Status of the GERmanium Detector Array Experiment (GERDA) at LNGS

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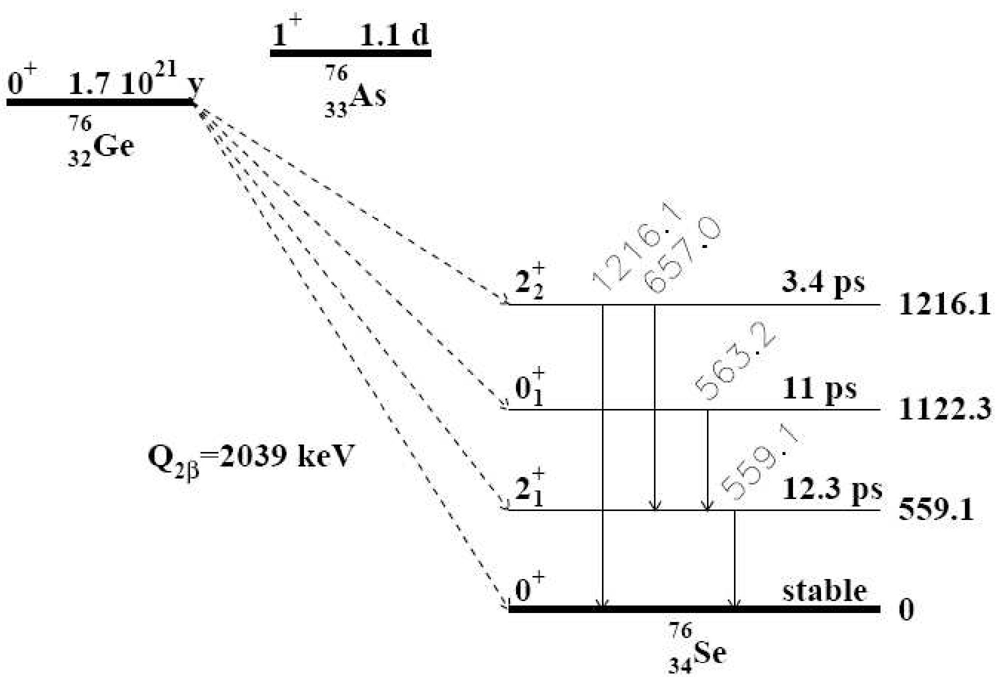
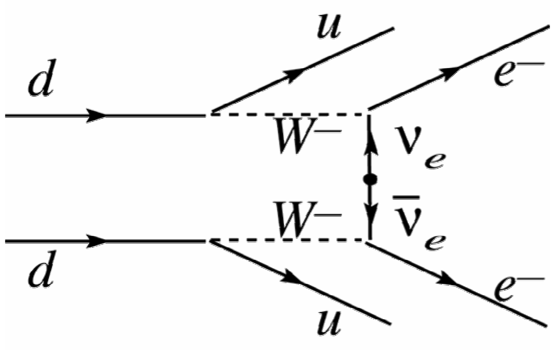
Per la collaborazione GERDA



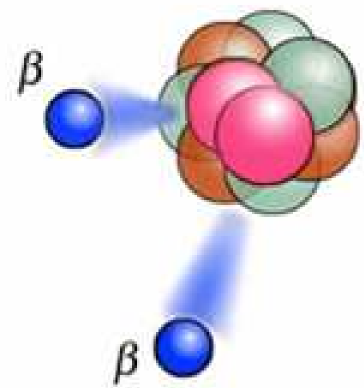
Outline

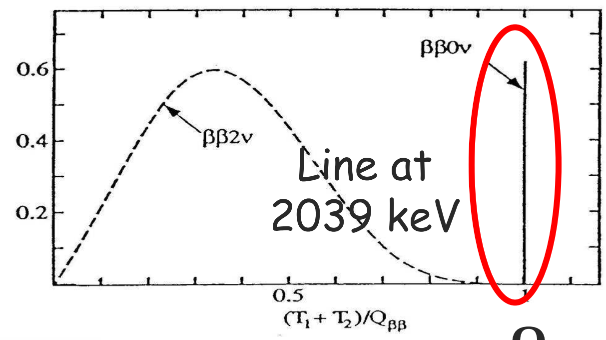
- Neutrinoless Double Beta Decay ($0\nu\beta\beta$) & ^{76}Ge
- The design and construction of the GERDA setup.
  - The milestones
  - The Water Tank & The Cerenkov Muon veto
  - The Cryostat
  - The Ge detectors
  - The Ge detectors readout
  - The calibration system
- The first 3 months of data taking
- Preparation of GERDA Phase II
- Conclusions

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



Feynman diagram of 0νbb





Proposed by Majorana & Racah in 1937 (*Il Nuovo Cimento*).

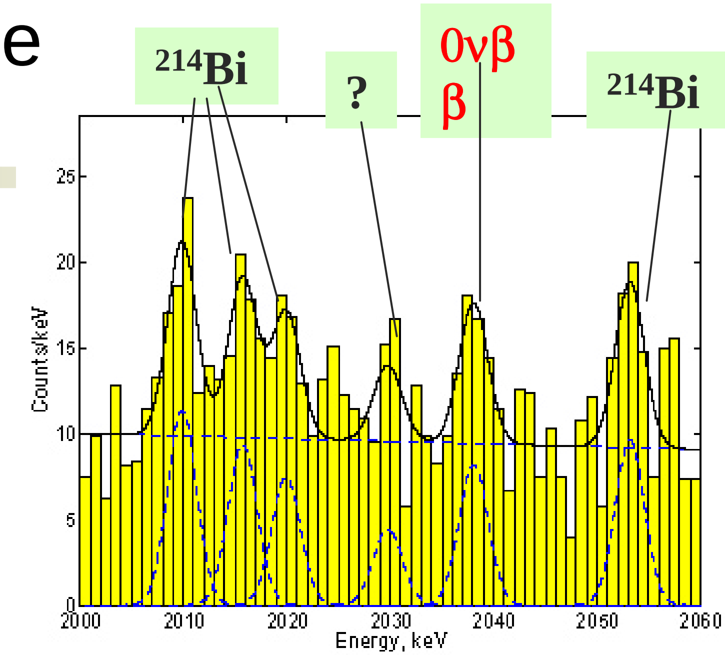
It is forbidden in SM and requires

- Lepton number violation $\Delta L = 2$
- Neutrino is a Majorana particle having finite mass $\nu_e = \bar{\nu}_e$

or $<m_\nu> \neq 0$

- Existence of W_R

Why another experiment on ^{76}Ge $0\nu\beta\beta$ decay?

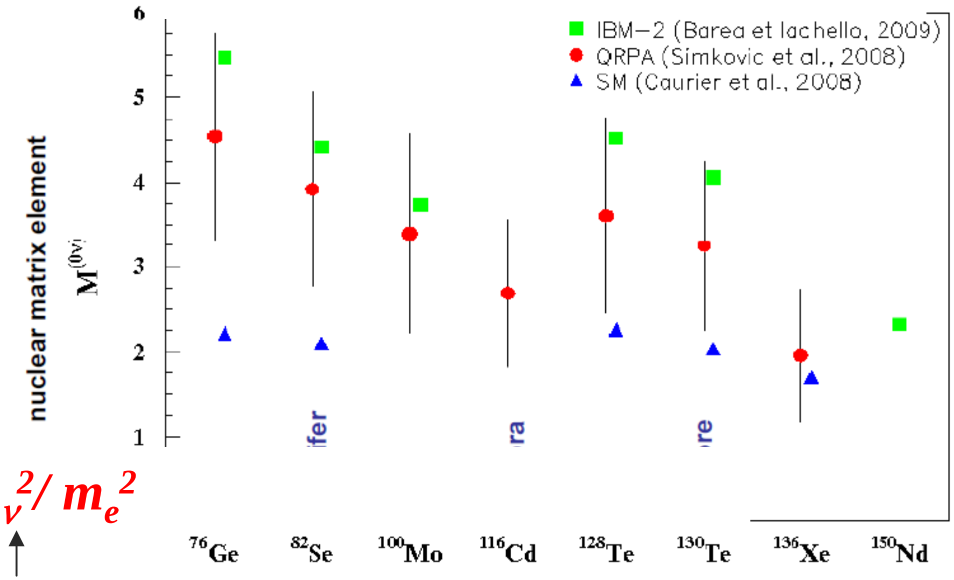


- A debated claim @ **4.2 σ** indicate evidence of $0\nu\beta\beta$ with

  $T_{1/2}$ = 1.2 x 10^{25} y

  m_{ee}= 440 meV with KK NME

- Estimated NME favorable in all the models $T_{1/2}^{0\nu} \sim 10^{27}$ y (for $<m_\nu>$= 40 meV: $M_{0\nu}^{nucl} \sim 4$
- $Q_{\beta\beta}$=2039.06±0.05 keV



$$(T_{1/2}^{0\nu})^{-1} \sim 5 \text{ x } 10^{-17} \,[y^{-1}]\, F_{0\nu}\,(Q,Z)\, |M_{0\nu}|^2\, m_\nu^2 / m_e^2$$

$0\nu\beta\beta$ half-life Measured qty

Scale factor

Phase pace…

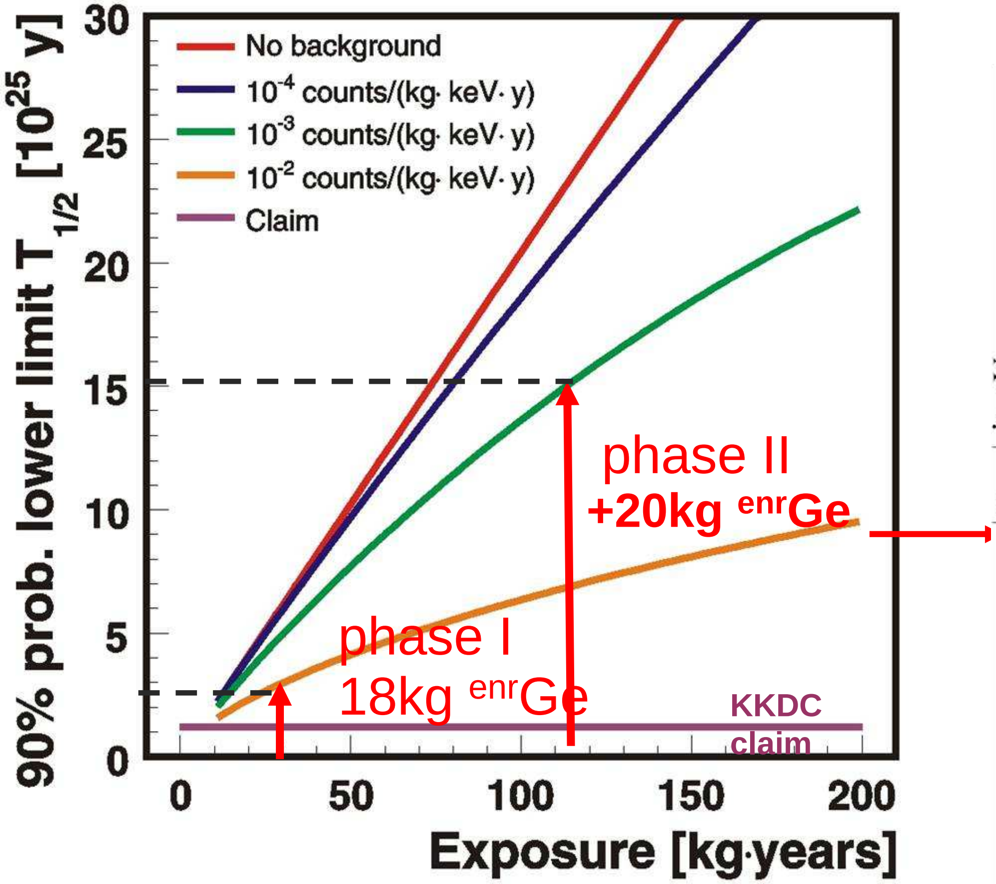
Nuclear Matrix Elements

Effective Majorana neutrino mass

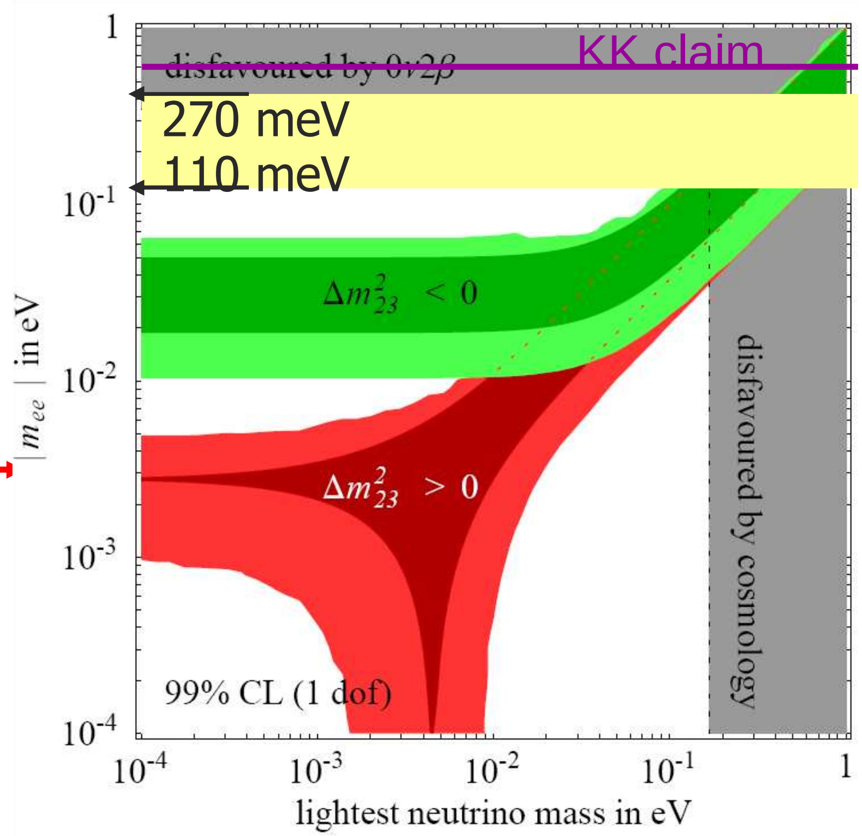
Deduced qty

GERDA: Sensitivity

Assumed E resolution: ΔE = 4 keV



From Vissani, Strumia hep-ph/0606054v2



GERDA I→ scrutinize in ~ 1 year data taking (assuming 18 kg y exposure) the KK claim: if true ββ decay GERDA will have 7 cts, above bckg of 0.5 cts → probability that bckg simulate signal ~ 10^{-5}

GERDA: The Collaboration

GERDA

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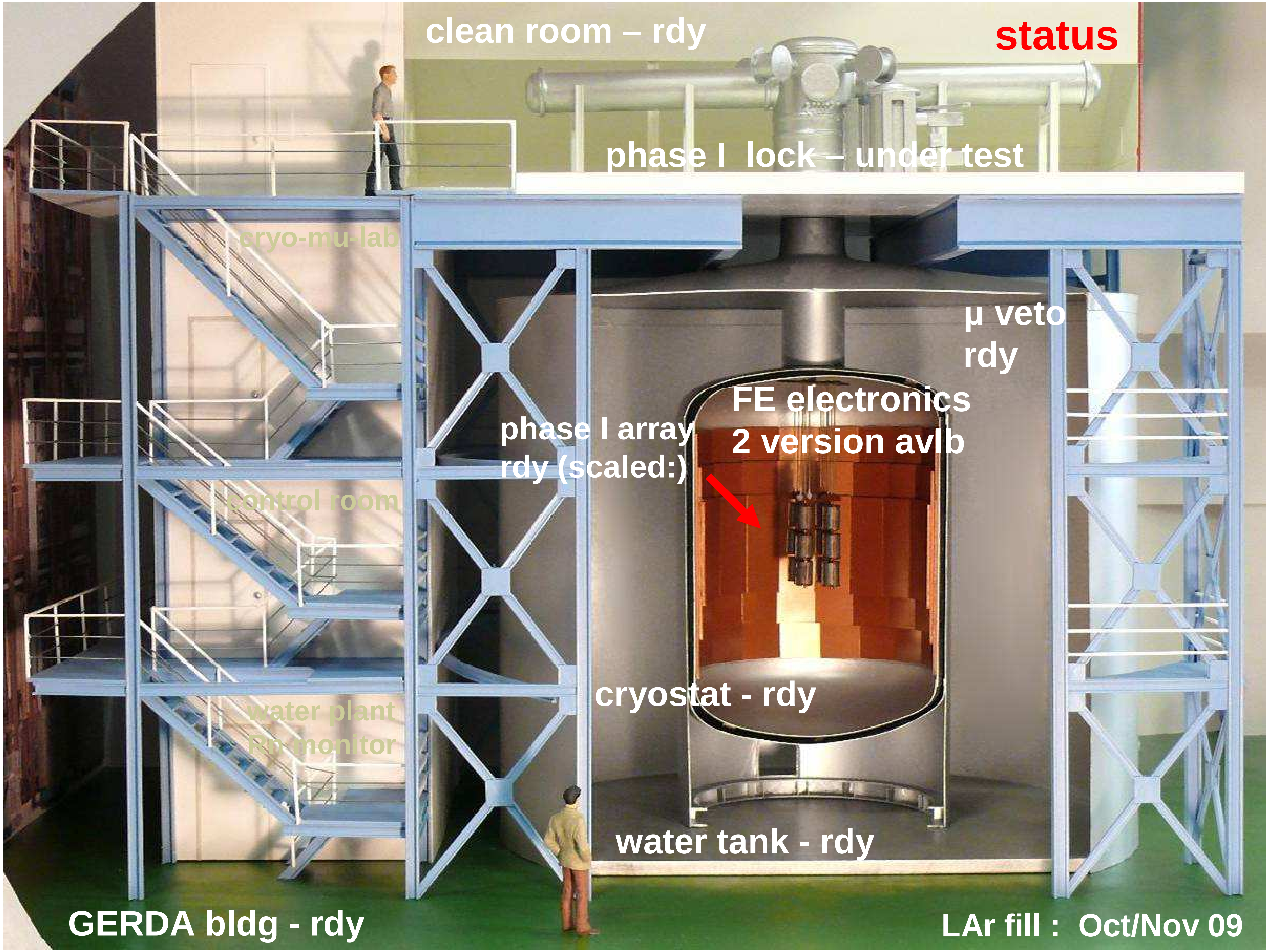
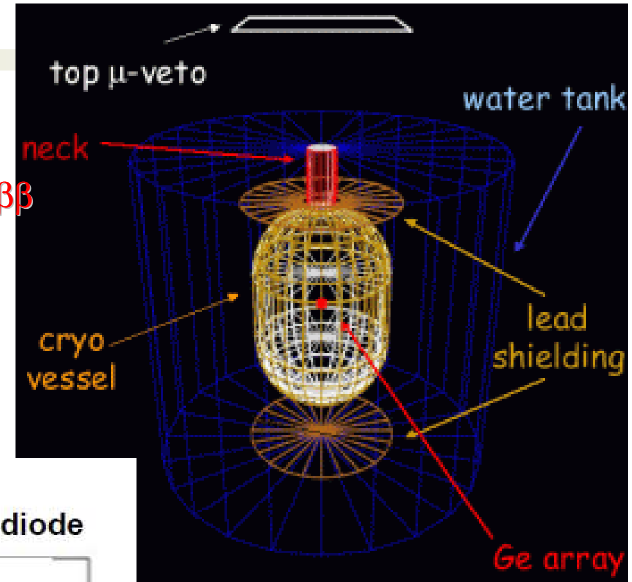
http://www.mpi-hd.mpg.de/GERDA

~ 95 physicists
17 institutions
6 countries
(Germany, Italy, Russia, Poland,Belgium,Switzerland)


status
clean room – rdy
phase I lock – under test
cryo-mu-lab
μ veto
rdy
FE electronics
2 version avlb
phase I array
rdy (scaled:)
control room
cryostat - rdy
water plant
Rn monitor
water tank - rdy
GERDA bldg - rdy
LAr fill : Oct/Nov 09

GERDA: a novel, ambitious approach to the background issues

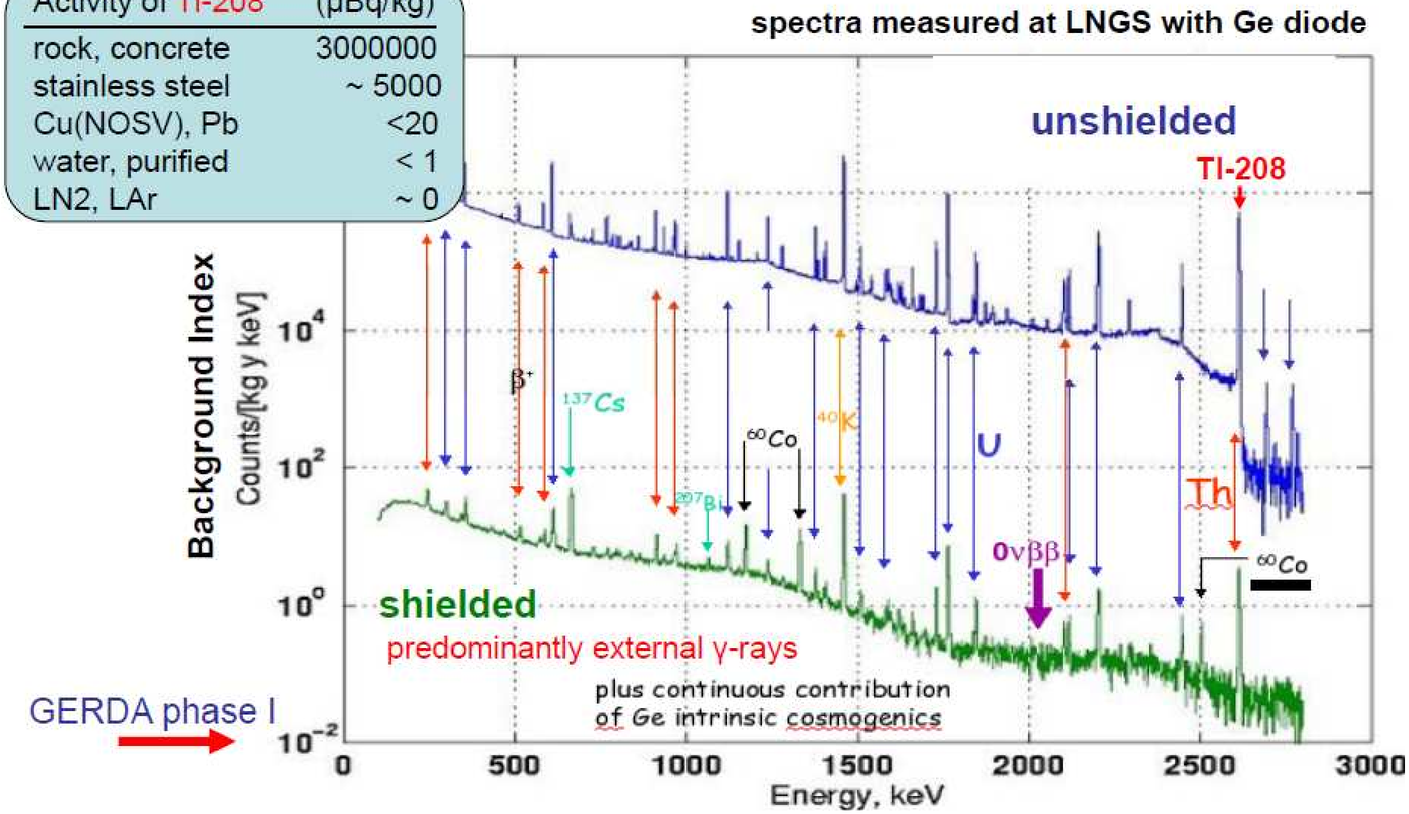


GERDA goal: build a setup with a B< 10^{-3} [c/kky] @ $Q_{\beta\beta}$

GERDA distinctive features to reduce bckrgd of 10^{-6}

- Ge diodes operated naked in LAr

Activity of Tl-208	(μBq/kg)
rock, concrete	3000000
stainless steel	~ 5000
Cu(NOSV), Pb	<20
water, purified	< 1
LN2, LAr	~ 0

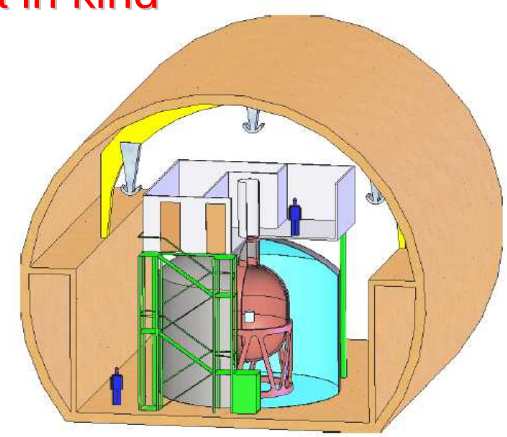


GERDA milestones

GERDA

The GERmanium Detector Array for the search of neutrinoless $\beta\beta$ decays of ^{76}Ge at LNGS

- Proposed in 2004 & funded by MPG
- Approved in 2005 by LNGS with location in Hall A
- 2005 Funded by BMBF, INFN, DFG (R&D), and Russia in kind
- WT & related plants:
  - Contract signed in 2006
  - Construction in LNGS Hall A 2007-2008
  - Muon veto constructed in 2009
- Cryostat & cryogenic systems
  - Contract signed in 2007
  - Construction @ company site in 2007-2008
  - Delivered @ LNGS in 2008
  - filled with LAr in Dec ’09 & cryogenic commissioning completed
- Building
  - Constructed in 2008
- Clean room & Lock
  - Constructed in 2009> Lock tested in 2009, moved underground in 2010
- Detectors:
  - Refurbishment technology defined in 2008 after proofing long term stability in LAr



Proposal

September 2004

Pictures from the construction time (2007-2010)

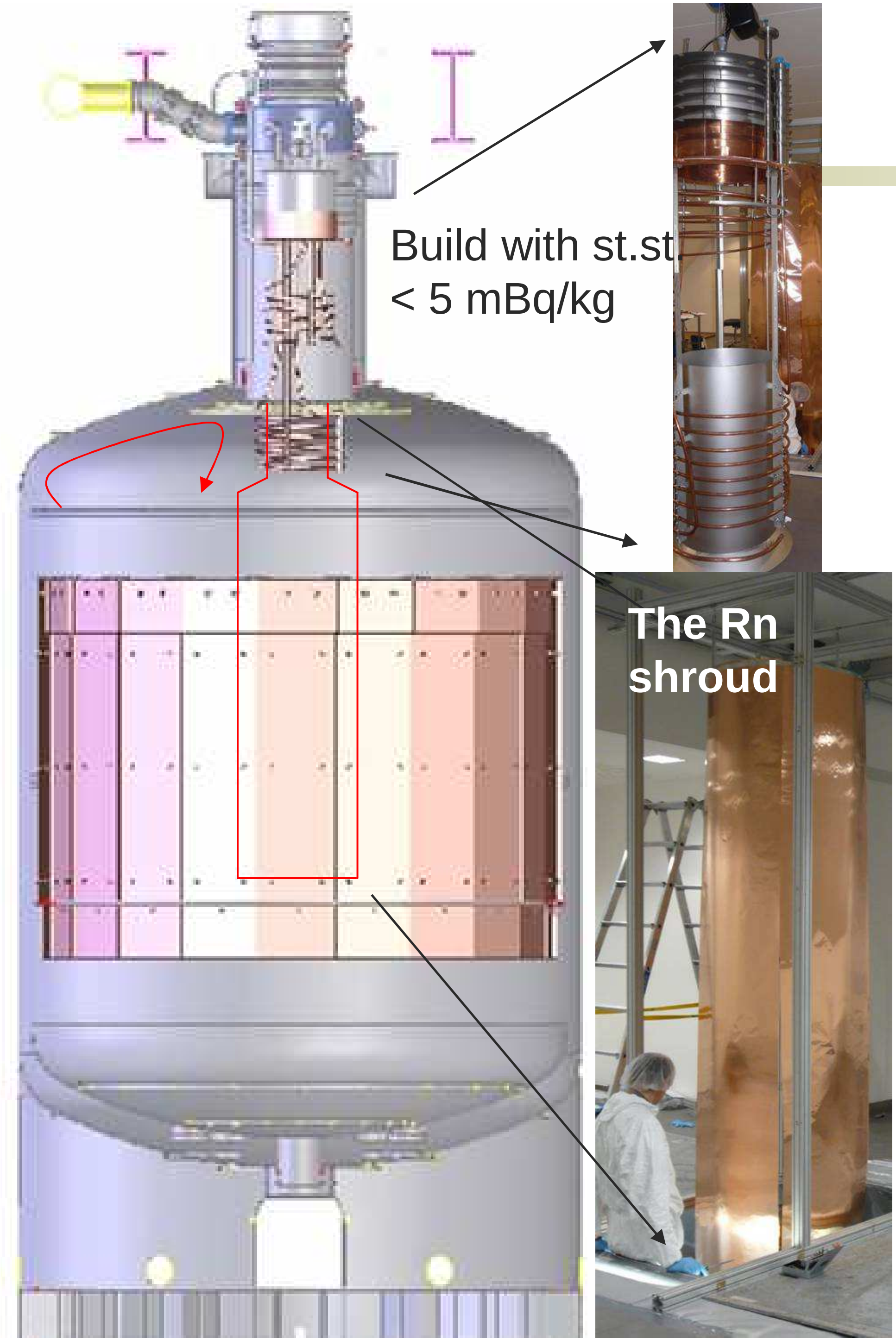
Pictures 010)

The main GERDA subsystems

GERDA is a composite setup. The main sub-systems are listed in the fololwing:

- Cryostat (and relate plants)
- Water tank e μ-veto (and related plants)
- Detectors insertion system (lock)
- Detectors
- Pulse readout and processing
- Calibration system

The Cryostat: design



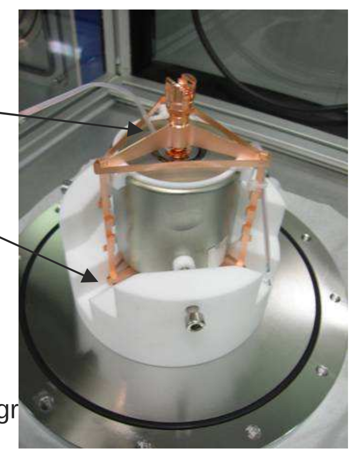
The cooling serpentine: to sub-cool the LAr. No LAr refilling needed

- dedicated meas show that Rn in cryostat
  ~55 mBq with manifold, bellow, piping, sensors, cabling, ….
- Temp. difference suppresses exchange of LAr from neck and tank
- Rn in convective layers w/o shroud:
  30 mBq => $2 \cdot 10^{-3}$ cts/(keV·kg·y)
- Rn in convective layers with shroud:
  30 mBq => $1.5 \cdot 10^{-4}$ cts/(keV·kg·y)
- Homogenous mixing of radon in LAr:
  30 mBq => $4 \cdot 10^{-4}$ cts/(keV·kg·y)

The Phase I ^{enr}Ge detectors

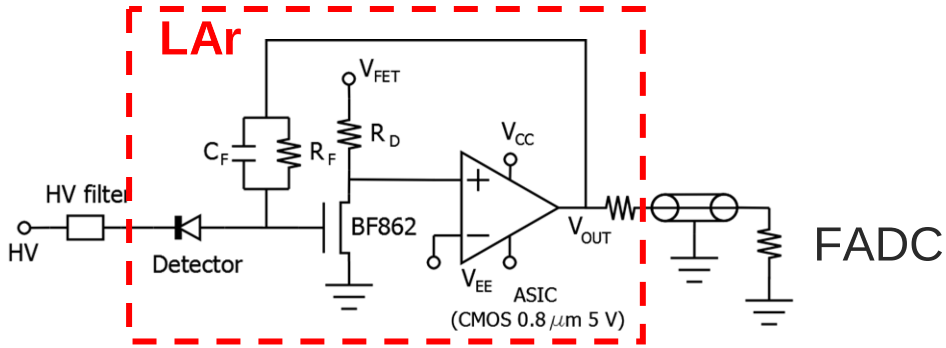
Detector	Total mass (g)	HV (V)
ANG 1	958	3500
ANG 2	2833	4000
ANG 3	2391	3000
ANG 4	2372	3000
ANG 5	2746	1800
RG 1	2110	4500
RG 2	2166	4000
RG 3	2087	3500
GTF 32	2321	3200
GTF 42	2467	3000
GTF 44	2465	3500
GTF 45	2332	1500
GTF 110	3046	3000
GTF 112	2965	2500
Prototype	1560	3000

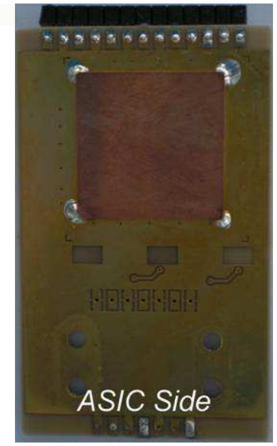
- 8 ^{enr}Ge (former HdM&IGEX) + 6 ^{nat}Ge (from GTF) p-type coaxial Ge detector available
- mass:1-3 kg
- C_{det} = 30-40 pF
- Deployed in strings of 3 detectors each
- Mounted in low-mass Cu holders
- HV contact: on Li surface by pressure
- Readout contact: in borehole spring-loaded
- All the detectors have been tested naked in LAr and perform well (I-V & R < 3 keV @ 1.332 MeV).
- Long term stability experimentally proved



The Ge detector readout: Front-end

- Cryogenic FE circuit g-ray spectrometry class. Architecture: external JFET + following amp. stage (CMOS OPAMP)





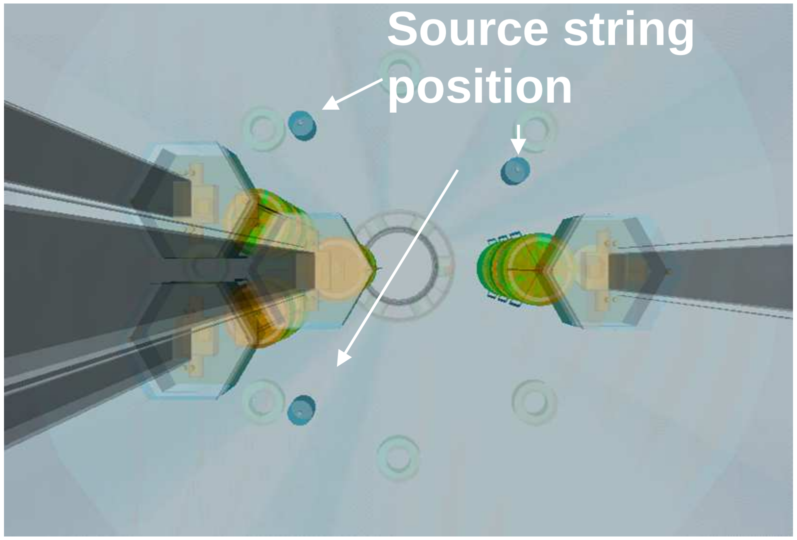
ASIC single-ended preamplifier produced in 0.8μm 5V CZX CMOS technology

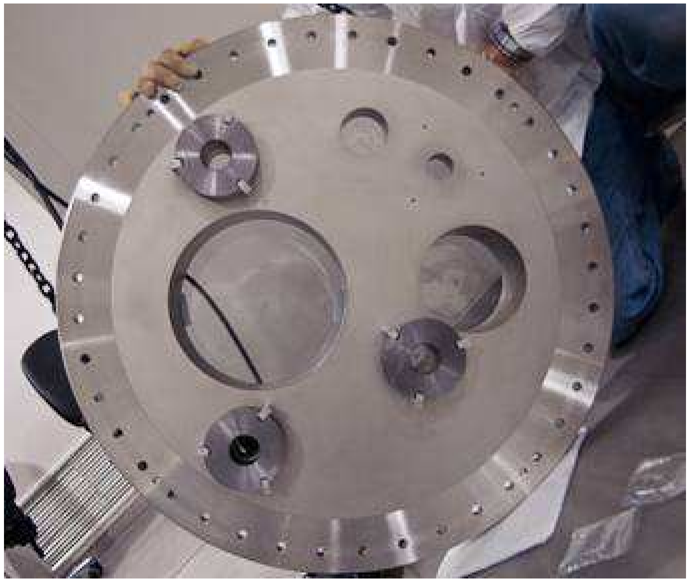
- Achieved Performances @ LN :
  - Intrinsic noise < 1 keV (< 150 e r.m.s.)
  - Rise time: 30-40 ns
- Radiopurity (^{232}Th) with screened components:
  - 350 μBq/PCB (3ch)for ASIC FE
  - 150 μBq/PCB (3ch) for CC2 (based on commercial CMOS OPAMP)

CC2 circuit based on CMOS OPAMP

The Calibration System

- ^{228}Th sources (γ-lines at 2614 keV, 2103 keV, 1592 keV, 583 keV) inserted besides detector strings
- a 20 kBq source provides an event rate in detectors of ~ 600 Hz in calibration, allowing calibration ~ 1 h



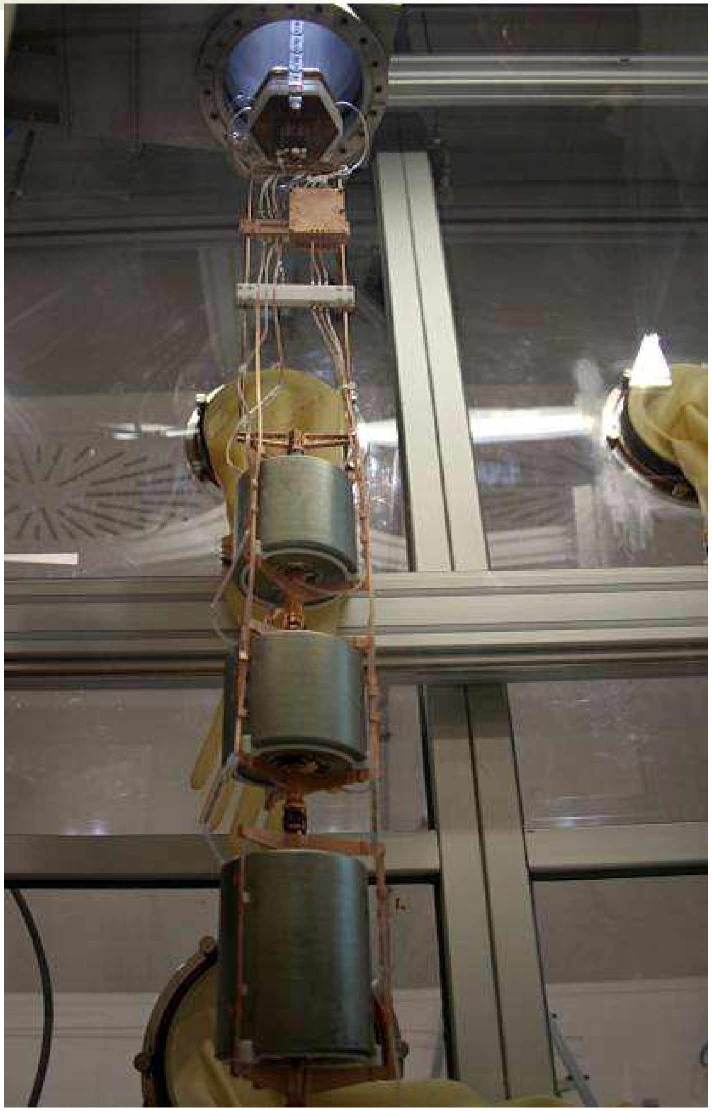


- **Ta ring**: to shield detectors when sources are in parking position
- **parasitic n-activity** of sources from (α,n) reaction on substrate materials measured with dedicated setup

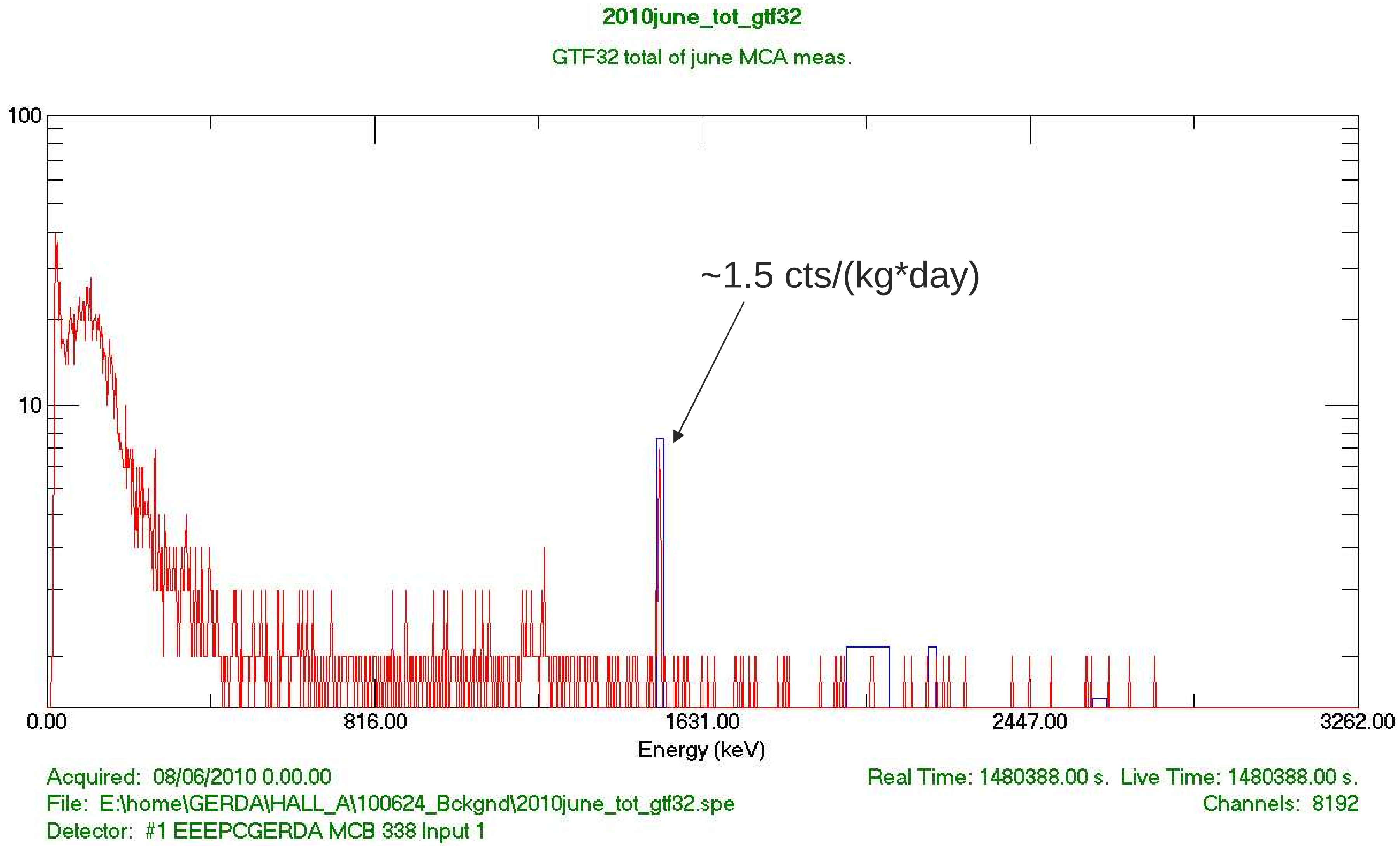
$(2.7 \pm 0.5) \times 10^{-2}$ n/s for the 14 kBq source

The first three months of data taking

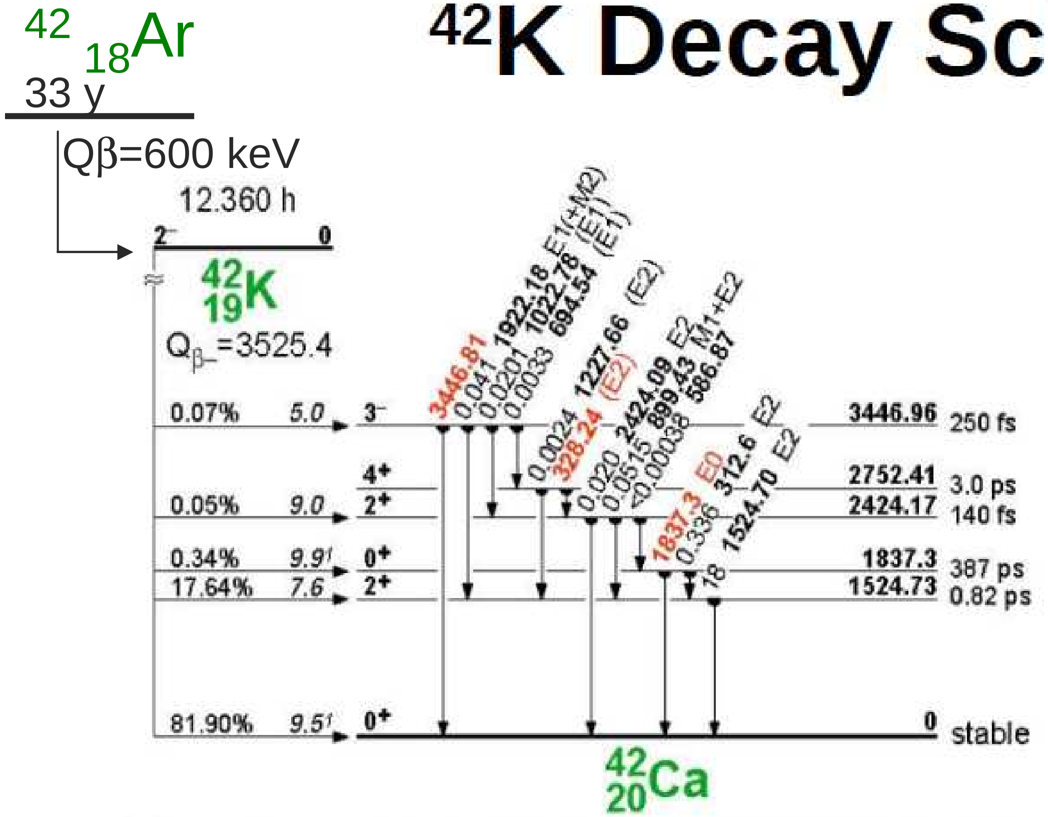
- GERDA started the commissioning data taking with a ^{nat}Ge pilot string (3 detectors for a total mass of 7.62 kg of ^{nat}Ge)
- Few technical problems related to HV → solved
- Up to now available a statistic of ~250 kg*d divided in runs taken in different configurations
- Bad news:
  - Immediately visible an ^{42}Ar signal much larger (~ 15) than expected at the 1524 keV γ-line
- Good news:
  - No peak visible from none of the ^{238}U (1764,2204), ^{232}Th(2614,583 etc.), ^{40}Kmain γ-lines



Spectra collected during 17 days with 2.3 kg ^{nat}Ge detector in GERDA setup



^{42}K Decay Scheme



- $T_{1/2}$ = 12.36 h
- Q = 3525.4 keV
- Mostly a pure β emitter
  - Most intense γ ray at 1524.73 keV (18.1%)

γ(^{42}Ca) from ^{42}K (12.360 h) β⁻ decay < *for Iγ% multiply by 0.1808 9*>

312.6 (I_γ 1.86 *11*) E2
586.87 (I_γ <0.0021)
694.54 (I_γ 0.018 *4*) (E1)
899.43 (I_γ 0.285 *14*) M1+E2: δ= −0.18 *2*
1022.78 (I_γ 0.111 *8*) (E1)
1227.66 (I_γ 0.013 *6*) (E2)
1524.70 (I_γ 100) E2
1922.18 (I_γ 0.228 *22*) E1(+M2): δ=+0.02 *7*
2424.09 (I_γ 0.110 *16*) E2

Background at $Q_{\beta\beta}$ by:

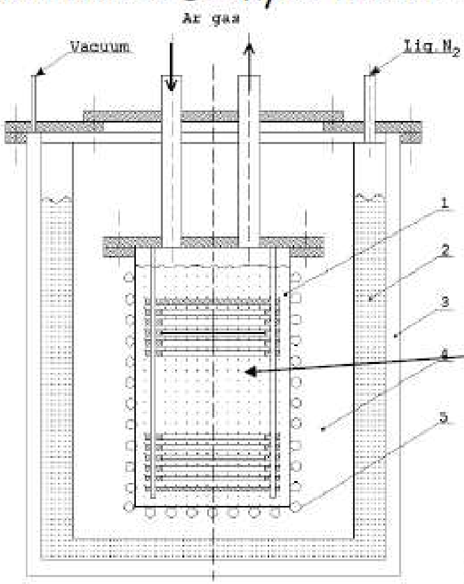
β, bremsstrahlung from β and 2424 keV γ-ray

^{42}Ar: expected values and possible origin

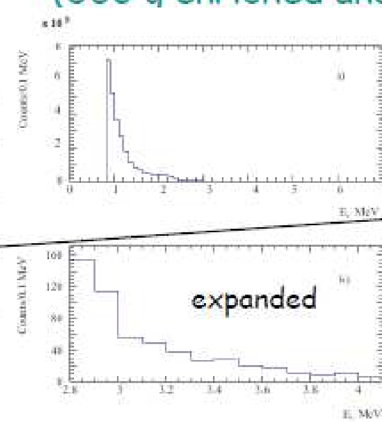
- ^{42}Ar is mainly generated by ^{40}Ar(α,2p)^{42}Ar reaction in atmosphere and fall-out from atmospheric nuclear explosions

measurements of upper concentration limits of ^{42}Ar in Ar [μBq/l LAR]

1992 Arpesella et al. LNGS internal report 92/27: 1.2×10^{-18} atoms 42/40 =	16800
1995 Cennini et al.(ICARUS 3t) NIM A 356,526-529: 4×10^{-18} atoms 42/40 =	56000
1998 Ashitkov V.D.et al. NIM A 416, 179-181: 6×10^{-21} atoms 42/40 =	84
1999 Ashitkov V.D. et al. Nucl. Phys.(Proc Suppl.)70,233: 5×10^{-21} g/g =	70
2002 Barabash A.S. Proc. W.S. Xenon detectors (2001): 3×10^{-21} atoms 42/40 =	42
2003 Ashitkov V.D. et al. arXiv:nucl-ex/0309001 : 4.3×10^{-21} g/g =	60
2004 Ruben Saakyan thesis. : 4.3×10^{-21} atoms 42/40 =	60



Liquid Ar ionization chamber to measure ^{100}Mo (306 g enriched and 138 g natural) 113 d and 13 d



energy spectrum of single electron events full dynamic range

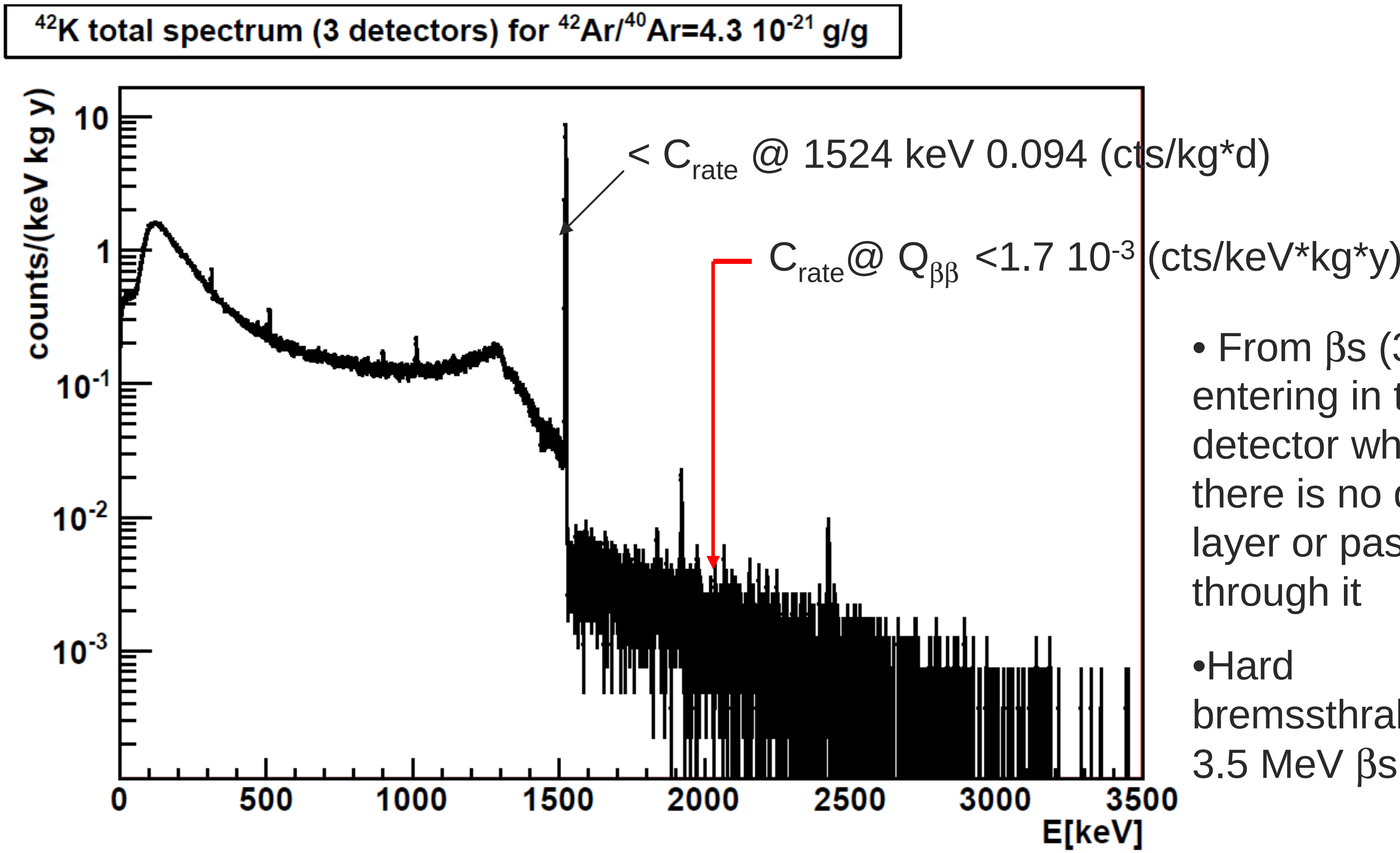
expanded

55 kg LAR

<0.094 c/(kg*d) in GERDA meas. geometry

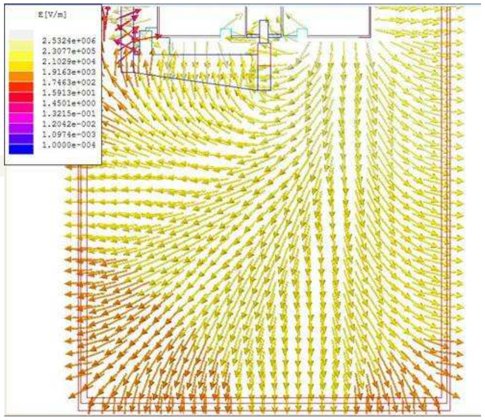
Figure 11: Energy spectrum of single-electron events (all detector sections summed). (a) The entire dynamic range of the detector, (0-7) MeV; (b) zoomed view ((2.8-4.1) MeV energy interval).

Simulated ^{42}Ar spectrum in GERDA geometry (detectors surrounded by homogeneous LAr bath)

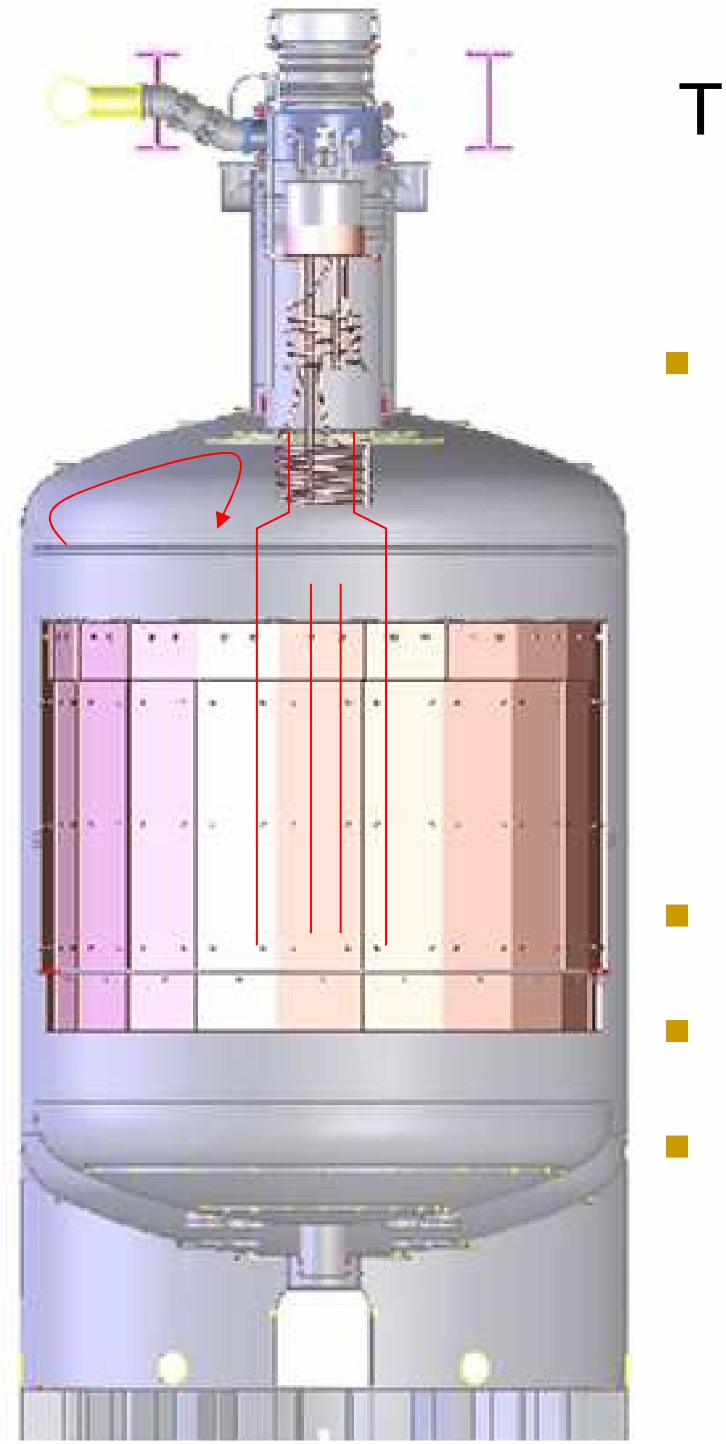


- From βs (3.5 MeV) entering in the detector where there is no dead layer or passing through it
- Hard bremssthralung of 3.5 MeV βs in LAr

Possible explanations and actions



- The reference ^{42}Ar conc. measurements are wrong (of a large factor →unlikely)
- The ^{42}Ar concentration in atmosphere has large variations, and the GERDA LAr has a particularly high concentration of ^{42}Ar
  - → measure in two independent setups (GERDA & LARGE).
- The $^{42}K^{+}$, which is produced positively charged in the ^{42}Ar β decay, is not uniformely distributed around the detectors: $^{42}K^{+}$ (lifetime in LAr unknown) is drifted towards the detectors holder (GNDed surfaces) and detector borehole, by the detector bias E_{field} dispersed in LAr (detectors are naked!):
  - indications of this mechanism comes from (Cts@Peak)/(Cts above peak) ratio
- → Perform a series of runs placing the metallic surfaces around the detectors (shroud and mini-shroud) at various potentials and measure the cts rate: → results encouraging, already achieved a relevant reducing factor. Continue on this road!



The mini-shroud

- A Cu mini-shroud has been inserted,
  - to close field lines onto a surface few cm away from the detector (not onto detector holders)
  - To prevent ions sucked from the from the LAr bath to reach the detector
- The detector string is inside the mini-shroud
- Significant ^{42}K signal reduction
- No bkgrd increase

The Next steps

In the next months our activity will follow this scheme :

- Complete the measurements devoted to understand the ^{42}Ar signal and pursue mitigation actions
- Installation of the 3-string arm
- Test of 3-string arm with mockup & capacitors.
- Optimization of noise in the underground setup (grounding, tests with FE+ capacitors and detector mockup).
- Deploy the ^{enr}Ge detectors

The preparation of GERDA Phase II: ^{enr}Ge processing

on 30 April 2010

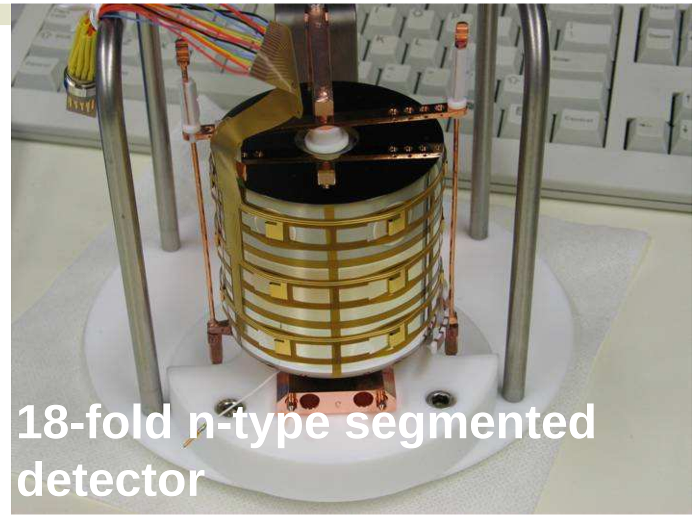
- 36.6 kg >50 Ohm material produced.

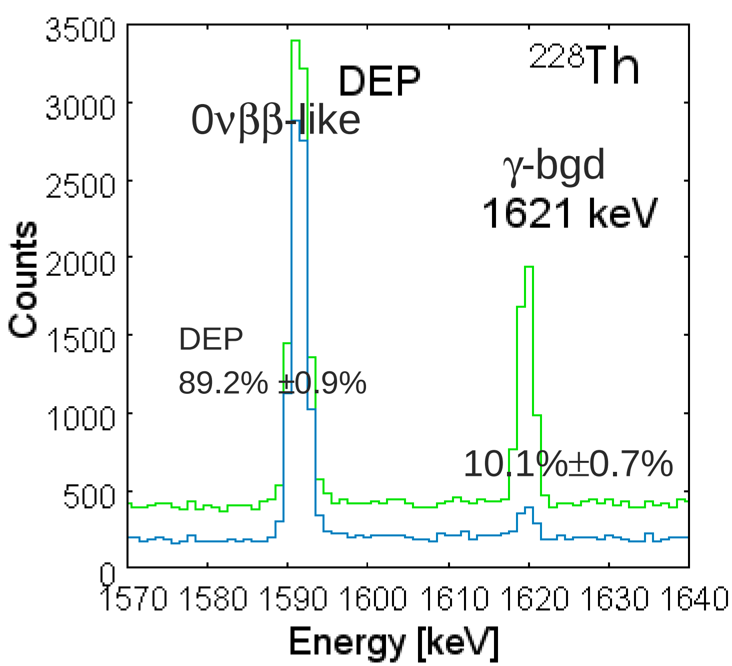
97% of the 37.5 kg available ^{enr}Ge is now 6N material.

- The integrated exposure has been about 5.2 days including the transport from Geel.

- All the material is packed in two boxes and is underground in the Rammelsberg mine.

PHASE II Detectors allowing enhanced PSD: Choice of BEGe as reference type



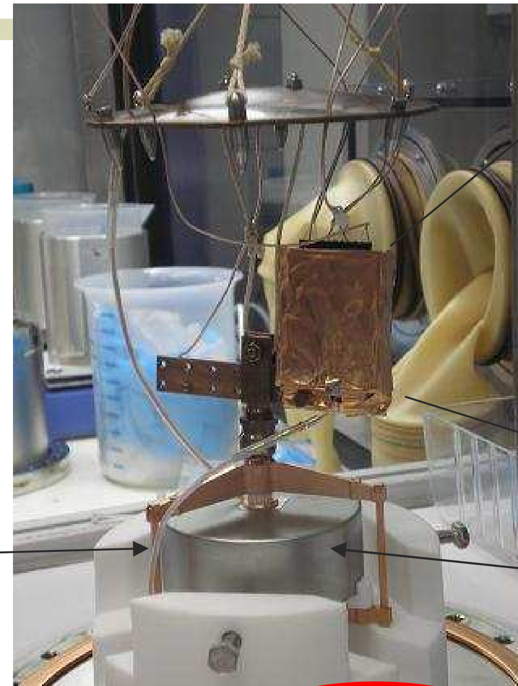


- Applying PSA cuts and requiring 90% survival probability for the ^{232}Th DEP (mostly Single Site Events → 0νββ-like)
- 12% survival of the γ-line ^{212}Bi line (mostly Multi-Site Events → γ-bgd like)
- Segmented & BEGe show similar PSD performances, but BEGe simplest readout and cabling → benefit for setup radiopurity
- 3 ^{nat}Ge + 2^{depl}Ge BEGe detctors tested so far: all of them excellent En Res < 2.0 keV @ 1.332 MeV

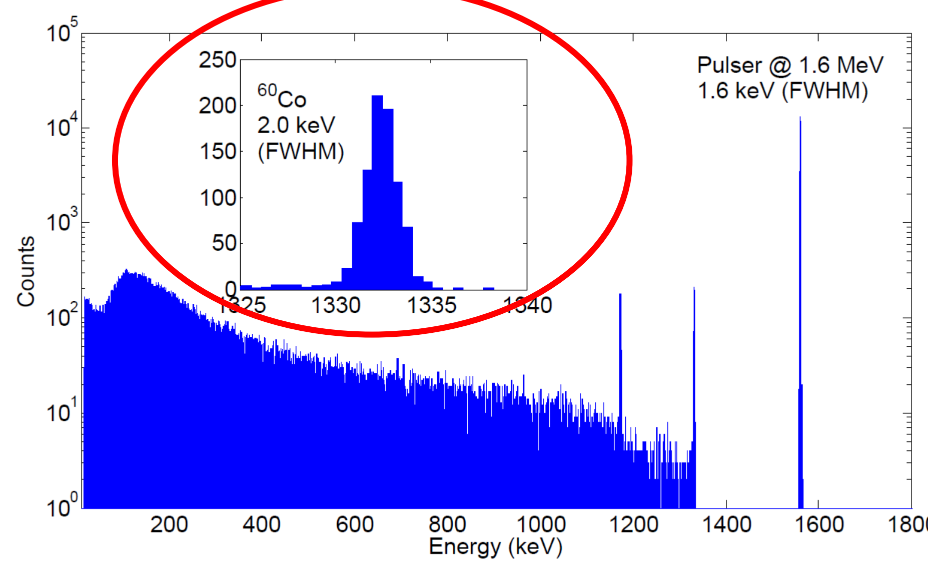
PSD: comparison of results from all the BEGe tested in GERDA

				PSD Acceptance [%]				
Dim.sns	Contact dim [mm]	Mass [g]	V_{depl} [V]	Compton @Qbb	DEP 1592 keV	FEP 1621 keV	SEP 2103 keV	FEP 2614 keV
81 x 32 Hd	15	868	4000 3700	39 ± 2	90±1.6	9.5±1.5	5.8 ± 0.6	7.7 ± 0.7
70 x 32 LNGS	15	632	3000 2600	37.5±0.5	90±0.6	11.5±0.1	6.2±0.4	6.4±0.1
60 x 26 Geel	15	390	3000	45 ± 2	90 ± 3	18 ± 3	6.8 ±1.7	14 ± 3
80 x 30 Geel	15	825	3500	49 ± 2	90 ± 3	29 ± 2	23 ± 2	Not avlbl
74 x 33 Depl CC	9	752	3500	38.3 ± 0.3	90 ±1.1	10 ± 0.6	5.4 ±0.3	8.3 ± 0.1
74 x 32 Depl DD	22	~750	3500	39.8±0.3	90±1.1	11.3±0.6	5.8±0.4	8.8±0.1

Phase II: The recentest results with bare BEGe (80 x 40 mm) & cold FE in LARGE setup (@GDL): long term stability proved



BEGe detector



Conclusions

- The construction of the GERDA setup at LNGS is completed since spring 2010.
- All the recommendations of the safety review have been implemented
- Commissioning started in june 2010 with a pilot string of 3 ^{nat}Ge detector
- Performances not as good as in September 2009 tests (R= 5-7 keV @ 2614 keV) dominated by EM disturbances
- Available a statistic of ~250 kg*d
- A concentration of ^{42}Ar a factor ~ 15 larger than expected (from measurements available in literature) is observed
- Actions are ongoing to understand the origin of the extra ^{42}Ar signal and to mitigate its impact on the detector background index
- Still no background visible from U, Th and K (B of the setup matches the design)
- Run with ^{enr}Ge will then follows (time schedule depends on the outcome of the ongoing commissioning)
- The BEGe detectors have been chosen as reference detectors for the GERDA PHASE II. We are defining and negotiating the contract with Canberra to produce the ^{enr}Detectors for GERDA Phase II. The x-tal pulling and diode production will start spring 2011.

EXTRA slides

Signature of 0νββ decay and sensitivity on $T^{0\nu}_{1/2}$

ε = detection efficiency

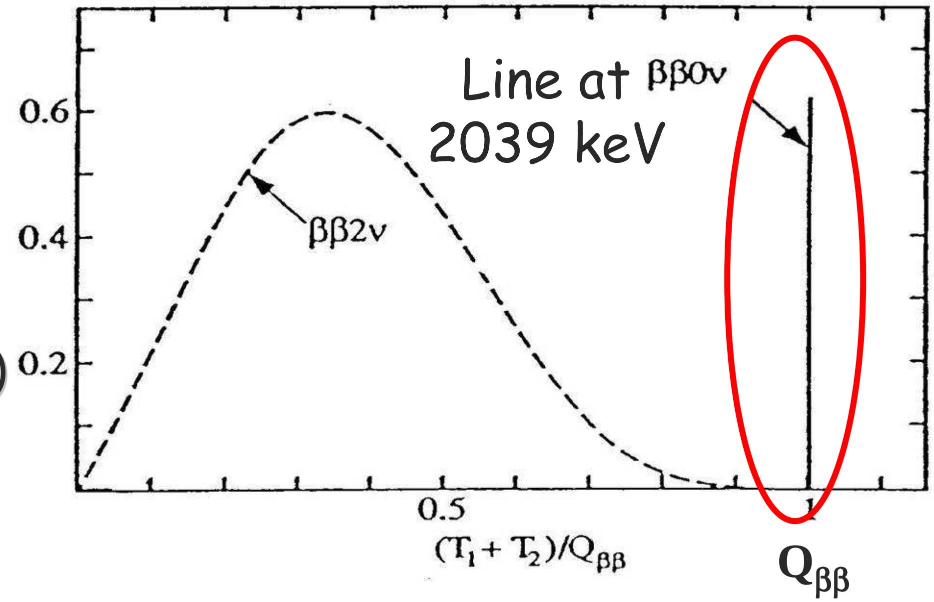
a = ββ isotope fraction → enrichment

M = mass of detector in kg

T = data taking time [y]

B = background index in cts/(keV kg y)

R = energy resolution at $Q_{\beta\beta}$ [keV]



With bck → $$T^{0\nu}_{1/2} \propto a\varepsilon\sqrt{\frac{MT}{BR}}$$

$$T^{0\nu}_{1/2} \propto a\varepsilon MT$$ ← Bck free

0νββ rate and the effective neutrino mass

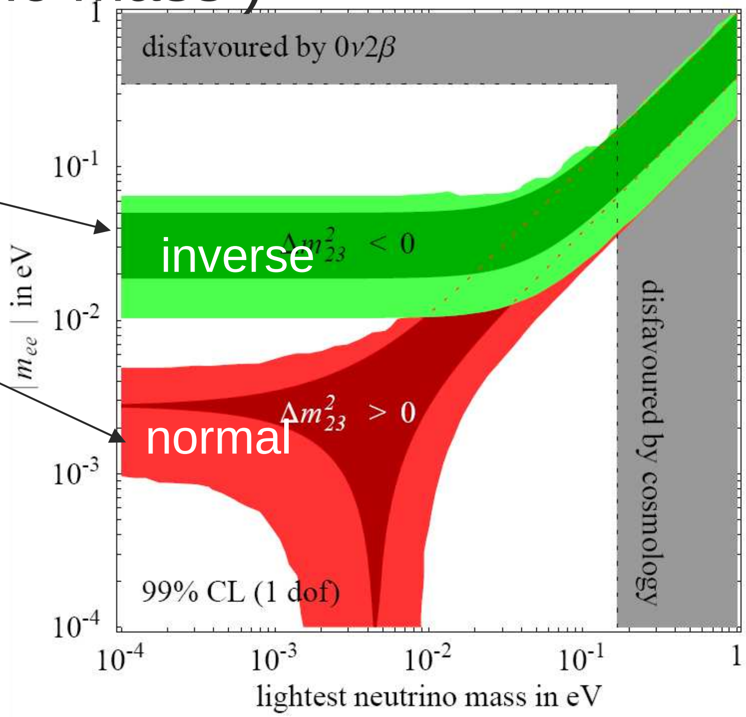
0νββ rate ~ (effective Majorana neutrino mass)^2

From Vissani, Strumia hep-ph/0606054v2

$$< m_\nu > \cong \sqrt{m_1^2 + \Delta m_{atm}^2} \left\| U_{e1}^L \right|^2 e^{i\phi 2} + \left| U_{e2}^L \right|^2 e^{i\phi 3} \right|$$

$$< m_\nu > \cong m_1 \left\| U_{e1}^L \right|^2 + \left| U_{e2}^L \right|^2 e^{i\phi 2} \left(1 + \frac{\delta m_{solar}^2}{2 m_1}\right) \right|$$

$$\Delta m_{atm}^2 = m_3^2 - (m_2^2 + m_1^2)/2$$



Rate is the quantity measured in ββ experiments

$$(T_{1/2}^{\,0\nu})^{-1} \sim 5 \times 10^{-17}\,[y^{-1}]\, F_{0\nu}\,(Q,Z)\, |M_{0\nu}|^2\, m_\nu^2 / m_e^2$$

0νββ half-life

Phase space…

Nuclear Matrix Elements

Effective Majorana neutrino mass

^{76}Ge is an appealing 0νββ candidate

- Germanium detectors are an established technology.
- Feasible to scale up experiment by subsequently adding more detectors→ GERDA staged approach (Phase I +Phase II)
- Ge density = 5.3 g cm^{-3} → compact setup
- Source = detector → high efficiency!
- High intrinsic purity and energy resolution *O*(0.1%-0.2%) allowing understanding of background sources and geometry.

Sensitivity on $T_{1/2}^{0\nu}$

$$T^{0\nu}_{1/2} = \frac{4.16 \cdot 10^{26}\, y}{n_{\sigma}} \frac{a\,\varepsilon}{W} \sqrt{\frac{Mt}{BR}}$$

0.89

> 0.9

20 kgy Phase I

110 kgy Phase II

< 4 keV

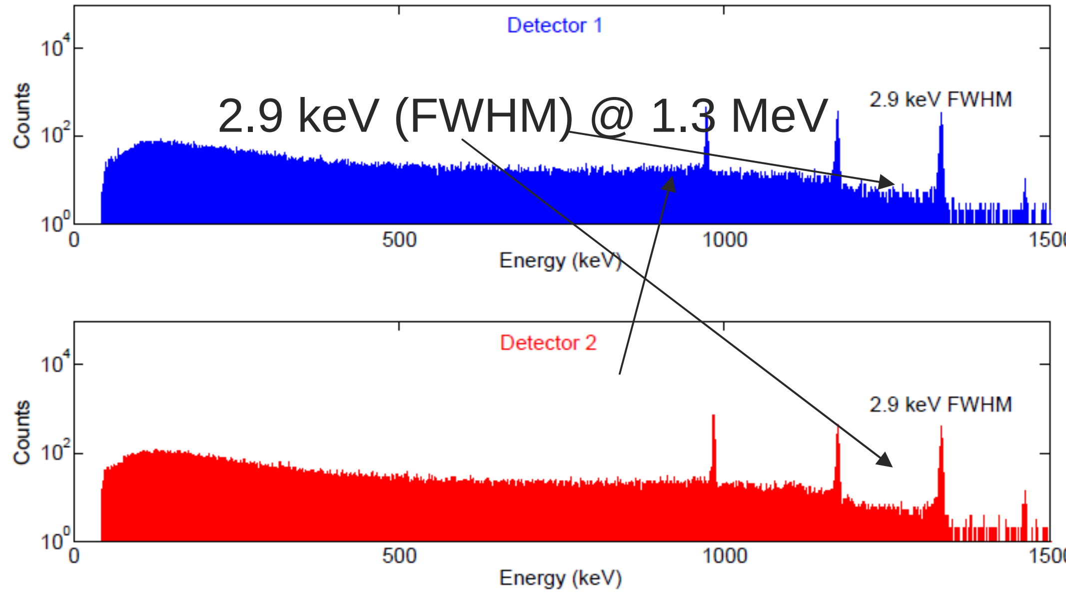
76

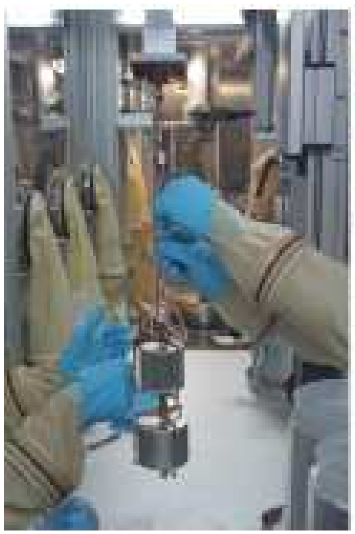
0.001-0.01 c/kky

- ^{76}Ge isotopic abundance = 7.44 %, but enrichment of ^{76}Ge possible at centrifuge up to >80% (reasonable cost)
- Low Atomic Weight (1 kg of ^{76}Ge = 13.1 Moles = 7.9 x 10^{24} nuclei)

The Ge detectors performances achieved so far in LAr in summer 2009 tests (first commissioning)

Modifications to the detector suspension and moving (up/down) defined and implemented in autumn/winter 2009-2010





Best resolution achieved in setup:
2.7 keV (FWHM)