# The GERDA Experiment: A Search for Neutrinoless Double Beta Decay

NPA5
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Matthias Junker (INFN — Laboratori Nazionali del Gran Sasso)
on behalf of the GERDA collaboration
GERDA publications: http://www.mpi-hd.mpg.de/GERDA

# GERDA

~ 100 members
19 institutions
6 countries


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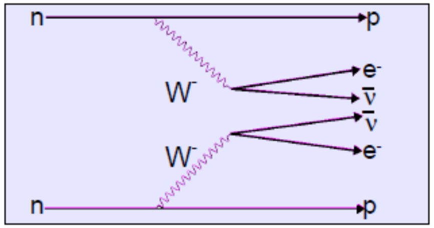
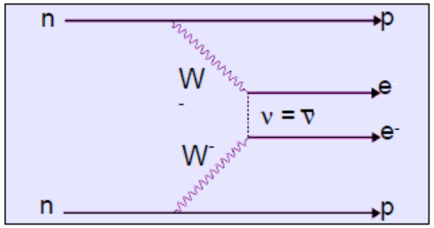
The GERmanium Detector Array (GERDA) experiment is designed to search for neutrinoless double beta decay ($0\nu\beta\beta$). The observation would imply:

- neutrino is a Majorana particle $(\nu = \bar{\nu})$
- lepton number violation $\Delta L=2$ $(A,Z) \rightarrow (A,Z+2) + 2e^-$
- effective neutrino mass
- determination of neutrino mass hierachy

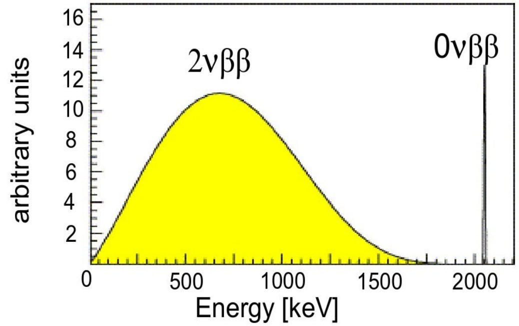
## 2νββ decay




## 0νββ decay




Example:
Expected spectrum of 0nββ of $^{76}$Ge




phase space — effective Majorana mass — nuclear matrix element

$$\left[T^{0\nu}_{1/2}\right]^{-1} = G^{0\nu}(E_0, Z)\ |M^{0\nu}|^2\ \langle m_{ee}\rangle^2$$

$$|m_{ee}| = \left|\sum_j m_j U^2_{ej}\right|$$ effective neutrino mass

**Beyond the Standard Model**

$T_{1/2}(^{76}Ge) \geq 1.9 \times 10^{25}$ y (90% C.L.)
*Eur. Phys. J. A12, 147-154 (2001)*

claim of signal from parts of HdM
*NIM A 522 (2004) 371-406*

# Claim for evidence of 0νββ of $^{76}$Ge in Heidelberg Moscow experiment

Data acquisition and analysis of the $^{76}$Ge double beta experiment in Gran Sasso 1990–2003

H.V. Klapdor-Kleingrothaus*[,1], A. Dietz, I.V. Krivosheina[2], O. Chkvorets

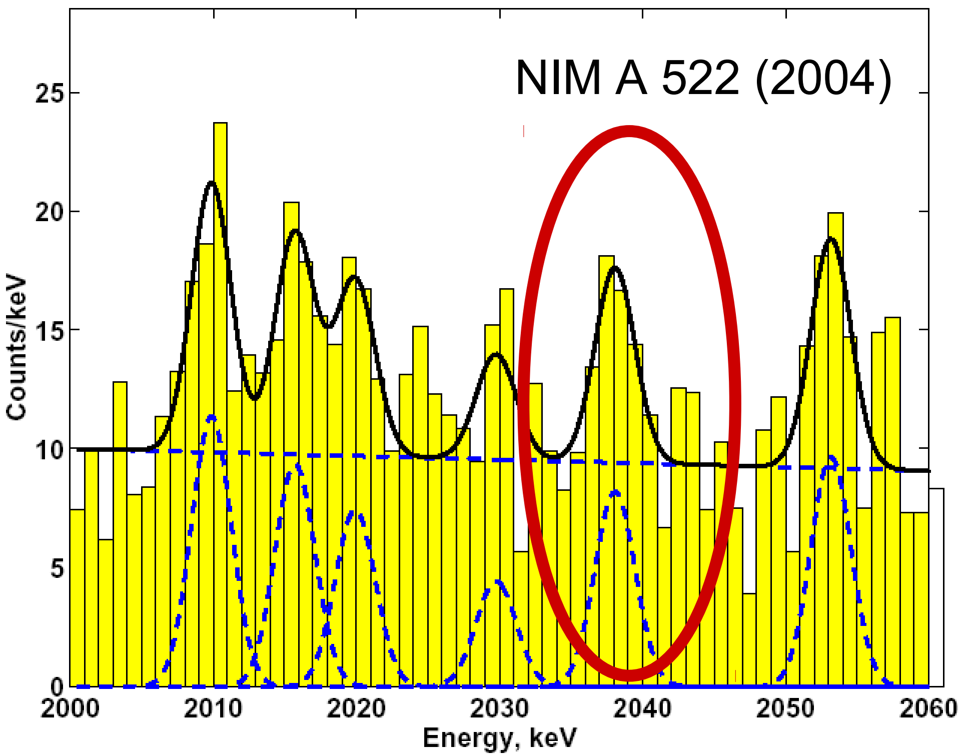



Fig. 17. The total sum spectrum of all five detectors (in total 10.96 kg enriched in $^{76}$Ge), for the period November 1990–May 2003 (71.7 kg year) in the range 2000–2060 keV and its fit (see Section 3.2).

- •Nov 1990- May 2003
- •71.7 kg year
- •**Bgd 0.11 / kg y keV**
- •28.75 ± 6.87 events (bgd:~60)
- •4.2 sigma evidence for 0νββ

- •0.34-2.03 x$10^{25}$ y (3 sigma)
- •Best fit 1.19 x$10^{25}$ y

- •$m_{ee}$ = 0.1-0.9 eV
- •best fit 0.44 eV

**<u>Note:</u> statistical significance depends on background model!**

# Claim for evidence of $0\nu\beta\beta$ of $^{76}Ge$ in Heidelberg Moscow experiment

O. Chkvorets, Diss. Univ. Heidelberg, 2008

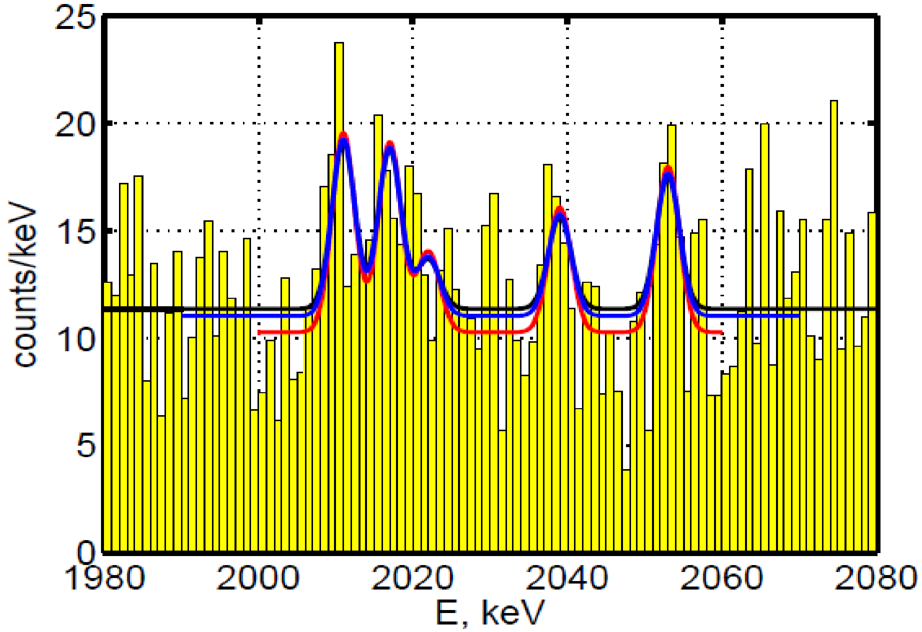
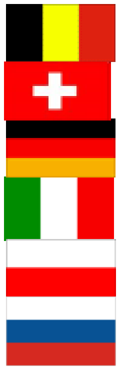


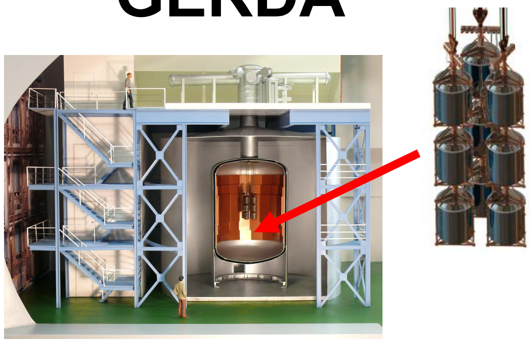

Figure 3.14: Fits of the HdM spectrum for three energy windows: 2000-2060 keV, 1990-2070 keV and 1980-2080 keV. The spectrum is fitted with fixed peak positions [28] and fixed peak widths (3.48 keV FWHM) defined by the energy calibration. The fitted background depends on the energy interval.

**Red: KK NIM 522 (2004)**
**Blue: Different background model**
**Black: Different background model**

# Two new $^{76}$Ge Projects:

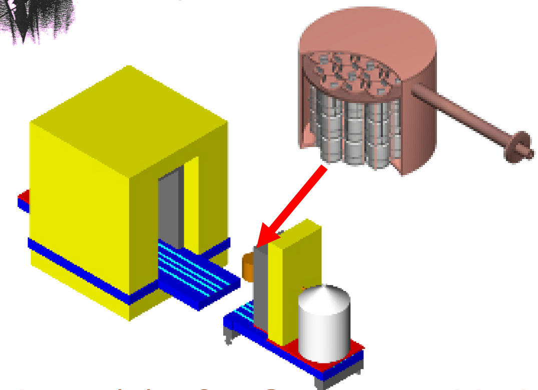
## GERDA

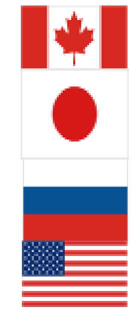




- ‘Bare’ $^{enr}$Ge array in liquid argon
- Shield: high-purity liquid Argon / $H_2O$
- Phase I: 18 kg (HdM/IGEX) / 15 kg nat.
- Phase II: add ~20 kg new enr. Detectors; total ~40 kg

## Majorana



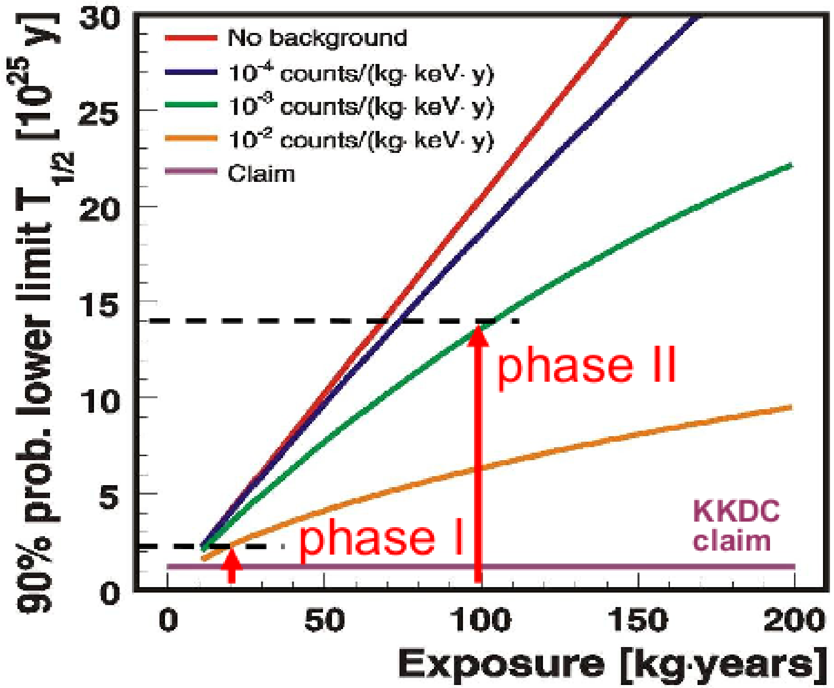


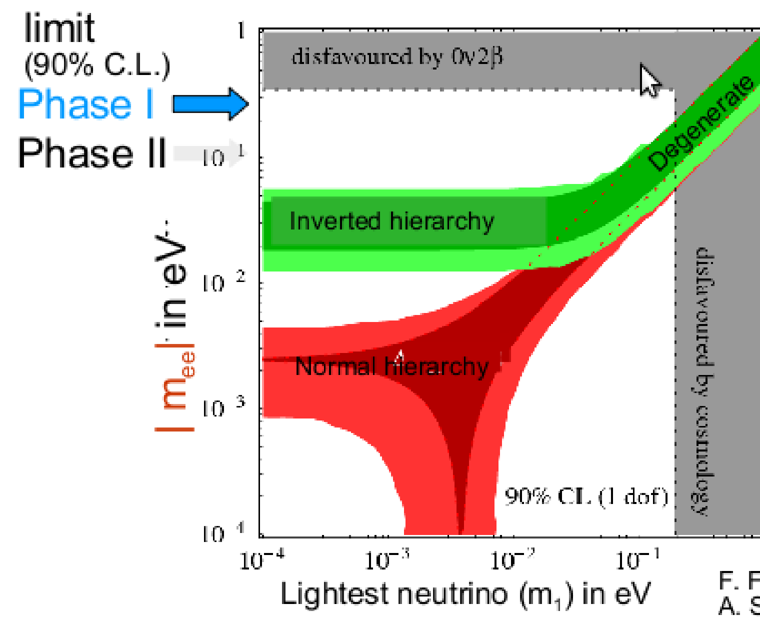
- Array(s) of $^{enr}$Ge housed in high-purity electroformed copper cryostat
- Shield: electroformed copper / lead
- Initial phase: R&D demonstrator module: Total ~60 kg (30 kg enr.)

**Physics goals:** degenerate mass range
**Technology:** study of bgds. and exp. techniques

**LoI**
- open exchange of knowledge & technologies (e.g. MaGe MC)
- intention to merge for O(1 ton) exp. ( inv. Hierarchy) selecting the best technologies teste in GERDA and Majorana

# Sensitivity of GERDA

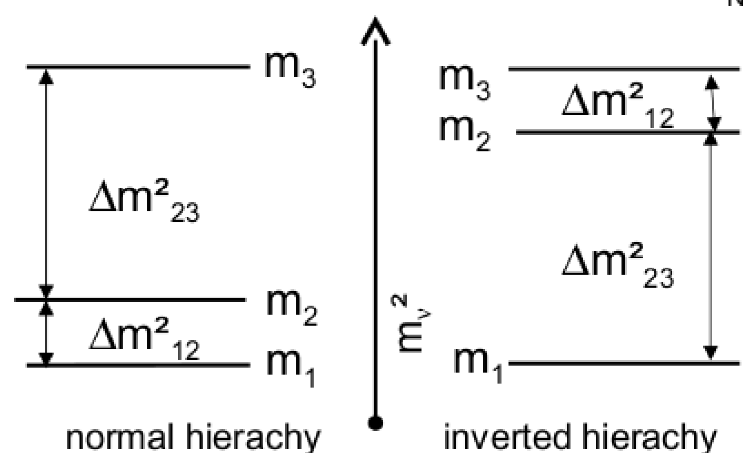


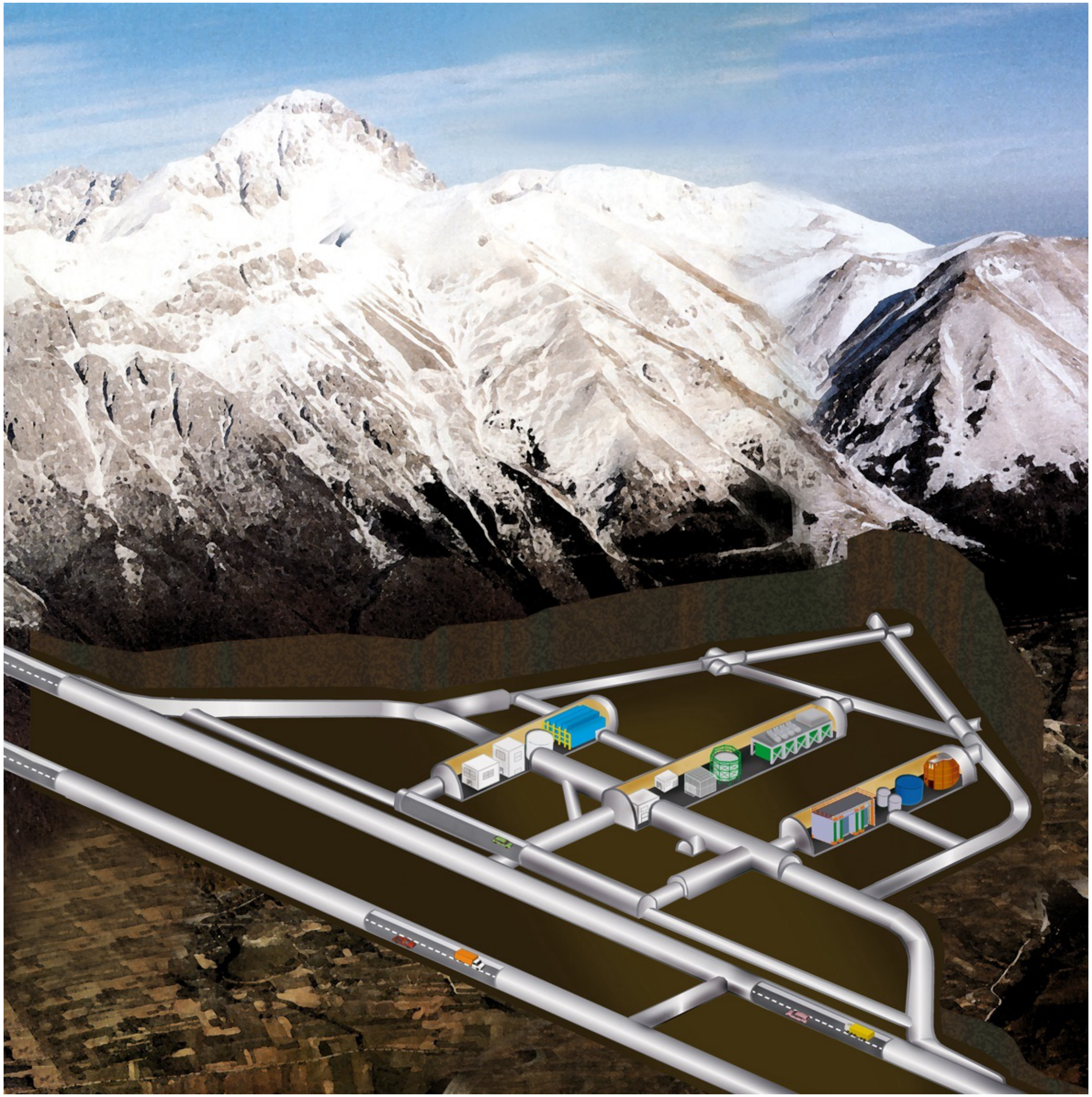

F. Feruglio, A. Strumia, F. Vissani, NPB 637

| | exposure | background |
|---|---|---|
| Phase I: | ~15 kg y | $10^{-2}$ cts/(keV kg y) |
| Phase II: | ~100 kg y | $10^{-3}$ cts/(keV kg y) |

Phase III:
joint venture with MAJORANA collaboration

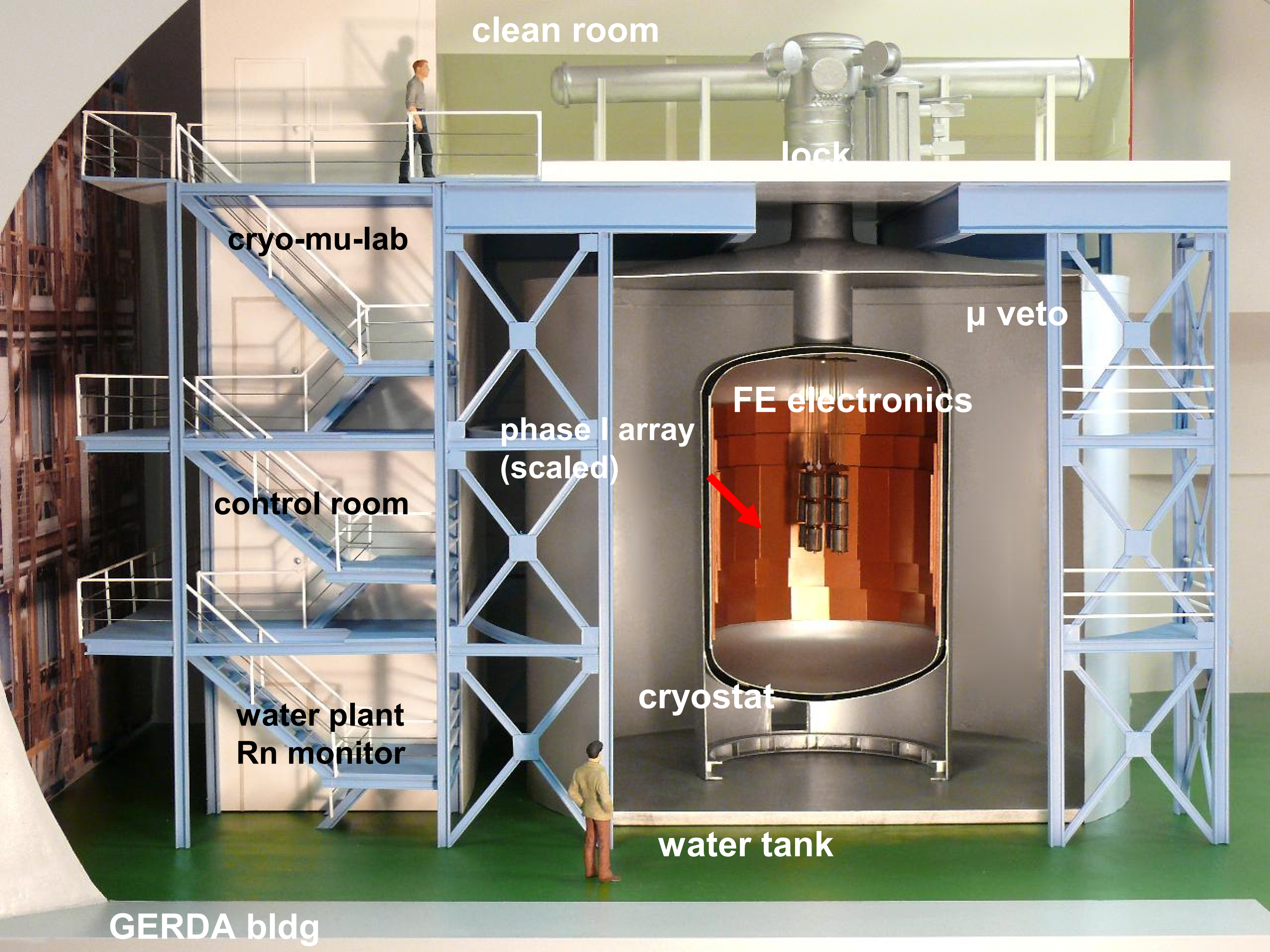


# GERDA @ LNGS, Italy



## Background reduction:

Deep underground site
3800 m.w.e.:
suppression of cosmic ray muons by factor $10^{-6}$
&
graded shielding against ambient radiation
&
rigorous material selection
&
signal analysis


clean room
lock
cryo-mu-lab
μ veto
FE electronics
phase I array
(scaled)
control room
cryostat
water plant
Rn monitor
water tank
GERDA bldg


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 $\gamma$,n,$\mu$ background ~$10^{-4}$ cts/(keV kg y)


construction of clean room
27 feb 09


clean room, active cooling device getting prepared for installation


Water tank and cryostat prior muon veto
installations

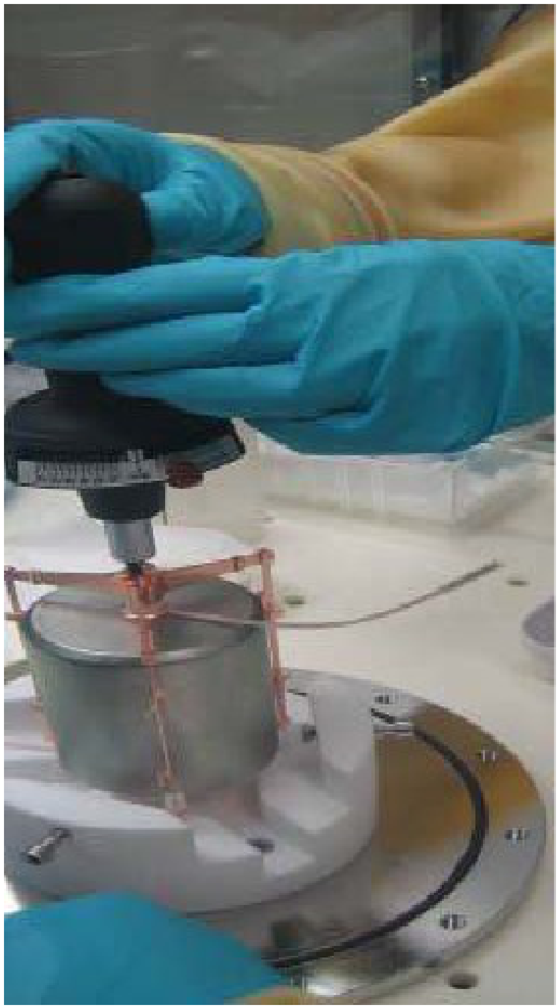

WT and cryostat with muon veto installed


"Pill box"


- **Nov/Dec.’09**: Liquid argon fill
- **Jan ’10:** Commissioning of cryogenic system
- **Apr/Mai ’10:** emergency drainage tests of water tank
- **Apr/Mai ’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
- **Soon**: start of Phase I physics data taking

# Glove-box for Ge-detector handling and mounting into commissioning lock under $N_2$ atmosphere installed in clean room

# Phase I Detectors



Bare diodes are operated in LAr
- p-type, coaxial
- low mass holder
- **Cold electronics in LAr driving 10m cable to FADC**

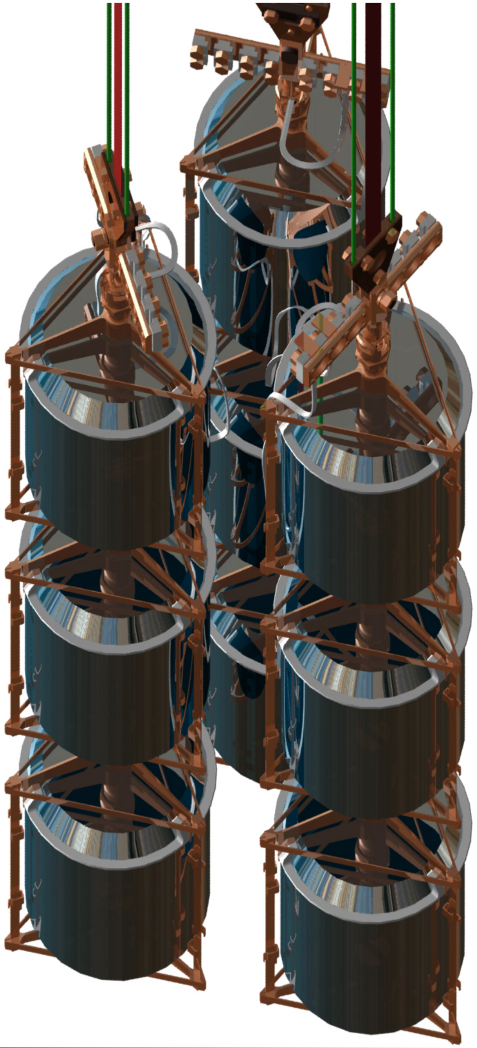
8 diodes (HdM, IGEX)
- isotopically enriched (86%)
- total mass of 17.66 kg

6 diodes (Genius-TF)
- $^{nat}$Ge detectors
- 15.60 kg

All diodes reprocessed and tested
they work stable in LAr
FWHM (1.33MeV) ~ 2.5 keV

# Phase I Detectors

## Full Phase I Detector Array



Bare diodes are operated in LAr
- p-type, coaxial
- low mass holder
- **Cold electronics in LAr driving 10m cable to FADC**

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- $^{nat}$Ge detectors
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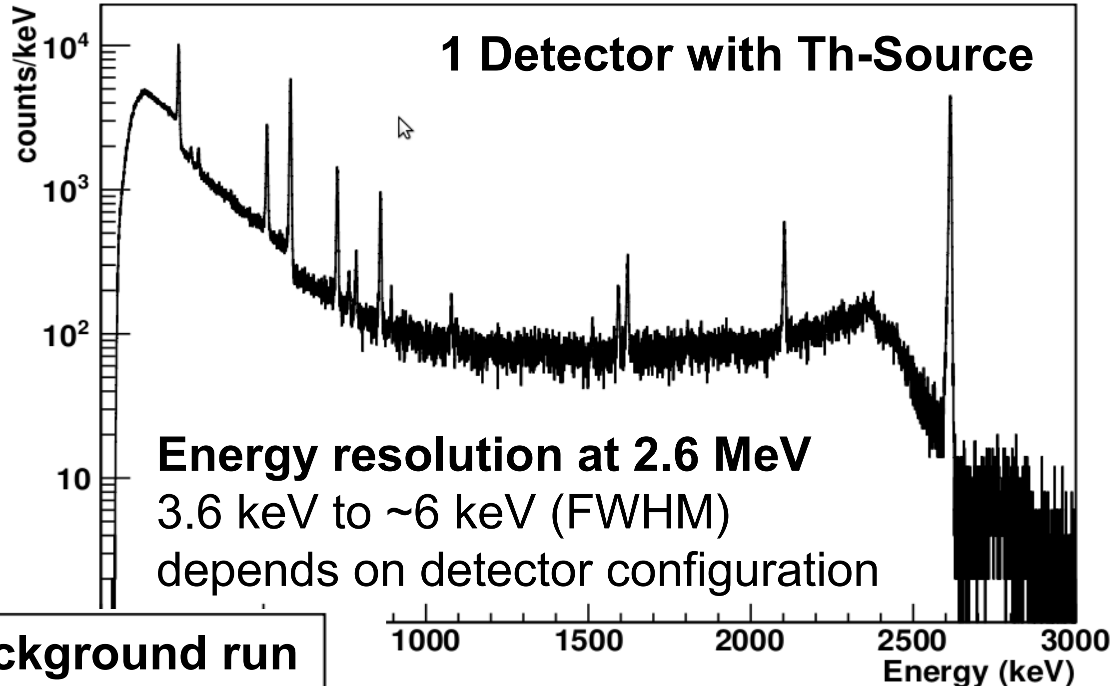
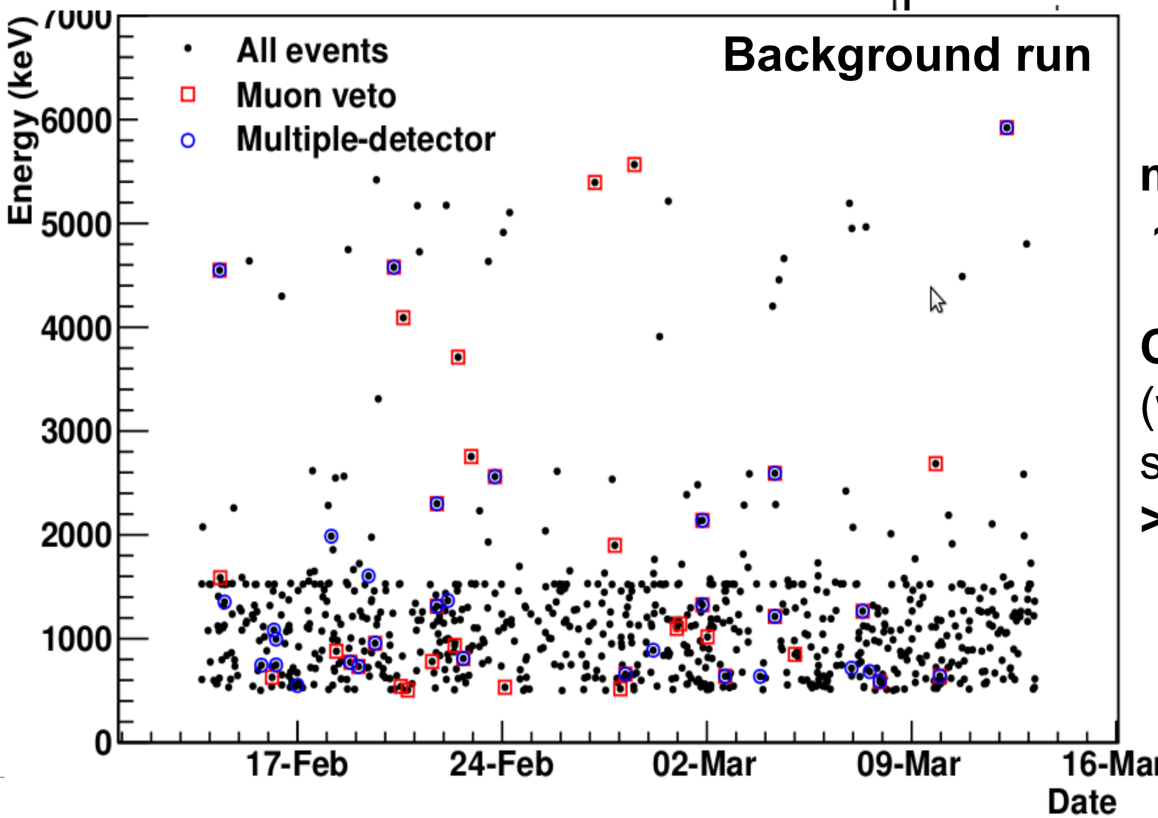
All diodes reprocessed and tested
they work stable in LAr
FWHM (1.33MeV) ~ 2.5 keV

**Commissioning Run**
- one string with three non-enriched detectors
- Exposure: 30 days
  0.587 kg * y)




**Energy resolution at 2.6 MeV**
3.6 keV to ~6 keV (FWHM)
depends on detector configuration

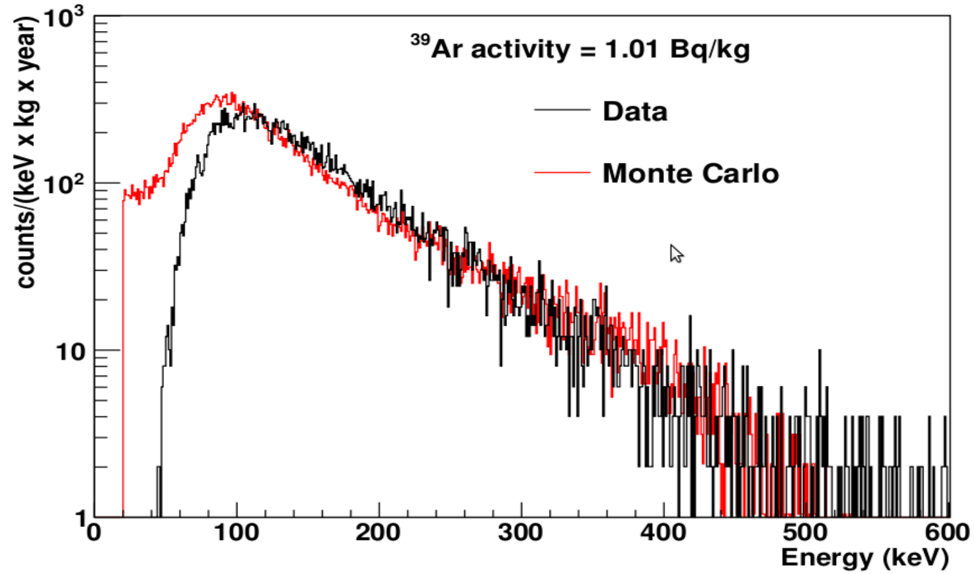


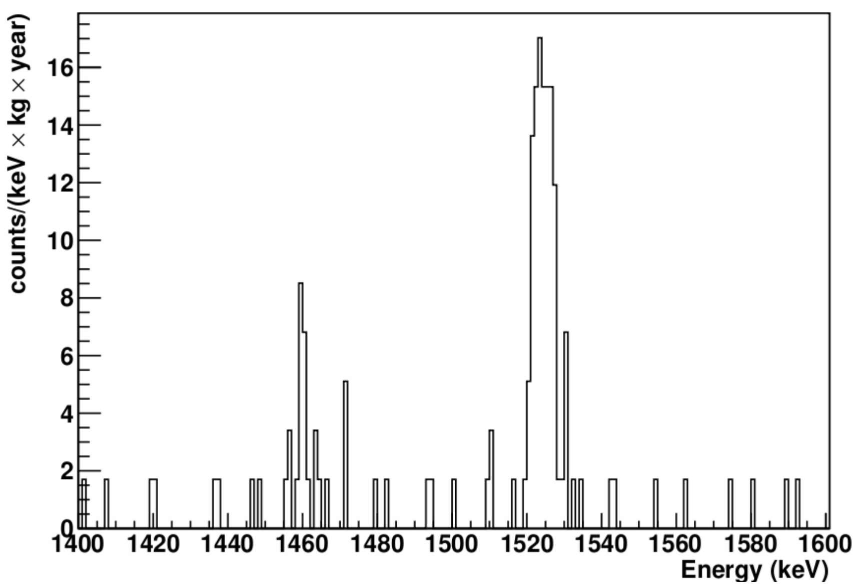

**muon induced rate**
**~ $1 \cdot 10^{-2}$ cnts/(keV·kg·year)**

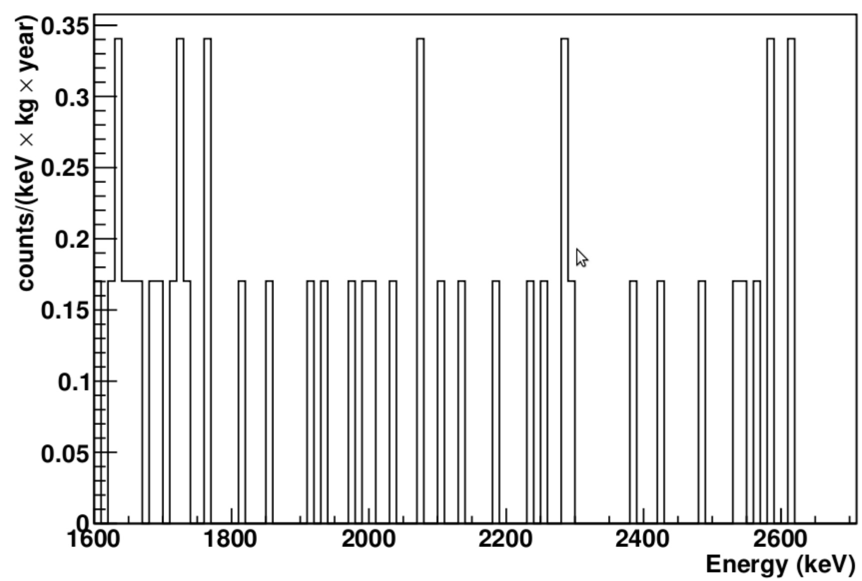
**Cosmic ray Veto efficiency**
(water Cherenkov only; plastic scintillator panels to be completed)
**>94% (preliminary)**

## Commissioning Run

- one string with
- three non-enriched detectors
- Exposure: 30 days
  0.587 kg * y)
- Anti coincidence
- Muon Veto



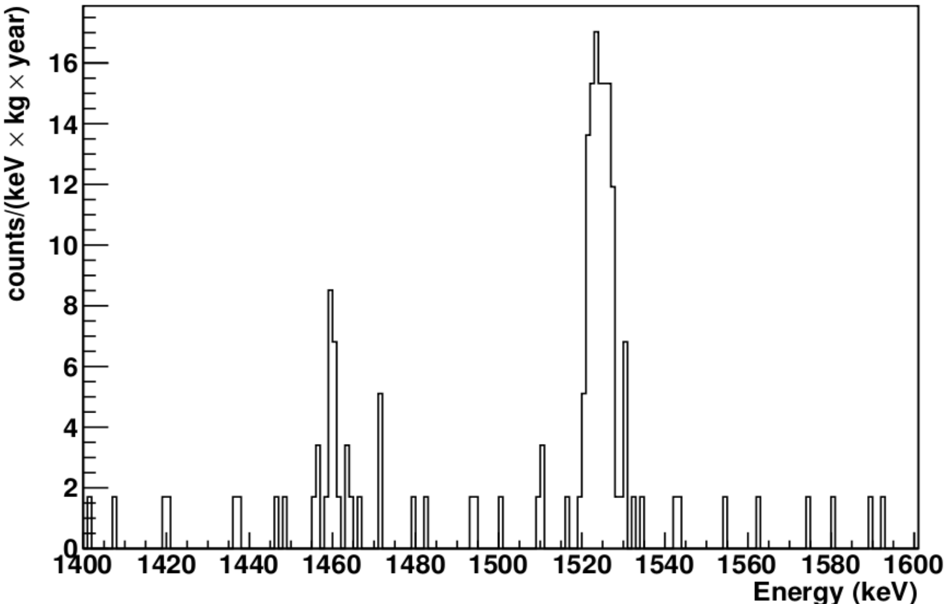



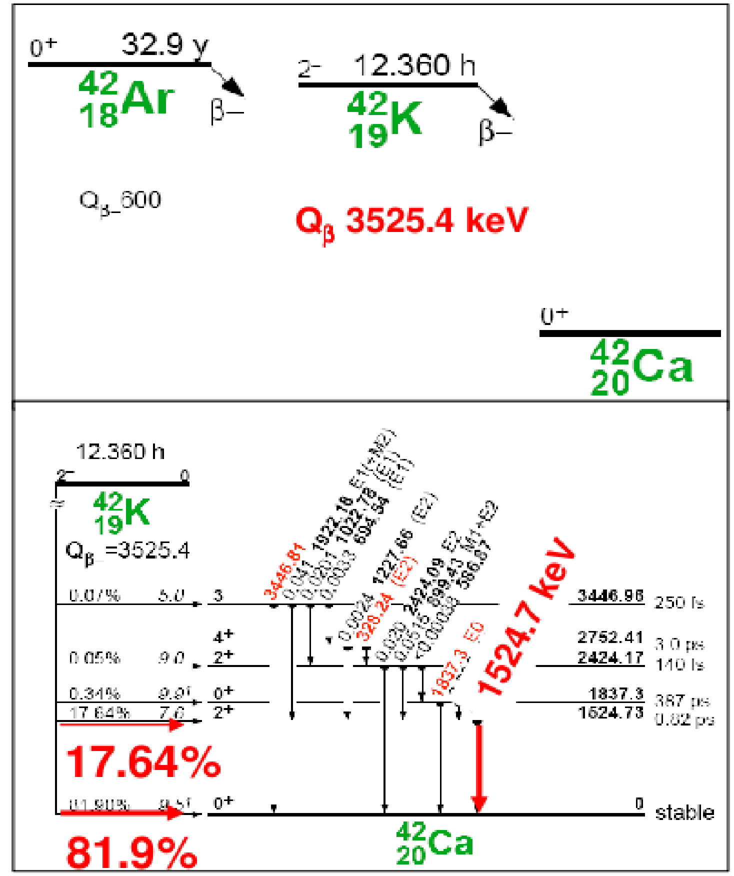



# $^{42}$Ar – The surprising background ...

**GERDA proposal:** $^{42}Ar/^{nat}Ar < 3 \cdot 10^{-21}$

[Barabash et al. 2002]



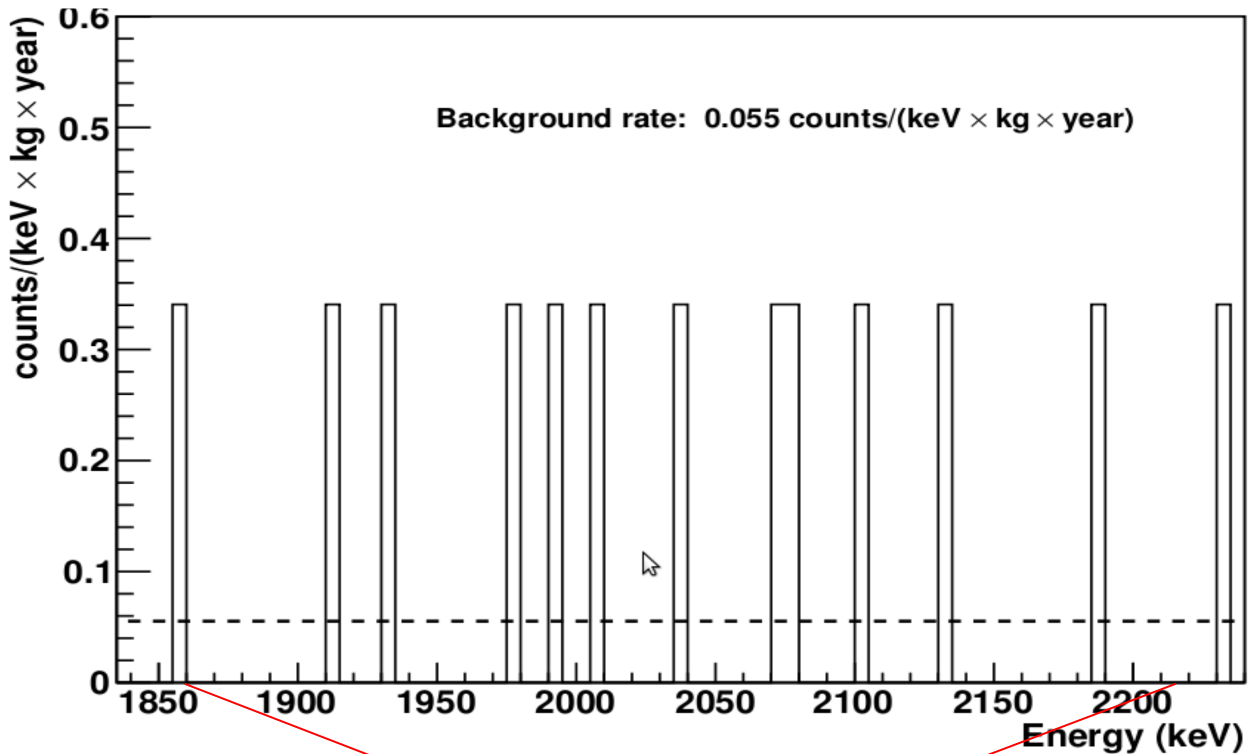




- True value could be x10 higher than limit;
- Additional enhancement of count rate due to collection of $^{42}$K ions by E-field of diodes
- If $^{42}$K decay on detector surface ⇒ bgd to $0\nu\beta\beta$

**Tests with different configurations ongoing**

## Commissioning Run

- one string with
- three non-enriched detectors
- Exposure: 30 days
  0.587 kg * y)
- Anti coincidence
- Muon Veto

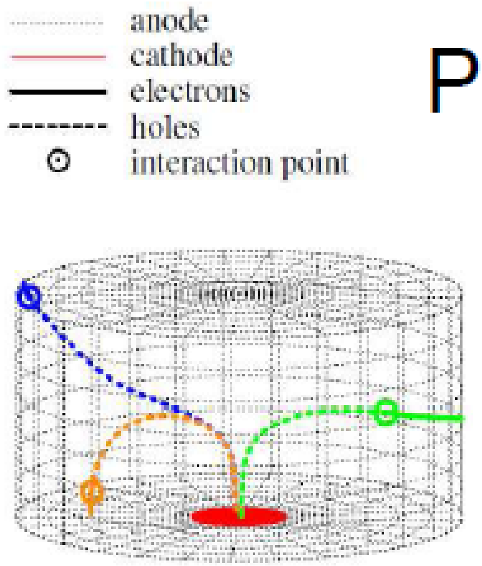


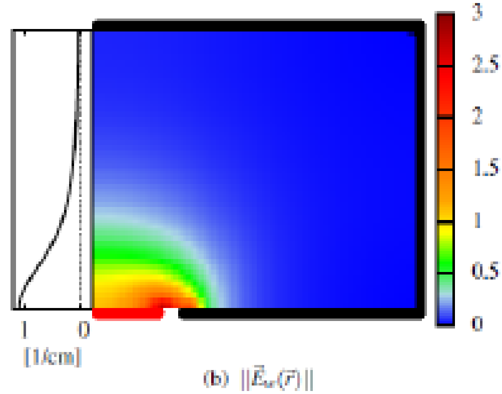

background rate in RoI ($Q_{\beta\beta}$±200 keV):
0.06 counts/(keV·kg·year)

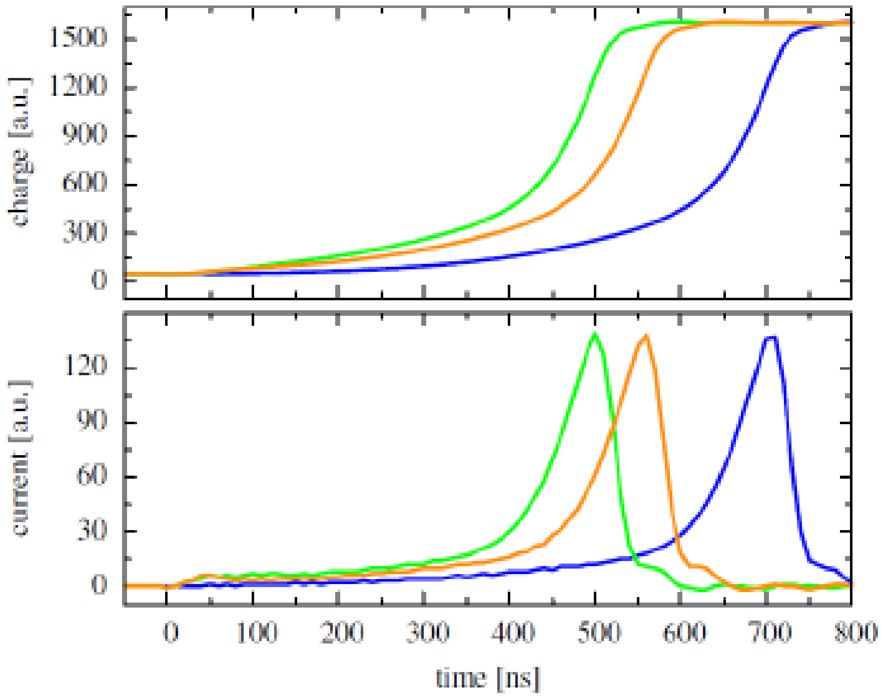
- Background rate significant lower than previous experiments (HdM, IGEX), but still higher than Phase I goals (0.01 counts/(keV·kg·year))
- Few more commissioning runs to optimize background (e.g. electric field configuration)

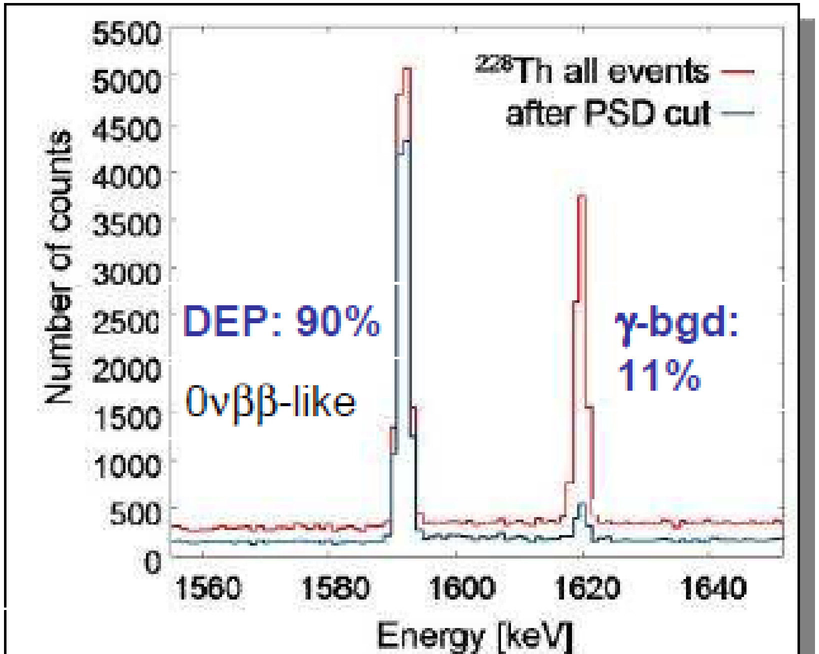
⇒ Deployment of 3 enriched detectors

# Phase II detectors



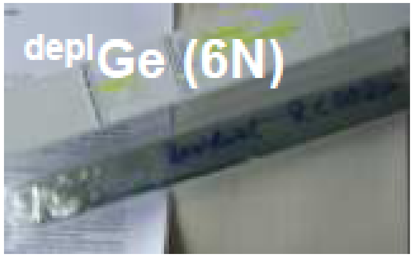



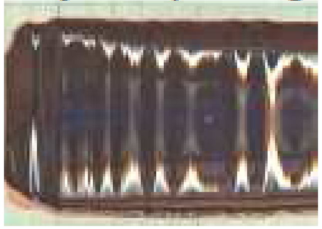

D. Budjas et al., JINST 4 P10007 (2009)

# Production of BEGe detectors from $^{enr}Ge$



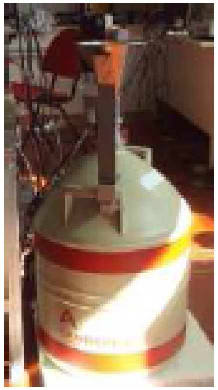


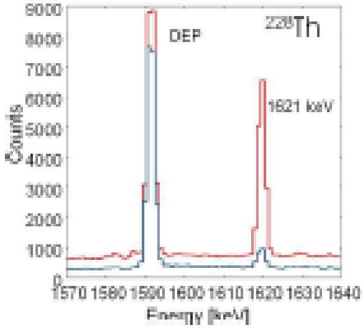
Crystal pulling



Full production chain tested with isotopic depleted germanium

crystal slice

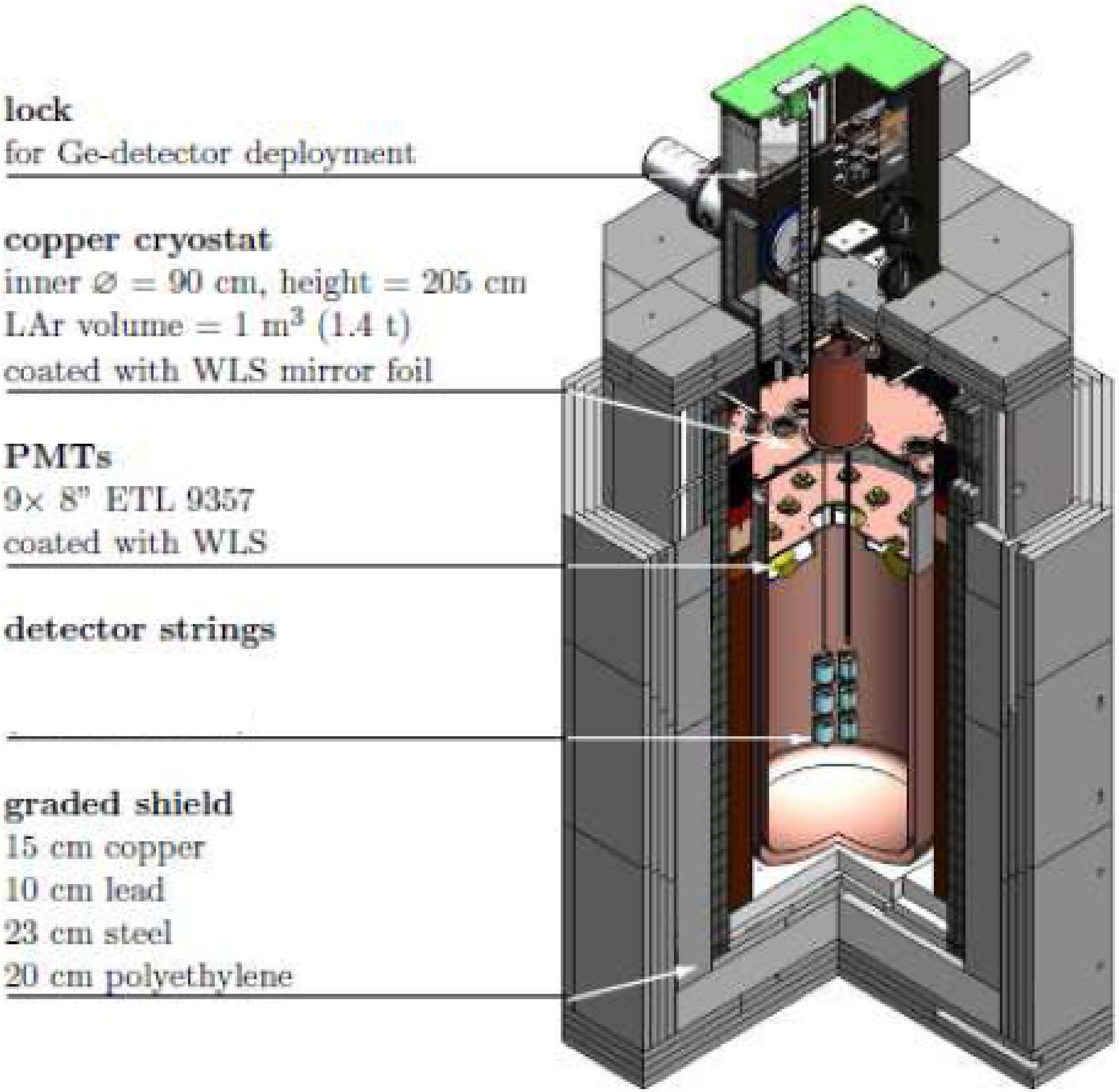





**After successful test of production production chain with $^{depl}Ge$:**

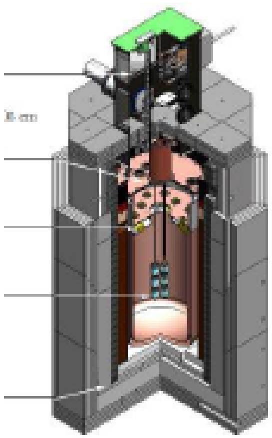
- **37.5 kg of 86% $^{enr}Ge$** (in form of GeO2) purified to **35.4 kg (94%) of 6N** (+ 1.1 kg tail = 97%);
- crystal pulling and detector fabrication under preparation

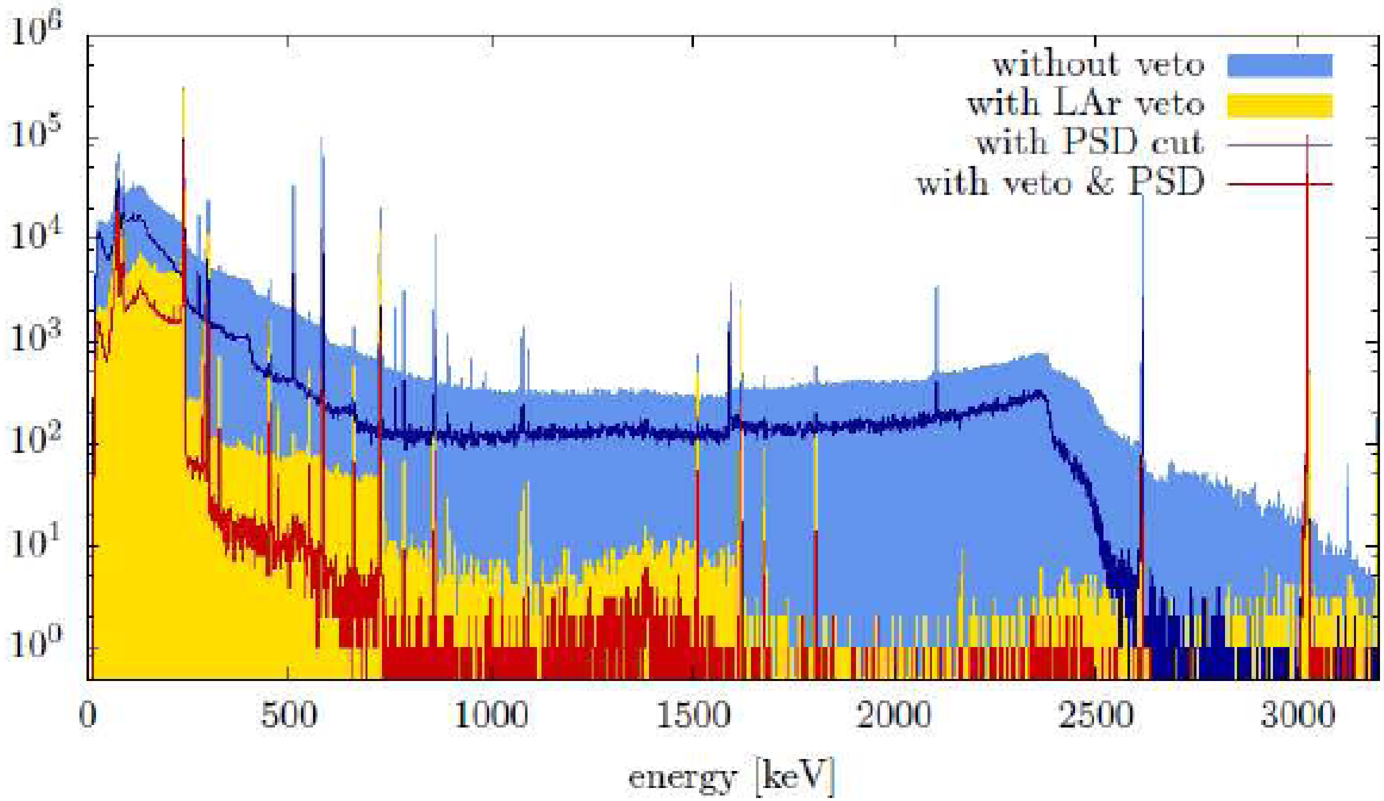
# R&D liquid argon instrumentation




Low background GERDA-LArGe test facility @ LNGS: Detection of coincident liquid argon scintillation light to discriminate background

# R&D liquid argon instrumentation






Operation of Phase II detector prototype in LArGe:
Measured suppression factor at $Q_{\beta\beta}$: ~$0.5 \cdot 10^4$ for a near $^{228}Th$ calibration source
Also: successful read out scintillation light with fibers coupled to SiPMs

# Conclusions & Outlook

- GERDA experimental installations completed successfully; cryogenic and auxiliary systems operate very stable
- Detector commissioning with non-enriched detectors started June 2010 (still ongoing)
- Initial count rate dominated by $^{42}K$ ($^{42}Ar$ progenitor) due to concentration of $^{42}K$ close to the detectors by E-field of diodes $\Rightarrow$ field-free configuration
- 12 commissioning runs with different detectors, read-out schemes, E-field configurations completed successfully still work needed to fully understand our background
- Background with non-enriched detectors currently at 0.06 cts/(keV kg year) without pulse shape analysis. Goal for Phase I: 0.01 cts/(keV kg year)
- Deployment of first string with enriched detectors soon
- Thick-window p-type BEGe detectors for Phase II: additional background discrimination by pulse shape analysis (MSE/SSE, contact-, surface events)
- Full production chain tested for BEGe Phase II detectors
- 37.5 kg of 86% $^{enr}Ge$ (in form of GeO2) successfully transformed to 35.4 kg (94%) of 6N
- Crystal pulling and detector production under preparation
- Liquid argon instrumentation shown in GERDA-LArGe test stand to be a powerful method to discriminate backgrounds (factor ~$10^3$): implementation in GERDA if needed