GERDA: results and future

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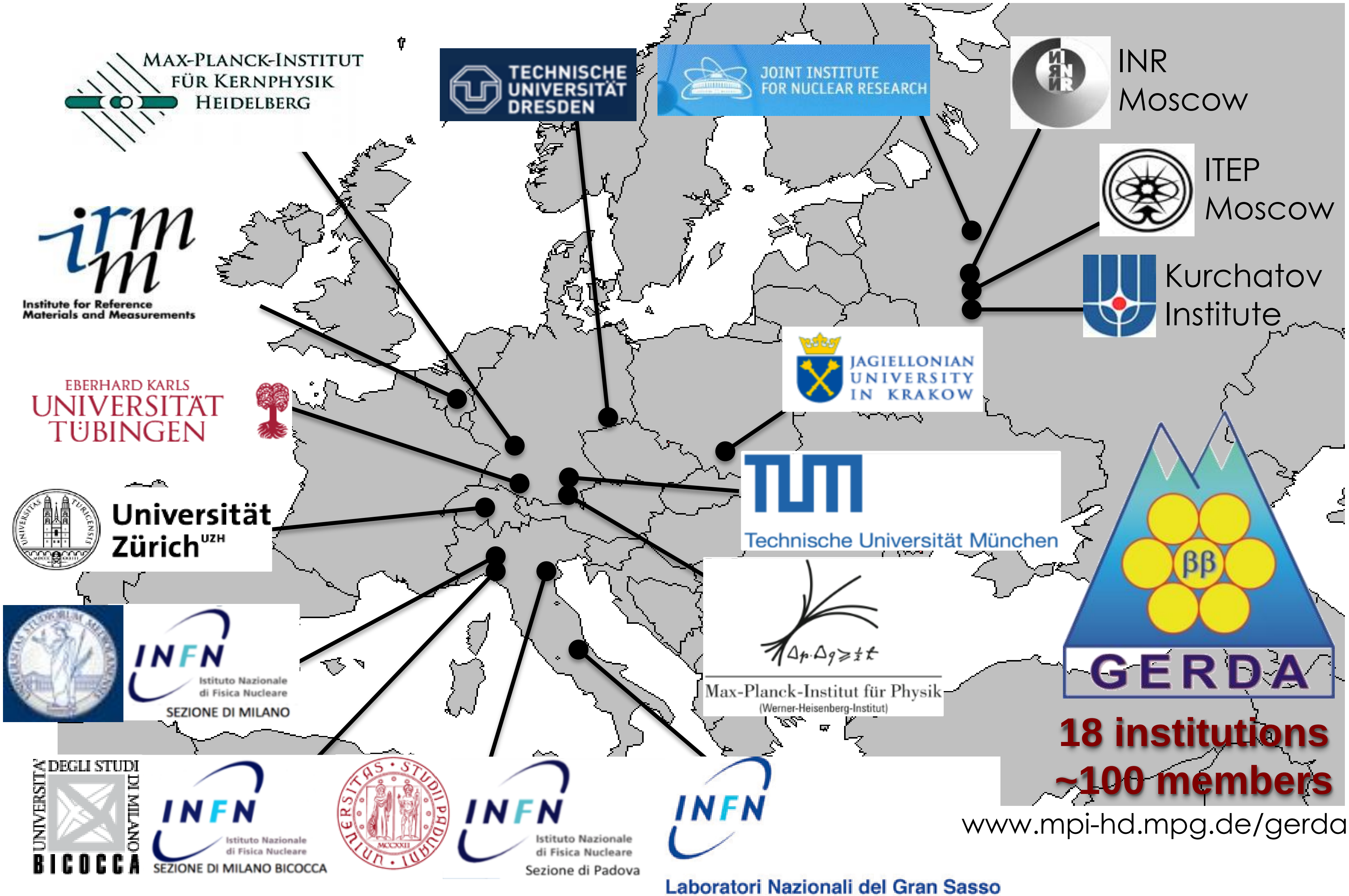
http://www.mpi-hd.mpg.de/GERDA

GERDA

E15

The GERDA collaboration



www.mpi-hd.mpg.de/gerda

Outline

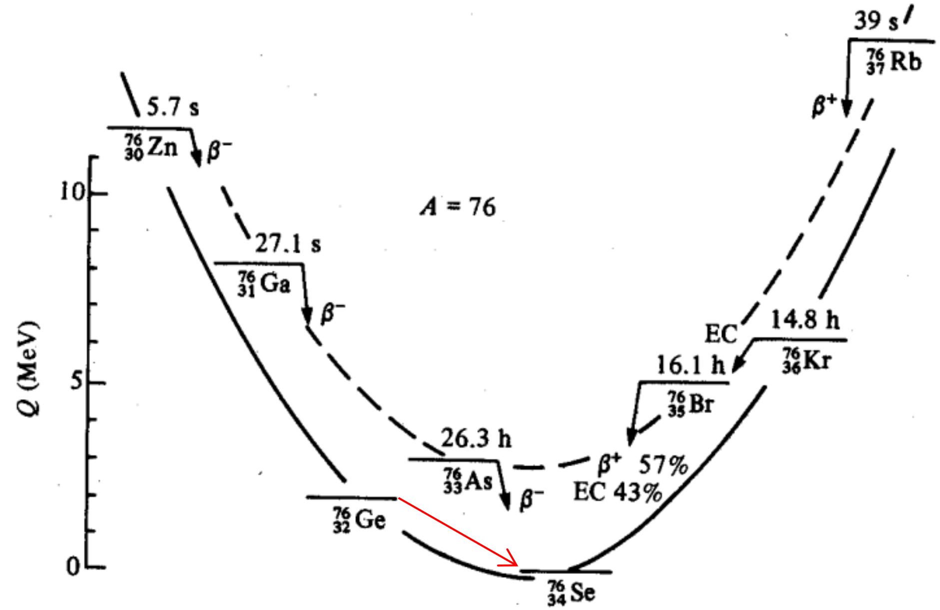
1. Experimental approach and design
2. Data and analysis
3. Result: $0\nu\beta\beta$ $T_{1/2}$ limit
4. Future: GERDA Phase II

GERDA: 0νββ-decay experiment

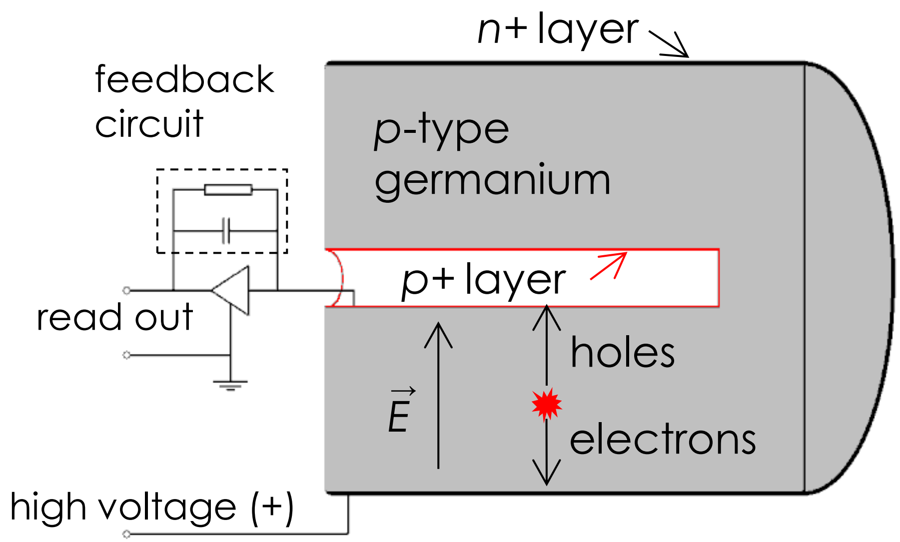
GERDA aims to search for the half-life of 0νββ decay of ^{76}Ge

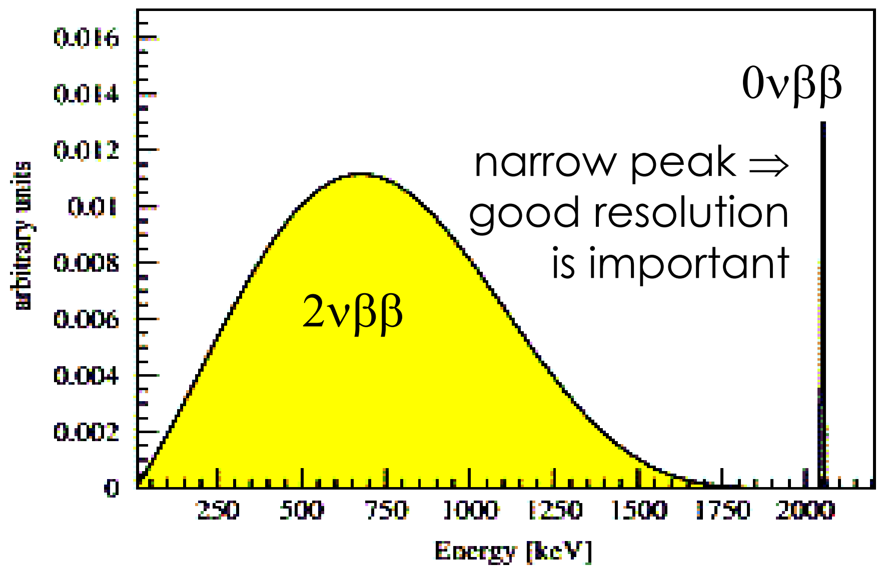
Germanium detectors:

- ultra high purity material
- excellent energy resolution
- enrichment in ^{76}Ge ~86%



$Q_{\beta\beta}$ = 2039.01(5) keV

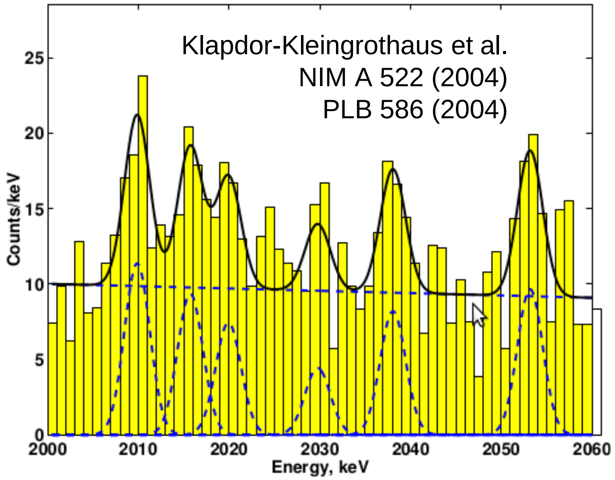




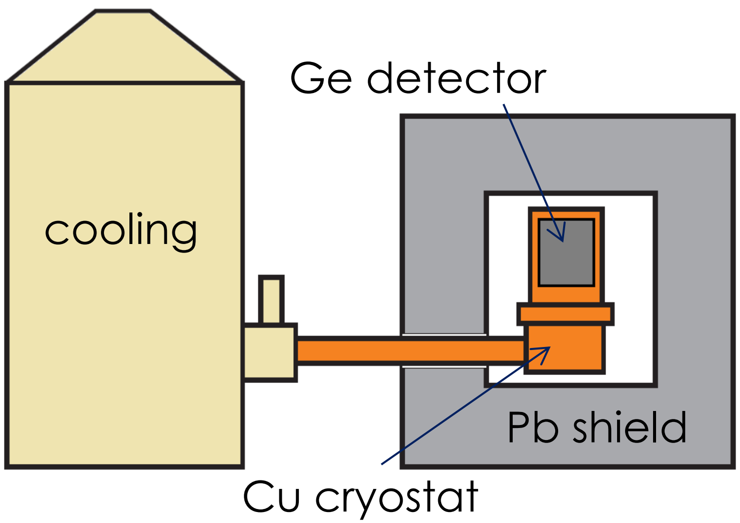
0νββ-decay search using ^{76}Ge

Germanium detectors:
historically most sensitive 0νββ probe

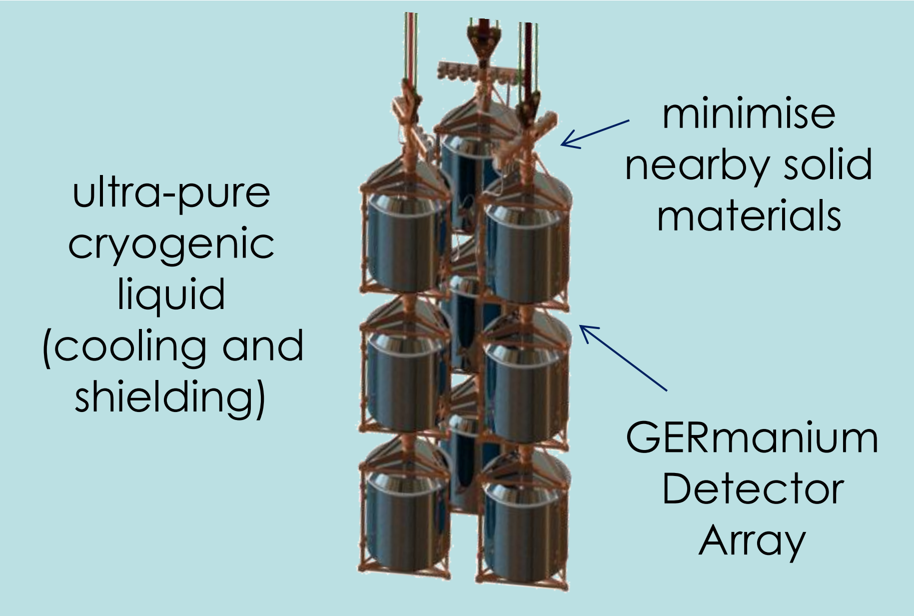
	$T_{1/2}^{0\nu}$ [10^{25} yr]
IGEX:	>1.6 (90% C.L.)
Heidelberg-Moscow:	>1.9 (90% C.L.)
Klapdor-Kleingrothaus claim:	$1.19^{+0.37}_{-0.23}$



Past approach (IGEX, HdM):



GERDA approach (Gerd Heusser '95):

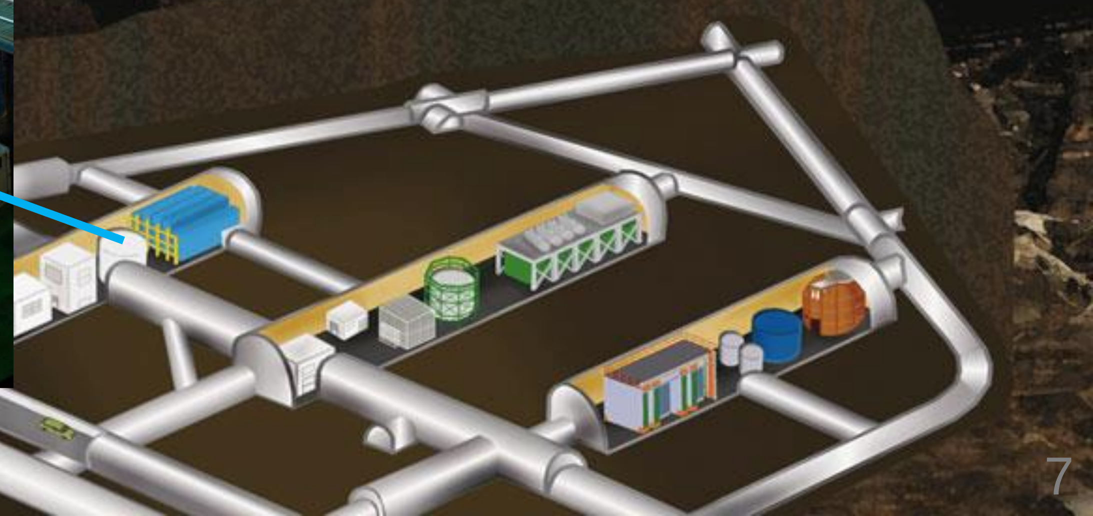


Eur. J. Phys. C73 (2013) 2330

Design of GERDA

Eur. J. Phys. C73 (2013) 2330

Design of GERDA



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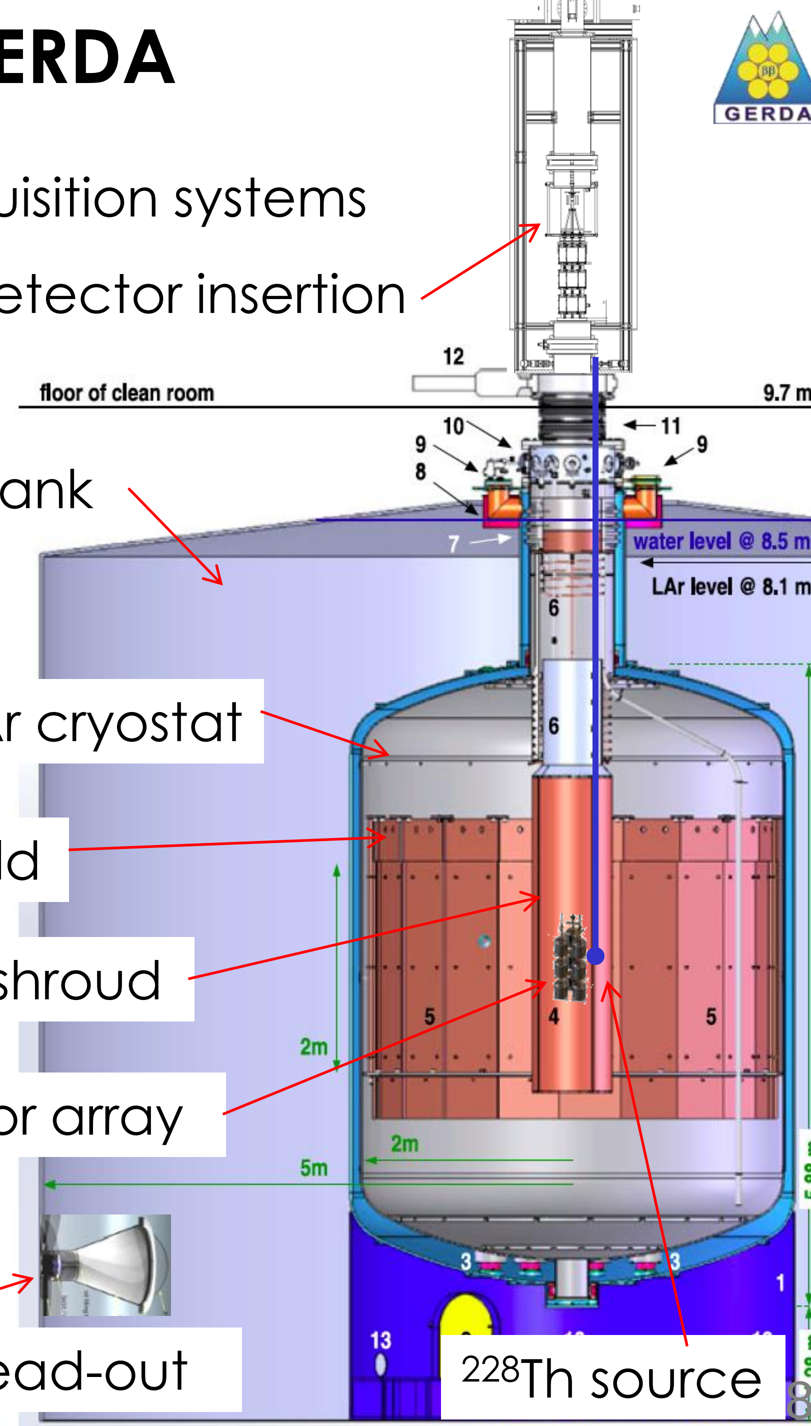
Design of GERDA

Clean room, data acquisition systems

Lock for detector insertion



Water tank

64m^3 LAr cryostat

Cu shield

Radon shroud

Detector array

PMT Cherenkov light read-out

^{228}Th source

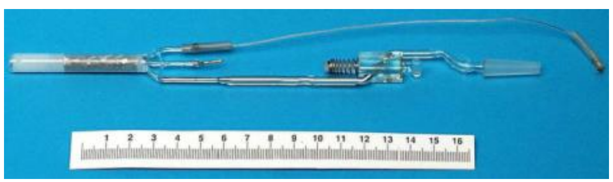
Water Cherenkov PMT muon veto

Low background challenge

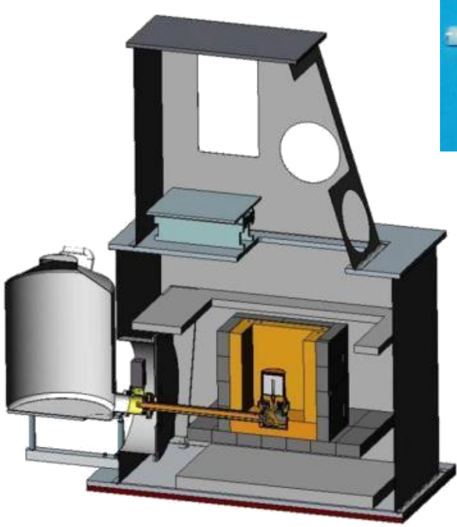
Samples of all materials measured and selected for low radioactivity.

Variety of ultra-sensitive methods:

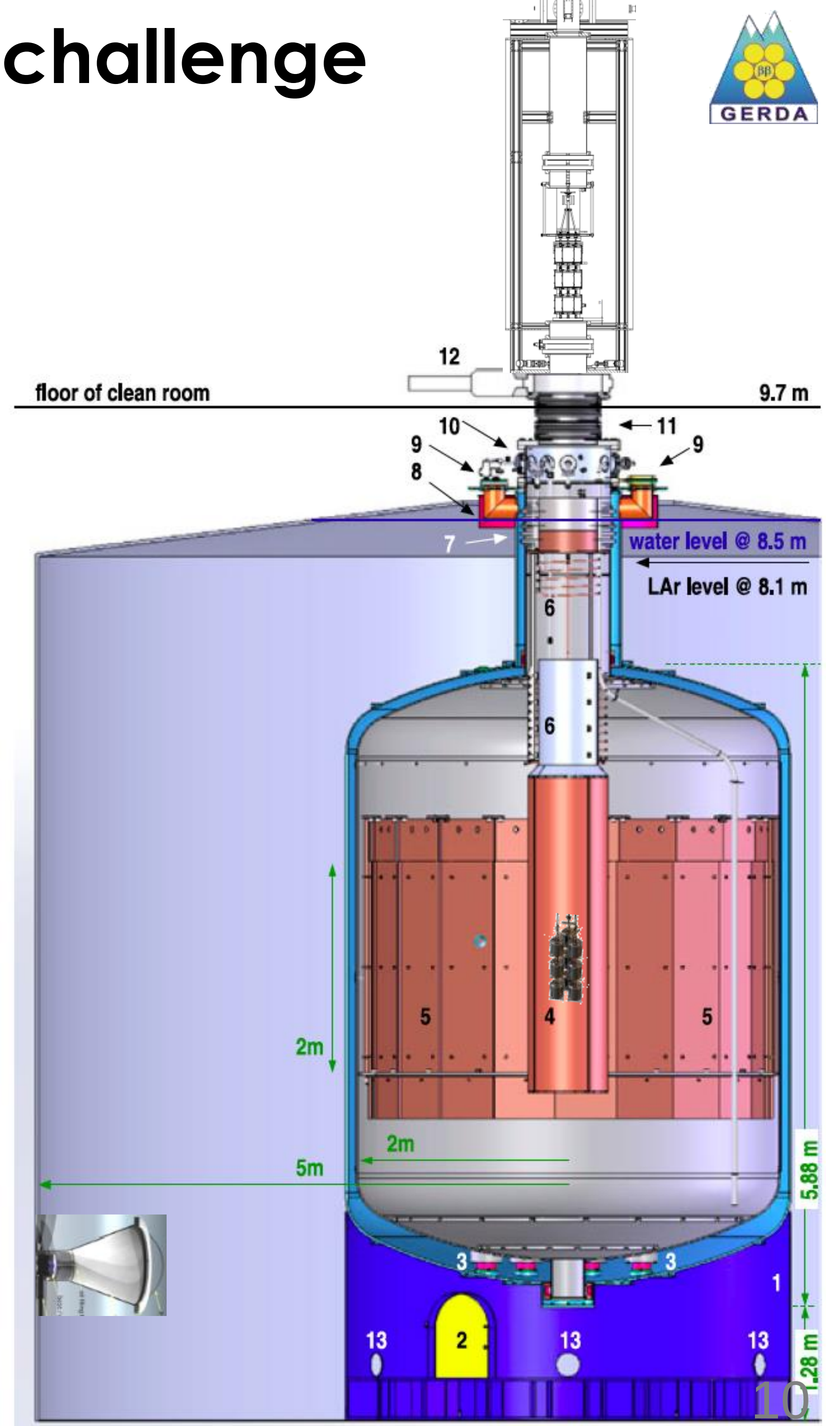
- Ge-detector spectrometry
- mass spectrometry
- neutron activation analysis
- radon emanation detection via proportional gas counters



proportional gas counter, GALLEX/GNO heritage



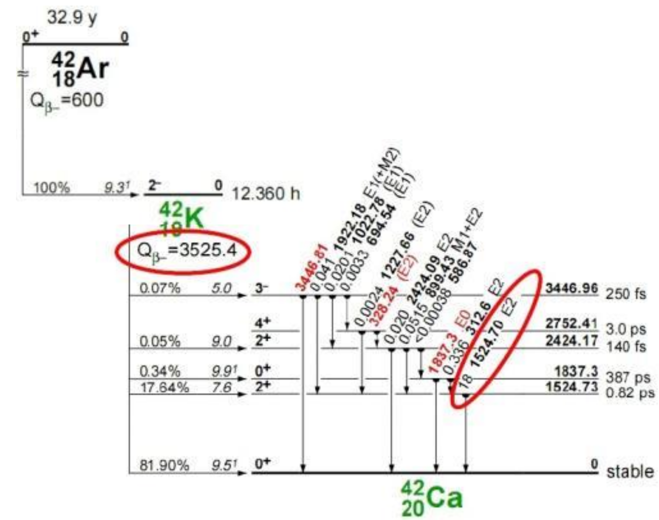
GeMPI spectrometer, evolution of Heidelberg-Moscow detector design

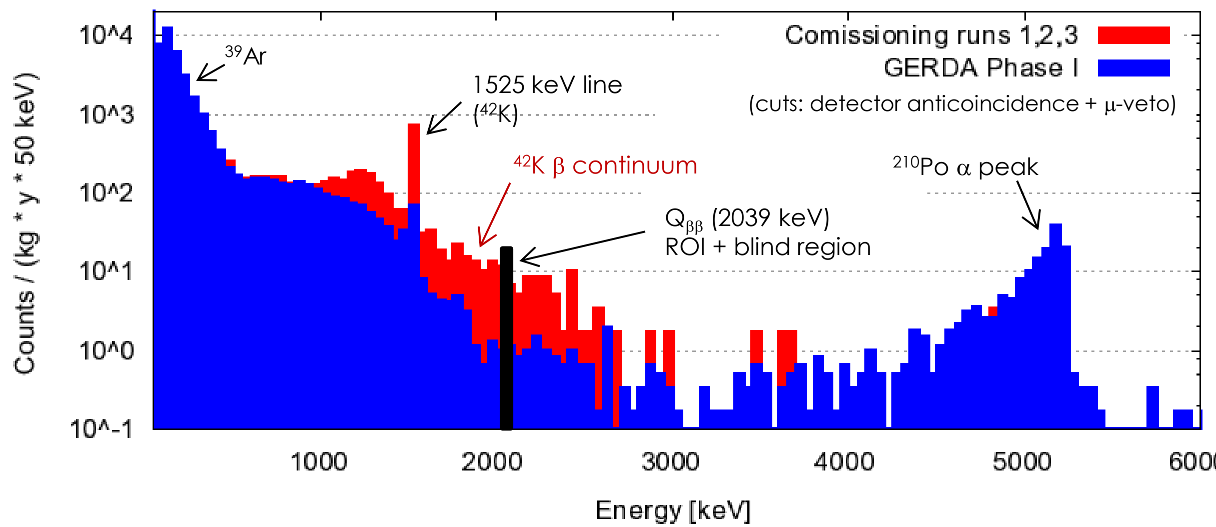


Low background challenge

^{42}Ar concentration in natural argon found much higher than expected.

⇒ solved by installing protective Cu-foil "mini-shroud" around detectors





GERDA Phase I detectors

Enriched coaxial (17.67 kg):
5 from Heidelberg-Moscow
3 from IGEX

Enriched BEGe (3.63 kg):
5 new (Phase II design)

1 non-enriched coaxial

Deployment: November 2011
BEGe: July 2012
Data taking until: May 2013

Total exposure for $0\nu\beta\beta$ analysis: 21.6 kg·yr

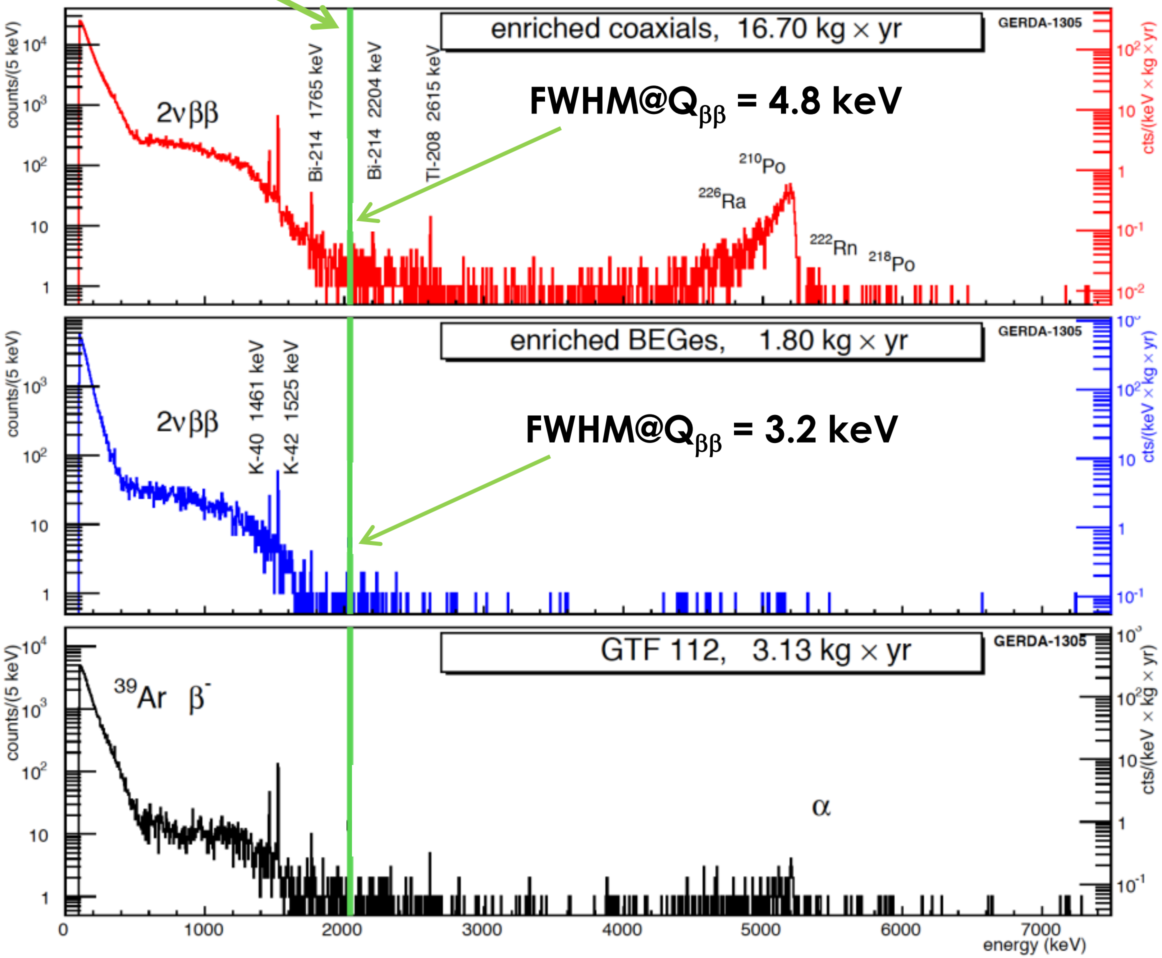
3 data-sets: 17.9 kg·yr "golden", 1.3 kg·yr "silver", 2.4 kg·yr "BEGe"

ANG 1 and RG 3 stopped soon after deployment, RG 2 near the end.
GD35C excluded from analysis due to system instability

GERDA Phase I data analysis

Background data:

blinded until all analysis procedures fixed



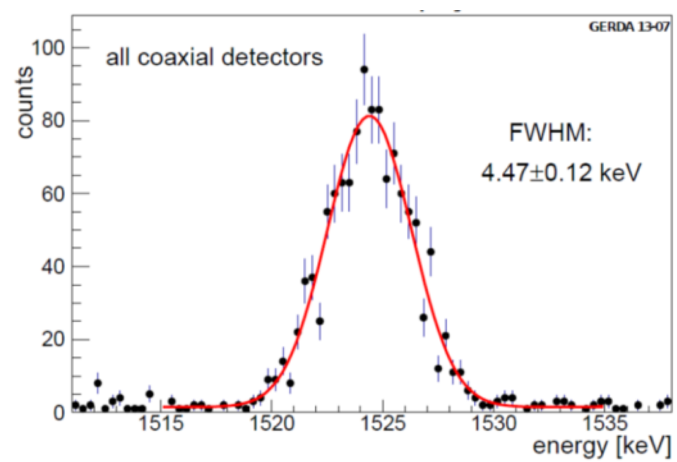
Analysis cuts:

muon-veto and Ge-array anti-coincidence: ~40% cut

signal quality: ~9% cut

Periodic calibration with ^{228}Th sources.

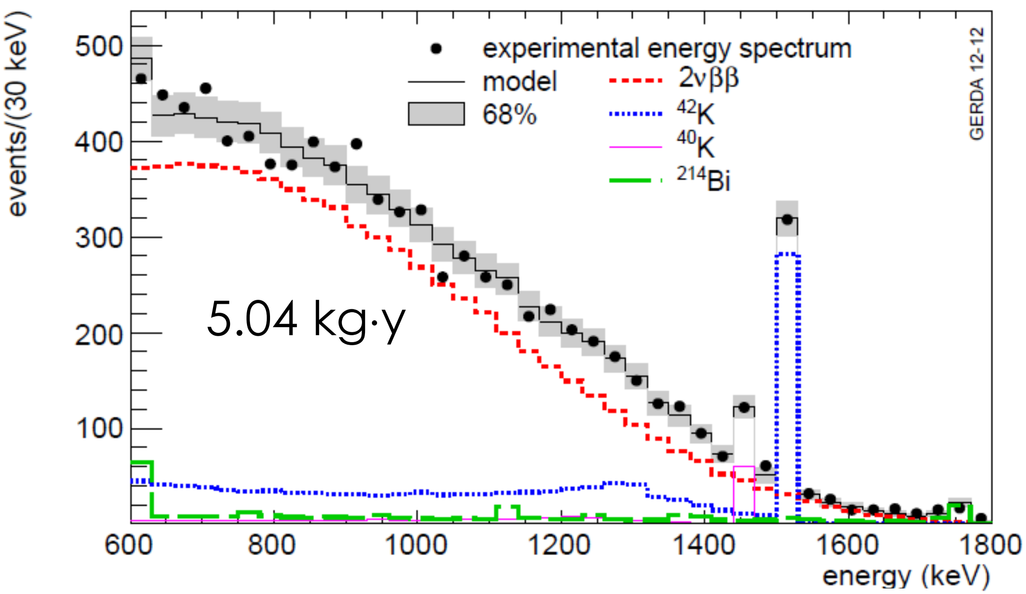
Stability cross-check in final summed physics data on ^{42}K background line:



FWHM only ~4% larger than expected

Background level improvement

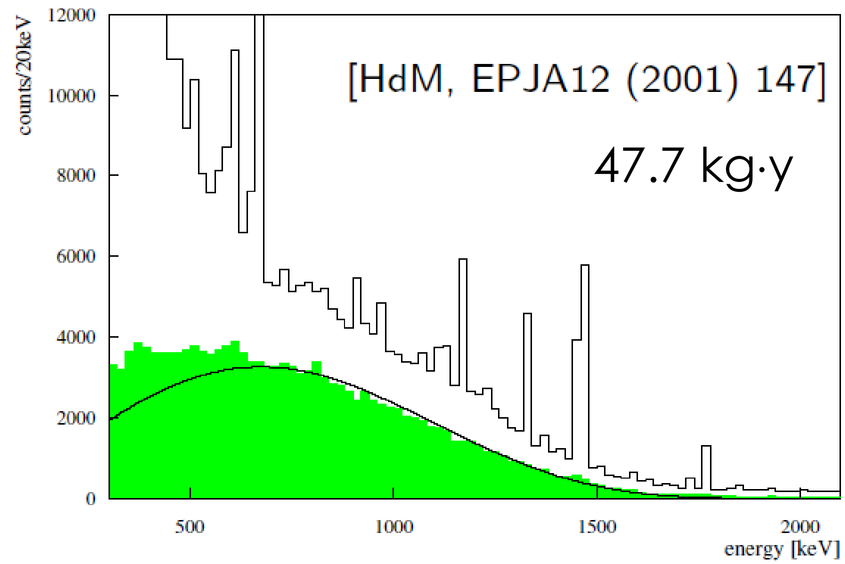
GERDA



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

[J.Phys.G 40 (2013) 035110]

Heidelberg-Moscow



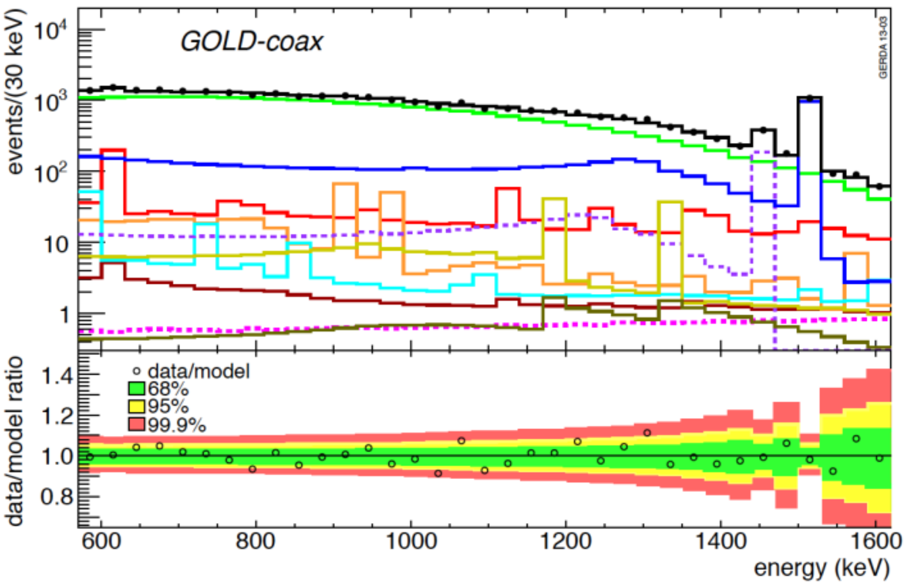
Average background at Qββ:

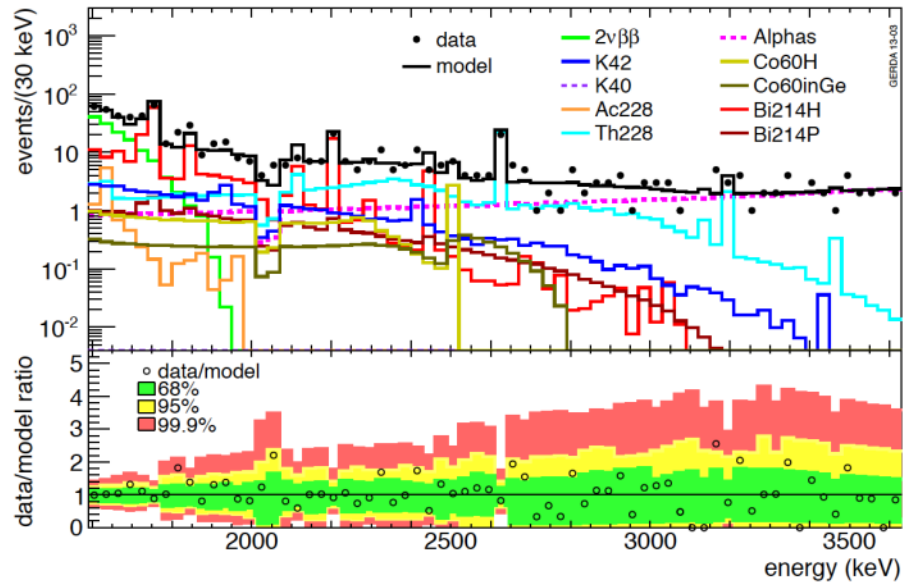
HdM: 0.16 cts/(keV·kg·y)

GERDA "golden": 0.02 cts/(keV·kg·y)

Background γ-lines typically ~10× lower than HdM (except for ^{42}K).

Before unblinding: background model

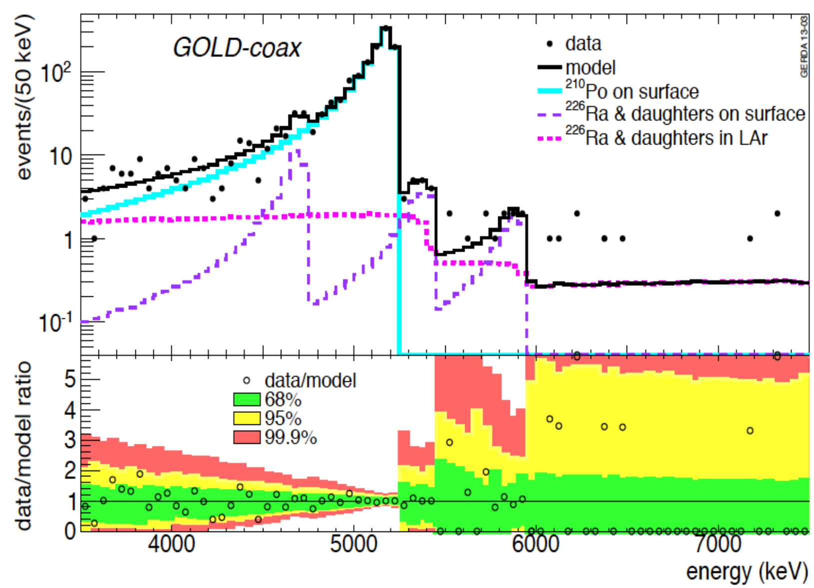




"Gold" data allow good-statistics fit

Main background sources:

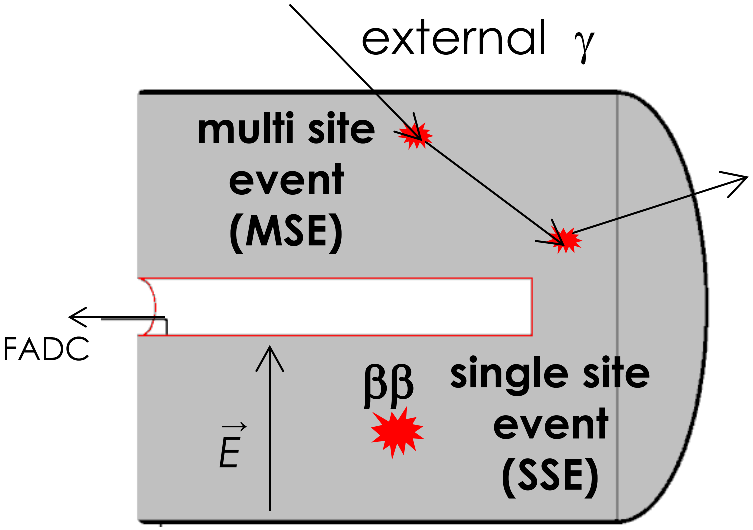
- ^{42}K
- Th and U(or Ra) contamination in materials near detectors
- Ra and Po contamination of detector surfaces (including α decays)



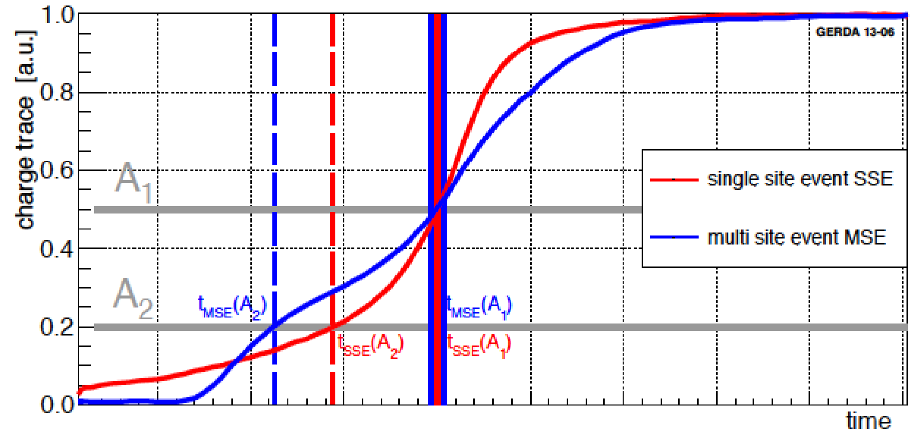
Background near $Q_{\beta\beta}$ flat (no lines).

arXiv:1306.5084

Before unblinding: pulse-shape discrimination



Signals recorded via FADC with 50 ns to 80 ns time resolution → **analyse time-structure**



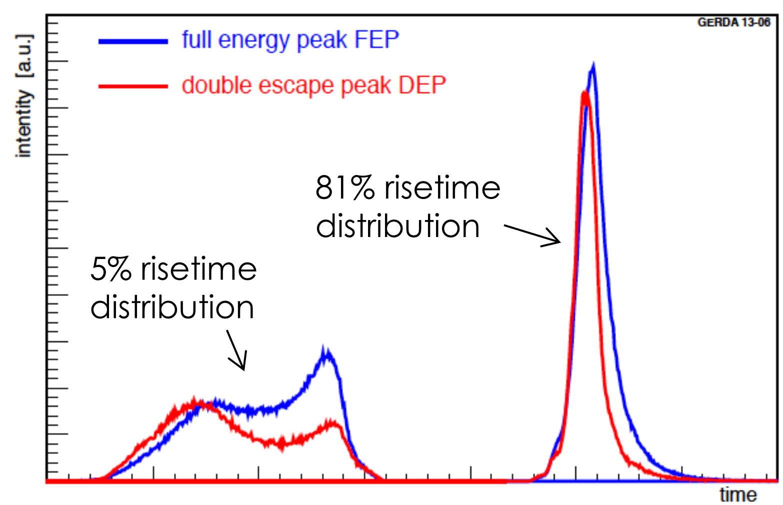
PSD for coaxial detectors:

- measure **50 rise time variables** (1,3,5,…99%)
- **Neural Network** (TMVA/TMlpANN) discriminates events

Trained on ^{228}Th calibration data:

- MSE training sample: 1621 keV γ-line (^{212}Bi)
- SSE training sample: 1592 keV DEP of 2.6 MeV line (^{208}Tl)

DEP (double escape peak) events have similar spatial structure like 0νββ

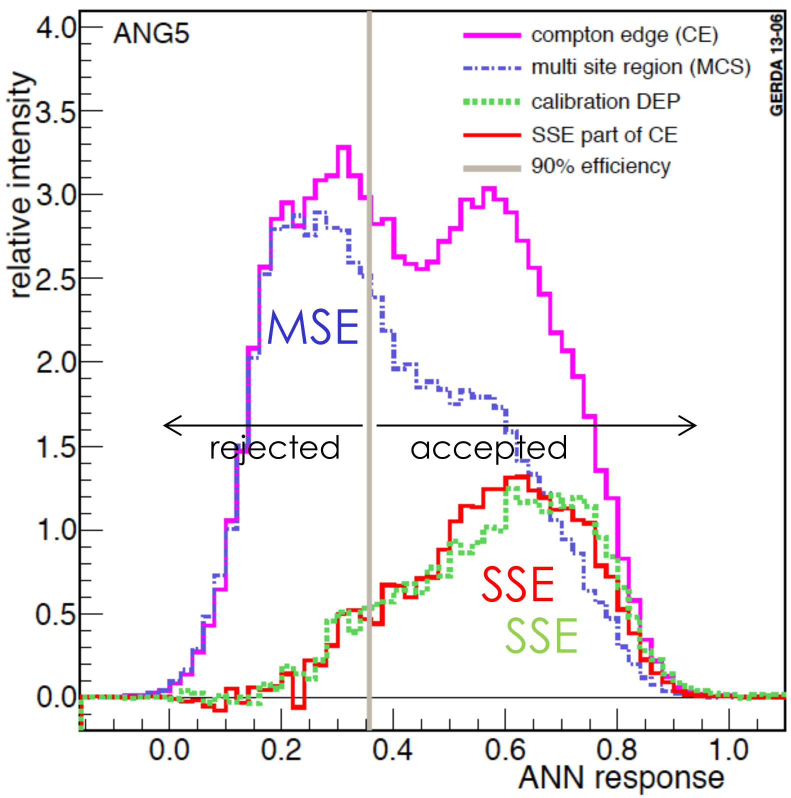


arXiv:1307.2610

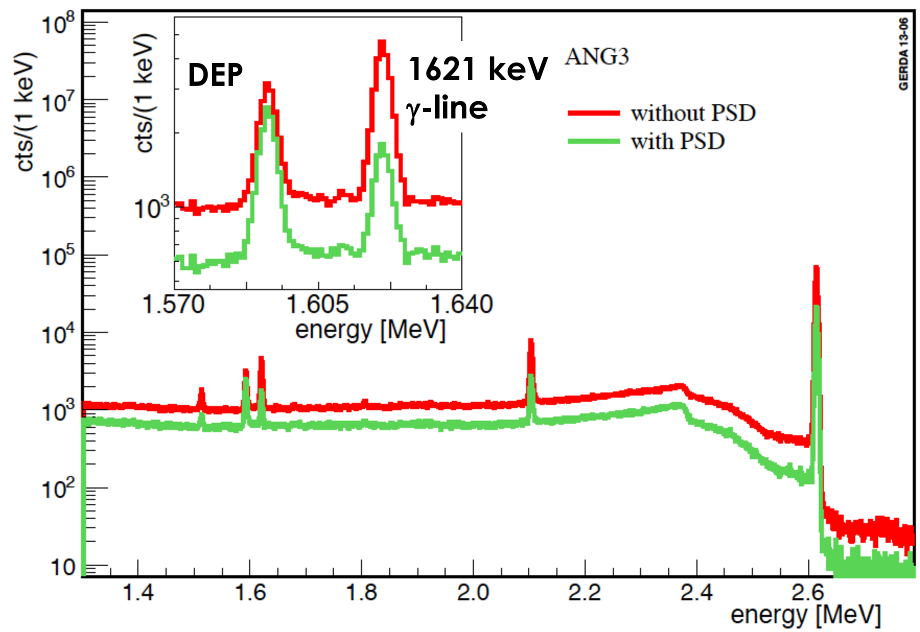
Before unblinding: pulse-shape discrimination

PSD for coaxial detectors

Neural Network response qualifier distribution:



PSD applied to ^{228}Th calibration spectrum:



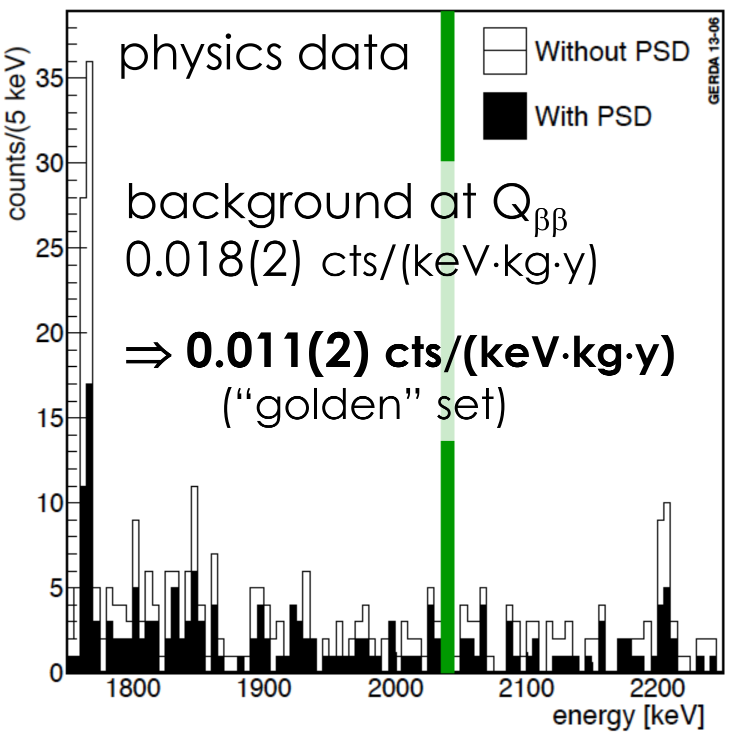
Cut is adjusted for each detector to 90% DEP survival.

Before unblinding: pulse-shape discrimination

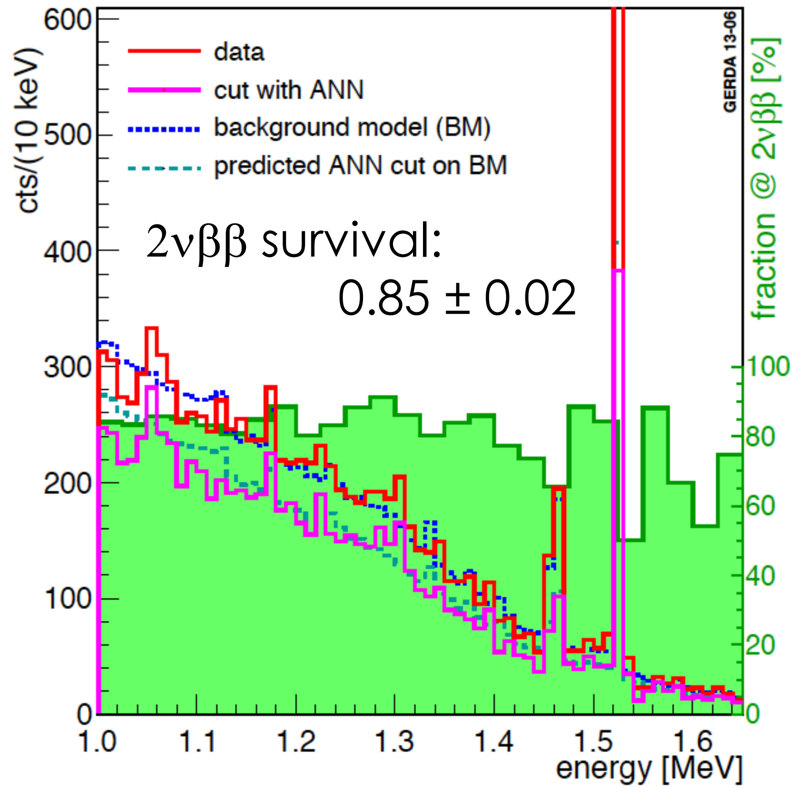
PSD for coaxial detectors

Determined Neural Network survival efficiency for 0νββ:

0.90 $^{+0.05}_{-0.09}$



Validity is cross-checked on 2νββ data:



Furthermore, 2 alternative PSD methods were developed and their results support the validity of the Neural Network method.

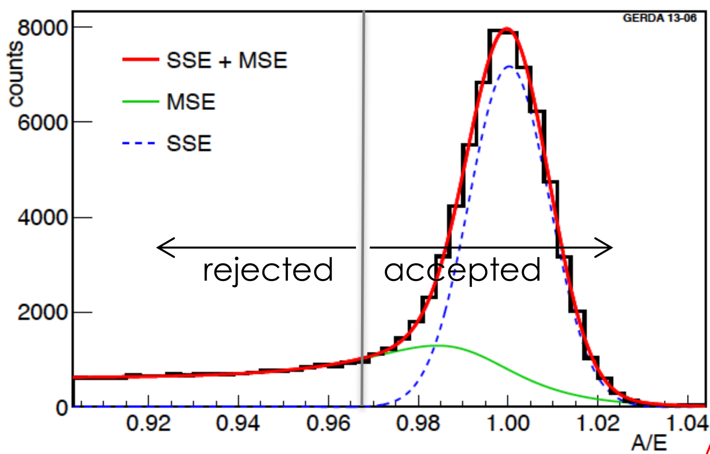
arXiv:1307.2610

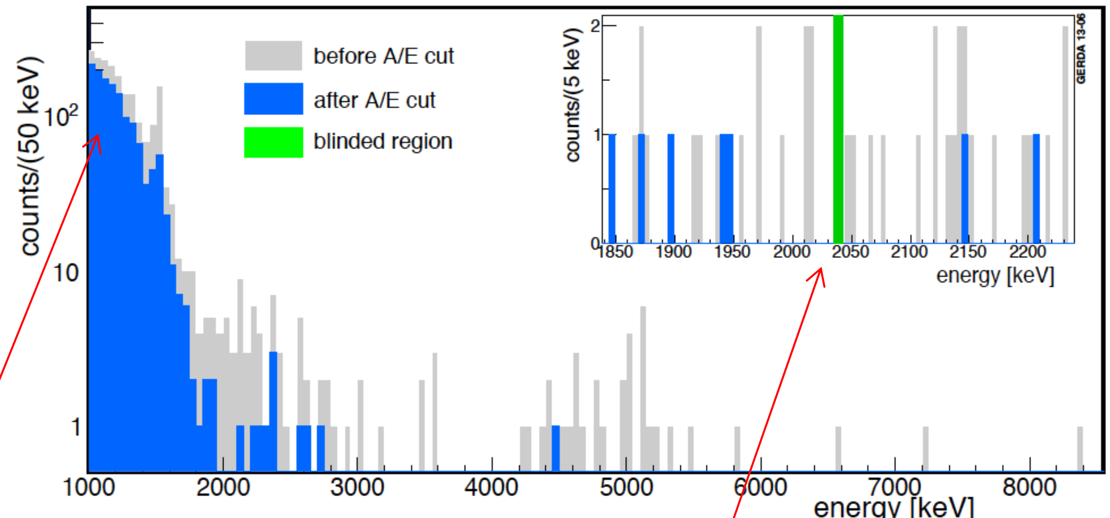
Before unblinding: pulse-shape discrimination

Separate analysis based on a single parameter used for **BEGe detectors** (more later).

survival efficiency for $0\nu\beta\beta$: **0.92 ± 0.02**

A/E parameter distribution:





$2\nu\beta\beta$ survival: 0.91 ± 0.05

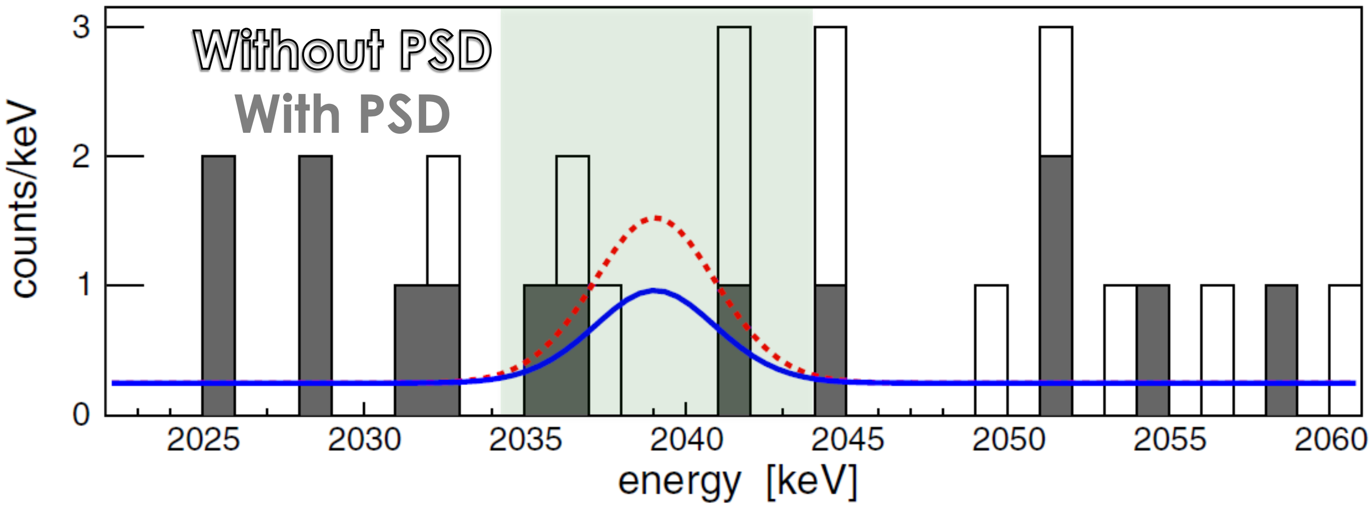
background at $Q_{\beta\beta}$

$0.042(^{+10}_{-8})$ cts/(keV·kg·y)

$\Rightarrow$ **$0.005(^{+4}_{-3})$ cts/(keV·kg·y)**

Unblinding

14 June 2013, in Dubna, Russia



evt cnt in ±5 keV	golden	silver	BEGe	total
expt. w/o PSD	3.3	0.8	1.0	5.1
obs. w/o PSD	5	1	1	7
expt. w/ PSD	2.0	0.4	0.1	2.5
obs w/ PSD	2	1	0	3

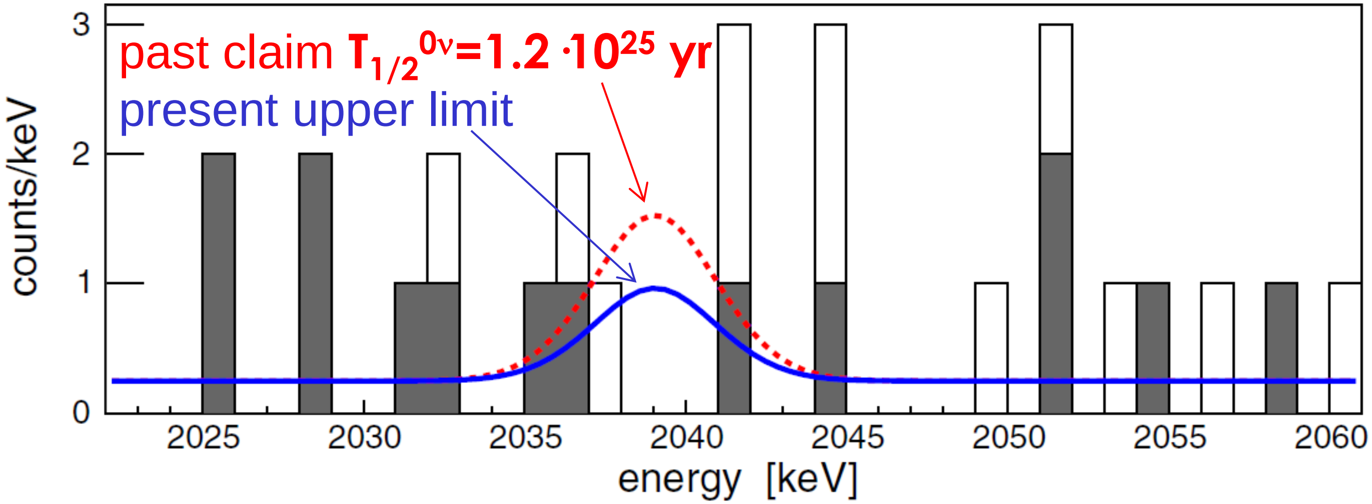
event count consistent with background

Best fit: $N^{0\nu} = 0$
profile likelihood upper limit:
$N^{0\nu} < 3.5$ cts @ 90% C.L.

Phys. Rev. Lett 111 (2013) 122503

"Neutrinoless Decays Are a No Show Again"

Limit on ^{76}Ge half life



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

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

data set	$\mathcal{E}$[kg·yr]	$\langle\epsilon\rangle$
with PSD		
golden	17.9	$0.619^{+0.044}_{-0.070}$
silver	1.3	$0.619^{+0.044}_{-0.070}$
BEGe	2.4	0.663 ± 0.022

$\Rightarrow$ **$T_{1/2}^{0\nu}$ > 2.1 ·10^{25} yr** @ 90% C.L.

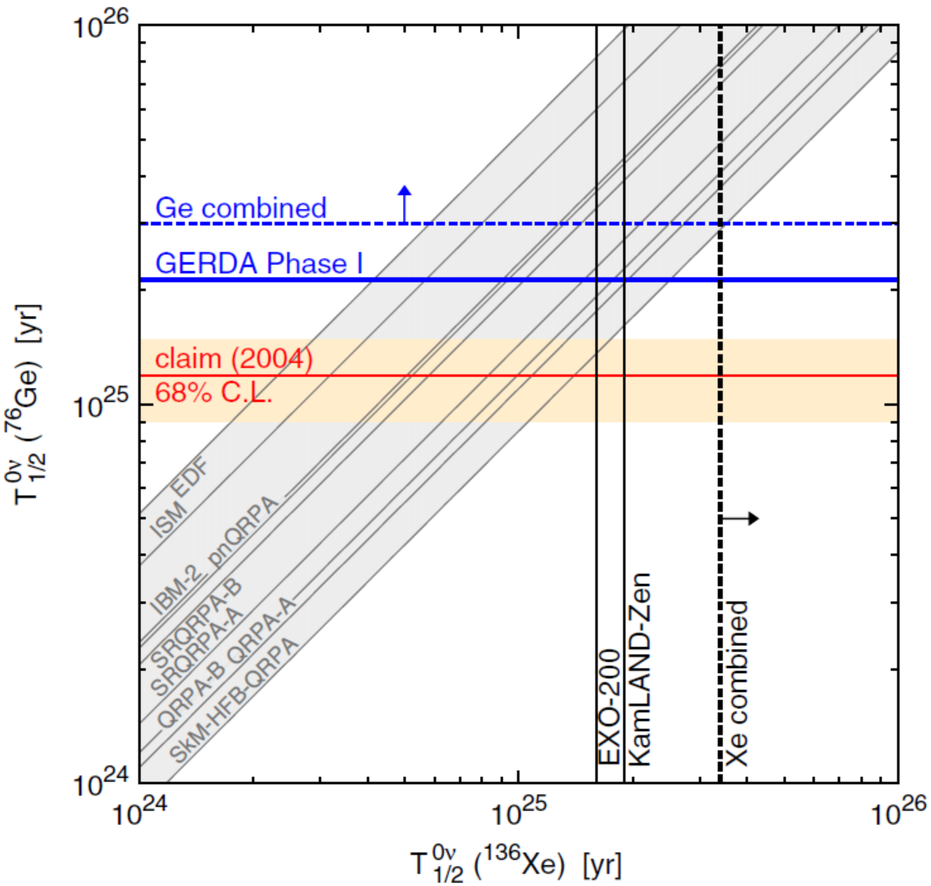
Combined with HdM and IGEX:

$T_{1/2}^{0\nu}$ > 3.0 ·10^{25} yr

$\langle m_{ee} \rangle$ < 0.2-0.4 eV

Phys. Rev. Lett 111 (2013) 122503

Past claim strongly disfavoured



H1: signal with $T_{1/2}^{0\nu} = 1.19\times10^{25}$ yr
H0: background only

	Isotop e	$P(H_1)/P(H_0)$	Comment
GERDA	^{76}Ge	0.024	Model independent
GERDA+HdM+IGEX	^{76}Ge	0.0002	Model independent
KamLAND-Zen*	^{136}Xe	0.40	**Model dependent**: NME, leading term
EXO-200*	^{136}Xe	0.23	**Model dependent**: NME, leading term
GERDA+KLZ*+EXO*	^{76}Ge + ^{136}Xe	0.002	**Model dependent**: NME, leading term

* with conservative (smallest) NME ratio $M_{0\nu}(^{136}Xe)/M_{0\nu}(^{76}Ge) \approx 0.4$ from:

F. Simkovic, V. Rodin, A. Faessler, and P. Vogel, Phys. Rev. C. **87**, 045501 (2013).
M. T. Mustonen and J. Engel, (2013), arXiv:1301.6997 [nucl-th].
P. S. Bhupal Dev *et al.*, (2013), arXiv:1305.0056 [hep-ph].

$T_{1/2}^{0\nu}$ claim from Mod. Phys. Lett. A 21 (2006) 1547 **not** considered because of the **inconsistencies** (efficiency factors not taken into account ⇒ $T_{1/2}^{0\nu}$ calculation incorrect) Ann. Phys. 525 (2013) 269

Phys. Rev. Lett 111 (2013) 122503

Physics goals of GERDA

(0 background approximation)

^{76}Ge 0νββ decay $T_{1/2}$ detection limit goals:

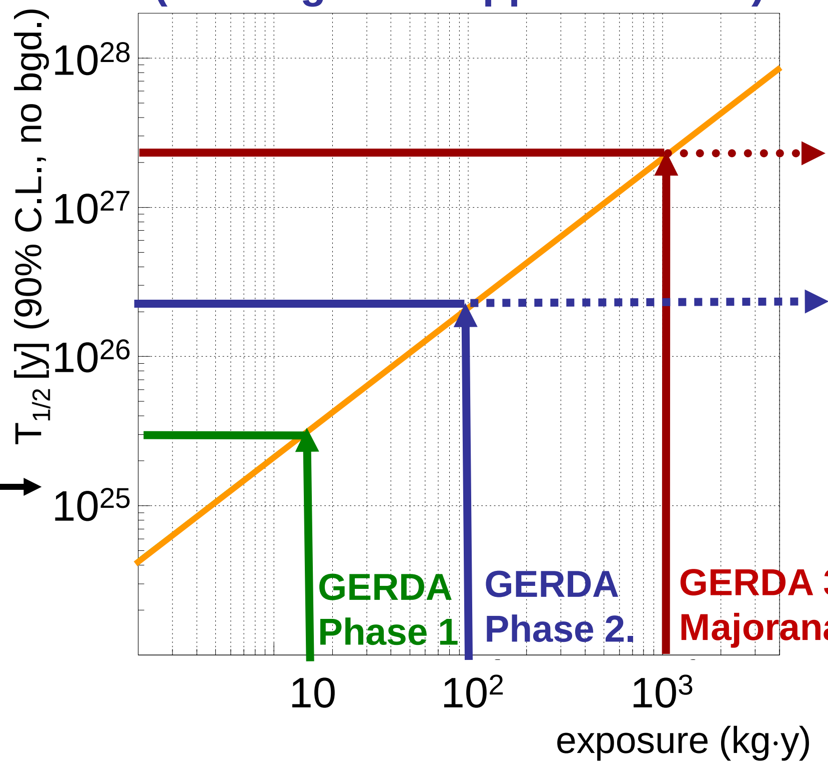
$2 \cdot 10^{27}$ y *

$2 \cdot 10^{26}$ y *

$3 \cdot 10^{25}$ y *

Claim →

(Klapdor Kleingrothaus)



neutrino mass scale:

<24 - 41 meV †

<75 - 129 meV †

† $|m_{ee}|$ assuming $|M^{0\nu}|$=2.99-8.99 [Smolnikov & Grabmayr PRC 81 (2010) 028502]

Background requirement (in ~6 keV wide ROI):		**^{76}Ge exposure:**
state-of-art (HdM)	0.16 counts/(kg·y·keV)	72 kg·y (HdM)
GERDA Phase 1	**<0.01 counts/(kg·y·keV)**	**21 kg·y** (HdM+IGEX+new detectors)
GERDA Phase 2	**<0.001 counts/(kg·y·keV)**	**100 kg·y** (old + new detectors)
GERDA 3 & Majorana ‡	**<0.0001 counts/(kg·y·keV)**	**1000 kg·y ‡**

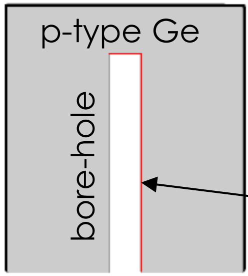
‡ GERDA-Majorana LoI: intention to merge for a 1 t experiment, not yet funded

GERDA Phase II

- Increase mass:
  additional 30 enriched BEGe detectors (~ 20 kg)
- new front end readout in close proximity (2 cm) to detectors (noise reduction)
- radiopurity improvements (new cables, detector supports)
- PSA discrimination with the BEGe's
- Liquid argon veto instrumentation

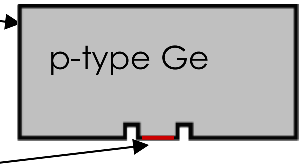
Phase II tools: Modified Broad-Energy Ge detectors

GERDA Phase I: semi-coaxial Ge detector



n⁺ electrode (≤mm thick) (HV contact)

p⁺ electrode (<μm thick) read-out contact

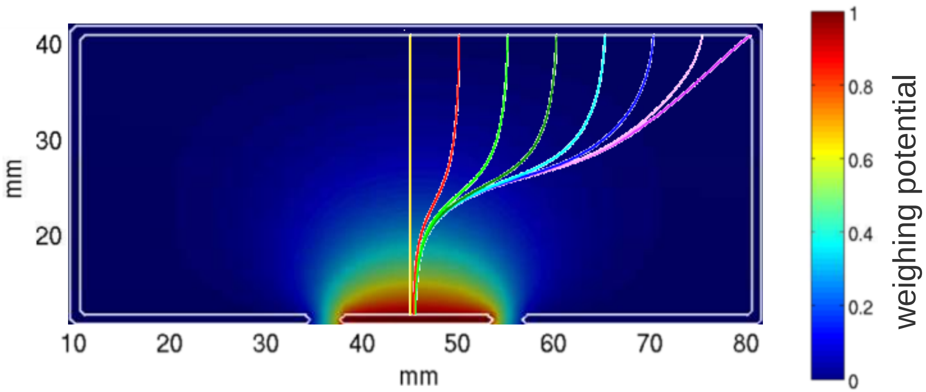


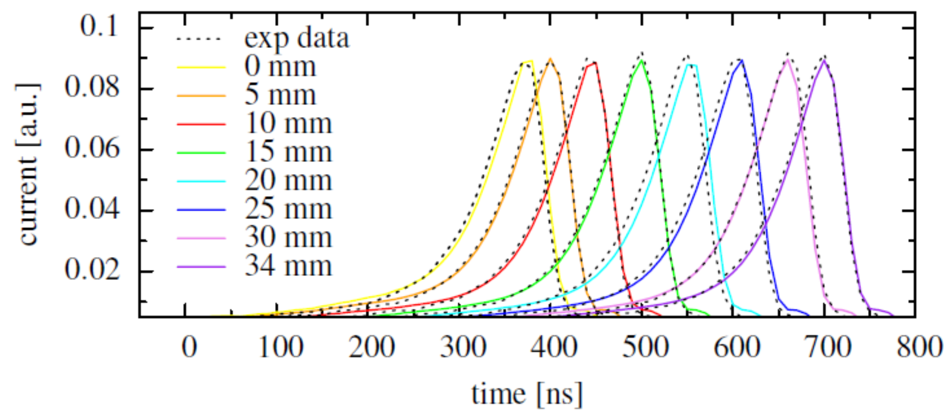
GERDA Phase 2: **modified BEGe detectors**

BEGe advantages:

1) smaller p+ electrode ⇒ less capacitance ⇒ **less noise ⇒ better energy resolution**

2) favourable internal electric field distribution ⇒ **powerful PSD capability**

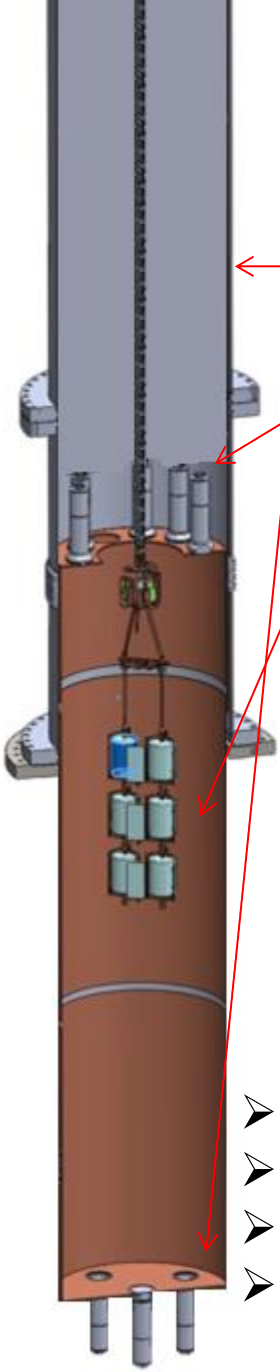




- narrow peak in current signal
- signal shape independent of interaction position (same final trajectory)
- current amplitude depends only on energy of interaction (~95% of volume)

 [D. Budjáš et al., JINST 4:P10007,2009] [M. Agostini et al., JINST 6:P03005, 2011]

Phase II tools: LAr instrumentation



PMT option (Ø500 mm)

new big lock

low-background PMTs on top & bottom

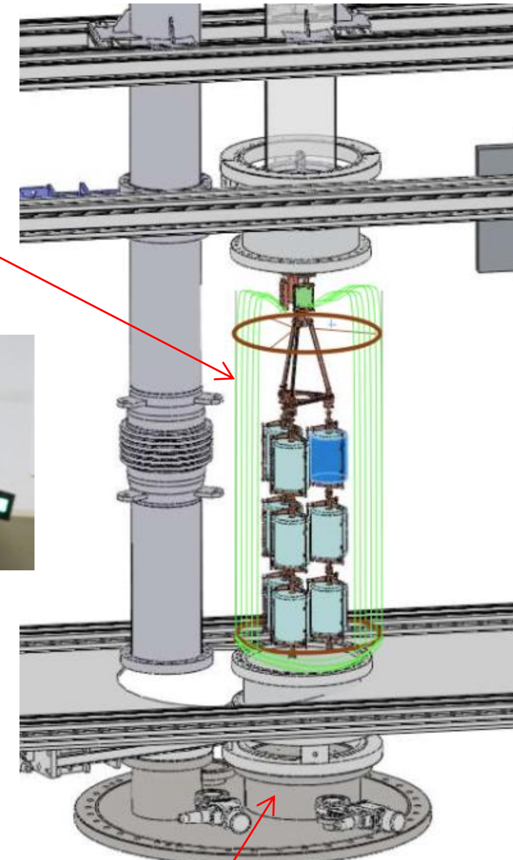
copper shroud

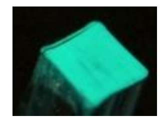
reflector foil coated with wavelength shifter

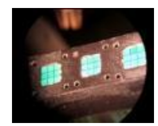
- approach validated in LArGe*
- PMTs available
- on-going testing in LAr
- mechanical mock-up in preparation

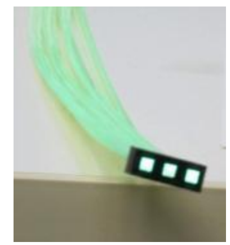
SiPM & scintillating fiber option

scintillating fibers form cylinder around Ge array (light detection inside & outside)

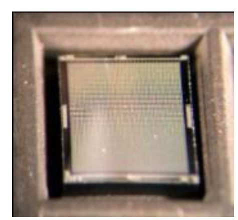








read-out by KETEK SiPMs



fits in present lock (Ø250 mm)

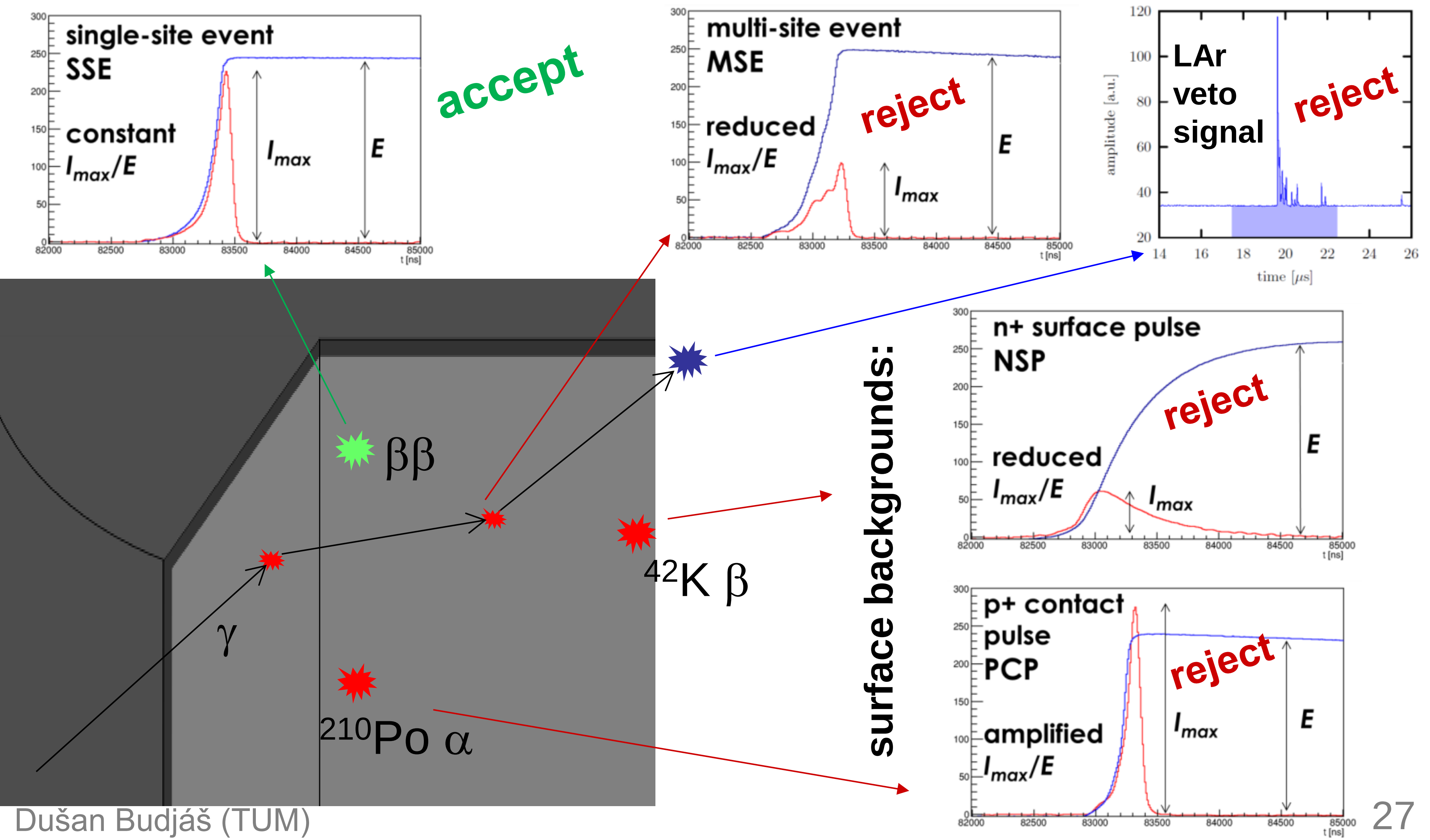
- approach tested on small scale
- fibers and SiPMs available
- test set-up in preparation

*[M. Heisel, Dissertation, University of Heidelberg (2011)]

Phase II tools: Background identification

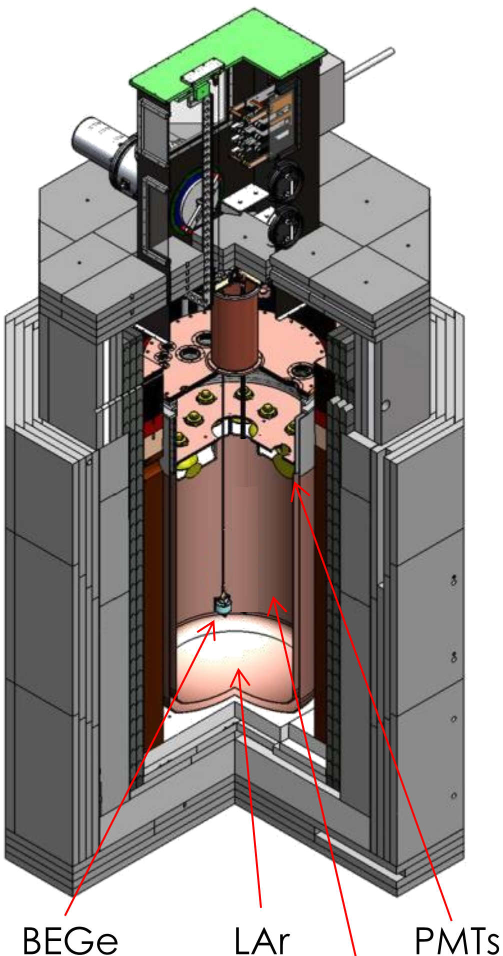
- identification and discrimination of events by **PSD** and **LAr veto**:

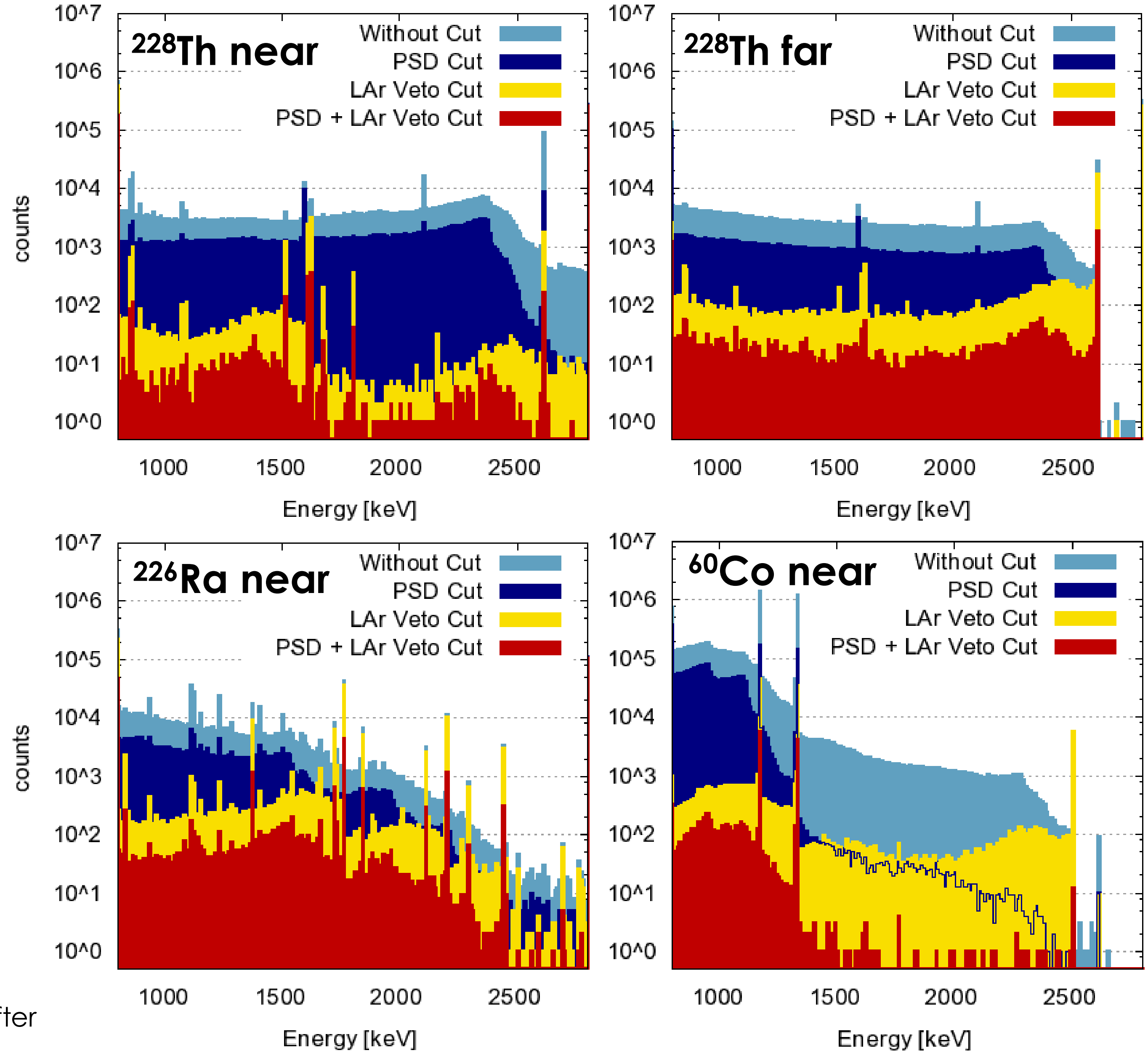
ββ-decay: β range in Ge ~mm **γ-ray backgrounds:** range in Ge ~cm



Performance studies: PSD and LAr veto in LArGe

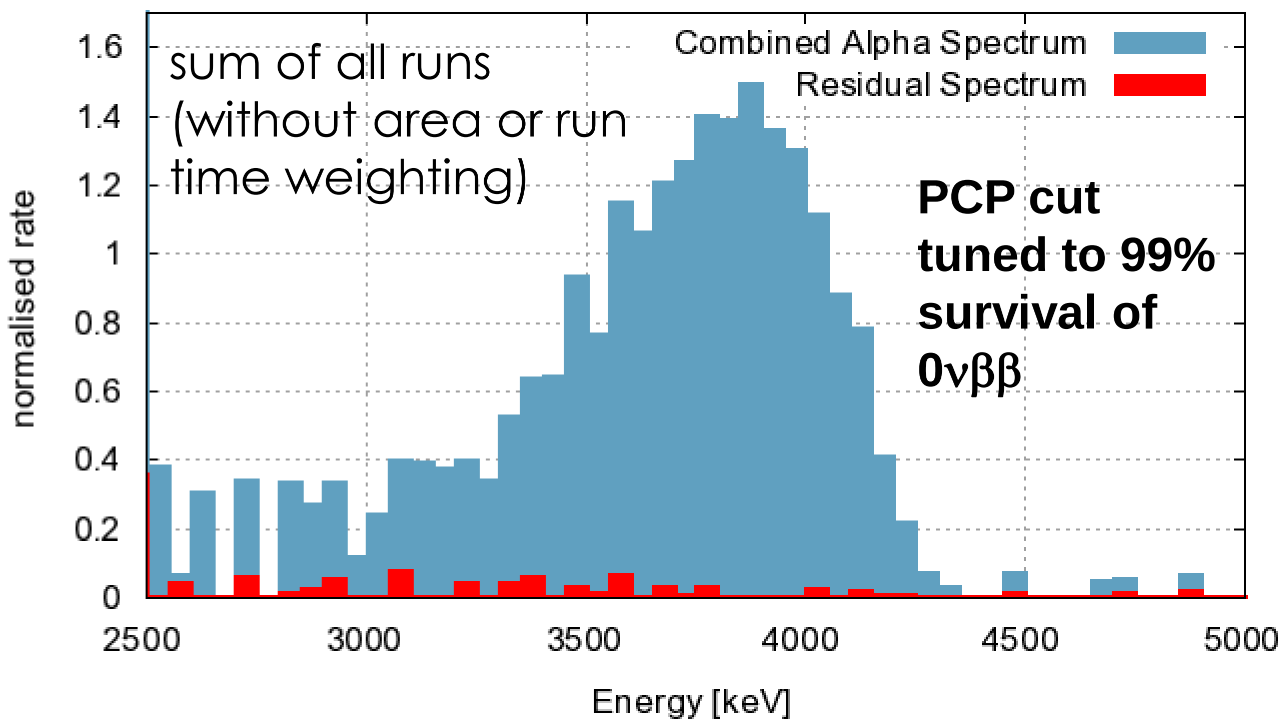
Low background test facility GERDA-LArGe at LNGS:





[M. Heisel, Dissertation, University of Heidelberg (2011)]

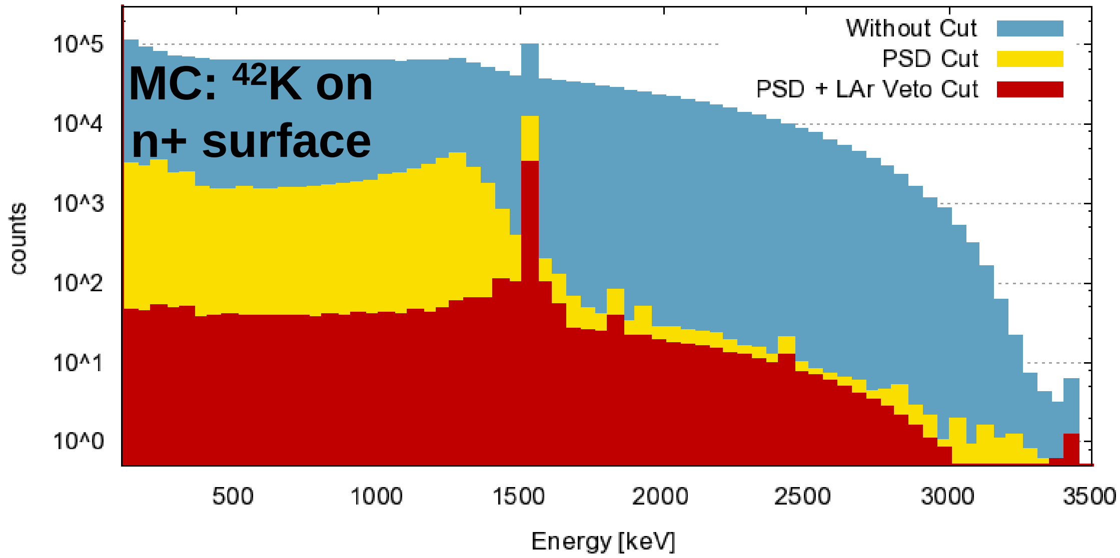
Performance studies: ^{241}Am p+ contact α events



surface	p+ contact	groove inner	groove bottom	groove outer
survival fraction *	< 1.1%	< 12%	< 1.0%	< 1.2%

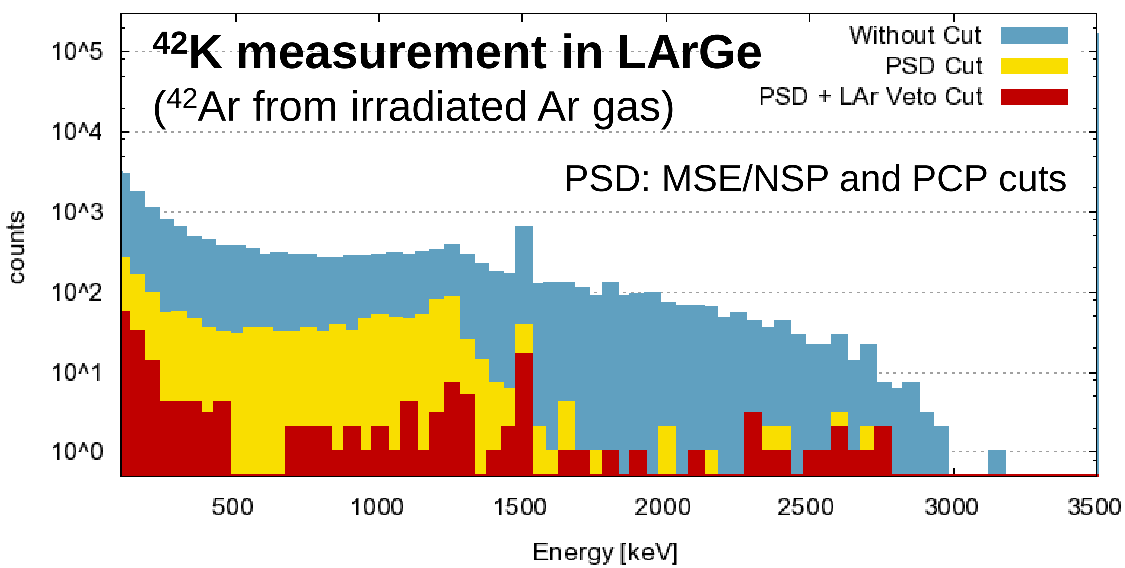
* 90% confidence-level upper limits
results limited by background in test setup; improved measurement analysis under way

Performance studies: surface ^{42}K with BEGe in LArGe



MC cut set to 0.1% survival of β-like events and 20% survival of γ-like events. LAr veto with 100 keV threshold.

expexted survival at $Q_{\beta\beta}$:
PSD only: $1.2\cdot10^{-3}$
PSD+LAr veto: $0.8\cdot10^{-3}$



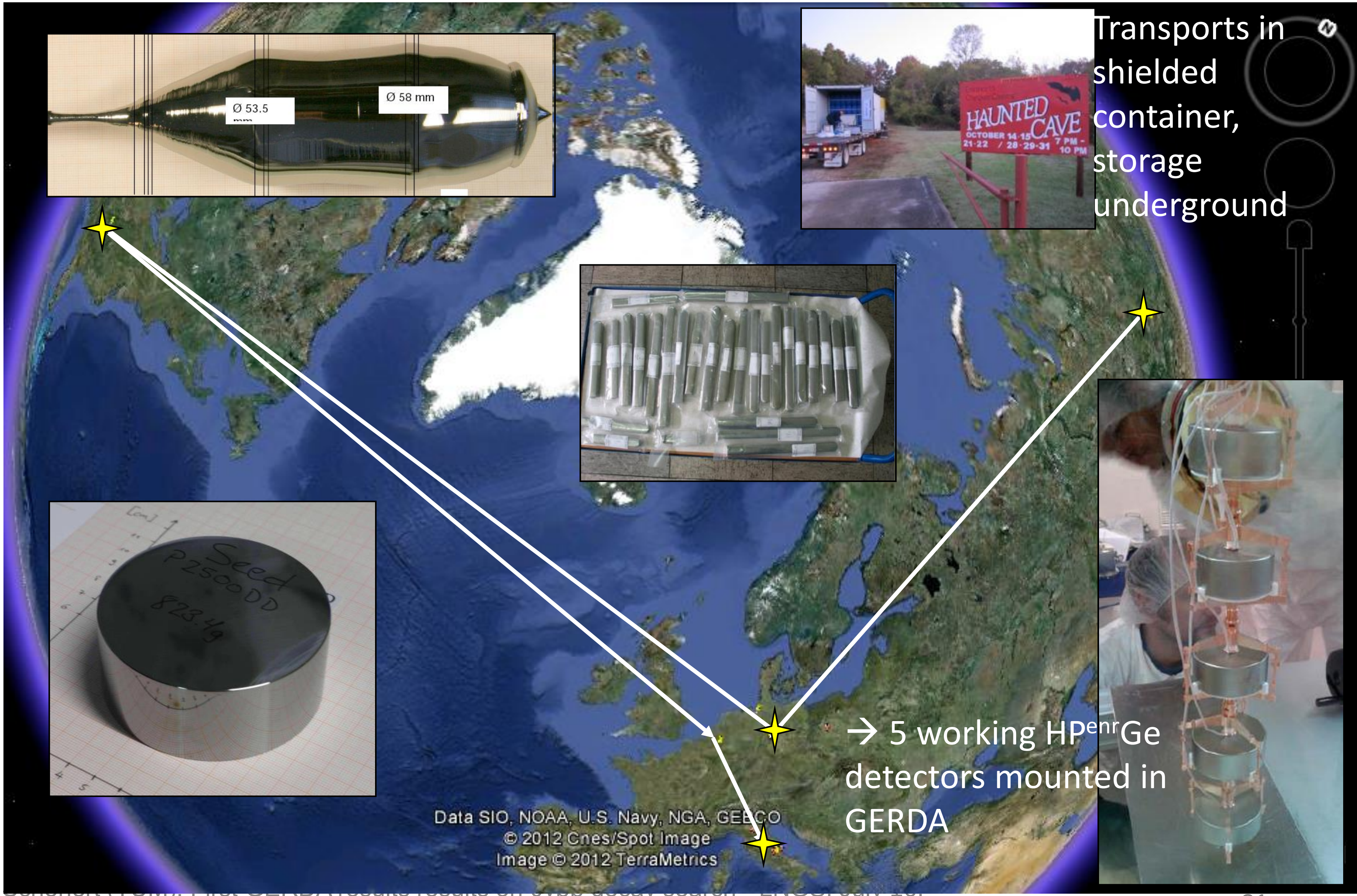
Veto + "standard" PSD cut :
$0\nu\beta\beta$ survival: 85%
^{42}K survival at $Q_{\beta\beta}$ (2 events):
$< 11\cdot10^{-3}$ (90% c.l.)

(noise limiting PSD performance)

Veto + "strong" PSD cut:
$0\nu\beta\beta$ survival: 71%
^{42}K survival at $Q_{\beta\beta}$ (0 events):
$< 5\cdot10^{-3}$ (90% c.l.)

(limited by avaliable statistics)

Production of ^{enr}Ge Phase II detectors



Transports in shielded container, storage underground

→ 5 working HP^{enr}Ge detectors mounted in GERDA

Phase II background summary: $Q_{\beta\beta}$

Background goal: < 10^{-3} cts/(keV·kg·yr) **PRELIMINARY**

background	without cuts [cts/(keV·kg·yr)]	PSD survival	LAr veto survival	after cuts [cts/(keV·kg·yr)]
^{208}Tl	≤ 0.01	0.4	$4 \cdot 10^{-3}$	≤ $1.6 \cdot 10^{-5}$
^{214}Bi	≤ 0.01	0.25	0.3	≤ $7.5 \cdot 10^{-4}$
^{60}Co	≤ $4 \cdot 10^{-4}$	0.01	0.02	≤ $8 \cdot 10^{-8}$
^{60}Co (in Ge)	≤ $4 \cdot 10^{-4}$	0.01	0.02	≤ $8 \cdot 10^{-8}$
^{68}Ga (in Ge)	≤ 0.015	0.05	0.2	≤ $3 \cdot 10^{-5}$
^{226}Ra (α on p+)	≤ $1.5 \cdot 10^{-3}$	< 0.03	–	< $3 \cdot 10^{-5}$
^{42}K (β on n+)	~0.2	< 0.05	0.68	< $0.86 \cdot 10^{-3}$

PSD and veto combined acceptance of $0\nu\beta\beta$-decay events is ~86%