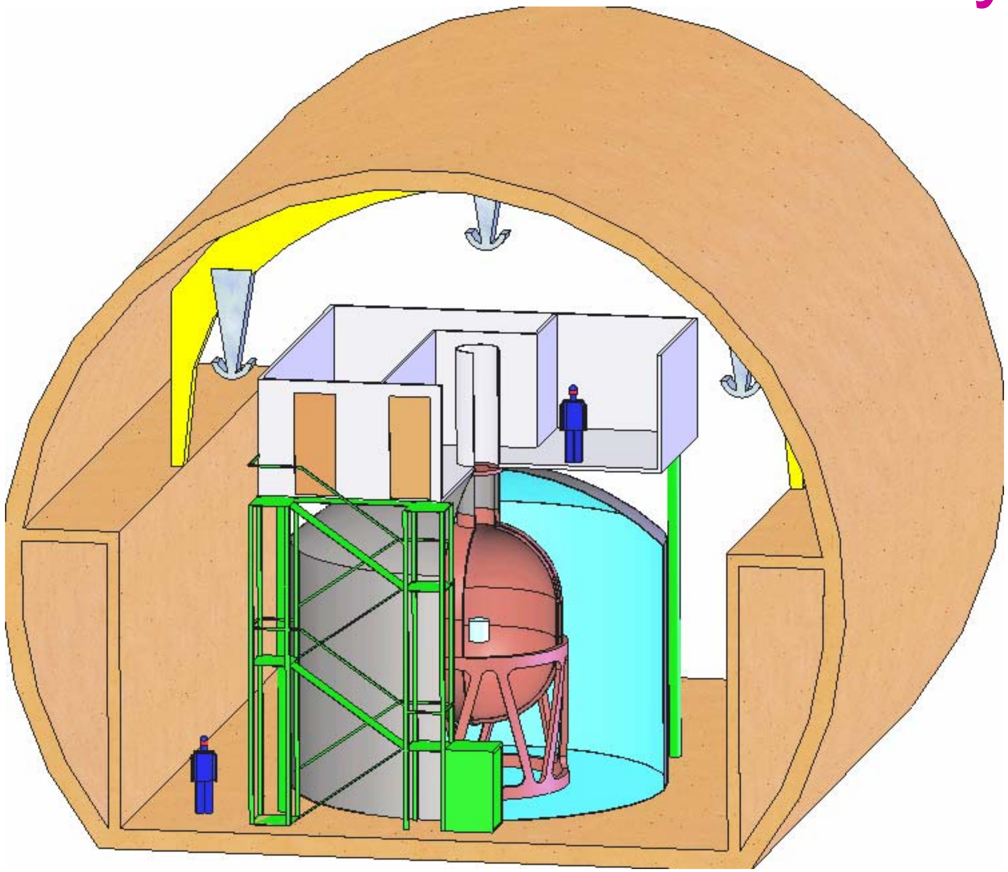
GERDA

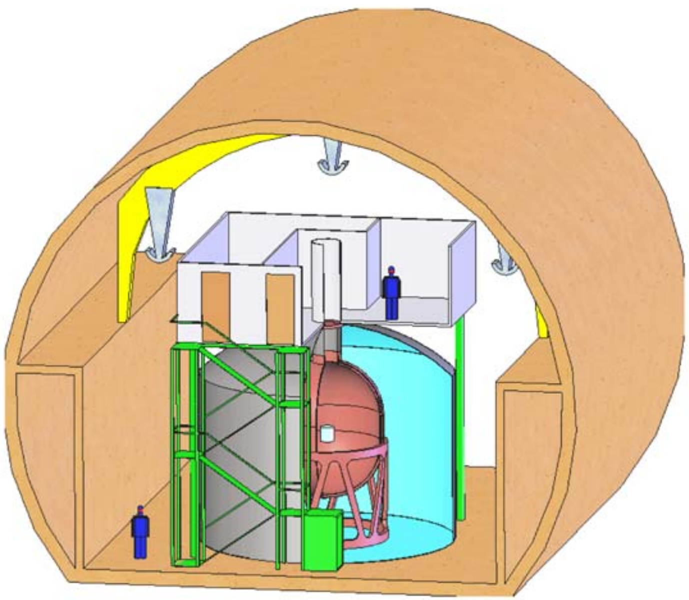
The GERmanium Detector Array for the search of neutrinoless double beta decay of ^{76}Ge



Bernhard Schwingenheuer, Max-Planck-Insitut Kernphysik, Heidelberg

GERDA

The GERmanium Detector Array for the search of neutrinoless $\beta\beta$ decays of ^{76}Ge at LNGS



Proposal

September 2004

Outline

- Physics Motivation
- Nuclear Matrix Elements
- Past ^{76}Ge Experiments
- The GERDA Approach
- Our Friends: the Competition
- Summary

GERDA Collaboration

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71 physicists / 12 institutions / 4 countries

spokesperson: Stefan Schönert, MPIK Heidelberg

Majorana versus Dirac Neutrino

ν oscillations → L_e, L_μ, L_τ violated, $m_\nu > 0$ (first non-SM effect!)

What about lepton number L?

If L violated → "there is no quantum number that makes ν and $\bar{\nu}$ different"

m_D, $\Delta L=0$

$\nu_R \rightarrow \times \rightarrow \nu_L$

M_R, $\Delta L=2$

$\nu_R \rightarrow \times \rightarrow (\nu_R)^C$

$$\mathcal{L} = m_D\, \bar{\nu}_L\, \nu_R + m_L\, \overline{(\nu_L)^C}\, \nu_L + M_R\, \overline{(\nu_R)^C}\, \nu_R + h.c.$$

See-saw: $M_R \gg m_D \gg m_L$ → $\nu_1 = \nu_L + (\nu_L)^C$ with mass $m_D{}^2/M_R$
$\nu_2 = \nu_R + (\nu_R)^C$ with mass M_R } Majorana particles !!!

for $m_D \sim$ GeV and $M_R \sim 10^{12}$ GeV → $m_1 \sim$ meV !!!

→ light left-handed neutrino & heavy right-handed neutrino (Majorana)

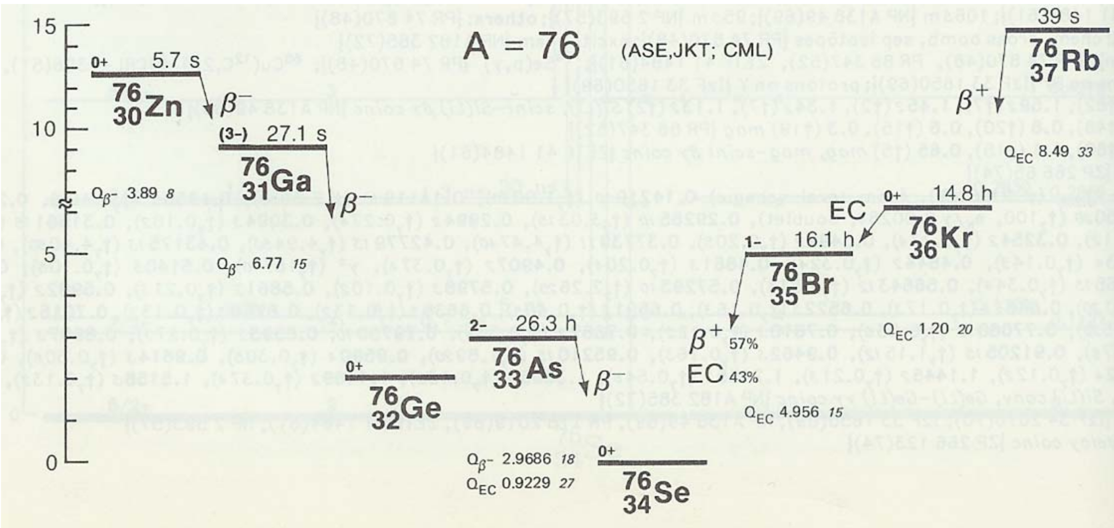
possible CP violation in ν_2 → higgs + ν_1

Leptogenesis: L asym. @ T = 10^{12} GeV →
via sphalerons B violation + B asym @ T = 100 GeV

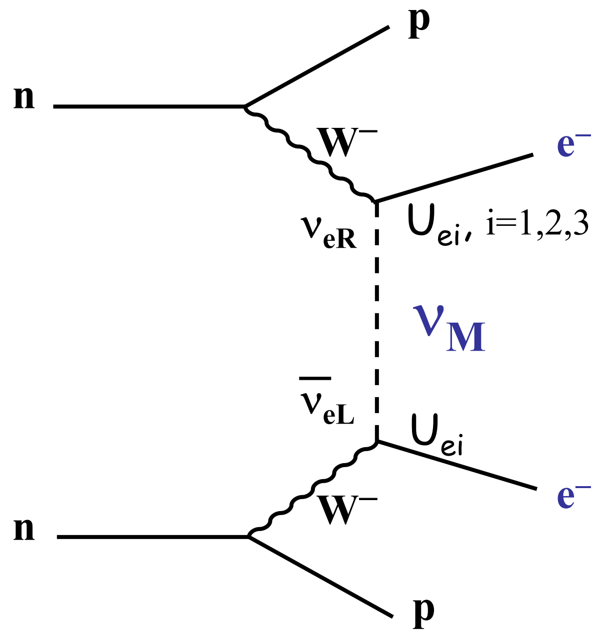
Is the neutrino a Majorana particle? YEA or NAY?

Motivation for 0νββ: $(A,Z) \rightarrow (A,Z+2) + 2e^- (+ 2\bar{\nu}_e)$

masses of A=76 nuclei



0νββ: ΔL = 2 process



$^{76}Ge \rightarrow {}^{76}Se + 2e^- + 2\bar{\nu}_e \quad \Delta L=0$

$T_{1/2}^{2\nu} \sim 10^{21}$ years measured !

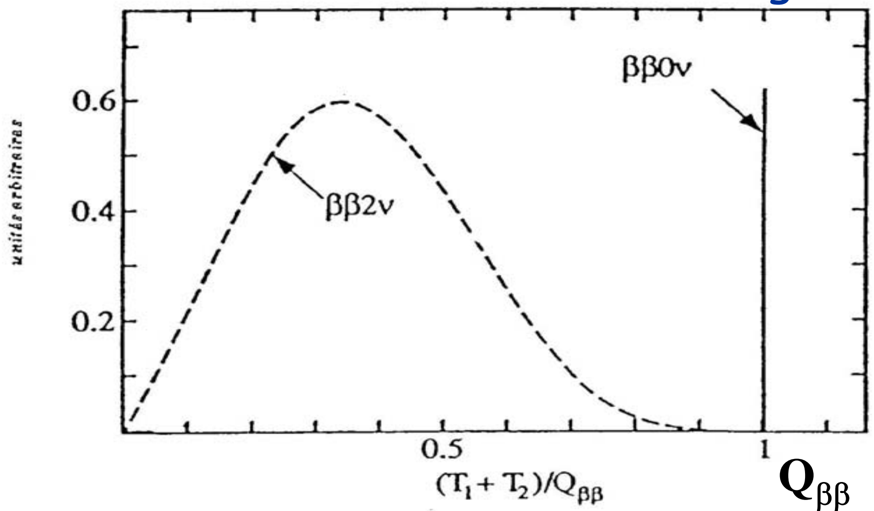
only possible if
neutrino is massive and
neutrino is Majorana particle

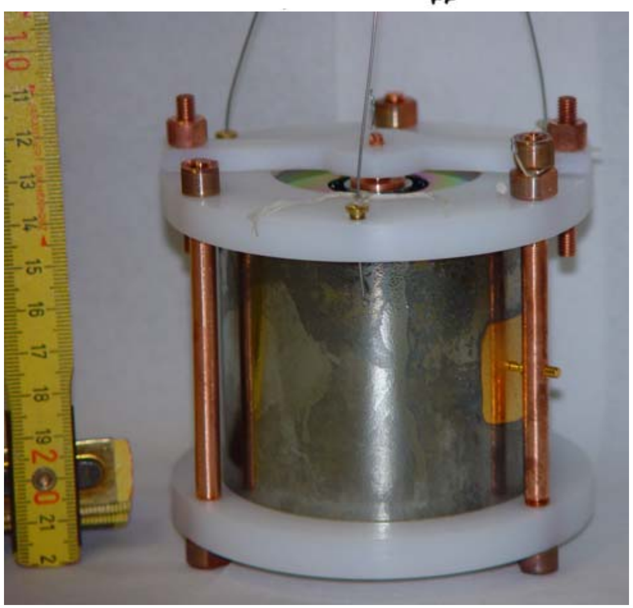
coupling $\sim \langle m_{ee} \rangle = \left| \sum_{i=1}^{3} U_{ei}^2 m_i \right|$

most sensitive probe today
alternative: SUSY interaction, ...

Experimental signature

sum of electron kinetic energies





Ge-76: source = detector (diode)

$T_{1/2}^{0\nu}$ sensitivity for ^{76}Ge

No background:

$$T_{1/2}^{0\nu}\,(\mathrm{y}) > 2.4\mathrm{x}10^{24}\ \varepsilon\, a\ \ \mathbf{m\ [kg]\ t\ [y]}$$

@ 90% C.L.

ε = detection efficiency
a = $\beta\beta$ isotope fraction
m = mass of detector in kg
t = measurement time in years

Large background:

$$T_{1/2}^{0\nu}\,(\mathrm{y}) > 4.3\mathrm{x}10^{24}\ \varepsilon\, a \sqrt{\frac{m\ t}{B\ R}}$$

@ 90% C.L.

B = background index in cts/(keV kg y)
R = energy resolution at $Q_{\beta\beta}$ in keV

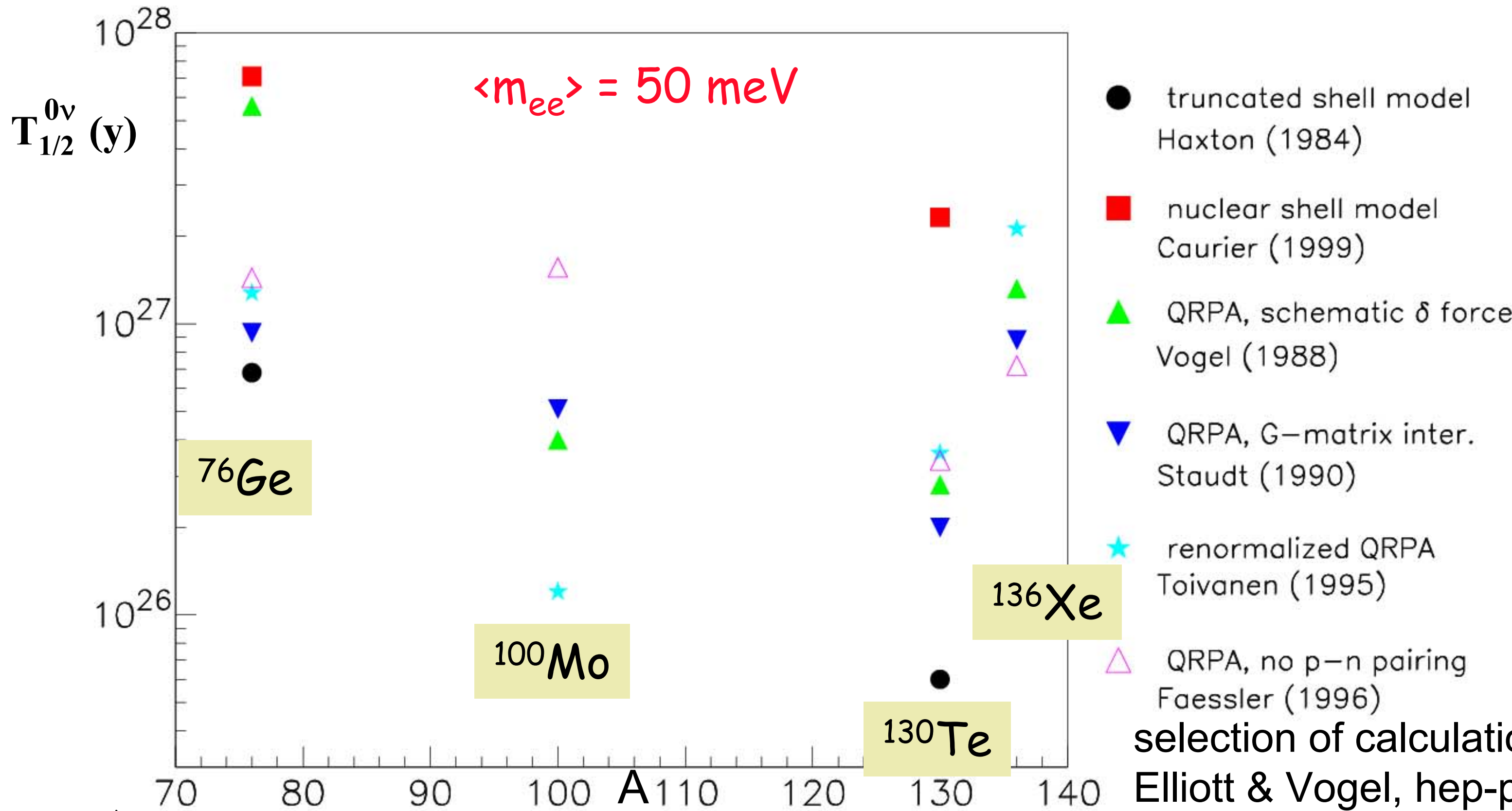
large experiment: **B ~ 10^{-4}/(kg keV y), R ~ 3 keV, m t = 1000 kg y → N_{bkg}~ 0.3, sensitivity ~ $2\mathrm{x}10^{27}$ y**

Nuclear Matrix Element Calculations

$$T^{0\nu}_{1/2} = \frac{1}{\Gamma(Q^5_{\beta\beta})\ M^2\ \langle m_{ee}\rangle^2}$$

$^{76}Ge \rightarrow {}^{76}Se$	$Q_{\beta\beta}$ = 2039 keV	nat. abund. = 7.4%
$^{100}Mo \rightarrow {}^{100}Ru$	$Q_{\beta\beta}$ = 3034 keV	nat. abund.= 9.6%
$^{130}Te \rightarrow {}^{130}Xe$	$Q_{\beta\beta}$ = 2529 keV	nat. abund.= 34%
$^{136}Xe \rightarrow {}^{136}Ba$	$Q_{\beta\beta}$ = 2479 keV	nat. abund.= 8.9%

$T_{1/2}$ for nuclear matrix element calculations



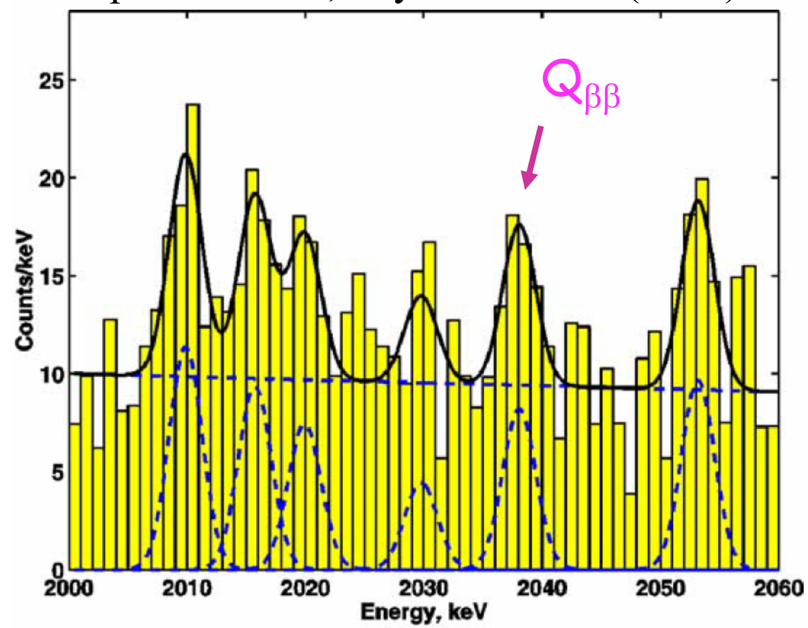
selection of calculations from Elliott & Vogel, hep-ph/0202264

need more than one isotope to get information about $\langle m_{ee}\rangle$

Current best sensitivity on <m_{ee}>

Isotope enriched Germanium diodes (86% in ^{76}Ge)

Klapdor-K. et al, Phys.Lett. B586(2004)198



Heidelberg-Moscow

5 detectors Ge (total mass = 10,9 kg, 71 kg*y)

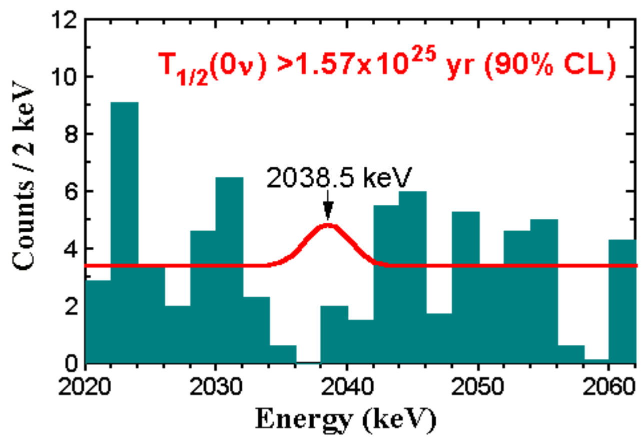
B = 0,2 cts/(keV kg y)

$T^{0\nu}_{1/2}$ **> 1.9 10^{25} y (90% C.L.) (2001)**

= (0.69 – 4.2) x 10^{25} y (3σ) (2004)

< m_{ee}> = 0.1 – 0.9 eV

IGEX (International Ge EXperiment)



Gonzales et al. Nucl. Phys. B (Proc. Suppl.) 87 (2000) 278

3 detectors Ge (total mass = 6 kg, 8.8 kg*y)

B = 0,2 cts/(keV kg y)

$T^{0\nu}_{1/2}$ **> 1.57 10^{25} y (90% C.L.)**

< m_{ee}> < 0.36 – 1.07 eV

Strategy of GERDA

- ^{76}Ge has been most successful in the past
- need much smaller backgrounds for improvement in sensitivity
  current best values O(0.1) cts/(keV kg y)
- add Ge detectors made out of isotope enriched material

Our Goal: background index of 0.001 cts/(keV kg y)

gigantic step in background reduction needed O(100),
there could be surprises on the way to our goal

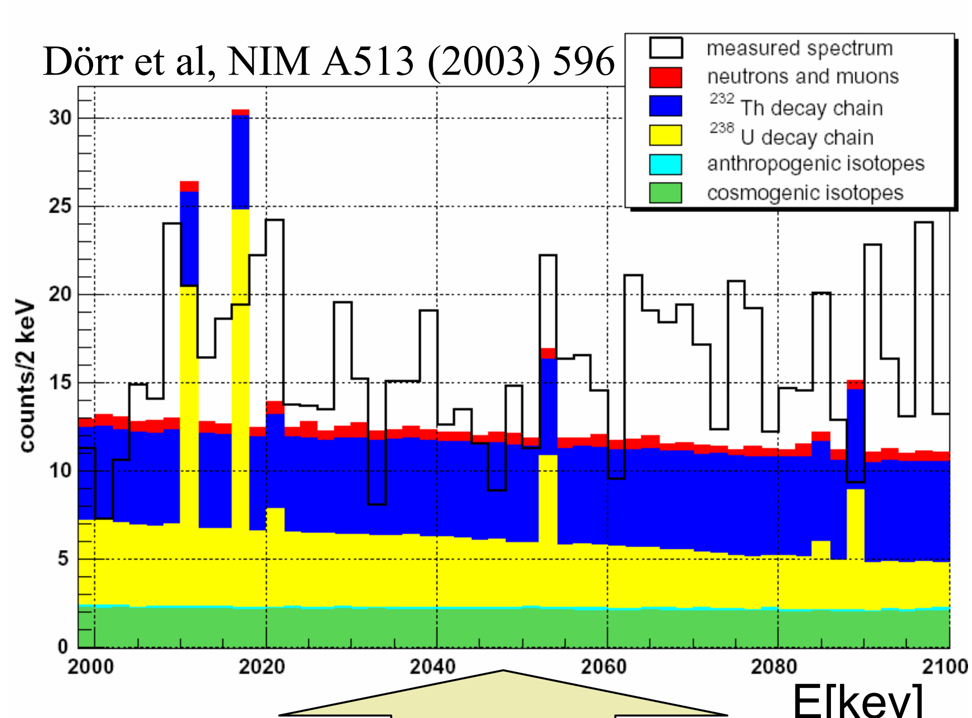
→ 2++ phase approach:
phase I: use existing ^{76}Ge detectors of Heidelberg-Moscow & IGEX,
establish background reduction
phase II: add new detectors depending on financial support

minimize cost/risk and still push the limit on $T_{1/2}$ by a factor of 10,
check Klapdor-Kleingrothaus result quickly with same isotope/diodes

phase III: worldwide new collaboration for "large" experiment

Understanding of Background sources

Heidelberg-Moscow background sources
total ~ 0.2 cts/(keV kg y)



simu = 660 ±93, data = 800 entries,
only external background contributions,
internal bkg should be present as well

External backgrounds

- γ from primodial decay chains, especially 2.615 MeV from ^{208}Tl, in concrete/rock, …
- neutrons from (α,n) reaction & fission in concrete/rock and from μ induced reactions

Internal backgrounds

- cosmogenic isotopes produced in spallation reactions (above ground), especially relevant ^{68}Ge and ^{60}Co with half lifetimes ~ year(s)

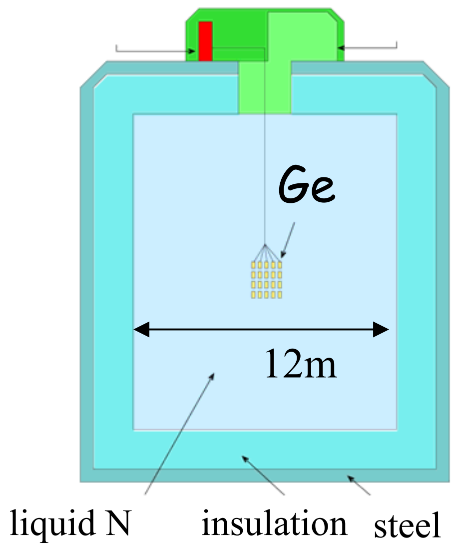
Shielding of external gamma background

material	activity of ^{208}Tl in μBq/kg
concrete	~3x10^{6}
copper(NOSV)	<10
lead	<10
water (purified)	<1
liquid N, Ar	~0
acryl (SNO)	1

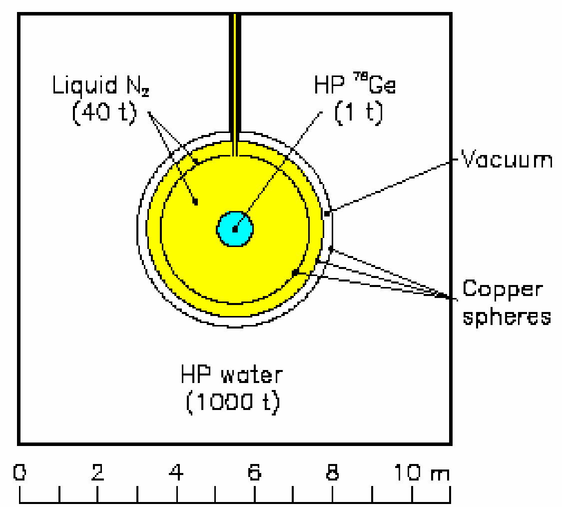
shielding (& cooling) with liquid nitrogen/argon is best solution
(Heusser, Ann.Rev.Nucl.Part.Sci. 45 (1995) 543)

"reduce all impure material close to diode as much as possible"

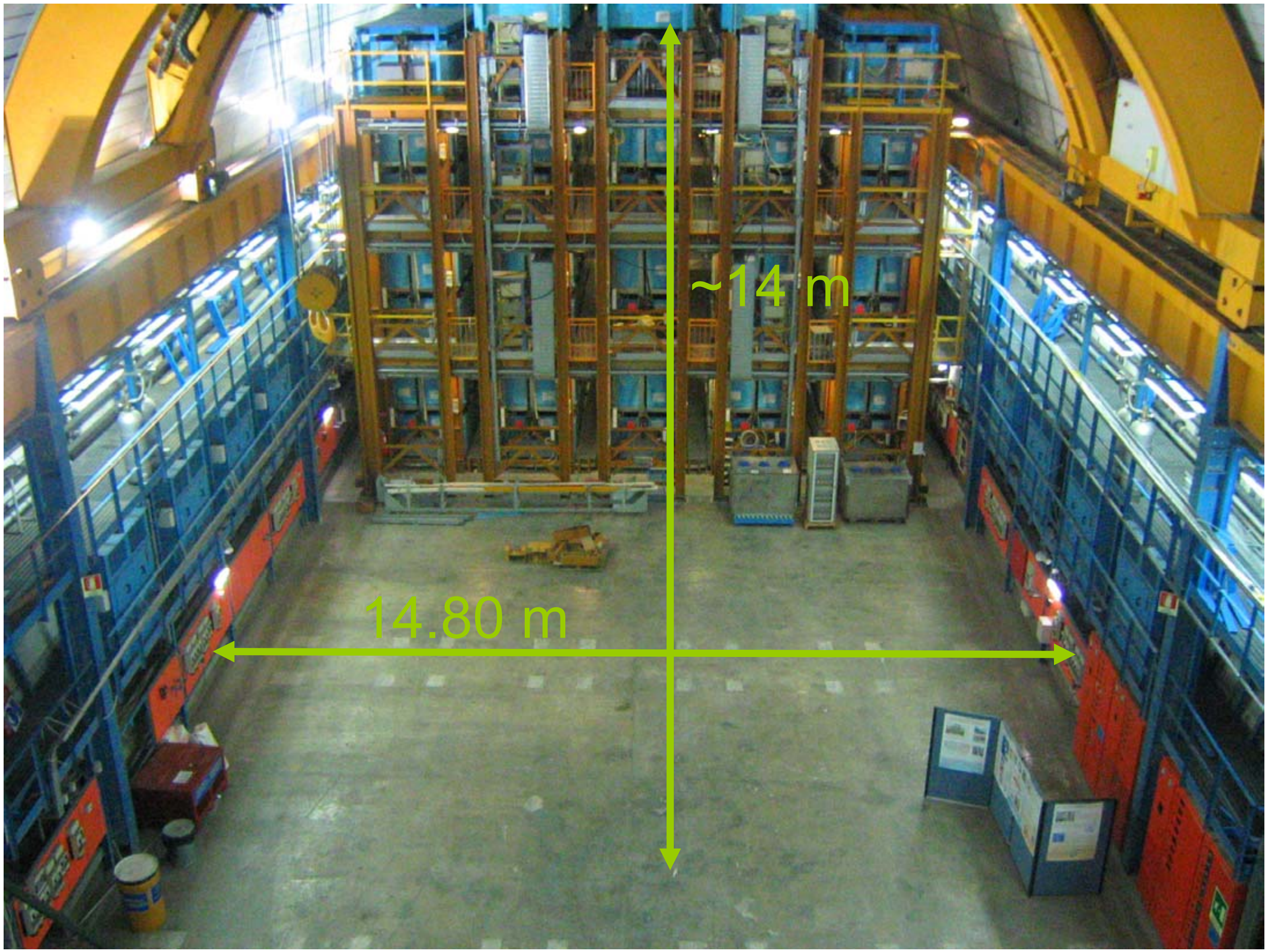
Genius, hep-ph/9910205



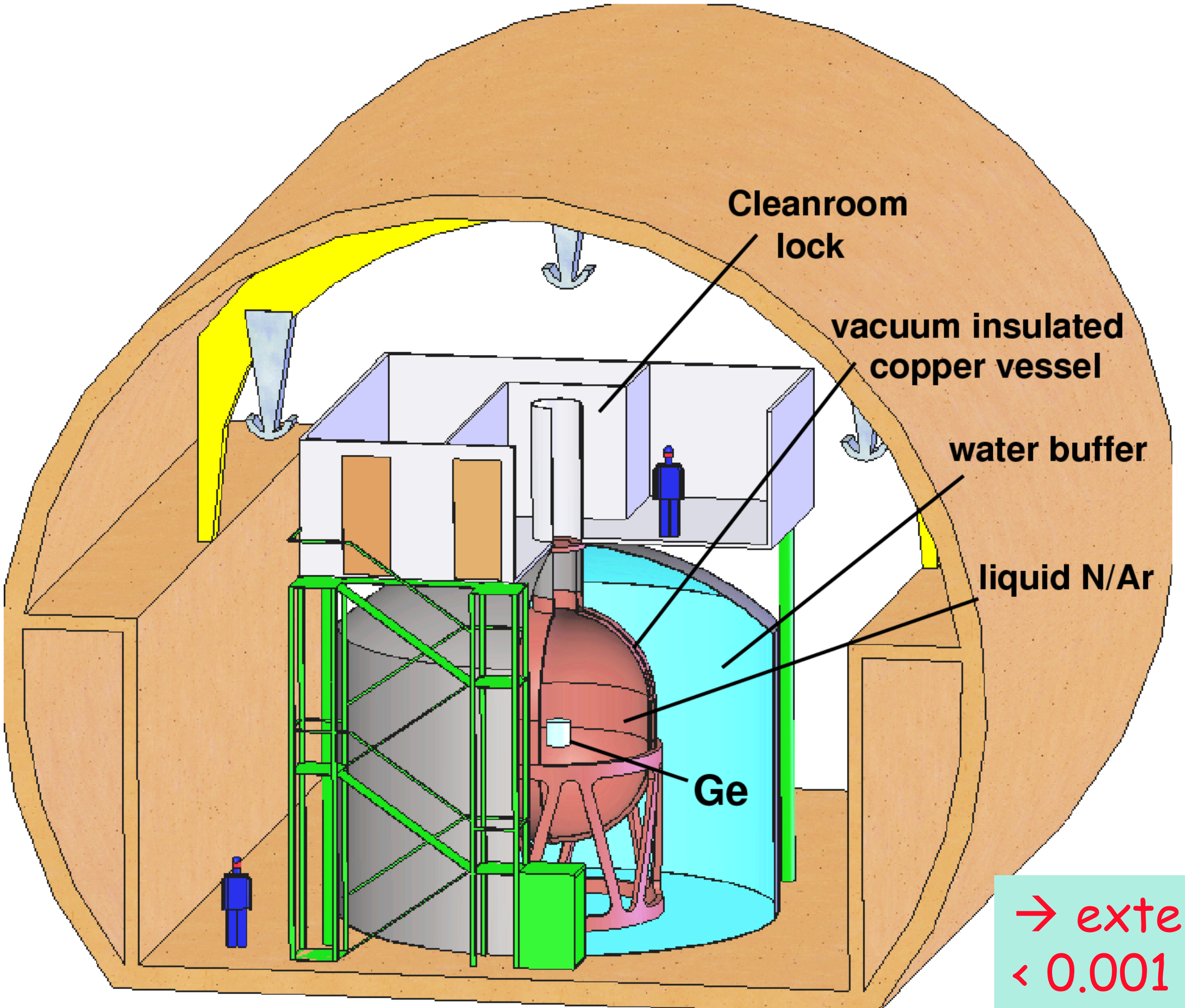
GEM, hep-ex/0106021



Available Space @ LNGS: sala A in front of LVD



Our solution for LNGS Hall A



50 m³ of liquid N, 700 m³ of water,
4m Ø Cu cryostat, 10 m Ø water tank

graded shielding for γ

Cu activity shielded by liquid N (or Ar)

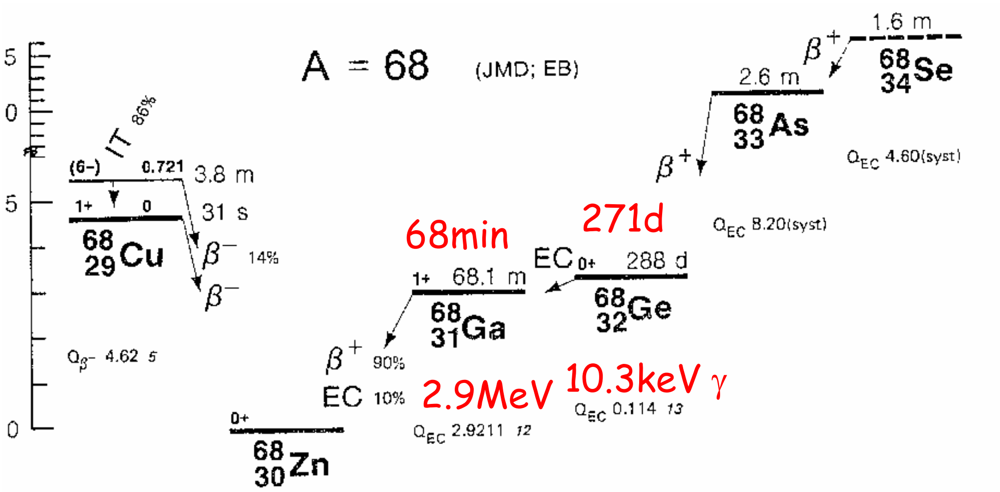
concrete activity by LN + water + Cu

advantages of water:
- shielding > than LN,
- cheaper,
- safer,
- neutron moderator,
- Cherenkov medium for muon veto

→ external $\gamma/n/\mu$ background < 0.001 cnt/(keV kg y) for LN will be reached, factor ~10 smaller for LAr

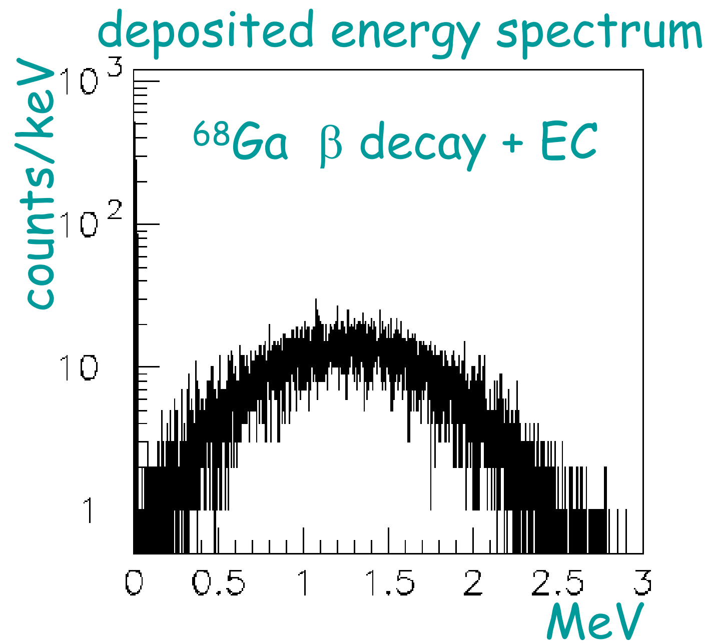
Internal Backgrounds: Cosmogenic ^{68}Ge production

cosmogenic production in ^{76}Ge above ground: about 1 ^{68}Ge / (kg day)
(Avignone et al., Nucl Phys B (Proc Suppl) 28A (1992) 280)



after 180 days above ground, 180 days storage below ground → 58 decays/(kg year) in 1st year

simulation of ^{68}Ge decay in Geant 4:

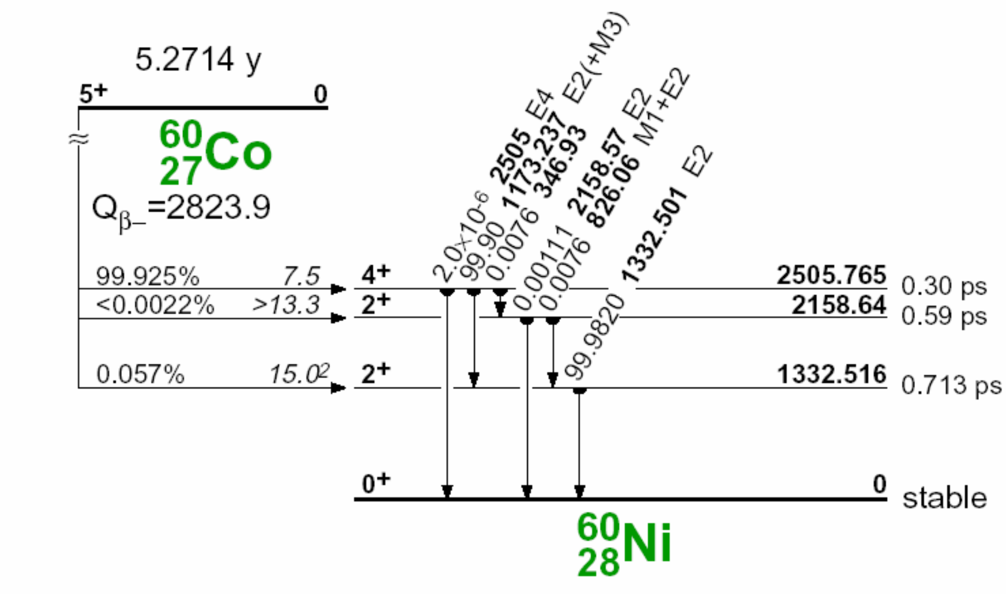


→bkg index = 0.012 cts/(keV kg y) = 12 x goal !!

→ need additional bkg rej. (time corr, ...)

^{60}Co activity

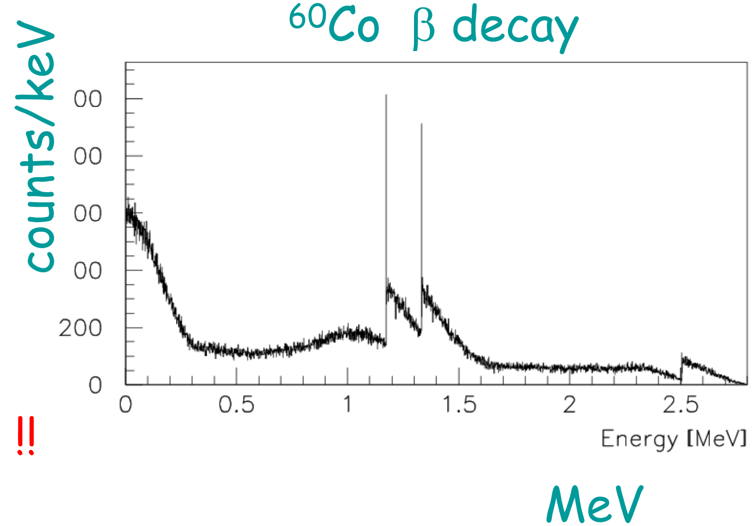
activation at sea level in nat Ge: 6.5 $^{60}Co/(kg\ d)$ Baudis PhD
4.7 $^{60}Co/(kg\ d)$ Avignone et al.



after 30 days of activation above ground
→ 15 decays/(kg y)

deposited energy spectrum

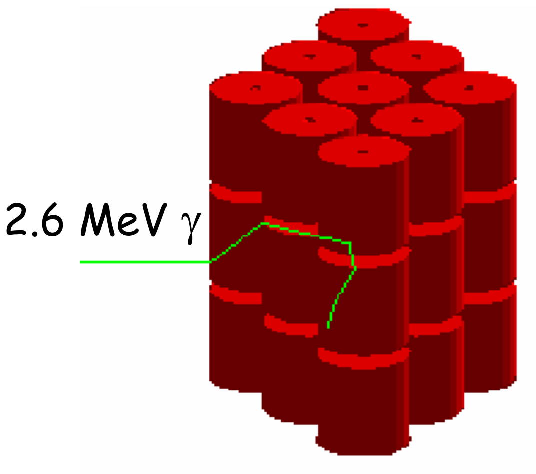
^{60}Co β decay



bkg index = 0.0025 cts/(keV kg y) = 2.5 x goal !!

→ need additional background suppression methods

Background discrimination methods



Methods:
- anti-coincidence of detectors
- veto multi site events with shape of pre-ampilfier signal
  mean free path of MeV gamma ~ 1 cm → multi site event
  mean free path of MeV electron ~ 1 mm → single site evt
- decay chain coincidence (^{68}Ge)
- waiting for decay of isotope (^{68}Ge, …)
- segmentation of detector (veto multi site events, only possible for new detectors)
- minimize time above ground for new detectors

Fraction of background events after each discrimination method (for LN)

method	^{60}Co	^{68}Ge	^{208}Tl concrete	^{208}Tl Ge support
det. anti-coin.	0.51	0.72	0.66	0.15
segmentation	0.19	0.25	0.55	0.25
pulse shape*	0.66	0.66	0.66	0.66
1 y waiting	0.87	0.39	1	1
decay chain	1	0.2	1	1
combined	0.06	0.01	0.24	0.02

* assumed rejection factor

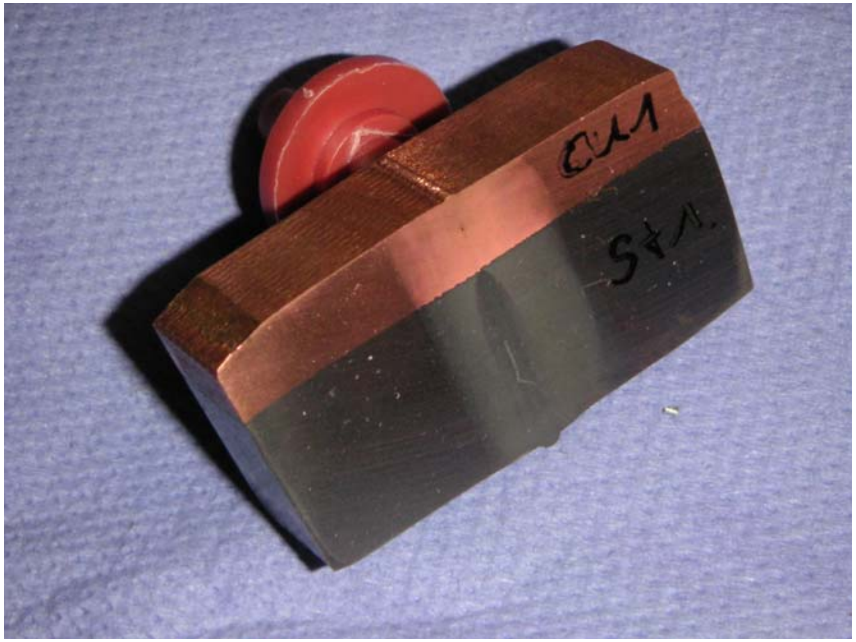
total bkg new detectors: 0.2 0.3 0.2 0.1 ($\times 10^{-3}$ cts/keV kg y)

for LAr: large suppression possible by detection of scintillation light

Technical Aspects of GERDA: Electron beam welding of Cu cryostat

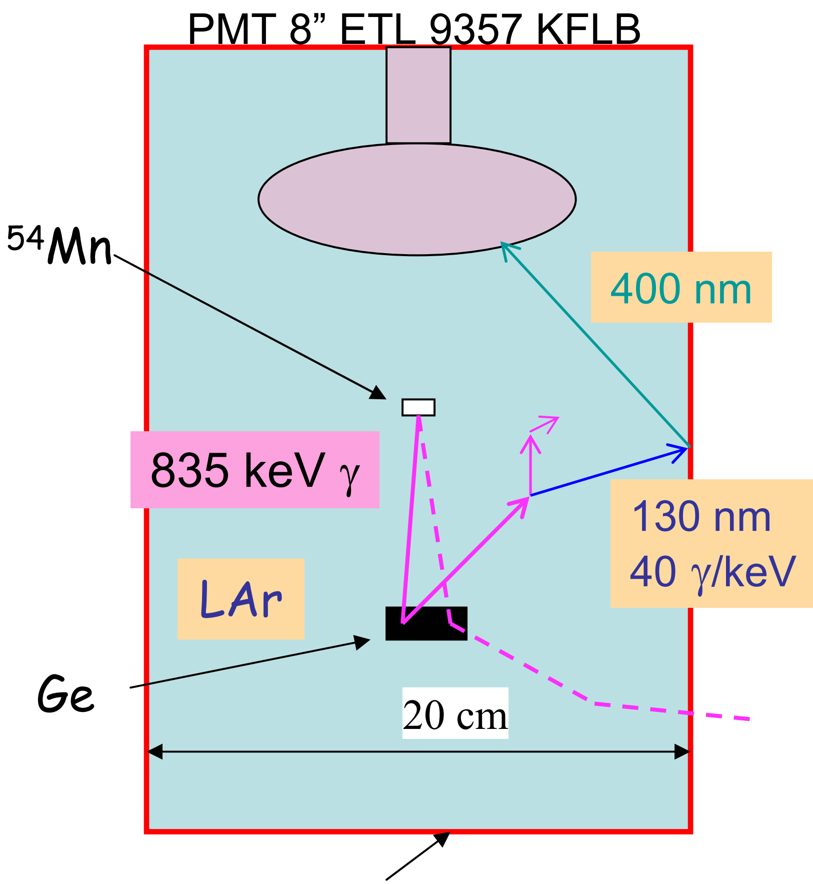
Facility in Burg, Germany
7m x 6m x 14m vacuum chamber

example of electron beam weld



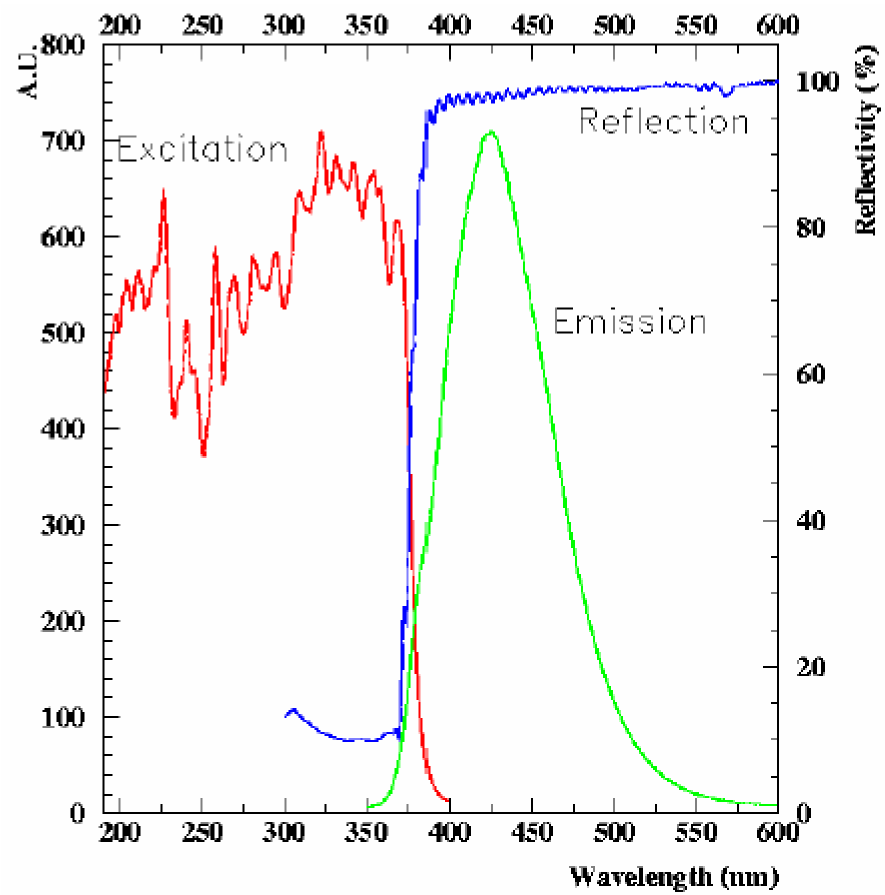
First LAr scintillation tests

Setup

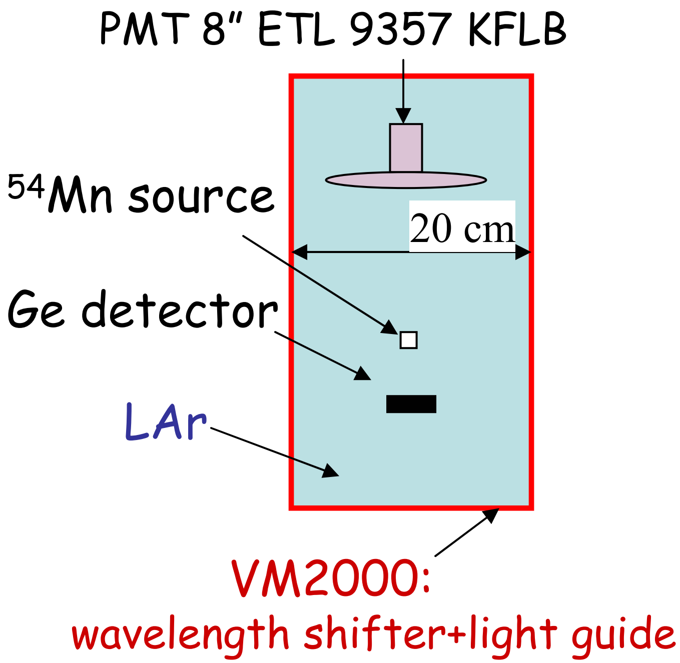


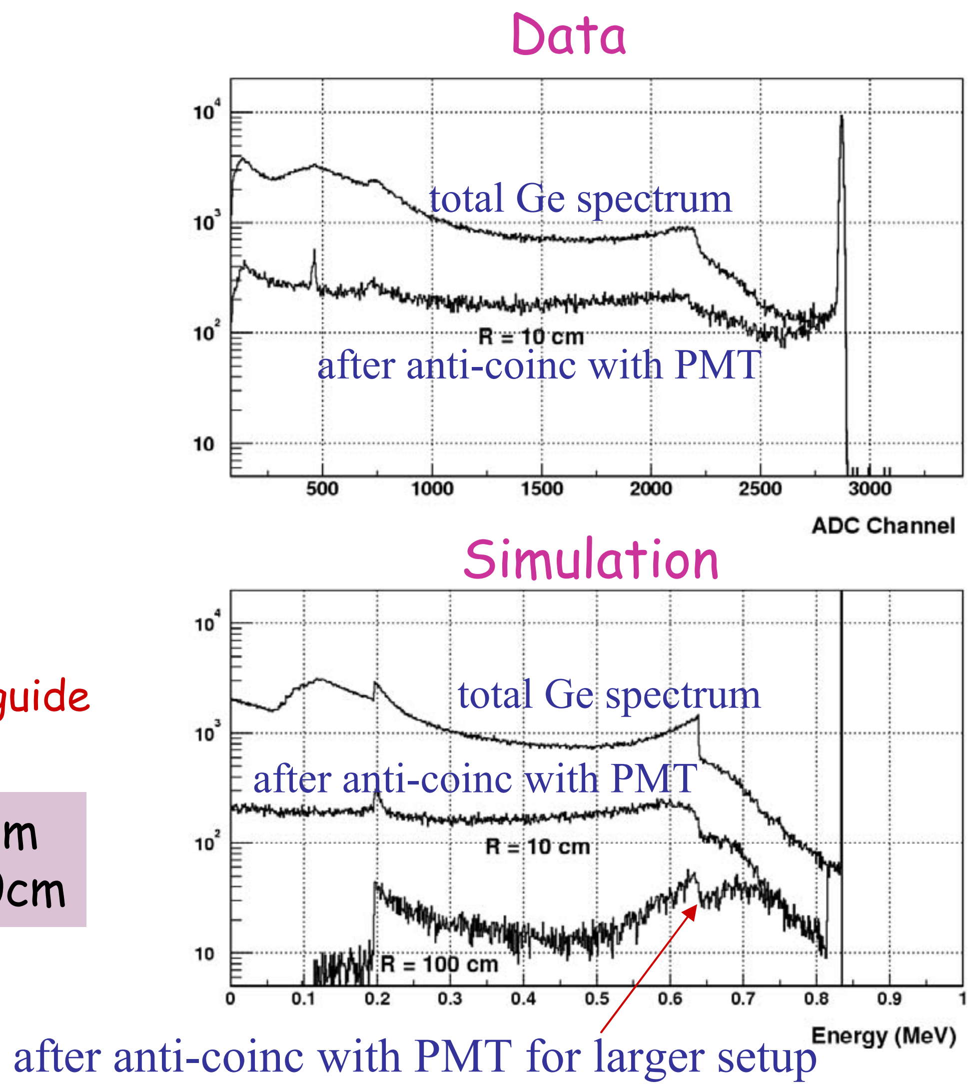
VM2000:
wavelength shifter + reflector

VM2000 properties



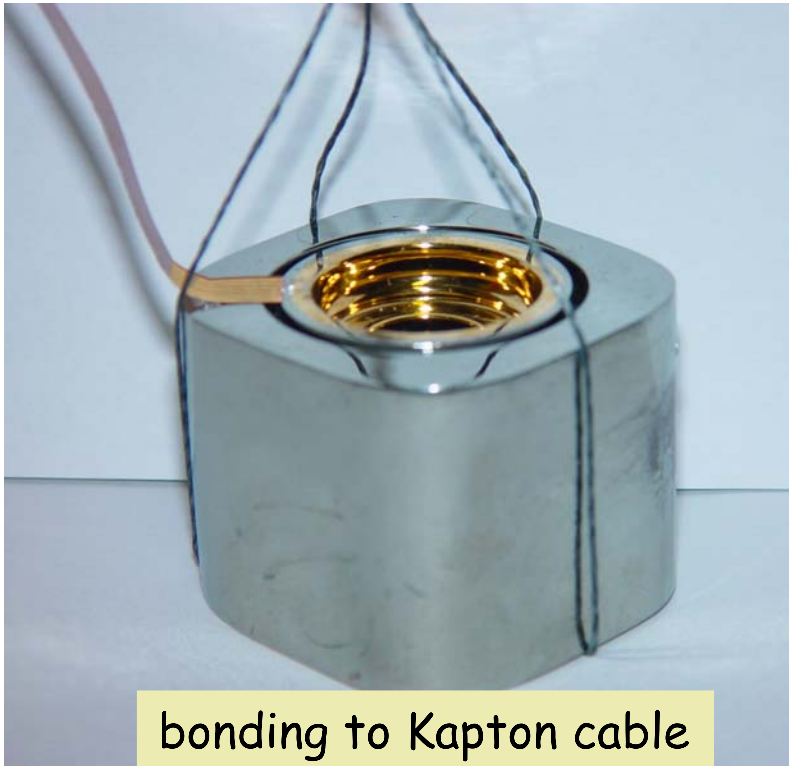
First LAr scintillation tests: results



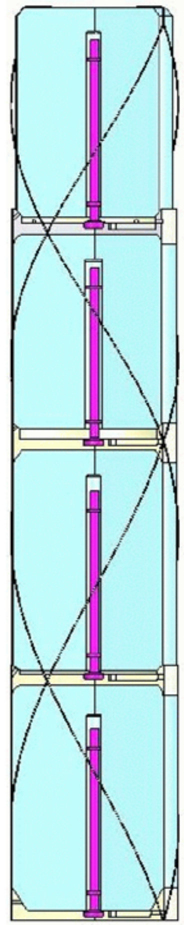


Factor 4 rejection for R=10cm
→ 40 rejection for R=100cm

Detector suspension & contact (first attempt)



bonding to Kapton cable
& operation of detector
successfully tested



aluminum mockup of HD-M detector

plastic spacer

rope out of high molecular PE

material screening to 10^{-12} level Th/U concentrations under way using Ge spectroscopy, ICPMS, neutron activation

N_2 & Ar purification from ^{222}Rn

- adsorption on highly pure activated carbon "CarboAct" at 77 Kelvin
- expertise available at MPI for purification & low concentration measurements

Low Temperature Adsorber (LTA) working at GS for Borexino

^{222}Rn in N_2 before purif. ~50 **µBq/m³**

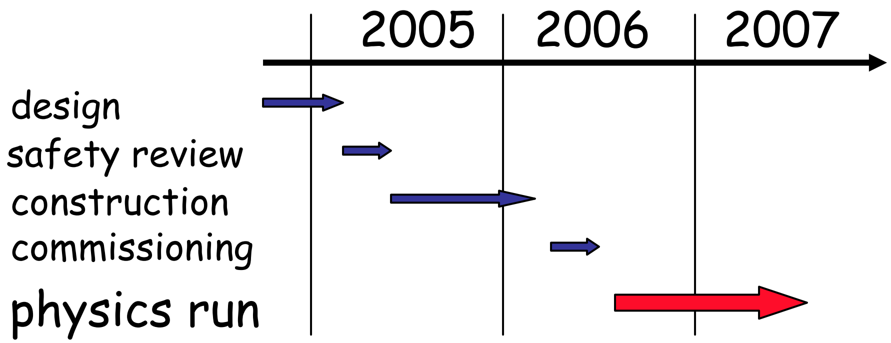
^{222}Rn in N_2 after purif. <0.3 **µBq/m³**

also available from Borexino CTF is water purification (µm filter, ion exchanger, …)

Time Schedule + Physics reach

t=0 at 16 October 2004: Scientific Committee meeting at LNGS

phase I:



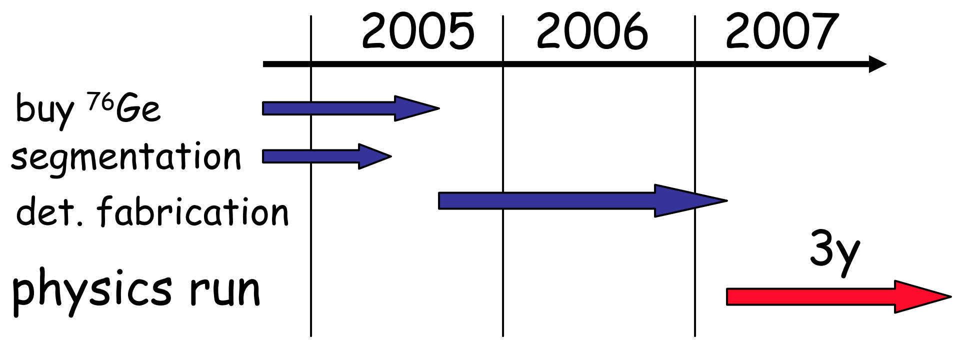
- o 15-20 kg existing ^{76}Ge detectors
- o intrinsic bkg may dominate
- o assume 0.01 cts/(keV kg y)
- o assume FWHM resolution = 3.6 keV

→N_{bkg} ~ 0.5 counts for 15 kg y

Klapdor-K.: 28.8±6.9 events in 71.7 kg y

expect 6.0±1.4 cts above bkg of 0.5
for ≤1 evt: signal excluded @ 98% CL

phase II:



- o buy 30 kg enriched material
- o produced 20 kg segmented detectors
- o verify bkg index 0.001 cts/(keV kg y)
- o statistics 3y * 35 kg ~ 100 kg y
- o N_{bkg} = 0.36 counts

$T^{0\nu}_{1/2}$ > 2x10^{26} y, <m_{ee}> < 0.09-0.29 eV

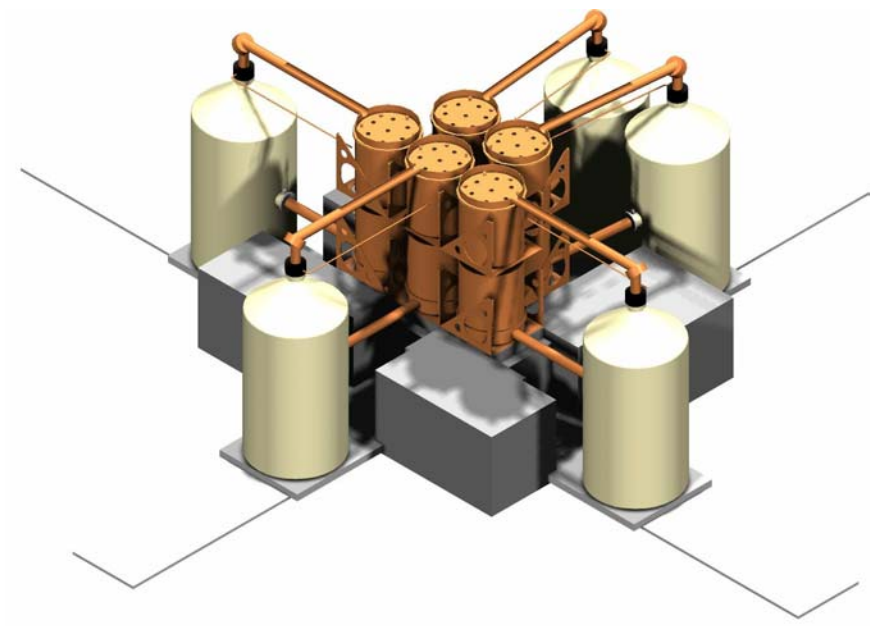
MAJORANA COLLABORATION

hep-ex/0201021 – 11 jan 2002

Brown, ITEP, JINR Dubna, LBL, Livermore, Los Alamos, New Mexico State, Oak Ridge, Osaka Univ., Pacific Northwest Natl Lab, Queen's Univ., TUNL, U of Chicago, U of South Carolina, U of Tennessee, U of Washington

enriched ^{76}Ge detectors: total mass = 500 kg (420 kg ^{76}Ge)

conventional shielding with copper and lead, n-type segmented detectors



Status: "Ready to go"
Proposal for 120 kg in preparation,
first money in October 2005?

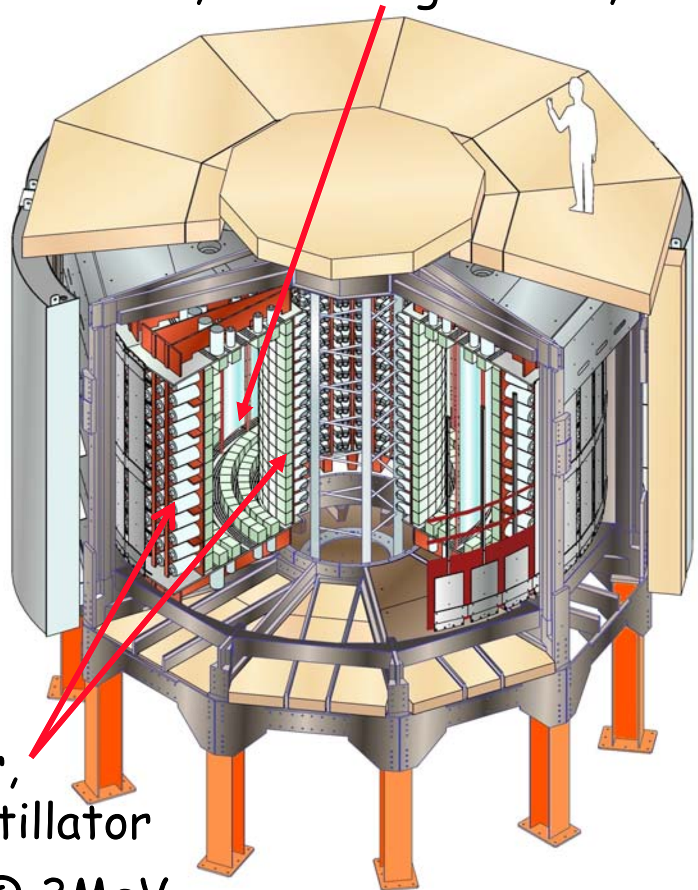
Expected sensitivity (500 kg, 10 y)
$T^{0\nu} = 4.0\ 10^{27}$ y
$\langle m_\nu \rangle = 0.02 – 0.07$ eV

GERDA is in close contact with Majorana, exchanging technical information,
best of the two experimental approaches should be used for common large ^{76}Ge exp.

NEMO3 : Neutrino Ettore Majorana Observatory

CENBG Bordeaux, Charles Univ. Prague, FNSPE Prague, INEEL, IReS Strasbourg, ITEP Moscow, JINR Dubna, Jyvaskyla Univ., LAL Orsay, LPC Caen, LSCE Gif, Mount Holyoke College, Saga Univ, UCL London

tracking detector, 6180 Geiger cells, B = 25 G

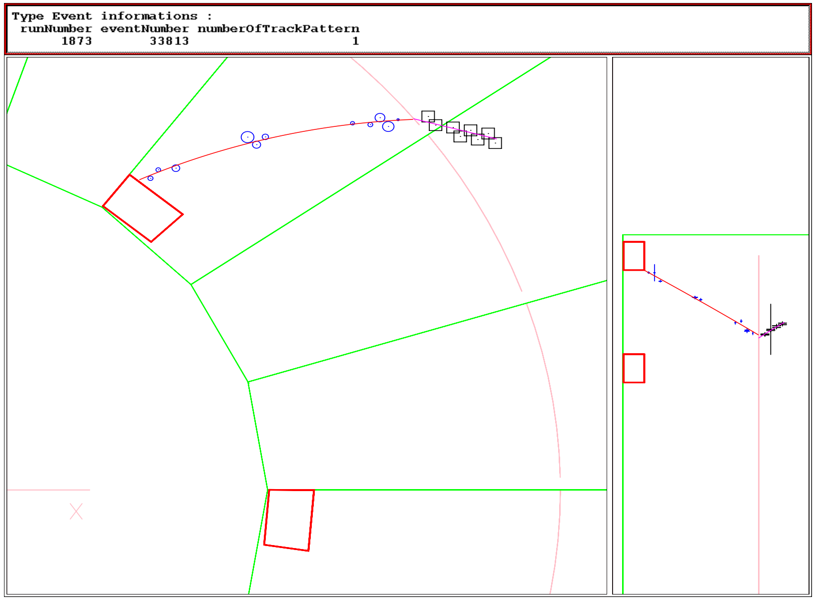


foil with
^{100}Mo, ^{82}Se, ...

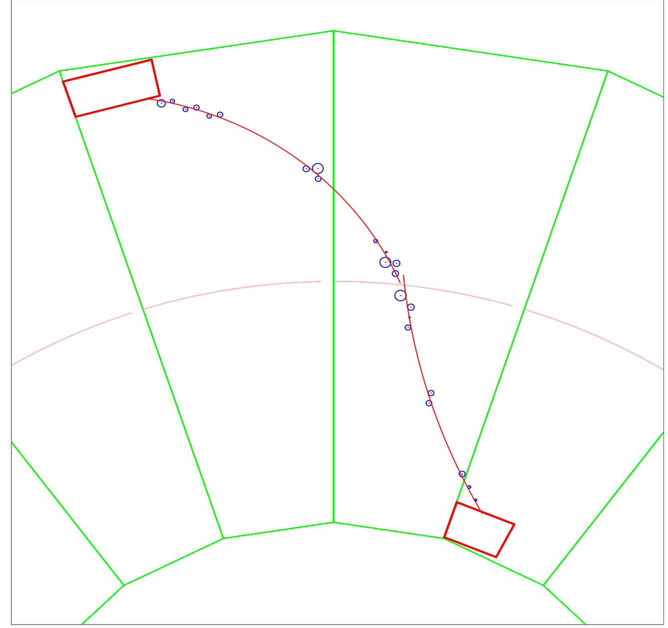
calorimeter,
plastic scintillator

$\sigma/E \sim 3\%$ @ 3MeV

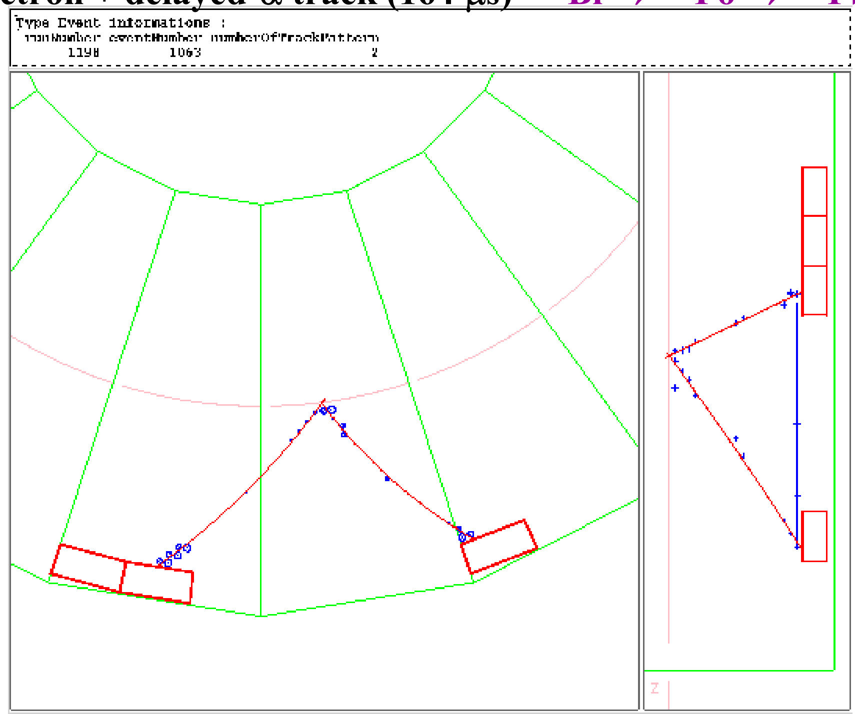
backgrounds can be identified by event topology
→ "only" $2\nu\beta\beta$ bkg remains due to limited energy resolution



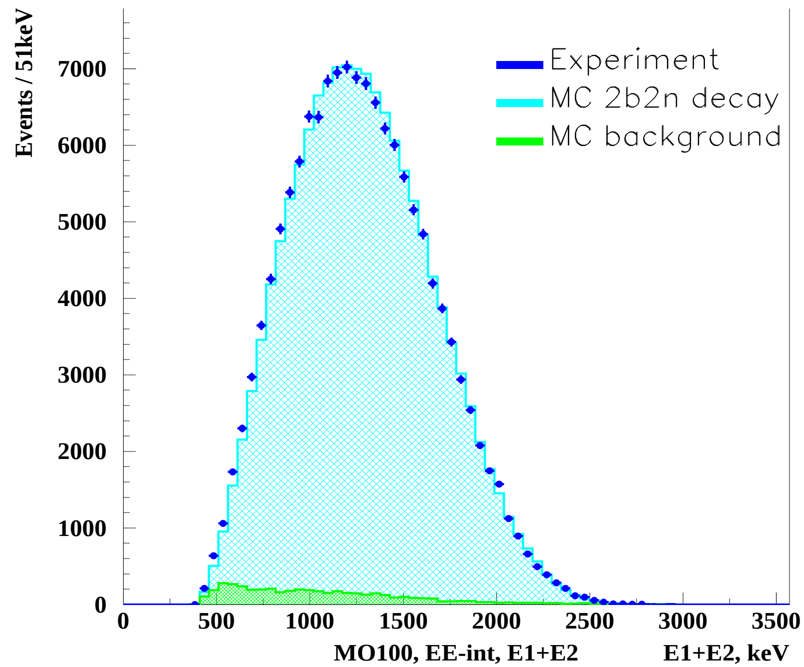
Electron + delayed-α track (164 μs) $^{214}Bi \rightarrow {}^{214}Po \rightarrow {}^{210}Pb$



2 Electrons **double beta decay candidate (with 2ν)**



Electron – positron pair **B rejection**



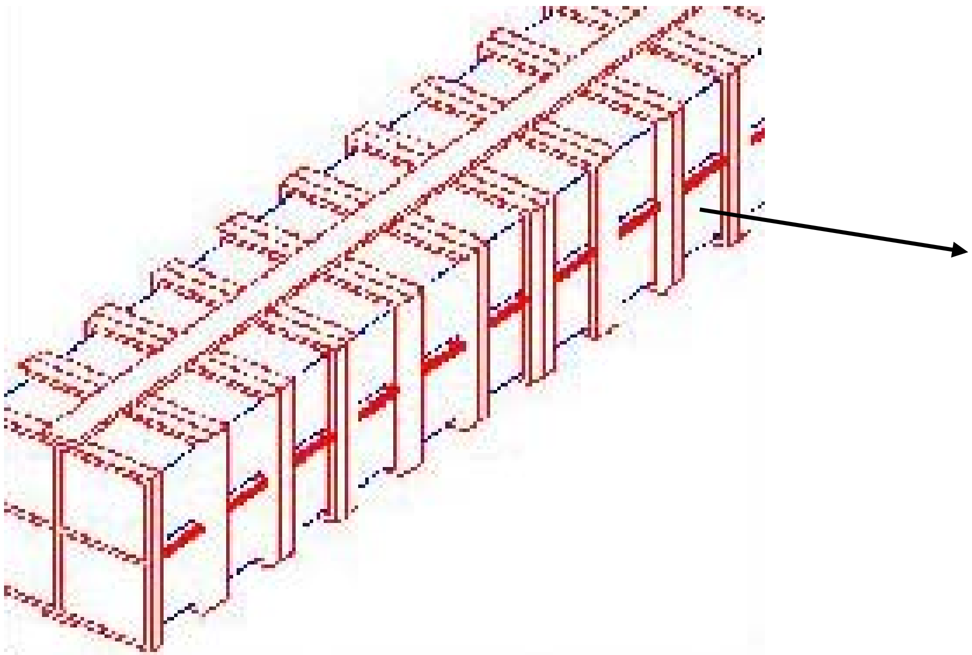
Double Beta Decay signal for ^{100}Mo

CUORICINO : "little" Cryogenic Underground Observatory for Rare Events

Firenze, Gran Sasso, Insubria, LBNL, Leiden, Milano, Neuchatel, South Carolina, Zaragoza
Begin operation : 2003 Gran Sasso Underground Laboratory

Bolometer: TeO_2 crystals operate at T ~ 10 mK → small heat capacity of C ~ 2 nJ/K
1 MeV energy deposition corresponds to 0,1 mK temperature rise
detected with Germanium thermistors, 100-300 μV/MeV

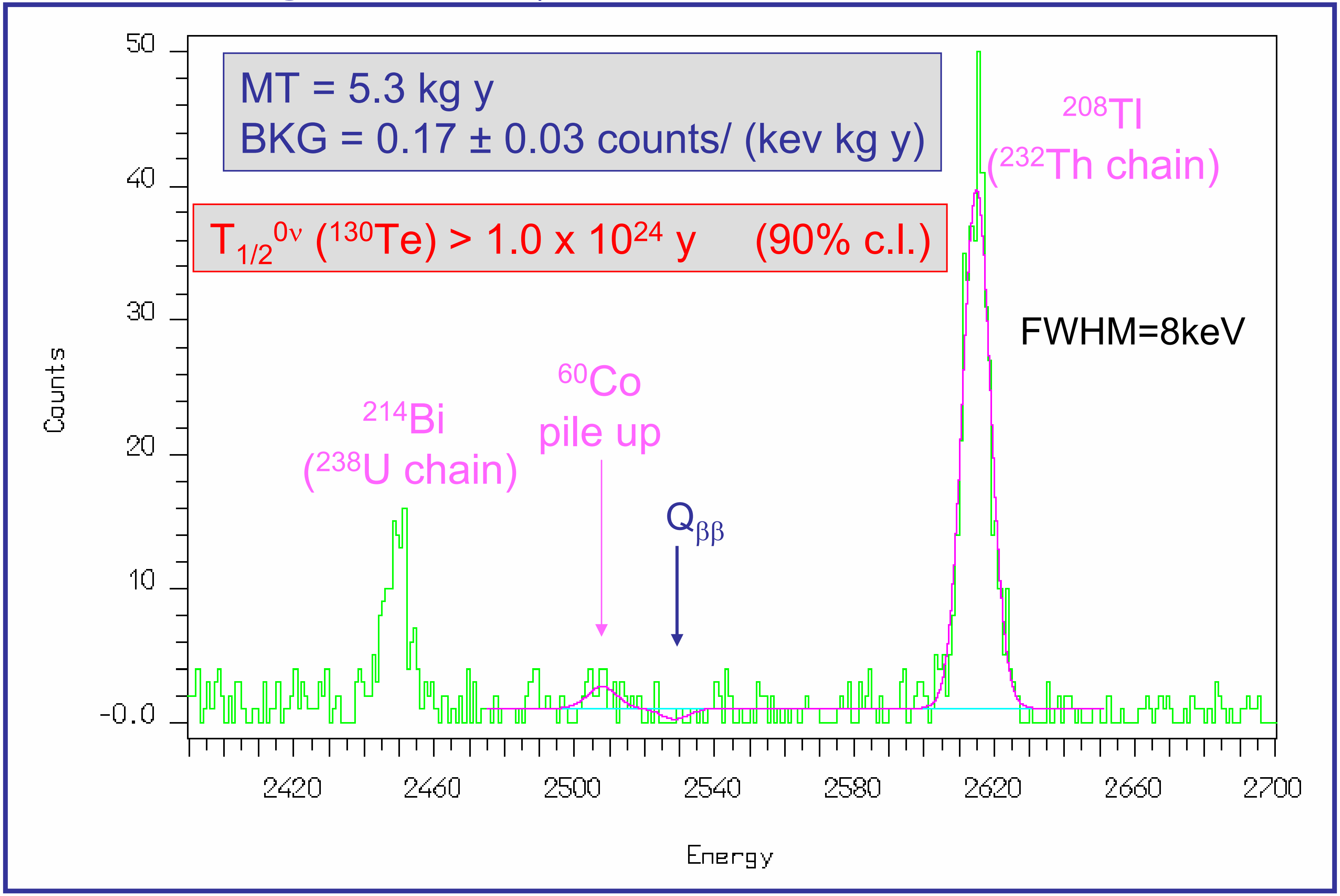
Cuoricino Tower: 13 planes, total 40 kg TeO_2, 13 kg ^{130}Te



Cuoricino Plane: 4 crystals (4x760 g)

One module with 4 TeO_2 crystals of 750 g

Cuoricino Background sum spectrum of all the detectors in the DBD region



CUORE = 19 towers = 200 kg ^{130}Te, proposal to funding agencies in January 2004

Present - Future

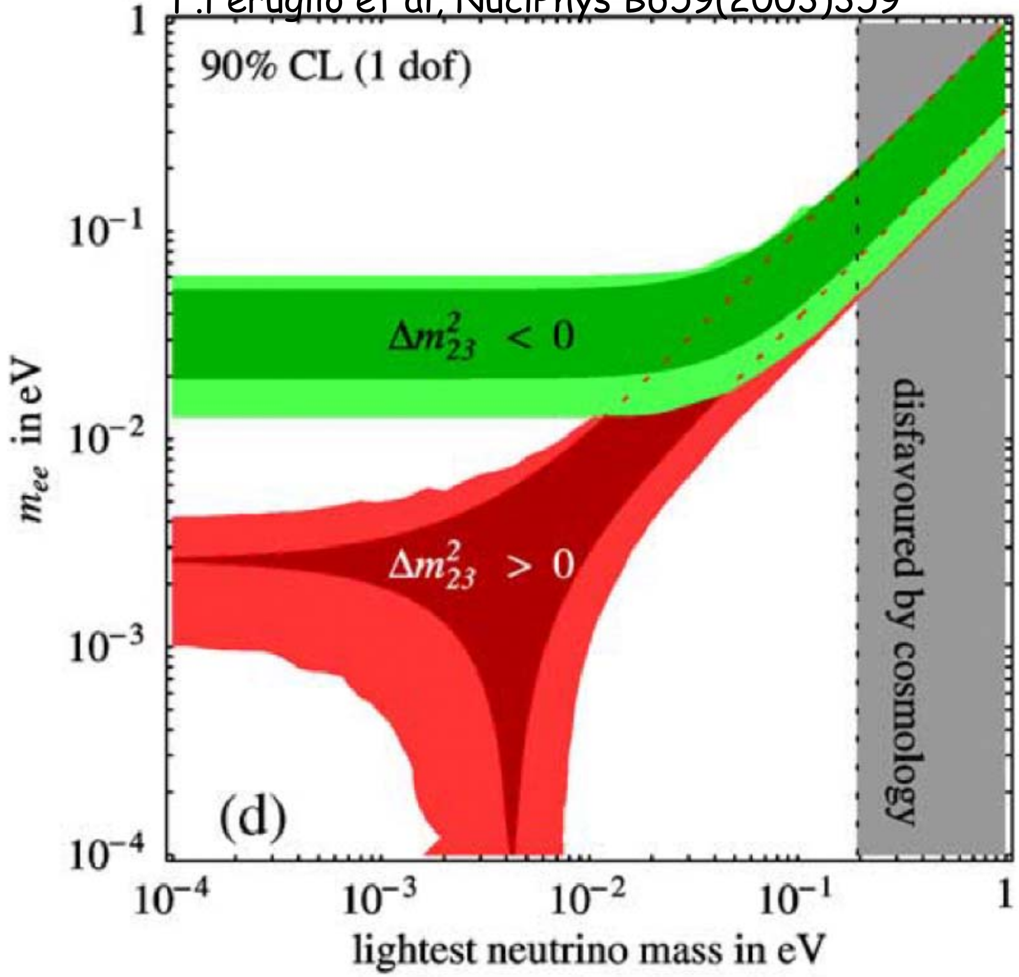
Experiment	Source	Sensitivity $T_{1/2}^{0\nu}$ (y)	m_ν (eV)	Year
IGEX	^{76}Ge	$> 1.6 \cdot 10^{25}$	0.36 - 1.07	2000
Heidelberg-Moscow	^{76}Ge	$0.7 - 4.2 \cdot 10^{25} (3\sigma)$	0.1-0.9 (3σ)	2004
Nemo3	^{100}Mo	$> 3.5 \cdot 10^{23}$	0.7-1.2	2004
		$5 \cdot 10^{24}$	0.2-0.4	2009
Cuoricino	^{130}Te	$> 1 \cdot 10^{24}$	0.4-1.0	2004
		$4 \cdot 10^{24}$	0.2-0.5	2007
Nemo-Next	^{100}Mo	$1 \cdot 10^{26}$	0.04-0.07	2015 ?
Cuore	^{130}Te	$3 \cdot 10^{26}$	0.02-0.09	2015 ?
Majorana	^{76}Ge	$4 \cdot 10^{27}$	0.02-0.07	2015 ?
Exo	^{136}Xe	$8 \cdot 10^{26}$	0.05-0.14	2015 ?
GERDA				
Phase I		$3 \cdot 10^{25}$	0.3-0.9	2007
Phase II		$2 \cdot 10^{26}$	0.09-0.29	2010
Phase III	world-wide collaboration			

Cuoricino & NEMO3 are not able to disprove the Heidelberg-Moscow result

Current “expectations” for effective mass

$$\langle m_{ee} \rangle = f(m_1, \Delta m^2_{sol}, \Delta m^2_{atm}, \theta_{12}, \theta_{13}, \alpha\text{-}\beta) = \left| \sum_{i=1}^{3} U_{ei}^2 \, m_i \right|$$

F.Feruglio et al, NuclPhys B659(2003)359



degenerate masses

inverted hierarchy

normal hierarchy

To test inverted & degenerate hierarchy need sensitivity <50 meV

Summary

Double Beta Decay is a very exciting physics topic,

the "only" method to discriminate Dirac/Majorana nature of ν
for sensitivity < 50 meV → large scale low background experiments
nuclear matrix elements → several isotopes (^{76}Ge, ^{130}Te, ...)

GERDA (^{76}Ge) will achieve background level of 0.001 cts/(keV kg y)
phase I: use existing diodes, test Klapdor-Kleingrothaus result in 1 y
phase II: add new segmented detectors → factor 10 in $T_{1/2}$ sensitivity

70% of funding secured, decision on proposal from LNGS expected soon

R&D: material screening for detector contacts, support, …
segmentation of Ge diode,
liquid argon scintillation,
ASIC for readout

Close coordination with Majorana, one large global ^{76}Ge experiment