Cosmogenic background for the GERDA experiment

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GERDA experiment at LNGS

The **GERmanium Detector Array** experiment will look for $0\nu2\beta$ decay in ^{76}Ge using HP-Ge detectors enriched in ^{76}Ge

Hosted in the Hall A of the Gran Sasso Laboratory (INFN), in central Italy

Suppression of μ-flux > 10^6

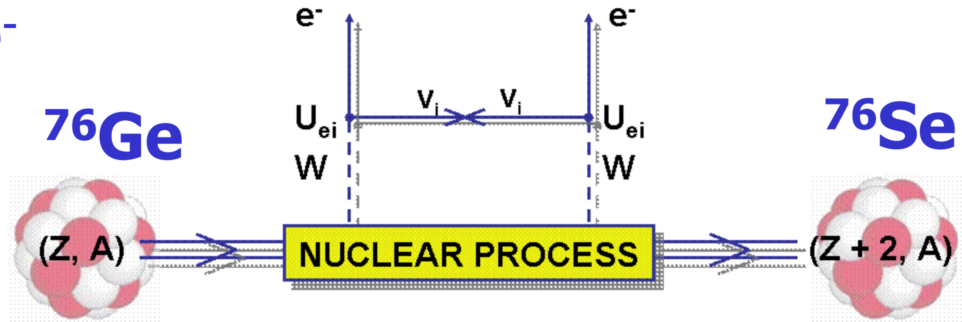
GERDA physics

$Q_{\beta\beta}$ = 2039 keV

$0\nu\beta\beta$: (A,Z) → (A,Z+2) + $2e^-$

Neutrinoless 2β-decay violates the lepton number conservation: **ΔL=2**

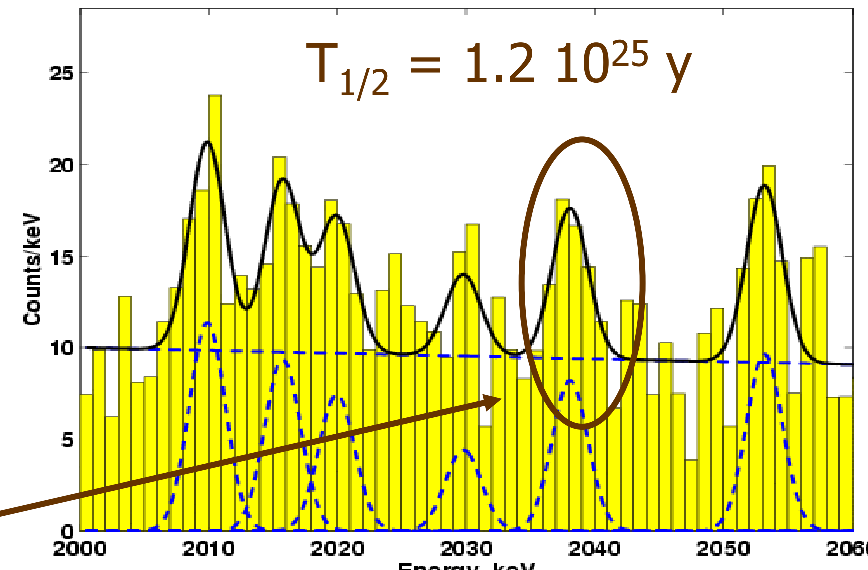
Explore the **Dirac/Majorana nature** of neutrino and the absolute **mass scale**



Very **rare process**: $T_{1/2} > 10^{25}$ y

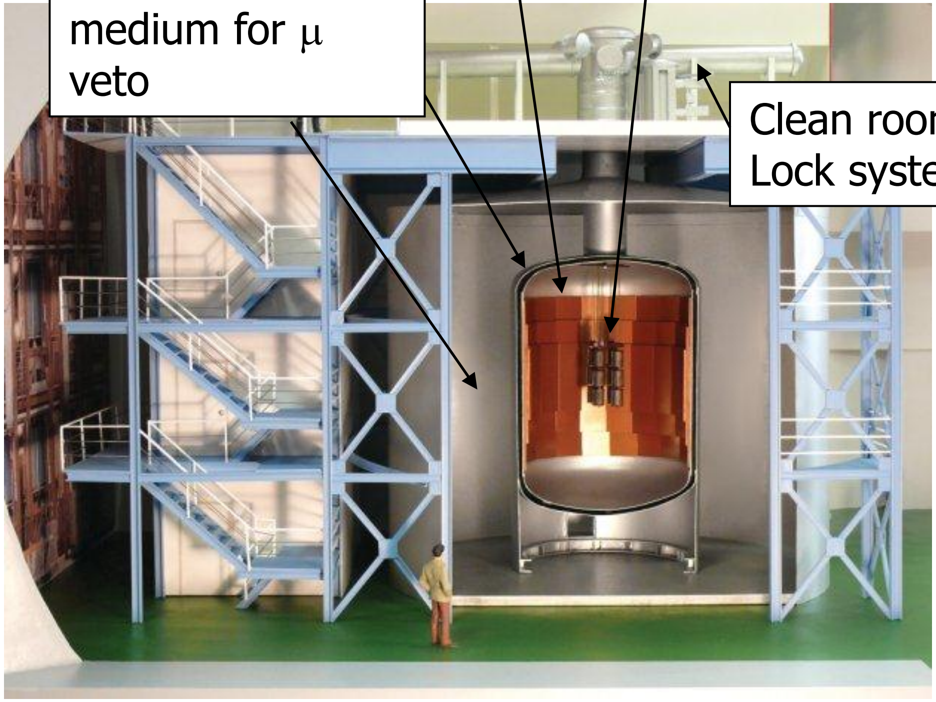
New generation experiments require unprecedented low-background conditions!

Claim from Klapdor-Kleingrothaus et al., NIM A 522 (2004) 371



GERDA concept

- Background reduction strategy:
  - Deep underground site for suppression of cosmic ray muons
  - graded shielding against ambient radiation (Water, LAr)
  - rigorous material selection for radiopurity
  - signal analysis
- Phase I: 15 kg of ^{enr}Ge (existing at LNGS). Goal: 10^{-2} counts/(keV kg y). Verify KK claim
- Phase II: add 20 kg of more ^{enr}Ge detectors. Goal: 10^{-3} counts/(keV kg y)



Unloading of vacuum cryostat
(6 March 08)

Produced from selected low-background austenitic steel

Construction of water tank

∅ **10 m**

H = 9.5 m

V = 650 m^3

Designed for external γ,n,μ background

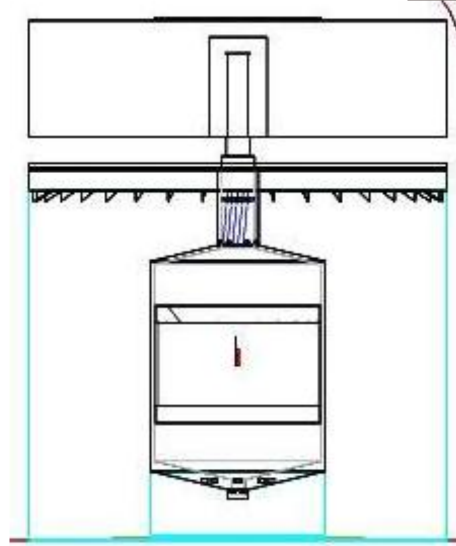
~10^{-4} cts/(keV kg y)

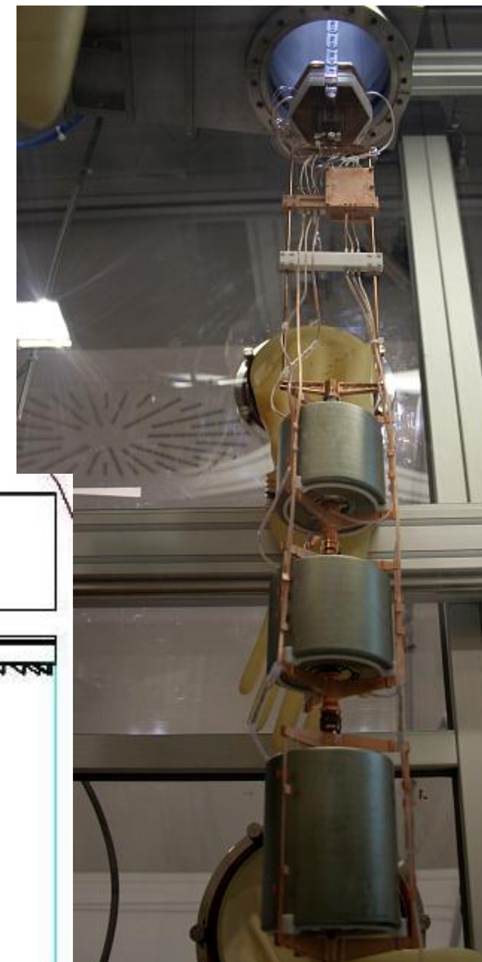
- **Nov/Dec.'09**: Liquid argon fillinf
- **Jan '10:** Commissioning of cryogenic system
- **Apr/May '10:** emergency drainage tests of water tank
- **Apr/May '10:** Installation c-lock
- **May '10:** 1st deployment of FE&detector mock-up (27 pF) - pulser resolution 1.4 keV (FWHM); first deployment of non-enriched detector
- **June '10:** Start of commissioning run with ^{nat}Ge detector string
- **Next**: start of Phase I physics data taking

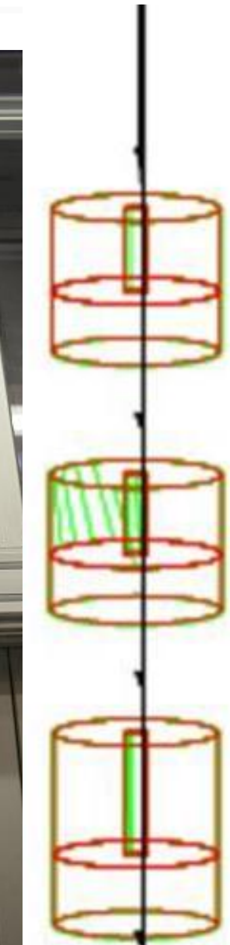
The detector string

- Three low-background **^{nat}Ge** detectors deployed in the commissioning string
- They belong to the former Genius Test Facility at LNGS (GTF) and are underground since several years
- Naked detectors, total Ge mass about 7.5 kg

- Dedicated MC simulation performed with the MaGe framework
- Help with the background analysis and interpretation





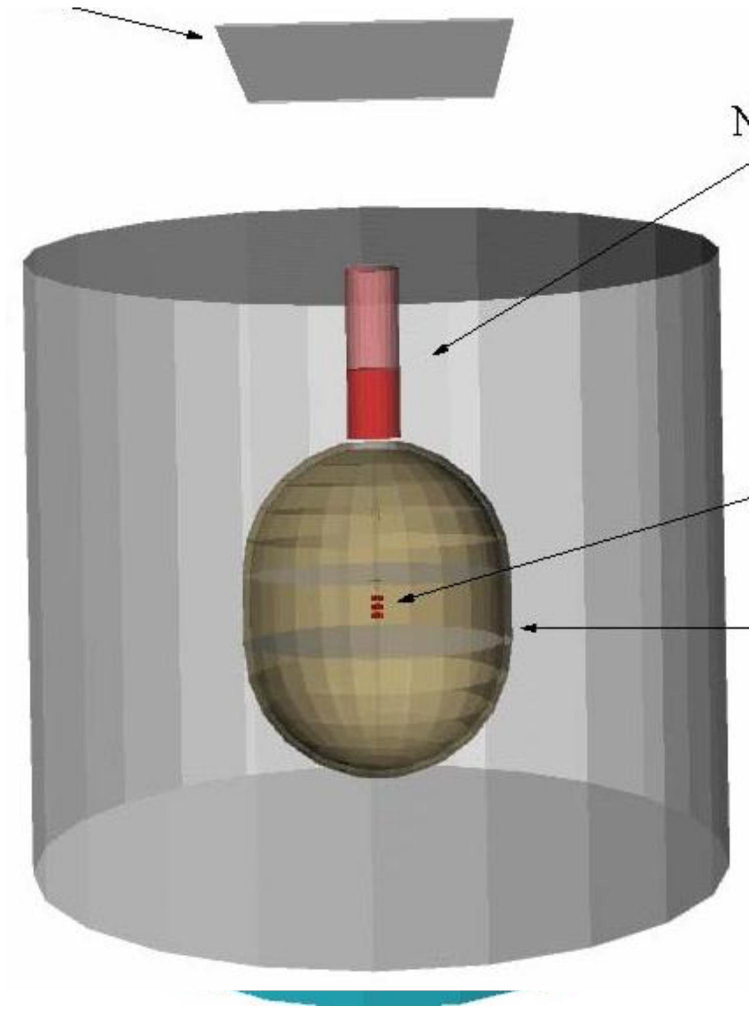


Cosmogenic background in GERDA

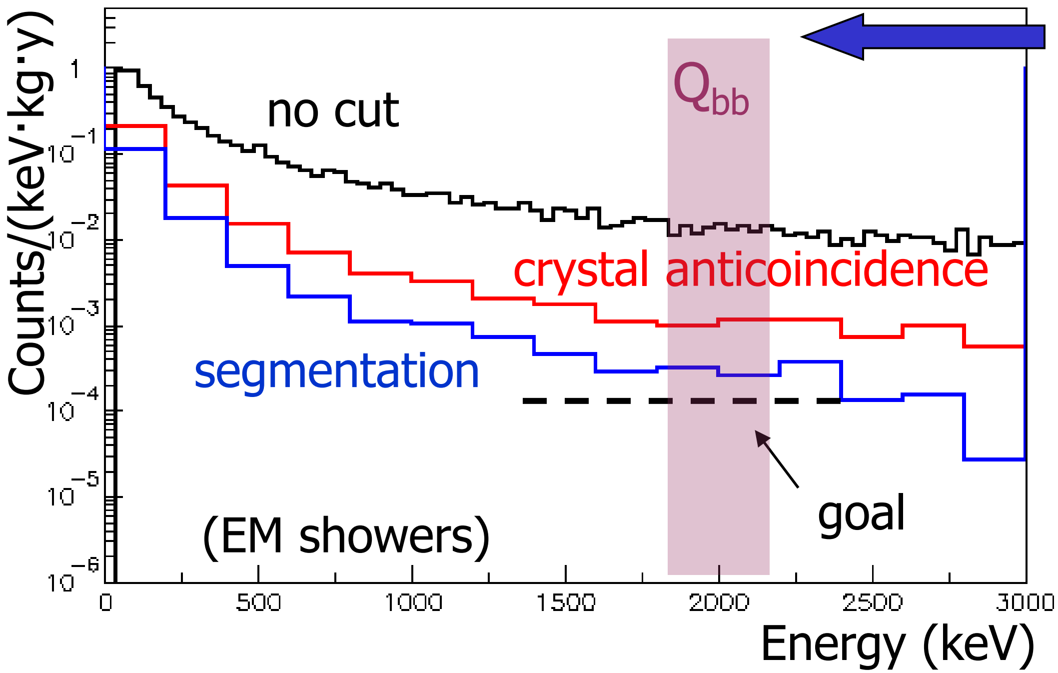
1. prompt μ-induced interactions underground
   - Cherenkov veto very effective
2. short-lived (but $T_{1/2}$ > 100 ms) isotopes produced by muon showers underground in detectors and other materials
   - ^{77}Ge, ^{77m}Ge, ^{40}Cl, ^{38}Cl, etc.
   - not always possible to use delayed coincidence with the μ veto signal
3. long-lived isotopes produced by cosmogenic activation **above ground** in detectors (^{60}Co, ^{68}Ge) or other materials (^{39}Ar, ^{60}Co, ...)
   - waiting is not an option: $T_{1/2}$ years or centuries

Monte Carlo simulations

- Run **MC campaign** in 2006-2007 using the reference GERDA design at that time
  - Cu cryostat
  - paper published on NIM A
- Re-run later on with the new design
  - Stainless steel cryostat with Cu internal lining
  - Unpublished → I cannot sell it as a "prediction"
- Used MaGe/Geant4 in both cases, primary spectrum from MUSUN



What did we expect? (1)



Energy spectrum in the detectors

Notice: simulation run for reference Phase-I array, **not** for commissioning string. For this plot, used the old version of GERDA geometry (Cu cryostat)

LP et al. NIM A 570 (2007) 149

LP, AIP Conf. Proc. 870 (2007) 105

For reference Phase I, *without* anti-coincidence, expected $1.9 \cdot 10^{-2}$ counts/(keV·kg·y)

For the real GERDA geometry (stainless steel cryostat) and the Phase I reference array expected $0.9 \cdot 10^{-2}$ counts/(keV·kg·y)

What did we expect? (2)

- Considered isotopes having Q-value > $Q_{\beta\beta}$ and 100 ms < $T_{1/2}$ < days
  - In crystals: ^{74}Ga, ^{75}Ga, ^{76}Ga, ^{68}Ge, ^{69}Ge, ^{77}Ge, ^{71}Zn
  - In cryoliquid: ^{13}N, ^{11}C, ^{12}B, ^{38}Cl, ^{39}Cl, ^{40}Cl
  - In water: ^{16}N, ^{14}O, ^{12}B, ^{6}He, ^{13}B

>10^{-6} counts/(keV kg y)

Isotope	Liquid Argon	
	nucl/(kg·y)	cts/(keV·kg·y)
^{74}Ga/^{75}Ga/^{76}Ga	< 0.1	$< 4\cdot10^{-5}$
^{68}Ge	0.08	$5\cdot10^{-6}$
^{69}Ge	1.8	$5\cdot10^{-6}$
^{77}Ge/^{77m}Ge	**0.51**	**$1.1\cdot10^{-4}$**
^{38}Cl	46 day^{-1}	$3.3\cdot10^{-5}$
^{40}Cl	2.7 day^{-1}	$4\cdot10^{-6}$

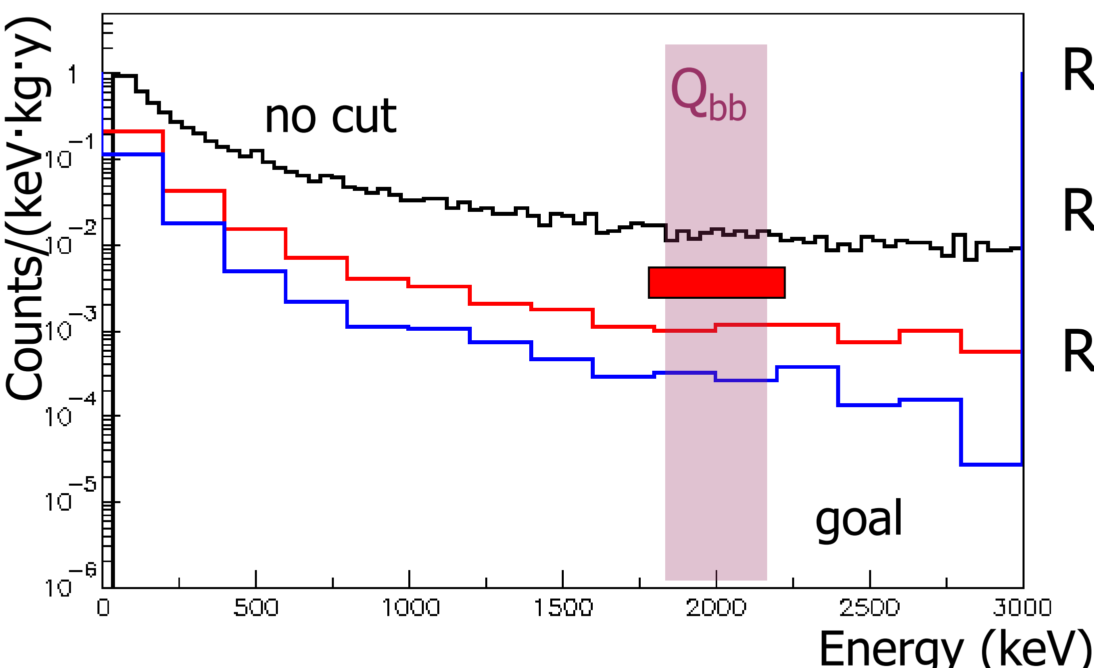
Results for the old GERDA geometry, but new ones are similar as order of magnitude. Notice: considered **^{enr}Ge**

LP et al. NIM A 570 (2007) 149

LP, AIP Conf. Proc. 870 (2007) 105

Now have a look at the data!

- Have a **look at the data** and verify the MC predictions!
- Check how many events observed in GERDA with the muon veto flag on (and correct for inefficiency)
  - to compare to simulation, do not apply anti-coincidence cut (different array, so different suppression efficiency)



$R_{exp} = (0.7 \pm 0.3) \cdot 10^{-2}$

$R_{MC}(old) = (1.90 \pm 0.04) \cdot 10^{-2}$

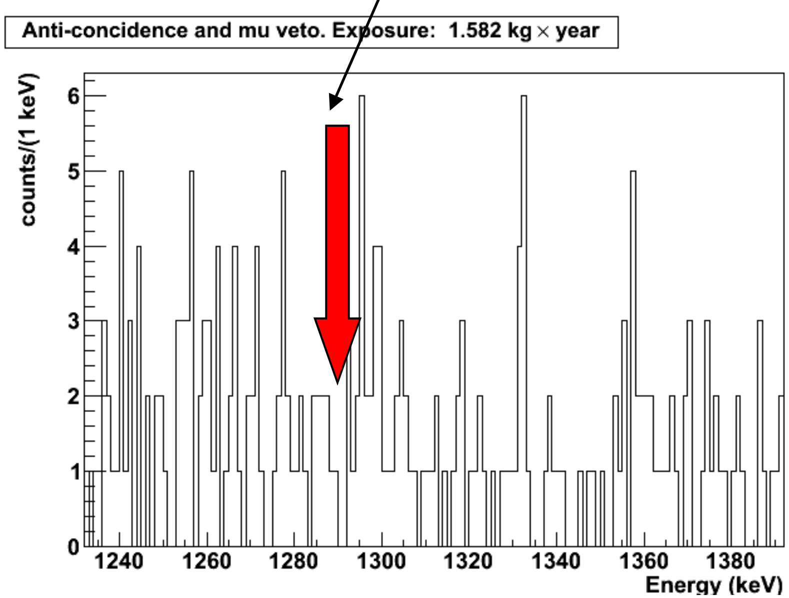
$R_{MC}(new) = (0.88 \pm 0.02) \cdot 10^{-2}$

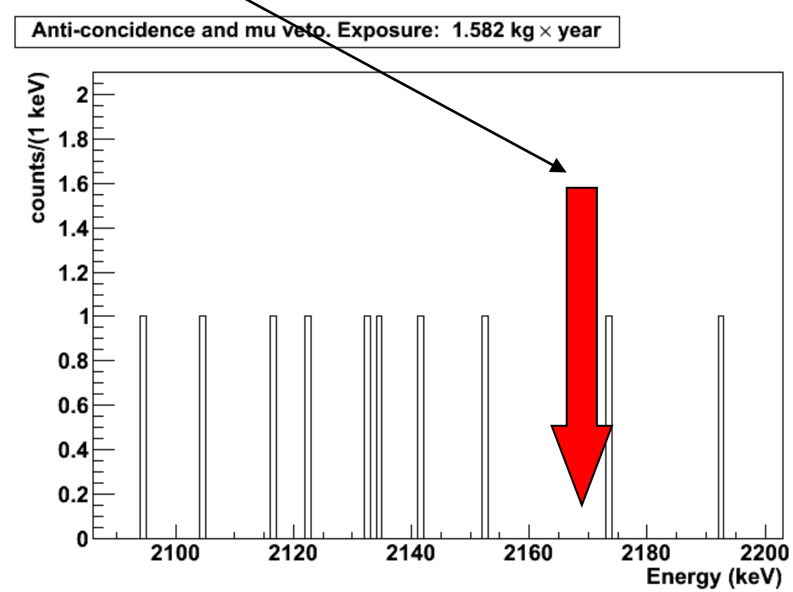
counts/(keV·kg·y)

Not too bad!

Now have a look at the data! (2)

- Agreement for prompt μ-induced background does not imply agreement also for isotope production underground!
- **Look** for lines in the experimental spectrum corresponding to ^{41}Ar (1293.6 keV), ^{38}Cl (2167 keV), ^{40}Cl (2839 keV)
  - most intense expected from the MC
  - still, no chance to see them with the GERDA exposure





Look for other cosmogenics

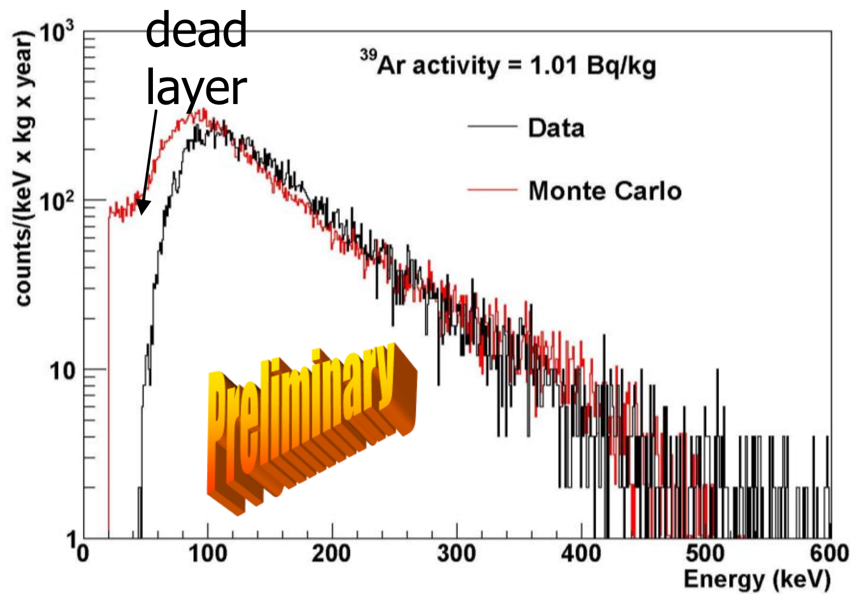
- Look for cosmogenic isotopes produced during the detector live **above ground** (^{60}Co, ^{68}Ge)
- GTF detectors are stored underground since years
- No indication of ^{60}Co and ^{68}Ge/^{68}Ga characteristic γ lines (1173 keV, 1332 keV, 1077 keV)
  - can place a limit on their activity in the detectors
  - need a Monte Carlo simulation
  - presently in progress

- Clearly seen ^{58}Co (811 keV line, $T_{1/2}$ = 70 day) coming from a Cu encapsulation (used only in one GERDA run) which was flown to LNGS

Cosmogenic contaminants of Ar (1)

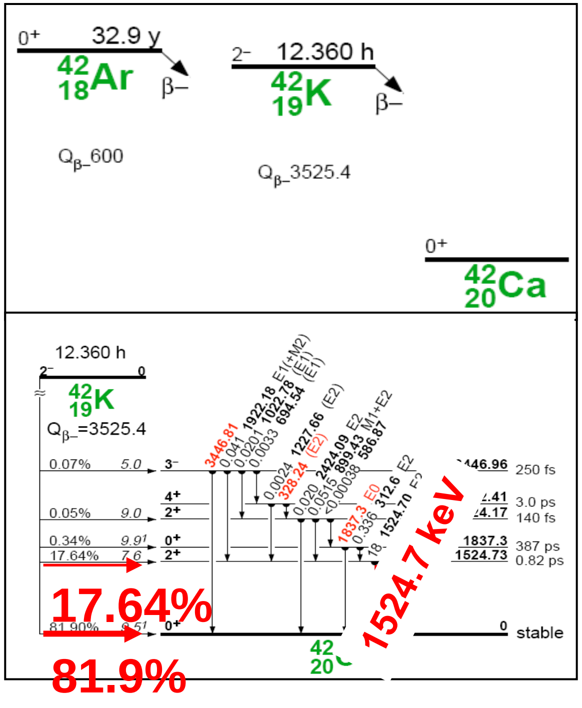
- **^{39}Ar** (1.01 Bq/kg, $T_{1/2}$=269 y)
  - pure beta emitter with low Q-value (565 keV)
    - not an issue for GERDA, much below the region of interest
  - dominates the low-energy counting rate
  - cosmogenic production in atmosphere via (n,2n)

❑ Can use GERDA low-energy data to cross-check the ^{39}Ar specific activity
❑ need a Monte Carlo to predict the ^{39}Ar contribution in the detector array (bremsstrahlung and direct β-rays)
❑ **preliminary** work done (simplified Monte Carlo) → **fair agreement** between GERDA signal and expectations for 1.01 Bq/kg rate



Cosmogenic contaminants of Ar (2)

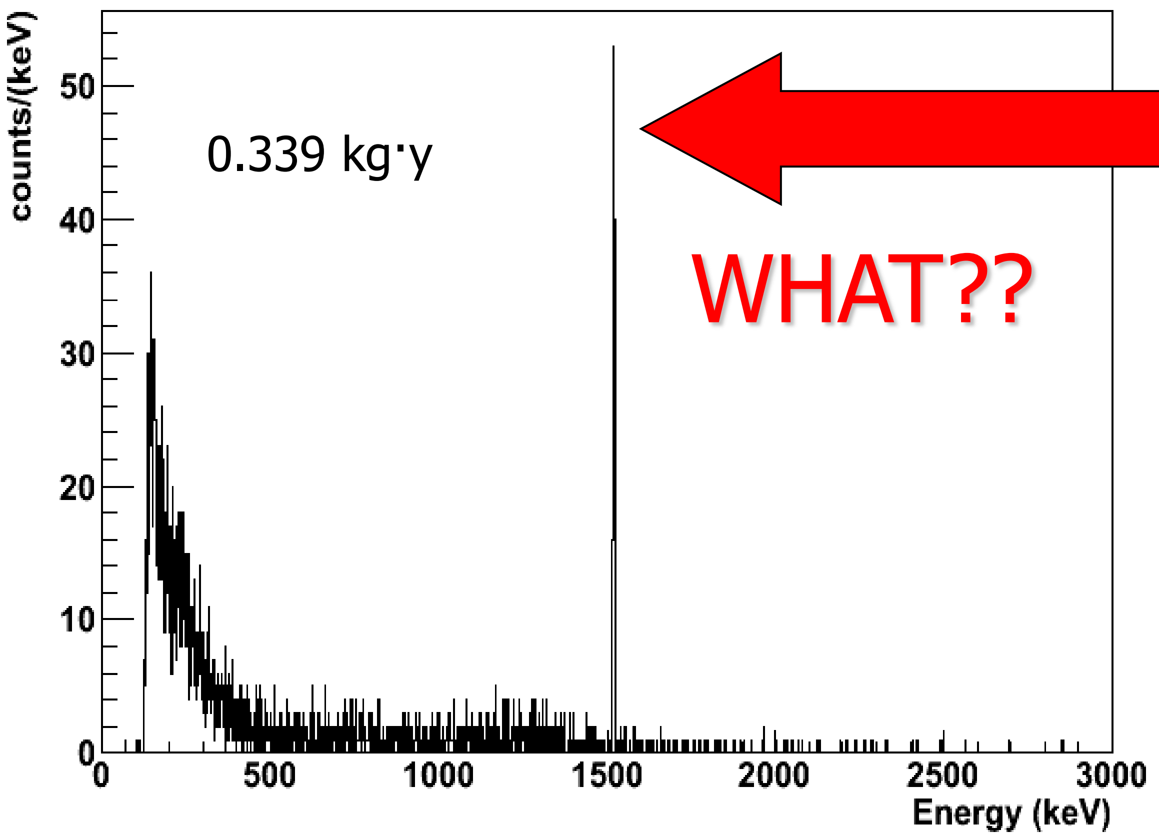
- **^{42}Ar** (<42 μBq/kg, $T_{1/2}$ = 32.9 y)
  - cosmogenic via (α,2p), nuclear explosions/reactors via (n,γ)(n,γ)
  - ^{42}Ar itself not a concern, but its **progeny ^{42}K is a background** source for GERDA (Q_β=3520 keV, $T_{1/2}$=12 h)



- Signature of ^{42}K: γ ray at 1524.7 keV (18%)
- Literature limit(*) corresponds to about **0.1 counts/(kg·d)** at 1525 keV for the GERDA 3-detector array
  - contribution at $Q_{\beta\beta}$ (MC) of a few 10^{-3}, counts/(keV kg y) dominated by β rays penetrating through the dead layer
- Only upper limits, no positive measurement

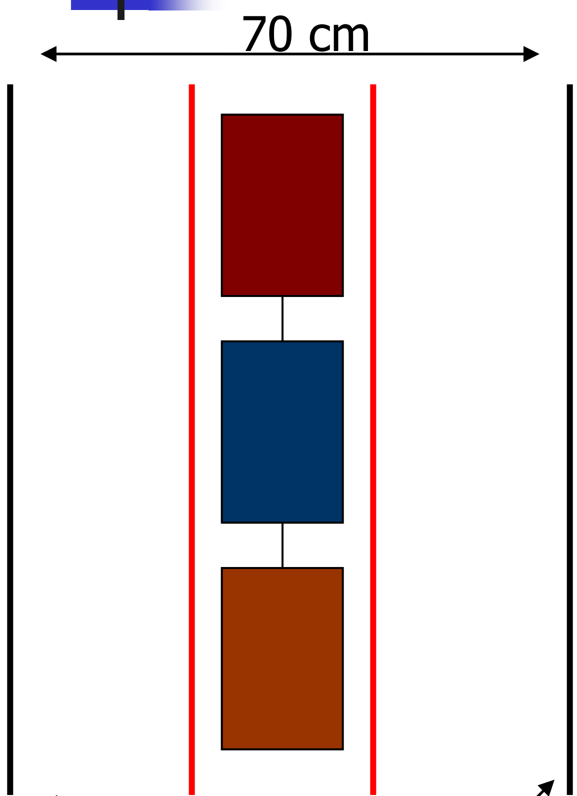
(*) Ashitkov at al., arXiv: nucl-ex/0309001

First GERDA Run: surprise!



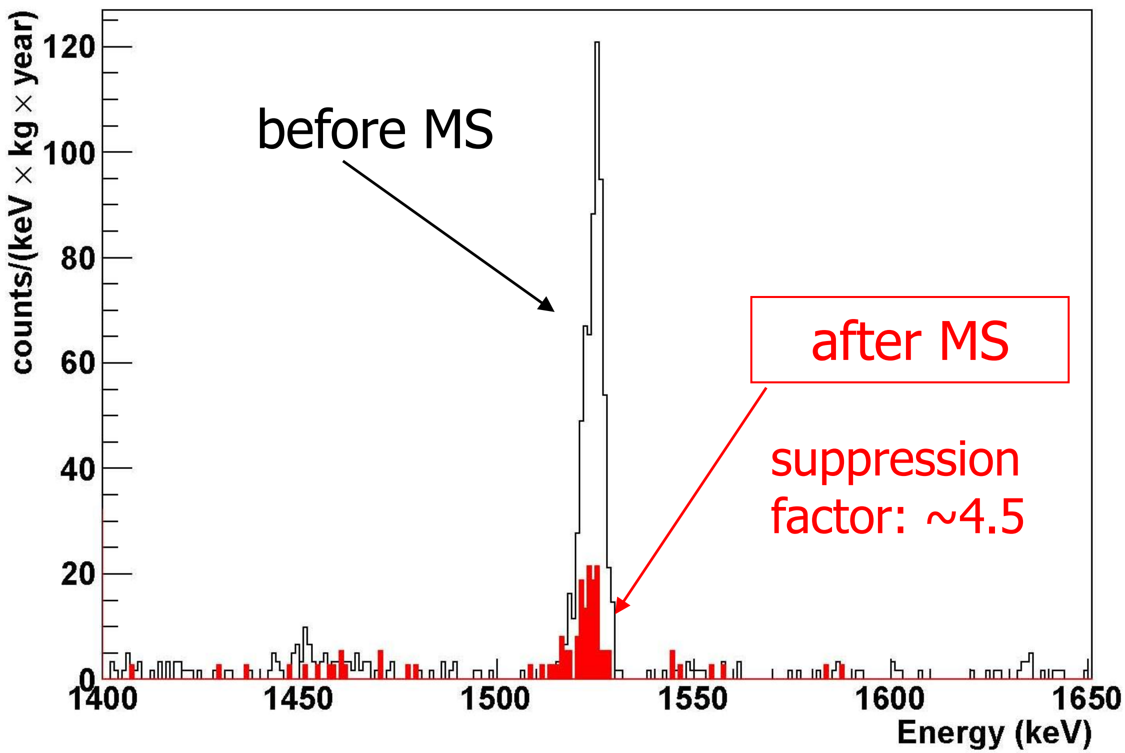
- Observed 1525 keV line at ca. 2 cts/(kg·d) → **x20** literature limit! **How possible?**
- But: we have electric fields dispersed in LAr...
  - not the case in standard cryostats
  - outer detector surface biased at 3 kV
  - ^{42}K may be charged
  - are we concentrating ^{42}K closer to the detectors?

Play with the electric fields (1)

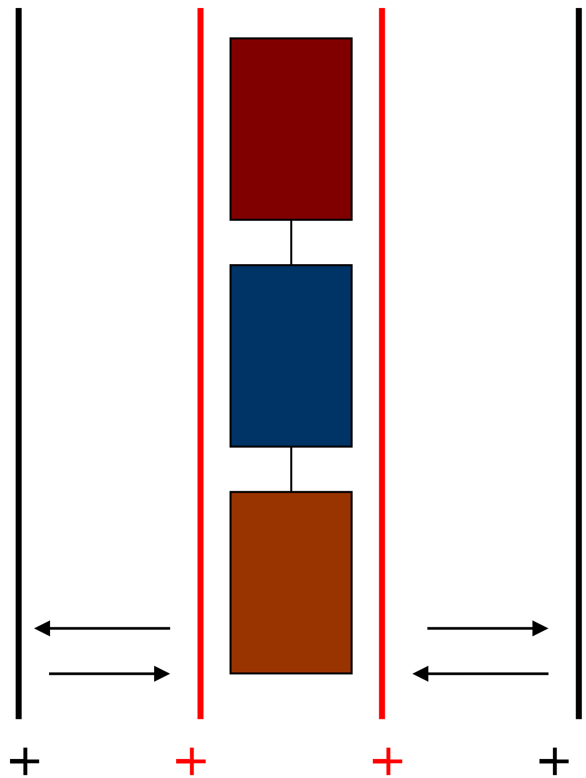


shroud (already installed to prevent ^{222}Rn concentration by drift/convection)

- Add a mini-shroud (MS) (thin Cu foil) to block drift and close electric field lines

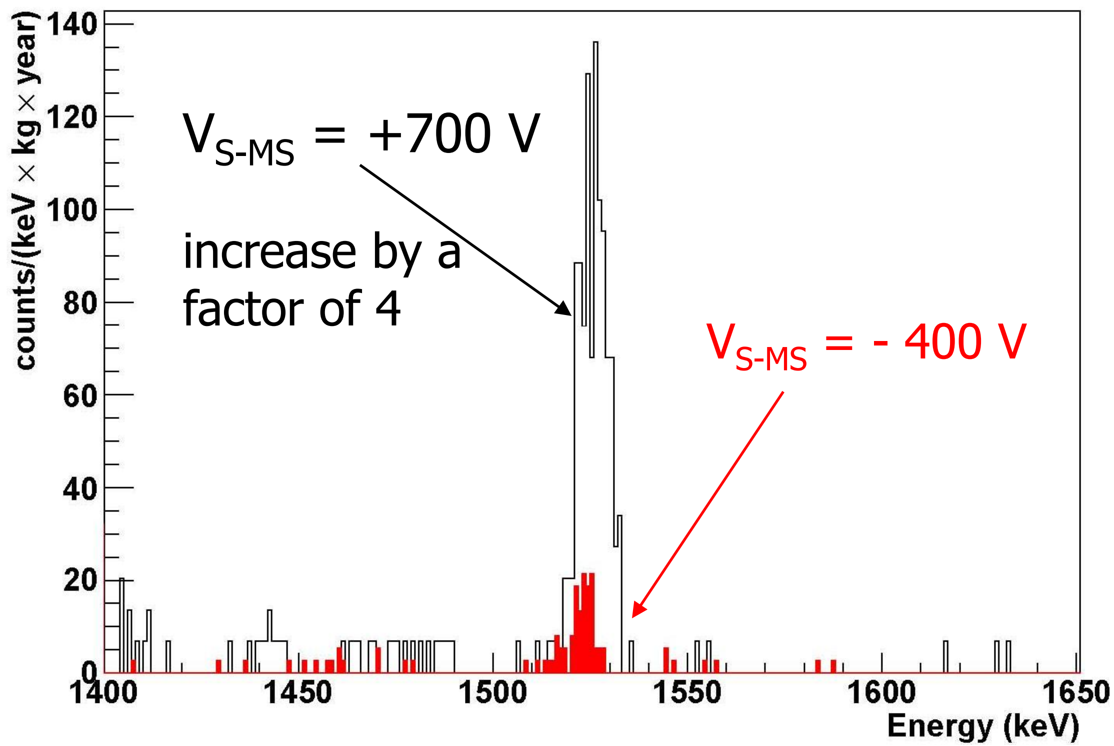


Play with the electric fields (2)



^{42}K signal sensitive to electric fields!

- In the **same setup**, one can also **change the relative V** between shroud and mini-shroud
- Check if you can **attract** ^{42}K ions!



^{42}Ar/^{42}K signal & GERDA

- Confirmed independently in the LArGe R&D setup underground at LNGS
- **Positive measurement** of ^{42}Ar contamination in Ar (for the first time!) → need field-free configuration to avoid bias
  - Anyway larger than the existing upper limit (43 μBq/kg)
- ^{42}K signal can be reduced/suppressed by electric field. Tried a few different configurations of electric fields
  - no major changes at $Q_{\beta\beta}$ → GERDA background not dominated by ^{42}K
- Anyway, danger at $Q_{\beta\beta}$ only if β-rays penetrate directly in the detector (only a rare high-energy γ)
  - expected $7 \cdot 10^{-3}$ counts/(keV kg y) for uniform distribution, OK for Phase I
  - many handles to further reduce: additional passivation, encapsulation, repel ^{42}K ions by electric fields, etc.

Conclusions

- GERDA experiment will look for $0\nu2\beta$ decay in ^{76}Ge at LNGS using naked HPGe detectors operated in LAr
- Construction completed, commissioning presently in progress: 3 ^{nat}Ge detectors operated
- Estimates/MC simulations for cosmogenic backgrounds: direct (prompt) μ-events, activation under ground and activation above ground → now can **check with data**
- Muon-induced background (prompt & delayed) **consistent** with expectations
- Surprise: relevant ^{42}Ar/^{42}K signal. First positive measurement
  - sensitive to electric fields
  - <u>not an issue</u>: several handles to reduce the background at $Q_{\beta\beta}$
  - run a field-free set-up to quantify the ^{42}Ar specific activity in LAr
    - but surely larger than upper limit from the literature