CUORE/CUPID Status
&
CUPID-China Discussions

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CUPID-China Meeting @ USTC
2018年6月25-26日

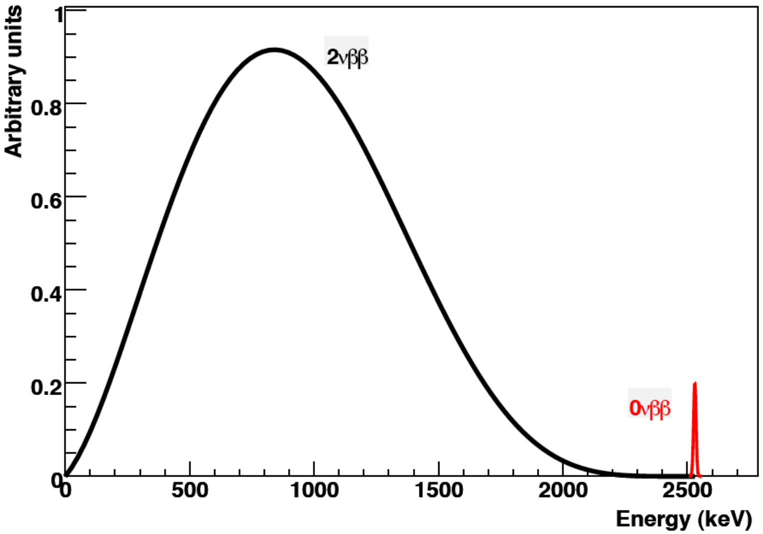
Outline

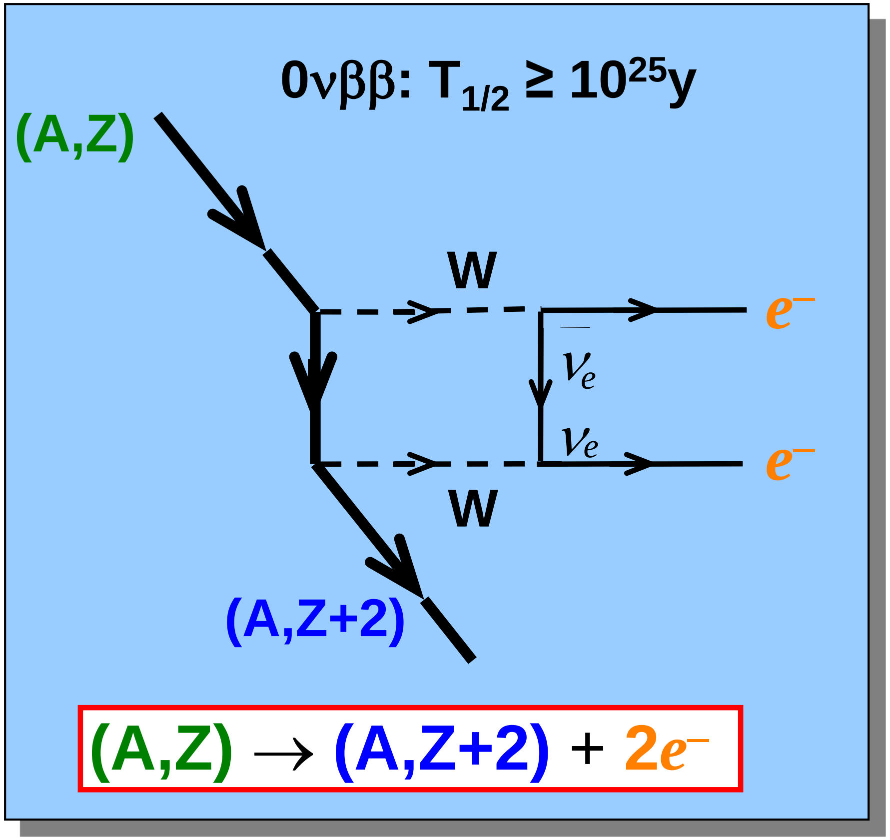
1) CUORE Status

2) CUPID Status
   TeO_2 – Cerenkov Light readout
   ZnSe – Crystal
   LMO -- Crystal

3) CUPID-China Path Forward

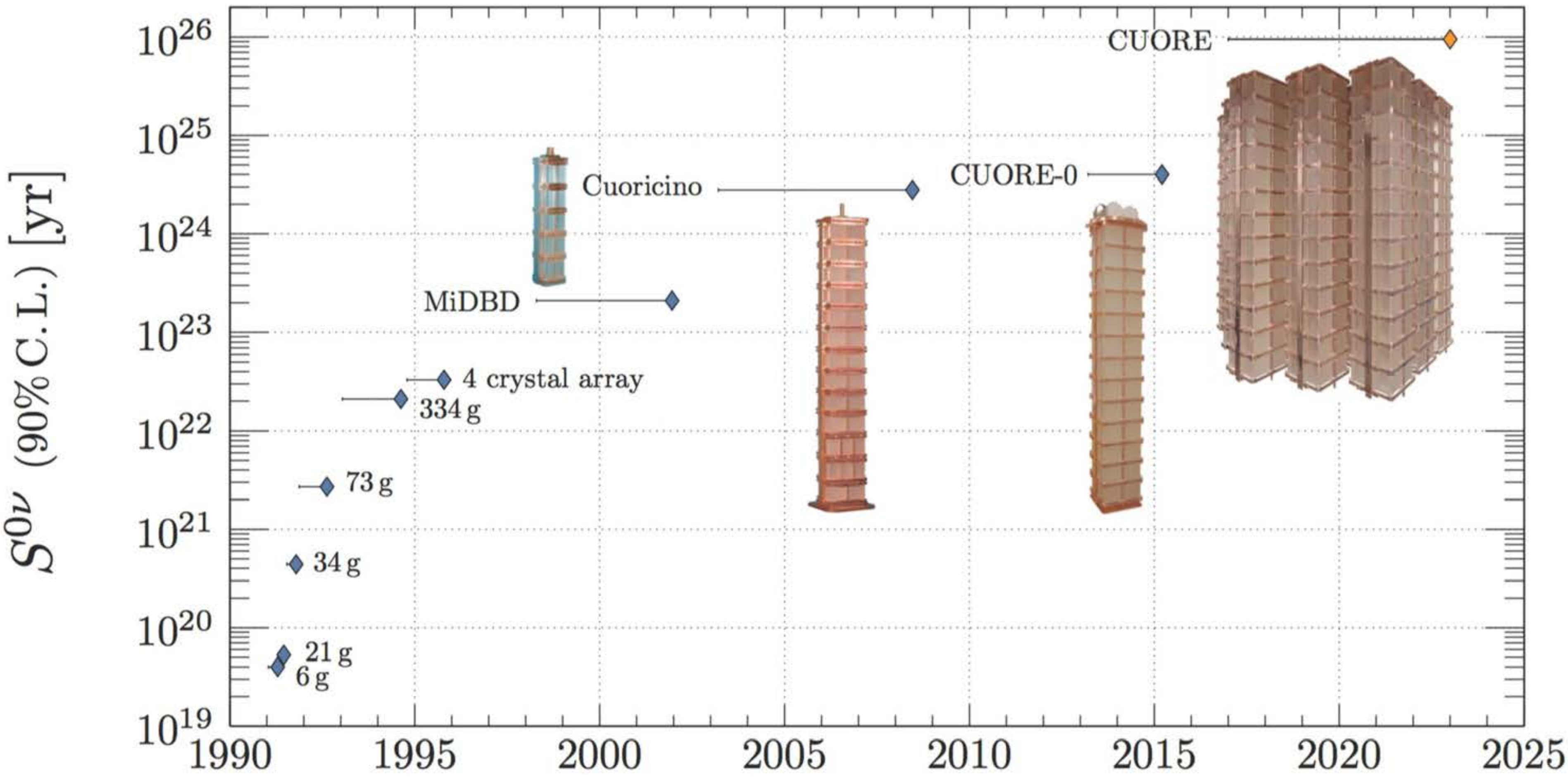
Majorana Neutrinos?





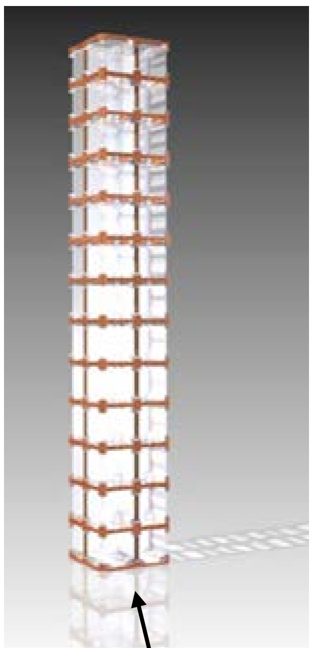
Majorana → neutrino = anti-neutrino
Lepton Number violation !

> 20 years of Detector Development

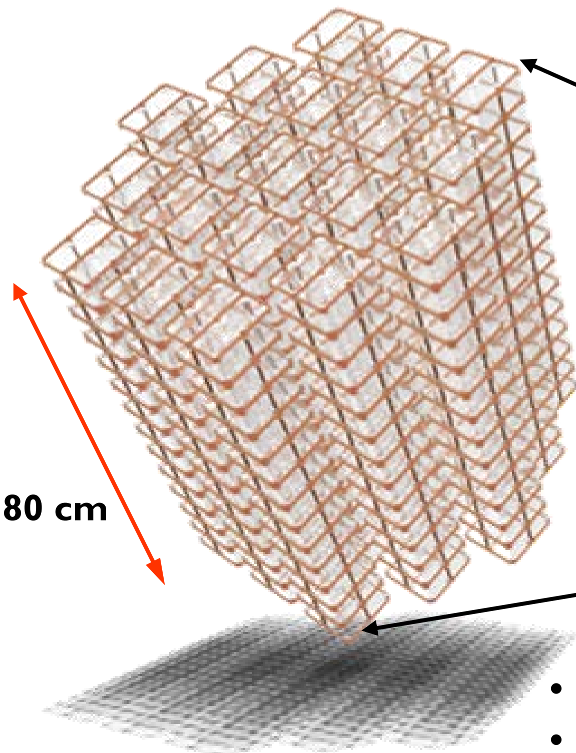


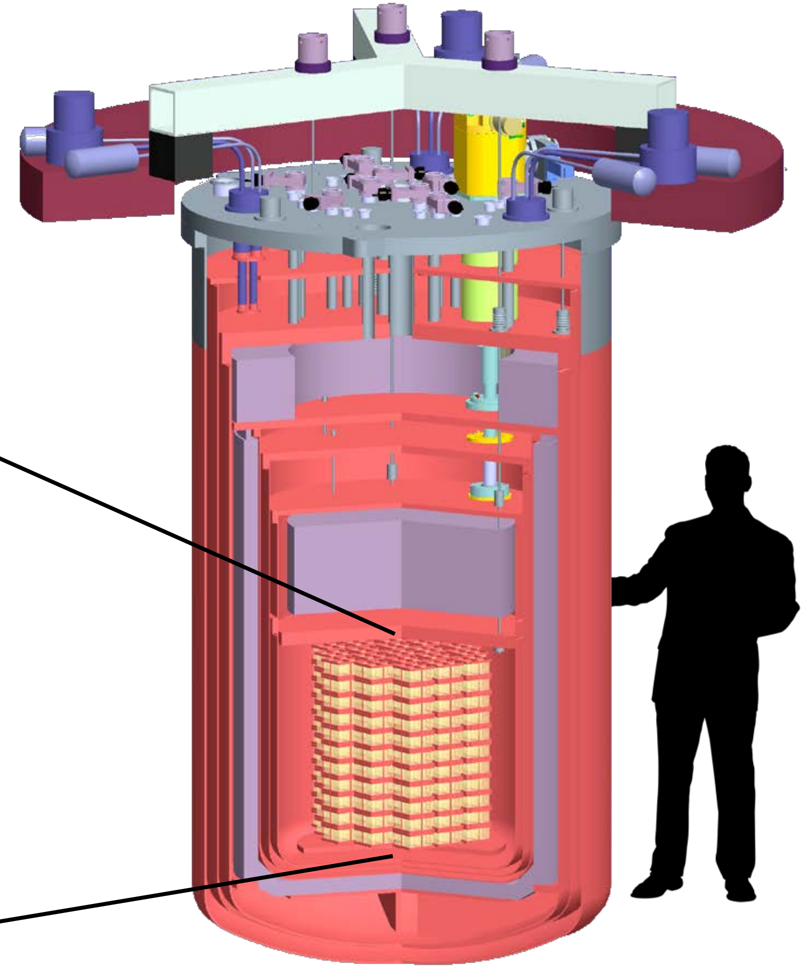
CUORE

CUORE: Cryogenic Underground Observatory for Rare Events will be a tightly packed array of **988 Bolometers** - M ~ 200 kg of ^{130}Te



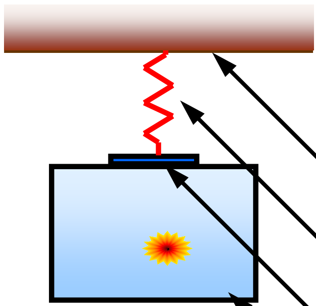
19 CUORICINO-like towers with 13 planes of 4 crystals each



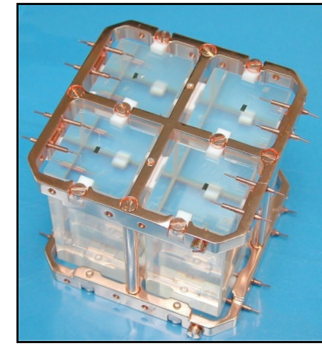


- Operated at Gran Sasso laboratory
- Special cryostat built w/ selected materials
- Cryogen-free dilution refrigerator
- Shielded by several lead shields

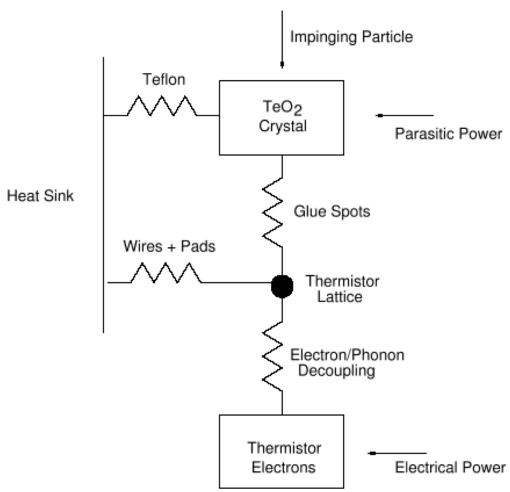
Bolometer

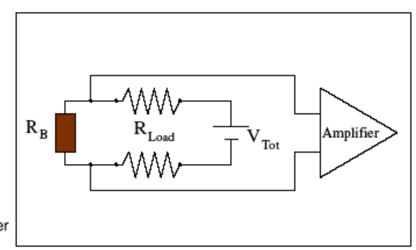


TeO$_2$ Bolometer: Source = Detector



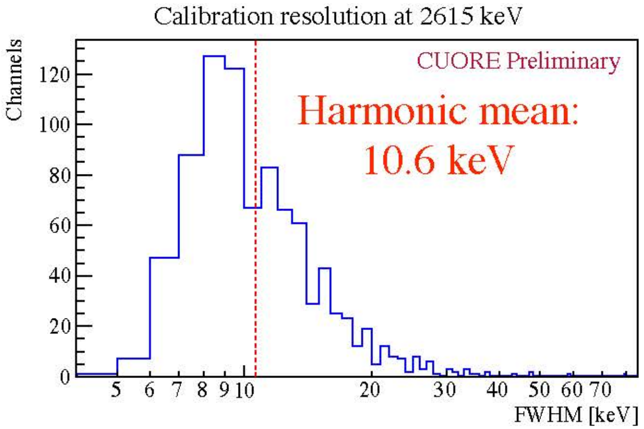
Heat sink: ~8-10 mK
Thermal coupling: Teflon
Thermometer: NTD Ge thermistor
Absorber: TeO$_2$ crystal

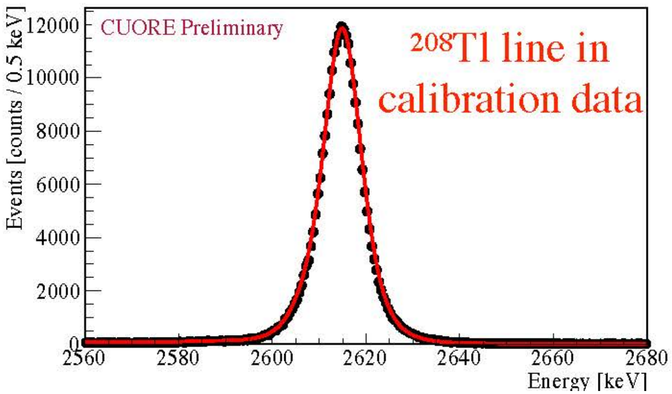




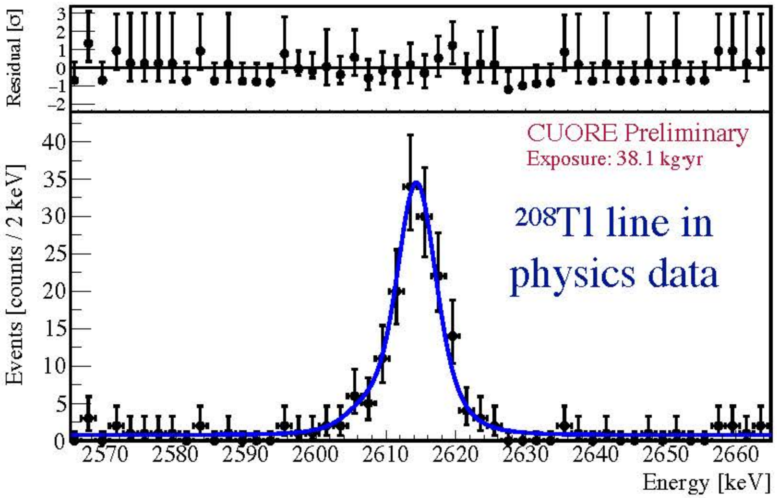
Energy resolution

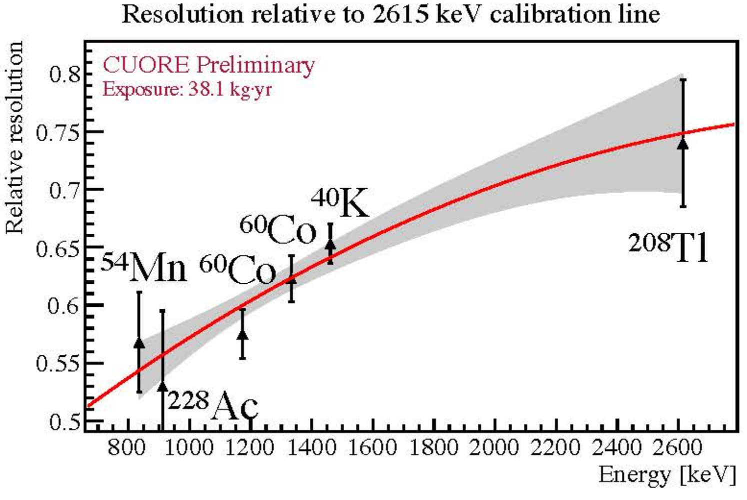
- Selected 899 (90%) "golden" channels:
  - Channels discarded due to high noise or PSA issues
  - could be recovered in the future
- Average energy resolution in calibration runs: 10.6 keV FWHM



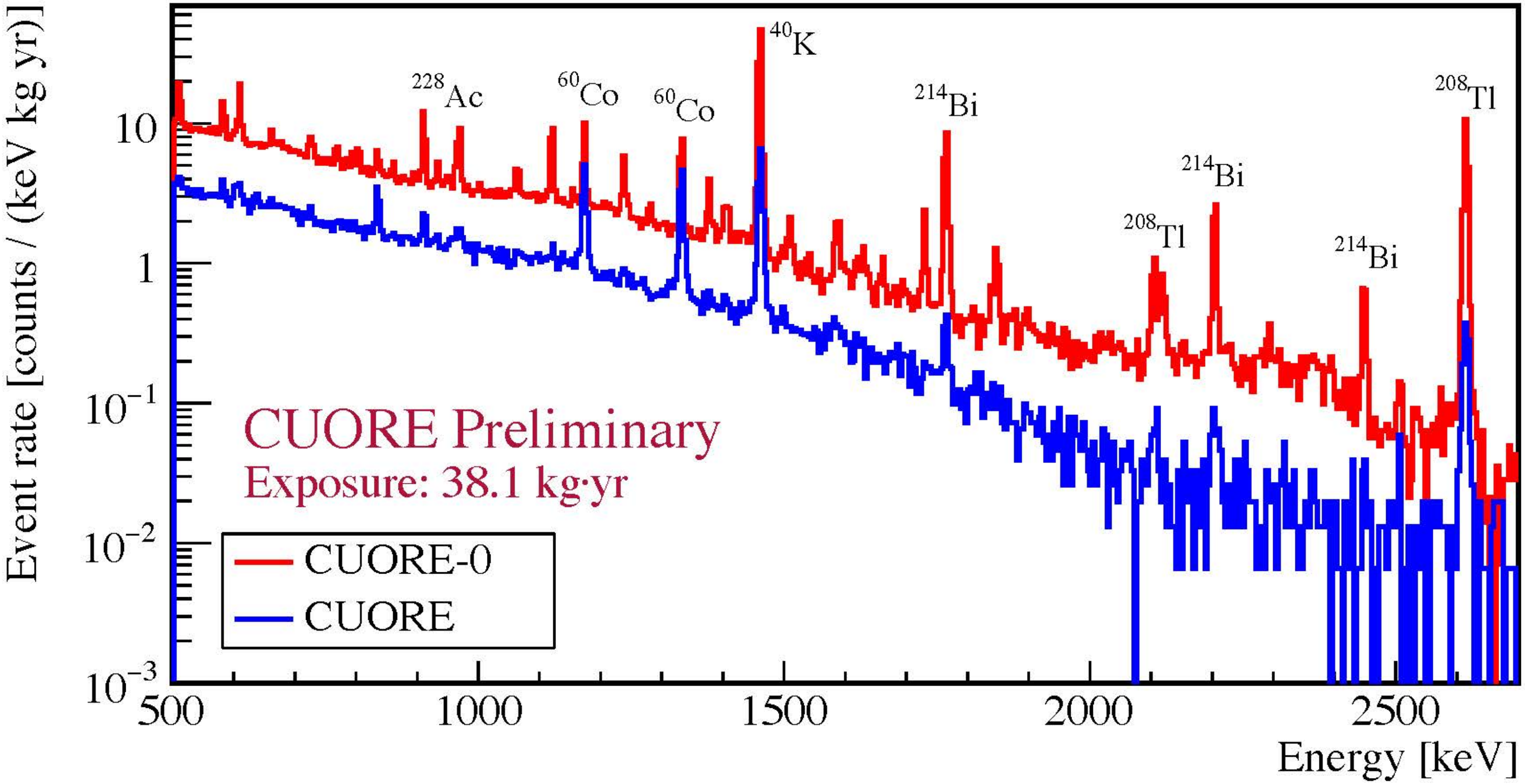


Significantly better performance in physics data:
(7.9 ± 0.6) keV FWHM



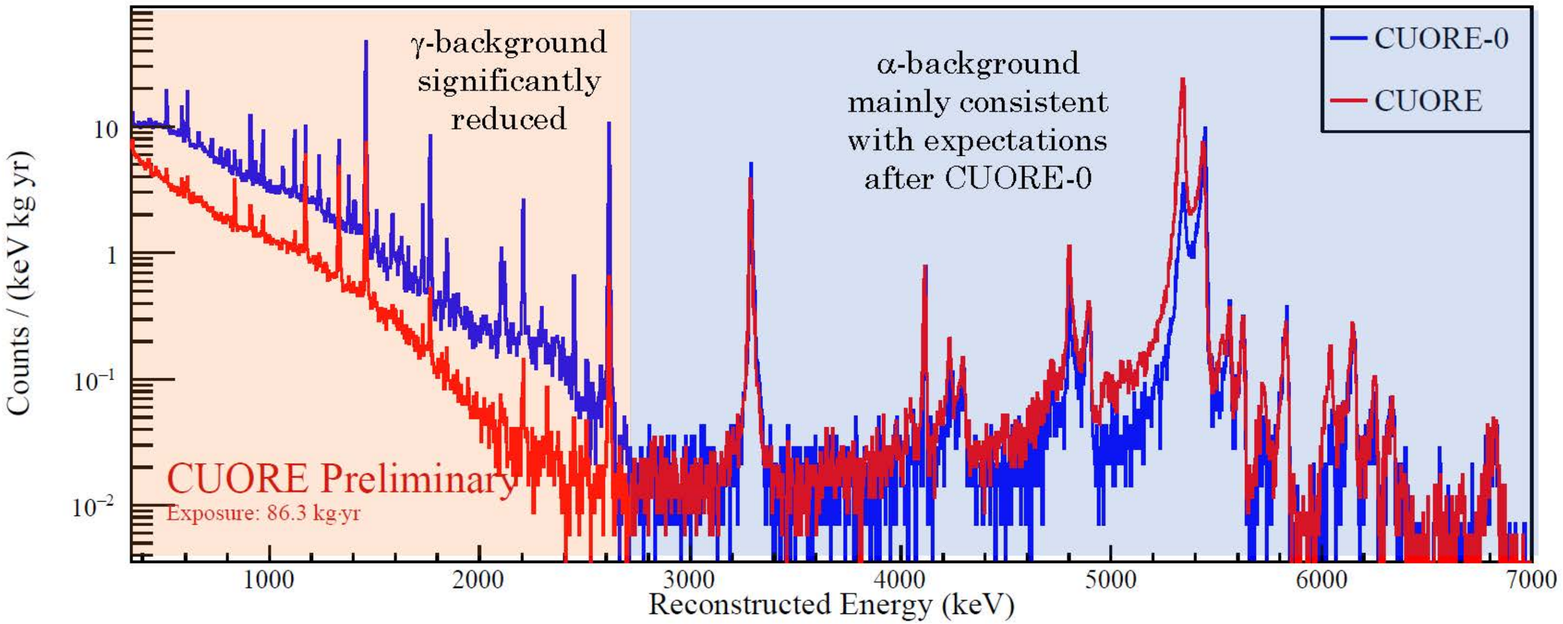


CUORE Background Spectrum



- Significant reduction in the γ region with respect to CUORE-0 (as expected)
- Spectrum is consistent with the background expectations

CUORE Background Level



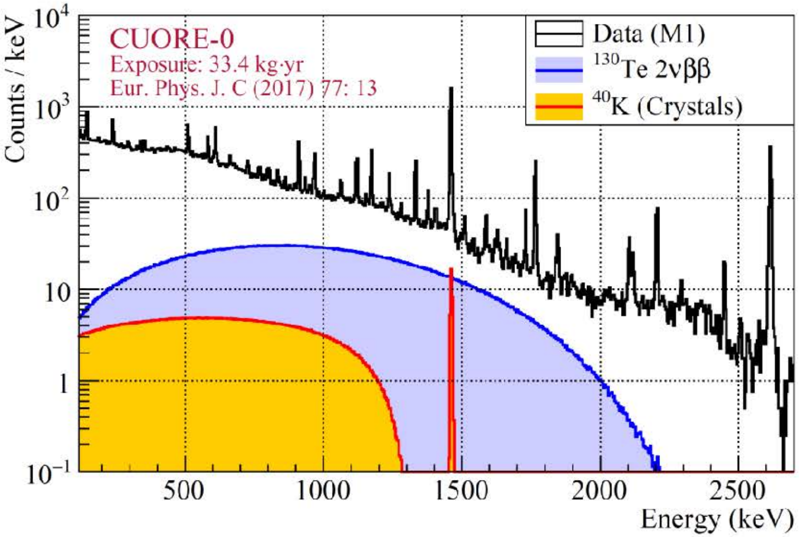
Background Level: design goal 1.0×10^{-2} cts/keV/kg/year

$(1.4 \pm 0.2) \times 10^{-2}$ cts/keV/kg/year

Additional Po210 contamination – unknown source

2νββ half-life measurement

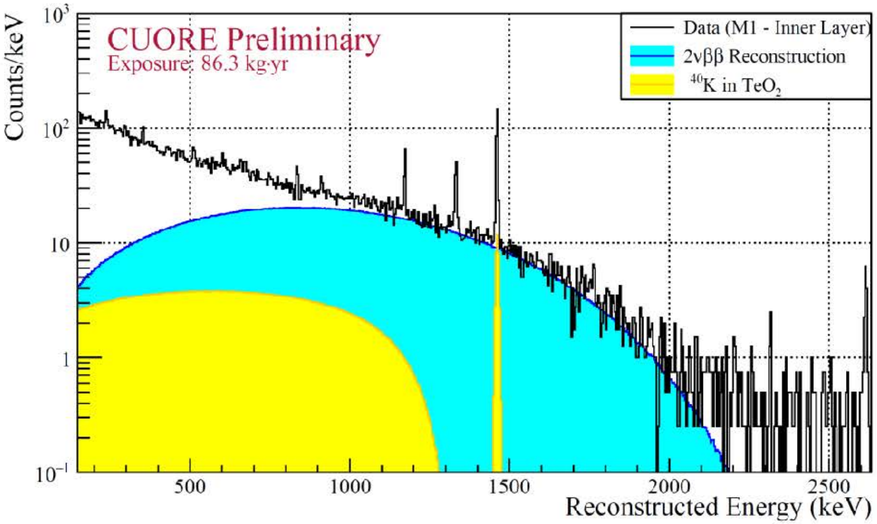
CUORE-0



In CUORE-0, 2νββ decay accounts for **~20% of the events** in the range 1 - 2 MeV of the M1 spectrum.

$$T_{1/2}^{2\nu} = (8.2 \pm 0.2_{stat} \pm 0.6_{syst}) \times 10^{20} \text{ yr}$$

CUORE

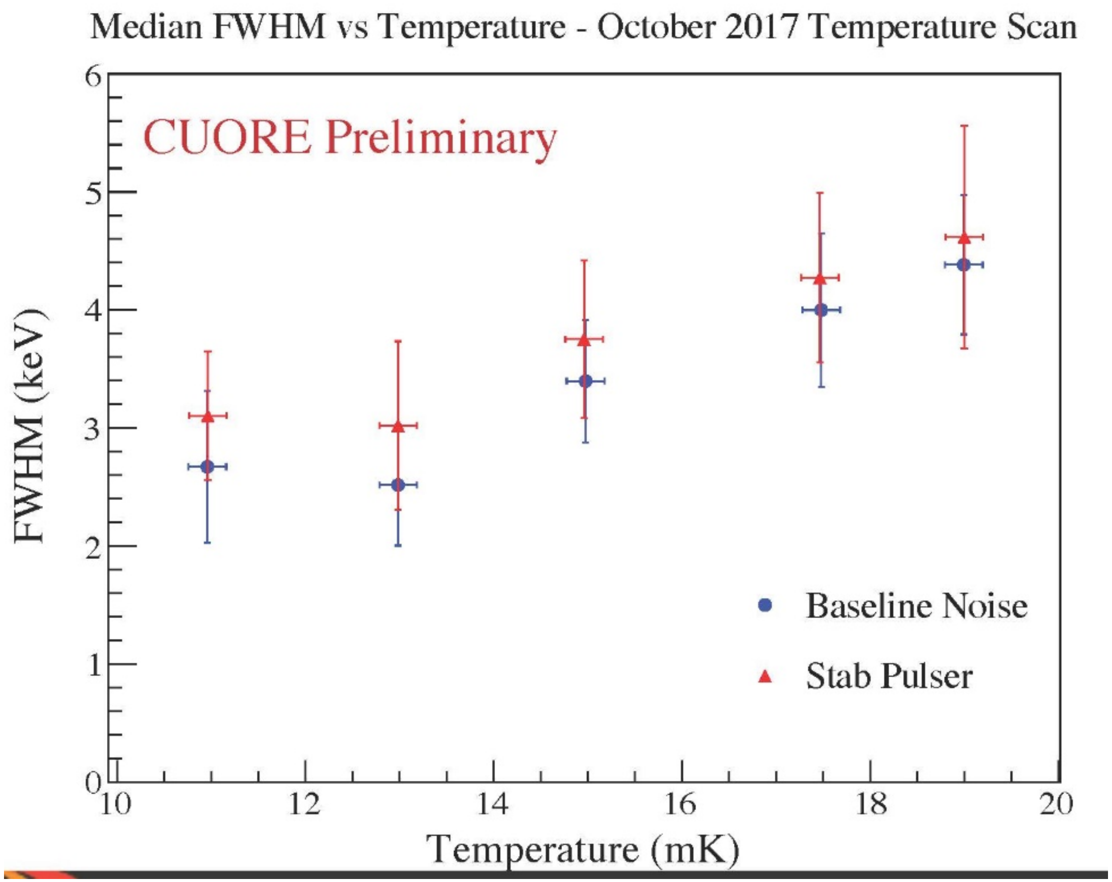


In CUORE, 2νββ decay accounts for **nearly all the events** in the range 1 - 2 MeV of the M1 spectrum.

$$T_{1/2}^{2\nu} = (7.9 \pm 0.1_{stat} \pm 0.2_{syst}) \times 10^{20} \text{ yr}$$

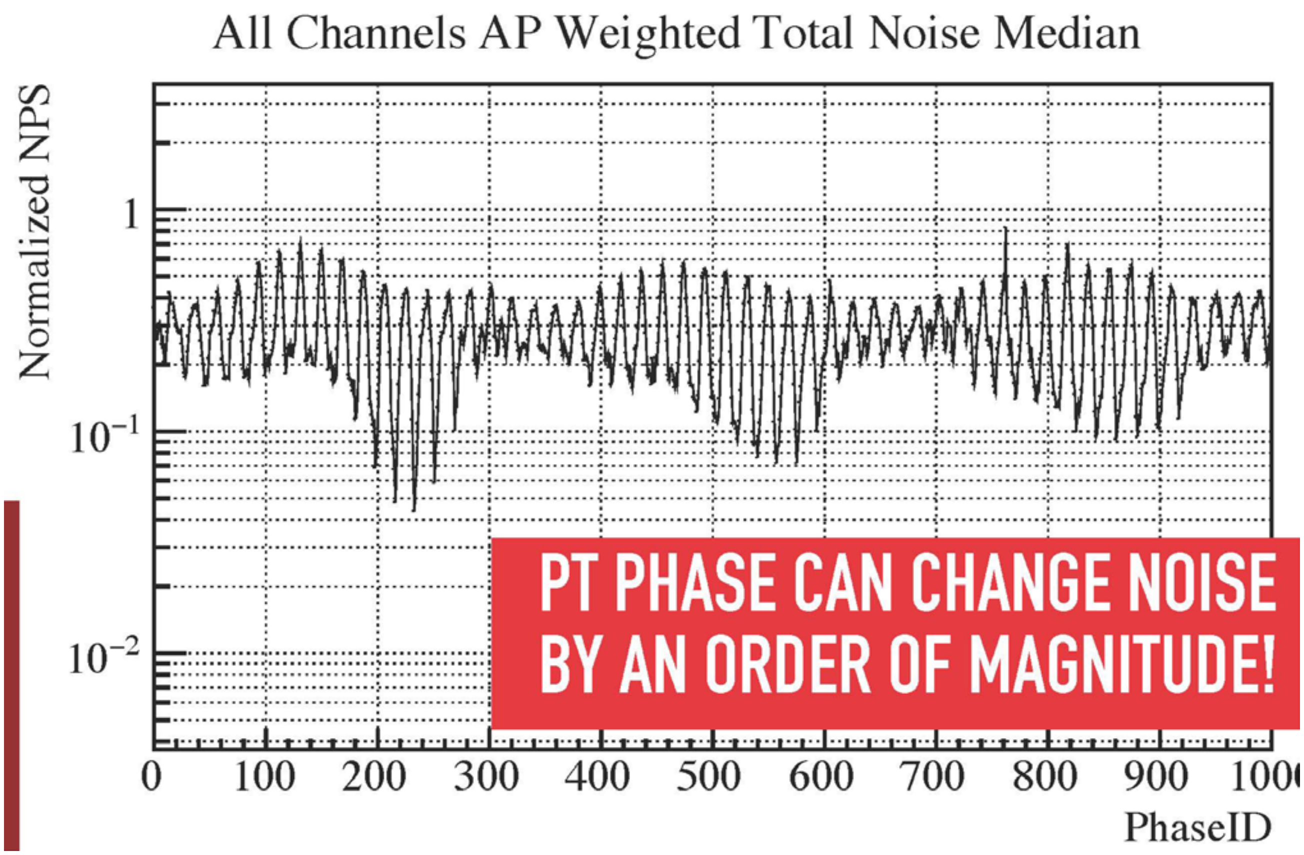
Residual Background: Copper and Crystal!

Optimizing Operating Temperature



Summer 2017 run @ ~ 15 mK or so;
aim at running at 12 mK or lower if possible

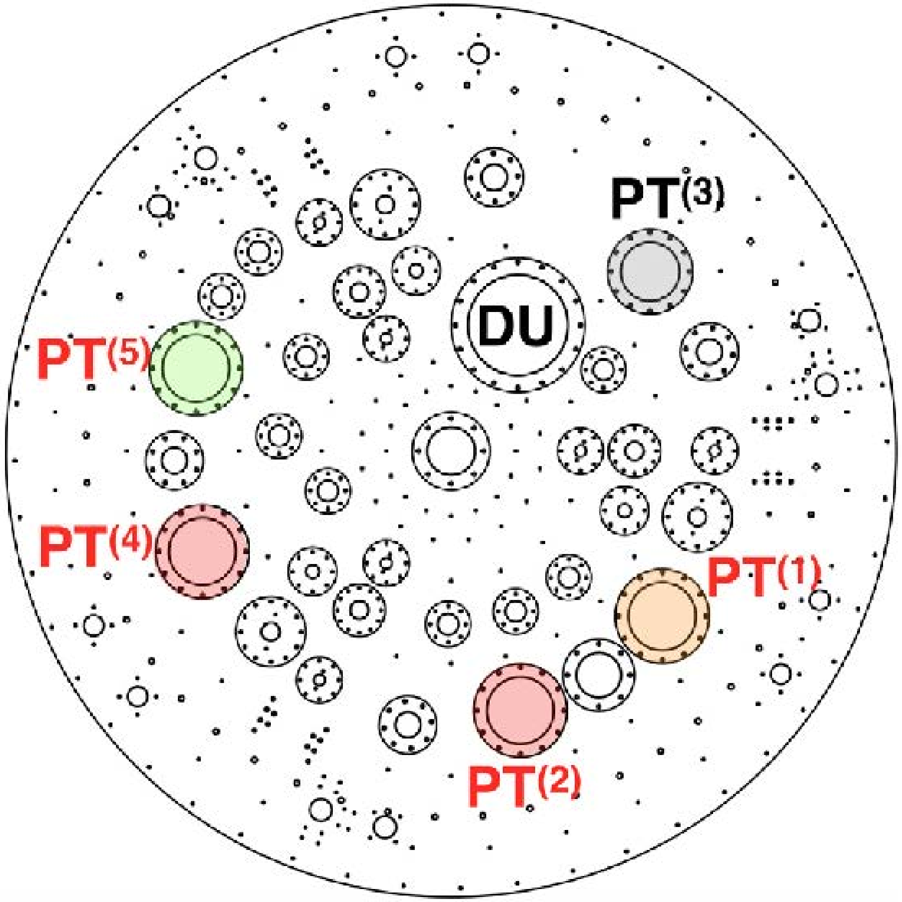
Pulse Tube Noise a Major Issue



Vibration noise from PT is a major concern for all applications !

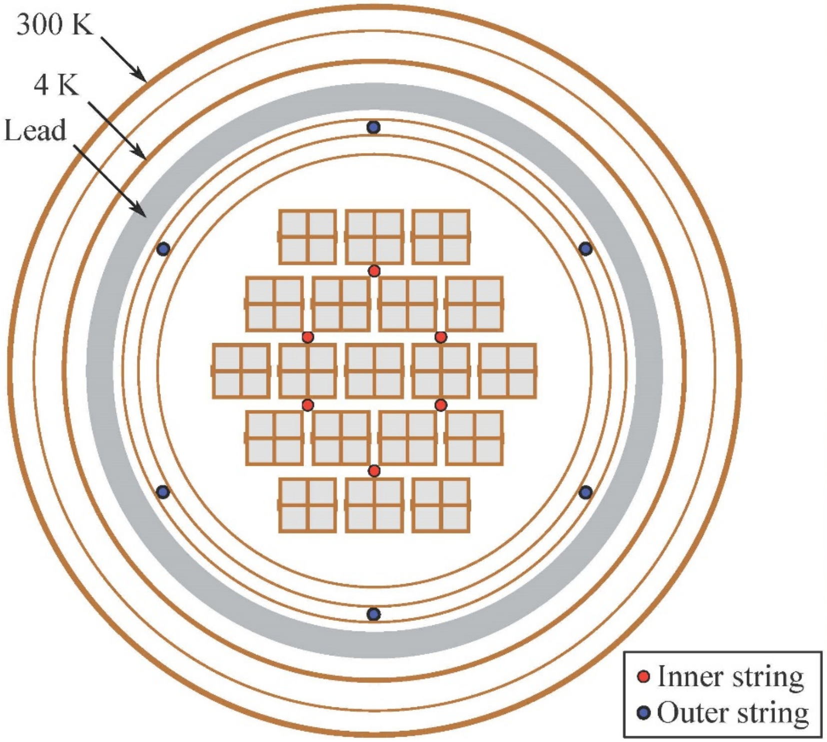
Pulse Tube Arrangement (#s and Locations)

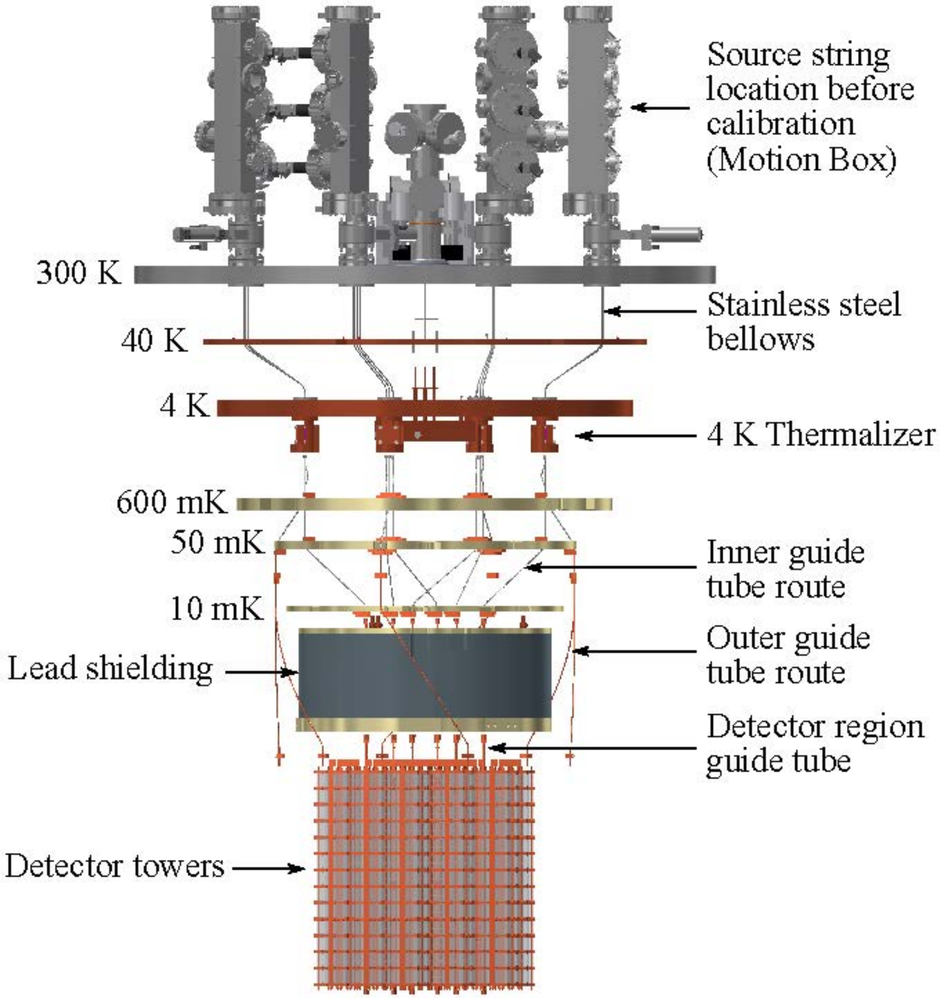
CUORE
5 PTs
PT(3) not turned on



Linear Power Supply

CUORE Calibration System



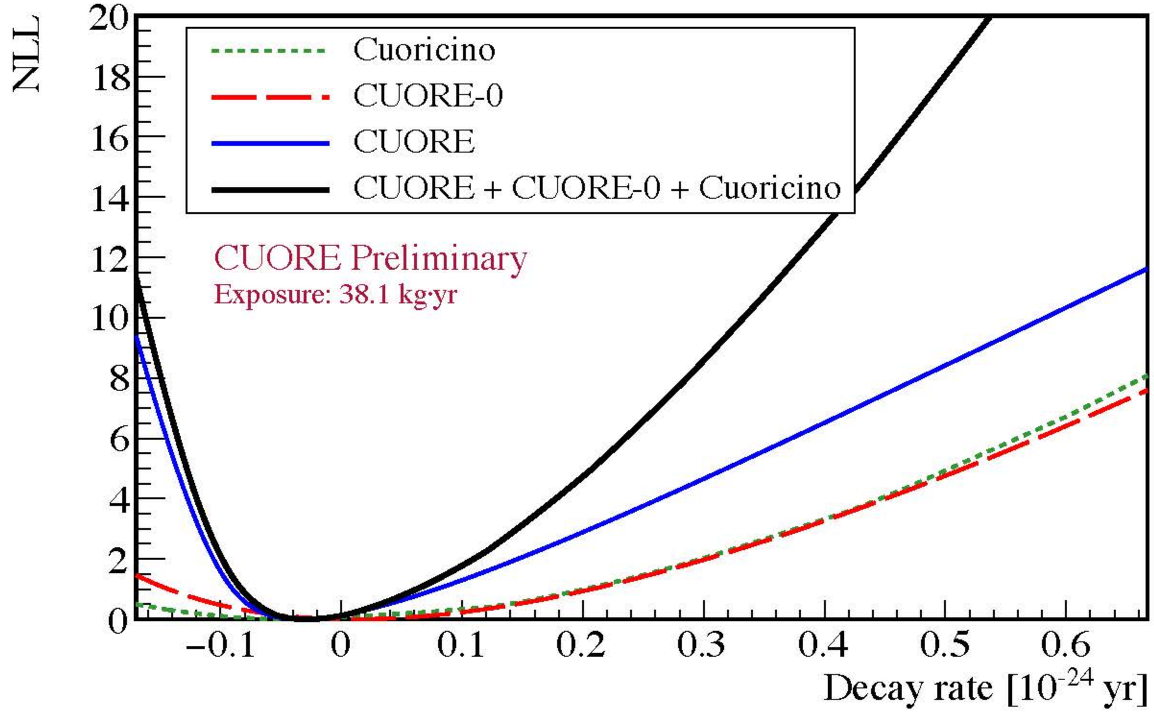


Gate Valve leaking
Reliable operation

Combination with Previous Results

We combine the CUORE result with the existing ^{130}Te data:

- Cuoricino: 19.8 kg·yr [Phys.Rev. **C78**, 035502 (2008)]
- CUORE-0: 9.8 kg·yr [Phys.Rev.Lett. **115**, 102502 (2015)]

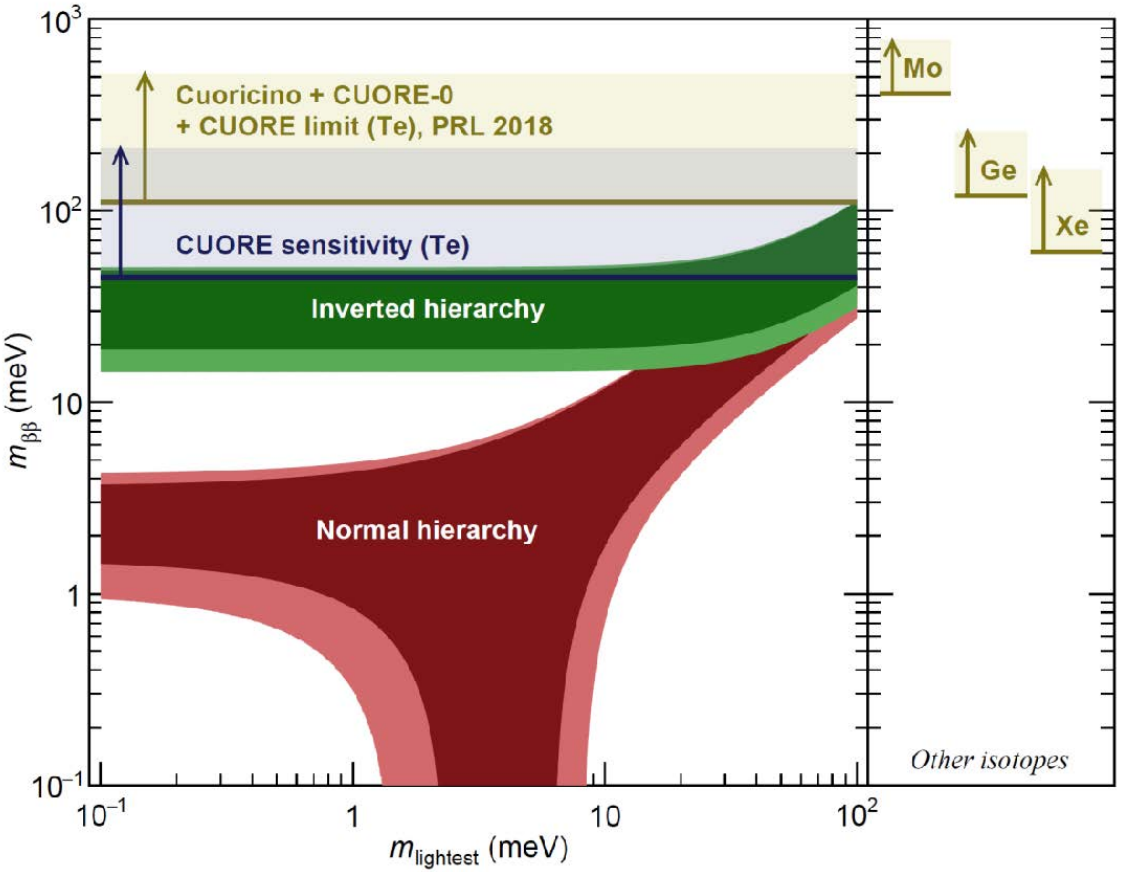


Bayesian limit @ 90% c.i. (flat prior for $\Gamma_{\beta\beta}$>0): $T_{1/2}^{0\nu\beta\beta} > 6.6 \times 10^{24}$ years

Profile likelihood ("frequentist") limit @ 90% CL: $T_{1/2}^{0\nu\beta\beta} > 8.1 \times 10^{24}$ years

W. Rolke et al., NIM A**551**, 493(2005)

Sensitivity on $m_{\beta\beta}$



$$\frac{1}{T_{1/2}^{0\nu}} = G_{0\nu} \left| M_{0\nu} \right|^2 \frac{\left| m_{\beta\beta} \right|^2}{m_e^2}$$

$$m_{\beta\beta} = \left| \sum_i U_{ei}^2 m_i \right|$$

^{76}Ge: 8.0×10^{25} yr from PRL 120, 132503 (2018)

^{136}Xe: 1.1×10^{26} yr from Phys. Rev. Lett. 117, 082503 (2016)

^{100}Mo: 1.1×10^{24} yr from Phys. Rev. D 89, 111101 (2014)

CUORE Limit

Background Level $1x10^{-2}$ cts/keV/kg/year

Next generation experiment
$1x10^{-4}$ cts/keV/kg/year

Scaling CUORE and Beyond

$$\left[T_{1/2}^{0\nu}\right]^{-1} = \frac{\left|\langle m_\nu \rangle\right|^2}{m_e^2} F_N$$

Figure of Merit

$$F_N \propto \varepsilon \frac{a}{A}\left[\frac{MT}{B\Gamma}\right]^{1/2}$$

Isotopic fraction

Detector efficiency

Detector Mass

Running time

Atomic mass

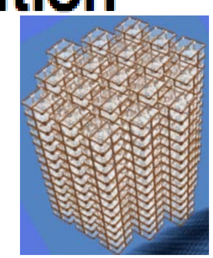
Background

Detector resolution

CUORICINO → CUORE

Numerator up by ~20

Denominator down by ~20



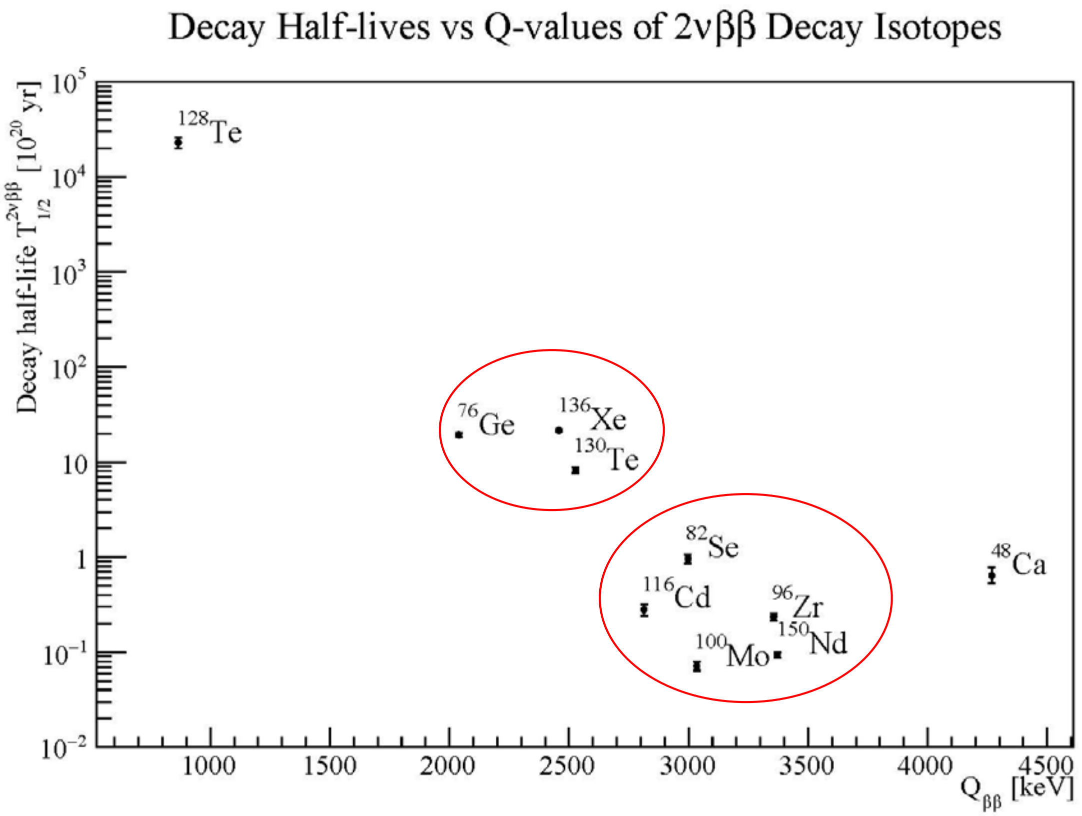
Candidate for Double beta Decays

	Q (MeV)	Abund.(%)
$^{48}Ca \rightarrow {}^{48}Ti$	4.271	0.187
$^{76}Ge \rightarrow {}^{76}Se$	2.040	7.8
$^{82}Se \rightarrow {}^{82}Kr$	2.995	9.2
$^{96}Zr \rightarrow {}^{96}Mo$	3.350	2.8
$^{100}Mo \rightarrow {}^{100}Ru$	3.034	9.6
$^{110}Pd \rightarrow {}^{110}Cd$	2.013	11.8
$^{116}Cd \rightarrow {}^{116}Sn$	2.802	7.5
$^{124}Sn \rightarrow {}^{124}Te$	2.228	5.64
$^{130}Te \rightarrow {}^{130}Xe$	2.528	34.5
$^{136}Xe \rightarrow {}^{136}Ba$	2.479	8.9
$^{150}Nd \rightarrow {}^{150}Sm$	3.367	5.6

Comments on Isotopes

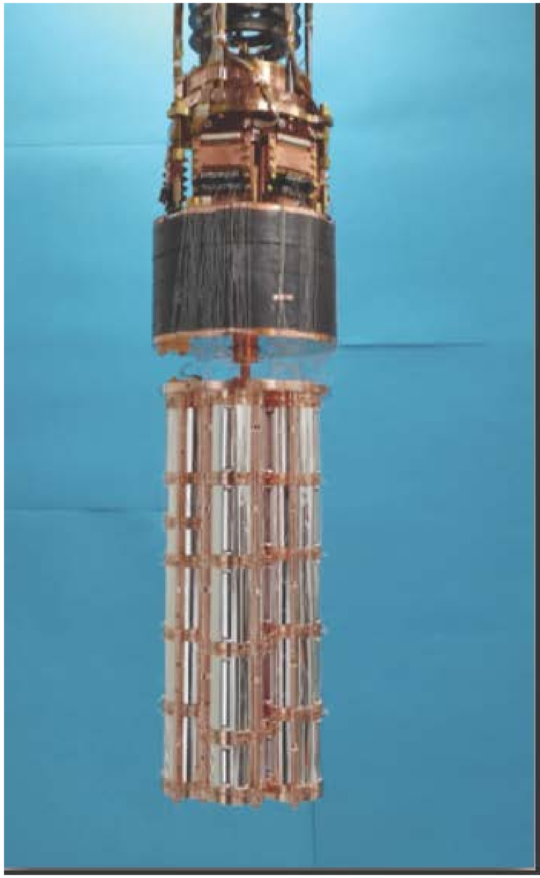
Enrichment Challenges

Te	**^{128}Te -- 31.7%**
	^{130}Te – 34.1%
Xe	**^{134}Xe – 10.4%**
	^{136}Xe – 8.9%
Mo	**^{98}Mo – 24.3%**
	^{100}Mo – 9.7%
Se	**^{80}Se -- 49.8%**
	^{82}Se – 8.8%
Ge	**^{74}Ge -- 36.5%**
	^{76}Ge – 7.8%

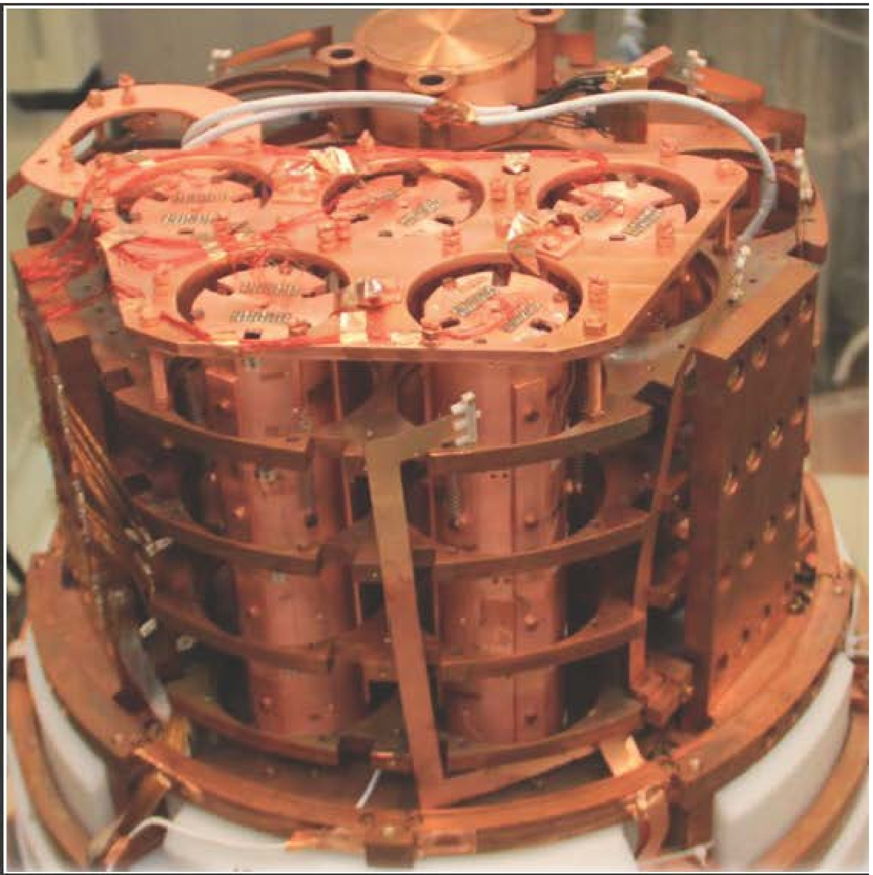


Te, Xe and Mo relatively less expensive to enrich
Bolometer technology can work with Te/Mo well

CUPID-Se and CUPID-Mo Prototype

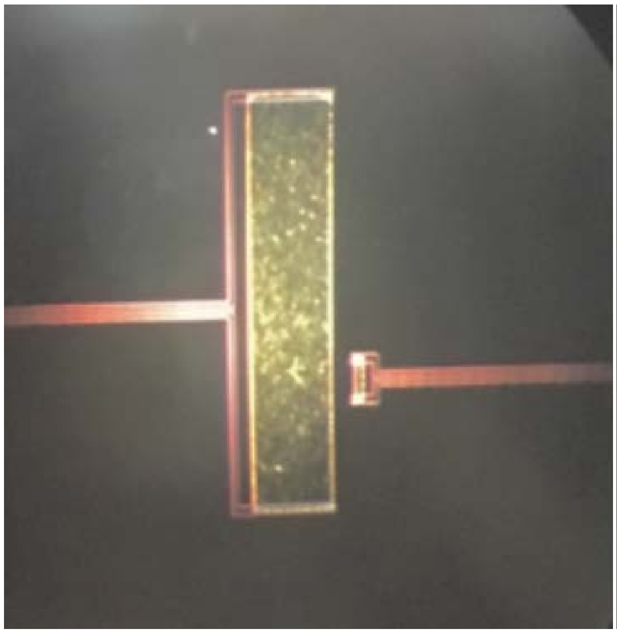


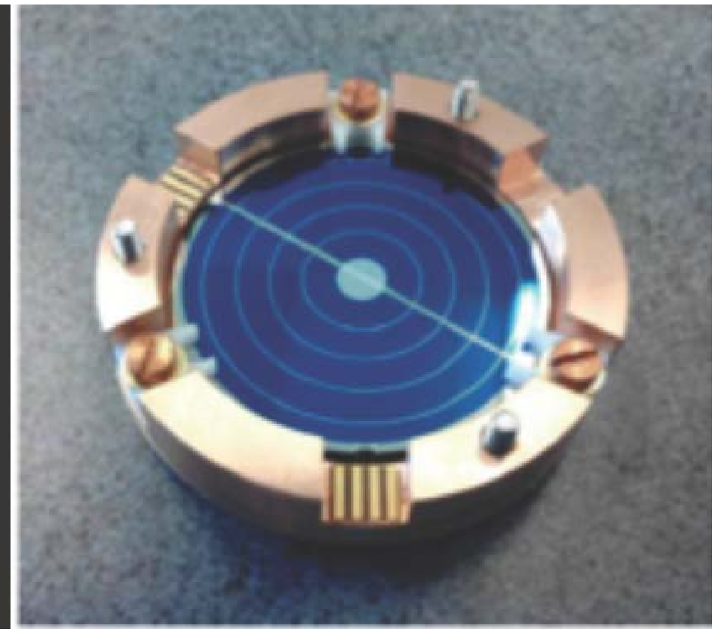
LNGS ZnSe Towers



Modane LMO Towers

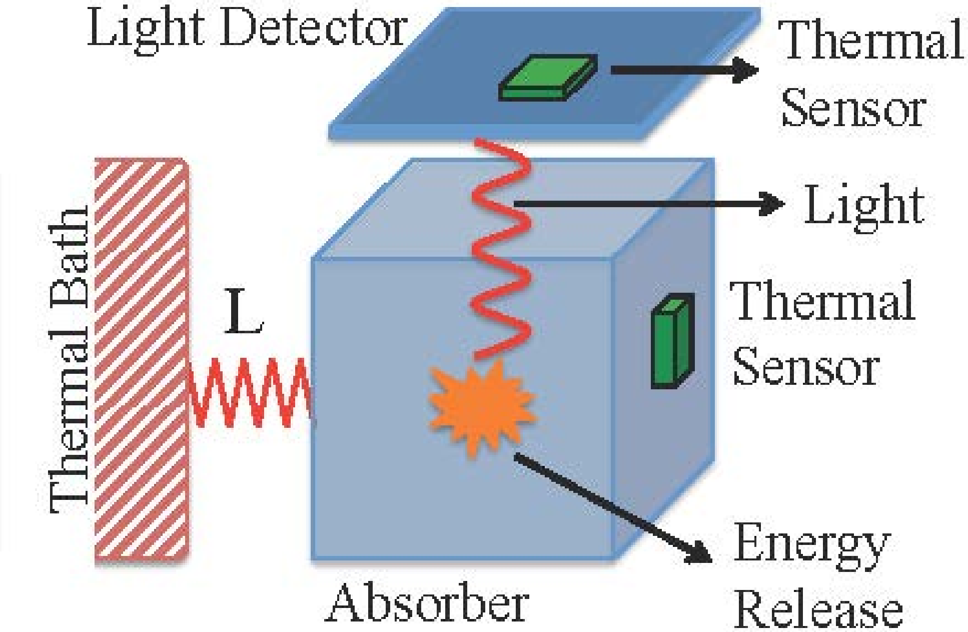
Light Detector Readout





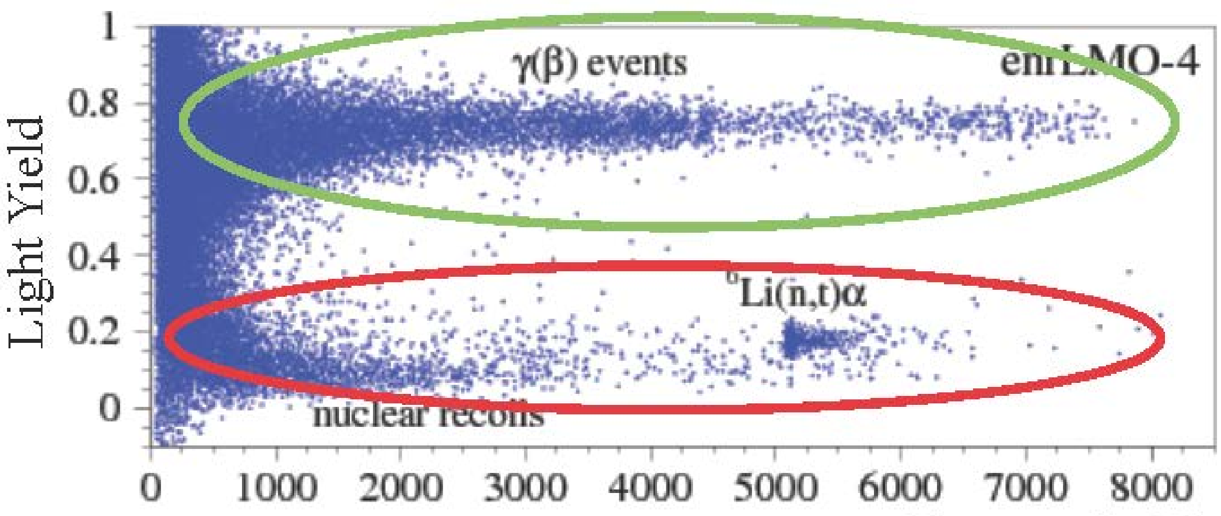
Luke-Neganov TES **Ge coated with SiO_2 LD**

TeO_2 Cerenkov light



LMO Performance

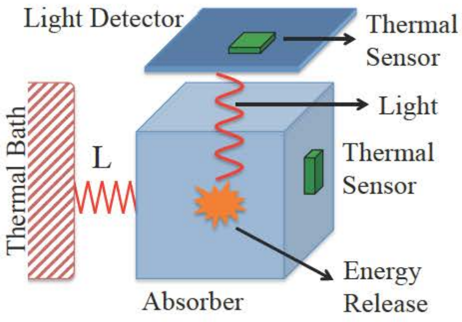
Most Promising Choice !

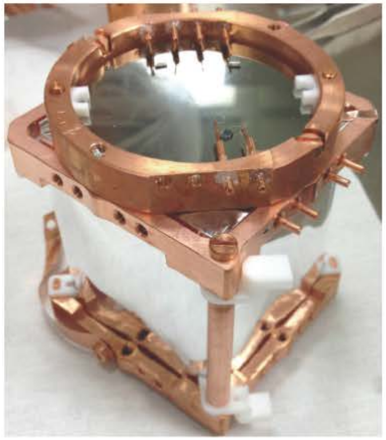


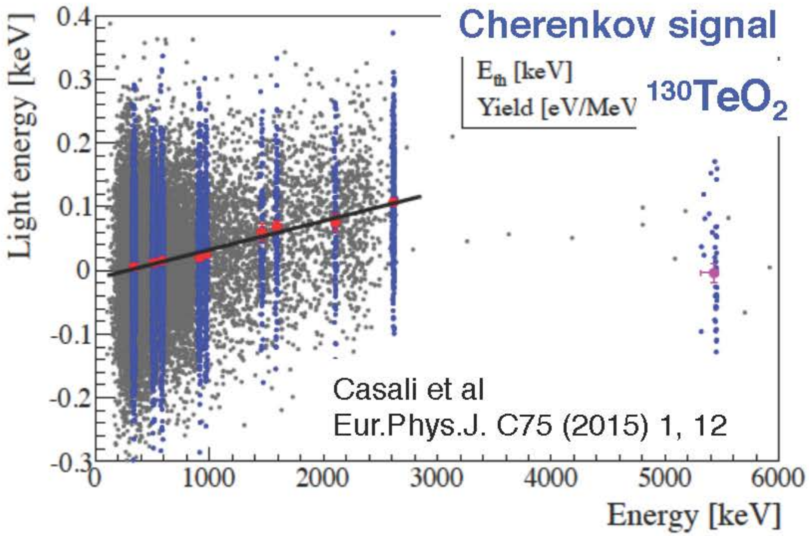
LUMINEU Collaboration

Beyond CUORE: Particle ID with Light Detectors

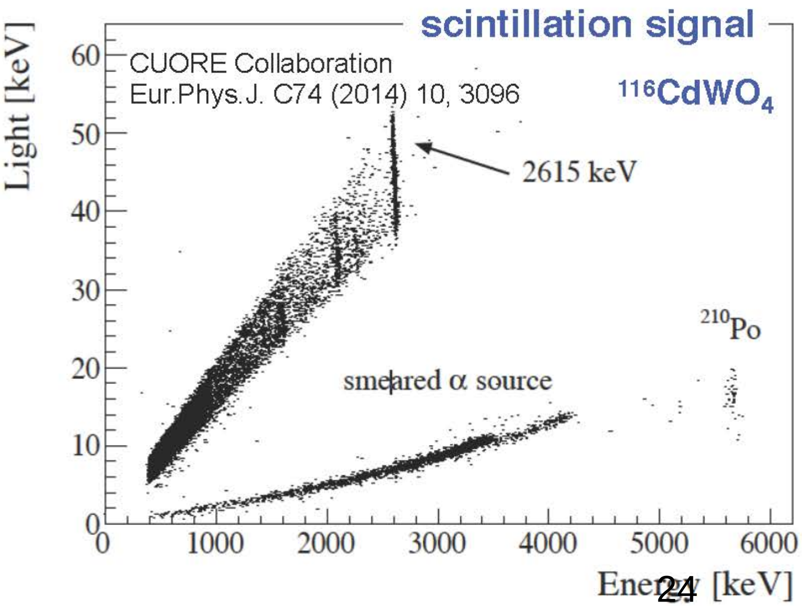
phonon+photon





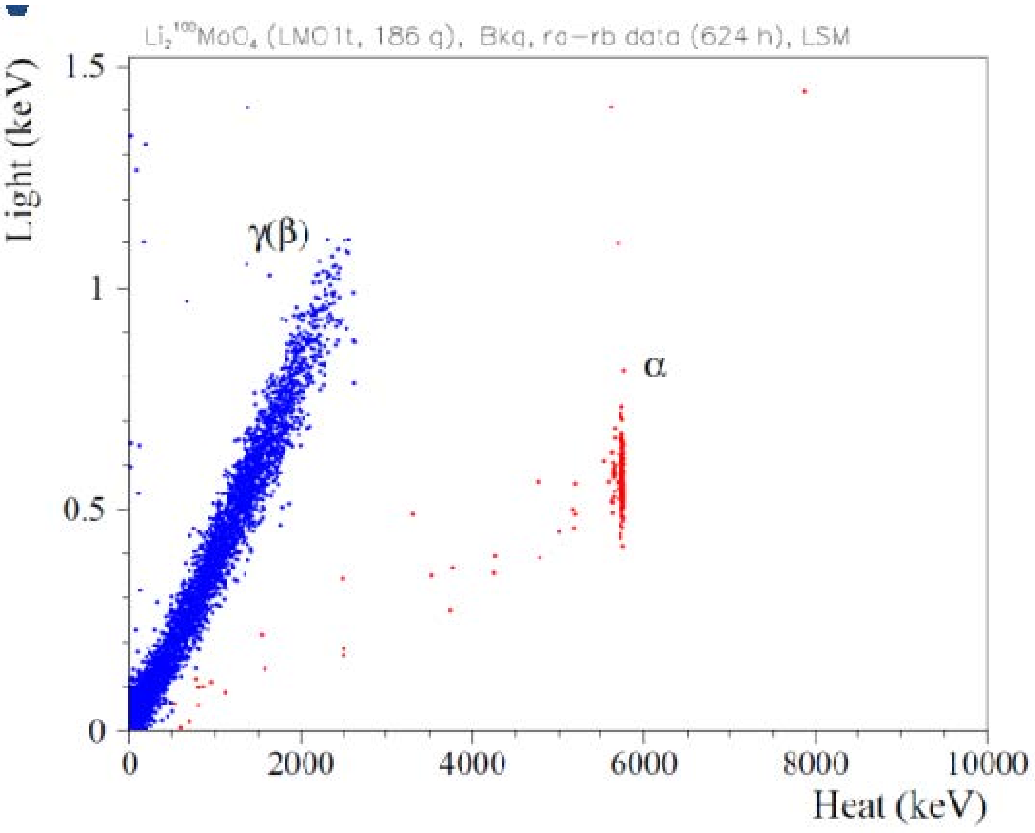


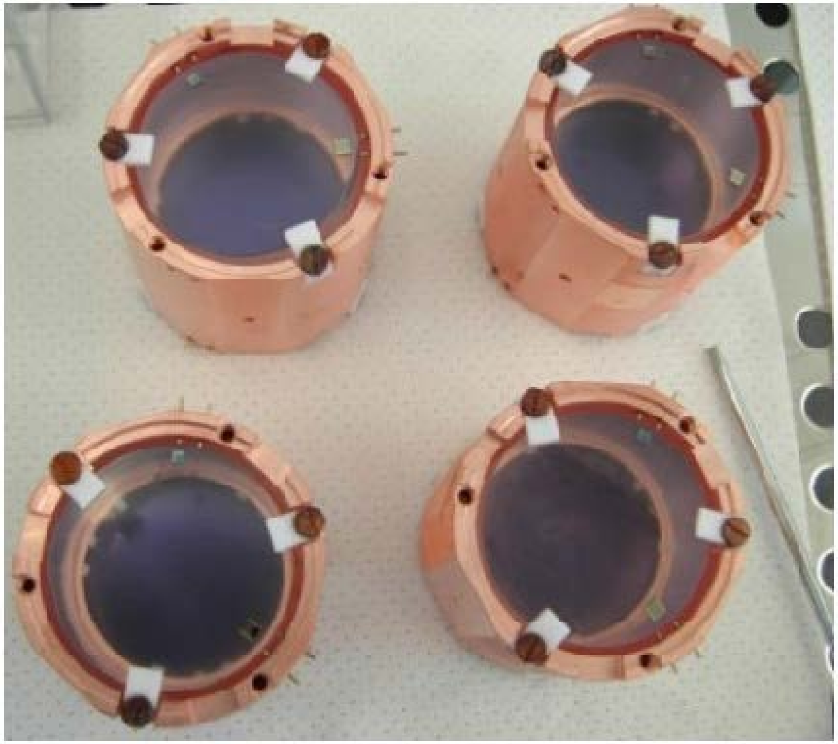
- Cherenkov light or scintillation to distinguish α from β/γ ($^{130}TeO_2$, $Zn^{82}Se$, $^{116}CdWO_4$, and $Zn^{100}MoO_4$)
- More rejection power needed: 99.9% α background suppression. Light detector R&D for better resolution.
- Background free search.



$$m_{\beta\beta} \sim (M \cdot t)^{-1/2}, \text{ not } (M \cdot t)^{-1/4}$$

CUPID-Mo at Modane





CUPID-China Approach

1) LMO vs TeO_2 Crystal
2) Light Detector Design
3) Thermistor – NTD or other
4) Calibration System

Cryogenic System – Dilution Unit

Pulse Tube Vibration

Readout Electronics

Shielding Design

Simulations

Infrastructure – Clean Room, Copper

Multiple Approaches Preferred

CUORE-- ^{130}Te/ ^{130}Mo

- -- Excellent Energy Resolution (FWHM 0.2%)
- -- Cost Effective
- -- Background Elimination (Q > 2615 keV)
- -- Particle ID Technique

GERDA/MAJORANA -- ^{76}Ge

- -- Ultra-Low Background Possible
- -- Detector Segmentation and Pulse Shape Analysis Possible
- -- Very Costly !

EXO/HPXe -- ^{136}Xe

- -- Easy to Scale Up
- -- Ba^{+} Tagging Challenging / FWHM ~1%
- -- Tracking Could Be Powerful

Measure different isotopes to establish 0vbb process !

CUPID Collaboration

Chinese participation

Our detector focus

Contribution to the overall all effort

Practical consideration

First kick-off meeting, Oct 2018 @ Boston

The END