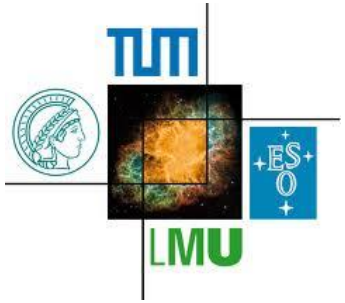
Search for the neutrinoless double beta decay (0νββ) of ^{76}Ge:

GERDA Phase II commissioning

Tobias Bode

for the GERDA collaboration

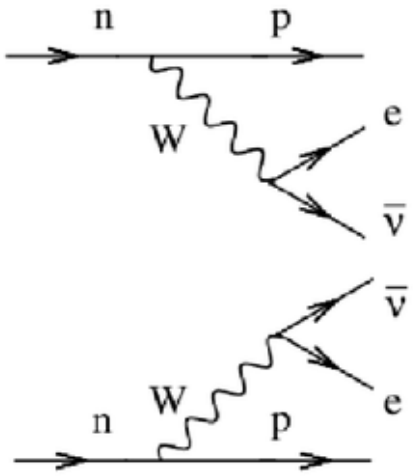
Technische Universität München



Outline

- Theory introduction
- The GERDA experiment
- Analysis of Phase I data
- Commissioning first detectors in GERDA Phase II
- Summary

Theory: double β-decay

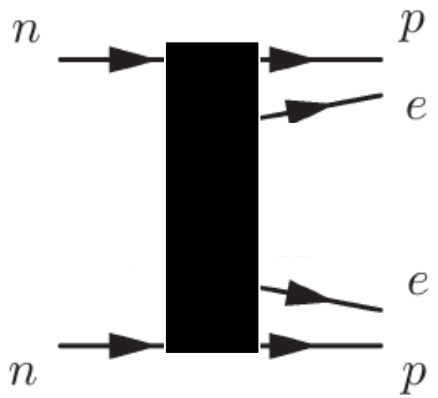


2-neutrino double β-decay (2νββ)

- $(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$
- Allowed in SM
- Measured in several isotopes with $T^{2\nu}_{1/2}$ in range of 10^{19} – 10^{24} a

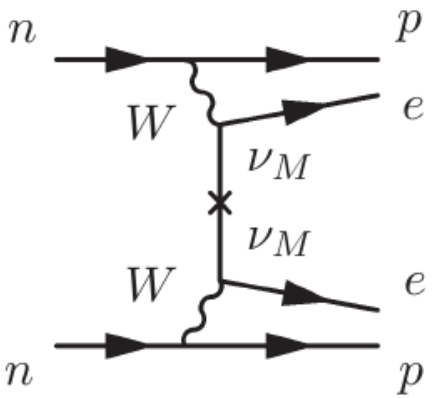
neutrinoless double β-decay (0νββ)

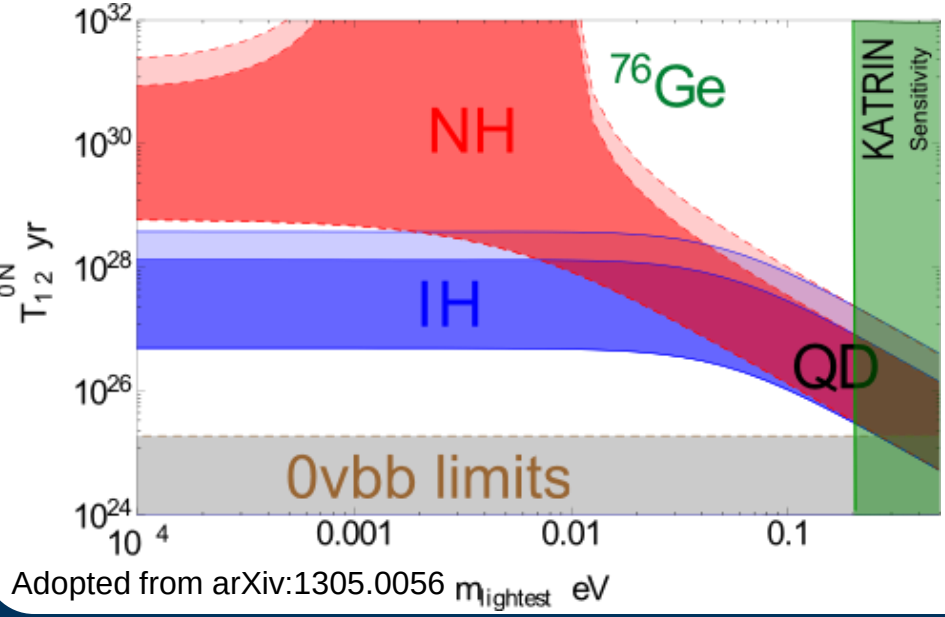
- Hypothetical process
- $(A, Z) \rightarrow (A, Z+2) + 2e^-$
- Lepton number violation(ΔL=2)
- Possible mediators: light majorana neutrino, right-handed weak currents, Majorons → Physics beyond SM
- Schechter-Valle theorem: majorana ν mass component if observed



Theory: 0νββ & neutrino properties

- Assuming light majorana ν_M exchange dominant channel
- Eff. majorana mass $\langle m_{\beta\beta} \rangle = \left| \sum_i U_{ei}^2 m_i \right|$
- Sensitive to absolute ν mass scale & hierarchy





Adopted from arXiv:1305.0056

Experimental signature of double beta decay (DBD)

- Sum-energy spectrum of 2 emitted electrons
- 2νββ: continous spectrum due to escaping ν‘s
- 0νββ: peak at Q-value ($Q_{\beta\beta}$)

$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu}(Q,Z)|M^{0\nu}|^2\langle m_{\beta\beta}\rangle^2$$

Phase space factor

Nuclear matrix element

Sensitivity for limit of $T_{1/2}$ of neutrinoless double beta decay

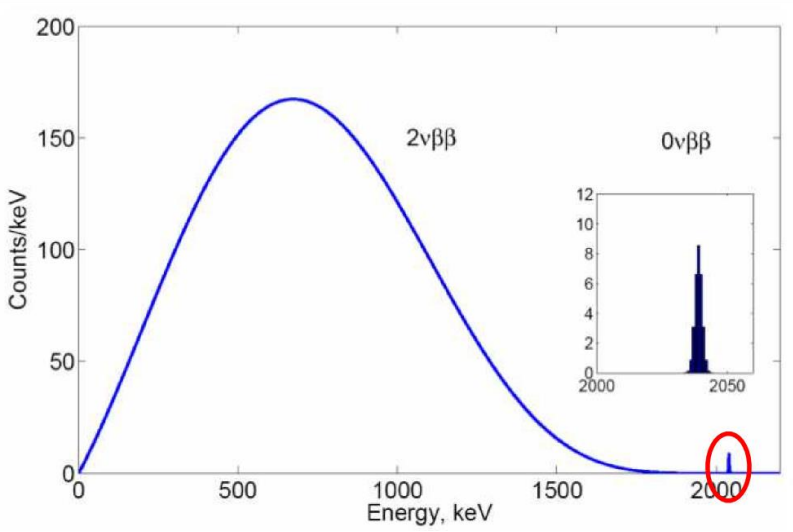
with bkg

$$T_{1/2} \propto \epsilon a \sqrt{\frac{Mt}{BI\,\Delta(E)}}$$

without bkg

$$T_{1/2} \propto \epsilon a \frac{Mt}{\Delta E}$$

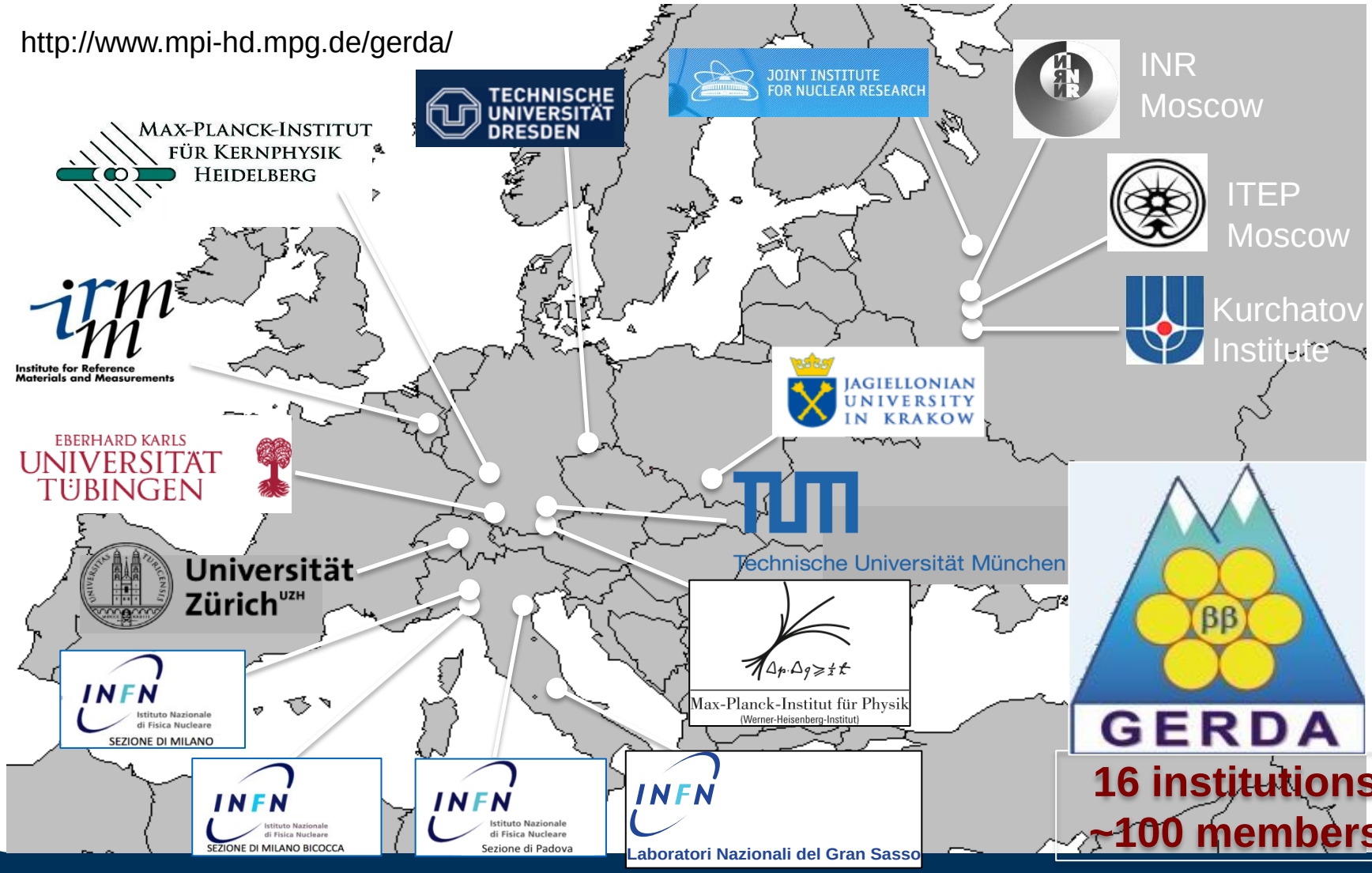
ε: detection effiency
a: abundance of Ge-76
M: mass [kg]
t: exposure time [yr]
BI: background index $[\frac{\text{counts}}{\text{keV}\cdot\text{kg}\cdot\text{yr}}]$
Δ (E): energy resolution at ROI around 2039 keV



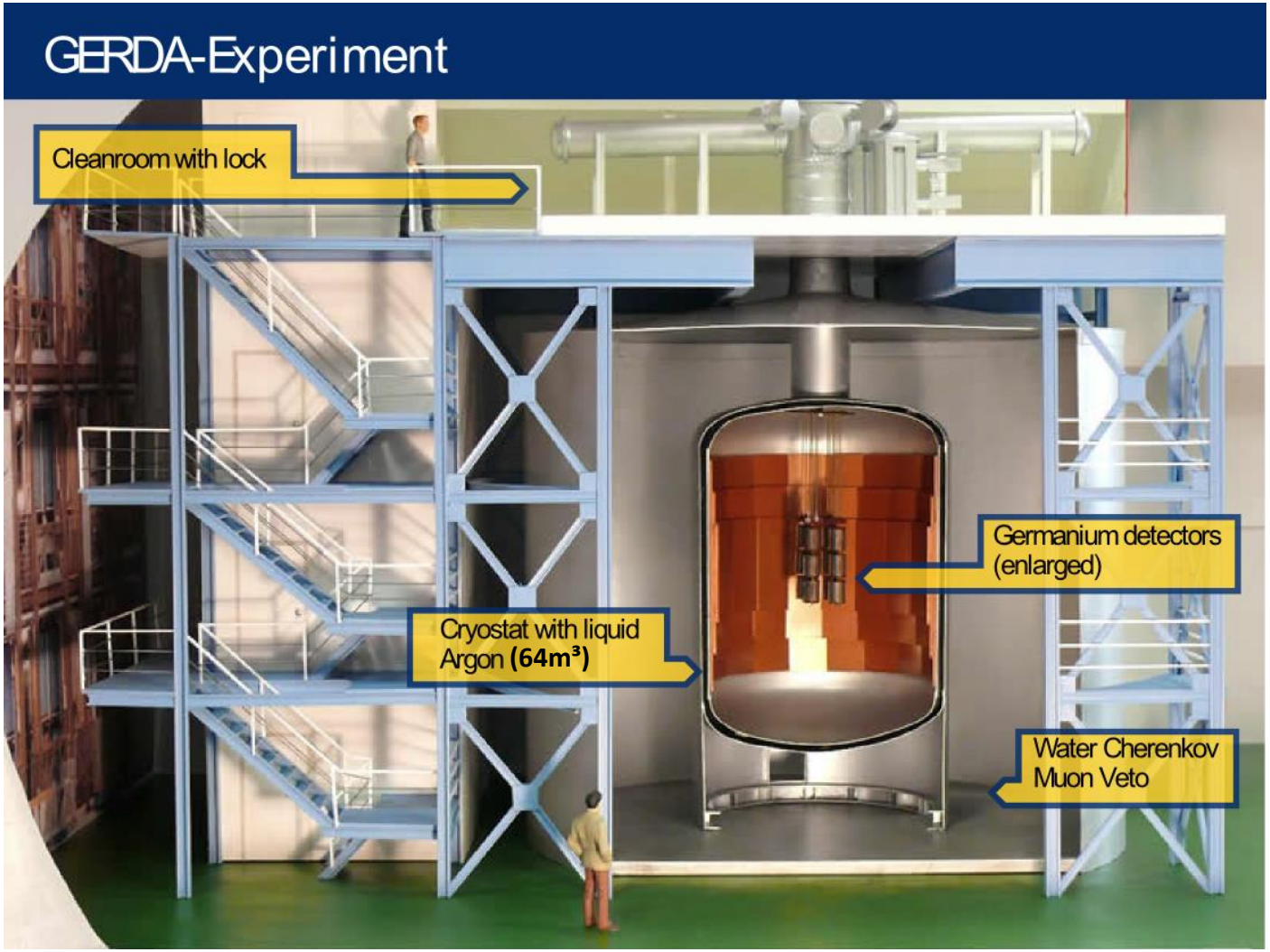
DBD sumenergy-spectrum of ^{76}Ge

GERDA: the Collaboration

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



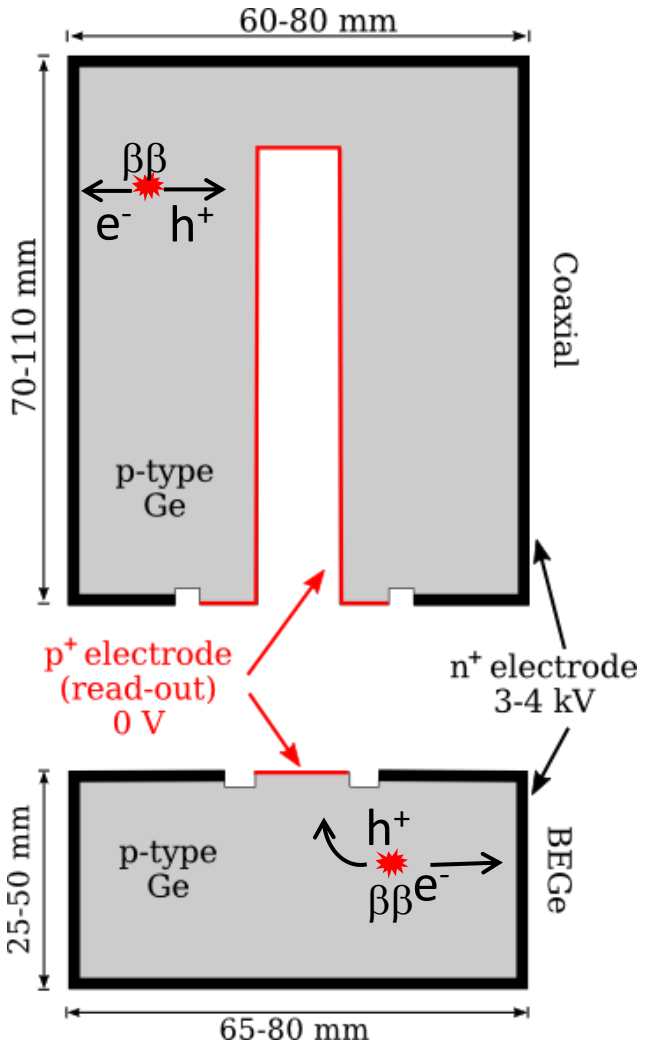
- Bare Ge detectors operated in LAr
- Rock, water & LAr as shield against external radiation
- Deep underground at LNGS (3600 m.w.e)



Detectors:

- **H**igh **P**urity **Ge**rmanium (HPGe) detectors enriched (87%) in ^{76}Ge
  - Excellent energy resolution (≈ 0.1 % at ROI/ $Q_{\beta\beta}$)
  - Long-term stability
  - Mature technology
  - Radio-purity

- Source = detector
  - High detection effiency
  - Peak at $Q_{\beta\beta}$



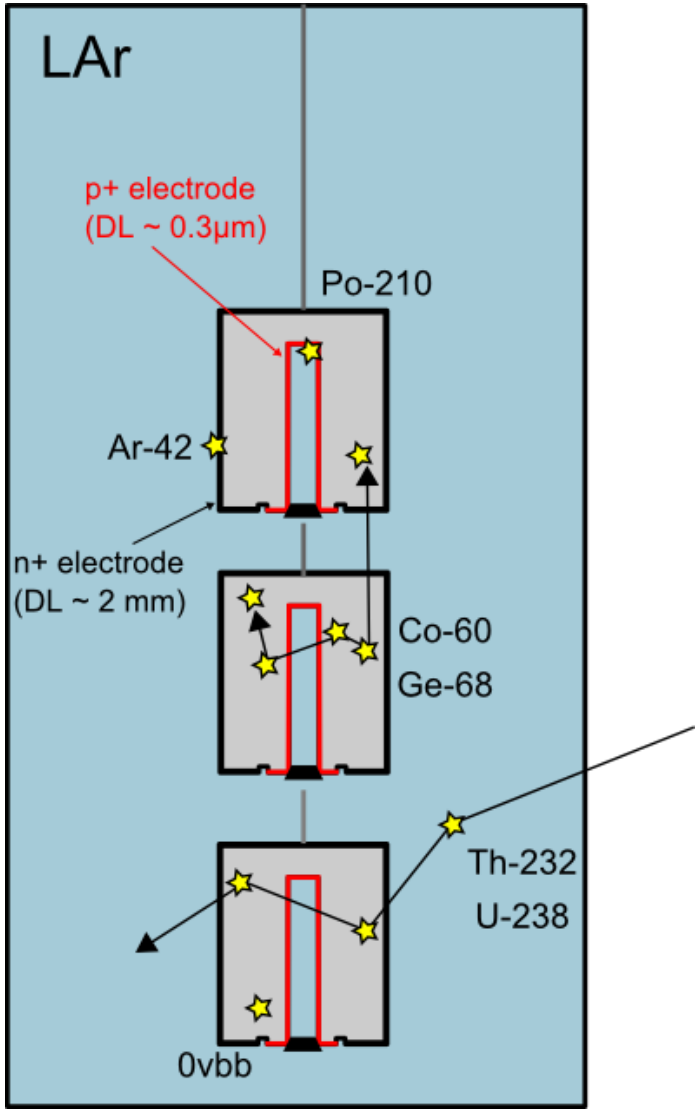
Background events in GERDA

- Natural radioactivity (^{232}Th & ^{238}U chains)
  - γ's (eg. ^{208}Tl & ^{214}Bi)
  - α's (eg.^{210}Po from surfaces, ^{222}Rn in LAr)

- Cosmogenic activated isotopes in Ge(^{68}Ge, ^{60}Co)
- Long lived cosmogenic isotopes in LAr (^{39}Ar, ^{42}Ar)

Supression strategies:

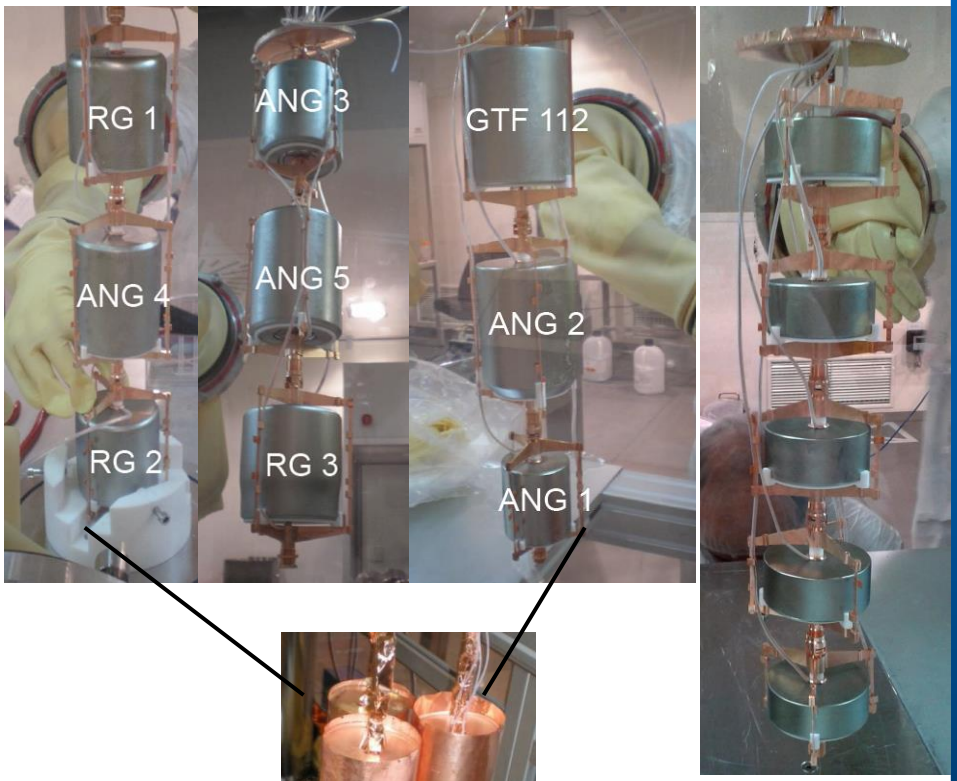
- Detector anti-coincidence
- Pulse-shape analysis (HK 70.3)
- LAr veto (in Phase II) (HK 70.4)
- Time-coincidence (Bi-Po)



GERDA Phase I

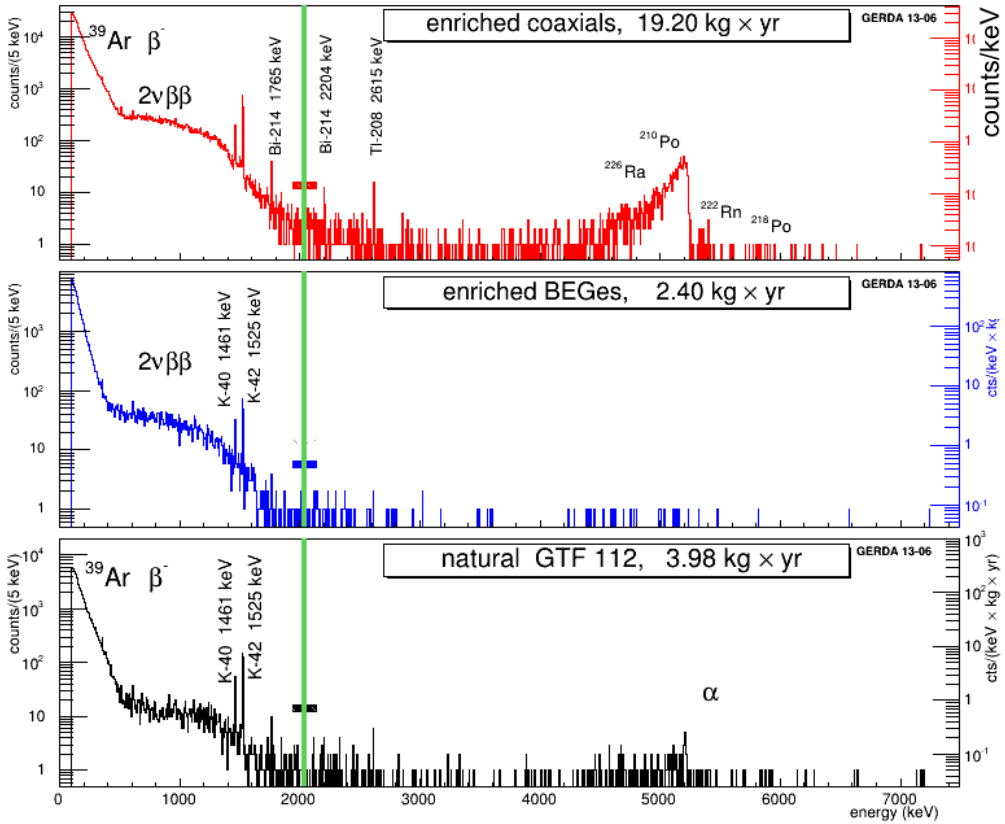
- Physics data taking Nov ’11- May ‘13
- ^{enr}Ge mass for physics analysis: 17.6 kg
- Total exposure: 21.6 kg·yr
- Duty cycle: 88%
- $\Delta E@Q_{\beta\beta}$:4.1 keV (coax) 2.8keV (BEGe) with advanced filtering (arXiv: 1502.04392)
- Average background index before PSA: 0.02 cts/(keV·kg·yr)
- Blind analysis:
  - Expected counts in $Q_{\beta\beta} \pm 5$keV after PSD: 2 ± 0.3
  - Observed: 3cts

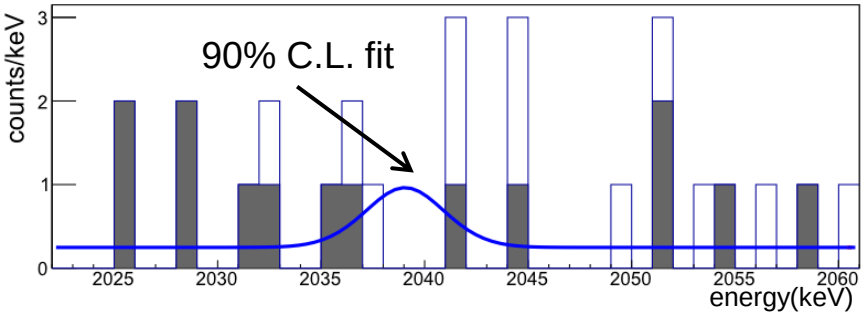
8 ^{enr}Ge +1 ^{nat}Ge coaxial detectors



5 ^{enr}Ge BEGe detectors

Phase I





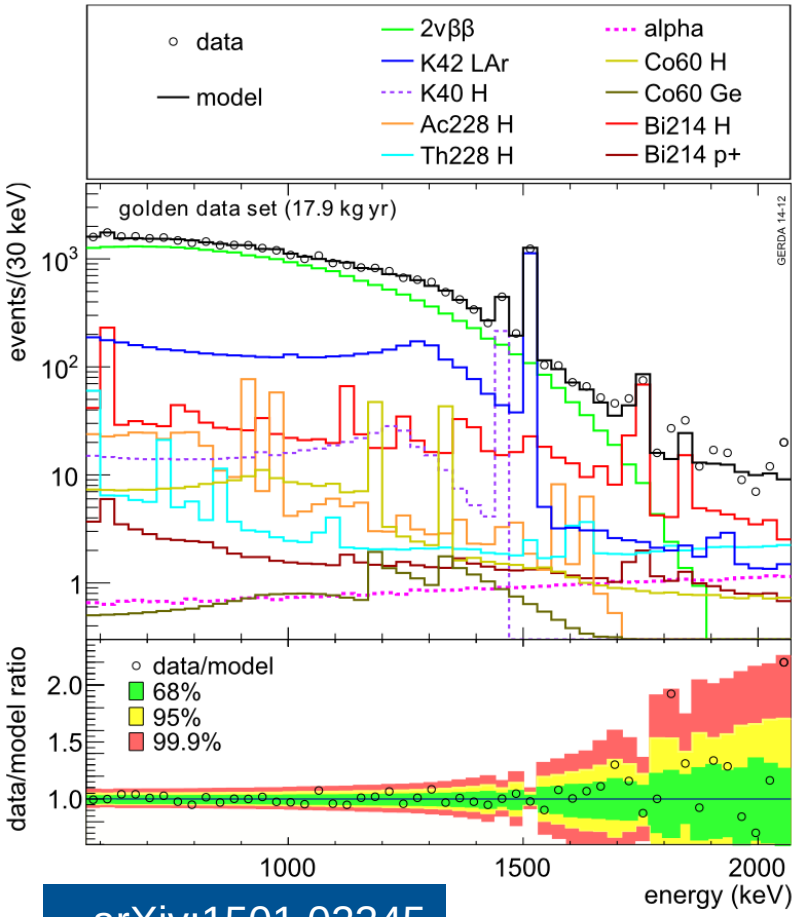
Open histogram before PSD; filled histogram after PSD

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

$$m_{\beta\beta}<0.2\text{-}0.4\ \text{eV}$$

PRL 111, 122503 (2013)

New 2νββ half-life analysis



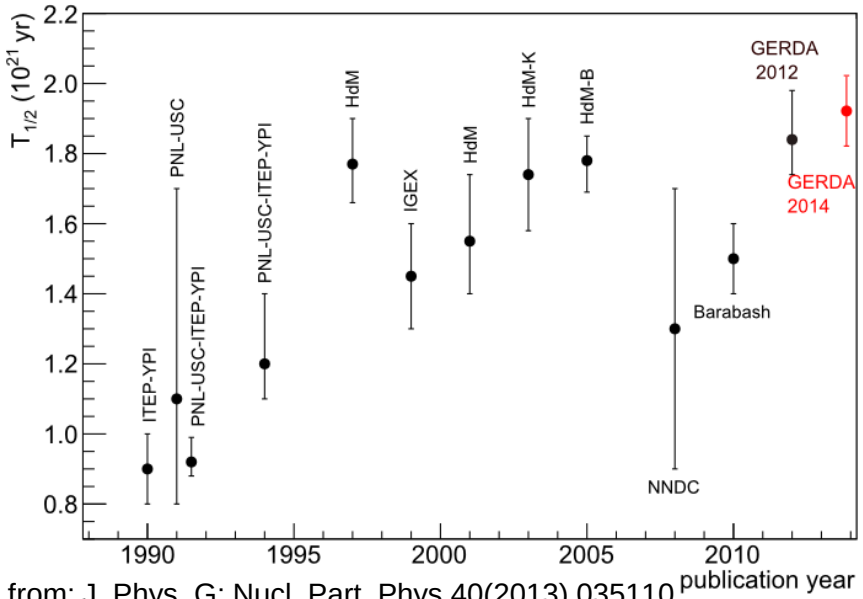
arXiv:1501.02345
Submitted to EPJC

- Previous GERDA result (2013) exposure: 5 kg yr

$$T_{1/2}^{2\nu} = (1.84^{+0.14}_{-0.10}) \cdot 10^{21}\ \text{yr}$$

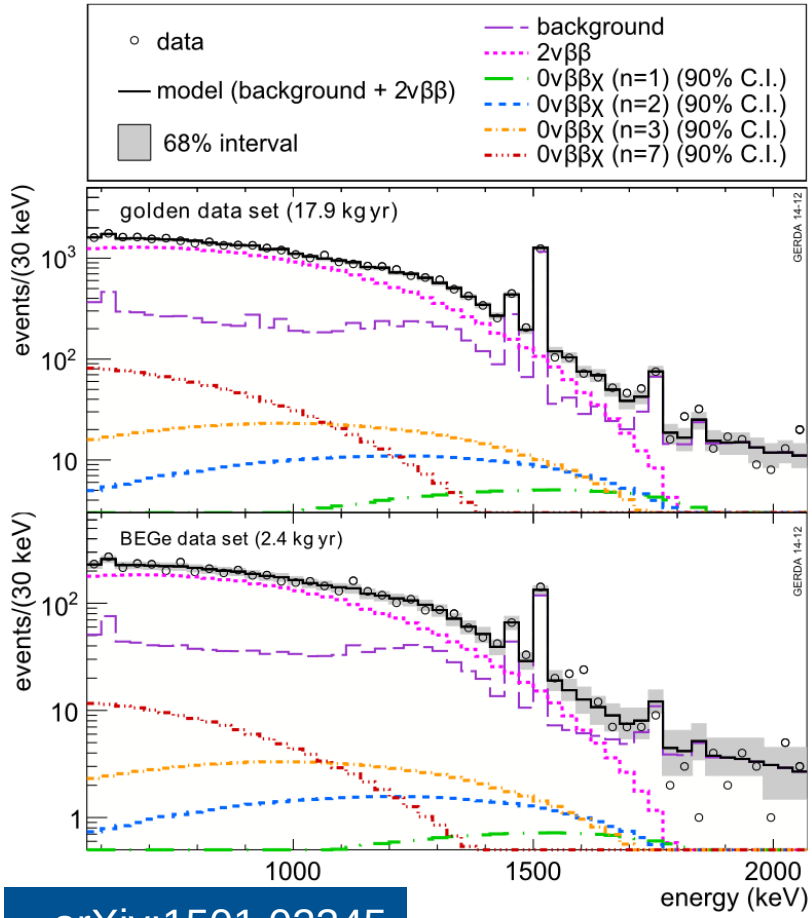
- New result (18 kg yr):

$$T_{1/2}^{2\nu} = (1.926 \pm 0.095) \cdot 10^{21}\ \text{yr}$$

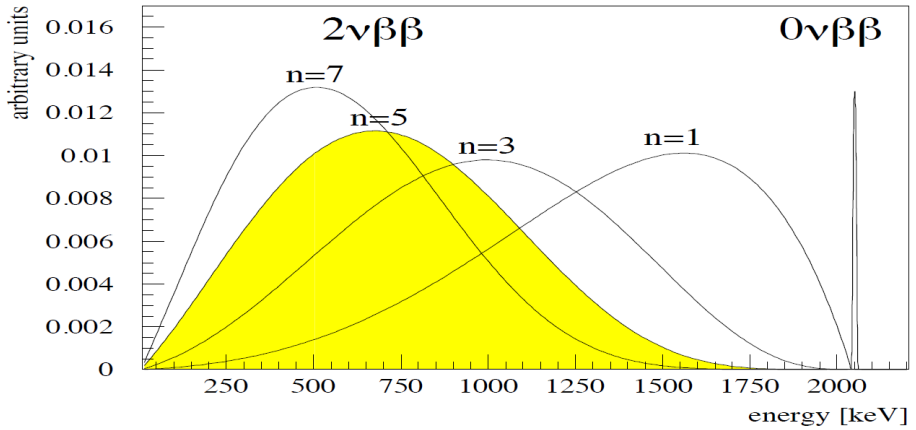


Adopted from: J. Phys. G: Nucl. Part. Phys.40(2013) 035110

0νββχ (majoron) half-life limit analysis



- 0νββχ hypothetical beyond SM process possible with different spectral indices n depending on model
- $T_{1/2}^{0\nu\chi} > (0.3 - 4.2) \cdot 10^{23}$ yr for diff. n
- Most stringent limit for ^{76}Ge yet

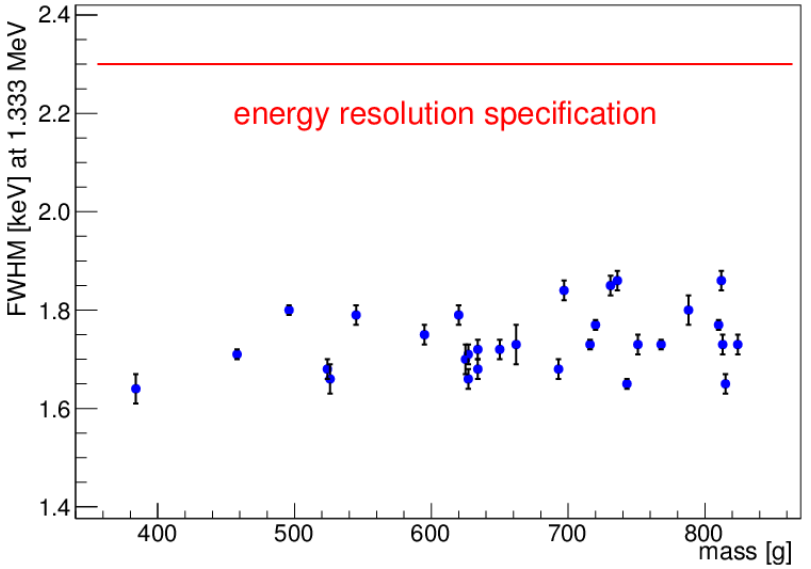


arXiv:1501.02345
Submitted to EPJC

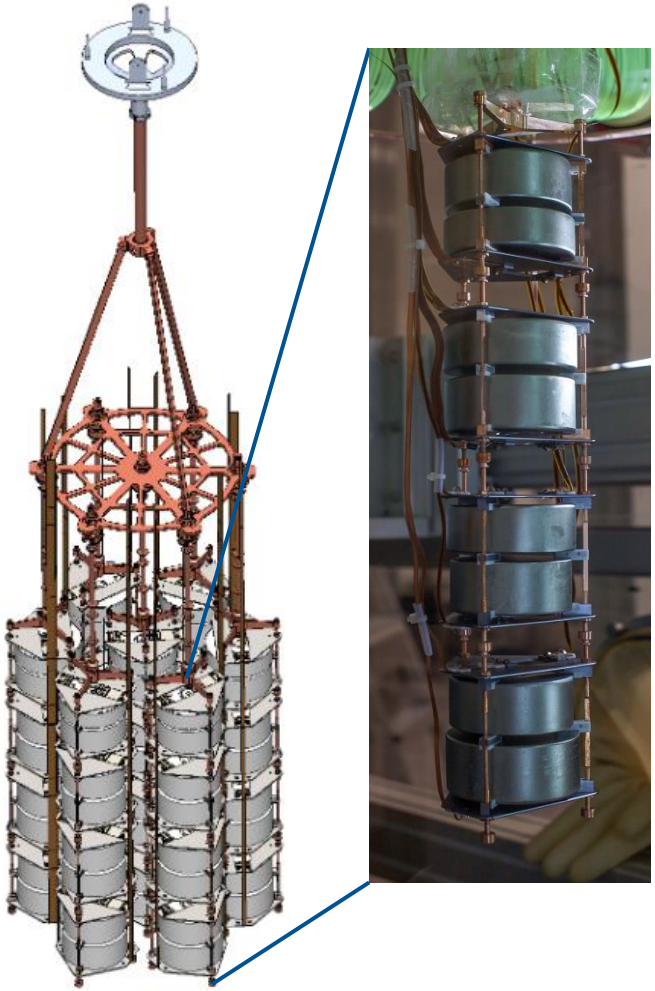
GERDA Phase II

- New custom-made detectors (BEGe) of ~20 kg total mass (18kg -> 38kg)
- Improved energy resolution ΔE & pulse shape discrimination capabilities by usage of new detector type
- Background index aim 10 times lower than Phase I: < 0.001 cts/(keV·kg·yr)

- Active reduction of background events
  - Pulse Shape Discrimination (PSD) (HK 70.3)
  - Instrumented liquid argon volume (HK 70.4)
  - Higher number & dense packing of detectors: better anti-coincidence cut

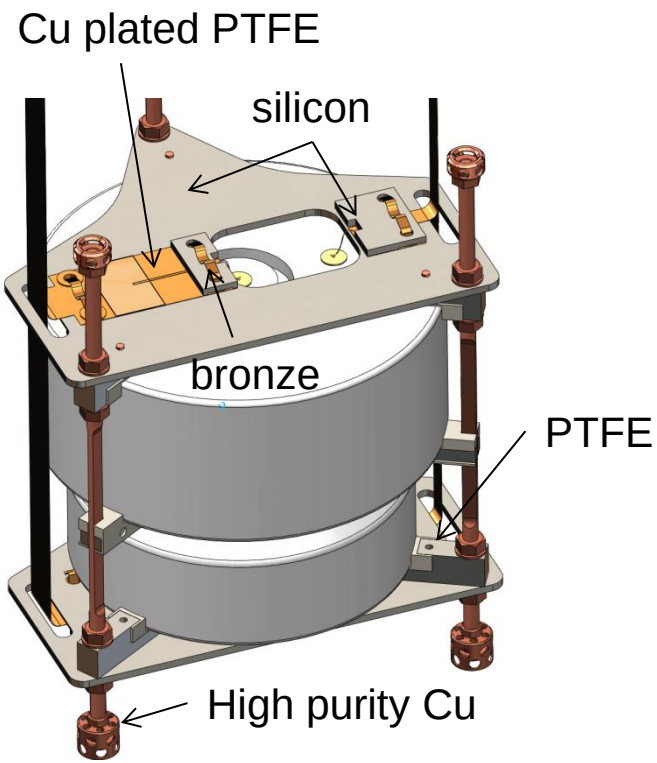


Phase II detector array & assembly



- 7 strings of detectors
- 15 pairs of ^{enr}Ge BEGe detectors mounted back-to-back
- 10 semi-coaxial detectors(7 ^{enr}Ge & 3 ^{nat}Ge)

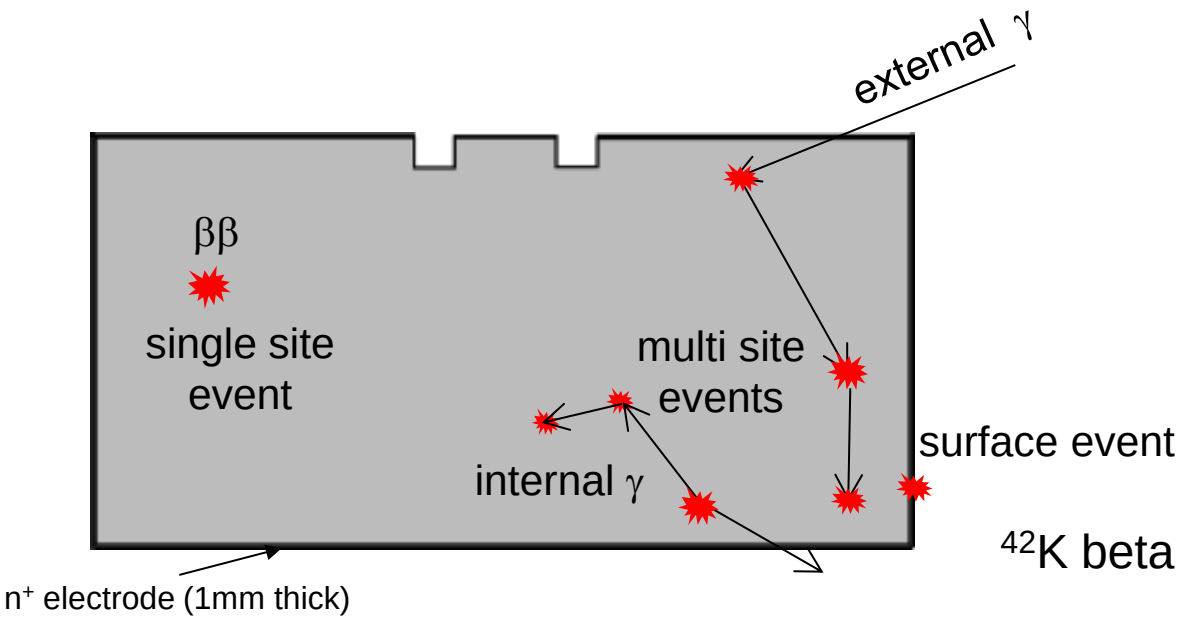
Phase II detector array & assembly



- 7 strings of detectors
- 15 pairs of ^{enr}Ge BEGe detectors mounted back-to-back
- 10 semi-coaxial detectors(7 ^{enr}Ge & 3 ^{nat}Ge)
- Reduction of material in vicinity of detectors
  - Detector mount & Front-end electronics
- ~1.5 reduction copper & PTFE mass per kg detector mass
- Replace as much copper as possible with intrinsically pure mono crystalline silicon

Pulse shapes discrimination (PSD) in BEGe detectors

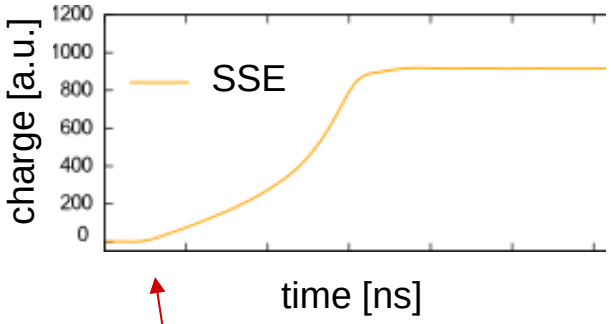
- Broad Energy Germanium Detectors (BEGe)
- Small read-out electrode -> low noise
- PSD enhanced by characteristic electric field in detector

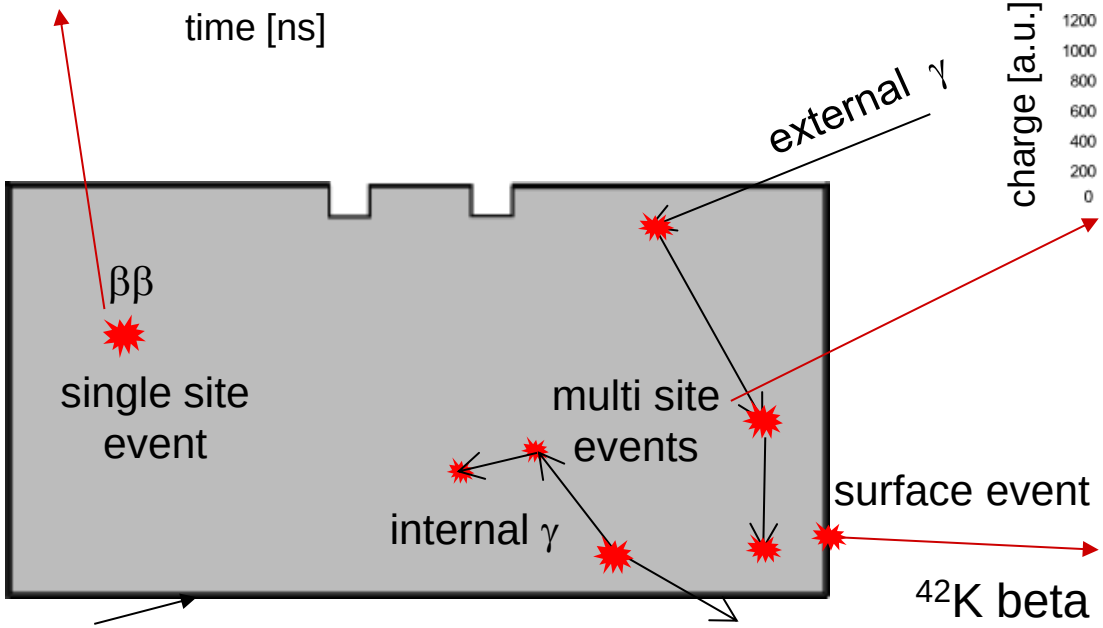


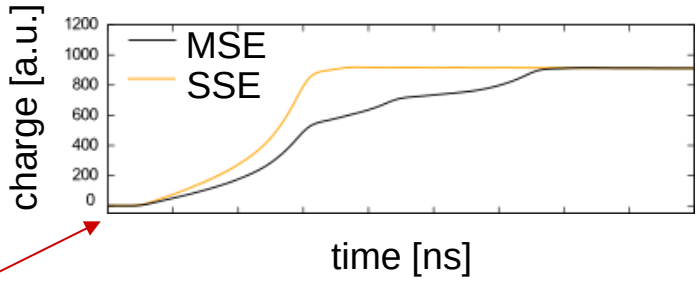
Pulse shapes discrimination (PSD) in BEGe detectors

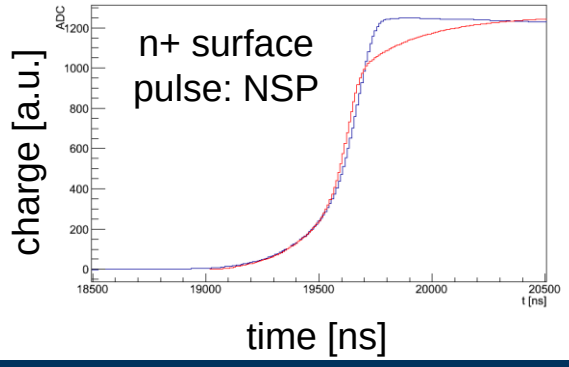
JINST, 4 (2009) P10007, JINST, 6 (2011) P03005,
Eur.Phys.J C73 (2013) 2583

Signal acceptance: 90%
Bkg acc. @$Q_{\beta\beta}$: <20% (Phase I)









LAr veto

- Energy deposition by background radiation

  → Characterisitic scintillation UV light @ 127 nm

  → Anti-coincidence veto

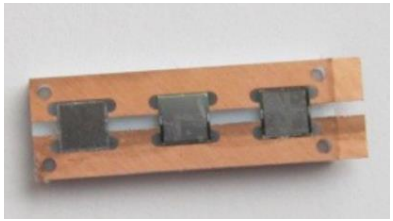
Requirements for instrumentation:

- Low induced background
- Deployment via GERDA lock
- Large instrumented volume

Design

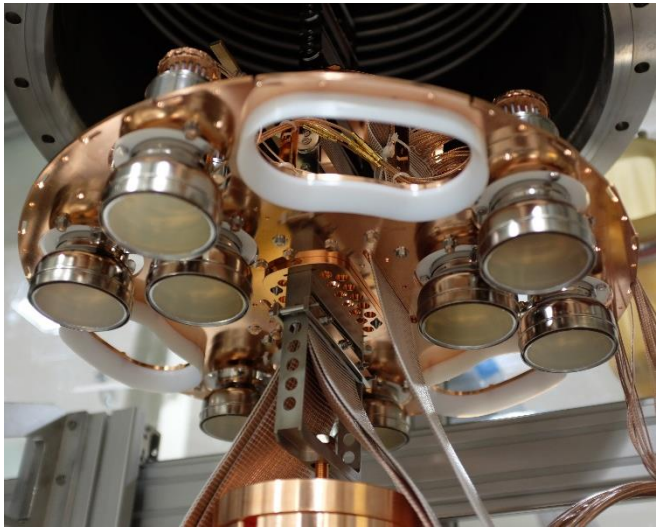
- Top/bottom plate: low bkg PMTs
- Optical fiber curtain coated with wavelength shifter TPB (127nm-> 430nm)
- „In-die“ SiPMs coupled to fibers

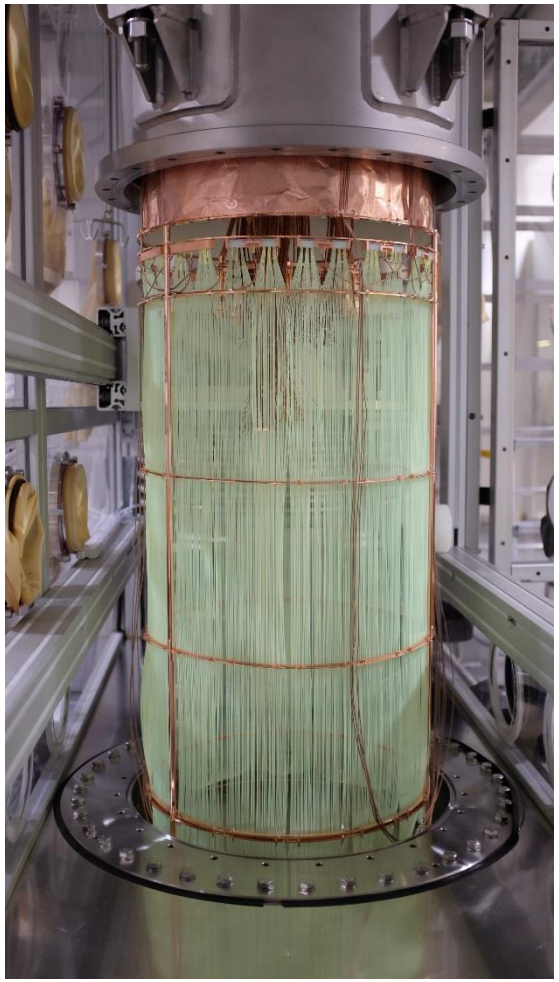
SiPM array



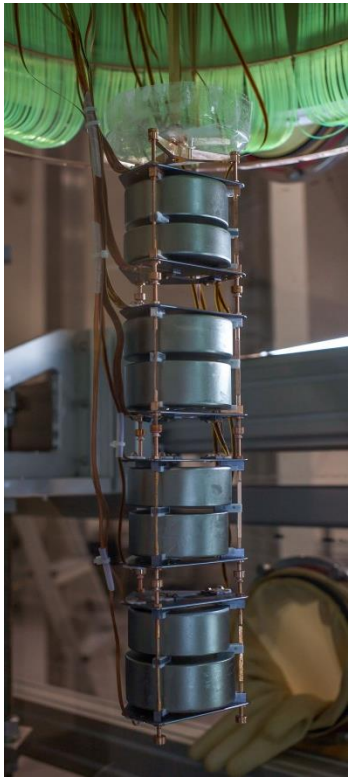
PMT

LAr veto

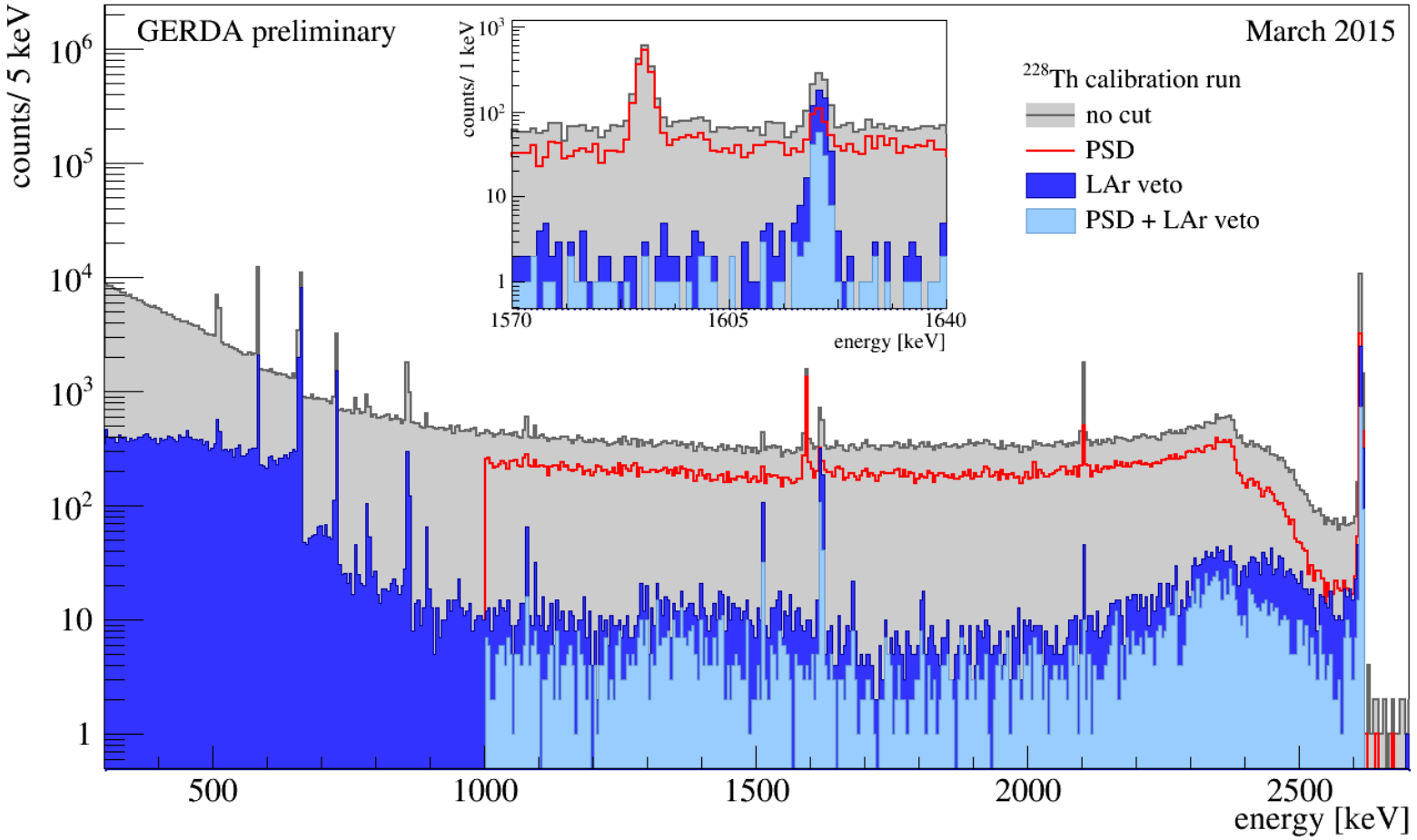




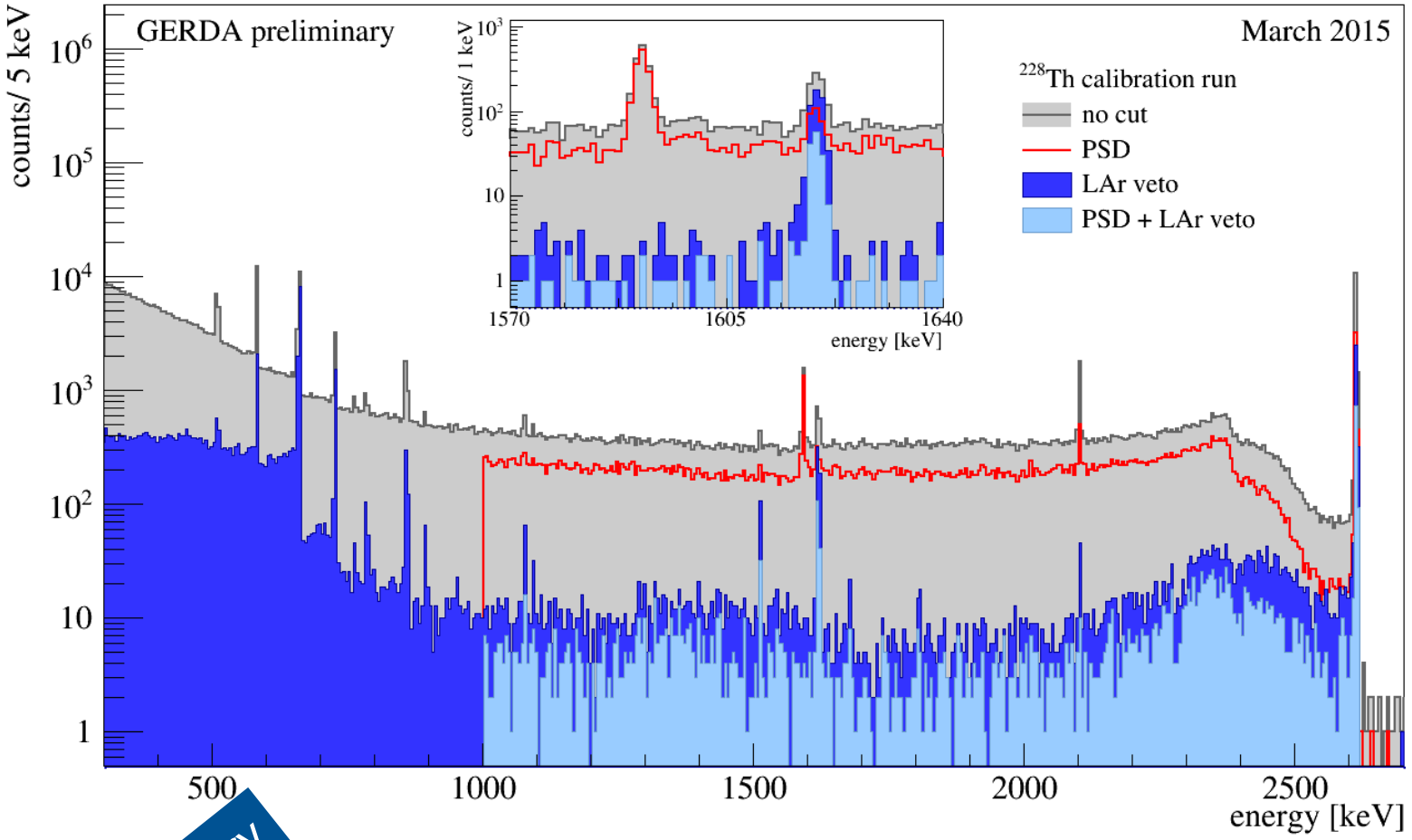
Phase II commissioning



- First integration of full string
- 4 BEGe from ^{enr}Ge
- 4 BEGe from ^{dep}Ge
- Preliminary energy resolution ΔE (FWHM)@ 2.6 MeV: ≈3keV



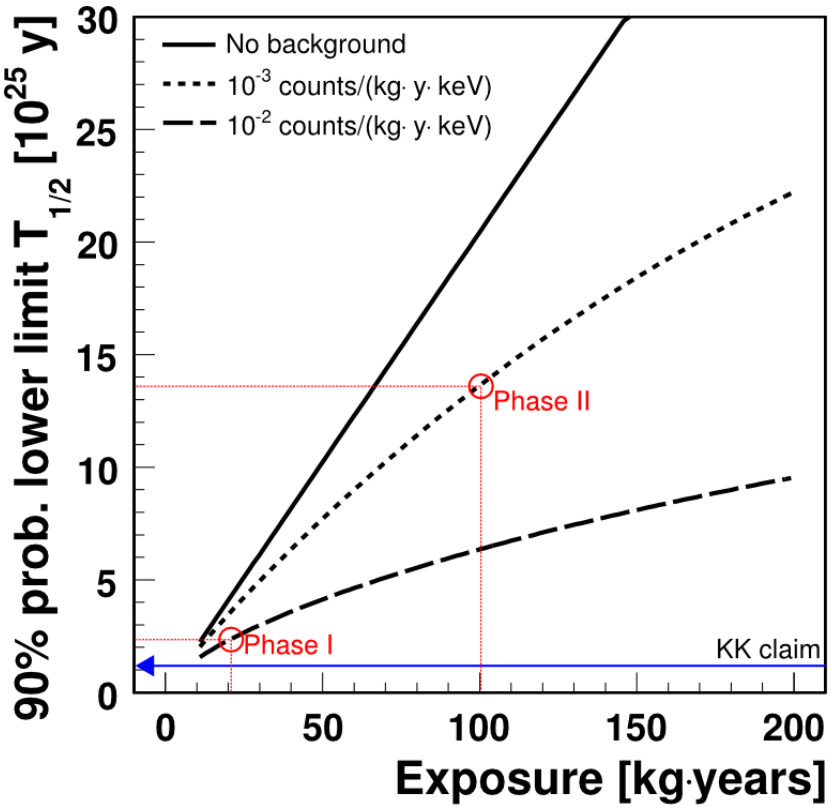
- 100 fold reduction of bkg around $Q_{\beta\beta}$ by combination of PSD and LAr veto cut with subset of Ge signal & LAr veto channels



- 100 f… duction of bkg around $Q_{\beta\beta}$ by combination of PSD and LAr veto cut wi… bset of Ge signal & LAr veto channels

Preliminary

Sensitivity of GERDA Phase II



- GERDA will reach 10^{26} half-life limit after 3 yr of data taking ($m_{\beta\beta}$<0.1 eV)
- For first year quasi-background free (expect <1 cts in ROI)

Summary and outlook

- Phase I successfully completed
- Several additional analysis carried out (2νββ & 0νββχ: arXiv:1501.02345; improved energy filtering: arXiv: 1502.04392)
- Improvements for Phase II extensive on all relevant parameters (mass, bkg, PSD efficiency,…)
- Commissioning of first string ongoing with promising preliminary results
- ΔE (FWHM)≈3keV@2.6MeV, supression factor (PSD & LAr veto) ≈ 100 for bkg events
- Work for deployment of full array ongoing

Thank you for your attention