Experimental Aspects of Neutrinoless Double Beta Decay

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- Neutrino Situation
- DBD0ν
- Experimental Strategies for DBD0ν research
- Present Experimental situation in DBD0ν research
- Next generation experiments prospects
- Conclusion

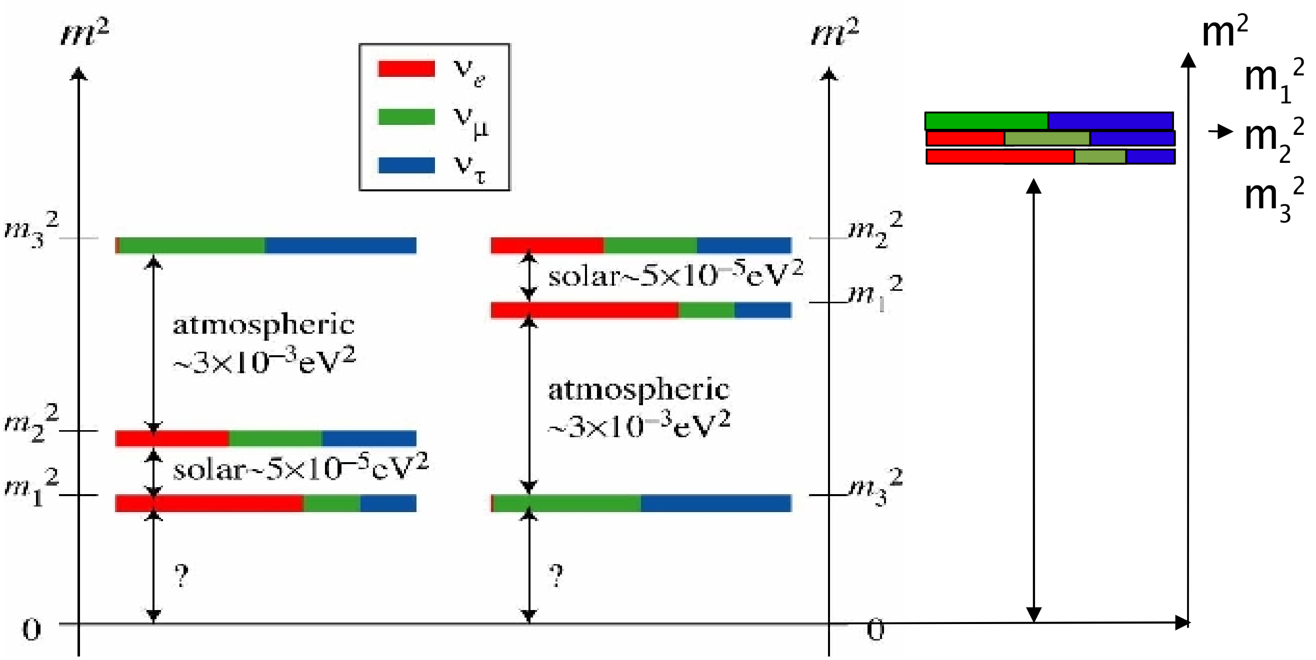
Neutrino situation

Oscillation and reactor experiments:

- have proven that neutrinos are massive and mixed particles
- can measure Δm^2_{ij}, θ_{ij}

Open questions:

- neutrino nature (Dirac/Majorana)
- absolute neutrino mass scale
- hierarchy
- CP Majorana phases



Normal hierarchy
$m_3 > m_2 \sim m_1$

Inverted hierarchy
$m_2 \sim m_1 > m_3$

Degenerate
$m_1 \approx m_2 \approx m_3 \gg |m_i - m_j|$

DBD0ν is the easiest way to give an answer

Neutrinoless Double Beta Decay

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

Phase space

NME

$\sim Q^5$

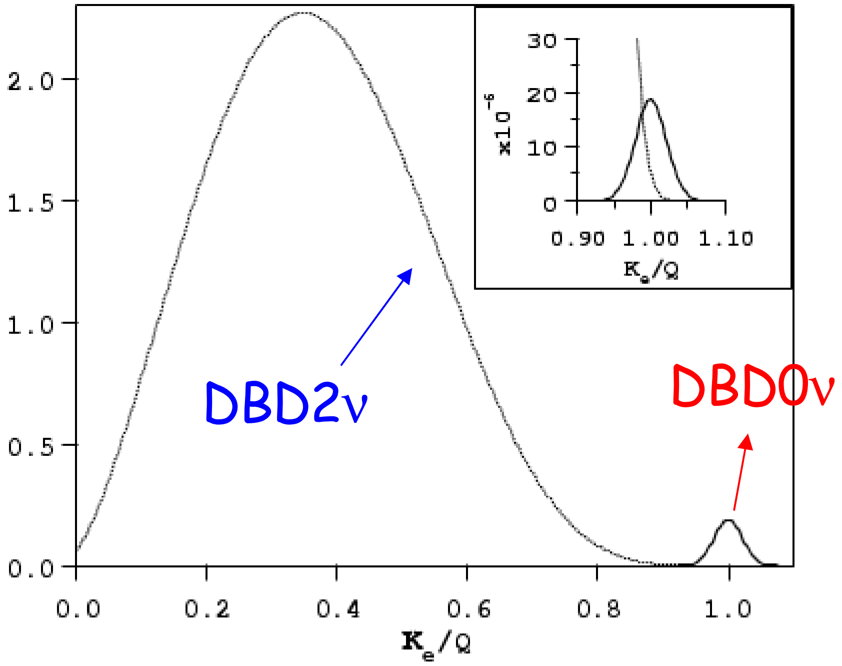
UNCERTAIN

$$\left(T^{0\nu}_{1/2}\right)^{-1} = \sum_k G_k(Q, Z) M_k^2 |<m_\nu>|^2$$

What experiments try to measure

What nuclear theorists try to calculate

2 electrons sum energy spectra



Parameter containing the physics

Mixing matrix

±1 if CP conserved

$$\left|\langle m_\nu \rangle\right| \equiv m_{ee} = \left|\sum_k U_{ek}^2 m_k\right| = \left|\sum_k |U_{ek}|^2 e^{i\alpha_{ek}} m_k\right|$$

Experimental strategies

1) Detect and identify the daughter nuclei (indirect search)

Geochemical experiments
Radiochemical experiments

It is not possible to distinguish the decay channel important in the 70s-80s – no more pursued now

2) Detect the two electrons with a proper nuclear detector (direct search)

- High energy resolution
- Low background
- Large source (many nuclides under control)
- Event reconstruction method

A peak must be revealed over background (0ν-DBD)

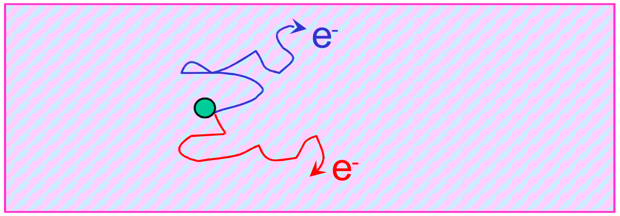
Shield cosmic rays (direct interactions and activations)
⇒ Underground

Very radio-pure materials
$^{238}U - ^{232}Th \Rightarrow \tau \sim 10^{10}$ y
Signal rate $\Rightarrow \tau \sim 10^{25}$ y

Present more sensitive experiments: 10 - 100 kg
Future goals: ~ 1000 kg $\Rightarrow 10^{27} - 10^{28}$ nuclides

- Reject background
- Study electron energy and angular distributions

DBD0n different techniques



Source = Detector

(calorimetric technique)

\+ high energy resolution (0.2-0.3%)

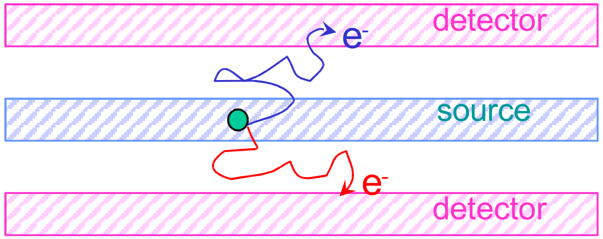
\- no event topology

Advantages:

- easy to reach a high N_{bb} (=> large masses)
- generally with high resolution detectors
- no background from 2n2b event
- good knowledge of background sources

disadvantages:

- no or little possibility to reject background
- constraints on detector material



Source ≠ Detector

\+ event shape reconstruction

\- low energy resolution (7-15%)

advantages:

- wider choice of sources
- different sources in the same apparatus
- clear reconstruction of event topology
- high efficiency in background rejection
- good knowledge of background sources

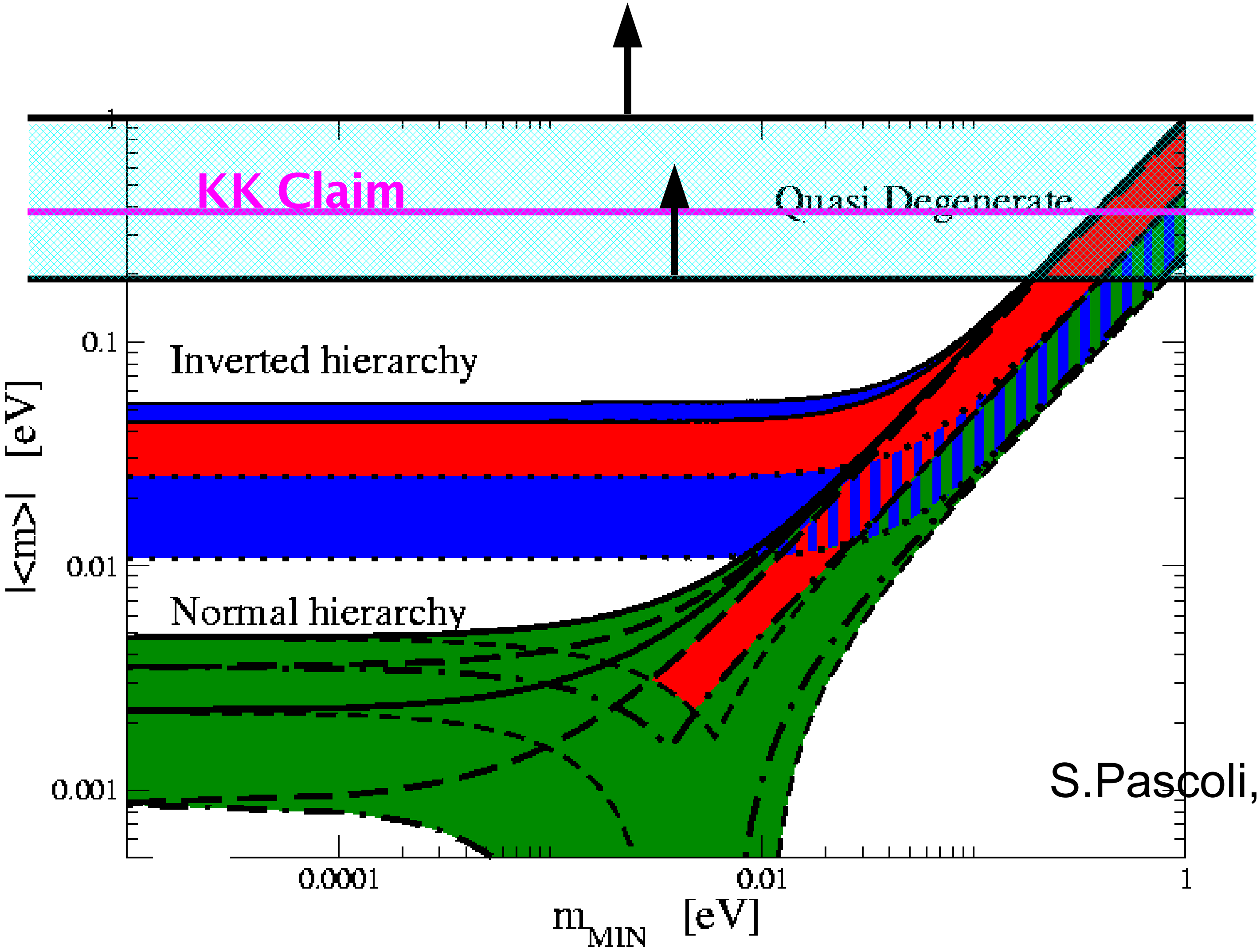
disadvantages:

- complicate apparatus
- growing in mass (N_{bb}) is not straightforward
- poor energy resolution
- bkg from 2n2b event can be a limiting factor

Present experimental situation

Nucleus	Experiment	%	Q	Enr	Technique	$_{0}$ y	<m >
^{48}Ca	Elegant IV	0.19	4271		scintillator	>1.4x10^{22}	7-45
^{76}Ge	Heidelberg-Moscow	7.8	2039	87	ionization	>1.9x10^{25}	.12 - 1
^{76}Ge	IGEX	7.8	2039	87	Ionization	>1.6x10^{25}	.14 – 1.2
^{76}Ge	Klapdor et al	7.8	2039	87	ionization	1.5x10^{25}	.39
^{82}Se	NEMO 3	9.2	2995	97	tracking	>2.1x10^{23}	1.2-3.2
^{100}Mo	NEMO 3	9.6	3034	95-99	tracking	>5.8x10^{23}	.6-2.7
^{116}Cd	Solotvina	7.5	3034	83	scintillator	>1.7x10^{23}	1.7 - ?
^{128}Te	Bernatovitz	34	2529		geochem	>7.7 10^{24}	.1-4
^{130}Te	Cuoricino	33.8	2529		bolometric	>2.4x10^{24}	.2-1.
^{136}Xe	DAMA	8.9	2476	69	scintillator	>1.2x10^{24}	1.1 -2.9
^{150}Nd	Irvine	5.6	3367	91	tracking	>1.2x10^{21}	3 - ?

Present experimental situation



Excluded by CUORICINO, NEMO3 (NME dependence)

S.Pascoli, S.T.Petcov

^{76}Ge: the Heidelberg-Moscow experiment (1)

exp. started in 1990

source=detector experiment

Location = Lab. Naz. del Gran Sasso - Italy
Collaboration = Germany + Russia

detector = 5 Ge diodes

source = 10.9 kg diodes

enriched in ^{76}Ge (i.a. 86%)

Q - value = 2039 keV

Statistics:

53.9 kg y, with PSA = 35.5 kg y

Performances :

4.2 keV FWHM resolution at DBD Q-value

Background in 0ν2b region :

0.19 ± 0.01 c/keV/kg/y

0.06 ± 0.01 c/keV/kg/y with PSA

Pulse Shape Analysis, used to identify and reject multi-site events (gamma background)

^{76}Ge: the Heidelberg-Moscow experiment (2)

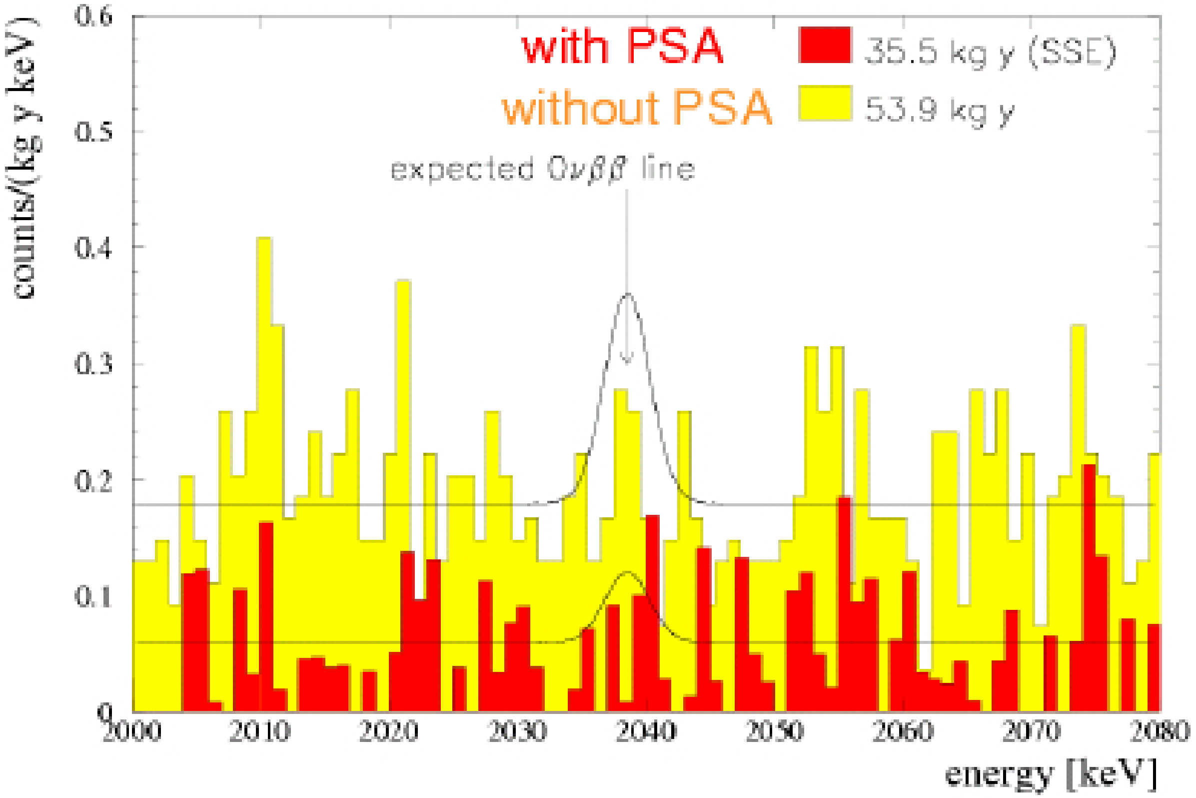
The entire collaboration (14 authors):

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

$t_{1/2}^{0n} > 1.9\ 10^{25}$ y at 90% C.L.

$<m_n> \ < \ 0.35$ eV *

* *using nuclear calculations of Staudt et al. Europhys. Lett 13 (1990) 31*



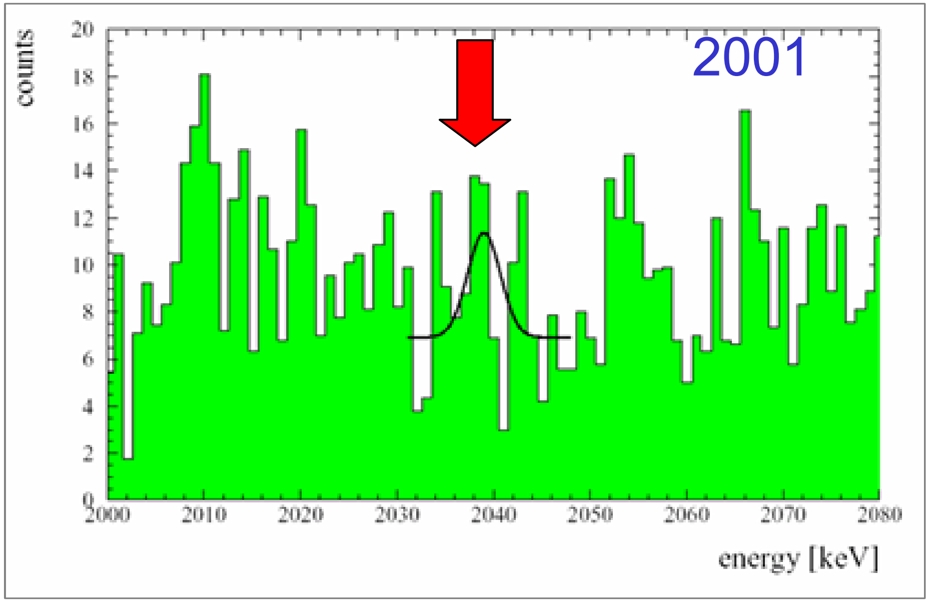
^{76}Ge: the Heidelberg-Moscow experiment (3)

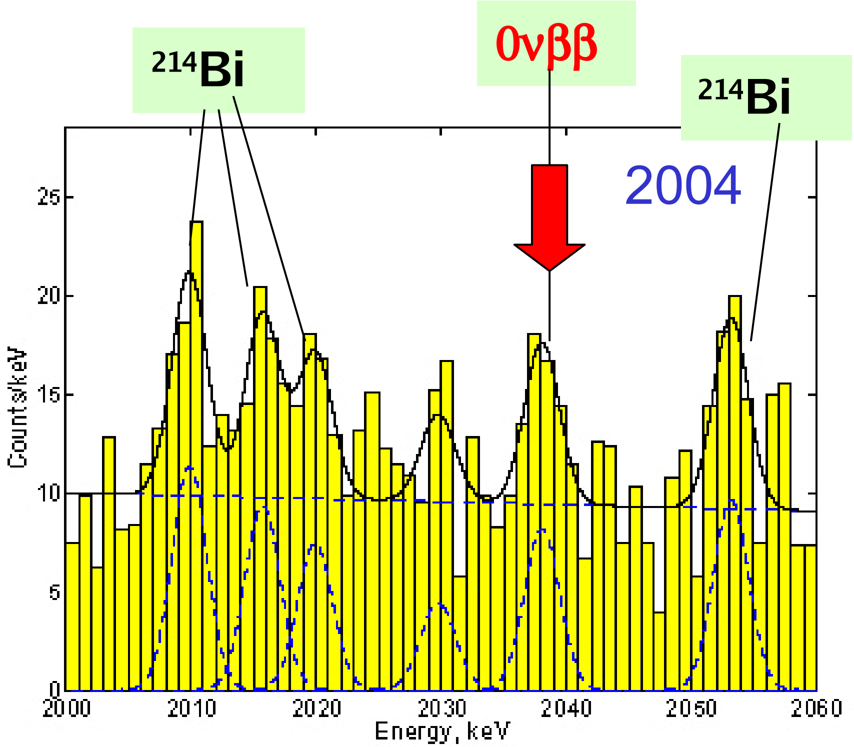
HM collaboration subset, December 2001:

4 authors (KDHK) of the HM collaboration claimed the **discovery of DBD0ν**

$\tau_{1/2}^{0\nu}\,(y) = 1.5 \times 10^{25}\ y$ (BEST VALUE)

$\langle m_{\beta\beta} \rangle = 0.05 - 0.84$ eV (95% c.l.) (0.39 meV with KK NME)





54.98 kg•y 2.2 σ

71.7 kg•y 4.2 σ

skepticism in DBD community in 2001

better results in 2004

^{100}Mo, … : NEMO3 (1)

source≠detector experiment

Location = Modane Underground Lab. (Frejus) - France

detector:

Tracking detector He+alcohol+Ar
(6180 drift wire chambers operated in Geiger mode)

Calorimeter
(1940 plastic scintillators + PMTs)

Magnetic field: 25 Gauss
Gamma shield: pure iron (18 cm layer)
Neutron shield:
borated water (ext. wall, 30 cm layer)
& wood (top and bottom, 40 cm layer)

sources:
cylindrical S=20 m², 60 mg/cm²
total mass ~ 10 kg

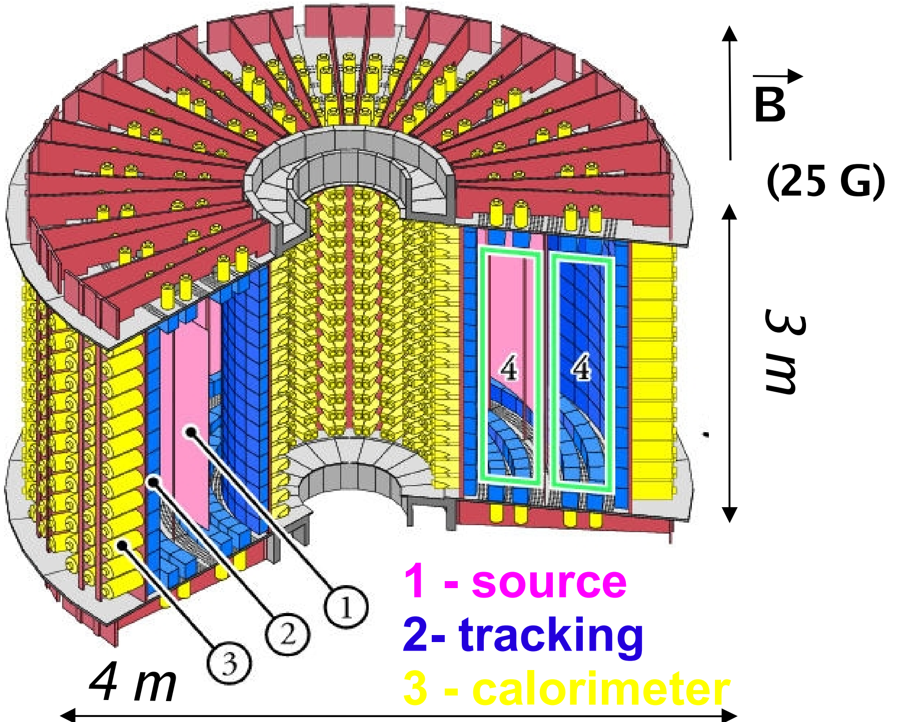
DBD2ν

^{116}Cd, ^{96}Zr, ^{150}Nd, ^{48}Ca, ^{130}Te, ^{nat}Te

^{100}Mo, ^{82}Se

DBD0ν

Performances and background :
track reconstruction
energy resolution s_E\E ~ 3% at 3 MeV
Background in DBD0ν region :
high efficiency in bkg rejection
bkg due to the DBD2ν is a limiting factor due to the poor energy resolution



^{100}Mo, … : NEMO3 (4)

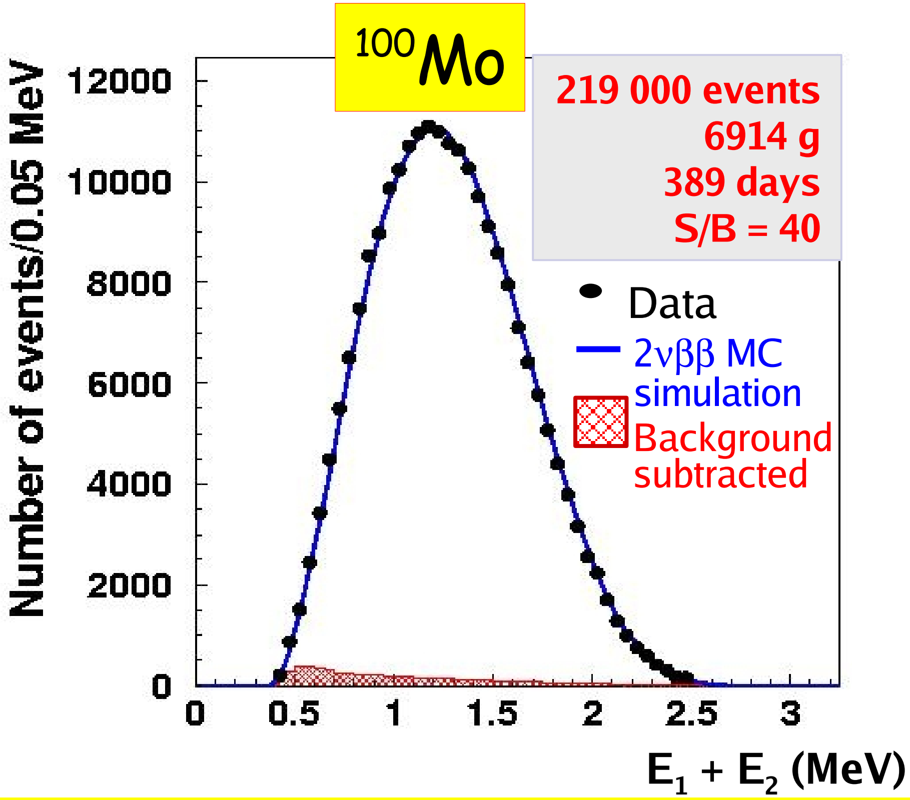
Preliminary results:

^{116}Cd: $T_{1/2}$ = [2.8 ± 0.1 (stat) ± 0.3 (syst)] × 10^{19} y (SSD)

^{150}Nd: $T_{1/2}$ = [9.7 ± 0.7 (stat) ± 1.0 (syst)] × 10^{18} y

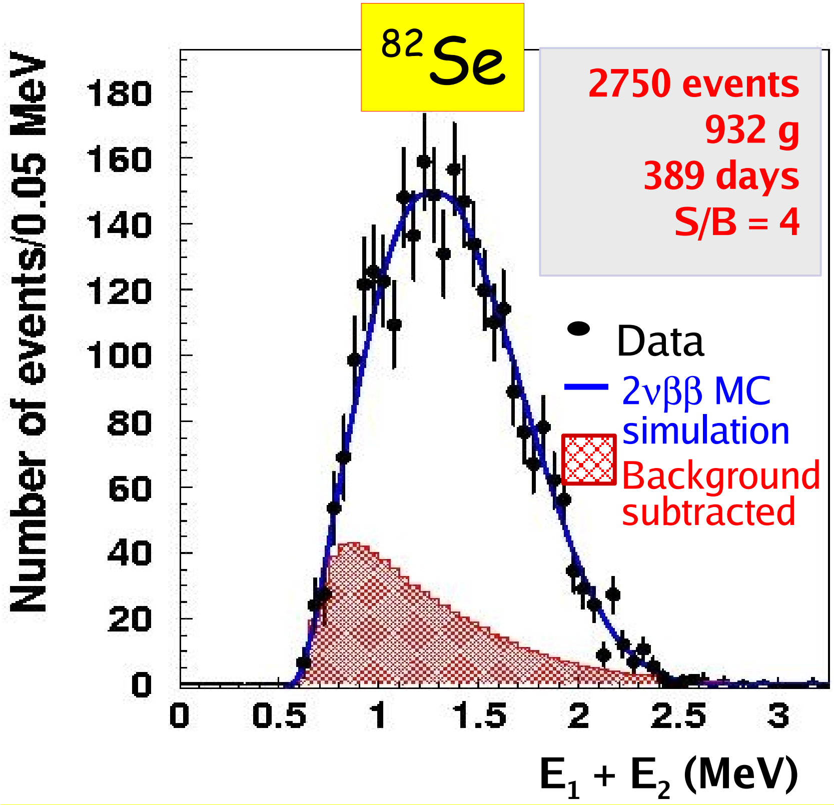
^{96}Zr: $T_{1/2}$ = [2.0 ± 0.3 (stat) ± 0.2 (syst)] × 10^{19} y

DBD2ν results



$T_{1/2}$ = [7.11 ± 0.02 (stat) ± 0.54 (syst)] × 10^{18} y

Phys. Rev. Lett. 95 (2005) 182302



$T_{1/2}$ = [9.6 ± 0.3 (stat) ± 1.0 (syst)] × 10^{19} y

Phys. Rev. Lett. 95 (2005) 182302

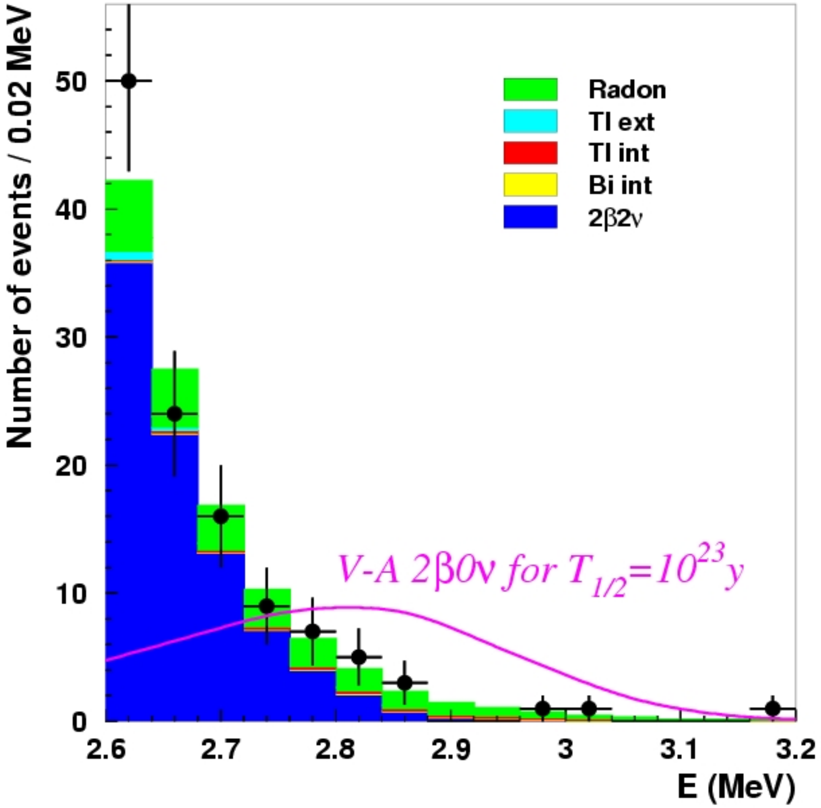
Silvia Capelli NUMMI07, 10-12 January 2007

^{100}Mo, … : NEMO3 (4)

DBD0ν results

^{100}Mo

693 days of data
Phase I + Phase II

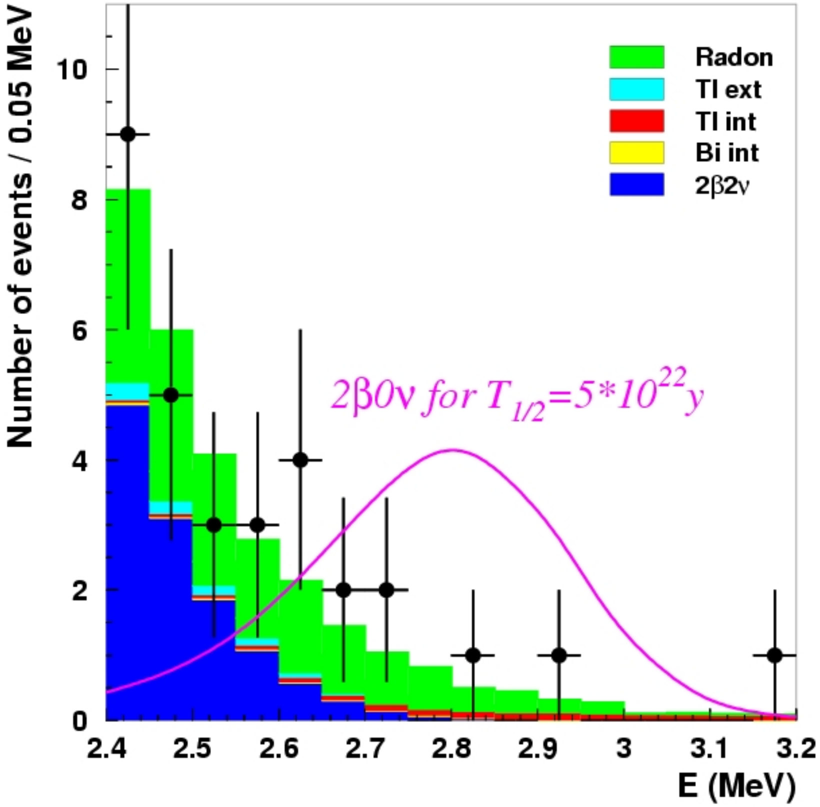


$T_{1/2}(\beta\beta0\nu) > 5.8\ 10^{23}$ (90 % C.L.)

$\langle m_\nu \rangle < (0.6 – 0.9)$ eV [1-3], $< (2.1 – 2.7)$ eV [4]

^{82}Se

693 days of data
Phase I + Phase II



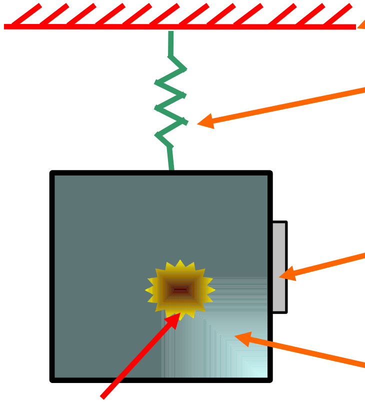
$T_{1/2}(\beta\beta0\nu) > 2.1\ 10^{23}$ (90 % C.L.)

$\langle m_\nu \rangle < (1.2 – 2.5)$ eV [1-3], $< (2.6 – 3.2)$ eV [4]

[1] F.Šimkovic et al.,Phys.Rev. C 60 (1999) 055502.
[2] S.Stoica et al., Nucl.Phys. A 694 (2001) 269.
[3] O.Civitarese et al., Nucl.Phys. A 729 (2003) 867.
[4] V.A.Rodin et al., Nucl.Phys. A 766 (2006) 107.
[5] J.Suhonen et al., Nucl.Phys. A 700 (2002) 649.

Bolometric technique with TeO_2

Source ≡ detector

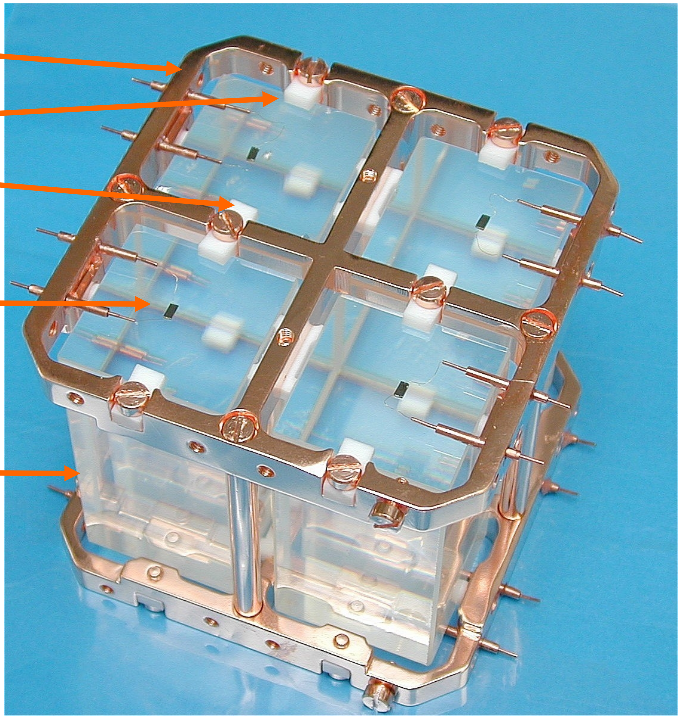


heat sink (~ 10 mK)

weak thermal coupling
(~ 4 pW/mK)

thermometer
$R(T) = R_0 \exp (T_0/ T)^{1/2}$

Crystal absorber
$C \div (T/ \theta_D)^3$



$\Delta T = E/C \div T^{-3}$ $\Delta V/\Delta E \cong 1$ mV/MeV

Why ^{130}Te

- High natural i.a. (33.87 %)
- High Q = 2530.3 keV
- Encouraging predicted DBD0v $t_{1/2}$

$\langle m_\nu \rangle \approx 0.3$ eV $t^{1/2}_{0\nu} \approx 10^{25}$ years

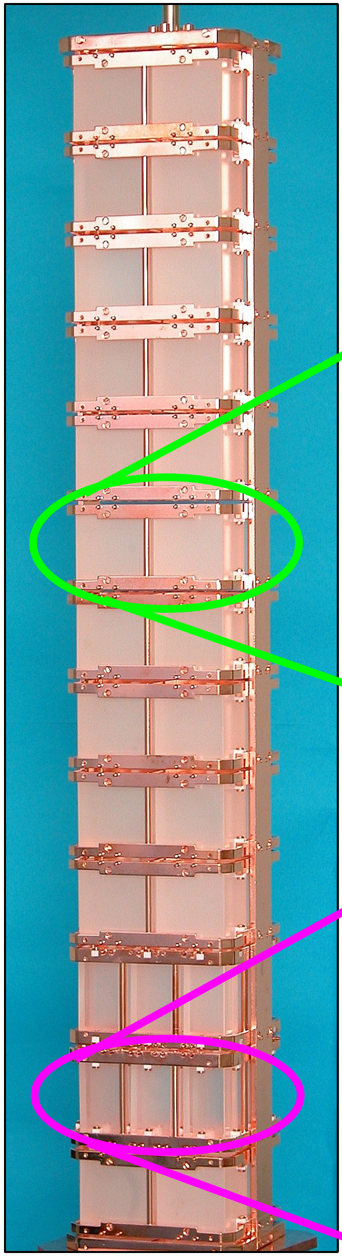
Why TeO_2:

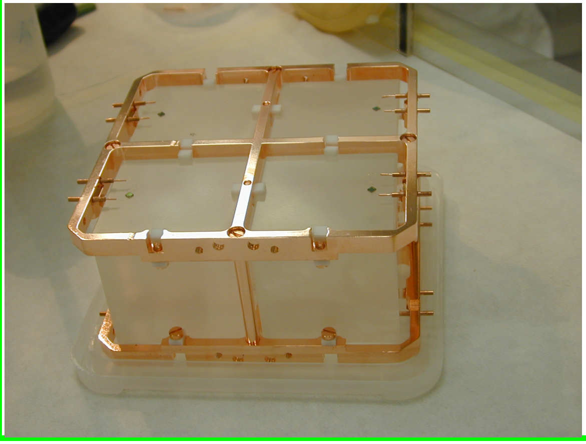
- Low heat capacity C
- Large crystal available
- radio pure crystals
- Good mechanical properties

CUORICINO

start April 2003

- 1st run stopped on November 2003 in order to recover lost channels
- 2nd run started on May 2004





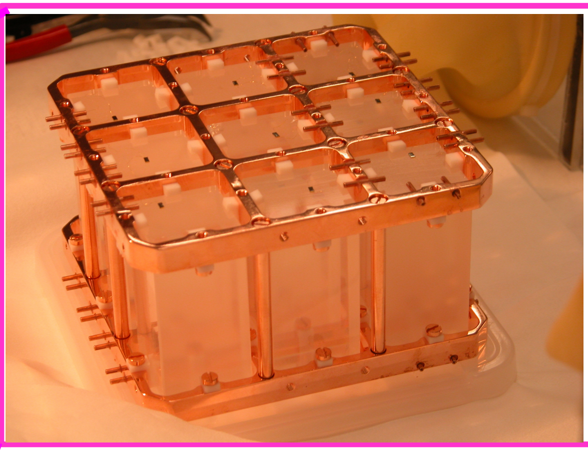
1 modules, 4 detector each

crystal dimension: 5x5x5 cm^3

crystal mass: 790 g

44 x 0.79 g = **34.76 kg of TeO_2**

Total mass:
40.7 kg of TeO_2
11.34 kg ^{130}Te



2 modules, 9 detector each

crystal dimension: 3x3x6 cm^3

crystal mass: 330 g

18 x 0.33 g = **5.94 kg of TeO_2**

2 enriched in ^{128}Te @ 82.3%
2 enriched in ^{130}Te @ 75%

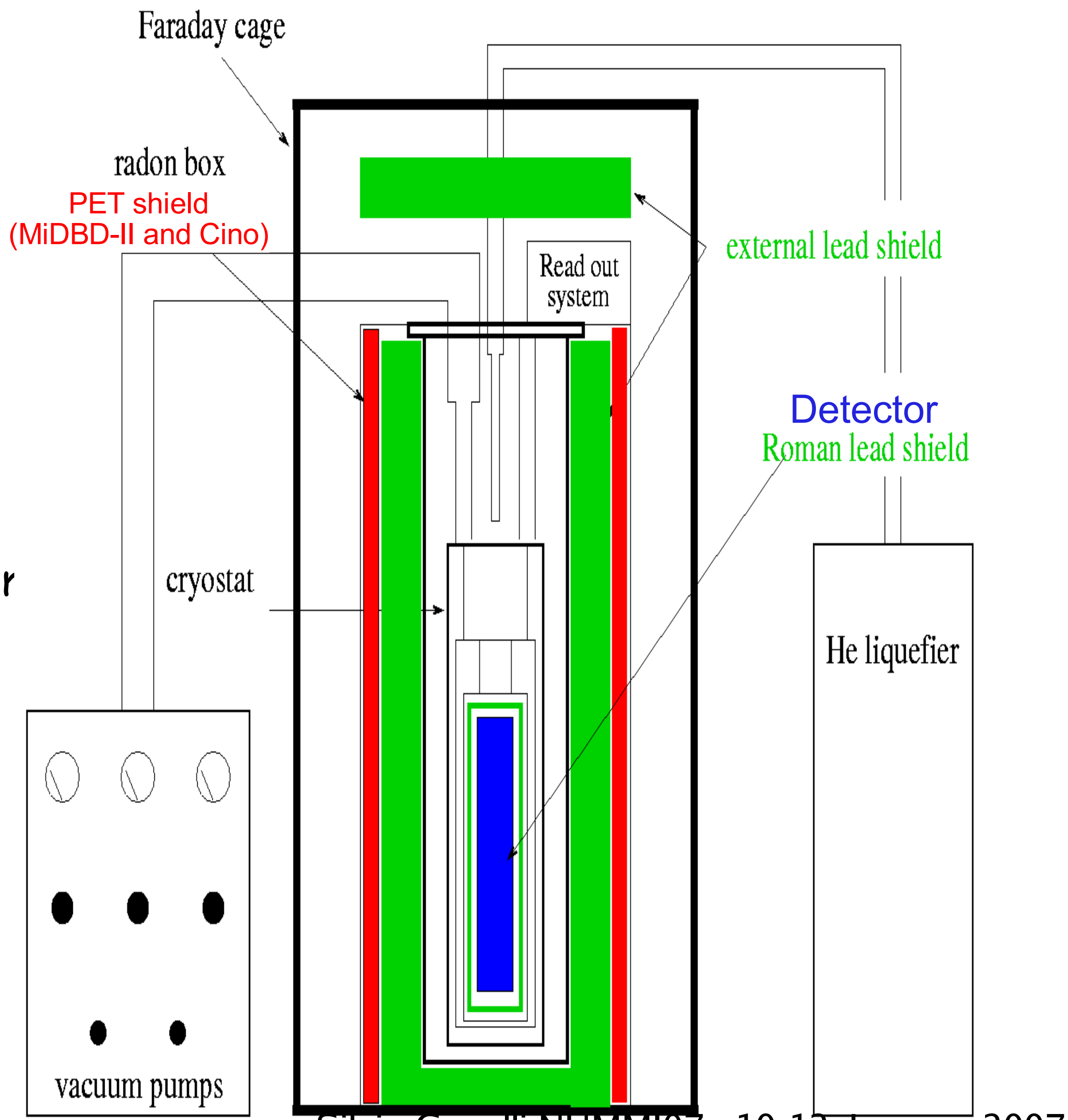
CUORICINO shields

Located at LNGS (3200 mwe) in a He^3/He^4 dilution refrigerator (T~10 mK)

- Cu shields
- Internal Roman Lead

(1.5 cm on side + 10 cm on top and bottor

- 20 cm external Lead
- Nitrogen overpressure
- 10 cm (10%) Borated PET
- Faraday Cage



CUORICINO lastest results

8.38 kg y ^{130}Te

FWHM measured on bkg spectrum at 2.6 MeV ~ 8 keV

bkg counting rate = 0.18 +/- 0.01 cnts/keV/kg/y

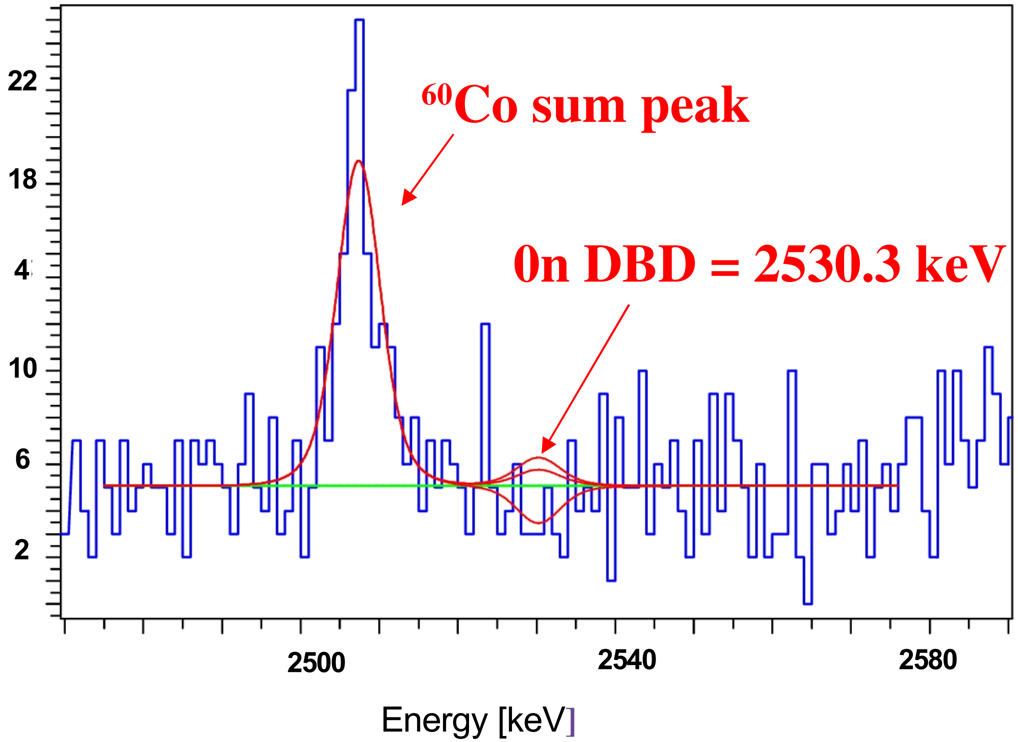
best fit yields NEGATIVE effect

- peak shape = N-gaussian (to account for the different – measured - energy resolutions)
- flat bkg + 2505 keV peak
- fit interval = 2475 – 2550 keV

$\tau_{1/2} > 2.4\ 10^{24}$ [y] @ 90% C.L

$\langle m_n \rangle < (0.18 \div 0.94)$ eV

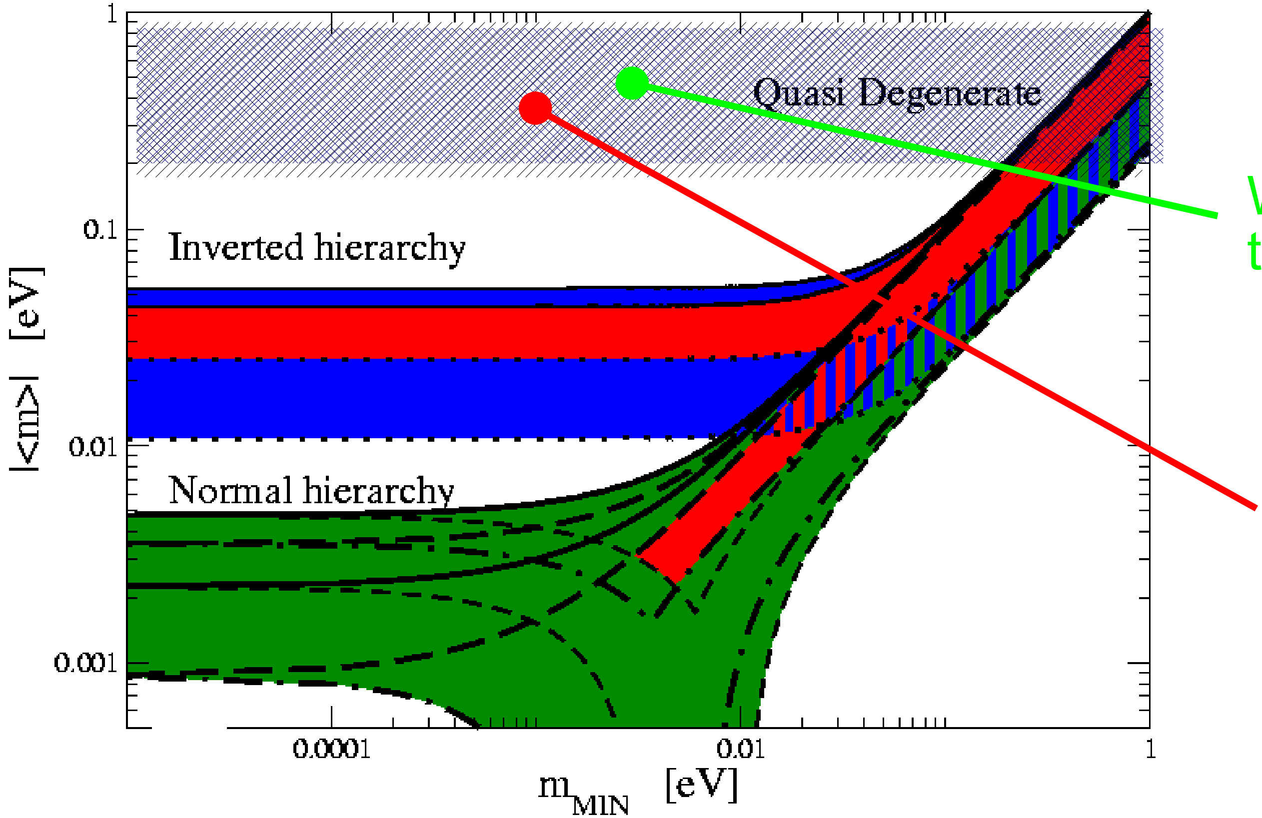
NME from
"New Limit on the Neutrinoless bb Decay of ^{130}Te",
C.Arnaboldi et al., PRL 95, 142501 (2005)



^{60}Co sum peak

0n DBD = 2530.3 keV

CUORICINO sensitivity



With the same matrix elements the Cuoricino limit is **0.46 eV**

Ge evidence

(best value 0.39 eV)

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

Sensitivity: half life corresponding to the minimal number of detectable events above background, for a given C.L.

$$S^{0\nu} = \ln 2 \times N_A \times 10^3 \times \frac{i.a.}{A} \left(\frac{M\,T}{b\,\Delta E}\right)^{1/2} \times \varepsilon$$

With 3 y live time:

$T_{1/2} \geq 7\times10^{24}$ y

$\langle m_\nu \rangle \leq 0.1 \div 0.6$ eV

CUORICINO bkg analysis

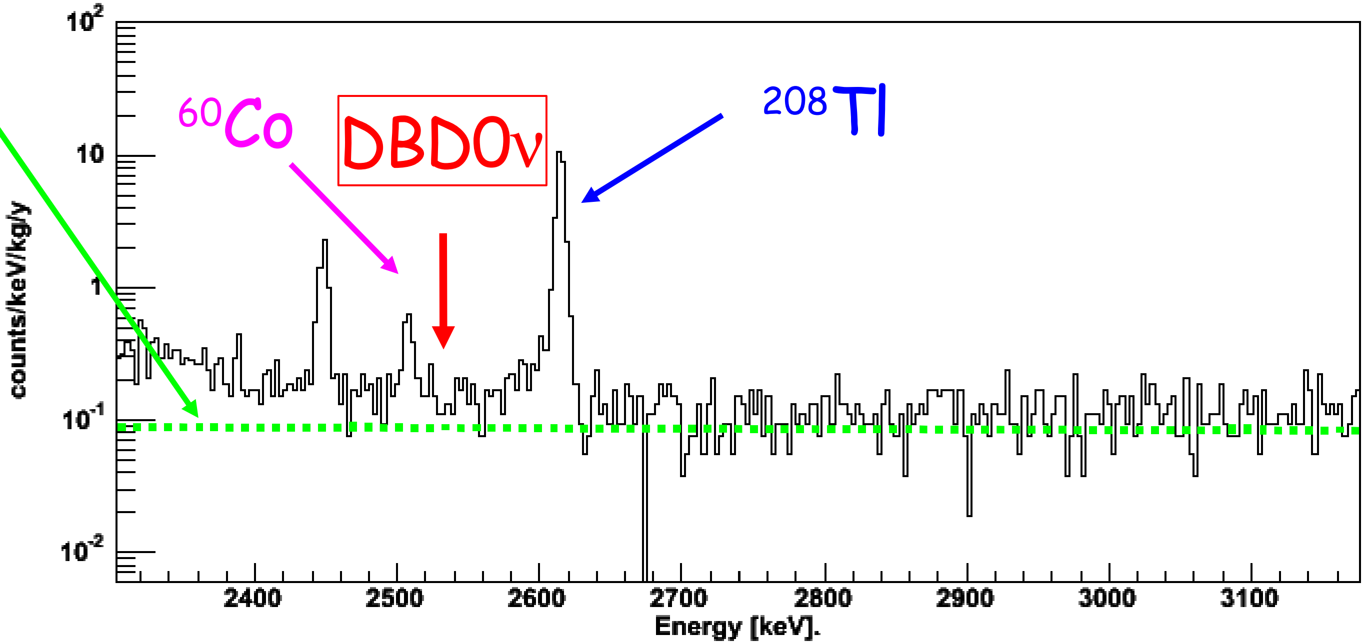
Evaluated contributions to the DBD0ν region bkg (0.18 +/- 0.01 cnts/keV/kg/y):

30 ± 10% from ^{208}Tl (2614.5 keV line) Compton events (^{232}Th in cryostat shields)

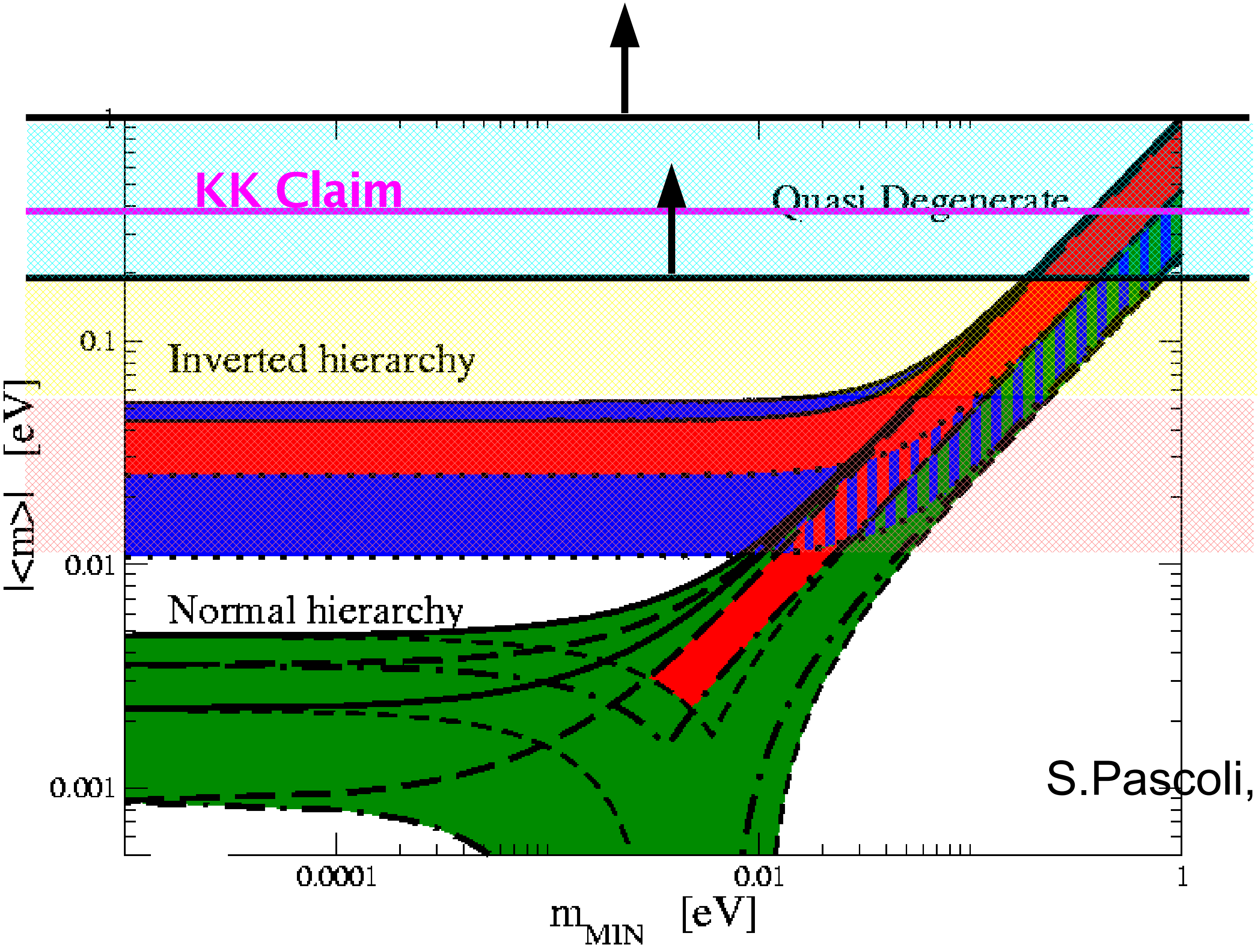
(easily avoided by proper material selection)

10 ± 5% from crystals surface ^{238}U and ^{232}Th contamination

50 ± 20% from degraded alpha produced by ^{238}U and ^{232}Th contaminations of mounting structure (main candidate the copper surface)



Experimental prospects



S.Pascoli, S.T.Petcov

Excluded by CUORICINO, NEMO3 (NME dependence)

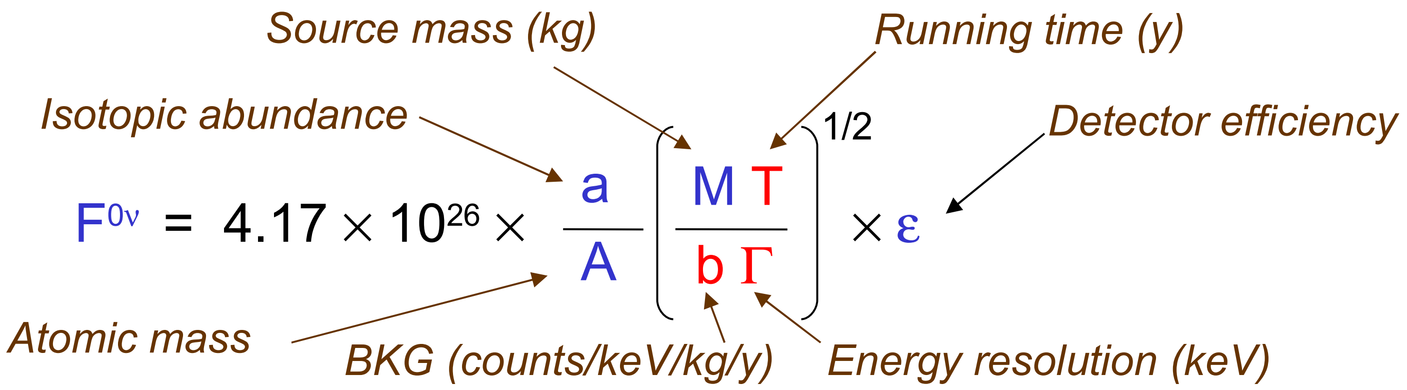
Approach the IHR in a 1st fase ($\langle m_\nu \rangle > 50$meV)

Exclude the IHR in a 2nd fase ($\langle m_\nu \rangle > 15$meV)

There are techniques and experiments in preparation which have the potential to reach these sensitivities

Experimental sensitivity

Sensitivity: Lifetime corresponding to the minimum detectable number of events above background at a given C.L.



Source mass (kg)

Running time (y)

Isotopic abundance

Detector efficiency

$$F^{0\nu} = 4.17 \times 10^{26} \times \frac{a}{A} \left(\frac{M\,T}{b\,\Gamma} \right)^{1/2} \times \varepsilon$$

Atomic mass

BKG (counts/keV/kg/y)

Energy resolution (keV)

Sensitivity to $\langle m_\nu \rangle$:

$$\langle m_\nu \rangle \div \frac{a/A \times \varepsilon}{G^{1/2}\,|\mathrm{Mnucl.}|} \left(\frac{b\Gamma}{MT} \right)^{1/4}$$

$\div\, Q^5$

REQUIREMENTS:

- Importance of the nuclide choice (but large uncertainty due to NME)
- Sensitive masses at the order or 1 ton scale
- Background at the order of 1-10 c/y/t in order to start to explore the IHR
- Background at the order of 0.1-1 c/y/t in order to cover the IHR

Next Generation DBD experiments

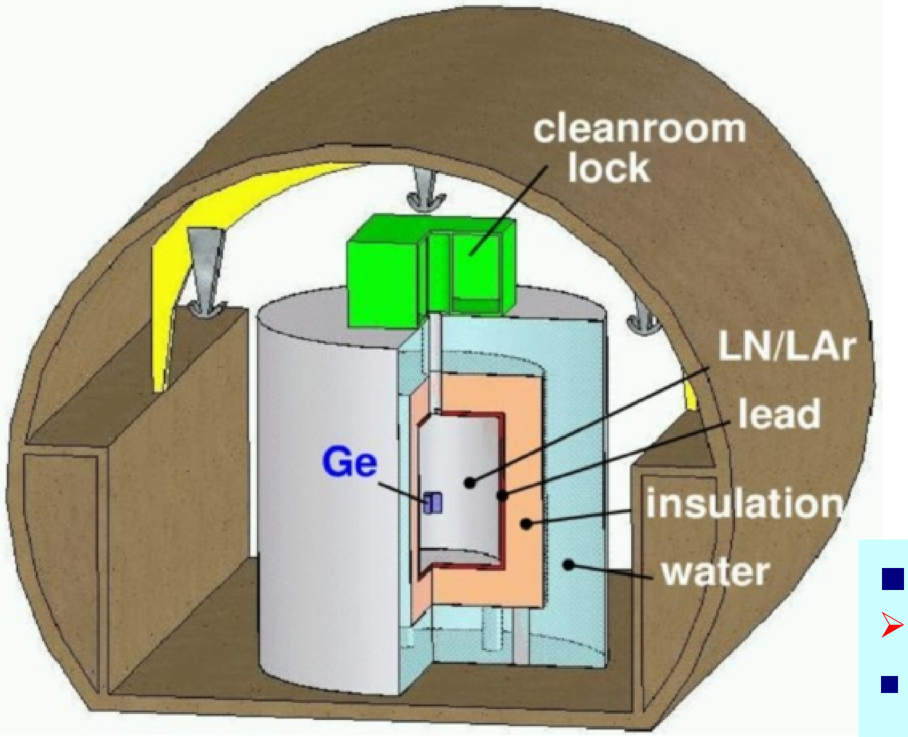
Experiment	Author	Isotope	Detector description	$T^{5y}_{1/2}$(y)	<m >*
CUORE	Bolometric	^{130}Te	760 kg of TeO_2 bolometers	7×10^{26}	0.027
COBRA	Ionization	^{130}Te	10 kg CdTe semiconductors	1×10^{24}	0.71
GERDA	Ionization	^{76}Ge	1 t enriched Ge diodes in liquid nitrogen	2×10^{27}	0.034
MAJORANA	Ionization	^{76}Ge	0.5 t enriched Ge segmented diodes	4×10^{27}	0.025
SUPERNEMO	Tracking	^{82}Se	100- 200 kg enriched Nd or Se foils between TPCs	2×10^{25}	
DCBA	Tracking	^{150}Nd	20 kg enriched Nd layers with tracking	2×10^{25}	0.035
MOON	Tracking	^{100}Mo	34 t natural Mo sheets between plastic scintillator	1×10^{27}	0.036
EXO	Tracking	^{136}Xe	1 t enriched Xe TPC	1.3×10^{28}	0.013
Xe	Scintillation	^{136}Xe	1.56 t of enriched Xe in liquid scintillator	5×10^{26}	0.066
XMASS		^{136}Xe	10 t of liquid Xe	3×10^{26}	0.086
CAMEO	Scintillation	^{116}Cd	1 t $CdWO_4$ crystals in liquid scintillator	$> 10^{26}$	0.069
CANDLES	Scintillation	^{48}Ca	tons of CaF_2 crystal in liquid scintillator	1×10^{26}	
GSO	Scintillation	^{160}Gd	2 t Gd_2SiO_5:Ce cristal scintillator in liquid scintillator	2×10^{26}	0.065

** using nuclear calculations of Staudt et al. Europhys. Lett 13 (1990) 31*

GERDA

- naked Ge crystals in LN2 or Lar

- 1.5 m LN2(LAr) + 10 cm Pb + 2 m water
- 2-3 orders of magnitude better bkg than present Status-of-the-Art (0.1 c/keV/kg/y)
- water: passive shielding for γ and n,
  active cherenkov against μ
- active shielding with LAr scintillation



3 PHASES EXPERIMENT:

- Phase I: ≈15 kg ^{76}Ge from HM and Igex
  - radioactivity tests: expected bkg 0.01 c/keV/kg/y (intrinsic)
  - check at 5σ HM evidence:
    with 15 kg×y 6 ± 1 events expected on 0.5
    (**for <1evt: signal excluded @ 98% CL)**

- Phase II: add new enriched segmented detectors with special care for activation
  - expected background ≈0.001 c/keV/kg/y
  - statistics 3y * 35 kg ~ 100 kg y:
    2×10^{26} y => *<m>* 10 ÷ 30 meV

- Phase III: => 10 meV with 1 ton Ge
  - worldwide collaboration

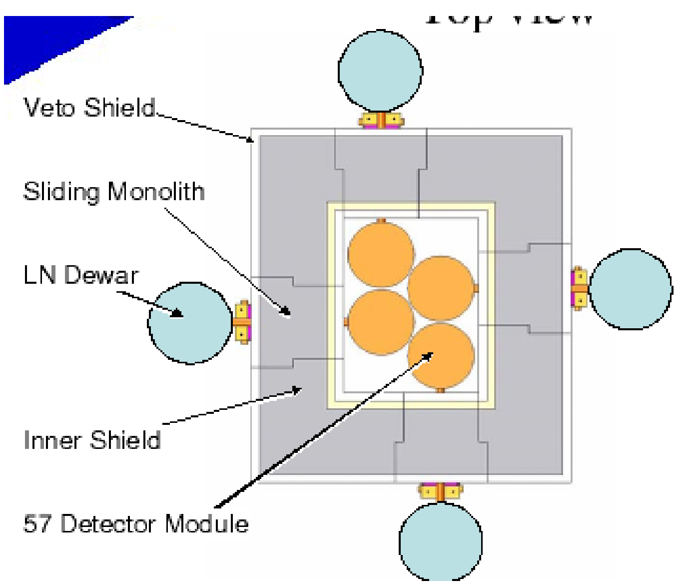
- Approved by LNGS S.C.
  - site: Hall A northern wing
- funded 40 kg enriched ^{76}Ge for phase II

MAJORANA

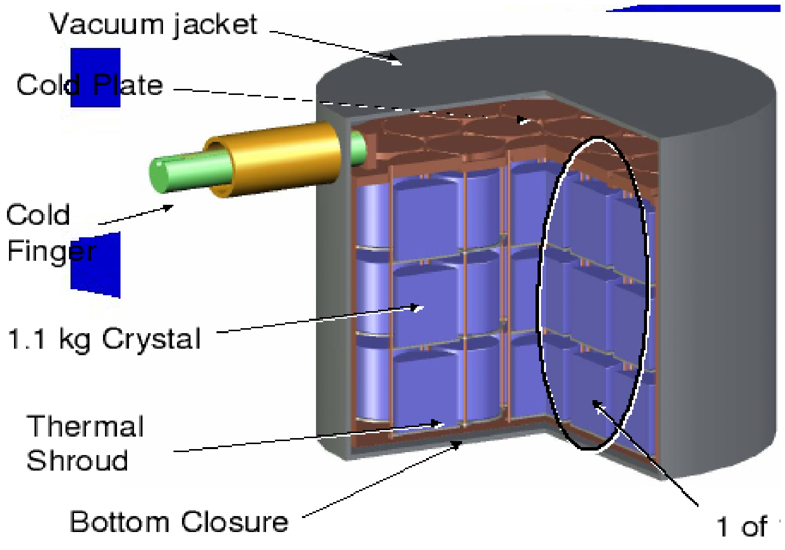
GOAL: $\langle m_\nu \rangle \sim 20 - 70$ meV

Main concern:

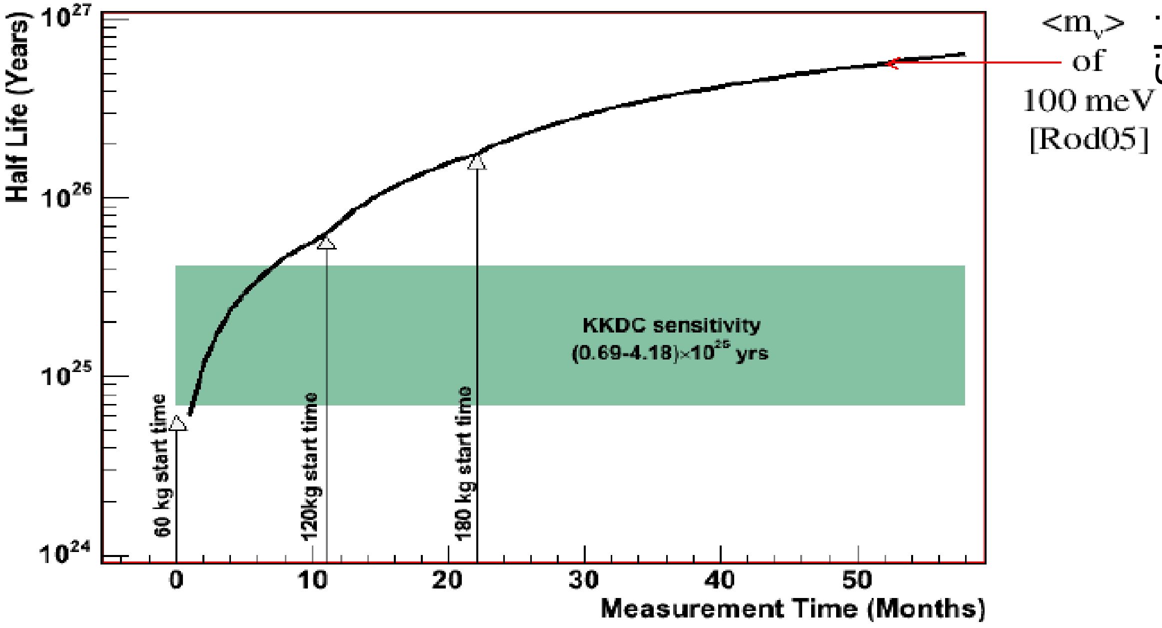
- cost and time for i.e. ^{76}Ge
- cosmogenic background
- material selection



- Deep underground location WIPP/Homestake
- 4 modules of 57 **Segmented** HPGe detectors each
- ~ 200 kg total mass in the final phase
- 85% enriched ^{76}Ge
- Traditional shielding (Pb+Cu+n) and active veto



September 13, 2005 Steve Elliott



SUPER NEMO

Extension of the NEMO 3 technique. Planar and modular design (20 modules)
100–200 kg of isotopes, thin source between tracking volumes, surrounded by calorimeter.

- **Source** 5 kg source foil (40 mg/cm^2) 12m^2 per module (enriched ^{150}Nd or ^{82}Se)
- **Tracking volume** (~3000 channels)
- **Calorimeter** (~1000 PMT)

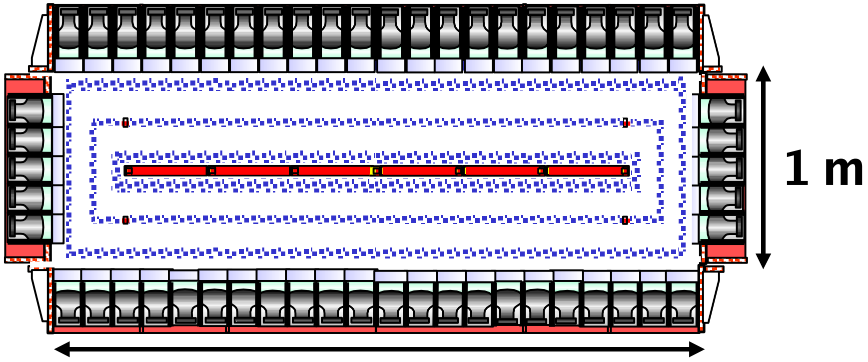
- **20 modules:**
  ~ 60 000 channels for drift chamber
  ~ 20 000 PMT

main improvements needed:

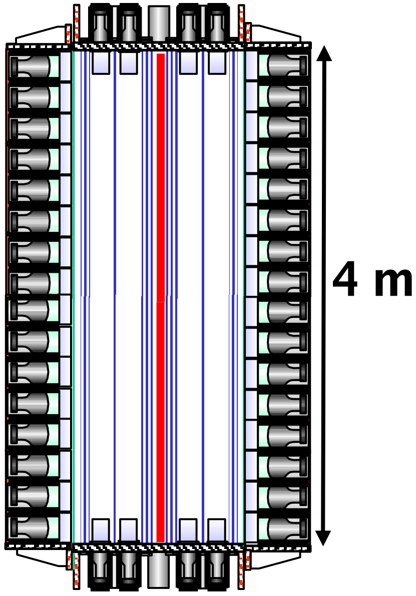
- energy resolution (FWHM @ 3 MeV = 4%)
- detection efficiency (factor of 2)
- source radio purity (factor of 10)
- background rejection methods

Water Shield: 2kT of water for 20 modules
B: 25 G

Sensitivity:
$T_{1/2}(0\nu\beta\beta) > 10^{26}$ y
$\langle m_\nu \rangle < 50$ meV



Top view



Side view

MOON

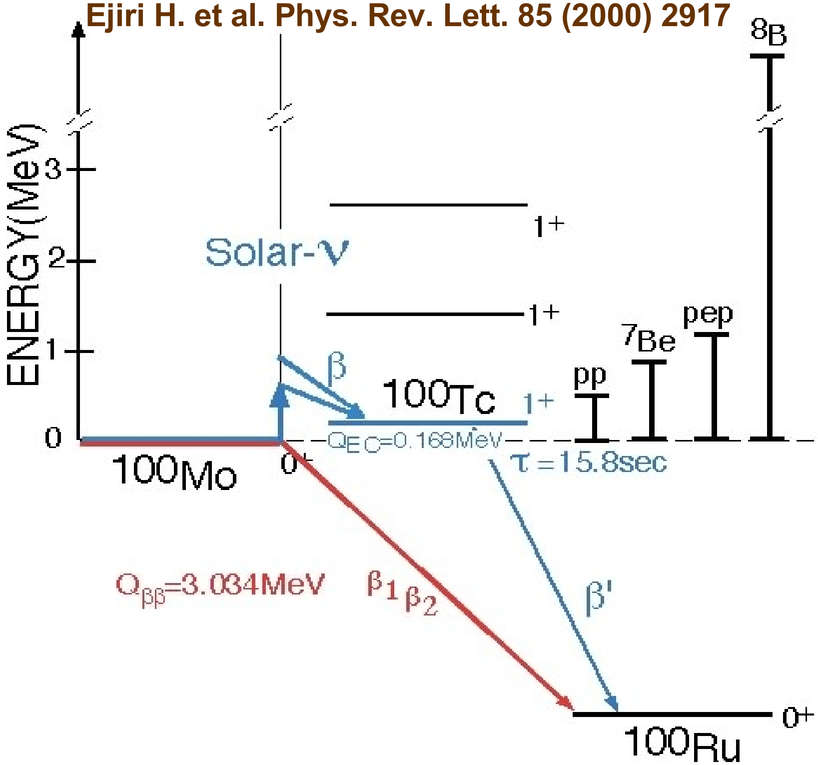
^{100}Mo → passive source for 0ν2β

^{100}Mo → target for solar neutrinos

- Oto Underground Laboratory - Japan
- source ≠ detector:

Thin ^{100}Mo foils sandwiched between
  - PL Scintillator Plates (Energy)
  - PL Scintillating Fibers (Position/Particle ID)
- 1 ton ^{100}Mo in the final design
- specially designed cryostat, at 10 mK

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



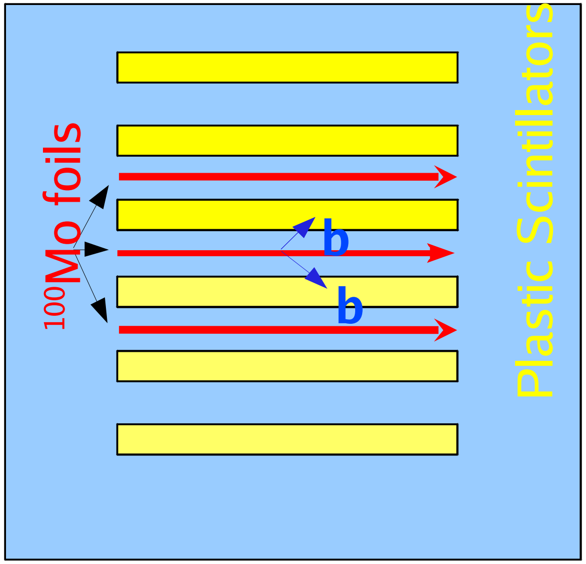
Main concerns:

- FWHM: 7%
- Mo radio-purity

GOAL: $\langle m_\nu \rangle$ ~ 50 meV

SCHEDULE:

- MOON 1 (in operation since April 2005) no position det.
- MOON 2 (2006-2007) with position det.
- MOON 3 (proposal 2008) 1 ton ^{100}Mo



EXO

- Source = detector
- two options with enriched ^{136}Xe
    - High pressure Xe TPC
    - LXe TPC + scintillation
- calorimetry + tracking

Full scale experiment

10 t (for LXe 3 m^3)

- at WIPP or SNOLAB
- Ba tagging to suppress background ($^{136}Xe \Rightarrow {}^{136}Ba^{++} + 2e$)
- single Ba$^+$ detected by optical spectroscopy
- expected bkg only by $\beta\beta$-2ν
- energy resolution = 2%

Prototype:

EXO-200 (fully funded):

- 200 kg enriched Liquid ^{136}Xe (80%)
- no Ba++ tagging
- all EXO functionality except Ba id
- operate in WIPP for ~ two years

Prototype goals:

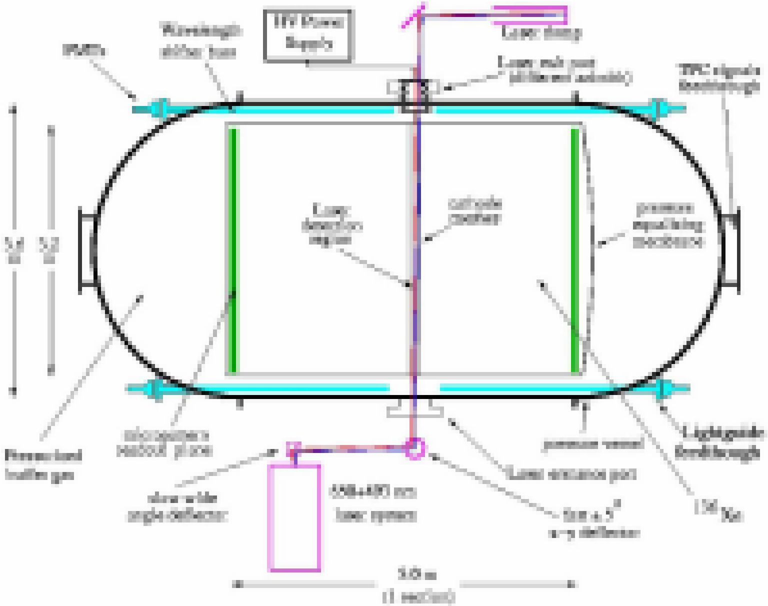
- Test all technical aspects of EXO (except Ba id)
- Measure 2ν mode
- Set decent limit for 0ν mode (probe Heidelberg- Moscow)

GOAL:

back ~ 4×10^{-3} c/keV/ton/y

$T_{1/2}$ ~1.3×10^{28} y in 5 years

$<m_\nu>$ ~ 0.013 ÷ 0.037 eV



Silvia Capelli NUMMI07, 10-12 January 2007

COBRA

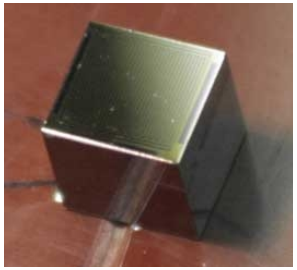
Source = detector

Array of 1 cm^3 CdZnTe Semiconductor det

Tracking („Solid state TPC")

Modular design (Coincidences)

Two isotopes at once



Prototype:

- 2x2 array of naked 1cm^3 CdZnTe installed at LNGS.
- 4.3 kg x days of data accumulated
- stopped March 2006
- First COBRA DBD results:

T. Bloxham et al., submitted

1st phase:

64 detector array (~ 0.5 kg of CdZnTe)

first 16 installed at LNGS in April 2006

scalable modular design

explore coincidences

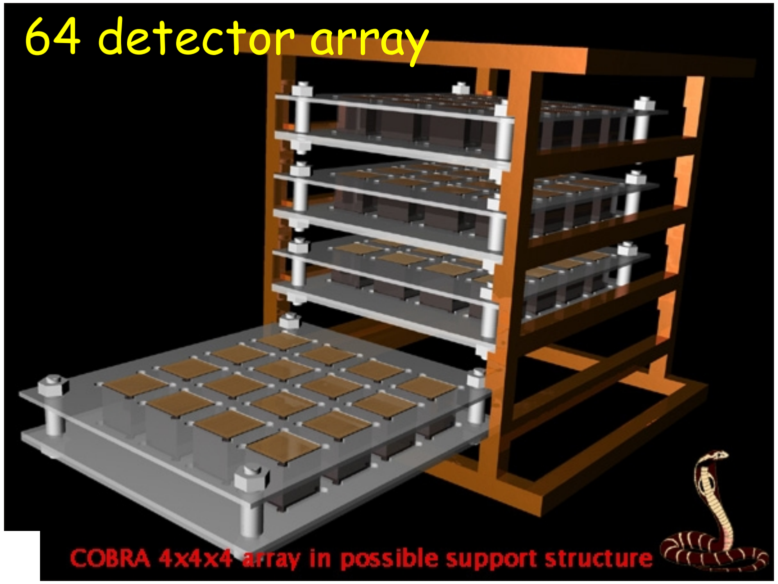
Future:

- reach the sensitivity $\langle m_\nu \rangle \sim 50$ meV
- A real time low-energy solar neutrino experiment?

Current idea:

40x40x40 CdZnTe detectors

= 420 kg, enriched in ^{116}Cd



Silvia Capelli NUMMI07, 10-12 January 2007

CUORE

- **Source = detector**
- 988 TeO2 bolometric detectors (741 kg)
- no enrichment needed (34% ^{130}Te n.a.)
- FWHM ≈ 0.2%
- cylindrically arranged
- Specially designed cryostat
- Cu and Roman Lead internal shields
- Lead and neutron external shields
- Nitrogen overpressure

MAIN CONCERN: background

✔ < 10^{-3} c/keV/kg/y from outside the internal Pb shield (cryostat + environmental)

✔ < 10^{-3} c/keV/kg/y internal Pb shield + Cu structure

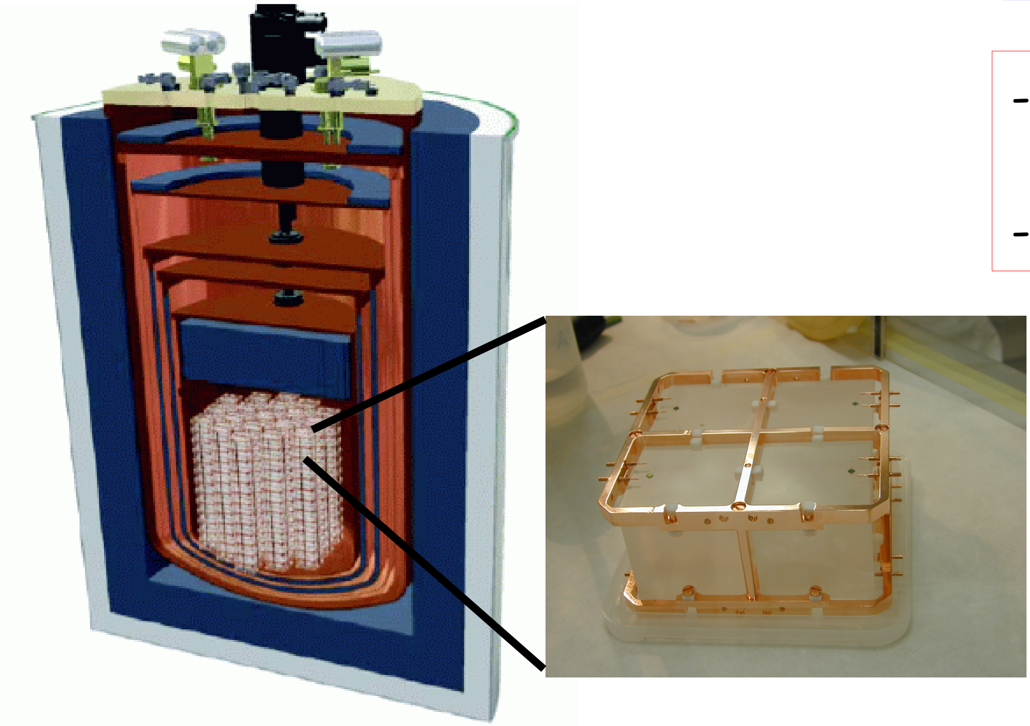
✔ < 10^{-3} c/keV/kg/y small parts bulk

✔ < 10^{-4} c/keV/kg/y crystals bulk

✔ < 3 10^{-3} c/keV/kg/y crystals surface

⚡ < 5 10^{-2} c/keV/kg/y copper surface

- Further reduction of a factor 2 thanks to a new mounting structure
- R&D still in progress

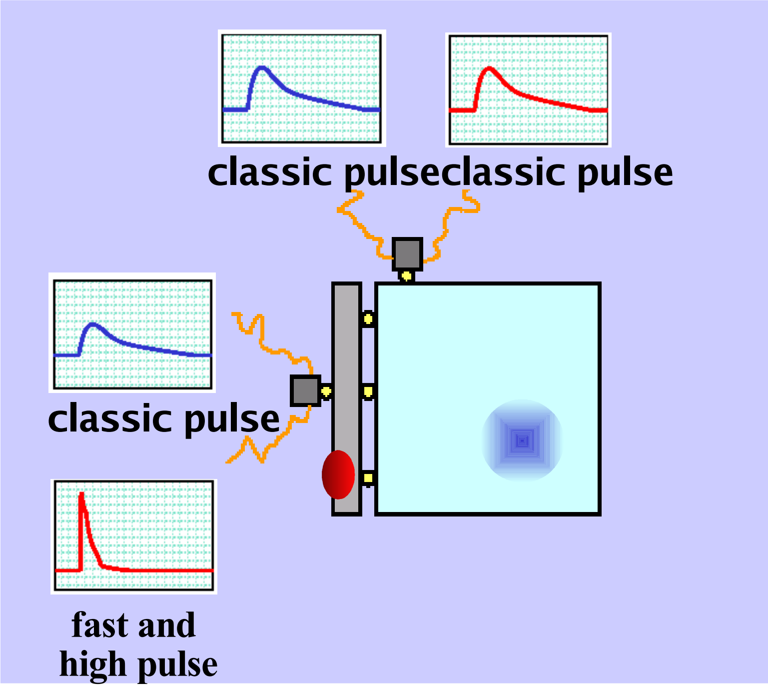


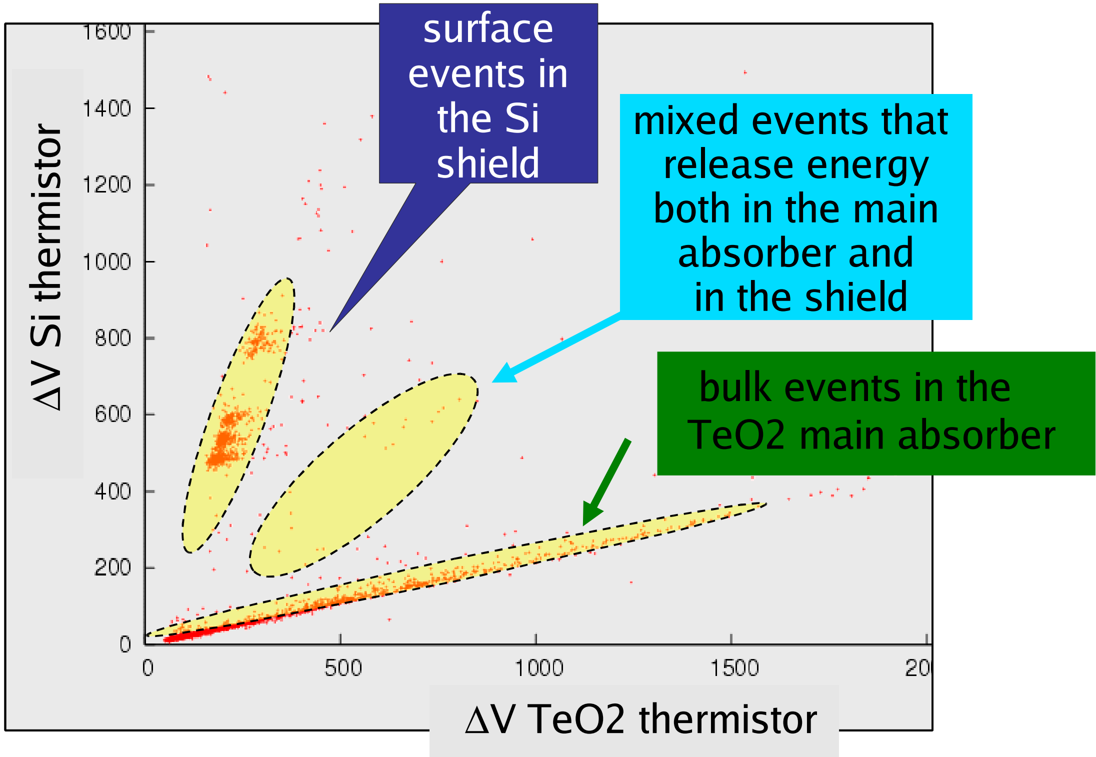
GOAL:

bkg: $10^{-2} \div 10^{-3}$ c/keV/kg/y

sensitivity: $\langle m_\nu \rangle \sim 30$ meV

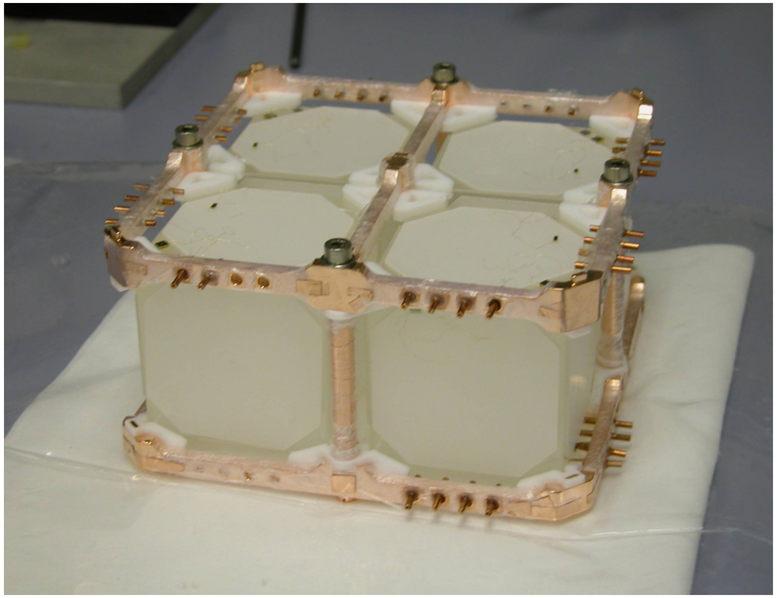
CUORE R&D: surface sensitive bolometers




surface events in the Si shield

mixed events that release energy both in the main absorber and in the shield

bulk events in the TeO2 main absorber



L. Foggetta et al., Appl. Phys. Lett. 86, p.134106 2005

CONCLUSIONS

- Neutrino oscillation experiments have demonstrated that neutrinos oscillate, mix and have finite mass

- The nature of the neutrino, the mass scale and hierarchy are still unknown

- DBD0ν is the most sensitive way to answer to these open questions (but NME uncertainty)

- This process has been indicated by an experiment (Klapdor) with a value of ~0.39 eV but not yet confirmed

- Future experiments on neutrinoless double beta decay will allow to reach the sensitivity predicted by oscillations under the inverse hierarchy hypothesis

Backup

^{76}Ge: GERDA

FASE I : test “Klapdor claim”

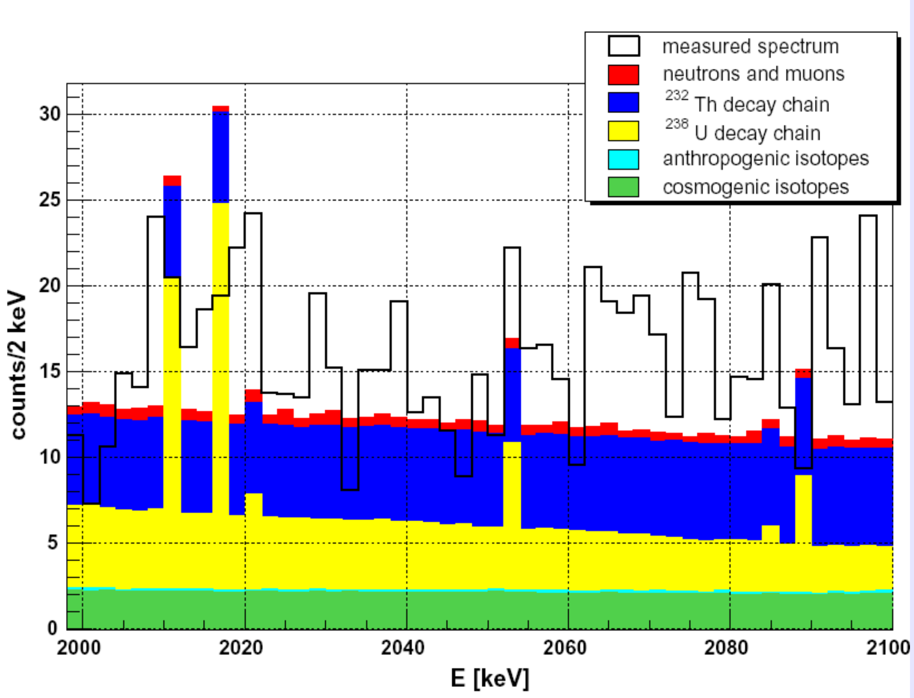
FASE II :<m > ~ 10 - 30 meV

Italia-Russia-Germania-Polonia

Laboratori Nazionali del Gran Sasso

Parte dall'esperienza di IGEX e HM con l'idea di ridurre a ~0 il fondo esterno e controllare molto bene quello intrinseco (^{60}Co e ^{68}Ge).

IL GOAL E' => passare da 0.1 c/(keV kg y) a 0.001 c/(keV kg y) FATTORE 100 !!!



Modello fondo esp. Heidelberg Moscow

contributi esterni:

- ***contaminazioni radioattive** dei materiali di costruzione (cemento/roccia ...) e in particolare 2.615 MeV from ^{208}Tl*
- ***neutroni** da reazioni (alpha,n) & fissione in cemento/roccia e da reazioni indotte dai mu*

contributi interni (nel Ge)

- ***attivazione cosmogenica** a livello del mare, particolarmente rilevante per gli isotopi ^{68}Ge e ^{60}Co con vite medie ~ anno(i)*

IONIZATION

MAJORANA

Aalseth CE et al. hep-ex/0201021

PNNL
South Carolina University
TUNL
ITEP
Dubna
NMSU
Washington University

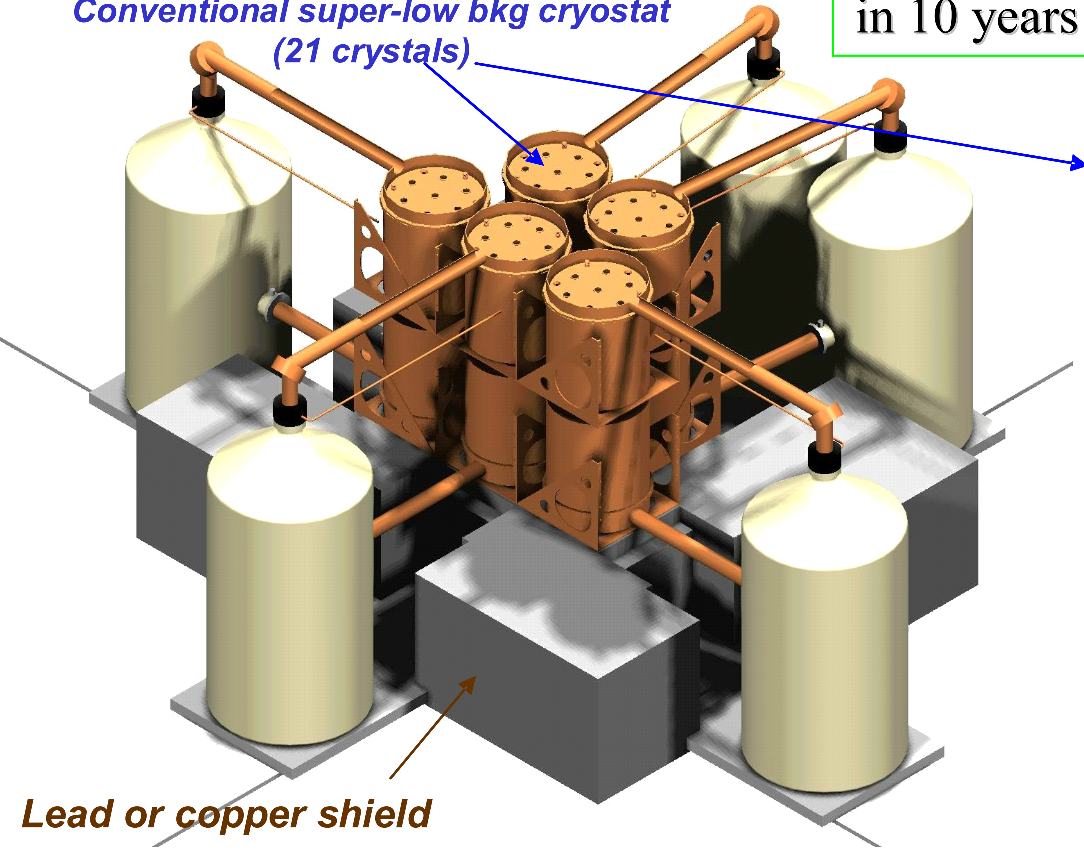
GOAL: $\langle m_{\nu} \rangle \sim 0.02-0.07$ eV

Main concern:

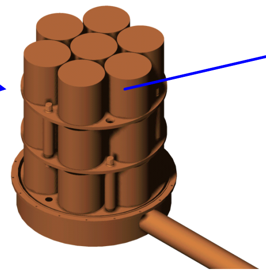
- **cost and time for i.e. ^{76}Ge**
- **cosmogenic background**
- **material selection**

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

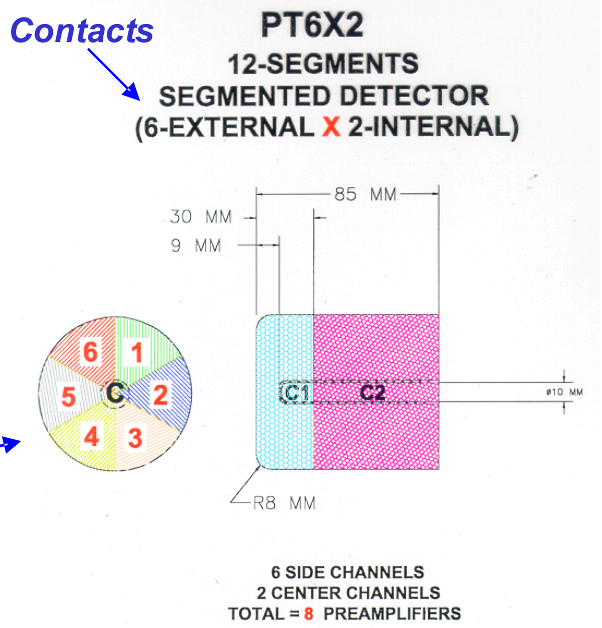
Conventional super-low bkg cryostat (21 crystals)



Lead or copper shield



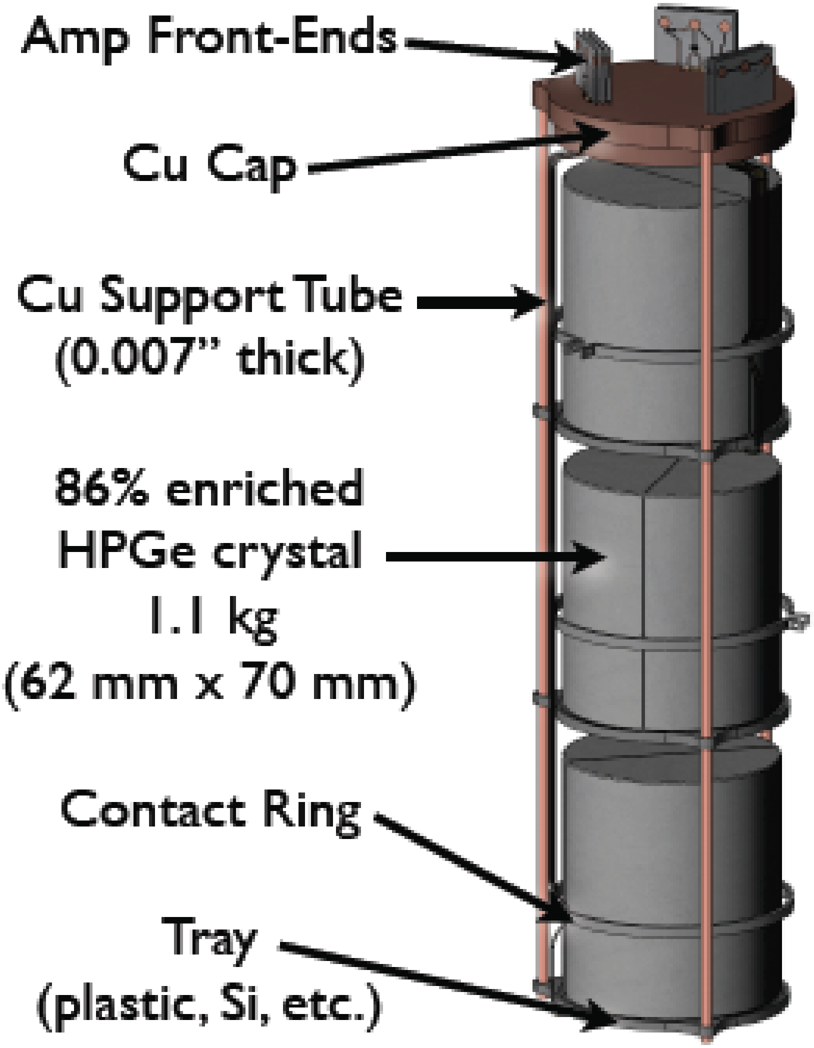
Perkin-Elmer design



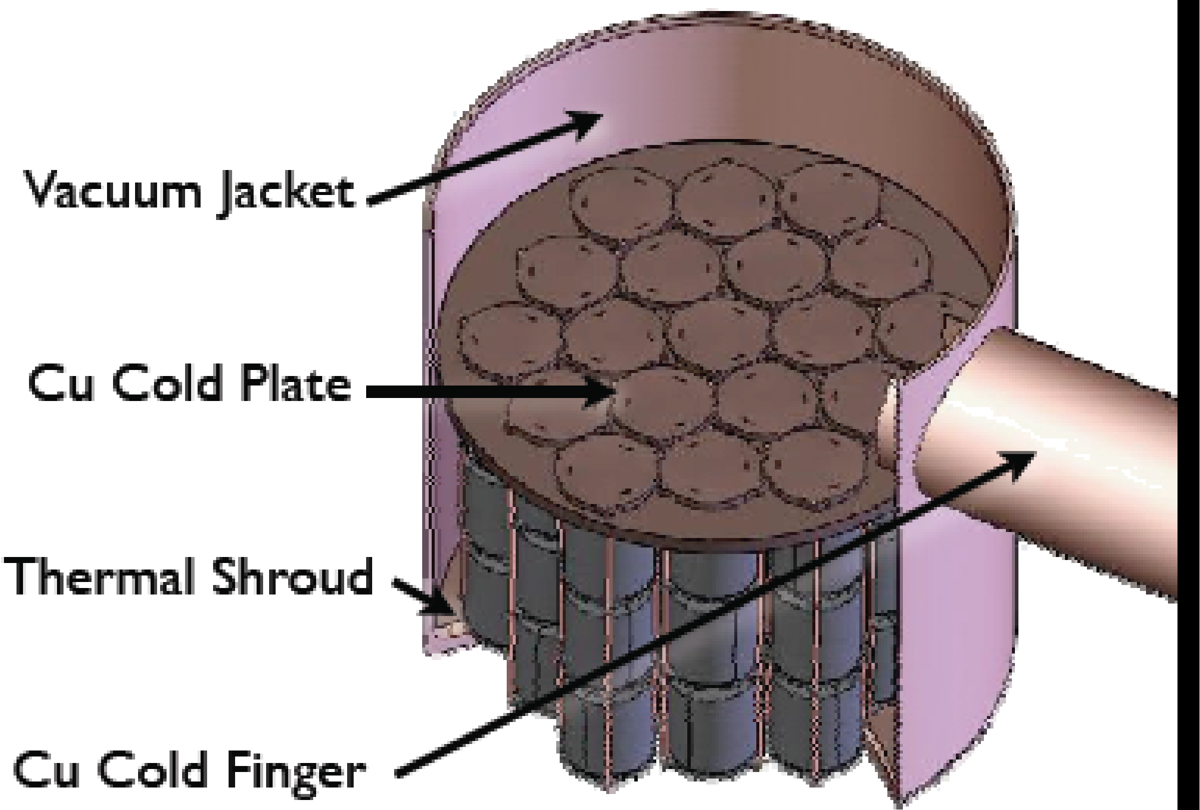
- **Deep underground location WIPP/Homestake**
- **~\$20M enriched 85% ^{76}Ge**
- **210 2kg crystals, 12 segments**
- **Advanced signal processing**
- **~\$20M Instrumentation**
- **Special materials (low bkg)**
- **10 year operation**

60 kg Modules

3-crystal string



57-crystal module



ββ Sources

Goal : $T_{1/2} > 10^{26}$ y
$\langle m_\nu \rangle \leq 50$ meV

$$\frac{1}{T_{0\nu}} = G_{0\nu}\, M_{0\nu}^2\, \langle m_\nu \rangle^2$$

^{82}Se

$Q_{\beta\beta} = 2.995$ MeV

Phase space factor $G_{0\nu} = 1.08 \times 10^{-25}$ $y^{-1}eV^{-2}$

Radiopurity requirements for the ββ source

^{214}Bi < 10 μBq/kg
^{208}Tl < 2 μBq/kg
Rn < 2 μBq/m^3

$T_{2\nu} = 9 \times 10^{19}$ y ⇒ Expected background from 2νββ = 1.4 evt/500kg.y in 200 keV

(200 keV energy window at $Q_{\beta\beta}$)

Enrichment by ultracentrifugation

---

^{150}Nd

$Q_{\beta\beta} = 3.367$ MeV

Phase space factor $G_{0\nu} = 8.00 \times 10^{-25}$ $y^{-1}eV^{-2}$

Radiopurity requirements for the ββ source

^{208}Tl < 2 μBq/kg

$T_{2\nu} = 9 \times 10^{18}$ y ⇒ Expected background from 2νββ = 2.2 evt/500kg.y in 200 keV

(200 keV energy window at $Q_{\beta\beta}$)

Enrichment by laser

The best choice for phase space and background

From NEMO3 to SuperNEMO... objectives

$$T_{1/2}(\beta\beta0\nu) > \ln 2 \times \frac{N_{avo}}{A} \times \frac{M \times \varepsilon \times T_{obs}}{N_{exclu}}$$

NEMO-3		SuperNEMO
^{100}Mo	Choice of isotope	^{150}Nd **or** ^{82}Se
7 kg	Isotope mass **M**	100-200 kg
8 %	Efficiency $\varepsilon(\beta\beta0\nu)$	~ 30 %
^{208}Tl < 20 μBq/kg ^{214}Bi < 300 μBq/kg	N_{exclu} = f(BKG) *Internal contaminations* ***^{208}Tl and ^{214}Bi** in the ββ foil*	^{208}Tl < 2 μBq/kg *(If ^{82}Se:* ^{214}Bi < 10 μBq/kg)
8% @3MeV	Energy resolution FWHM(calorimeter)	4% @3MeV
$T_{1/2}(\beta\beta0\nu) > 2.\ 10^{24}$ y $\langle m_\nu \rangle < 0.3 - 1.3$ eV	**SENSITIVITY**	$T_{1/2}(\beta\beta0\nu) > 10^{26}$ y $\langle m_\nu \rangle < 50$ meV

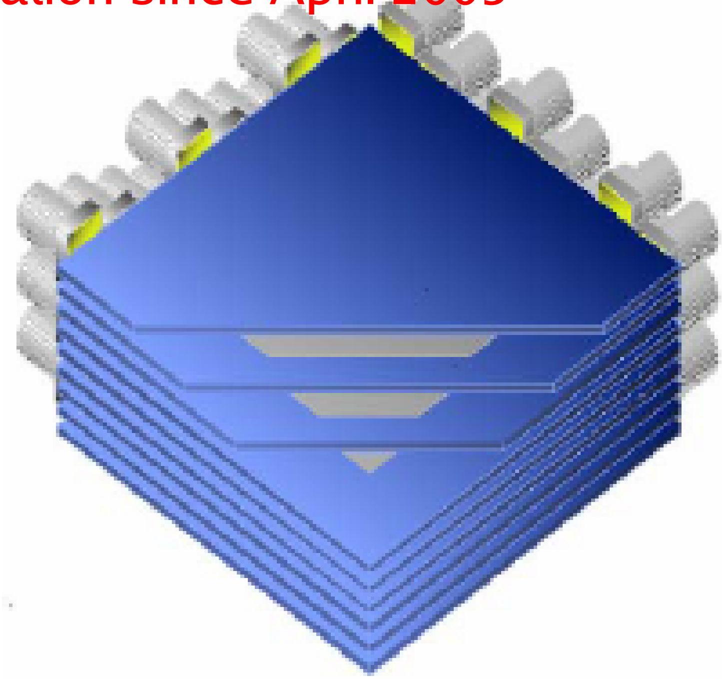
MOON : Majorana /Mo Observatory Of Neutrinos

Osaka, UW, FNAL, ICU, JINR, LANL, NIRS, Praha, Tokushima, UNC, VNIIEF.

TRACKING

1. Goal: $m_\nu \sim$ IH 30meV for ground and excited O+.
2. Detector $\neq$ ββ source. Use one or two of ^{100}Mo, ^{82}Se, ^{150}Nd with large Q > most RI .
3. ββ tracking E_1, E_2, Θ_{12} correlations to identify ν-mass term.
4. Application to low-E solar ν

MOON 1 in operation since April 2005



MOON detector

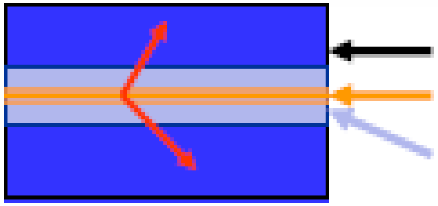
Multi-layer PL plates : compact & active self-shields
Position /particle ID by PL fiber or MWPC chamber
Enriched isotopes by centrifugal separation.

Sensitivity

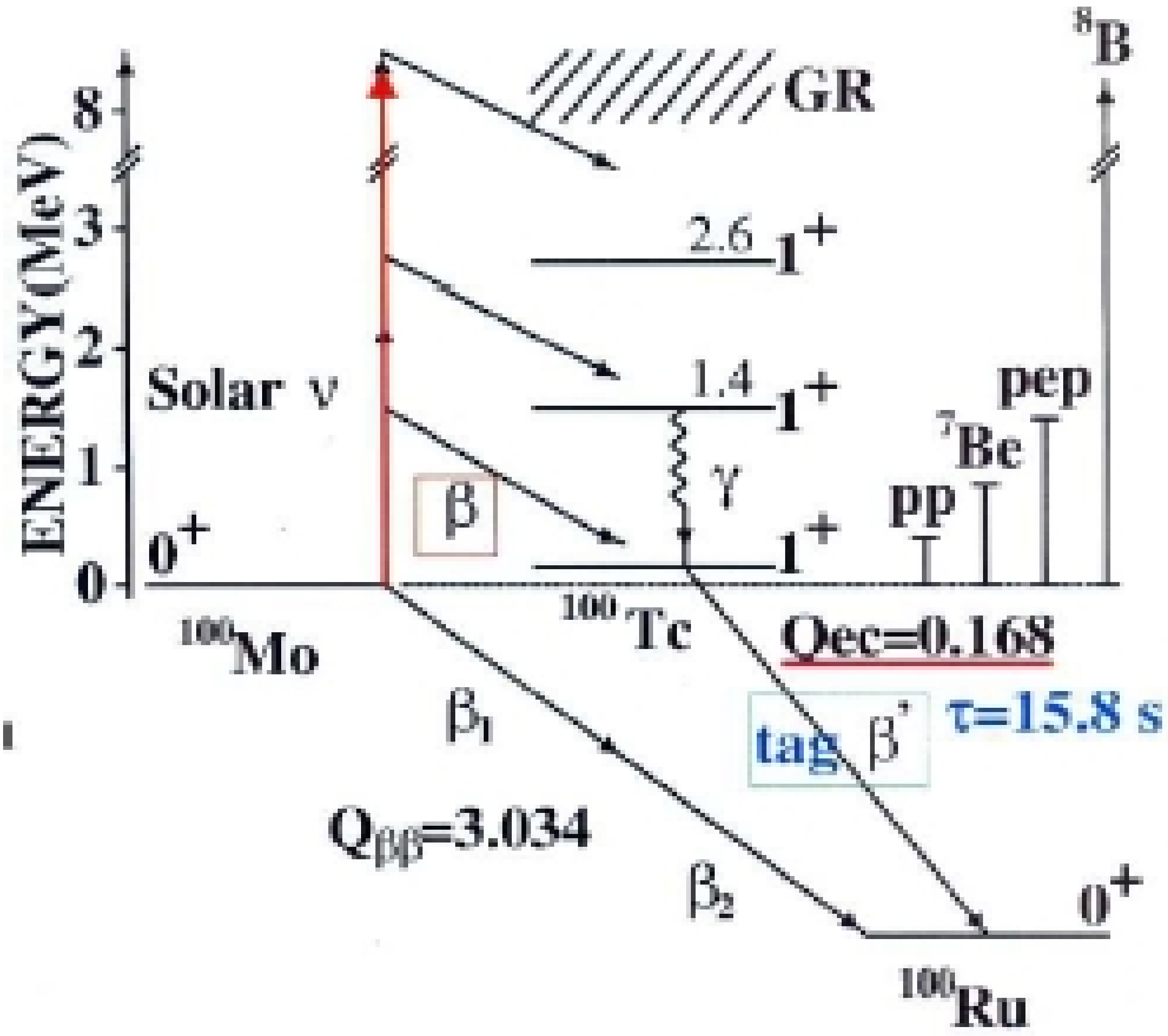
- 20-40 meV for ^{100}Mo, ^{82}Se, ^{150}Nd
  with 5 year-ton and σ = 2-3 % E-resolution.

Schedule (tentative)

2006 Prototype MOON-1 without position
2006-2007 MOON-2 with position detector
2008 (Proposal)



PL E detector
Mo
Position detector
(PL fiber or MWPC)


ENERGY(MeV)
8
3
2
1
0
Solar ν
0+
^{100}Mo
β
GR
2.6
1+
1.4
1+
γ
1+
^{100}Tc
pp
^{7}Be
pep
^{8}B
Qec=0.168
τ=15.8 s
tag β-
β1
Qββ=3.034
β2
0+
^{100}Ru

How EXO works

- 200 kg isotopically enriched liquid ^{136}Xe (80%)
  - Semi-cryogenic (-115 ^{o}C)
  - Source = detector
  - **$Q_{\beta\beta}$ = 2457.8±0.4 keV.** (M. Redshaw et al., to be submitted to Phys. Rev. C)

- $2\nu\beta\beta$, $0\nu\beta\beta$ (and background events) create ionization trails in LXe (e^- and Xe^+)
  - W_{Xe}~10 eV, $Q_{\beta\beta}$~2.5 MeV → ~10^5 e^-/event

- TPC: sum up e^- (no gain in liquid): energy of decay
  - Pulse height/timing analysis gives x-y position (Res.~1cm^2)

- APDs: collect 175 nm scintillation (e^- & Xe^+ recombination)
  - Timing gives a "start," and allows for z-position reconstruction

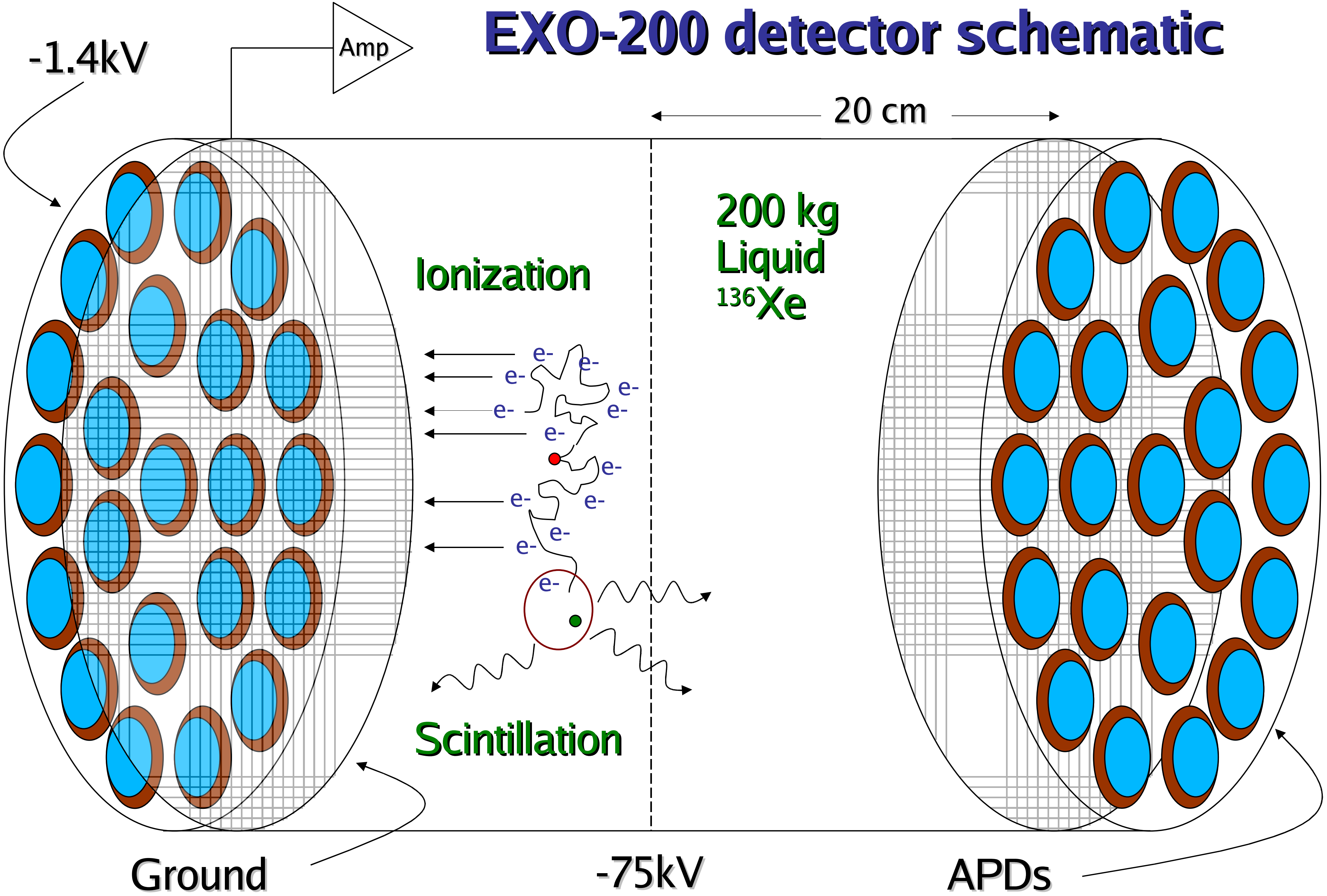
- Shielding: passive + plastic scintillator active veto

- Ba^{++} → Ba^+, analyzed with ion spectroscopy
- > 1000 kg isotopically enriched liquid 136Xe (80%)

EXO-200
(fully funded)

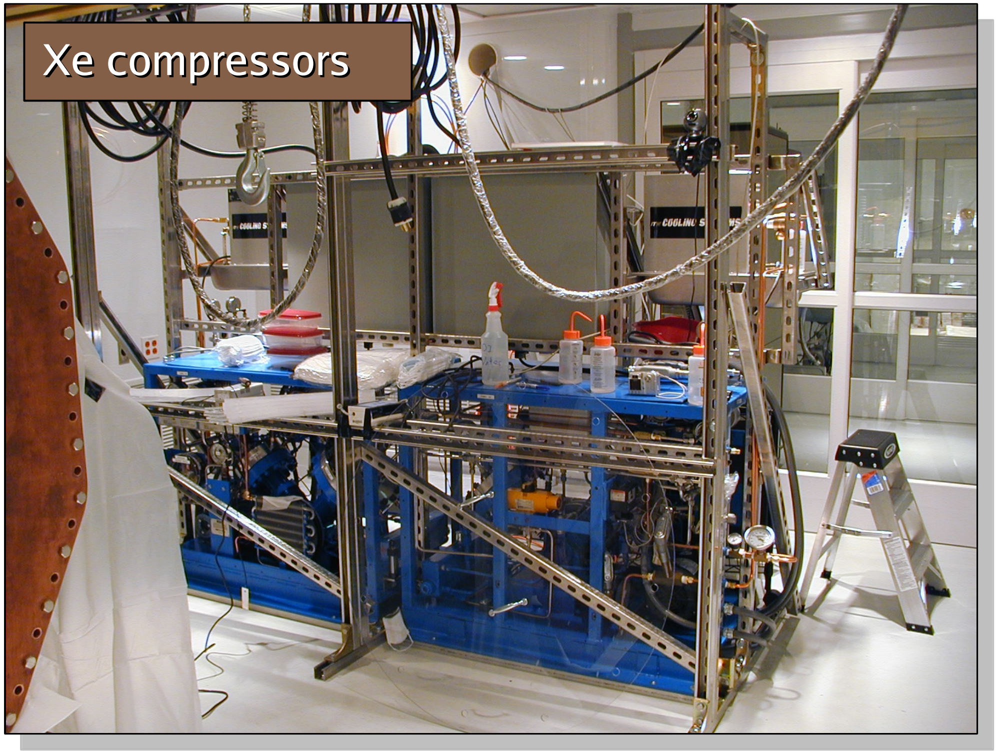
Full EXO

EXO-200 detector schematic



EXO-200 Installation Status


EXO-200 cleanrooms


Xe compressors


Refrigeration systems


Refrigerant storage

EXO-200 Majorana mass sensitivity

Assumptions:

2) 200kg of Xe enriched to 80% in 136
3) σ(E)/E = 1.4% obtained in EXO R&D, Conti et al., Phys Rev B 68 (2003) 054201
4) Low but finite radioactive background: 20 events/year in the ±2σ interval centered around the 2457.8(0.4) keV endpoint [a]
5) Negligible background from 2νββ ($T_{1/2}>1\cdot10^{22}$yr) [b]

Case	Mass (ton)	Eff. (%)	Run Time (yr)	σ_E/E @ 2.5MeV (%)	Radioactive Background (events)	$T_{1/2}^{0\nu\beta\beta}$ (yr, 90%CL)	Majorana mass (eV)	
							QRPA	NSM
EXO-200	0.2	70	2	1.6[*]	40	6.4×10^{25}	0.27[†]	0.38[♦]

[†] Rodin et al Phys Rev C 68 (2003) 044302

[♦] Courier et al. Nucl Phys A 654 (1999) 973c

[a] M. Redshaw, J., McDaniel, E. Wingfield and E.G. Myers (Florida State Precision Penning Trap), to be submitted to Phys. Rev C.

[b] R. Bernabei et al., Phys. Lett. B 546, 23 (2002)

Isotopes

COBRA: CdZnTe semiconductors

		nat. ab. (%)	Q (keV)	Decay mode
	Zn70	0.62	1001	- -
	Cd114	28.7	534	- -
➡	Cd116	7.5	2805	- -
	Te128	31.7	868	- -
➡	Te130	33.8	2529	- -
	Zn64	48.6	1096	+/ EC
➡	Cd106	1.21	2771	+ +
	Cd108	0.9	231	EC/EC
	Te120	0.1	1722	+/ EC

CUORE sensitivity

CUORE bkg goal: **0.001 ÷ 0.01 c/keV/kg/y**

$b=0.01$ c/keV/kg/y

$\Gamma=5$ keV

$F^{0\nu}=9.25\times10^{25}\sqrt{t}$ y

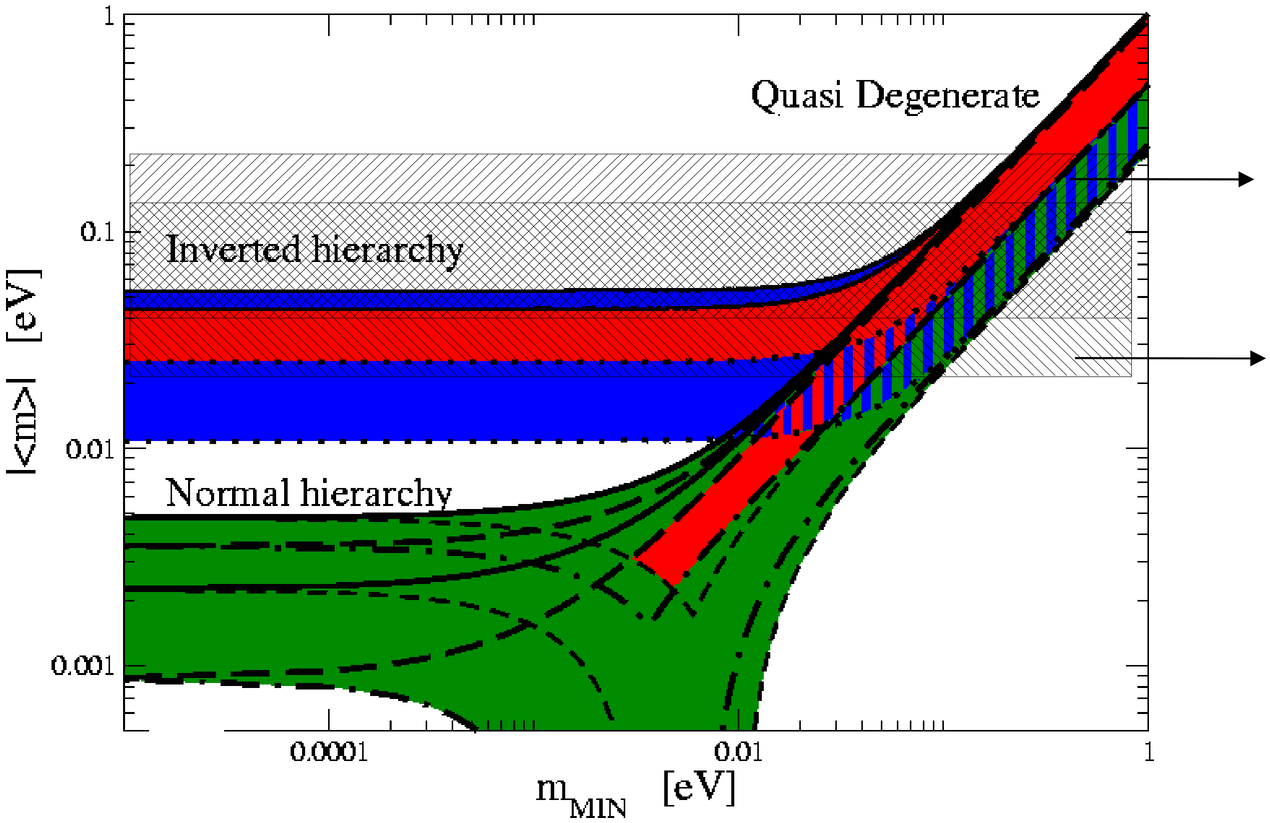
$\langle m_\nu\rangle=29\div150\ t^{-1/4}$ meV

$b=0.001$ c/keV/kg/y

$\Gamma=5$ keV

$F^{0\nu}=2.9\times10^{26}\sqrt{t}$ y

$\langle m_\nu\rangle=16\div85\ t^{-1/4}$ meV



R&D: background reduction

Cryostat ^{232}Th bulk contaminations contribution:

=> negligible by means of low radioactivity selected materials + optimized shields

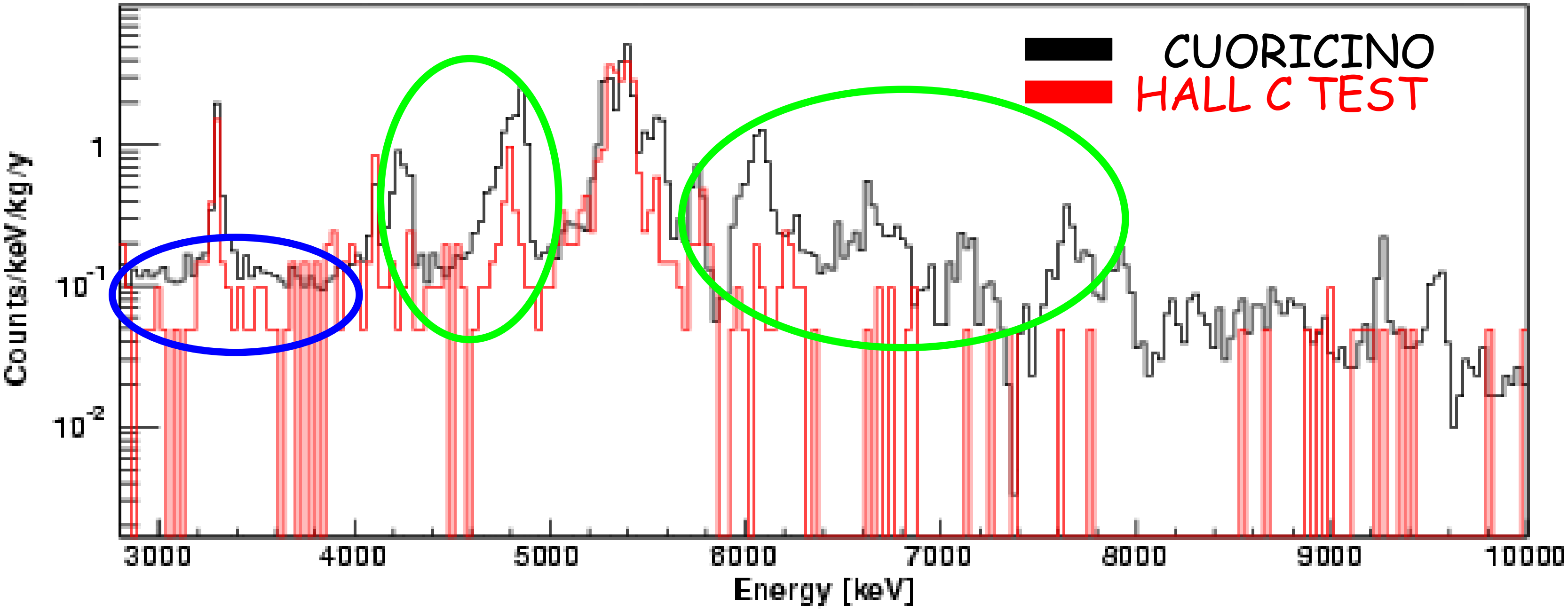
Surface contribution:

- Test with new crystal surface cleaning

  => reduction of a factor ~4 of crystal surface contamination contribution

- Test with almost complete coverage of Cu facing the crystals with 12 μm PET film

  => r



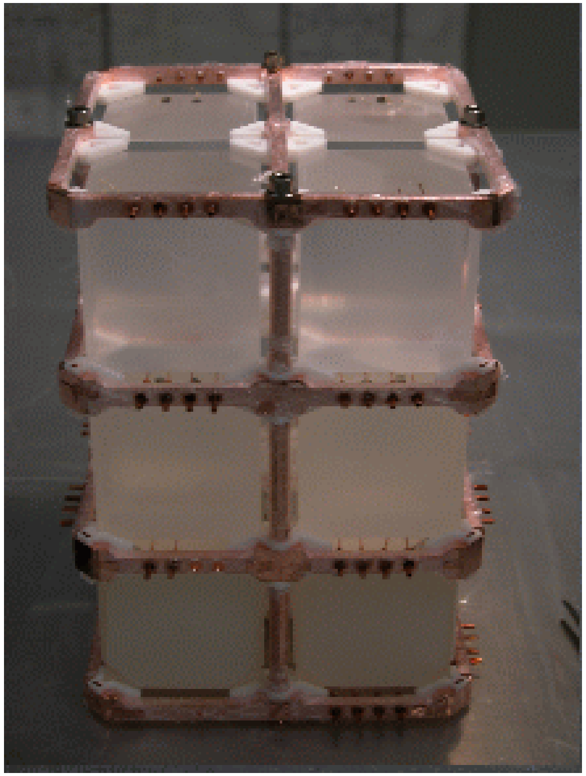
R&D: background reduction

The extrapolated contributions to CUORE bkg are:

Crystal surface contamination: < 3×10^{-3} c/keV/kg/y

Copper surface contamination: < 5×10^{-2} c/keV/kg/y

NEW structure with reduced Cu amount is being tested right now



Expected further reduction of the Cu surface contribution: < 2.5×10^{-2} c/keV/kg/y