Status of Cuoricino
Prospects for CUORE

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Frontiers in Contemporary Physics III

Vanderbilt University

May 23 - 28, 2005

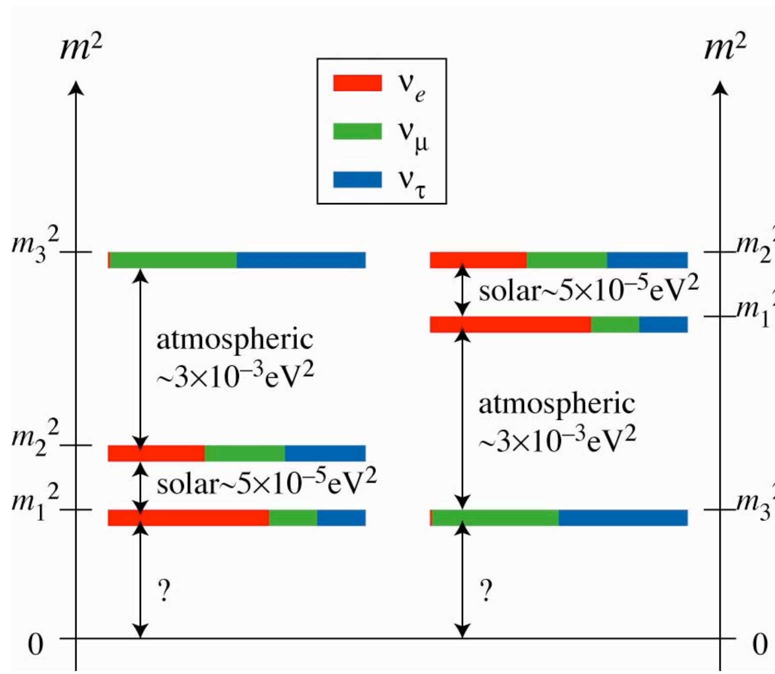
Recent Developments in Neutrino Physics

Since 1998, SuperKamiokande, SNO, and KamLAND have shown:

- Neutrinos undergo flavor-changing oscillations
- Neutrinos have finite masses

Open Questions in ν Physics:

- How many neutrinos?
- What is absolute scale of ν mass ?
- Are ν's Majorana or Dirac particles?



At least one ν has m > 55 meV

Decay Modes for Double Beta Decay

$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\nu_e$ ← allowed by the Standard Model $\tau \geq 10^{19}$ y

$(A,Z) \rightarrow (A,Z+2) + 2e^-$ ← open discussion on its observation $\tau \geq 10^{25}$ y

$(A,Z) \rightarrow (A,Z+2) + 2e^- + \chi$ ← Majoron (light neutral boson)

Observation of $\beta\beta0\nu$

$\Rightarrow$ ν's are Majorana particles

$\Rightarrow$ Violation of lepton number

$\Rightarrow$ another evidence for physics beyond the Standard Model

$\beta\beta 0\nu$ Rate and Neutrino Mass (If Majorana)

0ν-DBD rate

Phase space $\propto Q^5$

Nuclear matrix elements

Effective neutrino mass

$$1/\tau = G(Q,Z)\,|M_{nucl}|^2 \langle m_{\beta\beta}\rangle^2$$

high Q candidates preferred

large phase space

low background

^{238}U γ end at 2.4 MeV

^{232}Th γ end at 2.6 MeV

interesting range $\Rightarrow$ [2039 keV (^{76}Ge) - 4271 keV (^{48}Ca)]

several candidates

Choice of Isotope

$\beta\beta0\nu$ half life in [10^{26} y] for m_{ee} = 50 meV

Calculations

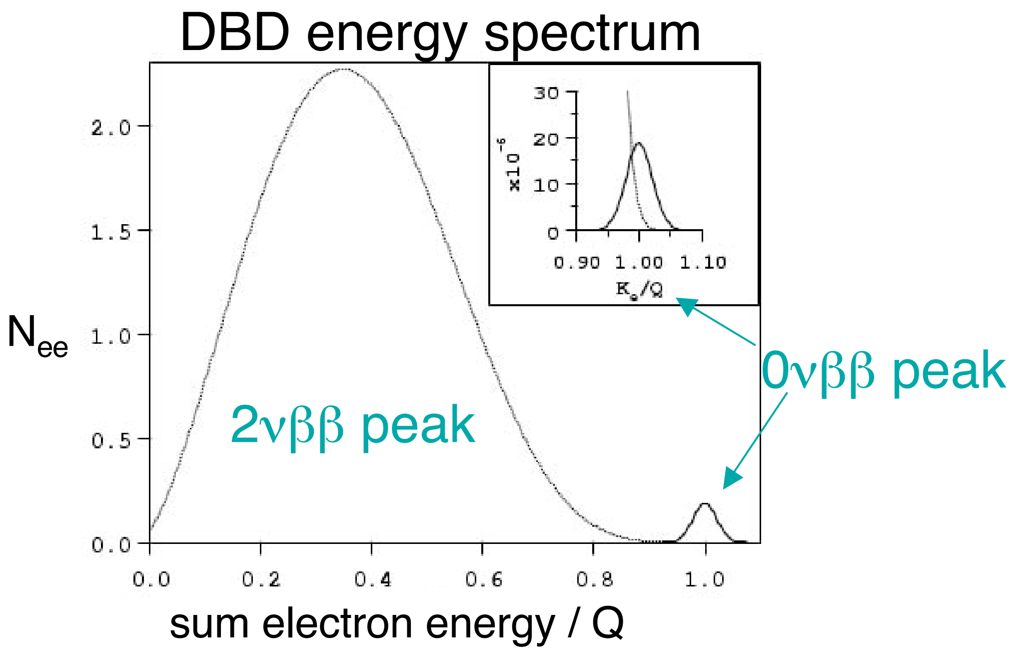
^{48}Ca	12.7	35.3	-	-	-	10.0
^{76}Ge	6.8	70.8	56.0	9.3	12.8	14.4
^{82}Se	2.3	9.6	22.4	2.4	3.2	6.0
^{100}Mo	-	-	4.0	5.1	1.2	15.6
^{116}Cd	-	-	-	1.9	3.1	18.8
^{130}Te	0.6	23.2	2.8	2.0	3.6	3.4
^{136}Xe	-	48.4	13.2	8.8	21.2	7.2
^{150}Nd$^{a)}$	-	-	-	0.1	0.2	-
^{160}Gd$^{a)}$	-	-	-	3.4	-	-

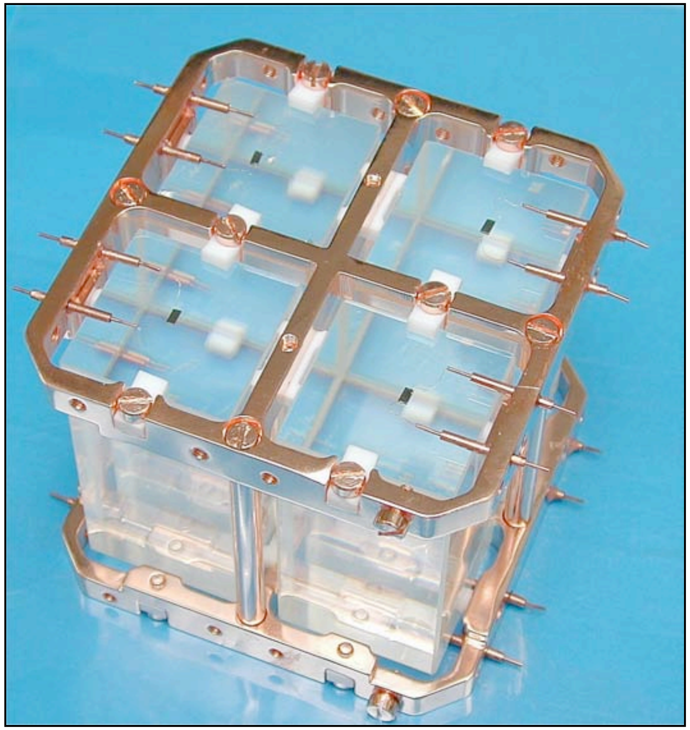
Elliot & Vogel Ann. Rev. (2002)

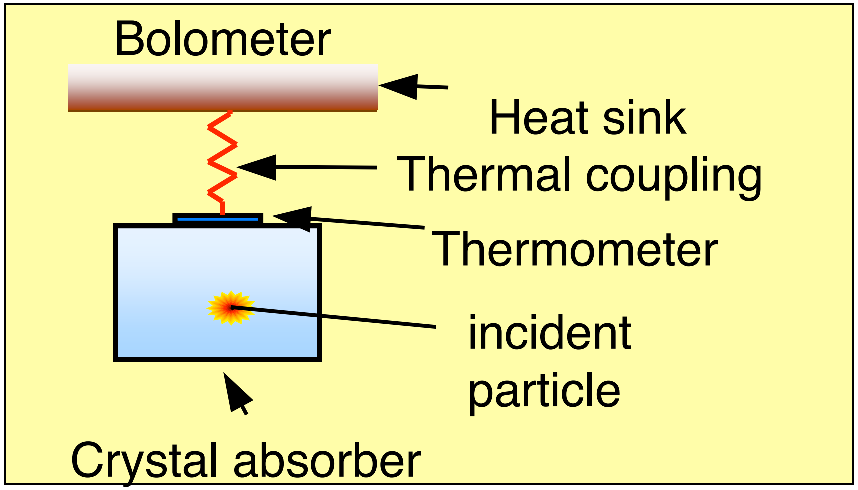
^{130}Te

- Isotopic abundance: 33.8%
- Q = 2528.8 ± 1.3 keV
  - outside the ^{238}U background
  - between ^{232}Th compton edge (2360 keV) and full energy 2615 keV γ
- Extensive R&D with TeO_2 bolometers

How to Search for 0ν DBD?



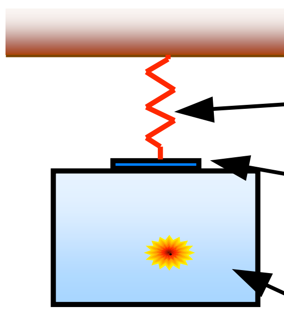




Signal: $\Delta T = E/C$
Time constant $= C/G$

Low heat capacity
Low temperatures
Dielectric diamagnetic materials

Cryogenic Bolometer



Heat sink: 8 mK

Weak thermal coupling: G = 4 pW/mK

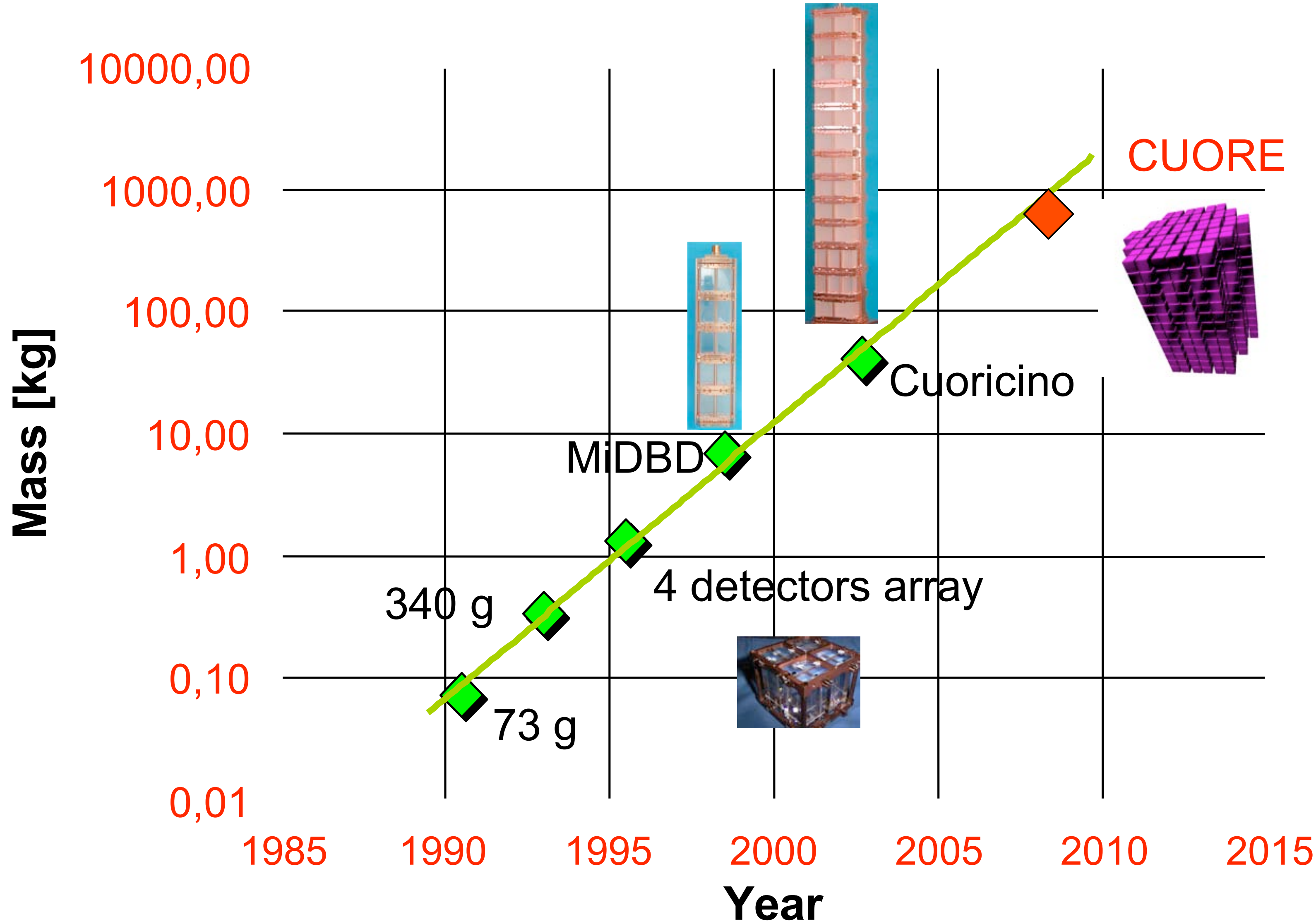
Thermister: NTD Ge-thermistor
$R \cong 100$ MΩ, $dR/dT \cong 100$ kΩ/μK

Crystal absorber: TeO_2 crystal
$C \cong 2$ nJ/K $\cong$ 1 MeV / 0.1 mK

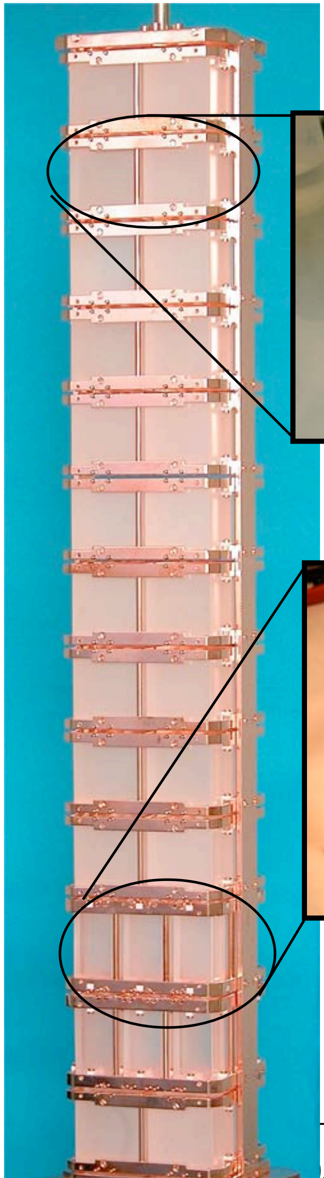
Temperature signal for E=1MeV:	**$\Delta T = E/C \cong 0.1$ mK**
Signal size: $\Delta V = I \times dR/dT \times \Delta T$	**1 mV/1 MeV**
Signal recovery time: $\tau = C/G$	**0.5 s**
Noise over signal bandwidth (few Hz):	**$V_{rms} = 0.2\ \mu V$**

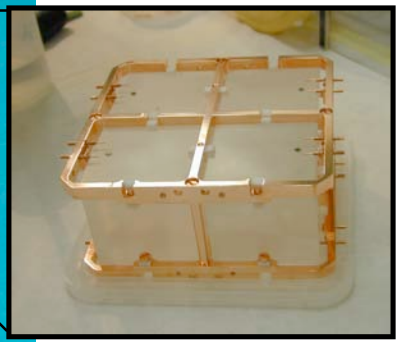
Energy resolution (FWHM): $\cong$ 1 keV

TeO_2 Experiments

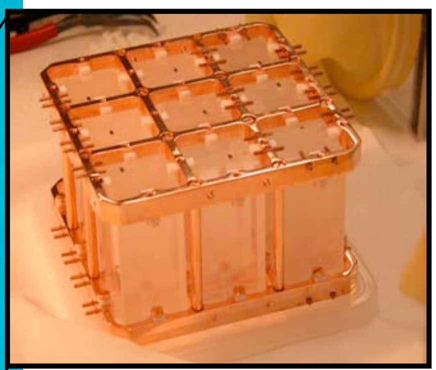


Cuoricino



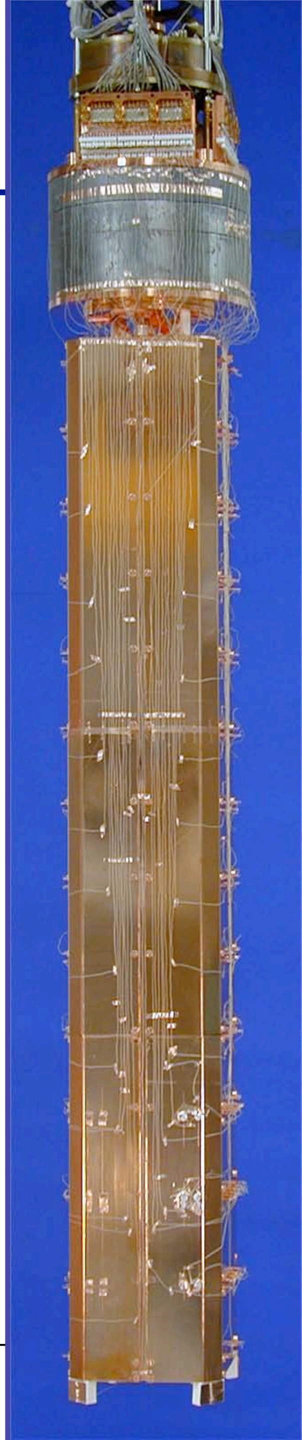


11 modules, 4 detector each,
crystal dimension: 5x5x5 cm^3
crystal mass: 750 g
44 x 0.79 = **34.76 kg of TeO_2**



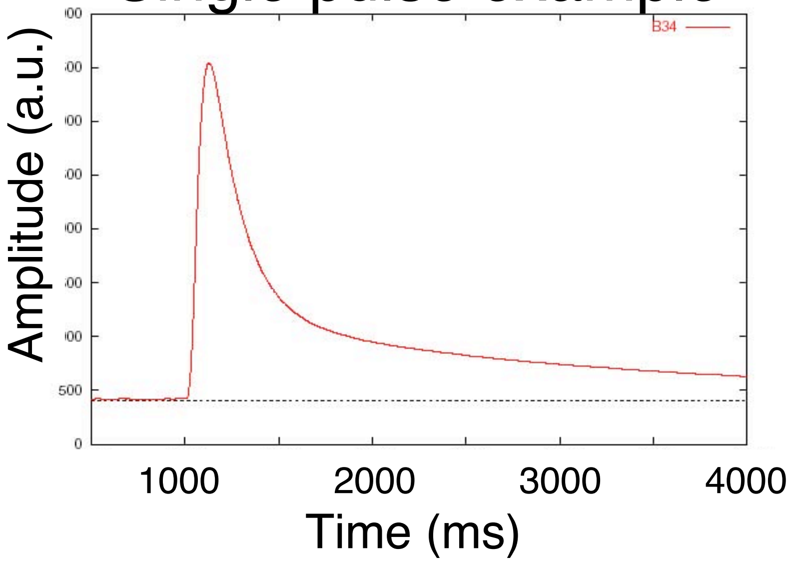
2 modules x 9 crystals each
crystal dimension: 3x3x6 cm^3
crystal mass: 330 g
9 x 2 x 0.33 = **5.94 kg of TeO_2**

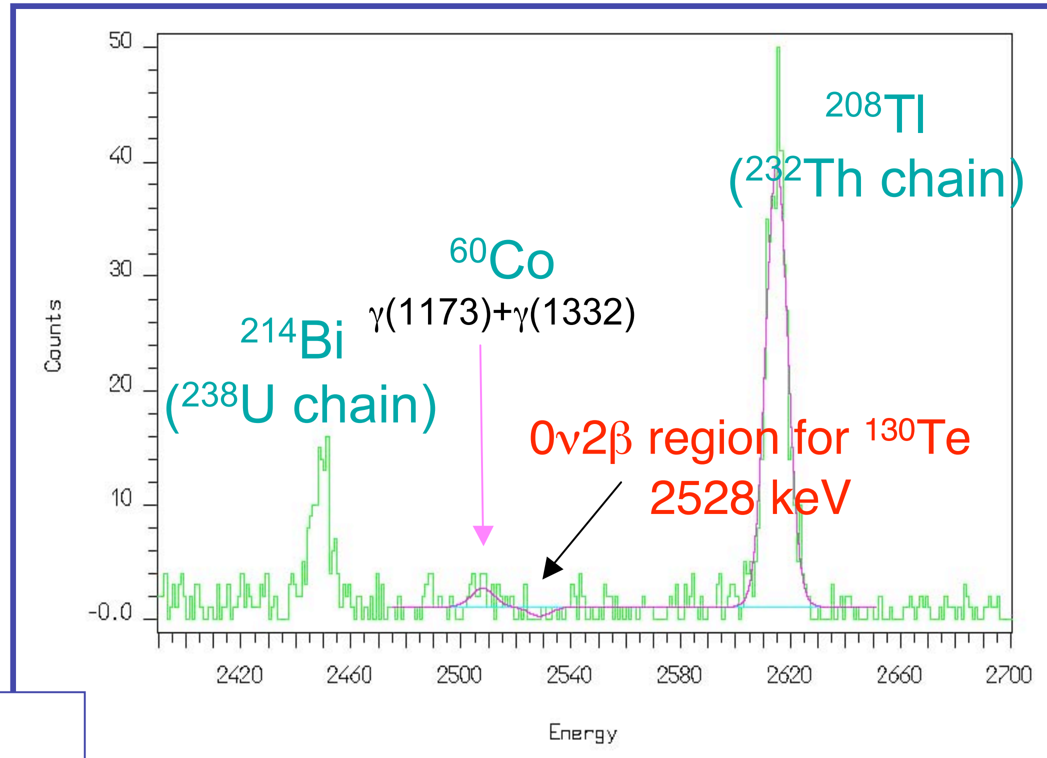
Total detector mass: 40.7 kg ⇒ **11.64 kg ^{130}Te**



Cuoricino Results

Single pulse example





Total Exposure: **10.85 kg-y**
BKG: **0.18 ± 0.01 cnts/(keV-kg-y)**
FWHM at 2615 keV: **9.2 ± 0.5 keV**

arXiv:hep-ex:0501034

$T_{1/2}^{0\nu}$ (^{130}Te) > 1.8×10^{24} y (90% C.L.)
$m_{ee} < 0.2 - 1.1$ eV

Cuoricino Sensitivity

Detector mass

Isotopic abundance

Running time

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

Background

Energy resolution

3 years of Cuoricino

$F^{0\nu} = 1 \times 10^{25}$ y $\quad\langle m_{ee}\rangle \approx 0.16 - 0.38$ eV

Klapdor et al., Phys. Lett B 586 (2004) 198

Klapdor Result:

$T = (0.67 - 4.45) \times 10^{25}$ years (99.73% C.L.)

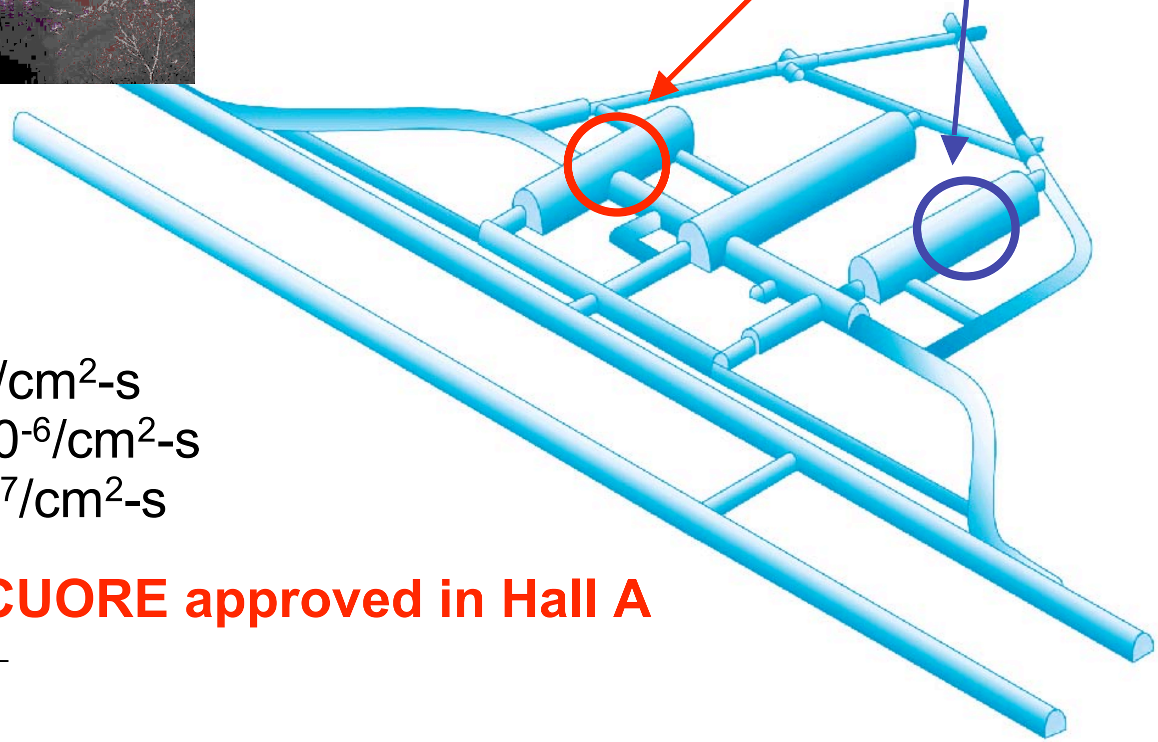
$m_\nu = (0.1 - 0.9)$ eV 99.73% C.L.

$m_{\nu\text{ best}} = 0.45$ eV

Cuoricino can see 3σ effect if nuclear matrix elements are favorable.
No signal does not disprove Klapdor.

Gran Sasso National Underground Laboratory

Two dilution refrigerators:
Hall A (CUORICINO)
Hall C (R&D final tests for CUORE)



Shielding: 3500 m.w.e.
Muons: ~2 x 10^{-8}/cm^2-s
Thermal neutrons: ~1 x 10^{-6}/cm^2-s
Epithermal neutrons: ~2 x 10^{-6}/cm^2-s
> 2.5 MeV Neutrons: 2 x 10^{-7}/cm^2-s

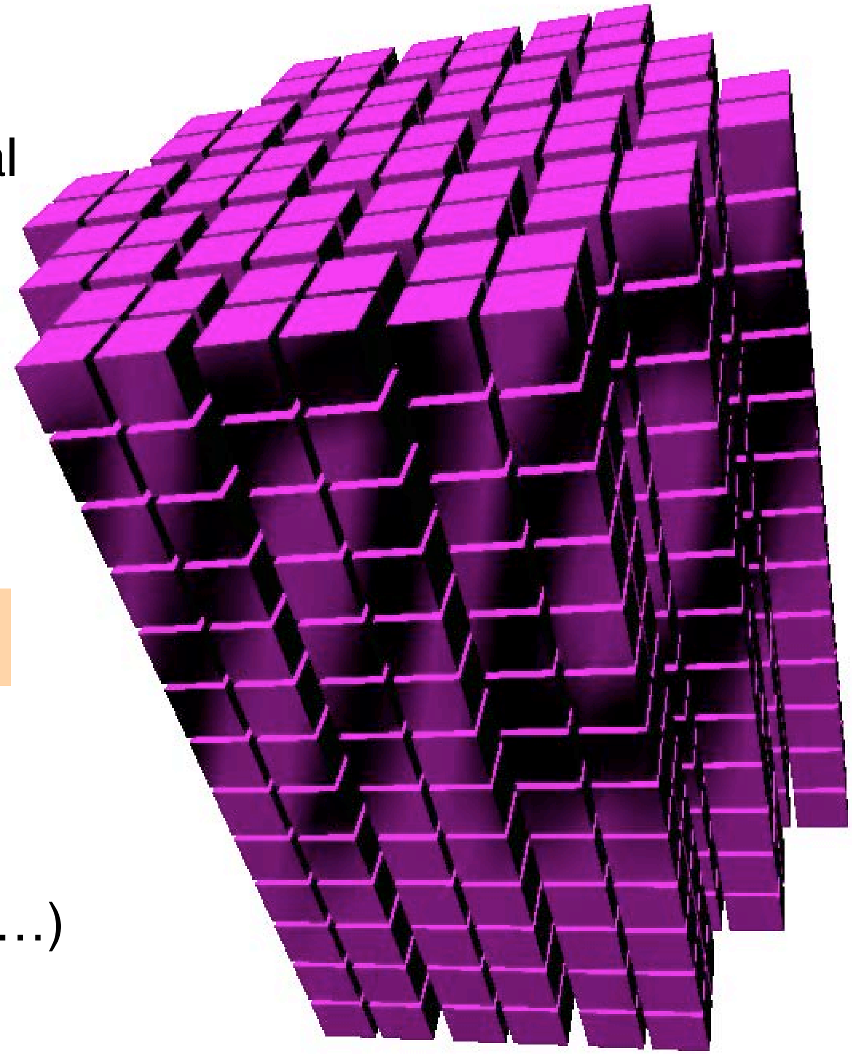
Site for CUORE approved in Hall A

The CUORE Project

Array of 988 TeO_2 crystals

- **19** towers suspended in a cylindrical structure
- **13** levels, **4** crystals each
- 5x5x5 cm^3 (750g each)
- ^{130}Te: 33.8% isotope abundance

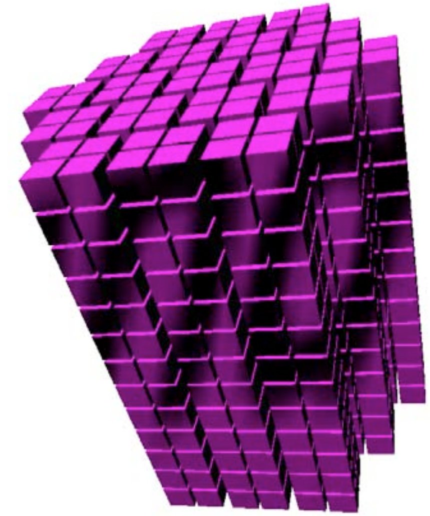
750 kg TeO_2 => **200 kg ^{130}Te**



- Time of construction: 4 yrs
- Total cost: $14M (depends on Euro…)

(approved by the Science Counsel of Gran Sasso Laboratory and by INFN)

CUORE Sensitivity



5 year sensitivity

Presently achievable

b.g. = 0.01 cnts/keV/kg/y

Γ = 5 keV

$F^{0\nu}$ = 2.1 x10^{26} y

m_{ee} < 20 – 103 meV

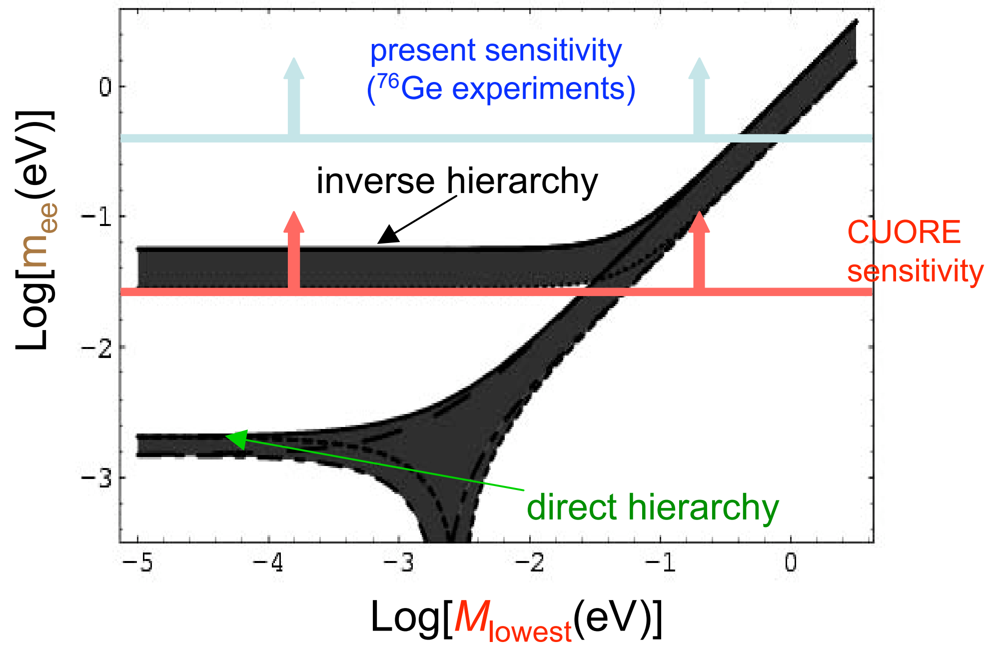
Further BG Reduction

b.g. = 0.001 cnts/keV/kg/y

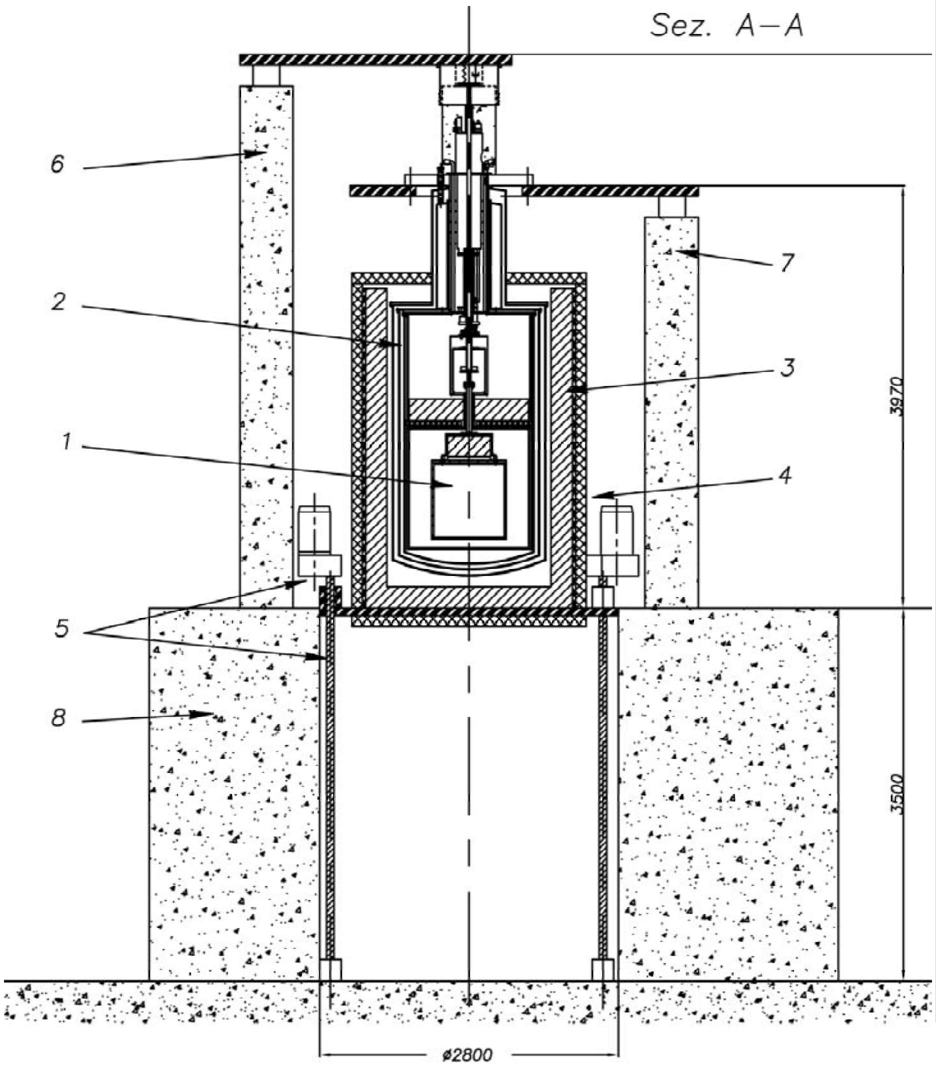
Γ = 5 keV

$F^{0\nu}$ = 6.5 × 10^{26} y

m_{ee} < 10 – 55 meV



CUORE Structure



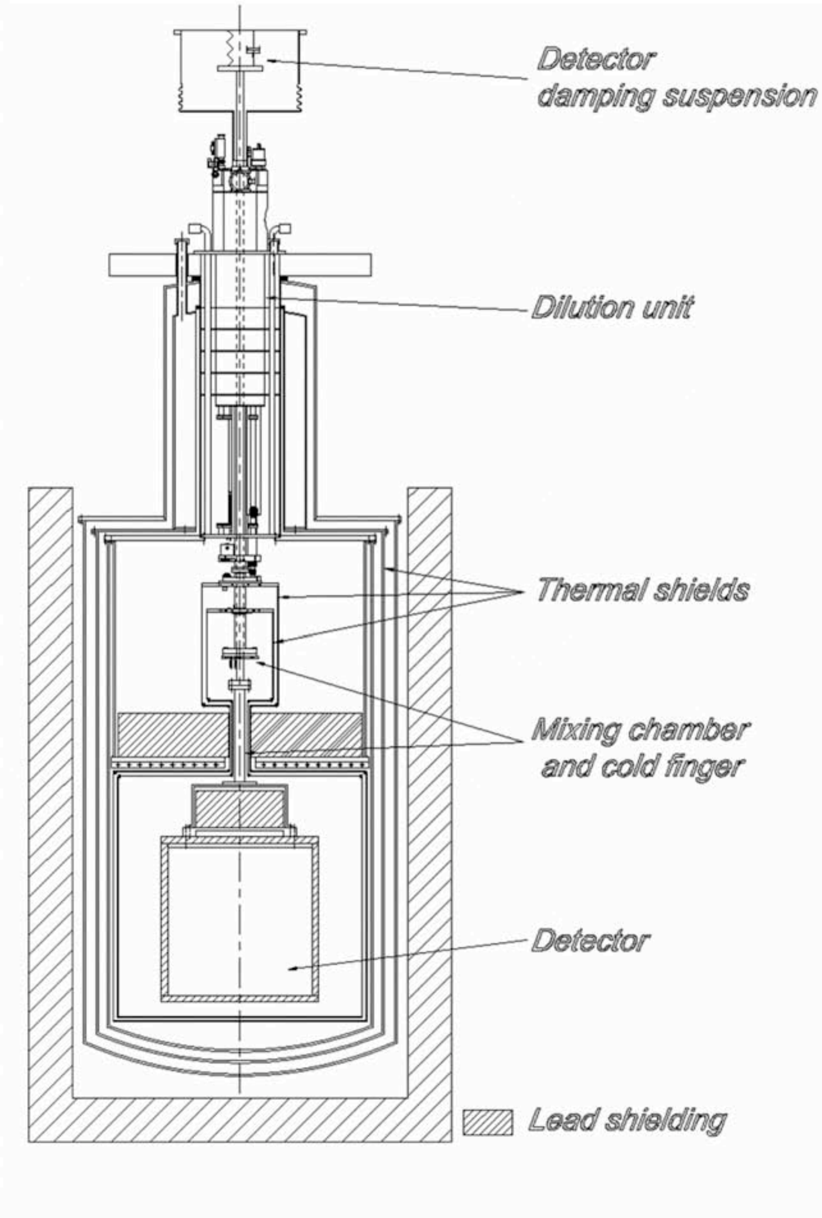
Powerful dilution refrigerator
- Operation at 7 - 10 mK
- similar to Nautilus Collaboration (2-ton gravitational antenna)
- 10 μW

Heat sources (total ~1μW):
- residual helium gas in the inner vacuum chamber (IVC)
- power radiated from the 50 mK shield facing the detector
- vibrational energy (microphonic noise)

Mechanical isolation

Access to crystals

Shielding



Roman Lead

- 3 cm immediately around detector with ^{210}Pb < 4mBq/kg

Low activity lead

- 16 Bq/kg of ^{210}Pb for the inner layer
- 150 Bq/kg for the outer layer

Borated polyethylene box

- neutrons eliminated
- hermetically sealed & dry nitrogen flushing to exclude radon

Faraday cage

- Important for near-threshold events
- 5keV - 10 keV for dark matter and solar axion searches

Background Sources in CUORE

Upper limit of bulk contamination in [p-gram/gram] (90% C.L.)

Contaminant	^{232}Th	^{238}U	^{40}K	^{210}Pb	^{60}Co
TeO_2	0.7	0.1	1.0	100 μBq/kg	0.2 μBq/kg
Copper	5.2	2	1	-	10 μBq/kg
Roman lead	50	30	2	4 mBq/kg	-
16 Bq/kg Pb	3.4	2.7	1.7	23 Bq/kg	18 μBq/kg

bolometric

Ge

Cosmogenic contribution

- Activation leading to ^{121}Te, ^{123}Te, ^{125}Te, ^{127}Te not a problem => short halflife
- Activation leading to ^{124}Sb, ^{125}Sb, ^{60}Co a problem => long halflife
- Calculated with the COSMO program, tested with irradiation at Berkeley of Te, Mo, Ge with 800 MeV protons.
- Only problem with ^{60}Co. 4 months of exposure => 0.2 μBq/kg

Background in CUORE

Monte Carlo simulation using background levels measured or from CUORICINO background analysis

- Bulk contamination of Cu and $TeO_2 \Rightarrow$ < 0.004 counts / keV kg y
- Surface contamination in Cuoricino $\Rightarrow$ 0.04 counts / keV kg y (factor of 2 reduction by minimizing Cu area)
- Unavoidable $\beta\beta(2\nu) \Rightarrow 10^{-4}$ counts / keV kg y

A reduction by a factor 10 in Cu surface contamination and by a factor 4 in TeO_2 surface contamination is mandatory for the success of CUORE

Copper cleaning procedure by chemical etching and surface passivation under development
Surface sensitive bolometer also promising
Muon tag and veto under consideration

CUORE for Multi-Isotope Search

In case of discovery or hints for discovery, cross checks are mandatory

- remove doubts about unexplained lines of other origin
- test nuclear models
- reduce systematic uncertainty on the relevant parameters, like m_{ee}

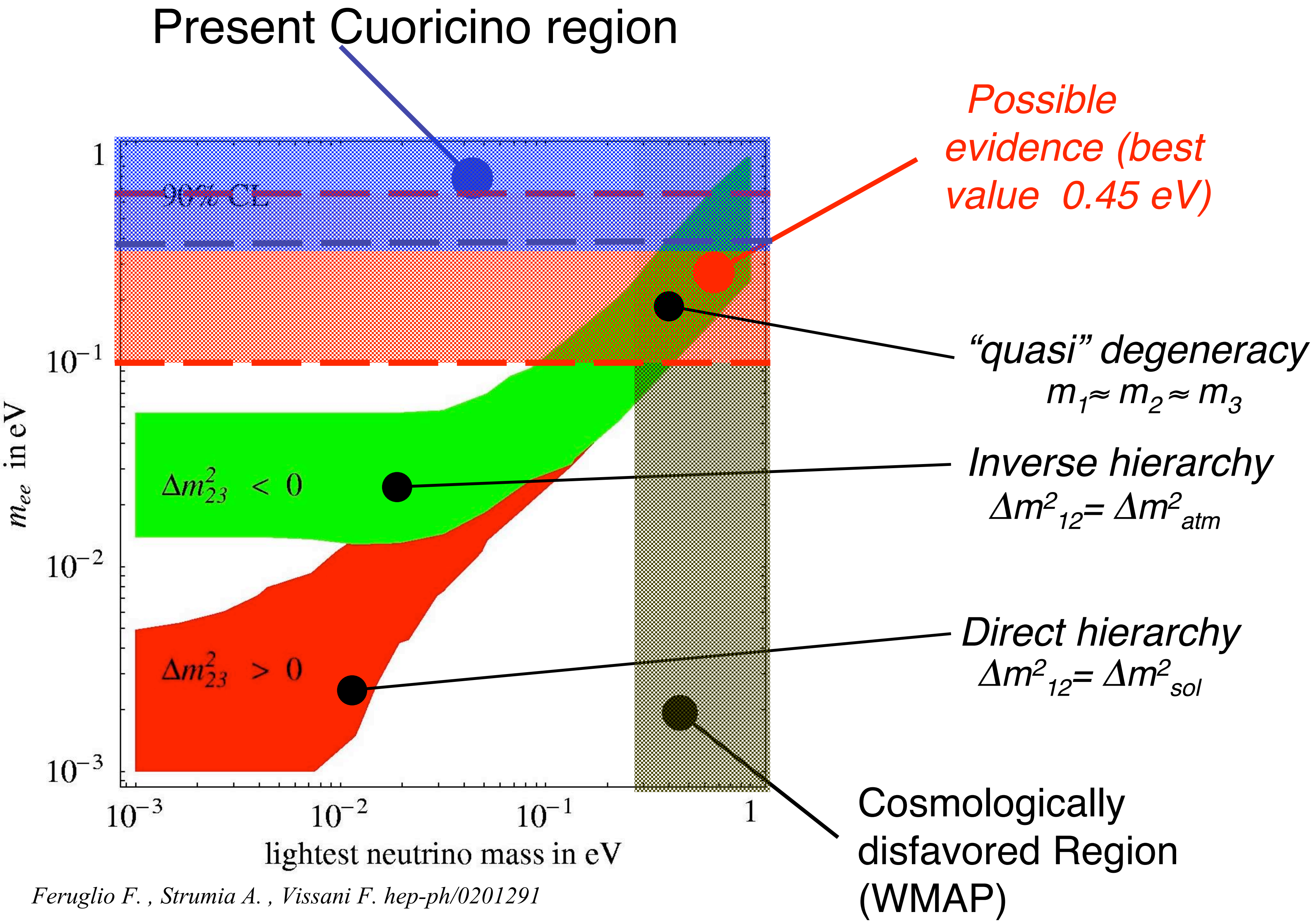
Modular design → may insert other isotopes

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

Already tested bolometrically
As good as TeO_2
CaF_2, Ge, $PbMoO_4$, $CdWO_4$

Tests are in progress

???



Feruglio F. , Strumia A. , Vissani F. hep-ph/0201291

The CUORE Collaboration

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Universita' di Firenze e Sezione di Firenze dell' INFN
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Laboratori Nazionali di Legnaro
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Politecnico di Milano
Universita' di Genova e Sezione di Genova dell' INFN
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