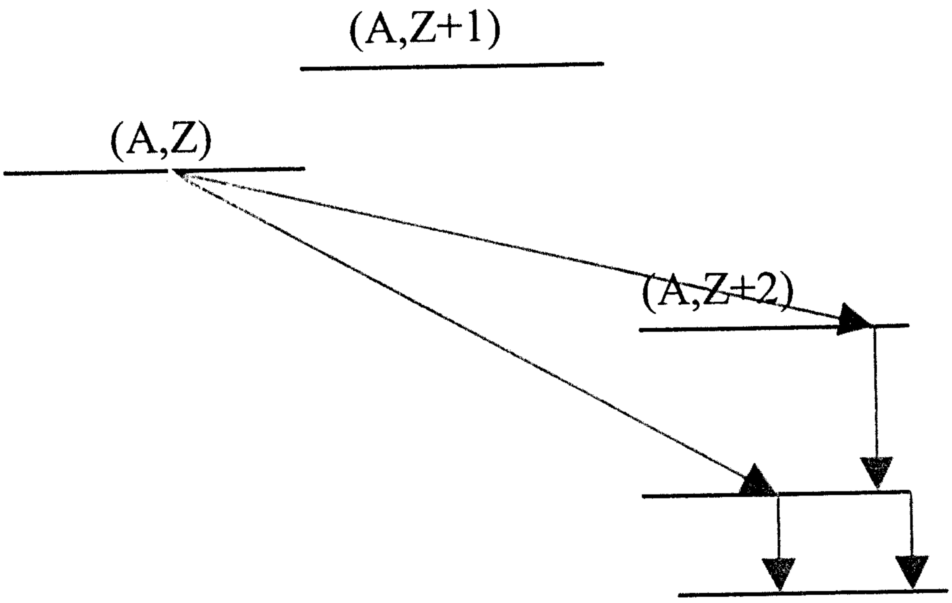
DOUBLE BETA DECAY AND NEUTRINO MASS

Ettore Fiorini
Varenna, June 12, 2002



(A,Z) → (A,Z+2) + 2 e^- + 2 $\bar{\nu}_e$
(A,Z) → (A,Z+2) + 2 e^- + χ (...χ's)
(A,Z) → (A,Z+2) + 2 e^-

also $\beta^+\beta^+$, β^+EC, ECEC (recent results by Dama,Barabash etc..)

EXPERIMENTALLY

- transition rate of neutrinoless DBD proportional to ε^5 instead than to ε^{10-11} for the two-neutrino channel. Less dependent on transition energy
- a peak should appear in the sum spectrum of the two electron energies

Evidence for two neutrino double beta decay found in

^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{130}Te, ^{136}Xe, ^{150}Nd, ^{238}U

also to excited states of ^{100}Mo

with direct, geochemical and radiochemical experiments

THEORETICALLY

- lepton number violation
- right handed currents η and λ
- non-zero "effective" neutrino mass $<m_\nu>$

$$[T^{\text{0í}}_{\text{ââ}}]^{-1} = C_{mm}<m_\upsilon>^2 + C_{\lambda\lambda}<\lambda>^2 + C_{\eta\eta}<\eta>^2 +$$

$$+C_{m\lambda}<m_\upsilon><\lambda> + C_{m\eta}<m_\upsilon><\eta> + C_{\lambda\eta}<\lambda><\eta>$$

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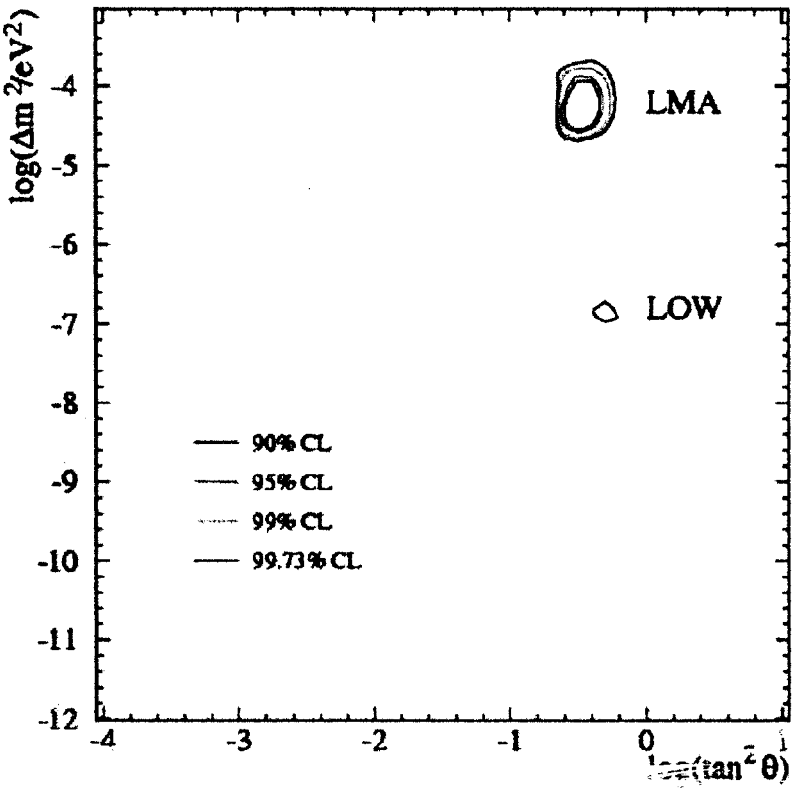
A. Hallin: The Sudbury Neutrino Observatory (28/33)

Global Fit with total SNO spectrum



without separate da and night spectra

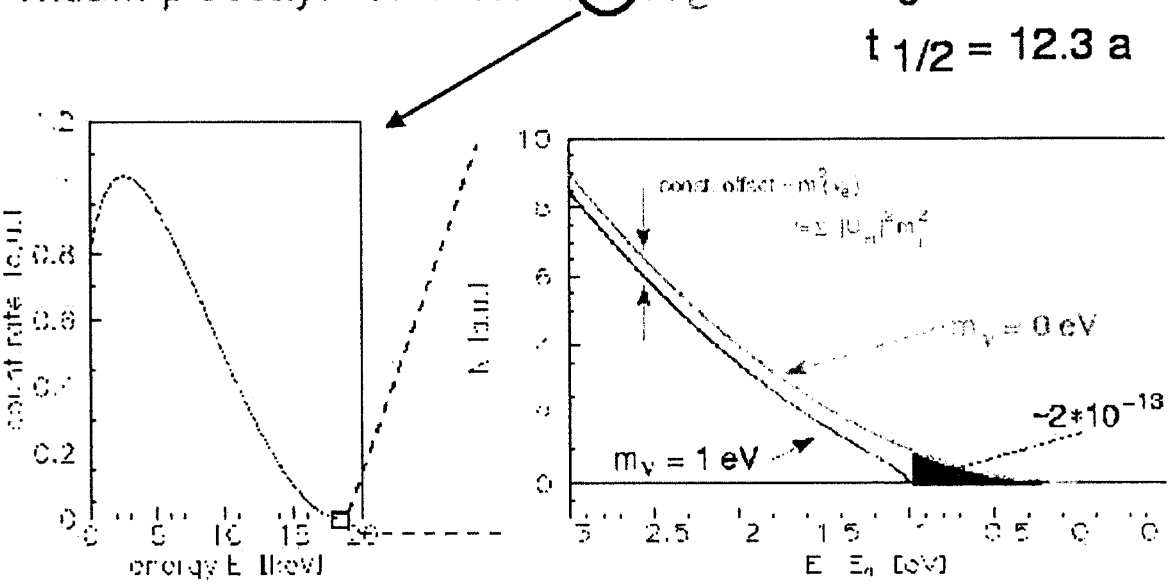
most of the MSW model constraints comes from SNO CC/NC!

Ch.Weinheimer: Direct Neutrino Mass Experiments: Present and Future (2/29)

Direct measurement of $m(\nu_e)$

Tritium β decay: $^3H \rightarrow {}^3He^+ + e^- + \bar{\nu}_e$

super–allowed
$E_0 = 18.6$ keV
$t_{1/2} = 12.3$ a



Need **very high energy resolution &**
very high signal rate &
very low background

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Technical challenges

- Recirculation and purification of tritium to a large extent (kCi)
- ≈ 30 superconducting solenoids
- UHV (< 10^{-11}mbar) in huge volume (1000m^2)
- HV calibration and stability on ppm level
- High resolution detectors
- ....

⇒ ideal place: Forschungszentrum Karlsruhe/Germa

Difficulties to calculate Nuclear Matrix Elements ->
measurements on many candidate nuclei are needed

EXTRAPOLATIONS OF $<m_\nu>$ (and m_β from direct measurements - Katrin → 0.3 eV) FROM THE PRESENT RESULTS ON NEUTRINO OSCILLATIONS

Various theoretical calculations (Bilenki et al -three and four neutrino mixing, Farzan et al, Pas and Weiler, Falcone and Tramontano, Klapdor et al, Vogel ...) not always in agreement.

Values of $<m_\nu>$ in the region of a few tens of eV seem interesting.

DBD & Neutrino Properties (2)

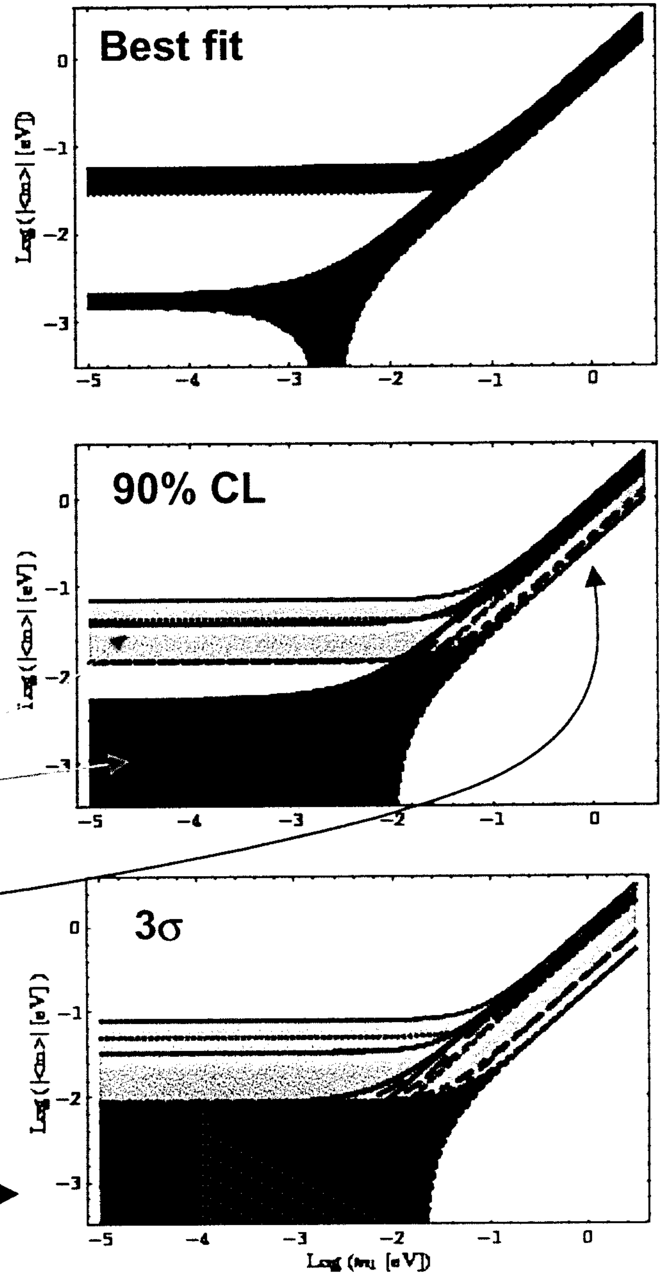
Neutrino oscillation experiments have given convincent evidences that **neutrinos are massive and mixed**

Missing informations:
- neutrino absolute mass scale
- nature (Dirac/Majorana)
- CP (Majorana) phases
- exotic processes

β-endpoint

0ν2β

0ν2β is a powerful tool to identify neutrino mass hierarchy:
- inverse
- direct
- quasi-degenerate



Spread due to Nuclear matrix elements indeterminations

Pascoli S Petcov ST hep-ph/0205022 implications from solar ν experiments (last SNO results included) in the framework of 3 Majorana ν mixing

Not included

EXPERIMENTAL APPROACHES

INDIRECT METHODS

(search for an abnormal abundance of (A,Z+2) in a material containing (A,Z+2))

Geochemical

RESULTS:

$^{82}Se \rightarrow {}^{82}Kr$ * $\tau_{1/2} = (1.2 \pm .1) \times 10^{20} - (2.1 \pm .3) \times 10^{20}$ a

$^{96}Kr \rightarrow {}^{96}Mo$ * $\tau_{1/2} = (3.9 \pm .9) \times 10^{19}$

$^{128}Te \rightarrow {}^{128}Xe$ $\tau_{1/2} = (1.5 \pm .2) \times 10^{24} - (7.7 \pm .4) \times 10^{24}$a

$^{130}Te \rightarrow {}^{130}Xe$ $\tau_{1/2} = (7.5 \pm .3) \times 10^{20} - (27 \pm 1) \times 10^{20}$ a

* confirmed by direct experiments

Advantage: long measuring times, good sensitivity

Disadvantages: 0_ν , 2_ν , χ' and excited states together, gas losses (difficult and not large - Milano experiment)

Radiochemical

Store large masses of (A.Z) underground and seach for (A.Z+2)

RESULT:

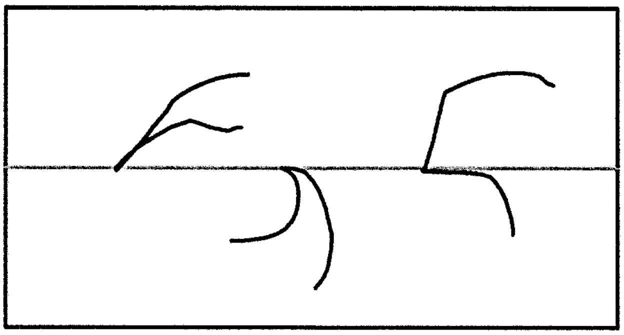
$^{238}U \to {}^{238}Pu$ $\tau_{1/2} = (2.0 \pm .6) \times 10^{21}$ (68% c.l.)

$\Rightarrow$ α decay ($\tau_{1/2} = 87.7$ a)

problems similar to those above

DIRECT METHODS

Source ≠ Detector



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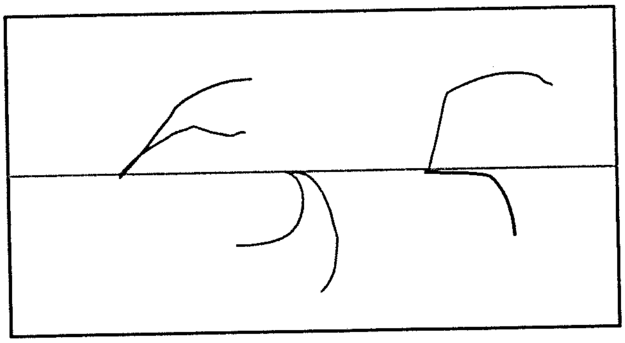
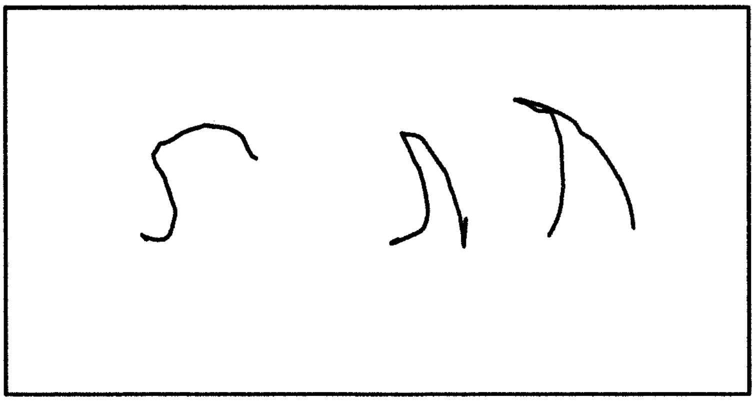


First result of $2\nu\beta\beta$ decay of ^{82}Se by Irvine Mont Holyhoke, Baksam-Moscow, Elegant's, Nemo II, NEMO III, Moon etc

Excellent for two neutrino double beta decay.

For neutrinoless double beta decay a good resolution is needed. Background from two neutrino double beta decay

Source = Detector



G.F. dell' Antonio and E. F.

CaF_2 scintillator Goldhaber, Bejing,Dama

Ge Milano, now Heidelberg-Moscow, IGEX

$CdWO_4$ Kiev-Florence

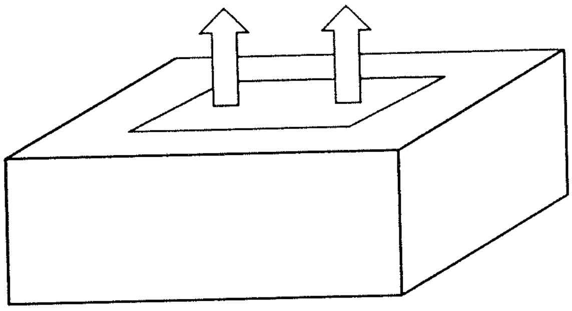
Xenon Proportional Counters, ionization chambers,

TPC, scintillators Gothhard, Dama with liquid Xe

THERMAL DETECTORS

E.F. and T.Niinikosky (1984)

$$\Delta T = \frac{Q}{C_v}$$



$$C_v = 1944\left(\frac{V}{Vm}\right)\left(\frac{T}{T_D}\right)^3 \text{ J/K}$$

$$\Delta E = \xi \sqrt{k\, C_V\, T^2}$$

ΔE @ 5 keV ~100 mk ~ 1 mg <1 eV ~ 5 eV

@ 2 MeV ~10 mk ~ 1 kg <10 eV ~ keV

Compound	**Isotopic abundance of the candidate nucleus**	**Transition energy**
$^{48}\mathrm{CaF}_2$ a	.0187 %	4272 keV
^{76}**Ge b**	7.44 "	2038.7 "
$^{100}\mathrm{MoPbO}_4$ **c**	9.63 "	3034 "
$^{116}\mathrm{CdWO}_4$**c**	7.49 "	2804 "
$^{130}\mathrm{TeO}_2$**d**	34 "	2528 "
$^{150}\mathrm{NdF}_2$e	4.64 "	3368 "

a. heat+scintillation proved, eliminates background from α particles

b. can be as good as Ge diodes

c. scintillates proved as thermal detectors

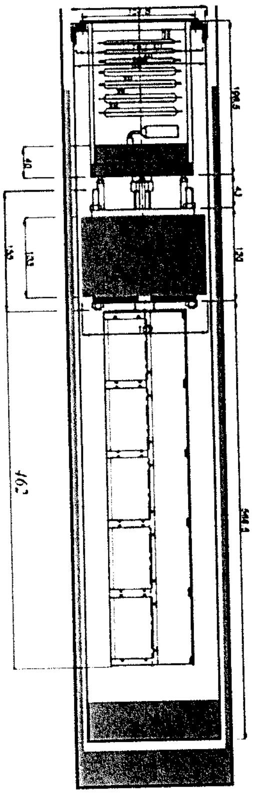
d. large isotopic abundance

e. difficult to cool

Present results on neutrinoless double beta decay of ^{130}Te

$> 2.1 \times 10^{23}$ a at 90% c.l.

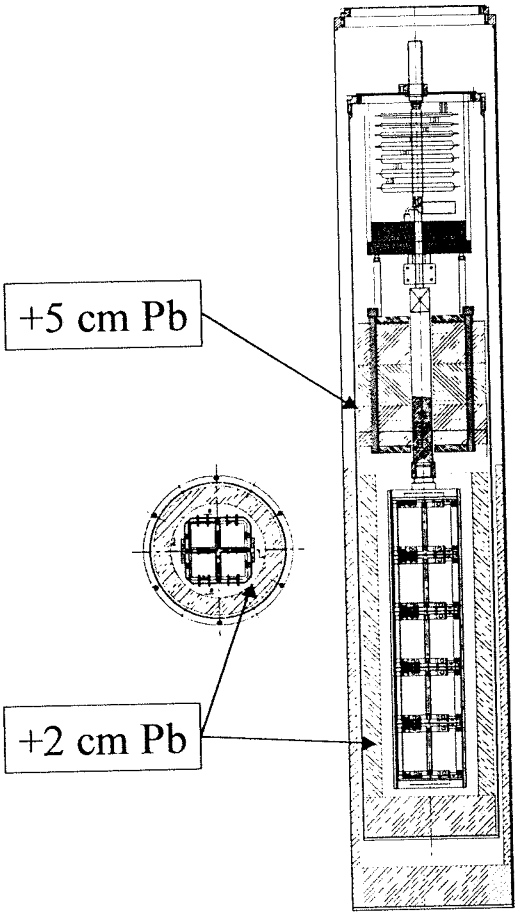
"OLD"



MC 23 kg
50 mK 13 kg
Still (18 + 60) kg

Total 114 kg

"NEW"



MC 35 kg
50 mK (13 + 41) kg
Still (18 + 40) kg

Total 156 kg

(+33 kg)

PRESENT RESULTS ON TWO NEUTRINO $\beta\beta$ DECAY

Nucleus	**Transition energy(keV)**	**Half lifetime (years)**
^{48}Ca	4276	$(4.3\pm^{.24}_{.11}\pm.14) \times 10^{19}$
^{76}Ge	2039	$(9.2\pm^{.7}_{.4}) \times 10^{20}$ $(17.7\pm.1\pm^{1.3}_{.1}) \times 10^{20}$ $(14.5\pm^{1.5}) \times 10^{20}$
^{82}Se	2992	$(1.08\pm^{.26}_{.06}) \times 10^{20}$ $(.83\pm^{.1}_{.07}) \times 10^{20}$
^{96}Zr	3351	**$(3.9\pm.9) \times 10^{19}$** $(2.1\pm^{.8}_{.4}\pm.2) \times 10^{19}$
^{100}Mo	3134	$(1.15\pm^{.3}_{.2}) \times 10^{19}$ $(.68\pm^{.38}_{.53}\pm.68) \times 10^{19}$ $(1.16\pm^{.34}_{.08}) \times 10^{19}$ $(.95\pm.04\pm.09) \times 10^{19}$
^{100}Mo(0^+ -0^{+*})	1904	$(6.1\pm^{1.8}_{1.1}) \times 10^{20}$
^{116}Cd	2804	$(2.6\pm^{.9}_{.5}\pm.35) \times 10^{19}$ $(2.7\pm^{.5}_{.4}\pm^{.9}_{.6}) \times 10^{19}$ $(3.75\pm.35\pm.21) \times 10^{19}$
^{128}Te	867	**$(7.7\pm.4) \times 10^{24}$**
^{130}Te	2528	**$(7\pm2) \times 10^{20}$** **$(28\pm3) \times 10^{20}$** **$(7.9\pm.1) \times 10^{20}$**
^{136}Xe	2467	$>7.3 \times 10^{20}, >1.1 \times 10^{22}$
^{150}Nd	3368	$(1.88\pm^{.66}_{.39}\pm.19) \times 10^{19}$
^{238}U	1437	$(2\pm.6) \times 10^{21}$

PRESENT RESULTS ON MAJORON ββ DECAY

Nucleus	**ΔE (keV)**	**$\tau_{0\nu}$ (years)**	**Limit on $G_{\nu\chi}$ $(x10^{-4})$**
^{48}Ca	4276		
^{76}Ge	2039	**7.9 x 10^{21}**	**2-10**
^{82}Se	2992	**2.4 x 10^{21}**	**2-7**
^{96}Zr	3351	**6.2 x 10^{21}**	**18**
^{100}Mo	3134	**5.4 x 10^{21} (68%)**	**1-2**
^{116}Cd	2804	**1.2 x 10^{21}**	**.3-.6**
^{128}Te	867	**(7.7 x 10^{24})**	
^{130}Te	2528	**1 x 10^{21}**	**2-7**
^{136}Xe	2467	**1.4 x 10^{22}**	**2-5**
^{150}Nd	3368	**2.8 x 10^{20}**	**1.4-1.9**
^{238}U	1437		

PRESENT RESULTS ON NEUTRINOLESS ββ DECAY

Nucleus	**ΔE (keV)**	**$\tau_{o\nu}$ (years)**	**Limit on $<m_\nu>$(eV)**
^{48}Ca	4276	**9.5×10^{19} (76%)**	**15-26**
^{76}Ge	2039	**1.9×10^{25} 1.6×10^{25}**	**.34-1.14 .40-1.35**
^{82}Se	2992	**2.7×10^{22} (68%)**	**4.7-14.4**
^{96}Zr	3351	**1×10^{21}**	**(33)**
^{100}Mo	3134	**6.5×10^{22} (68%)**	**2-4.4**
^{116}Cd	2804	**2.9×10^{22}**	**4.9-5.2**
^{128}Te	867	**7.7×10^{24}**	**.72-1.5**
^{130}Te	2528	**2.1×10^{23}**	**.8-2.**
^{136}Xe	2467	**4.2×10^{23} (7×10^{23})**	**1.8-5.4 (1.4-4.2)**
^{150}Nd	3368	**1.2×10^{21}**	**5.3-7.1**
^{238}U	1437	**8.4×10^{20}**	**(17.6-34.5)**

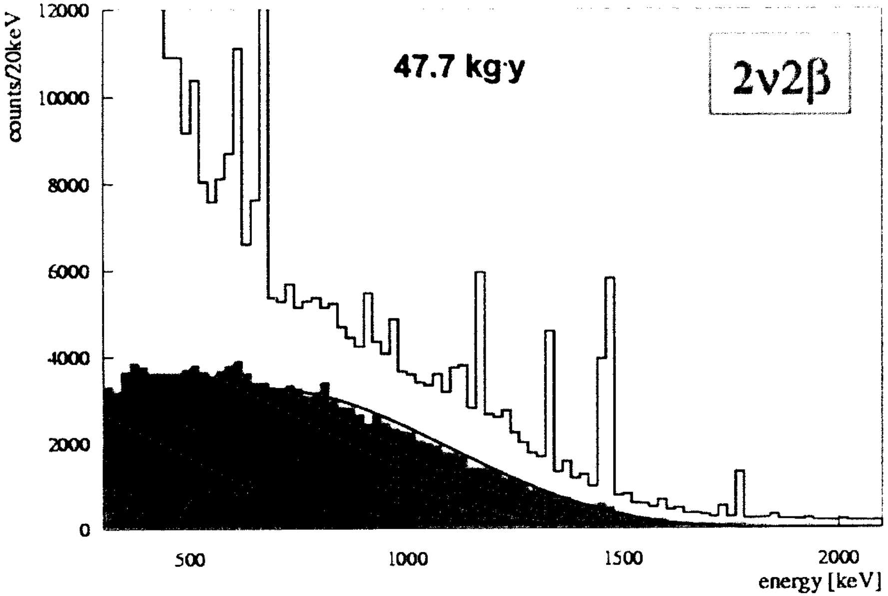
Heidelberg-Moscow

Max-Planck-Institut für Kernphysik
Russian Science Center Kurchatov Institute

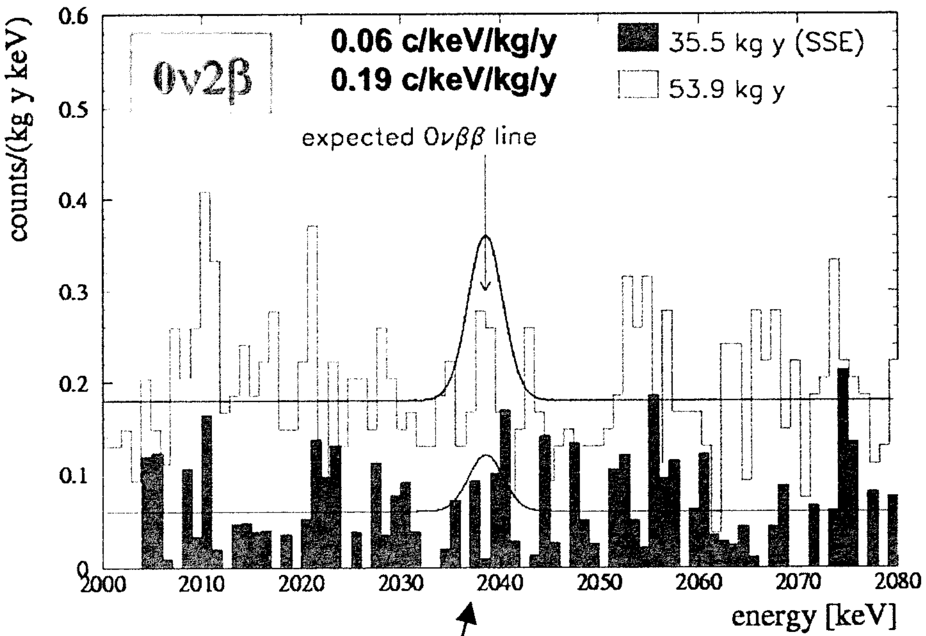
since 1990

Gran Sasso underground laboratory

- Five Ge diodes (overall mass 10.9 kg) isotopically enriched (86%) in ^{76}Ge
- Lead box and nitrogen flushing of the detectors
- Digital Pulse Shape Analysis (factor 5 reduction)



Klapdor-Kleingrothaus HV et al. Eur. Phys. J. 12 (2001) 147



$T_{1/2}^{0\nu} > 1.9 \times 10^{25}$ (90 % C.L.)
$<m_\nu> < 0.35$ (0.3-1.24) eV

Accurate background model:
$T_{1/2}^{2\nu} > (1.55 \pm 0.01(\text{stat})\ ^{+0.19}_{-0.15}\ (\text{syst})) \times 10^{21}$

Heidelberg-Moscow

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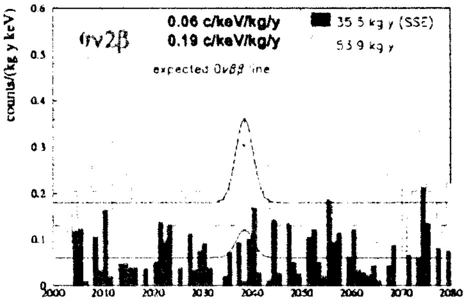

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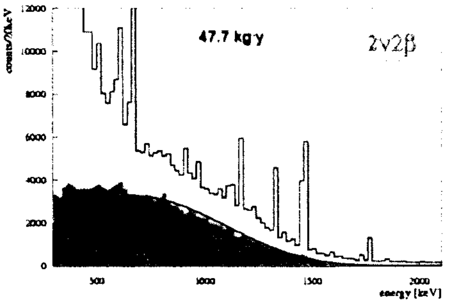

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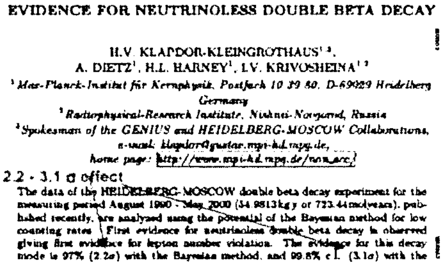
Evidence for 0ν2β: KDHK

Klapdor-Kleingrothaus HV et al. hep-ph/0201231

Klapdor-Kleingrothaus HV and Sarkar U. hep-ph/0201224



EVIDENCE FOR NEUTRINOLESS DOUBLE BETA DECAY

H.V. KLAPDOR-KLEINGROTHAUS[1,3],
A. DIETZ[1], H.L. HARNEY[1], I.V. KRIVOSHEINA[1,2]

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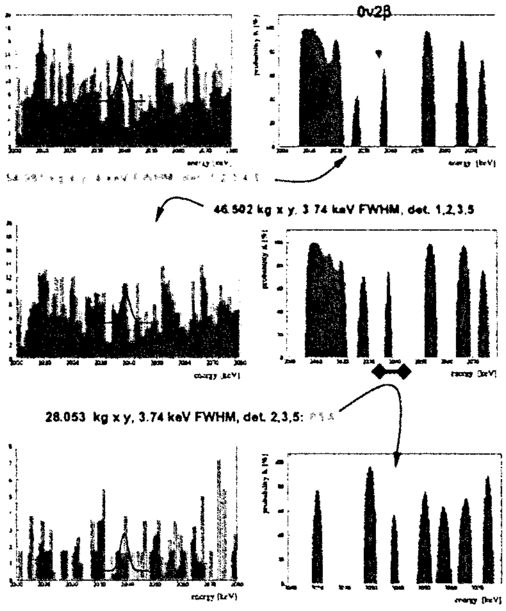
[2] *Radiophysical-Research Institute, Nishnii-Novgorod, Russia*

[3] *Spokesman of the GENIUS and HEIDELBERG-MOSCOW Collaborations, e-mail: klapdor@gustav.mpi-hd.mpg.de, home page: http://www.mpi-hd.mpg.de/non_acc/*

2.2 - 3.1 σ effect

The data of the HEIDELBERG-MOSCOW double beta decay experiment for the measuring period August 1990 - May 2000 (54.9813 kg y or 723.44 molyears), published recently, are analyzed using the potential of the Bayesian method for low counting rates. First evidence for neutrinoless double beta decay is observed giving first evidence for lepton number violation. The evidence for this decay mode is 97% (2.2σ) with the Bayesian method, and 99.8% c.l. (3.1σ) with the method recommended by the Particle Data Group. The half-life of the process is found with the Bayesian method to be $T_{1/2}^{0\nu} = (0.8 - 18.3) \times 10^{25}$ y (95% c.l.) with a best value of 1.5×10^{25} y. The deduced value of the effective neutrino mass is, with the nuclear matrix elements from 5, $\langle m \rangle = (0.11 - 0.56)$ eV (95% c.l.), with a best value of 0.39 eV. Uncertainties in the nuclear matrix elements may widen the range given for the effective neutrino mass by at most a factor 2. Our observation which at the same time means evidence that the neutrino is a Majorana particle, will be of fundamental importance for neutrino physics. PACS. 14.60.Pq Neutrino mass and mixing - 23.40.Bw Weak-interaction and lepton (including neutrino) aspects - 23.40.-s Beta decay, double beta decay, electron and muon capture.



46.502 kg x y, 3.74 keV FWHM, det. 1,2,3,5

28.053 kg x y, 3.74 keV FWHM, det. 2,3,5: PSA

Reanalysis of the 1990-2000 Heidelberg-Moscow data

- **Peak Detection Procedure**
- **Bayesian approach**

Natural radioactivity lines recognized!

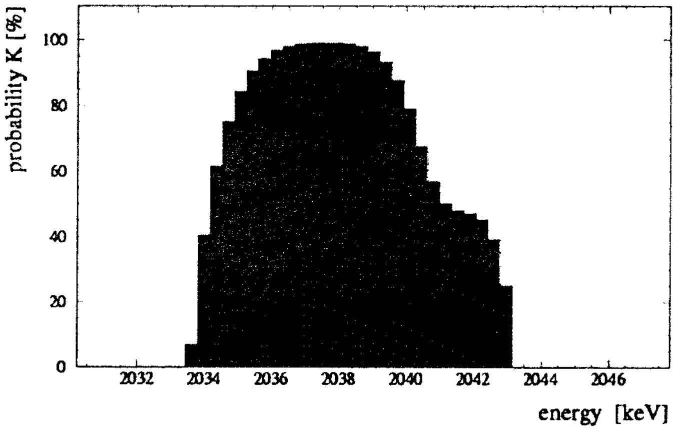
Select a small Energy interval around E

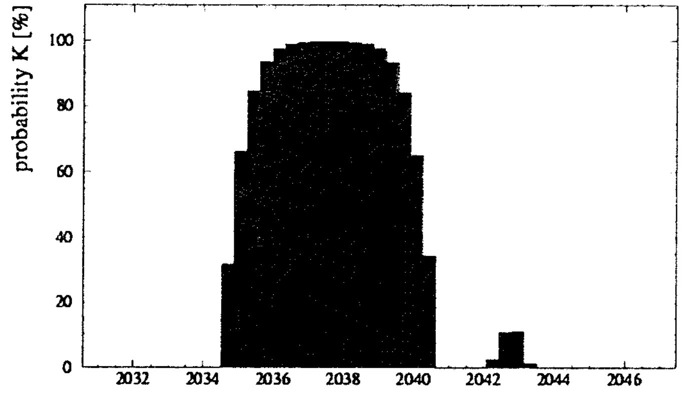
Evidence for 0ν2β: KDHK (2)

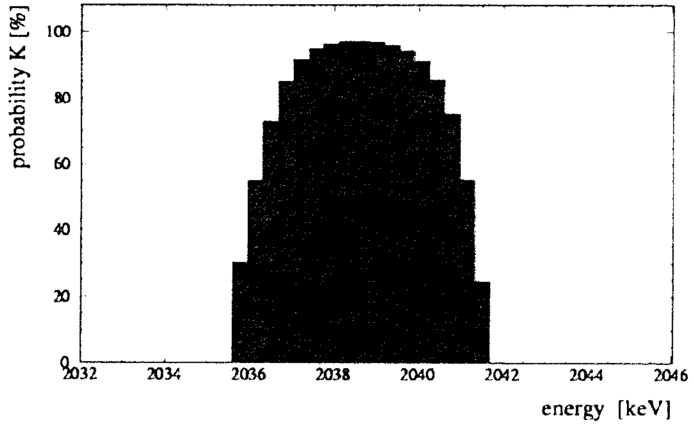
Key issue:
since 214Bi peaks have been identified in the large (2000-2080) interval, use a narrower interval (5σ)

Result:
a “clear” effect is apparent

Significance $[kg\,y]$	Detectors	$T^{0\nu}_{1/2}$ y	$\langle m \rangle$ eV	Conf. level
54.9813	1,2,3,4,5	$(0.80 - 35.07) \times 10^{25}$	(0.08 - 0.54)	95% *c.l.*
54.9813	1,2,3,4,5	$(1.04 - 3.46) \times 10^{25}$	(0.26 - 0.47)	68% *c.l.*
54.9813	1,2,3,4,5	1.61×10^{25}	0.38	Best Value
46.502	1,2,3,5	$(0.75 - 18.33) \times 10^{25}$	(0.11 - 0.56)	95% *c.l.*
46.502	1,2,3,5	$(0.98 - 3.05) \times 10^{25}$	(0.28 - 0.49)	68% *c.l.*
46.502	1,2,3,5	1.50×10^{25}	0.39	Best Value
28.053	2,3,5 SSE	$(0.88 - 22.38) \times 10^{25}$	(0.10 - 0.51)	90% *c.l.*
28.053	2,3,5 SSE	$(1.07 - 3.69) \times 10^{25}$	(0.25 - 0.47)	68% *c.l.*
28.053	2,3,5 SSE	1.61×10^{25}	0.38	Best Value



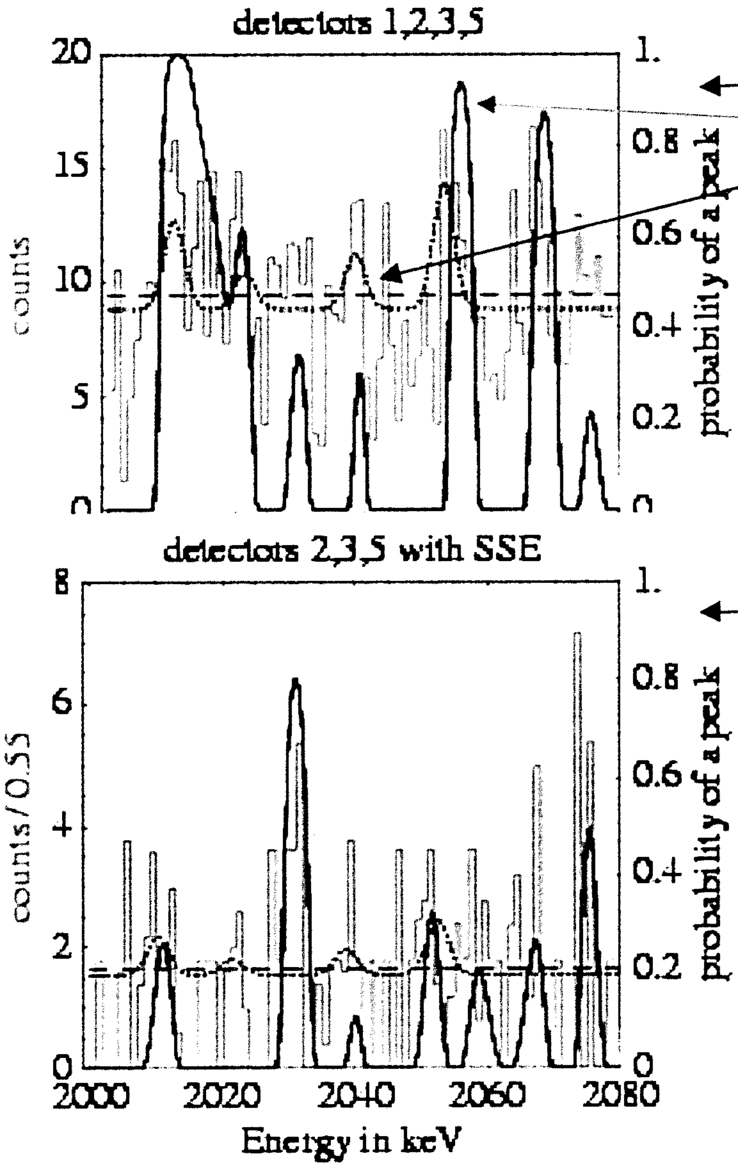




Possible Evidence for 0ν2β: comments

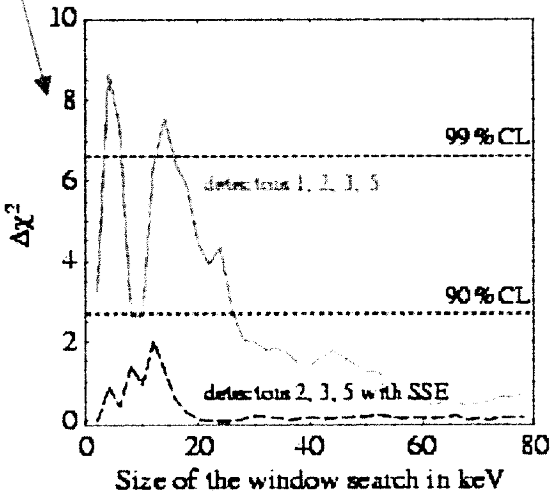
Feruglio F et al. hep-ph/0201291

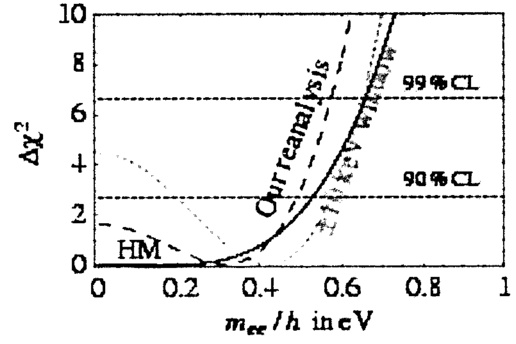
Reanalysis of H-M data sets # 2 and 3



- Peaks detection method: similar results
- **Global fit:** much less effect significance (1.5-0.7σ)
- **Fit with flat bkg**:
  - Dependence on the fit interval width
  - Bayes/Gauss approach: equivalent
- **Peaks identification** (^{214}Bi?): inconsistent

  criticised …
- PSA uniform suppression





Possible Evidence for 0ν2β: comments

Klapdor-Kleingrothaus HV hep-ph/0205228

21-05-2002

REPLY TO A COMMENT OF ARTICLE "EVIDENCE FOR NEUTRINOLESS DOUBLE BETA DECAY"

H.V. KLAPDOR-KLEINGROTHAUS[1,2]

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[2] *Spokesman of the HEIDELBERG-MOSCOW and GENIUS Collaborations,*
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home page: http://www.mpi-hd.mpg.de/non_acc/

Reply for each item in the "comment" defending original position of KDHK

More "soft" reply of H.L. Harney:

"*part of the criticism is justified*"

in particular:

"if the peaks at energies other than $Q_{\beta\beta}$ cannot be identified by way of the simulation the confidence on the possible structure at $Q_{\beta\beta}$ will be lower than given in KDHK"

New table (correct) of experimental and expected ^{214}Bi lines intensities

Still inconsistent!

Energy (keV) *)	Intensity of Heidelberg-Mos. Exper.	σ	Branching Ratios [%]	Simul. of Experim. Setup +)	Expect. rate accord. to sim.**)	Expect. rate accord. to ++)	Aalseth et al. [14] ***)
609.312(7)	4399±92		44.8(5)	5715270±2400			
1764.494(14)	1301±40		15.36(20)	1558717±1250			
2204.21(4)	319±22		4.86(9)	429673±656			
2010.71(15)	37.8±10.2	3.71	0.05(6)	15664±160	12.2±0.6	4.1±0.7	0.64
2016.7(3)	13.0±8.5	1.53	0.0058(10)	20027±170	15.6±0.7	0.5±0.1	0.08
2021.8(3)	16.7±8.8	1.90	0.020(6)	1606±101	1.2±0.1	1.6±0.5	0.25
2052.94(15)	23.2±9.0	2.57	0.078(11)	5981±115	4.7±0.3	6.4±1	0.99
2039.006	12.1±8.3	1.46					

Table 1. ^{214}Bi is product of the ^{238}U natural decay chain through β^- decay of ^{214}Pb and α decay of ^{218}At. It decays to ^{214}Po by β^- decay. Shown in this Table are the measured intensities of ^{214}Bi lines in the spectrum shown in Fig.1 of Ref. in the energy window 2000 - 2060keV, our calculation of the intensities expected on the basis of the branching ratios given in Table of Isotopes, with and without simulation of the experimental setup, and the intensities expected by Aalseth et al. [14], who do not simulate the setup and thus ignore summing of the γ energies.

*) We have considered for comparison the 3 strongest ^{214}Bi lines, leaving out the line at 1120.287keV (in the measured spectrum this line is partially overimposed on the 1115.55 keV line of ^{65}Zn). The number of counts in each line have been calculated by a maximum-likelihood fit of the line with a gaussian curve plus a constant background.

+) The simulation is performed assuming that the impurity is located in the copper part of the detector chamber (best agreement with the intensities of the strongest lines in the spectrum). The error of a possible misplacement is not included in the calculation. The number of simulated events is 10^8 for each of our five detectors.

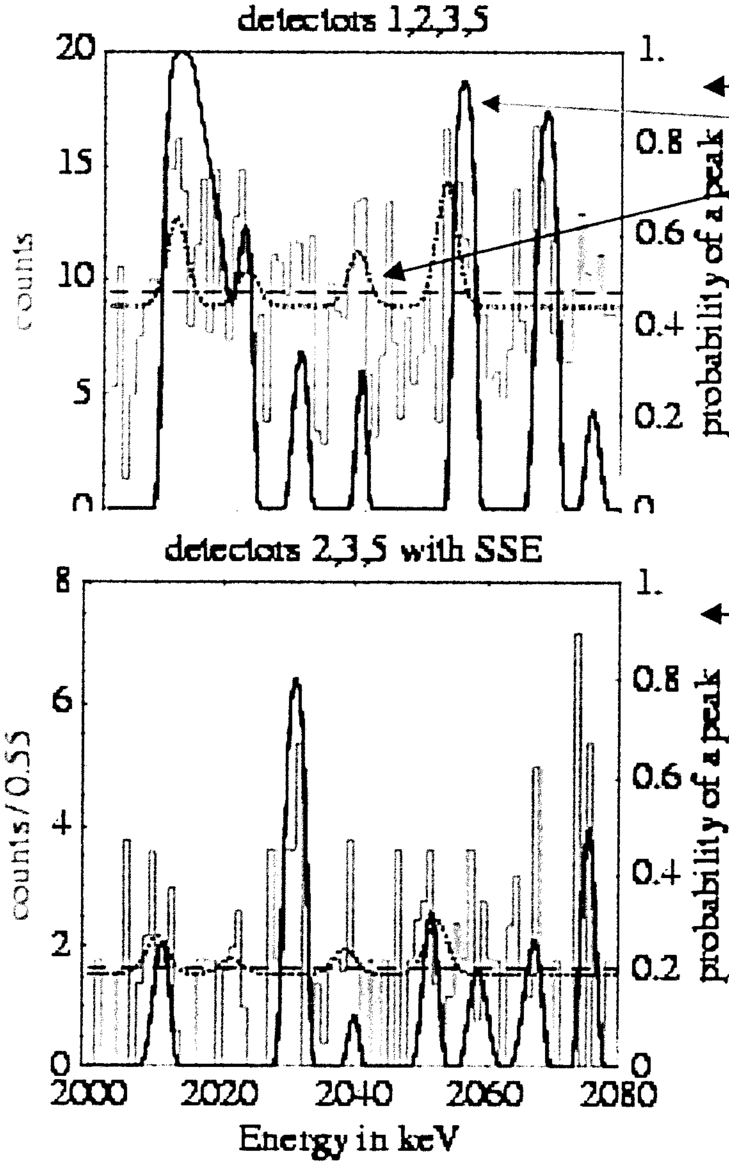
**) This result is obtained normalizing the simulated spectrum to the experimental one using the 3 strong lines listed in column one. Comparison to the neighboring column on the right shows that the expected rates for the weak lines can change strongly if we take into account the simulation. The reason is that the line at 2010.7keV can be produced by summing of the 1401.50keV (1.55%) and 609.31keV (44.8%) lines, the one at 2016.7 keV by summing of the 1407.98 (2.8%) and 609.31 (44.8%) lines; the other lines at 2021.8keV and 2052.94keV do suffer only very weakly from the summing effect because of the different decay schemes.

++) This result is obtained using the number of counts for the three strong lines observed in the experimental spectrum and the branching ratios from without including summing effects. For each of the strong lines the expected number of counts for the weak lines is calculated and then an average of the 3 expectations is taken.

***) Without simulation of the experimental setup. The numbers given here are close to those in the neighboring left column, when taking into account that Aalseth et al. refer to a spectrum which contains a normalization error of a factor of 9 (see also point 5).

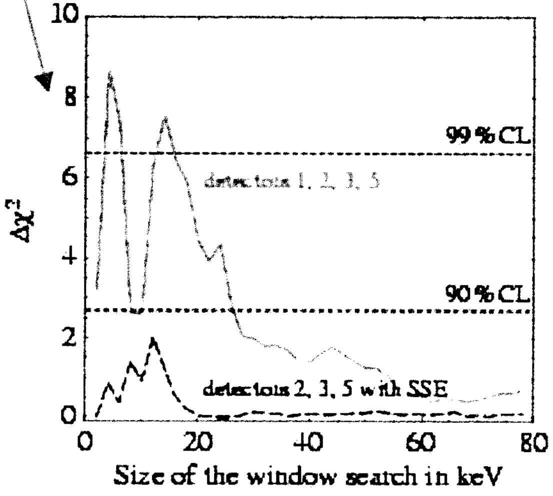
Possible Evidence for $0\nu2\beta$: comments

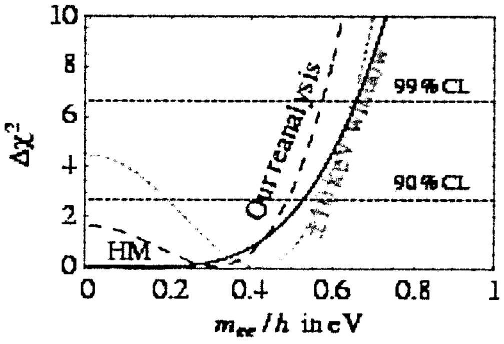
Feruglio F et al. hep-ph/0201291



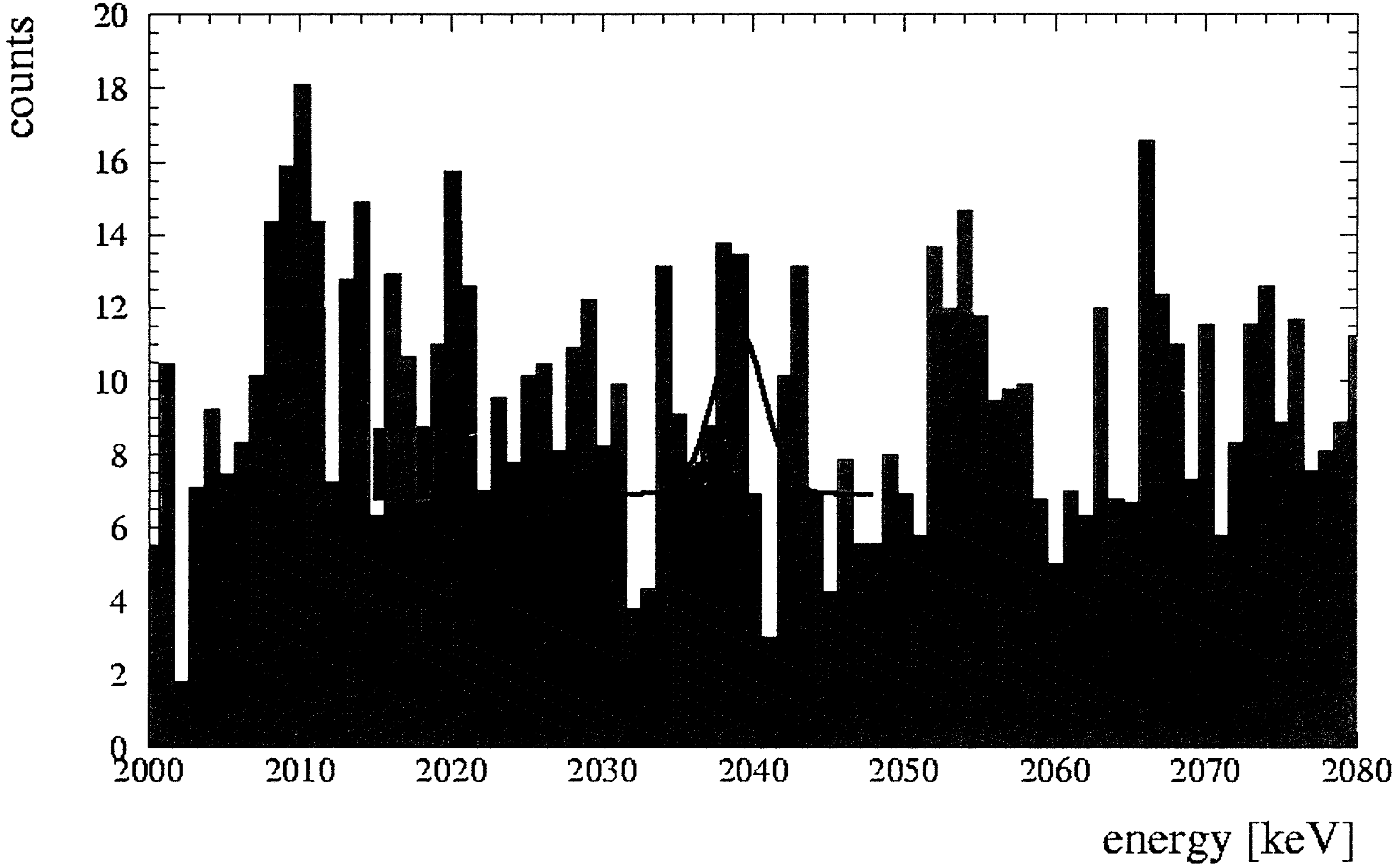
Reanalysis of H-M data sets # 2 and 3

- Peaks detection method: similar results
- **Global fit:** much less effect significance (1.5-0.7σ)
- **Fit with flat bkg**:
  - Dependence on the fit interval width
  - Bayes/Gauss approach: equivalent
- **Peaks identification** (^{214}Bi?): inconsistent *criticised …*
- PSA uniform suppression





Possible Evidence for $0\nu2\beta$: comments



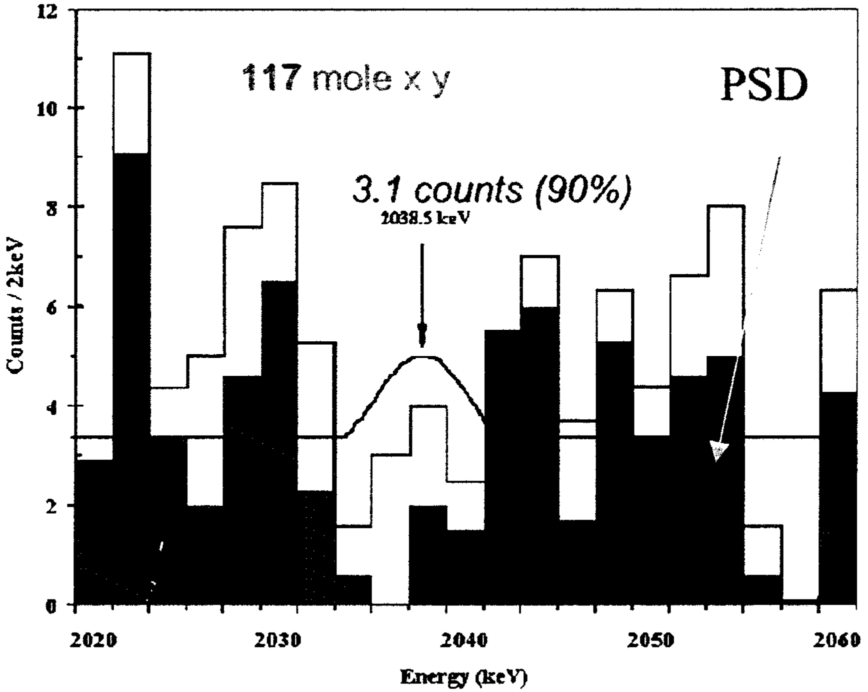
IGEX

hep-ex:0202026

Pacific Northwest National Laboratory (PNNL)
University of South Carolina (USC)
Institute for Theor and Exp Physics (ITEP, Rusia)
Institute for Nuclear Research (INR, Rusia)
Yerevan Physical Institute (Armenia)
University of Zaragoza (UZ)

$T_{1/2}(0\nu,0^+\rightarrow0^+) > 1.57 \times 10^{25}$ y (90%)

$<m_\nu> < 0.33\text{-}1.35$ eV



1994-2000
Canfranc underground laboratory
(Laboratory 3 at 2450 m.w.e.)

Three (2kg) Ge diodes (86% ^{76}Ge)

FWHM: 4 keV
Effective PSD (SSE): ~ 45% of total statistics

Heavy low activity shield:
- 40 cm of lead
- PVC box flushed with nitrogen
- 2mm of cadmium
- 20 cm of polyethilene
- active veto (plastic scintillators)

Future projects

Experiment	Author	Isotope	Detector description	$T^{0\nu}_{1/2}$(y)	$<m_\nu>$*
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
CUORE	**Arnaboldi et al. 2001**	**^{130}Te**	**760 kg of TeO_2 bolometers**	**7×10^{26}**	**0.027**
EXO	**Danevich et al 2000**	**^{136}Xe**	**1 t enriched Xe TPC**	**8×10^{26}**	**0.052**
GEM	Zdesenko et al 2001	^{76}Ge	1 t enriched Ge diodes in liquid nitrogen + water shield	7×10^{27}	**0.018**
GENIUS	Klapdor-Kleingrothaus et al 2001	^{76}Ge	1 t enriched Ge diodes in liquid nitrogen	1×10^{28}	**0.015**
MAJORANA	Aalseth et al 2002	^{76}Ge	0.5 t enriched Ge segmented diodes	4×10^{27}	**0.025**
DCBA	Ishihara et al 2000	^{150}Nd	20 kg enriched Nd layers with tracking	2×10^{25}	
CAMEO	Bellini et al 2001	^{116}Cd	1 t $CdWO_4$ crystals in liquid scintillator	$> 10^{26}$	0.069
CANDLES	Kishimoto et al	^{48}Ca	several tons of CaF_2 crystal in liquid scintillator	1×10^{26}	
GSO	Danevich 2001	^{160}Gd	2 t Gd_2SiO_5:Ce cristal scintillator in liquid scintillator	2×10^{26}	0.065
MOON	Ejiri et al 2000	^{100}Mo	34 t natural Mo sheets between plastic scintillator	1×10^{27}	0.036
Xe	Caccianiga et al 2001	^{136}Xe	1.56 t of enriched Xe in liquid scintillator	5×10^{26}	0.066
XMASS	Moriyama et al 2001	^{136}Xe	10 t of liquid Xe	3×10^{26}	0.086

* Staudt, Muto, Klapdor-Kleingrothaus Europh. Lett 13 (1990) 31

FUTURE Sensibility on 0νββ :

$$F_D^{0\nu} = 4.17\text{x}10^{26} \text{ x } \frac{a}{A}\sqrt{\frac{Mt}{b\Gamma}} \text{ x } \varepsilon$$

Exp	Nucl	M Kg	Technique	Lab.	Enr.
NEMO	Vari	10	Scintillators + GM	Frejus	**Yes**
GENIUS	76Ge	1000-10000	Solid state detector	LNGS or USA	**Yes**
Majorana	76Ge	500	Solid state detector	USA	**Yes**
Moon	100Mo	43000	Sandwich with scintillators	Japan	**Not decid**
EXO	136Xe	1000 10000	TPC + LASER	USA	**Yes**
CUORE	130TeO2 altri	760	Thermal detectors	LNGS	No

Other possibilities: Xenon o CdWo4 and even Ge in Borexino CTF, Drift Chamber Beta-ray analyzer, COBRA (CdZnTe) ecc.

Values of <mν> reacheable depend on background: Tens of meV, **similar with those suggested by oscillations**

CONVENTIONAL DETECTORS

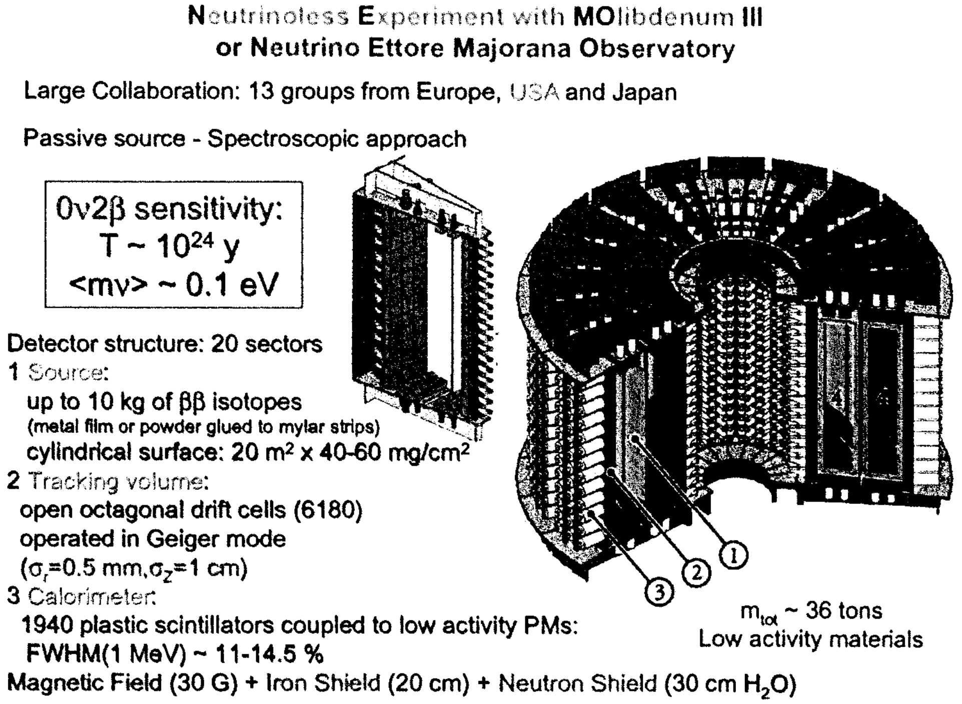
NEMO III

Being mounted in the Frejus tunnel Collaboration among 12 groups (Europe,Russia, USA)

10 kg of enriched isotopes Drift chambers "a la Geiger" and scintillators

Magnetic field , iron and neutron shield

$\tau_{1/2} = 10 \times 10^{24}$ a m_ν ~ 0.1 eV



Neutrinoless **E**xperiment with **MO**libdenum **III**
or Neutrino Ettore Majorana Observatory

Large Collaboration: 13 groups from Europe, USA and Japan

Passive source - Spectroscopic approach

0ν2β sensitivity:
T ~ 10^{24} y
<mν> ~ 0.1 eV

Detector structure: 20 sectors
1 Source:
up to 10 kg of ββ isotopes
(metal film or powder glued to mylar strips)
cylindrical surface: 20 m² x 40-60 mg/cm²
2 Tracking volume:
open octagonal drift cells (6180)
operated in Geiger mode
(σ_r=0.5 mm,σ_z=1 cm)
3 Calorimeter:
1940 plastic scintillators coupled to low activity PMs:
FWHM(1 MeV) ~ 11-14.5 %
Magnetic Field (30 G) + Iron Shield (20 cm) + Neutron Shield (30 cm H_2O)

m_{tot} ~ 36 tons
Low activity materials

GENIUS

Proposed for the LNGS and WIPP

Conventional technique , but shield with liquid nitrogen where nake detectors operate

270 enriched Ge detectors ~ 1 ton

GENIUS

Klapdor-Kleingrothaus HV hep-ph/0103074

Very large mass extension of the active source Ge-diodes approach

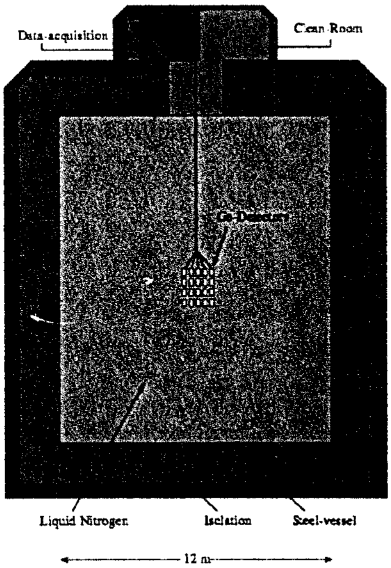
GOAL:

- $<m_{\nu}>$ sensitivity ~10-20 meV
- test all possible m_{ν} scenarios allowed by oscillation experiments
  - Reduce Background
  - Enlarge mass

SOLUTION:
large number (400) of naked i.e. (86%)
diodes (total mass ~1 ton) ⟶ 10 tons
suspended in a very large container of
liquid nitrogen (clean shield)

Gran Sasso or USA underground laboratory

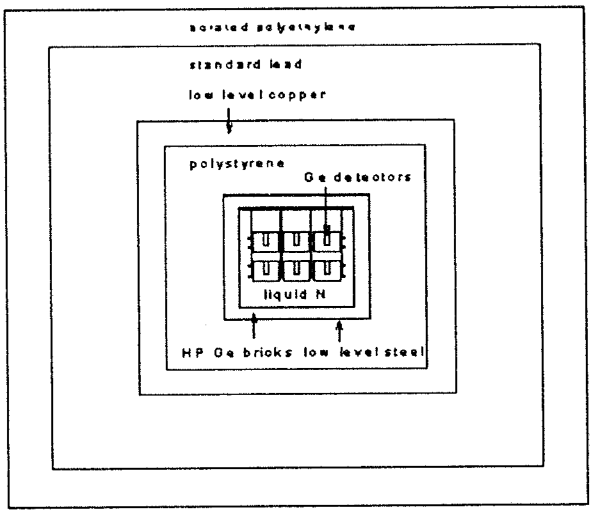
DM & Solar Neutrinos



GENIUS-TF

14 crystals of natural Ge to test background

approved



MAJORANA

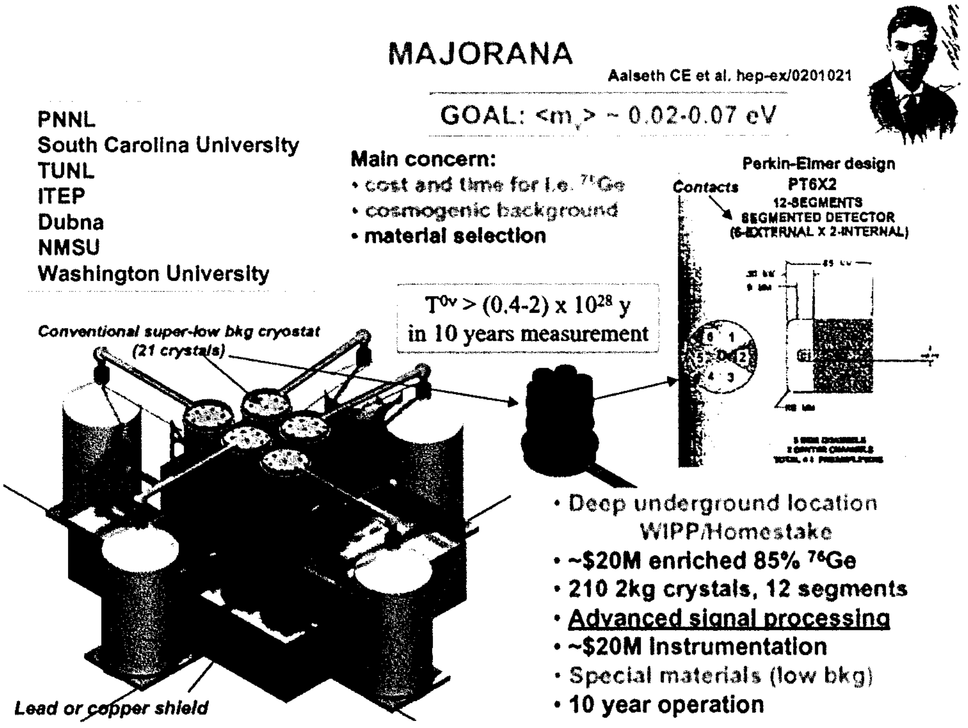
0..5 tons of enriched Ge

Segmented detectors

Pulse shape discrimination

To be installed in the USA underground laboratory

They have complete pre4vious test with a single Ge detector, and are now mounting 12 enriched crystals. Majorana will be made by 210 diodes



MAJORANA

Aalseth CE et al. hep-ex/0201021

GOAL: $<m_\nu> \sim 0.02\text{-}0.07$ eV

PNNL
South Carolina University
TUNL
ITEP
Dubna
NMSU
Washington University

Main concern:
- cost and time for i.e. ^{71}Ge
- cosmogenic background
- **material selection**

$T^{0\nu} > (0.4\text{-}2) \times 10^{28}$ y
in 10 years measurement

- Deep underground location WIPP/Homestake
- **~\$20M enriched 85% ^{76}Ge**
- **210 2kg crystals, 12 segments**
- <u>Advanced signal processing</u>
- **~\$20M Instrumentation**
- Special materials (low bkg)
- **10 year operation**

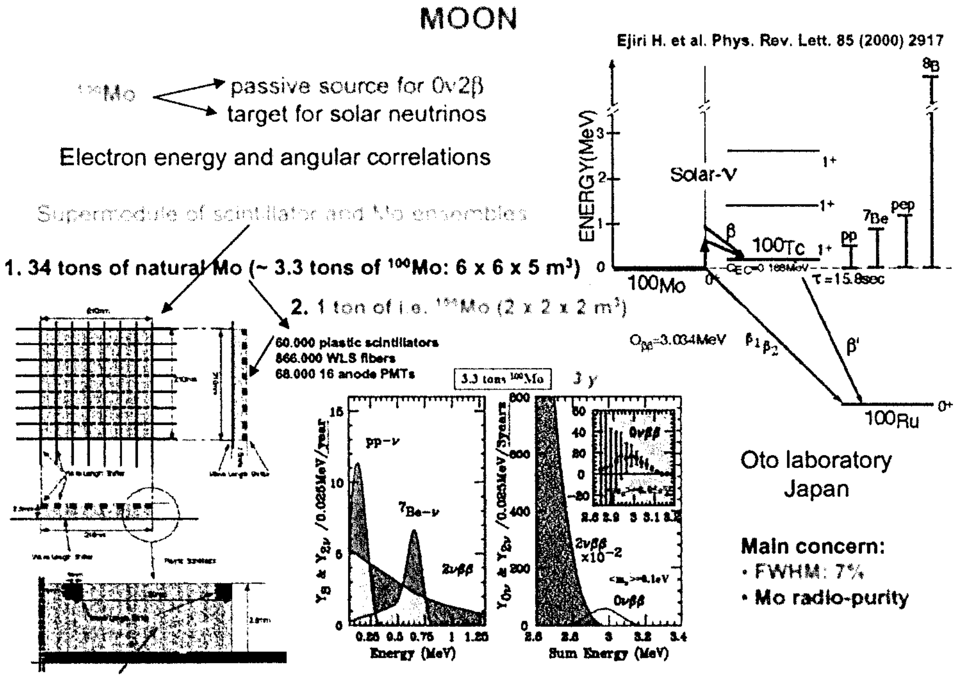
MOON

It is a source≠detector approach **(but they are also considering thermal detectors)**

To study at the same time solar neutrinos and double beta decay of ^{100}Mo

In Oto laboratory (Japan)

34 tons of natural Mo (sheets) interleaved with scintillators



MOON

Ejiri H. et al. Phys. Rev. Lett. 85 (2000) 2917

^{100}Mo → passive source for 0ν2β
→ target for solar neutrinos

Electron energy and angular correlations

Supermodule of scintillator and Mo ensembles

1. 34 tons of natural Mo (~ 3.3 tons of ^{100}Mo: 6 x 6 x 5 m^3)

2. 1 ton of i.e. ^{100}Mo (2 x 2 x 2 m^3)

60.000 plastic scintillators
866.000 WLS fibers
68.000 16 anode PMTs

Oto laboratory
Japan

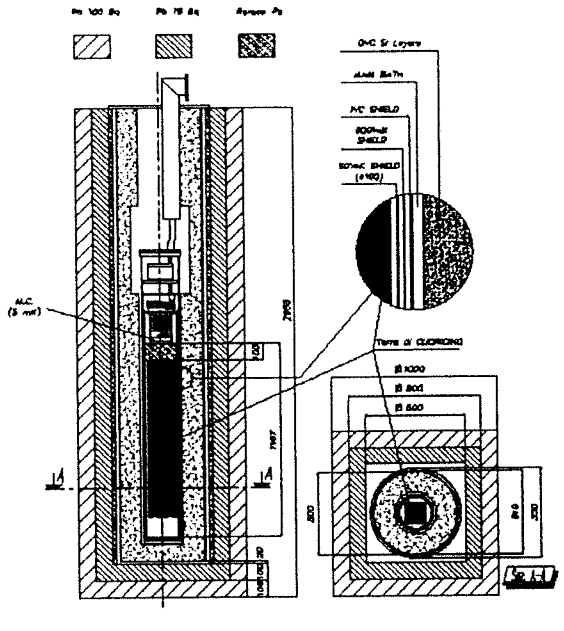
Main concern:
- FWHM: 7%
- Mo radio-purity

CUORE and CUORICINO

CUORE : an array of 1000 natural crystals of TeO_2 of 5x5x5 cm^3 -> 760 kg to study double beta decay of ^{130}Te. They have been already tested
ΔE = ~~40~~ 1 keV @ 46 keV and 3.2 keV @ 5.4 keV

CUORICINO has been approved :
44 crystals of 14 crystals of 5x5x5 cm^3 + 14 crystals 3x3x3 of natural TeO_2 + 2 crystals of $^{128}TeO_2$ + 2 crystals of $^{130}TeO_2$ TOTAL MASS ≃ 40 kg

Set-up di Cuoricino



M.C. 14 moduli da 4 cristalli ciascuno
Massa complessiva di TeO_2 : 42 kg

The CUORE set-up

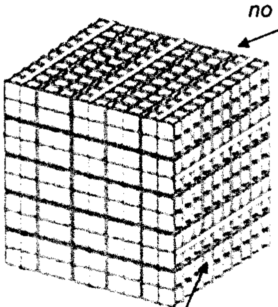
Cryogenic Underground Observatory for Rare Events

LBL – U. Como – U. Firenze – Legnaro (LNL)
LNGS – U. Milano – USC – U. Zaragoza

CUORE = closely packed array of 1000 detectors
25 towers - 10 modules/tower - 4 detector/module

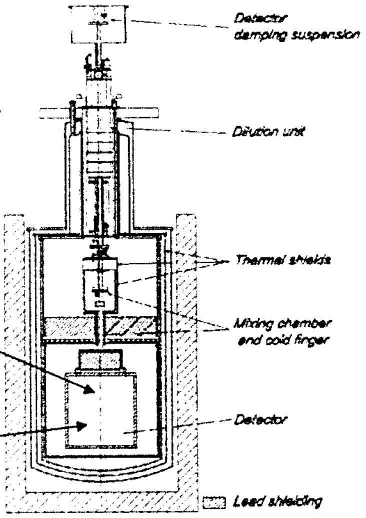
Cubic structure, ideal for active shielding

no more inert Cu plates facing crystals



M = 760 kg

Each tower is a CUORICINO-like detector



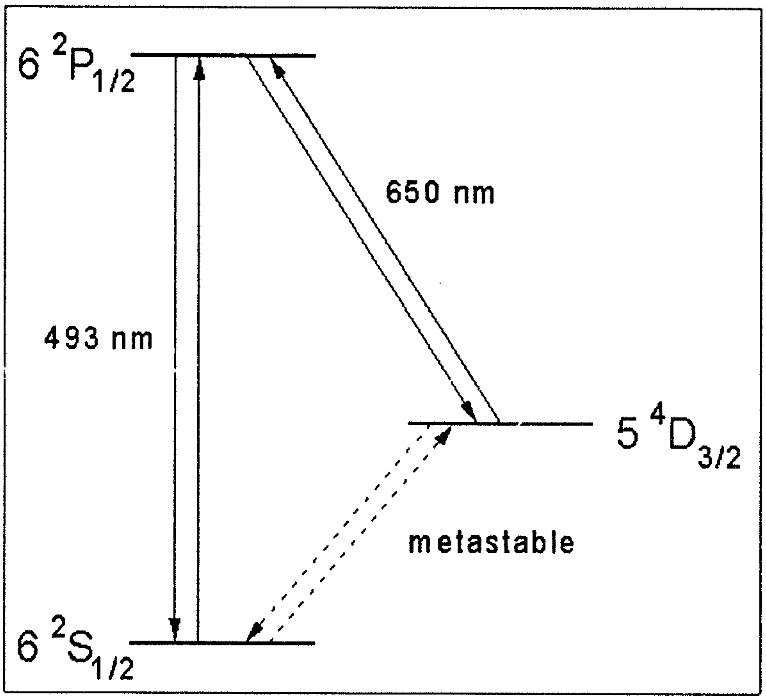
Special dilution refrigerator

EXO

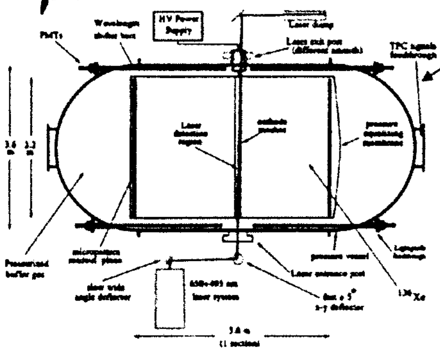
To study ^{136}Xe -> ^{136}Ba^{++} in gas xenon Possibility to look to Ba^{++} - Ba^{+} individually detected by LASER induced fluorescence

493 nm -.6 $^2P_{1/2}$ ->5 $^4D_{3/2}$ -> 650 nm->6 $^2P_{1/2}$ (blu)

Simpler approach : electrical collection of Ba atoms



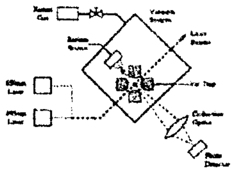
EXO (2)



Detector Configuration

Gas-Phase	
•Tracking: event topography	•High Pressure
•Additive gas for quenching and neutralization	•Large Size
•In situ Spectroscopy	
•No Cryogenics	
Liquid Phase	
•Small Size	•Cryogenics
•No High Pressure	•No tracking
•Ion analysys and quenching in vacuum	•No laser in liquid
	•Electrostatic Ion Extraction
	•Ba atom extraction for analysis

Single Ion Ba Spectroscopy:



- Ion trapping & measurement in vacuum
- Collisional broadening in Xe
- Ion lifetimes in Xe
- Distinguish ^{136}Ba from ^{137}Ba

Energy Resolution:
Ionization + Scintillation ⇒ 2%

100 kg PROTOTYPE goals
- Large Xe TPC engineering
- Energy resolution of large detector
- Background analysis

CONCLUSIONS

- SENSITIVITY DEPENDS, FOR A GIVEN ENRICHMENT ON ENERGY RESOLUTION, BACKGROUND, MASS, TIME
- BACKGROUND CAN BE EVALUATED WITH MONTE CARLO, BUT....
- TESTS WITH REDUCED MASS ARE ESSENTIAL
- STILL LARGE UNCERTAINTIES ON NUCLEAR MATRIX ELEMENTS EXIST AND CONSEQUENTELY ON $\langle m_\nu \rangle$
- SEARCHES ON $\beta\beta$ DECAY INVOLVE DIFFERENT TECHNIQUES: LOW RADIOACTIVITY, NUCLEAR DETECTORS, CHEMISTRY, MATERIAL SCIENCES, CRYOGENICS, GEOCHRONOLOGY
- SECOND GENERATION EXPERIMENTS ARE COMPETITIVE AND SEARCH ON DIFFERENT NUCLEI
- IMPORTANT SUBPRODUCTS (e.g. DARK MATTER, e-stability etc.
- PRESENT RESULTS ON ν OSCILLATION INDICATE AIMS REACHEBLE IN THE INVERSE HIERARCHY SCHEME AND PERHAPS IN THE NORMAL HIERARCHY ONE