Measurement of the neutrino less double beta-decay with GERDA

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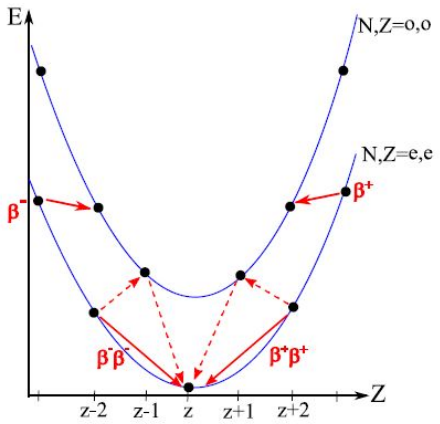
$0\nu\beta\beta$
- Quick $0\nu\beta\beta$ introduction
- Isotopes

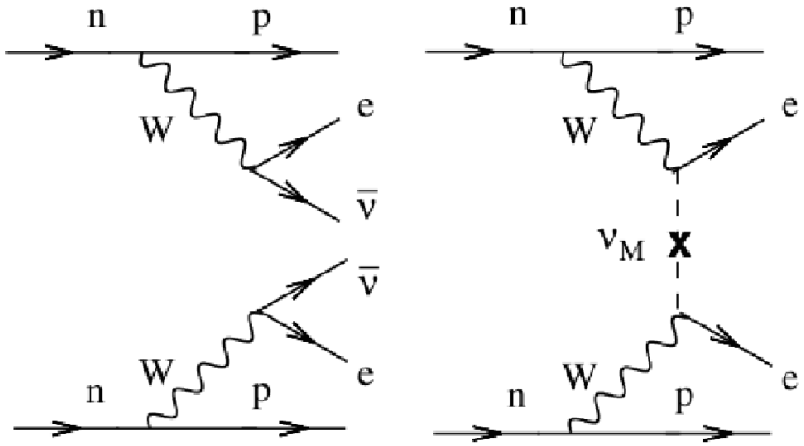
Sensitivities of Next Generation
- Scalibility
- Main Experiments
- Values

GERDA
- First Phase Results
- Second Pase
- Liquid Argon Scintillation Projects
- Light Attenuation

Other Projects

$2\nu\beta\beta$ and $0\nu\beta\beta$





- The following process defines double beta decay:

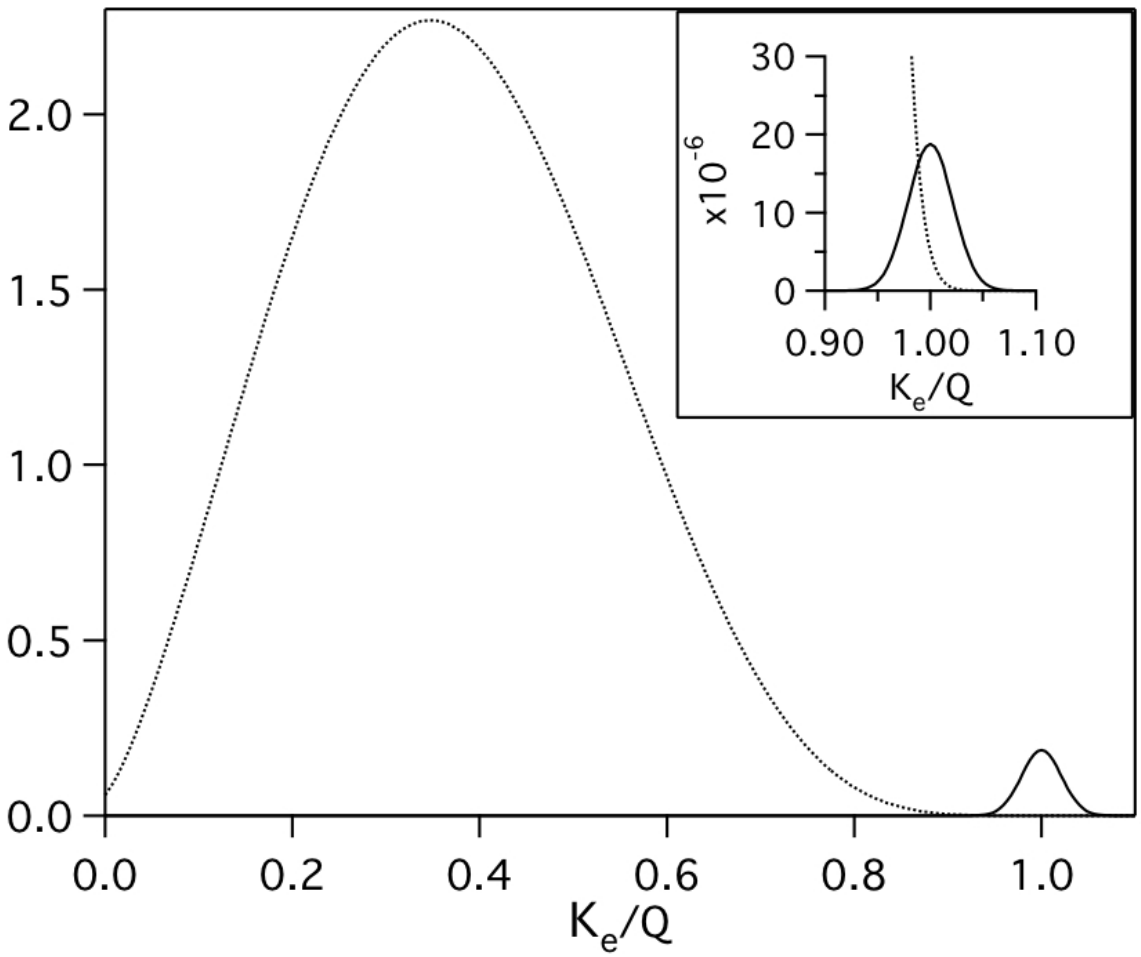
$$(Z, A) \rightarrow (Z{+}2, A){+}2e^{-}{+}2\bar{\nu}_e \ ,$$

- where as neutrinoless double beda decay is given as follows:

$$(Z, A) \rightarrow (Z + 2, A) + 2e^{-} \ .$$

- The rate of this process is linked to the mass of the neutrino as a helicity flip has to occur.

Signal Characteristics



$0\nu\beta\beta$ isotopes

Isotope	$Q_{\beta\beta}$[MeV]	Isotopic ab.(%)
^{48}Ca	4.271	0.0035
^{76}Ge	2.039	7.8
^{82}Se	2.995	9.2
^{96}Zr	3.35	2.8
^{100}Mo	3.034	9.6
^{116}Cd	2.802	7.5
^{128}Te	0.868	31.7
^{130}Te	2.533	34.5
^{136}Xe	2.479	8.9
^{150}Nd	3.367	5.6

- Balancing act between cost, scalability and price.
- A higher energy is preferred to escape from backgrounds.
- High abundance gets you more target material.

Tecnologys

To determine an experiments sensitivity to $0\nu\beta\beta$, it is convenient to define a sensitivity factor:

$$T_{1/2} \propto \epsilon \sqrt{\frac{M \cdot t}{\Delta E \cdot B}} \ ,$$

where ϵ is the efficiency in percent, $M \cdot t$ is the exposure in kg years, ΔE is energy resolution in keV (FWHM), B is background index in counts/(keV· kg ·yr). Current values for each experiment;

Solid State

- Exigent energy resolution.
- Low background index (BI).

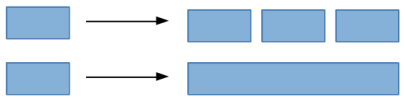
Scintillation

- Large amounts of isotopes.
- Great scalability

Scalability

Not all the experiments have economy of scale. Things to consider when it comes to scalability:

- **Modular** ($surf./vol. = const.$) vs. **monolithic** ($surf./vol. = 1/length$). Most of backgrounds come from the surface.



- **Target = detector** vs. **Target $\neq$ detector**.
- **Availability** of the isotope is limited, and they all depend on only a few isotopes. Supply and demand.
- **Cost** of element/enrichment can factor into the design of your experiment.

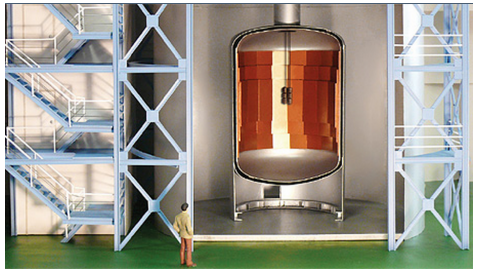
arXiv:1306.5654

Isotope	Q (meV)	Natural abund. (%)	Element cost ($/kg)	Annual world production (tons)
^{76}Ge	2.04	7.8	1650	118
^{82}Se	3.00	9.2	174	2000
^{130}Te	2.53	34.5	360	~150
^{136}Xe	2.46	8.9	1000	50

^{136}Xe is the easiest and least expensive to enrich (but still $\sim$ 20$/g)

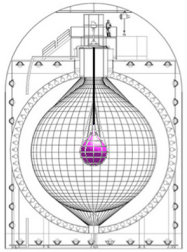
Quick Recap of Experimets

GERDA

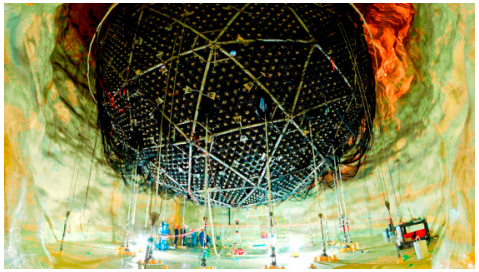


CUORE

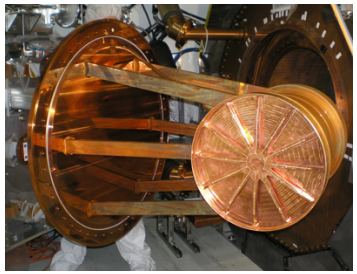
KAMLAND-ZEN

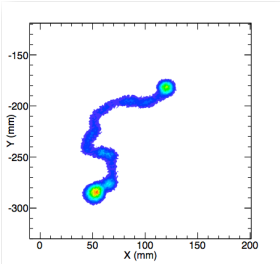


SNO+

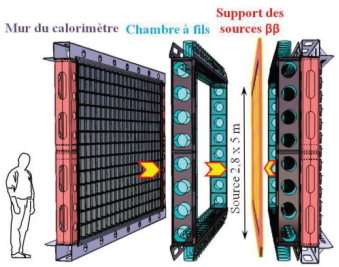


EXO-200 and NEXT





SuperNEMO



Considered Experiments

Each experiment can be understood in the following values. This helps to derive a figure of marit.

$$T_{1/2} \propto \epsilon \sqrt{\frac{M \cdot t}{\Delta E \cdot B}} \ .$$

Experiment	Isotope	Efficiency [%]	Mass [kg]	ΔE [keV]	B [$\times 10^{-3}$ckky]	Figure of Merit [1 kg $\cdot yr$]
NEXT	^{136}Xe	0.3	90	17.2	0.2	1.5
GERDA	^{76}Ge	0.8	15	3.3	10	0.5
EXO	^{136}Xe	0.7	160	81.1	1	1.0
KamLAND-Zen	^{136}Xe	0.8	360	233.5	0.5	1.4
CUORE	^{130}Te	0.8	200	4.6	40	0.8
SuperNEMO	^{82}Se	0.3	7	119.8	0.4	0.1
SNO+	^{150}Nd	0.5	50	164.3	10	0.1

Scalability of Next Generation

Improvement factor in sensitivity is quantified using the equation for the figure of merit,

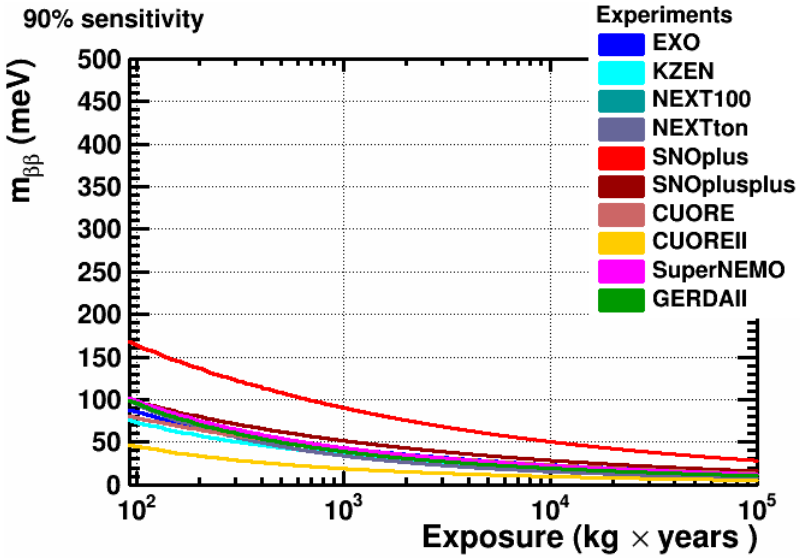
$$T_{1/2} \propto \epsilon \sqrt{\frac{M \cdot t}{\Delta E \cdot B}} \ ,$$

- Mass and background for current and future experiments taken from `arXiv:1010.5112`.
- Efficiency and resolution are assumed to remain the same.

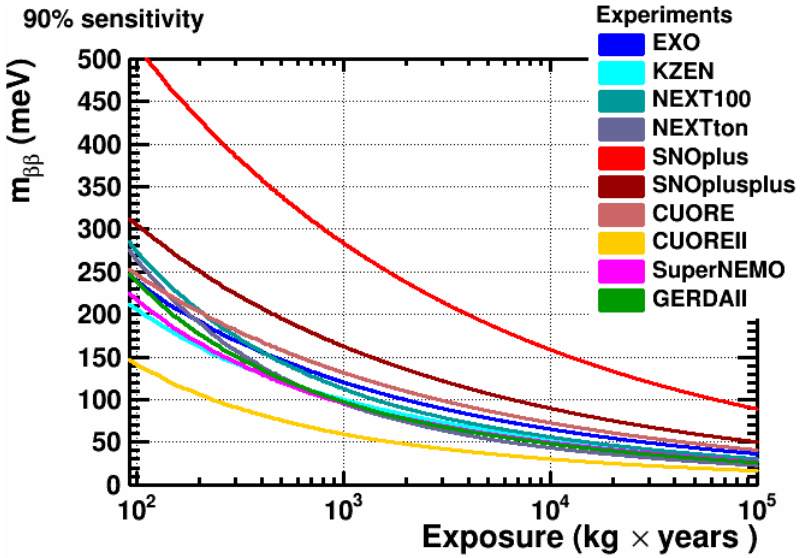
Experiment	$M_{future}/M_{current}$	$B_{current}/B_{future}$	Improvement factor
NEXT	11.11	3.33	6.09
GERDA	2.33	10	4.83
EXO	6.25	2	3.54
KamLAND-Zen	2.78	5	3.73
CUORE	2	40	8.94
SuperNEMO	14.28	6.67	9.76
SNO+	10	10	10

Sensitivity of next generation experiments

Best case NME (EDF)

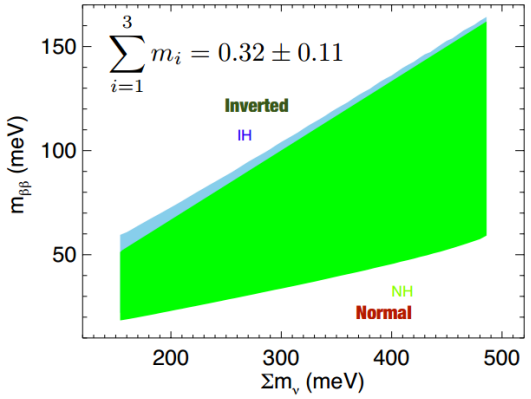


Worse case NME (ISM)



The smaller the better:

- Degenerate hierarchy: $m_{\beta\beta} \approx 50$ meV
- Inverse mass hierarchy: $m_{\beta\beta} \approx 20$ meV
- Normal mass hierarchy: $m_{\beta\beta} \approx 2$ meV

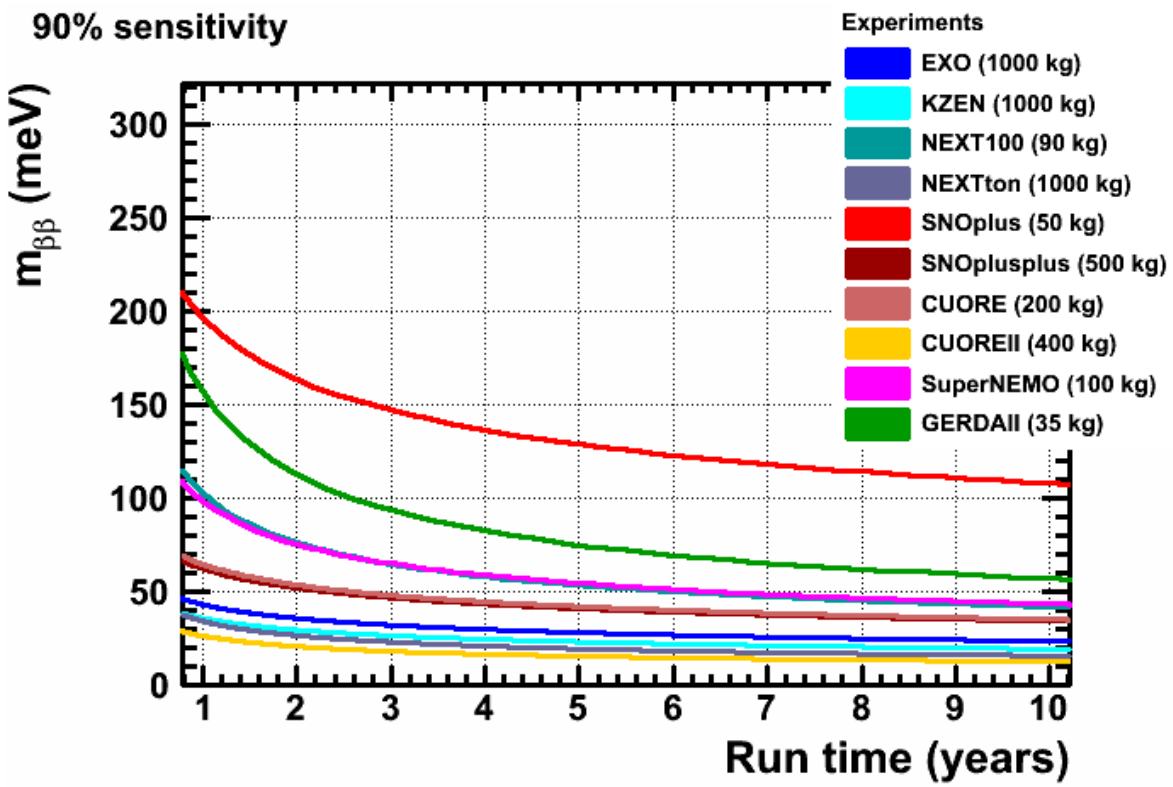


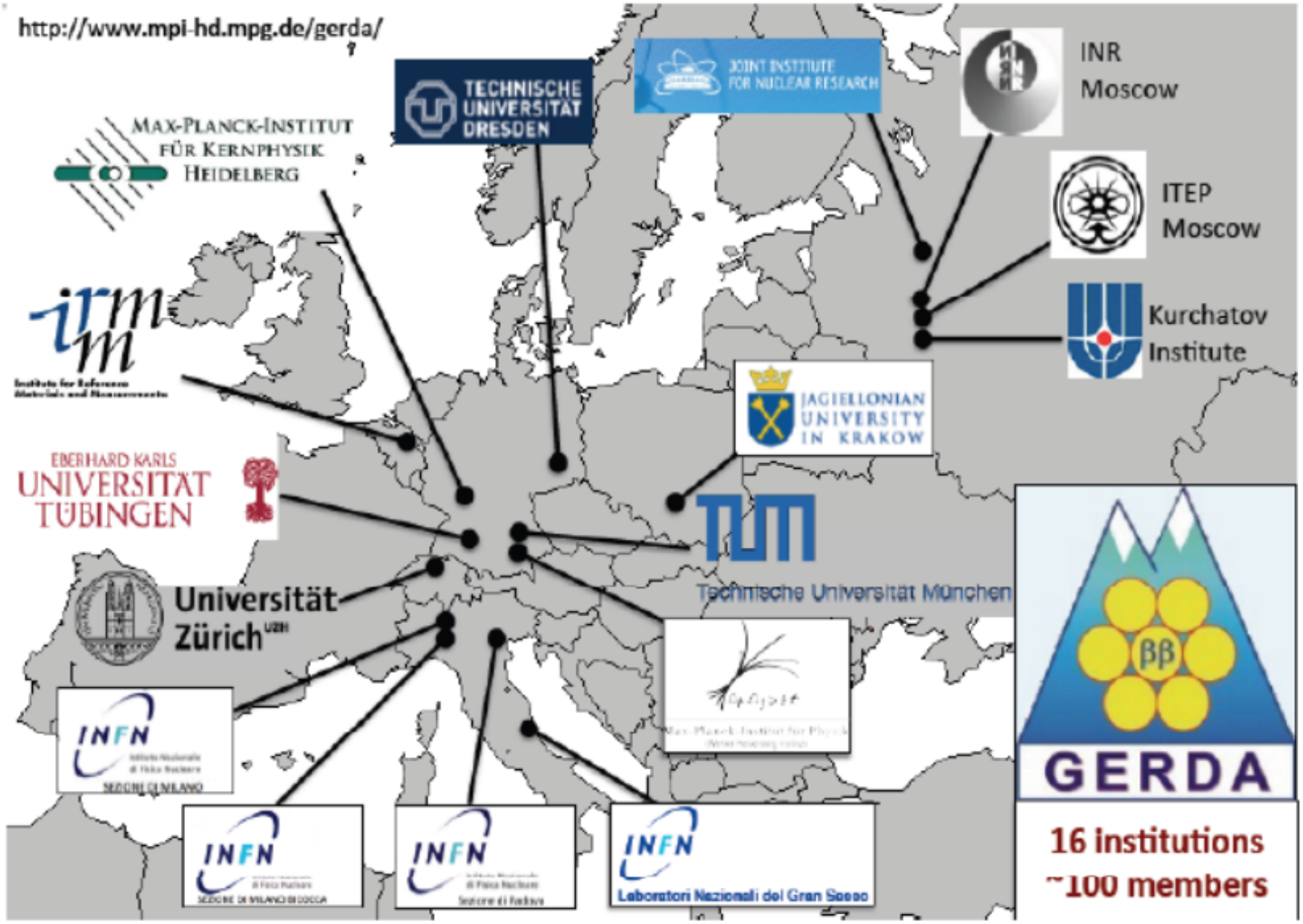
The program pybbsens was used to determine these plots.

JCAP 1303 (2013) 043
Phys. Rev. Lett. 112, 051303 (2014)

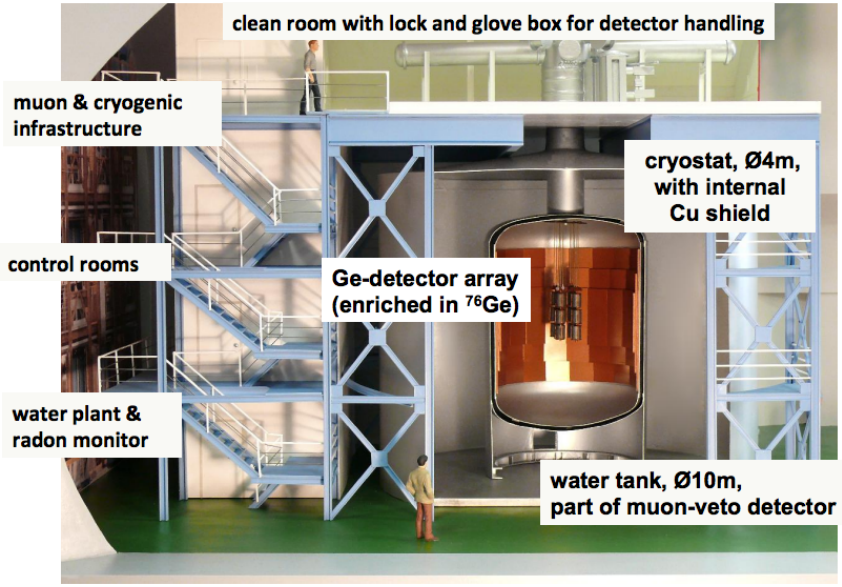
Caveat from simulation

Not all of the experiments can reach the same mass, the following plot takes that into account.




http://www.mpi-hd.mpg.de/gerda/
Max-Planck-Institut für Kernphysik Heidelberg
Technische Universität Dresden
Joint Institute for Nuclear Research
INR Moscow
ITEP Moscow
Kurchatov Institute
Jagiellonian University in Krakow
Eberhard Karls Universität Tübingen
Universität Zürich
Technische Universität München
INFN
INFN
INFN
INFN
Laboratori Nazionali del Gran Sasso
GERDA
16 institutions
~100 members

GERDA

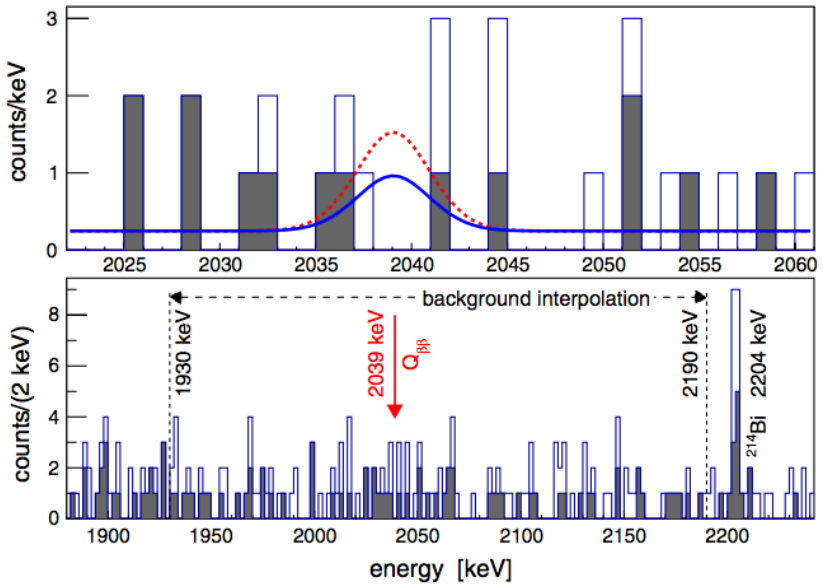


arXiv:1212.4067

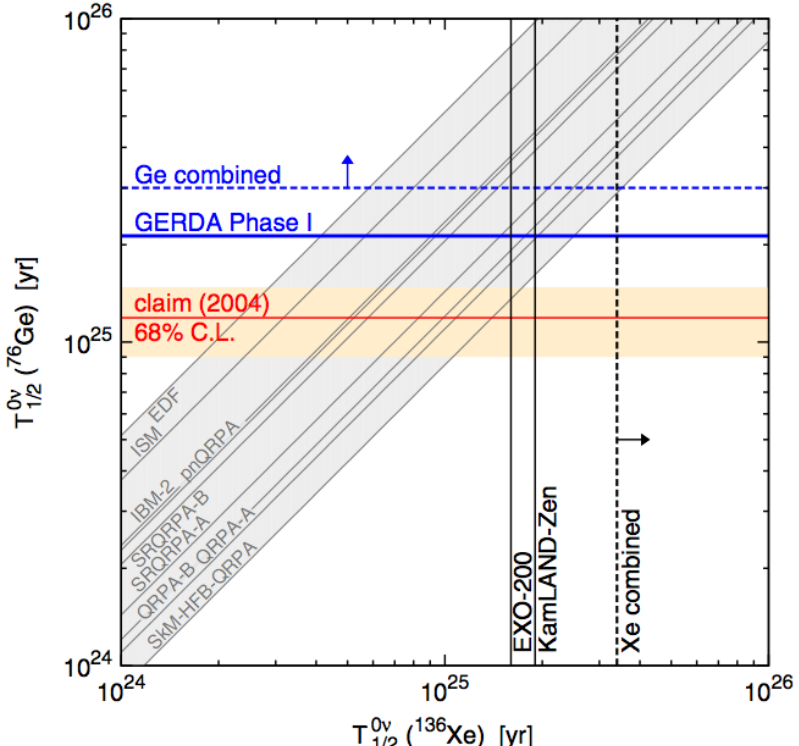
- Located at Gran Sasso National Laboratory (LNGS), which 3500 m.w.e overburden. This is to suppress cosmic ray activities.
- Various external plastic scintilator plus the water tank gives coverage to the muon flux.
- Detector array in very centre of protective structure.

Latest GERDA results

- After 21.6 kg yr exposure, with a background index of 1×10^{-2} counts / (keV kg yr).
- The new limit for the observation of $0\nu\beta\beta$ set by GERDA is 2.1×10^{25} yr (90% C.L.).
- ^{136}Xe has the next best limit at 3.4×10^{25} yr. This is a combined limit form EXO-200 and KamLAND-Zen.



Phys. Rev. Lett. 111 (2013) 122503



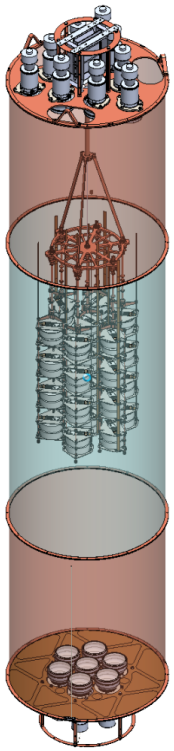
GERDA Phase 2

The aim for phase two is to reduce the background index to 1×10^{-3} ckky and increase the exposure to 40 kg.yr. The tactic on this is to implement the following,

- Enhanced pulse shape discrimination (PSD).
- Reduction in holder radioactivity.
- New electronics to give better resolution.
- ^{42}K background reduction with a transparent nylon mini shroud.
- Using liquid argon as a scintillator to veto events.

Liquid Argon Scintillation Project

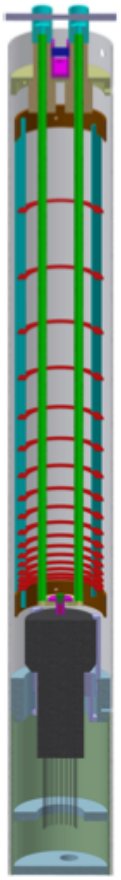
The goal of this project is to use the liquid argon (LAr) shielding material as a detector. For this purpose various equipment is begin installed inside the main cryostat.



- **PMTs**: Set up to detect energy deposited in the LAr.
- **Scintillating nylon shroud**: Keeps the ^{42}K from the crystals and increases PMT coverage.
- **Scintillating fibre net**: Acts as a net to catch the light and collects it in silicon based detectors.

Light Attenuation in LAr

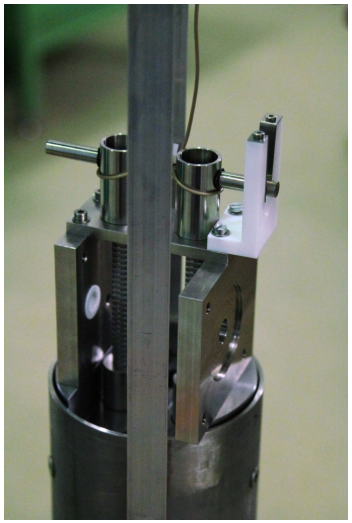
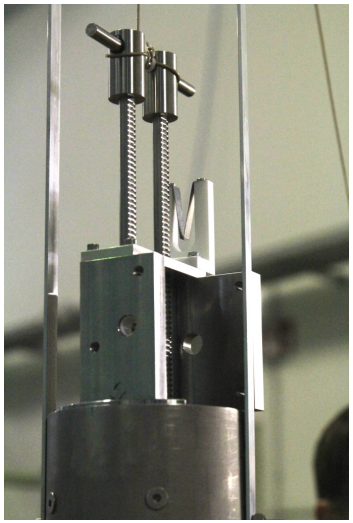
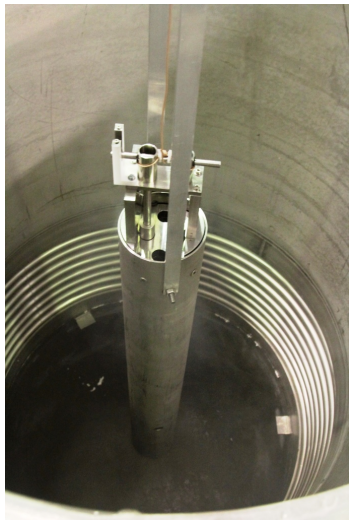
The goal of the liquid argon attenuation measurement if the determine experimentally the value of the attenuation for the light produced in scintillation (128 nm).

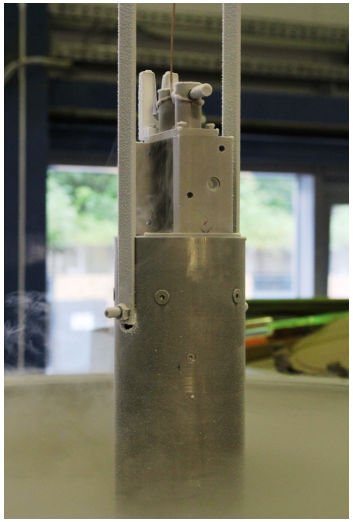
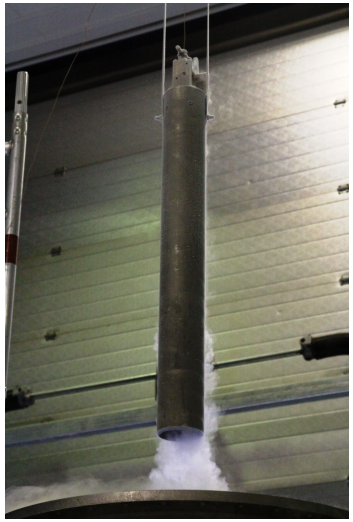


Specific design challenges:

- The setup has to fit inside the GERDA cryostat.
- The PMT has to work at cryogenic temperatures.
- There can be no contamination from the setup for the experiment.
- The set up must be able to detect a large range of attenuation lengths.

Testing of the LAr Attenuation Setup

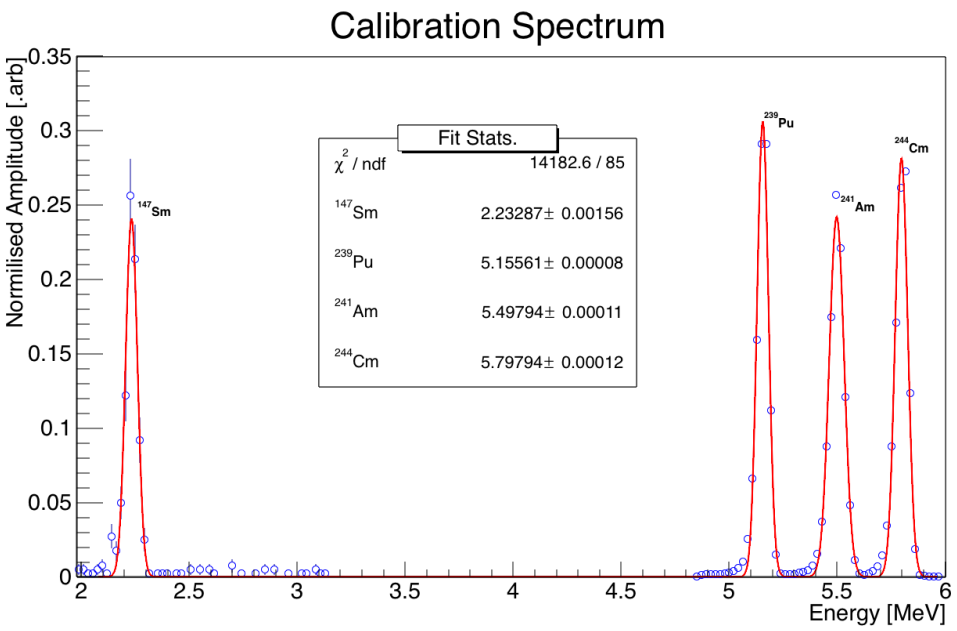




Other Projects

Alpha Chamber

The aim of this project is to develop a chamber that could detect the presents of long living alpha decay from the Th and U chains.



- Background is reduced to less than 8 counts per day.
- 96% alpha identification efficiency.
- 1.2% energy resolution at 2.23 MeV.
- Ability to have a stable run of more than 20 days.

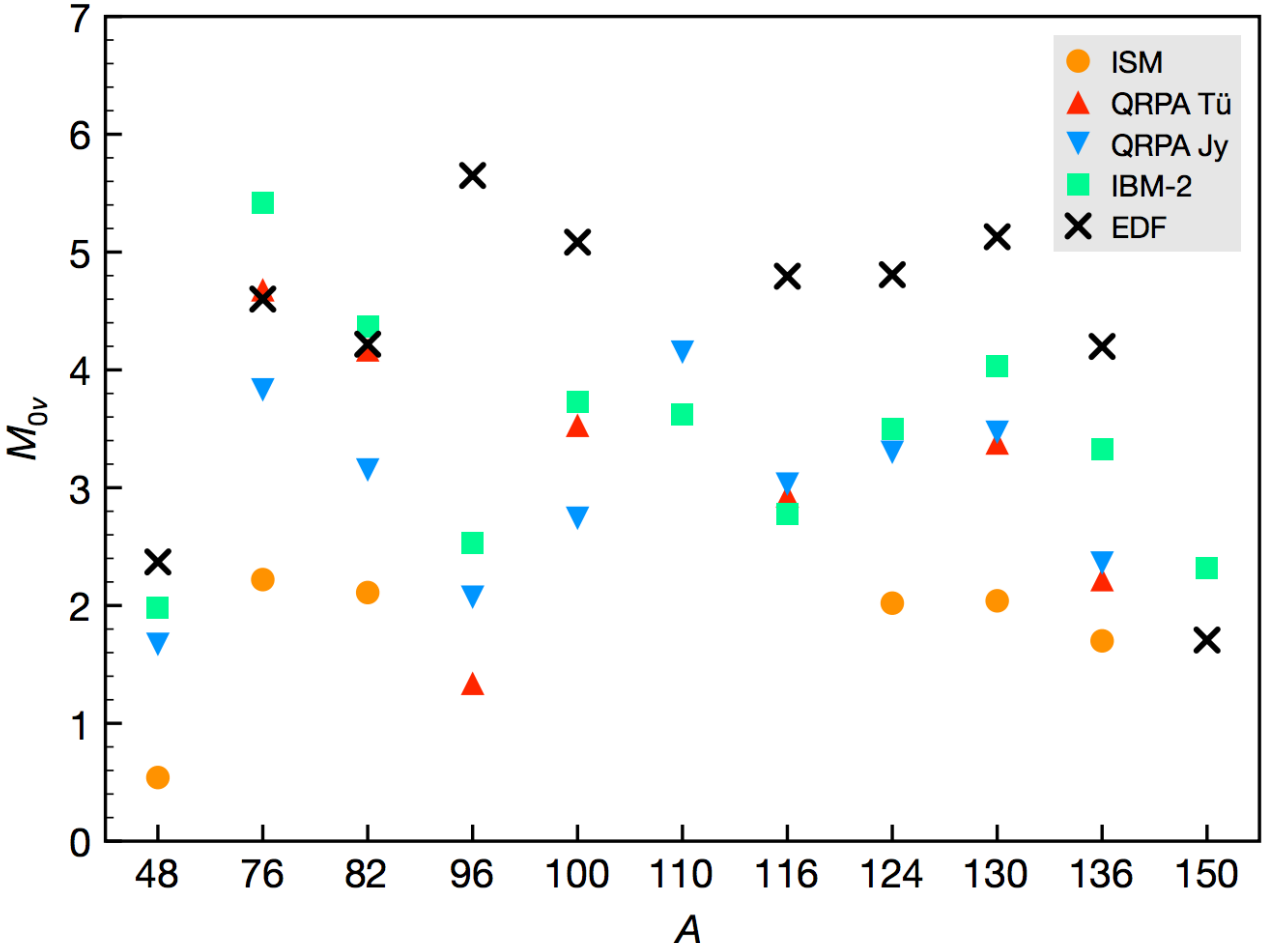
Thank you for listening!

Back Up Slides

NME

The nuclear matrix elements have different effect on the $m_{\beta\beta}$.

$$(T_{1/2})^{-1} = G^{0\nu}(Q, A)|M^{0\nu}|^2|m_{\beta\beta}|^2$$



Triplet Lifetime

The triplet lifetime is directly related to the purity of the liquid argon.

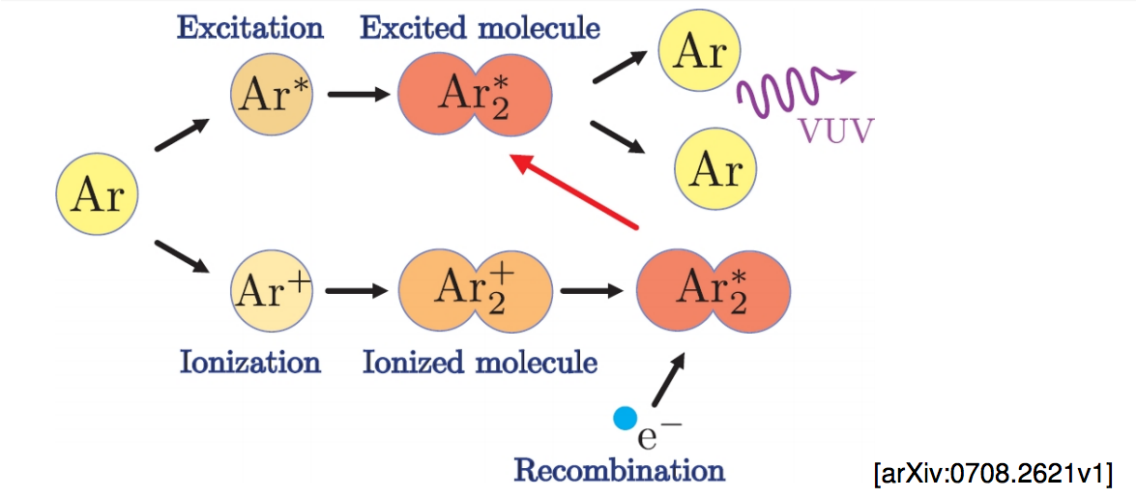


Figure : default

The shorter the triplet life time, the shorter the attenuation length and the more impurities in the LAr.