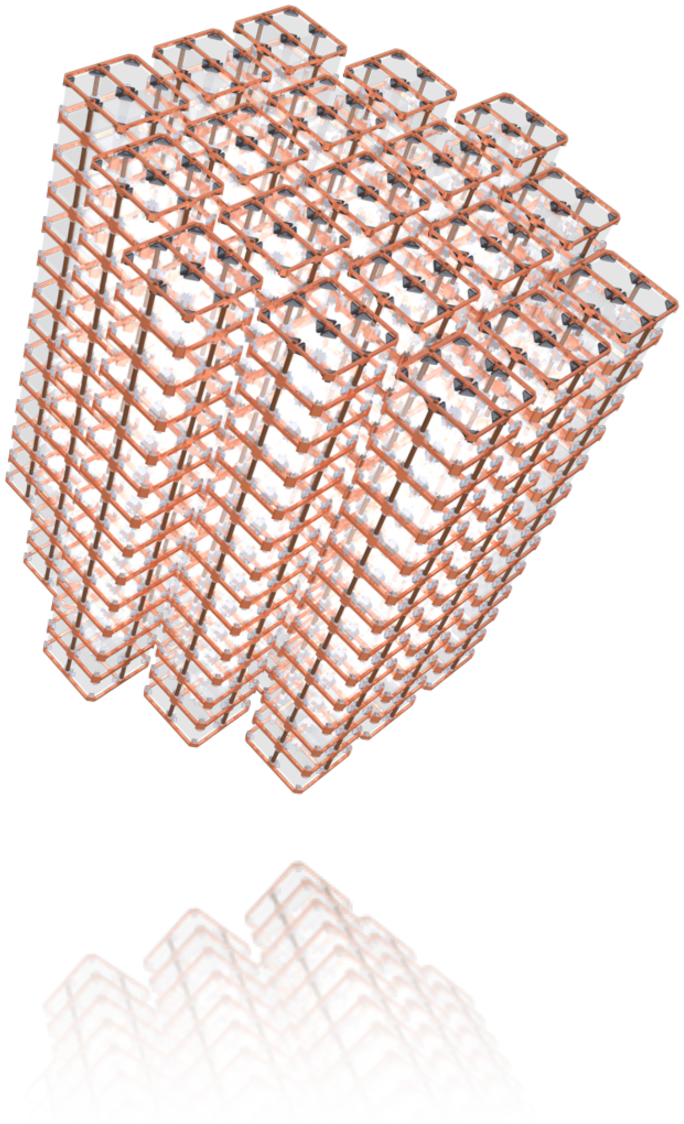
CUORE

Cryogenic Underground Observatory for Rare Events



Carlo Bucci

INFN - Laboratori Nazionali del Gran Sasso

The CUORE collaboration

CUORE

BERKELEY LAB

UCLA

Lawrence Livermore National Laboratory

SINAP

INFN Istituto Nazionale di Fisica Nucleare

UNIVERSITA' DEGLI STUDI DI MILANO BICOCCA

CAL POLY

THE UNIVERSITY of WISCONSIN MADISON

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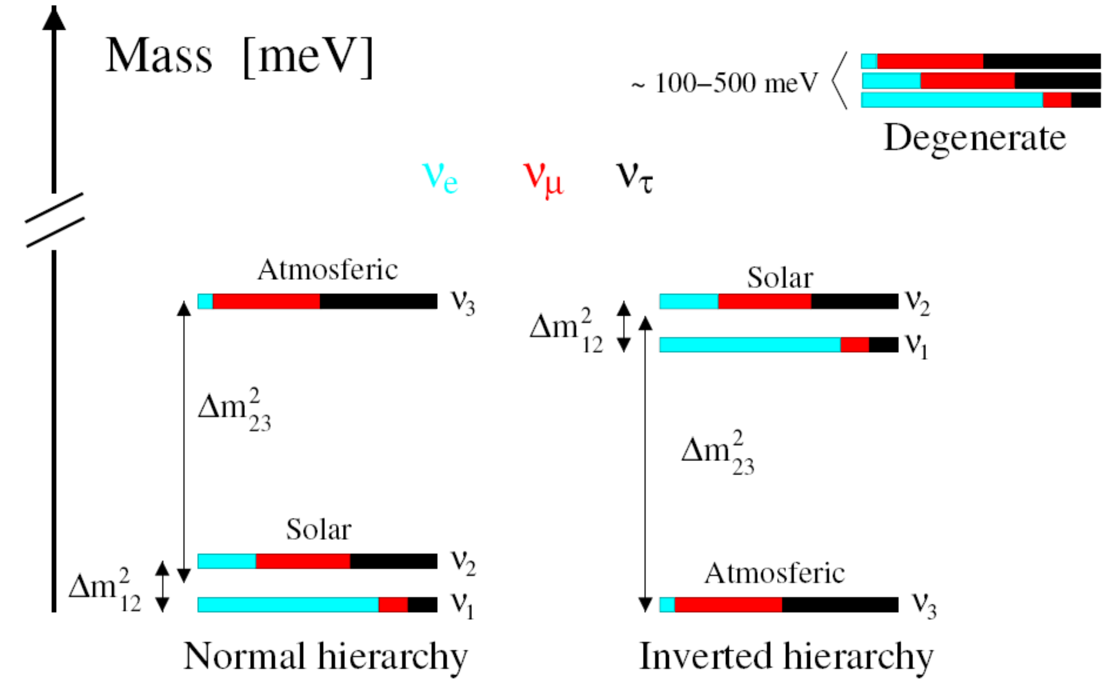
Neutrinoless Double Beta Decay

- 0ν-DBD is a fundamental tool to determine neutrino properties
  - Dirac or Majorana nature
  - Absolute mass scale
  - Mass hierarchy



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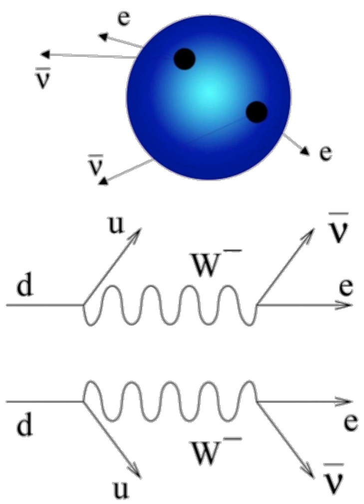
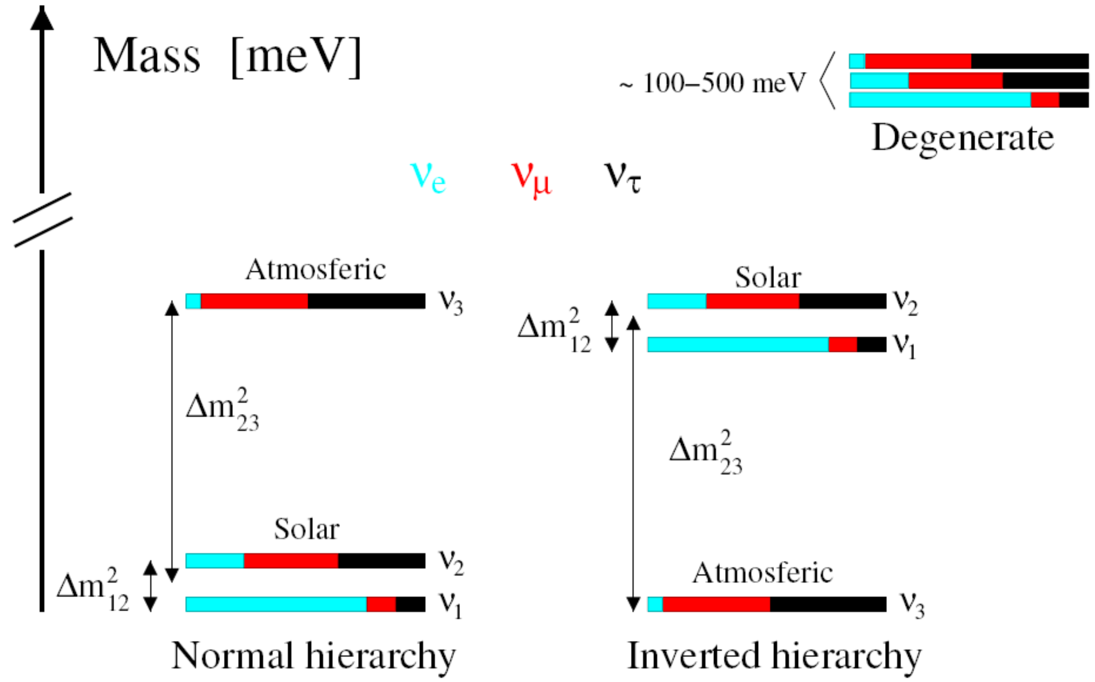


$$(A, Z) \rightarrow (A, Z+2) + 2e^-$$

- 2ν-DBD
  - 2^{nd} order process allowed in the SM
  - observed in several nuclei with $\tau^{2\nu} \sim 10^{19}$-10^{21} y



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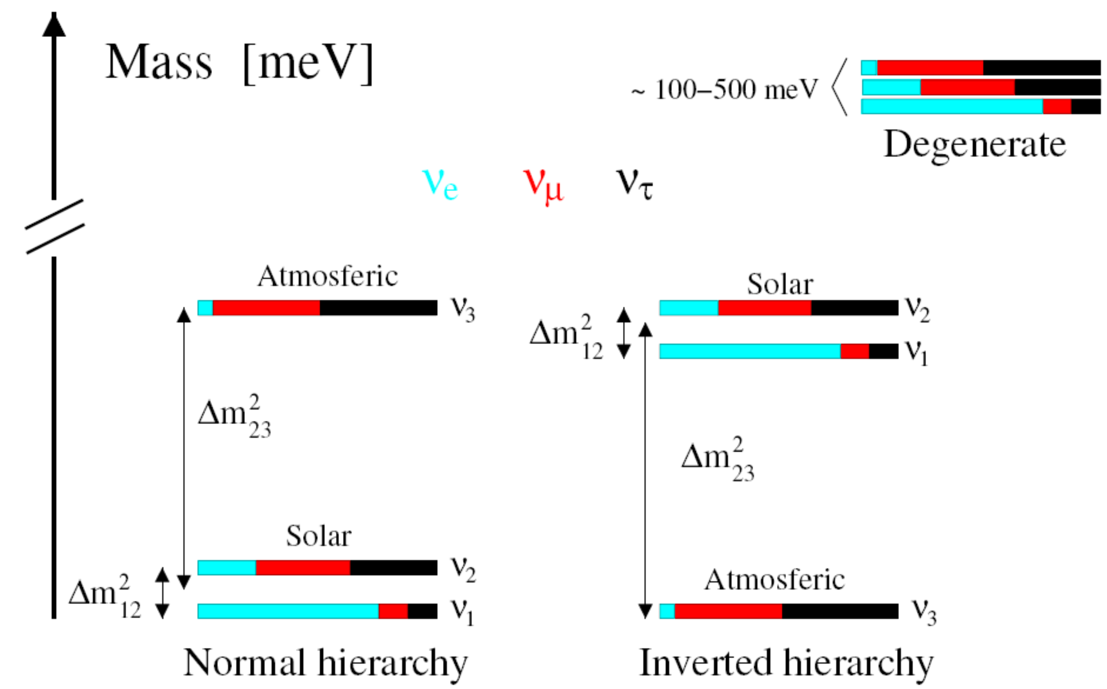

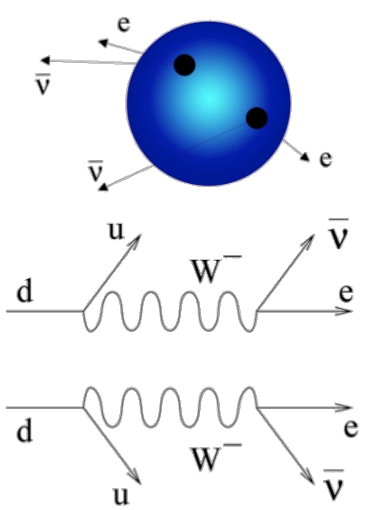

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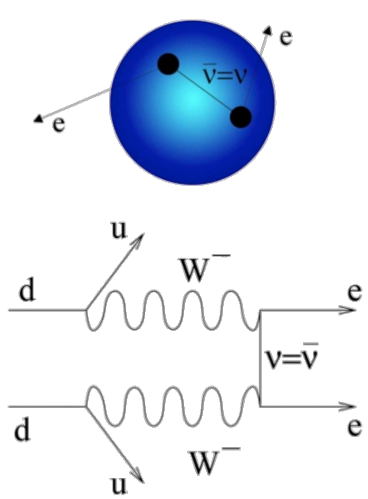

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  - $\tau^{0\nu} > 10^{24}$-10^{25} y
  - exists if neutrino is a Majorana particle and $m_\nu \neq 0$

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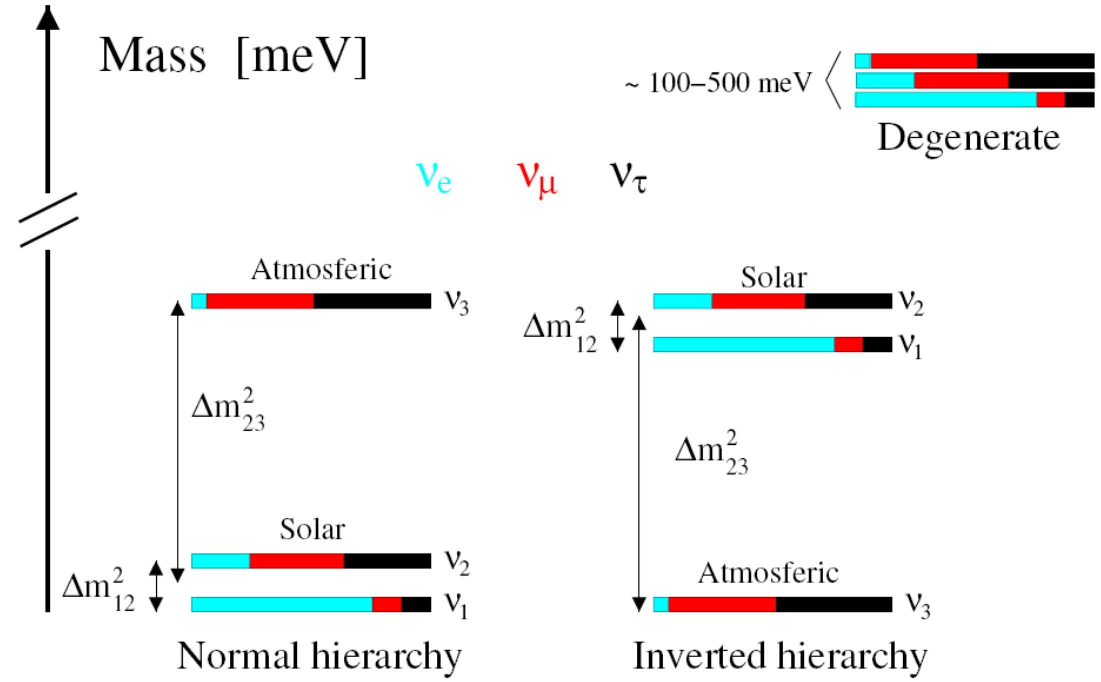

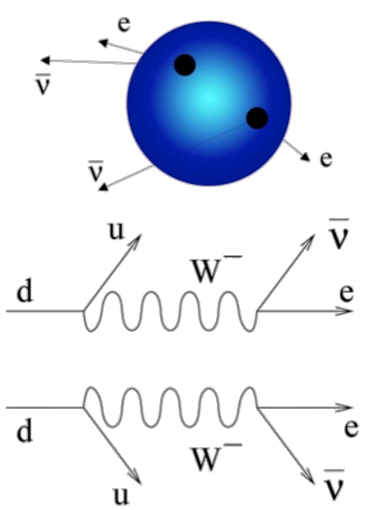

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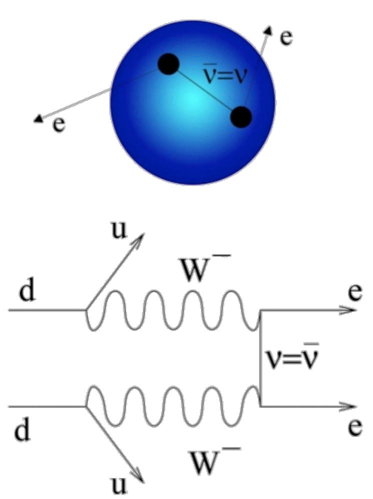

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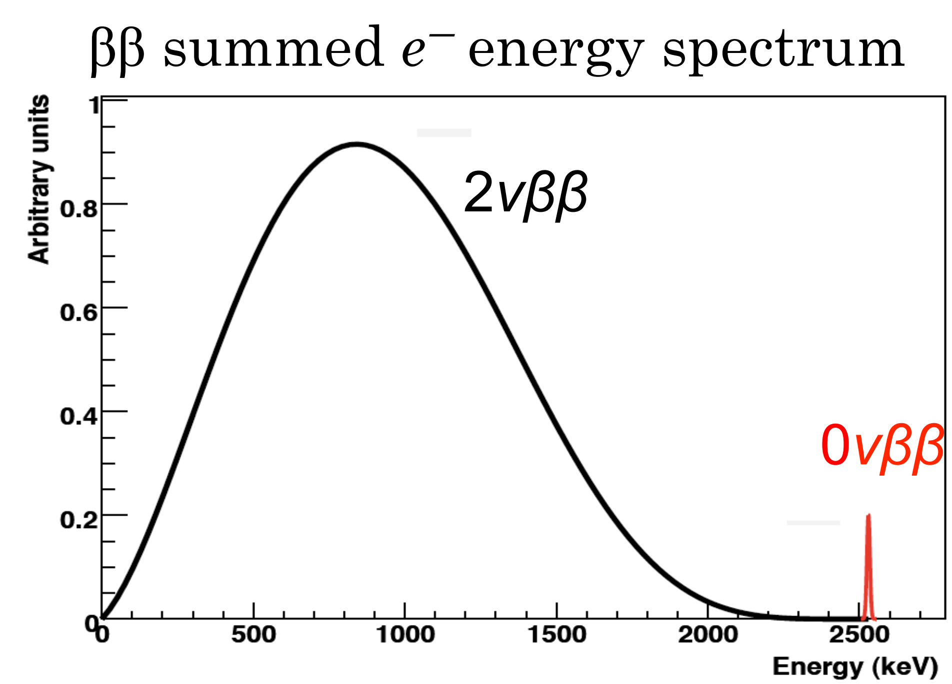


Sensitivity

- Half-life corresponding to the maximum signal n_B that could be hidden by the background fluctuations at a given statistical C.L.

$$T_{0\nu}^{1/2}(n_\sigma) = \frac{ln(2)}{n_\sigma} \frac{N_A \cdot i.a. \cdot \epsilon \cdot \eta}{W} \sqrt{\frac{M \cdot T}{\delta E \cdot b}} \cdot f(\delta E)$$

- M is the total active mass
- T is the total live time
- b is the background
- η is the stoichiometric coefficient of the 0νββ candidate
- W is the molecular weight of the active mass
- N_A is the Avogadro constant
- a.i. is the isotopic abundance
- ε is the detector efficiency
- δE energy range around the Q-value
- f(δE) fraction of signal events in δE

Above expression derived in the Gaussian approximation (not fully accurate for very-low-background experiments): useful to illustrate the qualitative relationship between sensitivity and, e.g., resolution.

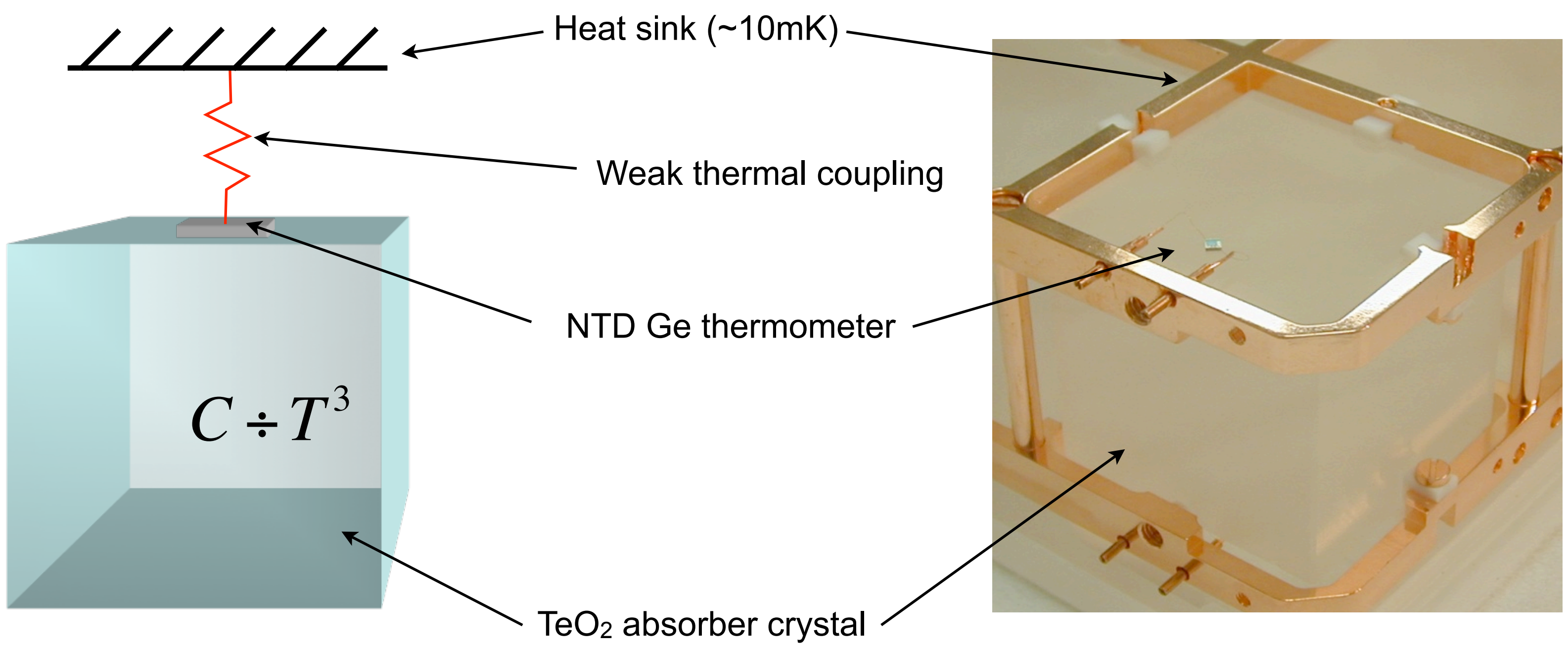
We use the Poisson extension of this expression at the 1σ significance level to calculate sensitivity curves for CUORE-0 and CUORE

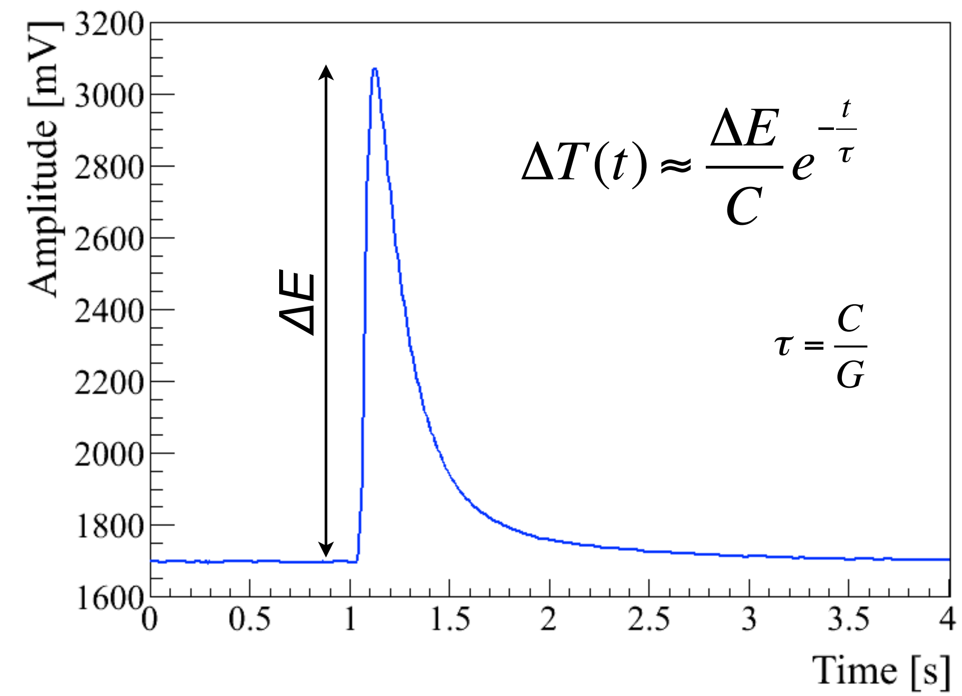
Assuming δE = ΔE:

$$T_{0\nu} \propto \frac{i.a. \cdot \epsilon \cdot \eta}{W} \sqrt{\frac{M \cdot T}{\Delta E \cdot b}}$$

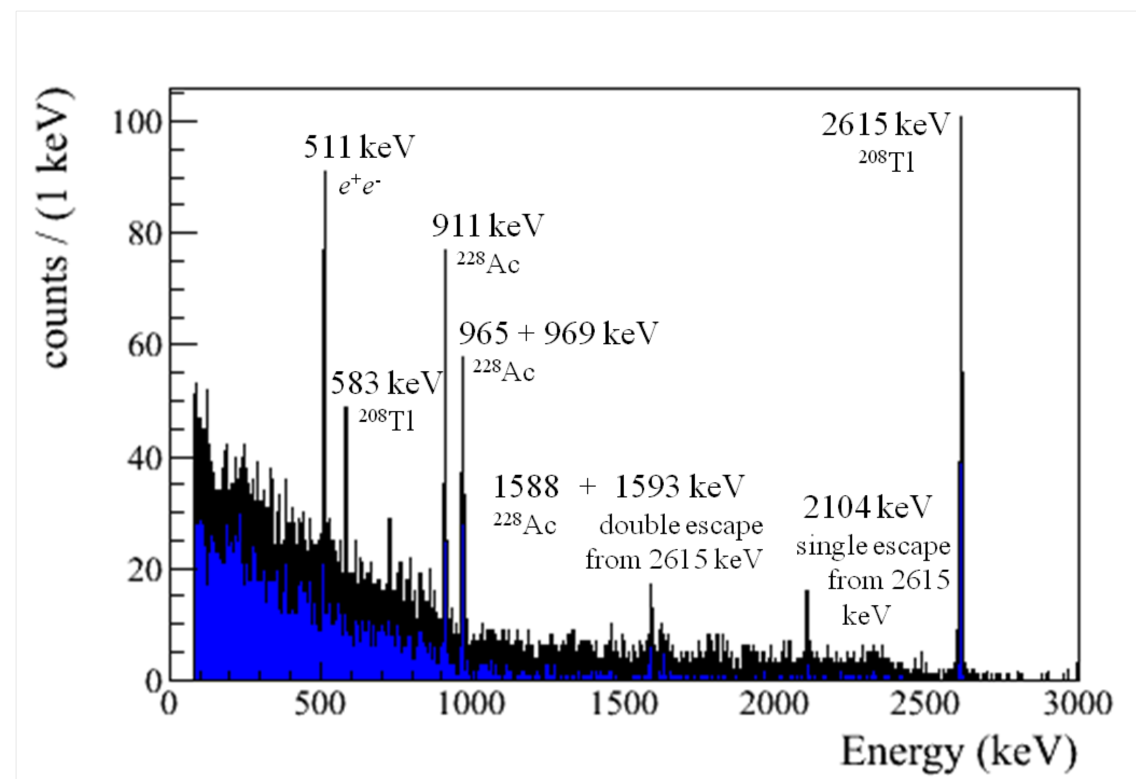
$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu}(Q,Z) \ \ |M^{0\nu}|^2 \ \ \frac{|\langle m_{\beta\beta}\rangle|^2}{m_e^2}$$

Thermal detectors





- wide choice of detector materials (TeO_2, $CaWO_4$, Ge, Si, Al_2O_3, $CaMoO_4$, BGO, Pb, etc.)
  - C sufficiently low @ T_{work}
- excellent energy resolution (~ 1 ‰ FWHM)
  - huge number of energy carriers (phonons)
- detector response independent from type of incident particle
  - true calorimeters
- slowness (in rare event search doesn't matter)



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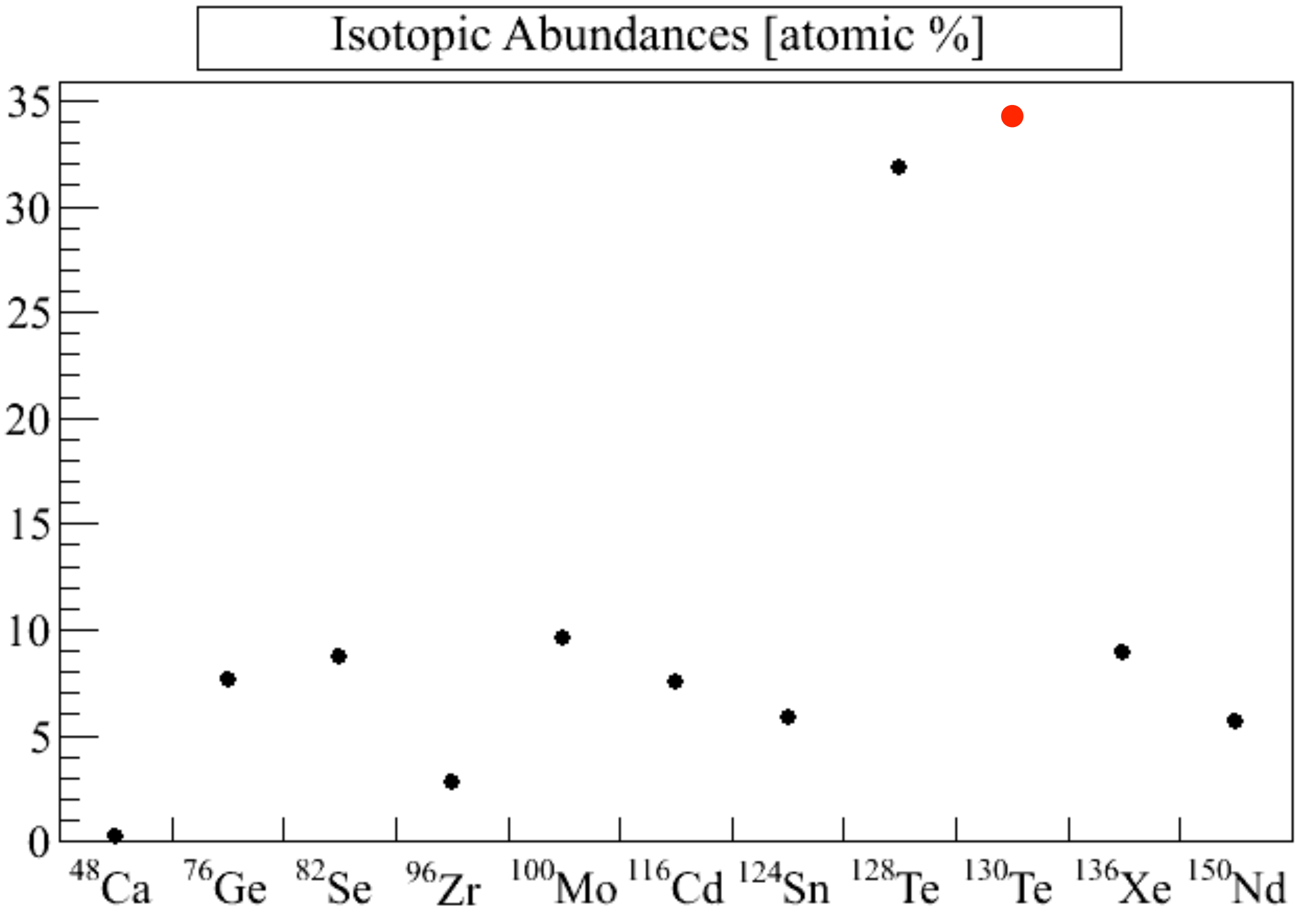
  - ^{130}Te isotopic abundance: 33.4%



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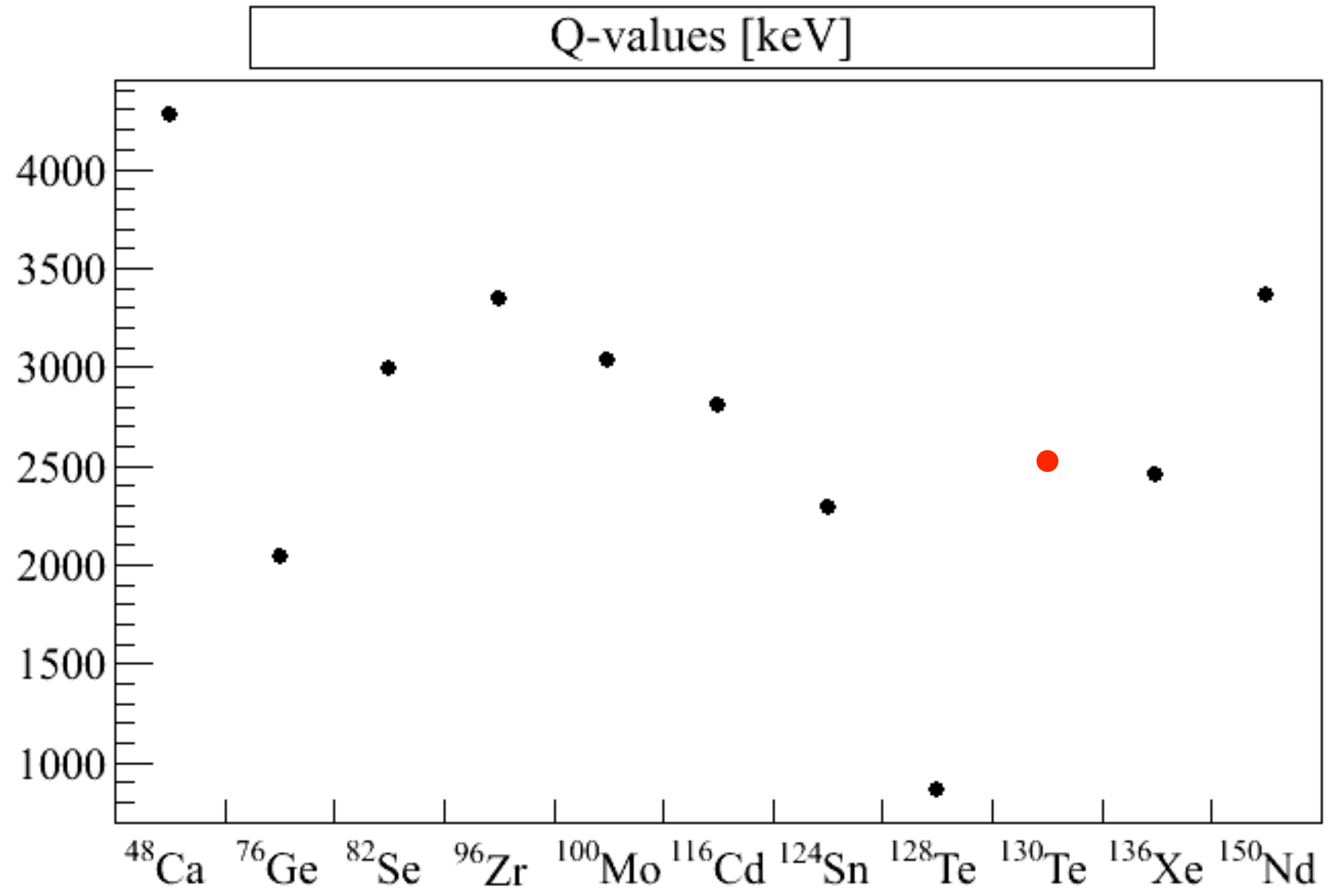
→ ^{130}Te → TeO_2

- Isotopic abundance: as high as possible
- Q-Value: as high as possible

- Q-value: 2527 keV



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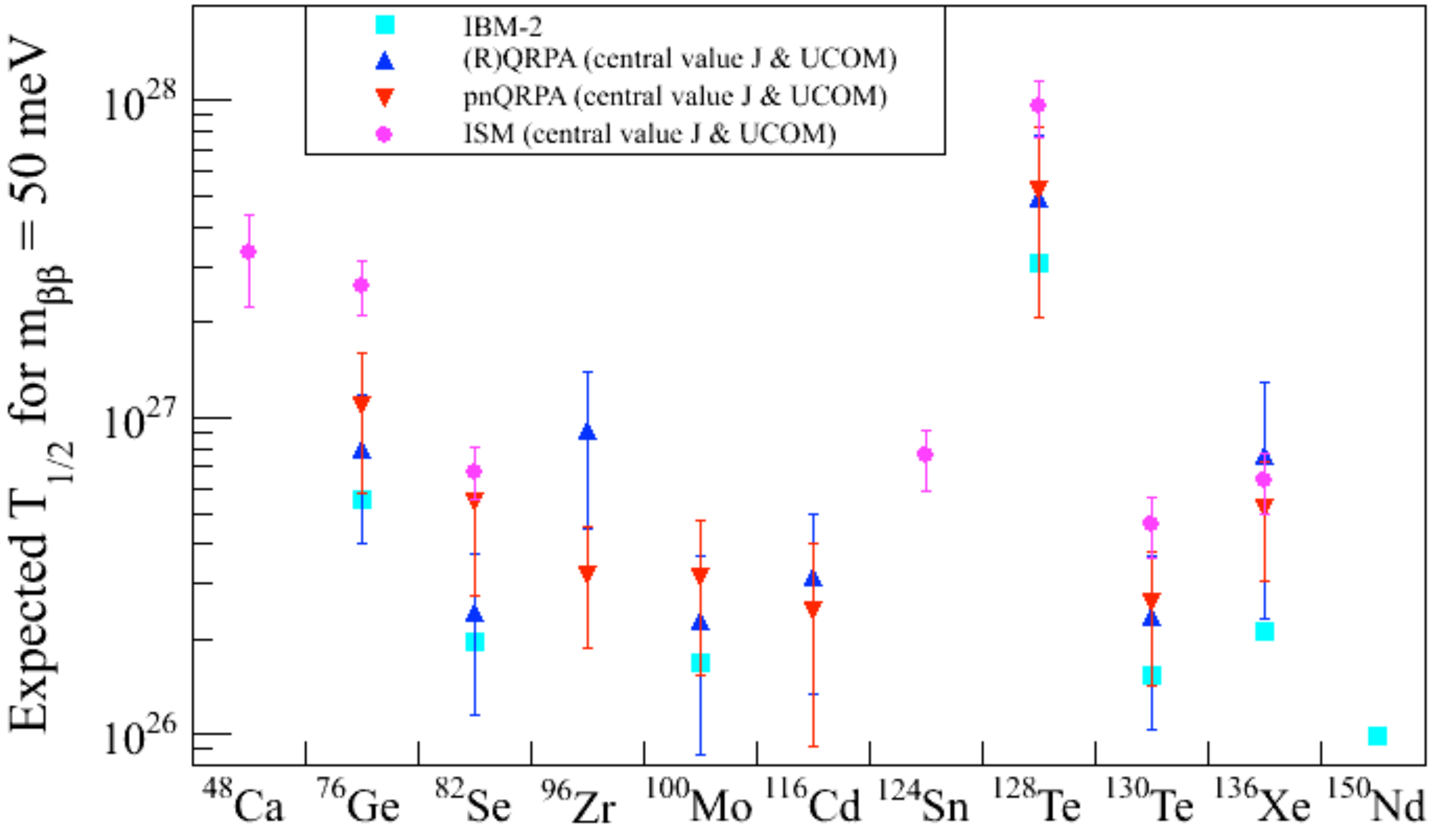

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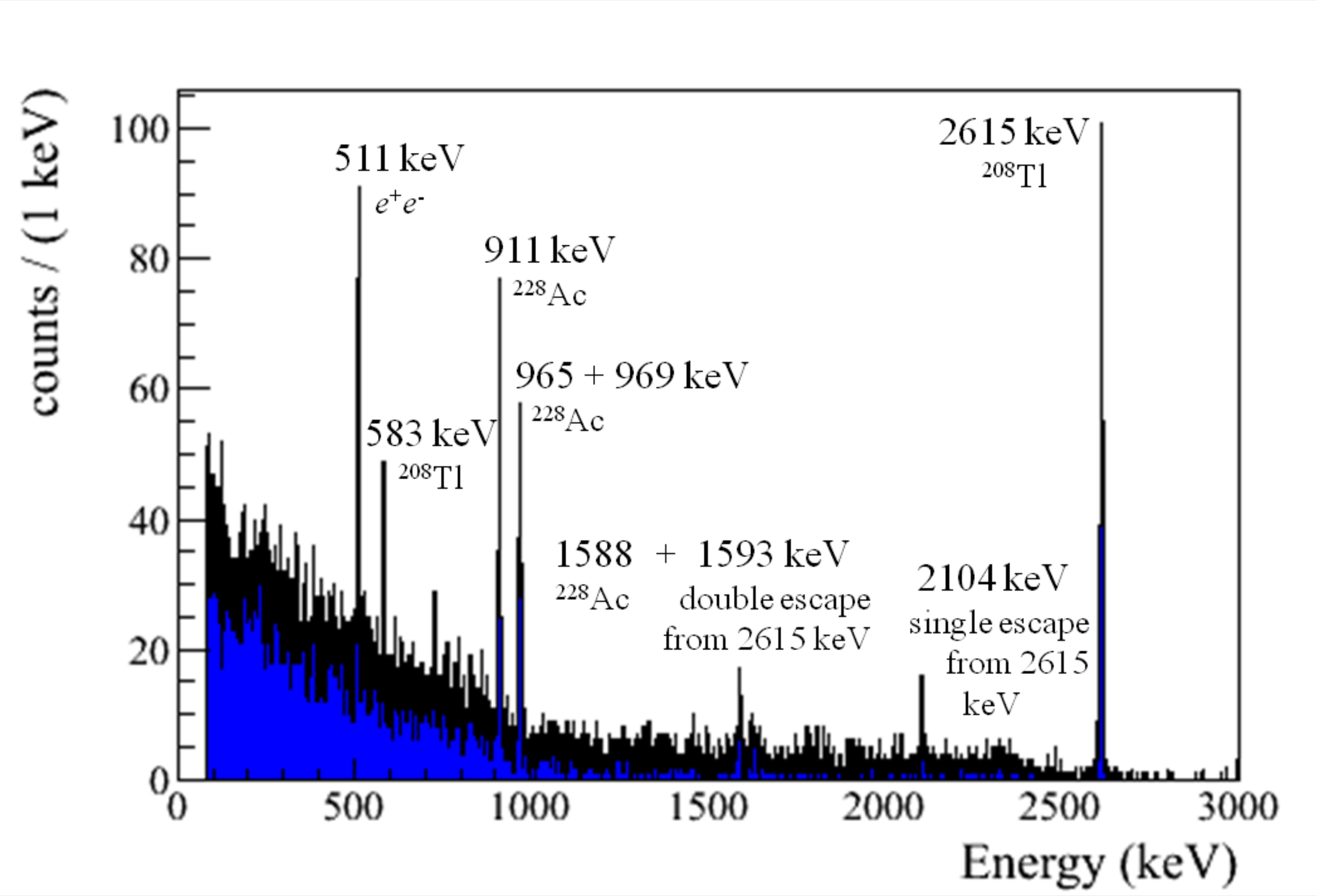

- ΔE_{FWHM}: ~ 1-2 ‰ @ Q-value
  - smaller ROI, lower background
  - easier to identify background sources

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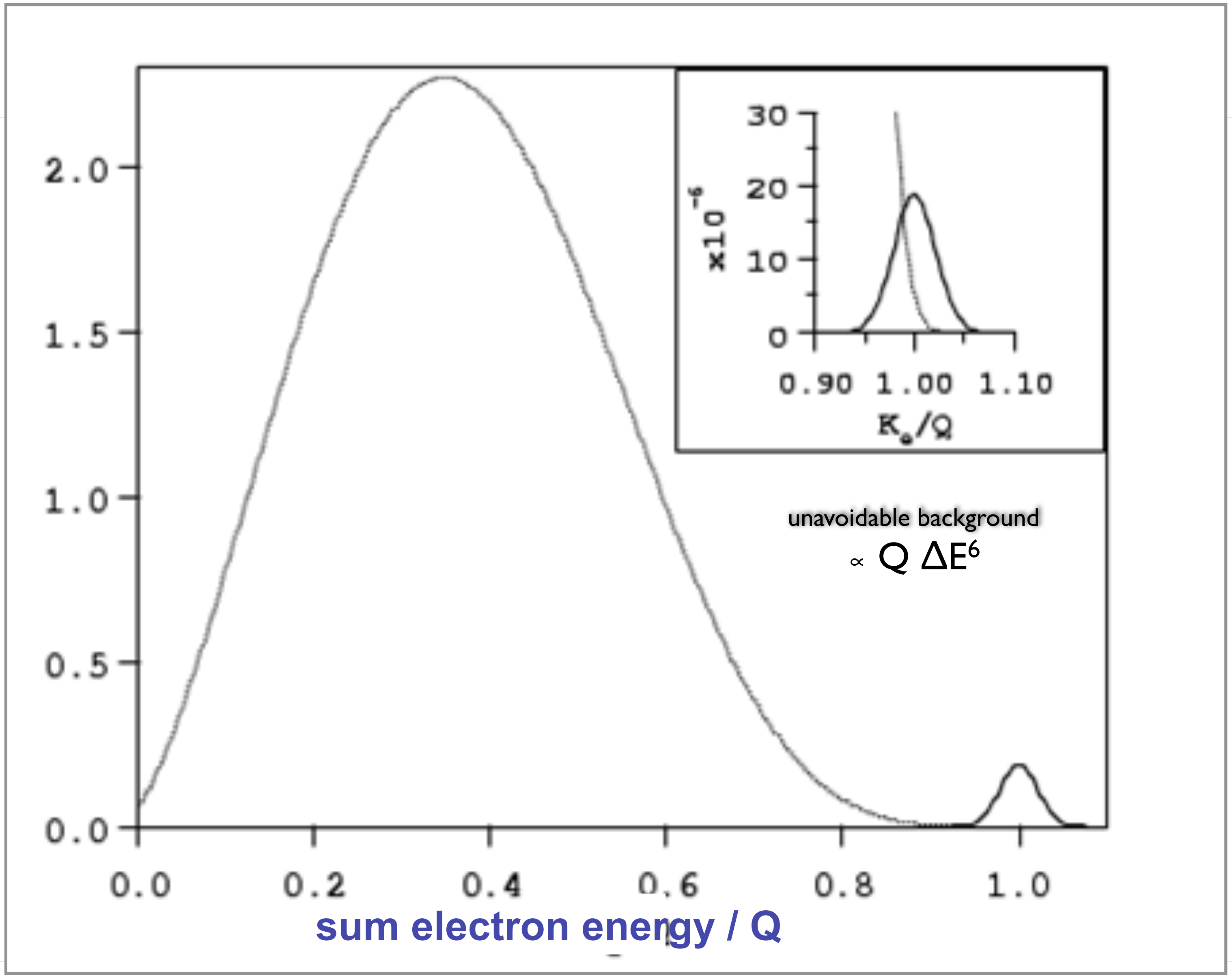
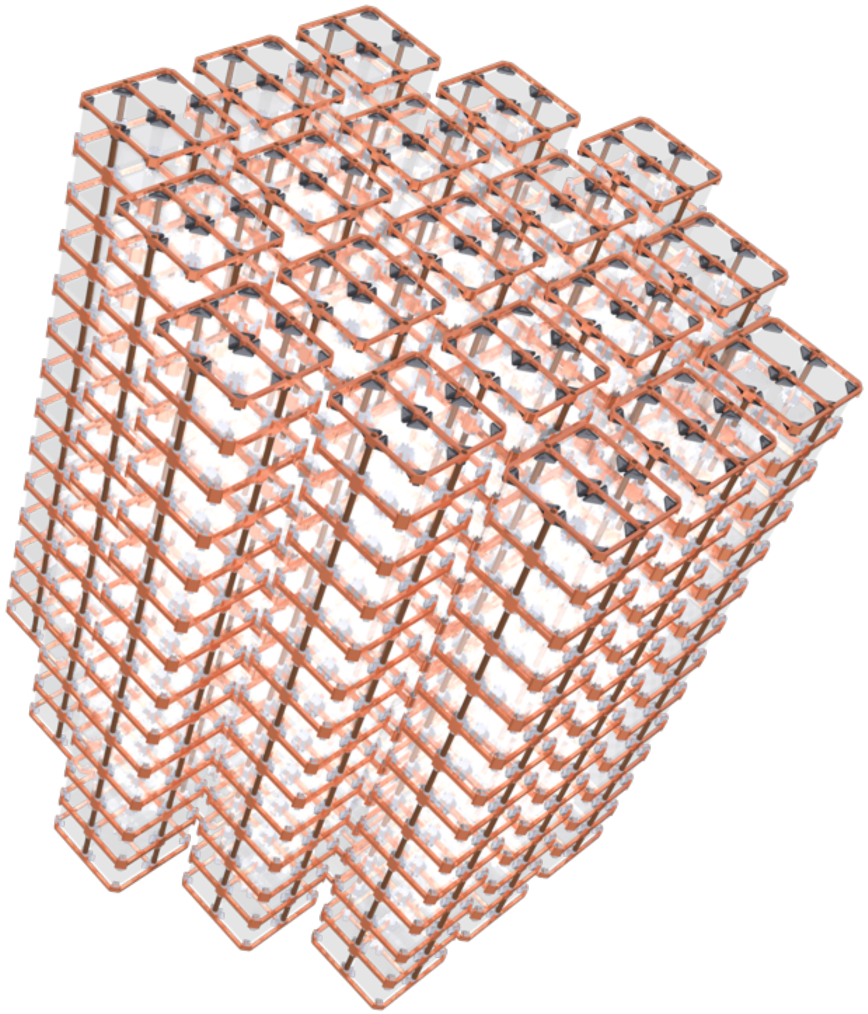


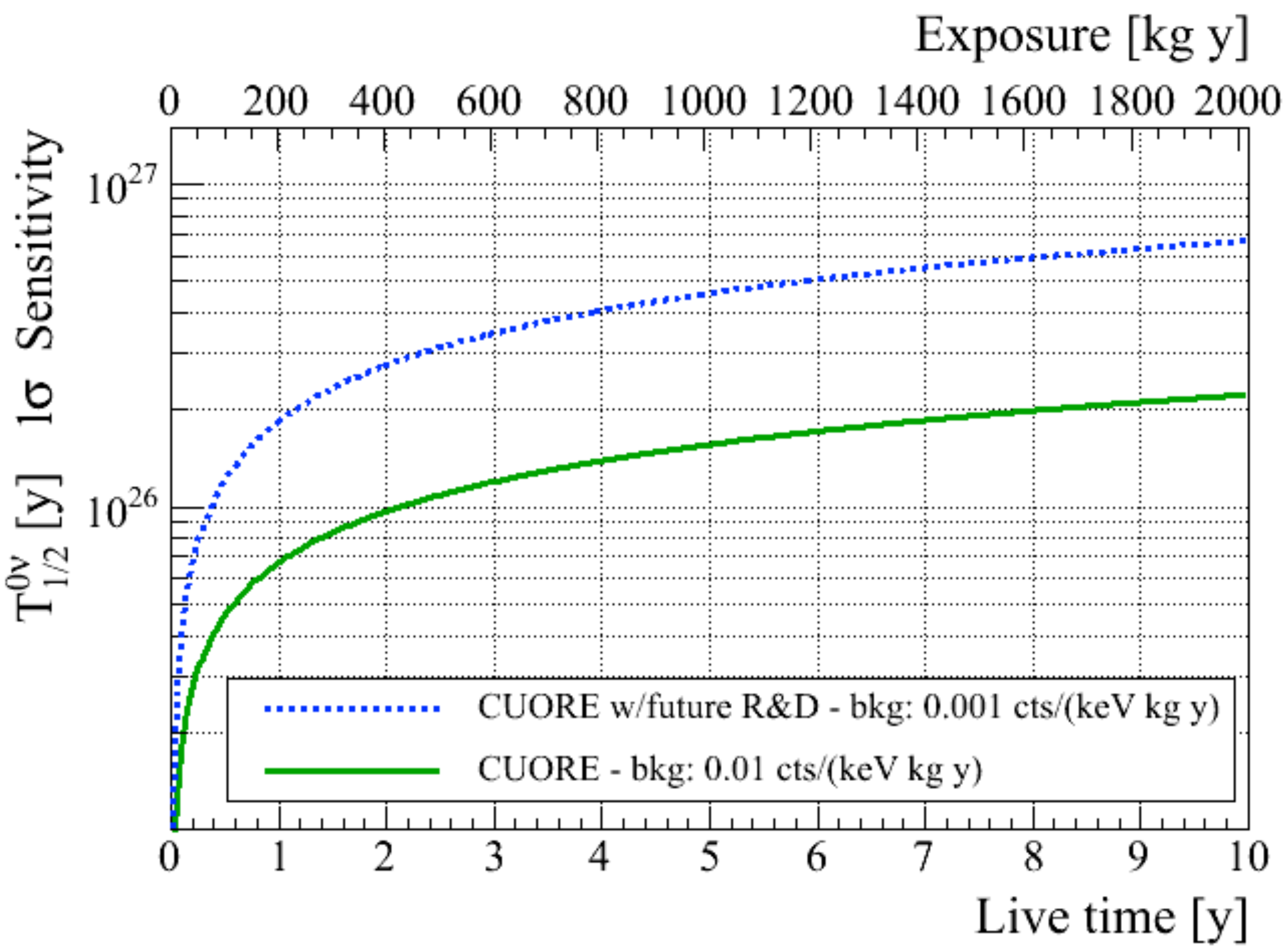
The CUORE challenge

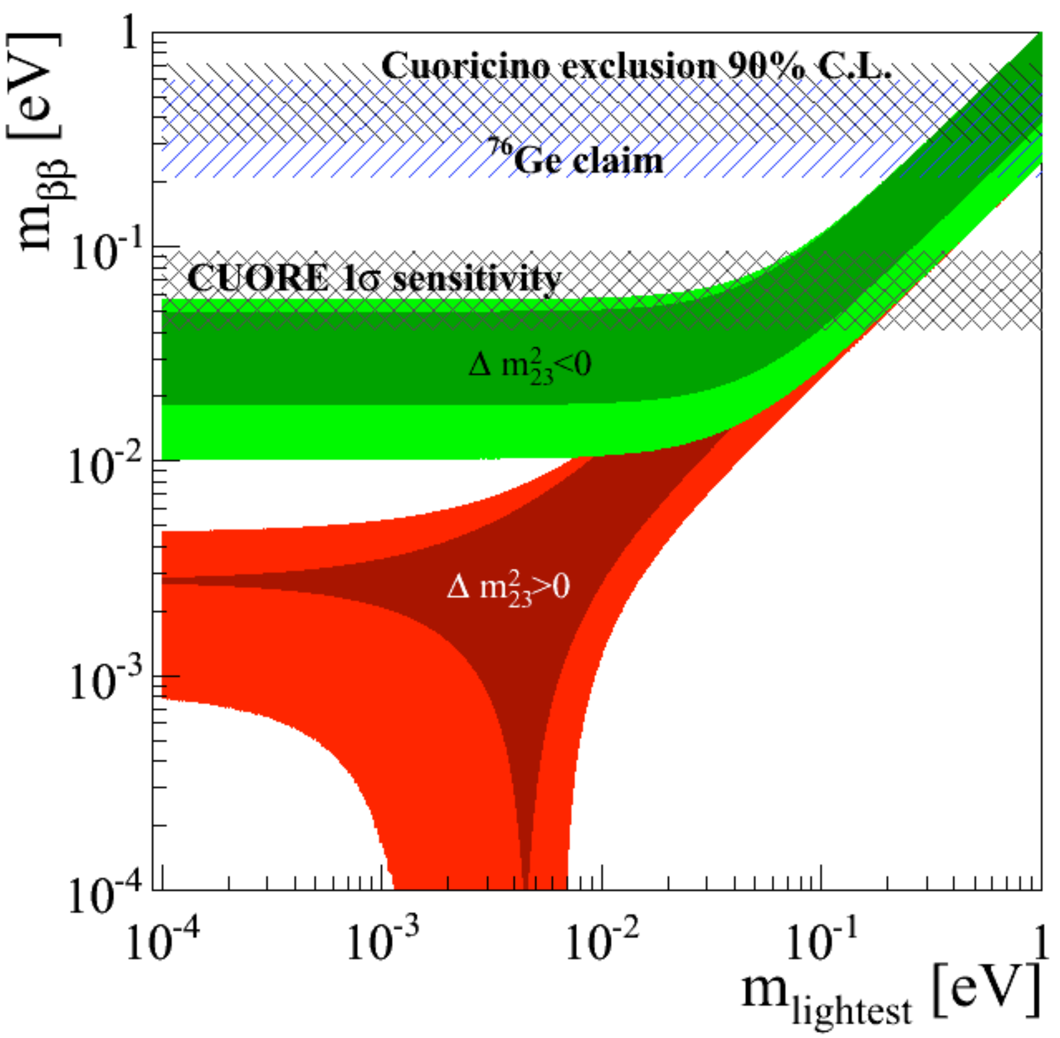
- Operate a huge thermal detector array in a extremely low radioactivity and low vibrations environment

  - Closely packed array of 988 TeO_2 crystals (19 towers of 52 crystals 5×5×5 cm^3, 0.75 kg each)
  - Mass of TeO_2: 741 kg (~206 kg of ^{130}Te)
  - Energy resolution: 5 keV @ 2615 keV (FWHM)
  - Stringent radiopurity controls on materials and assembly
  - Operating temperature: ~ 10 mK
  - Background aim: 10^{-2} c/keV/kg/years



CUORE goal





Cuoricino result and CUORE 1σ background-fluctuation sensitivity overlaid on plots that show the bands preferred by neutrino oscillation data (inner region: best-fit data; outer region: at 3σ). Both normal (red) and inverted (green) hierarchies are shown.

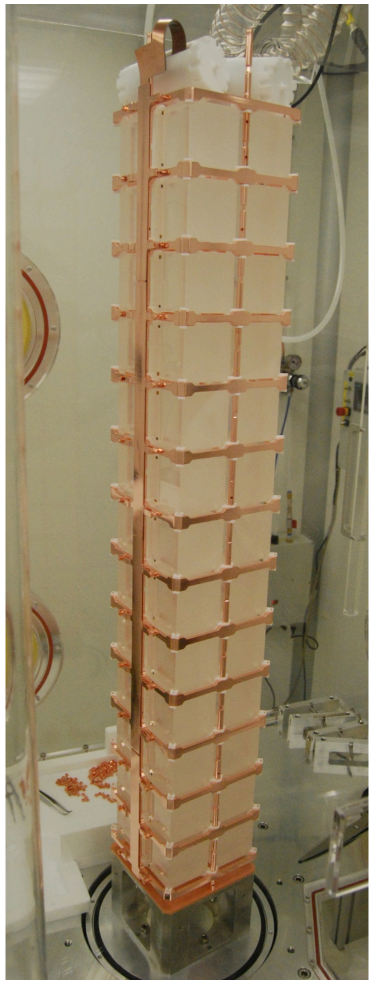
Background	ΔE	$T_{1/2}$	<m_{ee}>			
c/kev/kg/y	keV	10^{26} y	R(QRPA)[1]	np(QRPA)[2]	ISM[3]	IBM-2[4]
0.01	5	1,6	35-66	41-67	65-82	41
0.001	5	6.5	20-38	23-38	37-47	23

1 Šimkovic et al., PRC 77 (2008) 045503
2 Civitarese et al., JoP:Conference series 173 (2009) 012012
3 Menéndez et al., NPA 818 (2009) 139
4 Barea and Iachello, PRC 79 (2009) 044301

CUORE-0

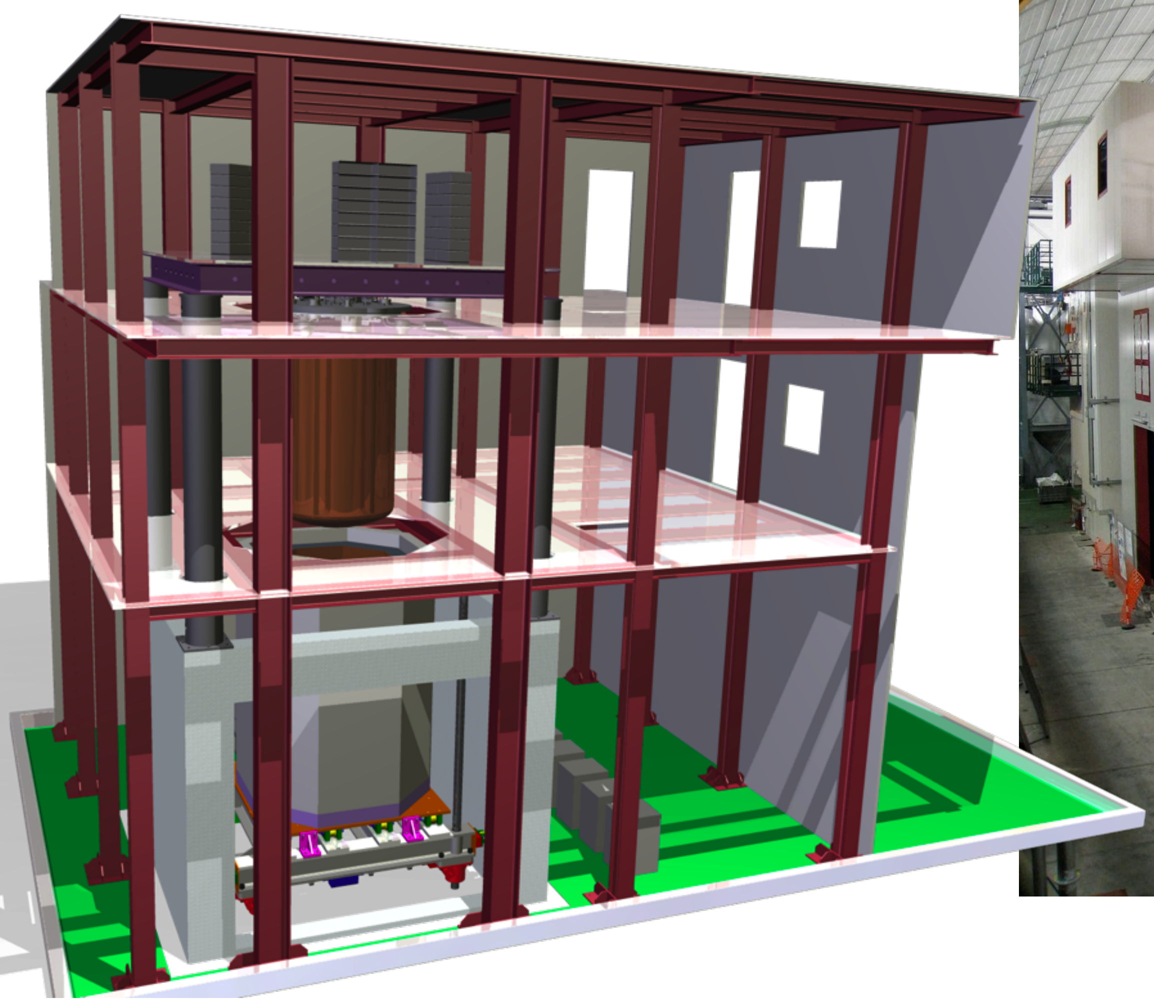
- 1^{st} tower of CUORE operated in the refurbished old Cuoricino cryostat
- Sensitive 0vDBD experiment
- Test of assembly line techniques of CUORE
  - high statistics check of the radioactive background reduction
  - high statistics check of the improved uniformity of bolometric response
  - identify which operations are critical for the success of CUORE
  - reveal flaws and inefficiencies in the assembly procedures
- Validation of cryogenics aspects
- Development and tuning of the CUORE analysis tools

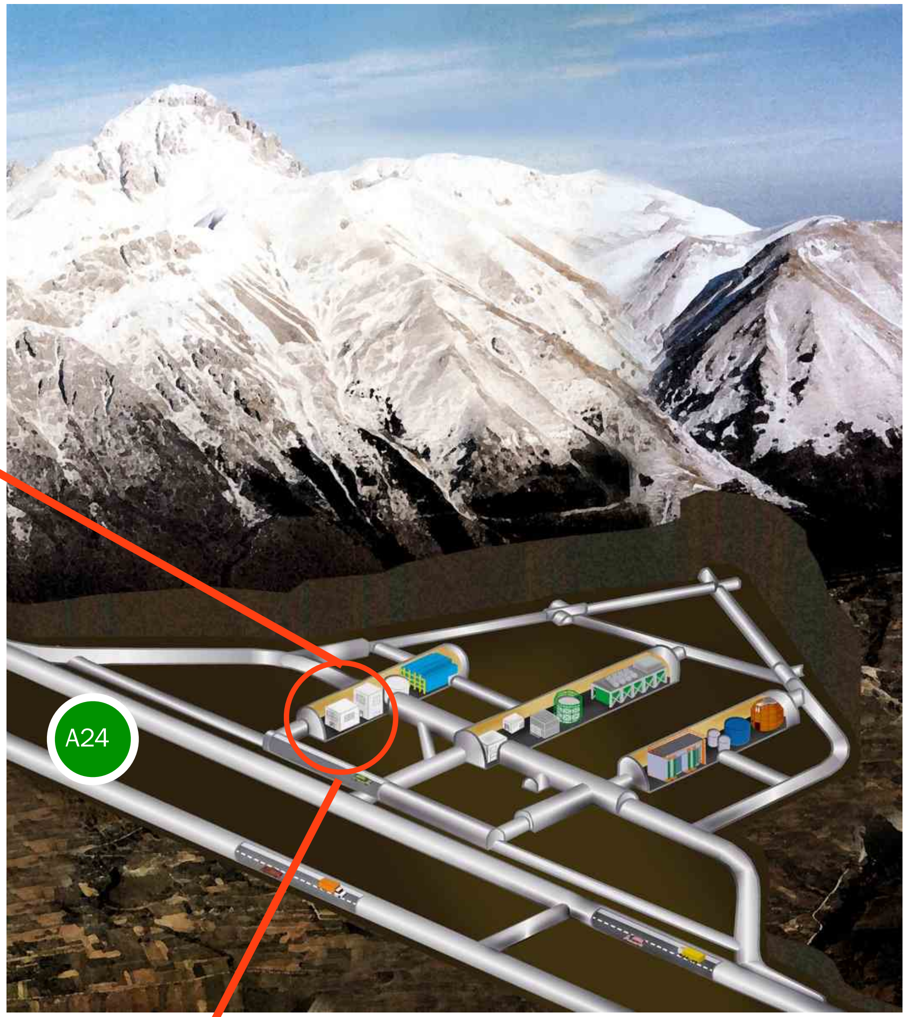
see Lucia's talk on CUORE-0



CUORE @ LNGS

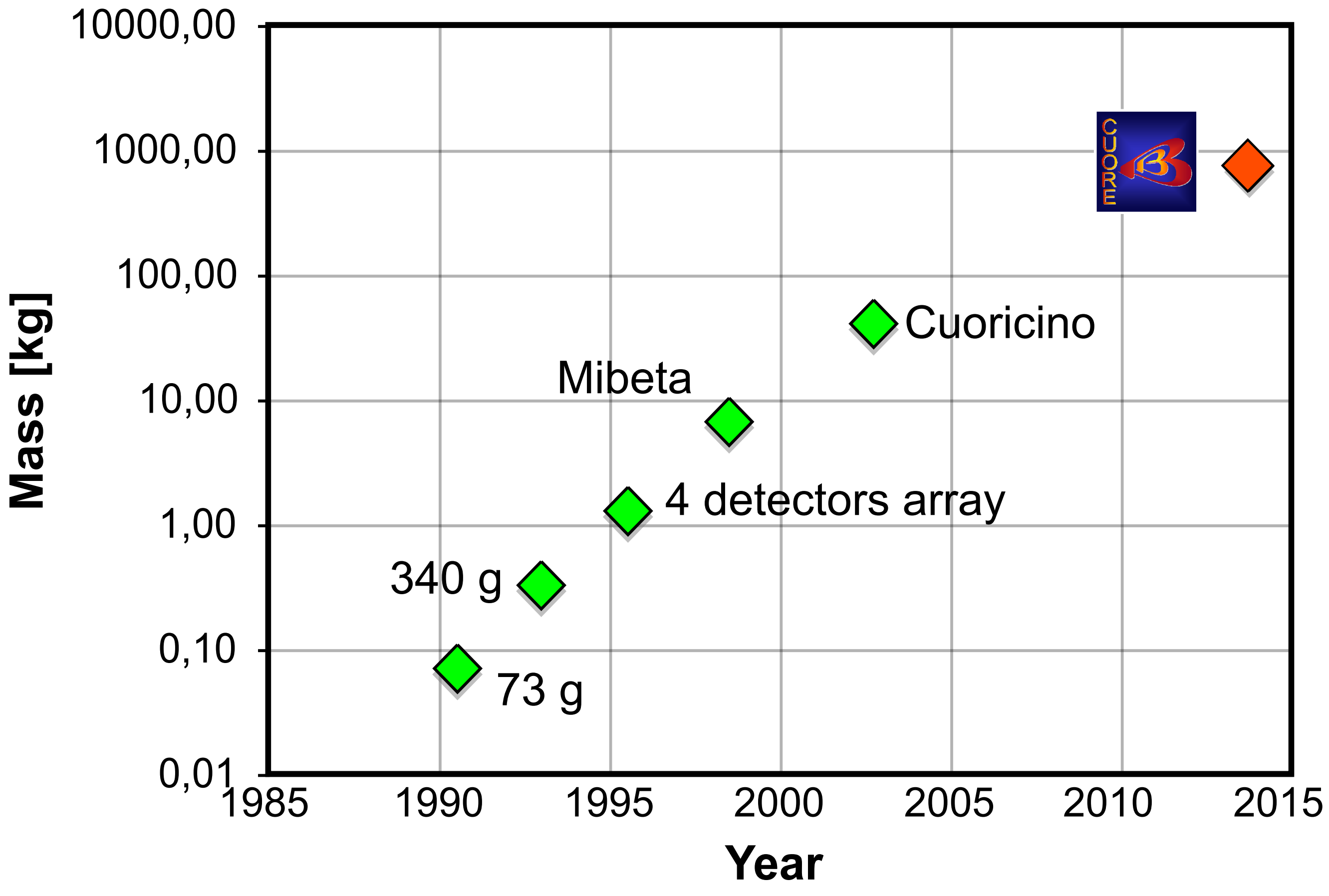
- Three story building in Hall A
  - Ground floor: pumps, compressors & shielding
  - First floor: clean room (Gluing, Assembly & Cryostat)
  - Second floor: service area, front-end & DAQ





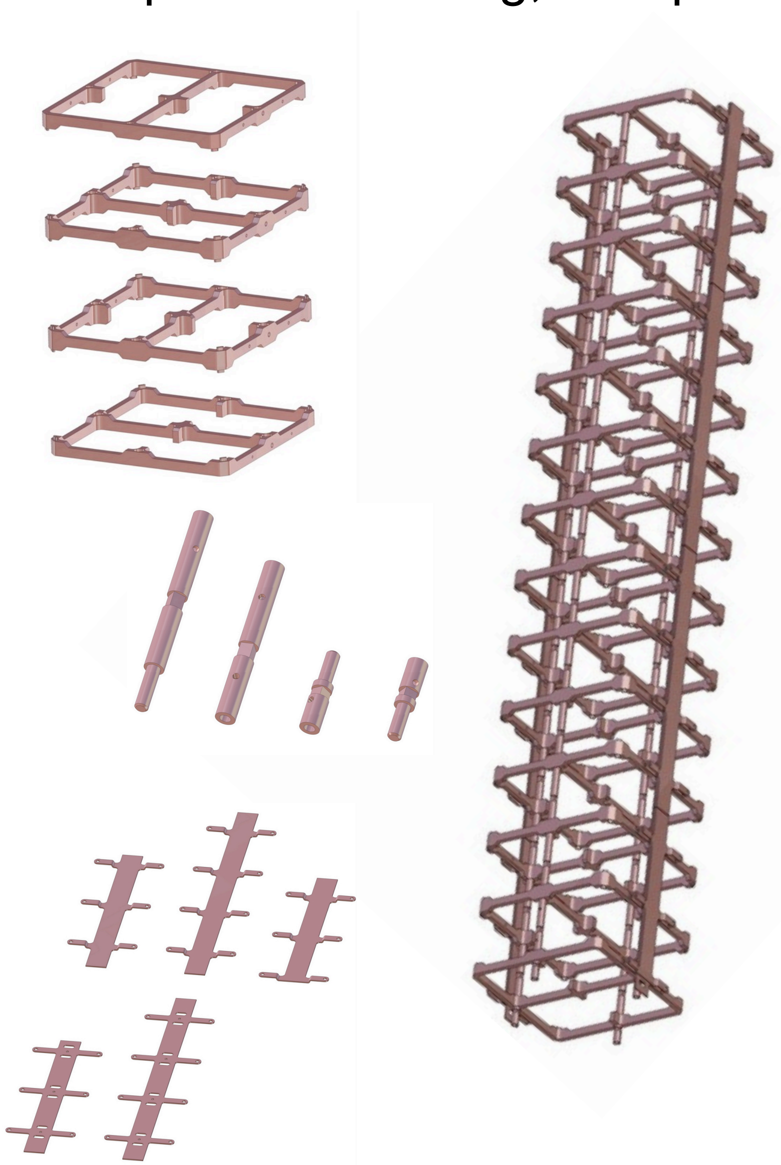
Mass: from few kg to almost a ton

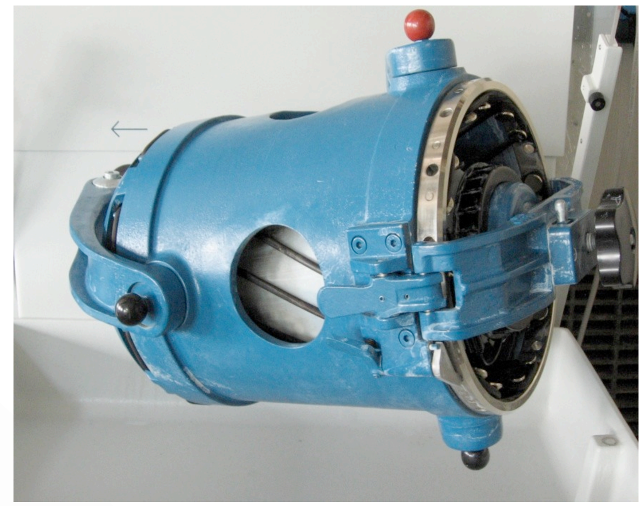
- The production of CUORE crystals started at SICCAS Jiading in 2008
  - ~ 30 crystals/month
  - delivery concluded in May 2013
  - 1063 crystals delivered @ LNGS (including CUORE-0)
  - repolishing of 46 crystals in June 2013 (from CCVR runs and failed gluing)
  - last shipment in this days (24 defective crystals)
  - stored in the PSA

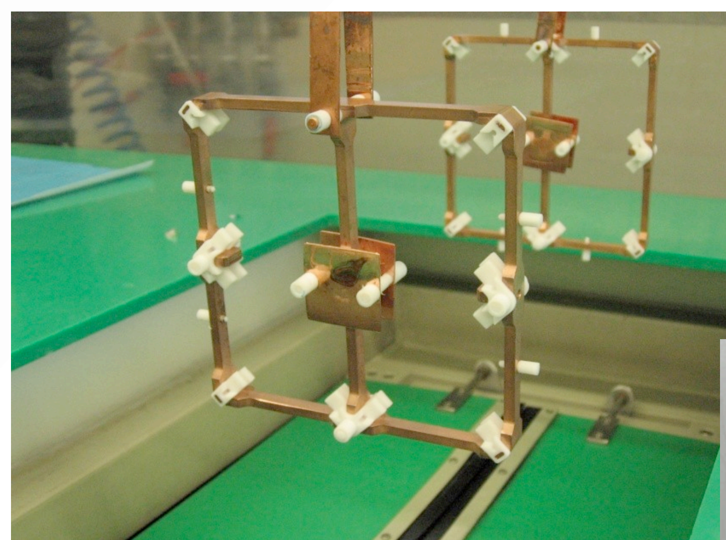


Background: copper cleaning @ LNL

- Almost 2000 copper pieces to be cleaned for the 19 CUORE towers
  - the cleaning sequence is composed by pre-cleaning, tumbling, electro-polishing, chemical etching, plasma cleaning, final packaging



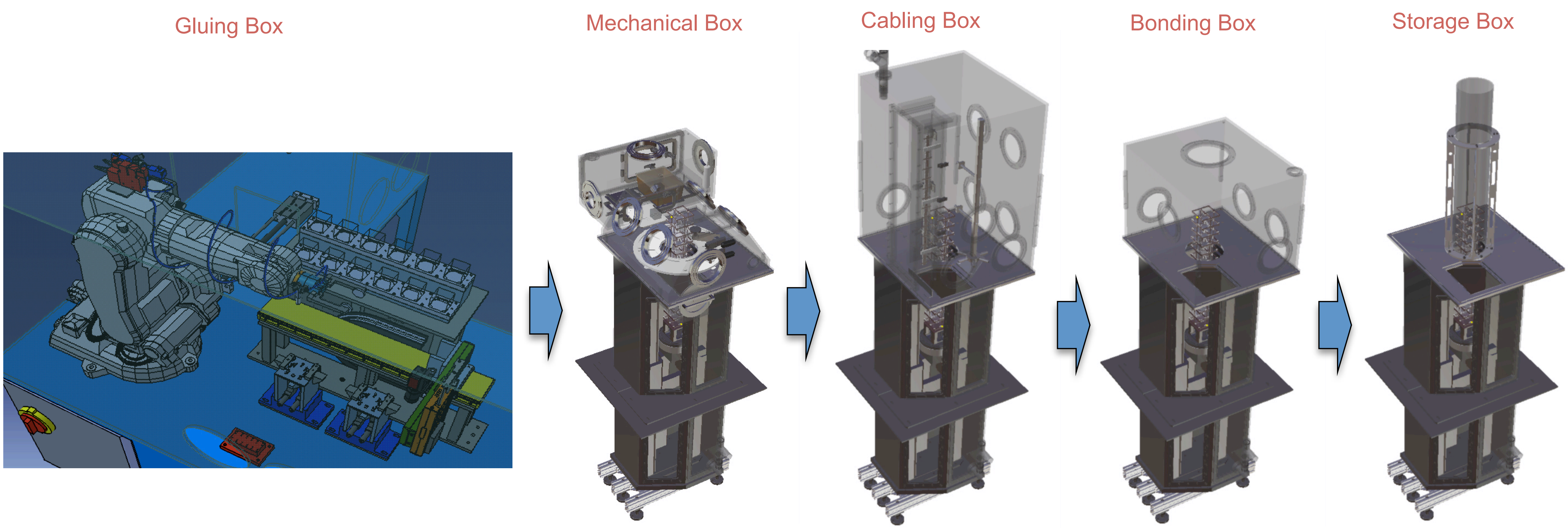




- Completion of production and cleaning of copper parts foreseen for April 2014

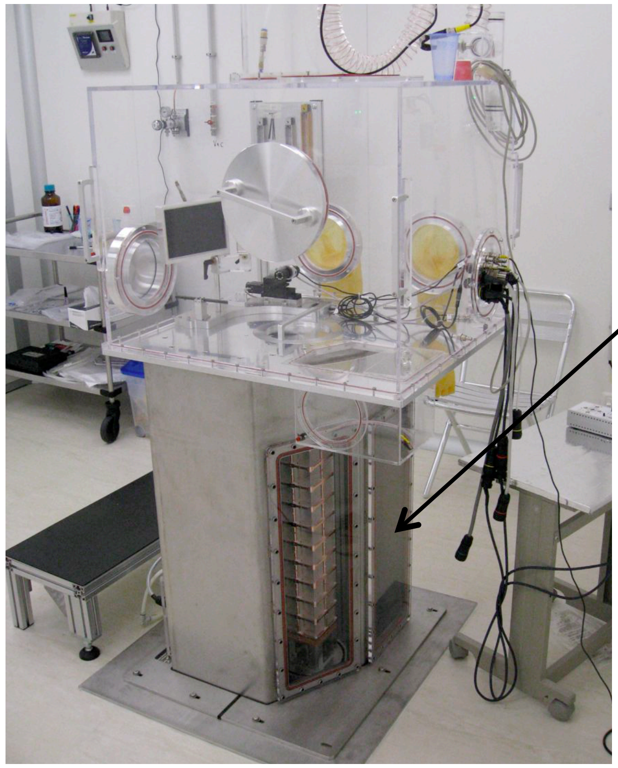
Background: detector assembly

- assembly line conceived in order to prevent external contamination the environment
  - tested in CUORE-0 and then upgraded in several aspects



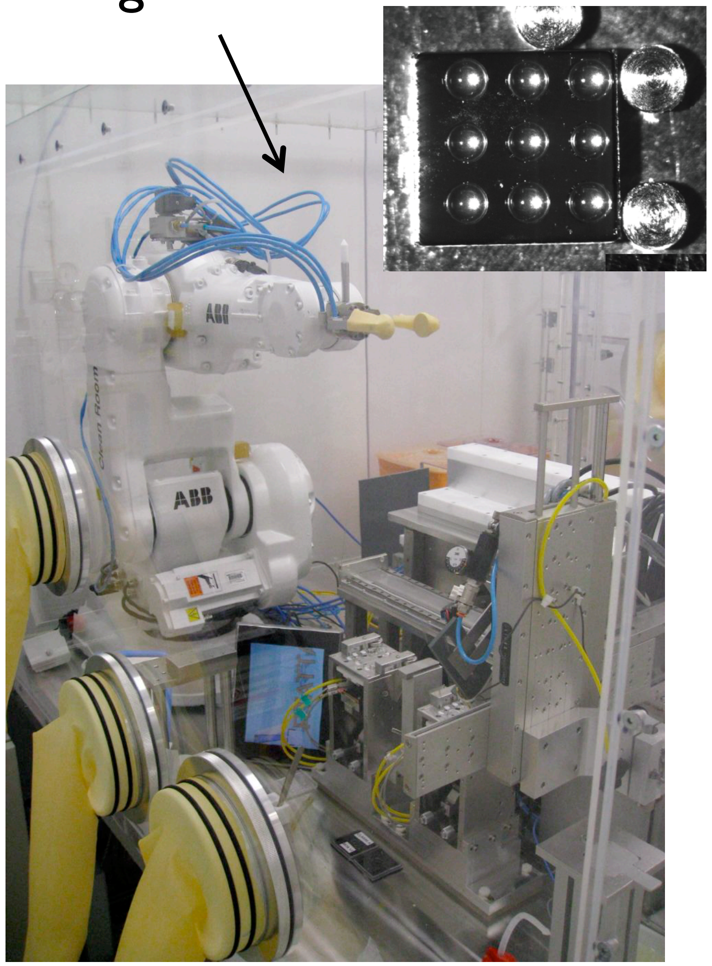
Towers assembly line

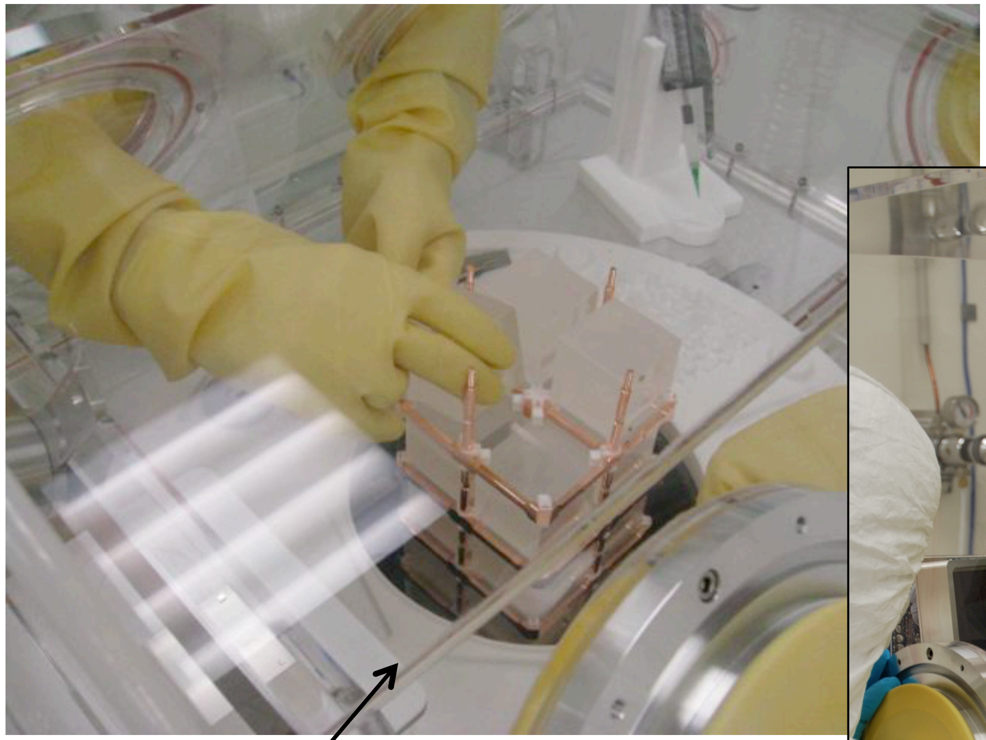
- In order to prevent contaminations:
  - Crystal cutting and lapping in clean room at SICCAS
  - Packaging and transport under vacuum and N_2 atmosphere
  - Gluing, Assembly and Bonding in glove box under N_2 atmosphere
  - Every step done inside clean room



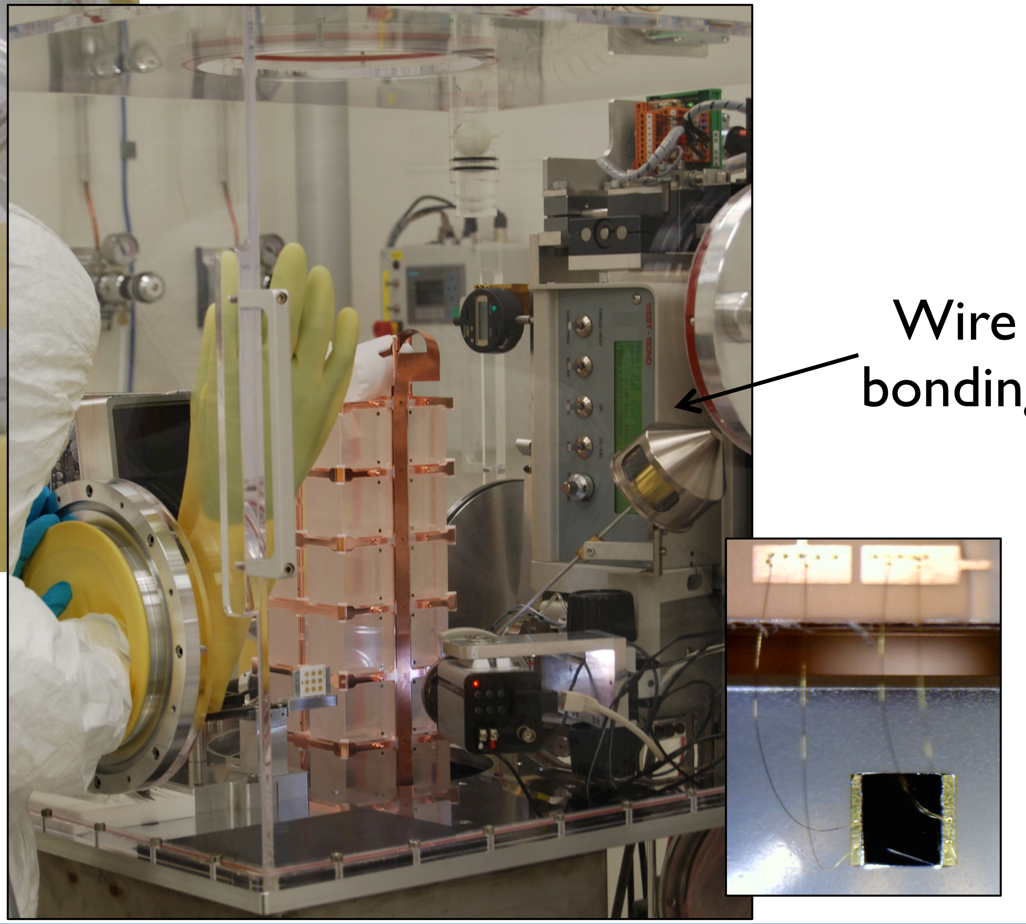
Tower garage

Gluing machine





Mechanical assembly



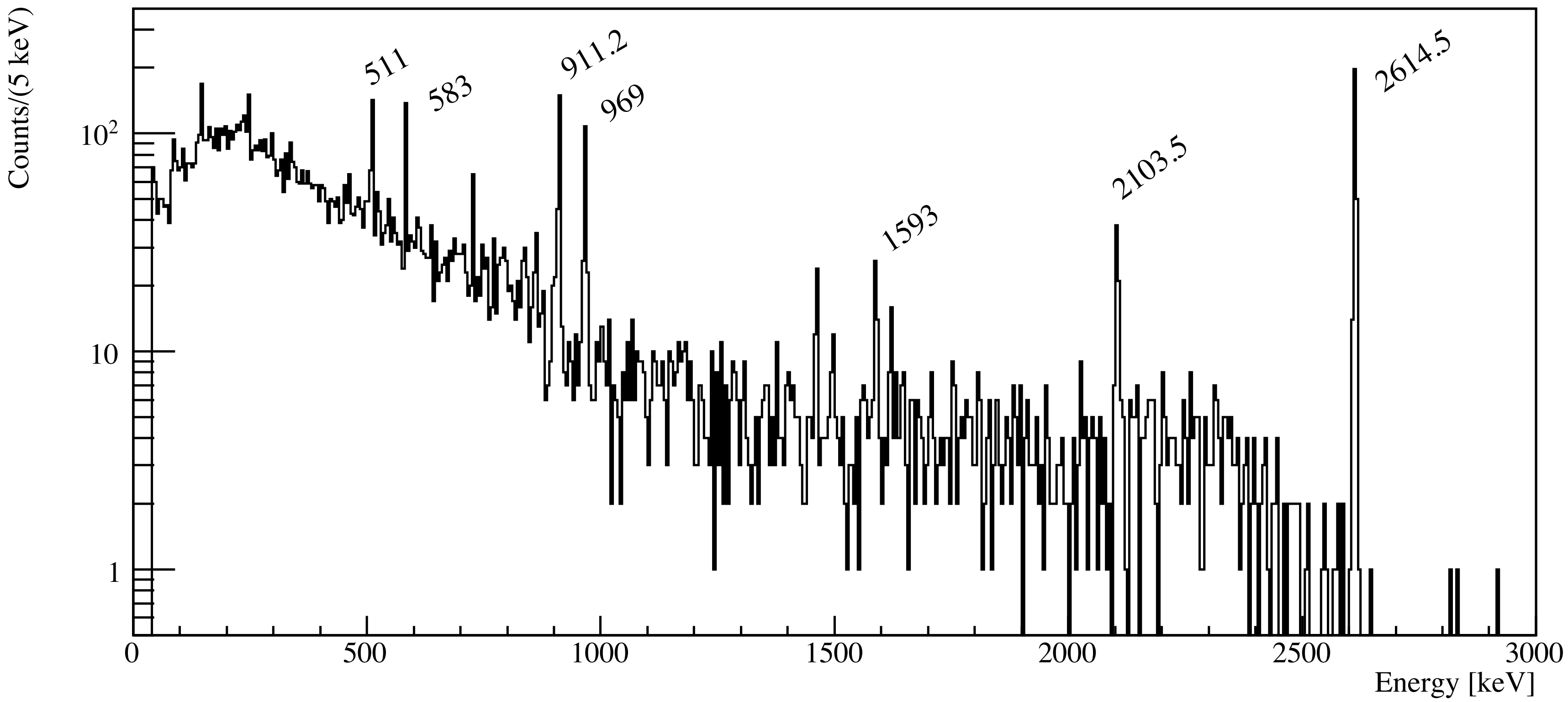
Wire bonding

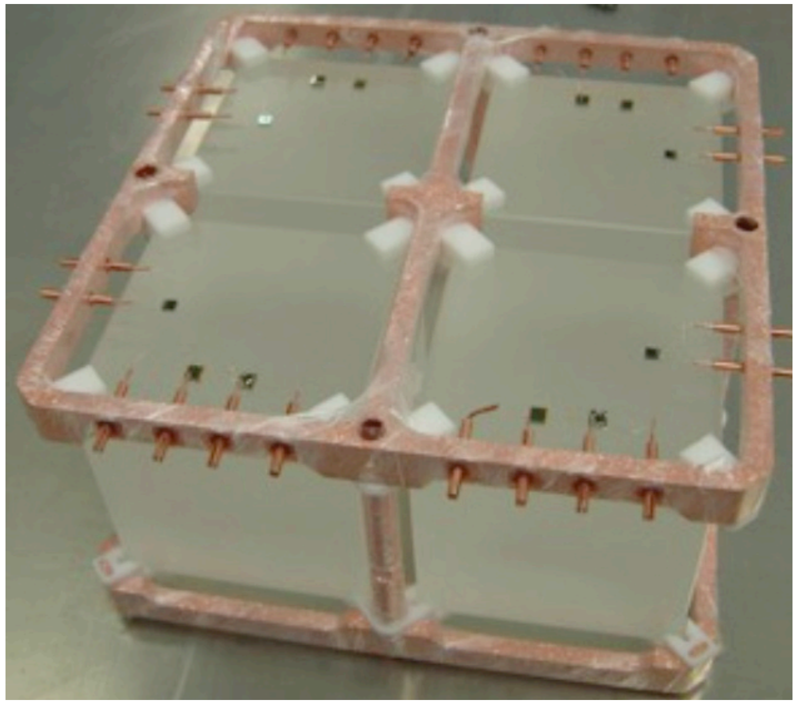
Towers Assembly status

- So far
  - 597/988 glued crystals (more than 11 towers)
  - 9/19 towers mechanically assembled
  - 7/19 towers completed
    - two towers not completed due to bonding difficulties on the NTD gold pads: studies going-on in order to understand if we can complete them or have to reprocess them. Outcome/decision shortly
- Reliability improved since CUORE-0
  - CUORE-0: 51/52 Ge NTD & 51/52 heaters
  - no failure on the 7 completed CUORE towers
- Towers Assembly end by July 2014
  - is not routine but still on schedule

Energy resolution: CCVR

- CUORE Crystals Validation Run: a dedicated cryogenic setup to test crystals extracted by every production batch.

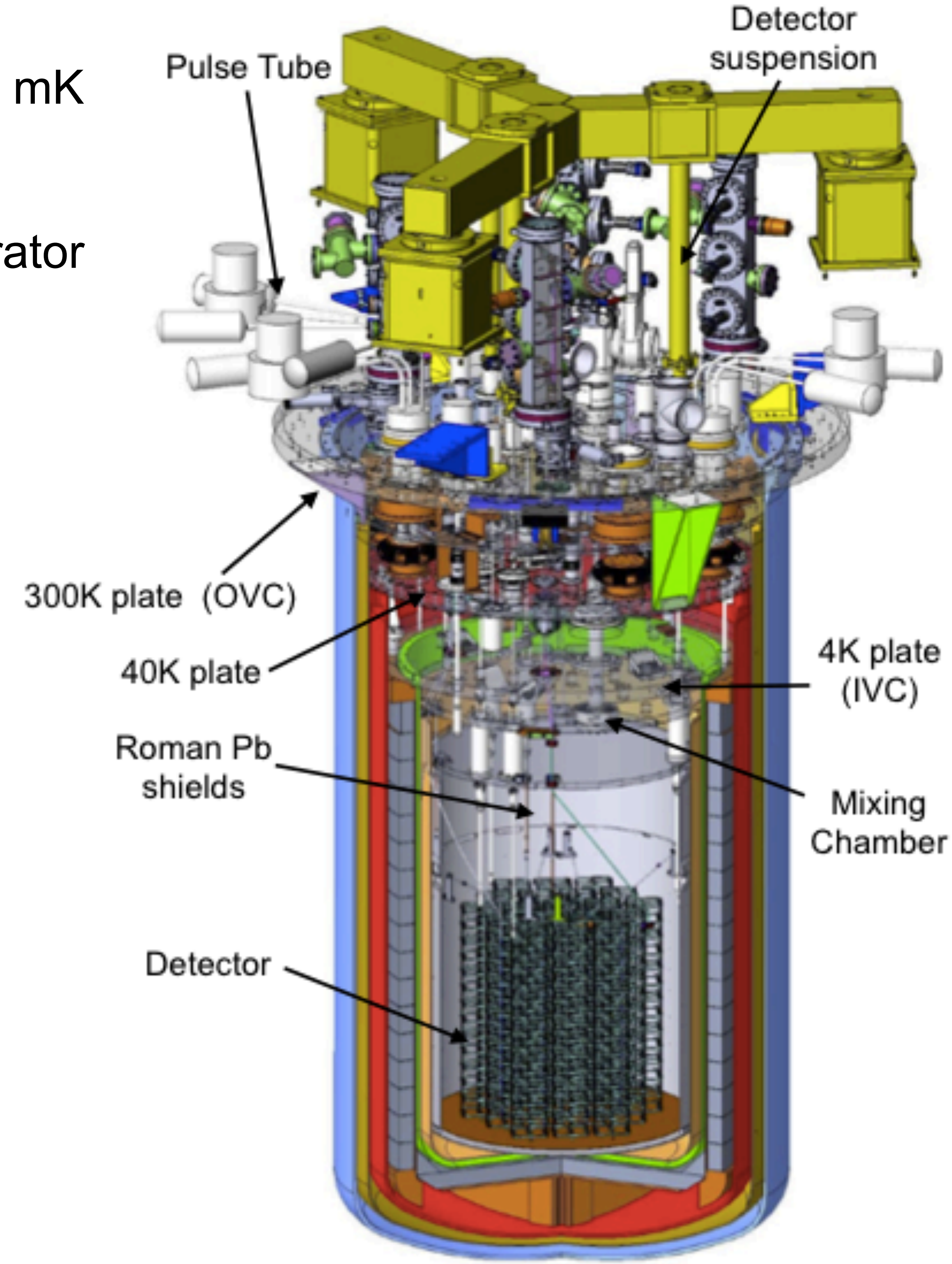




- 10 CCVR performed:
  - the bulk activity is within the limit specified in the contract with the crystals producer
  - improved the Cuoricino bolometric performance: FWHM on the calibration gamma line from ^{208}Tl (2615 keV) always consistent with the 5 keV CUORE goal

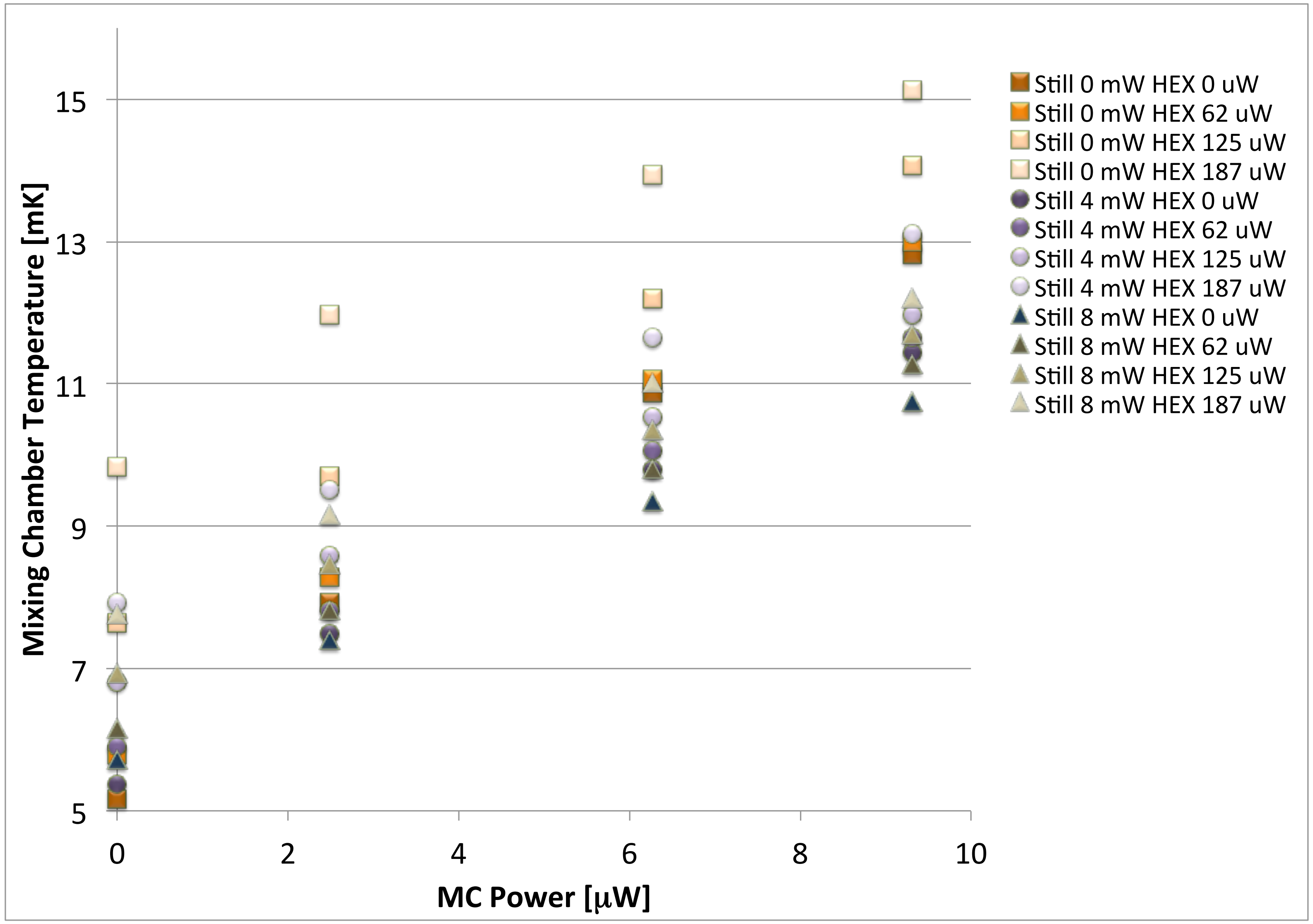
CUORE cryogenic system

- Custom, cryogen-free dilution refrigerator (5 mK base temperature)
- Detector suspension independent of refrigerator apparatus
- Total mass: ~ 20 tons
- Internal Roman lead shield: 6 cm thick

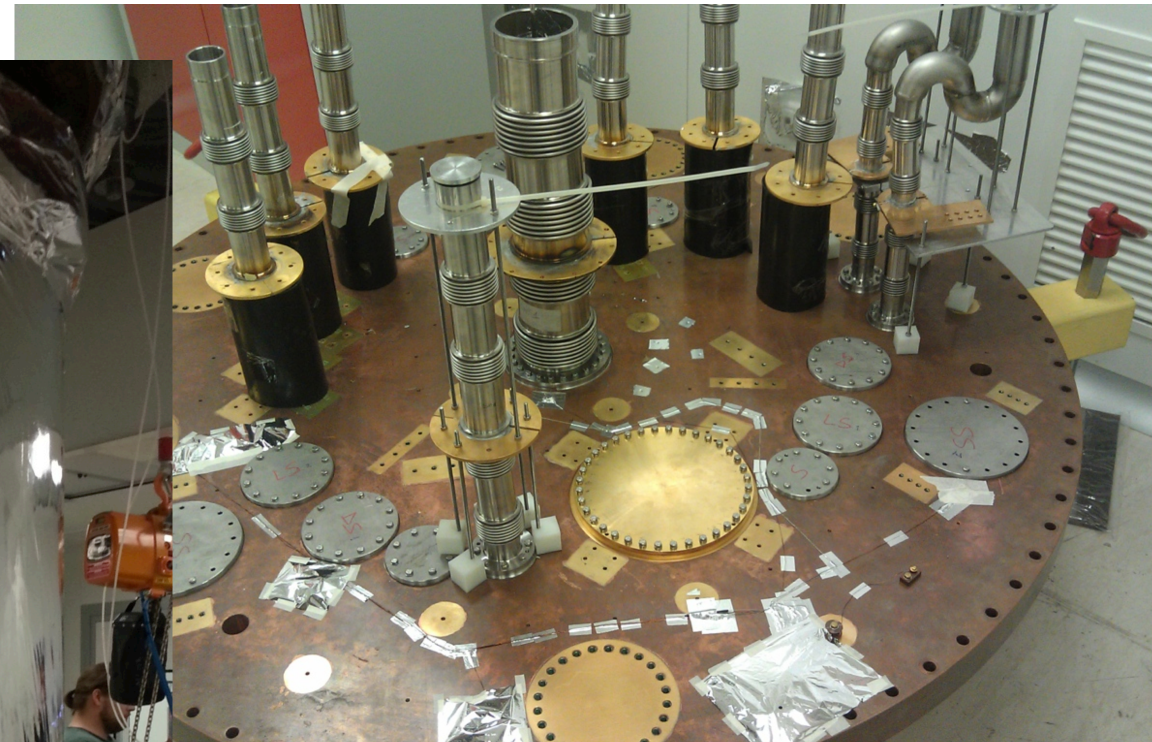


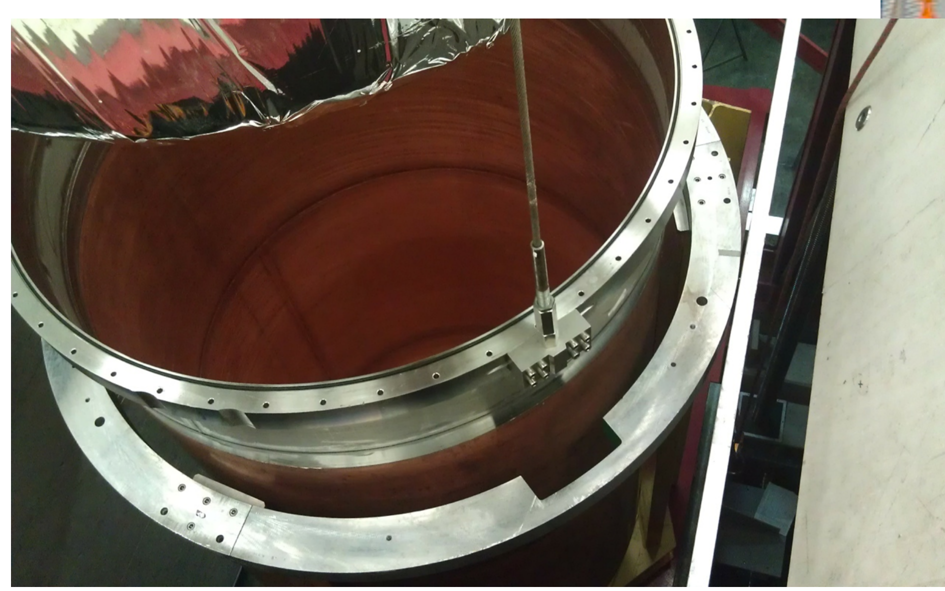
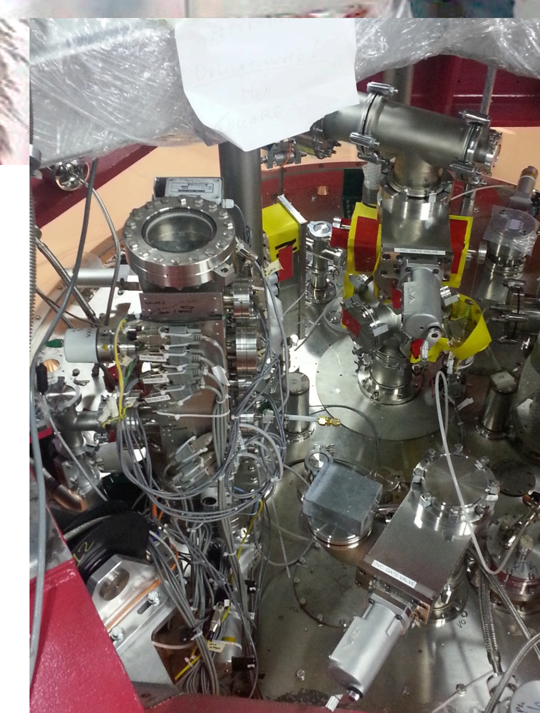
Dilution unit

- Custom dilution refrigerator ordered to Leiden Cryogenics
  - minimum base temperature reached 5.26 mK
  - more than 5 μW of cooling power @ 10 mK



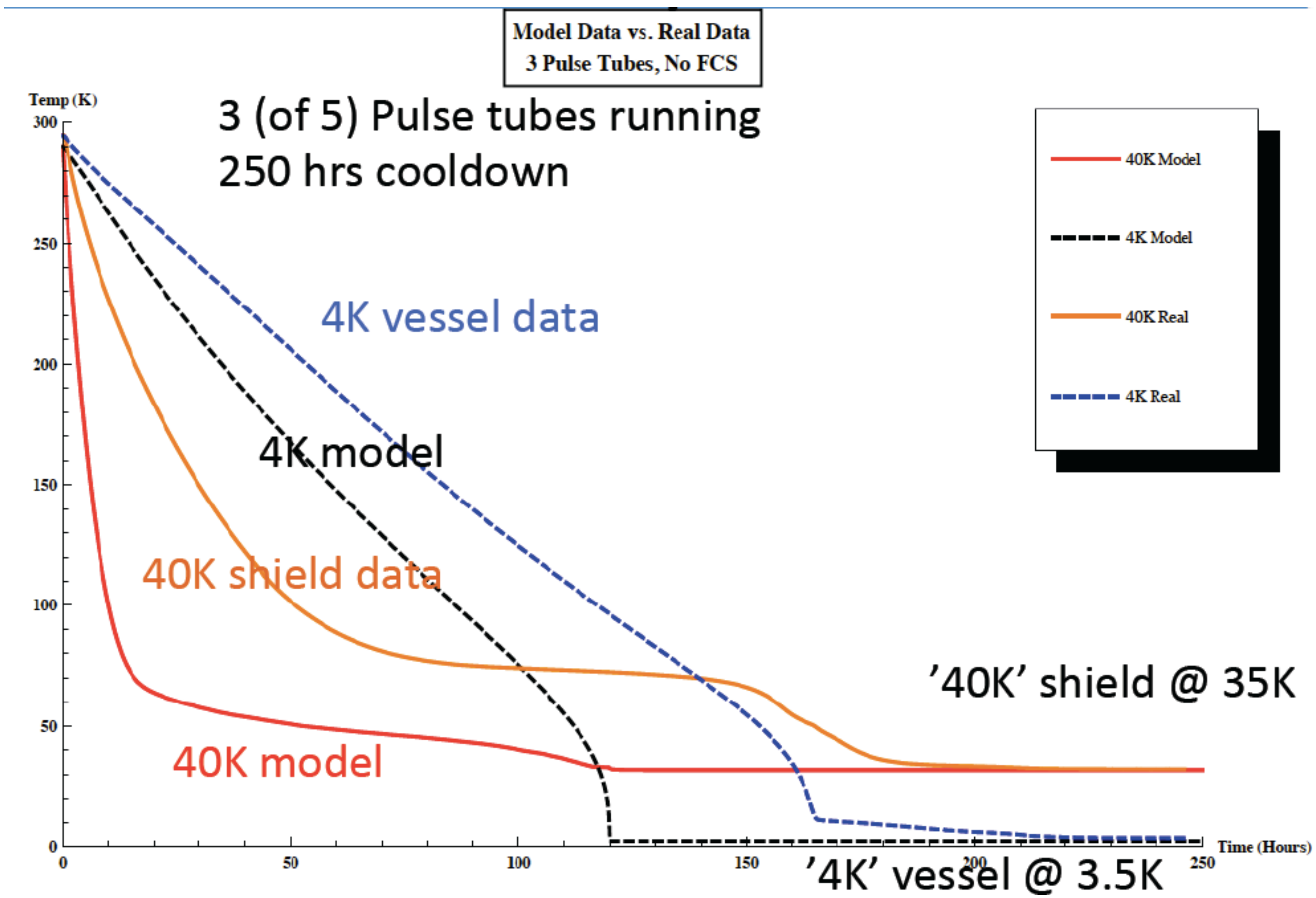
CUORE cryostat installation

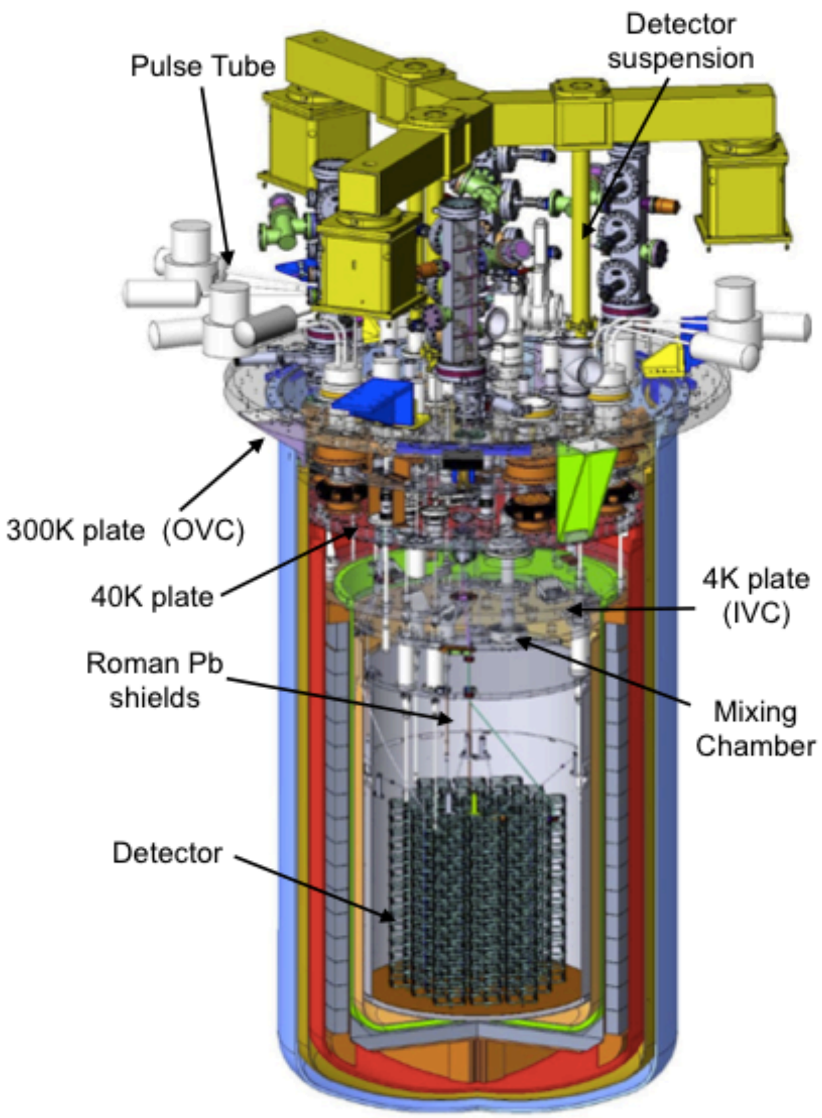
Cryostat cooldown

- Cryostat tested successfully down to ~3.5K



Cryogenic system phased program of tests

- Quite a bit of work in 2014
  - Add one by one all the components to debug the system
  - from 2nd run on we will add some real TeO_2 bolometers in order to check in advance vibrations level, detectors base temperature and maybe some hints on the background.



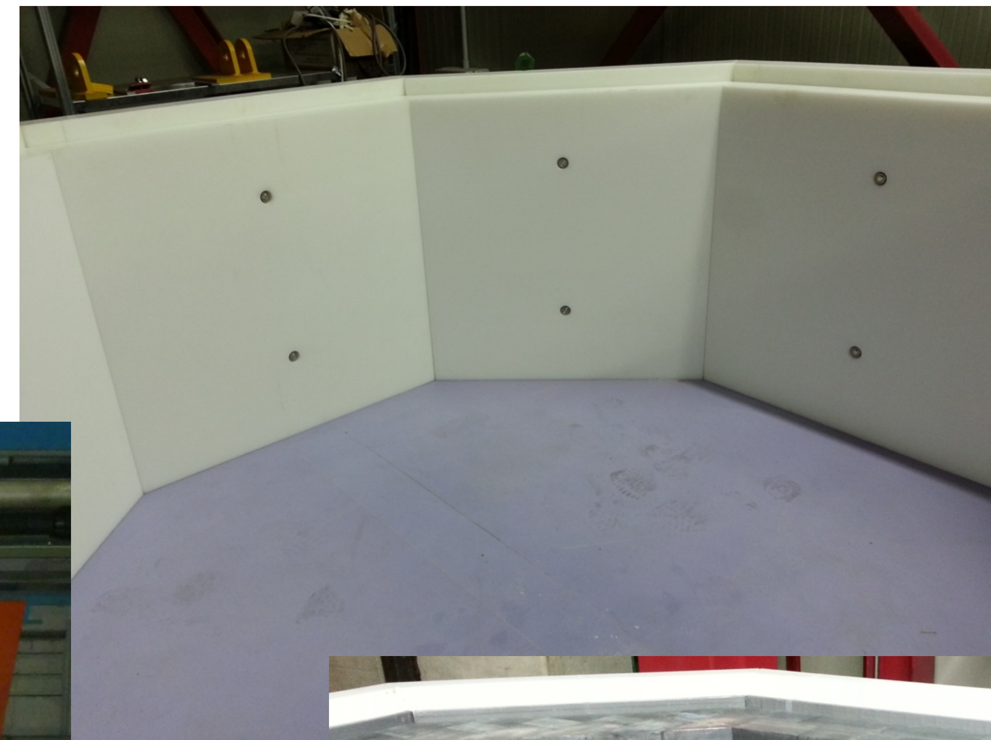
Insertion of few TeO_2 detectors

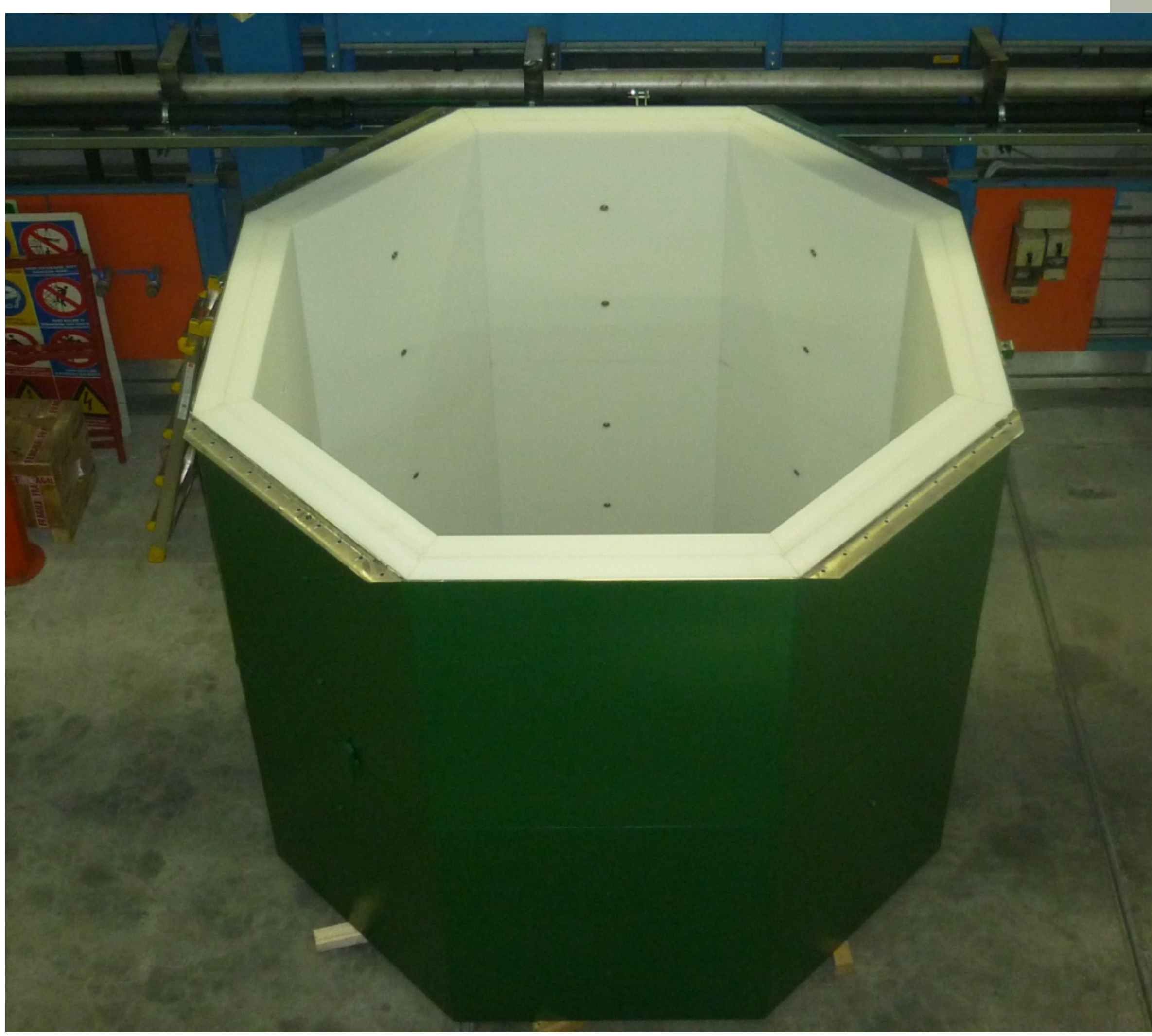
↓

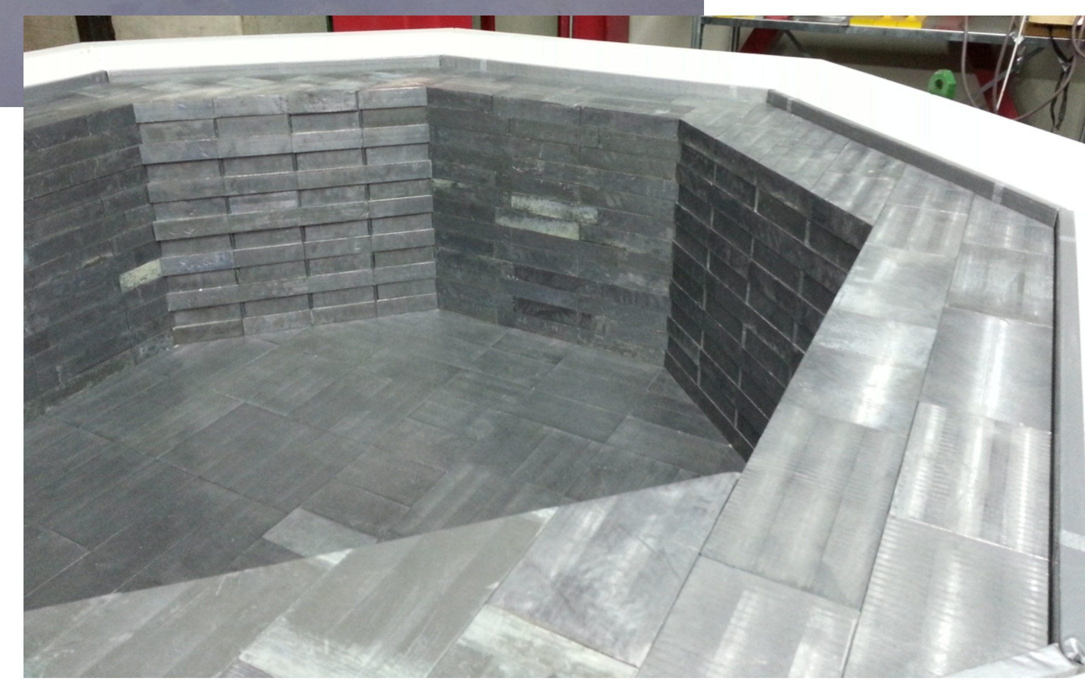
RUN 1: Cryostat + DU with no other load → RUN 2: Wiring → RUN 3: internal roman Pb shield + FCS → RUN 4: Top lead + Suspensions + Towers support plate

External shieldings

- Assembly ongoing
  - 18 cm of PE
  - 2 cm of H_3BO_3
  - 25 cm of Pb
  - Steel container for N_2 flushing







CUORE Schedule

- Next relevant milestones
  - January 2014: cryostat and DU integrated, 1st run at base T with no load
  - April 2014: copper cleaning completion
  - April 2014: 2nd cryostat run with wiring
  - July 2014: towers assembly completion
  - July 2014: 3rd cryostat run with roman Pb shield and Fast cooling system
  - November 2014: 4th cryostat run with Towers support plate and suspensions
  - December 2014: electronic installation
  - February 2015: detector installation

- Mainly driven by cryogenic system integration and commissioning

Conclusions

Conclusions

- The CUORE experiment is under construction
  - Delivery of TeO_2 crystals completed
  - Towers assembly line functioning; 7 out of 19 towers built to date
  - CUORE cryostat integration and commissioning started
  - CUORE-0 tower running in the old Cuoricino cryostat
- CUORE cooldown planned for beginning of 2015