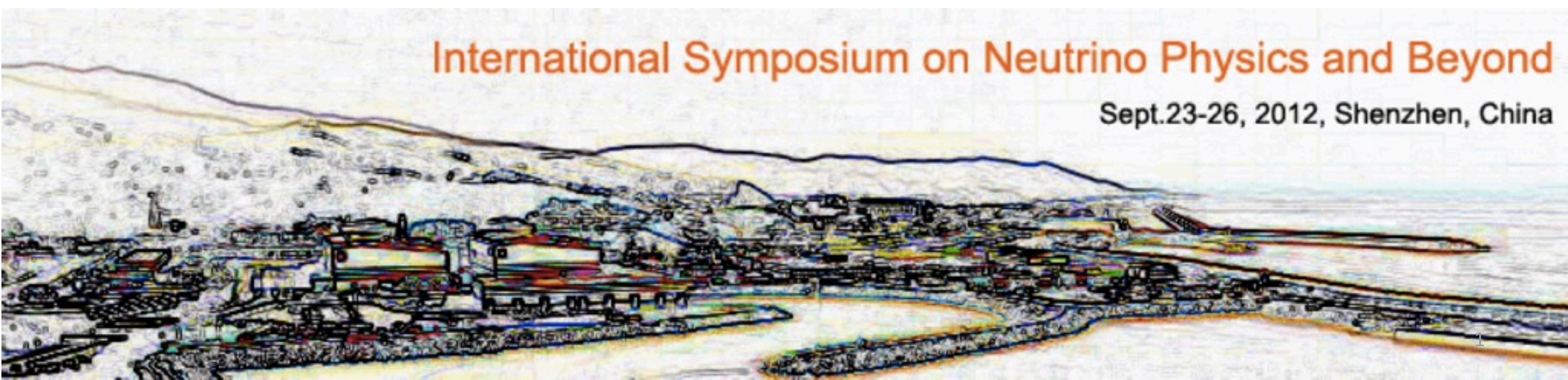
# STATUS OF THE CUORE0 AND CUORE EXPERIMENTS

**O.Cremonesi**

INFN – Sez. Milano Bicocca



# STATUS OF THE CUORE0 AND CUORE EXPERIMENTS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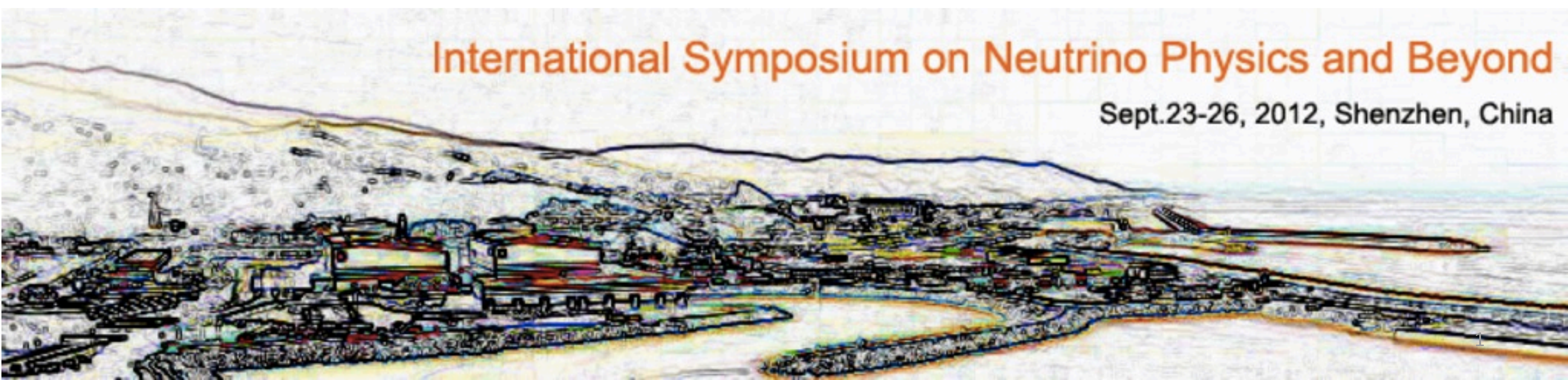
**Outine:**

- Scientific goal
- Experimental setup
- Status
- CUORE-0
- Conclusions



# CUORE

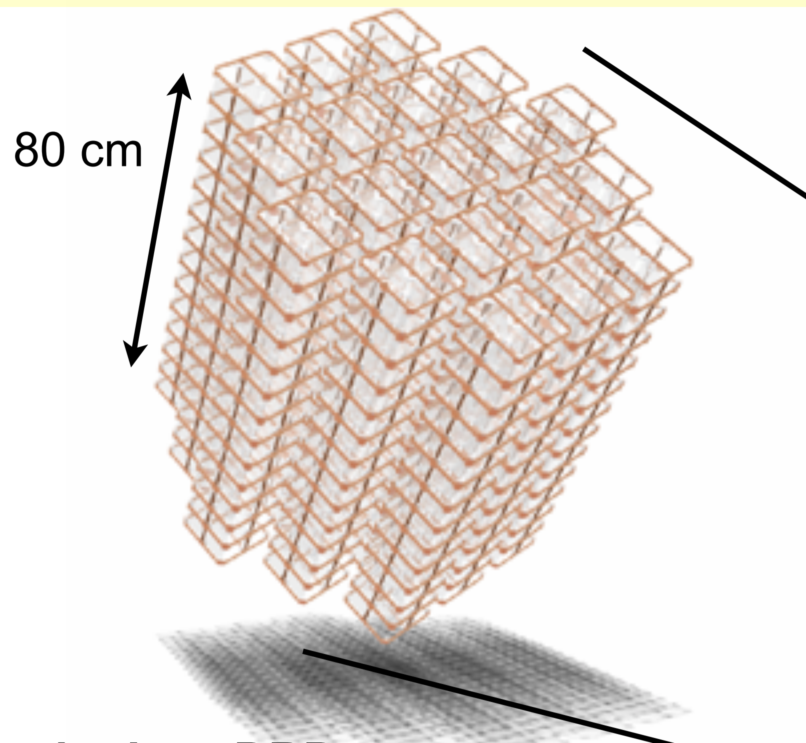
**Cryogenic Underground Observatory for Rare Events**

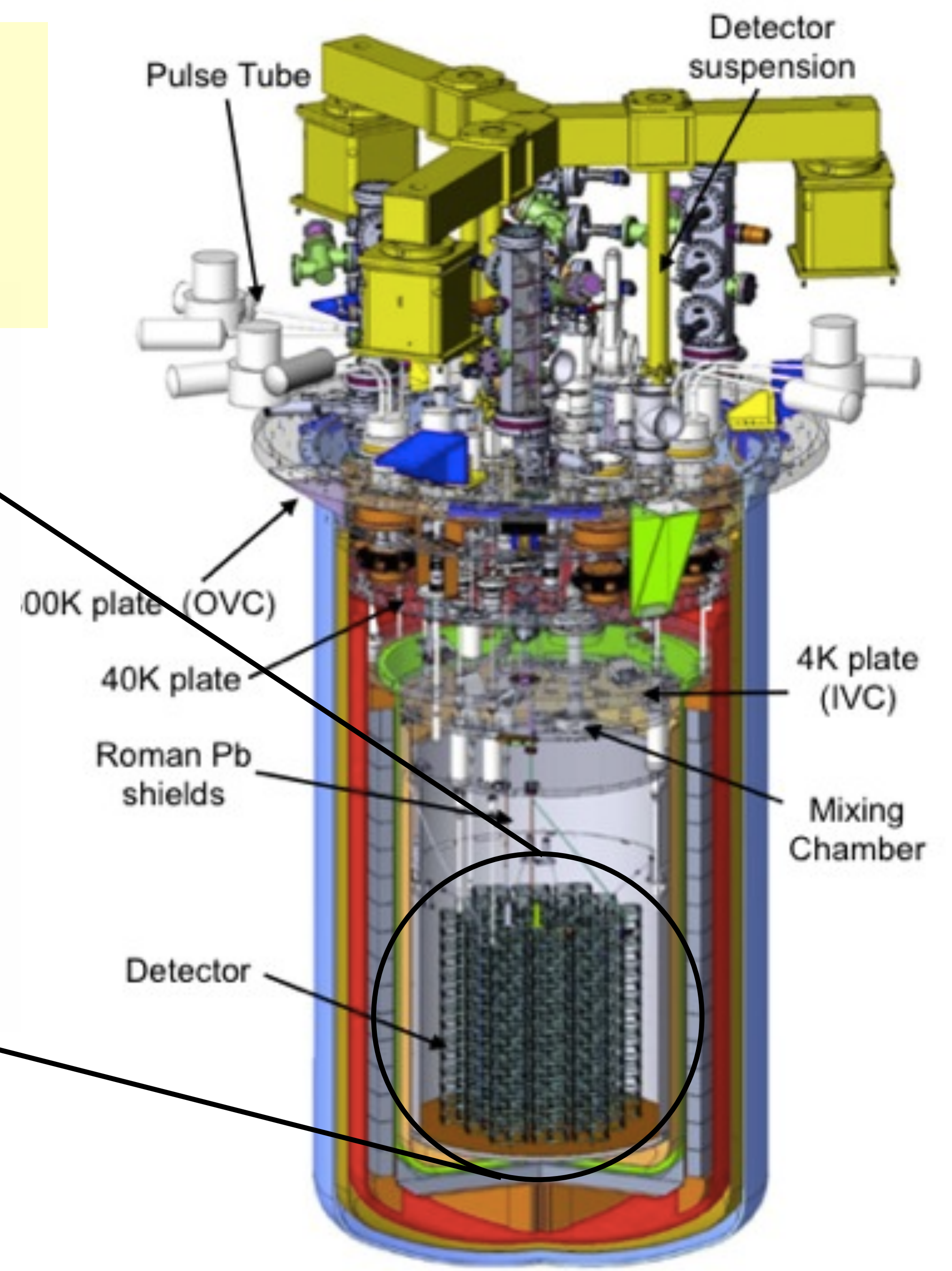
**Closely packed array of 988 $TeO_2$ crystals 5×5×5 $cm^3$ (750 g)**

**741 kg $TeO_2$ granular calorimeter**

**600 kg Te = 203 kg $^{130}Te$**

**19 towers**
**13 planes each**
**4 crystals each**




**Calorimetric experiment on 130Te neutrinoless DBD**

| Background | ΔE | $T_{1/2}$ | $\langle m_{ee} \rangle$ | | | |
|---|---|---|---|---|---|---|
| c/kev/kg/y | keV | $10^{26}$ y | R(QRPA)[1] | np(QRPA) | ISM[3] | IBM-2[4] |
| 0.01 | 5 | 2.1 | 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

Single cryogenic setup ($T_{work}$=10-15mK)
Complex system of radiation shields
Mechanical decoupling system
Detector calibration system
Underground laboratory (LNGS)

**Dark Matter search potential → F.Bellini talk**

# The CUORE Collaboration

Berkeley Lab

UCLA

INFN Istituto Nazionale di Fisica Nucleare

Università degli Studi di Milano Bicocca

Alma Mater Studiorum A.D. 1088

Lawrence Livermore National Laboratory

SINAP

unige

Cal Poly

The University of Wisconsin Madison

University of South Carolina

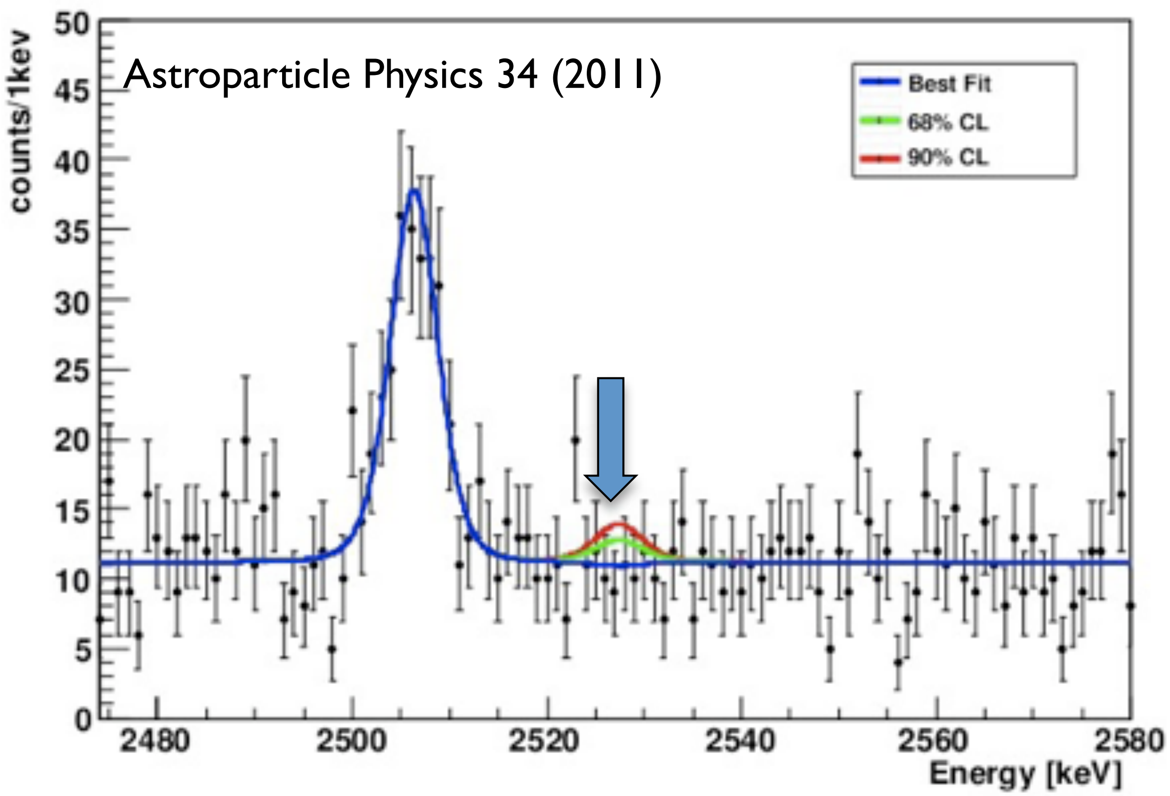
Sapienza Università di Roma

# TeO2 bolometers evolution

$\Delta E = 6.2 \pm 2.5$ keV (~0.3% FWHM)

Bkg = 0.169±0.006 c/keV/kg/y

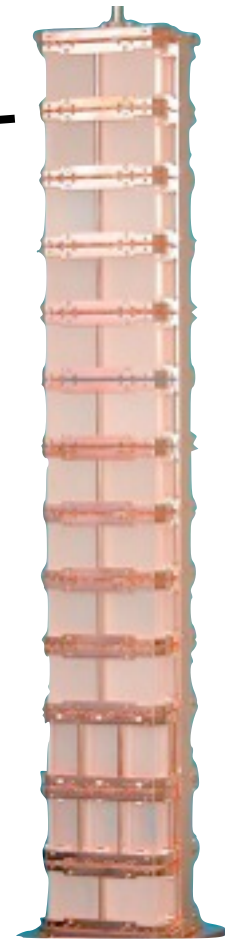
$T_{1/2}^{0\nu}$ (y) > $2.8 \times 10^{24}$ y (90% CL)




$\langle M_{bb} \rangle < 0.3 - 0.7$ eV

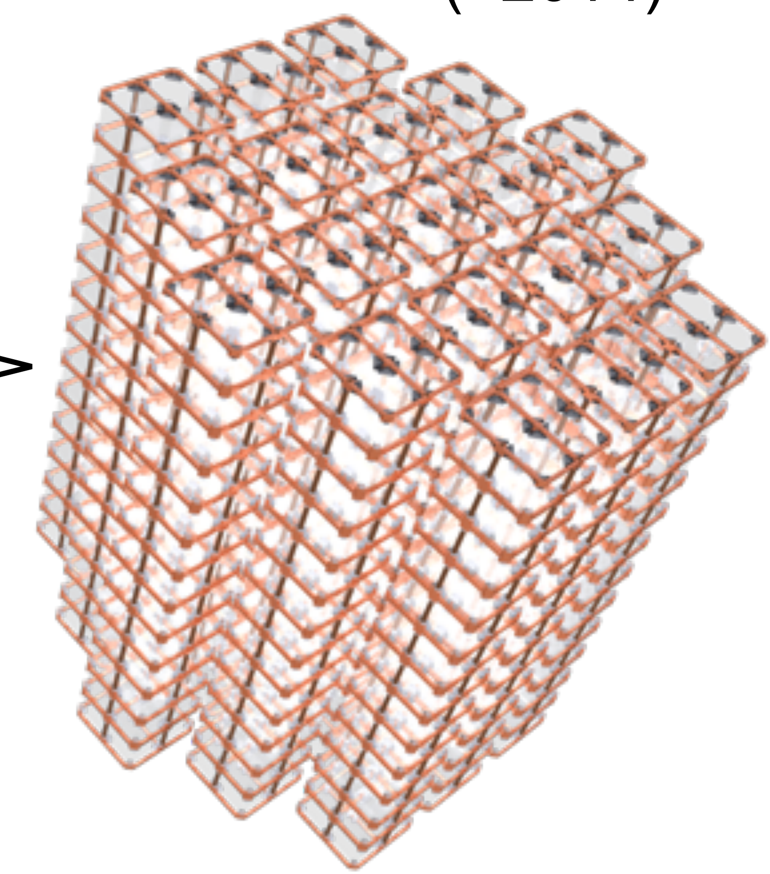
NME from F.Simkovic et al. Phys.Rev. C77
J.Suhonen et al. Int.Jou.Mod.Phys. E17
J.Menendez et al. Nucl. Phys. A818
J.Barea et al. Phys. Rev. C79

CUORICINO
40 kg
(2003-2008)



CUORE-0
(2012)

CUORE
1 ton
(~2014)



Extensive study of background sources

Careful design and construction of the setup

- Hut and infrastructures
- Detector
  - Crystals
  - Structure
  - Assembly
- Cryostat and shields
- Calibration system
- Electronics

# ββ0ν experimental sensitivity

$$S^{0\nu}_{1/2}(m_{ee}) \propto \epsilon \frac{i.a.}{A} \frac{1}{\sqrt{G^{0\nu}}|M^{0\nu}|} \sqrt[4]{\frac{bkg \cdot \Delta E}{M \cdot t_{meas}}}$$

- Isotope choice

- Mass
- Energy resolution
- Background level
- Long measure time

**ββ candidate:** $^{130}$Te **– Q** 2527.5 keV

**Source Mass:** 206 kg $^{130}$Te – $\mathbf{N_{\beta\beta}}$ 9.6 x$10^{26}$

**Projected Bkg: 0.01 c/keV/kg/y**

**Resolution:** ~ 5 keV @ROI

**Sensitivity $\mathbf{T_{1/2}^{0\nu}}$:** 1.6x$10^{26}$ y in 5 y

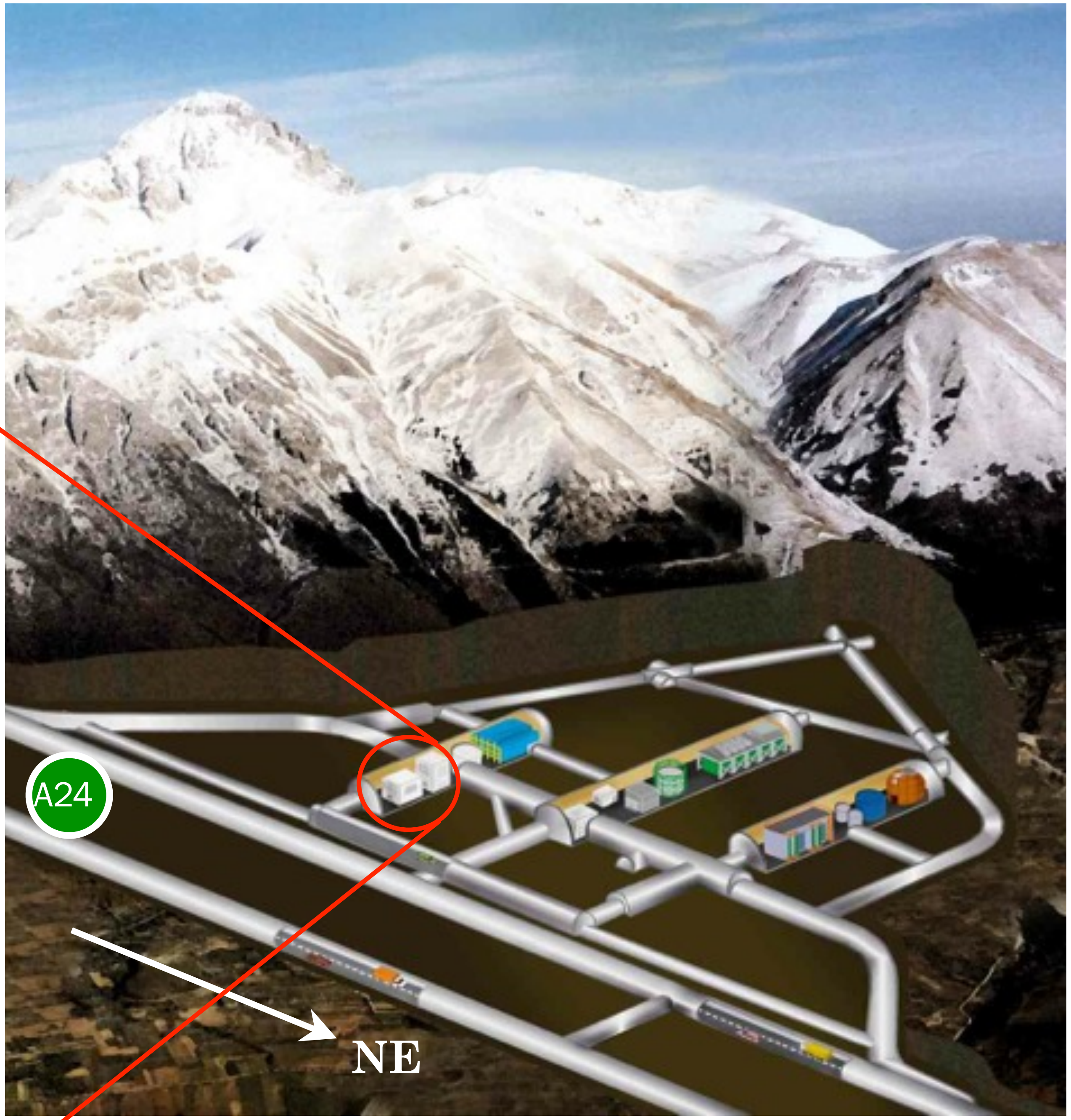
**Sensitivity <$\mathbf{m_{ee}}$>:**<$m_{ee}$> < 40 ÷ 94 meV in 5y (IH)

- ✦ Deep underground location
- ✦ Bolometric approach
- ✦ Large mass array
- ✦ Material selection
- ✦ Severe control of procedures
- ✦ Stable operating condition over several years

# The LNGS underground facility

CUORE hut (New Building)

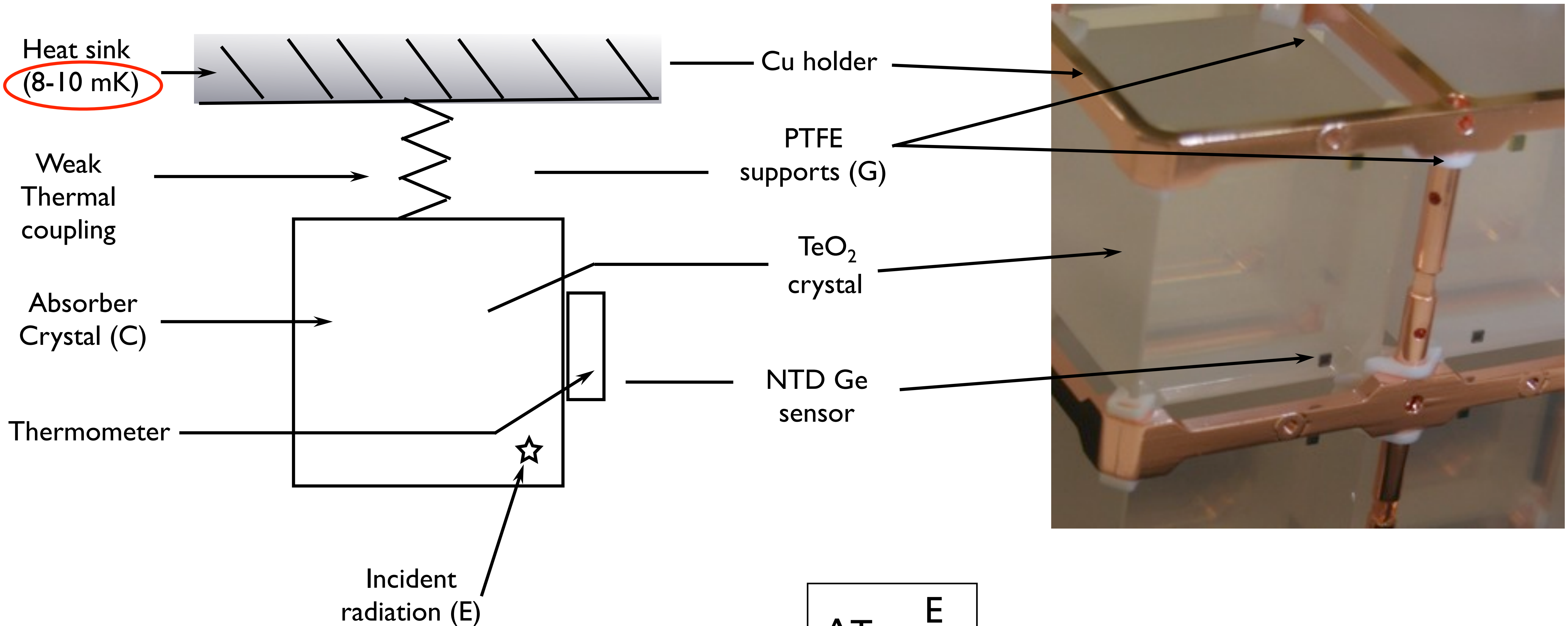
Cuoricino/CUORE-0 hut




Underground facility

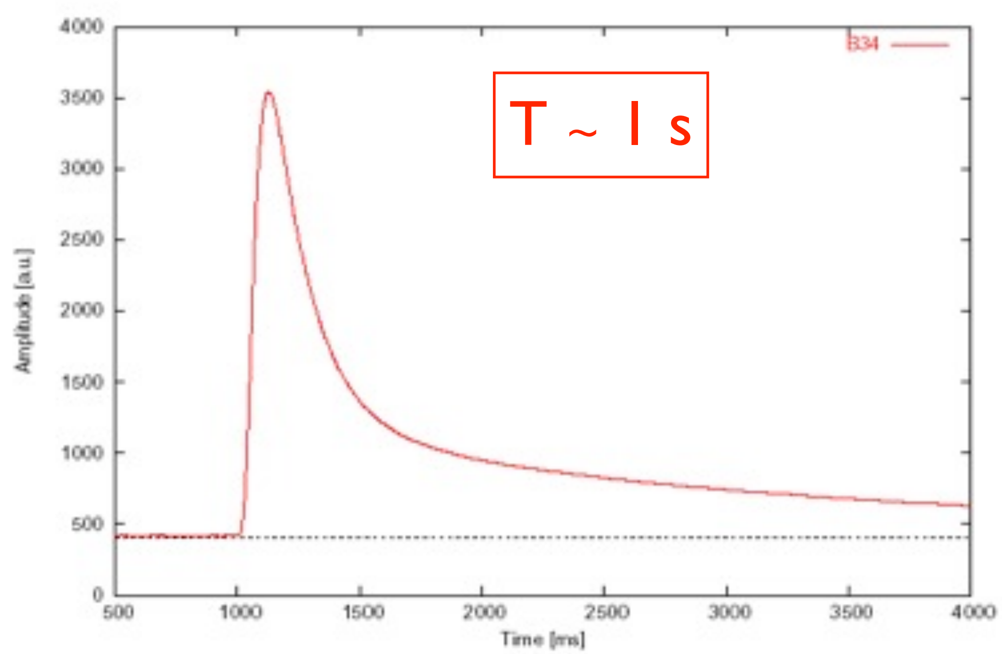
- Average depth ~ 3650 m.w.e.
- Factor $10^6$ reduction in muon flux to ~ $3 \times 10^{-8}$ μ/(s·cm$^2$)

# The CUORE $TeO_2$ bolometers




$$\Delta T = \frac{E}{C}$$

$$\tau = \frac{C}{G}$$

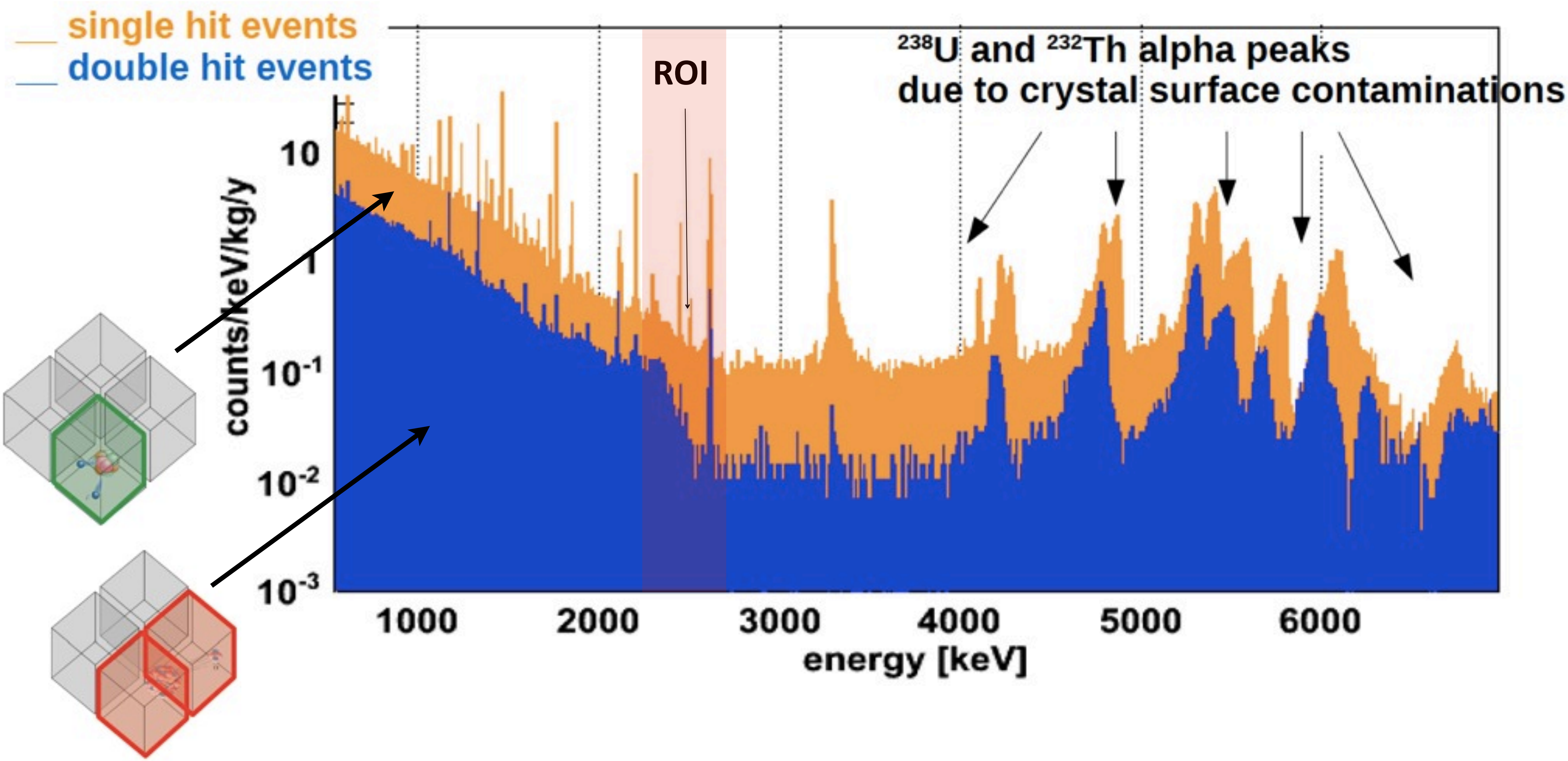



Pros: - good energy resolution
- different sources could be investigated
- high efficiency (internal sources)

Cons: - no dead layer
- low temperature tech required
- slow pulses

# Background contributions

Largest available statistics: Cuoricino

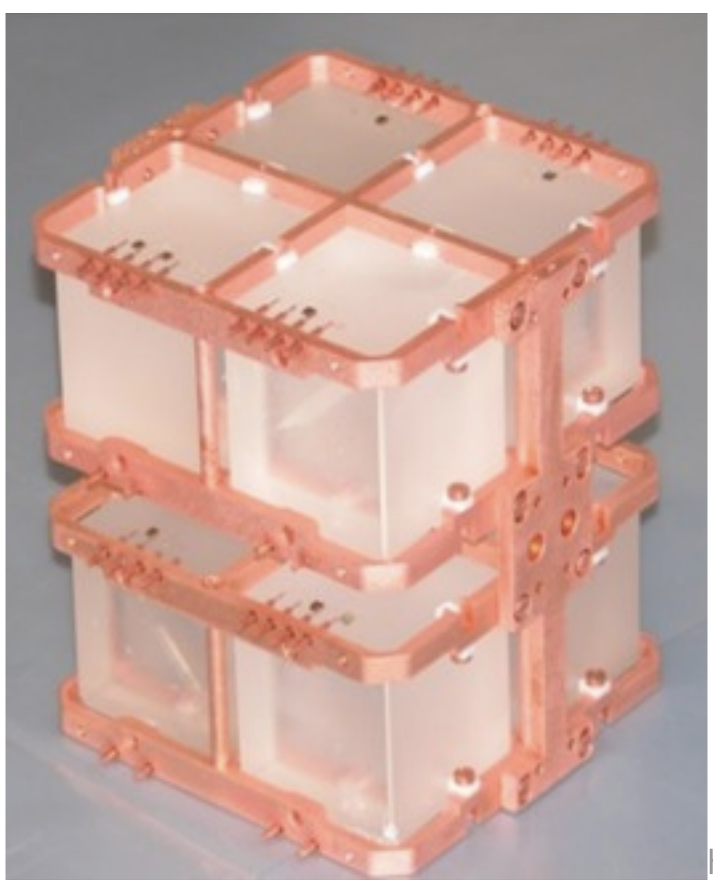
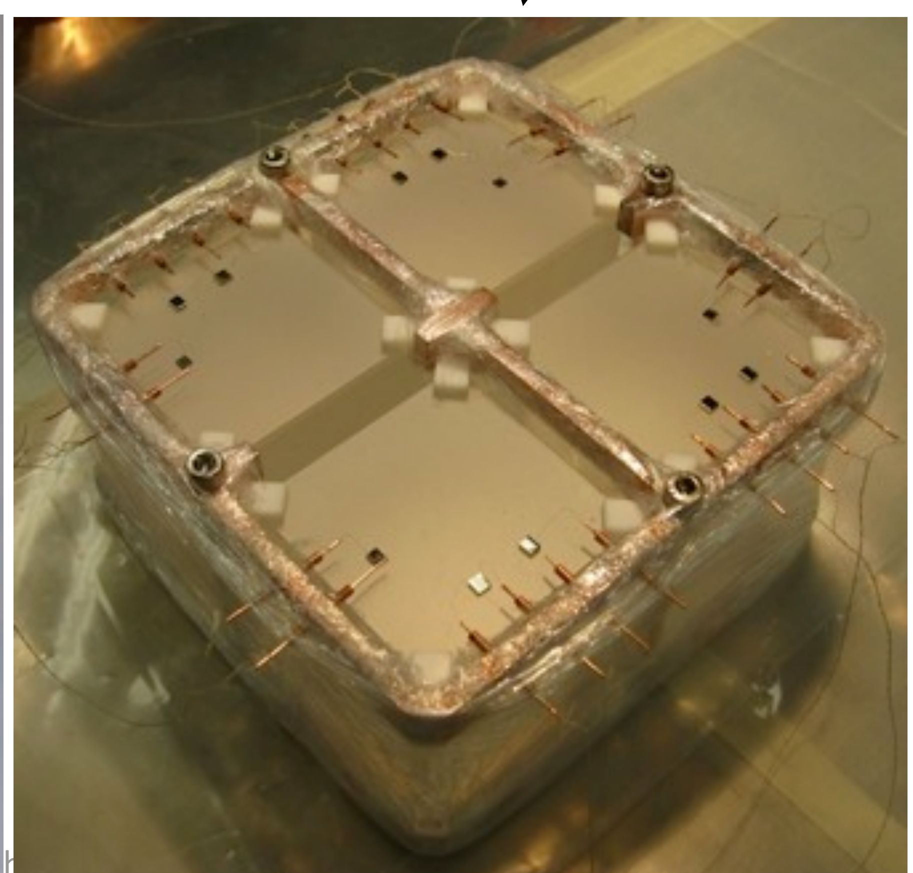


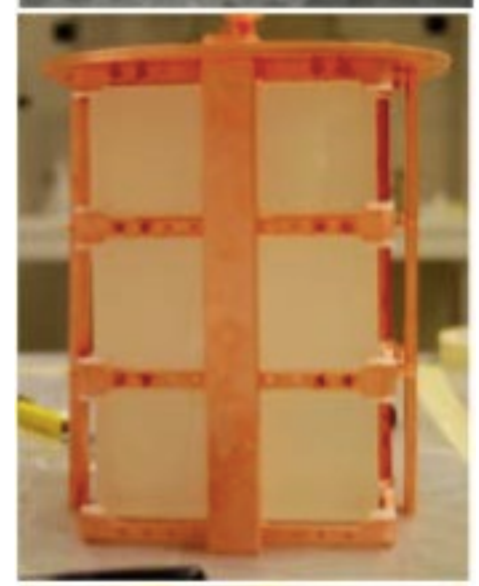
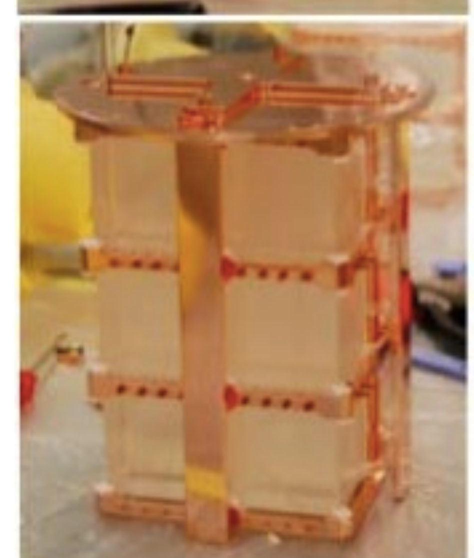

But a lot of information comes also from dedicated R&D bolometric measurements in an R&D cryogenic setup @ LNGS

# R&D and QC tests

- TTT (Three Tower [cleaning] Test)
- RAD (RADioactivity study setup)
- CCVR (CUORE crystal validation runs)

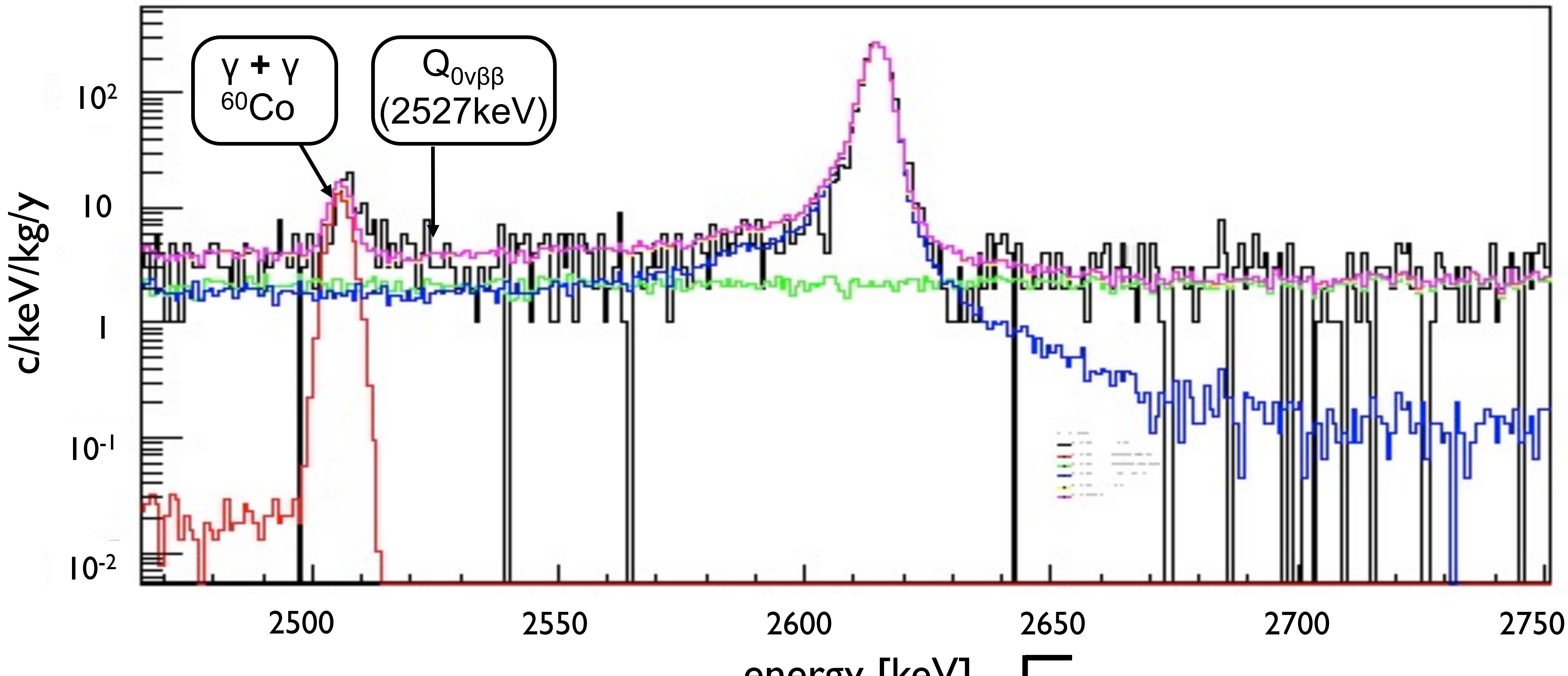
- No way of measuring directly the background level in the ββ0ν ROI
- Background model needed


# Background model

MC: the background in CUORICINO is due to degraded alpha particles which release only part of their energy in the detector (surface contamination)




Bkg @ 0vDBD region = 0.161 +/- 0.006 c/keV/kg/y
(ainticoincidence spectrum, 5x5x5 cm$^3$ crystals)

C.Arnaboldi et al. http://arxiv.org/abs/hep-ex/0212053

30 ± 10 % $^{232}$Th in cryostat (γ)

10 ± 5 % $TeO_2$ surface (α)

50 ± 20 % Cu surface (α)

C.Arnaboldi et al. Phys. Rev C 78 (2008) 035502

# Background budget

| Source | CUORE in the ROI c/(keV kg y) | Source of data |
|---|---|---|
| Cosmogenic activation of crystals (bulk) | ~ 1 $10^{-3}$ | NAA + MC |
| Gold wires ($^{232}$Th and $^{238}$U) (bulk) | < 1 $10^{-3}$ | Bolometric test + HPGe |
| Copper frames ($^{232}$Th) (bulk) | < 1.5 $10^{-3}$ | HPGe + NAA + MC |
| $^{232}$Th in the Roman lead shield (bulk) | < 4 $10^{-3}$ | Bolometric + HPGe |
| Muon interactions (bulk) | ~ 1.8 $10^{-3}$ | Measured fluxes + MC |
| $TeO_2$ crystals surface activity | < 4 $10^{-3}$ | Bolometric tests (CCVR) + MC |
| Surface activity of the mounting structure | < 2-3 $10^{-2}$ | Test on small tower + MC |
| | < 6 $10^{-2}$ | Test on small tower + MC |

If contamination in the R&D run are due to surface contamination of copper structure

If contamination in the R&D run are due to $^{210}$Pb contamination of PTFE (unlikely)

mutually exclusive hypotheses!

new measurement in progress


F.Alessandria et al. [CUORE coll.] http://arxiv.org/abs/1109.0494v1
C.Arnaboldi et al. Phys. Rev. C 78 (2008) 035502
F.Bellini et al. Astr.Phys. 33 (2010) 169
F.Alessandria et al. [CUORE coll.] http://arxiv.org/abs/1108.4757v1

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| Surface activity of the mounting structure | < 2-3 $10^{-2}$ | Test on small tower + MC |
| | < 6 $10^{-2}$ | Test on small tower + MC |

**Conservative values**

- Different depth profiles of surface contaminations compared and largest values quoted here

**Upper limits**

- Attribute all events in the target region as due solely from a certain source


F.Alessandria et al. [CUORE coll.] http://arxiv.org/abs/1109.0494v1
C.Arnaboldi et al. Phys. Rev. C 78 (2008) 035502
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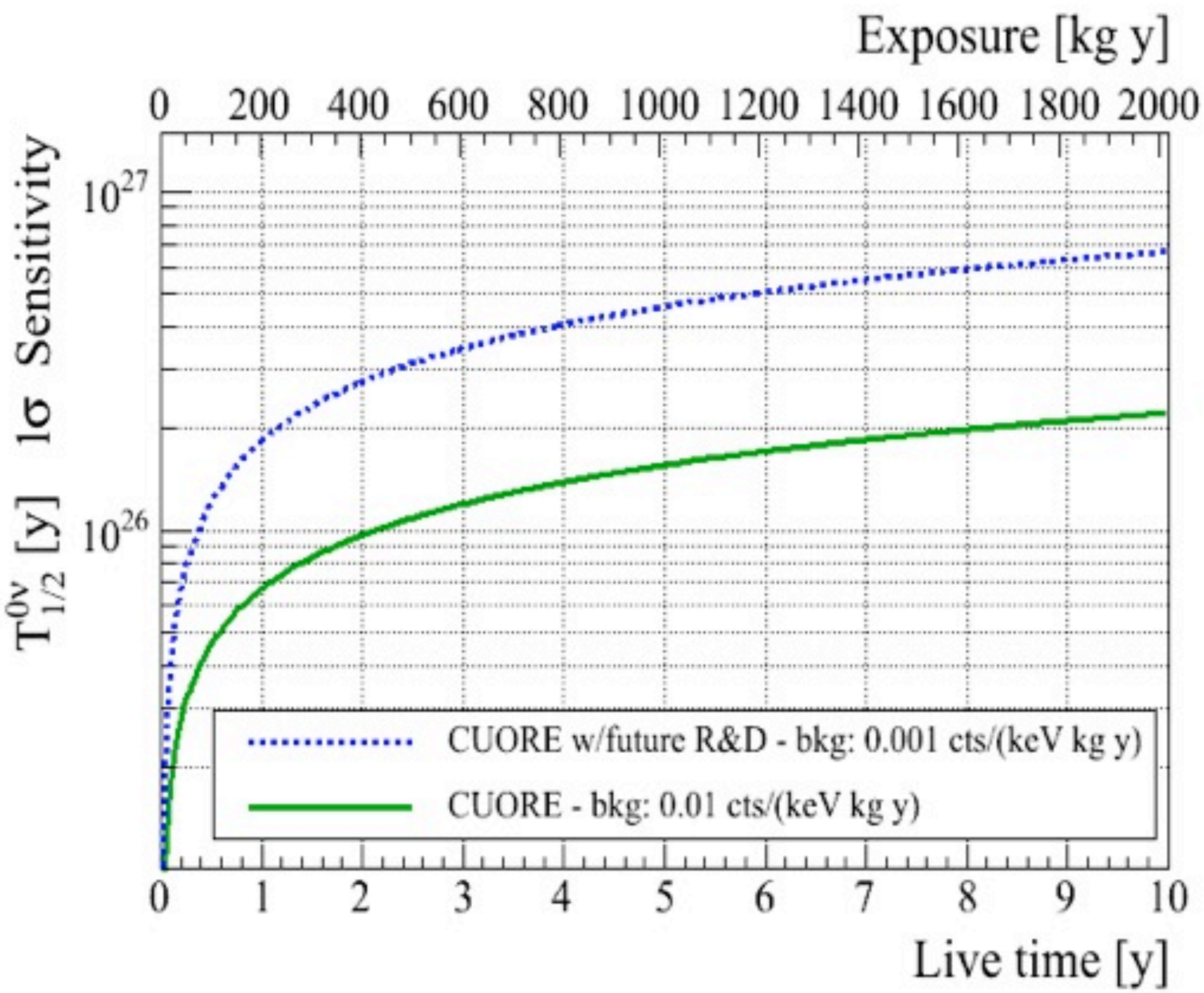
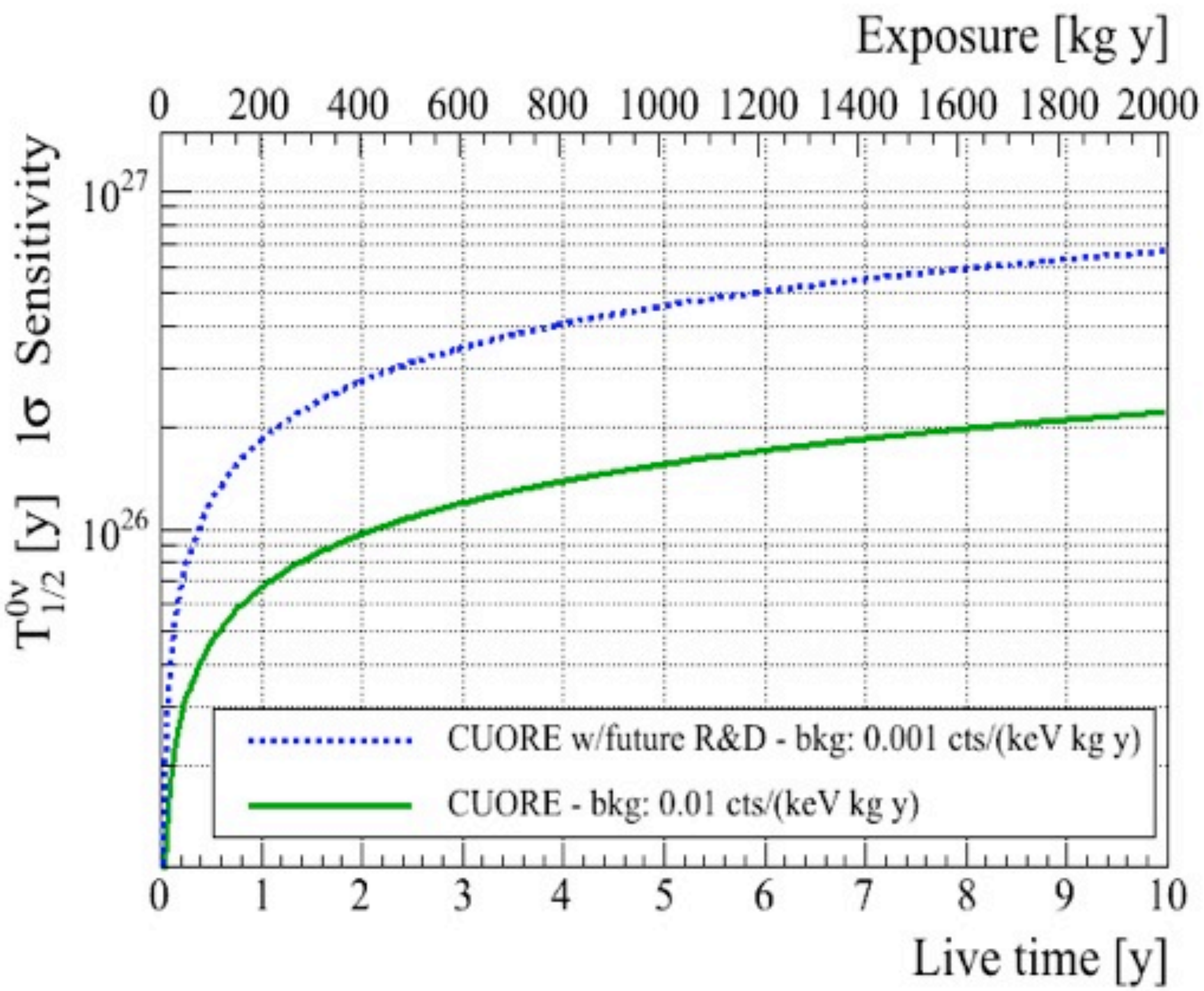
# CUORE sensitivity

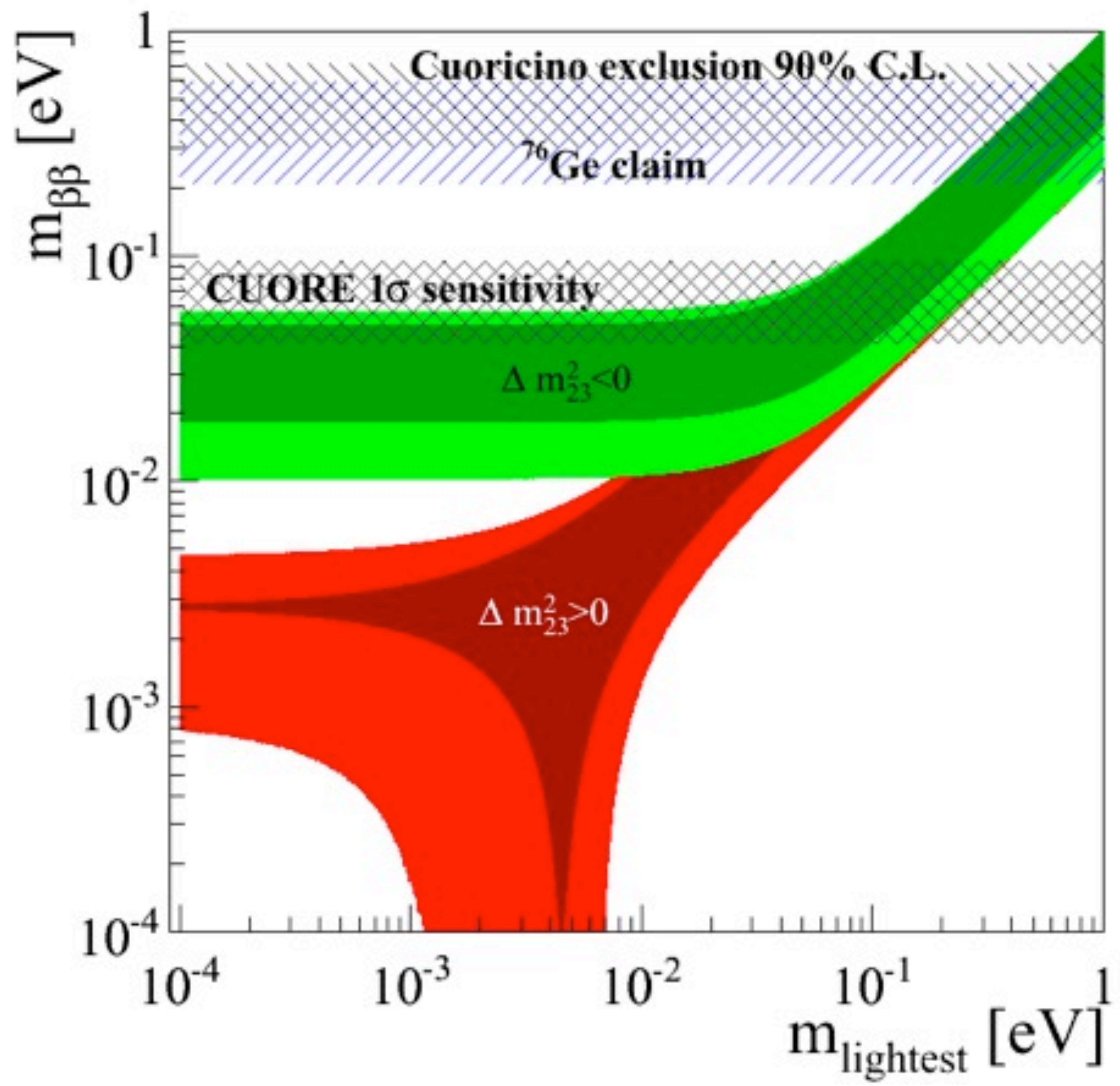



Background goal of 0.01 c/keV/kg/y

$T_{1/2}$ = 1.6 x $10^{26}$ y **$m_{\beta\beta}$ = 41-95 meV**

# CUORE sensitivity




Background goal of 0.01 c/keV/kg/y

$T_{1/2}$ = 1.6 x $10^{26}$ y **$m_{\beta\beta}$ = 41-95 meV**

The large mass and excellent energy resolution, make CUORE competitive to sound the IH region down to 41-95 meV

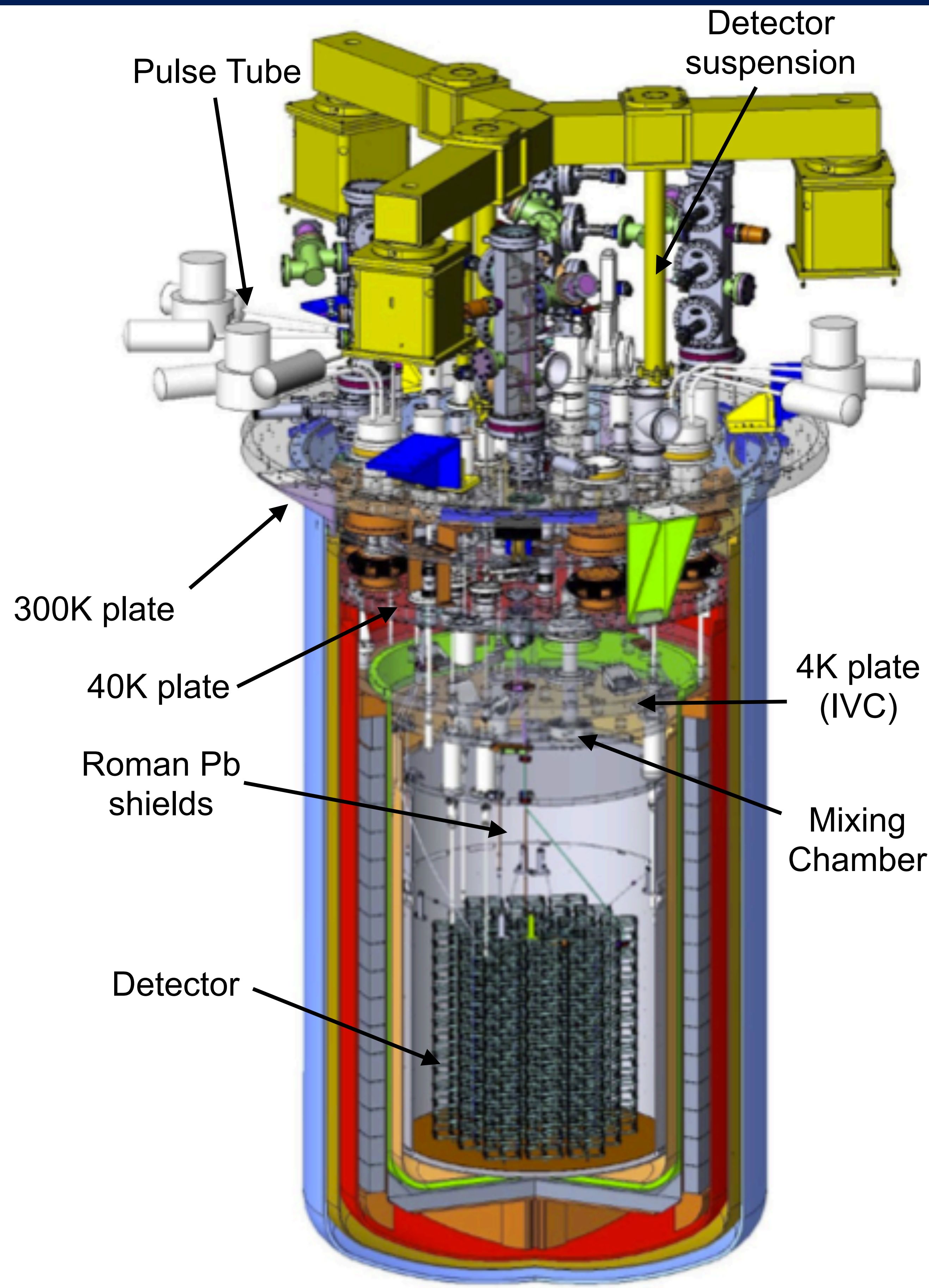
# CUORE experimental setup

**Custom cryogenic system @ LNGS.**

- Improved shielding and material selection.
- High efficiency in background rejection, due to the packed geometry: minimum lead thickness surrounding the detector ~ 36 cm
- No cryogenics liquids: better duty cycle
- Mechanical suspension of the detector assembly completely independent from the refrigerator structure: better control of noise induced by vibrations
- Severe control of the radioactivity of the set-up

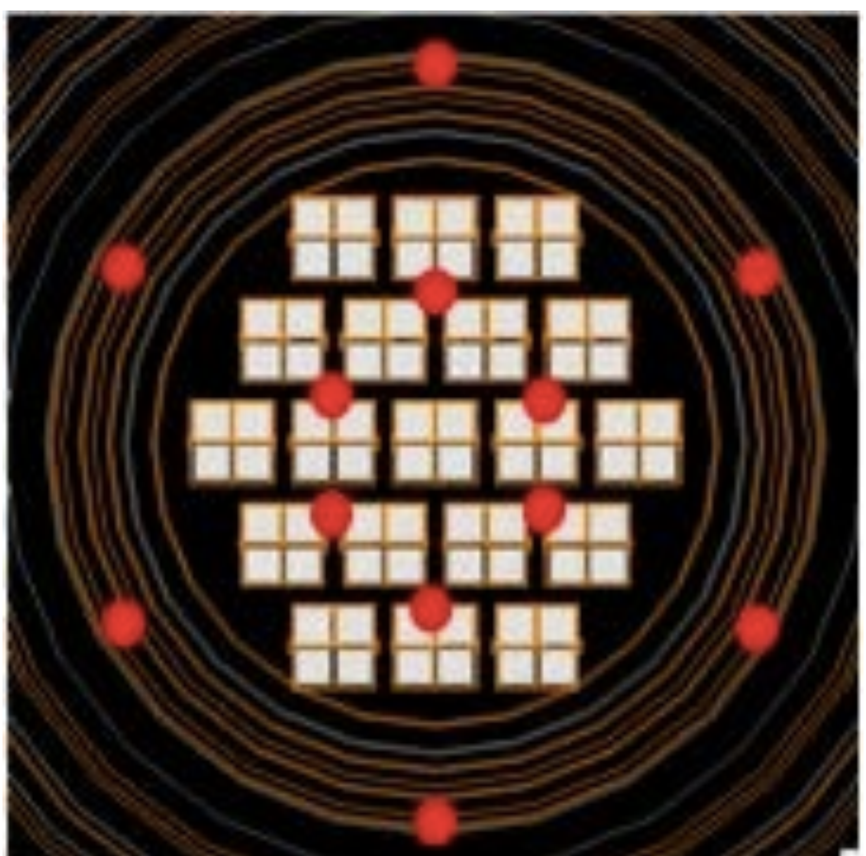
**Embedded in the setup (after a severe control of the radioactivity of the materials):**

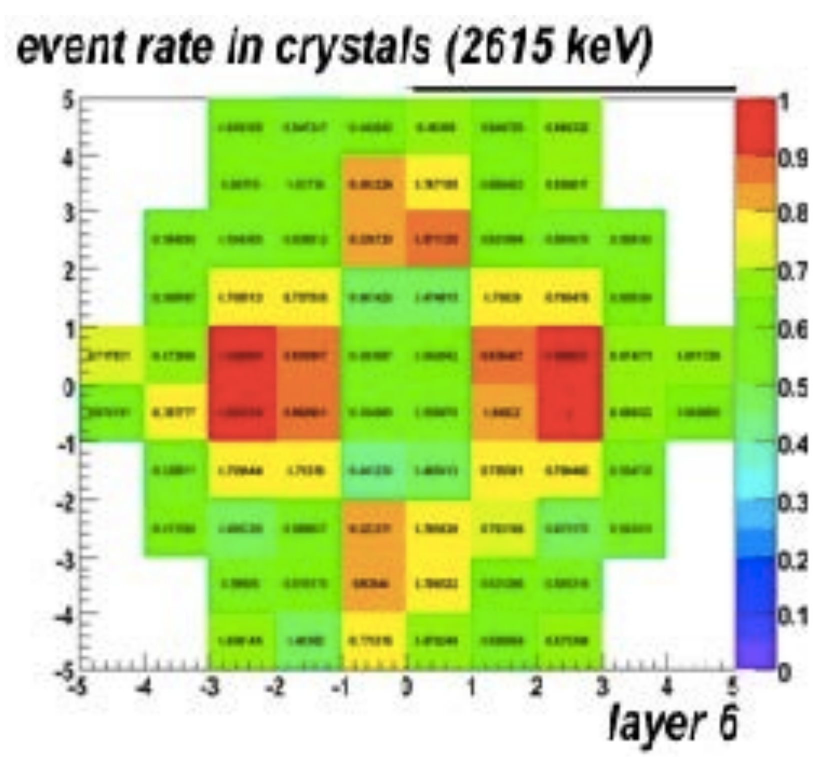
- Cryo-free dilution refrigerator (Leiden Cryogenics)
- Roman Lead (no 210Pb) cold shield
- Detector and Pd shiled suspension
- Calibration system

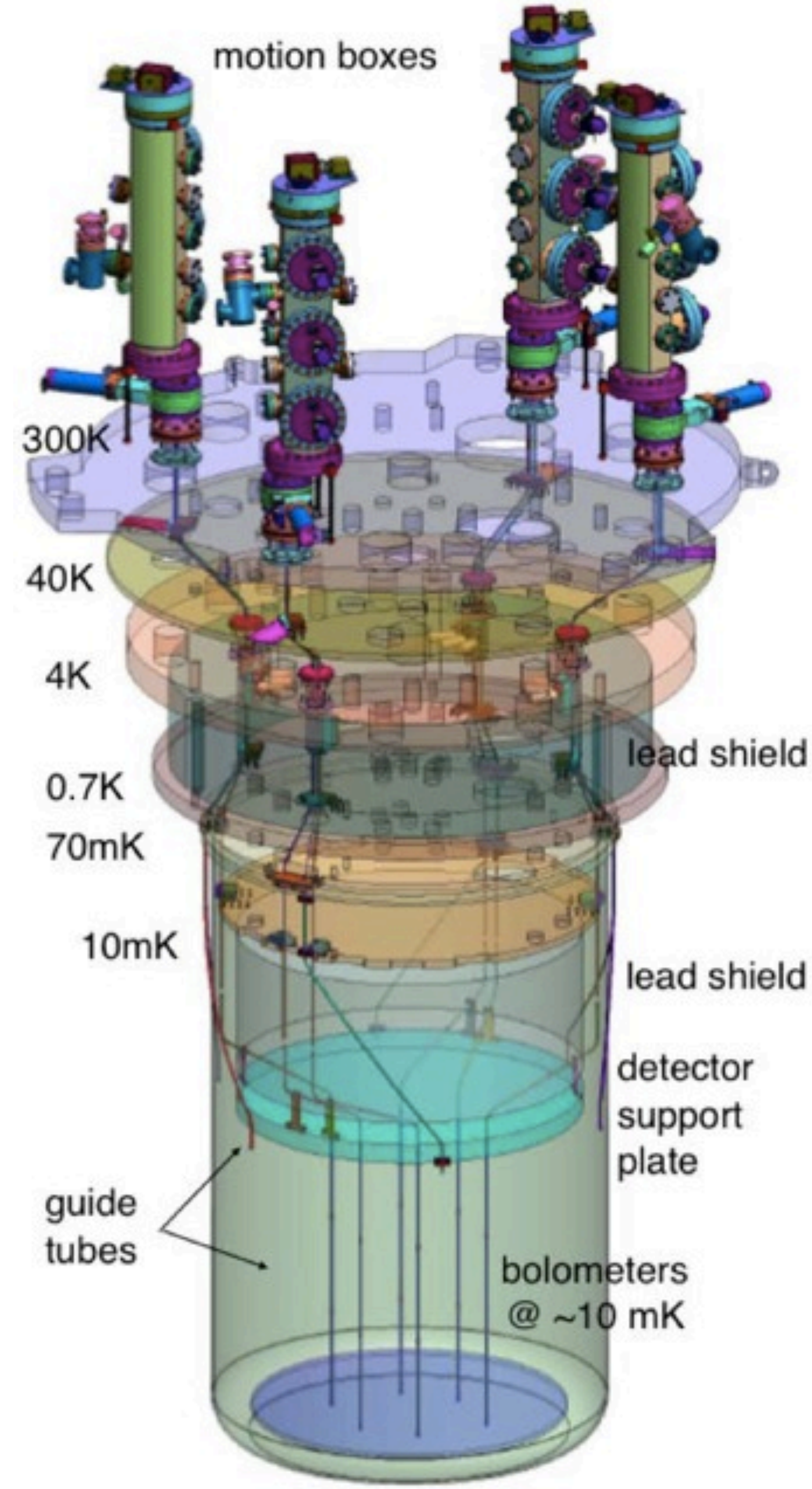


# Detector Calibration System

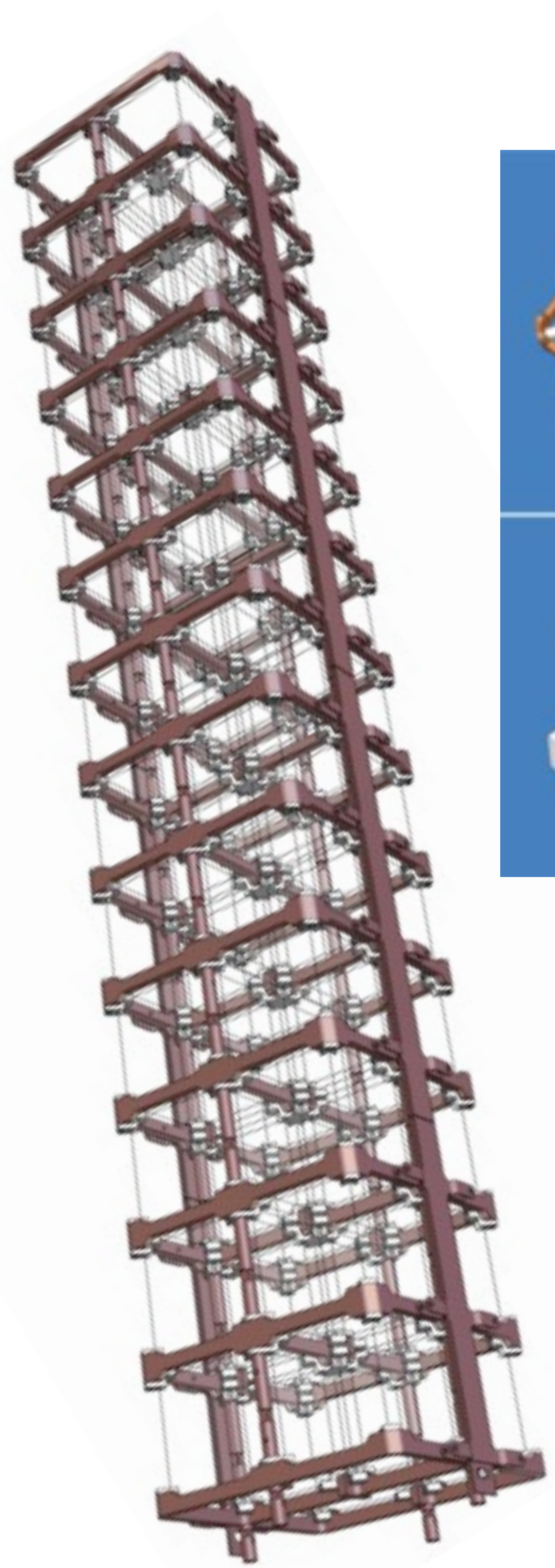
- 12 gamma source wires
  - $^{232}Th$: thoriated tungsten wire
  - $^{56}Co$: proton activated Fe wire
- Minimize down time but rate at each crystal not exceeding 150 mHz
- Stringent heat load requirement

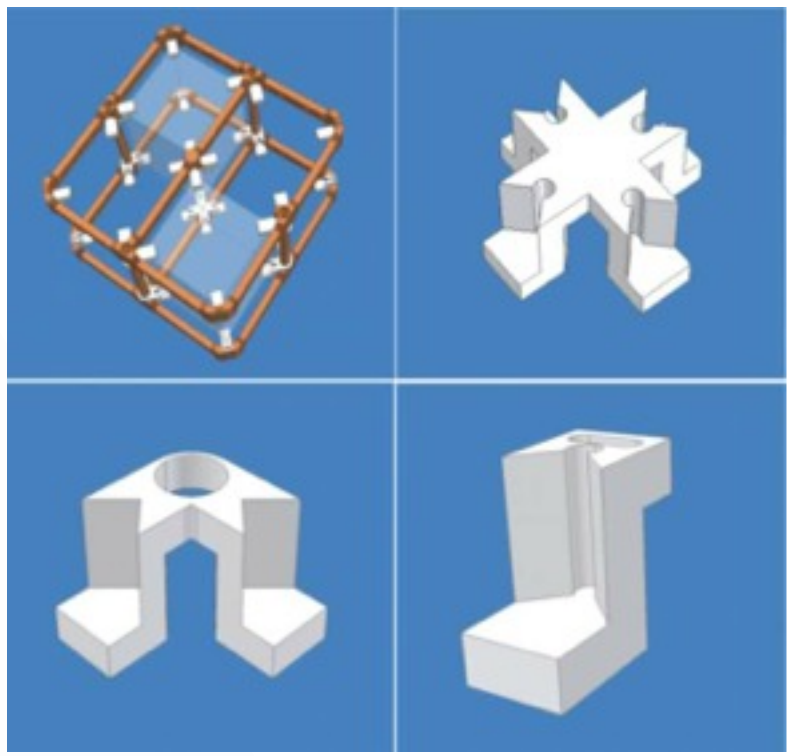


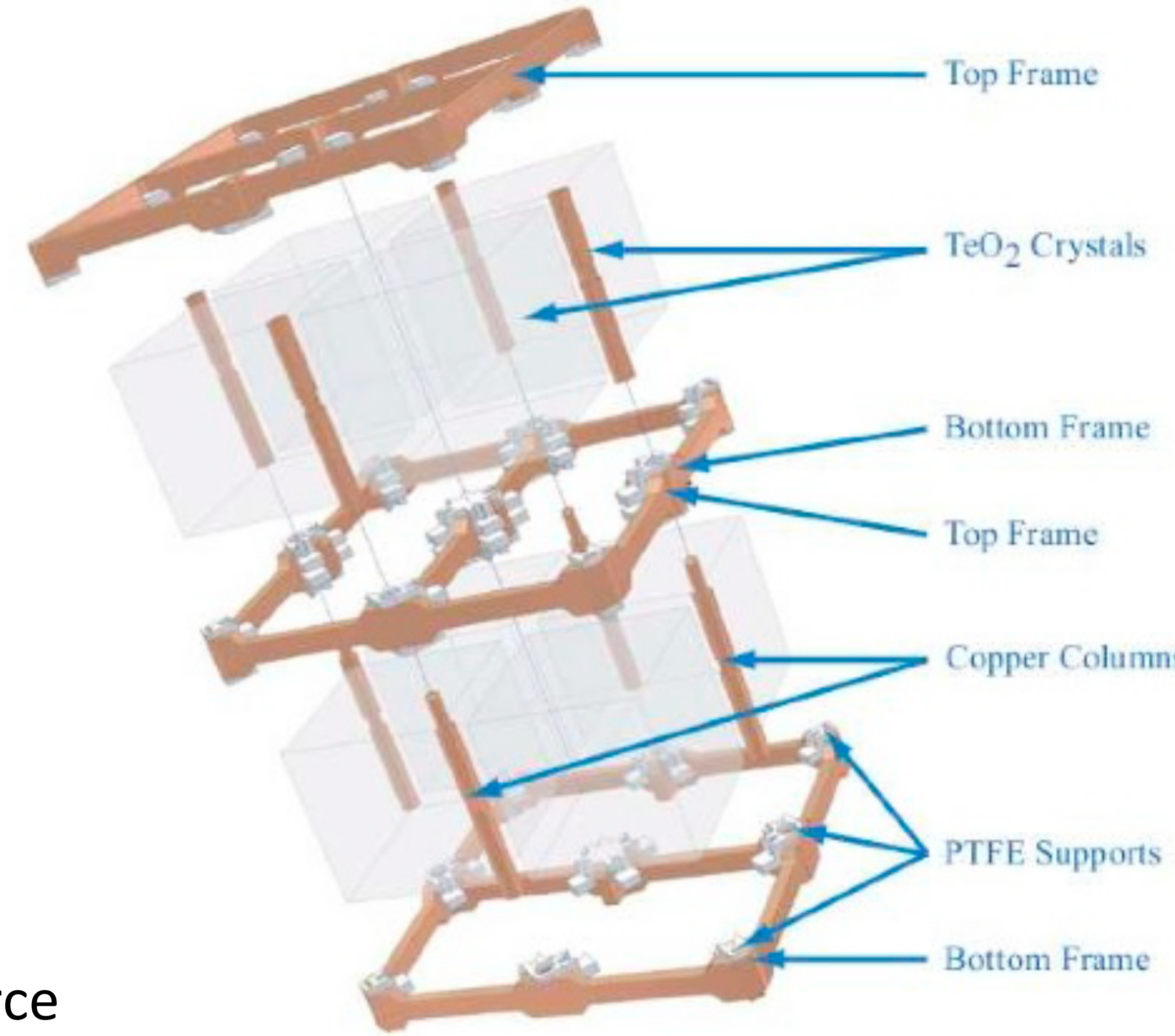


# An improved tower design





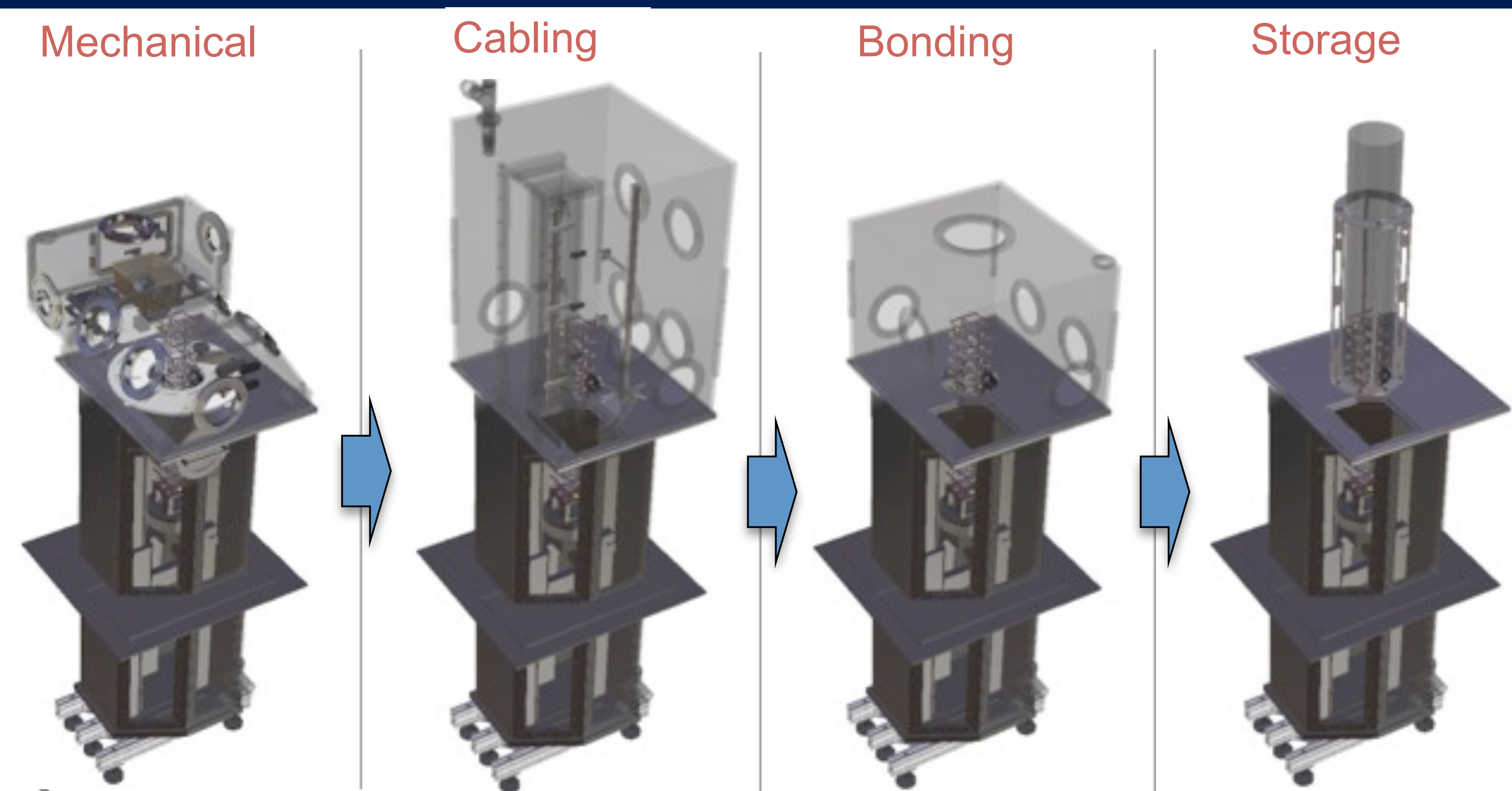


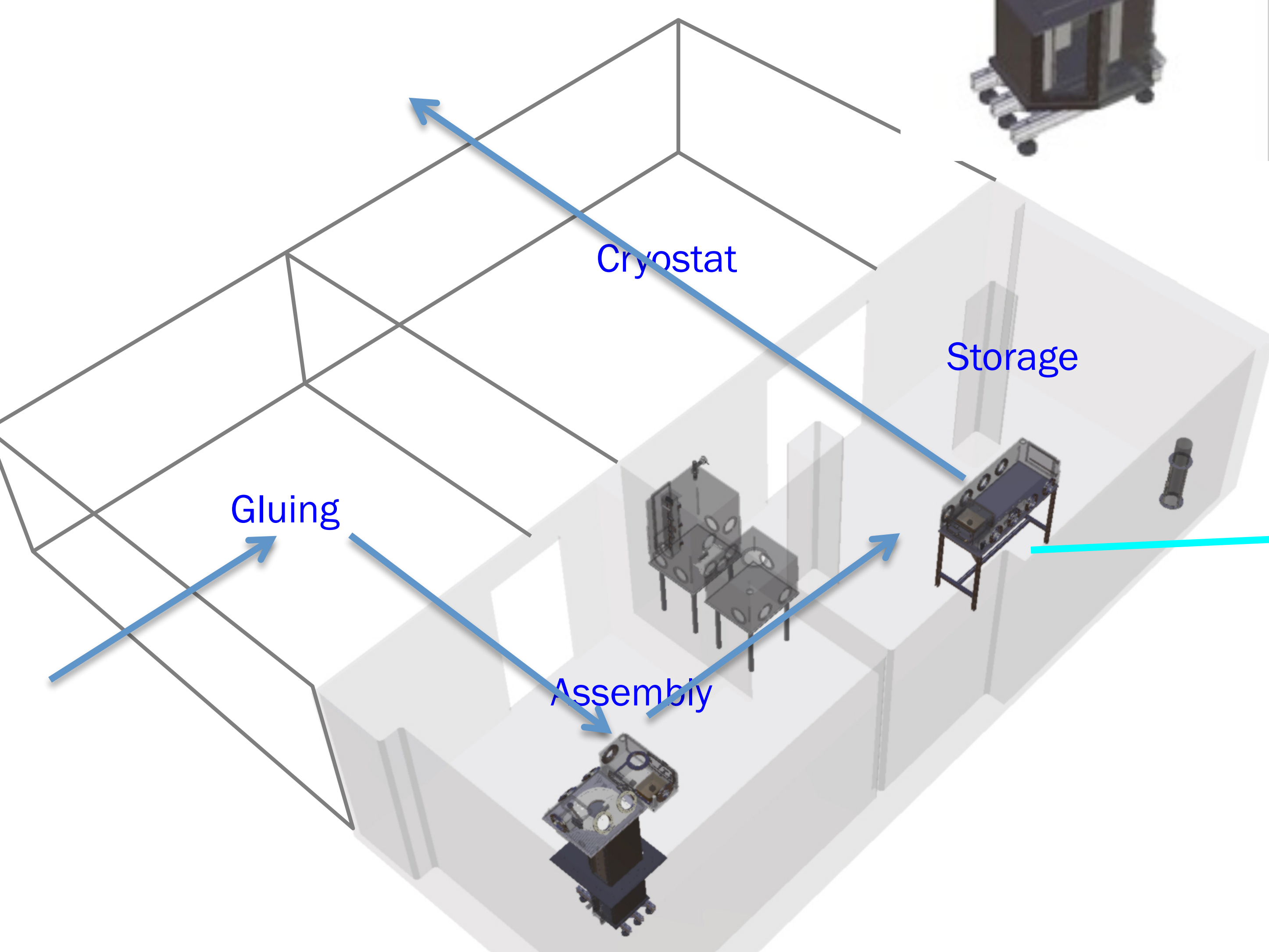

- Copper Frame:
  - Heat bath
  - Background source
- Teflon holders
  - The weak thermal link
  - Reduce vibration noise

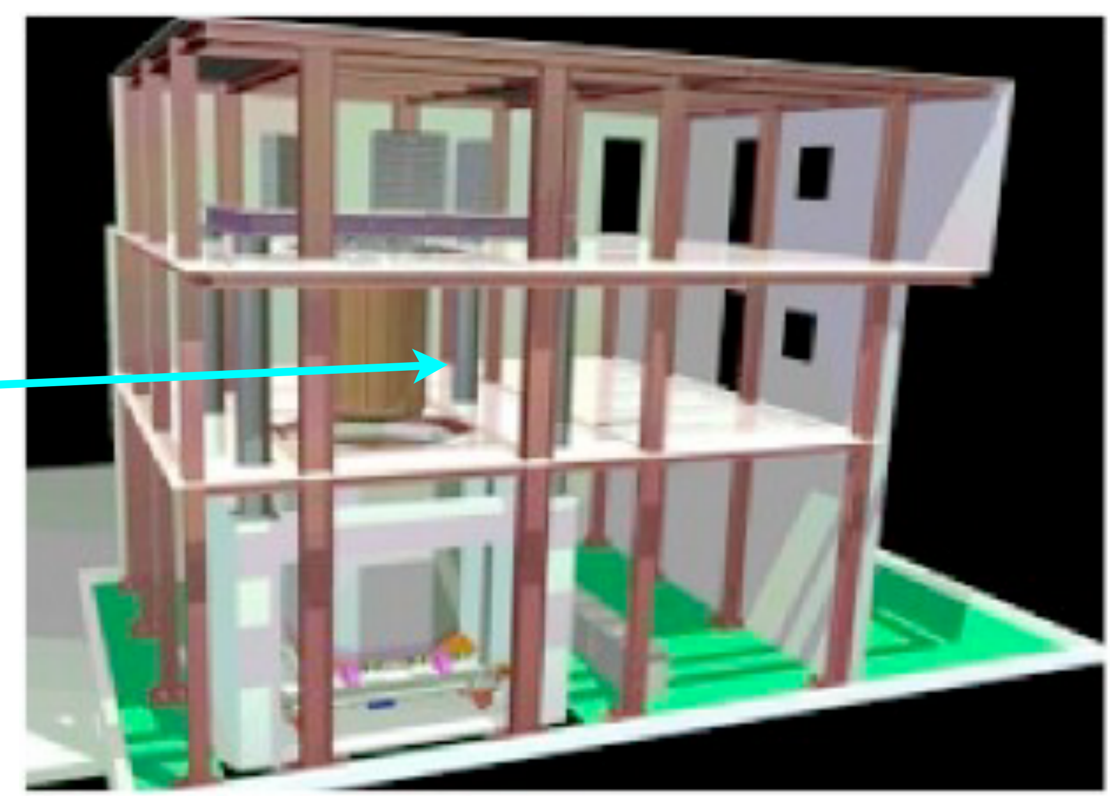
# CUORE tower assembly line

Set of specially designed Glove Boxes
- Rn free atmosphere
- strict control of materials
- reproducible protocol

**Completed Summer 2011**



# CUORE status & schedule

**Detector**

- Crystals, almost completely delivered at LNGS
- Copper parts machining and cleaning are progressing regularly
- Tower assembly line was completed in 2011 and tested on CUORE0. **Ready to start for the CUORE tower assembly in November 2012**
- Radon abatement system installed

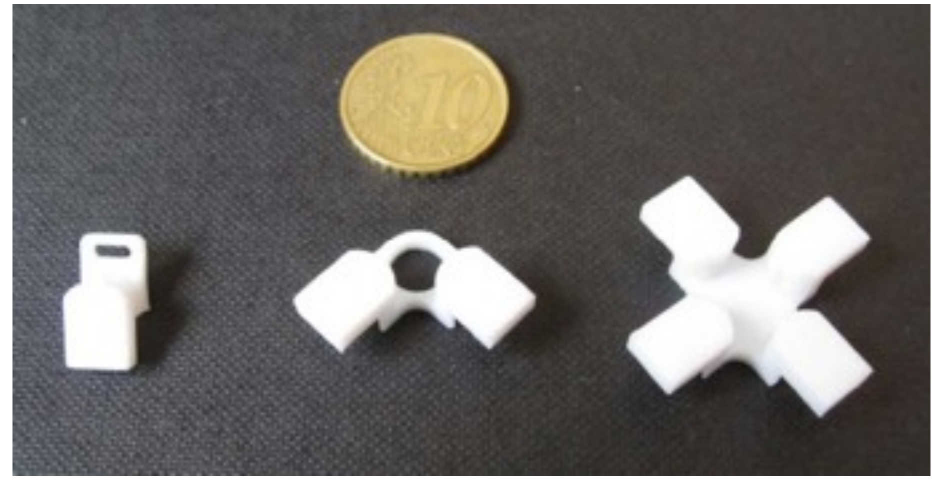
**CUORE Hut**, and most of all the infrastructures are ready

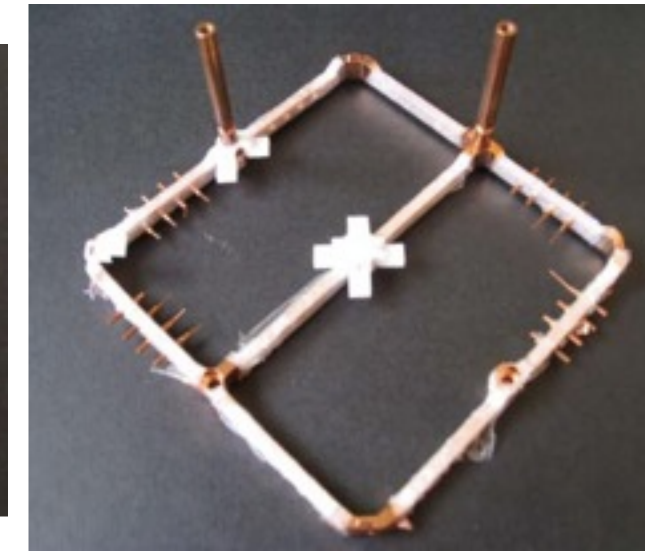
**Cryogenics**

- Dilution unit delivered to LNGS. Performance better than expected.
- 3 (of 6) cryostat vessels tested and delivered at LNGS
- **Commissioning of the cryogenic setup started on July 2012**

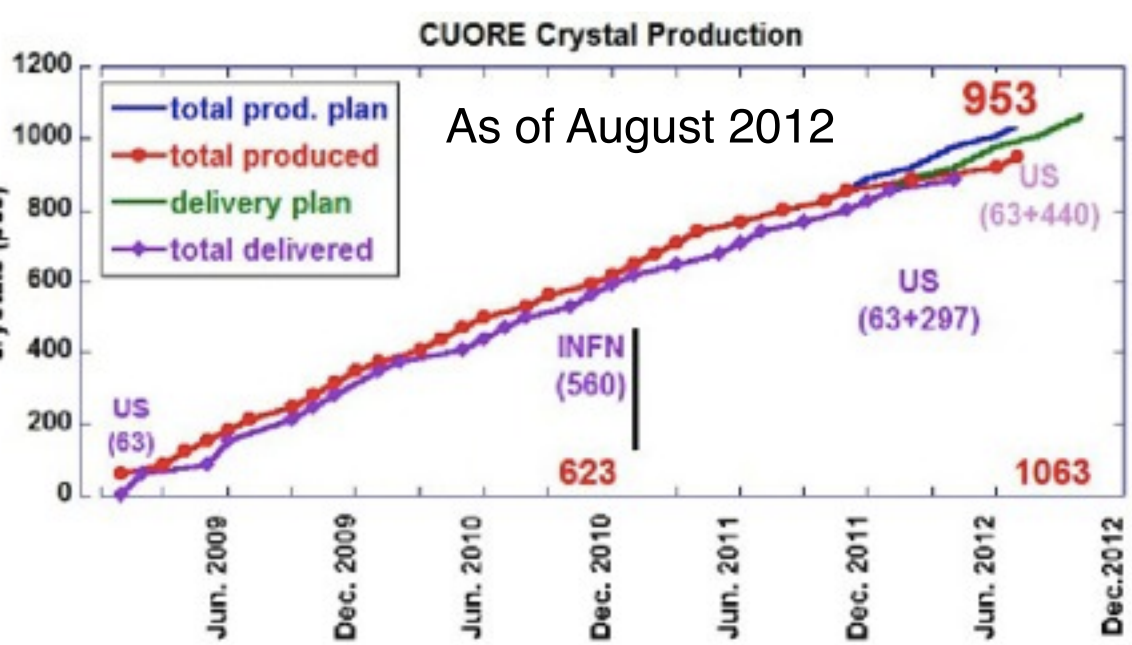
| | |
|---|---|
| Crystals | 12/12 |
| Thermistors | 13/03 |
| Cleaned Cu parts | 13/12 |
| Cryogenics | 13/12 |
| Tower Assembly | 14/04 |
| Detector insertion | 14/07 |
| **Cool Down** | **Fall 2014** |

# Detector parts

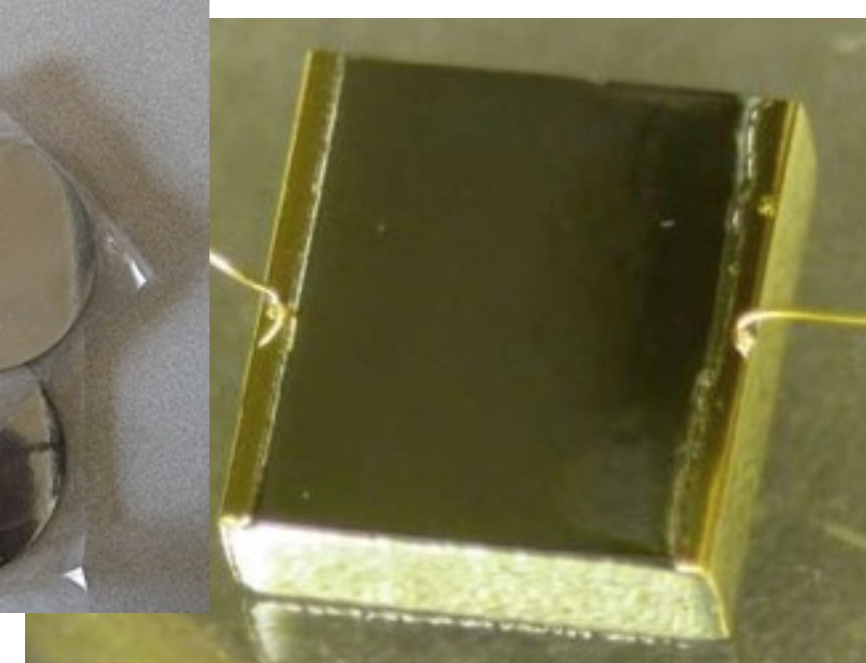




Teflon and Copper parts almost completed:
- Copper cleaning underway




TeO2 production @ SICCS close to completion



NTD's: 695 of 1250 already delivered

# CUORE-0

Critical points in the way of CUORE experiment:
- uniformity of the detector array
- control of possible recontamination during the detector construction

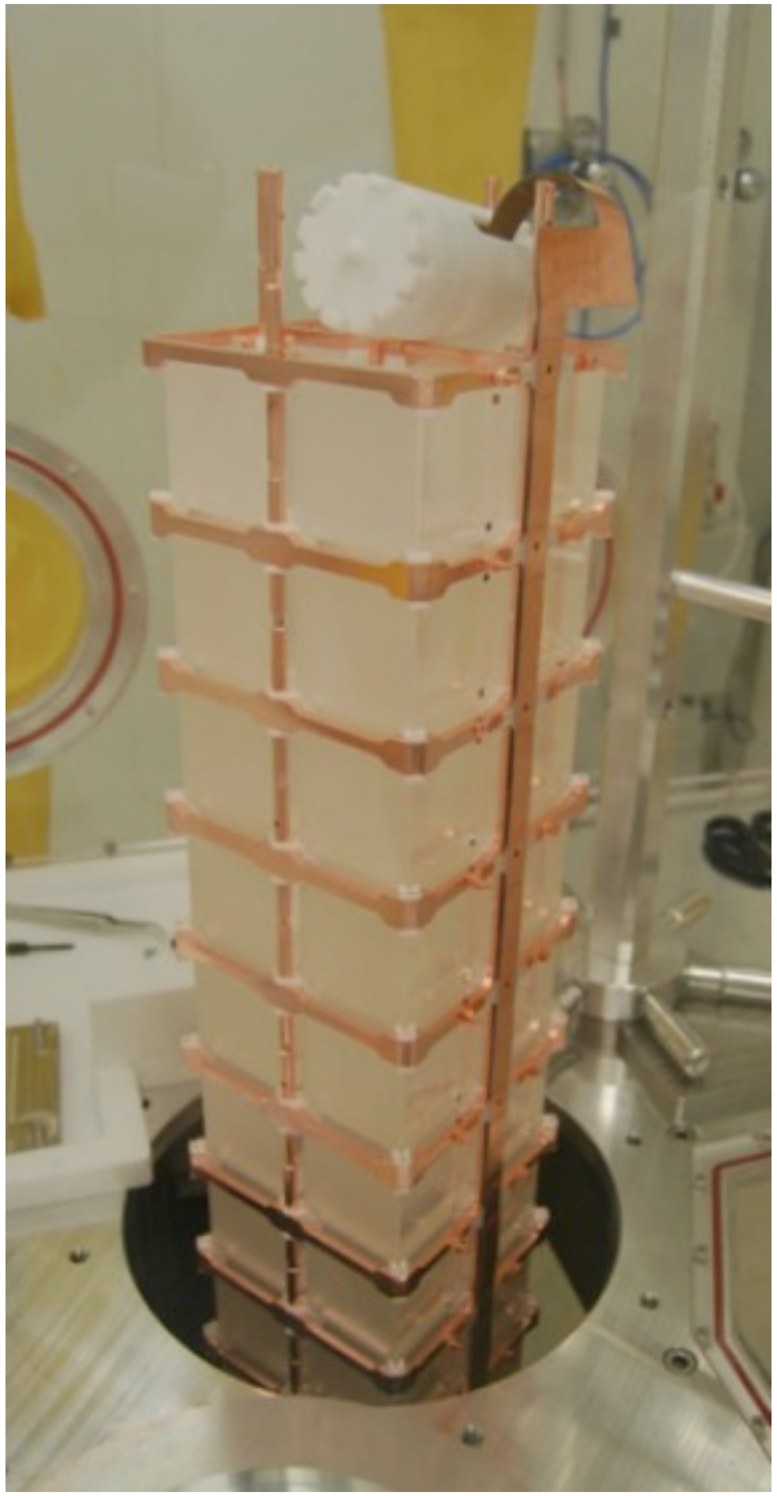
CUORE-0:
- first tower **from the CUORE assembly line**
- operated as a stand alone experiment in the CUORICINO cryostat

**CUORE-0 goals:**
- full test and debug of the new CUORE assembly line
  - 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

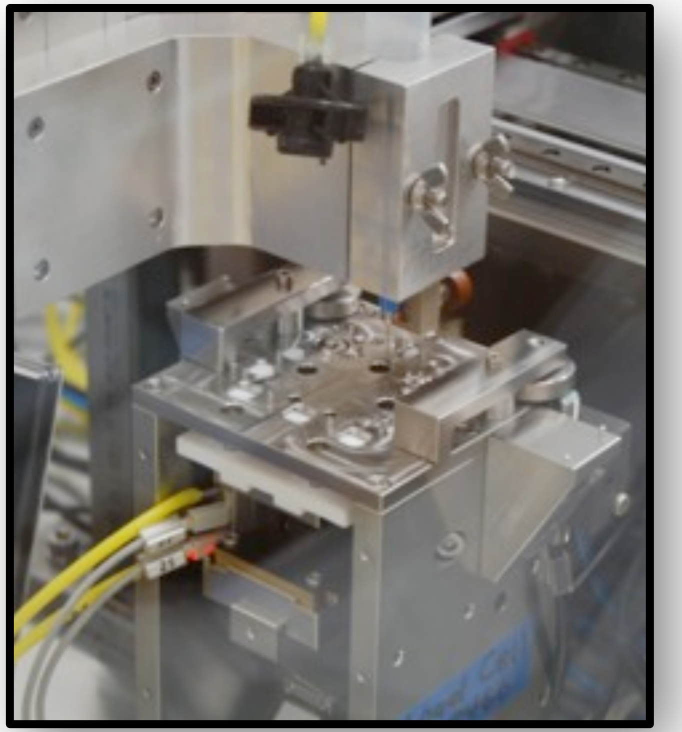
- thorough exercise of the analysis framework

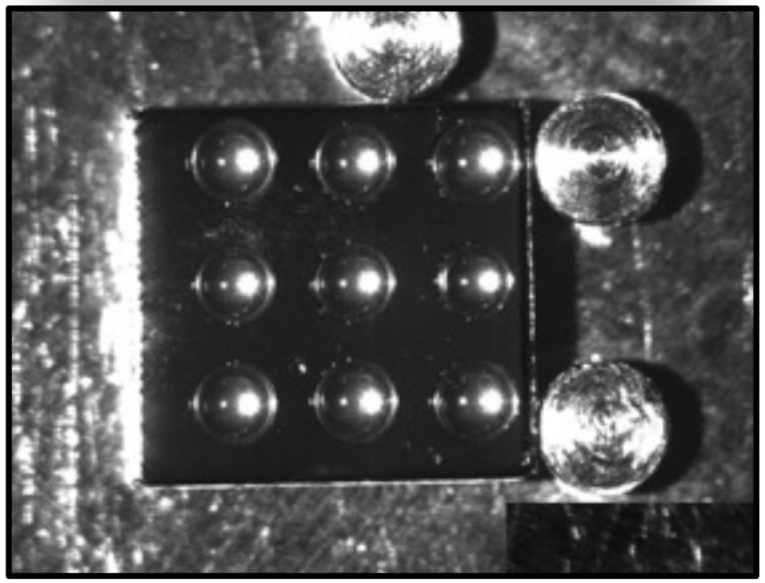
# CUORE0 construction

Mechanical assembly

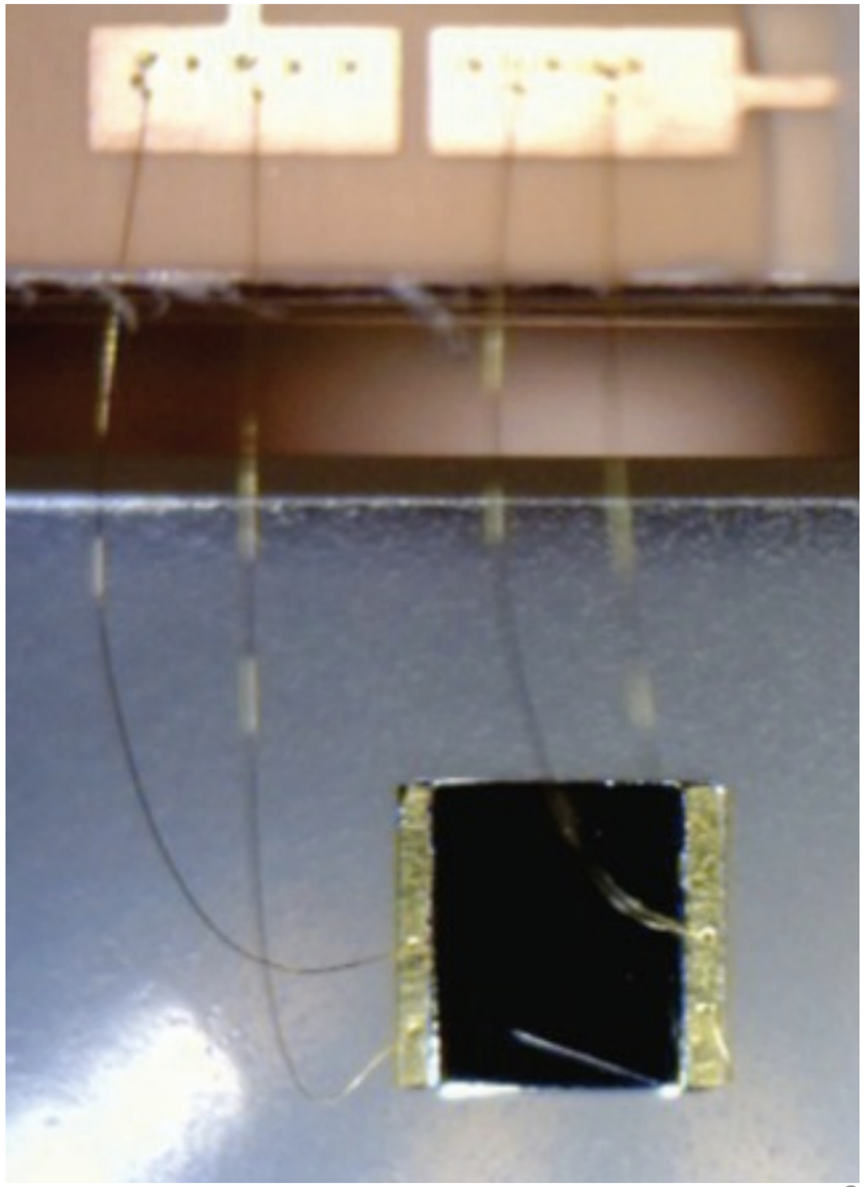


Sensors & heaters gluing
- semi-automated system

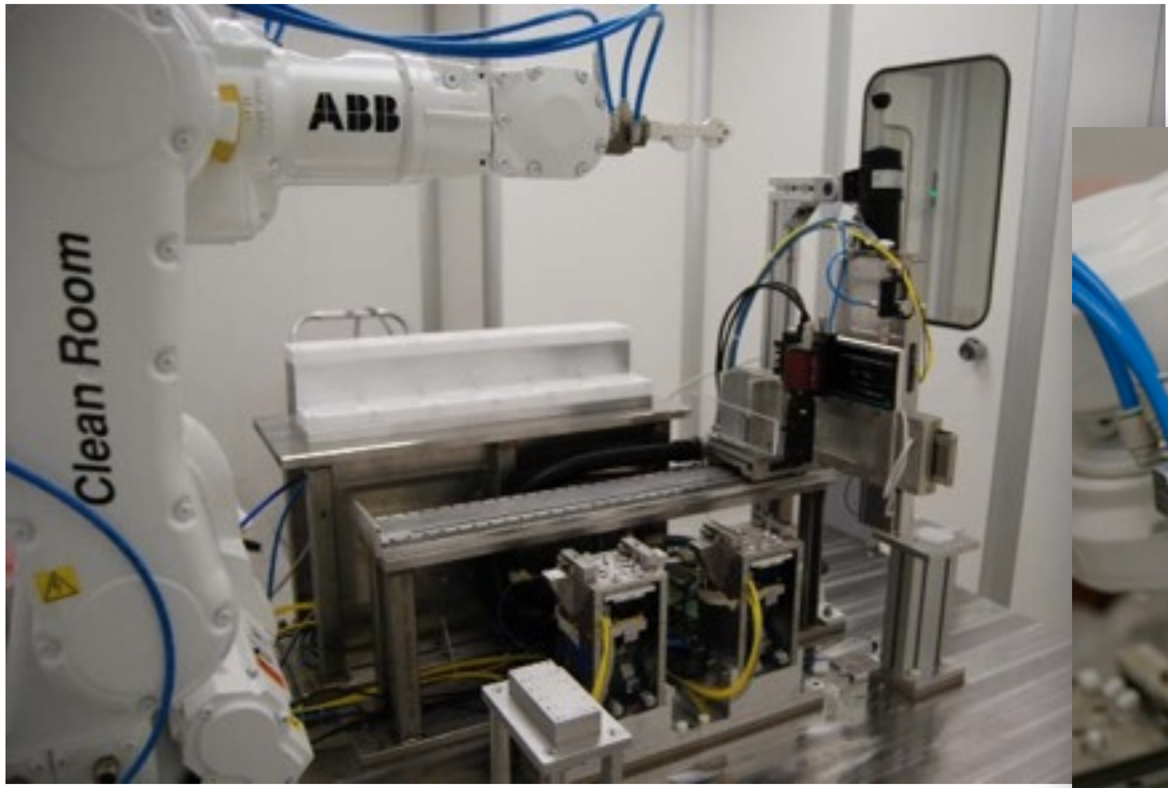


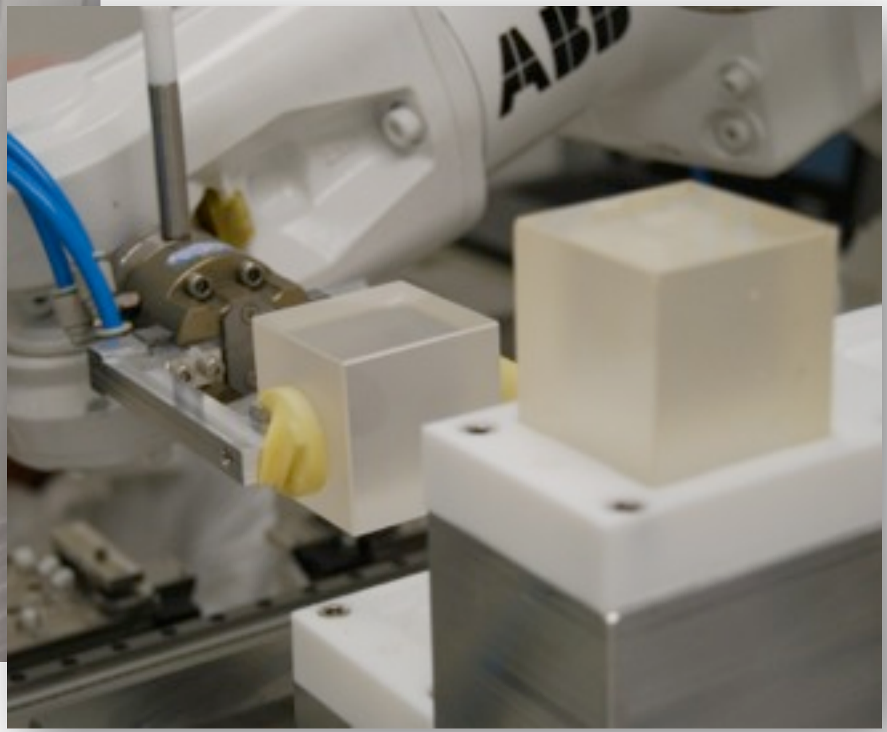


Sense wire (ball) bonding
- 50 μm gold wire
- direct bonding on final detector



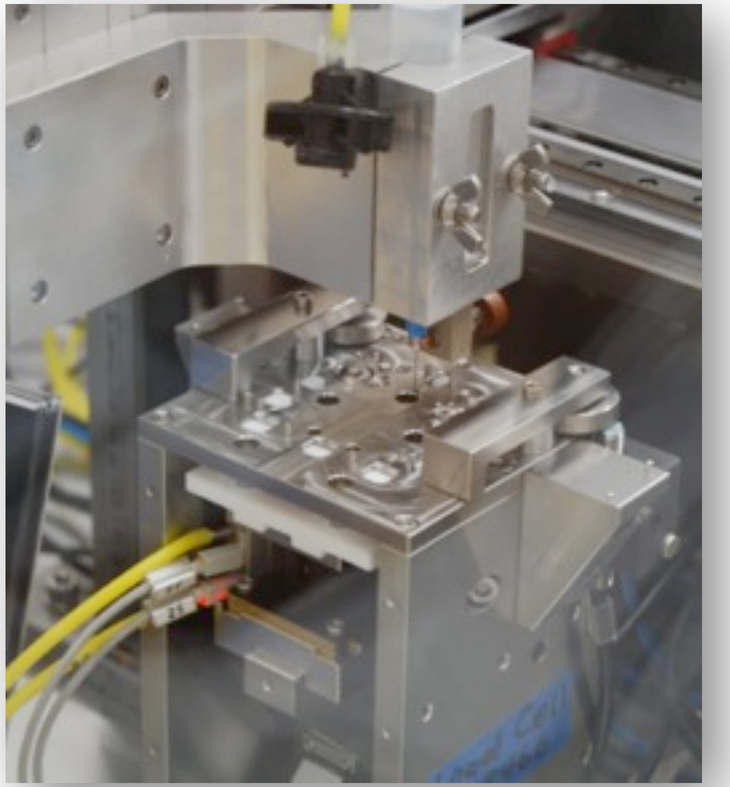
# Crystal-Sensor coupling

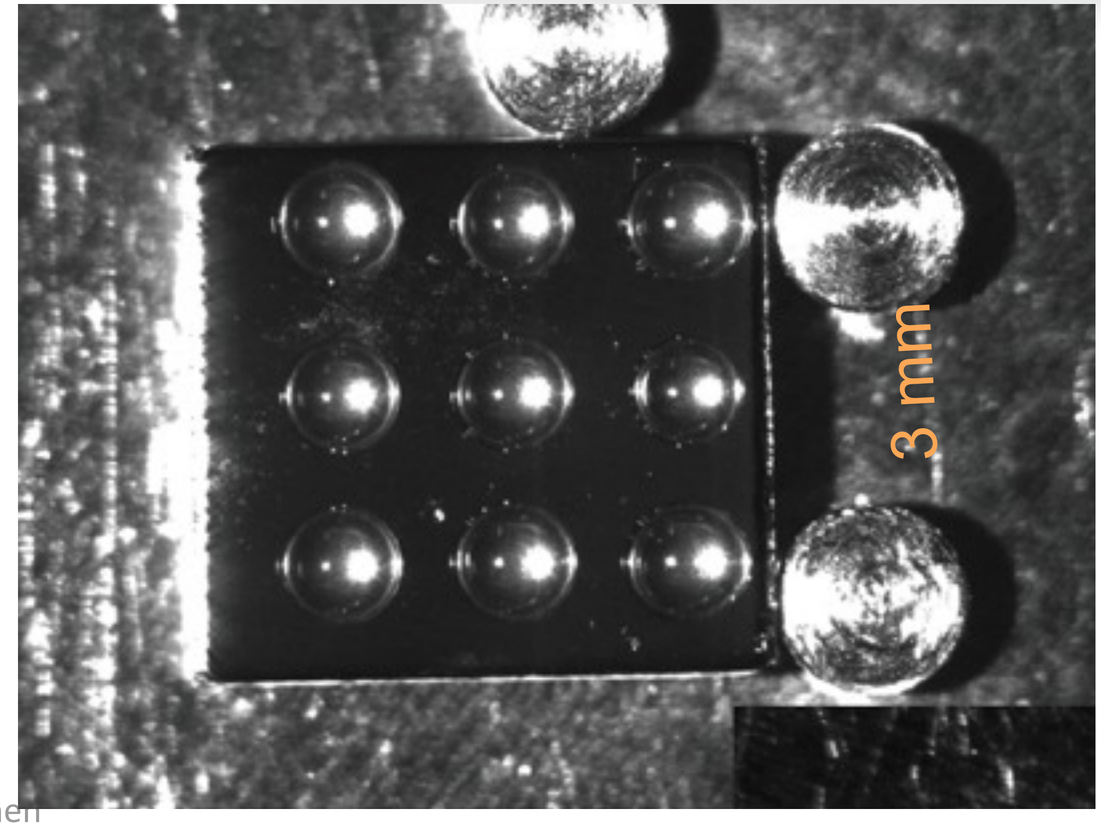


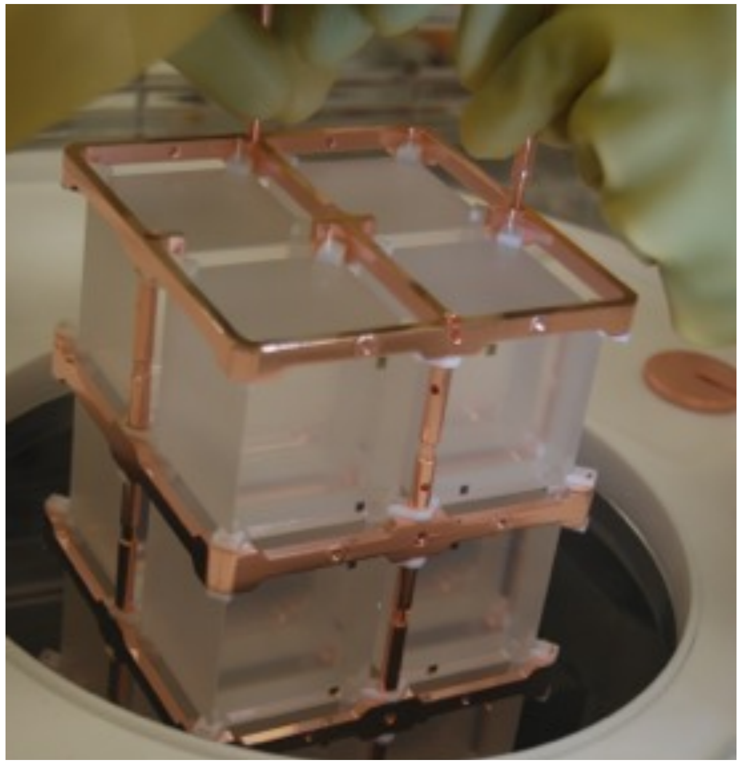

**Robotic gluing** for
- Uniformly sized
- Repeatable
- Controllable

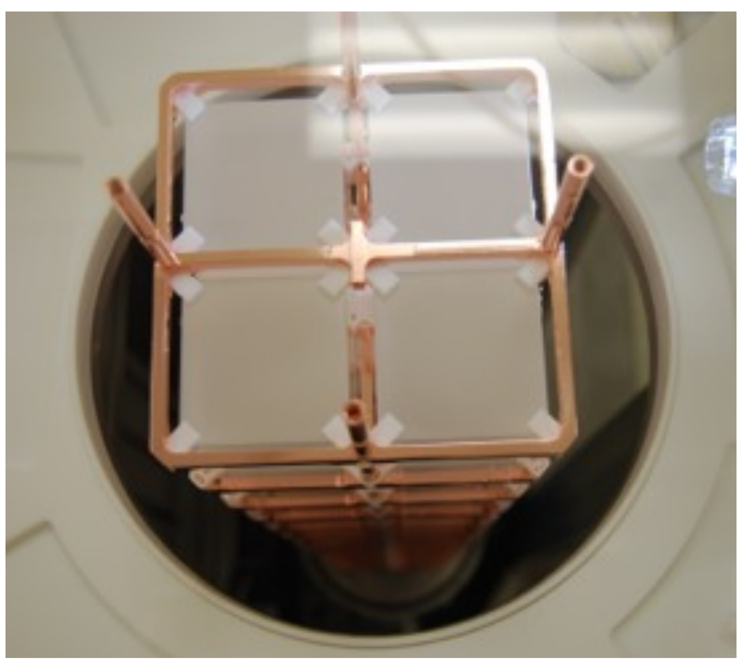
glue spots (and coupling)

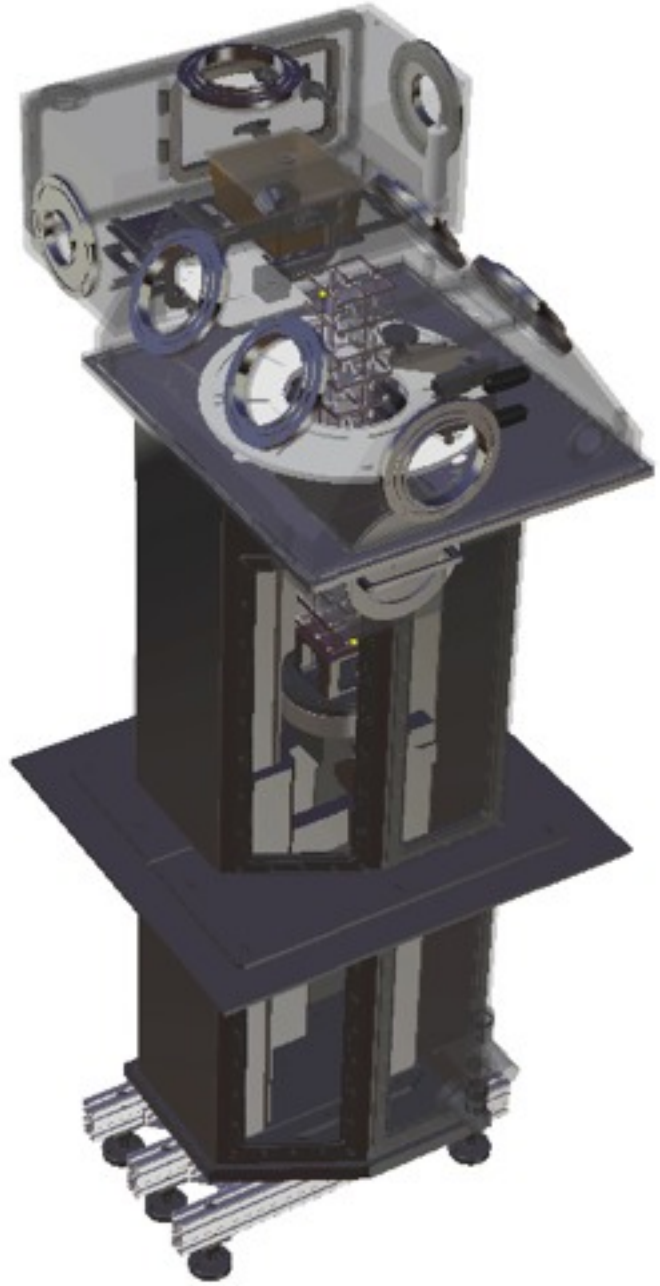


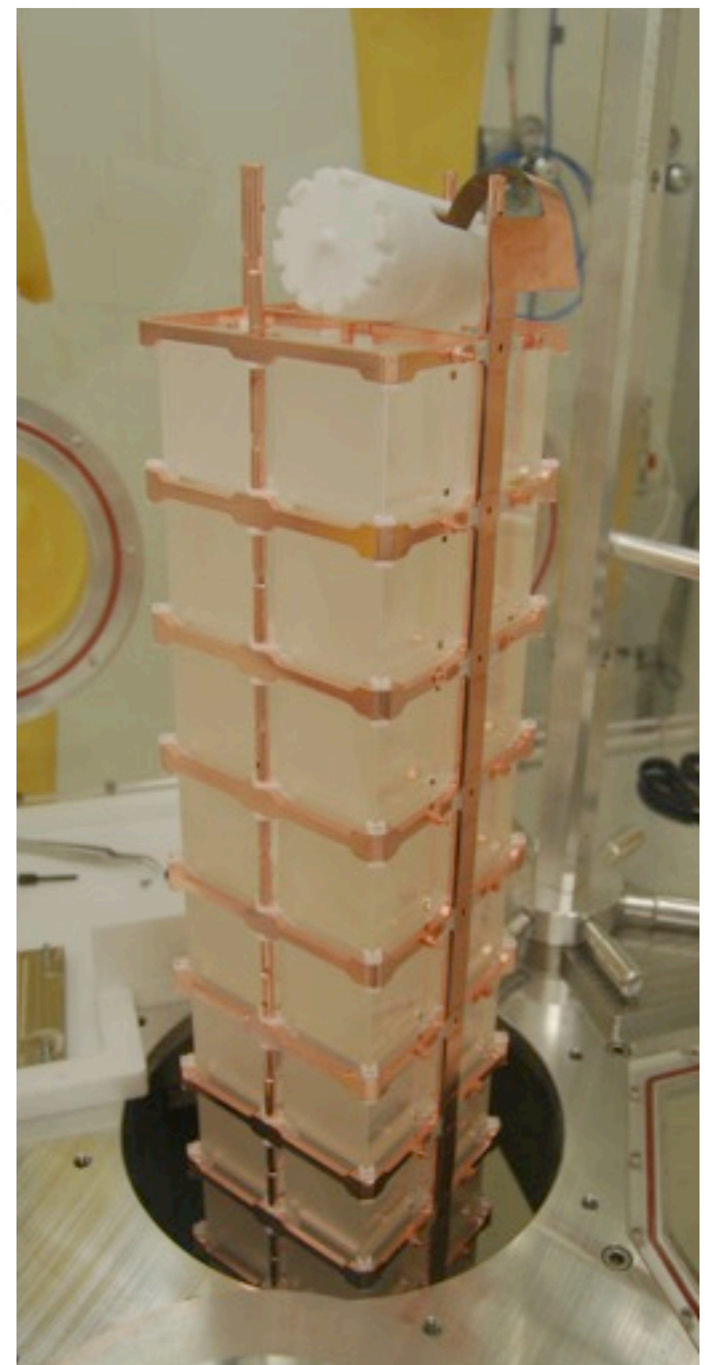


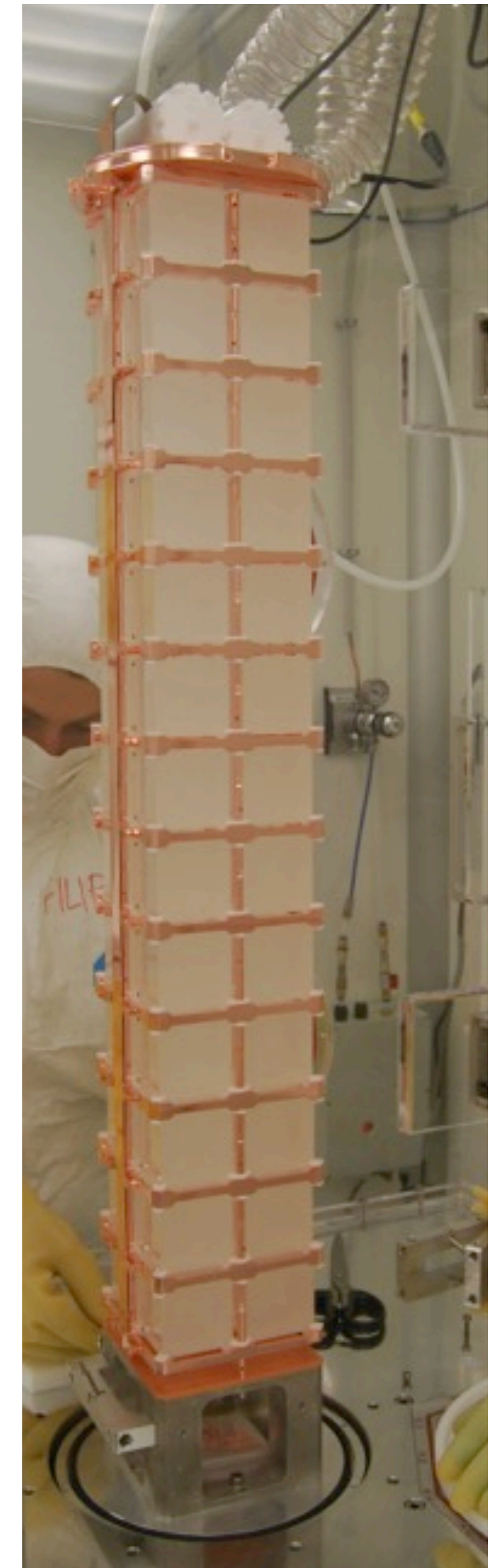
# Mechanical assembly



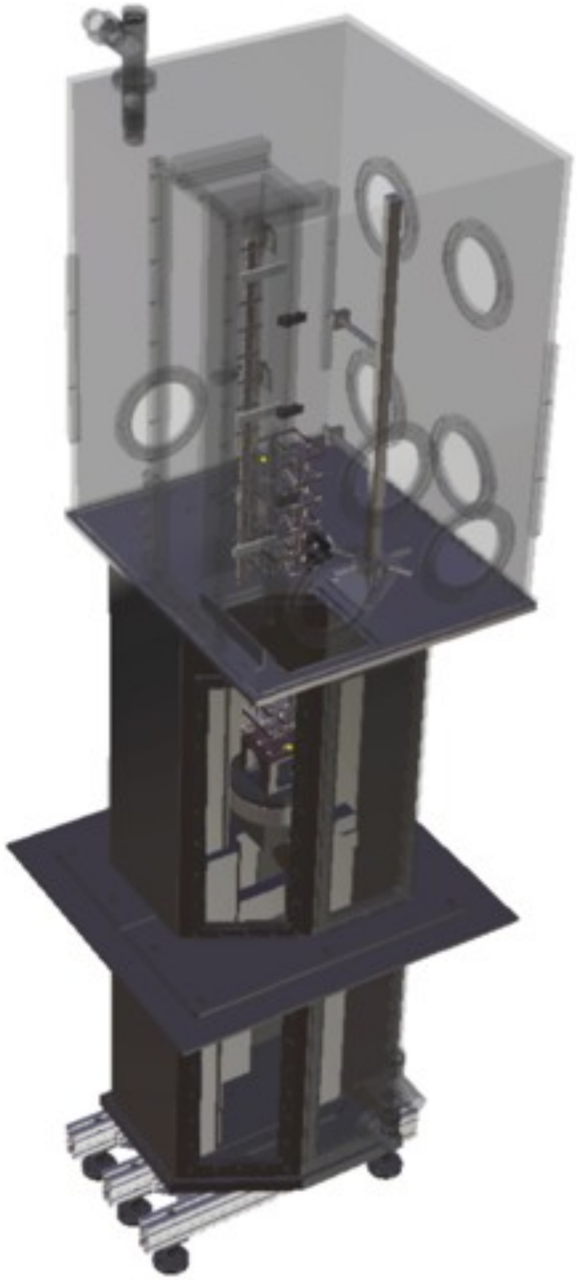


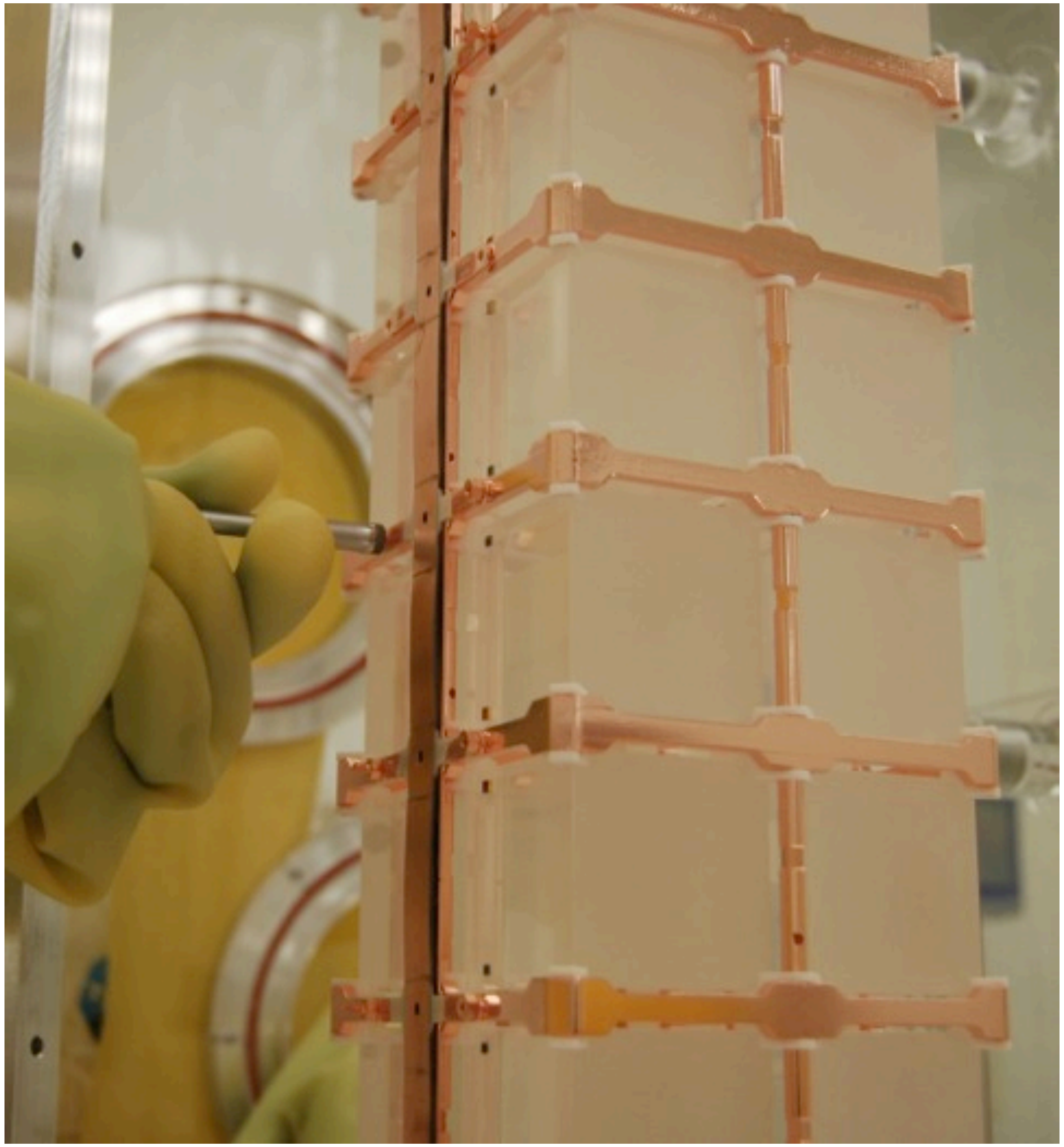






# Cabling





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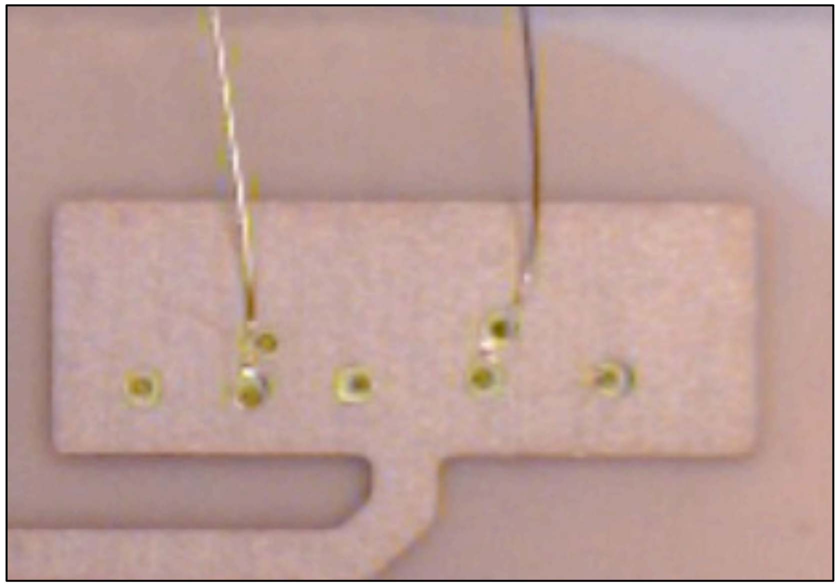
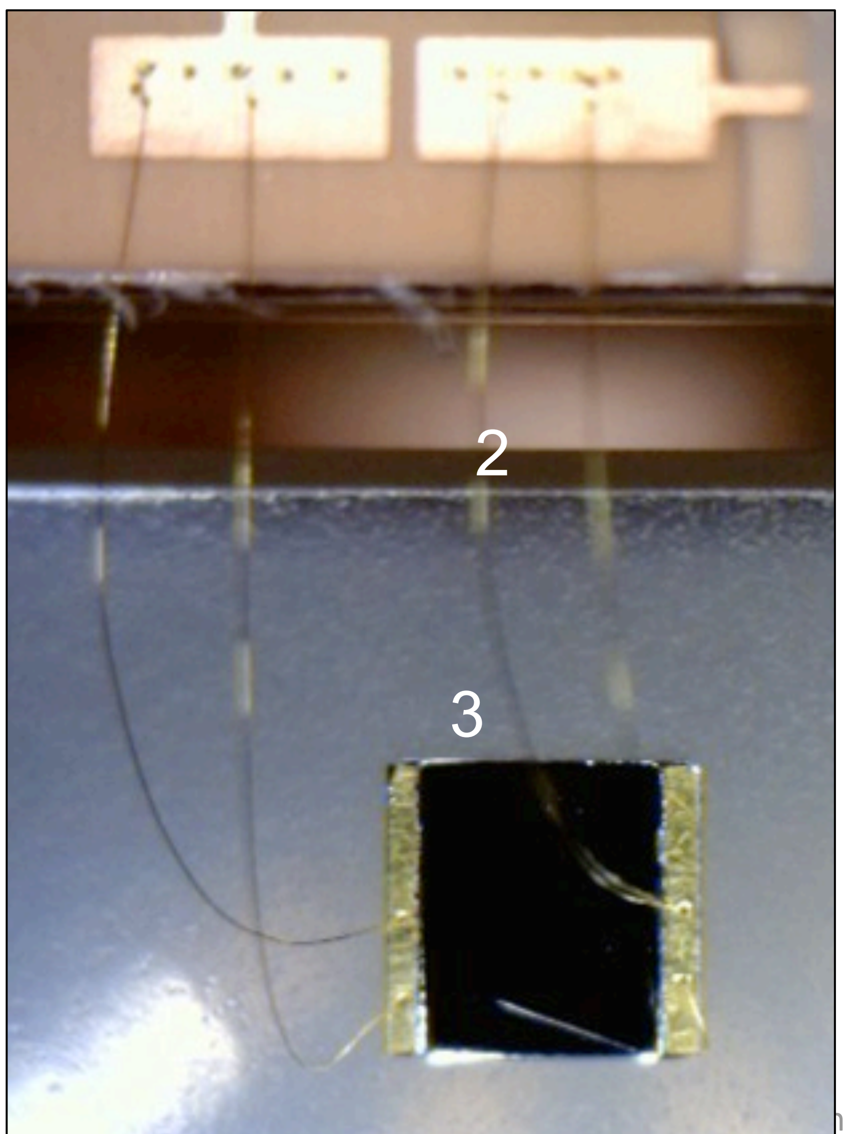
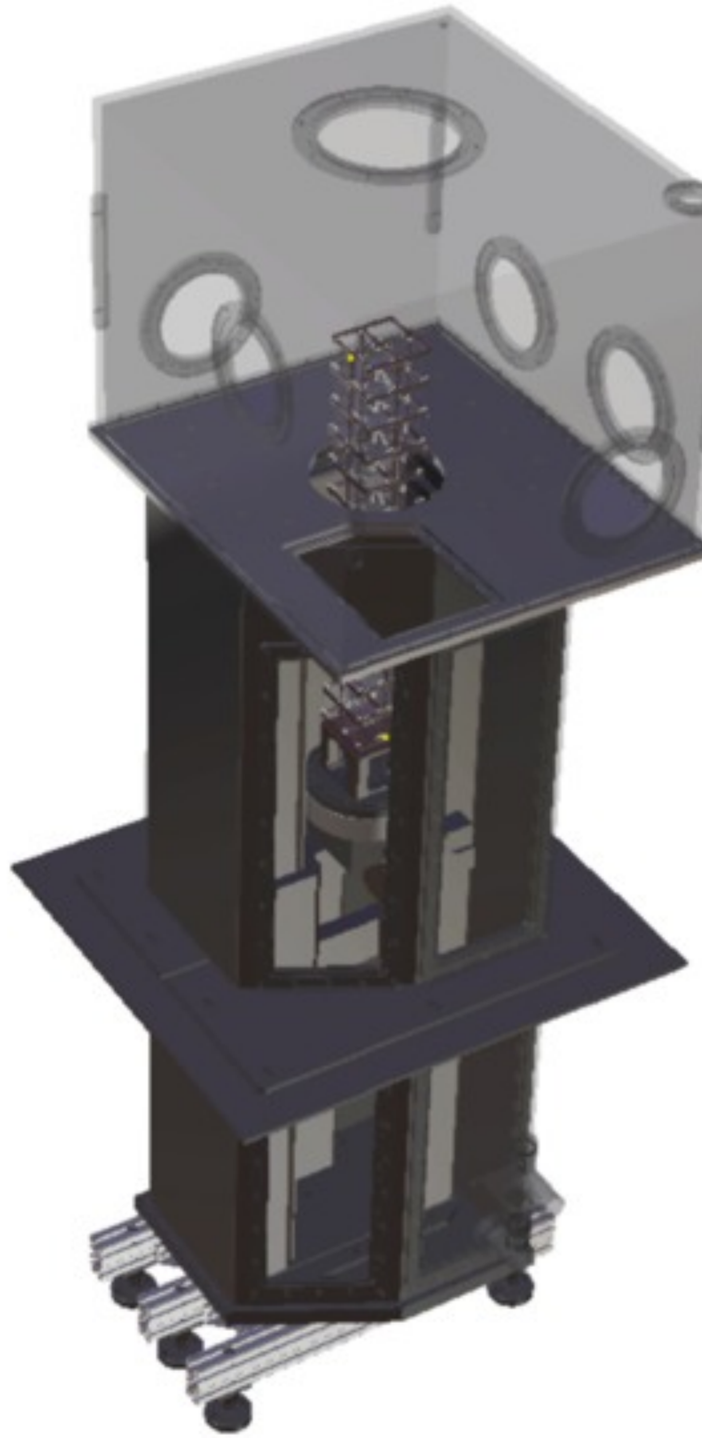
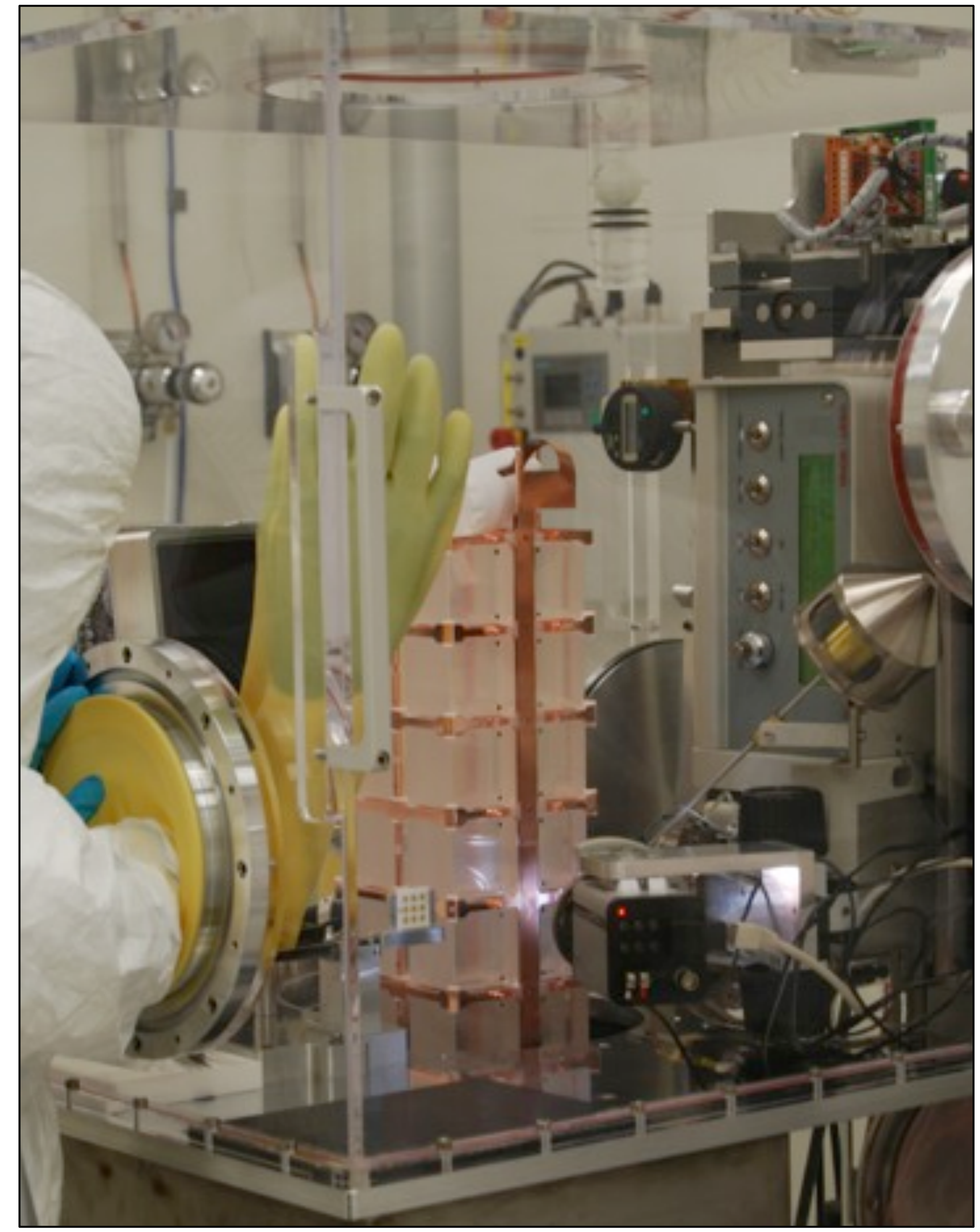
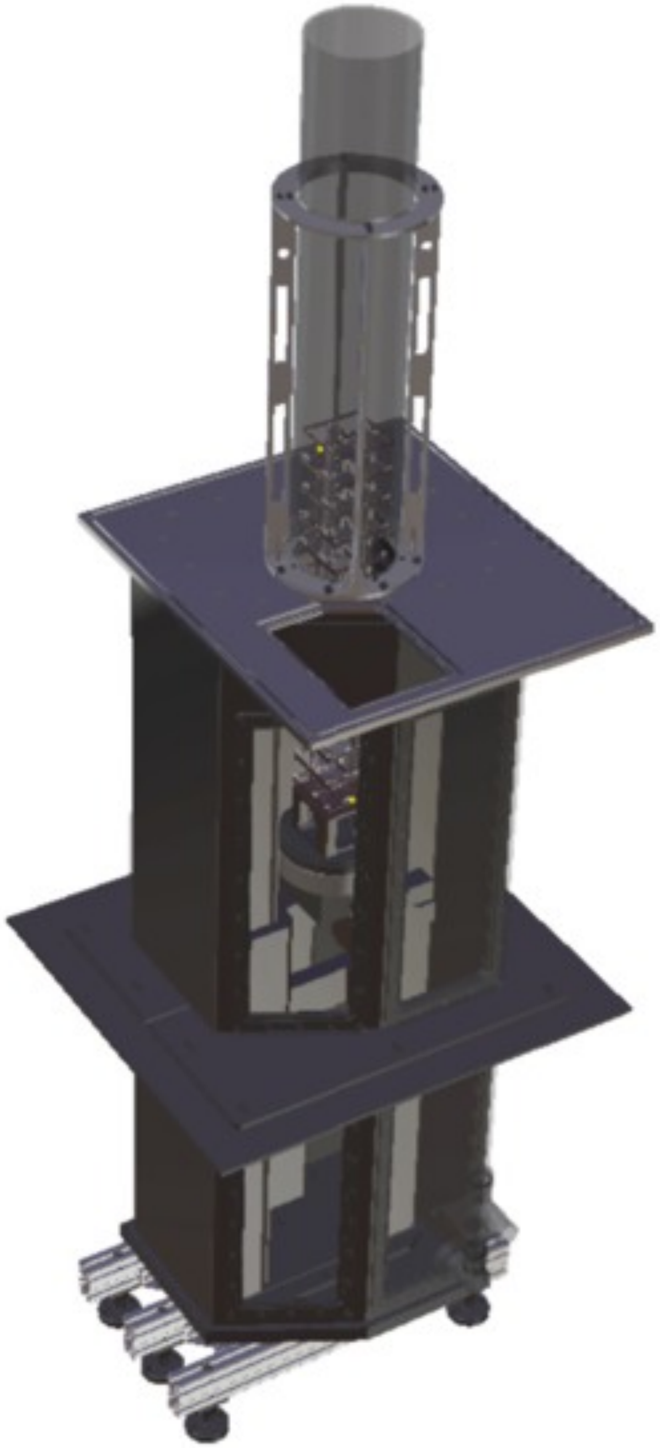






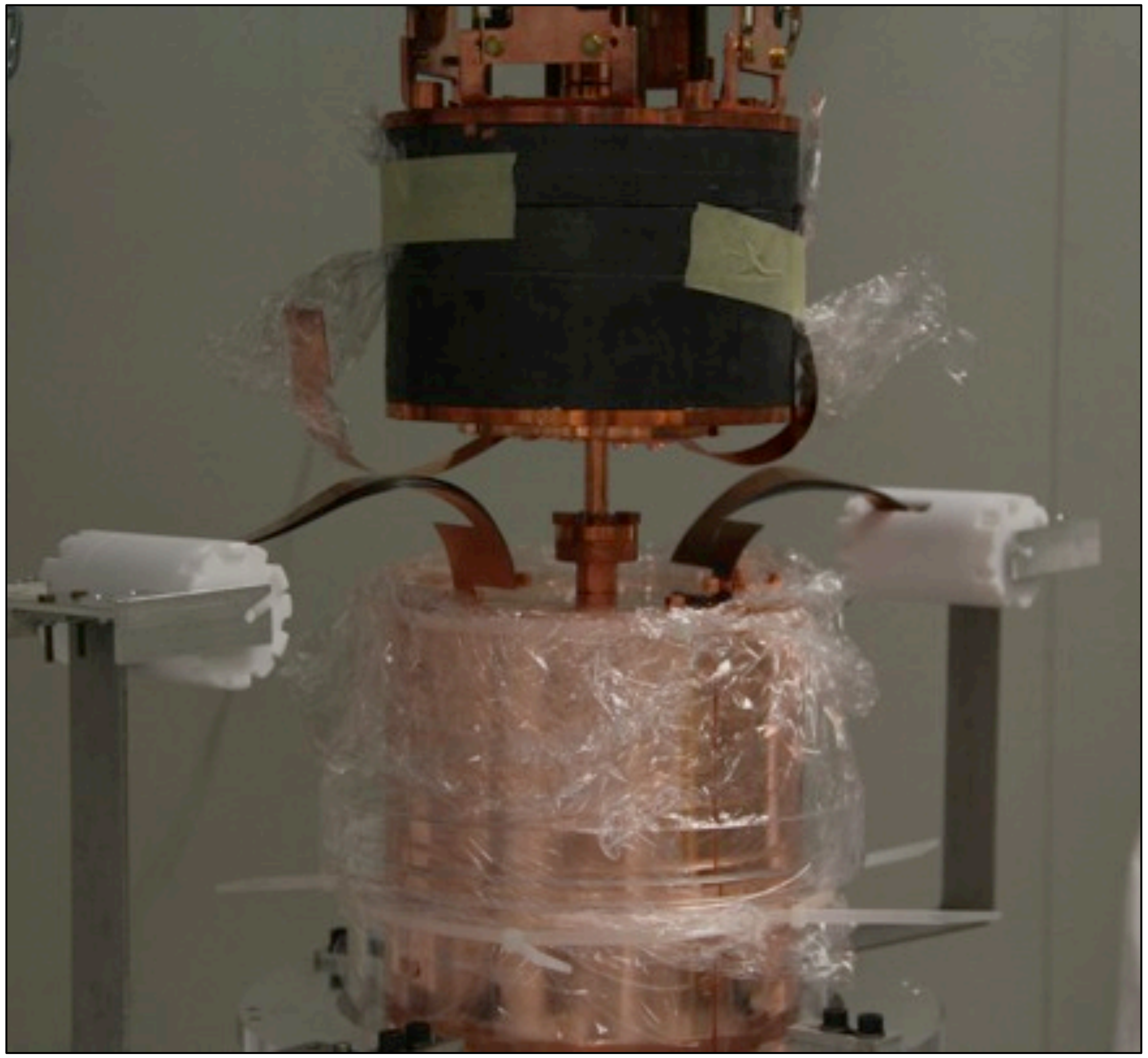
# Storage

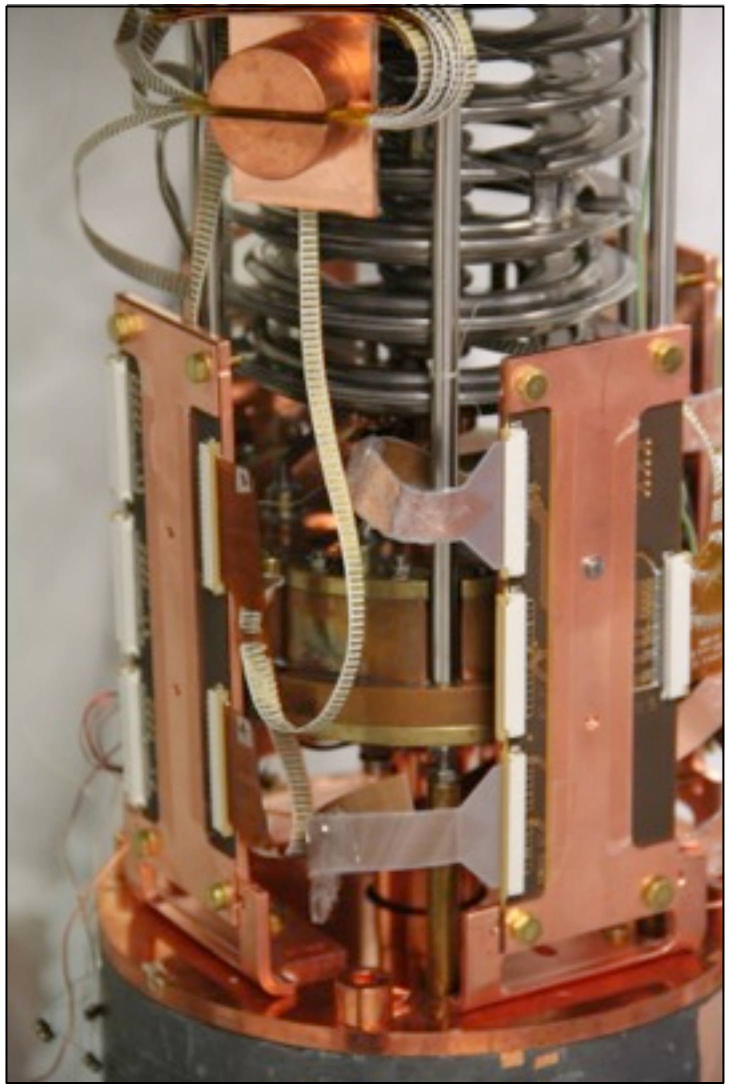


# CUORE0 installation

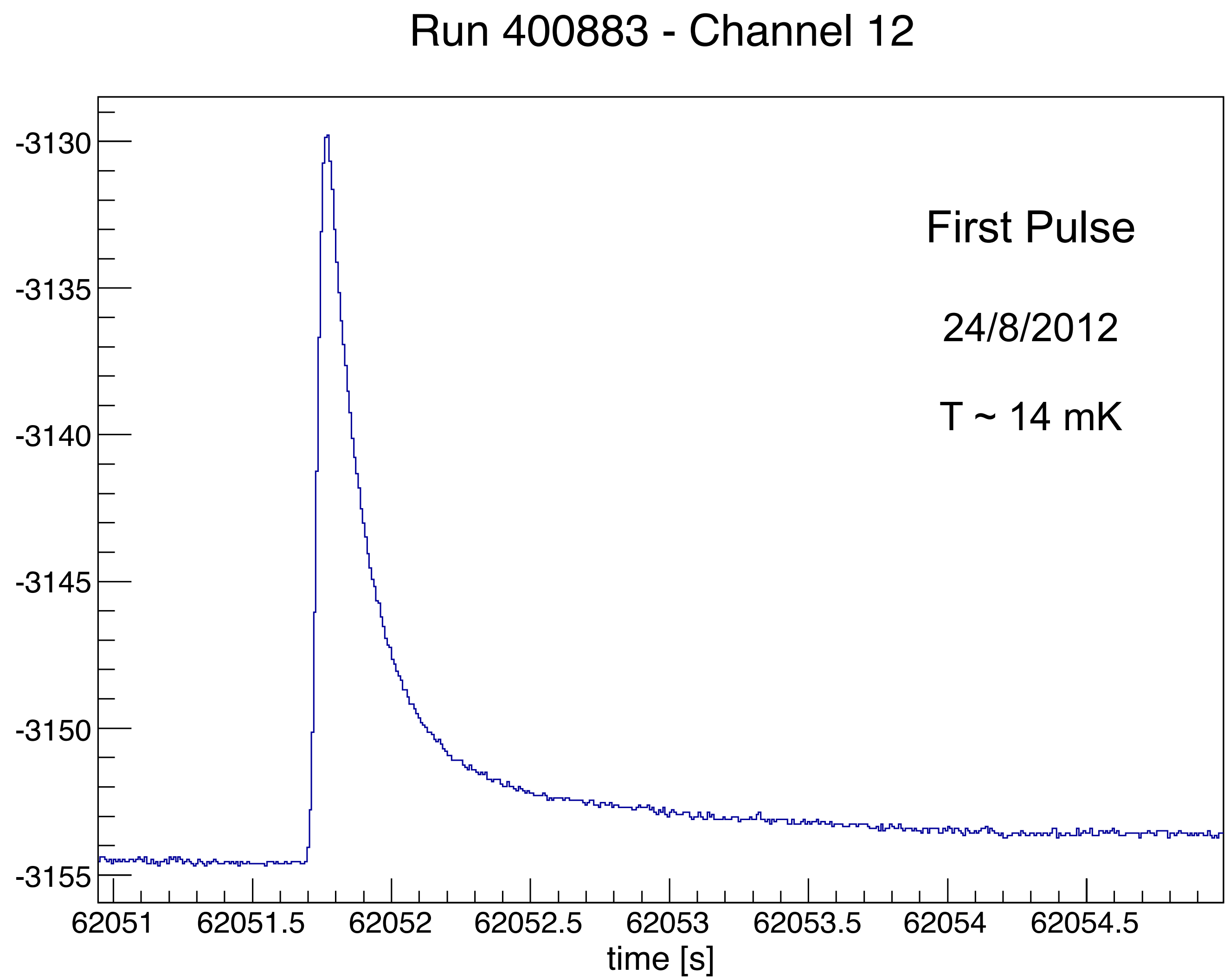
CUORE-0 assembly already gave us the opportunity to test and fix the procedures and the systems to realize the CUORE detector: a complete CUORE tower can be assembled in less than 4 weeks

Other innovative changes (e.g. sense wires) are also being tested





# CUORE-0 status

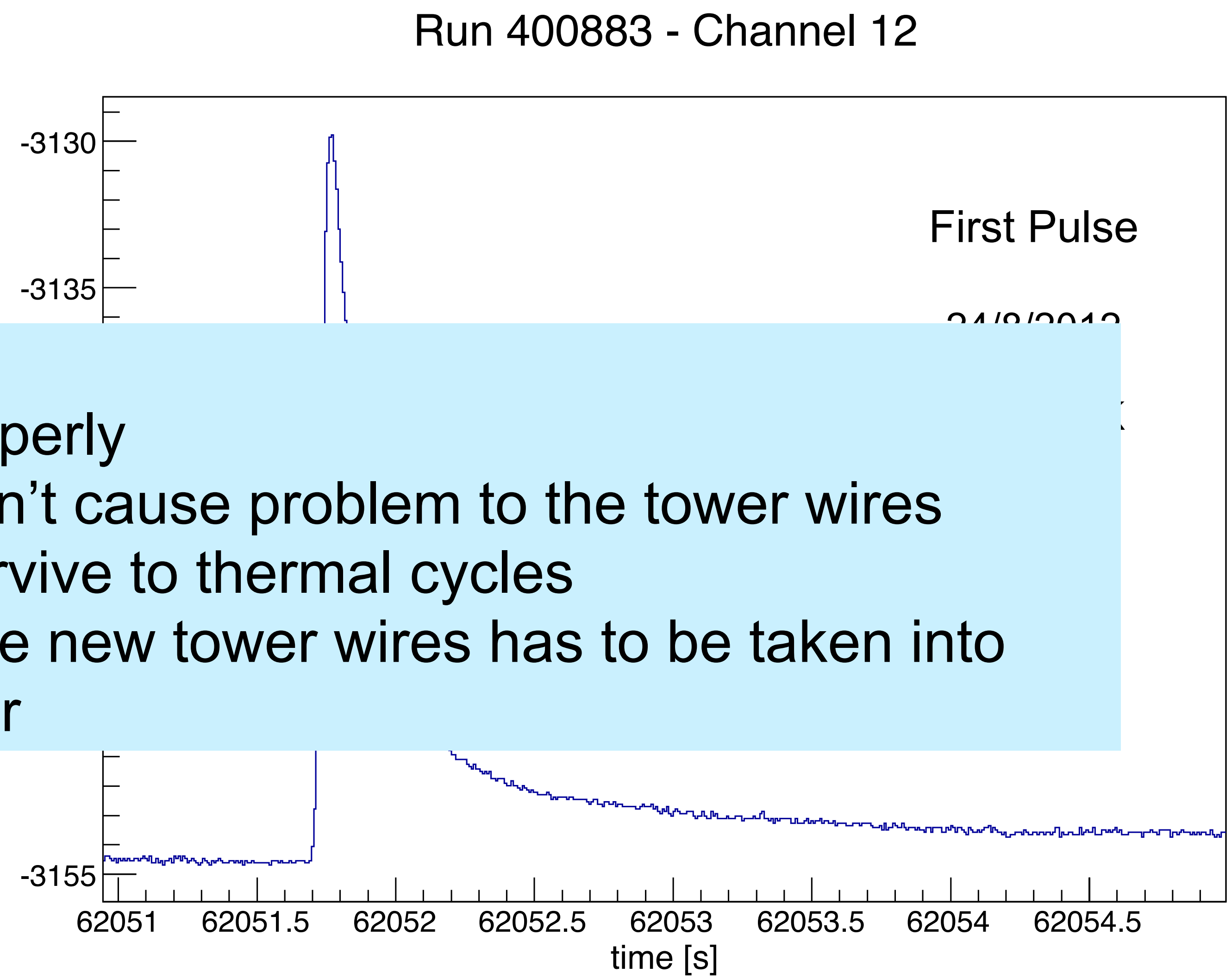

CUORE-0 is in the pre-operation phase

In August 2012 the detector reached base T of about 8 mK

All the active channels survived the cool-down

CUORE collaboration is not ready to release information on resolution and detector performances but these will come very soon

# CUORE-0 status




we already learned that:

- the assembly line works properly
- the thermal contractions didn't cause problem to the tower wires
- the bonding connections survive to thermal cycles
- the thermal conduction of the new tower wires has to be taken into account for CUORE detector

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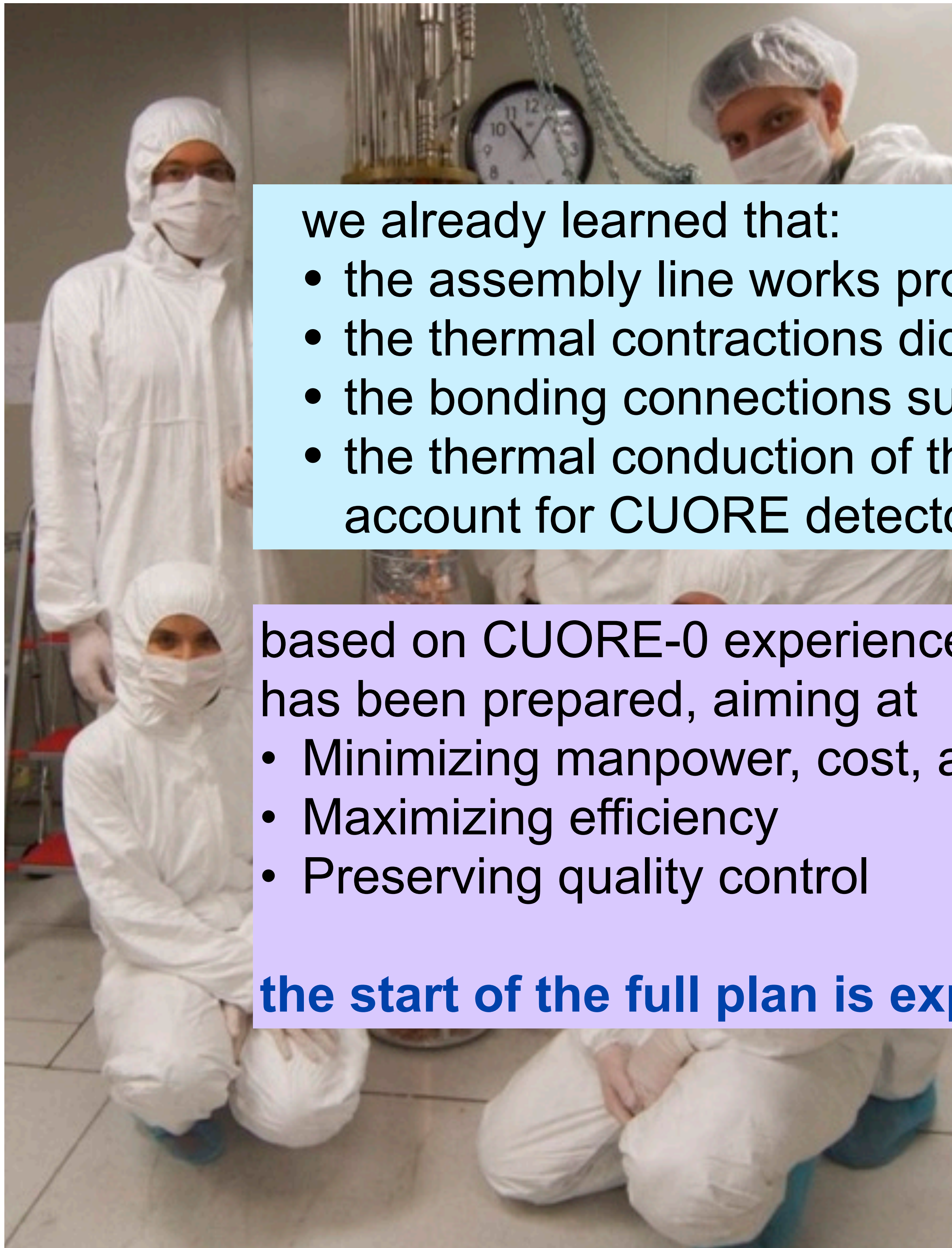

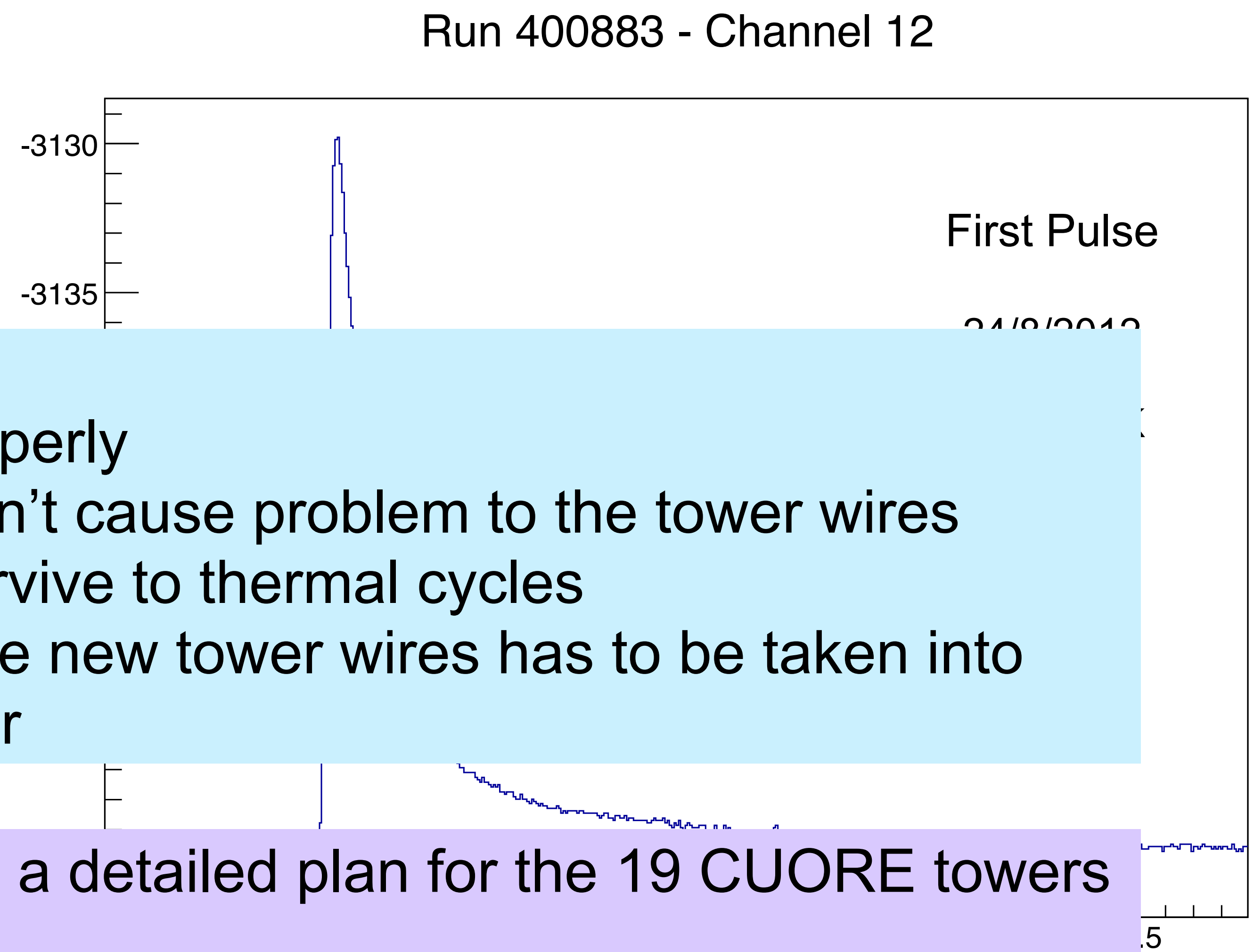


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- the assembly line works properly
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- the bonding connections survive to thermal cycles
- the thermal conduction of the new tower wires has to be taken into account for CUORE detector

based on CUORE-0 experience a detailed plan for the 19 CUORE towers has been prepared, aiming at

- Minimizing manpower, cost, and duration
- Maximizing efficiency
- Preserving quality control

**the start of the full plan is expected by the beginning of November**

e T of

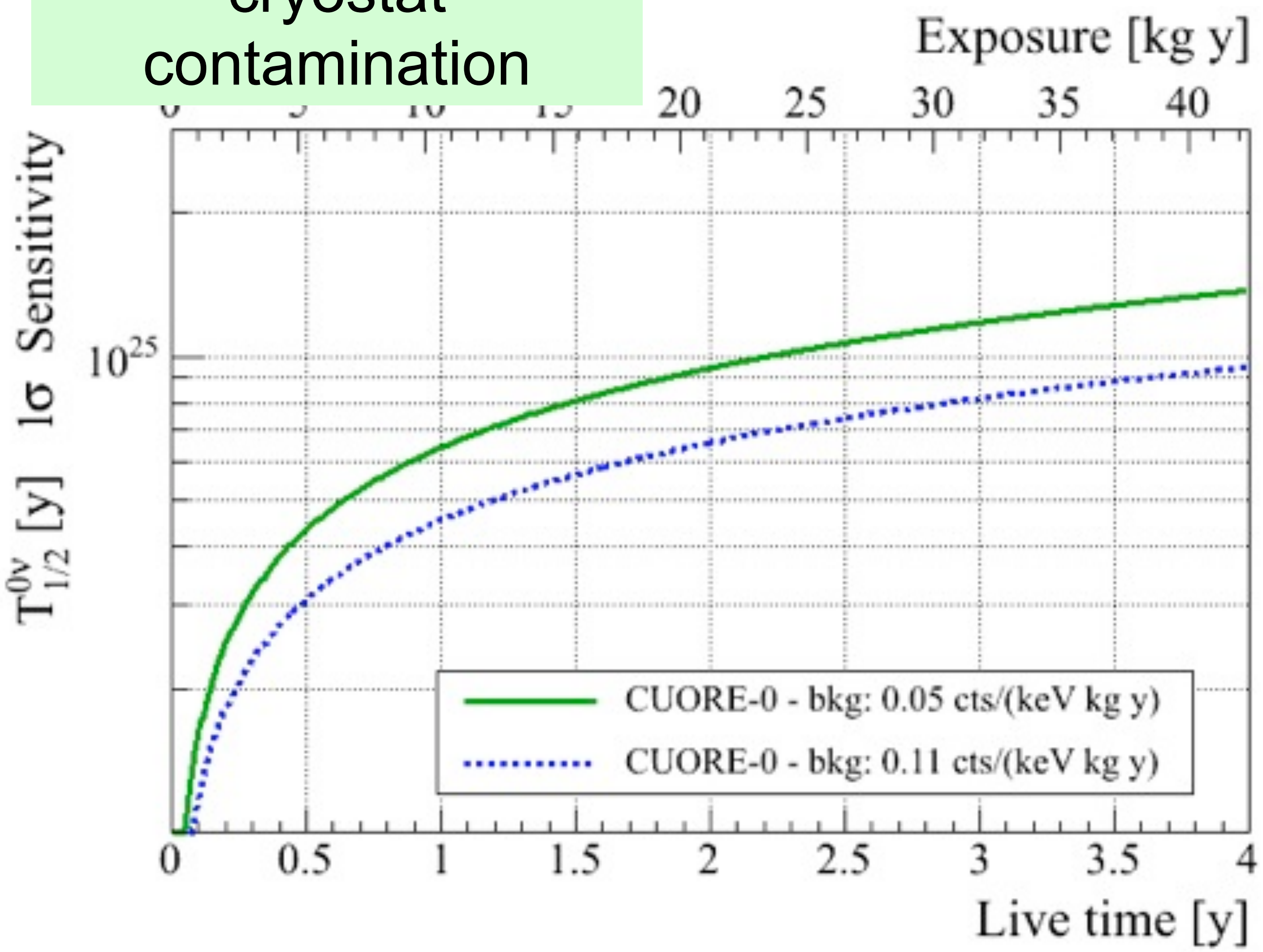
All the active channels survived the cool-down

CUORE collaboration is not ready to release information on resolution and detector performances but these will come very soon

# CUORE0 sensitivity

F.Alessandria et al. [CUORE coll.] http://arxiv.org/abs/1109.0494v1

Limited by bkg from cryostat contamination



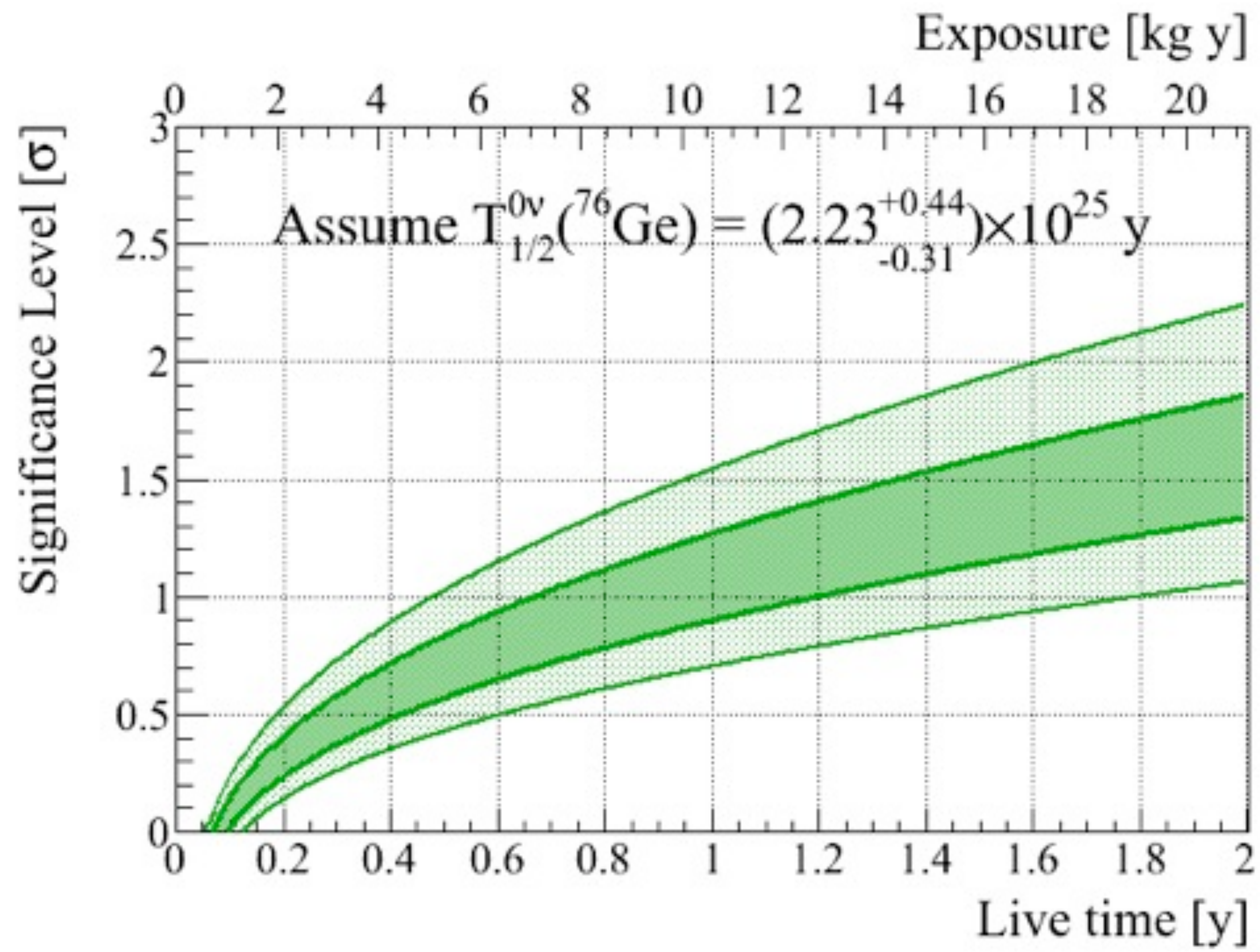

Background: 0.05-0.11 c/keV/kg/y range

If 0.05 c/(keV kg y), expected 2-year sensitivity is

$T_{1/2}$ = 5.9 x $10^{24}$ y @ 90%CL

(CUORICINO: $T^{0\nu}$ > 2.8×$10^{24}$ y)

**$m_{\beta\beta}$ = 170-390 meV**




Significance level at which CUORE-0 can observe a DBD signal consistent with the claim in $^{76}$Ge (KK-HK), assuming 0.05 c/keV/kg/y background

- The inner band corresponds to the best-fit value of the claim; the range arises from the "1σ" range of QRPA NME calculations in A. Faessler et al., Phys. Rev. D79 (2009) 053001
- The outer band also includes the 1σ error on the $^{76}$ Ge claim

# Cryogenics

The acceptance tests of the 2 vacuum tight chambers (300K and 4K) of the CUORE cryostat have started at the end of May 2012

- The test was comoleted mid July and the chambers delivered at LNGS by the end of July.
- **Since then we are following a detailed plan of commissioning of the cryogenic system which will last for the another 1.5 years**

4K vessel @ construction company (SIMIC)

The CUORE vessels @ LNGS (hall B)

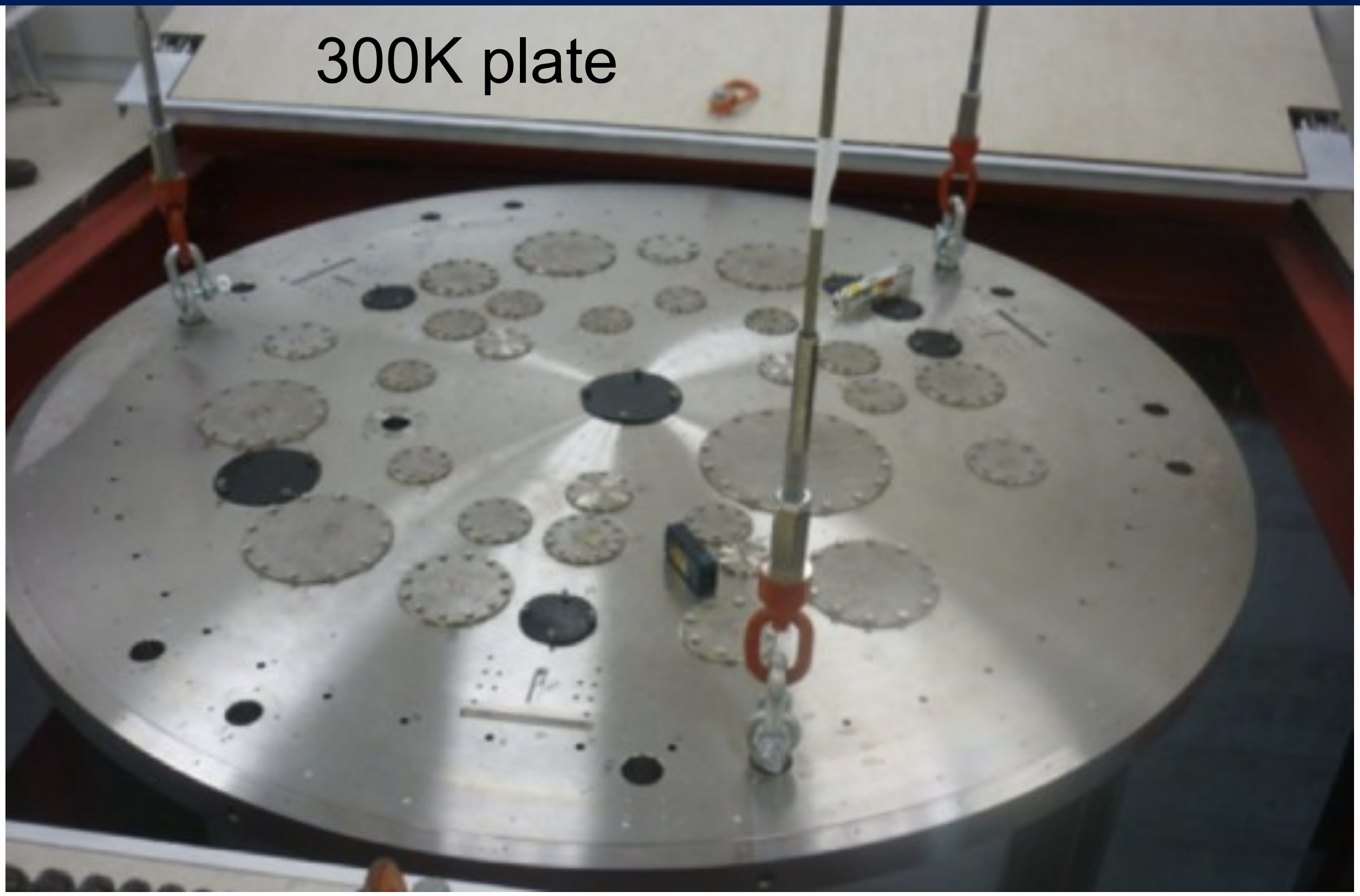
# Vacuum test @ SIMIC

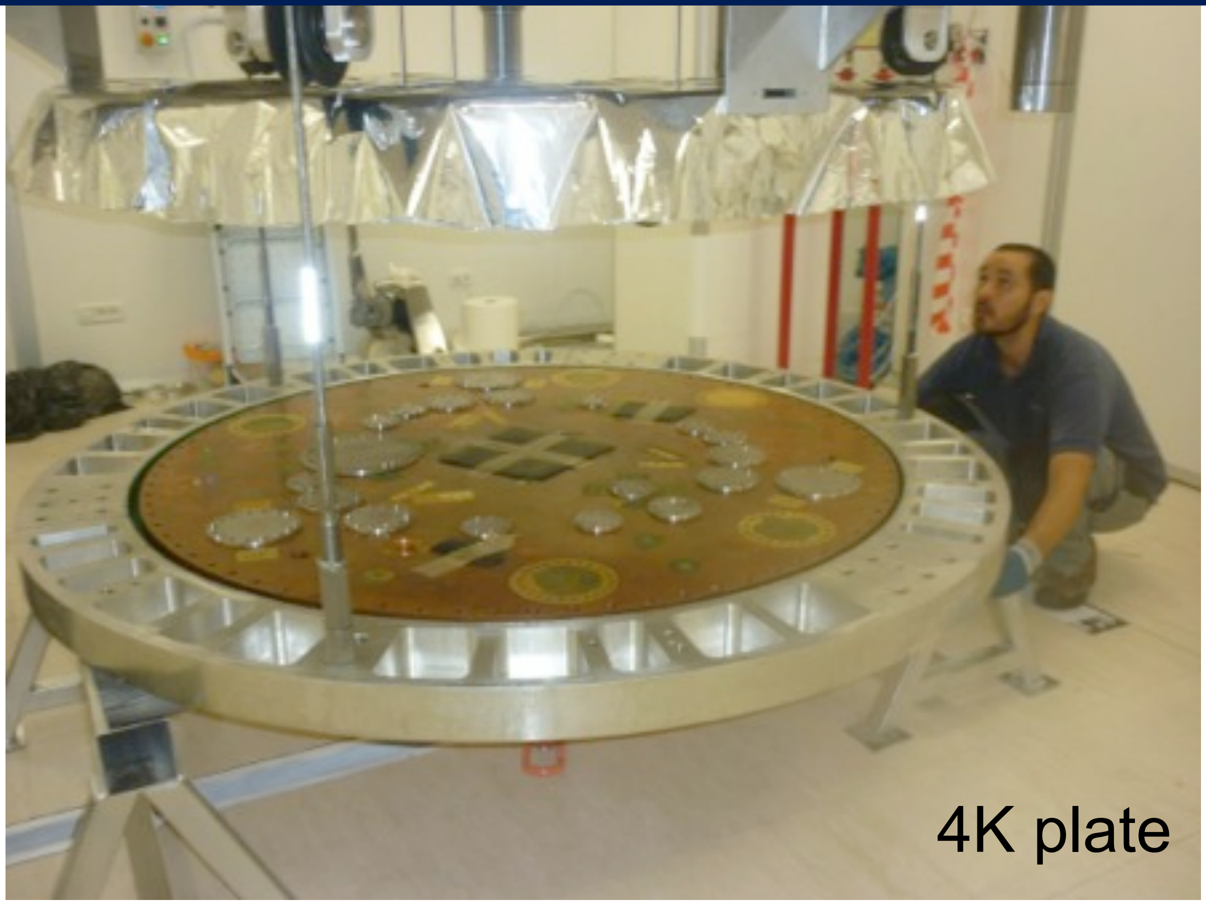
4k insertion

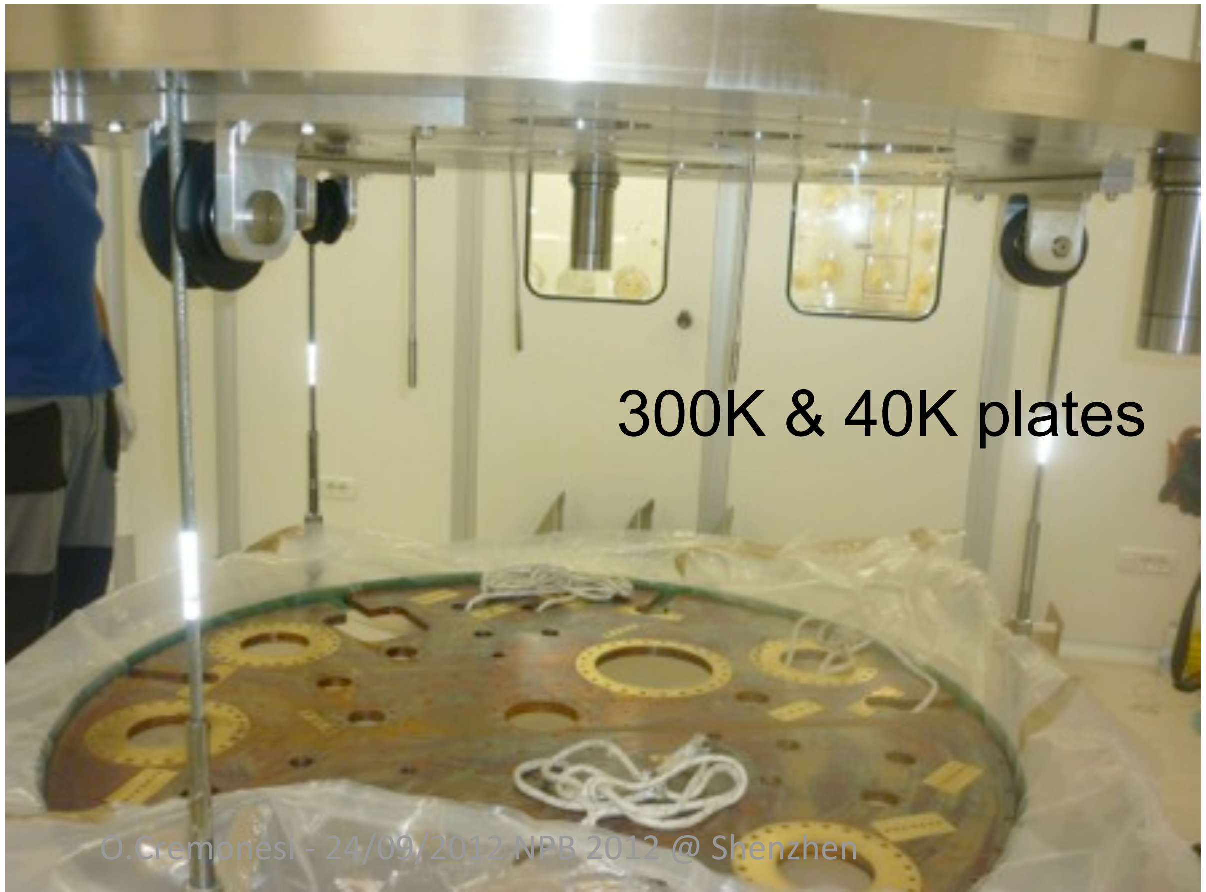
Cooldown preparation

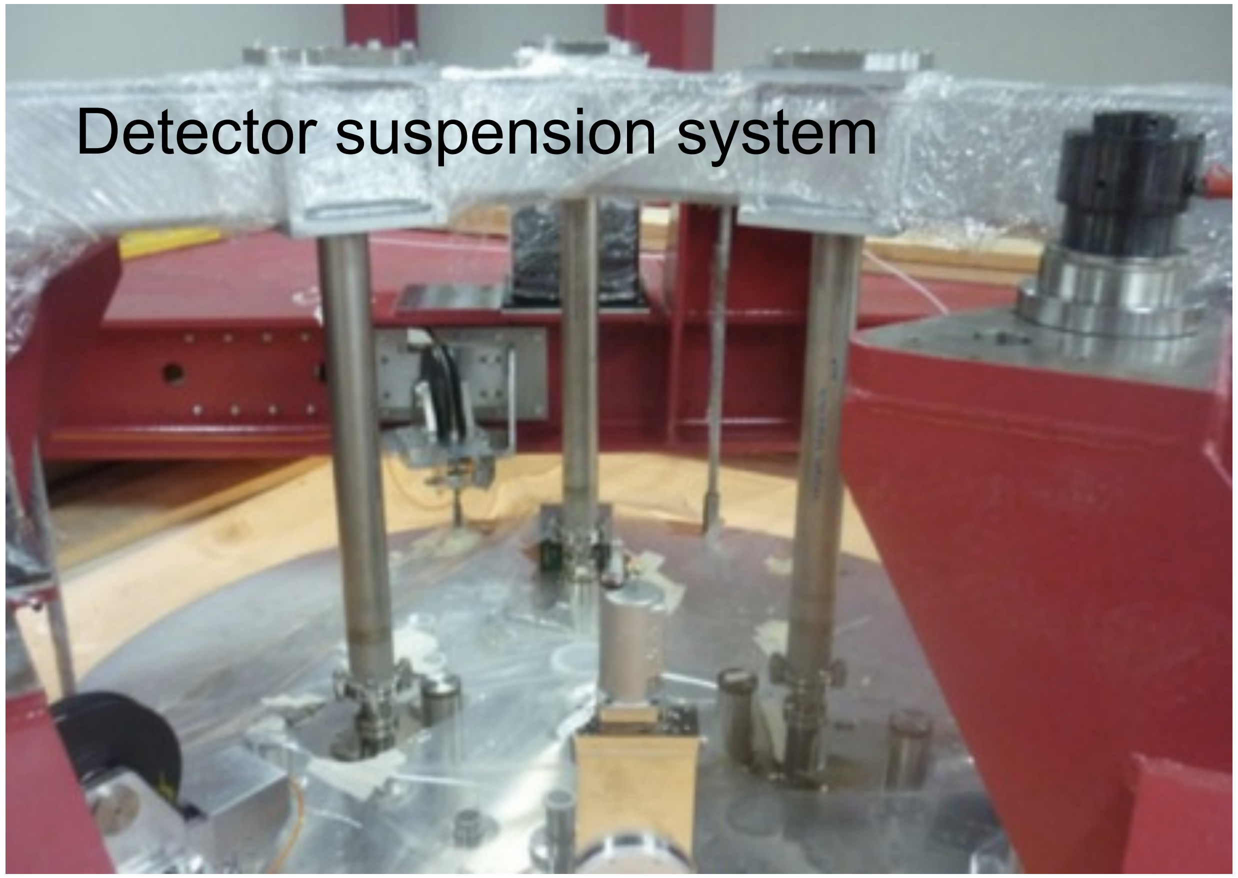
Superinsulation

# Setup commissioning @ LNGS



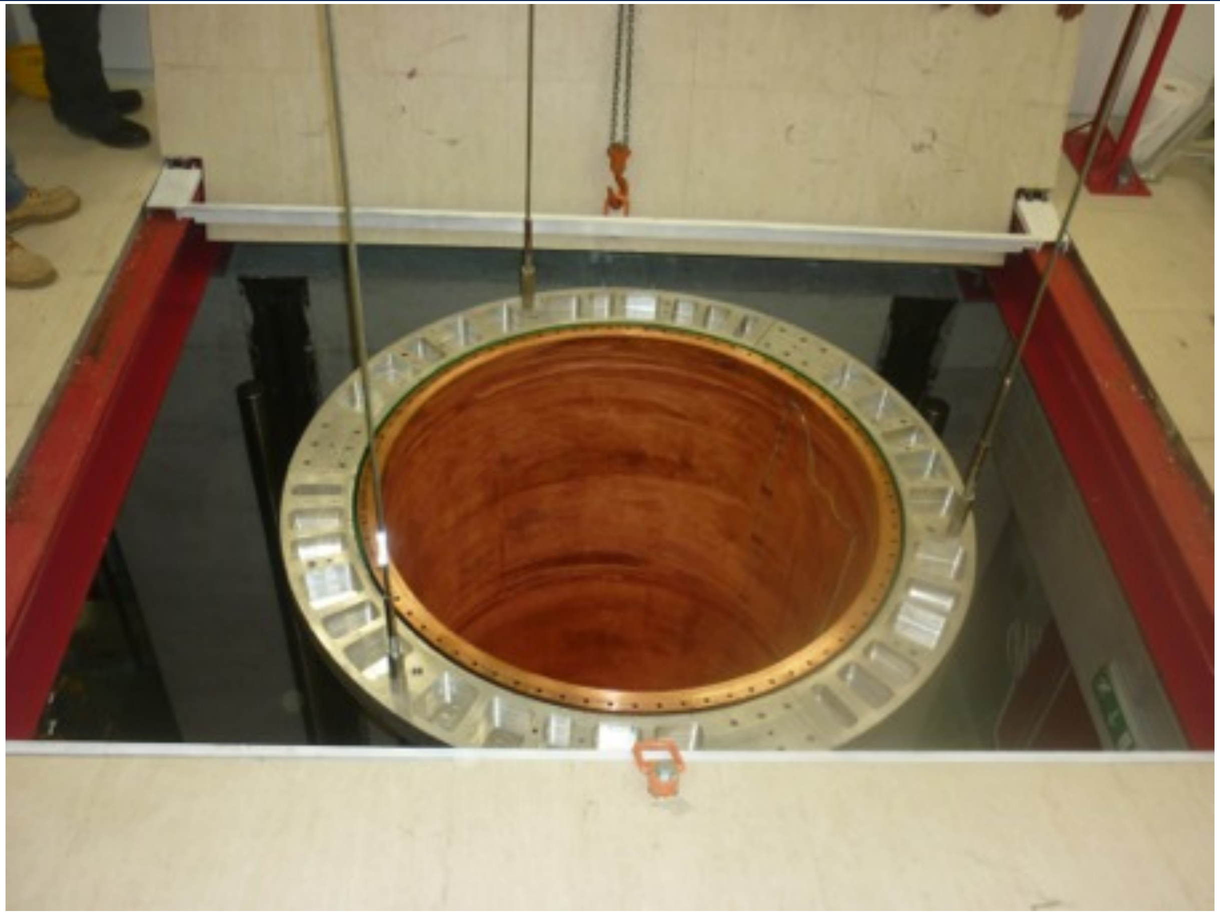



# Commissioning @ LNGS

4K vessel installation



operations under the 300K plate

# Conclusions

- With ~200 kg of 130Te and a resolution of 5 KeV FWHM, CUORE has the potential to explore the inverted mass hierarchy of neutrino mixing
- CUORE-0 has demonstrated that the collaboration can face the challenge of assembling the ~1000 CUORE bolometers (~10 k pieces) in extremely clean conditions
- CUORE towers assembly will start in a couple of months.
- Cryogenics commissioning  was finally started in July 2012. It will continue for the whole 2013.

- CUORE operation will start in 2014
- CUORE-0 prototype has been successfully  installed (in the CUORICINO cryostat) and is presently in the pre-operation phase. It will start to collect data very soongive us answers very soon.