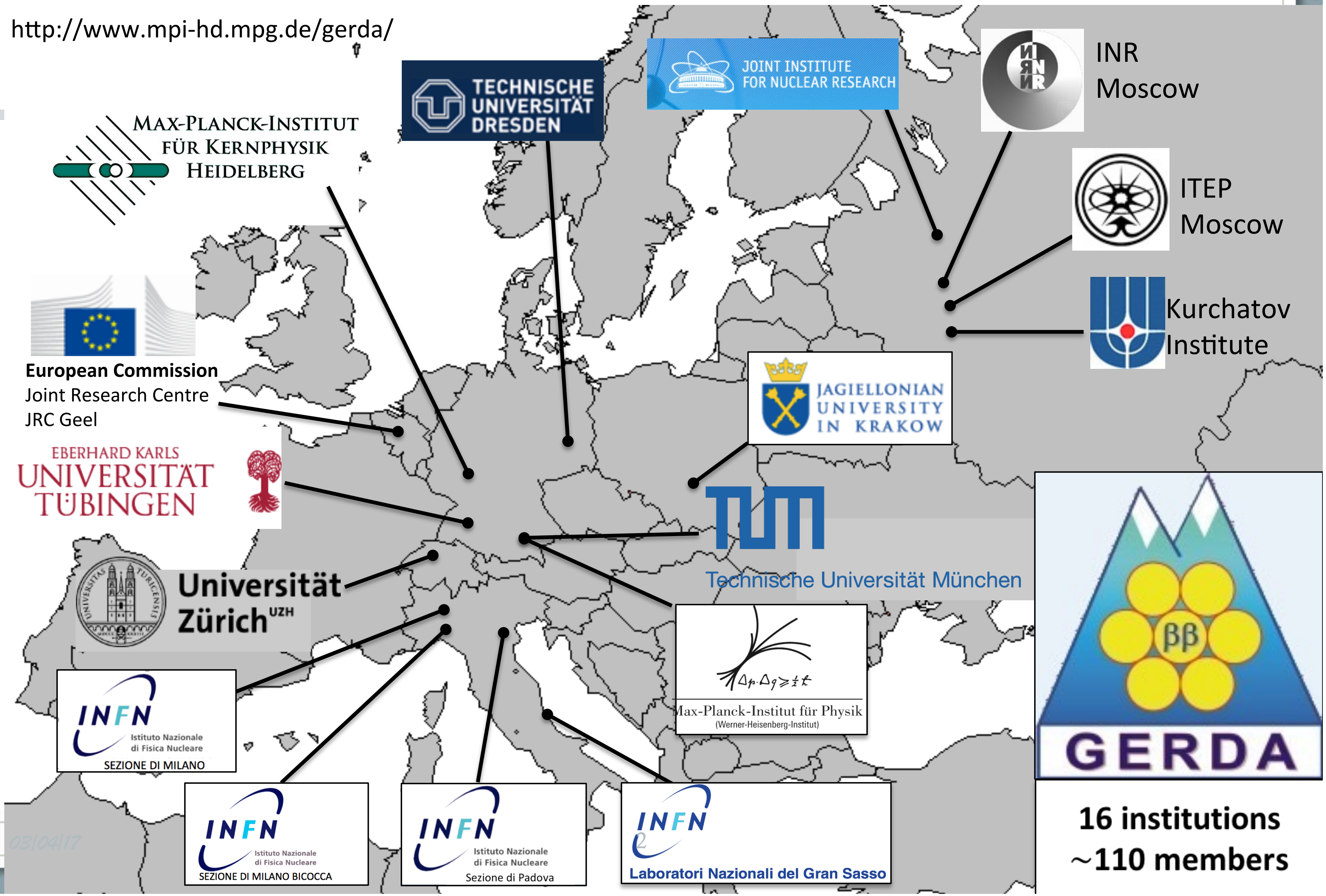
GERDA Phase II: status and prospects

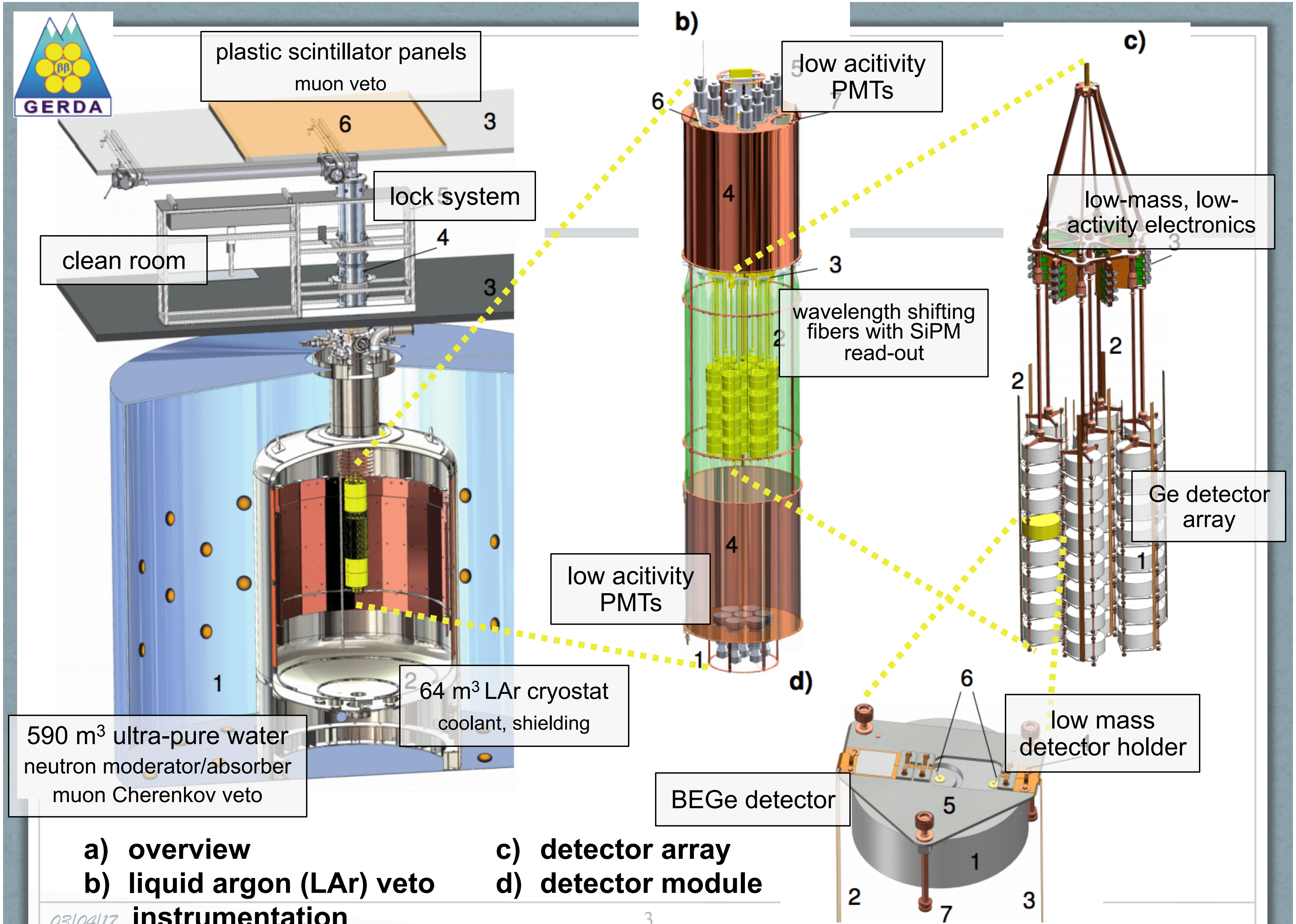
Matthias Laubenstein, LNGS
on behalf of the GERDA collaboration

XLVII meeting of the Gran Sasso Scientific Committee,
03-04 April 2017, Assergi, Laboratori Nazionali del Gran Sasso

the GERDA collaboration

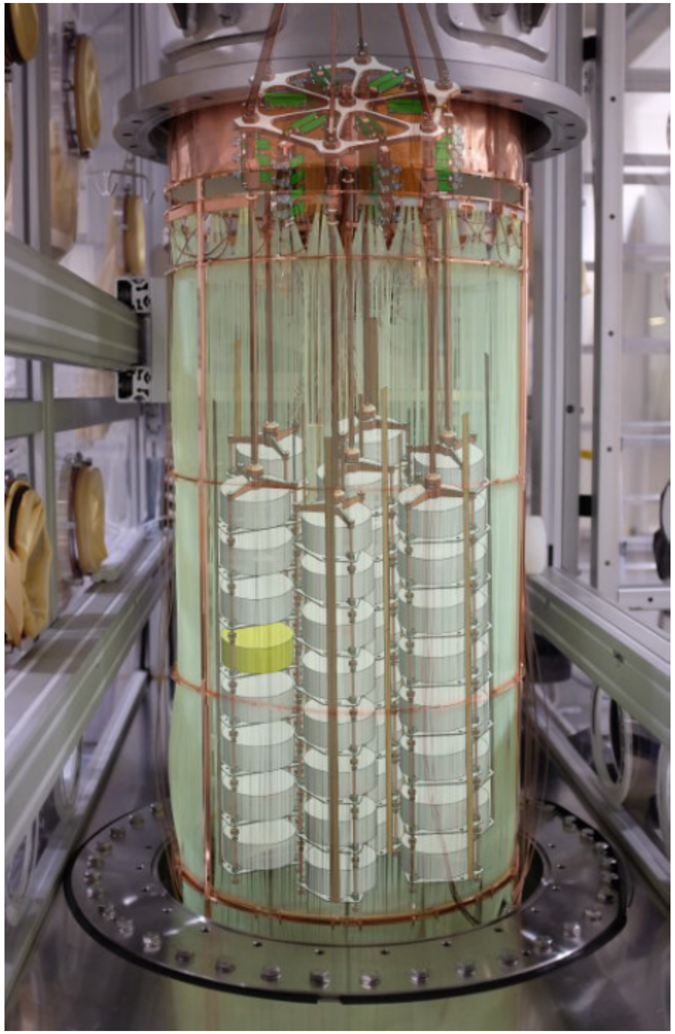
http://www.mpi-hd.mpg.de/gerda/

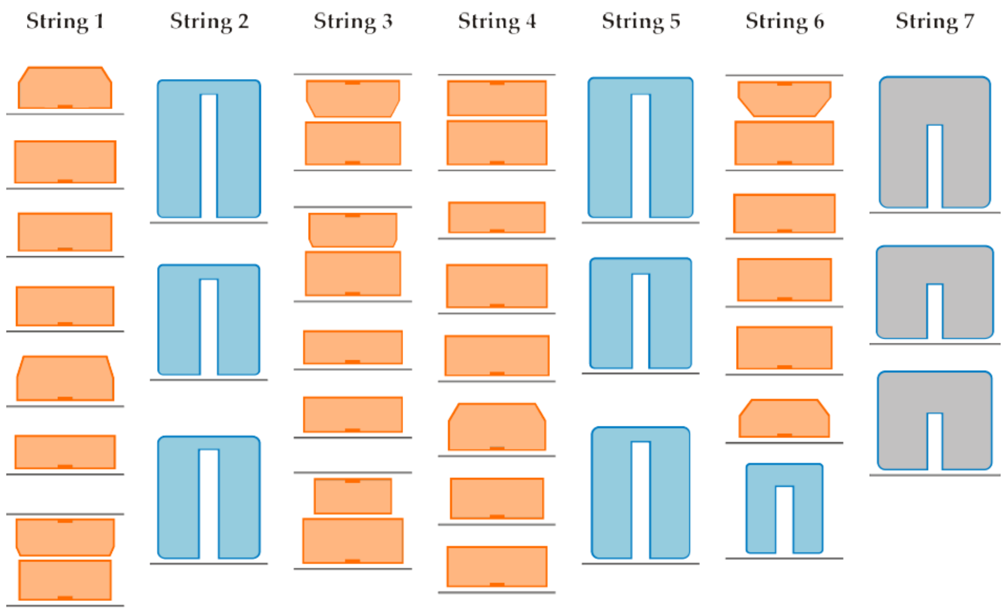




a) overview
b) liquid argon (LAr) veto instrumentation
c) detector array
d) detector module

Germanium Phase II detector array

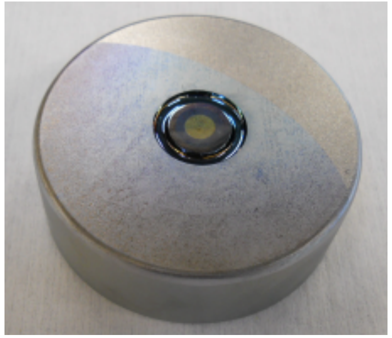




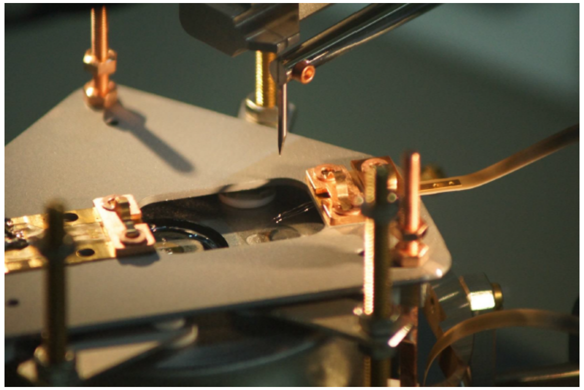
- 7 strings, 40 detectors in total
  - 7 enriched semi-coax (15.8 kg)
  - 30 enriched thick-window BEGe (20 kg)
  - 3 natural semi-coax (7.6 kg)
- HPGe array enclosed by liquid argon veto
- Phase II data started Dec. 2015

GERDA Phase II experimental setup at LNGS

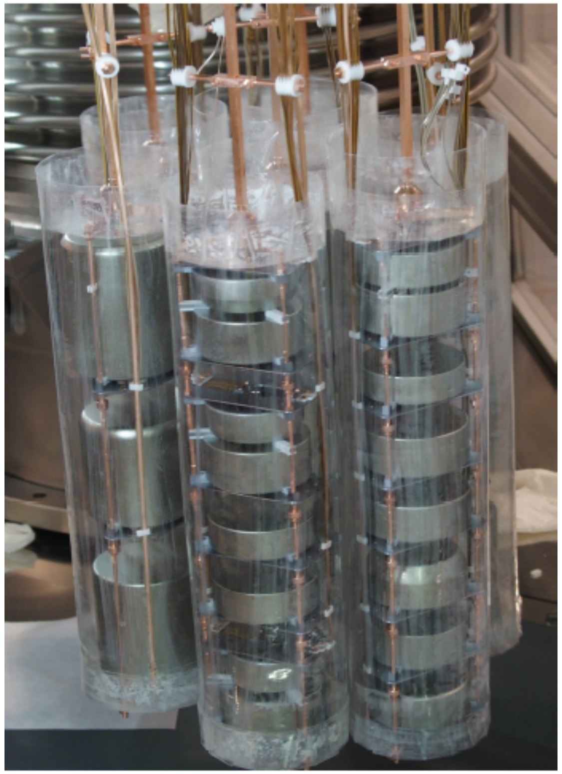
New low-mass detector holder (silicon, copper, PTFE)



New thick-window BEGe detectors

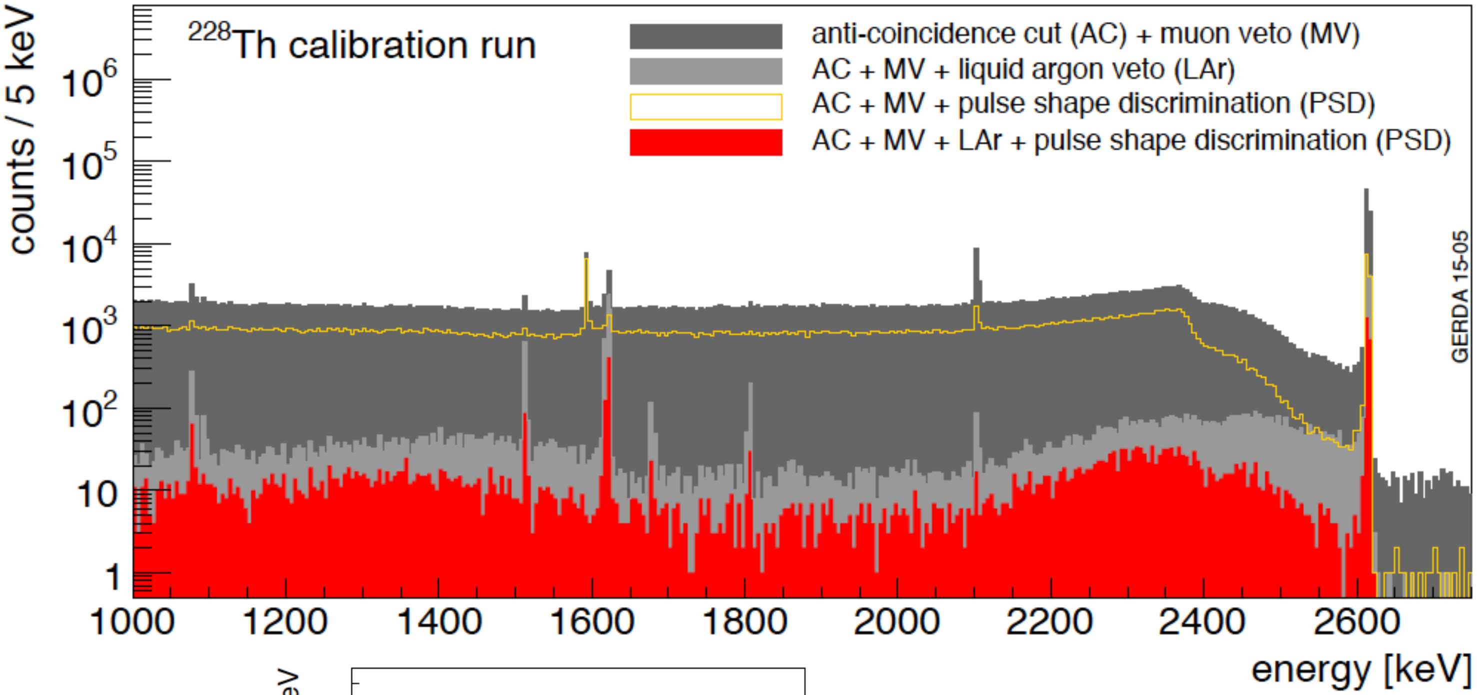


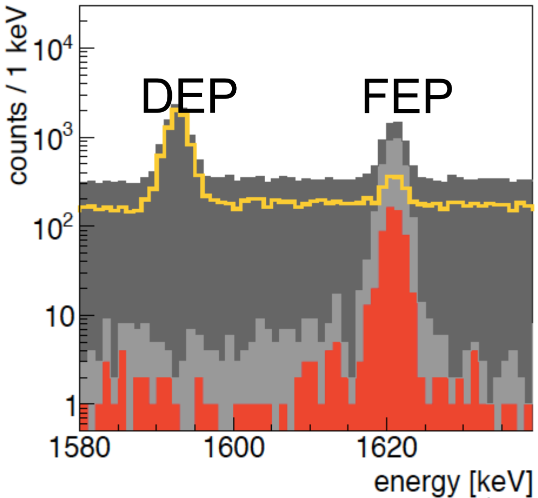
New signal and HV contacting by wire bonding flat ribbon cables



New TBP coated nylon (from Borexino, transparent wrt Cu) mini-shrouds to reduce attraction ^{42}K ions to n^+ surface

Background suppression (calibration data)



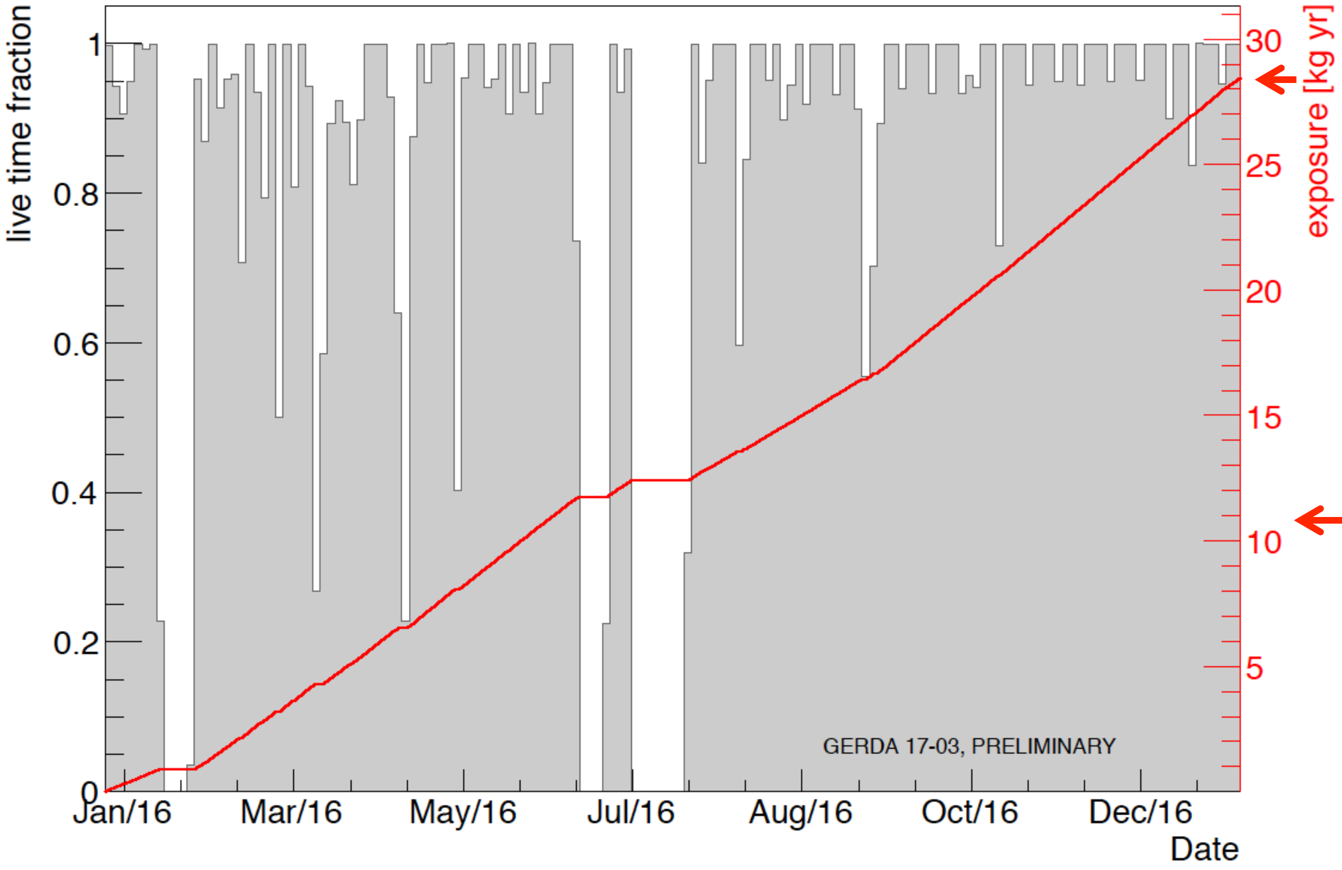


Background suppression by

- Muon veto (MV)
- Anti-coincidence detector array (AC)
- Liquid argon veto (LAr)
- Pulse shape discrimination (PSD)

Phase II data taking and exposure

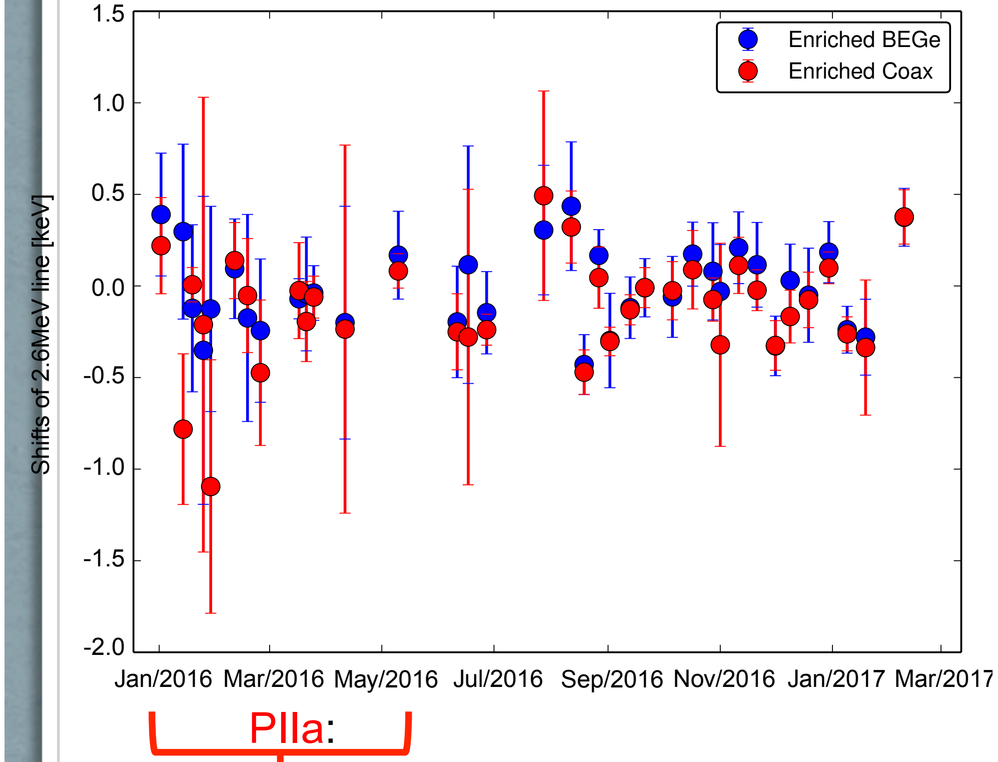
preliminary

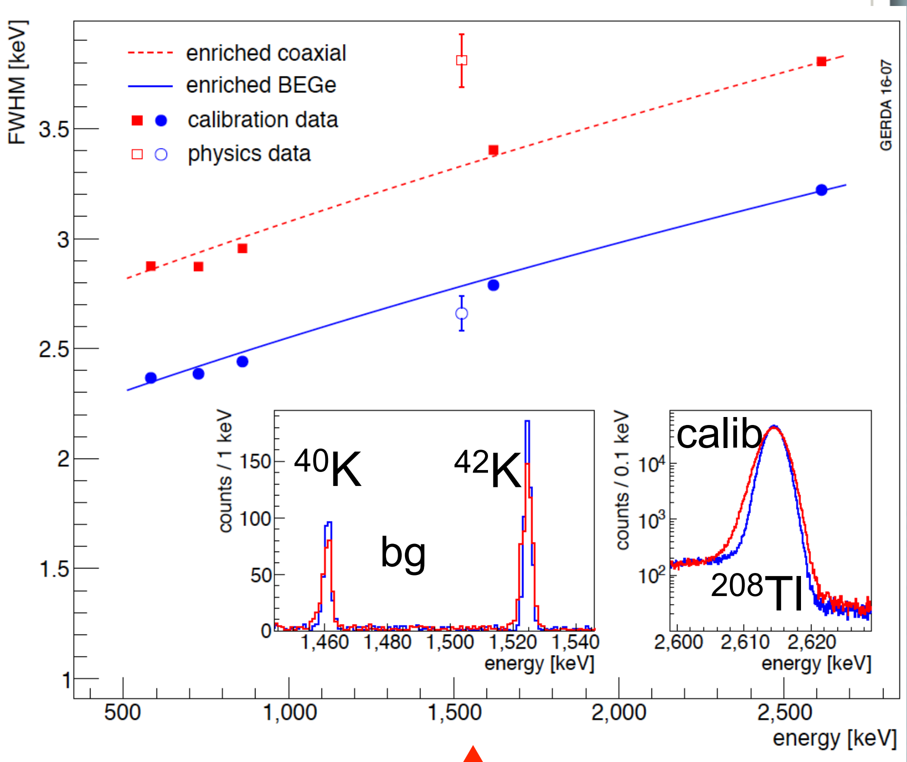


XVII NuTel Venice
28.5 kg yr
($Q_{\beta\beta}$±25 keV blind)

Neutrino 2016
10.8 kg yr
1st unblinding
arXiv:1703.00570
Nature April 6th, 2017

Calibration: stability and energy resolution

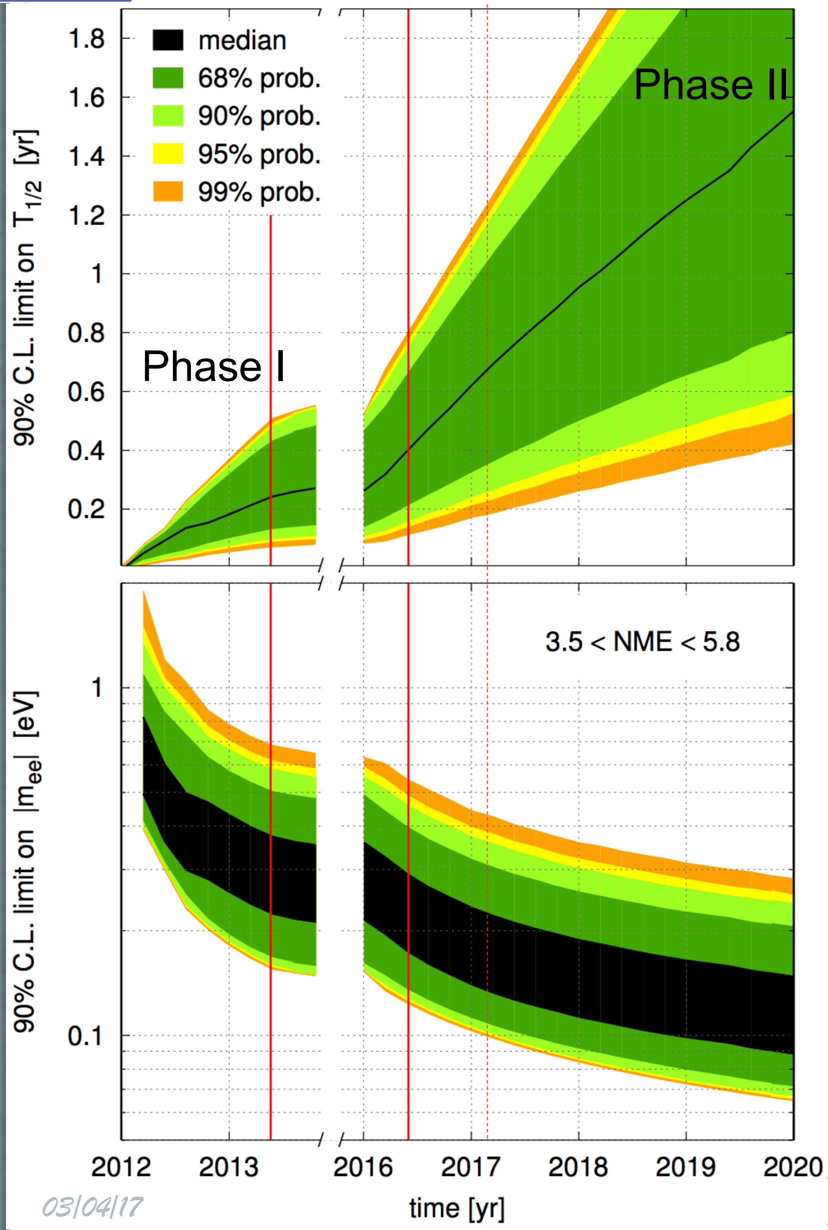




Energy resolution FWHM at at $Q_{\beta\beta}$ = 2039 keV:

- Coaxial: 4.0±0.2 keV
- BEGe: 3.0±0.2 keV

GERDA Phase II: first **background-free** 0νββ experiment



Phase I achievements	
background	$\sim 10^{-2}$ cts/(keV · kg · yr)
exposure	21.6 kg · yr
limit	$\mathbf{T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}}$ **yr (90% CL)**
	[Phys.Rev.Lett. 111 (2013) 122503]

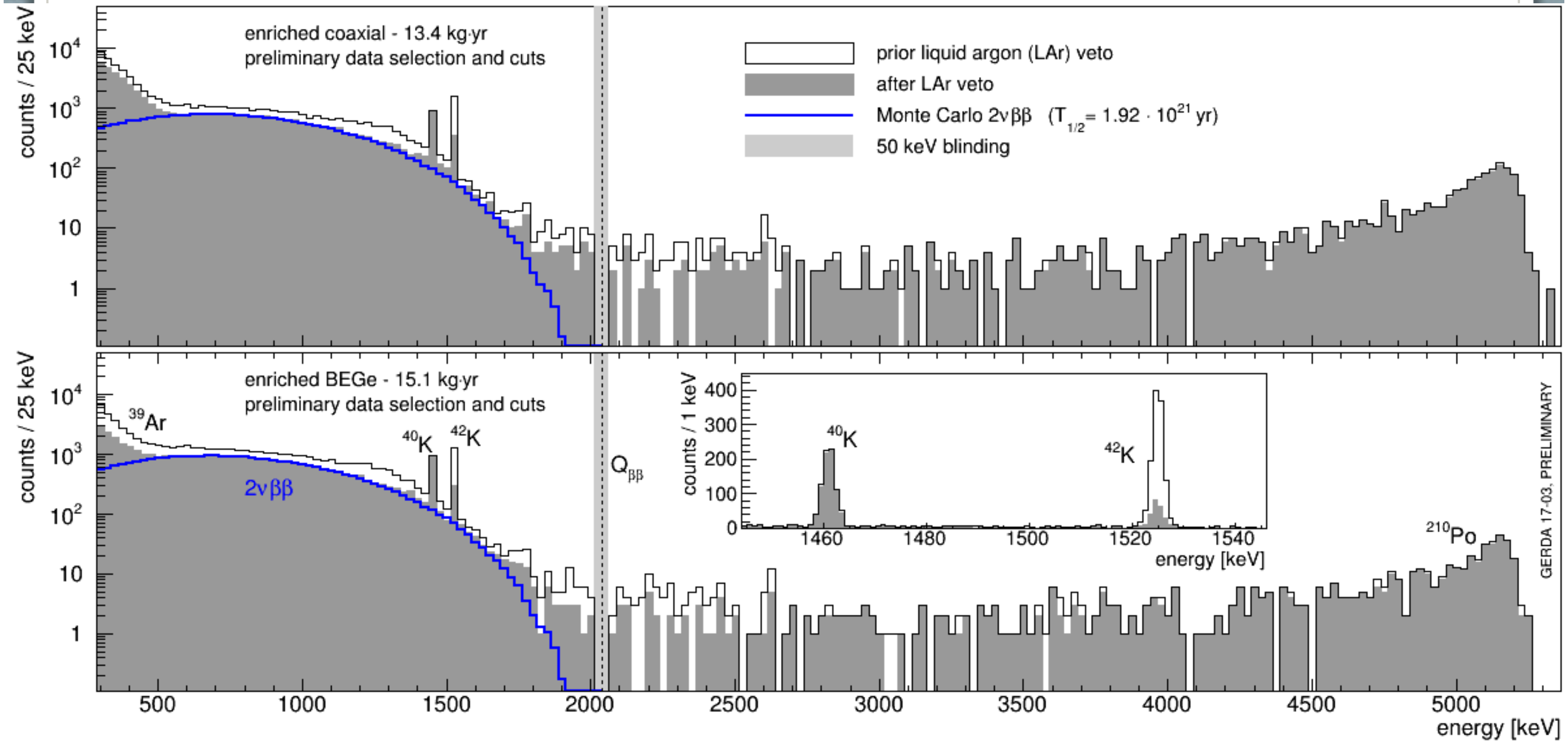
first Phase II achievements	
background	$\sim 10^{-3}$ cts/(keV · kg · yr)
exposure	10.8 kg · yr (34,4 kg · yr)*
limit	$\mathbf{T^{0\nu}_{1/2} > 5.3 \cdot 10^{25}}$ **yr (90% CL)**
	$\mathbf{m_{\beta\beta} < 0.15 - 0.33}$ **eV (90% CL)**
	[arXiv:1703.00570; Nature April 6th, 2017]

Phase II goals	
background	$\sim 10^{-3}$ cts/(keV · kg · yr)
exposure	$\gtrsim$ 100 kg · yr
sensitivity	$\mathbf{T^{0\nu}_{1/2} \gtrsim 10^{26}}$ **yr**

*combining Phase I and Phase II data

Energy spectra 28.5 kg yr: before and after LAr veto

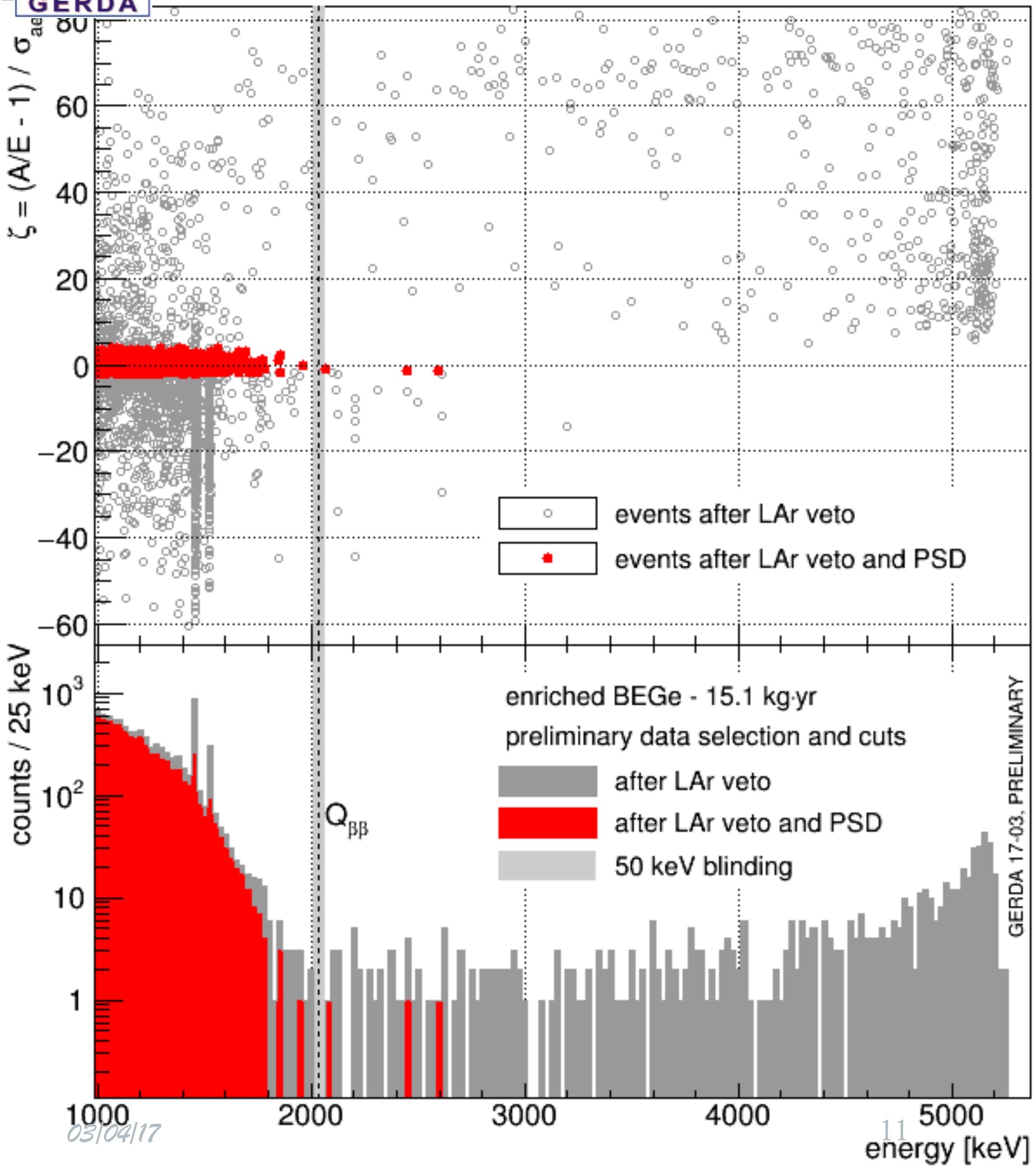
preliminary



- Same background contributions as in 10.8 kg yr data set
- Comprehensive background model under preparation
- Main contributions around $Q_{\beta\beta}$ from nearby sources: U/Th progenies, ^{42}K, surface α's

BEGe pulse shape spectra 15.1 kg yr

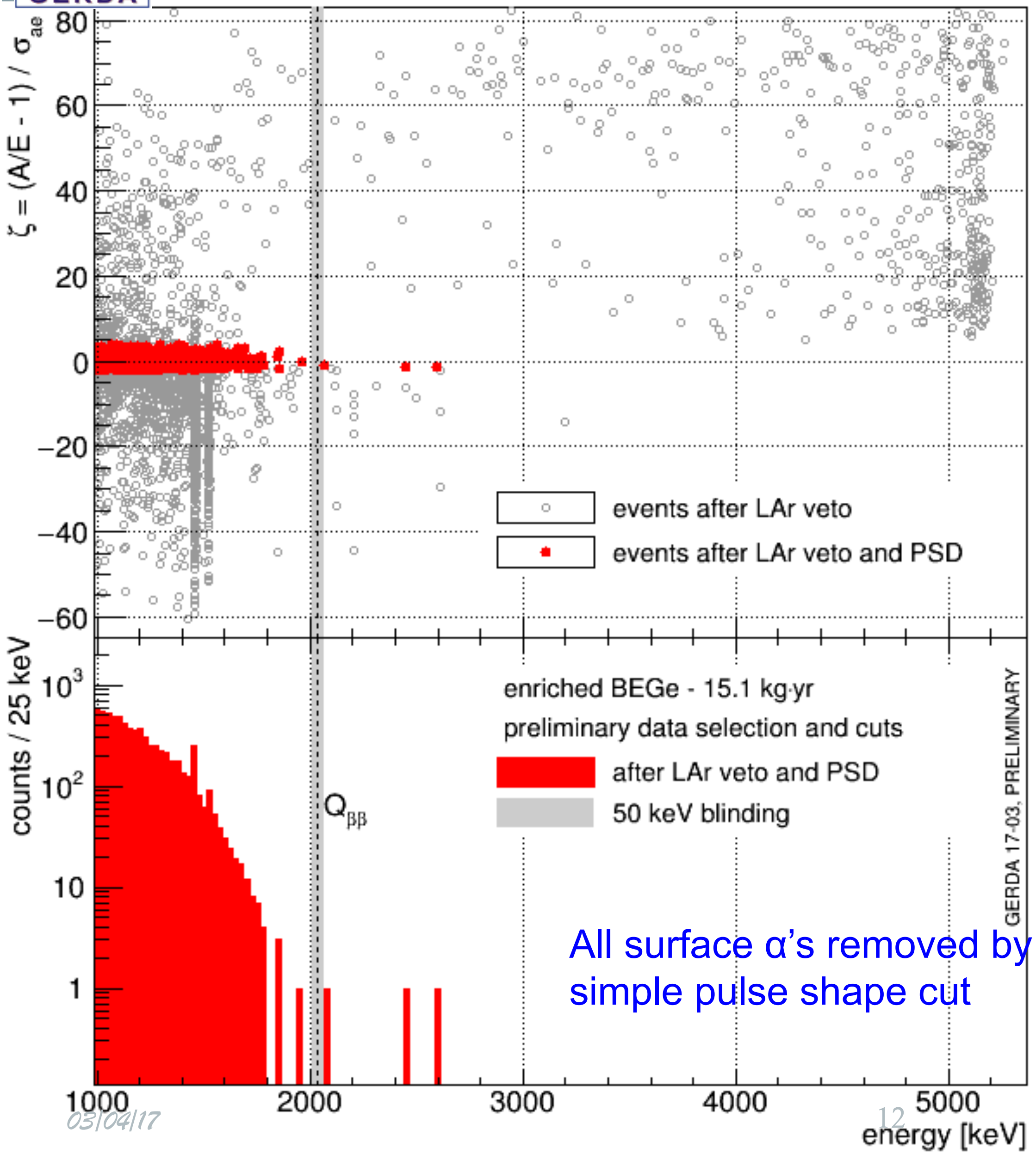
preliminary



Energy reconstruction & PSD cuts preliminary! $Q_{\beta\beta}\pm$ 25 keV blind!

BEGe pulse shape spectra 15.1 kg yr

preliminary

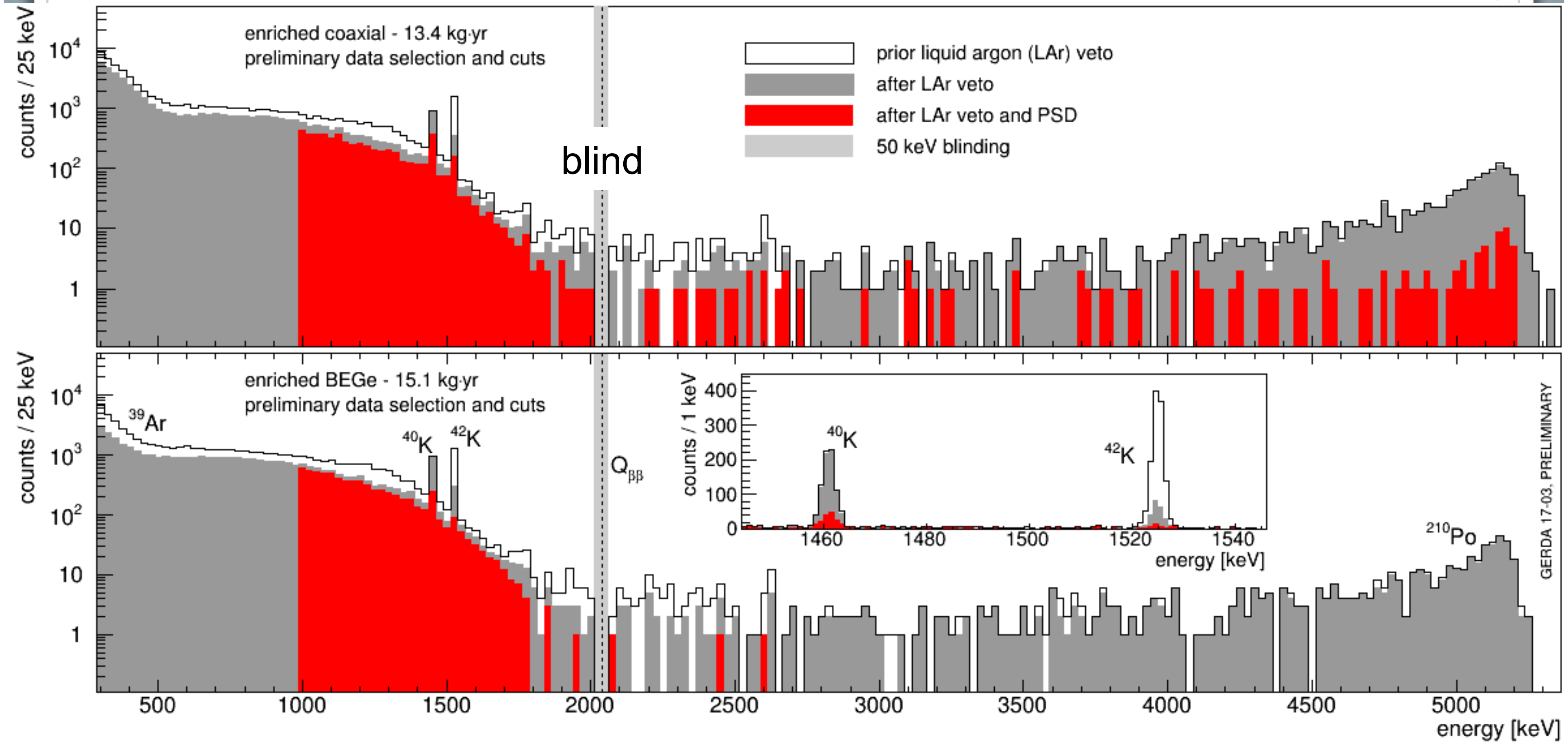


All surface α's removed by simple pulse shape cut

Energy reconstruction & PSD cuts preliminary! $Q_{\beta\beta}\pm$ 25 keV blind!

Energy spectra 28.5 kg yr: before and after LAr veto & PSD

preliminary



	exposure [kg · yr]	BI* $\left[10^{-3} \cdot \frac{\text{cts}}{\text{keV·kg·yr}}\right]$	(cts)	...after LAr veto		...after PSD		...after LAr veto + PSD	
EnrCoax	13.4	$16.7^{+2.7}_{-2.3}$	(46)	$8.0^{+1.9}_{-1.6}$	(22)	$8.0^{+1.9}_{-1.6}$	(22)	$\mathbf{2.2^{+1.1}_{-0.8}}$	(6)
EnrBEGe	15.1	$12.3^{+2.3}_{-1.8}$	(38)	$3.9^{+1.3}_{-1.0}$	(12)	$3.2^{+1.2}_{-0.9}$	(10)	$\mathbf{0.6^{+0.6}_{-0.4}}$	(2)

*background windows weighted by exposure (≈ 205 keV)

comparison experiments

		mass [kg]* (total/FV)	FWHM [keV]	background[&] [cnt/t yr FWHM]	$T_{1/2}$ limit sensitivity [10^{25} yr] after 4 yr	worst m_{ee} limit [meV] (lowest NME, g_A unquenched)	
Gerda II	Ge	35/27	3	5	15	190	running
MajoranaD	Ge	30/24	3	5	15	190	
EXO-200	Xe	170/80	88	220	6	240	
Kamland-Z	Xe	383/88 750/??	250	90 ?	6 50	240 85	design
Cuore	Te	600/206	5	230	9	210	
NEXT-100	Xe	100/80	17	30	6	240	
SNO+	Te	2340/260	190	60	17	160	
nEXO	Xe	5000/4300	58	5	600	24	future
Ge-200	Ge	200/155	3	1	100	75	
Ge-1000	Ge	1000/780	3	0.2	1000	24	

* total= element mass, FV= $0\nu\beta\beta$ isotope mass in fiducial volume (incl enrichment fraction)

[&] kg of $0\nu\beta\beta$ isotope in active volume and divided by $0\nu\beta\beta$ efficiency

Note: values are design numbers except for GERDA, EXO-200 and Kamland-Zen

Conclusions & outlook

- Established technology for ^{76}Ge isotope enrichment & Ge detector production
- Best energy resolution
- Lowest background in ROI

→ GERDA Phase II operates background-free within design exposure

- Flat background around $Q_{\beta\beta}$
- Contributing isotopes identified

→ All essential for **discovery**

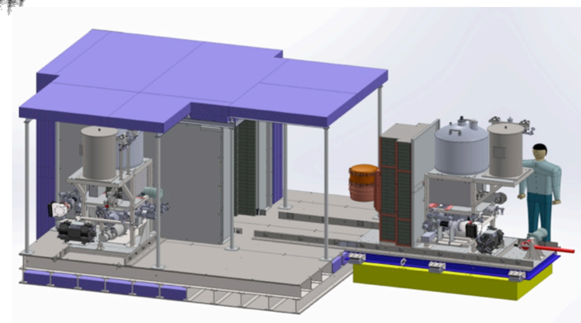
- Upgrade GERDA Phase II in preparation

Beyond GERDA

The ^{76}Ge-experiments: GERDA & Majorana-Demonstrator

GERDA

Majorana-Demonstrator (MJD)



- Bare ^{enr}Ge array in liquid argon
- Shield: high-purity liquid Argon / H_2O
- Phase I: 17 kg (HdM/IGEX) - completed
- Phase II: 38 kg enriched in ^{76}Ge

- Array(s) of ^{enr}Ge housed in high-purity electroformed copper cryostat
- Shield: electroformed copper / lead
- 30 kg enriched in ^{76}Ge

Physics goals: degenerate mass range
Technology: study of bgds. and exp. techniques

LoI
- open exchange of knowledge & technologies (e.g. MaGe MC)
- intention to merge for future large scale ^{76}Ge experiment selecting the best technologies tested in GERDA and Majorana

Large **E**nriched **G**ermanium **E**xperiment for **N**eutrinoless ββ **D**ecay – LEGEND

Laboratori Nazionali del Gran Sasso, Assergi, L'Aquila University and INFN, Gran Sasso Science Institute, Argonne National Laboratory, Univ. Texas, Tsinghua University, Lawrence Berkeley National Laboratory, Leibniz Institute for Crystal Growth (IKZ Berlin), Comenius University, North Carolina State University, University of North Carolina, University of South Carolina, Laboratori Nazionali del Sud (LNS), Jagiellonian University, Krakow, Banaras Hindu University, University of Dortmund, TU Dresden, Joint Institute for Nuclear Research (Dubna), Joint Research Centre, Geel, MPIK Heidelberg, Dokuz Eylul University (DEU), Queens University, University of South Dakota, South Dakota School of Mines and Technology, University of Liverpool, University College London, University of New Mexico, Los Alamos National Laboratory, Lund University,Milano Bicocca and INFN, Milano University and INFN, National Research Center Kurchatov Institute (NRC KI), Institute of Nuclear Research (Russian Academy of Sciences), Laboratory for Experimental Nuclear Physics of MEPhI, MPI Munich, TU Munich, Oak Ridge National Laboratory, Padova University and Padova INFN, IEAP Czech Technical University in Prague, Princeton University, University of Washington, Sichuan University, Chalmers Univ. of Technology, Academia Sinica, Taiwan, University of Tennessee, University of Tuebingen, University of Zurich

219 members, 48 institutions, 16 countries

Collaboration forming and consolidation ongoing

Interested groups contact Interim Steering Committee:

Steve Elliott, David Radford, Stefan Schönert, Bernhard Schwingenheuer, David Waters

Large **E**nriched **G**ermanium **E**xperiment for **N**eutrinoless ββ **D**ecay - LEGEND

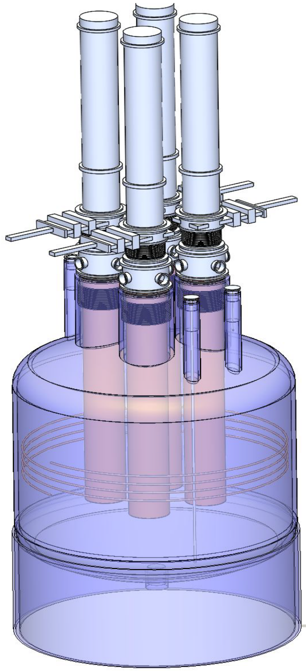
Collaboration forming:

- 1st Munich April 2016
- **2nd** Atlanta October 2016
- Next meeting at LNGS May 15-17

LEGEND mission: "The collaboration aims to develop a phased, Ge-76 based double-beta decay experimental program with **discovery potential** at a half-life significantly longer than 10^{27} years, using existing resources as appropriate to expedite physics results."

First stage:

- (up to) 200 kg in upgrade of existing infrastructure at LNGS
- bgd reduction by factor 3-5 w.r.t GERDA



Subsequent stages:

- 1000 kg (staged)
- timeline connected to DOE down select process
- Bgd factor 30 w.r.t GERDA
- Location tbd
- Required depth (Ge-77m) under investigation

Thank you!

Extra slides

Upgrade GERDA Phase II

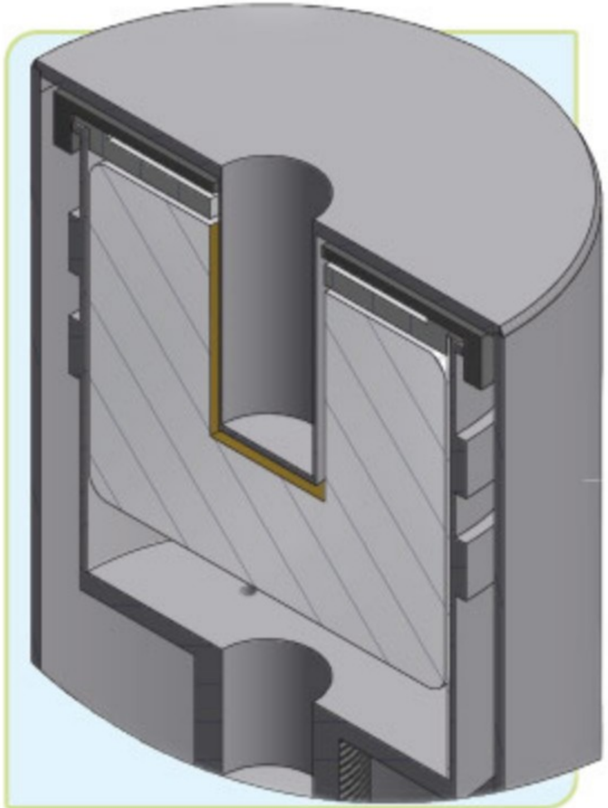
- Change configuration of BEGe detectors from double to single
- Replace 50% of cables with cleaner ones
- Replace one JFET (BEGe)
- Replace scintillating fibres with new ones (2x more LY)
- Replace natural Ge detectors with enriched detectors (inverted coaxial PPC)

→ 3 months stop will be recovered by 7.5 kg more mass

- Evaluate new radioactivity budget with new veto system
- Evaluate advantage of new vet system with dedicated MC

Upgrade GERDA Phase II

- Inverted coaxial PPC: ca. 1 kg, 1.8 keV @ 1332 keV
- 20 kg of enriched germanium already acquired (MPIK) and produced in Russia
- Transformation into diodes 2017-2018



Backgrounds: in-situ muon induced isotopes @ LNGS

Direct muons: muon veto (water Cherenkov & liquid argon) – no issue

Muon induced long-lived isotopes:

Isotope	$\mathbf{T_{1/2}}$	**decay**	**Q value [keV]**	**background [cnt/(ROI t yr)]**
^{74}Ga	8.1 m	β^-	5368	0.01
^{75}Ga	126 s	β^-	3392	0.01
^{76}Ga	33 s	β^-	7010	0.01
^{77}Ge	11.3 h	β^-	2702	0.1
^{77m}Ge	**53 s**	β^-	2861	0.1
^{38}Cl	37 m	β^-	4916	0.003
^{40}Cl	1.4 m	β^-	7482	0.003

Geant4+Musun MC simulations for GERDA Phase II by C.Macolino, L.Pandola

Most critical ^{77m}Ge (w/o γ) - mitigation: triple coincidence: μ, n-capture(γ), ^{77m}Ge-decay