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IN KRAKÓW

Searches for the Majorana neutrino in GERDA

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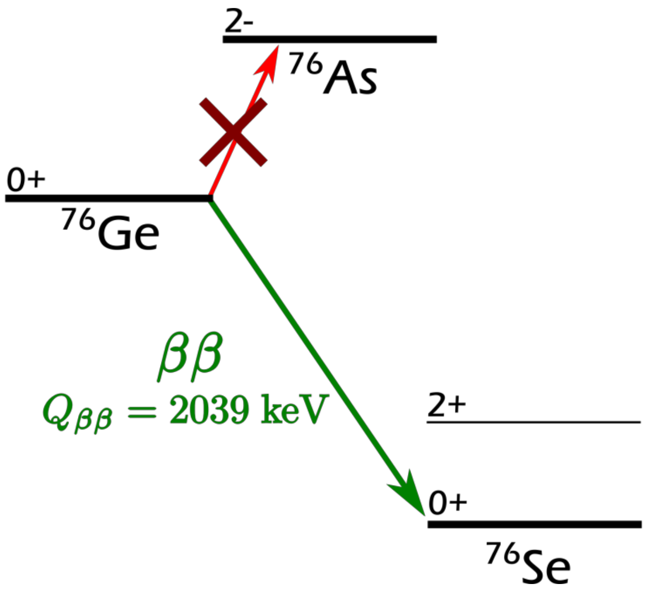
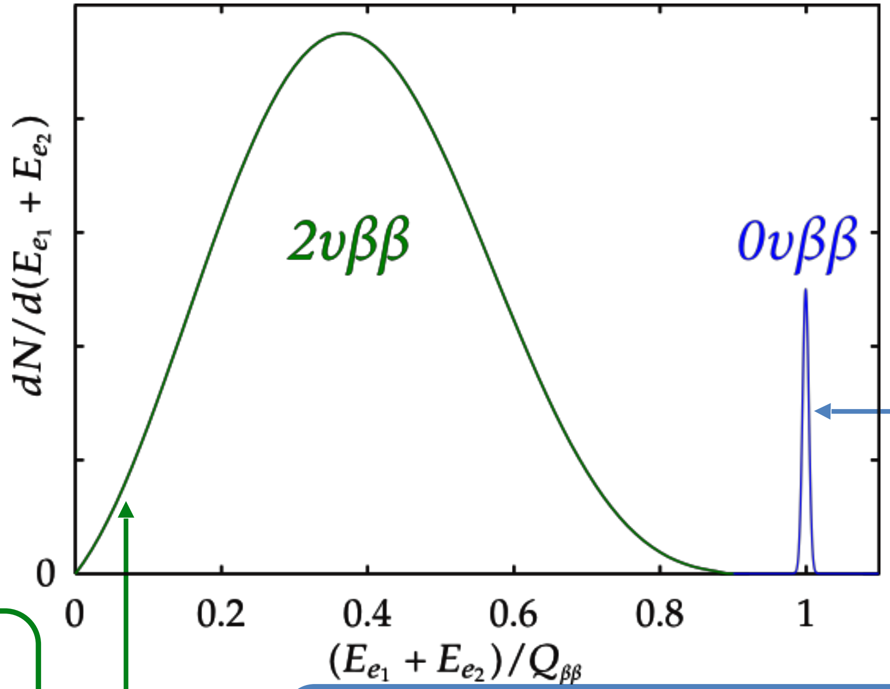
Outline

1. Majorana mass and neutrinoless double beta decay *(0νββ)*
2. GERDA experiment
3. LEGEND – towards 1 tone germanium *0νββ* observatory
4. Summary

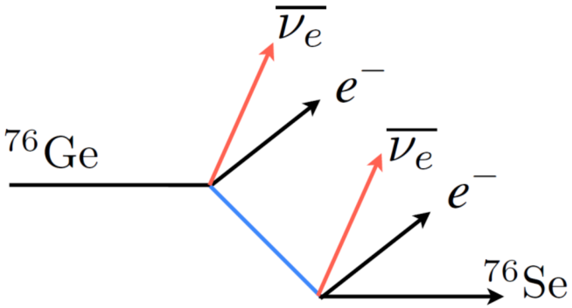
Neutrinoless double beta decay (0νββ)

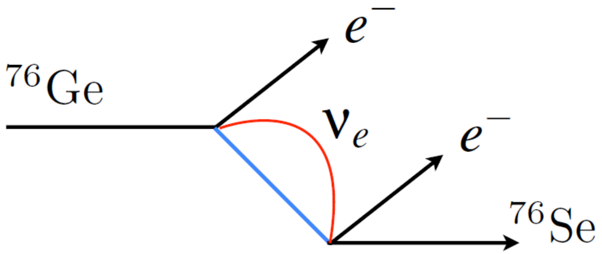




,

(^{76}Ge)

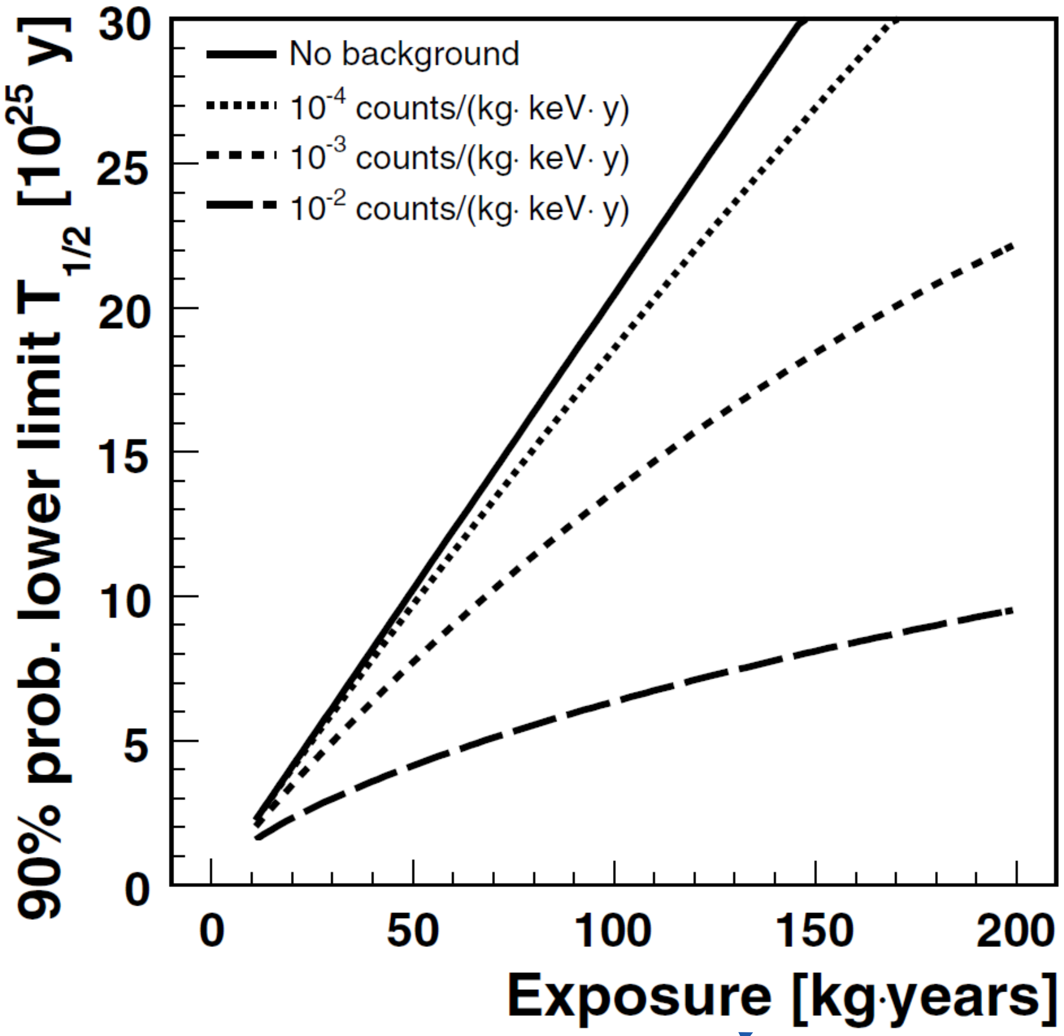




Neutrinoless double beta decay (*0νββ*)

- If *0νββ* observed:
  - violates the **Lepton Number by 2 units = New Physics!**
  - determines the nature of neutrinos: **Majorana particle ()**
  - gives information on the ***ν* mass via *$m_{\beta\beta}$*** (light neutrino exchange scenario)
  - has **never** been observed so far!

Sensitivity of the experiment



Exposure = isotope mass × meas. time

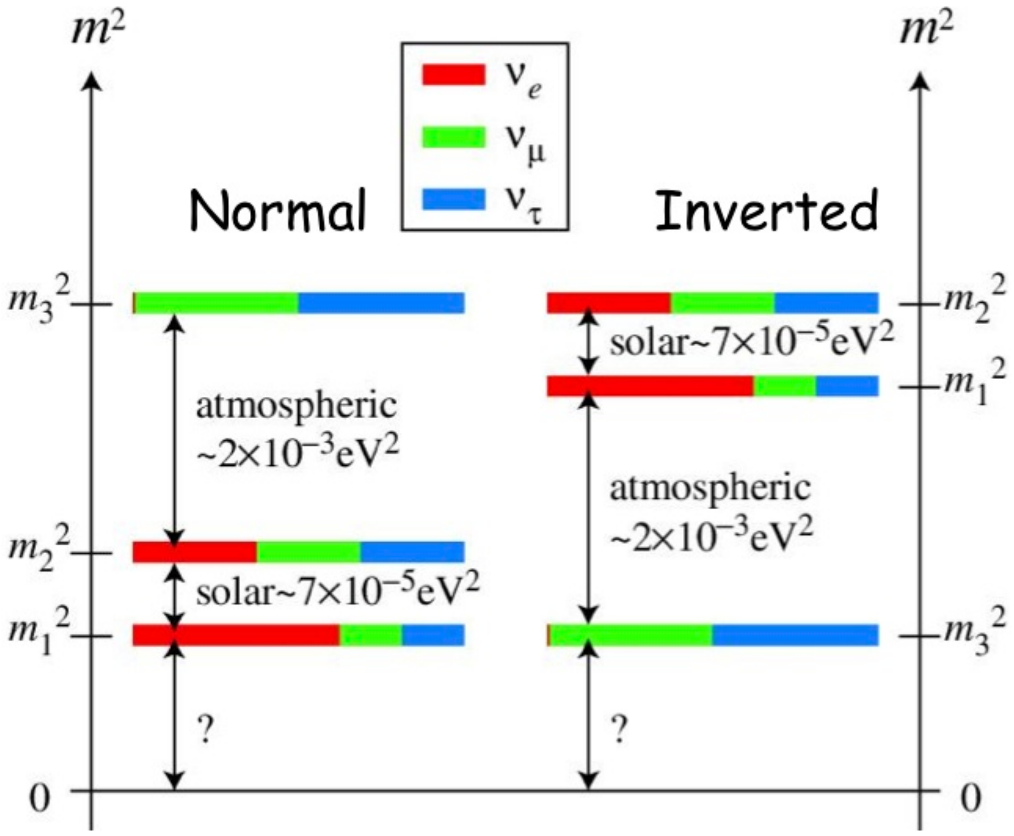
Half-life limit calculation:

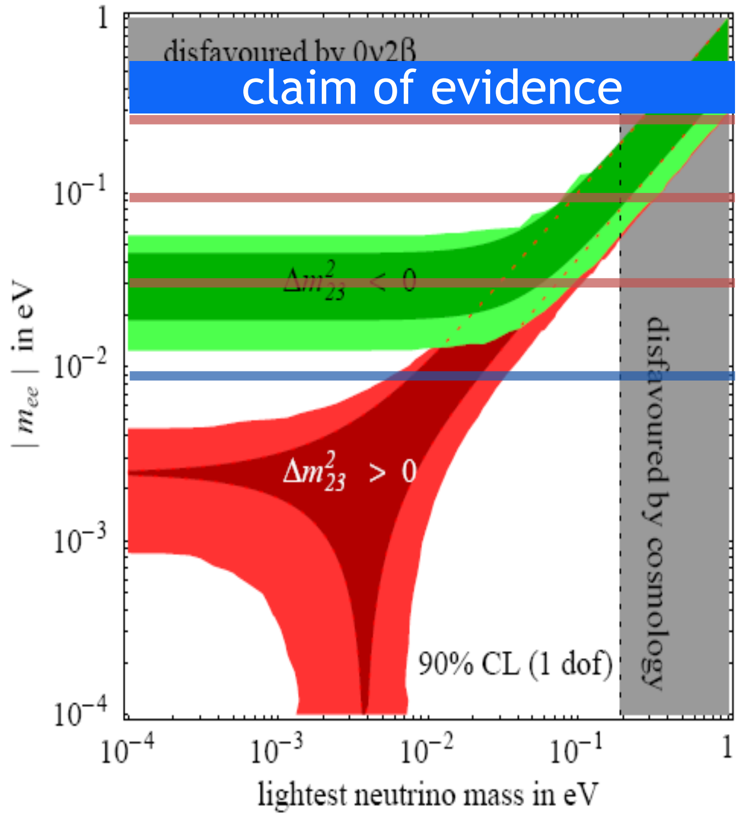
- No background:
- With background:

High **background level** (B) causes a saturation of the sensitivity curve!

Lowering background is the key in this kind of experiments!

Neutrino mass – inverted or normal hierarchy?





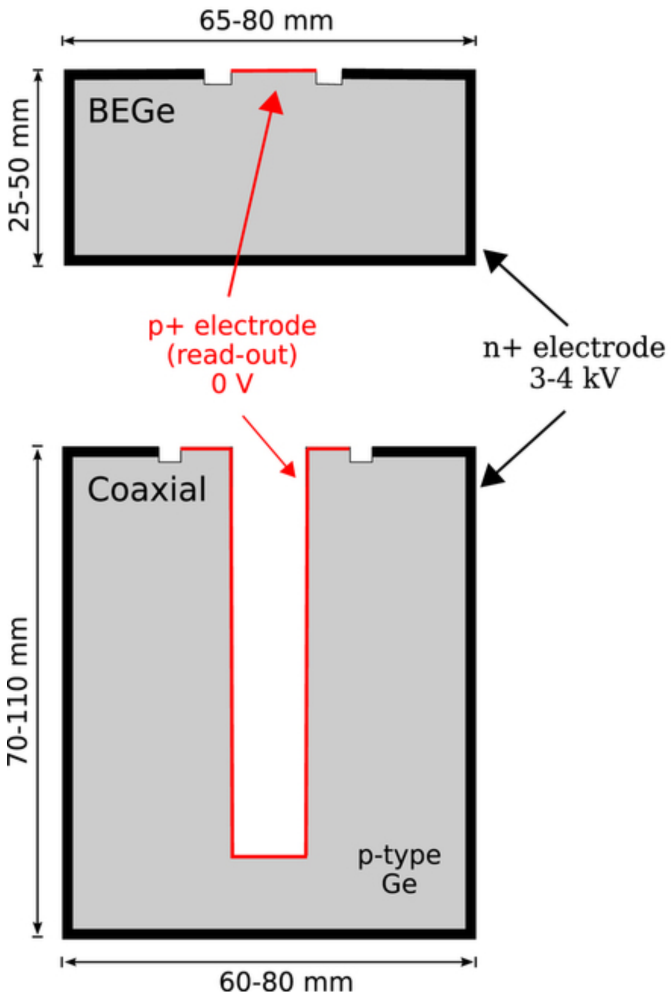
- Determining the limit on effective neutrino mass can reject **inverted hierarchy** hipothesis

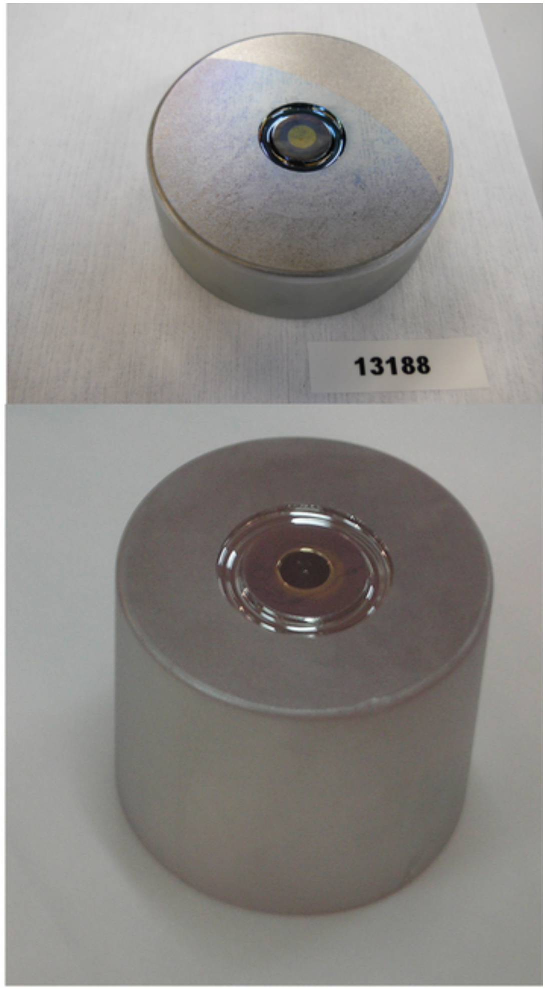
Effective neutrino mass calculation:

- effective neutrino mass
- space phase factor
- nuclear matrix element

GERDA experiment

- **GERDA** (**GER**manium **Detector Array**) has been designed to investigate neutrinoless double beta decay of ^{76}Ge ()
  - Ge mono-crystals are **very radiopure**
  - Ge detectors **have excellent energy resolution**
  - High **detection efficiency** (detector = source,)
  - Enrichment of ^{76}Ge required (7.4% → 86%)

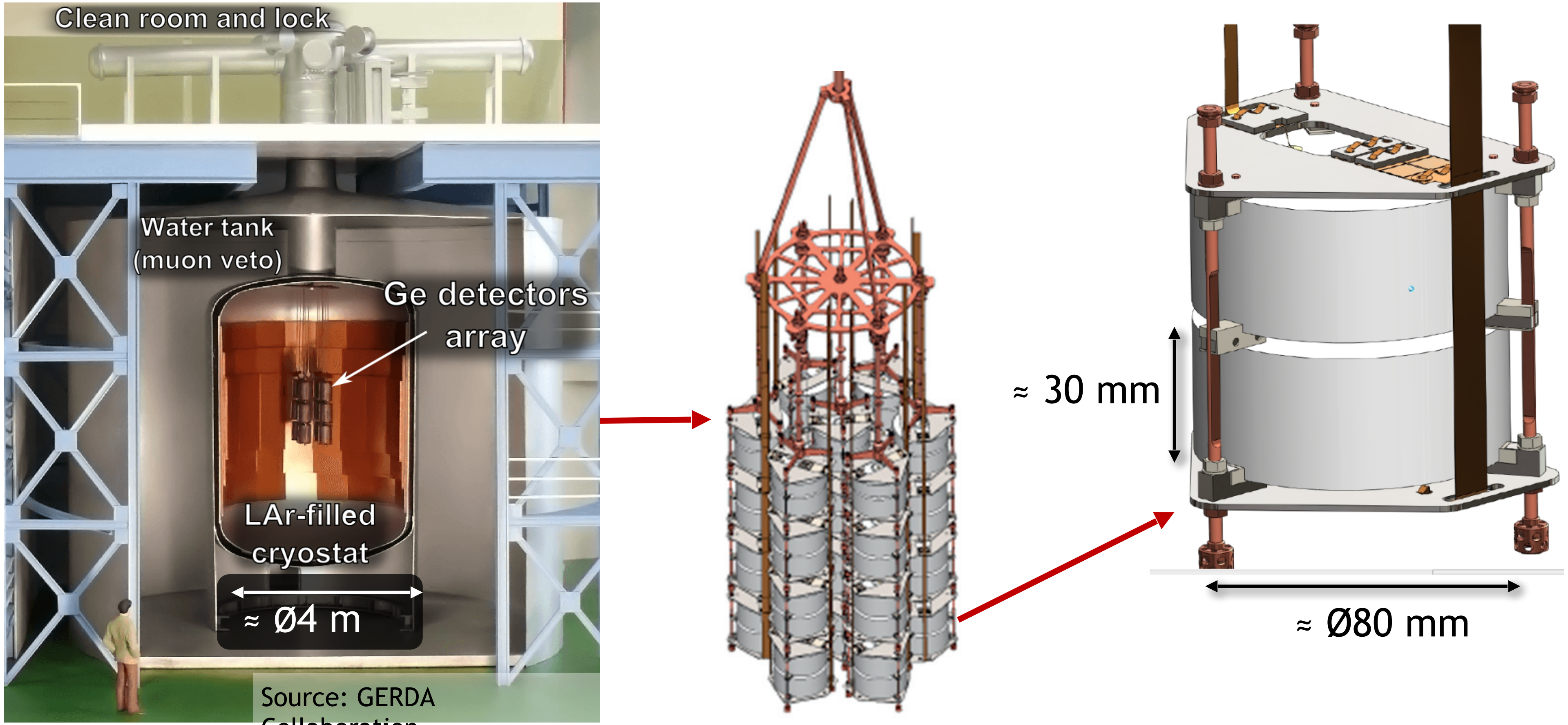




Source: GERDA collaboration

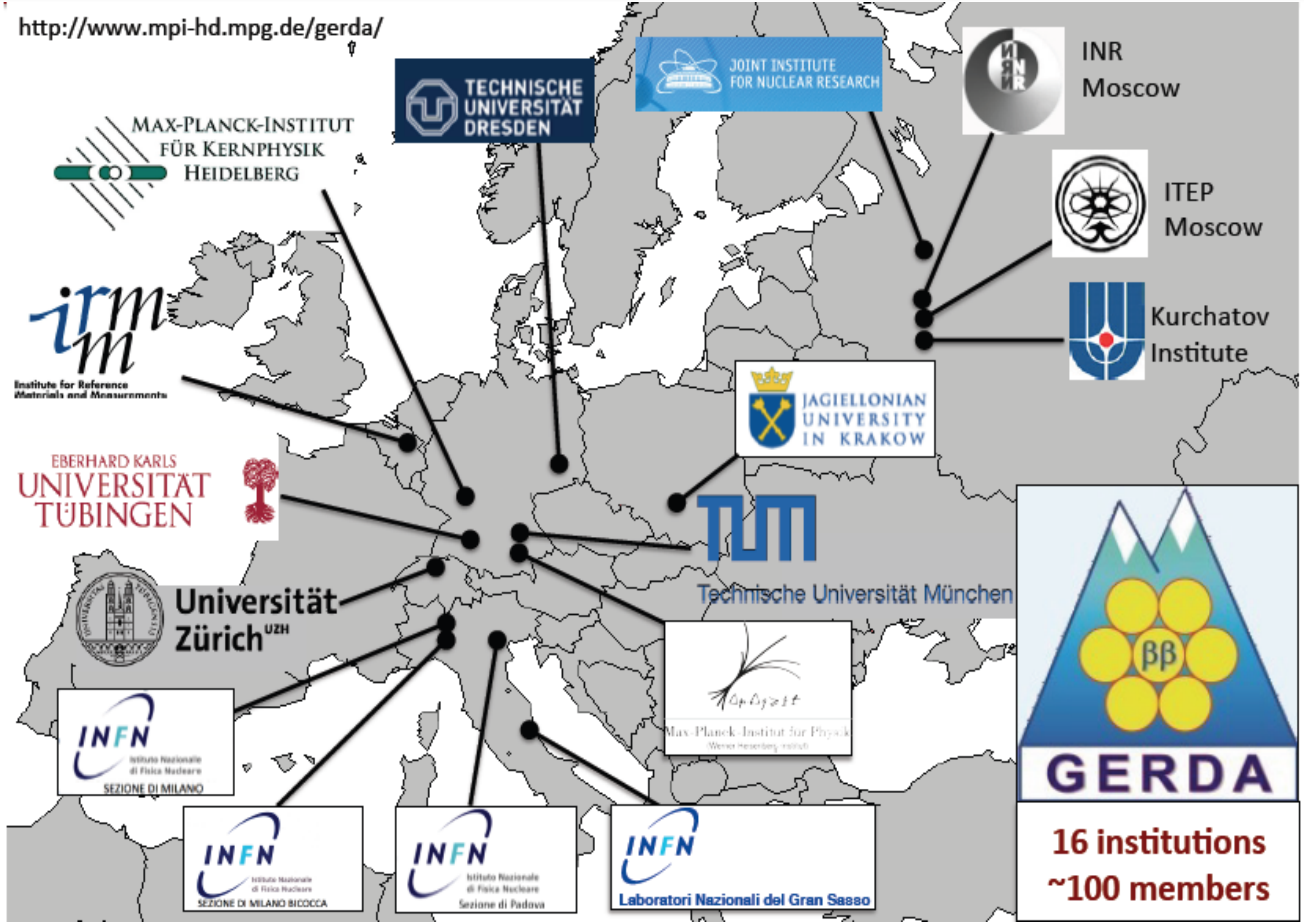
Design of GERDA

- Main design features:
  - bare HPGe diodes immersed in LAr (cooling)
  - Readout of LAr scintillation light via PMTs and SiPM (active veto)
  - Readout of germanium signals

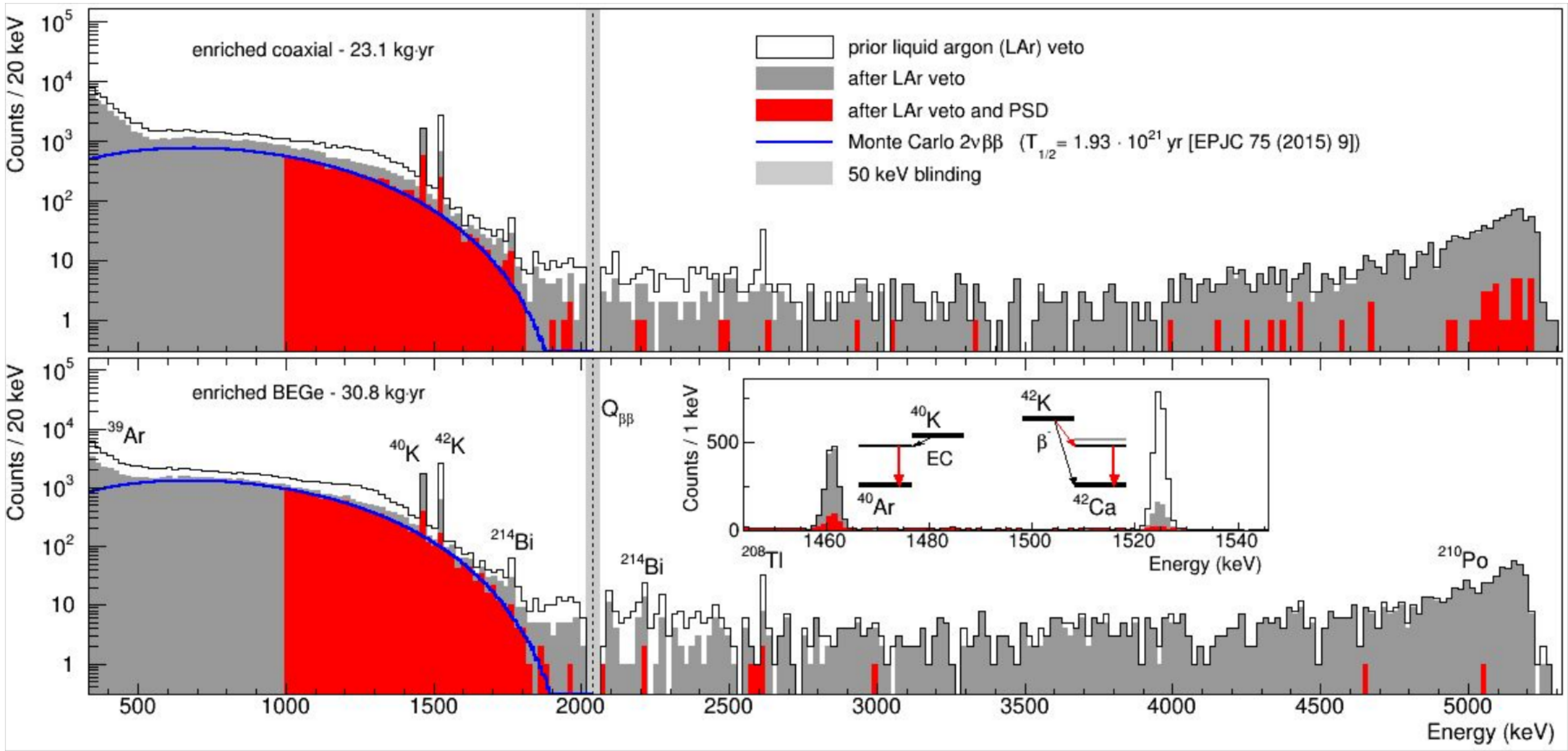


Source: GERDA Collaboration

GERDA: the collaboration



GERDA Phase II results

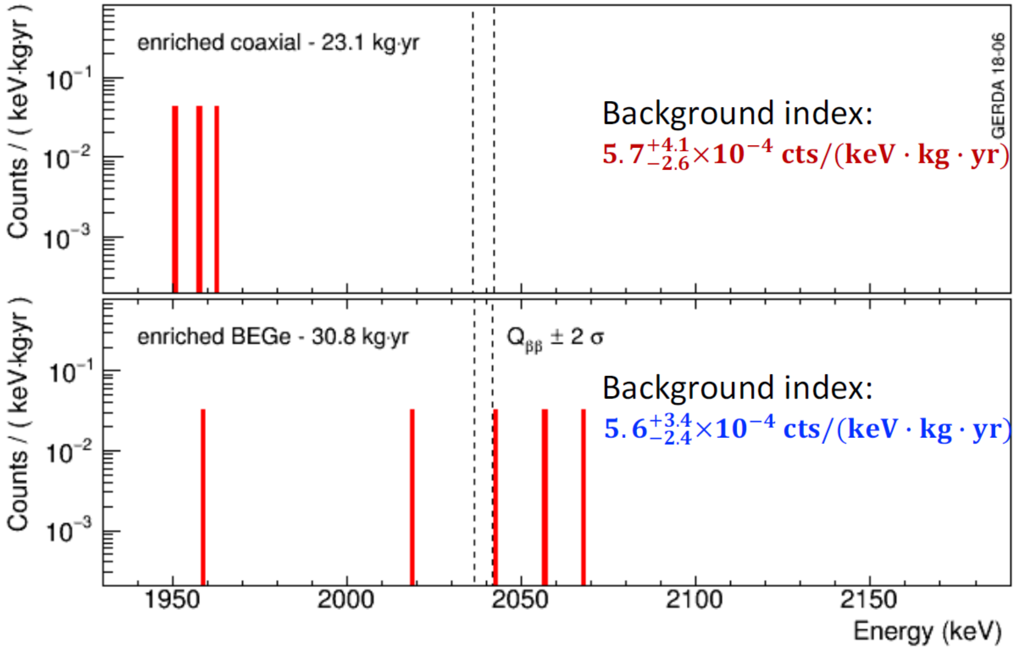


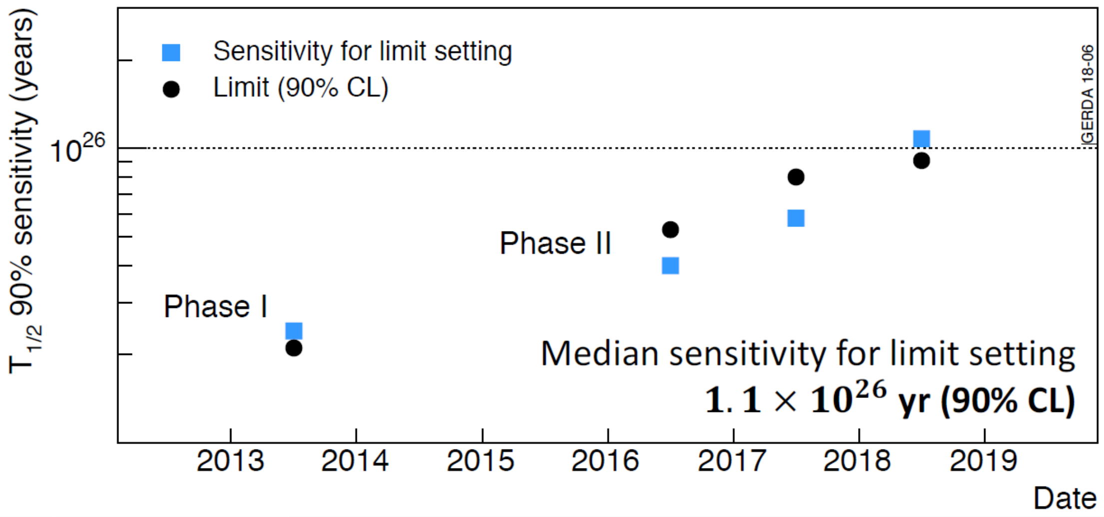
10.5281/zenodo.1287604
Neutrino (2018)
Y. KERMAÏDIC @ La Thuile 2019

- Energy spectrum of GERDA Phase II (**58.9 kg·yr of exposure**)
- [600-1300] keV - $2\nu\beta\beta$ decays produce single-site events -> No suppression
- [1450-1530] keV - Strong suppression of ^{40}K and ^{42}K gamma lines (MSE)
- [> 3000] keV - Suppression of almost all α events (p^+ contact)

GERDA Phase II results

- Achieved **extremely low background index** (for both semi-coaxial and BEGe datasets)
  - best in the field when normalized to FWHM (ca. 3.0-3.5 keV)
- Median sensitivity for limit setting **$1.1 \cdot 10^{26}$ yr (90% CL):**
  - Best fit → no signal
  - $T_{1/2} > 0.9 \cdot 10^{26}$ yr (90% CL)
- GERDA is operating in **background-free** regime (linear increase of sensitivity)
- **100 kg·yr of exposure** is planned to be reached by the end of 2019
- **$1.3 \cdot 10^{26}$ yr** (for the limit) or ~ **$8 \cdot 10^{25}$ yr** (50% for 3σ discovery)





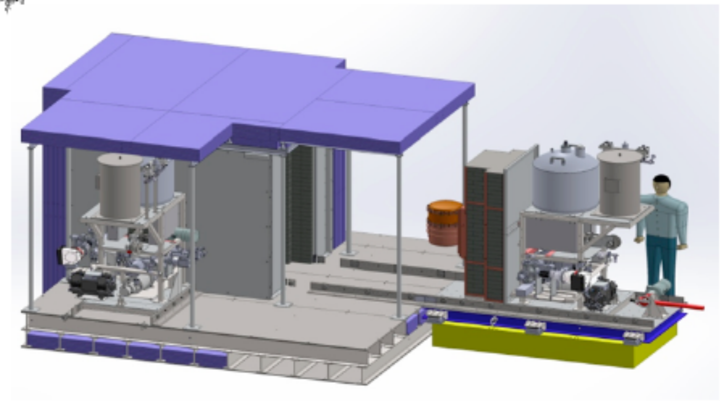
10.5281/zenodo.1287604 Neutrino (2018), Y. KERMAÏDIC @ La Thuile 2019

LEGEND: beyond GERDA Phase II

GD + MJD + new groups = LEGeND (Large Enriched Germanium Experiment for Neutrinoless Double Beta Decay)

GERDA

Majorana-Demonstrator (MJD)



- **Physics goals:** investigation of degenerate neutrino mass range
- **Technology:** study of background reduction techniques
- First phase: LEGEND 200 → exposure of 1 t·yr
- Final phase: LEGEND 1T → exposure of 10 t·yr

LEGEND design

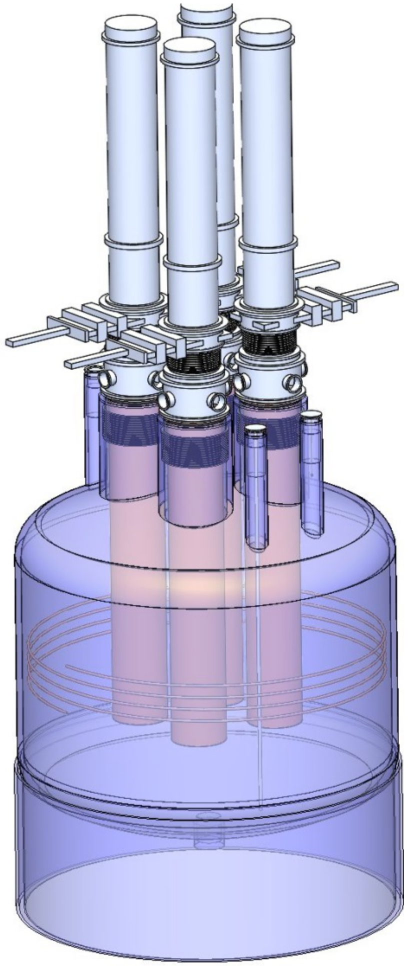
First phase:
- (up to) 200 kg
- Adaptation of existing GERDA infrastructure at LNGS
- Background goal (3-5x lower)

GERDA cryostat

LEGEND

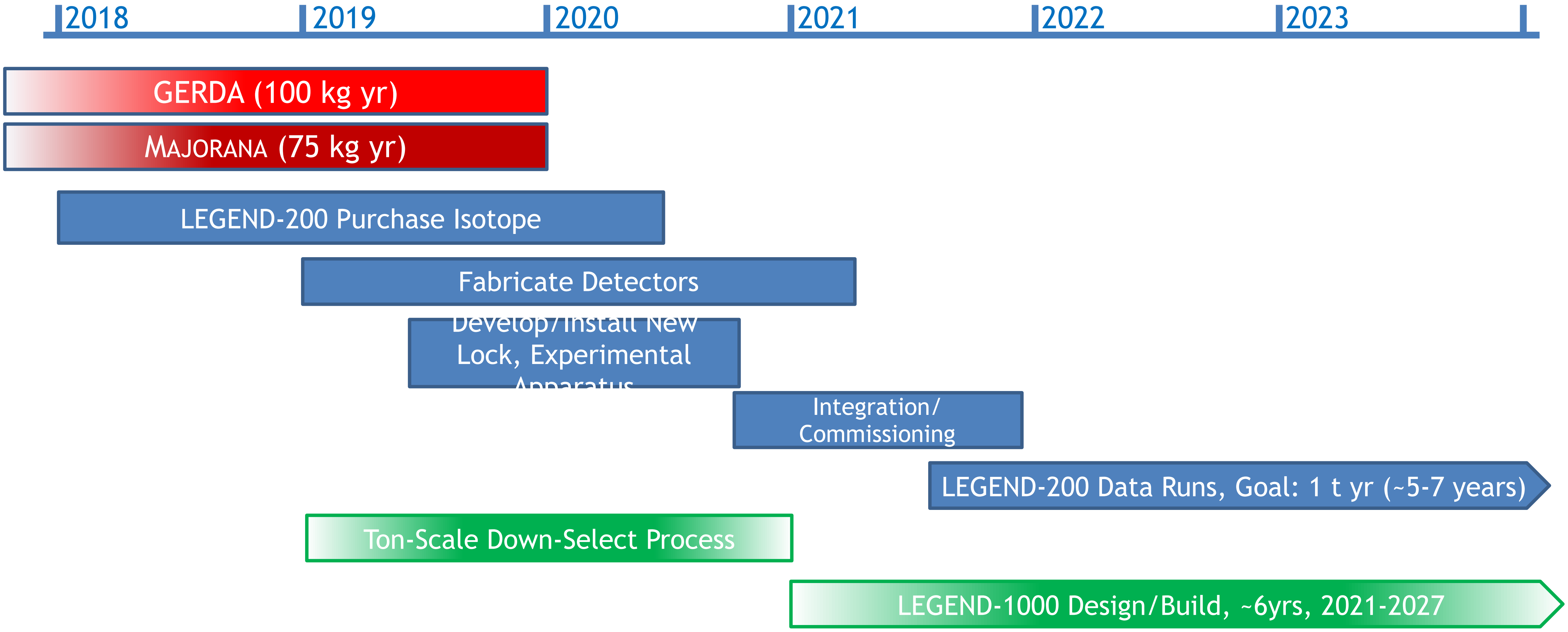
Large Enriched
Germanium Experiment
for Neutrinoless ββ Decay

Next stages:
- 1000 kg (staged)
- Background reduction: factor 30 w.r.t GERDA
- Location: TBD



LEGEND 1000:
Baseline design
of the cryostat

LEGEND - schedule



Earliest LEGEND-1000 Data Start 2025/6

GERDA: Polish contribution and acknowledgments

- IF UJ: member of the GERDA collaboration since its formation
- Contribution to **low background techniques**, **electronics** and **data analysis**:
  - **Removal of radon daughters** from metals
  - Investigation of **radon daughters** in cryogenic liquids
  - **LArGe** – **liquid argon veto** test facility
  - **Pulse Shape Discrimination** in semicoaxial detectors using Projective Likelihood method
  - **PMT scaler** used for **LAr veto** in Phase II
  - research on **HPGe detectors technology**

- Cracow's group involvement in GERDA supported by **National Science Centre** and **Foundation for Polish Science** grants (UMO-2012/05/E/ST2/02333, UMO-2016/21/B/ST2/01094, TEAM/2016-2/2017)

- **The most important papers:**
  - The GERDA experiment for the search of 0νββ decay in ^{76}Ge, ***The European Physical Journal C***, 2013
  - Results on Neutrinoless Double-β Decay of ^{76}Ge from Phase I of the GERDA Experiment, ***Phys. Rev. Lett.*** **111**, 2013
  - Background-free search for neutrinoless double-β decay of ^{76}Ge with GERDA, ***Nature***, 2017

National Science Centre
Poland

FNP Foundation for Polish Science

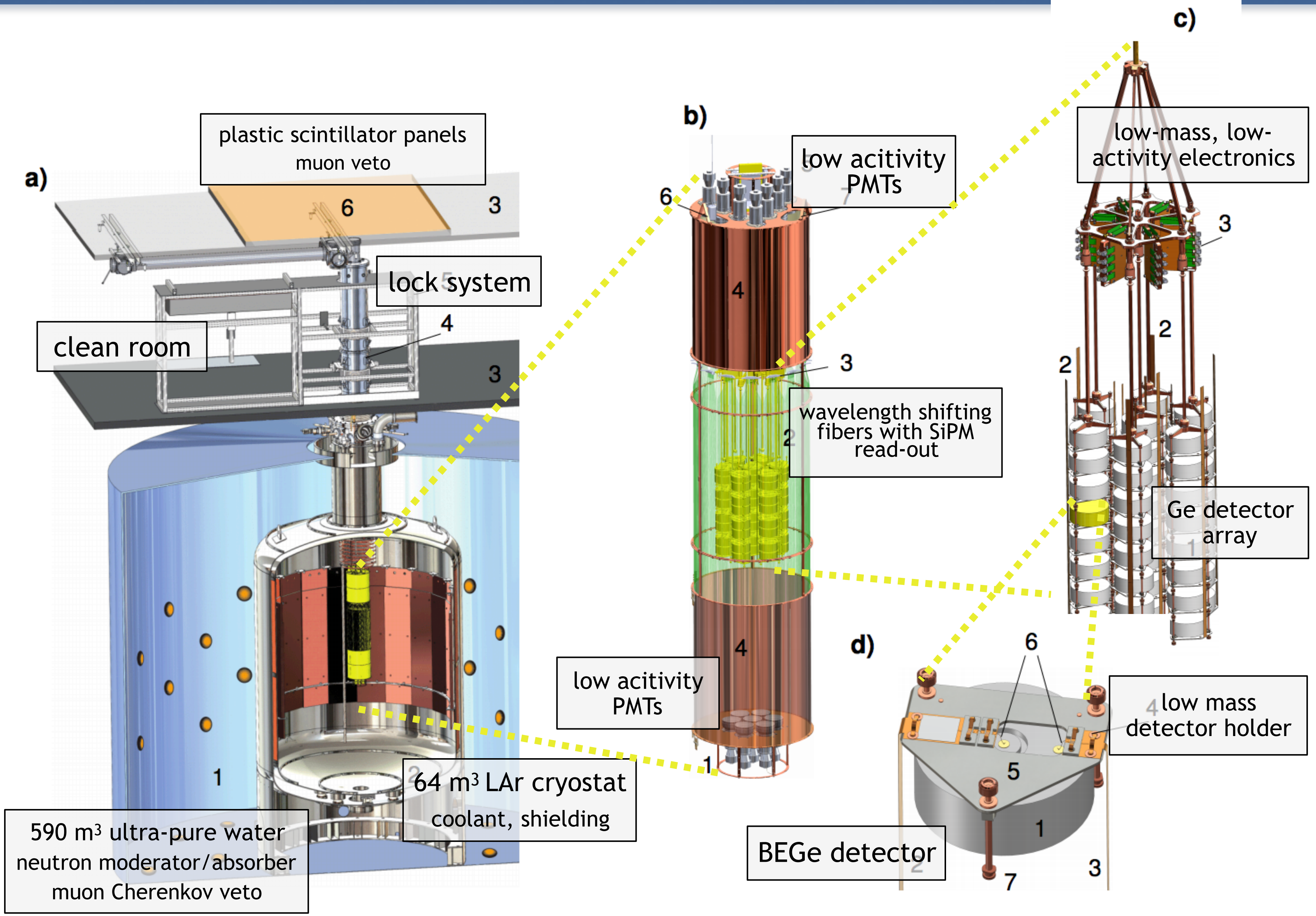
Summary

- **GERDA**– searching for **$0\nu\beta\beta$ in ^{76}Ge** (best en. resolution, high radiopurity)
- Lowest background level achieved in the field of $0\nu\beta\beta$ experiments ()
- Operating in the background-free regime (**< 1 cts** in the $Q_{\beta\beta}$ energy window for the target exposure of **100 kg·yr**)
- The decay is **not yet observed**, the limit on the half-life: $T_{1/2}$ **> 0.9·10^{26}** yr (90% CL)
- **LEGEND** – worldwide collaboration, aiming at **10 t·yr** → $T_{1/2}$ **> 10^{28}** yr → $m_{\beta\beta}\approx$**17 meV**
  - Possibility to exclude inverted-hierarchy hypothesis, but also large discovery potential!

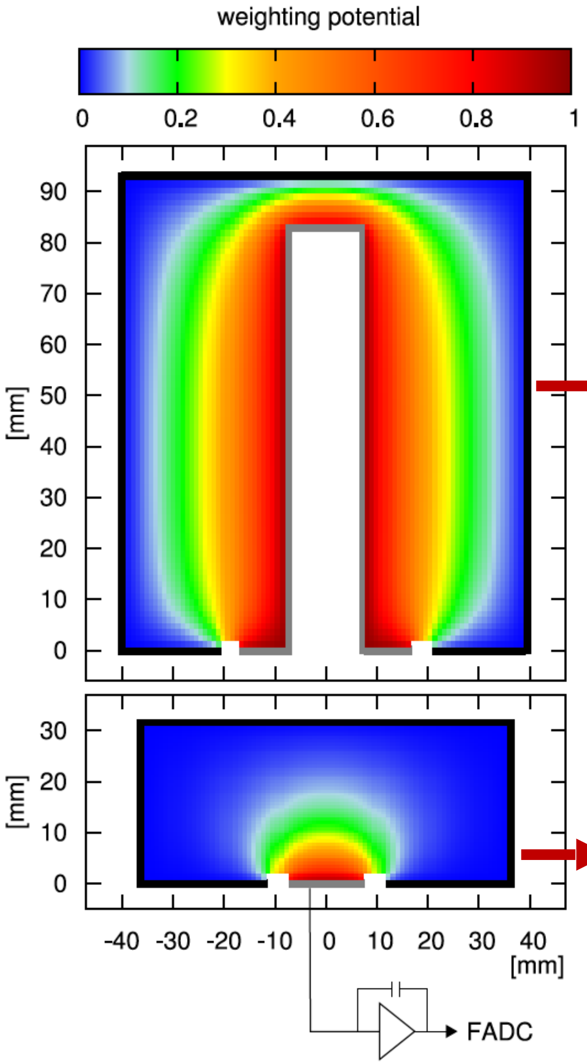
Thank you for attention!

Backup slides

GERDA in more detail

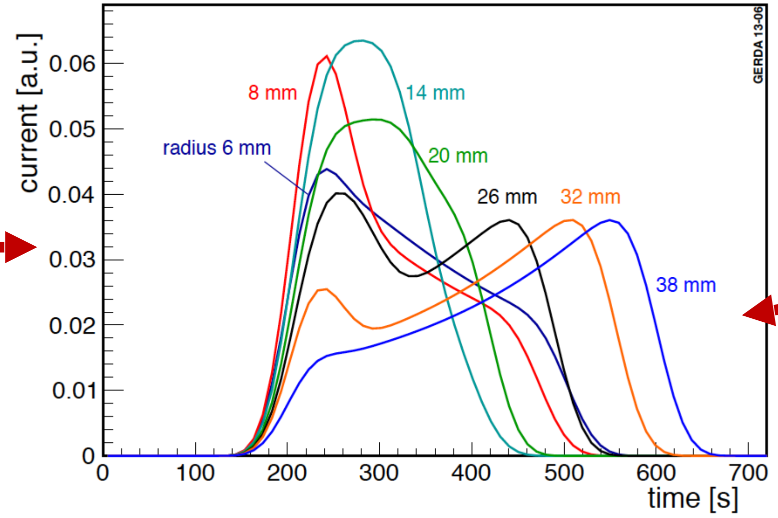


Pulse Shape Analysis

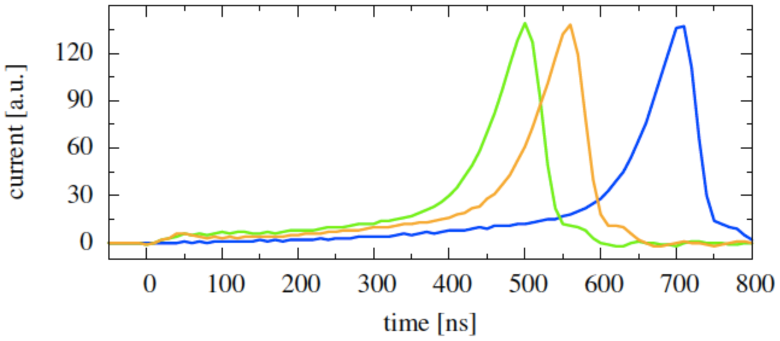


[arXiv:1307.2610](https://arxiv.org/abs/1307.2610), [arXiv:1012.4300](https://arxiv.org/abs/1012.4300)

Simulated current pulses
in a semi-coaxial detector

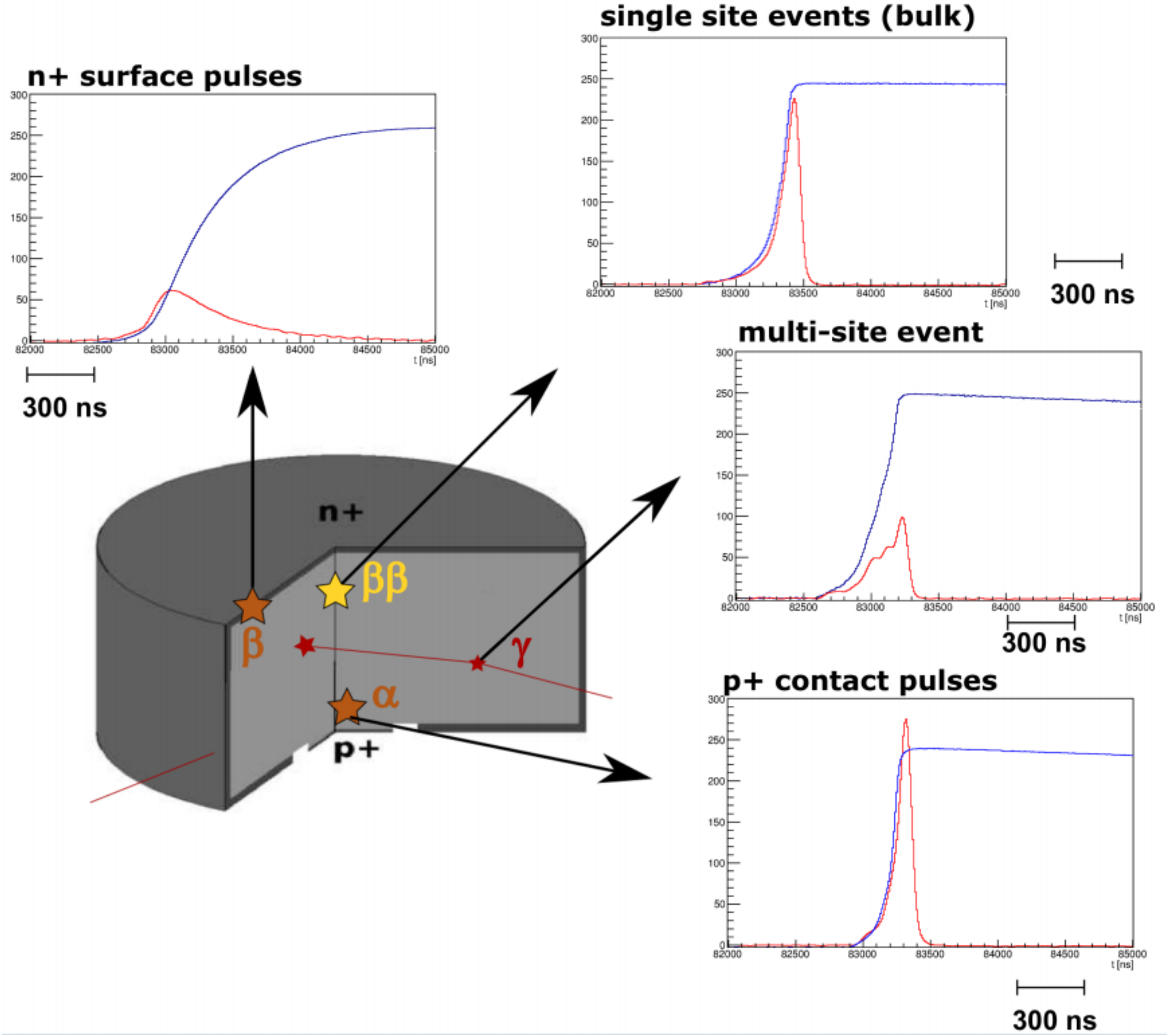


Simulated current pulses in a BEGe



Different signal structure than in BEGes (due to E-field) - A/E does not work!

Pulse Shape Analysis

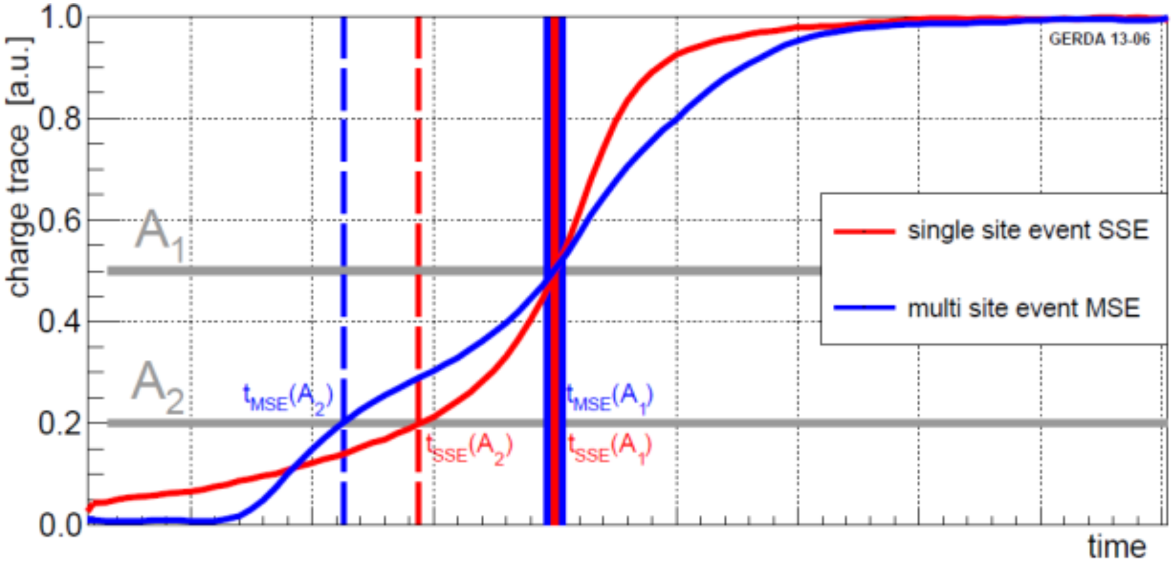


Source: A. Lazzaro talk at DPG Spring meeting, "Hadronen und Kerne" HK, 23.-27.3. 2015

- **Single site events** – single energy deposition in the detector (, single Compton scattering)
- **Multi site events** – multiple energy deposition in detector (gamma Full Energy Peaks, Single Escape Peak)
- **Surface events (n^+ and p^+ contacts) -** α and β particles

Pulse Shape Analysis

- PSD for coax detectors less effective than for BEGes
- Artificial neural network (**ANN**), as in Phase I
  - Trained on signal (SSE) : ^{208}Tl (2614 keV) DEP at 1592 keV
  - Background (**MSE**): ^{212}Bi @ 1620 keV FEP γ-line
  - Acceptance for 0νββ events: **(85±5)%**
    - Double check with Compton edge and 2ν2β
    - MC simulation of waveforms



Eur. Phys. J. C 73 (2013) 2583
Nature 544 (2017) 47

Analysis range