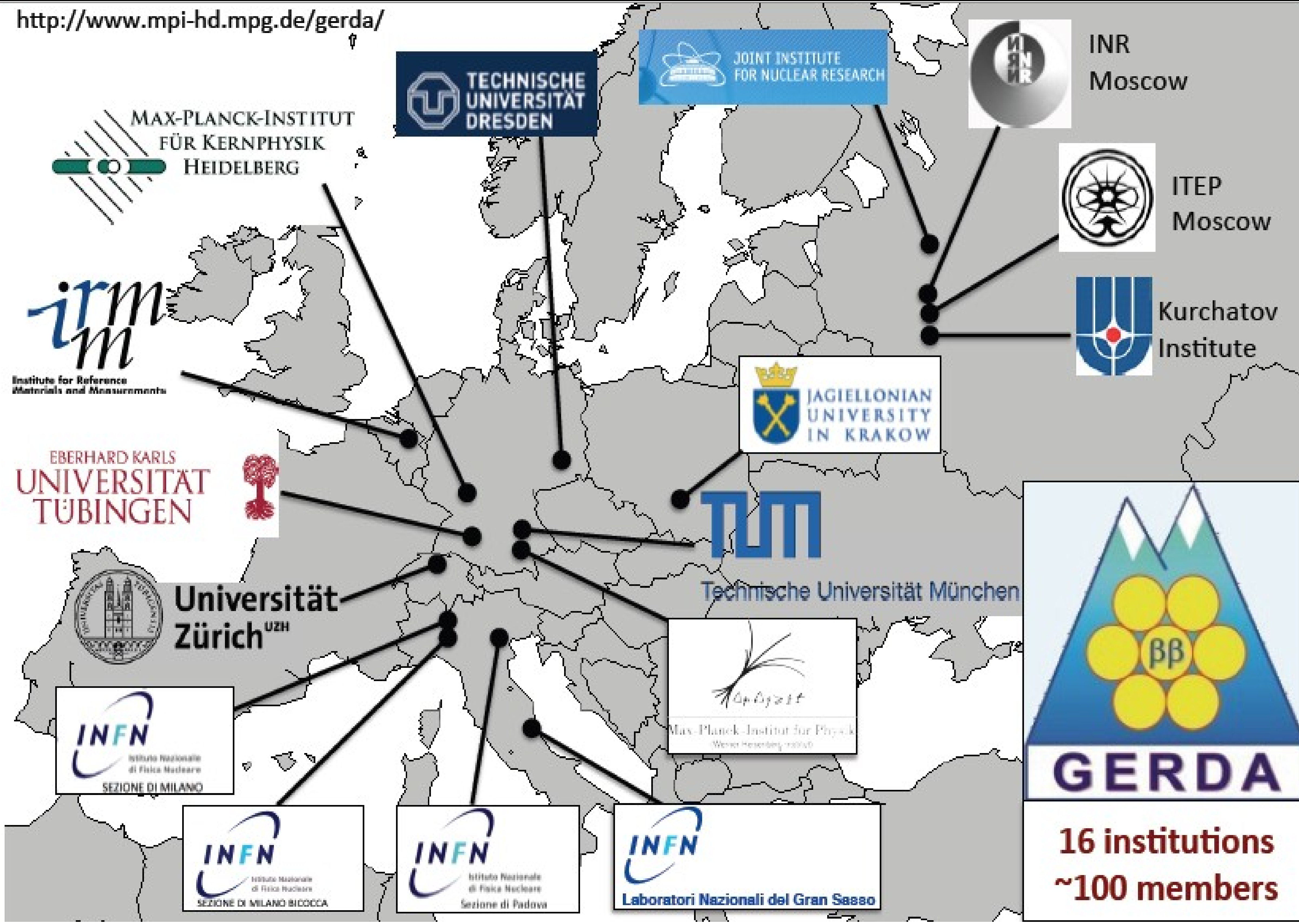
First results of neutrinoless double beta decay search with the **GER**manium **D**etector **A**rray "**GERDA**",

József, Janicskó Csáthy for the GERDA collaboration

GERDA


http://www.mpi-hd.mpg.de/gerda/
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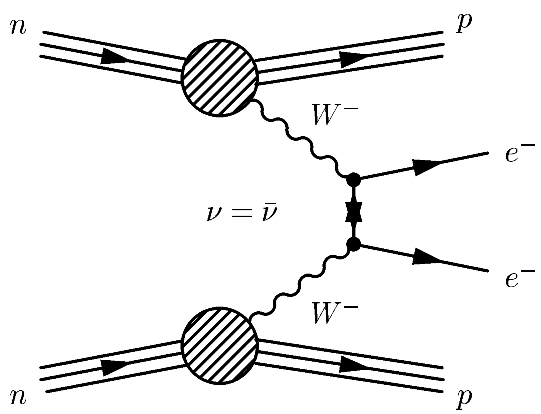
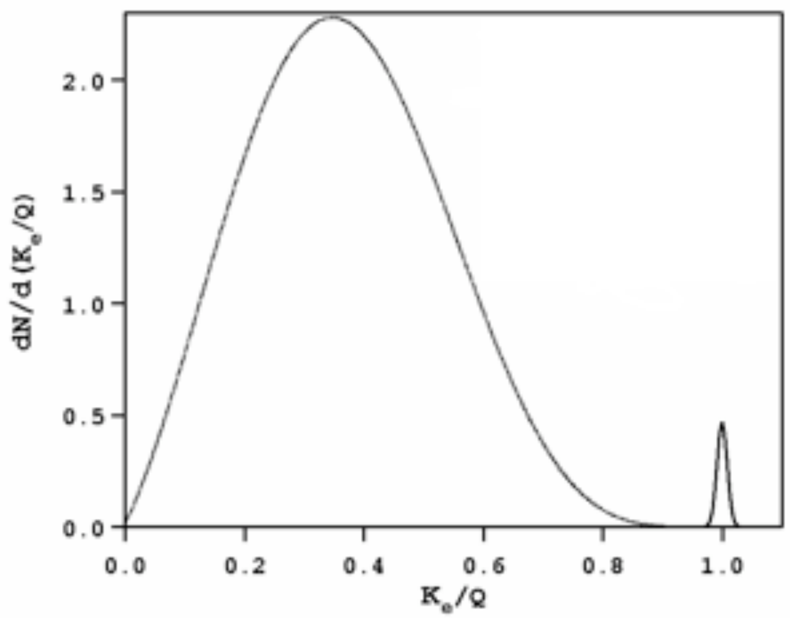
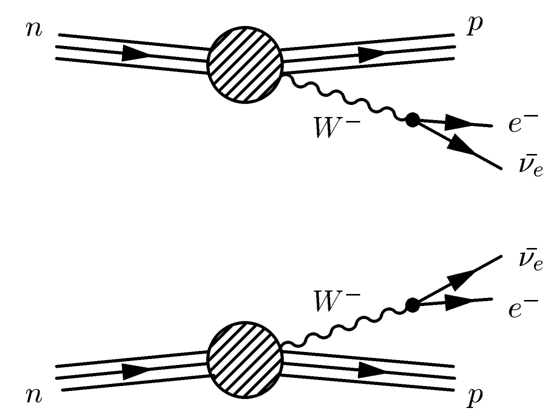
INFN Laboratori Nazionali del Gran Sasso
GERDA
16 institutions
~100 members

0νββ decay



2β decay with 2 neutrinos





2β decay with 0 neutrinos

(A,Z)→(A,Z+2) + 2e⁻ +2$\bar{\nu}_e$

allowed and observed

(A,Z)→(A,Z+2) + 2e⁻

violates lepton number conservation

$$\left(T^{0\nu}_{1/2}\right)^{-1} = F^{0\nu} \cdot \left|\mathcal{M}^{0\nu}\right|^2 \cdot m^2_{\beta\beta}$$

$$\langle m_{\beta\beta}\rangle^2 = \left|\sum_i U^2_{ei} m_{\nu i}\right|^2$$

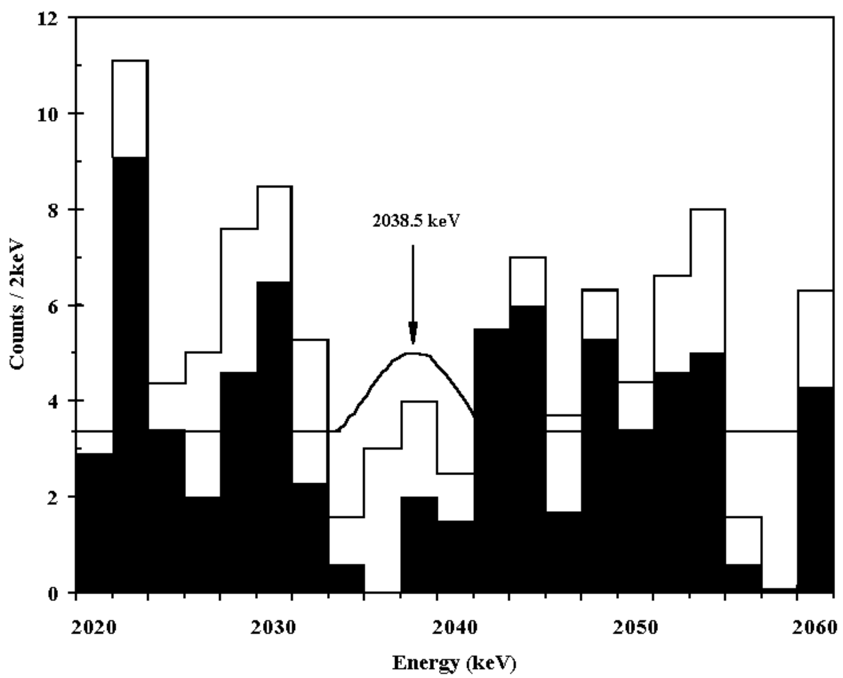
$M^{0\nu}$ - nuclear matrix element

$F^{0\nu}$ - phase space integral depends on the Q value

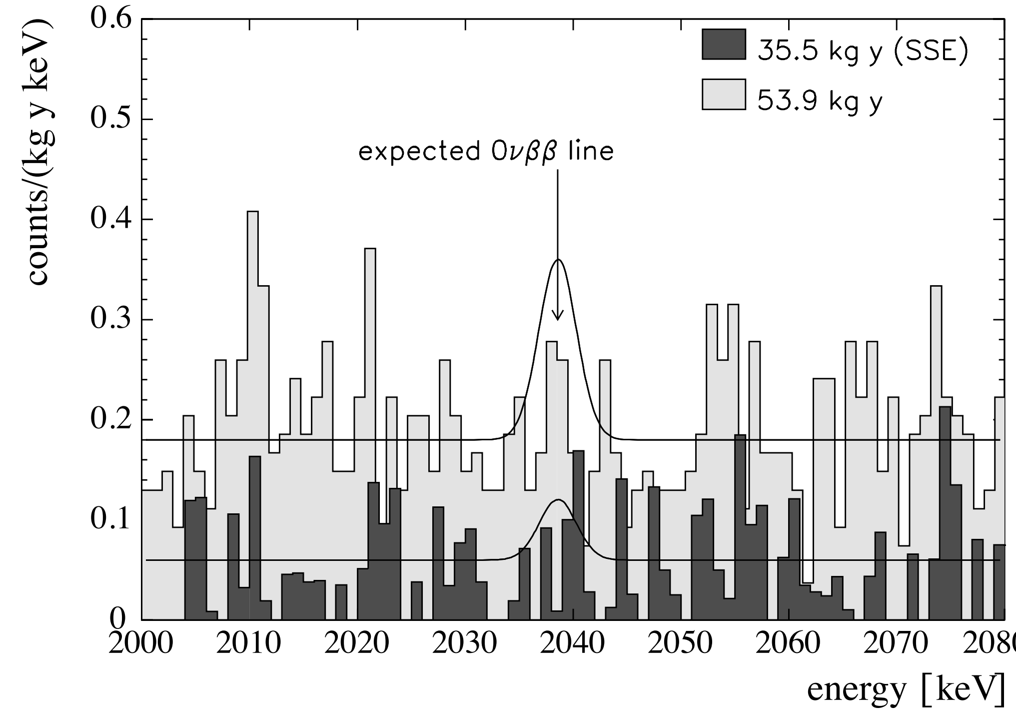
$\langle m_{\beta\beta}\rangle$ - effective neutrino mass

$0\nu\beta\beta$ in ^{76}Ge

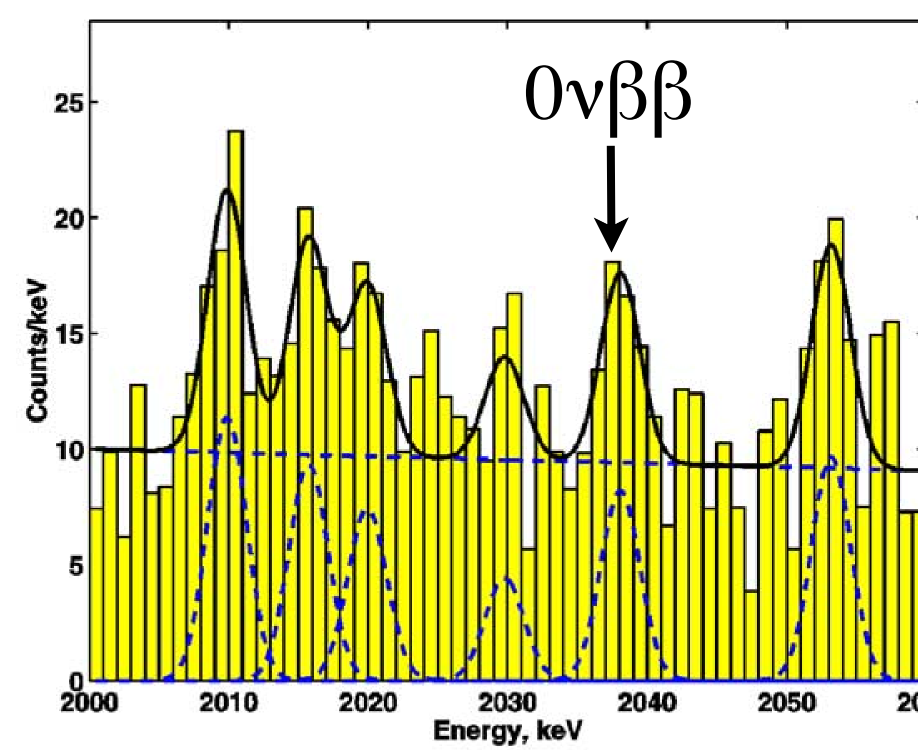
PHYSICAL REVIEW D, VOLUME 65, 092007



Eur. Phys. J. A 12, 147–154 (2001)



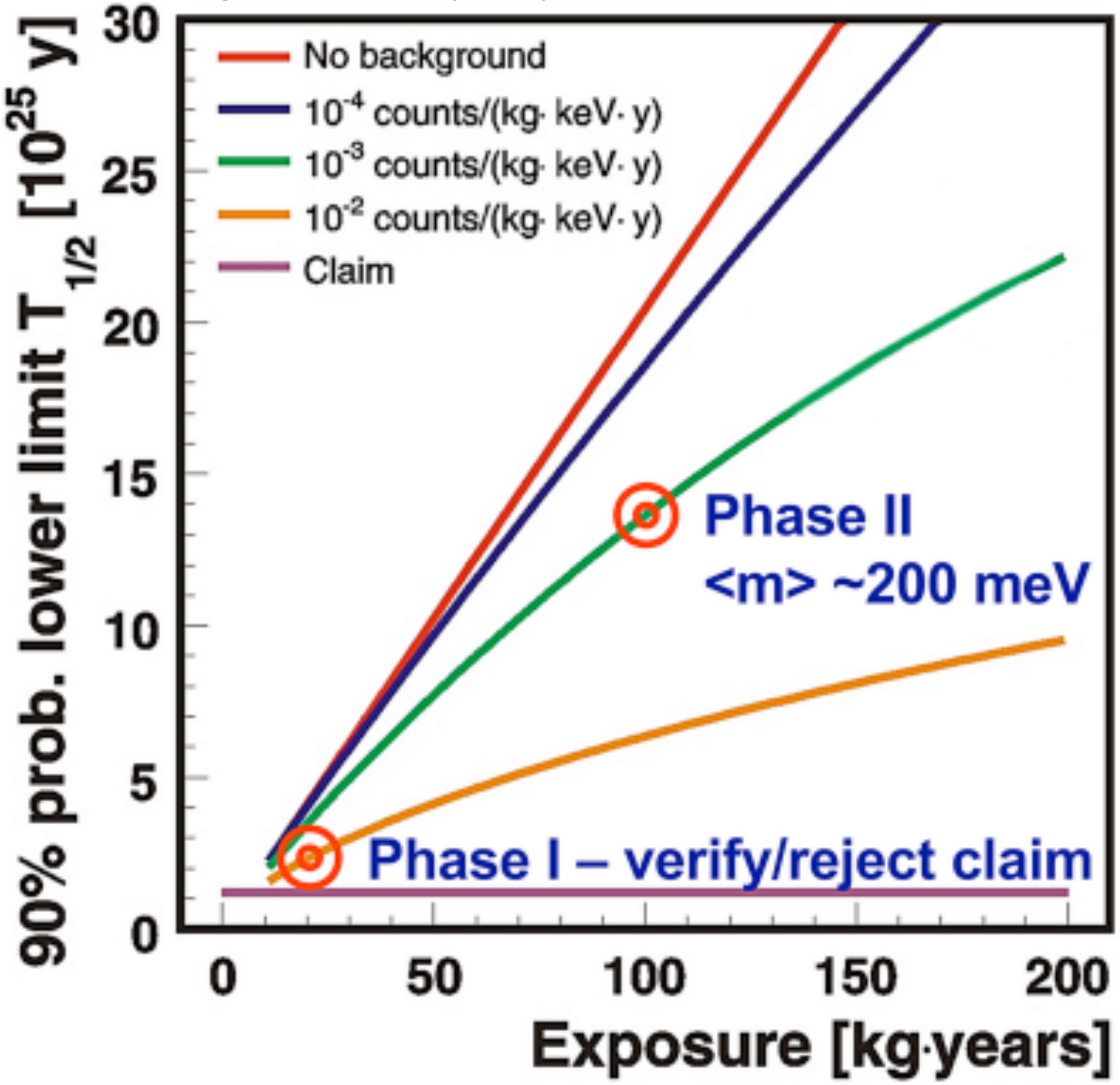
H.V. Klapdor-Kleingrothaus et al. / Physics Letters B 586 (2004)



- IGEX no signal $T_{1/2} > 1.6 \times 10^{25}$ yr
- HdM no signal $T_{1/2} \geq 1.9 \times 10^{25}$ yr
- Klapdor-Kleingrothaus *et alii* claim of evidence: $T_{1/2} = 1.9 \times 10^{25}$ yr

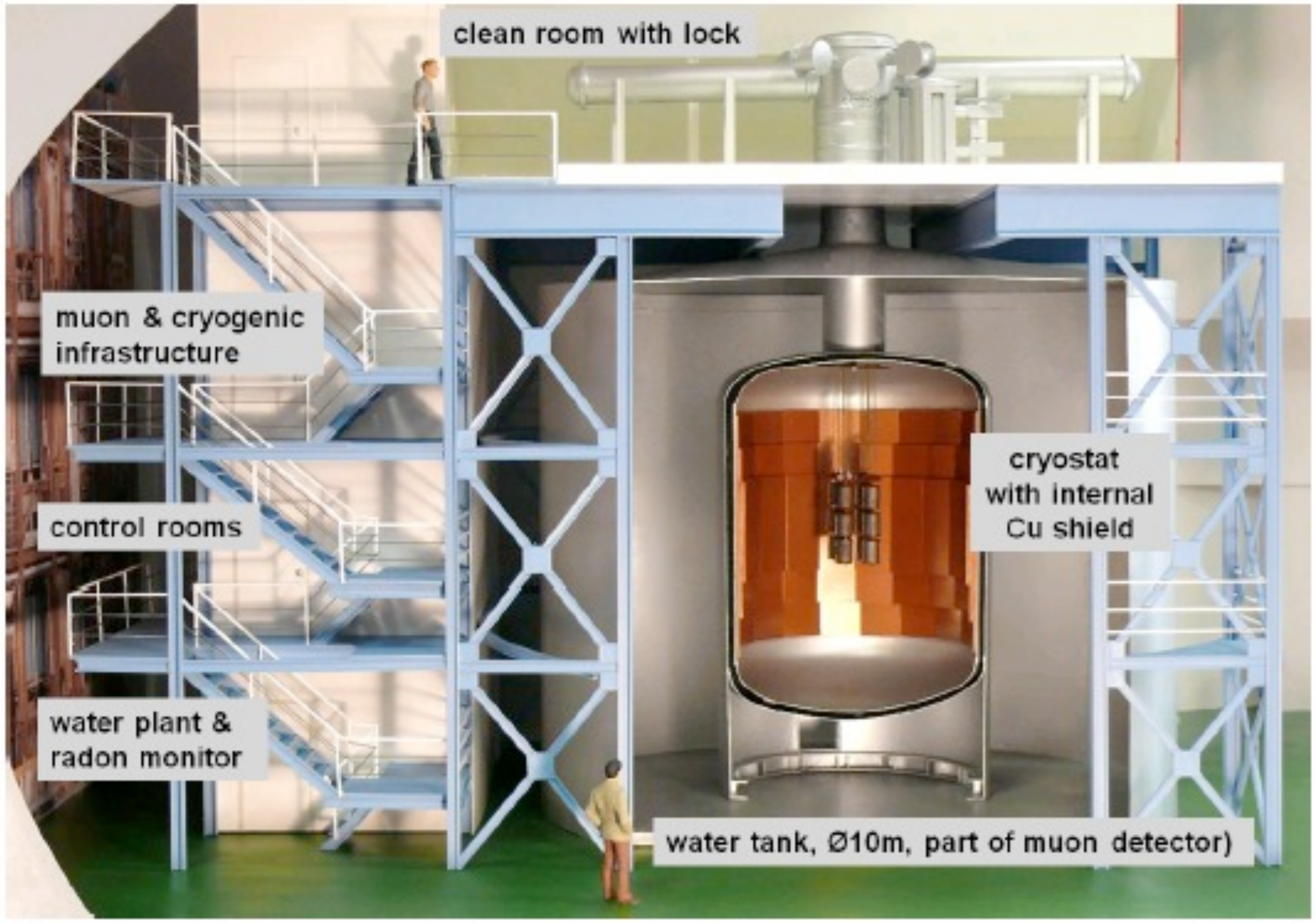
GERDA status

Phys.Rev. D 74 (2006) 092003



- *Goal of Phase I*: Re-deploy HdM and IGEX detectors (18 kg) in LAr with a background of 0.01 cts/(keV kg yr), scrutinize the claim
- *Status of Phase I*: data taking ended with 21.6 kg · y exposure: from Nov. 2011 to May 2013
- *Goal of Phase II*: background level of 0.001 cts/(keV kg yr) and 100 kg yr exposure
- *Status of Phase II*: under construction: 30 new HPGe detectors (~20 kg) are ready to be deployed

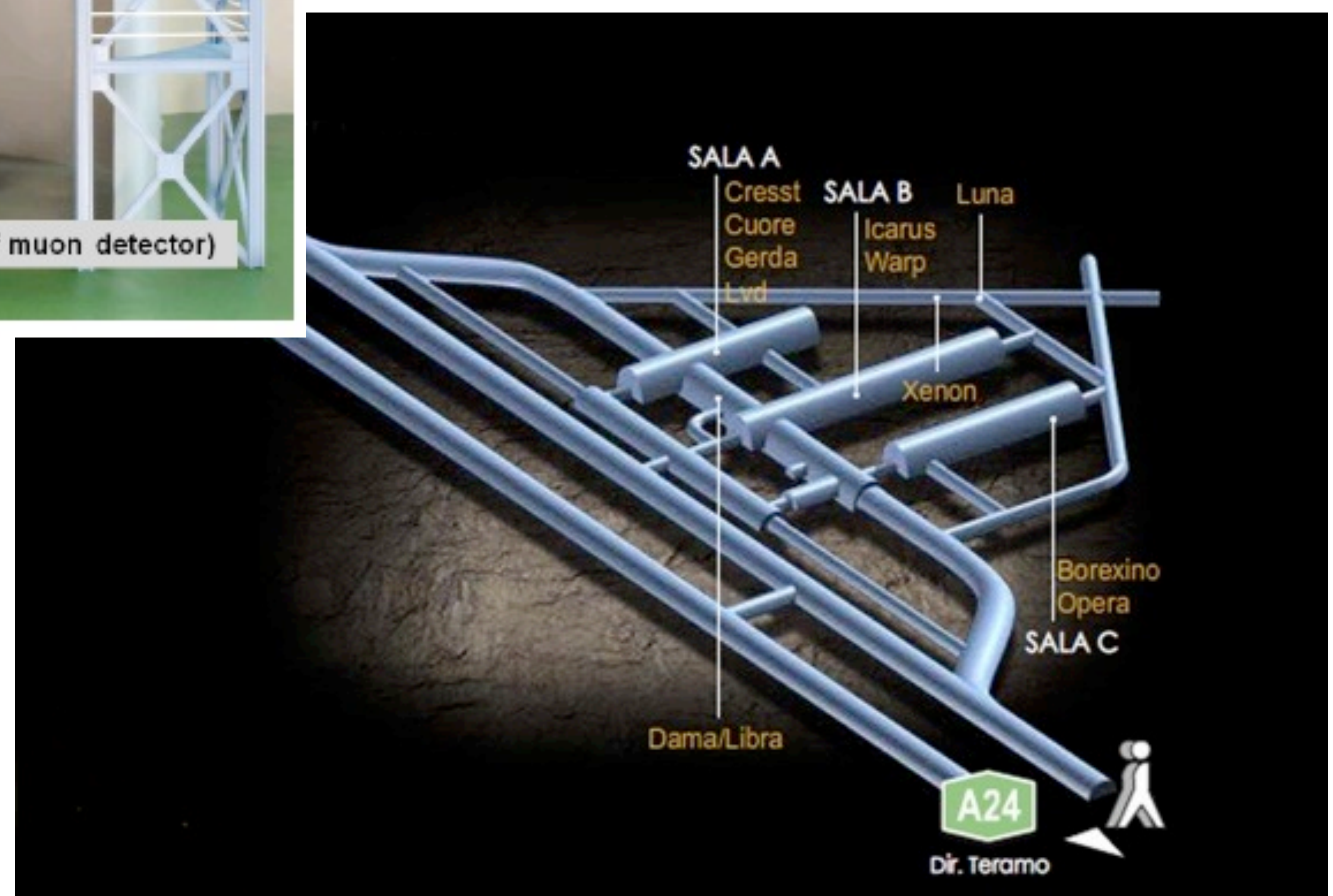
GERDA at Gran Sasso



Under a 3000 m high mountain,

inside 590 m^3 water tank,

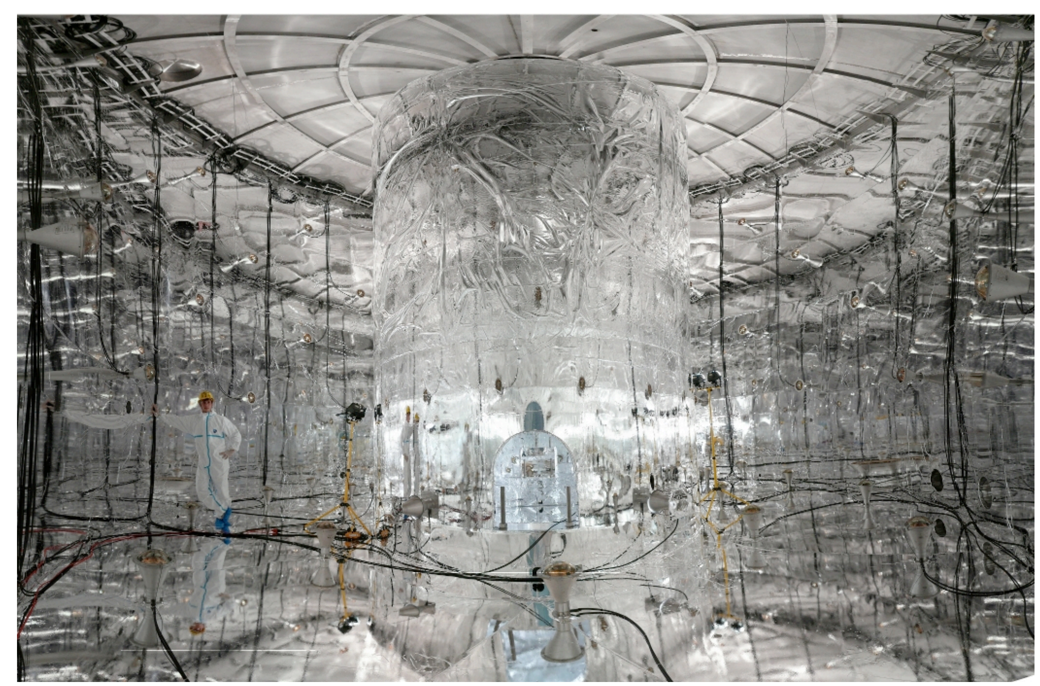
in a 64 m^3 LAr cryostat ...



... there are some germanium detectors

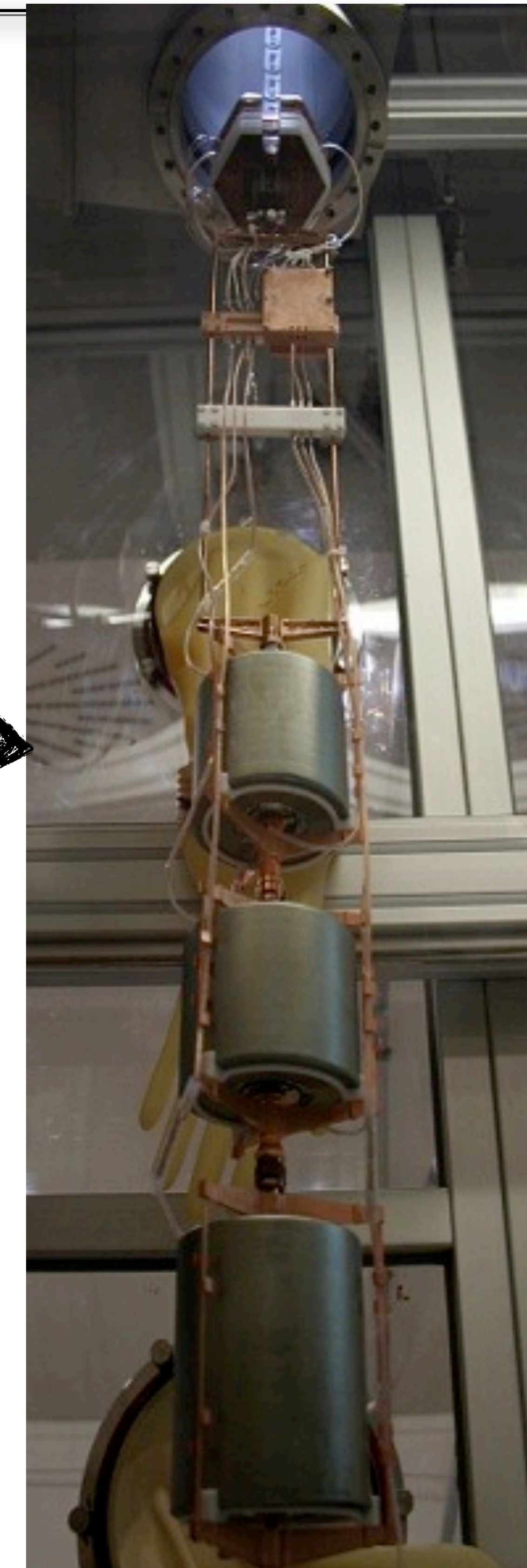
GERDA milestones

- Construction started in 2008
- Cryostat, water tank, clean room ready in 2009
- Dec. 2009 cryostat filled with LAr
- Water-Cerenkov veto completed in 2010



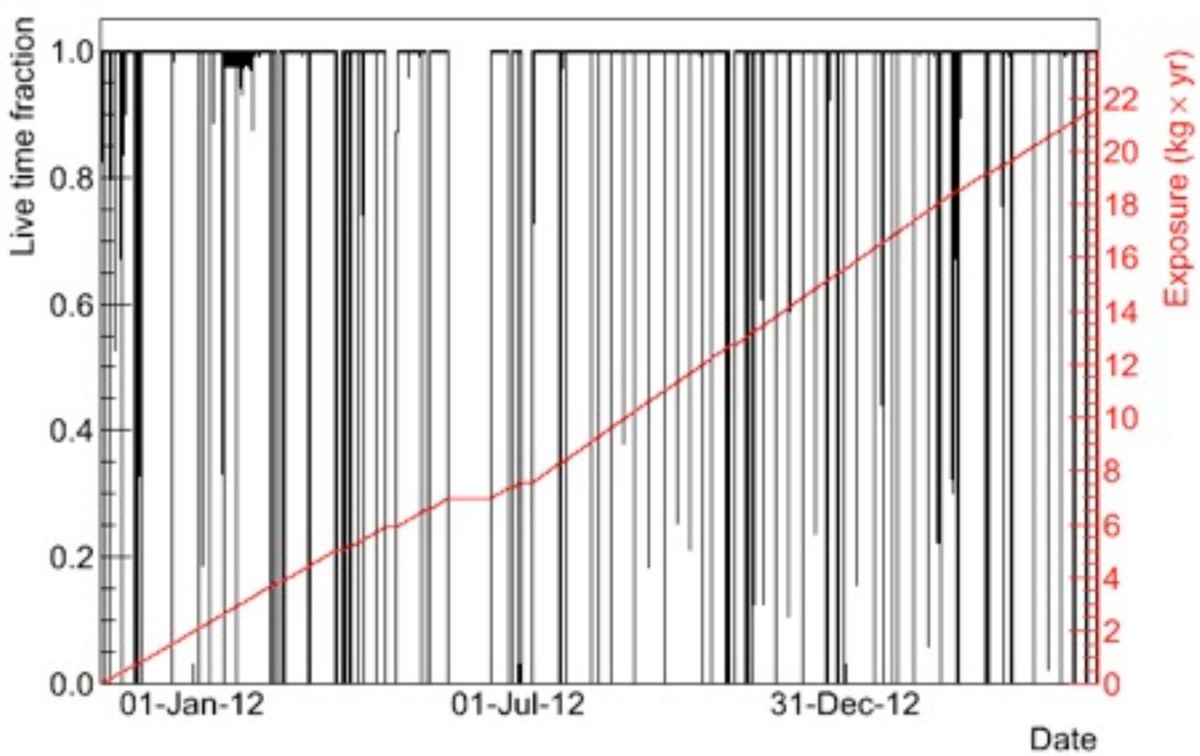
GERDA milestones

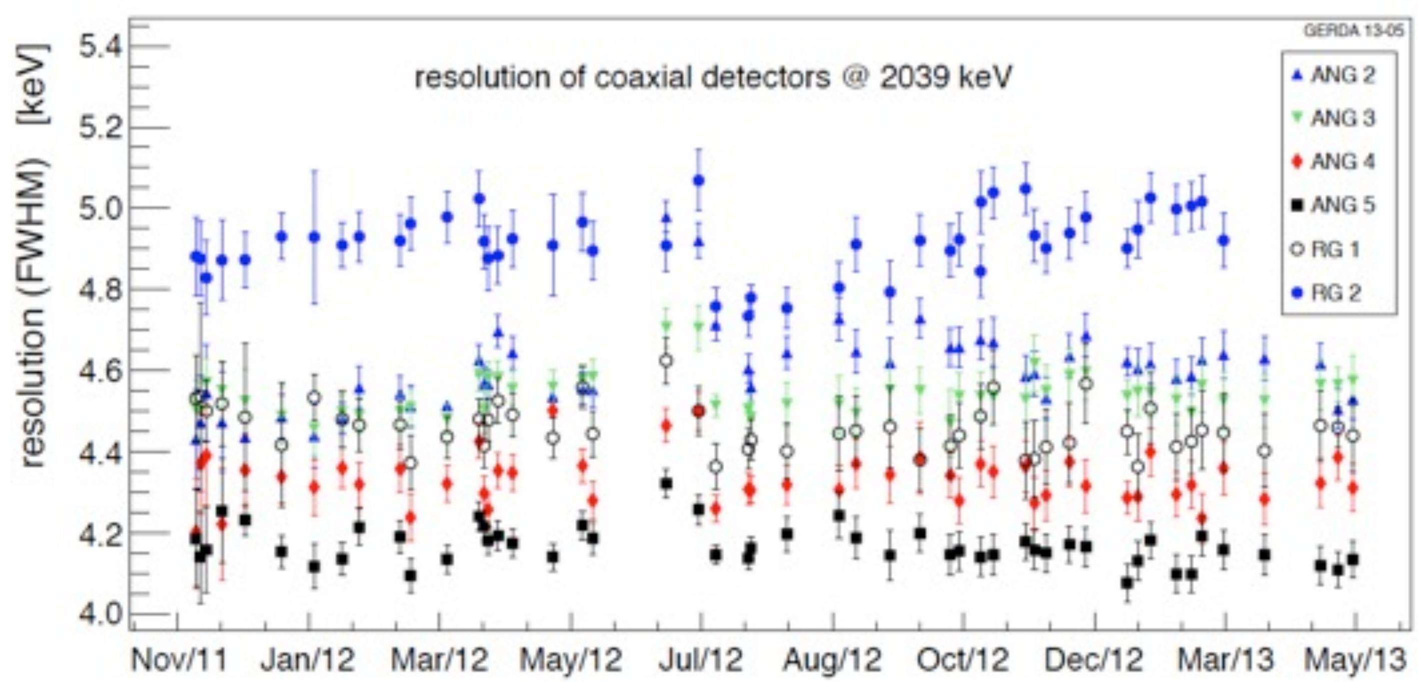
- HdM and IGEX detectors refurbished at Canberra
- Mounted in low-mass holders and deployed in LAr
- Commissioning runs: 2010 - 2011
- Physics run with 9 detectors: from 2011 Nov. (+5 BEGe in July 2012)



Run history

- Total exposure of 21.6 kg yr between Nov. 2011 and May 2013
- 6 coax detectors from Nov. 2011 to May 2013
- + 4 BEGe detectors since June 2012 to May 2013
- Weekly callibration runs with ^{228}Th source
- Mean resolution at 2 MeV: coax 4.8 keV, BEGe 3.2 keV FWHM





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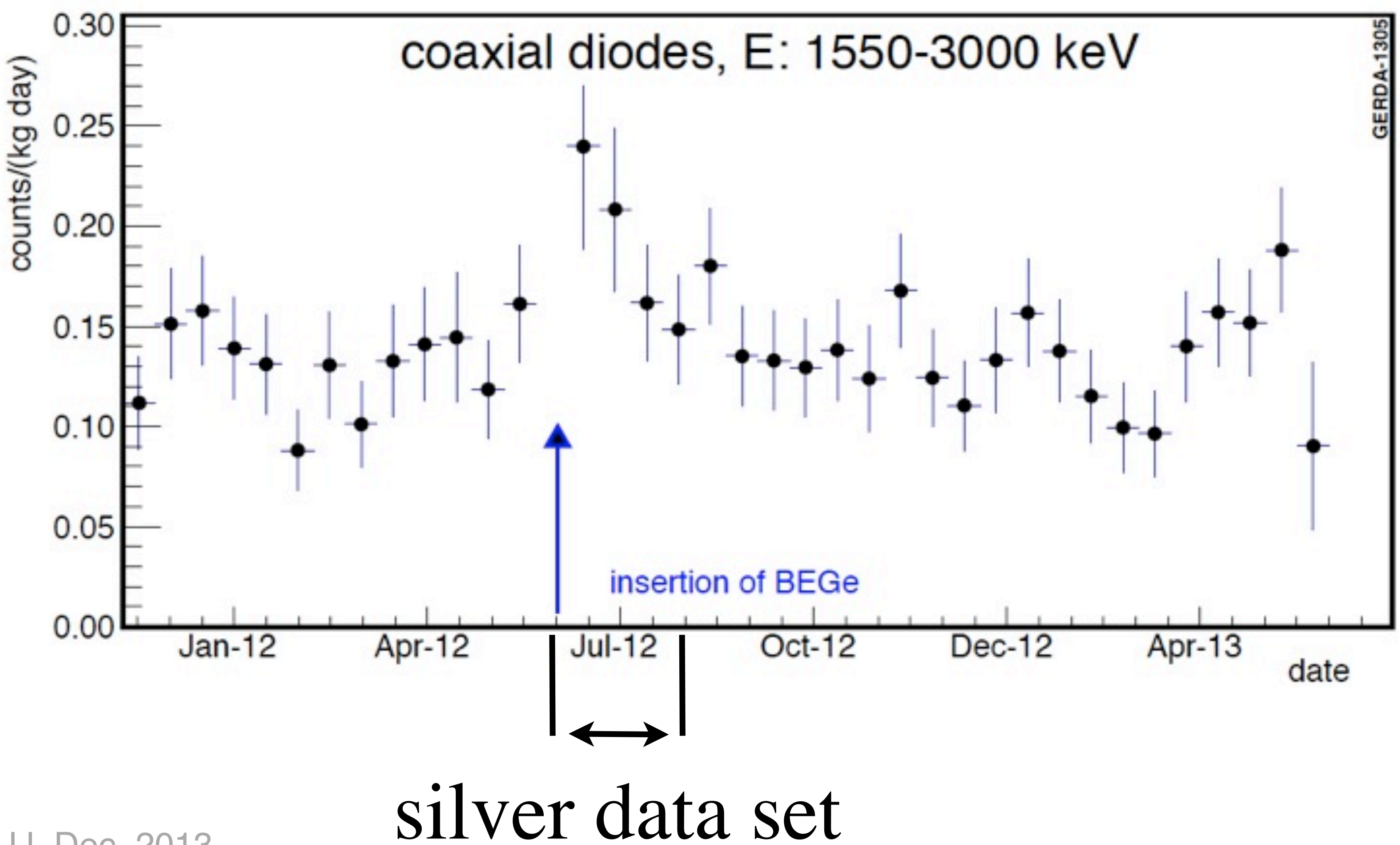
Background

- Background rate stable, except when the new Phase II detectors were inserted
- Data divided in ‘golden’ ‘silver’ and ‘BEGe’ data set
- Background rate golden coax: 1.8×10^{-2} cts/(keV kg yr)



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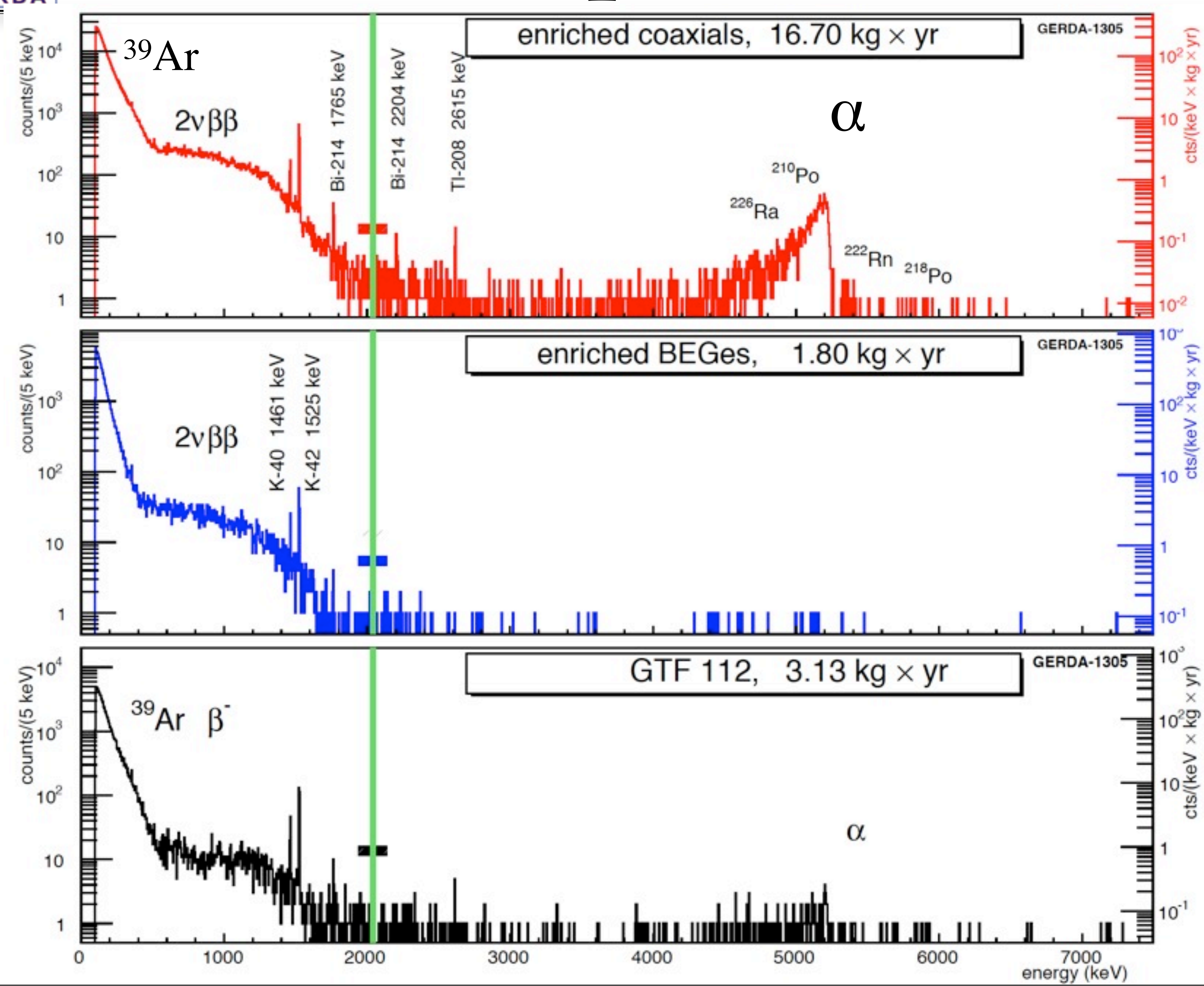
Full Spectrum



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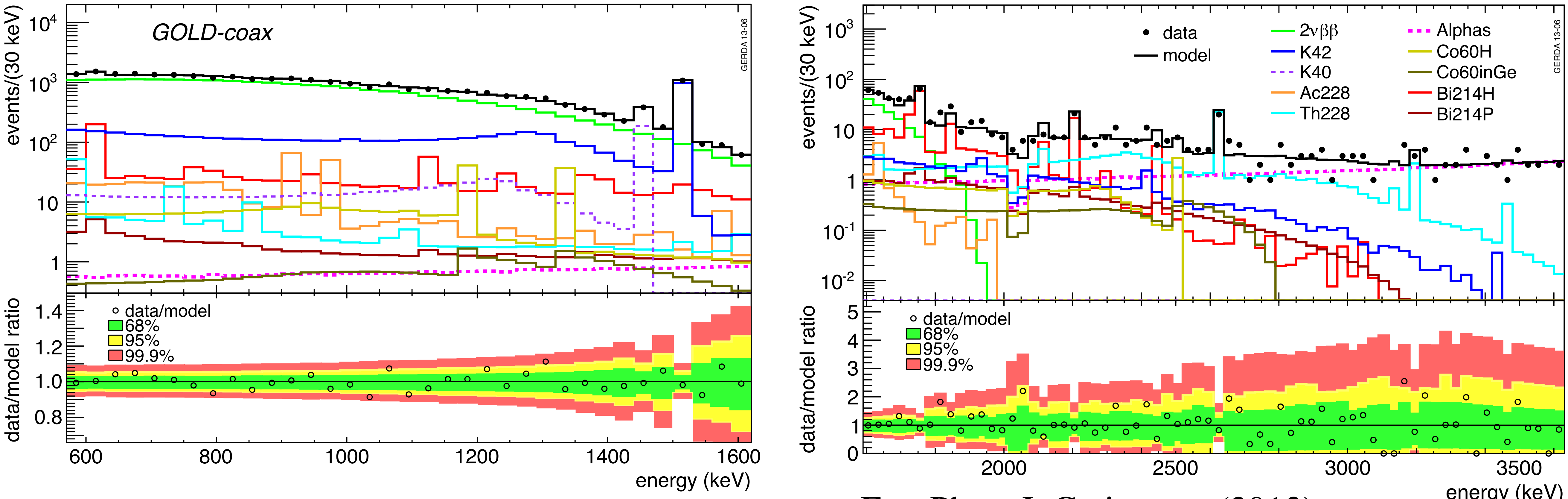
Background

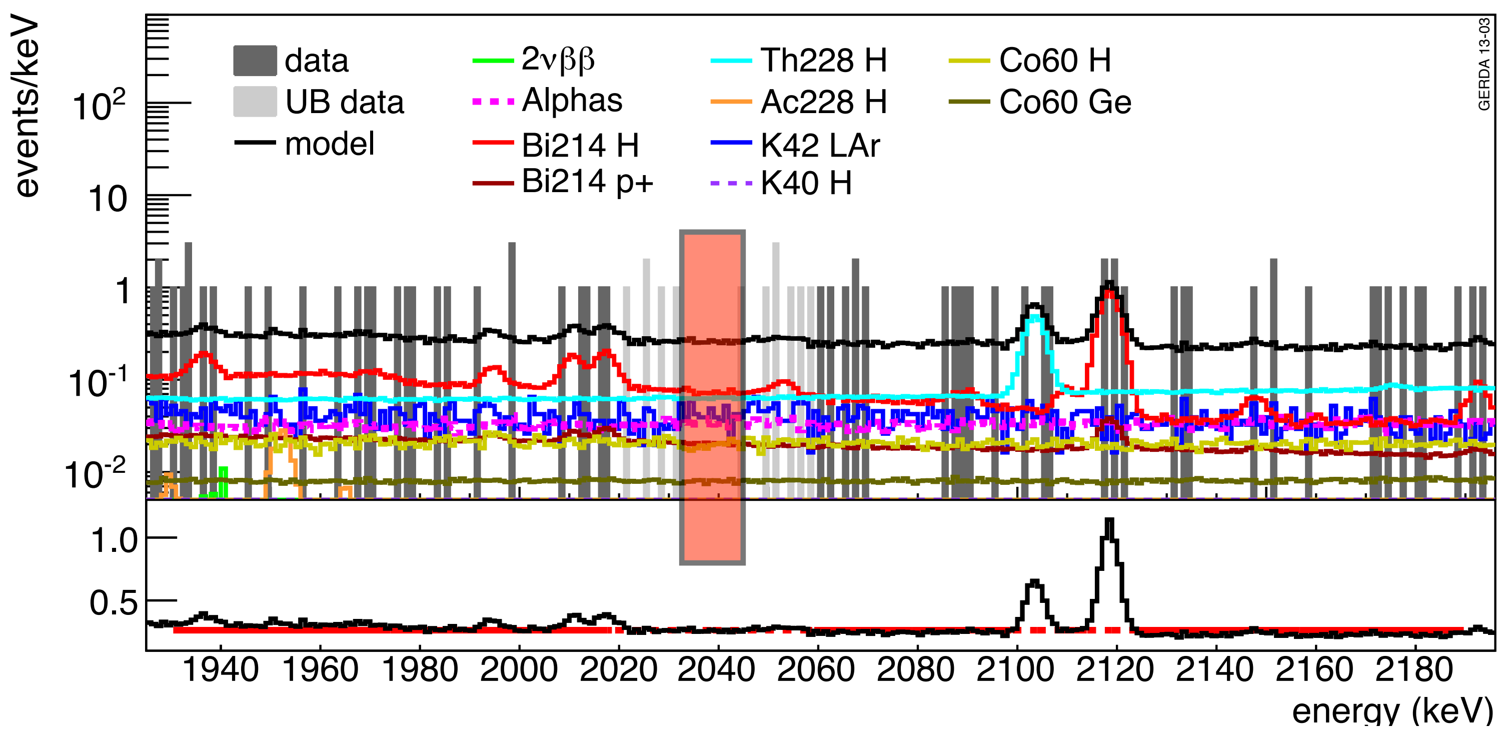


Eur. Phys. J. C . in press(2013)

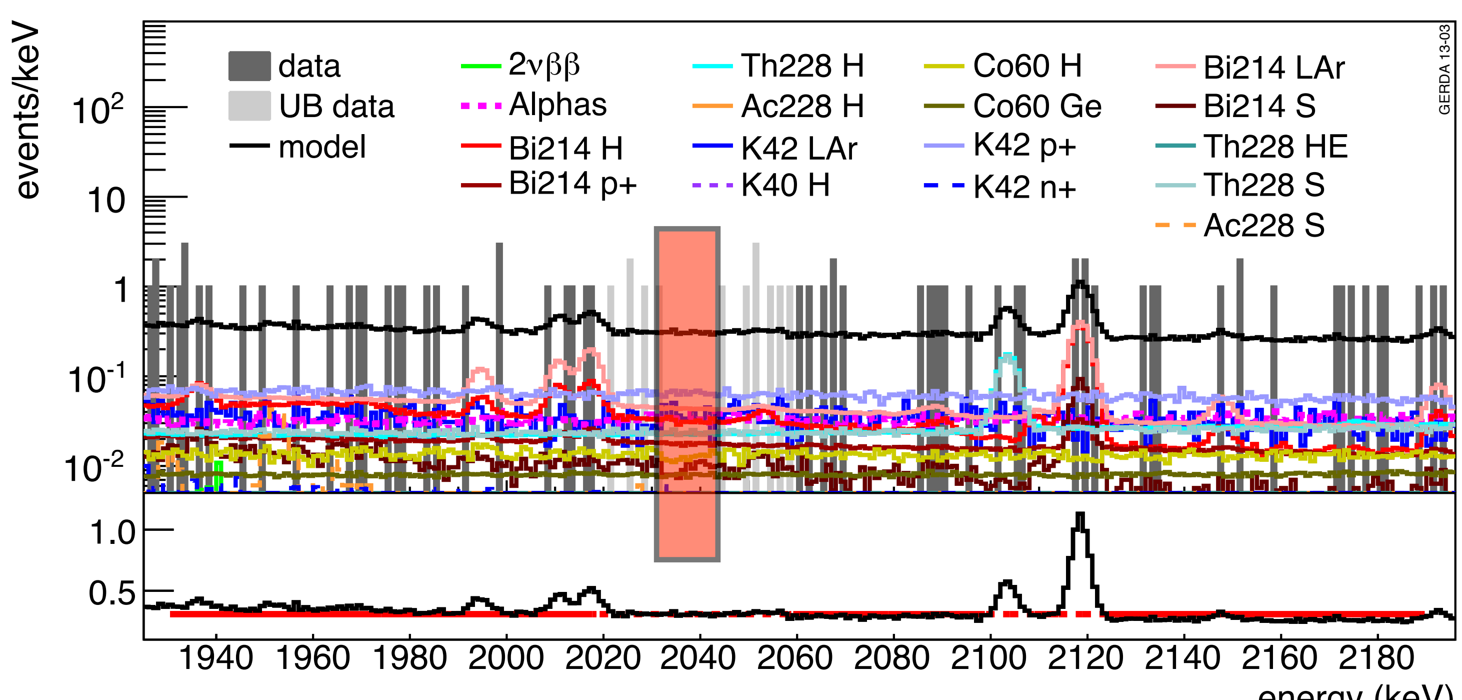
- Dominated by ^{214}Bi and ^{228}Th nearby sources (det. holders etc.) and surface contaminations - ^{42}K and alphas $\Longrightarrow$ *minimal background model*
- Contribution of remote sources is <u>negligible</u>
- The strongest gamma line is 1525 keV from ^{42}K
- Background model predicts flat background around 2 MeV

Background

Minimal model



Maximal model



- Background model predicts flat background around 2 MeV - no gamma lines
- Including all possible sources the spectrum do not change
- Predicted BI in the blinded window: 1.7 -2.9 x 10^{-2} cts/(keV kg yr)

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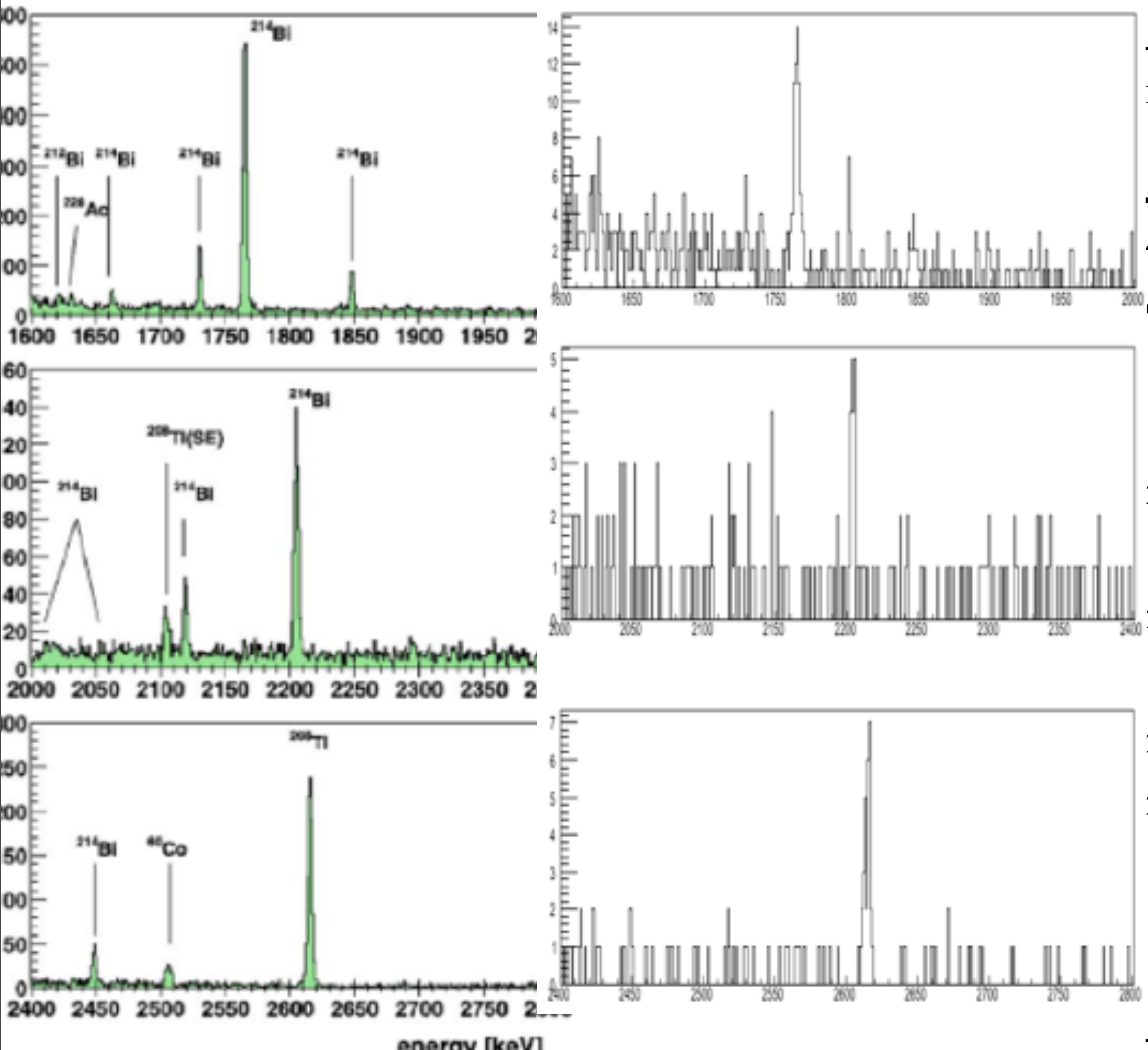
Background

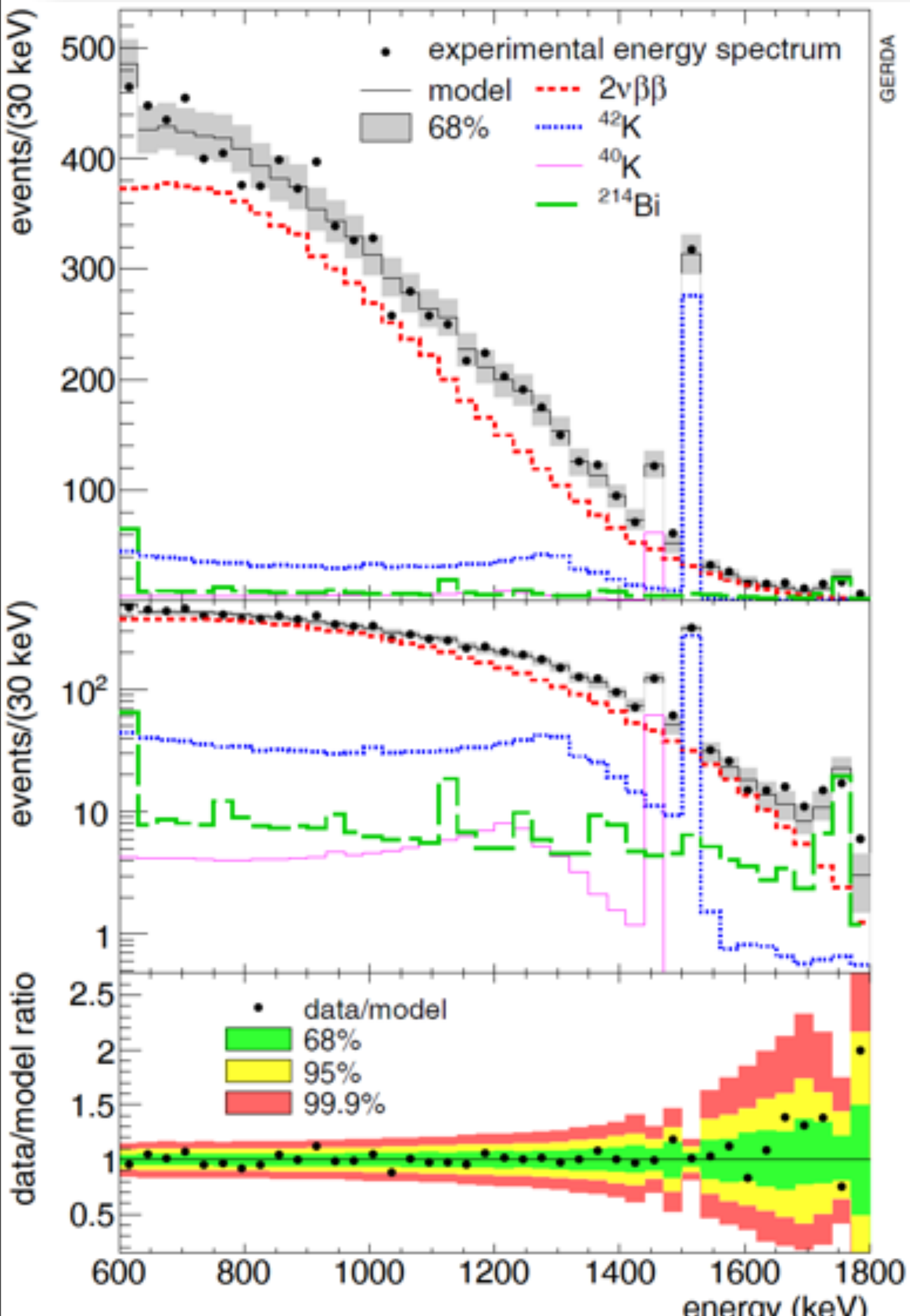
- Count-rate under the peaks 10x less than in the HdM experiment



Eur. Phys. J. C (2013) 73:2330

isotope	energy [keV]	GERDA rate [cts/(kg yr)]	HDM (71.7 kg yr) rate [cts/(kg yr)]
^{40}K	1460.8	$13.5^{+2.2}_{-2.1}$	181 ± 2
^{60}Co	1173.2	$4.8^{+2.8}_{-2.8}$	55 ± 1
	1332.3	<3.1	51 ± 1
^{137}Cs	661.6	<5.9	282 ± 2
^{228}Ac	910.8	<5.8	29.8 ± 1.6
	968.9	$2.7^{+2.8}_{-2.5}$	17.6 ± 1.1
^{208}Tl	583.2	<7.6	36 ± 3
	2614.5	$1.5^{+0.6}_{-0.5}$	16.5 ± 0.5
^{214}Pb	352	$12.5^{+9.5}_{-7.7}$	138.7 ± 4.8
^{214}Bi	609.3	$6.8^{+3.7}_{-4.1}$	105 ± 1
	1120.3	<6.1	26.9 ± 1.2
	1764.5	$3.6^{+0.9}_{-0.8}$	30.7 ± 0.7
	2204.2	$0.4^{+0.4}_{-0.4}$	8.1 ± 0.5

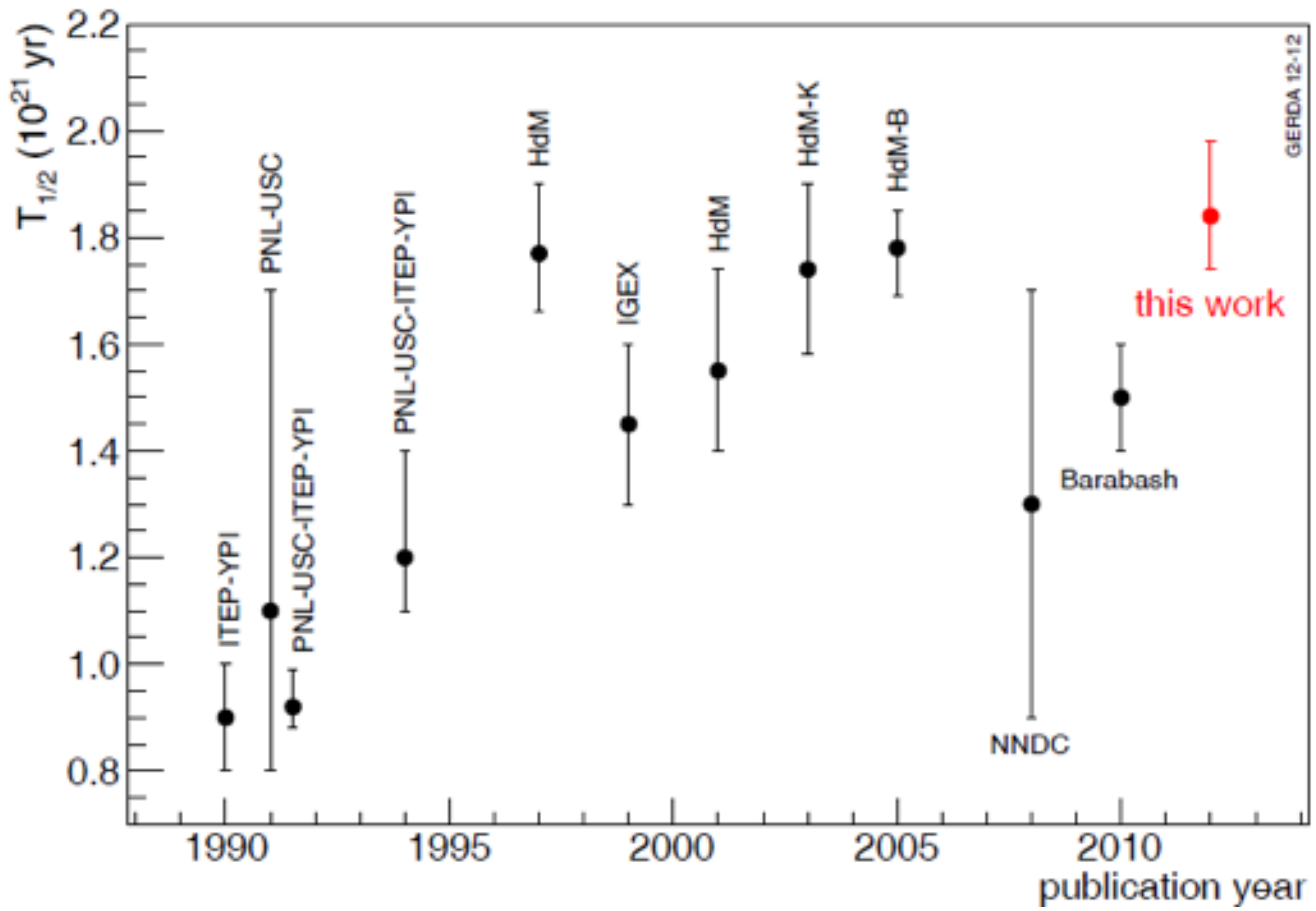
$2\nu\beta\beta$ - $T_{1/2}$



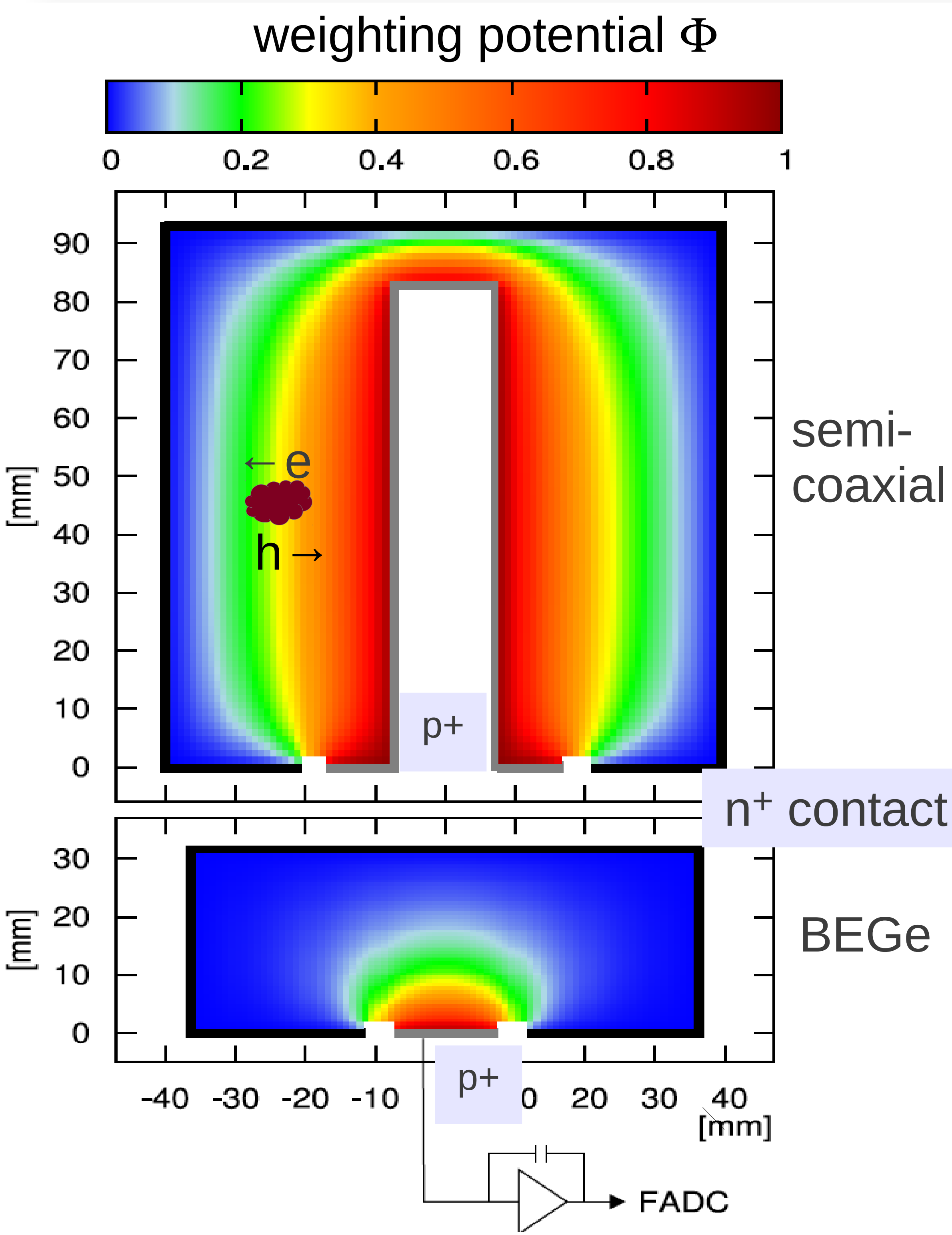
- With only 5.04 kg yr exposure the $2\nu\beta\beta$ $T_{1/2}$ could be already measured

$$T^{2\nu}_{1/2}(^{76}Ge) = 1.84 \times 10^{21}\ yr$$

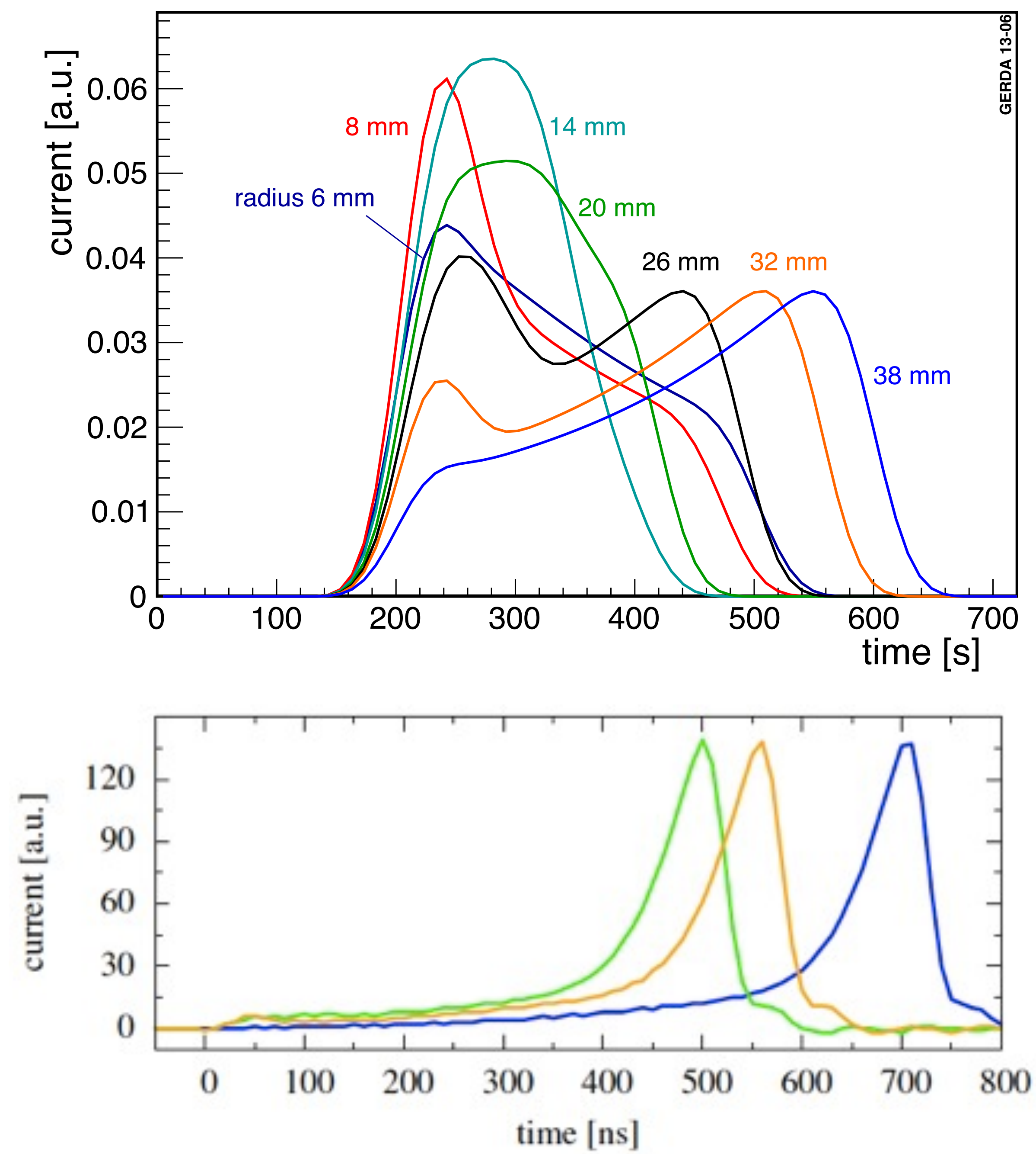
J. Phys. G: Nucl. Part. Phys. 40 (2013) 035110



Pulse-shape analysis



Simulated pulse shapes at different radii



 JJ, Dec. 2013

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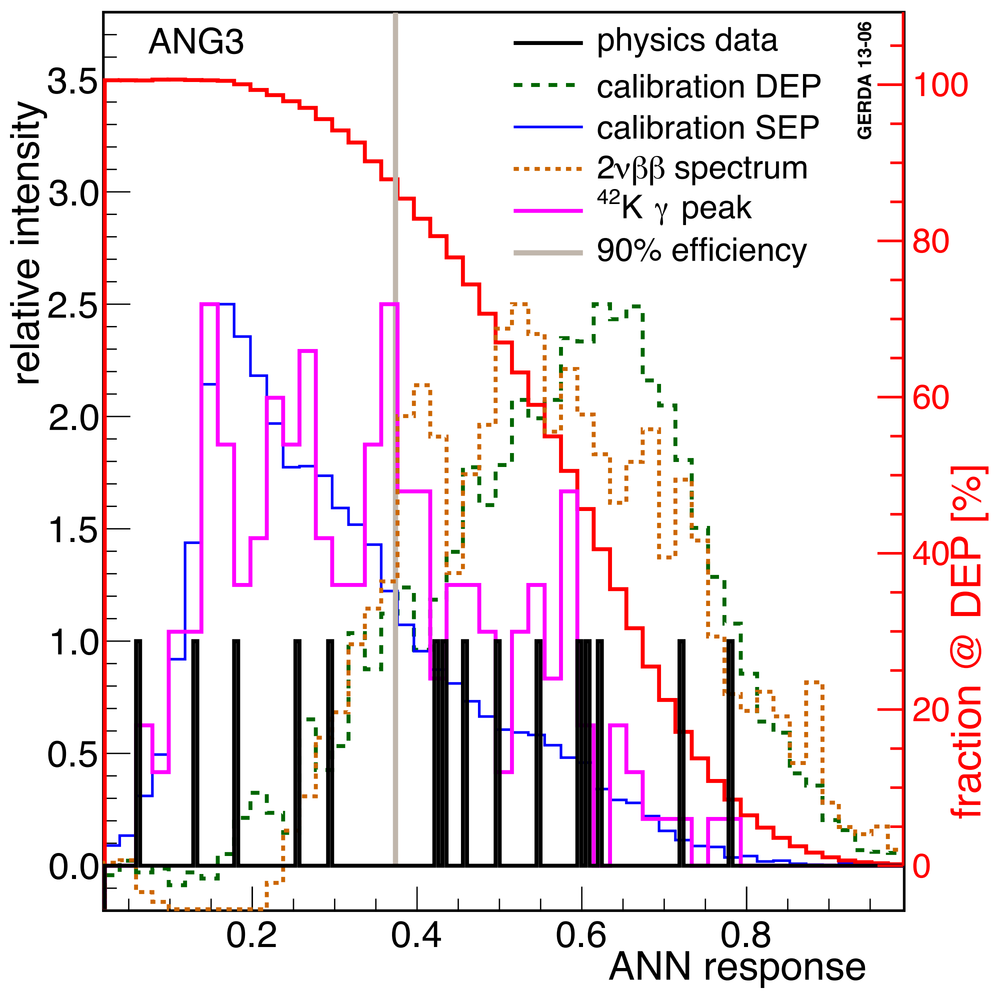
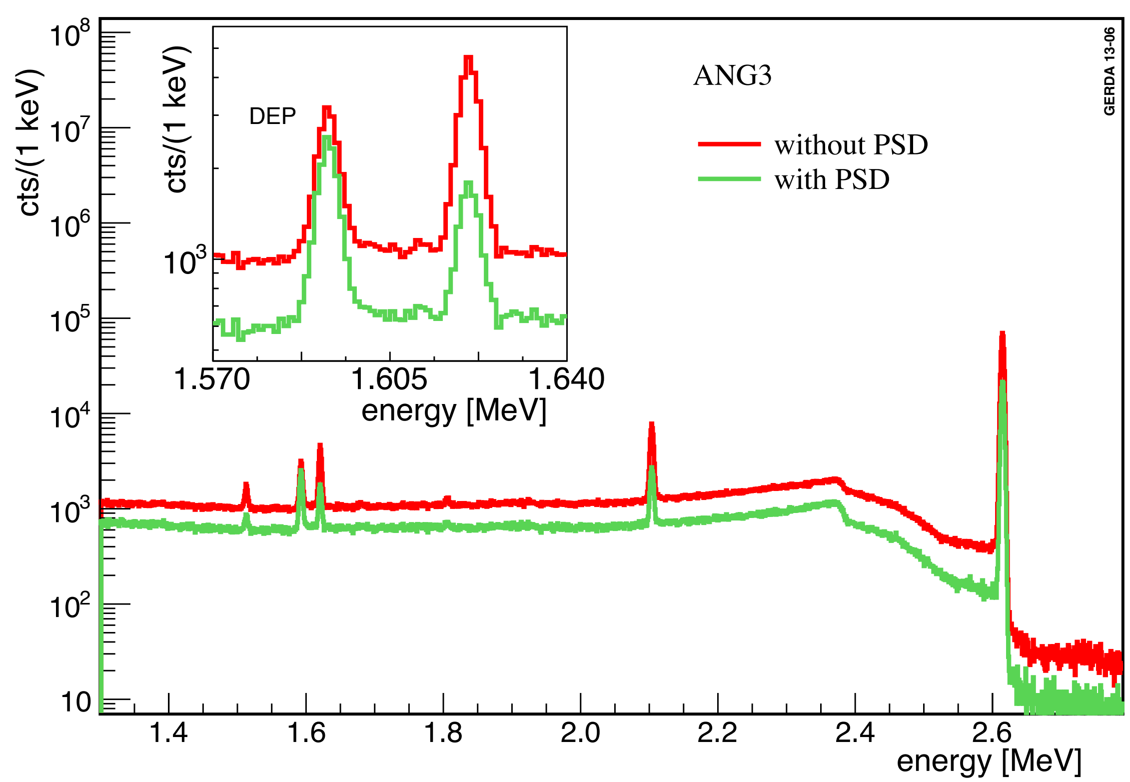
Thursday, December 5, 13

Pulse-shape analysis

- PSD has to be tuned for each detector, for each run period.
- PSD is tuned to retain 90% of the DEP of the ^{228}Th 2.6 MeV line. (90% signal efficiency) ⇒ Typical background survival prob. ~60%
- 3 different methods used: ANN, likelihood analysis, pulse-asymmetry cut.
- From the events rejected by one method 90% are rejected by the other methods as well.



Eur. Phys. J. C (2013) 73:2583



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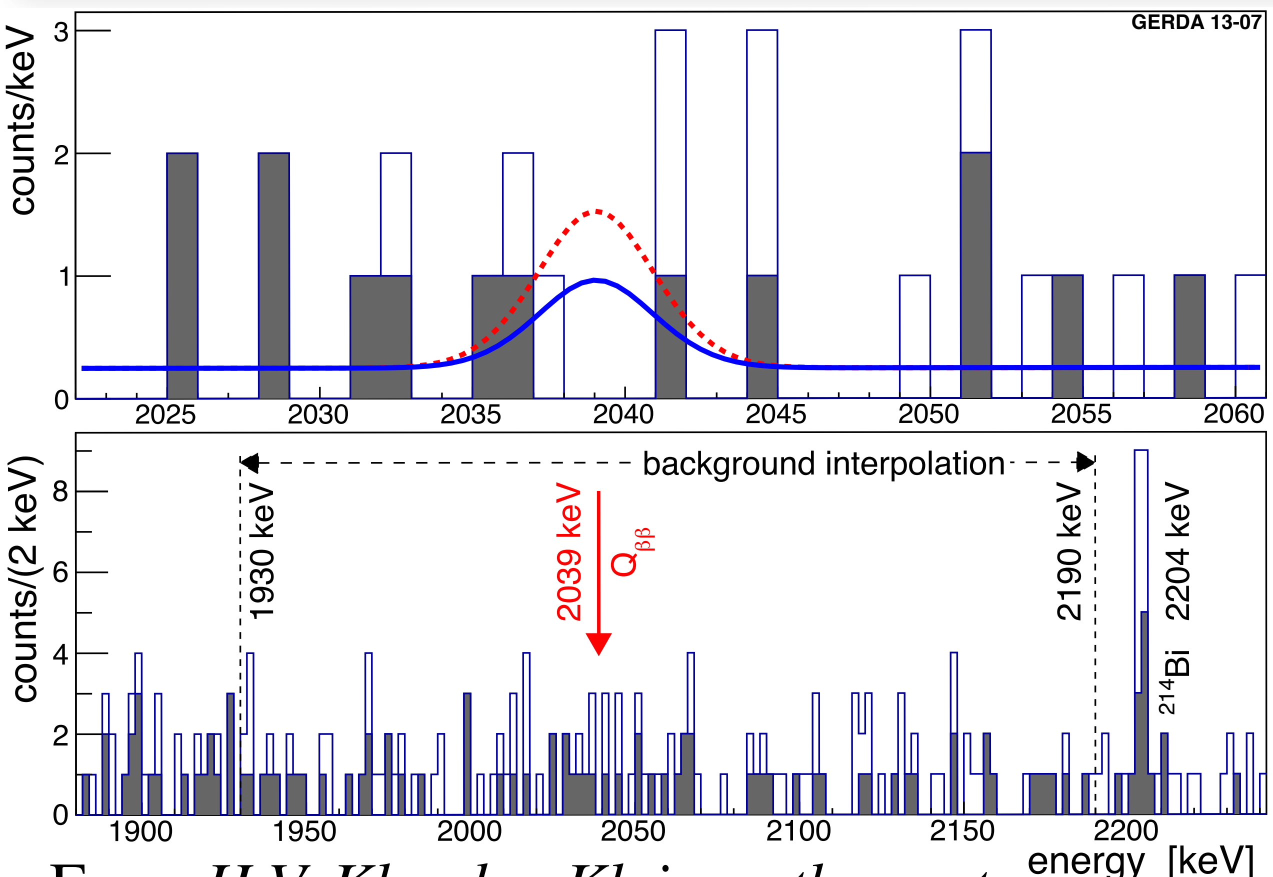
GERDA results

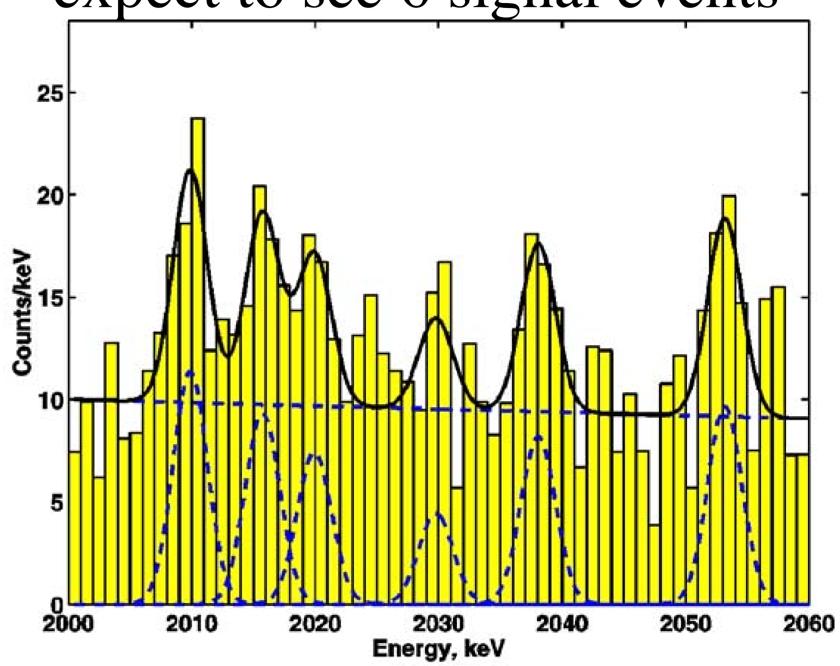


No counts in $Q_{\beta\beta} \pm \sigma$

$T^{0\nu}_{1/2} > 2.1 \times 10^{25}$ yr (90% C.L.)

Phys. Rev. Lett. **111**, 122503 (2013)

From *H.V. Klapdor-Kleingrothaus et al. / Physics Letters B 586 (2004)* we expect to see 6 signal events



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

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

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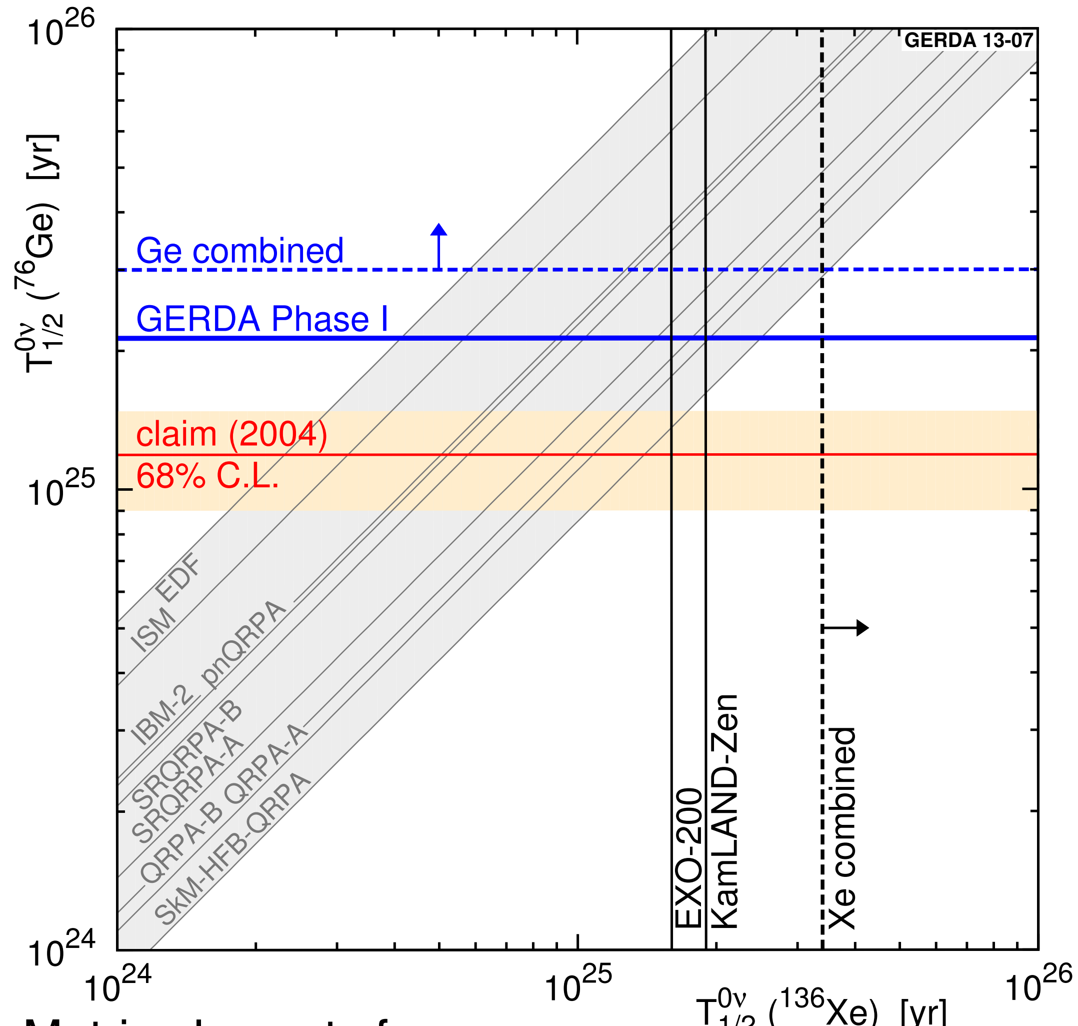
Combined results

- All ^{76}Ge experiments combined give: $T_{1/2} > 3.0 \times 10^{25}$ yr
- The claim is disfavored also by the ^{136}Xe experiments

H1: signal with $T_{1/2}^{0\nu} = 1.19 \times 10^{25}$ yr
H0: background only

	Isotope	$P(H_1)/P(H_0)$	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



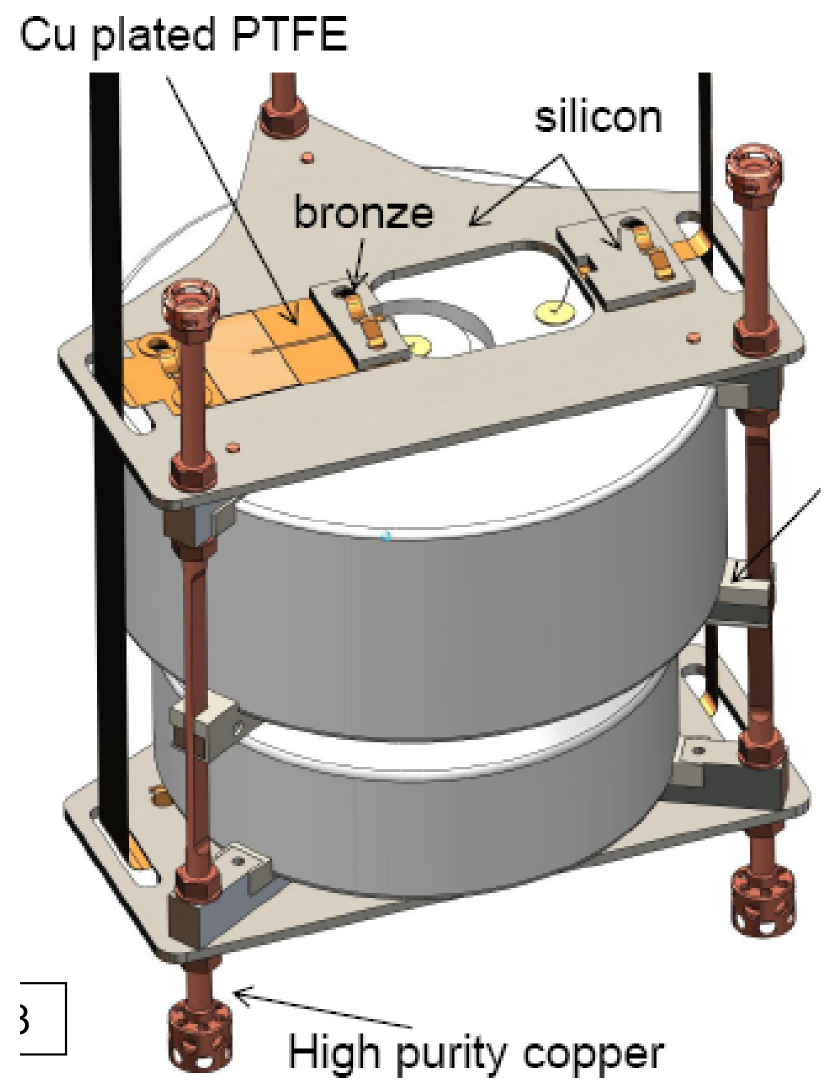
Matrix elements from:

P. S. Bhupal Dev *et al.*, (2013), arXiv:1305.0056

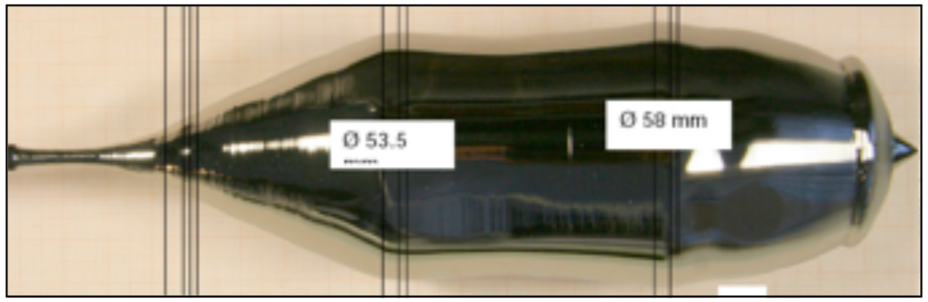
Phase II preparation

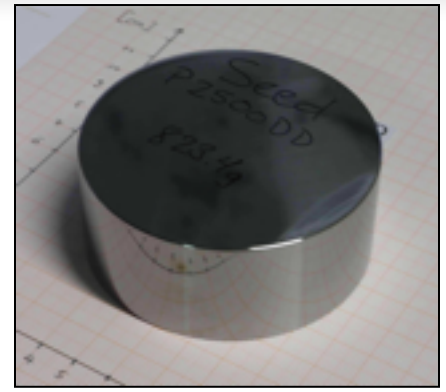
Strategy for better $T_{1/2}$ limit

- More mass: + ~20 kg
- Better PSD: BEGe detectors
- Cleaner detector holders
- cleaner FE-electronics
- LAr veto



Phase II preparation

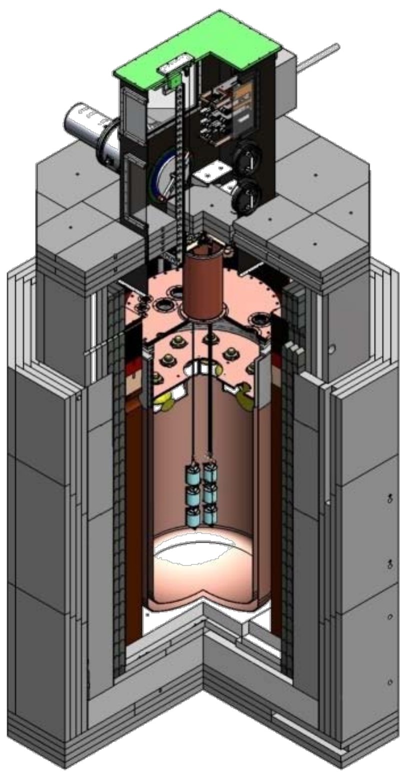


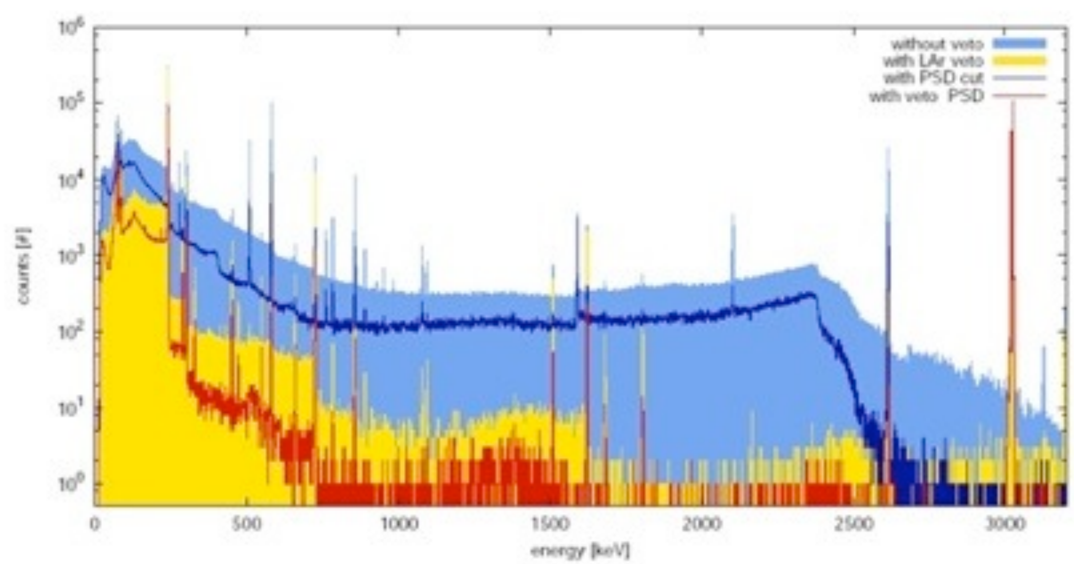


- From the available 37.5 kg enriched germanium 30 new detectors were produced (~20 kg)
- 5 of the new BEGe detectors already deployed in Phase I.
- New lock was built to accommodate 7 detector strings, the LAr veto with PMTs and WLS fibers

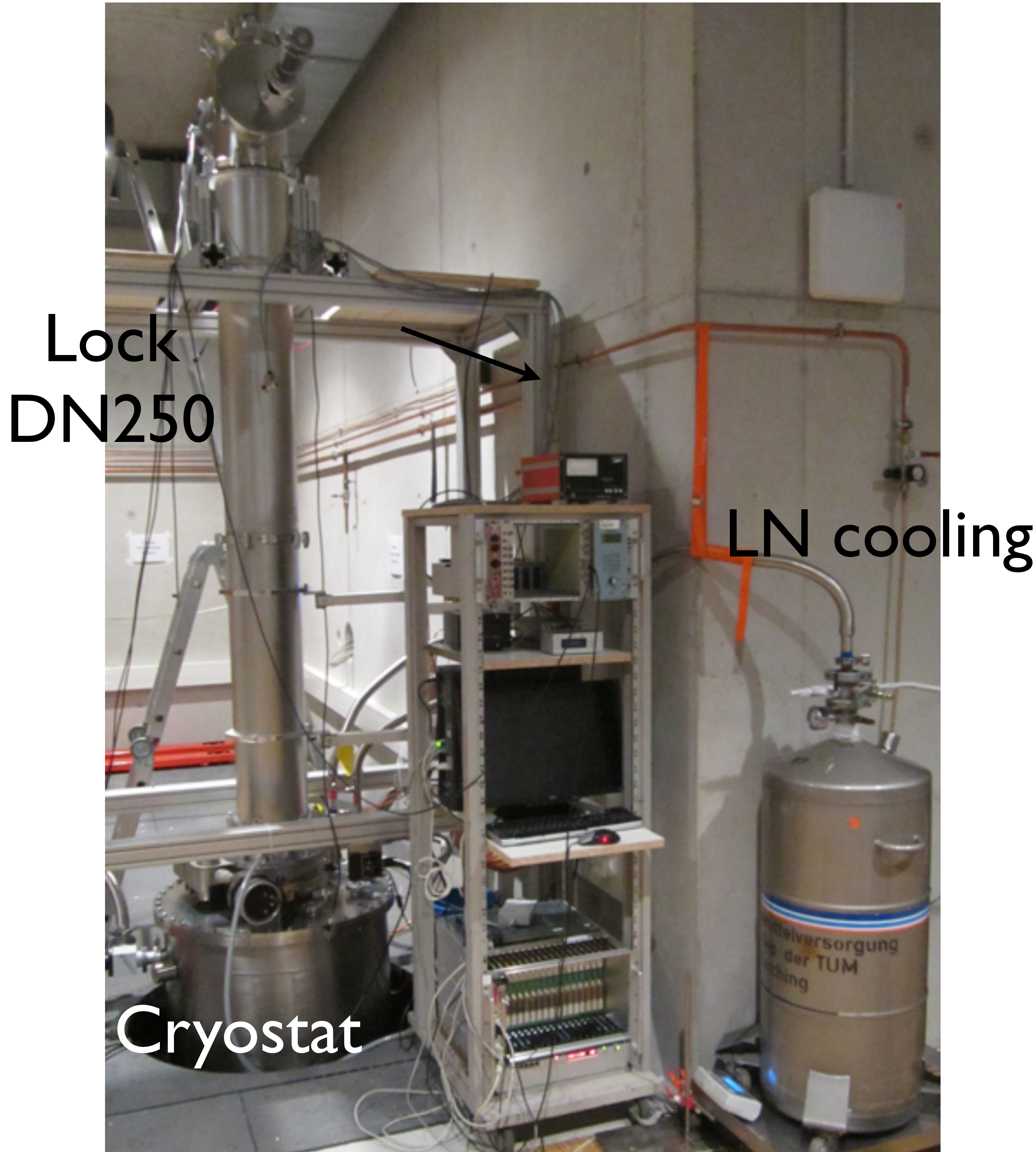
Phase II preparation

- Up to 1000 fold reduction of the Compton background was demonstrated (LArGe)
- In GERDA 10x background reduction is possible only with LAr veto
- Instrumentation is constrained by radiopurity and available space
- Hybrid system with PMTs, WLS fibers + SiPMs





TUM -UGL test stand



Conclusion

- Sept. 30, 2013 the Phase I of GERDA was ended with 21.6 kg yr exposure.
- Background goal of 0.01 cts/(keV kg yr) was achieved
- No indication of $0\nu\beta\beta$ signal $\Rightarrow$ $T_{1/2} > 2.1 \times 10^{25}$ yr
- Phase II: 30 new detectors are ready, construction started ...