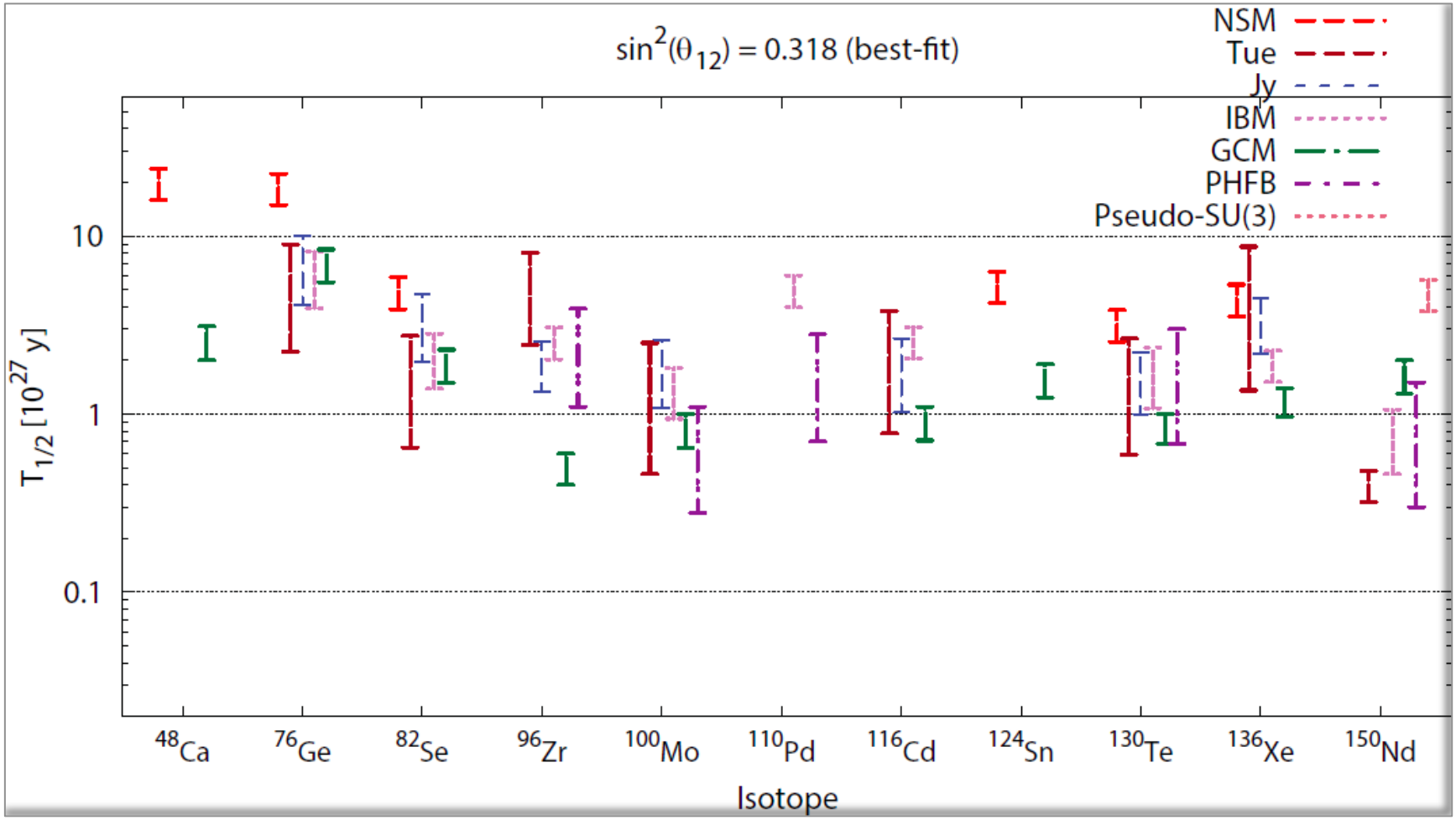
STAGED IMPLEMENTATION TOWARDS A LARGE-SCALE ^{76}GE NEUTRINOLESS DOUBLE BETA DECAY EXPERIMENT

Stefan Schönert, TU München

NDM15, Jyväskylä, Finland, June 1-5, 2015



g_A=1.25, $\langle m_{ee} \rangle$ = 17.5 meV, bars from variation of nucl matrix element calc & ±3σ vari. of U, Δm^2

from DOE Nuclear Science Advisory Committee report on 0νββ (24 April 2014)

N.B.: 17 meV is useful benchmark, but plenty of physics opportunities on the way towards 10^{27} yrs….

Why ^{76}Ge?

From DOE Nuclear Science Advisory Committee report on 0nbb (24 April 2014):
list of highly desirable design features of any next-generation double beta decay search

- Very low, and preferably flat, background within the spectral region of interest, relative to the signal size anticipated at the half-life sensitivity goal; **YES**
- Good energy resolution with excellent energy calibration, to enhance a potential signal above backgrounds & to minimize the 2νββ tail underneath the 0νββ peak; **YES**
- Ability to scale the experimental approach to larger masses at realizable cost, as needed to maximize the discovery potential within the inverted hierarchy region; **YES**
- Tracking capability to enhance identification of 0νββ decay event topology; **YES**
- A favorable 0νββ Q-value to enhance the phase space factor and provide a region of interest above many of the gamma ray lines from U- and Th-chain contaminants; **NO** but low A compensates (more mole/kg, larger matrix elements, smaller gA quenching, ...)
- Ability to remove or replace the enriched isotope without affecting detector performance, in order to verify the reality of a possible non-null signal. **YES**

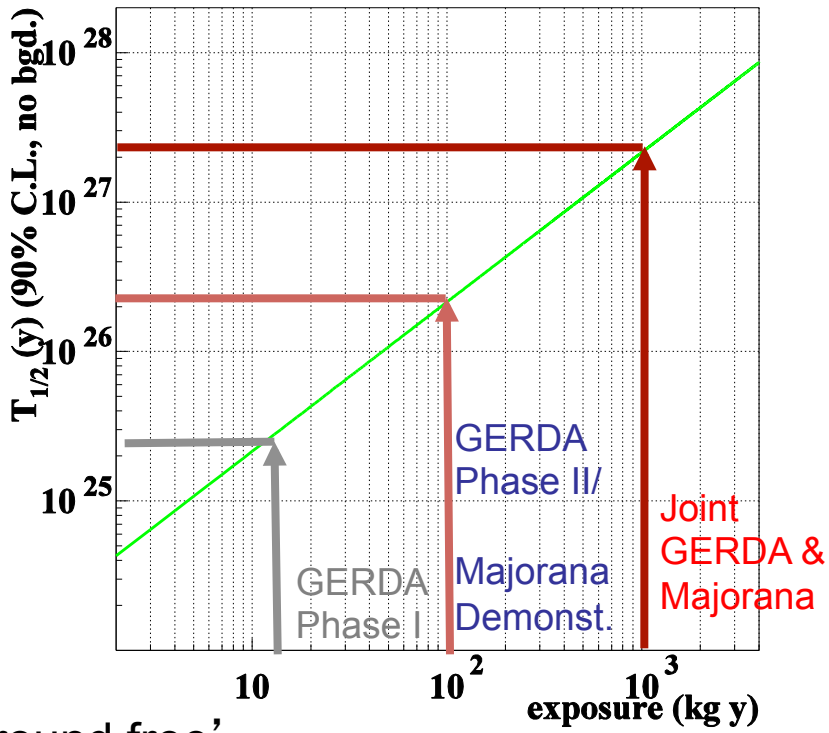
Staging: not a new concept

>10^{27} *

>10^{26} *

>10^{25} *

*: no event in ROI



Goal: operate quasi-free of background

required for 'background free' exp. with ΔE~3 keV (FWHM): O(10^{-3}) O(10^{-4}) counts/(kg·y·keV)

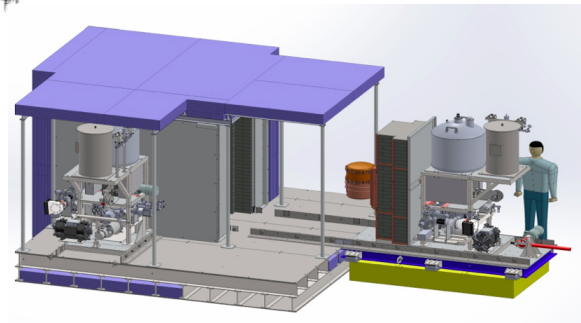
⇒ reduction of background by factor 10/100/1000 w.r. to precursor exps. for bgd free operations

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

GERDA

- 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

Majorana-Demonstrator (MJD)



- 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

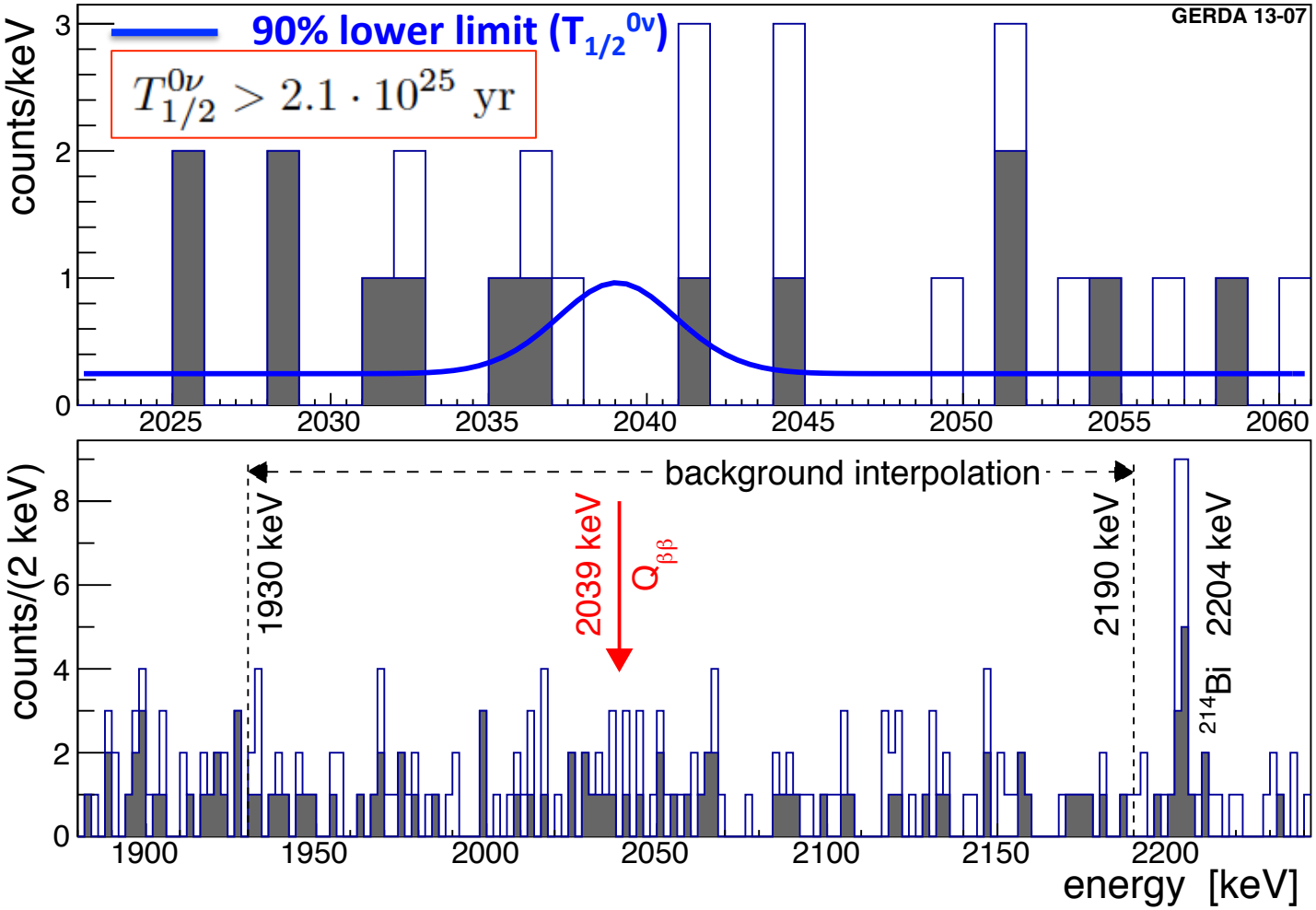
LoI

- 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

Also interests / discussion in China (Jin Ping)

GERDA Phase I results

PRL 111 (2013) 122503



Comparison and reach of current Experiments

		mass [kg]* (total/FV)	FWHM [keV]	background& [cnt/mol yr FWHM]	$T_{1/2}$ limit [10^{25} yr] after 4 yr	$<m_{ee}>$ limit [meV]	date
Gerda II	Ge	35/27	3	0.0004	15	80-190	-2019
MajoranaD	Ge	30/24	3	0.0004	15	80-190	-2019
EXO-200	Xe	170/80	88	0.03	6	80-220	-2019
KLZen	Xe	383/88 (600/?)	250	0.03	20	44-120	-2018
NEXT	Xe	100/80	17	0.0036	6	100-200	-2020
Cuore	Te	600/206	5	0.02	9	50-200	-2019
SNO+	Te	2340/160	270	0.02	9	50-200	-2020

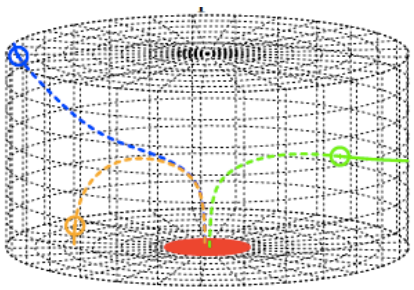
Table from B. Schwingenheuer

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

& mol of $0\nu\beta\beta$ isotope in active volume and divided by $0\nu\beta\beta$ efficiency

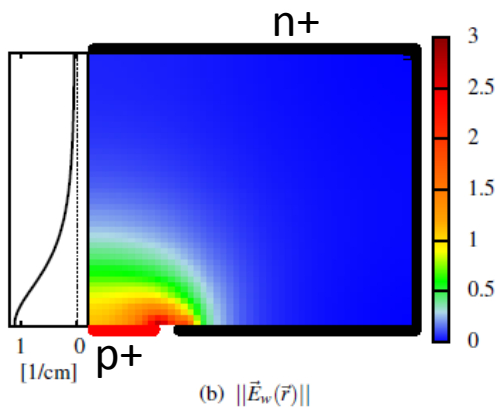
N.B.: values are design numbers except for EXO-200 and Kamland-Zen

Key developments: novel p-type HPGe detectors



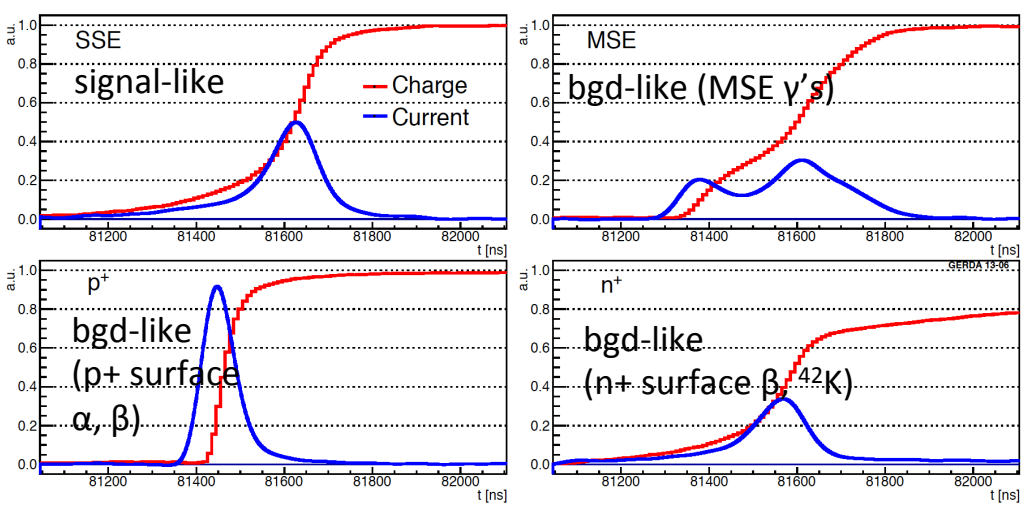
Modified BEGe (GERDA)

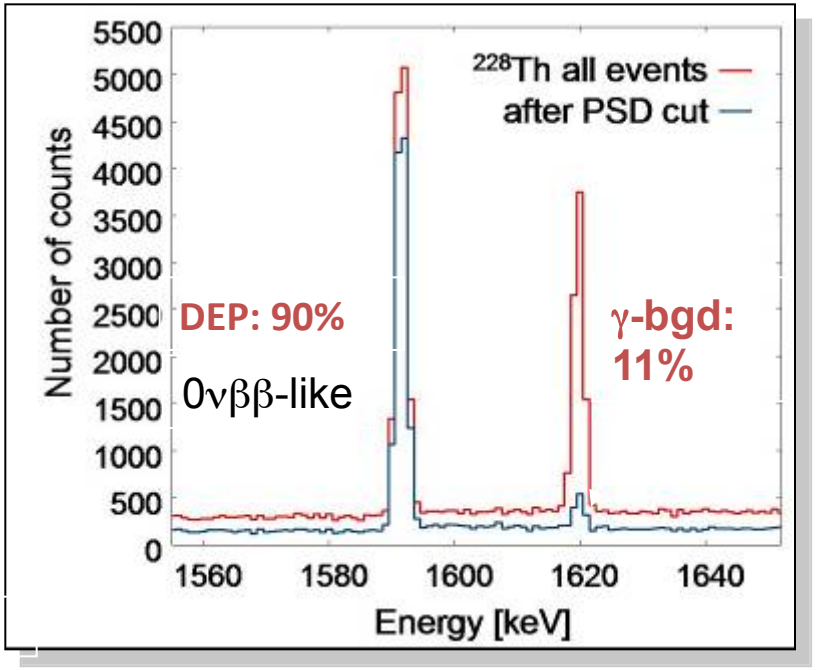
(Similar results with MJD ppc)



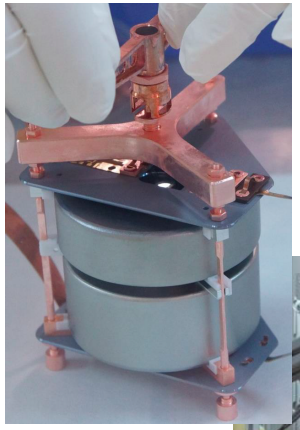
Signal shape provides clear topology for event-by-event signal ID / bgd discrimination:

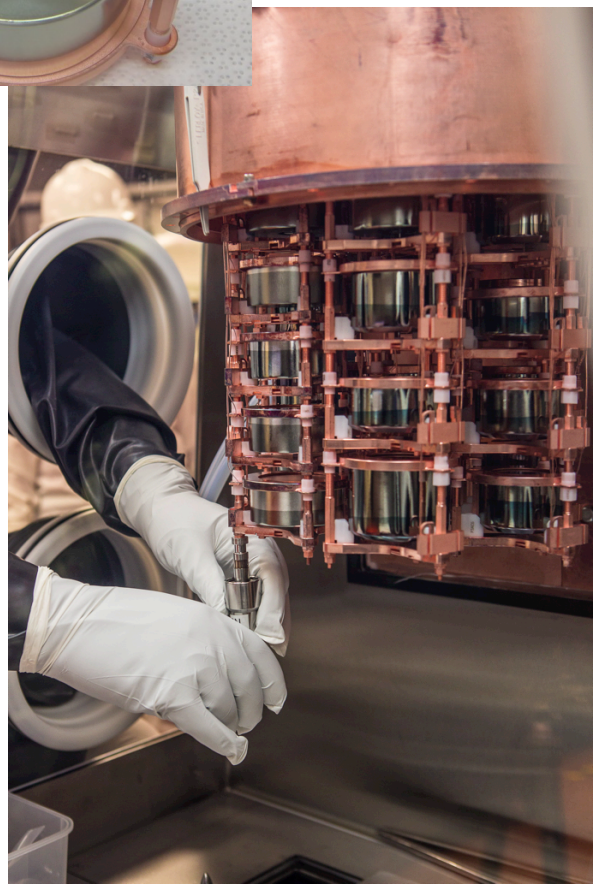
- **SSE/MSE** discrimination
- **Surface** events:
  - n+ slow pulses
  - p+: 'amplified' current pulses





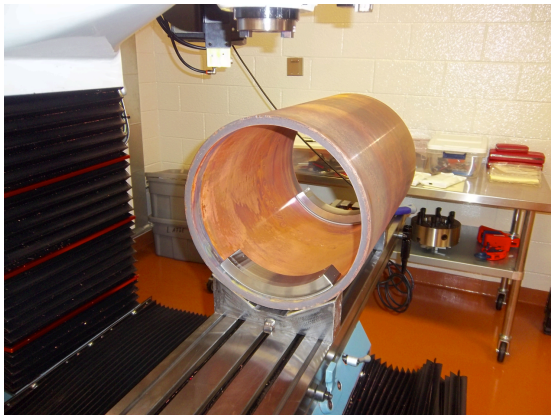
Key developments: novel p-type HPGe detectors

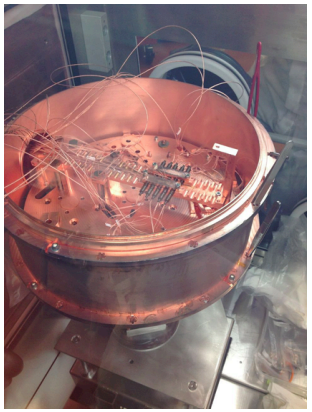




Key developments: high-purity copper

Underground production and machining of high-purity electroformed copper

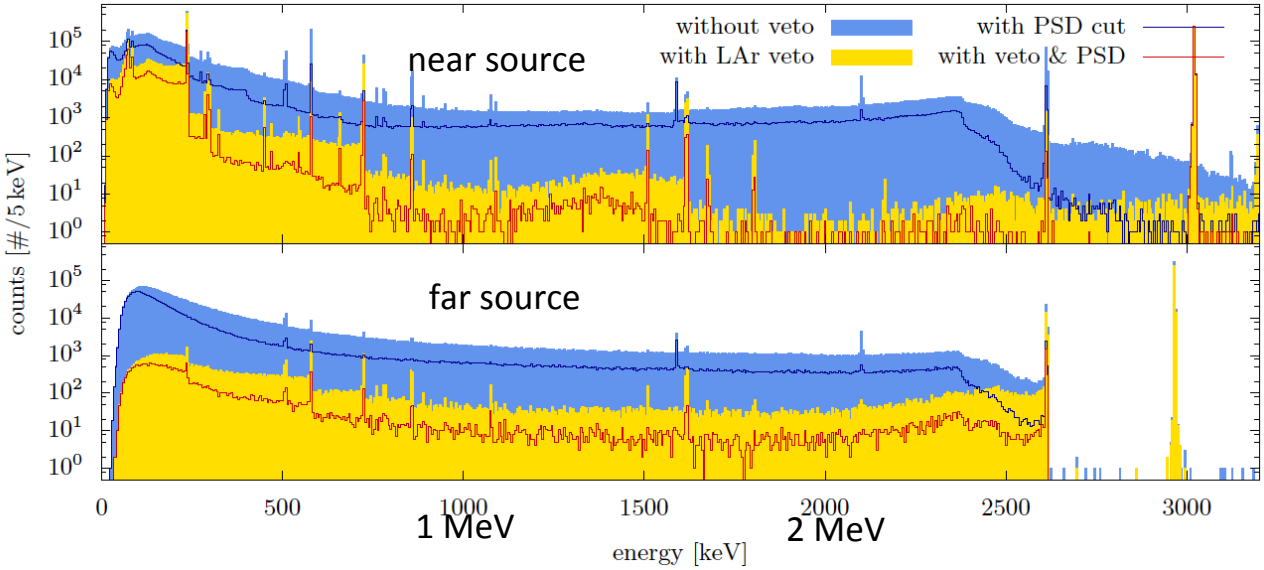


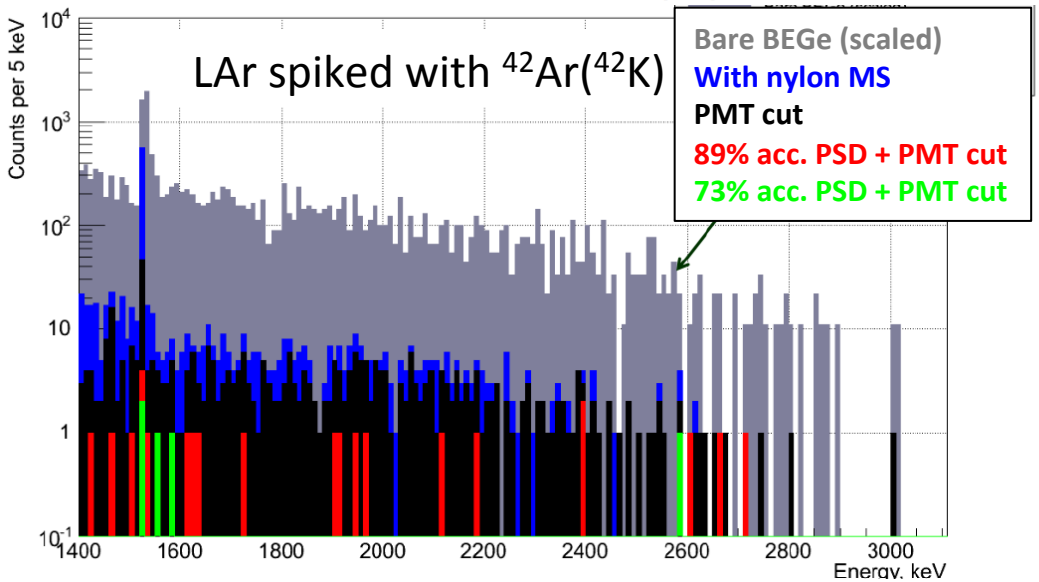


^{232}Th <0.06 μBq/kg
^{238}U <0.10 μBq/kg

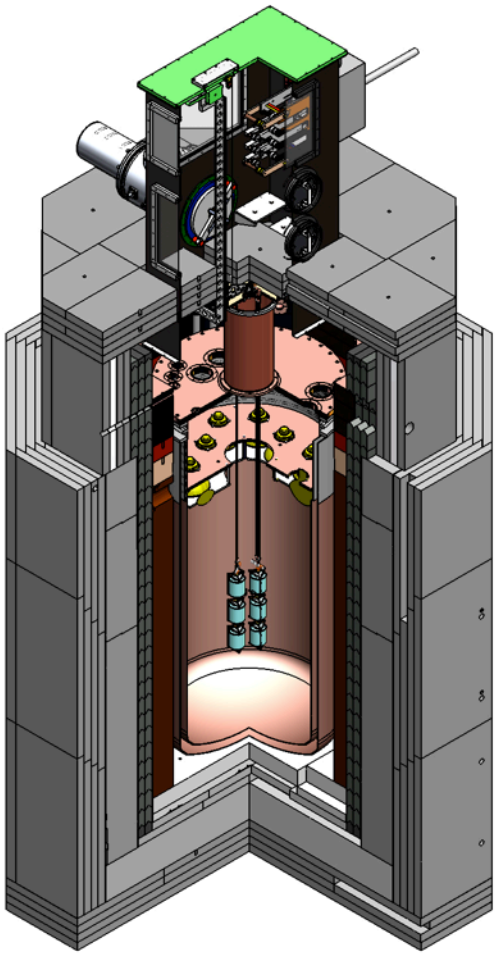
Key developments: liquid argon scintillation veto

Calibration with ^{228}Th source

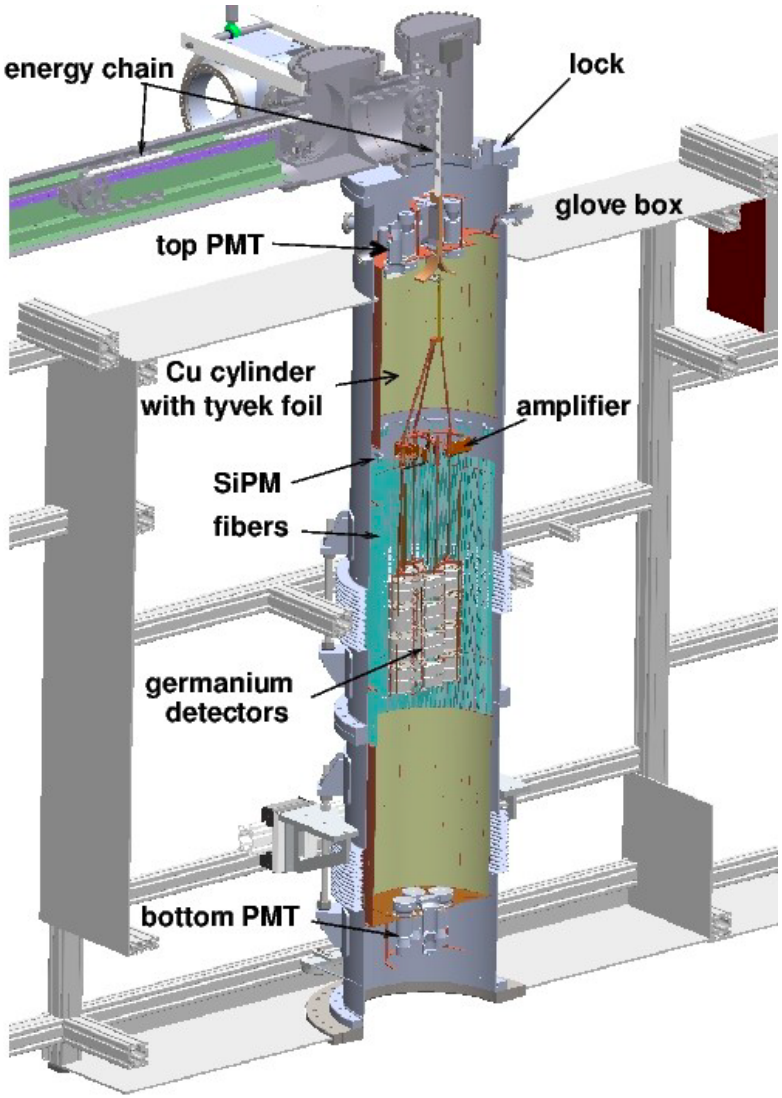


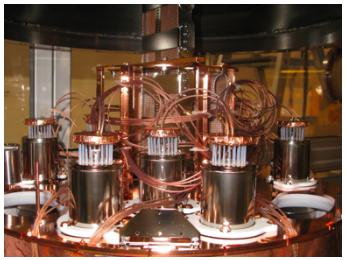


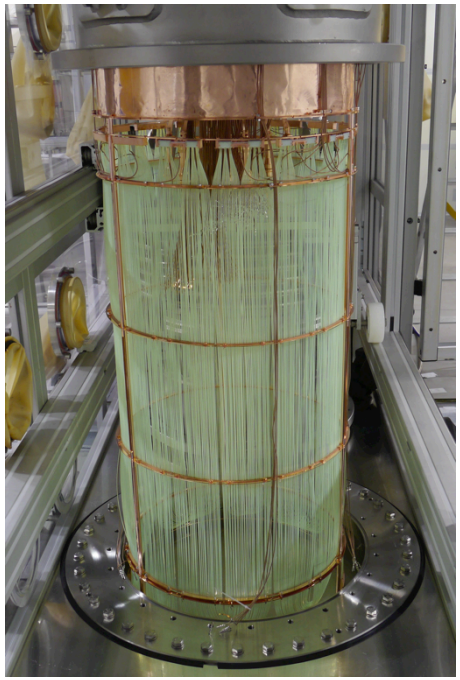
LArGe test stand @ LNGS

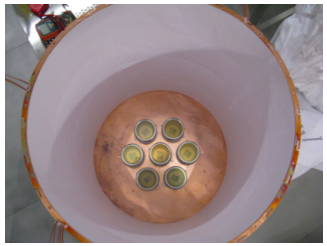


Key developments: liquid argon scintillation veto

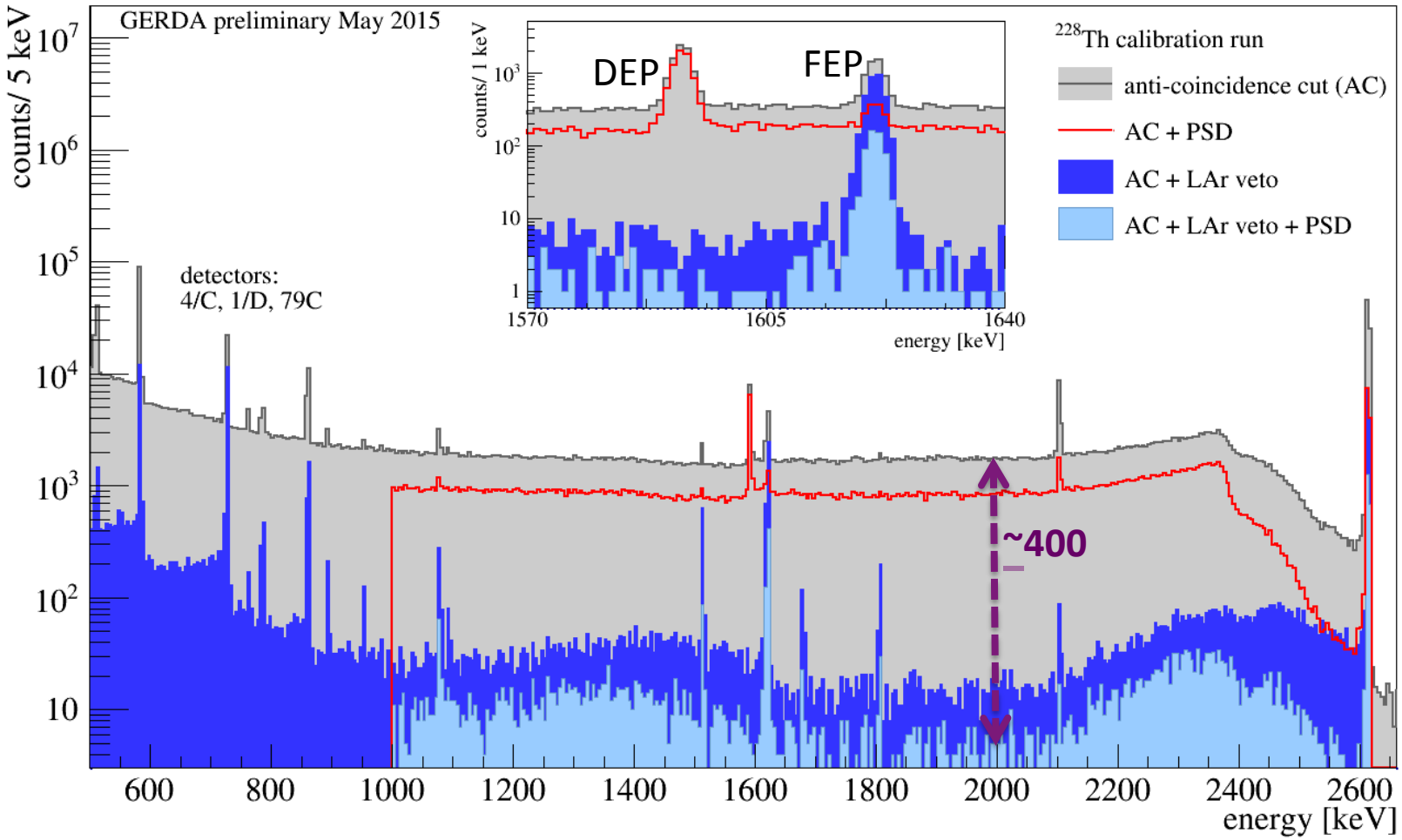






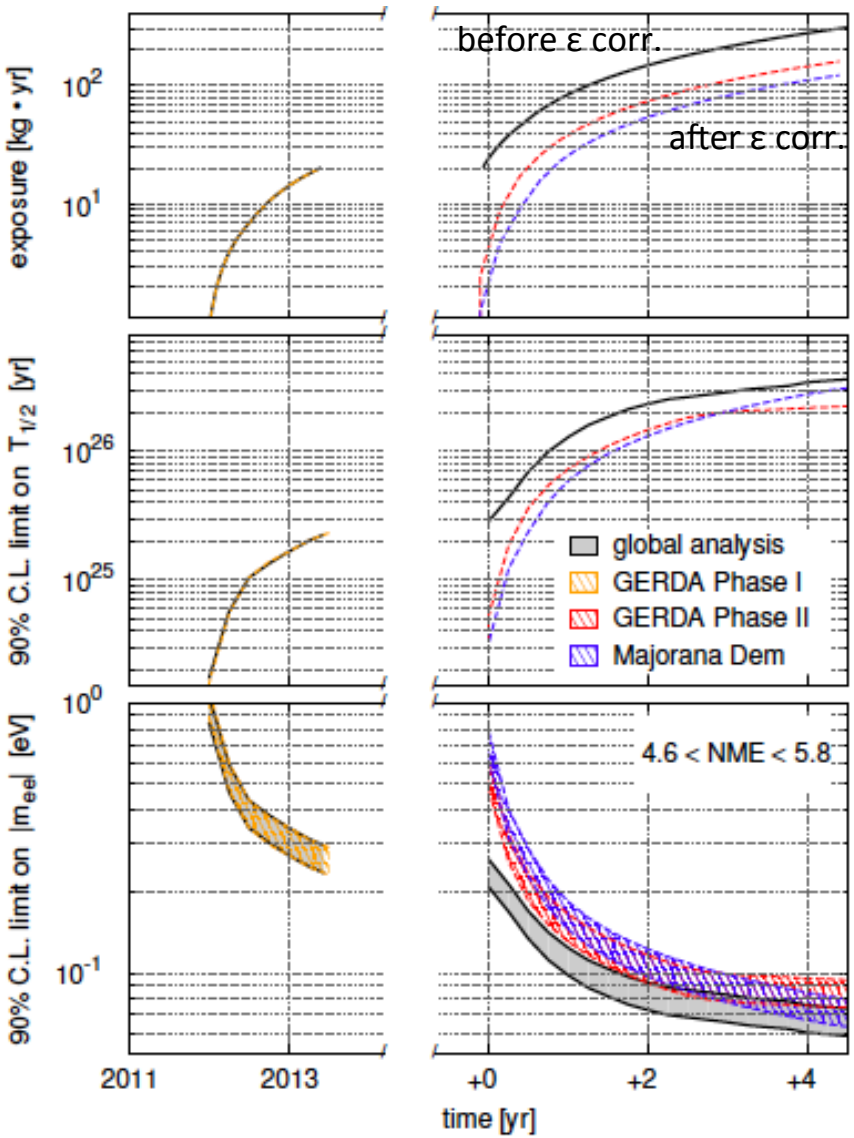


Key developments: liquid argon scintillation veto & PSD



^{228}Th calibration in GERDA during May commissioning run: factor 400 suppression @ $Q_{\beta\beta}$

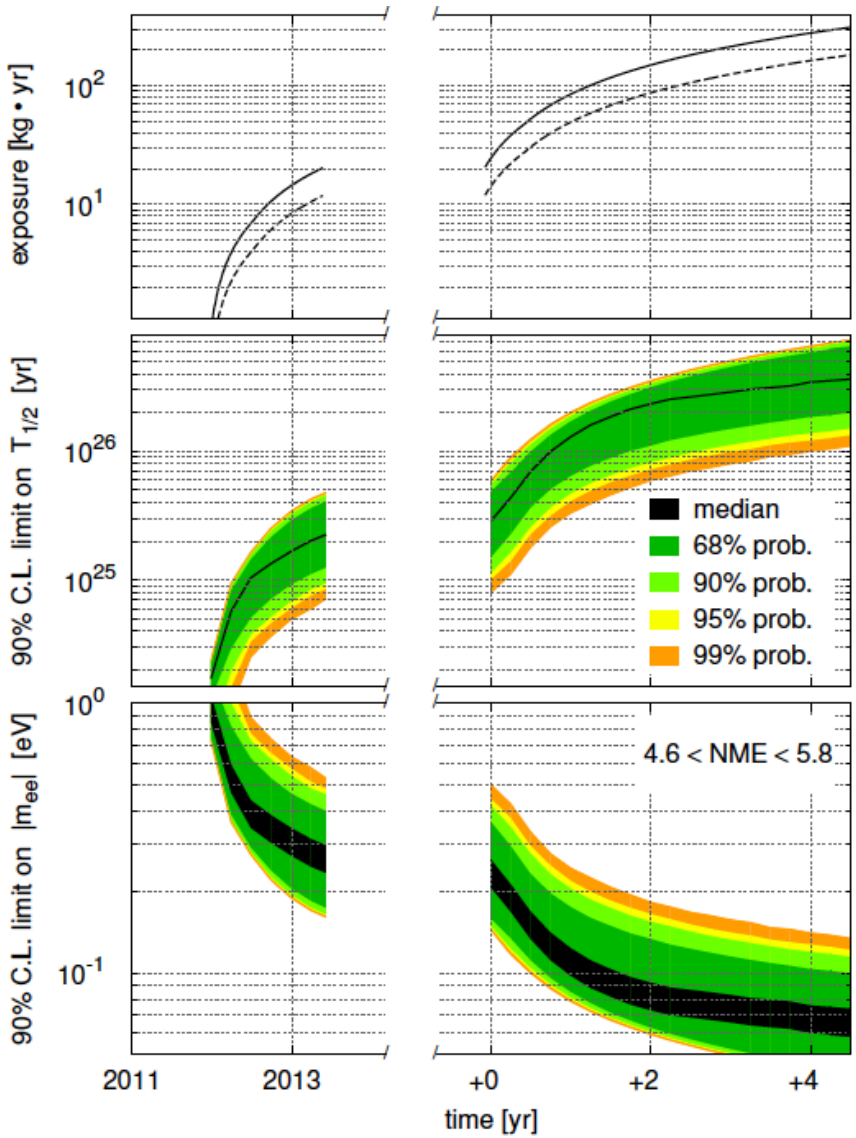
Sensitivity: GERDA & MJD



Data set	mass [kg]	ϵ	background $\left[\frac{\text{cts}}{\text{keV}\cdot\text{kg}\cdot\text{yr}}\right]$	FWHM [keV]
GERDA PHASE I:				
coaxial	12.2	0.62	$1.1\cdot 10^{-2}$	4.4
BEGe	2.8	0.66	$0.5\cdot 10^{-2}$	2.9
GERDA PHASE II:				
coaxial	17.7	0.62	$1\cdot 10^{-3}$	4.0
BEGe	20	0.65	$1\cdot 10^{-3}$	2.5
MAJORANA DEMONSTRATOR:				
mod1	20	0.65	$0.8\cdot 10^{-3}$	3.0
mod2	10	0.65	$0.8\cdot 10^{-3}$	3.0

Sensitivity study by M. Agostini

Sensitivity: GERDA & MJD combined



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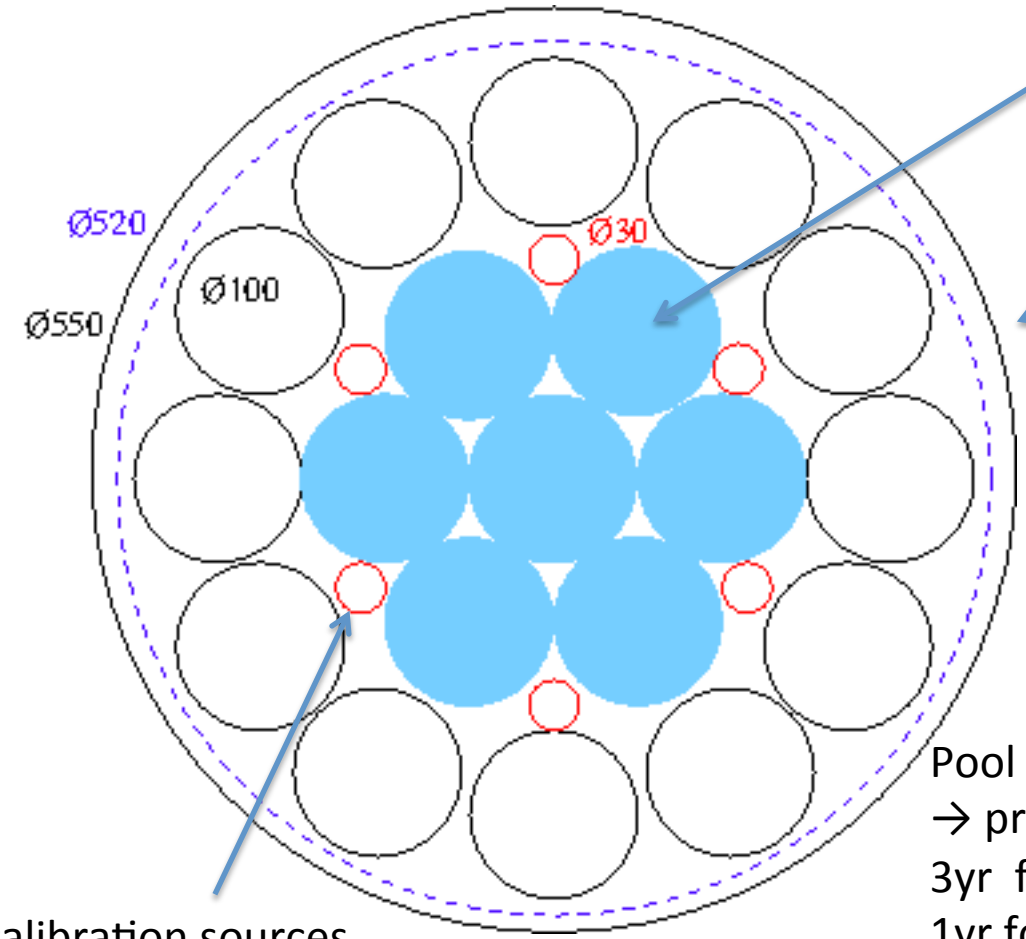
Sensitivity study by M. Agostini

Possible next step beyond GERDA Phase II and MJD: deploy 200 kg in GERDA cryostat

See also B. Schwingenheuer's presentation at LNGS , April 15

Bare detectors à la GERDA



7 strings in Phase II

up 19 strings fit into Ø 500
usable Ø of cryostat ~550

space for LAr veto Ø ~520?
calibration sources

16 BEGe / string
→ **300 detectors / 200 kg**

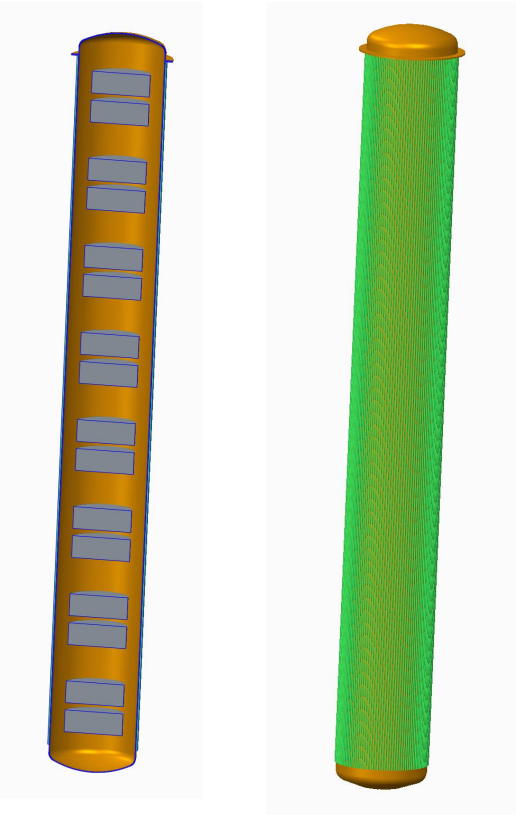
calibration sources

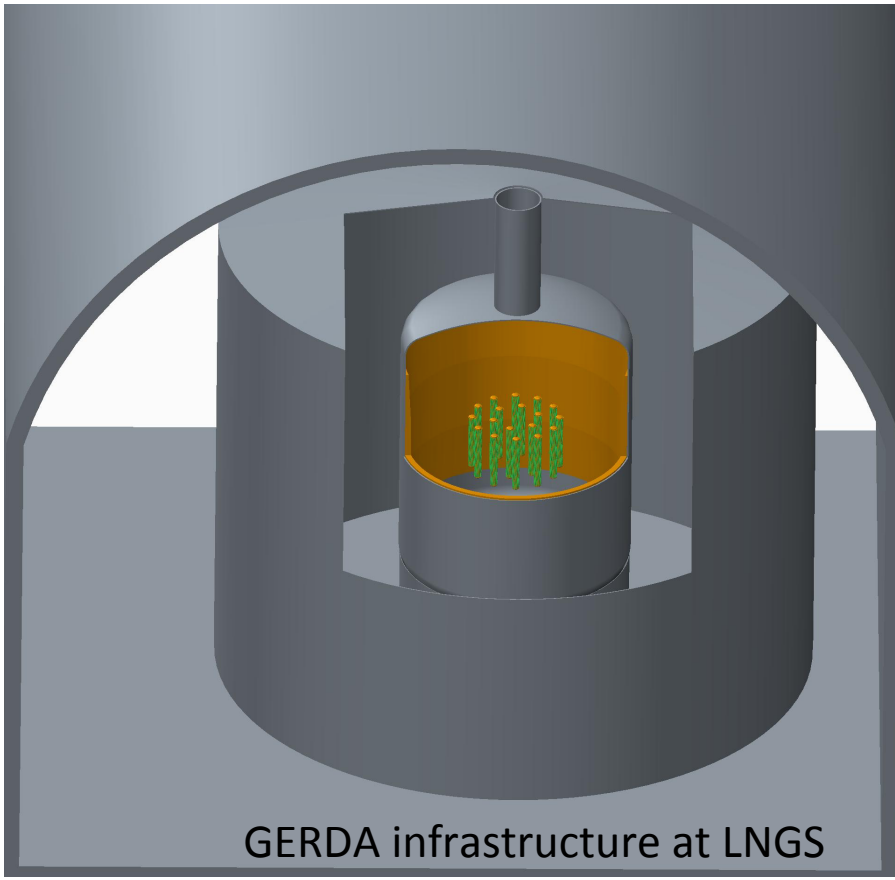
Pool ^{76}Ge material from **GERDA & MJD**
→ procure addition 140 kg ^{76}Ge
3yr for enrichment & detector production
1yr for installation

Possible next step beyond GERDA Phase II and MJD: deploy 200 kg in GERDA cryostat

GERDA-MJD hybrid

Thin-wall copper container with integrated fiber-SiPM light instrumentation operated in LAr as coolant and active shield (artist's view)





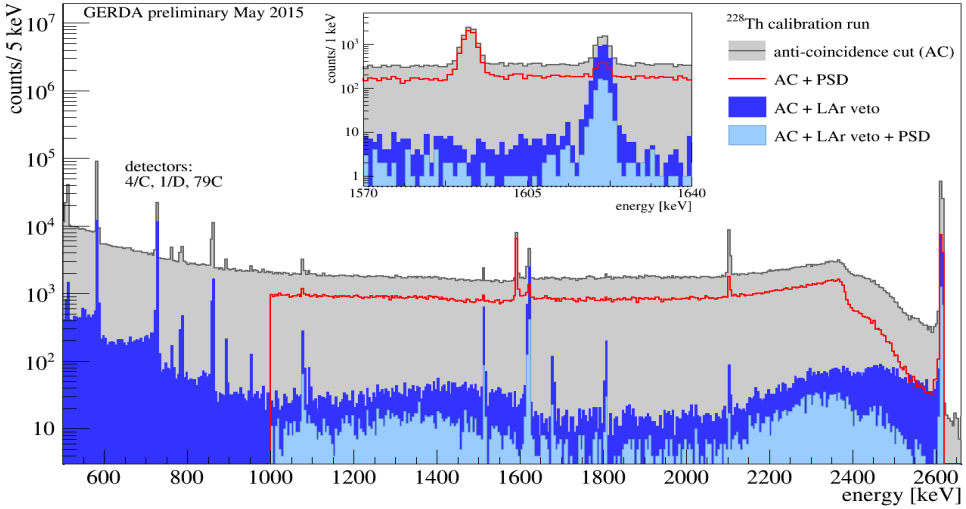
Modular design: mass can further be increased by denser packing and/or new infrastructure

Backgrounds: ^{238}U & ^{232}Th progenies

Far sources (cryostat, tank, rocks): ^{232}Th< 0.3 cnt/(ROI t yr); ^{226}Ra factor 5 less (for central location, no LAr veto, no PSD)

(NIM A606 (2009) 760, NIM A593 (2008) 448)

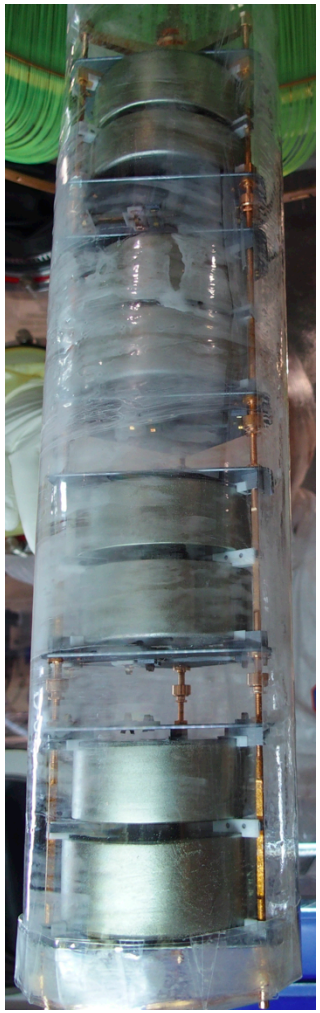
Close sources (cables, holders, VFE): dominate bgd; efficiently suppressed with LAr veto & PSD (prelim: x400 for ^{208}Tl; x10 for ^{214}Bi)



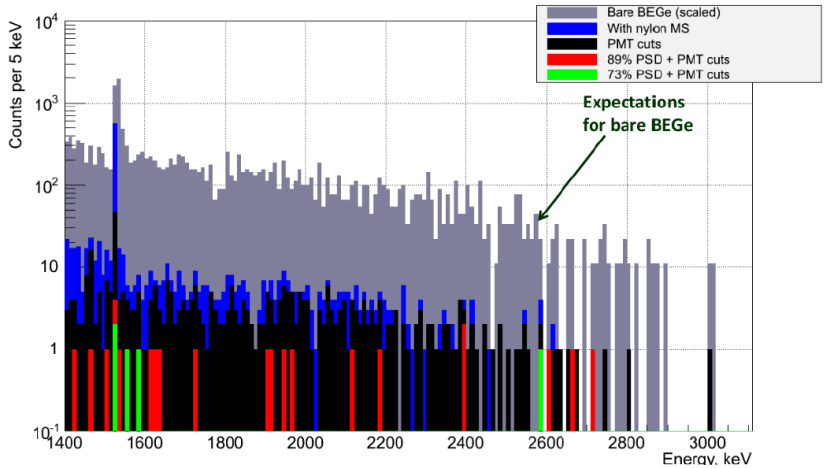
GERDA Phase II: 0.5 cnt/(ROI t yr) dominated by ^{226}Ra

no special Cu, PTFE production → for "200 kg Majorana copper / PTFE quality required

Backgrounds: $^{42}K(^{42}Ar)$



LArGe test stand:
1 ton LAr doped with ^{42}Ar, ~1000x conc. of ^{nat}Ar
BEGe det. in nylon cylinder, LAr veto with PMTs
→ bgd suppression factor SF = 15 from nylon
→ LAr veto + Ge det. pulse shape SF = 70
→ expect in GERDA 0.6-2 cnt/(ROI t yr) for current n+ dead layer



for "200 kg" add. SF by PSD or hardware
(e.g thicker n+ dead layer or hybrid design)

Backgrounds: in-situ muon induced isotopes @ LNGS

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

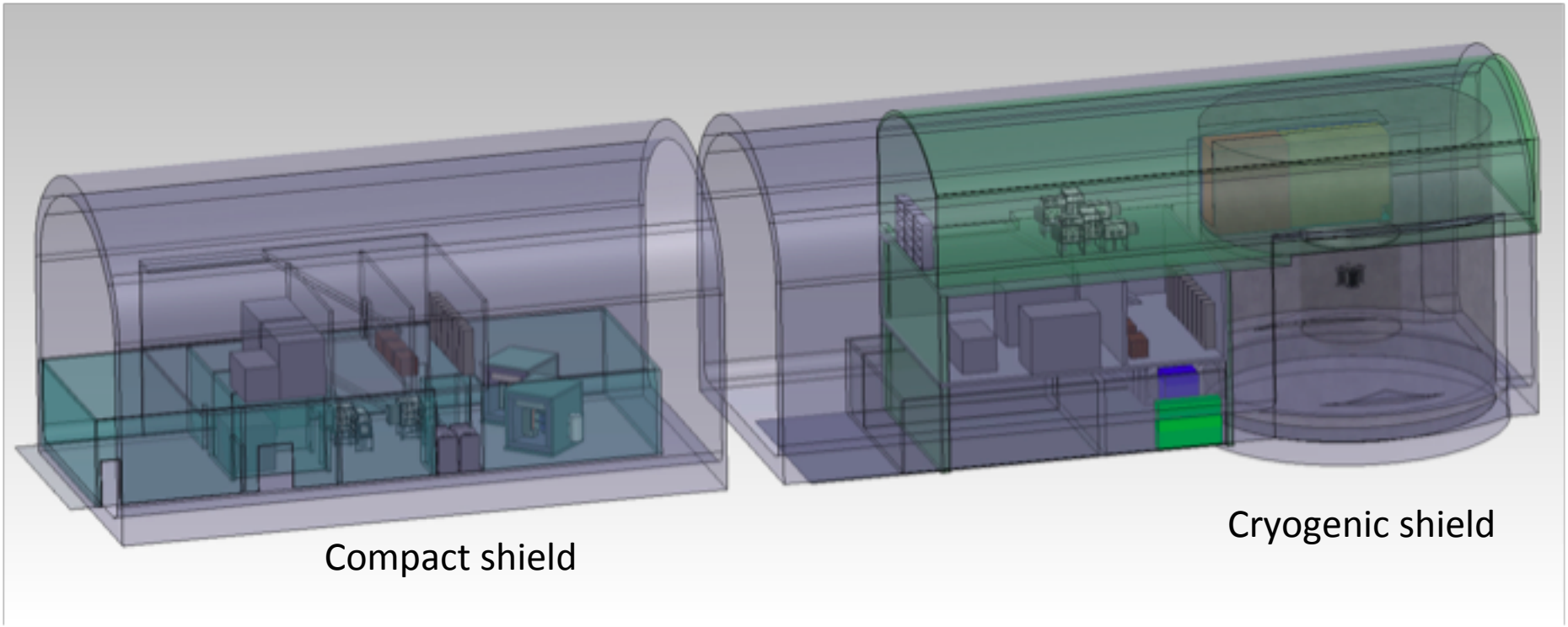
Muon induced long-lived isotopes:

Isotope	$T_{1/2}$	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

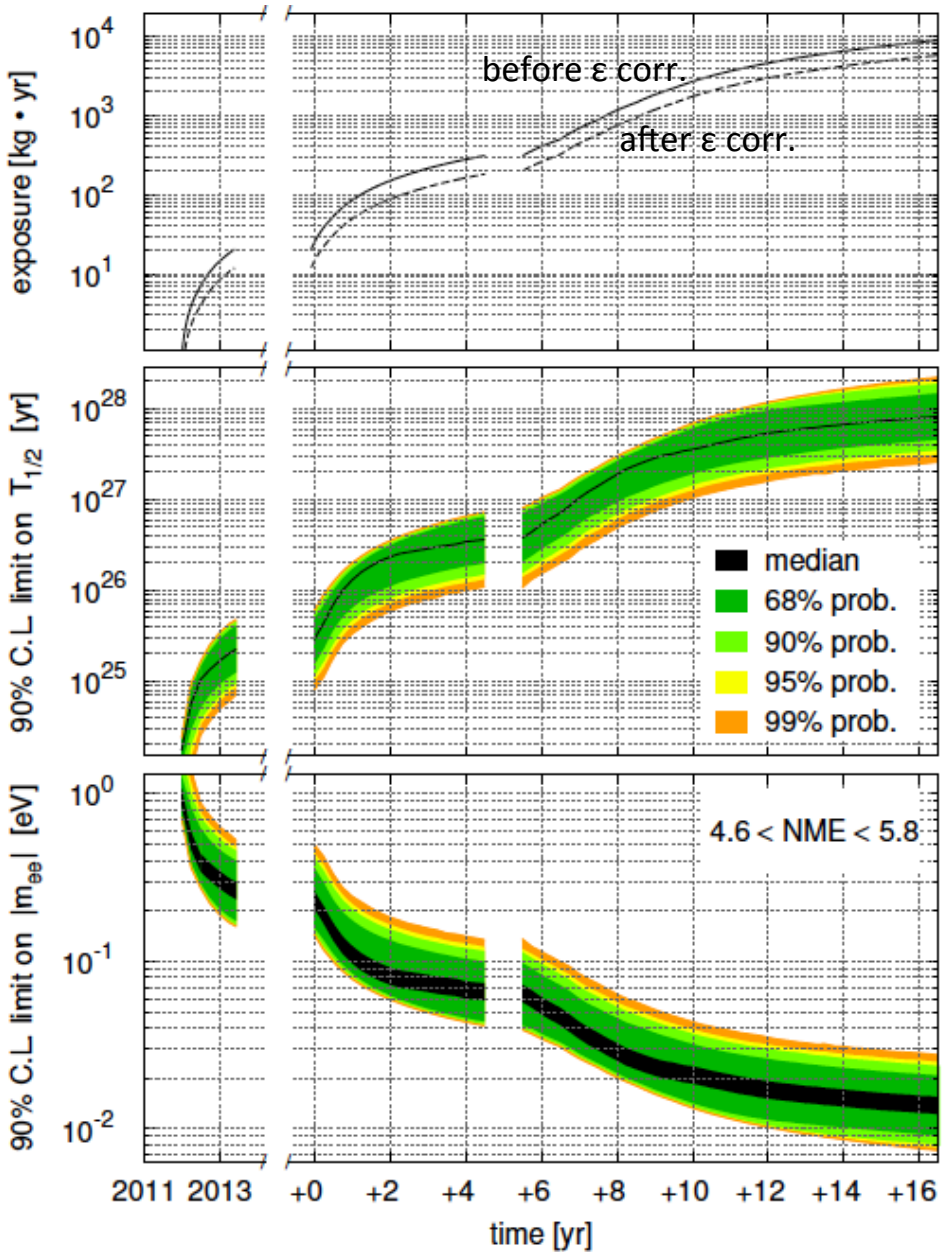
Towards a large scale ^{76}Ge experiment



Envision a phased, stepwise implementation; e.g. 250 → 500 → 1000 kg

J. Wilkerson, LRP Resolution Meeting April 18, 2015

A large scale staged ^{76}Ge experiment: sensitivity vs. time



Assumptions:

Data set	mass [kg]	ϵ	background $\left[\frac{\text{cts}}{\text{keV}\cdot\text{kg}\cdot\text{yr}}\right]$	FWHM [keV]	time [start/stop]
Future large scale (LSGe) experiment:					
mod1	200	0.65	$1\cdot10^{-4}$	2.5	Jan 21 / Jan 31
mod2	200	0.65	$1\cdot10^{-4}$	2.5	Jan 22 / Jan 31
mod3	200	0.65	$1\cdot10^{-4}$	2.5	Jan 23 / Jan 31
mod4	200	0.65	$1\cdot10^{-4}$	2.5	Jan 24 / Jan 31
mod5	200	0.65	$1\cdot10^{-4}$	2.5	Jan 25 / Jan 31

Sensitivity study by M. Agostini

Summary

<u>^{76}Ge detector features:</u>

- known technology (enrichment + diode production)
- best energy resolution
- lowest bgd in ROI per mol of isotopes
- flat background at Q value
- excellent PID through PSD and LAr-veto

→ important features for discovery

GERDA Phase II & Majorana Demonstrator start data taking soon

<u>If current experiments meet specifications:</u>

- possible next step: combine existing detectors and add new ^{76}Ge
- GERDA infrastructure can in principle host 200 kg of Ge detectors
- Bare detectors in LAr - but also hybrid design conceived
- bgd reduction x3 relative to Phase II goal required to be ”background free”
- $T_{1/2}$ sensitivity for 90% CL limit ~ 10^{27} yr

<u>In parallel:</u>

- Prepare for subsequent stages towards ton-scale experiment
- New infrastructure required