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Riccardo Brugnera
Padova University and INFN

on behalf of the
GERDA Collaboration

Search of neutrinoless double beta decay of ^{76}Ge with the Germanium Detector Array "GERDA"

Outline:
- Double Beta Decay
- GERDA design
- Present Status
- R&D
- Summary

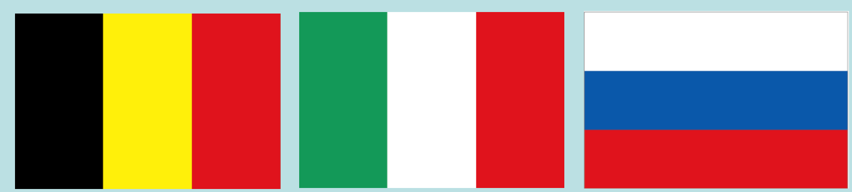
GERDA: The GERmanium Detector Array for the search of neutrinoless ββ decays of ^{76}Ge at LNGS

A.M. Bakalyarov[l], M. Balata[a], I. Barabanov[j], M. Barnabe-Heider[f], L. Baudis[q], C. Bauer[f], E. Bellotti[g,h], S. Belogurov[k,j], S.T. Belyaev[l], A. Bettini[n,o], L. Bezrukov[j], V. Brudanin[d], R. Brugnera[n,o], D. Budjas[f], A. Caldwell[m], C. Cattadori[g,h], O. Chkvorets[f], E.V. Demidova[k], A. Denisiv[j], A. Di Vacri[a], A. D'Andragora[a], V. Egorov[d], A. Ferella[q], F. Froborg[q], A. Gangapshev[j], A. Garfagnini[n,o], J. Gasparro[e], P. Grabmayr[p], G.Y. Grigoriev[l], K.N. Gusev[l], V. Gutentsov[j], W. Hampel[f], M. Heisel[f], G. Heusser[f], W. Hofmann[f], M. Hult[e], L.V. Inzhechik[l], J. Janicsko[m], M. Jelen[m], J. Jochum[p], M. Junker[a], J. Kiko[f], S. Kionanovsky[j], I.V. Kirpichnikov[k], A. Klimenko[d,j], M. Knapp[p], K-T. Knoepfle[f], O. Kochetov[d], V.N. Kornoukhov[k,j], V. Kusminov[j], M. Laubenstein[a], V.I. Lebedev[l], D. Lenz[m], M. Lindner[f], J. Liu[m], X. Liu[m], B. Lubsandorzhiev[j], B. Majorovits[m], A. Manzur[q], G. Marissens[e], G. Meierhofer[p], I. Nemchenok[d], S. Nisi[a], J. Oehm[f], L. Pandola[a], P. Peiffer[f], F. Potenza[a], A. Pullia[i], S. Riboldi[i], F. Ritter[p], C. Rossi Alvarez[o], V. Sandukovsky[d], J. Schreiner[f], J. Schubert[m], U. Schwan[f], B. Schwingenheuer[f], S. Schönert[f], M.V. Shirchenko[l,d], M. Shirchenko[l], H. Simgen[f], A. Smolnikov[d,j], L. Stanco[o], F. Stelzer[m], M. Tarka[q], A.V. Tikhomirov[l], C.A. Ur[o], A.A. Vasenko[k], S. Vasiliev[d,j], M. Wojcik[b], E. Yanovich[j], J. Yurkowski[d], S.V. Zhukov[l], F. Zocca[i], K. Zuber[c], and G. Zuzel[f].

The GERmanium Detector Array Collaboration

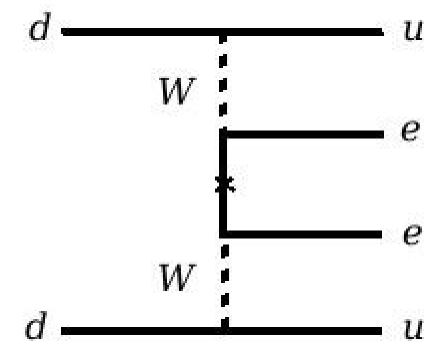
http://www.mpi-hd.mpg.de/GERDA

[a]) INFN Laboratori Nazionali del Gran Sasso, LNGS, Assergi, Italy
[b]) Institute of Physics, Jagellonian University, Cracow, Poland
[c]) Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
[d]) Joint Institute for Nuclear Research, Dubna, Russia
[e]) Institute for Reference Materials and Measurements, Geel, Belgium
[f]) Max Planck Institut für Kernphysik, Heidelberg, Germany
[g]) Dipartimento di Fisica, Università Milano Bicocca, Milano, Italy
[h]) INFN Milano Bicocca, Milano, Italy
[i]) Dipartimento di Fisica, Università degli Studi di Milano e INFN Milano, Milano, Italy
[j]) Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia
[k]) Institute for Theoretical and Experimental Physics, Moscow, Russia
[l]) Russian Research Center Kurchatov Institute, Moscow, Russia
[m]) Max-Planck-Institut für Physik, München, Germany
[n]) Dipartimento di Fisica dell'Università di Padova, Padova, Italy
[o]) INFN Padova, Padova, Italy
[p]) Physikalisches Institut, Eberhard Karls Universität Tübingen, Tübingen, Germany
[q]) Physik Institut der Universität Zürich, Zürich, Switzerland



~ 95 physicists from 17 institutions

motivation for 0νββ decay searches



- Only way to determine if neutrino is its own antiparticle:

  $\nu = \bar{\nu}$ ⇨ ***Majorana particle***

  If YES:

- would provide access to ***absolute neutrino mass scale***

$$\left(T^{0\nu}_{1/2}\right)^{-1} = G^{0\nu}(E_{0,} Z)\ \left|M^{0\nu}\right|^2 \left(\frac{\langle m_\nu \rangle}{m_e}\right)^2$$

$$\langle m_\nu \rangle = \left| \sum_i U^2_{ei} m_i \right|$$

nuclear matrix element

phase space factor

effective Majorana neutrino mass

- would establish ***lepton number violation*** ΔL = 2
- more ***physics beyond standard model***
- would provide ***important input to cosmology***

2νββ and 0νββ decays

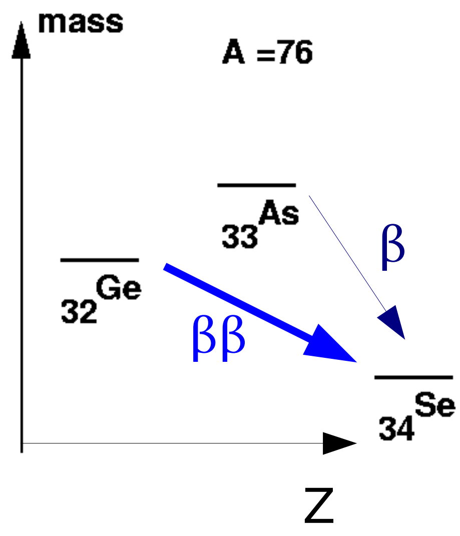
2νββ : $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$

2nd order process, observed, $T_{1/2} \sim 10^{19}$-10^{21} yrs

Ge-76: $T_{1/2} = 1.4 \cdot 10^{21}$ yrs

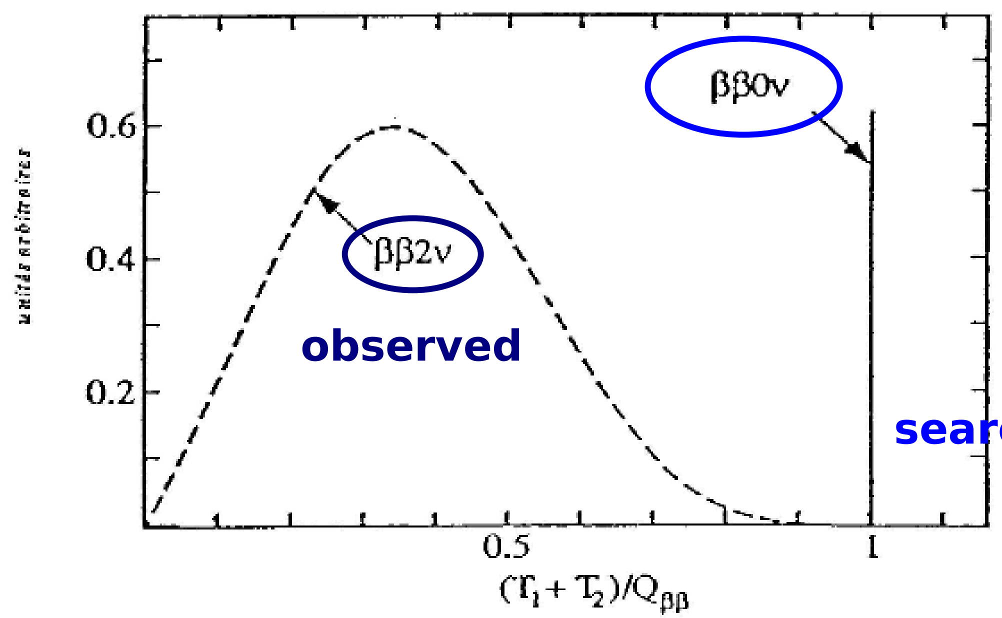
0νββ : $(A,Z) \rightarrow (A,Z+2) + 2e^-$

new physics, $T_{1/2} > 10^{25}$ yrs



Signature for 0νßß decays:

Ge-76 : $Q_{\beta\beta}$=2039 keV



searched for

best limits/value

KKDC: H.V. Klapdor-Kleingrothaus et al.
Phys. Lett. B 586 (2004) 198

5 enriched **Ge-76** diodes (10.9 kg / 71.7 kg·y)
'Background Index' B = ~0.1 cts / (keV·kg·y)

$T^{0\nu}_{1/2} = (0.69 - 4.18) \times 10^{25}\, y$ (3σ range)

$T^{0\nu}_{1/2} = 1.19 \times 10^{25}\, y$ (best fit)

IGEX: D. Gonzalez et al.
NP B (Proc. Suppl.) 87 (2000) 278

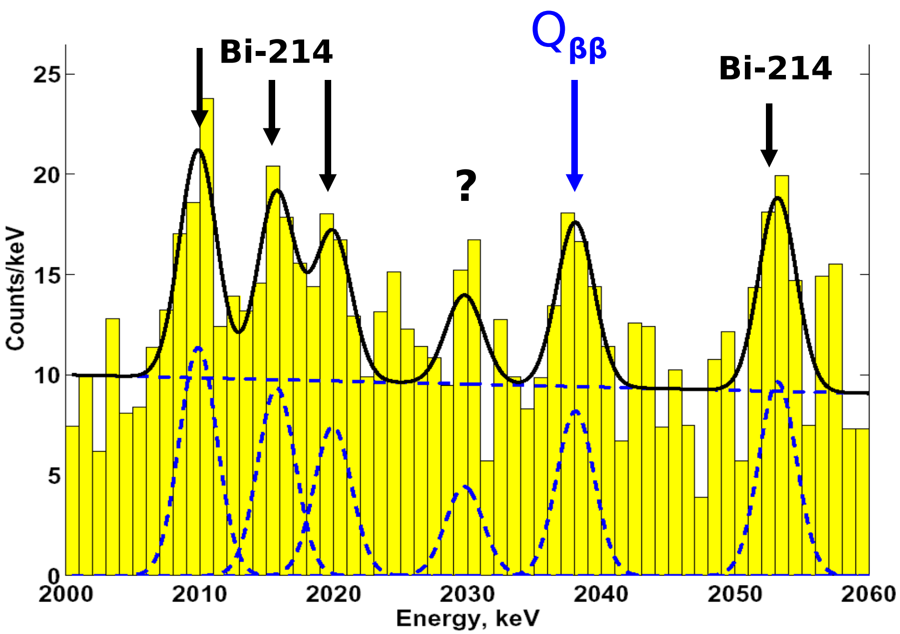
Ge-76 diodes (8.87 kg·y)

$T^{0\nu}_{1/2} > 1.57 \times 10^{25}\, y$ (90% CL)

CUORICINO: C. Arnaboldi et al.
Phys. Rev. C 78 (2008) 035502

62 $\mathbf{TeO_2}$ bolometers (40.7 kg/11.83 kg·y)

$T^{0\nu}_{1/2} \geq 3.0 \times 10^{24}\, y$ (90% CL)

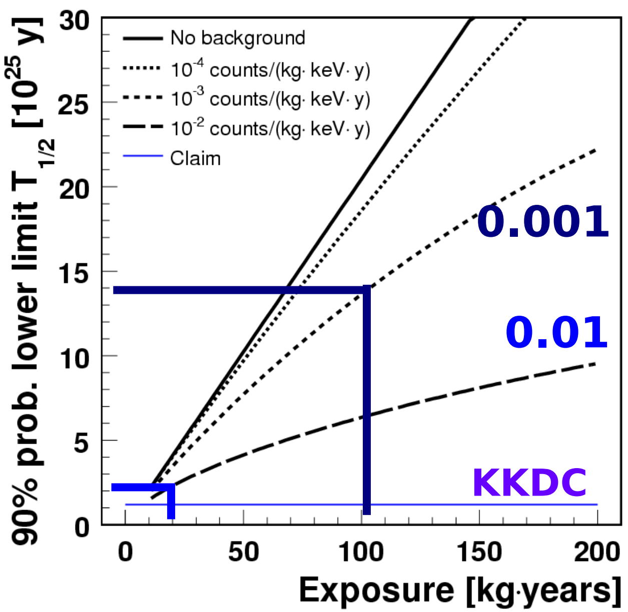


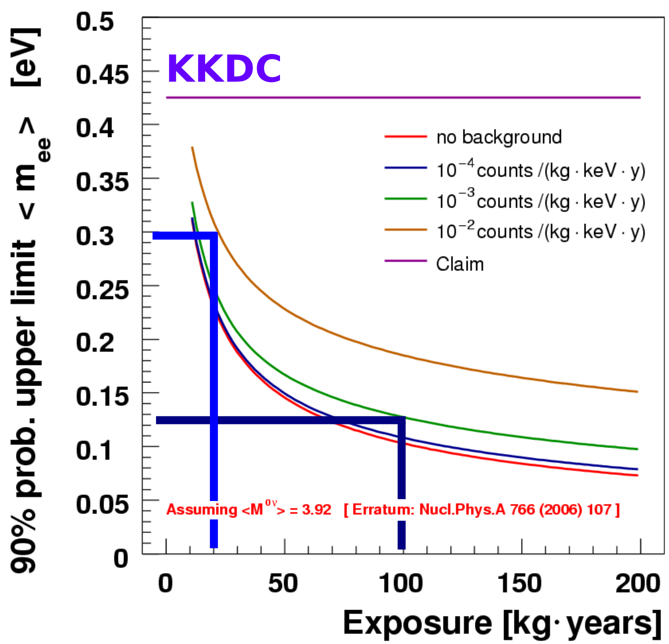
- **Confirmation needed with same & different isotopes**
- **key: reduce background by *O*(100) for better sensitivity**

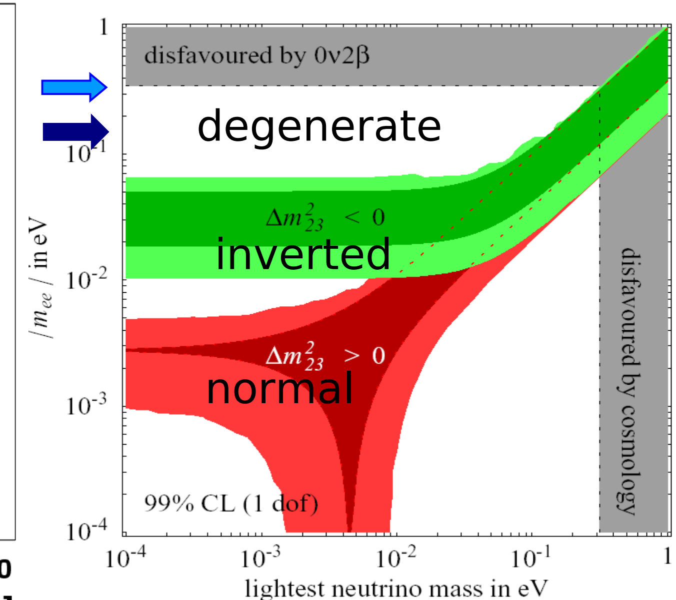
GERDA goals and sensitivity

GERDA's goal : reach background index at $Q_{\beta\beta}$= 2039 keV of 0.01 / 0.001 cts / (keV·kg·y)

measured → deduced → mass hierarchy







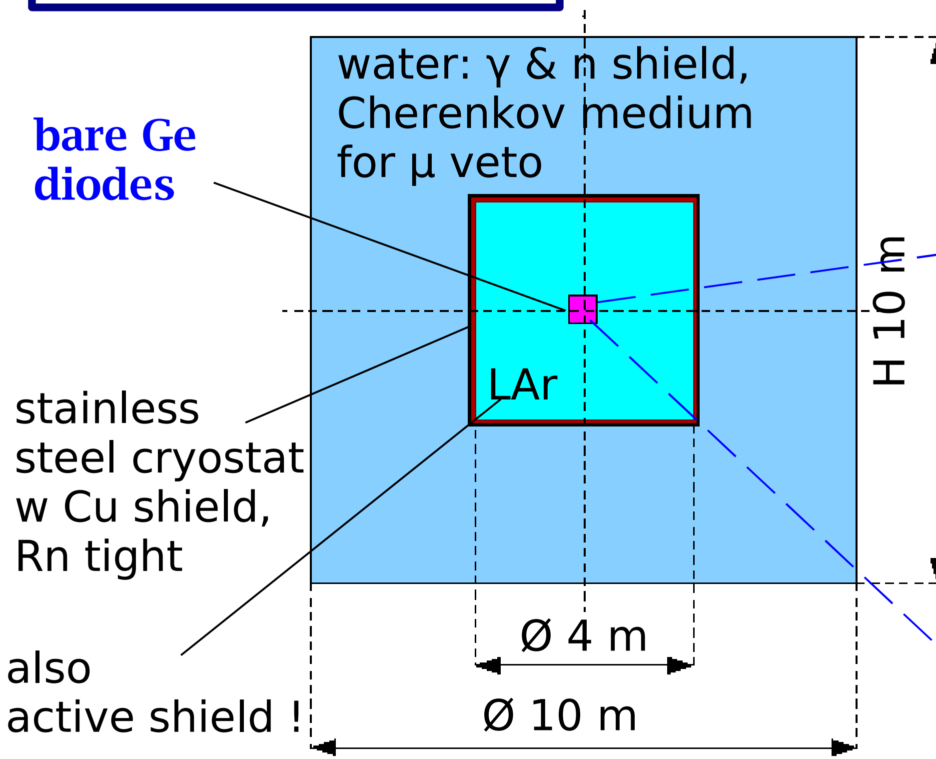
A.Strumia & F.Vissani, hep-ph / 0503246

- **phase I** :use existing Ge-76 diodes of Heidelberg-Moscow experiment & IGEX (~18kg) ~0.01 cts/(keV·kg·y) intrinsic background expected
- **phase II** :add new enriched Ge-76 detectors, ~20 kg, (37.5 kg enriched Ge-76 bought) ~0.001 cts/(keV·kg·y) bkg expected ▶100 kg·y
- phase III:depending on results worldwide collaboration for real big experiment close contacts & MOU with MAJORANA collaboration established

background reduction

External bkgs: γ(Th,U), n, μ

Shielding possible



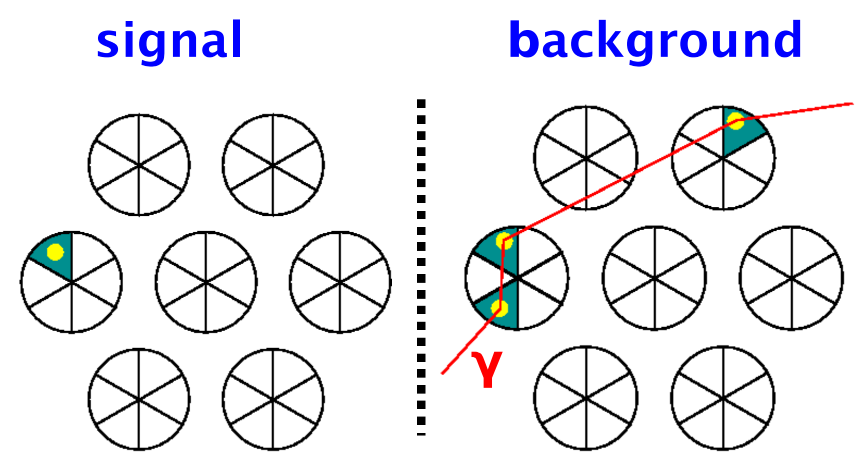
Intrinsic or very close bkgs:

cosmogenic: ^{60}Co(5.3a), ^{68}Ge(270 d)

radioactive surface contaminations

Discriminate single & multi site events:

▶ **SSE: ββ, DEP** ▶ **MSE: Compton**

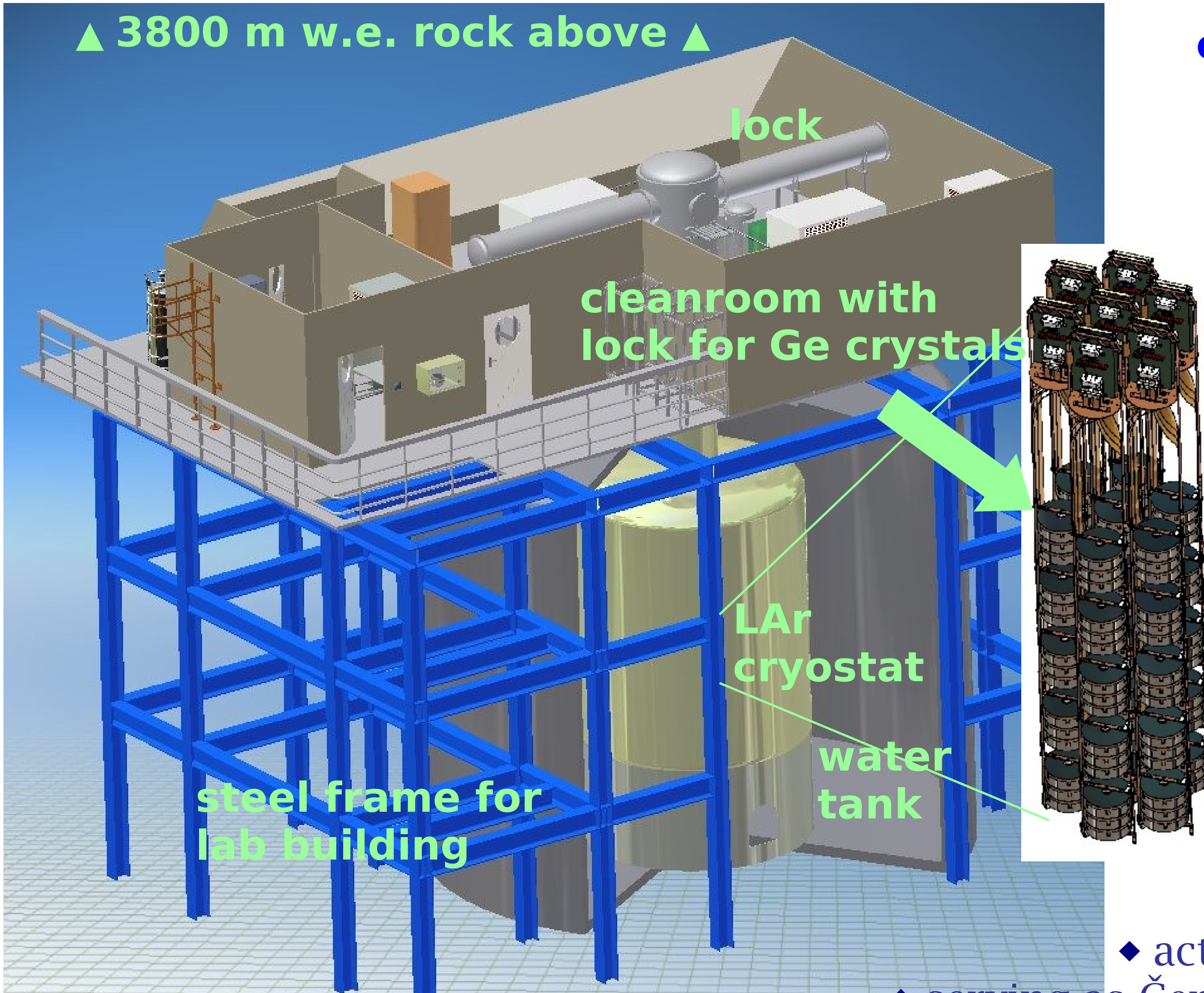


array of segmented Ge detectors

▶ **anti-coincidence of detectors & detector segments**

▶ **pulse shape analysis (PSA)**

designer's view of GERDA in LNGS Hall A



designed for
external γ,n,μ background
~0.0001 cts /(keV·kg·y)

Ø 10 m water vessel
Ø 4.2 m LAr cryostat
internal Cu liner

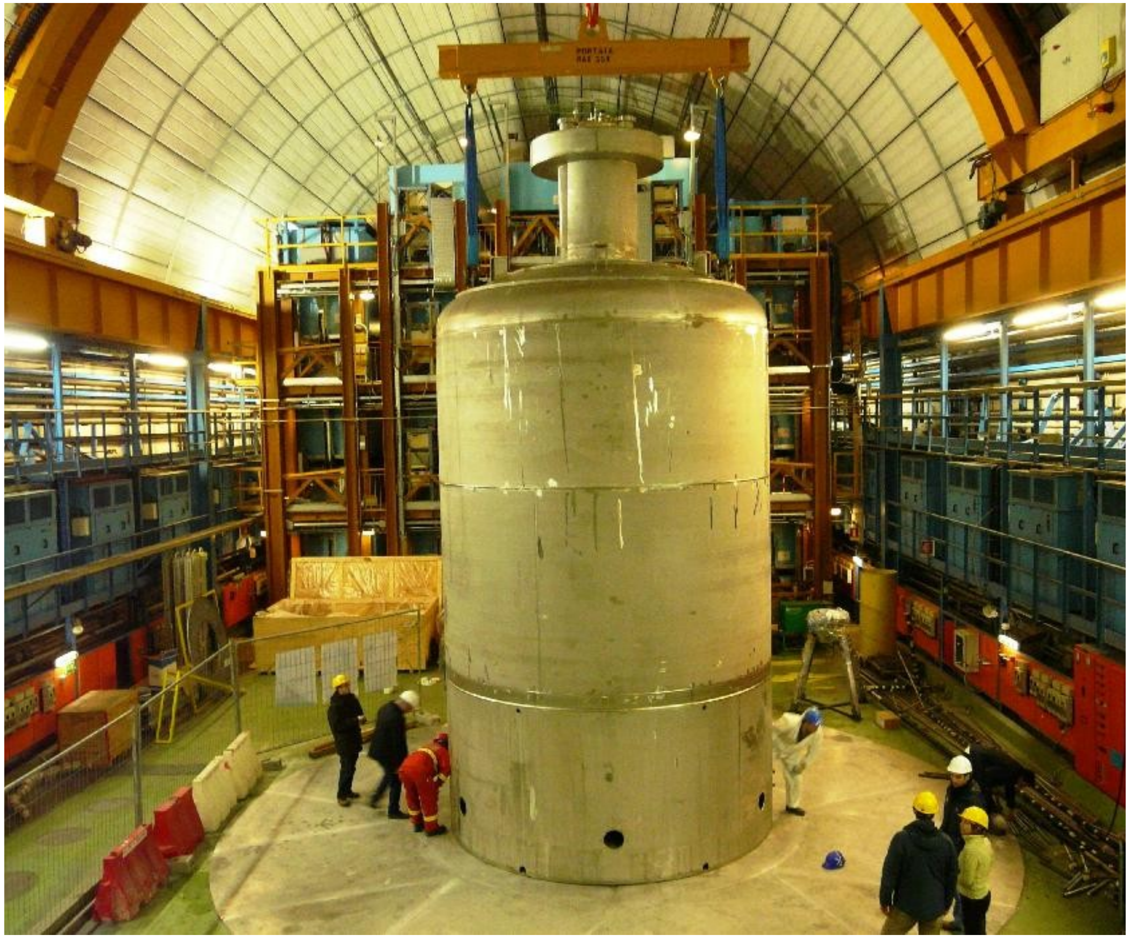
70 m³ of LAr
650 m³ of water

up to five Ge diodes arranged in strings, total of 16 strings

water:

- acting as neutron moderator
- serving as Čerenkov medium for μ veto
- cheaper, safer, more effective than LN2 (LAr)

Cryotank and water tank constructed



cryotank (Mar. 2008)

water tank (Aug. 2008)

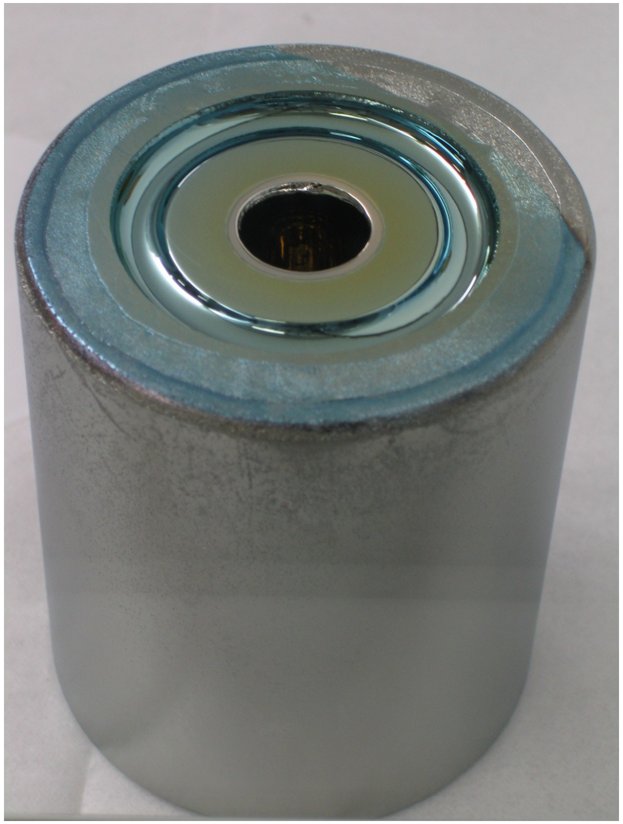
Clean room and PMTs in water tank almost ready

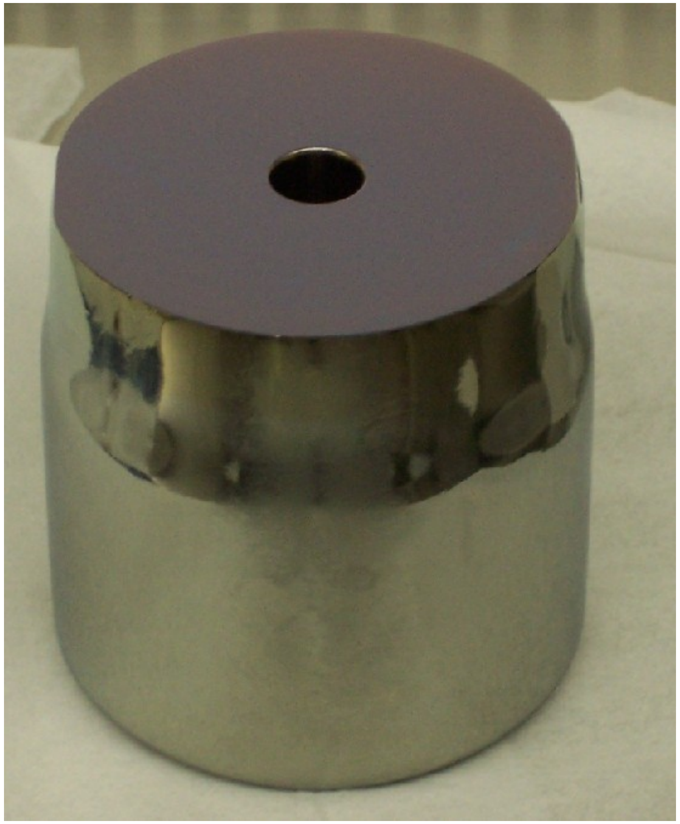
clean room
(May 2009)

mounting PMTs in water tank
(May 2009)

Phase–I detector status

Phase I: 3 IGEX & 5 HdMo detectors, in total 17.9 kg





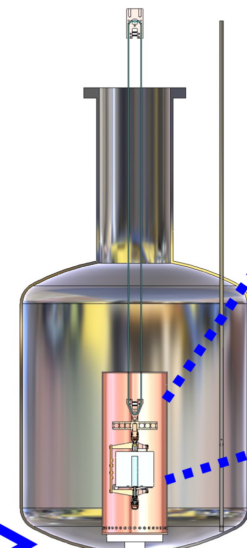
Heidelberg-Moscow & IGEX
(before reprocessing)

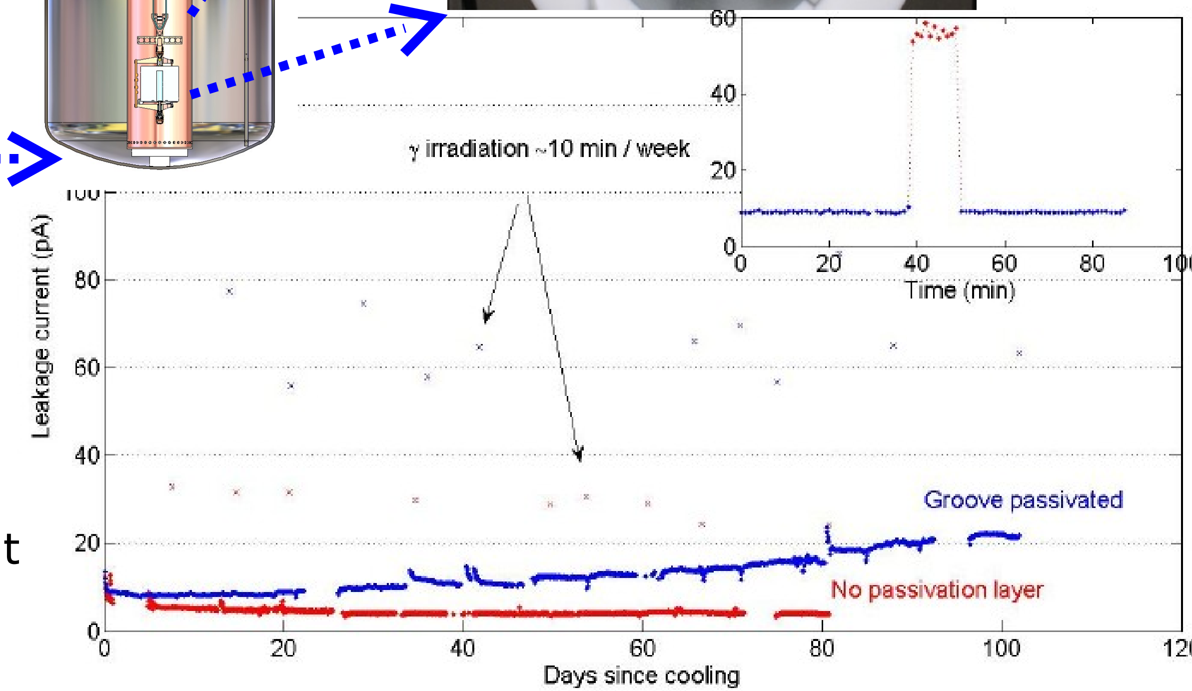
All detectors reprocessed and tested in liquid Argon
FWHM ~2.5keV (at 1332keV), leakage current (LC) stable

R&D: long term stability of Ge diodes in LAr

- A well tested procedure for handling detectors defined.
- Observed increase of LC well understood,
  due to charge trapping above passivation layer (PL)
- Detector without PL inside groove, long term performance stable.

detector test bench

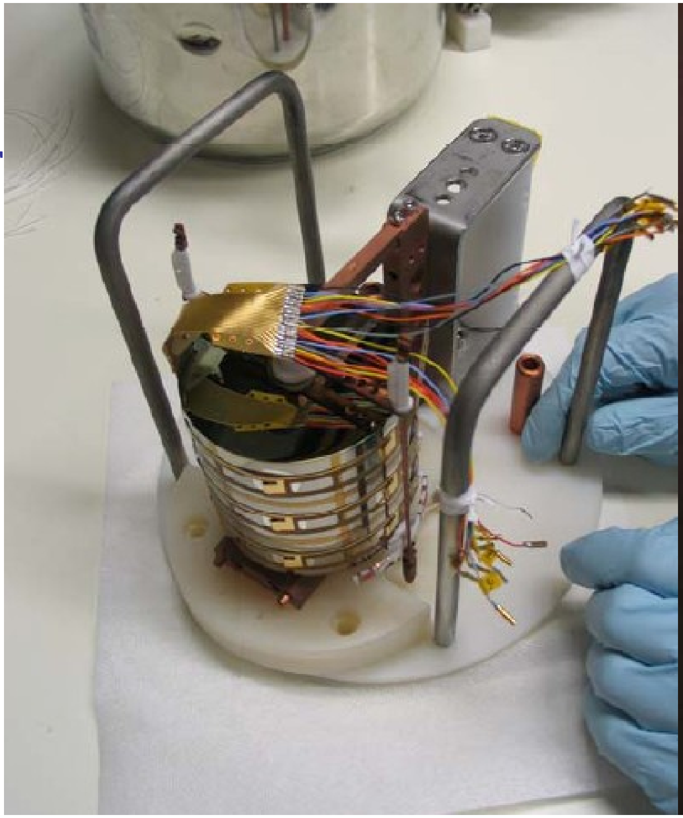


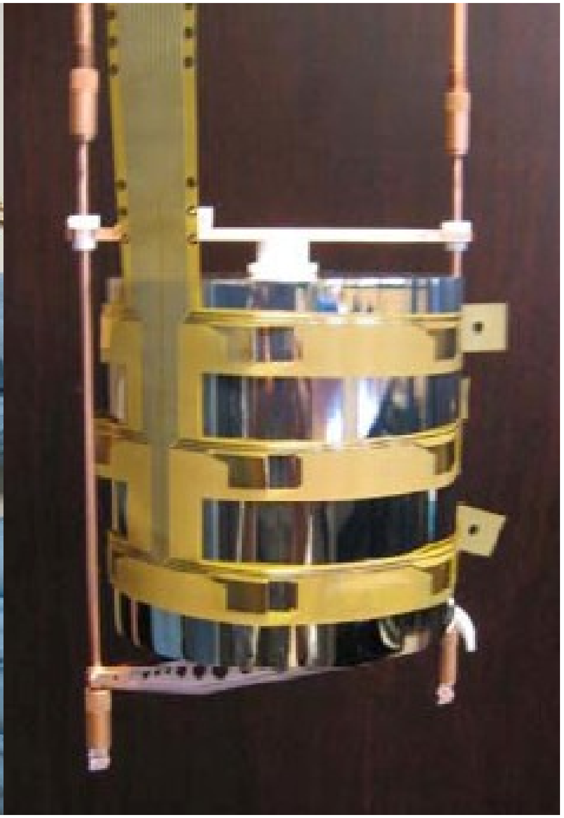


detector leakage current with & without PL

R&D: phase II detectors

- 37.5 kg of enriched Ge (86% Ge–76) have been procured by MPI Munich and are stored underground.
- Natural Ge–dioxid has been reduced to metal and purified to 6N material for Czochralski pulling
- First Ge–nat crystal pulled with dedicated puller at Institut für Kristallzüchtung (IKZ) at Berlin (no company found)



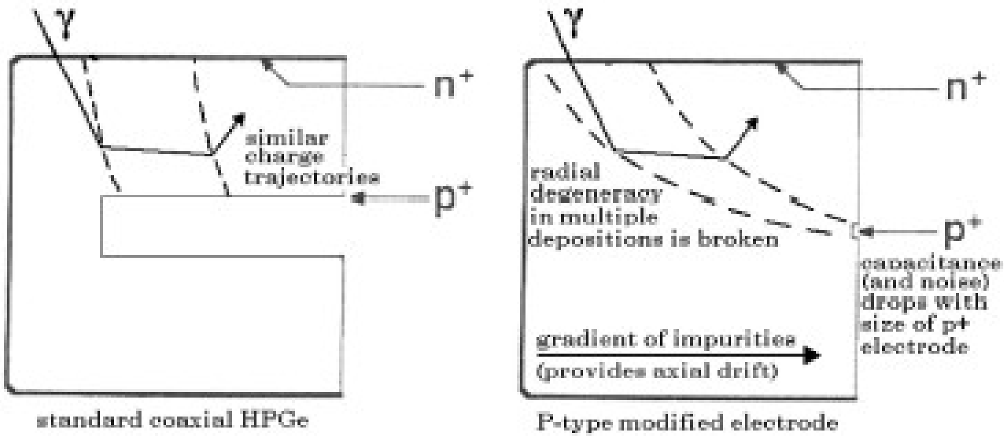


- 3x6–fold segmented prototype detector works fine: 3keV resolution at 1.3 MeV for both core and segments
- Novel low mass contacting scheme verified (Abt et al, NIM A577 (2007) 574)

- Functioning of contacts also verified in LN2, good energy resolution w/o optimization

Interesting alternative:
► point contact detector

R&D : pulse shape analysis (PSA)



'modified electrode detector'

Luke et al. , IEEE TNS 36 (1989)
Barbeau et al., nucl-ex/0701012v1

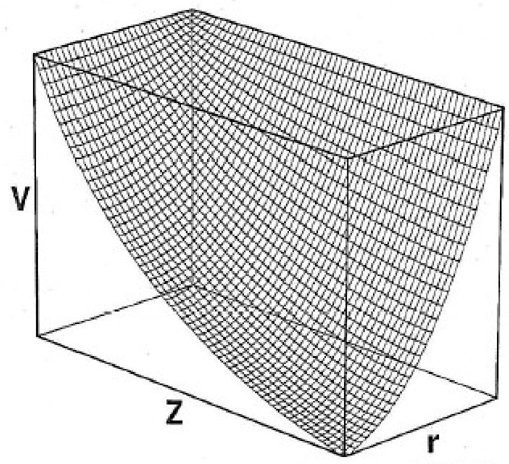


Fig. 4. Calculated potential distribution of the experimental shaped-field detector.

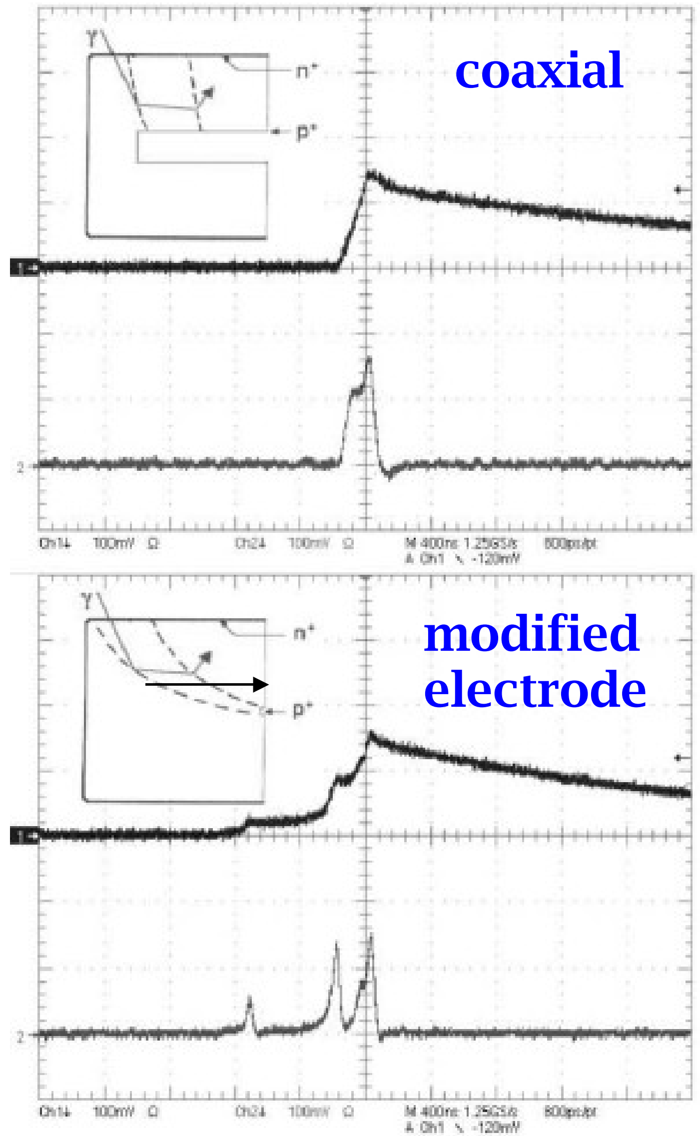
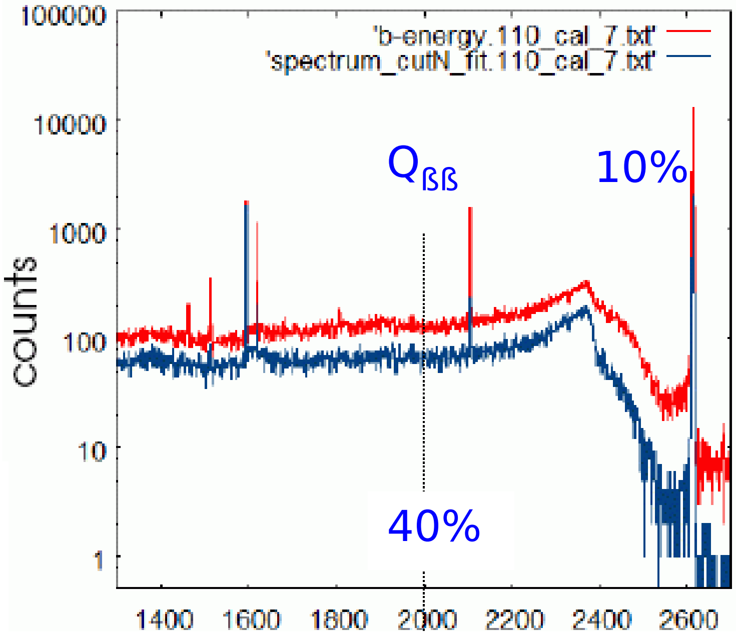


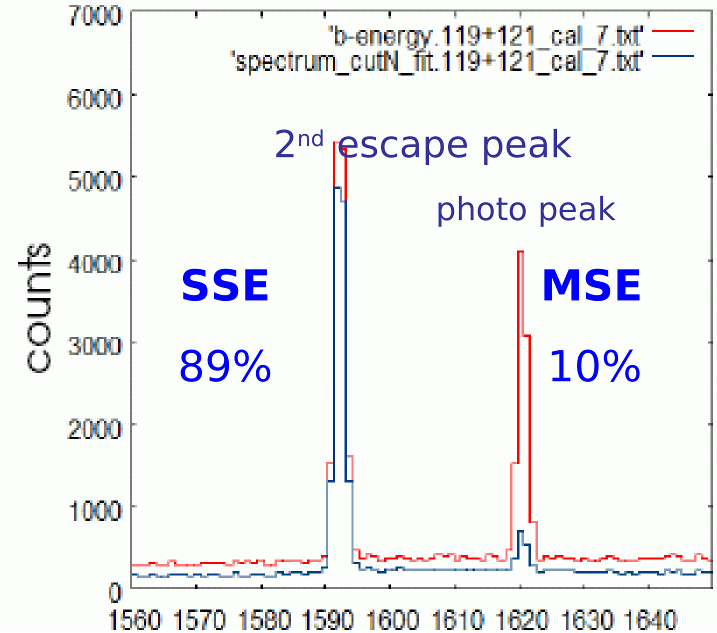
FIG. 10: Effect of electrode geometry on pulse formation for a multiple-site gamma interaction (see text).

- Non–segmented but powerful PSA
- very interesting candidate if mass production feasible

R&D: SSE/MSE discrimination examples Th-228

log scales

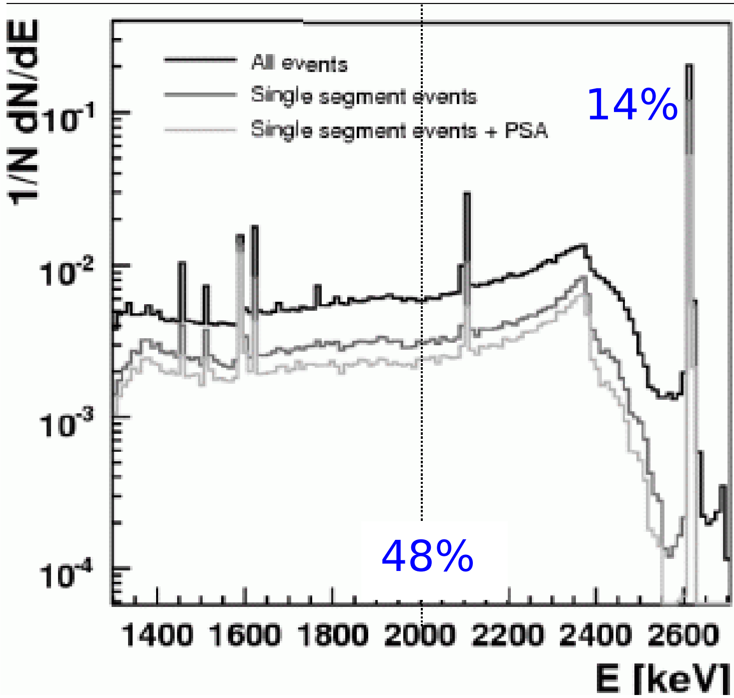


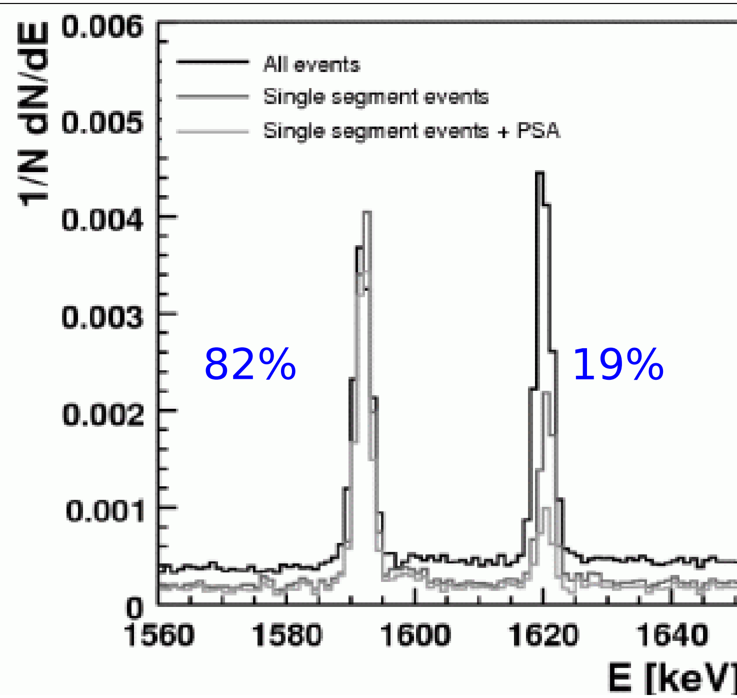


BEGe point-contact detector (Canberra)

fractions after PSA cut

D..Budjas et al. arXiv:0812.1735





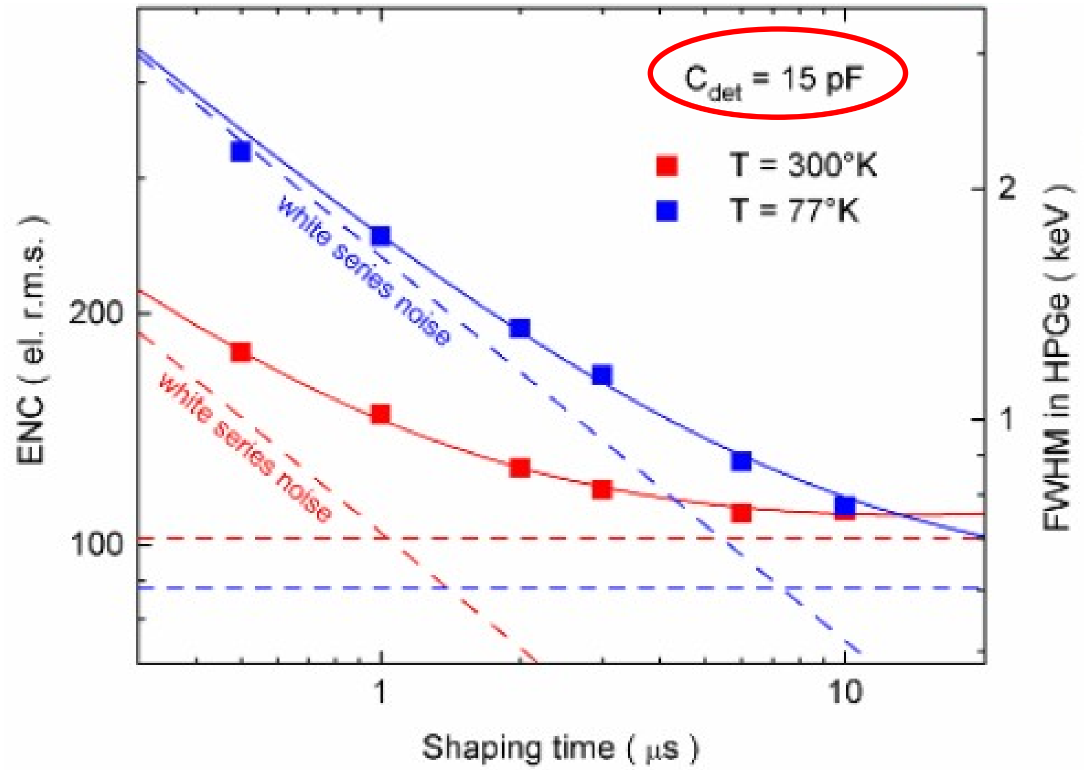
3x6-fold segmented coax detector

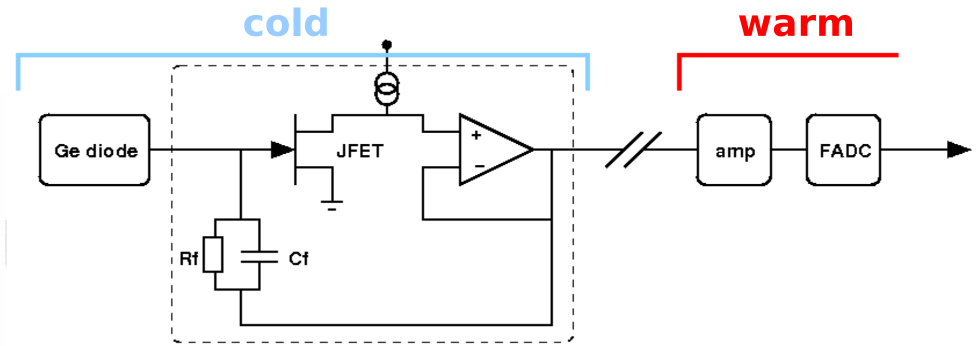
fractions after single-segment & PSA cut

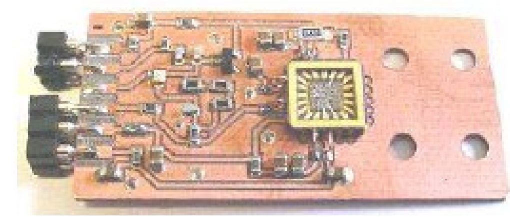
Abt et al. Eur.J.Phys. C52 (2007) 19

R&D: ASIC preamplifier for 77 K

Equivalent noise charge at 77K (300K)

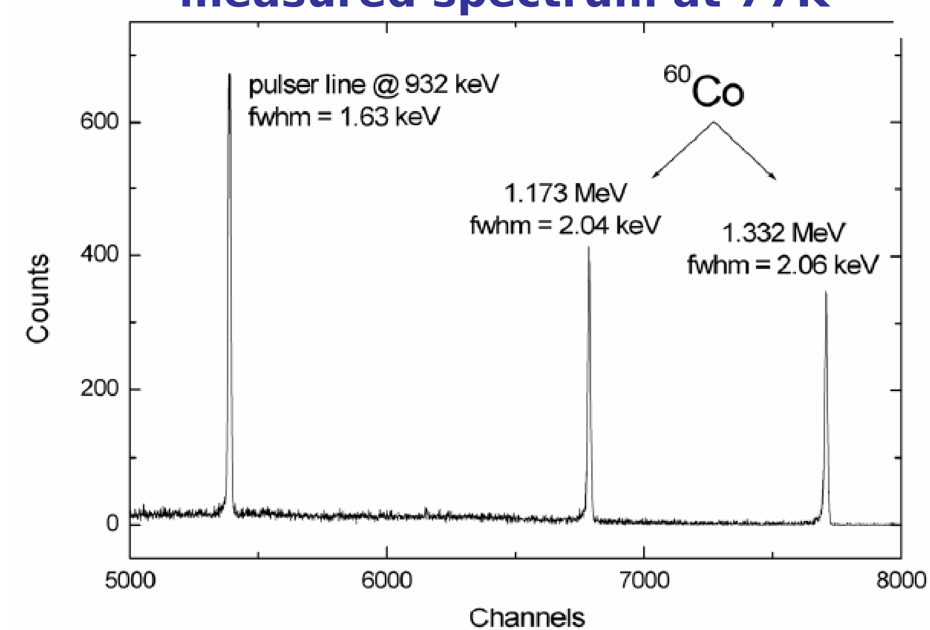






PZ-0

measured spectrum at 77K



PZ-0

- built in AMS HV 0.8 μm CZX
- input JFET, R_f & C_f discrete
- 15 ns rise time with 10m coax cable

summary

- approved in 2005 by LNGS with its location in hall A
- construction started in LNGS hall A
- all phase I detectors (8 pcs, ~18 kg) refurbished & ready
- parallel R&D for phase II

- 2009: finish installation, do commissioning
  - goals: phase I: background 0.01 cts/ (kg·keV·y)

    ▶ **scrutinize KKDC result within ~ 1 year after start of background measurement**

    phase II: background 0.001 cts/ (kg·keV·y)

    ▶ **$T_{1/2} > 1.5 \cdot 10^{26}$ y, $<m_\nu> < 0.15$ eV***

*** with nucl. m.e. from Rodin et al.**

backup slides

attractiveness of Ge-76

- Ge semiconductor ► source & detector
- intrinsic Ge material ► purest available solid state material
- established enrichment from 7.44% (nat.) to 86% , still affordable at ~50$/g
- very good energy resolution, <0.2% at 2039 keV ► narrow ROI of 4 keV

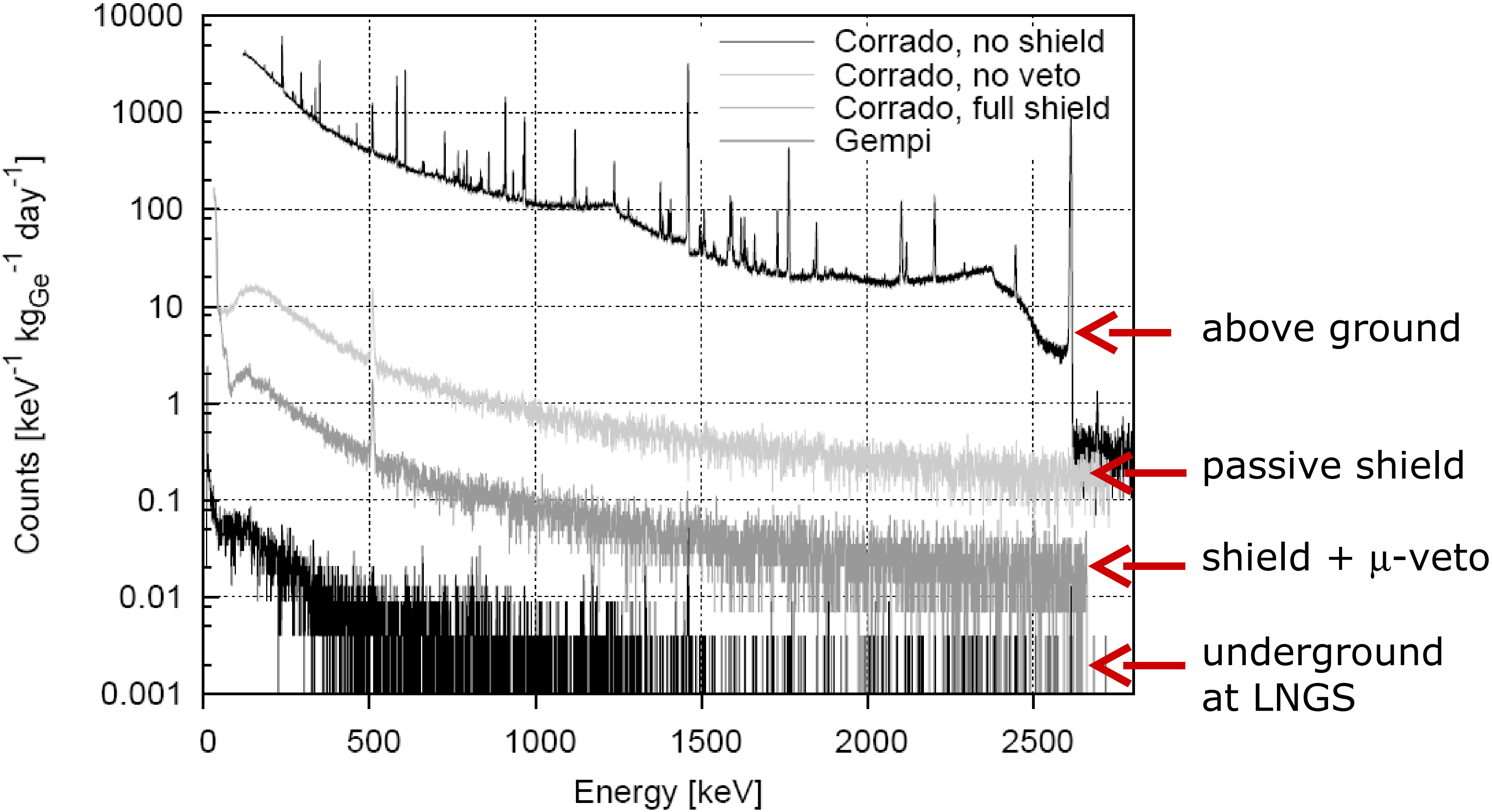
  ►negligible overlap with 2νßß background; $\sim(2 \cdot 10^{-3})^6$ for same $T_{1/2}$

- favorable product of phase space factor & nuclear matrix element

last not least: best limits on resp. claimed evidence of 0νßß decay
(Cuoricino, however, reporting now very similar limit!)

Exp.	Isotope	mass/enrichment	$Q_{ßß}$ / resolution	BI (cts / kg•yr•keV)
CUORE	Te-130	741 kg / 34%	2528 keV / 0.28%	$\sim 10^{-3}$
EXO	Xe-136	200 kg / 80%	2479 keV / 1.4%	10^{-2} - 10^{-3}
GERDA	Ge-76	18-40 kg / 86%	2039 keV / <0.2%	10^{-2} - 10^{-3}

Energy spectra of a p-type high purity Ge detector (HPGE)



D. Budjáš, et al. arXiv.0812.0768

Muon and neutron background

Muon ("*MC evaluation of muon-induced background in* GERDA" NIM A570 (2007) 149-158)

prompt events:

$10\gamma/m^2 \cdot h$, $6 neutron/m^2 \cdot h$

80% veto efficiency, 10E-4 cts/(keV·kg·year)

with ideal muon veto < 10E-5 cts/(keV·kg·year)

delayed events from neutron activation:

dominated by Ge77m ($T_{1/2}$: 53seconds, Q 2861keV)

dedicated coincidence cuts below 10E-4

Neutron (negligible)

from LNGS rock, 3.8 10E-6 /cm2·s

negligible after 3 meter of water, negligible through neck.

2.2MeV photon from neutron absorption negligible,

activated Ar41 and C15 negligible, will be evaluated.

from U238 *spontaneous fission and* (alpha,n) *reaction in cryotank*

neutron production estimated by "SOURCE 4A",

flux 4.7 10E-10 /cm3·s, 1860 neutron/ton·year

at RoI 7 10E-6 cts/(keV·kg·year)

delayed signal Ar41, Ge71, Ge75, Ge77, Ge77m,

will be evaluated

Purification at PPM Pure Metals

Underground storage of depGeO2 in **Langelsheim** municipal mining museum

a) Reduction procedure
- depGeO2 ⇨ depGe
- Technical grade (99,8%)
- No isotope dilution effect was detected
- Yield = 98,5%

b) Three steps zone refinement
- depGe ⇨ depGe
- 99,8% ⇨ 6N ($\rho \geq 50$ Ohm*cm)
- 10^{13} cm^{-3} ⇨ 10^{11} cm^{-3}
- Yield = 91%

Unrecoverable loss is 0.4%.
Total yield of 6N material was 88%
Total exposure of the material at sea level < 2–3 days/purification

Material characterization

- Resistivity measurements at RT, Ohm*cm

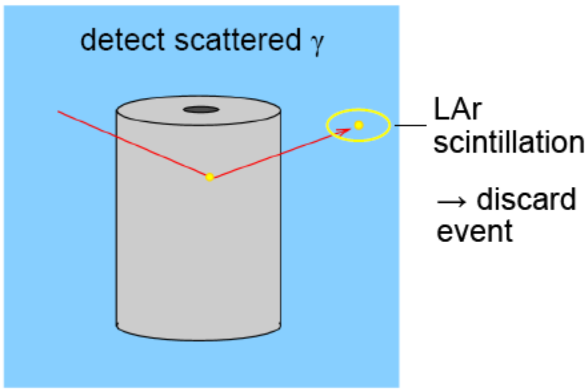
- Hall effect measurements at 77 K:
  - $|N_D - N_A| \sim 10^{11} \div 10^{13}$ cm^{-3} (detector grade $\sim 10^{10}$ cm^{-3})
  - Mobility at RT and 77K

- PTIS (Photo Thermal Ionization Spectroscopy) measurements
  - Identification of donors and acceptors

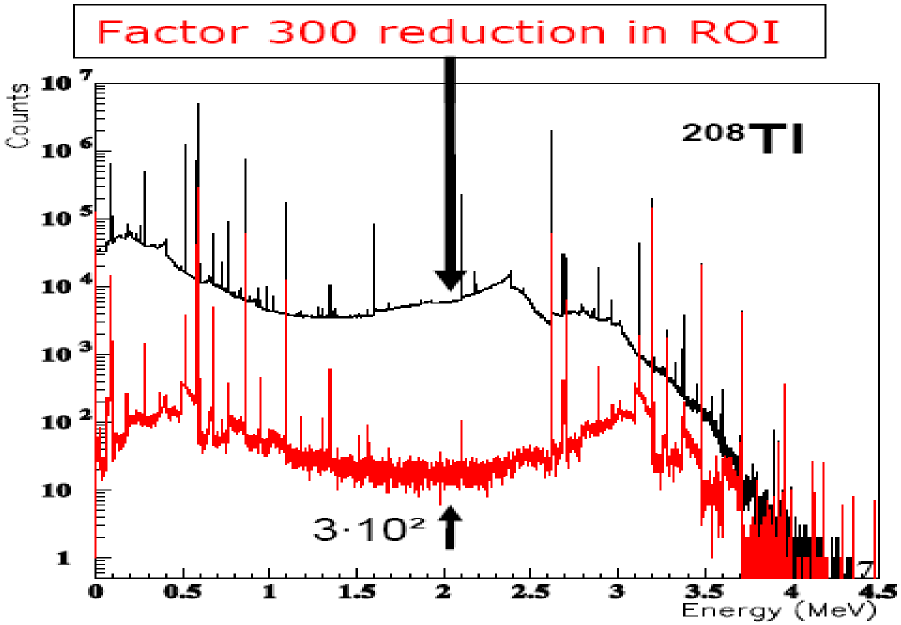
- Optical measurements:
  - Dislocation density ($\sim 10^2 - 10^4$ cm^{-2})

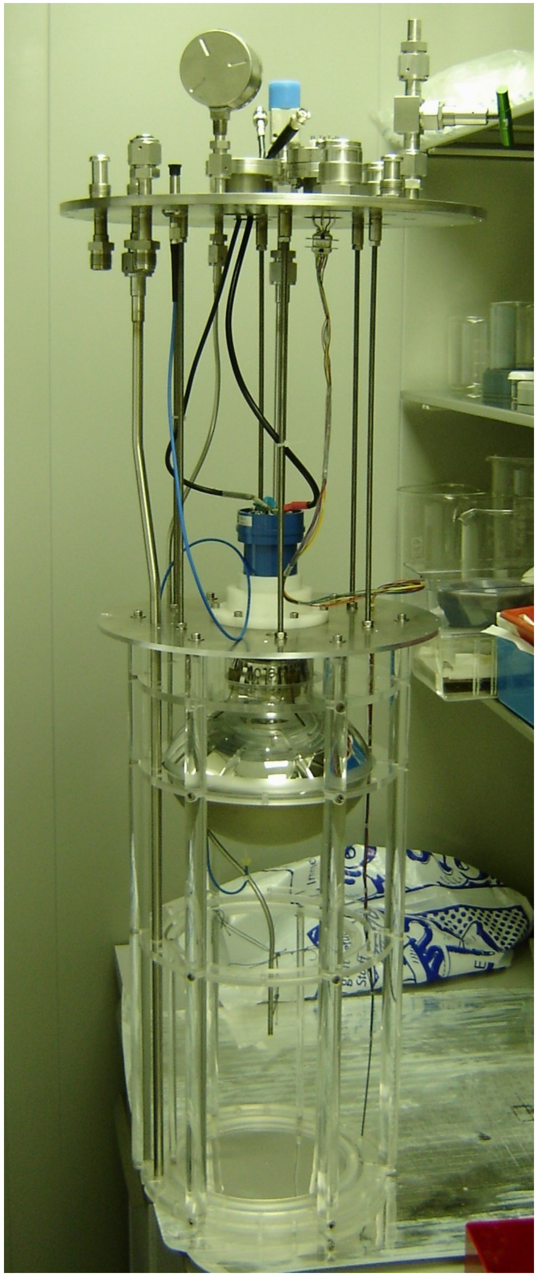
- Photoluminescence measurement (Dresden):
  - Identification of donors and acceptors (As and P, no Al and B)

Liquid Argon scintillation



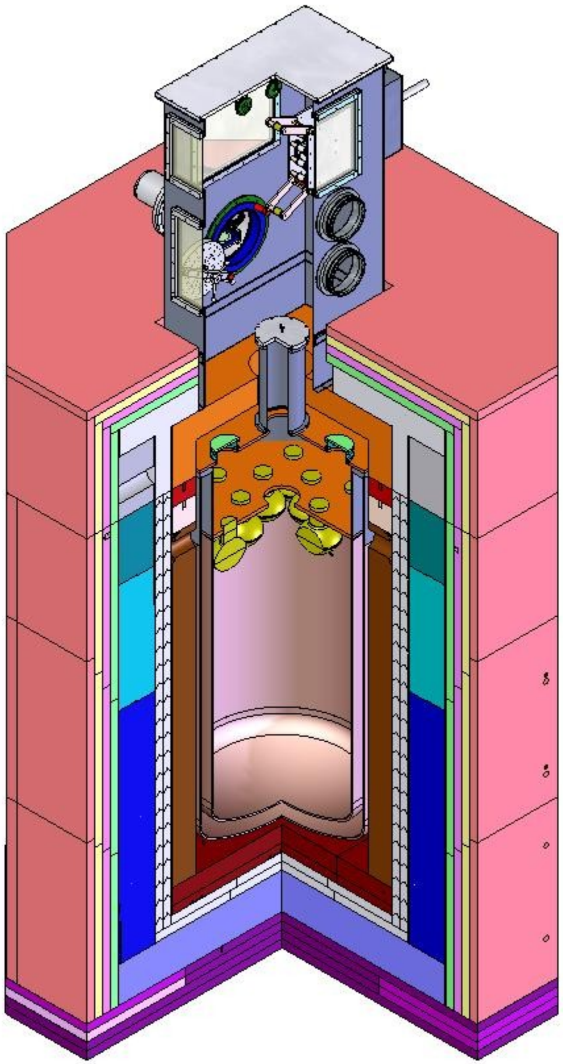
MC simulation: Background suppression for contaminations located in detector support:





Test facility MiniLArGe at MPIK

Low background test stand LArGe (Heidelberg, Gran Sasso)



Cryostat:
Inner diameter: 90 cm
Volume: 1000 liter
(under construction)

PMT: 9 x 8” ETL9357
(delivered)

Shield:

Cu	15 cm
Pb	10 cm
Steel	23 cm
PE	20 cm

(in place)

Lock: Construction completed

Can house up to 3 Phase 1 strings (9 Ge detectors)