Search for neutrino-less double beta decay of ^{76}Ge in the GERDA experiment

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Outline

- Introduction to the double beta decay and neutrino mass problem
- Goals of GERDA
- GERDA design
  - Cryostat
  - Water tank and the muon veto
  - Cleanroom and the lock system
- Status of selected subprojects
  - Phase I detectors
  - Phase II detectors
- Background in GERDA
  - Internal
  - External
- Summary

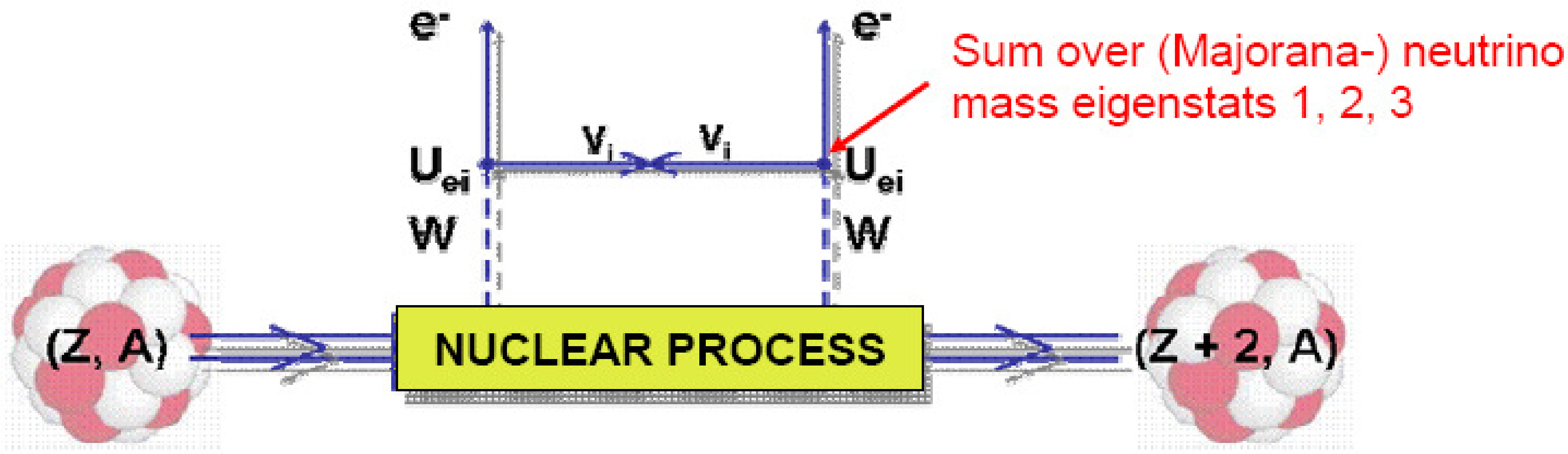
Double beta decay

Rare, spontaneous nuclear reaction:

$2\nu\beta\beta$: $(Z, A) \rightarrow (Z+2, A) + e^- + e^- + 2\nu$ $\Delta L = 0$ *($T_{1/2} \sim 10^{21}$ y)*

$0\nu\beta\beta$: $(Z, A) \rightarrow (Z+2, A) + e^- + e^-$ $\Delta L = 2$ *($T_{1/2} > 10^{25}$ y)*

Lepton number violation (unexpected in the SM)



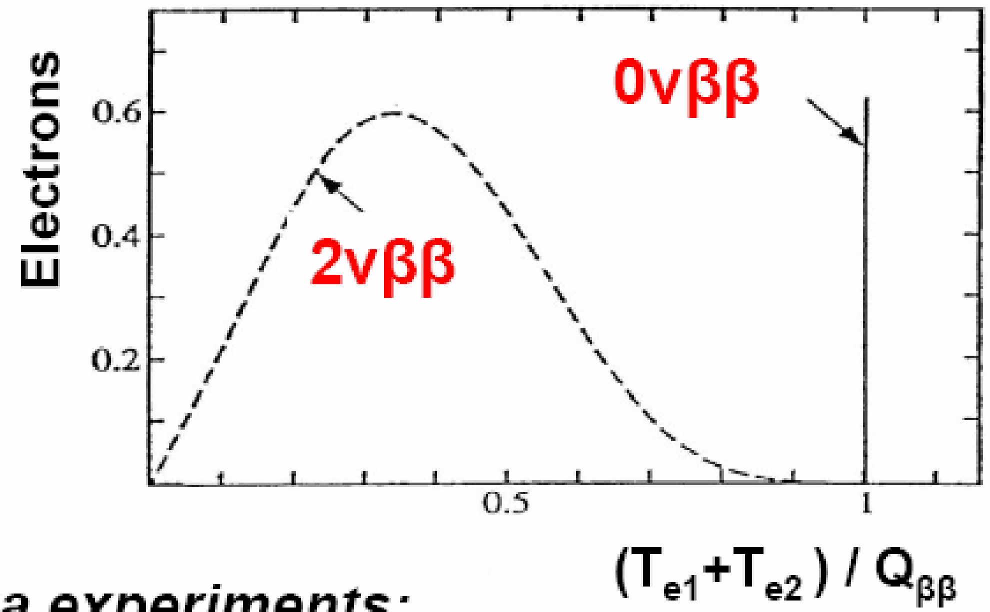
Double beta decay

Defined energy spectrum

$$T_{e1} + T_{e2} = Q_{\beta\beta}$$

Low decay rate: ~ 20 per year

@ 40 kg



Requirements for double beta experiments:

- Large amount of ββ isotops (enrichment if necessary)
- Long measuring time (5 – 10 years)
- Good suppression of background
- Good energy resolution (<10 keV)

Absolute neutrino mass scale

- ^3H beta-decay, electron energy measurement Mainz/Troisk Experiment: $m_{\nu e} < 2.2$ eV $\rightarrow$ KATRIN

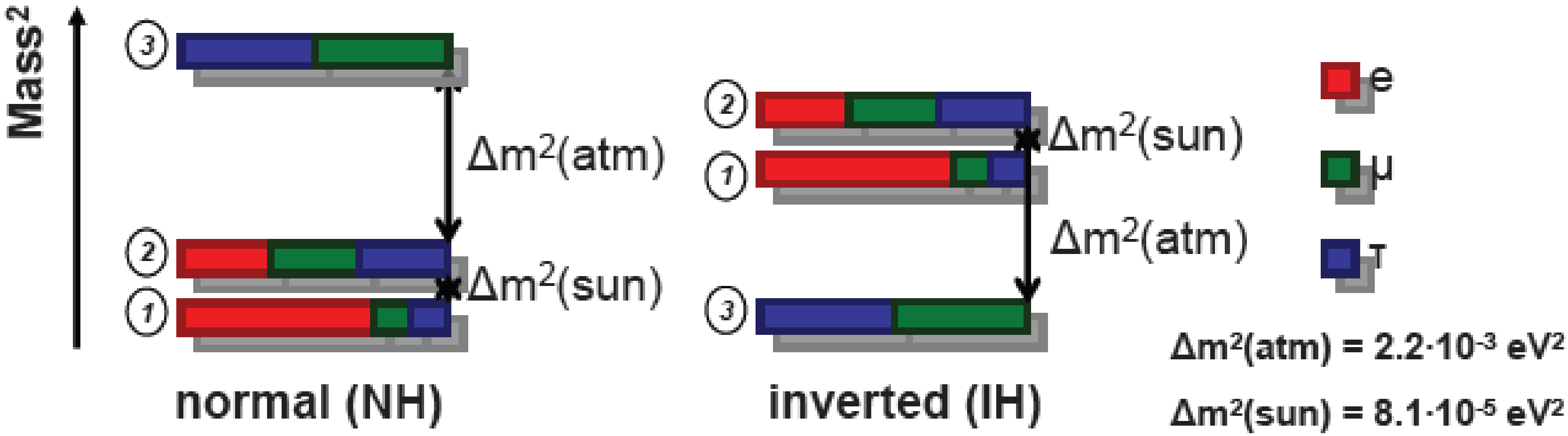
- Cosmology, Large Scale Structure WMAP & SDSS: cosmological bounds $\Sigma m_\nu < 0.8$ eV

- Neutrinoless double beta decay evidence/claims?? Majorana ν mass: $\langle m_{ee} \rangle \sim 0.4$ eV

Neutrino mass hierarchy

quasi-degenerate (QD) mass spectrum

$m_{\nu min} >> (|\Delta m_{21}^2|)^{1/2}$ as well as $m_{\nu min} >> (|\Delta m_{32}^2|)^{1/2}$



Open questions

- What is the nature of neutrino? Dirac or Majorana?
- Which mass hierarchy is realized in nature?
- What is the absolute mass-scale for neutrinos?

A neutrinoless double beta decay experiment, like GERDA has the potential to answer all three questions

Goals of GERDA

- Investigation of neutrino-less double beta decay of ^{76}Ge
- Significant reduction of background around $Q_{\beta\beta}$ down to $\leq 10^{-3}$ cts/(keV·kg·y)
  - Use of bare diodes in cryogenic liquid (LAr) of very high radiopurity
  - Use of segmented detectors
  - Passive/active background suppresion
- If KKDC-evidence not confirmed:
  - (1 ton) experiment in worldwide collaboration (cooperation with Majorana)

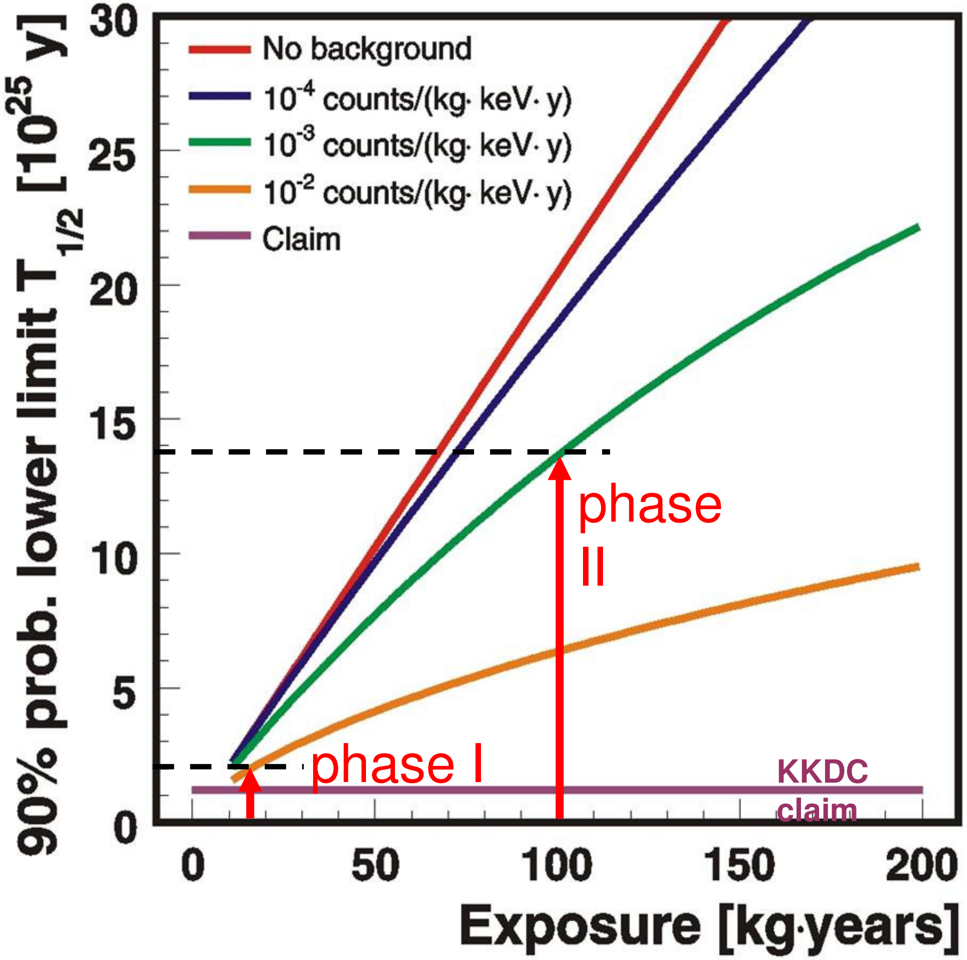
Why ^{76}Ge?

- Enrichment of ^{76}Ge possible
- Germanium semiconductor diodes
  - source = detector
  - excellent energy resolution
  - ultrapure material (monocrystal)
- Long experience in low-level Germanium spectrometry

Phases of GERDA

- Phase I:
  - Use of existing ^{76}Ge-diodes from Heidelberg-Moscow and IGEX-experiments
  - 17.9 kg enriched diodes ⇒ ~15 kg ^{76}Ge, exposure ~18 kg·y
  - Background-free probe of KKDC evidence
- Phase II:
  - Adding new segmented diodes (total: ~40 kg ^{76}Ge), exposure ~100 kg·y
  - Demonstration of bkg-level $<10^{-3}$ count/(keV·kg·y)
- Phase III:
  - If KKDC-evidence not confirmed: (1 ton) experiment in worldwide collaboration

Sensitivity

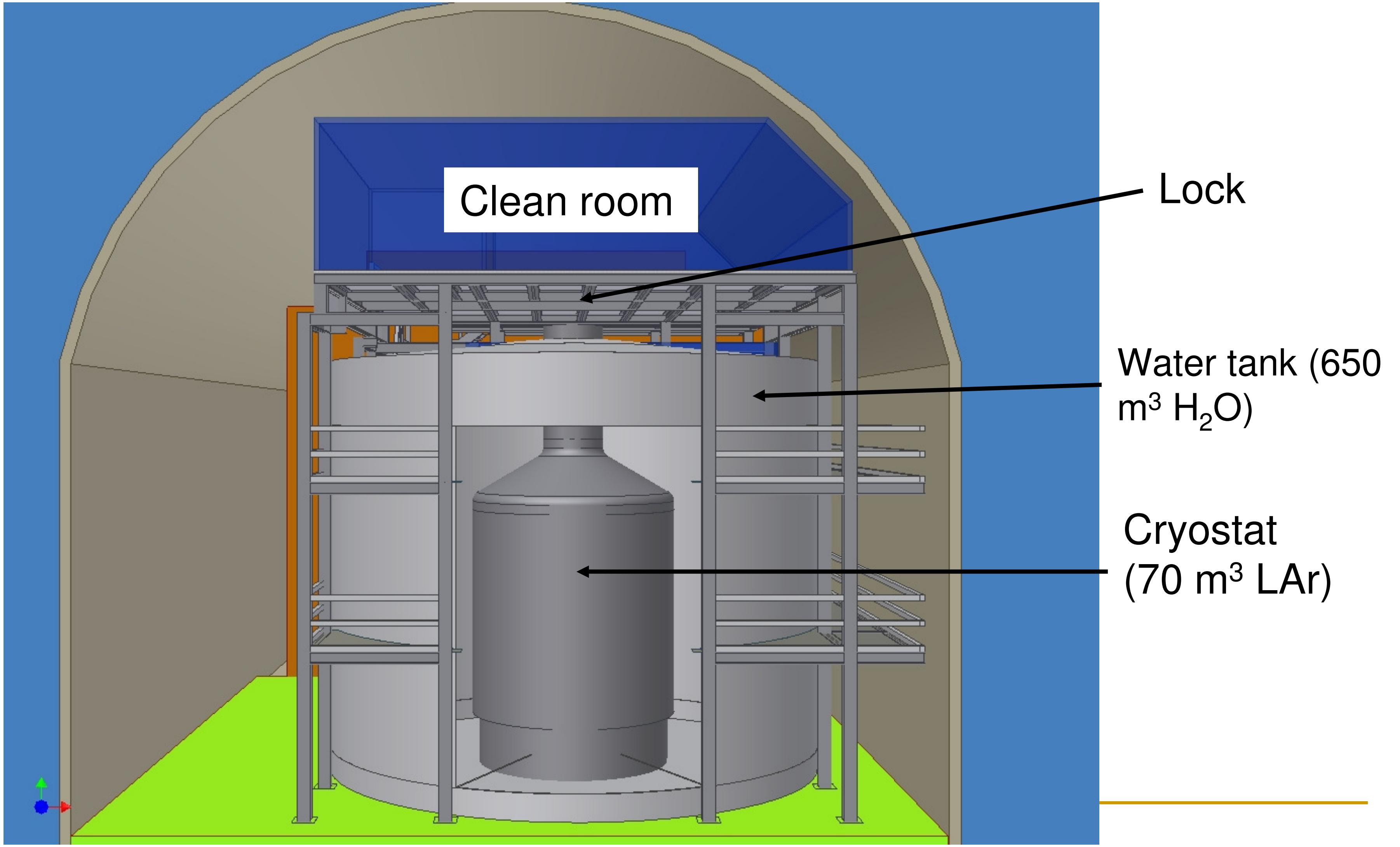


Assumed energy resolution:

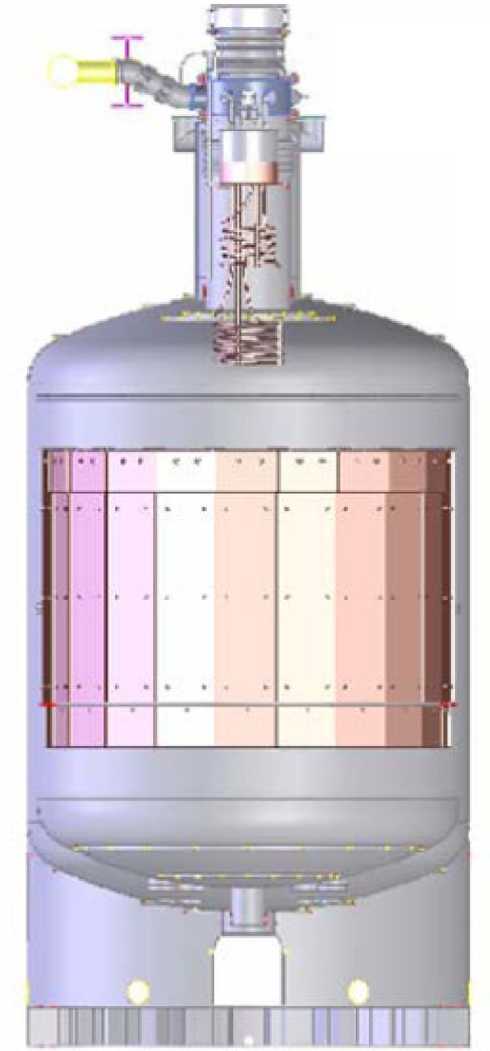
$\Delta E = 4$ keV

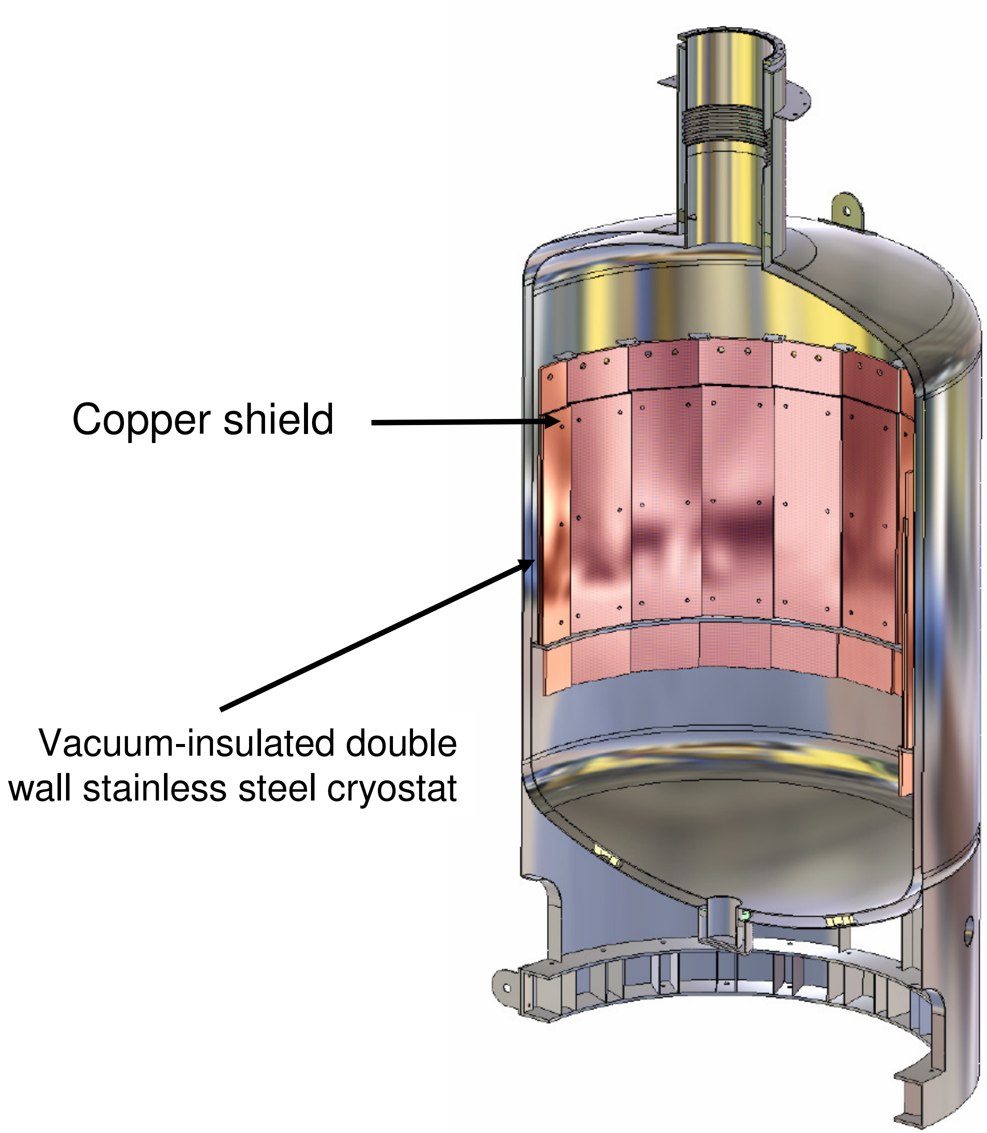
Background reduction is critical!

GERDA design

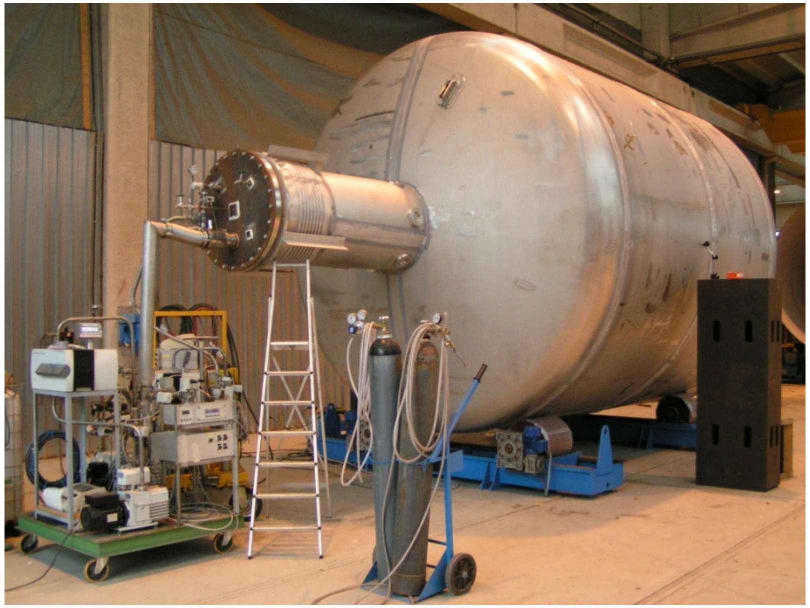


Cryostat



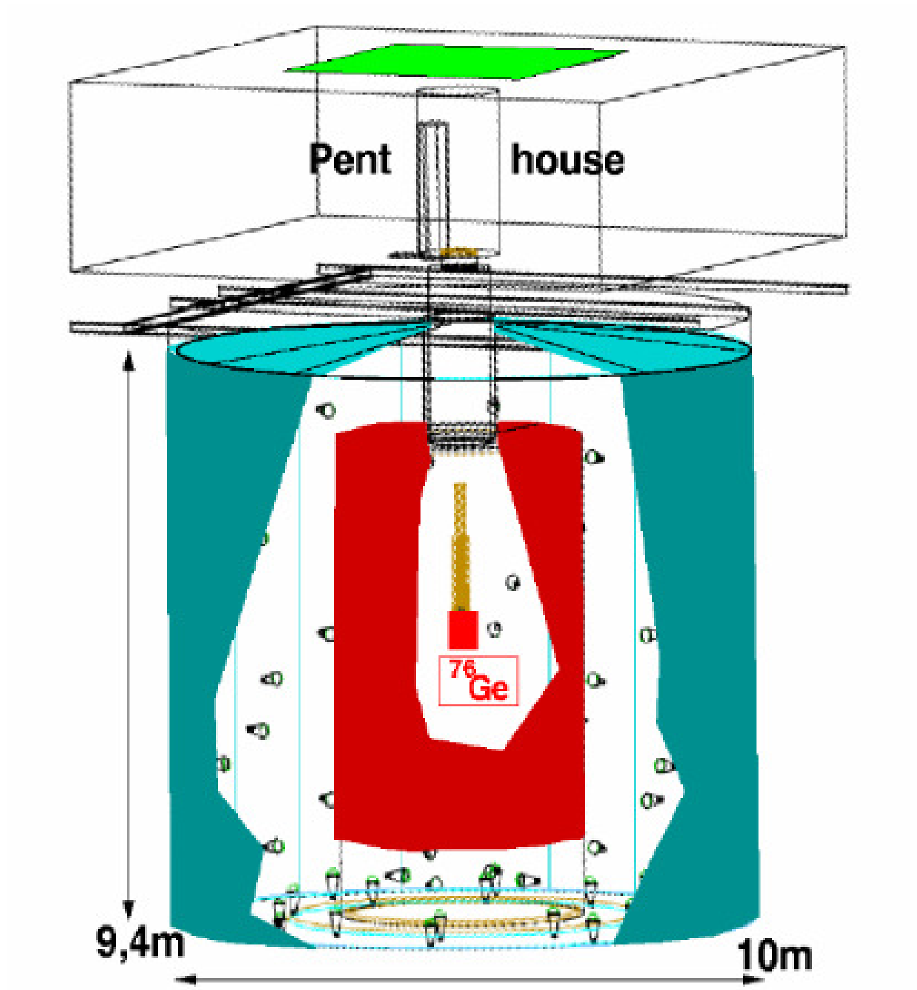

Copper shield
Vacuum-insulated double
wall stainless steel cryostat

Cryostat



Water tank and muon veto

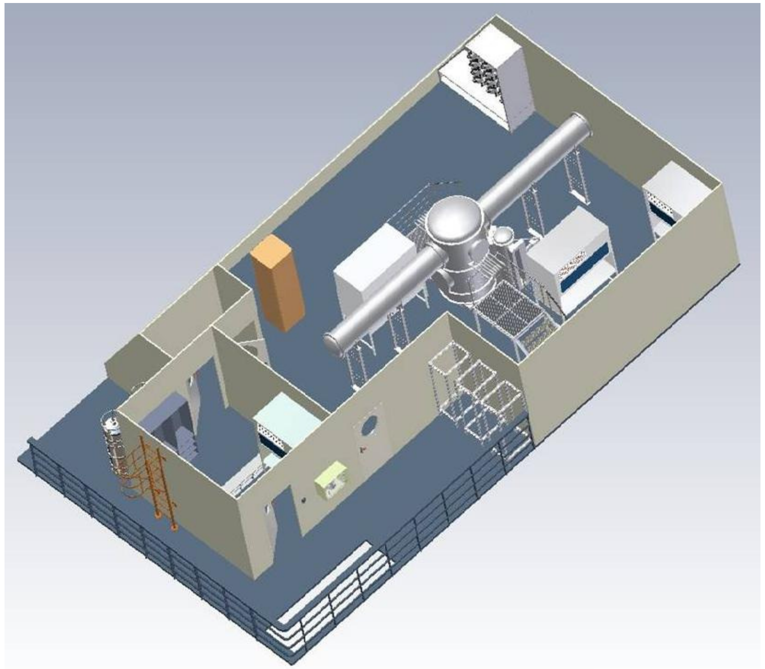
- Passive shield
- Filled with ultra-pure water
- 66 PMTs: Cherenkov detector
- Plastic scintillator on top

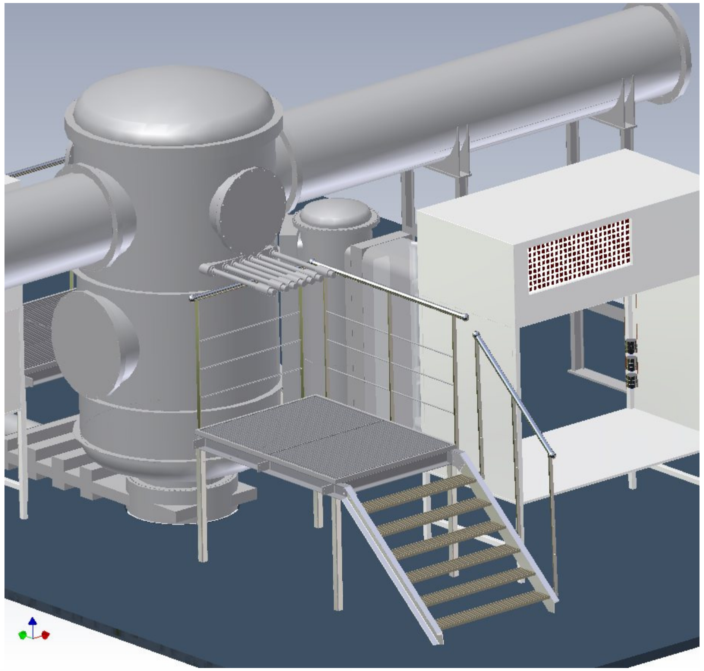


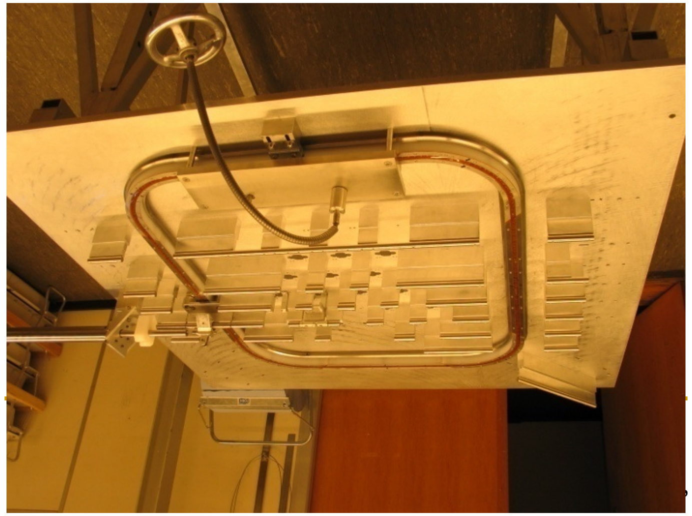
GERDA Cryostat
March 2008

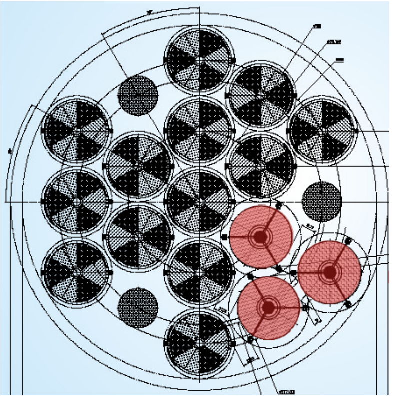
GERDA Water Tank and Superstructure August 2008

Cleanroom and the lock system

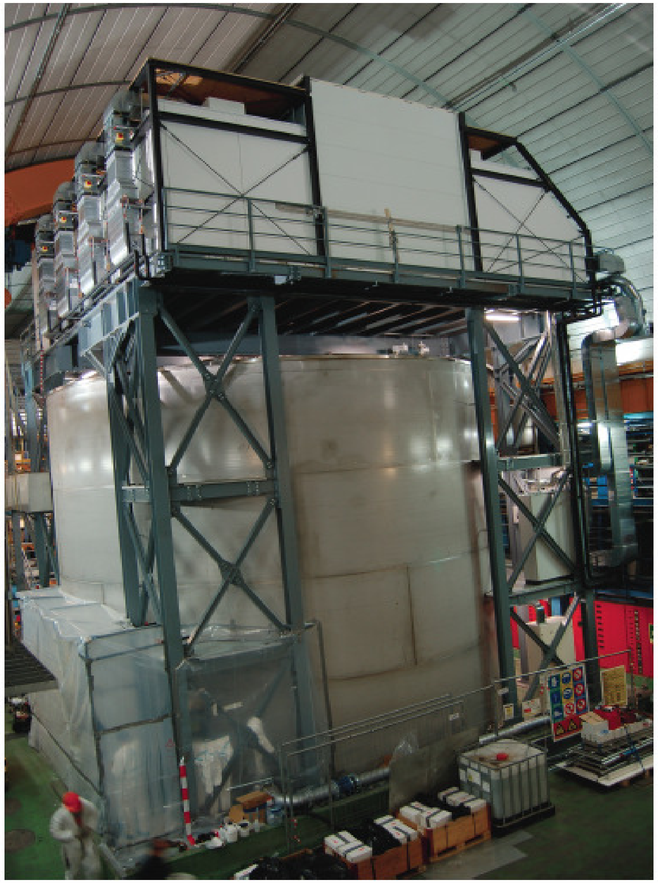








GERDA Clean Room and PMT installation

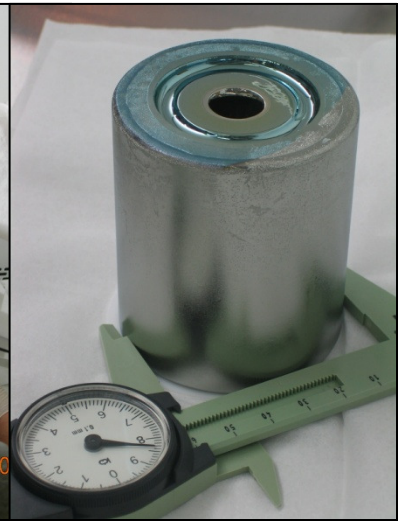


Clean Room (May 2009)

PMT installation
inside Water Tank (May 2009)

Phase I diodes

- 3- IGEX and 5- HdM diodes were removed from their cryostats
- Dimensions were measured
- Construction of dedicated low-mass holder for each diode
- Reprocessing of all diodes at manufacturer
- All detector tested in LAr
- FWHM (1.33 MeV ~2.5 keV)
- Leakage current stable
- 17.9 kg enriched and 15 kg non-enriched crystals (GENIUS-TF) are available



Phase II detectors

- 37.5 kg ^{enr}Ge produced
  - ~87% ^{76}Ge enrichment in form of GeO_2
- Underground storage
- Investigation of different options for crystal pulling – IKZ Berlin
- 18-fold n-type diodes preferred:
  - Segmentation easier
  - Thin outside dead layer
    ⇒ little loss of active mass

Background in GERDA

- External background

  - γ from U, Th decay chain, especially **2.615 MeV** from ^{208}Tl in concrete, rock, steel, copper,...

  - **neutrons** from (α,n) reaction and fission in concrete, rock and from μ induced reactions

  external background will be reduced by passive and active shield

- Internal background

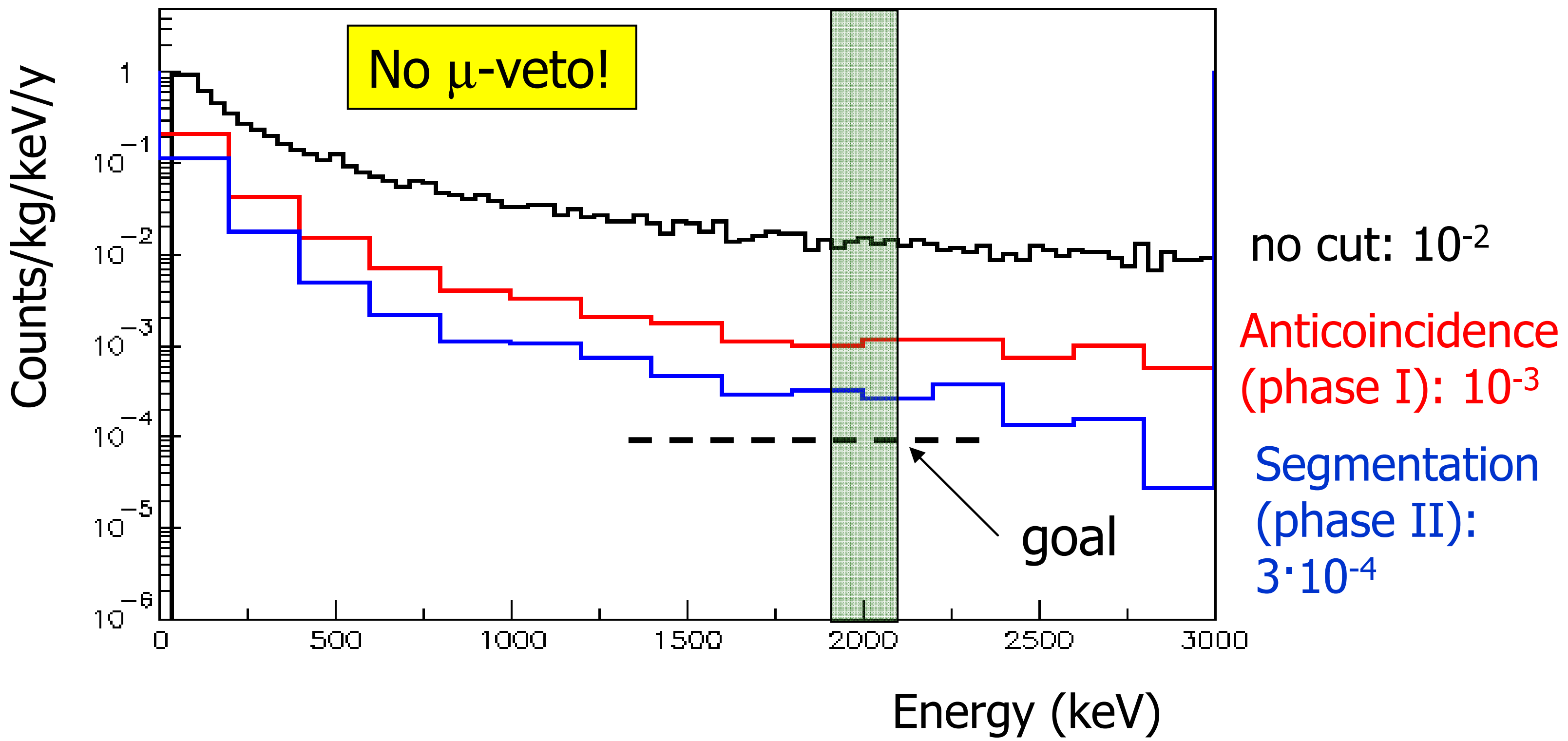
  - cosmogenic isotopes produced in spallation reactions at the surface, ^{68}Ge and ^{60}Co with half lifetimes ~year(s)

  - surface and bulk Ge contamination

  internal background will be reduced by anticoincidence between segments and puls shape discrimination

External background reduction

Muon-induced background: Prompt background



75% effective muon-veto is sufficient to achieve 10^{-4} counts/(keV·kg·y)

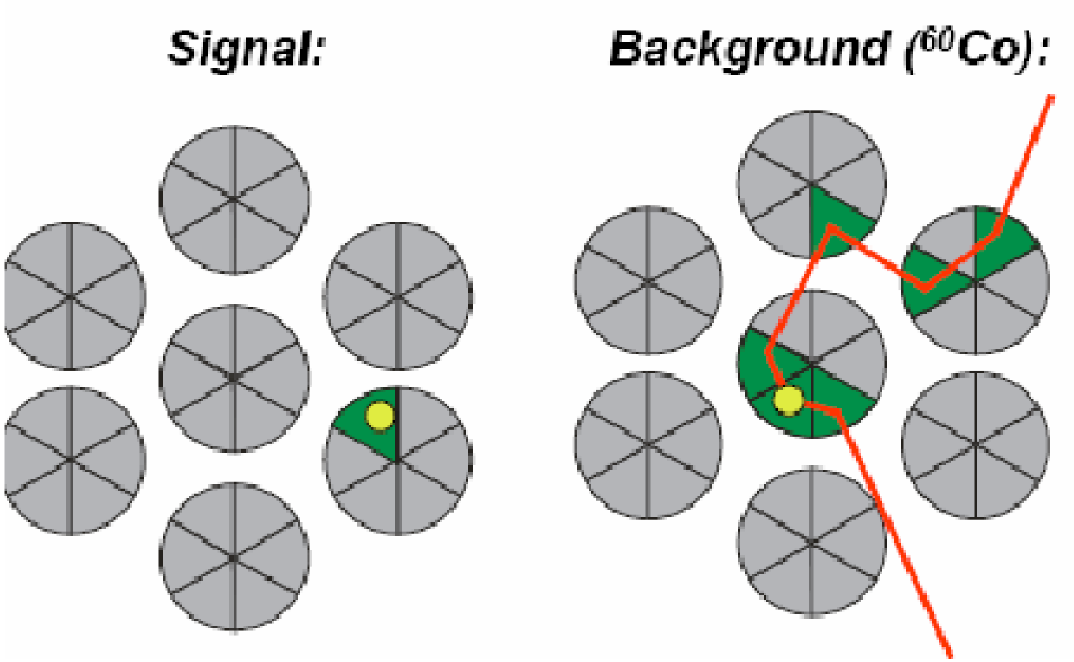
Internal background reduction

Photon – Electron discrimination

- Signal: local energy deposition – single site event
- Gamma background: compton scattering – multi site event

Anti-coincidence between segments suppr. factor ~10

Puls shape analysis suppr. factor ~2



Summary and Outlook

- Construction started and is ongoing
- **Phase I:**
  - Phase I detectors refurbished and tested in LAr
  - Reach 0.01 cts/(keV·kg·y)
  - Test neutrinoless double beta decay claim
- Parallel R&D for **Phase II:**
  - Reach 0.001 cts/(keV·kg·y)
  - Test $T_{1/2} \geq 1.35 \cdot 10^{26}$ y and $\langle m_{ee} \rangle \leq 0.12$ eV (NME - Rodin et al.)
- Rich R&D program
  - n-type segmented detector working in LN_2
  - p-type not-segmented detector - powerful PSA
- Complete installation and start apparatus commissioning in this year

GERDA Collaboration

- Jagellonian University, Cracow Poland
- Technische Universität Dresden, Germany
- Joint Institute for Nuclear Research, Dubna Russia
- Institute for Reference Materials and Measurements, Geel Belgium
- Max-Planck-Institut für Kernphysik, Heidelberg Germany
- Institute for Nuclear Research of the Russian Academy of Sciences, Moscow Russia
- Institute for Theoretical and Experimental Physics, Moscow Russia
- Russian Research Center Kurchatov Insitute, Moscow Russia
- Gran Sasso National Laboratory, Assergi Italy
- Universita Milano Bicocca and INFN, Italy
- Max-Planck-Institut für Physik, Munich Germany
- Universita di Padova and INFN, Italy
- Eberhard Karls University, Tübingen Germany
- University of Zürich, Switzerland