Neue $0\nu\beta\beta$-Germanium Experimente: GERDA & Majorana

Stefan Schönert, MPIK Heidelberg
GERDA collaboration

Astroteilchenphysik in Deutschland: Status und Perspektiven

Desy Zeuthen, Februar 25-26, 2010

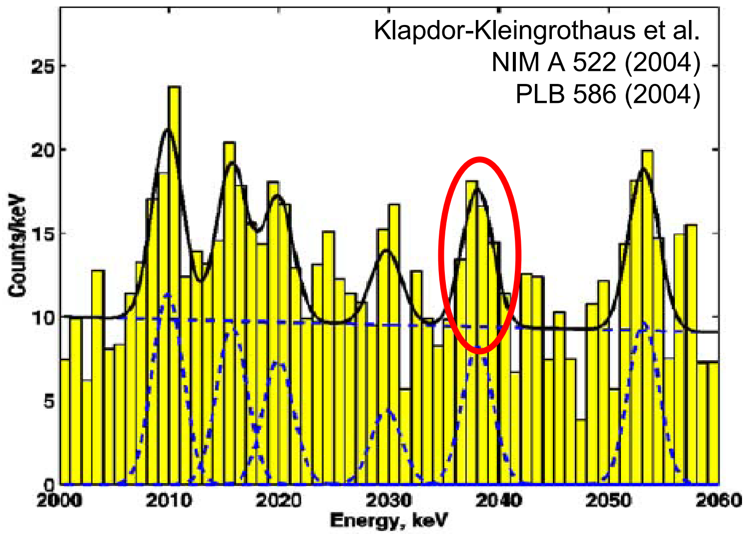
Outline

- Characteristics of Ge-76 and sensitivity
- Main experimental differences between GERDA & Majorana:
  - 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

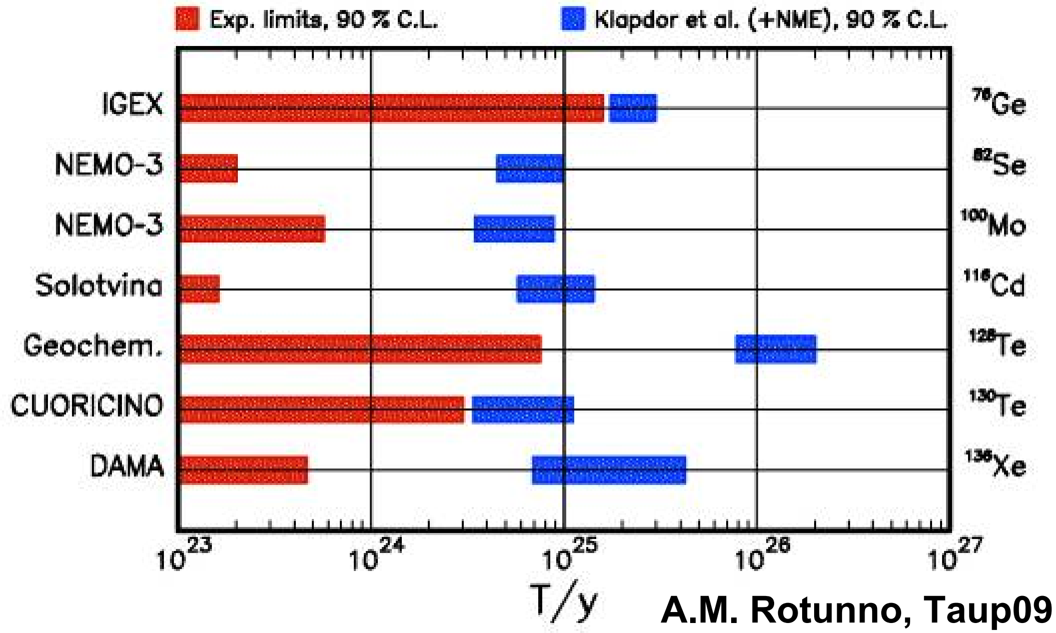
- Favorable nuclear matrix element $|M^{0\nu}|=3 - 9$
- Reasonable slow $2\nu\beta\beta$ rate ($T_{1/2} = 1.4 \times 10^{21}$ y) and high $Q_{\beta\beta}$ value (2039 keV)
- Ge as source and detector
- Elemental Ge maximizes the source-to-total mass ratio
- Intrinsic high-purity Ge diodes
- HP-Ge detector technologies well established
- Industrial techniques and facilities available to enrich from 7% to ~88%
- Excellent energy resolution: FWHM ~3 keV at 2039 keV (0.16%)
- Powerful signal identification & background rejection possible with modern detectors: time structure of charge signal (PSA), granularity (segmentation & close packing), liquid 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) [& claim for evidence]

State-of-the-art: limits & claim



- 71.7 kg year - Bgd 0.11 / (kg y keV)
- 28.75 ± 6.87 events (bgd:~60)
- Claim:4.2σ evidence for $0\nu\beta\beta$
- (0.69–4.18) $\times 10^{25}$ y (3σ)
- Best fit: 1.19 $\times 10^{25}$ y (NIMA 522/PLB 586)
- PSA analysis (Mod. Phys. Lett. A21): (2.23 + 0.44 – 0.31)$\times 10^{25}$ y
- Tuebingen/Bari group (PRD79): m_{ee} /eV = 0.28 [0.17-0.45] 90%CL

Significance and $T_{1/2}$ depend on bgd discription:
- Strumia & Vissani Nucl.Phys. B726 (2005)
- Chkvorets, PhD dissertation Univ. HD, (2008): using realistic background model
  $\Rightarrow$ peak significance: **1.3σ**,
  $\Rightarrow T_{1/2} = 2.2 \times 10^{25}$ y



A.M. Rotunno, Taup09 (PRD 79)

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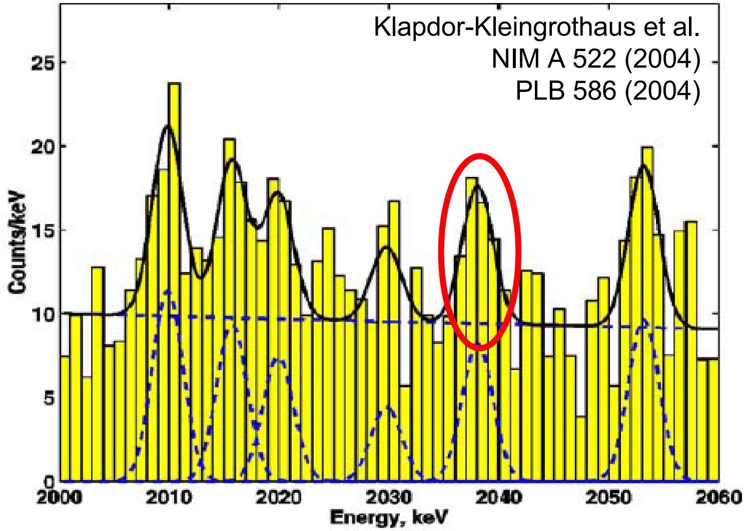

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- Chkvorets, PhD dissertation Univ. HD, (2008): using realistic background model
  $\Rightarrow$ peak significance reduced to 1.3σ,
  $\Rightarrow T_{1/2} = 2.2\text{x}10^{25}$ y

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- 28.75 ± 6.87 events (bgd:~60)
- Claim:4.2σ evidence for $0\nu\beta\beta$
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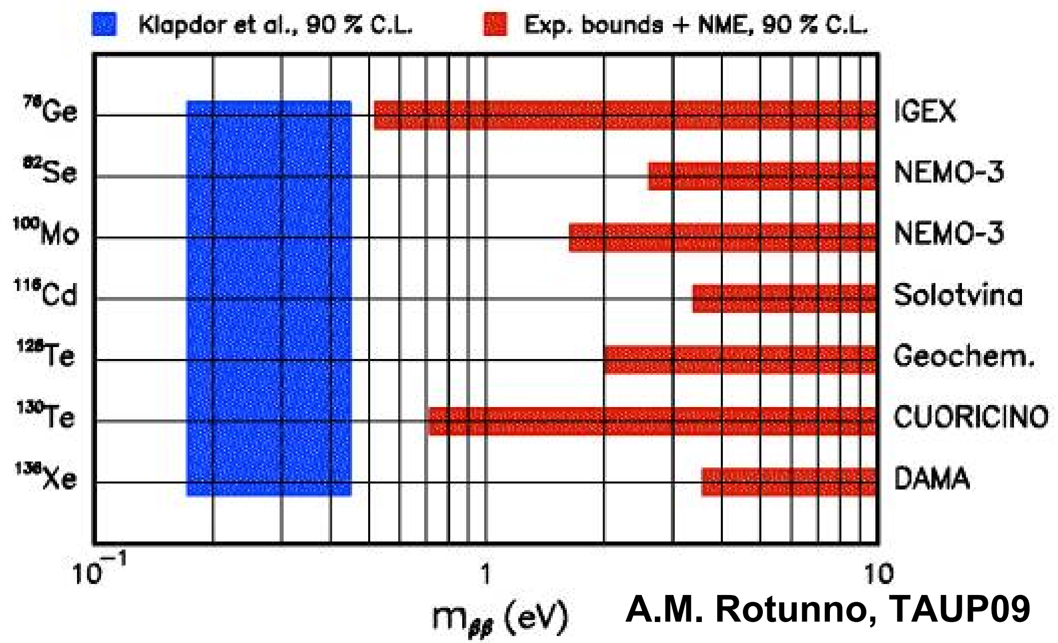
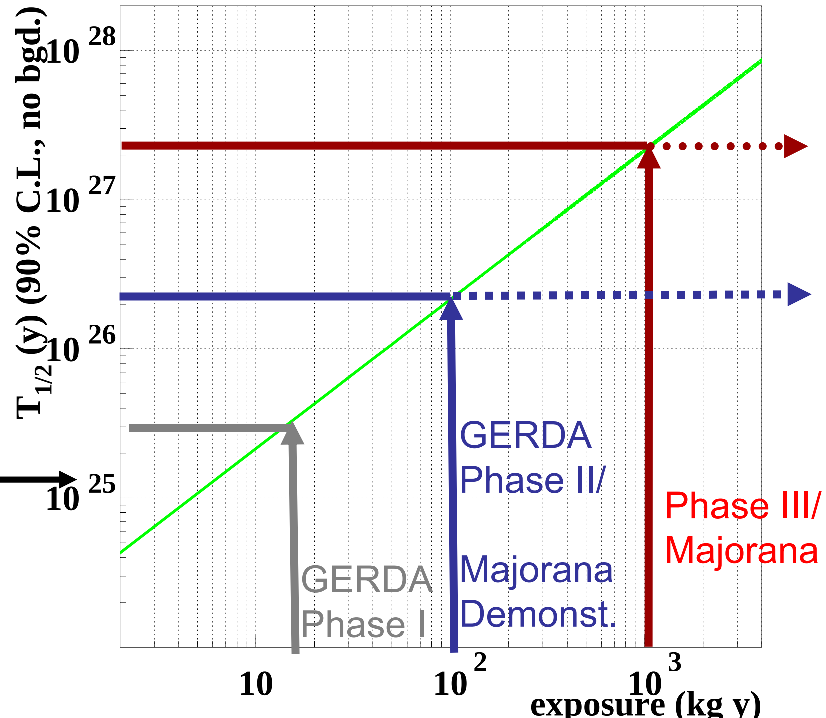


A.M. Rotunno, TAUP09

$\Rightarrow$ Claim must be scrutinized with ^{76}Ge AND other isotopes

Phases and physics reach



$2 \cdot 10^{27}$ (90 % CL) * → <24 - 41 meV

$2 \cdot 10^{26}$ (90 % CL) * → <75 - 129 meV

$3 \cdot 10^{25}$ (90 % CL)*

KK →

*: no event in ROI

assuming $|M^{0\nu}|$=2.99-8.99 [Smol&Grab PRC'10] and 89% enrichment

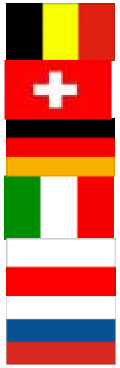
required for 'background free' exp. with ΔE~3.3 keV (FWHM): $O(10^{-3})$ $O(10^{-4})$ counts/(kg·y·keV)

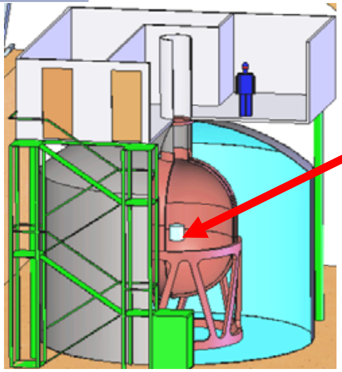
Background requirement for GERDA/Majorana:

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

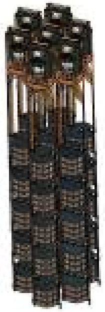
⇒Degenerate mass scale **$O(10^2$ kg·y)** ⇒ Inverted mass scale **$O(10^3$ kg·y)**

Two new ^{76}Ge Projects:

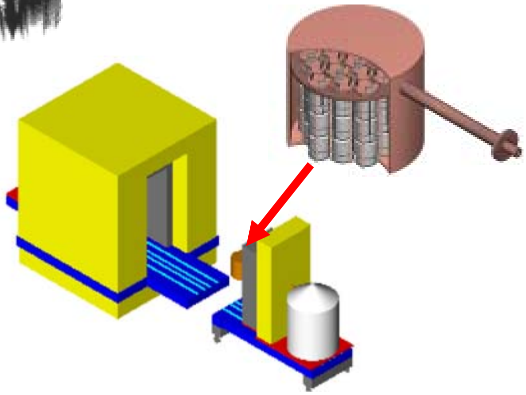


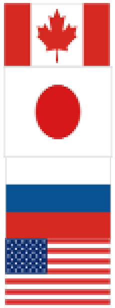


GERDA



Majorana





- ‘Bare’ ^{enr}Ge array in liquid argon
- Shield: high-purity liquid Argon / H_2O
- Phase I: 18 kg (HdM/IGEX) / 15 kg nat.
- Phase II: add ~20 kg new enr. Detectors; total ~40 kg

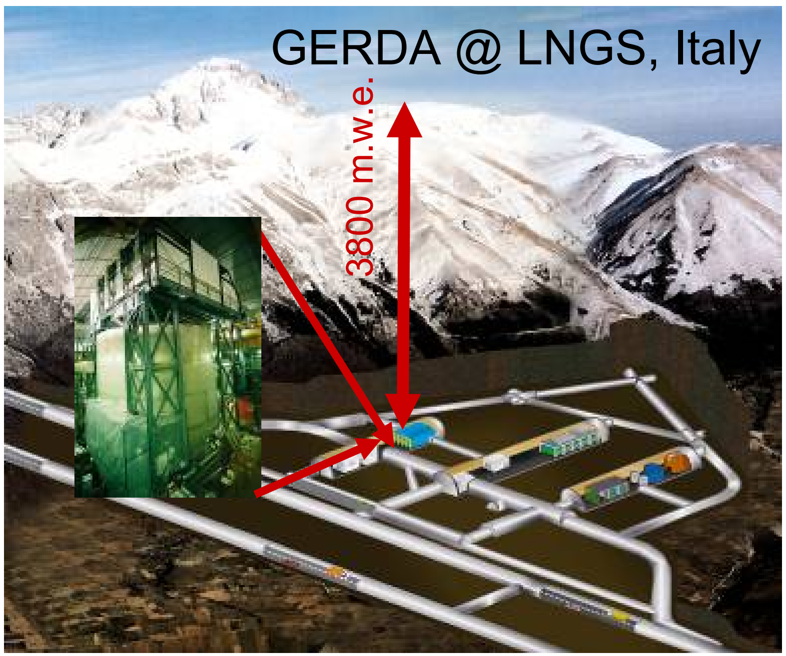
- Array(s) of ^{enr}Ge housed in high-purity electroformed copper cryostat
- Shield: electroformed copper / lead
- Initial phase: R&D demonstrator module: Total ~60 kg (30 kg enr.)

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

LoI
- open exchange of knowledge & technologies (e.g. MaGe MC)
- intention to merge for O(1 ton) exp. (inv. Hierarchy) selecting the best technologies tested in GERDA and Majorana

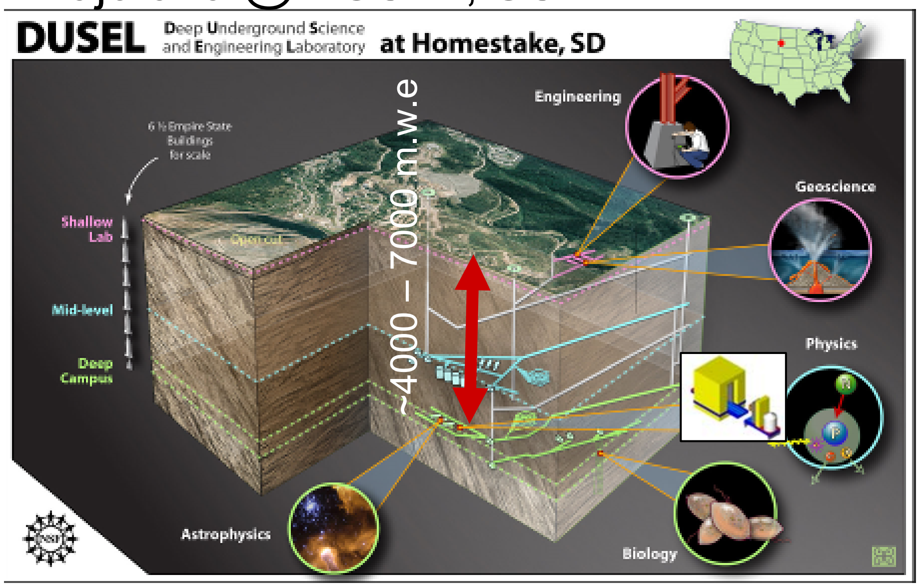
Background reduction:

Deep underground sites for suppression of cosmic ray muons



Suppression of μ-flux > 10^6

Majorana @ DUSEL, USA

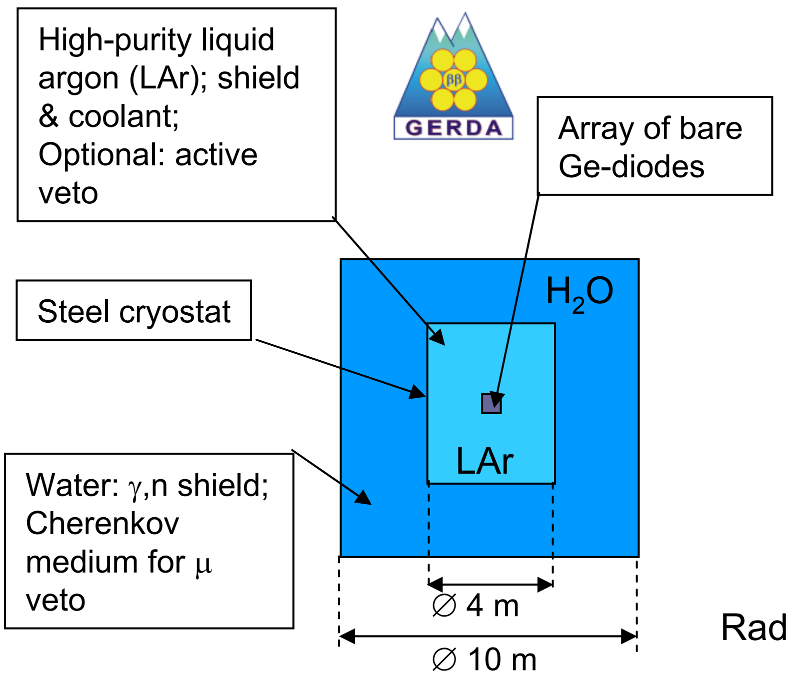


Partly funded; under construction

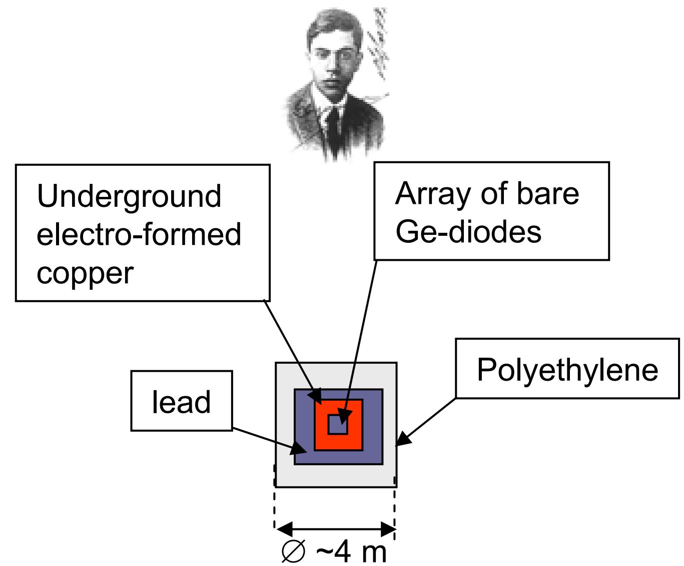
Background reduction:

external bgds: γ, n, residual-μ

GERDA shielding



Majorana shielding



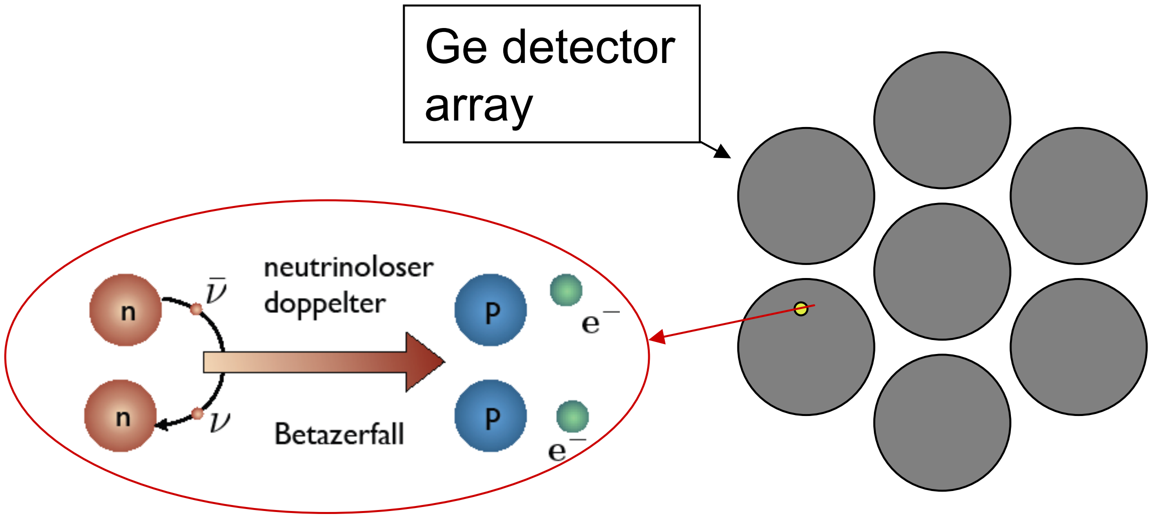
Radio purity of shield <0.1 μBq ^{222}Rn (^{226}Ra)/kg !

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

0νββ-signal & background reduction



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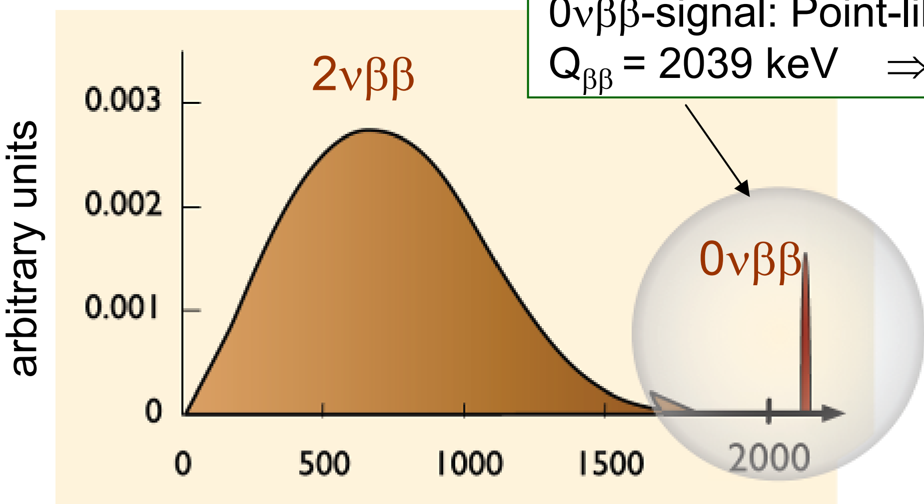
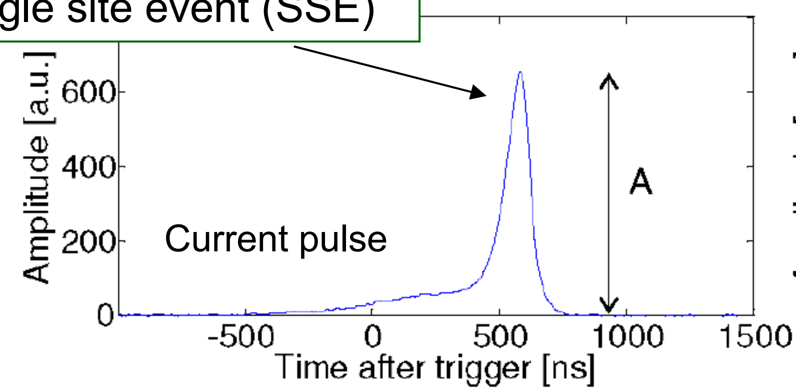
0νββ-signal: Point-like energy deposition at $Q_{\beta\beta}$ = 2039 keV ⇒ single site event (SSE)

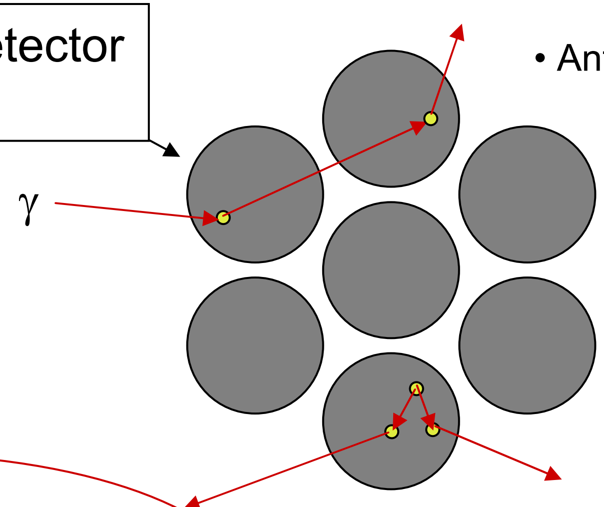




0νββ-signal & background reduction

internal bgds: e.g. ^{60}Co (5.3 a), ^{68}Ge (270 d), …
contaminations close by: e.g. U/Ra/Th in holders, cables, FE, …

Ge detector array

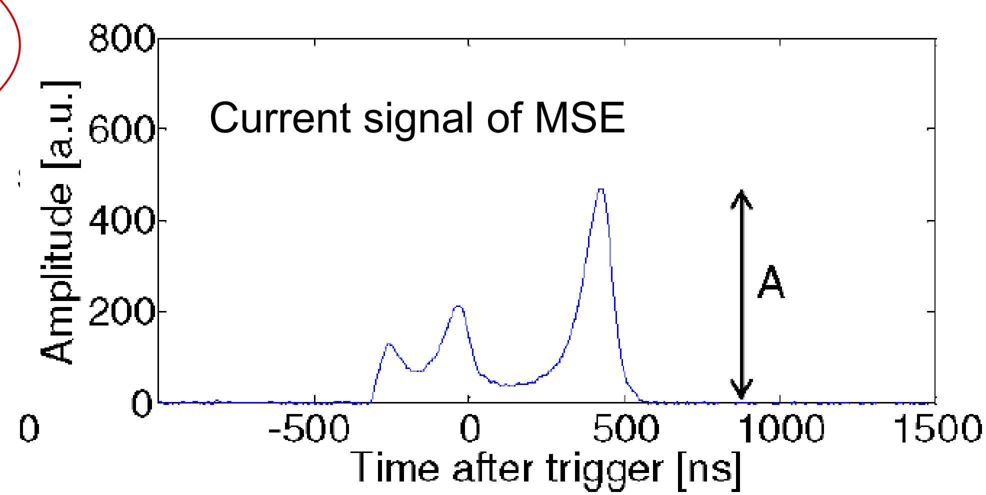


• Anti-coincidence of detectors

& 

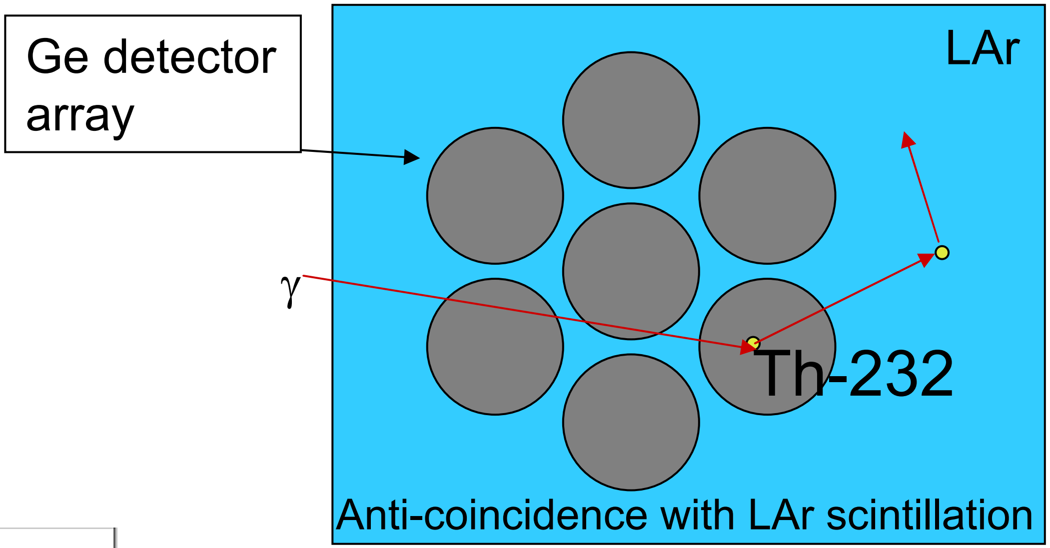
• Pulse shape analysis
• Anti-coincidence of detector segments

^{60}Co bgd: multiple energy deposition at $Q_{\beta\beta}$ = 2039 keV
⇒ Multi site event (MSE)

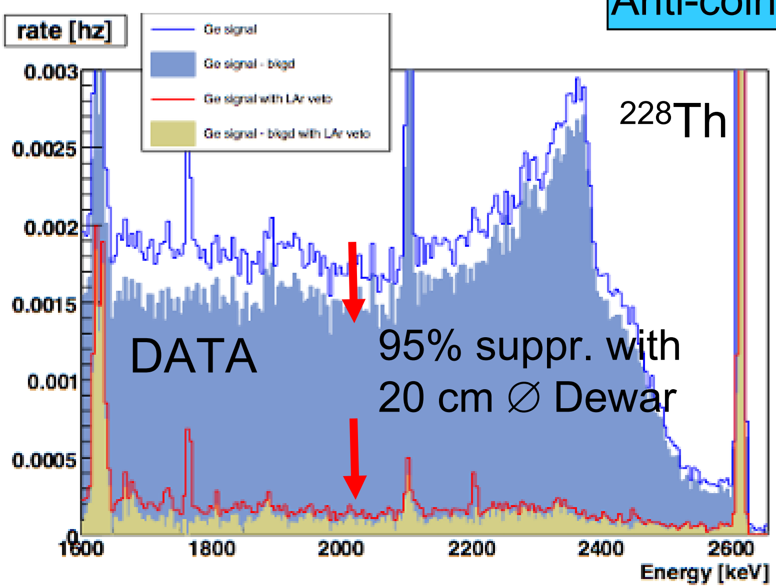


$0\nu\beta\beta$-signal & background reduction

…

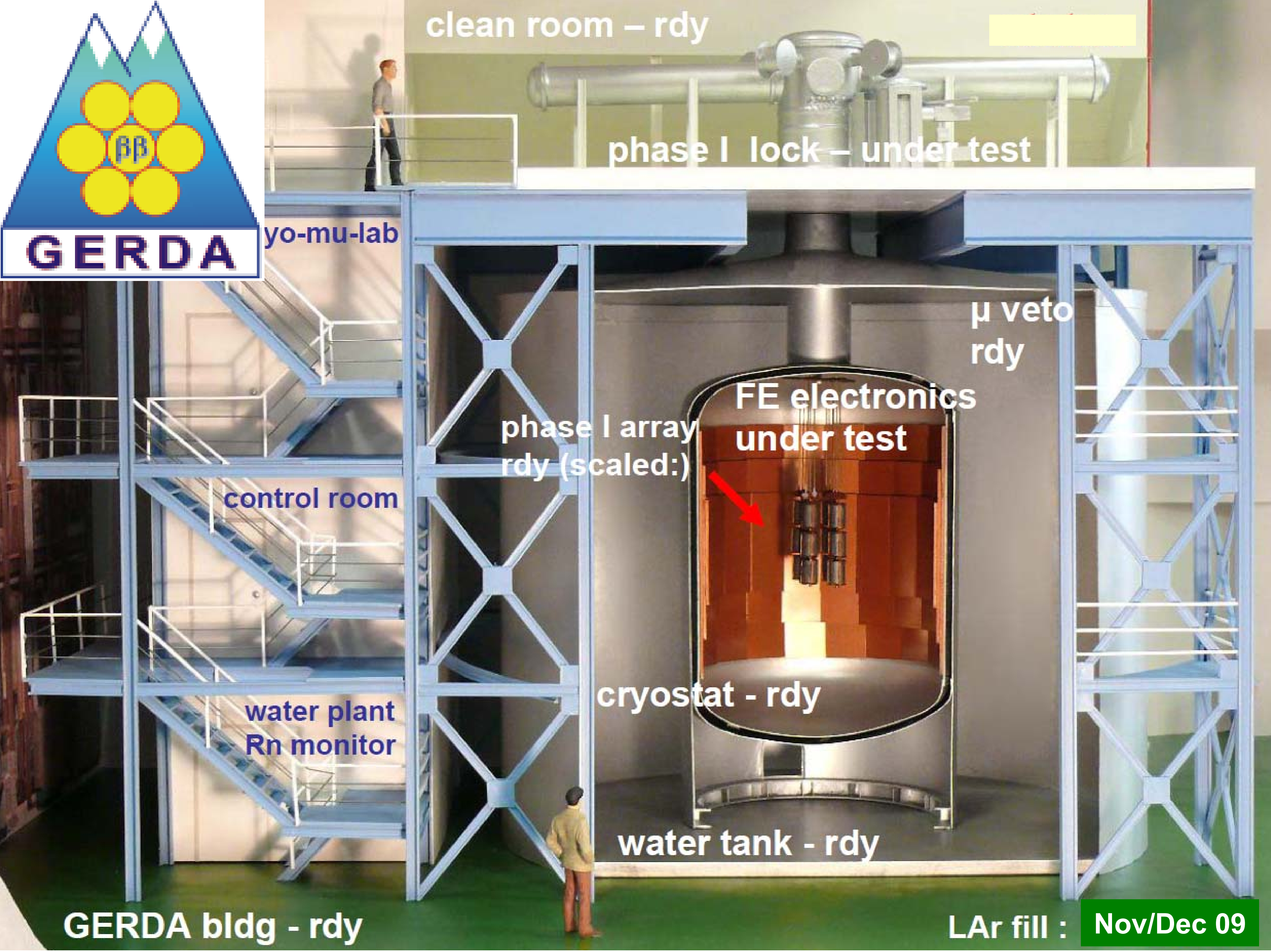


R&D



Majorana project status

- CD-1 document submitted in Nov ’09 for “Demonstrator” (30 kg ^{nat}Ge & 30 kg ^{enr}Ge). 21-28 M$ (fixed in April’10) for FY10-FY13. Decision in May.
- Objective: achieve background of 1 cts/(t y ROI)
- Schedule:
  - start of electroforming in January 2010 at 4850 level of Sanford lab (DUSEL).
  - First cryostat of the Demonstrator running with 20 kg of ^{nat}Ge June 2011.


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

Unloading of vacuum cryostat
(6 March 08)

Produced from selected low-background austenitic steel

Construction of water tank

∅ 10 m

H = 9.5 m

V = 650 m³

Designed for external γ,n,μ background ~10^{-4} cts/(keV kg y) construction of clean room

clean room, active cooling device getting prepared for installation


Water tank and cryostat prior muon veto installations


WT and cryostat with muon veto installed


“Pill box”

Glove-box for Ge-detector handling and mounting into commissioning lock under N_2 atmosphere installed in clean room

Feb ‘10

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**

Selection of R&D of GERDA Task Groups

• **TG01**	**Modification & test of existing Ge diodes**
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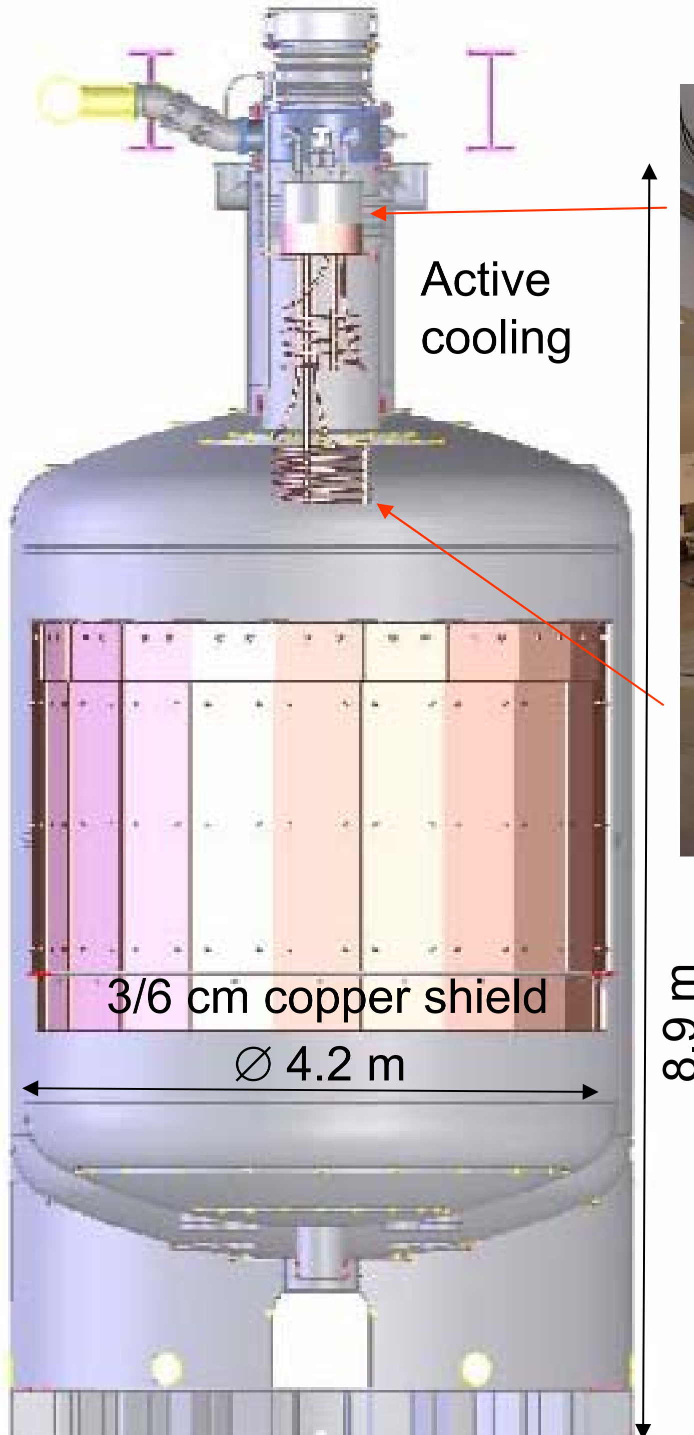
GERDA cryostat

- 65 m^3 volume for LAr
- 200W measured thermal loss
- active cooling with LN_2
- internal copper shield
- detailed risk analysis of cryostat in 'water bath'

Screening of all stainless steel sheet batches by underground γ-spectroscopy at MPI-HD and LNGS prior construction
⇒Th-228 <0.1 – 5, typically <2 mBq/kg

MC ⇒ cryostat + copper shield + LAr
<2 · 10^{-4} cts / (keV·kg·y)

NIM A593 (2008) 448, NIM A606 (2009) 790



in Deutschland 2010

Cryostat: Rn emanation

Measurements of Rn emanation [a] at various fabrication/installation steps with MoREx[b]

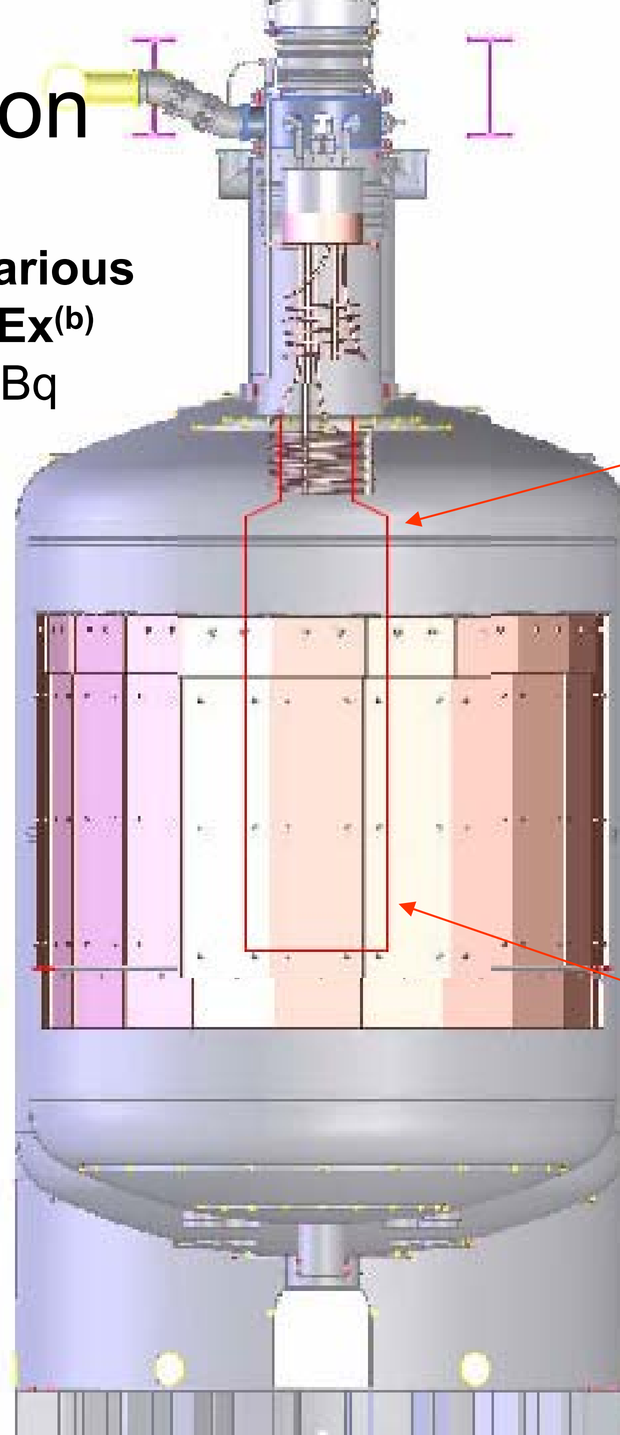
after 1./2. cleaning	23±4 / 14±2 mBq
after copper mount	34±6 mBq
after 3. cleaning	31±2 mBq
after cryogenics mount	55±4 mBq**

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

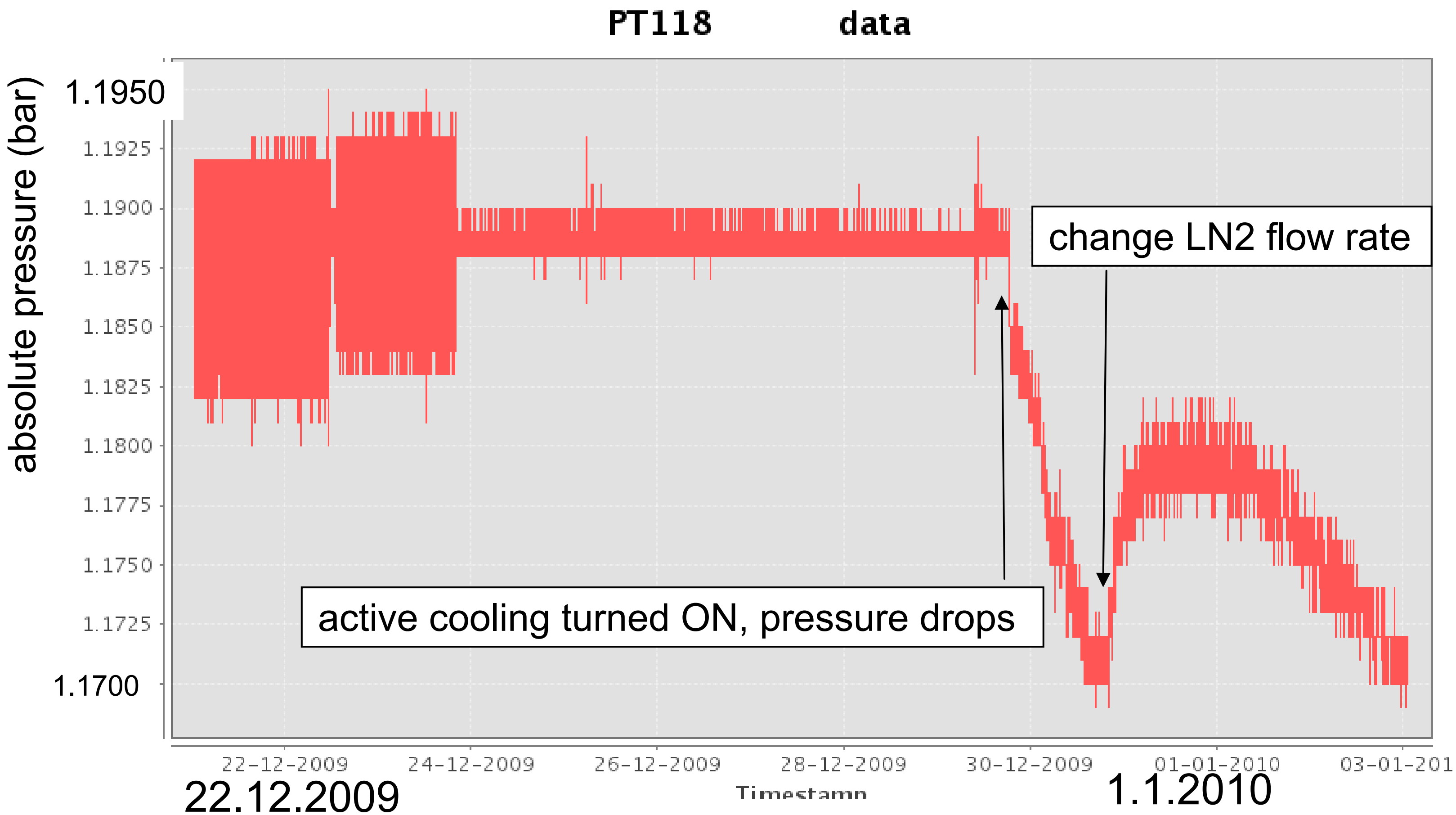
Rn shroud: 30 μm copper
Ø 0.8m , 3 m height
to prevent convective transport of Rn from walls/copper to Ge diodes
BI ~ 1.5 10^{-4} cts / (keV·kg·y)

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

[b] Appl.Rad.Isot. 52(2000) 691



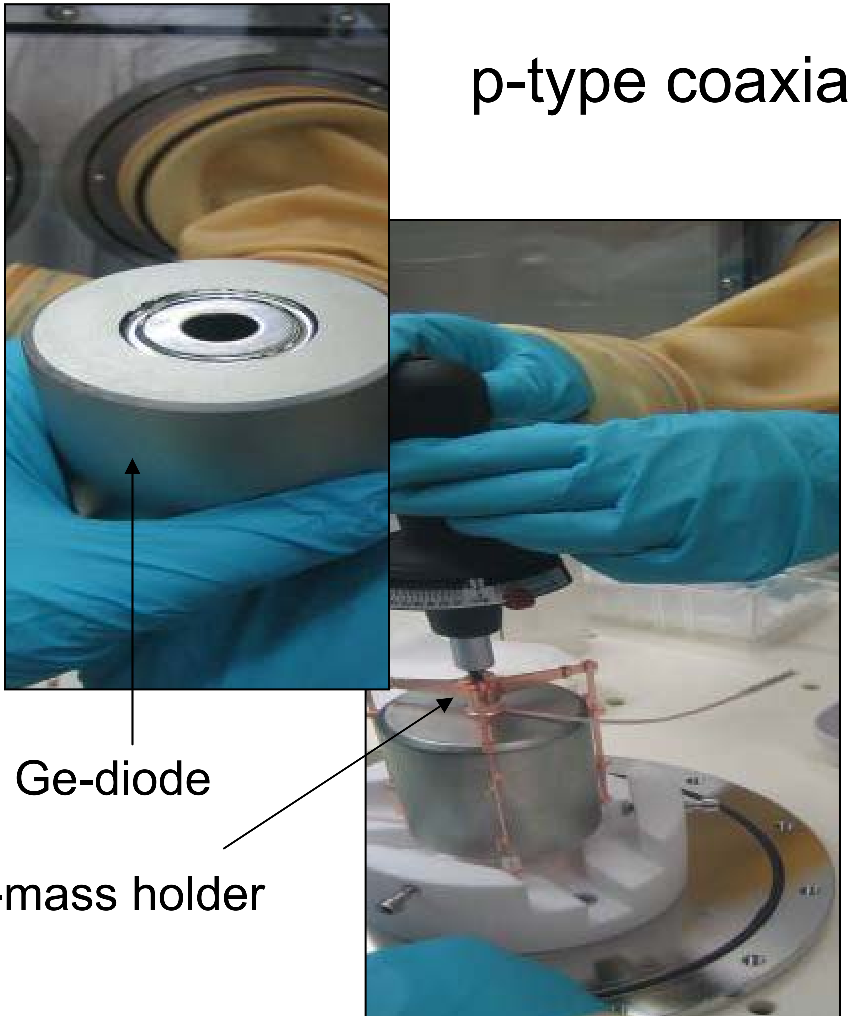
Cryostat filling with LAr in Nov/Dec '09



Cryogenic commissioning successful!
Active cooling operational since Jan. '10,
Stable operations - no loss of argon

Phase I detectors

p-type coaxial detectors



Detector handling under N_2 atmosphere

<u>8 diodes (from HdM, IGEX):</u>

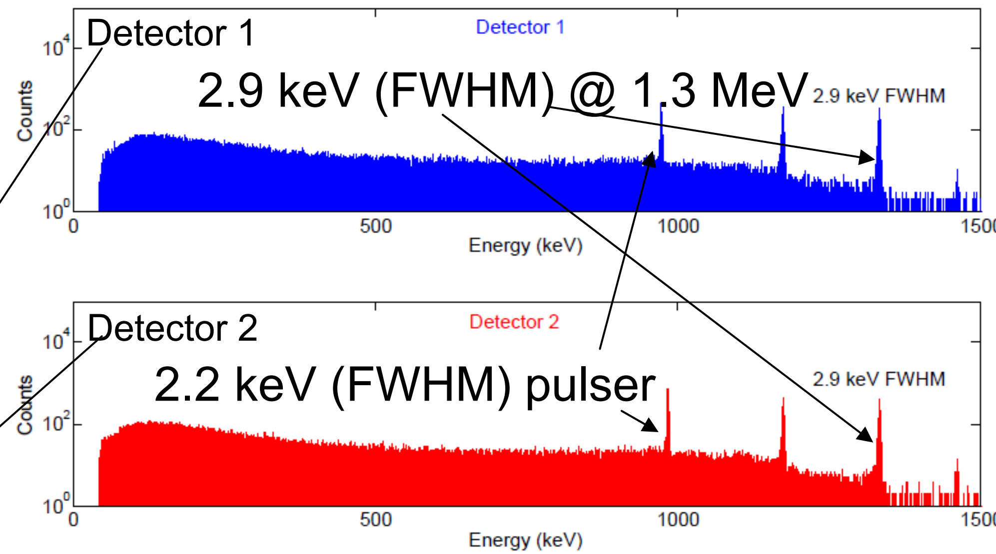
- Enriched 86% in ^{76}Ge
- All diodes refurbished with new contacts optimized for LAr
- Energy resolution in LAr: ~2.5 keV (FWHM) @1.3 MeV
- Well tested procedure for detector handling
- Total mass 17.66 kg (after refurbishing)

<u>6 diodes from Genius-TF ^{nat}Ge:</u>

- Same refurbishing & testing as enriched diodes
- Total mass: 15.60 kg

Test of full read out chain

Summer/ autumn 2009:
Integration test of phase I detector string, FE, lock, DAQ, LAr dewar with active cooling



Best resolution achieved in setup: 2.7 keV (FWHM)

Phase II detectors

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

^{enr}Ge & ^{depl}Ge:

- 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 (with same chemical history) and in use for test

Reduction & purification:

- procedure tested and optimized with ^{dep}Ge at PPM Pure Metals GmbH
- total yield >90% for >6N quality
- no isotopic dilution
- short exposure to cosmic rays (underground storage)
- begin of purification of enriched material next month

Crystal pulling:

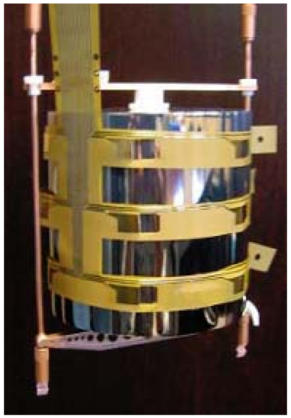
n-type for segmented detectors:

- R&D for n-type pulling by Institut für Kristallzüchtung, Berlin
- yet, impurity concentration too high (10^{11} to 10^{13} cm^{-3}, 10^{10} cm^{-3} needed)
- Czochralski puller recently refurbished, new crystal pulling started this week

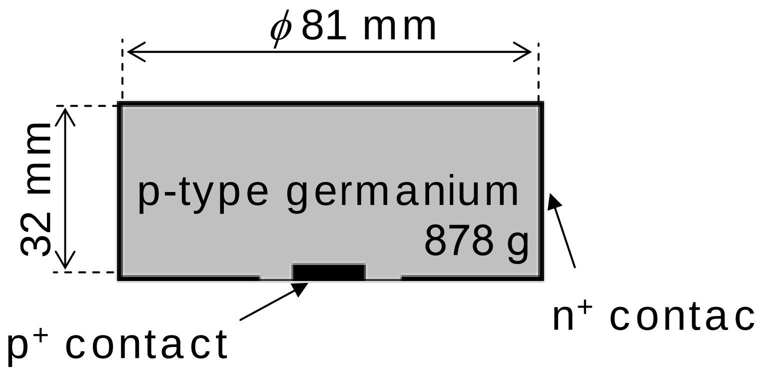
p-type for BEGe detectors:

- Canberra, Oakridge, US (commercial producer) for p-type BEGe crystals
- Test run with ^{depl}Ge from ECP purified at PPM successful
- 1st ^{depl}BEGe detector working (Feb 2010)

Phase II R&D: Novel Ge-detectors with advanced 0νββ-signal recognition & background suppression

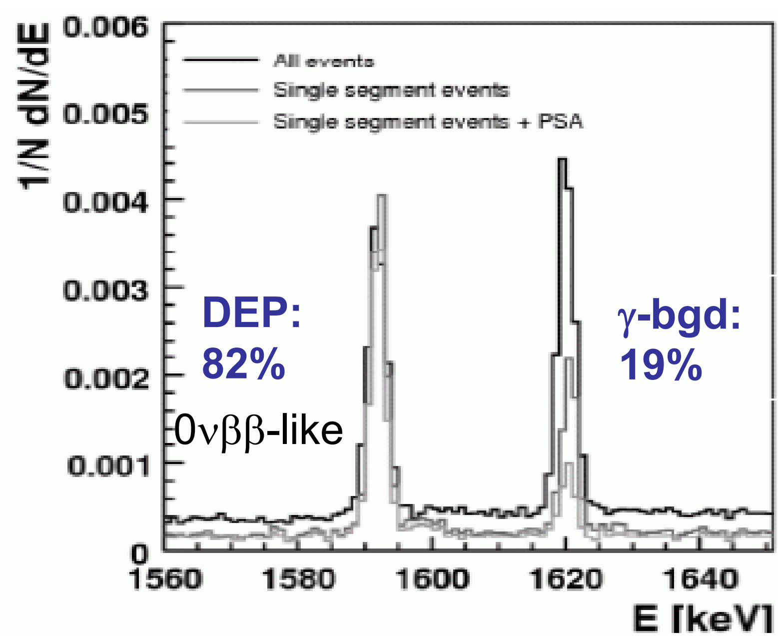


n-type detectors with 18-fold segmented electrodes, 1.6 kg

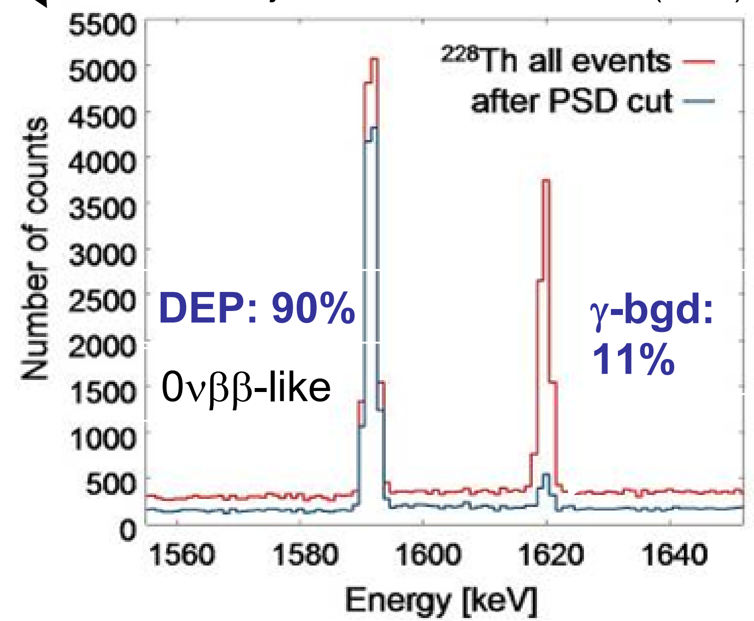


In vacuum cryostat

I.Abt et al., NIMA 583 (2007), Eur. J. Phys. C 52 (2007)



D. Budjas et al., JINST 4 P10007 (2009)



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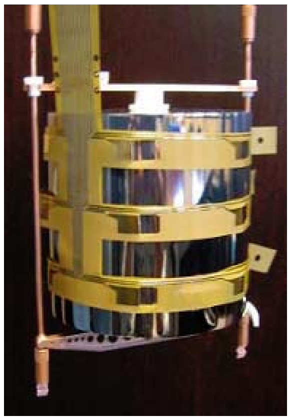
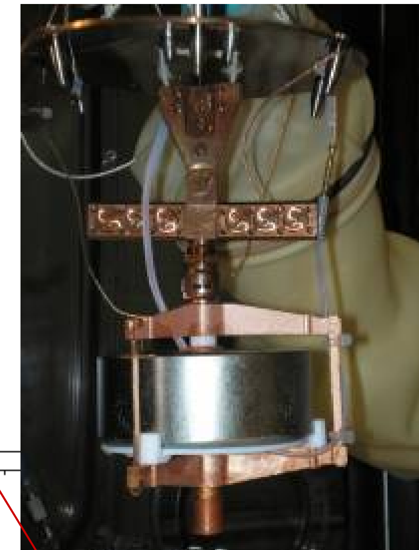
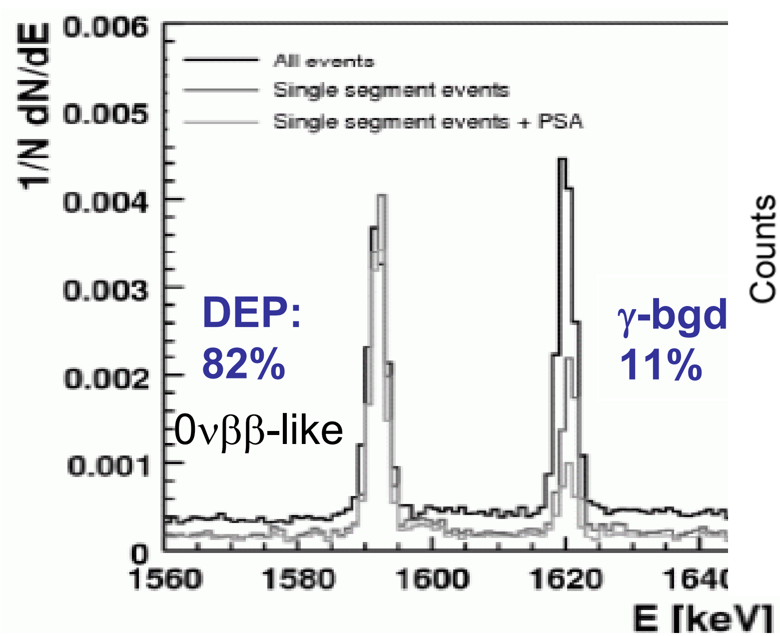


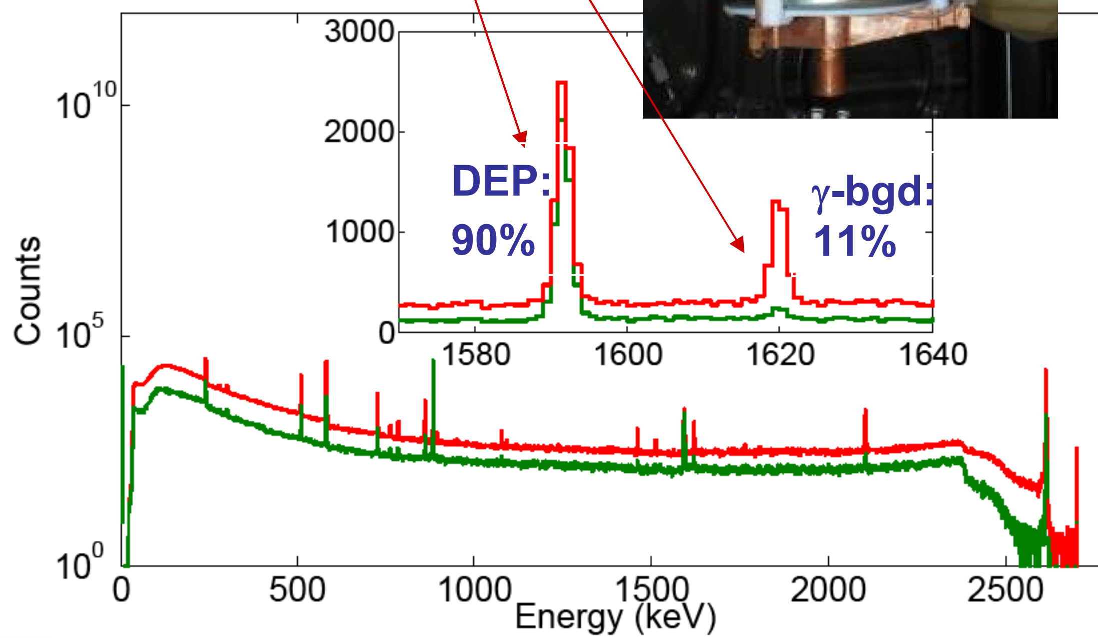
n-type detectors with 18-fold segmented electrodes, 1.6 kg

I.Abt et al., NIMA 583 (2007).
Eur. J. Phys. C 52 (2

Same results with bare detector in liquid argon test stand!







Summary & outlook

- Proposed in 2004
- Approved in 2005 by LNGS with location in Hall A
- Funded by BMBF, INFN, MPG, DFG (R&D), and Russia in kind
- Construction completed in LNGS Hall A
- Cryostat filled with LAr in Dec ’09 & cryogenic commissioning completed
- First technical run planned for March ’10
- Goals:

  Phase I: background 0.01 cts / (kg keV y)

  $\Rightarrow$ scrutinize KKDC results with ~1 year of data

  $\Rightarrow T_{1/2} > 2.2\ 10^{26}$ y, $<m_{ee}> < 0.23 – 0.39$ eV [PRC81 2010]

  Phase II: background 0.001 cts / (kg keV y)

  $\Rightarrow T_{1/2} > 1.5\ 10^{26}$ y, $<m_{ee}> < 0.09 – 0.15$ eV [PRC81 2010]

GERDA

GERDA Collaboration Meeting

Jagiellonian University in Kraków, 18th-20th February 2008

Uniwersytet Jagielloński w Krakowie

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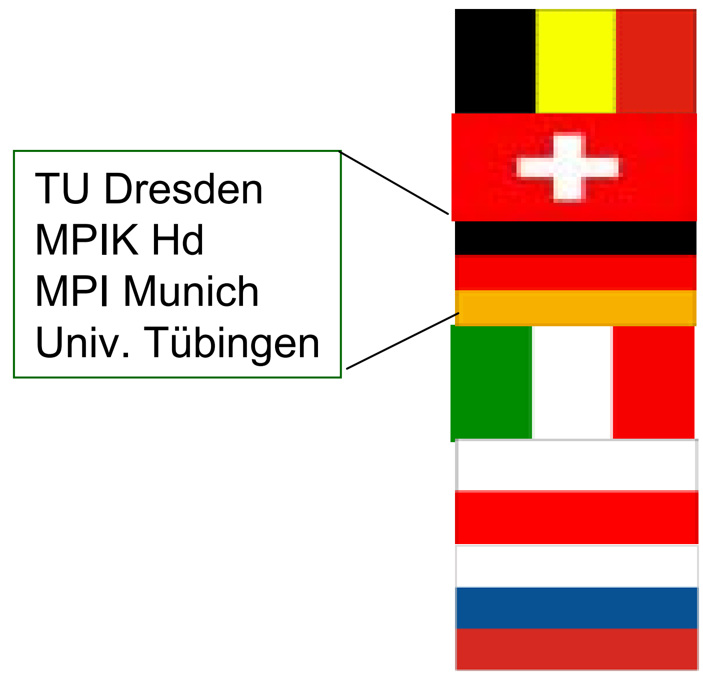
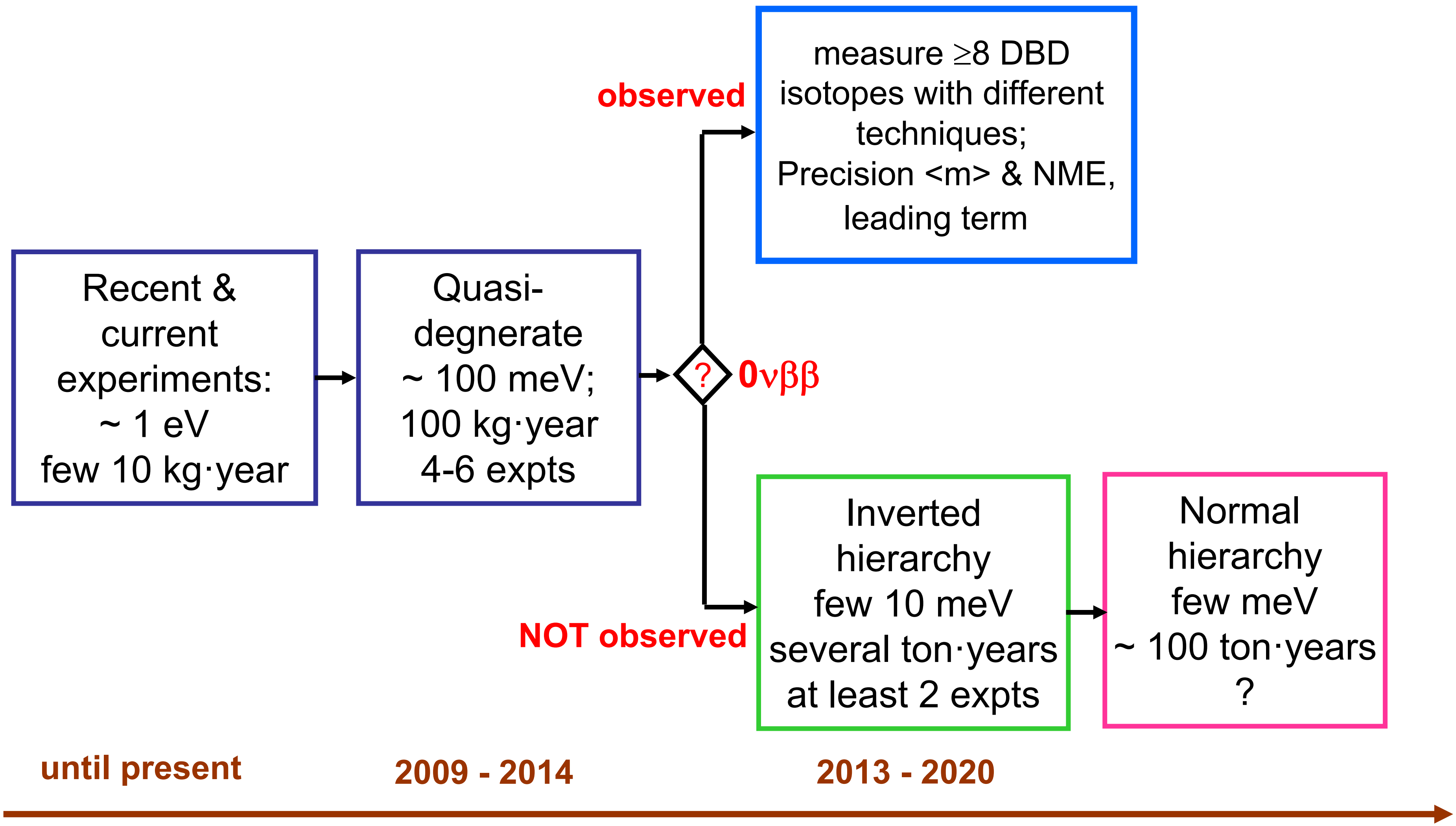


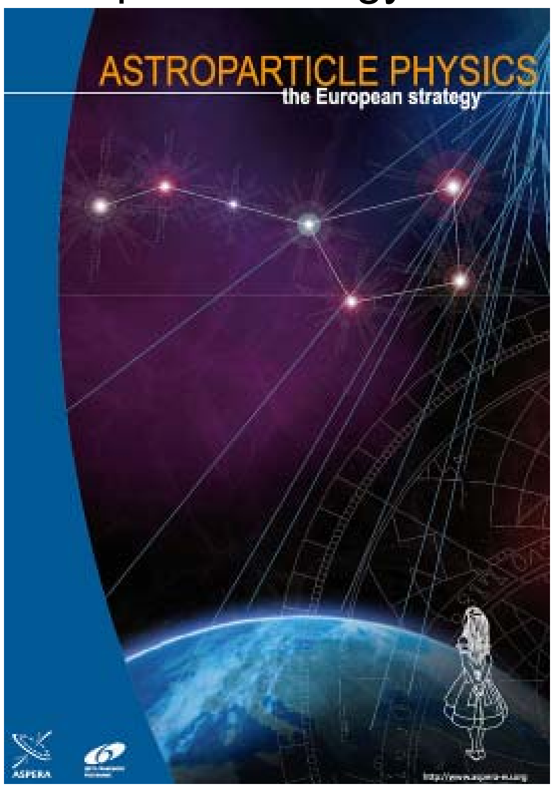
Summary & Outlook

0νββ experimental strategy during the next decade

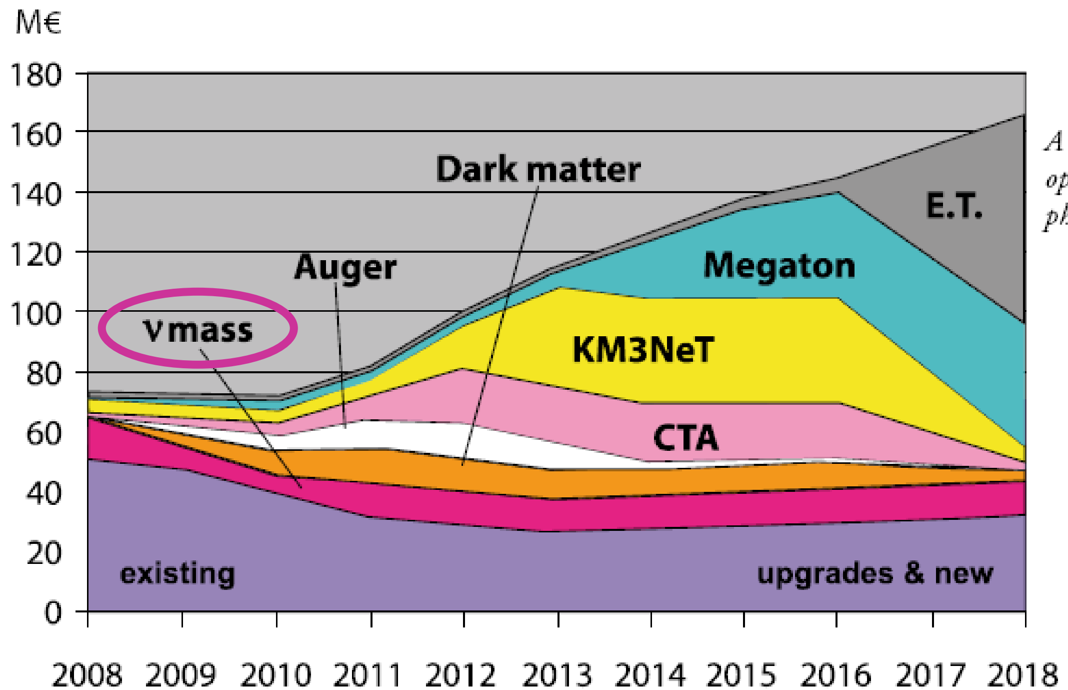


Outlook

ASPERA
European strategy



ASPERA recommendation for Neutrino Mass: Depending on the outcome of the present generation of double beta decay experiments being prepared, we recommend the eventual construction and operation of **one or two double beta decay experiments** on the **ton-scale**, capable of exploring the inverted-mass region, with a **European lead role or shared equally with non-European partners**. A decision on the



Similar financial efforts from North America & Japan required to realize ton scale experiments !

Extra slides

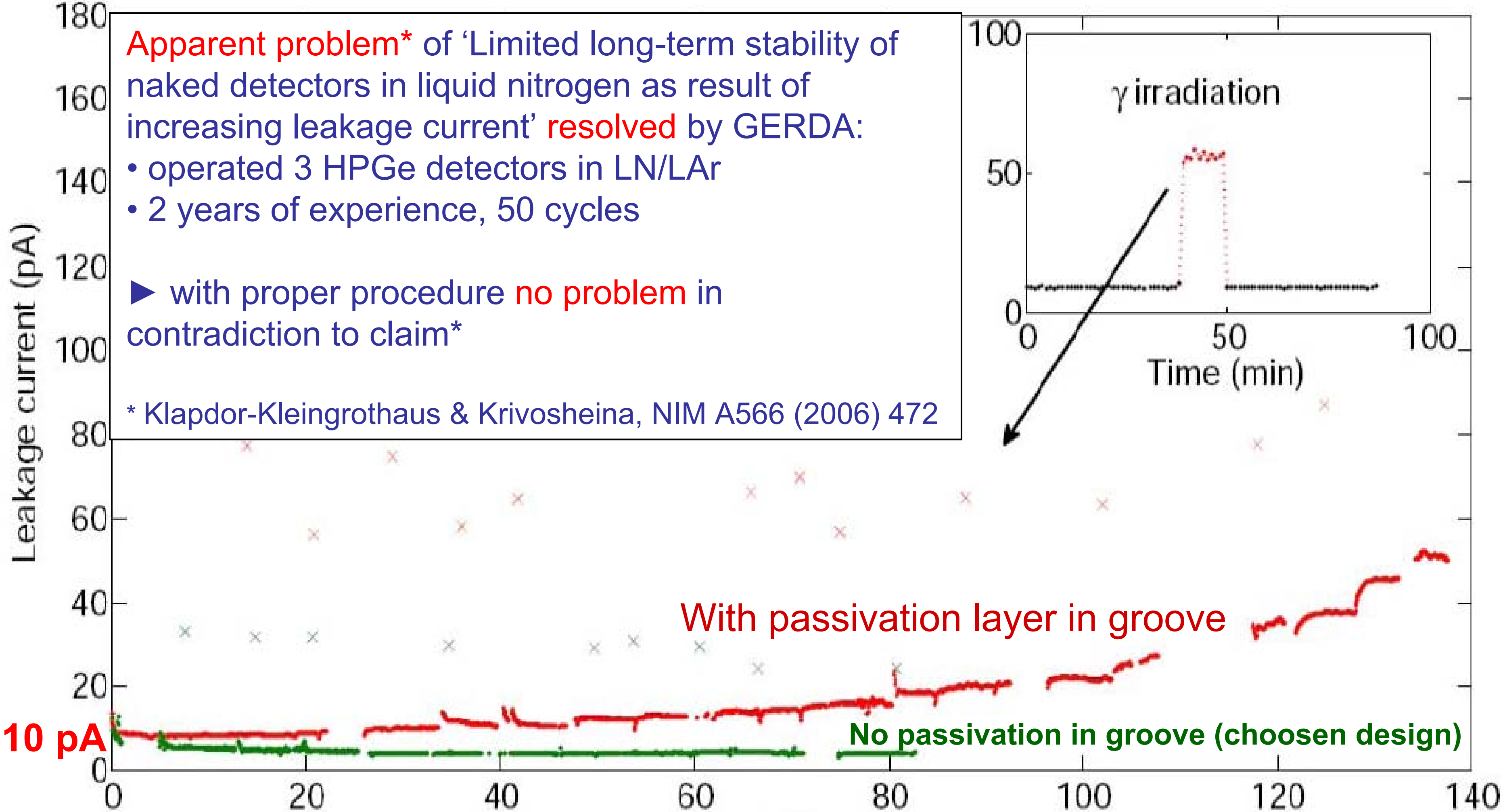
R&D long-term stability of phase I detectors in LAr/LN_2

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*

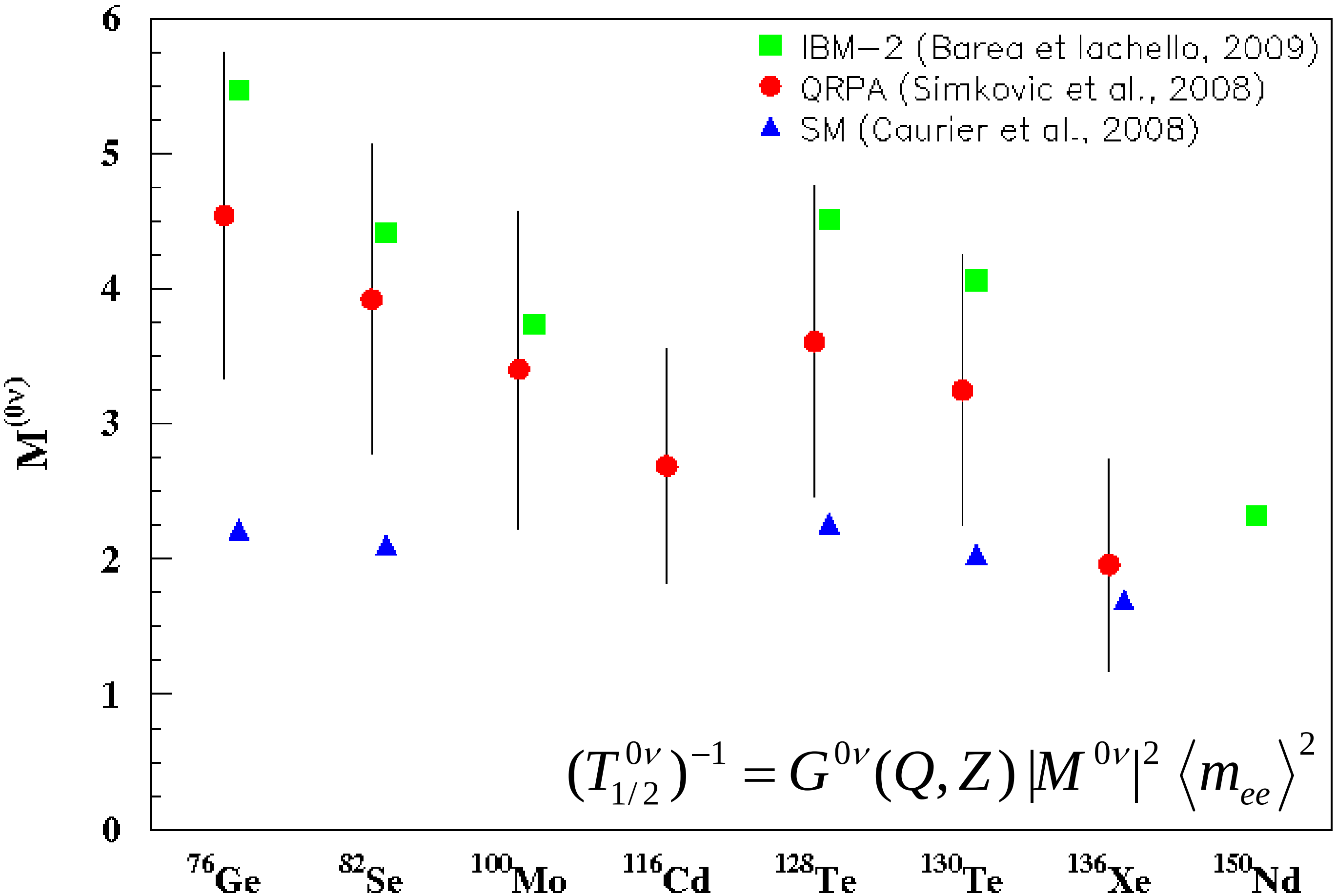
* Klapdor-Kleingrothaus & Krivosheina, NIM A566 (2006) 472



no deterioration after 1 year of operation in LAr

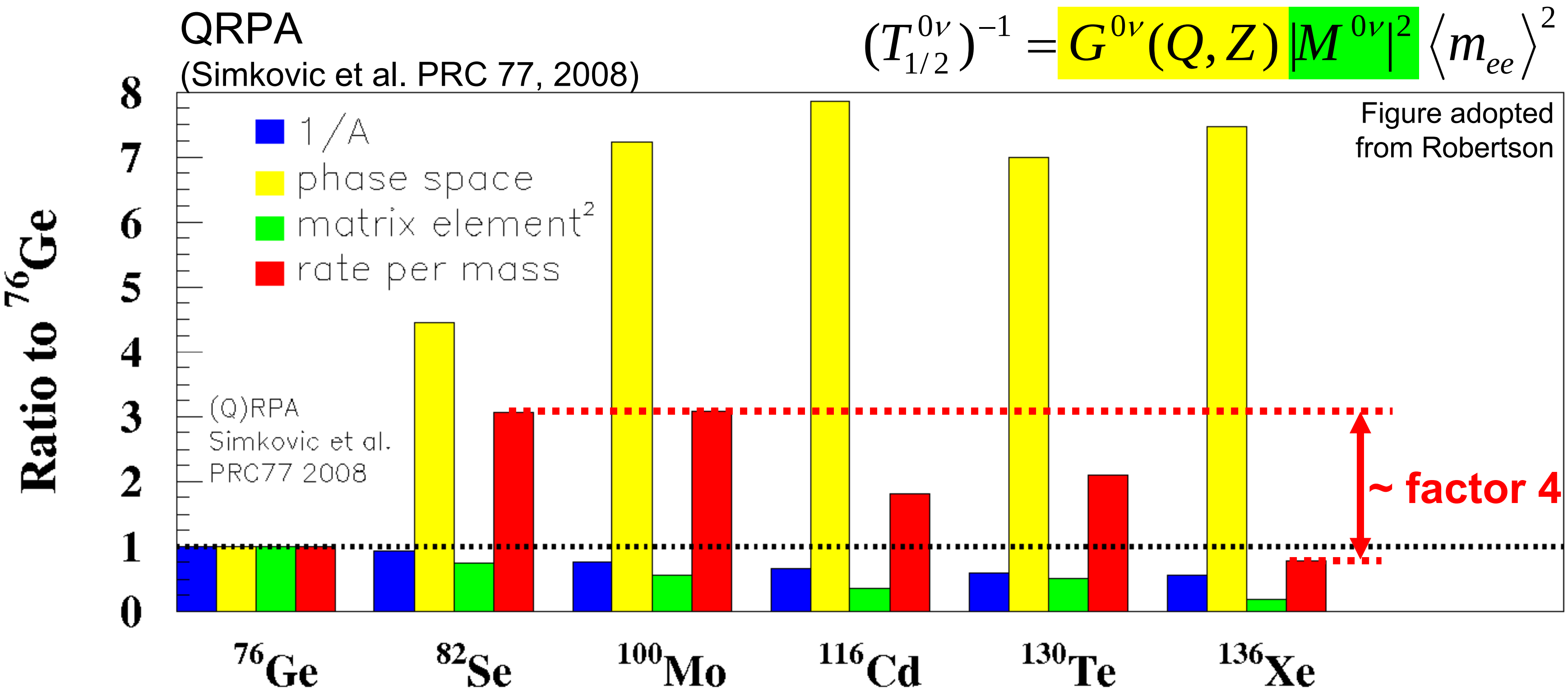
M. Barnabé-Heider, PhD thesis '09

Comparison of DBD isotopes: Recent calculations of nuclear matrix elements



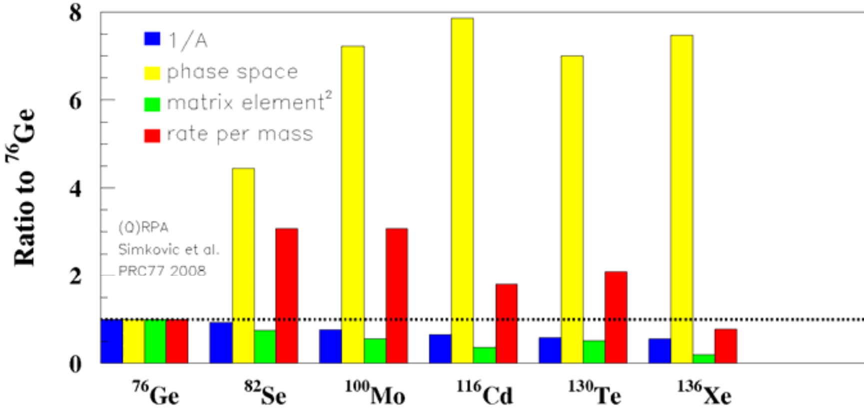
Is M decreasing with $A^{-2/3}$ (IBM-2, QRPA) or constant with A (SM) ?

Comparison of isotopes:
Is there a *super-DBD-isotope* ?



Expected 0νββ **rates per mass** vary within a factor ~ 4 !

QRPA
(Simkovic et al. PRC 77, 2008)

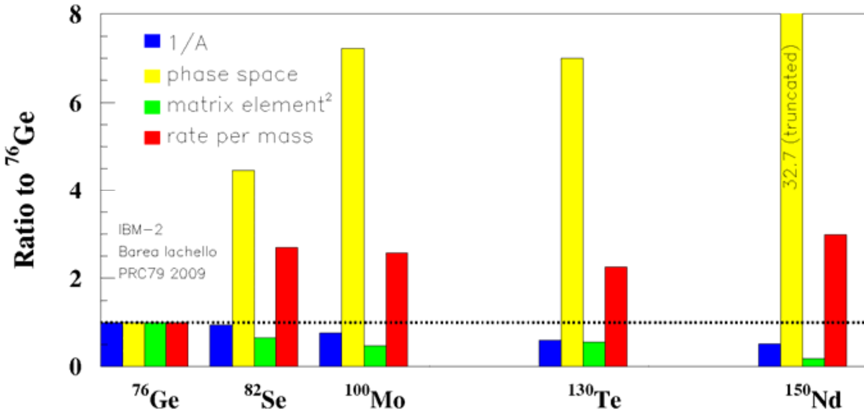


~4

for $\langle m \rangle = 50\,\mathrm{meV}$:

9.1 cts/(ton year)

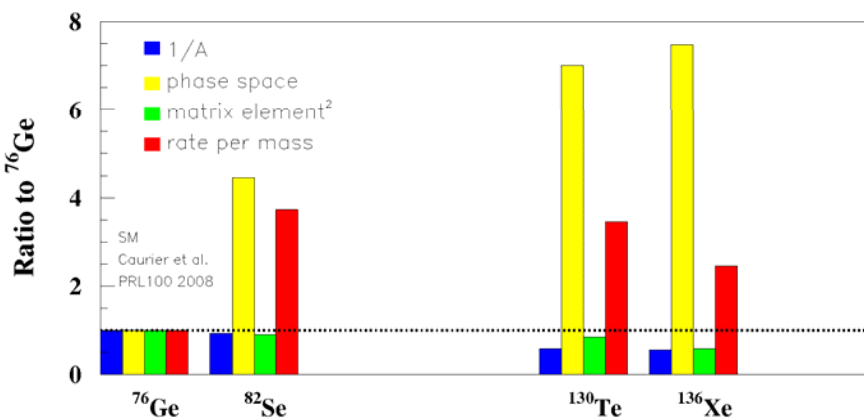
IBM2
(Barea and Iachello, PRC 79, 2009)



~3

13.2 cts/(ton year)

SM
(Caurier et al., PRL 100, 2008)



~4

2.2 cts/(ton year)