with 10 PMTs, will cover the wall of the water tank in heights ranging from 1.50 to 7 meters. 20 more will be placed on the bottom of the water tank in two rings around the cryostat. The muon veto is completed with another small water Cherenkov detector just below the cryostat housing 6 photomultipliers, detecting muons passing straight from above through the neck, the cryostat, and finally the veto.

The photomultipliers are 8 inch types from Electron Tubes Limited. For the wall of the water tank the type 9350KB will be used, while PMTs with ultra low background glass (type 9354KB) will equip the inner ring on the bottom and the small Cherenkov veto below the cryostat as they are closest to the germanium crystals.
To increase the amount of detected photons, 'VM2000', a reflector foil by 3M will cover most surfaces of the inside of the water tank and the outside of the cryostat. This foil has a reflectivity of nearly 100 % for optical photons and additionally shifts photons from the ultra violet region, where most of the Cherenkov photons are produced, into the optical range, just where the maximum of the photomultiplier sensitivity is (see Fig. 2).

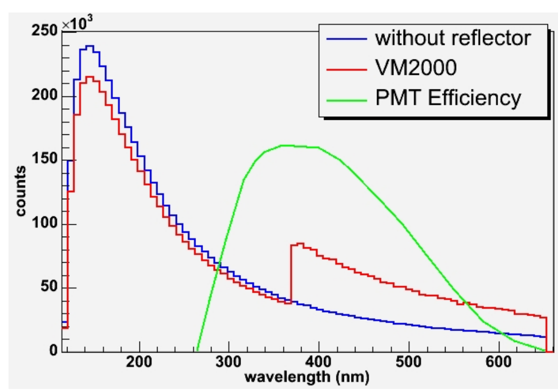

Figure 2. Simulation of the increase of photons in the detectable range due to the use of VM2000

2.1. Encapsulation

As the photomultipliers are operated under water they have to be protected against the water and in case of an implosion of one of the PMTs also against the shockwave. Therefore, they are encapsuled based on the Borexino design [4] in stainless steel housings with a PET-window at the

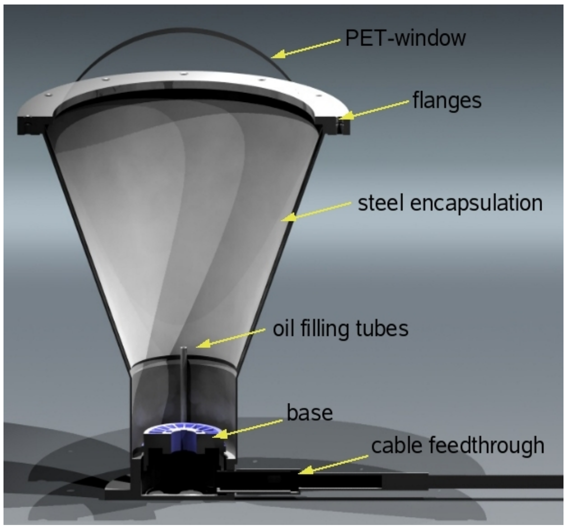

Figure 3. Sketch of the photomultiplier encapsulation

front (see Fig. 3), to allow light to reach the cathode. Polyurethane and a shrinking hose seal the cable feedthrough and hold the voltage divider into position while a layer of silicone seals the upper flanges holding the PET window. Silcone is poured over the contacts of the voltage divider as a backup if somehow water enters the encapsulation. The volume between the steel encapsulation and the PMT is filled with oil allowing a smooth optical coupling between the PET-window and the photomultiplier. Only little refraction takes place, due to $n_{PET} \approx n_{oil} \approx n_{PMTglass}$.

2.2. Calibration system

To monitor the performance of the photomultipliers during the duration of the experiment a calibration system is currently under development. Light from one LED will be fed to all photomultipliers via optical fibers, thus allowing to compare the signals from different PMTs illuminated by the same source of light.
A second system will be used to calibrate the system considering position dependances. Several diffusor balls will be inserted into the water tank, thus comparing the PMT response to light coming from seperate single spots in the water tank. With these two systems a constant monitoring and calibration will be easily achieved.

2.3. Data aquisition

The data aquisition will use the same Flash ADCs (SIS 3301 from Struck) as for the read out of the germanium crystals, thus an easy communication between the two systems is possible. The trigger for the muon veto can be generated with leading edge discriminators, demanding the firing of at least five PMTs in the main water tank volume or three PMTs in the second Cherenkov veto below the cryostat. With this system, a random coincidence rate of around $2 \cdot 10^{-3}$ Hz is expected, while an efficiency for muons recognition of about 98 % should be feasible. Another version, using the Flash ADCs as trigger, has a higher random coincidence rate and a smaller detection efficiency due to the necessary grouping of the PMTs. A sketch of the data aquisition is shown in Fig. 4.

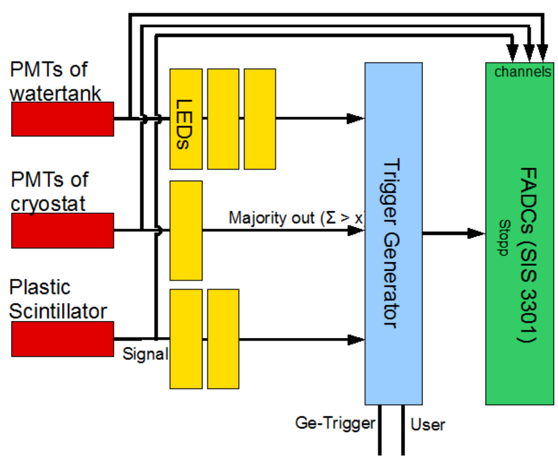

Figure 4. Muon Veto data aquisition

3. Monte Carlo studies

As only a limited number of photomultipliers was available, the distribution of those had to be optimized long before the Cherenkov veto could be built up. To define this PMT array, extensive Monte Carlo studies were done, using the object oriented MaGe framework [5] based on Geant4 from the CERN libs. To save CPU time, a selection of dangerous muons was made in a first step. 135 million muons, corresponding to approximately 10 years of data taking, have been simulated. Out of these, around 600 muons produced a total energy deposition in the germanium crystals around the expected 2039 keV (in fact, only 30 of those faked the $0\nu\beta\beta$ signal with a single site energy deposition). These are called dangerous muons.
With this batch of muons, Cherenkov light intensity maps were produced showing where most light reaches the surface of the water tank (see Fig. 5). These maps were then used to optimize the positions of the photomultiplier in the final design of the Cherenkov muon detector.
Additionally a simulation of the VM2000 has been made showing that the use of this foil should roughly double the amount of photons that the photomultipliers can detect (see Fig. 2).
For the final distribution of the PMTs, including the VM2000 in the setup, simulations show that an efficiency of more than 98 % to recognize dangerous muons should be achieved, which means, within total in around 20 years of data taking 1.2 dangerous muons is not vetoed.

4. Conclusion

Gerda searches for the neutrinoless double beta decay of ^{76}Ge. For this it aims to a background level of less than 10^{-3} background events/(keV·kg·y). This can only be achieved with a Cherenkov muon veto, facilitating the large water tank surrounding the cryostat of the experiment. This muon veto has been designed and extensively been simulated showing that an efficiency of at least 98 % is easily achieved. It is currently built up at the LNGS in Italy.

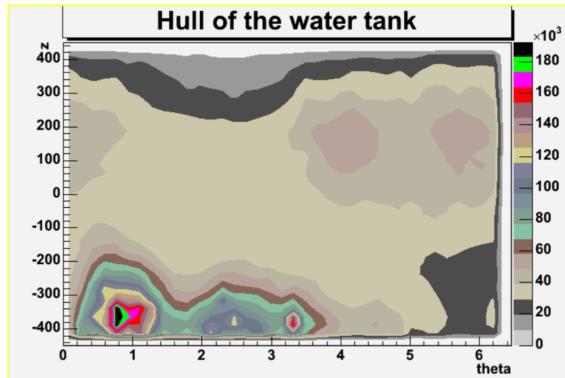

Figure 5. Photon intensity map of the hull of the water tank

Acknowledgements

The authors want to thank Daniel Greiner, Carlos Bahamondes and James Monahan from the Double Chooz Collaboration for their help during the assembly of the encapsuled photomultiplier.
This work is supported by BMBF (05A08VT1).

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