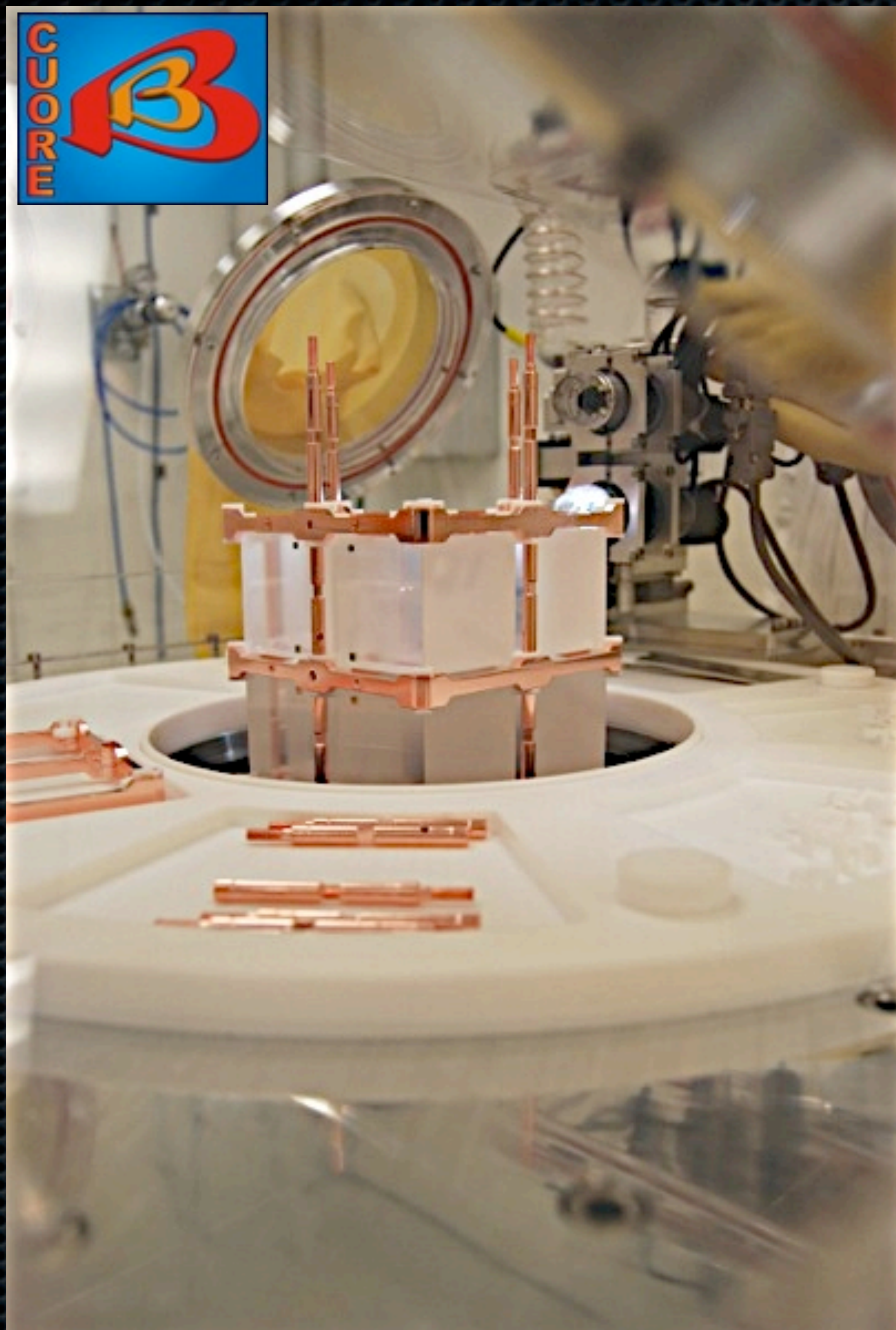


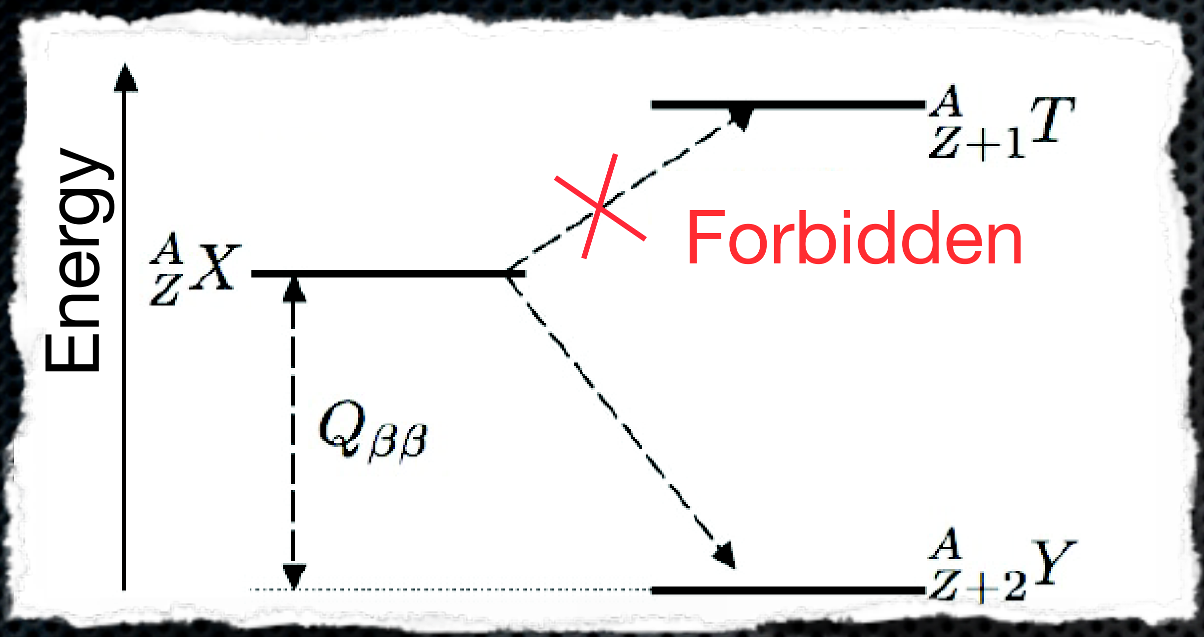
CUORE-0 and CUORE for DBD: status and plans

Filippo Orio
(INFN Rome)

on behalf of the CUORE collaboration

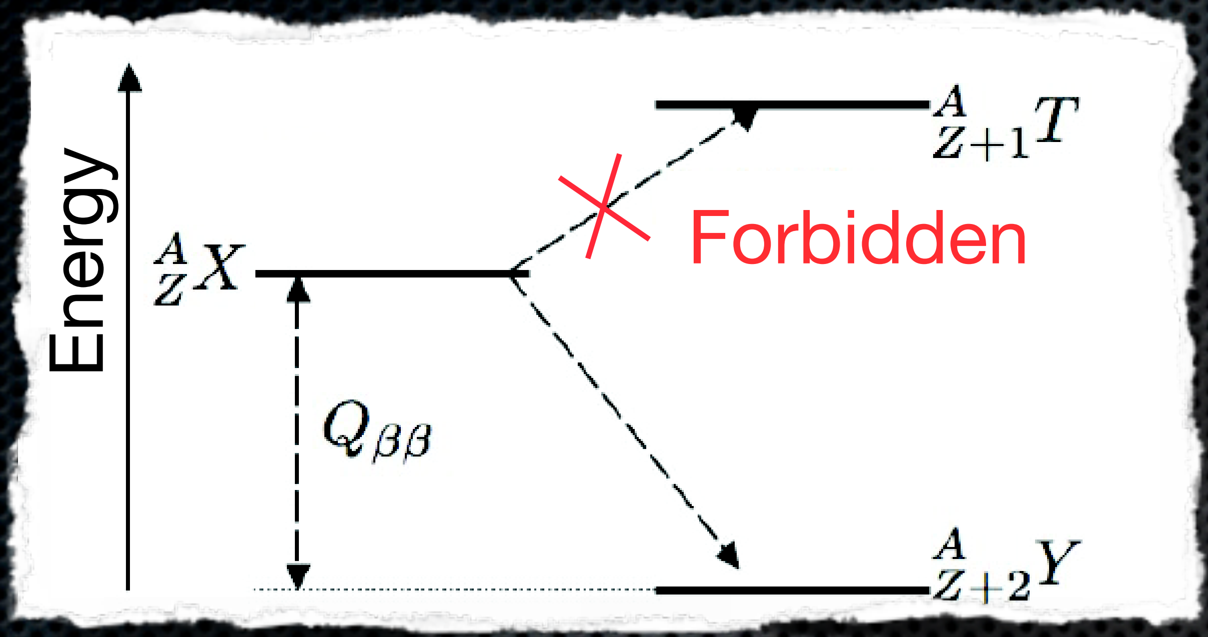
4th International Symposium on Neutrinos and Dark Matter in Nuclear Physics
June 11-15th, 2012, Nara, Japan

The Double Beta Decay



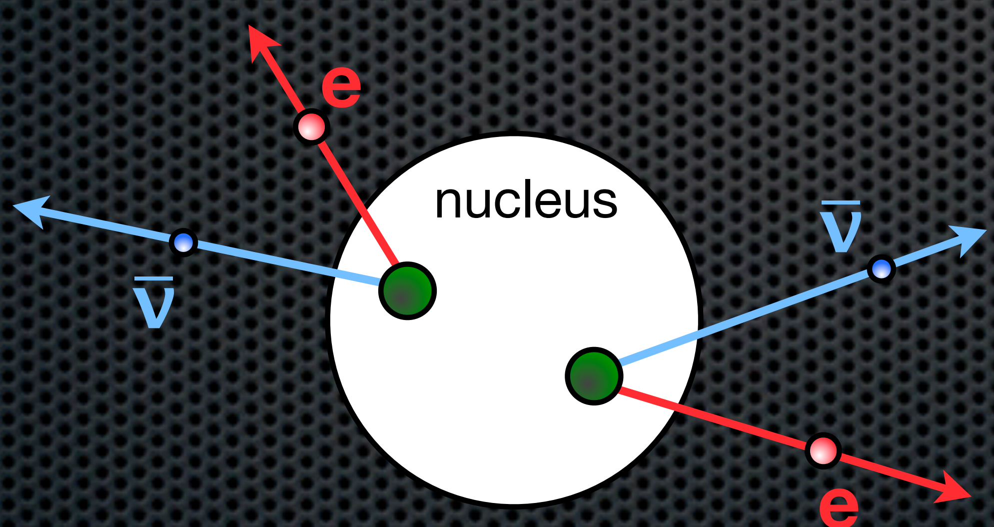
Extremely rare decay, possible only in few isotopes in which single β decay is forbidden

The Double Beta Decay



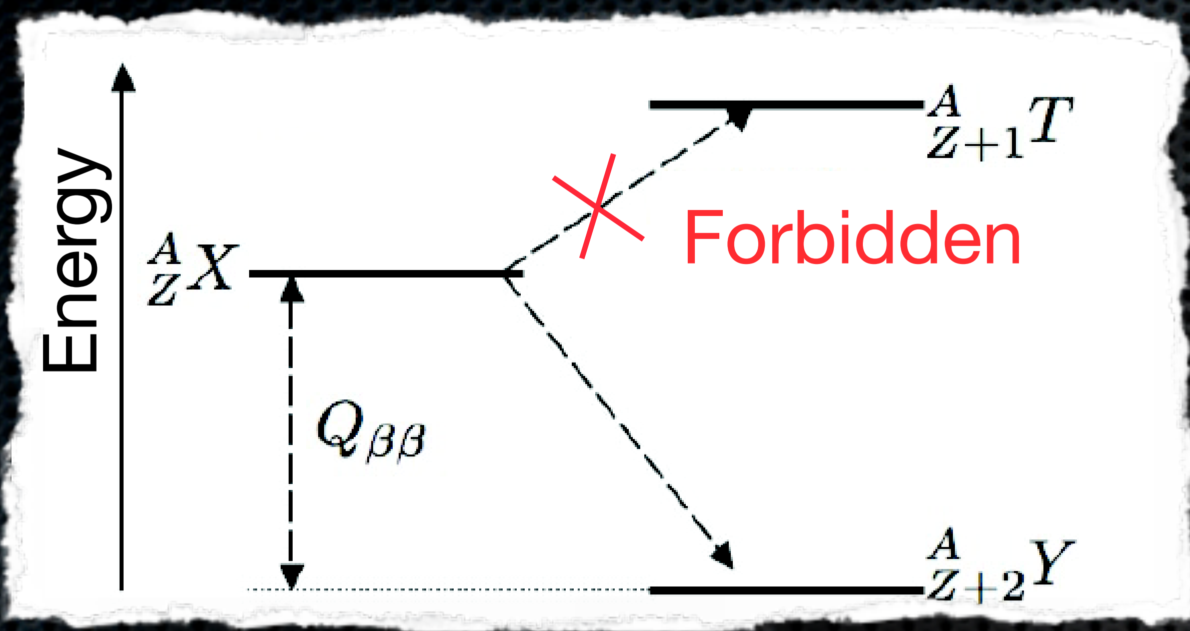
Extremely rare decay, possible only in few isotopes in which single β decay is forbidden

With neutrinos (2vDBD)



Allowed by Standard Model and experimentally observed

The Double Beta Decay



Extremely rare decay, possible only in few isotopes in which single β decay is forbidden

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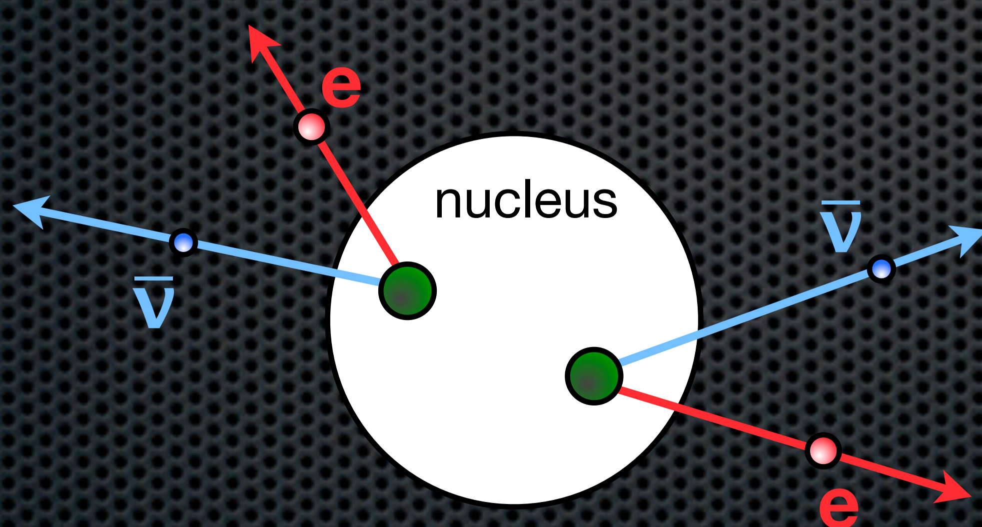
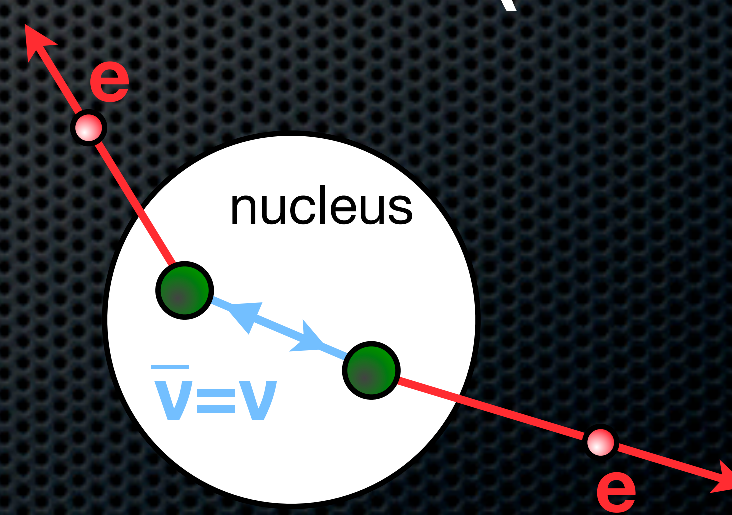


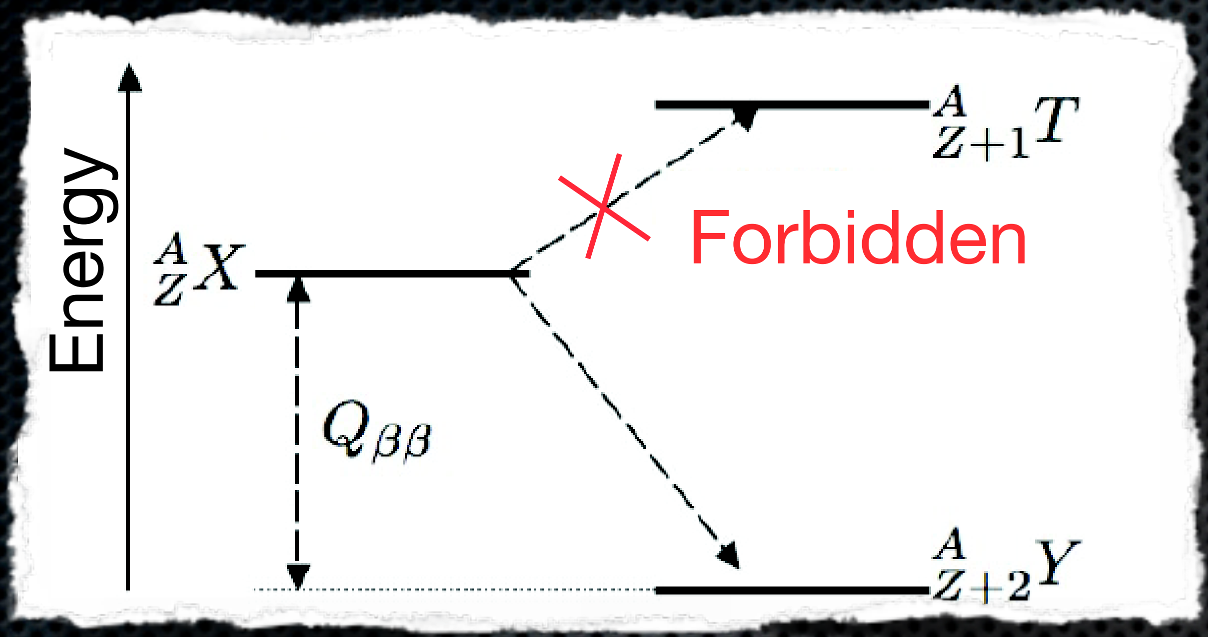
Allowed by Standard Model and experimentally observed

Neutrinoless (0vDBD)



Not allowed by Standard Model and not observed yet (except one controversial claim)

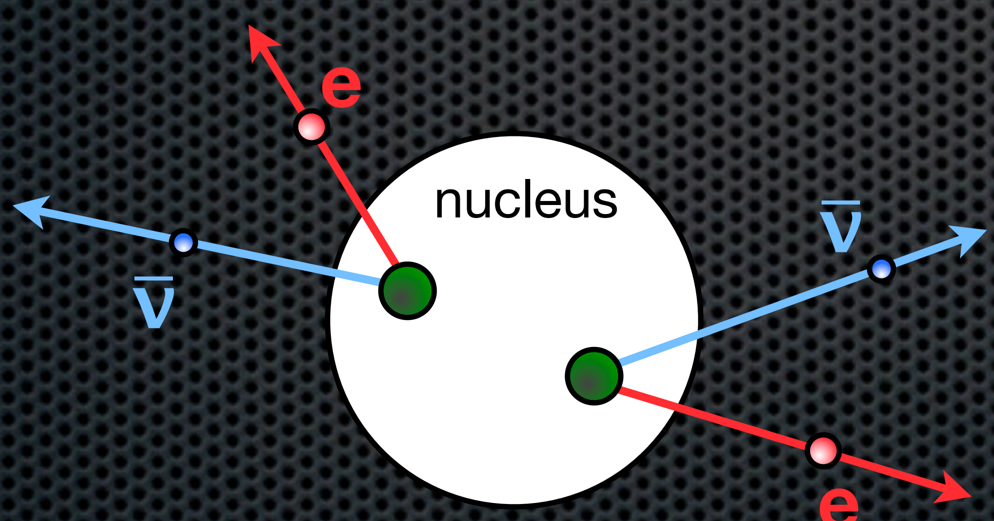
The Double Beta Decay



If 0vDBD is observed:

- ✓ Majorana neutrino
- ✓ Neutrino mass measurement
- ✓ Lepton number violation

With neutrinos (2vDBD)



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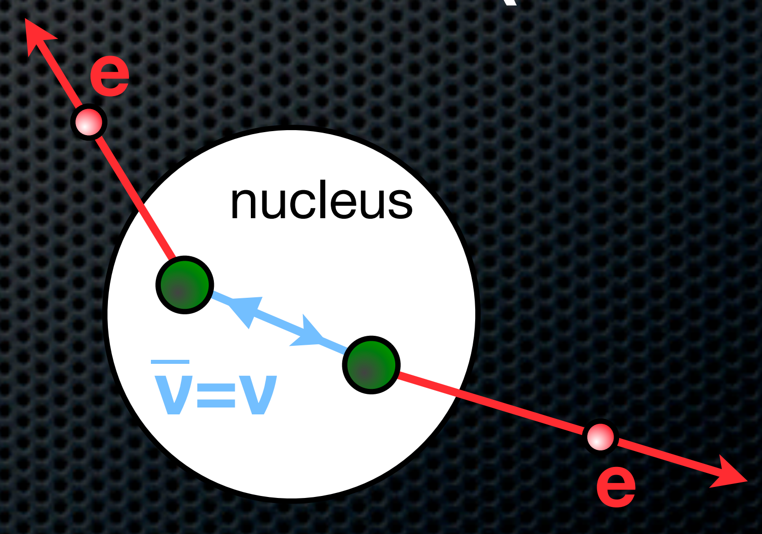

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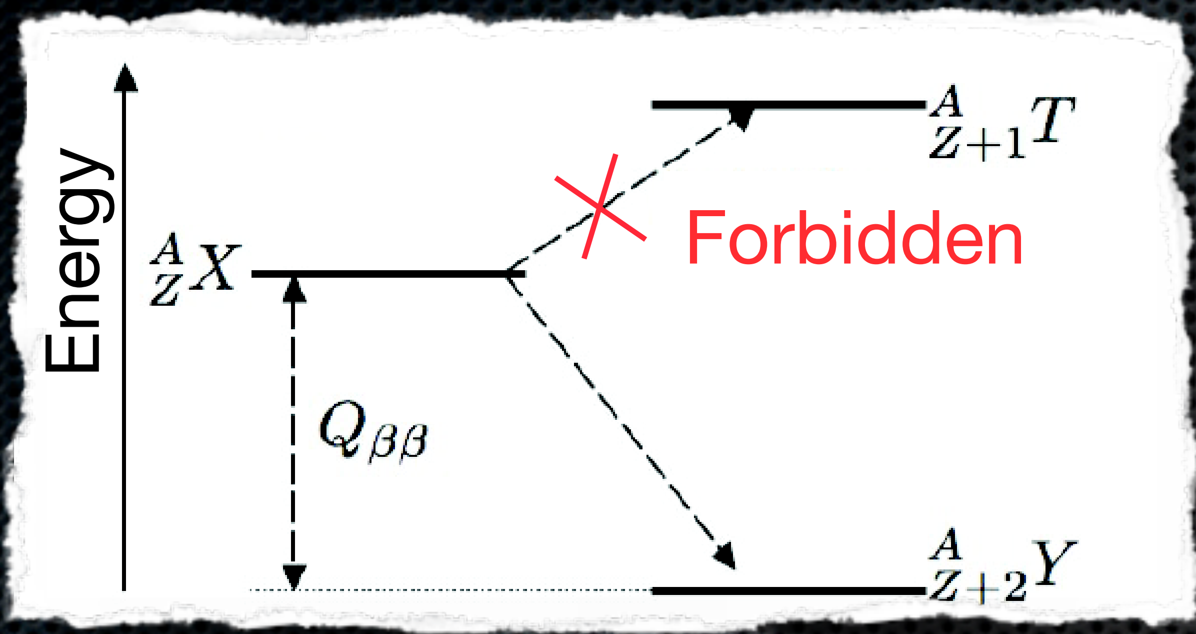


If 0vDBD is observed:

- ✓ Majorana neutrino
- ✓ Neutrino mass measurement
- ✓ Lepton number violation

Experiments measure

the process half-time ($T^{0\nu}_{1/2}$)

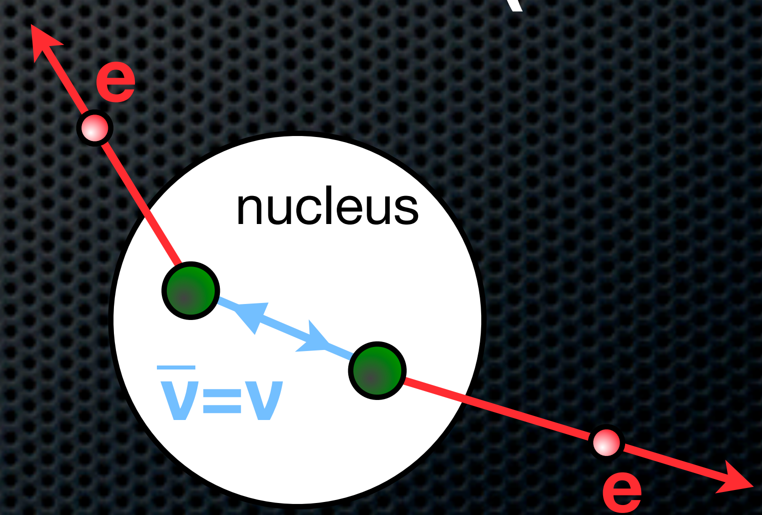
$$\frac{1}{T^{0\nu}_{1/2}} = G(Q,Z)\,|M_{nucl}|^2\,|m_{\beta\beta}|^2$$

Phase space factor ($\propto Q^5$)

Nuclear Matrix Element

Effective neutrino mass

Neutrinoless (0vDBD)



Not allowed by Standard Model and not observed yet (except one controversial claim)

Experimental approaches for 0νDBD

Isotopic abundance

Detector mass (kg)

Measurement time (y)

$$S^{0\nu} = \ln 2 \, N_A \, \frac{\eta}{A} \sqrt{\frac{M\,t}{b\,\Delta E}} \, \epsilon$$

Efficiency

Atomic mass

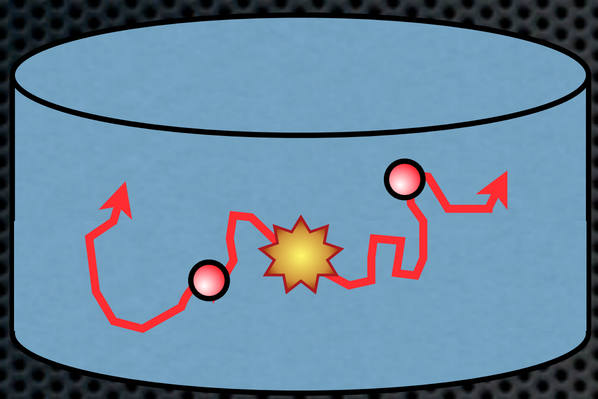
Energy Resolution (keV)

Background (counts/keV/kg/y)

Experimental approaches for 0νDBD

$$S^{0\nu} = \ln 2\, N_A \frac{\eta}{A} \sqrt{\frac{M\,t}{b\,\Delta E}}\,\epsilon$$

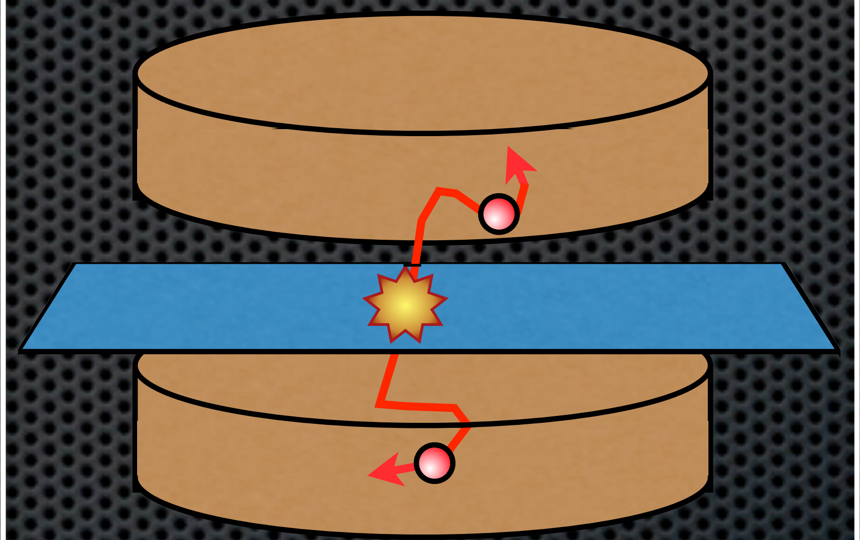
Calorimetry



Emitter = Detector

Very high efficiency
Good energy resolution
Large active mass
No possibility of background discrimination

Tracking



Emitter ≠ Detector

Low geometric efficiency
Poor energy resolution
Reduced active mass
Background discrimination based on event topology

Loaded liquid scintillator

Pre-existing experiments
Large active mass
Bad energy resolution
No possibility of background discrimination

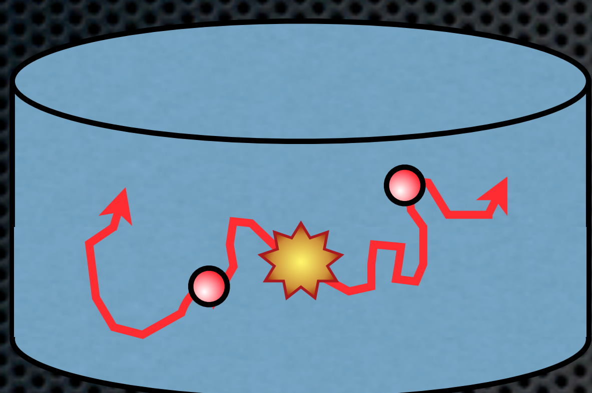
Time projection chambers

Background discrimination based on event topology

Experimental approaches for 0νDBD

$$S^{0\nu} = \ln 2 \, N_A \, \frac{\eta}{A} \sqrt{\frac{M\,t}{b\,\Delta E}}\,\epsilon$$

Calorimetry

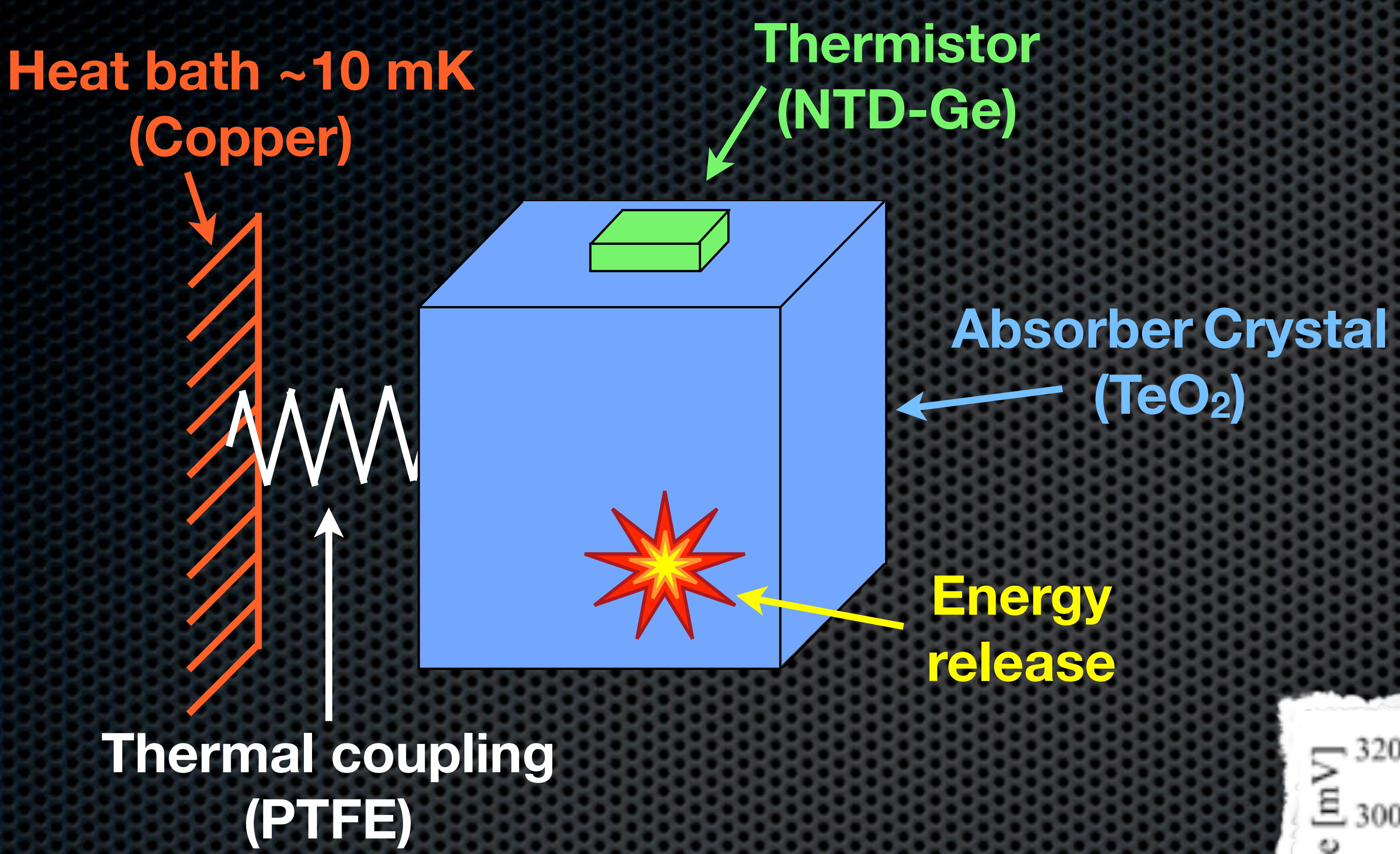


Emitter = Detector

Very high efficiency
Good energy resolution
Large active mass
No possibility of background discrimination

It's the CUORE choice

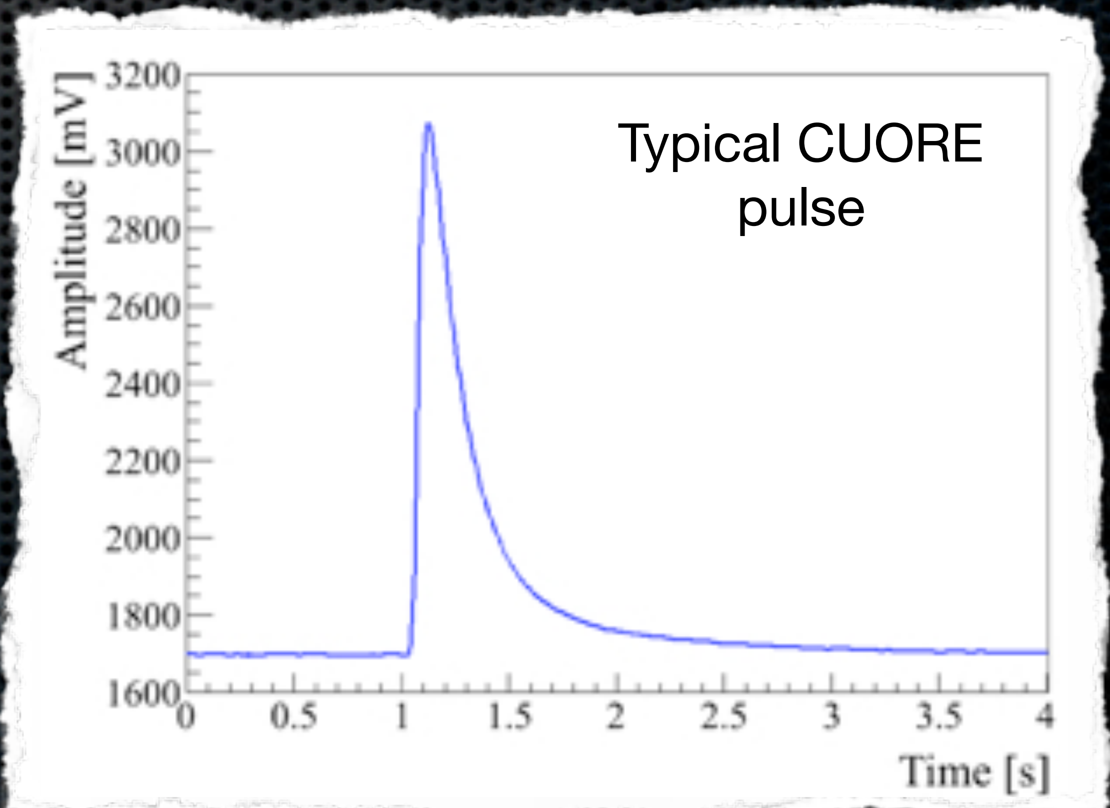
The bolometric technique



All the particle energy is converted into phonons, producing a crystal temperature variation of ~0.1 mK/MeV.

Crystal heating changes the thermistor resistance of ~3MΩ/MeV, determining a voltage variation of ~0.3 mV/MeV.

FWHM resolution
~ 5 keV @0vDBD (2528 keV)

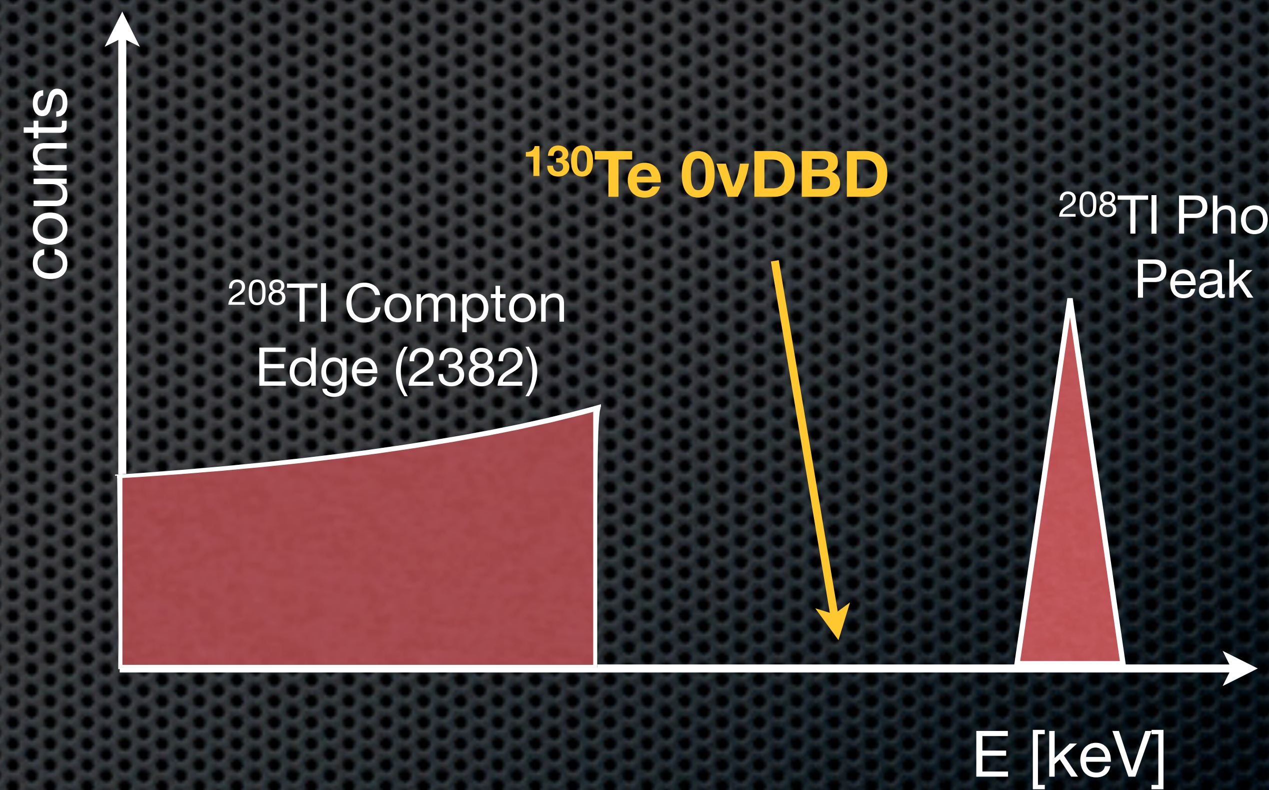


The isotope choice

Decay	i.a. [%]	Q [keV]
$^{48}Ca \rightarrow {}^{48}Ti$	0.187	4271
$^{76}Ge \rightarrow {}^{76}Se$	7.8	2040
$^{82}Se \rightarrow {}^{82}Kr$	9	2995
$^{94}Zr \rightarrow {}^{94}Mo$	17.4	1145
$^{96}Zr \rightarrow {}^{96}Mo$	2.8	3350
$^{100}Mo \rightarrow {}^{100}Ru$	9.6	3034
$^{110}Pd \rightarrow {}^{110}Cd$	11.7	2013
$^{116}Cd \rightarrow {}^{116}Sn$	7.5	2802
$^{124}Sn \rightarrow {}^{124}Te$	5.8	2288
$^{130}Te \rightarrow {}^{130}Xe$	34.2	2528
$^{136}Xe \rightarrow {}^{136}Ba$	8.9	2479
$^{150}Nd \rightarrow {}^{150}Sm$	5.6	3367

Naturally abundant, no need of isotopic enrichment

Looking for the highest possible Q-value ($G \propto Q^5$), far from know radioactive peaks



Other TeO_2 features:

- **Good intrinsic purity**
- **Low thermal capacity**
- **Can be grown in “big” crystals**

CUORE precursor: Cuoricino

Lower limit (90% C.L.), half-life

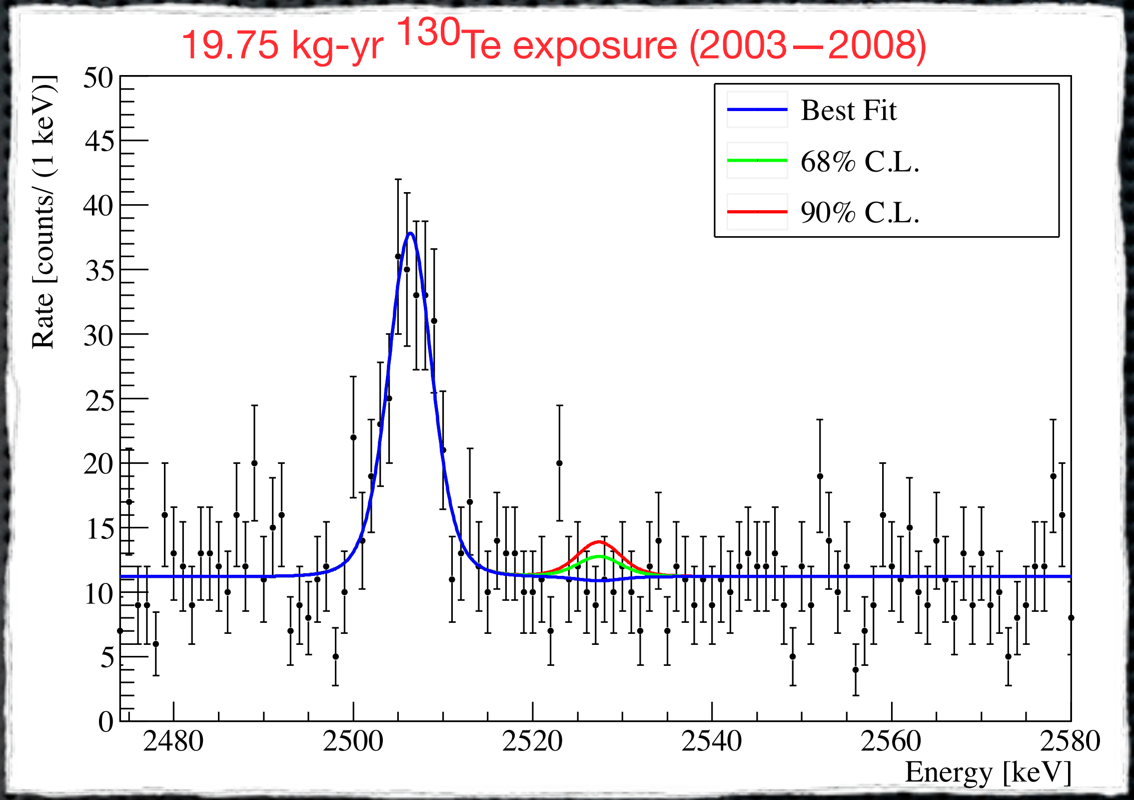
$T^{0\nu DBD}(^{130}Te) \geq 2.8 \cdot 10^{24}$ y

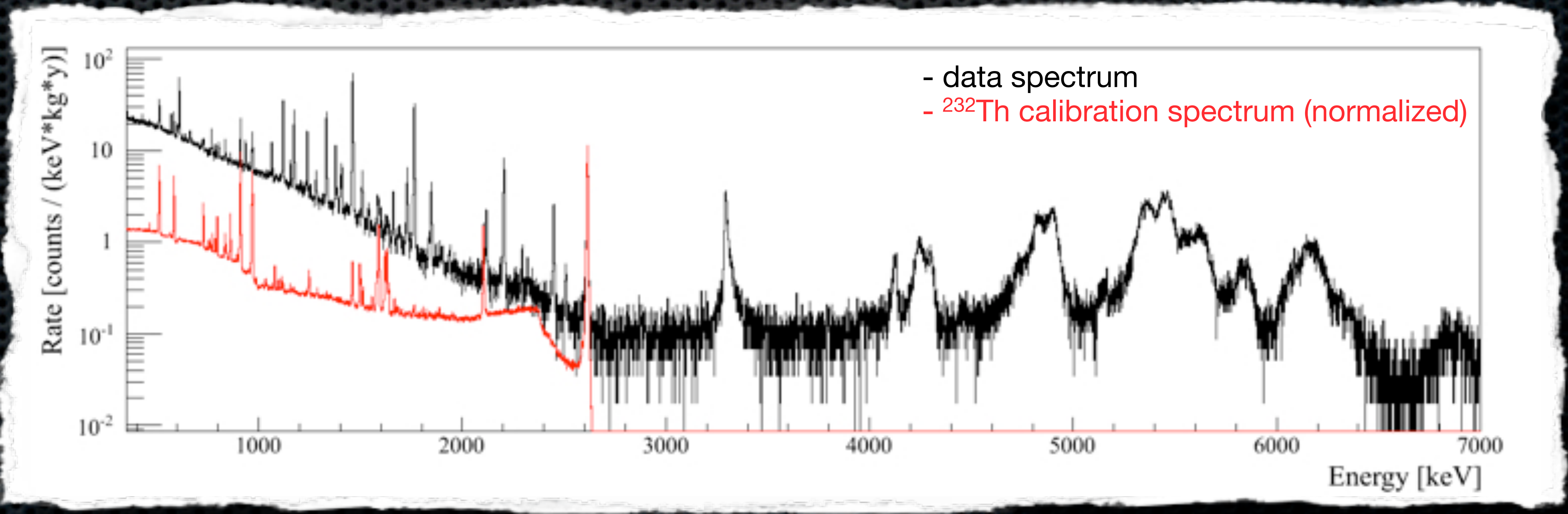
Upper limit, Majorana ν mass

$m_{\beta\beta} < 300 - 710$ meV

Background in the ROI

0.169 ± 0.006 counts/keV/kg/y



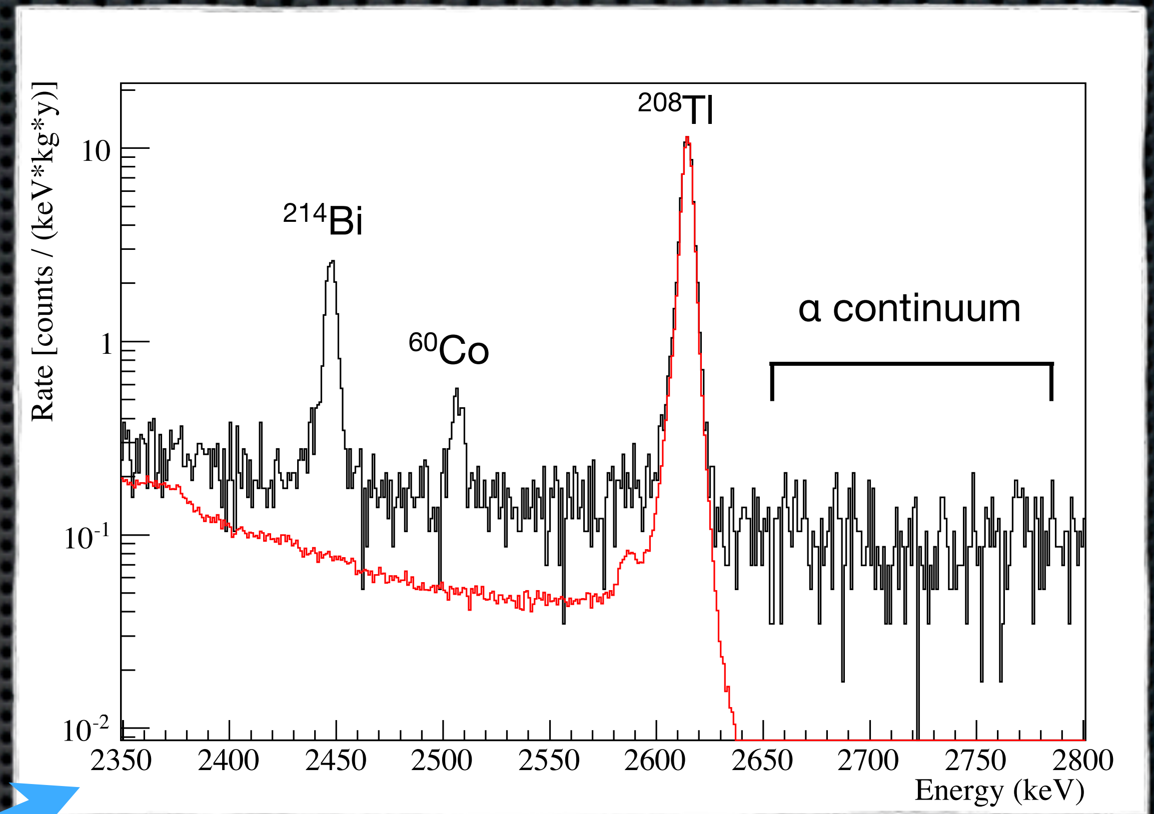


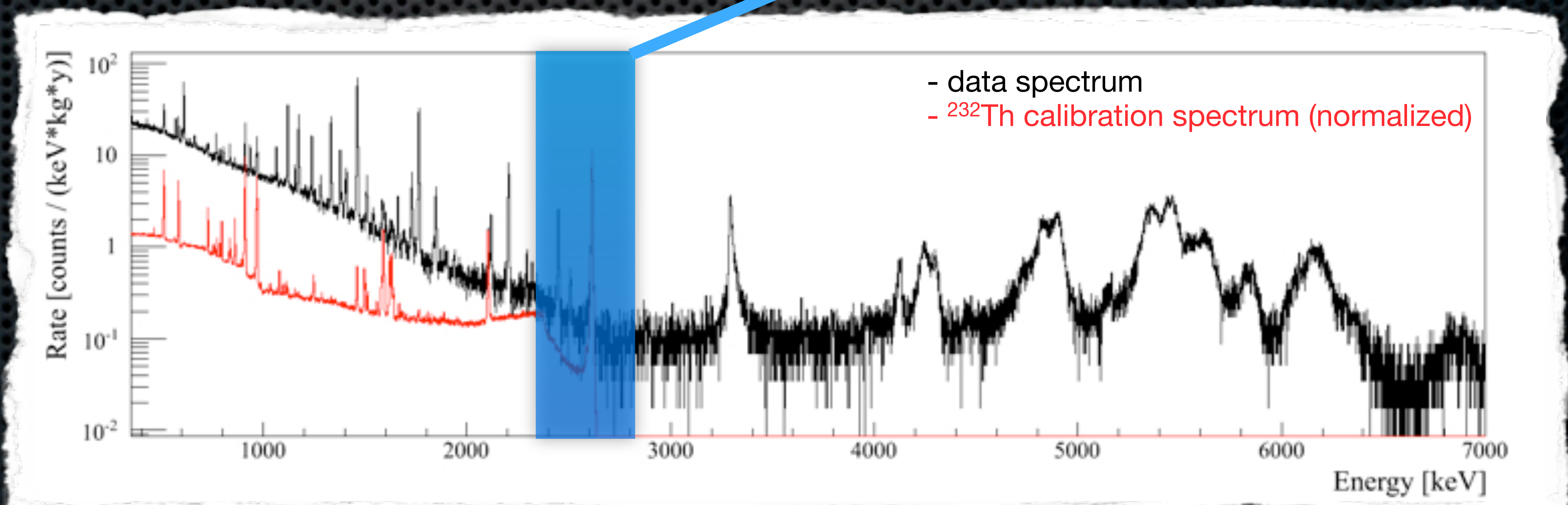
E. Andreotti et al. (CUORICINO Collaboration), Astropart. Phys. 34: 822–831 (2011) [arXiv:nucl-ex/1012.3266].

CUORE precursor: Cuoricino

More than 60% of the background is due to degraded α from surfaces

Background in the ROI
0.169 ± 0.006 counts/keV/kg/y





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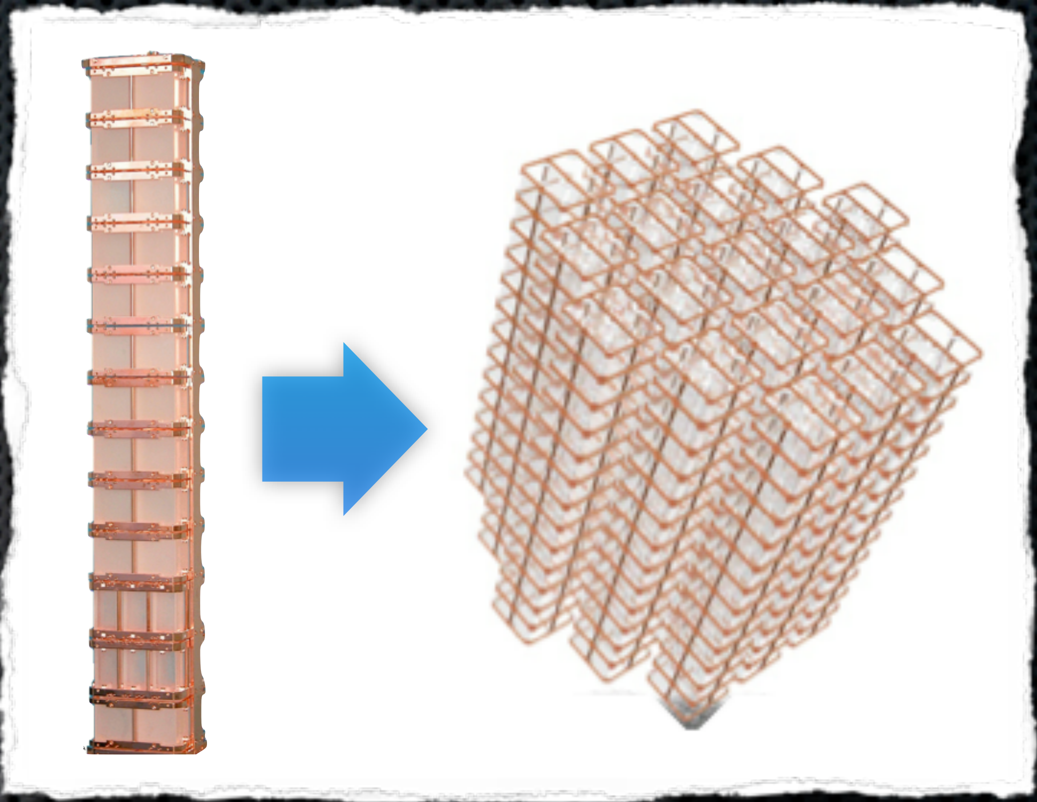
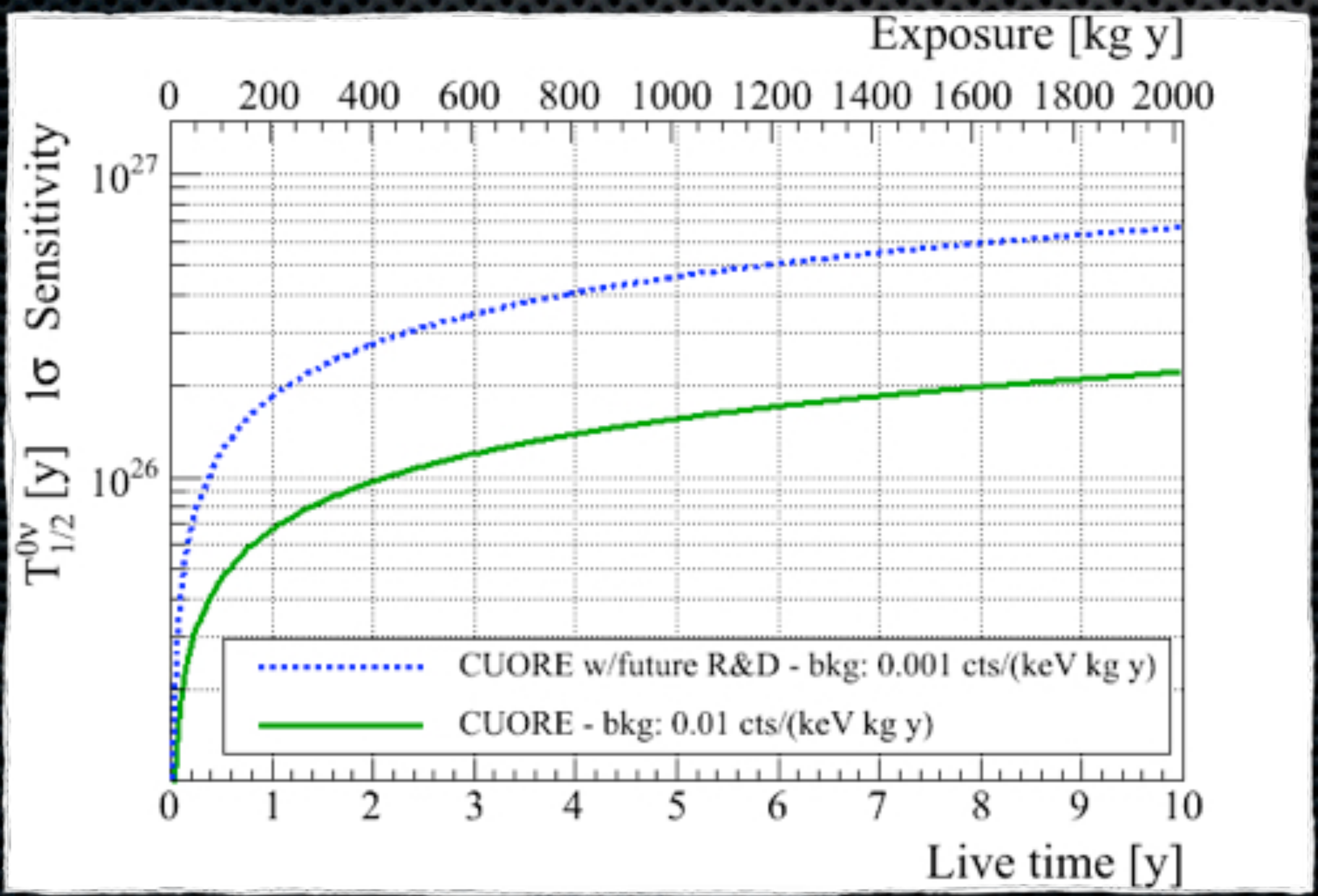
From Cuoricino to CUORE

- 19 towers, 52 detectors each
- 988 TeO_2 crystals (5x5x5 cm^3)
- Total detector mass: 741 kg
- Total ^{130}Te mass: 206 kg
  (natural abundance)





M×20 T×2 B/20 ΔE/1.5

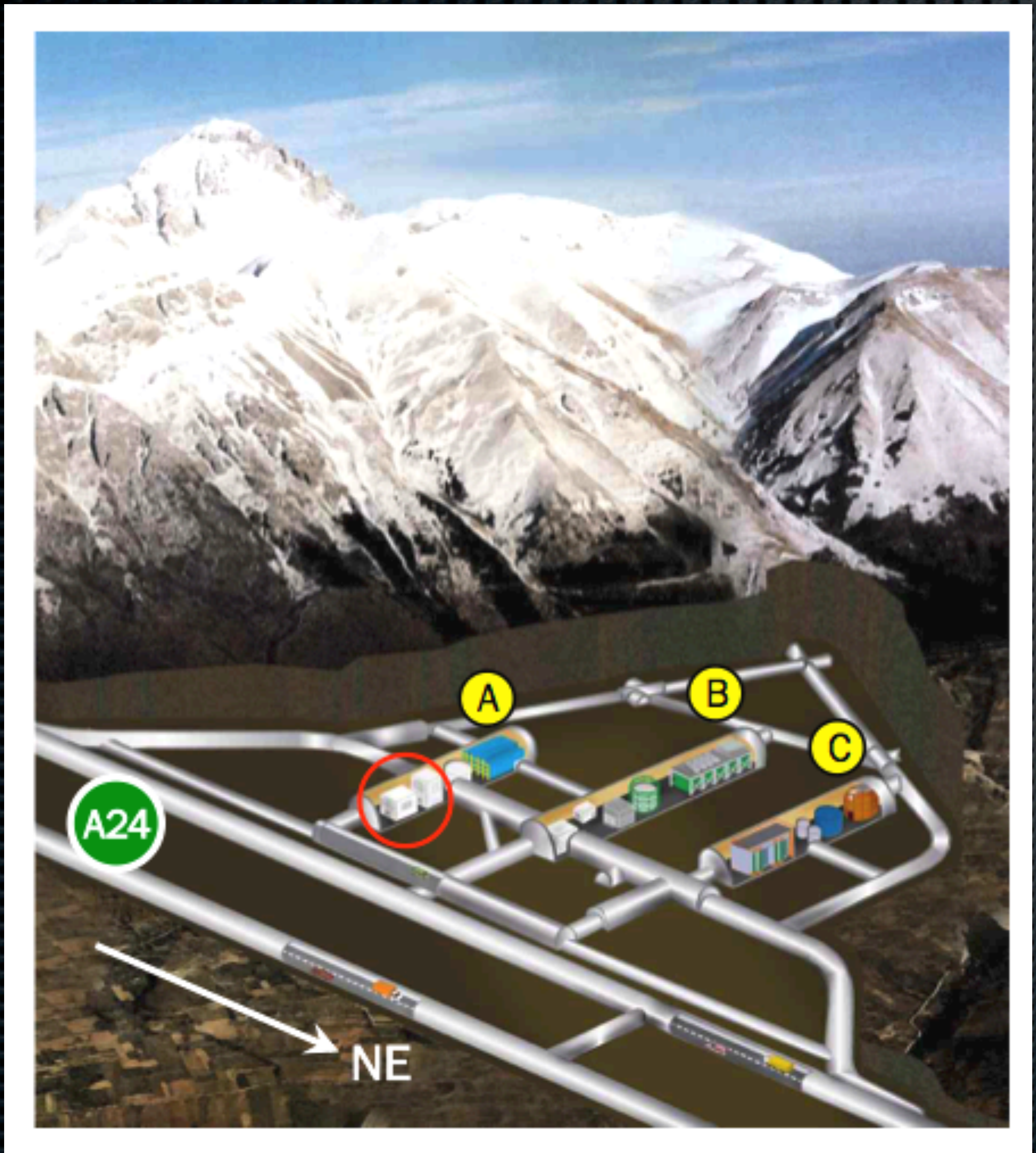
Sensitivity increased of a factor ~ 35

The CUORE Collaboration

19 groups:
10 Italy
6 USA
1 France
2 associated institutes

115 researchers/authors:
69 Italy
36 USA
2 France
8 associated institutes

CUORE Location



Laboratori Nazionali del Gran Sasso - Assergi, L'Aquila (Italy)

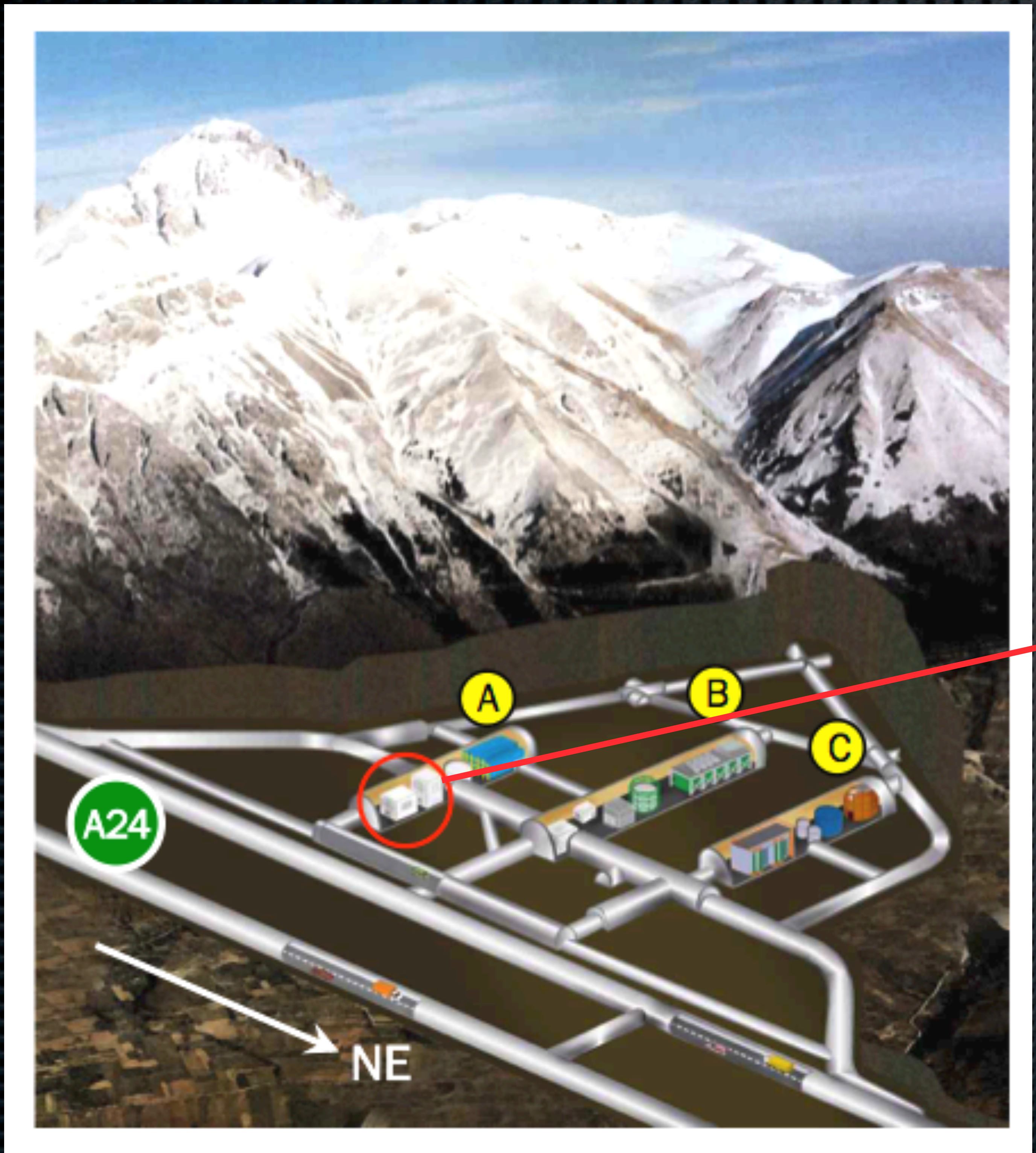
A natural shield of 1500 m of rock (3650 meters of water equivalent)

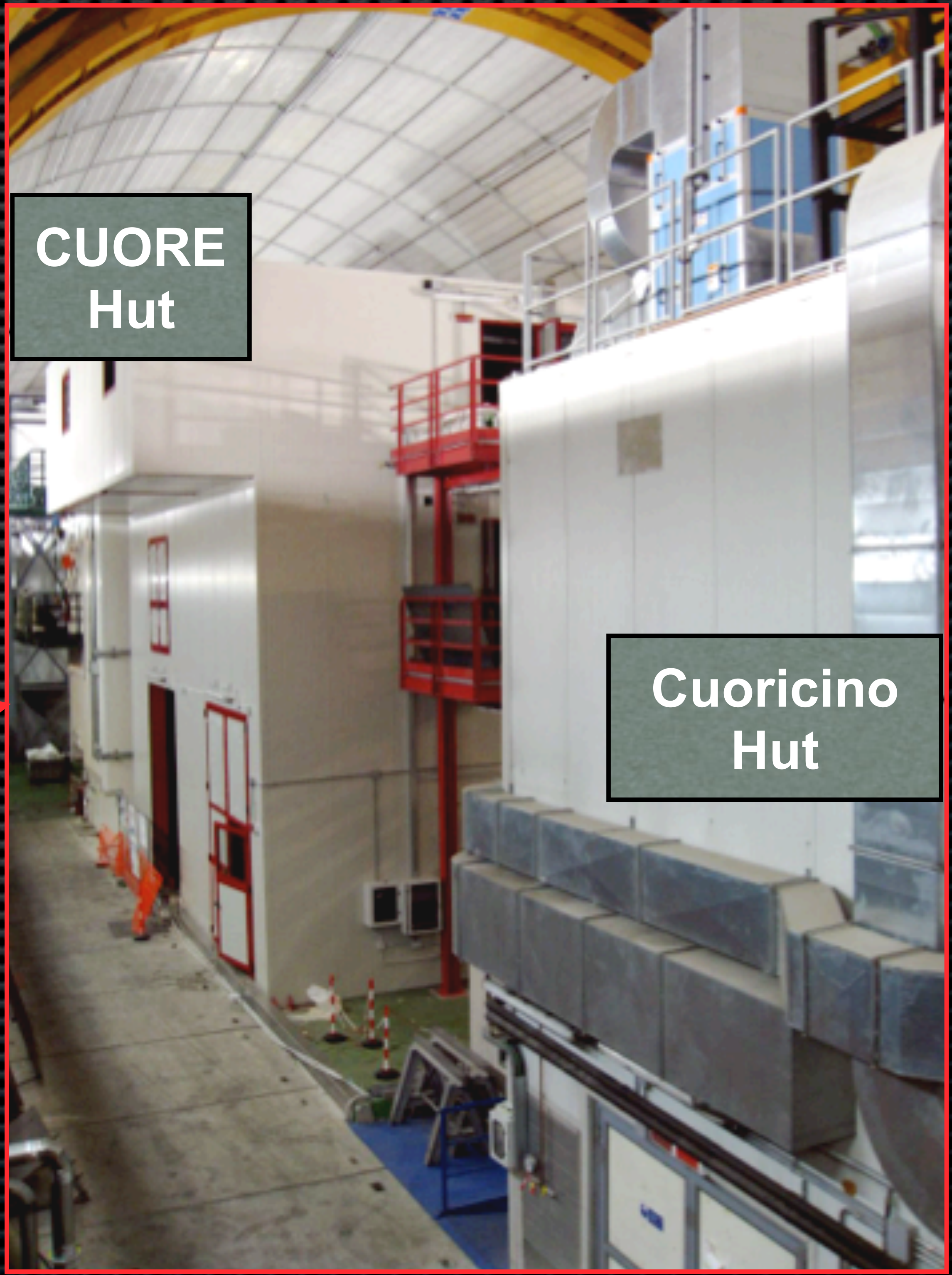
Muon Flux:
$(2.58\pm0.3)\times10^{-8}$ μ/(s cm^2)

Neutron Flux below 10 MeV:
~4×10^{-6} n/(s cm^2)

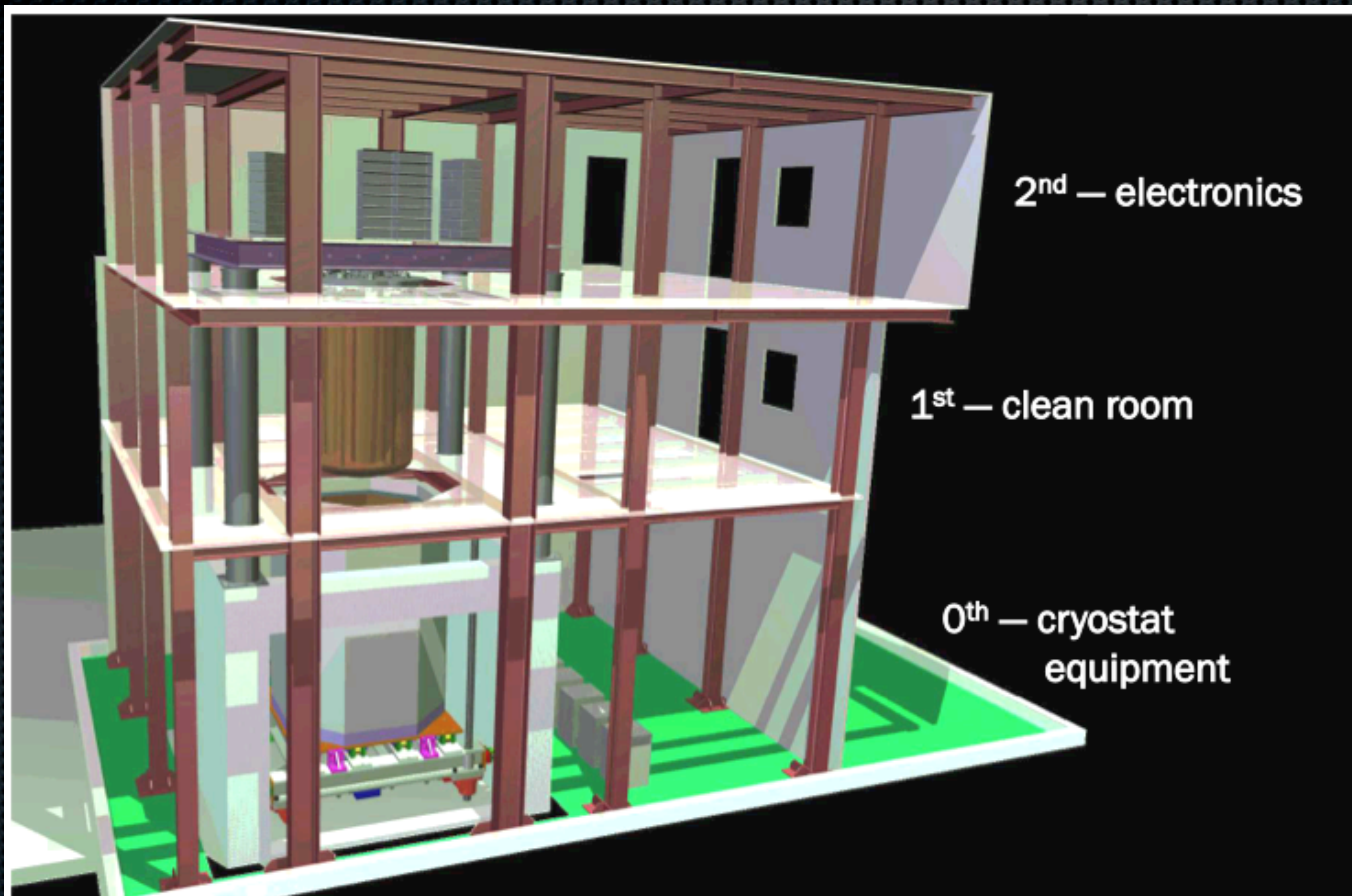
Gamma Flux:
~0.73 γ/(s cm^2)

CUORE Location





CUORE construction status @ LNGS



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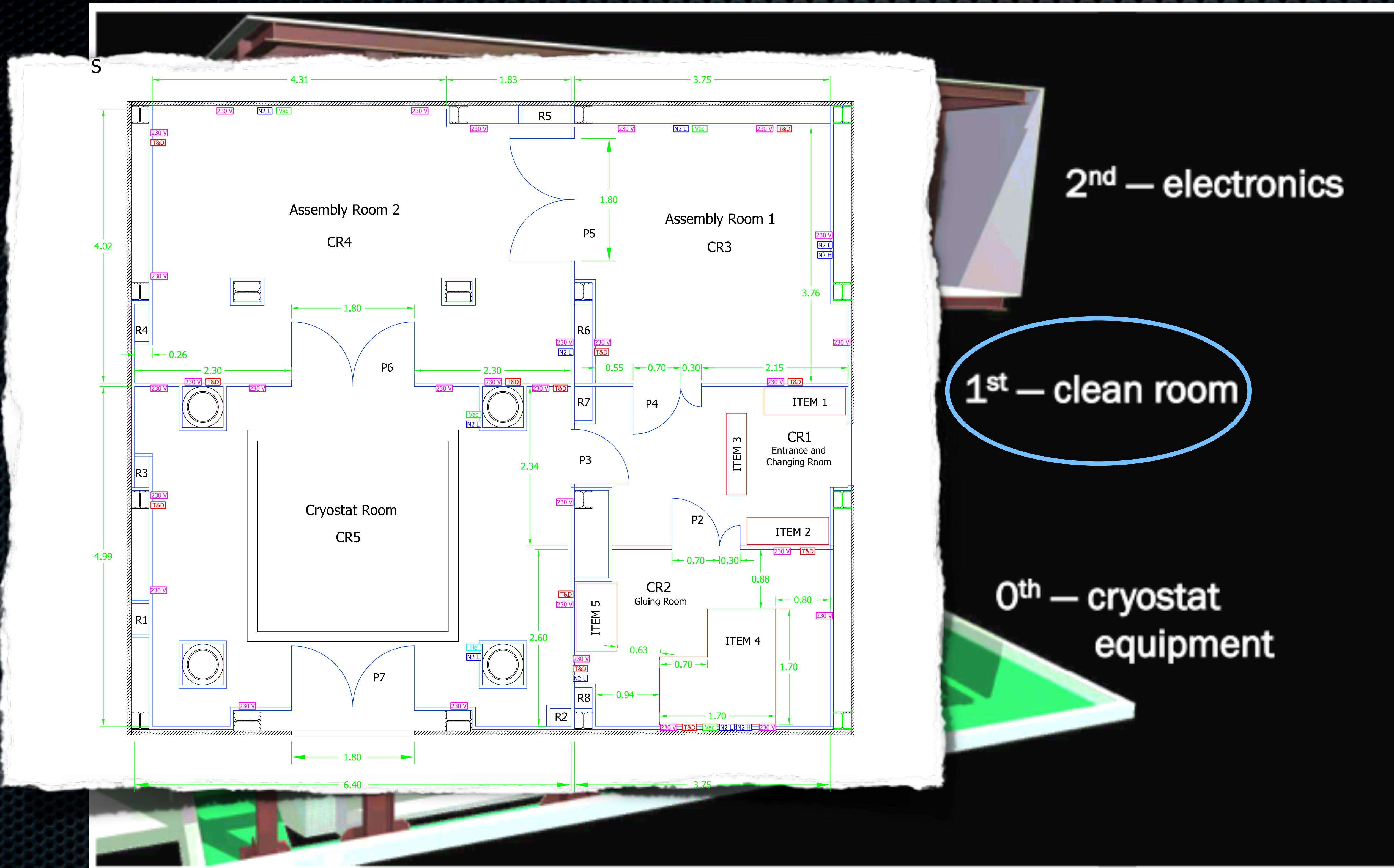
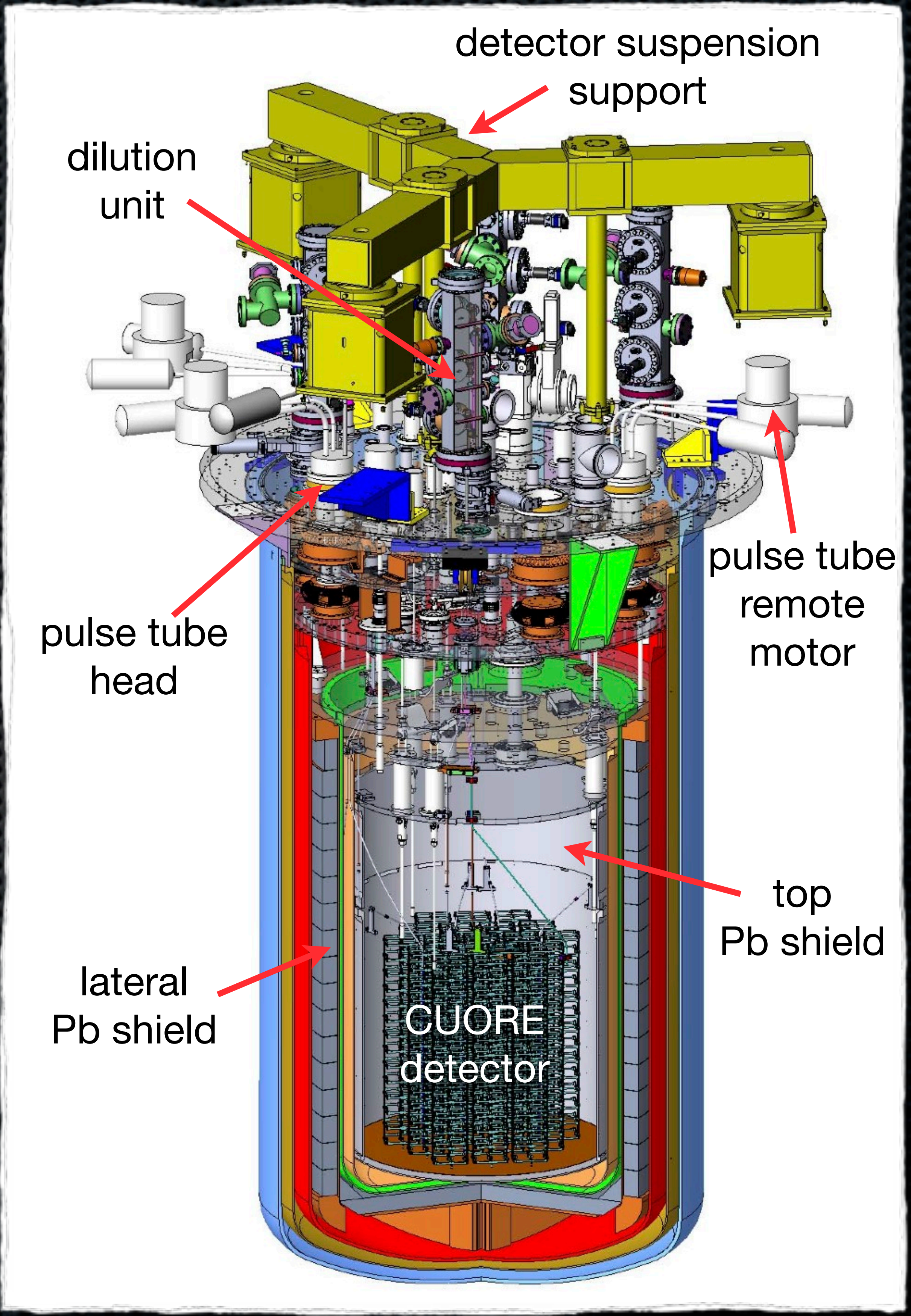


CUORE cryostat

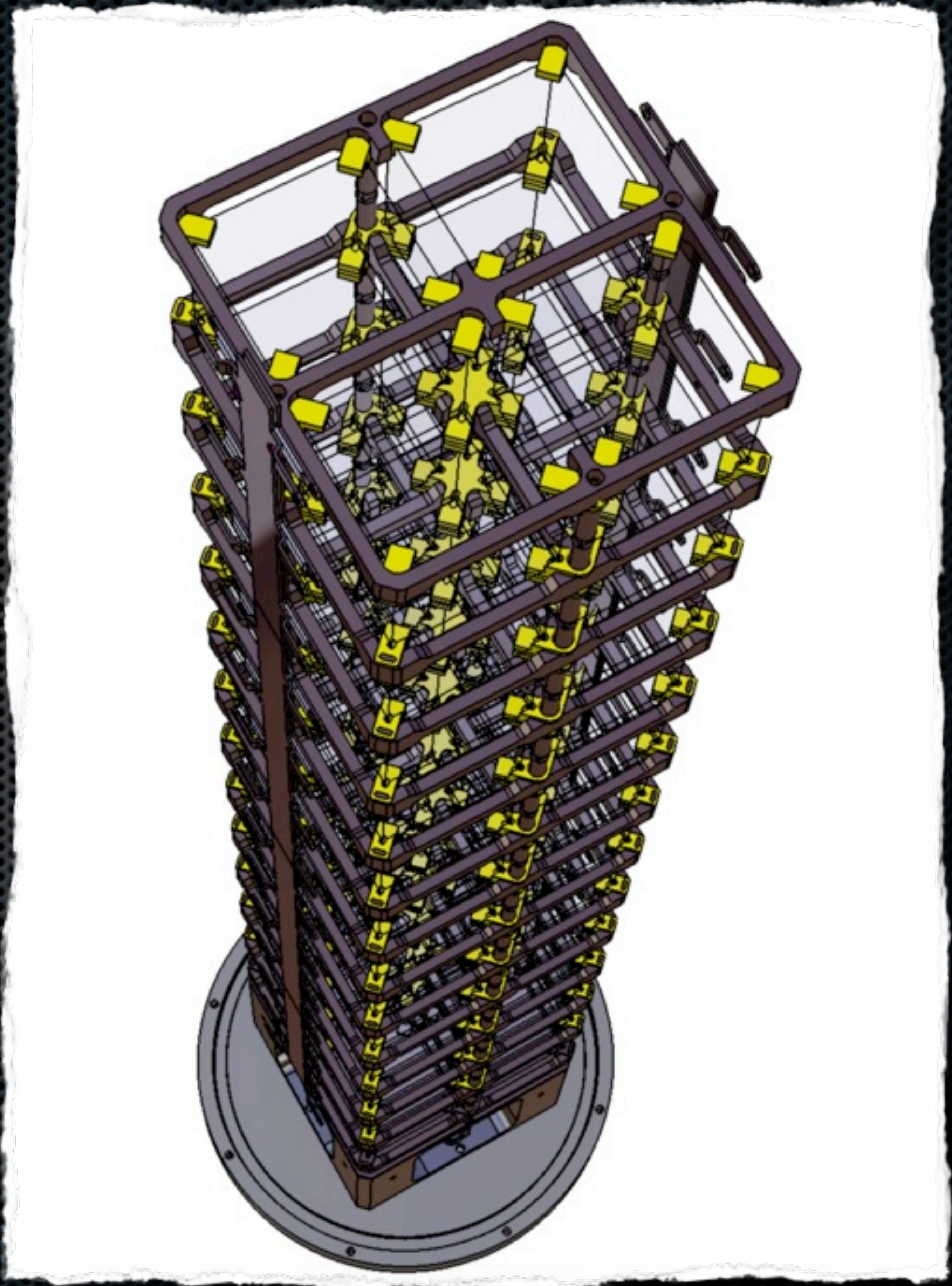
- New custom dilution refrigerator, made by Leiden Cryogenics in Netherlands
- Cryogen-free ➡ better duty cycle
- Detector suspensions independent of refrigerator apparatus ➡ less vibrational noise
- Minimum lead thickness ~ 36 cm
- Stringent radiopurity controls on materials and assembly

Full commissioning is starting now



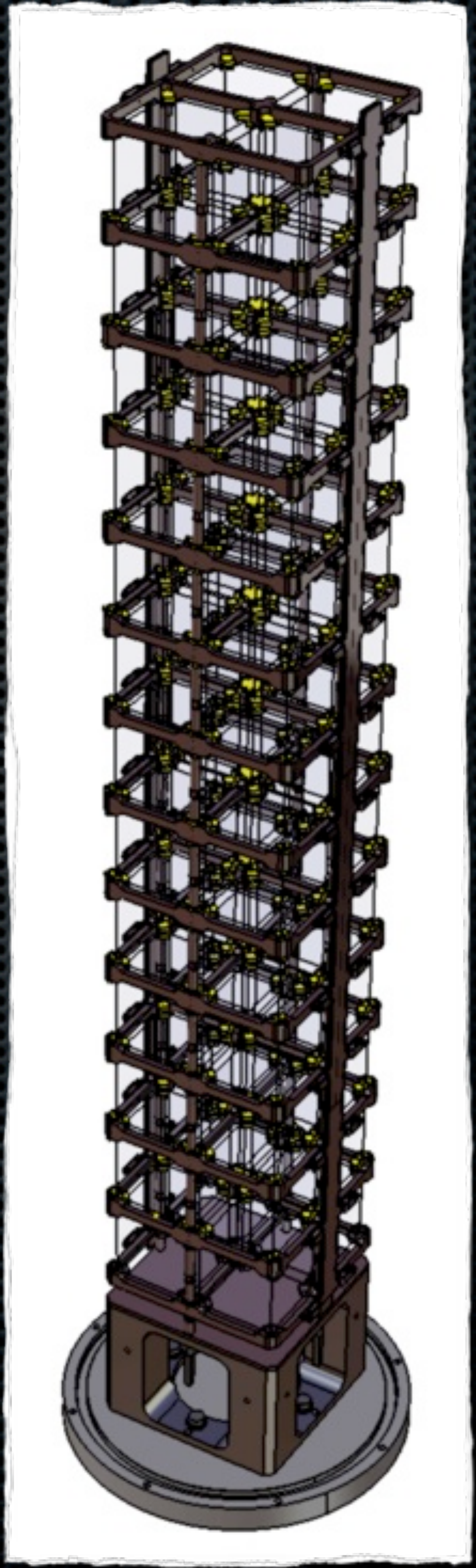
On the road to CUORE: CUORE-0

- 52 CUORE crystals mounted in CUORE-style frames as a single tower with a total TeO_2 mass of 39 kg
- Assembled from detector components manufactured, cleaned and stored following the same stringent protocols defined for CUORE
- Will be operated in the Cuoricino cryostat in LNGS

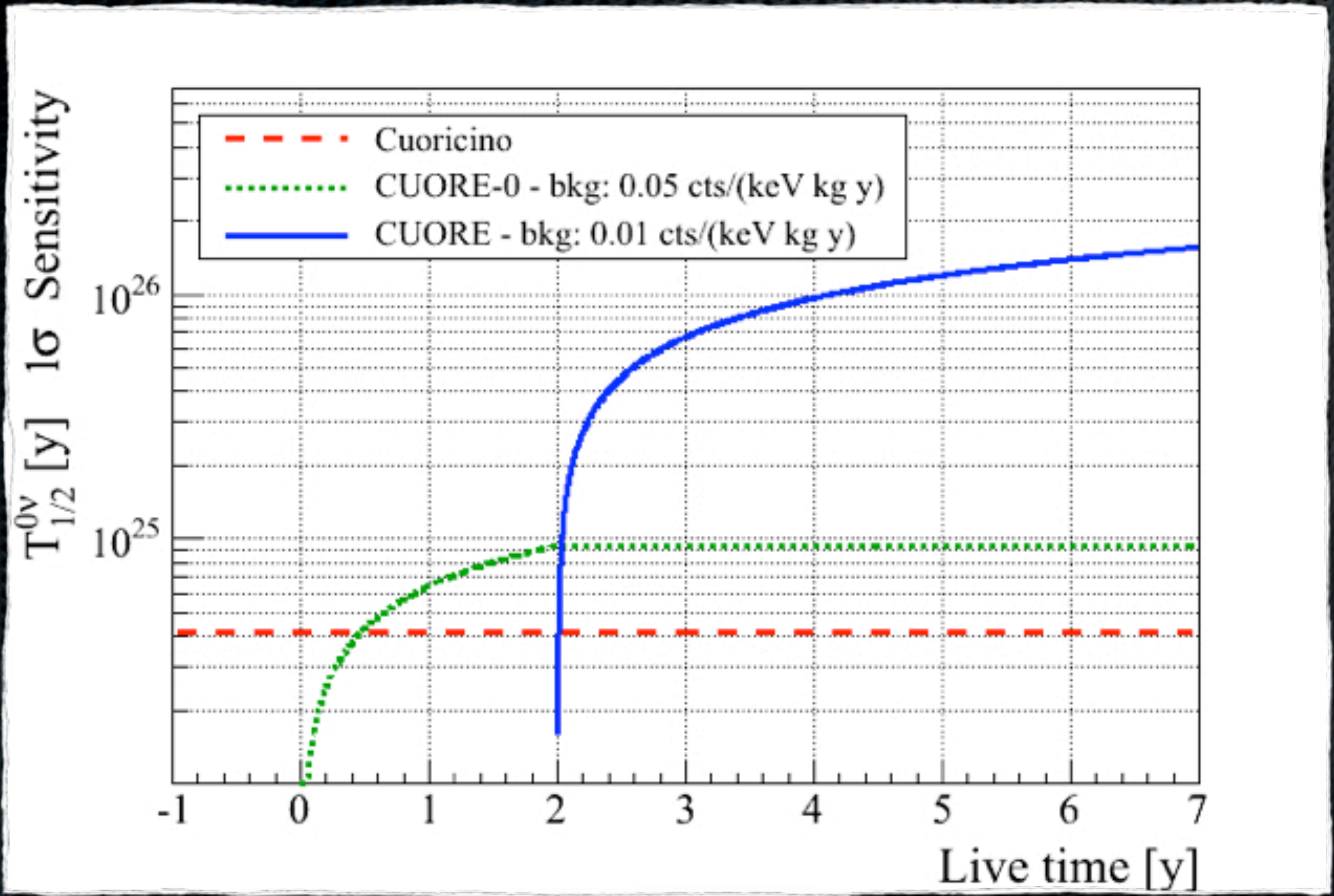


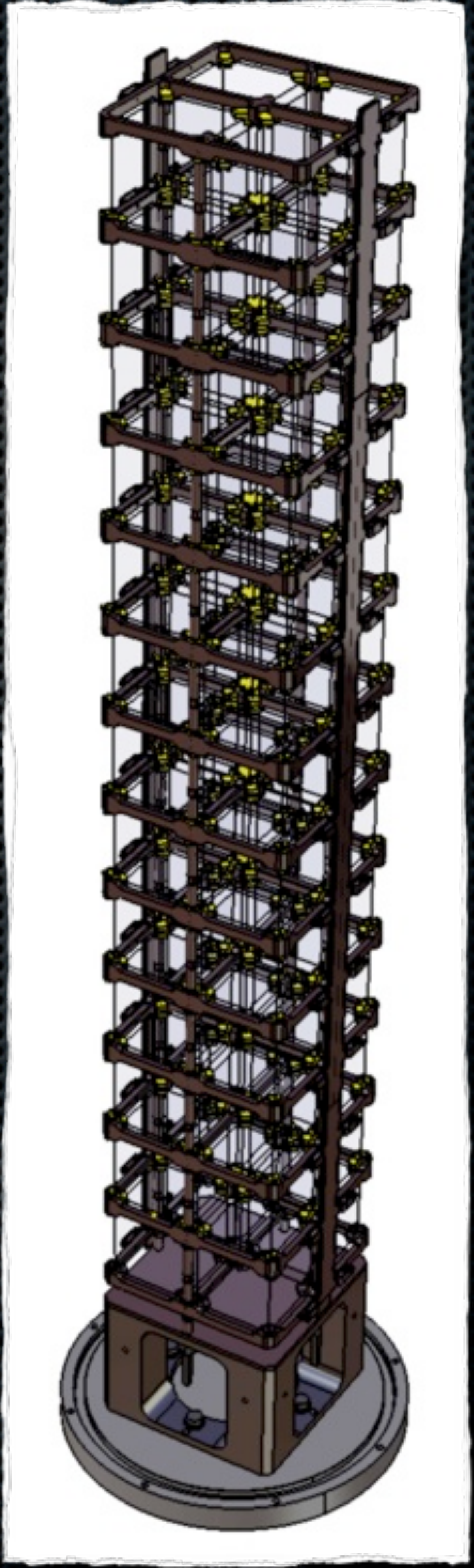
CUORE-0 goals

- Perform a full test and debugging of hardware, software and procedures developed in recent years for the CUORE detector
  - Validation of the background reduction measures
  - Final test of the CUORE Tower Assembly Line
  - High statistics check of the improved uniformity of bolometric response
- Surpass Cuoricino in physics reach while CUORE detector is being assembled



CUORE-0 goals



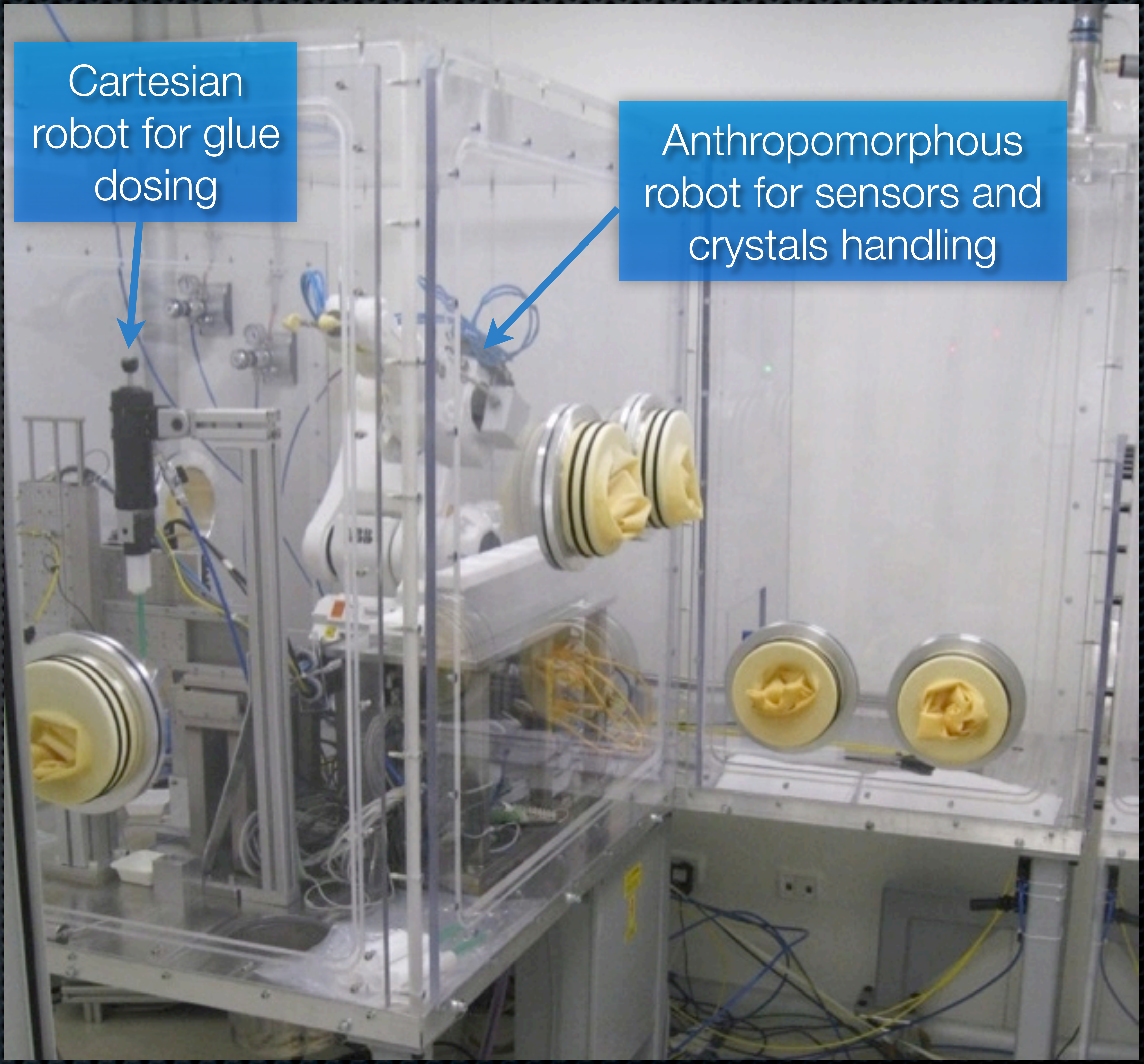


- Surpass Cuoricino in physics reach while CUORE detector is being assembled

Sensor-to-crystal connections

- Semi-automatic procedure
- Control of the operation timing
- All the parameters are stored in a dedicated database

October 2011: CUORE-0 crystals “glued”



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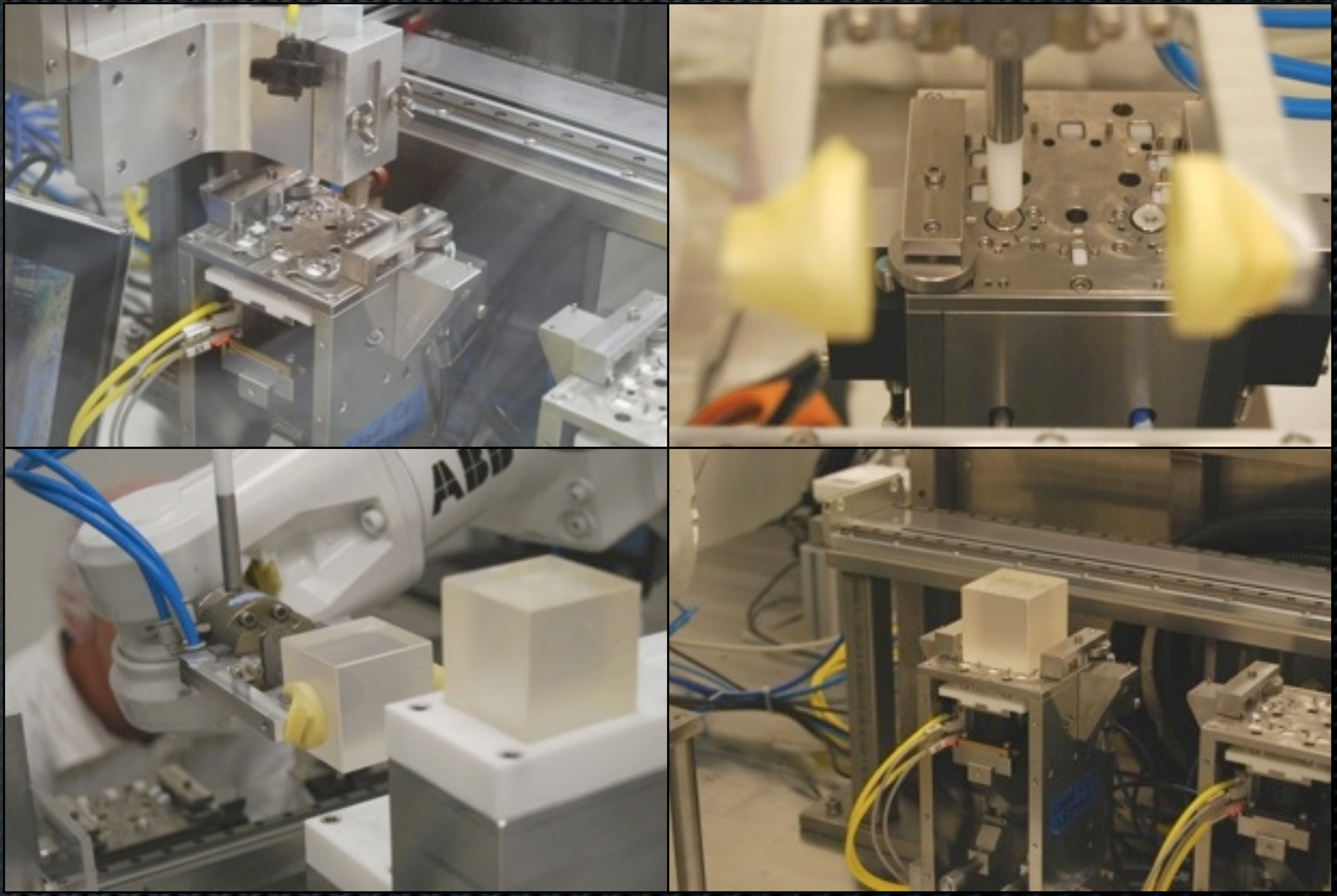

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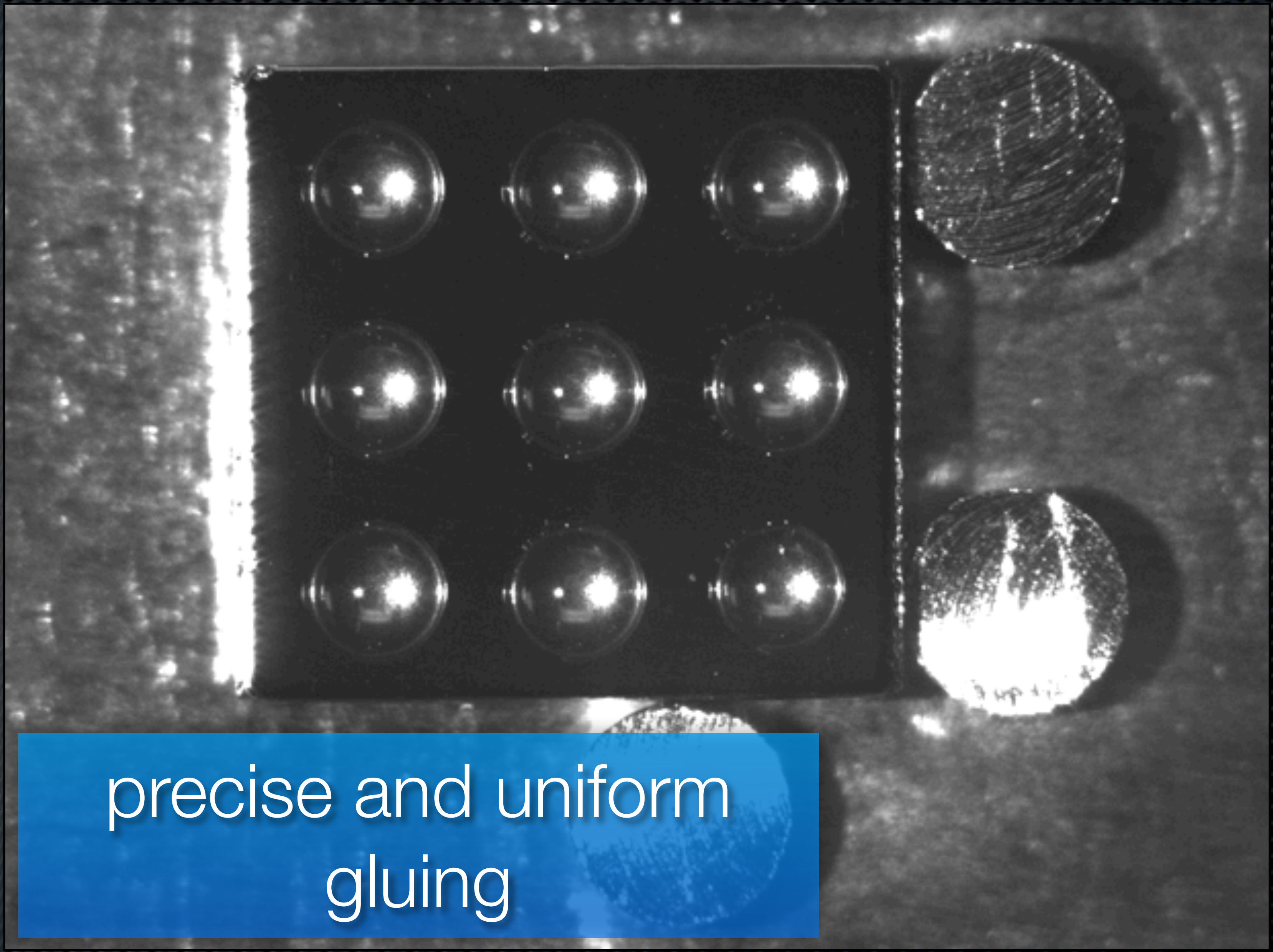

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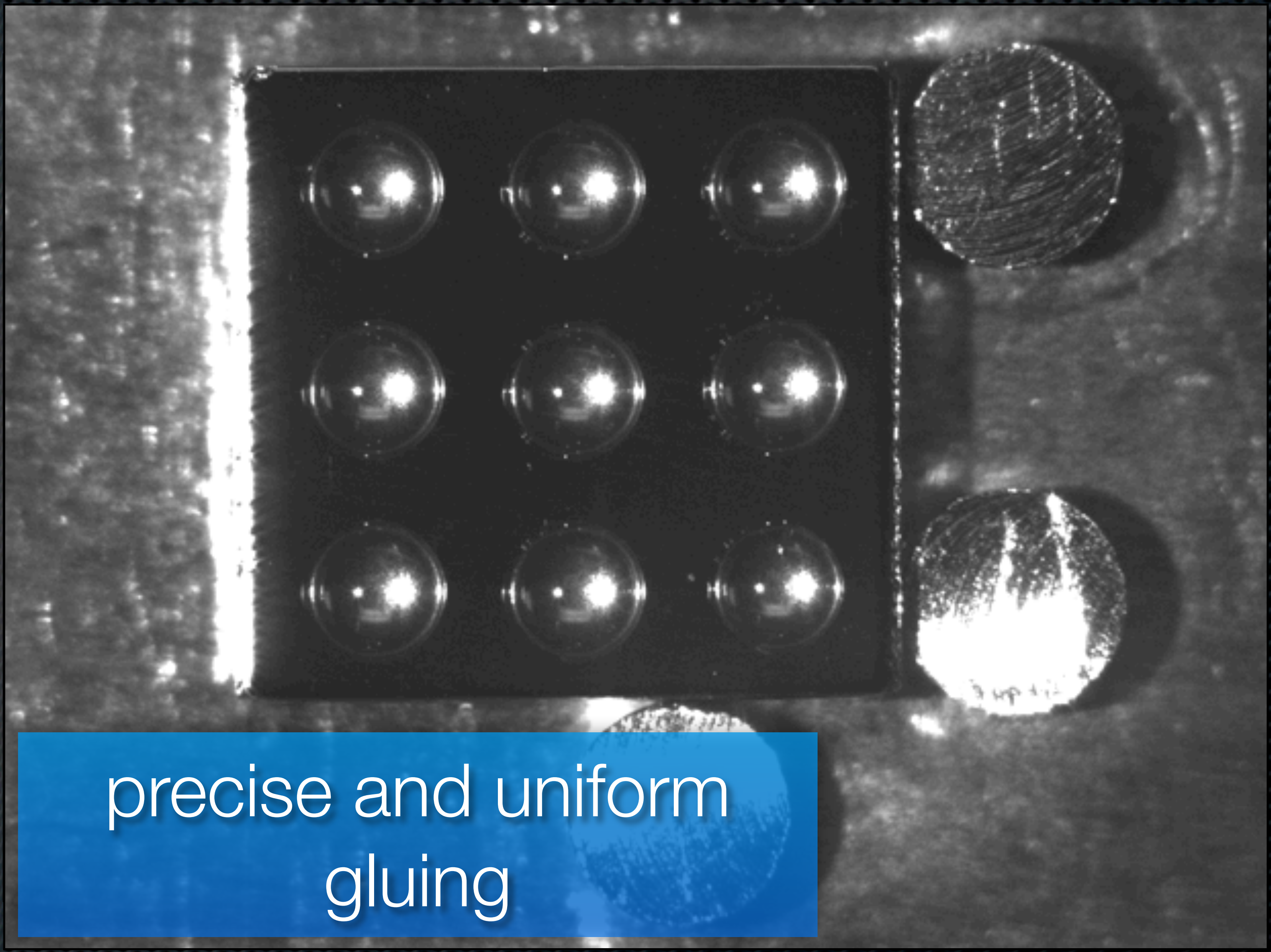
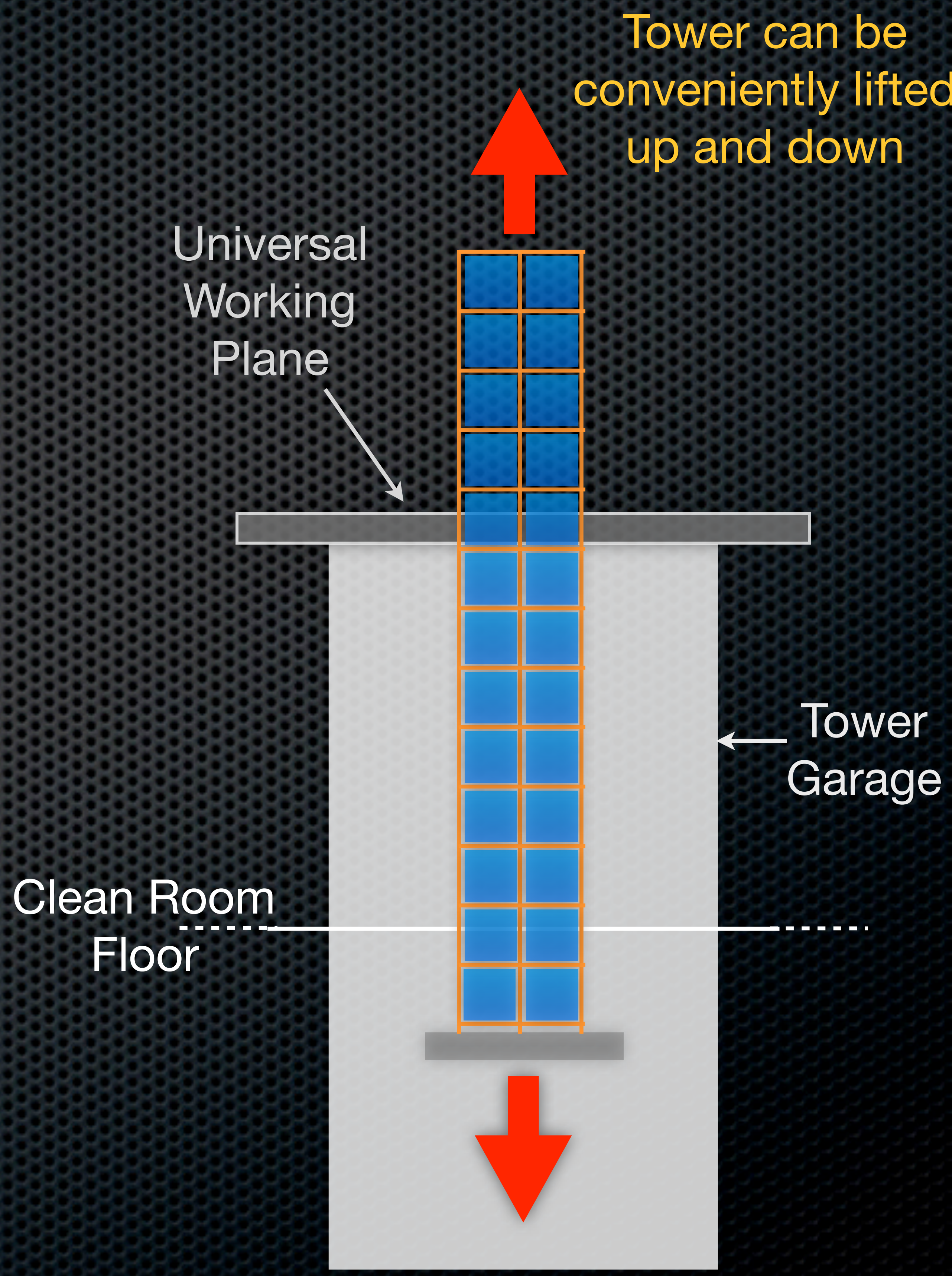


CUORE crystals gluing procedures are fully tested

CUORE Tower Assembly Line

- A single assembly station with 4 interchangeable glove boxes for specific tasks
  - Mechanics
  - Wiring/shielding
  - Bonding
  - Storage
- Zero contact system
- All the steps are performed in controlled nitrogen atmosphere



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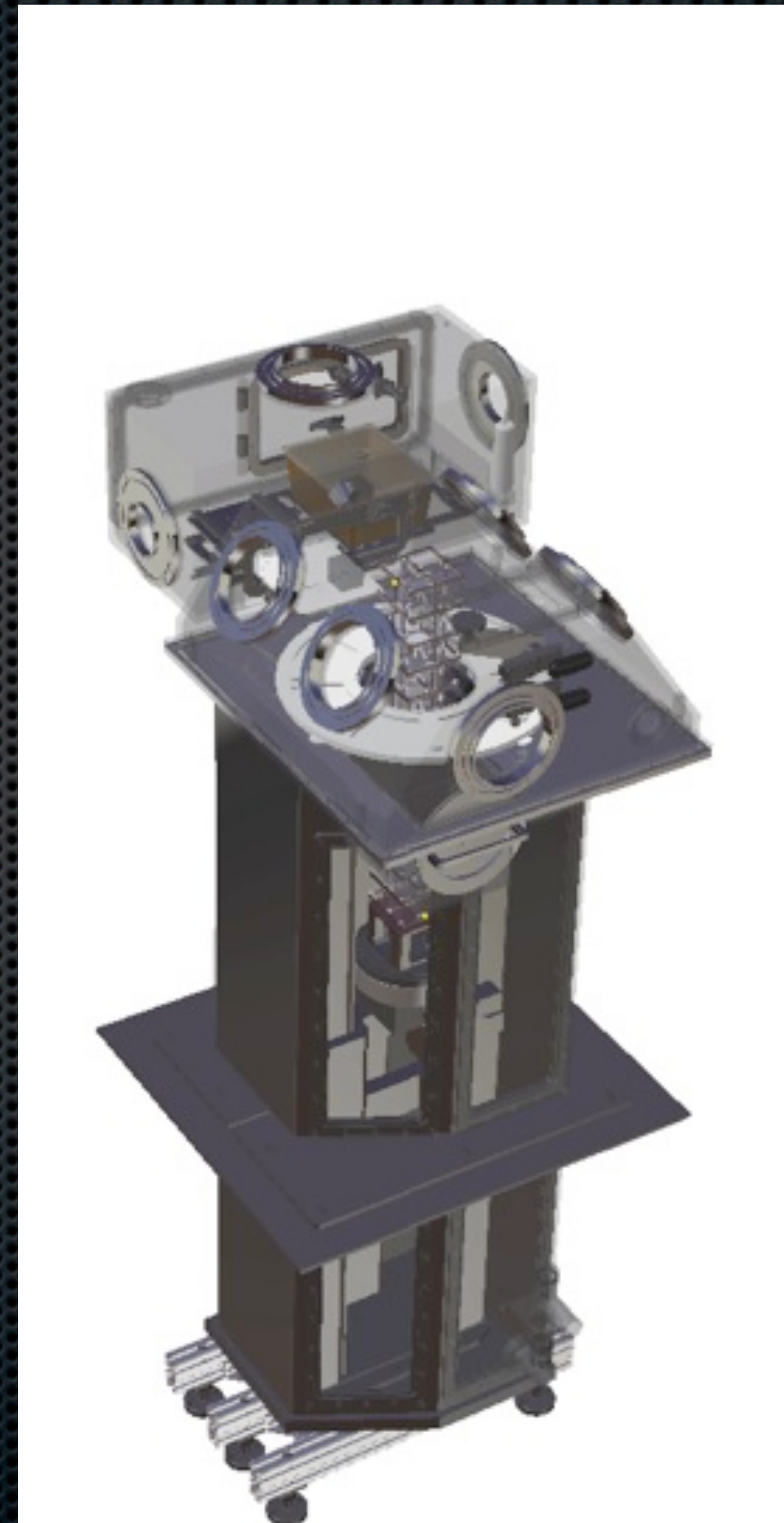
MechBox



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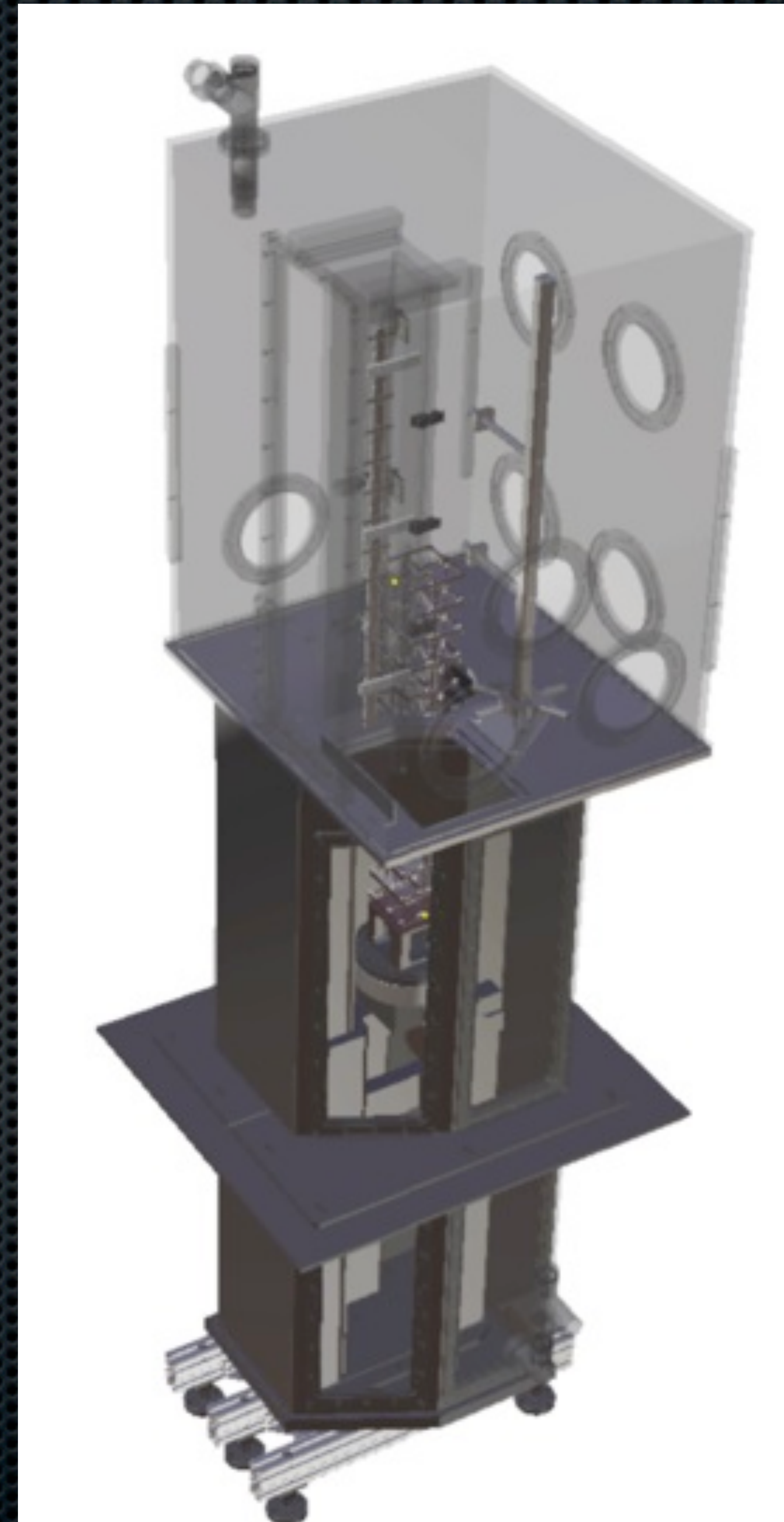
CablingBox



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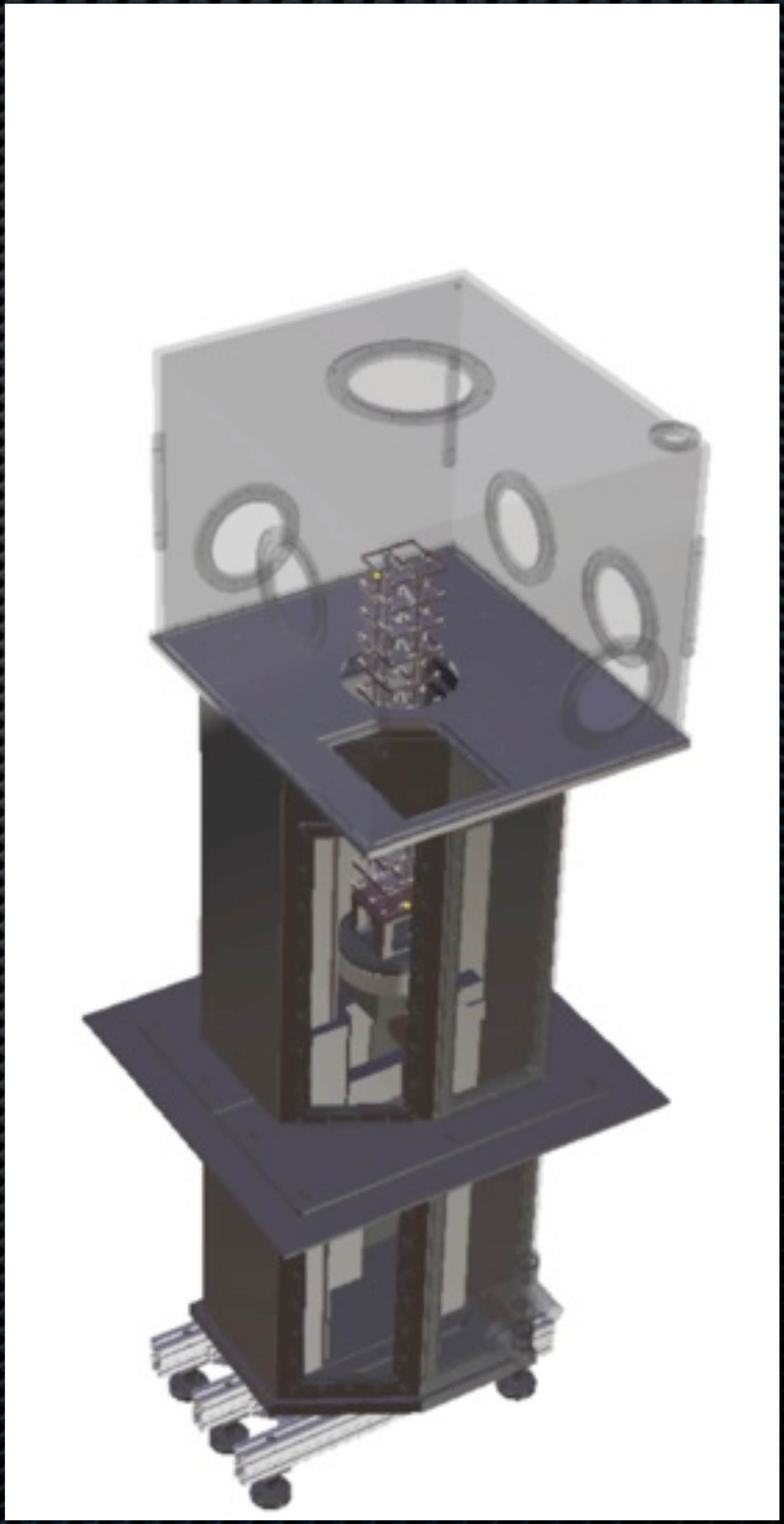
BondingBox



CUORE Tower Assembly Line

- A single assembly station with 4 interchangeable glove boxes for specific tasks
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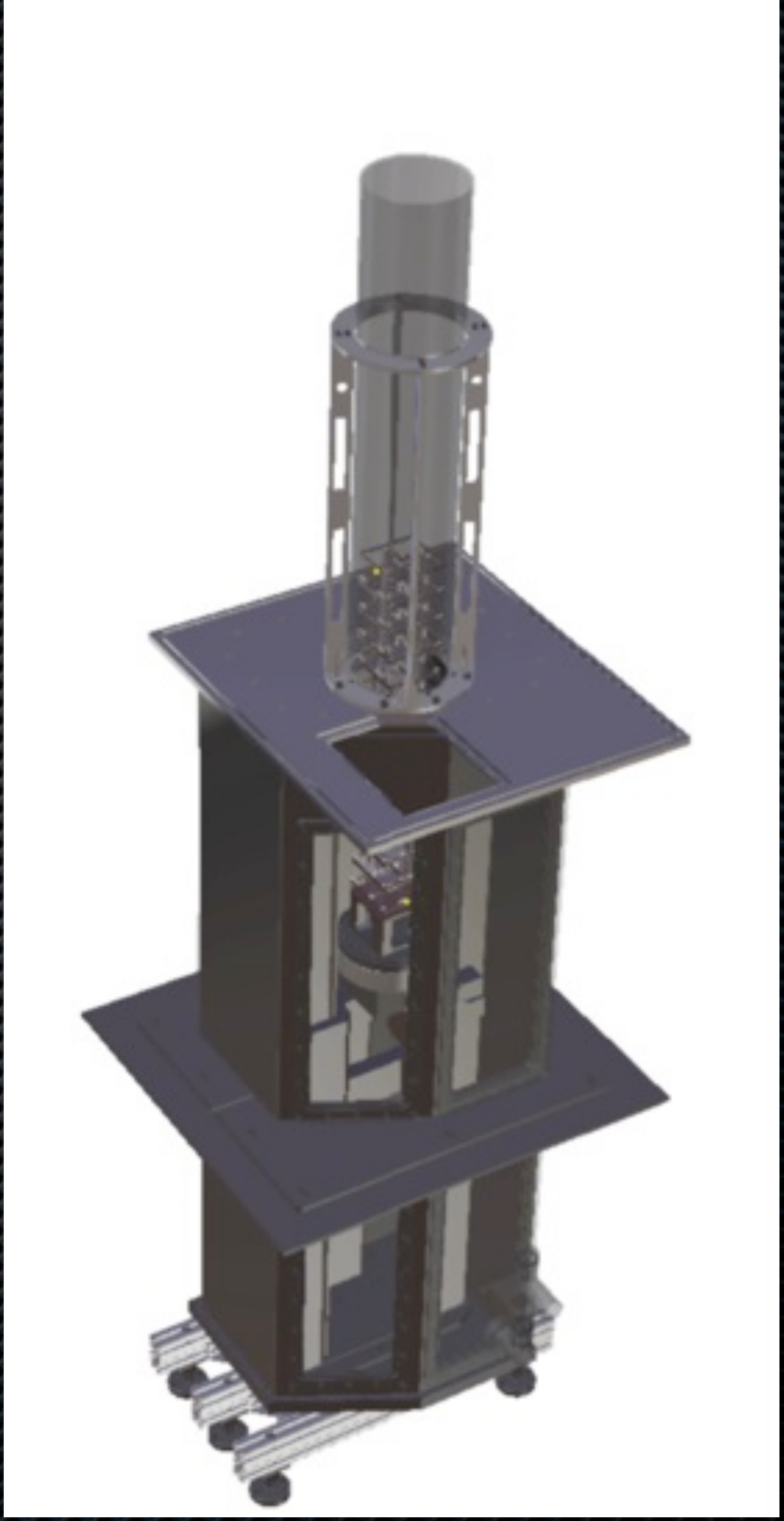
  - Bonding
  - Storage

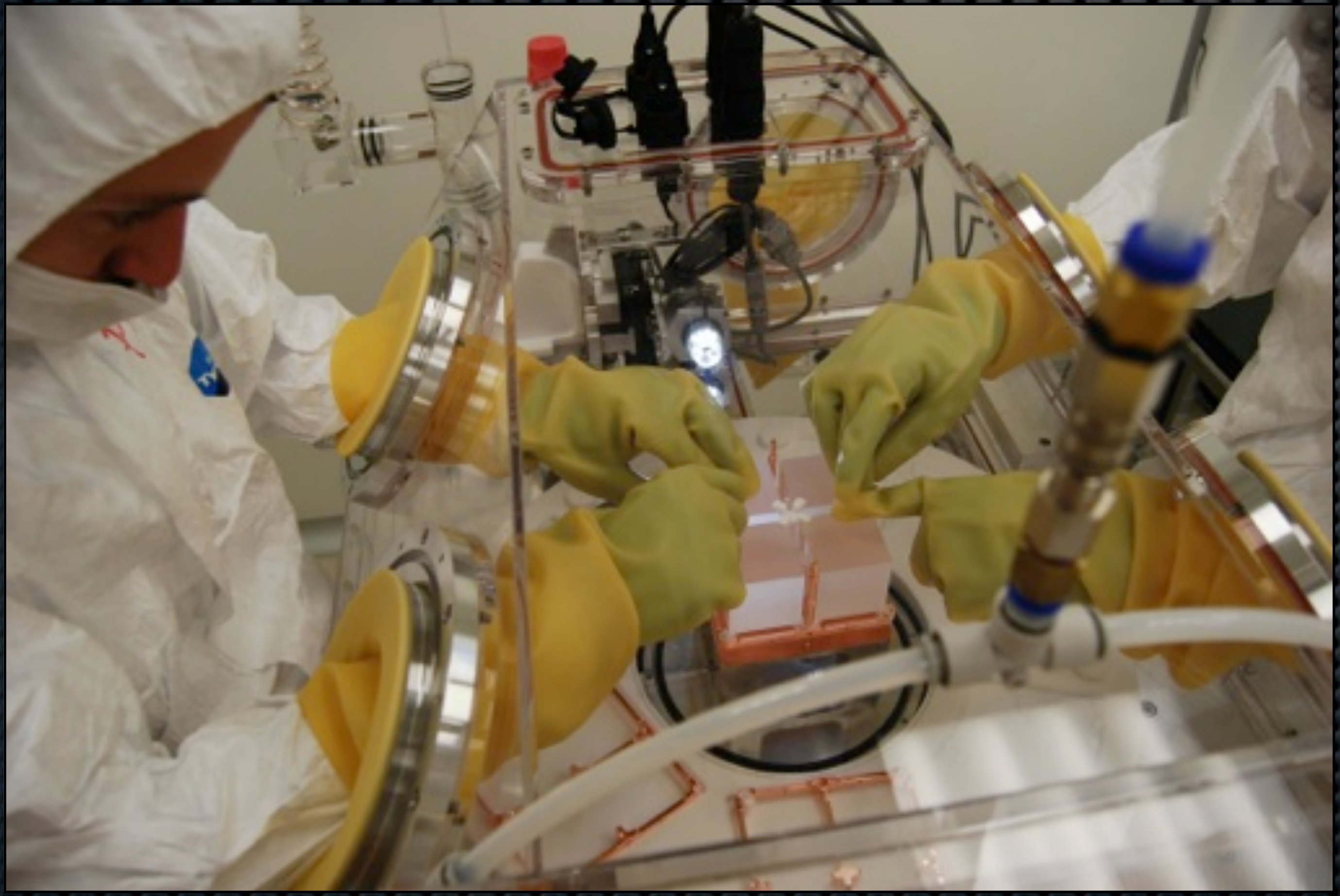
StorageBox

- Zero contact system
- All the steps are performed in controlled nitrogen atmosphere



Tower Assembly

- CUORE-0 tower was built inside the MechBox, continuously monitored by two microscopes to ensure right floor heights



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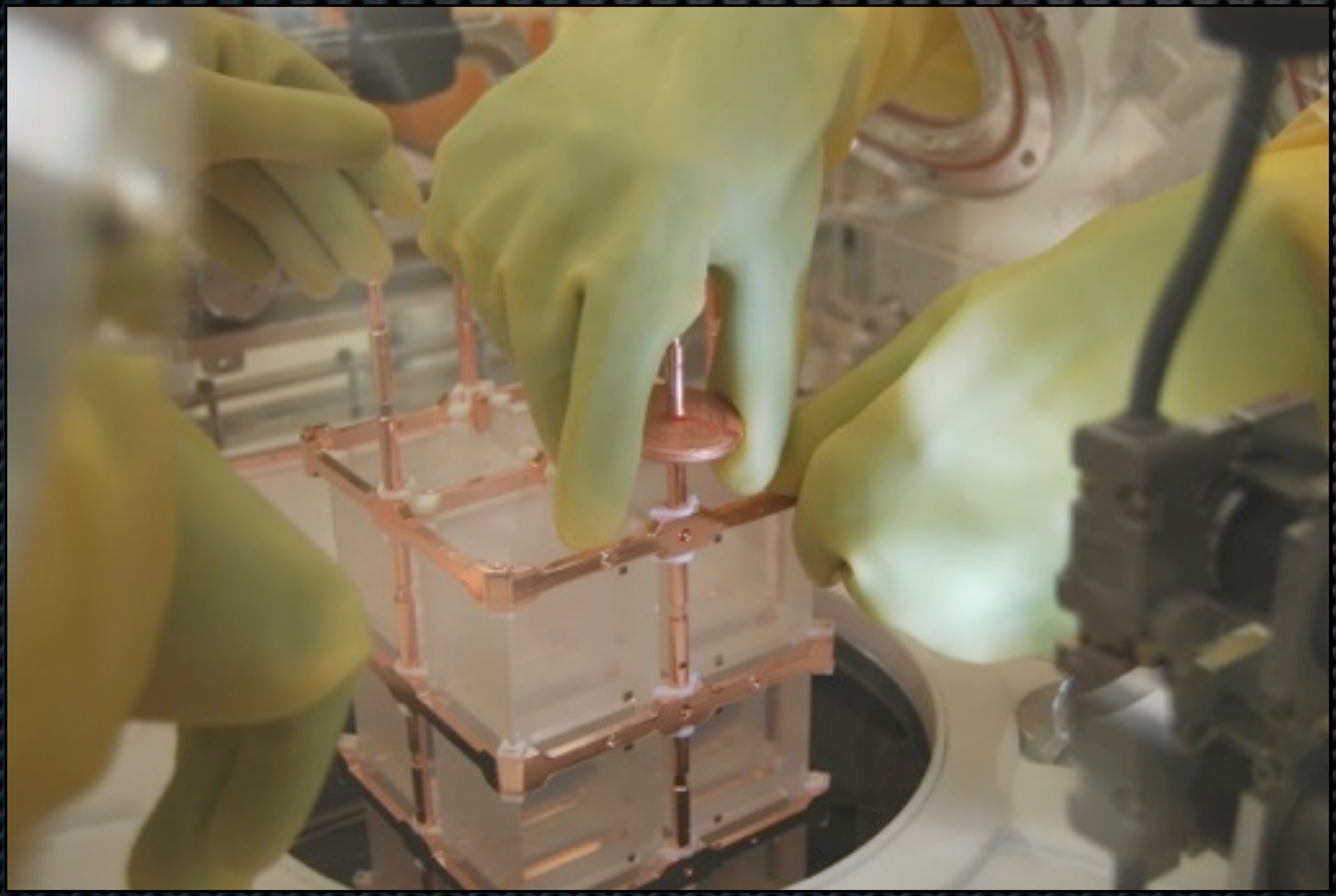
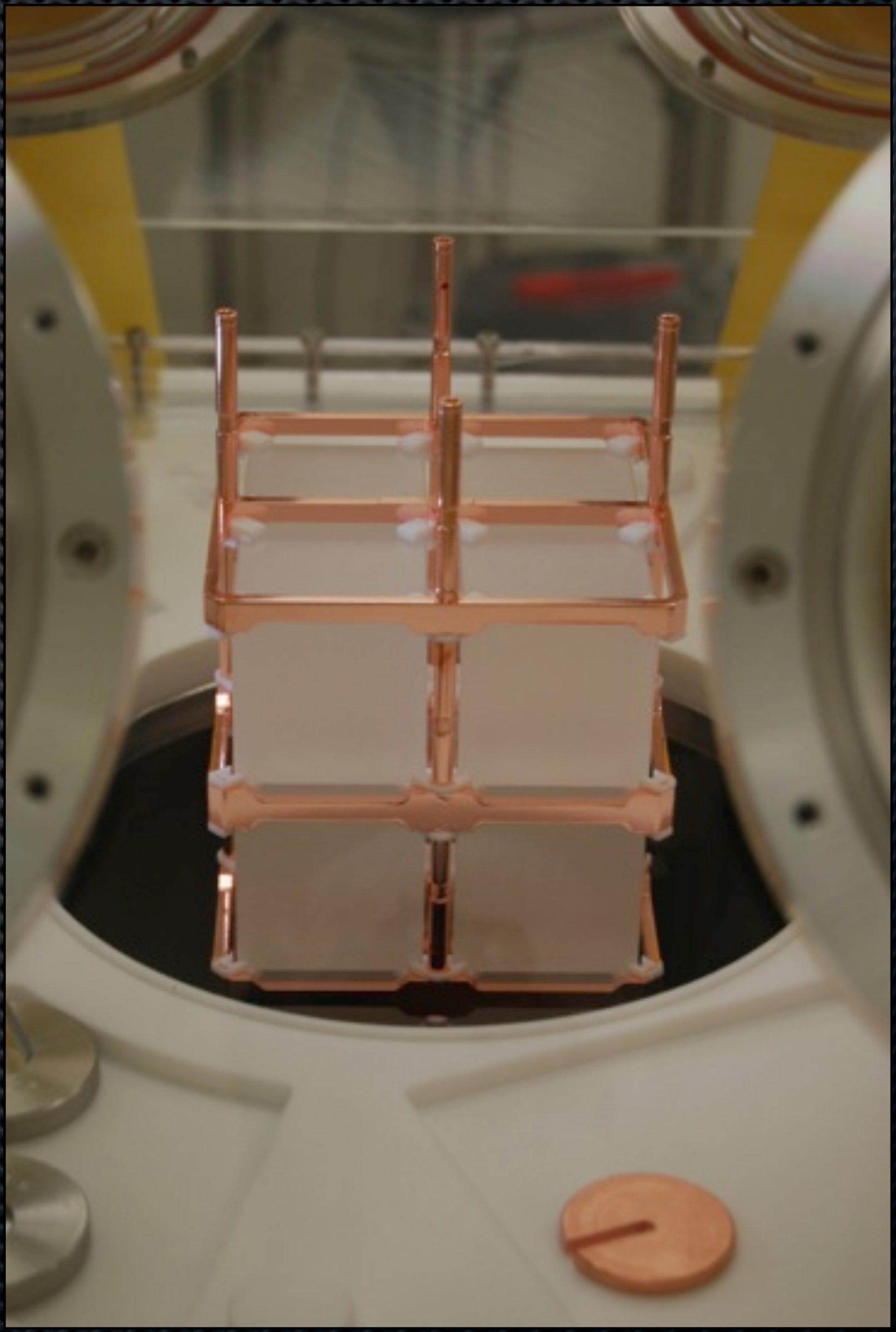
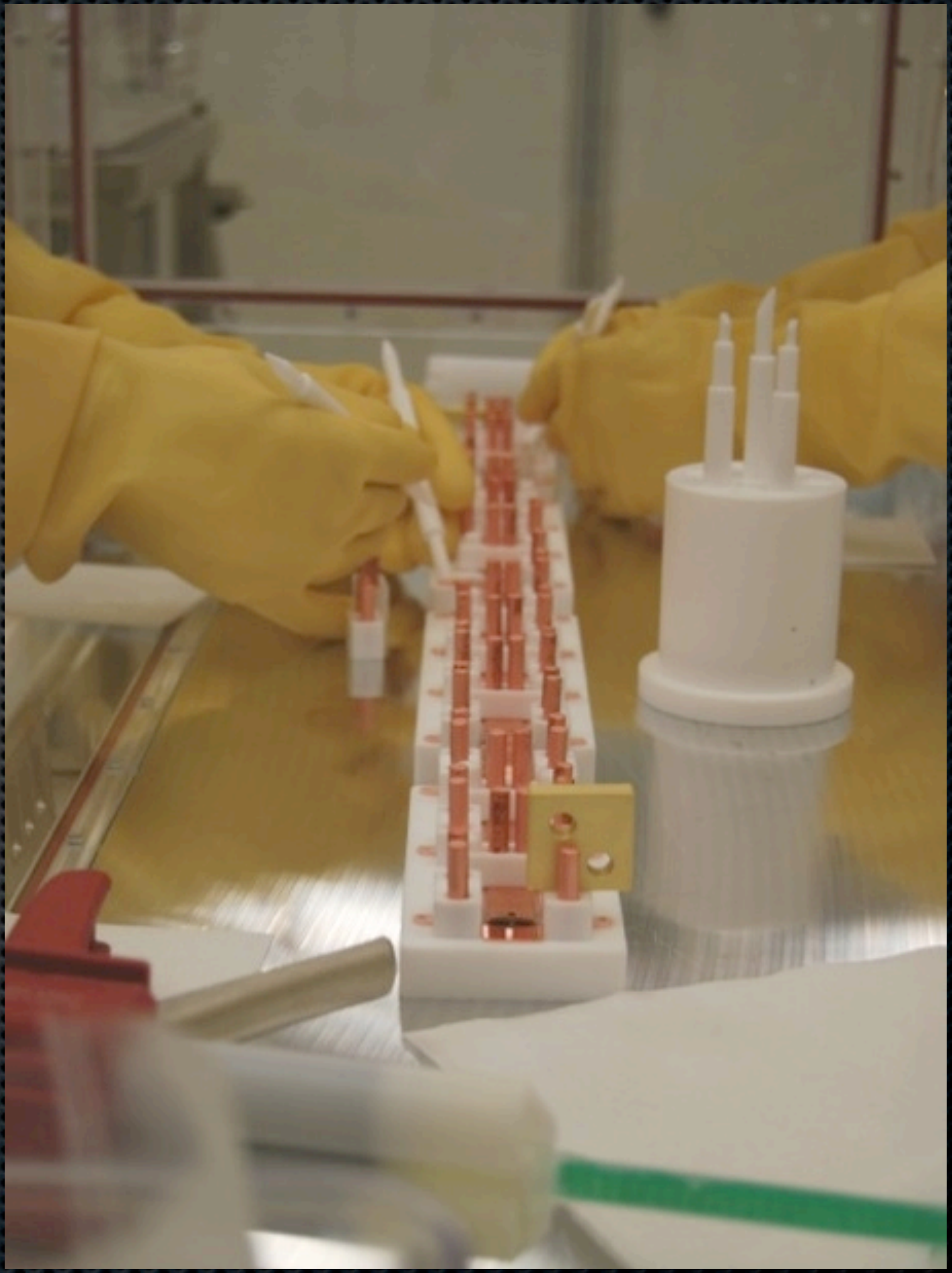




Tower wiring

- Readout ribbons were glued on the two wire trays
- The wire trays were fixed on the tower
- NTD thermistors were bonded with Cu pads on the ribbons



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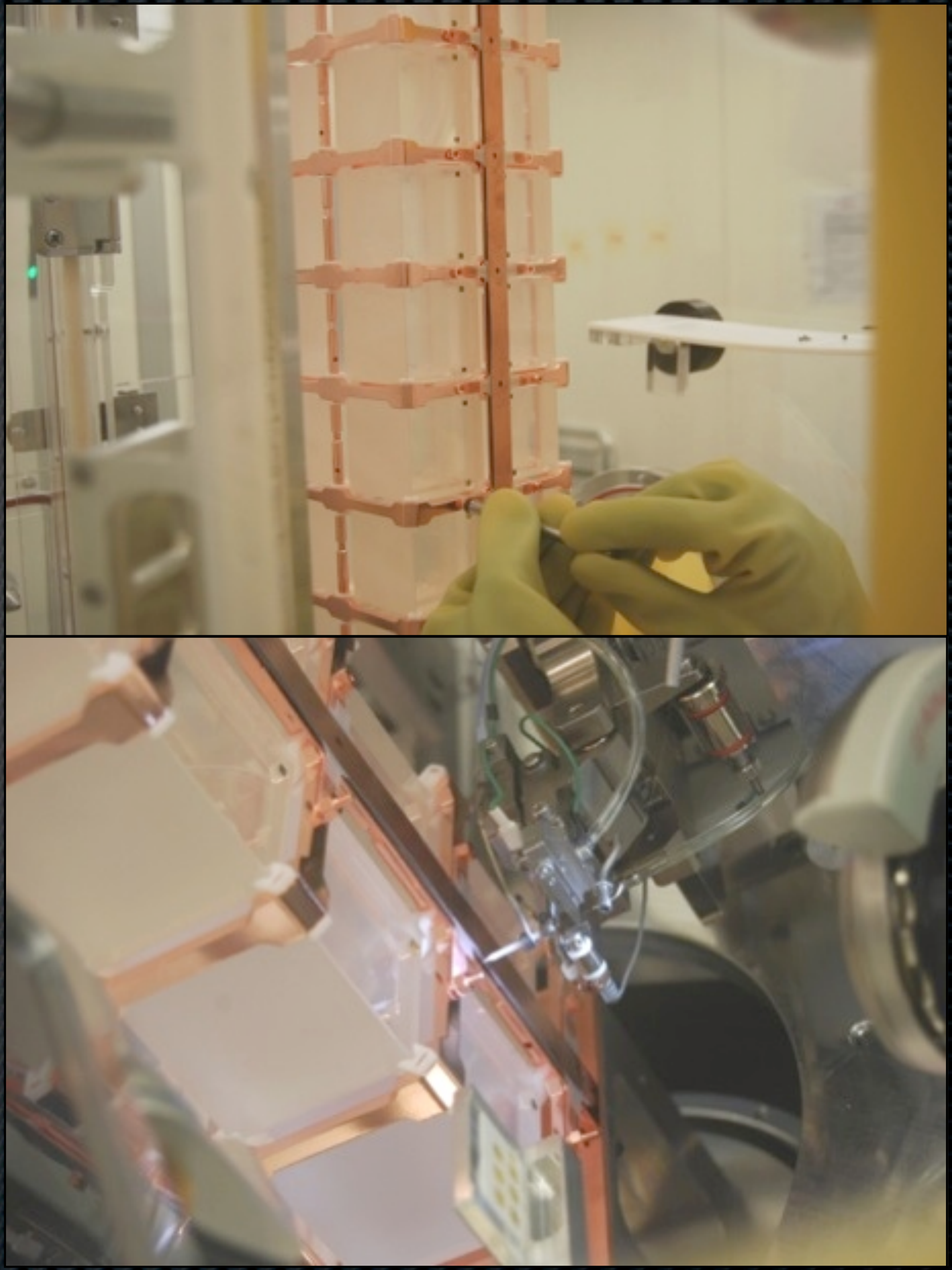

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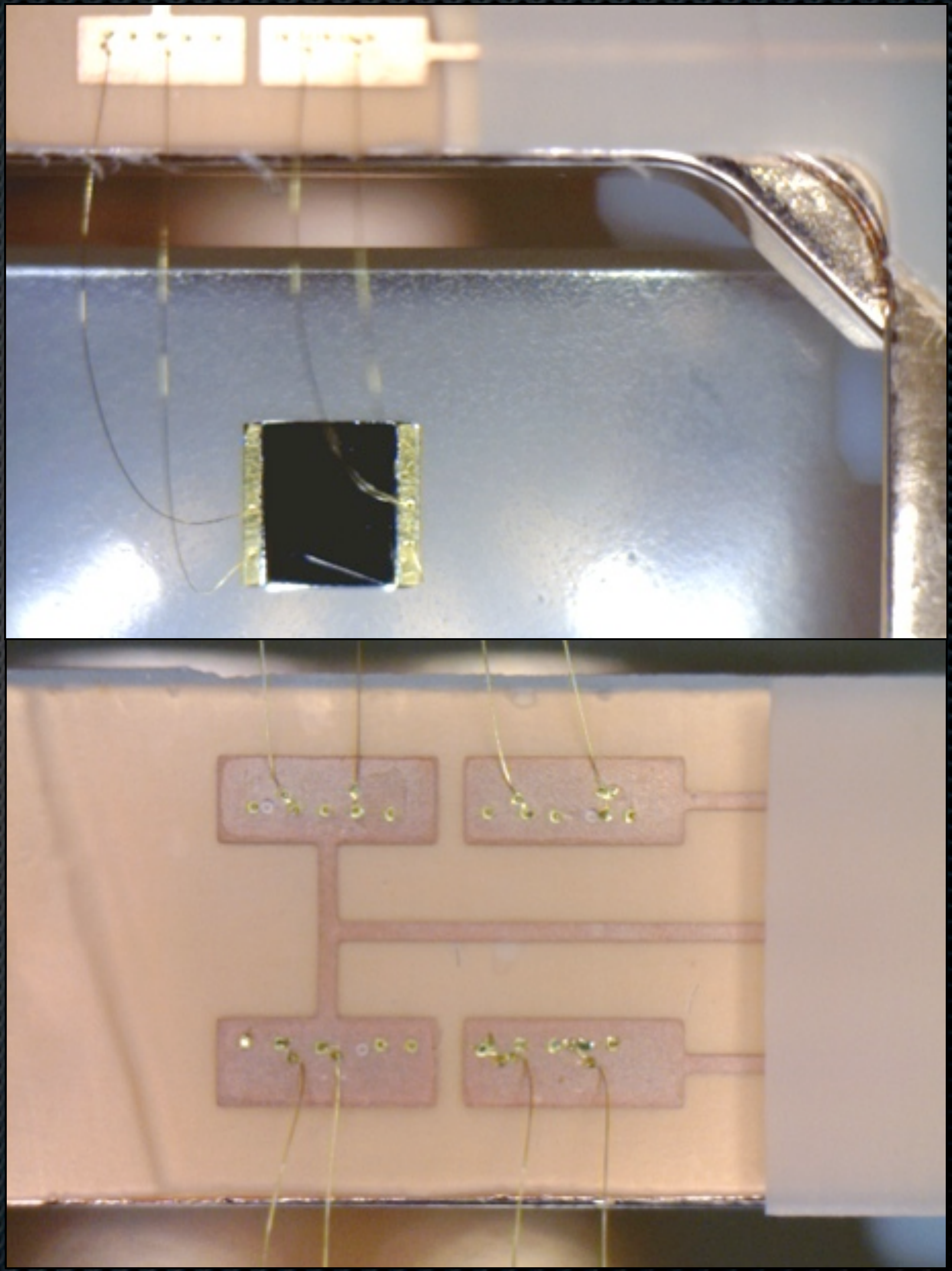

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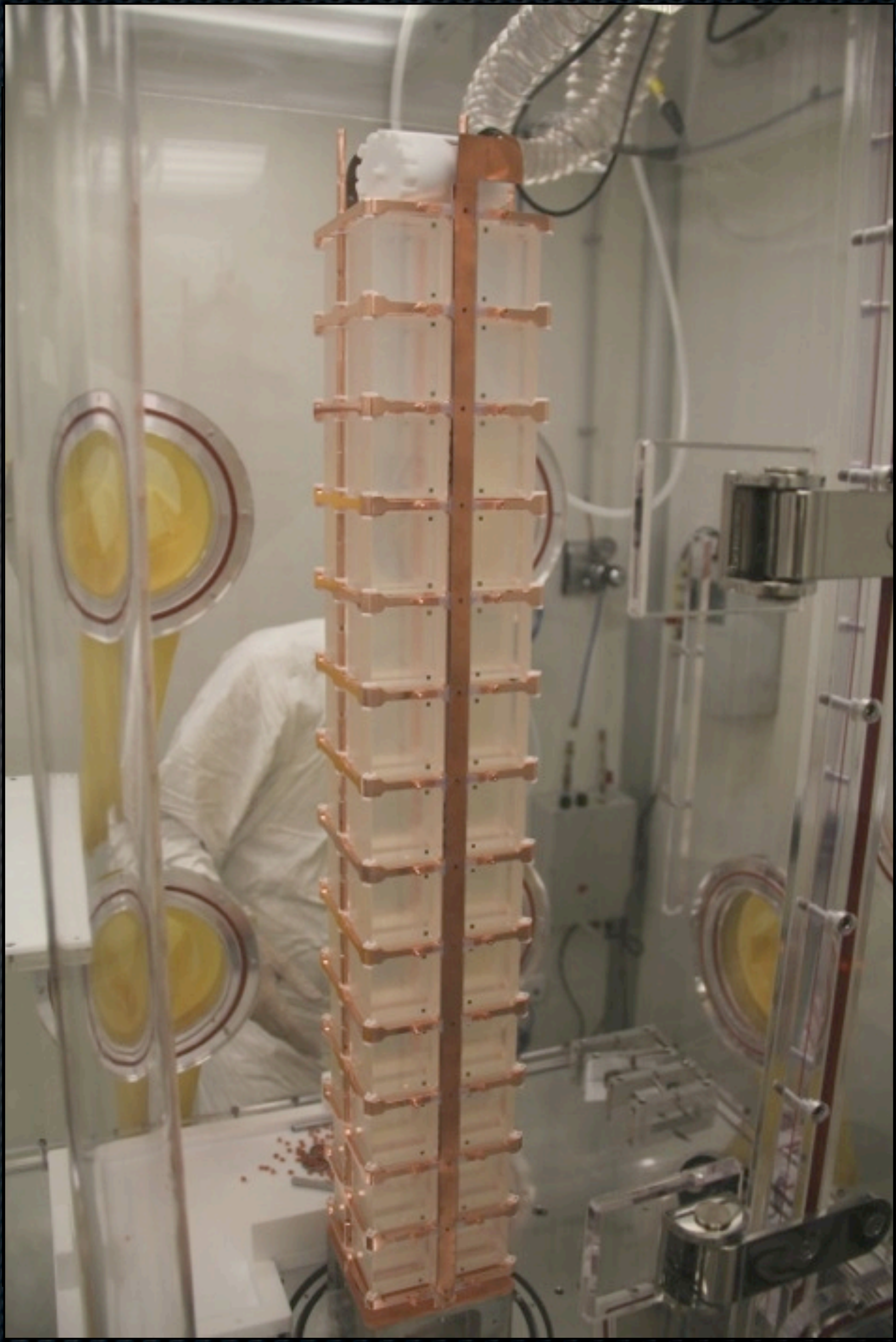
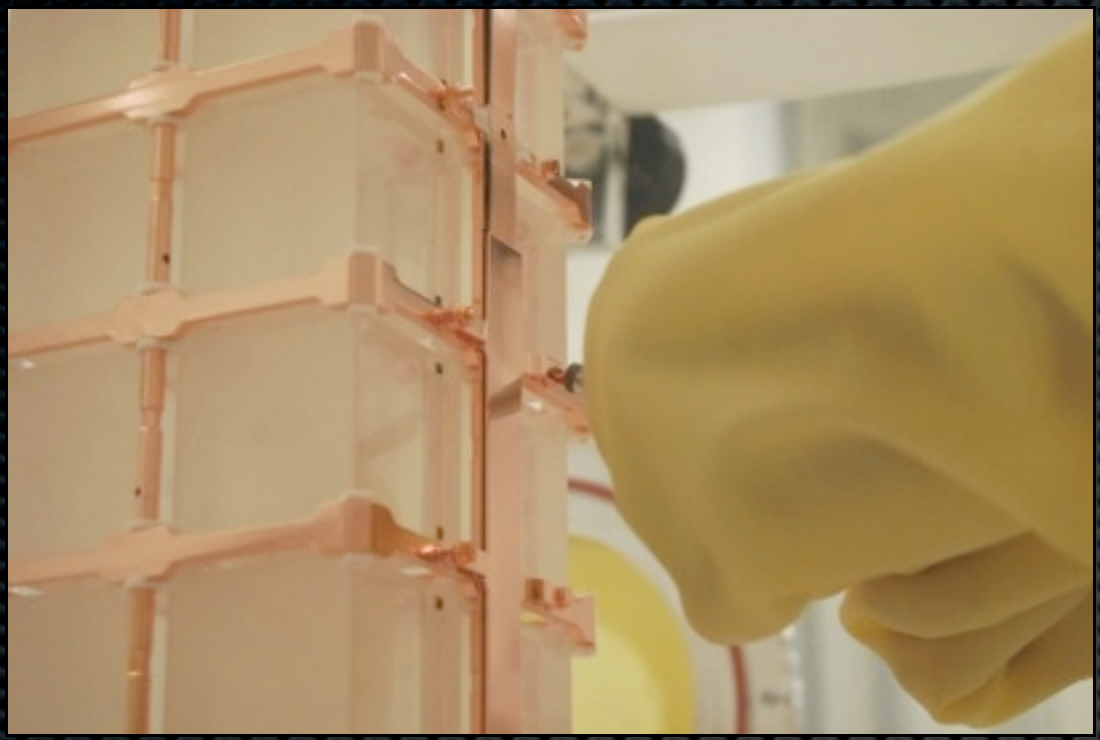
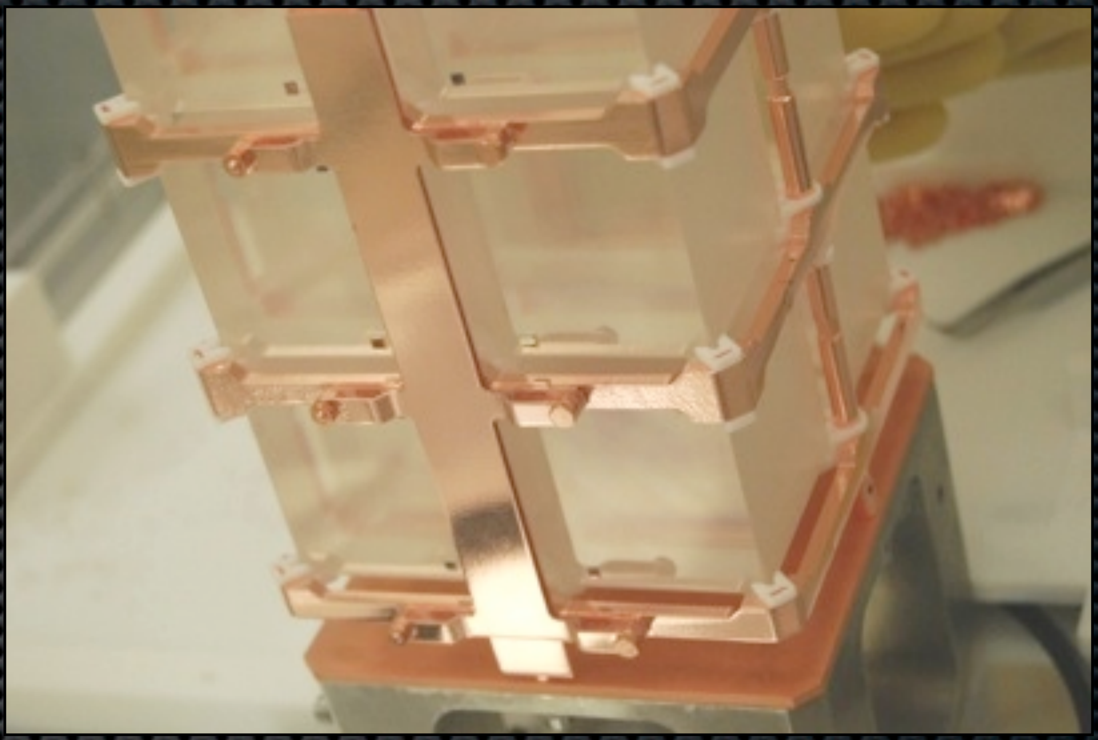
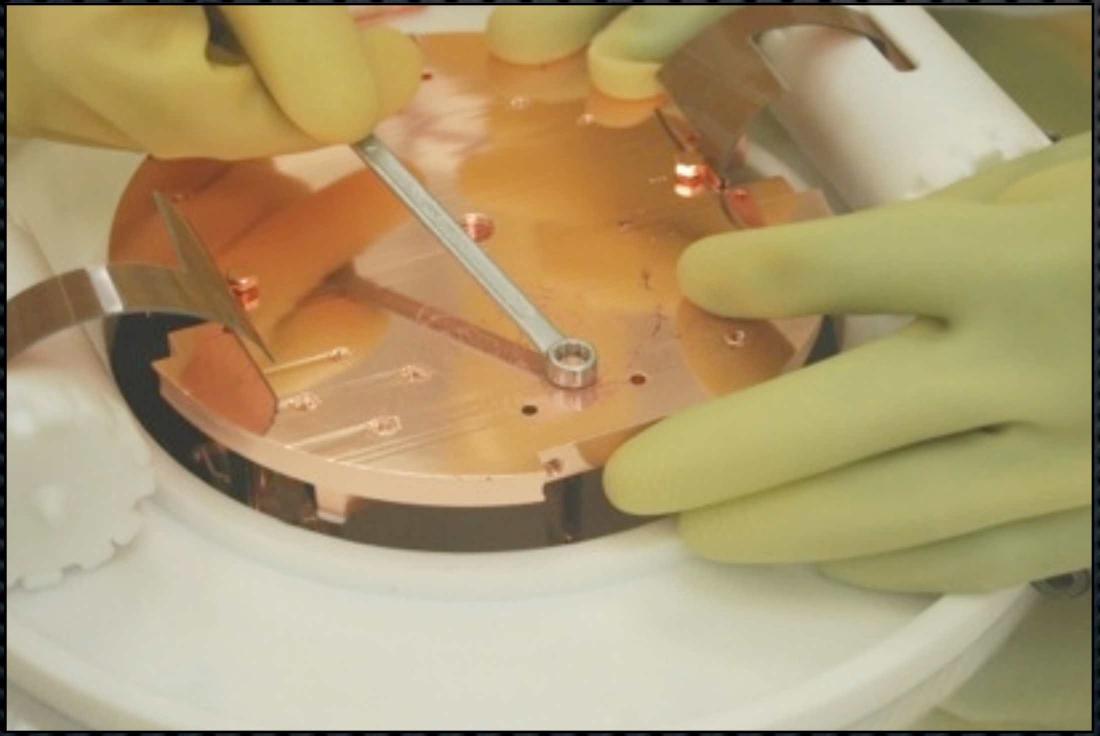
51/52 NTD successfully bonded



Shieldings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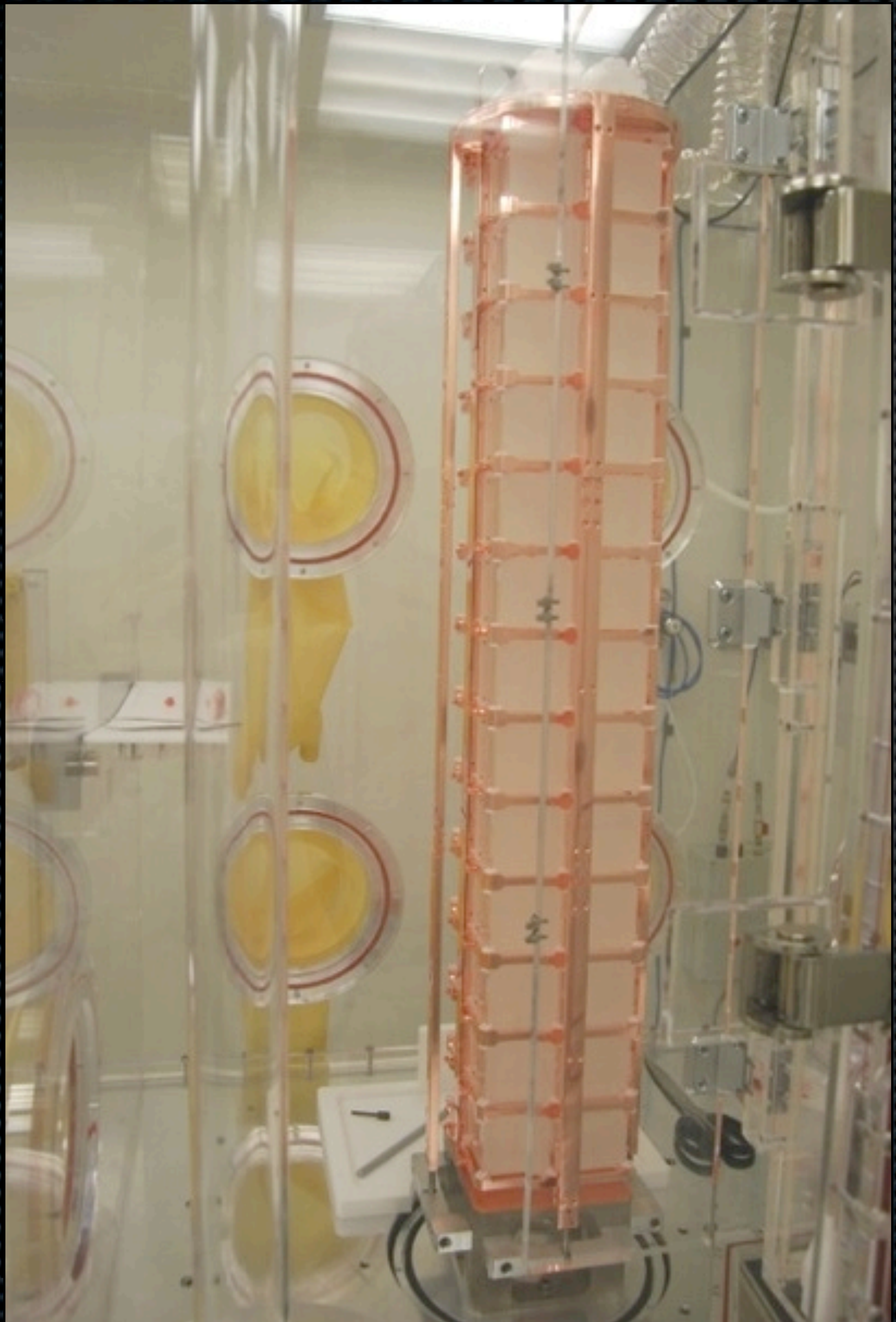

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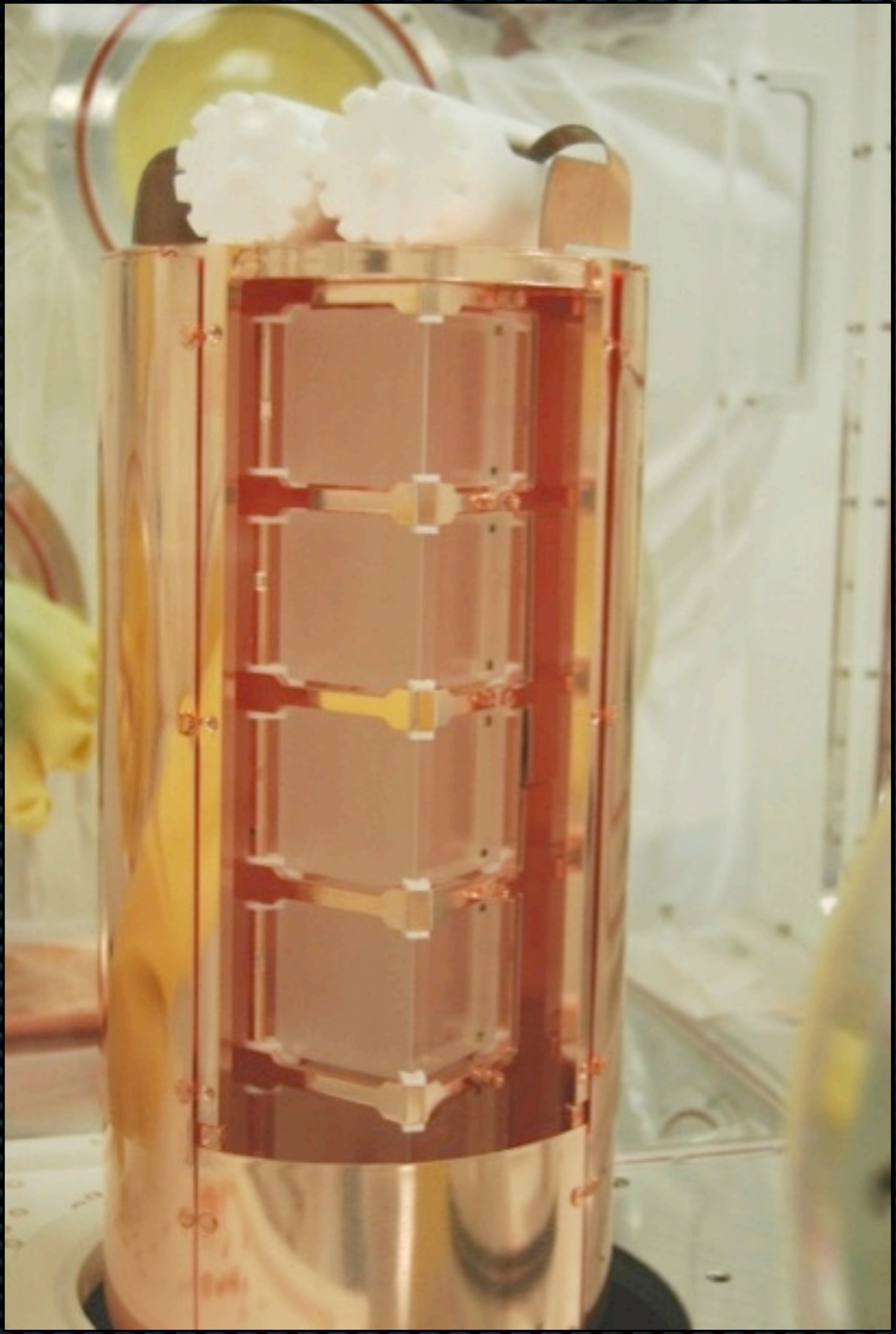

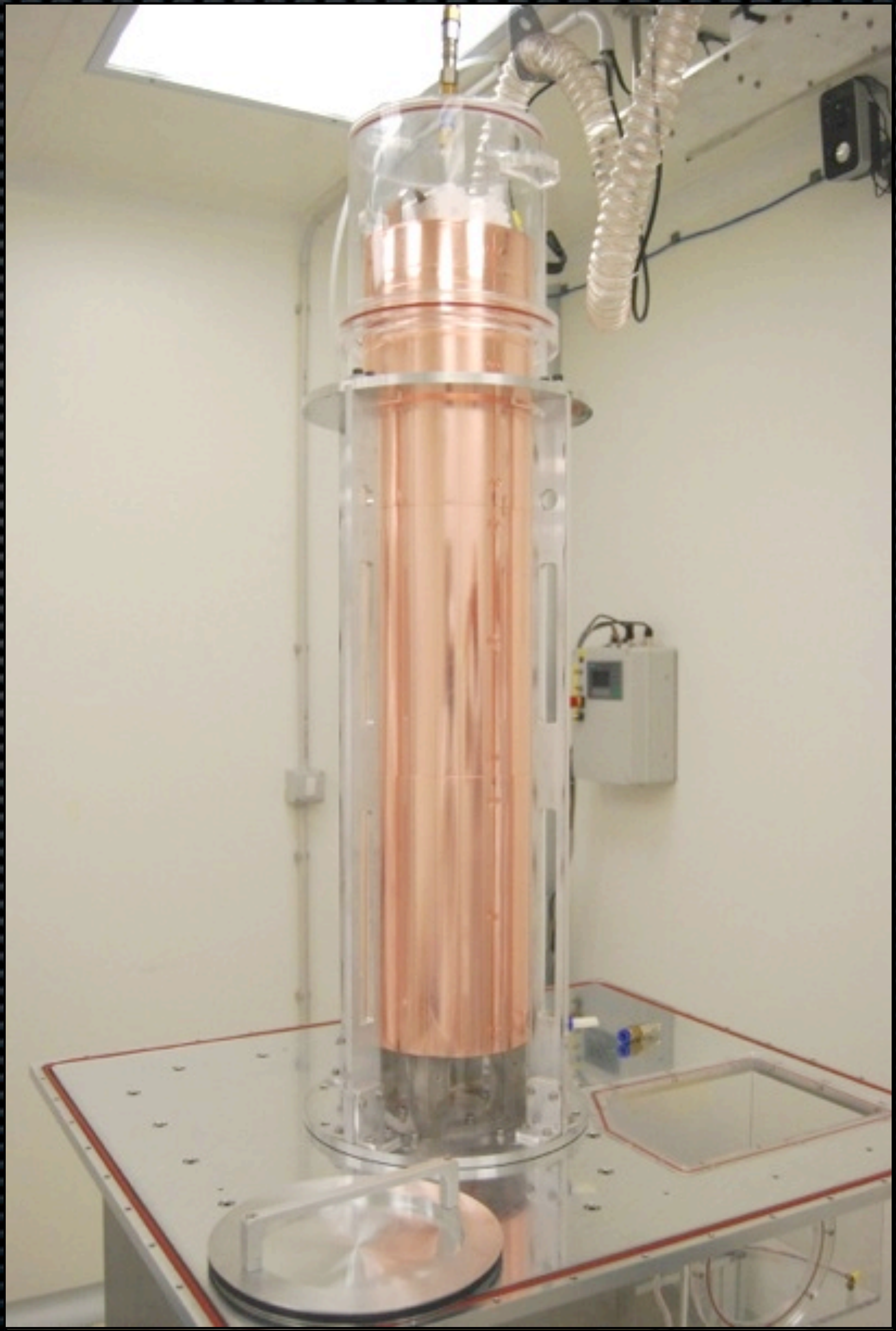

Present status

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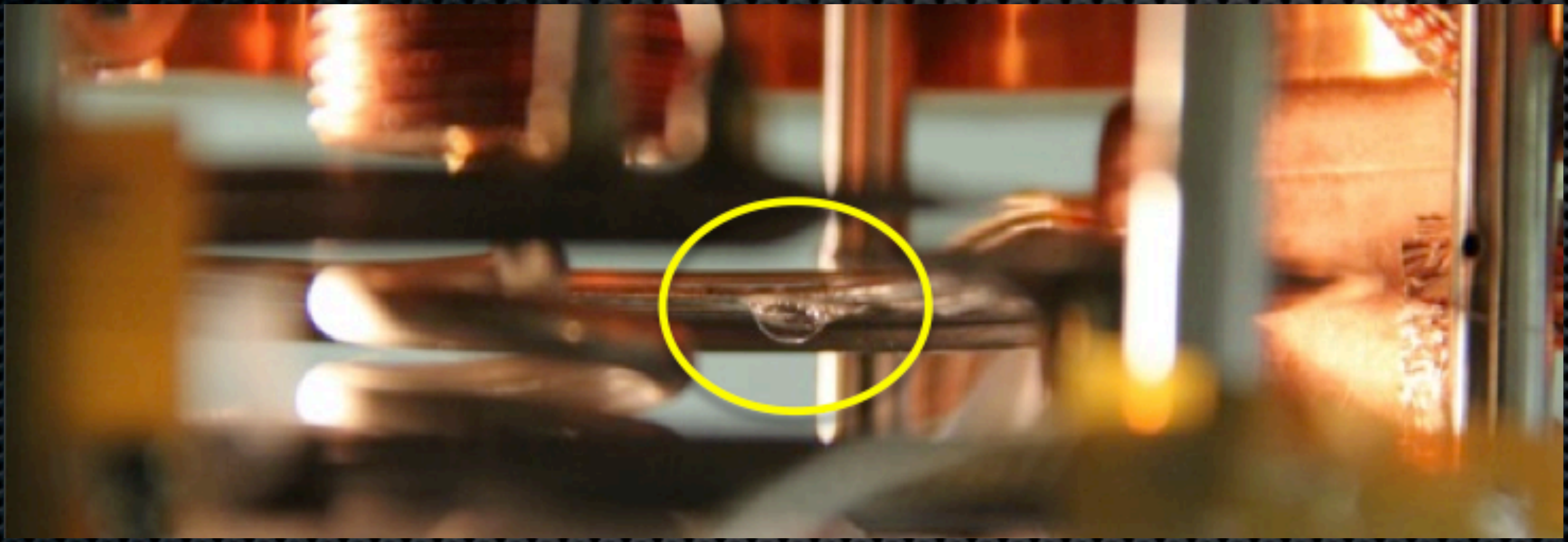

- We discovered a leak in the cryostat dilution unit
- Fixing determined a delay of more than two months
- CUORE-0 will be cooled down in the next weeks

First physics data in the very next months!

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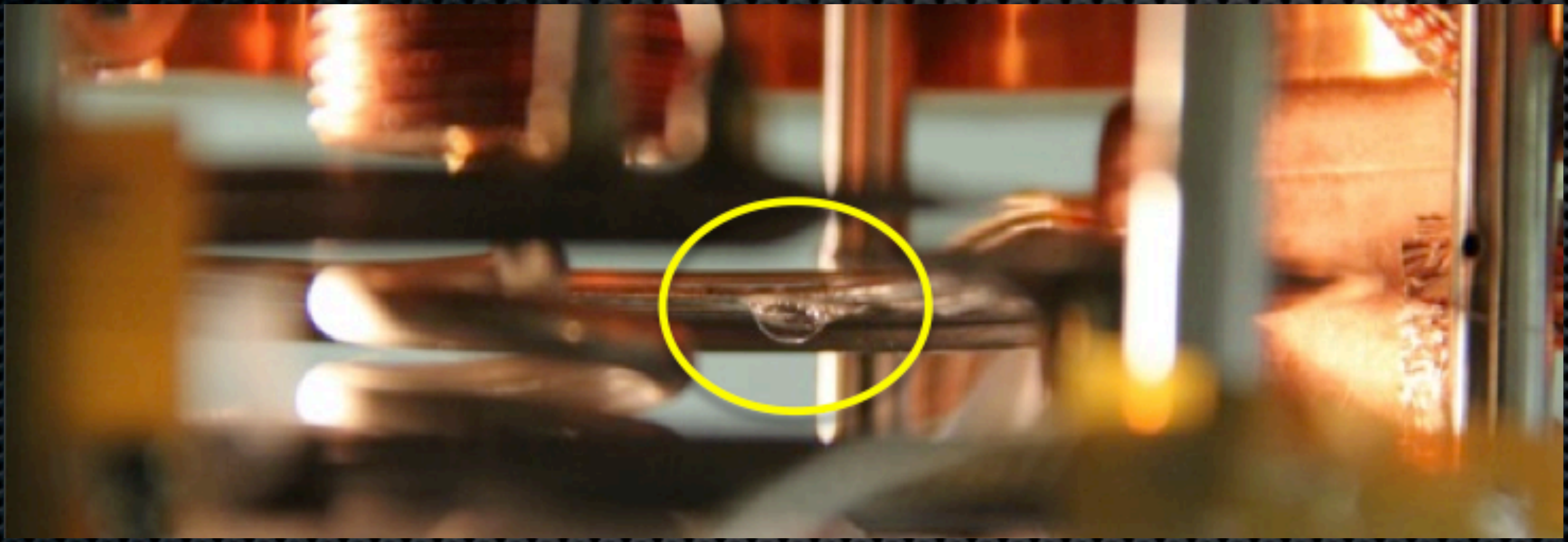

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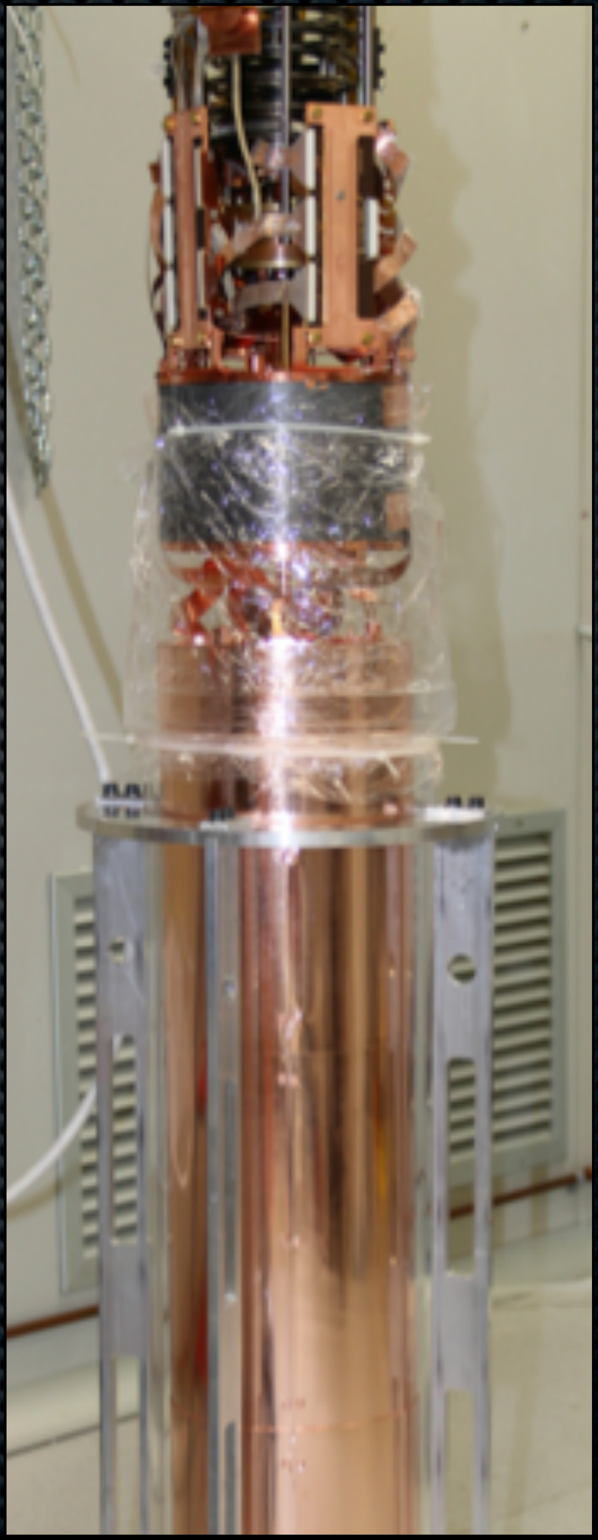
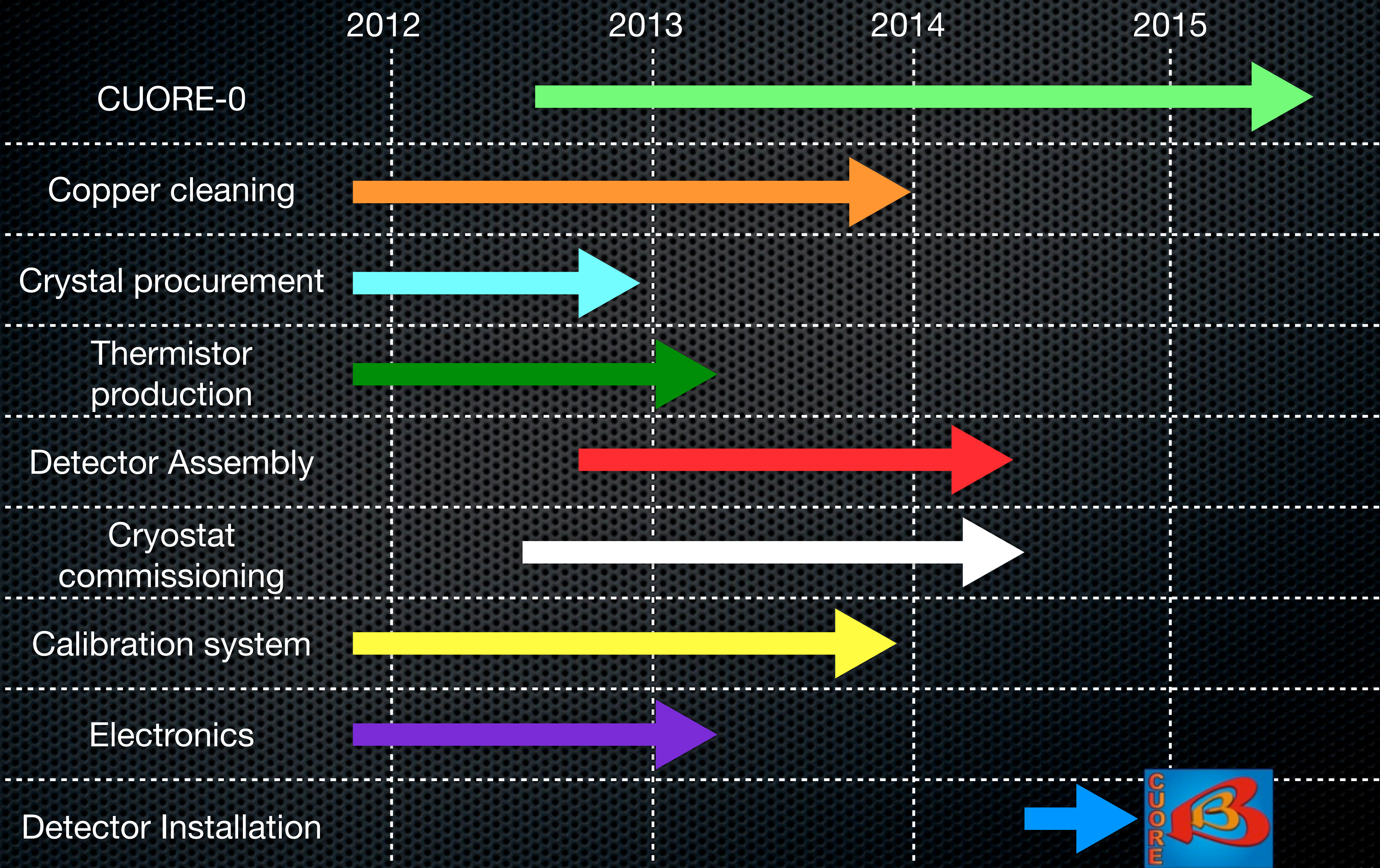


CUORE assembly procedures are fully tested

CUORE project roadmap



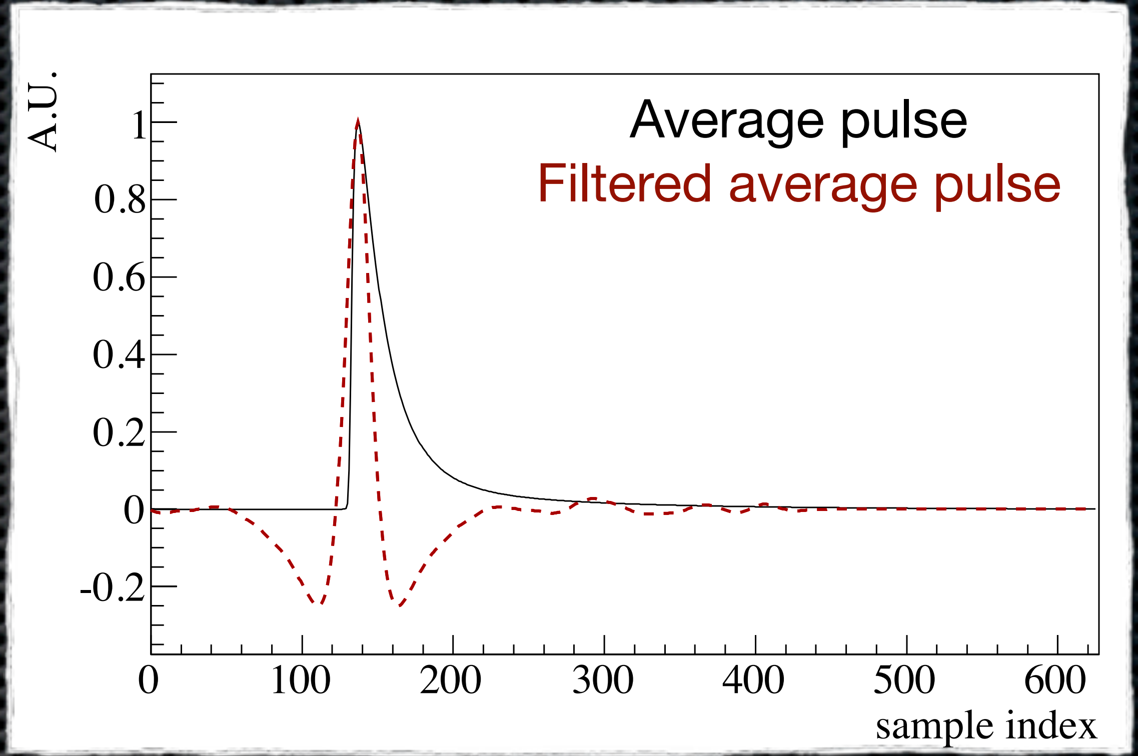
Not only ^{130}Te 0νDBD

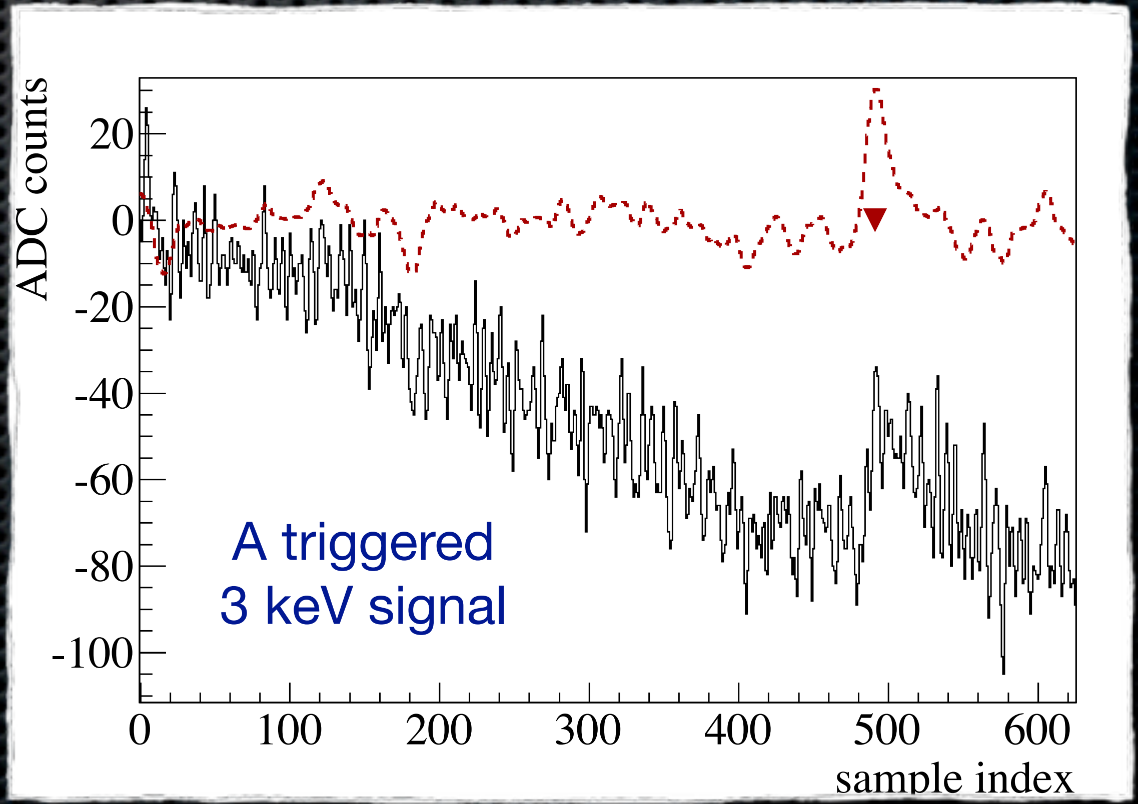
A lot of different analysis can be performed in CUORE framework:

- ^{130}Te DBD to the first excited state 0^+ of ^{130}Xe
  [Phys. Rev. C 85, p. 045503, 2012]
- β^+/EC DBD of ^{120}Te [Astrop. Ph. 34, p. 643-64, 2011]
- Other rare nuclear decays (e.g. Te isotopes)
- Dark Matter searches [Paper in preparation]
- Solar axions searches [Paper in preparation]
- Detection of supernova neutrinos

CUORE low energy trigger

- Based on matched filter technique [E. Gatti and P. F. Manfredi, Rivista del Nuovo Cimento 9N1 (1986) 1]
- The trigger is implemented as a simple threshold trigger on the filtered samples, with debounce time related to the width of the filtered average pulse.
- The trigger threshold is set a priori in terms of the filter theoretical resolution.

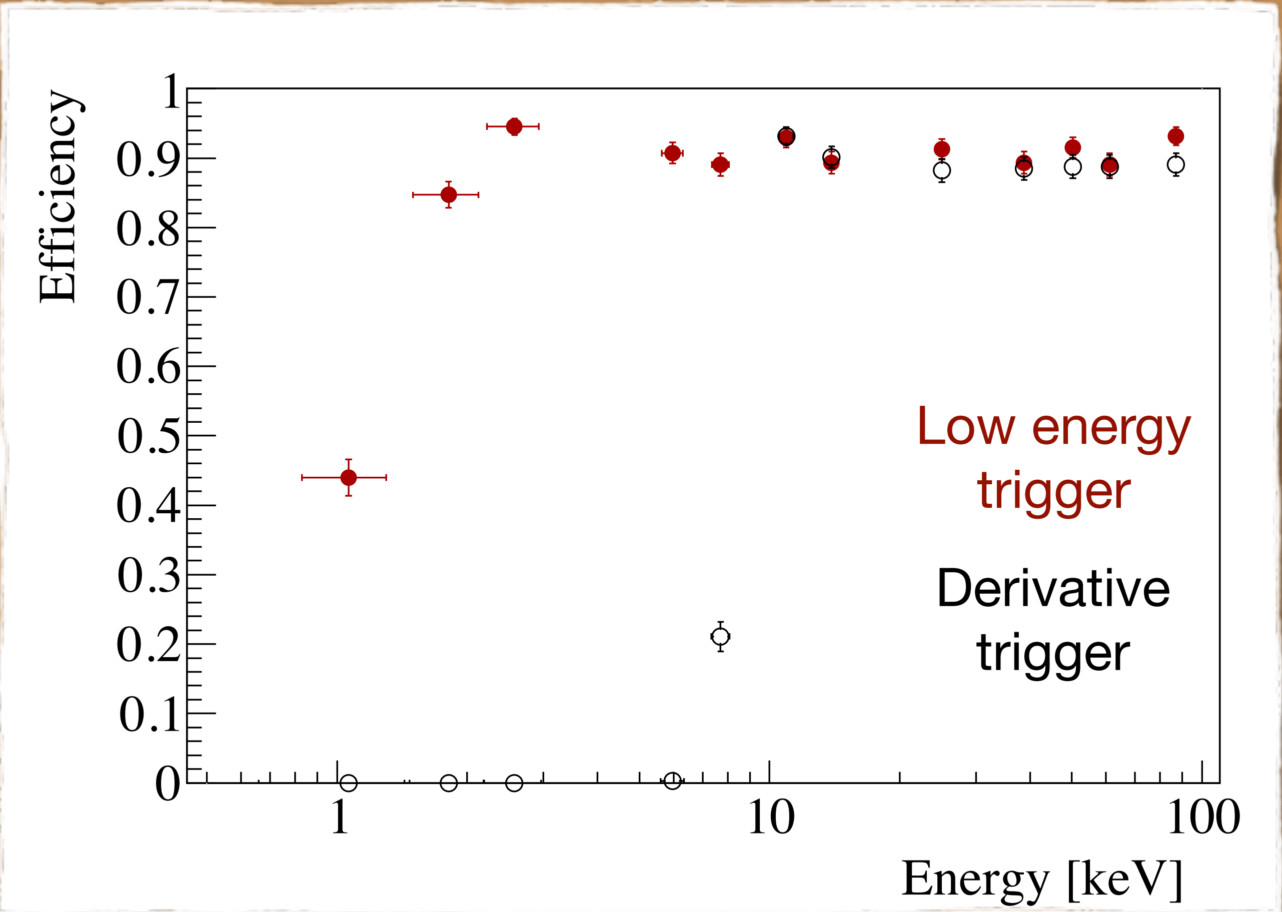


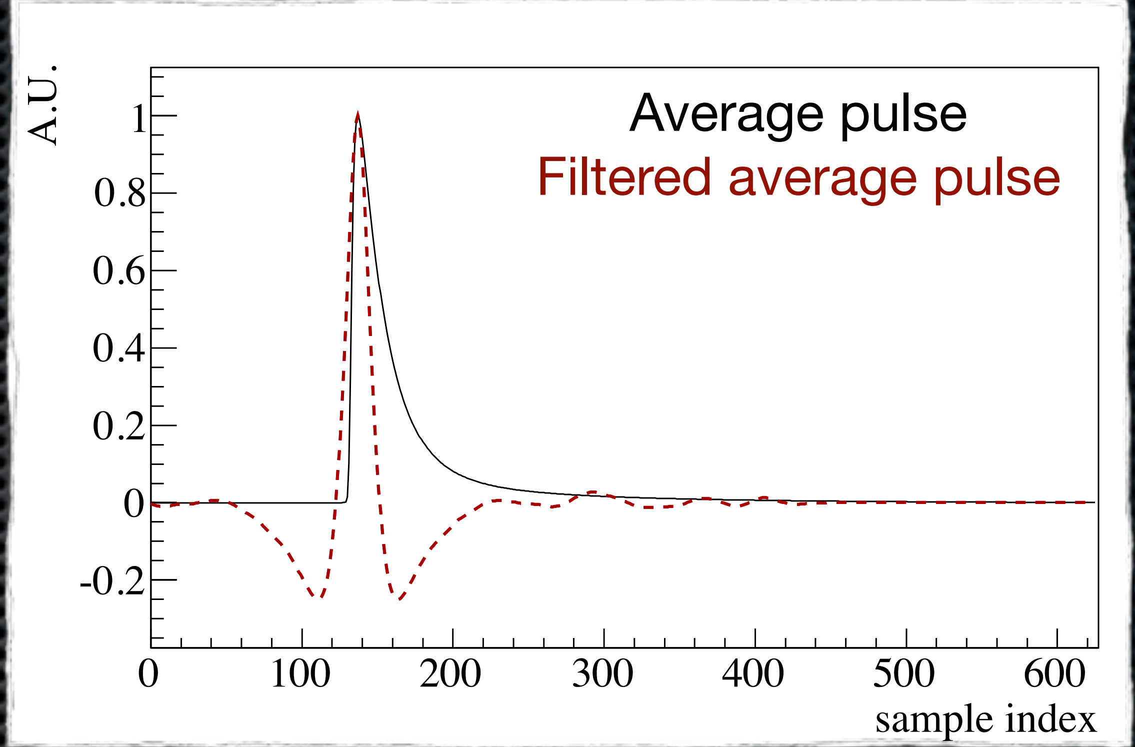


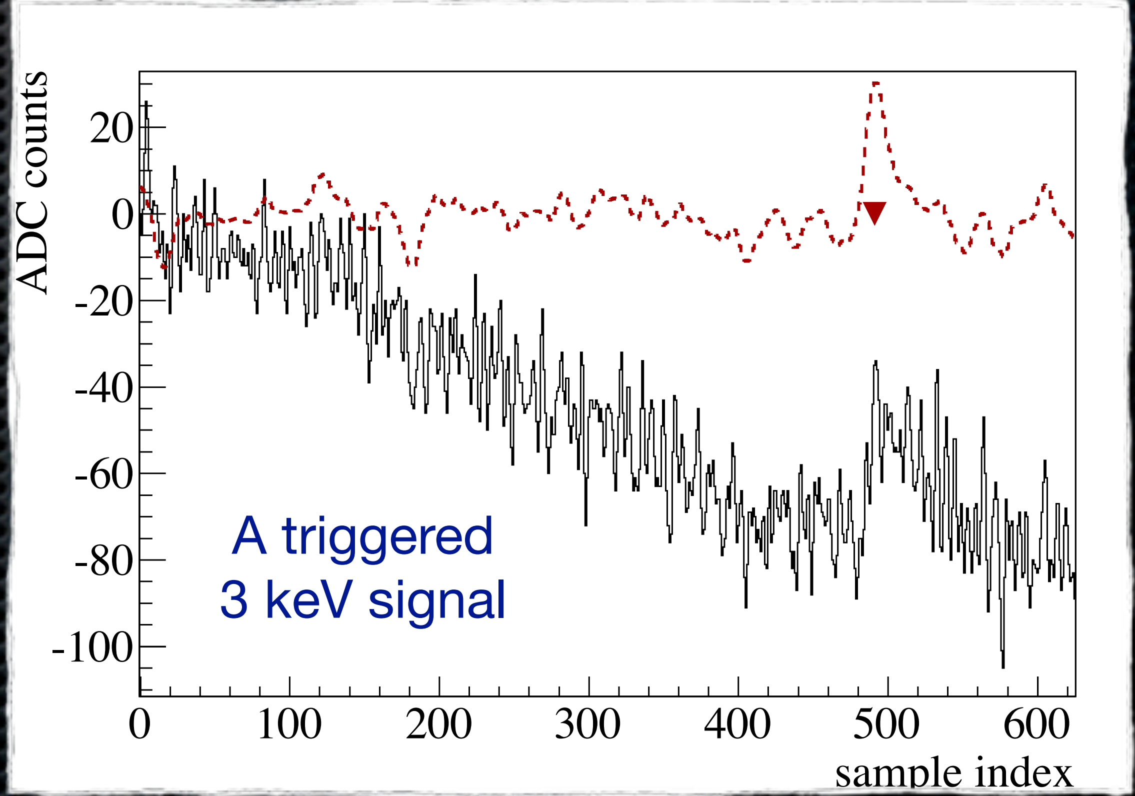
Di Domizio, Orio, Vignati, JINST 6, P02007 (2011)

CUORE low energy trigger

Using this trigger, the energy thresholds result lowered by an order of magnitude in respect to CUORE standard trigger





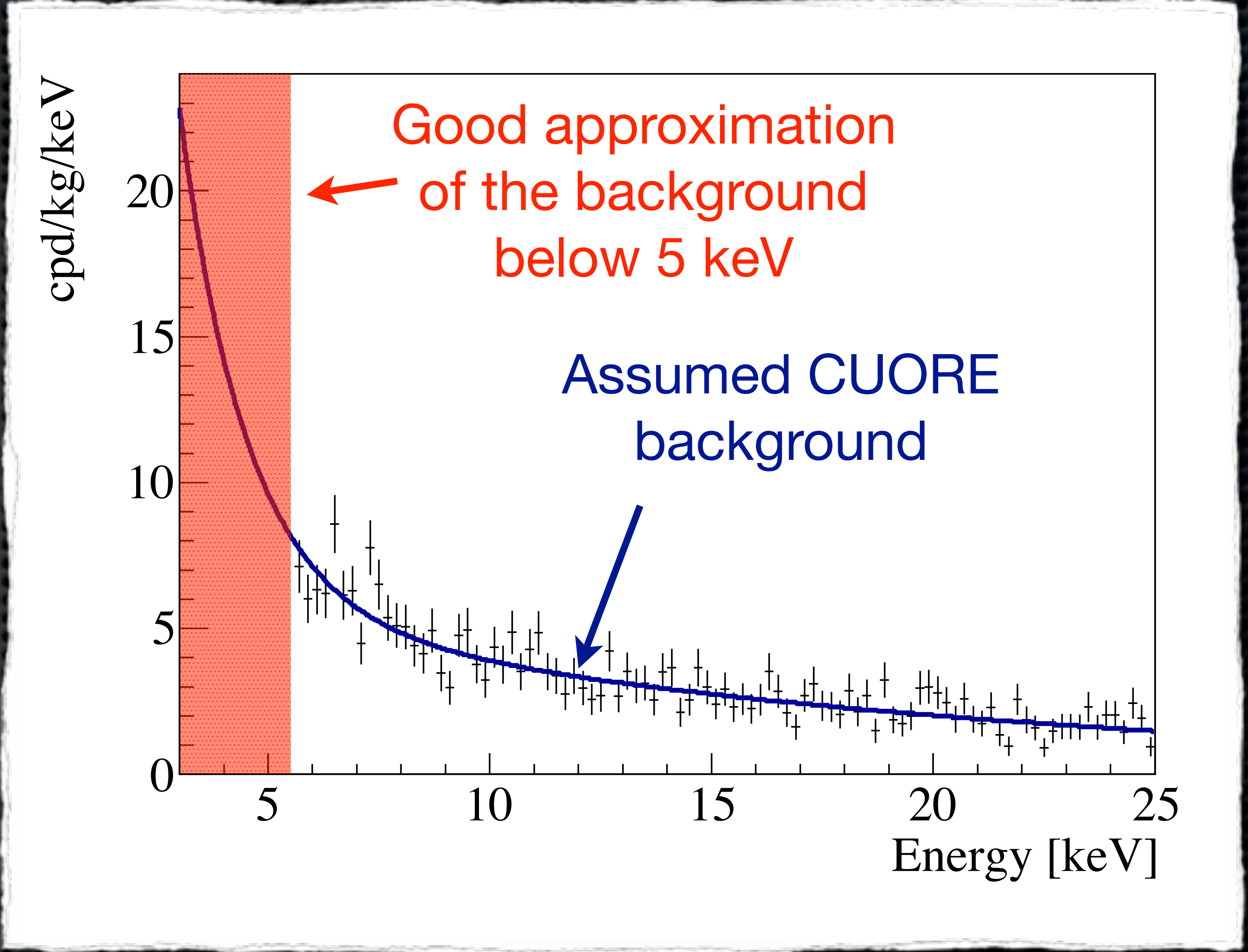


Di Domizio, Orio, Vignati, JINST 6, P02007 (2011)

Dark Matter searches in CUORE

The background averaged over three CUORE test crystals can be projected to CUORE-0 and CUORE, assuming that it will be the same.

Even if the background is too high to give stringent limits on Dark Matter interactions, the effect of a Dark Matter modulation signal can be simulated.



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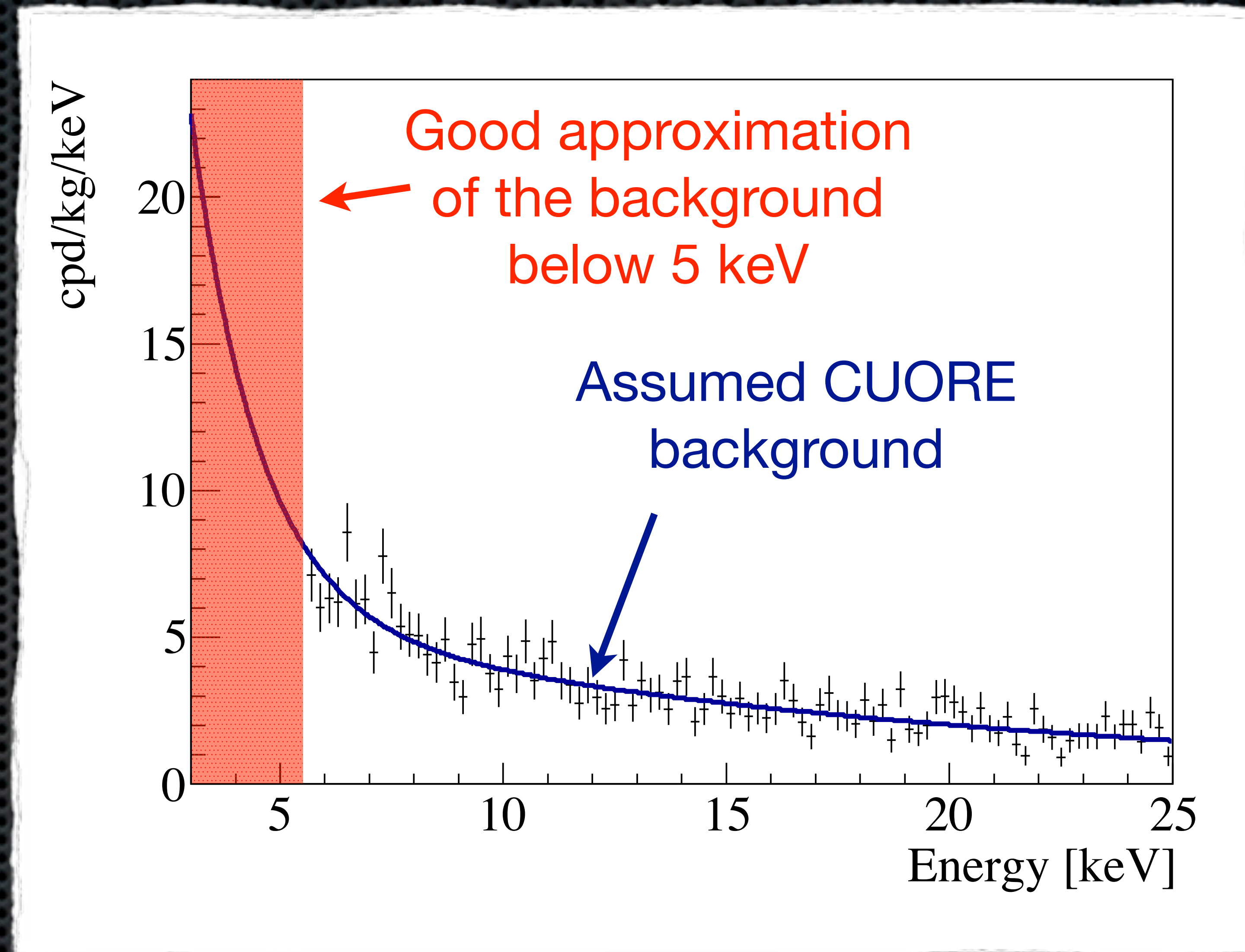

Assuming that the quenching factor for nuclear recoils in TeO_2 bolometers is 1 (A. Alessandrello et al., NIM A, vol. 409, pp. 451–453,1998), the sensitivity to a spin independent WIMP modulation signal in CUORE-0 (39 kg of TeO_2, 3 years) and in CUORE (741 kg of TeO2, 5 years) is evaluated via toy MonteCarlo's.

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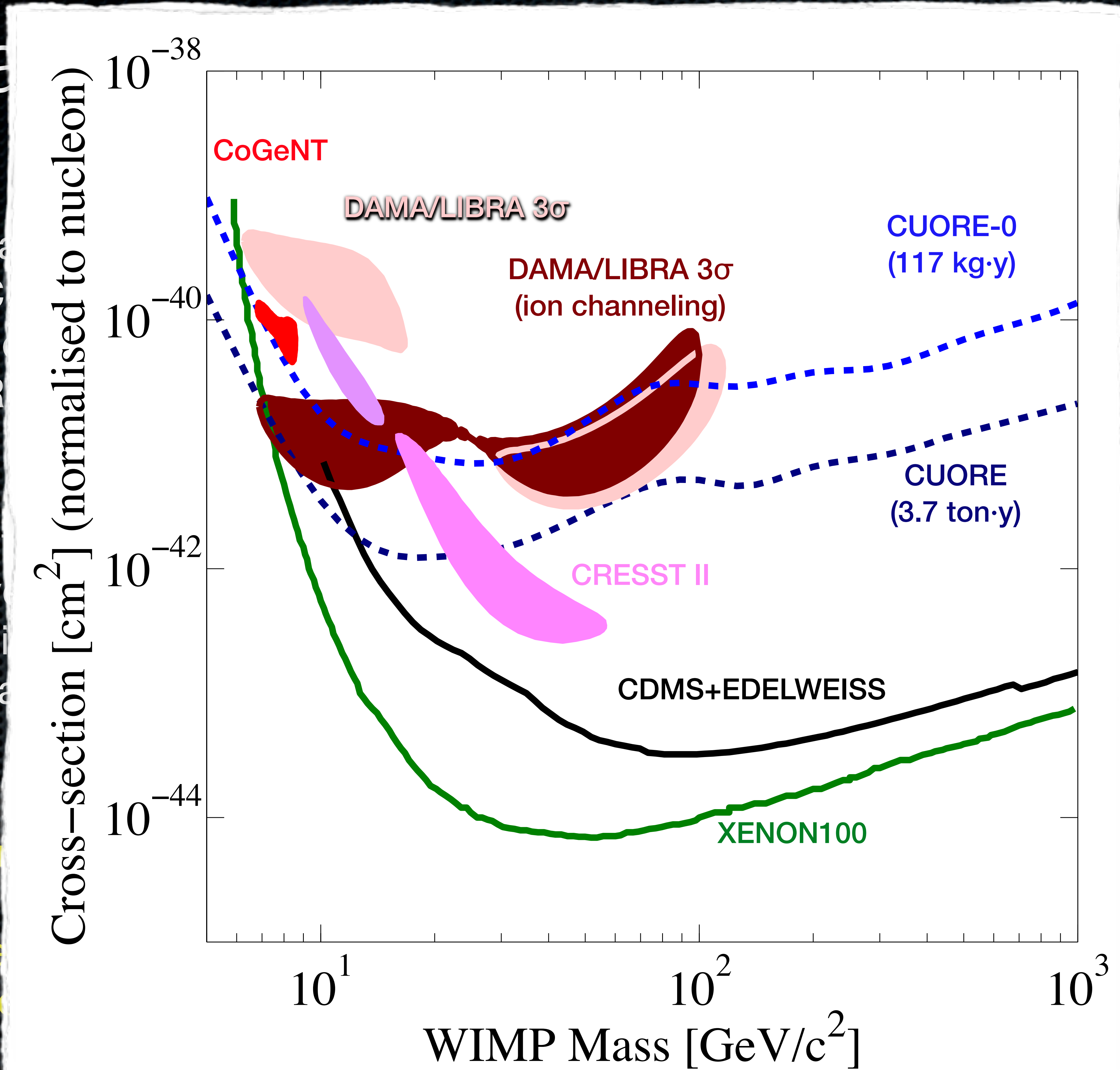

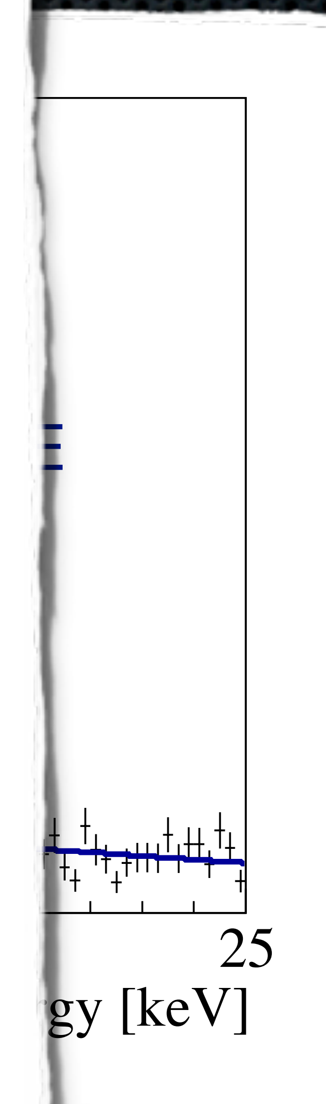

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Conclusions

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Thanks for your attention!