MC Benchmarks for LAr Instrumentation in GERDA

Björn Lehnert

Institut für Kern- und Teilchenphysik
TU-Dresden

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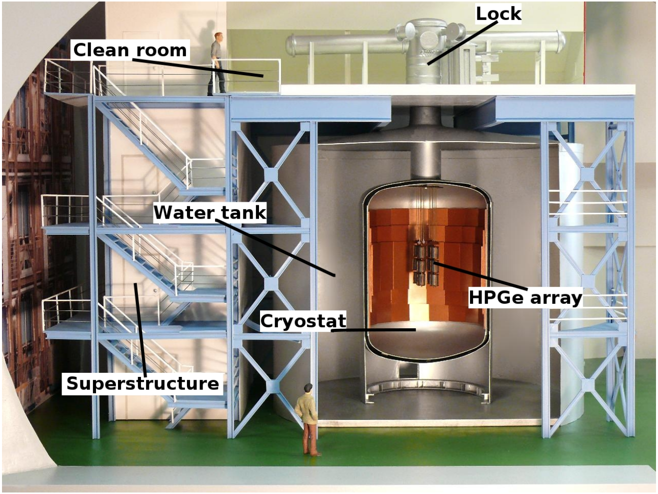
GERDA - GERmanium Detector Array

Novel idea: Operate germanium detectors naked in liquid argon

- Serving as cooling
- Serving as shielding
- Possible to implement as active veto



LAr as an active veto
Plans for GERDA

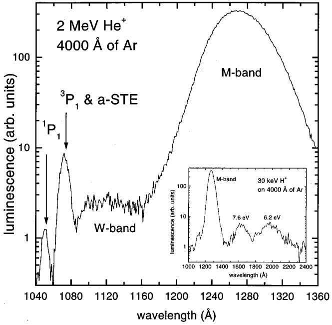
- Instrument the LAr to detect scintillation light.
  - Veto backgrounds from coincidence between Ge and LAr events.
  - Principle already demonstrated in test facility (LArGe).
  - Aim implementation for GERDA phase II.
- Two major instrumentation designs (J. Janicsko, HK 18.2).
  - Optical fiber design.
  - PMT design.

Goals for the MC:

- Estimate background suppression (veto efficiency) of the design.
- Optimize the design to maximize background suppression.

LAr optical properties

- High light yield: $\sim 4 \times 10^4$ photons/MeV.
- Single re-emission peak ($\lambda = 128$ nm).
  - Not directly detectable.
  - Use wavelength shifter (eg. VM2000).
- Short scattering length in emission range ($\sigma_{128nm} \approx 80$ cm).
- Properties strongly affected by impurities (eg.: Xe, N_2).
- Transparent in the visible range ($\sigma_{550nm} > 1$km).



Gosjean, Phys. Rev. B 56(1997)

Types of studied backgrounds

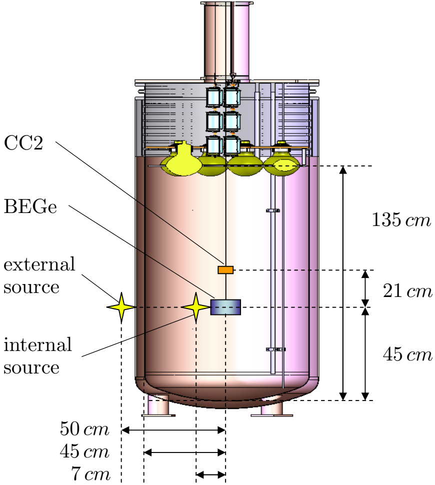
- Internal backgrounds:
  - Mostly cosmic activations (^{60}Co).
- Backgrounds in LAr:
  - Backgrounds distributed in LAr (^{214}Bi, ^{42}K).
  - Backgrounds on the surface of crystals (mostly α : ^{210}Po).
- Bulk contamination of support structures:
  - ^{208}Tl (^{232}Th chain), ^{214}Bi (^{226}Ra).
- **Only background events that deposit $Q_{\beta\beta} \pm 50keV$ in Ge are relevant.**
- Different veto energy thresholds are tested.

Information for all simulated sources:

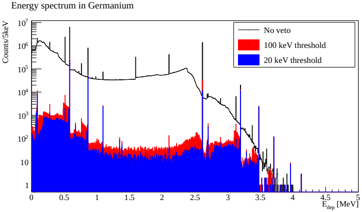
- Suppression factor $S_{eff} = \frac{N_{Ge}}{N_{Ge_{nv}}}$.

Validation of the MC with LArGe

- Use these measurements as a base to validate the MC.
  - No measurements with GERDA and LAr veto.
  - Simpler geometry.
  - Smaller scale (LAr volume).
- Tune the MC (eg.: optical properties of Argon).
- Several measurements with calibration sources performed in LArGe.
  - Using both internal and external sources.
  - A single BEGe as the Germanium detector.
- Estimated energy threshold veto is ~ 100 keV.



Validation of the MC
Results with LArGe



^{228}Th:

- Only ^{208}Tl was simulated (major contributor).
- Some results:

  Rate of backgrounds in $Q_{\beta\beta}$: 0.078 % w.r.t. simulated events.

  $S_{100\,keV}$: 1507

  $S_{20\,keV}$: 2748

  $S_{measured}$: 1180 ± 250

^{226}Ra:

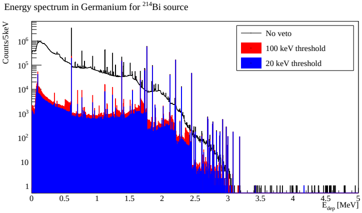
- Only ^{214}Bi was simulated.
- Results:

  Rate of backgrounds in $Q_{\beta\beta}$: 7×10^{-3} % w.r.t. simulated events.

  $S_{100\,keV}$: 5.6

  $S_{20\,keV}$: 8.1

  $S_{measured}$: 4.6 ± 0.2



Validation of the MC

Results with LArGe

^{60}Co:

- Activation from cosmic rays.
- Some results:

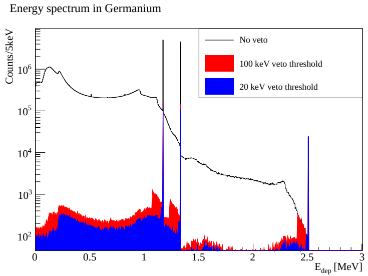
  Rate of backgrounds in $Q_{\beta\beta}$:

  2.93×10^{-3} %.

  S_{100keV}: 55

  S_{20keV}: 73

  $S_{measured}$: 27 ± 1.7.



Summary of LArGe MC tests:

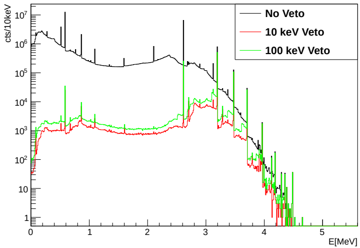
- MC consistent with the experimental measurements.
  - The MC is not yet fully tuned.
- Discrepancy in ^{60}Co simulation likely due to imprecise information:
  - Position of the source.
  - Design of the source.
  - Geometrical effects (shadows).

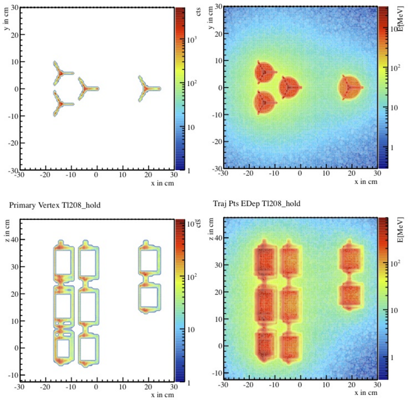
MC Status for GERDA Phase-I

- Principle similar to LArGe.
- Considerably more complex geometry.
  - Multiple Ge detectors instead of a single one.
  - Additional detector components (holders, cables).
- Simulations of major backgrounds estimated through the deposited energy:
  - These tests do not yet allow to properly compare designs.
  - It serves as an indication of the best possible scenario for the veto.

MC Status for GERDA Phase-I

Bulk contamination (^{208}Tl on crystal holders)





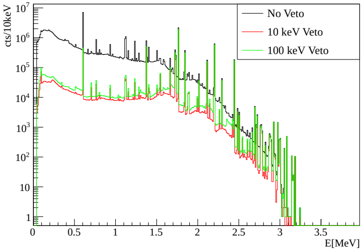
$S_{100\,keV}$: 254

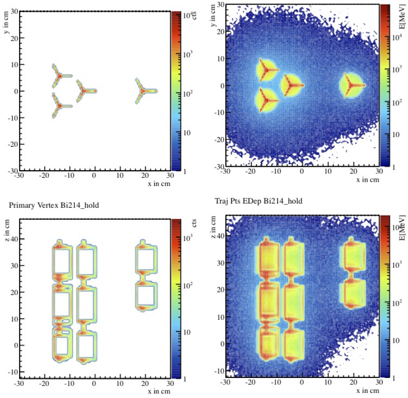
$S_{10\,keV}$: 354

- High efficiency due to multiple γ.

MC Status for GERDA Phase-I

Bulk contamination (^{214}Bi on crystal holders)





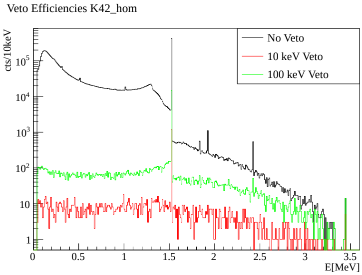
$S_{100\,keV}$: 3.5

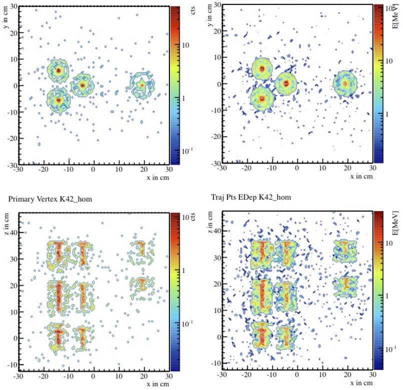
$S_{10\,keV}$: 4.4

- Single γ lowers veto efficiency.

MC Status for GERDA Phase-I

Bulk contamination (^{42}K in LAr)





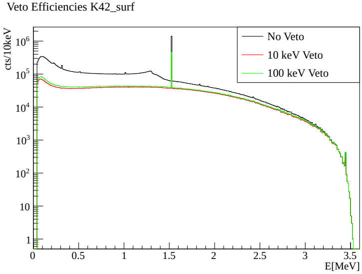
$S_{100\,keV}$: 6.0

$S_{10\,keV}$: 54.8

- Major background visible in GERDA.
- Distribution known to be not homogeneous.

MC Status for GERDA Phase-I

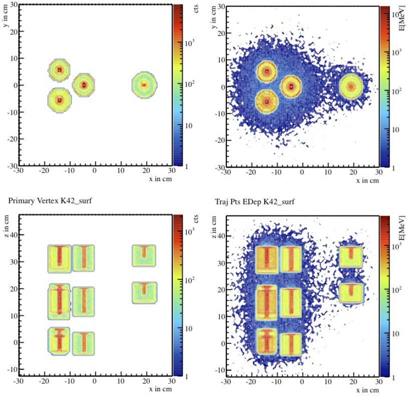
Bulk contamination (^{42}K on crystal surface)



$S_{100\,keV}$: 1.3

$S_{10\,keV}$: 1.4

- Major background visible in GERDA.
- Distribution known to be not homogeneous.



Summary of results so far

Isotope	Location	Suppression factor	
		100 keV	10 keV
^{280}Tl	Holders	254	354
^{214}Bi	Holders	3.5	4.4
	Crystal surface	13.8	20.1
^{42}K	Homogeneous in LAr	6.0	54.8
	Surface of Crystal	1.3	1.4
^{60}Co	Homogeneously in Crystals	57	68
^{210}Po	Surface of Crystal	2.1	2.2

- Values serve as an optimistic indicator of efficiency.

Conclusion

- Currently MC for LAr veto designs is an ongoing project.
- MC being tuned using LArGe results as base.
  - Initial results are already promising.
- LAr veto instrumentation able to reduce background index by 2 orders of magnitude (on specific backgrounds).
  - Limited efficiency on most visible GERDA background ($^{42}\mathrm{K}$).
  - Different approaches being followed in this case.
  - Will become a key component to achieve the background index aimed for phase II (10^{-3} counts/(kg·yr·keV)).
  - Present background index : $\sim 10^{-2}$ counts/(kg·yr·keV).
- Full simulation with photon tracking under preparation.