Neutrino-less Double Beta Decay, Dark Matter and Axion Searches with CUORE

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- Bolometric technique
- The demonstrator: Cuoricino
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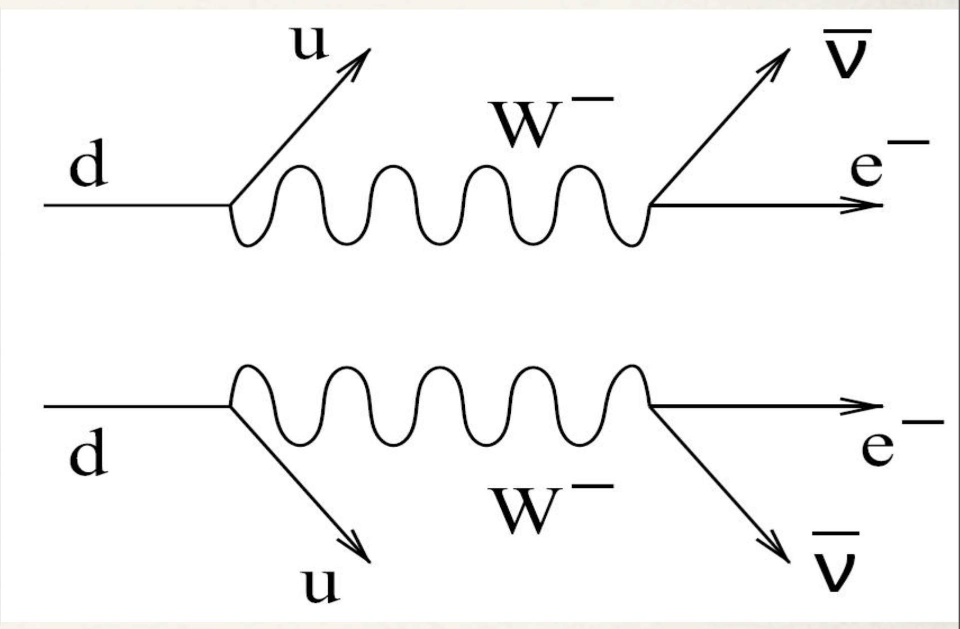
Neutrino-less Double Beta Decay

Double Beta Decay:

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

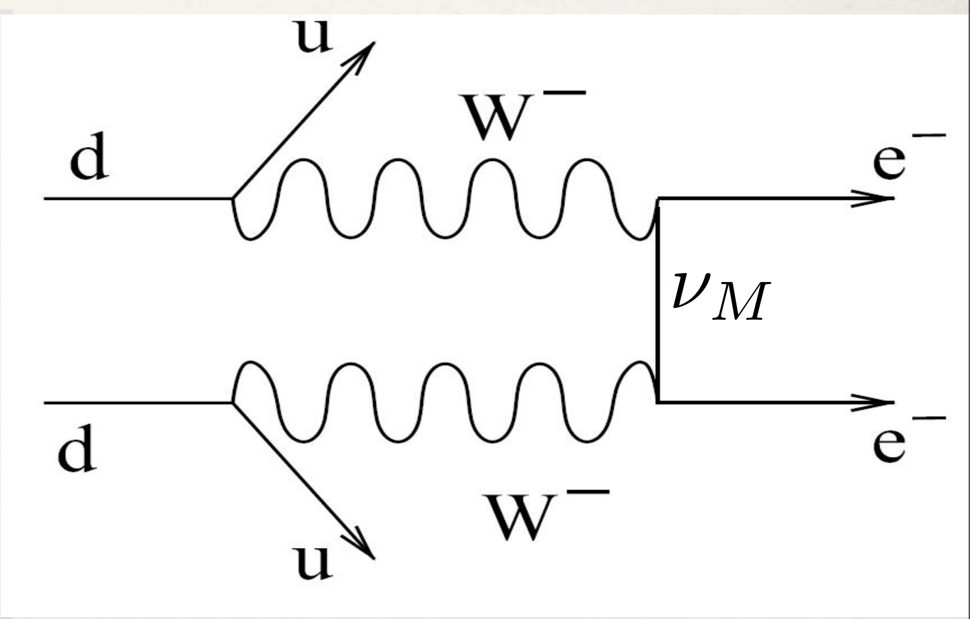
- Second order SM weak process
- Observed with lifetimes $T_{½} \sim 10^{19} - 10^{21}$ y



Neutrinoless Double Beta Decay:

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

- Not allowed by the Standard Model ($\Delta L=2$)
- Possible only if neutrinos are Majorana particles



0νDBD and neutrino mass

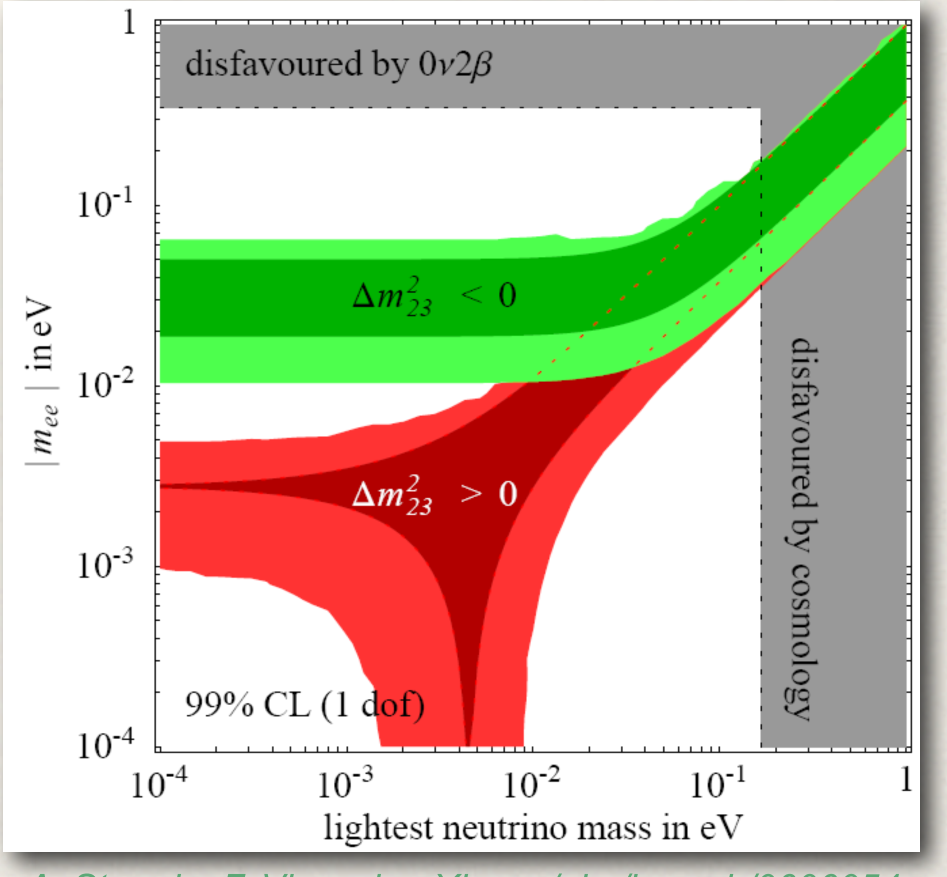
- Experiments can measure the half-life:

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

Phase space factor ~Q^5

Nuclear matrix element

Effective neutrino mass

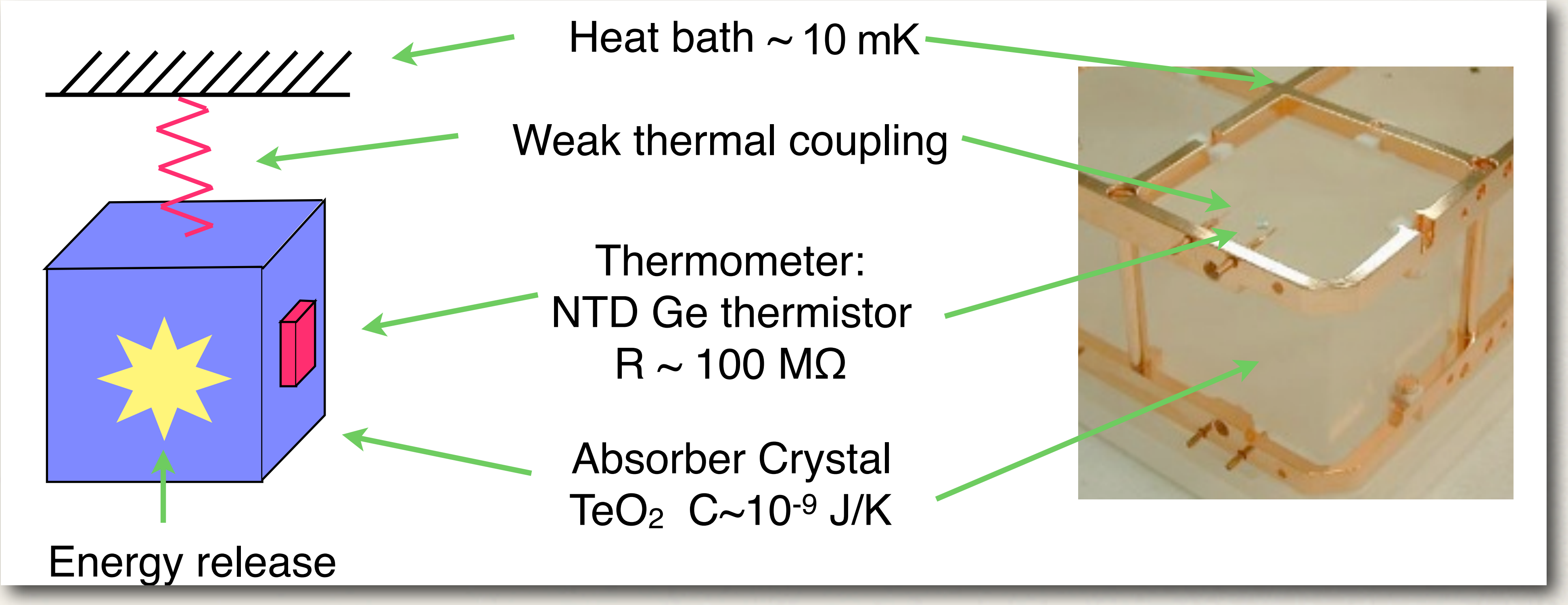


A. Strumia, F. Vissani, arXiv.org/abs/hep-ph/0606054

- The observation of 0νDBD
  - proof of the Majorana nature of neutrinos
  - constraint on the ν "mass hierarchy"

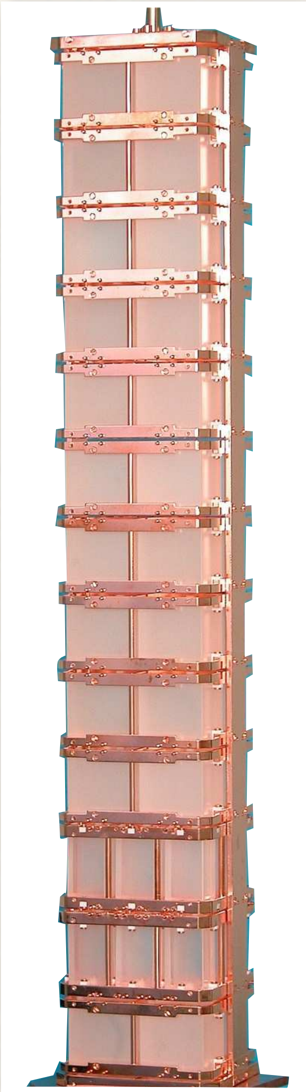
Bolometric technique

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



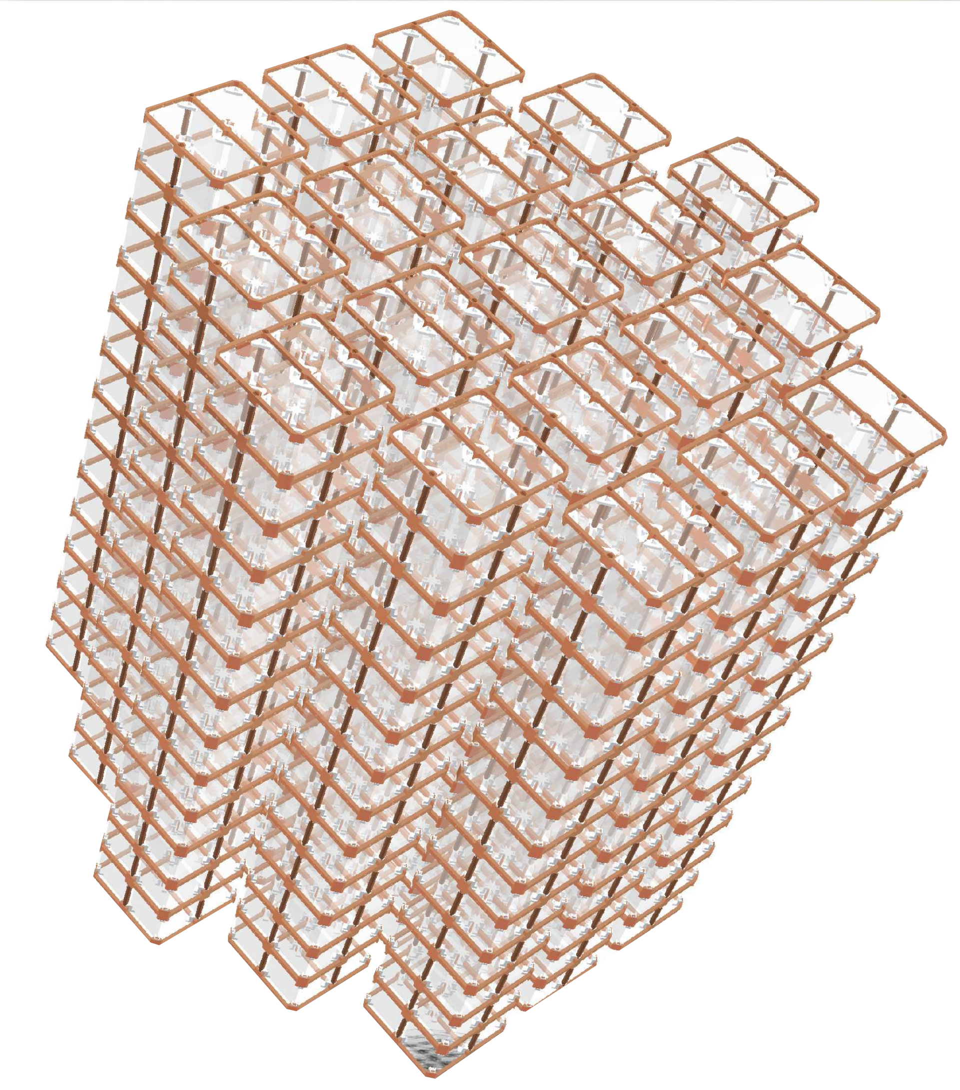
- Bolometer: particle energy converted into phonons
- Low heat capacitance and low base temperature to see small temperature variations
- TeO_2 crystals, searching for 0νDBD of ^{130}Te: source = detector
- Resolution @ 0νDBD (2527 keV) ~ 5 keV FWHM

The CUORE program



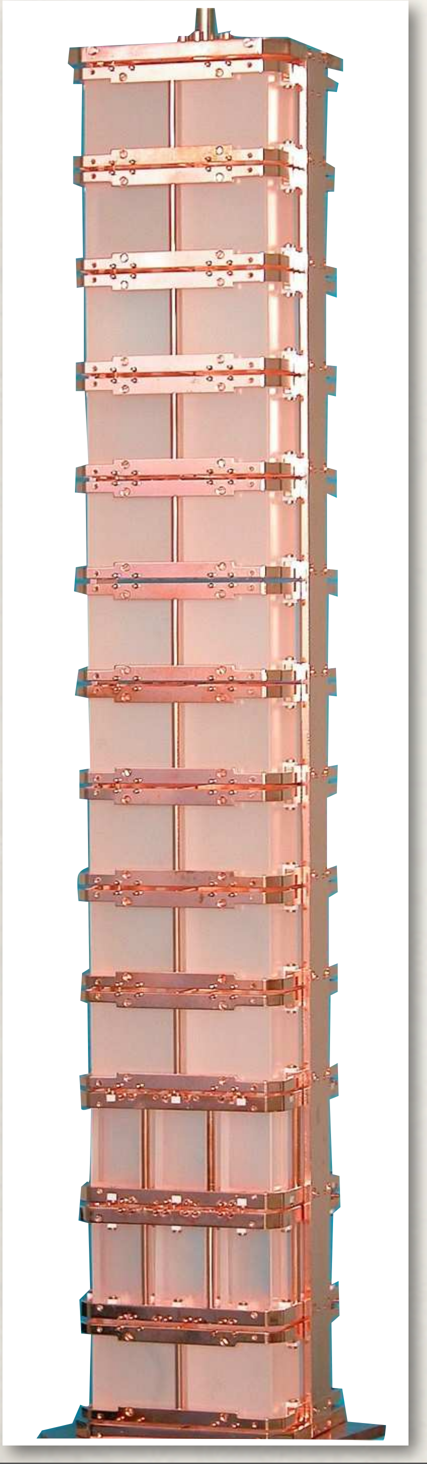
Cuoricino
2003-2008
~11kg ^{130}Te

CUORE-0
2011-2014
~11kg ^{130}Te



CUORE
2014-2019
~200kg ^{130}Te

The demonstrator: CUORICINO

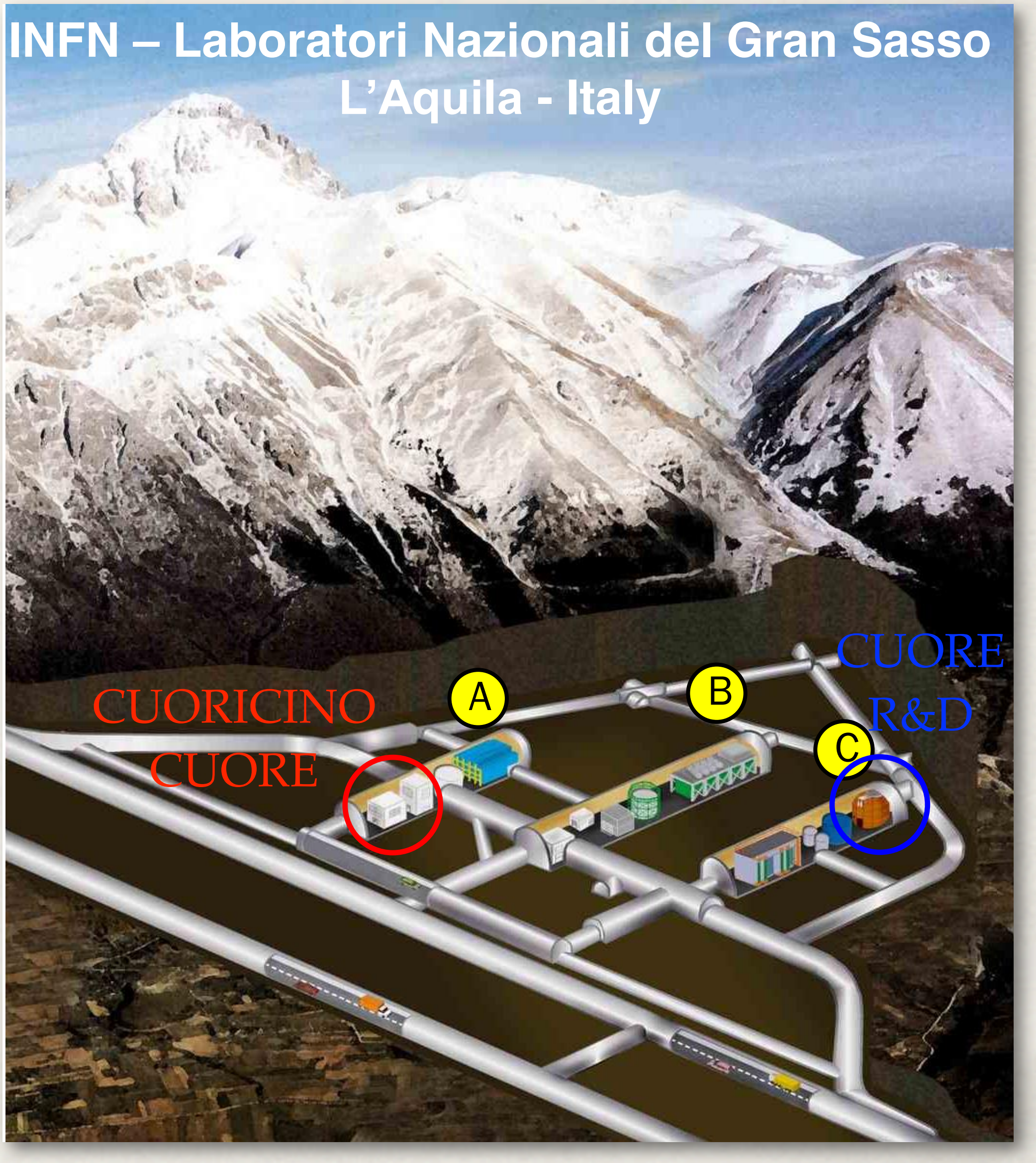


- Hosted in Hall A at the Underground National Laboratory of Gran Sasso (Italy), shielded by ~3650 m.w.e. against cosmic rays

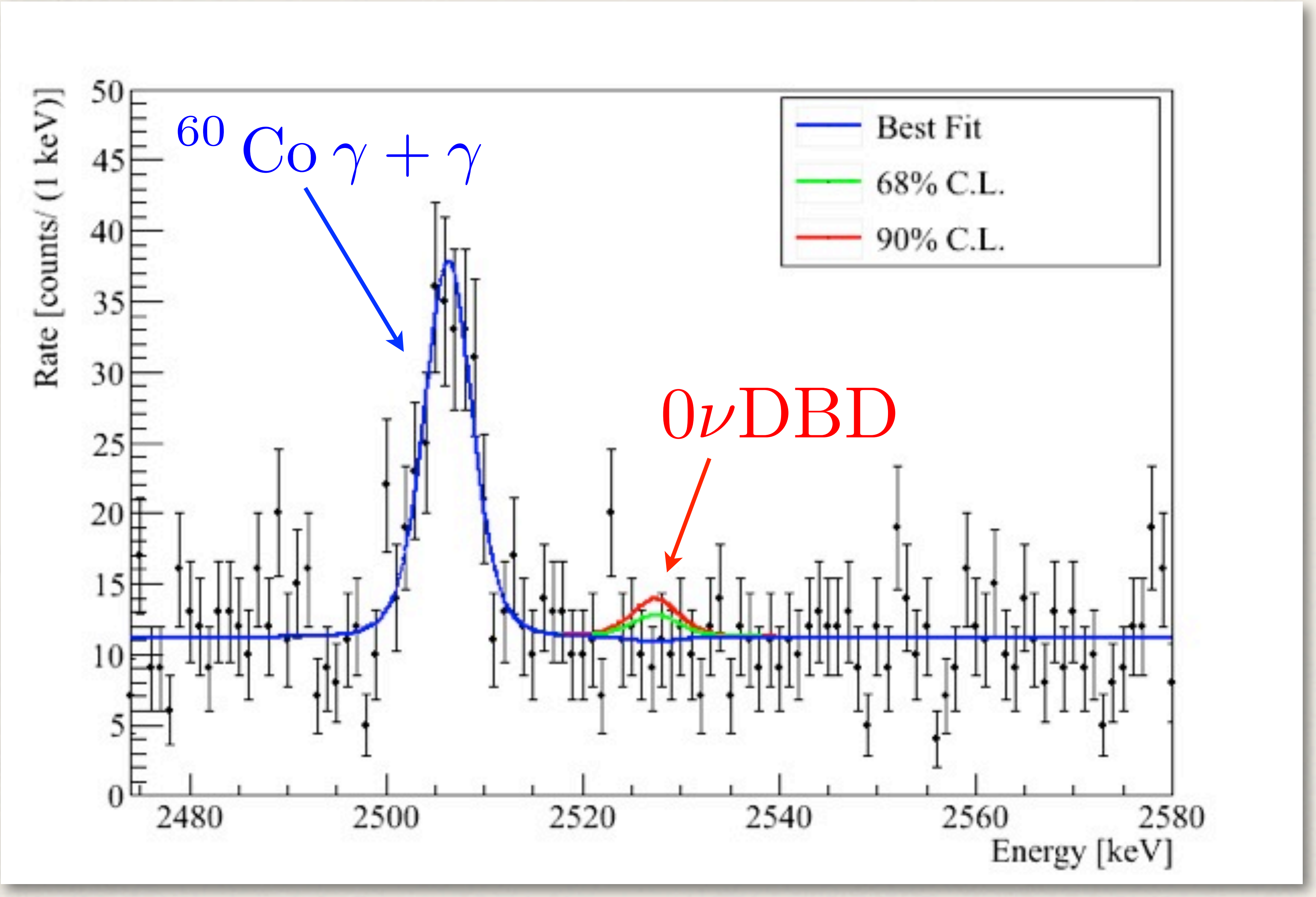
- Installed in a dilution refrigerator at ~10mK

- Several shields in Copper, Lead and Borated polyethylene

- Active mass:
  TeO_2=40.7 kg
  ^{130}Te=11.3 kg



CUORICINO limit on 0νDBD



Astropart. Phys. (2011), doi:10.1016/j.astropartphys.2011.02.002

Analyzed statistic:

$$M \cdot t = 19.75 kg(^{130}Te) \cdot y$$

0νDBD limit (90% C.L.)

$$T_{1/2} > 2.8 \cdot 10^{24} y$$

Effective neutrino mass limit:

$$m_{\beta\beta} < 0.3 \div 0.7 eV$$

Resolution:

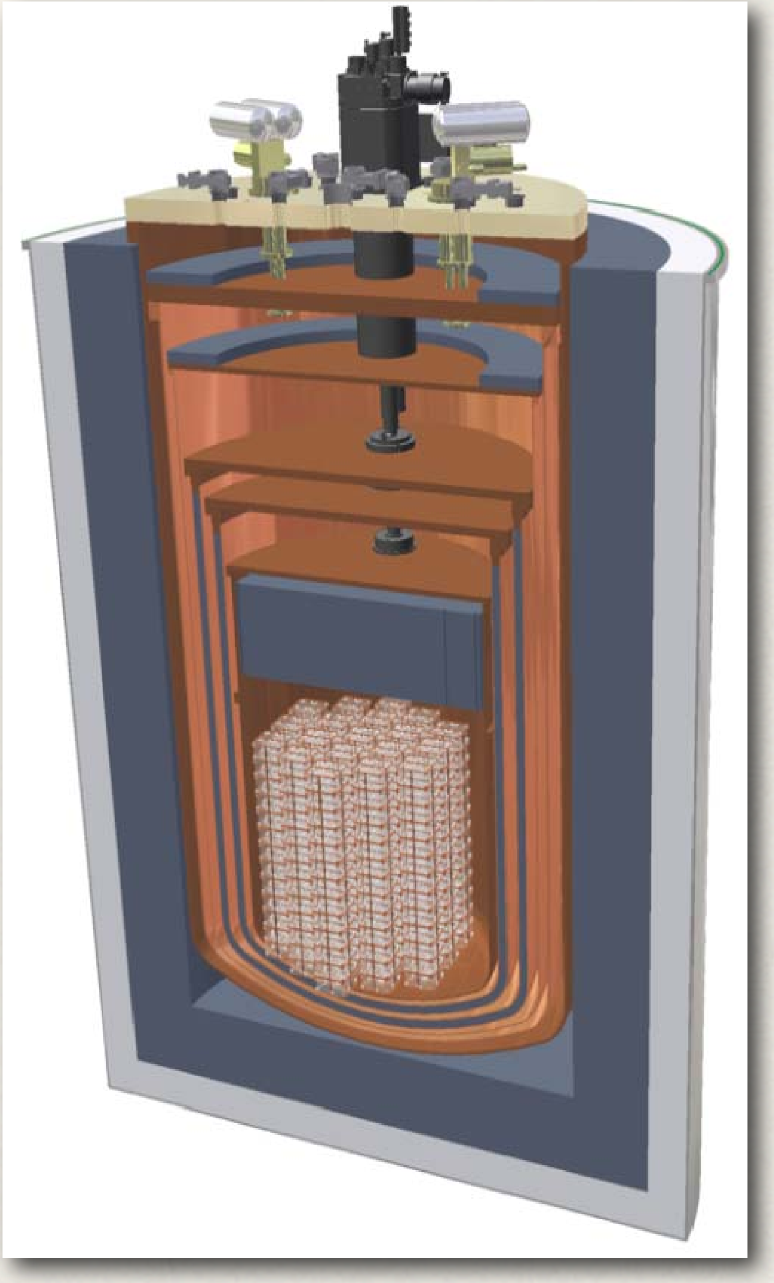
$$\Delta E = (6.3 \pm 2.5)\,\mathrm{keV\ \ FWHM}$$

CUORE-0: on the way to CUORE

- A single CUORE tower, realized with the same procedure as CUORE:
  - same assembly line
  - same Crystals and PTFE
  - same copper and surface cleaning
- The CUORE-0 detector will replace the CUORICINO tower in the Hall A dilution refrigerator
- CUORE-0 will be assembled during the summer and data taking will start before the end of the year

The CUORE detector

- 19 tower, with 988 TeO_2 crystals, $5x5x5 cm^3$ each
- **Total active mass:** 741 kg (~200 kg of ^{130}Te)
- **Energy resolution:** 5 keV @ 2615 keV (FWHM)
- **Background aim:** $< 10^{-2}$ counts/keV/kg/year



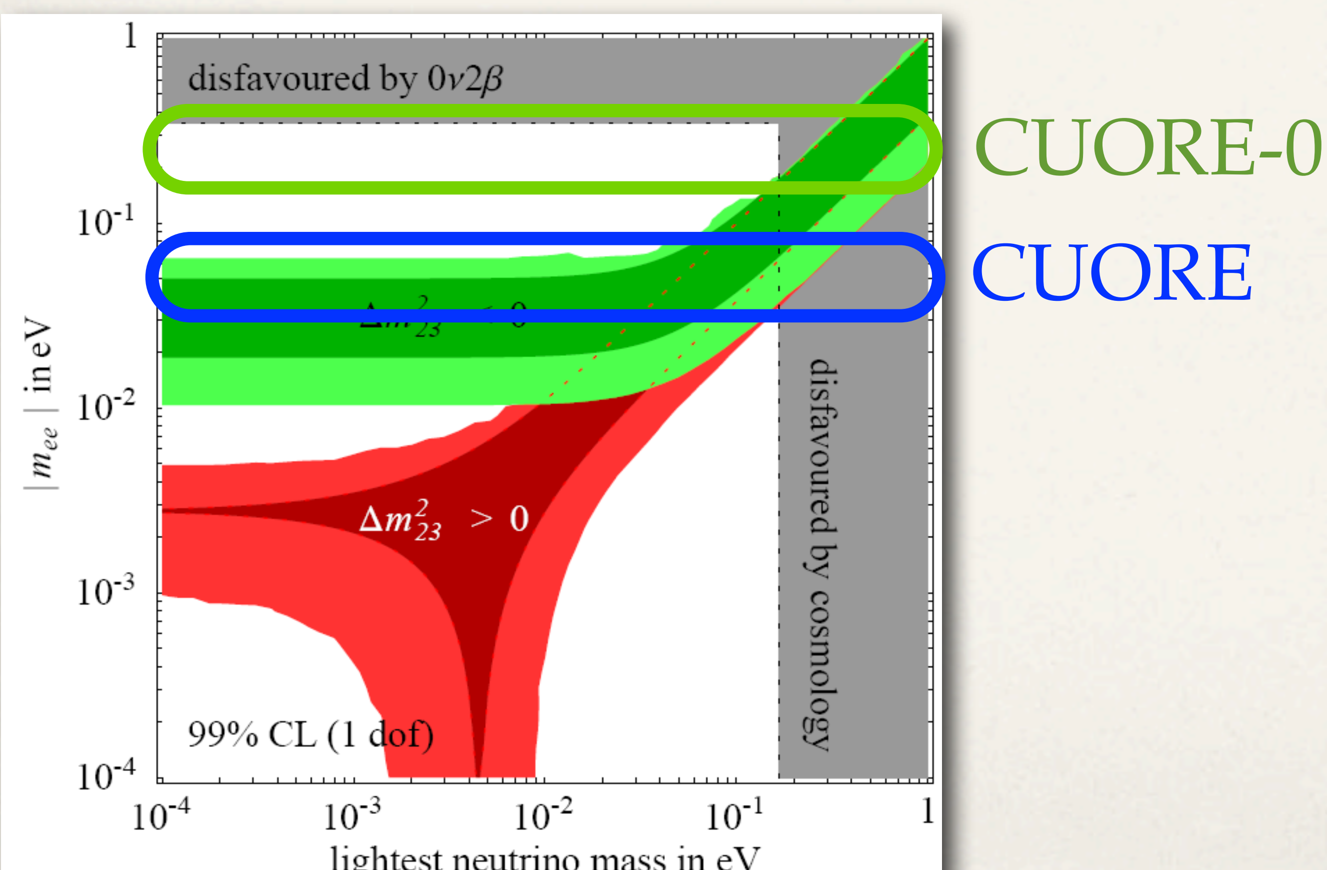
- Custom dilution refrigerator @ LNGS
- Improved shielding and material selection
- High efficiency in background rejection, due to the packed geometry

Data taking will start in 2014

CUORE sensitivity

M: mass [kg]
t: measuring time [y]
ΔE: energy resolution [keV]
B: background [c/keV/kg/y]

$$S_{0\nu} \propto \sqrt{\frac{M \cdot t}{B \cdot \Delta E}}$$



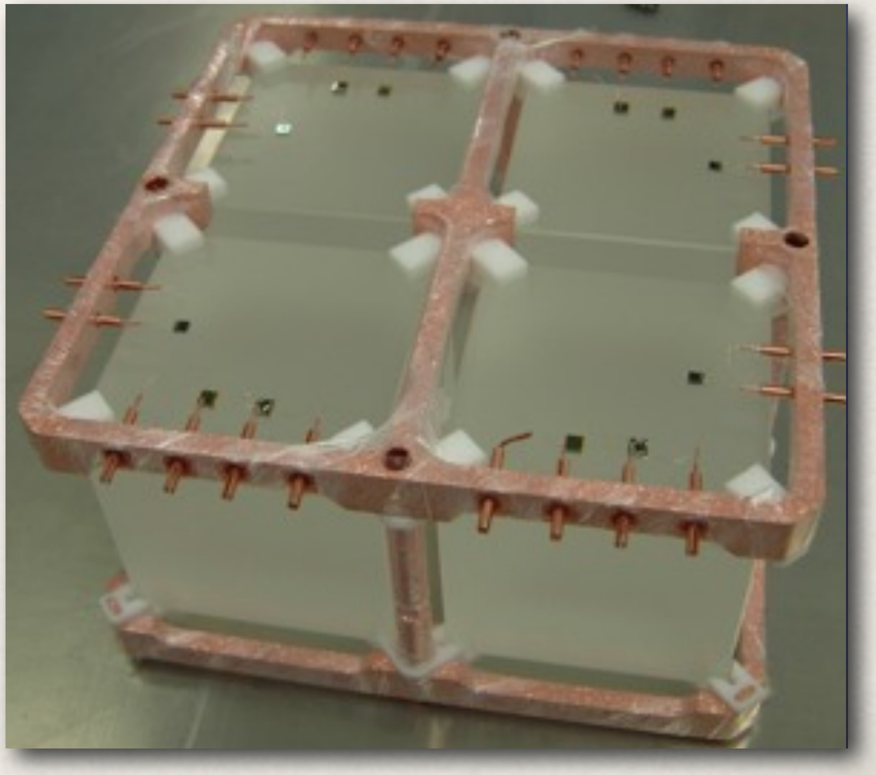
After 5 years of live time, assuming a background of 0.01 counts/keV/kg/y CUORE will have at 1σ of C.L. the sensitivity of $T_{0\nu}$= 2.1·10^{26} y
⇒ effective Majorana neutrino mass: [35 ÷ 82] meV

A new challenge: low energy region

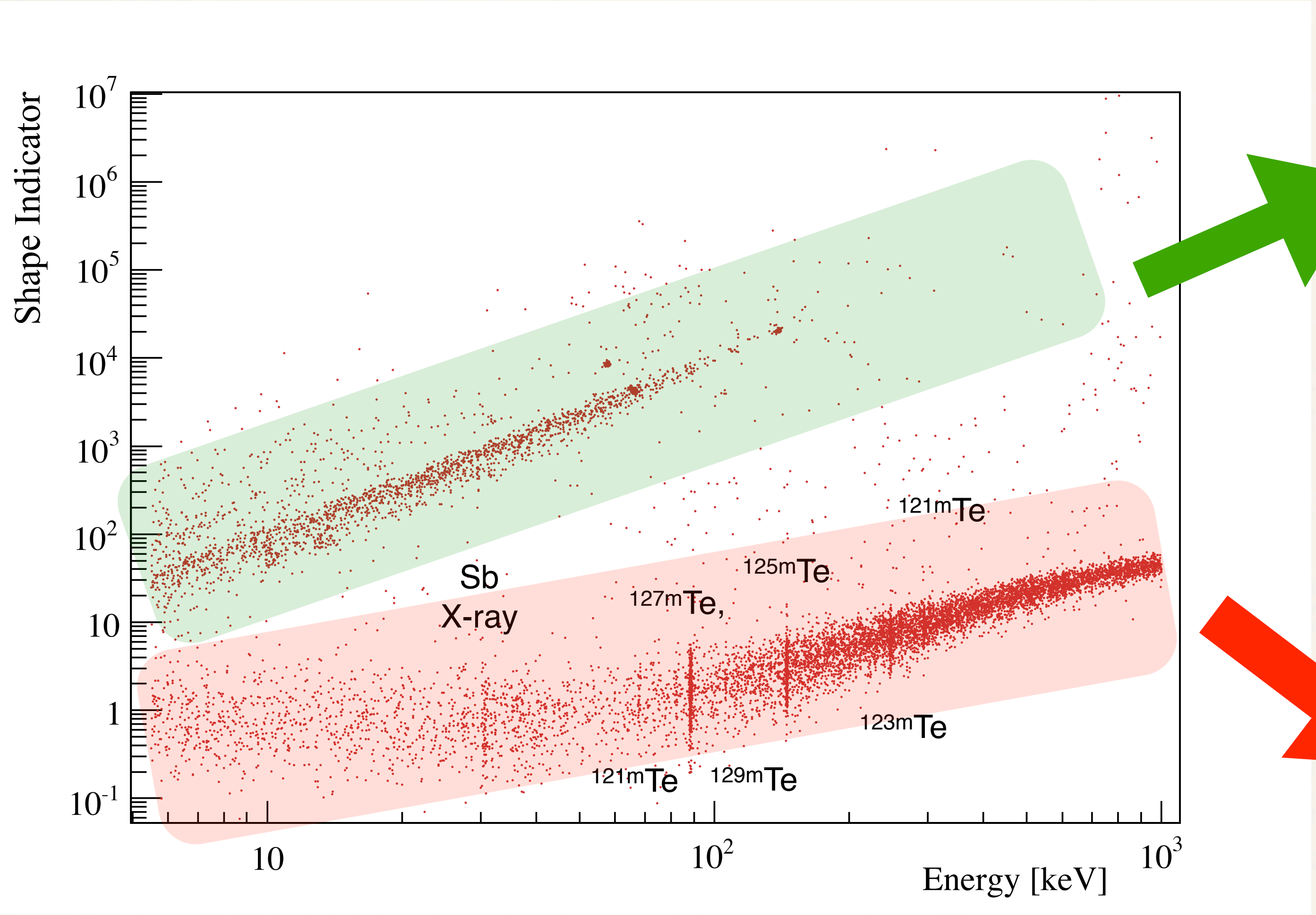
- Even if the main scientific aim of CUORE is the 0νDBD detection, we have to consider to use bolometric detectors to look for rare decays in other energy regions

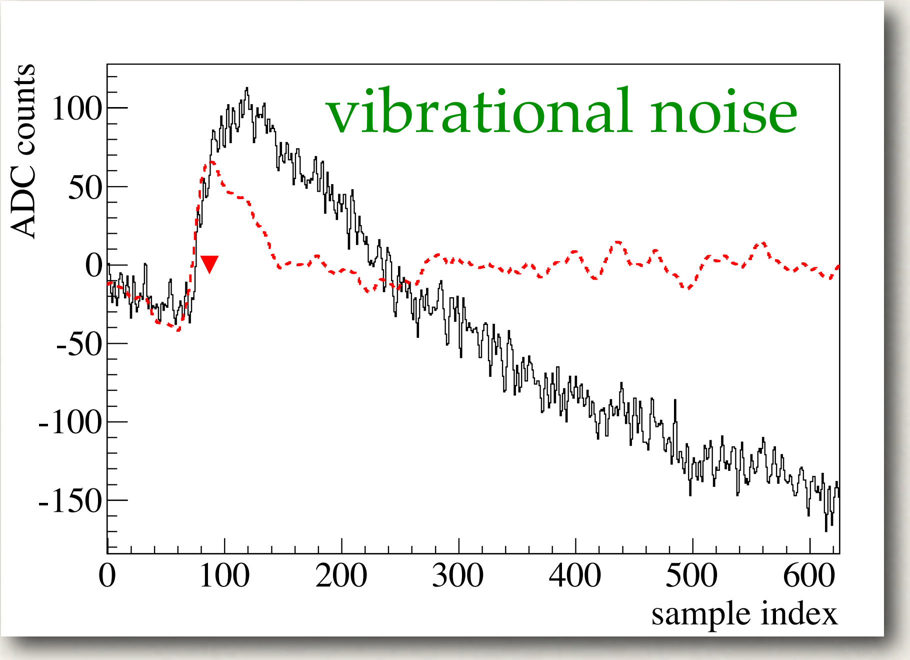
- A new trigger based on the matched filter technique and a pulse shape algorithm have been recently developed to lower the threshold down to the few keV region

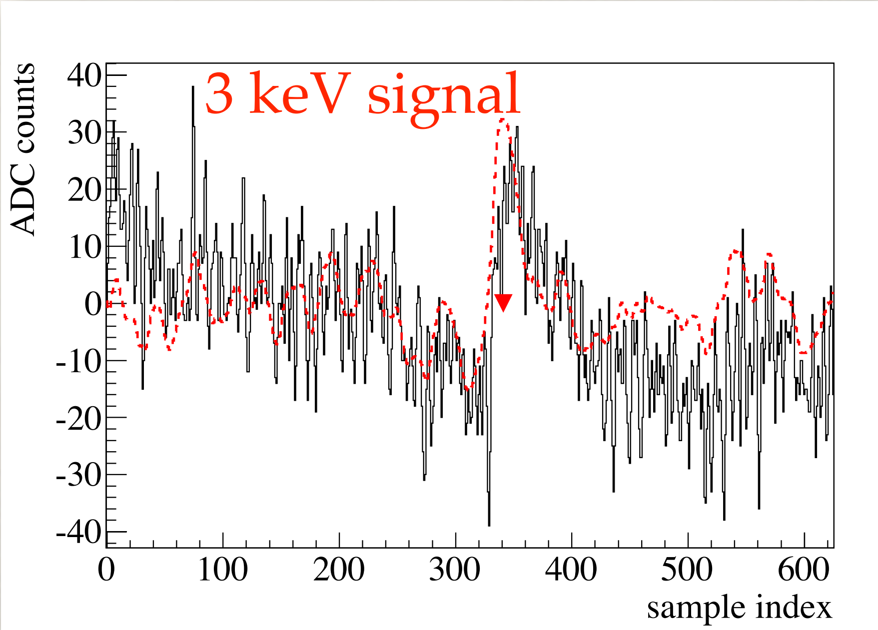
- The new analysis has been applied on a CUORE crystal validation run: 4 crystals arranged in a CUORE-like floor, operating in the Hall-C R&D cryostat



The new analysis

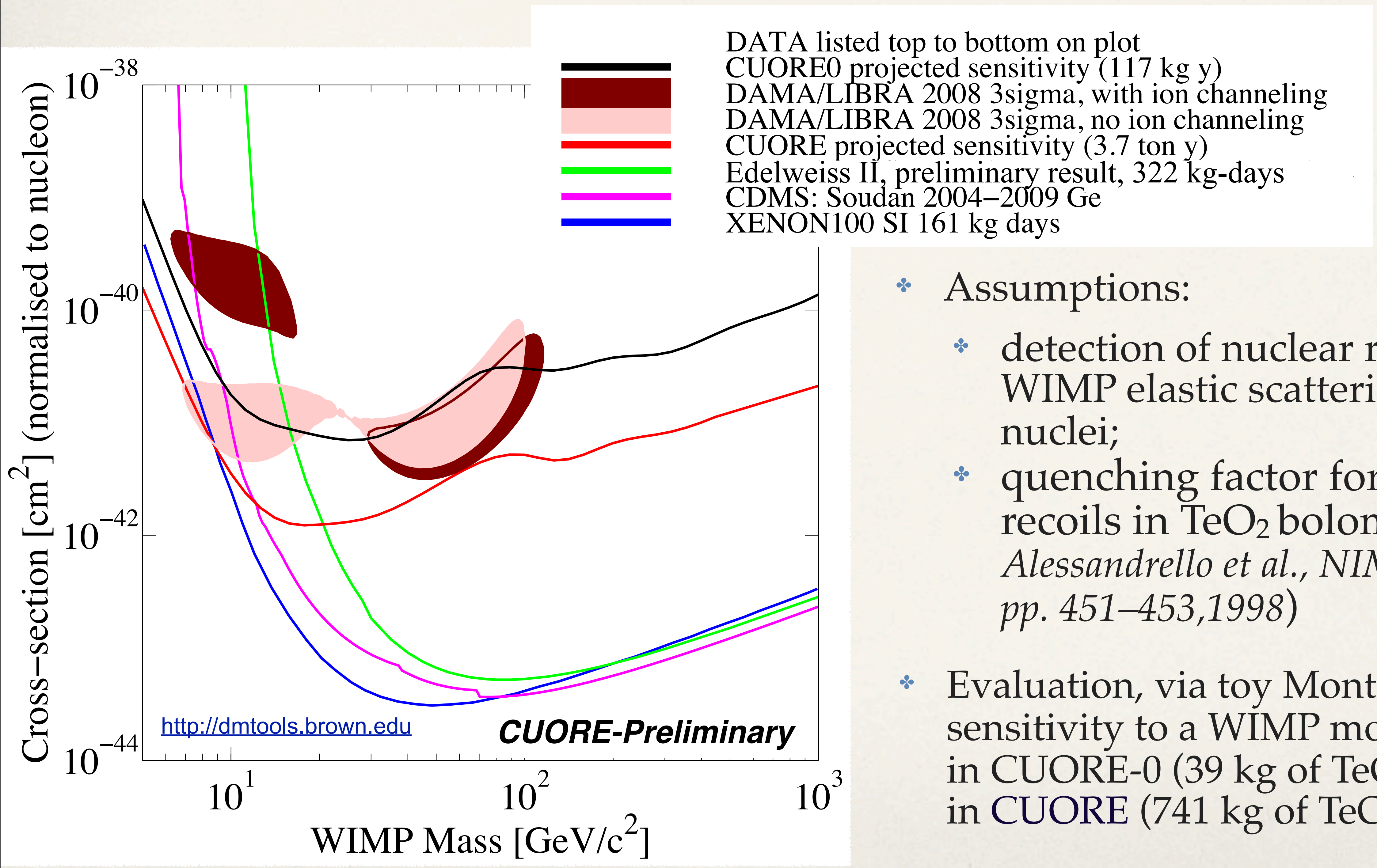






Discrimination of low energy
physical pulses from noise events

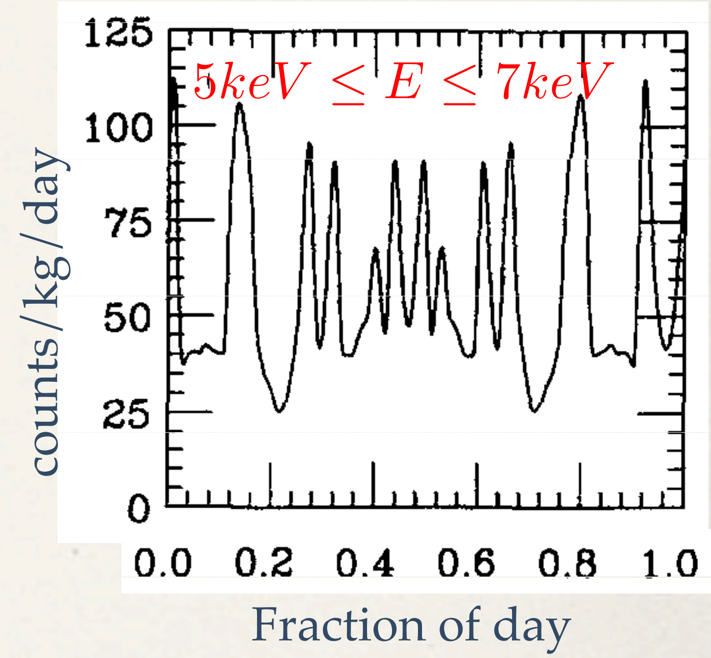
Sensitivity to Dark Matter search



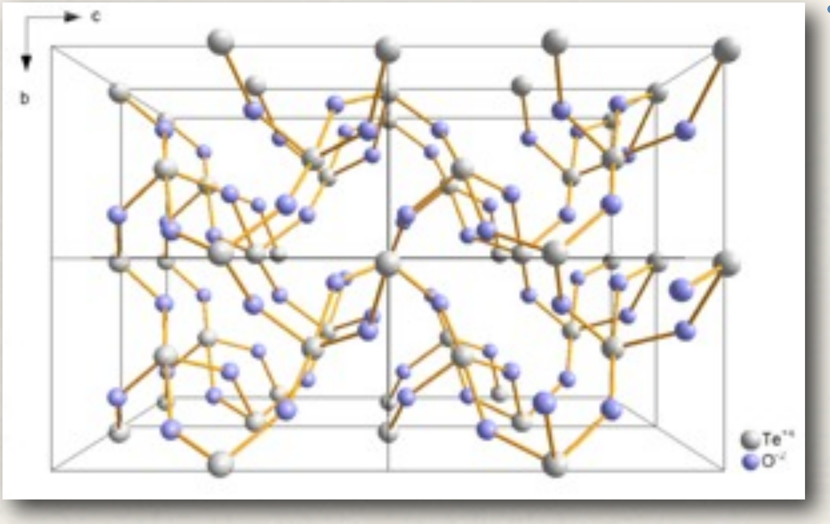
- Assumptions:
  - detection of nuclear recoils due to WIMP elastic scattering on TeO_2 nuclei;
  - quenching factor for nuclear recoils in TeO_2 bolometers is 1 (*A. Alessandrello et al., NIM A, vol. 409, pp. 451–453,1998*)
- Evaluation, via toy MonteCarlo's, of the sensitivity to a WIMP modulation signal in CUORE-0 (39 kg of TeO_2, 3 years) and in CUORE (741 kg of TeO2, 5 years)

Axion searches with CUORE

- The axion has been postulated to solve the strong CP problem in QCD
- Axion: a neutral pseudo-scalar particle, light and weakly coupled to matter
- Experimental approach: detection of solar axions through the Primakoff coherent conversion into photons. Strongly enhancement when the Bragg-Coherence condition on TeO_2 lattice is satisfied



S. Cebrian et al., Astroparticle Physics 10 (1999) 397-404.



- Requirements:
  - low threshold
  - low background
  - crystal orientation must be known
  - time series analysis techniques to detect the modulation

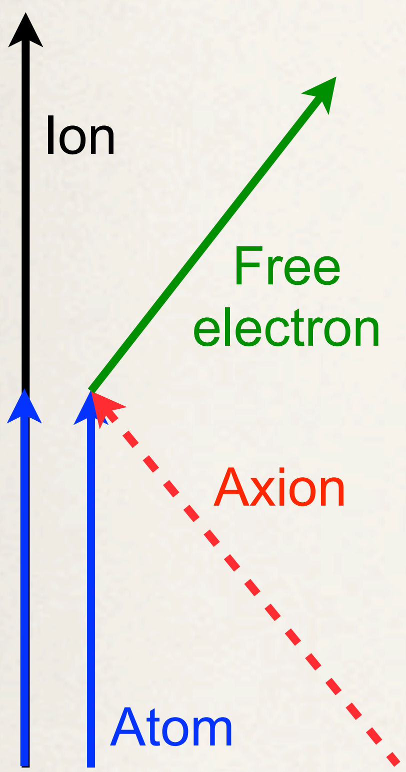
On going studies

Axion searches with CUORE

- Other detection possibility: axio-electric effect of solar axion from ^{57}Fe M1 line at 14.4 keV.

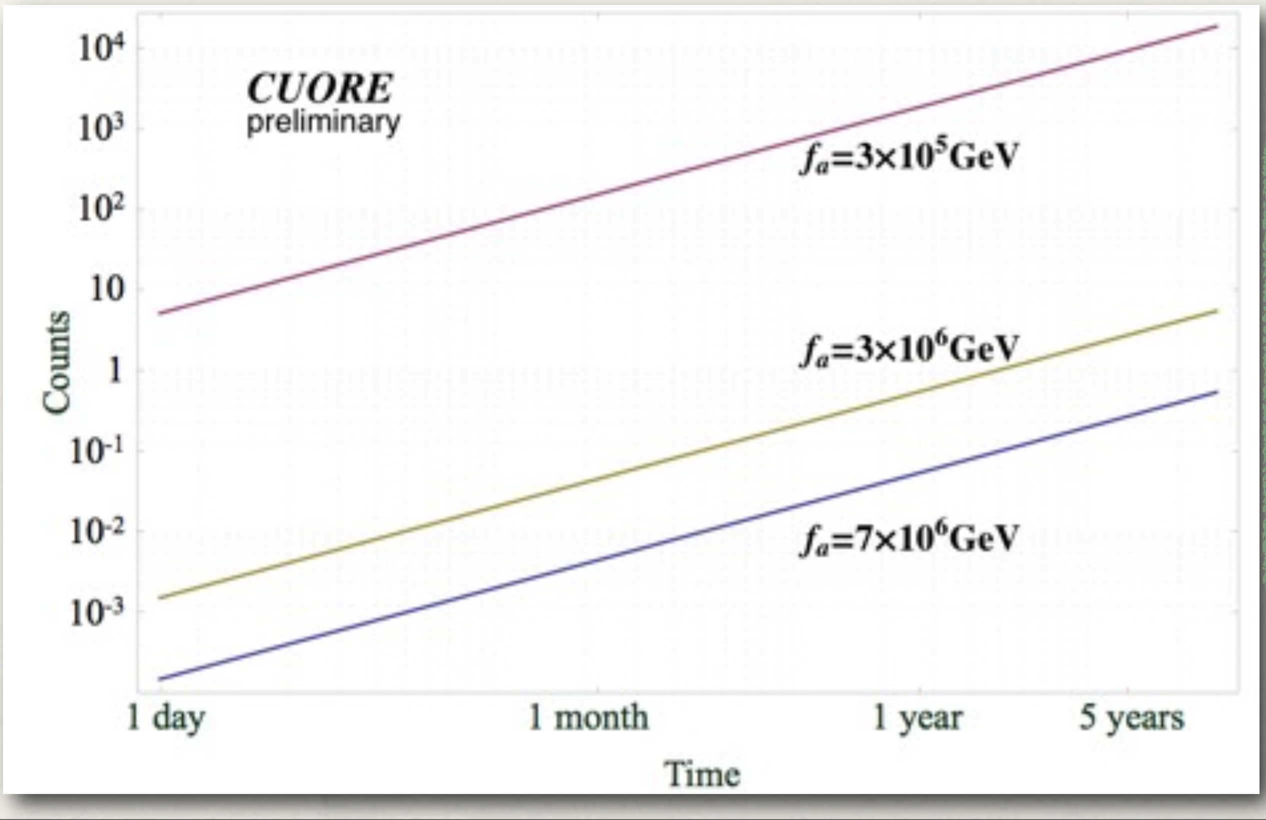
$$\Phi_a(14.4\,keV) = 1.0 \times 10^{11}\,cm^{-2}s^{-1}\left(\frac{10^6\,GeV}{f_a}\right)^2 C(F,D,S,z)^2$$

$$C(F,D,S,z) = -1.19\left(\frac{3F - D + 2S}{3}\right) + (D+F)\frac{1-z}{1+z}$$



where F=0.48, D=0.77, z=0.56, $0.15 \leq S \leq 0.55$
(F. T. Avignone, Phys. Rev. D 79, 035015 (2009)).

CUORE Axion detection rates (S=0.55)



On going analysis on a test detector: Stay tuned!

Conclusions

- TeO_2 bolometers represent a well established technique, very competitive for the 0νDBD search
- CUORICINO has provided one of the most stringent limits on 0νDBD
- CUORE will have the capability of exploring the inverse hierarchy on neutrino mass spectrum
- CUORE-0 will be the final test for CUORE and will soon overtake CUORICINO sensitivity to 0νDBD
- Lowering the threshold with the new trigger technique, CUORE could play an important role in the Dark Matter and Axion searches