Neutrinoless Double Beta Decay search with CUORICINO and CUORE experiments

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Outline

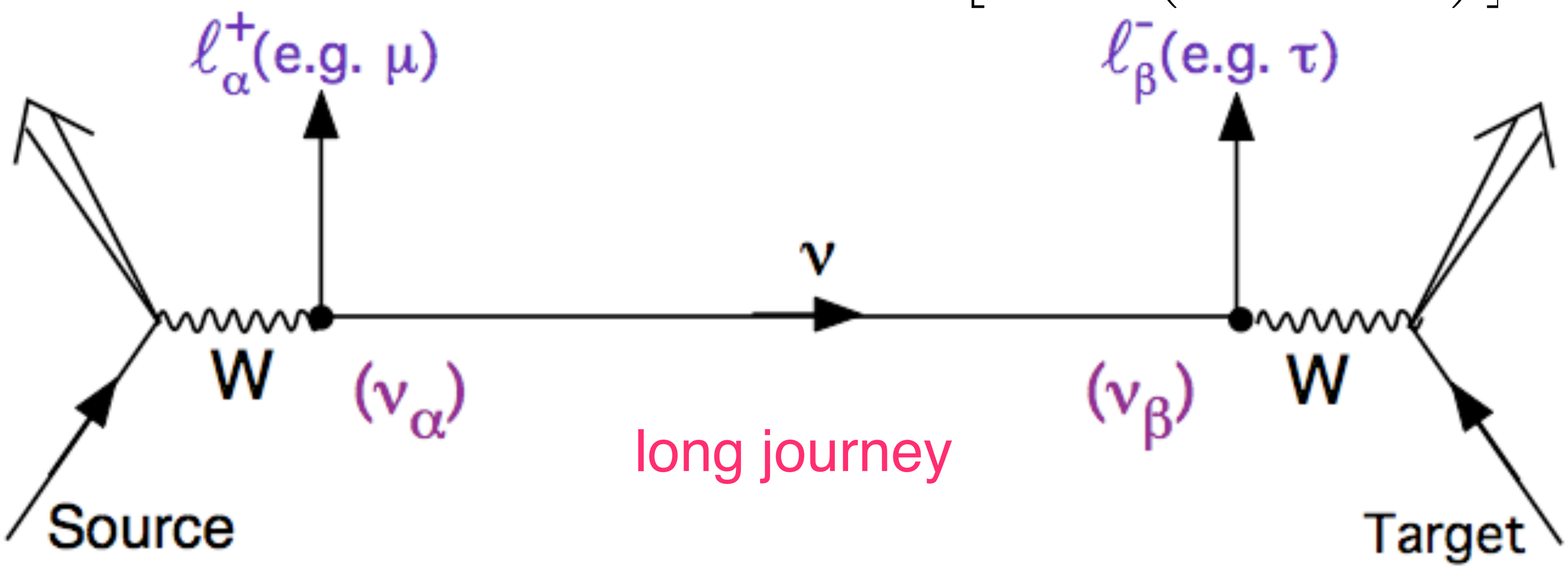
- Neutrino physics status:
  - oscillation experiments
  - the problem of neutrino mass and nature.
- Neutrinoless double beta decay (0νDBD), a golden probe to measure neutrino mass and nature.
- Tellurium dioxide bolometers for 0νDBD search.
- CUORICINO, an array of TeO_2 bolometers: the most sensitive 0vDBD experiment presently running.
- CUORE: the CUORICINO successor.

Neutrinos today

- Neutrinos have mass: $m_\nu \neq 0$
- They mix: $\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$

$$U = \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\phi} \\ 0 & 1 & 0 \\ -s_{13}e^{i\phi} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{i\alpha} & 0 \\ 0 & 0 & e^{i\beta} \end{pmatrix}$$

- They oscillate: $P(\nu_\alpha \to \nu_\beta) \simeq \sin^2 2\theta \, \sin^2 \left[\frac{\Delta m^2 L}{E} \left(1.27 \, \frac{\mathrm{eV}^2 \, \mathrm{Km}}{\mathrm{GeV}} \right) \right]$

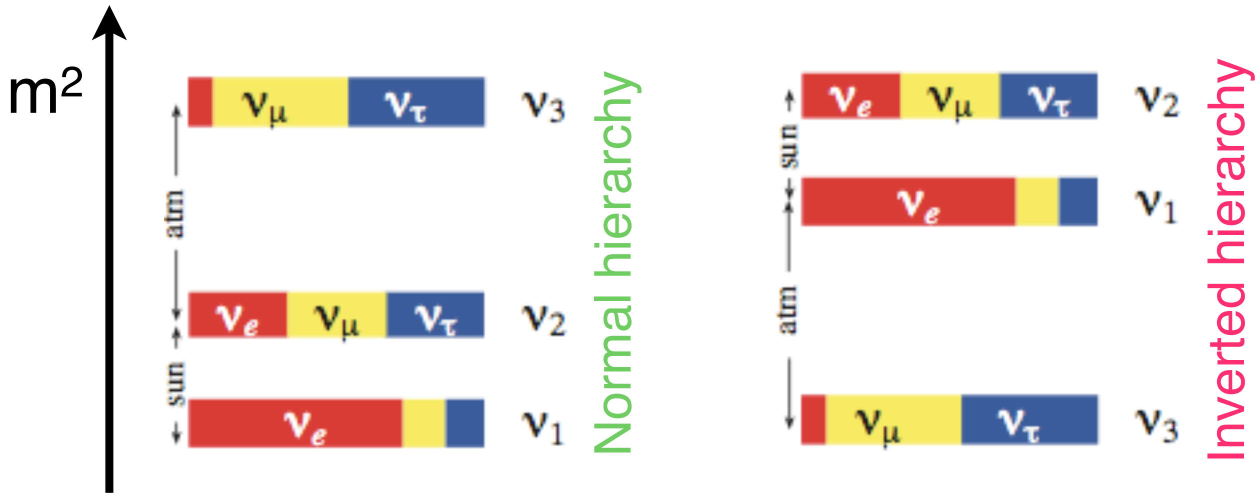


Oscillation Results

- Almost all oscillation parameters have been measured:

Oscillation Parameter			Value
solar mass splitting	Δm^2_{21}	$=$	$(7.59 \pm 0.21) \times 10^{-5}\,\mathrm{eV}^2$
atmospheric mass splitting	$\lvert\Delta m^2_{23}\rvert$	$=$	$2.38^{+0.20}_{-0.16} \times 10^{-3}\,\mathrm{eV}^2$
solar mixing angle	$\tan^2\theta_{12}$	$=$	$0.47^{+0.06}_{-0.05}$
atmospheric mixing angle	$\sin^2 2\theta_{23}$	$=$	$1.00_{-0.08}$
'CHOOZ' mixing angle	θ_{13}	$<$	10°

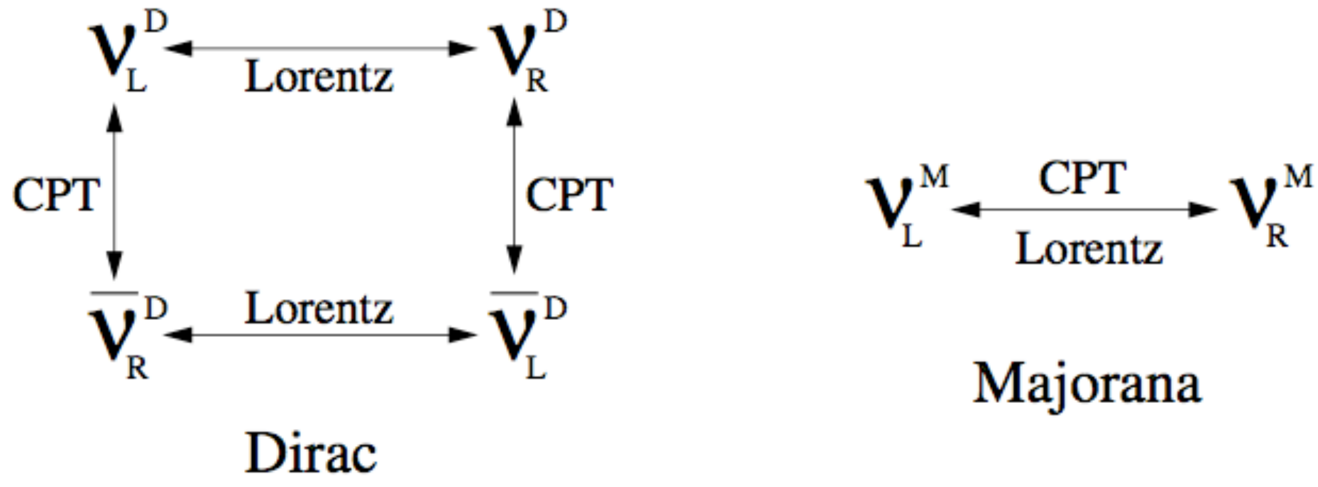
- However the sign of Δm^2_{23} is still unknown allowing two possible mass configurations:



- Moreover which is the absolute mass scale?

Neutrino nature

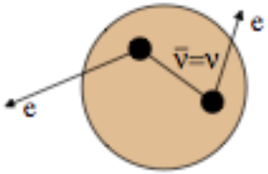
- If we discard leptonic number neutrino is a neutral fermion
- So if leptonic number is not conserved neutrinos can be Majorana particles:
    - Particle and antiparticle differs only by chirality.

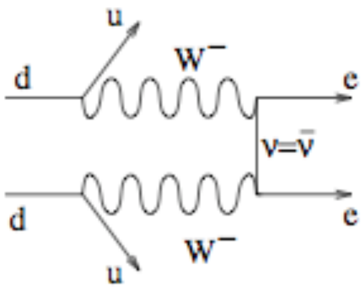


- It is still not clear today whether neutrinos are Dirac or Majorana particles.

0νDBD in Theory

- Nuclear process: (A,Z) → (A,Z+2) + 2 e^-
- Can only happen if lepton number is not conserved.
- The decay amplitude depends on the effective Majorana mass $m_{\beta\beta}$:





$$m_{\beta\beta} = \cos^2\theta_{13}(m_1\cos^2\theta_{12} + m_2 e^{2i\alpha}\sin^2\theta_{12}) + m_3 e^{2i\beta}\sin^2\theta_{13}$$

- The measurable quantity is the half-life ($\tau^{0\nu}_{1/2}$):

Phase space factor: ~ Q^5

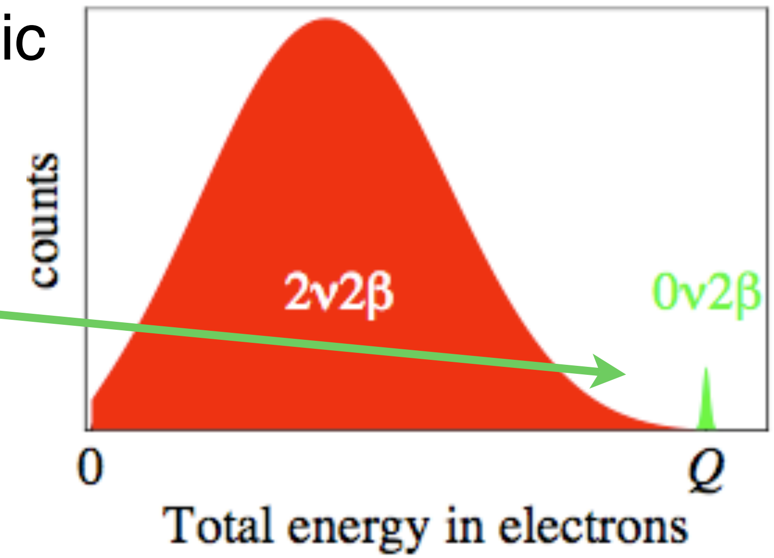
Effective neutrino mass

$$\frac{1}{(\tau^{0\nu}_{1/2})} = G(Q,Z)|M_{nucl}|^2|m_{\beta\beta}|^2 = F_N\frac{|m_{\beta\beta}|^2}{m_e^2}$$

Nuclear Matrix element

0νDBD in Experiments

- Experiments measure the sum of the kinetic energies of the two emitted electrons.
  - Signature: monochromatic line at the Q-value of the decay.
- Sensitivity ($S^{0\nu}$): lifetime corresponding to the minimum number of detectable events above background at a given C.L.:



$$S^{0\nu} = \ln 2 N_A \cdot \frac{a}{A} \left(\frac{Mt}{B \Delta E} \right)^{1/2} \cdot \epsilon$$

Isotopic abundance → a

Detector mass (kg) → M

Measurement time (y) → t

Efficiency → ϵ

Atomic mass → A

Background (counts/KeV/Kg/y) → B

Energy Resolution (KeV) → ΔE

Summary

- Open questions:
  - Normal / Inverted hierarchy
  - Absolute mass scale
  - Dirac / Majorana nature

- If 0νDBD is observed $\rightarrow$ triple discovery:

1) Lepton number is not conserved.
2) Measurement of the absolute neutrino mass.
3) Neutrino is a Majorana particle.

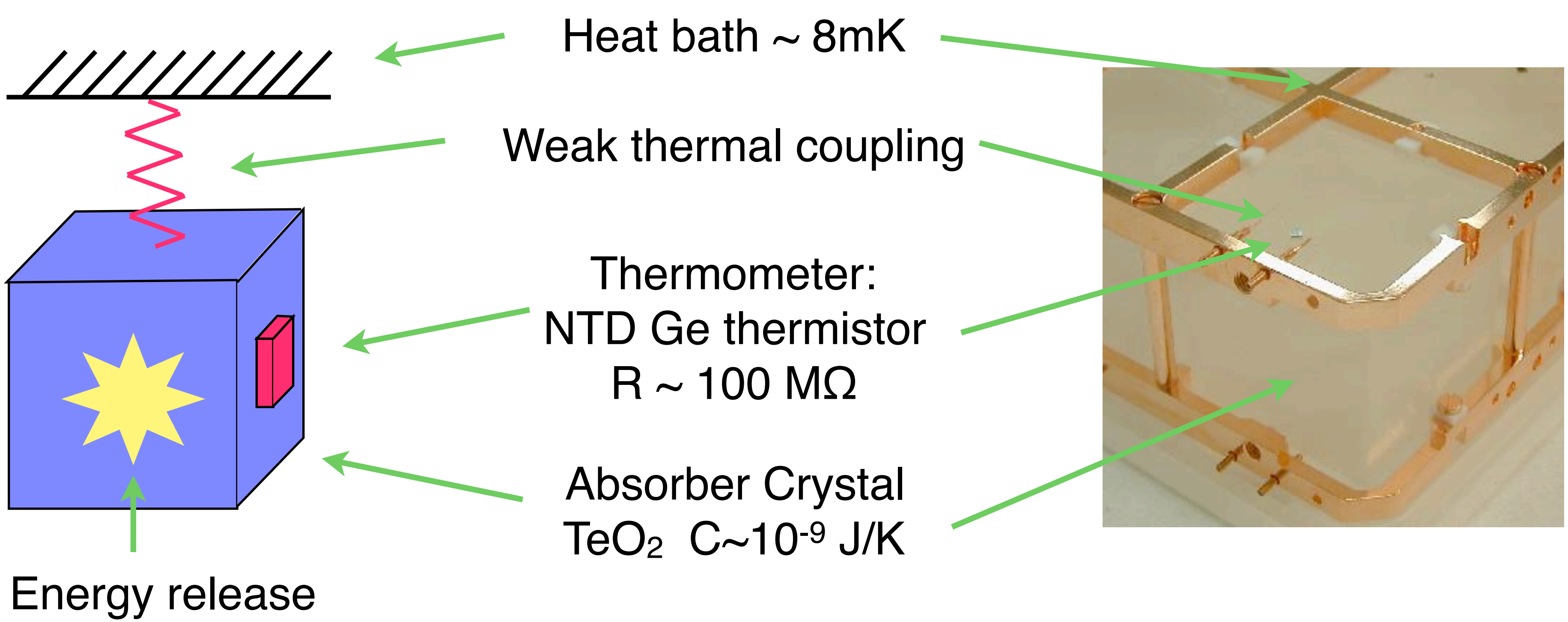
0νDBD with Tellurium

- Active isotope: ^{130}Te, Decay: $^{130}Te \rightarrow {}^{130}Xe + 2e^-$
- Natural abundance: 33.8 % → no need for enrichment
- Q-value ~ 2530 KeV → reasonably high: leads to high phase space and is almost above natural radioactivity background.
- 2β emitters of experimental interest:

Parent Isotope	$F_N(y^{-1})$	$Q_{\beta\beta}$ (KeV)	Ab(%)
^{48}Ca	$(5.4^{+3.0}_{-1.4}) \cdot 10^{-14}$	4271	0.187
^{76}Ge	$(7.3 \pm 0.6) \cdot 10^{-14}$	2039	7.8
^{82}Se	$(1.7^{+0.4}_{-0.3}) \cdot 10^{-13}$	2995	9
^{100}Mo	$(5.0 \pm 0.15) \cdot 10^{-13}$	3034	9.6
^{116}Cd	$(1.3^{+0.7}_{-0.3}) \cdot 10^{-13}$	2902	7.5
^{130}Te	$(4.2 \pm 0.5) \cdot 10^{-13}$	2530	33.9
^{136}Xe	$(2.8 \pm 0.4) \cdot 10^{-14}$	2479	8.9
^{150}Nd	$(5.7^{+1.0}_{-0.7}) \cdot 10^{-12}$	3367	5.6

Bolometric technique

- Particle energy converted into phonons → temperature variation.
- TeO_2 crystals (dielectric, diamagnetic) ⟶ detector = source
- Low crystal heat capacity and low base temperature to see small temperature variations.



- Detector response in this configuration: ~ 0.2 mK / MeV
- Resolution @0νDBD ~ 0.3%

Cuoricino

Hosted @ Laboratori Nazionali del Gran Sasso, Italy.
A natural shield of 1500 m of rock (3500 m.w.e.)

Active mass:

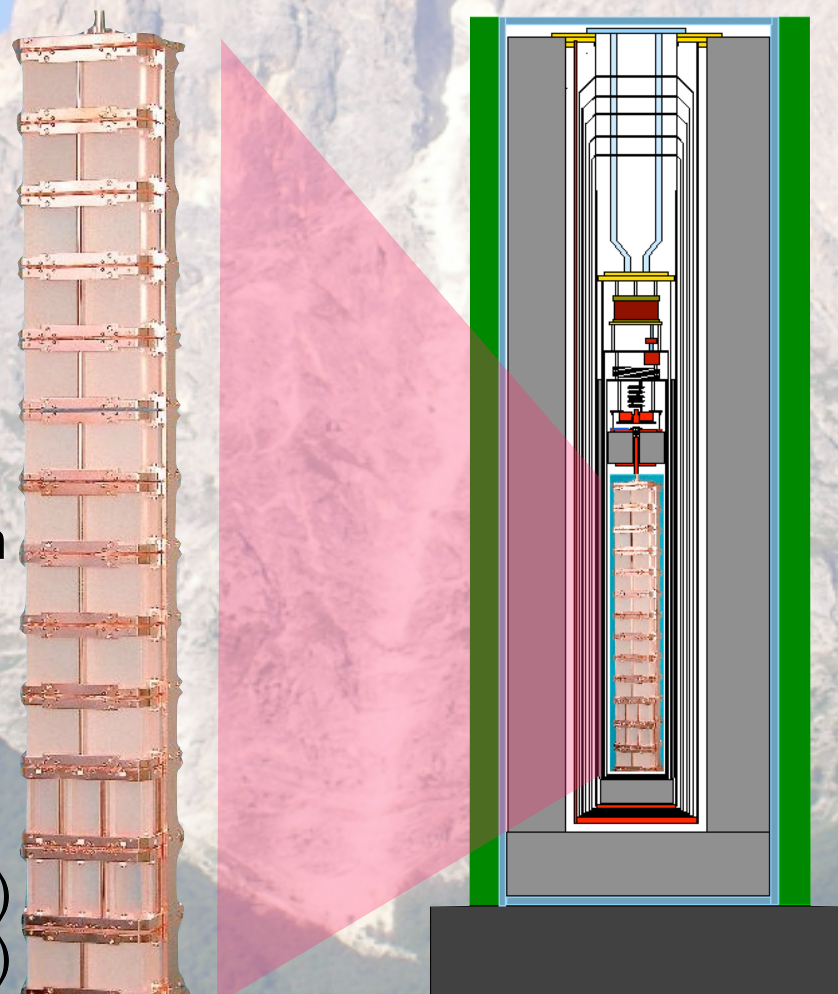
- TeO_2: 40.7 Kg
- ^{130}Te: 11.3 Kg
- ^{128}Te: 10.5 Kg

11 modules:

- 4 detectors of
  $5x5x5\ cm^3$ = 790 g each

2 modules:

- 9 detectors of
  $3x3x6\ cm^3$ = 330 g each
  2 enriched in ^{128}Te (82%)
  2 enriched in ^{130}Te (75%)

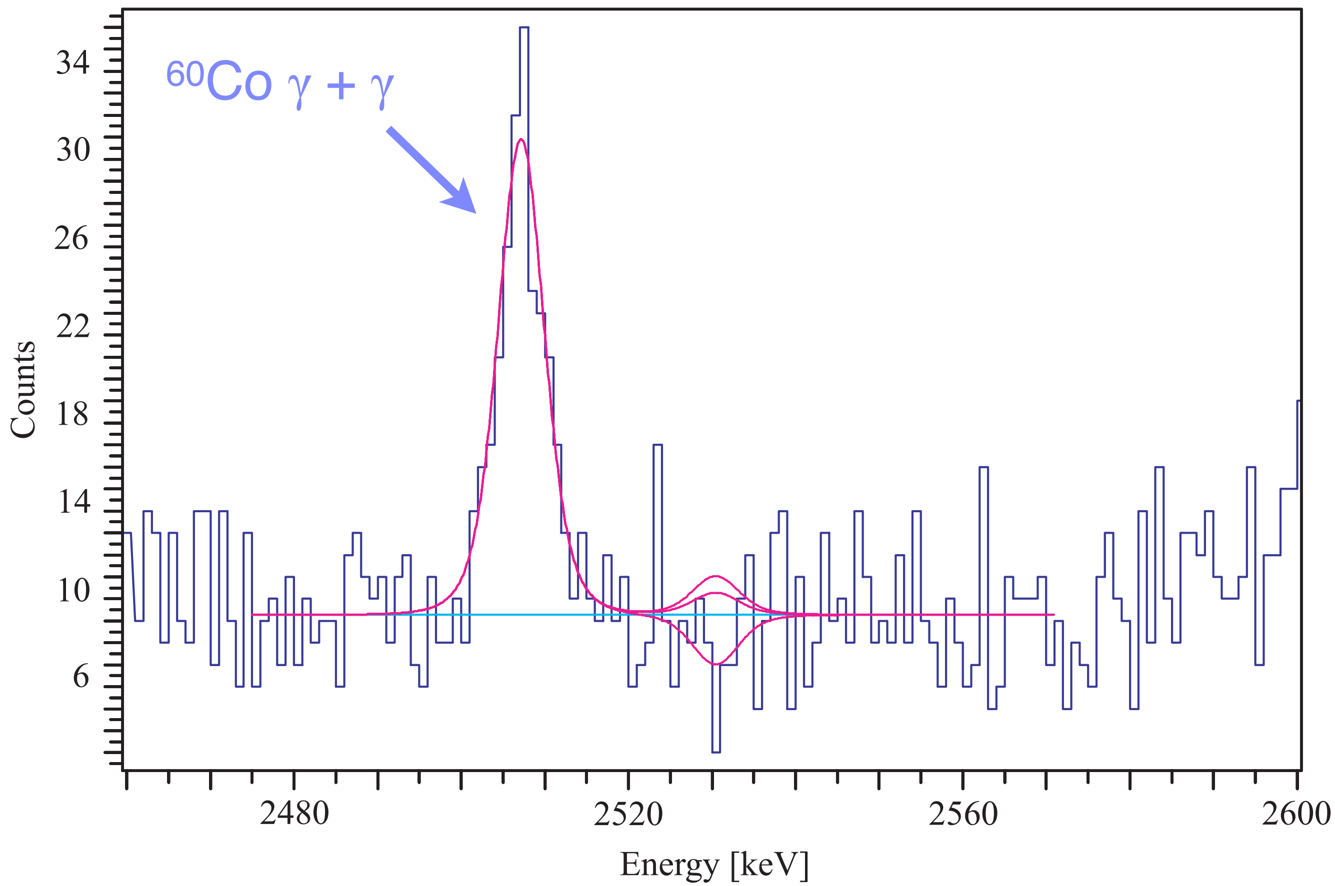


Installed in a dilution refrigerator:

- Inner shield:
  - 1cm Roman Pb
    A (^{210}Pb) < 4 mBq/Kg
- External Shield:
  - 20 cm Pb
  - 10 cm Borated polyethylene
- Nitrogen flushing to avoid Rn contamination.

Cuoricino Results (preliminary)

- Collected Statistics: $M \cdot t = 15.53\ \mathrm{Kg}\ {}^{130}\mathrm{Te} \cdot \mathrm{y}$
- Background level: $b = 0.18 \pm 0.01\ (\mathrm{c/KeV/Kg/y})$
- 0νDBD Half-life limit (90% C.L): $\tau_{1/2}^{0\nu} > 3.1 \cdot 10^{24}\ \mathrm{y}$
- Effective neutrino mass limit: $m_{\beta\beta} < 0.20 \div 0.68\ \mathrm{eV}$



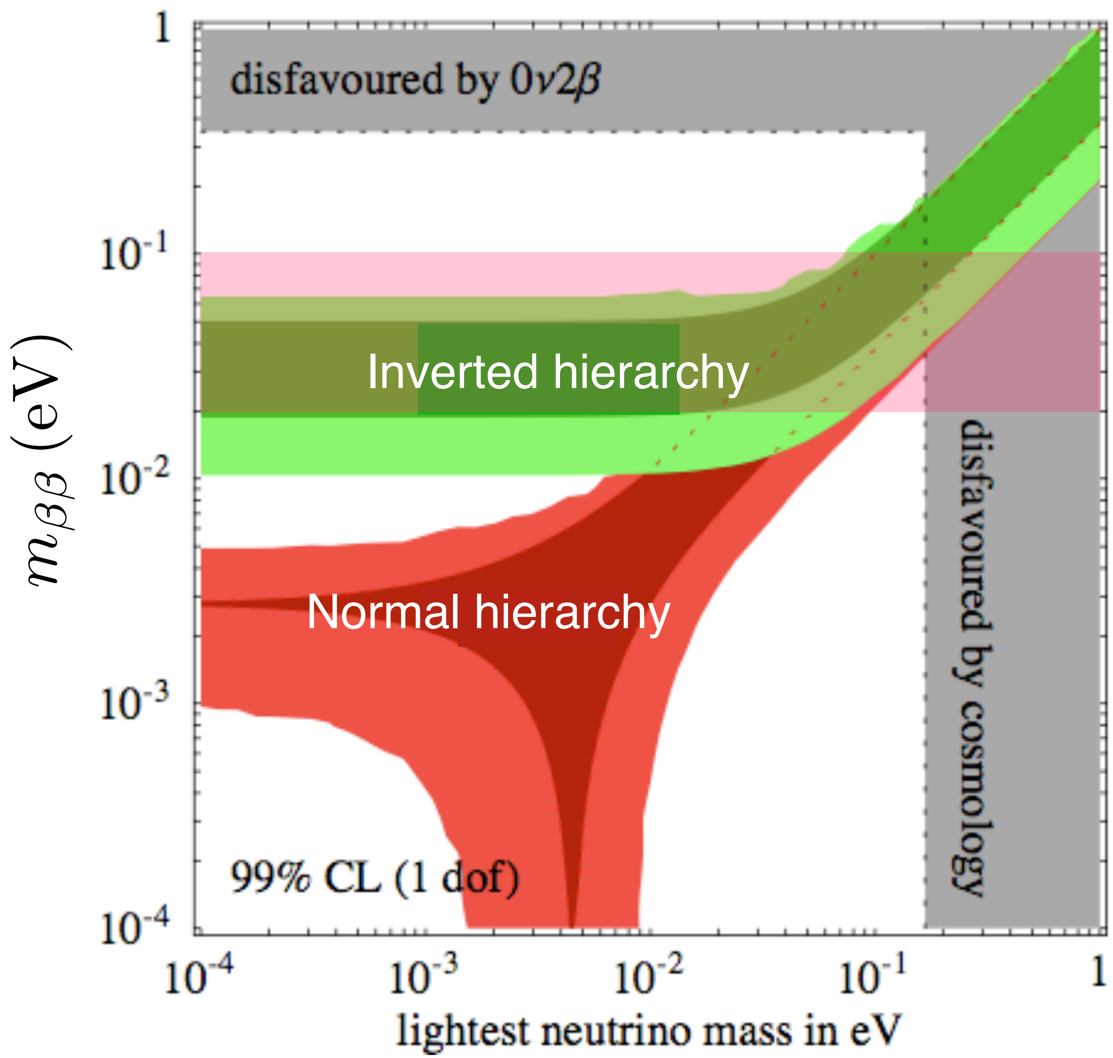
Where we are and where we will be

- Express the effective neutrino Majorana mass in terms of the measured oscillation parameters and the unknown lightest neutrino mass: $m_{\beta\beta} = f(U_{ek}, m_{lightest}, \Delta m_{12}, \Delta m_{13})$

CUORICINO →

Expected sensitivity of CUORE →

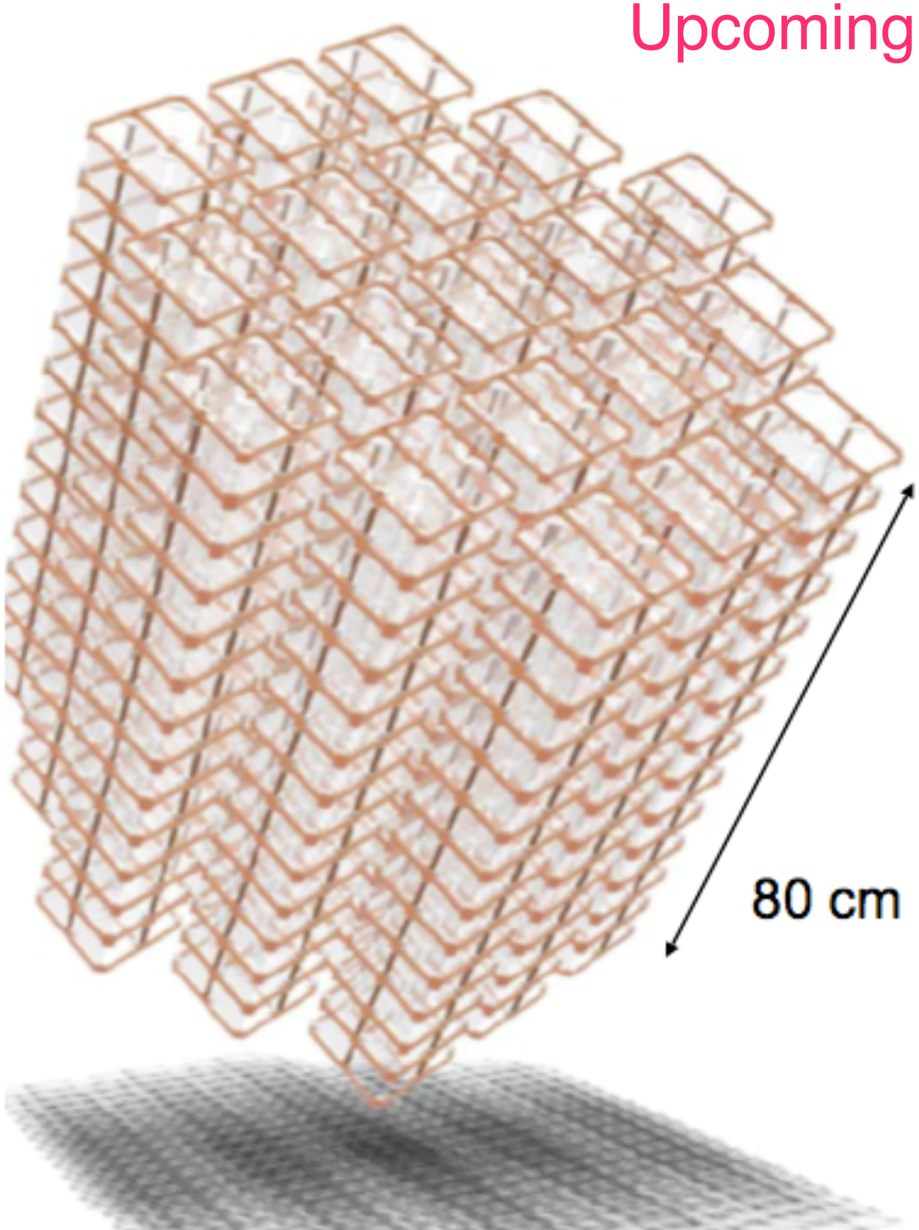
Future generation experiments →

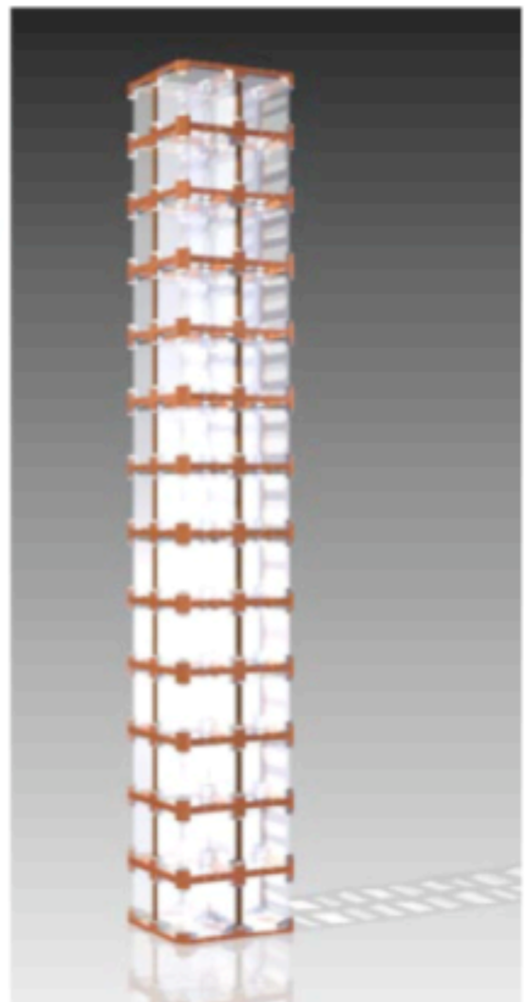


A. Strumia, F. Vissani, arXiv.org/abs/hep-ph/0606054

CUORE

Upcoming new experiment: 19 times CUORICINO





- 988 TeO_2 crystals
- 19 towers of 52 crystals each
- 741 Kg Te
- 203 Kg ^{130}Te
- Expected bkg: 10^{-2} c/KeV/Kg/y
- Start in 2011

Conclusions

- Whether neutrinos are Dirac or Majorana particles is a fundamental question we need to answer.
- 0νDBD might be the only chance to probe the absolute neutrino mass scale.
- CUORICINO demonstrate the feasibility of a large scale bolometric detector with good energy resolution and background.
- The construction of CUORE, a second generation detector, is started. CUORE will have the capability to explore the inverse hierarchy mass region.
- CUORE data taking is scheduled in 2011.