Results and Perspectives of GERDA: on the way to Phase II

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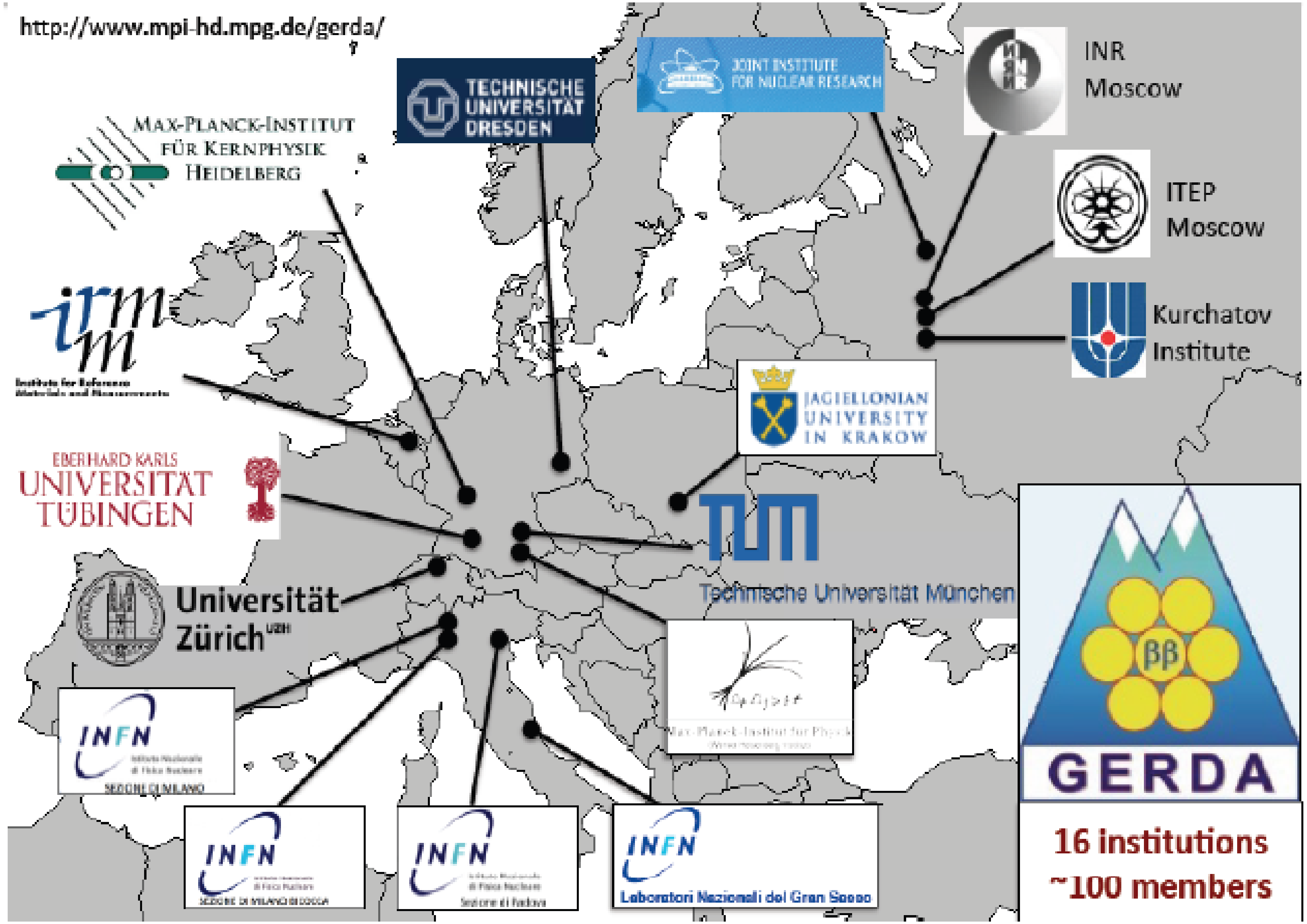
on behalf of the GERDA collaboration

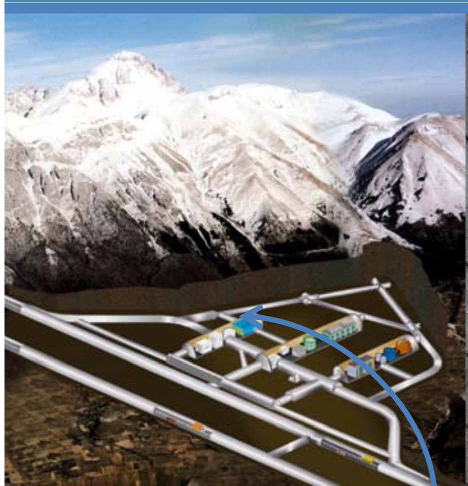
NOW 2014

Conca Specchiulla 8-14 September 2014

GERDA collaboration

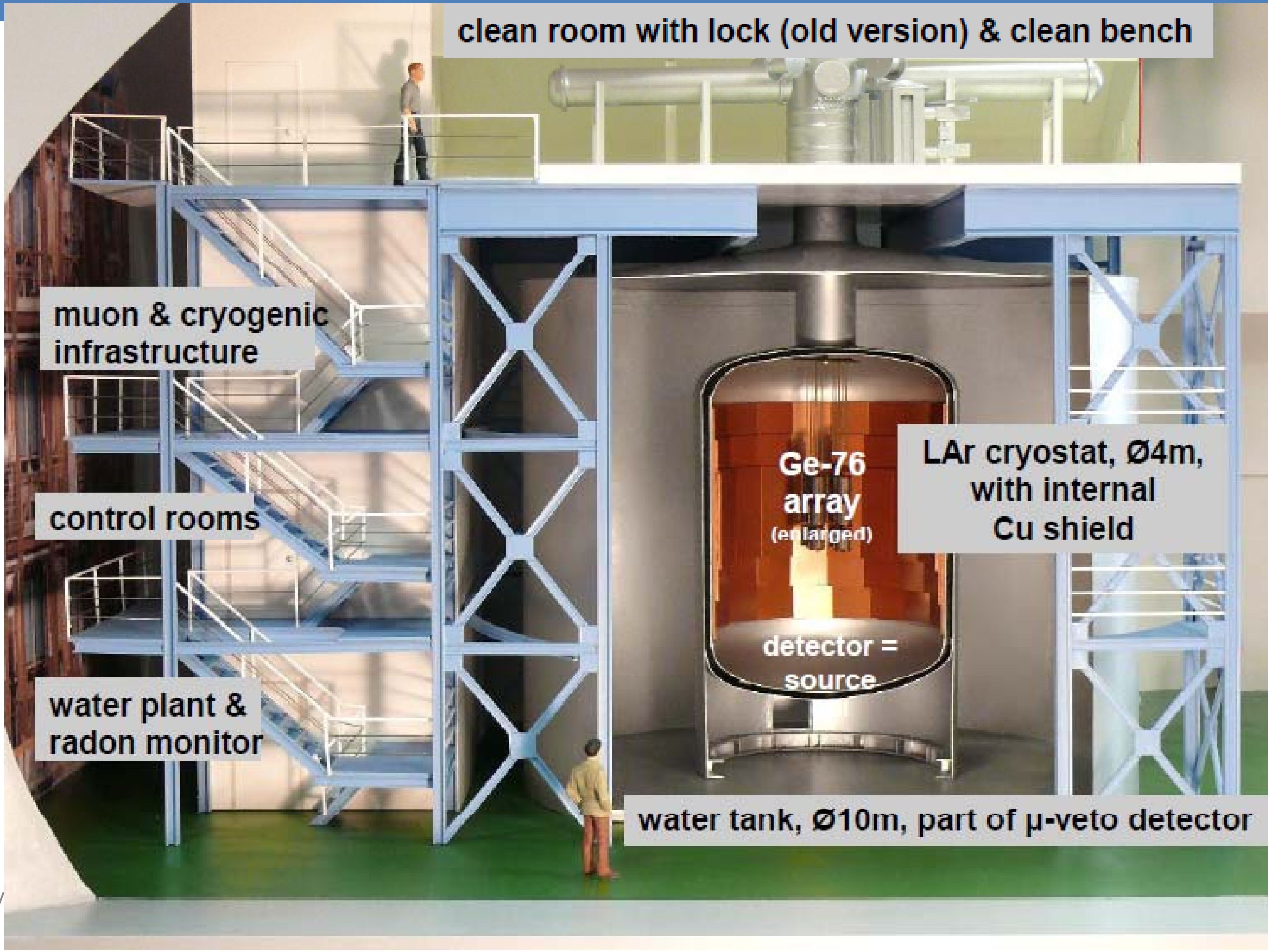


GERDA Installations

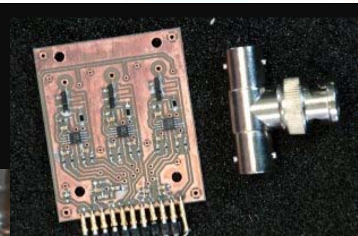


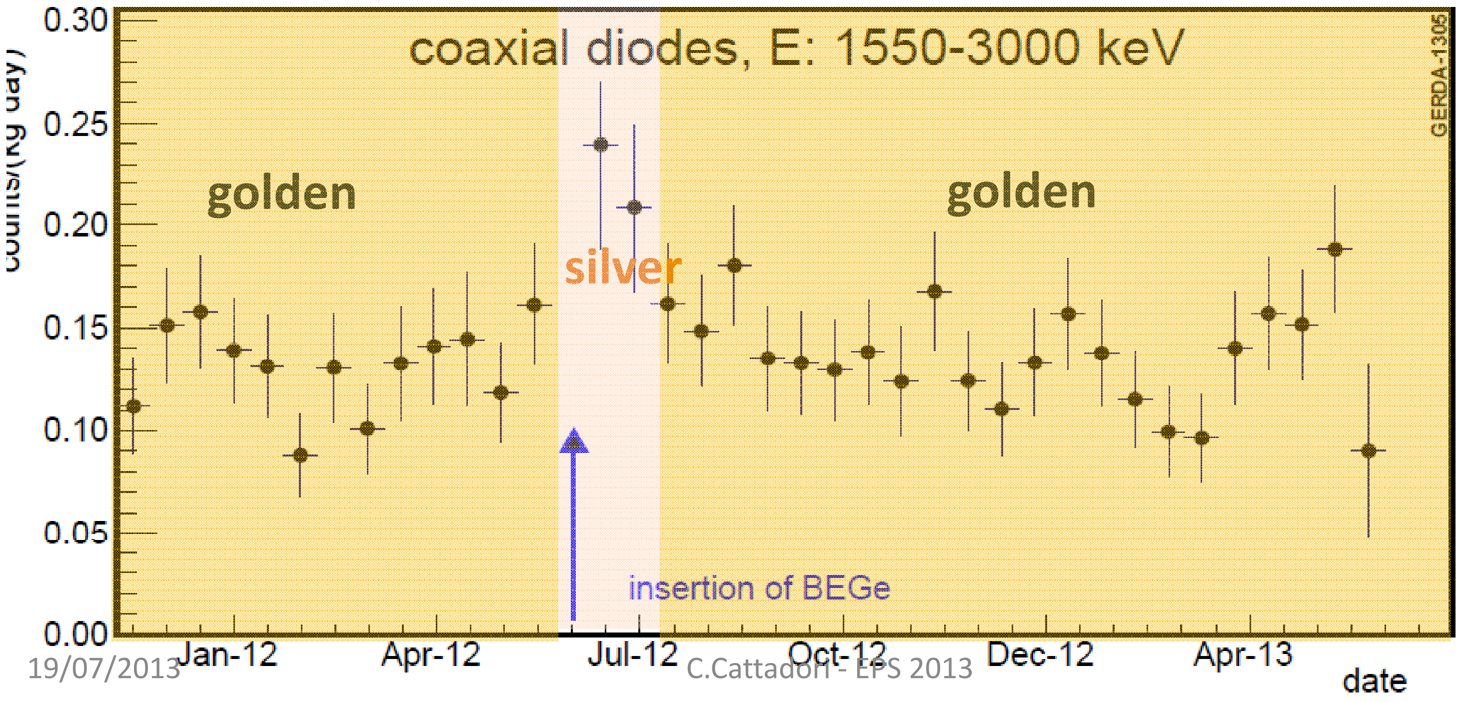
Located in Hall A
@ LNGS

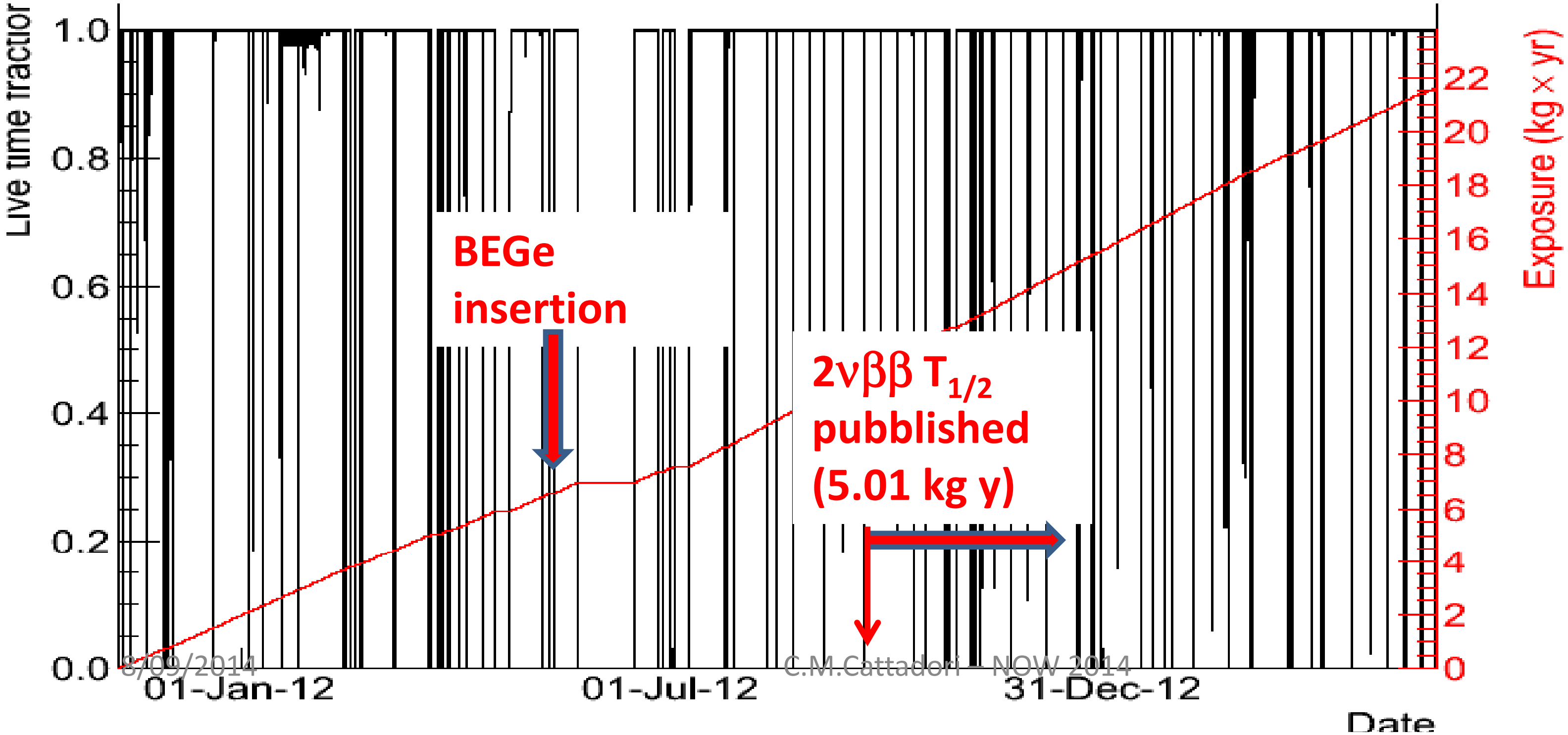
GERDA Installations




Pictures from GERDA





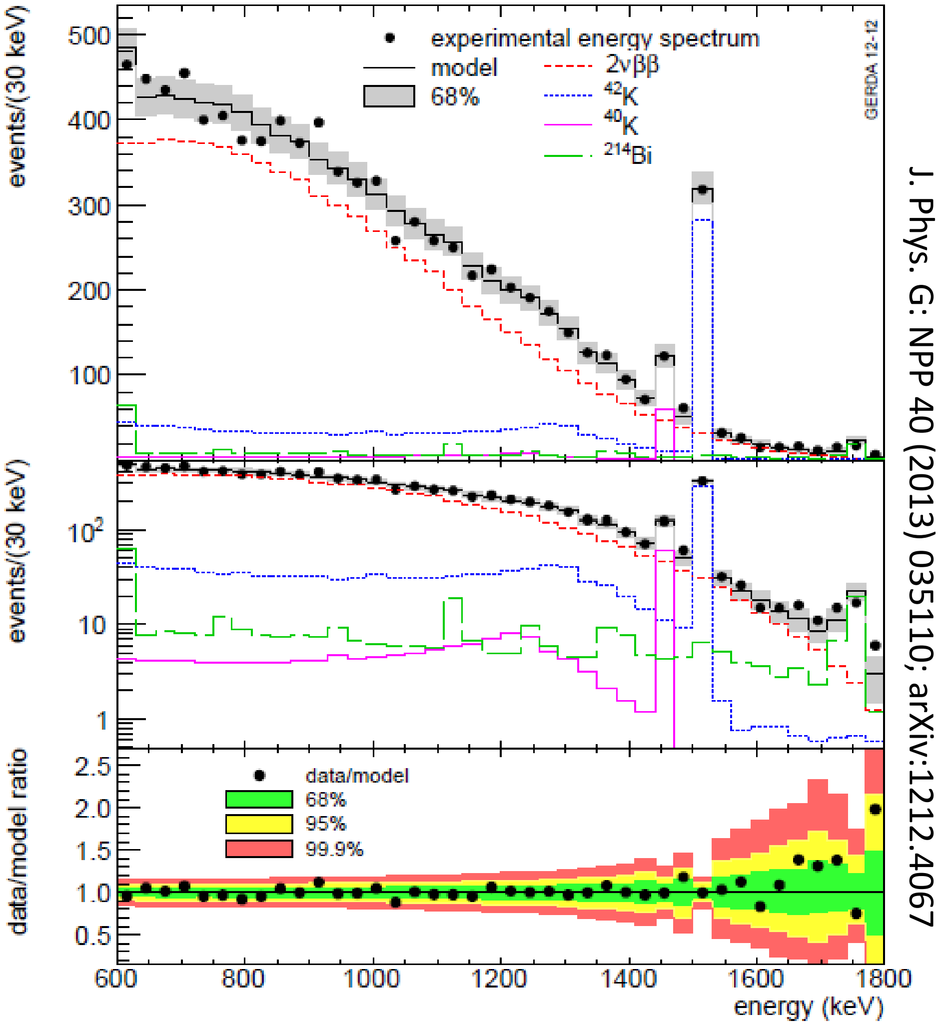
Data taking: Nov 2011- June 2013

Goal: Scrutinize claim Demon- strate BI

Exposure: 21.6 kg y

Observation of 2νββ

J. Phys. G: Nucl. Part. Phys. 40 (2013) 035110



J. Phys. G: NPP 40 (2013) 035110; arXiv:1212.4067

$$T_{1/2}^{2\nu} = (1.84^{+0.09}_{-0.08\ \mathrm{fit}}\ {}^{+0.11}_{-0.06\ \mathrm{syst}}) \cdot 10^{21}\ \mathrm{yr}$$

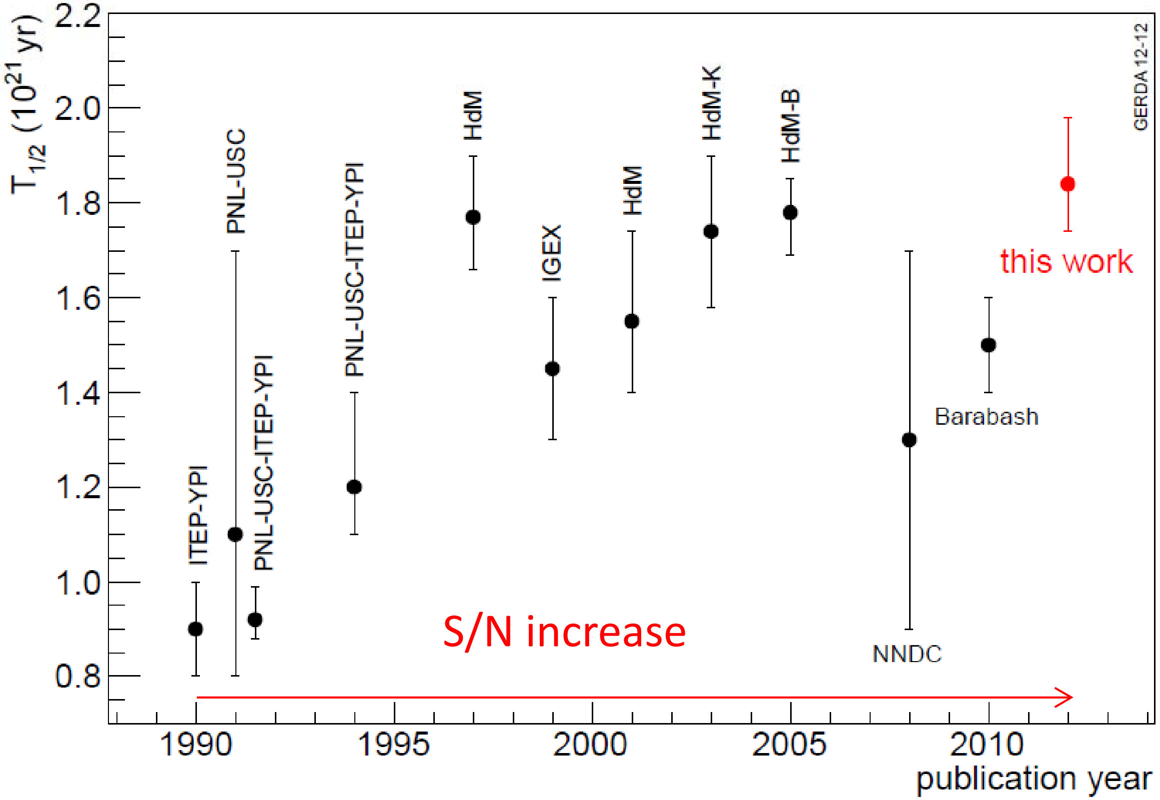
- Exposure: 5kg·y
- 6 independent models for the 6 detectors (5 x 6=30 detector parameters)
- $T^{2\nu}_{1/2}$ common in 6 detectors
- Background from 3 sources: ^{42}K,^{40}K,^{214}Bi (γ-lines used for normalization)
  - ^{42}K: homogeneusly distributed
  - ^{40}K & ^{214}Bi: close sources
- Detectors active masses and enr. factors are nuisance parameters in the fit.

ββ spectrum: 8796 events:

Model of the residual background: 80% 2νββ, 14% ^{42}K, 3.8% ^{214}Bi, 2% ^{40}K,

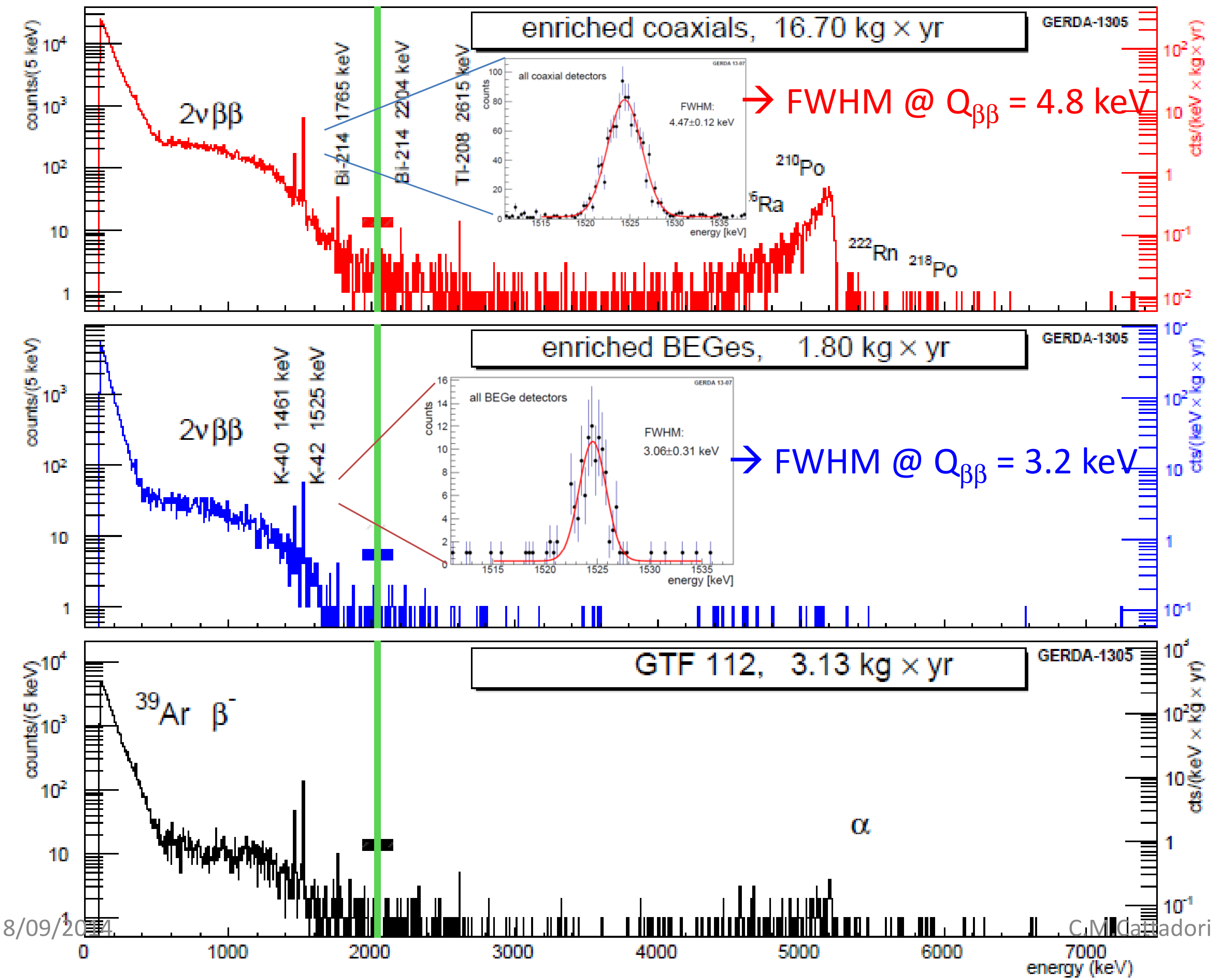
GERDA vs previous measurements of $T^{2\nu}_{1/2}$

$$T^{2\nu}_{1/2} = (1.84^{+0.09}_{-0.08}\,\text{fit}\;^{+0.11}_{-0.06}\,\text{syst}) \cdot 10^{21}\ \text{yr} = (1.84^{+0.14}_{-0.10}) \cdot 10^{21}\ \text{yr}$$



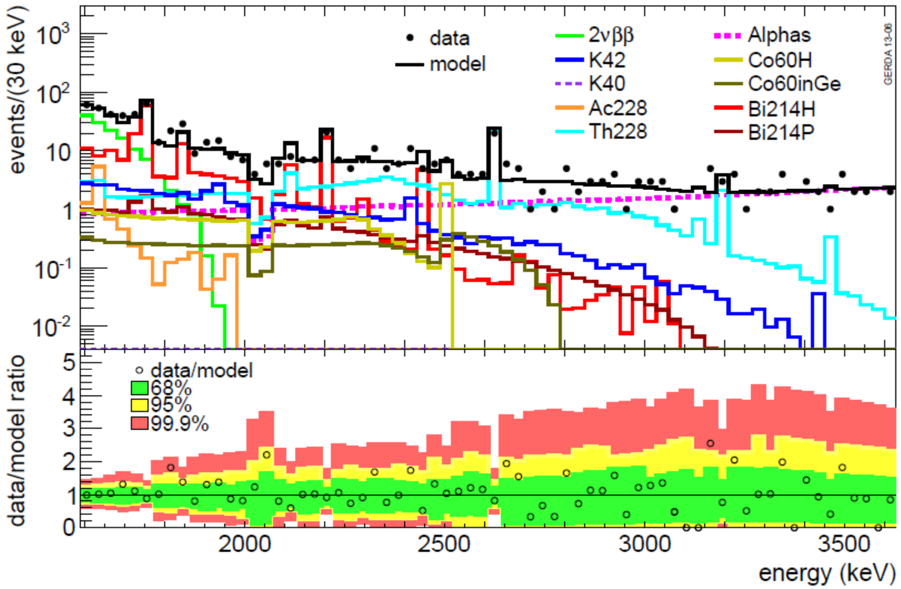
- ❑ GERDA result consistent with HdM-B $T^{2\nu}_{1/2} = 1.78^{+0.07}_{-0.09} \cdot 10^{21}$
- ❑ Thanks to low BI reached comparable sensitivity with ~1/10 exposure
- ❑ 2νββ results will improve with
  - New measurement of coax active volumes
  - Include larger statistics (already available)

0νββ Search – Blinded analysis: events in ±20 keV around $Q_{\beta\beta}$ not reconstructed



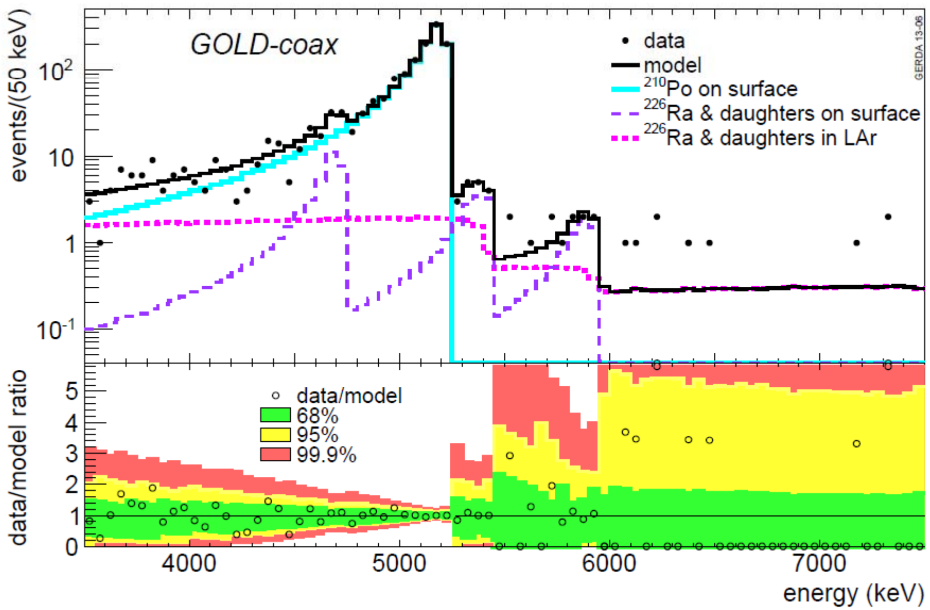
Identification of Background Components

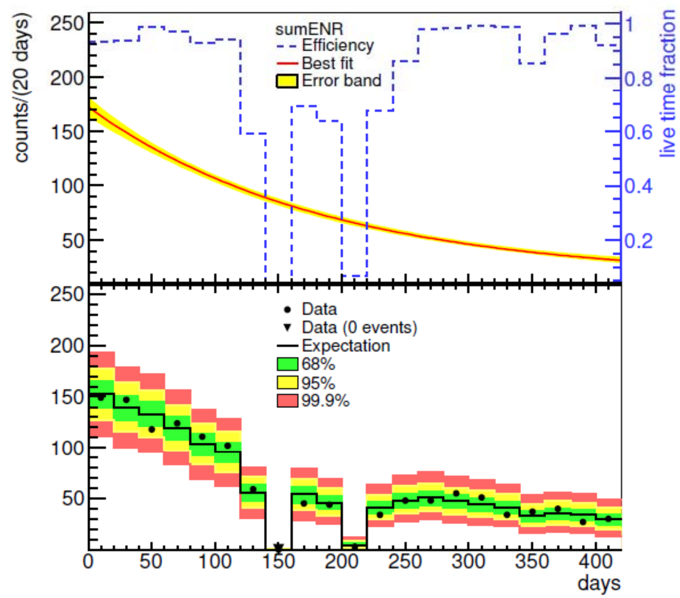
[Eur. Phys. J. C 74 (2014) 2764]



Main Contamination in COAX (with large variations among detectors):

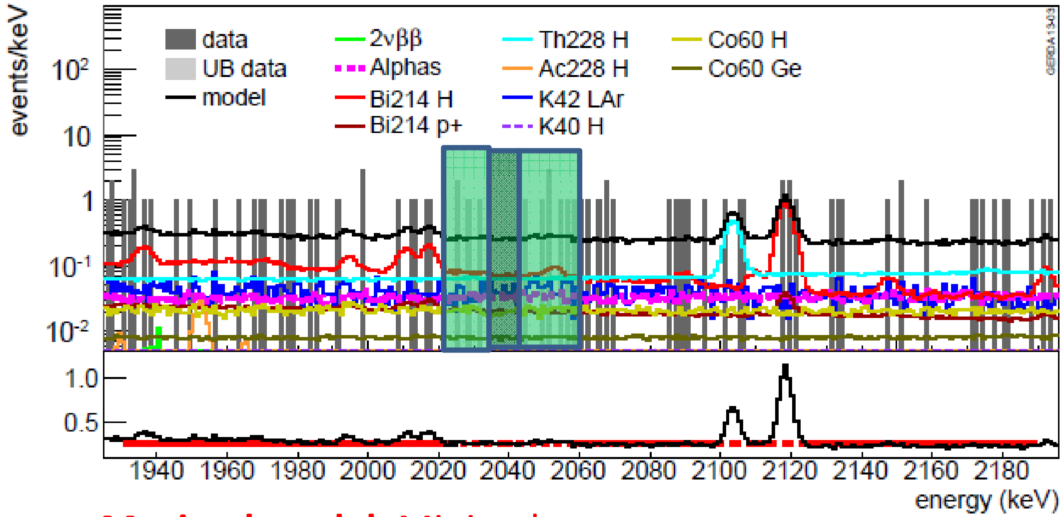
- α contamination from ^{210}Po.
- contamination at time of refurbishment mostly on thin p+ contact
- ^{210}Po decaying away ($t_{1/2}$=138 d)
- BEGes much cleaner in ^{210}Po (> factor 10) than COAX



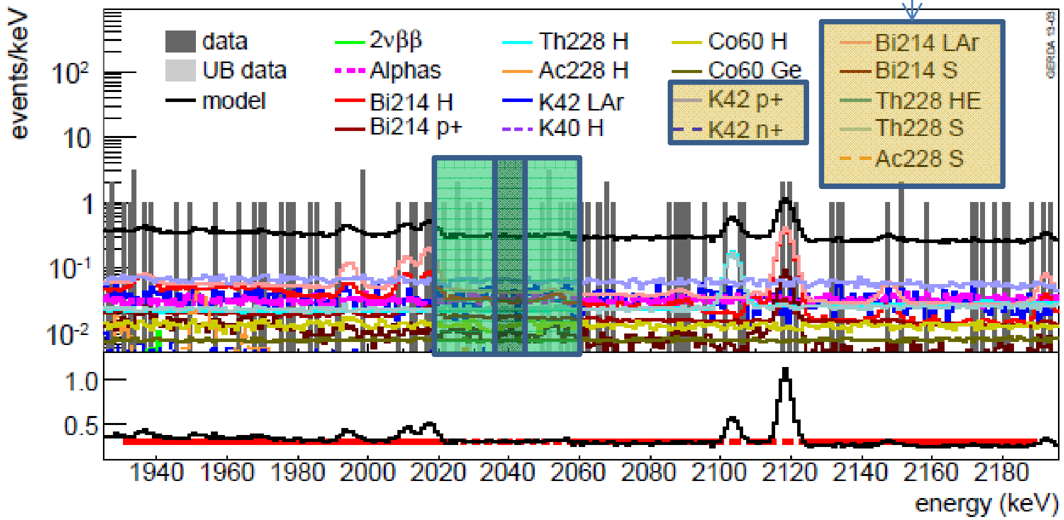


Background model predictions vs data in 260 keV range around $Q_{\beta\beta}$

Minimal model



Maximal model: Minimal +



- The model reproduces a flat bckgrd around $Q_{\beta\beta}$ (data still blinded)
- No γ-lines visible in the 30 keV around the Q_ββ

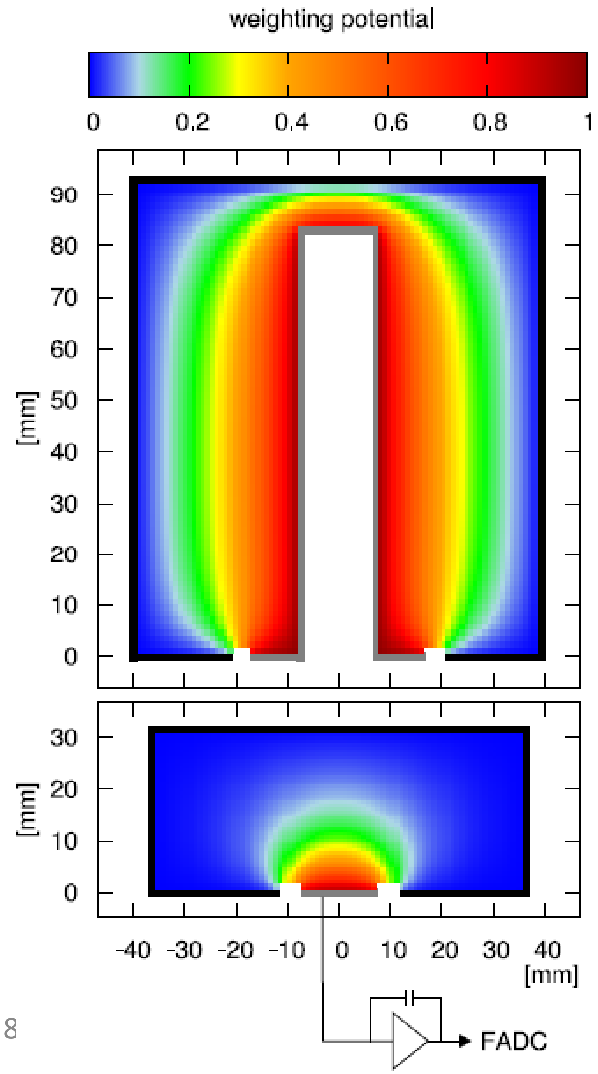
→ spectra can be fitted with a flat background apart from ^{214}Bi lines @ 2104 keV and 2119 keV

Eur. Phys. J. C 74 (2014) 2764

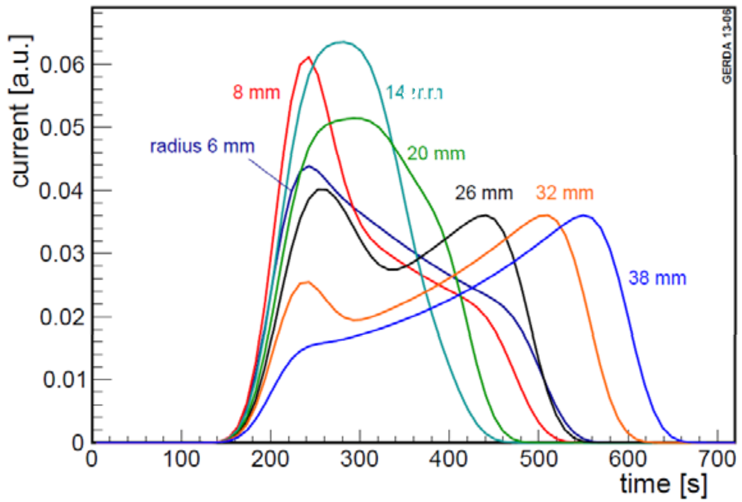
Pulse Shape Discrimination (PSD) to discriminate ββ-like (SSE) to γ-like (MSE) events

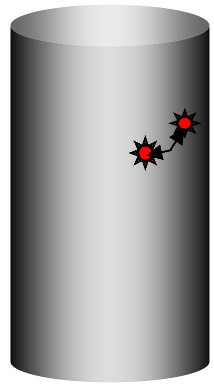
EPJC 73(2013) 2583

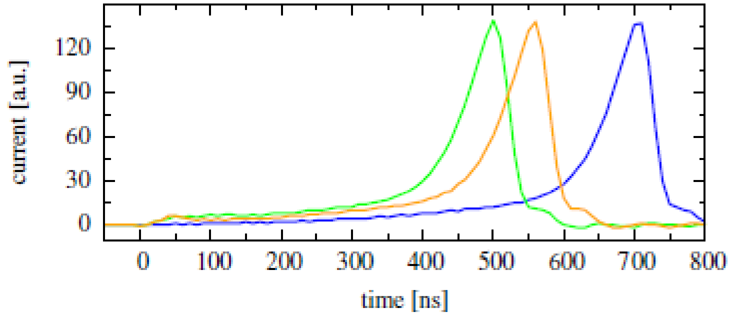
Different weighting potentials for Coax and BEGe

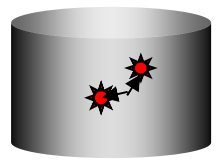


COAX: Artificial Neural Network (ANN) estimator used as PSD parameter





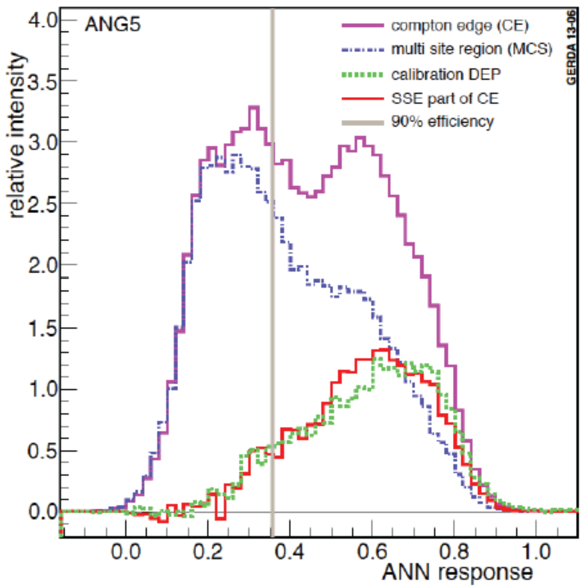




BEGe: Amplitude of Current/Amplitude of Charge Pulse (A/E) is the PSD parameter

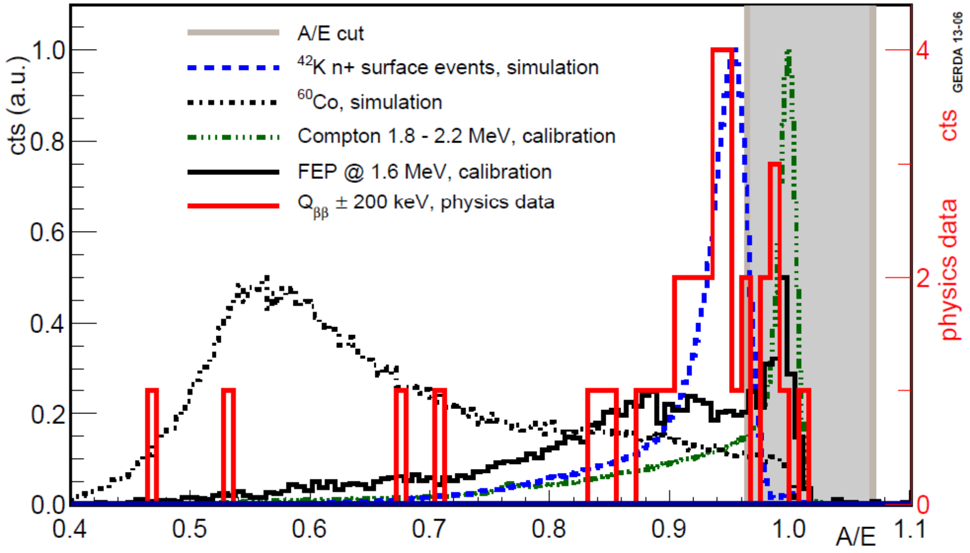
PSD efficiencies

EPJC 73(2013) 2583



PSD Efficiencies experimentally determined @$Q_{\beta\beta}$ & for $2\nu\beta\beta$ events (1MeV < E < 1.5 MeV)
from calibration (Double Escape Peak of 2.6 MeV line)

	$\varepsilon_{2\nu\beta\beta}$	$\varepsilon_{0\nu\beta\beta}$
Coax	0.85 ± 0.02	$0.90^{+0.05}_{-0.09}$
BEGe	0.91 ± 0.05	0.92 ± 0.02



Unblinded counts & efficiencies

PRL111(2013)122503

GERDA

$$T^{0\nu}_{1/2} = \frac{\ln 2 \cdot N_A}{m_{enr} \cdot N^{0\nu}} \cdot \mathcal{E} \cdot \epsilon$$

$$\epsilon = f_{76} \cdot f_{av} \cdot \varepsilon_{fep} \cdot \varepsilon_{psd}$$

In 230 keV @$Q_{\beta\beta}$

In ROI ± 5 keV

Expected bckgd only

data set	$\mathcal{E}$[kg·yr]	$\langle\epsilon\rangle$	bkg	BI †)	cts	Expected bckgd only
without PSD		4.5%				
golden	17.9	0.688 ± 0.031	76	18 ± 2	5	5.1
silver	1.3	0.688 ± 0.031	19	63^{+16}_{-14}	1	
BEGe	2.4	0.720 ± 0.018 (2.5%)	23	42^{+10}_{-8}	1	
with PSD		7.1%				
golden	17.9	$0.619^{+0.044}_{-0.070}$	45	11 ± 2	2	2.5
silver	1.3	$0.619^{+0.044}_{-0.070}$	9	30^{+11}_{-9}	1	
BEGe	2.4	0.663 ± 0.022 (3.3%)	3	5^{+4}_{-3}	0	

†) in units of 10^{-3} cts/(keV·kg·yr).

Bckgrd Rej $_{PSD}$ ^{Coax} ~ 43%

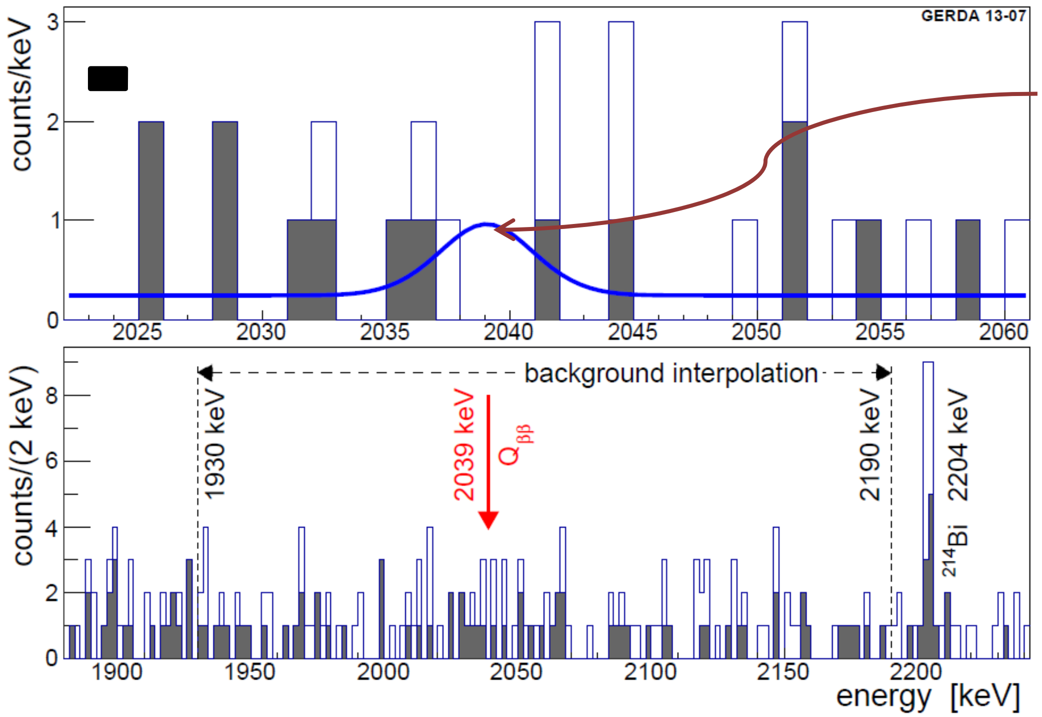
Bckgrd Rej $_{PSD}$ ^{BEGe} ~ 87%

From Counts to $T_{1/2}^{0\nu}$

PRL111(2013)122503

Performed Profile Likelihood fit of the 3 data sets

- B+S: described by constant term + Gaus($Q_{\beta\beta}$,σ_E)
- 4 free parameters in the fit B_{gold}, B_{silv},B_{BEGe},$1/ T_{1/2}^{0\nu}$
- Systematics folded in



Frequentist approach

Best fit: $N^{0\nu} = 0$

$N^{0\nu} < 3.5$ cts @ 90% C.L.

$T_{1/2}^{0\nu} > 2.1 \times 10^{25}$ yr @ 90% CL

Median sensitivity:

$T_{1/2}^{0\nu} > 2.4 \times 10^{25}$ yr

Bayesian approach

Flat prior for $1 / T_{1/2}^{0\nu}$

Best fit: $N^{0\nu} = 0$

$T_{1/2}^{0\nu} > 1.9 \times 10^{25}$ yr @ 90% CI

Median sensitivity:

$T_{1/2}^{0\nu} > 2.1 \times 10^{25}$ yr

GERDA (all data sets) vs 0νββ observation claim

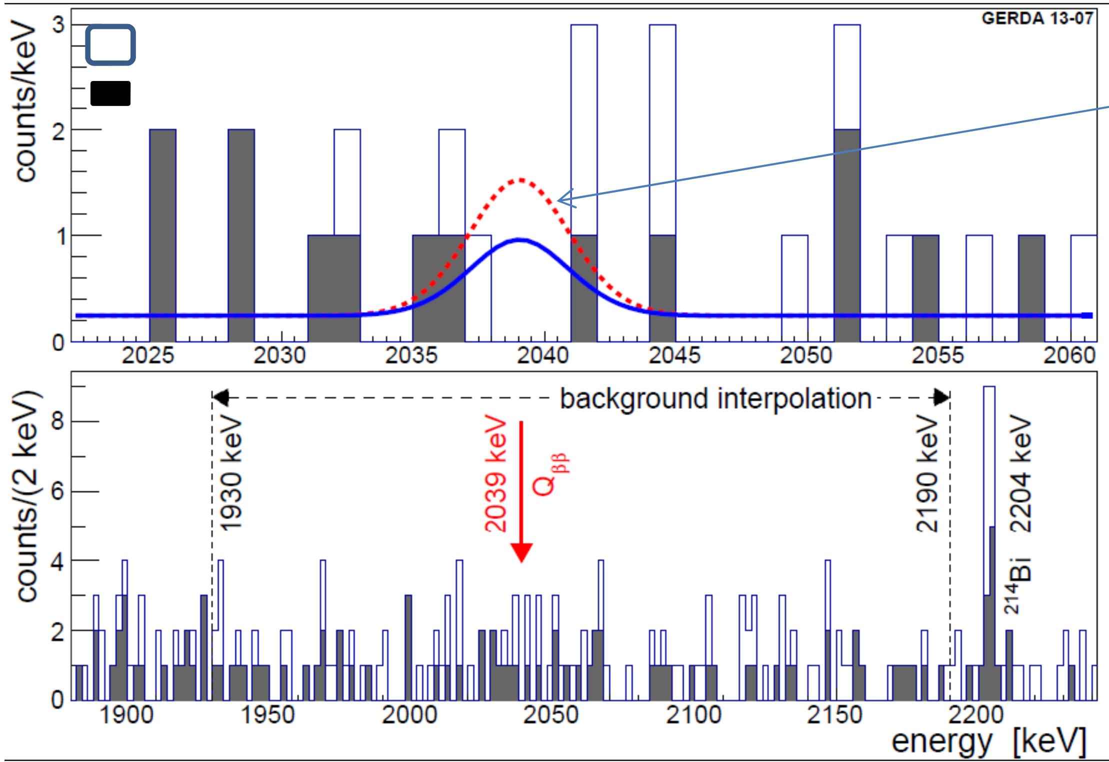
PLB 586(2004)

For $T_{1/2}^{0\nu}$ = 1.19 x 10^{25} yr

Expected Signal (after PSD): 5.9 ± 1.4 cts in ±2σ

Expected Bckgd (after PSD): 2.0 ± 0.3 cts in ±2σ

Observed: 3.0 (0 in ±1σ)



From profile likelihood

Assuming H1 true→

P ($N^{0\nu}$=0)=1%

Comparing

H1: Claimed signal

H0: Background only

Bayes factor

P(H1)/P(H0)=0.024

(uncertainties on claim included)

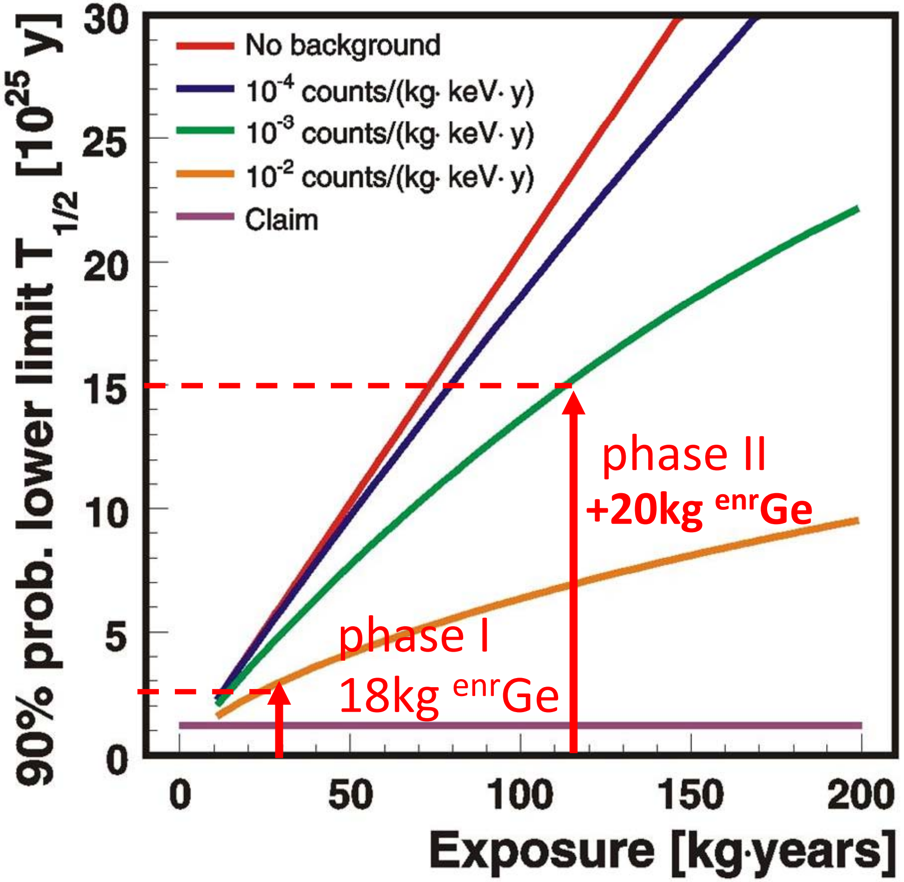
Claim poorly credible

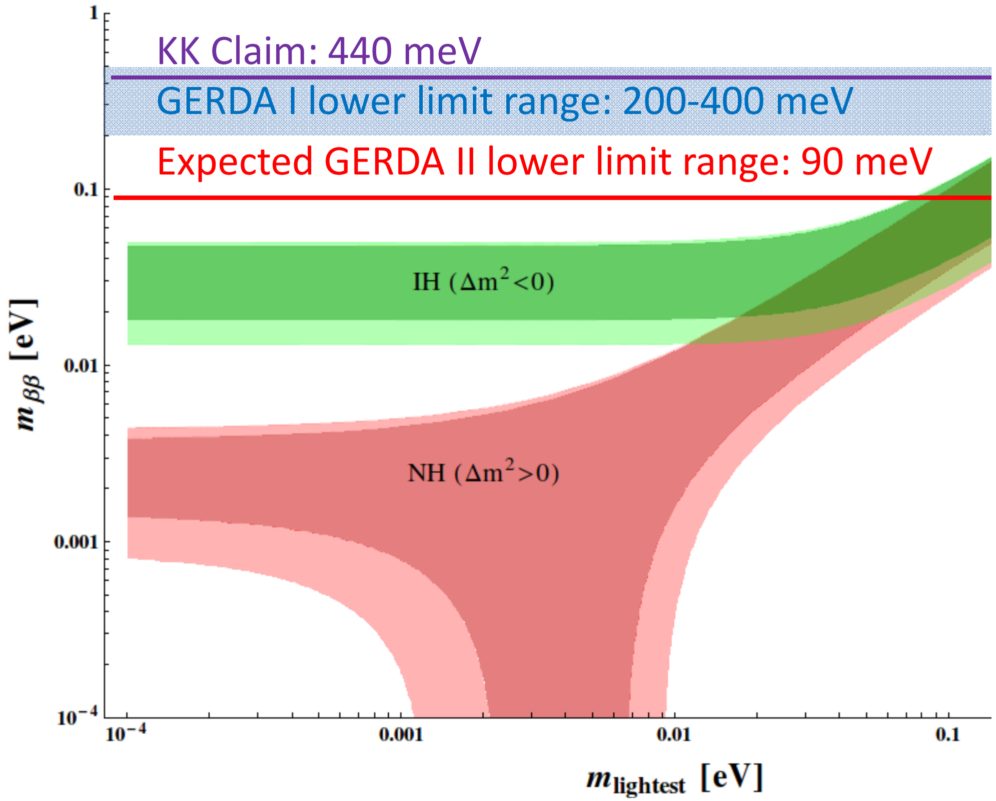
Status of experimental searches

Isotope	$T^{2\nu}_{1/2}$ (10^{19} y)	$T^{0\nu}_{1/2}$ (10^{24} y)	$<m_{\beta\beta}>$ (meV)
^{48}Ca	4.4 ± 0.5(stat) ± 0.4(syst)	>0.058	3515-14133
^{76}Ge	$1.78^{+0.07}_{-0.09}$	$22.3^{+4.4}_{-3.1}$	400
^{76}Ge	184 ±90 (stat) ±11(syst)	>21.0 > 30 GERDA&IGEX&HdM	201-638
^{82}Se	9.6±0.1(stat) ±1.0(syst)	>0.32	884-2631
^{96}Zr	2.35 ± 0.14 (stat) ± 0.16 (syst)	>0.0092	4207-15139
^{100}Mo	0.716 ± 0.001 (stat) ± 0.054 (syst)	> 1.0	334-946
^{116}Cd	2.88 ± 0.04 (stat) ± 0.16 (syst)	> 0.17	1300-2440
^{130}Te	70 ± 9 ±(stat) 11 (syst)	> 2.8	296 – 773
^{136}Xe	217.2 ± 1.7 (stat) ± 6 (syst)	>26	140-280
^{150}Nd	0.911 ± 0.025 (stat) ± 0.063 (syst)	> 0.018	2622-5678

GERDA II Expected Sensitivity

Assumed E resolution: ΔE = 4 keV



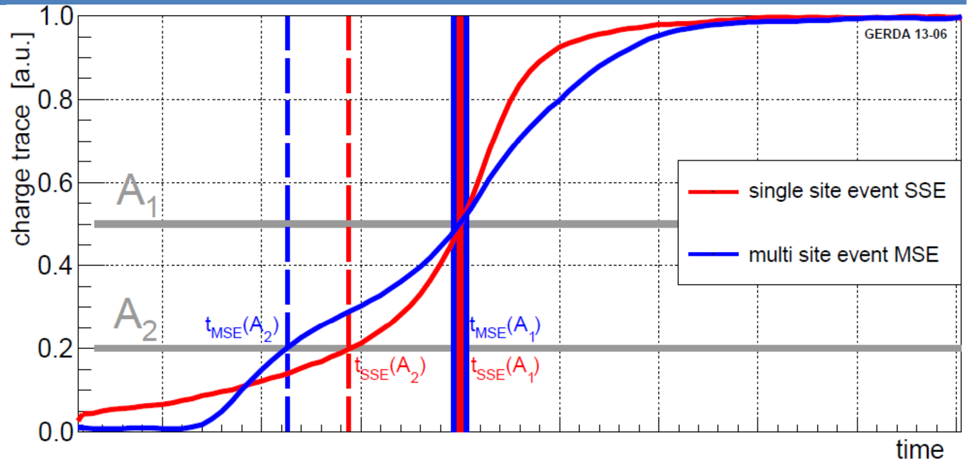


From Dell'Oro, Marcocci,Vissani, hep-ph/1404.2616v1

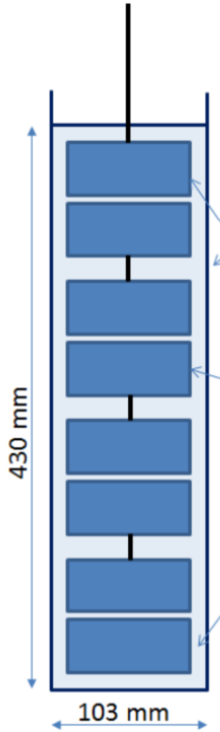
- ❑Reach a BI ~ 10^{-3} cts/(keV· kg· yr) at Q_{bb} (±200 keV ROI)
- ❑ Reach $\mathbf{T^{0\nu}_{1/2} \sim 1.5 \cdot 10^{26}}$ **yr** (120 kgy exposure) → $\langle m_{\beta\beta} \rangle \leq$ 0.09-0.15 eV

GERDA Strategy to improve $T_{1/2}$ limits

- Increase ^{enr}Ge mass (~40 kg in total) 21 kg in form of Ge-BEGe detectors
- →enhanced PSD to pinpoint ββ events (Single Site) vs residual γ events (Multi Site)



- Reduce radioactivity of Ge holders and mechanical structures
- New Ge readout electronics with closer FE devices in die for improved FWHM
- LAr as active media(active detector) and not only as passive shield
- ^{42}K bkgd: Transparent Nylon Mini Shroud (NMS) coated with WLS (instead of Cu opaque) surrounding each BEGe detector string.



GERDA Phase II

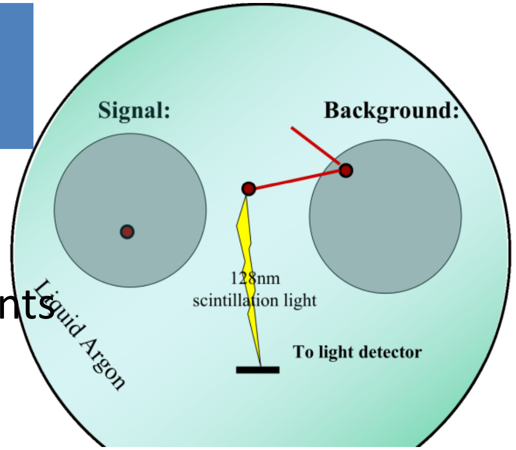
Phase I: 13 kg of enrGe COAX Detectors
3 kg of enrBEGe Detectors
w. enhanced PSD

Phase II: 18 kg of ^{enr}Ge COAX Detectors
21 kg of ^{enr}Ge BEGe Detectors
w. enhanced PSD

Readout of Liquid Argon Scintillation Light

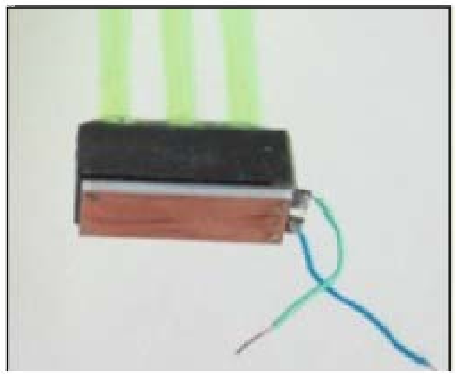
Strategy: Wide angle *eye*: 16 PMTs
Closer *eye*: Fiber Shroud readout by SiPMs

Expected: Suppression factor ~10 for ^{214}Bi and >>10 for ^{232}Th events



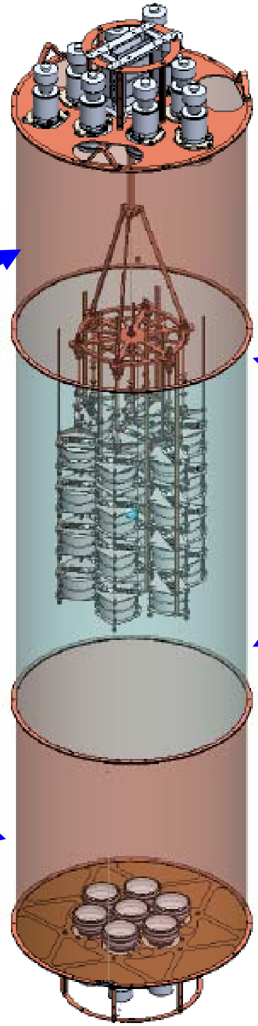
Inner Fiber Shroud: SiPMs + WLS Fibers

SiPM/Fiber readout



Top/Bottom: PMTs

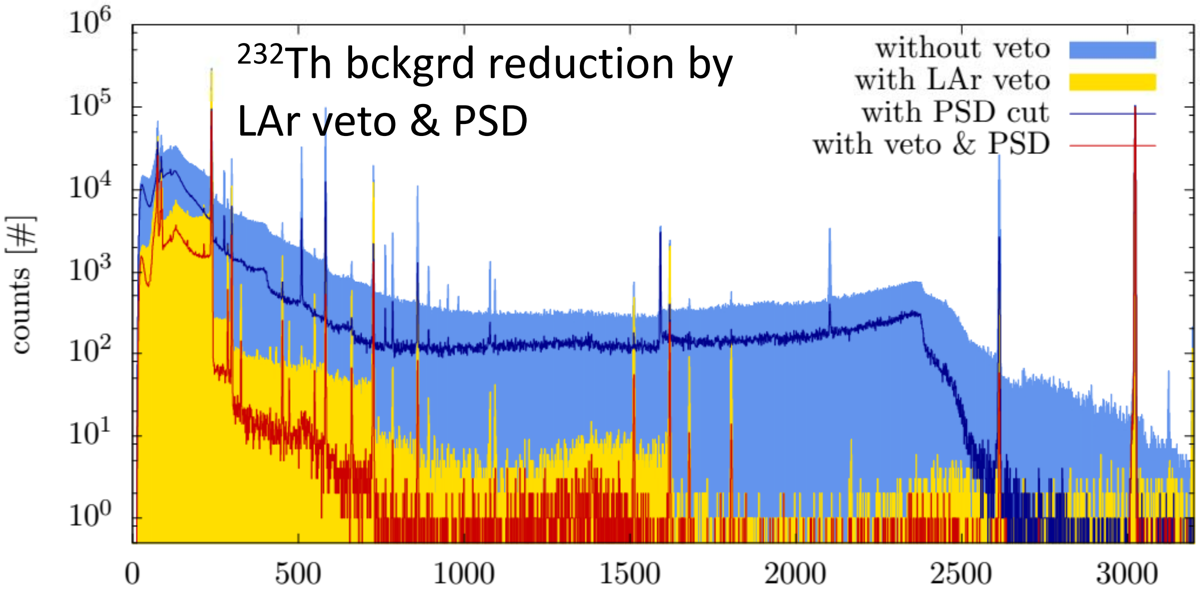
TOP:9 PMTs
CU shroud 1
h:60 cm
diam:49 cm



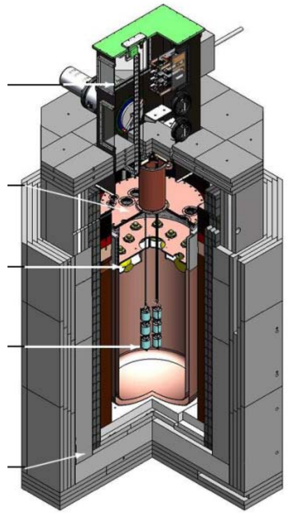
MIDDLE
h:100 cm,
diam:47 cm
Dense curtain of scintillating fibers readout by SiPMs

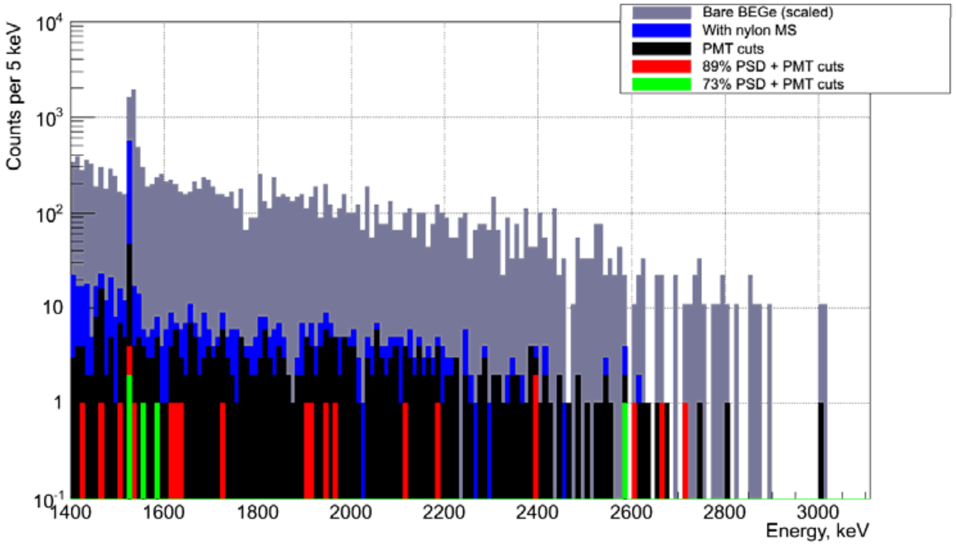
BOTTOM:7 PMTs
CU shroud 2
h:60 cm
diam: 49 cm

^{42}K backgrd mitigation by Nylon Mini Shroud and LAr veto



Measured ^{42}K bckgrd reduction: 1BEGe in Nylon Mini Shroud (NMS)& PMTs & PSD 10^2-10^3





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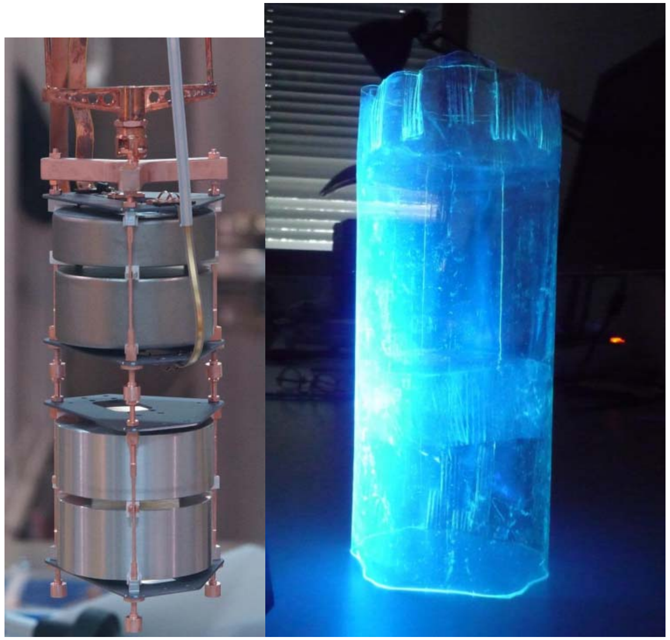
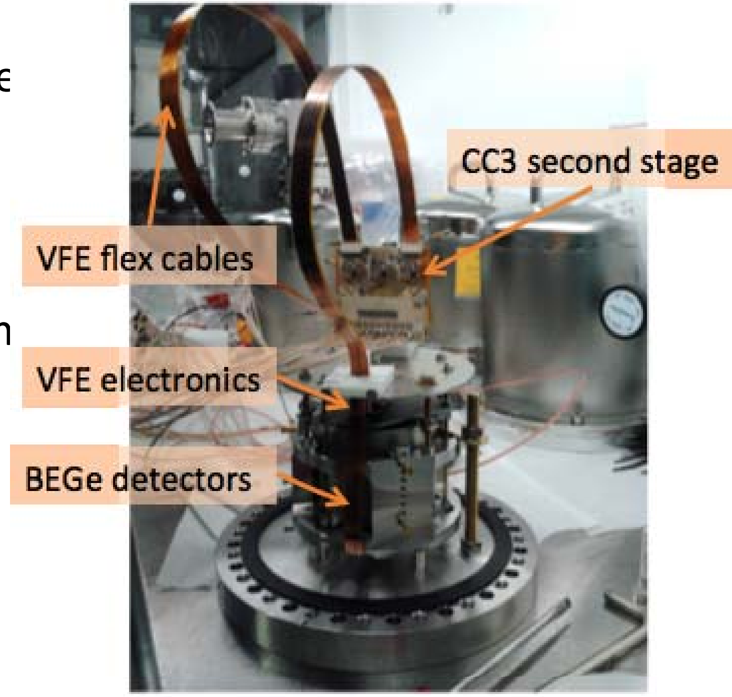
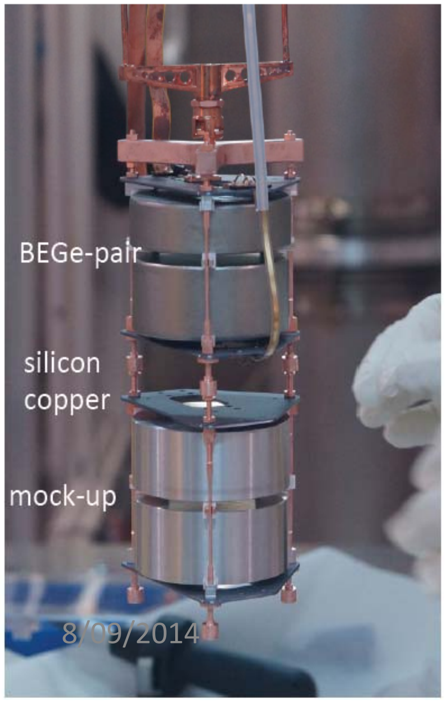


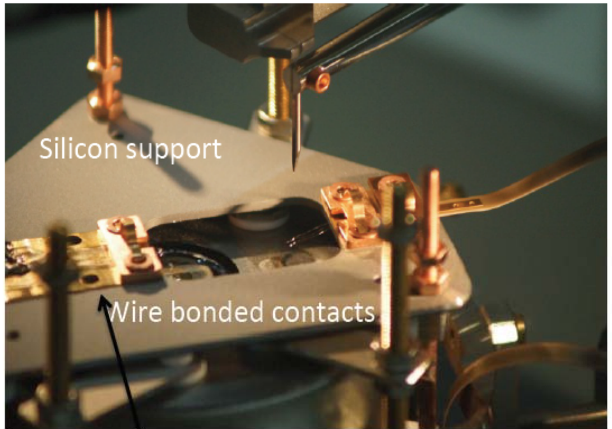
Ge detectors holders and Front End (FE) Electronics

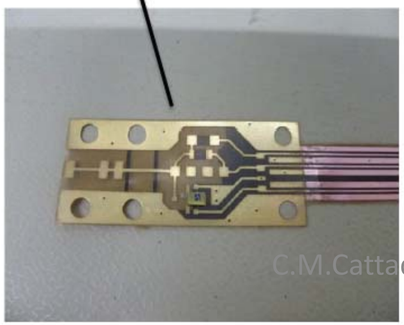
- Holders: Si plates instead of Cu (improved radiopurity)
- Upgraded Circuit (based on commercial CMOS selecte for cryogenic applications.
- Phase II FE: FE Devices (JFET in die Feedback R and C) onto the Si Plate
- Phase I FE: On CSA PCBs at 80 cm distance from botton detector



Phase II detector assembly



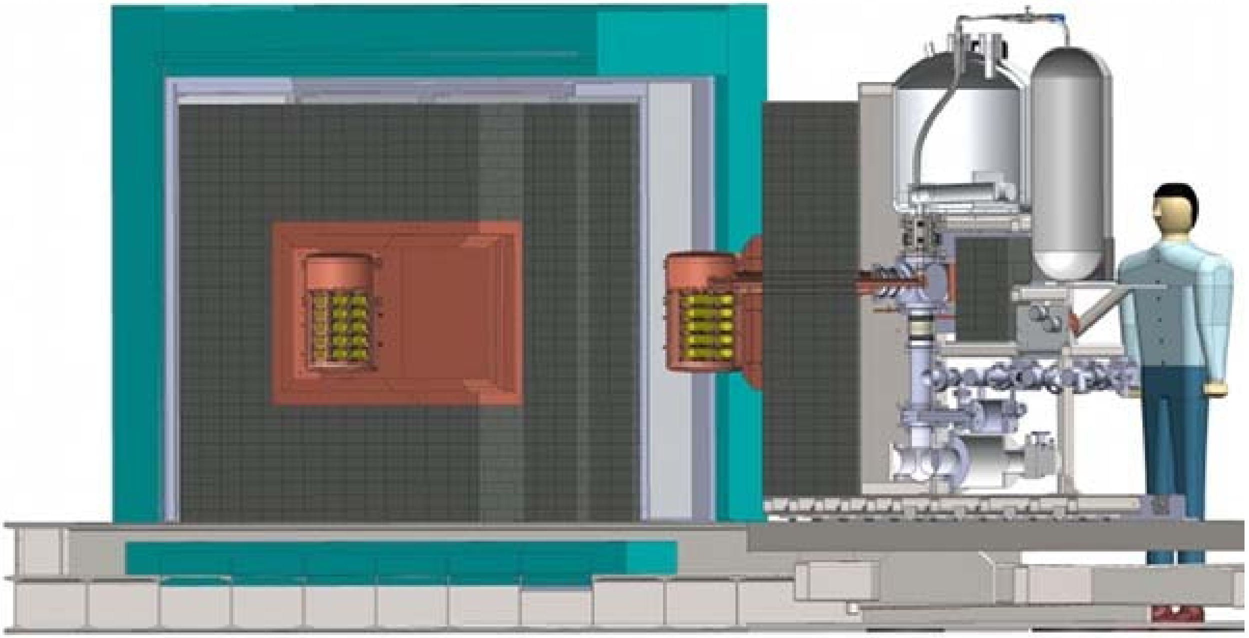




flex cables with JFET and feedback resistor/capacitor

Achieved in Phase II Tests
•FWHM: 2.6 keV @ 2.6 MeV
•Electronic Noise: 0.9 keV
•FWHM of PSD Parameter: ~ 1%
•Survival Fraction of Compton Continuum @$Q_{\beta\beta}$ after PSD Cut ~ 50%

What Next GERDA II ?



• Majorana Demonstrator at SURF (Sanford Underground Facility) is in advanced stage of construction. Operation of the First String is expected soon.
• It consist of 40 kg of Ge BEGe/PIN Point Detectors 30 kg are ^{enr}*Ge.*
•The goal of the demonstrator is to show that the chosen technique (operate detectors in cryostat made of Cu electroformed underground) can achieve a BI of 1 cts/(t·y) in a 4 keV ROI @ $Q_{\beta\beta}$ (i.e. < 10^{-3} cts/(keV·kg·y))
•At the completion of GERDA II and Majorana Demonstrator physics program, Gerda & Majorana projects could merge data & detectors, pinpointing the best technique.

Summary

- GERDA I collected 21.6 kg·y exposure in the time period 2011-2013, with
  - BI 10^{-2} cts/(keV · kg · y) and
  - FWHM ~ 4.8 keV (for COAX detectors)
  - FWHM ~ 3.2 keV (for BEGe detectors)
  - Pulse Shape Discrimination with 90% acceptance for efficiency for single site events
- No excess count has been found over the expected background

  After PSD: 3 cts found vs 2.5 expected

  Best fit: $N^{0\nu} = 0$

  $N^{0\nu} < 3.5$ cts @ 90% C.L.

  $T_{1/2}^{0\nu} > 2.1 \times 10^{25}$ yr @ 90% CL
- The $0\nu\beta\beta$ claim has not been confirmed
- Since 2013 GERDA is upgrading to complete Phase II of the foreseen experimental program
  - 21 kg of BEGe detectors w. Enhanced PSD capabilities + 18 kg COAX detectors
  - LAr will be readout and will act as veto
  - FWHM expected <3 keV for BEGe detectors
- The expected sensitivity
  - **$T_{1/2}^{0\nu} > 1.5 \times 10^{26}$ yr @ 90% CL for an exposure of 120 kg·y → m_{ee}<90 meV**