Results from CUORE-0, Status of CUORE

Reina Maruyama (Yale University)
on behalf of the CUORE Collaboration

October 5 - 7, 2014, Waikoloa, HI, USA

DBD2014

International Workshop on "Double Beta Decay and Underground Science"

CUORE in context

Current Projects

Project	Isotope	Isotope Mass (kg fiducial)	Currently Achieved (10^{26} yr)
CUORE	^{130}Te	206	>0.028
MAJORANA	^{76}Ge	36.8	
GERDA	^{76}Ge	18-20	>0.21
EXO200	^{136}Xe	79	>0.11
NEXT-100	^{136}Xe	100	
SuperNEMO	^{82}Se+	7	>0.001
KamLAND-Zen	^{136}Xe	434	>0.19
SNO+	^{130}Te	160	
LUCIFER	^{82}Se	8.9	

Primary goals:

- Demonstrate background reduction for next generation experimen
- Extend sensitivity to $T_{1/2}$~10^{26} years.

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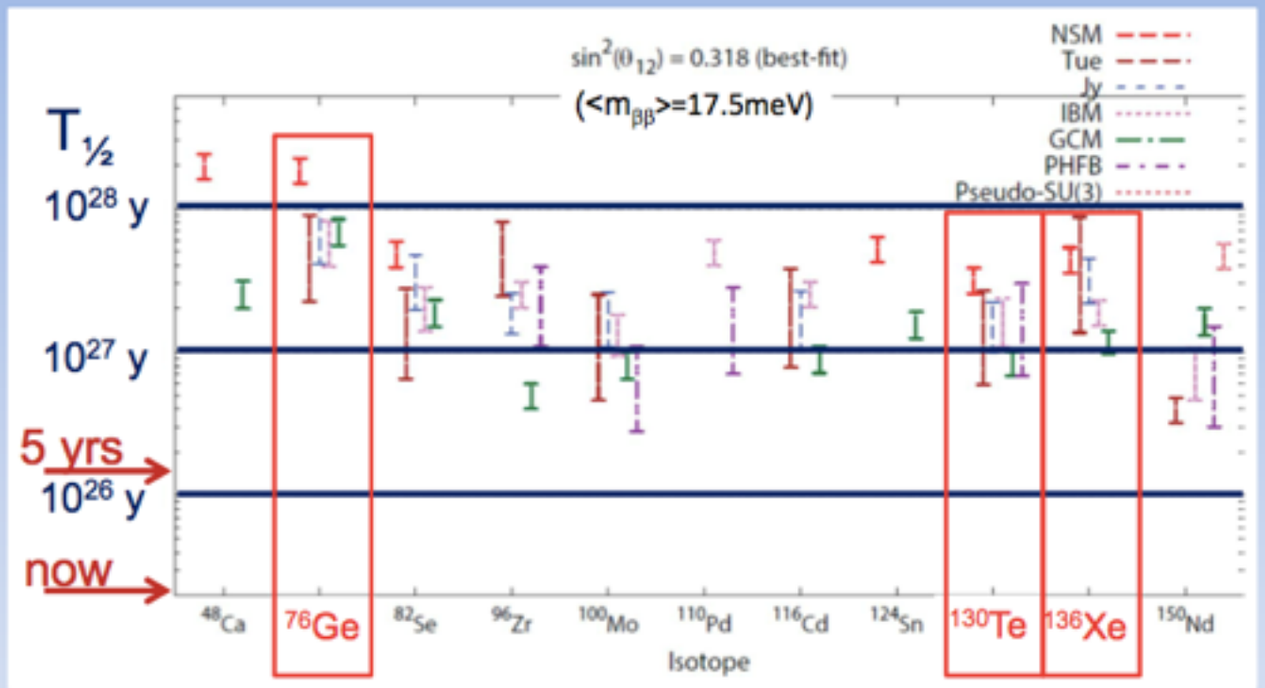
Inverted Hierarchy Coverage



$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu} \cdot |M^{0\nu}|^2 \cdot \langle m_{\beta\beta} \rangle^2$$

Figure source: A. Dueck, W. Rodejohann, and K. Zuber, Phys. Rev. D83 (2011) 113010.

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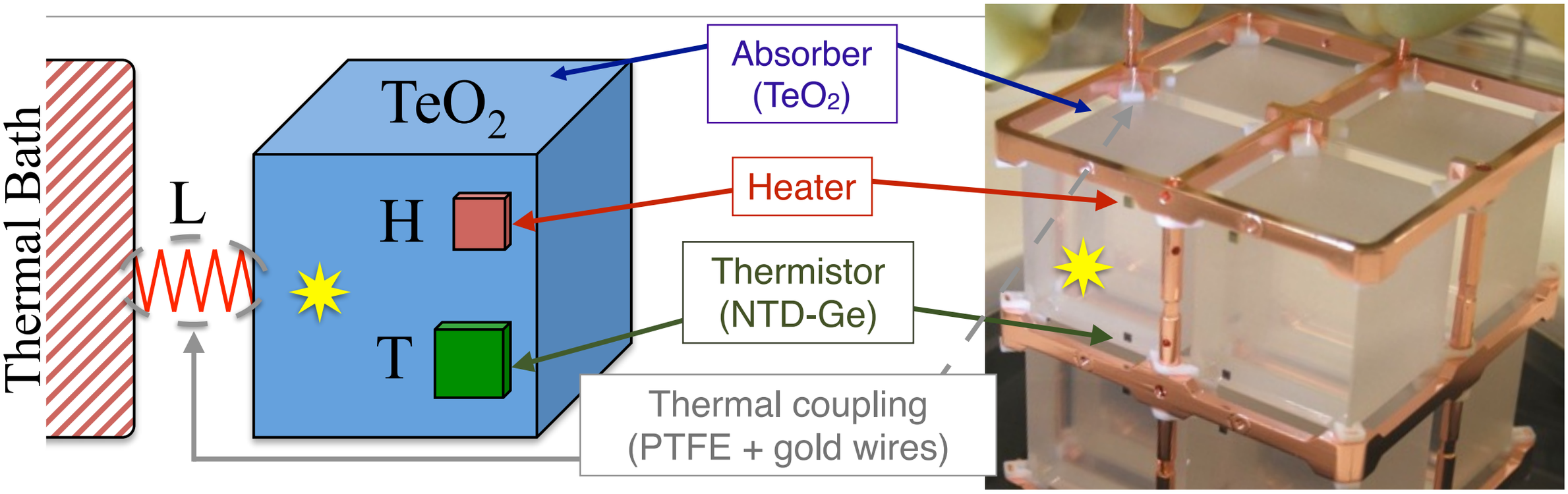
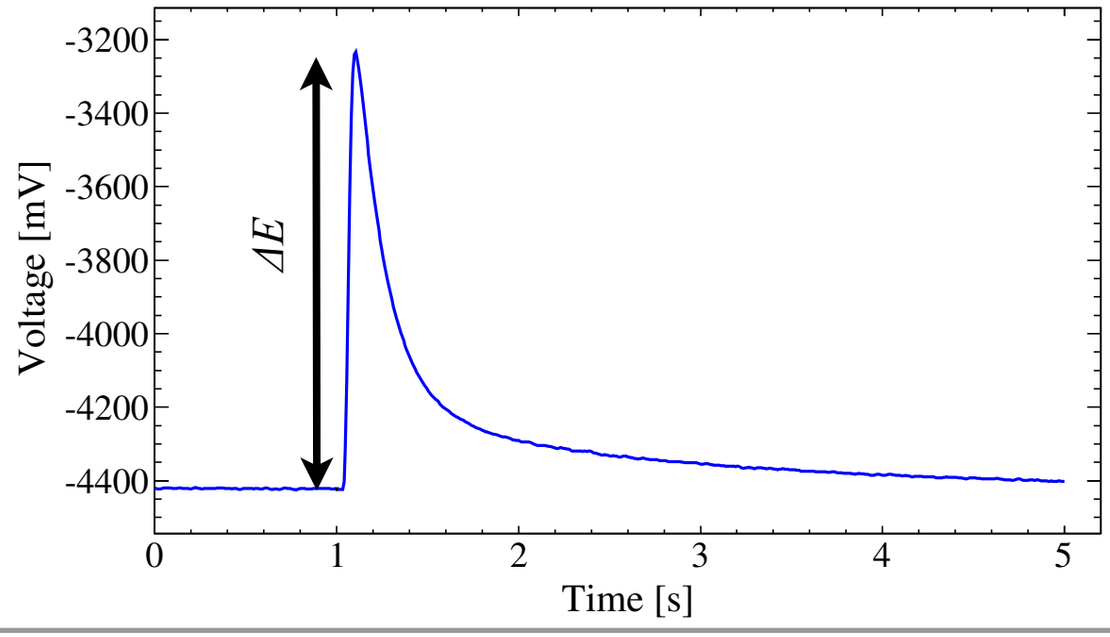
- McKeown - DBD2014 Sunday

TeO_2 Bolometers for 0νββ Search



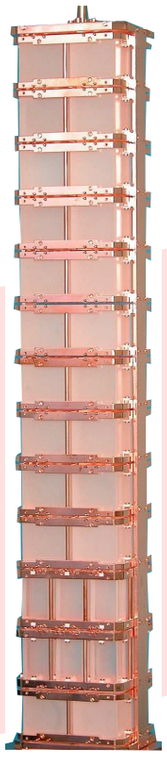
$\Delta T_{crystal} \sim 10 - 20\ \mu K/MeV$

- ^{130}Te is a good 0νββ source
  - high isotopic abundance
  - high Q-value
- TeO_2 bolometer provides excellent energy resolution (0.2% at Q-value)



The CUORE 0νββ Search

Cuoricino
(2003-2008)



Astropart. Phys. 34
(2011) 822–831

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

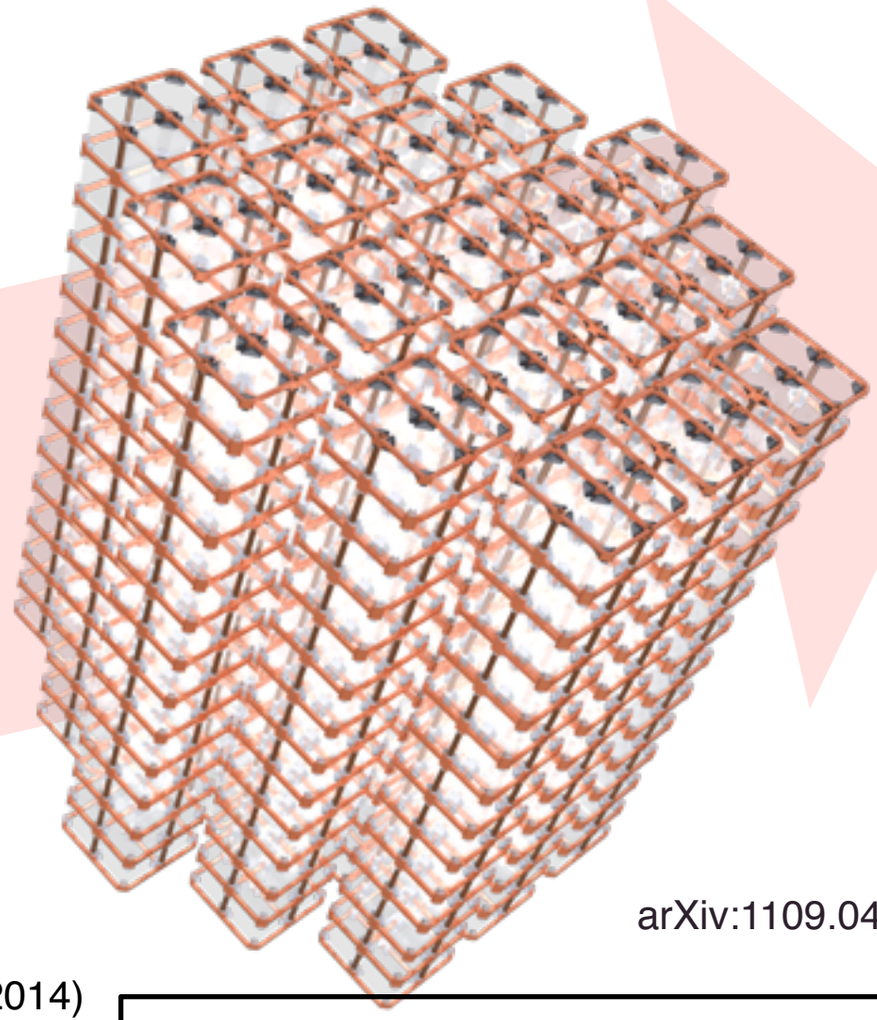
$\langle m_{\beta\beta} \rangle_{90\%\ \mathrm{C.L.}} = 300 - 710\ \mathrm{meV}$

CUORE-0
(2013-2015)

EPJC 74, 2956 (2014)

Surpass Cuoricino w/ ~1-yr data

CUORE
(2015-2020)



arXiv:1109.0494

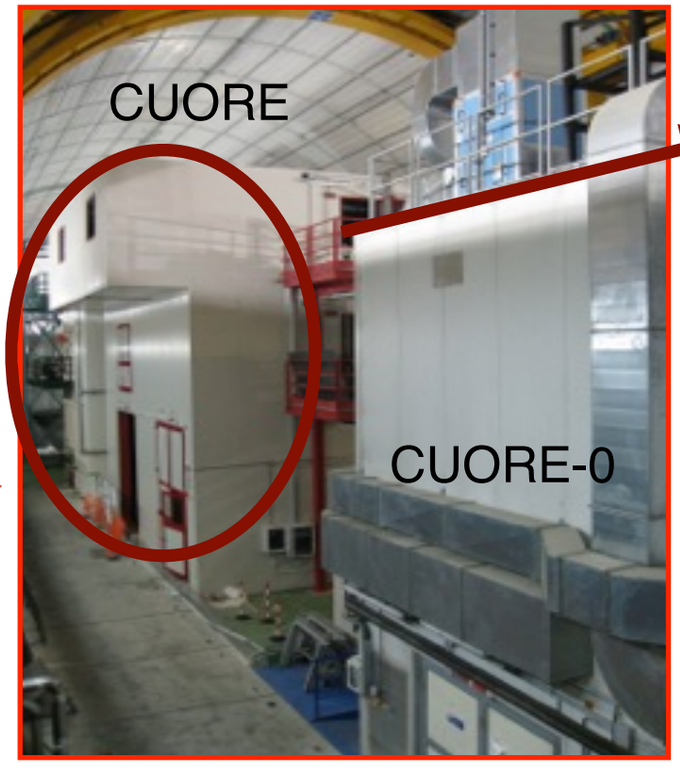
Projected
$T_{1/2}^{0\nu\beta\beta} > 9.5 \times 10^{25}$ yr (90% C.L.)

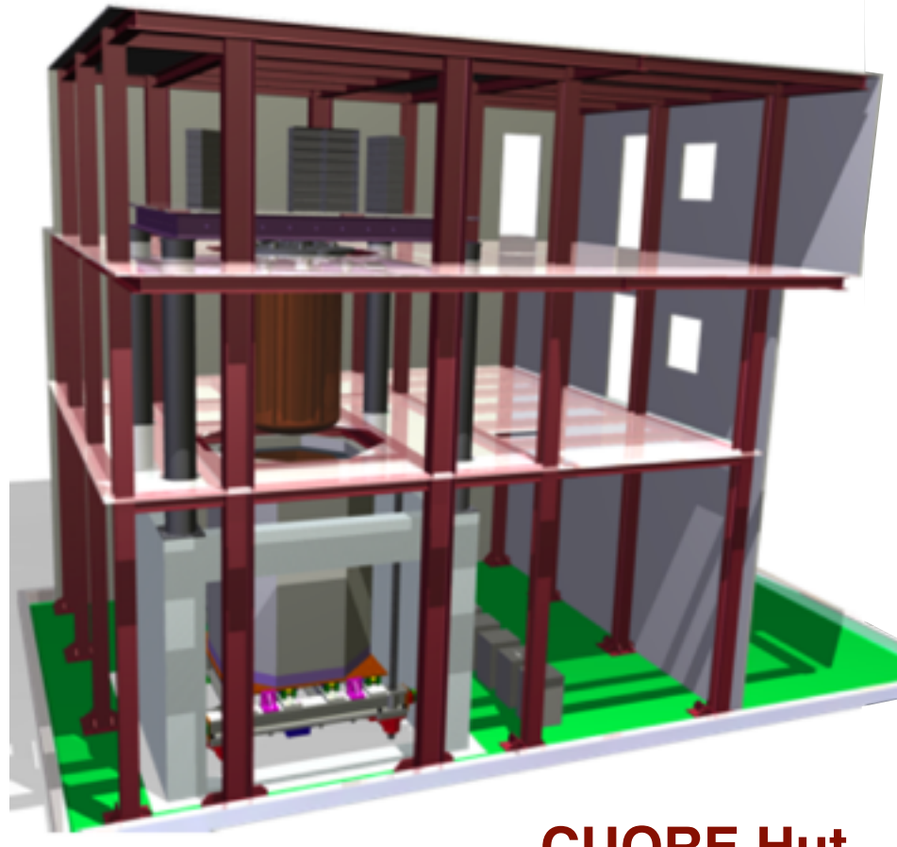
$\langle m_{\beta\beta} \rangle_{90\%\ \mathrm{C.L.}} = 51 - 133\ \mathrm{meV}$

CUORE at LNGS

Gran Sasso National Laboratory

Hall A



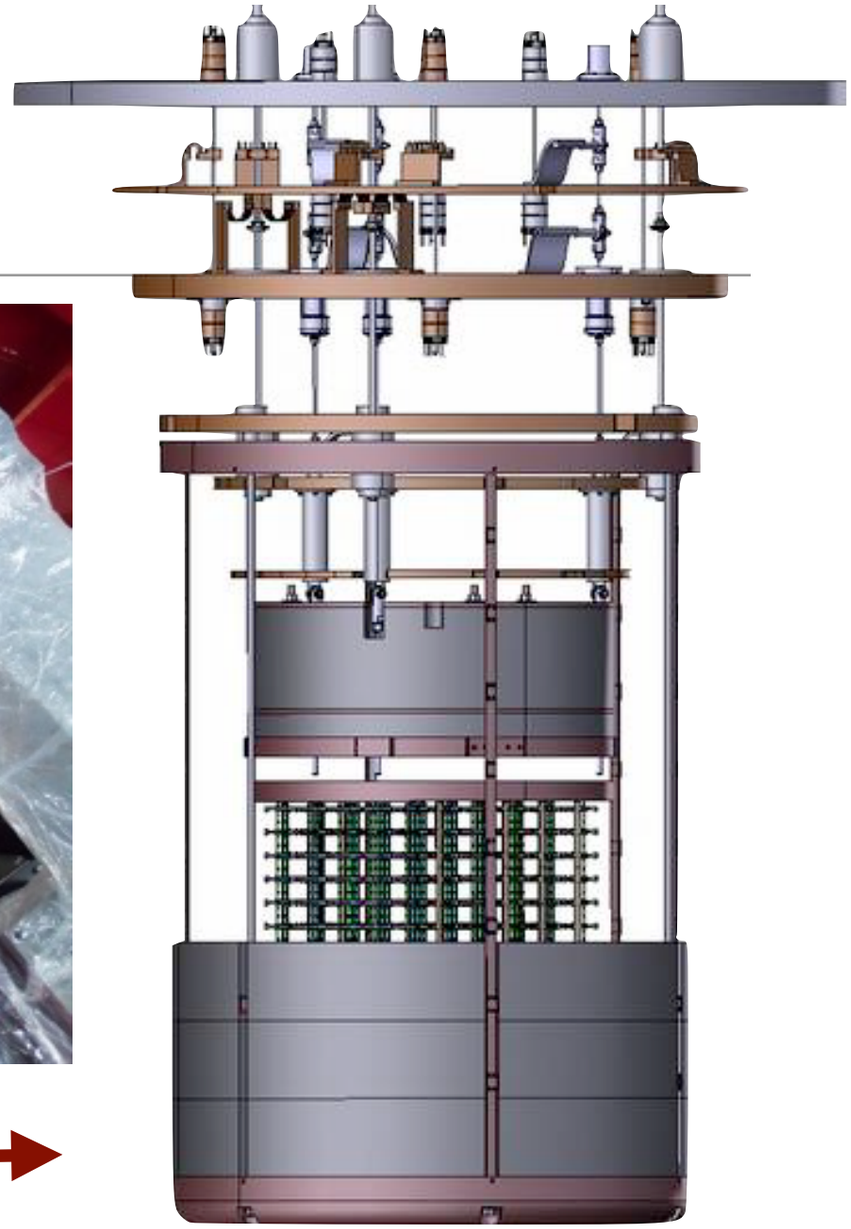


CUORE Hut

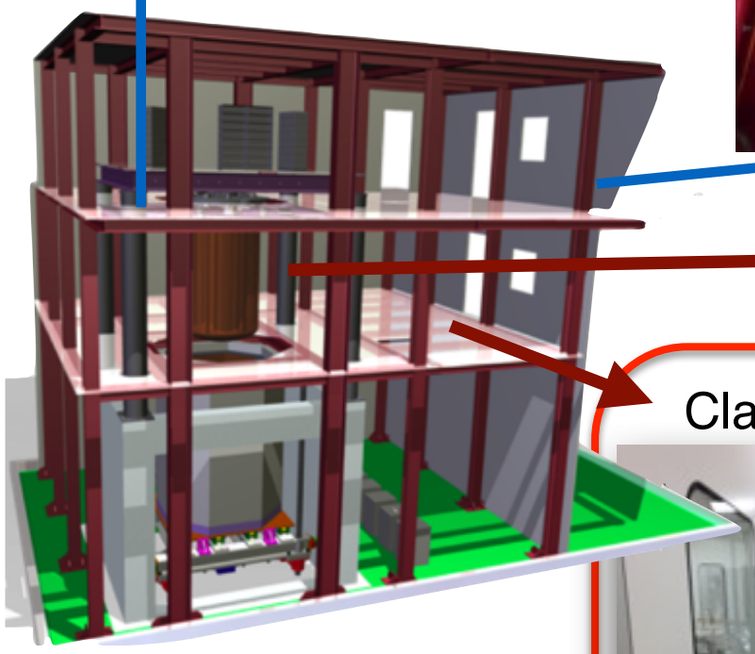
Average depth ~ 3600 m.w.e.
μ: 3 x 10^{-8} μ/s/cm²
n < 10 MeV: 4 x 10^{-6} n/s/cm²
γ < 3 MeV: 0.73 γ/s/cm²

CUORE

Top Floor



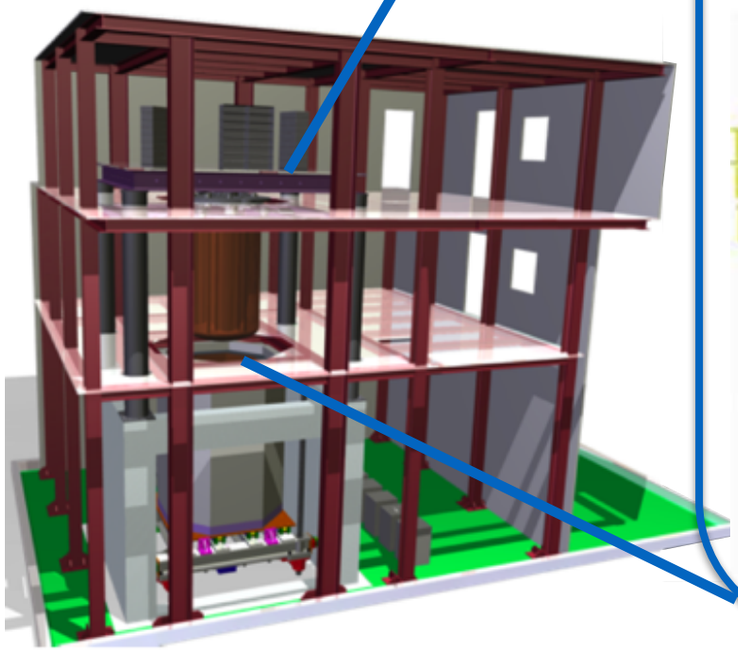
CUORE Hut

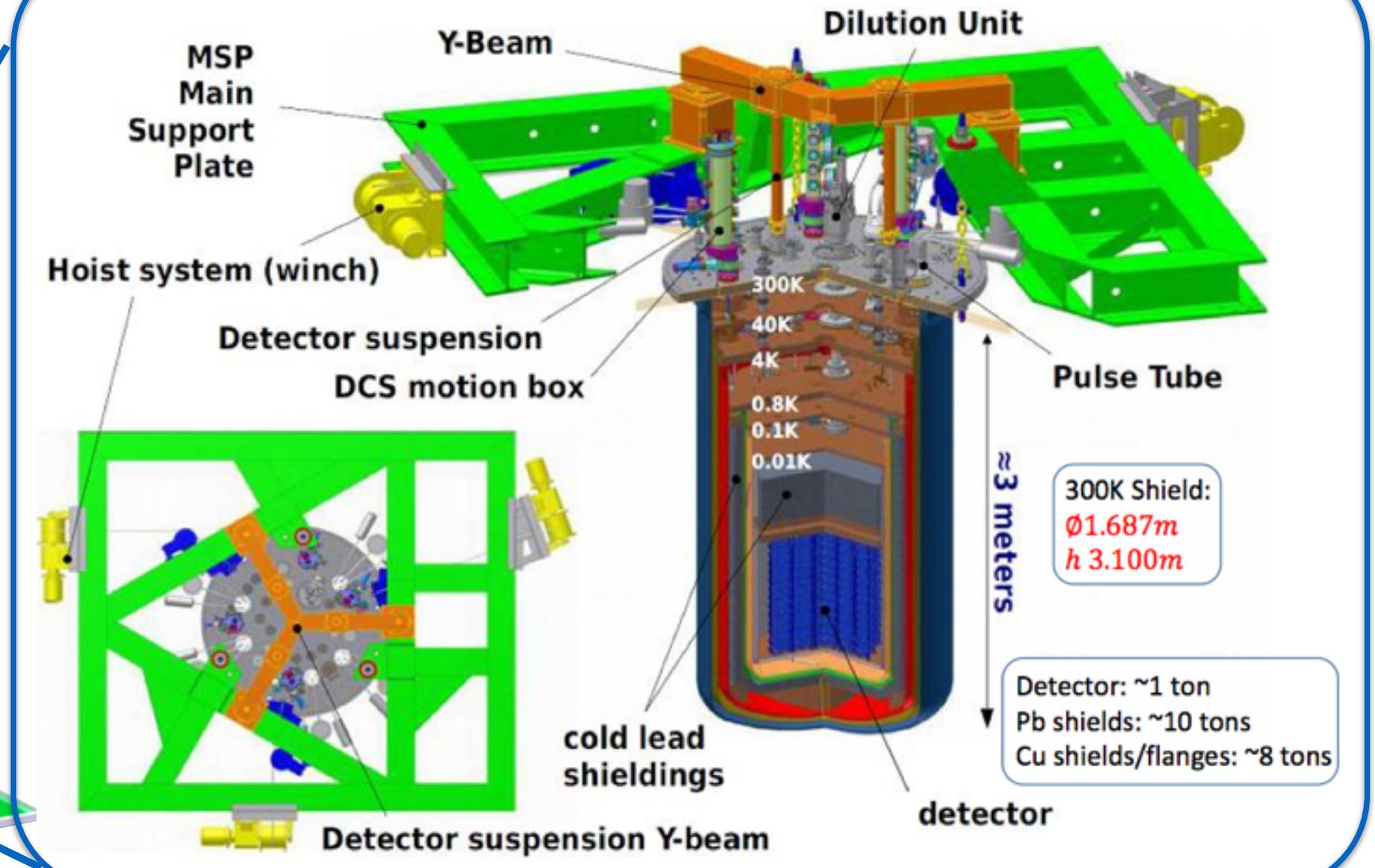


Class 1000 Clean Room for Detector Assembly and Storage

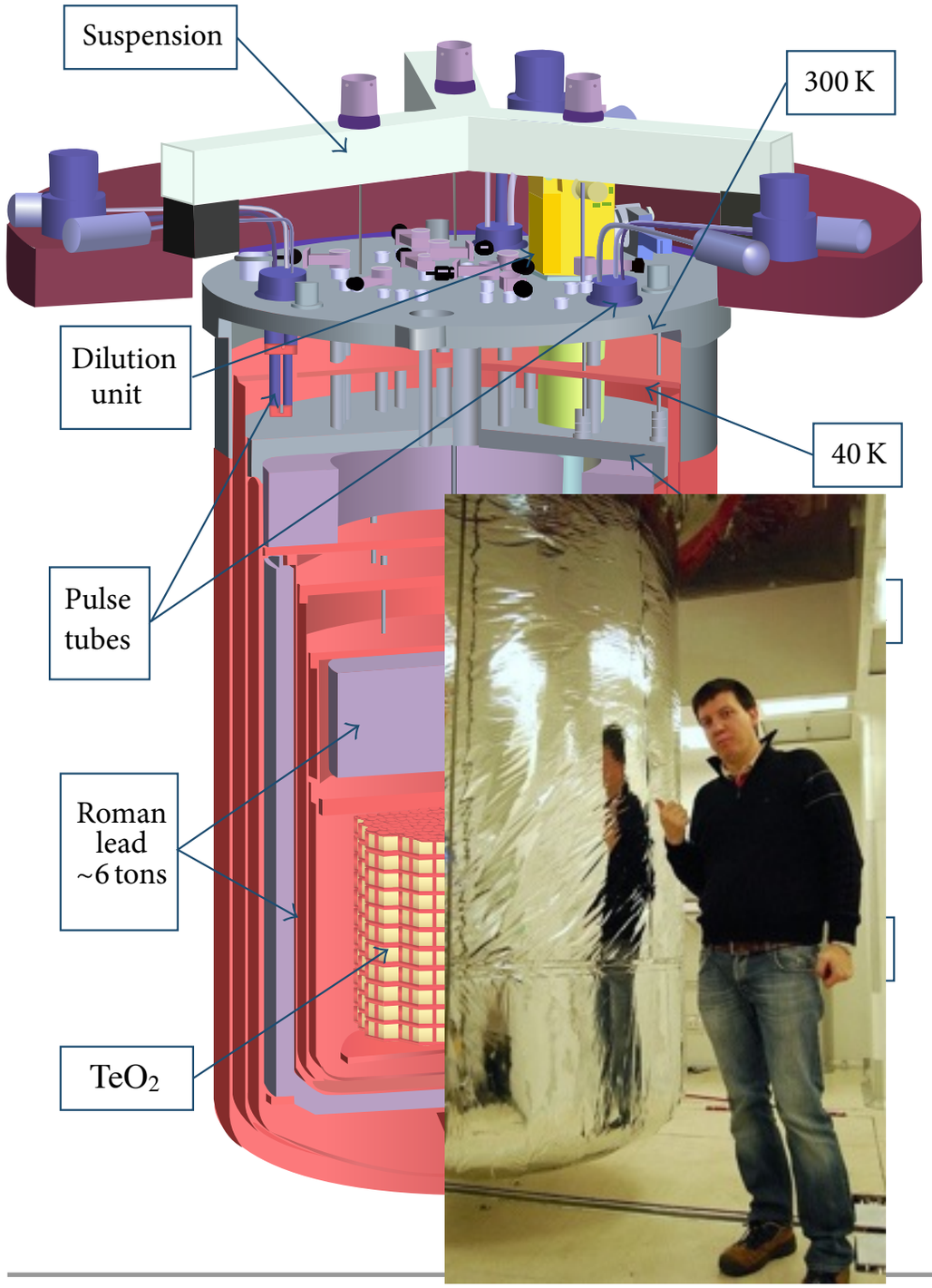
CUORE Suspension & Detector Systems

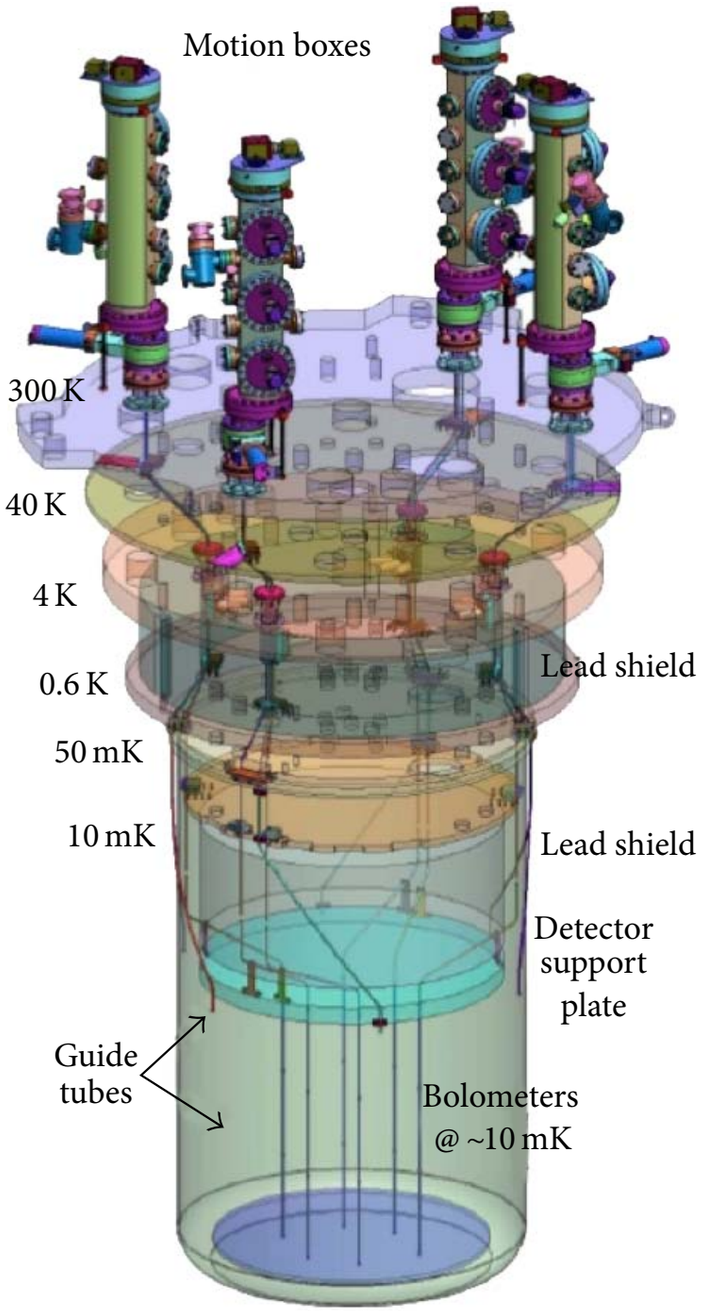
CUORE Hut

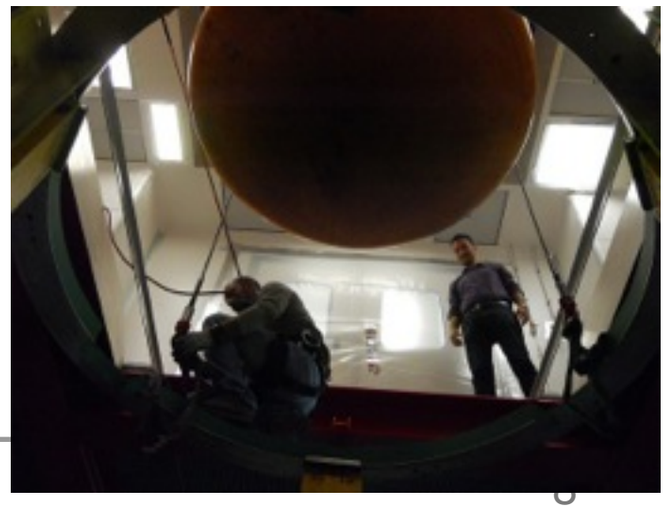




CUORE Cryostat

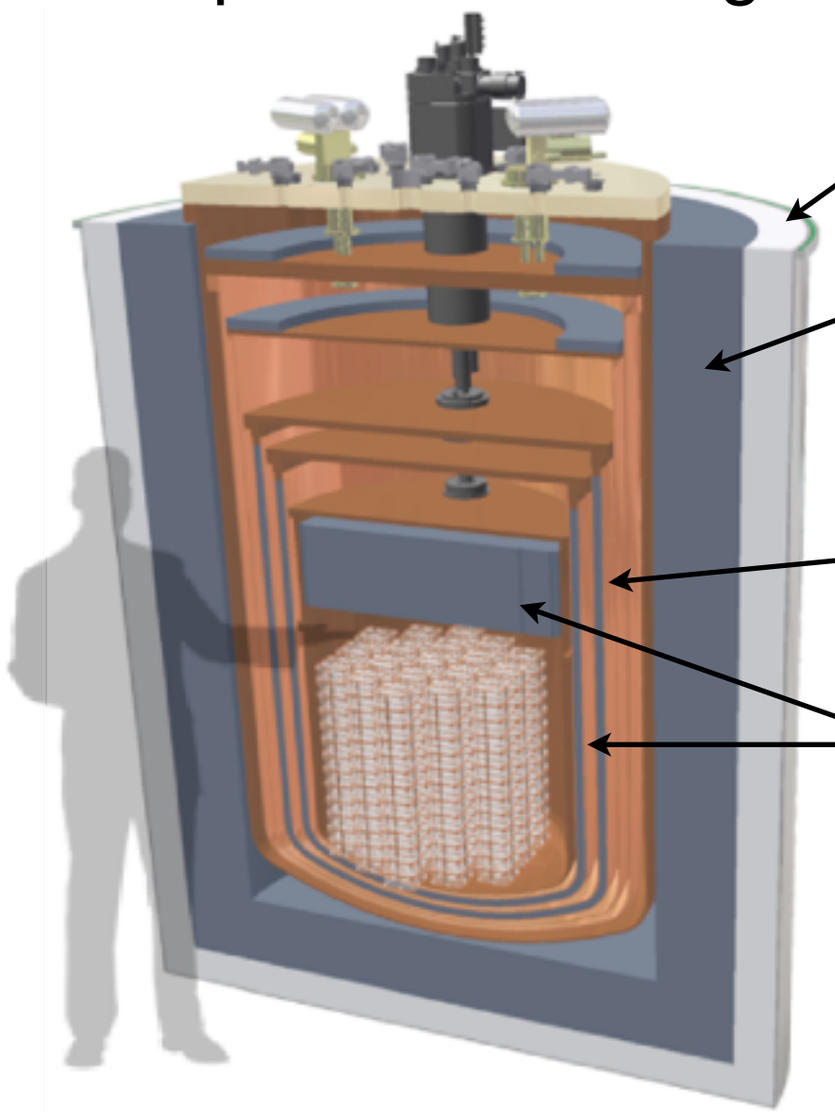






Lowering Background: Shielding

- Improved shielding

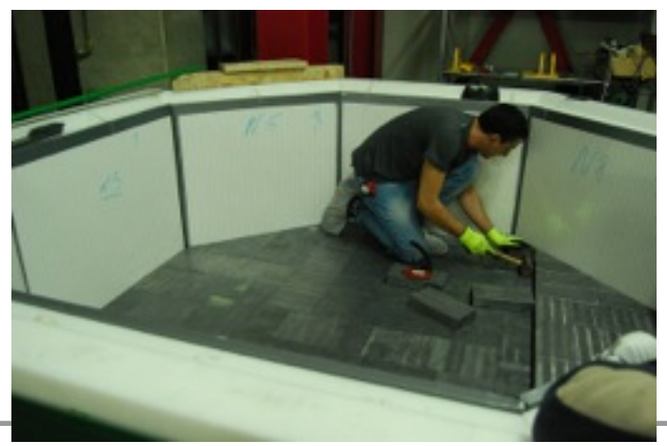


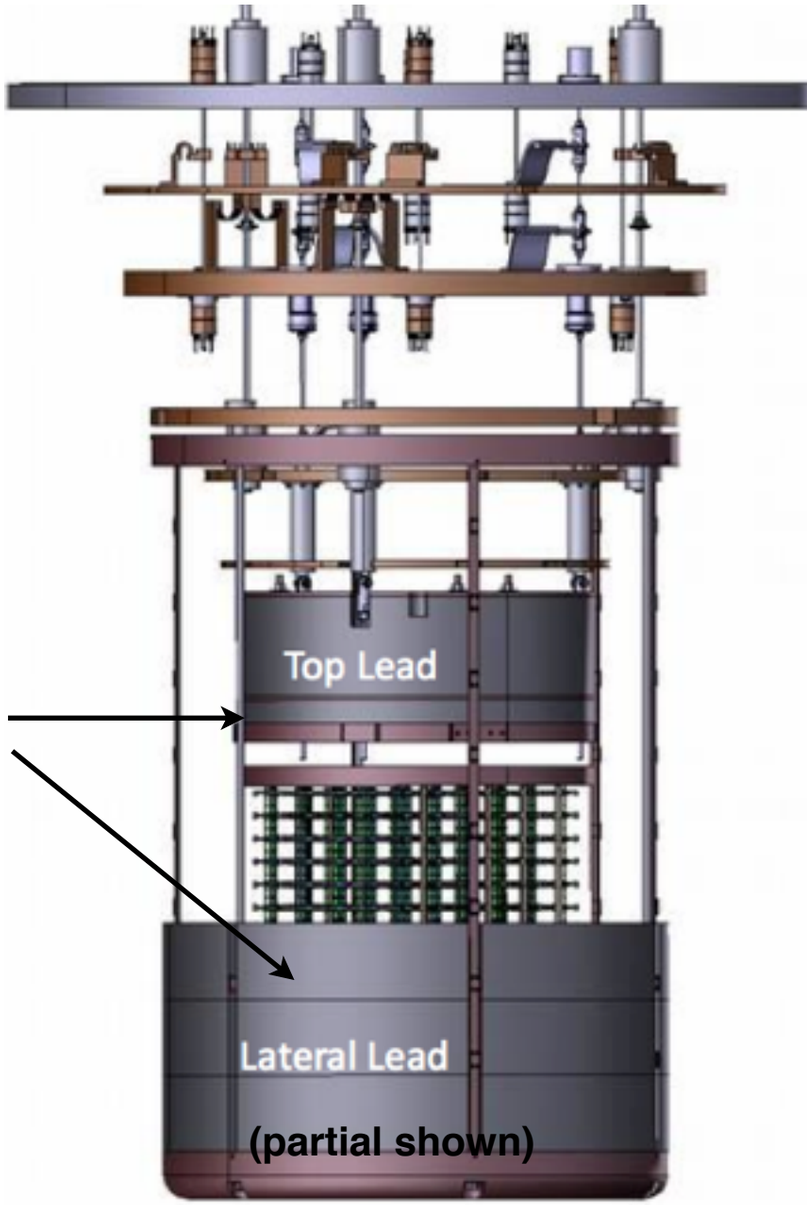
Neutron shield
(18 cm PET + 2cm of H_3BO_3)

External lead shield
(thickness >35 cm)

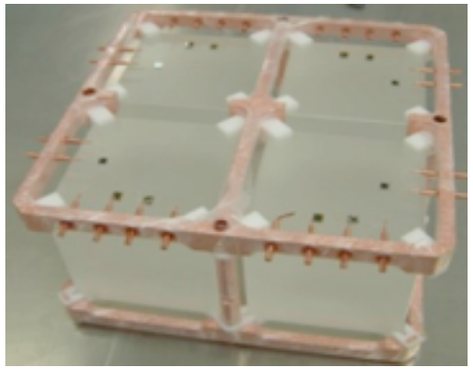
Low-radioactivity copper for
cryostat vessels and flanges

Internal lead shield
(low-radioacivity/ancient lead)





Lowering Background: Crystals & Copper



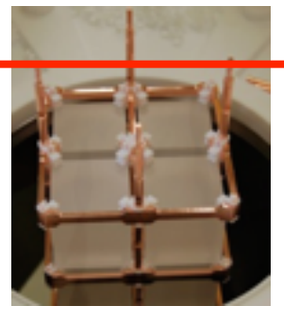
Ultra-pure TeO2 crystal array

Bulk activity 90% C.L. upper limits:

$8.4 \cdot 10^{-7}$ Bq/kg (^{232}Th), $6.7 \cdot 10^{-7}$ Bq/kg (^{238}U), $3.3 \cdot 10^{-6}$ Bq/kg (^{210}Po)

Surface activity 90% C.L. upper limits:

$2 \cdot 10^{-9}$ Bq/cm^2 (^{232}Th), $1 \cdot 10^{-8}$ Bq/cm^2 (^{238}U), $1 \cdot 10^{-6}$ Bq/cm^2 (^{210}Po)

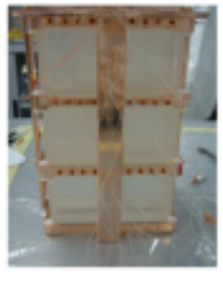


- Crystal holder design optimized to reduce passive surfaces (Cu) facing the crystals

- Developed ultra-cleaning process for all Cu components:
  - Tumbling
  - Electropolishing
  - Chemical etching
  - Magnetron plasma etching

T1

T2

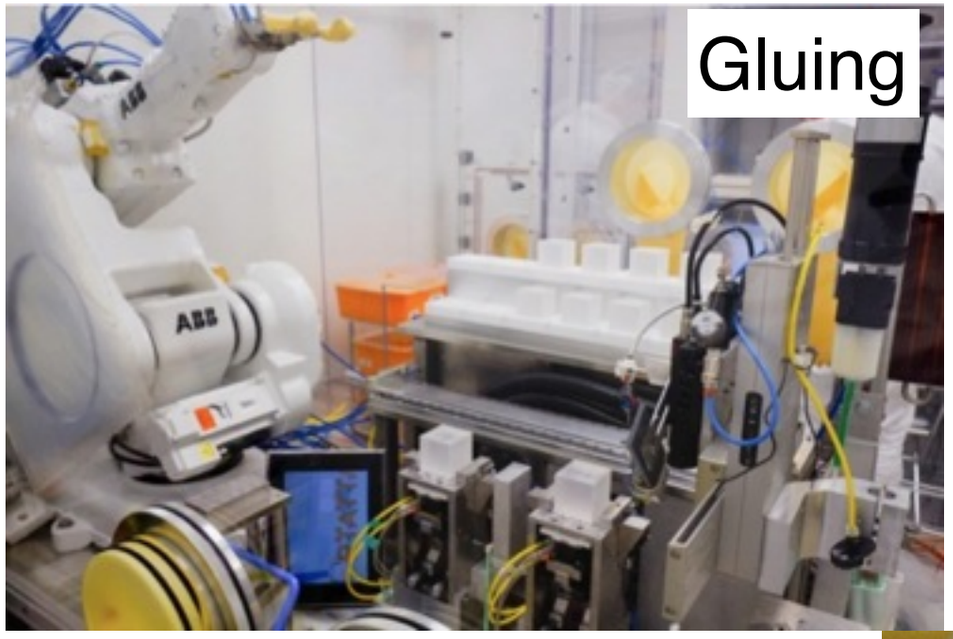


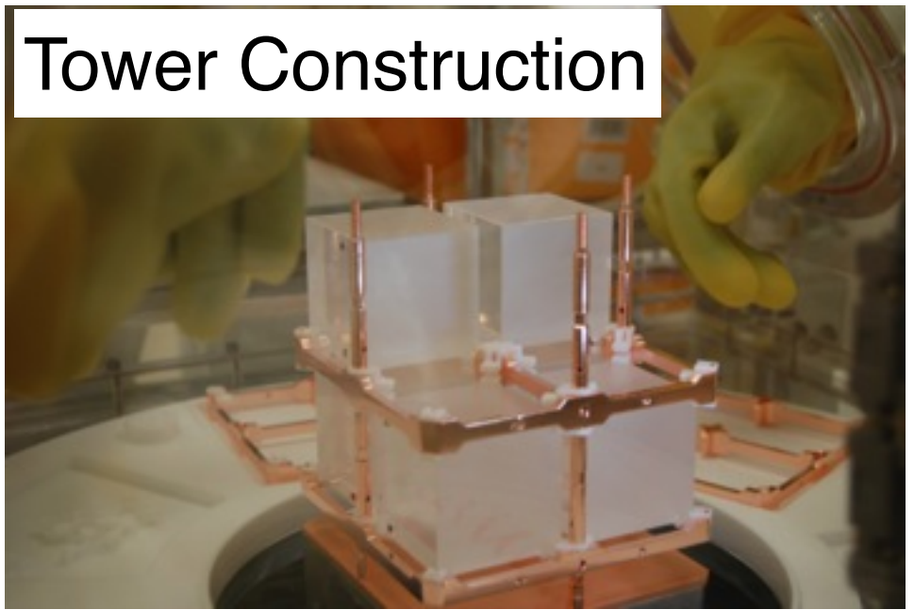
T3

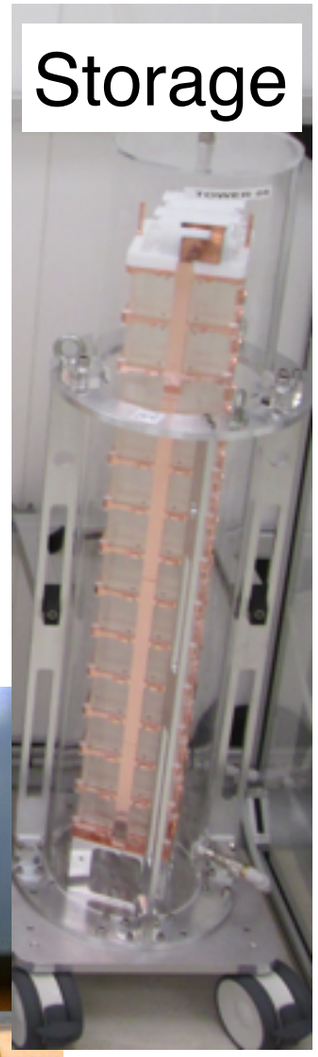
- Benchmarked in dedicated bolometer run at LNGS
  - Residual ^{232}Th / ^{238}U surface contamination of Cu: $< 7 \cdot 10^{-8}$ Bq/cm^2
- Validated by CUORE-0

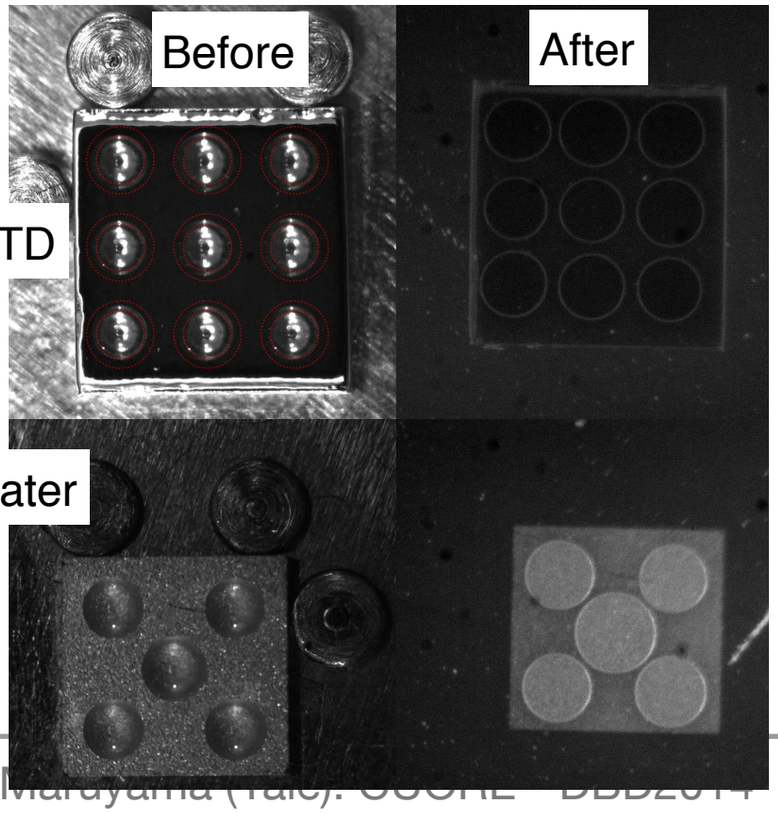
- All parts stored underground, under nitrogen after cleaning

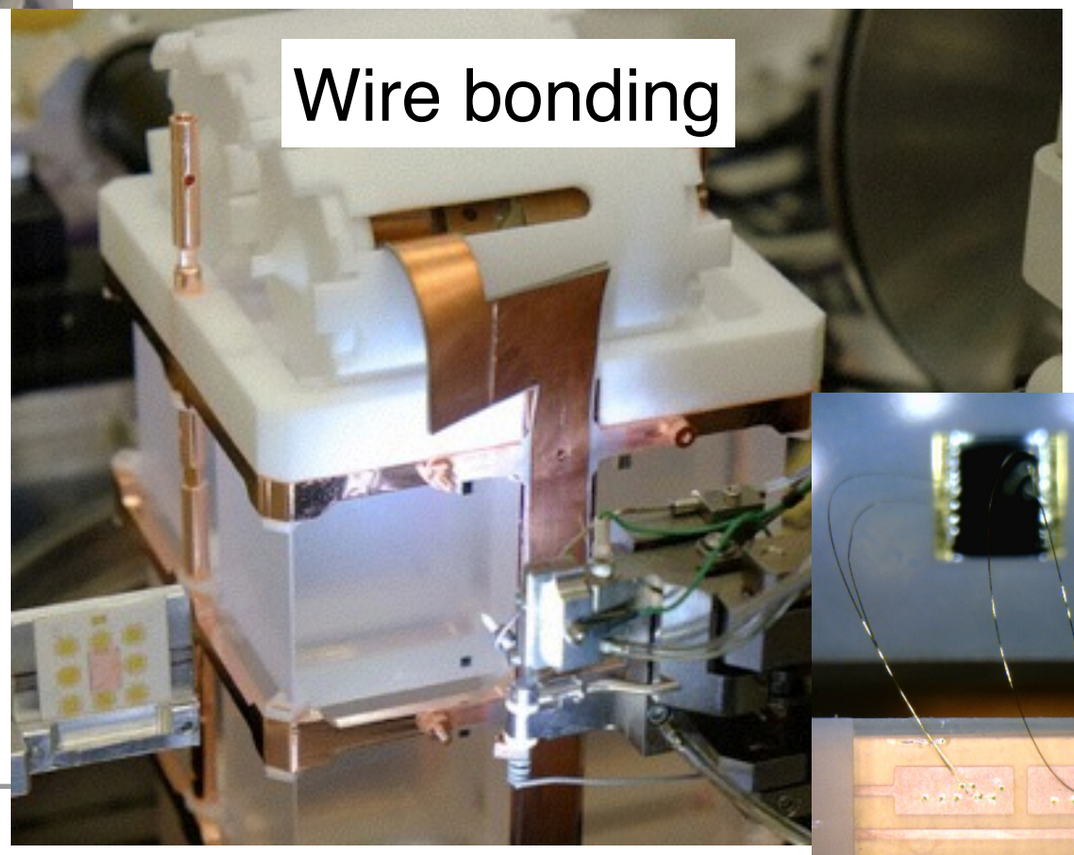
Tower Assembly





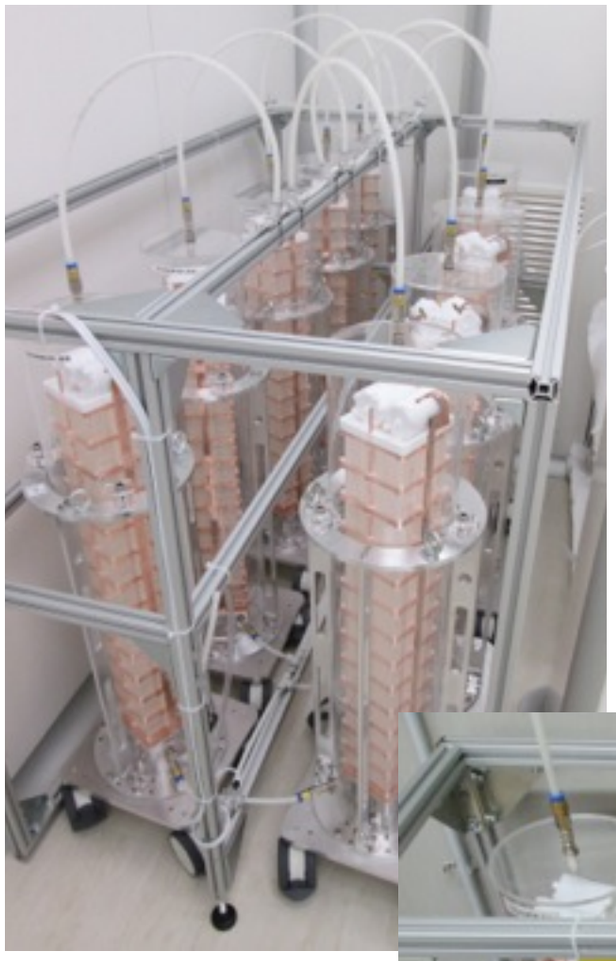


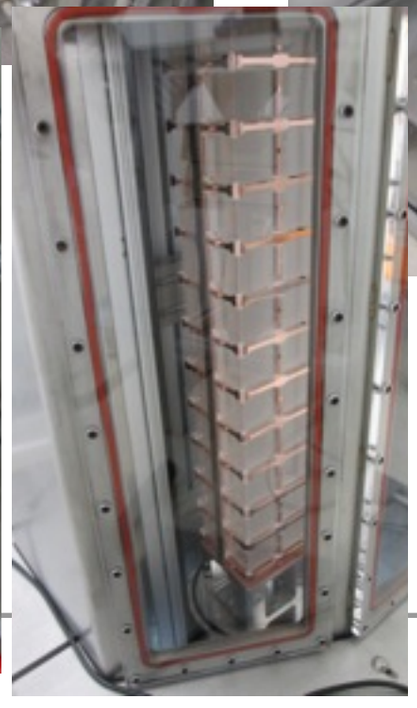


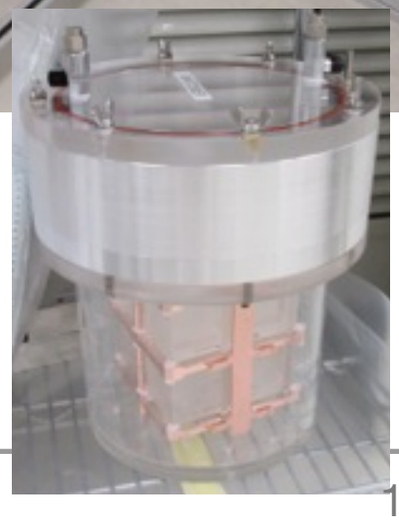


Detector Towers

Assembly of all 19+ towers is complete!

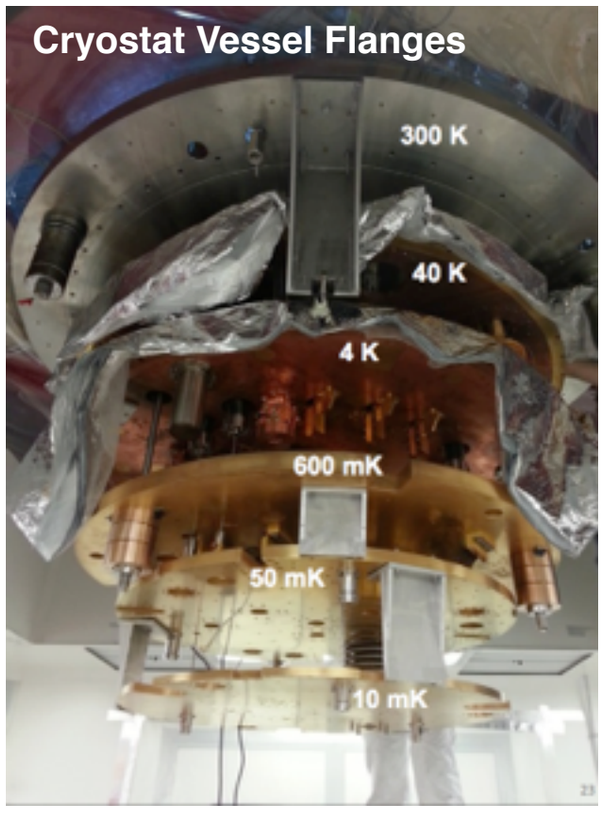


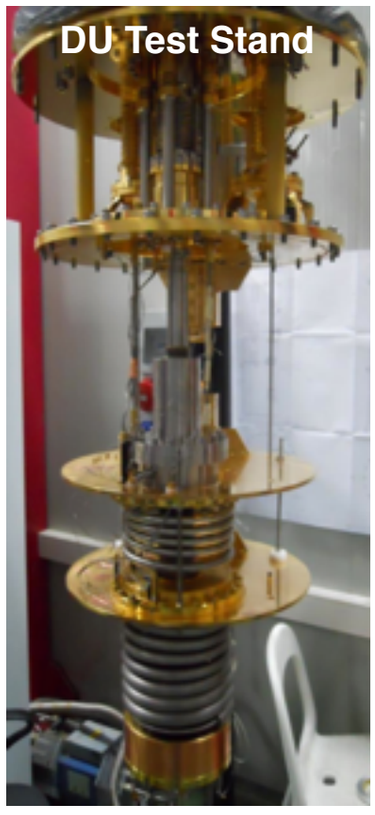


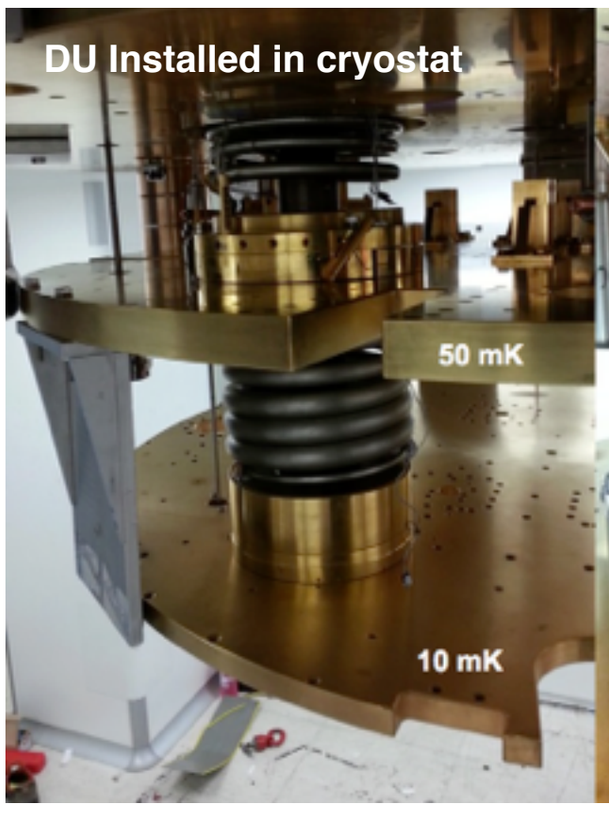


Cryogenic System & Commissioning

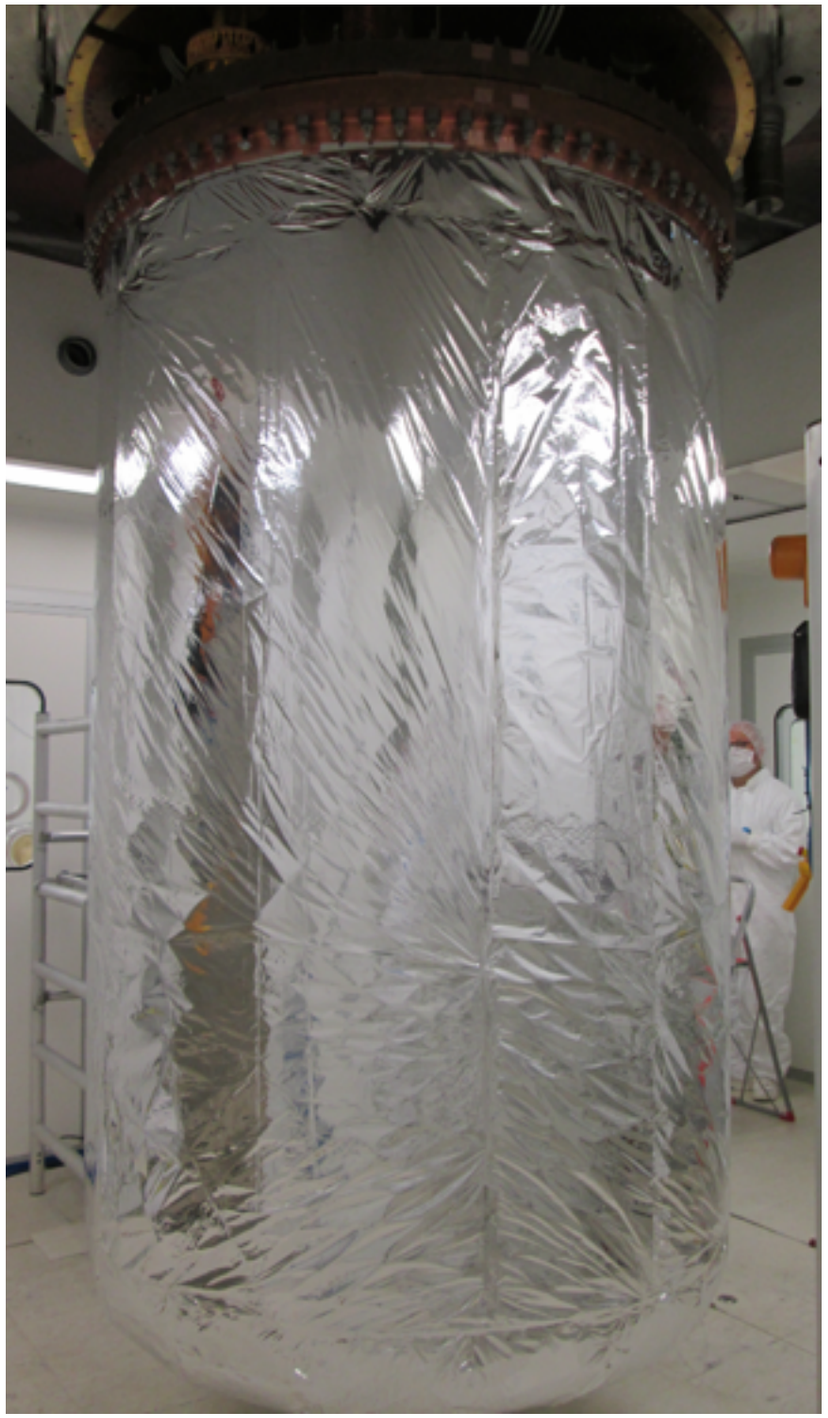
- Cryostat assembled, passed commissioning tests.
- Dilution unit delivered to LNGS, series of integration and commissioning runs being carried out to ensure full operation in 2015
- Full integration of DU in cryostat ongoing
  - 6 mK stable base temperature achieved!



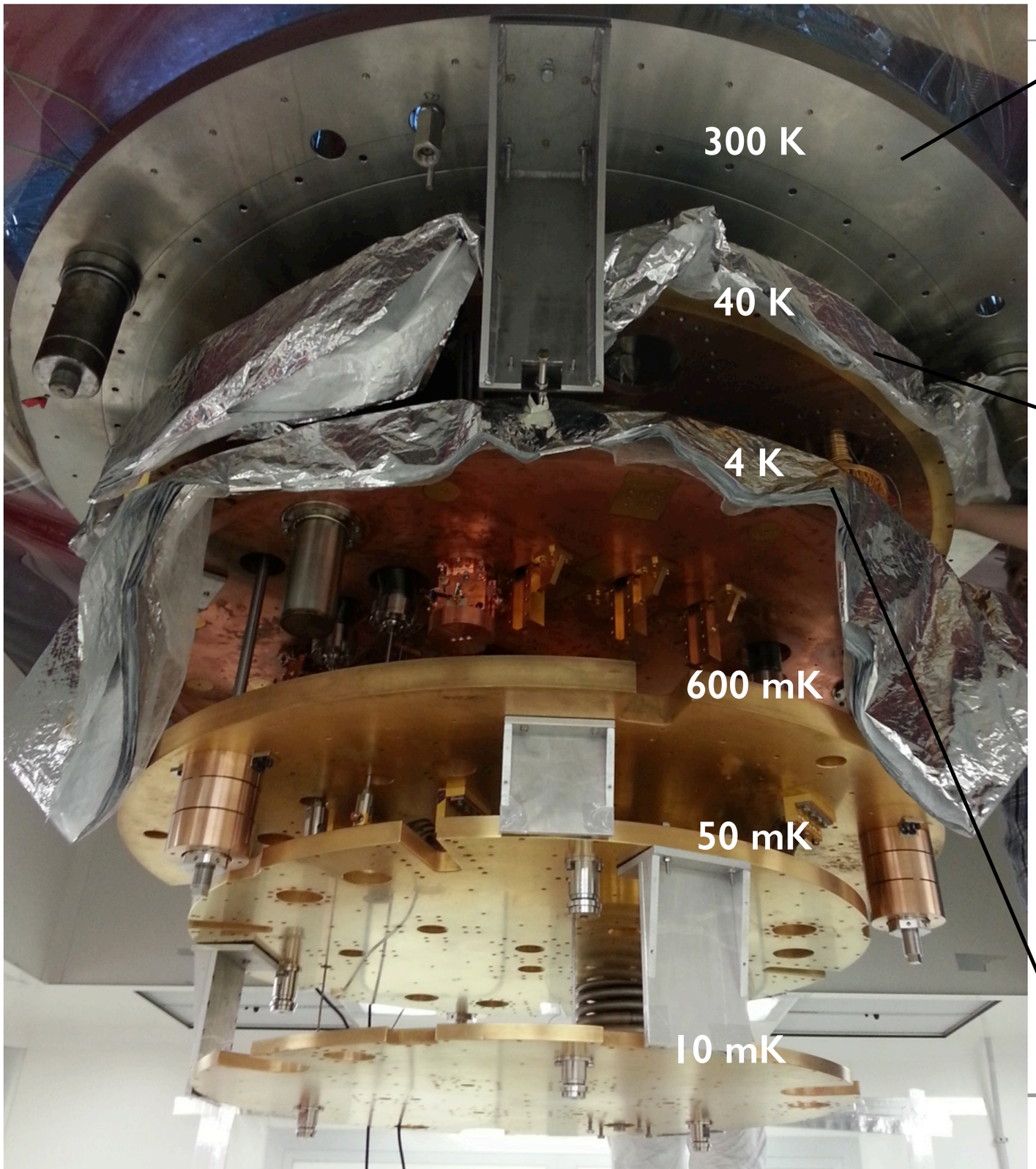


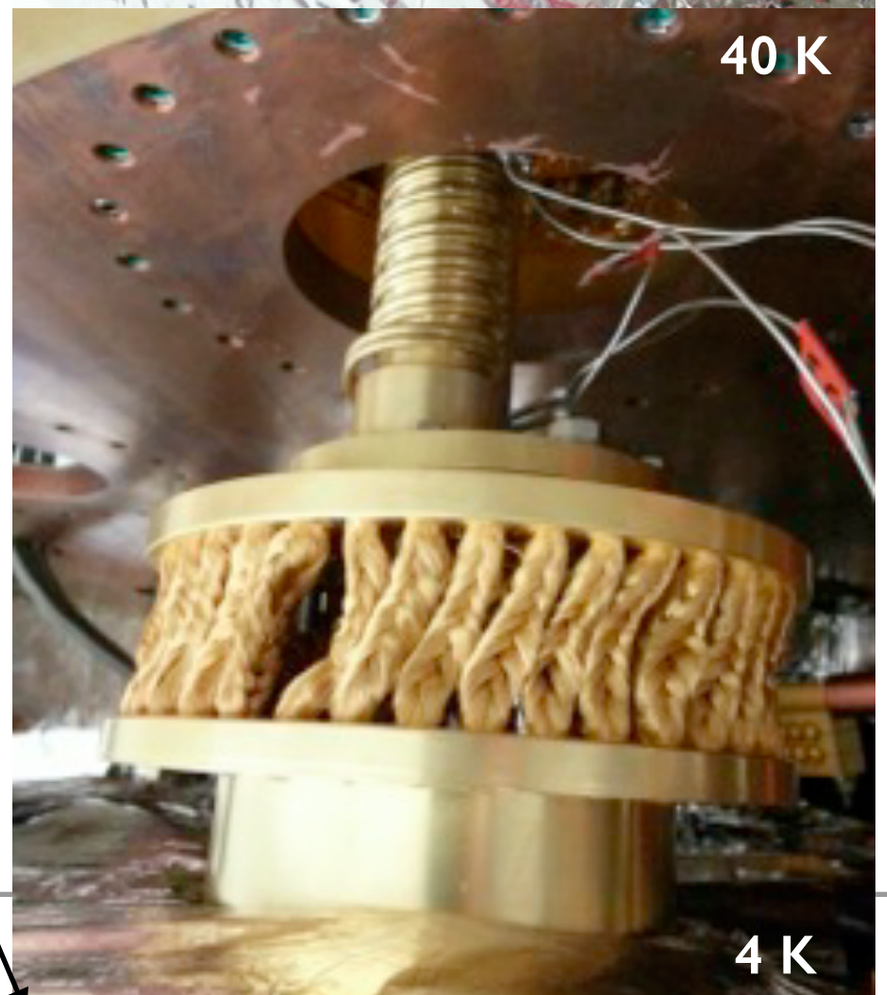


Status of CUORE



Status of CUORE: Cryogenics





Status of CUORE: Cryogenics

Commissioning Plan

Phase I: 4K system check

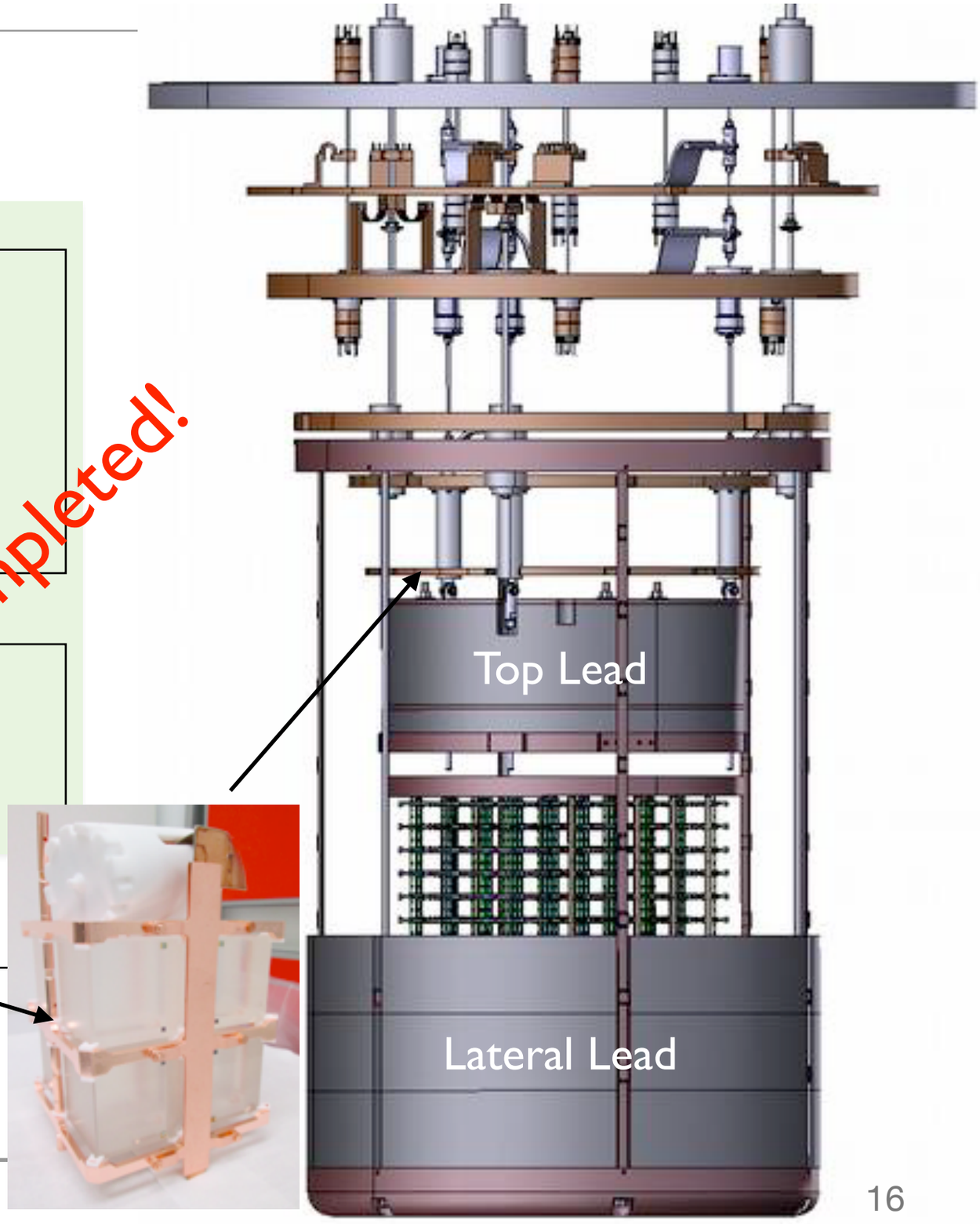
- Outer/Inner vacuum chamber test
- Cryogenic verification of detector calibration system
- Commissioning test of DU

completed!

Phase II: full cryostat vessel check

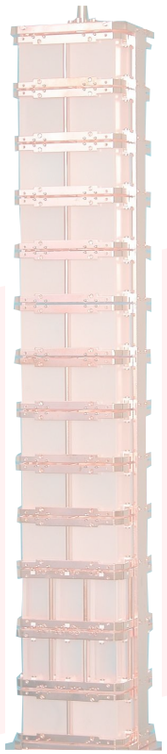
- Full assembly of cryostat
- Cool down of cryostat
- Integration of test tower, calibration system

Physics run start expected in 2015



The CUORE 0νββ Search

Cuoricino
(2003-2008)



Astropart. Phys. 34
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$T_{1/2}^{0\nu\beta\beta} > 2.8 \times 10^{24}$ y (90% C.L.)

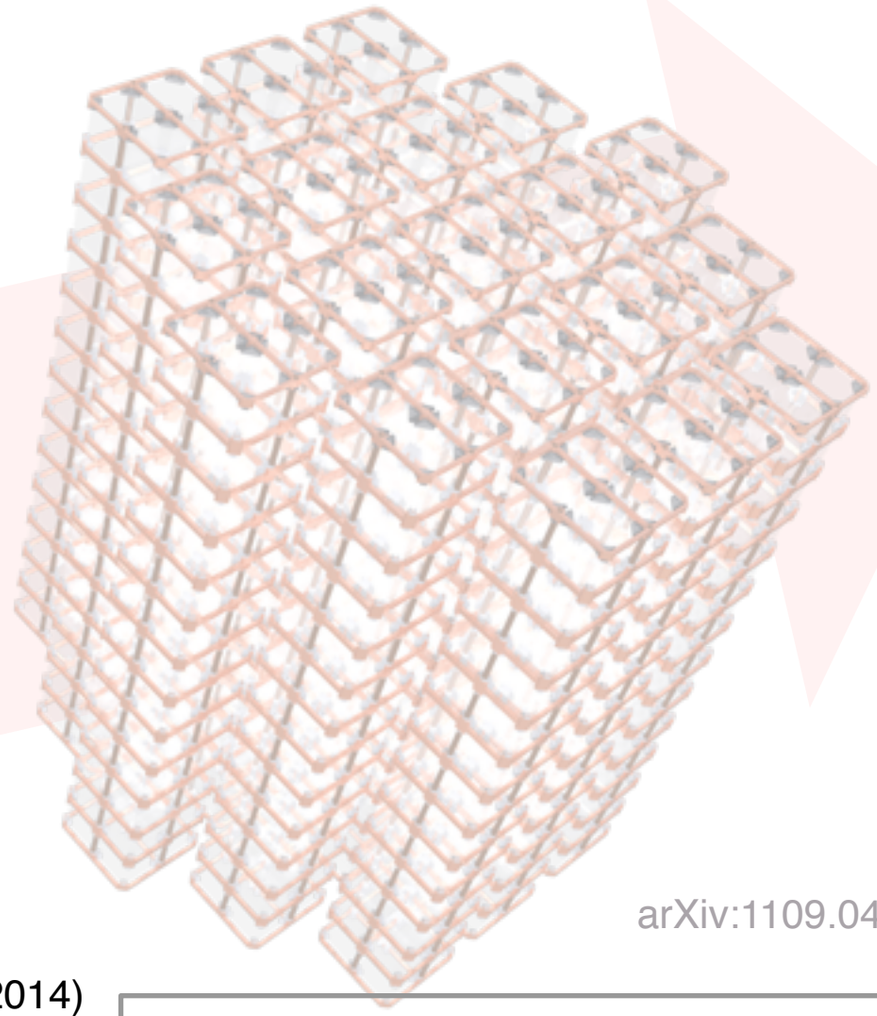
$\langle m_{\beta\beta} \rangle_{90\%\ \mathrm{C.L.}} = 300 - 710\ \mathrm{meV}$

CUORE-0
(2013-2015)

EPJC 74, 2956 (2014)

Surpass Cuoricino w/ ~1-yr data

CUORE
(2015-2020)



arXiv:1109.0494

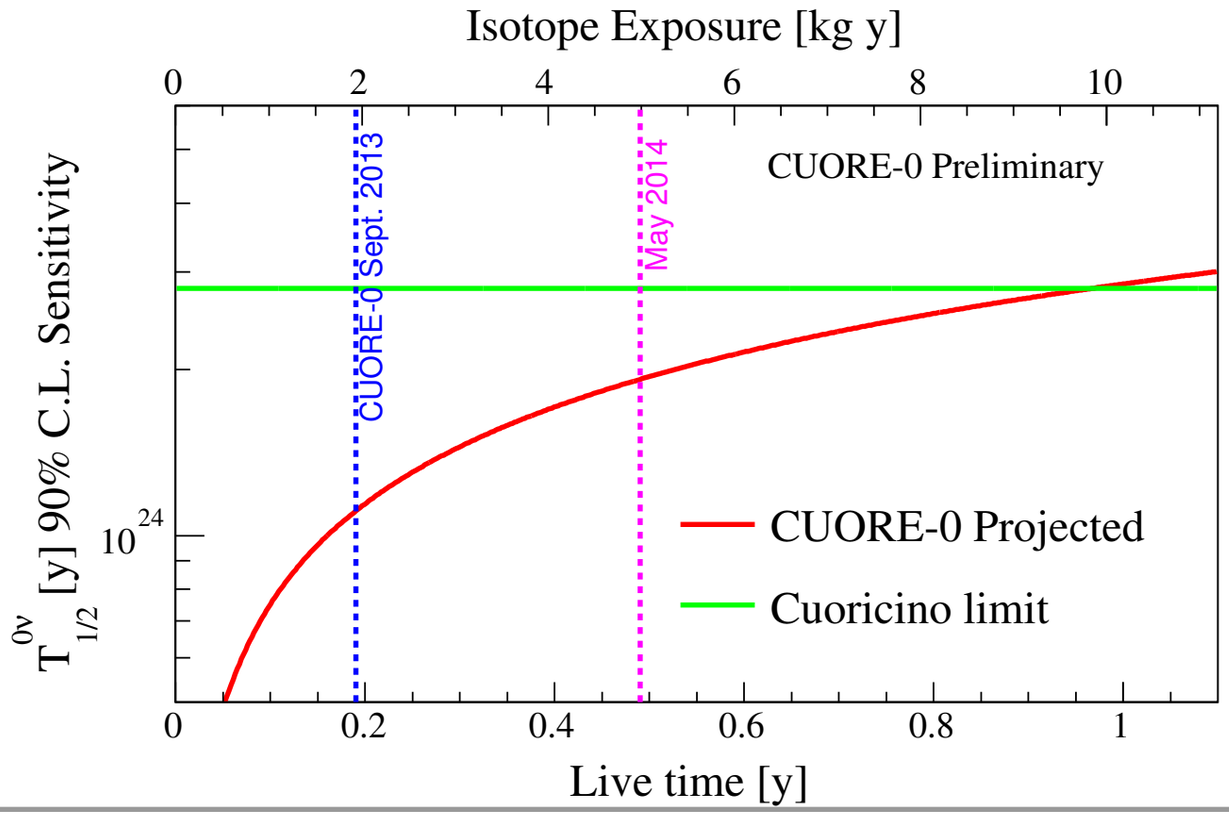
Projected

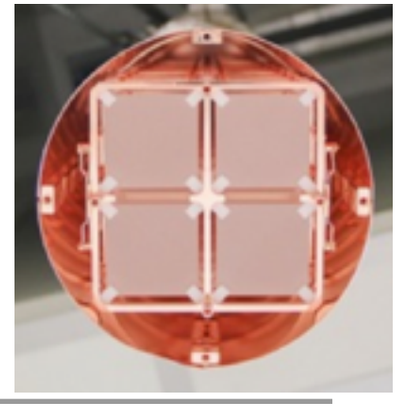
$T_{1/2}^{0\nu\beta\beta} > 9.5 \times 10^{25}$ yr (90% C.L.)

$\langle m_{\beta\beta} \rangle_{90\%\ \mathrm{C.L.}} = 51 - 133\ \mathrm{meV}$

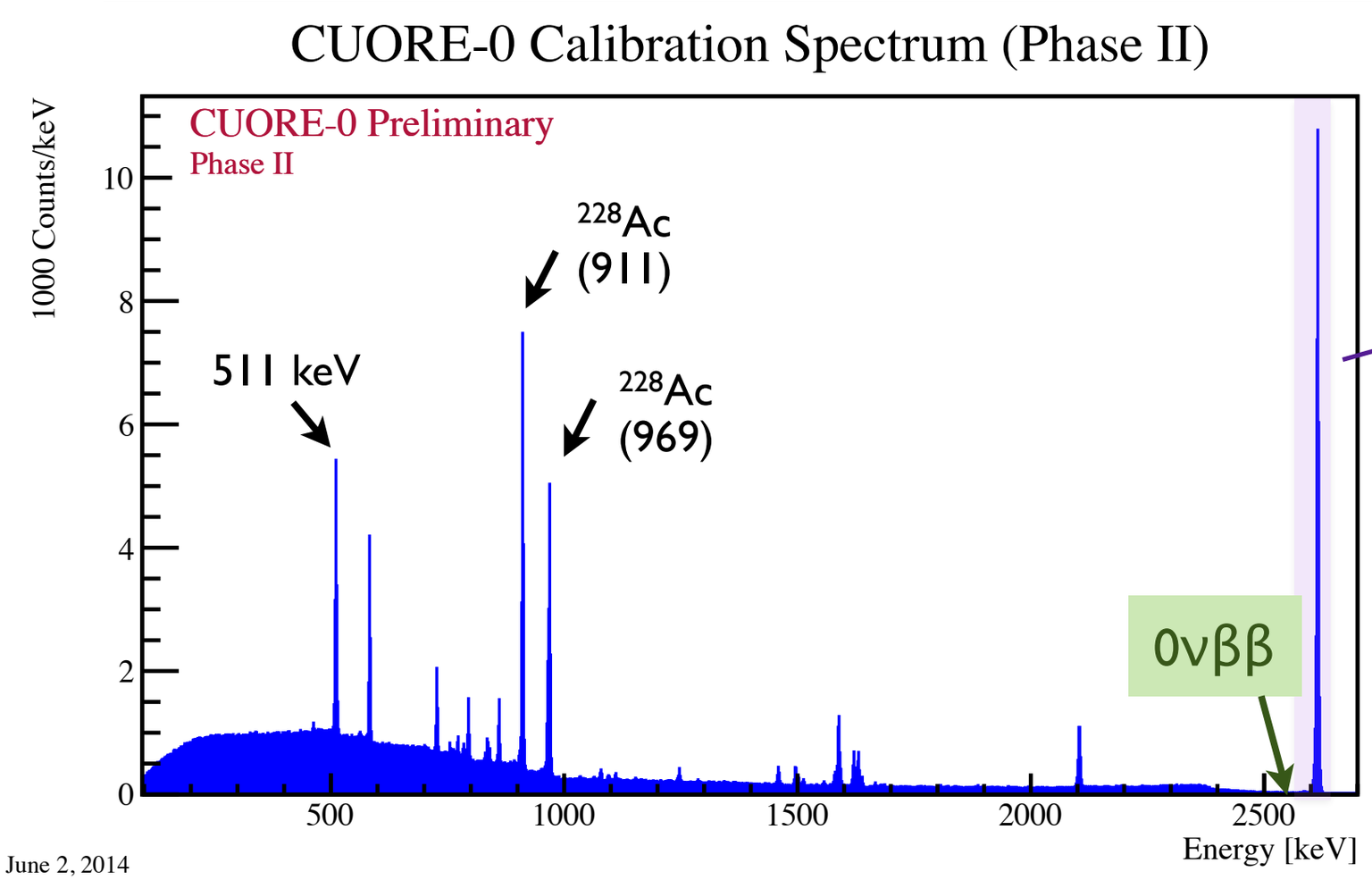
CUORE-0

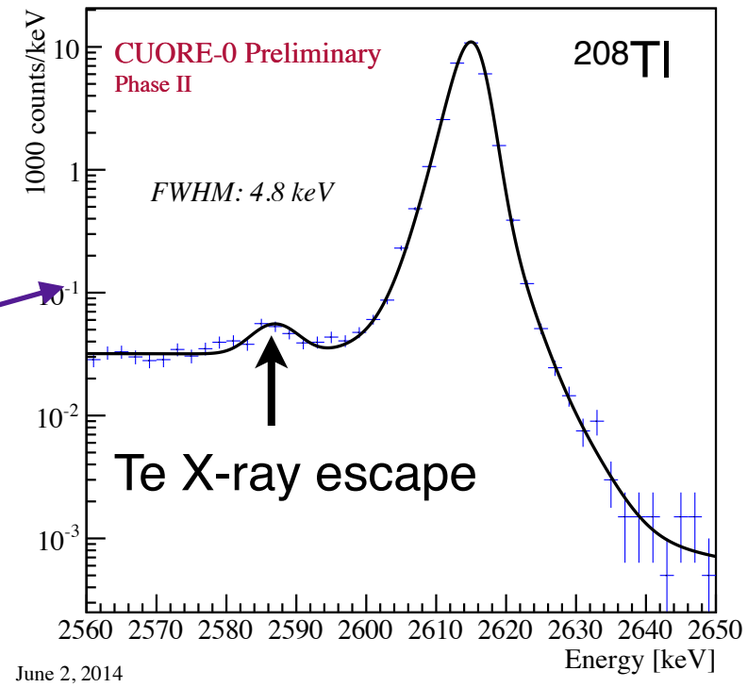
- A single CUORE-like tower ~11 kg of ^{130}Te running in CUORICINO shielding & cryostat since March 2013
- Goals:
  - Validate new cleaning and assembly procedures for CUORE
  - stand-alone DBD experiment
- First results (Phase I data analysis) ***EPJC 74, 2956 (2014).***
- Phase II data w/ improved detector operation condition ongoing.
- Expect to reach CUORICINO sens. with ~ 1yr lifetime (unblind early 2015)

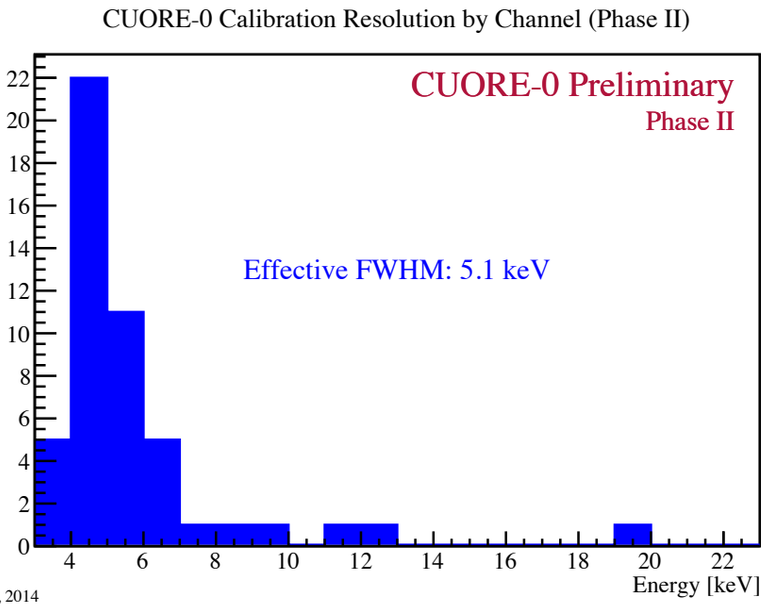




CUORE-0 Energy Resolution



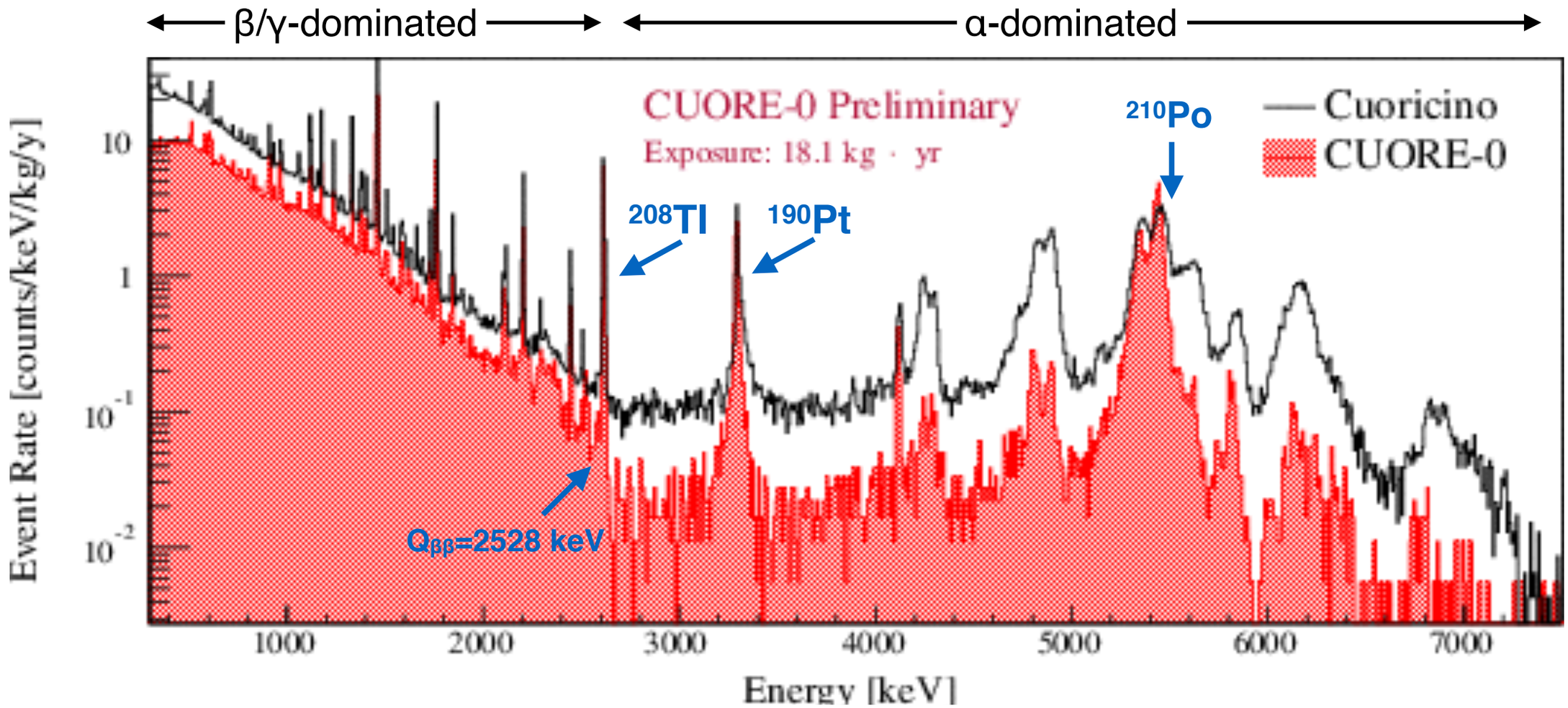




- Total ^{232}Th activity of 100 Bq via two thoriated wires outside the cryostat
- Improved detector operation in Phase II
  - ➡ CUORE goal of 5 keV FWHM near ROI achieved.

CUORE-0 Background Measurement

Eur. Phys. J. C 74, 2956 (2014)



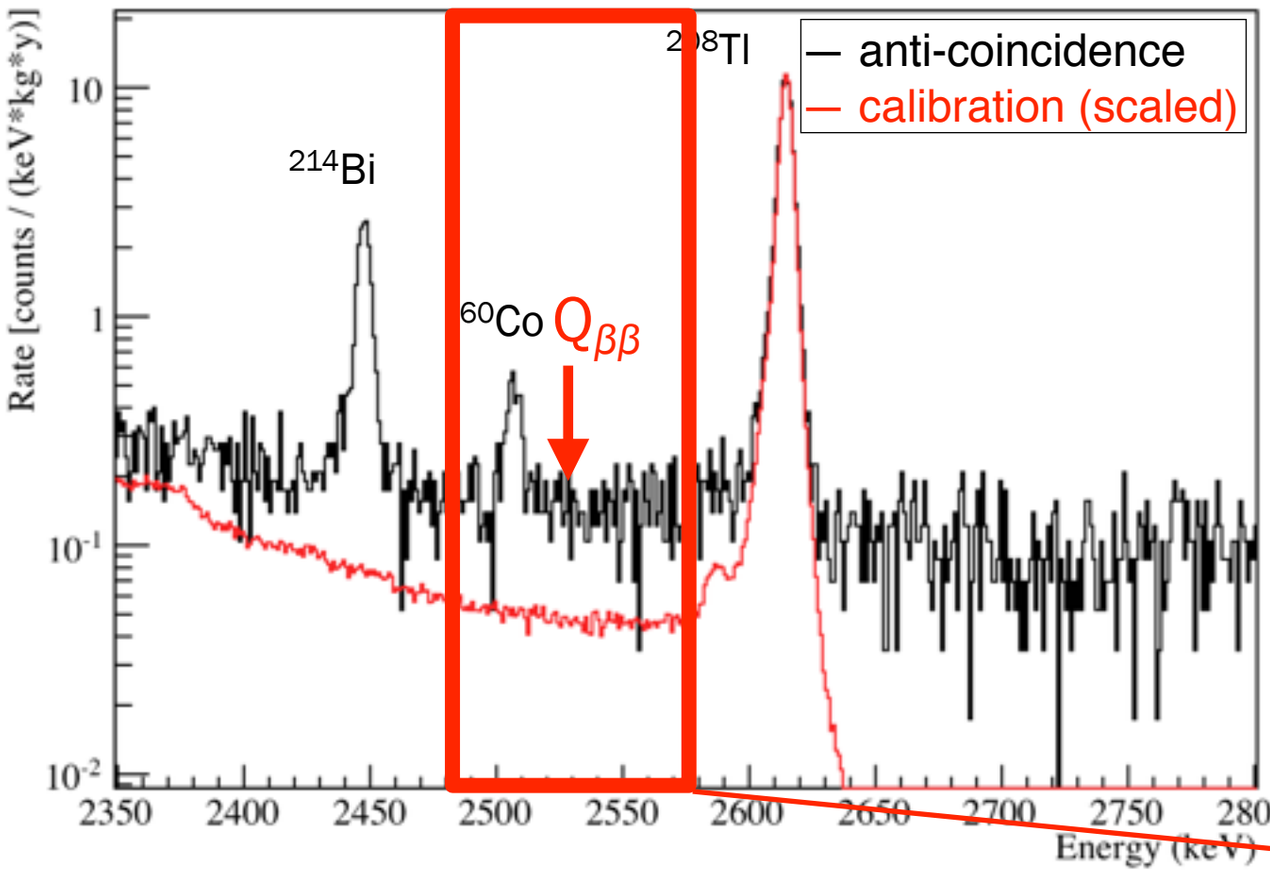
	0νββ region [c/keV/kg/yr]	2700-3900 keV * [c/keV/kg/yr]
CUORICINO ε=83%	0.153 +/- 0.006	0.110 +/- 0.001
CUORE-0 **ε =78%**	**0.063 +/- 0.006**	**0.020 +/- 0.001**

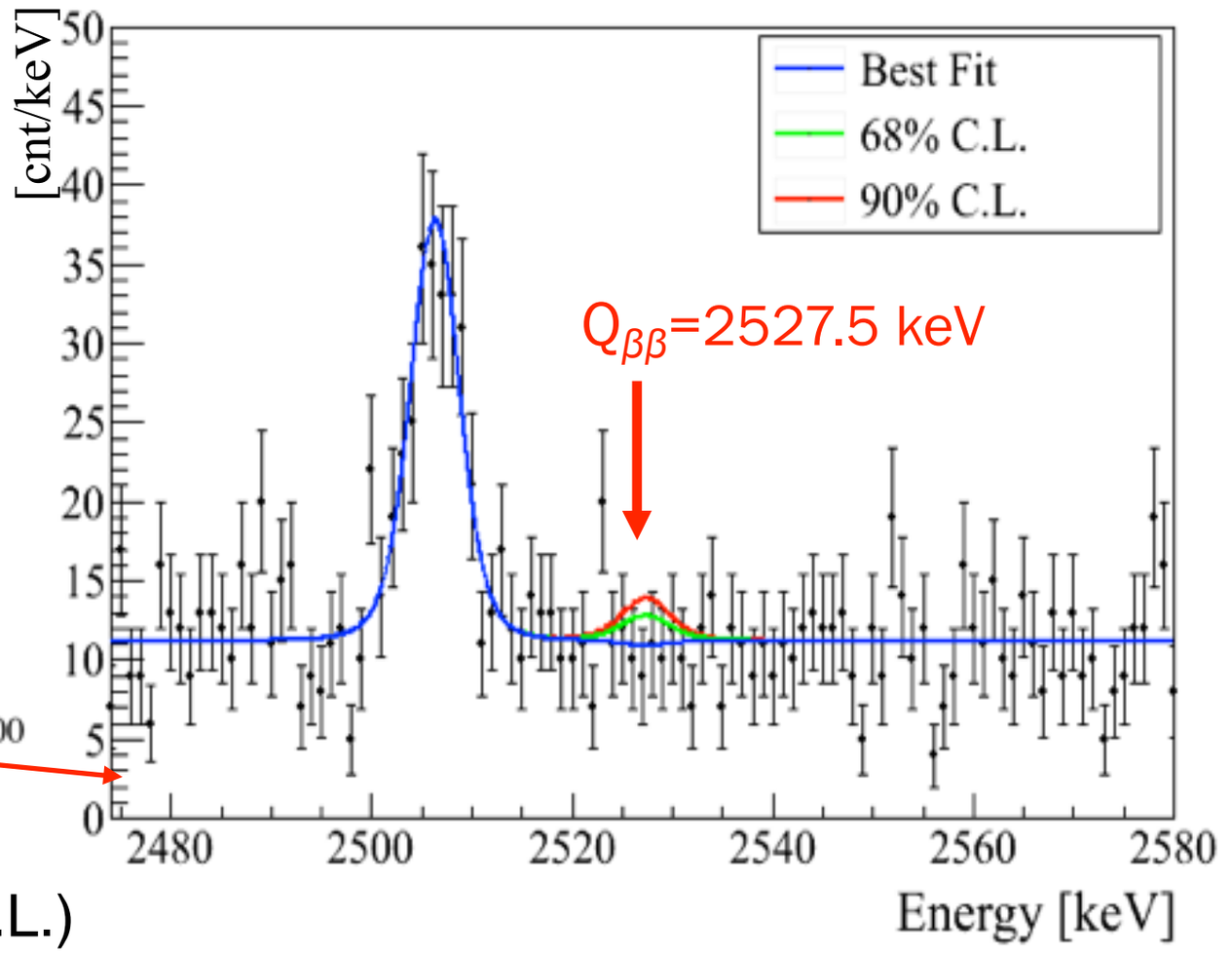
* excluding the ^{190}Pt peak region

- α-dominated bkg: 6-fold reduction
  - Ultra-cleaning of CUORE-0 Cu surfaces
- 2.5-fold reduction of bkg in ROI
  - stringent radon control in COURE-0
- β/γ bkg from cryostat ^{232}Th remains the same
- **Consistent with the Cuoricino bkg model**

CUORICINO Result

Astropart. Phys. 34 (2011) 822–831





Half-life limit (^{130}Te) ≥ 2.8×10^{24} y (90% C.L.)

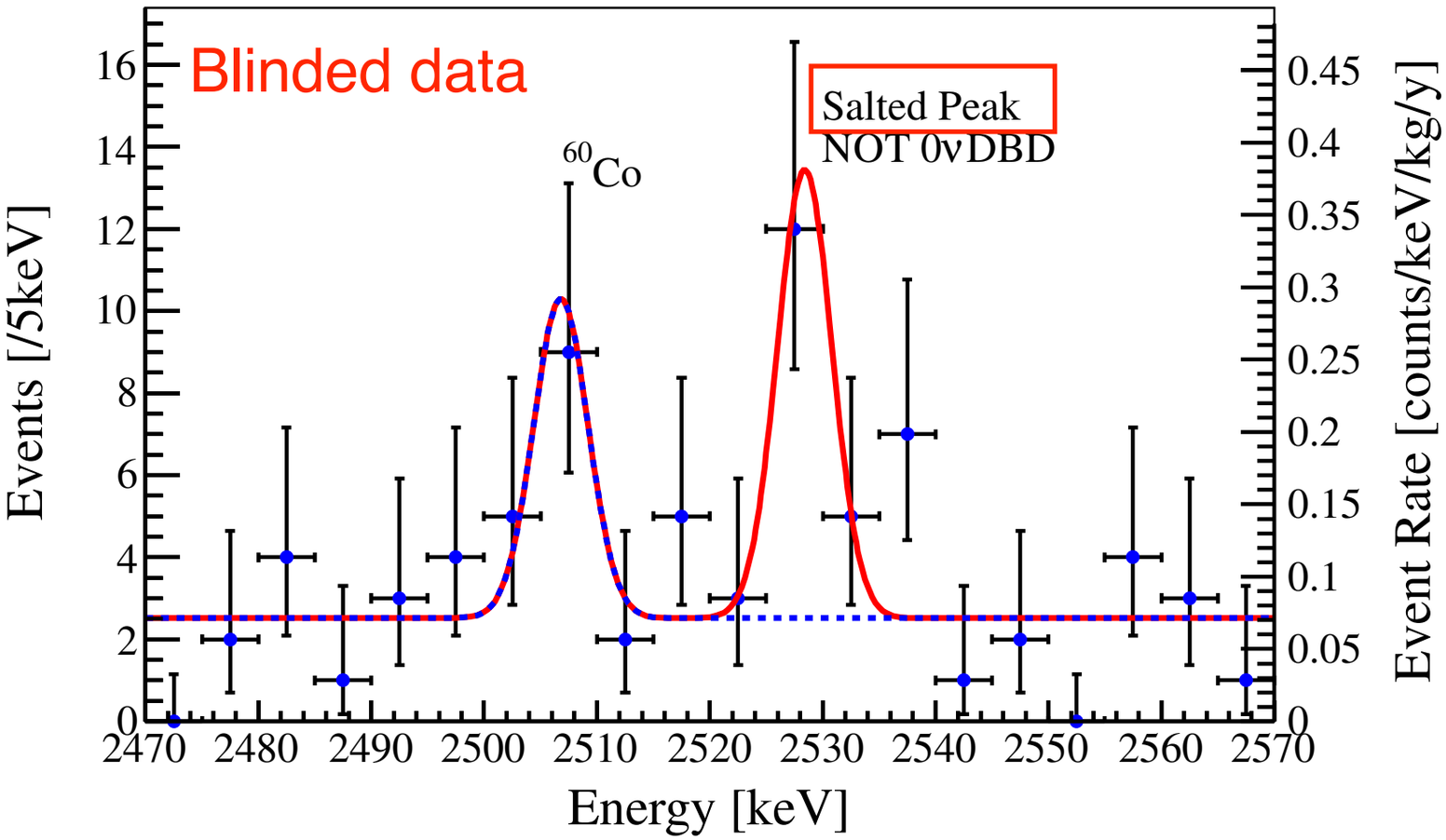
Background: 0.169 ± 0.006 counts/keV/kg/y

No evidence of neutrinoless double beta decay in ^{130}Te.

data: 2003 – 2008
19.75 kg-yr ^{130}Te exposure

Upper limit, Majorana mass: $m_{\nu_e} < 300 – 710$ meV

CUORE-0 DBD Region

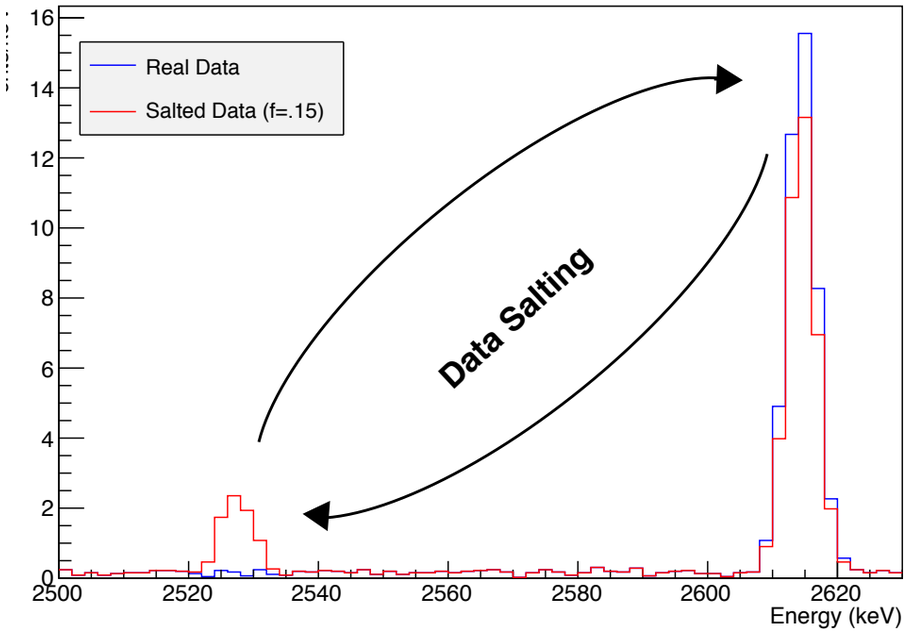


EPJC 74, 2956 (2014)

- Region of Interest was blinded by "salting": exchange a small (and ***blinded***) fraction of the events in ^{208}Tl peak with events in the 0νDBD region to produce an artificial peak.

Unblinding in 2015

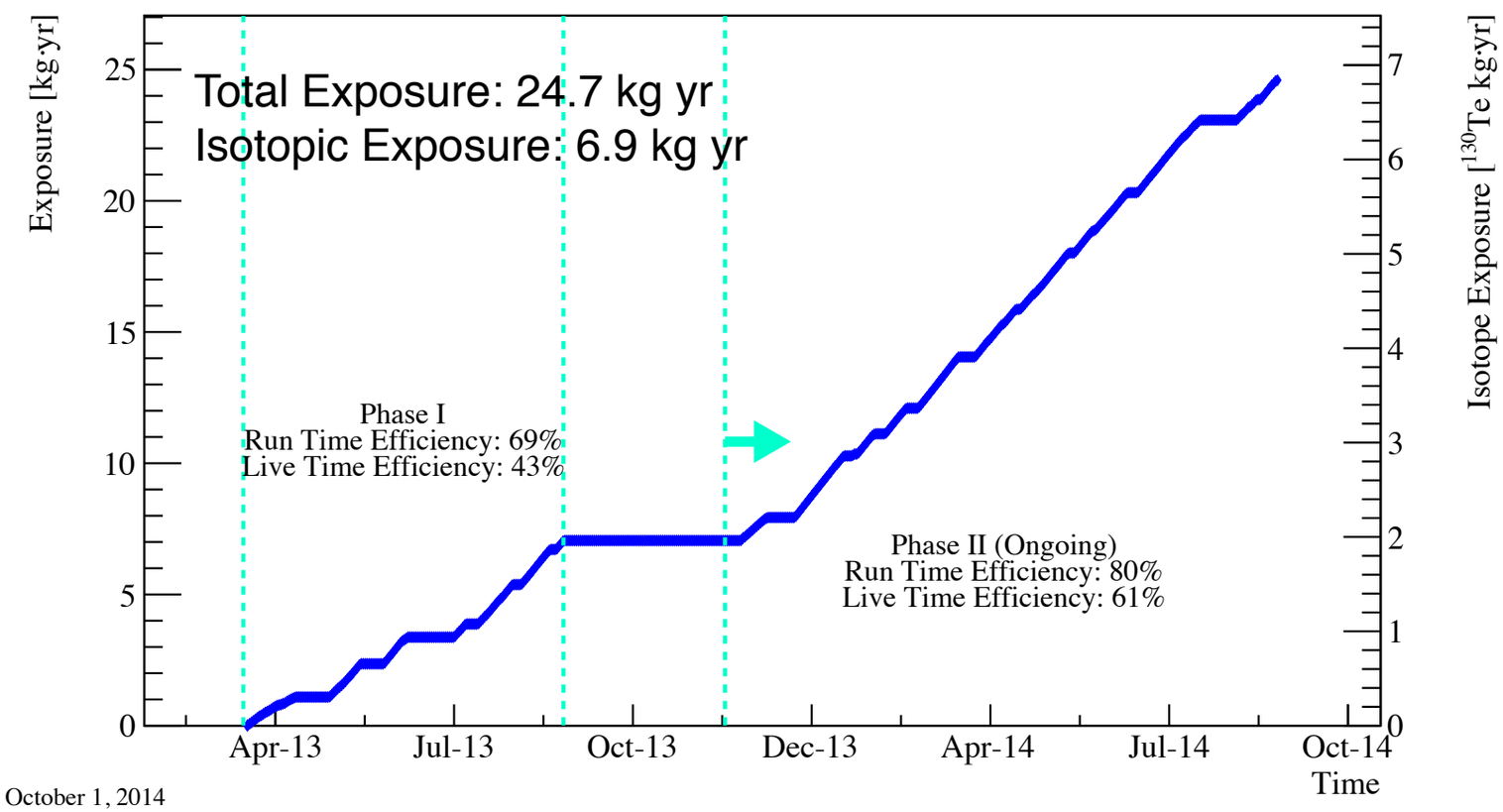
Simulated Salted CUORE-0 Data



Analysis improvements underway

- Noise reduction - decorrelation
  - see J. Ouellet's talk: CM.00007 Wed Oct. 8 @ 8:45 PM
- heater-less gain stabilization
- calibration, pulse-shape, and multiplicity-cuts
- Low-energy PSA for dark matter searches
- background model

CUORE-0 Sensitivity



CUORE-0 expected to surpass Cuoricino at ~ 1 year of live time.

CUORICINO vs. CUORE-0: improved δE & bgd

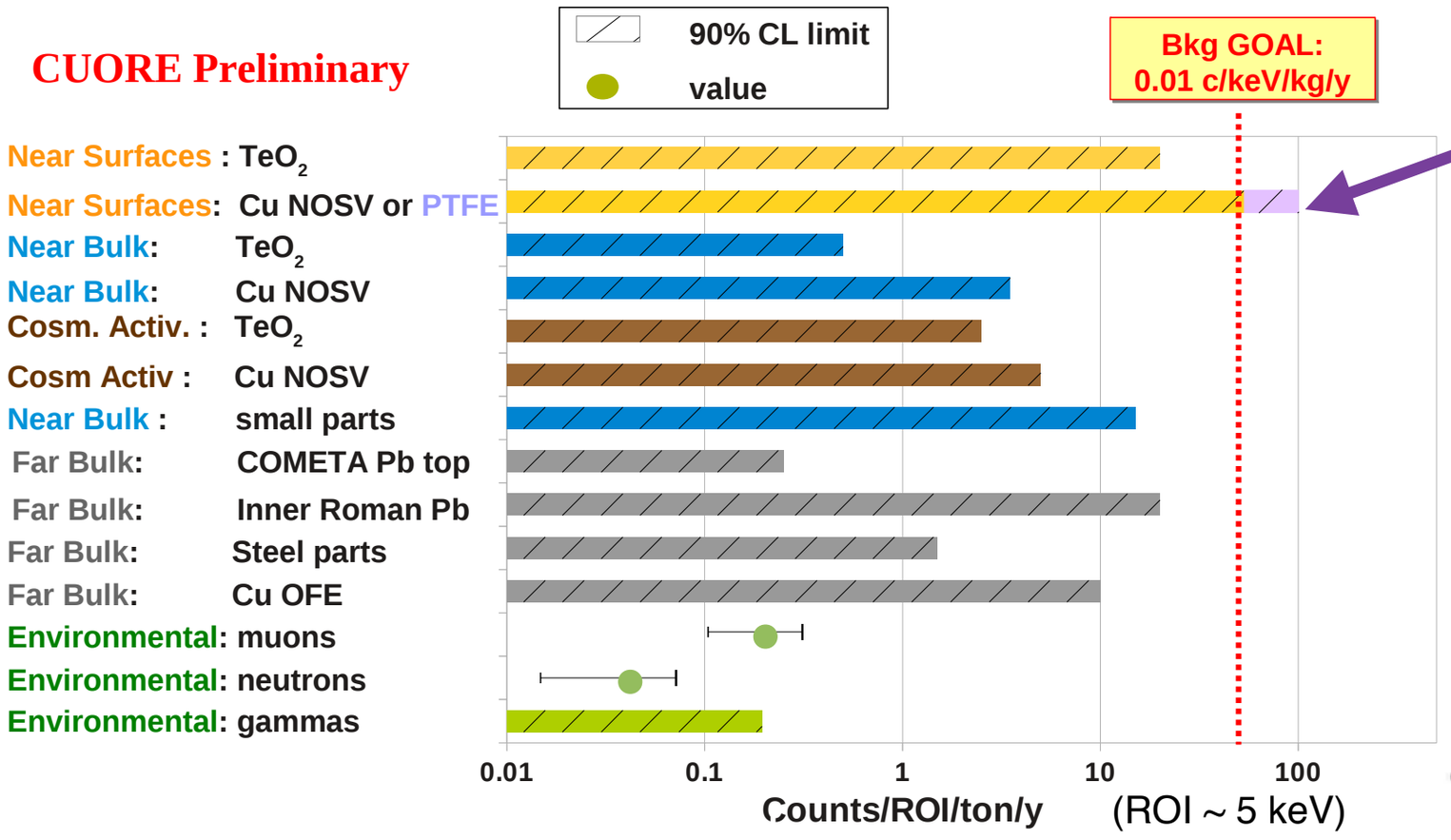
δE: 4.8 keV FWHM @ ROI

background: 0.063±0.006 cnts/(keV·kg·yr)

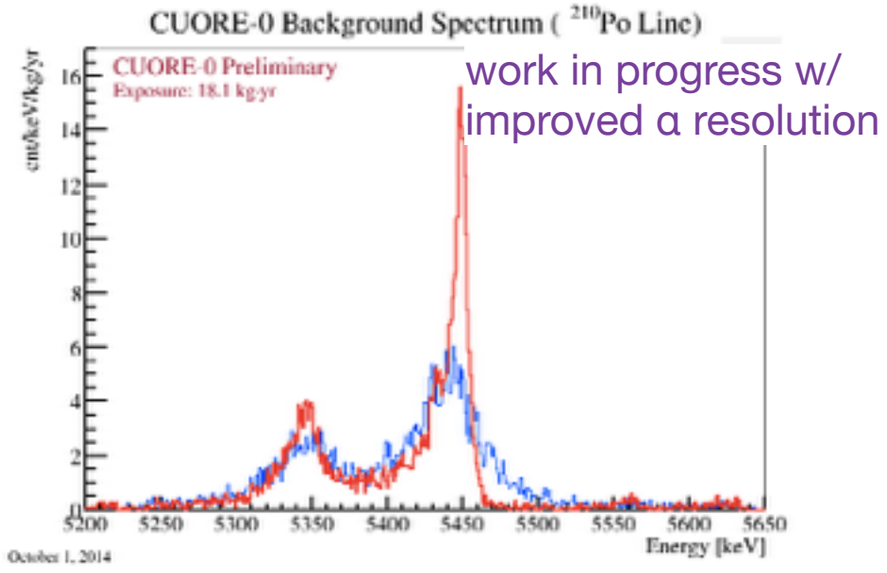
EPJC 74, 2956 (2014)

Projected CUORE Background

- CUORE-0 - provides bench mark for remaining background with new assembly & crystal/Cu cleaning protocols
- CUORE - results of CUORE-0 + screening campaign results -> CUORE MC



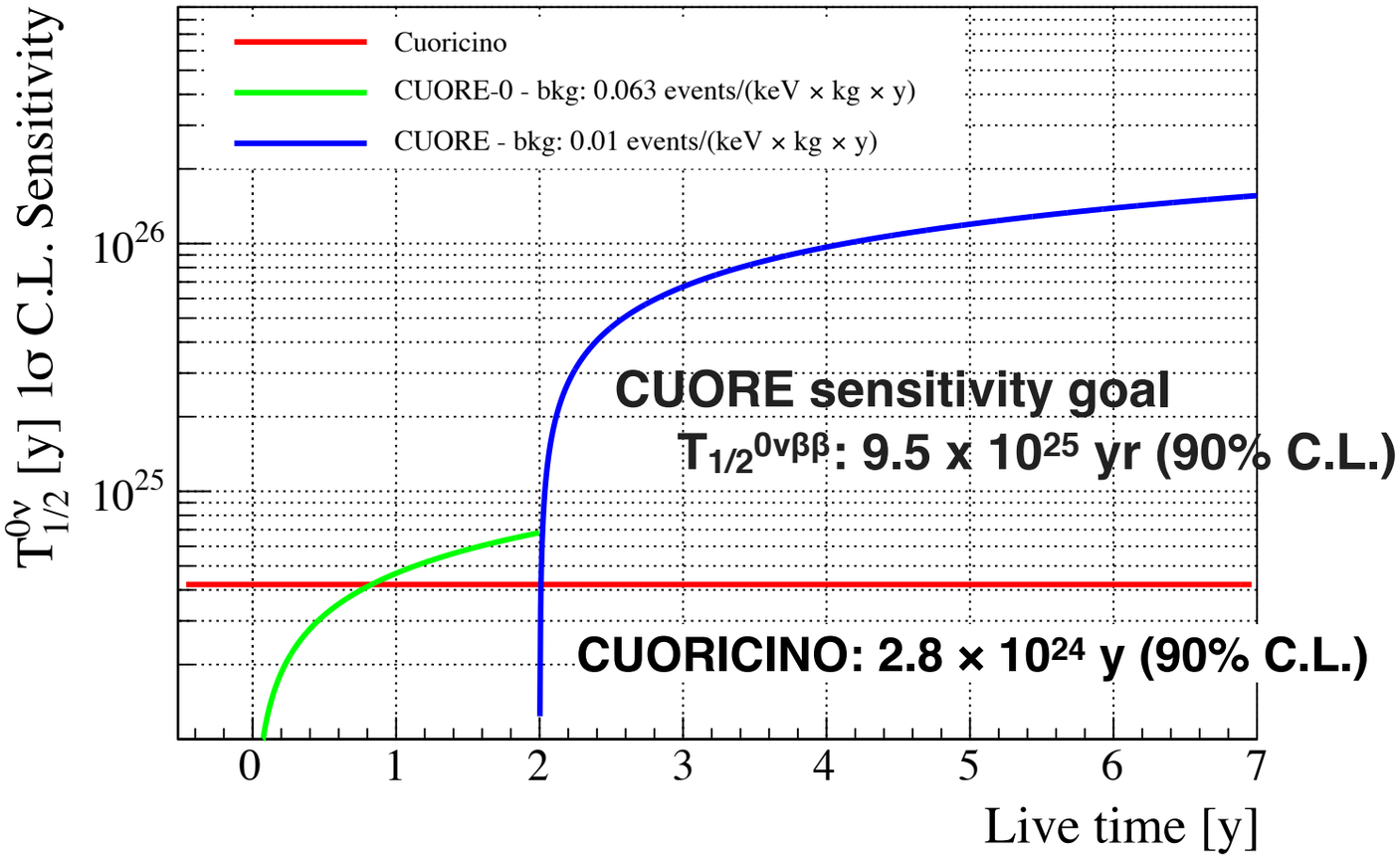
Detailed studies of surface vs. bulk contamination underway

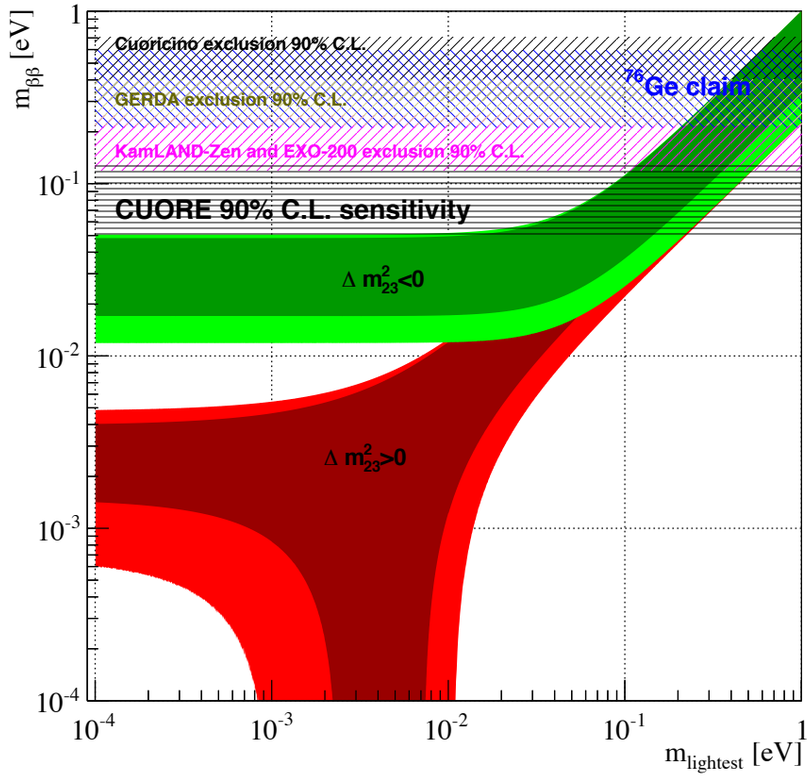


work in progress w/ improved α resolution

Conservatively extrapolate measured α-region bkg from CUORE-0 assuming all bkg is from $^{238}U/^{232}Th/^{210}Po$ individually

CUORE Sensitivity



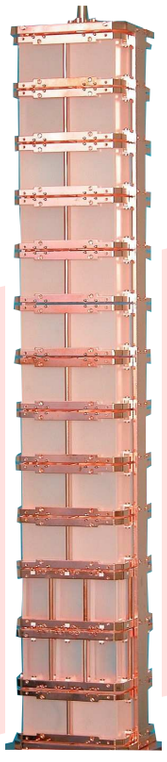


- CUORE sensitivity goal:
  - **$T_{1/2}^{0\nu\beta\beta}$ > 9.5 x 10^{25} yr** @ 90% C.L.
- Effective Majorana mass 51 - 133 meV @ 90% C.L.
  - Assumptions: 5 keV FWHM ROI resolution (δE), background rate (b) of 0.01 counts/(keV·kg·yr), 5 years of live time.

arXiv:1109.0494

The CUORE 0νββ Search

Cuoricino
(2003-2008)



Astropart. Phys. 34
(2011) 822–831

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

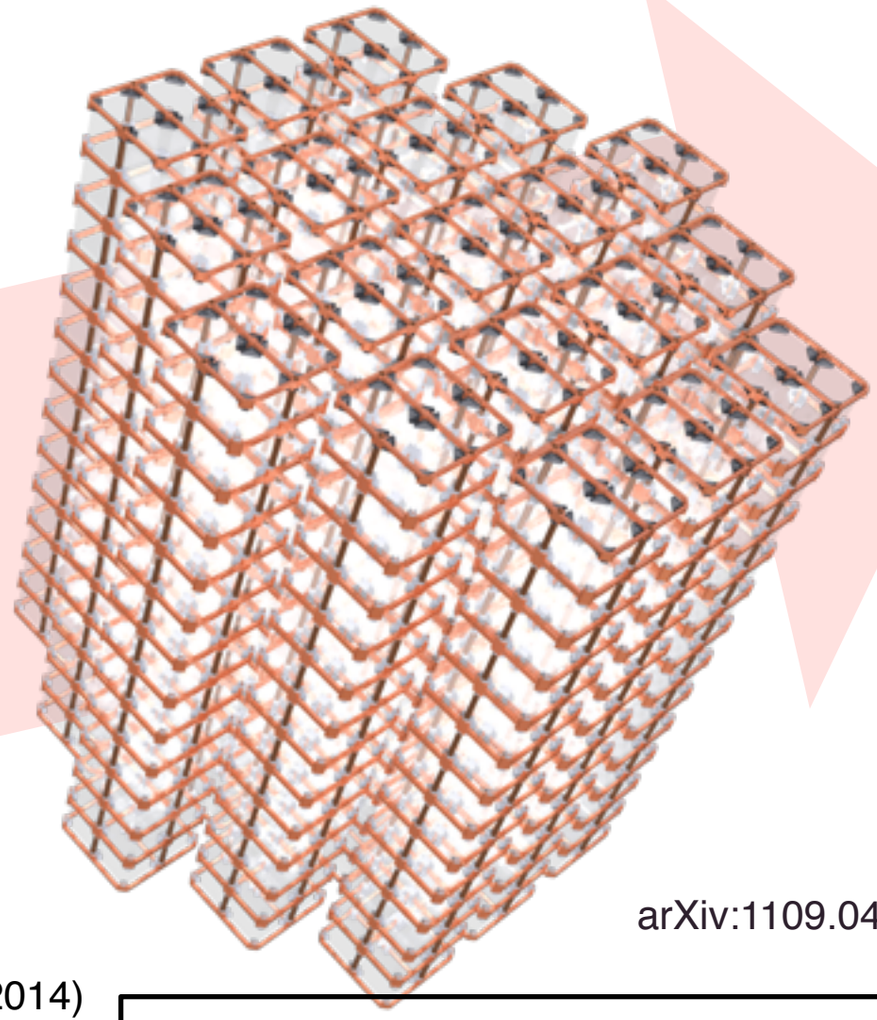
$\langle m_{\beta\beta} \rangle_{90\%\ \mathrm{C.L.}} = 300 - 710\ \mathrm{meV}$

CUORE-0
(2013-2015)

EPJC 74, 2956 (2014)

Surpass Cuoricino w/ ~1-yr data

CUORE
(2015-2020)



?

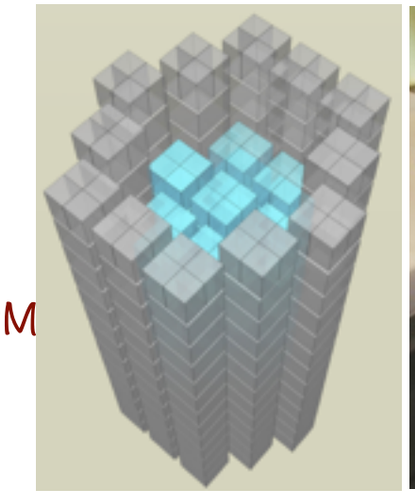
arXiv:1109.0494

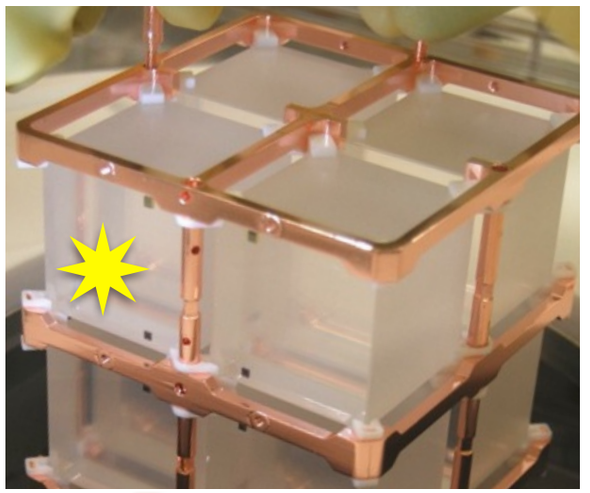
Projected
$T_{1/2}^{0\nu\beta\beta} > 9.5 \times 10^{25}$ yr (90% C.L.)

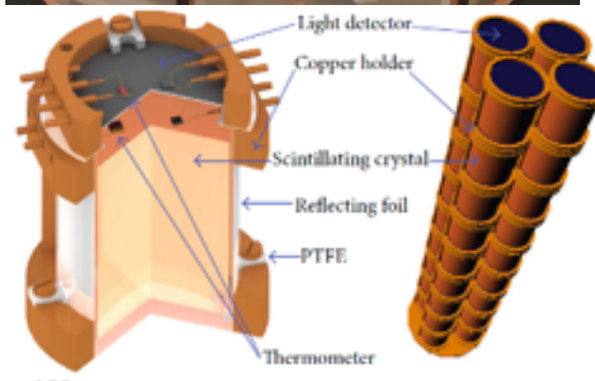
$\langle m_{\beta\beta} \rangle_{90\%\ \mathrm{C.L.}} = 51 - 133\ \mathrm{meV}$

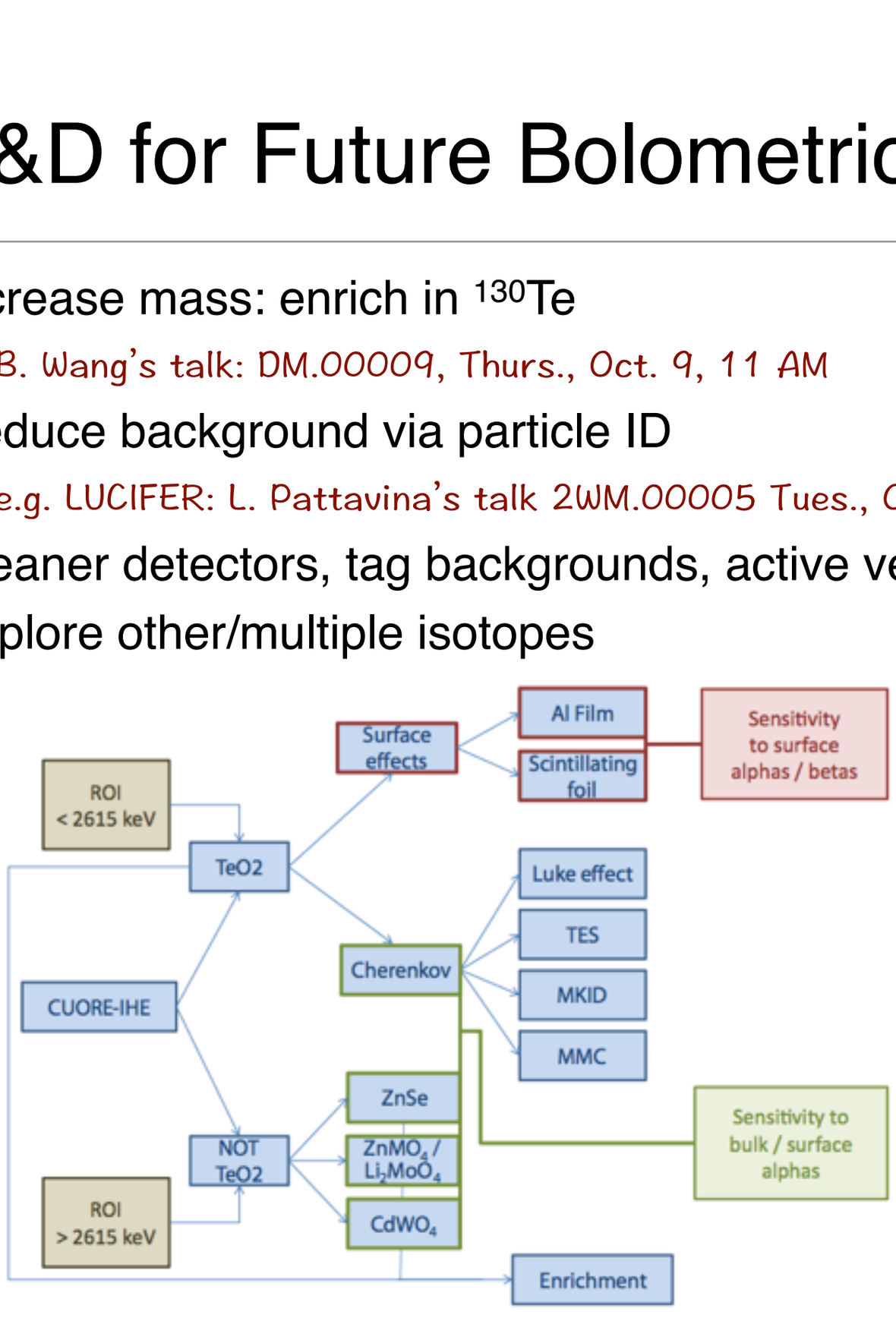
R&D for Future Bolometric 0νββ Searches

- Increase mass: enrich in ^{130}Te
  - B. Wang's talk: DM.00009, Thurs., Oct. 9, 11 AM
- Reduce background via particle ID
  - e.g. LUCIFER: L. Pattavina's talk 2WM.00005 Tues., Oct. 7, 4PM
- Cleaner detectors, tag backgrounds, active veto
- Explore other/multiple isotopes



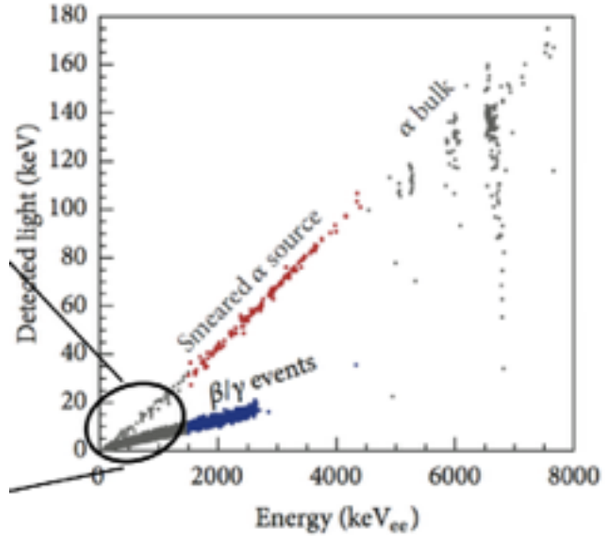






Bolometer R&D:

- CALDER
- Cherenkov/TeO_2
- LUCIFER
- LUMINEU



Summary

- CUORE builds on the success of CUORICINO and its predecessors
- CUORE-0 has been running since March 2013. It demonstrates:
  - successful background mitigation and confirms the Cuoricino background model
  - Goal of < 5 keV FWHM for ROI energy resolution reached
  - further analysis underway.
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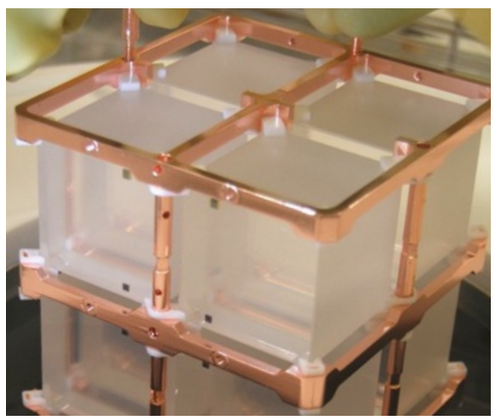
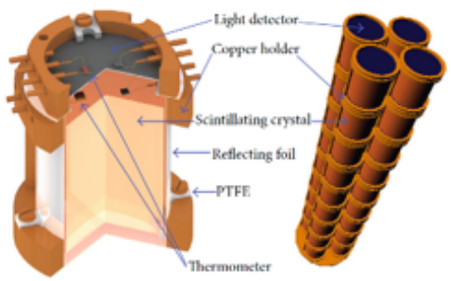
- Physics data taking expected to start in late 2015.
- R&D effort is underway for 0νββ search beyond CUORE.

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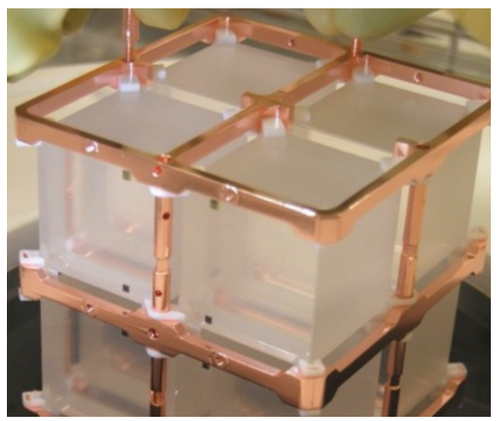
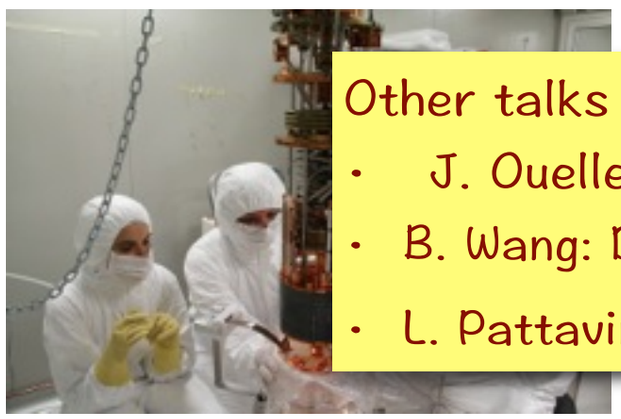
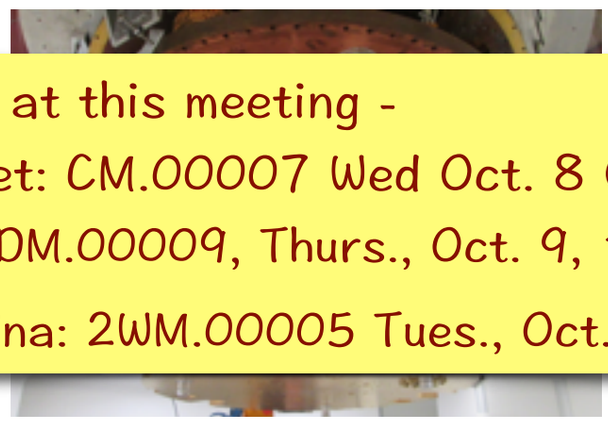

Other talks at this meeting -

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