Status and Progress of GERDA
'The GERmanium Detector Array'

Karl Tasso Knöpfle
MPI Kernphysik, Heidelberg
on behalf of the GERDA collaboration
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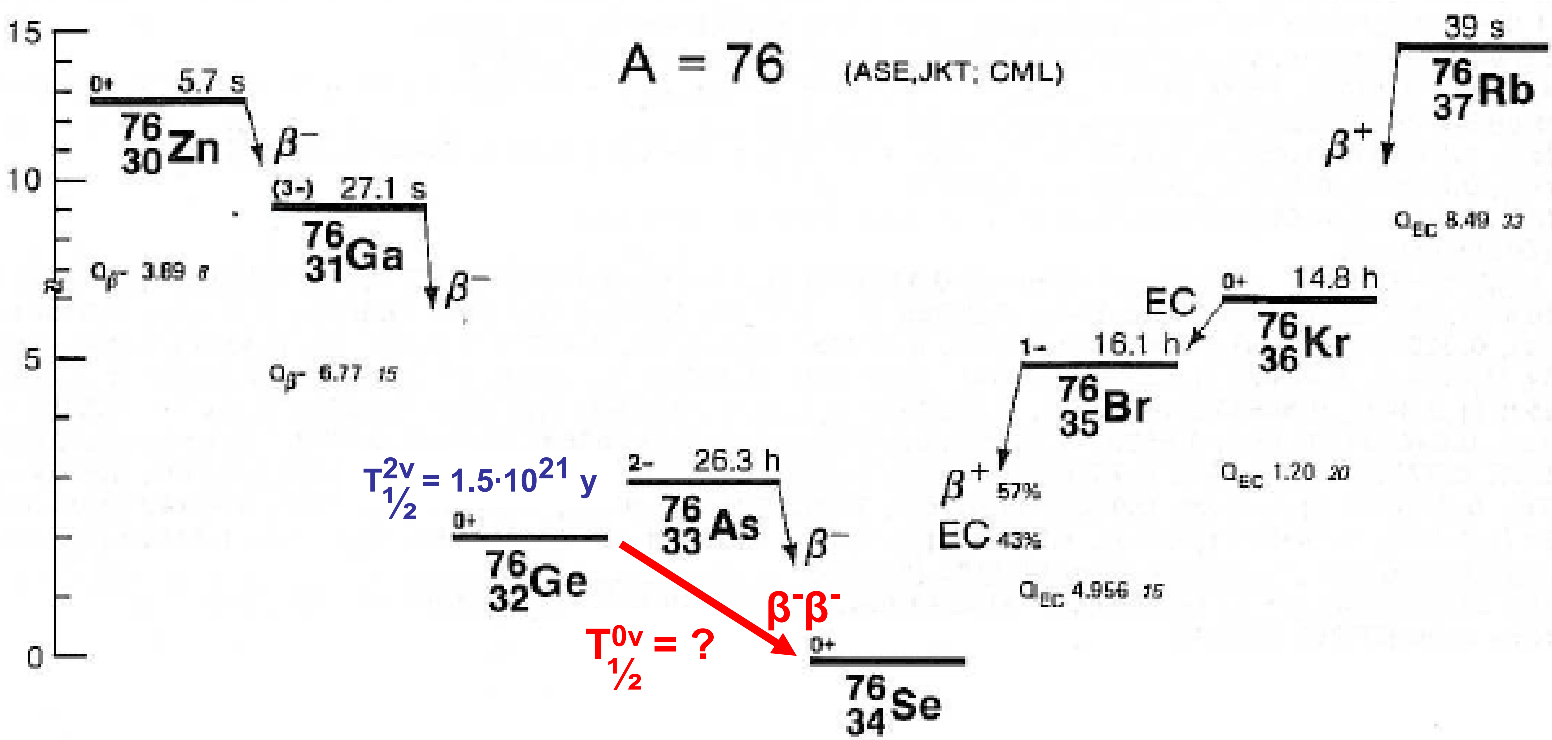
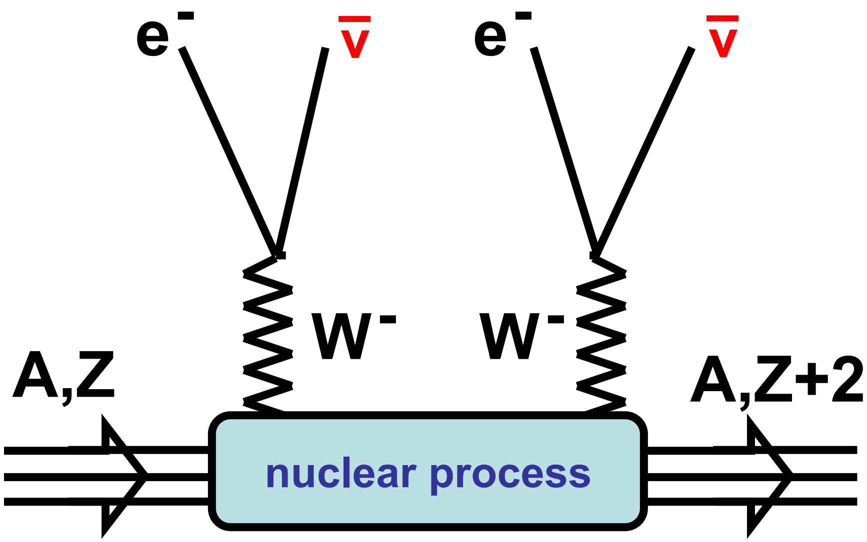


Int. Workshop on Double Beta Decay & Related Neutrino Measurements (DBD09)
Hawaii, October 11 – 13, 2009

$2\nu\beta\beta$

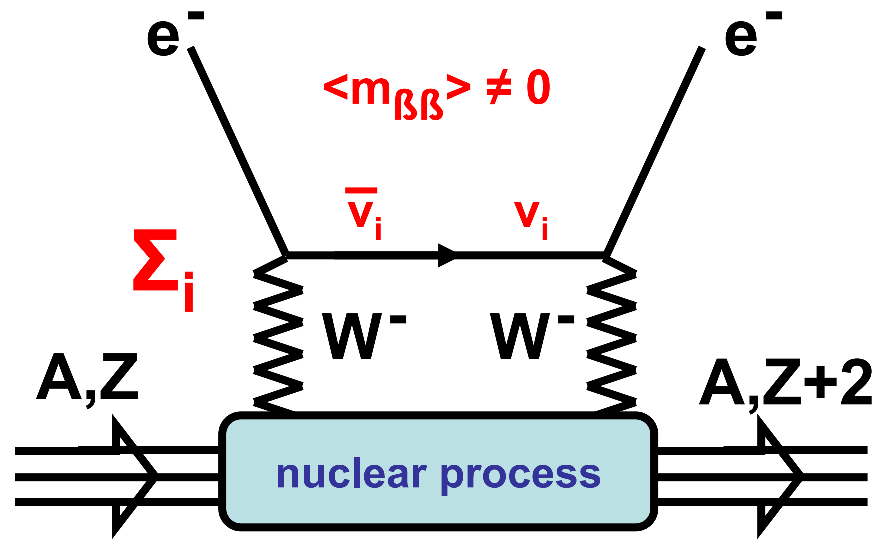


conventional 2nd order process

observed in various nuclei

$T_{1/2} \sim 10^{19} - 10^{21}$ yrs

$0\nu\beta\beta$



hypothetical process , $T_{1/2} > 10^{25}$ yrs,

only possible if

neutrino is massive Majorana particle

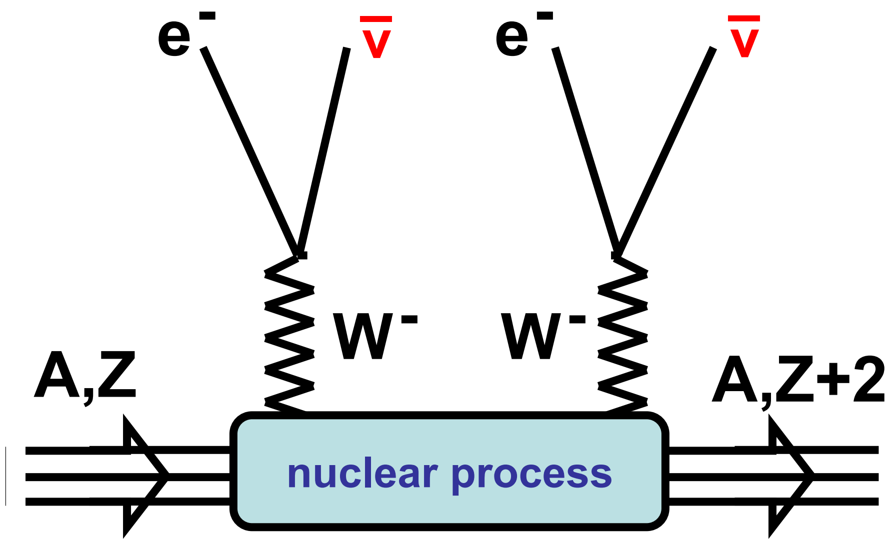
► lepton number violation $\Delta L=2$

► access to absolute ν mass scale

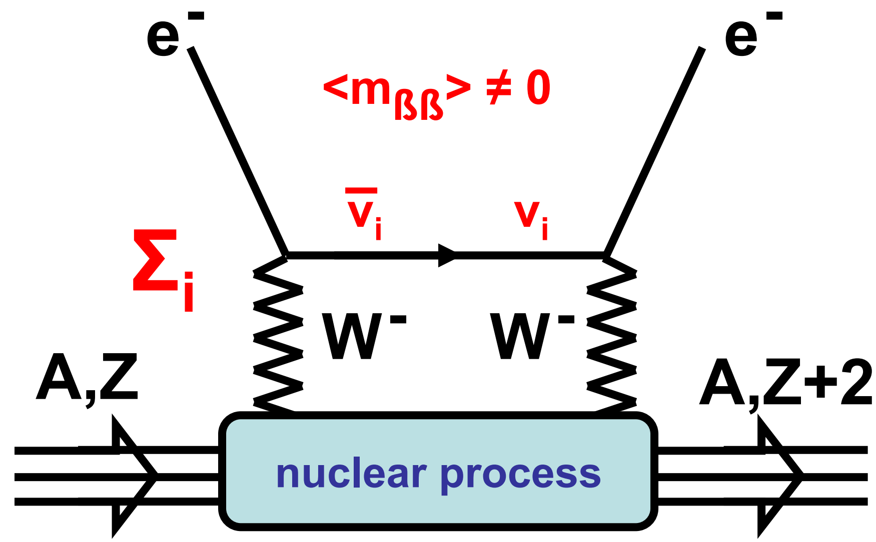
► physics beyond s.m.

sum of kinetic energies

2νßß



0νßß



conventional 2
observed in va
$T_{1/2} \sim 10^{19} - 10$

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r violation ΔL=2
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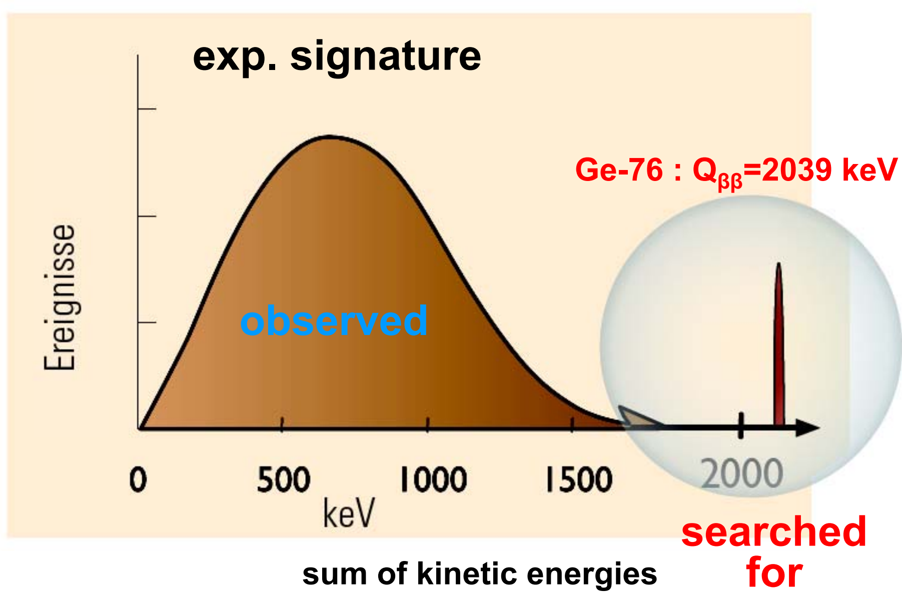
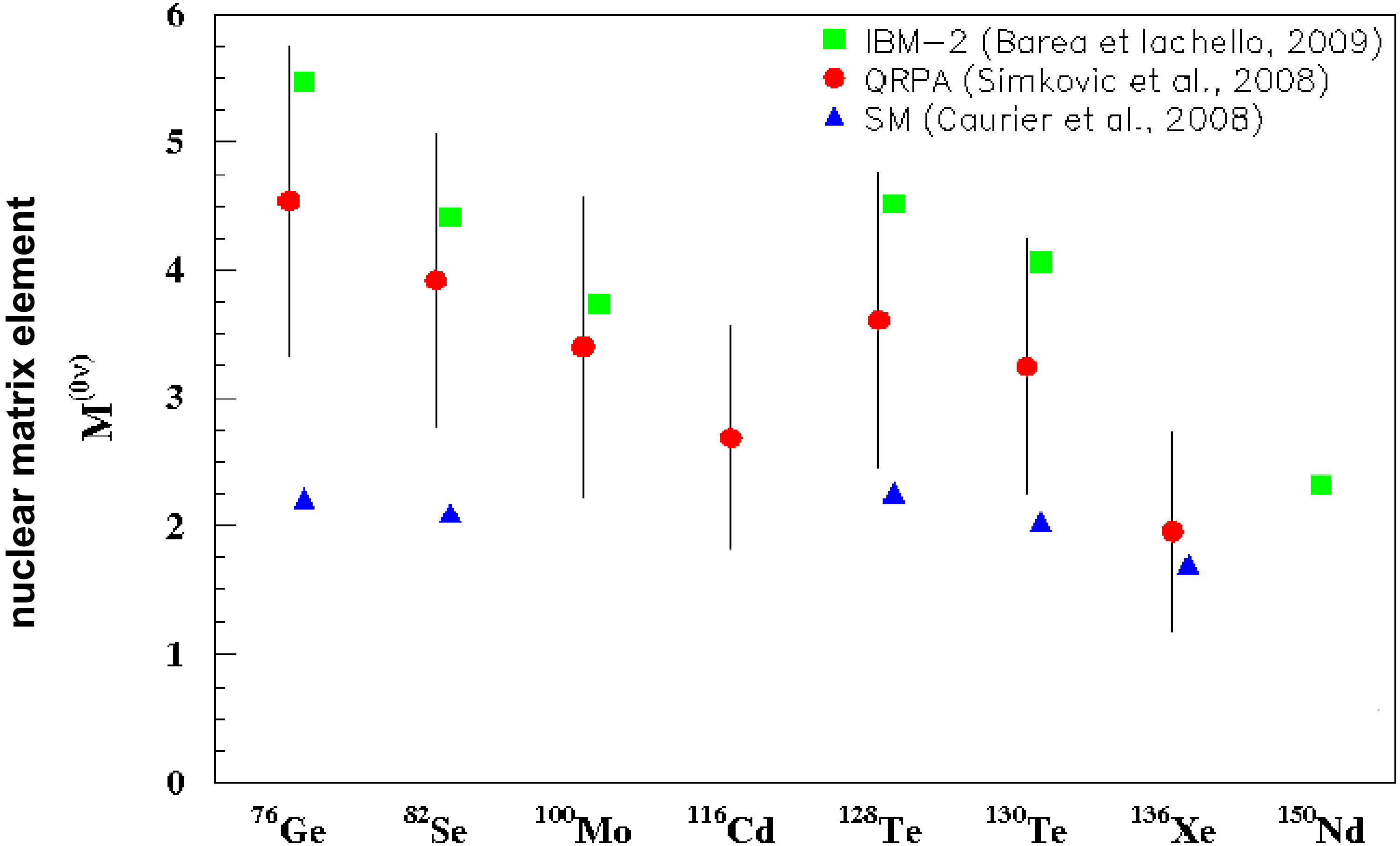
d s.m.



halflife – effective mass relation

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q,Z)\,|M^{0\nu}|^2\,\langle m_{ee}\rangle^2$$

measured deduced



Schönert
taup2009

dbd isotopes in comparison

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

$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu}(Q,Z)\,|M^{0\nu}|^2\,\langle m_{ee}\rangle^2$$

isotope specific

quantity	^{76}Ge	lowest / ave / highest
Q $Q_{\beta\beta}$-value / MeV	2.04	^{76}Ge / 2.8 / ^{48}Ca: 4.3
$G^{0\nu}$ phase space / (10^{25} y eV^2)	0.2	^{76}Ge / 2.4 / ^{150}Nd: 8
a isotopic abundance	7.4 %	^{48}Ca: 0.19% / 9.6% / ^{130}Te: 35%

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experiment specific

detection efficiency (=1 if source=detector)

sensitivity*

$$T_{1/2}^{0\nu}(n_\sigma) = \frac{4.16\times 10^{26} y}{n_\sigma}\left(\frac{\varepsilon a}{W}\right)\sqrt{\frac{Mt}{b\Delta(E)}}$$

exposure [kg y]

instrumental spectral width

molecular weight of source

background index [cts/(keV kg y)]

*RevModPhys 80(08)481

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experiment specific

detection efficiency (=1 if source=detector)

86%

70 kg y

exposure [kg y]

sensitivity*

$$T_{1/2}^{0\nu}(n_\sigma) = \frac{4.16\times 10^{26} y}{n_\sigma}\left(\frac{\varepsilon a}{W}\right)\sqrt{\frac{Mt}{b\Delta(E)}}$$

achieved with ^{76}Ge

3.3 keV

instrumental spectral width

molecular weight of source

background index [cts/(keV kg y)]

0.1

*RevModPhys 80(08)481

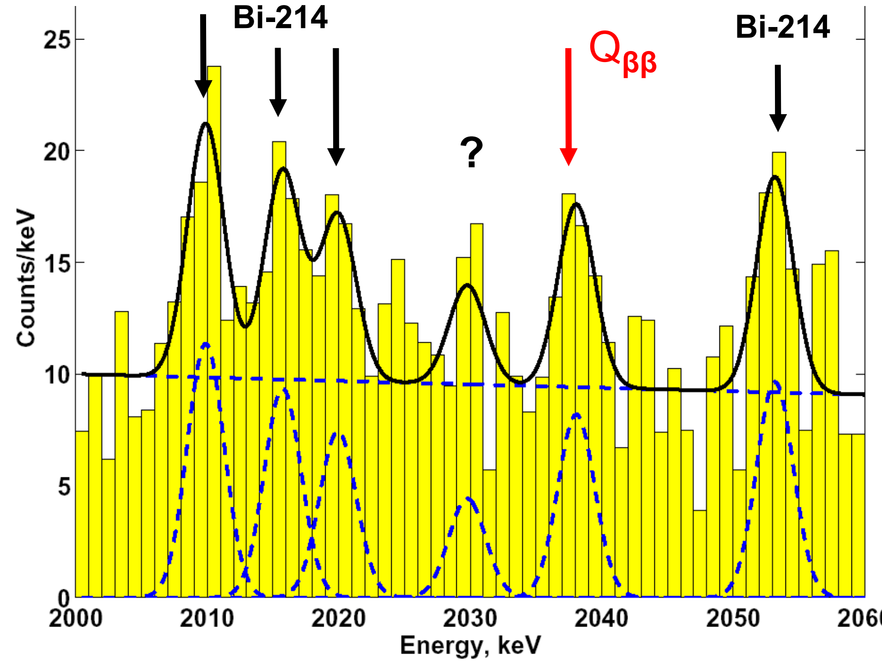
$<m_{\beta\beta}>$ best limits* / value

Heidelberg – Moscow Experiment
5 enriched Ge-76 diodes (EPJ A12 ('01) 147)
background index ~0.1 cts/ (kev ·kg ·y)

35.5 kg y : $T_{1/2} \geq 1.9 \cdot 10^{25}$ y (90% CL)
$<m_{\beta\beta}> < 0.3 – 1$ eV
(similar limit by **IGEX**, NP B87 ('00) 278)

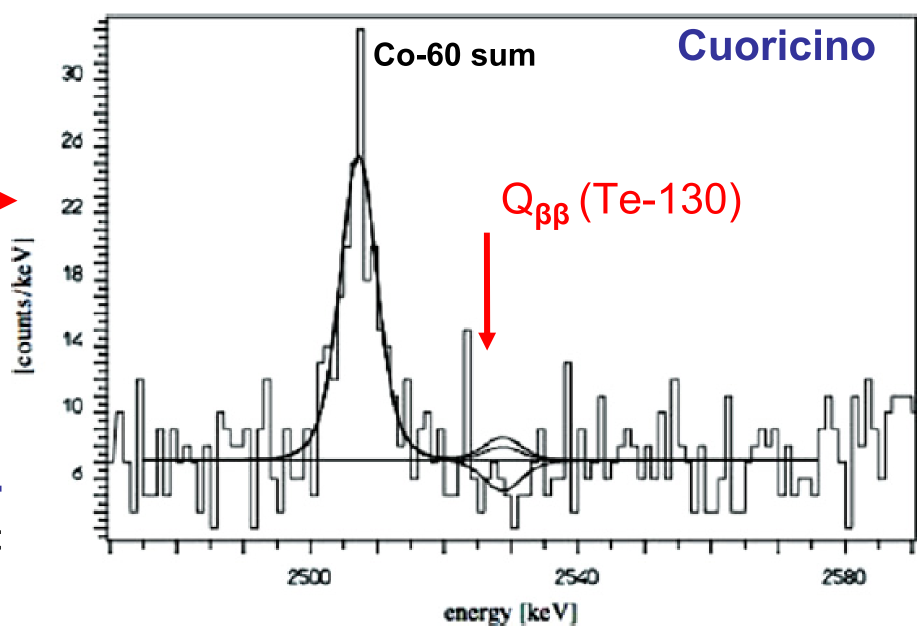
part of collaboration claims signal (PL B586 ('04) 198)
71.7 kg y : $T_{1/2} = 1.2\ (0.7\text{-}4.2)\cdot 10^{25}$ (3σ range)
$<m_{\beta\beta}> = 0.44\ (0.24 – 0.58)$ eV

Claimed 4σ significance dependent on background model (Strumia&Vissani '06, O. Chkvorets, PhD th. '08)



Cuoricino
62 TeO_2 bolometers (PR C7 ('08) 035502)
background index ~0.2 cts/ (kev ·kg ·y)

11.8 kg y : $T_{1/2} \geq 3.0 \cdot 10^{24}$ y (90% CL)
$<m_{\beta\beta}> < 0.19 – 0.68$ eV



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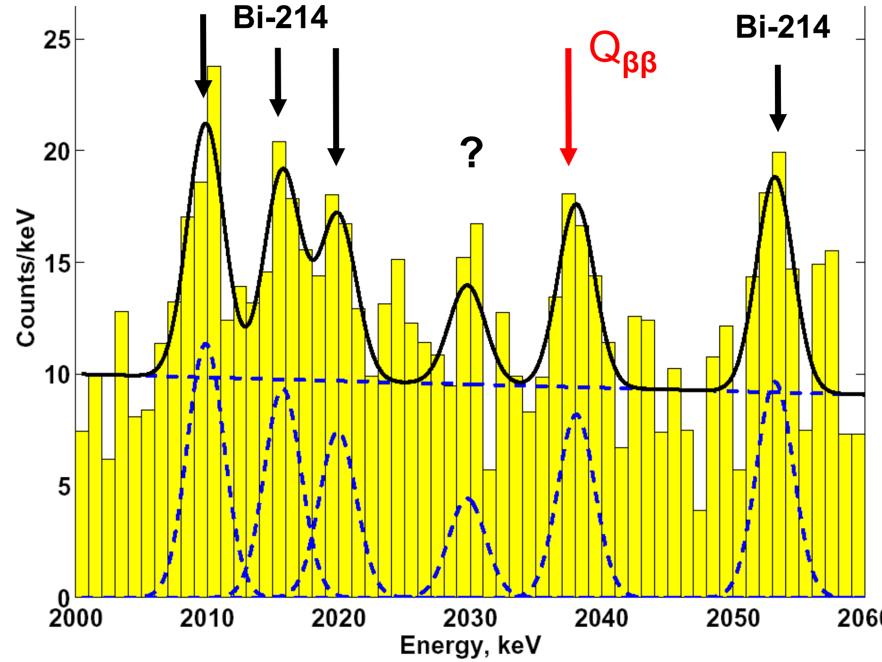

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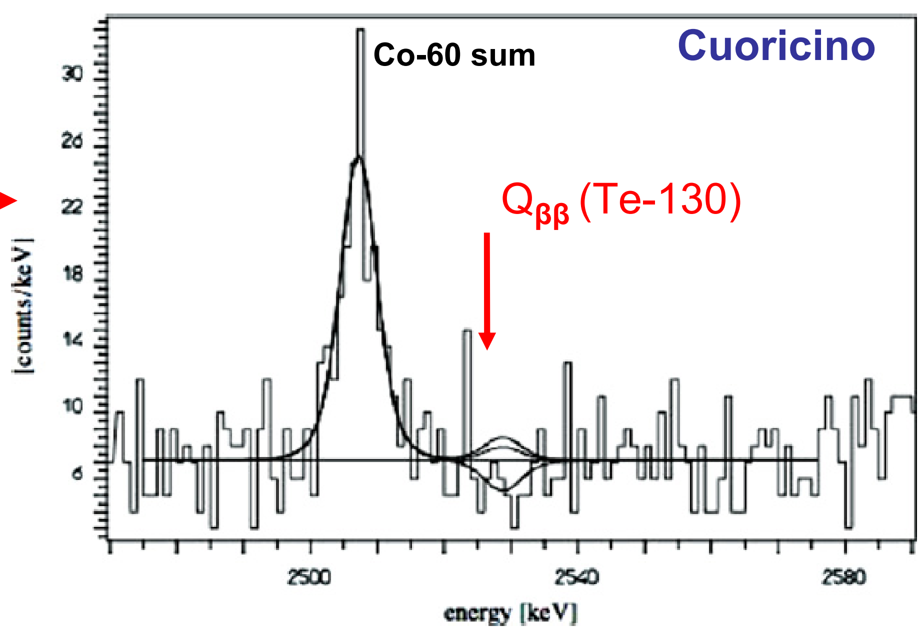
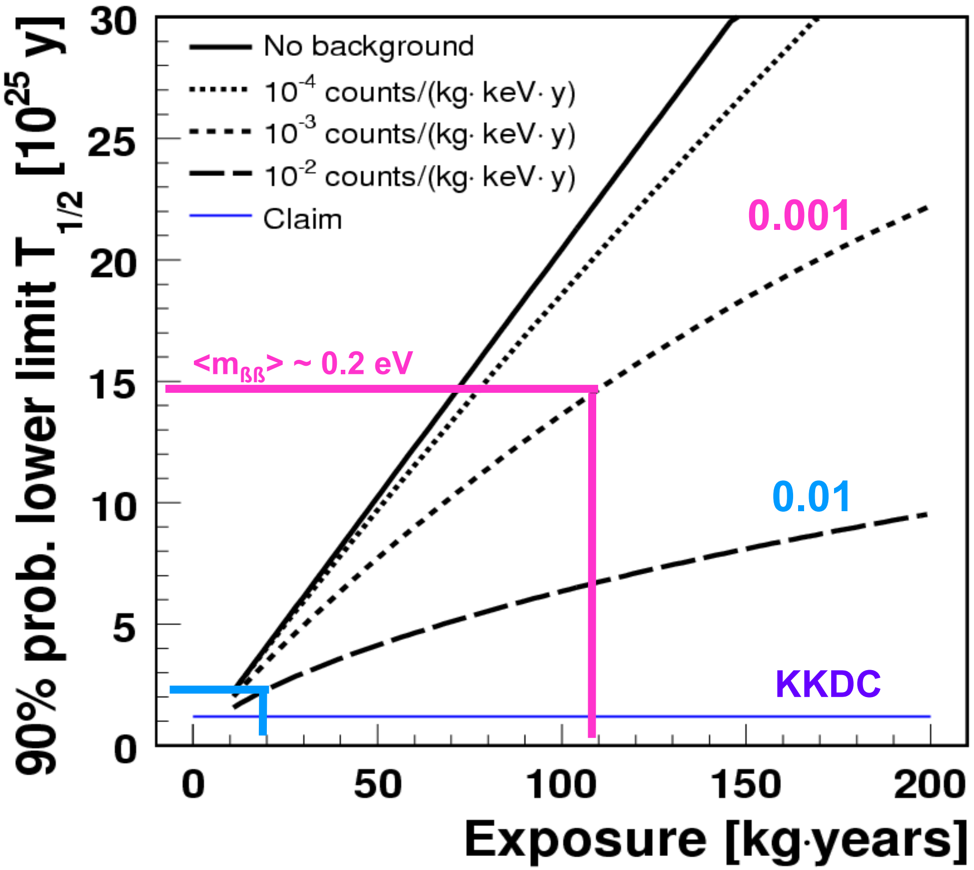
Evidence remains unclear - confirmation needed with same & different isotopes
► reduce background by *O*(100) for better sensitivity



GERDA goals & sensitivity

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



phase II :
add new enriched Ge-76 detectors, 20 kg
B ~ 0.001 cts / (keV·kg·y)
► 37.5 kg enriched Ge-76 bought
3 y·35 kg exposure

phase I :
use Ge-76 diodes of HD-Moscow & IGEX
~18 kg
B ~ 0.01 cts / (keV·kg·y)
intrinsic background expected

phase III: depending on results worldwide collaboration for real big experiment
close contacts & MoU with MAJORANA collaboration

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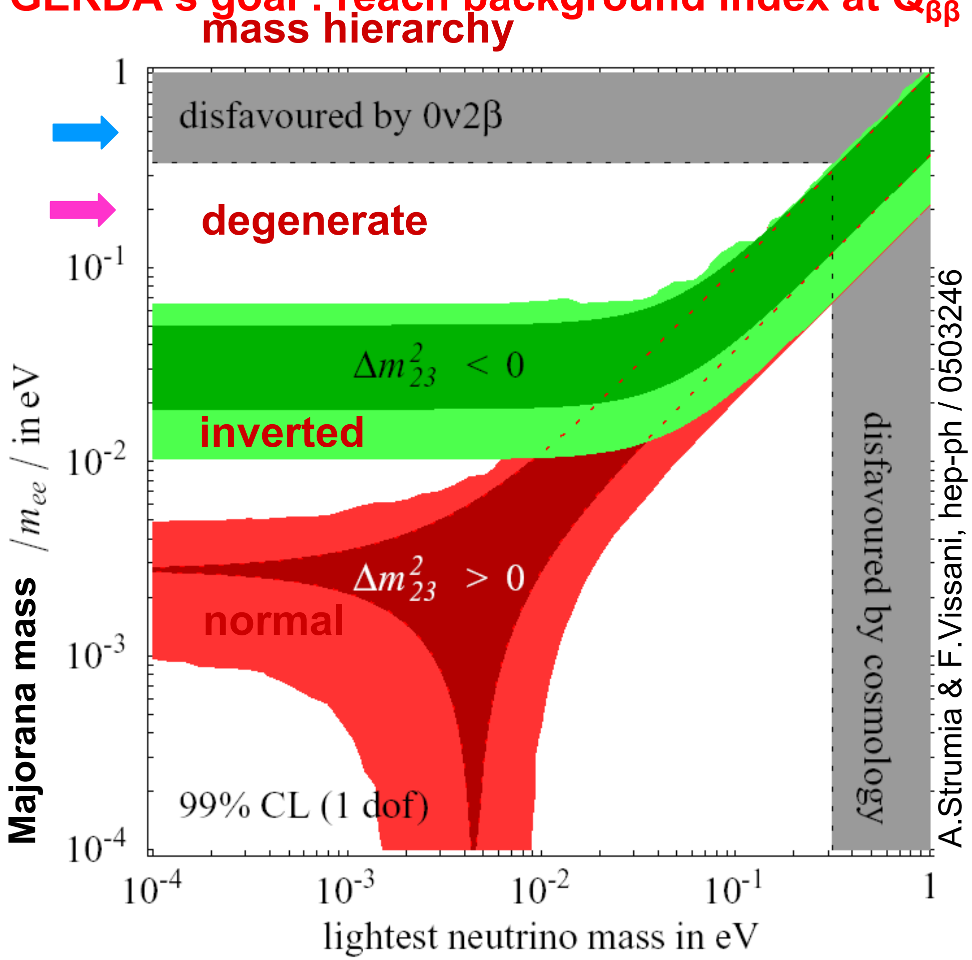

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GERDA background reduction

EXTERNAL bgnds: γ(Th, U), n, μ

INTRINSIC or VERY CLOSE bgnds :
cosmogenic - ^{60}Co (5.3 a), ^{68}Ge (270 d)-
contaminated holders, FE, cables …

GERDA background reduction

EXTERNAL bgnds: γ(Th, U), n, μ

LNGS: Laboratori Nazionali del Gran Sasso

GERDA background reduction

EXTERNAL bgnds: γ(Th, U), n, μ

Shielding possible

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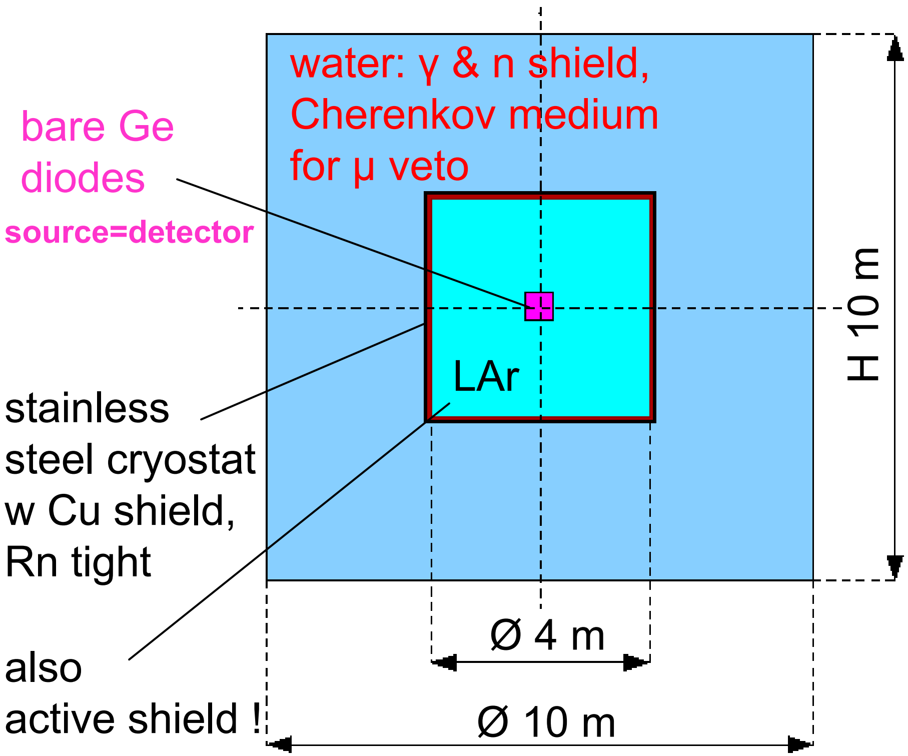

α(LAr) = 0.050/cm α(Cu) = 0.34/cm
α(H_2O) = 0.043/cm α(Pb) = 0.48/cm

GERDA background reduction

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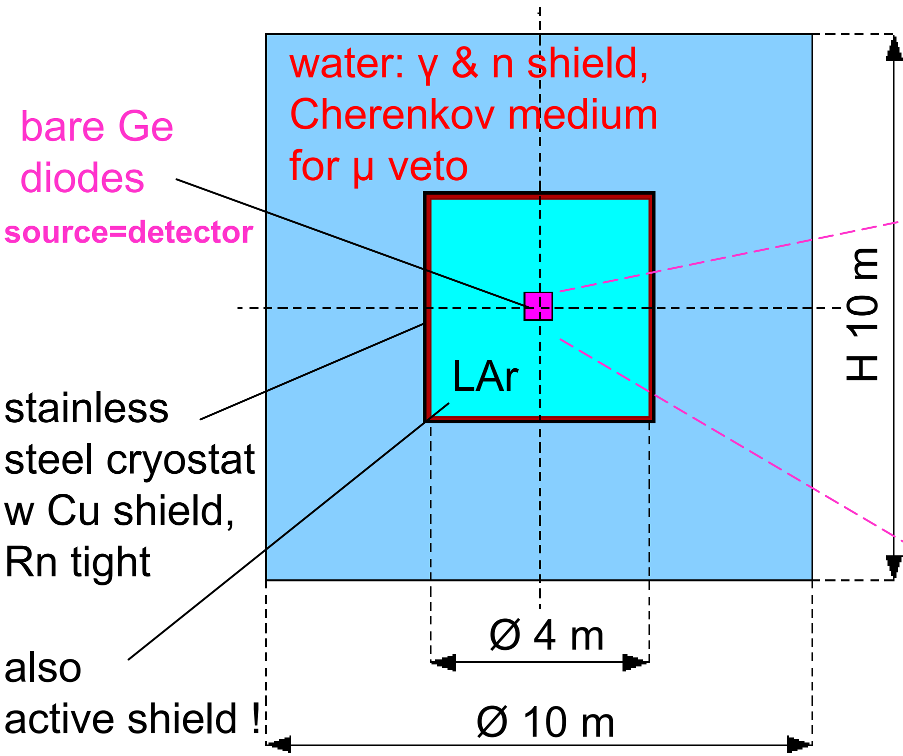
Shielding possible



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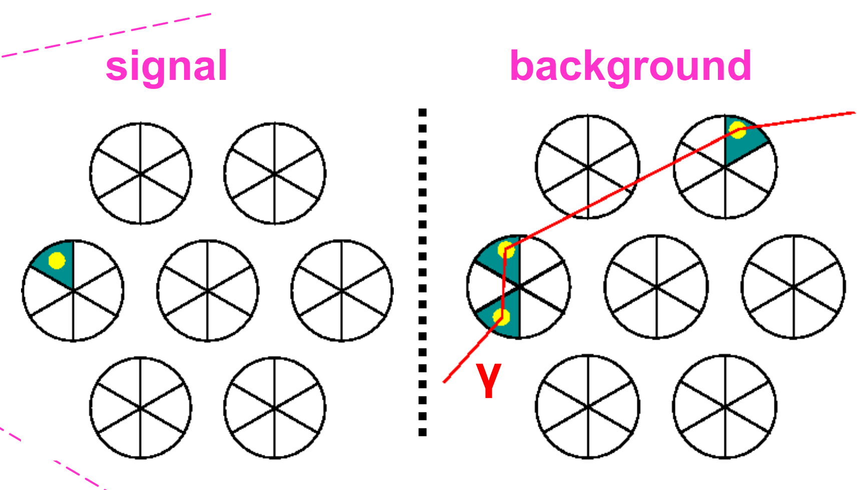
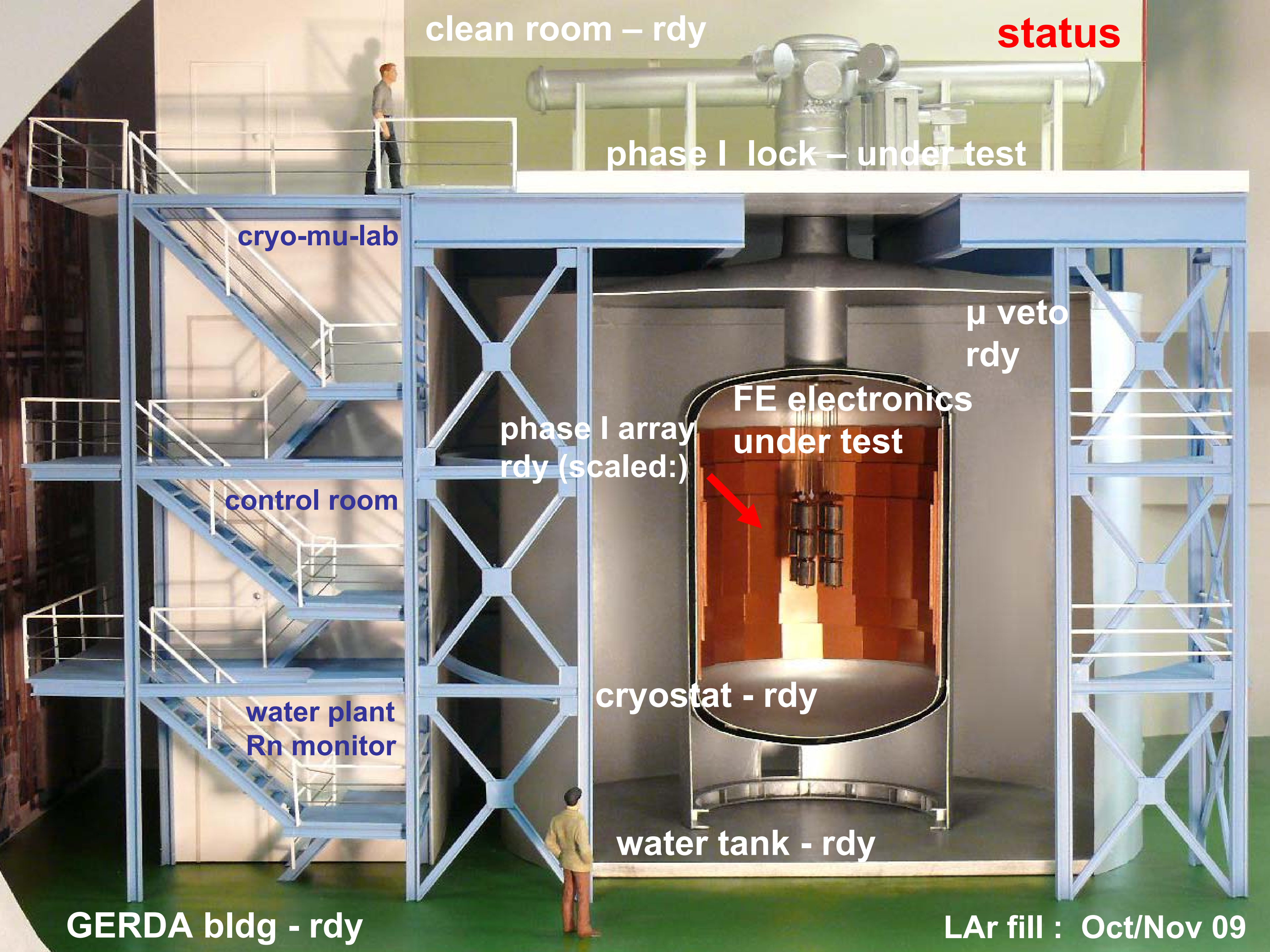
INTRINSIC or VERY CLOSE bgnds :
cosmogenic - ^{60}Co (5.3 a), ^{68}Ge (270 d)-
contaminated holders, FE, cables …

Discriminate single & multi site events !
► SSE: ßß, DEP ► MSE: Compton



array of segmented Ge detectors

- **► anti-coincidence of detectors & detector segments**
- **► pulse shape analysis (PSA)**



clean room – rdy
status
phase I lock – under test
cryo-mu-lab
μ veto
rdy
FE electronics
under test
phase I array
rdy (scaled:)
control room
cryostat - rdy
water plant
Rn monitor
water tank - rdy
GERDA bldg - rdy
LAr fill : Oct/Nov 09


unloading of cryostat
6 mar 08

water tank:

Ø 10 m
h = 9.5 m
V = 650 m^3

designed for external
γ,n,μ background
~10^{-4} cts /(keV·kg·y)


construction of clean room
27 feb 09

clean room, active cooling device getting prepared for installation

muon veto in water tank

12 aug 09

R&D of GERDA Task Groups

• **TG01**	**Modification & test of existing Ge diodes**
• **TG02**	**Design & production of new Ge diodes**
• **TG03**	**Front end electronics**
• **TG04**	**Cryostat and cryogenic infrastructure**
• **TG05**	**Clean room and lock system**
• **TG06**	**Water tank and water plants**
• **TG07**	**Muon veto**
• **TG08**	**Infrastructure & logistics**
• **TG09**	**DAQ electronics & online software**
• **TG10**	**Simulation & background studies**
• **TG11**	**Material screening**
• **TG12**	**Calibration**

'LArGe' R&D - active LAr veto - topic of TG01

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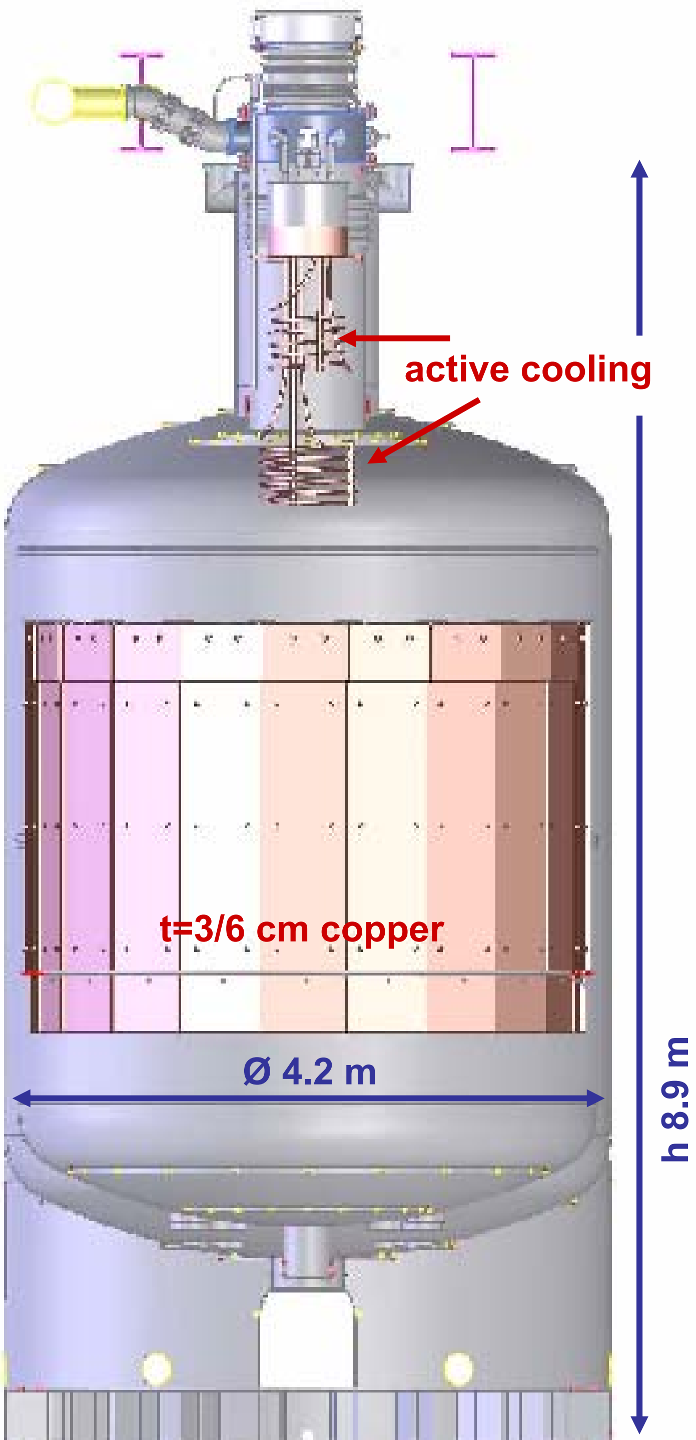
'LArGe' R&D - active LAr veto - topic of TG01
► JINST 3 (2008) P08007

cryostat



65 m^3 volume for LN/LAr

200W measured thermal loss

active cooling with LN

internal copper shield

detailed risk analysis of
cryostat in 'water bath'

- leak before break principle
- 0.6g earth quake tolerant
- certified pressure vessel
- no penetrations below fill level
- redundant safety systems

detailed radio assay ►

1. Screening of all stainless steel sheet batches (13 x ~50kg) by underground γ spectroscopy at MPI-HD and LNGS **(NIM A593 (2008) 448)**

In 1.4571 material (X6CrNiMoTi17-12-2) total of 14 isotopes quantitatively identified including

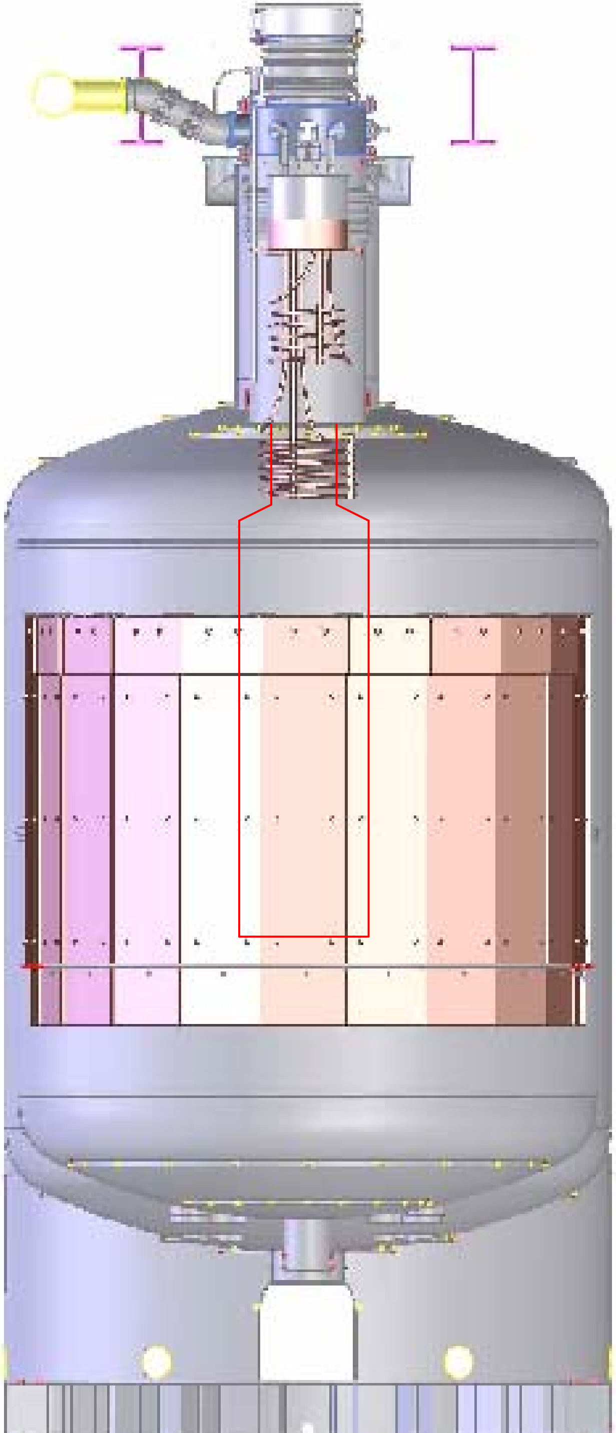
Th-228 <0.1 – 5, typically <2 mBq/kg

much lower than expected – 10 mBq/kg!
► reduction of internal copper shield

2. MC deduced contribution to background index background

cryostat + copper shield + LAr	**$<2 \cdot 10^{-4}$ cts / (keV·kg·y)**
shielding against external γ rays including water tank	**$0.1 \cdot 10^{-4}$ cts / (keV·kg·y)**

(NIM A606 (2009) 790)



3. Measurements of Rn emanation* at various fabrication/installation steps with MoREx**

after 1./2. cleaning	23±4 / 14±2 mBq
after copper mount	34±6 mBq
after 3. cleaning	31±2 mBq
after cryogenics mount	55±4 mBq**

**evidence: ^{222}Rn concentrated in neck!

Rn shroud of 30 µm copper
Ø 0.8m , 3m height
to prevent convective transport
of Rn from walls/copper to Ge diodes

BI ~ 1.5 10^{-4} cts / (keV·kg·y)

* Uniform ^{222}Rn distribution of 8 mBq
implies b = 10^{-4} cts/(keV kg y) in phase I.

**Appl.Rad.Isot. 52(2000) 691

p-type coaxial detectors

8 diodes (from HdM, IGEX) – total of 17.9 kg ^{76}Ge

- **all diodes refurbished, changed contacting scheme for improved operation in LN/LAr**
- **well tested procedures for mounting & handling**
- **FWHM at 1.33 MeV ~ 2.5 keV**
- **long term stability in LAr established**

in addition:

6 former Genius-TF ^{nat}Ge diodes

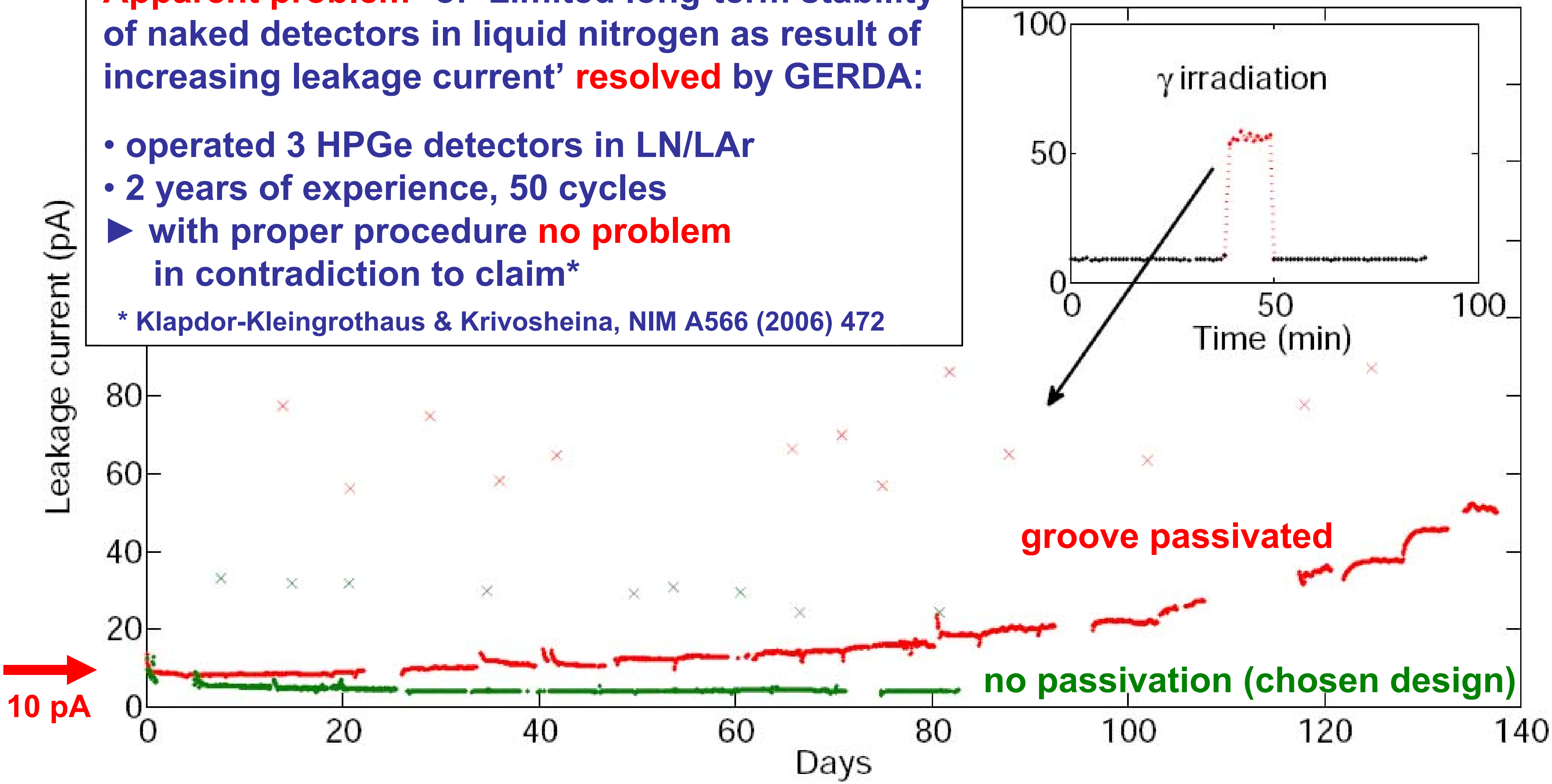
R&D: long term stability of Ge diodes in LN_2 / LAr

Apparent problem* of 'Limited long-term stability of naked detectors in liquid nitrogen as result of increasing leakage current' resolved by GERDA:

- **operated 3 HPGe detectors in LN/LAr**
- **2 years of experience, 50 cycles**

► with proper procedure no problem in contradiction to claim*

* Klapdor-Kleingrothaus & Krivosheina, NIM A566 (2006) 472



no deterioration after 1 year of operation in LAr

M. Barnabé-Heider, PhD thesis '09

Two technologies pursued: 1) n-type segmented 2) p-type BEGe

enriched & depleted Germanium

- 37.5 kg of 86% ^{enr}Ge (in form of GeO_2) in hand, stored underground at IRRM
- 84 kg of $^{dep}GeO_2$ acquired (relict of enrichment) and in use for tests

purification

- a solved problem (PPM Pure Metals, GmbH)
- no isotopic dilution
- total yield >90% for >6N quality
- total exposure at sea level < 3 days per purification
- negotiations for purification of enriched material started

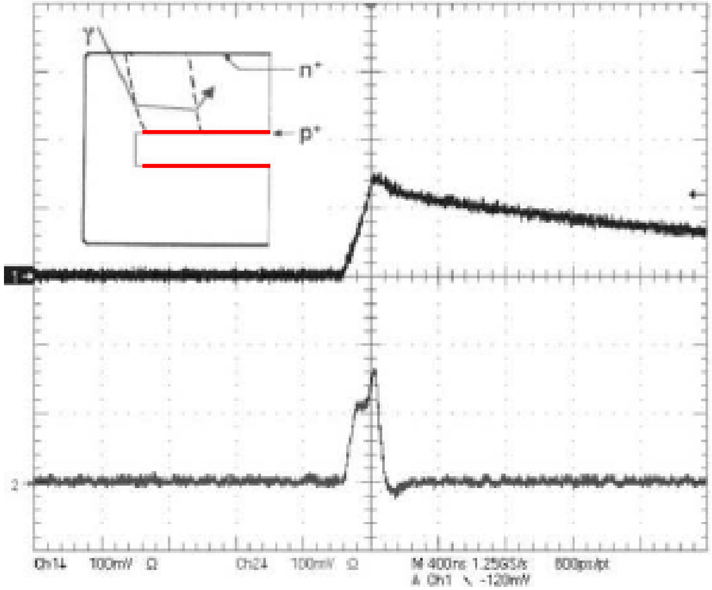
crystal growing (n-type)

- natural Ge crystals pulled from 6N material by Institut für Kristallzüchtung, Berlin
- impurity density ~ 10^{11} to 10^{13} cm^{-3}, 10^{10} cm^{-3} needed
- too high As concentration, to be reduced by refurbishing Czochralski puller
- recent alternative: p-type BEGe diodes from Canberra Belgium

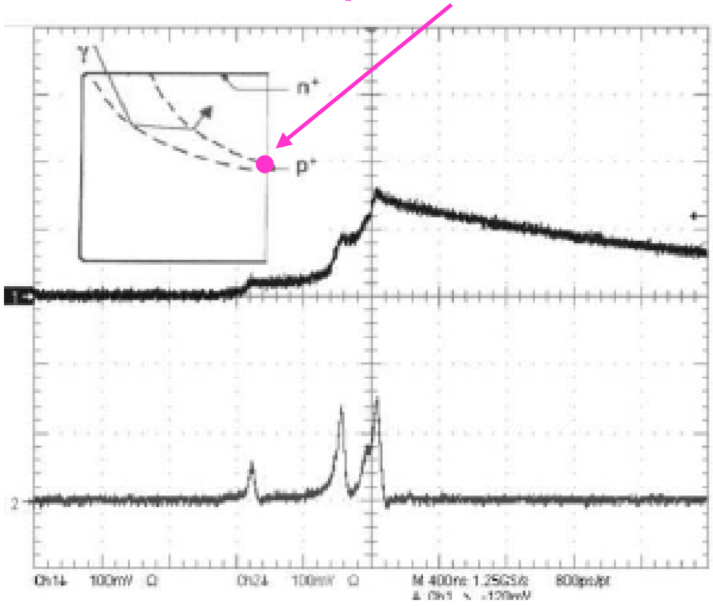
R&D : pulse shape analysis (PSA)

Effect of electrode geometry on pulse-formation for a multi site gamma interaction

standard coaxial HPGe



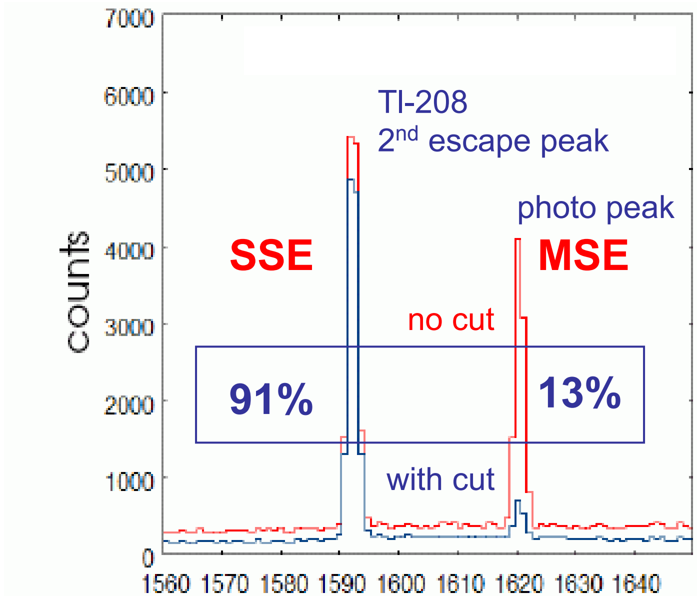
'modified electrode detector' with 'point contact'



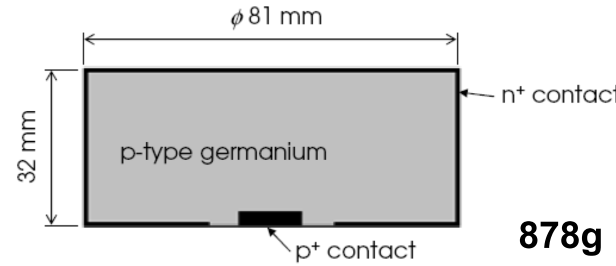
Luke et al. , IEEE TNS 36 (1989)
Barbeau et al., nucl-ex/0701012v1

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

R&D: Single / Multi Site Event discrimination



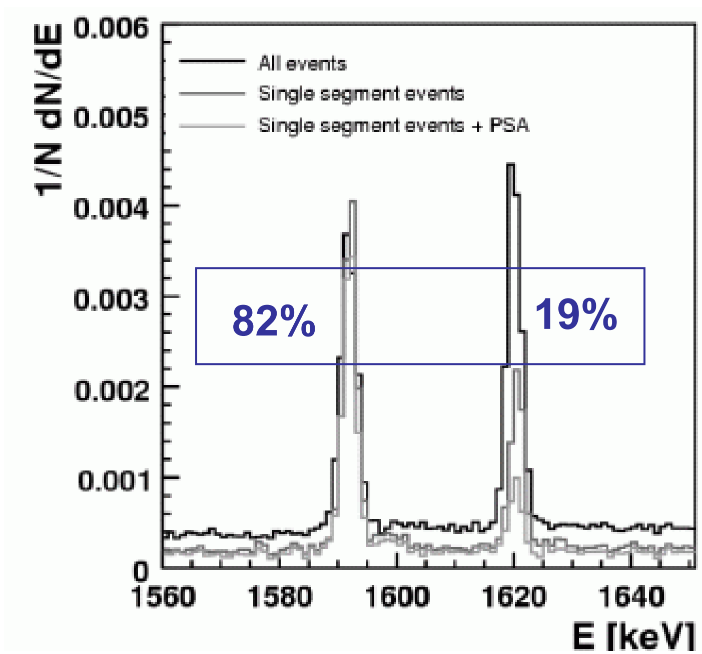
BEGe point-contact detector – p-type (COTS of Canberra)



878g

fractions after PSA cut

D..Budjas, PhD thesis '09
arXiv:0812.1735 [nucl-ex]
JINST, in press

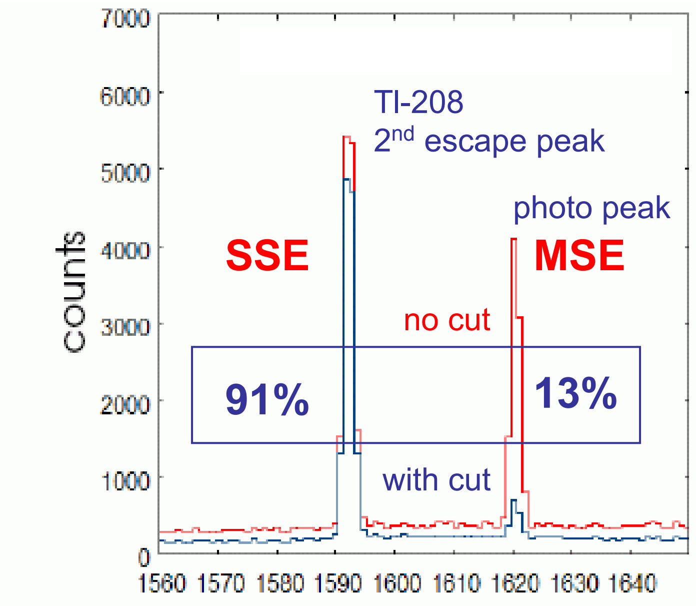


3x6-fold segmented coax detector - n-type

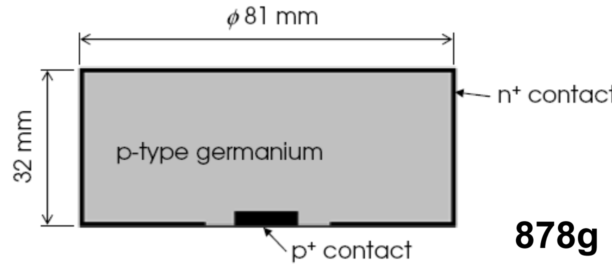
fractions after single-segment & PSA cut

Abt etal NIM A583 (2007),
Eur.J.Phys. C52 (2007)

R&D: Single / Multi Site Event discrimination



BEGe point-contact detector (COTS of Canberra)



878g

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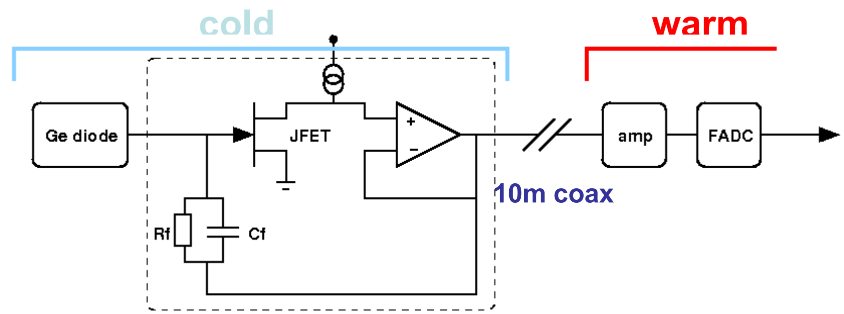
arXiv:0812.1735 [nucl-ex]
JINST, in press

similar / better suppression obtained for K-40, Co-60 & Ra-226 contaminations

Results so convincing that GERDA collaboration has ordered at Canberra US/Belgium several crystals/ BEGe detectors made from the depleted Ge
► test of complete production chain
latest news of Oct 05:
first detector grade crystal pulled from the depleted Ge in Oak Ridge

test of full readout chain



3-channel PZ-0 ASIC
- **built in AMS HV 0.8 μm CZX**
- **input JFET, R_f & C_f discrete**

set up in Hall di Montaggio of LNGS:
clean bench for Ge handling
phase I lock prototype
test dewar with active cooling
prototype Ge-diode with final mount, cabling & electronics

achieved: 2.9 keV with Co-60 source
test with 2 diodes in progress

conclusion

- approved in 2005 by LNGS with its location in hall A,
- funded by BMBF, INFN, MPG, and Russia in kind
- construction completed in LNGS Hall A
- all phase I detectors (8 pcs ,~18 kg) refurbished & ready

► LAr fill of cryostat in Nov '09 with subsequent start of commissioning / parallel R&D for phase II

goals: phase I : background 0.01 cts / (kg·keV·y)

► scrutinize KKDC result within ~1 year

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

► $T_{1/2} > 1.5 \cdot 10^{26}$ y , $\langle m_{ee} \rangle < 0.2$ eV *

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

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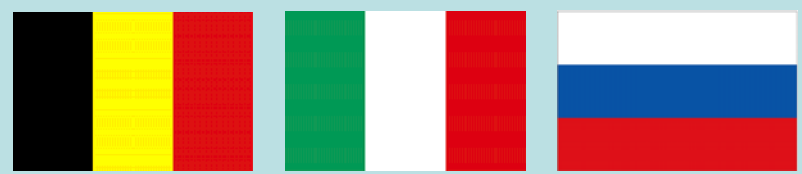

~ 95 physicists from 17 institutions

the end