Ge detectors and 0νββ-decay: GERDA

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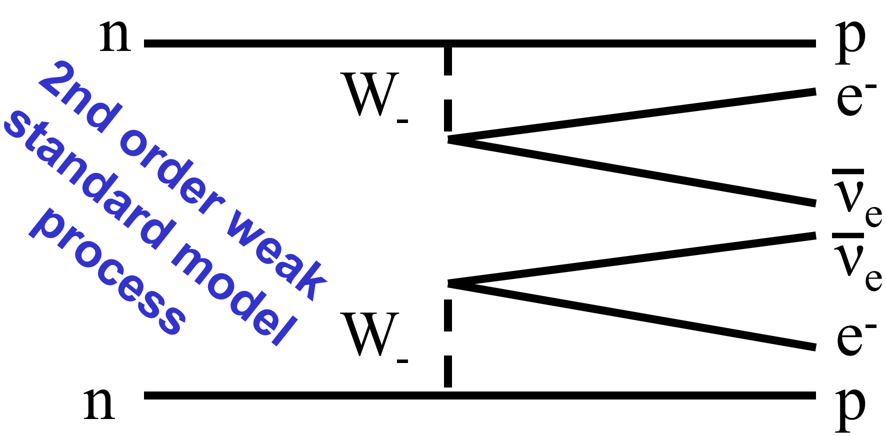
- Why and how to search for 0νββ-decay
- The GERDA experiment
- GERDA Phase I Results
- GERDA Phase II
- Germanium for ton scale?

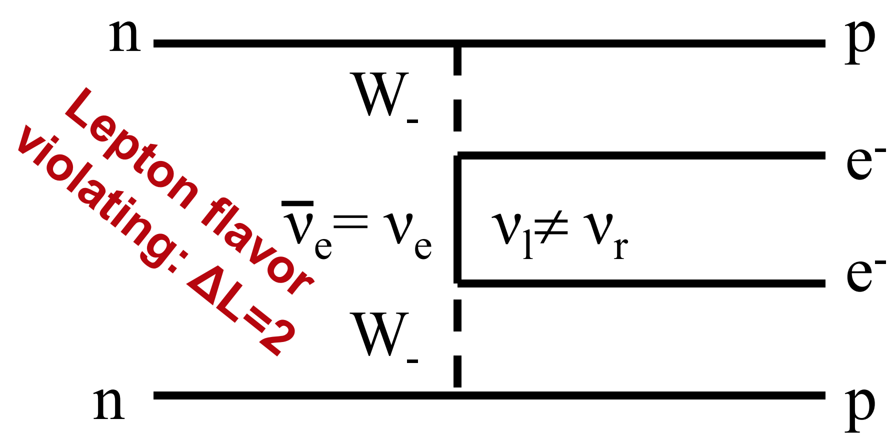
19.Oct.2015, Ringberg, Castle

Why to search for 0νββ decay?

2νββ-decay:



0νββ-decay:



Neutrinoless mode of ββ-decay only possible if:

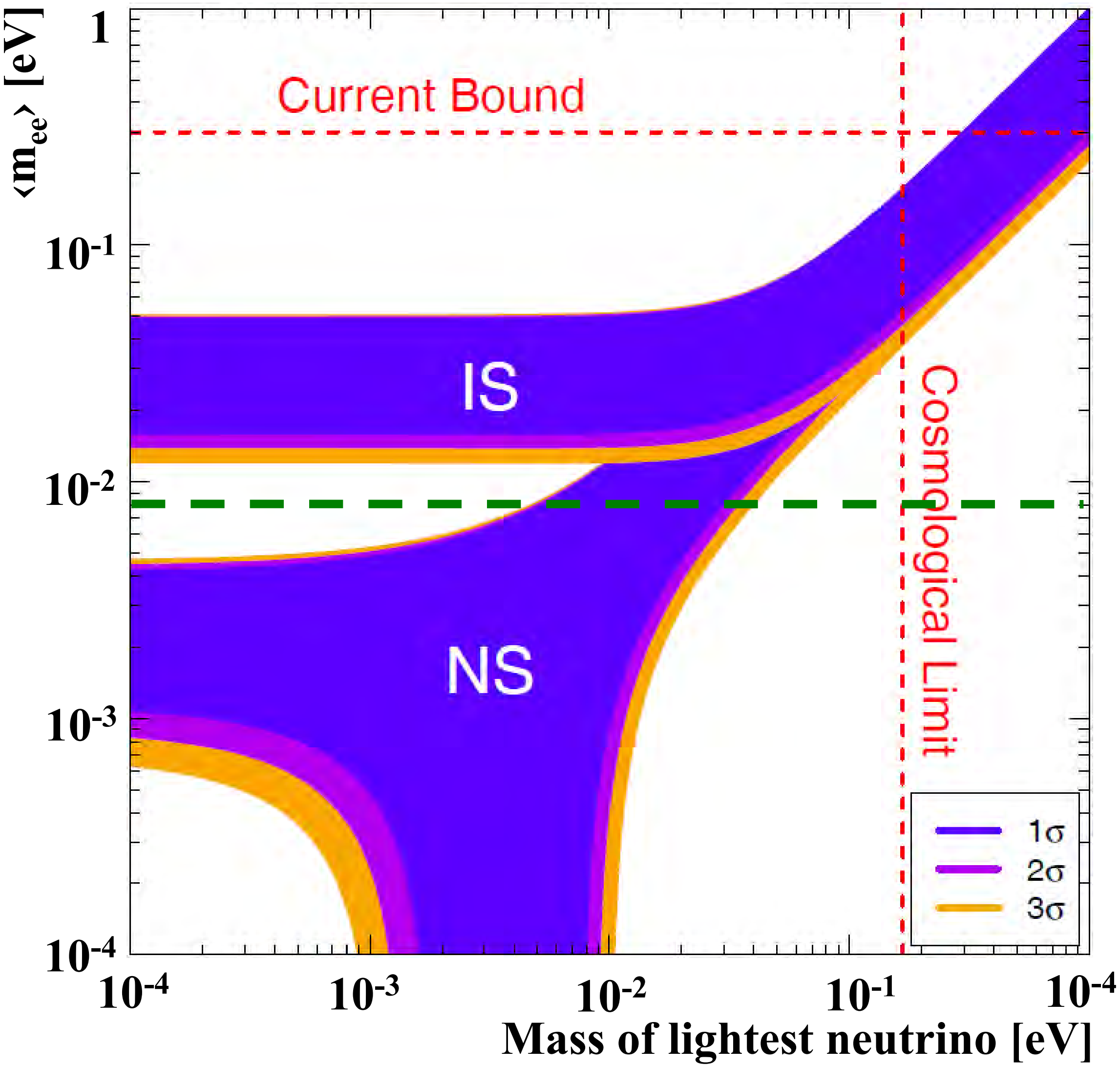
- Neutrino is a Majorana particle
- Helicity flip can occur in the vertex

Effective Majorana neutrino mass contributes to 0νββ-decay rate:

$$\boxed{1/\tau = G(Q^5) \cdot g_A^{\,4} \cdot |M_{nucl}|^2 \cdot \langle m_{ee}\rangle^2/m_e^{\,2}}$$

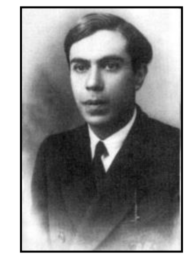
$1/\tau$	$G(Q^5)$	g_A^4	$\lvert M_{nucl}\rvert^2$	$\langle m_{ee}\rangle^2$	m_e^2
0νββ decay-rate	Phase space factor	Eff. ax. vec. coupling const	Matrix element	Effective Majorana Neutrino mass	Electron mass

Why to search for 0νββ decay?



Observation of 0νββ decay:

- Lepton number violation!
- Neutrino must have Majorana nature!



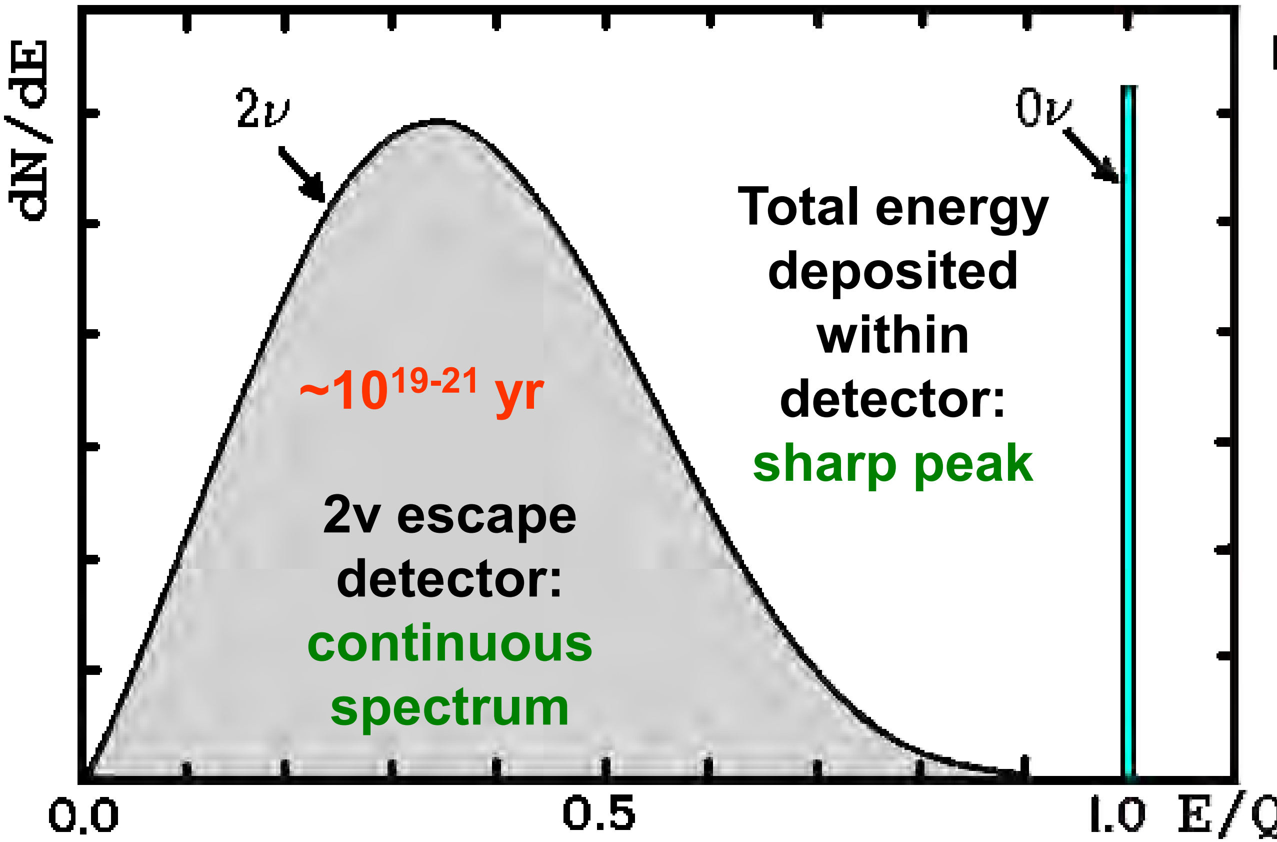
- Determination of absolute mass scale (?)
- Mass hierarchy of Neutrinos (?)

- Information on CP violating phases?

→ Baryogenesis via Leptogenesis?

How to search for 0νββ decay?

Signature: Sharp peak at Q-value of the decay



Peak height not to scale!

for ‹m_{ee}› =10 meV

$T_{1/2}$~ 10^{28-29} yr

Non vanishing CP violating Majorana phases can suppress ‹m_{ee}› even to zero!

Half life [years]	~Signal [cts/(t·yr)]
$1 \cdot 10^{26}$	50
$5 \cdot 10^{27}$	1
$1 \cdot 10^{29}$	0.05

→ < 1 event per year per ton of ββ emitting isotope!

→Tolerate < 0.1 bkg events per year per ton in RoI!

How to search for 0νββ decay?

Figure of merit for a LIMIT setting sensitivity:

b>0 : $^{0\nu}T_{1/2} \propto a\,\varepsilon \sqrt{\frac{m\,t}{b\,\delta E}}$

b=0 : $T_{1/2} \propto a\,\varepsilon\, m\, t$

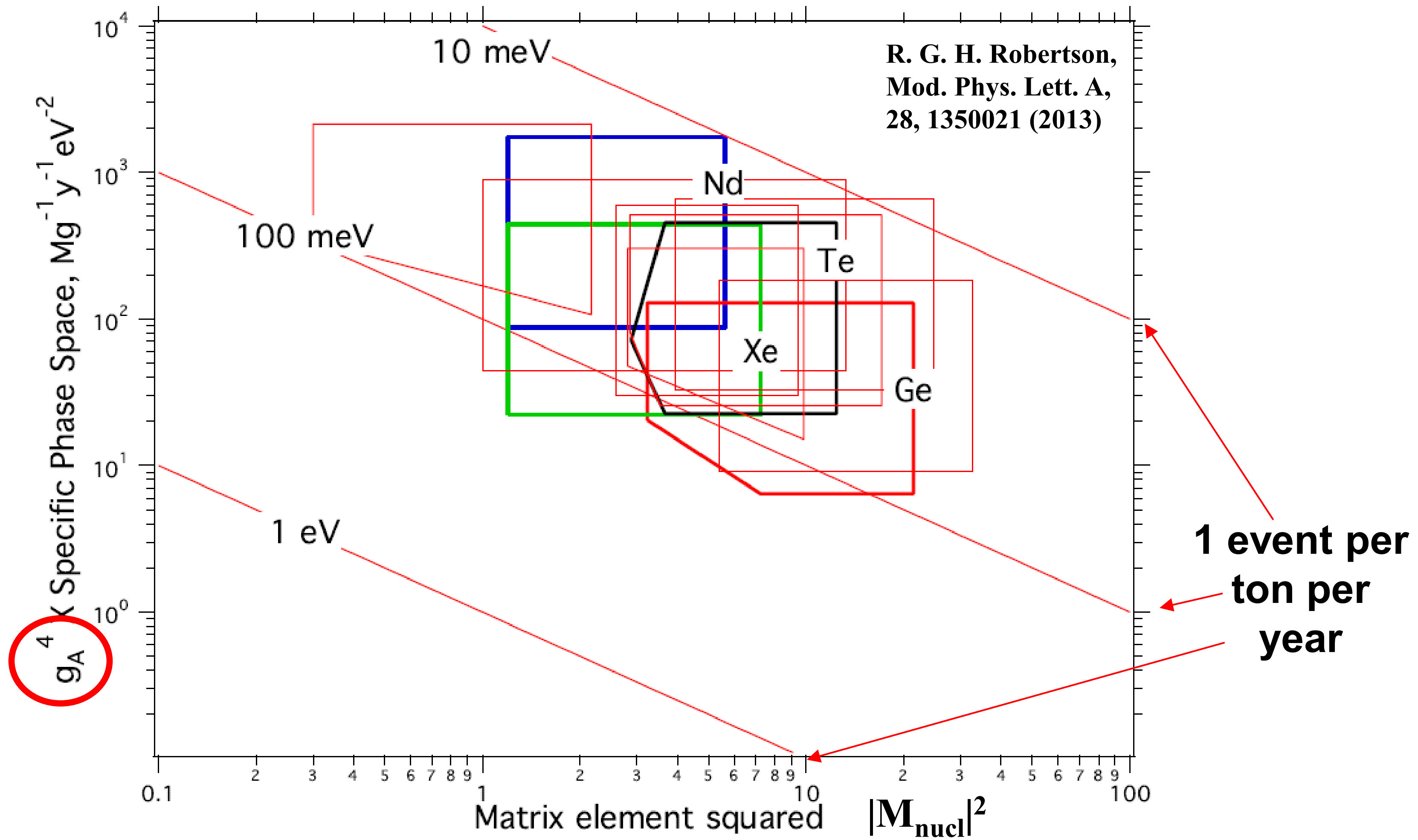
M_{nucl}	Nuclear matrix element	Select Isotope
b	background rate of the experiment	Minimize and select material
a	abundance of isotope under consideration (< 1.0)	Use isotope with high natural abundance or enrich material
m	active target mass of the experiment	Increase target mass
ε	signal detection efficiency (<1.0)	Source = Detector
δE	Energy resolution	Use high resolution spectroscopy
t	Measuring time (< 20y)	

M_{nucl} enters the equation if $^{0\nu}T_{1/2}$ sensitivity is converted to $\langle m_{ee}\rangle$

How to search for 0νββ decay?

Chose your isotope: expected decay rates per unit target mass:

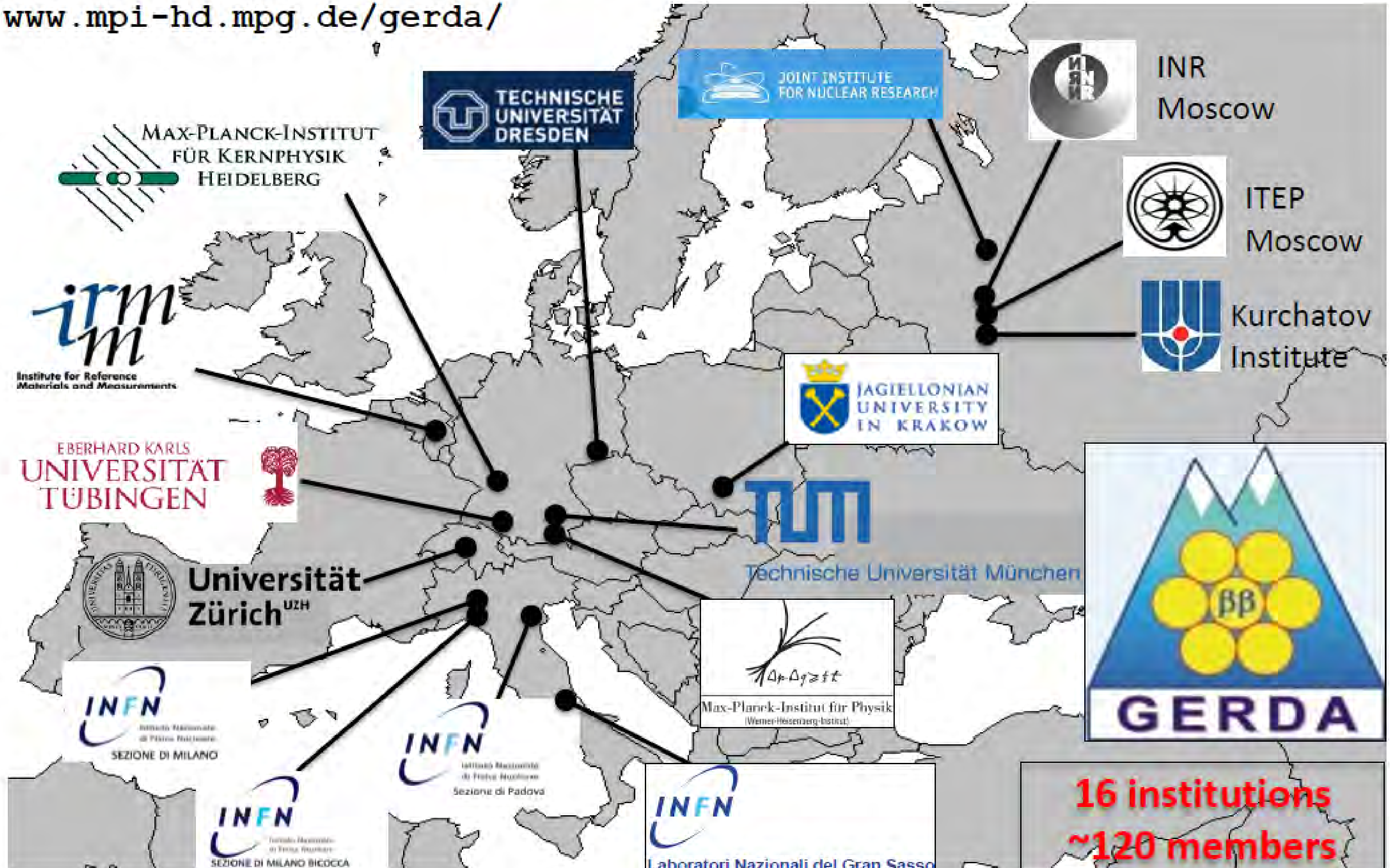
$$1/\tau = G(Q^5) \cdot g_A^4 \cdot |M_{nucl}|^2 \cdot \langle m_{ee}\rangle^2/m_e^2$$



→ Considerable uncertainties!
No isotope preferred

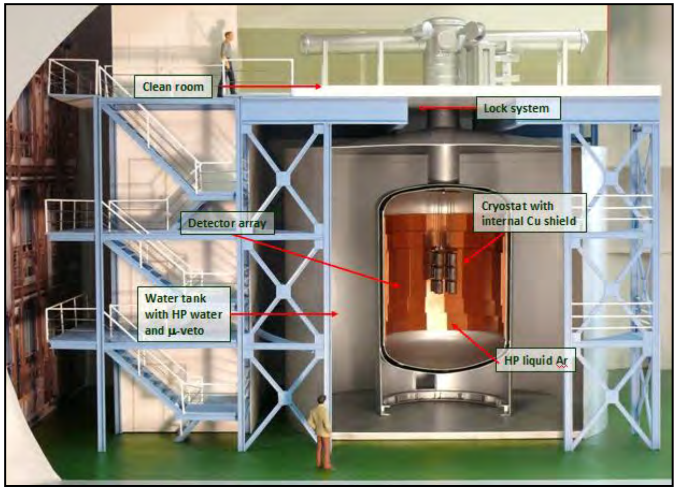
GERDA: the Collaboration

www.mpi-hd.mpg.de/gerda/



16 institutions
~120 members

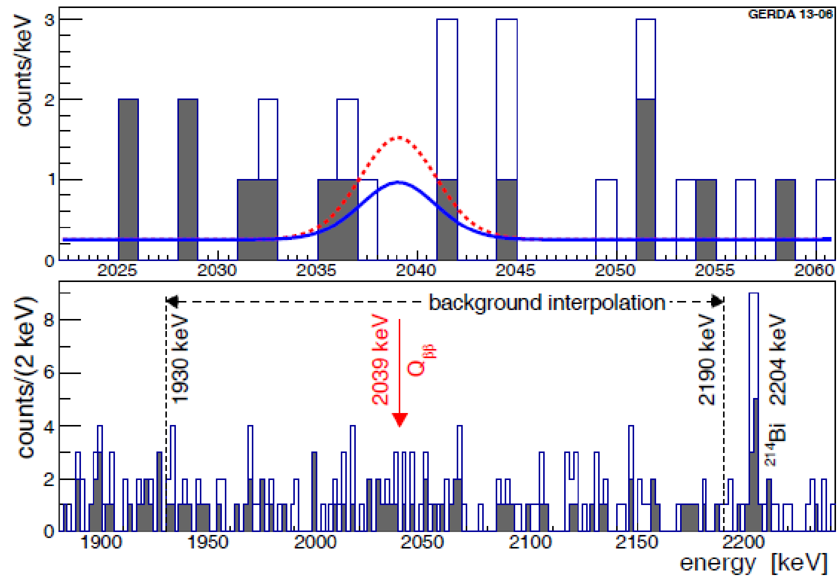
GERDA Phase I results



Operate HPGe detectors directly in cryogenic liquid

Phase I data taking: Nov. 2011 to May 2013

14.6 kg coaxial detectors
3.0 kg BEGe detectors → **21.6 kg yr exposure**



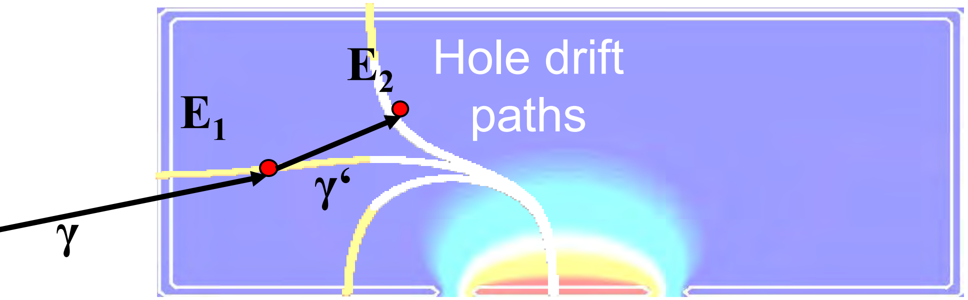
PRL 111 (2013) 122503 [arXiv:1307.4720]

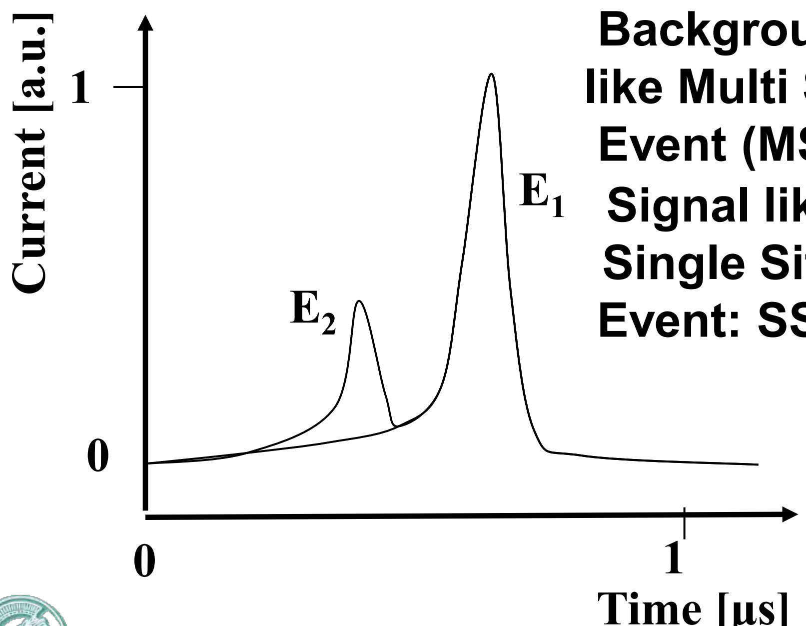
→ $^{0\nu}T_{1/2}(^{76}Ge) > 2.1\ 10^{25}$ yr (90% C.L.) frequentist analysis

median sensitivity: $T_{1/2}(0\nu\beta\beta) > 2.4\ 10^{25}$ yr

GERDA Phase II

Additional 20kg BEGe detectors with point like contact:

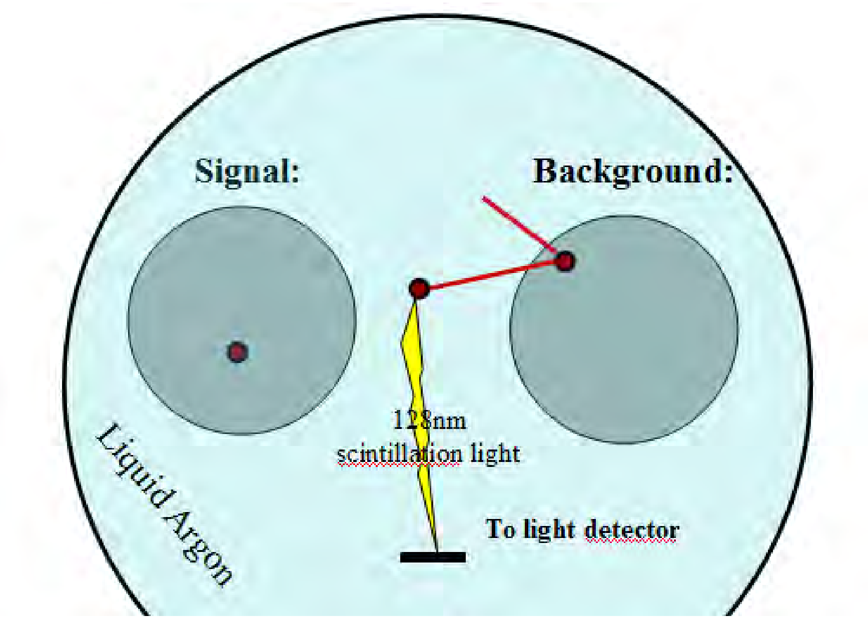




Background like Multi Site Event (MSE)

Signal like Single Site Event: SSE

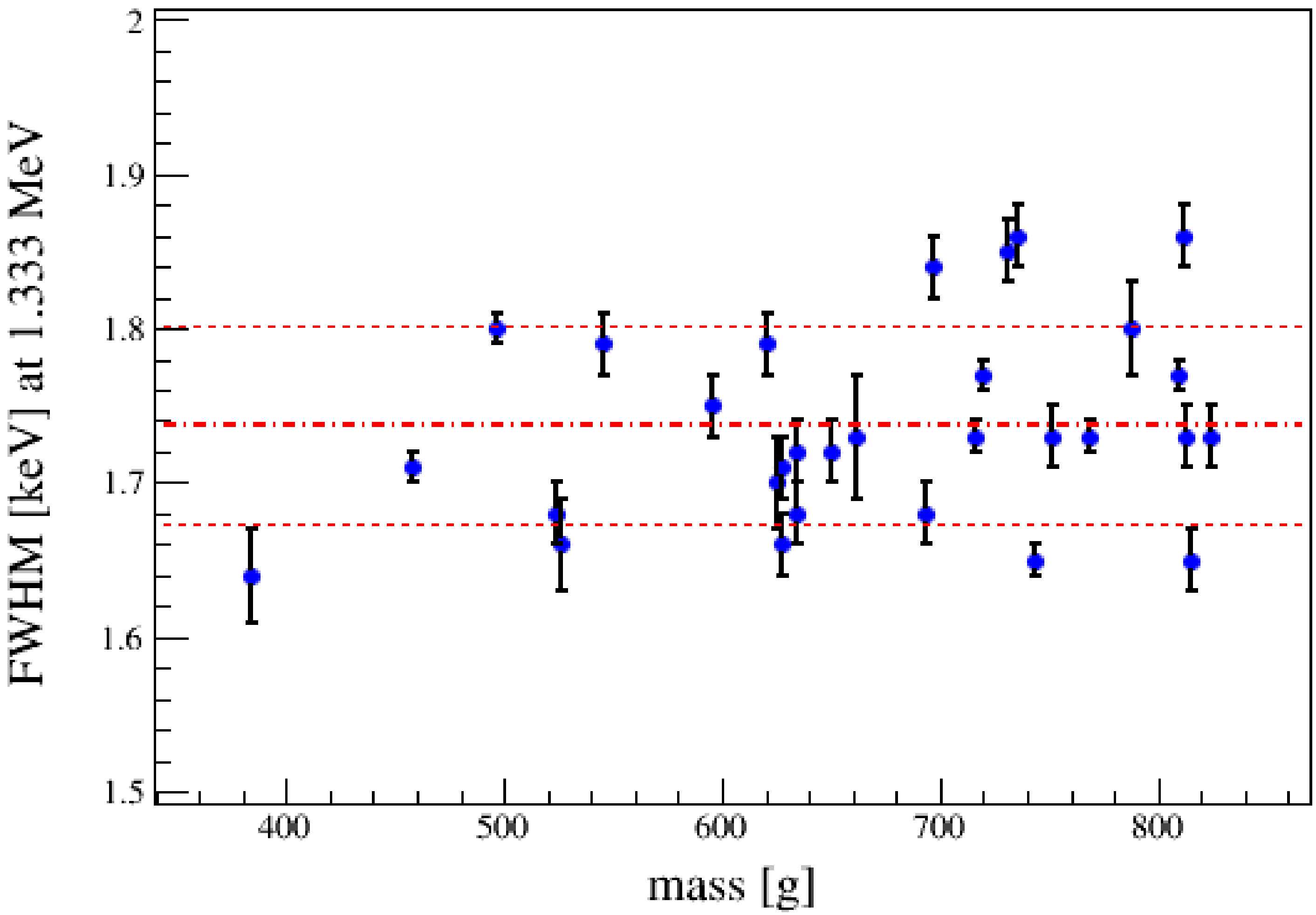
Use LAr veto:



GERDA Phase II: New detectors

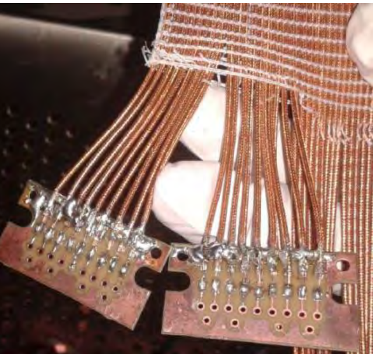
Production and characterization of BEGes

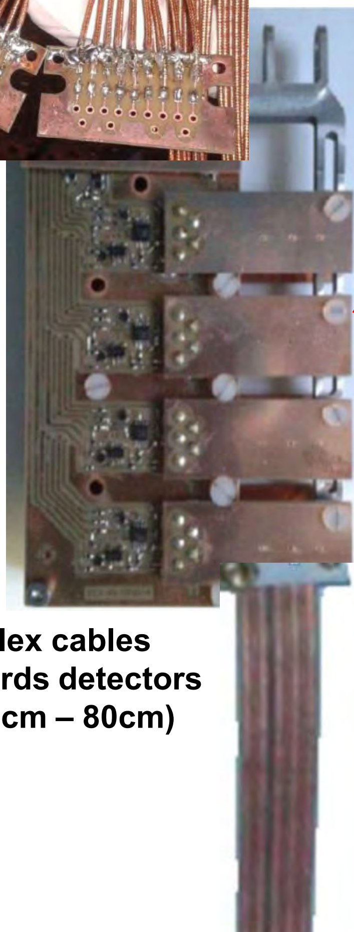
Energy resolution of GERDA BEGe detectors in vacuum cryostat



GERDA Phase II preparations: Front end

Coax cable
towards DAQ
(~ 10m)





Flex cables
towards detectors
(40cm – 80cm)

Original plan: JFET on BEGe holder plates:
High JFET mortality

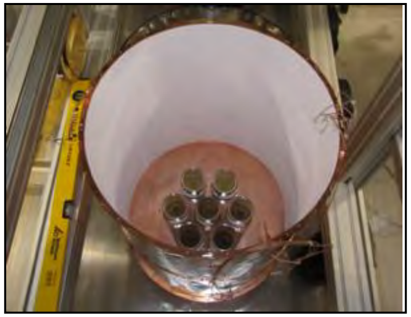
→ Start with Phase I like readout:
VFE at CC3 level > 40 cm from detectors

Knowledge from Phase I (5 BEGes):
FHWM ok, PSD ok

Flexible cables (signal and HV) in use between
detectors and CC3:
CuFlon, Pyralux (Kapton family)

GERDA Phase II preparations: the LAr veto:

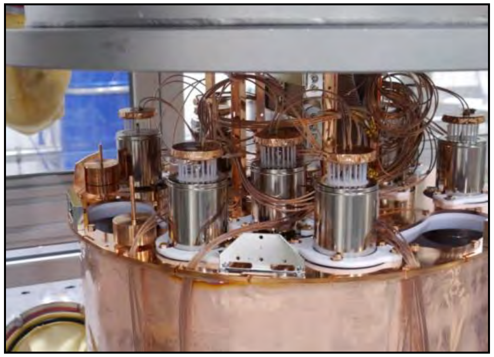
Copper shroud lined with reflecting TPB coated Tetratex



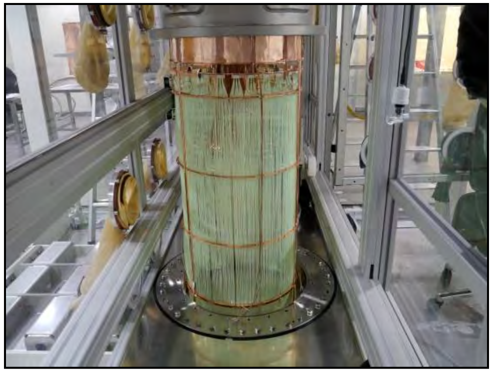
7 bottom 3" PMTs

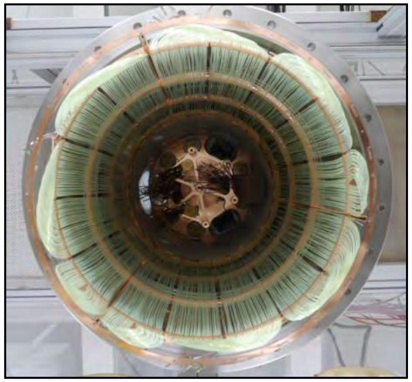
GERmanium Detector Array

9 top 3" PMTs



TPB coated fiber shroud with SiPMs





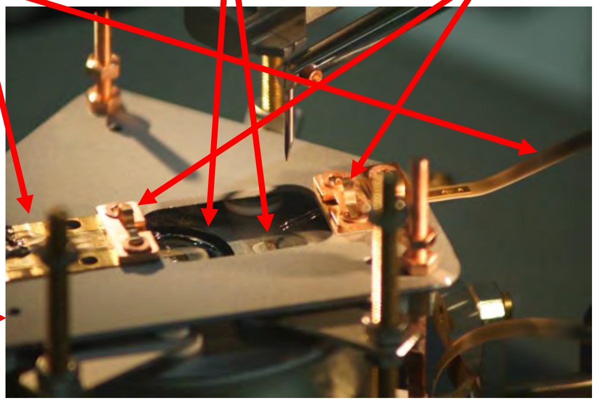
GERDA Phase II preparations:

Signal & HV cables

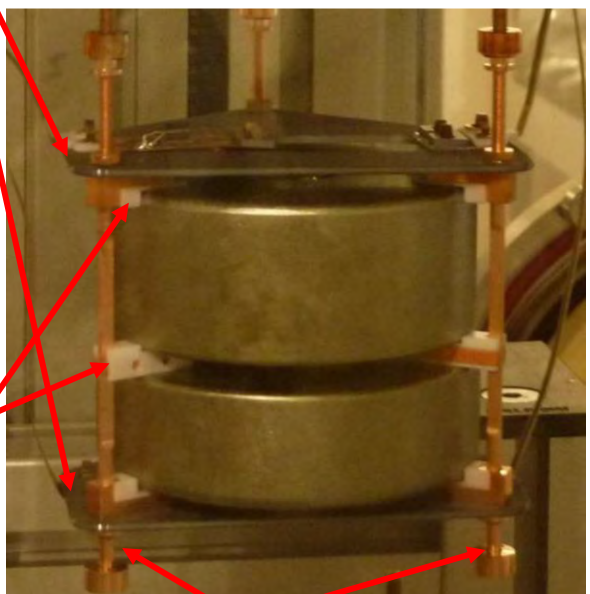
bonded contacts

CuSn6 clamps

Si plates

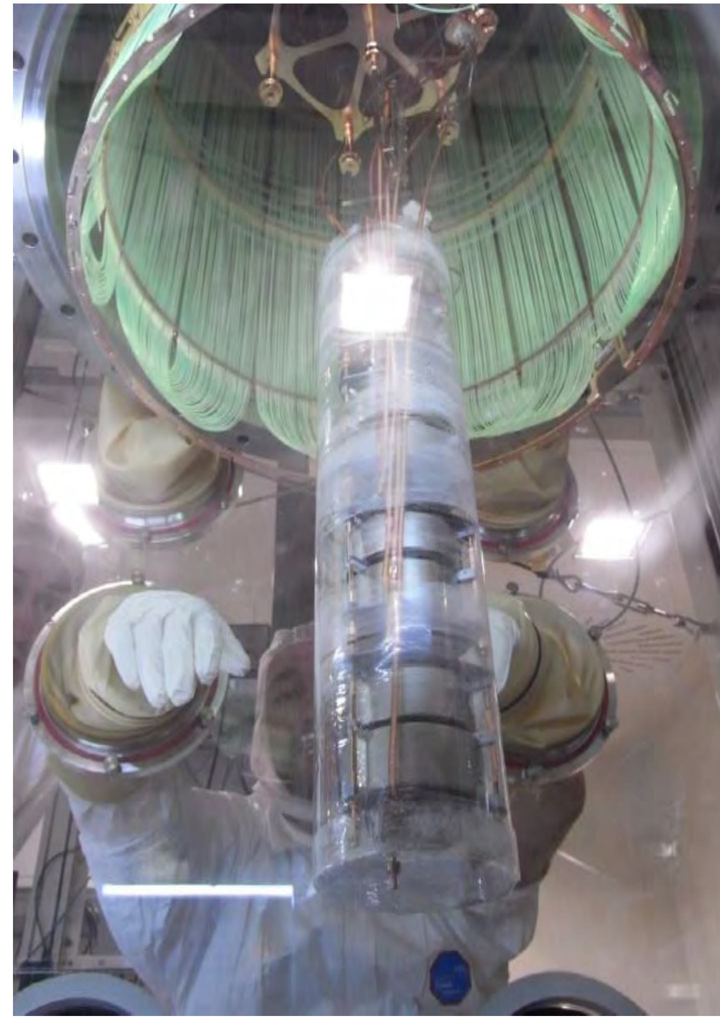


PTFE spacers



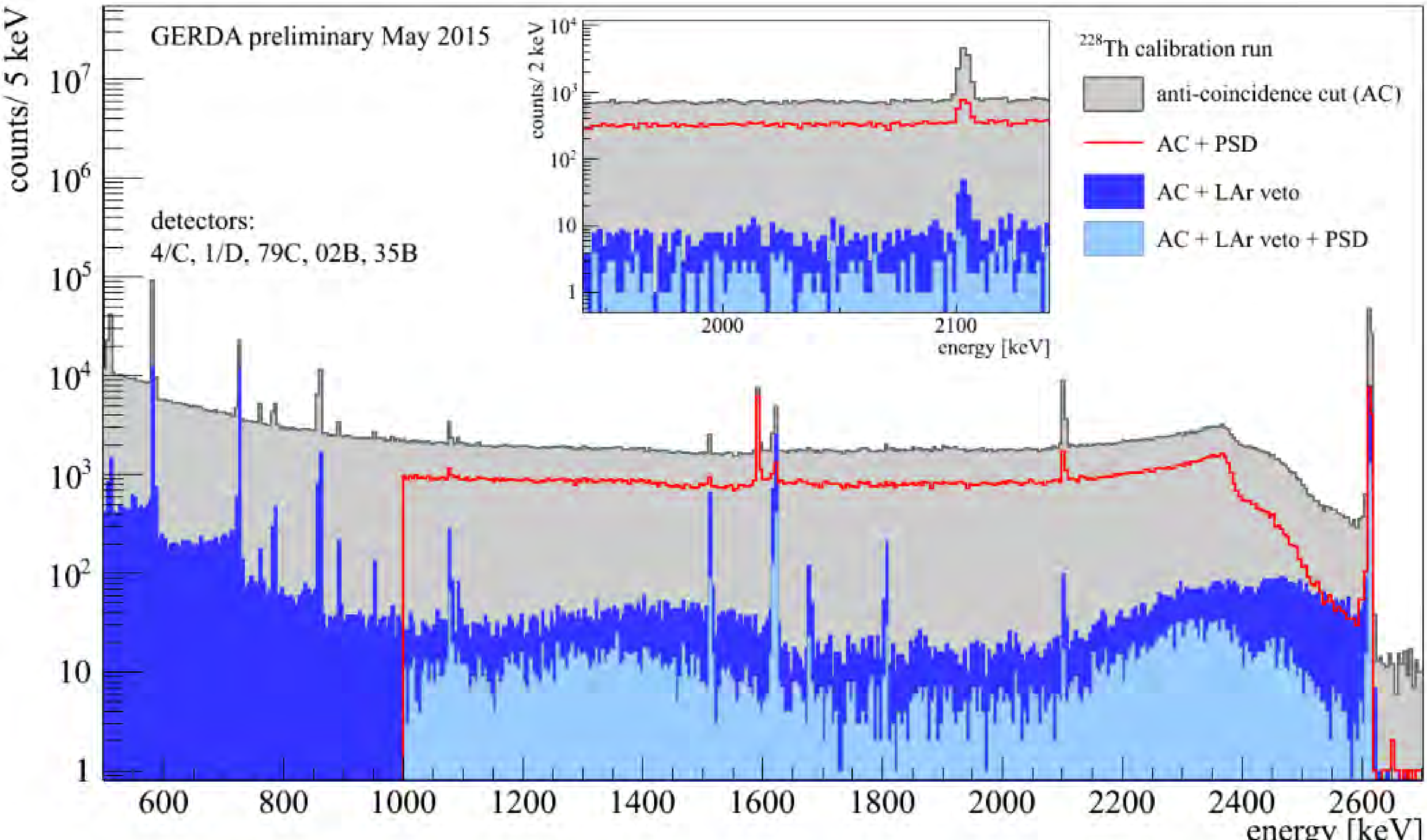
Cu support

pilot string



with TPB COATED nylon mini-shroud

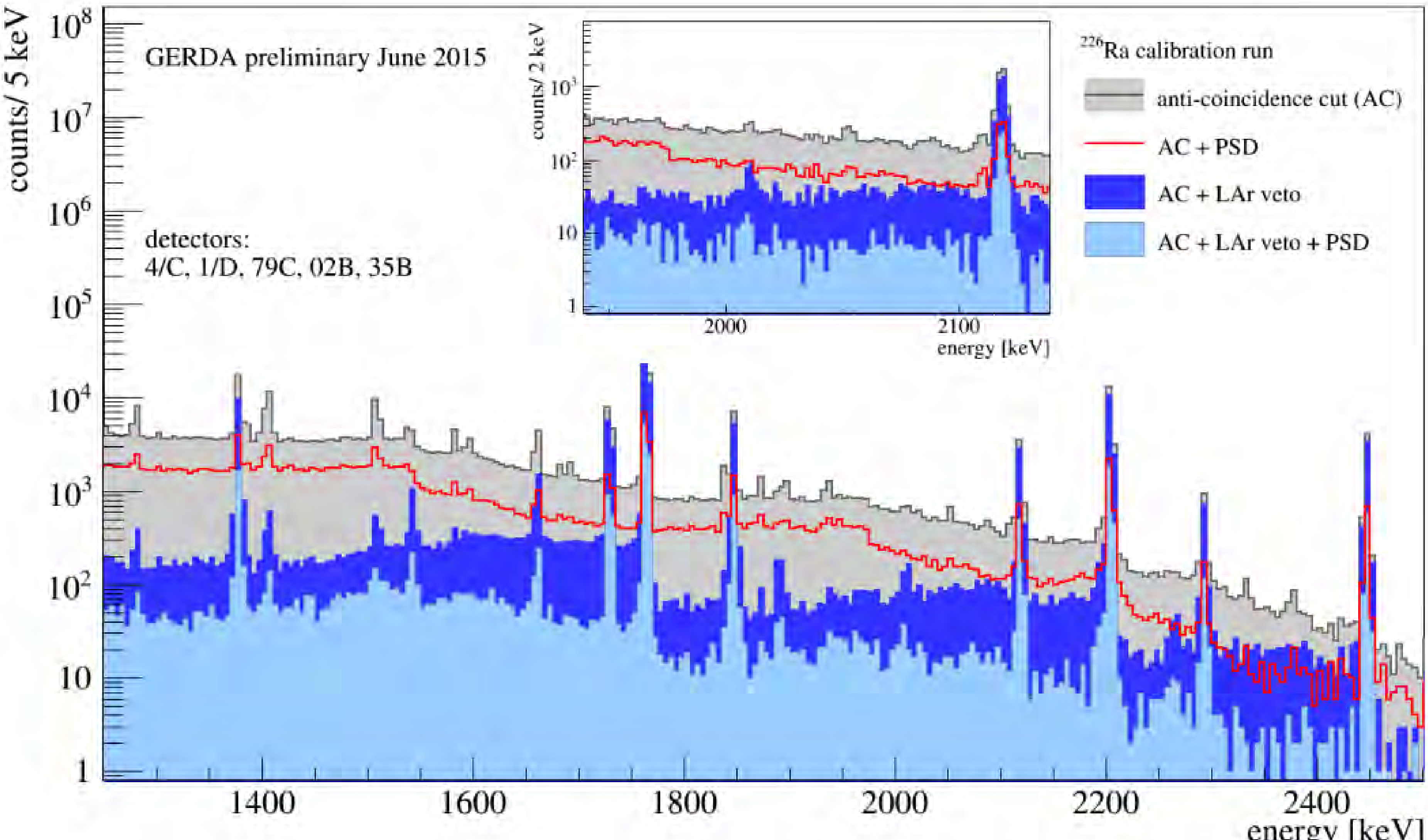
GERDA Phase II LAr veto results:



External ^{228}Th background supression factor

AC + LAr veto & BEGe PSD: 433.1 ± 30.7

GERDA Phase II LAr veto results:

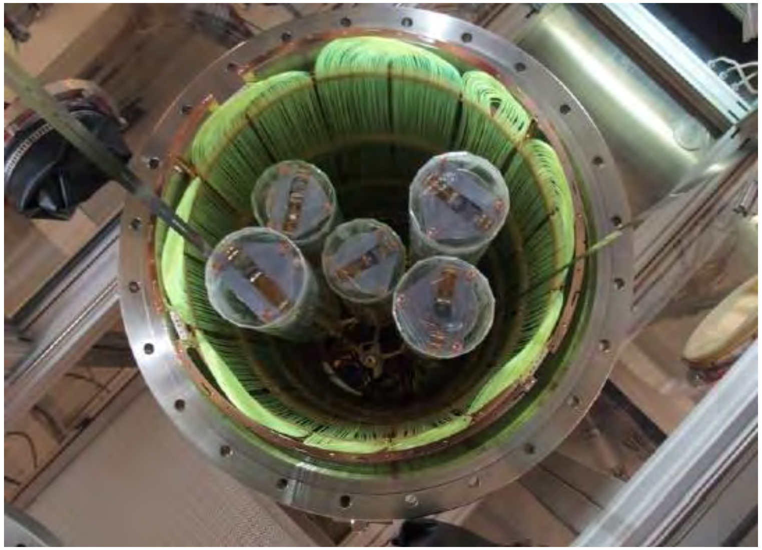


External ^{226}Ra background supression factor

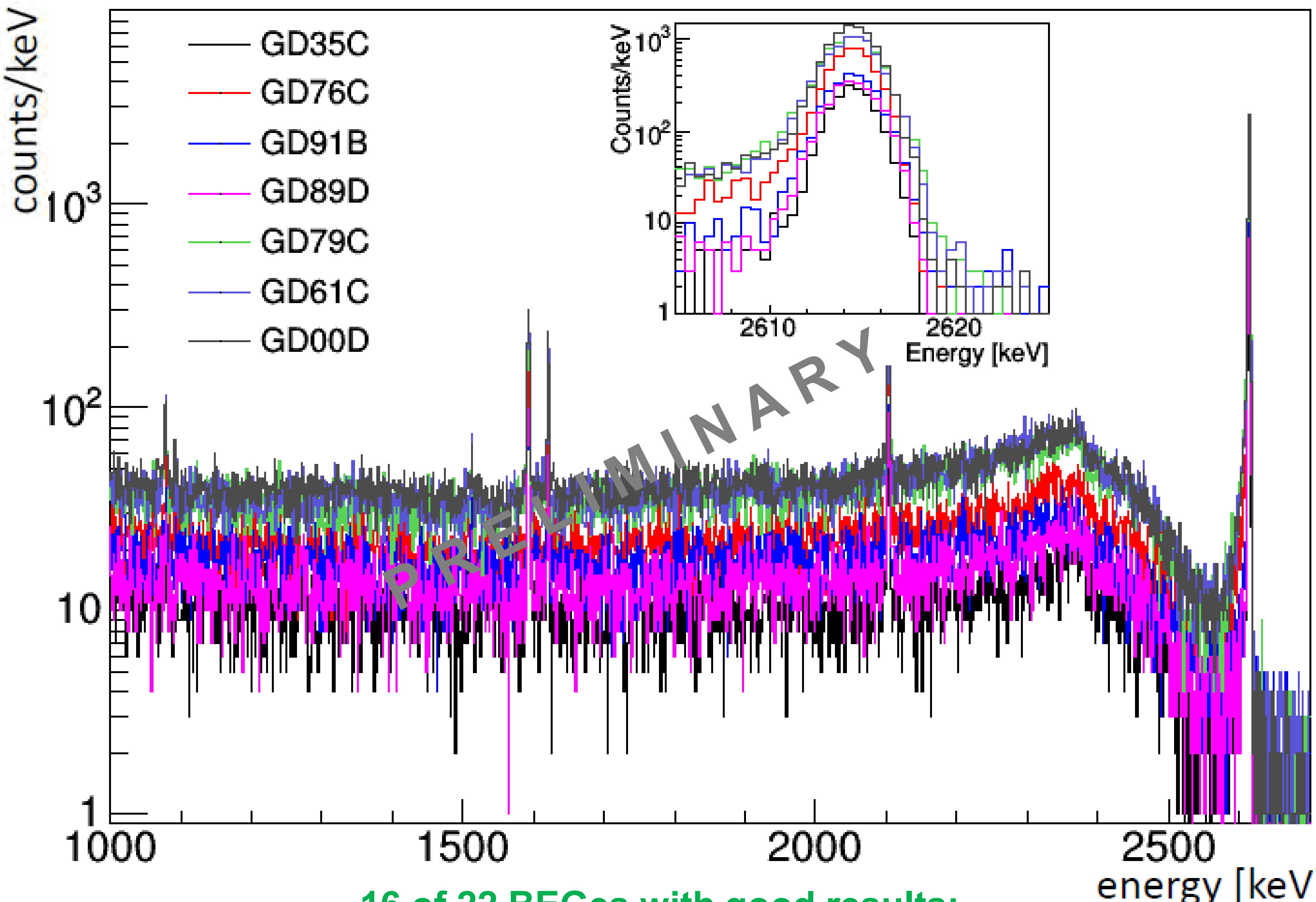
AC + LAr veto + BEGe PSD: 29.4 ± 2.5

GERDA Phase II preparations:

All BEGe 30 detectors mounted into their holders and tested
Aug 2015: Mounted 5 string array (22 BEGes, 5 Coax)



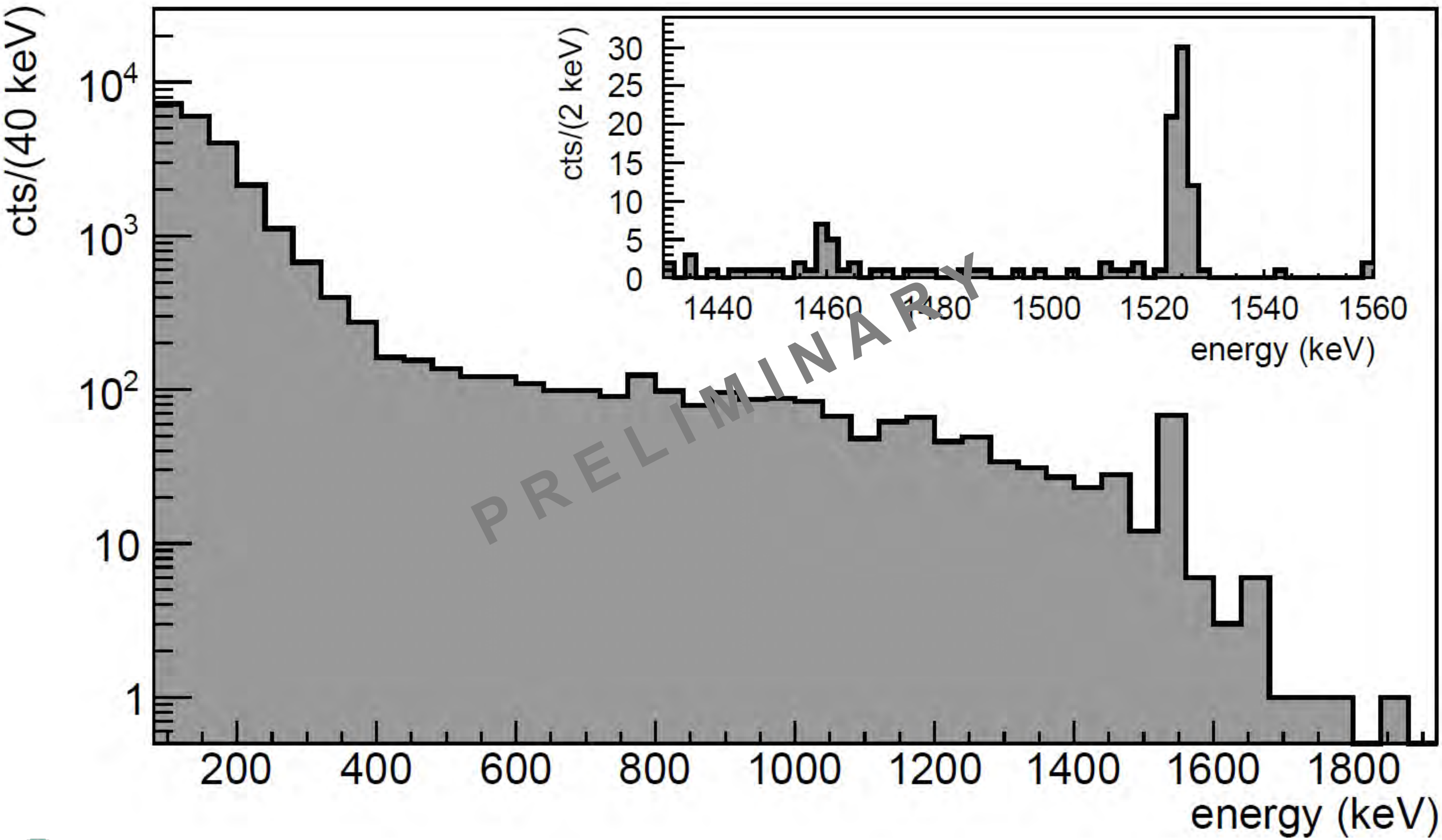
GERDA Phase II: 5 string array results



16 of 22 BEGes with good results:
FWHM @ 2.6 MeV: 2.7 keV – 3.4 keV

GERDA Phase II: 5 string array results

~ 1 kg yr of background data taken: no real surprises



GERDA Phase II: Present status and plans:

- Some BEGes showed unacceptable leakage current
  → 7 out of 30 BEGes are being reprocessed at manufacturer site
- Probably most critical source for bad detector performance in GERDA surrounding identified: contacts facing upward
  (particulates from mounting procedure in grove)
  → Designed new holder concepts for all contacts facing downwards
- Remaining coax detectors being processed at manufacturer
- Presently: 3 strings installed with
  8 BEGes and 4 coax detectors
  (7 BEGEs and 3 Coax working with acceptable FWHM)

Next integration campaign:

Nov./Dec. with (hopefully) all detectors available

Germanium for ton scale?

Comparison of experimental efforts with different isotopes:

Isotope	Experiment	Active target mass	Planned active exposure	FWHM energy resolution at RoI	Projected Bkg in RoI	Projected Bkg in RoI	Limit setting sensitivity
		[moles]	[mol yr]	[keV]	[cts/(keV kg yr)]	[cts/(RoI t yr)]	[10^{26}yr]
^{76}Ge	GERDA Phase II	360	1400	3	0.001	3	~2
^{76}Ge	Majorana demonstrator	415	1400	3	0.00075	3	~2
^{76}Ge	Ton scale initiative	10000	10000	3	0.00003	0.3	~60
^{82}Se	SuperNEMO prototype	85	250	120	-	just 2nbb	~0.7
^{82}Se	SuperNEMO 20 modules	1200	8400	120	-	just 2nbb	1
^{82}Se	CUPID	4000	40000	< 5	< 0.0001	0.5	~50
^{116}Cd	COBRA	350	2000	35	0.001	35	~2
^{130}Te	CUORE	1600	8000	5	0.01	50	1
^{130}Te	SNO+	1230	6150	120	0.00006	7	1
^{130}Te	SNO+ Phase II	7380	36900	75	0.00006	4	6
^{136}Xe	EXO200	1450	3700	60			0.6
^{136}Xe	NEXO Phase I	33000	165000	60	-	4	6
^{136}Xe	NEXO Phase II	33000	330000	60	-	just 2nbb	300
^{136}Xe	Next	660		17	0.0005	10	6
^{136}Xe	KAMLAND ZEN	650	1300	240	0.0007	175	0.3
^{136}Xe	KAMLAND ZEN next phas	1000	2000	150	<0.0007	<100	2

Germanium for ton scale?

→ Goal: Sensitivity for ~10 meV detection to cover IH

→ sensitivity to $\langle m_{\beta\beta} \rangle$: 8 meV → Half lives 10^{28} yr to 10^{29} yr

Need ~ 10 ton·yr exposure with ~ 10^{-4} cts/(kg yr) background in RoI

- Need ton scale (isotope!) experiment(s)
- Good energy resolution essential:
  - Bolometric
  - Germanium, semiconductor
  - Xenon?
- Need better understanding of matrix elements (g_A!)
- Need even better control of backgrounds
- Need multi isotope approach

→Germanium is one of the few isotopes!

Conclusions:

- Search for 0νββ-decay has high priority
- No ββ isotope really preferred
- The combination of high energy resolution and cleanliness make germanium a very good candidate for 0νββ-decay searches
- GERDA Phase I reached its goals
- GERDA Phase II preparations:
  - Detectors are available
  - LAr veto works
  - Integration mechanically feasible
  - Detector performance in GERDA surrounding can be good
  - Physics data taking may start soon
- Germanium is one fo the few isotopes feasible for ton scale
- Need concentrated R&D efforts