# GDR Neutrino Meeting 2013

# CUORE-0

Matteo Biassoni on behalf of the CUORE Collaboration

Paris, May 22, 2013

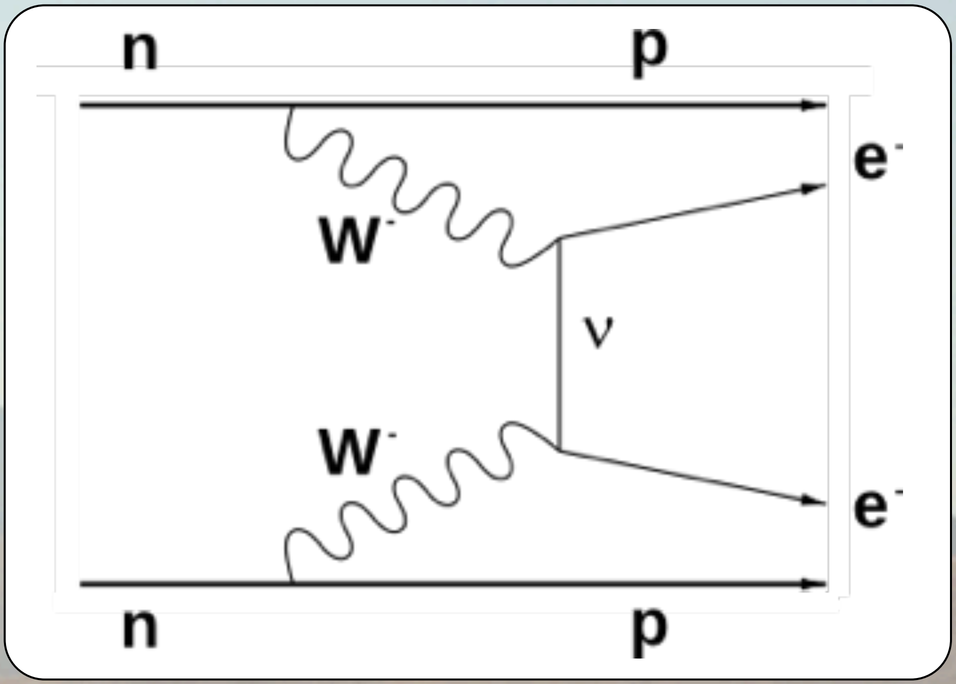
# OUTLINE

- Neutrinoless Double Beta Decay (theoretical and experimental point of view)
- the bolometric technique and the $0\nu\beta\beta$ research with $TeO_2$
- CUORE features and construction status
- CUORE-0: CUORE first tower
- CUORE-0: sensitivity and preliminary results
- conclusions

# $0\nu\beta\beta$

**(A,Z) --> (A,Z+2) + 2e$^-$ (+ 2ν)**

- Channel for ββ decay **forbidden by SM (ΔL=2)**
- Extremely **rare** process ($T_{1/2} > 10^{22} - 10^{24}$ y)
- **Never observed** (but $Ge^{76}$ claim [1])
- Its observation would prove **ν Majorana nature**




For **light $\nu_M$** exchange the **Decay Rate** is:

$$(T_{0\nu})^{-1} \propto G_{0\nu}(Q,Z)|M^{0\nu}|^2 \langle m_{ee} \rangle$$

Phase Space Factor
ATOMIC PHYSICS

Nuclear Matrix Element
NUCLEAR PHYSICS

Effective Majorana mass
PARTICLE PHYSICS

**The observation of $0\nu\beta\beta$:**

Is currently the only feasible method to establish:

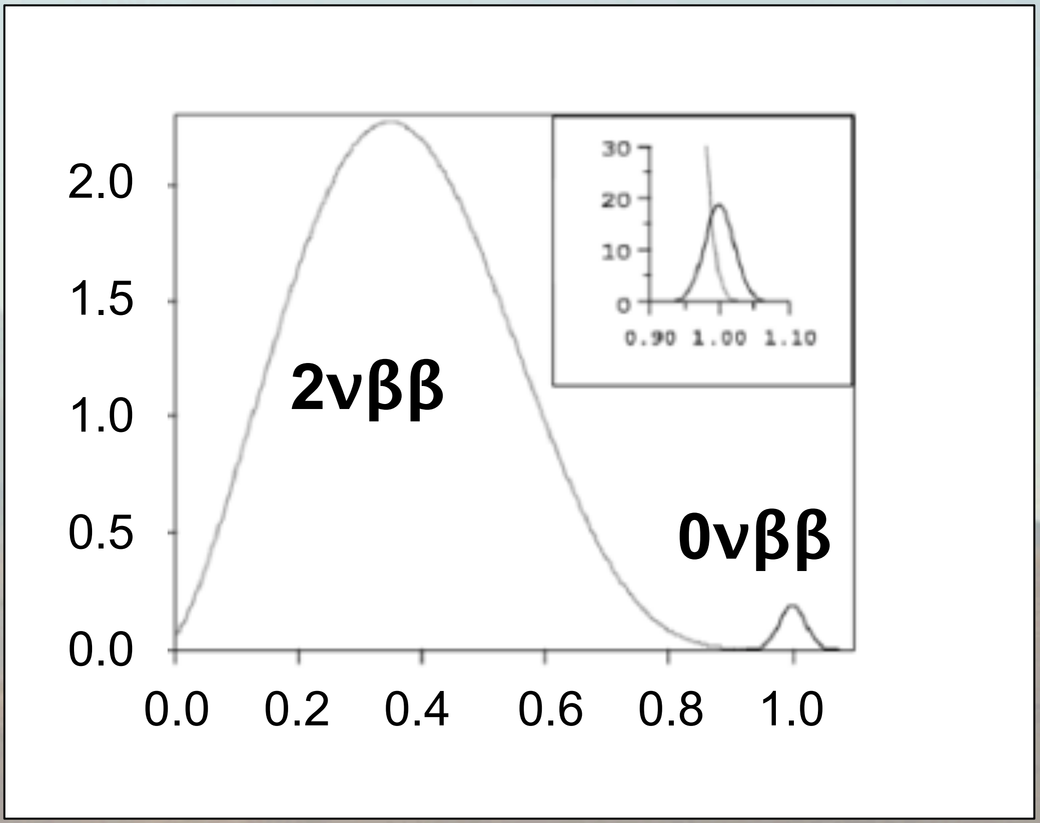
- **Majorana nature** of the neutrino
- **Lepton number** violation

Can give important information about:

- Absolute neutrino **mass scale**
- Neutrino mass **hierarchy**
- **CP** Majorana phases

# Experimental search

**Main signature:**
0νββ exhibits a **peak at Q** over 2νββ tail enlarged only by detector resolution




Defining the **experimental sensitivity $S^{0\nu}$** as the lifetime corresponding to the minimum detectable number of events over background at a given C.L.

**M**: total active mass in kg
**e**: detector efficiency
**a.i.**: isotopic abundance
**b**: background in c/keV/kg/y
**ΔE**: detector resolution @ ROI in keV
**T**: total live time in y

$$S^{0\nu} \propto \frac{\epsilon \; a.i.}{A} \left( \frac{MT}{b \, \Delta E} \right)^{1/2} \qquad b \neq 0$$

Qualitative expression in the Gaussian approximation
(not fully accurate for very low background experiments)

# Experimental strategies

**Additional signatures can be looked for:**

Single electron energy spectrum

Angular correlation between the two electrons

Track and event topology

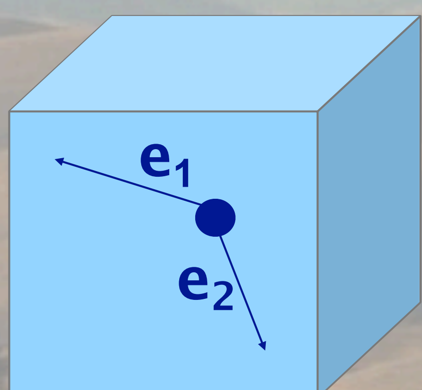
Time Of Flight

Daughter nuclear specie

**Two** main approaches: **calorimetric** (source = detector) or **external-source** detector

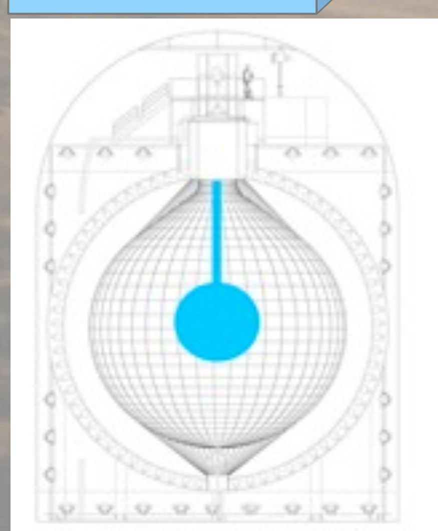
## Calorimeters

**Solid**




- *Large M possible*
- *High efficiency*
- *High resolution*
- *Event topology (pixellated detectors)*

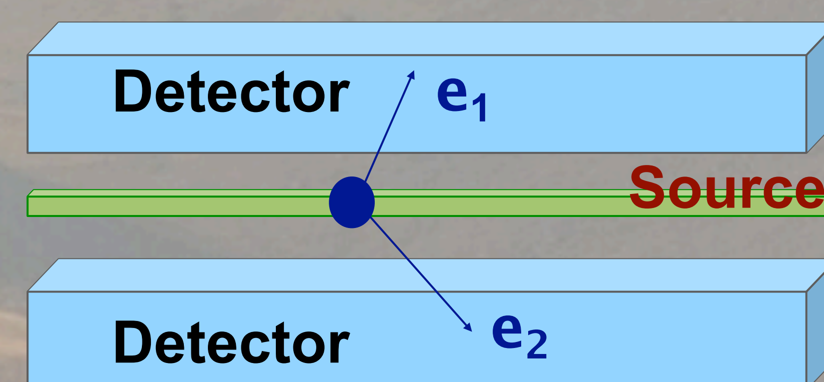
**Liquid**



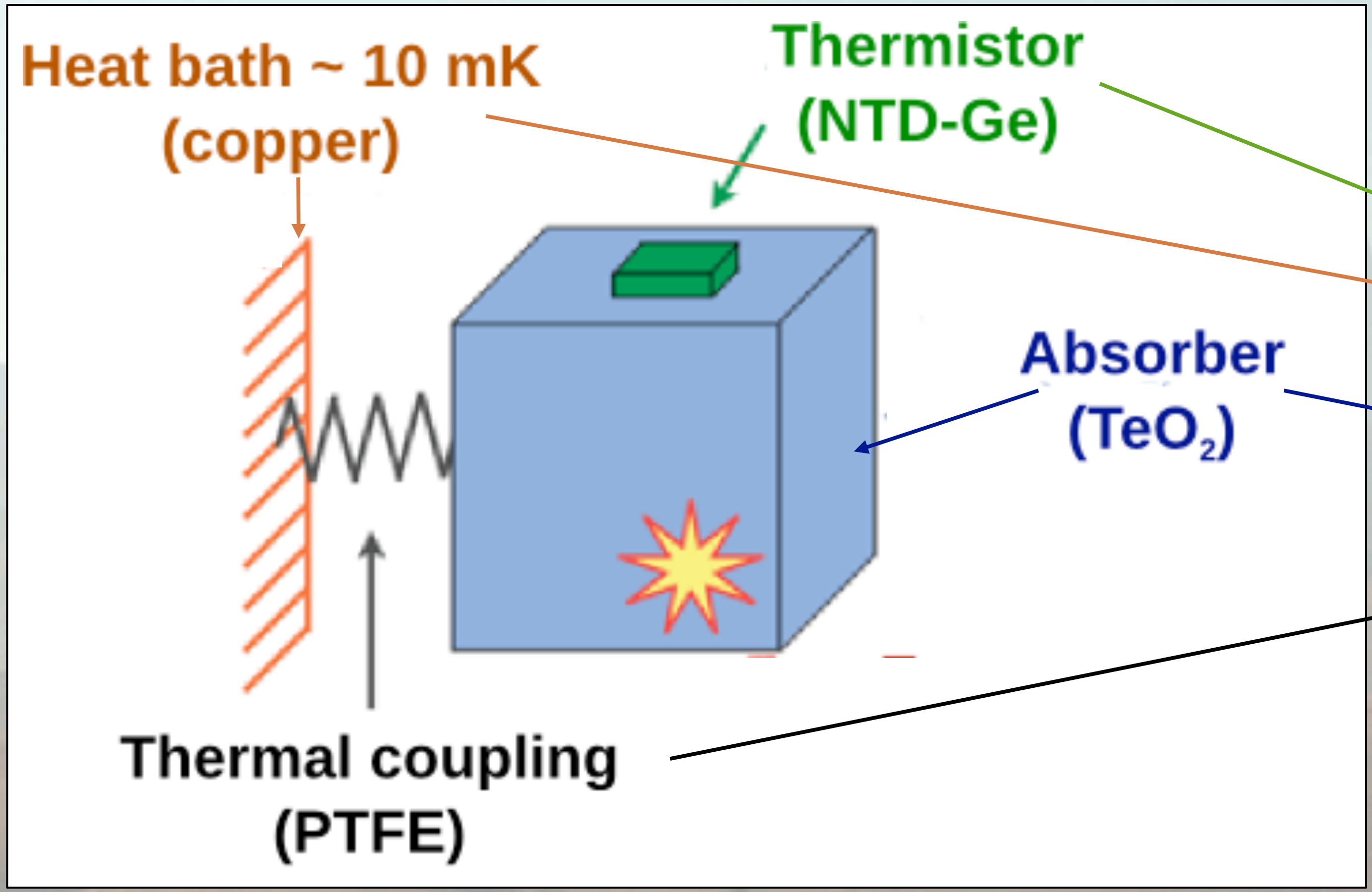
- *High M possibles*
- *High efficiency*
- *Re-use of existing exp.*
- *Event topology, particle ID (Xe TPC)*

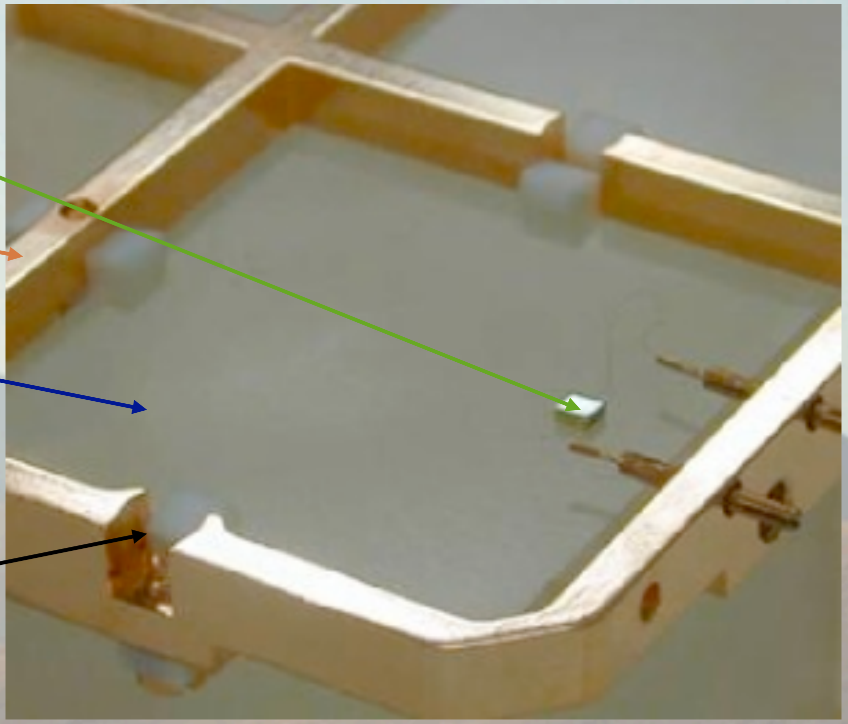
## External-source detectors

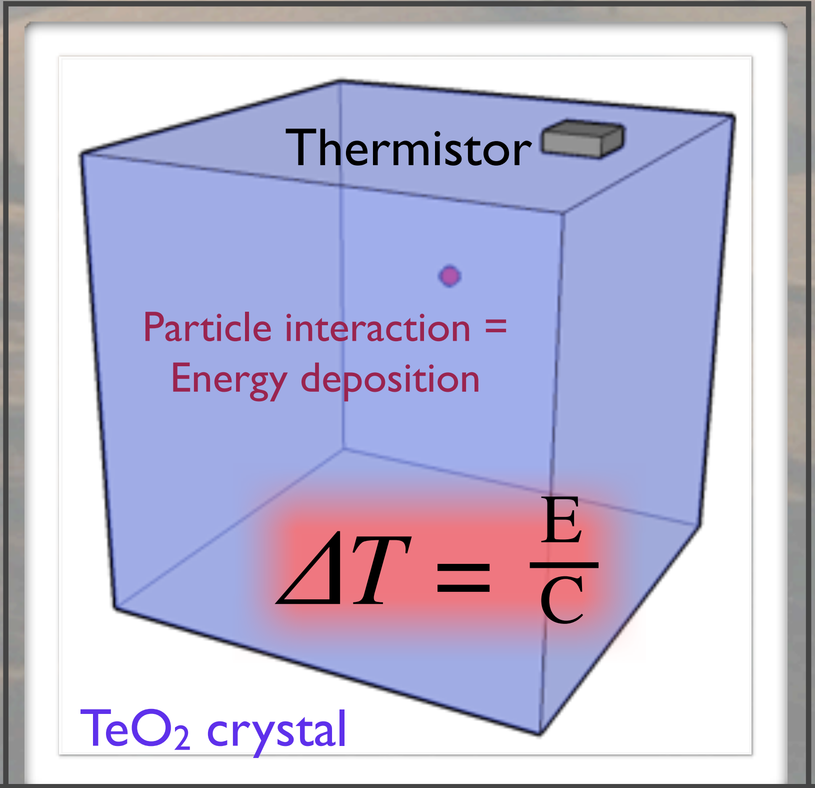
- *Event topology, particle ID*
- *More ββ candidates in same det.*



# Bolometric technique






**Particle energy is converted into phonons** by dielectric and diamagnetic absorbers whose heat capacity ($C \propto T^3$) is very low at low T (~10mK)

- **Crystal Absorber ($TeO_2$): $E \rightarrow \Delta T$**
- **Biased T sensor (NTD-Ge): $\Delta T \rightarrow \Delta V$**
- **Thermal link (PTFE+gold wires): $T_0$~10 mK**

# 0νββ research with $TeO_2$

- ☑ **$^{130}$Te** is a **good** DBD candidate ( $^{130}Te \rightarrow {}^{130}Xe + 2e^-$) with **high natural i.a.** (34.2 %) and reasonably **high Q-value** (Q~2528 keV) leading to **high G(Q,Z)** and low background
- ☑ **$TeO_2$** is a compound with **good mechanical and thermal properties** containing $^{130}$Te
- ☑ 5x5x5 $cm^3$ $TeO_2$ crystals have a high detection efficiency for 0νββ events: **~87.4%**

**MiDBD**
~ 6.8 kg

**1997-2001**

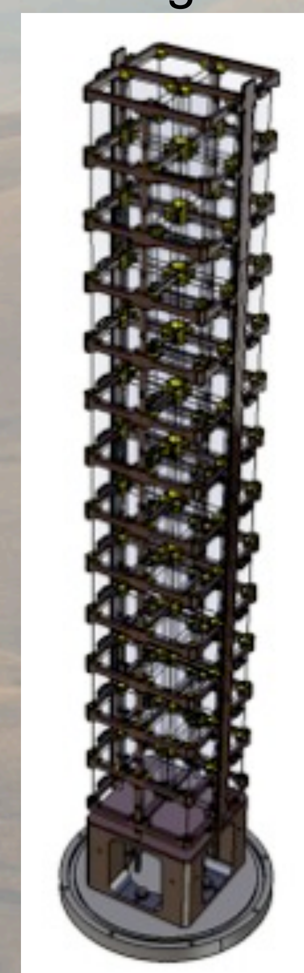
M >
B <

**Cuoricino**
~ 11 kg $^{130}$Te

**2003-2009**

M =
B <

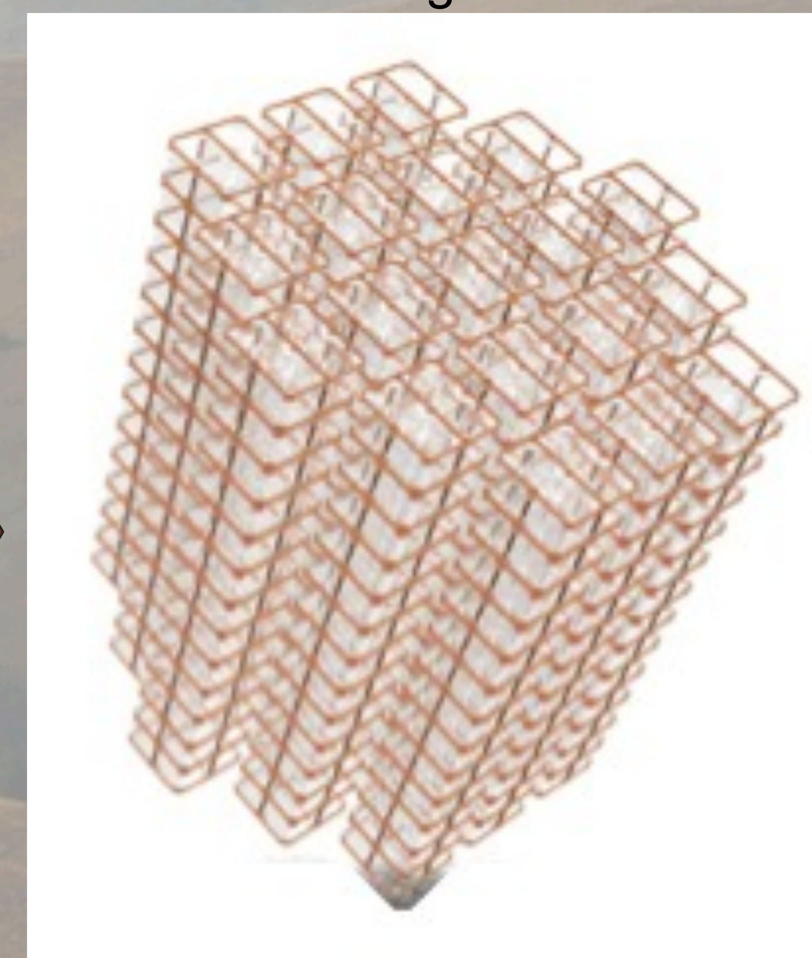
**CUORE-0**
~ 11 kg $^{130}$Te



**2012...2014**

M >
B <

**CUORE**
~ 206 kg $^{130}$Te



**2014...**

# Background reduction

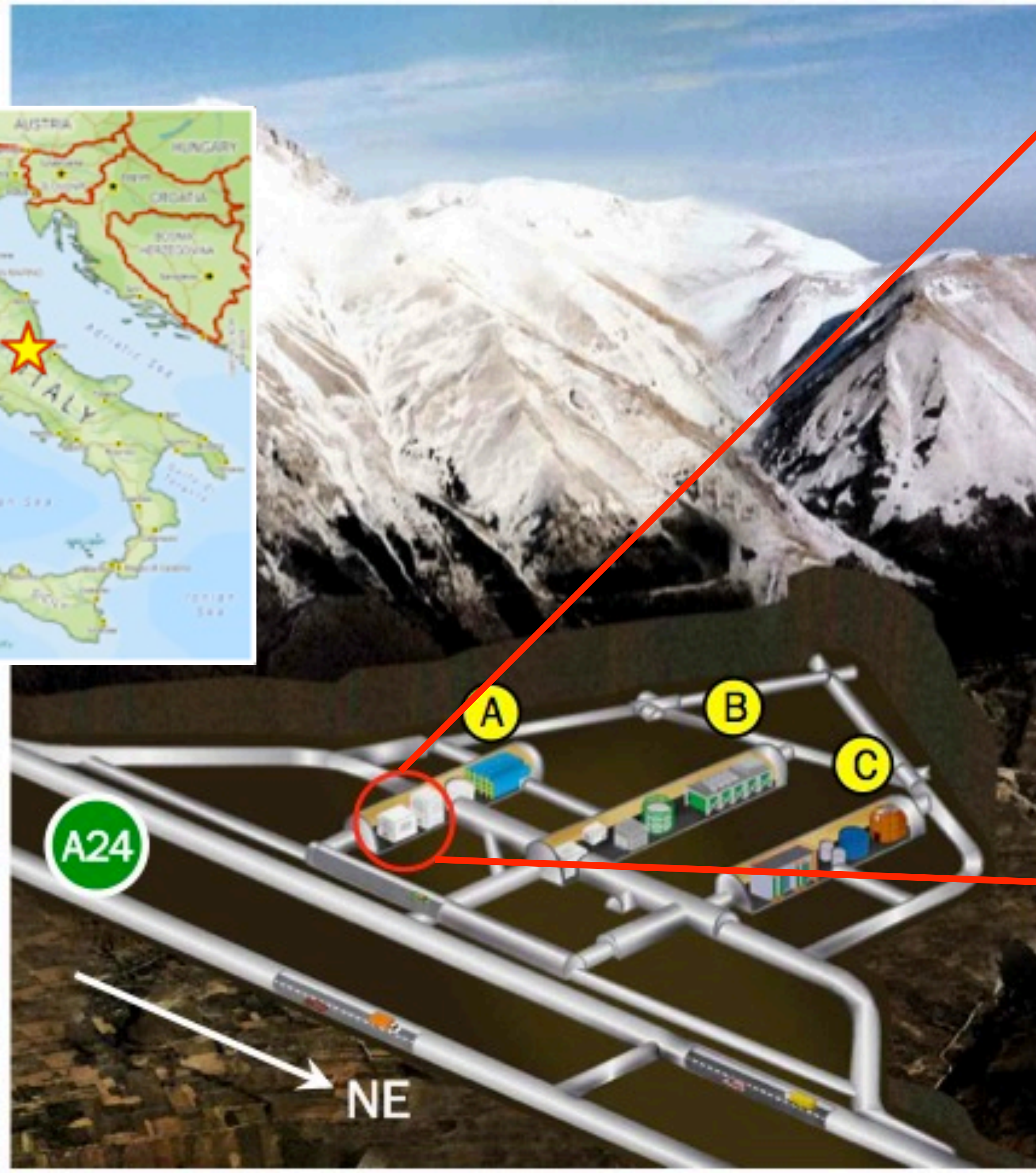
**Passive methods adopted for CUORE** while testing different active methods (i.e. Surface sensitive bolometers, scintillating bolometers) for future improvements

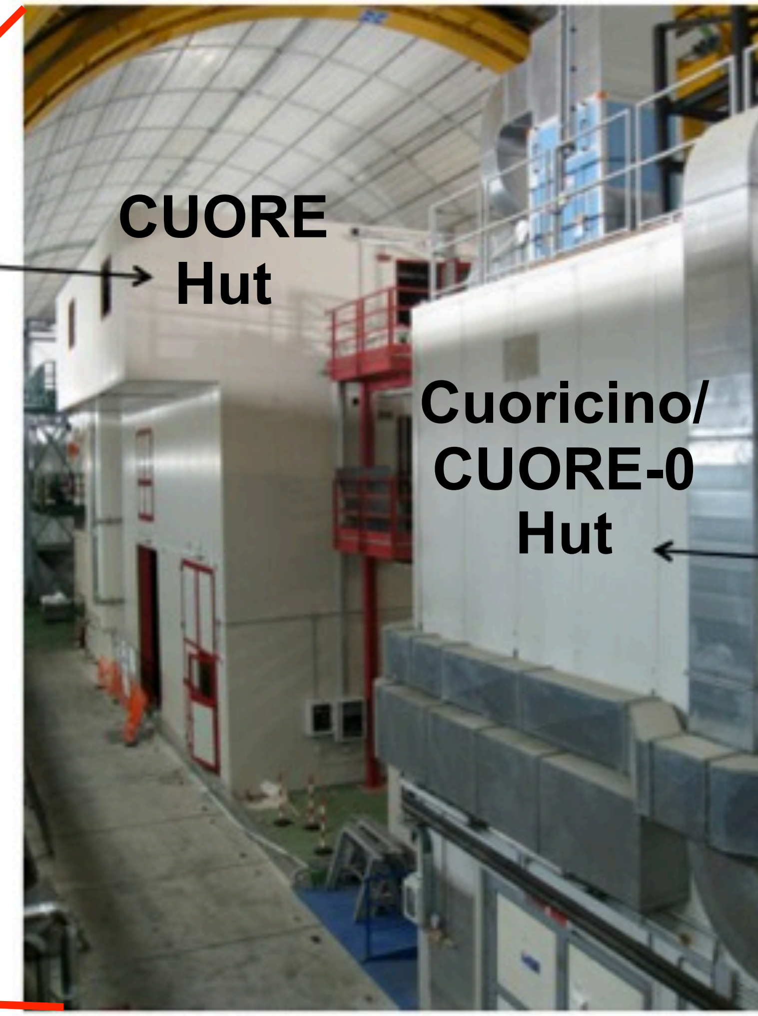
- **Shields design and materials selection**
- **New holder design** to reduce the amount of copper facing the crystals
- **$TeO_2$ crystals bulk contamination control**: strict protocol for $TeO_2$ production [20]
- **Crystals surface contamination reduction**: new treatment developed
  - **=>** bolometric tests on 4 sample crystals from each batch: **CCVR [9] tests**
- **Surface contamination of the copper facing the crystals reduction**:
  - **=>** bolometric tests of three different surface treatments: **Three Tower Test (TTT)**
- Further improvement thanks to **detector granularity**

# CUORE status

| Feature | Status |
| --- | --- |
| 988 $TeO_2$ crystals, 19 towers - total mass 741kg (206kg $^{130}$Te) | >95% stored underground @LNGS (or already assembled) |
| Ultra-clean copper structure/ shields | >50% stored underground @LNGS (or already assembled), delivery by end 2013 |
| Thermistors | production complete, under testing |
| Dedicate hut and clean room | fully equipped |
| Detector assembly line | ready, being used for the assembly of the first towers |
| Calibration system | construction started |
| Ultra-clean cryostat to keep >1ton @10mK with high duty-cycle | commissioning of first 3 shields on-going at LNGS, commissioning of dilution unit completed (8muW@10mK) |
| Radon abatement system | installed |
| DAQ and Analysis tools | are being tested with CUORE-0 |

# CUORE(-0) location




**In Hall A of LNGS, Italy**
**(Laboratori Nazionali del Gran Sasso)**

Average depth ~ 3650 m.w.e. [10]

μ flux: $(2.58 \pm 0.3) \cdot 10^{-8}$ m/s/cm$^2$ [11]

n flux <10 MeV: $4 \cdot 10^{-6}$ n/s/cm$^2$ [12,13]

γ flux < 3 MeV: 0.73 g/s/cm$^2$ [14,15]

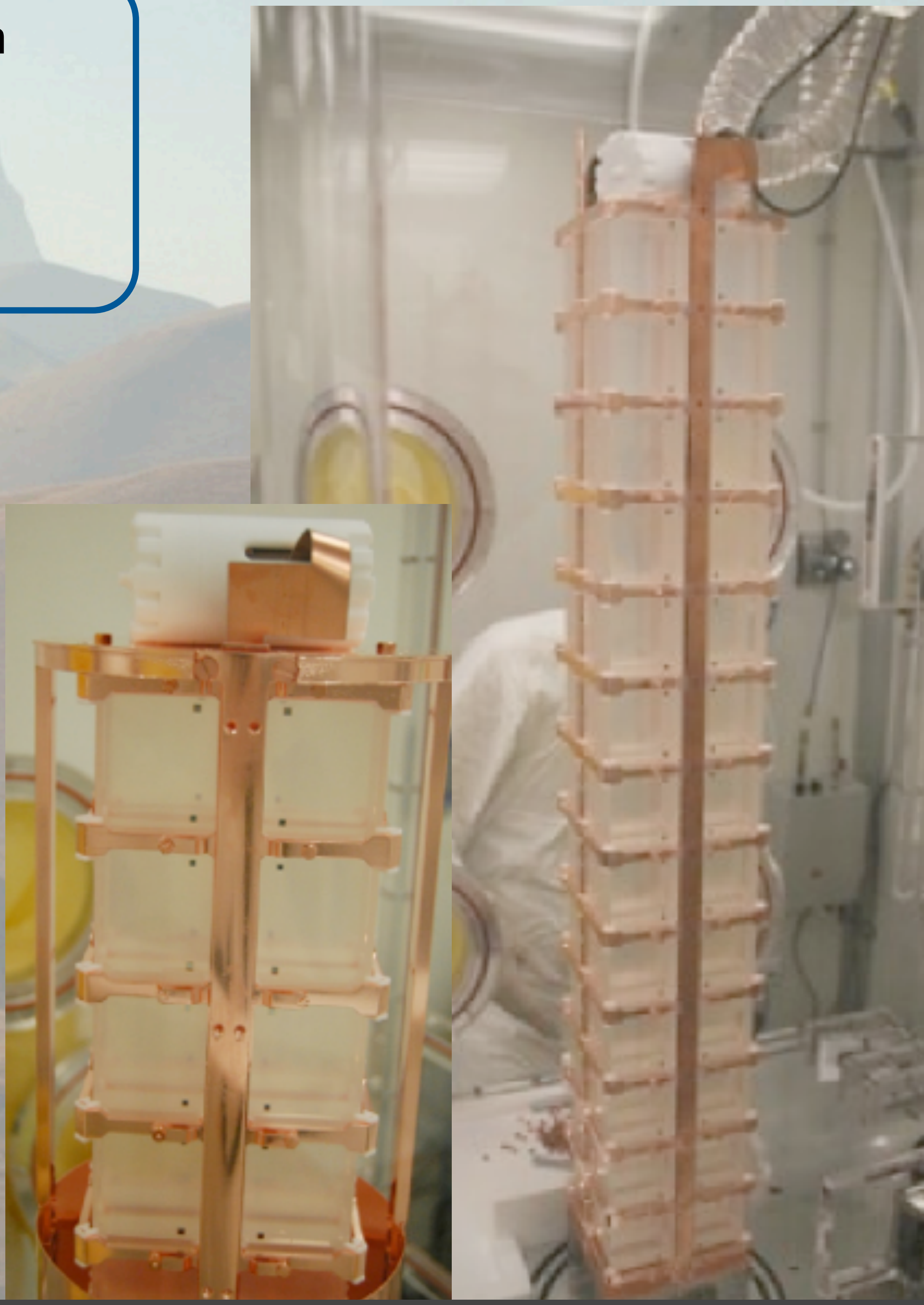
# CUORE-0

**1 CUORE-like tower** of 13 planes - 4 crystals each
**52 $TeO_2$** $5x5x5\ cm^3$ crystals (750 g each)
**Detector Mass:** 39 kg $TeO_2$
**$^{130}Te$ mass (natural i.a.):** 11 kg of $^{130}Te$

- All detector components manufactured, cleaned and stored with protocols defined for CUORE
- Assembled with the same procedures foreseen for CUORE
- In the 25 years-old CUORICINO cryostat

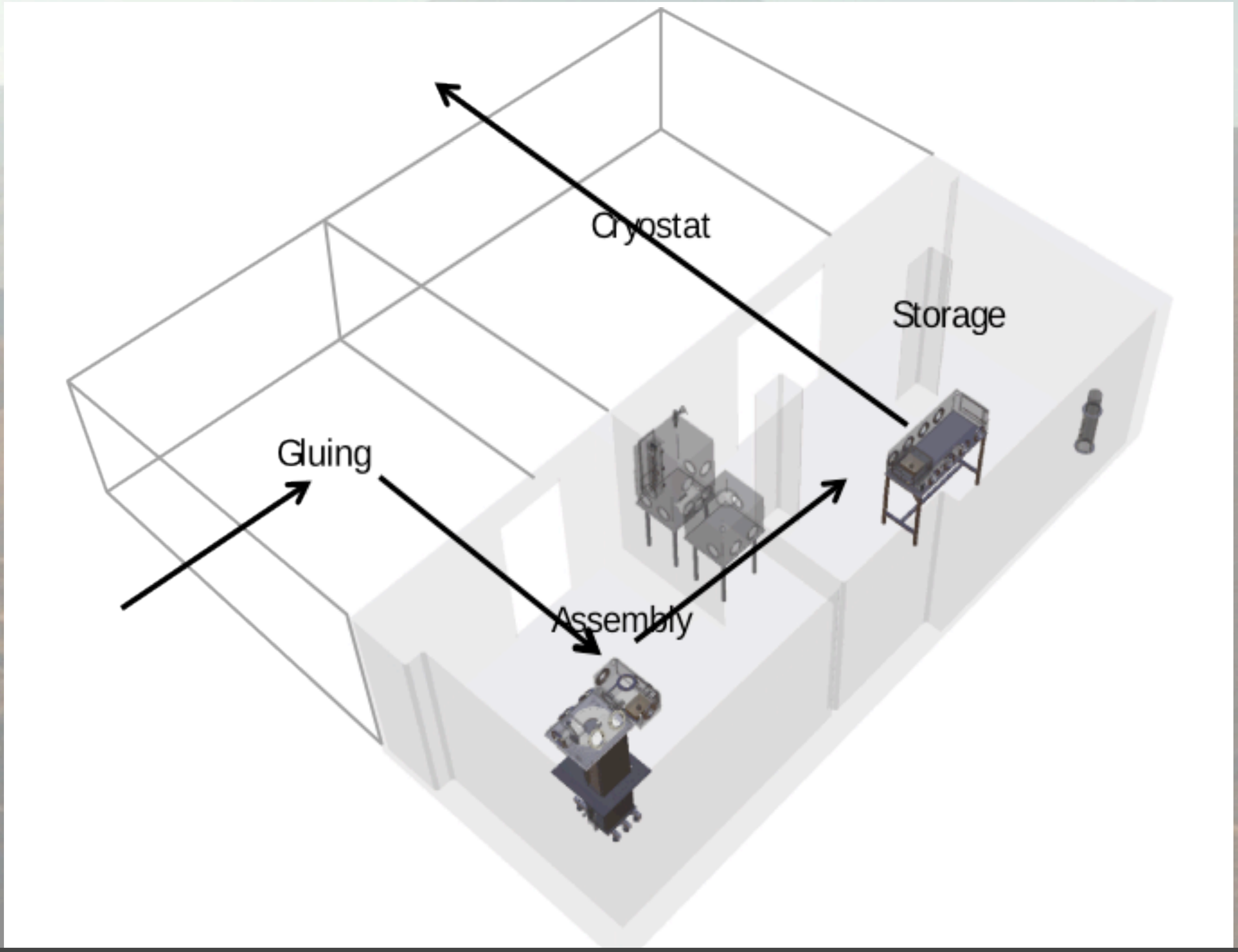
**GOALS:**

- Proof of Concept for CUORE in all stages
- Test and debug the CUORE assembly line (thermistor gluing, signal wires bonding, tower assembly)
- Test of the CUORE DAQ and analysis framework
- Extend the physics reach beyond CUORICINO while CUORE is being assembled
- Demonstrate potential for DM and Axion detection



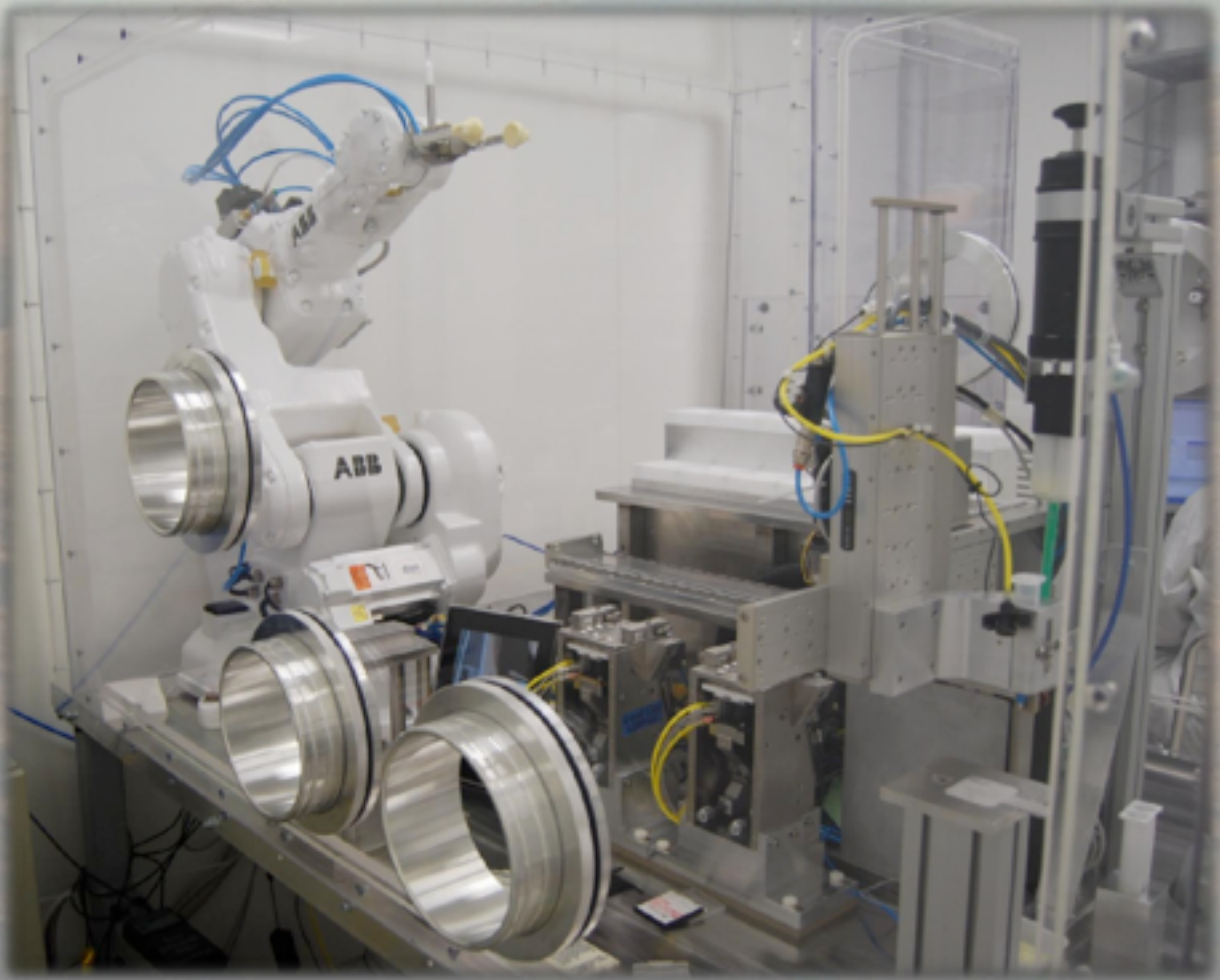
# Assembly procedure

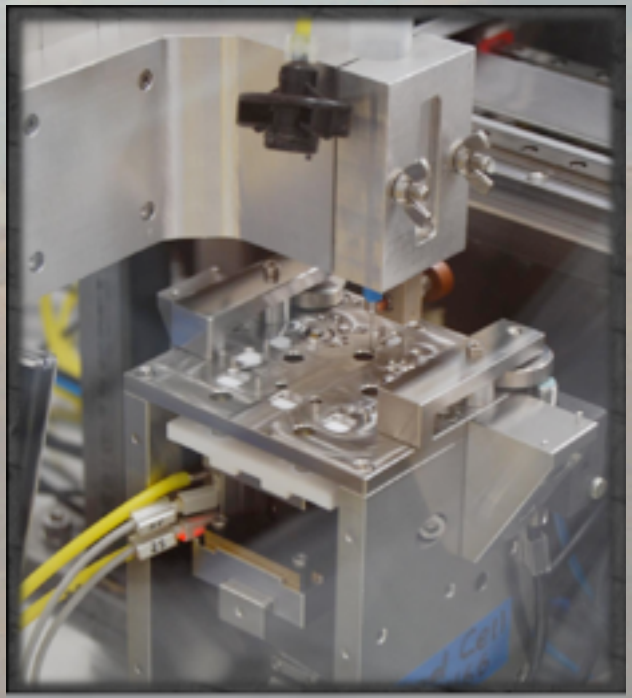
**CUORE-0 assembly** was performed in the new CUORE clean room following all the stages and using **all the equipment developed for CUORE**

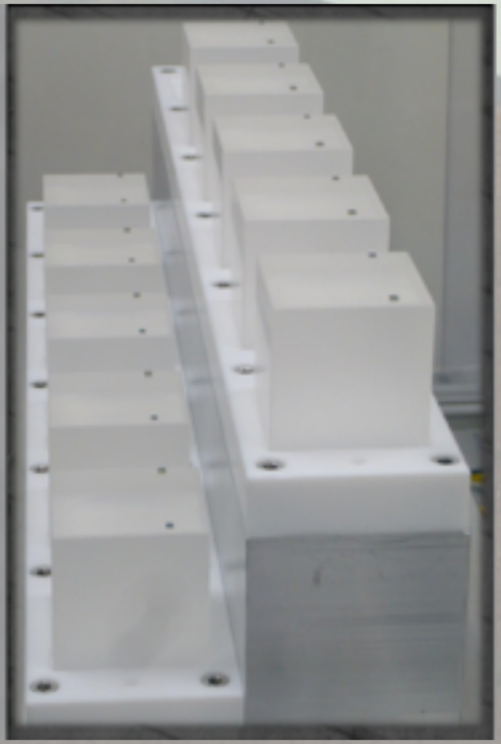


# Thermistor gluing

The gluing of CUORE-0 thermistor to crystals was performed with the **new CUORE gluing semi-automatic machine** (in a $N_2$ flushed glove box): fast, operator independent, minimizes radioactive contaminations, makes this stage more reproducible thus improving detector uniformity.

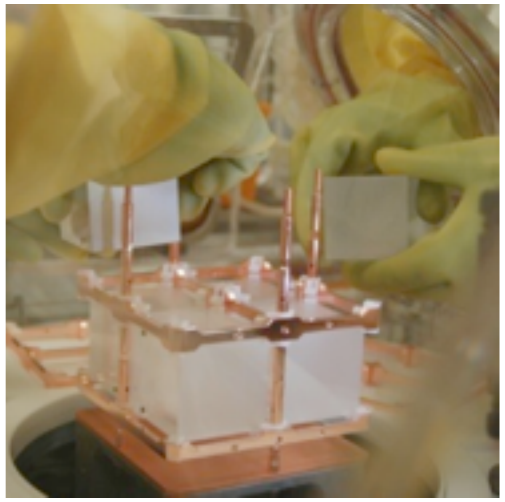


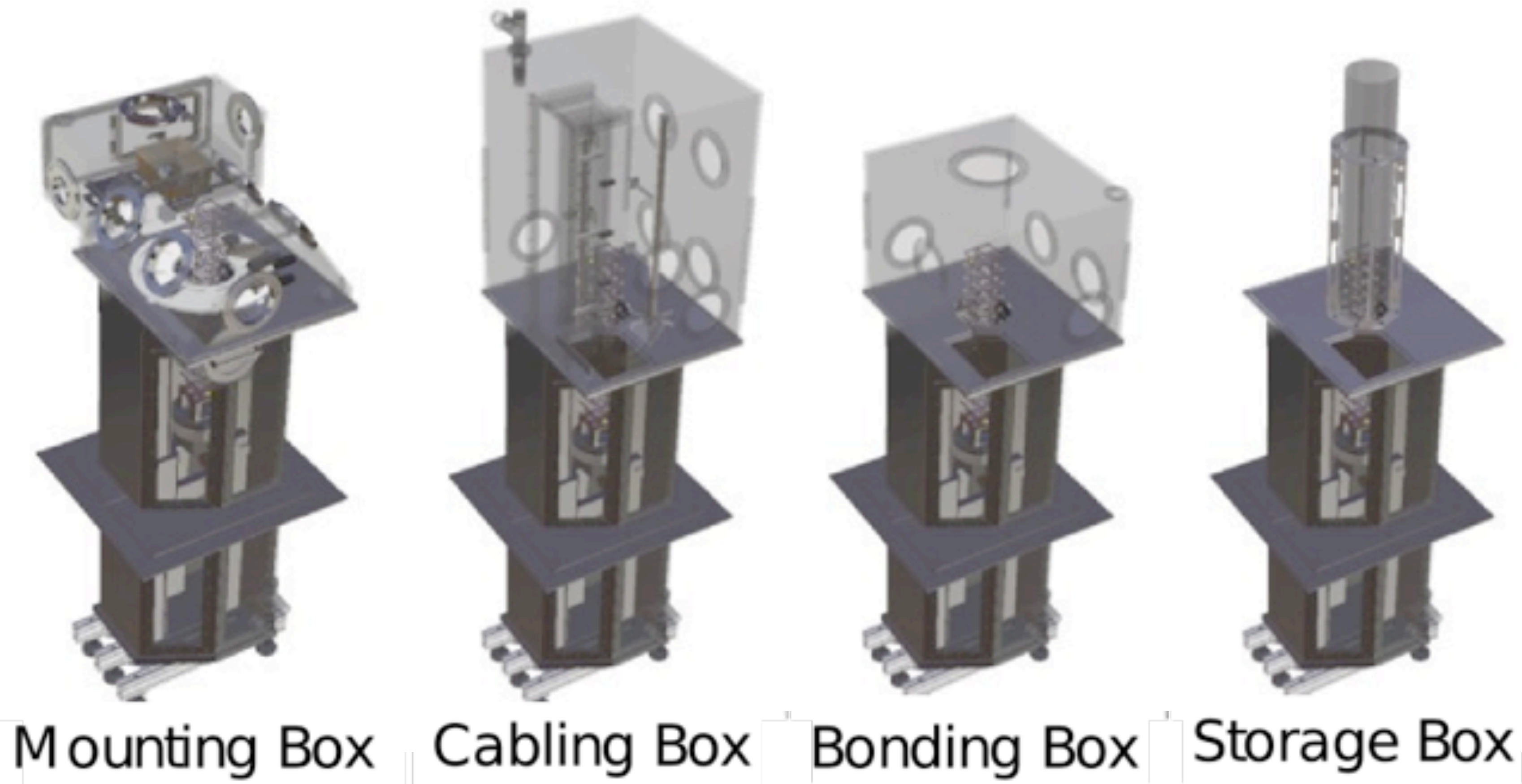



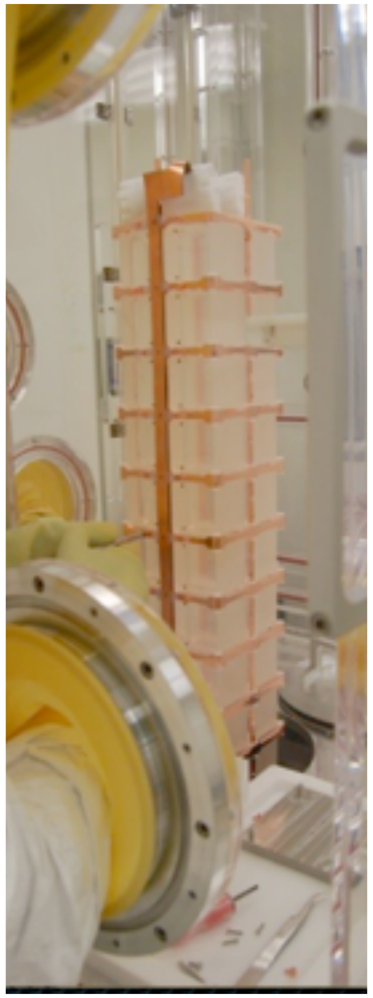


# Tower assembly

The assembly of the tower was done with the **CTAL (CUORE Tower Assembly Line)** provided of a sealed and flushed stainless steel chamber (Garage) supporting a working plane where **4 different glove boxes switch** allowing 4 operations to be performed (mounting, cabling, bonding and tower storage) with radioactivity control and reproducible protocols.

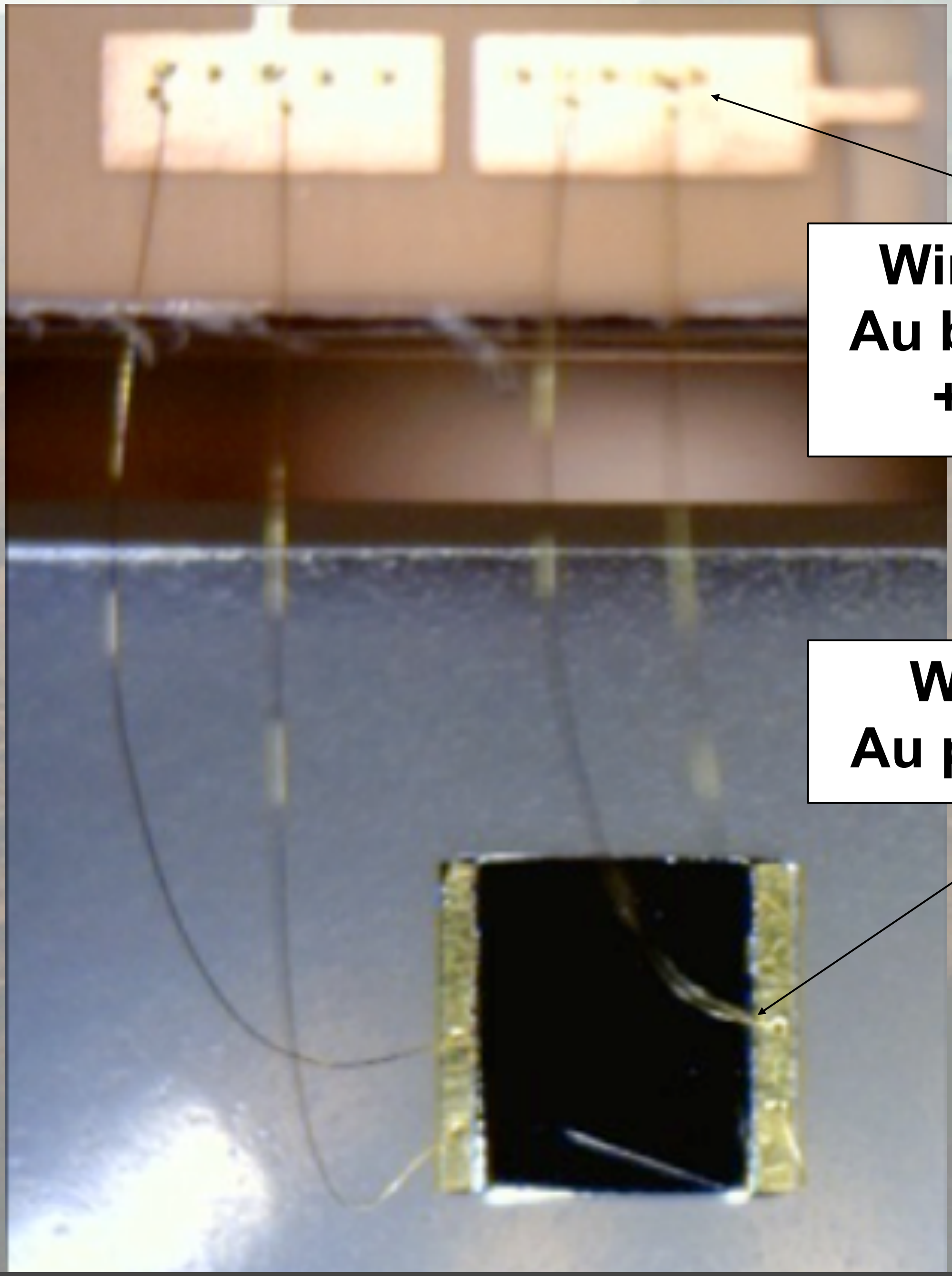




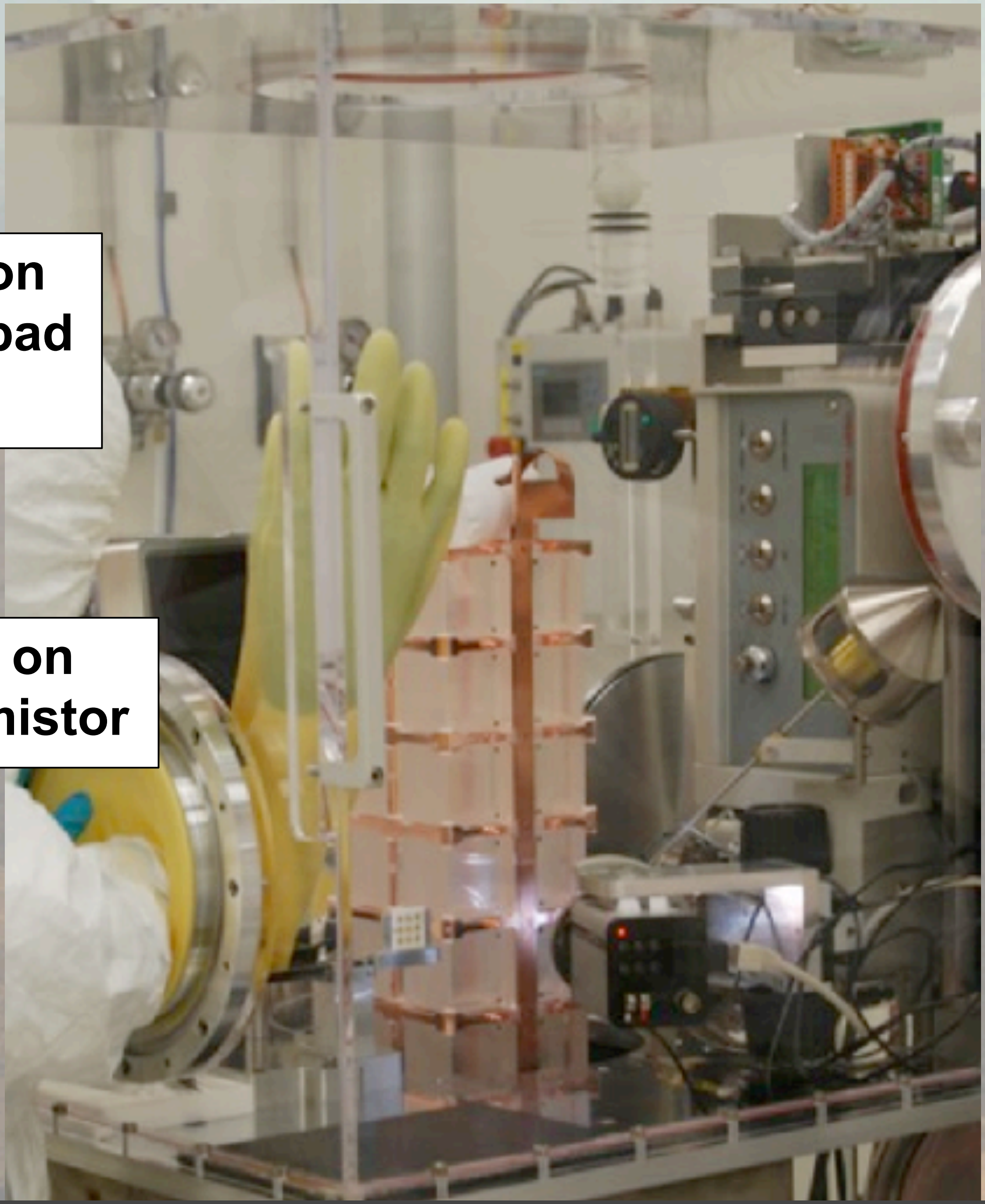
# Signal wires connection

The signal readout is provided by **gold wires directly bonded** on the assembled tower in a $N_2$ fluxed glove box. The bonding proceeds in **3 main steps**: 1. ball bonding on a Au pad on the thermistor; 2. bonding of the wire on Au balls on a Cu pad; 3. reinforcing.



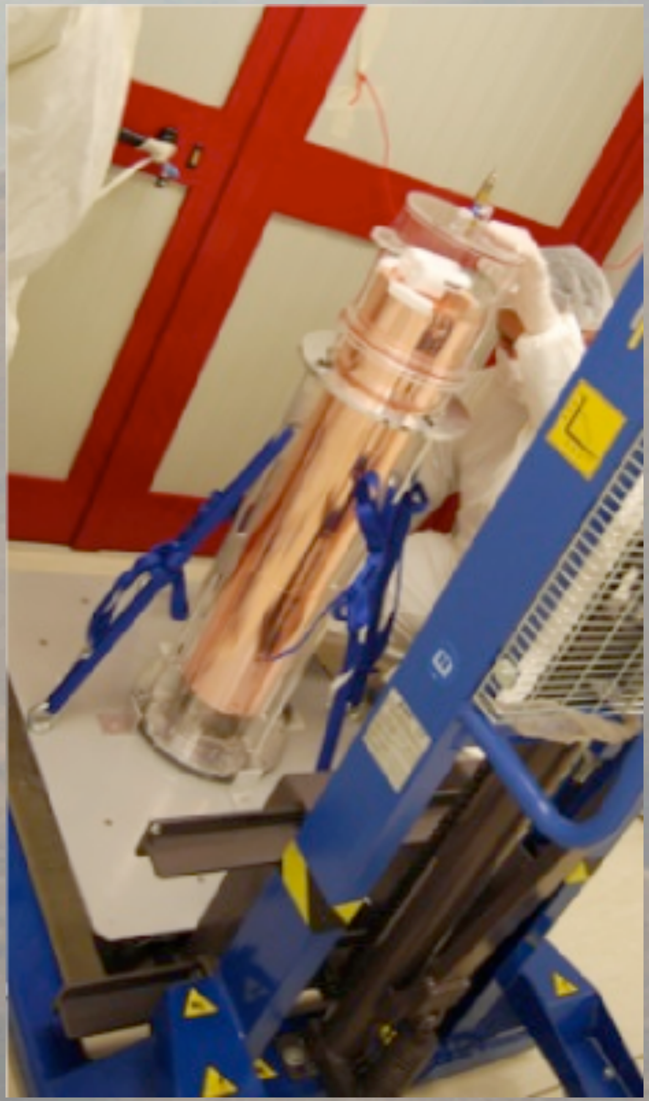
**Wire Bonding on Au balls on Cu pad + reinforcing**

**Wire Bonding on Au pad on thermistor**



# Installation

After shield installation the tower has been closed in a flushed Plexiglas box, then moved to the special opening door of the **CUORE clean room** with a trans-pallet. It has then been lifted with a fork-lift to the **CUORICINO clean room** where it has been joined to the cryostat dilution unit (operations not necessary for CUORE).

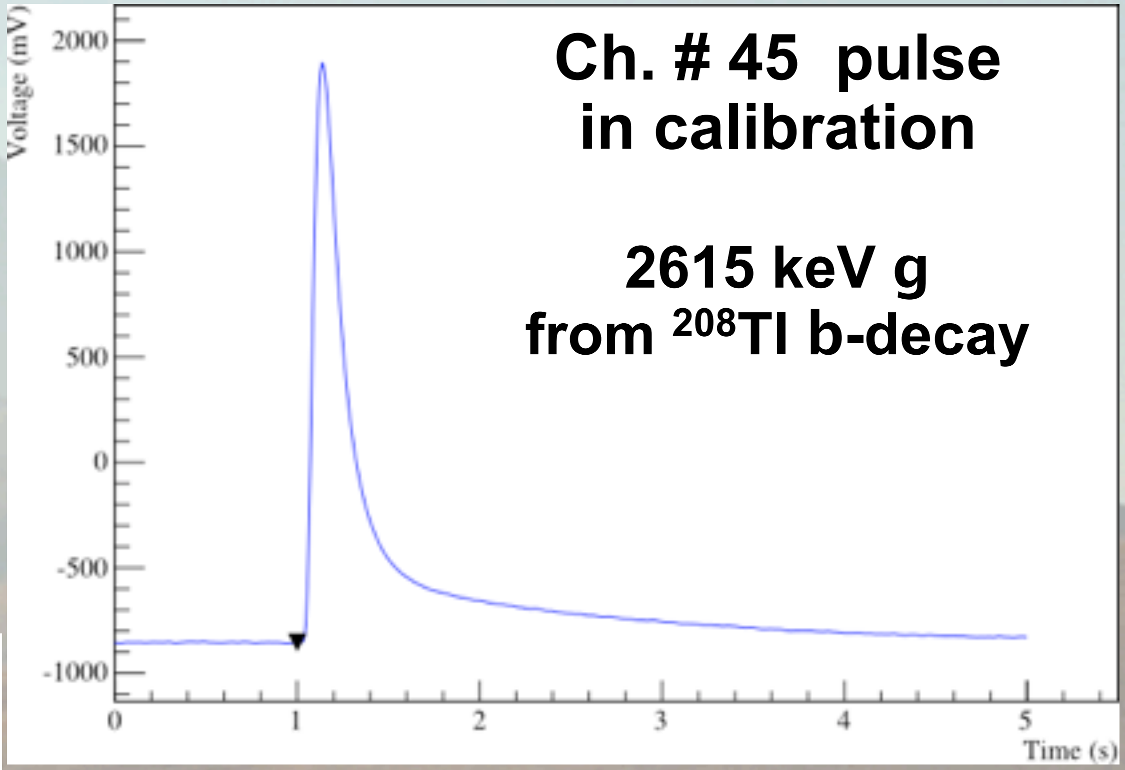


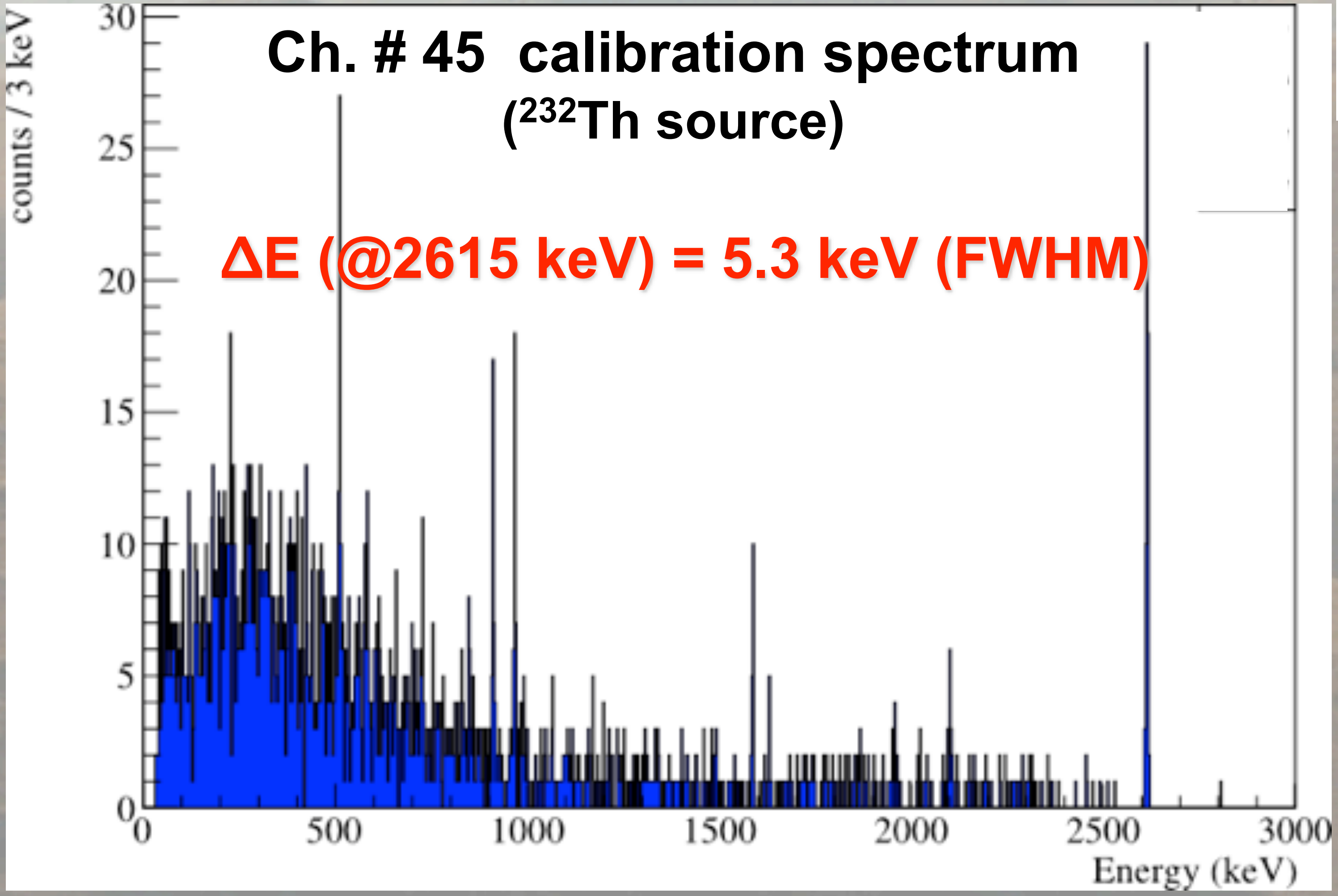
# CUORE-0 status

- CUORE-0 was **cooled down** to a base T **~ 8 mK** to start the pre-operation and optimization phase **in August 2012**
- Pre-operation was disturbed by 2 vacuum leaks (the cryostat is ~25 years old) which deteriorated detector performances
- We were able to perform **calibrations** despite the leaks, showing reasonable detector performance
- The **second leak has been fixed** at the beginning of February
- **Pre-operation** and optimization phase **restarted** in mid-March

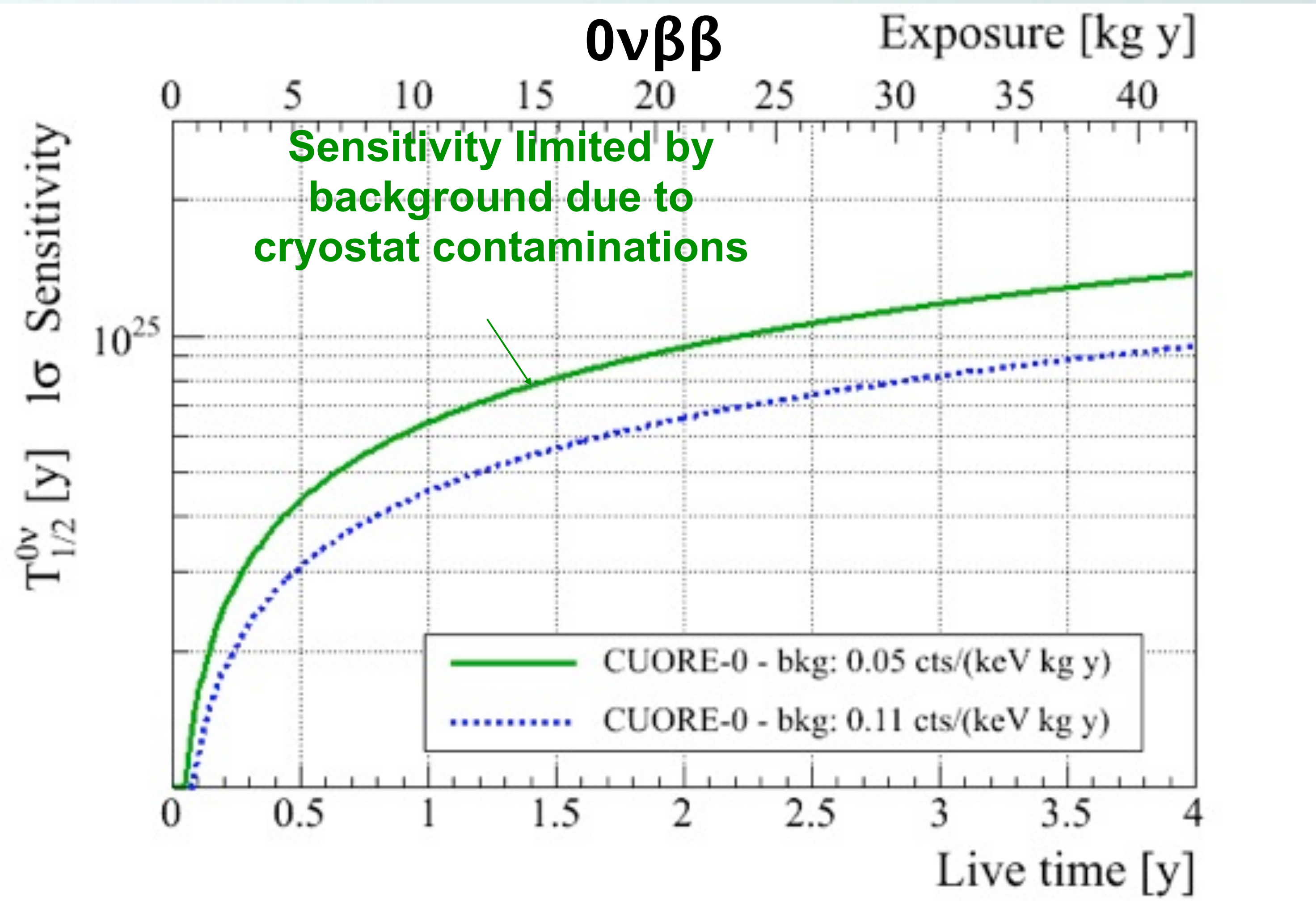
# Detector performance

- **Successfully tested** and defined the CUORE **assembly procedures**
- Demonstrated that **a complete CUORE tower** can be assembled in **less than 4 weeks**
- **51 detectors alive** (out of 52)



# 0νββ and DM sensitivity



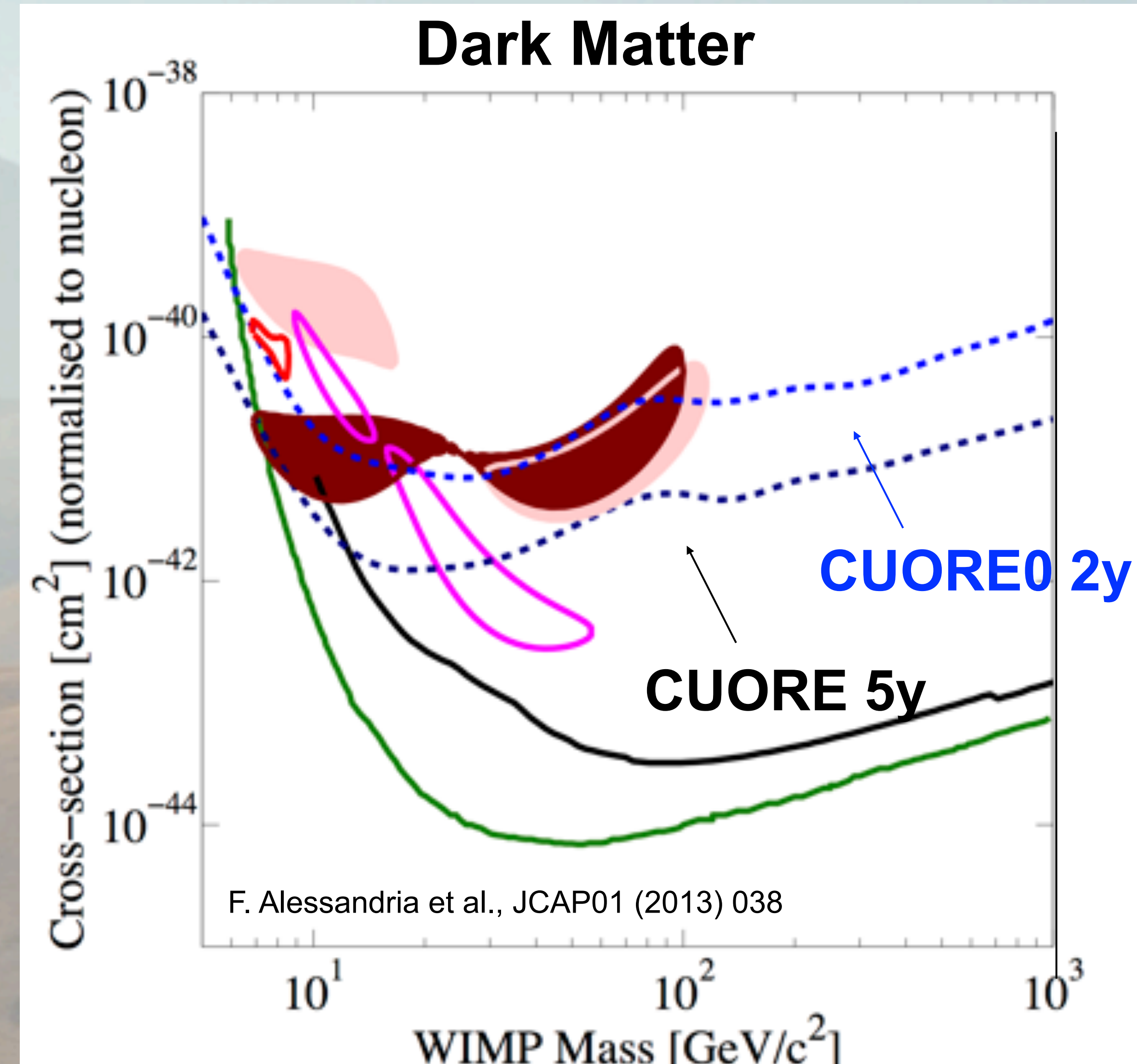

b = 0.05 c/keV/kg/y, T = 2 y

**$T_{1/2}$ sensitivity = 5.9 x $10^{24}$ y (90% CL)**

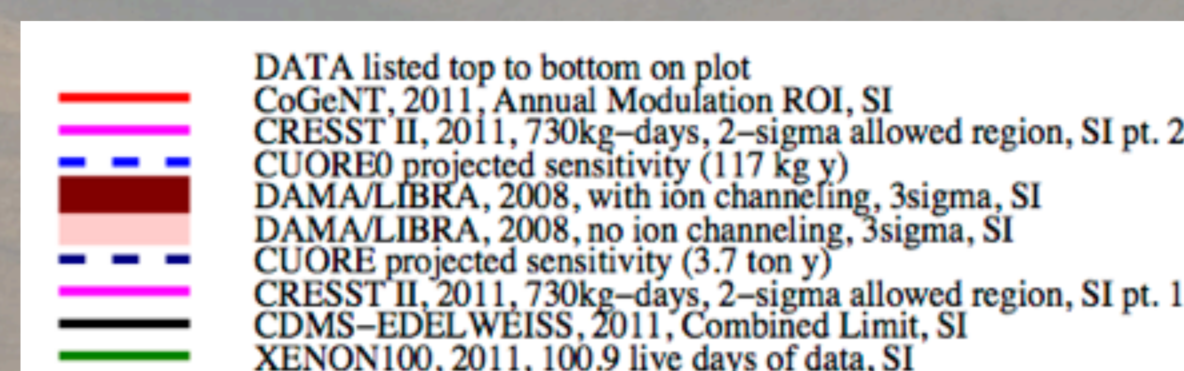
**$\langle m_{ee} \rangle$ < (204 ÷ 533) meV** ( [*])

[*] PSF from Kotila and Iachello, PRC 85 (2012) 034316

NME from Poves et al., NPA 818 (2009) 139; Faessler et al., JoP G: Nucl. Part. Phys. 39 (2012) 124006; Fang et al. , PRC 83 (2011) 034320; Suhonen et al., JoP G: Nucl. Part. Phys. 39 (2012) 124005; Iachello et al., PRC 87 (2013) 014315; P.K. Rath et al., Phys. Rev. C82 064310 (2010); T. R. Rodriguez et al., Phys. Rev. Lett 105 252503 (2010)




90% C.L. sensitivity to the cross-section for spin independent interactions normalized to nucleon



# Conclusions

- $TeO_2$ bolometers represent since many years a competitive detector for $0\nu\beta\beta$ research
- Going from CUORICINO to CUORE a strong R&D has been performed in order to reduce the background in the ROI (the main challenge being surface contaminations of detector and facing parts)
- Bolometric tests after improving surface treatments demonstrate that the CUORE goal of 0.01 c/keV/kg/y is just behind the corner. Copper/PTFE surface is the most crucial issue
- CUORE is under construction: LNGS hut and clean room ready, cryostat commissioning on-going, crystal production and storage almost complete, assembly of the first two towers almost complete
- CUORE cool down foreseen for end 2014
- First CUORE tower, CUORE-0, is cold in the CUORICINO cryostat at LNGS and in preliminary data-taking

# Bibliography


[1] H.V. Klapdor-Kleingrothaus et al., Mod. Phys. Lett. A 21 (2006) 1547
[2] S.M. Bilenky and C.Giunti, Mod.Phys.Lett. A27 (2012) 1230015
[3] M. Auger et al., Phys. Rev. Lett. 109 (2012) 032505, arXiv:1205.5608 [hep-ex]
[4] A. Gando et al., Phys. Rev. C 85 (2012) 045504, arXiv:1205.6130v1 [hep-ex]
[5] E. Andreotti at al., Astrop. Phys. 34 (2011) 822-831
[6] Simkovic et al., PRC 77 (2008) 045503
Citarese et al., JoP:Conference series 173 (2009) 012012
Menendez et al., NPA 818 (2009) 139
Barea and Iachello, PRC 79 (2009) 044301
[7] C. Arnaboldi et al., Phys. Rev. Lett. 95, 142501 (2005)
[8] C. Arnaboldi et al., Phys. Rev. C 78, 035502 (2008)
[9] F. Alessandria et al., Astrop. Phys. 35, 839-849 (2010)
[10] Mei and Hime, Phys. Rev. D 73, 053004 (2006)
[11] MACRO Coll., M.Ambrosio et al. Phys. Rev. D52, 3793 (1995)
MACRO Coll., M.Ambrosio et al., Astrop. Phys. 19, 313 (2003)
[12] F.Arneodo et al. Il Nuovo Cim. 112A, 819 (1999)
[13] P.Belli et al., Il Nuovo Cim. 101A, 959 (1989)
[14] C. Bucci et al. Eur. Phys. J. A 41:155-168 (2009)
[15] F.Bellini et al. Astrop. Phys 33, 169-174 (2010)
[16] L.Foggetta et al. Appl. Phys. Lett. 86, 134106, 2005
[17] J.W.Beeman et al., Astrop. Phys. 35, 558-562 (2012)
[18] T.Tabarelli de Fatis, Eur. Phys. J. C65, 359-361 (2010)
[19] F.Vissani, A.Strumia, http://arxiv.org/pdf/hep-ph/0606054v3.pdf
[20] C.Arnaboldi et al., J. Cryst. Growth 312 (2010) 2999–3008