CUORE and beyond: bolometry techniques to explore the inverted neutrino mass hierarchy

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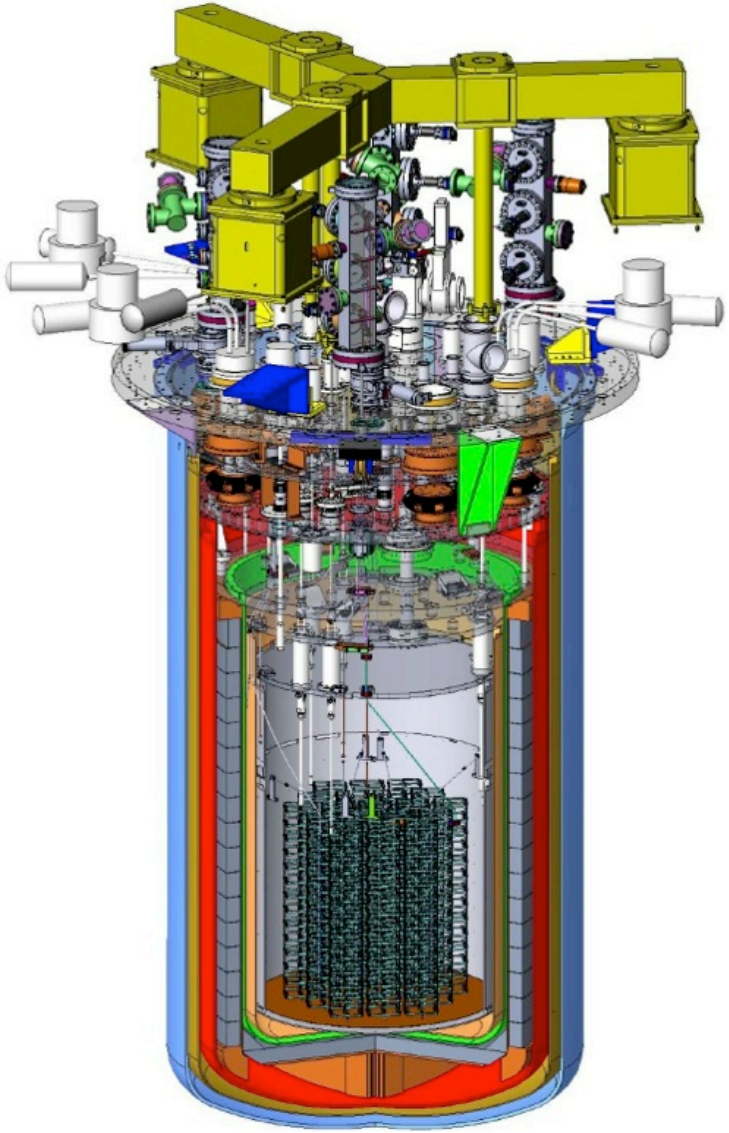
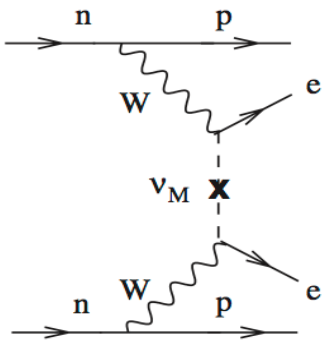
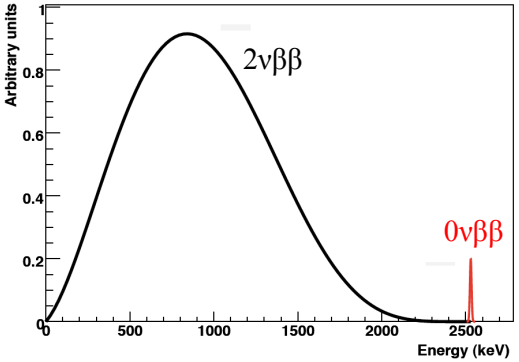
On behalf of the CUORE collaboration

TAUP, Asilomar, CA
September 8 - 13, 2013

CUORE



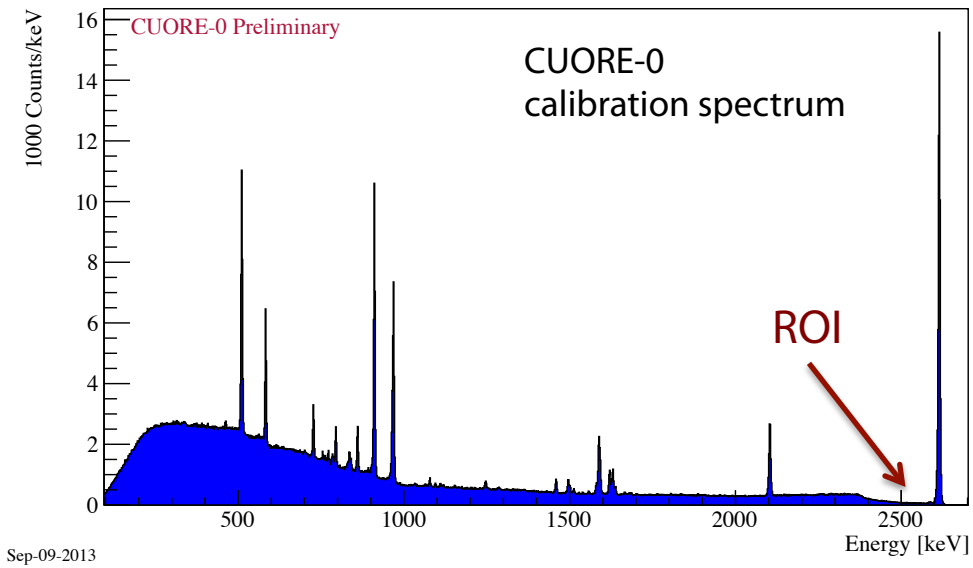




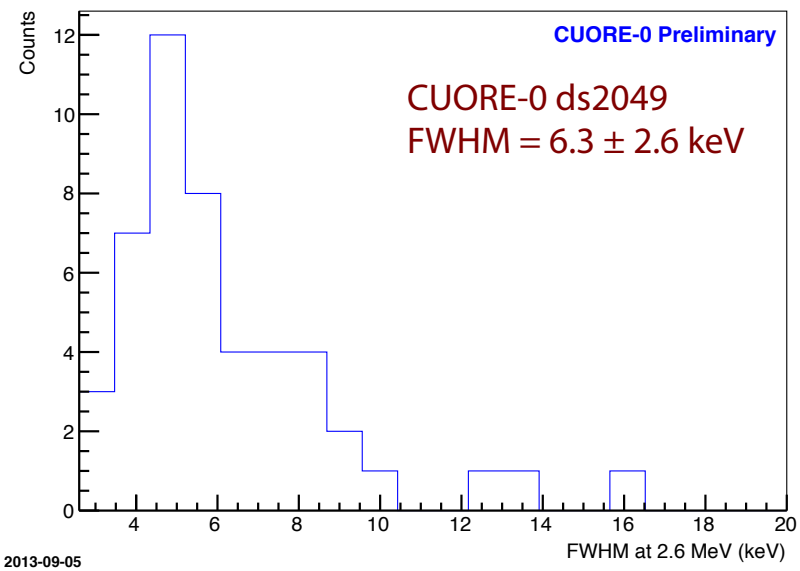
Cryogenic Underground Observatory for Rare Events

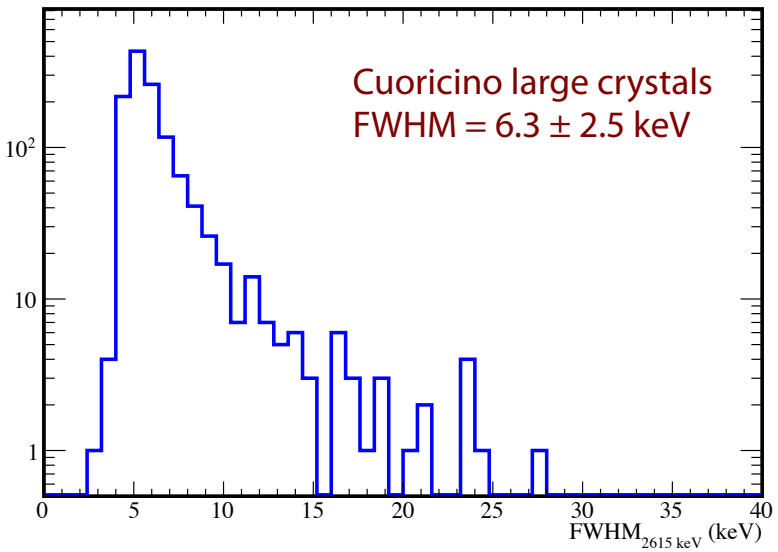
- 988 TeO_2 crystals run as a bolometer array
  - 5x5x5 cm^3 crystal, 750 g each
  - 19 Towers; 13 floors; 4 modules per floor
  - 741 kg total; 206 kg ^{130}Te
  - 10^{27} ^{130}Te nuclei
- Excellent energy resolution of bolometers
- New pulse tube dilution refrigerator and cryostat
- Radio-pure material and clean assembly to achieve low background at ROI

Excellent energy resolution



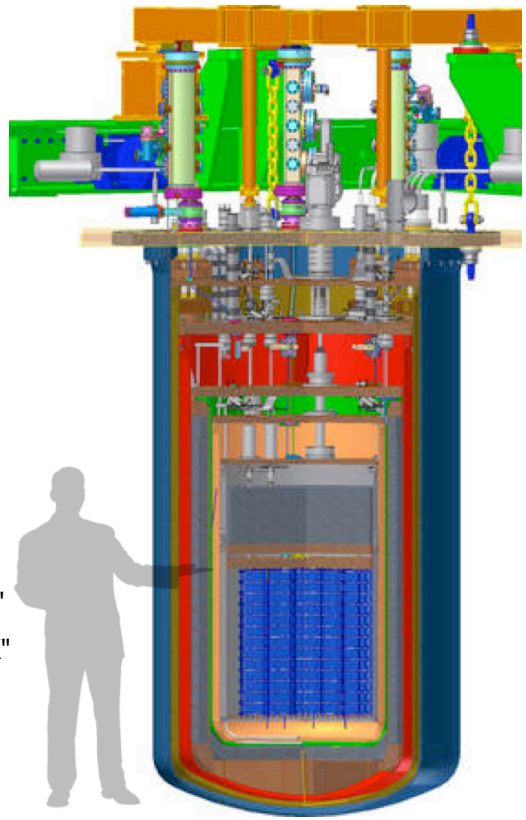
- CUORE-0 matches the performance of Cuoricino, without much tuning
  - New wiring scheme (required by assembly procedure)
  - Resolution and energy threshold optimization is under way.



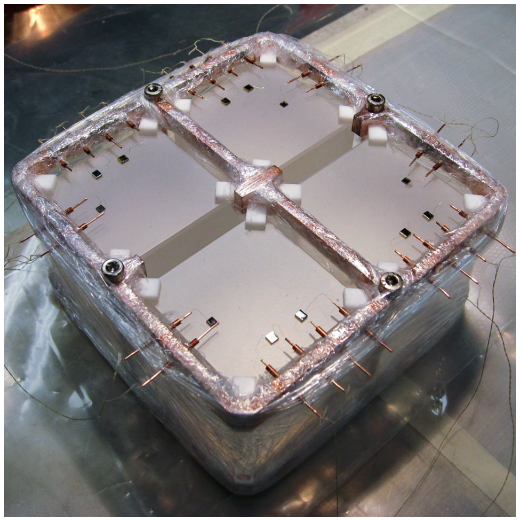


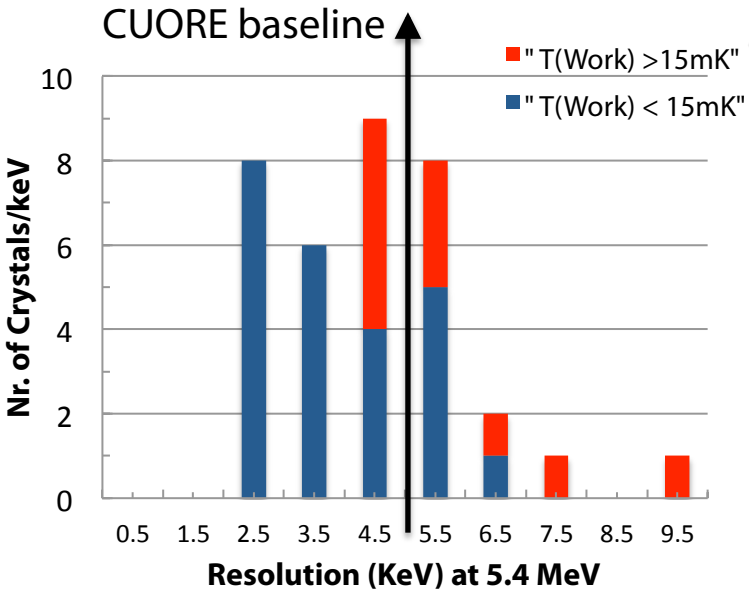
Demonstrated 5 keV energy resolution

- < 5 keV resolution routinely achieved in our R&D runs.
- Obvious temperature dependence.
- CUORE's new cryostat
  - 10 mK base temperature → larger signal
  - Independent suspension of the detector array from the dilution unit. → smaller noise

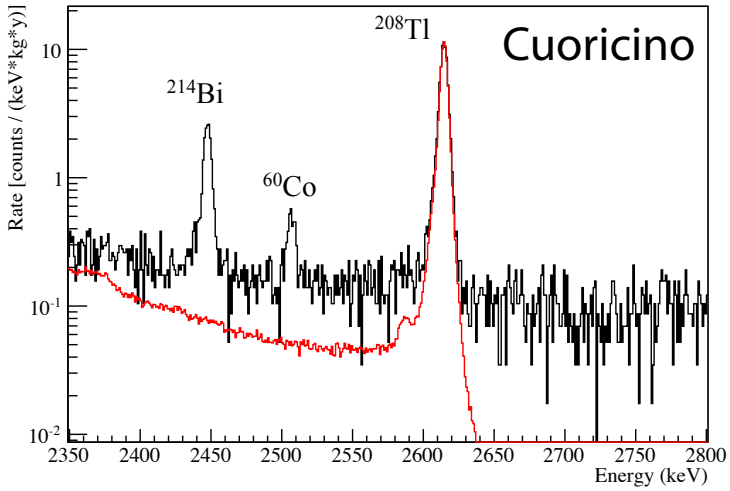


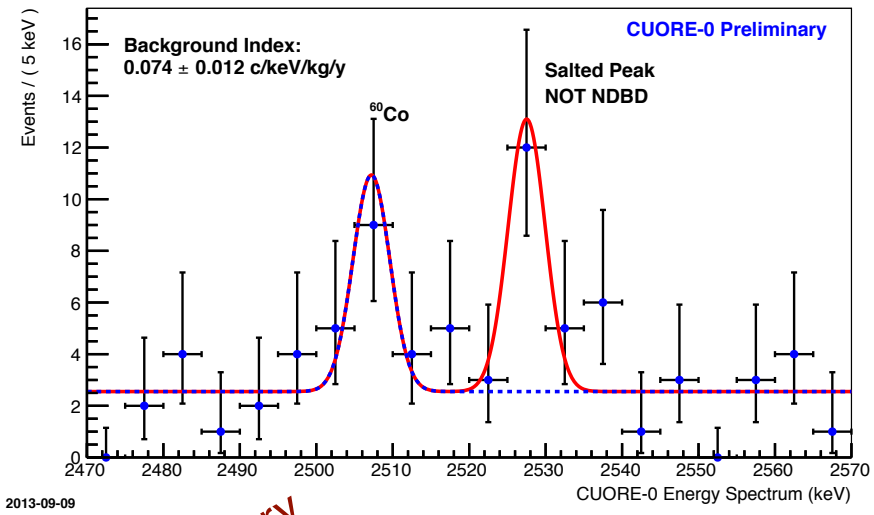
R&D Runs: CCVR





Background reduction





Preliminary

Cuoricino background in the ROI:
0.153±0.006 cts/ (keV kg y)

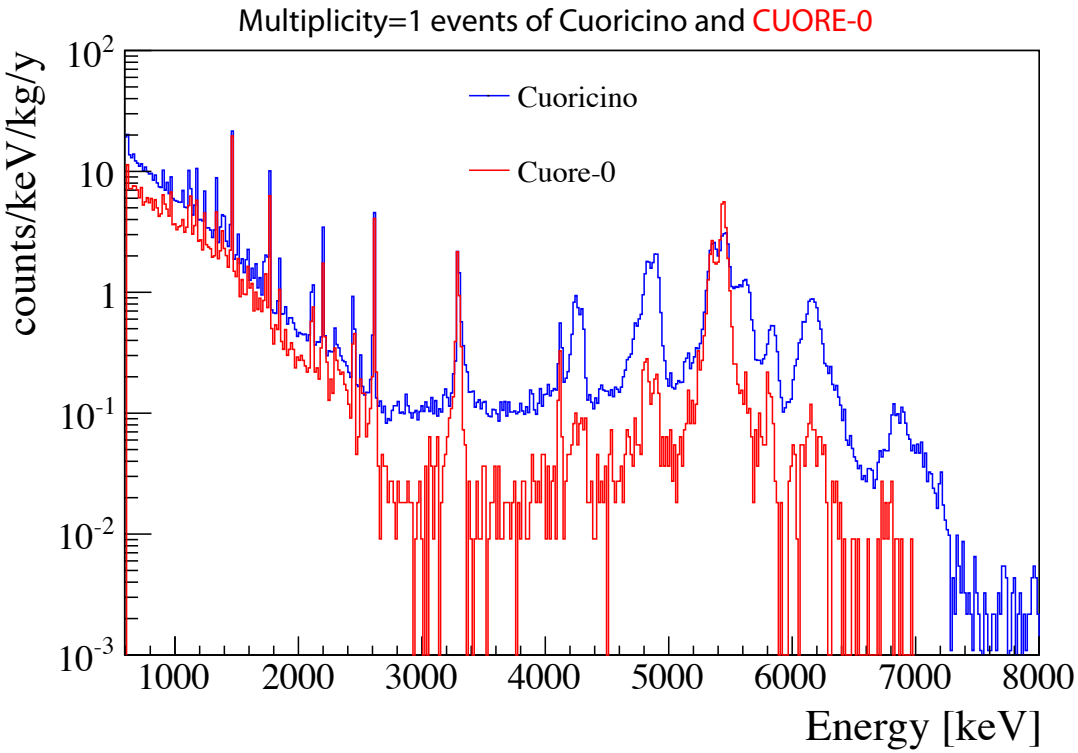
CUORE-0 background in the ROI:
0.074±0.012 cts/ (keV kg y)

1. 0.05 ~ 0.06 from γ peak of ^{208}Tl —Same Cryostat→ 1. γ peak of ^{208}Tl: the same

2. ~0.1 from copper surface contamination
3. ~0.01 from crystal surface contamination

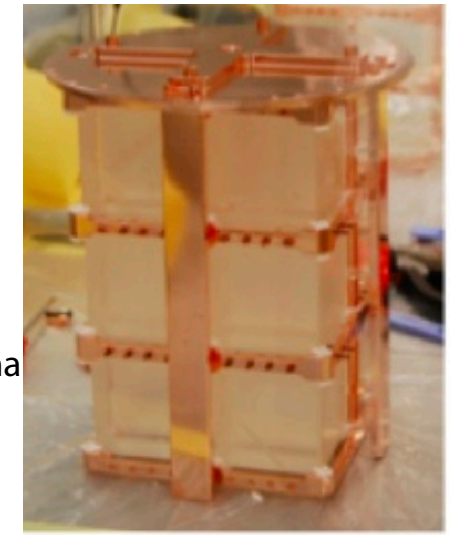
} —Copper cleaning, Clean assembly, Better surface treatment→ 2. 0.019±0.002: copper and crystal surface contamination

CUORE-0 background improvement in alpha region



Copper surface treatment

- Tumbling
- Electro-polishing
- Chemical etching
- Magnetron Plasma etching

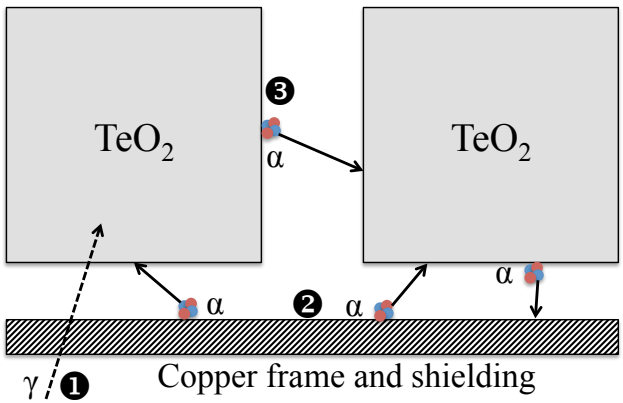


TECM cleaned copper

Minimize re-contamination

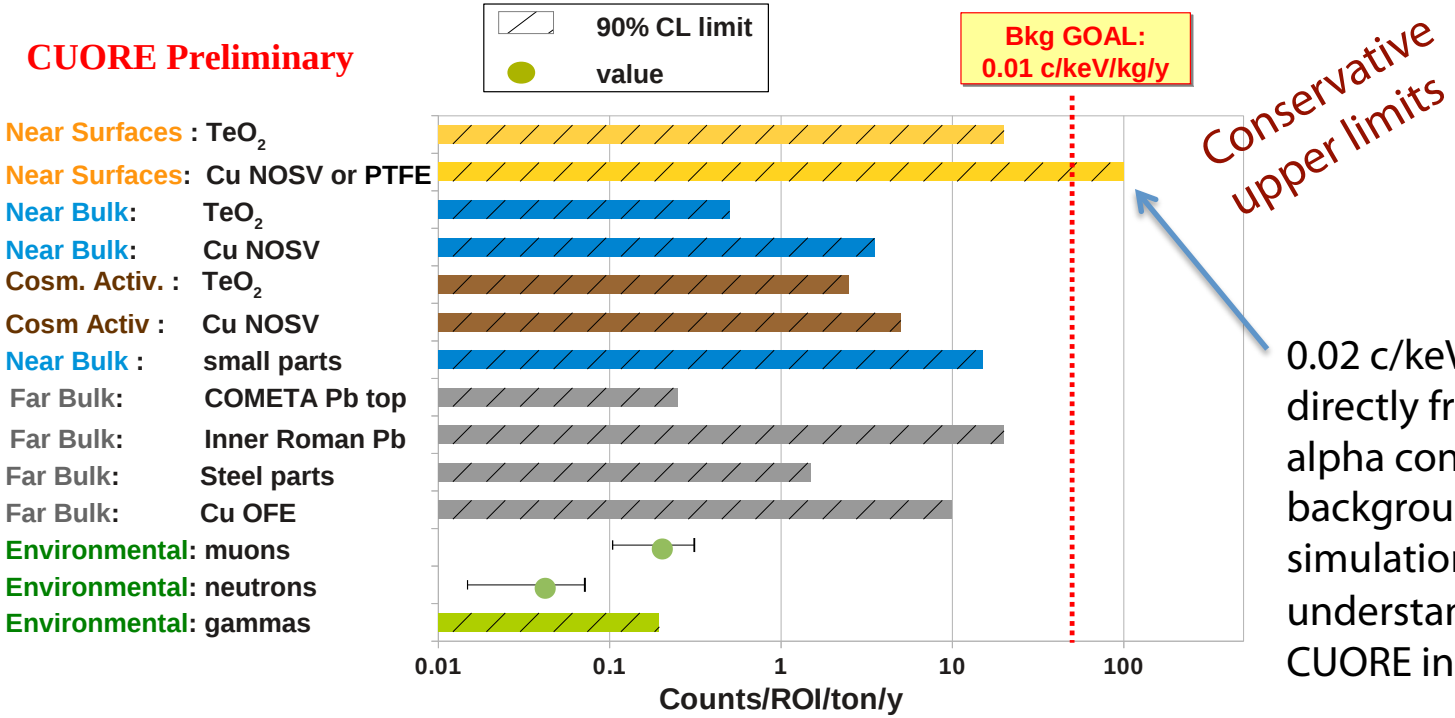
- Clean storage under N_2 and careful tracking
- Better glove boxes and certified clean tools
- Stringent assembly procedure

Background: from CUORE-0 to CUORE



CUORE background in ROI

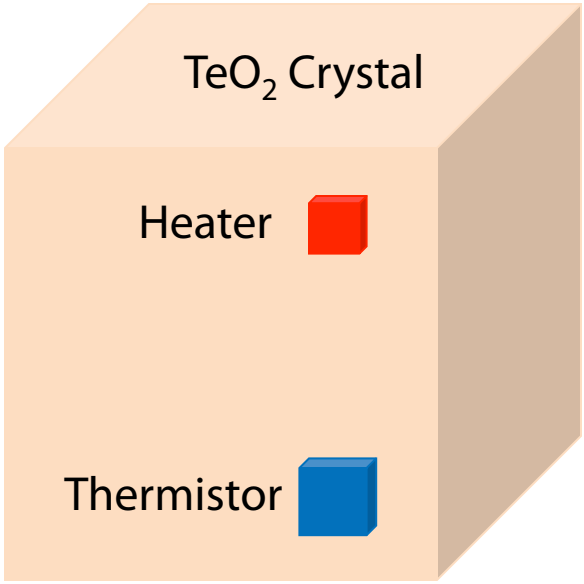
1. New cryostat with radio-pure materials
   → negligible gamma contributions
2. More effective self-shielding
   → Copper surface background can be reduced below background goal.
3. More effective anti-coincidence
   → negligible surface alpha from crystals.

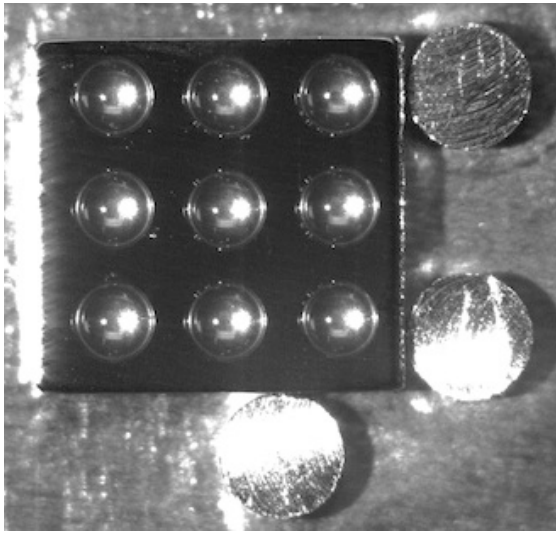


Conservative upper limits

0.02 c/keV/kg/y directly from CUORE-0 alpha continuum background. Full MC simulation to understand scaling to CUORE in progress.

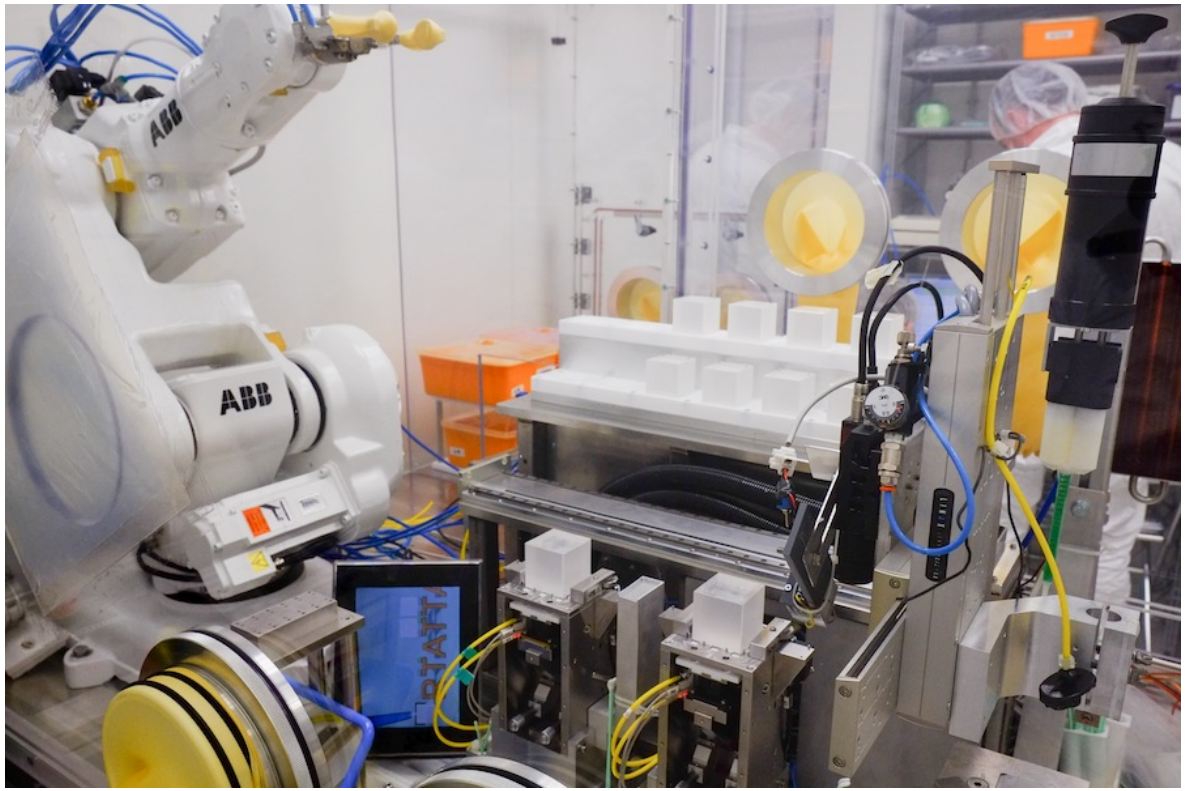
Instrumenting a tower -- Gluing





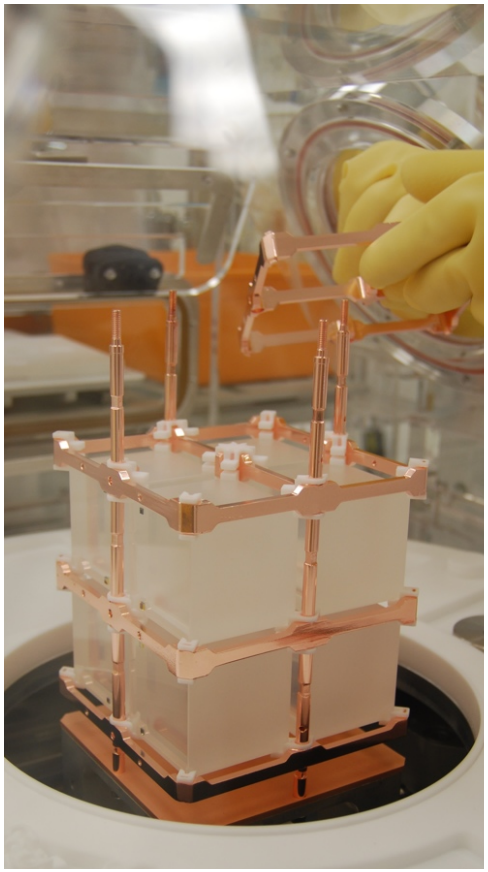
Robotic system attaches thermistors and heaters to crystals

- Uniformity attempts to make more uniform energy resolution
  - Uniformly sized glue dots. Size controllable and repeatable.
- Increase the survival fraction of the crystals.



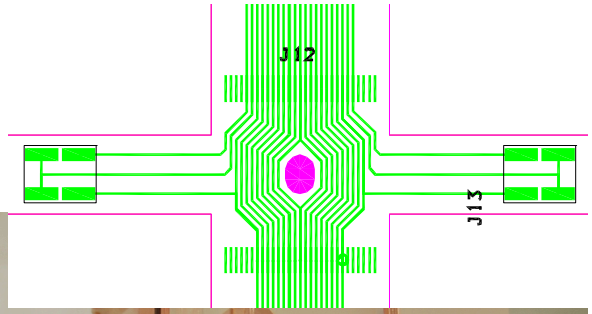
Instrumenting a tower – mechanical assembly

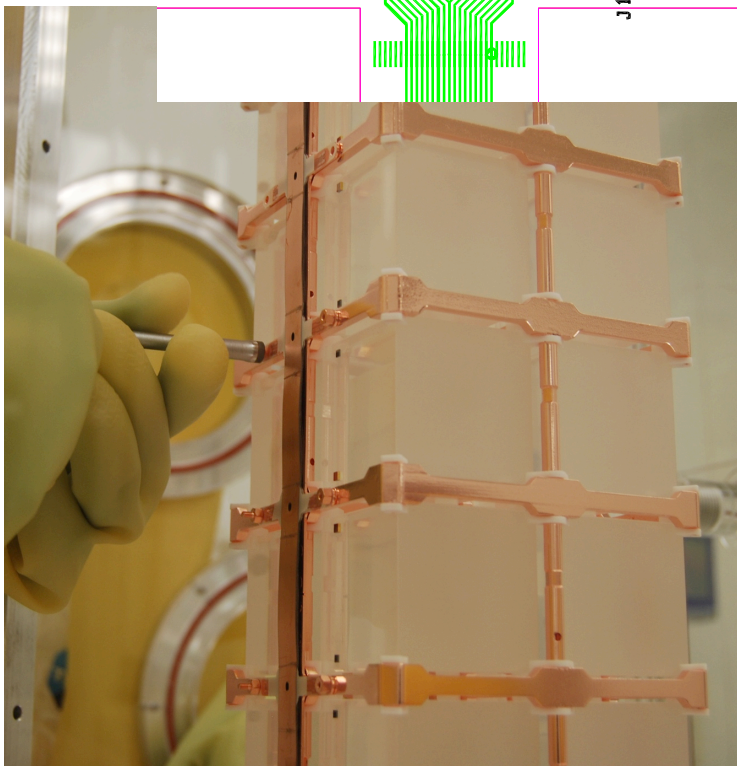
Copper dry run



Mechanical assembly of crystals and copper frames into towers

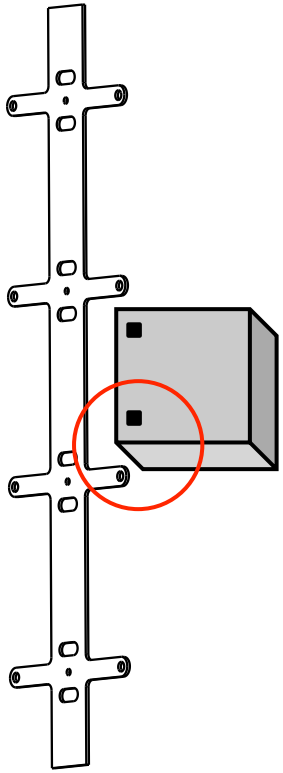
Attach flex copper traces with bonding pads on the tower

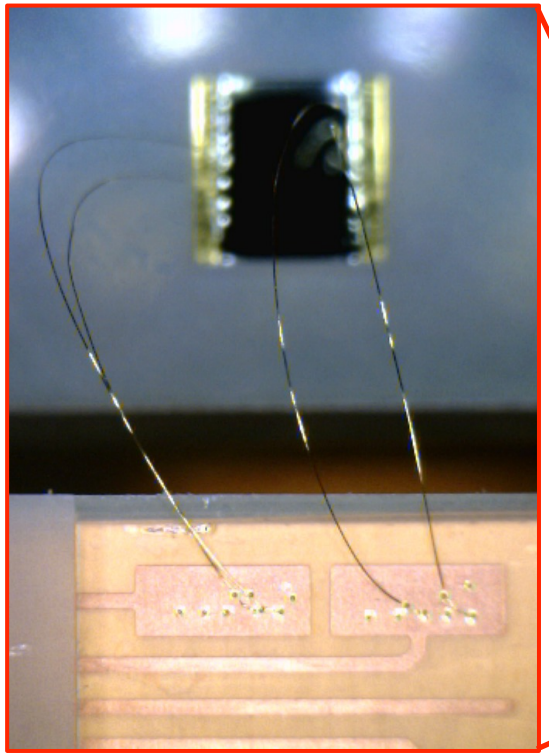


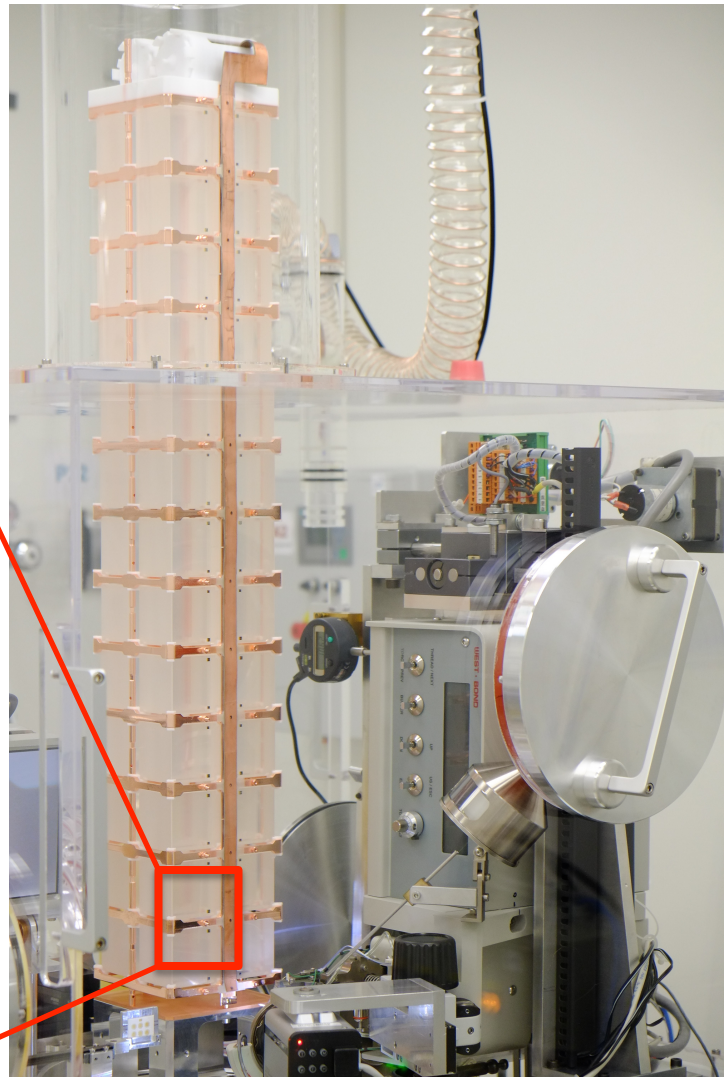


Instrumenting a tower – wire bonding

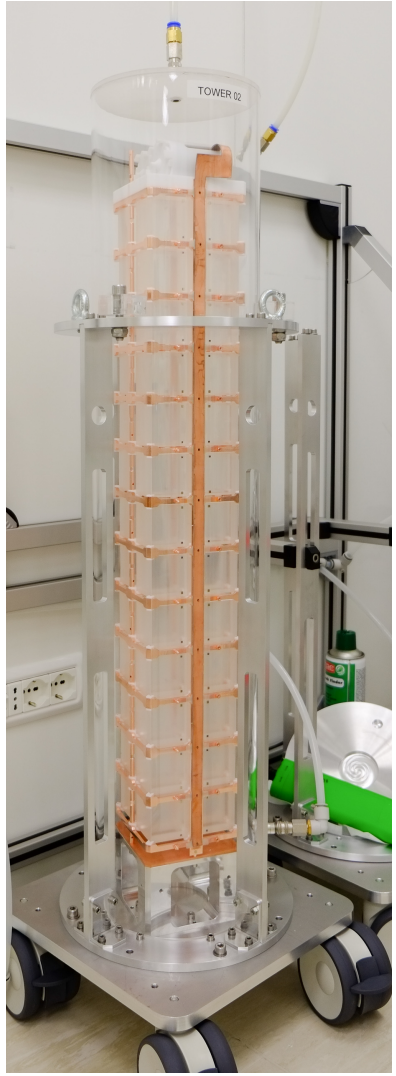
Wire bond thermistors and heaters to tower cabling







Assembly on schedule

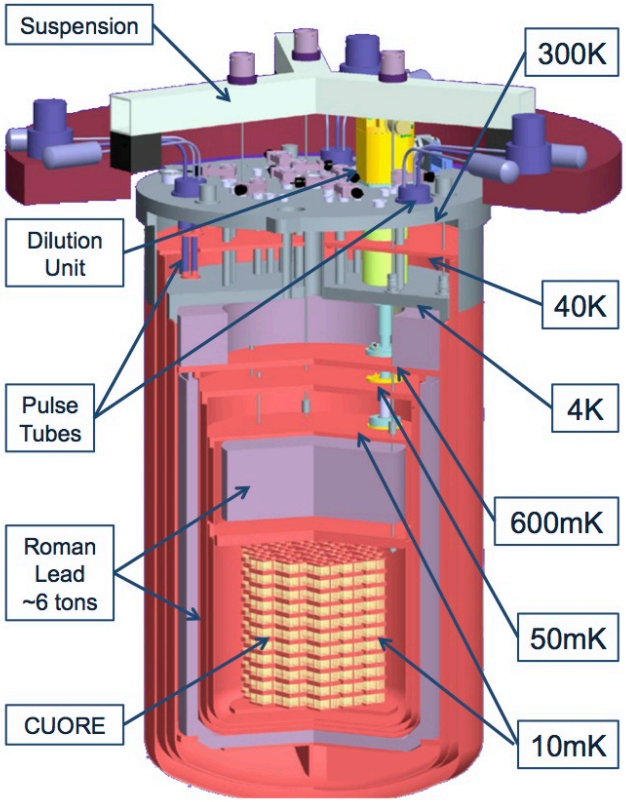


X19

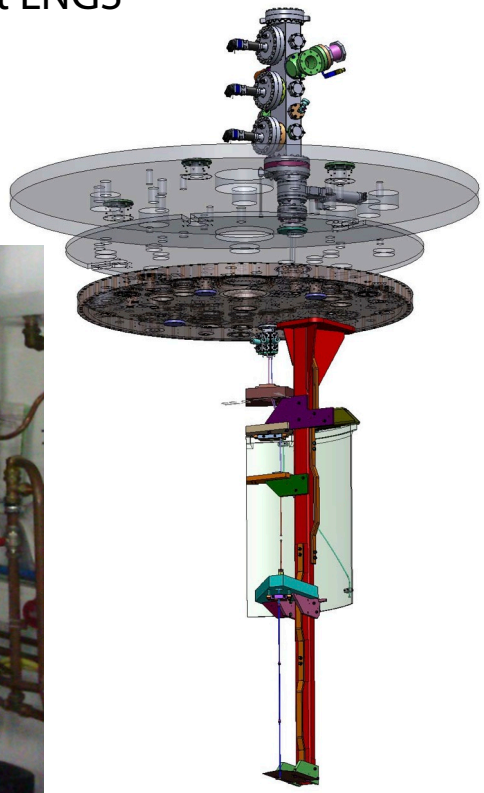
- Tower assembly started in February 2013 and will finish by June 2014.
- Must transform ~10000 components into 19 ultra-clean towers.
- All operations in five glove boxes
- We are on schedule
  - 10 towers worth of crystals glued with thermistors and heaters.
  - 6 towers assembled,
  - 4 towers bonded and put to storage
- Considerable experience gained during the assembly process, but assembly is not routine.

CUORE cryogenics and calibration system

- ~ 1 ton of bolometer array at 10 mK baseline temperature
- ~20 tons at various low temperatures
- Stringent heat load requirement for calibration system

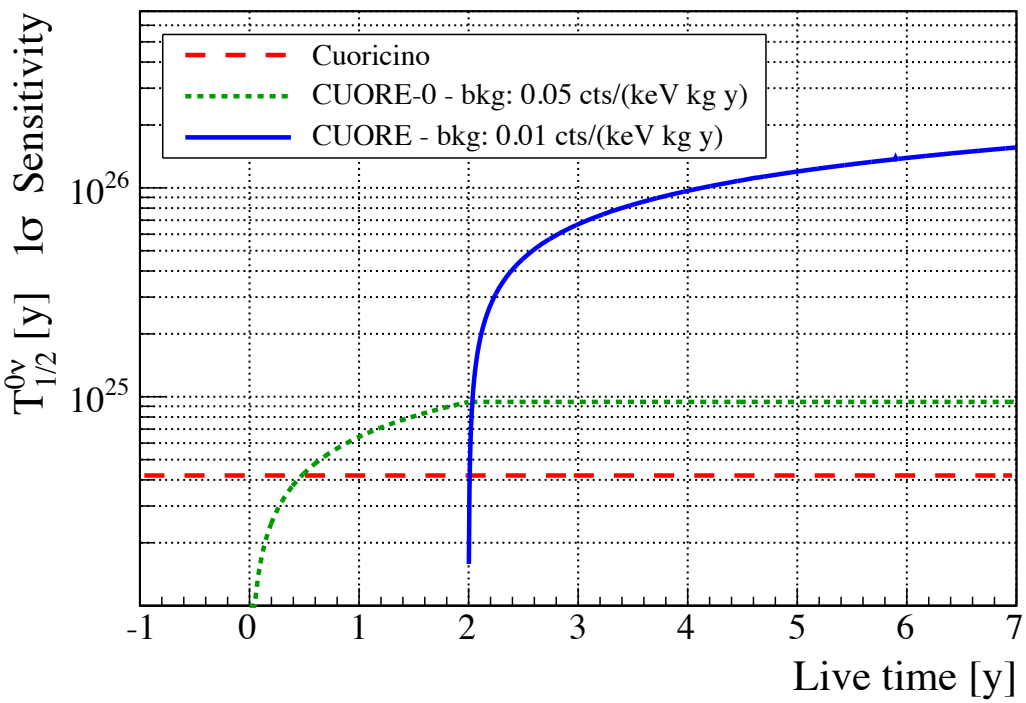


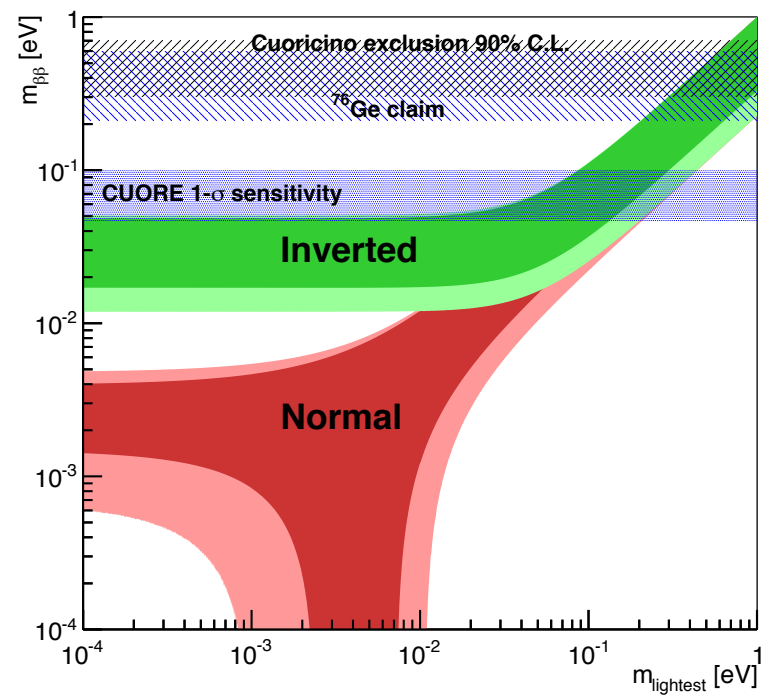
- Cryostat 4K test passed: IVC stable at 3K.
- Dilution unit: ~5 mK reached in test setup at LNGS
- Calibration system passed 4K test at LNGS



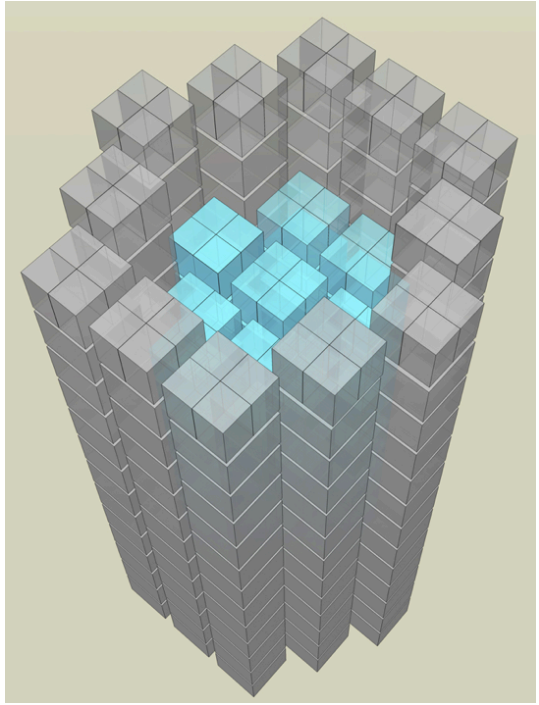
CUORE sensitivities

- 1σ sensitivity $T_{1/2}^{0\nu\beta\beta} = 1.6 \times 10^{26}$ y; effective Majorana mass down to 47-100 meV.
  - Assuming a background rate of 10^{-2} counts/(keV kg y), and 5 keV FWHM
  - 5 years of live time
- Detector assembly will be finished by June 2014, followed by installation in July and commissioning by the end of 2014.
- Data taking will start in 2015.





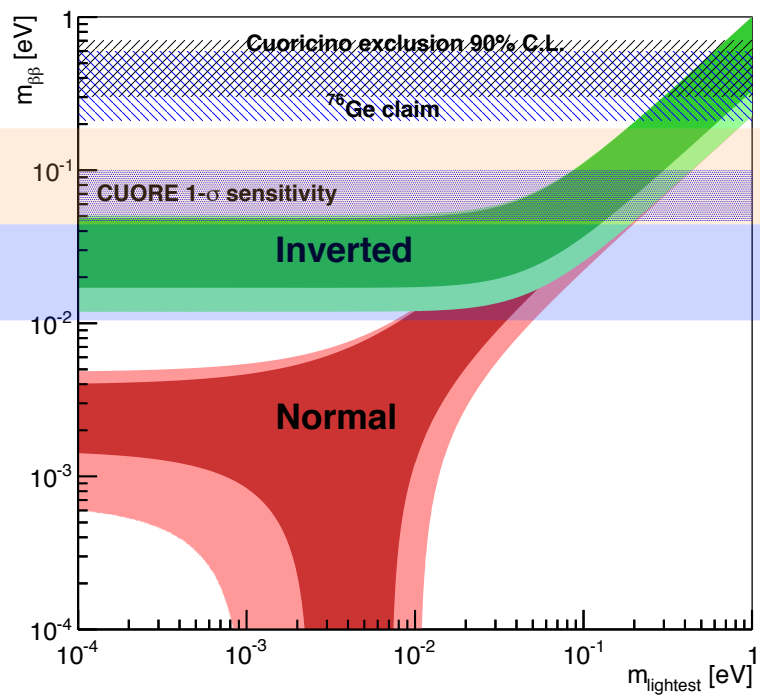
Beyond CUORE: ^{130}Te enrichment



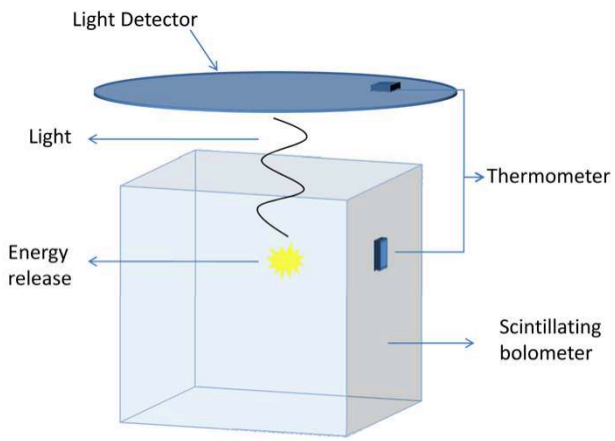
- A natural next step for CUORE
  - Increase # of parent nuclei, not the detector mass (# of background events)
- ^{130}Te enrichment is relatively cheap at $17K/kg
  - Compared to ^{76}Ge enrichment at $50-80 K/kg
- 500 gram of enriched ^{130}Te metal is sent to SICCAS for enriched crystal growth.

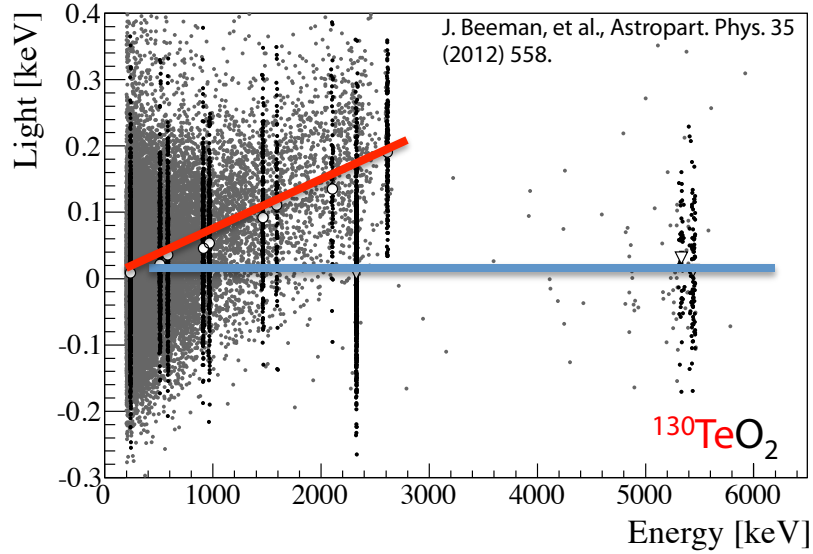
$$m_{\beta\beta} \sim \frac{m_e}{\sqrt{F_N \cdot \varepsilon \cdot \eta \sqrt{\frac{M \cdot t}{b \cdot \delta E}}}}$$

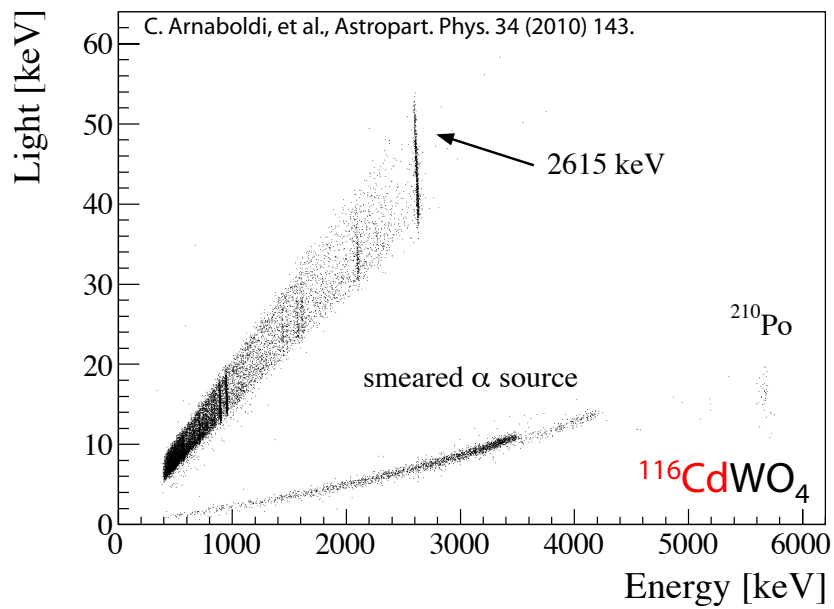
F_N	Nuclear figure of merit: nuclear matrix element x phase space factor		
ε	Detection efficiency	t	Live time [year]
η	Isotopic abundance	b	Background [< 0.01/kg/keV/y]
M	Detector total mass [kg]	δE	Energy resolution [keV]



Beyond CUORE: particle identification with light detectors

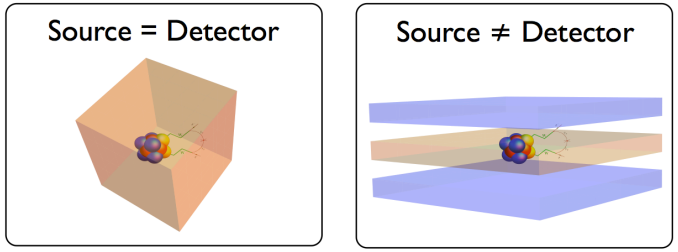






- Cherenkov light or scintillation to distinguish α from β/γ
  - $^{130}TeO_2$, $Zn^{82}Se$, $^{116}CdWO_4$, and $Zn^{100}MoO_4$
- More rejection power needed: 99.9% α background suppression ← Light detector R&D for better resolution
  - R&D on TES in US
  - R&D on MKID in Italy
- Background free search
  $m_{\beta\beta} \sim (M \cdot t)^{-1/2}$, not $(M \cdot t)^{-1/4}$

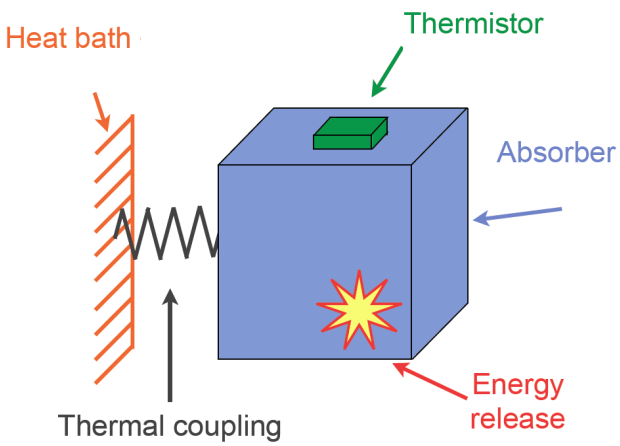
Beyond CUORE: possibility to search $0\nu\beta\beta$ of different isotopes

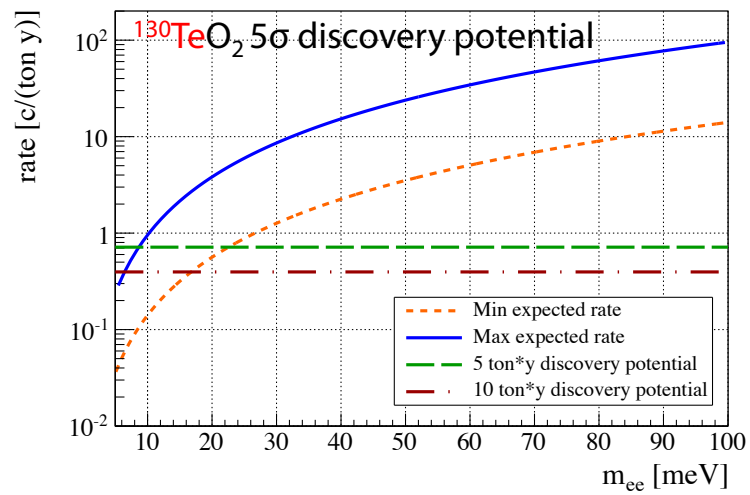


- Next generation Inverted Hierarchy Explorer (IHE) to fully cover the IH region
  - Phonon + photon
  - CUORE operations and scientific success are critical for the future bolometric program.

Bolometry - best of both worlds

- Bolometer utilizes only the low heat capacity of dielectric crystal.
- High efficiency and flexibility in candidate isotope choices.
- Especially valuable for discovery confirmations in different isotopes.

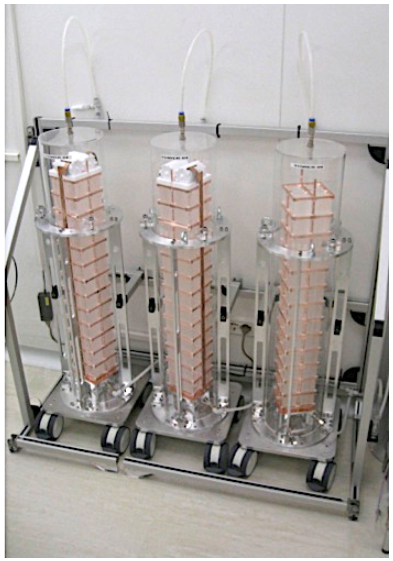




CUORE Collaboration, *"The frontier of neutrinoless double beta decay with bolometers"* (to be submitted)

90% sensitivity limits

Crystal	Exposure [ton·y]	half-life sensitivity [10^{27}y]	$\lvert m_{ee}\rvert_S$ [meV]
ZnSe	5	3.3	9 - 26
	10	6.5	6 - 18
$CdWO_4$	5	1.5	14 - 26
	10	3.0	10 - 18
$ZnMoO_4$	5	0.9	11 - 32
	10	1.4	9 - 25
TeO_2	5	3.4	8 - 22
	10	6.8	6 - 16

Summary

- CUORE, with 206 kg of ^{130}Te and 5 keV energy resolution, is able to reach 47-100 meV effective Majorana mass.
- CUORE-0 demonstrated the feasibility of CUORE background goals.
  - Stringent cleaning and assembly procedure paid off
- 6 of 19 CUORE towers assembled; Cryostat and dilution unit passed specs.
- Detector assembly will be finished in June 2014 and commissioning at the end of 2014.
- Large mass bolometry offers a realistic path to explore the inverted mass hierarchy.
  - Enrichment
  - Light detection
  - Isotope swap