

# Status of the **GERDA** experiment

May 2012



**GERDA: the GERmanium Detector Array**  
to search for Neutrinoless Double Beta Decay

**A. Smolnikov** on behalf of the GERDA collaboration

*24<sup>th</sup> Rencontres de Blois, Particle Physics and Cosmology, May 28 -1 June 1, 2012, Blois, France*

The **GERDA** experiment is based on using very low background High-Purity-Germanium (HPGe) detectors.

HPGe detector fabricated from germanium enriched in  $^{76}\text{Ge}$  isotope (up to 86 %) is simultaneously the  $\beta\beta$  decay source and the  $4\pi$  detector.

The advantages of such type experiments (in comparison with the other types) are due to:

- 1) the excellent energy resolution (4 keV at 2 MeV) ,
- 2) the high purity of Ge crystals (very low intrinsic background),
- 3) and the high signal detection efficiency (close to 100%).

### Disadvantages:

- 1) not the highest  $\beta\beta$ -transition energy for  $^{76}\text{Ge}$ :  $Q_{\beta\beta}=2039$  keV (in comparison with the more promising isotopes, such as Mo-100, Nd-150, Ca-48)
- 2) only one characteristic of  $\beta\beta$  decay - sum energy of two electrons – is possible to detect.

*Nevertheless, up to now ....*



# GERDA: the GERmanium Detector Array

## Neutrinoless Double Beta Decay Experiment



Clean room:  
Detector handling

Lock system:  
Detector insertion

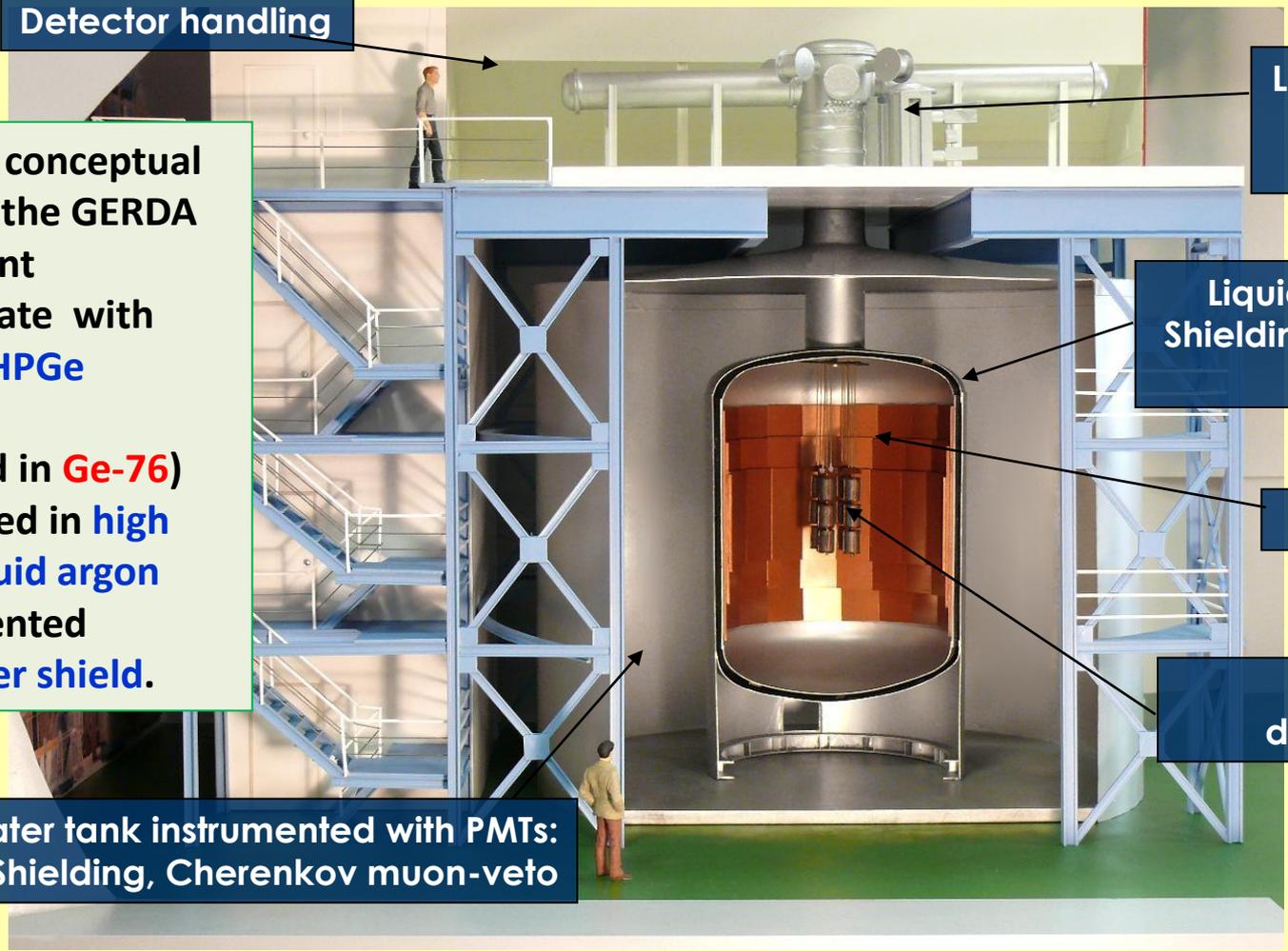
The main conceptual design of the GERDA experiment is to operate with “naked” HPGe detectors (enriched in Ge-76) submerged in high purity liquid argon supplemented by a water shield.

Liquid Ar cryostat:  
Shielding, cooling of detectors

Cu shield

Phase I detector array

Water tank instrumented with PMTs:  
Shielding, Cherenkov muon-veto



Construction of the **GERDA set up** started in 2007 in Gran Sasso National Laboratory (LNGS), Italy. Installation of the “nested type” assembly **completed in 2010** in the deep underground facility at 3400 m w.e.

- **End of 2009**: Cryostat was filled with **95 t of liquid argon**.
- Summer 2010**: Water tank was filled with **565 t of ultrapure water**.

- **June 2010**: Start of commissioning runs with **3 <sup>nat</sup>Ge detectors**



**November 2011: Start of Phase I.**

All 8 <sup>76</sup>Ge + 3 <sup>Nat</sup>Ge detectors deployed in GERDA

**Phase I detectors**

**8 enriched HPGe detectors**  
(in total ~ **18 kg of <sup>76</sup>Ge**)

from HdM and IGEX experiments,  
**3 natural HPGe detectors**  
(in total ~ **7.6 kg of <sup>Nat</sup>Ge**)  
from the Genius T-F

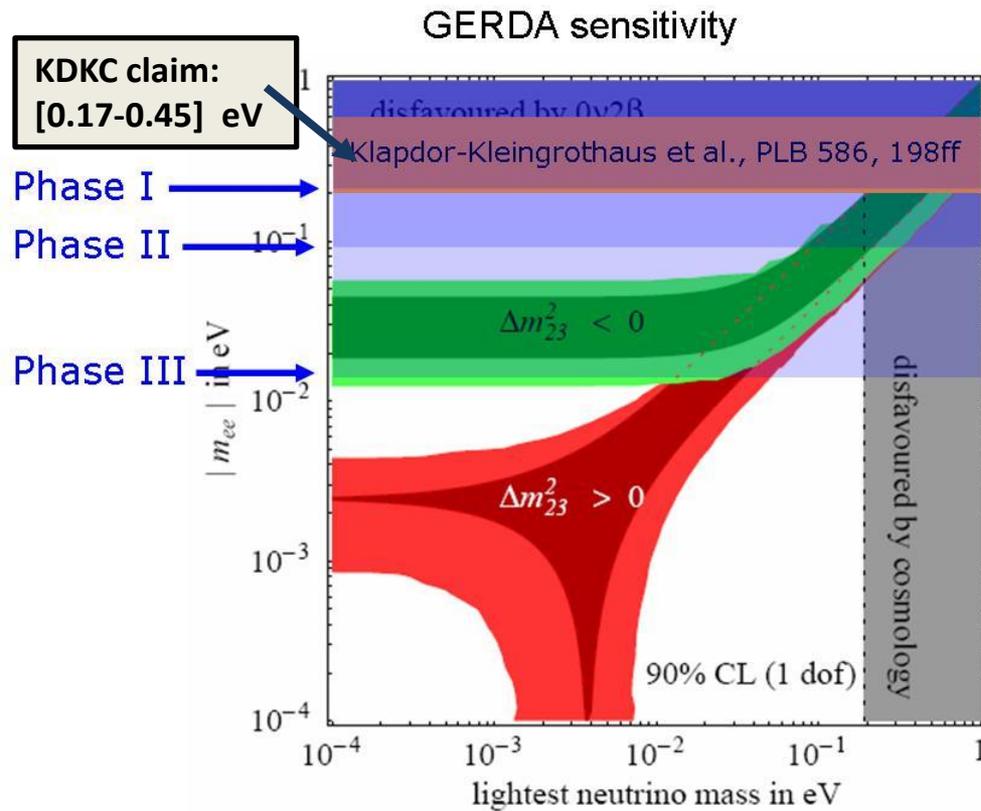
**Soon**: 5 BEGe from <sup>76</sup>Ge will be implemented (**June 2012**)

**Phase II detectors**

the new BeGe detectors (~ **25 kg of <sup>76</sup>Ge**) made from **enriched in <sup>76</sup>Ge material** will be added.

In total: about **40 kg of <sup>76</sup>Ge**

# Expected sensitivity of the GERDA experiment



## GERDA phase I :

background **0.01** cts / (kg · keV · y)

► to scrutinize KKDC result within 1 year

## GERDA phase II :

background **1** cts / (ton ! · keV · y)

► to cover the degenerate neutrino mass

hierarchy  $\langle m_{ee} \rangle < 0.08 - 0.29$  eV

## Phase III :

**GERDA –MAJORANA** collaboration

background **0.1** cts / (ton · keV · y)

► to cover the inverted neutrino mass

hierarchy  $\langle m_{ee} \rangle \sim 10$  meV

# GERDA Commissioning

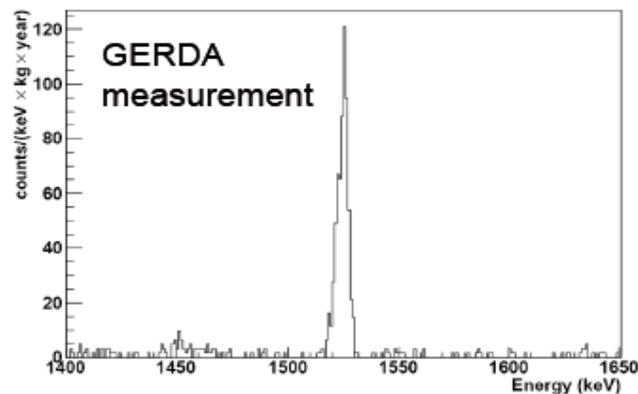
The first commissioning runs revealed a count rate due to presence of  $^{42}\text{Ar}$  in the liquid argon significantly above the rate expected on the basis of known experimental upper limits.

- production:  $^{40}\text{Ar}(,2p)^{42}\text{Ar}$  reaction in atmosphere and fall-out from atmospheric nuclear explosion

## The unexpected $^{42}\text{Ar}$ ( $^{42}\text{K}$ ) Signal

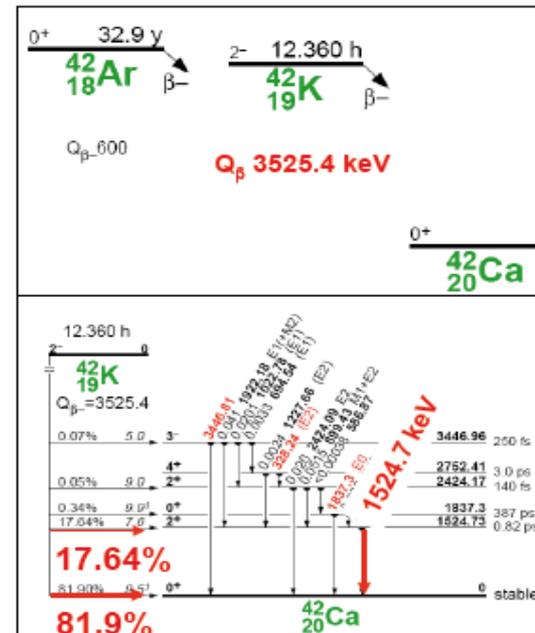
**GERDA proposal:**  $^{42}\text{Ar}/^{\text{nat}}\text{Ar} < 3 \cdot 10^{-21}$

[Barabash et al. 2002]



### Surprise:

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



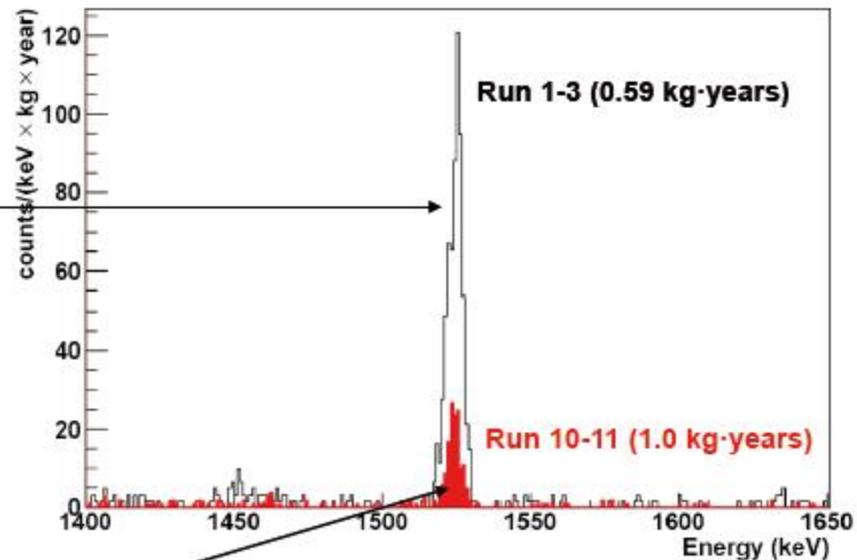
The GERDA collaboration investigated the  $^{42}\text{Ar}$  issue carefully by testing different field configurations in LAr around detectors and performed 12 runs with different fields..

## $^{42}\text{Ar}$ ( $^{42}\text{K}$ ) Count Rate & E-Field of Detectors

+HV on n+ contact  
(w/o mini-shroud)

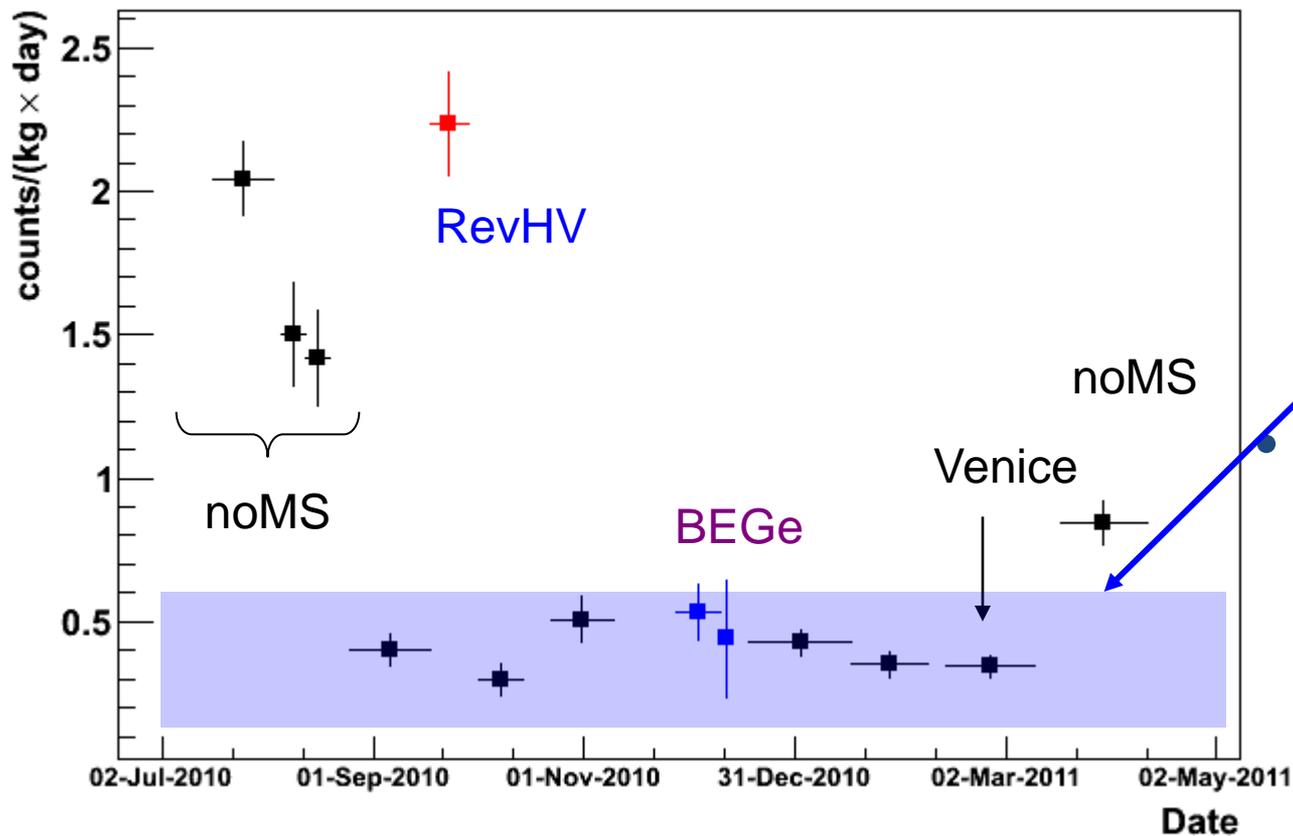


mini-shroud  
shields  
E-field &  
possible  
convections



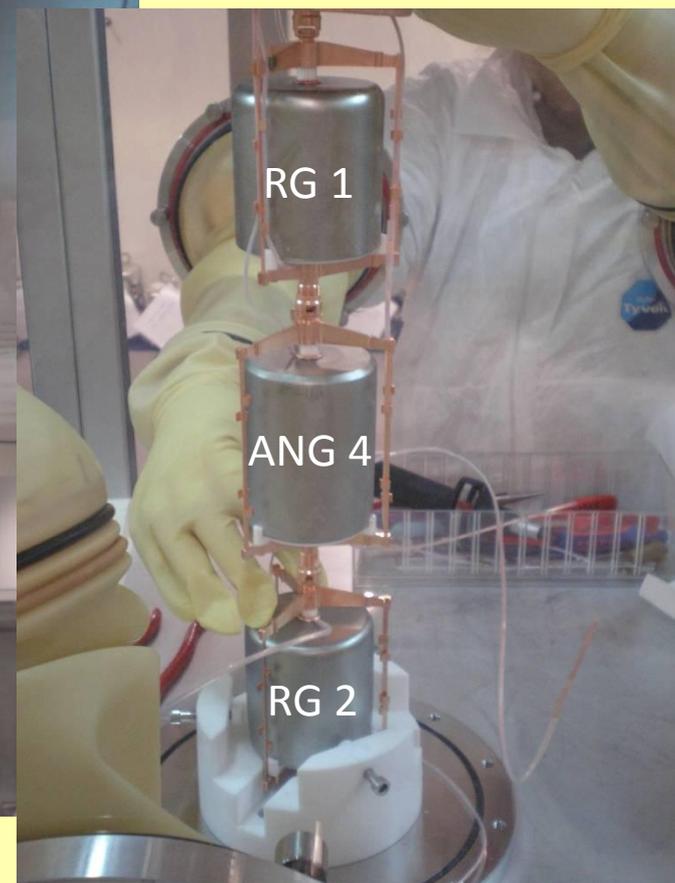
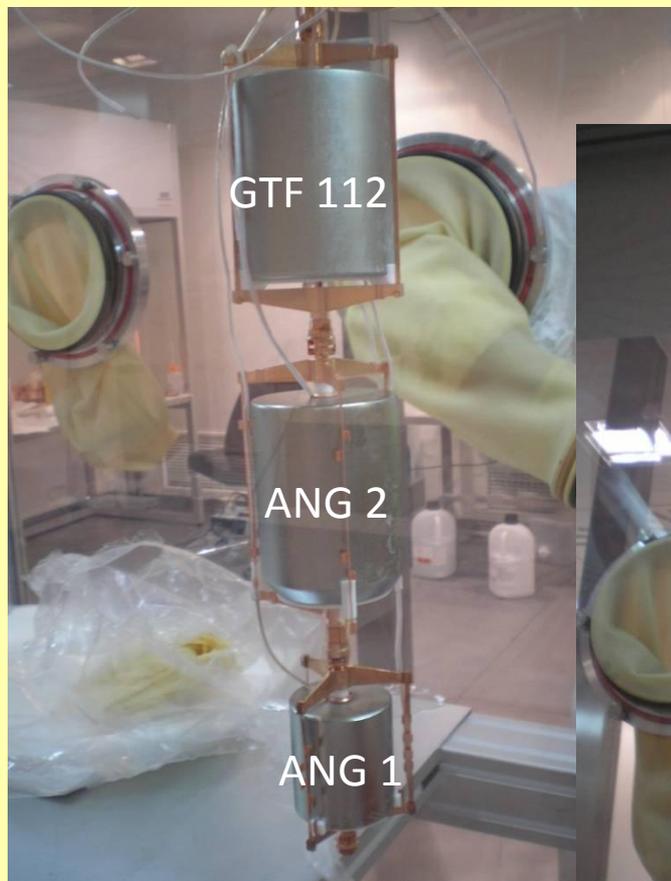
# GERDA Commissioning

Counting rate at the 1525-keV  $\gamma$  line

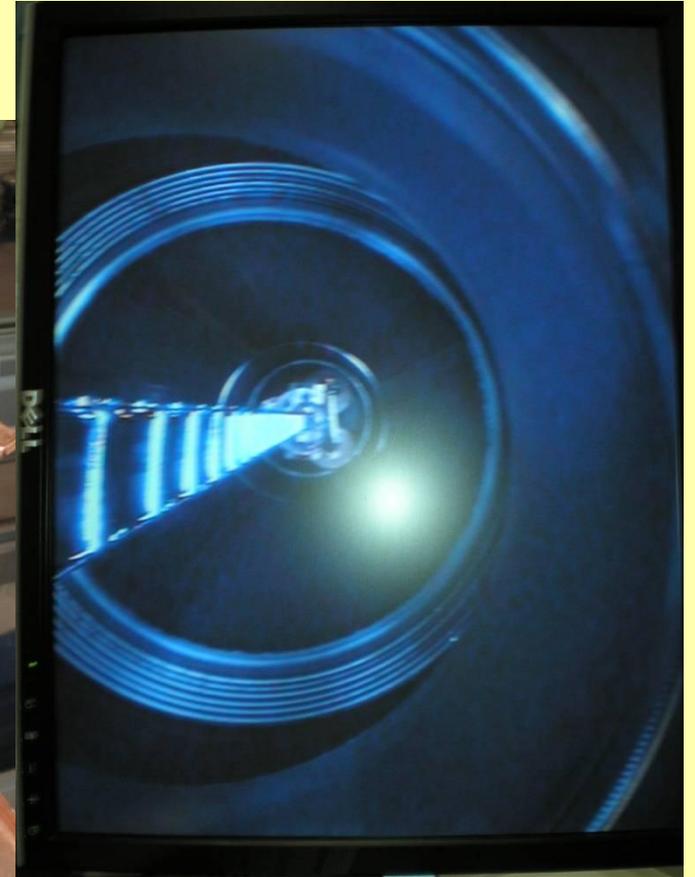


- $^{42}\text{K}$  counting rate in (quasi) null-field configurations:  $\sim$  **0.3 counts/(kg day)** Consistent with LArGe data

# October 2011: All enriched Phase I detectors deployed in GERDA



# Deployment of GERDA Phase I detectors



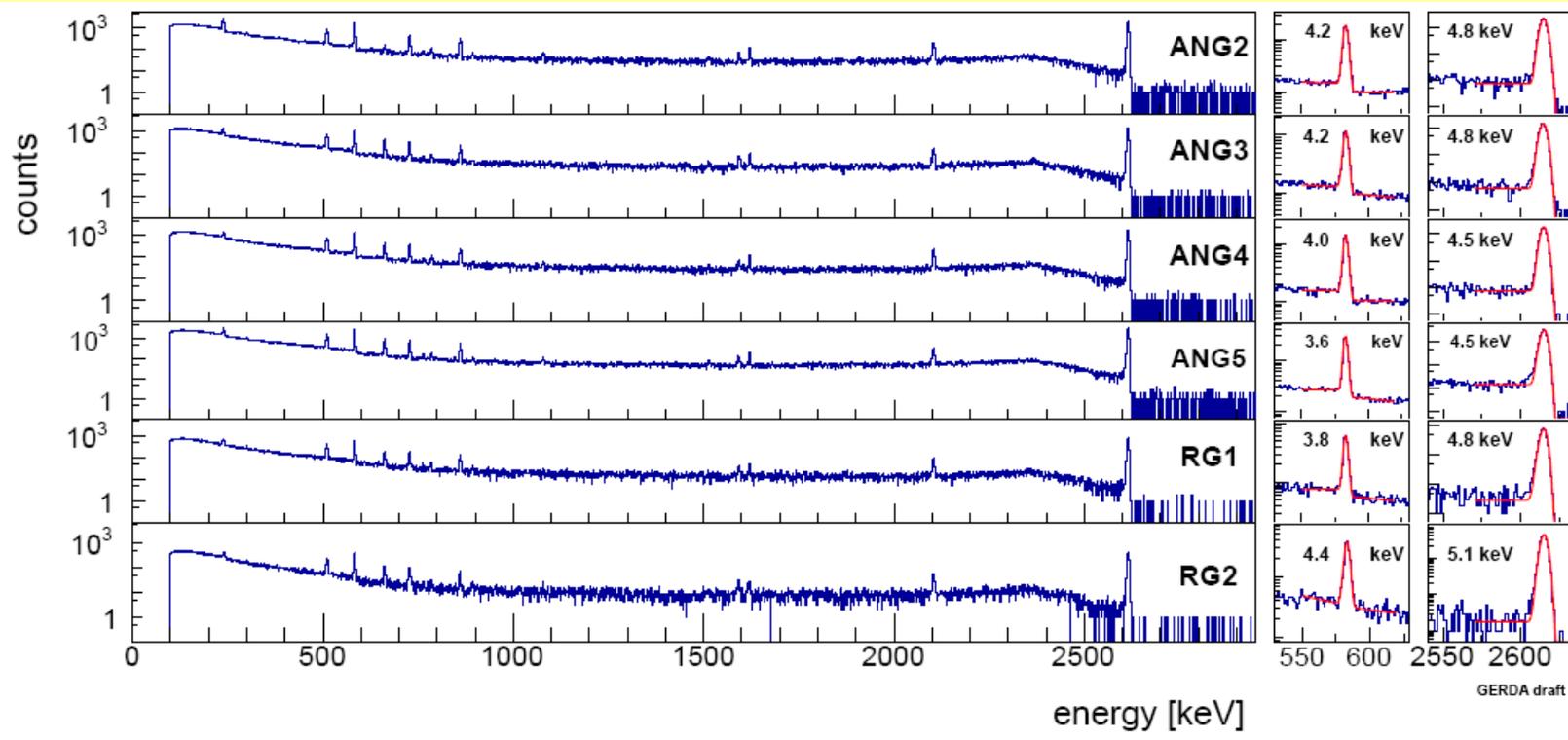
# Phase I detector performance in GERDA

Detector	Total mass, g	HV <sub>dep</sub> , V	HV, V	FWHM (2.6 MeV)		LC, pA
				MCA	FADC	
<i>Enriched</i>						
ANG 1	958	3000	4000	3.6	3.8	40
ANG 2	2833	3000	3500	4.4-4.5	4.6	20
ANG 3	2391	3000	3500	4.4-4.6	4.9	<10
ANG 4	2372	2800	3200	4.0-4.5	4.4	<10
ANG 5	2746	1000	2000	4.0	4.2	<10
RG 1	2110	4200	4500	4.4-4.5	4.8	<10
RG 2	2166	3800	4000	4.7-5.0	5.1	<10
RG 3	2087	3300	3300	5.4	6.1	1360
<i>Non-enriched</i>						
GTF 112	2957	2000	3000	3.7	4.3	<10

RG3 and ANG1 had increased LC which deteriorated with time. Removed from Physics analysis: **total mass of <sup>enr</sup>Ge: 14.6 kg**  
**GTF45 & GTF32 in single-string (AC-read out). Total mass <sup>nat</sup>Ge: 7.6 kg**

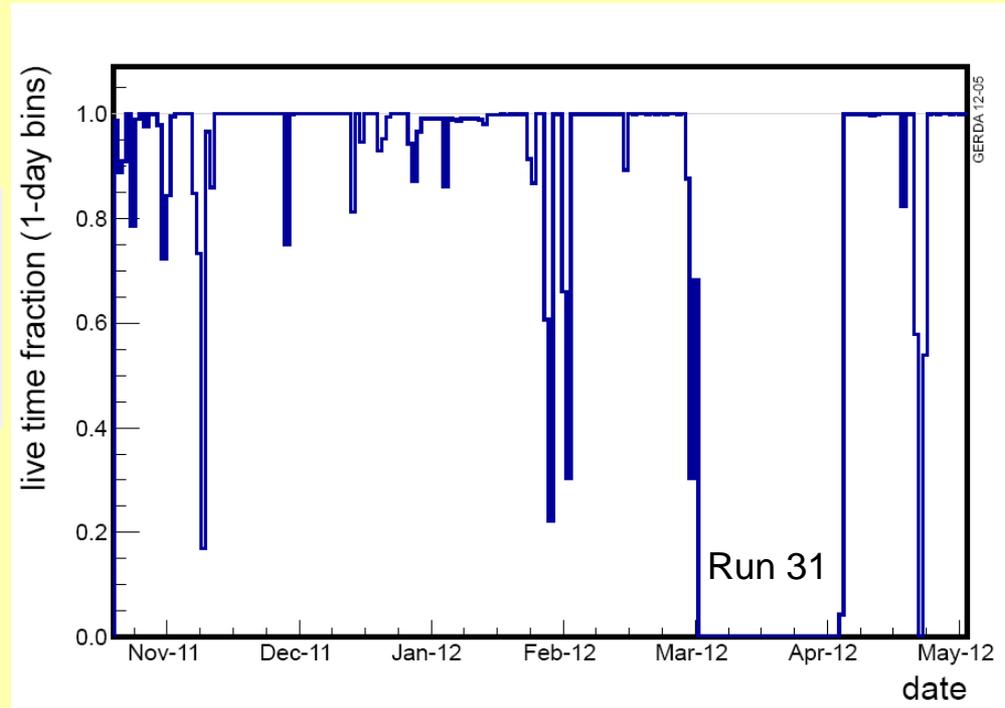
# Phase I detector performance in GERDA

## Energy calibration with $^{228}\text{Th}$ source



# 9 November 2011: Start of physics data taking of GERDA Phase I

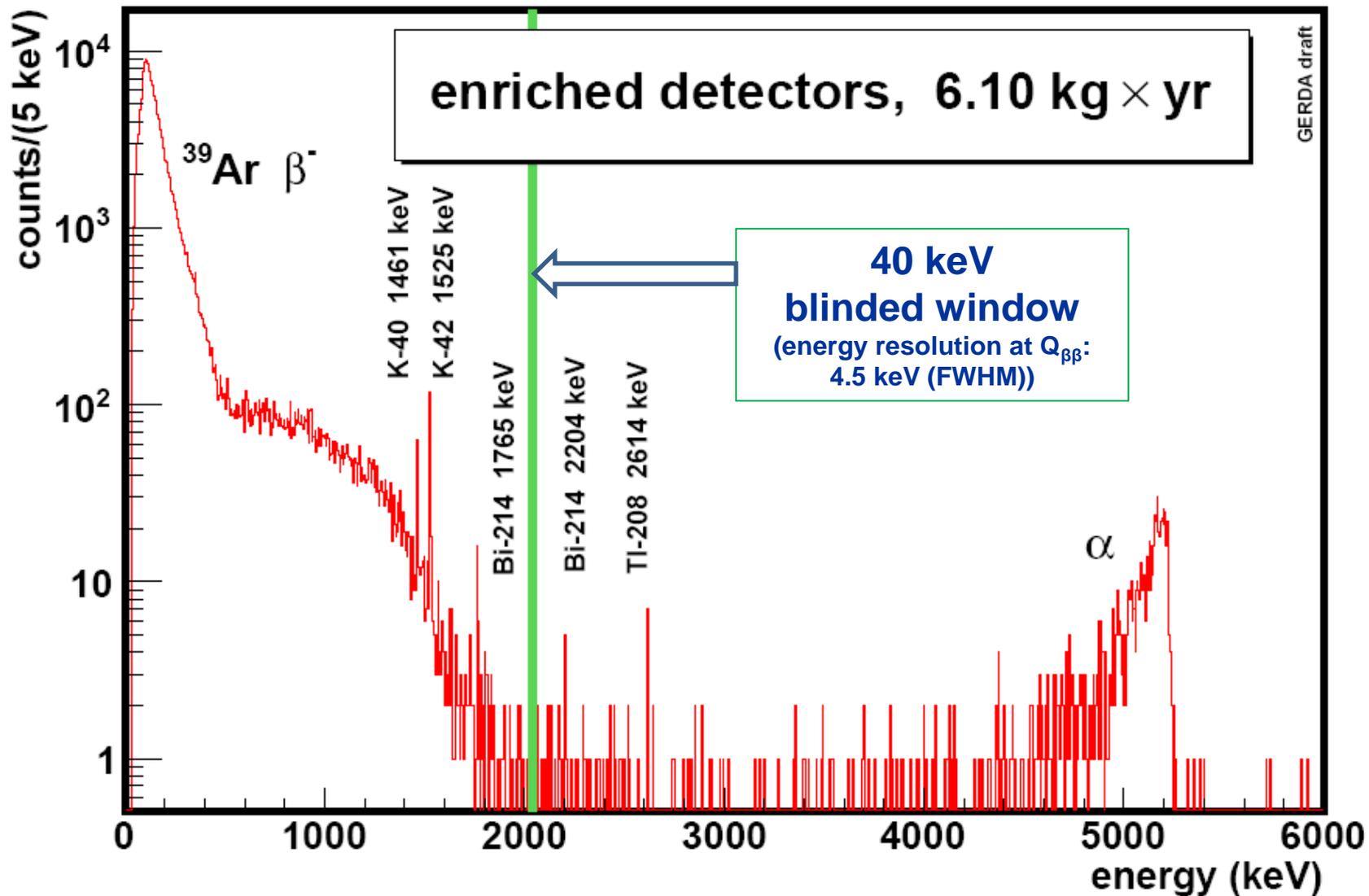
Live time: 152.49 days  
Duty cycle: 92.6%  
(without Tech.Run 31)

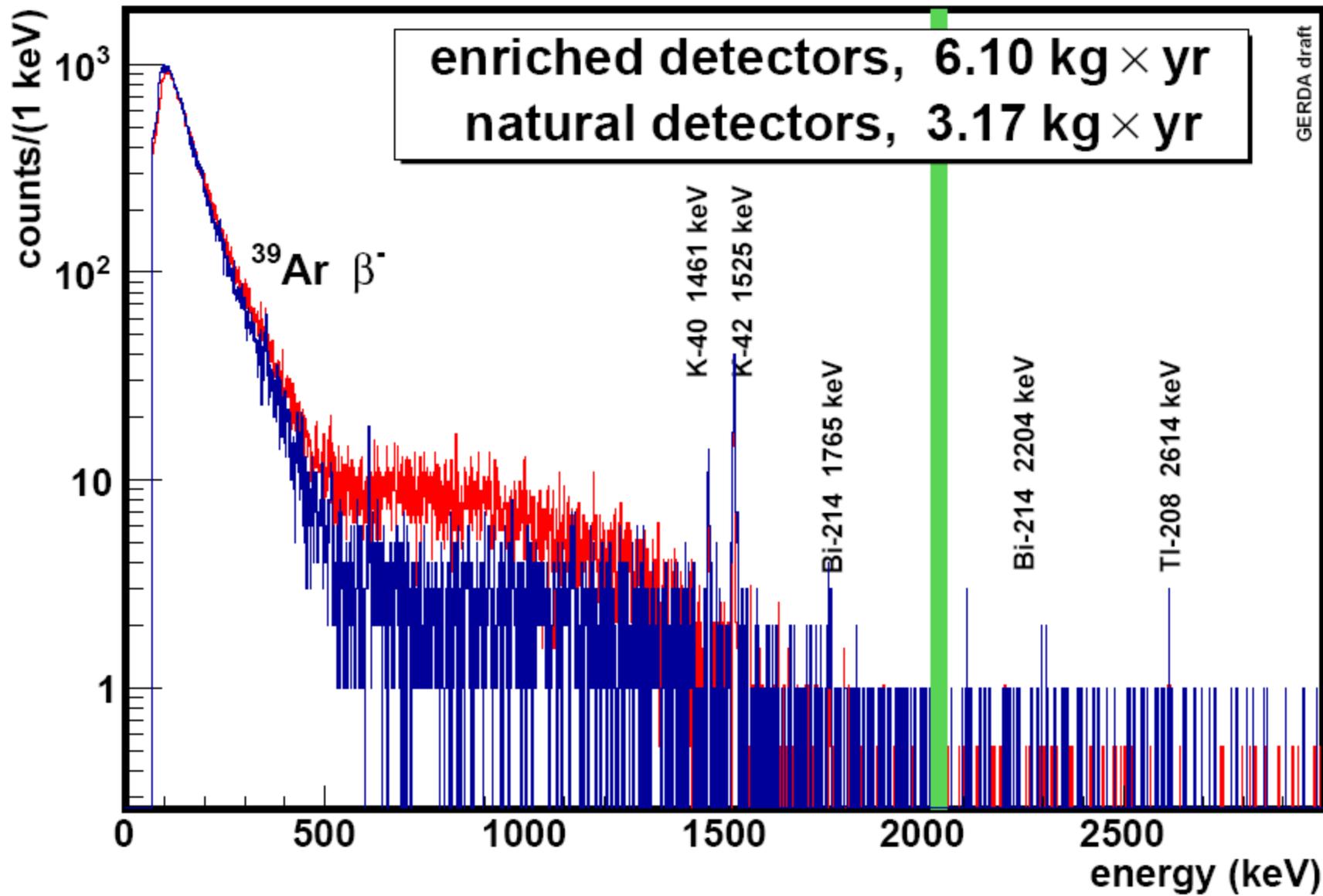


Enriched Ge  
mass:  
**14.63 kg**

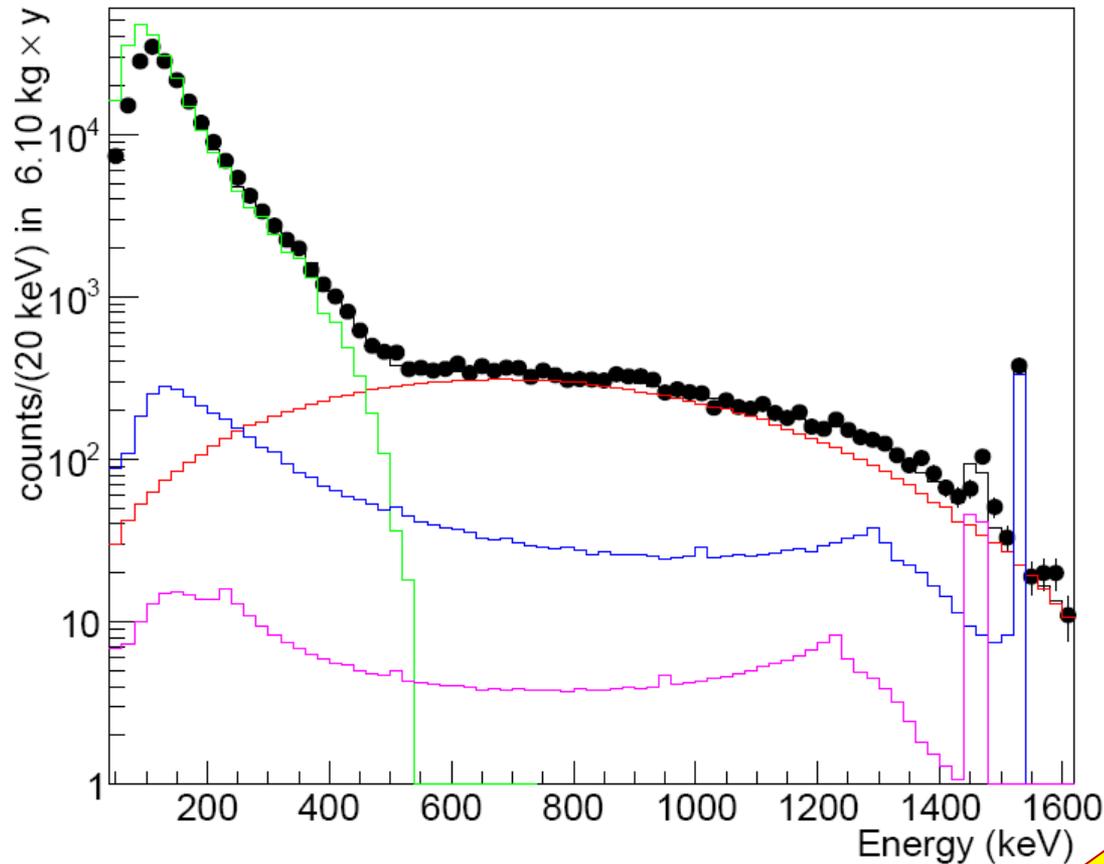
Natural Ge  
mass:  
**7.59 kg**

- Data in this talk from **9.11.2011** until **22.05.2012**:
- **6.104 kg\* year** (enriched) and **3.168 kg\*year** (natural)
- Duty cycle until today: > 90%
- **Since 11.1.2012**: Events with energy between 2019 and 2059 keV are filtered out from the files for analysis ("**blind analysis**")





# $2\nu\beta\beta$ of $^{76}\text{Ge}$



Experimental spectrum,  
**6.1 kg\* year** (enriched)

$2\nu\beta\beta$   $^{76}\text{Ge}$ ,  
 $T_{1/2} = 1.84 \cdot 10^{21}\text{y}$

$^{42}\text{K}$ : homogeneously distributed  
decays in LAr (normalized to peak)

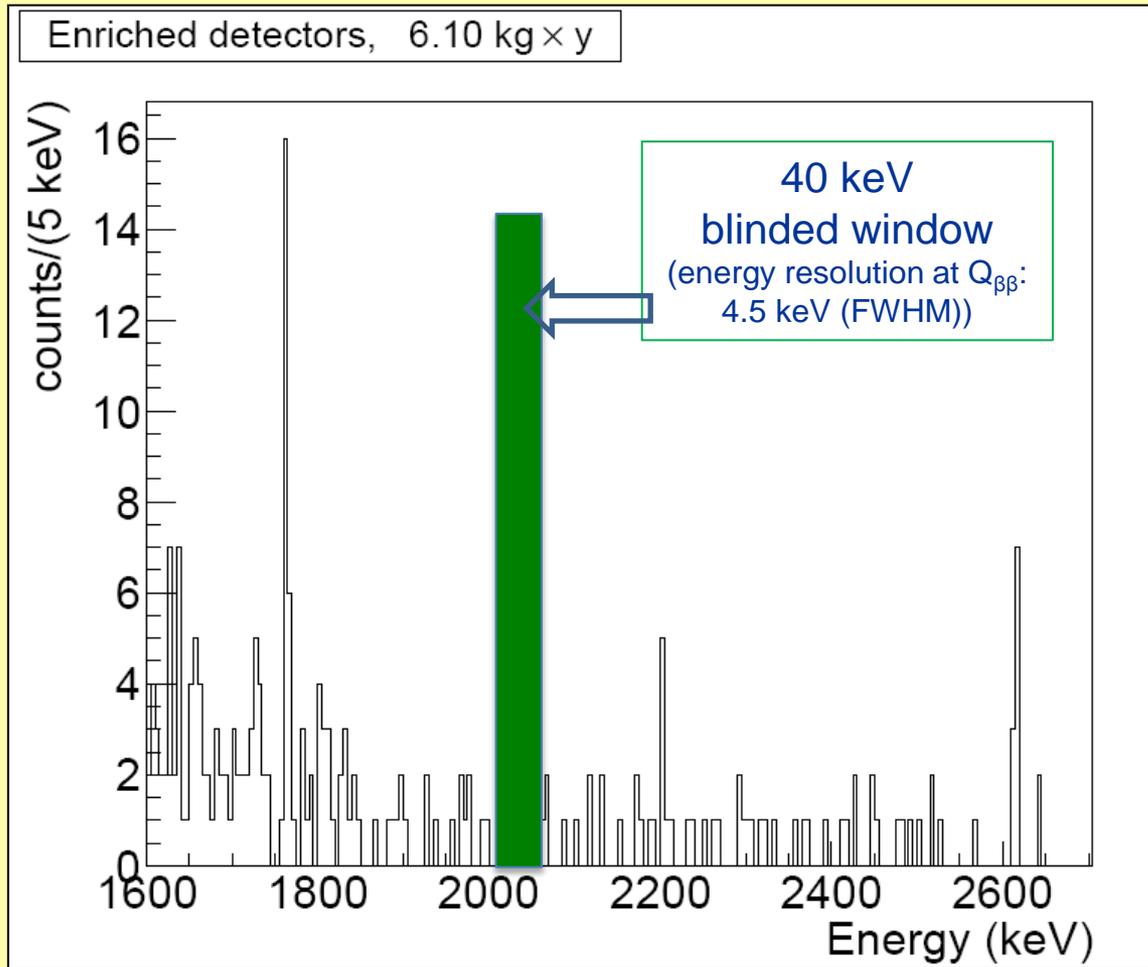
$^{40}\text{K}$ : simulated decays in detector  
holders (normalized to peak)

$^{39}\text{Ar}$ : 1.01 Bq/kg from WARP  
[NIM A574 83-88 (2007)]

preliminary

$T_{1/2}(2\nu\beta\beta \text{ } ^{76}\text{Ge}) = (1.84 \pm 0.05 \text{ stat} \pm 0.10 \text{ syst}) \cdot 10^{21}\text{y}$

# Zoom into ROI of background spectrum of the $^{76}\text{Ge}$ detectors



Candidate background contributions at  $Q_{\beta\beta}$  ROI:

- $\gamma$ 's from  $^{214}\text{Bi}$  and  $^{208}\text{Tl}$ ,
- degraded  $\alpha$ 's from  $^{210}\text{Po}$  (and possibly  $^{222}\text{Rn}$  and progenitors)
- $\beta$ 's from  $^{42}\text{K}$
- possibly from internal contaminations like  $^{60}\text{Co}$ .

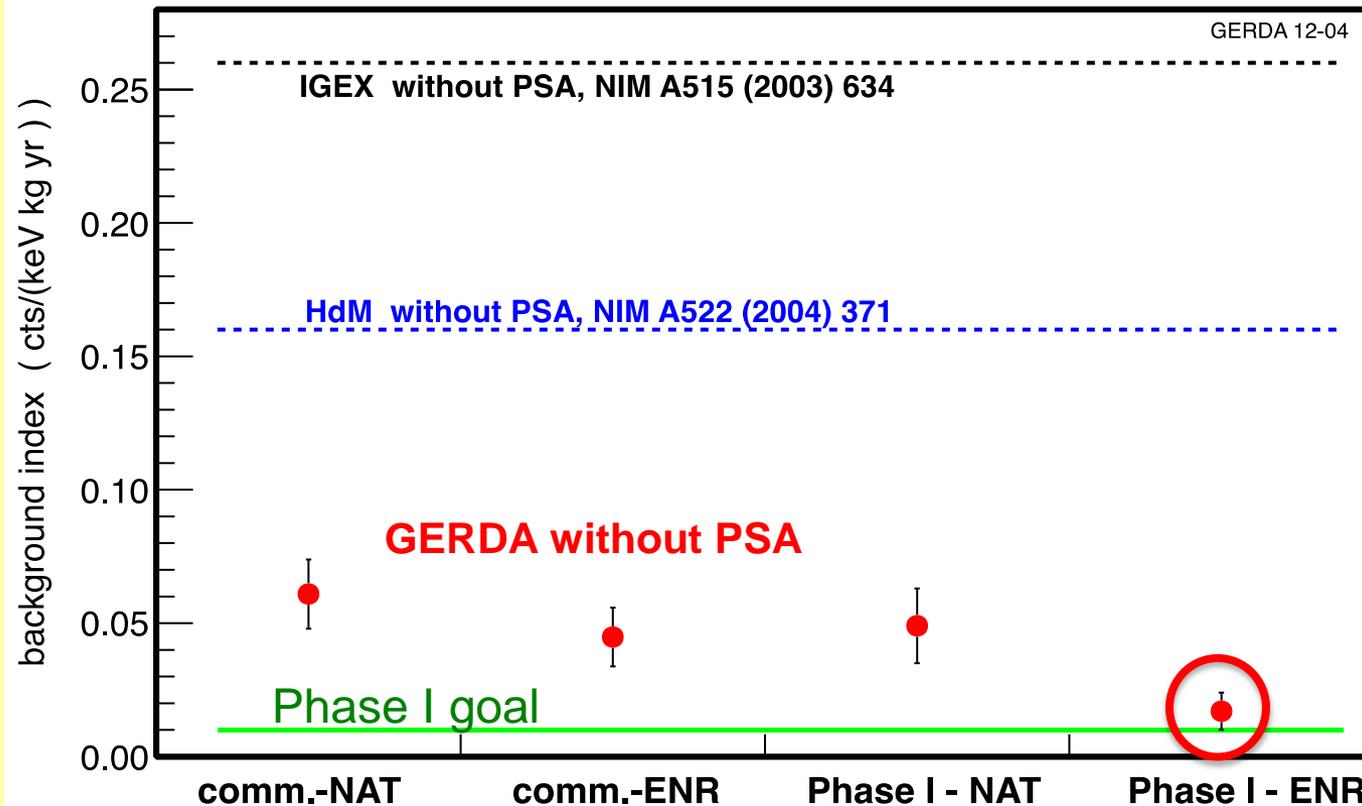
Quantitative estimate of their relative contributions is ongoing

Background index at  $Q_{\beta\beta} \pm 200$  keV :

$$\text{enr Ge: } 0.020 \pm 0.006 \pm 0.004 \text{ cts}/(\text{keV} \times \text{kg} \times \text{y})$$

Note: Pulse Shape Discrimination not applied yet

# Background comparison



→ factor ~ 8 lower than previous experiments (HdM, IGEX)

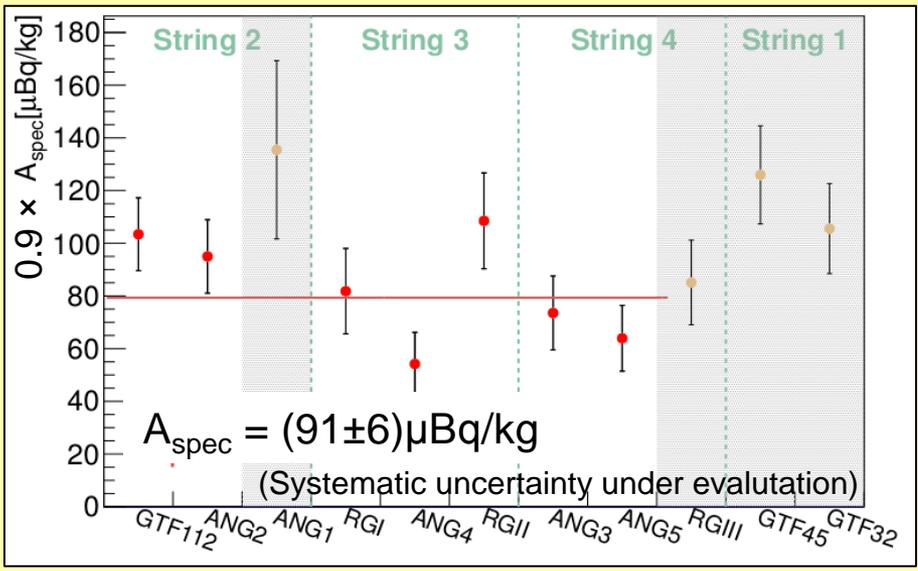
→ after applying PSA (as it was already shown additional factor of background reduction > 2) **Phase I goal will be reached soon !**

# Two independent measurements of $^{42}\text{Ar}$ concentration in LAr

preliminary

## GERDA:

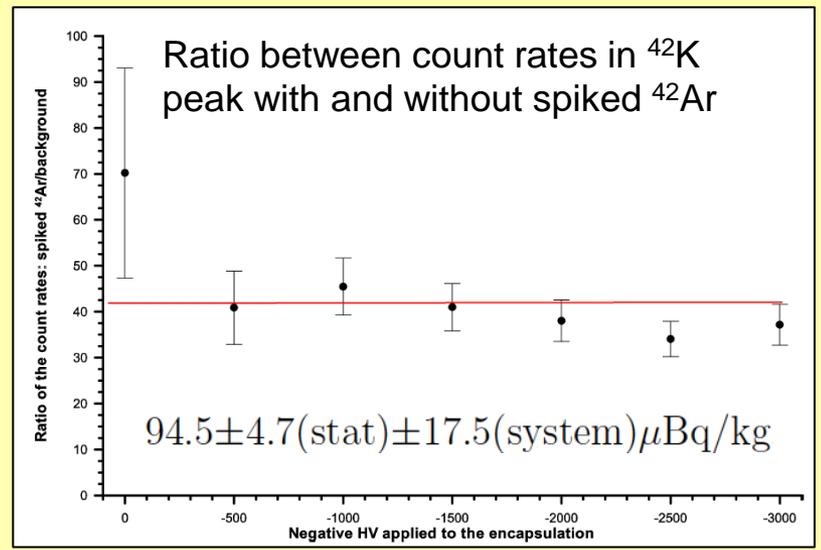
Measurement in best 'E-field free' configuration & comparison MC



preliminary

## LArGe test facility:

LAr spiked with known amount of  $^{42}\text{Ar}$  & measurements at different HV



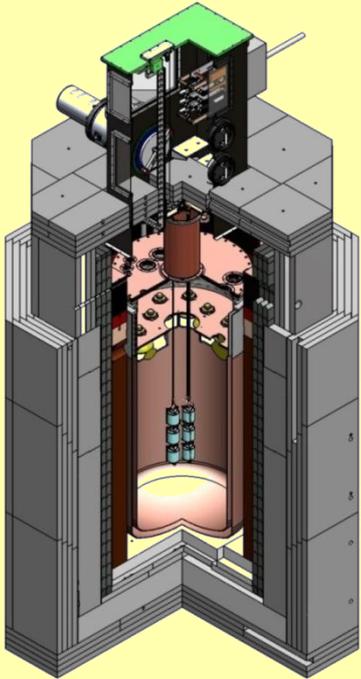
Previous best limit:  $< 4.3 \cdot 10^{-21}$  g/g (or  $< 41 \mu\text{Bq/kg}$ ) (90% CL), V.D. Ashitkov et al. 2003

# R&D for GERDA Phases II and III

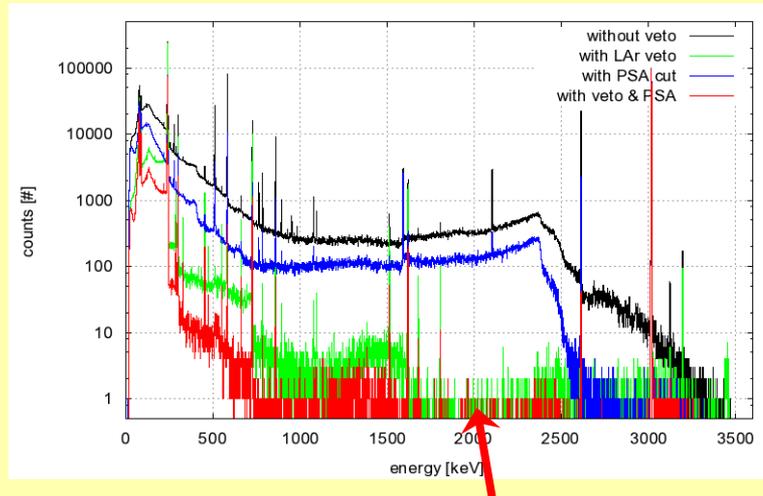
## LArGe test facility + BEGe detectors

### The LArGe Setup with 1.4 tons of LAr

9 PMTs: 8" ETL9357;  
 Reflector: VM2000  
 & wavelength shifter;  
 Cryostat:  $\varnothing$  90 cm x 205 cm,  
 volume: **1000 liter**;  
 Shield: Cu -15 cm, Pb -10  
 cm, Steel- 23 cm, PE- 20 cm.



The LArGe set up was assembled at LNGS in 2010 and operates with naked Ge detectors immersed in 1.4 tons of LAr served as scintillation veto. Efficiency of the LAr scintillation veto and pulse shape discrimination (PSD) of signals from the BEGe detector inside the LArGe were tested and optimized. It was shown that the internal background from Th-228 suppressed in LArGe by factor 5000 after applying LAr veto and PSD.

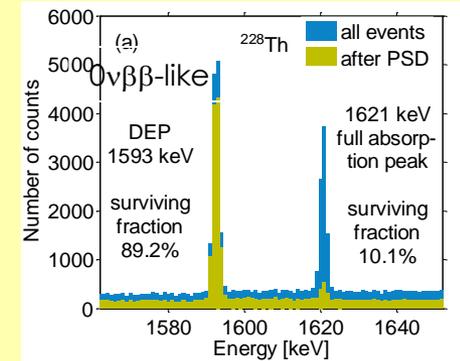


ROI – reduction factor > 5000

### First naked BEGe inside LArGe



**BEGe parameters in LArGe:**  
 High voltage 4000 V  
 Leakage current ~ 4 pA  
 FWHM @ 1.33 MeV 1.8 keV  
 mass 878 g



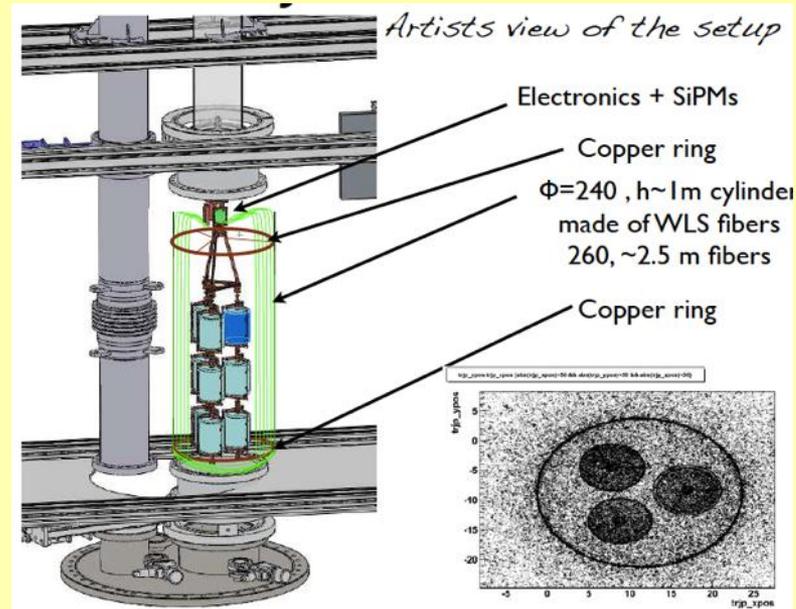
First results obtained with LArGe + BEGe successfully demonstrate possibility of considerable background reduction for GERDA Phase II and III by using LAr scintillation veto + BeGe PSD.

# LAr VETO instrumentation for Phase II

## PMT option (Ø500)

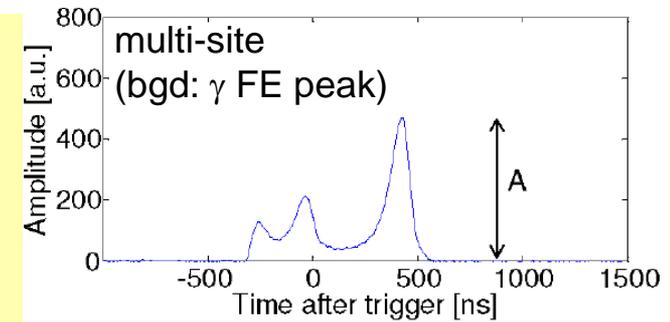
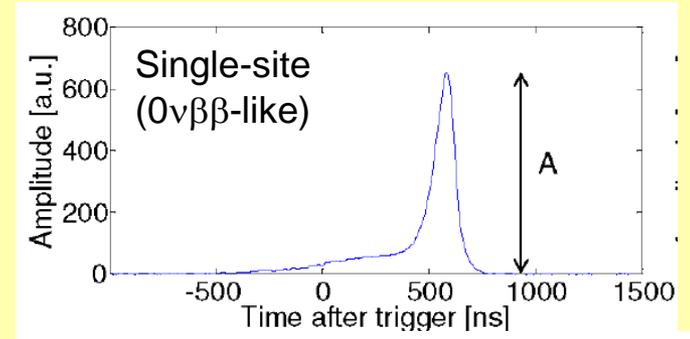
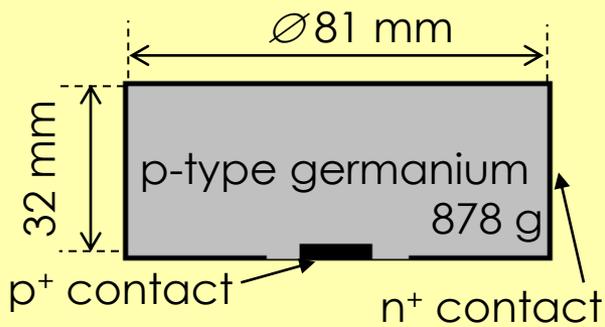


## SiPM & scintillating fiber option (Ø250)

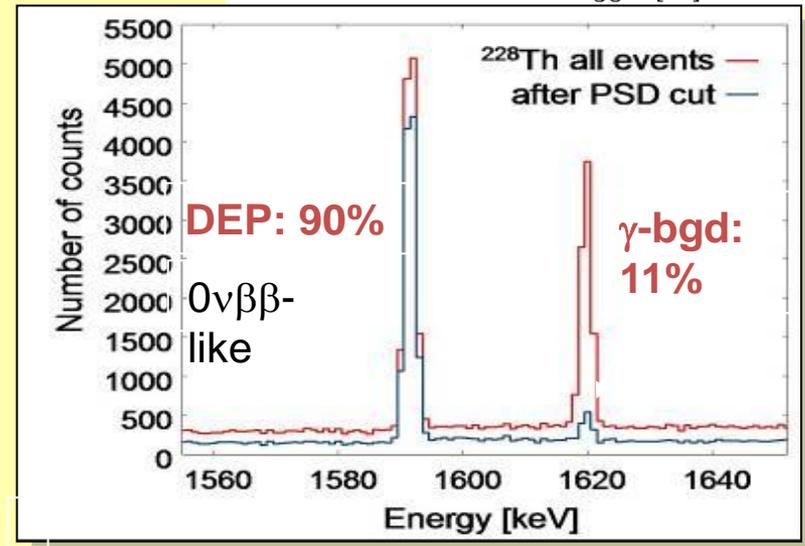
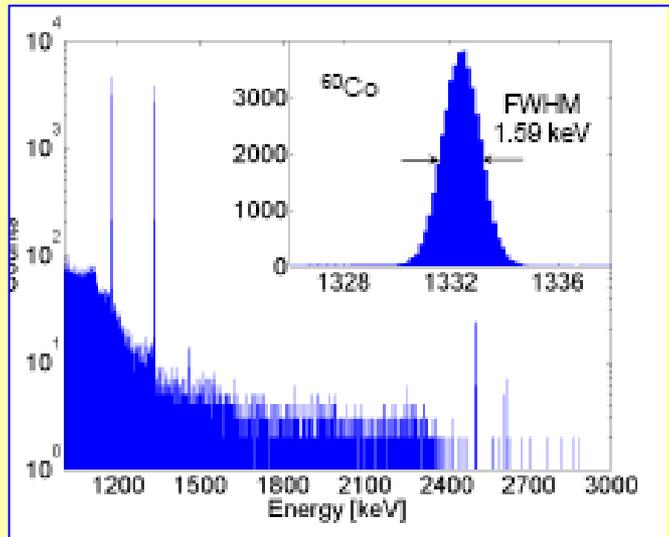


- 3<sup>rd</sup> option: R&D on large area avalanche photodiodes or UV sensitive SiPMs on custom low activity substrates has started
- MC campaign to compare competing options ongoing
- Hardware for PMT and fiber options available & prototype/test setup construction started
- Aim: down-selection in summer

# Phase II detectors - BEGe



FWHM @ 59.5 keV    0.49 keV  
 FWHM @ 1.33 MeV    1.59 keV

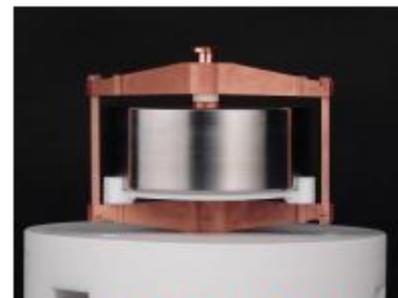


# BEGe production (from $^{76}\text{Ge}$ )



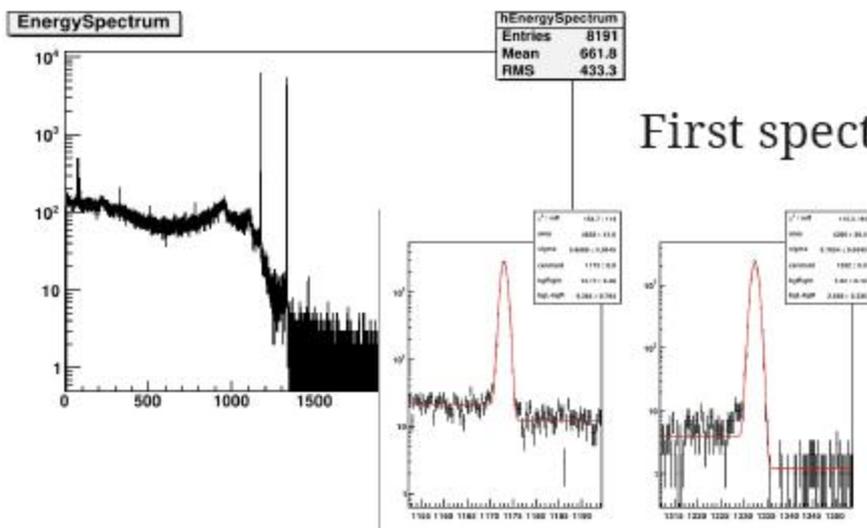
**ONGOING**

Crystal pulling at Canberra:  
Oakridge, TN, USA



**ONGOING**

BEGe detector diode  
production: Olen, BE

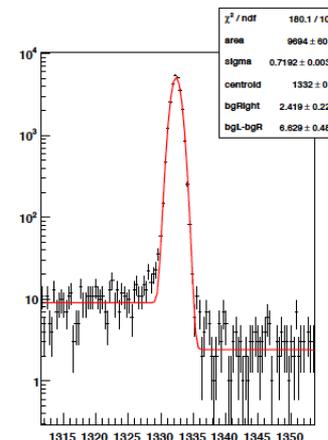
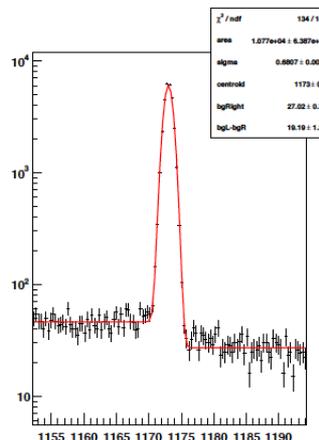


**ONGOING**



BEGe acceptance  
tests: Hades, BE

# Acceptance test of the **first 7 enriched BEGe detectors** underground at HADES facility (vicinity of Canberra, Olen, Belgium)



Complete detector characterization including energy resolution, dead layer, active volume, PSA, precision surface scan

## Test production of 7 crystal slices:

- All detectors have excellent energy res.: **1.7 keV** (FWHM) @1.3 MeV

Diode	Crystal	Mass (kg)	Resolution (keV) <sup>60</sup> Co (1173 keV)	Average Dead layer (mm) <sup>133</sup> Ba
ARCHIMEDES	#2432AA	0.5	$1.62 \pm 0.02$	0.8
AGAMENNONE	#2432BB	0.7	$1.64 \pm 0.01$	0.8
ANDROMEDA	#2432CC	0.7	$1.59 \pm 0.01$	0.8
ANUBIS	#2432DD	0.7	$1.59 \pm 0.01$	0.8
ARGO	#2435AA	0.8	$1.60 \pm 0.01$	0.7
ACHILLES	#2435BB	0.8	$1.65 \pm 0.01$	0.8
ARISTOTELES	#2435CC	0.6	$1.62 \pm 0.02$	-

Table 2: First results of the first <sup>enr</sup>BEGe prototypes. The diodes have been produced from different slices (AA-DD and AA-CC) from two grown crystals (#2432 and #2435).

# Summary and outlook

- **GERDA Phase I data taking started in November 2011.**
- Problem with unexpectedly high contribution from  $^{42}\text{Ar}$  decays was investigated both in GERDA and LArGe and **specific  $^{42}\text{Ar}$  activity in LAr is evaluated.**
- Background in ROI  **$2 \cdot 10^{-2}$  cts/(keV kg y)** is very promising and lower than in previous experiments ( $\sim$  factor 8), but slightly higher than design goal (without PSA yet, - **in progress** ).
- **$2\nu\beta\beta$  spectrum** well reproduced by MC (taking into account contributions from  $^{39}\text{Ar}$ ,  $^{42}\text{Ar}$ ,  $^{40}\text{K}$  ).
- **About 1/2 of desired exposure** (Phase I) has been reached.
- **Phase II detector production** and R&D on **LAr scintillation light** readout ongoing.
- **First BEGes tested** with excellent resolution (**1.7 keV** at 1.3 MeV).

**Soon : 5 BEGe from  $^{76}\text{Ge}$  will be implemented already in Phase I (June 2012)**

# GERDA collaboration

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