LArGe

R&D for active background suppression in GERDA

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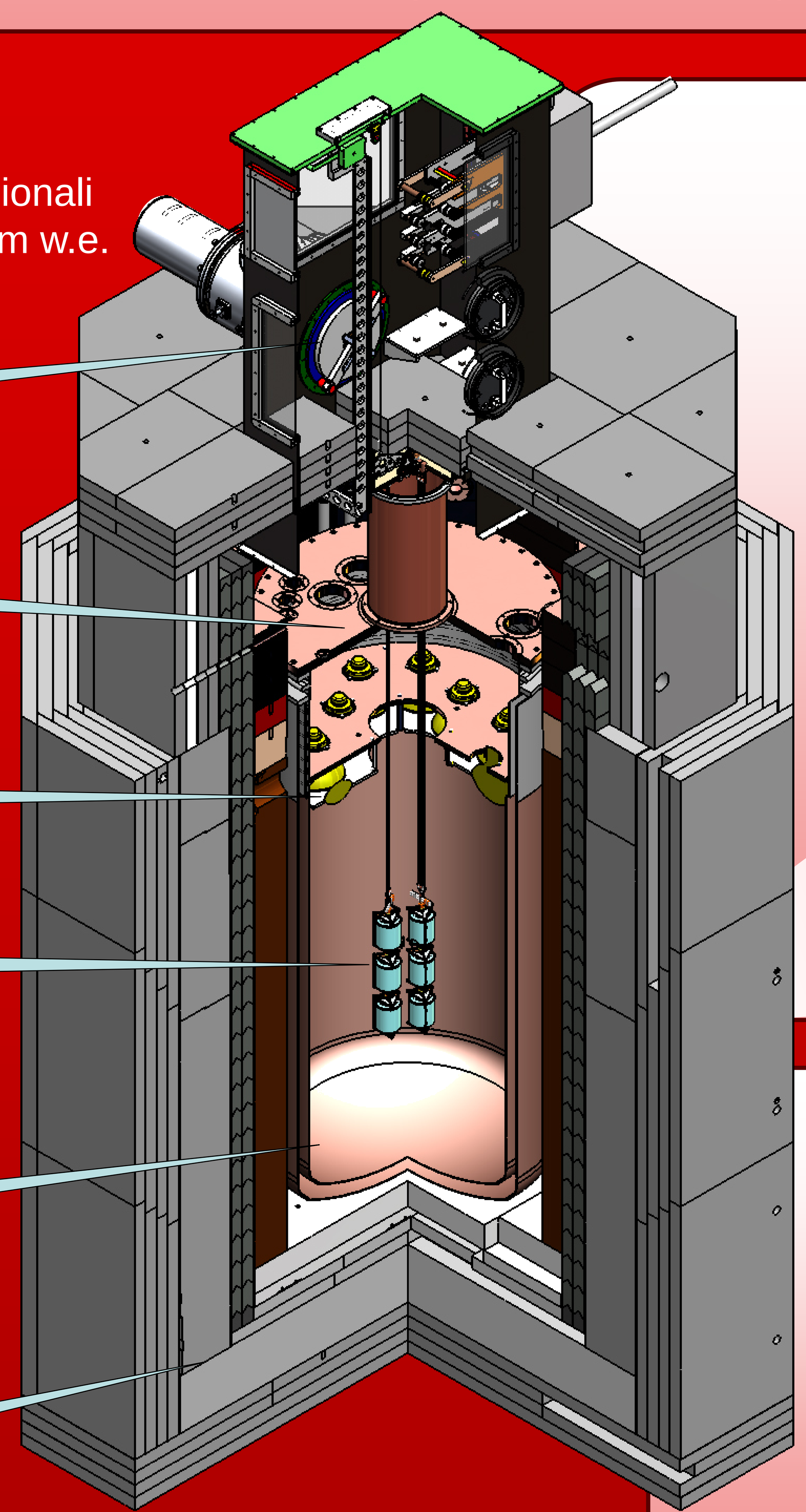
LArGe is a GERDA low-background test facility to study novel background suppression methods in a low-background environment, for future application in the GERDA experiment. GERDA searches for the neutrinoless double-beta decay in ^{76}Ge, by operating naked germanium detectors submersed into 64 m^3 of liquid argon [1]. Similarly, LArGe runs Ge-detectors in 1 m^3 (1.4 tons) of liquid argon, which in addition is instrumented with photo multipliers to detect argon scintillation light [2]. The light is used in anti-coincidence with the Ge-detectors, to effectively suppress background events that deposit energy in the liquid argon. The background suppression efficiency was studied in combination with a pulse shape discrimination (PSD) technique for various sources, which represent characteristic backgrounds to GERDA. Suppression factors of a few times 10^3 have been achieved. First background data of LArGe (without PSD) yield a background index of (0.12-4.6)·10^{-2} cts/(keV·kg·y) (90% c.l.), which is at the level of the GERDA phase I design goal. As a consequence of these results, the development of an active liquid argon veto in GERDA is pursued.

Setup description:

located at the Laboratori Nazionali del Gran Sasso (Italy), 3800 m w.e.



lock: can house up to 3 detector strings (9 Ge-detectors)

cryostat with LAr: volume: 1000 l (1.4 t) with active LN-cooling

9 PMTs: for the detection of Ar-scintillation

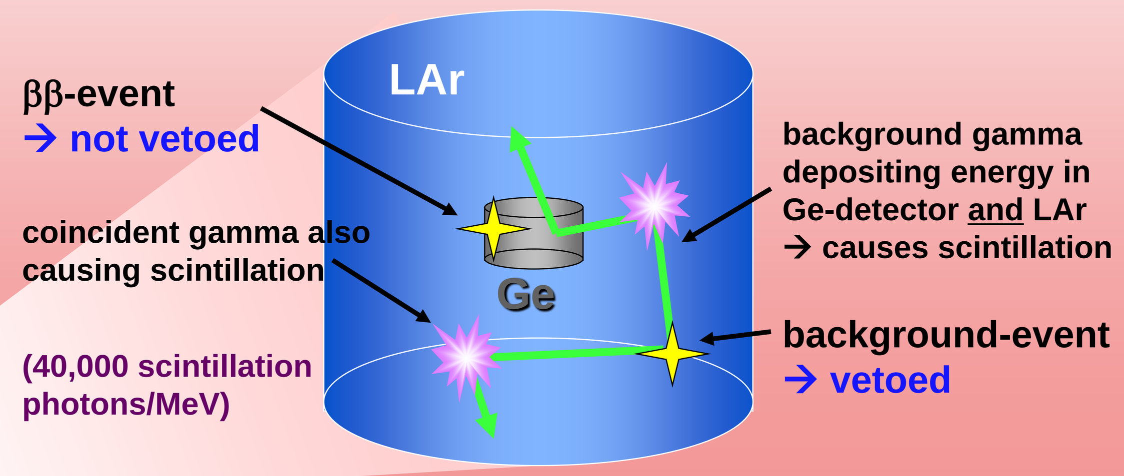
naked Ge-detectors (currently one in use)

reflector foil & wavelength shifter on inner cryostat walls for light collection

high purity shield: Cu 15 cm, Pb 10 cm, steel 23 cm, PE 20 cm

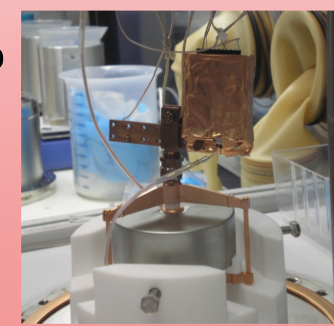
Principle of active background suppression using Ar-scintillation

Liquid argon scintillates upon the interaction with ionizing radiation, and produces ~40,000 photons per MeV deposited energy. Typical background events to GERDA have excess energy, which is deposited outside the Ge-detectors in the surrounding LAr. In contrast, ββ-events are *single site events* confined to the Ge-diode, so that no scintillation light is triggered. Therefore, by detecting scintillation in anti-coincidence to Ge-signals one can actively suppress background events (LAr veto) [3].



Principle of pulse shape discrimination (PSD)

The objective of PSD is to distinguish *single site events* (SSE) of the ββ-decay from *multi site events* (MSE) of common gamma-background with multiple interaction vertices within the Ge-diode. It has been demonstrated [4] that by using the signal-time-structure of a BEGe-type detector, one can efficiently discriminate SSE from MSE, and thus efficiently suppress background. In LArGe such a BEGe detector was used to study the combined suppression efficiency of LAr veto and PSD.

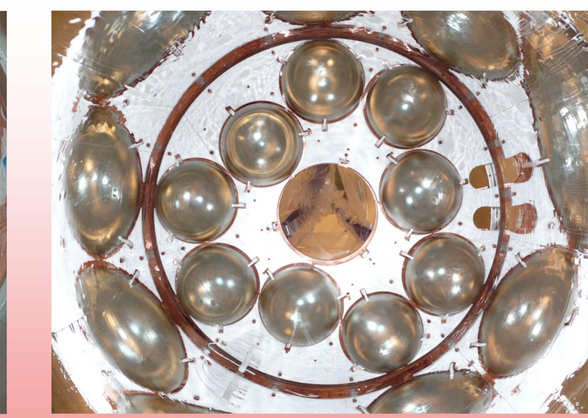


Right: the BEGe detector in a low mass holder prior to deployment into LArGe

LAr instrumentation in LArGe

The inner wall of the cryostat is lined with VM2000 mirror foil to guide the scintillation light towards nine 8" ETL PMTs located at the top. Both, mirror foil and the photocathodes, are covered with a 1-4 µm thin layer of wavelengthshifter (TPB in polystyrene), to convert the 128 nm scintillation photons into the sensitive range of the PMTs around ~420 nm.

The cryostat beeing lined with VM2000 mirror foil during installation



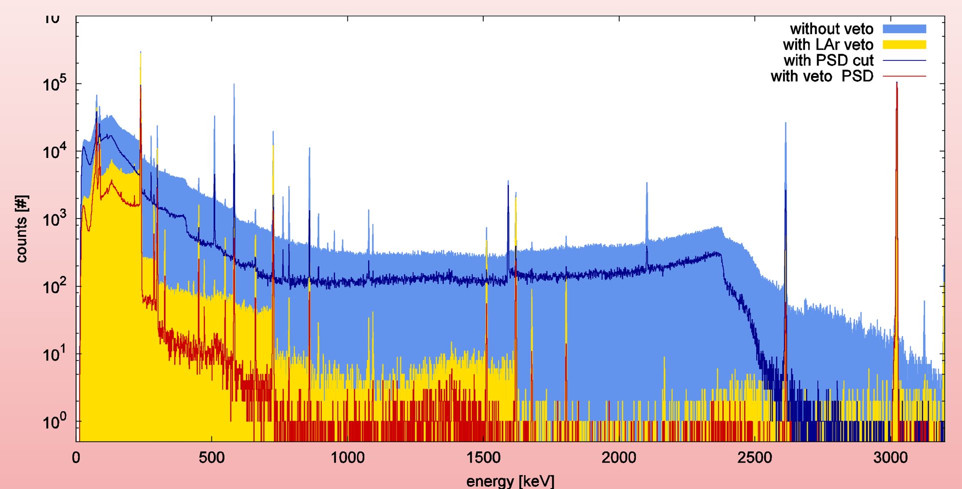
Bottom view of the PMTs in final position inside the cryostat.

Background suppression measurements with various sources

The background suppression efficiency was studied for different gamma sources (^{137}Cs, ^{60}Co, ^{226}Ra, ^{228}Th) in different locations (close-by and external), which represent characteristic background sources to GERDA.

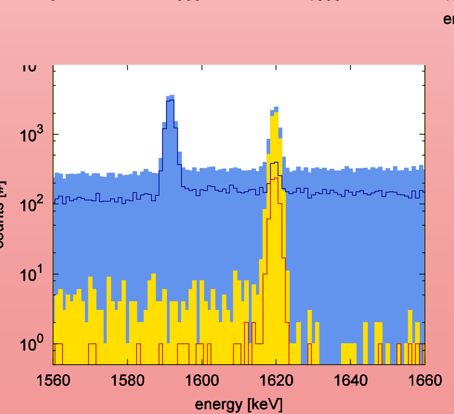
Characteristic suppression of LAr veto and PSD

LAr veto and PSD act differently on different background lines – shown here for internal ^{228}Th (source 7 cm away from detector):

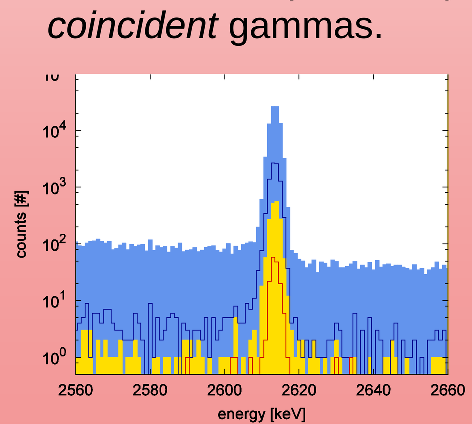


Left: full spectrum of internal ^{228}Th. A pulser at 3 MeV yields a LAr veto acceptance for single site events (SSE) of >95%.

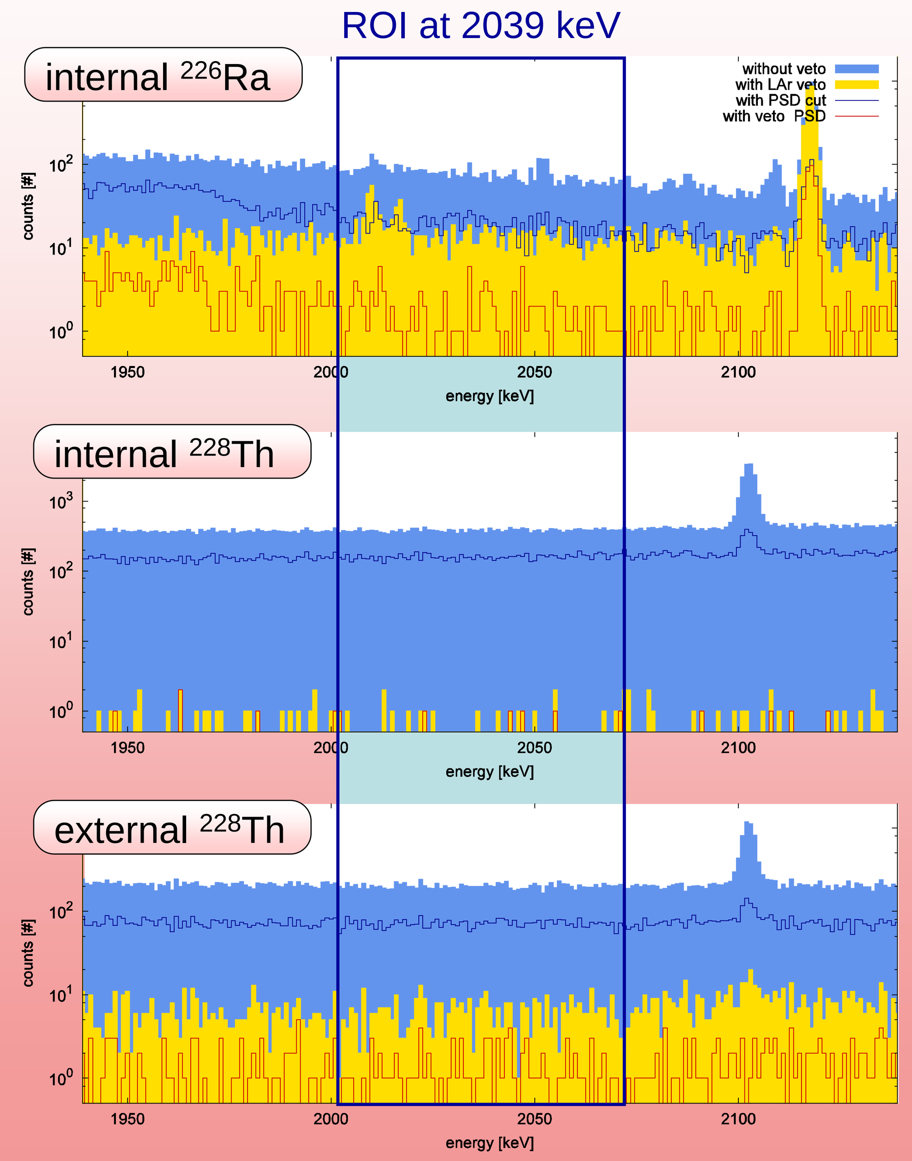
Bottom: the 2615 keV line is accompanied by *coincident* gammas.



Left: the *double escape peak* at 1593 keV is SSE and therefore not rejected by PSD, but by the LAr veto. The 1621 keV peak is a *single* gamma from ^{212}Bi.



Background suppression in the region of interest of the 0νββ-decay



Left: example close-ups of the region of interest (ROI) for ^{226}Ra and ^{228}Th. Generally external sources are suppressed less by the LAr veto than inner sources, whereas PSD is largely position independent. In addition, the suppression factor depends on whether *single* or *coinident* gammas are emitted, and on their excess energy.

Bottom: summary table of suppression factors for different sources. On average the combined suppression of the LAr veto and PSD is enhanced by a factor (1.8 ± 0.2), compared to the product of the individual suppression factors. This is very utile for its application in GERDA.

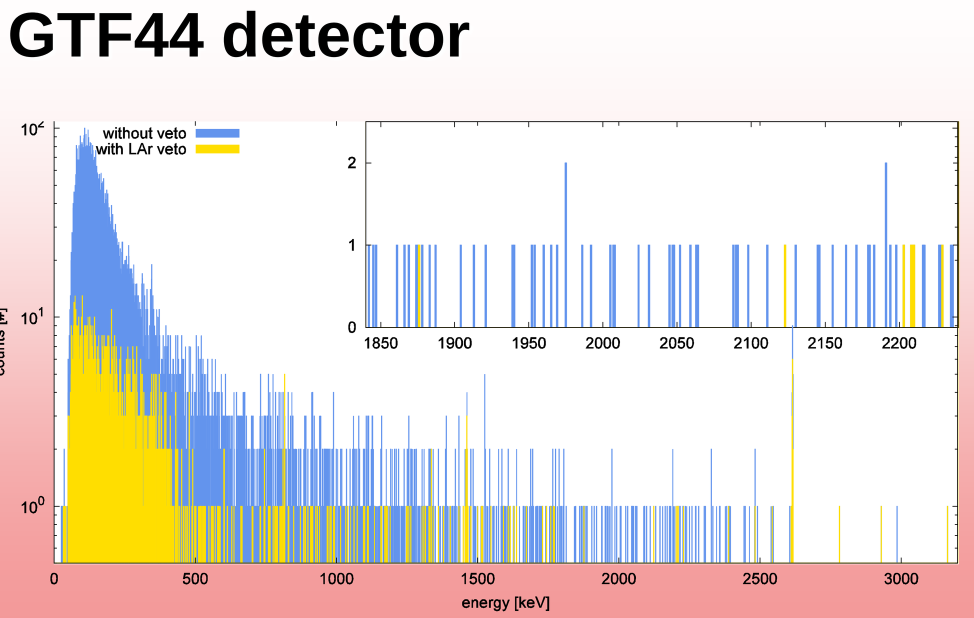
source	position	suppression factor		
		LAr veto	PSD	total
^{60}Co	int	27 ± 1.7	76 ± 8.7	3900 ± 1300
^{226}Ra	ext	3.2 ± 0.2	4.4 ± 0.4	18 ± 3
	int	4.6 ± 0.2	4.1 ± 0.2	45 ± 5
^{228}Th	ext	25 ± 1.2	2.8 ± 0.1	129 ± 15
	int	1180 ± 250	2.4 ± 0.1	5200 ± 1300

Background measurement with GTF44 detector

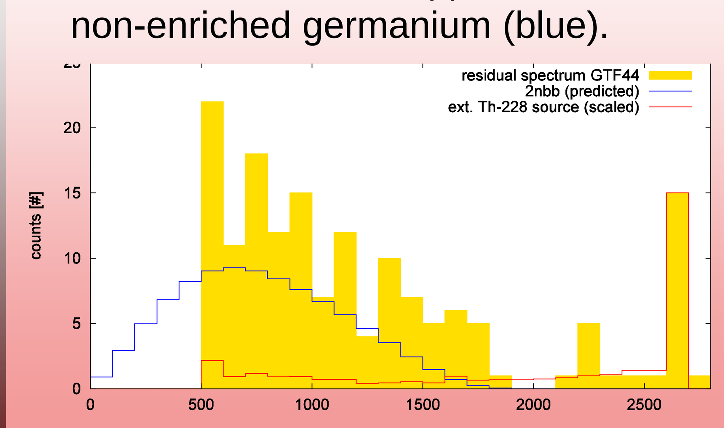
A background measurement with an exposure of 116 kg·d was carried out with the low-background HPGe-coaxial GTF44 detector. Yet, no PSD was available and the LArGe passive shield is incomplete. The achieved background index is:

(0.12 - 4.6) · 10^{-2} cts/(keV·kg·y) (90% c.l.)

Right: background spectrum with a close-up of the region of interest around $Q_{\beta\beta}$ at 2039 keV.



Bottom: residual vetoed spectrum after subtracting background lines (811 keV, 1460 keV). About half of the counts stem from 2νββ-events of the non-enriched germanium (blue).



References

[1] GERDA collaboration, *Gerda -- The GERmanium Detector Array for the search of neutrinoless ββ decays of ^{76}Ge at LNGS*, 2004 URL http://www.mpi-hd.mpg.de/gerda/public/

[2] M. Heisel, *LArGe – A liquid argon scintillation veto for GERDA*, PhD thesis, Universität Heidelberg, 2011

[3] P. Peiffer et al., *Pulse shape analysis of scintillation signals from pure and xenon-doped liquid argon for radioactive background identification*, JINST 3 P08007, 2008

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