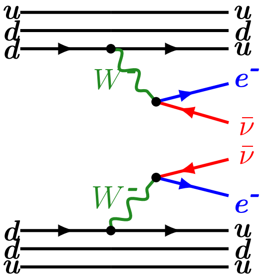
Current status and plans of the Gerda experiment

R. Mingazheva for the Gerda collaboration

University of Zurich

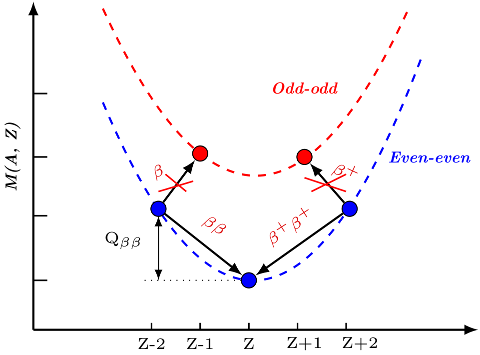
23 Aug 2016

Motivation for $0\nu\beta\beta$ searches. Double beta decay

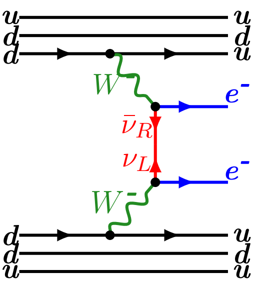


- A(Z, N) → A(Z+2, N) + 2e⁻ + $2\bar{\nu}$
- second order weak SM process
- can be observed for even-even nuclei if β-decay is forbidden

- has been observed for 11 nuclei
- ^{76}Ge: $T_{1/2}^{2\nu\beta\beta} = (1.926 \pm 0.095) \cdot 10^{21}$yr [Eur. Phys.J. C75 (2015), no.9, 416]

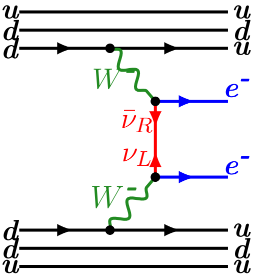


Motivation for $0\nu\beta\beta$ searches



- A(Z, N) → A(Z+2, N) + 2e⁻
- Hypothetical non-SM process, ΔL=2
- $\bar{\nu} = \nu$, $m_\nu \neq 0$
- e.g. light Majorana neutrino exchange

Motivation for $0\nu\beta\beta$ searches



- A(Z, N) → A(Z+2, N) + 2e-
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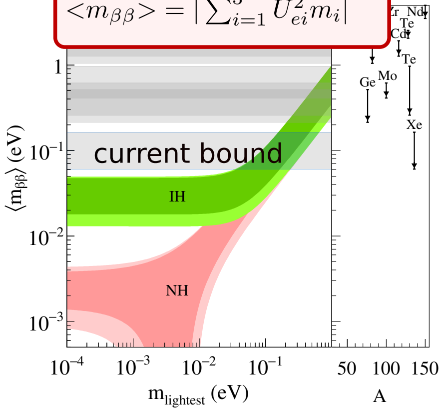
$$<m_{\beta\beta}> = |\sum_{i=1}^{3} U_{ei}^2 m_i|$$



It would shed light on...

- absolute neutrino mass scale
- neutrino nature e.g. Majorana vs. Dirac

How to claim a discovery?

- Signal/background

$$N_{sig} \approx \frac{Mt}{m_{iso}} \cdot \alpha \cdot \epsilon \cdot \frac{ln(2)}{T^{0\nu}_{1/2}}$$

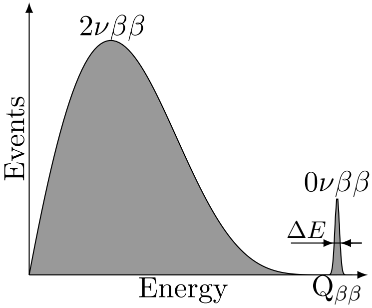
$$N_{bg} \approx BI \cdot \Delta E \cdot Mt$$

- We claim a discovery with 99.7% CL when:
  $N_{sig} \geq 3\sigma_{bg}$, where $\sigma_{bg} \approx \sqrt{N_{bg}}$

$$T^{0\nu}_{1/2} \propto \epsilon \sqrt{\frac{Mt}{BI \cdot \Delta E}}$$

- Background-free case:

$$T^{0\nu}_{1/2} \propto \epsilon \cdot Mt$$



^{76}Ge detectors

- High intrinsic purity
- $Q_{\beta\beta}$= 2039 keV
- Best energy resolution (3-4 keV at $Q_{\beta\beta}$)
- 86% enrichment of ^{76}Ge

Mt - exposure
BI - backgr. index
α - enrichment factor
ϵ - detection efficiency

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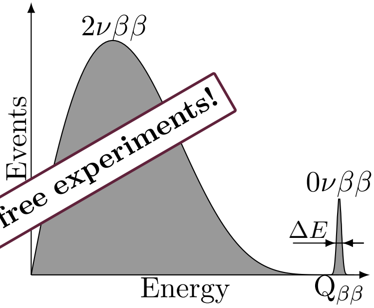
- Backgr… …ee case:

$$T^{0\nu}_{1/2} \propto \epsilon \cdot Mt$$

We need large scale and background free experiments!



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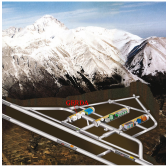
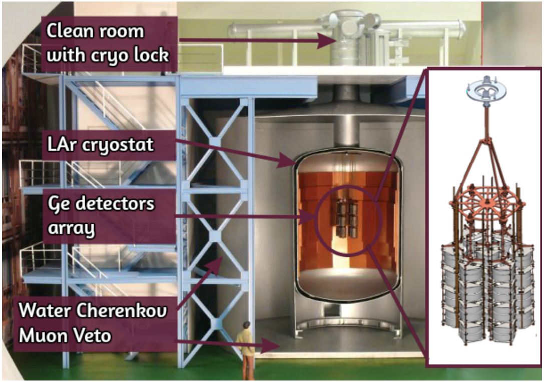
GERmanium Detector Array (GERDA)

- LNGS underground laboratory:
  - covered by 1400m rock
  - reduced muon flux ($\approx 1 \cdot m^{-2} h^{-1}$)



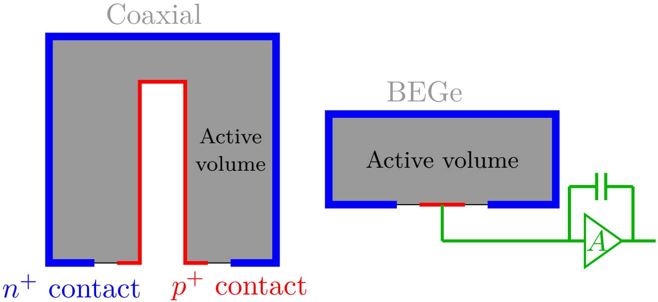


Background rejection

- Active veto:
  - Water tank: $\oslash = 10m$
  - LAr cryostat: $\oslash = 4m$
- Ultra-clean materials
- High-pure ^{76}Ge detectors

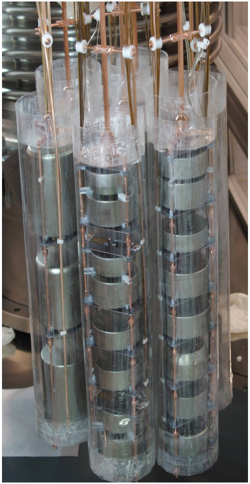
^{76}Ge detectors in GERDA

- Coaxial detectors (from HdM, IGEX)
  - Enriched: 7 detectors, 15 kg total mass
  - Natural: 3 detectors, 7 kg total mass

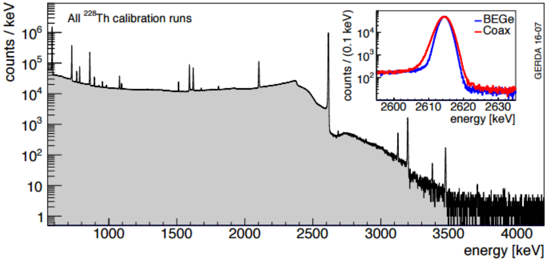


- BEGe (Broad Energy Germanium) detectors (produced by Canberra)
  - 30 detectors, 20 kg total mass
  - higher energy resolution
  - better background events discrimination

- 7 strings



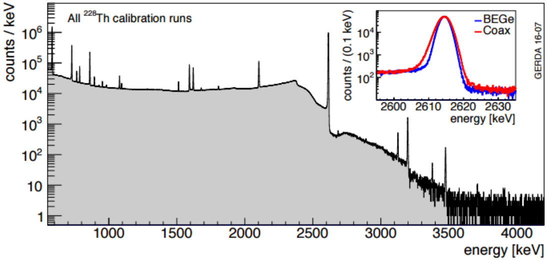
- Weekly calibration using ^{228}Th source
- Monitoring of energy scale stability



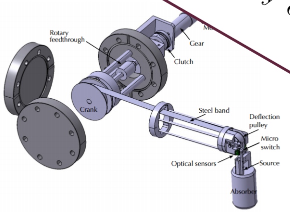
[G. Benato. Doctoral thesis]

Under the responsibility of the Zurich group

- Weekly calibration using ^{228}Th source
- Monitoring of energy scale stability



[G. Benato. Doctoral thesis]



- During the calibration each source is lowered to the required position
- During the physics data taking sources are kept shielded in the position above ^{76}Ge strings

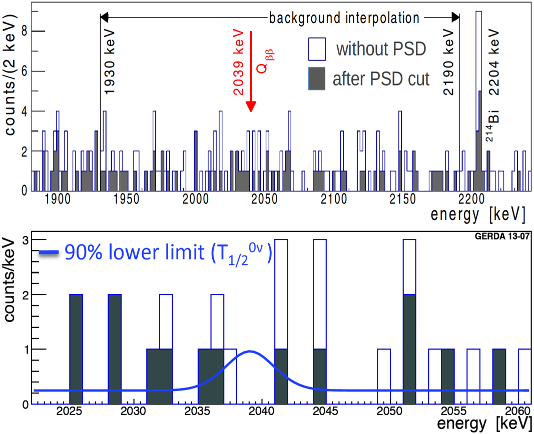
GERDA Phase I. Results

Nov 2011 - May 2013

- 15 kg of ^{76}Ge
- Exposure: 21.6 kg·yr

ROI: $Q_{\beta\beta}\pm 5$keV

- Blind analysis
- $N_{exp} = 2.0 \pm 0.3$
- $N_{obs} = 3$
- Profile LL: $N_{0\nu}=0$



[Phys. Rev. Lett. 111, 122503 (2013)]

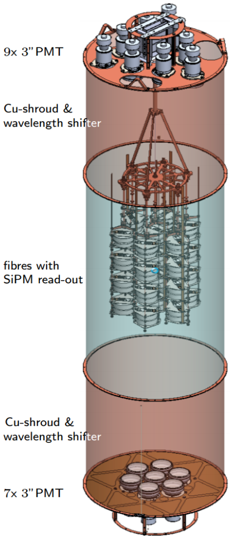
- No $0\nu\beta\beta$ observation
- BI: $1{\cdot}10^{-2}$ cts/(keV·kg·yr)
- $T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}$yr - world best limit for ^{76}Ge

Upgrades

- Increased mass of BEGe detectors
- Reduce close background sources: cleaner materials
- LAr veto to reject external background:
  - 16 PMT
  - SiPM and optics fiber read out

Phase II goals

- Background $< 10^{-3}$ cts/(keV·kg·yr)
- Exposure ≥ 100 kg · yr
- Sensitivity $T^{0\nu}_{1/2} > 10^{26}$ yr



Phase II. First unblinding

BEGe

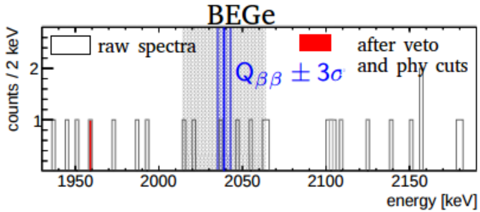
- exposure: 5.8 kg·yr
- in the $Q_{\beta\beta}\pm 25$ keV:
  - $N^{bg}_{exp}=0.3$
  - $N_{obs}=0$
- $BI = 7^{+11}_{-5}\cdot 10^{-4}$

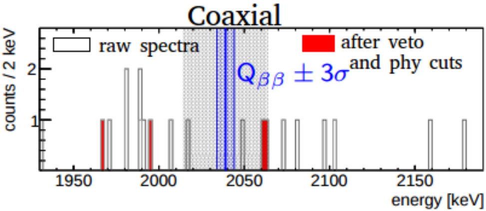
Coaxial

- exposure: 5.0 kg·yr
- In the $Q_{\beta\beta}\pm 25$ keV:
  - $N^{bg}_{exp}=0.8$
  - $N_{obs}=2$
- $BI = 35^{+21}_{-15}\cdot 10^{-4}$

BI is shown in the units $cts/(keV \cdot kg \cdot yr)$

Dec. 2015 - May 2016





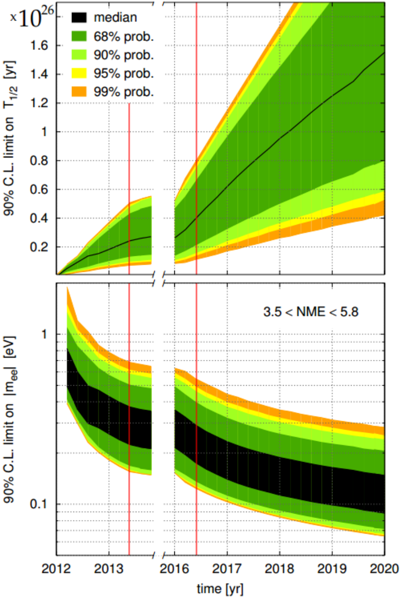
FWHM at $Q_{\beta\beta} = 3-4$ keV

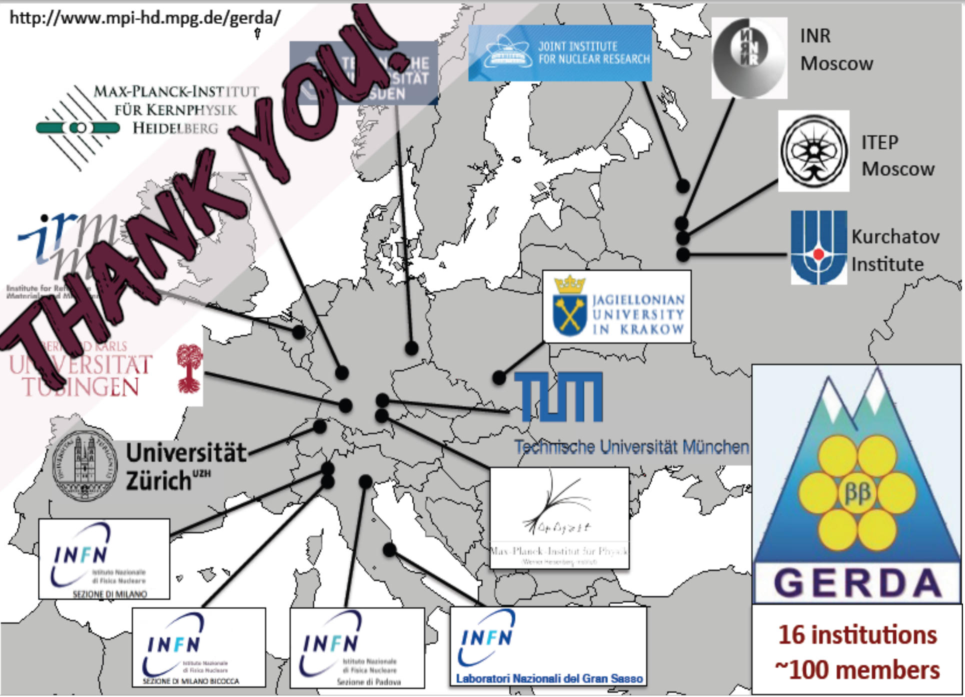
Conclusion & outlook

- Achieved lowest ever background:
  BEGe:
  $7^{+11}_{-5} \cdot 10^{-4}$ cts/(keV·kg·yr)
  Coax:
  $35^{+21}_{-15} \cdot 10^{-4}$ cts/(keV·kg·yr)
- No evidence for $0\nu\beta\beta$ found
- $T^{0\nu}_{1/2} > 5.2 \cdot 10^{25}$ yr (90% C.L.)
- $|m_{ee}| < [160, 260]$ meV (90% C.L.)
- Goal: total exposure of 100 kg·yr and sensitivity $T^{0\nu}_{1/2} > 10^{26}$yr

[Talk at Neutrino 2016]

Follow us: it will be published soon!




http://www.mpi-hd.mpg.de/gerda/
THANK YOU!
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JOINT INSTITUTE FOR NUCLEAR RESEARCH
INR Moscow
ITEP Moscow
Kurchatov Institute
JAGIELLONIAN UNIVERSITY IN KRAKOW
Technische Universität München
Universität Zürich UZH
Max-Planck-Institut für Physik
INFN Istituto Nazionale di Fisica Nucleare SEZIONE DI MILANO
INFN Istituto Nazionale di Fisica Nucleare SEZIONE DI MILANO BICOCCA
INFN Istituto Nazionale di Fisica Nucleare Sezione di Padova
INFN Laboratori Nazionali del Gran Sasso
GERDA
ββ
16 institutions
~100 members

BackUp: Neutrino Double Beta Decay

- Postulated in 1935
- First observation in 1980s
- Can occure if single beta decay is forbidden due to spin-coupling, seen by the pairing term in the semi-empirical mass formula.
- $T_{1/2}^{2\nu\beta\beta} \approx (10^{18} - -10^{24}) yr$

$$M(A, Z) = Zm_p + N m_n - a_V A + a_S A^{2/3} + a_C \frac{Z^2}{A^{1/3}} + a_A \frac{(N - Z)^2}{A} + \boxed{\delta(A, Z)}$$

Backup: Signal and background events topology

Signal

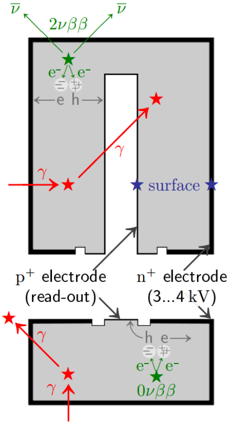
Localized energy deposition within ≈ 1mm in one detector (Single Side Events [SSE])

Background

- Multiple energy deposition in one detector (Multi Side Events, removed by Pulse Shape Discrimintaion [PSD])
- Events with coincident energy deposition in the LAr (active veto)

Surface events

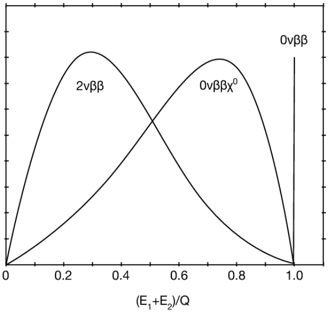
- fast (p^+) and slow (n^+) rising signals (PSD)

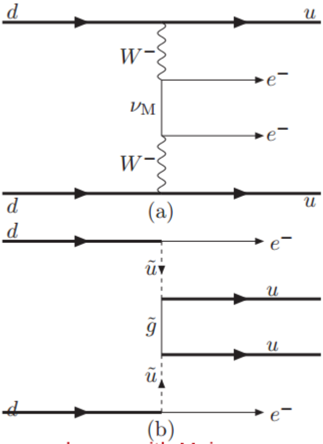


Main positive results for $2\nu\beta\beta$ to the ground state

Isotope	Experiment (type)	$T_{1/2}(2\nu)$ (years)	Reference(s)
^{48}Ca	Hoover Dam (TPC)	$[4.3^{+2.4}_{-1.1}\,(\text{stat.}) \pm 1.4\,(\text{syst.})] \times 10^{19}$	35
	TGV (planar HPGe)	$(4.2^{+3.3}_{-1.3}) \times 10^{19}$	36
	NEMO3 (track calorimeter)	$(4.4 \pm 0.64) \times 10^{19}$	34
^{76}Ge	IGEX (HPGe)	$(1.45 \pm 0.15) \times 10^{21}$	48
	Heidelberg–Moscow (HPGe)	$[1.74 \pm 0.01\,(\text{stat.})^{+0.18}_{-0.16}\,(\text{syst.})] \times 10^{21}$	49
	GERDA (HPGe)	$1.84^{+0.14}_{-0.10} \times 10^{21}$	28
^{82}Se	Geochemistry	$(1.3 \pm 0.05) \times 10^{20}$	50
	NEMO3 (track calorimeter)	$[0.96 \pm 0.03\,(\text{stat.}) \pm 0.1\,(\text{syst.})] \times 10^{20}$	51
^{96}Zr	Geochemistry	$(3.9 \pm 0.9) \times 10^{19}$	52
	Geochemistry	$(0.94 \pm 0.32) \times 10^{19}$	53
	NEMO3 (track calorimeter)	$[2.35 \pm 0.14\,(\text{stat.}) \pm 0.16\,(\text{syst.})] \times 10^{19}$	54
^{100}Mo	Geochemistry	$(2.1 \pm 0.3) \times 10^{18}$	55
	Hoover Dam (TPC)	$[6.82^{+0.38}_{-0.53}\,(\text{stat.}) \pm 0.68\,(\text{syst.})] \times 10^{18}$	56
	DBA (liquid argon TPC)	$[7.2 \pm 1.1\,(\text{stat.}) \pm 1.8\,(\text{syst.})] \times 10^{18}$	57
	NEMO3 (track calorimeter)	$[7.17 \pm 0.01\,(\text{stat.}) \pm 0.54\,(\text{syst.})] \times 10^{18}$	34
^{116}Cd	Solotvina (scintillator)	$[2.9 \pm 0.06\,(\text{stat.})^{+0.4}_{-0.3}\,(\text{syst.})] \times 10^{19}$	37
	NEMO3 (track calorimeter)	$(2.88 \pm 0.17) \times 10^{19}$	34
^{128}Te	Geochemistry	$\sim 2.2 \times 10^{24}$, $(7.7 \pm 0.4) \times 10^{24}$	58, 59
^{130}Te	Geochemistry	$\sim 0.8 \times 10^{21}$, $(2.7 \pm 0.1) \times 10^{21}$	58, 59
	MiBETA (bolometer)	$[6.1 \pm 1.4\,(\text{stat.})^{+2.9}_{-3.5}\,(\text{syst.})] \times 10^{20}$	60
	NEMO3 (track calorimeter)	$[7.0 \pm 0.9\,(\text{stat.}) \pm 1.1\,(\text{syst.})] \times 10^{20}$	61
^{136}Xe	EXO-200 (LXe TPC)	$[2.11 \pm 0.04\,(\text{stat.}) \pm 0.21\,(\text{syst.})] \times 10^{21}$	38
	KamLAND–Zen	$[2.38 \pm 0.02\,(\text{stat.}) \pm 0.14\,(\text{syst.})] \times 10^{21}$	39
^{150}Nd	Hoover Dam (TPC)	$[6.75^{+0.37}_{-0.42}\,(\text{stat.}) \pm 0.68\,(\text{syst.})] \times 10^{18}$	56
	NEMO3 (track calorimeter)	$[9.11^{+0.25}_{-0.22}\,(\text{stat.}) \pm 0.63\,(\text{syst.})] \times 10^{18}$	62
^{238}U	Radiochemistry	$(2.0 \pm 0.6) \times 10^{21}$	22

BackUp: Other mechanism of the DBD



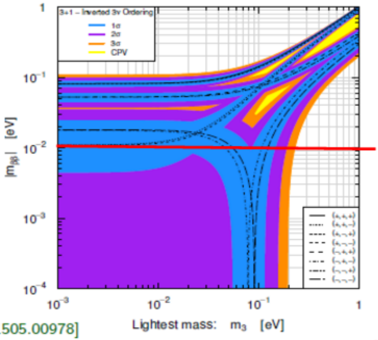


a - exchange with Majoron

b - squark and gluino in RPV SUSY

IS

m_0



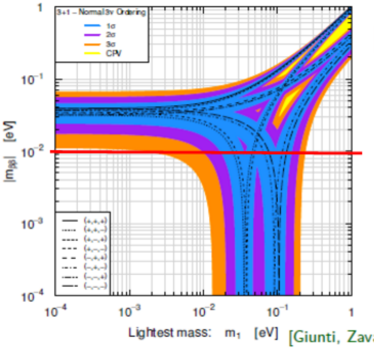
Xiv:1505.00978]

IS & $m_{\beta\beta}$<m_0 :

- Sterile neutrino keeps our model valid
- $m_{\beta\beta}$<m_0 : unconfirm

NS

m_0



[Giunti, Zavanin, ar

NS & $m_{\beta\beta}$<m_0 :

$m_{\beta\beta}$<m_0 : unconfirm

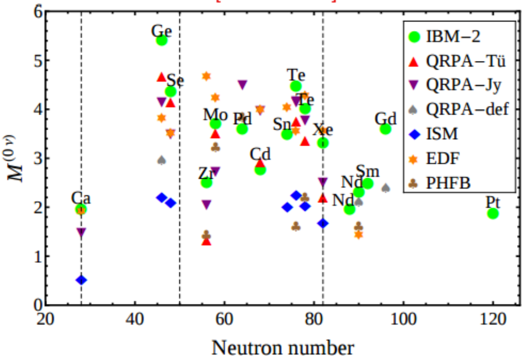
- Need to build 100 ton scale experiments!

BackUp: From $0\nu\beta\beta$ to neutrino mass

BackUp: NME

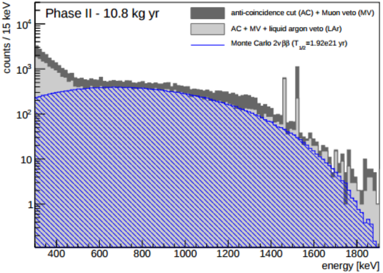
$M^{0\nu} = <f||O^K||i>$
O^K operator, which creates two protons and annihilate two neutrons. Depends on the distance between nucleons, and on their quantum numbers

[1301.4203v1]



- ***ISM***: the interacting shell model
- ***QRPA***: the quasiparticle random-phase approximation
- ***IBM-2***: the interacting boson model
- ***EDF***: and the energy density functional method

BackUp: LAr background suppression.



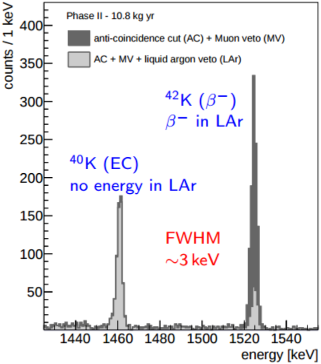
- ^{40}K/^{42}K Compton continuum fully suppressed
- (70.4±0.3)% survival fraction (0.6-1.3 MeV)
- LAr veto generates 2.3% dead time
- $T_{1/2}^{2\nu} = 1.9 \cdot 10^{21}$ yr taken from Phase I [EPJC 75 (2015) 416]

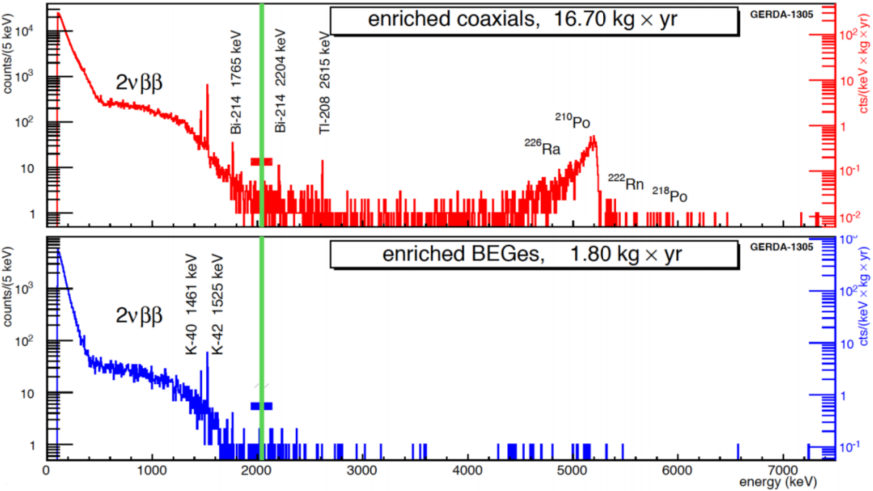
γ-lines from:

$^{40}\mathrm{K} \rightarrow {}^{40}\mathrm{Ar} + \gamma$ (1.4 MeV) [EC]

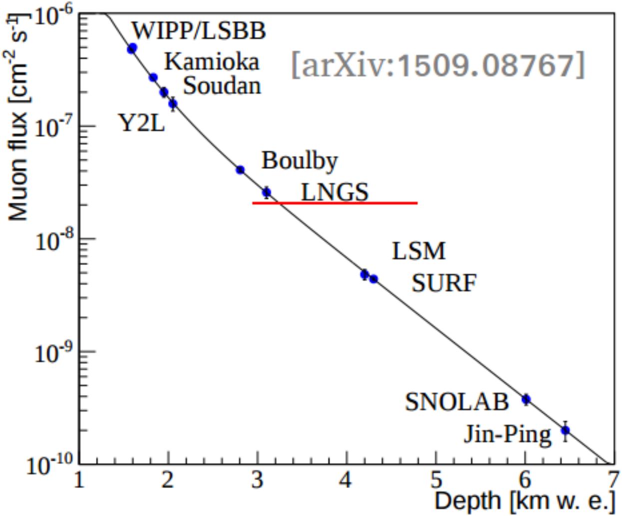
$^{42}\mathrm{K} \rightarrow {}^{42}\mathrm{Ca} + \gamma$ (1.5 MeV)

$+\ e^-$ (up to 2 MeV)




enriched coaxials, 16.70 kg × yr
GERDA-1305
counts/(5 keV)
cts/(keV × kg × yr)
2νββ
Bi-214 1765 keV
Bi-214 2204 keV
Tl-208 2615 keV
210Po
226Ra
222Rn
218Po
enriched BEGes, 1.80 kg × yr
GERDA-1305
K-40 1461 keV
K-42 1525 keV
0
1000
2000
3000
4000
5000
6000
7000
energy (keV)

BackUp: muon flux



BackUp: From mass eigenstates to effective majorana neutrino mass

$$|m_{\beta\beta}| = \left|\sum_{i=1}^{3} U_{ei}^2 m_i\right| \quad ,$$

$c_{jk}(s_{jk}) = cos\theta_{jk}(\sin\theta_{jk})$.

$$\begin{aligned}|m_{\beta\beta}| =& \left|c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 m_2 e^{i\alpha} + s_{13}^2 m_3 e^{i\beta}\right| = \\ =& \Big|\big(c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 m_2 \cos\alpha + s_{13}^2 m_3 \cos\beta\big) + \\ & + i\big(s_{12}^2 c_{13}^2 m_2 \sin\alpha + s_{13}^2 m_3 \sin\beta\big)\Big| \quad ,\end{aligned}$$

$$|m_{\beta\beta}| = \sqrt{\big(c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 m_2 \cos\alpha + s_{13}^2 m_3 \cos\beta\big)^2 + \big(s_{12}^2 c_{13}^2 m_2 \sin\alpha + s_{13}^2 m_3 \sin\beta\big)^2} \quad .$$

- θ_{12} and θ_{13},
- m_1, m_2 and m_3,
- the two Majorana phases α and β