New Techniques in $0\nu\beta\beta$ Germanium Experiments

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GERDA collaboration

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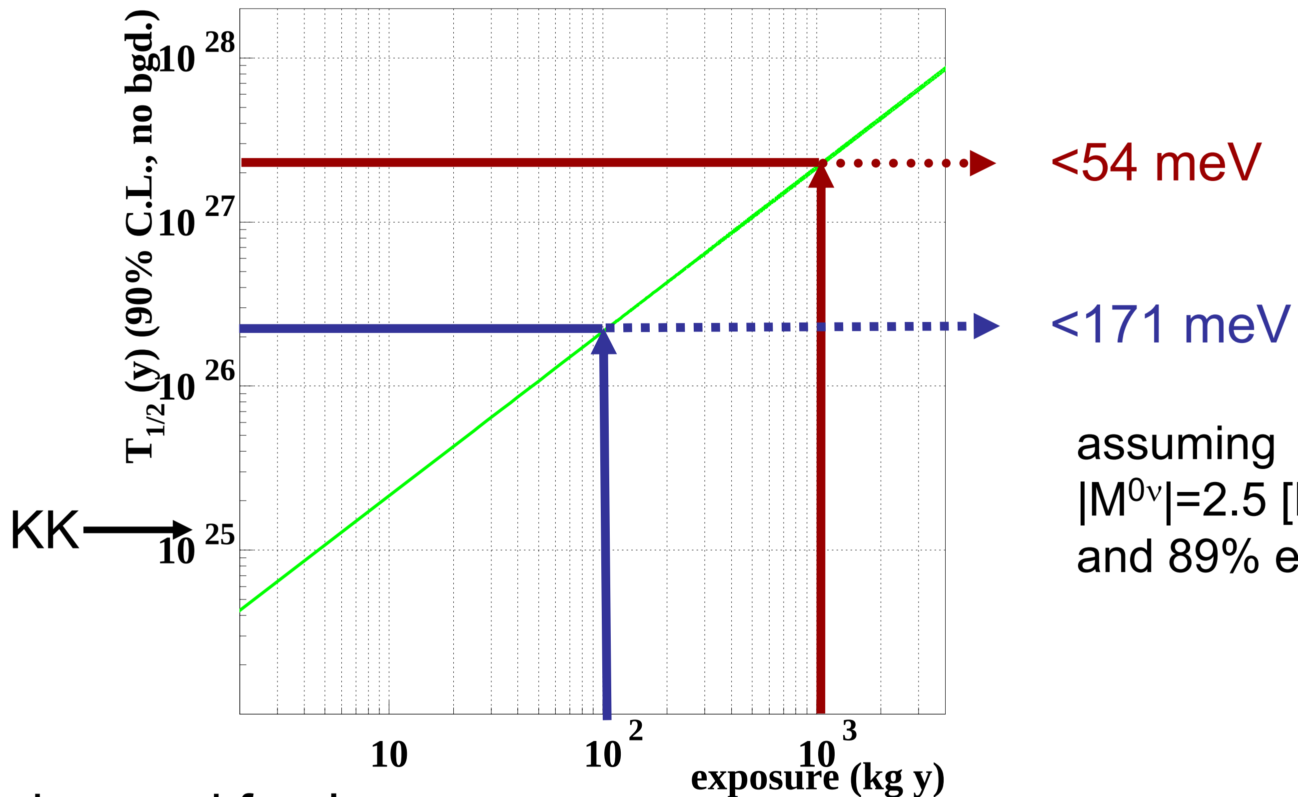
Outline

- Characteristics of Ge-76 and sensitivity
- Two new Ge experiments: GERDA & Majorana
- Main experimental differences:
  - Cryogenic liquid shield (GERDA)
  - Electroformed copper (Majorana)
- Background suppression techniques common to both experiments
  - Pulse shape analysis
  - Segmentation & neighbor anti-coincidence
  - R&D: liquid argon scintillation (LArGe)
- Progress Majorana / Progress GERDA
- Outlook

Characteristics of ^{76}Ge for $0\nu\beta\beta$ search

- Favorable nuclear matrix element $|M^{0\nu}|=2.5$ [Rod06]
- Reasonable slow $2\nu\beta\beta$ rate ($T_{1/2} = 1.4 \times 10^{21}$ y) and high $Q_{\beta\beta}$ value (2039 keV)
- Ge as source and detector
- Elemental Ge maximizes the source-to-total mass ratio
- Intrinsic high-purity Ge diodes
- HP-Ge detector technologies well established
- Industrial techniques and facilities available to enrich from 7% to ~88%
- Excellent energy resolution: FWHM ~3.3 keV at 2039 keV (0.16%)
- Powerful background rejection possible: granularity (segmentation & close packing), timing, pulse shape discrimination, argon scintillation
- Best limits on $0\nu\beta\beta$ - decay used Ge (IGEX & Heidelberg-Moscow)
  $T_{1/2} > 1.9 \times 10^{25}$ y (90%CL)

Sensitivity assuming no events in ROI



assuming
$|M^{0\nu}|$=2.5 [Rod06]
and 89% enrichment

required for 'background free'
exp. with ΔE~3.3 keV (FWHM): **$O(10^{-3})$** **$O(10^{-4})$** counts/(kg·y·keV)

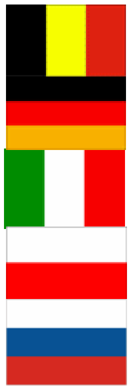
New experiments:

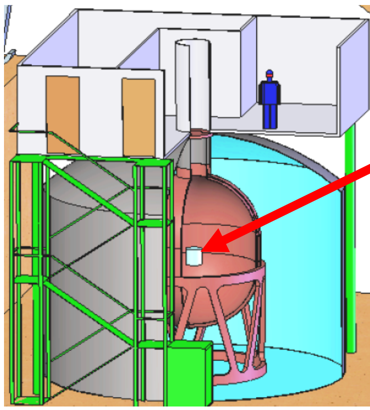
⇒Background reduction by factor **10^2** **-** **10^3** required w.r. to precursor exps.

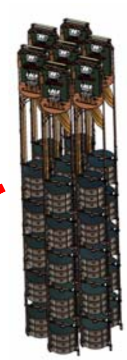
⇒Degenerate mass scale **$O(10^2$ kg·y)** ⇒ Inverted mass scale **$O(10^3$ kg·y)**

Two new ^{76}Ge Projects:

GERDA

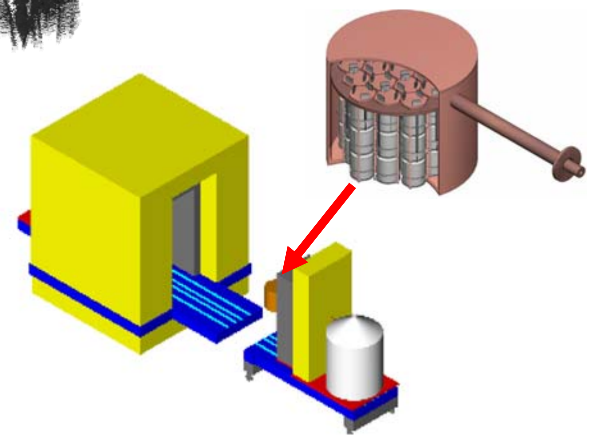


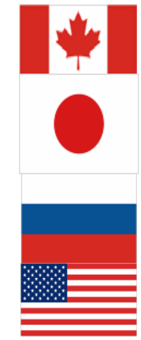




- ‘Bare’ ^{enr}Ge array in liquid argon (nitrogen)
- Shield: high-purity liquid Argon (N) / H_2O
- Phase I: ~18 kg (HdM/IGEX diodes)
- Phase II: add ~20 kg new enr. Detectors; total ~40 kg

Majorana





- Array(s) of ^{enr}Ge housed in high-purity electroformed copper cryostat
- Shield: electroformed copper / lead
- Staged approach based on 60 kg arrays (60/120/180 kg)

Physics goals: degenerate mass range
Technology: study of bgds. and exp. techniques

LoI
- open exchange of knowledge & technologies (e.g. MaGe MC)
- consider to merge for O(1 ton) exp. (inv. Hierarchy)

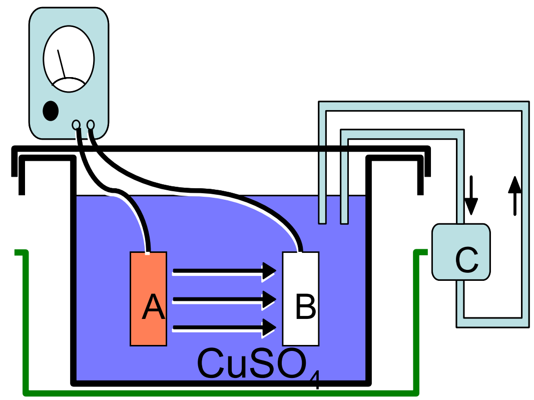
Backgrounds and reduction strategies

Source	Action GERDA	Action Majorana
γ's external to crystals from ^{208}Tl (^{232}Th), ^{214}Bi (^{226}Ra), ^{60}Co,…	Shield: high-purity liquid argon (nitrogen) / water shield	Shield: Electroformed copper, lead
Front-end electronics	ASIC (77/85° K)	Discrete low-level design
μ induced prompt signals	Underground location LNGS (3400 mwe); Water Cherenkov μ-veto	Underground location >4500 mwe; plastic scintillator μ-veto
μ induced delayed signals (e.g. n+^{76}Ge$\rightarrow$^{77}Ge$\xrightarrow{53s}$ ^{77}As	Low-Z material shield (Ar/water)	high-Z shield: deep under-ground location >4500 mwe
Internal to crystal: cosm. ^{60}Co ($t_{1/2}$= 5.27 y)	Minimize time above ground after crystal growing (30d$\rightarrow$2.5·10^{-3} cts/(keV kg y)	same
Internal to crystal: cosm. ^{68}Ge ($t_{1/2}$= 270 d)	Minimize time above ground after end of enrichment; shielded transp. container (180d$\rightarrow$12·10^{-3} cts/(keV kg y)	same

Materials in close vicinity of Ge diodes

GERDA: bare diodes submerged in **high-purity liquid Ar (N)**

Majorana: diodes housed in vacuum cryostat made of **electroformed cupper**



Main isotopes of concern in shielding materials:

Goal/achieved: <1μBq/m³ (STP) ^{226}Rn (^{214}Bi) in LN and LAr

Goal: <0.3μBq/kg ^{208}Tl (<1 μBq/kg ^{232}Tl)
Achieved: <2-4 μBq/kg ^{232}Th (ICPMS)

N.B.: shield design has impact on μ induced backgrounds

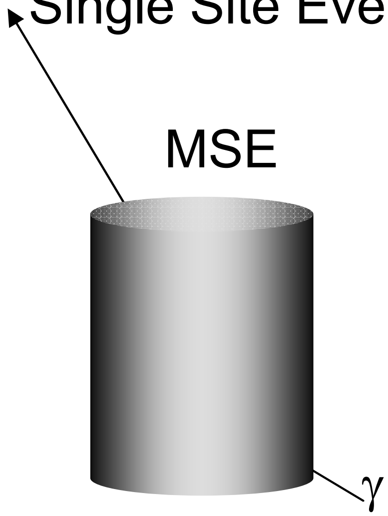
Low-Z shield ⇒LNGS 3400 mwe ok with water Cherenkov μ-veto

Pb/Cu shield requires depth >4500 mwe ⇒SNOlab, DUSEL

Common to GERDA & Majorana

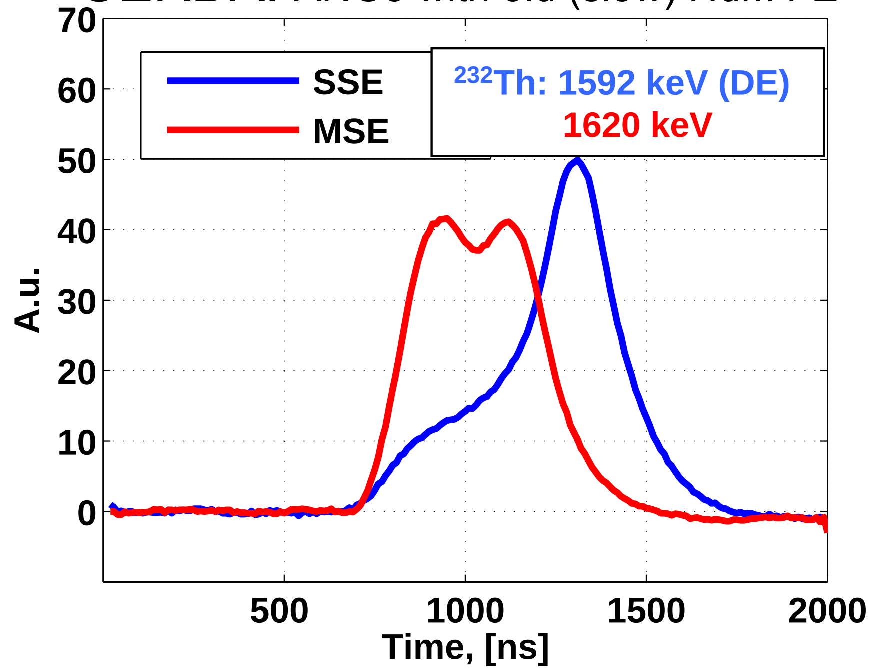
Background suppression techniques:

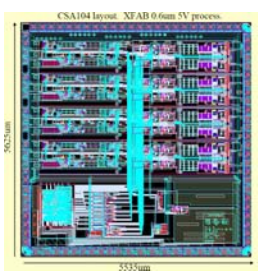
Discrimination of Multi Site Events (MSE) (e.g. Compton bgd.) from Single Site Events (SSE) (e.g. $0\nu\beta\beta$) by: **pulse shape analysis**



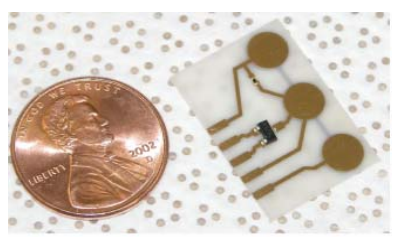
low-background FE electronics to be located close to diodes for high band width

GERDA: ANG5 with old (slow) HdM FE





ASIC FE (GERDA); 'true co-axial' det.



Discrete low-background FE (Majorana)

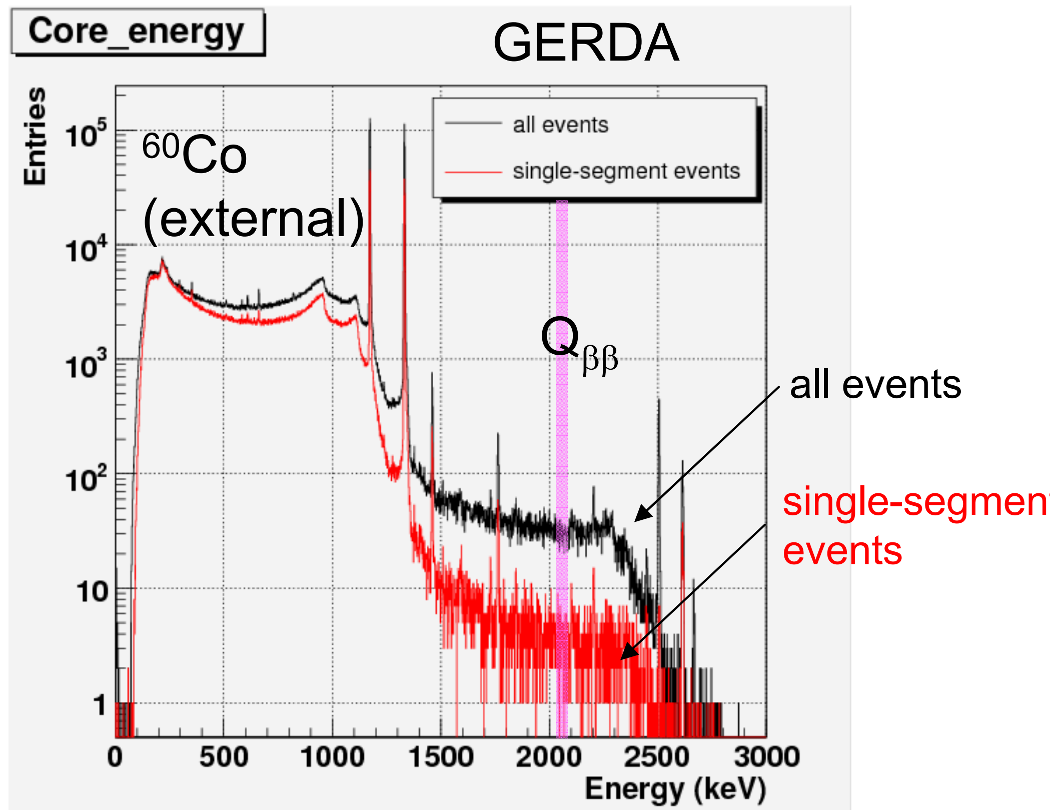
goal: effective MSE suppression with minimal loss of SSE's (i.e. $\beta\beta$ events)

Background suppression techniques:

Discrimination of Multi Site Events (MSE) (e.g. Compton bgd.) from Single Site Events (SSE) (e.g. $0\nu\beta\beta$) by: **granularity by segmented electrodes**

Segmentation of electrodes with individual electronic read-out channels

Segmentation scheme:
18–fold (6-ϕ; 3-z) segmented n-type crystal

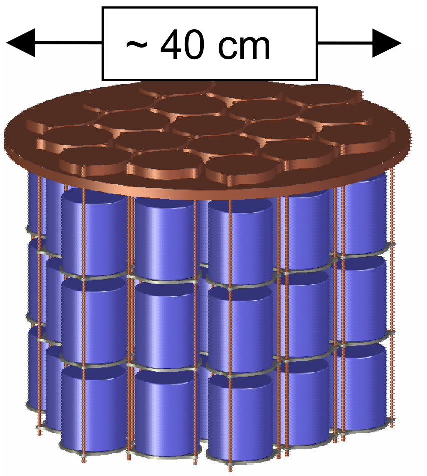


First test data with 18-fold prototype detector in standard cryostat (June)

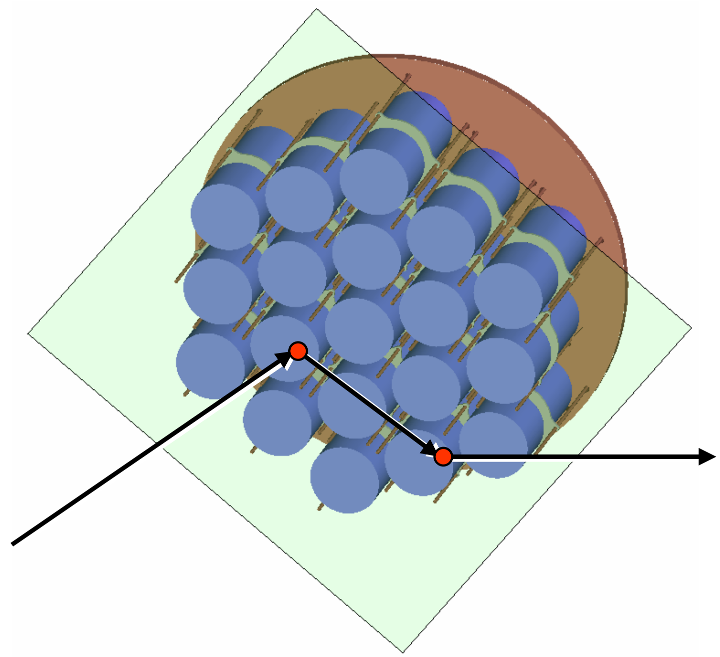
Common to GERDA & Majorana

Background suppression techniques:

Discrimination of Multi Site Events (MSE) (e.g. Compton bgd.) from Single Site Events (SSE) (e.g. $0\nu\beta\beta$) by: **granularity by close crystal packing**



Majorana detector array

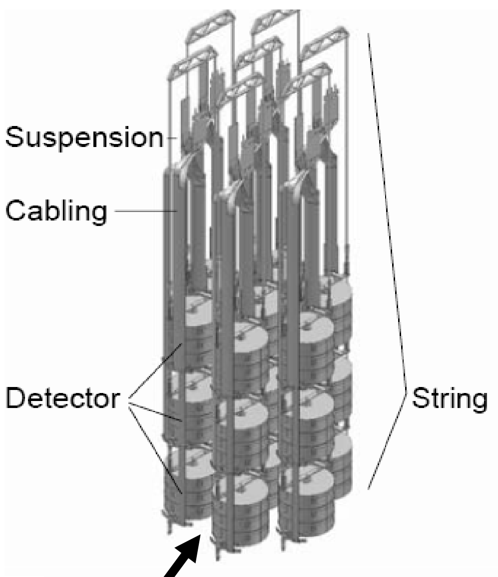


Granularity cut: Simultaneous signals in two or more crystals are rejected as $0\nu\beta\beta$ candidate events

Common to GERDA & Majorana

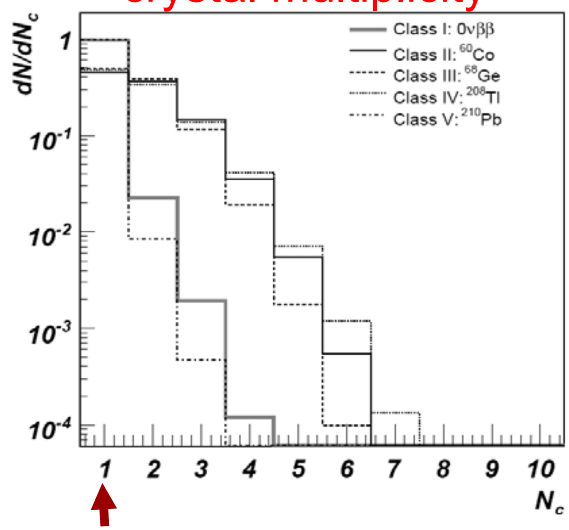
Background suppression techniques:

MC study (MaGe) of background suppression / $0\nu\beta\beta$ acceptance of GERDA array by **granularity cut**



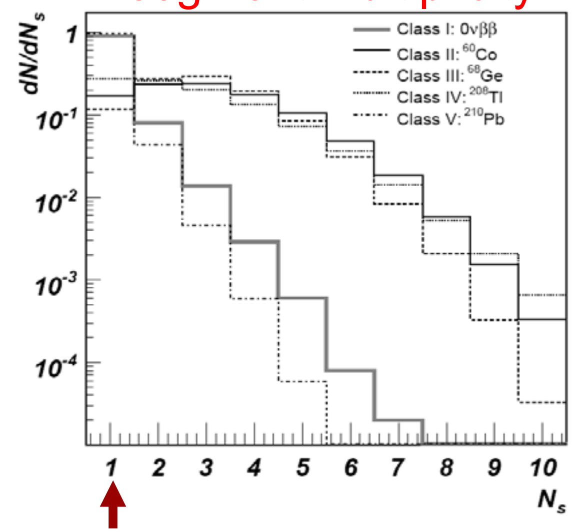
GERDA array with 21 detectors with 6ϕ-$3z$ segmentation

crystal multiplicity



single crystal hit
(Edep at $Q_{\beta\beta}$)

segment multiplicity



single segment hit
(Edep at $Q_{\beta\beta}$)

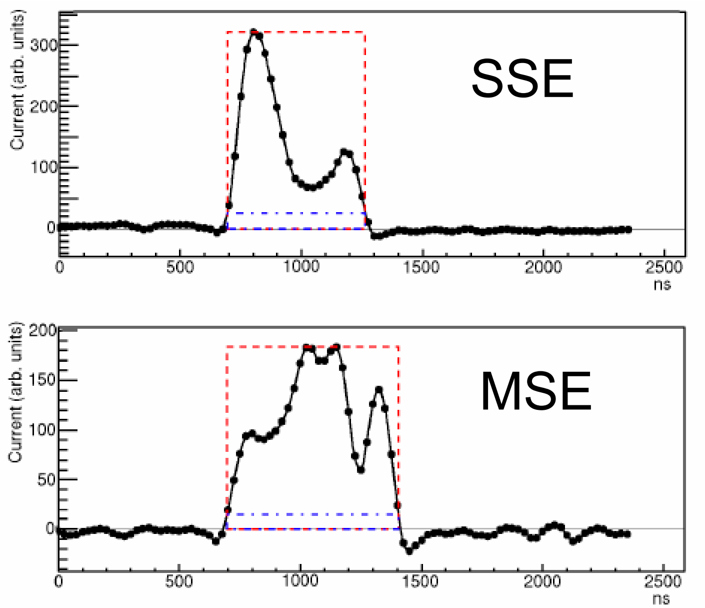
•$0\nu\beta\beta$ acceptance ~90% •Background suppression factors (SF) strongly dependent on: ⇒Isotope ⇒location	Range of suppression factors for single segment cut: ^{208}Tl: 3 – 13 ^{214}Bi: 6-13 ^{68}Ge: 18 (inside crystal) ^{60}Co: 38 - 157

Similar results in Majorana study

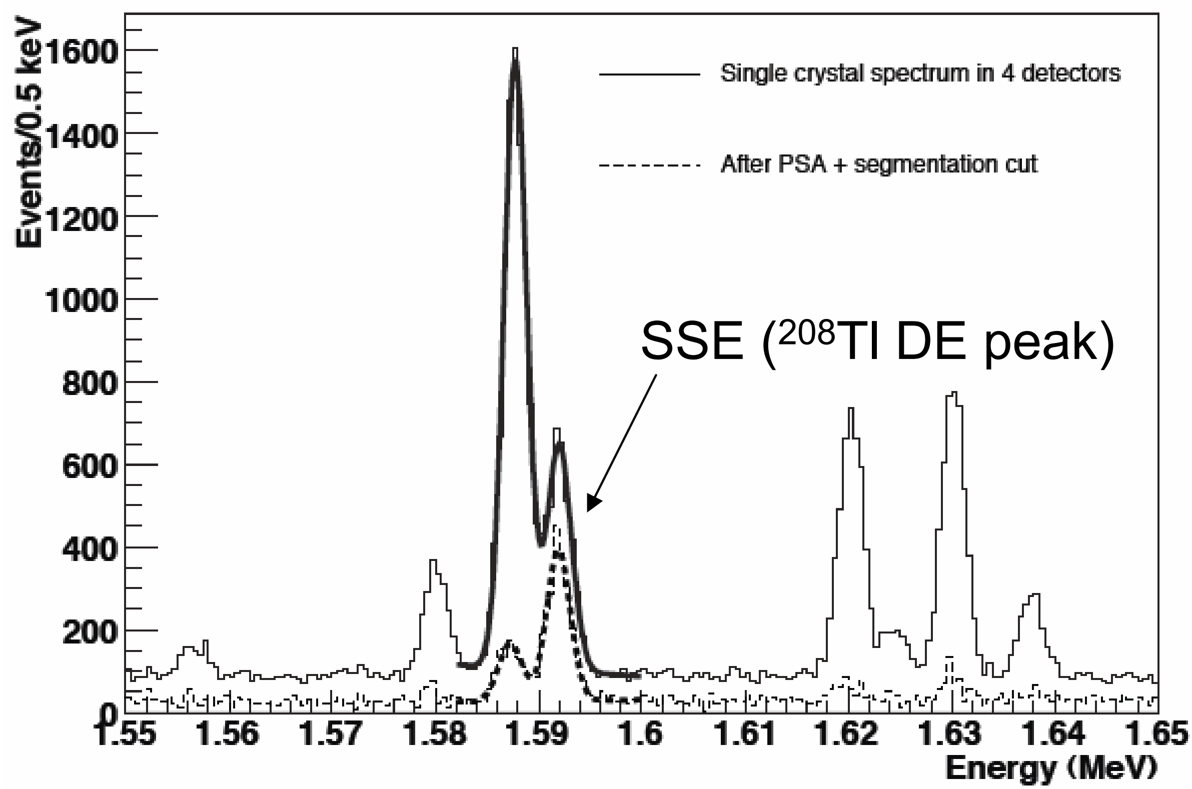
Common to GERDA & Majorana

Background suppression techniques:

Discrimination of Multi Site Events (MSE) (e.g. Compton bgd.) from Single Site Events (SSE) (e.g. $0\nu\beta\beta$) by: **segmented electrodes AND pulse shape**



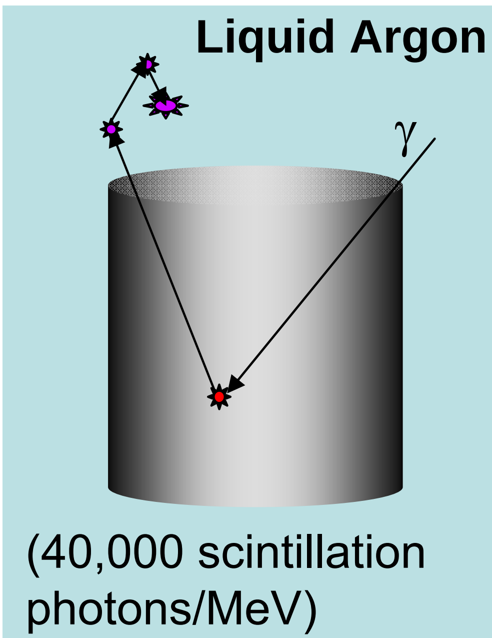
Majorana data

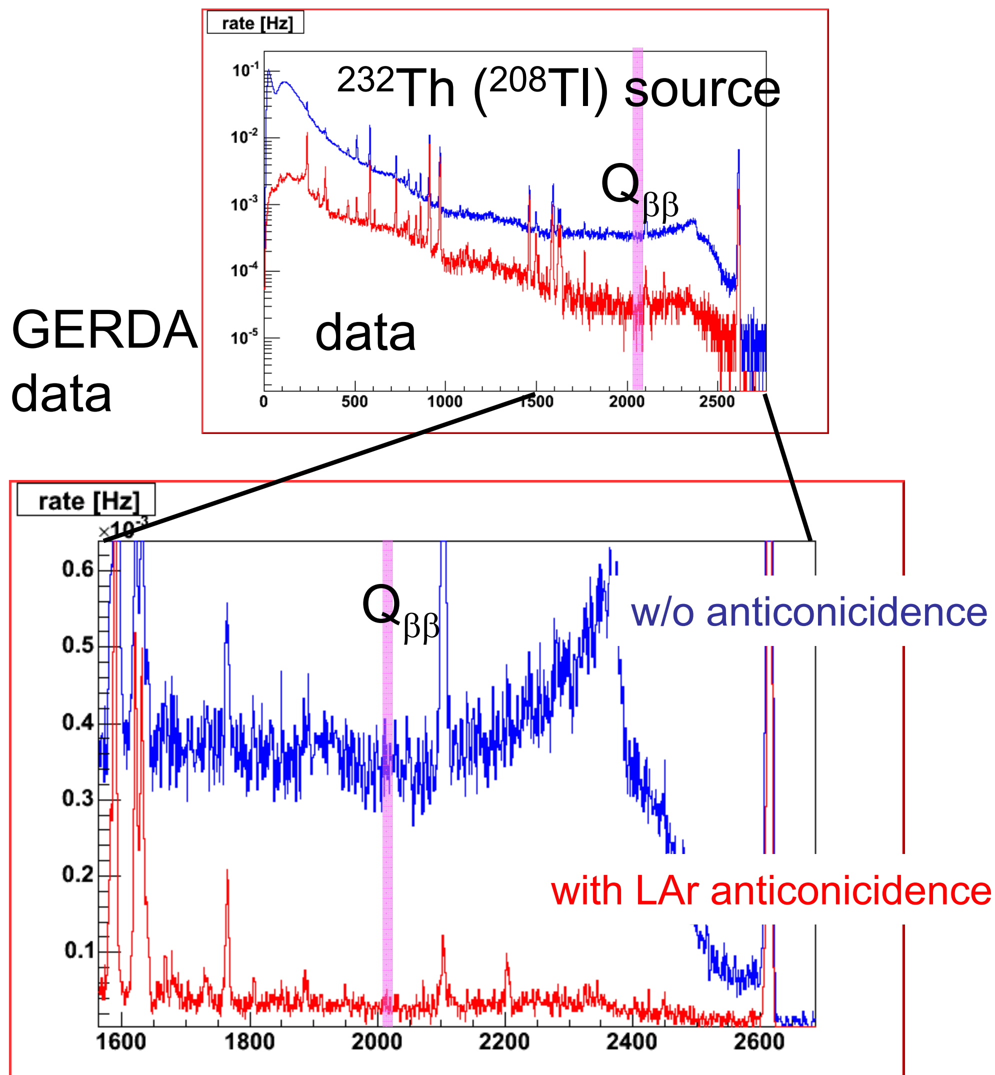


GERDA R&D project (also Majorana)

Background suppression techniques:

Discrimination of Multi Site Events (MSE) (e.g. Compton bgd.) from Single Site Events (SSE) (e.g. $0\nu\beta\beta$) by: **liquid argon scintillation anti-coincidence (LArGe)**





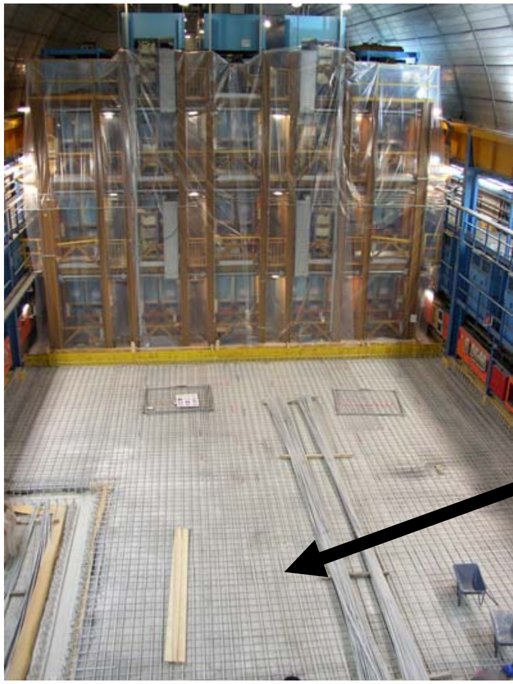
- 20 cm diameter test setup
- Suppression factor (~20) limited by escape from setup

Progress GERDA

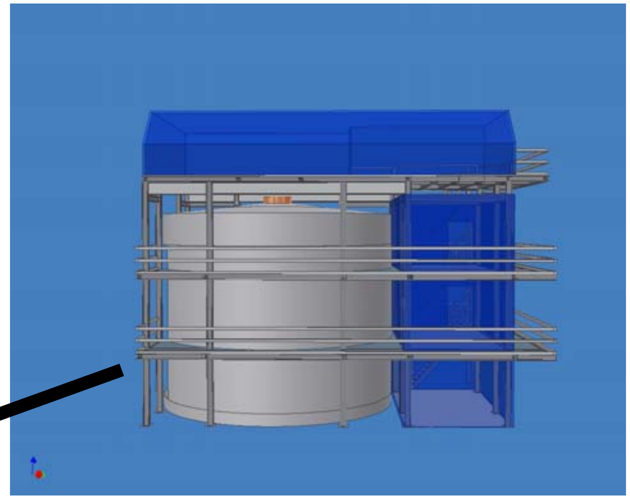
- Approved by LNGS with location in Hall A
- Funding: MPG, BMBF, INFN, Russia
- 18 kg of enriched detectors at LNGS – 37.5 kg of new enriched material stored underground
- Underground detector laboratory operational at LNGS
- Preparation for LNGS safety review of stainless steel cryostat
- LNGS Hall A under preparation for start of construction of main infrastructures in 2006

GERDA photo gallery

Preparation of concrete basement for GERDA in Hall A of LNGS

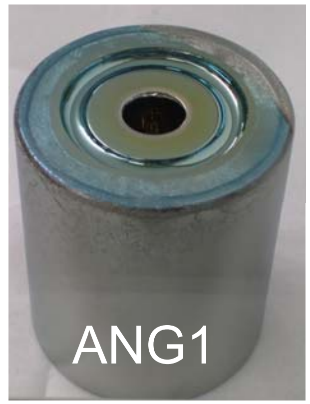


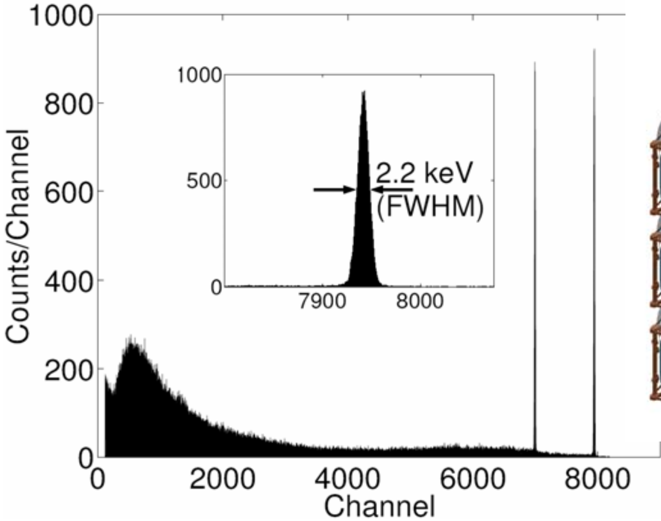
Water tank, cryostat, clean room & infrastructures

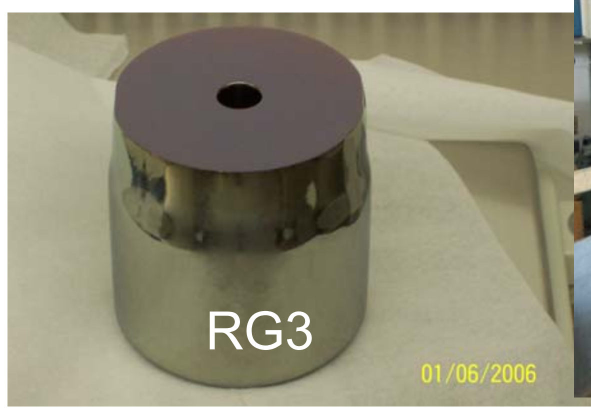


LArGe underground detector laboratory at LNGS

Enriched detectors





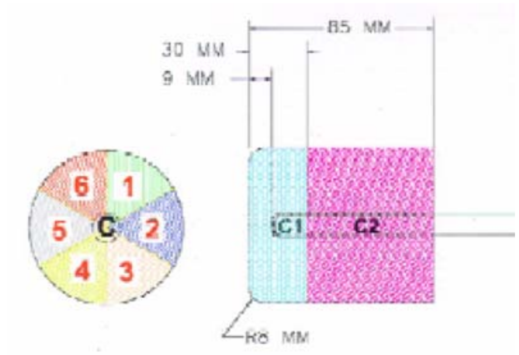


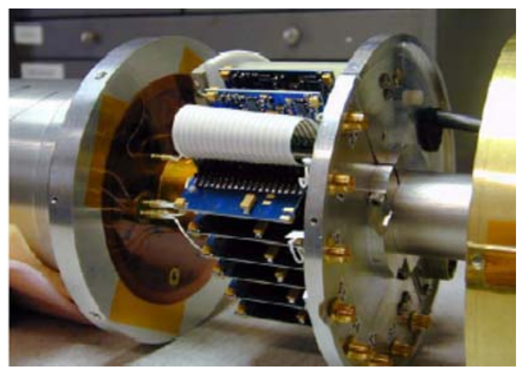
37.5 kg of enriched 87.5% germanium

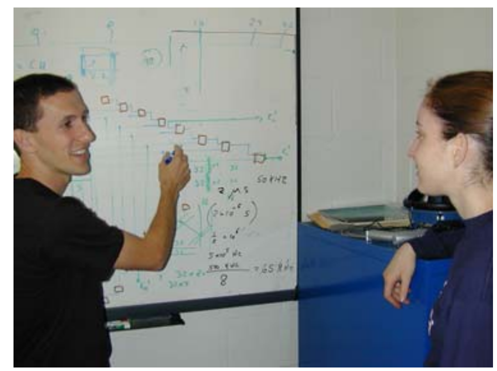
Progress Majorana

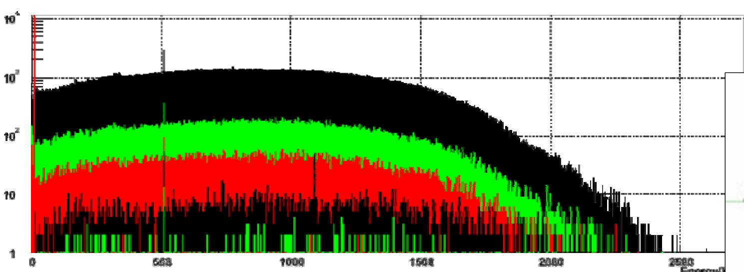
- DOE Office of Nuclear Physics (NP) has identified $0\nu\beta\beta$ as a mission need, and approved Majorana to pursue R&D and to prepare for a Conceptual Design Review (CDR)
- External panel review: “essentially ready for CD-1 review; time critical!”
- Start with 60 kg array (optional: 120/180 kg)
- Site: SNOlab or DUSEL (depth > 4500 mwe)

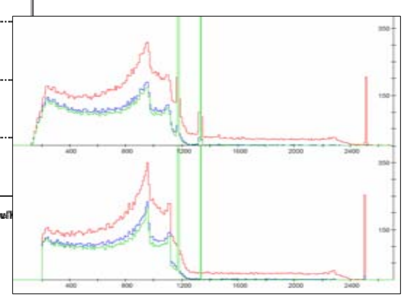
Majorana photo gallery

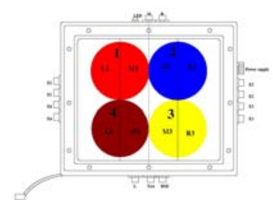


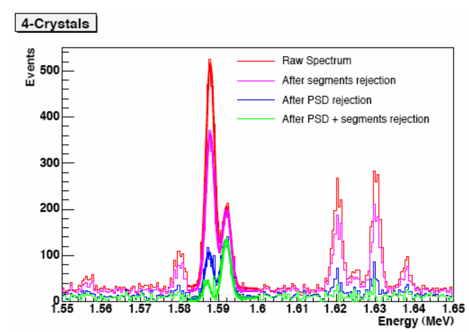












Summary/Outlook

- ^{76}**Ge detector technology** provides powerful tools for **background suppression** and **$0\nu\beta\beta$ event recognition**
- GERDA & Majorana have **different shield** concepts, but **common background reduction** techniques
- **GERDA**
  - Funded; main infrastructure construction starting in 2006
  - **Phase I :** background 0.01 cts / (kg·keV·y)
    - scrutinize KKDC result
  - **Phase II :** background 0.001 cts / (kg·keV·y)
    - $T_{1/2} > 2 \cdot 10^{26}$ y , $<m_{ee}> < 90 – 290$ meV
- **Majorana**
  - R&D funding; preparing for DOE CD-1 review
  - **Staged approach** based on 60 kg detector assemblies
  - 2x60kg arrays and 4.5 years, or 0.46 t-y of ^{76}Ge exposure

    $T_{1/2} >= 5.5 \times 10^{26}$ y (90% CL)

    $<m_{\nu}> < 100$ meV (90% CL) ([Rod06] RQRPA matrix elements)

    or a 10-20% measurement assuming a 400 meV value.

Summary/Outlook

- **GERDA & Majorana**
  - Exchange of information and cooperation well established
  - Consider to merge for O(1t) experiment with ~50 meV sensitivity
  - Select best techniques developed and tested in GERDA Phase I+II and Majorana 60/120/180 kg. Therefore: important that Majorana funding comes timely