MaGe: a Monte Carlo framework for the Gerda and Majorana double beta decay experiments

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What is MaGe?

MaGe is a Monte Carlo simulation package dedicated to experiments searching for $0\nu2\beta$ decay in ^{76}Ge. Created by the Majorana collaboration, MaGe is now developed jointly by the Majorana and GERDA simulation groups.
MaGe is based on GEANT4, a software well established and widely used in experimental physics.

The idea of MaGe is to share a common simulation framework with an abstract set of interfaces, while each experiment adds its concrete implementations (geometry, output, etc...).

Majorana geometry → **MaGe** ← GERDA geometry

Event generators, description of physics processes, properties of the materials, management

MJ output | GERDA output

No constraints to both sides (geometry, physics, etc.) → each component can be independently re-written

The whole package can be **configured and tuned by macros** without accessing the code → accessible to new users and non experts of C++

Present status of MaGe

A common CVS repository is hosted at Munich, allowing people from both groups to easily commit new contributions to the code and keep their version of MaGe always up to date.

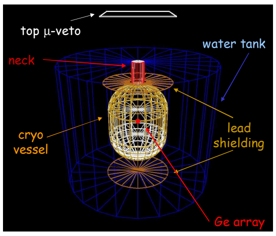
A discussion forum is hosted at Berkeley to periodically exchange ideas and suggestions for the development of the package and to keep both sides informed about recent implementations and results.

Why MaGe?

- ✓ **avoids duplication** of the work for the common parts of the simulations (generators, physics, materials, management)
- ✓ provides the **complete** simulation chain
- ✓ allows a more extensive **validation** of the simulation with experimental data coming from both experiments
- ✓ can be run by **script** and is **flexible** for experiment-specific implementation of geometry and output;
- ✓ is suitable for the **distributed** development

The Gerda ^{76}Ge $0\nu2\beta$ experiment

GERDA is a new experiment for the search of ^{76}Ge neutrinoless double-β decay at the **Gran Sasso Laboratory** (LNGS). The basic principle is to operate Ge detectors made out of isotopically enriched material inside a cryogenic fluid shield.



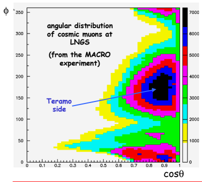
MaGe simulation of the **GERDA** geometry including the detectors and the shielding

GERDA will be located in **Hall A of LNGS**. The main goals of the experiment are:

- to **probe the neutrinoless double beta decay** of ^{76}Ge with a sensitivity of $T_{1/2} > 2\cdot10^{26}$ y at 90% CL, corresponding to a range of effective neutrino mass < 0.09 - 0.20 eV **within 3 years**.
- to be a pioneering **low-level facility** demonstrating the possibility of reducing the background by 2-3 orders of magnitude below the current state-of-the-art.

Muon background Study @ LNGS

The MaGe simulation package has been used to study the **background induced by cosmic muons** in the GERDA experiment and to optimize the design of the muon veto (plastic scintillators and Cerenkov μ-veto)



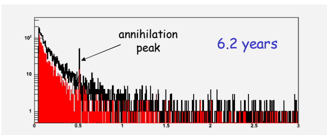
Energy window (1.5 – 2.5) MeV

Results on the efficiency of the muon vetoes	Background index (cts/keV kg y)
No cuts	$1.9\cdot10^{-3}$
Ge anti-coincidence	$4.1\cdot10^{-4}$
Ge anti-coincidence Top μ-veto (above penthouse)	$3.5\cdot10^{-4}$
Cerenkov μ-veto (thr = 120 MeV, 30,000 photons)	$< 3\cdot10^{-5}$ (95% CL)

Meets the requirements of GERDA in terms of background !

Simulation of muon-induced spectrum in germanium

Phase I: 9 Ge crystals for a total mass of 19 kg. The threshold for Ge crystals is 50 keV



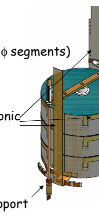
Sum spectrum without and with anticoincidence

Reduction of more than a factor 4 by means of the anticoincidence

Radioactive bck Study @ MPI Munich

Background events from decays of radioactive elements (^{60}Co, ^{40}K, ^{238}U & ^{232}Th chains) inside crystals, support and electronic cables are studied.

Most background events come from photons, depositing energy in several crystal segments, while signal events have electrons depositing energy **locally**.



Segment anticoincidence cut → background < 10^{-3} cts/keV/kg/y Signal efficiency > 85%.

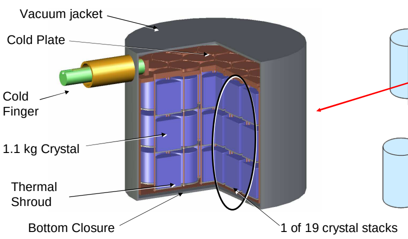
Pulse-shape under study, will further reject background.

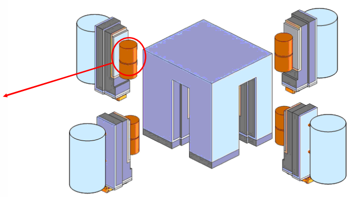
Source	Activity	Survival probability	Background Index [10^{-3} cts/kg/keV/y]
^{208}Tl (support)	9 μBq/kg	$1.2\cdot10^{-4}$	0.3
^{214}Bi (support)	25 μBq/kg	$2.5\cdot10^{-5}$	0.2
^{68}Ge (crystal)	*60 /kg/year**	*$2.2\cdot10^{-4}$*	*0.8*
^{60}Co (crystal)	15 /kg/year	$4.7\cdot10^{-5}$	0.07
$2\nu\beta\beta$	$T_{1/2} = 1.74\cdot10^{21}$ y	$< 10^{-6}$	< 0.45

* First year only

The Majorana ^{76}Ge $0\nu2\beta$ experiment

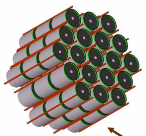
- **Majorana** is US, Canadian, Russian, and Japanese Collaboration, about 50 scientists are involved.
- The initial, proposed deployment consists of 180 kg of crystals, scalable to 500kg.
- The expected sensitivity is $T_{1/2} \sim 5\times10^{26}$ y within 3 years.
- The shielding consists of ultra-pure copper, ancient lead and active muon veto.
- **Majorana** uses careful material selection. Crystal-to-crystal veto, segmentation, pulse-shape discrimination, deep site location, and other techniques are used to reduce backgrounds.



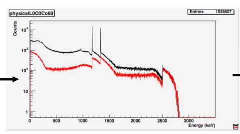


Selected Majorana Studies with MaGe

Background Model for Proposal

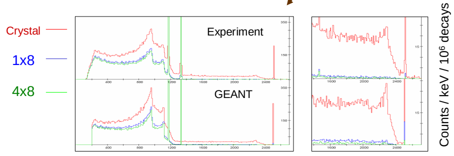


Proposed Geometry



Background Source		Gross and Net Rates for Important Isotopes (Counts in ROI per t-y)			Total Est. Background (per t-y) (Counts in ROI)
		^{68}Ge	^{60}Co		
Germanium (100 day exp)	Gross	2.54	1.22		
	Net	0.01	0.02		0.03
		^{208}Tl	^{214}Bi	^{60}Co	
Inner Mount	Gross	0.12	0.03	0.26	
	Net	0.01	0.00	0.00	0.01
Cryostat	Gross	0.77	0.16	0.58	
	Net	0.22	0.04	0.00	0.26
Copper Shield	Gross	2.28	0.30	0.02	
	Net	0.64	0.06	0.00	0.70
Small Parts	Gross	0.18	0.04	0.34	
	Net	0.02	0.01	0.00	0.03
External Sources (6000 mwe)		muons	cosmic activity	(α,n)	
	Gross	0.03	1.33	0.003	
	Net	0.003	0.18	0.003	0.18
2ν ββ -decay					< 0.01
	TOTAL SUM				1.21

Segmentation Studies



Ionization Energy Distribution