The GERDA Experiment for the Search of Neutrinoless Double Beta Decay

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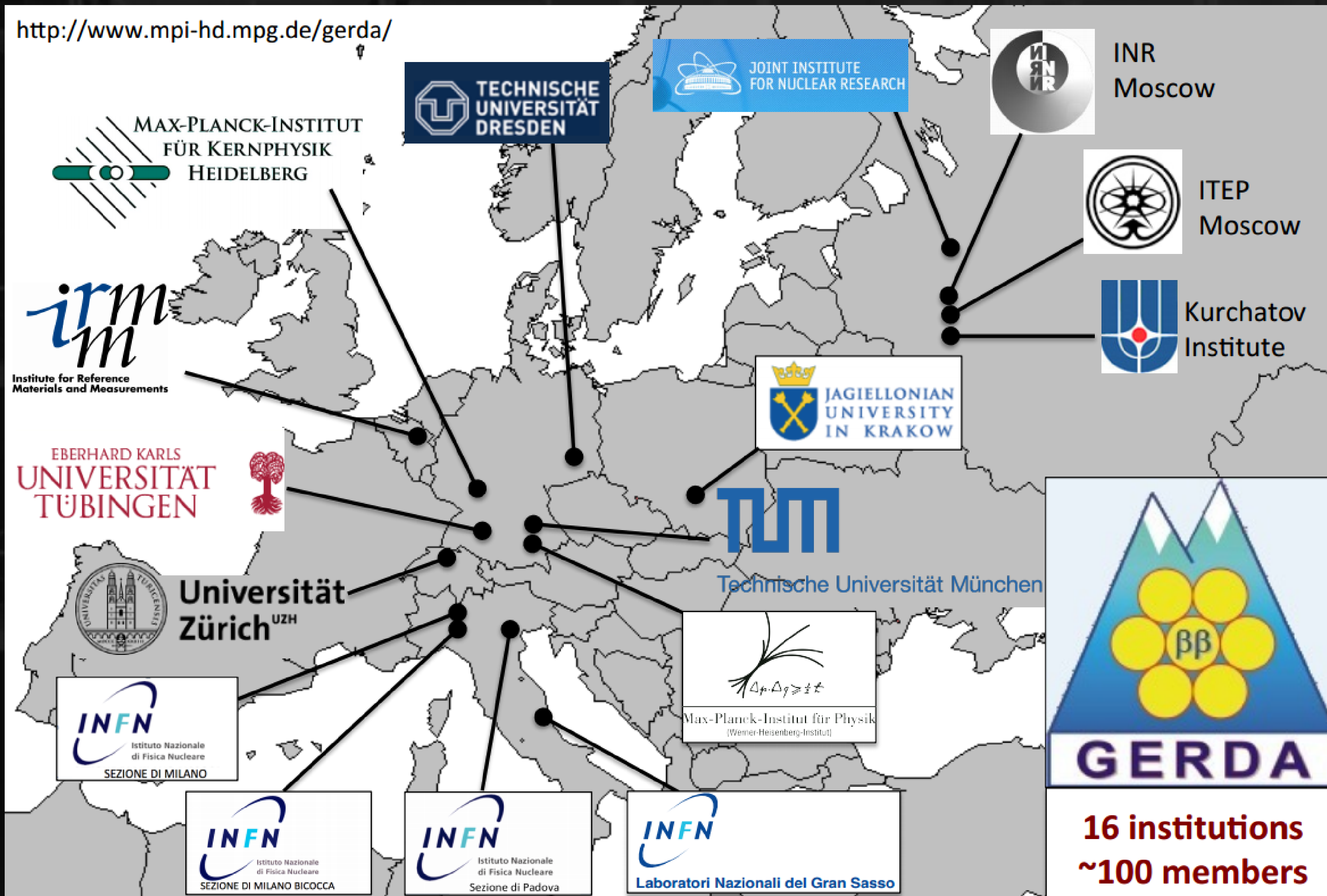
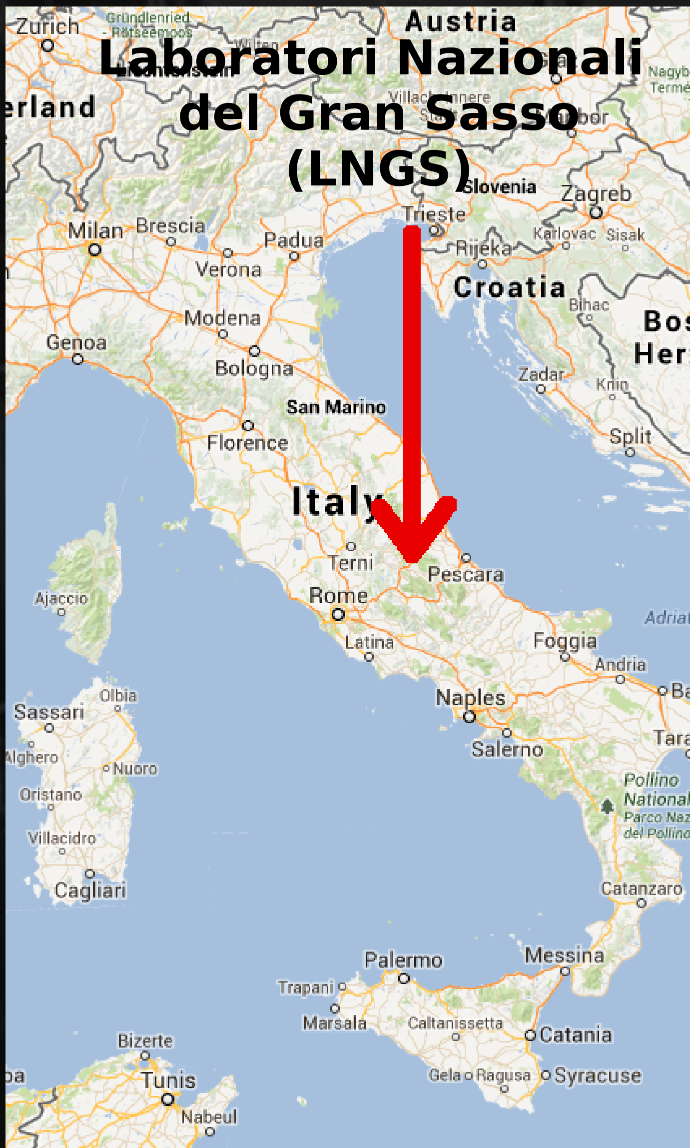
The GERDA Collaboration



Situated in Hall A of LNGS



[Map from google maps]

[Image from LNGS]

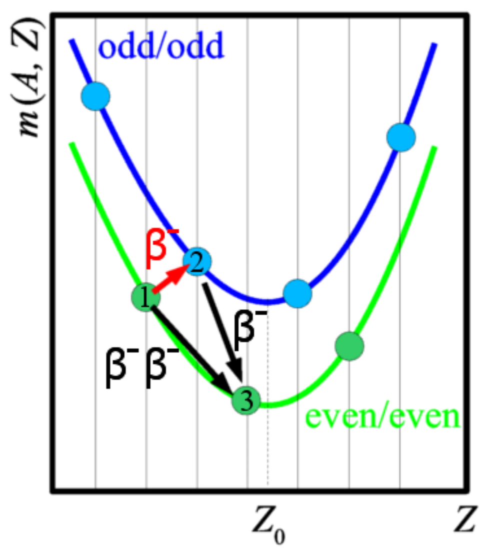
Double Beta Decay

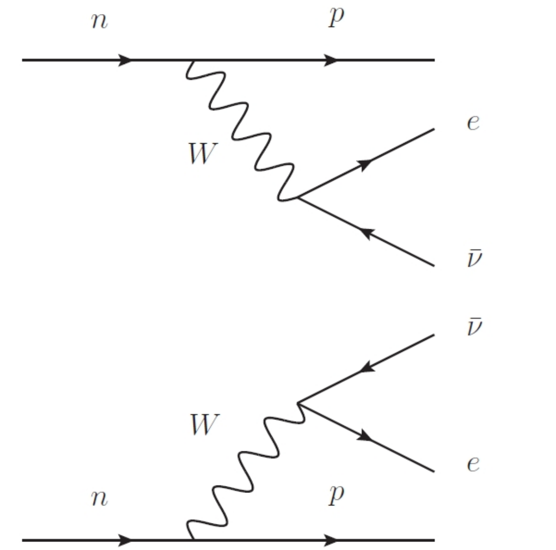
$2\nu\beta\beta$ standard model process known for: ^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{130}Te, ^{150}Nd, ^{238}U, ^{130}Ba, ^{136}Xe with $T_{1/2}$ between $7 \cdot 10^{18}$ yr and $2.5 \cdot 10^{24}$ yr,

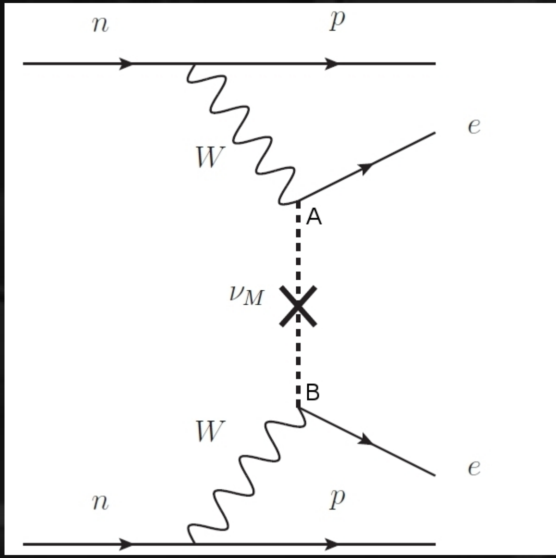
$1.84^{+0.14}_{-0.10} \cdot 10^{21}$ yr for ^{76}Ge [1].

$0\nu\beta\beta$ not allowed in the standard model:
Controversial claim for ^{76}Ge with $T_{1/2} = 1.19 \cdot 10^{25}$ yr by a subgroup of the HdM experiment [2].

- Existence would imply violation of lepton number conservation.
- Most likely mechanism is "massive Majorana neutrino exchange".

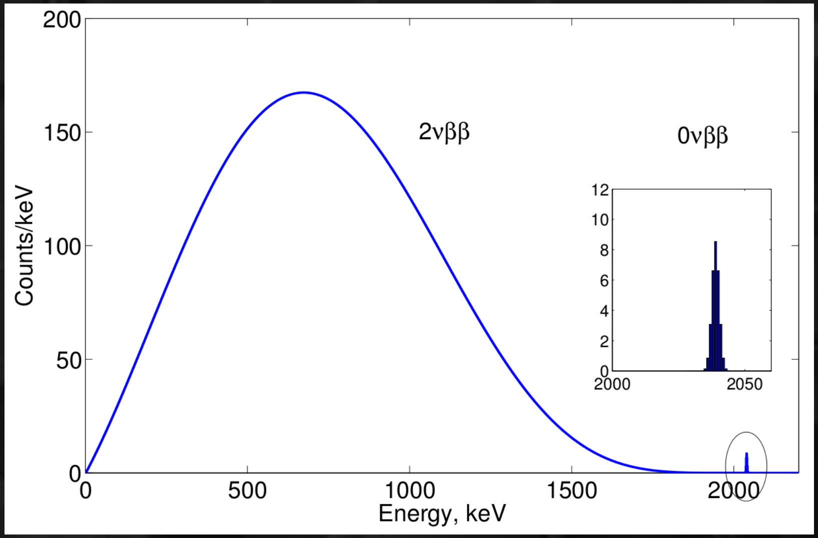






[1] GERDA collaboration, J. Phys. G: Nucl. Part. Phys. 40 (2013) 035110
[2] H.V. Klapdor-Kleingrothaus et al., Phys. Lett. B586, 198 (2004).

Double Beta Decay Detection



Spectrum of summed electron energies.

2νββ produces a continuous spectrum as the ν energy is not detected.

0νββ results in a peak at the Q-value of ^{76}Ge at 2039 keV.

Ge has several advantages:

- Ge detectors are used as both the decay source and the detection device.
- Ge has a very high energy resolution:
  - The higher the energy resolution, the higher the signal to background ratio.

0νββ Ultra Low BG Experiment GERDA

Schematic view of the GERDA experiment [1].

Bare Ge diodes enriched to 86% of ^{76}Ge directly immersed in a 5.5 m high 64 m^3 liquid Ar cryostat.

- Ar serves as coolant (87 K) and shielding.

High purity water tank for additional shielding and to veto muons by their Cherenkov light.

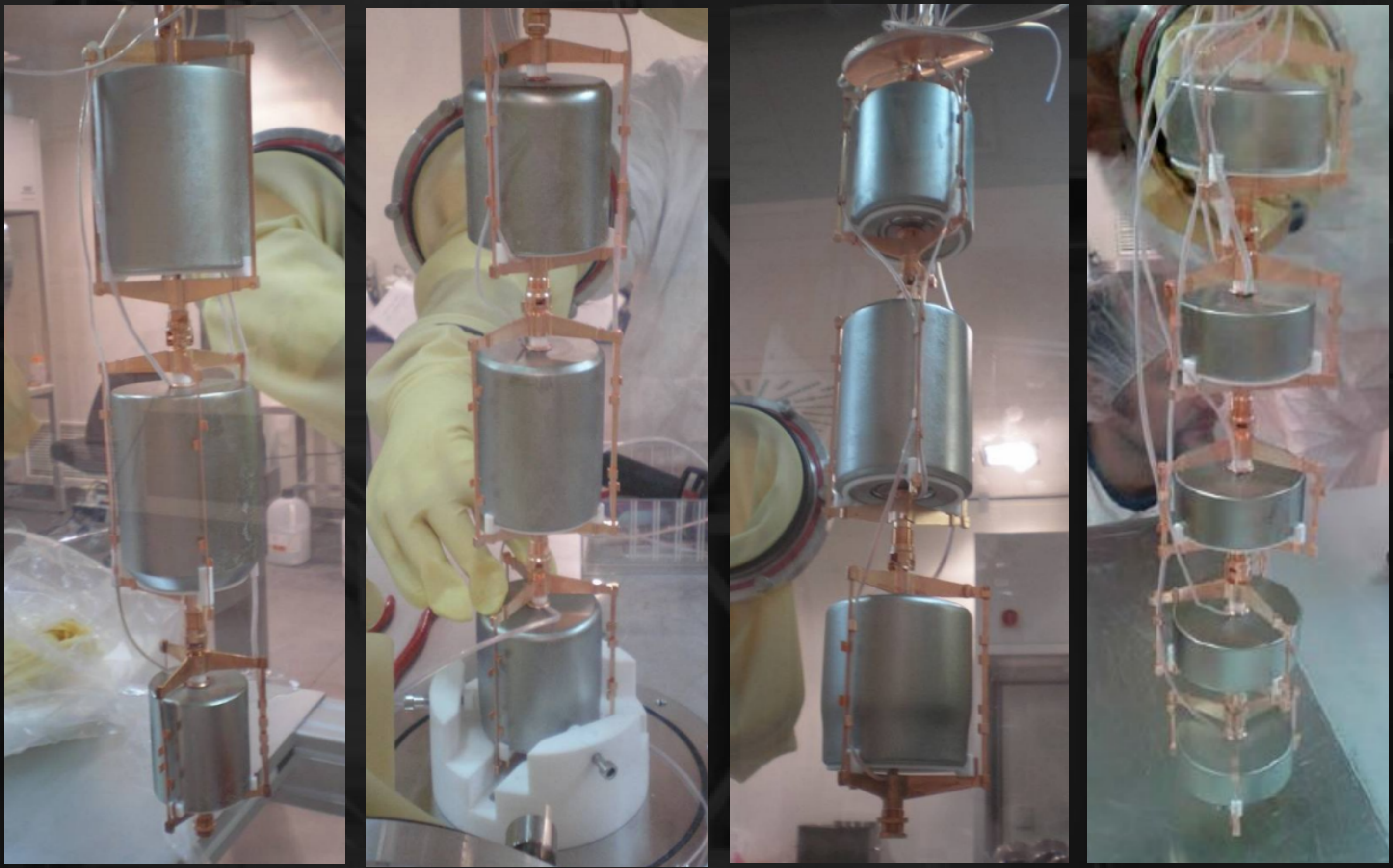
Muon veto panels above the water tank.

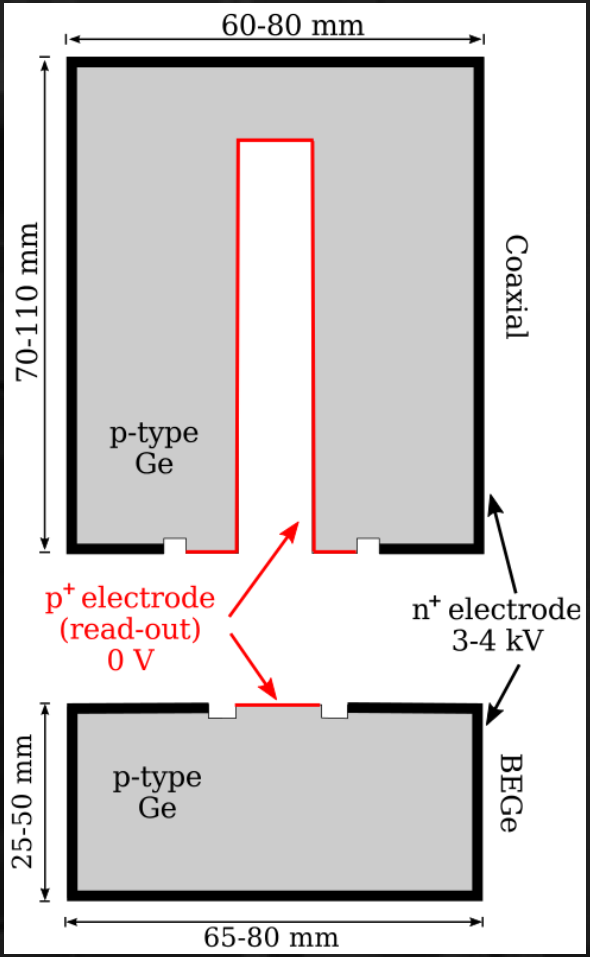
Running in two Phases:

- Phase I: Nov 2011 to May 2013
  - ≈18 kg of enriched Ge.
- Phase II: Starting end of 2013,
  - + 20 kg of enriched Ge, factor 10 less background.

[1] GERDA collaboration, arXiv:1212.4067 [physics.ins-det] (2013).

Phase I Configuration





8 enriched coaxial detectors from IGEX and HdM, previously used for the claimed observation:

- 2 quickly developed high leakage currents ⇒ not used.

1 non enriched.

5 Phase II type BEGe detectors since July 2012, 1 had energy drifts ⇒ not used.

Phase I Data Taking

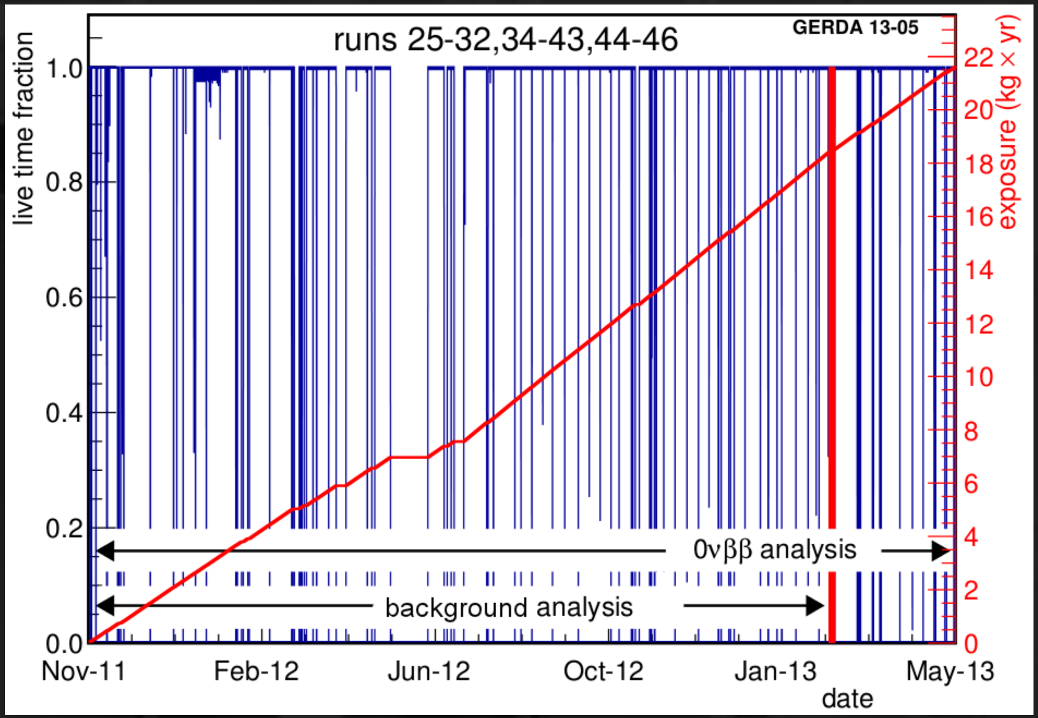
High average live time fraction.

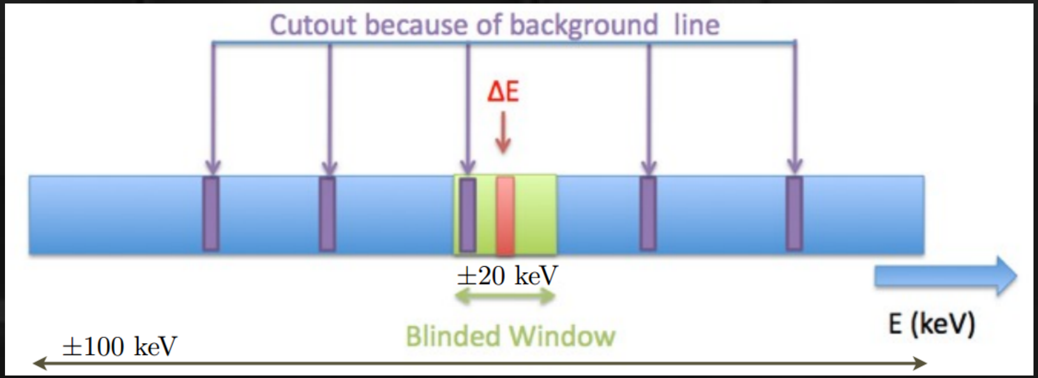
- Spikes due to calibration.

Total exposure of enriched Ge detectors 21.6 kg yr [1].

Data was taken with a blinded energy window of $Q_{\beta\beta} \pm 20$ keV (FWHM ≈ 4.5 keV):

- Background models and analysis methods were developed.
- Unblinding of side bands: Background models verified and analysis methods frozen.
- Final unblinding performed on 14th of June and the analysis applied.
  - Will be published soon!

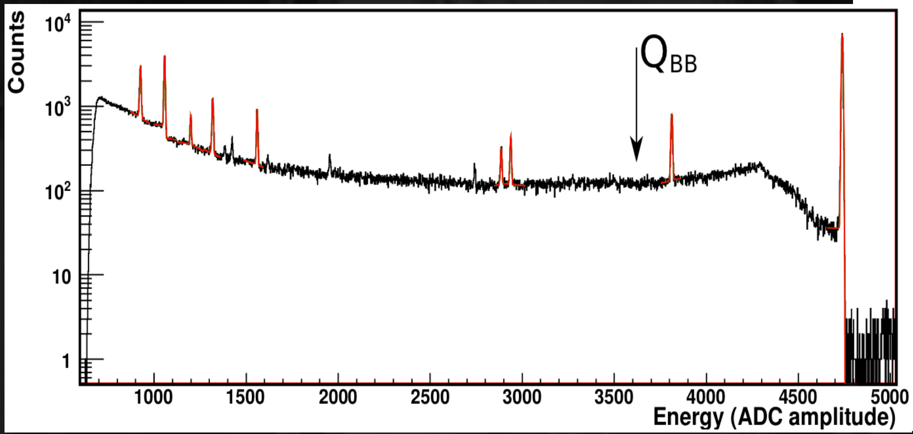


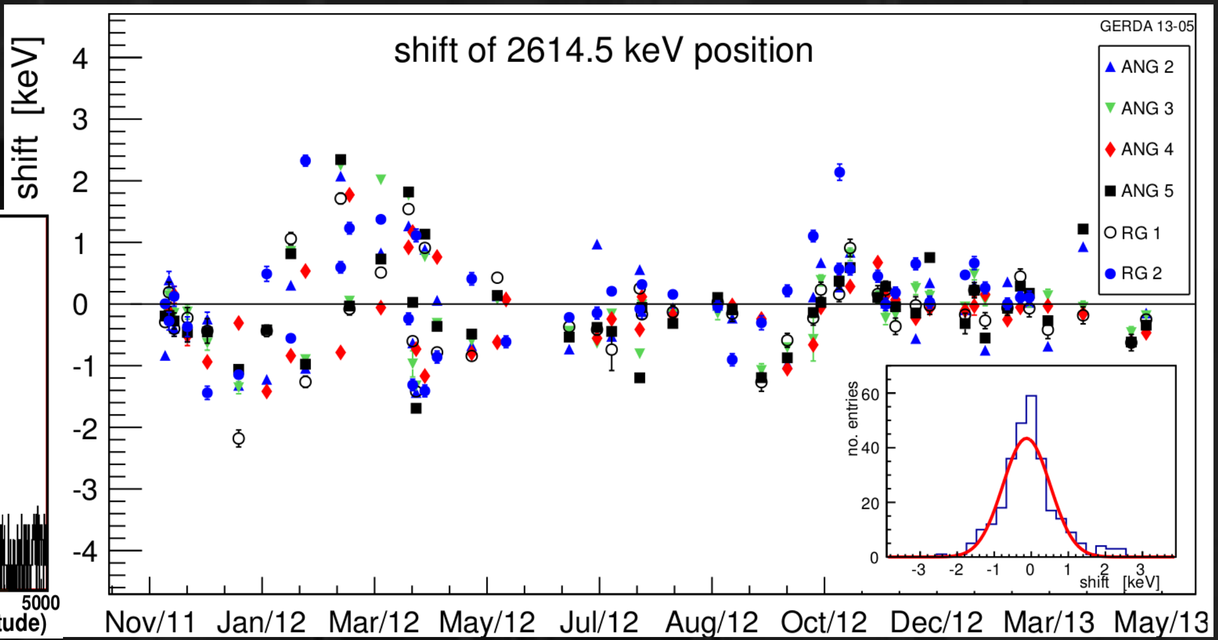


[1] GERDA collaboration, arXiv:1306.5084 [physics.ins-det] (2013)

Detector Stability

Use peaks from a ^{228}Th source for calibration.

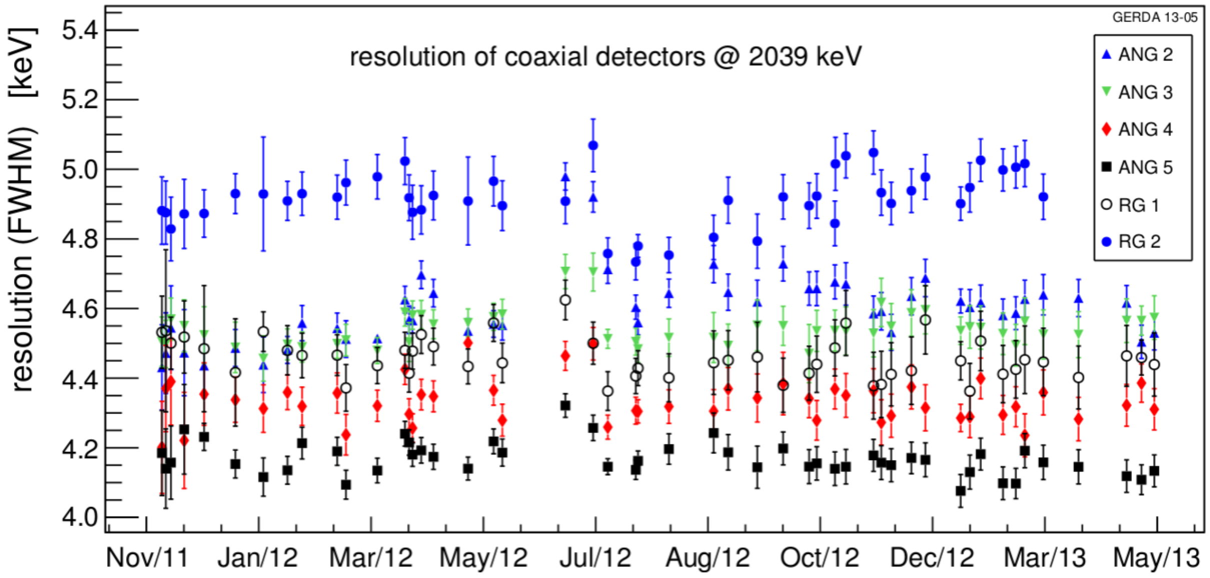




Stable energy calibration: shift < 2 keV over the full data taking period.

- As important as the energy resolution.

Stable energy resolution.



Phase I Background

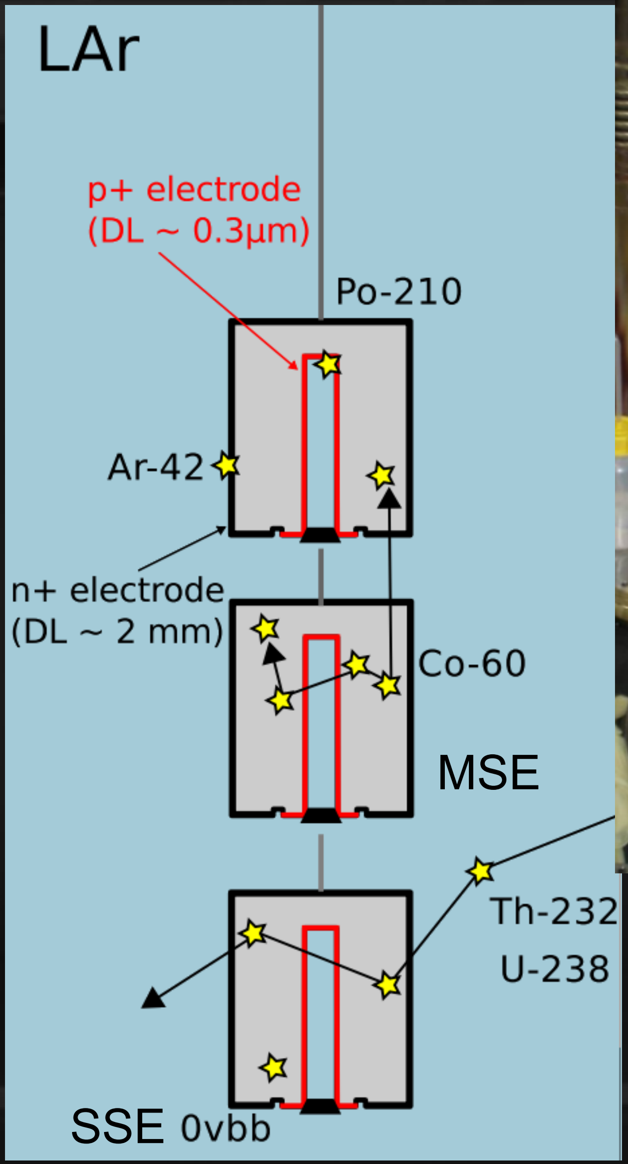
The outer most, so called Dead Layer, of the detectors is not active.

Background sources:

- α decays on the p+ surface,
- β decay of ^{42}K on the surface or close to the detector which comes from ^{42}Ar (factor ≈ 10 higher than expected!),
- β decay of ^{60}Co inside the detectors,
- γ from ^{208}Tl, ^{214}Bi from various set-up components.

Phase I background reduction:

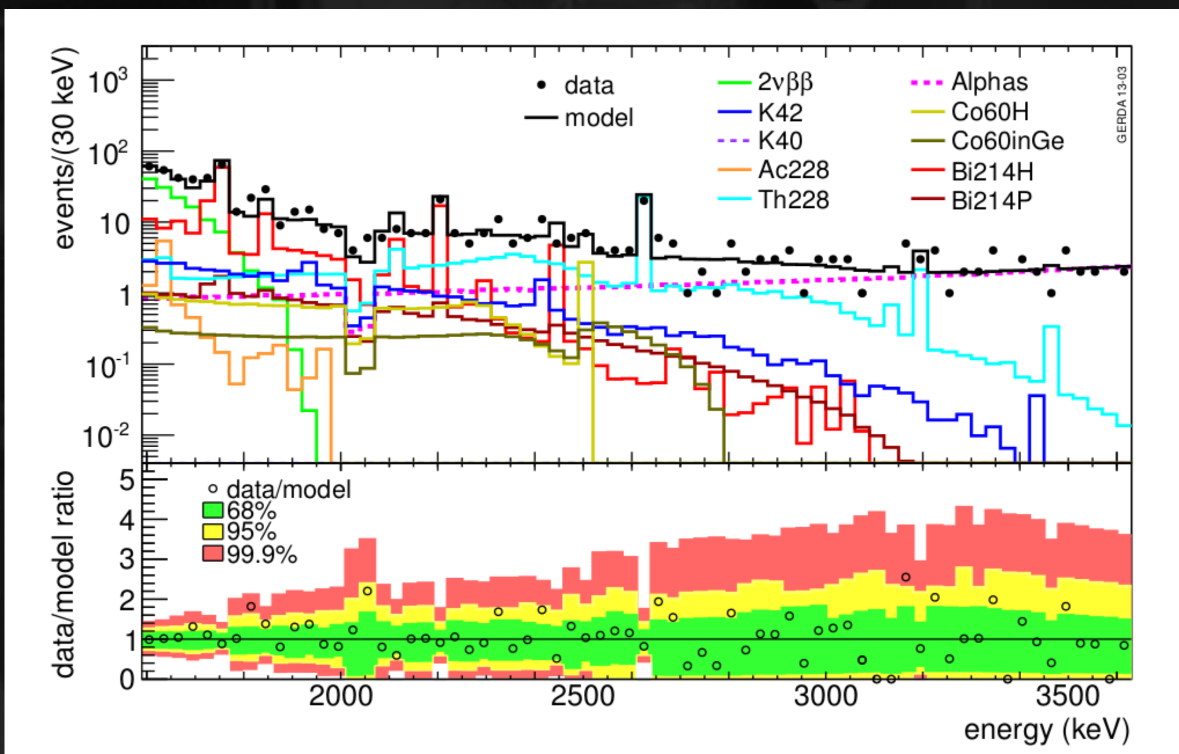
- Cut detector coincidences,
- prevent ^{42}K ions from drifting to the detectors using minishrouds.

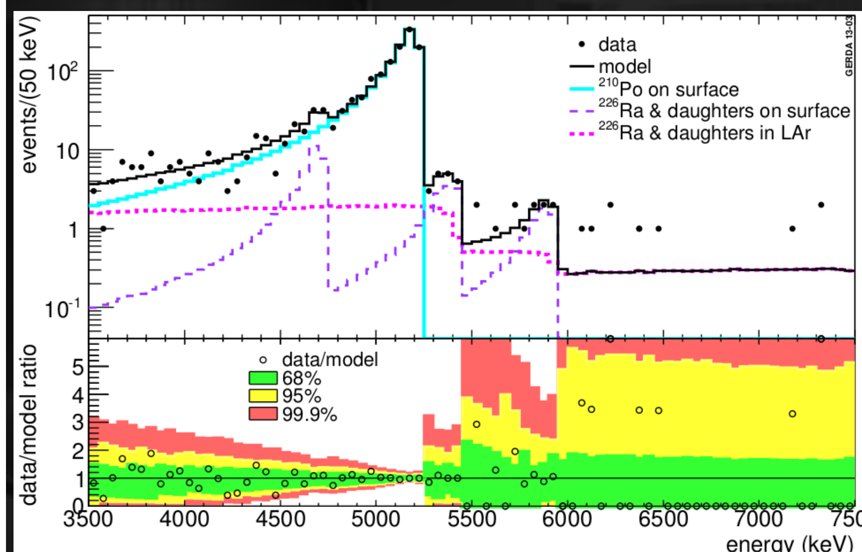


Phase I Background

Determination Method:

- Simulate spectral shape of individual background sources.
- Add minimal number of spectra necessary to fit the measured spectrum ⇒ Minimal Model.





Shown analysis is for coaxial detectors, which yield for most of the exposure.

Background in the BEGe detectors is slightly higher due to ^{42}K, which can be rejected by the pulse shape.

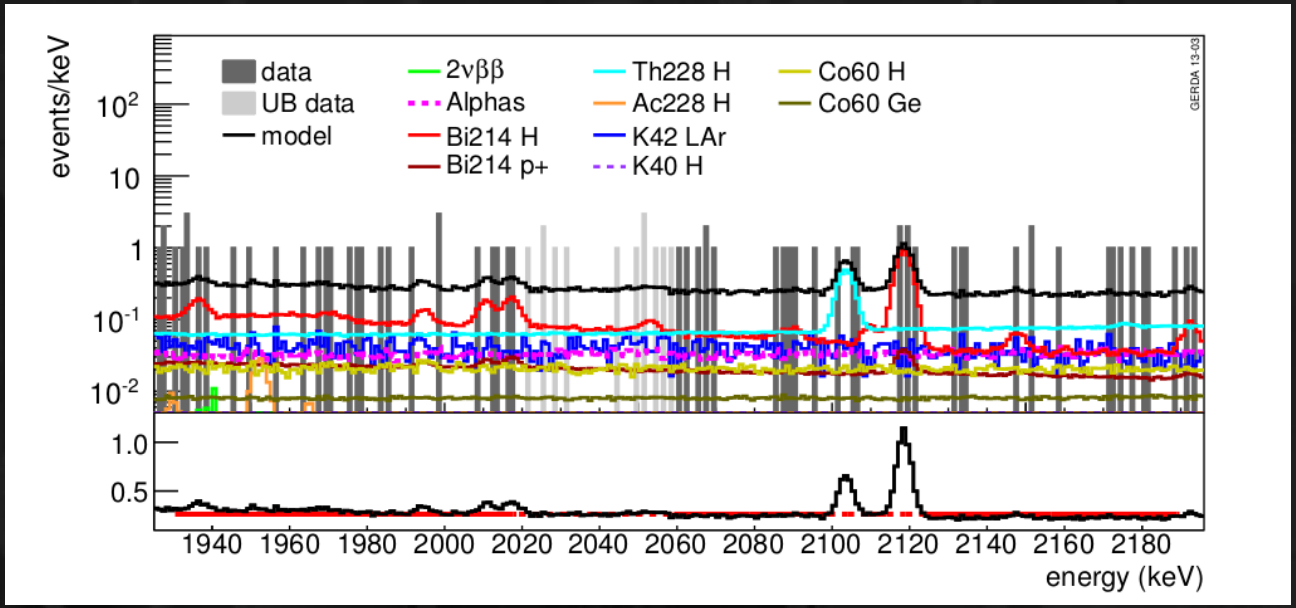
Phase I Background at $Q_{\beta\beta}$

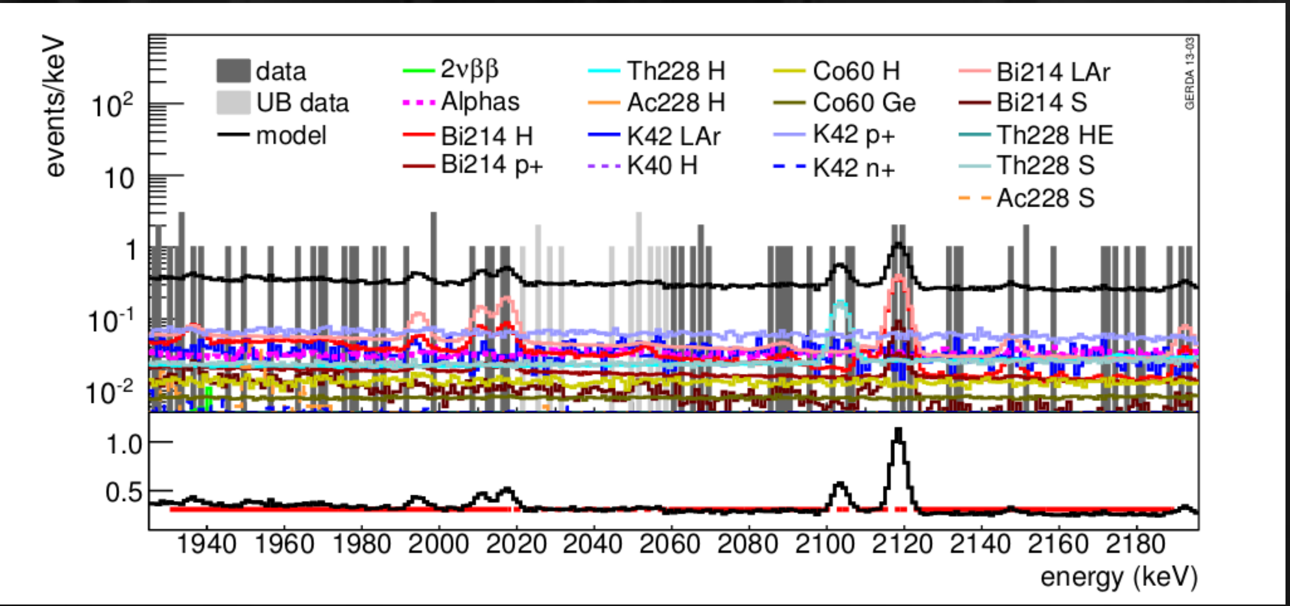
Maximal Model:
Use same isotopes as for the Minimal Model but more possible source positions to fit the background.

For both models no background peaks expected at Q_{bb}!

Background is constant at Q_{bb}±100 keV for both models.

Coaxial background prediction at Q_{bb}: 1.76 to $2.38 \cdot 10^{-2}$ cts/(keV kg yr), 68% C.L., consistent with interpolation from constant background.

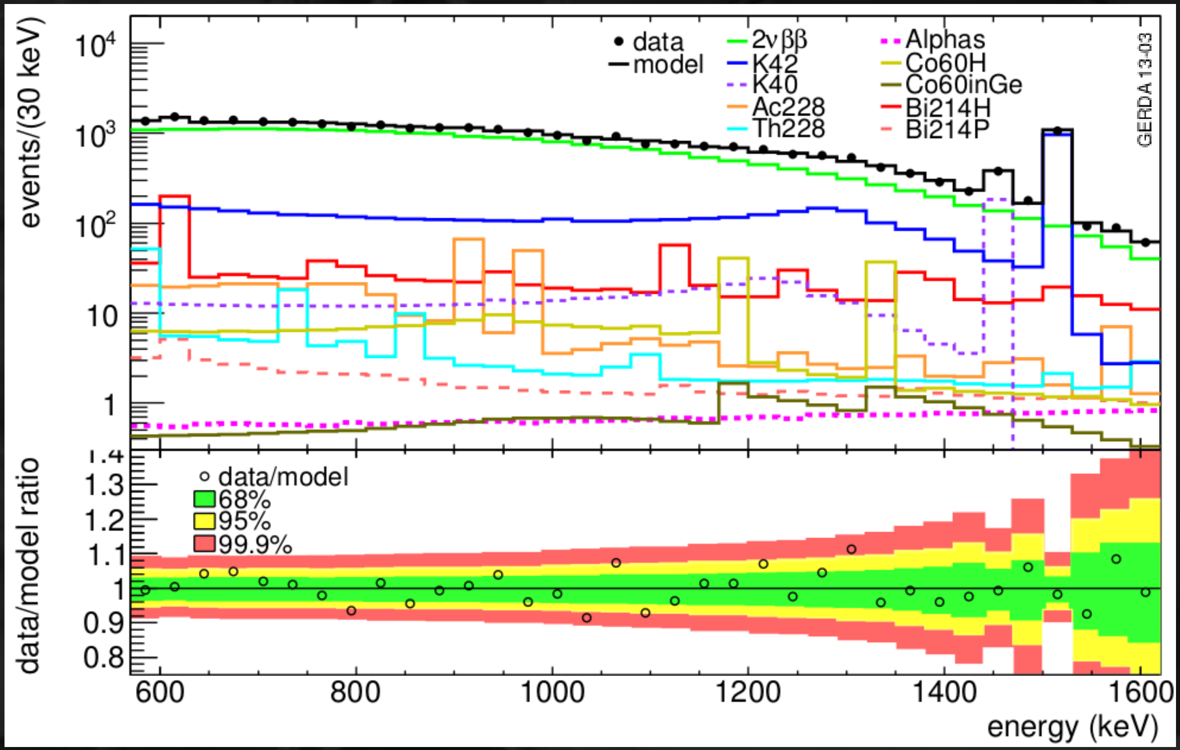




Phase I Background

600 to 1600 keV range dominated by $2\nu\beta\beta$ events.

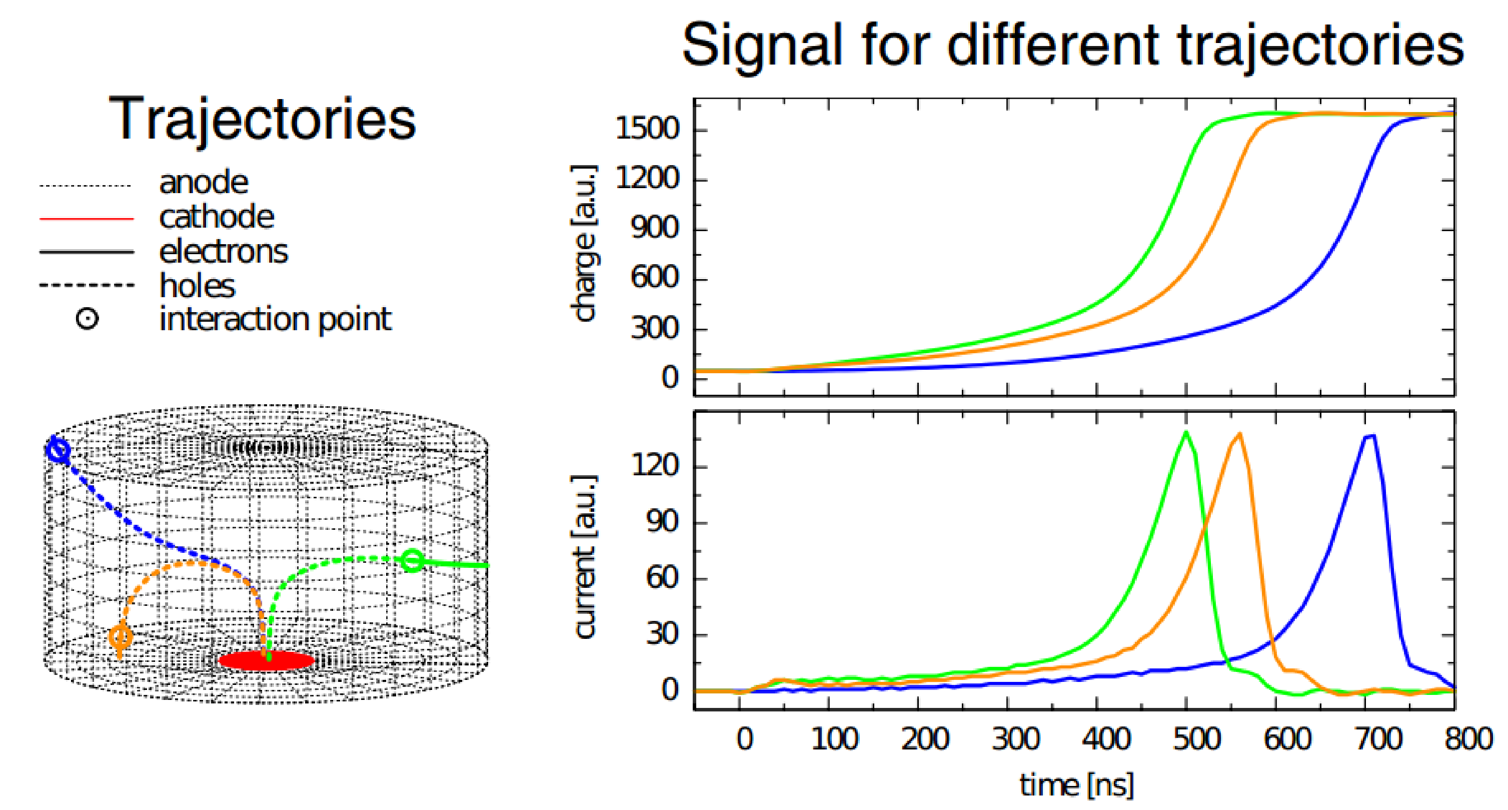
Both background models provide a half life which is consistent with our previously published value of $T_{1/2\ 2\nu\beta\beta} = 1.84^{+0.14}_{-0.10} \cdot 10^{21}$ yr [1].



[1] GERDA collaboration, J. Phys. G: Nucl. Part. Phys. 40 (2013) 035110

Phase II

Phase II BEGe Detectors



Geometry results in well separated current peaks for different interaction points:

- Efficient rejection of multi site events [1].

Lower capacity results in a higher energy resolution: 2.7 keV instead of 4.5 keV (FWHM) at $Q_{\beta\beta}$.

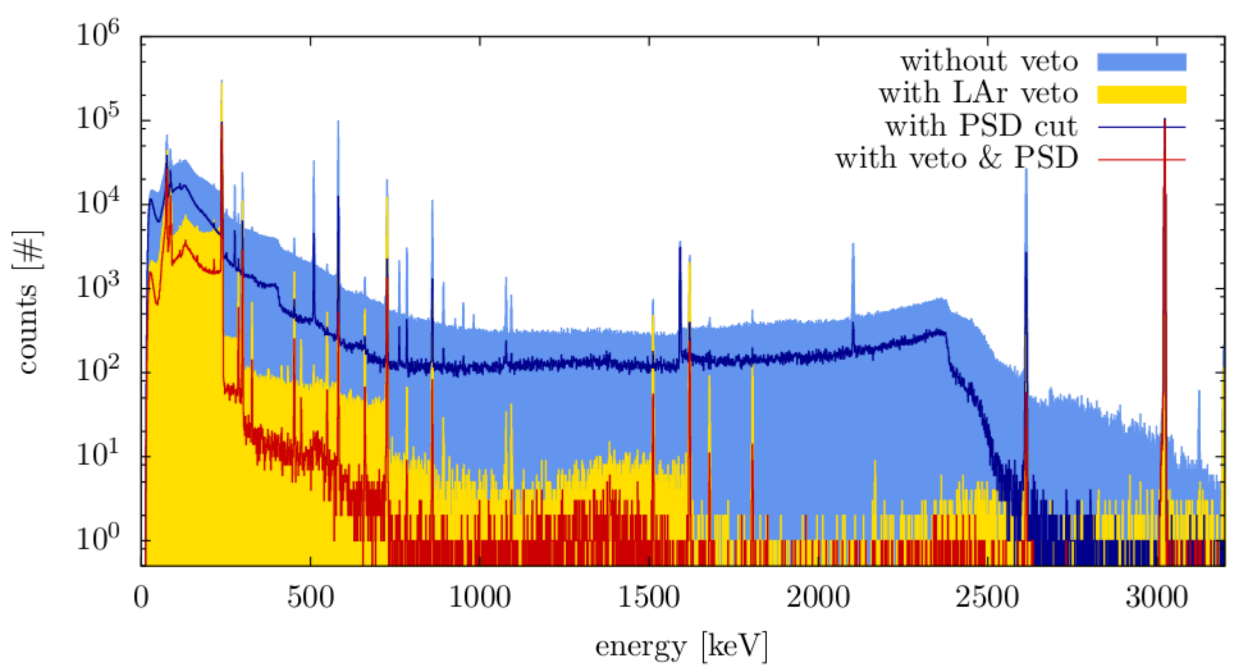
[1] D. Budjas et. al, JINST 8 P04018 (2013)

Liquid Ar Veto

Many background events at $Q_{\beta\beta}$ are in coincidence with an energy deposition in LAr.

Ar is a scintillator ⇒ can be used to efficiently suppress background.

Background suppression of a LAr veto and pulse shape discrimination was measured for a close ^{228}Th source (in a test set-up):
Typical suppression factors in the ROI: ^{208}Tl: 1180, ^{214}Bi: 4.6 [1].



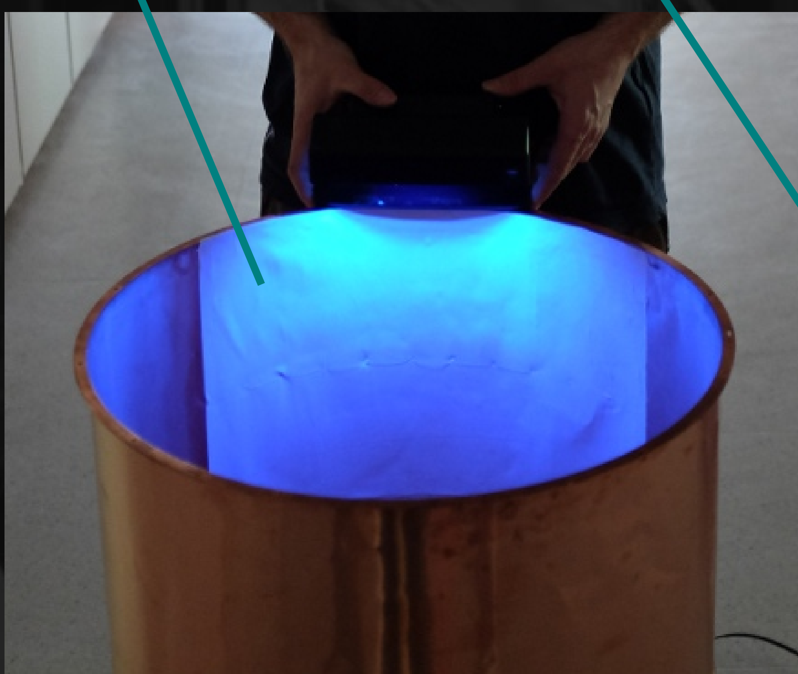
Representative for impurities in holders, pre-amplifiers and other close objects.

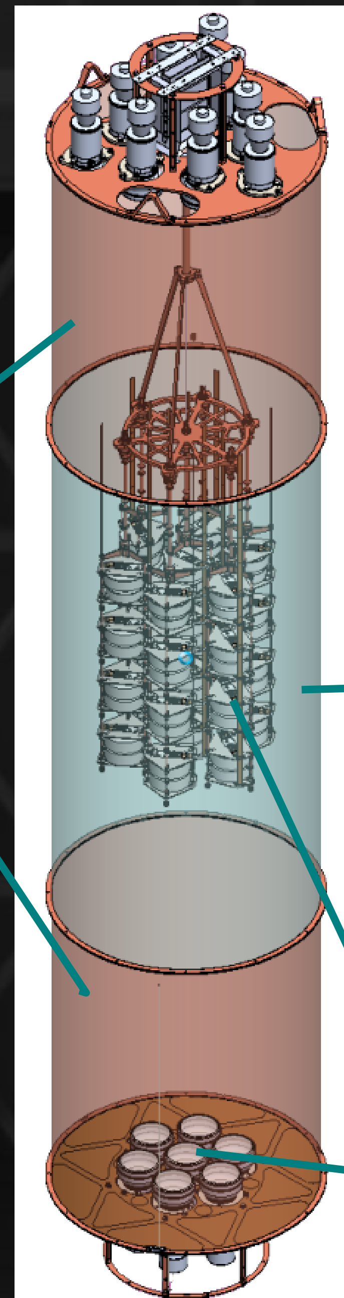
Peak at 3 MeV from pulser.

[1] "A liquid argon scintillation veto for Gerda", PhD thesis, M. Heisel, 2011.

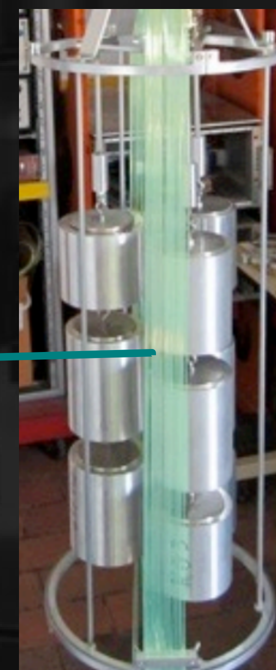
GERDA LAr Veto System

- Scintillation light has 128 nm $\Rightarrow$ needs to be converted to longer wavelength before detection.
- Performed by Tetraphenyl butadiene (TPB) coated onto Tetratex (a PTFE fabric).
- Tetratex is fixed to Cu shrouds.





Middle part surrounded by $\approx$ 1000 m of wavelength shifting fibres equipped with Si-photomultiplier.



Allows to detect light from outside of the cylinder.

Ge detector array.

Low radioactivity Photomultiplier tubes (PMTs) R11065-20.

Conclusion

Phase I data taking successfully finished with a background rate of about $2 \cdot 10^{-2}$ cts/(keV kg yr).

Background is flat at $Q_{\beta\beta}$.

Phase I results will be published soon.

Transition to Phase II started:

- Background rate: $1 \cdot 10^{-3}$ cts/(keV kg yr).
- Observation or limit of $T_{1/2} = 15 \cdot 10^{25}$ yr.

Thank you!

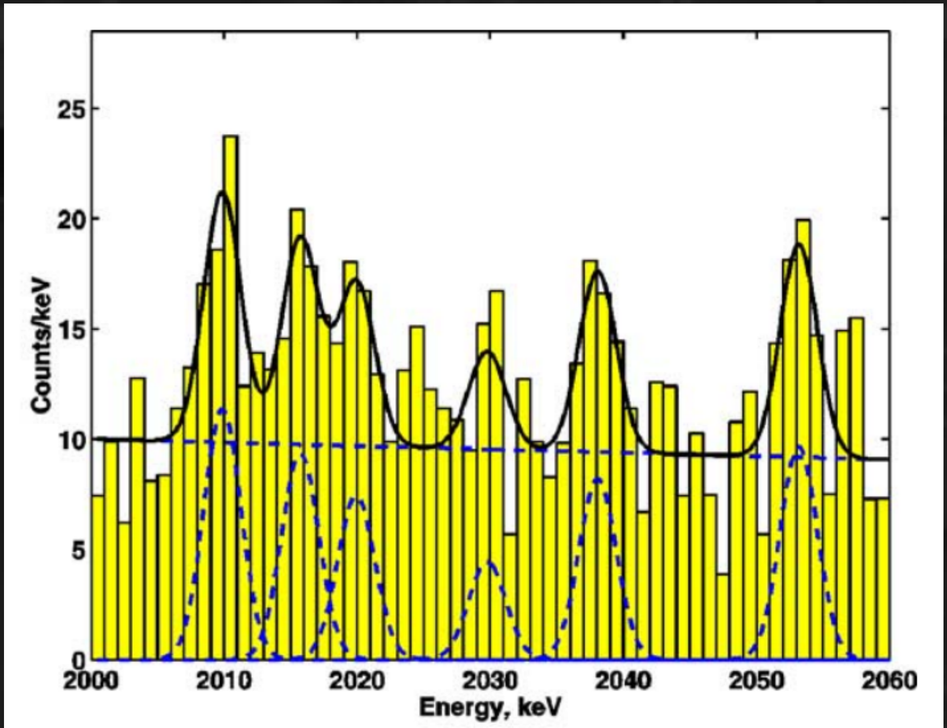
Backup Slides

Controversial Claim

Claiming a 4.2σ confidence level of the observation of $0\nu\beta\beta$ in ^{76}Ge.

Extending the energy window increases the background and decreases the signal count by up to 40 %. [2]

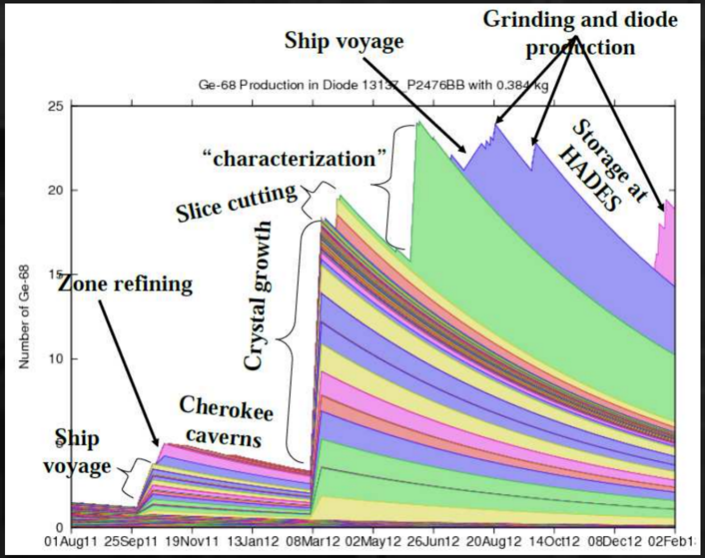
Results from Kamland-Zen and EXO suggest that the Claim is wrong.



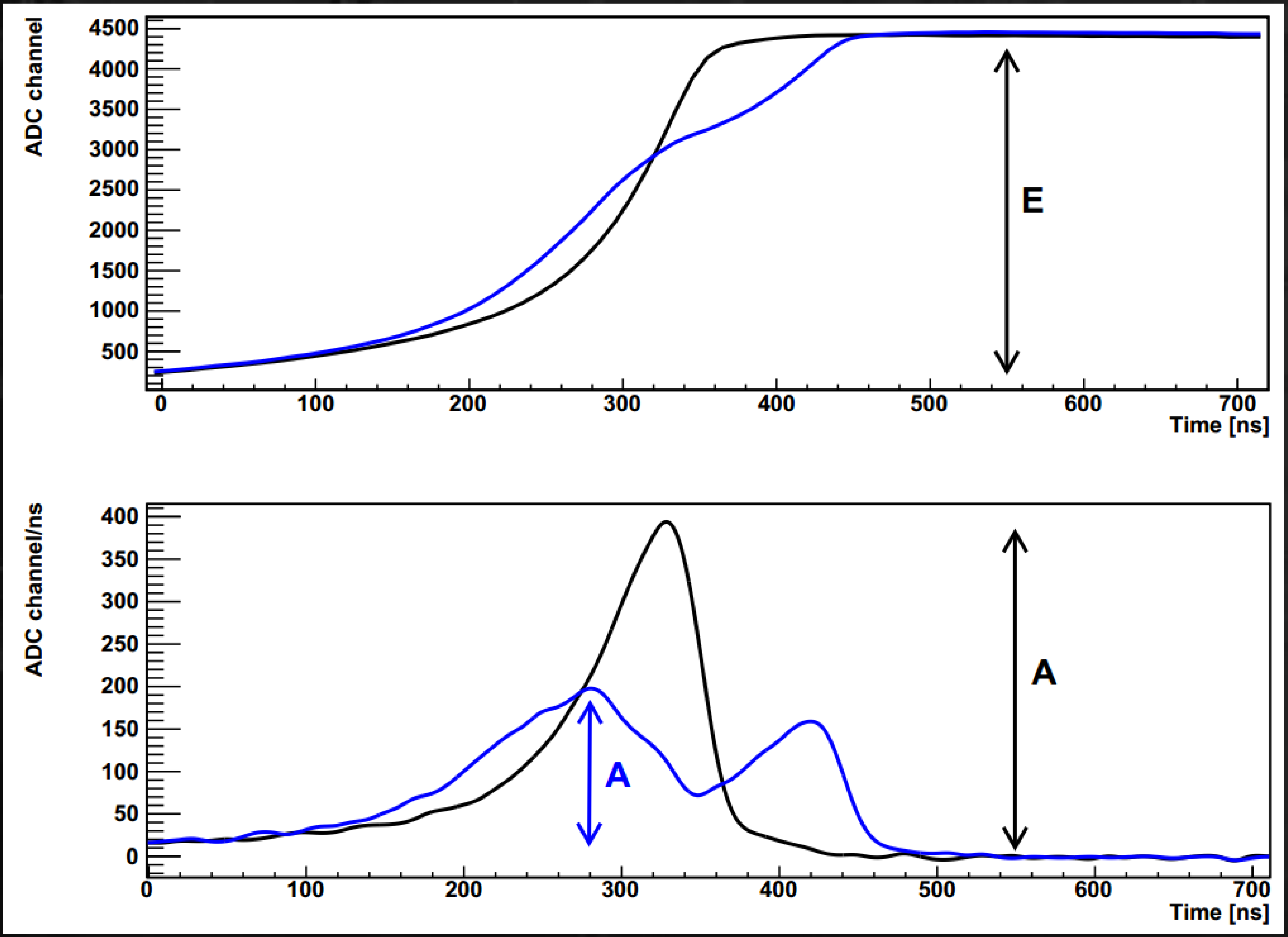
[1] H.V. Klapdor-Kleingrothaus et al., Phys. Lett. B586, 198 (2004).

[2] O.Chkvorets, PhD thesis, Universität Heidelberg, arXiv:0812.1206

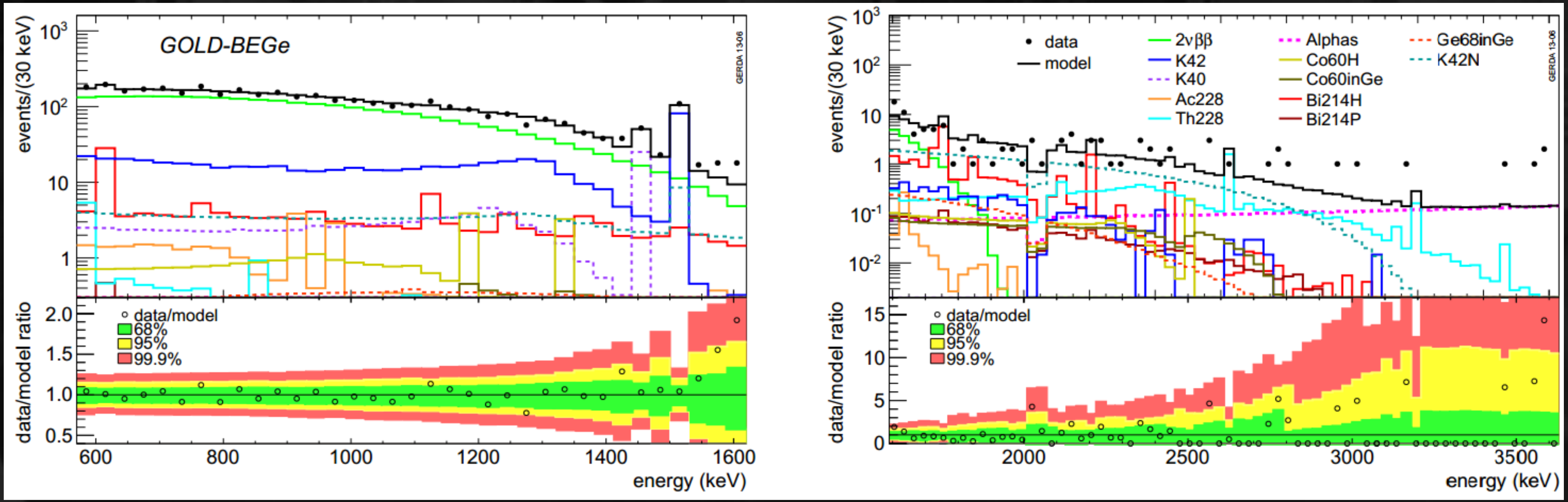
BEGe Production



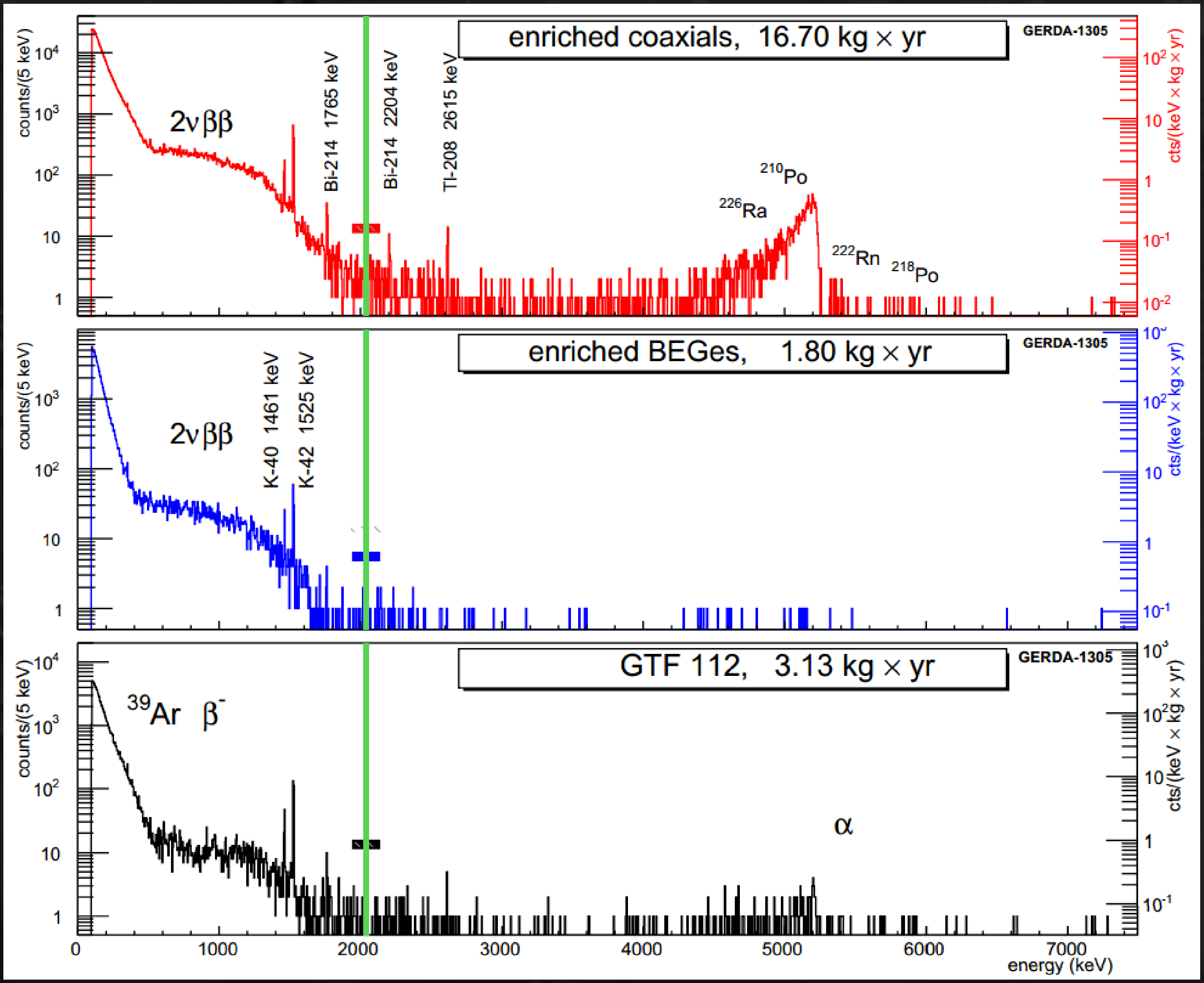
SS and MS Event in a BEGe Detector



BEGe Background

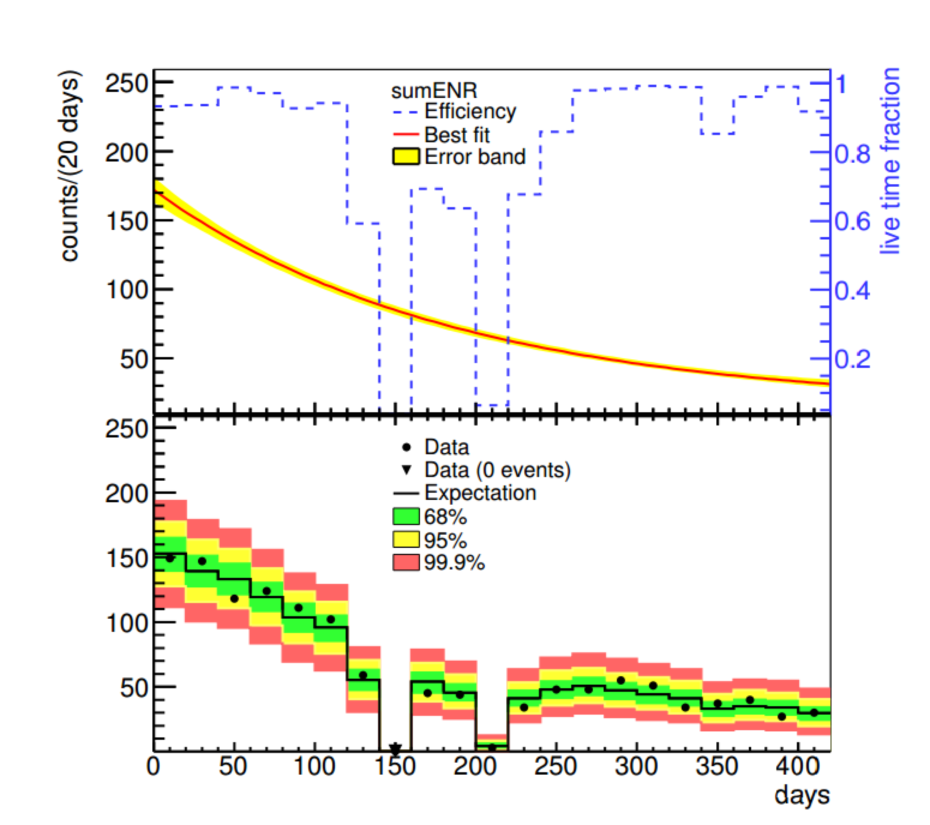


Full Spectra



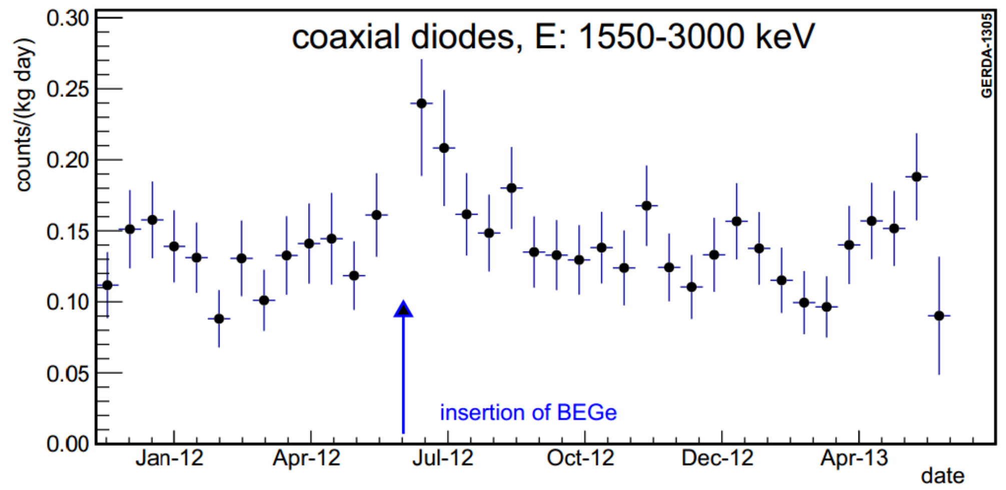
Time Evolution of Background

Event rate in the Gold Coaxial data set.



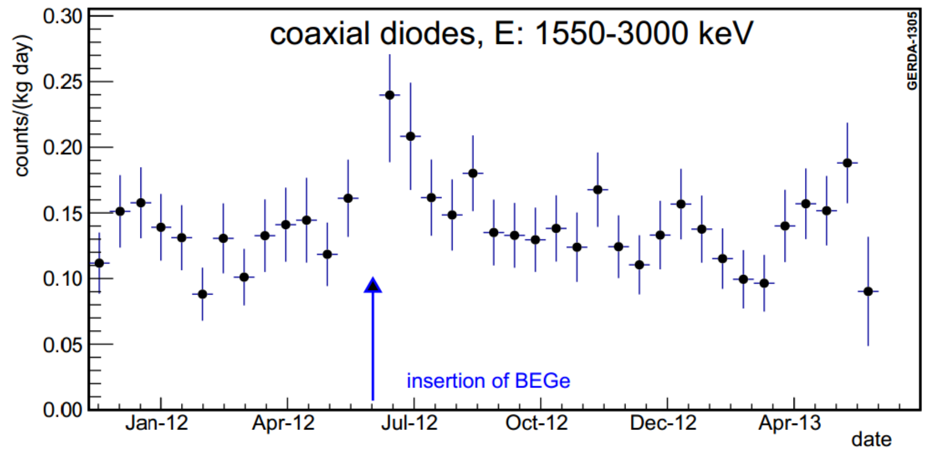
In the energy range of 3.5 to 5.3 MeV a decrease of the event rate with time is observed with a half life of 138.4 ± 0.2 d (statistical uncertainty only), which is compatible with the half life of ^{210}Po of 138.38 d.

Above it is constant with time.



Data Sets

Silver-Coax data set consists of data taken within 30 days after the immersion of the BEGe-detectors.



data set	detectors	exposure $\mathcal{E}$ this analysis	exposure $\mathcal{E}$ $0\nu\beta\beta$ analysis
		kg·yr	kg·yr
SUM-coax	all enriched coaxial	16.70	19.20
GOLD-coax	all enriched coaxial	15.40	17.90
SILVER-coax	all enriched coaxial	1.30	1.30
GOLD-nat	GTF 112	3.13	3.98
GOLD-hdm	ANG 2, ANG 3, ANG 4, ANG 5	10.90	12.98
GOLD-igex	RG 1, RG 2	4.50	4.93
SUM-bege	GD32B, GD32C, GD32D, GD35B	1.80	2.40

Detector Specifications

detector	f_{76}	M g	$M_{act}(\Delta M_{act})$ g	$f_{av}(\Delta f_{av_t})$	d_{dl} mm
enriched coaxial detectors					
ANG 1 †)	0.859(29)	958	795(50)	0.830(52)	1.8(5)
ANG 2	0.866(25)	2833	2468(145)	0.871(51)	2.3(7)
ANG 3	0.883(26)	2391	2070(136)	0.866(57)	1.9(7)
ANG 4	0.863(13)	2372	2136(135)	0.901(57)	1.4(7)
ANG 5	0.856(13)	2746	2281(132)	0.831(48)	2.6(6)
RG 1	0.855(15)	2110	1908(125)	0.904(59)	1.5(7)
RG 2	0.855(15)	2166	1800(115)	0.831(53)	2.3(7)
RG 3 †)	0.855(15)	2087	1868(113)	0.895(54)	1.4(7)
enriched BEGe detectors					
GD32B	0.877(13)	717	638(19)	0.890(27)	1.0(2)
GD32C	0.877(13)	743	677(22)	0.911(30)	0.8(3)
GD32D	0.877(13)	723	667(19)	0.923(26)	0.7(2)
GD35B	0.877(13)	812	742(24)	0.914(29)	0.8(3)
GD35C †)	0.877(13)	635	575(20)	0.906(32)	0.8(3)
natural coaxial detectors					
GTF 32 †)	0.078(1)	2321	2251(116)	0.97(5)	0.4(8)
GTF 45 †)	0.078(1)	2312			
GTF 112	0.078(1)	2965			

Liquid Ar as an active veto

Main BG in ROI:
  β and γ from ^{214}Bi, β from ^{42}K and γ ^{208}Tl:

- Often in coincidence with an energy deposition in LAr.

Ar is a scintillator => can be used as a veto.

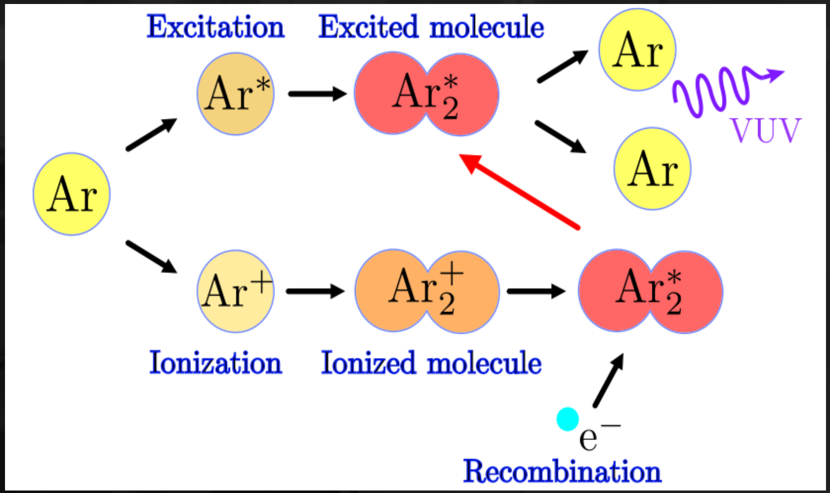
128 nm => needs to be converted to longer wavelength before detection.

- Performed by reflector foils coated with Tetraphenyl butadiene (TPB).
- Conversion yield determines rejection efficiency.

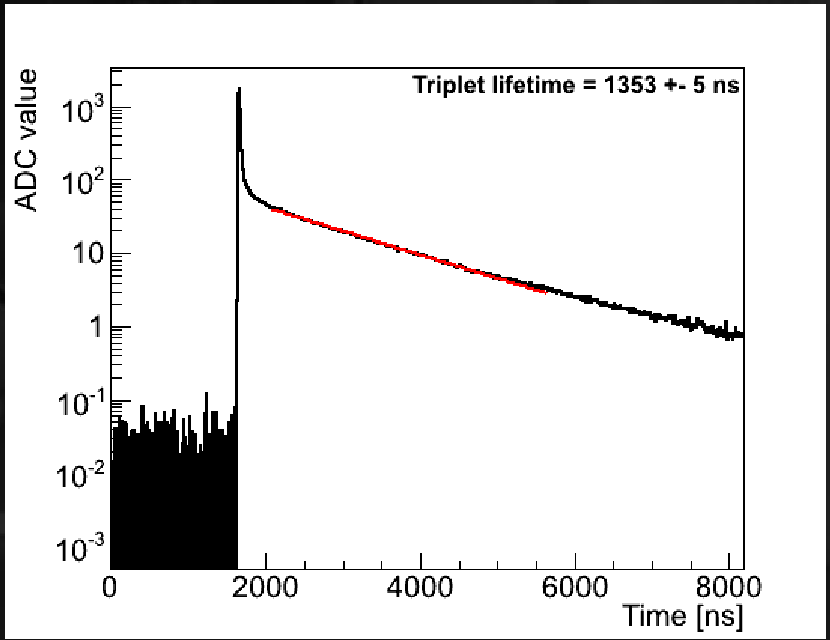
Light is produced by triplet and singlet state excimers with very distinct life times.

Typical suppression factors (measured [1]) in the ROI (source in active volume):

- ^{208}Tl: 1180, ^{214}Bi: 4.6 [1].



Scintillation process in Ar.



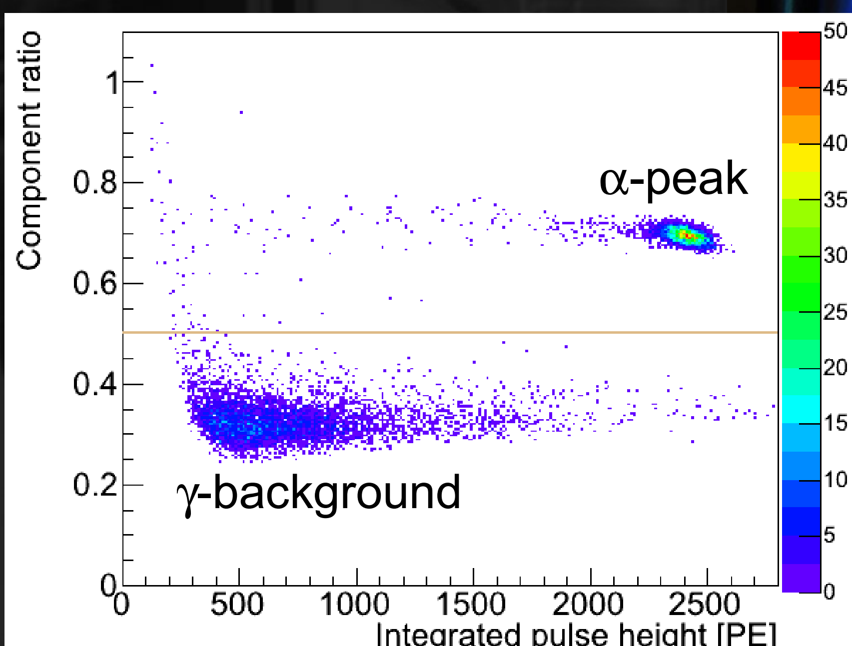
Mean PMT trace of Ar scintillation light.

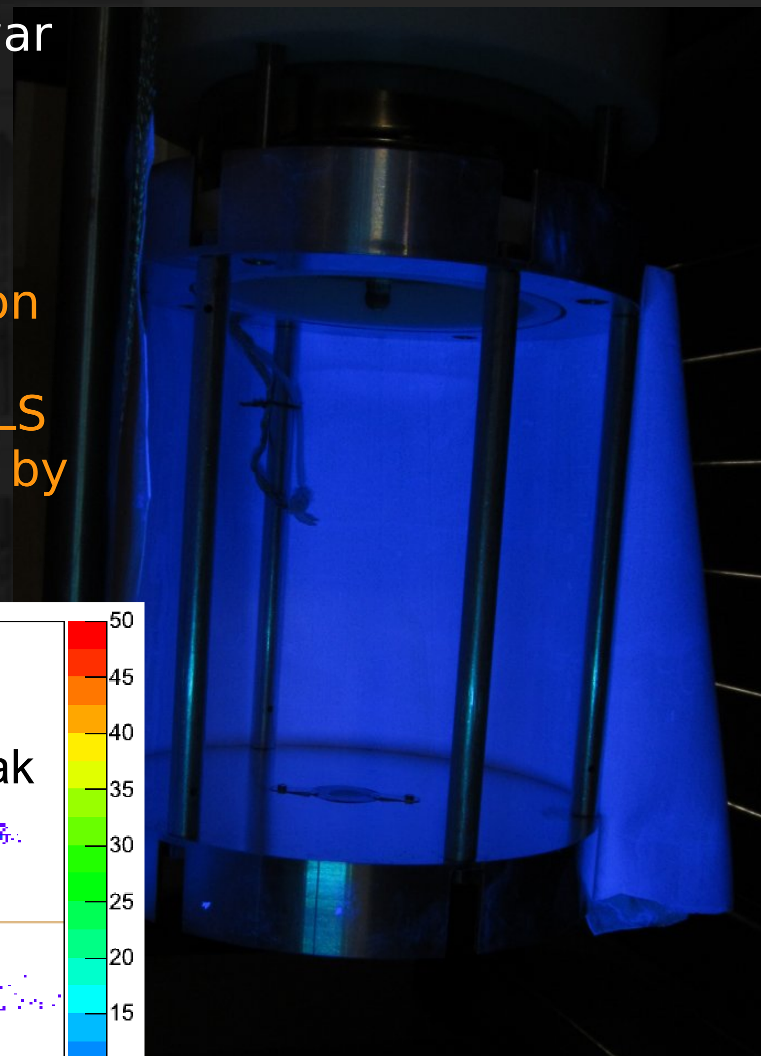
[1] "A liquid argon scintillation veto for Gerda", M. Heisel, 2011.

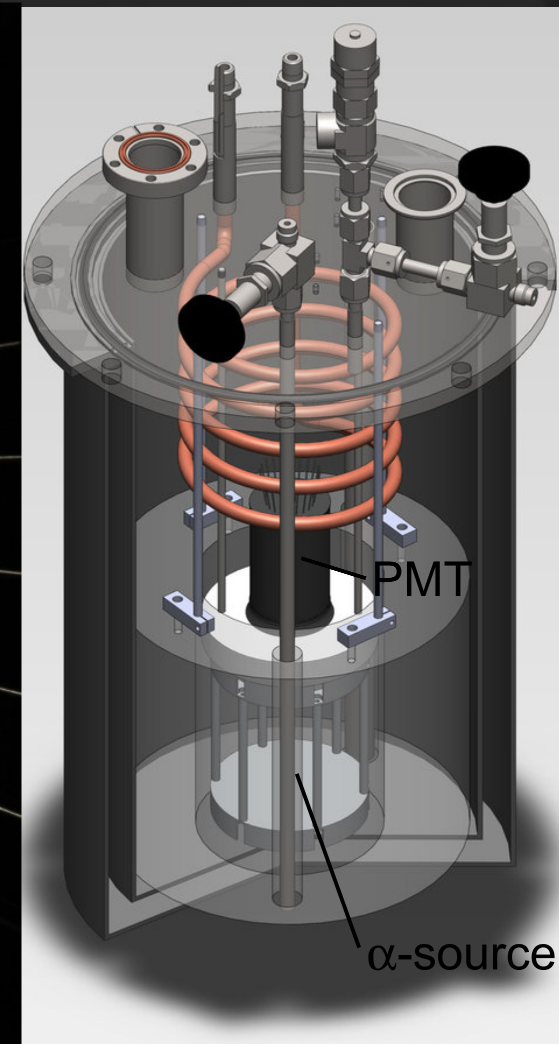
Liquid Ar Set-up at Uni Zürich

Cooling by LN_2 flowing through Cu coil in the dewar condensing high purity Ar gas (6.0).

Ar is excited by α-particles from ^{241}Am. The scintillation light is shifted by a surrounding cylinder of WLS reflector foil and detected by a R11065-10 PMT.

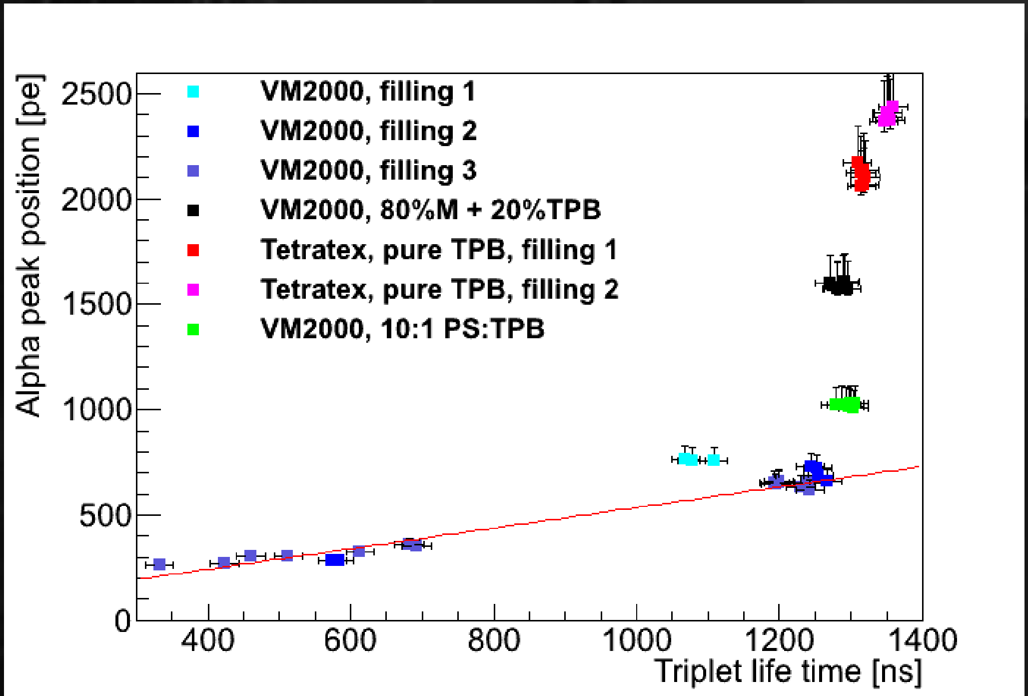






Schematic view of the LAr Set-up.

Results



	rel. efficiency
VM2000	1.0
VM2000, PS + TPB (10/1), 0.073 mg/cm²	1.5
VM2000, 80% M + 20% TPB , 0.082 mg/cm²	2.3
Tetratex, pure TPB, 0.88 mg/cm²	3.3

Efficiencies are measured relative to an uncoated VM2000.

To compare efficiencies of different coatings at the same triplet lifetime a linear function is fit to the peak position versus triplet lifetime of VM2000.

Highest efficiency for TPB on Tetratex.

For all coatings:

- WLS appears to resist cooling cycles (visual inspection of the setup and the coating with a UV lamp).

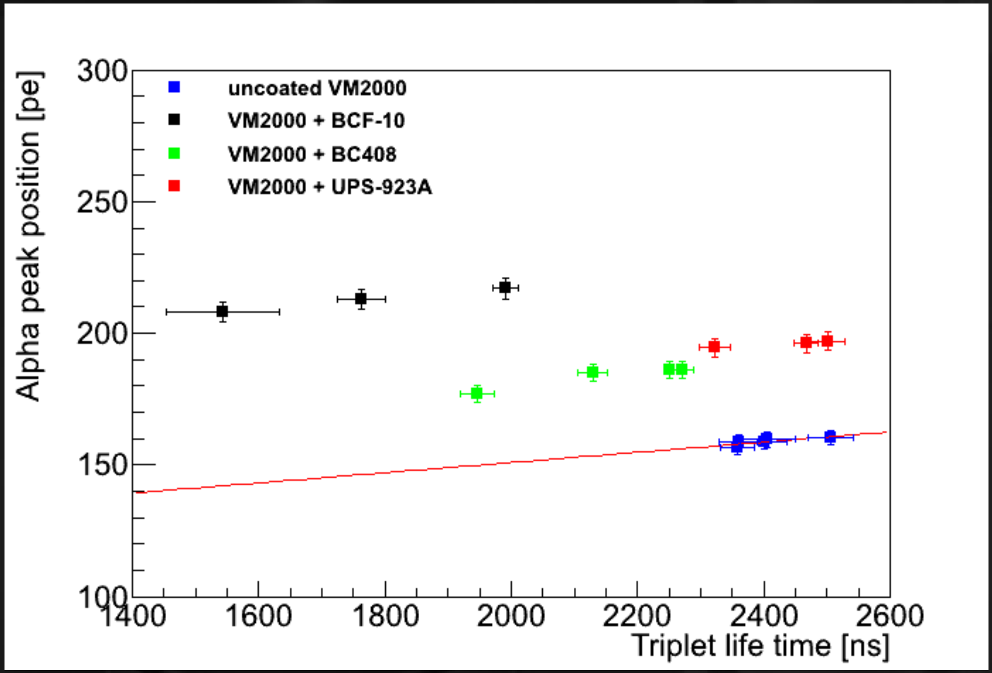
Commercial Scintillators as WLS

BC408, UPS-923A and BCF-10 fibre dissolved in Toluene (3.3 g/100 ml) and wet coated onto VM2000.
⇒ thickness of:

- UPS-923A: 0.16 mg/cm², BCF-10: 0.26 mg/cm² and BC 408: 0.25 mg/cm².

Efficiency measured using GAr scintillation light, relative to VM2000:

- 1.2 for BC408 and UPS-923A,
- 1.5 for BCF-10 fibre (like PS + TPB from LAr).



Result: These commercial scintillators with a high light yield coated to VM2000 are less efficient than TPB on Tetratex.

TPB Concentration Optimisation

- Concetration/thickness dependent efficiency measured using GAr scintillation light (error bars statistical only).
- Most coatings measured several times (unmounted between measurements): $\Rightarrow$ fluctuation $\approx$ 8.6 %.
- Optimal thickness at about 0.8 mg/cm^2 (error bars from fluctuation).
- Coating test successfully performed on a 45 cm x 93 cm sheet of Tetratex.