The search of neutrinoless double decay with the CUORE experiment

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on behalf of the CUORE collaboration

Outline

- Bolometric technique for neutrinoless double-beta decay ($\beta\beta0\nu$)

- Update of Cuoricino results

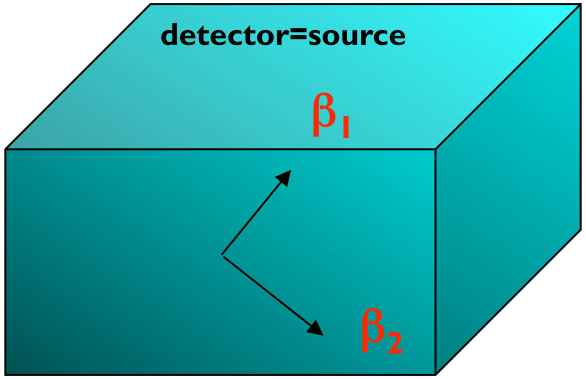
- From Cuoricino to CUORE
- Background reduction
- Energy calibration system

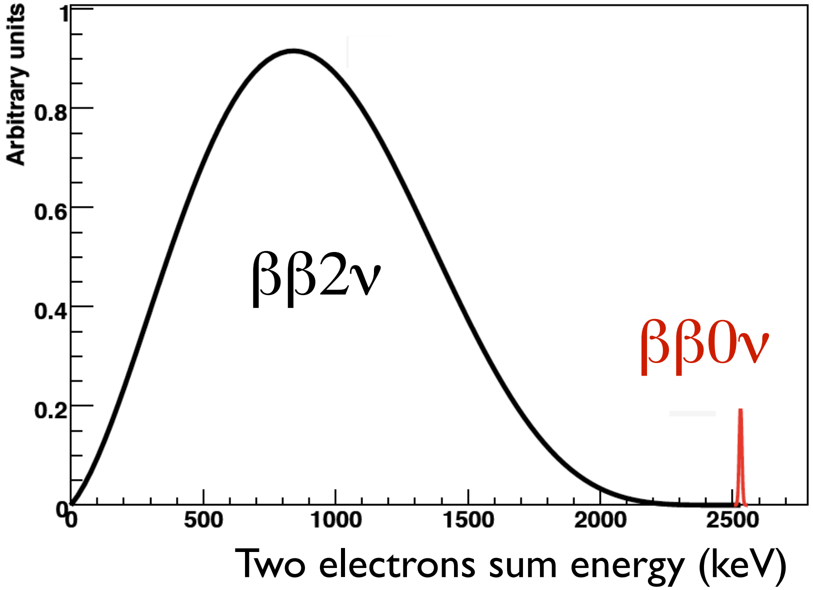
- Present status and future of CUORE

Calorimetric approach to ββ0ν

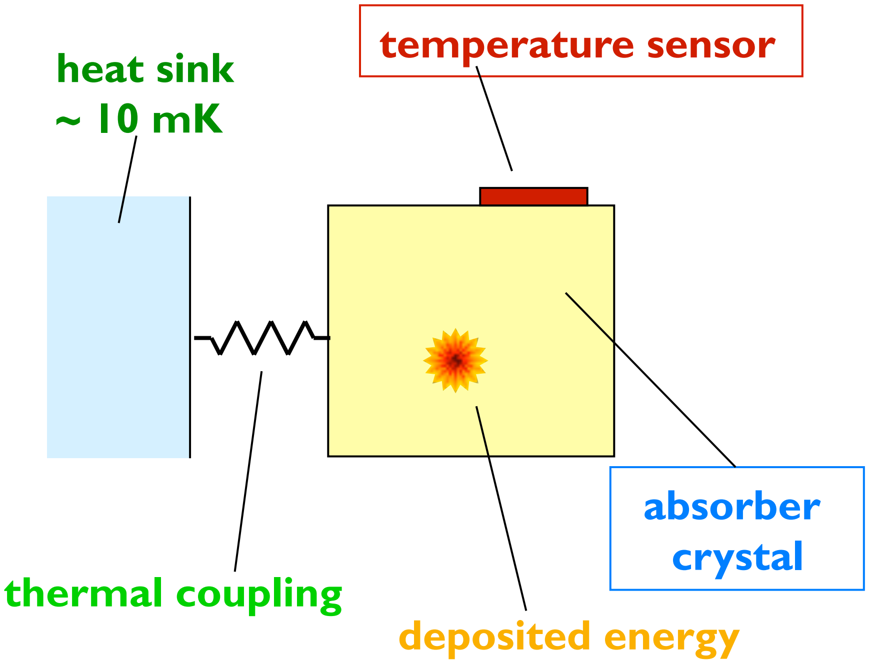
- Several different techniques are being used to search for ββ0ν
- Calorimetric approach
  - source $\subseteq$ detector
  - large masses
  - all energy measured
  - no event topology

$$\beta\beta 0\nu: \quad (A,Z) \rightarrow (A,Z+2) + 2e^{-}$$





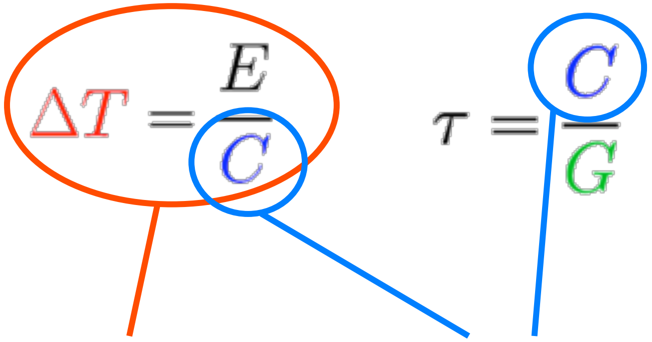
Bolometric technique



Properties:

- ☺ high energy resolution
- ☺ large choice of absorber materials
- ☹ only energy and time information
- ☹ slow response time

Operated as **perfect calorimeters**: all energy converted into phonons

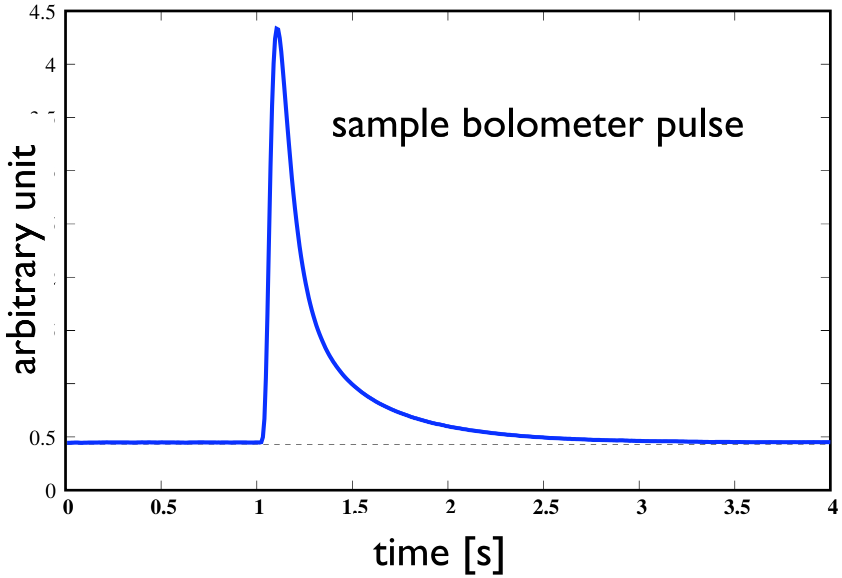


$$\Delta T = \frac{E}{C} \qquad \tau = \frac{C}{G}$$

complete and instantaneous thermalization

temperatures ~ 10mK

dielectric and diamagnetic materials



TeO_2 bolometers

Absorber crystal

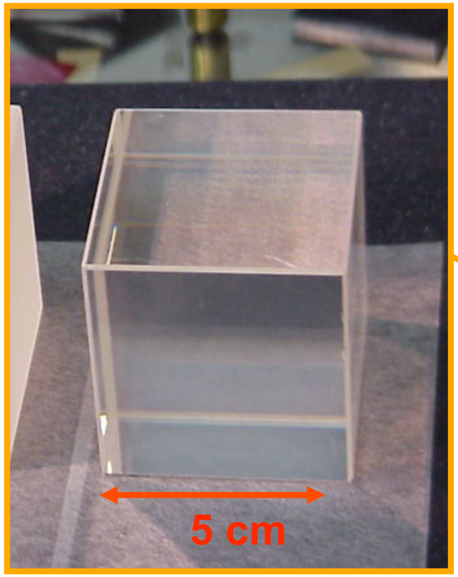
The absorber is a 5x5x5 cm^3 (790 g) crystal of TeO_2 which contains the ββ0ν candidate ^{130}Te

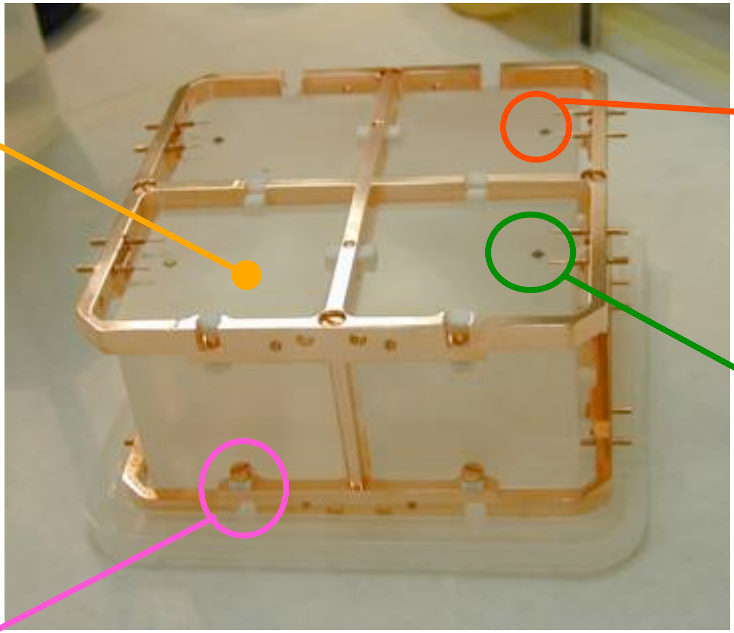
Temperature sensor

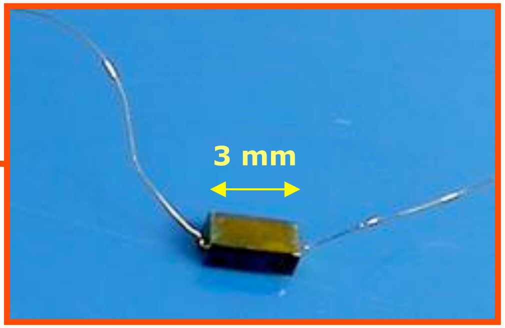
The thermal signal is measured by means of an NTD Ge Thermistor

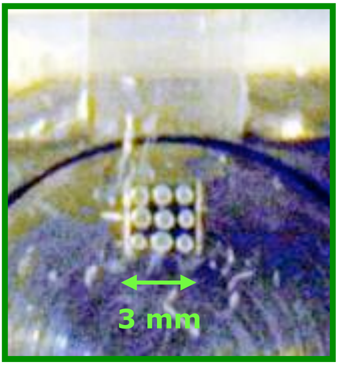
$$R(T) = R_0 e^{\sqrt{\frac{T_0}{T}}}$$

An electrical read-out converts resistance changes into voltage pulses





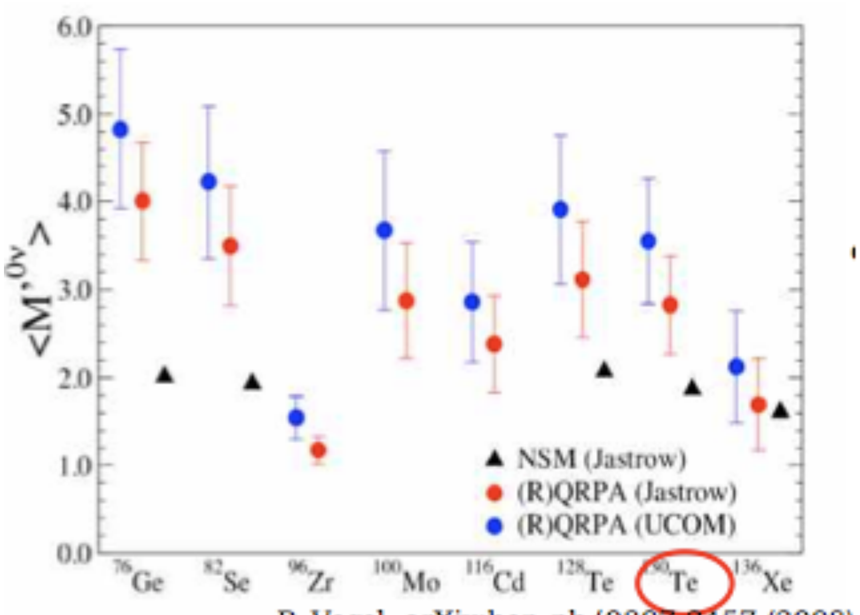




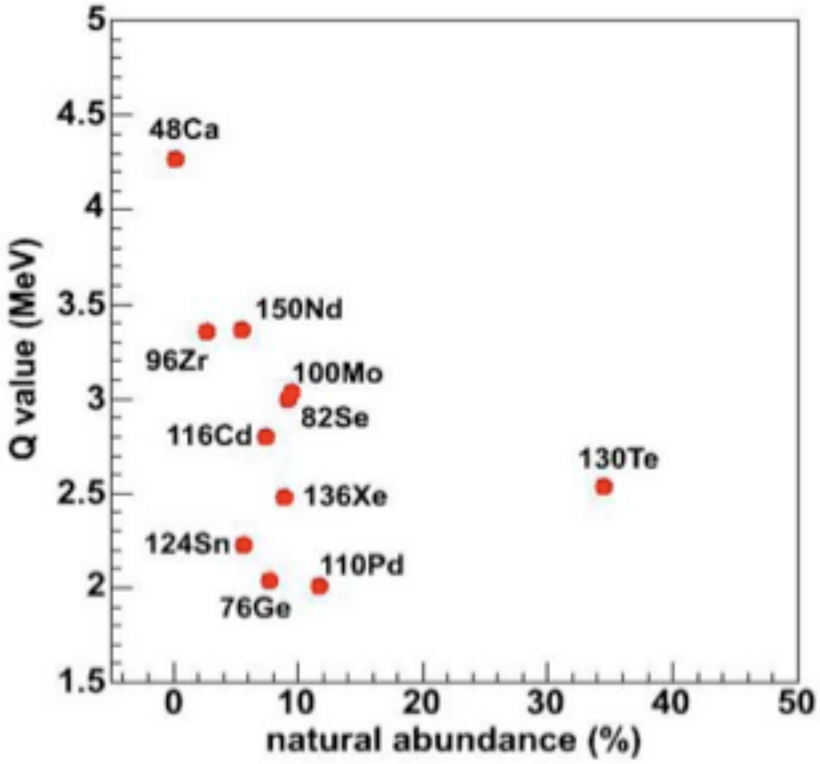
Properties of ^{130}Te

Among the possible $\beta\beta0\nu$ candidates, ^{130}Te presents several nice features

- high natural isotopic abundance (I.A. = 33.87 %)
- high transition energy (Q ~ 2527 keV)
- average theoretical calculations of the Nuclear Matrix Elements (NME)



P. Vogel, arXiv:hep-ph/0807.2457 (2008)

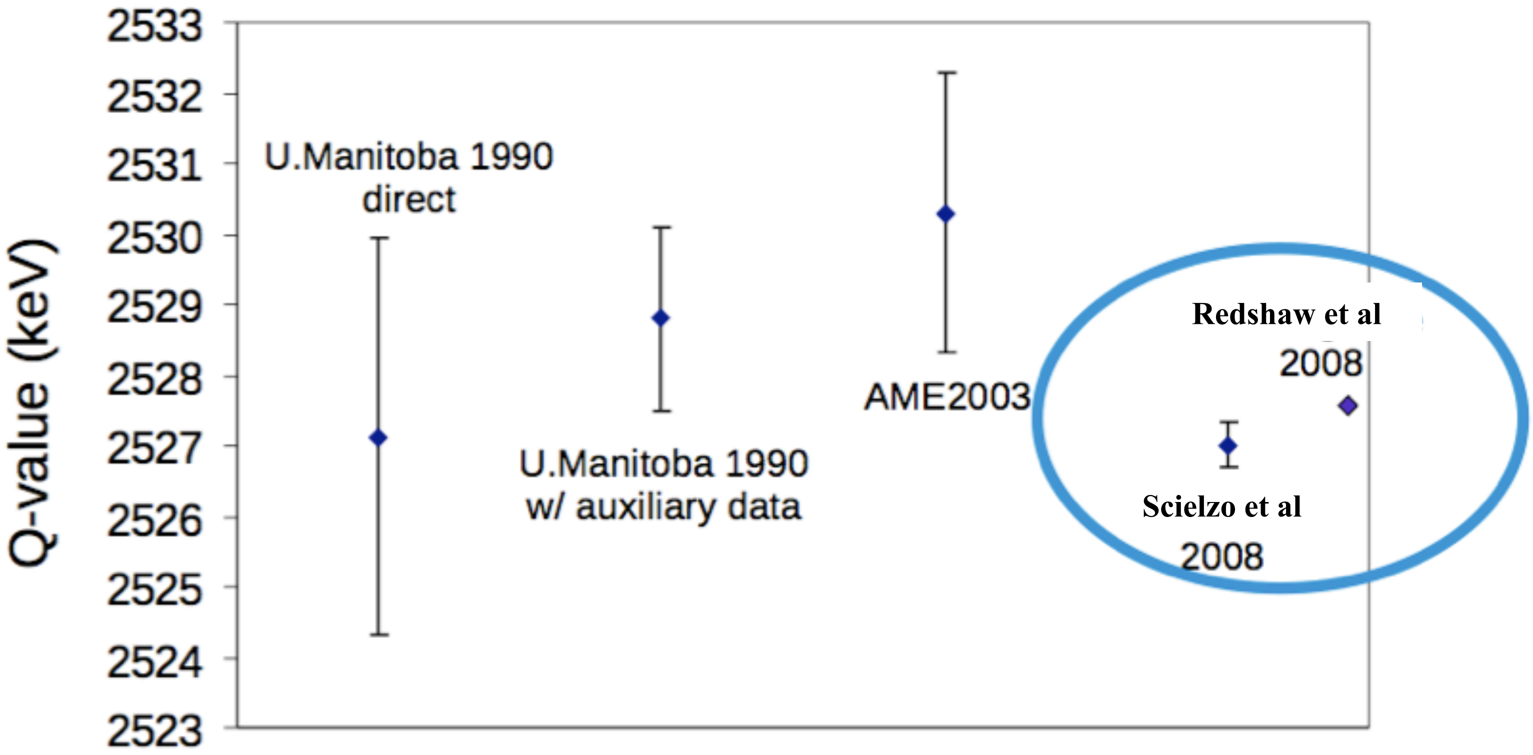


Recent update of 130Te Q-value

~~$Q_{\beta\beta0\nu}(^{130}Te) = 2530.30 \pm 1.99$ keV~~ old value

$Q_{\beta\beta0\nu}(^{130}Te) = 2527.01 \pm 0.32$ keV Scielzo et al., nucl-ex/0902.2376

$Q_{\beta\beta0\nu}(^{130}Te) = 2527.518 \pm 0.013$ keV Redshaw et al., nucl-ex/0902.2139

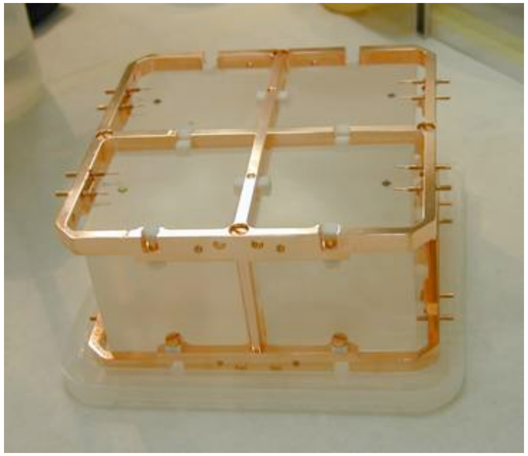


The Cuoricino experiment

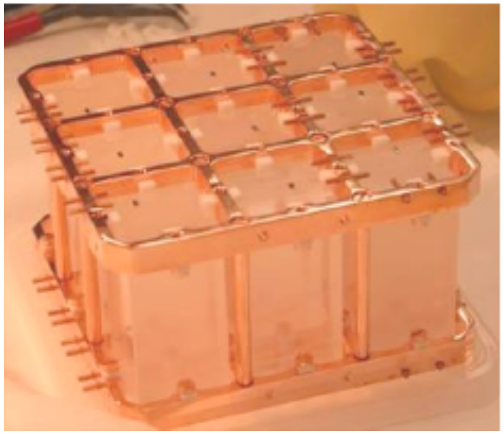
Operated at GranSasso Underground Laboratory (Italy) from 2003 to 2008

62 TeO_2 crystals
detector mass: 40.7 kg
^{130}Te mass: 11 kg ~ 5x10^{25} ^{130}Te nuclides

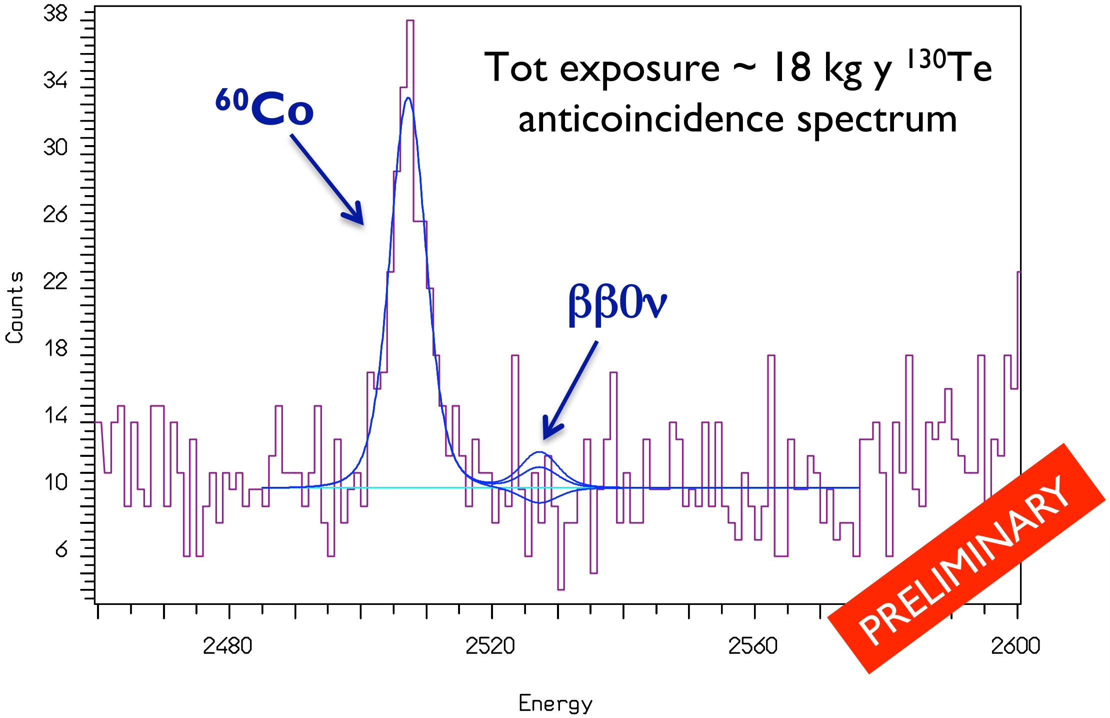
11 modules, 4 detectors each
crystal size: 5x5x5 cm^3
crystal mass: 790 g



2 modules, 9 detectors each
crystal size: 3x3x6 cm^3
crystal mass: 330 g



Cuoricino results



Background in ββ region

0.18 ± 0.01 c/keV/kg/y

Average resolution @ 2615keV

~ 8keV

during calibrations, only 5x5x5 cm^3 crystals

$T_{1/2}^{0\nu} \geq 2.9 \times 10^{24}$ y (90%CL)

$m_{\beta\beta} < 0.21 - 0.70$ eV

using NME from Rodin et al, Nucl. Phys. A 776 (2006)
and erratum arXiv::nucl-th/0706.4304

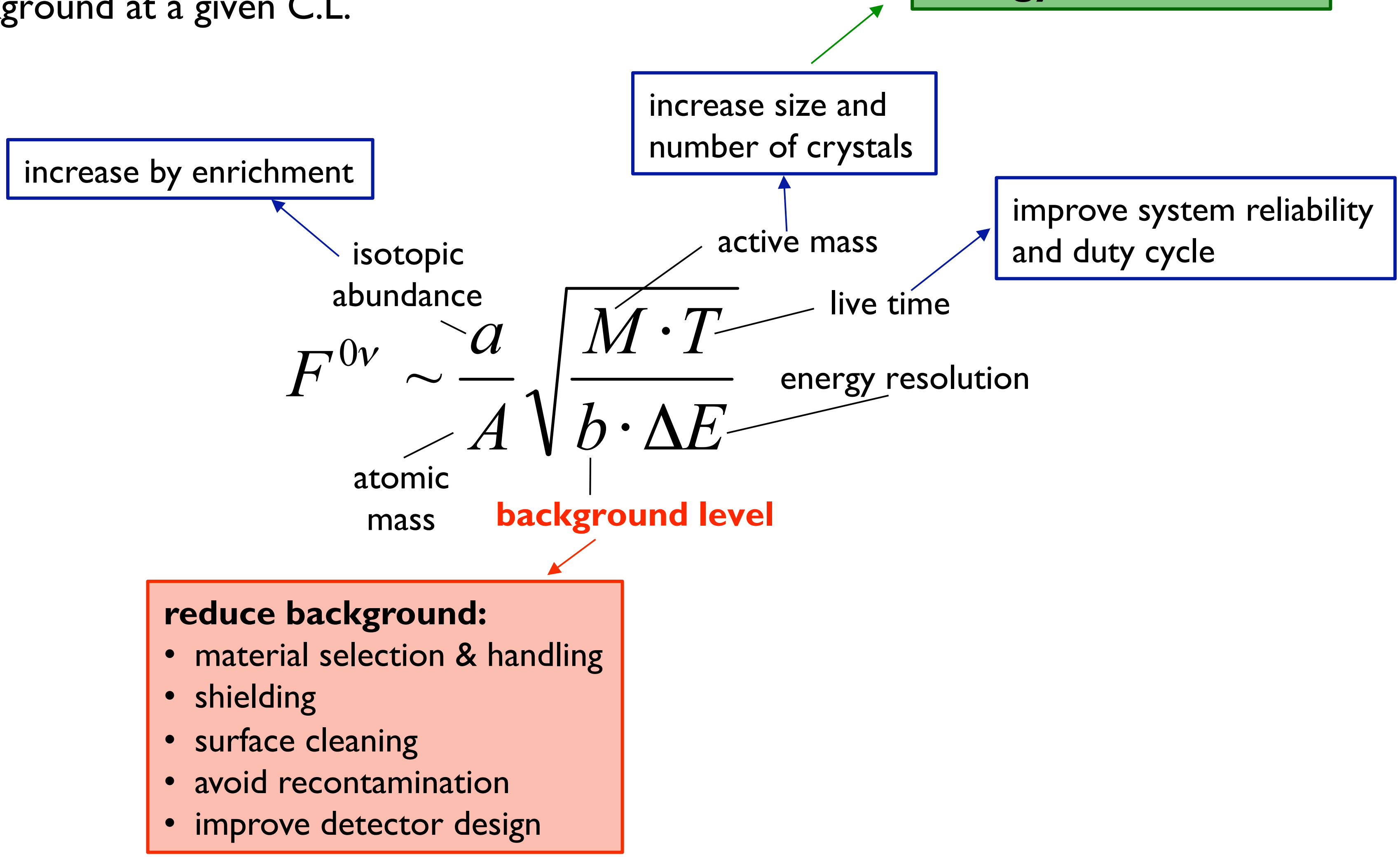
- Use new more accurate Q-value
- Updated statistics through Jan 2008

Cuoricino achievements

- Provides the best limit to date on ^{130}Te half-life and a competitive limit on the Majorana mass of the neutrino
- Demonstrates the feasibility of a large scale bolometric detector with good energy resolution and background

From Cuoricino to CUORE

Sensitivity $F^{0\nu}$ **:** Lifetime corresponding to the minimum number of detectable events above background at a given C.L.



$$F^{0\nu} \sim \frac{a}{A}\sqrt{\frac{M \cdot T}{b \cdot \Delta E}}$$

isotopic abundance

atomic mass

active mass

live time

energy resolution

background level

increase by enrichment

increase size and number of crystals

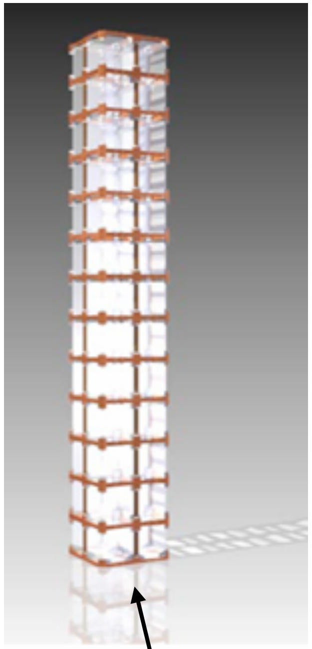
new procedure for **energy calibration**

improve system reliability and duty cycle

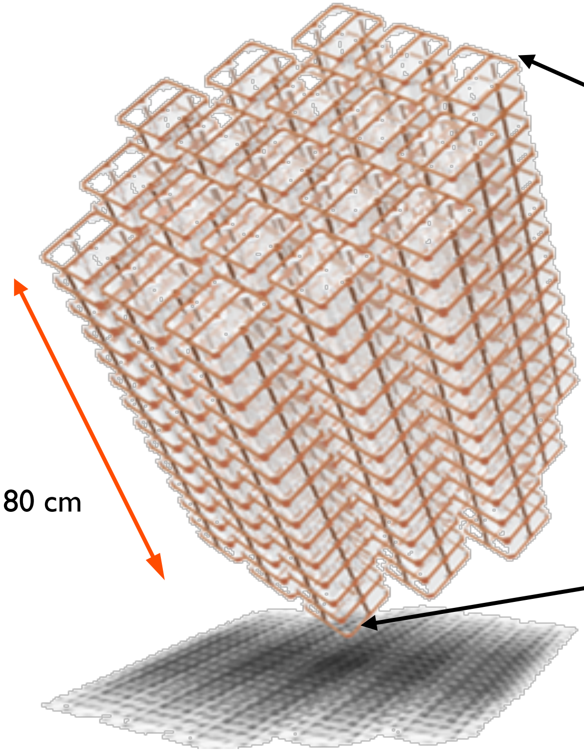
reduce background:
- material selection & handling
- shielding
- surface cleaning
- avoid recontamination
- improve detector design

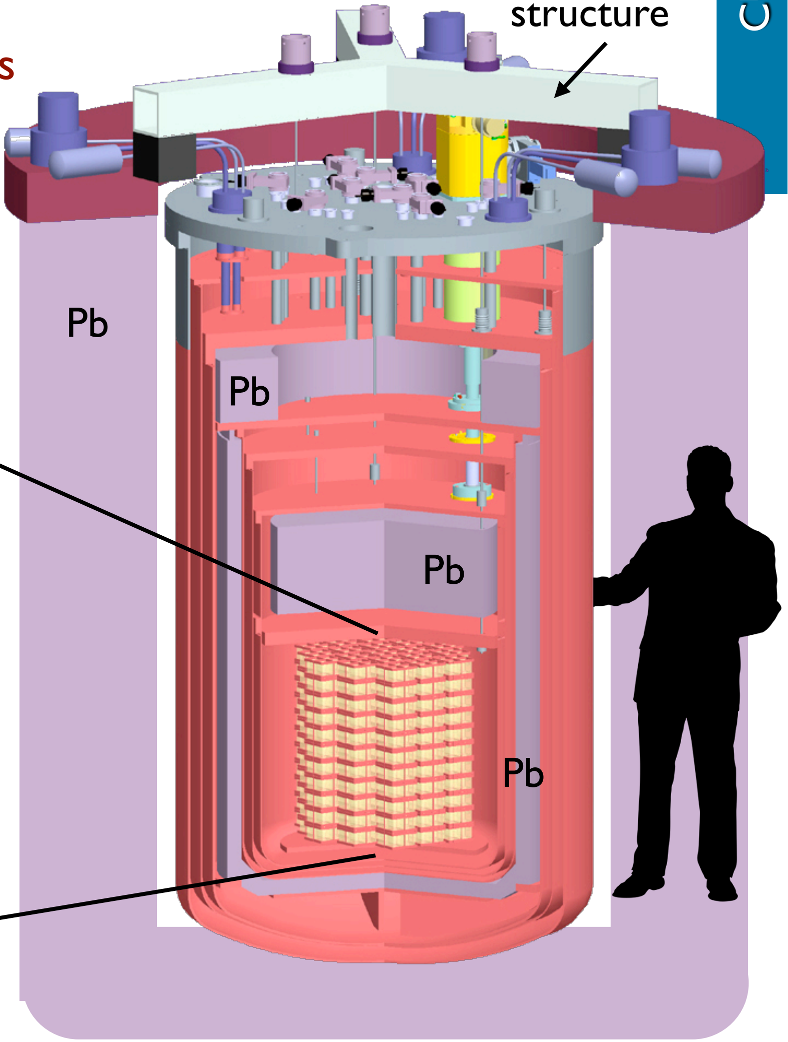
CUORE

Cryogenic **U**nderground **O**bservatory for **R**are **E**vents will be a tightly packed array of **988 bolometers** - M ~ 200 kg of ^{130}Te



19 Cuoricino-like towers with 13 planes of 4 crystals each



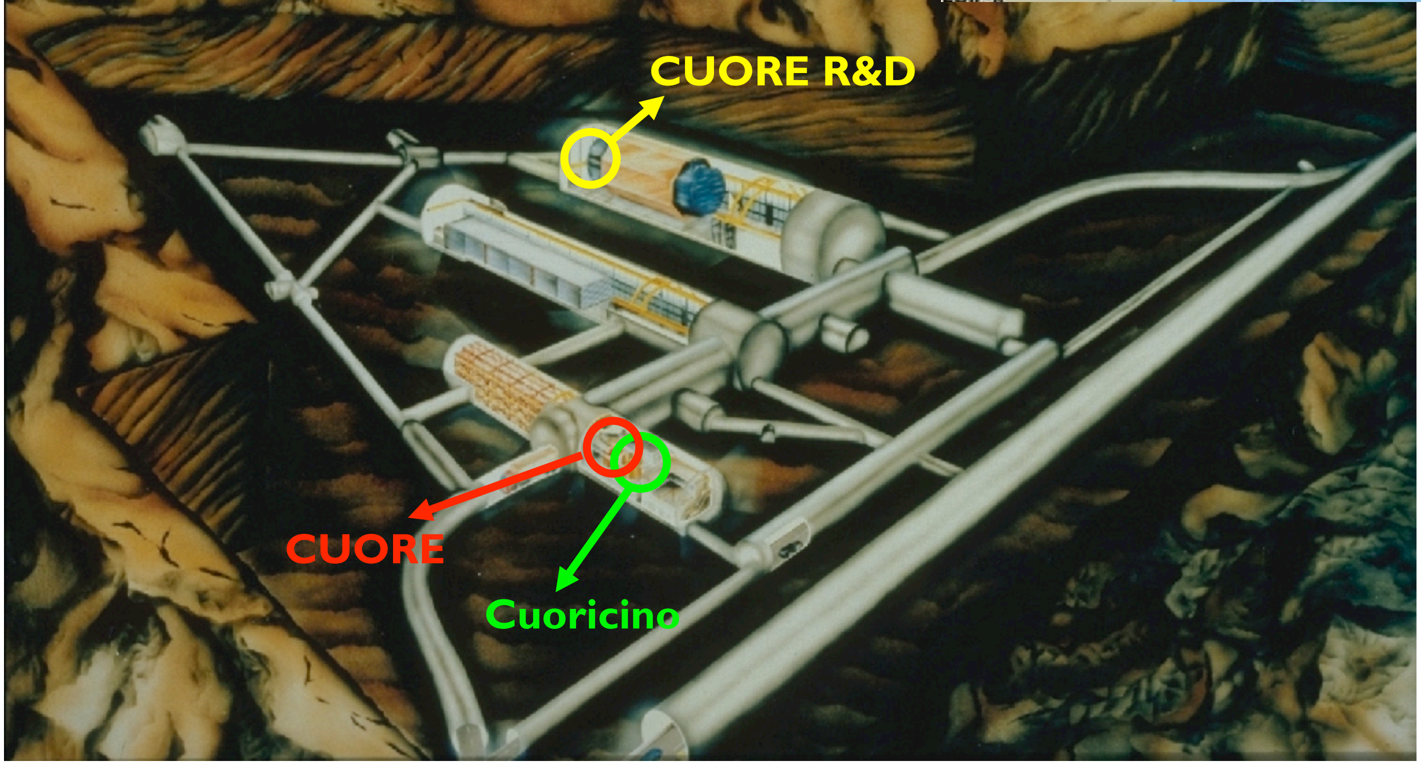


- Special cryostat built w/ selected materials
- Cryogen-free dilution refrigerator
- Shielded by several lead shields

CUORE @ LNGS

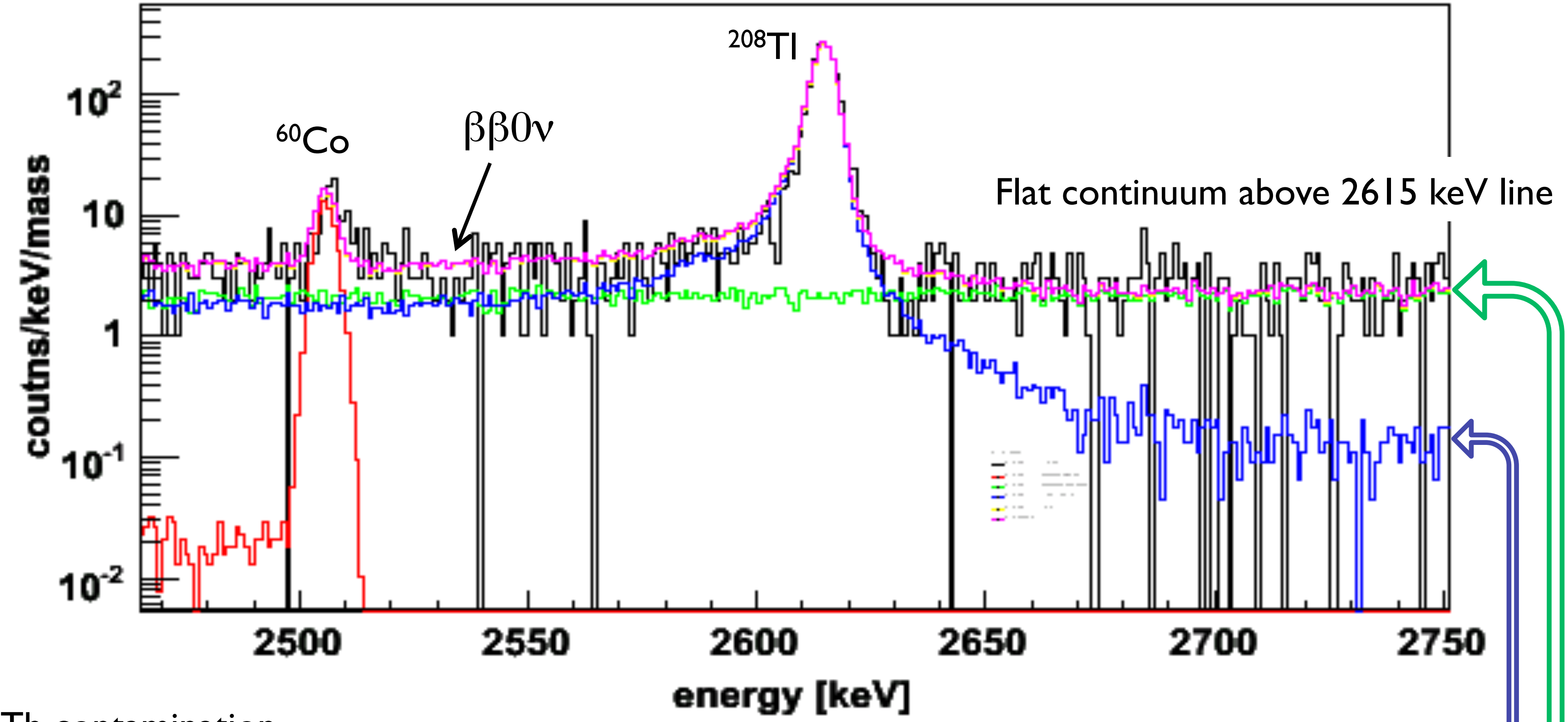
3200 m.w.e overburden

Laboratori Nazionali del Gran Sasso, Italy



Understanding Cuoricino background

Comparison of Cuoricino data with Monte Carlo simulations

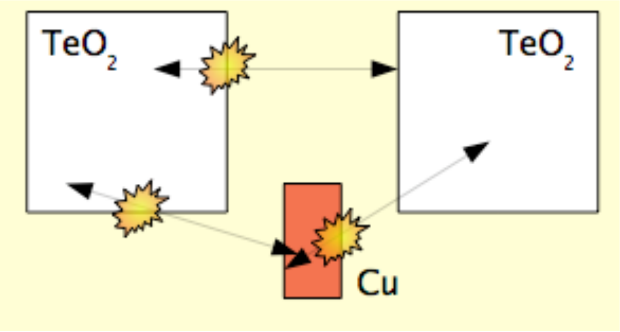


Flat continuum above 2615 keV line

U/Th contamination on surfaces

↓

degraded alphas



30 ± 5 % ^{232}Th in cryostat

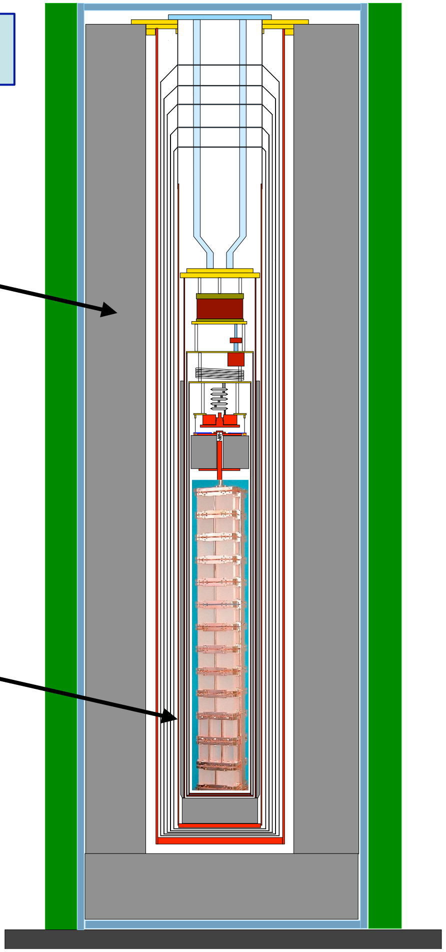
20 ± 5 % TeO$_2$ surface

50 ± 10 % Cu surface

in the ββ0ν region

From Cuoricino to CUORE: shielding

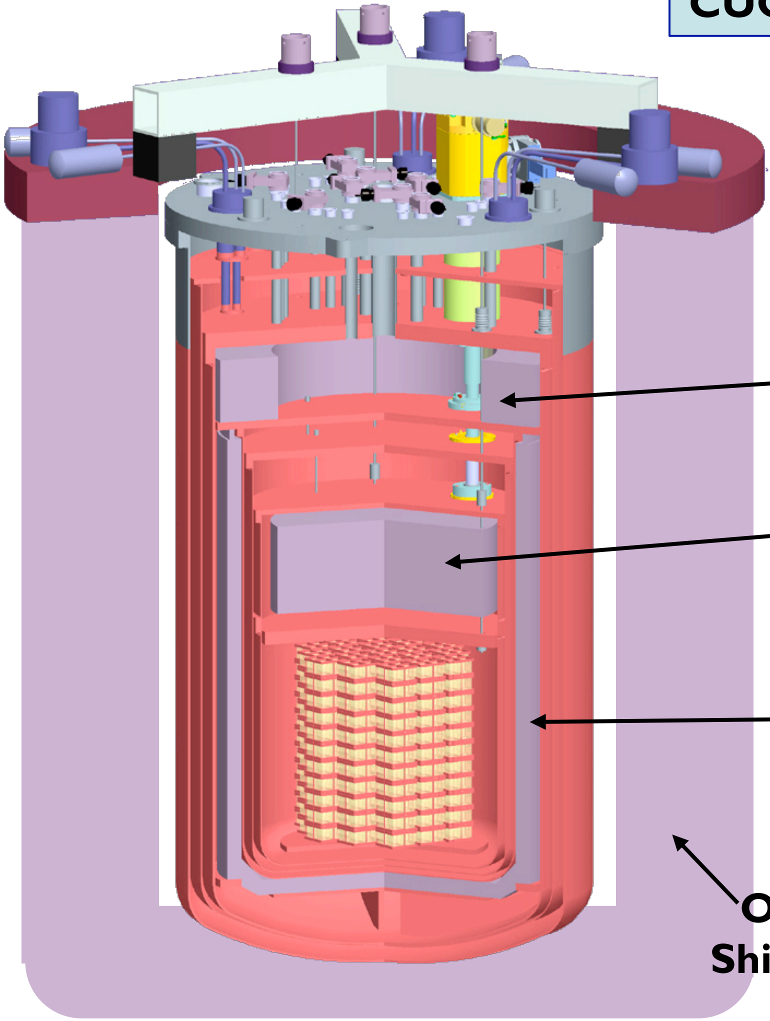
Cuoricino



20 cm lead

1.2 cm ancient lead

CUORE



Inner Shielding

25 cm lead

38 cm ancient lead

6 cm ancient lead

Outer Shielding

- Low radioactivity materials for cryostat parts
- Neutron shielding: Borated polyethylene box
- Sealed and flushed with Nitrogen to eliminate Radon

Prediction of CUORE background

- ^{232}Th from cryostat and environment
  - reduced by use of selected materials
  - improved shielding
- Muons, neutrons, and cosmogenic activation: negligible

- **Surface contaminations**

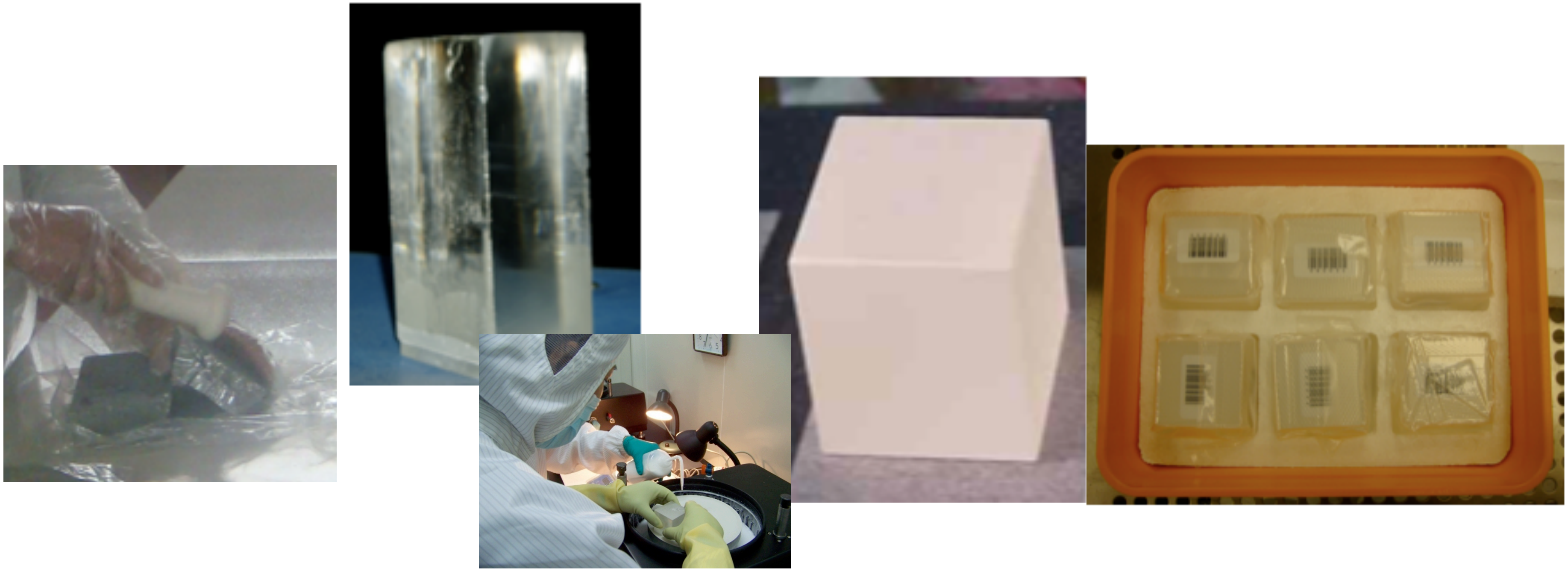
  R&D activity at LNGS demonstrated:
  - reduction of crystal surface contamination by a factor ~5
  - reduction of continuum background in 3-4 MeV region of a factor ~ 2

- Monte Carlo projected contaminations in CUORE based on measured contaminations, and Cuoricino and R&D results: **< 0.04 c/kg/keV/y**

CUORE background goal: < 0.01 c/keV/kg/y
still working to improve the background reduction

Background reduction in CUORE

- CUORE dedicated crystal growth facility @ SICCAS, China
  - definition of a precise production protocol
  - strict control of all materials, tools and supplies used during all production step



Te → oxide powder → crystal growth → cutting, grinding, shaping, lapping → packaging → shipment

Background reduction in CUORE

- CUORE dedicated crystal growth facility @ SICCAS, China
  - definition of a precise production protocol
  - strict control of all materials, tools and supplies used during all production step
- Copper surface cleaning
  - Tumbling, Electrochemical, Chemical, Magnetron sputtering (TECM) + Ultrasonic cleaning

Background reduction in CUORE

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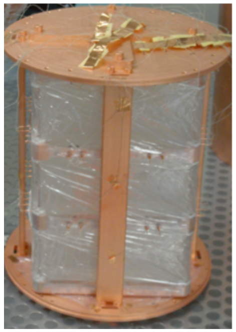
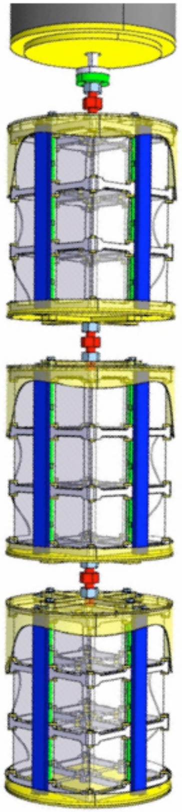
  - definition of a precise production protocol
  - strict control of all materials, tools and supplies used during all production step
- Copper surface cleaning
  - Tumbling, Electrochemical, Chemical, Magnetron sputtering (TECM) + Ultrasonic cleaning
  - Three Towers Test currently taking data at LNGS (12 bolometers for each tower)





Complete TECM procedure

Chemical cleaning

Copper covered by 50 μm of PET foil

Projected sensitivity for CUORE

Detector resolution: ~ 5 keV
Live time: 5 years

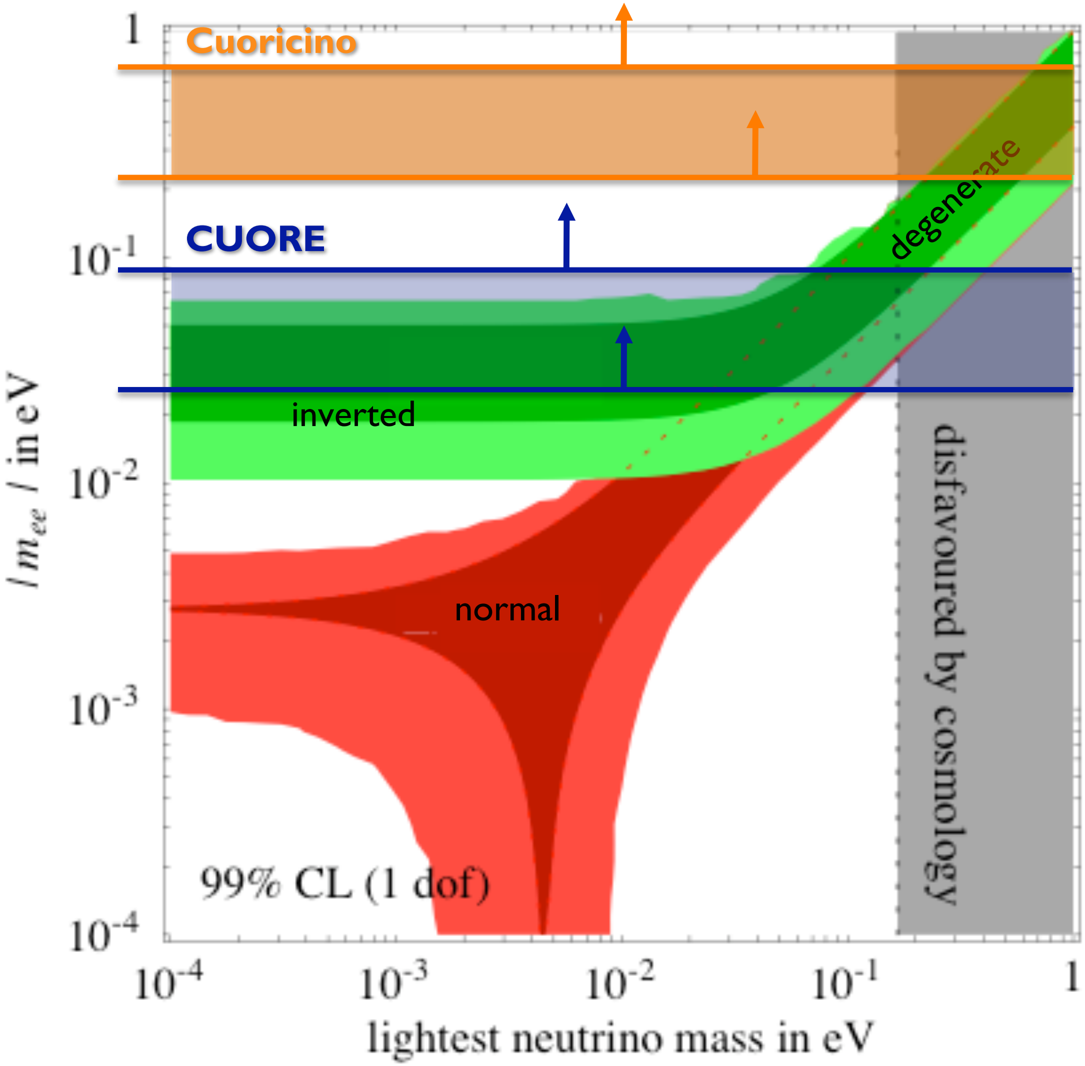
Background in $0\nu\beta\beta$ region
(conservative goal)
0.01 c/keV/kg/y

$T_{1/2}^{0\nu}$ (^{130}Te) > 2.1 x 10^{26} y
$m_{\beta\beta}$ < 24 - 83 meV

Background in $0\nu\beta\beta$ region
(demonstrated)
0.04 c/keV/kg/y

$T_{1/2}^{0\nu}$ (^{130}Te) > 1.0 x 10^{26} y
$m_{\beta\beta}$ < 34 - 117 meV

NME from Rodin et al, Nucl. Phys. A 776 (2006)
and erratum arXiv::nucl-th/0706.4304

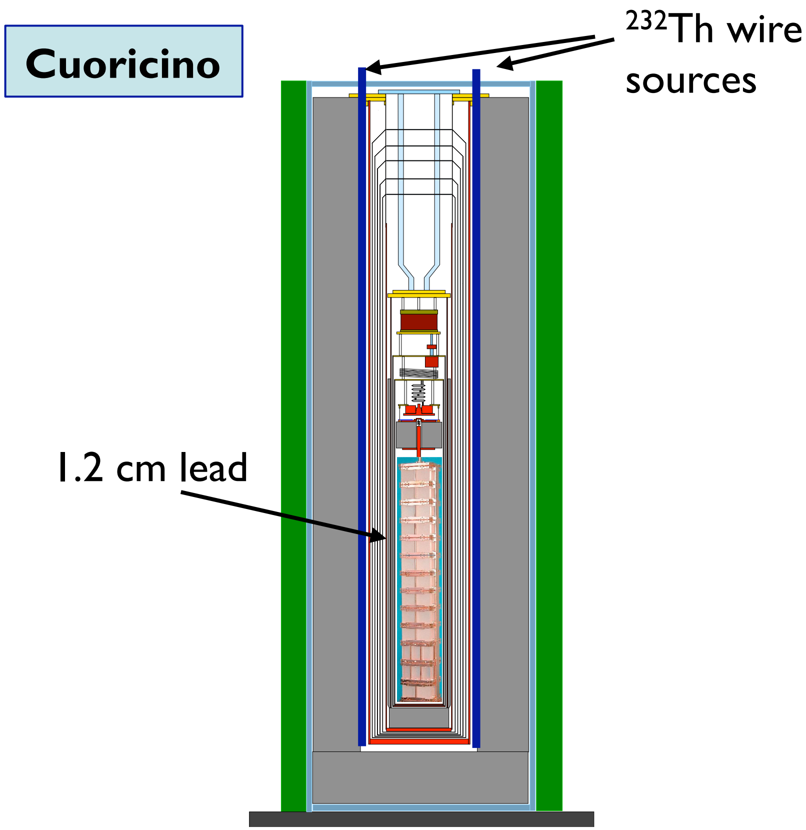


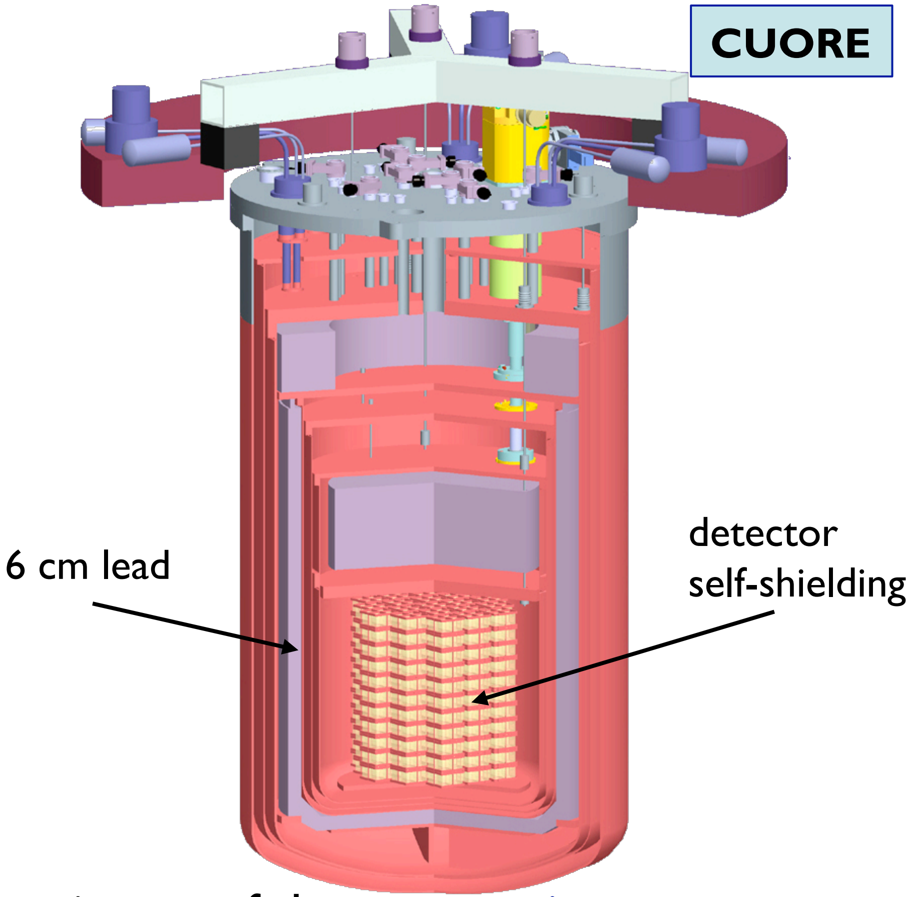
Strumia, Vissani arXiv:hep-ph/0606054v2

CUORE aims at probing the region of inverted mass hierarchy

From Cuoricino to CUORE: calibration

- For each bolometer, Voltage vs Energy relationship need to be experimentally measured on a regular basis
- Monthly calibration measurements with γ sources of known energies (^{232}Th)

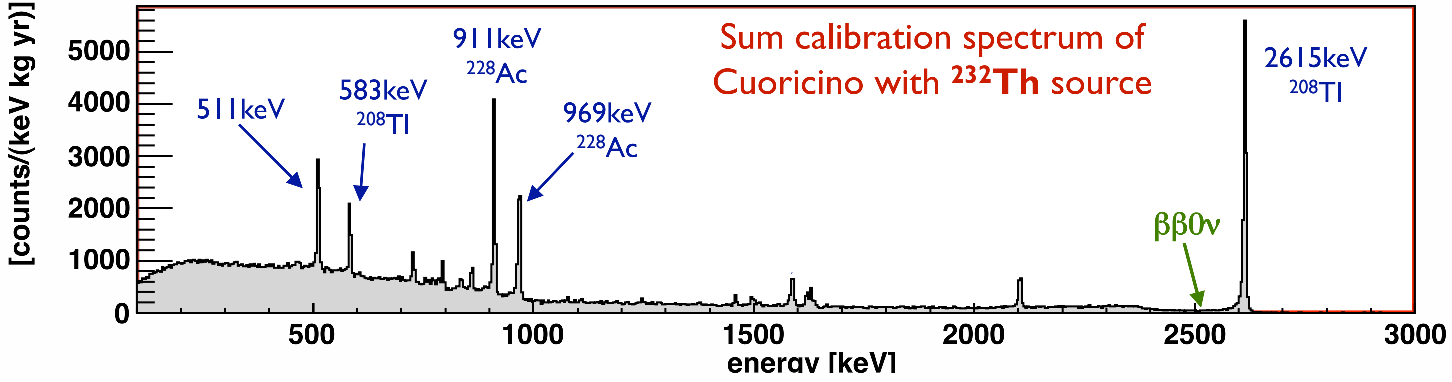




- The calibration uncertainty is one of the systematic errors in the determination of the ββ0ν half life

CUORE calibration requirements

- Uniform illumination of all detectors with 5 calibration lines clearly identified in the energy spectrum between 511 keV and 2615 keV



- Sources can be replaced. Other source isotopes can be used if necessary (e.g. ^{56}Co has been studied)

- Calibration time does not significantly affect detector live time

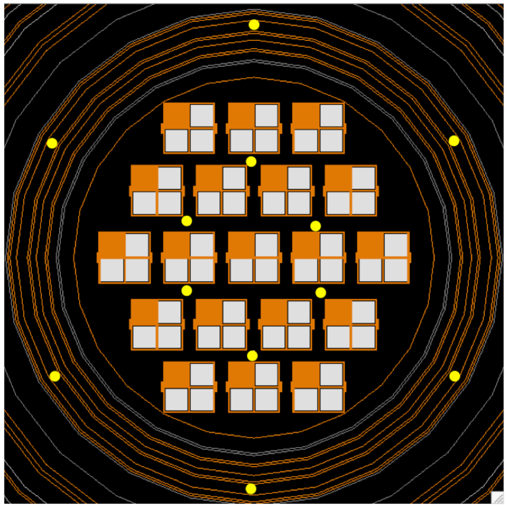
- Negligible contribution to radioactive background in the ββ0ν region

- Minimize the uncertainty in the energy calibration. Goal: residual calibration uncertainty in ββ0ν region < 0.05 keV

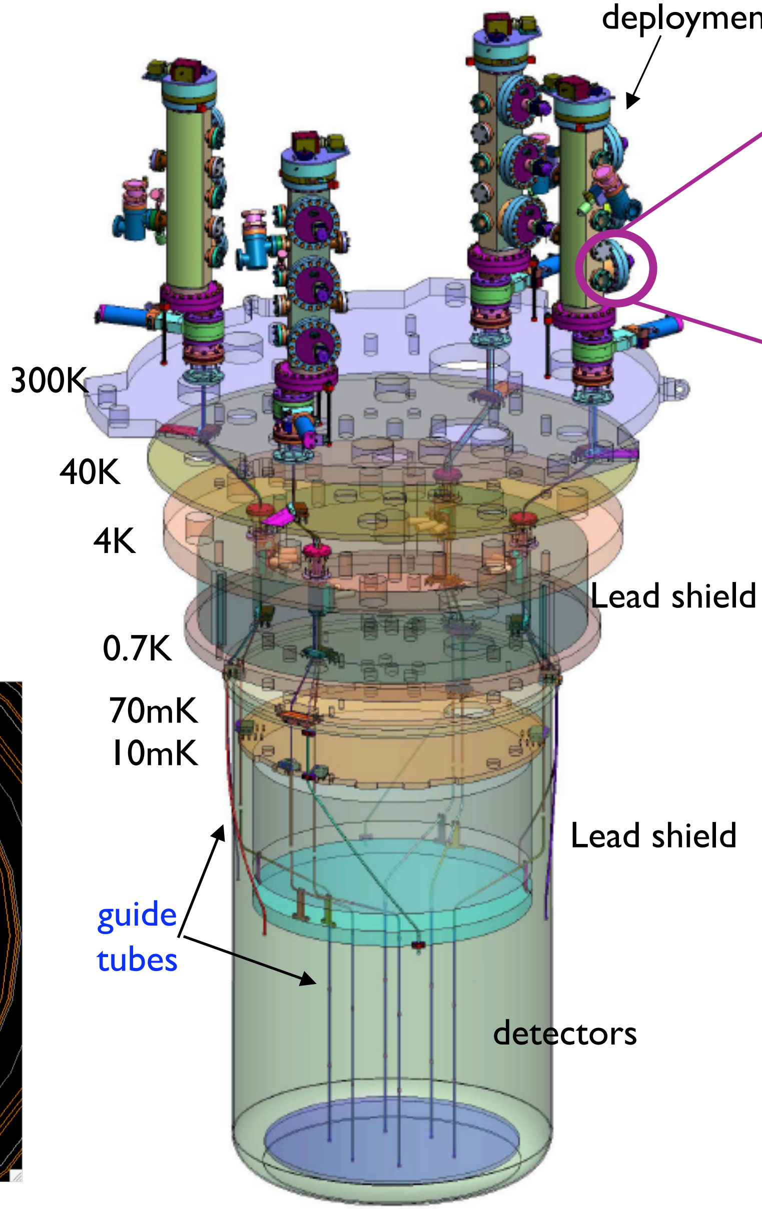
CUORE calibration system

Insertion of 12 γ sources that are able to move, under their own weight, through a set of guide tubes that route them from the deployment boxes on the 300K flange down into position in the detector region

source locations



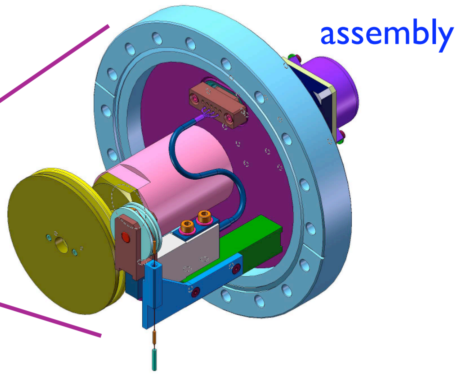
top view of detector array with source positions



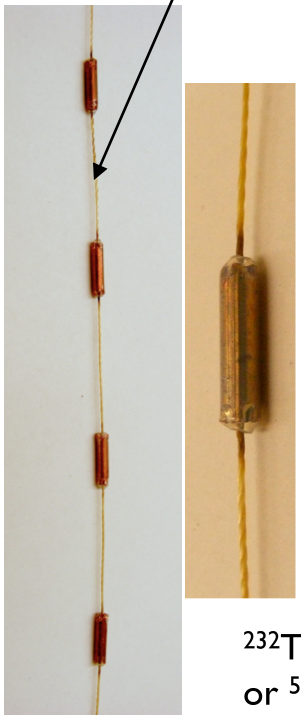
computer controlled motion box for source deployment

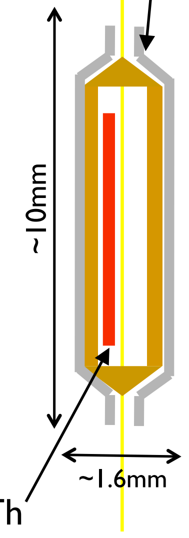
guide tubes

drive assembly



radioactive capsules crimped on a Kevlar string





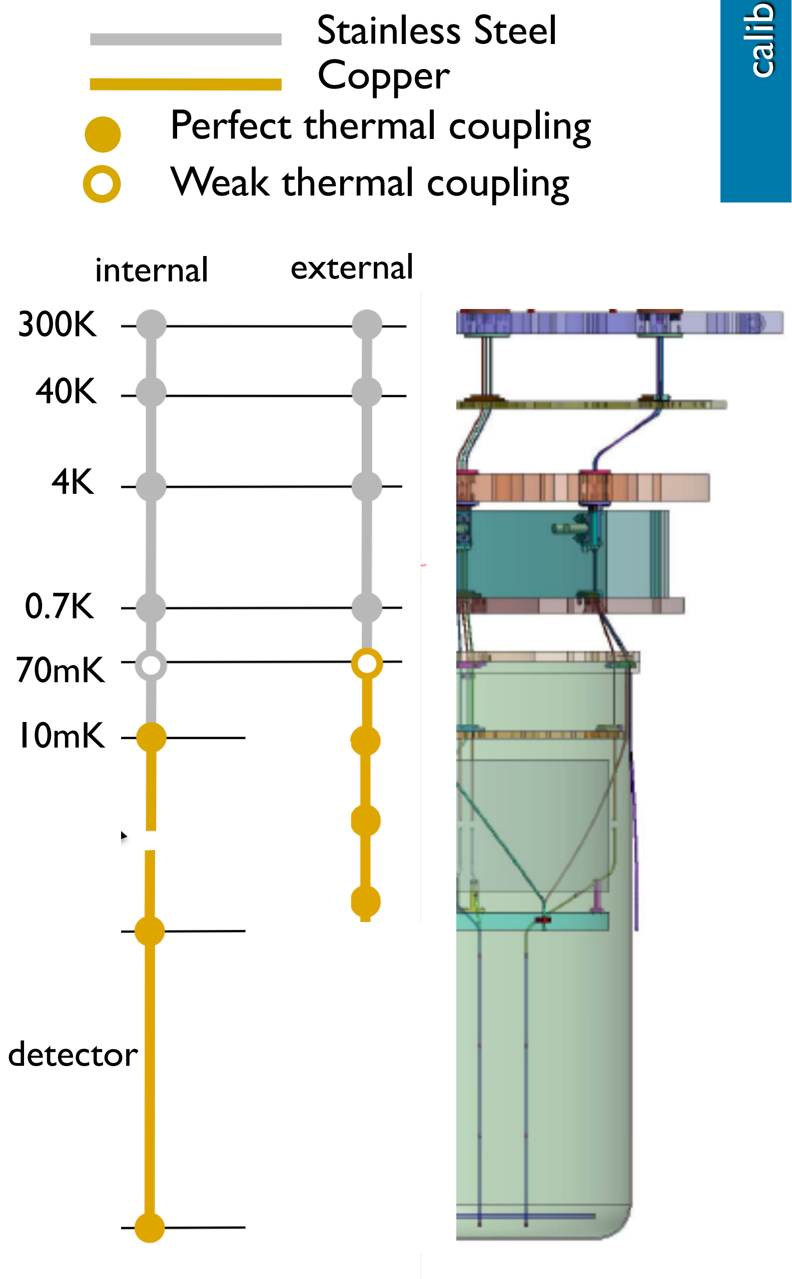
Cryogenic considerations

Sources of heat load:

- Conductance of the guide tubes
- Radiation funneled by guide tubes
- Conductivity of source string
- Radiation emitted by the source string

Stage	T [K]	Cooling power available to calibration [W]	Static heat load from guide tubes	Radiation from source string at 4K
40K	40 – 50	~ 1	~1	--
4K	4 – 5	0.3	0.02	--
0.7K	0.6 – 0.9	0.55m	0.13m	0.08μ
70mK	0.05 – 0.1	1.1μ	negligible	0.3μ
10mK	0.01	1.2μ	1.07μ	0.08μ
detector	0.01	< 1μ	--	0.25μ

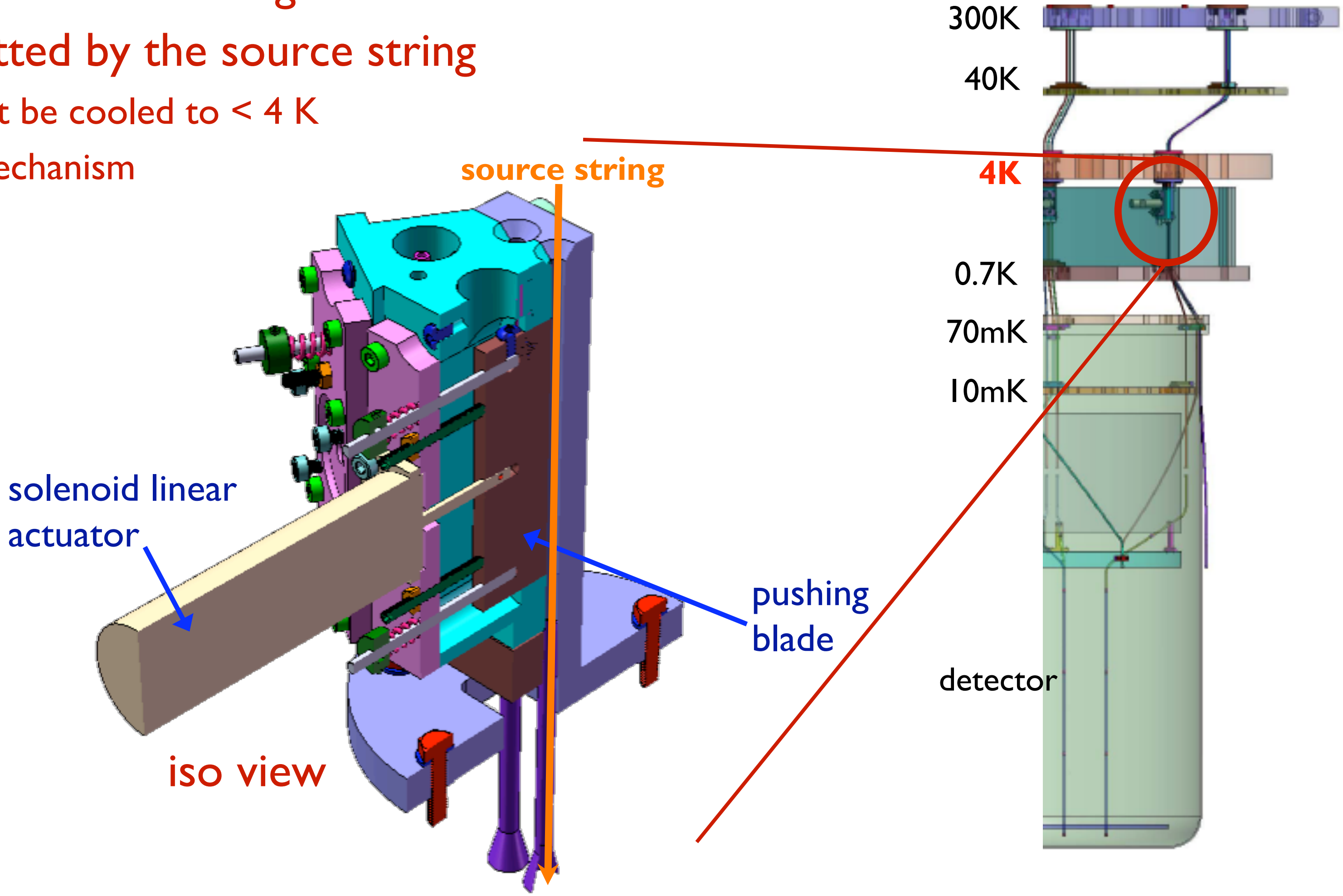
Scheme of guide tube materials and thermal couplings



Challenges for calibration

Sources of heat load:

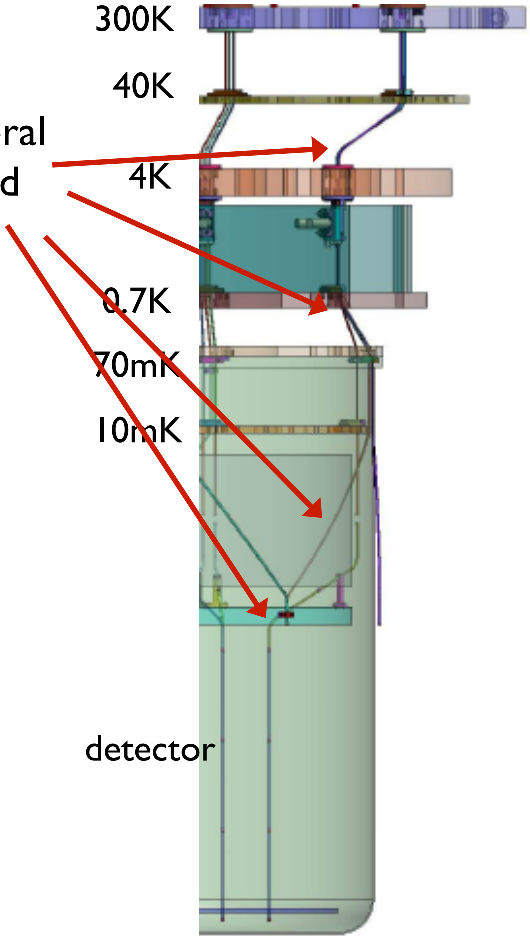
- Conductance of the guide tubes
- Radiation funneled by guide tubes
- Conductivity of source string
- Radiation emitted by the source string
  - sources must be cooled to < 4 K
  - squeezing mechanism



Challenges for calibration

Sources of heat load:

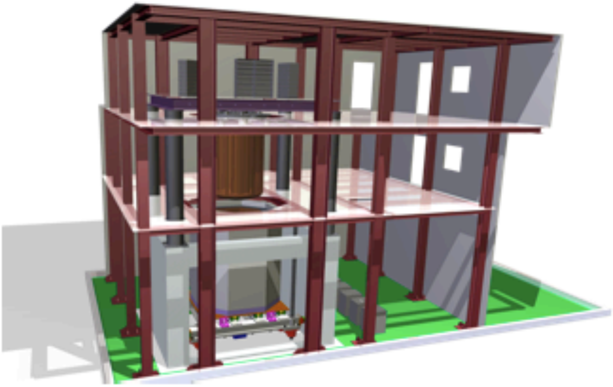
- Conductance of the guide tubes
- Radiation funneled by guide tubes
- Conductivity of source string
- Radiation emitted by the source string
  - cooling mechanism required at 4K
- Friction during insertion/extraction
  - sliding friction + exponential friction at bends
  - low friction materials
  - source staggering
  - speed adjustment



each guide tube routing has several bends and sloped sections

CUORE construction status

- CUORE has a dedicated site in Hall A at LNGS
- CUORE building and cryostat support structure are completed
- The cryostat has been purchased. Delivery of dilution unit and flanges in early 2010



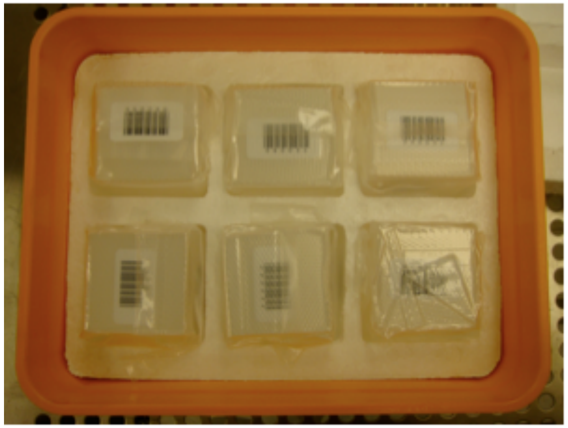
January 2008

June 2008

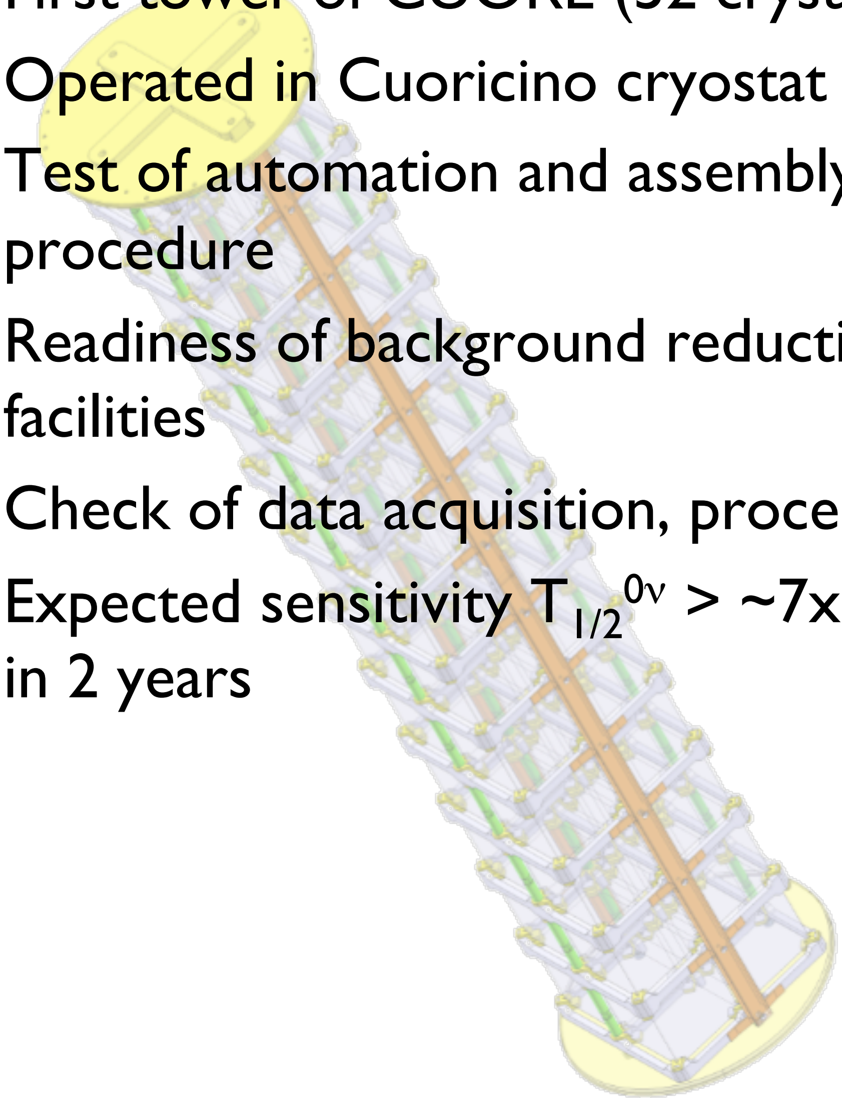
May 2009

CUORE construction status

- Production of 1000 crystals started in 2008
- 157 crystals have been already delivered to LNGS and safely stored
- For each shipment, 4 samples are operated as bolometers to check performance and contamination
  - Bulk: < 10^{-13} g/g ^{238}U and ^{232}Th
  - Surface: < 10^{-8} Bq/cm^2
  - energy resolution < 5 keV



The next step: CUORE-zero



- First tower of CUORE (52 crystals)
- Operated in Cuoricino cryostat
- Test of automation and assembly procedure
- Readiness of background reduction facilities
- Check of data acquisition, processing
- Expected sensitivity $T_{1/2}^{0\nu} > \sim 7\times10^{25}$ y in 2 years

CUORE schedule

2009 **2010** **2011** **2012**

3-tower test → **CUORE-0 construction** → **CUORE-0 data taking**

background R&D

assembly tests

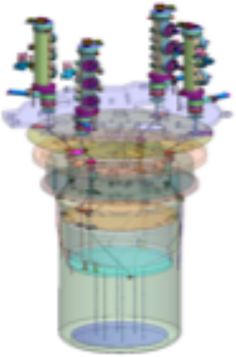
single tower assembly (in Cuoricino cryostat)

CUORE construction → **CUORE data taking**

utilities

clean room

external shielding



cryostat assembly

calibration system 4k test

cryostat test cooldown

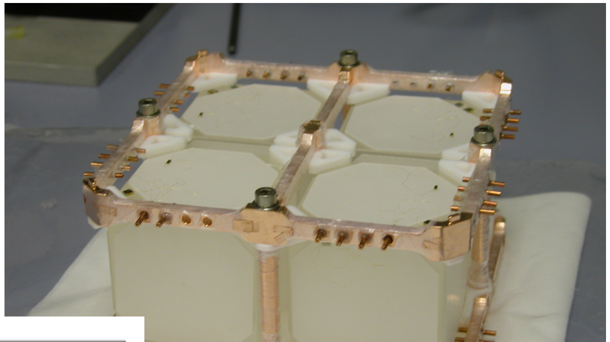
detector assembly: - 18+1 towers

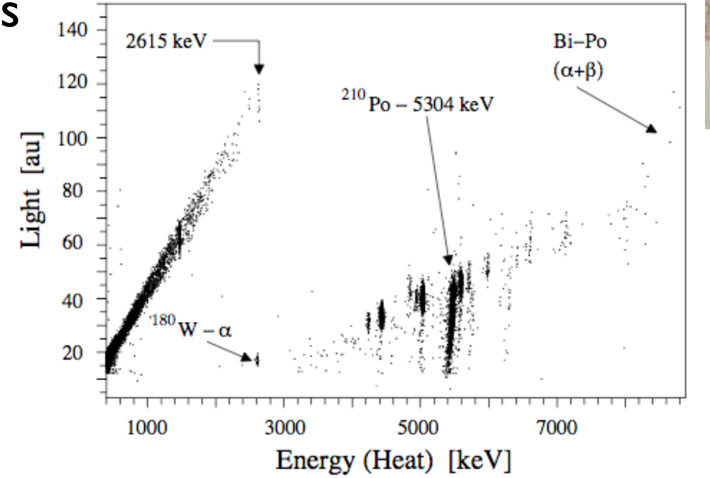
- ~1000 detectors

front-end electronics DAQ

Beyond CUORE …

- Isotopic enrichment of ^{130}Te
  - up to > 2x more sensitive on ^{130}Te half-life
  - no change needed to the experimental infrastructure
- Use other isotopes
  - some compounds of Mo, Cd or Ge have been already tested bolometrically with success
- Advanced detectors
  - discriminate surface contamination
  - surface sensititive bolometers
  - scintillating bolometers





Conclusions

- Cryogenic detectors represent a well established and competitive technique for $0\nu\beta\beta$ search.

- Cuoricino demonstrated the feasibility of a large cryogenic detector with high energy resolution and low background. It also provided the most stringent limit on ^{130}Te $\beta\beta0\nu$ half life: $T_{1/2}^{0\nu} \geq 2.9 \times 10^{24}$ y

- CUORE is based on the outstanding experience and knowledge gained with Cuoricino and aims at exploring the region of the inverted hierarchy of neutrino masses, with a sensitivity $T_{1/2}^{0\nu} \geq 2.1 \times 10^{26}$ y

- The CUORE collaboration has made good progress in reducing the background and developing a calibration system. With the techniques at hand, we are confident we can reach our goals.

- The construction of CUORE is already started.

CUORE collaboration

18 Institutions

64 European collaborators
32 US collaborators
5 Chinese collaborators

Backup slides

Calibration of bolometers

- Bolometer are operated as perfect calorimeters
  - energy is the most relevant information extracted
- For each bolometer:
  - Voltage vs Energy relationship is needed
  - Calibration with γ sources of known energies (e.g. ^{232}Th)
  - The pairs (E_i,V_i) are fitted with a proper calibration function
  - The calibration measurement is performed regularly (~ monthly)

- The calibration uncertainty is one of the systematic errors in the determination of the ββ0ν half life

spectrum of single channel and single dataset