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

24th 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}Ge isotope (up to 86 %) is simultaneously the ββ decay source and the 4π detector.

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

1) the excellent energy resolution (4 кэВ 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:

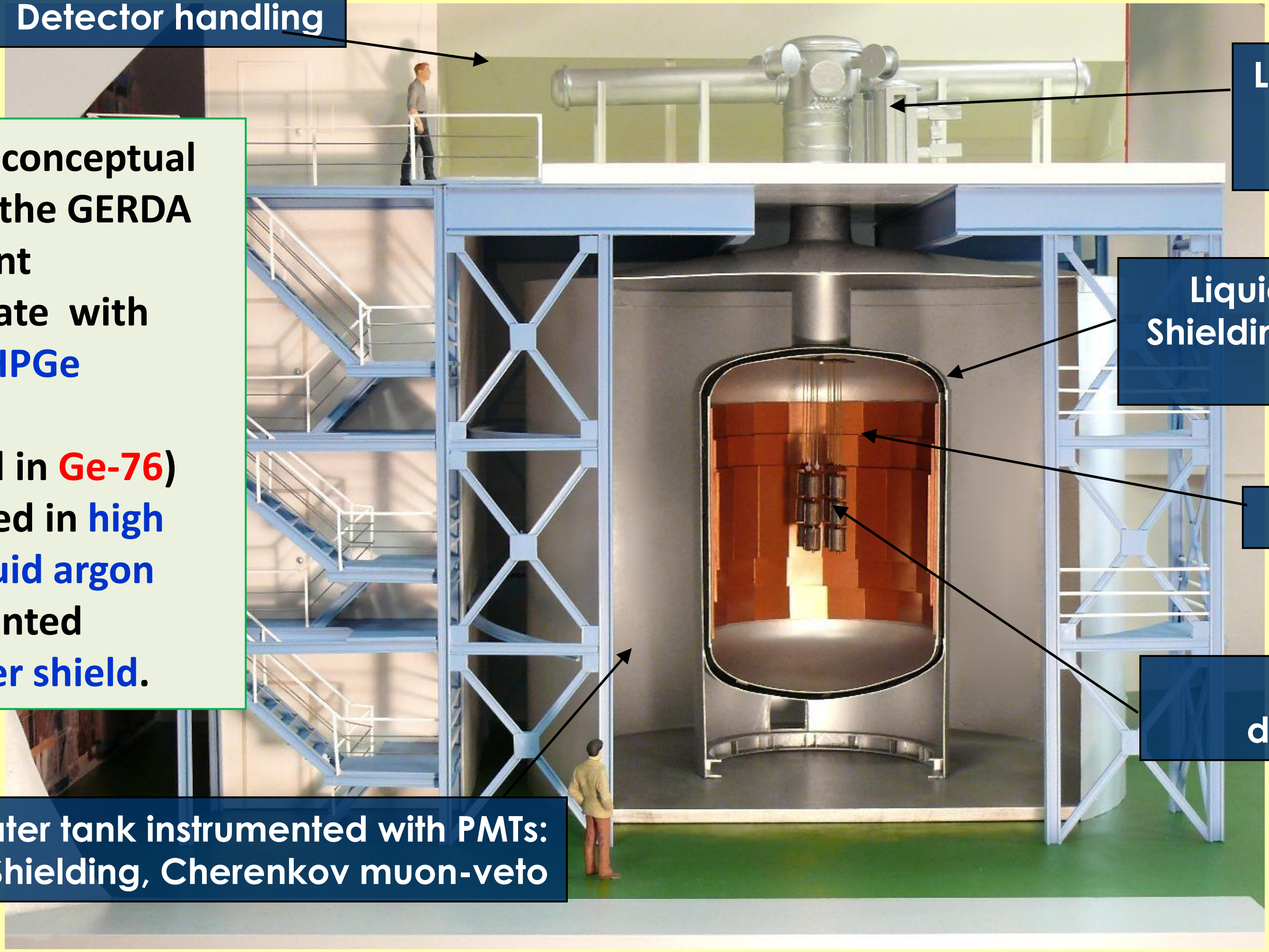
1) not the highest ββ–transiton energy for ^{76}Ge: Q_{bb}=2039 keV (in comparison with the more promising isotopes, such as Mo-100, Nd-150,Ca-48)
2) only one characteristic of ββ decay - sum energy of two electrons – is possible to detect.

Nevertheless, up to now ….

GERDA: the GERmanium Detector Array

Neutrinoless Double Beta Decay Experiment

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.

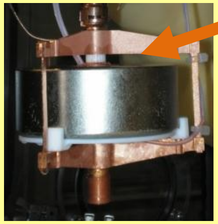


Construction of the GERDA set up started in 2007
in Gran Sasso National Laboratory (LNGS), Italy.
Installation of the “nested type” assembly
completed in 2010
in the deep underground facility at 3400 m w.e.

- 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 ^{nat}Ge detectors



November 2011: <u>Start of Phase I</u>.
All 8 ^{76}Ge + 3 ^{Nat}Ge detectors deployed in GERDA

Phase I detectors

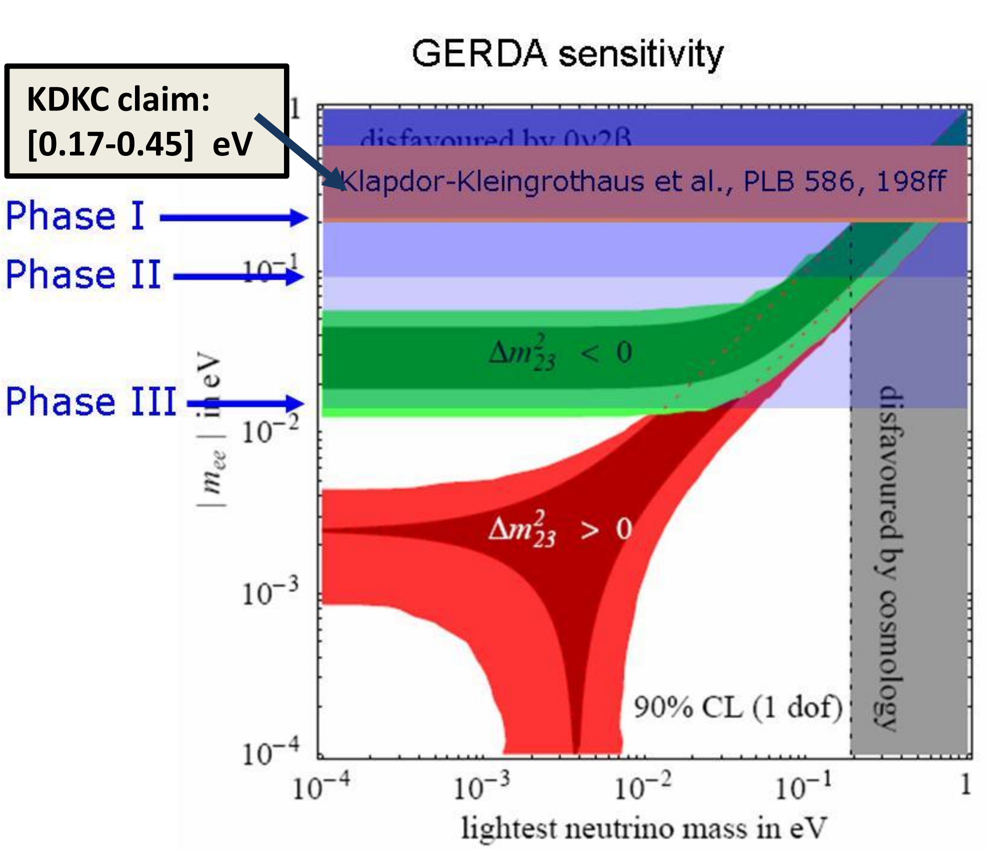
8 enriched HPGe detectors
(in total ~ 18 kg of ^{76}Ge)
from HdM and IGEX experiments,
3 natural HPGe detectors
(in total ~ 7.6 kg of ^{Nat}Ge)
from the Genius T-F

Soon: 5 BEGe from ^{76}Ge will be implemented (June 2012)

Phase II detectors

the new BeGe detectors (~ 25 kg of ^{76}Ge) made from enriched in ^{76}Ge material will be added.
In total: about 40 kg of ^{76}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 $<m_{ee}>$ < 0.08 – 0.29 eV

Phase III :

GERDA –MAJORANA collaboration

background 0.1 cts / (ton · keV · y)

▶ to cover the inverted neutrino mass hierarchy $<m_{ee}>$ ~10 meV

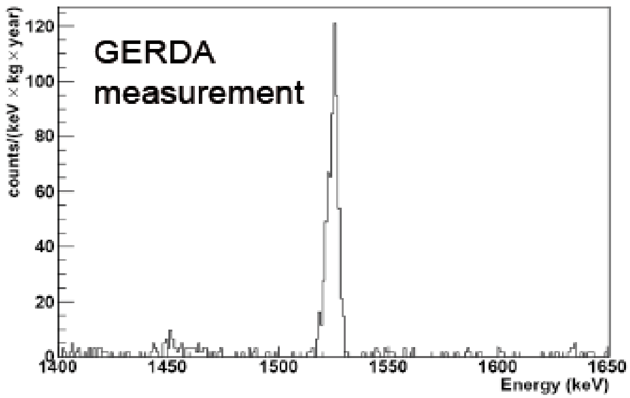
GERDA Commissioning

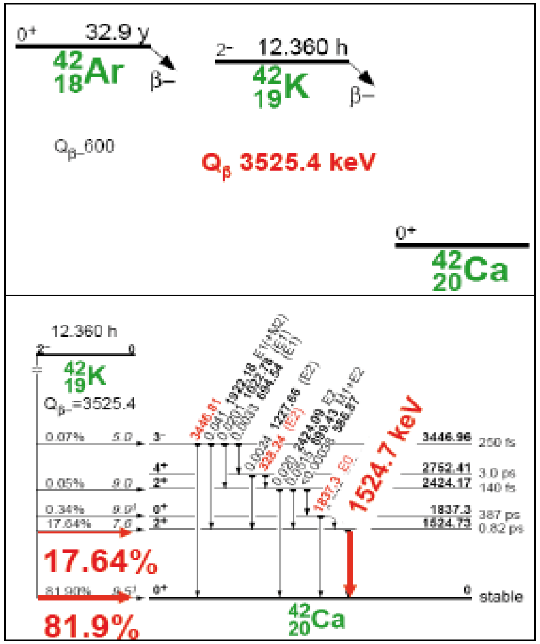
The first commissioning runs revealed a count rate due to presence of ^{42}Ar in the liquid argon significantly above the rate expected on the basis of known experimental upper limits.

- production: 40Ar(,2p)42Ar reaction in atmosphere and fall-out from atmospheric nuclear explosion

The unexpected ^{42}Ar (^{42}K) Signal

GERDA proposal: $^{42}Ar/^{nat}Ar < 3\cdot 10^{-21}$
[Barabash et al. 2002]

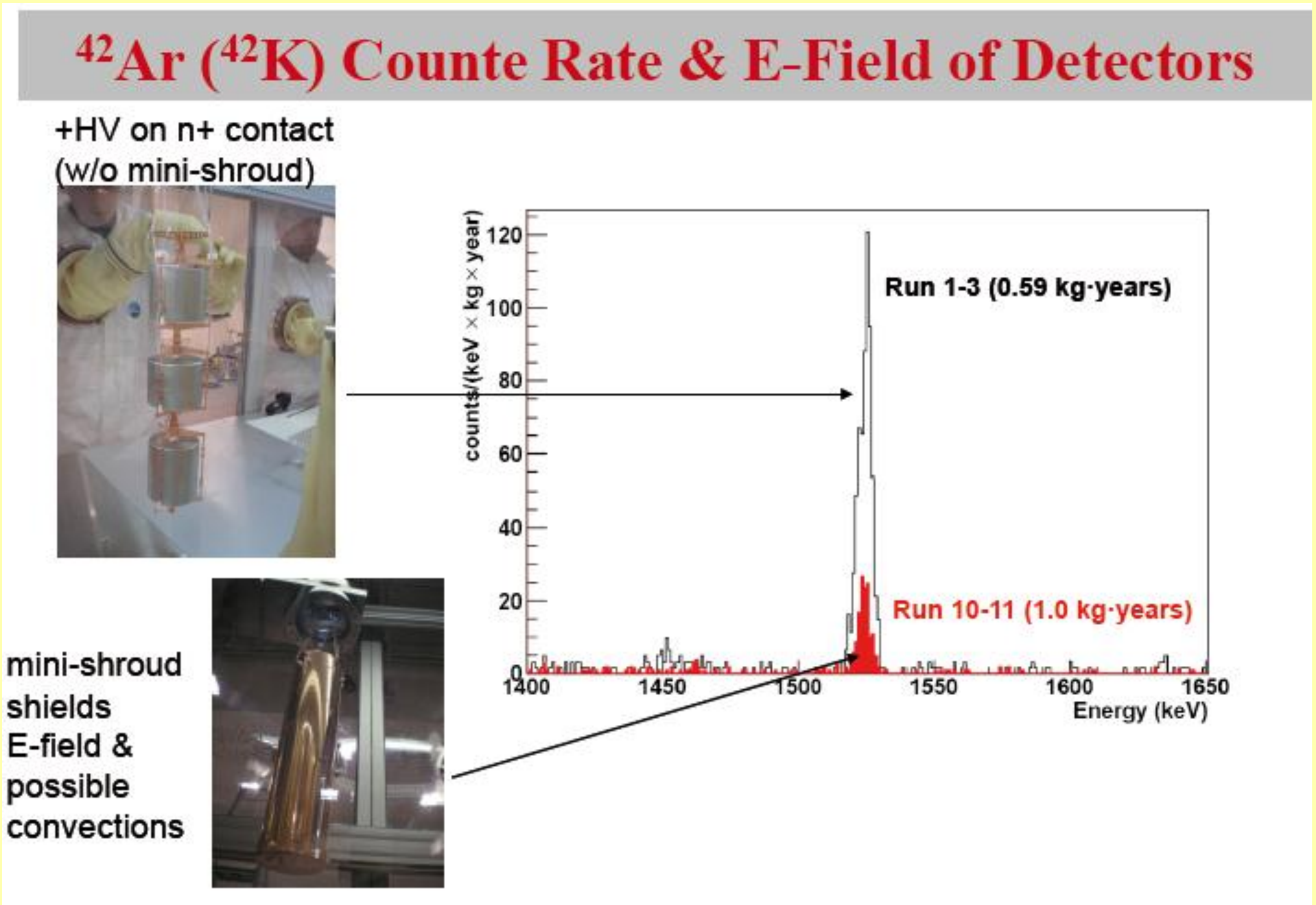




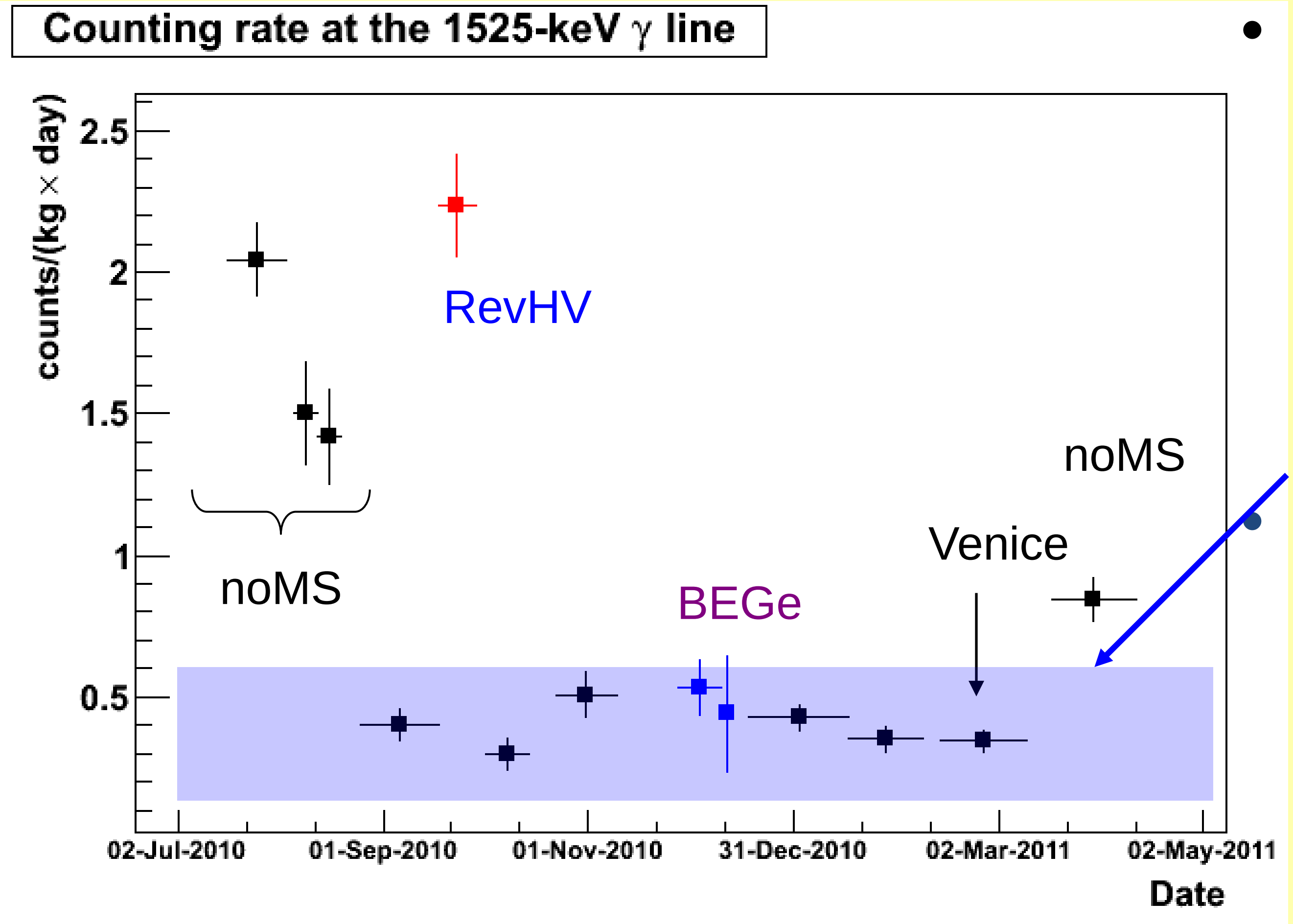
Surprise:

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

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

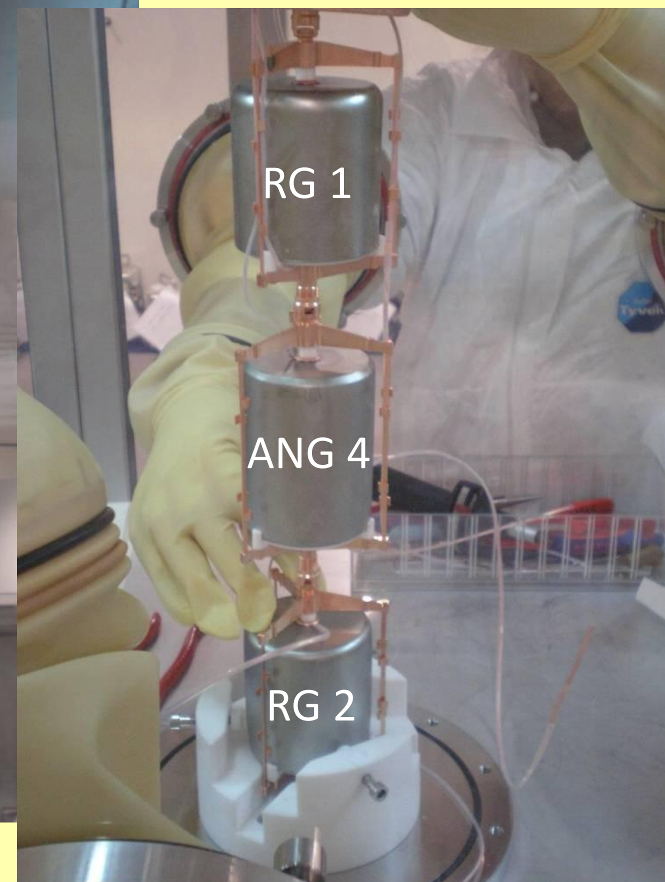


GERDA Commissioning

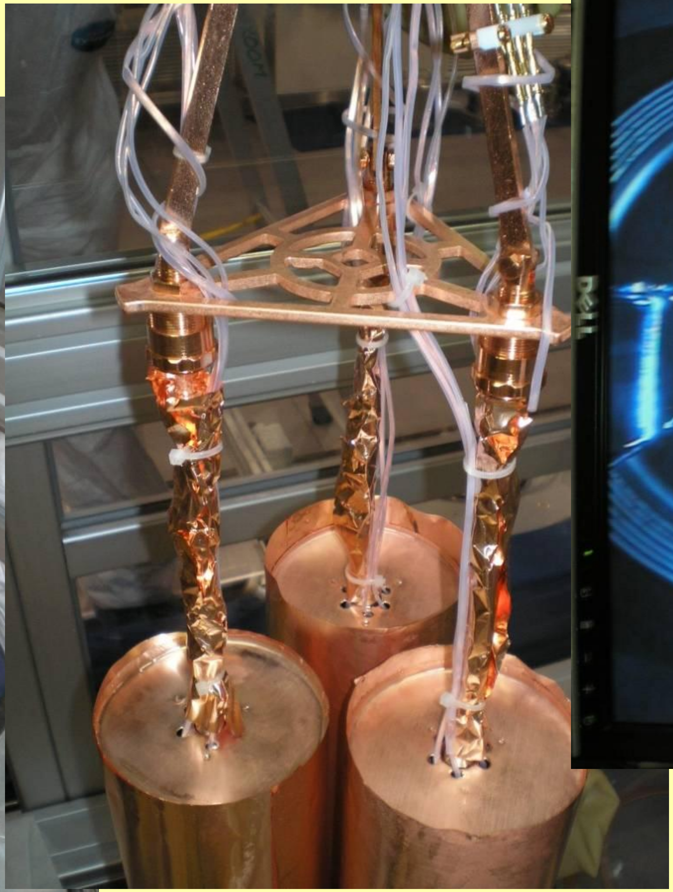


- ^{42}K counting rate in (quasi) null-field configurations: ~ **0.3 counts/(kg day)**
- Consistent with LArGe data

October 2011: All enriched Phase I detectors deployed in GERDA



Deployment of GERDA Phase I detectors



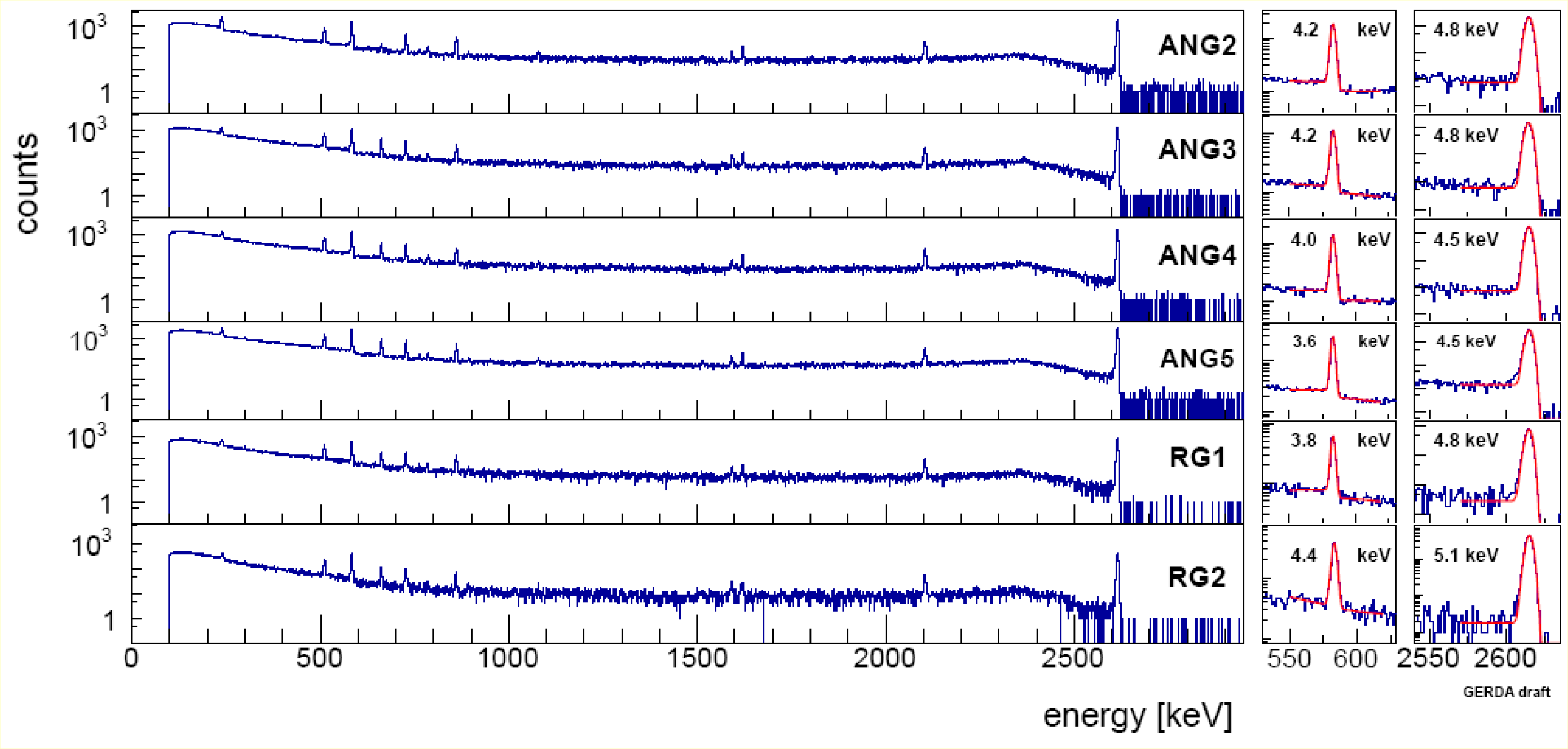
Phase I detector performance in GERDA

Detector	Total mass, g	HV_{dep}, V	HV, V	FWHM (2.6 MeV)		LC , pA
				MCA	FADC	
Enriched						
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
Non-enriched						
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 ^{enr}Ge: 14.6 kg
GTF45 & GTF32 in single-string (AC-read out). Total mass ^{nat}Ge: 7.6 kg

Phase I detector performance in GERDA

Energy calibration with 228Th source

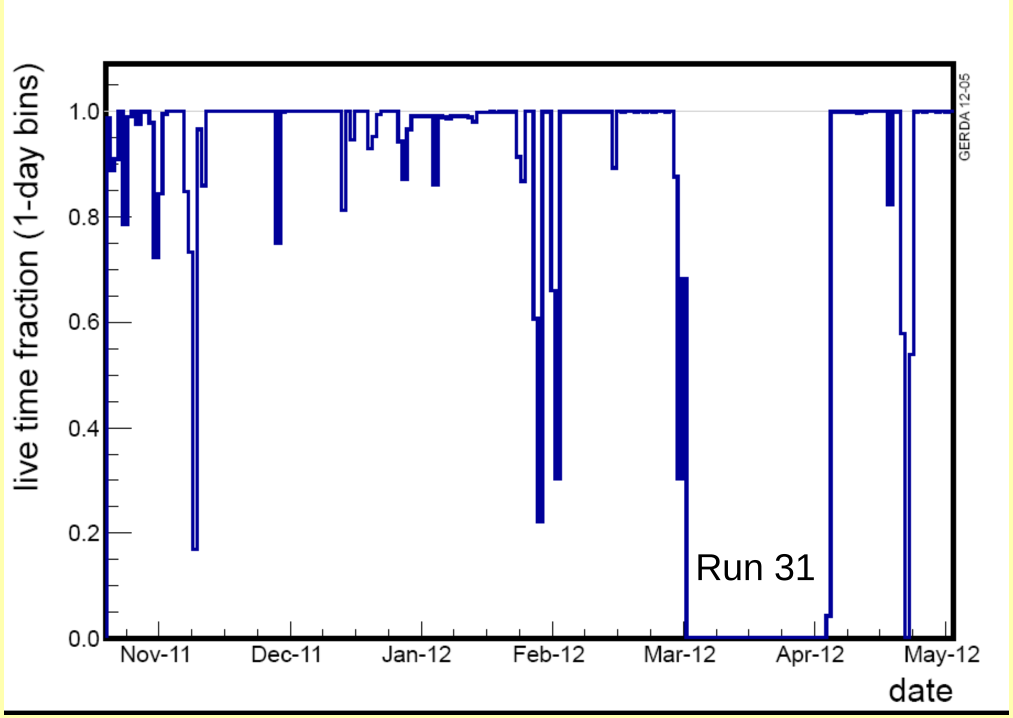


9 November 2011: Start of physics data taking of GERDA Phase I

Live time: 152.49 days

Duty cycle: 92.6%

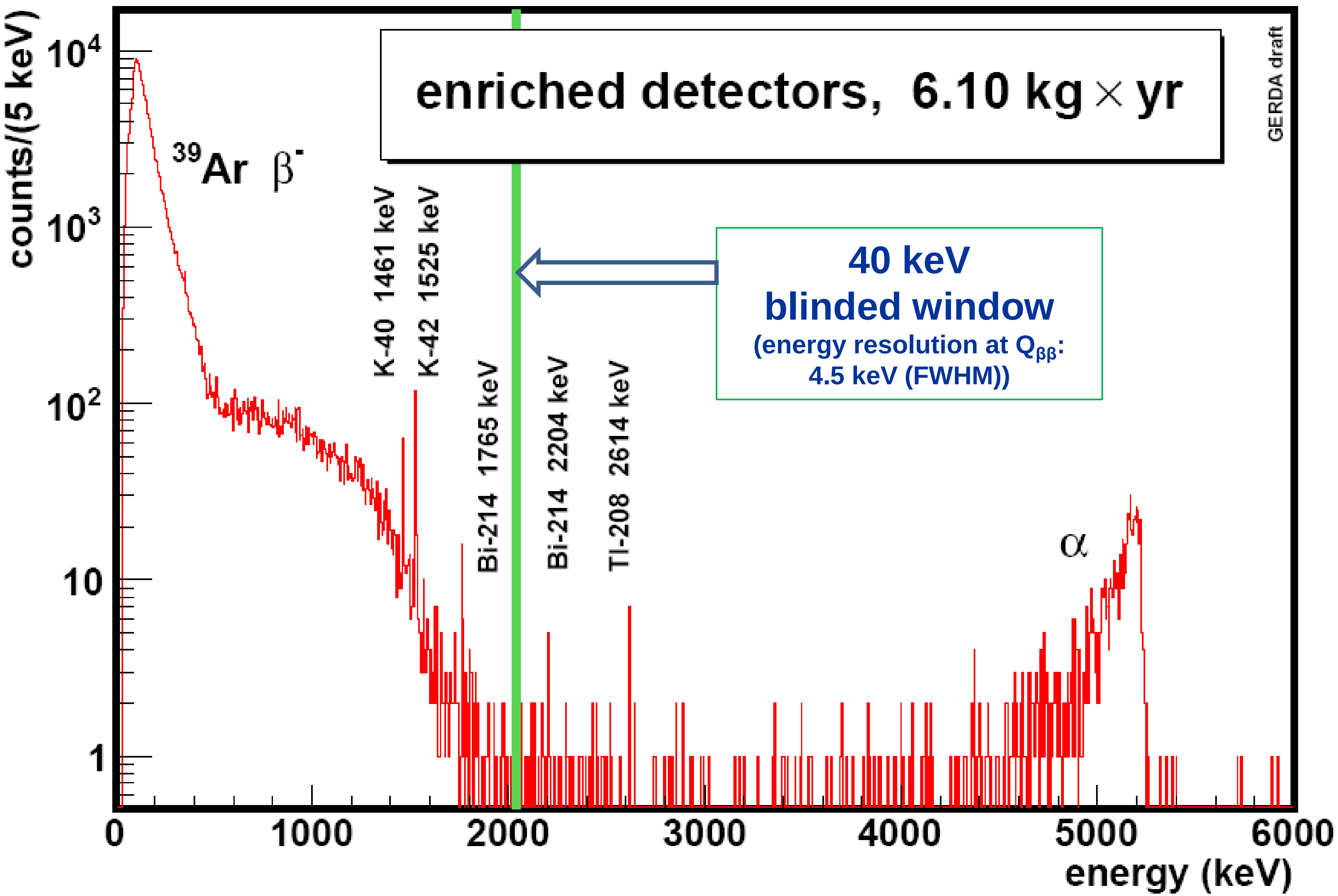
(without Tech.Run 31)



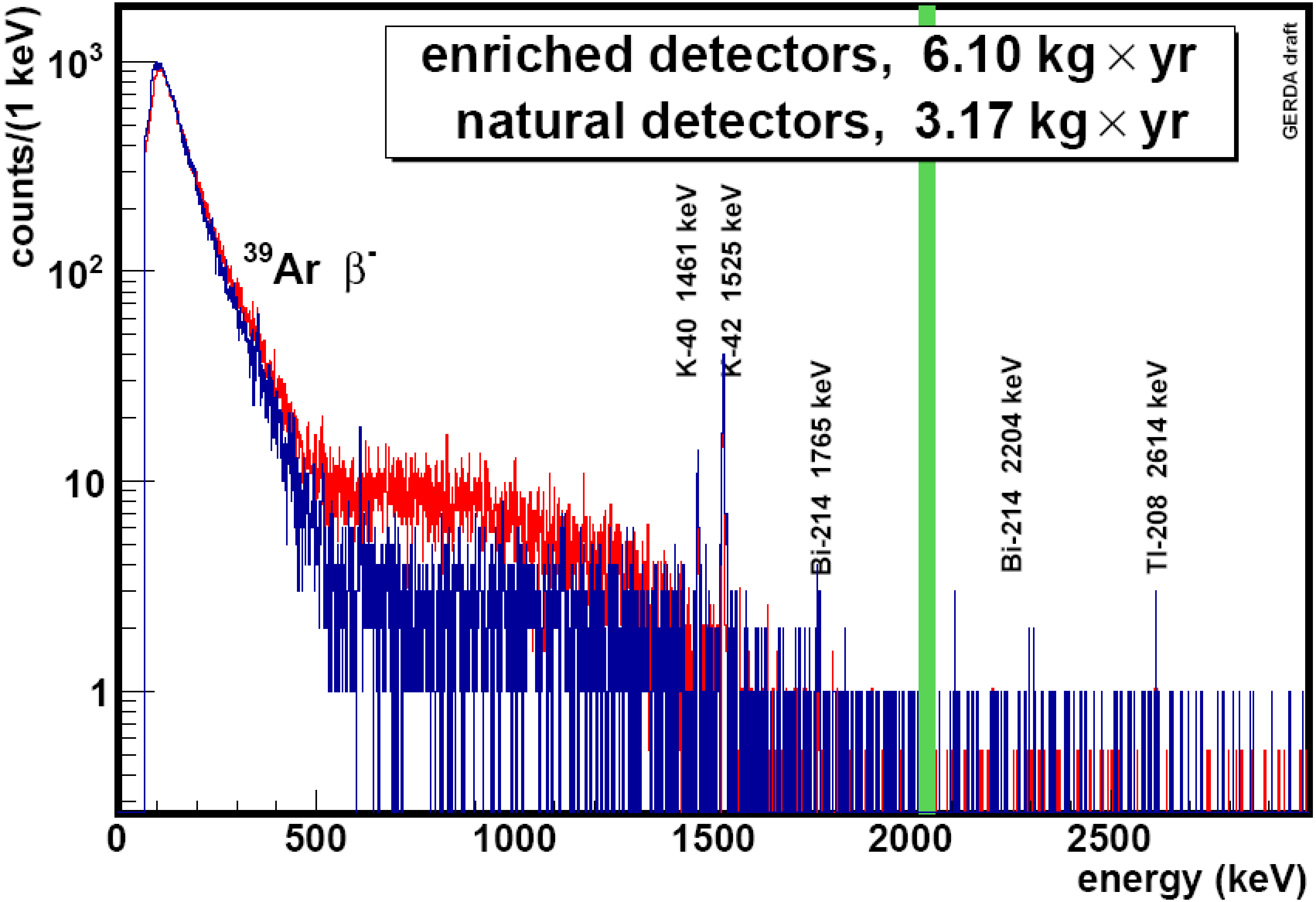
Enriched Ge mass:
14.63 kg

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 analisys ("blind analysis")**

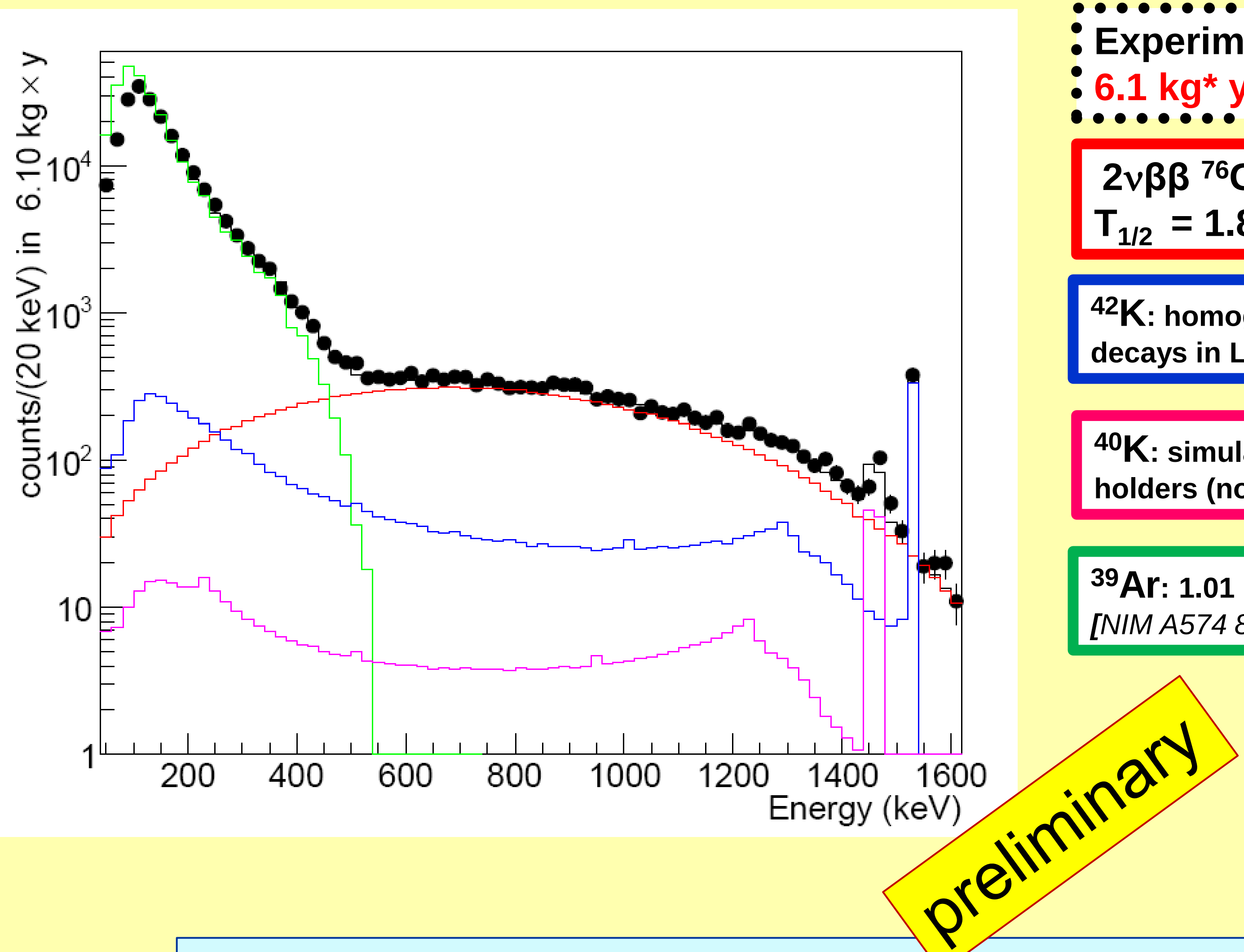


enriched detectors, 6.10 kg × yr
40 keV
blinded window
(energy resolution at $Q_{\beta\beta}$:
4.5 keV (FWHM))
^{39}Ar β⁻
K-40 1461 keV
K-42 1525 keV
Bi-214 1765 keV
Bi-214 2204 keV
Tl-208 2614 keV
α
GERDA draft
counts/(5 keV)
energy (keV)
10^4
10^3
10^2
10
1
0
1000
2000
3000
4000
5000
6000



enriched detectors, 6.10 kg × yr
natural detectors, 3.17 kg × yr
GERDA draft
counts/(1 keV)
10^3
10^2
10
1
^{39}Ar β$^-$
K-40 1461 keV
K-42 1525 keV
Bi-214 1765 keV
Bi-214 2204 keV
Tl-208 2614 keV
0
500
1000
1500
2000
2500
energy (keV)

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



Experimental spectrum, 6.1 kg* year (enriched)

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

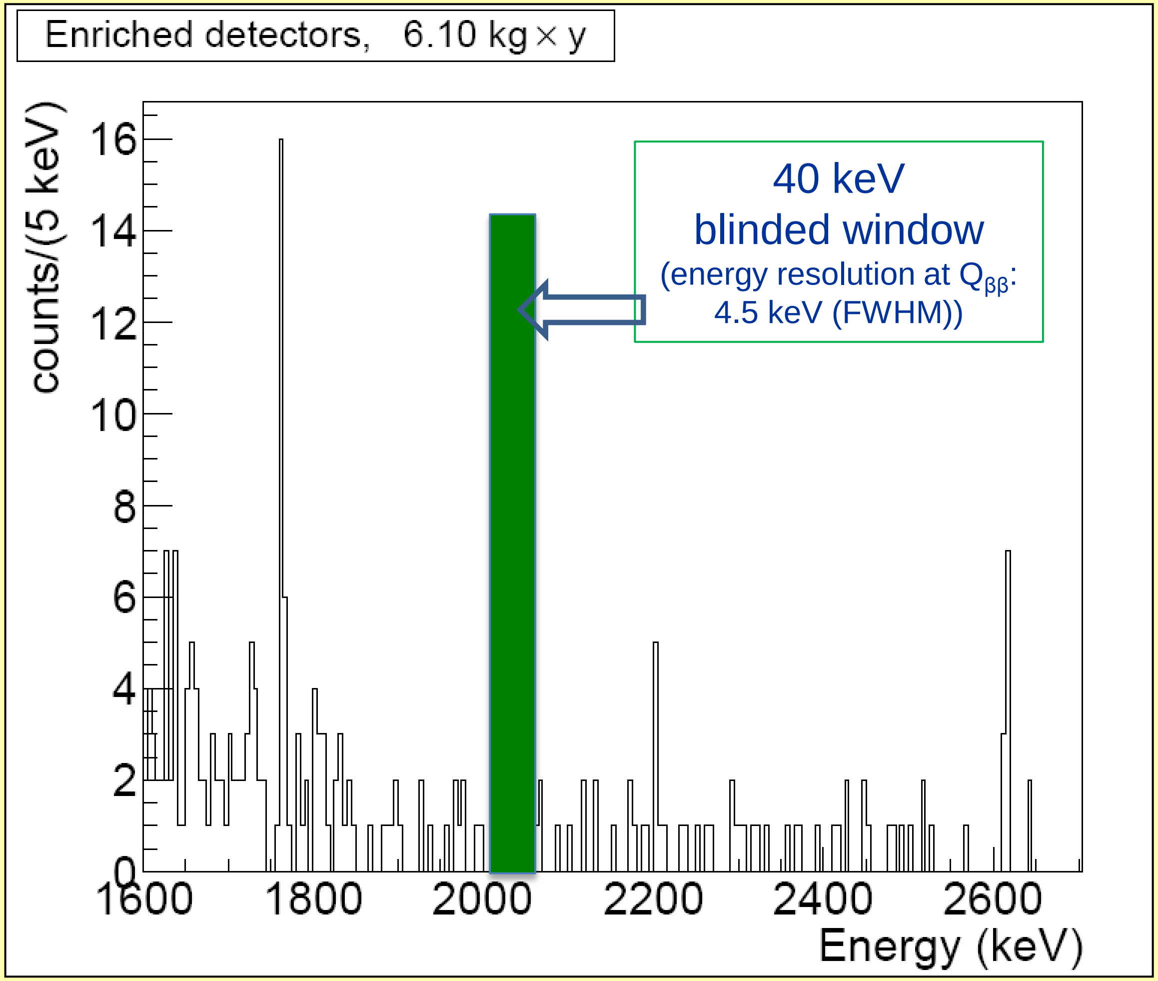
^{42}K: homogeneously distributed decays in LAr (normalized to peak)

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

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

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

Zoom into ROI of background spectrum of the ^{76}Ge detectors



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

- γ's from ^{214}Bi and ^{208}Tl,
- degraded α's from ^{210}Po (and possibly ^{222}Rn and progenitors)
- β's from ^{42}K
- possibly from internal contaminations like ^{60}Co.

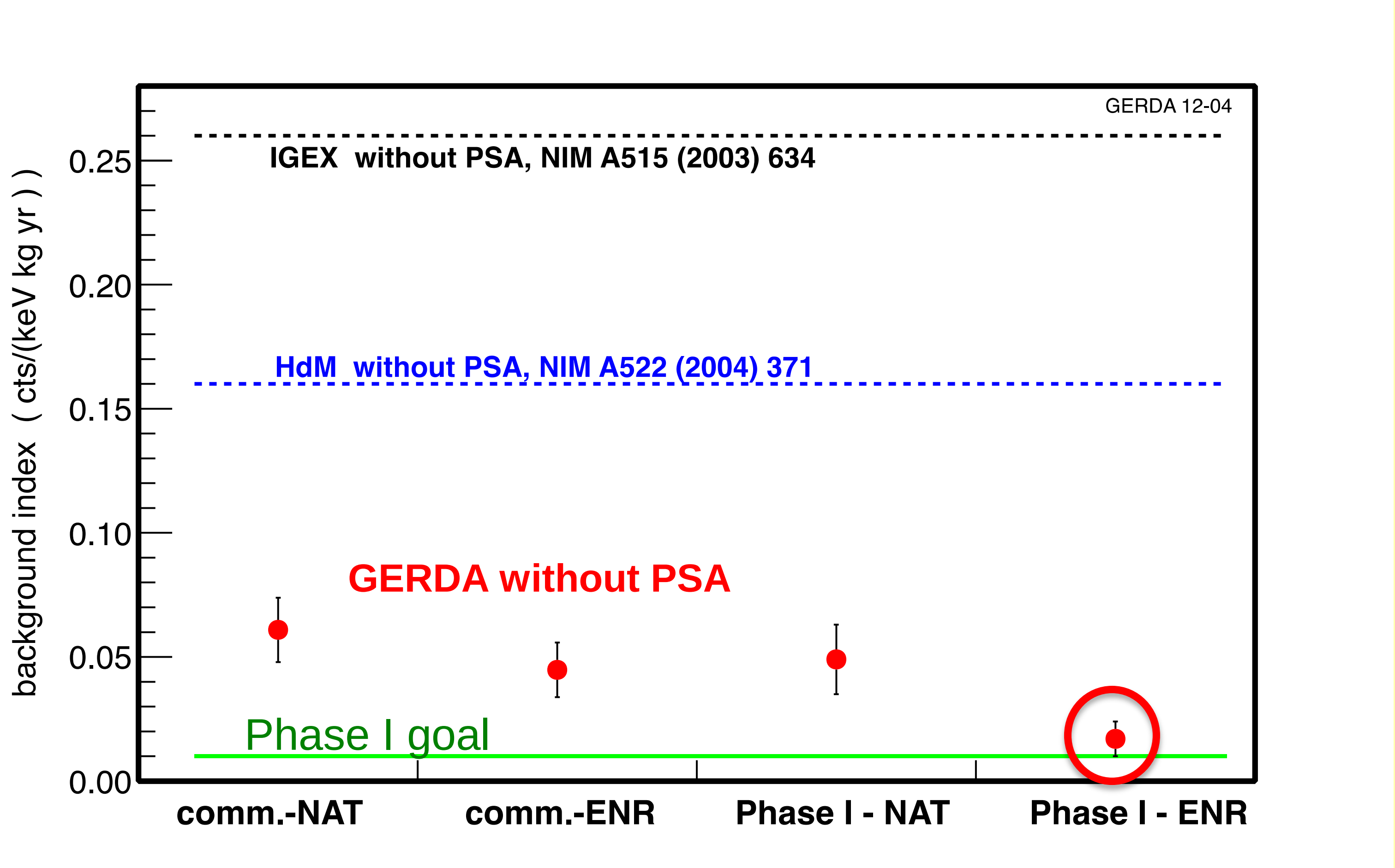
Quantitative estimate of their relative contributions is ongoing

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

^{enr}Ge: 0.020 +0.006 –0.004 cts/(keV× kg × y)

Note: Pulse Shape Discrimination not applied yet

Background comparison



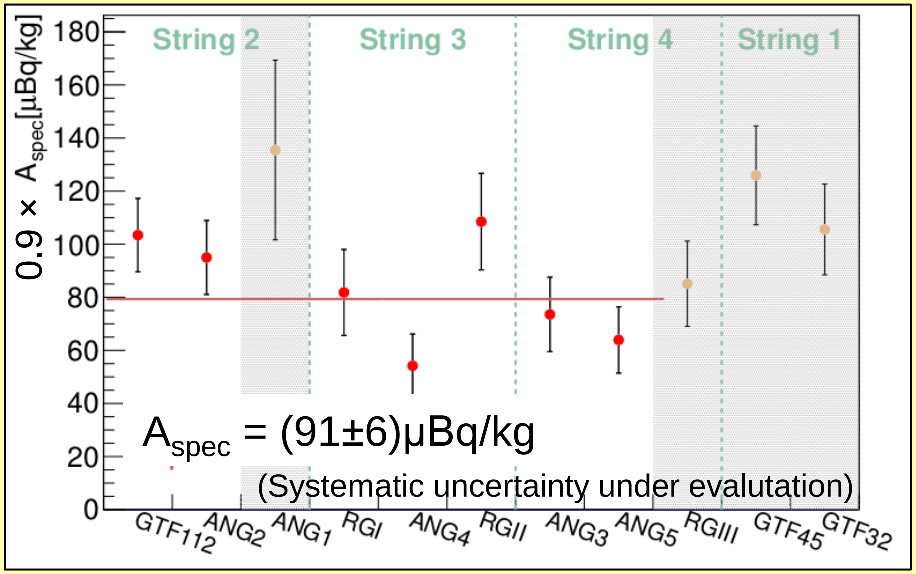
➔ **factor ~ 8 lower than previous experiments (HdM, IGEX)**

➔ 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}Ar concentration in LAr

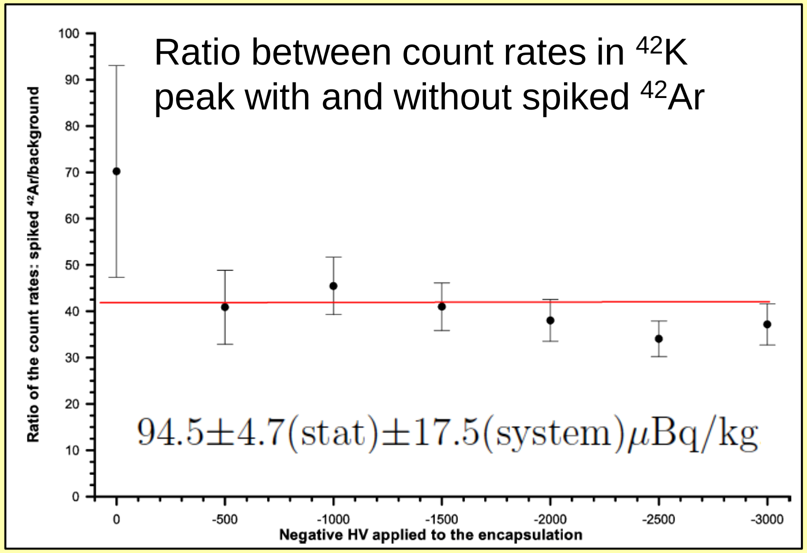
preliminary

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



preliminary

LArGe test facility:
LAr spiked with known amount of ^{42}Ar & measurements at different HV

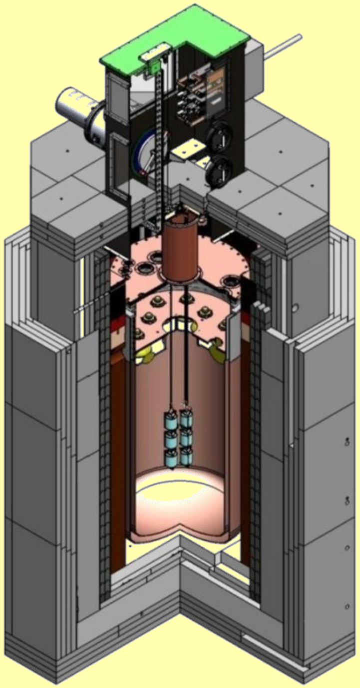


Previous best limit: <4.3 10^{-21} g/g (or < 41 µBq/kg) (90% CL) , V.D. Ashitkov et al. 2003

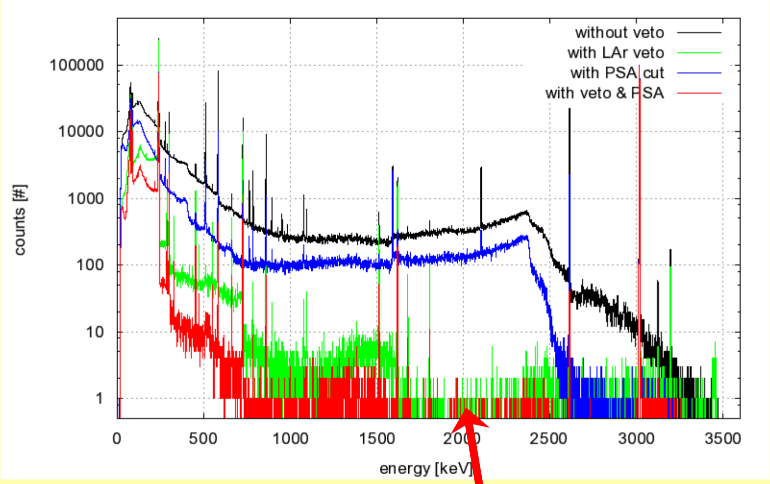
R&D for GERDA Phases II and III
LArGe test facility + BEGe detectors

The LArGe Setup
with 1.4 tons of LAr

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



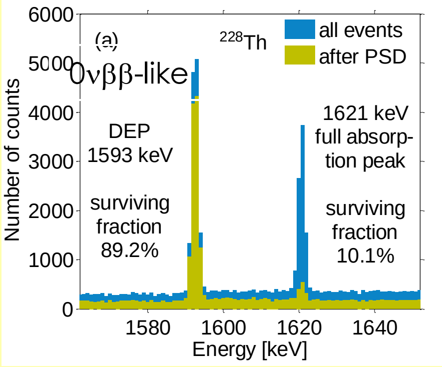
The LArGe set up was assembled at LNGS in 2010 and operates with naked Ge detectors immersed in 1.4 tons of LAr served as scintillation veto. Efficiency of the LAr scintillation veto and pulse shape discrimination (PSD) of signals from the BEGe detector inside the LArGe were tested and optimized . It 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

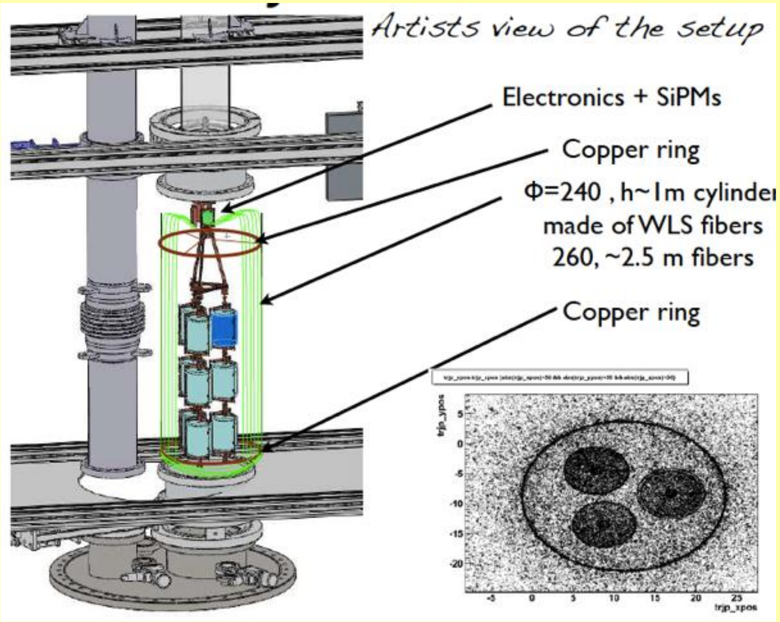


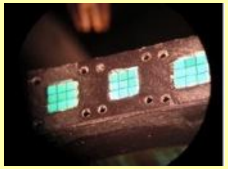
First results obtained with LArGe + BEGe successfully demonstrate possibility of considerable background reduction for GERDA Phase II and III by using LAr scintillation veto + BeGe PSD.

LAr VETO instrumentation for Phase II

PMT option (Ø500)

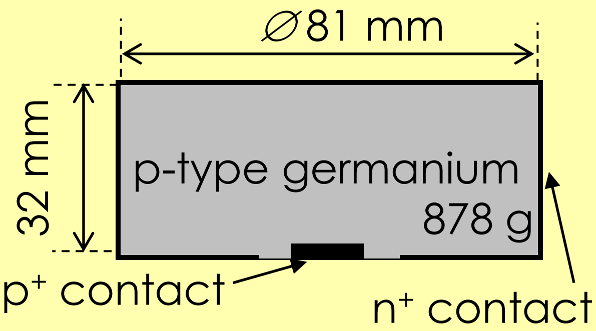
SiPM & scintillating fiber option (Ø250)

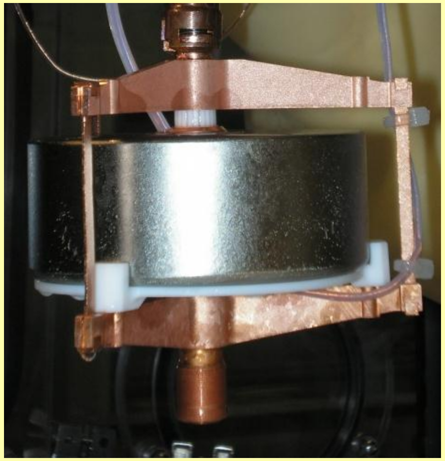


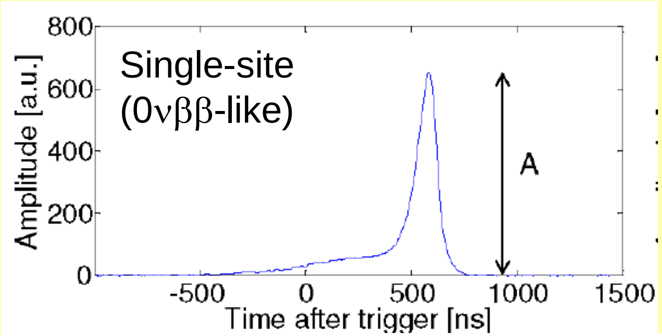


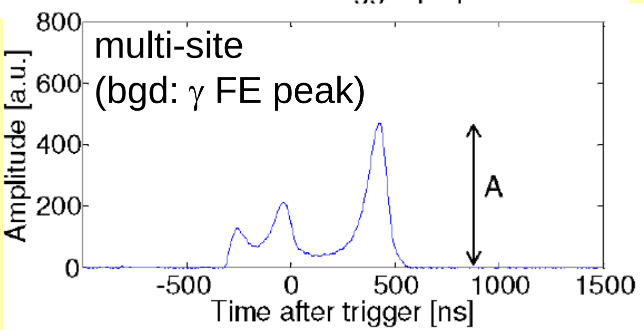
- 3rd option: R&D on large area avalanche photodiodes or UV sensitive SiPMs on custom low activity substrates has started
- MC campaign to compare competing options ongoing
- Hardware for PMT and fiber options available & prototype/test setup construction started
- Aim: down-selection in summer

Phase II detectors - BEGe

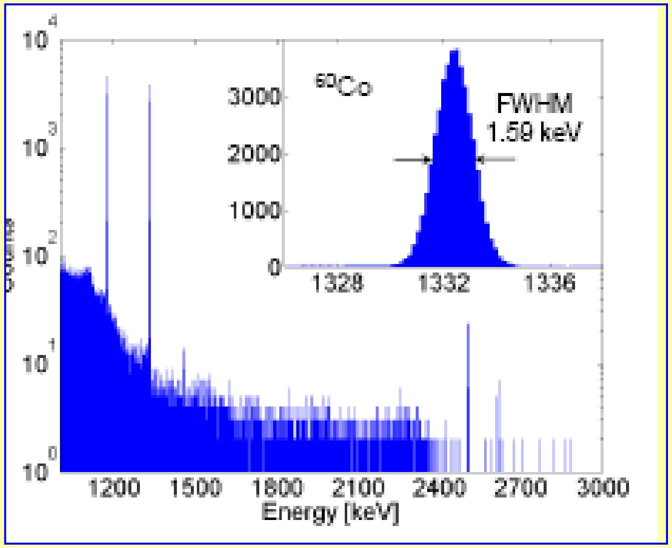


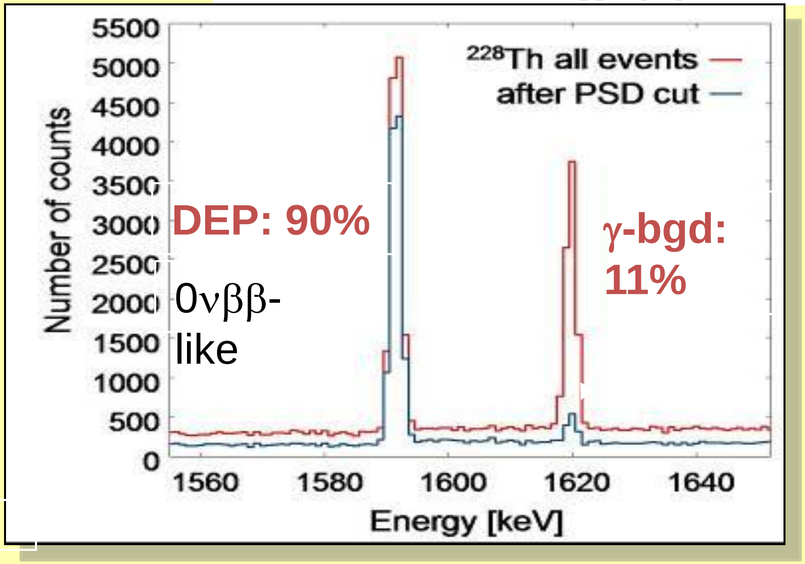




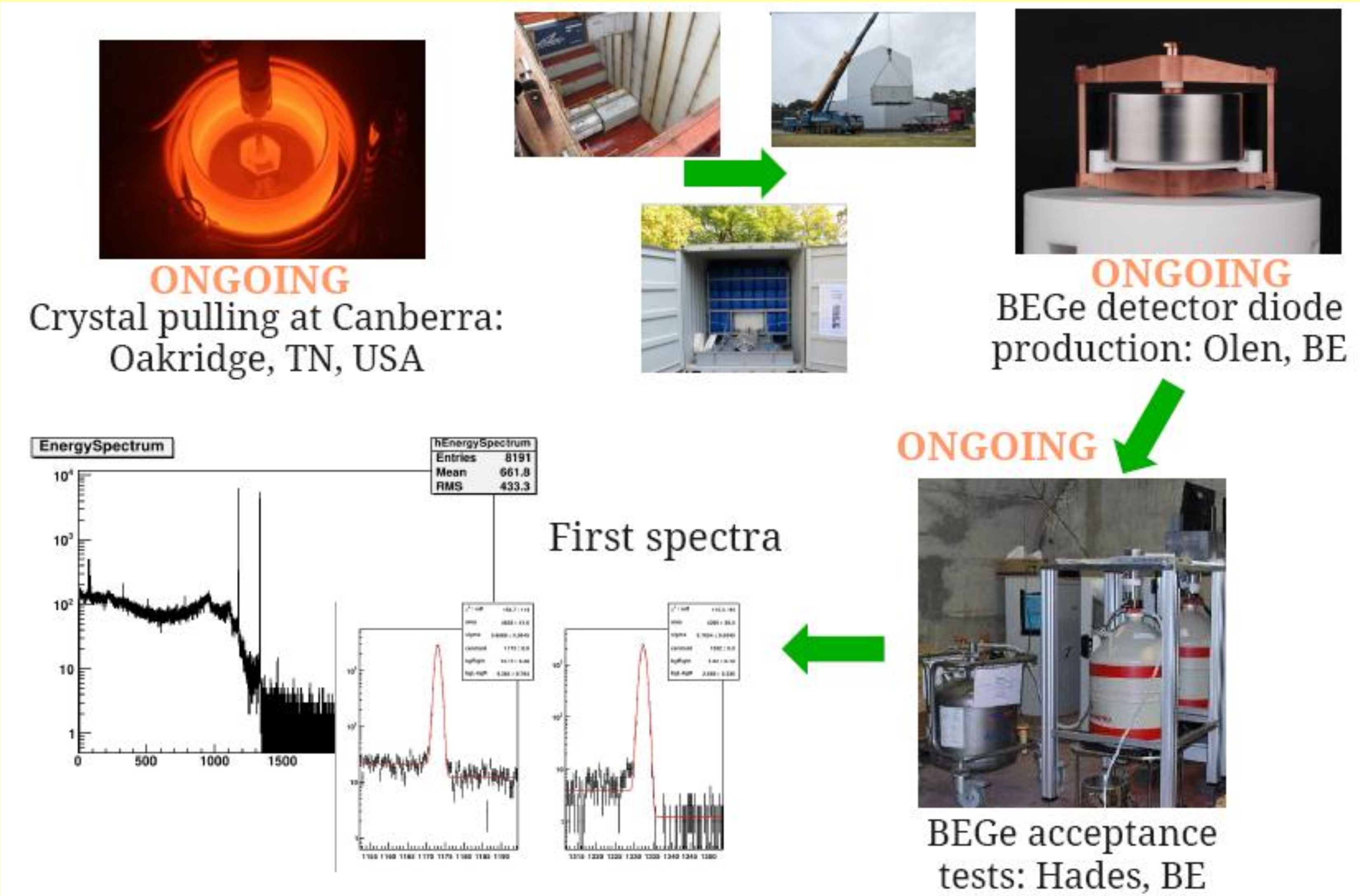


FWHM @ 59.5 keV	0.49 keV
FWHM @ 1.33 MeV	1.59 keV

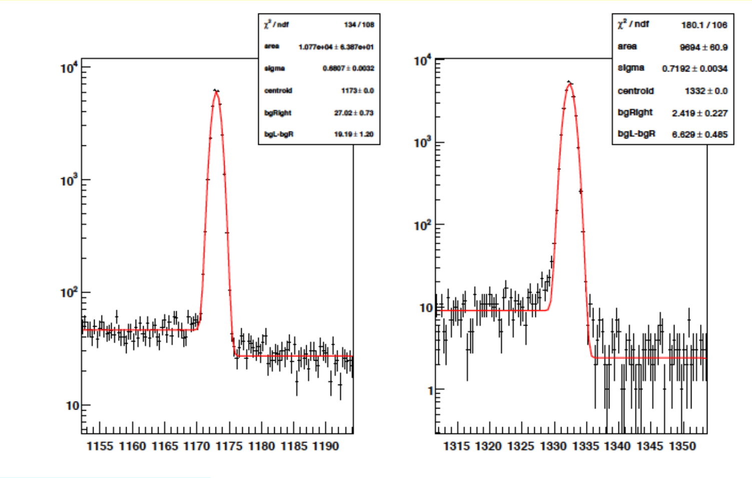




BEGe production (from ^{76}Ge)



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) ^{60}Co (1173 keV)	Average Dead layer (mm) ^{133}Ba
ARCHIMEDES	#2432AA	0.5	1.62 ± 0.02	0.8
AGAMENNONE	#2432BB	0.7	1.64 ± 0.01	0.8
ANDROMEDA	#2432CC	0.7	1.59 ± 0.01	0.8
ANUBIS	#2432DD	0.7	1.59 ± 0.01	0.8
ARGO	#2435AA	0.8	1.60 ± 0.01	0.7
ACHILLES	#2435BB	0.8	1.65 ± 0.01	0.8
ARISTOTELES	#2435CC	0.6	1.62 ± 0.02	-

Table 2: First results of the first ^{enr}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 42Ar decays was investigated both in GERDA and LArGe and **specific 42Ar 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 (~ factor 8),
but slightly higher than design goal (without PSA yet, - **in progress**).

- **2νββ spectrum** well reproduced by MC (taking into account contributions from ^{39}Ar, ^{42}Ar, ^{40}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}Ge will be implemented already in Phase I (June 2012)**

GERDA collaboration