JAGIELLONIAN UNIVERSITY
IN KRAKOW

GERDA experiment: latest results of the neutrinoless double beta decay search

Krzysztof Panas
Jagiellonian University, Cracow
(on behalf of the GERDA collaboration)

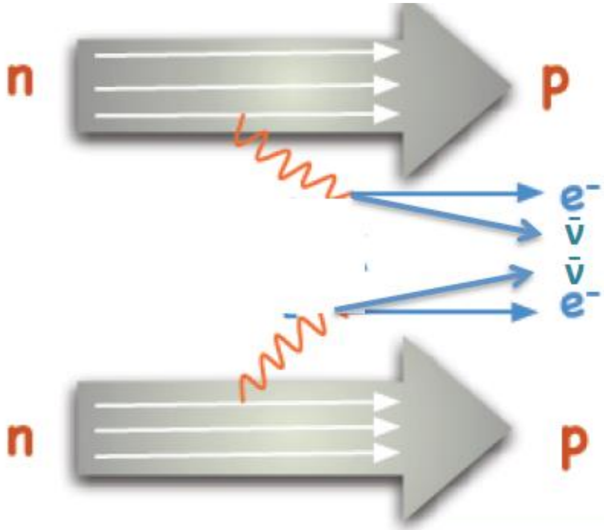
Astrofizyka Cząstek w Polsce 2017

Outline

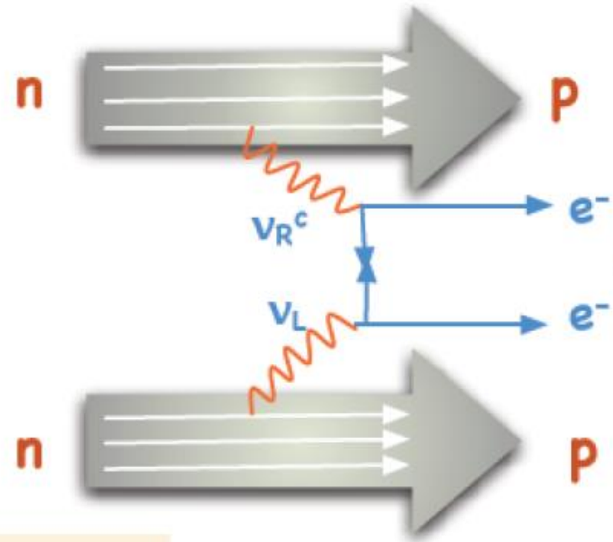
1. Introduction to neutrinoless double beta decay ($0\nu\beta\beta$)
2. Design of the GERDA experiment
3. Recent results
4. Conclusions

Neutrinoless double beta decay

$2\nu\beta\beta$

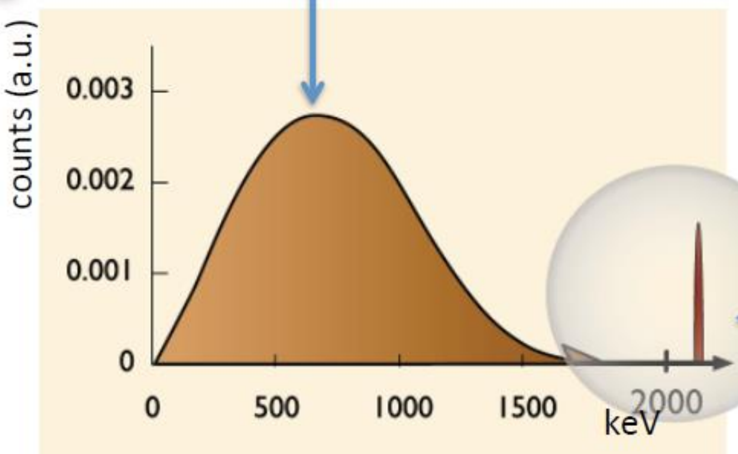


$0\nu\beta\beta$



$\Delta L = 0$

$T_{1/2} \sim 10^{18} - 10^{24}$ yr



$\Delta L = 2$

$T_{1/2} > 8.0 \times 10^{26}$ yr

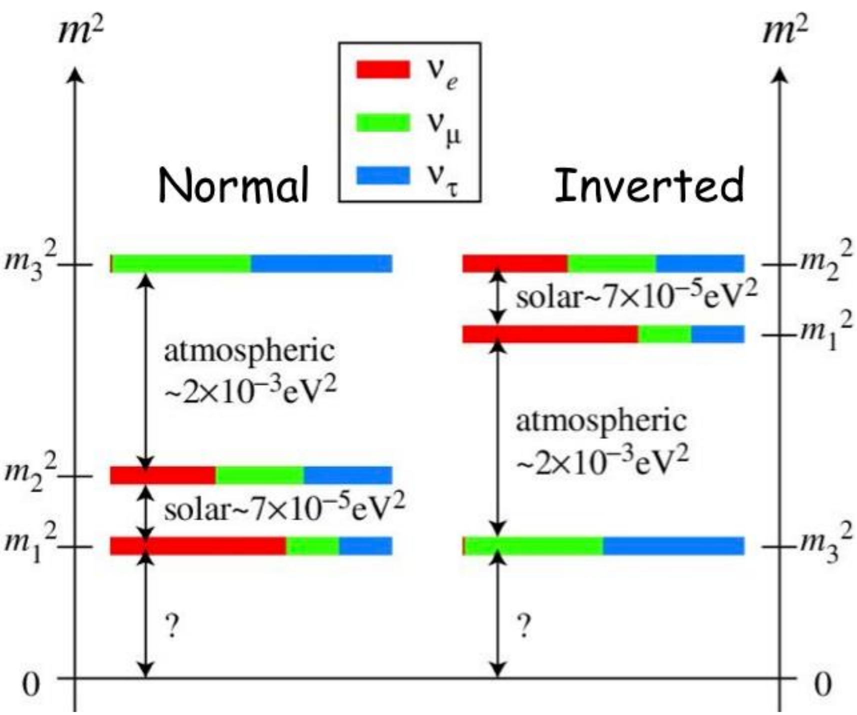
Source: S.Schönert's talk at TAUP 2017

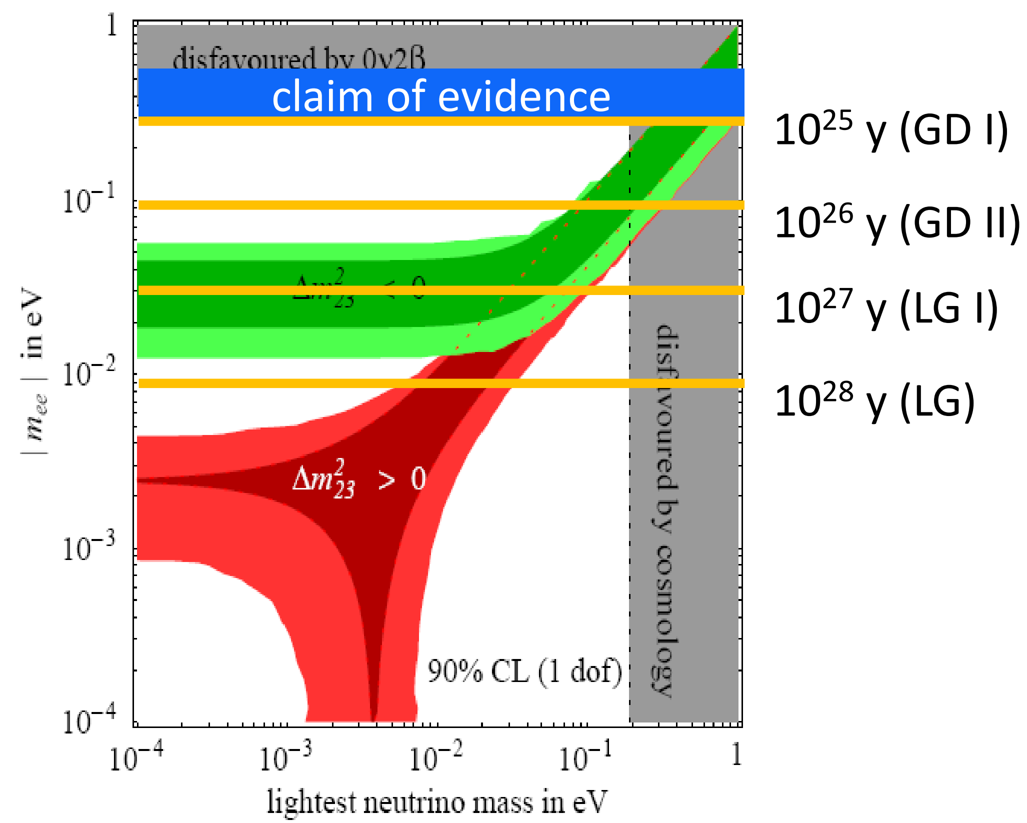
Neutrinoless double beta decay

- If $0\nu\beta\beta$ observed:
  - Neutrino is a Majorana particle (its own antiparticle)
  - Lepton number is not conserved
  - Dealing with physics beyond the Standard Model
  - Possibility to fix the absolute neutrino mass scale
  - Possibility to determine the neutrino mass hierarchy

Significant contribution to Particle Physics, Astrophysics and Cosmology

Neutrino mass – inverted or normal hierarchy?





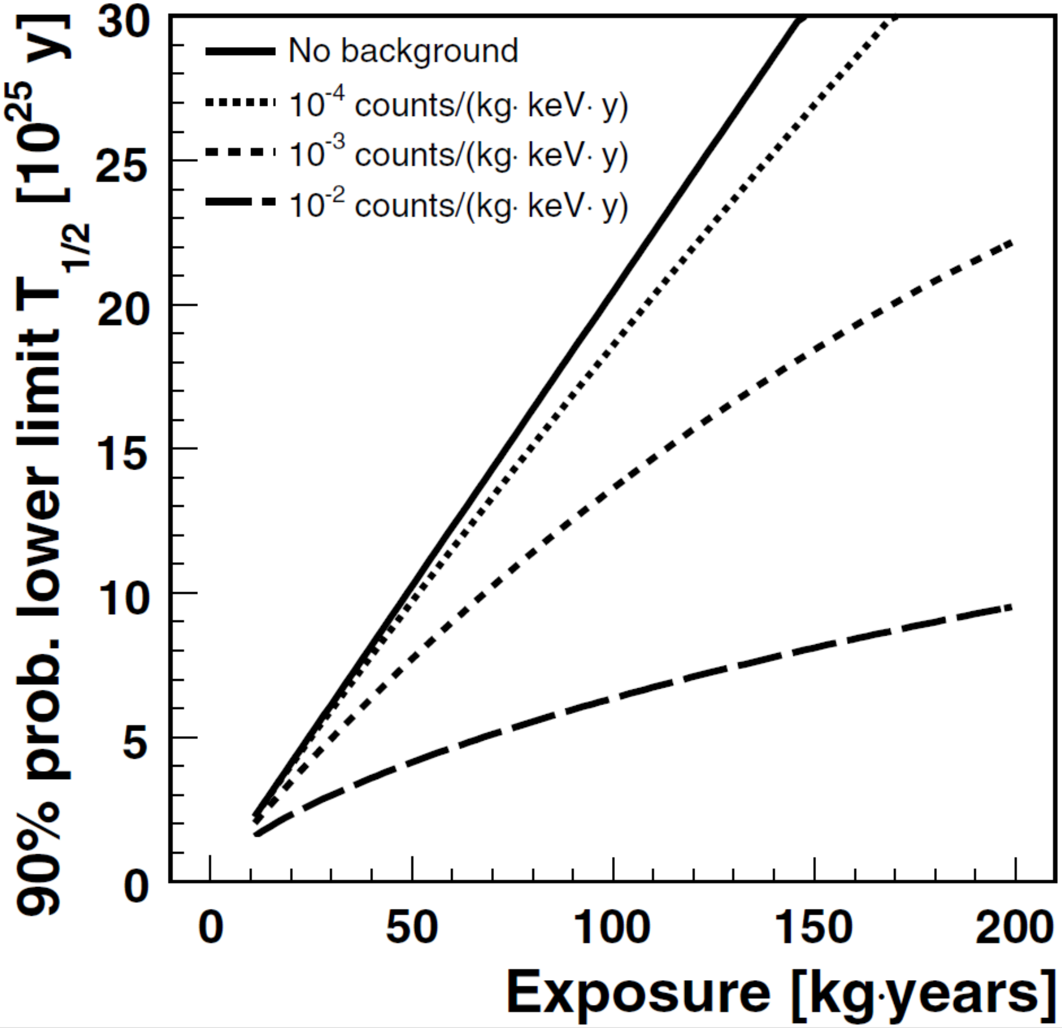
- Determining the limit on neutrino mass can reject inverted hierarchy hipothesis

Effective neutrino mass calculation:

$$\frac{1}{T_{1/2}} = G(Q,Z) \cdot |Mnuc|^2 \cdot < m_{ee} >^2$$

$< m_{ee} >$ - effective neutrino mass
$G(Q,Z)$ - space phase factor
M_{nuc} – nuclear matrix element

Sensitivity of the 0νββ experiment



Half-life limit calculation:

- No background:

$$T_{1/2}(90\%\ CL) > \frac{ln2}{1.64}\frac{N_A}{A}\epsilon \cdot a \cdot M \cdot T$$

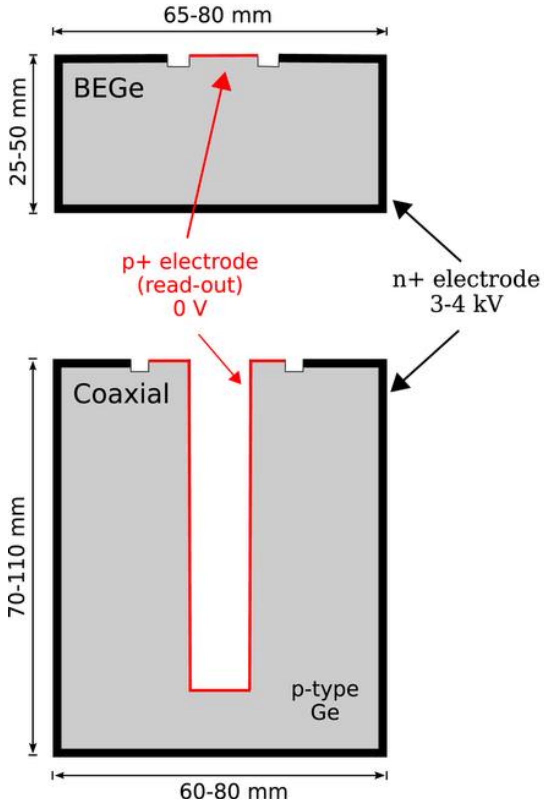
- With background:

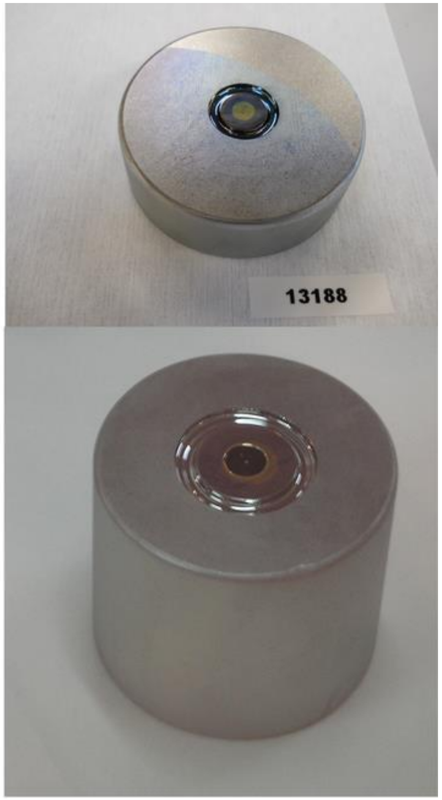
$$T_{1/2}(90\%\ CL) > \frac{ln2}{1.64}\frac{N_A}{A}\epsilon \cdot a\sqrt{\frac{M \cdot T}{B \cdot \Delta E}}$$

Exposure = isotope mass × meas. time

GERDA experiment

- **GERDA** (**GER**manium **D**etector **A**rray) has been designed to investigate neutrinoless double beta decay of ^{76}Ge ($Q_{\beta\beta} = 2039$ keV)
  - Ge mono-crystals are very radiopure
  - Ge detectors have excellent energy resolution
  - Detector = source ($\epsilon \approx 1$)
  - Enrichment of ^{76}Ge required (7.4% $\rightarrow$ 86%)

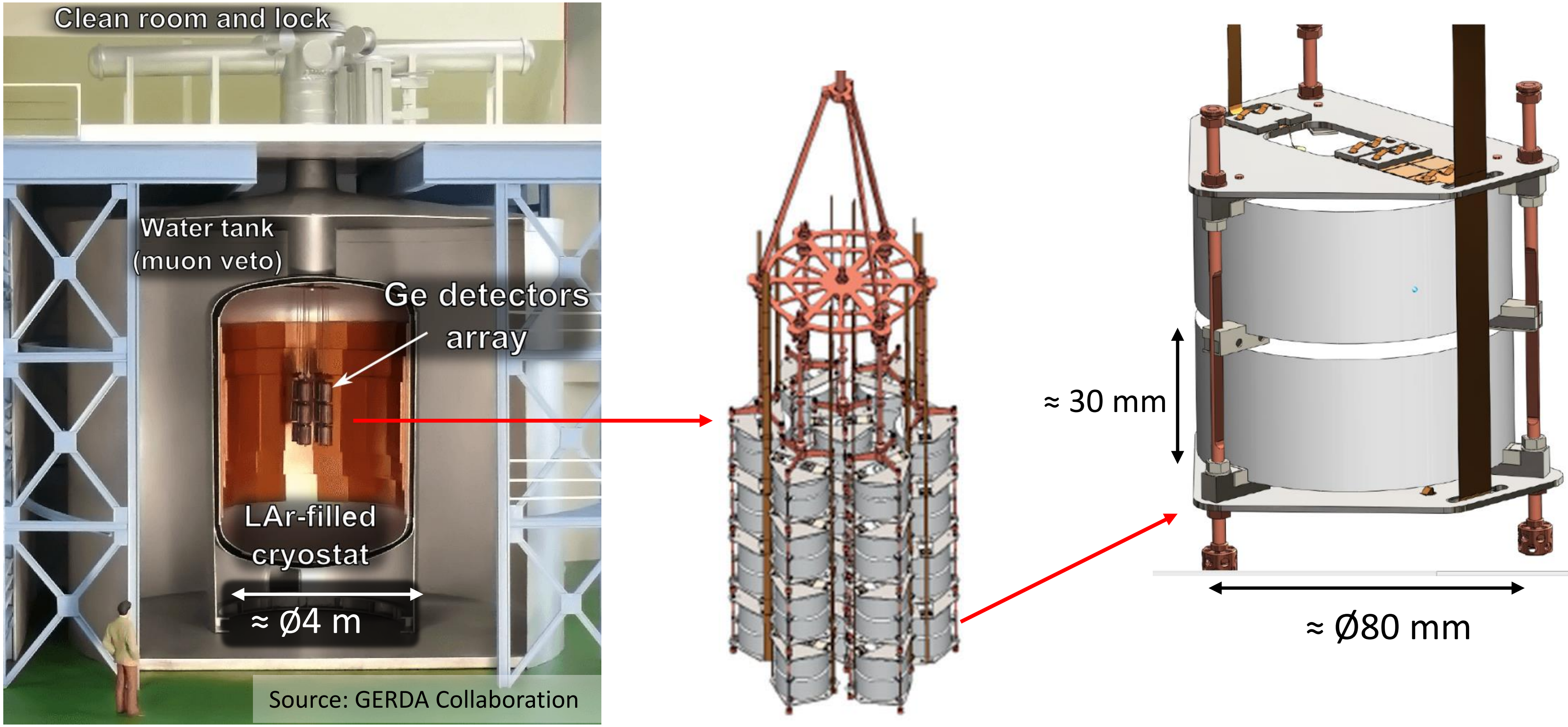




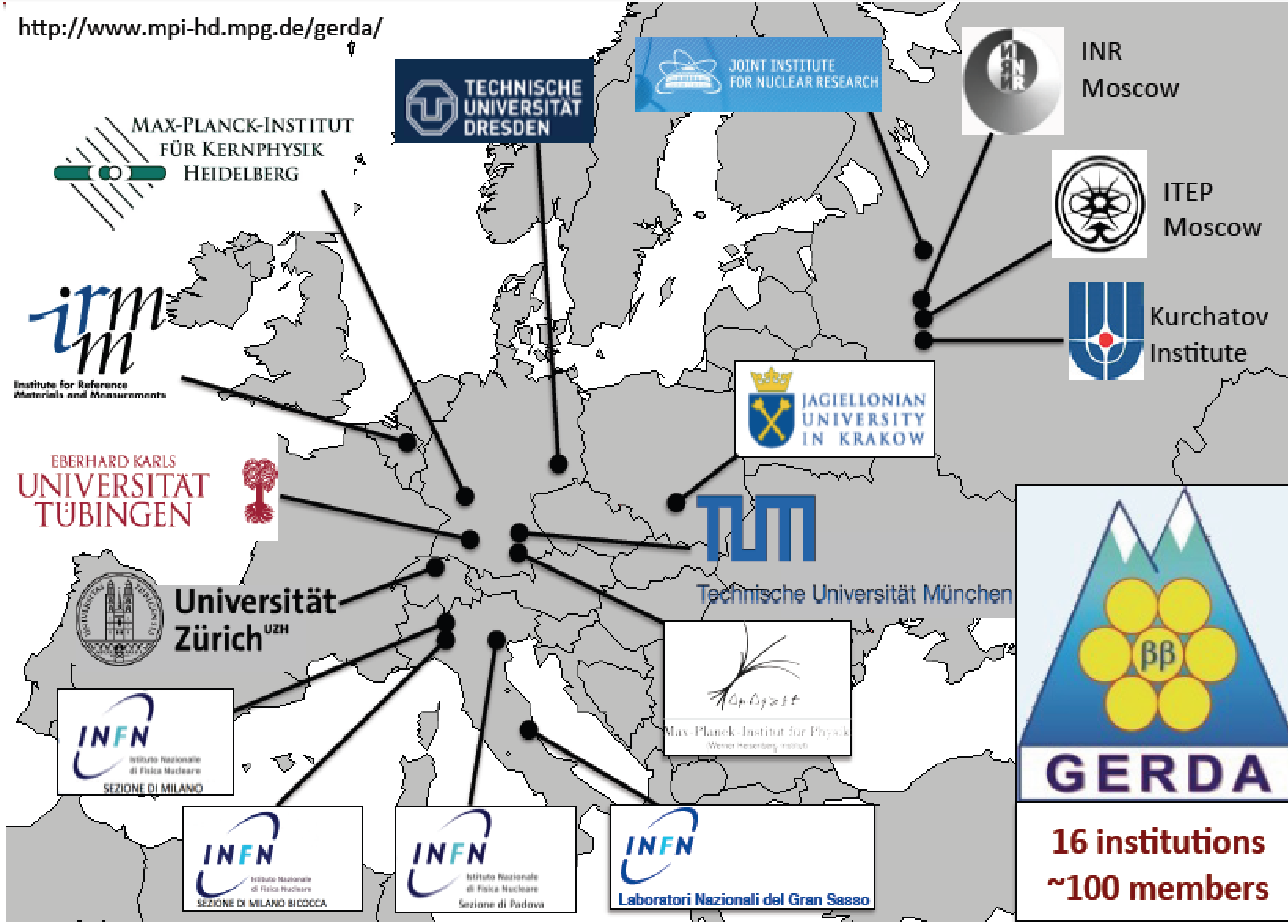
Source: GERDA collaboration

Design of GERDA

- Main design features:
  - bare HPGe diodes immersed in LAr (cooling, passive shield and veto)
  - Readout of LAr scintillation light via PMTs and SiPM
  - Currently ≈ 30 kg of enriched germanium



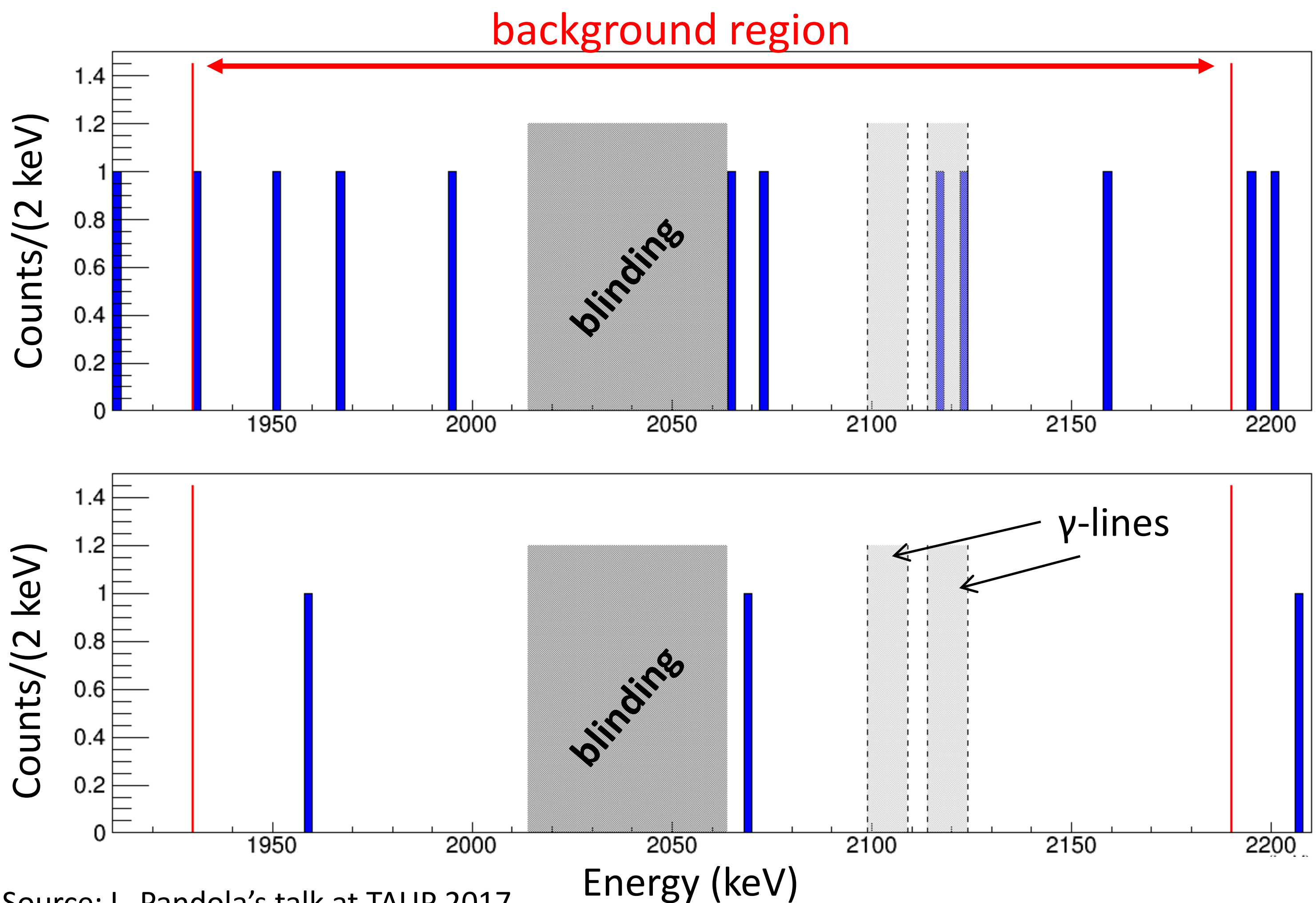
GERDA: the collaboration



GERDA latest data release

- Most recent unblinding during GERDA meeting in Cracow (June 2017)

GERDA Phase II ROI



^{enr}Coax
16.2 kg·yr
(all cuts)

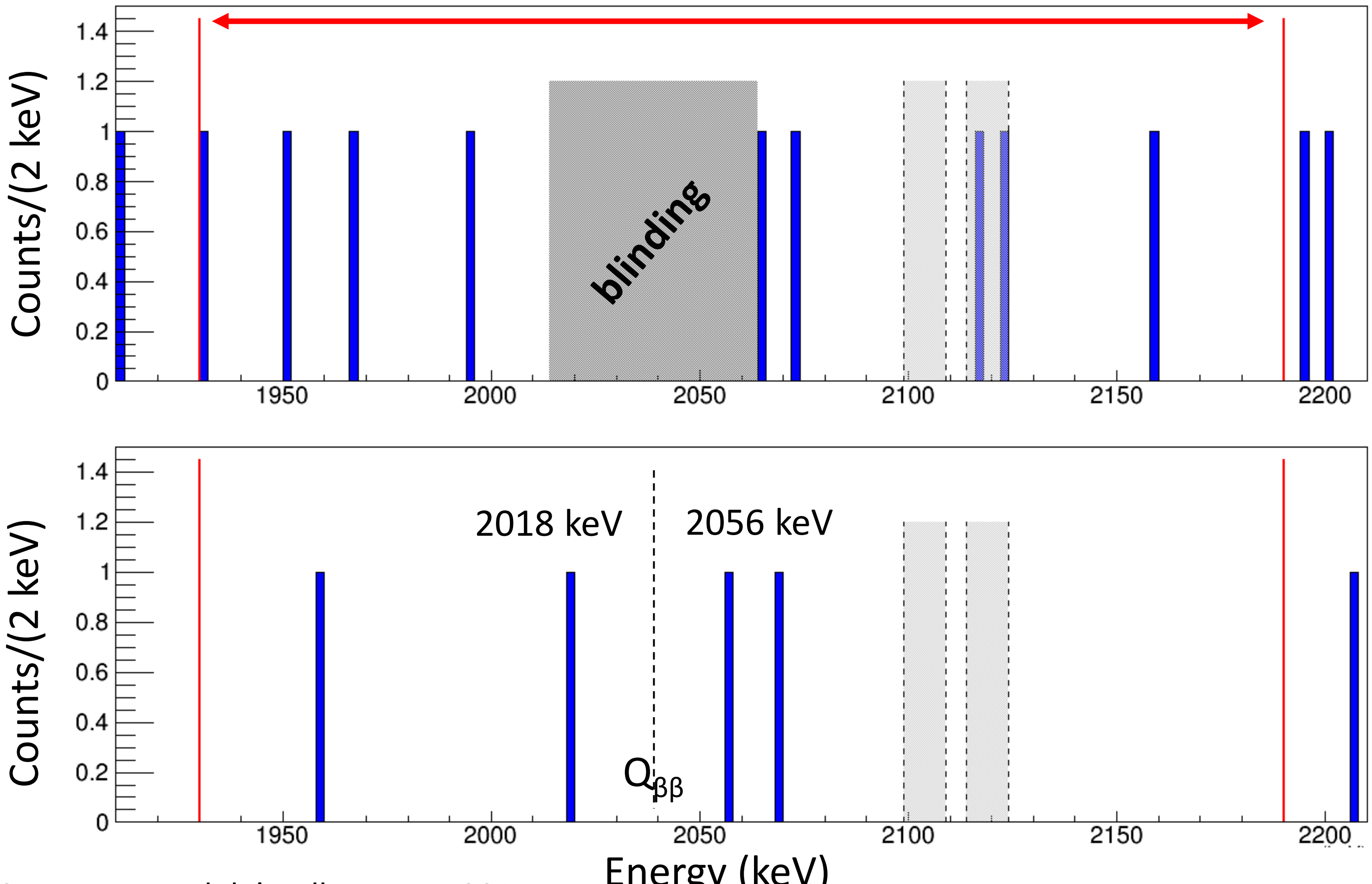
7 cts (+2 blinded)
$2.7^{+1.0}_{-0.8}\ 10^{-3}$
cts/(keV kg yr)

^{enr}BEGe
18.2 kg·yr
(all cuts)

2 cts
$0.5^{+0.5}_{-0.3}\ 10^{-3}$
cts/(keV kg yr)

Source: L. Pandola's talk at TAUP 2017

GERDA Phase II ROI



^{enr}Coax
16.2 kg·yr
(all cuts)

7 cts (+2 blinded)
$2.7^{+1.0}_{-0.8}$ 10^{-3} cts/(keV kg yr)

^{enr}BEGe
18.2 kg·yr
(all cuts)

2 cts **+ 2 new** (>10σ from $Q_{\beta\beta}$)
$1.0^{+0.6}_{-0.4}$ 10^{-3} cts/(keV kg yr)

Source: L. Pandola's talk at TAUP 2017

GERDA Phase II results


ARTICLE

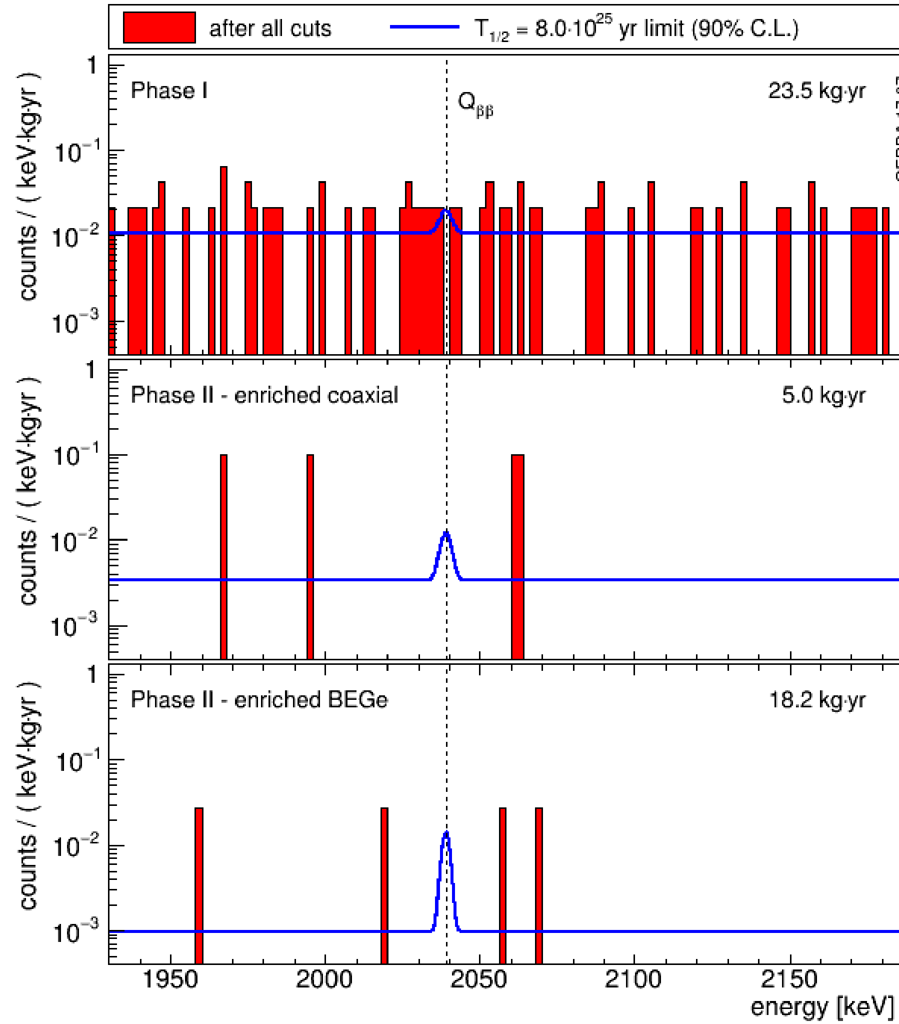
doi:10.1038/nature21717

Background-free search for neutrinoless double-β decay of ^{76}Ge with GERDA

The GERDA Collaboration*

- Phase II published results:
  - **$T_{1/2}$ > 5.3·10^{25} yr @ 90% CL**
  - *(Nature* 544, 2017)

- **Preliminary results from the newest data:**
  - **$T_{1/2}$ > 8.0·10^{25} yr @ 90% CL** (TAUP 2017 conf.)
- Next steps:
  - If no signal observed, expected to reach 10^{26} yr limit next year
- Final exposure: 100 kg yr:
  - final sensitivity **1.3·10^{26} yr** (for the limit) or **~ 8 10^{25} yr** (50% for 3σ discovery)



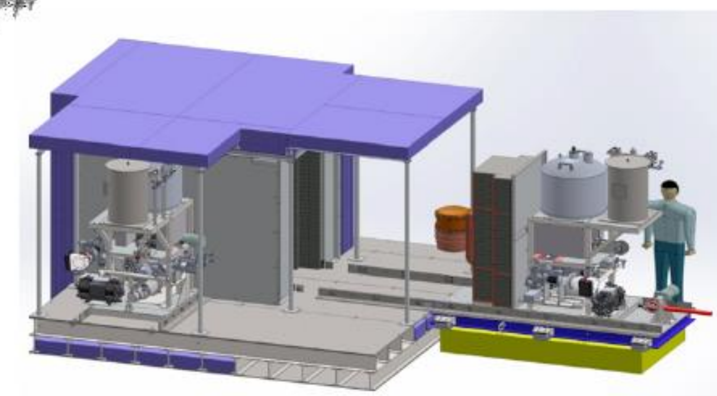
Source: GERDA collaboration

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

GERDA: Cracow’s contribution

- 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 criogenic 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

FNP Foundation for Polish Science

NATIONAL SCIENCE CENTRE POLAND

- Cracow’s group involvement in GERDA supported by **National Science Centre** and **Foundation for Polish Science** grants
- **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

Conclusions

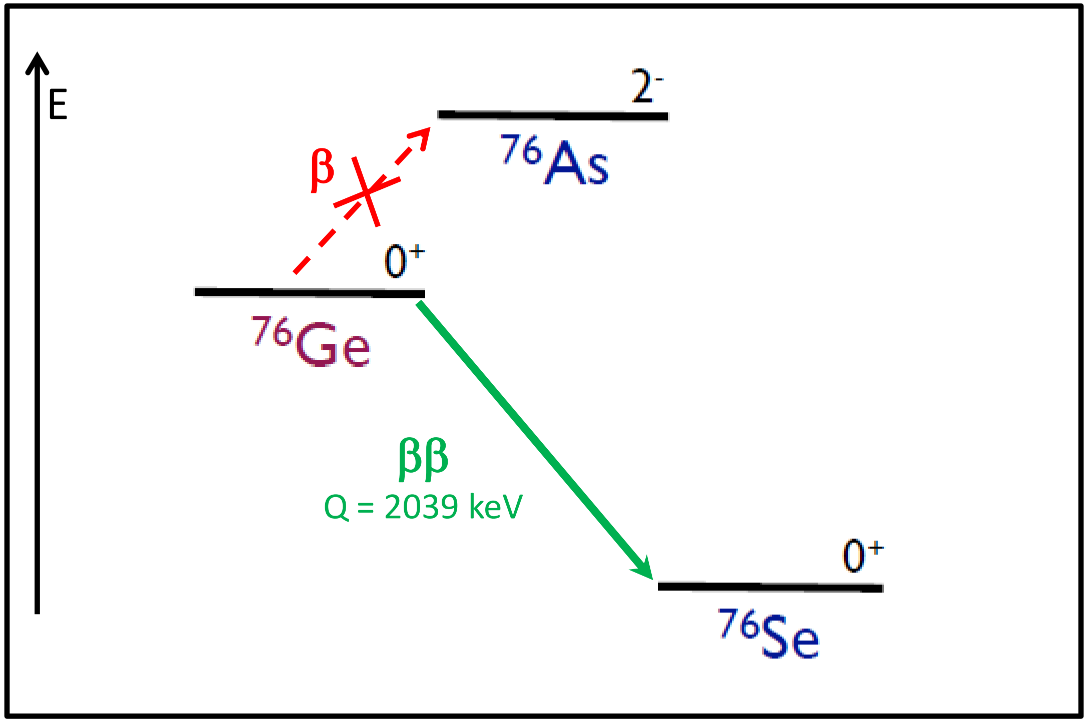
- $0\nu\beta\beta$ decay - an important probe of the fundamental neutrino properties and its mass hierarchy
- GERDA – data-taking in progress
- Very good **background level** at $Q_{\beta\beta}$ confirmed (BEGe: $1.0^{+0.6}_{-0.4} \times 10^{-3}\ [\frac{\mathrm{cts}}{\mathrm{keV\ kg\ yr}}]$)
  - Will allow to achieve **O(< 1 count) in the ROI** for the full design exposure
- Lowest background (~10x) in ROI w.r.t. other isotope experiments
- Next year: possible increase to $\mathbf{10^{26}}$ **yr** in median sensitivity
- Next years:

Thank you for your attention!

Backup

Double beta decay

- In a number of even-even nuclei, β decay is energetically forbidden, while double beta decay from a nucleus of (A,Z) to (A, Z+2), is energetically allowed:



^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr ^{100}Mo, ^{116}Cd ^{128}Te, ^{130}Te, ^{136}Xe, ^{150}Nd

Half-life to eff. neutrino mass

Half-life limit calculation:

$$T_{1/2}(90\%\ CL) > \frac{ln2}{1.64}\frac{N_A}{A}\epsilon \cdot a \cdot M \cdot T \qquad \Leftarrow \text{ no background}$$

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

ε – detection efficiency
A – isotope molar mass
a – isotope mass fraction
M – active mass
T – measurement time
B – background rate
ΔE – energy resolution
M·T – exposure

Effective neutrino mass calculation:

$$\frac{1}{T_{1/2}} = G(Q,Z) \cdot |M_{nuc}|^2 \cdot < m_{ee} >^2$$

$$< \boldsymbol{m_{ee}} > \sim \frac{\mathbf{1}}{\sqrt{\boldsymbol{T_{1/2}}}} \sim \sqrt[4]{\frac{\boldsymbol{B \cdot \Delta E}}{\boldsymbol{M \cdot T}}}$$

$< m_{ee} >$ - effective neutrino mass
$G(Q,Z)$ - space phase factor
M_{nuc} – nuclear matrix element

Experimental challenge:

$$(\boldsymbol{M \cdot T})\uparrow \boldsymbol{x}\ \mathbf{100} \rightarrow \boldsymbol{T_{1/2}} \uparrow \mathbf{10} \rightarrow < \boldsymbol{m_{ee}} > \downarrow \boldsymbol{x} \sim \mathbf{3}$$

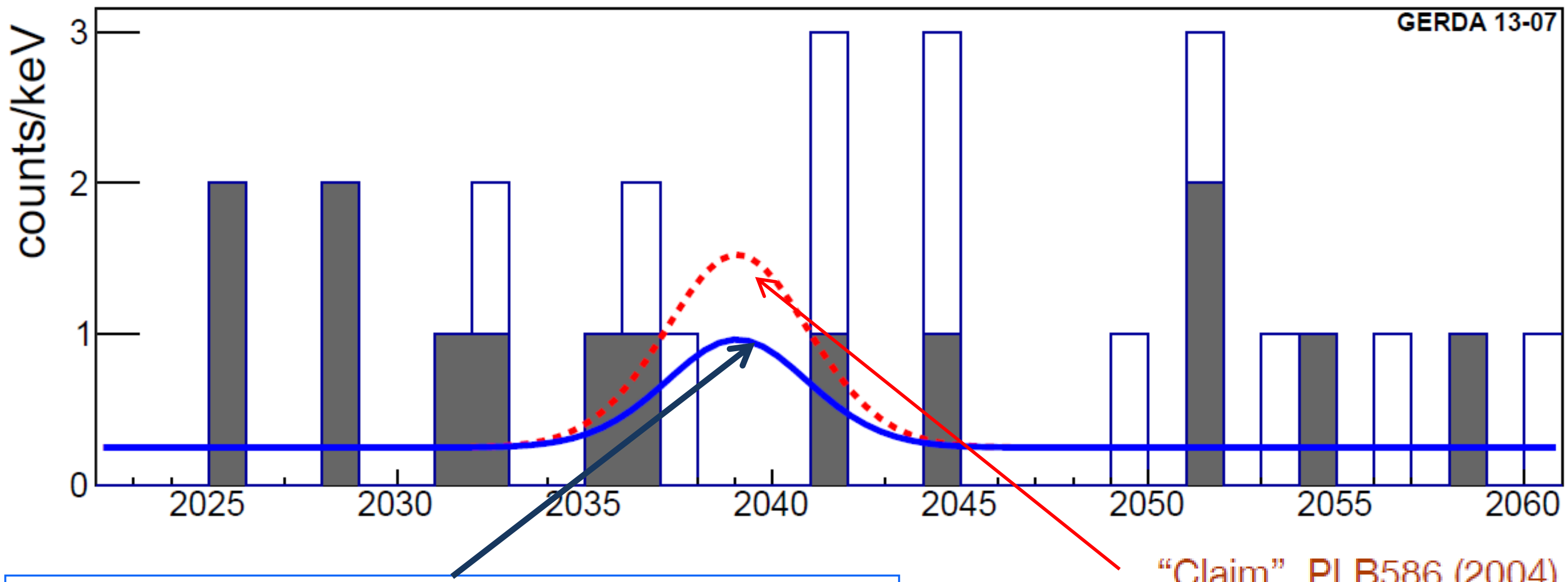
GERDA Phases

- Data-taking divided into phases:
  - Phase I (Nov 2011 – May 2013), rejection of the claim from Heidelberg-Moscow experiment, data unblided in Dubna
  - Phase II (Dec 2015 - ongoing):
    - Phase **IIa** – unblinding in **June 2016**
    - Phase **IIb** – partial (BEGe only) unblinding in **June 2017**

- Blind analysis strategy:
  - Events at $\mathbf{Q_{\beta\beta} \pm 25}$ **keV blinded**
  - Unblinding when all cuts **finalized**

Phase I results after unblinding

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



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

$$T^{0\nu}_{1/2} = \ 1.19 \times 10^{25}\,\mathrm{yr}\ (90\%\,\mathrm{C.L.})$$

GERDA vs. KamLAND-Zen (L. Pandola TAUP 2017)

- **Frequentist** analysis according to same recipe → numbers comparable

	GERDA I+II	KamLAND-Zen
Median sensitivity	**5.8 10^{25} yr**	5.6 10^{25} yr
90%CL Limit	8.0 10^{25} yr (30%)	**1.07 10^{26} yr (12%)**
Exposure	470 mol·yr	**3700 mol·yr**
Background	**5-20 cts/(ton_{iso} ROI yr)**	60-100 cts/(ton_{iso} ROI yr)

PRL **117** (2016) 082503

arXiv: 1705.02996