Search for neutrinoless ββ decay Results from Phase I of the GERDA experiment

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on behalf of the GERDA Collaboration

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National Centre for Nuclear Research (NCBJ) and the Department of Physics of the University of Warsaw (UW)

Outline

- Design and goals of GERDA
- Phase I results
- Phase II status
- Conclusions

Neutrinoless ββ beta decay (0νββ)

If 0νββ is observed:

- Neutrino is a Majorana particle (its own antiparticle)
- Lepton number is not conserved
- Dealing with physics beyond the Standard Model

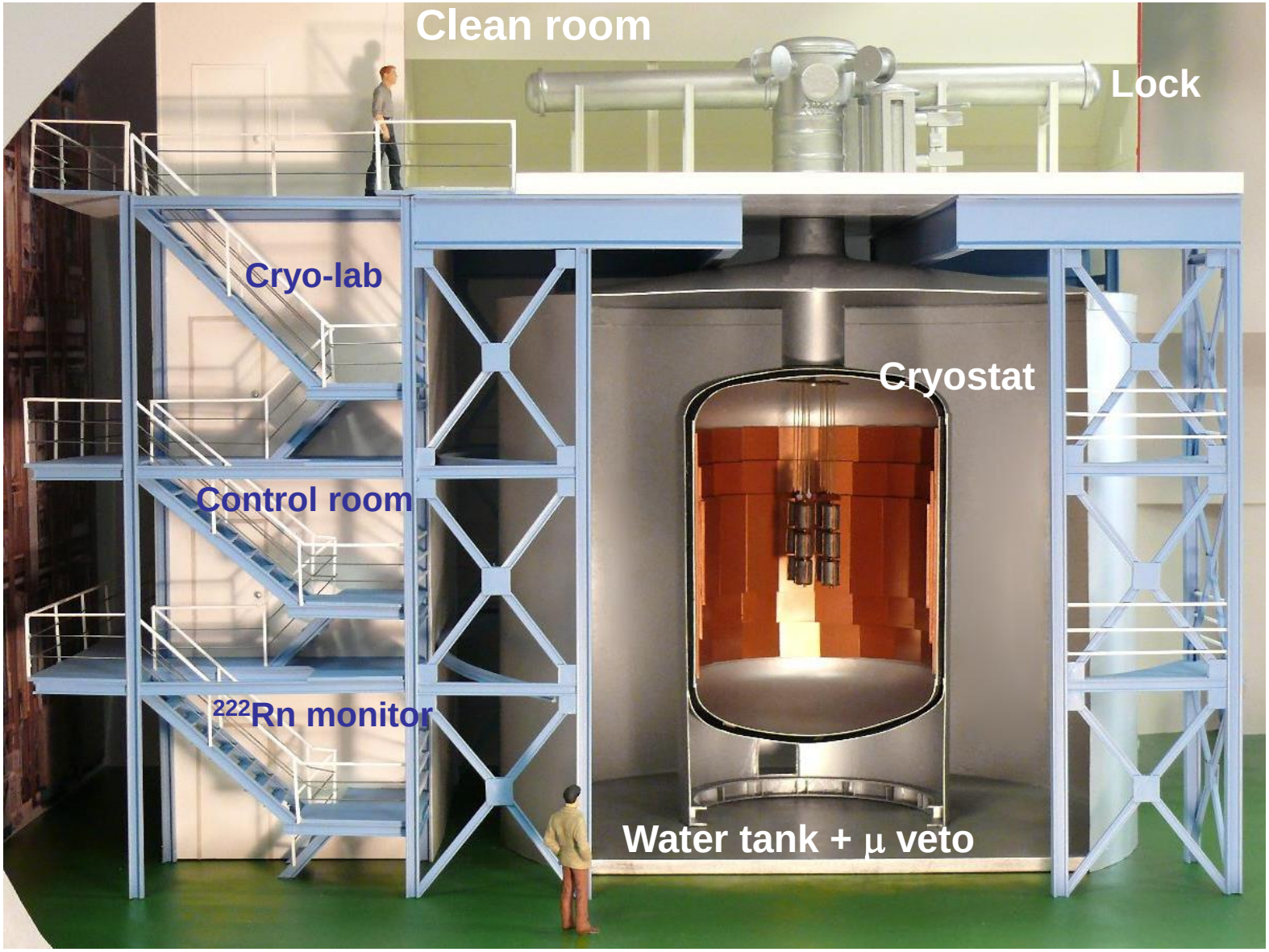
- Absolute neutrino mass scale
- Neutrino mass hierarchy

Significant contribution to Particle Physics, Astrophysics and Cosmology

GERDA

- GERDA (GERmanium Detector Array) has been designed to investigate neutrinoless double beta decay of ^{76}Ge ($Q_{\beta\beta}$ = 2039 keV)
  - Ge mono-crystals are very pure
  - Ge detectors have excellent energy resolution
  - Detector = source ($\varepsilon \approx 1$)
  - Enrichment required (7.4 % $\rightarrow$ 86 %)
- Background (index) around $Q_{\beta\beta}$: 10^{-2} – 10^{-3} cts/(keV×kg×yr); 10 – 100 times lower compared to previous experiments (HDM/IGEX)

GERDA Detector Design



- GERDA D&G
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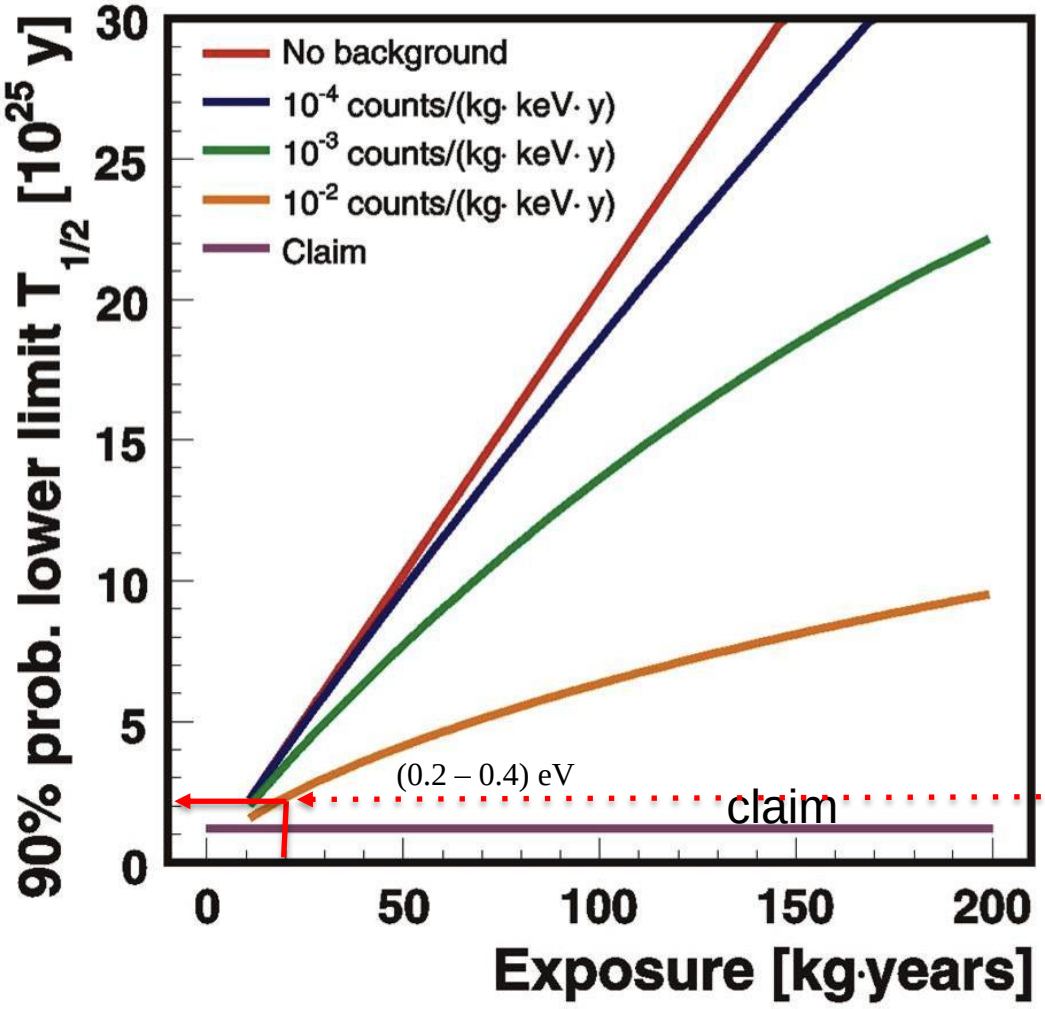
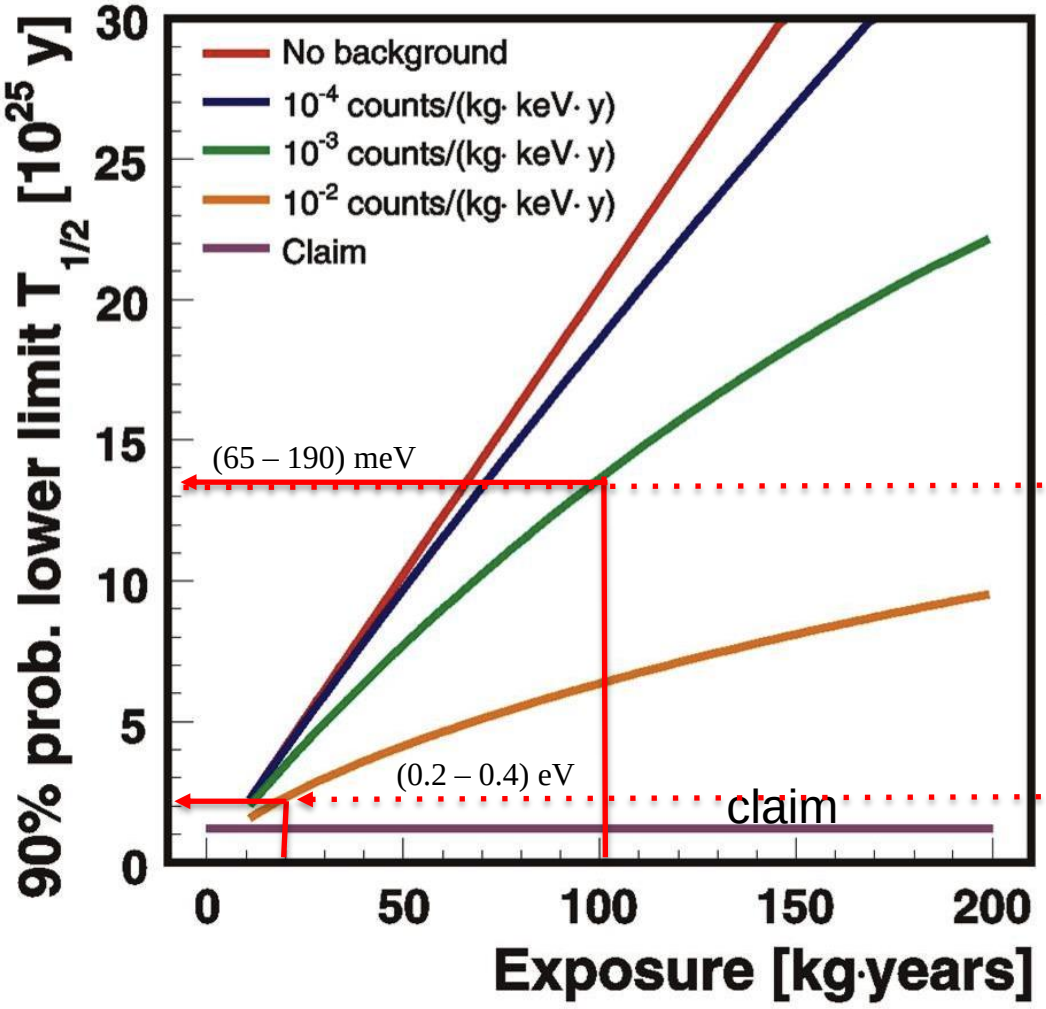
GERDA

Realization in phases



Phase I:
Use refurbished
HDM & IGEX (18 kg)
BI ≈ 10^{-2} cts / (keV×kg×yr)
Sensitivity after 20 kg×yr

Realization in phases



Phase II:
Add new enr. BEGe detectors (+20 kg, 35 kg tot.)
BI ≈ 10^{-3} cts / (keV×kg×yr)
Sensitivity after 100 kg×yr

Phase I:
Use refurbished HDM & IGEX (18 kg)
BI ≈ 10^{-2} cts / (keV×kg×yr)
Sensitivity after 20 kg×yr

GERDA

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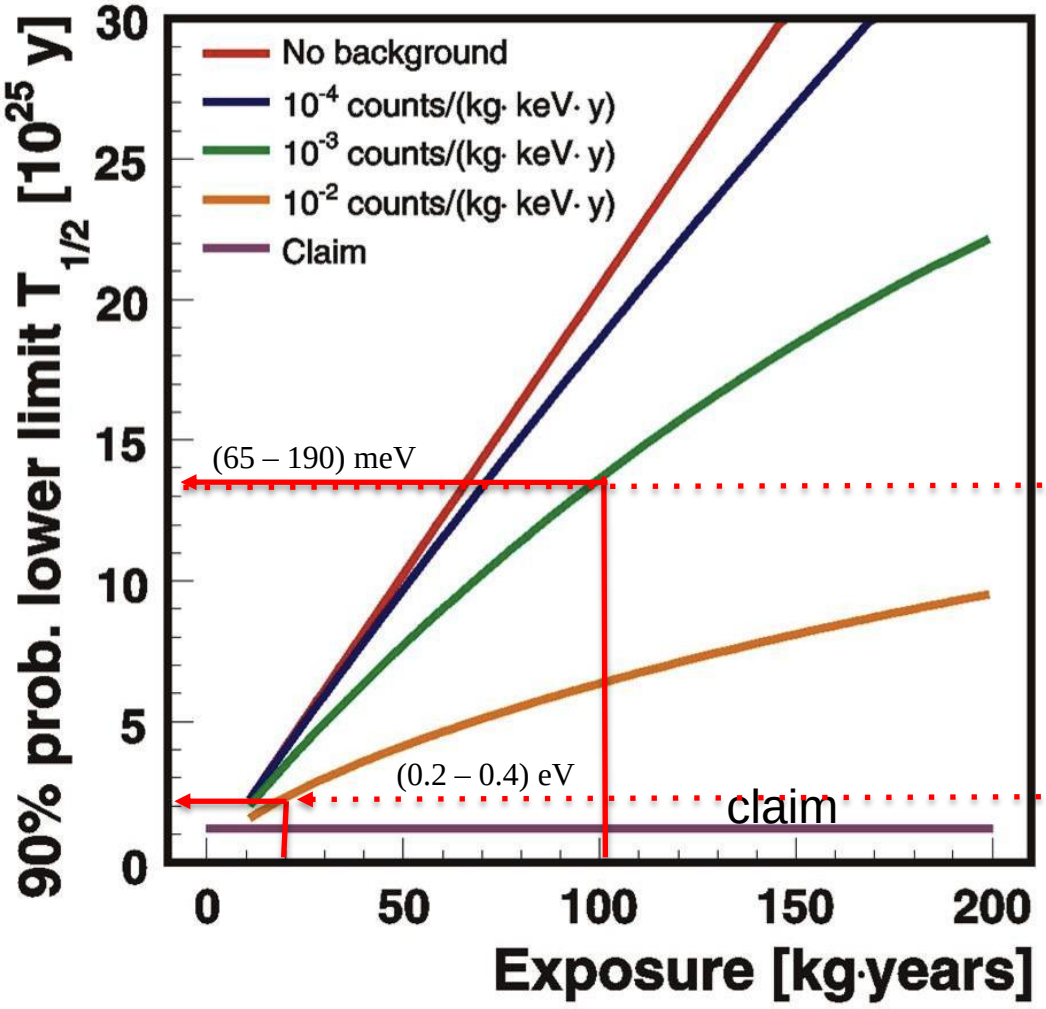
Realization in phases

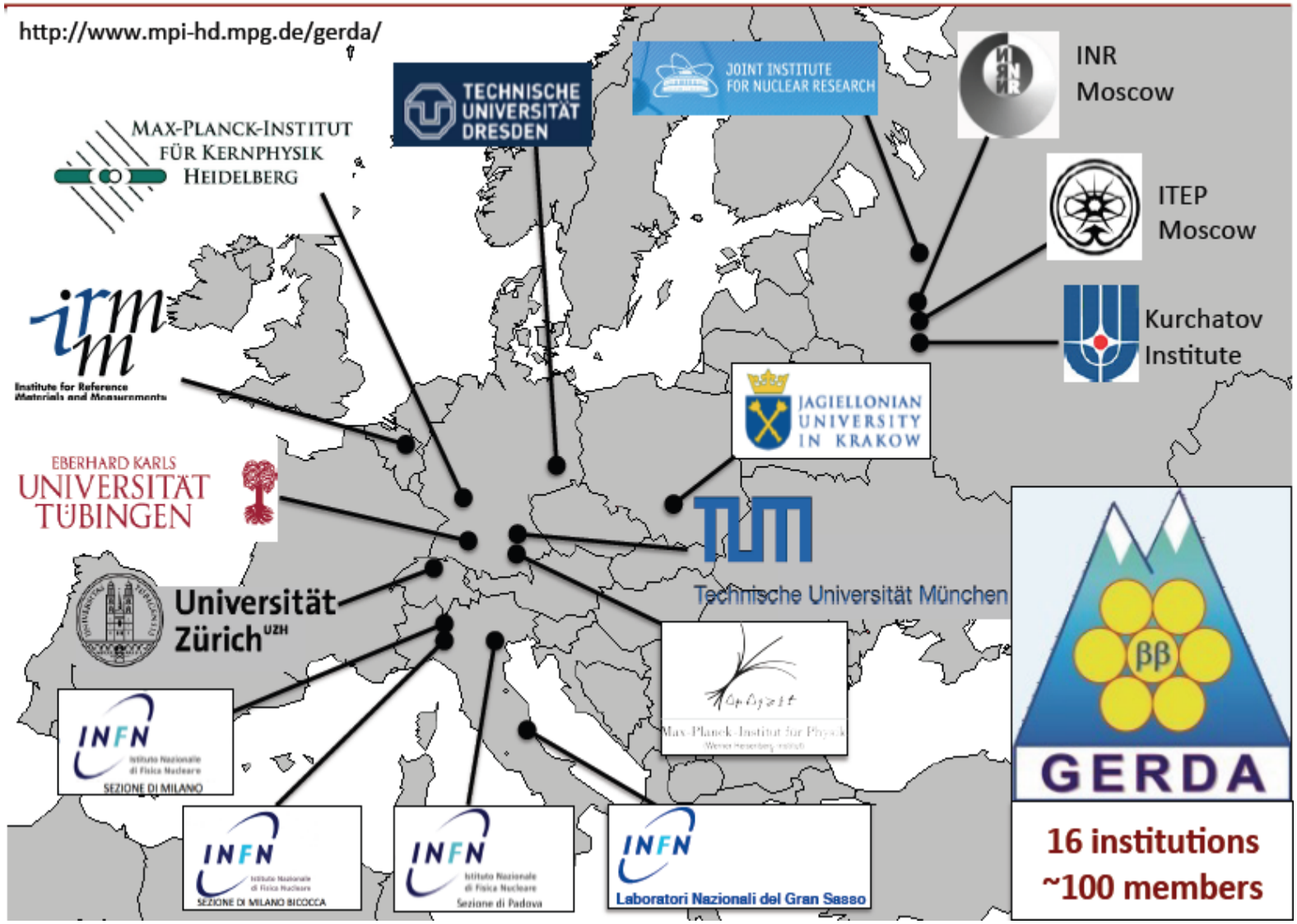


Phase III: (GD + Majorana)
^{76}Ge mass ~1 T
BI ≈ 10^{-4} cts / (keV×kg×yr)
Sensitivity: ~3×10^{27} yr
$\langle m_{ee} \rangle$ ~ 15 – 45 meV

Phase II:
Add new enr. BEGe detectors (+20 kg, 35 kg tot.)
BI ≈ 10^{-3} cts / (keV×kg×yr)
Sensitivity after 100 kg×yr

Phase I:
Use refurbished HDM & IGEX (18 kg)
BI ≈ 10^{-2} cts / (keV×kg×yr)
Sensitivity after 20 kg×yr

The GERDA Collaboration



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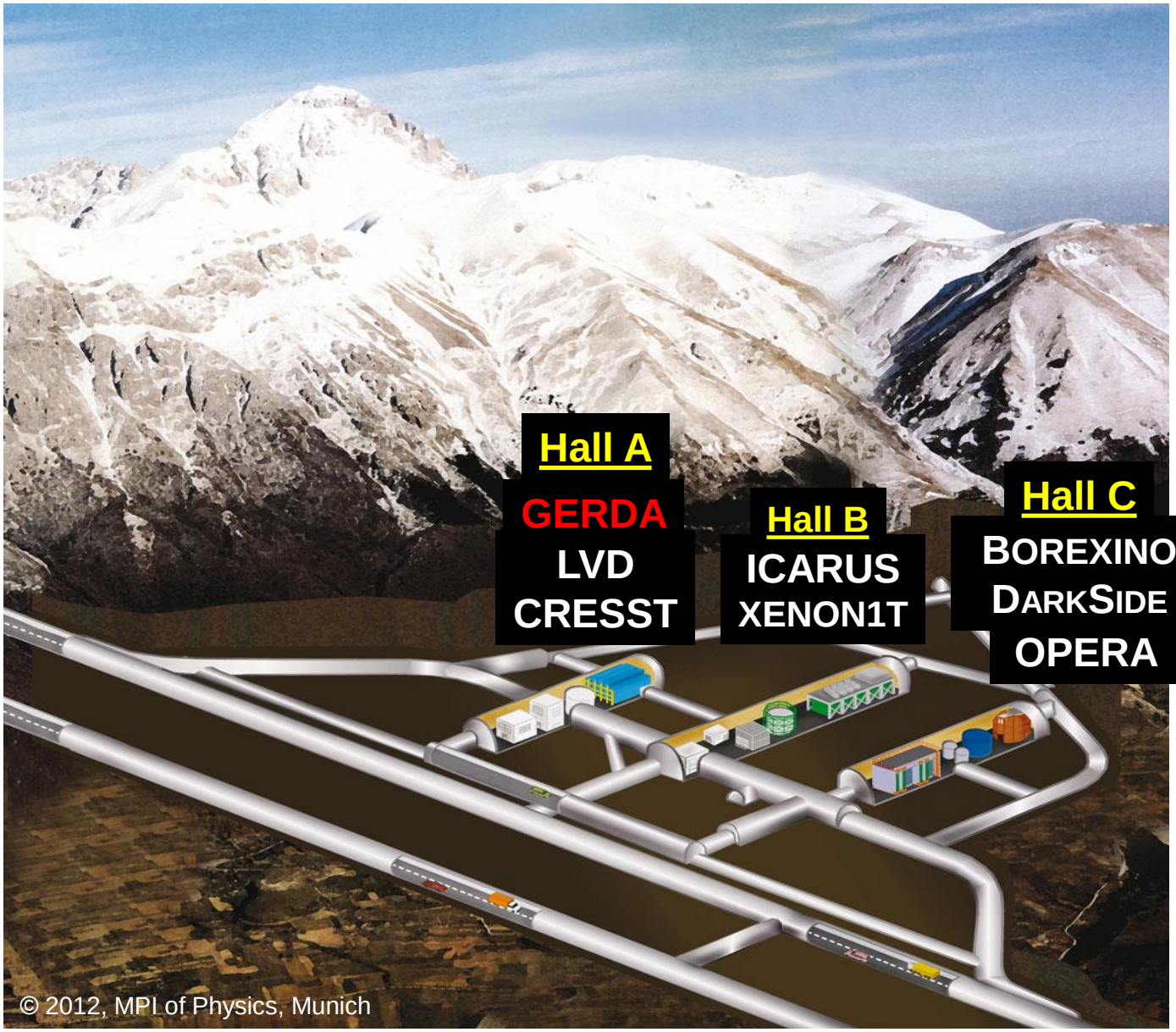
GERDA at LNGS



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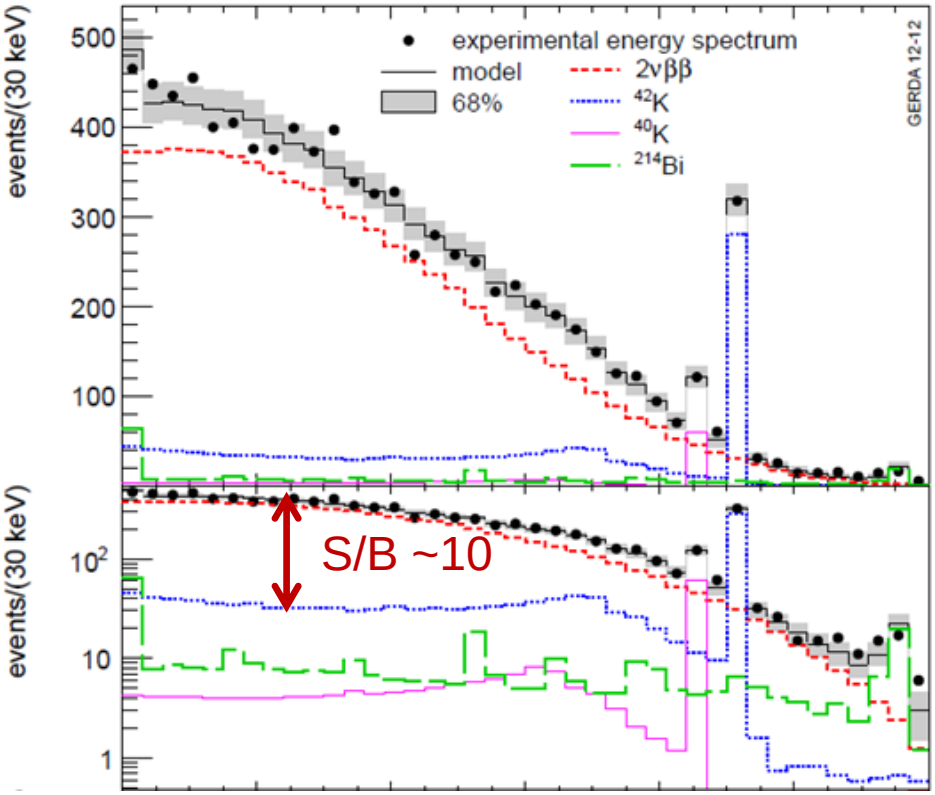
GERDA Phase I data analysis

- Phase I data: 09.11.11 – 21.05.13 (21.6 kg×yr acquired)
- Data around $Q_{\beta\beta}$ (±20/5 keV) was blinded
- Background analyzed in a wider window of $Q_{\beta\beta}$ ± 200 keV
- PSD procedures (for coax and BEGe detectors) developed and documented in advance
- Discussion and freezing of all parameters and methods prior to unblinding
- Unblinding at the Dubna Collaboration meeting (22 – 24 June 2013)

GERDA Phase I data analysis

- Stability of the detectors was monitored every week with a ^{228}Th source: peak position stability of 2614.5 keV calibration line coax was 1.5 keV and BEGe 1.0 keV (FWHM)
- Half life for 2νββ decay was determined with high precision

$$T^{2\nu}_{1/2} = 1.84^{+0.9}_{-0.8} \times 10^{21}\ \text{yr}$$



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

GERDA Phase I data analysis

- Detailed background model has been developed:

  Eur. Phys. J. C (2014) 74:2764

  - **No background peaks** expected around $Q_{\beta\beta}$
  - BI at $Q_{\beta\beta}$ **(17.6 – 23.8) ×10^{-3} cts /(keV×kg×yr)**
  - Spectrum can be modeled with **flat background** in 1930 – 2190 keV excluding known peaks at 2104 and 2119 keV
  - Prediction for 30 keV blinded side wings: min./max model 8.2 – 9.1 / 9.7 – 11.1, observed: 13.

- Acheived background level ~10 times lower compared to the previous experiments:

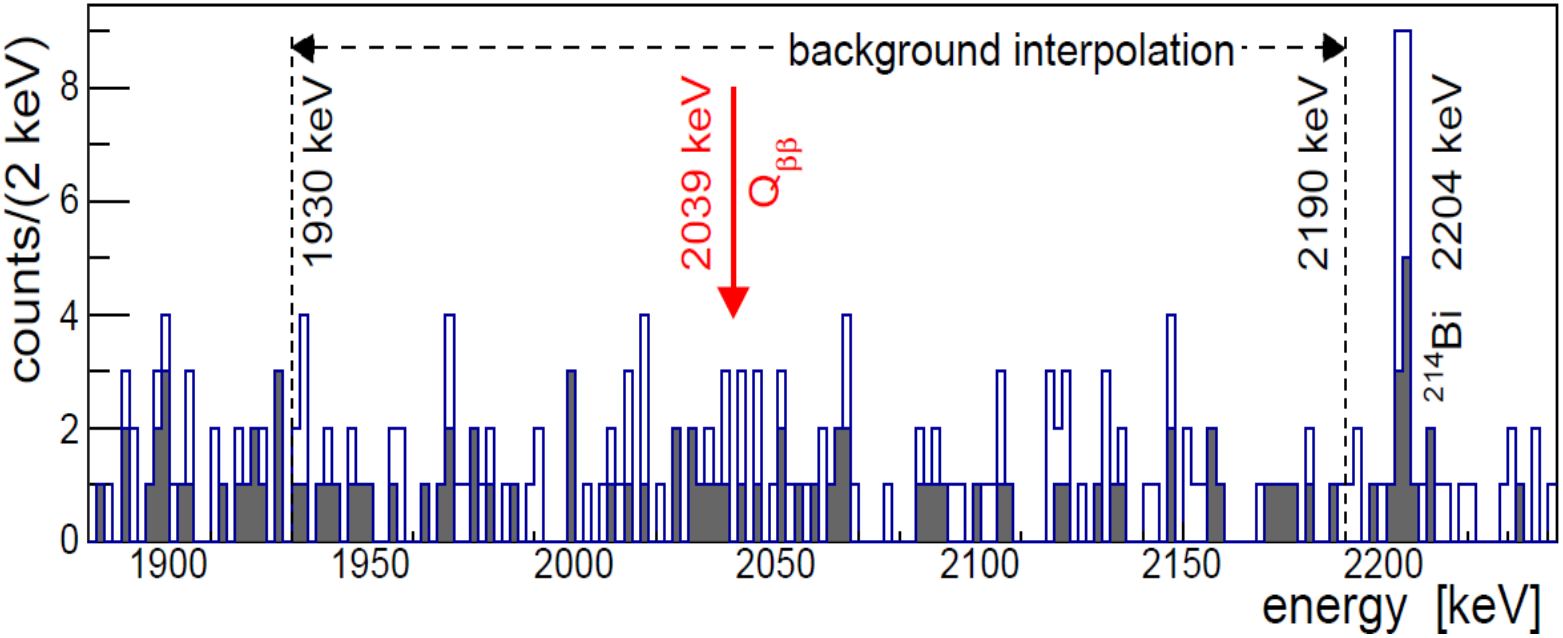
Line / ROI	GERDA	HDM
2615 keV [cts/(kg×yr)]	1.1 ± 0.3	16.5 ± 0.5
1764 keV [cts/(kg×yr)]	3.3 ± 0.5	30.7 ± 0.7
BI at $Q_{\beta\beta}$ [cts/(keV×kg×yr)]	0.018 ± 0.002	0.16 ± 0.005

- Pulse shape discrimination (PSD) methods have been developed for the Phase I detectors

  Eur. Phys. J. C (2013) 73:2583

After data unblinding

Phys. Rev. Lett. 111 (2013) 122503
(Highlighted by the APS)

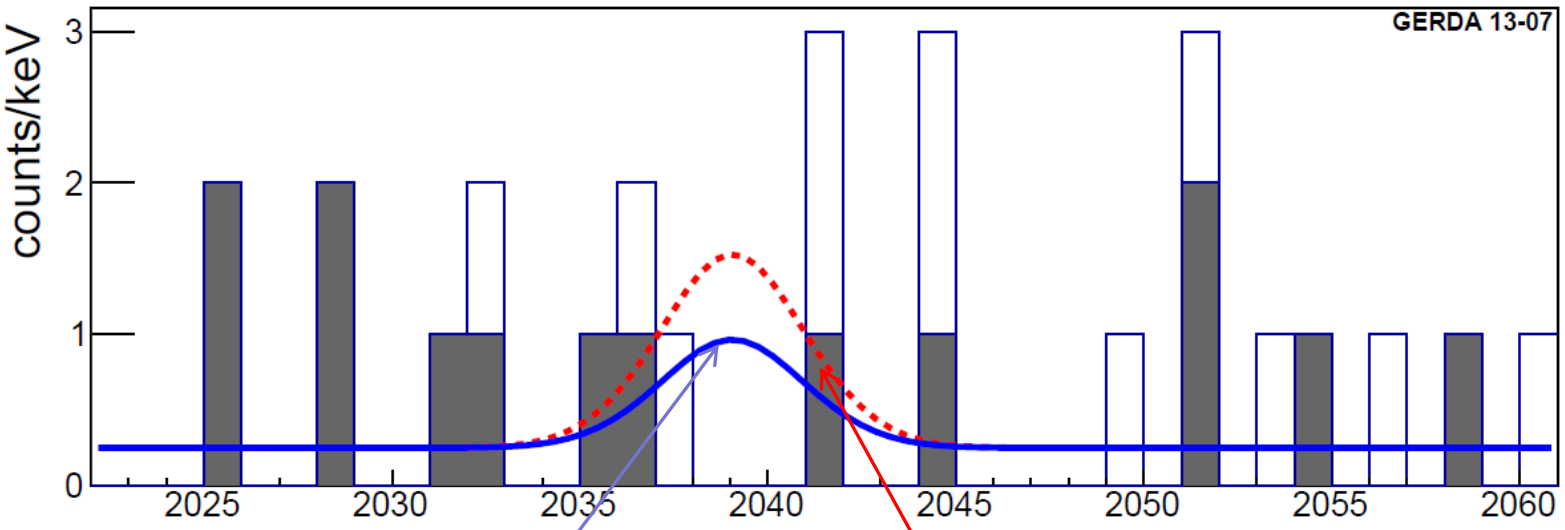


before PSD

after PSD

Total counts in BW	Expected (bgd only)	Observed
without PSD	5.1	7
with PSD	2.5	3

After data unblinding



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

- 90% lower limit derived from profile likelihood (Frequentist limit, flat background)
- Best fit: $N^{0\nu} = 0$
- **No excess** of signal counts above the background
- Limit on half-life corresponds to $N^{0\nu} < 3.5$ cts

Comparison with the claim

Expectation for claimed $T_{1/2}^{0\nu} = 1.19 \times 10^{25}$ yr: 5.9 ±1.4 signal over 2.0 ± 0.3 background in ±2σ energy window to be compared with 3 cts (0 in ±1σ)

H1: claimed signal: 5.9 ± 1.4 cts
H0: background only

Bayes factor: P(H1)/P(H0) = 0. 024

p-value from profile likelihood
$P(N^{0\nu} = 0|H1) = 0.01$

➔Claim refuted with high probability

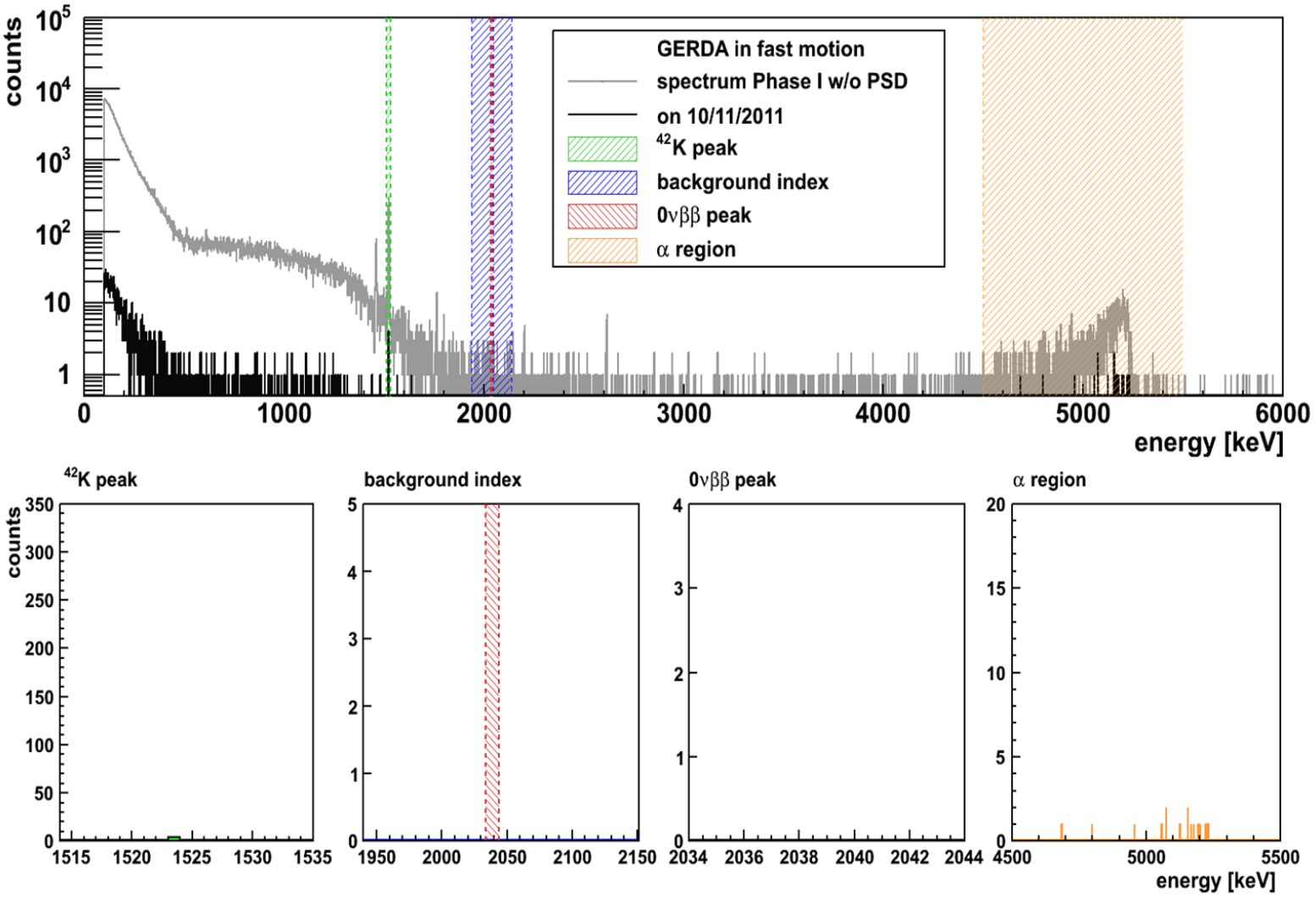
Combining available Ge data:

HdM: Eur. Phys. J. A 12, 147 (2001)
IGEX: Phys. Rev. D 65, 092007 (2002)
Phys. Rev. D 70 078302 (2004)

$$T_{1/2}^{0\nu} > 3.0 \cdot 10^{25} \text{ yr} \quad (90\% \text{ C.L.})$$

P(H1)/P(H0) = 2×10^{-4} strongly disfavors the claim.
Comparison is independent of NME and of physical mechanism which generates 0νββ

After data unblinding



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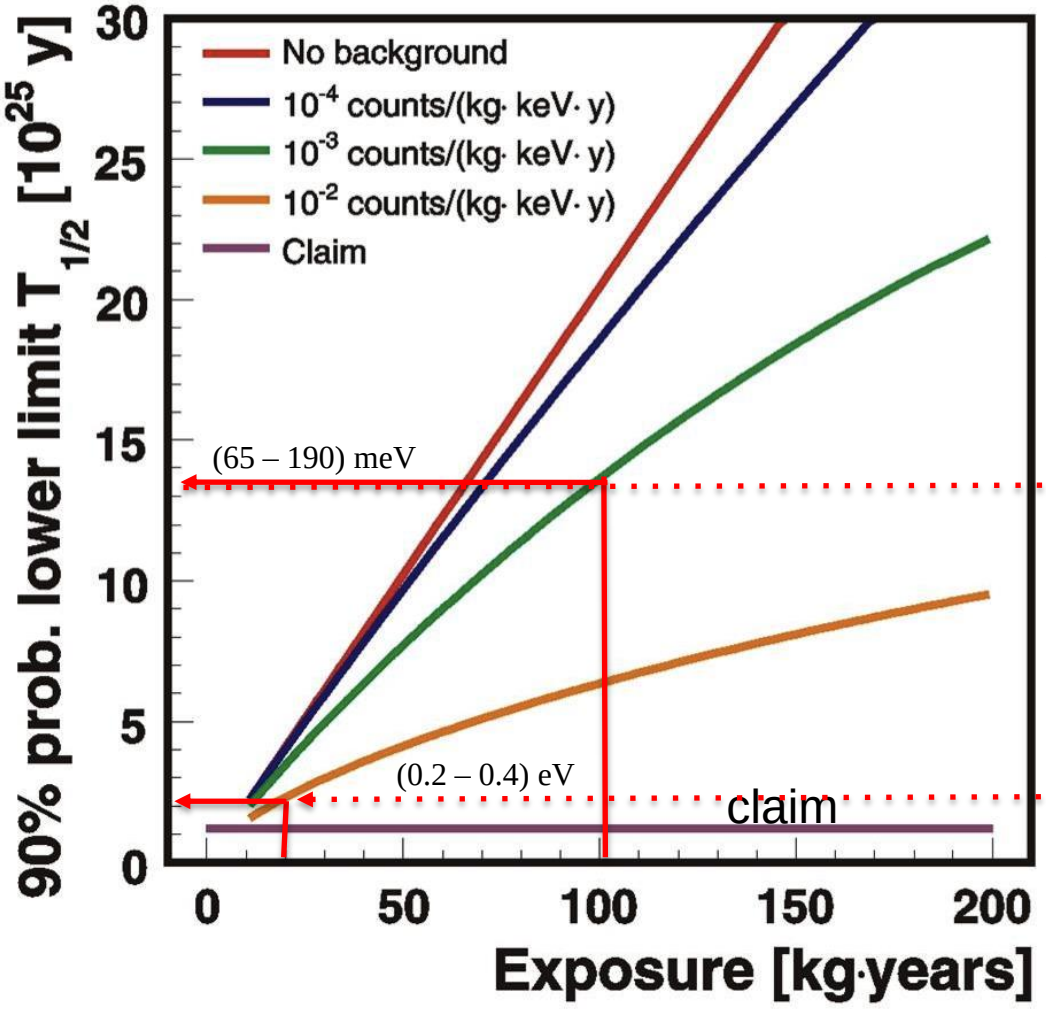
Towards GERDA Phase II

$$T_{1/2}(90\%\ CL) > \frac{ln2}{1.64}\frac{N_A}{A}\epsilon\cdot\gamma\sqrt{\frac{M\cdot T}{B\cdot\Delta E}}$$



Phase II:
Add new enr. BEGe detectors (+20 kg, 35 kg tot.)
BI ≈ 10^{-3} cts / (keV×kg×yr)
Sensitivity after 100 kg×yr
(after 3 years of live-time)

Phase I:
Use refurbished HDM & IGEX (18 kg)
BI ≈ 10^{-2} cts / (keV×kg×yr)
Sensitivity after 20 kg×yr

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Towards GERDA Phase II

More ^{76}Ge mass

- 30 new enriched BEGe detectors are ready (20.0 kg) with efficient PSD algorithms developed
- 3 years of data taking

Lower background

- Liquid argon instrumentation – active veto in liquid argon
- Lower mass (new Si detector holders) around the detectors with improved radio-purity
- New Very Front-End (VFE) electronics

Conclusions

- **GERDA Phase I design goals reached:**
  - Background index after PSD: 0.01 cts / (keV×kg×yr)
  - Exposure 21.6 kg×yr
- **No 0νββ-signal observed at $Q_{\beta\beta}$ = 2039 keV; best fit: $N^{0\nu} = 0$**
  - Background-only hypothesis H_0 strongly favored
  - Claim strongly disfavored
    (independent of NME and of the leading term)
- **Limit on half-life:**

  GERDA: $T_{1/2}^{0\nu} > 2.1\times10^{25}$ yr (90% C.L.)

  GERDA+IGEX+HdM: $T_{1/2}^{0\nu} > 3.0\times10^{25}$ yr (90% C.L.)

  $\langle m_{ee} \rangle < 0.2 - 0.4$ eV
- Results reached after only 21.6 kg×yr exposure because of **unprecedented low background:** BI after analysis cuts and corrected for efficiencies: 0.006 cts /(mol×yr×FWHM)
- Ongoing analysis: 2νββ to excited state, 0νββ exc. state, Majoron
- **Phase II under preparation – start exp. at the beginnig of 2015**
  - 30 new BEGe detectors ready, LAr instrumentation
  - Expected BI ~10^{-3} cts/(keV×kg×yr)
  - Exploring $T_{1/2}(0\nu\beta\beta) \sim 10^{26}$ y