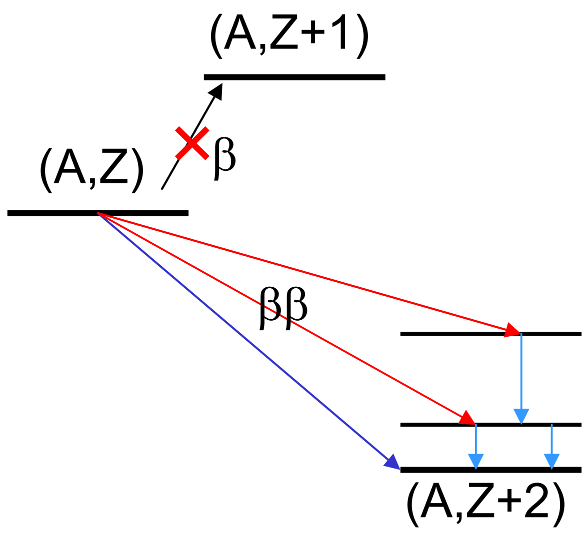
Double Beta Decay searches by semiconductor detectors

C. Cattadori INFN-Milano Bicocca
on behalf of GERDA collaboration

Outline

- Neutrinoless Double Beta ($0\nu\beta\beta$) Decay : The process and the effective Majorana neutrino mass.
- $0\nu\beta\beta$ searches of ^{76}Ge by germanium detectors
  - Motivations
  - Pioneering experiments
  - Recent Past experiments: HdM, IGEX
- Forthcoming experiments
  - GERDA (Status report)
  - Majorana (Status report)
- Other semiconductor experiments (R&D): COBRA
- Conclusions

2νββ



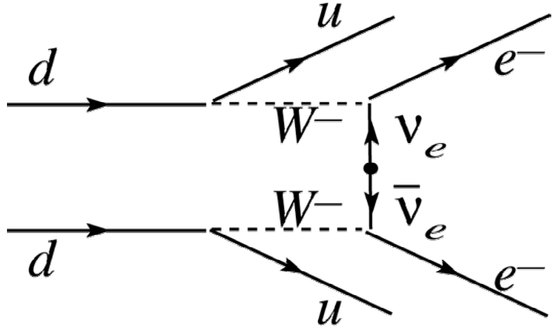
- 2νββ proposed to explain existence of isobars triplets (A,Z),(A,Z+1),(A,Z+2) were β decay (A,Z) → (A,Z+1) is forbidden for energetic reasons. 2νββ allows (A,Z) →(A,Z+2).
- Described and calculated for the first time by M. Goeppert-Mayer (Phys. Rev.1935).

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

- 2^{nd} order process of weak interactions.
- Observed for many isotopes (^{76}Se, ^{100}Mo, ^{48}Ca,^{76}Ge …). $T_{1/2}^{2n} \sim 10^{19} \div 10^{21}$ y.

0νββ

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



Feynman diagram of 0νbb

Proposed by Majorana & Racah in 1937 (*Il Nuovo Cimento*). It is forbidden in SM and requires

- Lepton number violation $\Delta L = 2$
- Neutrino is a Majorana particle having finite mass o $\nu_e = \bar{\nu}_e$ $< m_\nu > \neq 0$

or

- Existence of W_R

0νββ and the effective neutrino mass

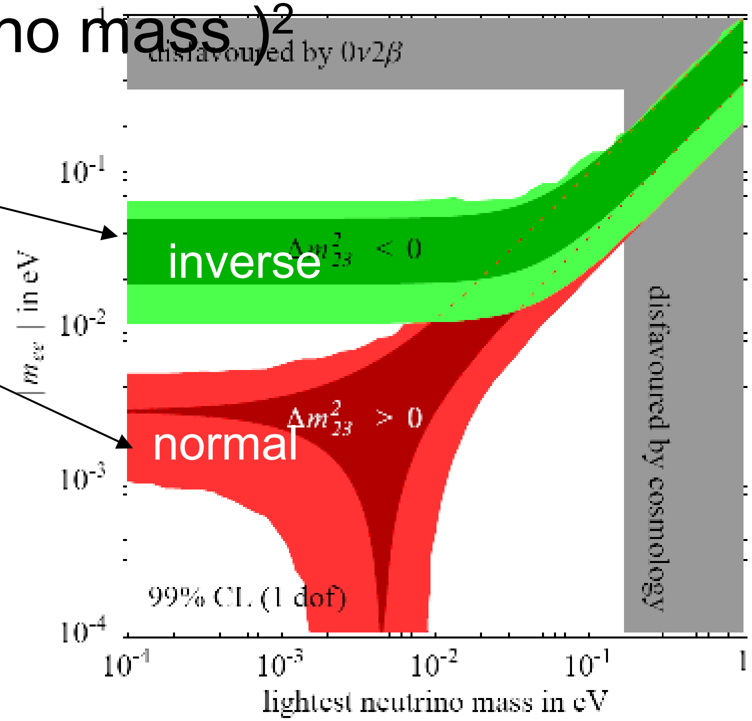
From Vissani, Strumia hep-ph/0606054v2

0νββ rate ~ (effective Majorana neutrino mass $)^2$

$$< m_\nu > \cong \sqrt{m_1^2 + \Delta m_{atm}^2}\left| |U_{e1}^L|^2 e^{i\phi 2} + |U_{e2}^L|^2 e^{i\phi 3} \right|$$

$$< m_\nu > \cong m_1 \left| |U_{e1}^L|^2 + |U_{e2}^L|^2 e^{i\phi 2}\left(1+\frac{\delta m_{solar}^2}{2m_1}\right) \right|$$

$$\Delta m_{atm}^2 = m_3^2 - (m_2^2 + m_1^2)/2$$



Remember: rate is the quantity measured in ββ experiments

$$(T_{1/2}^{0\nu})^{-1} \sim 5 \times 10^{-17}\,[y^{-1}]\; F_{0\nu}(Q,Z)\; |M_{0\nu}|^2\; m_\nu^2/m_e^2$$

0νββ half-life

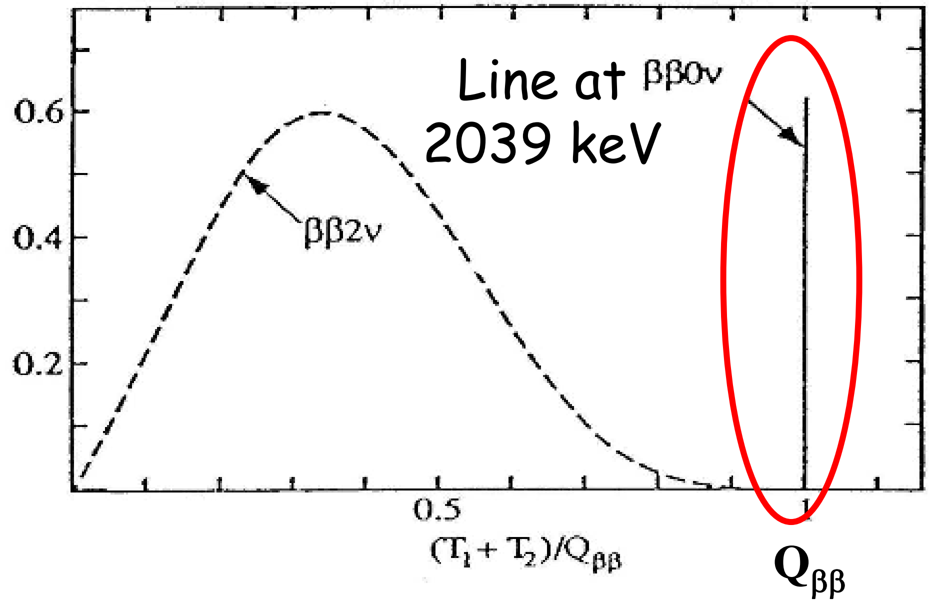
Phase space…

Nuclear Matrix Elements

Effective Majorana neutrino mass

Experimental sensitivity on $T^{0\nu}_{1/2}$

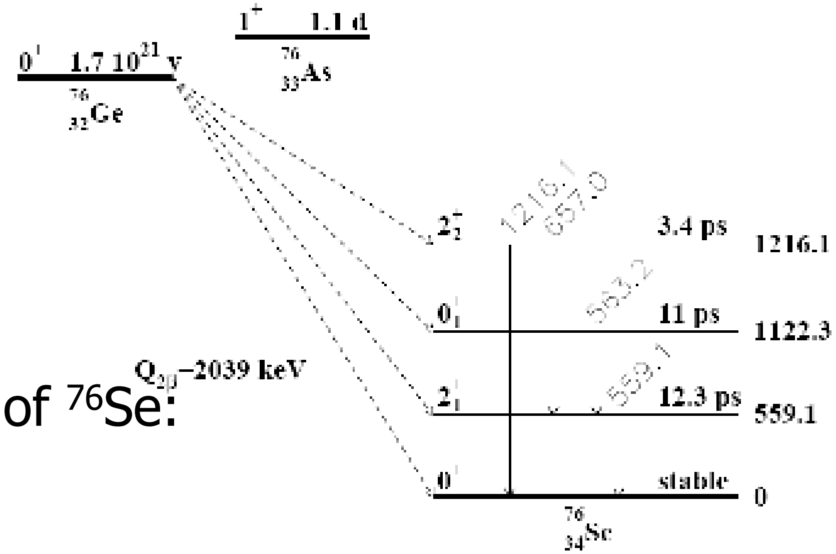
ε = detection efficiency
a = ββ isotope fraction → enrichment
M = mass of detector in kg
T = data taking time [y]
B = background index in cts/(keV kg y)
R = energy resolution at $Q_{\beta\beta}$ [keV]



With bck → $$T^{0\nu}_{1/2} \propto a\varepsilon\sqrt{\frac{MT}{BR}}$$

$$T^{0\nu}_{1/2} \propto a\varepsilon MT$$ ← Bck free

^{76}Ge $\beta\beta$ features



- $Q_{\beta\beta}$=2039.06±0.05 keV
- $2\nu\beta\beta$ of ^{76}Ge observed on ground state of ^{76}Se:
  - $T_{1/2}{}^{2\nu}$: 1.4 x 10^{21} y
- Estimated $T_{1/2}{}^{0\nu} \sim 10^{27}$ y
  (for $<m_\nu>$= 40 meV, and $M_{0\nu}{}^{nucl}$ = 3.9 (QRPA Rodin et al erratum)) .

Why $\beta\beta$ searches of ^{76}Ge have so long history?

- Germanium detectors is an established technology: adopted since the '60 to search for $0\nu\beta\beta$ of ^{76}Ge.
- Feasible to scale up experiment by subsequently adding more detectors.
- Source = detector → high efficiency!
- High intrinsic purity and energy resolution $\mathcal{O}$(0.1%-0.2%) allowing understanding of background sources and geometry.
- ^{76}Ge isotopic abundance = 7.44 %, but enrichment of ^{76}Ge possible at centrifuge up to >80%.
- Ge density = 5.3 g cm^{-3} → compact setup
- Low Atomic Weight (1 kg of ^{76}Ge = 13.1 Moles = 7.9 x 10^{24} nuclei)

ββ searches of ^{76}Ge by germanium detectors: first experiment

Volume 25B, number 10 PHYSICS LETTERS 27 November 1967

27 November 1967

A SEARCH FOR LEPTON NON-CONSERVATION IN DOUBLE BETA DECAY WITH A GERMANIUM DETECTOR

E. FIORINI and A. PULLIA
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G. BERTOLINI, F. CAPPELLANI and G. RESTELLI
Euratom, CCR, Ispra, Italy

Received 30 October 1967

A new technique is applied to the search for neutrinoless double β decay. A Ge(Li) crystal is used both as source and as detector of the ^{76}Ge → ^{76}Se transition. Our negative result ($T_{\frac{1}{2}} > 3 \times 10^{20}$ y) is consistent with the lepton conservation law.

Volume 25B, number 10 PHYSICS LETTERS 27 November 1967

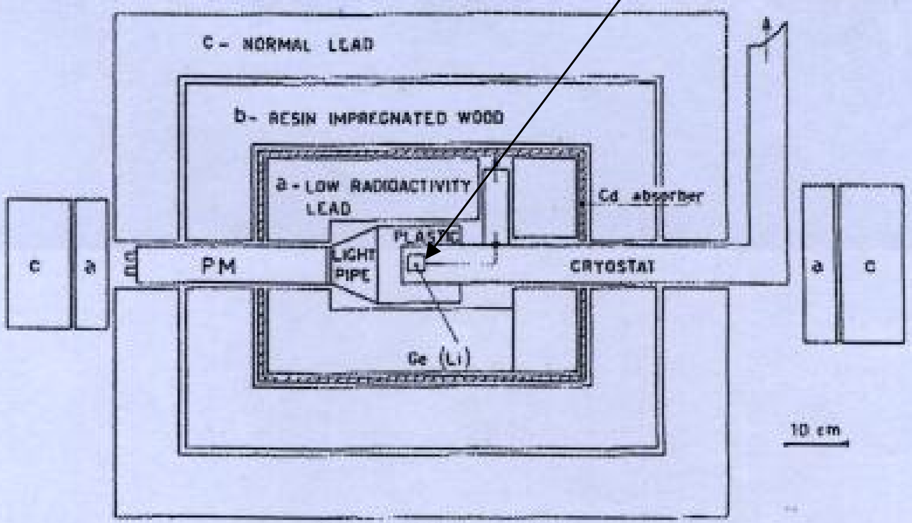


Fig. 1. Experimental setup.

Ge(Li) mass 90 g.

Resolution 4.7 keV @ 1.32 MeV

Running time = 712 h

Result:

$T_{1/2} > 3.1 \times 10^{20}$ y (68% C.L.)

Bckgrd = 1.1×10^{-2} h^{-1} keV^{-1}

Lepton no. is conserved.

Expected $T_{1/2}$:

$0\nu\beta\beta$: $10^{17\pm 2}$ y

$2\nu\beta\beta$: $10^{20\pm 2}$ y

…. Then followed by Mont Blanc experiment (2xGe(Li)): final results '87

…..Caldwell experiments ('88)

$0\nu\beta\beta$ searches of ^{76}Ge : experimental results from the '70s-'80s

TABLE I: Recent $\beta\beta_{0\nu}$ Results for the 0^+-0^+ Transition in ^{76}Ge

Group	Background c/keV·y·kg	Ge kg	$T_{1/2}$ Limit 10^{23}y (1σ)
Zaragoza-Bordeaux-Strasbourg	40	2.2	0.2
Caltech-SIN-Neuchatel	4	0.48	0.6
Osaka	6	0.88	0.7
Pacific Northwest-South Carolina	2.4	0.67	1.4
Guelph-Aptec-Queens	~2	3.0	1.6
Milan	24.4	1.4	1.8
UCSB-LBL	1.7	7.1	4.1

While the limits have improved appreciably in recent years, further improvements will come slowly. Quantities of Ge will not undergo very large increase, backgrounds will improve but not by large factors, and the limit improves only as the square root of the counting time. The one way there could be a significant change in the prospects for Ge experiments is if the Moscow-Leningrad-Heidelberg collaboration succeeds in fully utilizing the large quantity of enriched ^{76}Ge they and they alone are able to obtain. The promised 15 kg of ^{76}Ge would be worth several hundred million dollars in the West. If that could all be used effectively, they would have a factor 20 advantage over the UCSB-LBL experiment. There is normally a large loss of material in making the crystal and a lesser loss in making detectors from the crystal. Also, separated isotopes tend to have radioactive contamination. However, if these problems can be overcome, the next big step for Ge experiments should be taken by this group.

From Caldwell talk
Nu1986 @ Sendai

Heidelberg-Moscow experiment @ LNGS: claim of evidence of 0νββ of ^{76}Ge (2004)

***MT* = 10.9 kg (86% ^{76}Ge) x 13 yr x 0.8%**
= 72 kg yr

***b* = 0.11 cts/(kg keV yr) before PSA**

Resolution ΔE = 3.27 keV

Claimed evidence of 0νββ @ 4.2 σ

$T_{1/2}$ = 1.2 x 10^{25} y

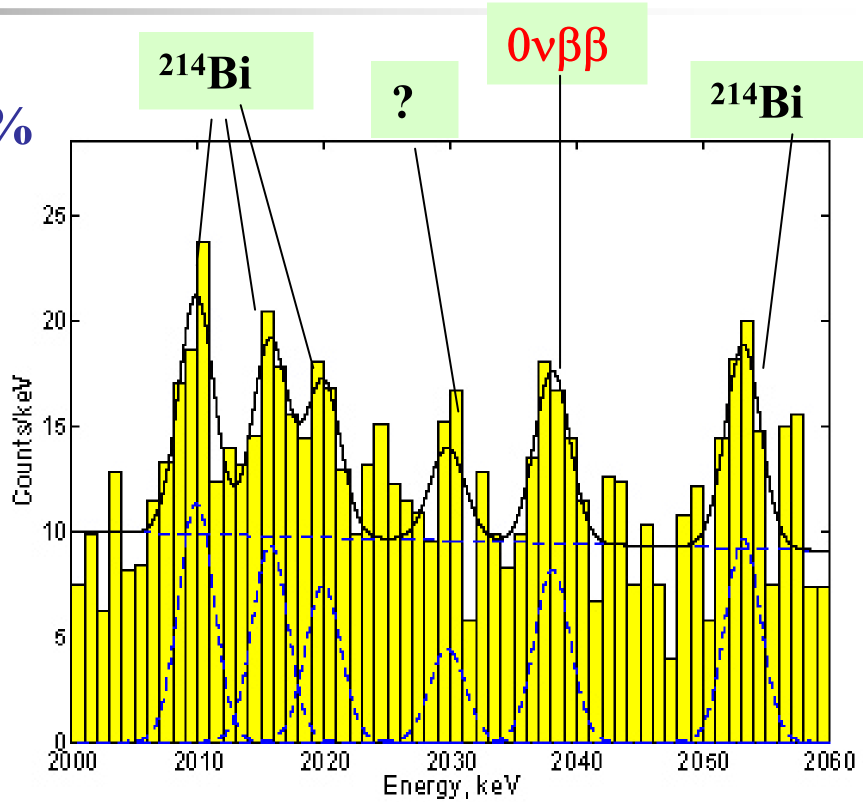
Corresponding to

M_{ee}= 440 meV with KK ME

Signal found at

$Q_{\beta\beta}^{exp}$ = 2038.70 ± 0.44 keV

$Q_{\beta\beta}^{theo}$ = 2039.06 ± 0.05 keV



IGEX

Collaboration: (**ITEP,INR,U.South Carolina PNNL, U. of Zaragoza, Yerevan)**

Location: Canfranc UL (Spain)

- Pulse shape discrimination
- 117 mol · y = 8.9 kg · y
- Bkg at 2 Mev ≈ 0.1 (with PSA)/ 0.2 (without PSA) [cts/(keV· y)]
- Enriched Ge diodes
  - **$T_{1/2} > 1.57\ 10^{25}$y with PSA**
  - **$M_{ee} < 0.33\text{-}1.3$ eV**

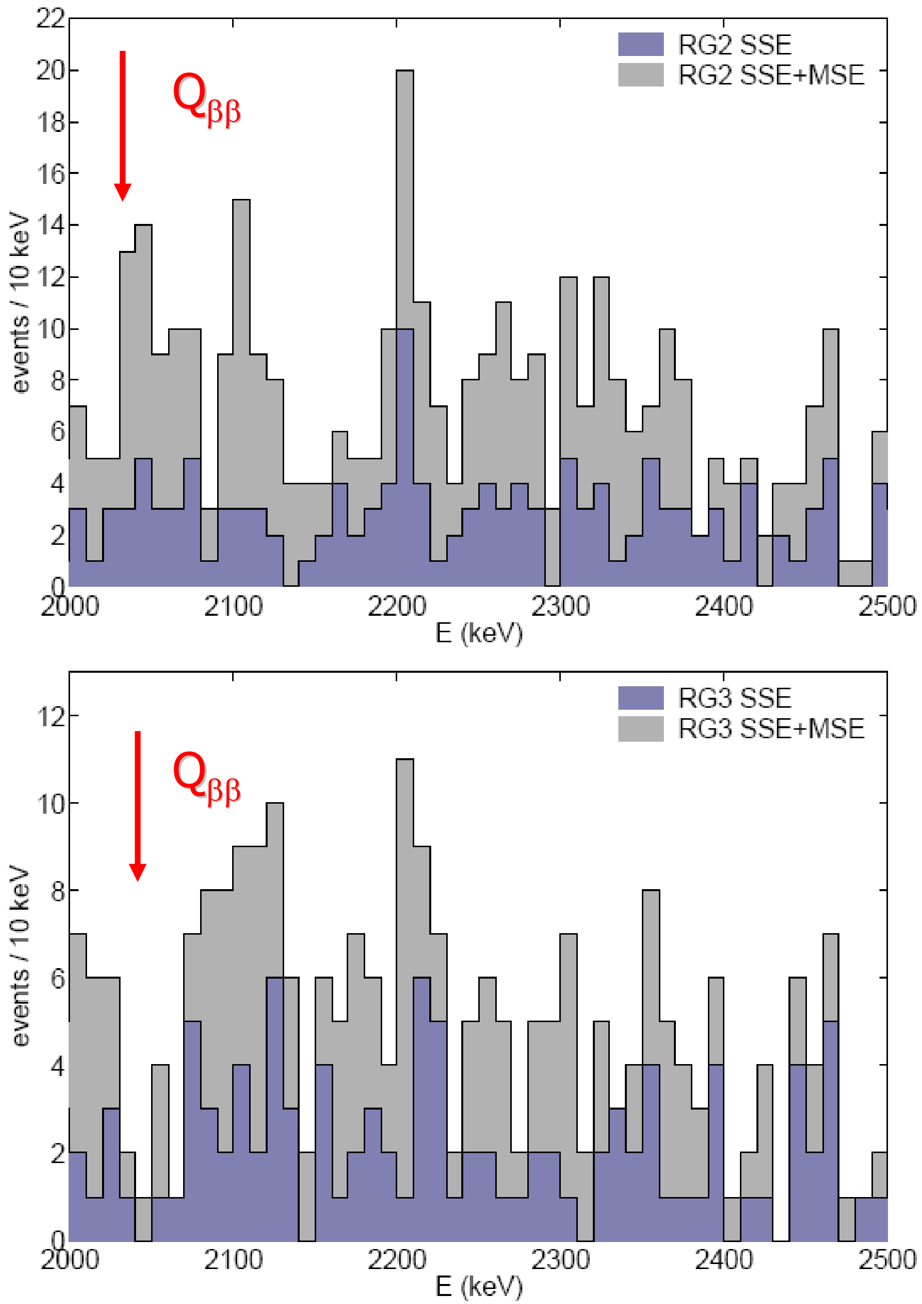


Figure 10: Background spectra before and after the PSD based on the counting of the number of lobes for detectors RG2 (top) and RG3 (bottom).

GERDA: Collaboration

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~85 physicists
15 institutions
6 countries

Goals and distinctive features of GERDA
(GERmanium Detector Array)

- Investigation of $0\nu\beta\beta$ decay of ^{76}Ge. Location:
  - Staged Approach (Phase I + Phase II+ …).

- Build a setup having a background @ $Q_{\beta\beta} \leq 10^{-3}$ cts/(kg·keV·y) adopting passive/active shielding.

- Use of bare diodes in cryogenic liquid (LAr) of very high radiopurity. Technique proposed by G. Heusser (Ann. Rev. Nucl. Part. Sci. 45(1995)543) and tested by KK in GENIUS_TF @ LNGS (GENIUS proposed in 2000) with non encouraging results (NIM2004) . Problems reported have been overcome by GERDA collaboration.

- Use of detectors with improved SSE/MSE discrimination (Phase II).

Phases of GERDA

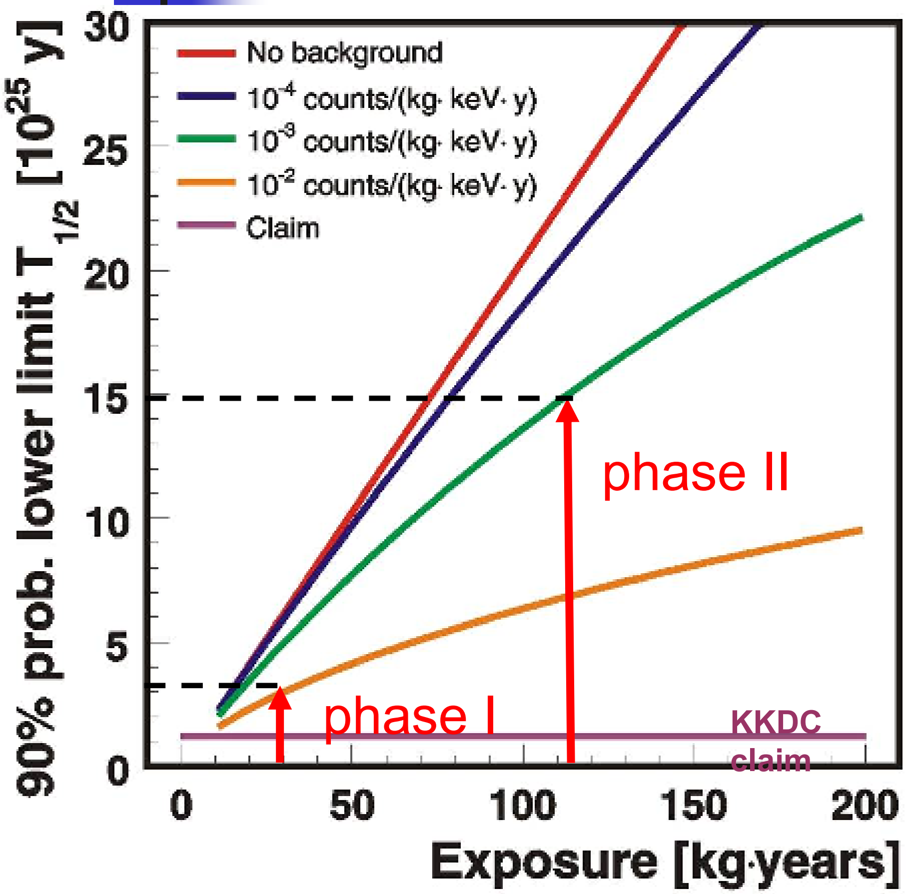
- Phase I:
  - Use of existing ^{76}Ge-diodes from Heidelberg-Moscow and IGEX-experiments
  - 8 detectors for 17.9 Kg of ^{enr}Ge
  - Expected Background ~ 10^{-2} count/(kg·keV·y) dominated by crystal internal backg. → KKDC evidence verified in an external background-free setup.

- Phase II:
  - Add new diodes (+22 kg, total: ~40 kg ^{enr}Ge) able to discriminate SSE/MSE.
  - Demonstration of bkg-level $<10^{-3}$ count/(kg·keV·y)

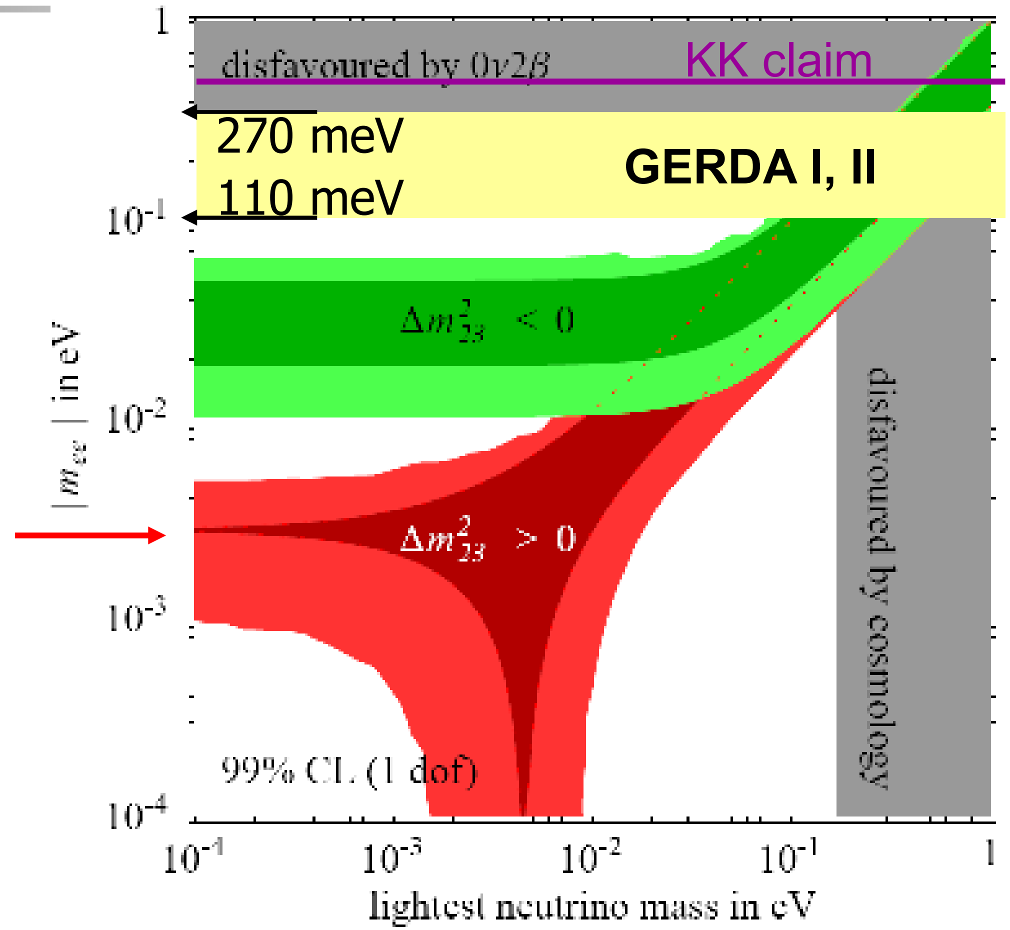
- Eventually Phase III:
  - If background OK
  - If KKDC-evidence not confirmed: $\mathcal{O}$(1 ton) experiment by a worldwide collaboration with Majorana

GERDA: Sensitivity

Assumed E resolution: ΔE = 4 keV

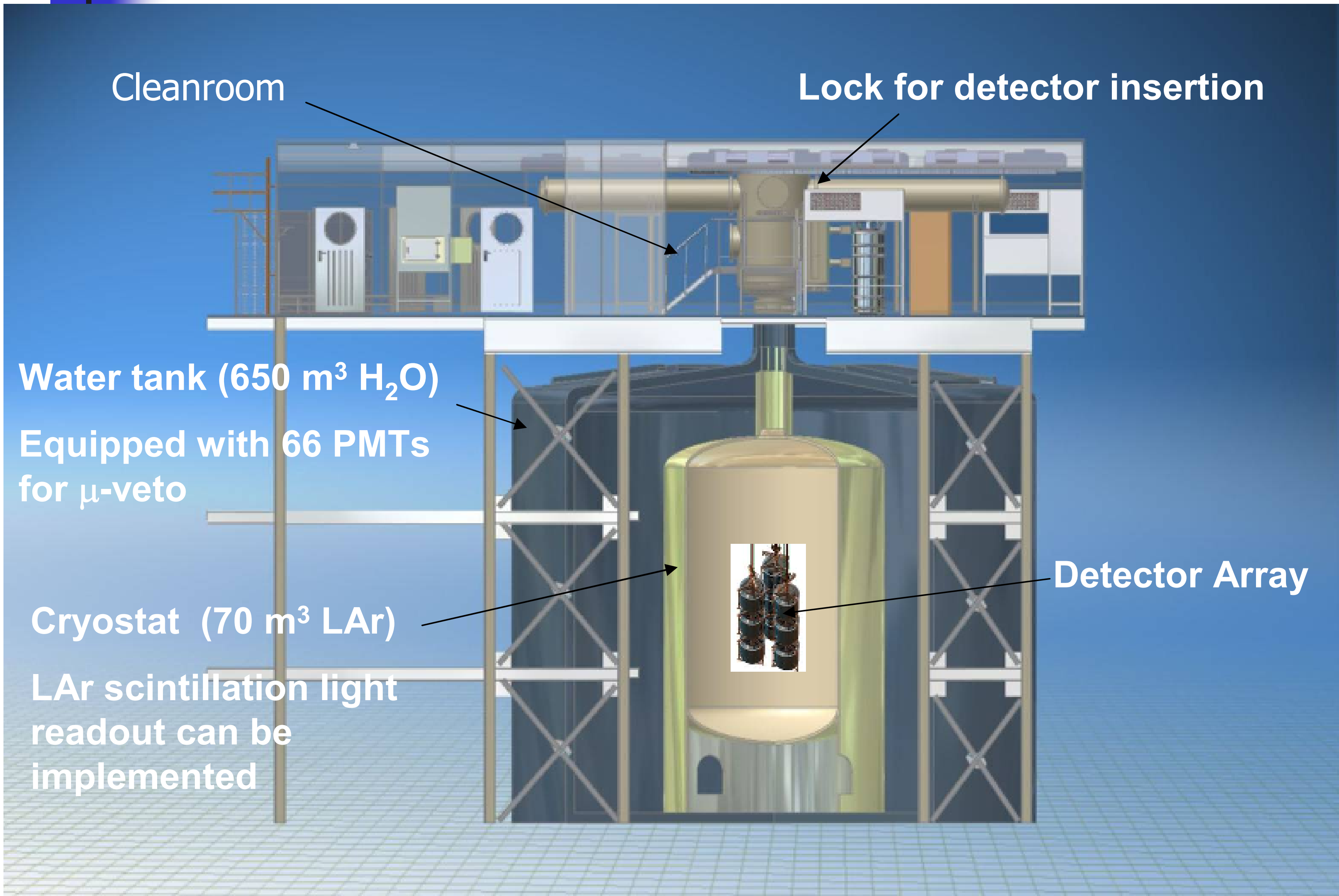


From Vissani, Strumia hep-ph/0606054v2



→ if signal found in HM by KK is true ββ decay, this would produce in ~ 1 year GERDA I data taking (assuming 18 kg y exposure) 7 cts, above bckg of 0.5 cts → probability that bckg simulate signal ~ 10^{-5}

GERDA design



GERDA:Status of Cryostat

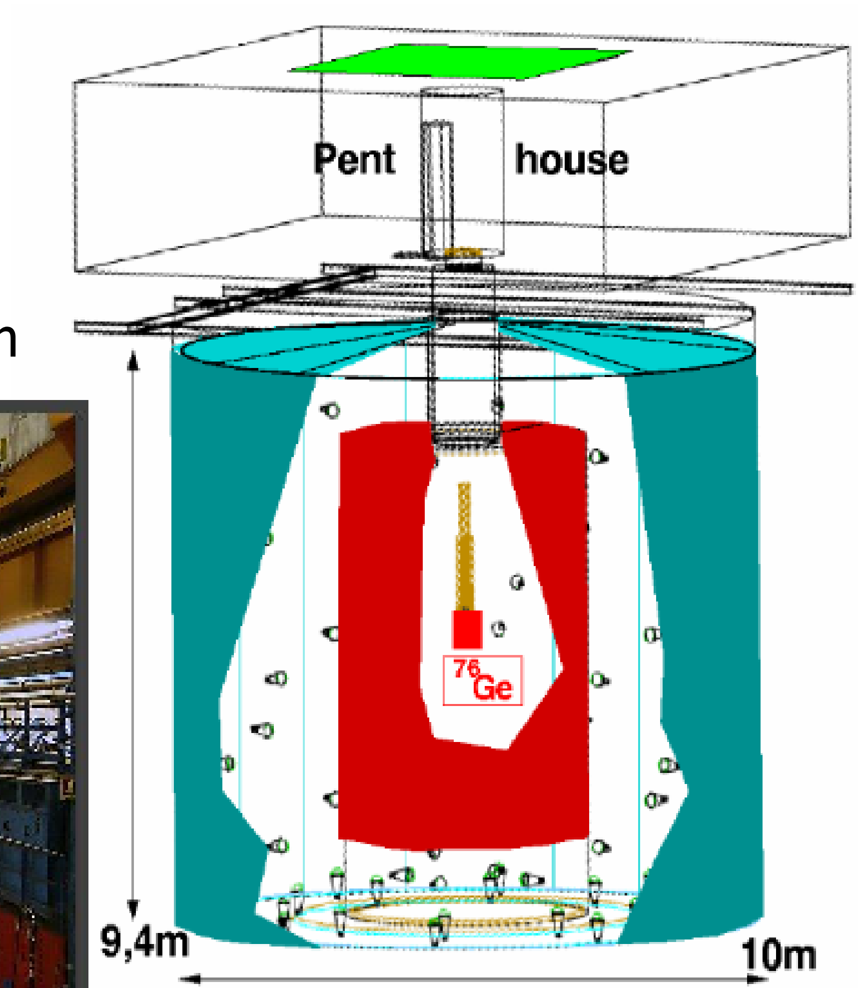
Built with low activity steel

1-5 mBq/kg

- Cryostat arrived at LNGS: 6 March 2008
- Rn emanation OK
- Mounting of inner Cu shielding plates (thickness 3/6 cm) completed
- LAr evaporation rate tested (< 2% day^{-1})
- LAr scintillation light readout to reduce external bckg in detectors can be implemented

Water tank and muon veto

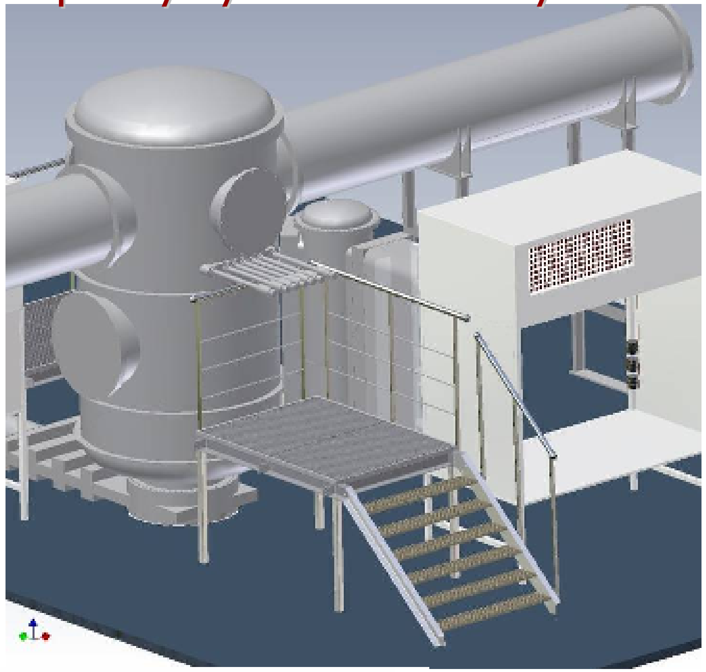
- Active shield
- Filled with ultra-pure water from Borexino plant
- 66 PMTs: Cherenkov detector
- Plastic scintillator on top of cleanroom

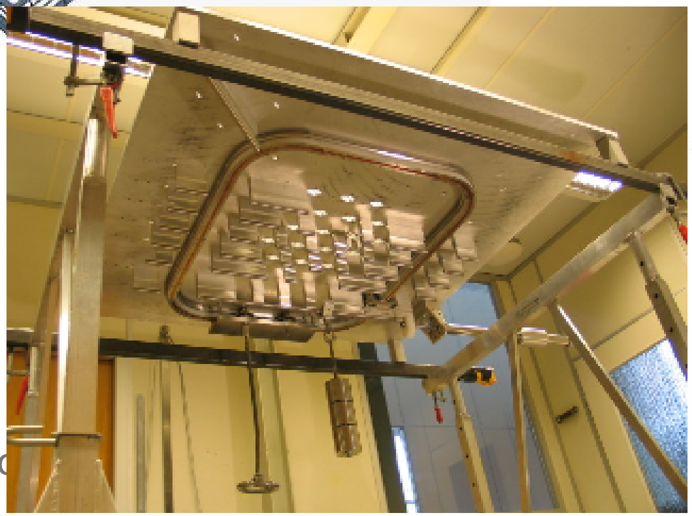


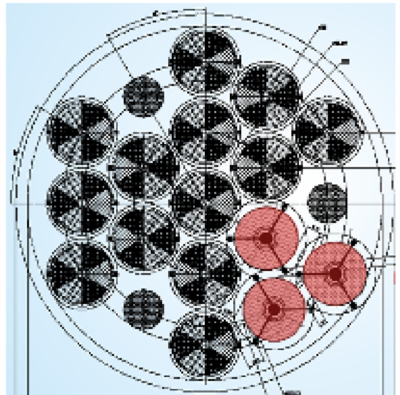

19 may 2008

Cleanroom and the lock system

Positioning of strings inside lock by internal rail system. Push strings to array position with magnet arms. Linear pulley system driven by motors. Control through PLC system

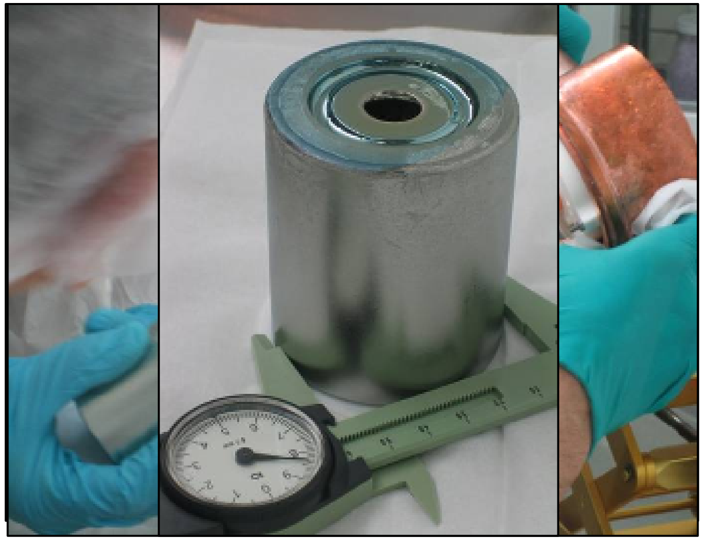






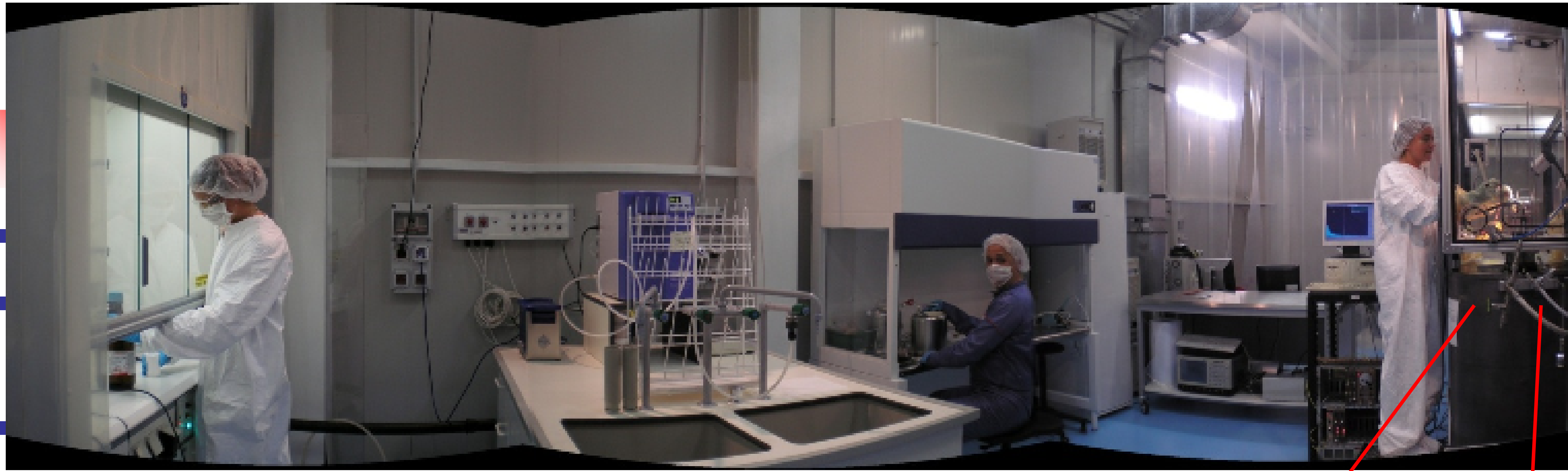
Status of Phase I detectors

- IGEX and HdM diodes were removed from their cryostats and measured
- 17.9 kg enriched and 15 kg non-enriched crystals (GENIUS-TF) available
- Reprocessing of all diodes at manufacturer (ongoing)
- Stored underground during reprocessing dead-time (HADES)
- Dedicated low-mass Cu holder constructed for each diode.

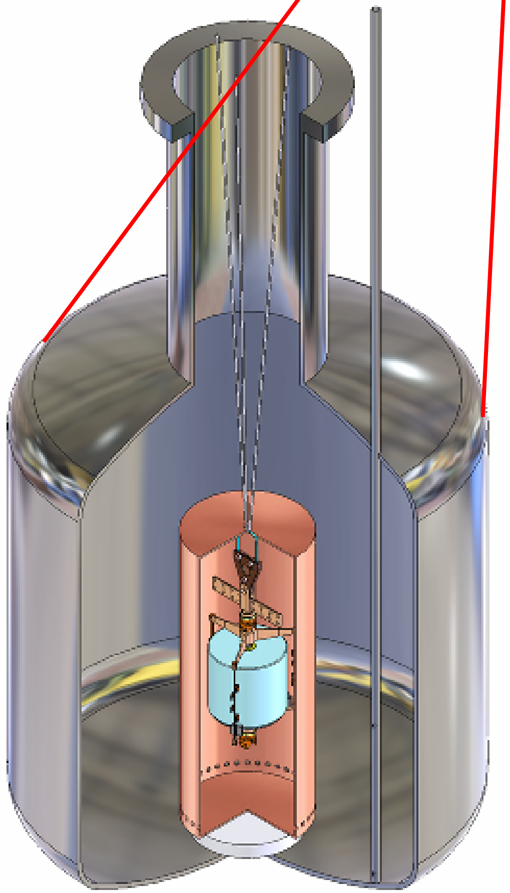


Resolutions of former HdM (ANG) and IGEX (RG) detectors measured in original cryostats after delivery and maintenance to LNGS

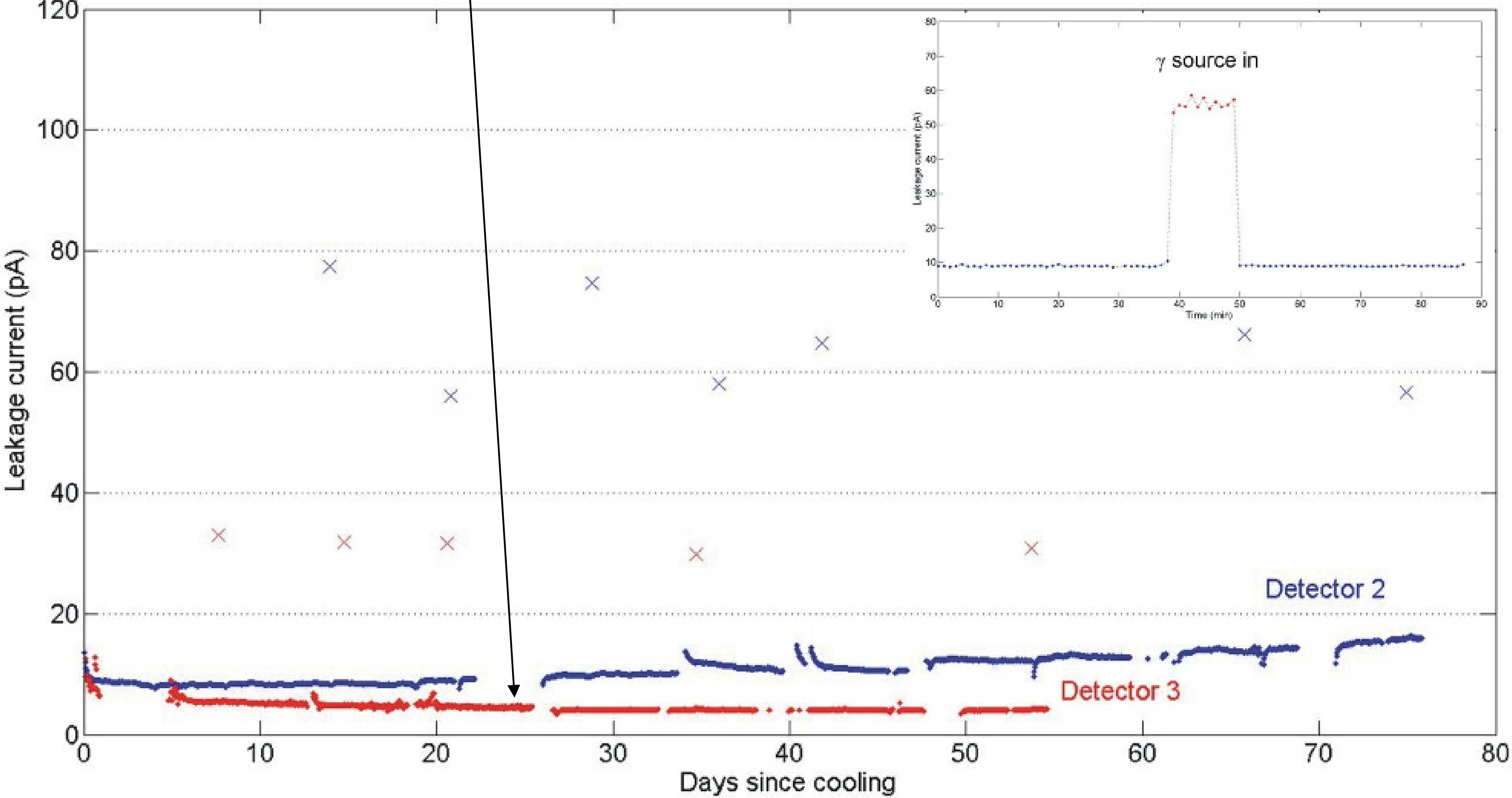
	ANG1	ANG2	ANG3	ANG4	ANG5	RG1	RG2	RG3
FWHM [keV]	2.54	2.29	2.93	2.47	2.59	2.21	2.31	2.26
Mass [kg]	0.980	2.906	2.446	2.400	2.781	2.150	2.194	2.121



- Detector leakage current stable and under control allowing weekly calibrations.
  - Observed effect i.e. LC increase, as a consequence of γ-ray irradiation understood and under control
- Long-term stability tests : OK
- The same performance in LAr and LN_2 observed.
- Resolution achieved in LAr @ ^{60}Co, warm preamplifier (CSA):
  - 2.2 keV, CSA @ d=40 cm from detector
  - 3 keV CSA @ d=80 cm from detector



New: Prototype detectors performances and stability

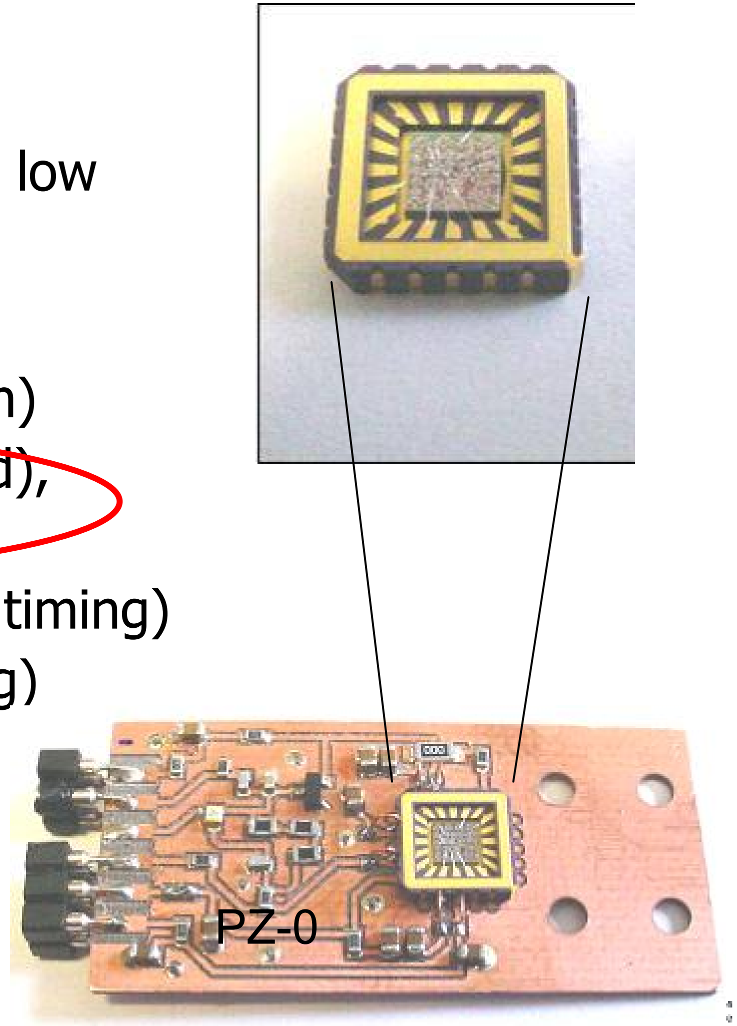


Poster n. 55 in Poster Session

PHASE I Front-End (FE) electronics & DAQ

FE CSA will be located and operated at the top of the string, i.e. in LAr at 87 K.

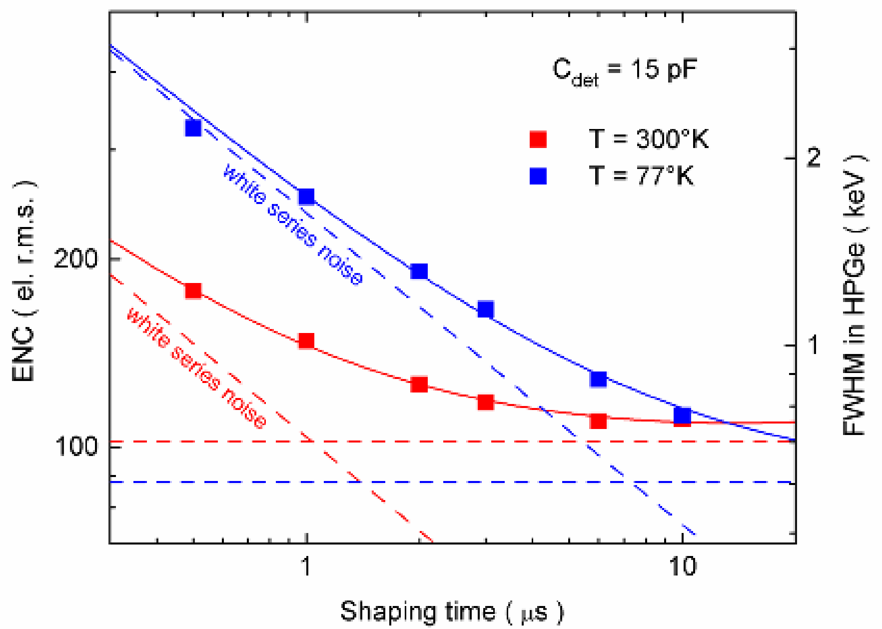
- Requirements:
  - Low noise, low radioactivity i.e. low mass, low power consumption, operational at 87 K
- Few Candidates:
  - F-CSA104 (fully integrated, poor resolution)
  - PZ-0 (ASIC CMOS:FET,Cf,Rf not integrated),
  - SR-1 (ASIC CMOS: Fully Integrated)
  - IPA4 (not fully integrated, good E_{res},poor timing)
  - CSA-77 (partly cold, good E_{res}, good timing)



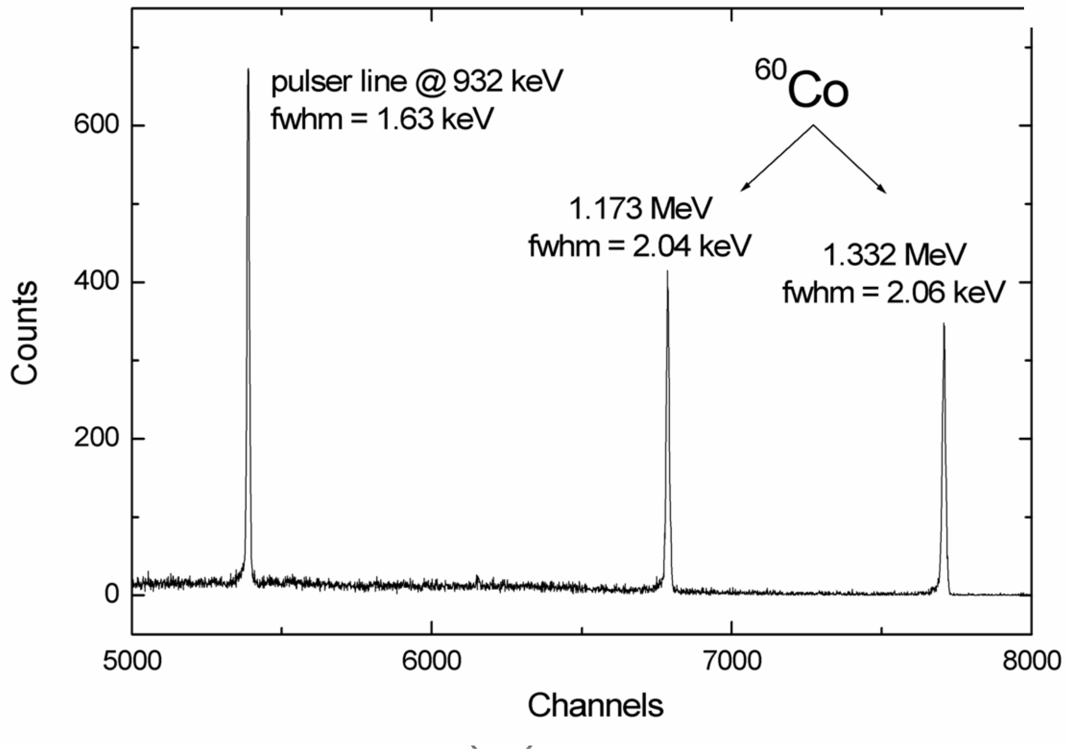
DAQ system: FADC based

New: performances wit

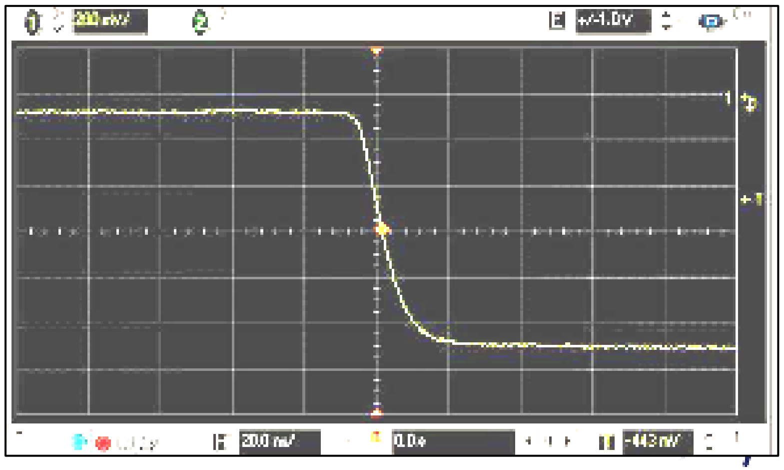
Comparison between **noise measured** at room temperature (T=300°K) and in LN (T=77°K)



Best resolution obtained with (encapsulated) prototype crystal and cold PZ0 CSA



Acquired output signal driving a 50 Ω coaxial cable of ~ 10 m : rise time of ~ 15 ns

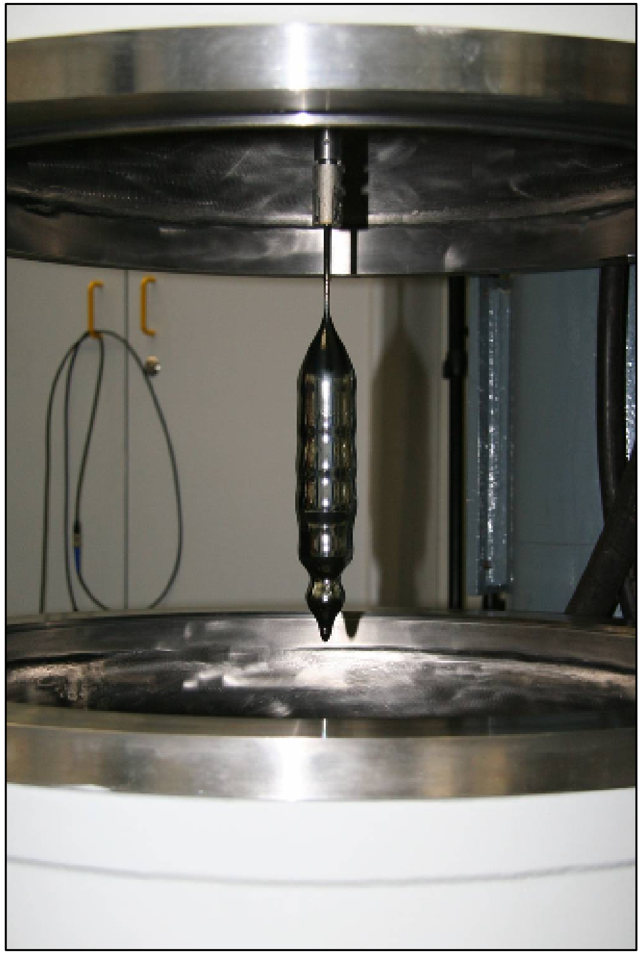


C. Cattadori

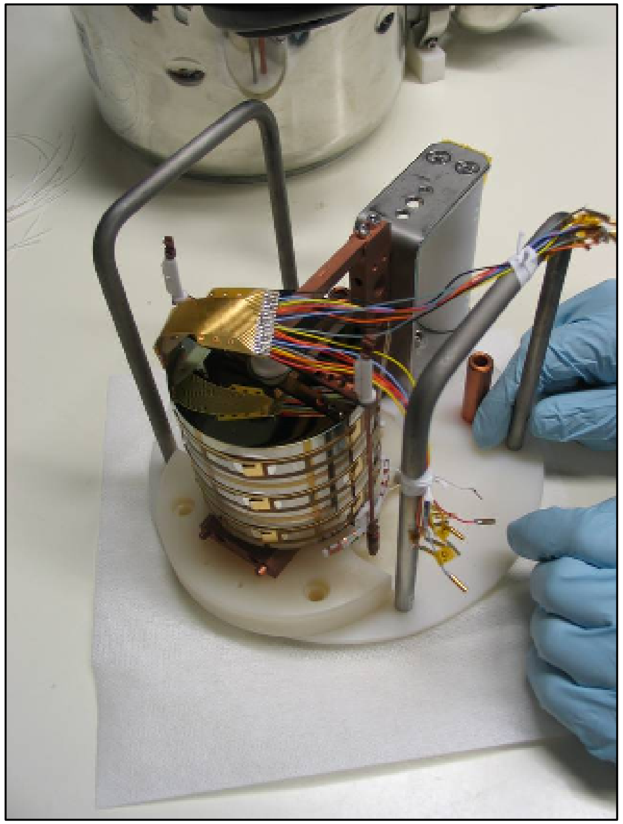
INFN Istituto Nazionale di Fisica Nucleare

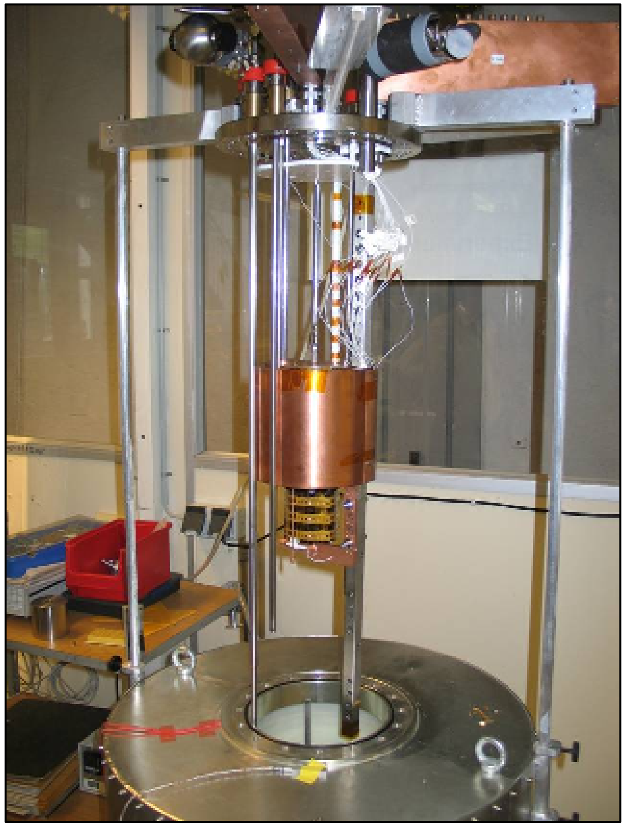
Phase II crystal pulling

- ^{enr}Ge purchased (37.5 kg) presently stored at HADES
- Activities related to crystal pulling started on ^{nat}Ge
    - @ PPM for GeO_2 purification
    - @ IKZ (Berlin) for crystal pulling
- $^{nat}GeO_2$ reduced to metal bars and purified to 6N material for Czochralski pulling
- No impurities detected with ICPMS measurements
- First crystal pulled@ IKZ Berlin, characterization will follow



Phase II: Results with prototype detectors



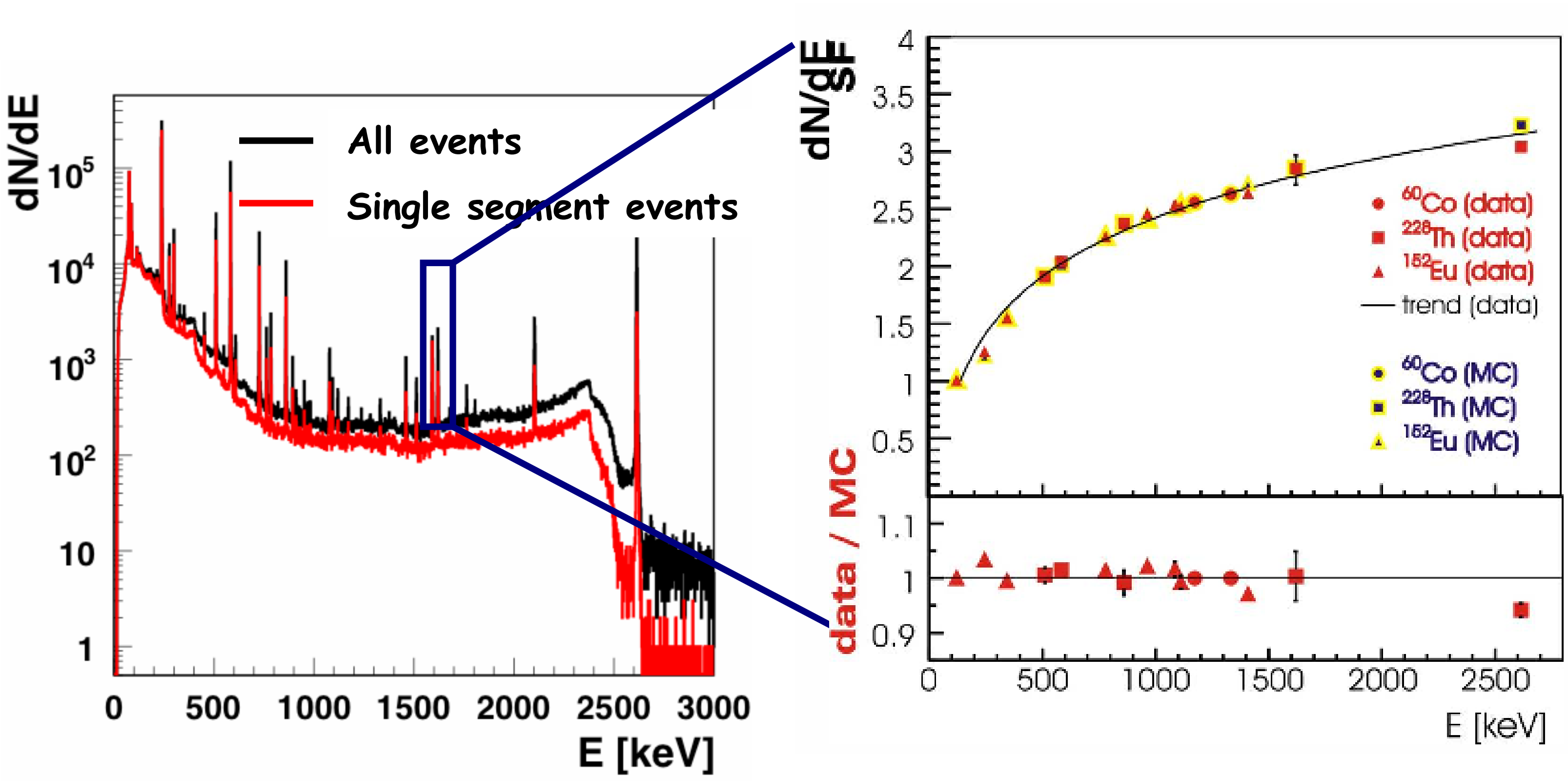


A possible segmentation scheme is 18 fold (6 Φ x 3 z). Tested contacting technique: it works in cryogenic liquid. First spectra taken with core and all 18 segments. Energy resolution(core): ~ 4 keV @ 1.3MeV (preliminary).

We are considering the use of point contact detectors: much simpler readout. First PS studies encouraging!

Phase II: Results with prototype detector

Study of ^{208}Tl Double Escape Peak @ 2614-1022 keV= 1592 keV



Compton Background Suppression factor @ $Q_{\beta\beta}$: ~ 3

Agreement with MC

GERDA: Background evaluation and reduction

Source	Actions
γ's from external environment ^{208}Tl and ^{214}Bi	▪Shield with hyperpure liquids (H_2O 3 m+LAr 2 m) $\Rightarrow$ 3×10^{-5} kg^{-1}y^{-1}keV^{-1}
^{228}Th (<10 mBq/kg) in Cryostat (SS)	▪HP Cu shield (25 µBq/kg; 10-15 cm thick)+LAr
μ induced prompt signals	▪~1400 m rock overburden ▪Anticoincidence between crystals(&segments) ▪μ-vetoes: top (plastic scint.) +Water Cherenkov $\Rightarrow$ 10^{-4} kg^{-1}y^{-1}keV^{-1}
μ induced delayed signals n+^{76}Ge$\rightarrow$^{77m}Ge$\Rightarrow$^{77}As ($t_{1/2}$= 53 s)	▪Low-Z shields ▪Delayed concid. Tag decay chain $\Rightarrow$ 10^{-4} kg^{-1}y^{-1}keV^{-1}
Internal to crystals Cosmogenic ^{60}Co ($t_{1/2}$= 5.27 y) (crystal production)	▪Minimize time above ground after crystal growing ▪Diode & segments antic., PSA $\Rightarrow$$3.5\times10^{-5}$ kg^{-1}y^{-1}keV^{-1}
Internal to crystals Cosmogenic ^{68}Ge ($t_{1/2}$= 270 d) (crystal and detector productions)	▪Minimize time above ground after enrichment; shielded transport container After two years underground $\Rightarrow$ 5×10^{-4} kg^{-1}y^{-1}keV^{-1} Reduce by segmentation and PSA
Front-end electronics, cables, support	▪Materials minimisation (grams) & selection. Still under R&D $\Rightarrow$ $\approx5\times10^{-4}$ kg^{-1}y^{-1}keV^{-1}

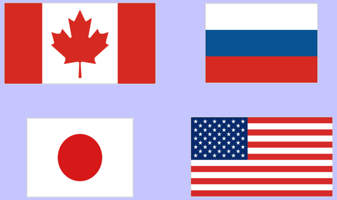
Schedule of forthcoming activities (2008-2009)

- Water Tank & PMTs for μ-veto water Cerenkov May-June 2008.
- Technical Building & Superstructure: Summer 2008
- Lock & Clean Room: 2008-2009
- Commisioning: ~ first semester 2009

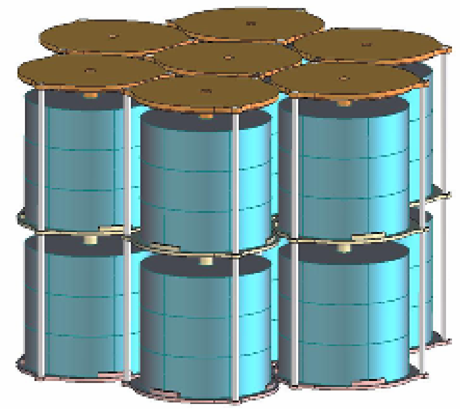
In parallel:

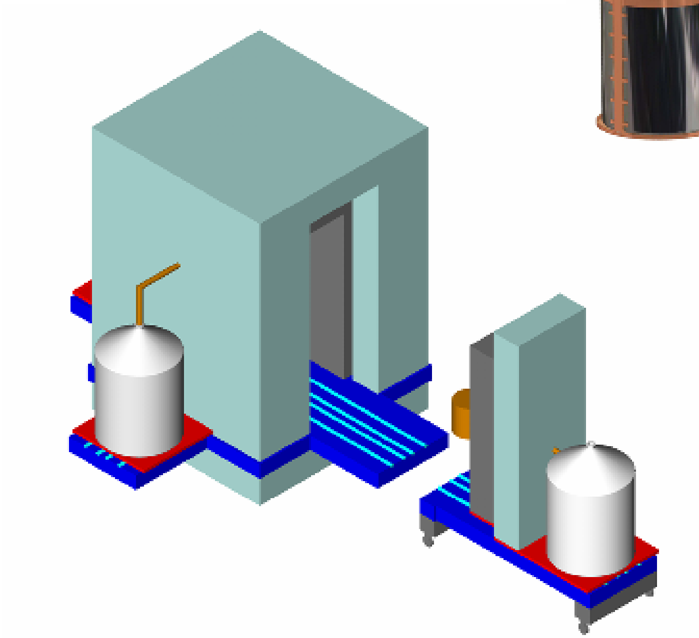
- Complete Reprocessing of all Phase I crystals, assemble 3-fold strings, integrate cold FE with detector string, etc…………….

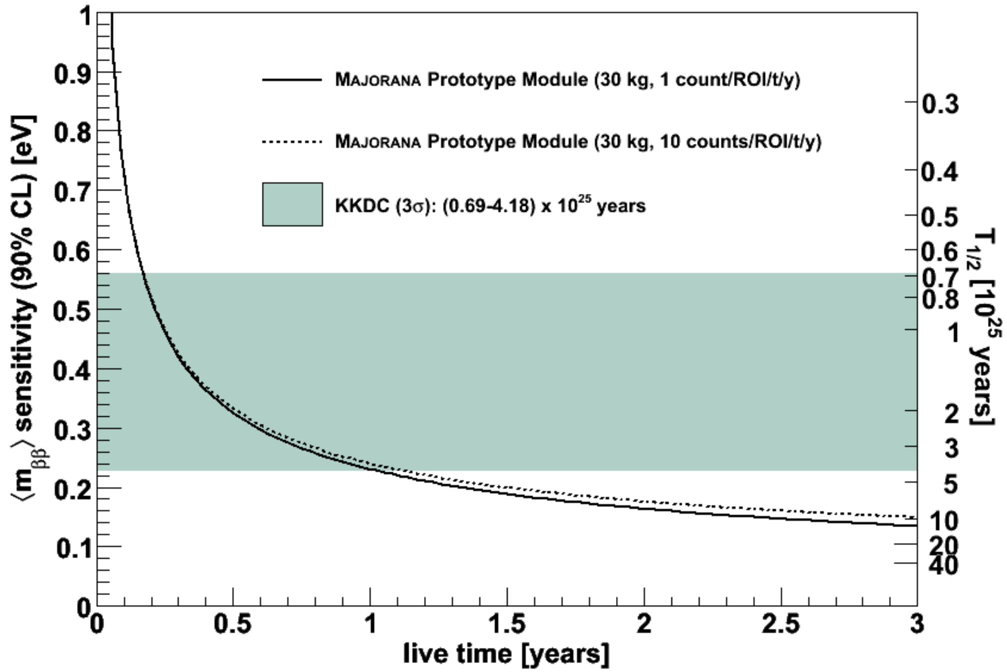
MAJORANA ^{76}Ge $0\nu\beta\beta$ -decay



Slides courtesy of dr. Steve Elliott



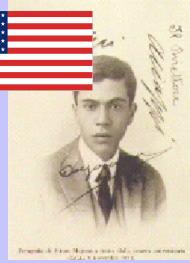




POSTER #56

The MAJORANA Collaboration

Note: Red text indicates students



Duke University, Durham, North Carolina , and TUNL
James Esterline, Mary Kidd, Werner Tornow

Institute for Theoretical and Experimental Physics, Moscow, Russia
Alexander Barabash, Sergey Konovalov, Igor Vanushin, Vladimir Yumatov

Joint Institute for Nuclear Research, Dubna, Russia
Viktor Brudanin, Slava Egorov, K. Gusey, S. Katulina, Oleg Kochetov, M. Shirchenko, Yu. Shitov, V. Timkin, T. Vvlov, E. Yakushev, Yu. Yurkowski

Lawrence Berkeley National Laboratory, Berkeley, California and the University of California - Berkeley
Yuen-Dat Chan, Mario Cromaz, Jason Detwiler, Brian Fujikawa, Bill Goward, Donna Hurley, Kevin Lesko, Paul Luke, Alan Poon, Gersende Prior, Craig Tull

Lawrence Livermore National Laboratory, Livermore, California
Dave Campbell, Kai Vetter

Los Alamos National Laboratory, Los Alamos, New Mexico
Steven Elliott, Gerry Garvey, Victor M. Gehman, Vincente Guiseppe, Andrew Hime, Bill Louis, Geoffrey Mills, Kieth Rielage, Larry Rodriguez, Laura Stonehill, Richard Van de Water, Hywel White, Jan Wouters

North Carolina State University, Raleigh, North Carolina and TUNL
Henning Back, Lance Leviner, Albert Young

Oak Ridge National Laboratory, Oak Ridge, Tennessee
Cyrus Baktash, Jim Beene, Fred Bertrand, Thomas V. Cianciolo, David Radford, Krzysztof Rykaczewski, Chang-Hong Yu

Osaka University, Osaka, Japan
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Fraser Duncan, Art McDonald

University of Alberta, Edmonton, Alberta
Aksel Hallin

University of Chicago, Chicago, Illinois
Phil Barbeau, Juan Collar, Charles Greenberg, Brian Odom, Nathan Riley

University of North Carolina, Chapel Hill, North Carolina and TUNL
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University of South Carolina, Columbia, South Carolina
Frank Avignone, Richard Creswick, Horatio A. Farach, Todd Hossbach

University of South Dakolta, Vermillion, South Dakota
Tina Keller, Dongming Mei, Zhongbao Yin

University of Tennessee, Knoxville, Tennessee
William Bugg, Yuri Efremenko

University of Washington, Seattle, Washington
John Amsbaugh, Tom Burritt, Peter J. Doe, Jessica Dunmore, Alejandro Garcia, Mark Howe, Rob Johnson, Michael Marino, R. G. Hamish Robertson, Alexis Schubert, Brent VanDevender, John F. Wilkerson

MAJORANA Collaboration Goals

–Science goal: build a prototype module to test the recent claim of an observation of 0νββ. This goal is a litmus test of any proposed technology.

–Technical goal: Demonstrate background low enough to justify building a tonne scale Ge experiment.

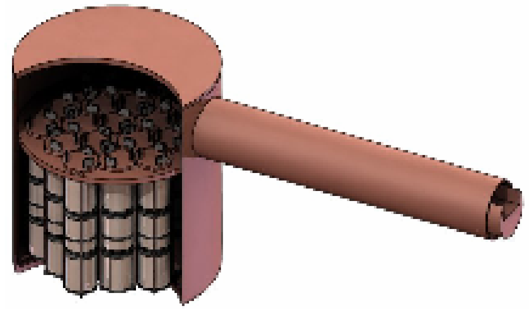
–Work cooperatively with GERDA Collaboration to prepare for a single ^{76}Ge 0νββ-decay experiment, 1-tonne scale that combines the best technical features of MAJORANA and GERDA.

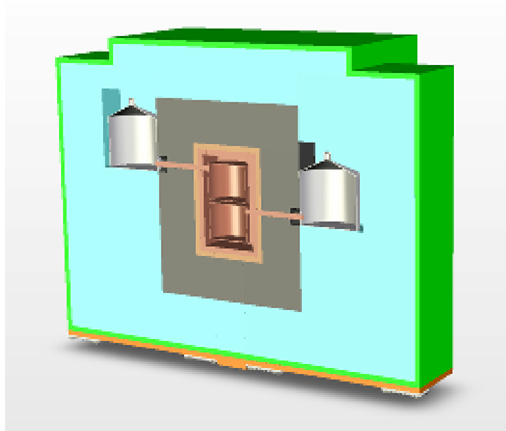
Guided by advice from NuSAG, an independent external panel review (Mar. 06), and a DOE NP 0νββ pre-conceptual design review panel (Nov. 06)

–Pursue longer term R&D to minimize costs and optimize the schedule for a 1-tonne experiment.

The MAJORANA Demonstrator Module

Detectors are deployed in string and operated in an ultra-clean, electroformed Cu cryostat





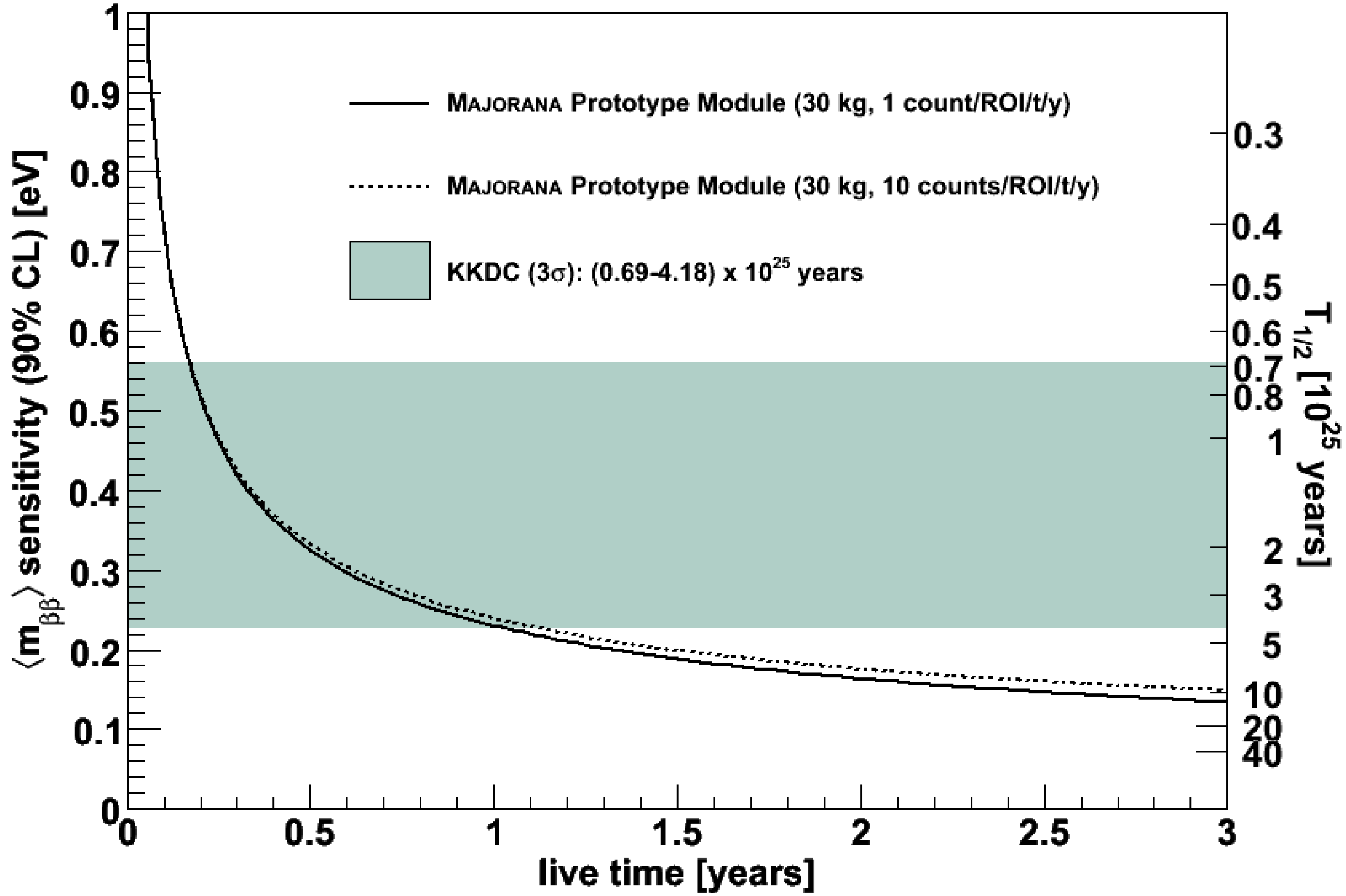
- 60-kg of Ge detectors
  - 30-kg of 86% enriched ^{76}Ge crystals required for science goal; 30-kg non enriched
  - Examine detector technology options p- and n-type, segmentation, point-contact.
- Low-background Cryostats & Shield
  - ultra-clean, electroformed Cu
  - naturally scalable
  - Compact low-background passive Cu and Pb shield with active muon veto
- Located underground 4850' level at SUSEL/DUSEL
- Background Goal in the $0\nu\beta\beta$ peak region of interest (4 keV at 2039 keV)
  - **~ 1 count/ROI/t-y** (after analysis cuts)

MAJORANA Demonstrator Module Sensitivity

- **Expected Sensitivity to 0νββ**

(30 kg enriched material, running 3 years, or 0.09 t-y of ^{76}Ge exposure)

$T_{1/2} \geq 10^{26}$ y (90% CL).Sensitivity to <m_ν> < 140 meV (90% CL) [Rod05,err.]



MAJORANA technical progress - past year

- *Materials & Assay* - Samples of low-activity plastics and cables have been obtained for radiometric counting and neutron activation analysis. Additional improvements have been gained in producing pure Cu through electroforming at PNNL and we have established an operating pilot program demonstrating electroforming underground at WIPP.
- *Ge Enrichment* - Options available for germanium oxide reduction, Ge refinement, and efficient material recycling are being considered, including developing this capability located near detector fabrication facilities.
- *Detectors* - Additional p-type point contact (PPC) detectors have been ordered. Progress has been made in E-M modeling. A PPC detector has been successfully fabricated at the LBNL Instrument Support Laboratory. Efforts to deploy a prototype low-background N-type segmented contact (NSC) detector using our enriched SEGA crystal are underway. This will allow us to test low-mass deployment hardware and readout concepts while working in conjunction with a detector manufacturer.
- *Cryostat Modules* - A realistic prototype deployment system has been constructed at LANL. First measurements, with one string and a single P-type HPGe detector have been completed.
- *DAQ & Electronics* - Modeling of preamps to optimize noise are being compared to measurements. SORCA support for a TCP-IP based VME crate controller has been completed.
- *Facilities* - Designs for an underground electroforming facility and a detector laboratory located on the 4850' level in the Homestake Mine have been developed in conjunction with SUSEL engineers.
- *Simulations* - Several papers describing background studies have been published and our simulation framework has been submitted for publication (joint effort with GERDA).

Present Status

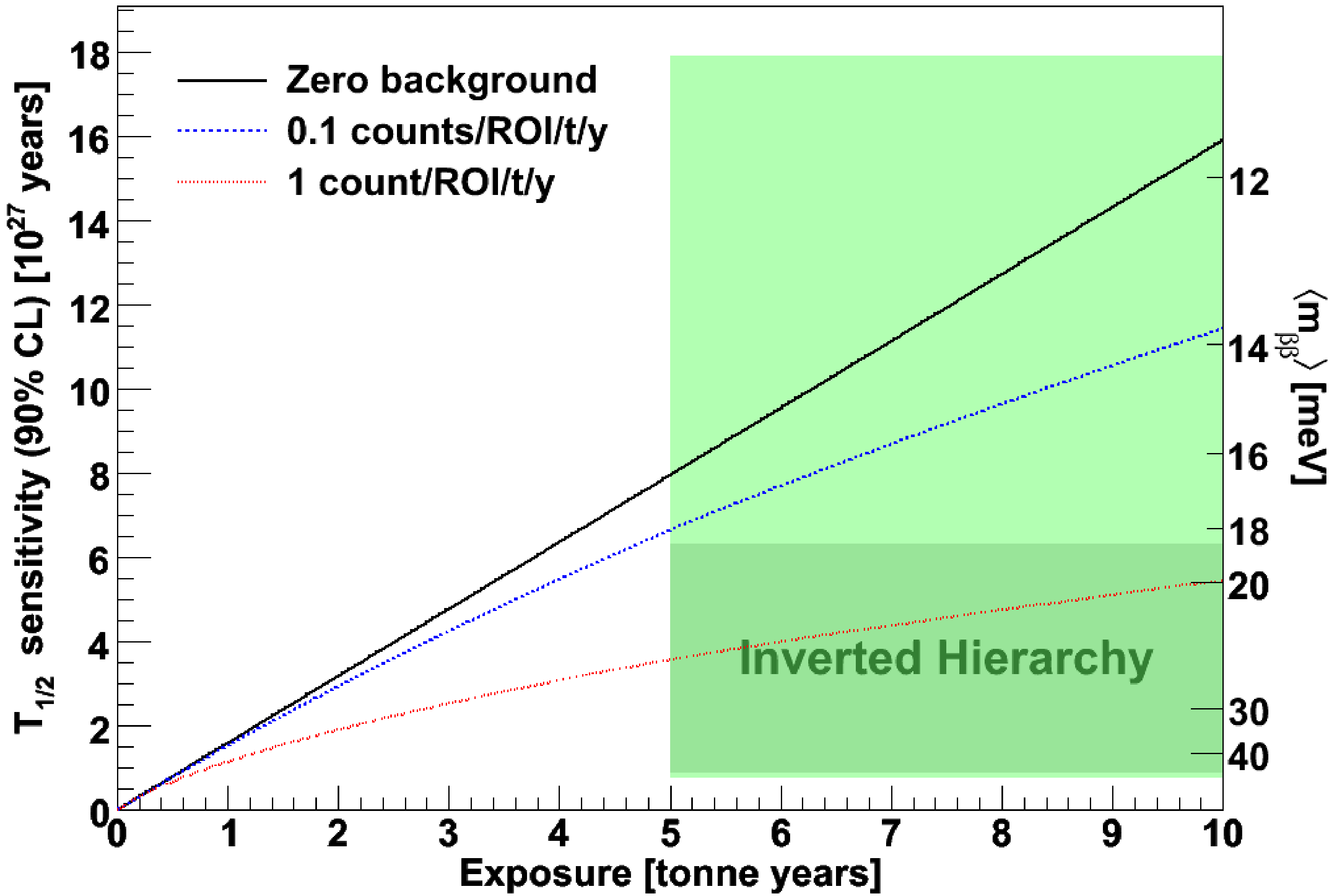
- Approved & Supported: As a R&D Project by DOE NP & NSF PNA

- Progress towards Demonstrator Module
  - UG clean room laboratory space should be available early 2009 at Sanford Laboratory (Homestake gold mine, Lead, SD).
  - UG Electroforming facility will be initial focus due to required time to prepare Cu parts of shield.
  - Early prototype cryostat with point-contact detectors will soon follow.
  - Working with industrial partner to develop Ge refinement process that could be located either near detector fabrication facility or UG.

- SEGA: enriched segmented detector
  - We have completed our initial performance testing of this detector
    - First enriched segmented detector: works well as designed
  - Presently assembling detector into low-background cryostat
    - Plan to move to WIPP for operation in late 2008

1-tonne Ge - Projected Sensitivity vs. Background

$T_{1/2}^{0\nu} = \ln(2) N \varepsilon t / UL(B)$



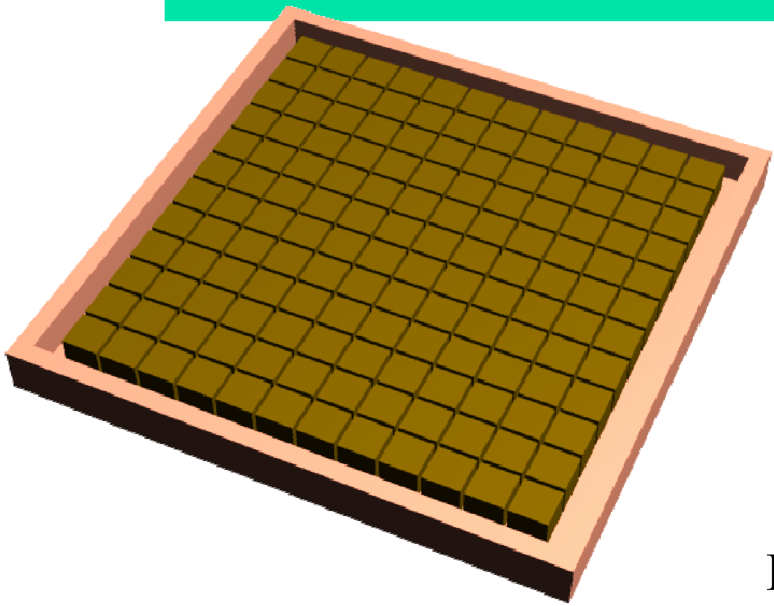
COBRA

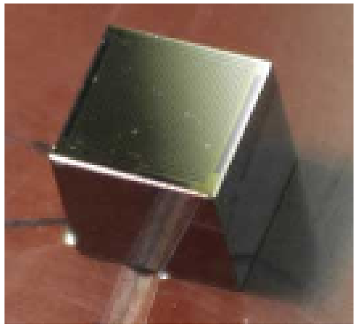
http://cobra.physik.uni-dortmund.de

Slides courtesy of Kay Zuber.

Location

Use large amount of CdZnTe Semiconductor Detectors





Large array of CdZnTe detectors

K. Zuber, Phys. Lett. B 519,1 (2001)

COBRA collaboration

TU Dresden
TU Dortmund
Material Research Centre Freiburg

Washington University at St. Louis

Technical University Prague

Laboratori Nazionali del Gran Sasso

University of Bratislava

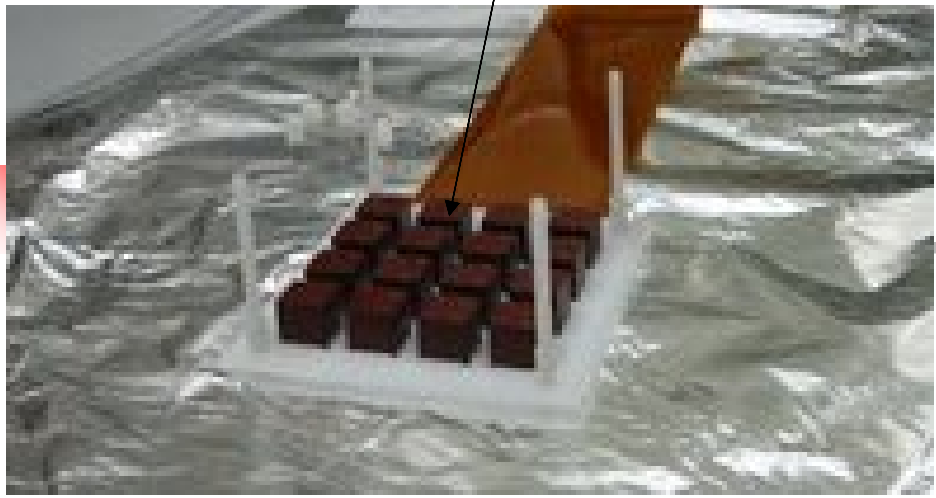
University of Jyvaskyla

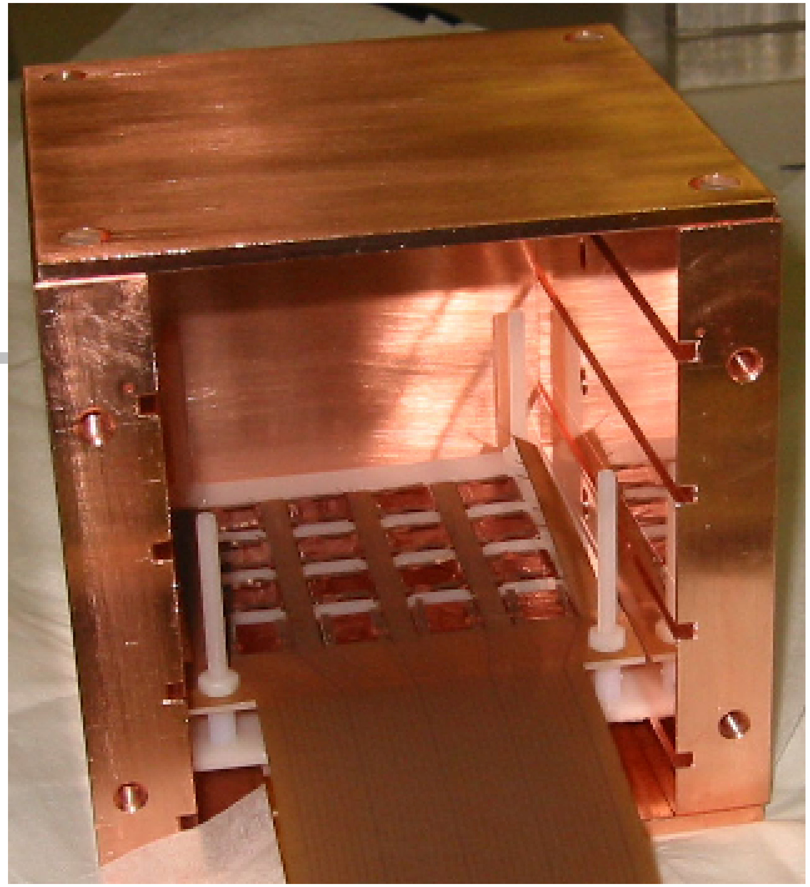
University of La Plata

More welcome

Supporting institutes: University of Hamburg (Germany), Jagellonian University (Poland), Los Alamos Nat. Lab. (USA)

The first layer(16 detectors, 1 cm^3 , 6.4 g each) of CdZnTe array: full array 64 detectors

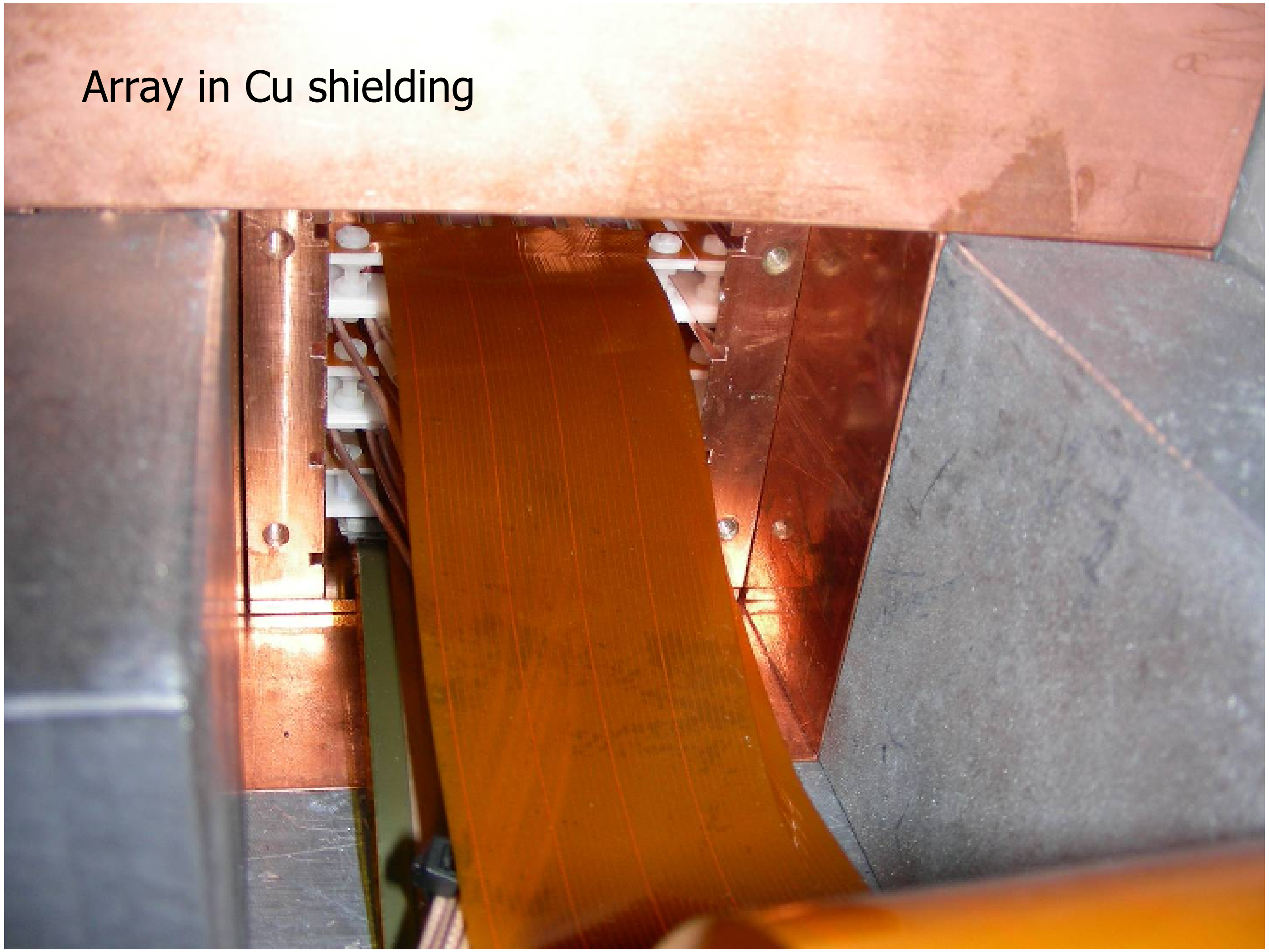




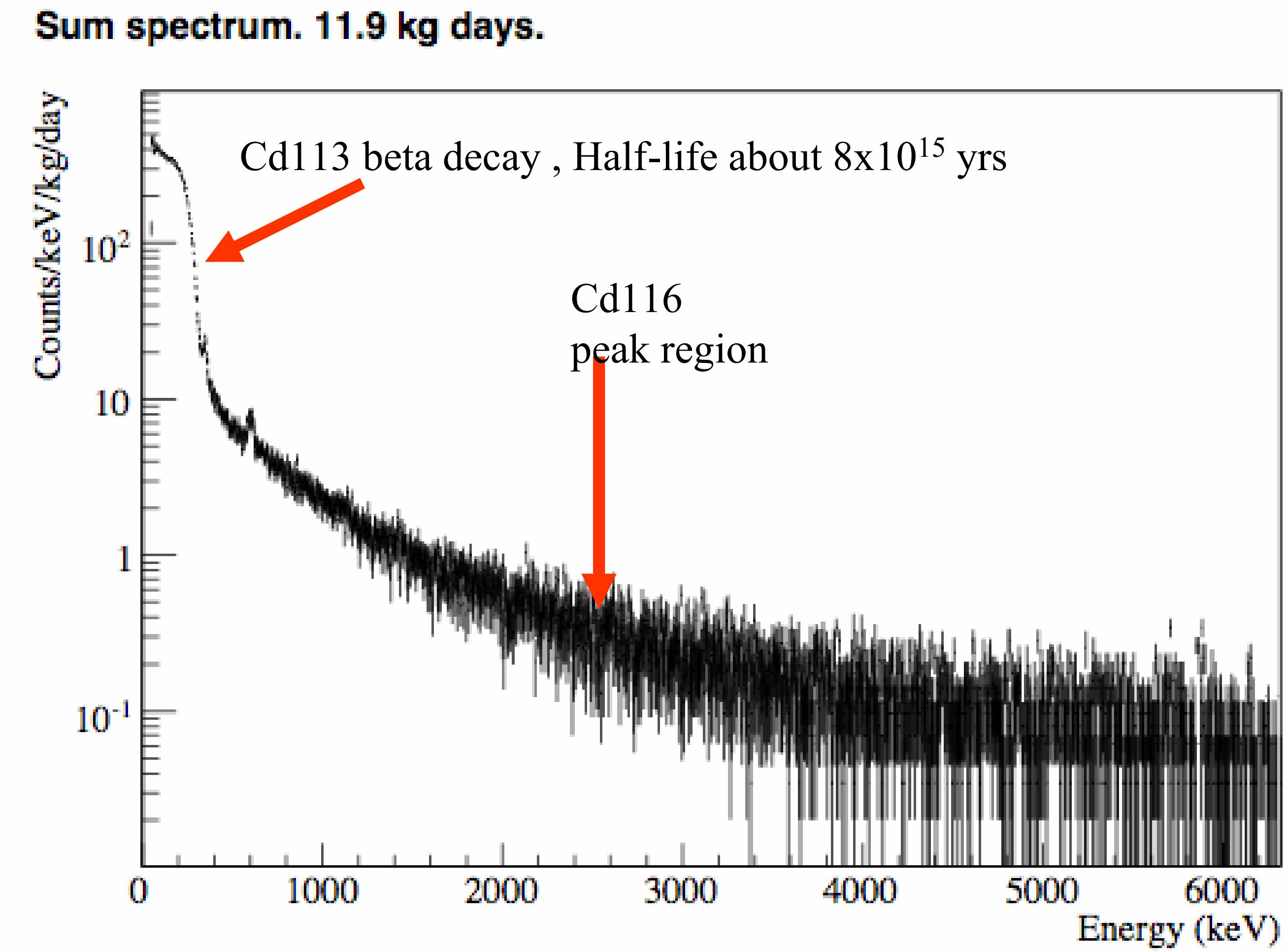
Readout: Energy

Started installation at LNGS in april 2006, world wide largest array of this type of detector

64 detector array (Oct. 07)



Sum spectra of first 16 detectors



Dominated by radon in air and red passivation on detector surface

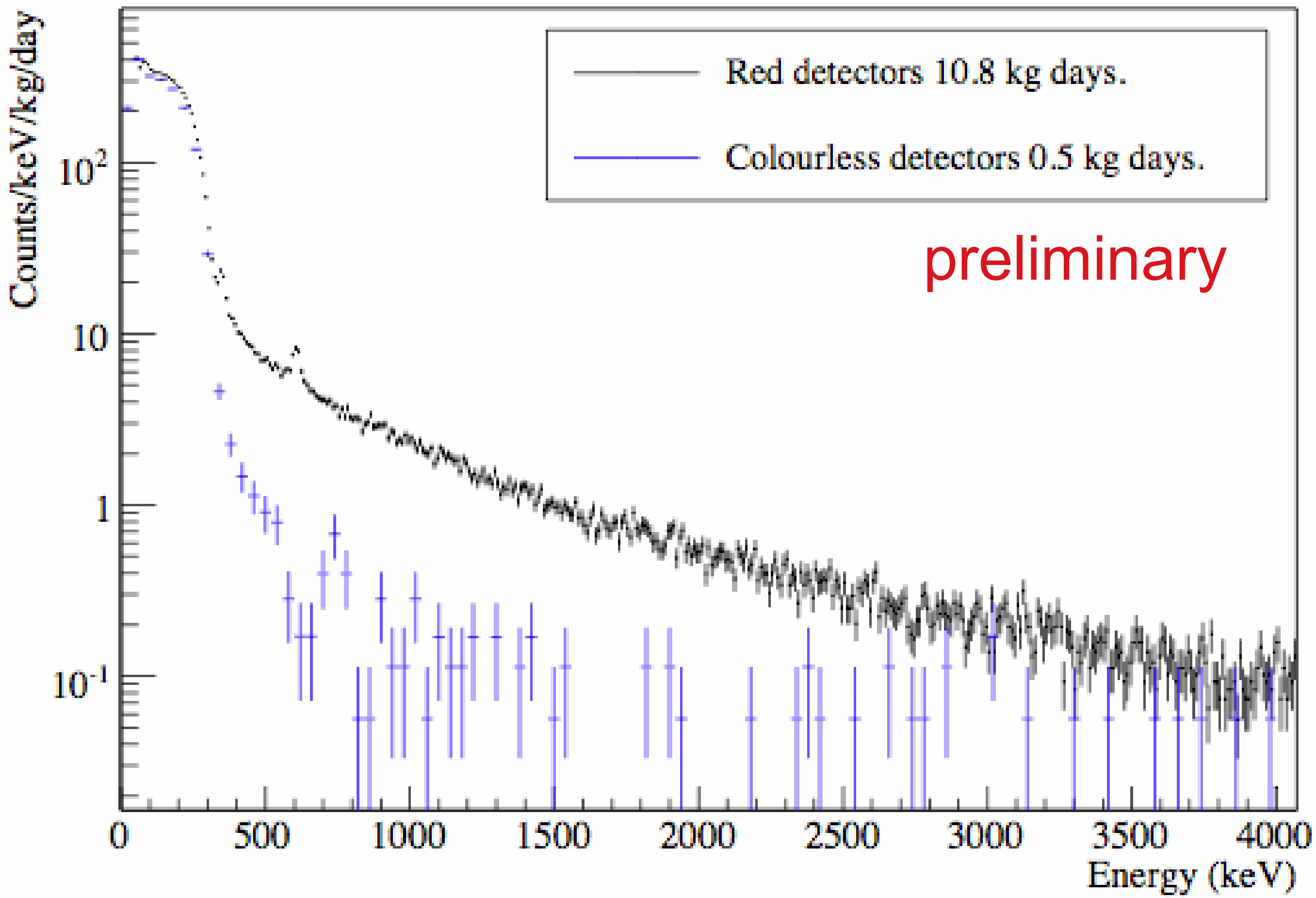
New Results from data subset of 16 detectors array

PRELIMINARY PRELIMINARY

Pubblished by same group in 2007

Isotope and Decay		T_{half} limit (years, 90% C.L.)	
		Current Data	Previous
$\beta^+\beta^+$ Decays			
^{64}Zn	$0\nu\beta^+$EC to g.s.	1.18×10^{18}	2.78×10^{17}
^{64}Zn	$0\nu2$EC to g.s.	$\mathbf{7.43}\times10^{18}$	1.19×10^{17}
^{120}Te	$0\nu2$EC to g.s.	$\mathbf{1.13}\times10^{17}$	2.68×10^{15}
^{120}Te	$0\nu2$EC to 1171keV	$\mathbf{3.43}\times10^{16}$	9.72×10^{15}
^{106}Cd	$0\nu\beta^+\beta^+$ to g.s.	5.12×10^{18}	4.50×10^{17}
^{106}Cd	$0\nu2$EC to g.s.	$\mathbf{5.48}\times10^{18}$	5.70×10^{16}
^{106}Cd	$0\nu\beta^+\beta^+$ to 512keV	7.17×10^{17}	1.81×10^{17}

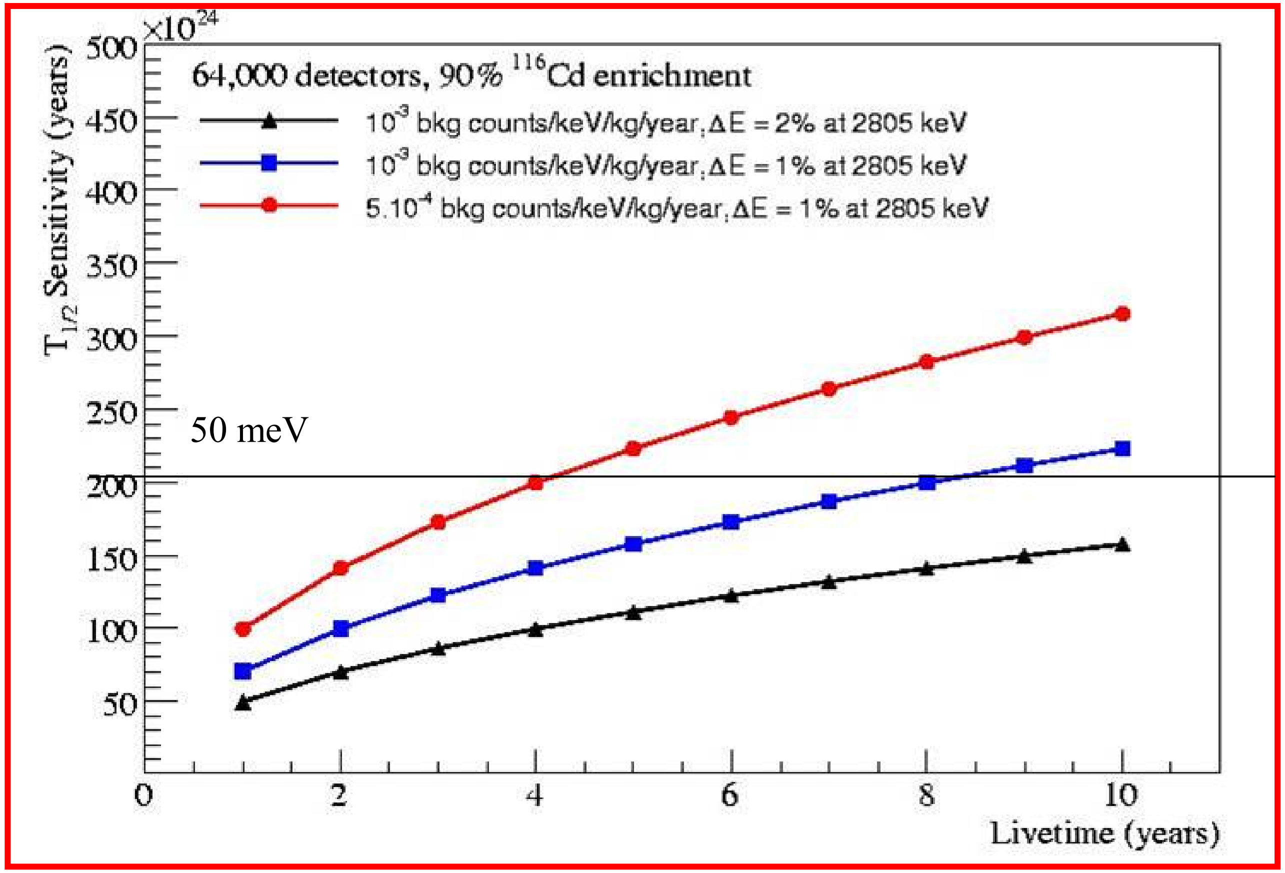
Alternative painted detectors (four 1 cm^3 CdZnTe)



blue= colourless painted detectors + nitrogen flushing
black = 16 layer with red passivation + air

Estimated Sensitivity of 64,000 detectors array

$$T_{1/2} \propto \sqrt{M \times t / \Delta E \times B}$$



Conclusions

- ^{76}Ge $0\nu\beta\beta$ decay searches by Ge detectors started 40 years ago: since then the experimental sensitivity improved of 10^5
- HpGe detectors are an established detection technique characterized by high resolution and intrinsically low background
- In 2004 a claim of evidence of ^{76}Ge $0\nu\beta\beta$ decay with $T_{1/2} = 1.2 \times 10^{25}$ has been published with a statistics of 72 kg y.
- Two forthcoming experiments can probe this claim:
  - GERDA: operates ^{enr}Ge detectors naked in LAr, deployed in strings
  - MAJORANA: operates ^{enr}Ge detectors in Cu cryostat, deployed in strings
- GERDA is in construction @ LNGS: it will be completed by spring 2009. The setup is designed for a $B < 10^{-3}$ c/(keV kg y) @ $Q_{\beta\beta}$. Commissioning: 2009.
- GERDA Phase I (17.9 kg ^{enr}Ge) will have enough sensitivity to probe claim of evidence of $0\nu\beta\beta$, GERDA Phase II (add ~ 20 kg ^{enr}Ge) will further improve the sensitivity in case of non observation of $0\nu\beta\beta$, demonstrate that the design background index is achievable ($B < 10^{-3}$ c/(keV kg y) @ $Q_{\beta\beta}$).

Conclusions

- MAJORANA (foreseen location SUSEL/DUSEL) aims to the construction of a demonstrator (30-60 kg of ^{enr}Ge) having a $B < 10^{-3}$ c/(keV kg y) @ $Q_{\beta\beta}$,. Technical progress in point contact detector, cryostat design and prototype.

- GERDA and Majorana are in close contact
  - MC simulating signal, background, geometries etc (MAGE toolkit),
  - reciprocal participation at collaboration meetings,

  in view, eventually, of a joint collaboration for a 1 ton scale ^{76}Ge $0\nu\beta\beta$ experiment having a sensitivity on $<m_{ee}> \sim 10$ meV.

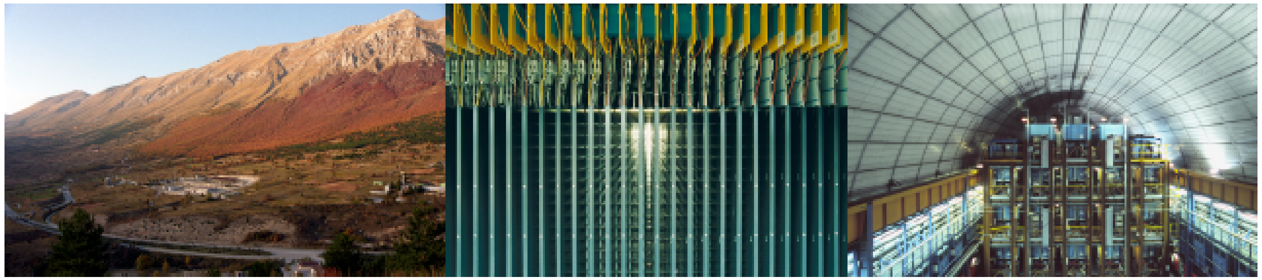
- COBRA: Recent progress, but far away from bckg index allowing adequate sensitivity.

The LNGS organizing committees have the pleasure to announce:

TAUP 2009: July 01 - 05, 2009

and

WIN 2009: September 10 - 15, 2009



at Laboratori Nazionali del Gran Sasso

ISTITUTO NAZIONALE DI FISICA NUCLEARE INFN

LNGS Laboratori Nazionali del Gran Sasso

Extra slides

The neutrino masses and mixings angles

We know from atmospheric, solar and reactor neutrino experiments that

- Neutrino flavour eigenstates ≠ neutrino mass eigenstates
- $\Delta m^2_\nu \neq 0$.

Measured values

θ_{12}= 34.1°±1.5°

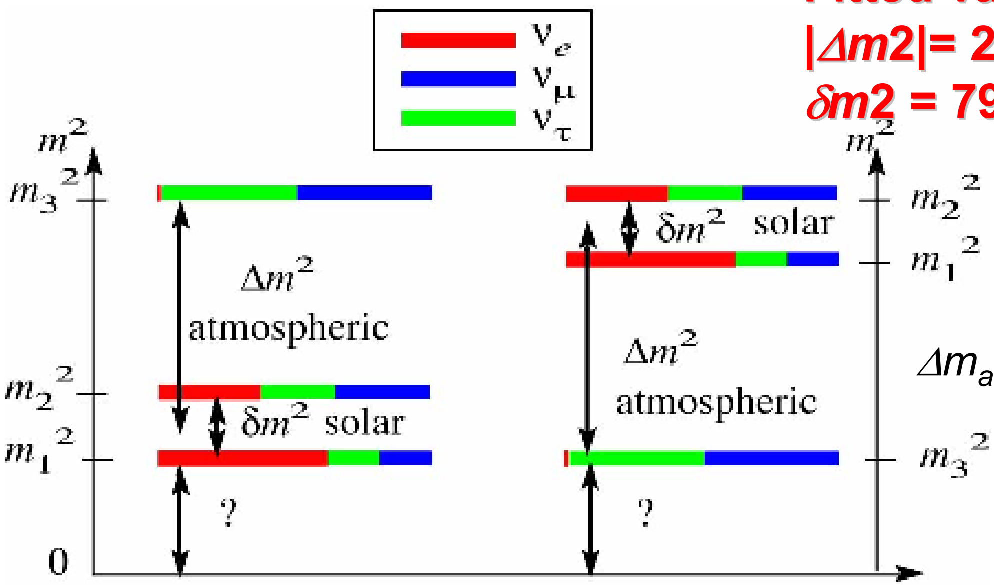
θ_{23}= 42°+4.6°/–2.5°

θ_{13}< 8°

Fitted values

$|\Delta m2|$= 2600±180 meV^2 (8%)

$\delta m2$ = 79.2±3.6 meV^2 (4.5%)



$\Delta m_{atm}^{\ 2}=m_3^{\ 2} - (m_2^{\ 2} + m_1^{\ 2})/2$

$m_3 > \sqrt{\Delta m^2} \approx 50$ meV

$m_2 > \sqrt{\delta m^2} \approx 8.5$ meV

$m_1, m_2 > \approx 50$ meV

$m_3 > \approx 8.5$ meV

We don't know absolute neutrino mass value and hyerarcy i.e. sign of Δm^2

GERDA I Physics reach

$$T_{1/2} > 4.3 \cdot 10^{24} \cdot \varepsilon \cdot a \sqrt{\frac{M \cdot t}{B \cdot FWHM}}$$

Assumption for GERDA I

FWHM= 3.6 keV , ε = 95%

M =15 kg (86% enriched)

t = 1 year → Effective Ge mass = 15· 0.86 kg y

B_{tot} = B_{ext} (10^{-3} cts/(kev · kg · y))+B_{int} (10^{-2} cts/(kev · kg · y)) = 0.5 counts

→ if no counts happens (60% chance)

$T_{1/2} > 3.0 \cdot 10^{25}$ at 90% CL, $m_{ee} < 0.24 – 0.77$ eV → ββ claim ruled out at 99.6% CL

→ if non-zero counts (μ =0.5 counts Poissonian fluctuated)

$T_{1/2} > 2.2 \cdot 10^{25}$ at 90% CL, $m_{ee} < 0.28 – 0.9$ eV (if 1 cts ββ claim ruled out at 97.8% CL

→ if signal found in ββ HM is true ββ decay, this would produce in GERDA I (= 15 kgy) 6 ± 1.4 cts, above bckgrd of 0.5 cts → 5σ confirmation

GERDA II Physics reach

With new segmented detectors and keeping the isotope separation+ crystal growing time within 180 days →B ~ 10^{-3} cts /(keV kg y)

With mass of 40 kg y x 3 years

FWHM = 3.6 keV

→B = 0.36 background counts expected

$T_{1/2} > 2.0 \cdot 10^{26}$ at 90% CL, $m_{ee} < 0.09 – 0.29$ eV

MAJORANA technical progress - past year

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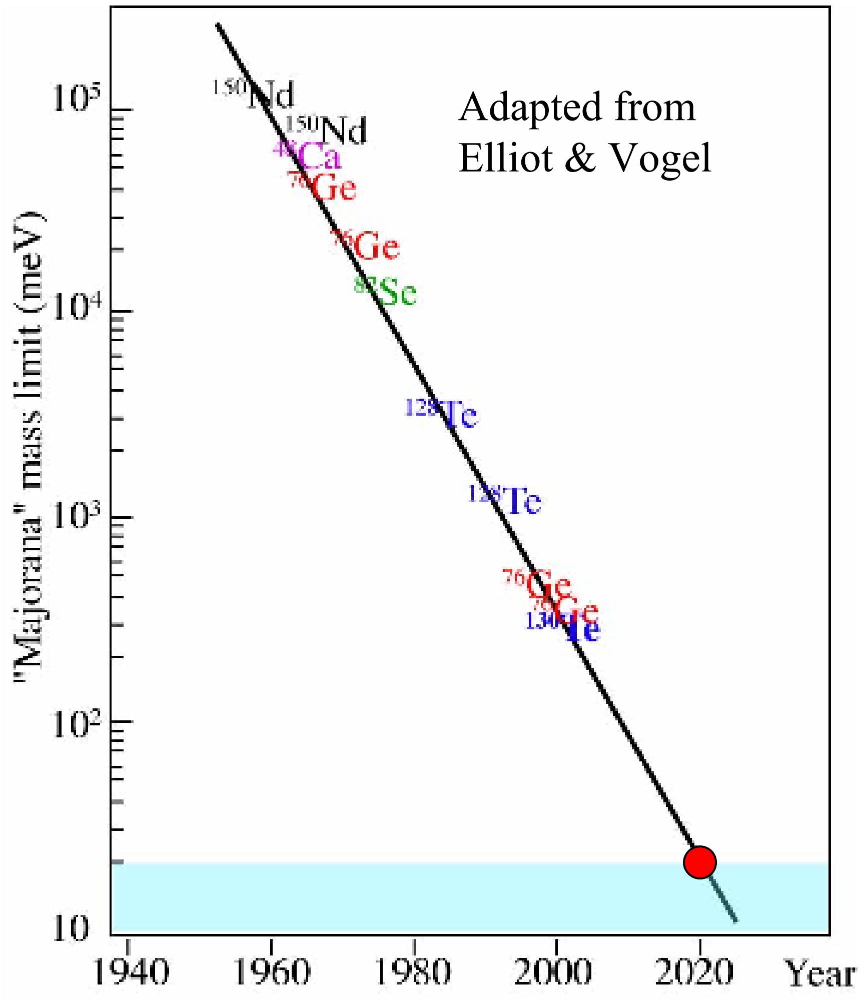
bb searches of ^{76}Ge by germanium detectors: pioneering experiments



Nuclear matrix