What about GERDA?

Public Lecture

on the occasion of the GERDA house warming party

Karl Tasso Knöpfle

MPI Kernphysik, Heidelberg

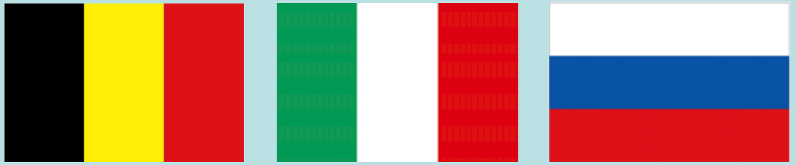
GERDA Collaboration Meeting at LNGS
1-3 March 2010

M. Allardt[c], A.M. Bakalyarov[l], M. Balata[a], I. Barabanov[j], M. Barnabe-Heider[f], L. Baudis[q], C. Bauer[f], N. Becerici-Schmid[m], 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], F. Cossavella[m], E.V. Demidova[k], A. Denisiv[j], A. Di Vacri[a], A. Domula[c], A. D'Andragora[a], V. Egorov[d], A. Ferella[q], K. Freund[p], F. Froborg[q], N. Frodyma[b], A. Gangapshev[j], A. Garfagnini[n,o], R. Gonzalea de Orduna[e], P. Grabmayr[p], G.Y. Grigoriev[l], K.N. Gusev[l,d], V. Gutentsov[j], W. Hampel[f], M. Heisel[f], S. Hemmer[m], G. Heusser[f], W. Hofmann[f], M. Hult[e], L. Iannucci[a], L.V. Inzhechik[l], J. Janicsko[m], J. Jochum[p], M. Junker[a], 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], B. Lehnert[c], D. Lenz[m], S. Lindemann[f], M. Lindner[f], I. Lippi[o], X. Liu[m], B. Lubsandorzhiev[j], B. Majorovits[m], G. Marissens[e], G. Meierhofer[p], I. Nemchenok[d], S. Nisi[a], L. Pandola[a], K. Pelczar[b], F. Potenza[a], A. Pullia[i], S. Riboldi[i], F. Ritter[p], C. Rossi Alvarez[o], R. Santorelli[q], J. Schreiner[f], U. Schwan[f], B. Schwingenheuer[f], S. Schönert[f], M. Shirchenko[l], H. Simgen[f], A. Smolnikov[d,j], L. Stanco[o], F. Stelzer[m], H. Strecker[f], M. Tarka[q], A.V. Tikhomirov[l], C.A. Ur[o], A.A. Vasenko[k], S. Vasiliev[d,j], A. Volynets[m], M. Weber[f], M. Wojcik[b], E. Yanovich[j], 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

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[q]) Physik Institut der Universität Zürich, Zürich, Switzerland

Dubna05 logo contest

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NEGETEL

LANOG

GESINE

MEGERA

GLOBUS

CLOG

GERDA

ETTORE

B4S

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EGEO

URGEND

GAUSS

LOGO

LENIN

CRYLOG

ENGELS

GEDEON

NUGGET

LEGENDA

NEGA

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Heidelberg04 name contest

PUTIN
Powerful Underground Telescope for INvestigation

INGA

NEGETEL

LANOG

GESINE

MEGERA
Una delle tre Erinni o Furie ?

GLOBUS

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GERDA

ETTORE

B4S

NIGER

EGEO

URGEND

GAUSS

LOGO

LENIN
Large Electron Neutrino INstrument

CRYLOG

ENGELS
Enriched Naked GE exp in Large Scale

GEDEON

NUGGET

LEGENDA

NEGA

LOBAGE

Heidelberg04 name contest

PUTIN

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Investigation of Neutrino with Germanium Assembly

NEGETEL

LANOG

MEGERA

GESINE
Germanium Setup In Noble gas Environment

GLOBUS

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ETTORE
!!!

B4S
Beyond four Sigma

NIGER

EGEO
Enriched Germanium Observatory

URGEND

GAUSS

LOGO
Low background Ge Observatory

ENGELS

CRYLOG

LENIN

GEDEON

NUGGET

LEGENDA
Large Enriched Germanium Naked Detector Assembly

NEGA

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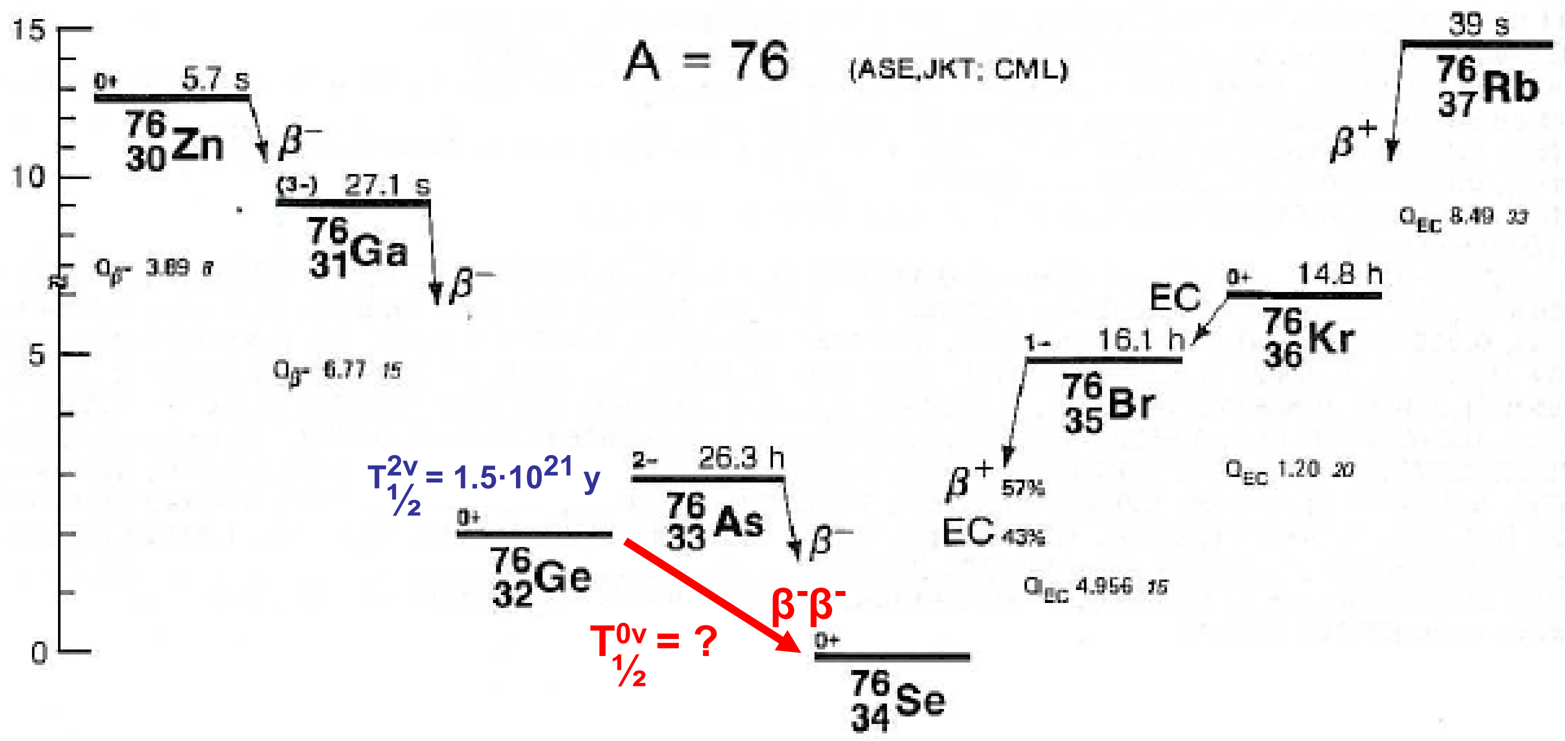
Double beta decay of Ge-76

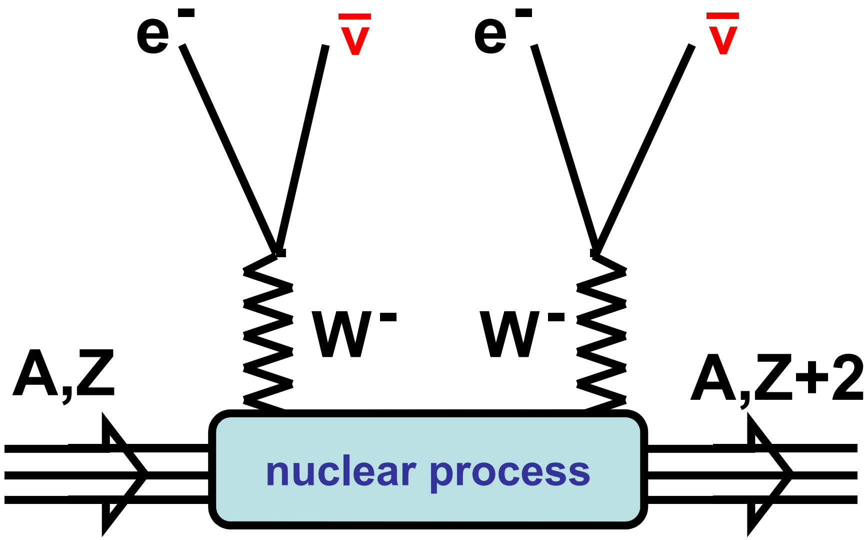
2ν2β ✓

0ν2β ?!



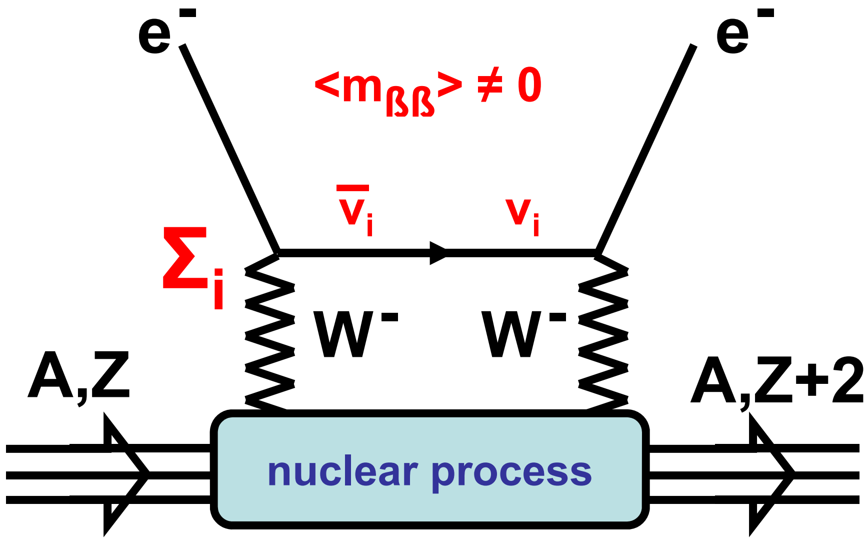
double beta decay

2νßß



conventional 2nd order process
observed in various nuclei
$T_{1/2} \sim 10^{19} – 10^{21}$ yrs

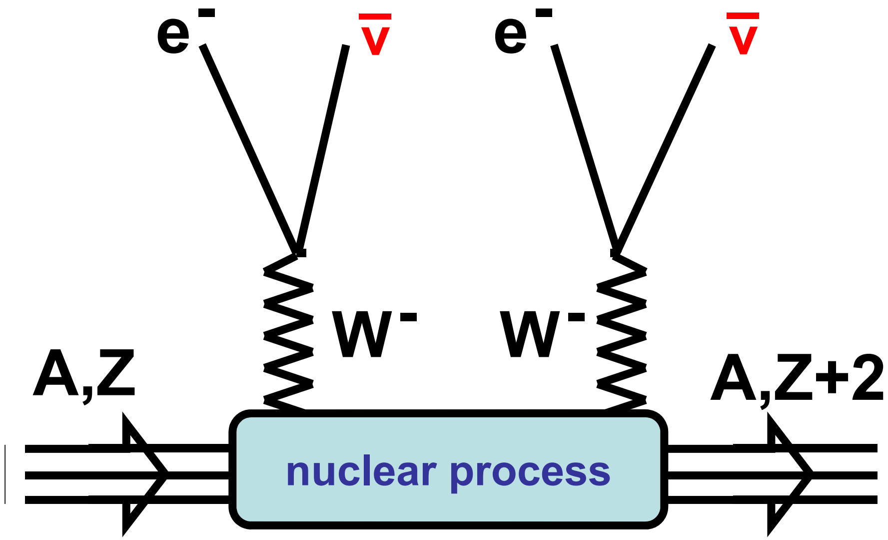
0νßß



hypothetical process , $T_{1/2} > 10^{25}$ yrs,
only possible if
neutrinos have Majorana masses

► lepton number violation ΔL=2
► access to absolute ν mass scale
► physics beyond s.m.

2νßß



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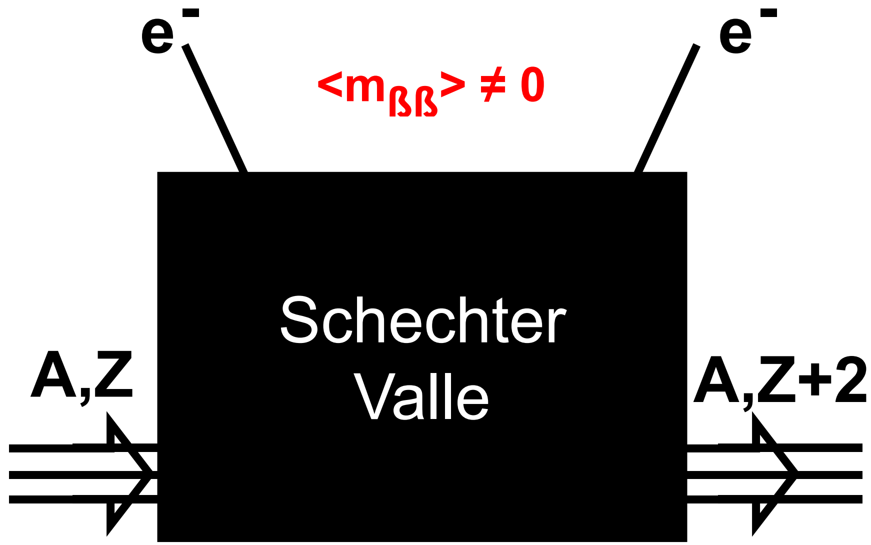

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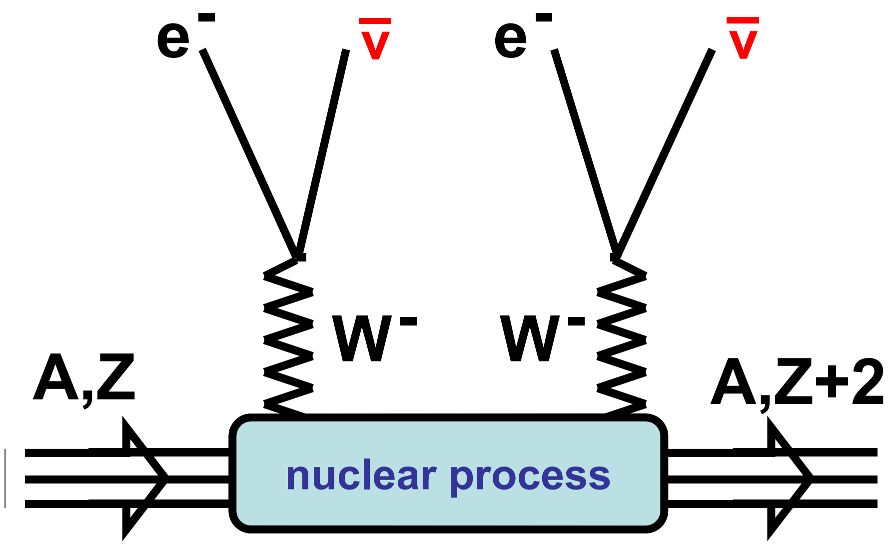
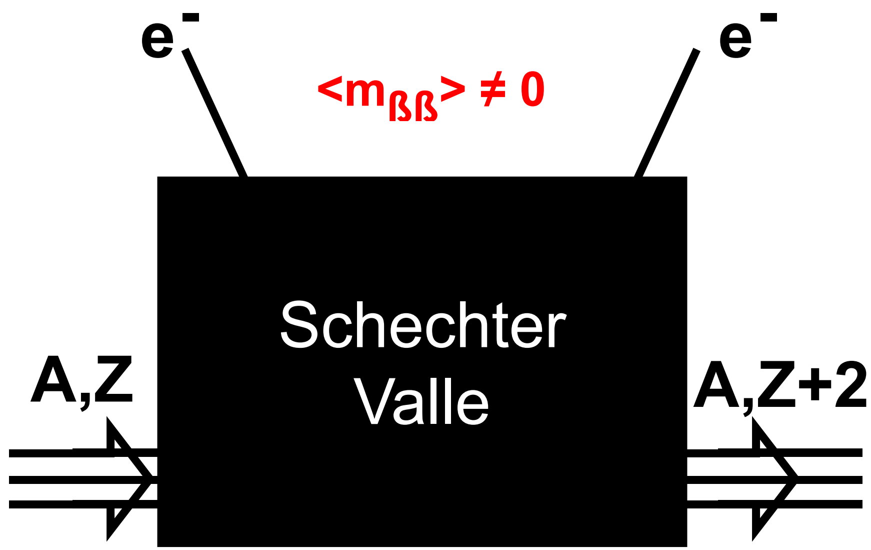
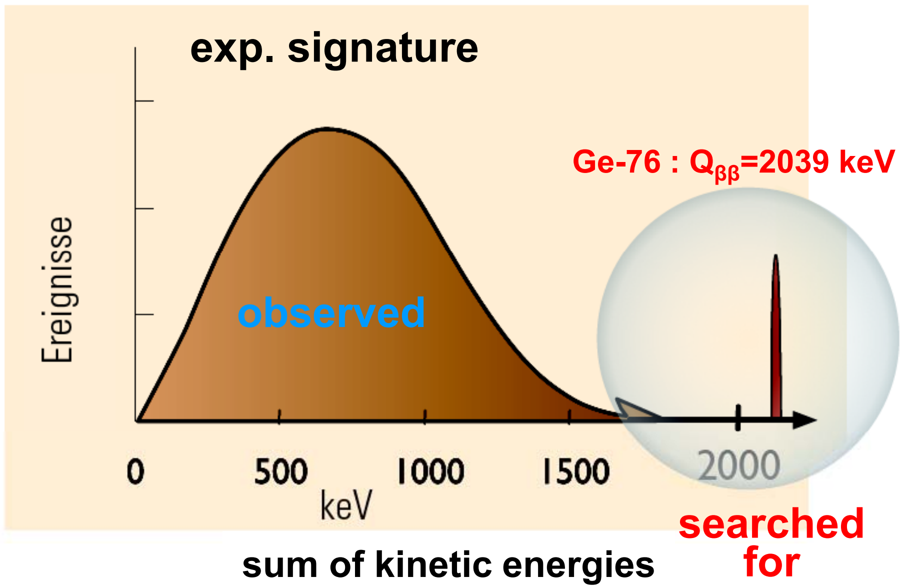
2νßß



0νßß



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



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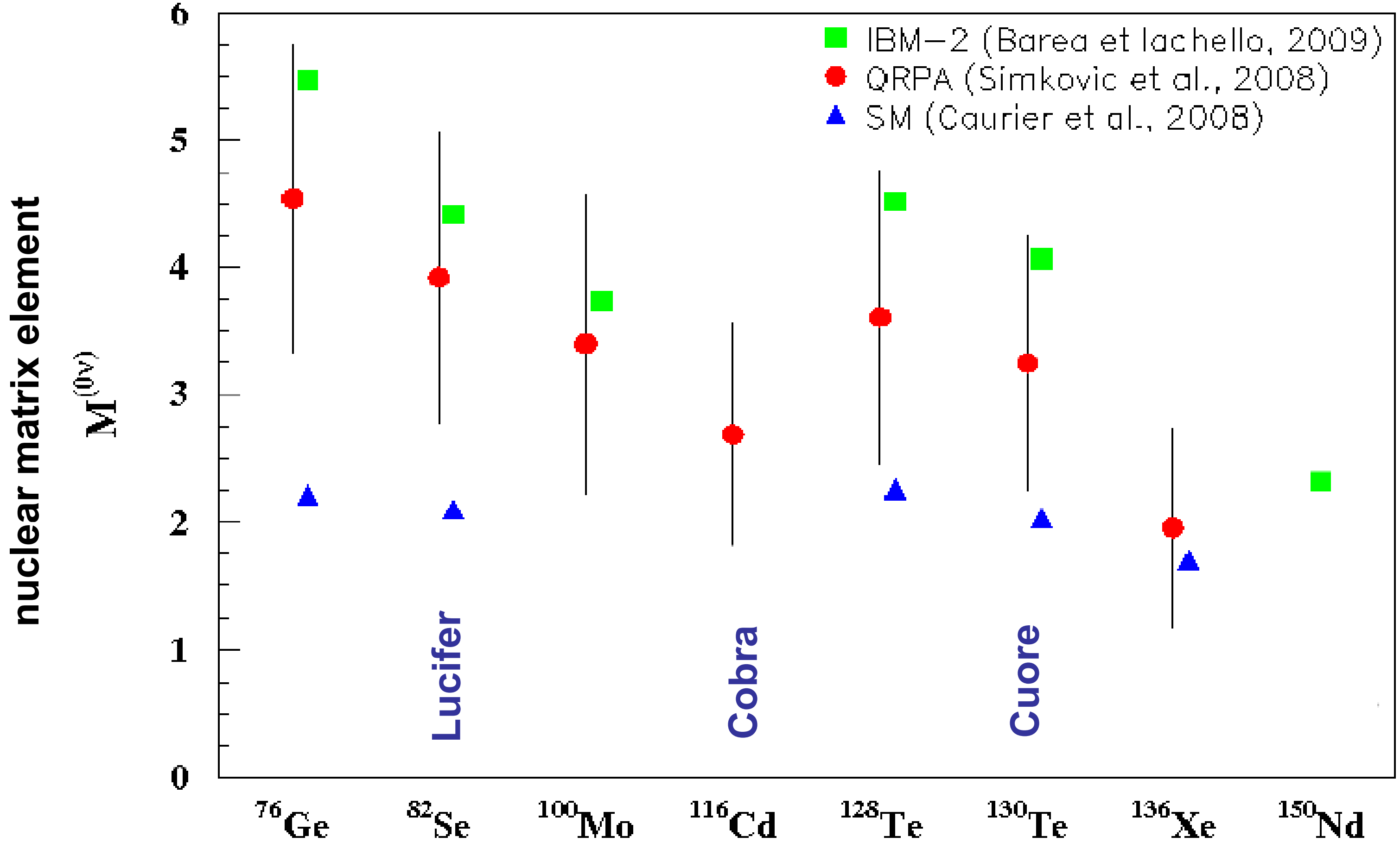
lajorana masses
r violation ΔL=2
lute ν mass scale
d s.m.

halflife – effective mass relation

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

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

sensitivity*

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

detection efficiency (=1 if source=detector)

exposure [kg y]

molecular weight of source

instrumental spectral width

background index [cts/(keV kg y)]

*RevModPhys 80(08)481

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a isotopic abundance	7.4 %	^{48}Ca: 0.19% / 9.6% / ^{130}Te: 35%

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

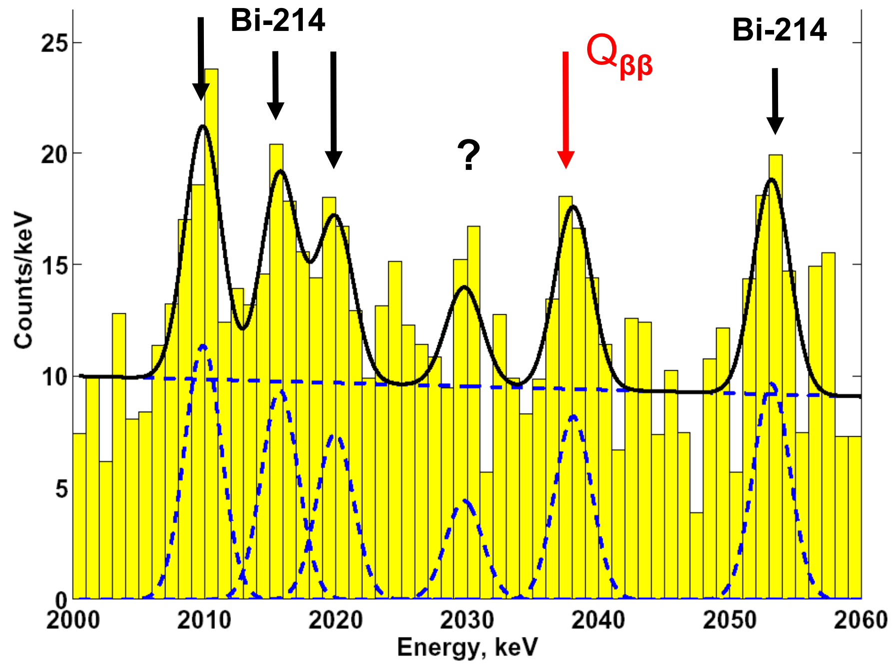
(similar limit by **IGEX**, NP B87 ('00) 278)

part of collaboration claims signal (PL B586 ('04) 198)

71.7 kg y : $T_{1/2}$ = 1.2 (0.7-4.2)$\cdot 10^{25}$ (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)



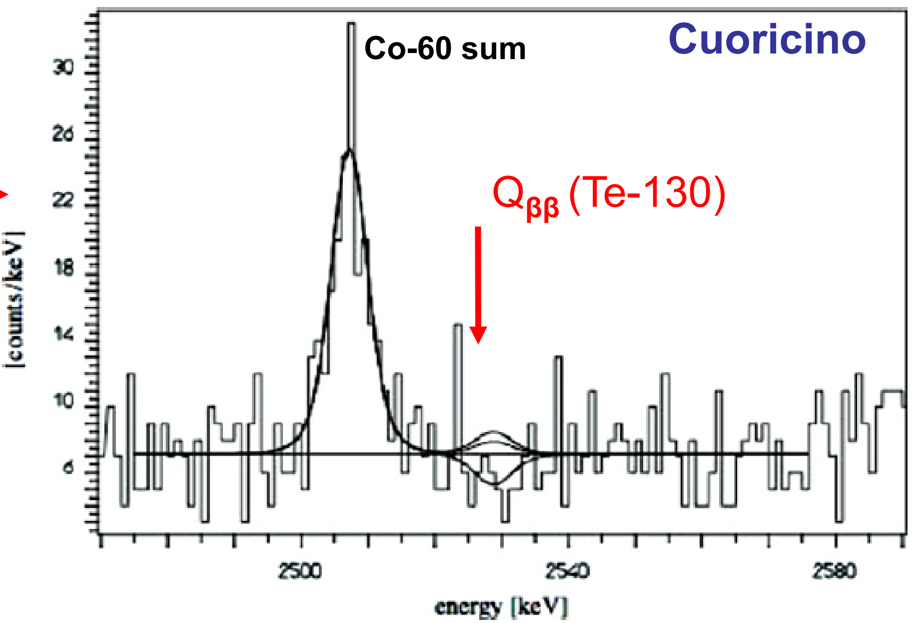
Cuoricino

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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71.7 kg y : $T_{1/2} = 1.2\ (0.7\text{-}4.2) \cdot 10^{25}$ (3σ range)
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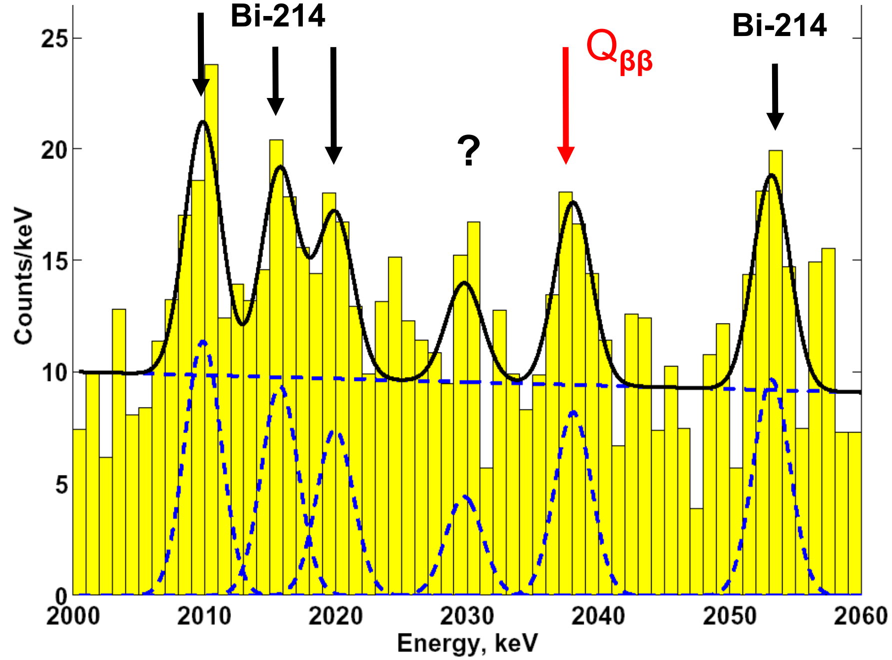

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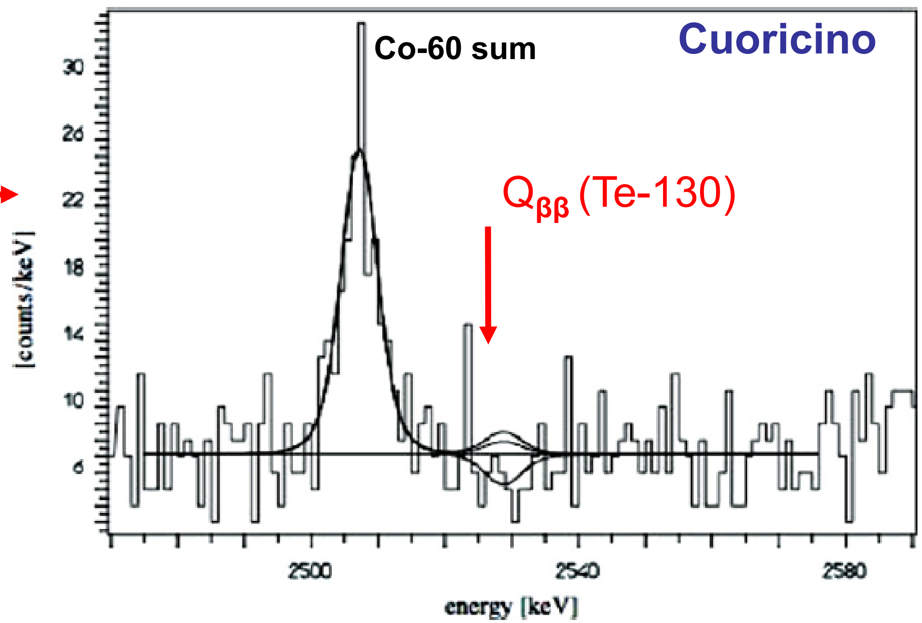
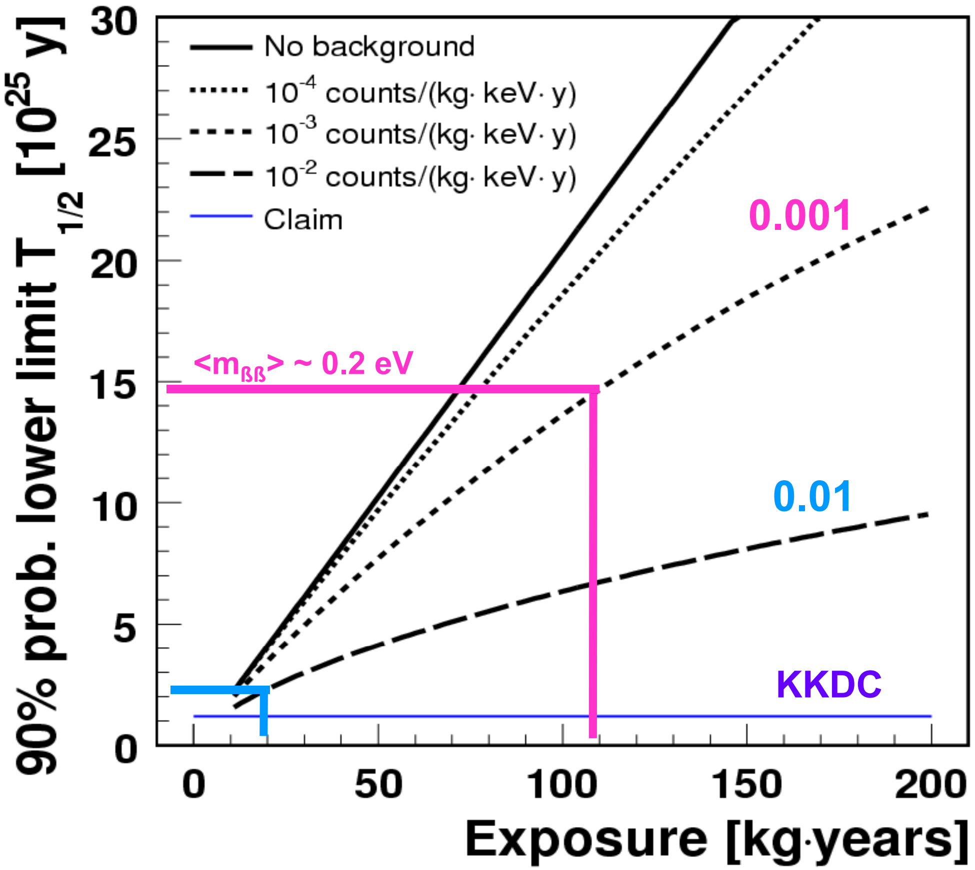
Evidence remains unclear - confirmation needed with same & different isotopes
► reduce background by *O*(100) for better sensitivity



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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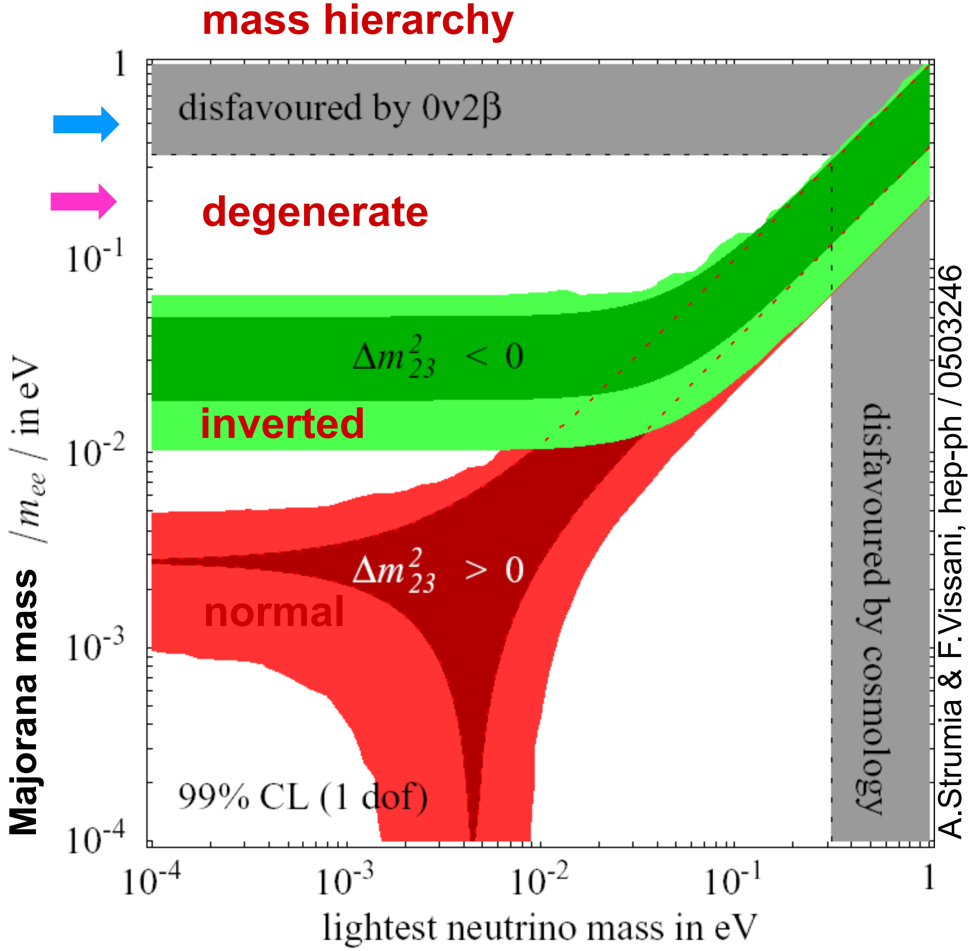

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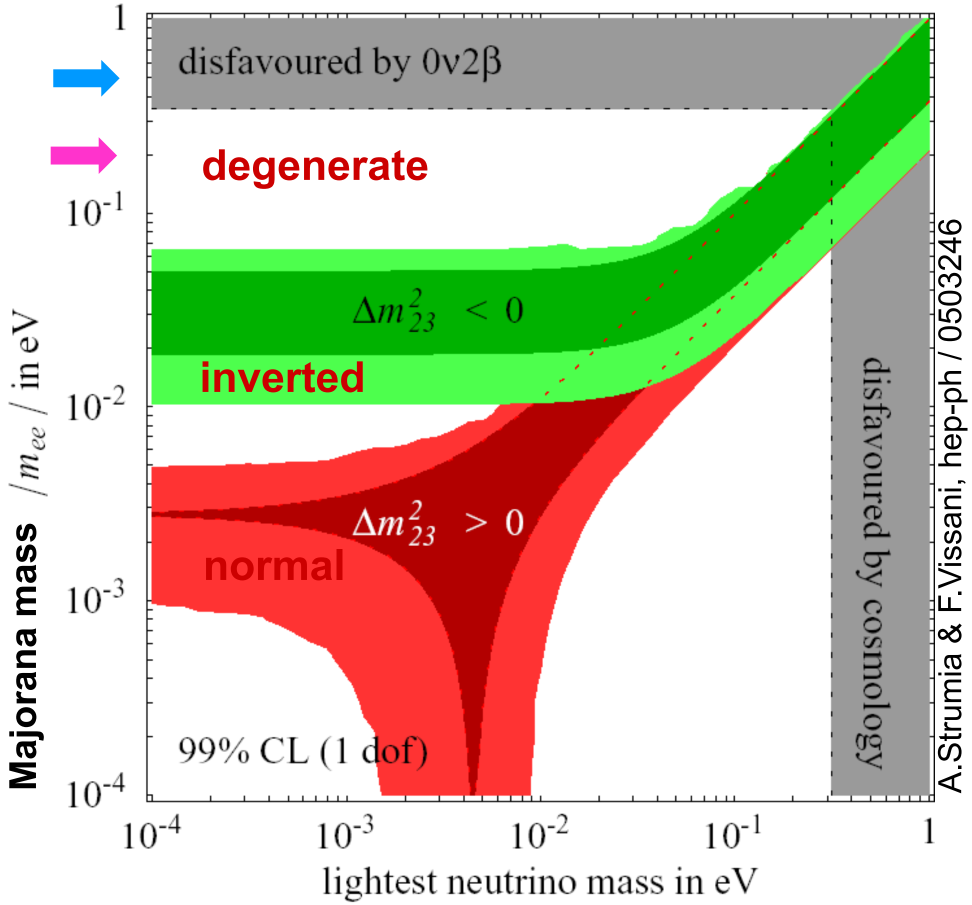
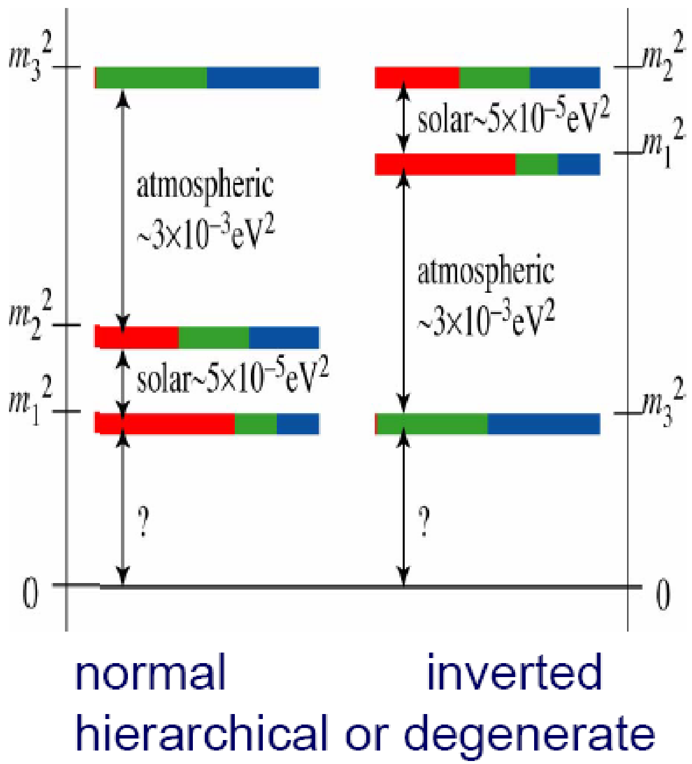
mass hierarchy





phase III: depending on results worldwide collaboration for real big experiment
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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 …

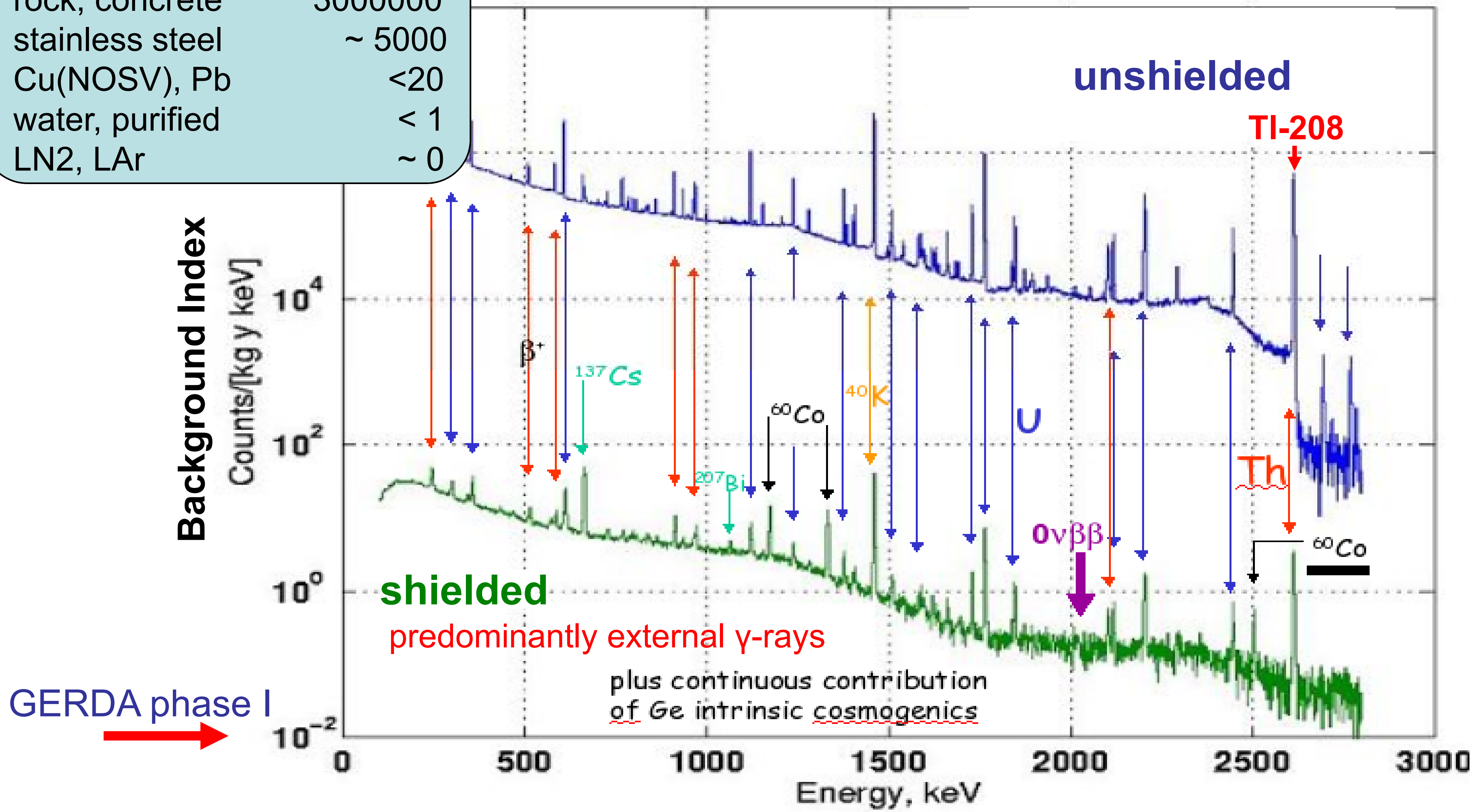
GERDA background reduction

EXTERNAL bgnds: γ(Th, U), n, μ

background seen with Ge diode

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



GERDA background reduction

EXTERNAL bgnds: γ(Th, U), n, μ

Shielding possible

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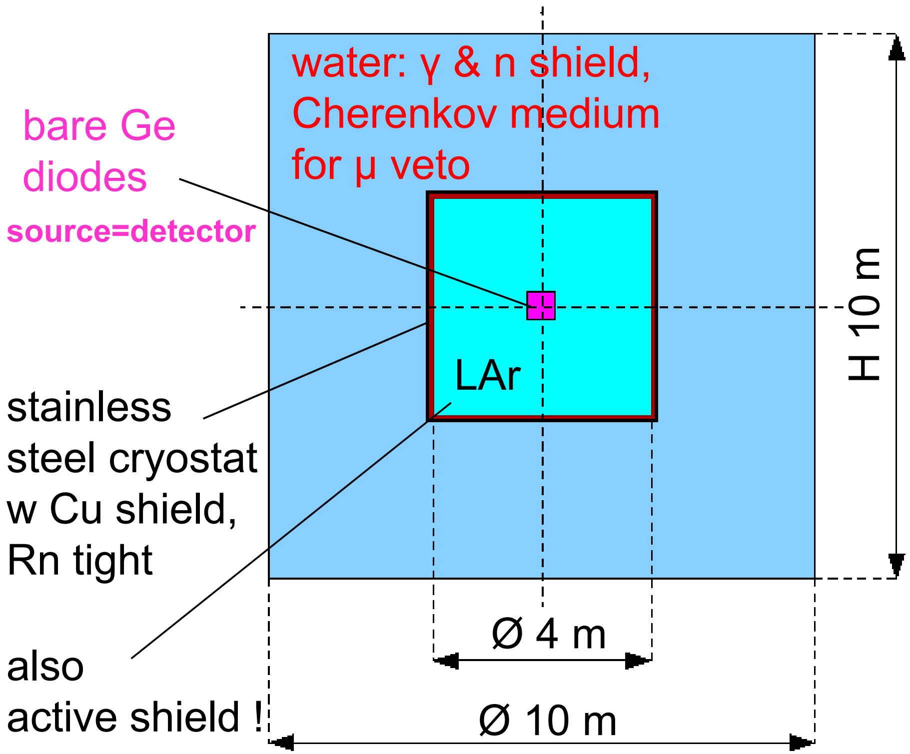
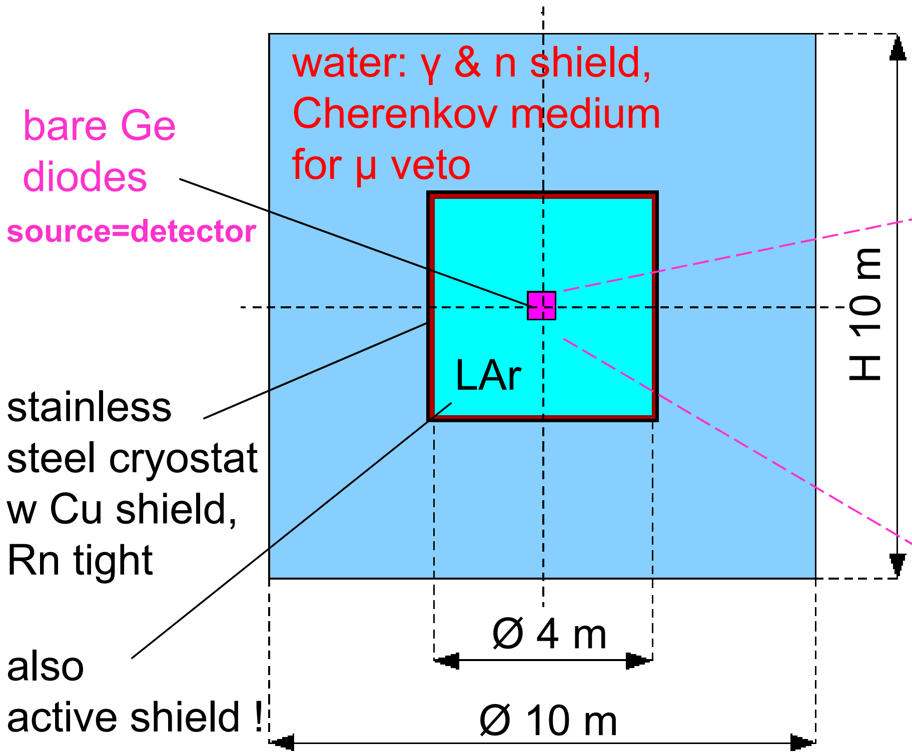


$\alpha(LAr) = 0.050/cm$ $\alpha(Cu) = 0.34/cm$
$\alpha(H_2O) = 0.043/cm$ $\alpha(Pb) = 0.48/cm$

GERDA background reduction

EXTERNAL bgnds: γ(Th, U), n, μ

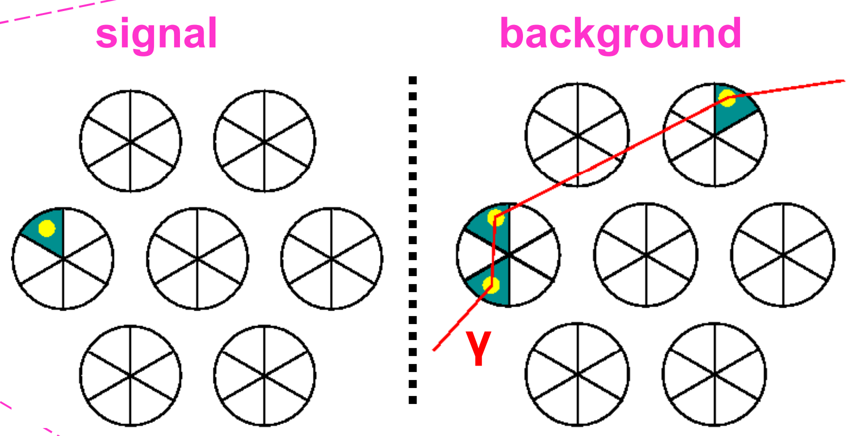
Shielding possible



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

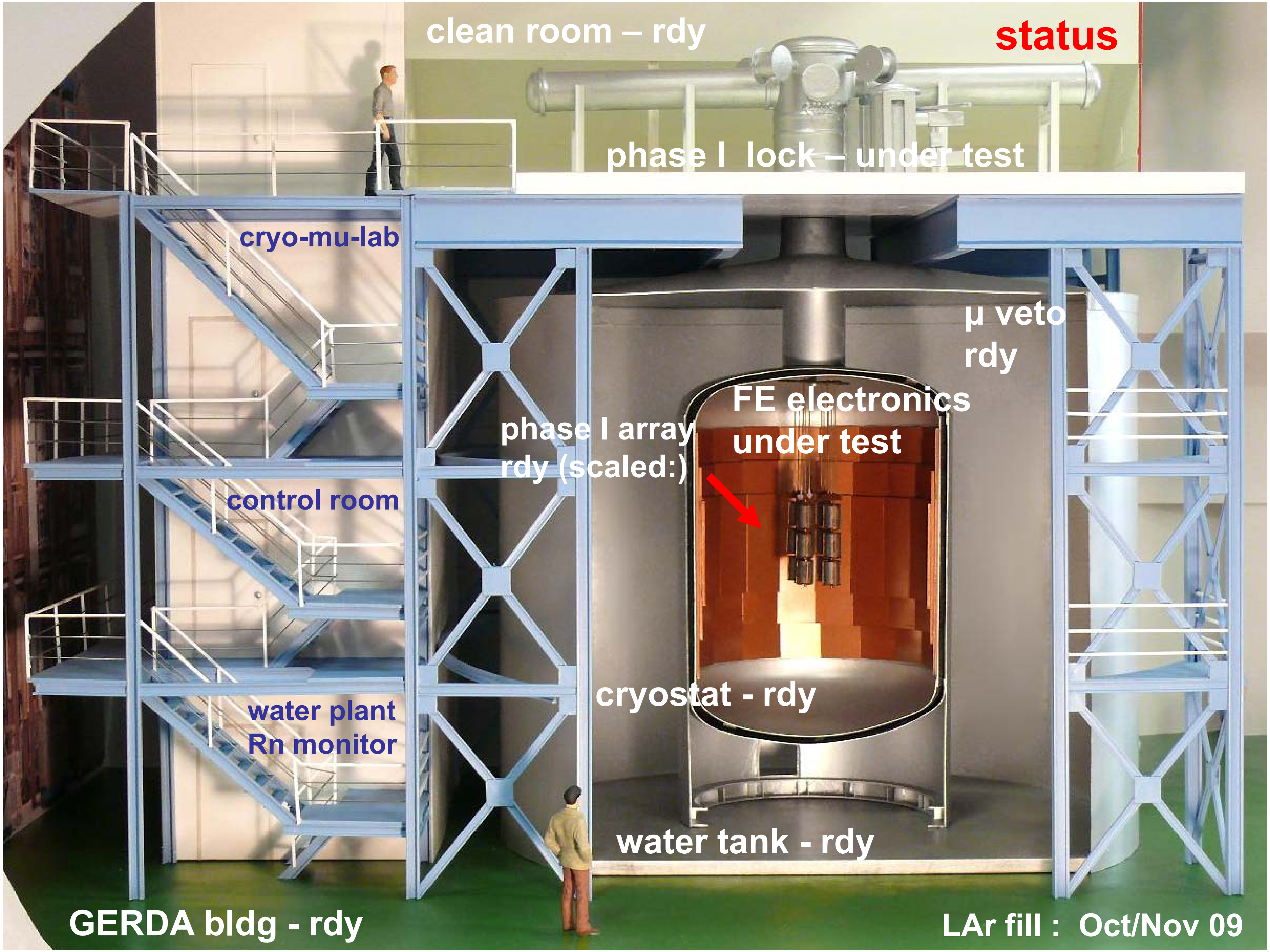
INTRINSIC or VERY CLOSE bgnds :
cosmogenic - ^{60}Co (5.3 a), ^{68}Ge (270 d)-
contaminated holders, FE, cables …

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



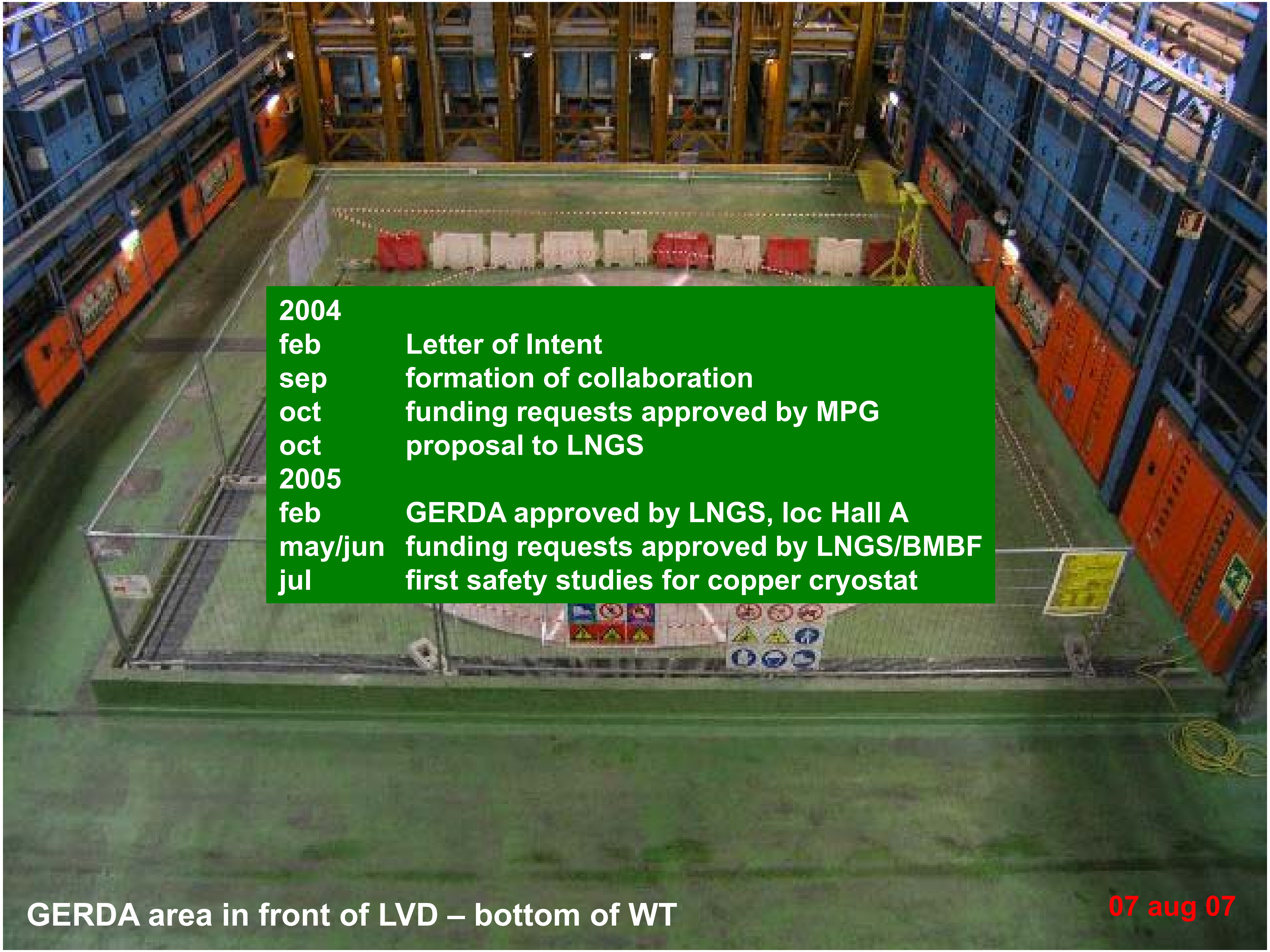
array of segmented Ge detectors

- **► 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

GERDA area in front of LVD – bottom of WT

07 aug 07



2004	
feb	Letter of Intent
sep	formation of collaboration
oct	funding requests approved by MPG
oct	proposal to LNGS
2005	
feb	GERDA approved by LNGS, loc Hall A
may/jun	funding requests approved by LNGS/BMBF
jul	first safety studies for copper cryostat

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2006	
apr	all HDM & IGEX detectors functional at LNGS
may	contract for water tank – decision for stainless steel cryostat
jul	safety reviews continued for stainless steel cryostat
aug	LNGS Hall A ready for installation
dec	safety review available – cryostat ordered
	all HdM & IGEX diodes at refurbishment company

GERDA area in front of LVD – bottom of WT

07 aug 07

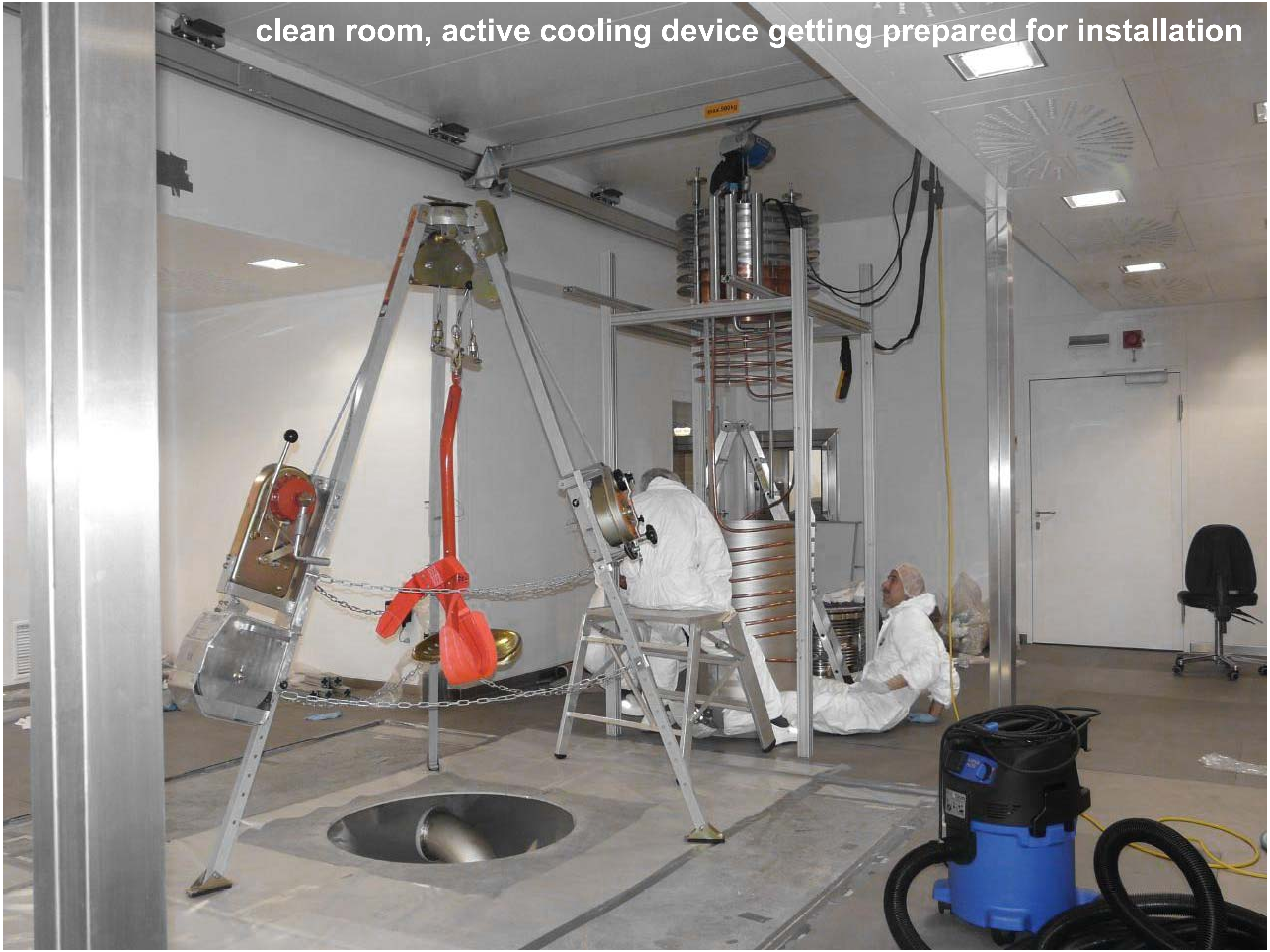

unloading of cryostat
6 mar 08

water tank:

Ø 10 m
h = 9.5 m
V = 650 m^3

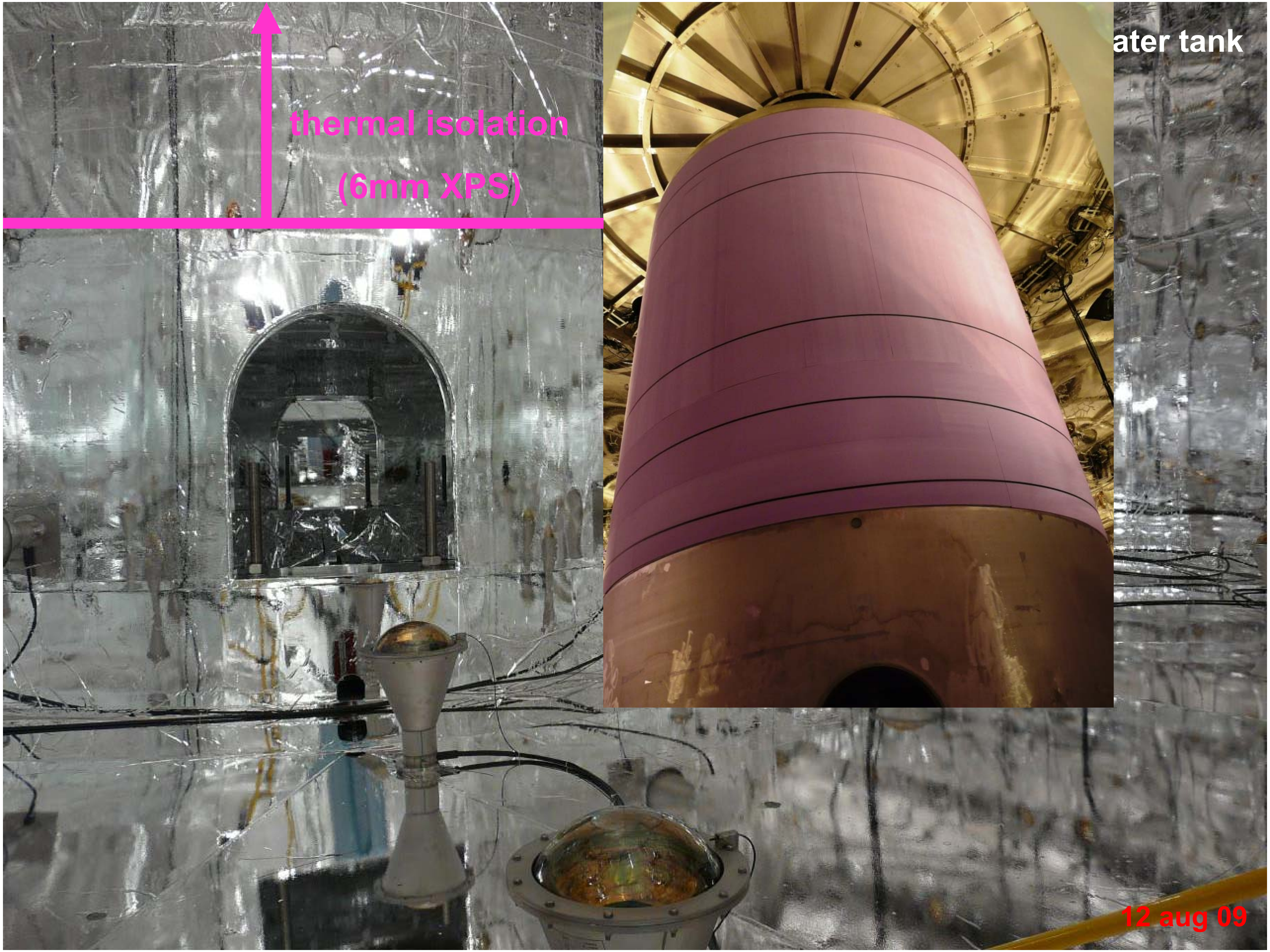
designed for external
γ,n,μ background
~10^{-4} cts /(keV·kg·y)


construction of clean room
27 feb 09

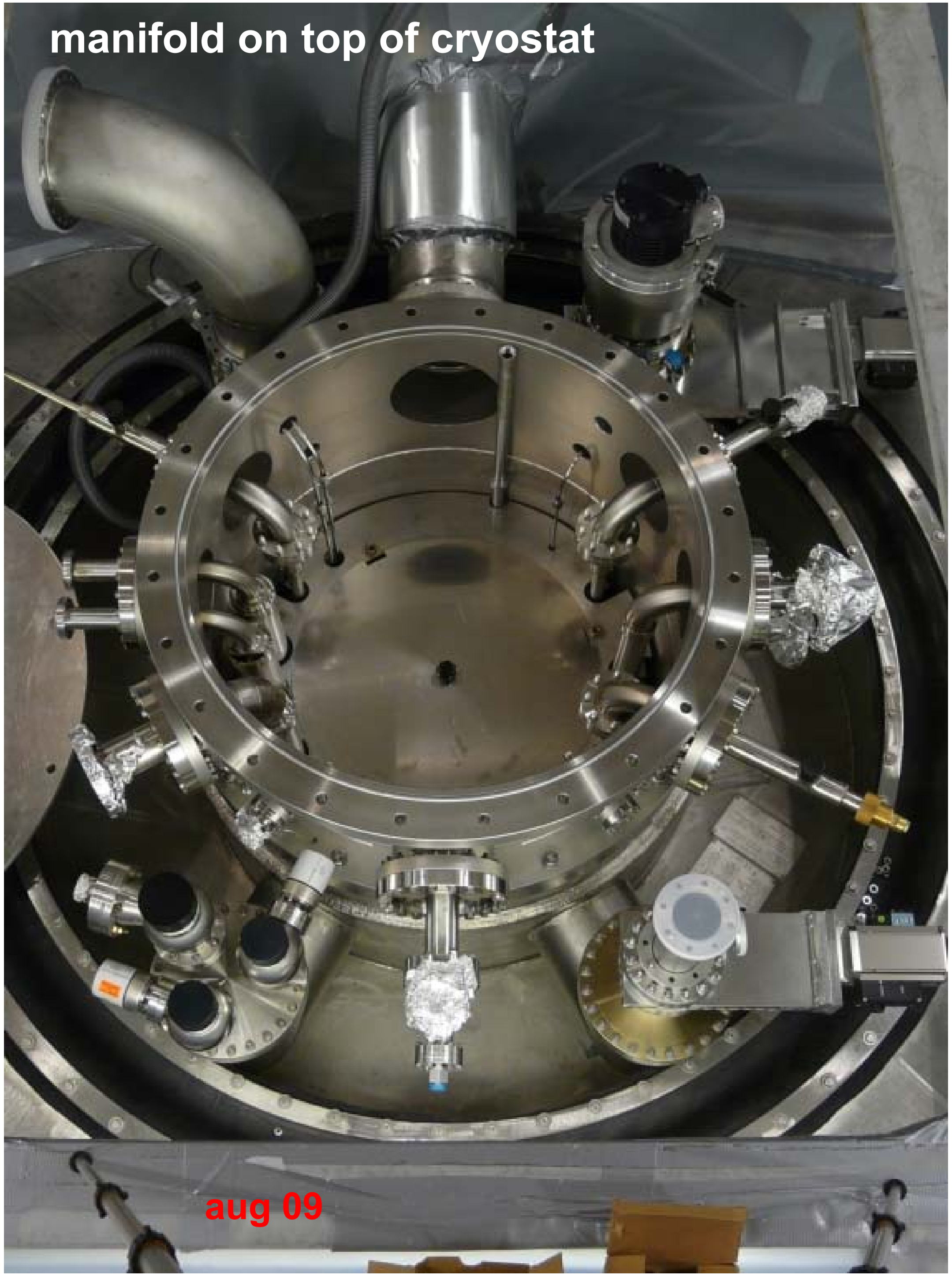


clean room, active cooling device getting prepared for installation


muon veto in water tank
12 aug 09



ater tank
thermal isolation
(6mm XPS)
12 aug 09


manifold on top of cryostat
aug 09


control & safety valves
heater
aug 09

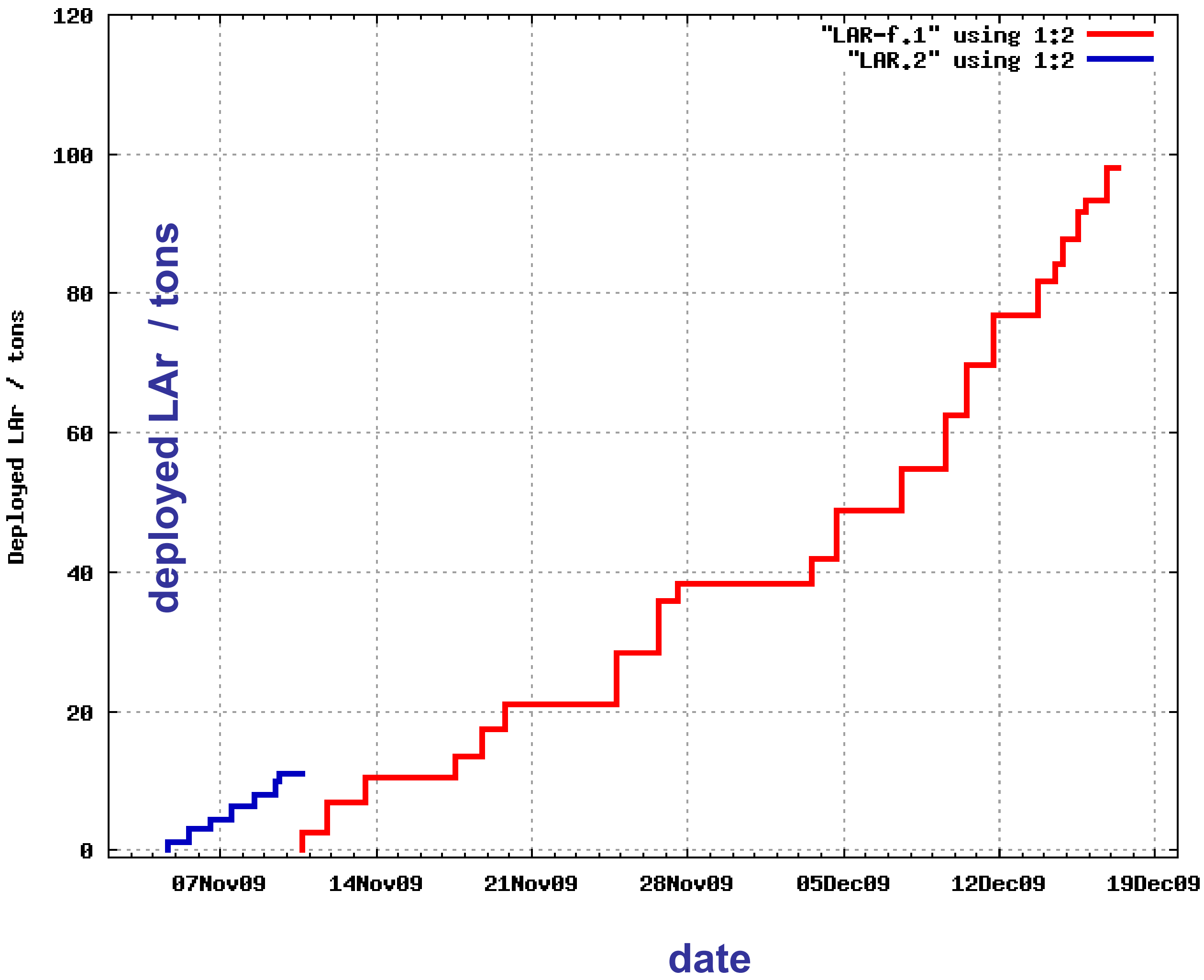

transfer of clean bench
from Hall di Montaggio
to cleanroom in Hall A
29 nov 09
USCITA

clean bench in clean room

29 nov 09

cool down and filling of cryostat

LAr for cool down and filling taken from storage tank.



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
► JINST 3 (2008) P08007

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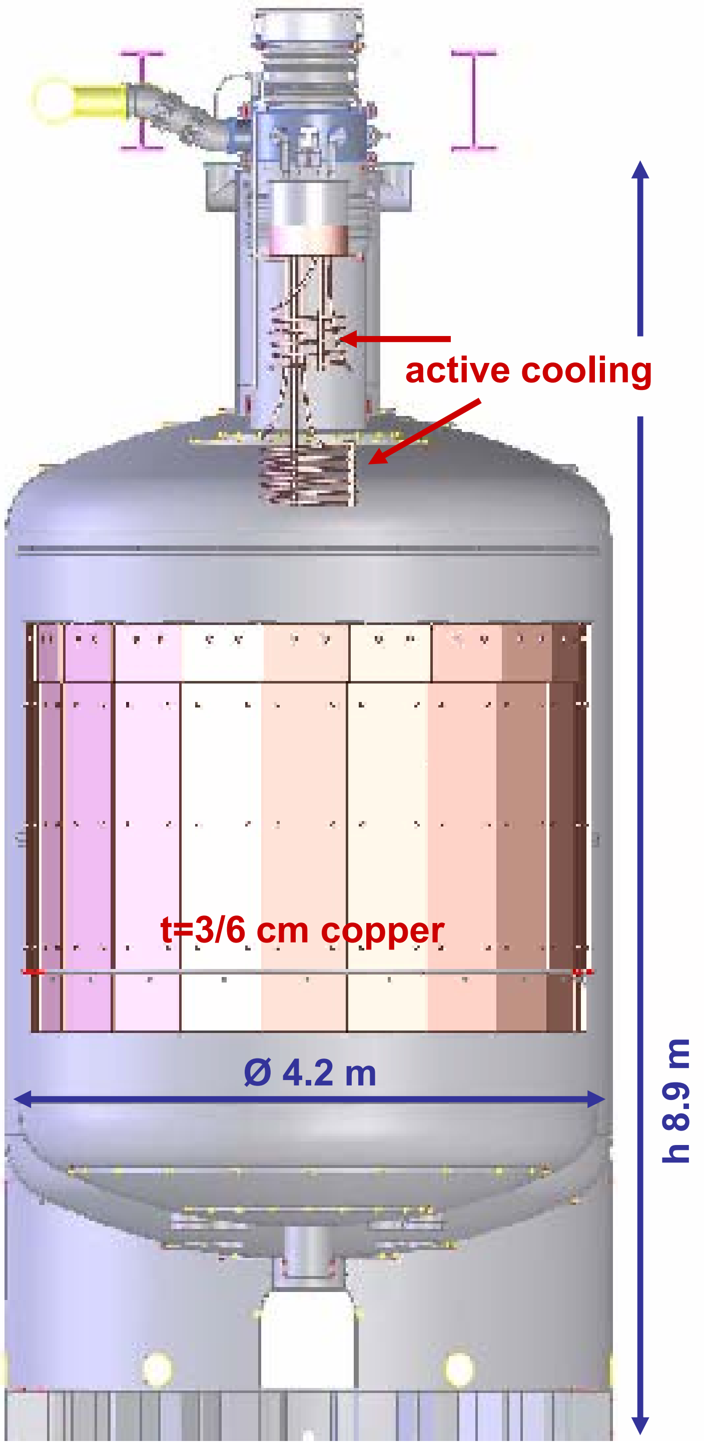


cryostat

65 m^3 volume for LN/LAr

200W measured thermal loss

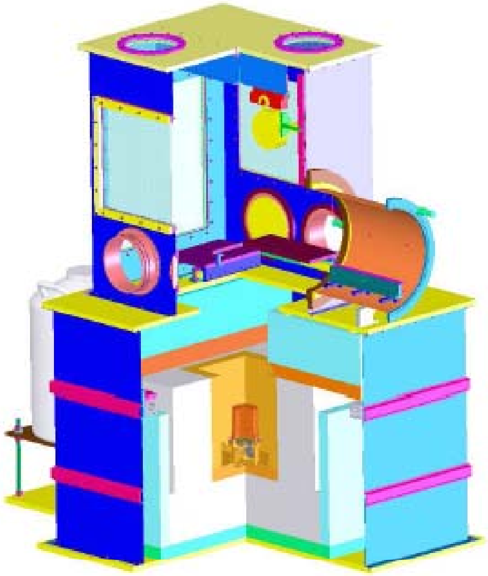
active cooling with LN

internal copper shield

hi-rel design
detailed risk analysis of
cryostat in 'water bath'
(to be discussed later)

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)**



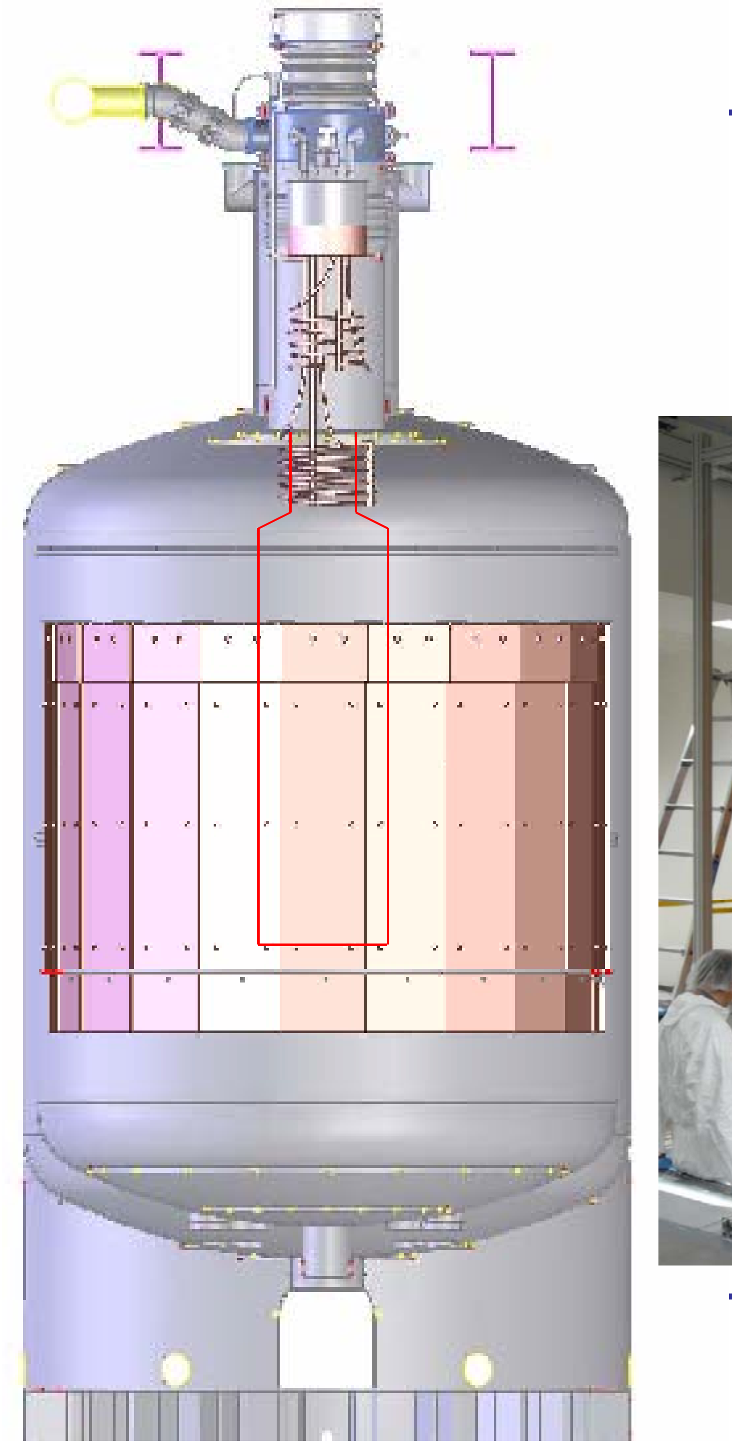
In 1.4571 material (X6CrNiMoTi17-12-2) total of 14 isotopes quantitatively identified including

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 · 10^{-4} cts / (keV·kg·y)**
shielding against external γ rays including water tank	**0.1· 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

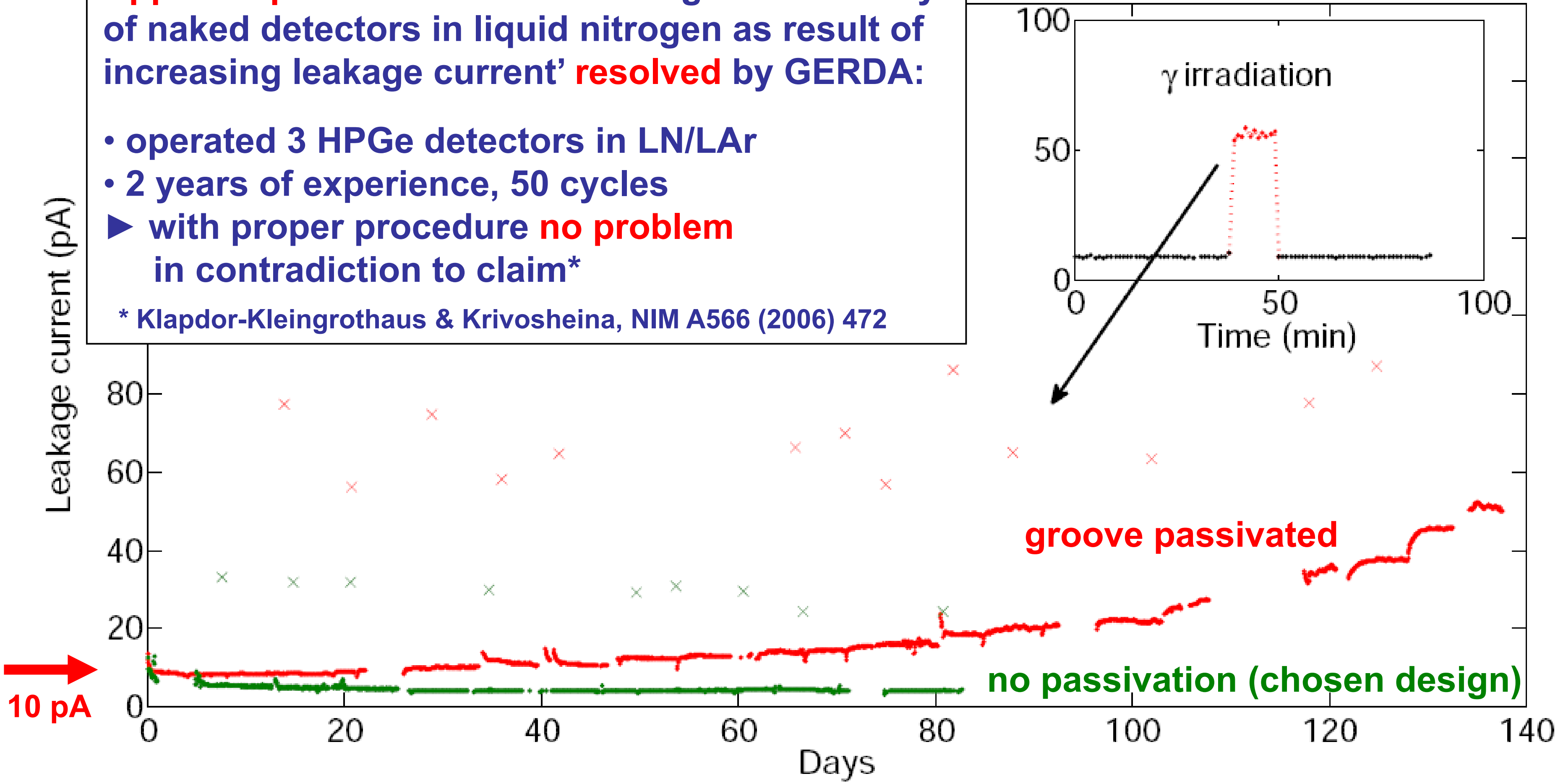
R&D: long term stability of Ge diodes in LN_2 / LAr

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

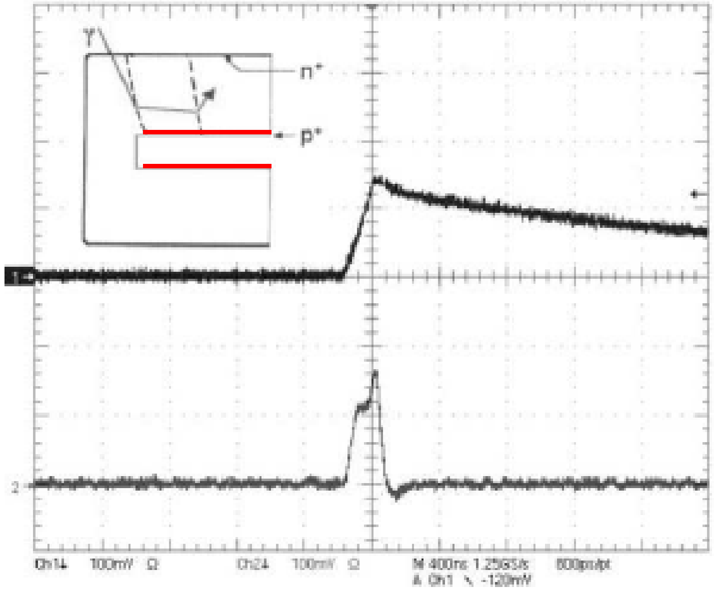
crystal growing (n-type)

- 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

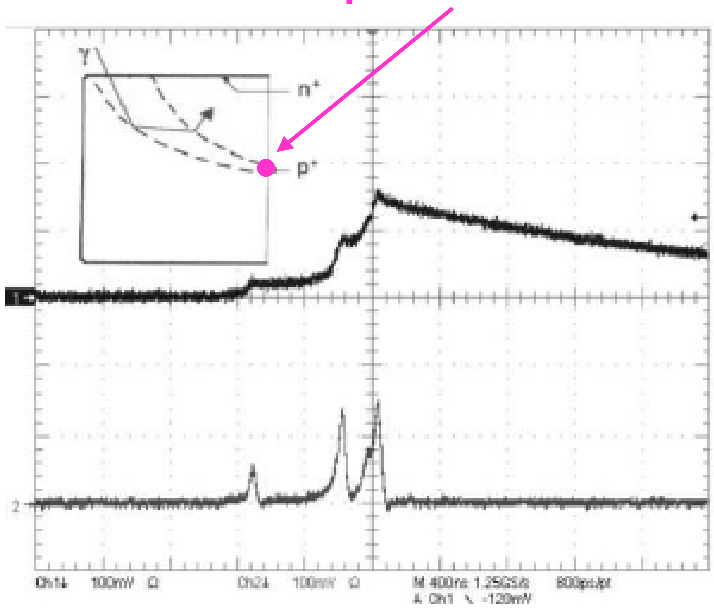
R&D : pulse shape analysis (PSA)

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

standard coaxial HPGe



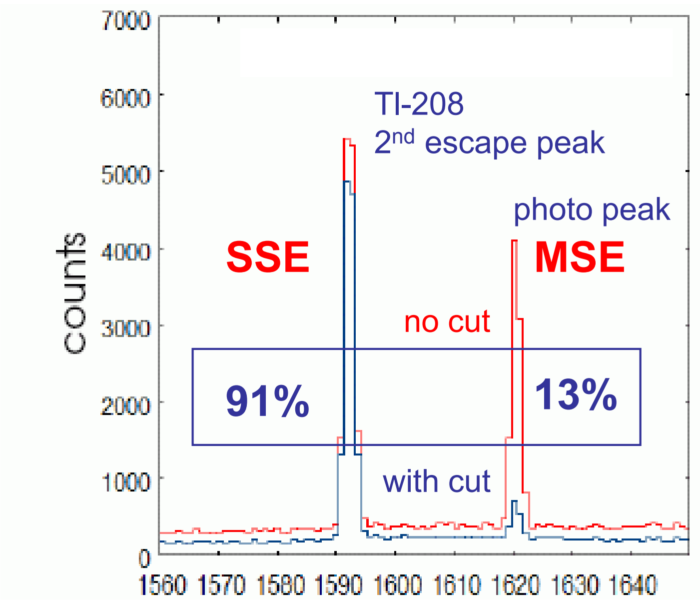
'modified electrode detector' with 'point contact'



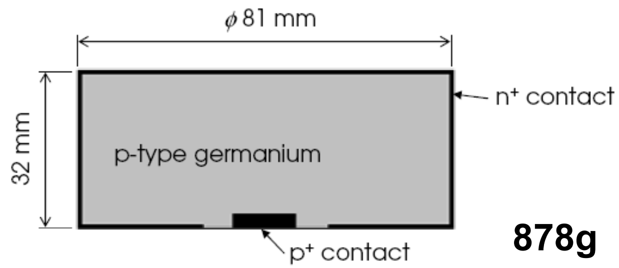
Luke et al. , IEEE TNS 36 (1989)
Barbeau et al., nucl-ex/0701012v1

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

R&D: Single / Multi Site Event discrimination



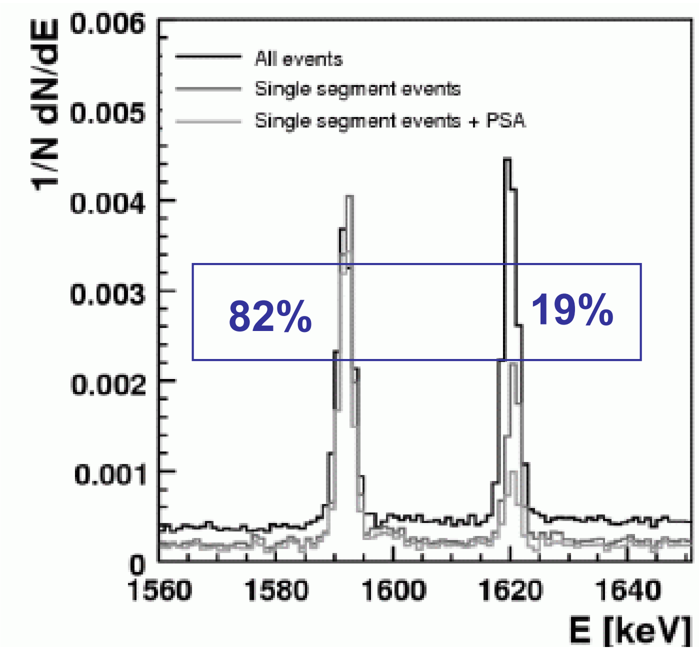
BEGe point-contact detector – p-type (COTS of Canberra)



878g

fractions after PSA cut

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

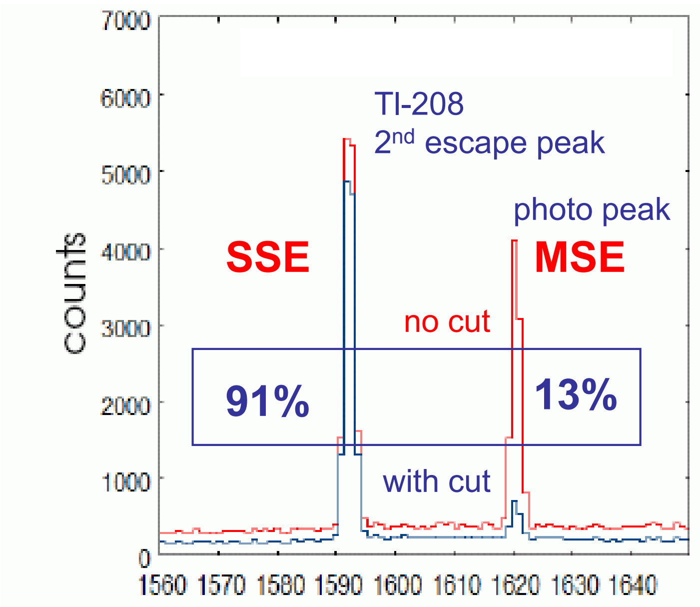


3x6-fold segmented coax detector - n-type

fractions after single-segment & PSA cut

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

R&D: **S**ingle / **M**ulti **S**ite **E**vent discrimination



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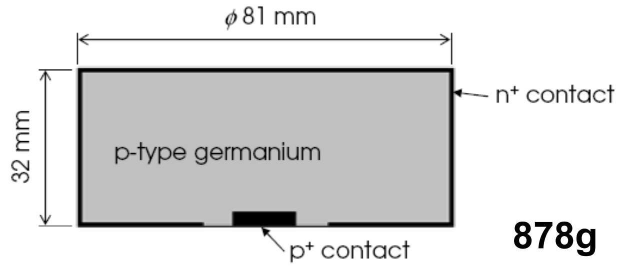

878g

← **fractions after PSA cut**

D..Budjas, PhD thesis '09
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JINST, in press

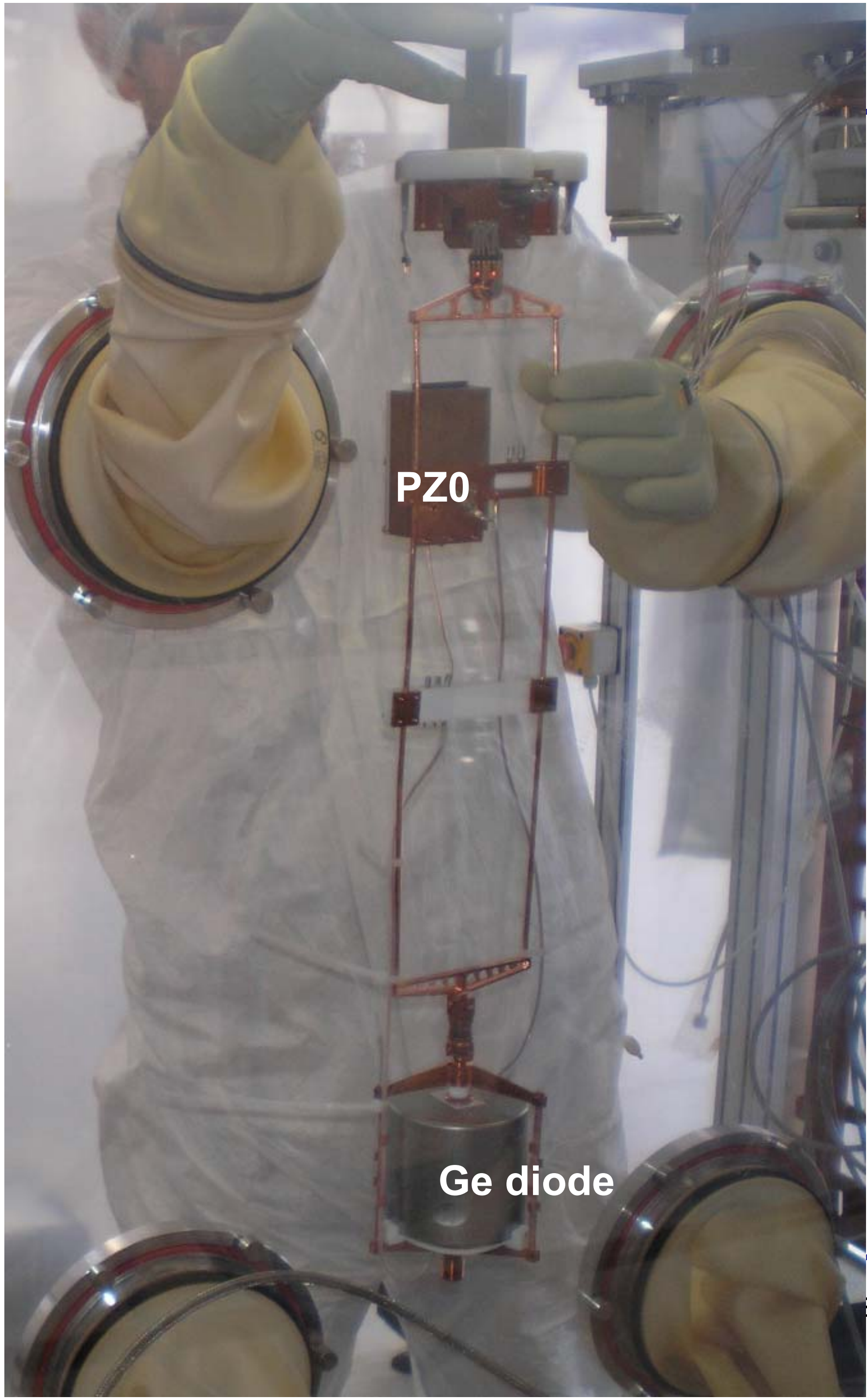
similar / better suppression obtained for K-40, Co-60 & Ra-226 contaminations

Results so convincing that GERDA collaboration has ordered at Canberra US/Belgium several crystals/ BEGe detectors made from the depleted Ge

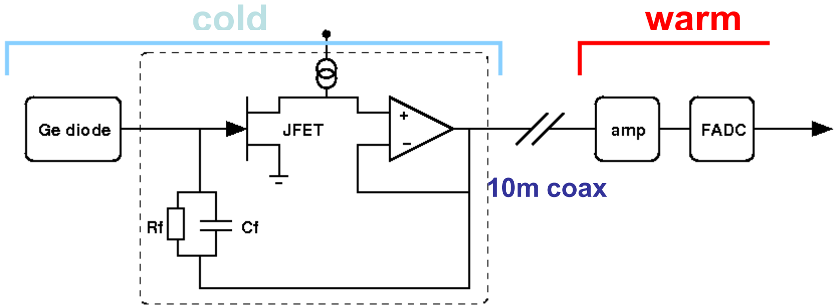
► test of complete production chain

latest news:

first BEGe detector delivered – stable operation in LAr since several weeks with resolution of better than 1.9 keV.



test of full readout chain



3-channel PZ-0 ASIC for cryogenic operation
- **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
successful test of 2 diode string

Principle: Safety first !

Detailed risk analysis of cryostat in 'water bath' by two companies

- leak before break principle
- 0.6g earth quake tolerant
- certified pressure vessel for 1.5 barg, operational pressure 0.2 barg
- no penetrations below fill level
- redundant safety systems
- cryogenic & WT system monitored and controlled by PLC

Water tank can be drained in less than 2 hours.
Heater for Ar exhaust gas is overdesigned by factor five.
Ventilation in Hall A can be increased on demand up to 30000 m3 / hour.

Hierarchical alarm system and corresponding actions by PLC & guards defined & tested - powerful graphical information system.

► Examples for graphical information system. & PLC performance

last not least: **safety**

Left unintentionally blank for temporarily lost photo

showing - during a break of a safety meeting -

the happy participants including

Barone, Passardi, Scaramelli, Zappellini (NIER), SPP staff

and more…

GERDA's and my personal sincere thanks to the LNGS directorate, the staff and the consultants for the excellent collaboration in the crucial issues of integration and safety!

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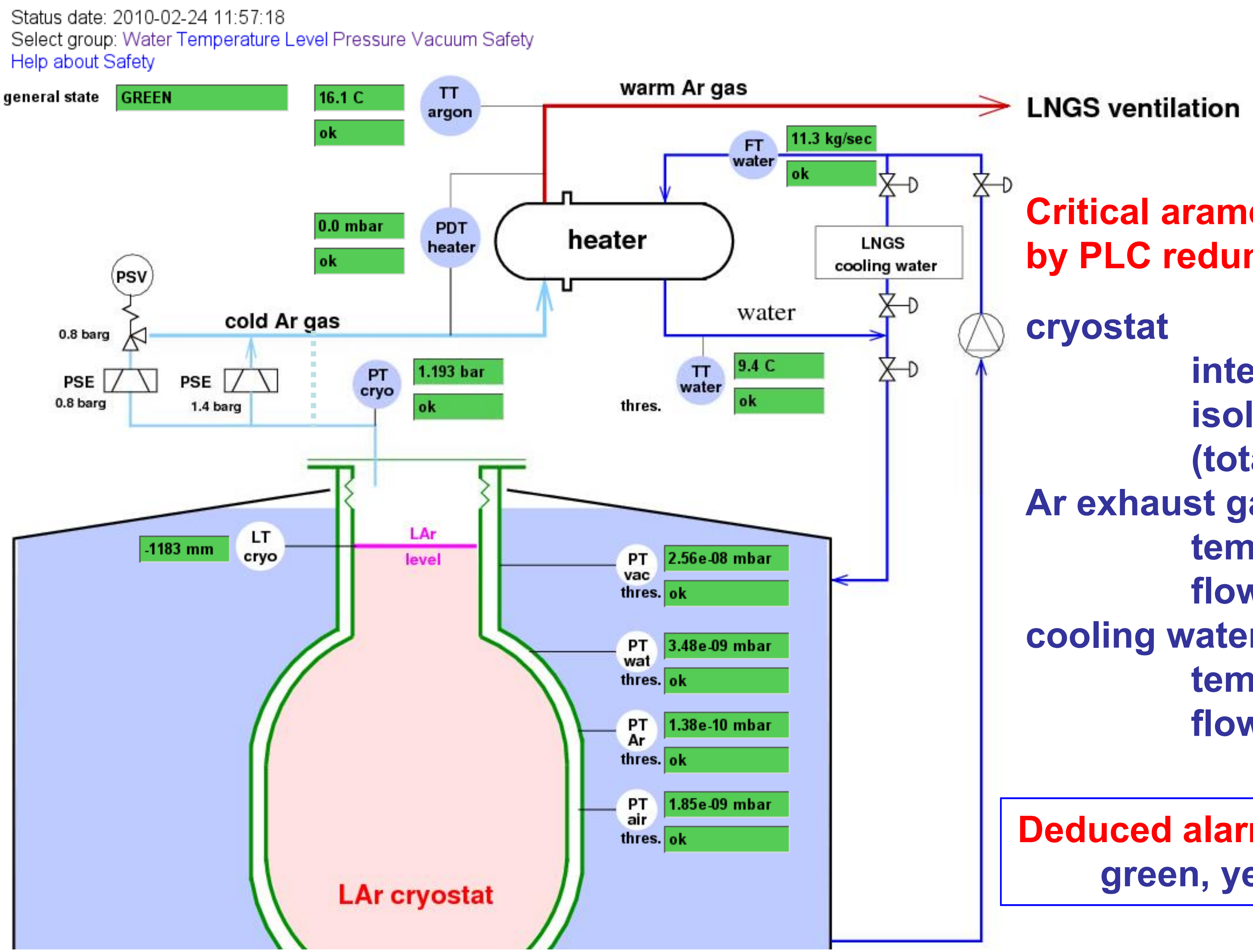
► **Examples for graphical information system. & PLC monitoring / performance**

GERDA safety webpage: safety status overview



Critical arameters monitored by PLC redundantly:

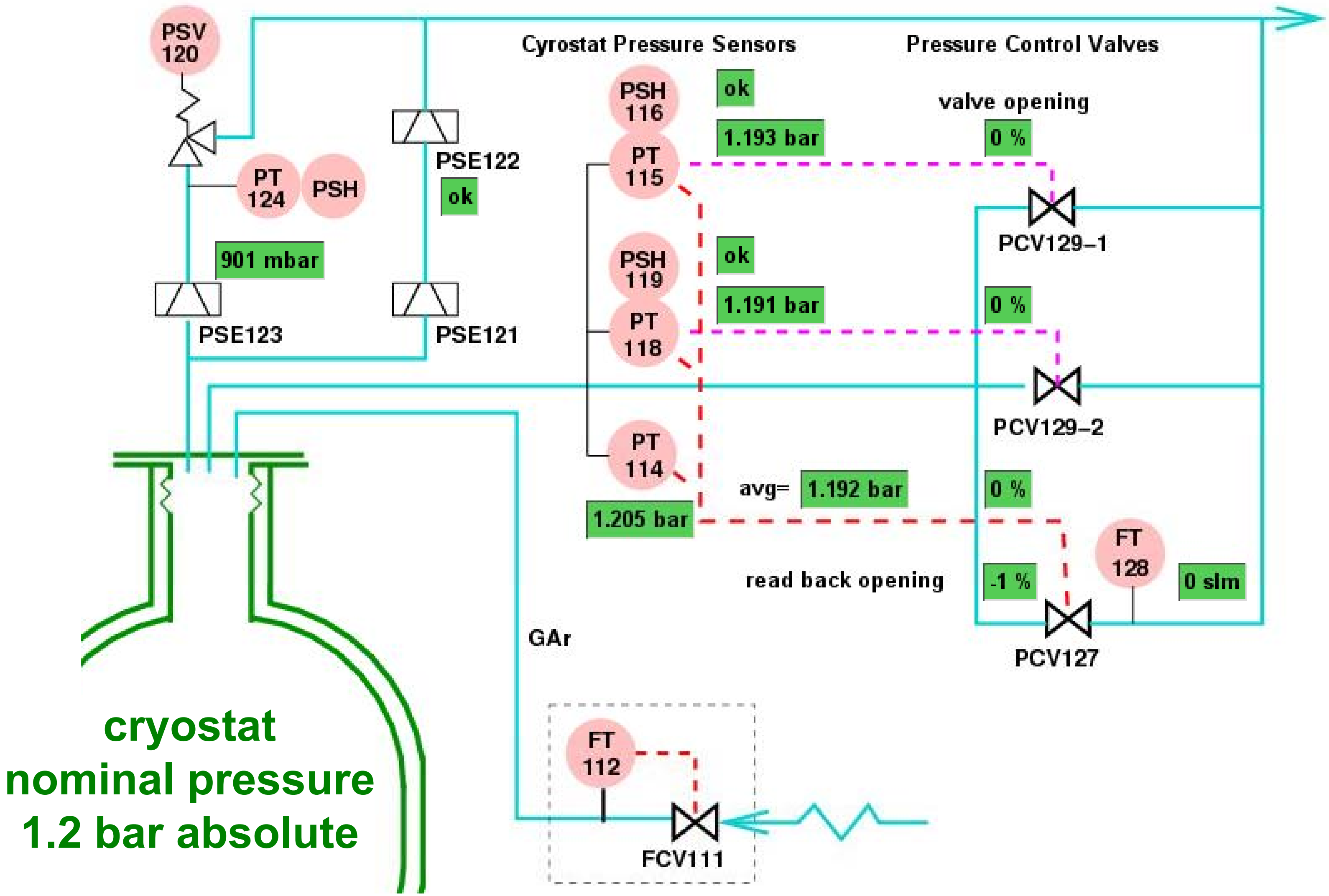
cryostat
- **internal pressure**
- **isolation vacuum**
- **(total & partial press.'s**

Ar exhaust gas
- **temperature**
- **flow rate**

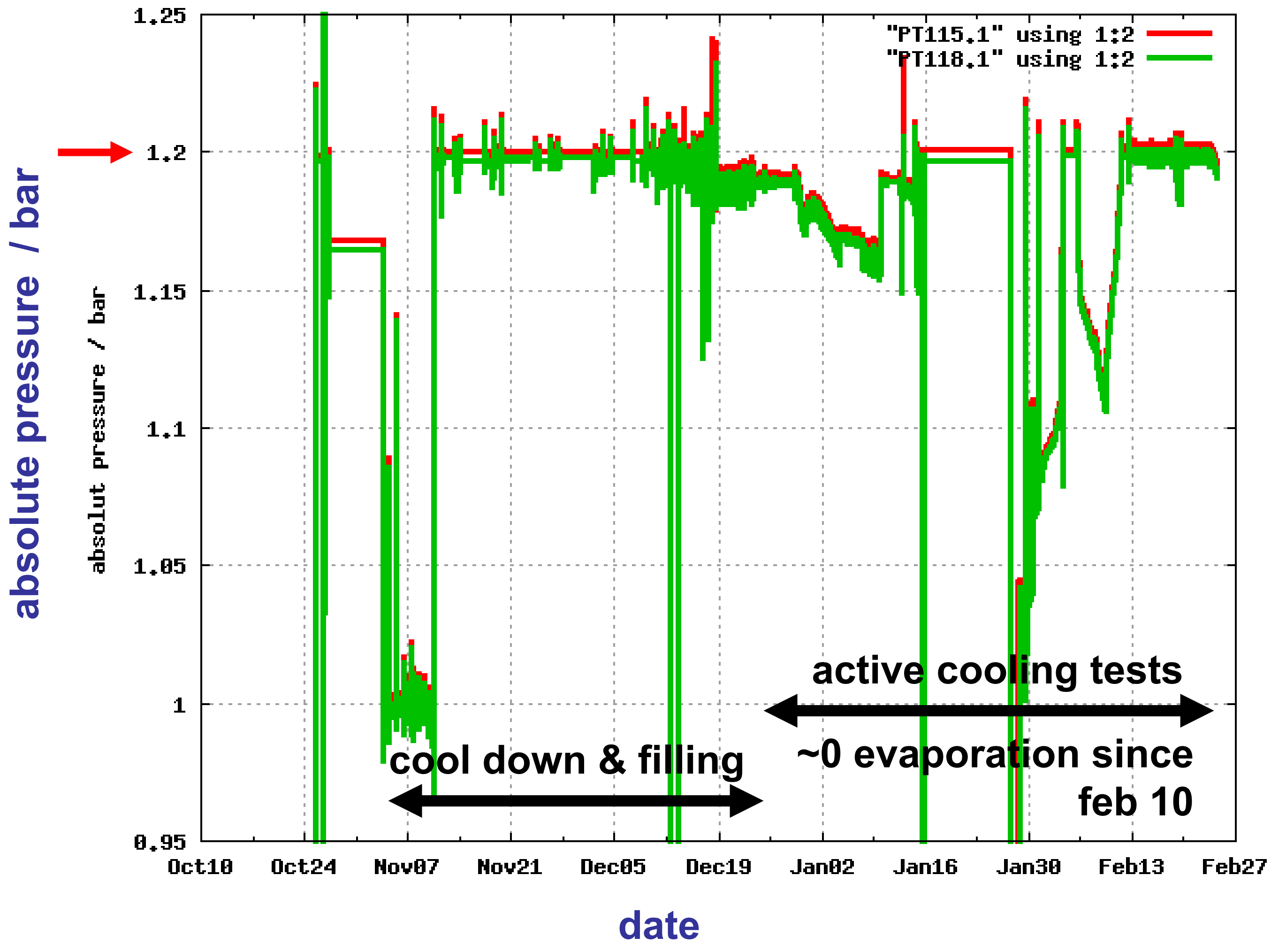
cooling water
- **temperature**
- **flow rate**

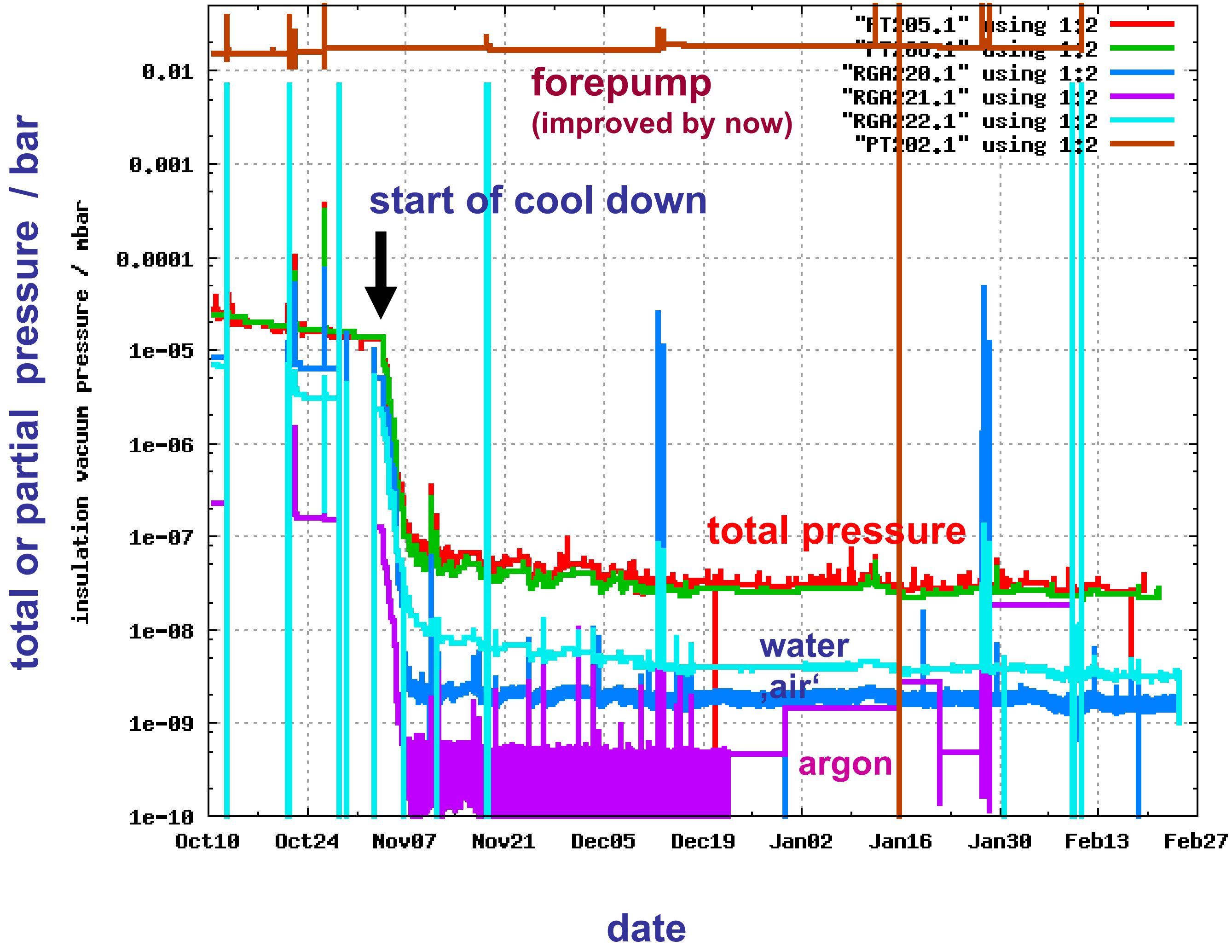
Deduced alarm levels:
green, yellow, orange, red

safety – cryostat's pressure control

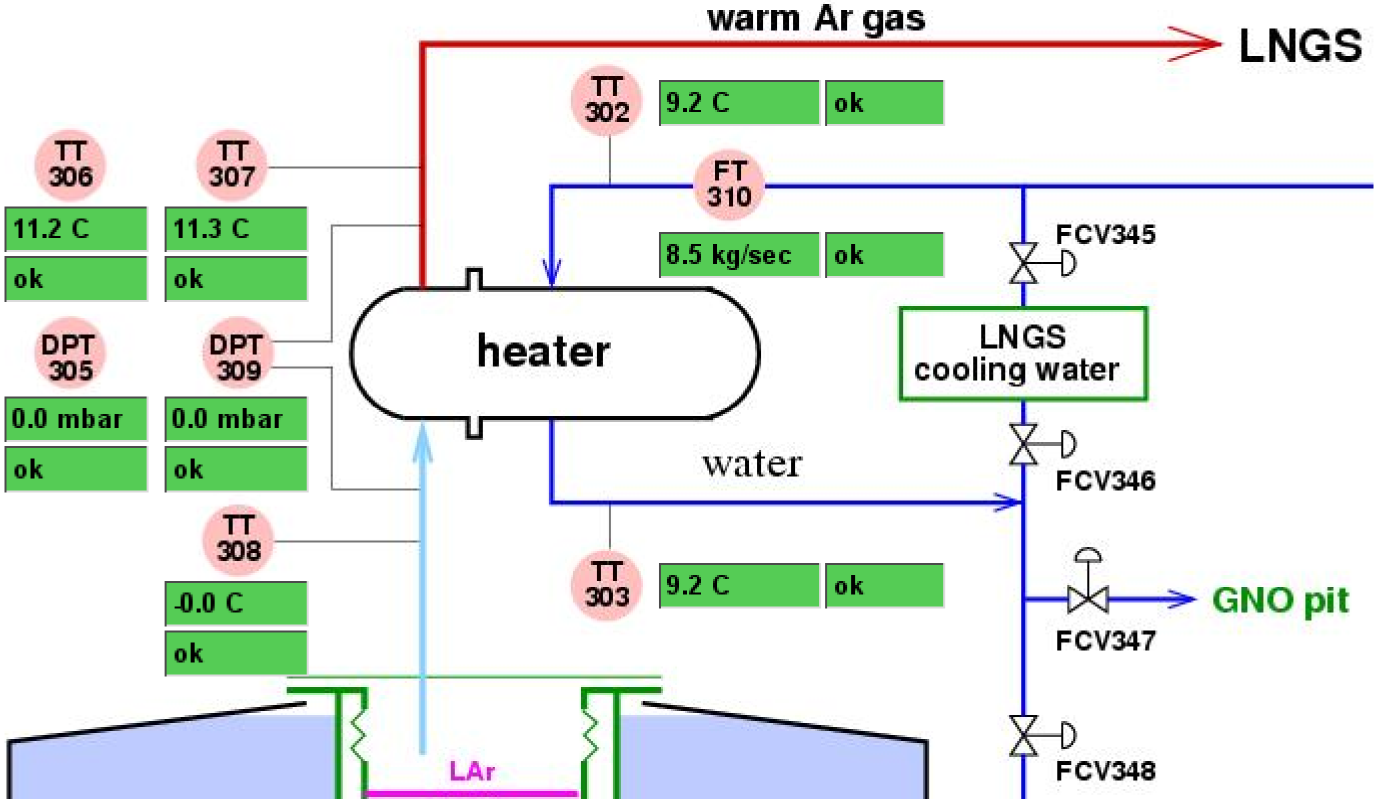


safety – pressure inside cryostat

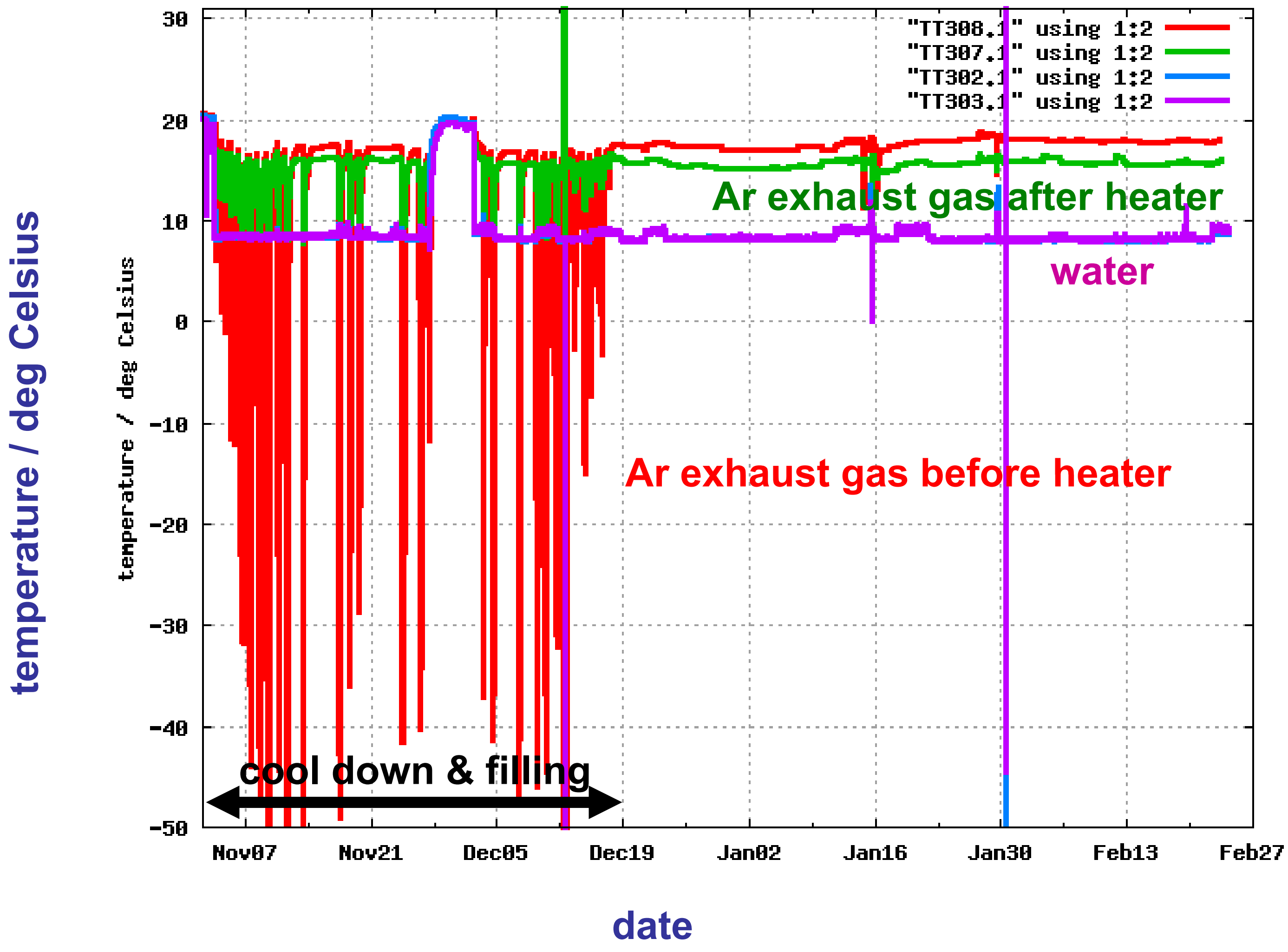



total or partial pressure / bar
insulation vacuum pressure / mbar
date
forepump
(improved by now)
start of cool down
total pressure
water
‚air'
argon
"PT205.1" using 1:2
"PT206.1" using 1:2
"RGA220.1" using 1:2
"RGA221.1" using 1:2
"RGA222.1" using 1:2
"PT202.1" using 1:2
0.01
0.001
0.0001
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
Oct10
Oct24
Nov07
Nov21
Dec05
Dec19
Jan02
Jan16
Jan30
Feb13
Feb27

safety – Ar exhaust gas



safety – Ar exhaust gas



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

► Cryostat filled with LAr in in Dec ’09 – plan to immerse first Ge diodes this March / 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 , $<m_{ee}> < 0.2$ eV *

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

Thanks to all who have supported and will continue to support GERDA so strongly !

NOT the end !

You all are most welcome to tonight´s GERDA & friends house warming party!

► Paganica - 19:30 – Maneggio St. Just ◄