GERDA and Majorana

Search for neutrinoless double beta decay in Ge-76

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The GERmanium Detector Array Collaboration
http: //www.mpi-hd.mpg.de/GERDA

The Majorana Collaboration

http://majorana.pnl.gov

Belgium	(1)
Germany	(4)
Italy	(3)
Poland	(1)
Russia	(4)

~ 70 physicists
13 institutions
5 countrys

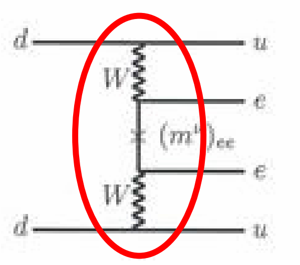
Intro & Basics
Sensitivities
Background Reduction
R&D
Status
Conclusions

Canada	(1)
Japan	(1)
Russia	(2)
USA	(11)

~ 100 physicists
15 institutions
4 countrys

Close contacts, common MC, MoU

motivation for 0vßß decay searches



- Only way to determine if neutrino is its own antiparticle, $v = \overline{v}$

  ► Majorana particle

  if YES:

- would provide access to absolute neutrino mass scale

$$\boxed{T^{0v}_{1/2} = 1 / [\ \Gamma(Q_{\beta\beta}{}^{5})\ |M_{nucl}|^2 <m_{ee}>^2\ ]}$$

$$\boxed{<m_{ee}> = |\ \Sigma_i\ \ U_{ei}{}^2 m_i\ |}$$

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

2vßß and 0vßß decays

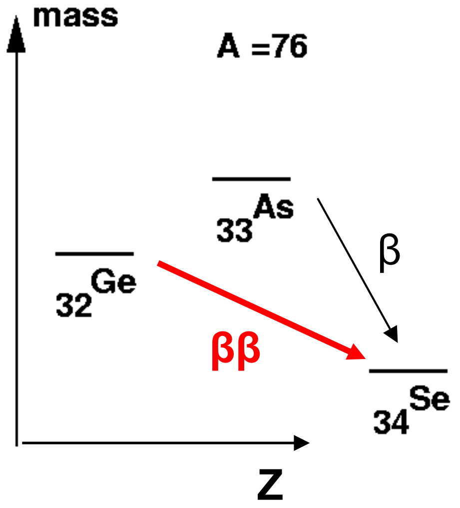
2vββ : $(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{v}_e$

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

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

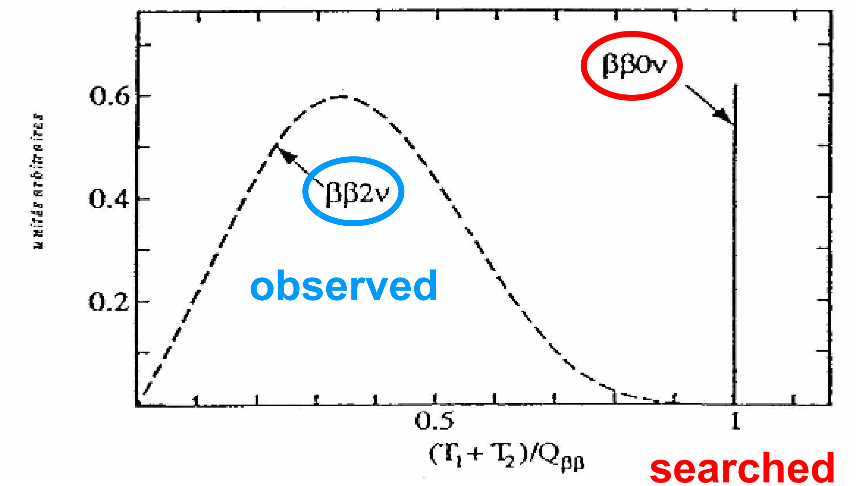
0vββ : $(A, Z) \rightarrow (A, Z+2) + 2e^-$

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



Signature for 0vßß decays:

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



searched for

attractiveness of Ge-76

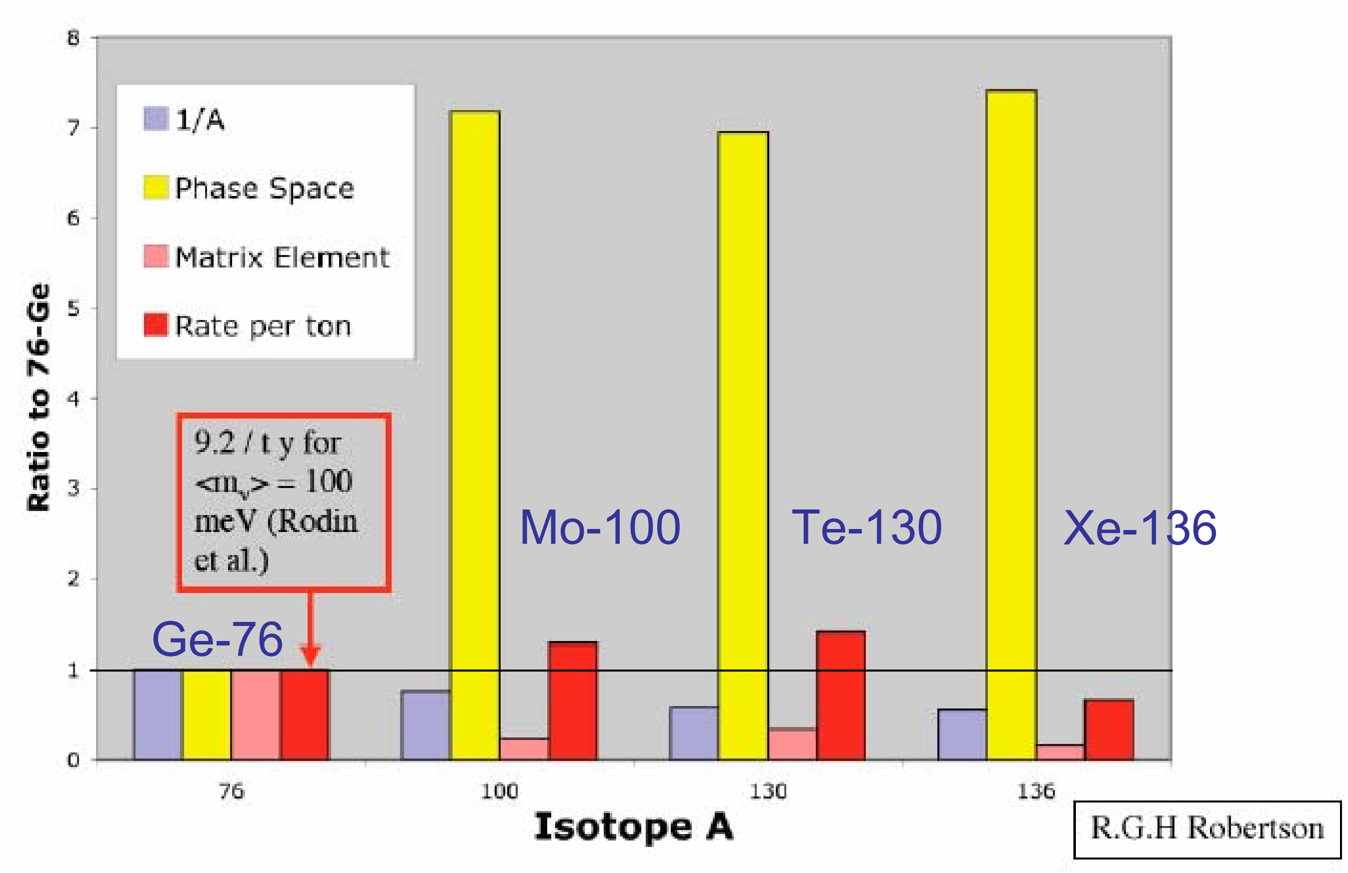
- Ge semiconductor ► source & detector
- intrinsic Ge material ► purest available solid state material
- established enrichment from 7.44% (nat.) to 86% , still affordable at ~50$ / g
- very good energy resolution, <0.2% at 2039 keV ► narrow ROI of 4 keV

  ►negligible overlap with 2vßß background; ~$(2\cdot10^{-3})^6$ for same $T_{1/2}$
- favorable product of phase space factor & nuclear matrix element

  ► next slide

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

phase space & nuclear matrix elements



Error of matrix elements: 30% minimum

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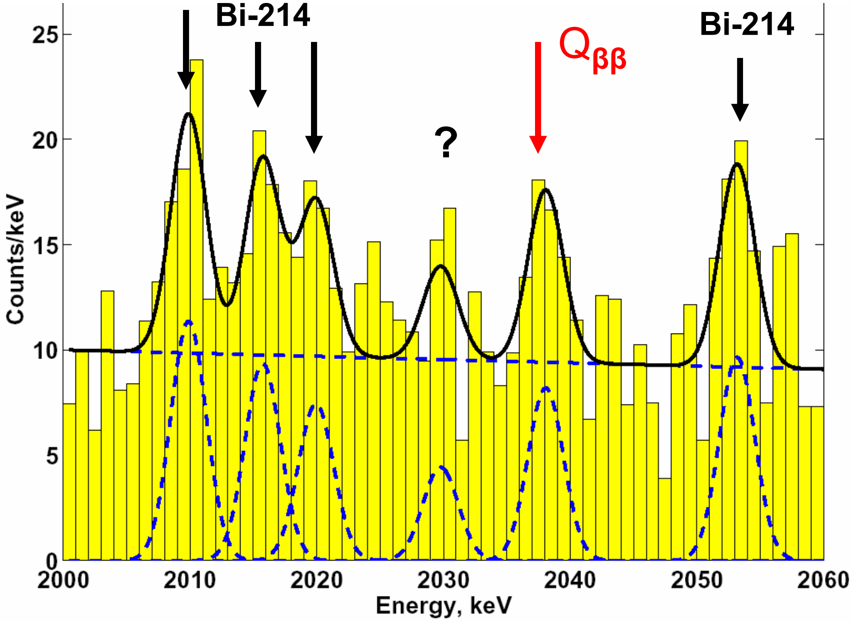
last not least: best limits on resp. claimed evidence of 0vßß decay

(Cuoricino, however, reporting now very similar limit!)

$<m_{ee}>$ best limits / value

KKDC: H.V.Klapdor-Kleingrothaus, I.V.Krivoshina, A.Dietz, O.Chkvorets, Phys.Lett. B586 (2004) 198

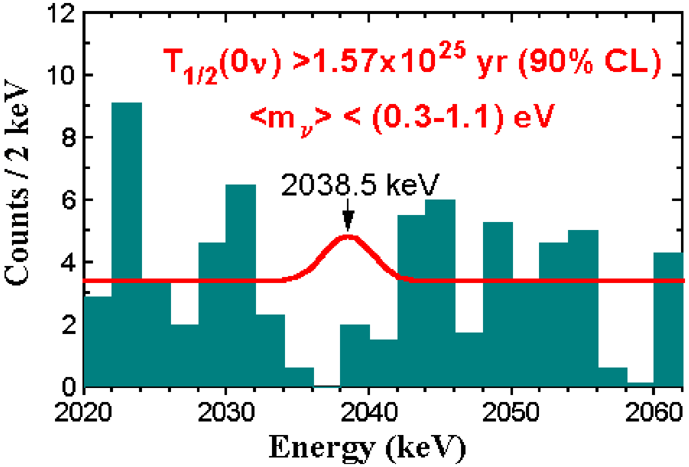


5 enriched Ge-76 diodes (10.9 kg / 71.7 kg·y)

'Background Index' B = ~0.1 cts / (keV·kg·y)

$T_{1/2}^{0\nu}$ = (0.69 - 4.18)·10^{25} y (3σ range)

IGEX : **Gonzales et al., NP B87(2000)278**



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

sensitivities

$$T_{1/2} = \frac{\ln 2 \cdot \#atoms \cdot time}{\#decays} \overset{\text{Ge-76}}{=} \frac{5.47 \cdot 10^{24} \cdot (mass / kg) \cdot (time / yrs)}{\#decays} \quad \text{[yrs]}$$

1) 90% confidence limit (C.L.) in case of zero event (FC: #decays=2.44):

$T_{1/2} > 2.2 \cdot 10^{24} (m / kg) \cdot (t / yrs)$ [yrs]

► increase mass and time, naïve:

2) sensitivity in case of background :

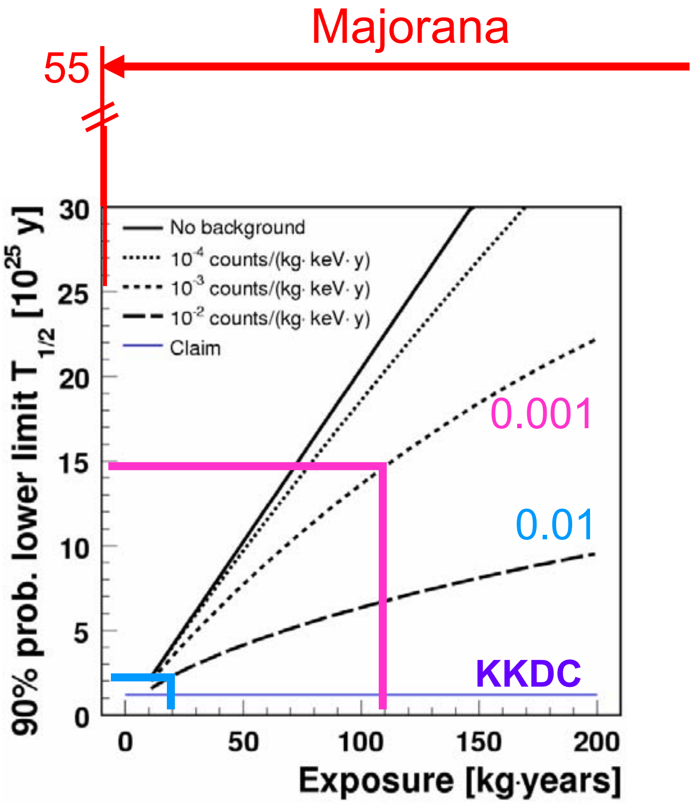
$$\#decays = \sqrt{background} = \sqrt{\underset{[cts/(kg \cdot keV \cdot yrs)]}{B} \cdot m \cdot t \cdot \underset{[keV]}{\Delta E}}$$

$$T_{1/2} > const \sqrt{(m \cdot t) / (B \cdot \Delta E)}$$

► reduce background index B ◄

► optimize energy resolution ΔE◄

GERDA, phase I : 0.01 cts/(kg·keV·yrs) , 20 kg·yrs
phase II : 0.001 cts/(kg·keV·yrs), 105 kg·yrs
Majorana : 0.00025 cts/(kg·keV·yrs), 460 kg·yrs



sensitivities

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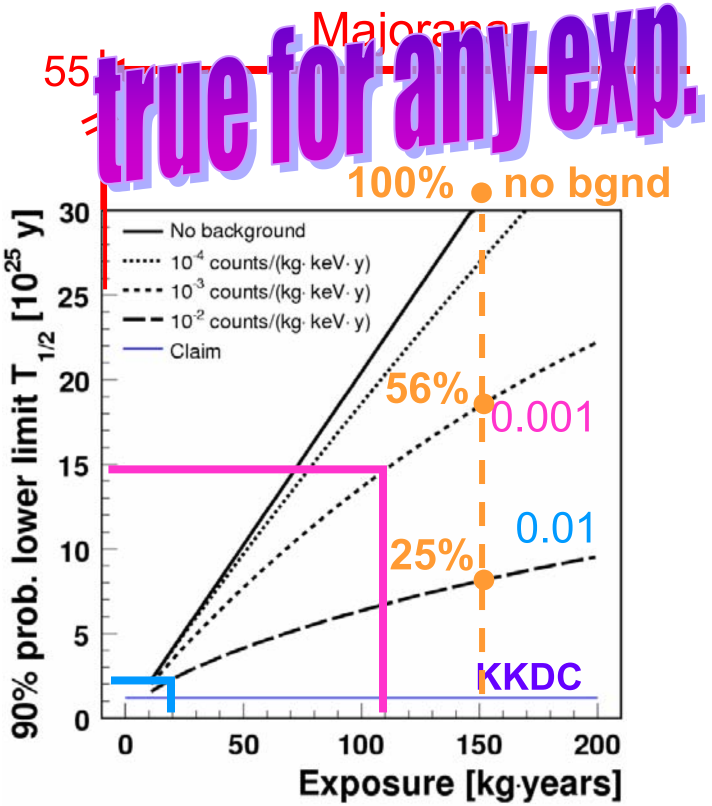
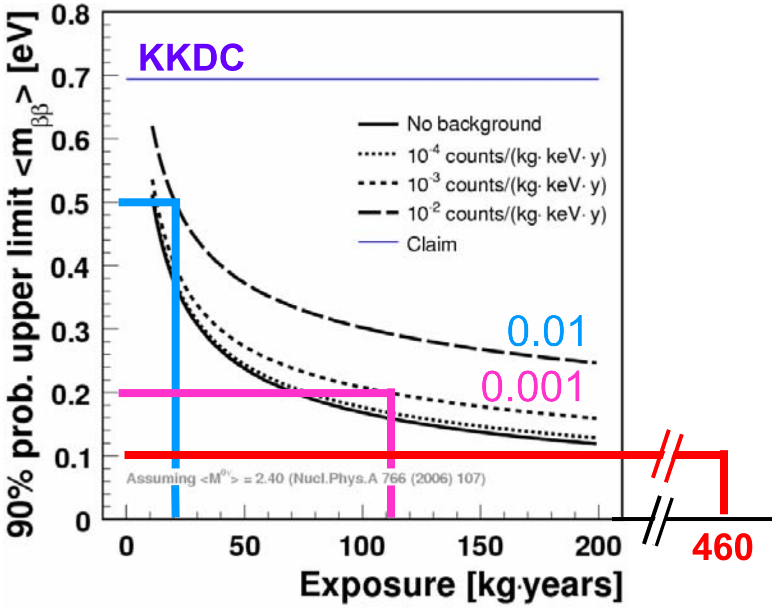
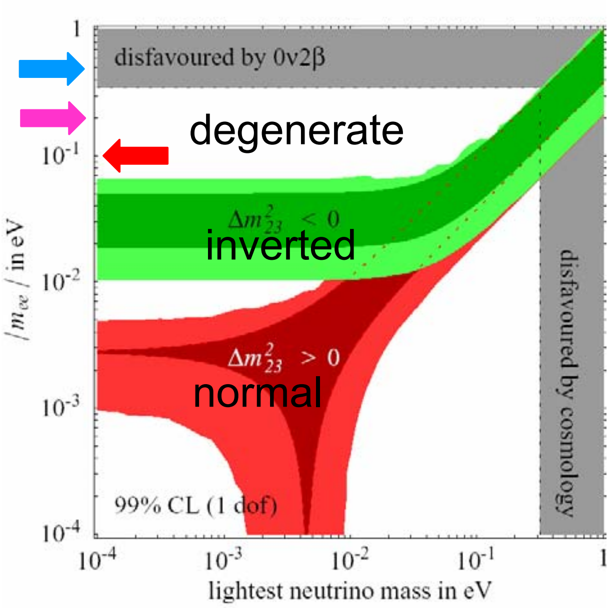


from $T_{1/2}$ deduced information

Measured $T_{1/2}$ ⟶ deduced $<m_{ee}>$ ⟶ info on mass hierarchy





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

- phase I : ~15 kg exisiting Ge-76 diodes of HD-Moscow & IGEX experiments ► 20 kg yrs
- phase II : ~20 kg of new enriched Ge-76 detectors ► 105 kg yrs
- Majorana: 2x 60 kg enriched Ge-76 detectors ► 460 kg yrs

- phase III: depending on results, worldwide collaboration for bigger experiment (0.5 - 1 ton)
  close contacts & MoU with MAJORANA collaboration established

background sources

- **EXTERNAL to crystals**

γ rays from primordial Th and U decay chains

► Tl-208 (Th-232) , Bi-214 (Ra-226)

neutrons from fission, (α,n) & μ-induced reactions

muons from cosmic showers

Activity of Tl-208	(μBq/kg)
rock, concrete	3000000
stainless steel	~ 5000
Cu(NOSV), Pb	<20
water, purified	< 1
LN2, LAr	~ 0

Shielding possible .

- **INTRINSIC or VERY CLOSE to crystals**
(mounting material, cables, electronics,…)

2νßß, irreducible but not relevant because of ΔE~0.2%

radioactive impurities in crystal, on surface

cosmogenic: Co-60 (5.3 yrs) , Ge-68 (270 d)

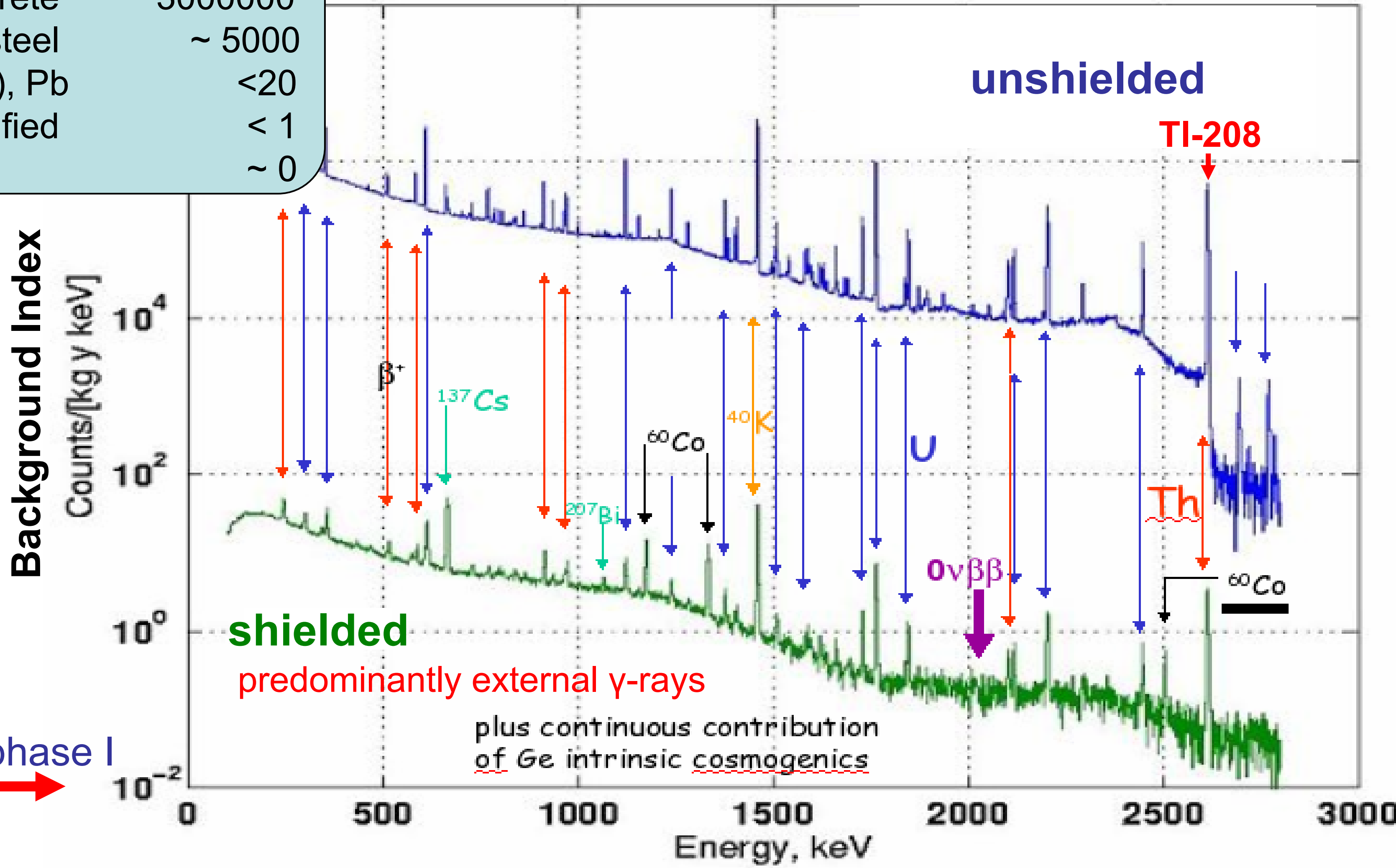
…..

Background reduction / rejection techniques needed !

background (1)

Activity of Tl-208	(μBq/kg)
rock, concrete	3000000
stainless steel	~ 5000
Cu(NOSV), Pb	<20
water, purified	< 1
LN2, LAr	~ 0

spectra measured at LNGS with Ge diode



predominantly external γ-rays

plus continuous contribution of Ge intrinsic cosmogenics

GERDA phase I →

generic external background shields

GERDA (low Z shield)

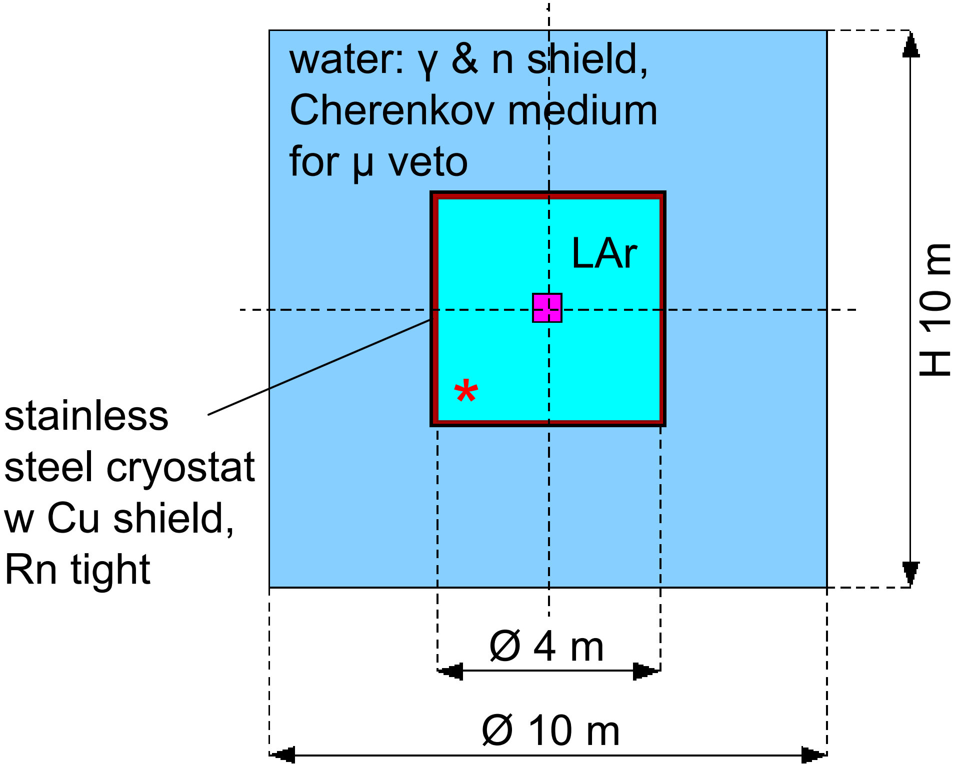
Majorana (high Z shield; deep underground)

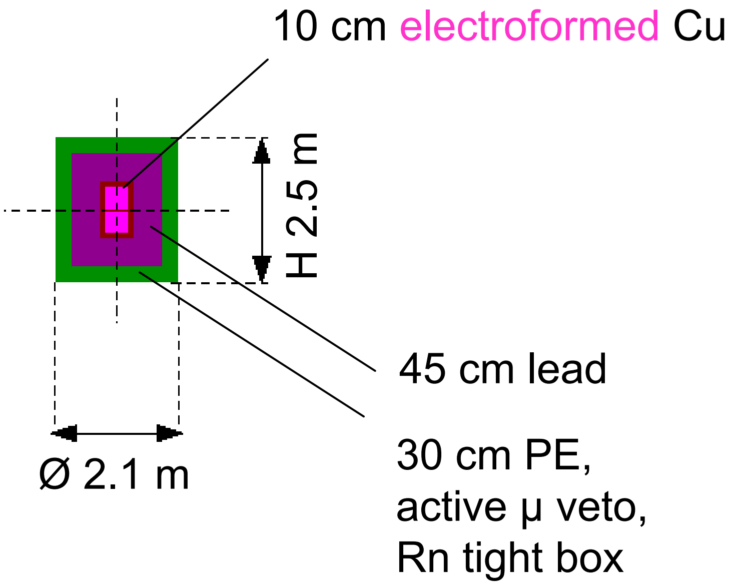
bare Ge diodes in high-purity LAr

< 1μBq/m³ STP Rn-222 (established)

Ge diodes housed in vacuum cryostat, ultra-high-purity electroformed Cu shield

< 1 μBq/kg Th-232 (not yet established)





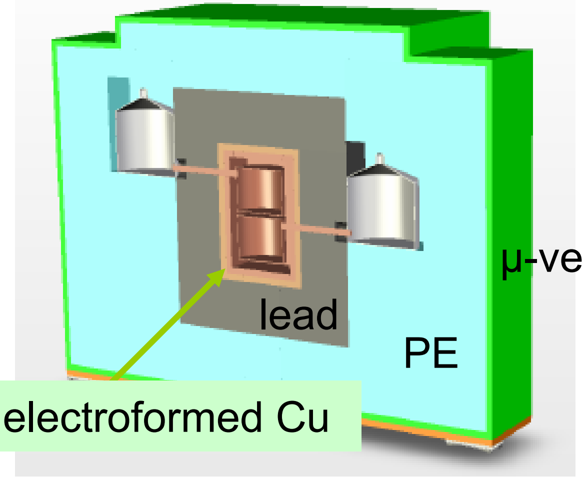
* LAr can be also active shield !

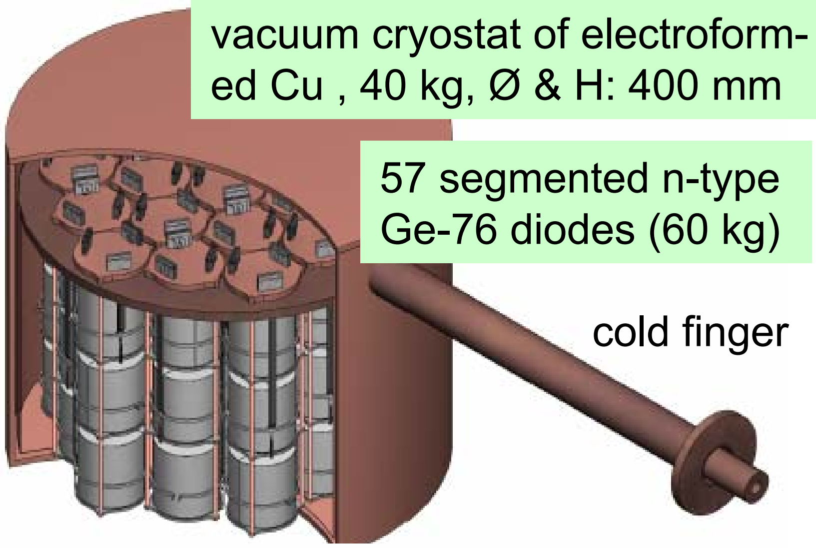
$\alpha(\mathrm{LAr}) = 0.050/\mathrm{cm}$ $\alpha(\mathrm{Cu}) = 0.34/\mathrm{cm}$

$\alpha(\mathrm{H_2O}) = 0.043/\mathrm{cm}$ $\alpha(\mathrm{Pb}) = 0.48/\mathrm{cm}$

Majorana setup

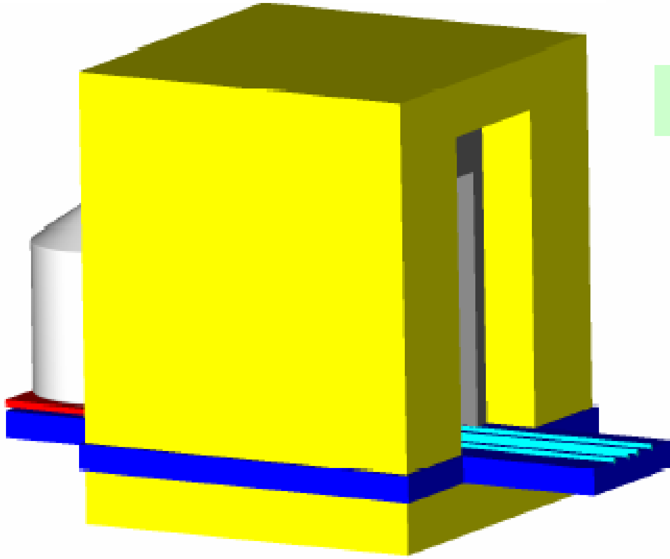
▲ 5000 m w.e. rock above ▲

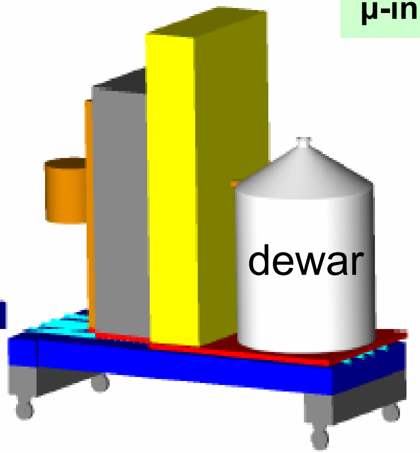




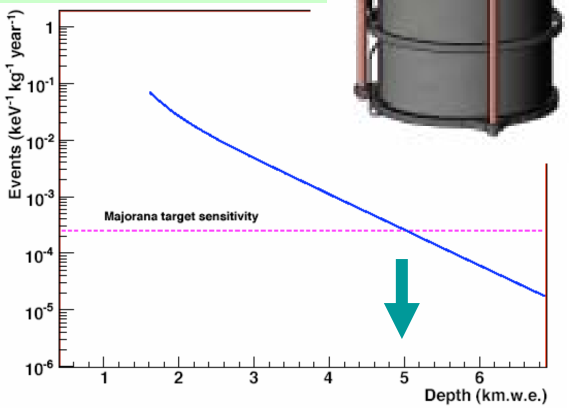
vacuum cryostat of electroformed Cu , 40 kg, Ø & H: 400 mm

57 segmented n-type Ge-76 diodes (60 kg)





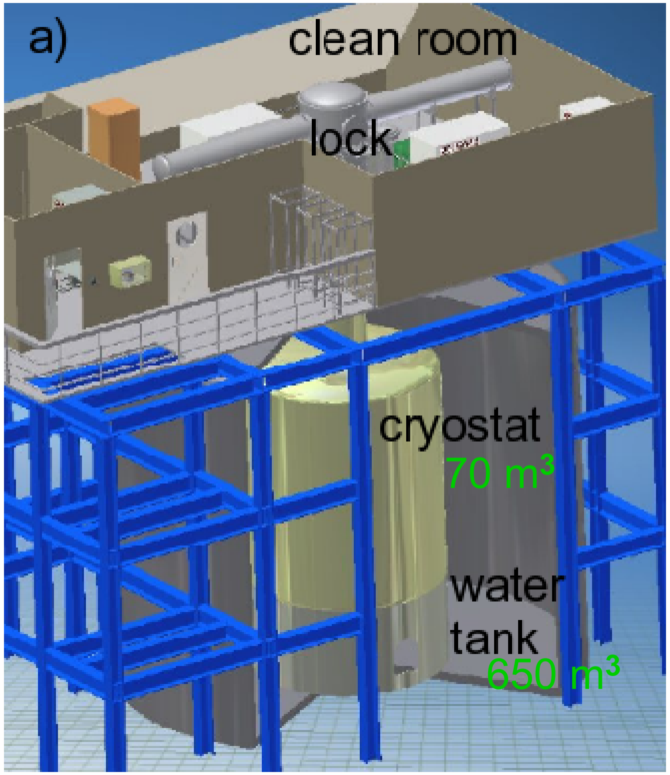
μ-induced events vs depth



GERDA setup

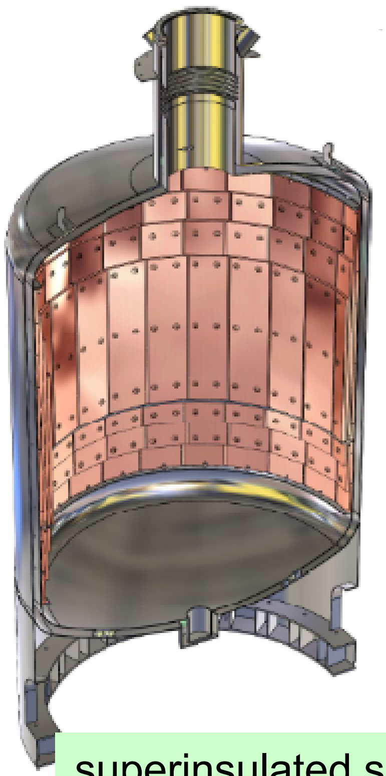
▲ Gran Sasso ▲

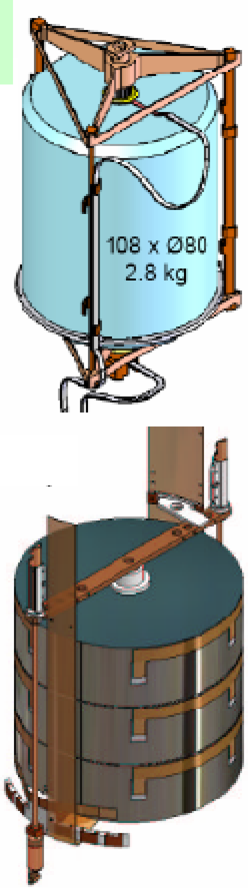
▲ 3800 m w.e. rock above ▲



Future view in hall A of LNGS just in front of LVD

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





superinsulated stainless steel cryostat with internal Cu shield (t = 3 – 6 cm)

background (2)

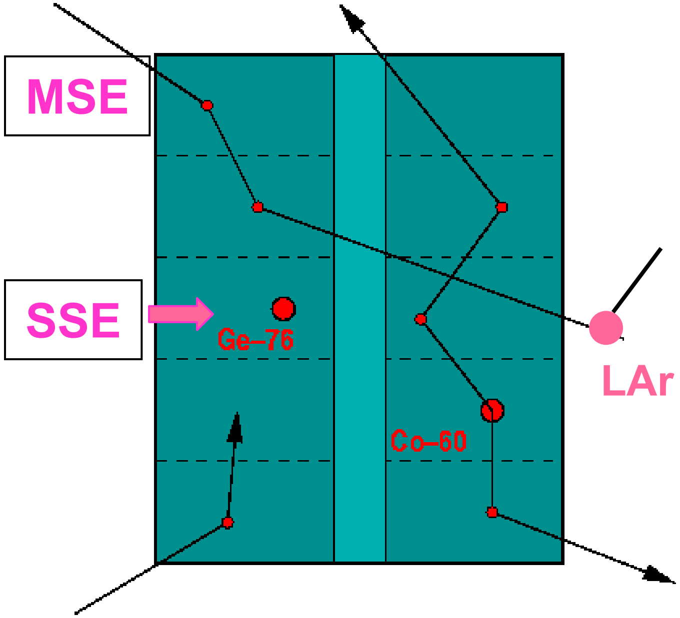
INTRINSIC BACKGROUNDS:

- cosmogenic isotopes (Ge-68, Co-60) due to spallation reactions above ground and $T_{1/2}$~yrs.

SUPPRESSION OF INTRINSIC BACKGROUND:

avoid it – keep enriched material underground

► discriminate between **SSE** and **MSE** events ◄



SSE Single Site Events:
energy deposition within a few mm
e.g. **ββ events**, double escape peak

MSE Multi Site Events:
energy deposition in full detector volume
e.g. Compton scattering

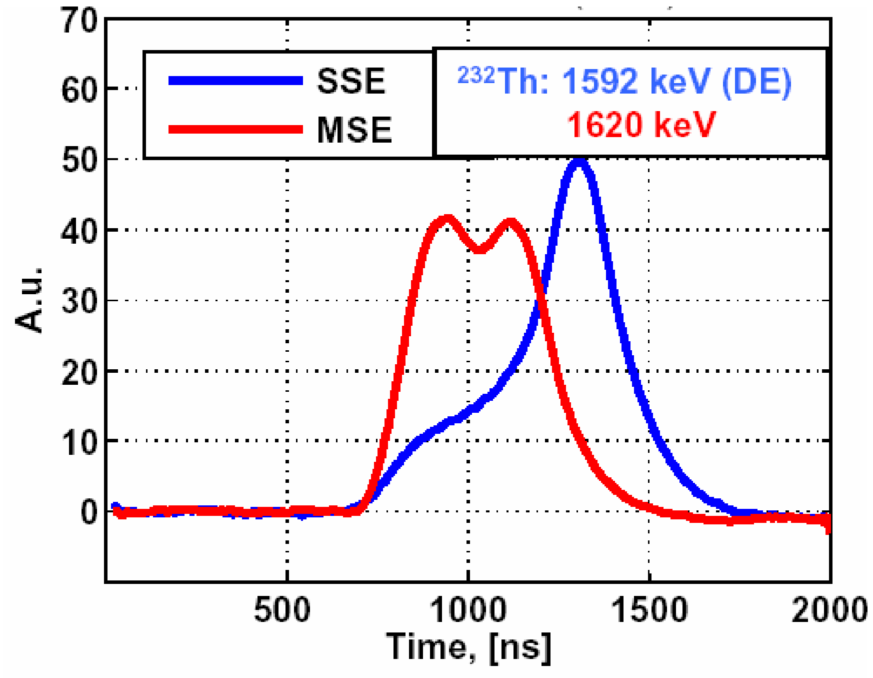
SSE / MSE discrimination methods:

- pulse shape analysis (PSD)
- anti-coincidence between
  - ► detectors,
  - ► detector segments,
  - ► detectors and LAr

example for background ID & suppression

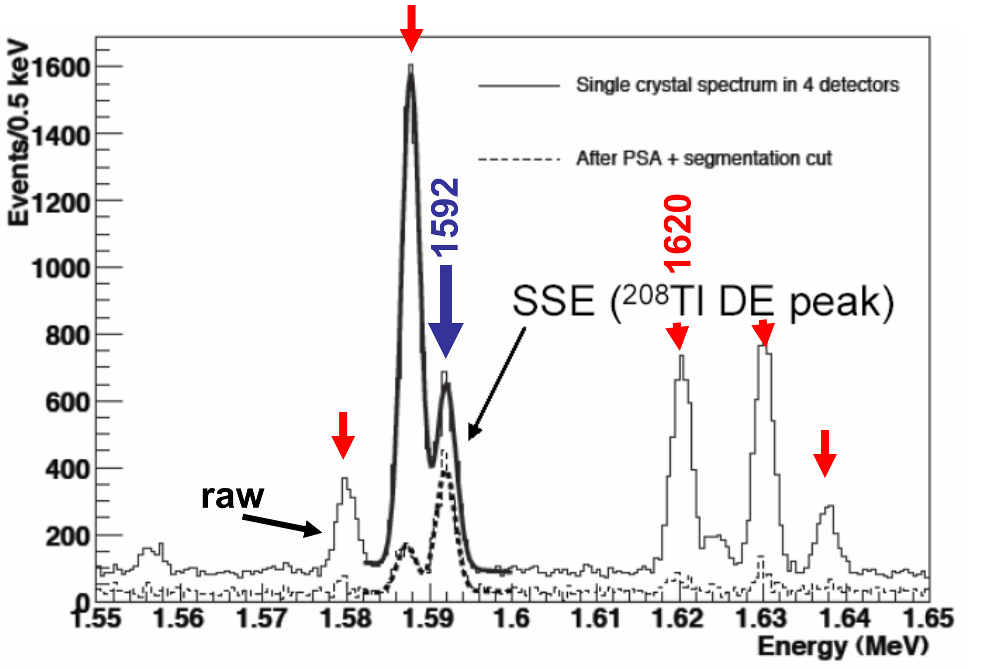
pulse shape discrimination

pulse shapes from **SSE** and **MSE** events



measured with ANG5 of HdM and old
i.e. slow front end electronics

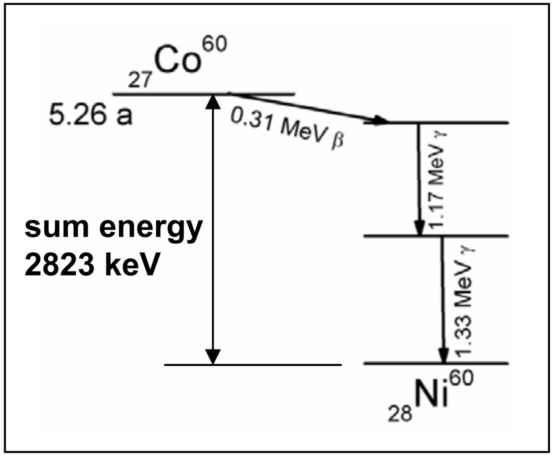
raw spectrum and after PSD & segmentation cut

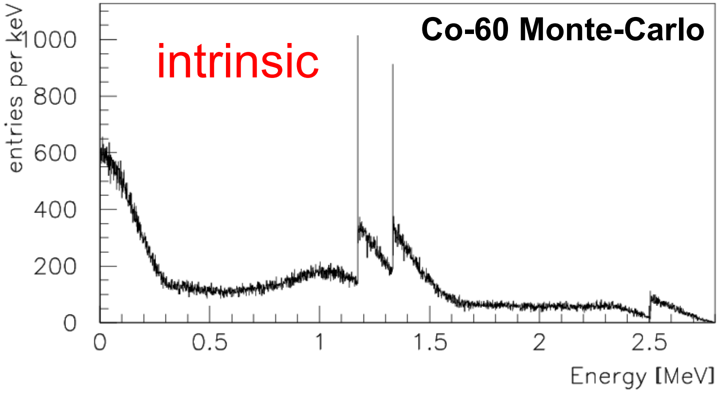


Majorana data

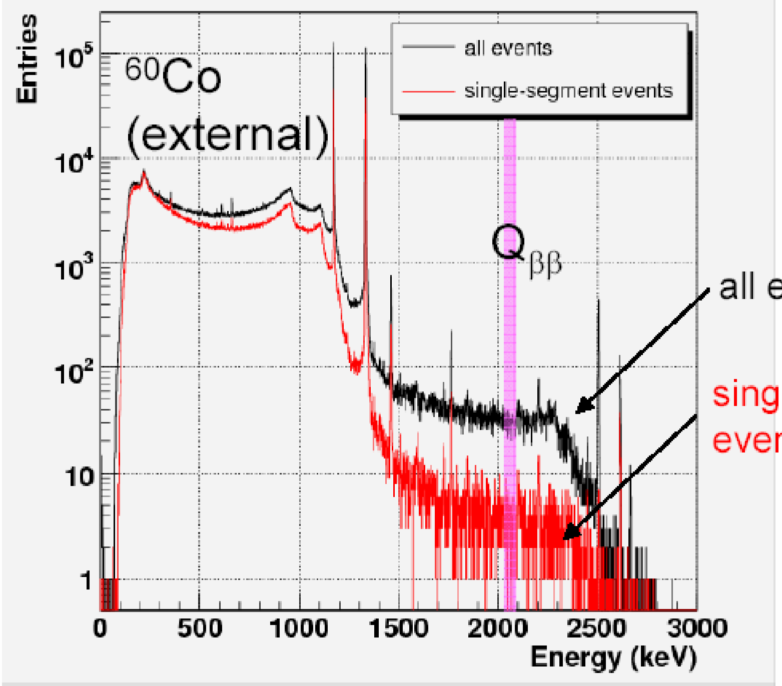
examples for background suppression

anti-coincidences





vetoing MSE in segmented Ge diode



all events

single-segment events

measured with 3x6 segmented true-coaxial n-type prototype crystal for GERDA phase II

► large suppression factors, *O*(5-50) depending on source & geometry

ongoing R&D

- **mechanics**

  low mass detector supports

- **electronics**

  low mass front end electronics, ASICs
  low mass, radiopure cables

- **material screening & purification**

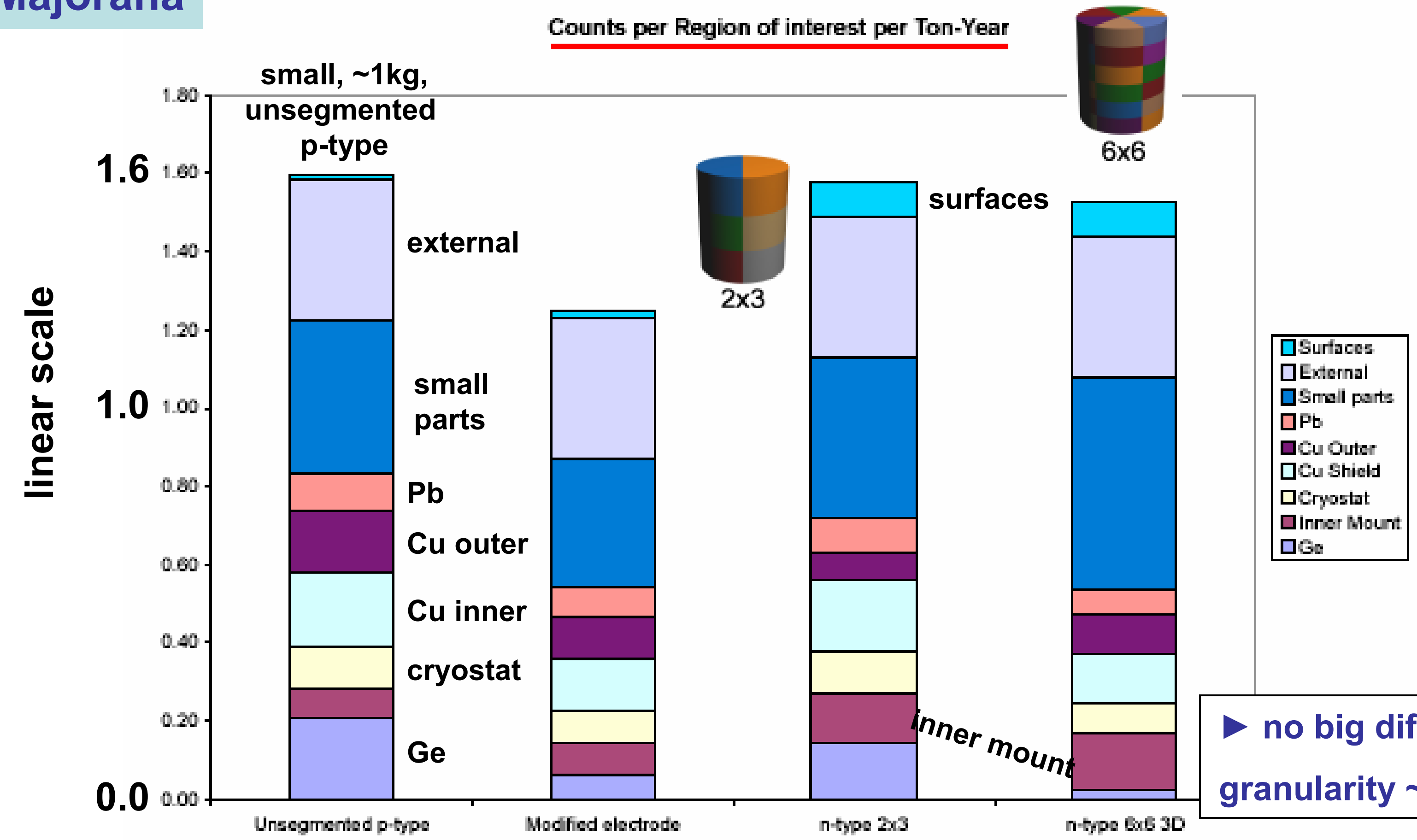
- **detector procurement and R&D**

- **Monte Carlo simulations**

- **LAr scintillitation studies for active veto**

R&D : detector segmentation/electrode configuration

Majorana



▶ no big differences

granularity ~ segmentation

!?

(my personal favorite: min. cable area)

N.B.: Cheap, reliable, fast detector fabrication crucial for 0.1 to 1 t experiments!

also relevant for GERDA !

R&D: material screening / purification

Ge γ spectrometers

- Baksan 600 m w.e. (soon → 4900 m w.e.) 4-fold spectrometer
- Hades 500 m w.e. Ge-2 – Ge-9
- MPI-K 15 m w.e. 3 diodes
- LNGS 3500 m w.e. GeMPI 1,2,(3) S : ~ *O*(10[100]) µBq/kg for heavy [light] samples

Rn-222 diagnostics / monitoring

- emanation technique S : 0.5 µBq / m^2 , 10 µBq / kg
- gas purity analysis
- electrostatic chamber : 0.1 – 1 mBq / m^3

α spectrometer

- Baksan (ionization chamber) S : 10 Bq/m^3 (quick), background: 0.002 / ($cm^2 \cdot h$)
- Krakow

ICPMS (inductively coupled plasma mass spectrometry)

- Frankfurt U S : U/Th ~ 1 µBq / kg > secular equilibrium? <
- LNGS & commercial

(measured materials: Kapton, Teflon, Torlon, MLI, PMT glass, Cu, steel, Cu/P granulate)

►Challenge: screening of plastic materials at required Th sensitivity

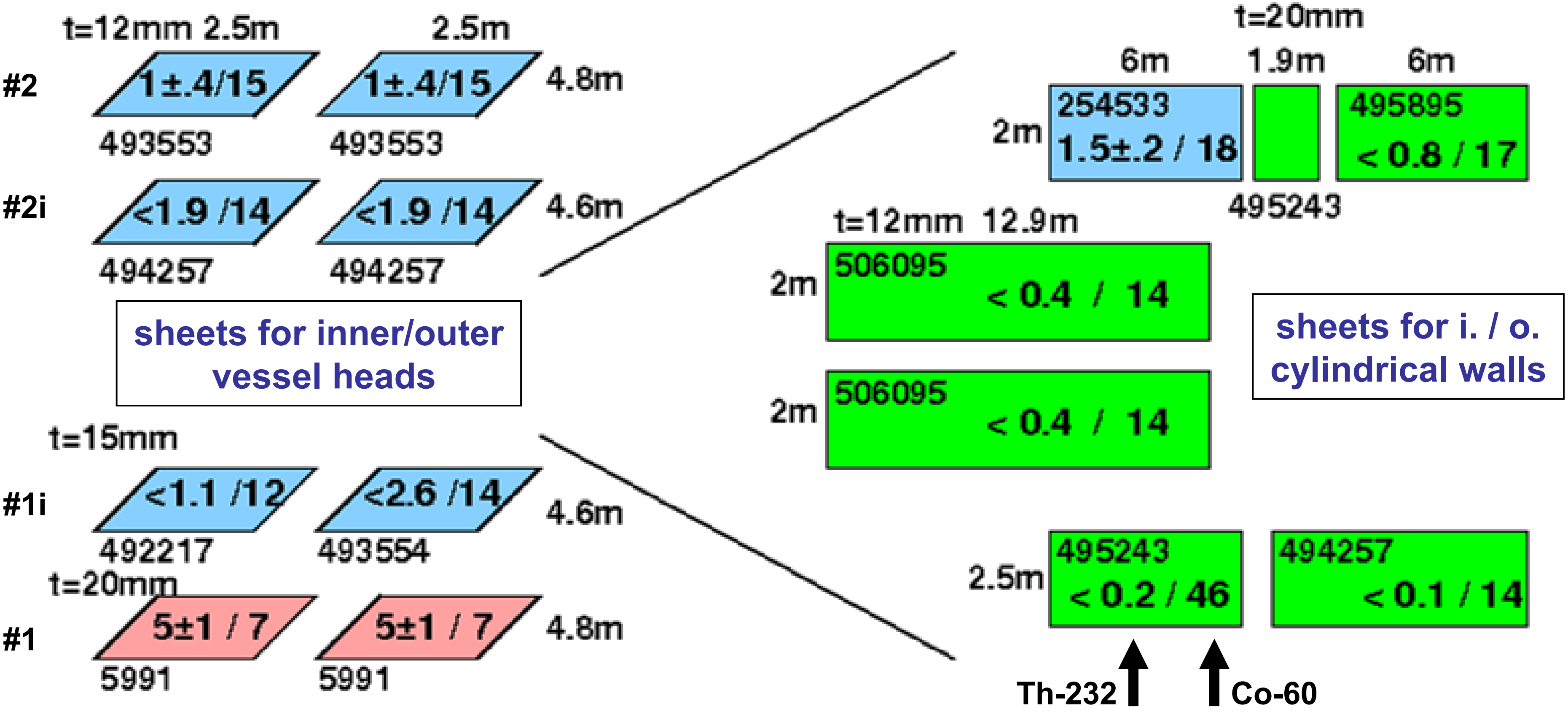
Surface purification studies (cryostat > 100 m^2)

- Cu disks radiated with strong Rn source S : 1 µBq / m^2

► talk by Grzegorz Zuzel

screening of cryostat's ss sheets

results from γ spectroscopy at LNGS and MPI HD
(more data available)



#2
t=12mm 2.5m
2.5m
1±.4/15
1±.4/15
4.8m
493553
493553

#2i
<1.9 /14
<1.9 /14
4.6m
494257
494257

sheets for inner/outer vessel heads

t=15mm

#1i
<1.1 /12
<2.6 /14
4.6m
492217
493554

t=20mm

#1
5±1 / 7
5±1 / 7
4.8m
5991
5991

t=20mm
6m
1.9m
6m
2m
254533
1.5±.2 / 18
495895
< 0.8 / 17
495243

t=12mm 12.9m
2m
506095
< 0.4 / 14
2m
506095
< 0.4 / 14

sheets for i. / o. cylindrical walls

2.5m
495243
< 0.2 / 46
494257
< 0.1 / 14

Th-232
Co-60

unexpected low Th-232 activity, typ. <1 mBq/kg ► less massive Cu shield needed

... and still more R&D for phase II

phase II detector R&D

- optimization of purification of enriched Ge-76 oxide to 6N grade metal
- optimization of production of new enriched Ge-76 diodes
- commissioning of test stands for the characterization of Ge-diodes
- study of segmented n- and p-type true-coaxial Ge-diodes

- detailed Monte-Carlo simulations

example

phase II background index
for available materials
in 10^{-4} cts / (keV·kg·y)

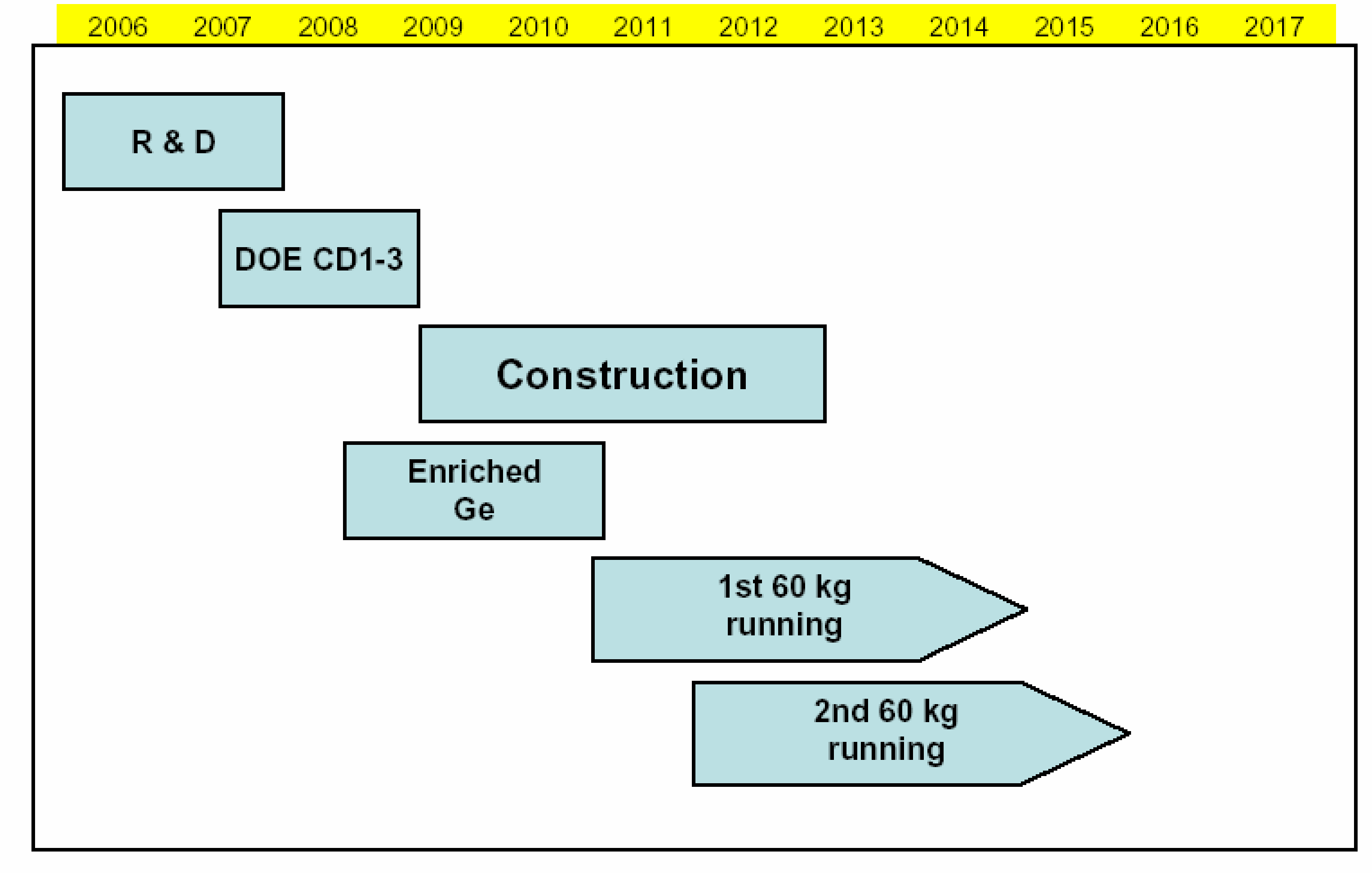
detector	5
holder (copper)	4
holder (Teflon)	8
cabling	6
electronics	3
infrastructure	4
muons, neutrons	2
sum	32

to be improved!

- study of active LAr shield
- and more …

Majorana schedule

assuming two 60 kg modules



GERDA status & schedule

2004	
• Feb	Letter of Intent to LNGS, **hep-ex/0404039**
• Sep	formation of collaboration
• Oct	► funding requests approved by MPG
• Oct	Proposal to LNGS, **www.mpi-hd.mpg.de/GERDA/proposal.pdf**
2005	
• Feb	GERDA approved by LNGS, location in Hall A in front of LVD
• May / Jun	► funding requests approved by INFN / BMBF
• Jul	FMECA & HAZOP safety studies for GERDA with copper cryostat
• Dec	electron beam welding certification for copper cryostat
2006	
• Feb	delivery of 37.5 kg enriched Ge-76
• Apr	all HdM & IGEX detectors fully functional at LNGS
• May	contract for water tank concluded, decision for stainless steel cryostat
• Jun	successful test of 3x6 segmented true-coaxial n-type Ge diode
• Jul	safety review for GERDA with stainless steel cryostat started
• Aug	LNGS hall A ready for installation, tender for cryostat published
• Dec	safety review available, all HdM & IGEX diodes & six ^{nat}Ge diodes at refurbishment company, underground storage, cryostat ordered
2007 / 2008	installation / commissioning

summary

- approved in 2005 by LNGS with its location in hall A,
- funded by BMBF, INFN, MPG, and Russia in kind
- construction started in LNGS Hall A
- parallel R&D for phase II

- 2007 / 08 ► continue / finish installation, do commissioning

goal: 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 , $<m_{ee}> < 0.2$ eV *

- R&D funding; prepared for DOE CD-1 review
- staged approach with two 60 kg detector modules

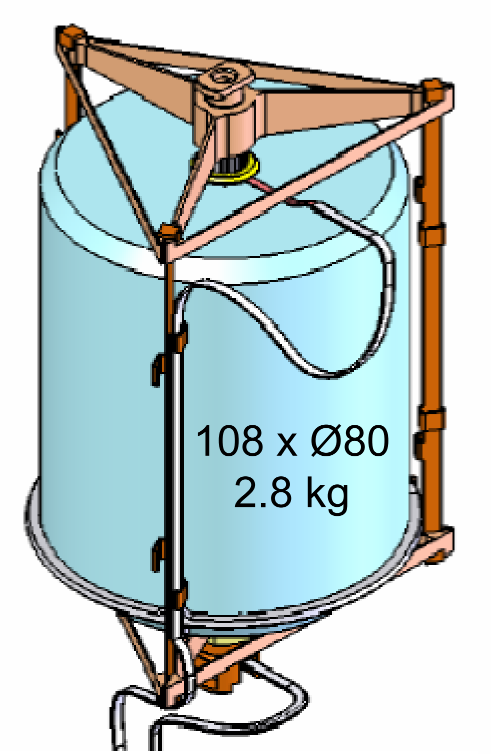
goal: 0.46 t·y Ge-76 exposure at the background of about 0.00025 cts / (kg·keV·y)

► $T_{1/2} > 5.5 \cdot 10^{26}$ y , $<m_{ee}> < 0.1$ eV *

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

finis / backup slides

R&D: low mass diode supports and contacts



108 x Ø80
2.8 kg

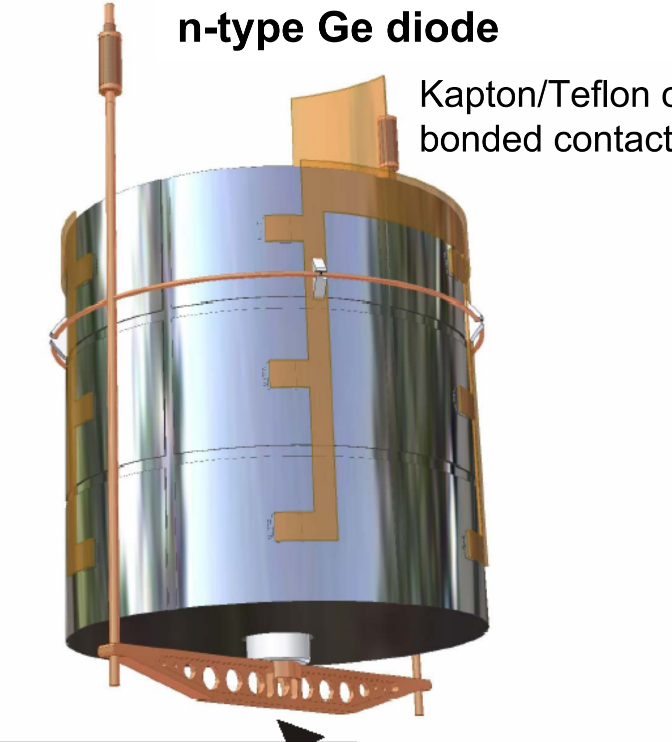
phase I

HdM & IGEX
p-type Ge diodes

Cu	80.8 g
Si	4.5 g
PTFE	6.4 g

phase II

true-coaxial 3x6 segmented
n-type Ge diode

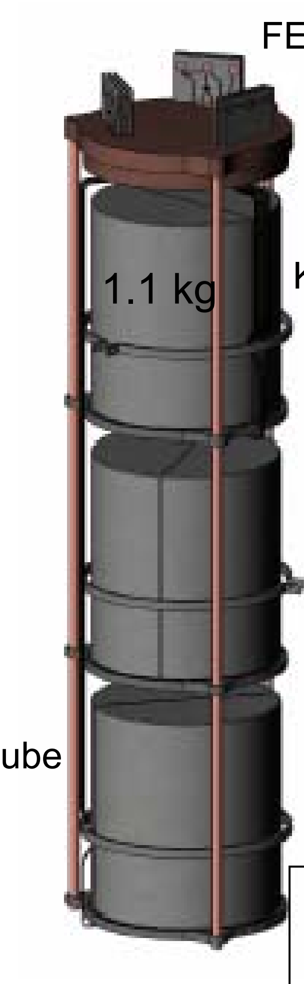


Kapton/Teflon cable
bonded contacts

total of ~30g mounting material

HV

Majorana



FE electronics

thick Cu lid

1.1 kg

Kapton cable

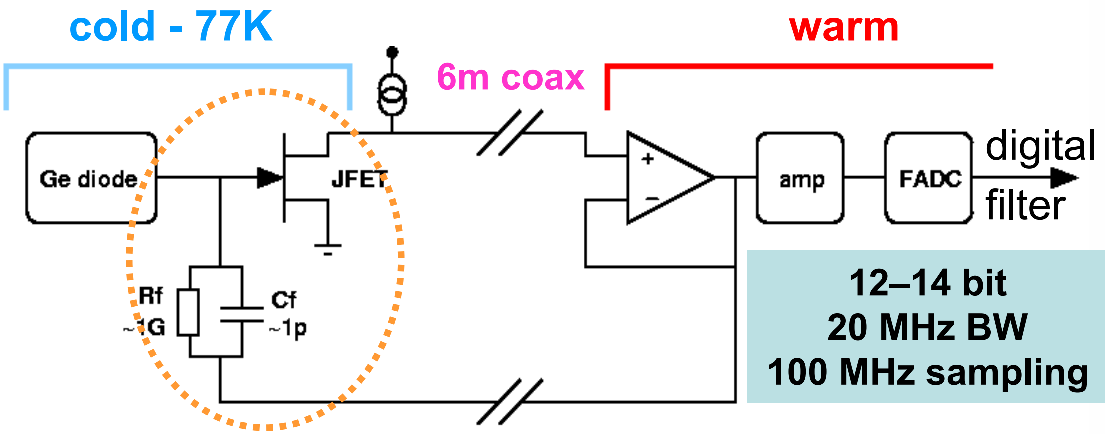
PCTFE
support tray

contact pressure
ring

Cu tube

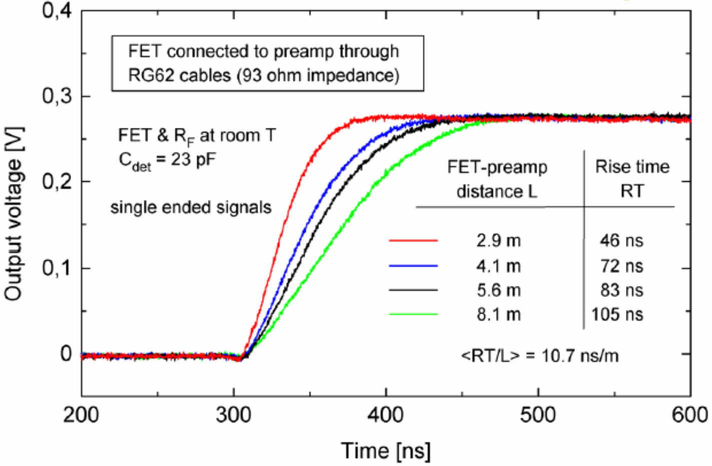
Cu tubes	11g
plastics	24g
cables	4g

R&D: low mass frontend electronics (1&2)



12–14 bit
20 MHz BW
100 MHz sampling

rise times for various coax lengths



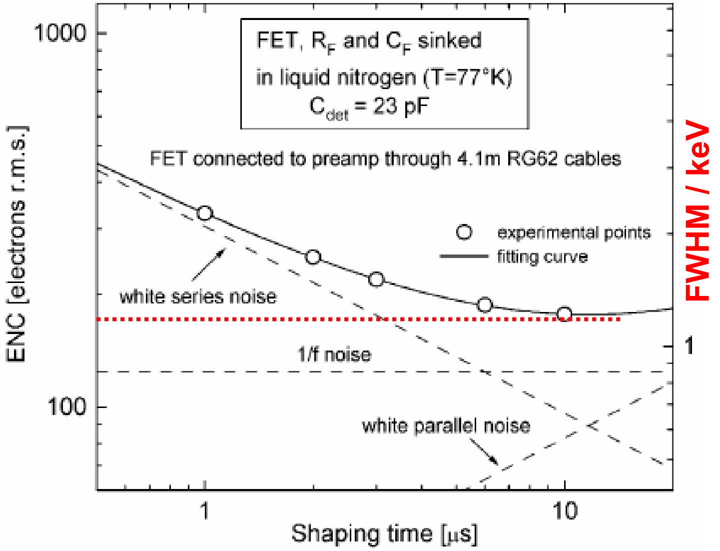
Majorana development
16x23 mm^2

Aalseth et al., IEEE NSS-MIC, 2004

+ available & working
  ► phase I
- increased rise time
- potential for noise pickup

2nd solution: cold monolithic JFET preamp IPA4
► present solution for phase I
+ available & exc. noise: ENC ~ 150e$^-$ rms
- external FET, Rf, Cf, bias supplies

ENC vs. shaping time @ 77 K



R&D: low mass frontend electronics (3)

WANTED: ASIC frontend indispensable for phase II with segmented detectors!

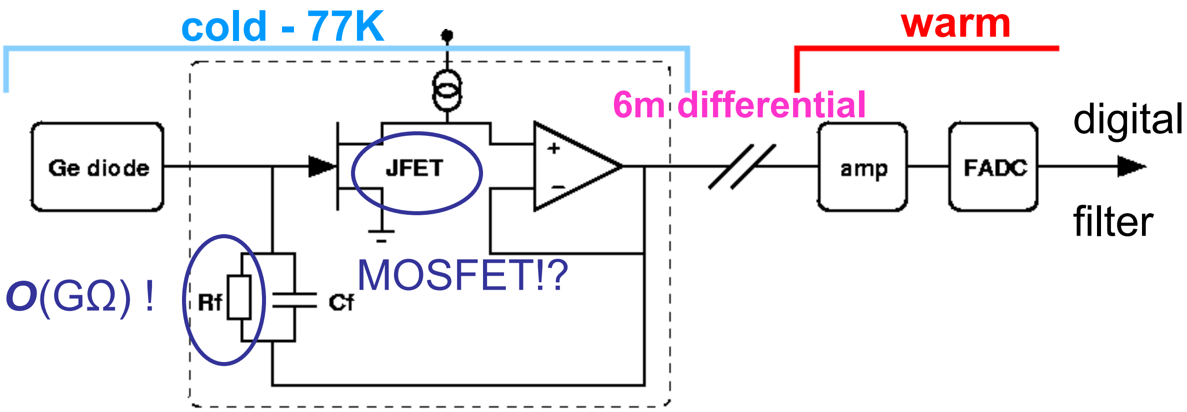
Specs for 77K ASIC

gain	200 mV/MeV
dyn. range	2000
BW	20-30 MHz
ENC	<100e @ 30 pF
output	differential

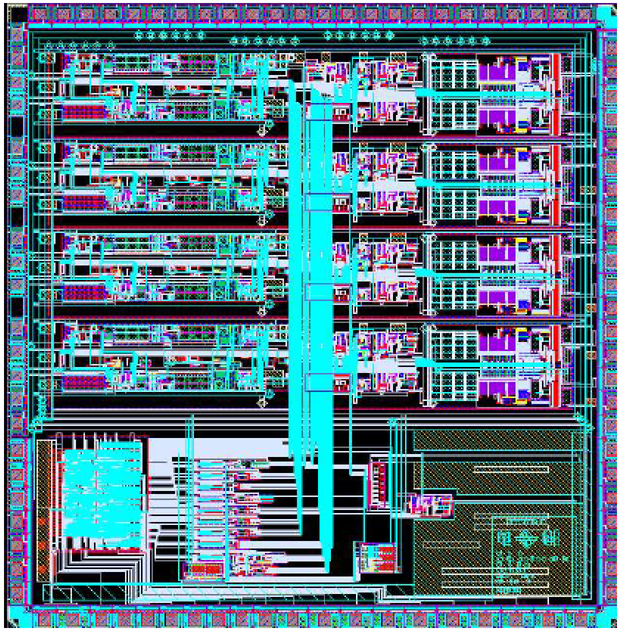
► ASIC development in CMOS
challenges: Rf, 1/f noise of MOSFET

i) ASIC in 0.8µ AMS process,
w / wo integrated input FET,
Rf and Cf not integrated,
very good results

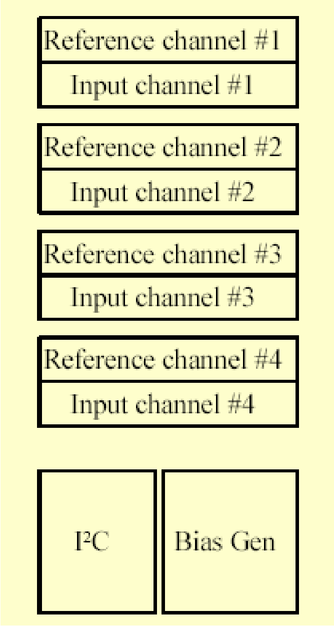
ii) ASIC in 0.6µ, 5V XFab process,
w / wo integrated input FET,
integrated Rf, Cf and bias supplies,
tests in progress



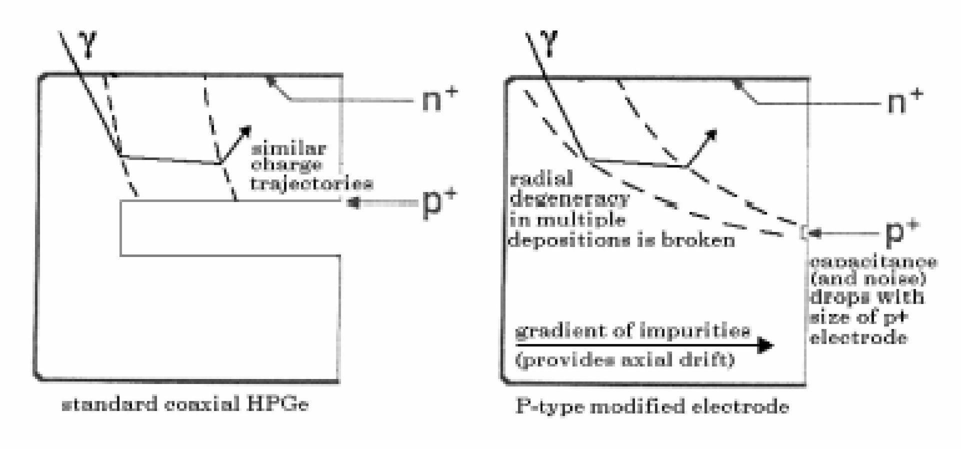
CSA104, 4 channels, 5.6x5.5mm^2



floor plan



R&D : modified electrode detector



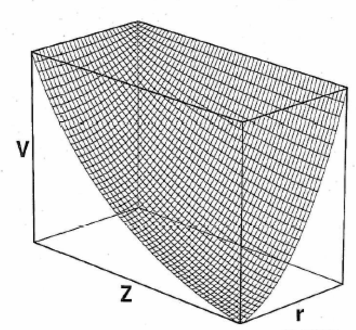


Fig. 4. Calculated potential distribution of the experimental shaped-field detector.

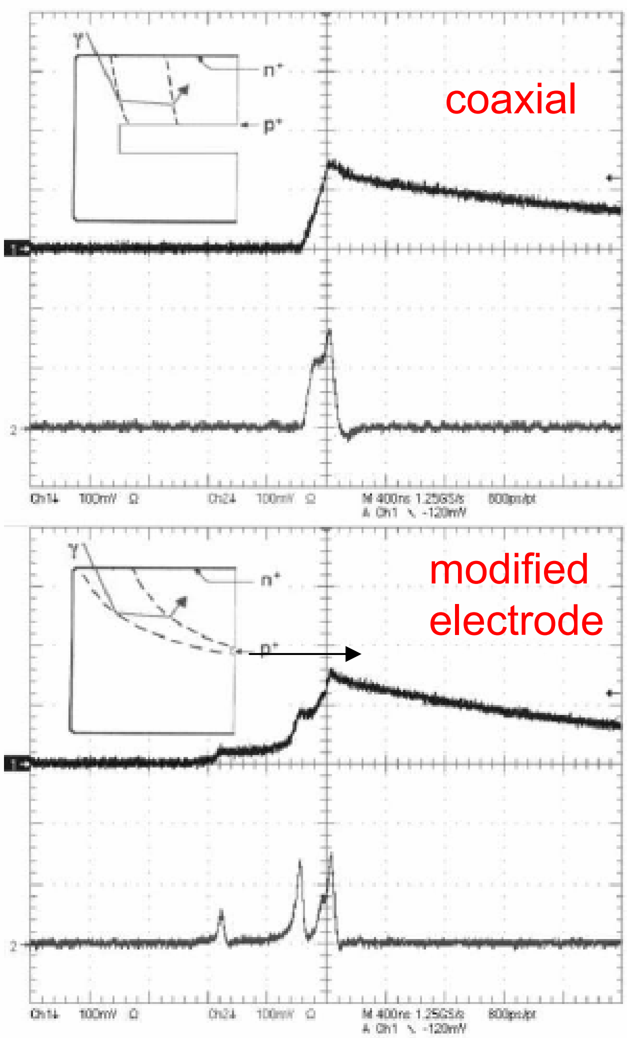


FIG. 10: Effect of electrode geometry on pulse formation for a multiple-site gamma interaction (see text).

- Non-segmented but powerful PSD
- most interesting candidate if mass production feasible

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

nuclear matrix elements

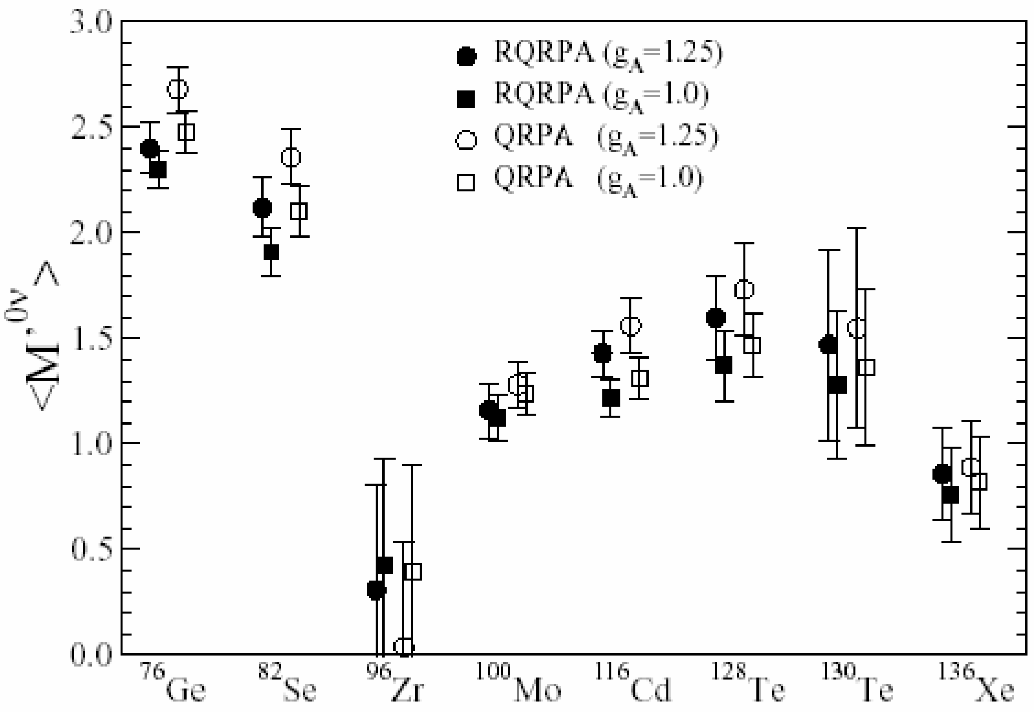


FIG. 2: Average nuclear matrix elements $\langle M^{0\nu} \rangle$ and their variance (including the error coming from the experimental uncertainty in $M^{2\nu}$) for both methods and for all considered nuclei. For ^{136}Xe the error bars encompass the whole interval related to the unknown rate of the $2\nu\beta\beta$ decay.

V.A.Rodin, A.Faessler, F.Simlovic & P.Vogel, NP A766 (2006) 107-131