ICHEP 2012 MELBOURNE
JULY 2012

S. Di Domizio
University and INFN Genova

on behalf of the CUORE collaboration

INFN

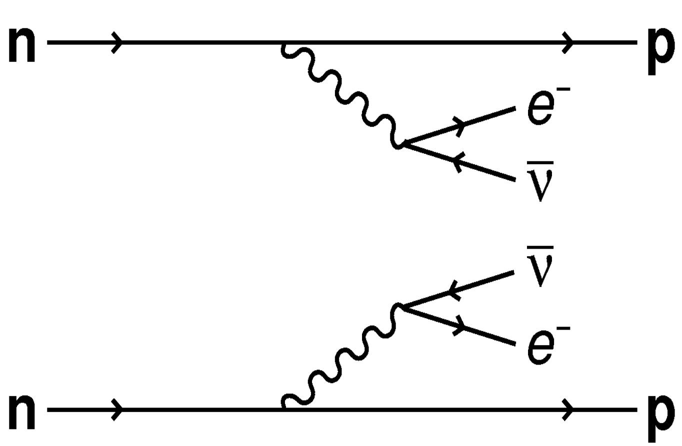
CUORE

Status of the CUORE experiment at Gran Sasso

Double beta decay

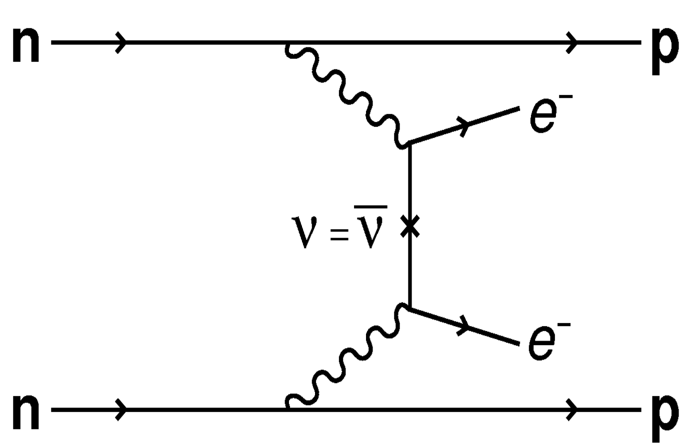
- Rare nuclear decay: (A, Z) $\rightarrow$ (A, Z+2) + $2e^-$ (+2$\bar{\nu}_e$)
- Occurs on nuclei with an even number of protons and neutrons where single beta decay is energetically forbidden

2vDBD



- Allowed by the standard model
- Rarest decay ever observed
- $T_{1/2} \sim 10^{19} – 10^{21}$ yrs

0vDBD



- Forbidden by the standard model: $\Delta L = 2$
- Never observed
- $T_{1/2} > 10^{22} – 10^{25}$ yrs

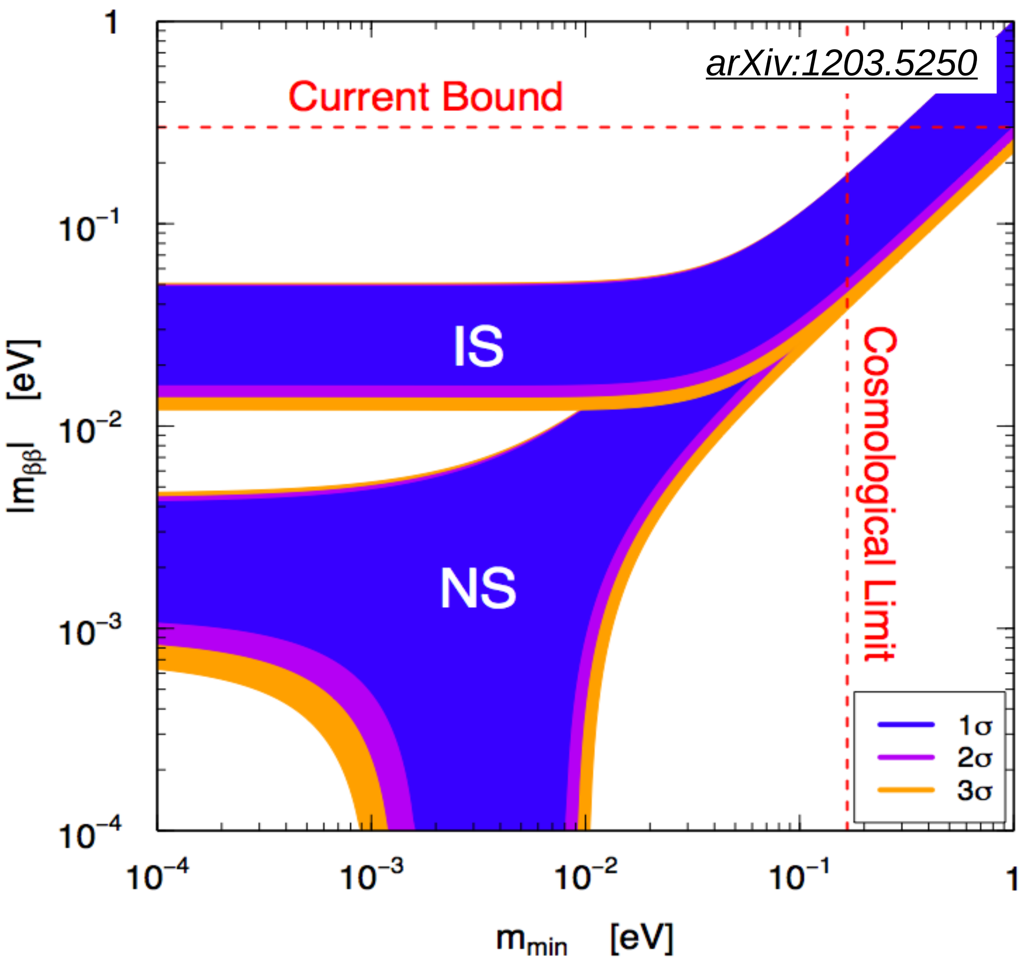
Observation of 0vDBD would prove that neutrino is a Majorana particle

Decay rate

Nuclear matrix element

$$\Gamma^{0\nu} = \frac{\ln 2}{T^{0\nu}_{1/2}} = G_{0\nu} \left|M_{0\nu}\right|^2 \left|m_{\beta\beta}\right|^2$$

Phase space



Effective Majorana mass

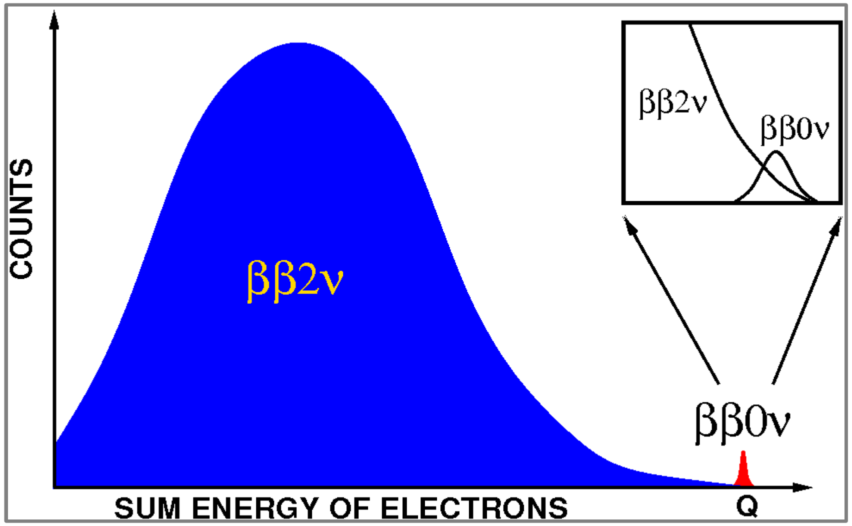
$$m_{\beta\beta} = \sum m_i U_{ei}^2$$

0vDBD also contains information on neutrino mass hierarchy and scale

$$m_{\beta\beta} = f\left(\theta_{12}, \theta_{23}, \theta_{13}, \Delta m_{12}^2, \pm\Delta m_{23}^2, m_{min}\right)$$

Signature and sensitivity

- Detect the two emitted electrons
- Q-value of the order of few MeV
- 2vDBD: continuous spectrum
- 0vDBD: monochromatic peak



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

$$S^{0\nu} = ln2 \; N_a \frac{a}{A} \varepsilon \sqrt{\frac{M \cdot t}{b \cdot \Delta E}}$$

Isotopic abundance (a)

Detection efficiency (ε)

Detector mass (M)

Meas. time (t)

Energy resolution (ΔE)

Background index counts/(keV kg y) (b)

Atomic mass (A)

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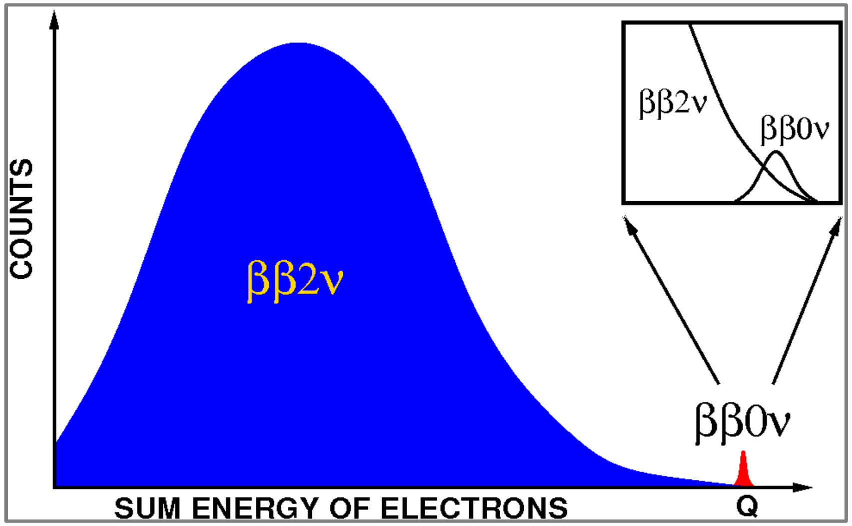

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- Isotopic abundance (a)
- Detection efficiency (ε)
- Detector mass (M)
- Meas. time (t)
- Energy resolution (ΔE)
- Background index (b), counts/(keV kg y)
- Atomic mass (A)

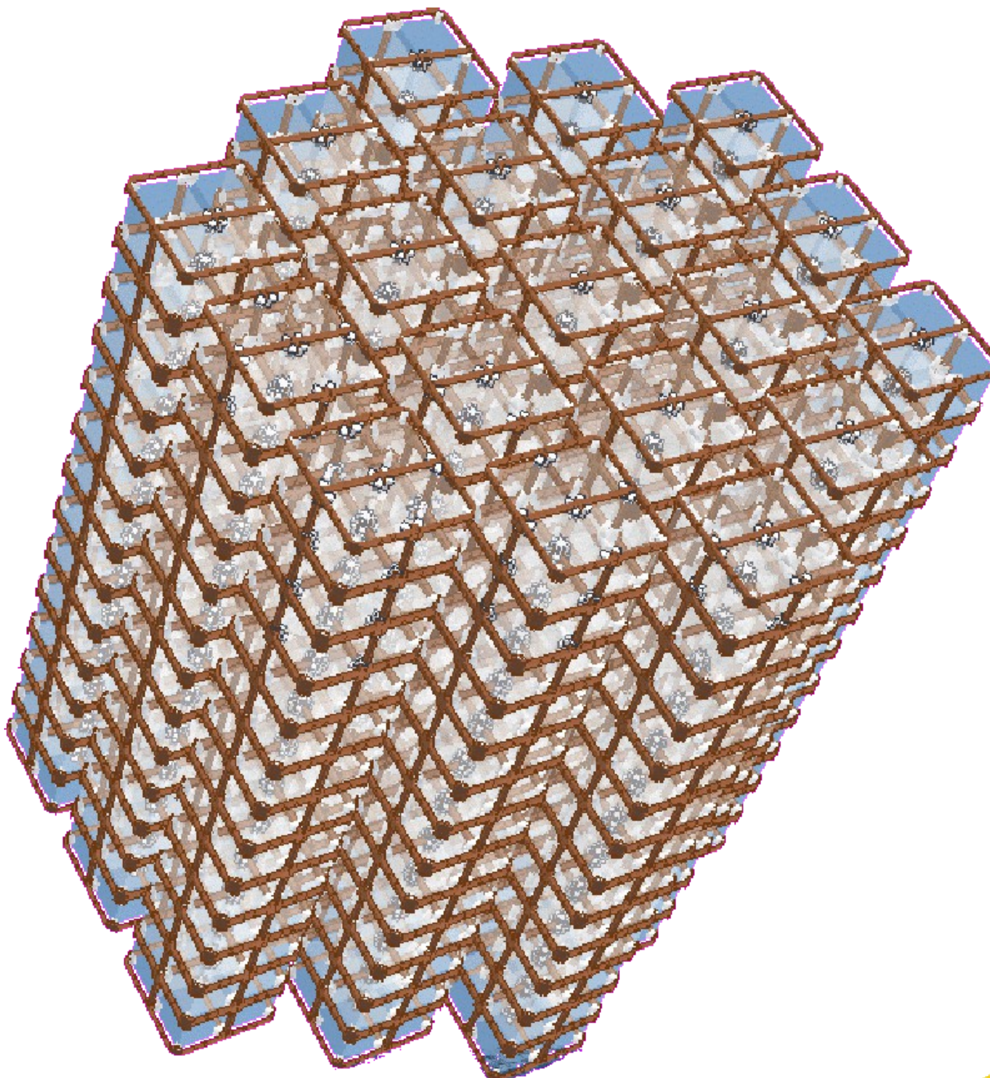
CUORE collaboration

- INFN LNGS Laboratories
- INFN & University Milano Bicocca
- INFN Roma & Sapienza University
- INFN Roma Tor Vergata
- INFN & University Genova
- INFN & University Firenze
- INFN LNL Laboratories
- INFN LNF Laboratories
- INFN Padova
- INFN and University Bologna

- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- University of California Berkeley
- University of California Los Angeles
- University of South Carolina
- California Politechnic state University
- University of Wisconsin Madison
- CNRS – CSNSM Orsay
- Shanghai Institute of Applied Physics
- University of Zaragoza

CUORE: a Cryogenic Underground Observatory for Rare Events

- Tightly packed array of TeO_2 bolometers
- DBD isotope: ^{130}Te
- Single bolometer mass: 0.75 kg
- Arranged in 19 towers
- Total mass: 741 kg
- ^{130}Te mass: 200 kg
- Energy resolution: 5 keV FWHM
- bkg goal: 0.01 counts/(keV kg y)
- Sensitivity after 5 yrs: $T_{1/2} > 1.6 \times 10^{26}$ yrs
- $m_{\beta\beta} < 40 – 94$ meV
- Data taking will start in 2014



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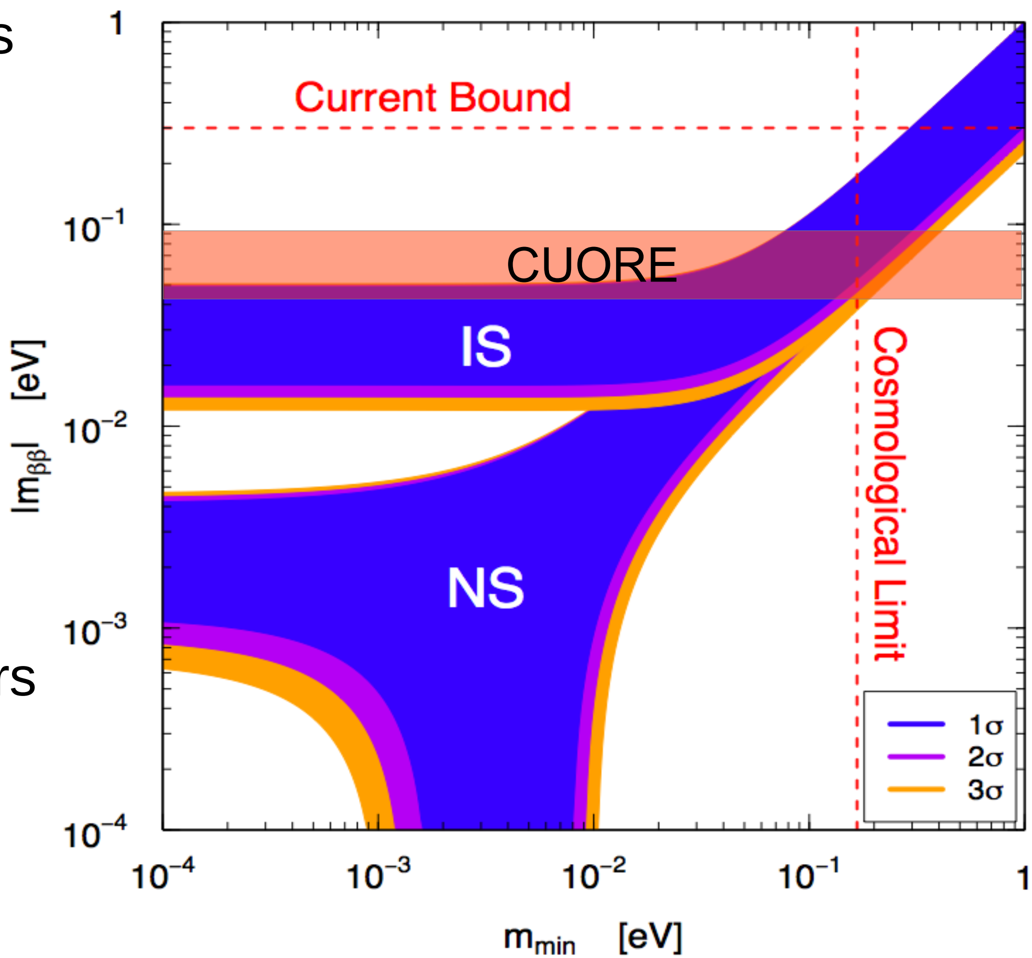
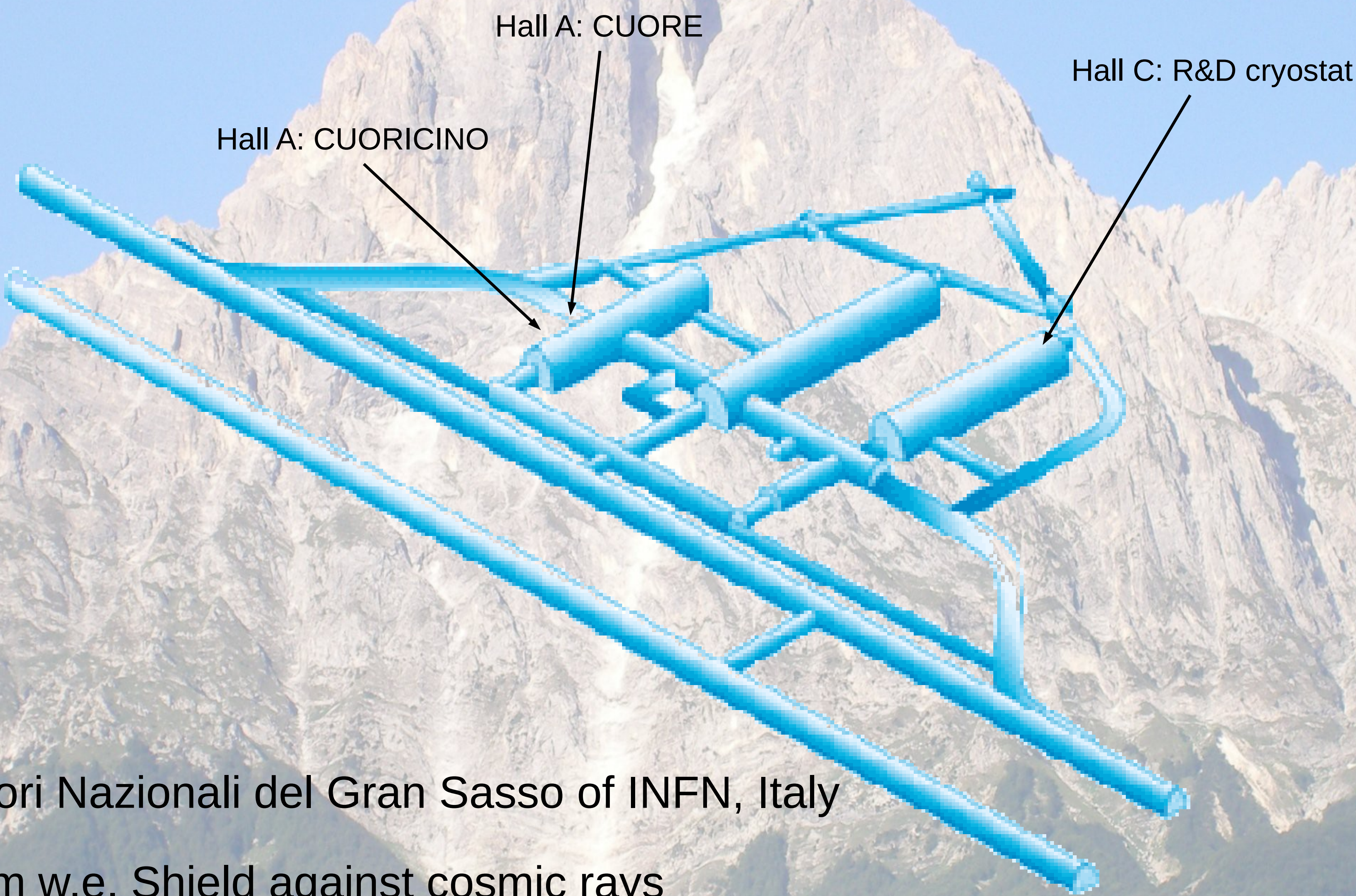


Experiment location



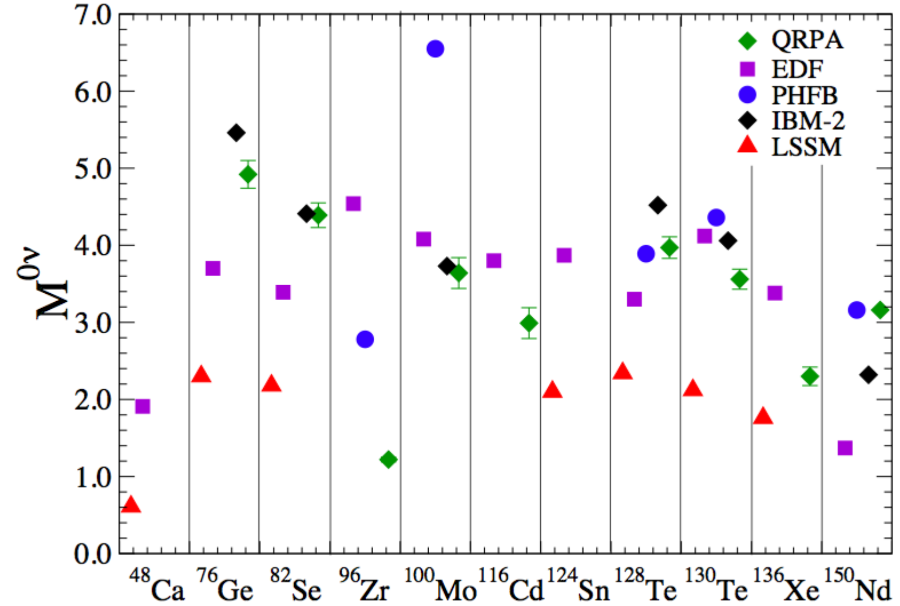
Laboratori Nazionali del Gran Sasso of INFN, Italy

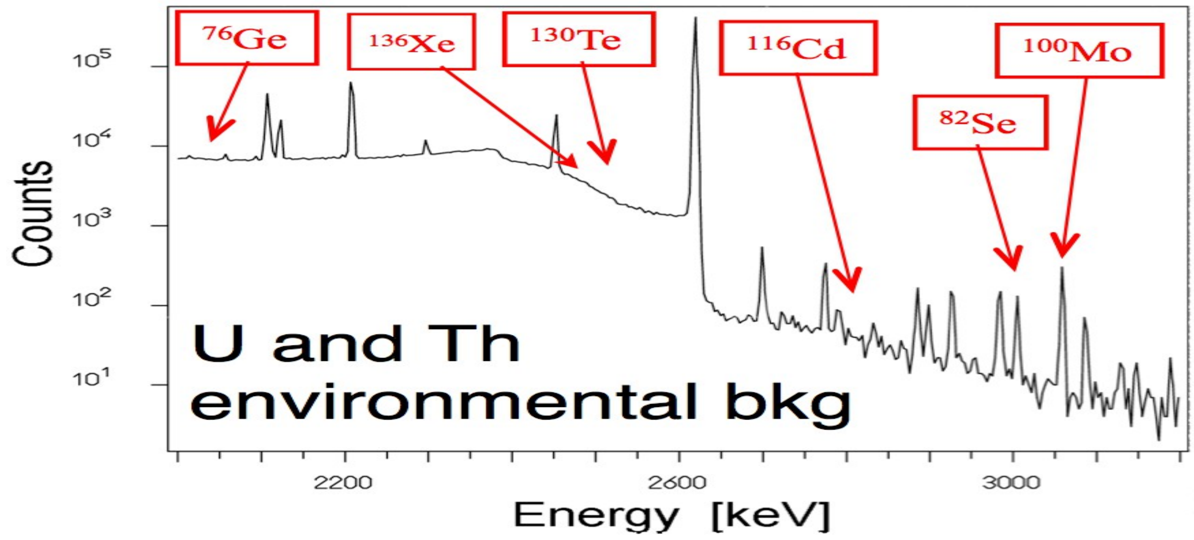
- 3650 m w.e. Shield against cosmic rays
- 2.6×10^{-8} $\mu/cm^2/s$ – flux reduced by ~ 10^6 wrt earth surface

Isotope choice: ^{130}Te

isotope	$G^{0\nu}$ $[\frac{10^{-14}}{y}]$	$Q_{\beta\beta}$ [keV]	nat. abund. [%]	$T^{2\nu}_{1/2}$ $[10^{20}$ y]
^{48}Ca	6.3	4273.7	0.187	0.44
^{76}Ge	0.63	2039.1	7.8	15
^{82}Se	2.7	2995.5	9.2	0.92
^{100}Mo	4.4	3035.0	9.6	0.07
^{116}Cd	4.6	2809	7.6	0.29
^{130}Te	4.1	2530.3	34.5	9.1
^{136}Xe	4.3	2461.9	8.9	21
^{150}Nd	19.2	3367.3	5.6	0.08

arXiv:1201.4916

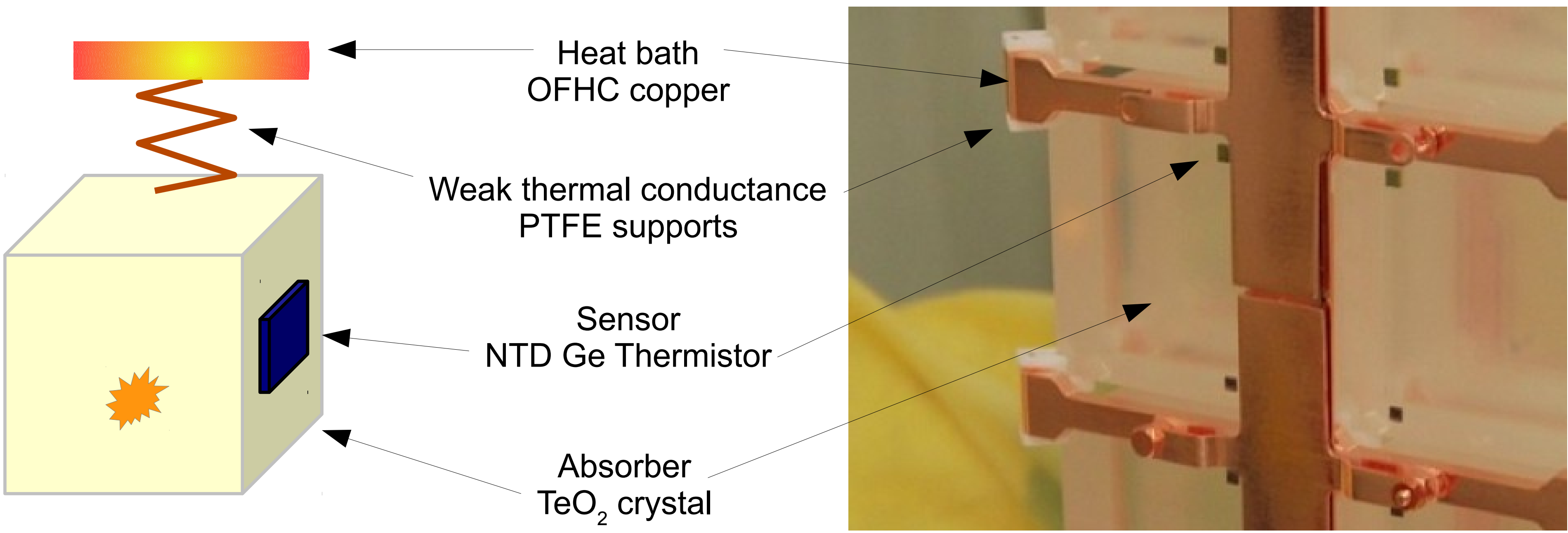




Bolometers

Energy releases produce a measurable temperature rise of the absorber crystal: $\Delta T = \frac{E}{C}$

Working temperature: ~ 10 mK

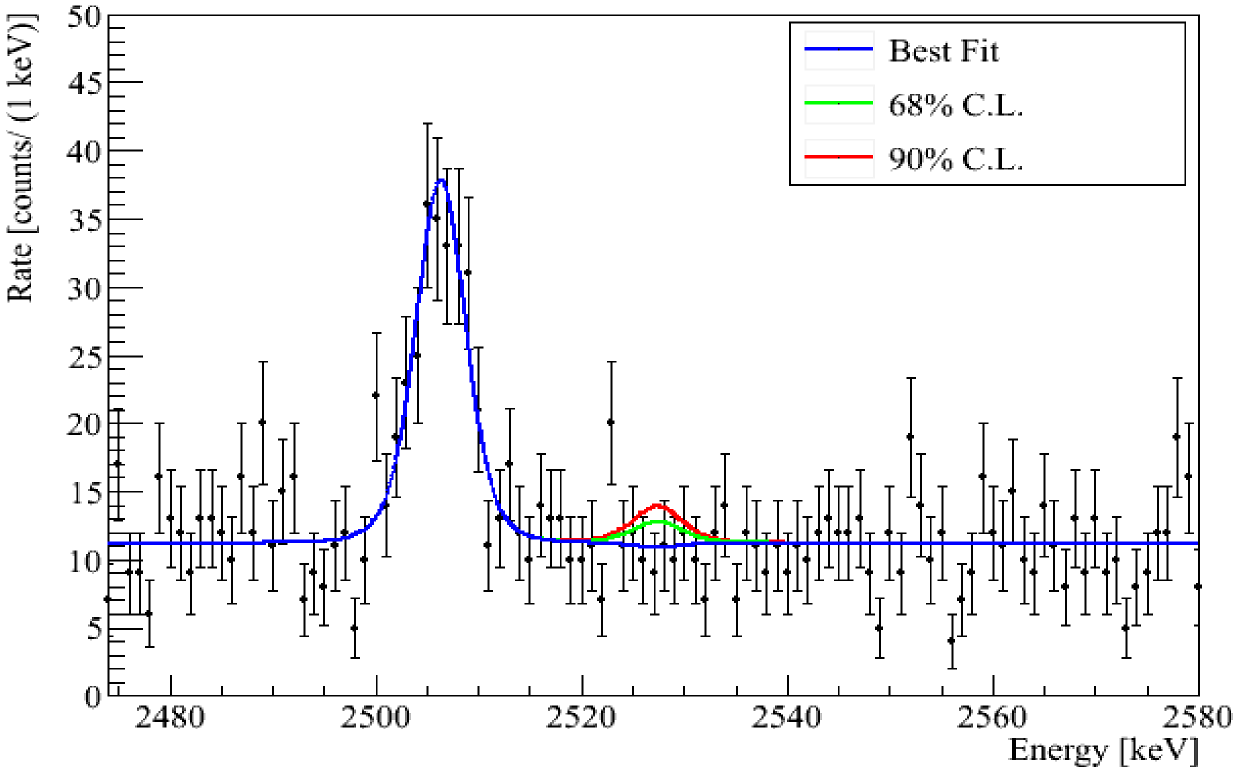


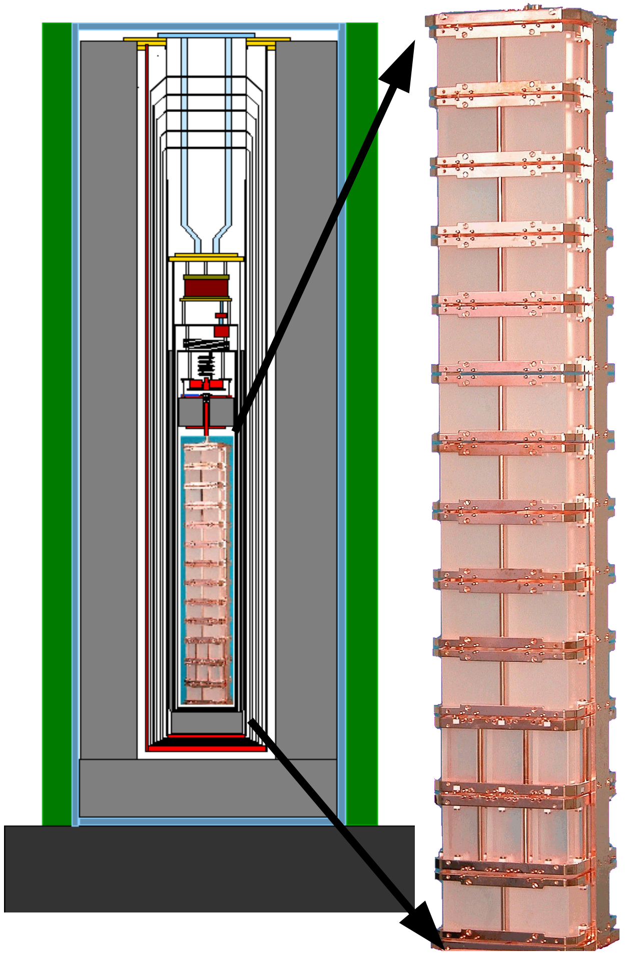
- Absorber
  - M ~ 0.75 kg
  - C ~ 10^{-9} J/K
  - ΔT/ΔE ~ 100 μK/MeV
- Sensor
  - $R = R0 \exp[(T_0/T)^{1/2}]$
  - R ~ 100 MΩ
  - ΔR/ΔE ~ 3 MΩ/MeV
- Output signal
  - ΔV/ΔE ~ 100 μV/MeV
  - Signal bandwidth ~ 12 Hz
  - Signal duration ~ 5s

The past: CUORICINO

- 62 TeO_2 bolometers
- 40.7 kg (11.3 kg in ^{130}Te)
- Data taking: 2003-2008

- Statistics: 19.75 kg x yr in ^{130}Te
- Avg resolution: 6.3 keV FWHM
- Bkg in ROI: 0.17 counts/(keV kg yr)





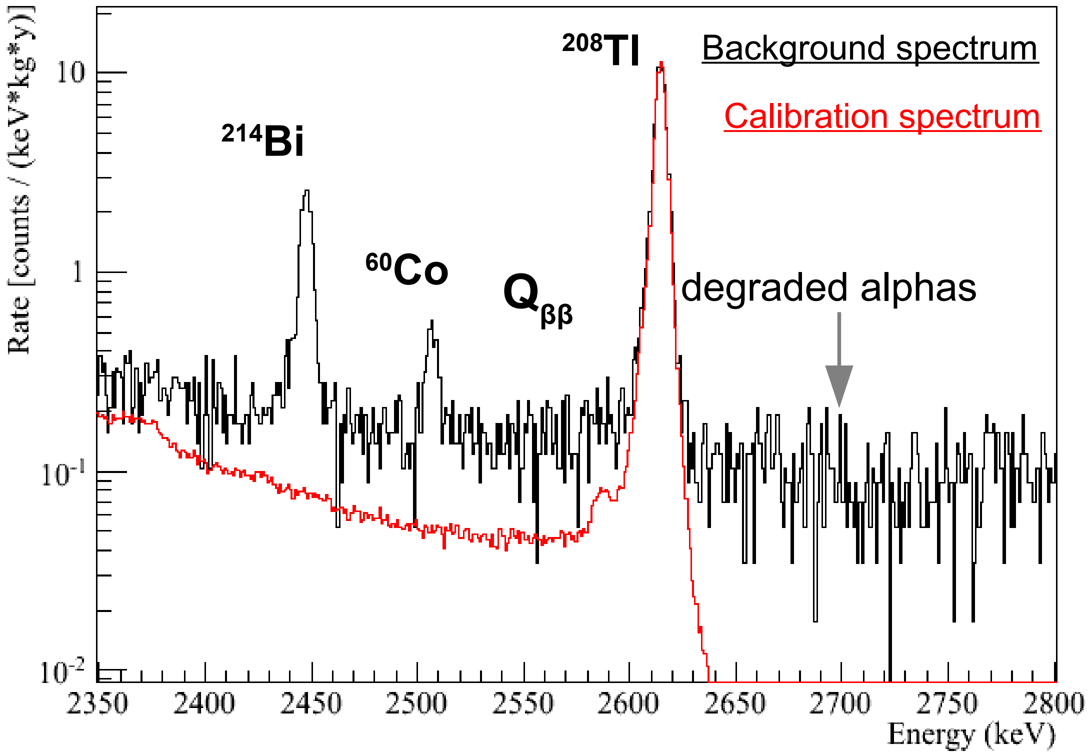
- Internal and external lead shield
- Borated polyethylene shield
- Anti-Rn box

$$T^{0\nu}_{1/2} > 2.8 \times 10^{24}\, y \quad @90\%\, CL$$

$m_{\beta\beta} < 0.30 \div 0.71\, eV$ range due to different NME calculations

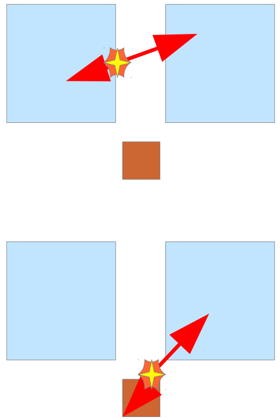
Astropart. Phys. 34 (2011) 822–831

CUORICINO background



Surface alphas produce a continuous spectrum that extends down to $Q_{\beta\beta}$

Contributions of copper and crystal contaminations can be disentangled



Main background contributions at $Q_{\beta\beta}$

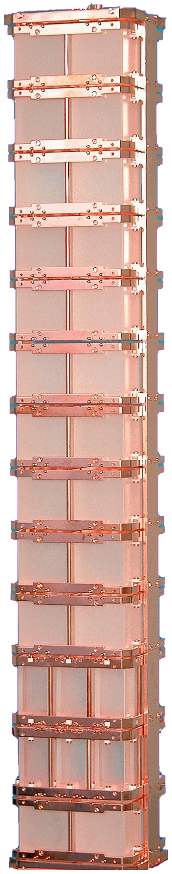
- Multi-Compton from ^{208}Tl (^{232}Th cont. in cryostat shields): (30±10)%
- Degraded alphas from crystal surfaces: (10±5)%
- Degraded alphas from Cu holders surfaces: (50±20)%

The key point is material cleanliness

- Dedicated tests in the Hall C R&D facility
- crystal contribution now under control
- copper contribution is still 4x above the CUORE goal -- 10^{-2} cts/(keV kg y)

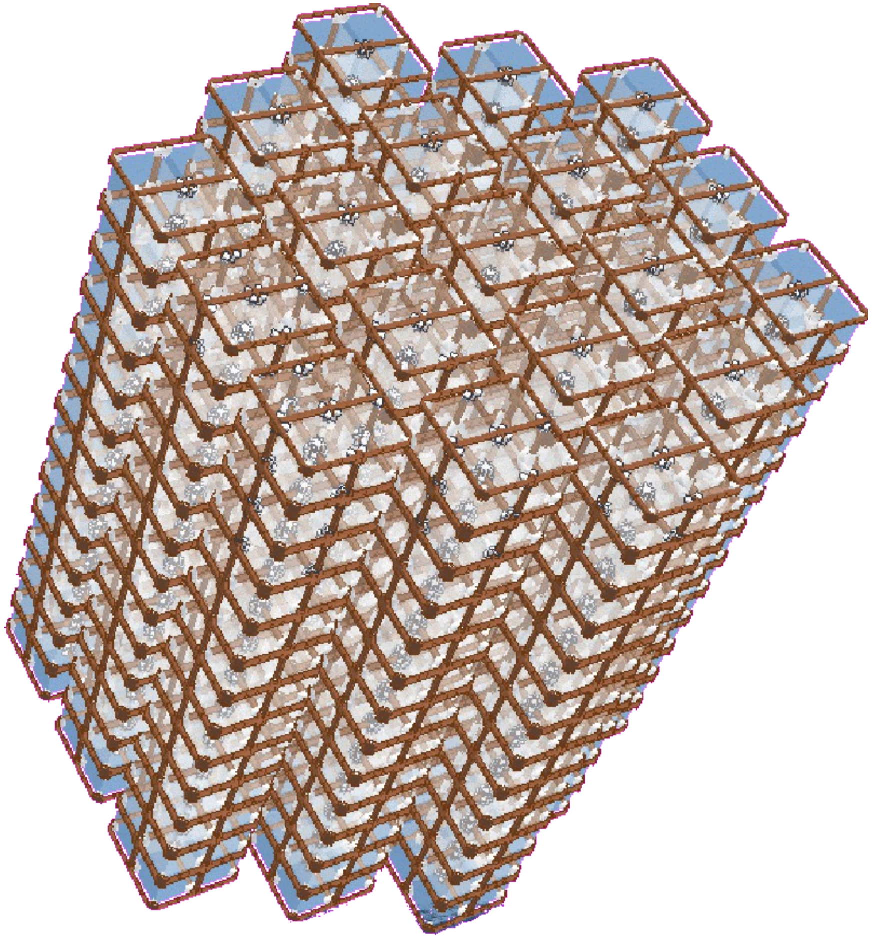
From CUORICINO to CUORE

CUORICINO
2003-2008



41 kg

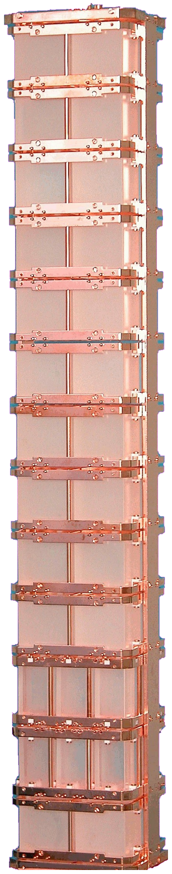
CUORE
2014 →



741 kg

CUORE-0

CUORICINO
2003-2008

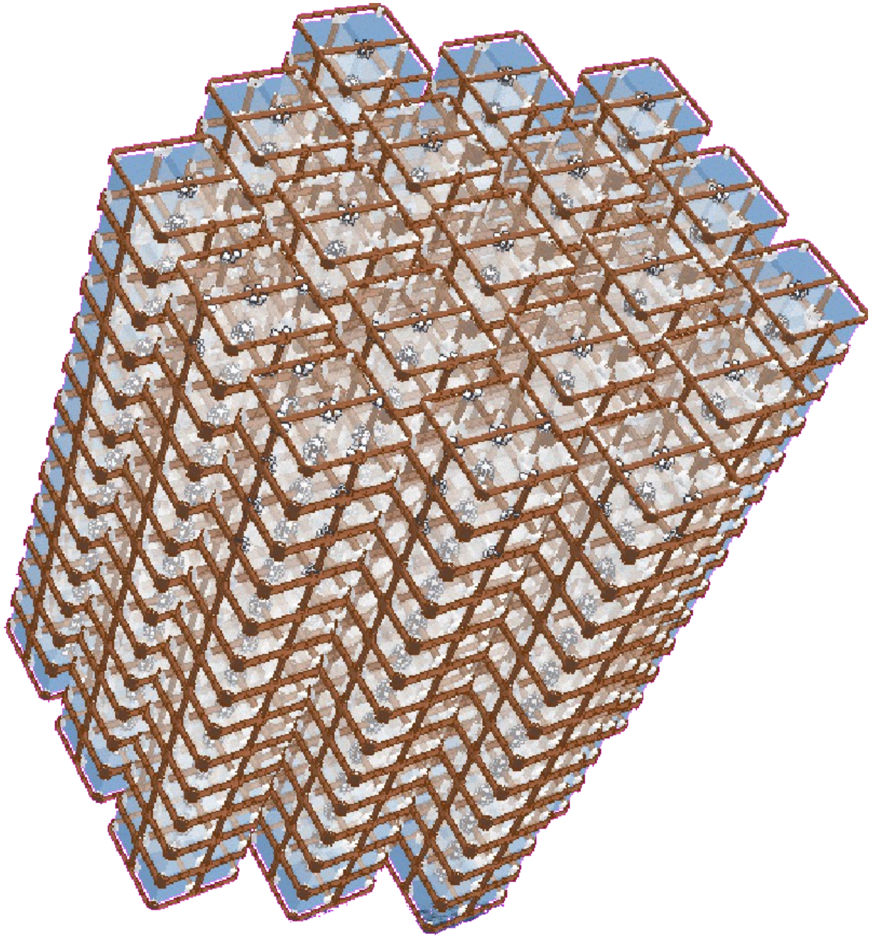


41 kg

CUORE-0
2012-2014

41 kg

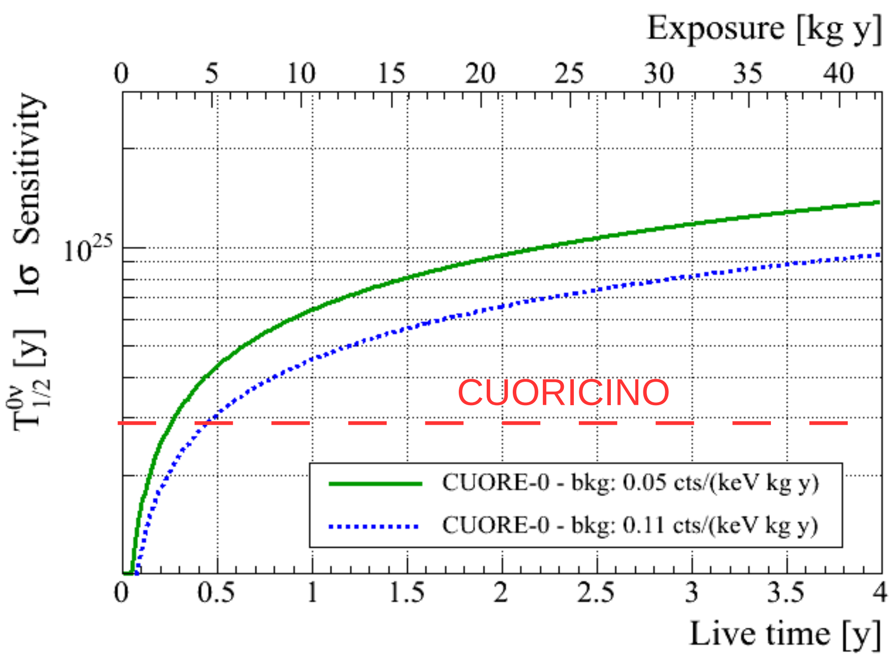
CUORE
2014 →



741 kg

CUORE-0

- A single CUORE-like tower installed in the CUORICINO cryostat
- Test of the detector assembly procedure
- High statistics test of the uniformity in the bolometers response
- High statistics test of the background reduction achieved
- Will improve the the CUORICINO limit by a factor 2 in 2 years of data taking
- Data taking will start at the end of July



arXiv:1109.0494

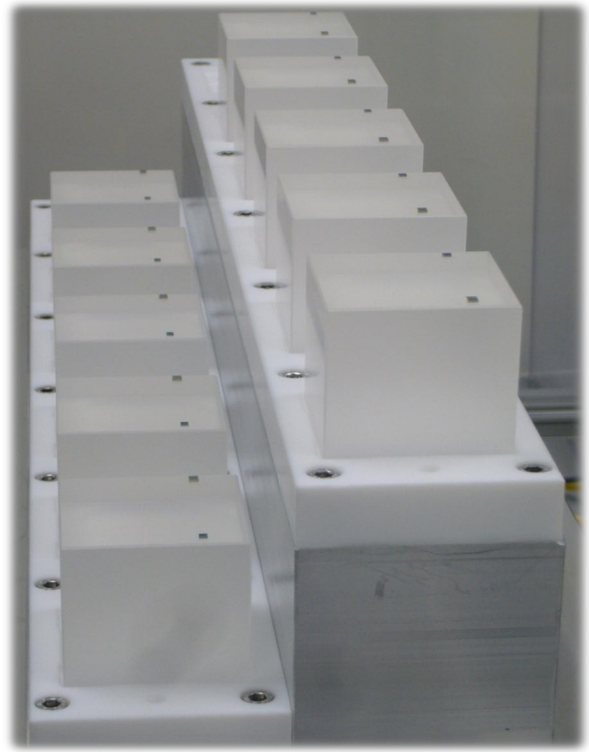
CUORE-0 sensitivity

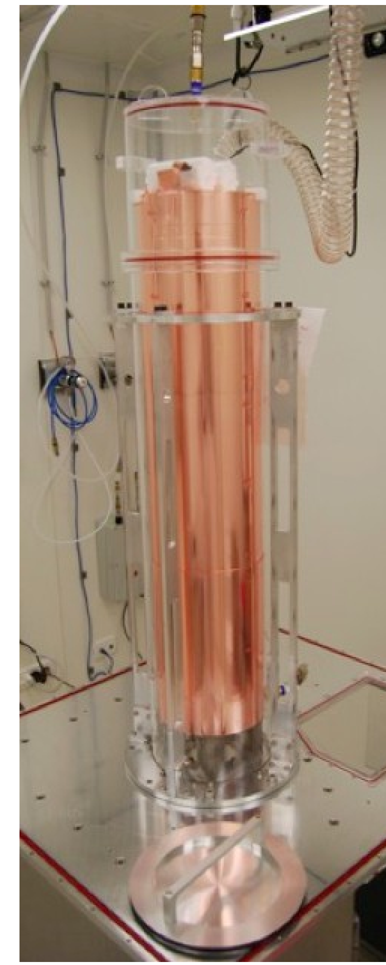
- Expected bkg: 0.05 – 0.11 counts/(keV kg yr)
- Background limited by contaminations in the cryogenic apparatus
- If bkg will be 0.05 counts/(keV kg yr), after 2 years of data taking:
  - $T_{1/2}$: 5.9 x 10^{24} @90% CL
  - $m_{\beta\beta}$ < 0.17 - 0.39 eV

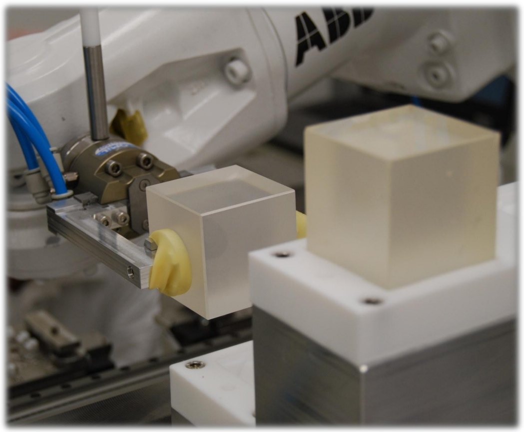
CUORE-0 construction

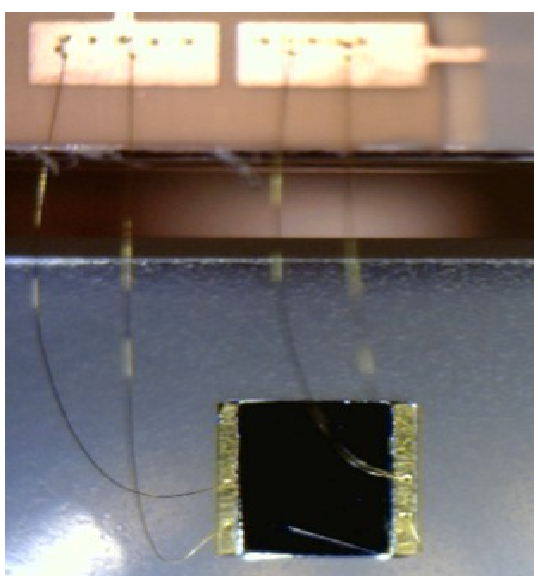
Standardized detector assembly procedure

- Handle a large number of detectors
- Improve reproducibility
- Ensure cleanliness







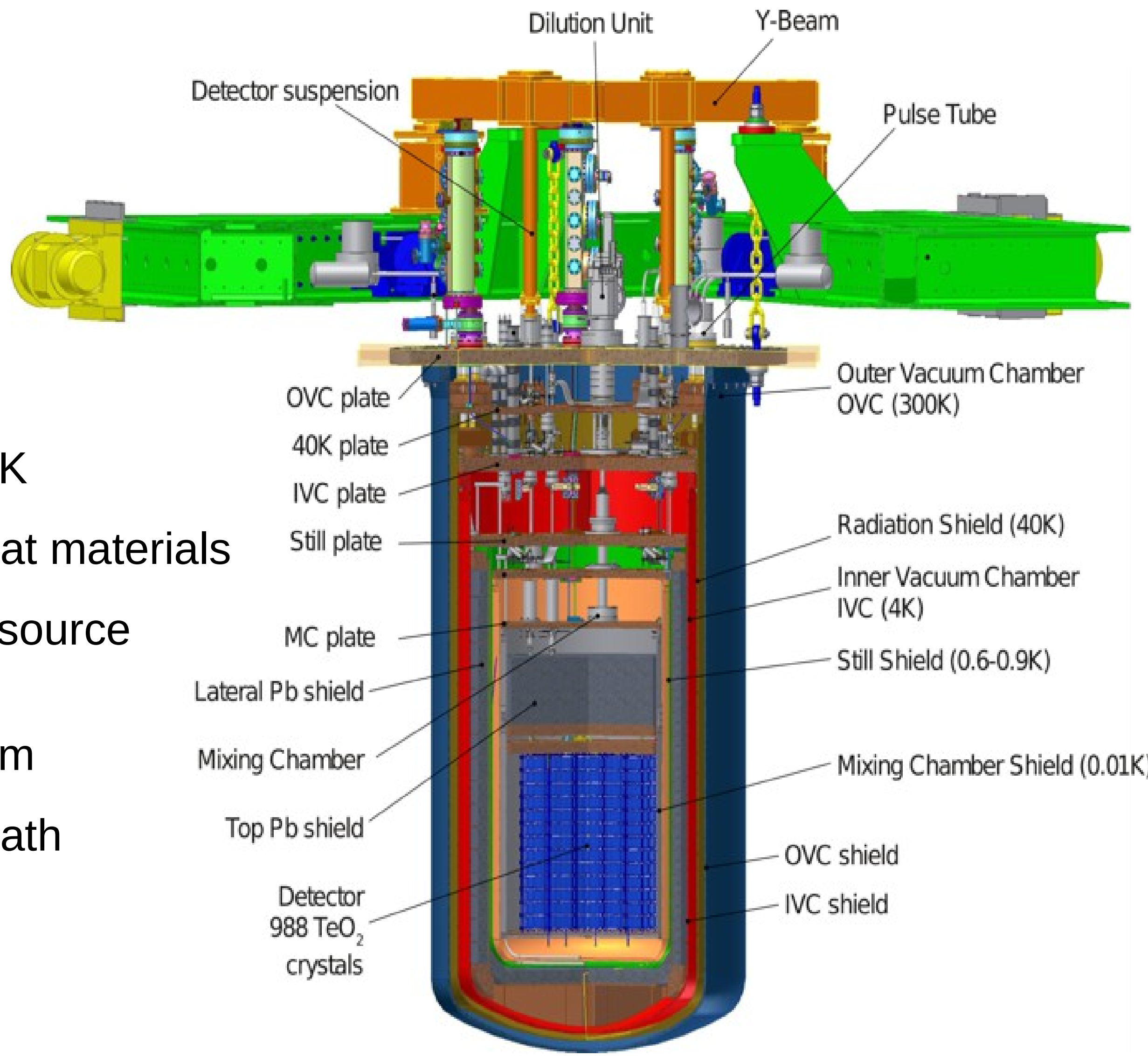


3 main steps

- Sensor gluing
- Tower assembly
- Bonding of sensor wires

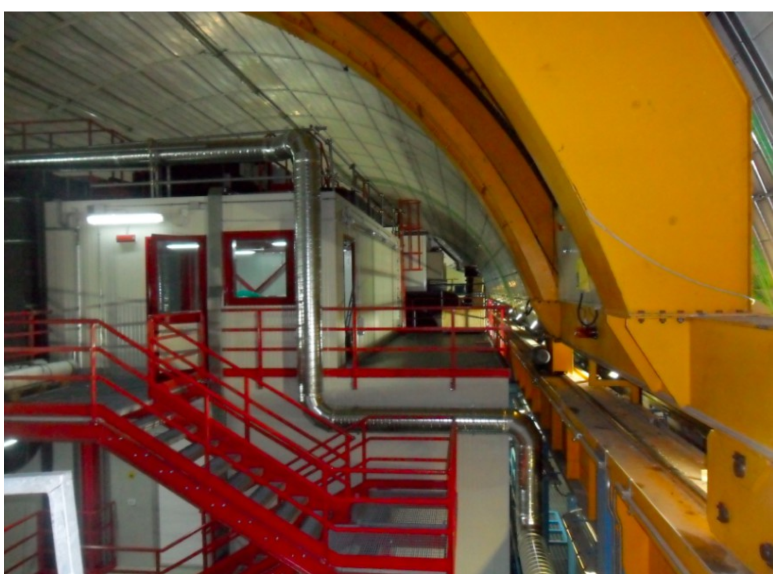
CUORE cryogenic apparatus

- The largest mass ever cooled to 10 mK
- Radioactivity constraints on the cryostat materials
- Calibration: periodic insertion of ^{232}Th source wires between the CUORE towers
- Multi-stage detector suspension system
- No cryogenic liquids: 1K-pot, helium bath



CUORE status

- Crystal delivery complete by the end of 2012
  - 90% already delivered @LNGS
  - 4 crystals from each batch undergo bolometric tests of contract specifications: *Joirnal of Crystal Growth 312 (2010) 2999, Astropart. Phys 35 (2012) 839-849*
- NTD sensors delivered at the beginning of 2013
- Cleaned Cu parts will delivered by the end of 2013
- Cryostat commissioning will start this summer
- Detector assembly: early 2014
- Detector insertion: summer 2014
- Cool down: autumn 2014



Conclusions

- CUORE will start probing the inverted hierarchy region of the Majorana neutrino mass
- The experimental technique was proved by CUORICINO
- The procedure for assembling the CUORE towers is proved by the successful construction of CUORE-0
- CUORE-0 data taking will start in summer 2012
- CUORE data taking will start in 2014