CUPID

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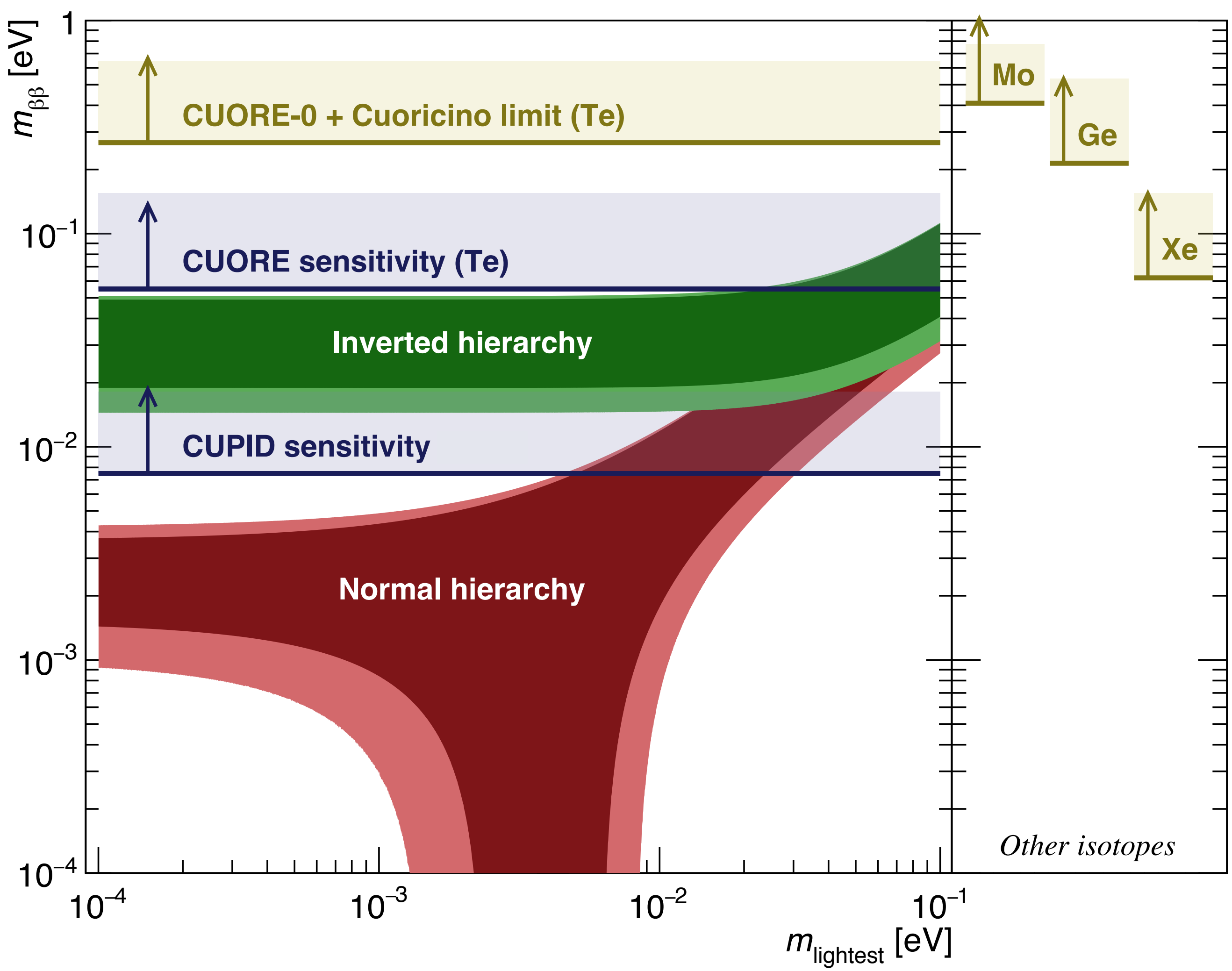
on behalf of the CUPID group of interest

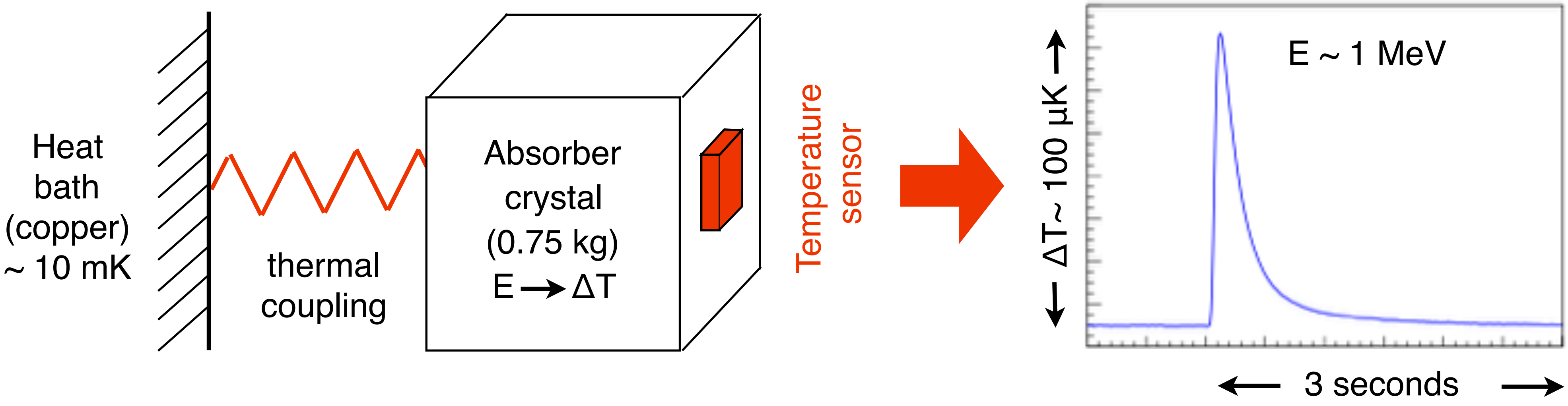
DBD16, 8-10 november 2016, Osaka

Cuore Upgrade with Particle ID

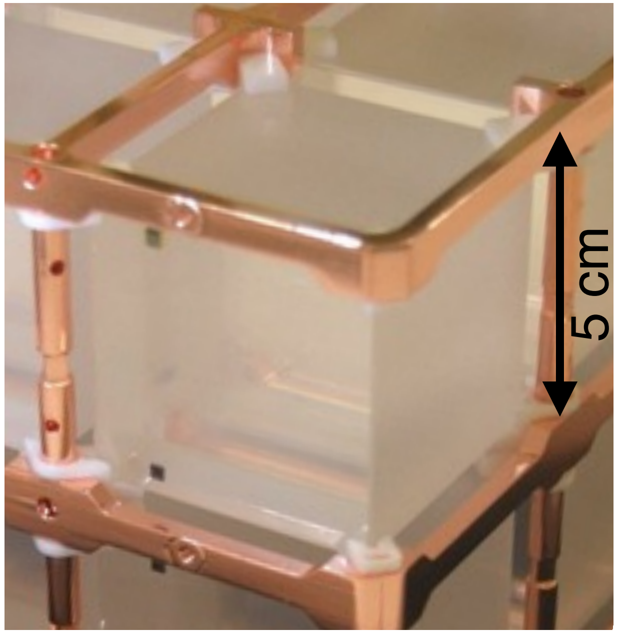
- ΔE < 10 keV (Bolometers)
- CUORE infrastructure
- ~1 ton isotope (^{130}Te, ^{82}Se, ^{100}Mo)
- Background 0.1 count / ton y



Bolometric technique



- Dielectric crystals (low heat capacitance)
  source embedded in the detector
- NTD-Ge thermistor: $R(T) \simeq 1\,\Omega \cdot \exp\left(\frac{3\,\mathrm{K}}{T}\right)^{\frac{1}{2}}$
- Resolution @$0\nu\beta\beta$ energy (2528 keV):
  ΔE ~ 5 keV FWHM
- No particle identification



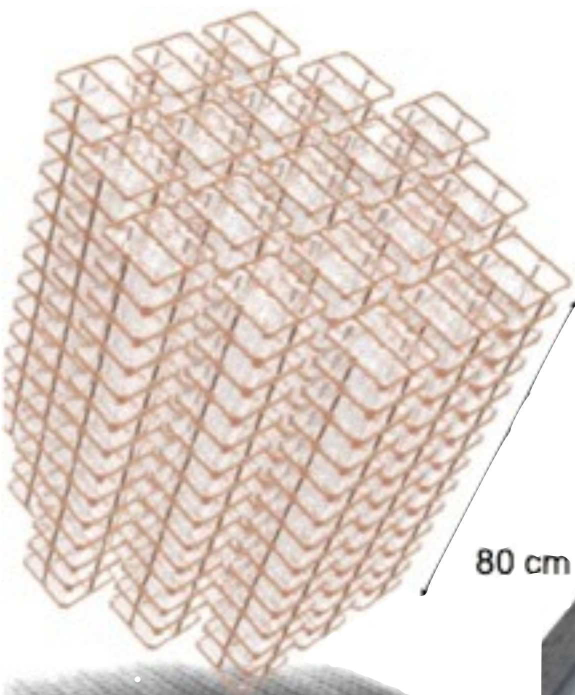
CUORE at Gran Sasso lab in Italy

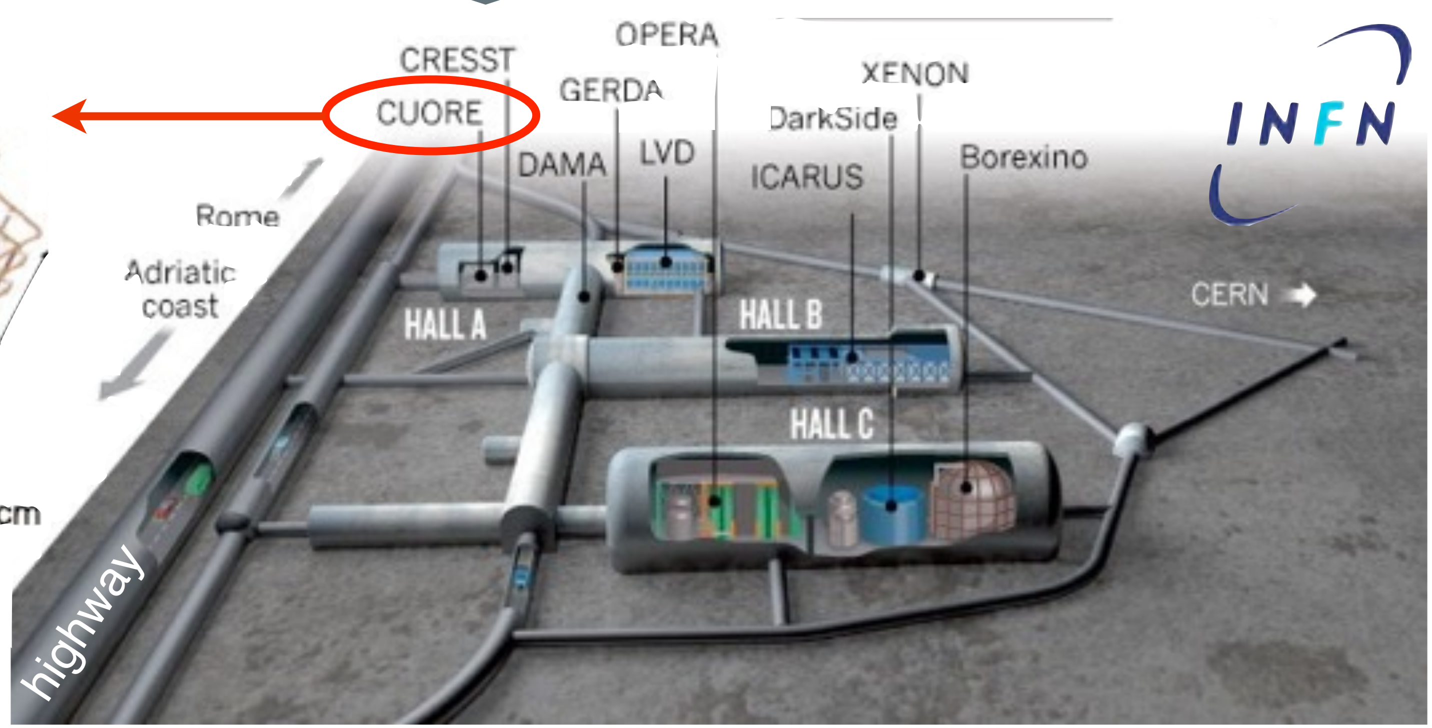
CUORE

988 $^{nat}TeO_2$ bolometers

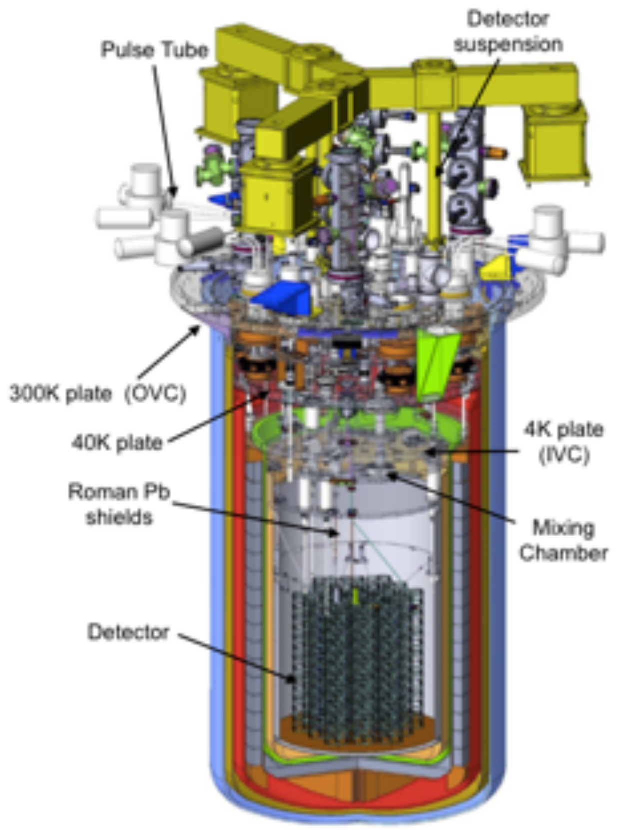
206 kg ^{130}Te
(34% abundance in Te)

Start data taking
at the end of 2016



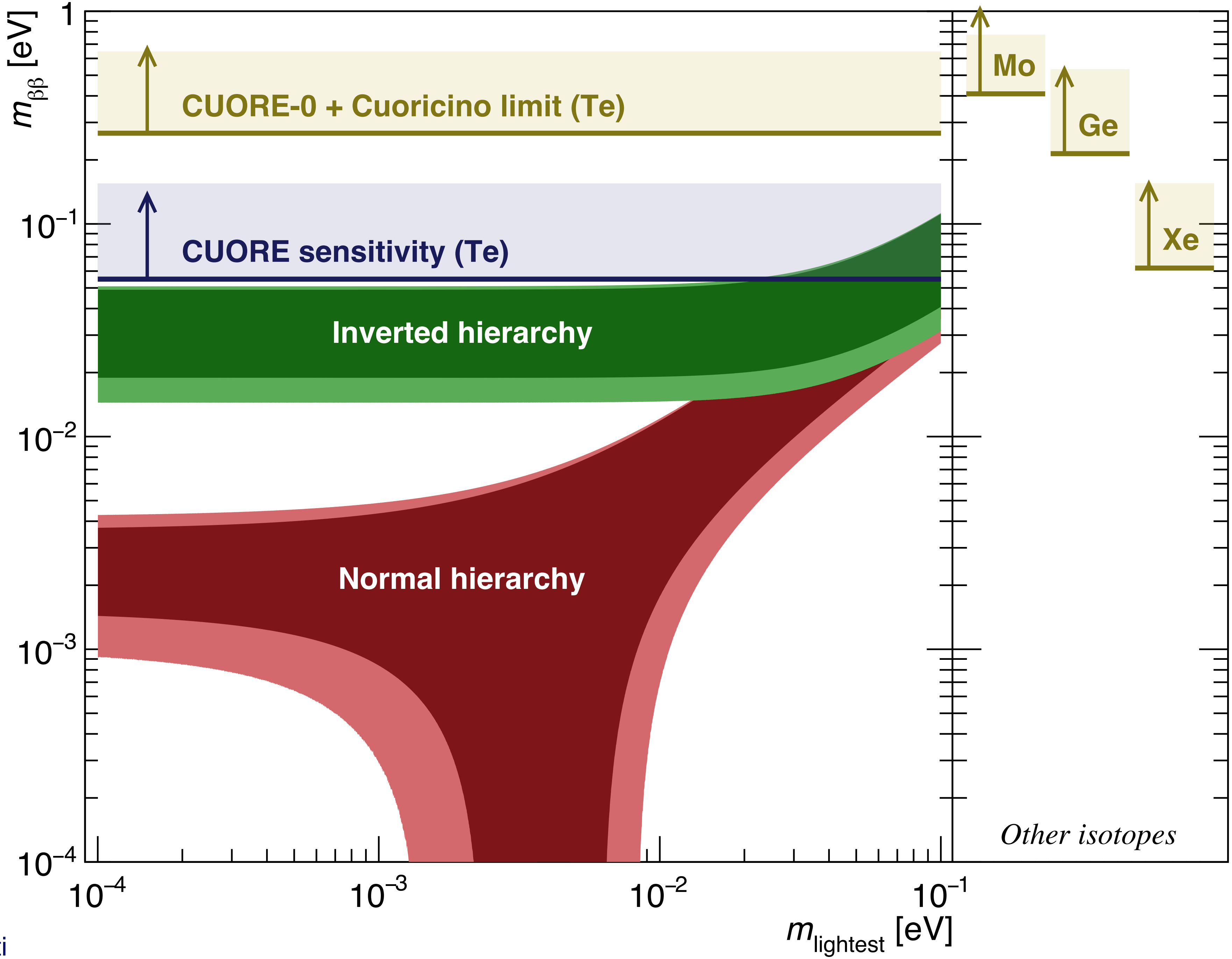


CUORE cryostat

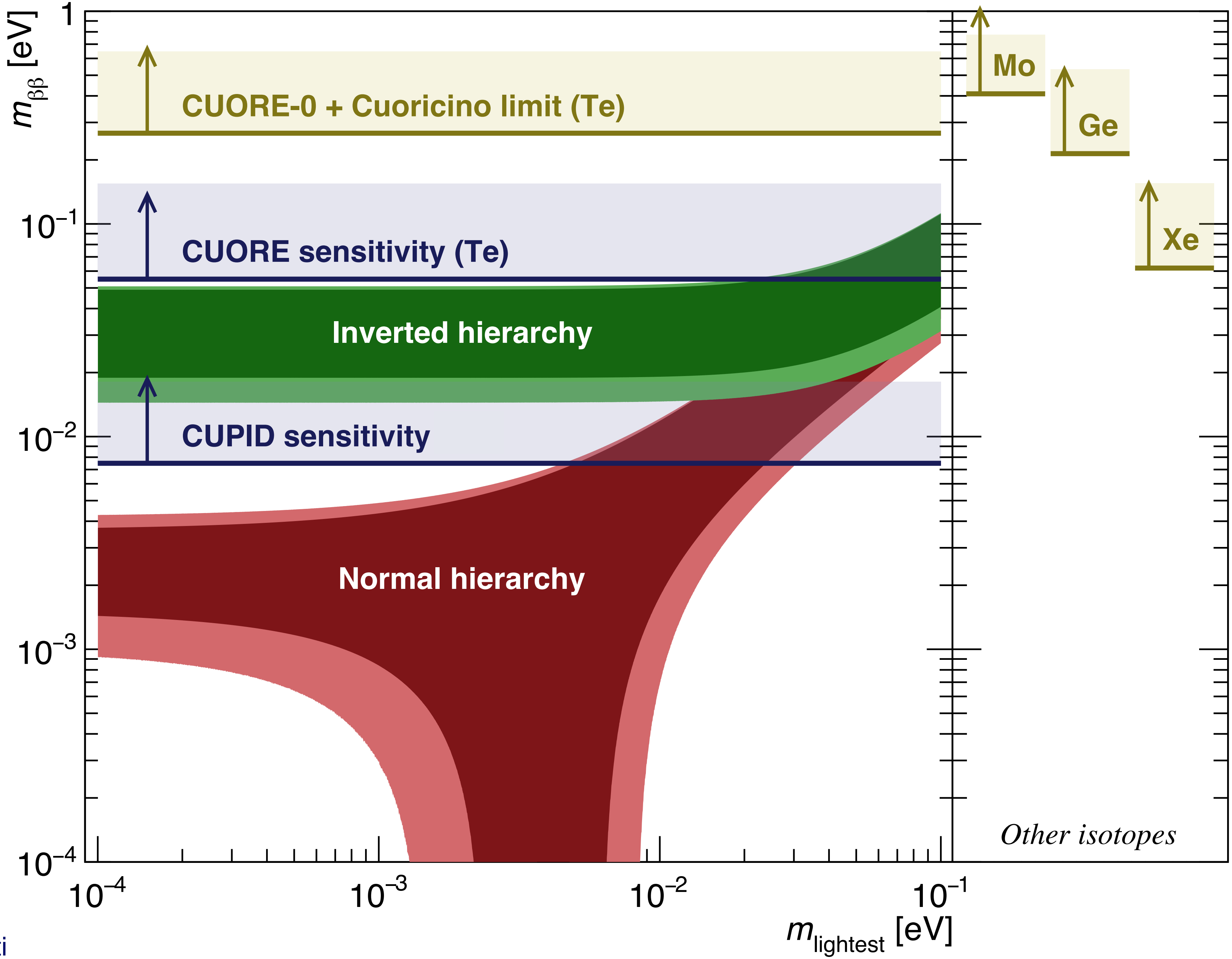


- More than 15 tons of lead and copper at low temperature.
- Detector calibration system: ^{232}Th calibration sources deployed from 300 K to 10 mK
- Base temperature: 6.3 mK
- Cooling power: 3µW @ 10 mK

CUORE sensitivity



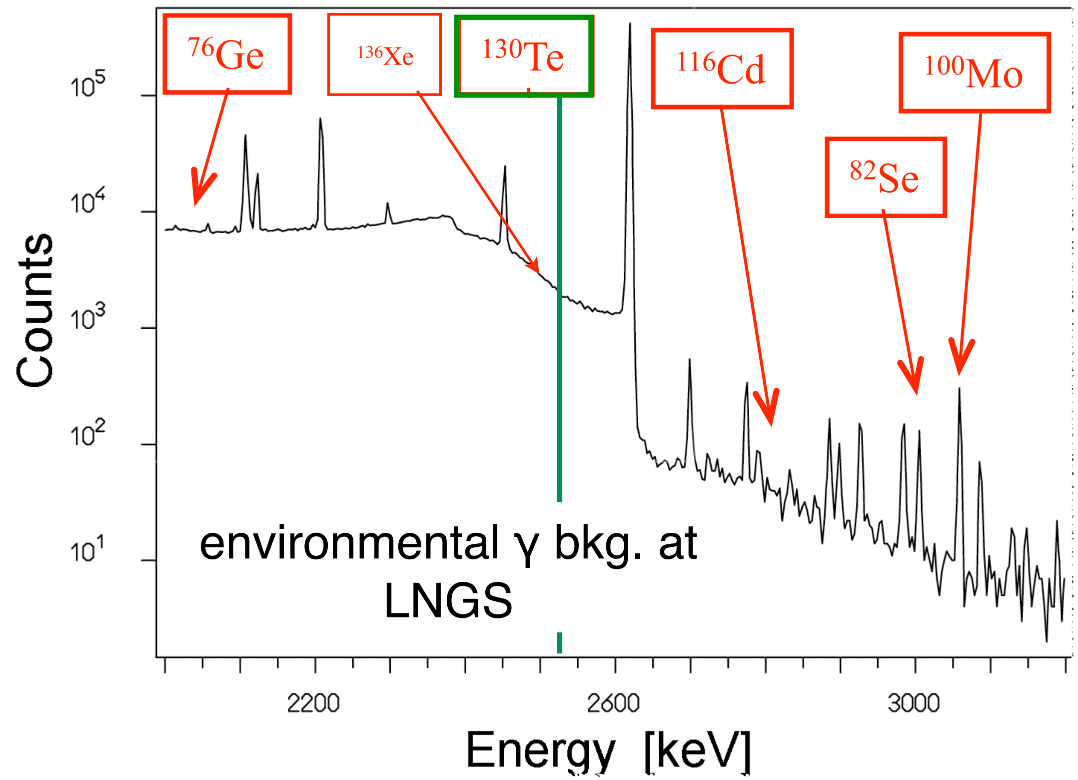
CUPID sensitivity



CUPID

arXiv:1504.03599 and 1504.03612

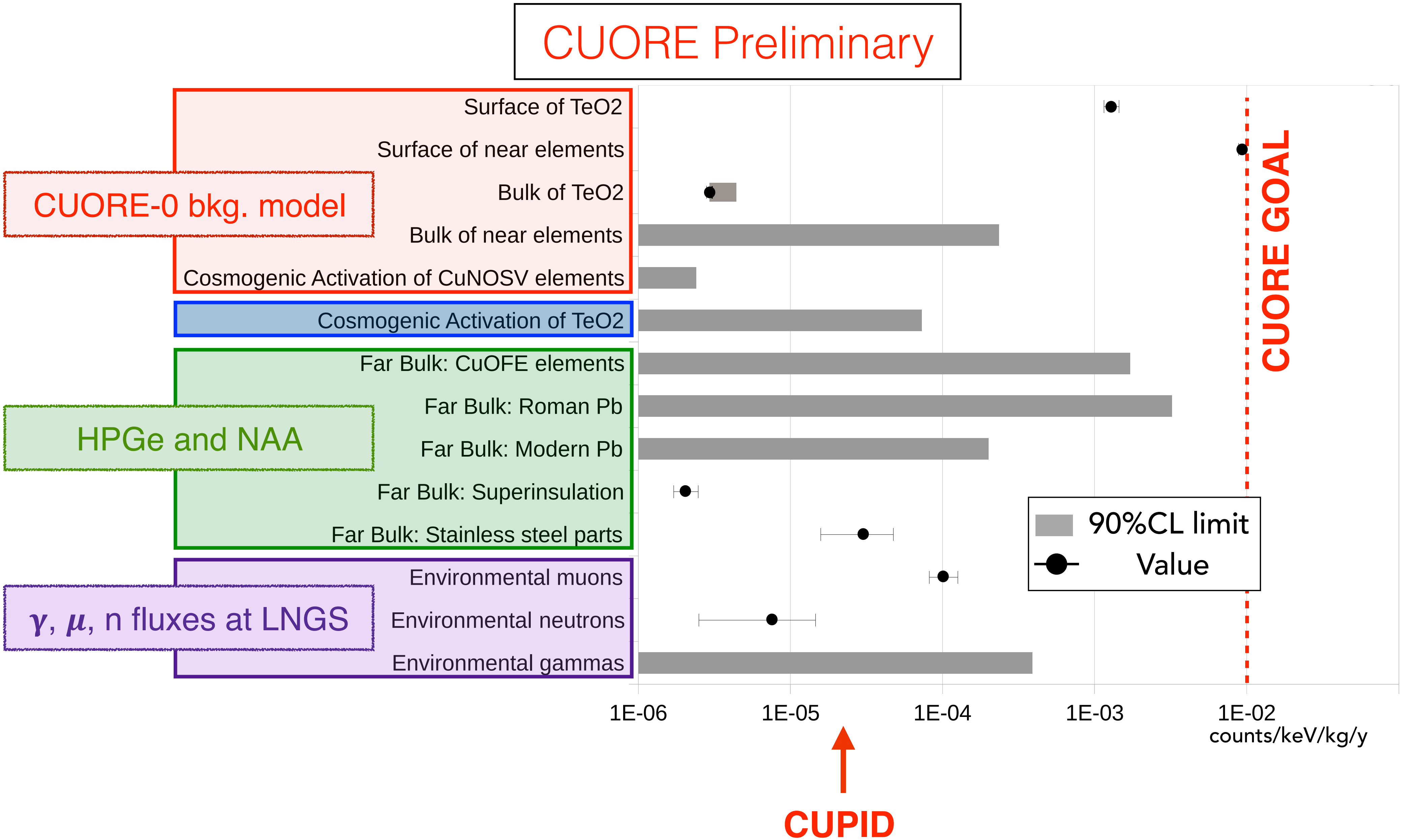
- Use enriched isotope to increase DBD nuclei by a factor ~3.
- Enable particle ID to suppress background.
- Select ultra-low background materials.
- Switch from Tellurium to another isotope?



Can make a bolometer

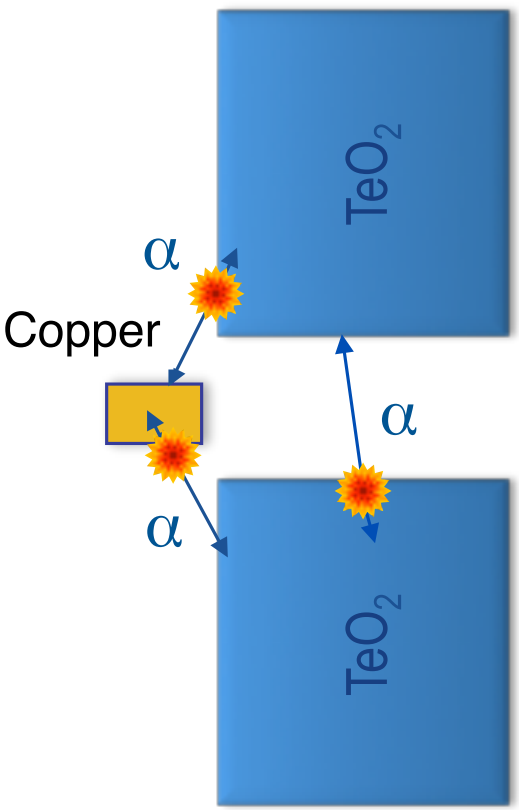
isotope	$G^{0\nu}$ $[10^{-14}y^{-1}]$	$Q_{\beta\beta}$ [keV]	nat. abund. [%]	$T^{2\nu}_{1/2}$ [10^{20} y]
^{48}Ca	6.3	4273.7	0.187	0.44
^{76}Ge	0.63	2039.1	7.8	15
● ^{82}Se	2.7	2995.5	9.2	0.92
● ^{100}Mo	4.4	3035.0	9.6	0.07
● ^{116}Cd	4.6	2809	7.6	0.29
● ^{130}Te	4.1	2528	34.2	9.1
^{136}Xe	4.3	2461.9	8.9	21
^{150}Nd	19.2	3367.3	5.6	0.08

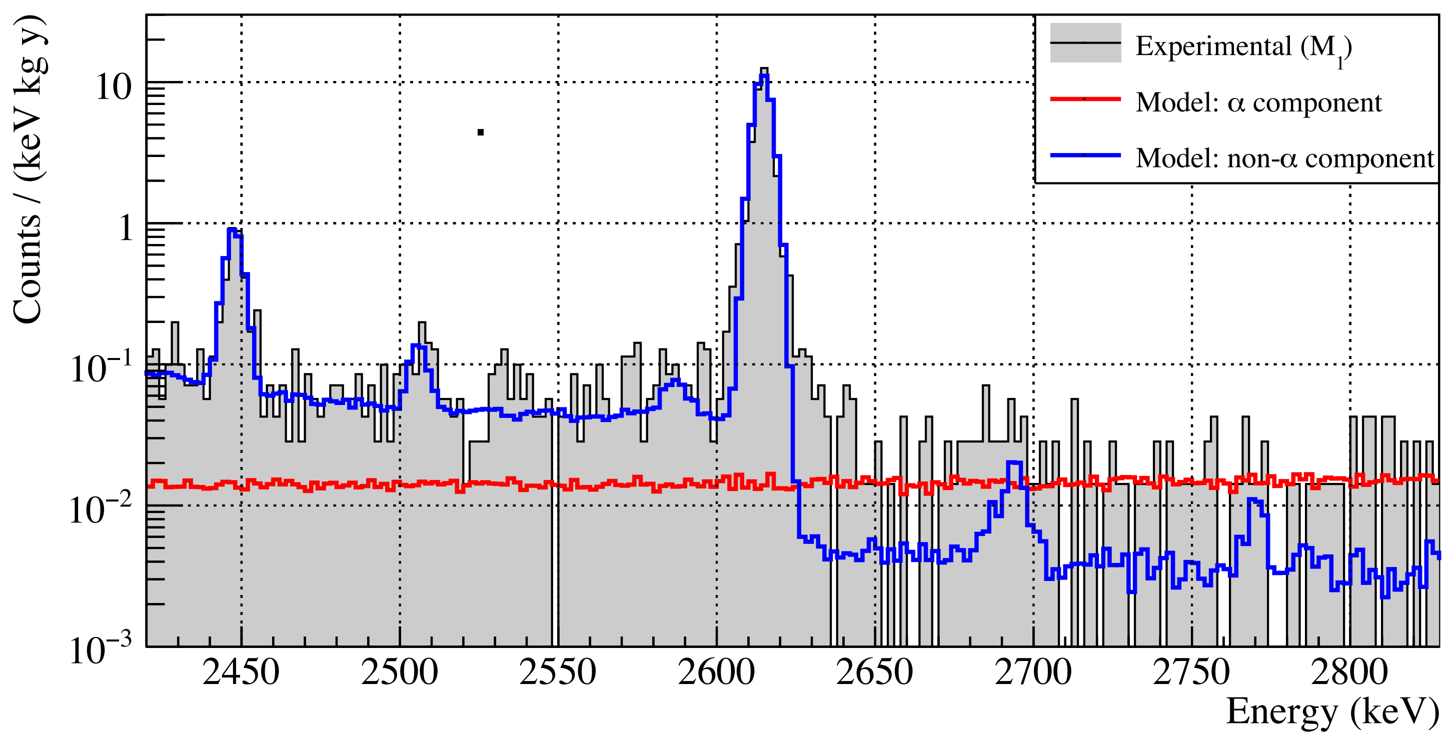
Background expected in CUORE



α background

CUORE-0, the test of a single CUORE tower, showed that most of the background in CUORE will be dominated by degraded α particles from natural radioactivity.



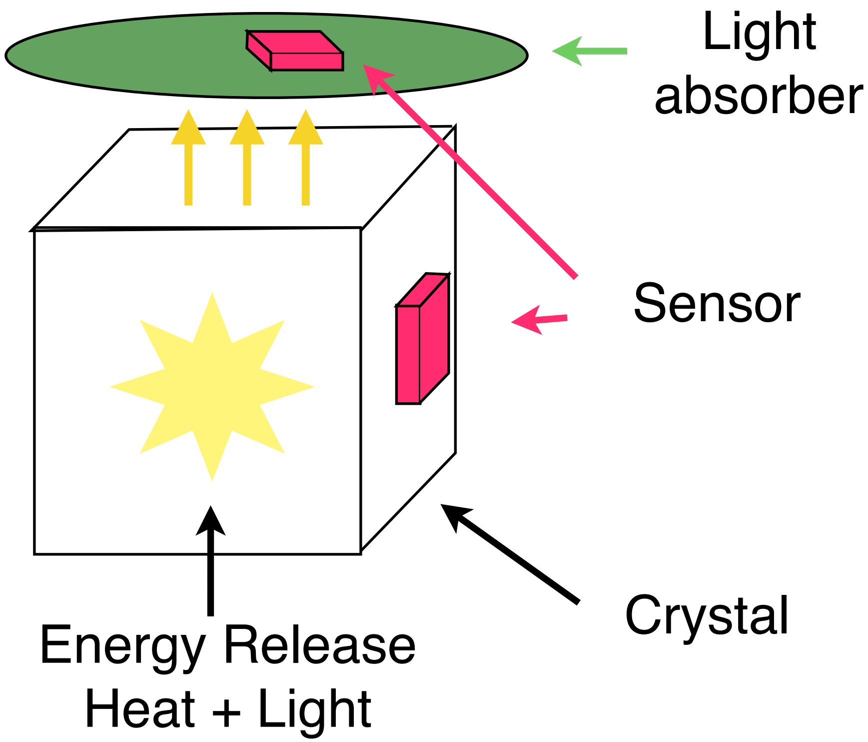


CUORE Coll, arXiv:1609.01666

Light readout in bolometers

β/γ particles emit different amount of light than αs.

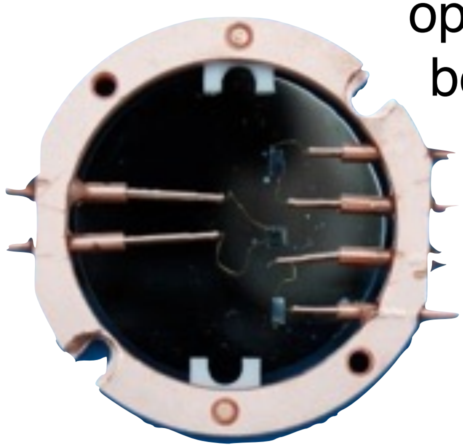
Light can be produced by scintillation or by Cherenkov effect.

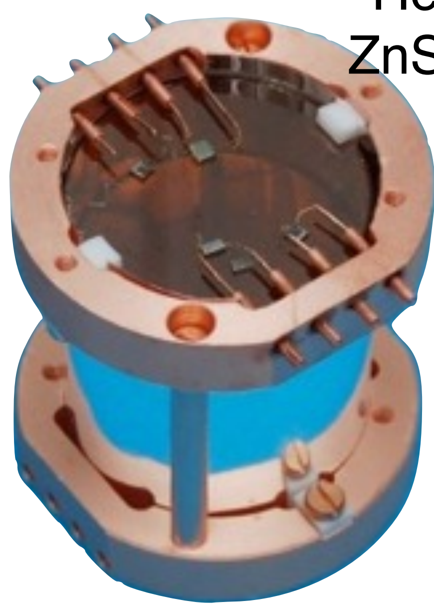


Option:
scintillating crystals

$Zn^{82}Se$

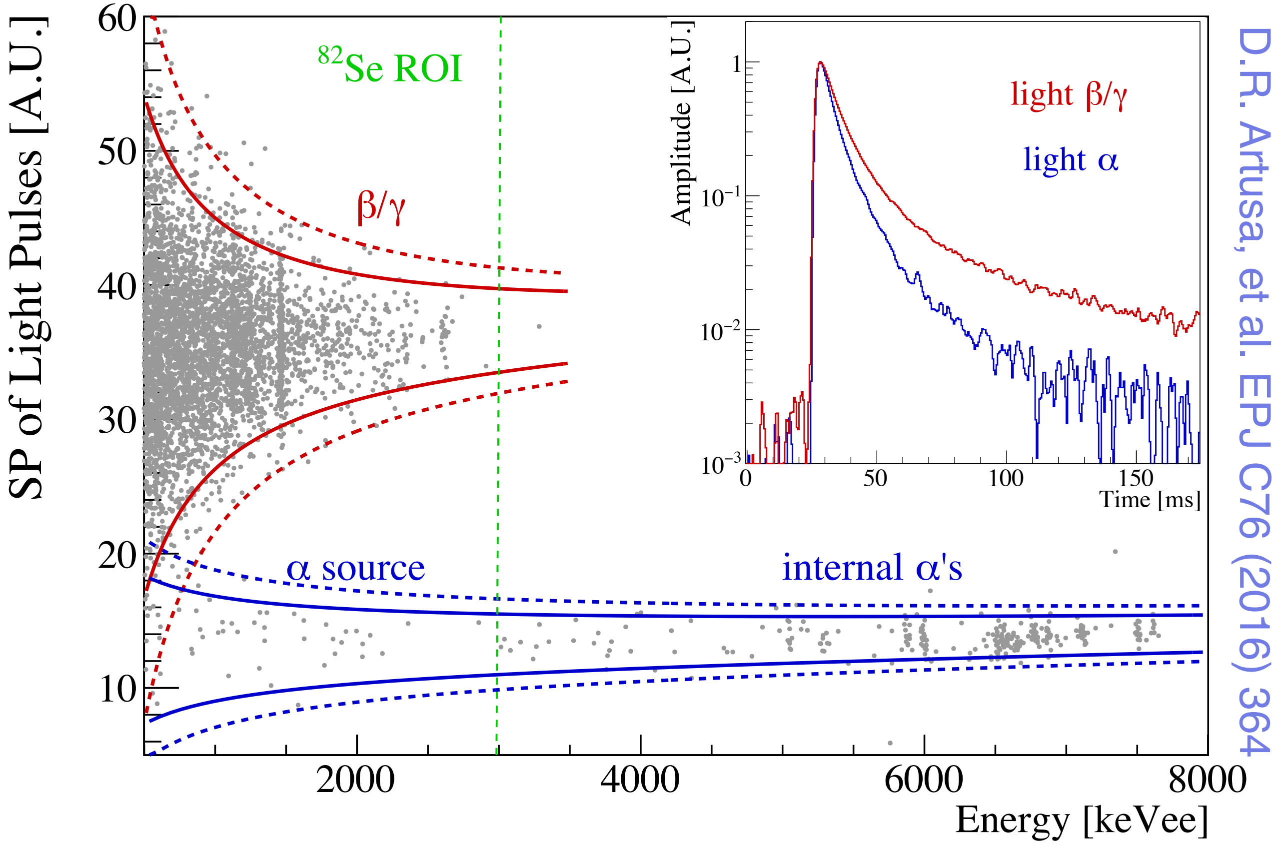
	$Zn^{82}Se$
Q-Value [keV]	2998
Isotopic abundance [%]	9.2
$T^{2\nu}$ [years]	9×10^{19}
ΔE [keV FWHM]	10-30 (430 g bolometer)
Pros	Q-value R&D concluded
Cons	ΔE *^{214}Bi at 3000 keV*





$Zn^{82}Se$ crystal test

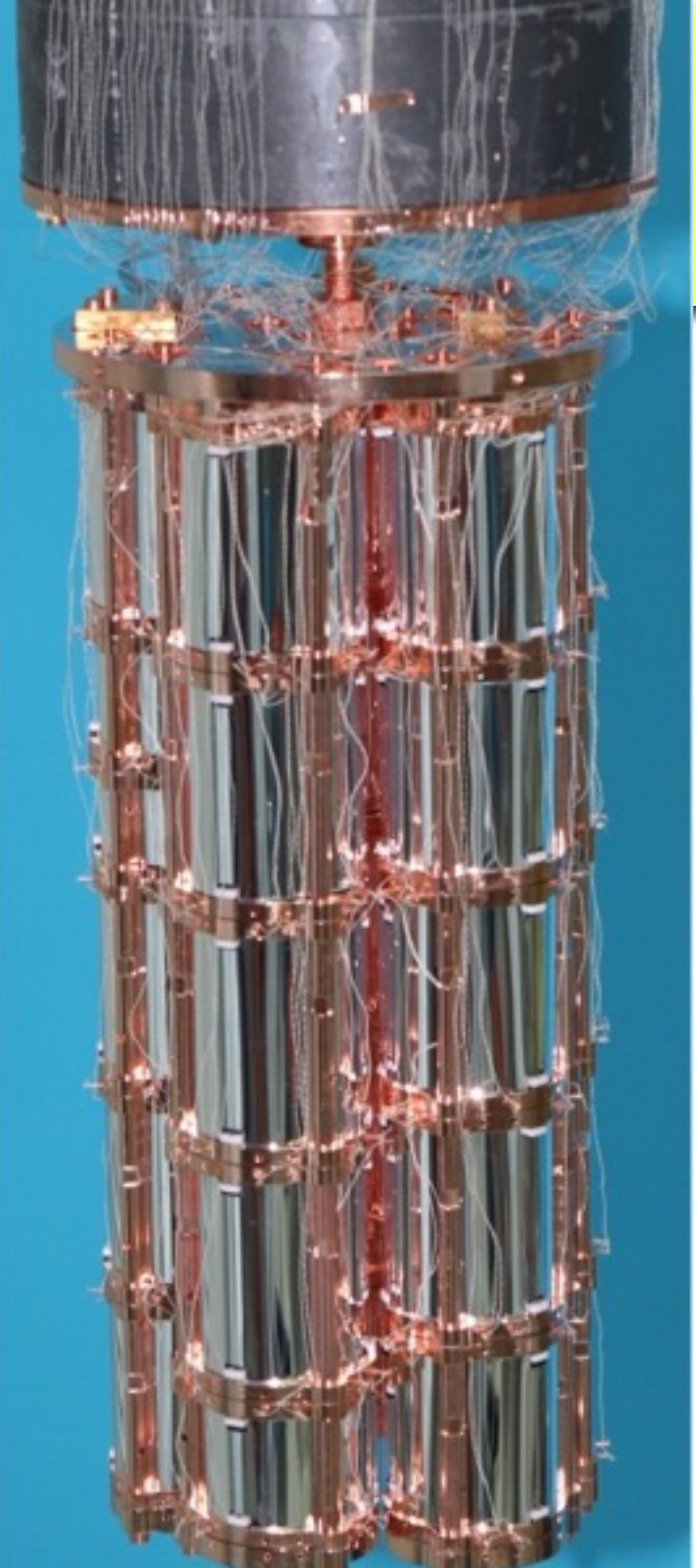
- Preliminary test with 3 $Zn^{82}Se$
- Smeared α source for discrimination power (DP)
- Operation in Hall C LNGS cryostat: working temperature not optimal ~20 mK
  - energy resolution spoiled ~30 keV
  - but excellent α background rejection



Discrimination power:

$$DP(E) = \frac{|\mu_\alpha(E) - \mu_{\beta\gamma}(E)|}{\sqrt{\sigma_\alpha^2(E) + \sigma_{\beta\gamma}^2(E)}}$$

Crystal	$DP(Q_{\beta\beta})$
ZnSe-1	12
ZnSe-2	11
ZnSe-3	10



CUPID-0: $Zn^{82}Se$ pilot experiment

- 24 $Zn^{82}Se$ (~95% enr.) + 2 naturals ZnSe
  - ^{82}Se mass: ~5.2 kg ($3.9 \cdot 10^{25}$ atoms)
- OFHC Cu frame + TECM cleaning
- PTFE stands + standard CUORE cleaning
- 3M ESR reflective foil

- Installed last month at Gran Sasso lab
- Data taking by the end 2016.

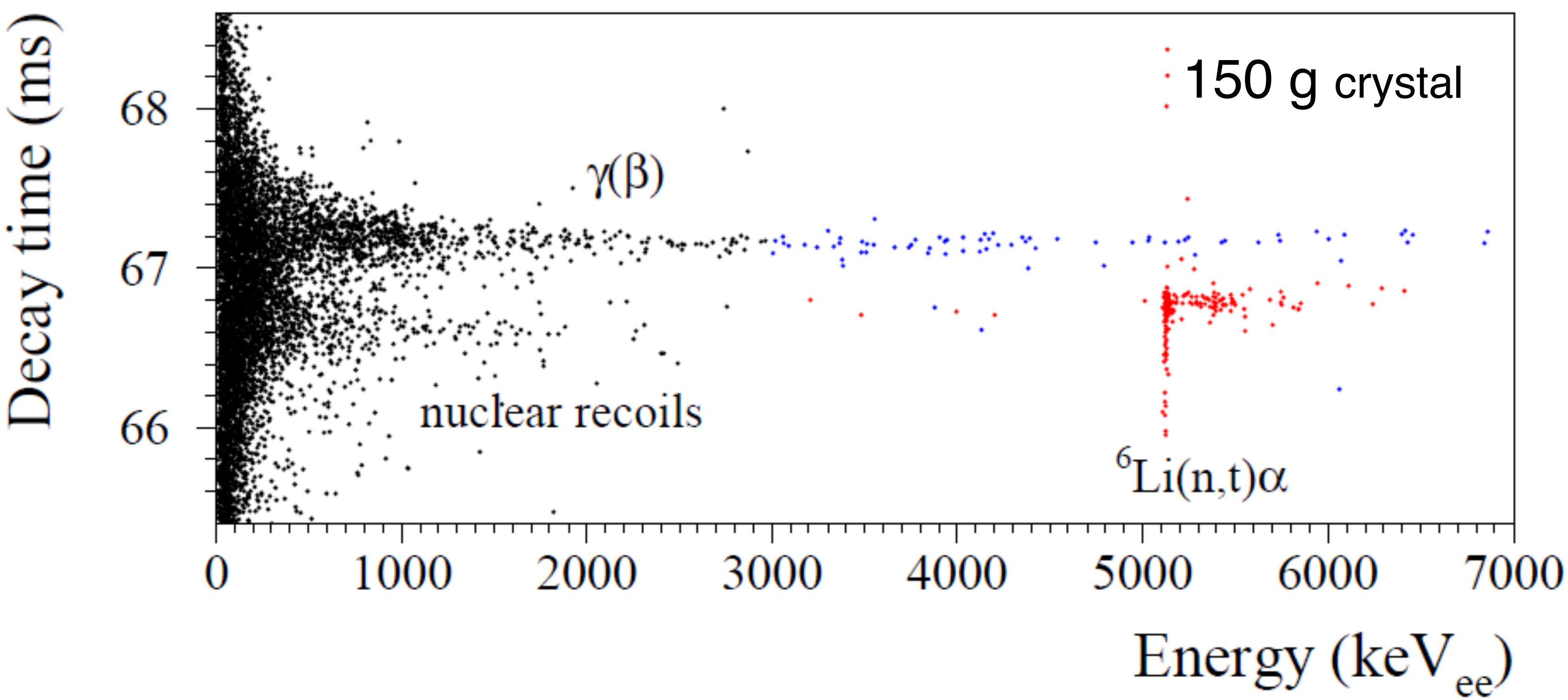
- Expected bkg. < $1.5\ 10^{-3}$ counts/keV/kg/y
- Sensitivity in 1 year: 9×10^{24} y

$Li_2{}^{100}MoO_4$

	$Zn^{82}Se$	$Li_2{}^{100}MoO_4$
Q-Value [keV]	2998	3034
Isotopic abundance [%]	9.2	9.7
$T^{2\nu}$ [years]	9×10^{19}	7×10^{18}
ΔE [keV FWHM]	10-30 (430 g bolometer)	5-8 (210 g)
Pros	Q-value R&D concluded	Q-value *PID w/o light detector*
Cons	ΔE *^{214}Bi at 3000 keV*	2ν pileup bkg.

$Li_2{}^{100}MoO_4$ crystal test

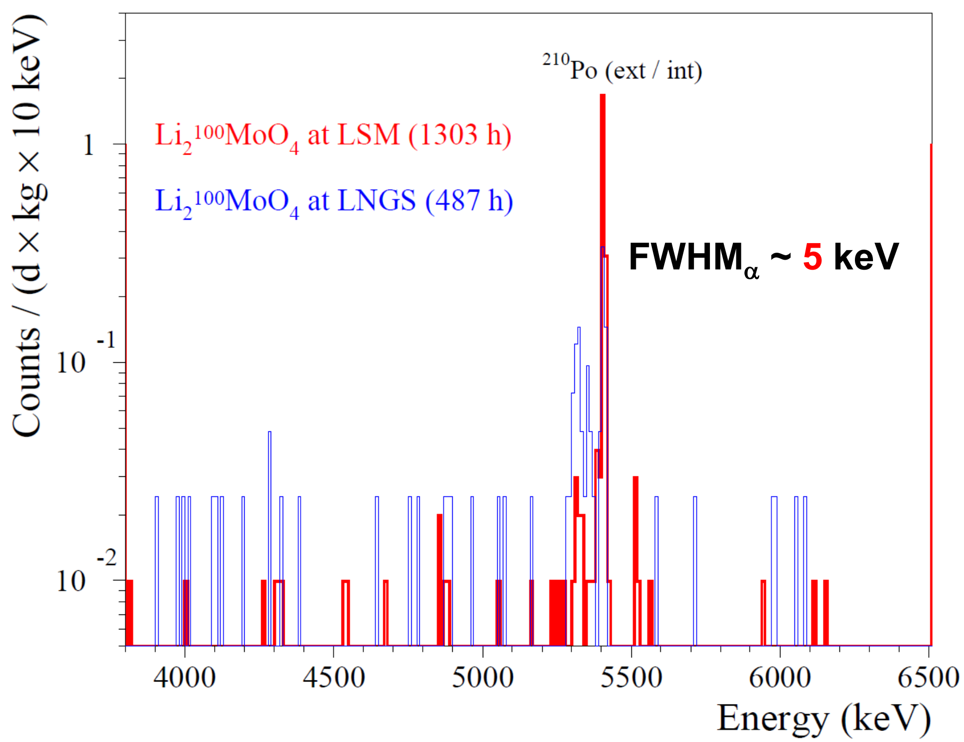
- Control of crystal internal content of ^{40}K < 5 mBq/kg (Random coincidences: 2v2β + ^{40}K << 2v2β + 2v2β)
- Mo purification / crystallization protocol with irrecoverable losses < 4%.
- Excellent crystal radiopurity and ease of production.
- Particle ID on heat channel via pulse shape



$Li_2{}^{100}MoO_4$: Pilot experiment

- Background due to 2ν pileup: 10^{-4} counts/keV/kg/y to be improved via advanced pulse shape analysis.

- 20 crystals (209g each) have been ordered and will be operated at Modane and/or Gran Sasso *(under discussion)*.
  - 2.46 kg of ^{100}Mo - 1.35 x 10^{25} nuclei.
  - Another 20 crystals to be ordered.



E. Armengaud et al., in preparation

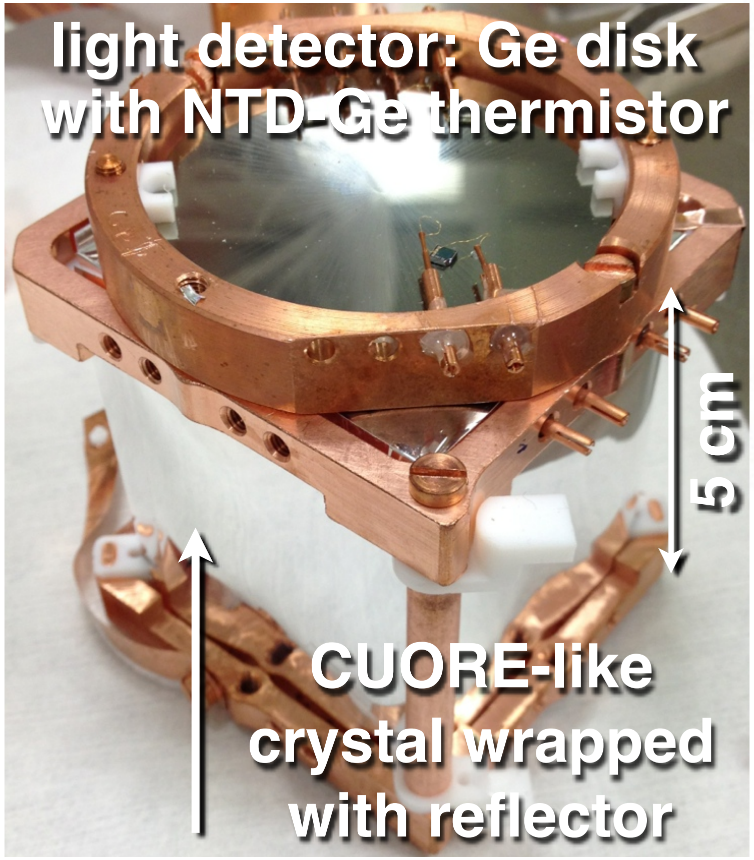
	μBq/kg	
	top	bottom
^{232}Th	≤ 3	≤ 11
^{228}Th	≤ 8	≤ 6
^{238}U	≤ 5	≤ 11
^{226}Ra	≤ 7	≤ 11
^{210}Po	230(20)	60(10)
^{40}K	≤ 4.6×10^3	≤ 6.6×10^3

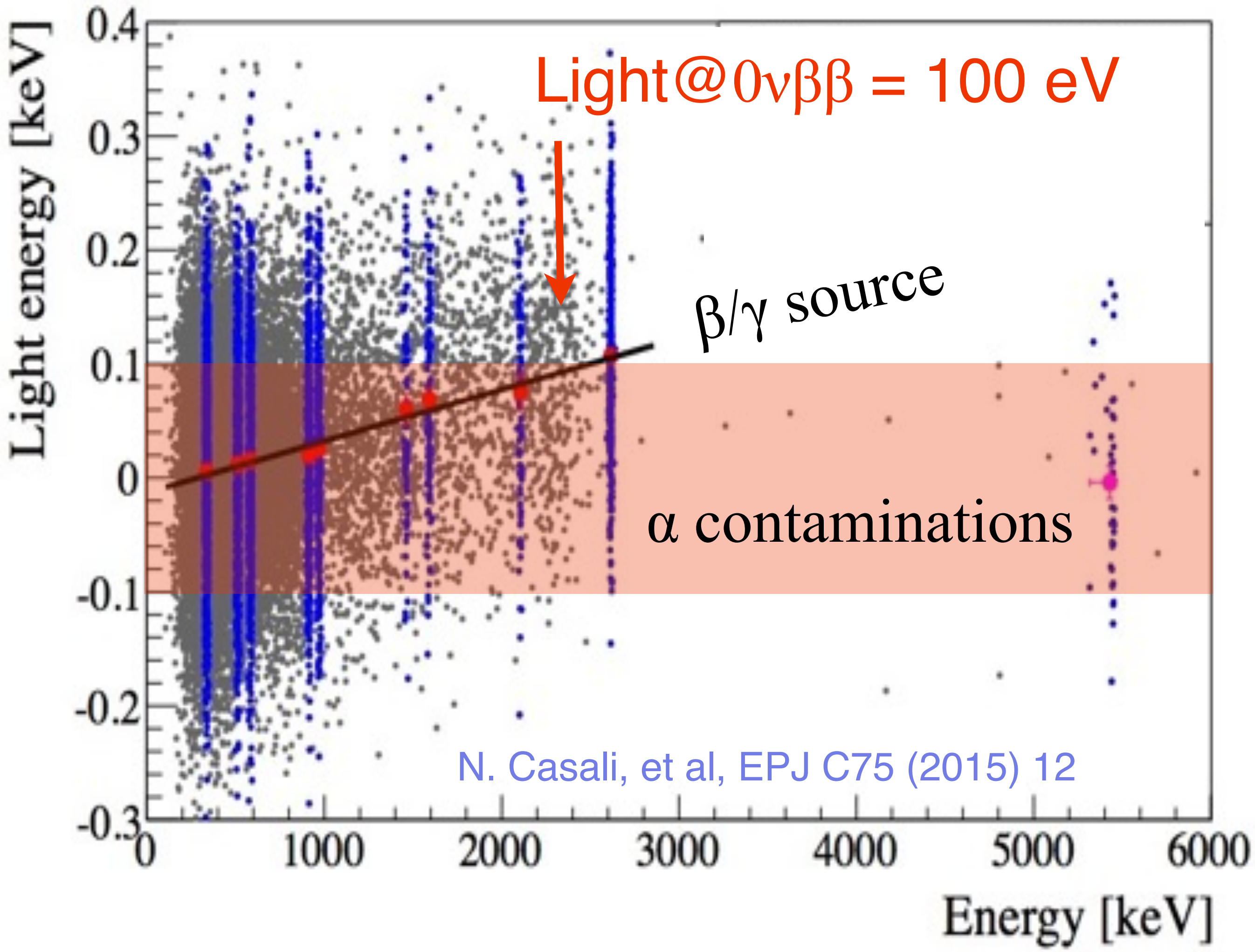
Option:
TeO_2, again

$^{130}TeO_2$

	$Zn^{82}Se$	$Li_2{}^{100}MoO_4$	$^{130}TeO_2$
Q-Value [keV]	2998	3034	2528
Isotopic abundance [%]	9.2	9.7	34
$T^{2\nu}$ [years]	9×10^{19}	7×10^{18}	8×10^{20}
ΔE [keV FWHM]	10-30 (430 g bolometer)	5-8 (210 g)	5 (750 g)
Pros	Q-value R&D concluded	Q-value *PID w/o light detector*	ΔE
Cons	ΔE *^{214}Bi at 3000 keV*	2ν pileup bkg.	*γ bkg.* Challenging PID

Cherenkov readout from TeO_2

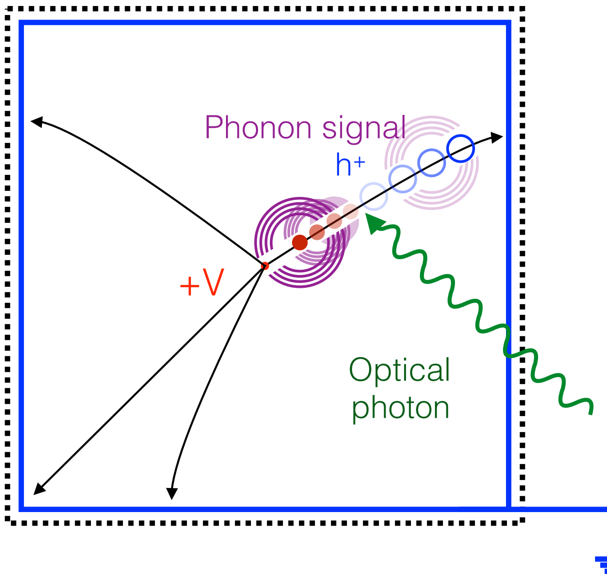




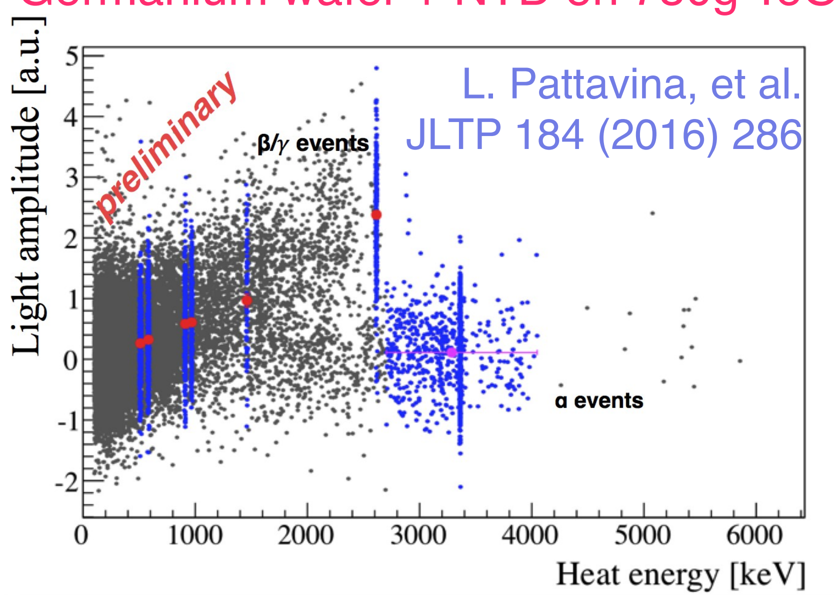
Noise of NTD-Ge light detectors is too high (30 -100 eV) compared to the signal (100 eV) ⟶ **need noise lower than 20 eV RMS, with a technology scalable to 1000 detectors.**

Light detectors: Neganov Luke

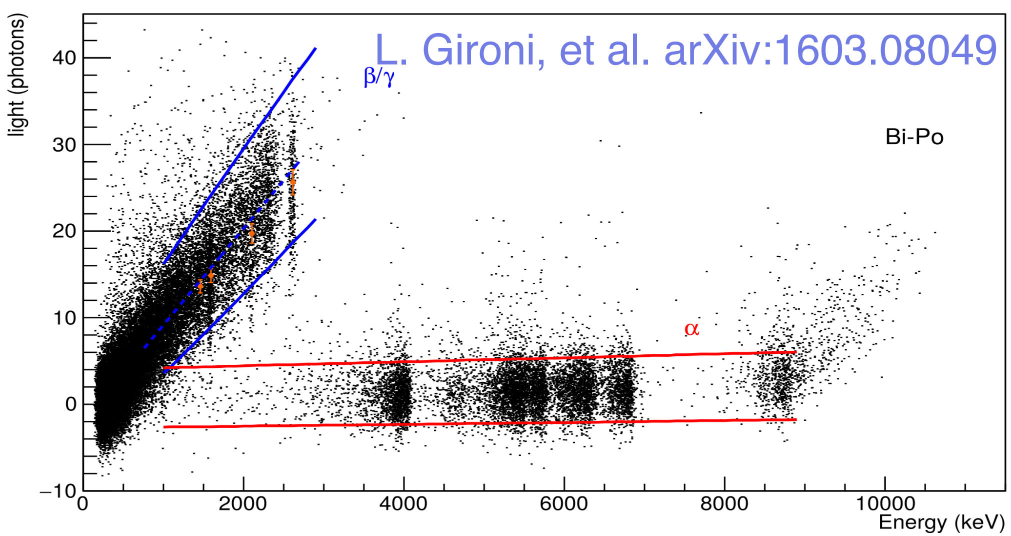
- Apply DC voltage to the wafer of the light detector.
- e-h pairs produced by photons are accelerated by the electric field → energy transfer to the wafer lattice → heat.
- Use NTD-Germanium thermistor as sensor.



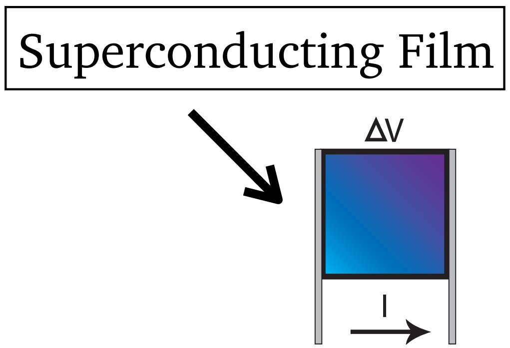
Germanium wafer + NTD on 750g TeO_2

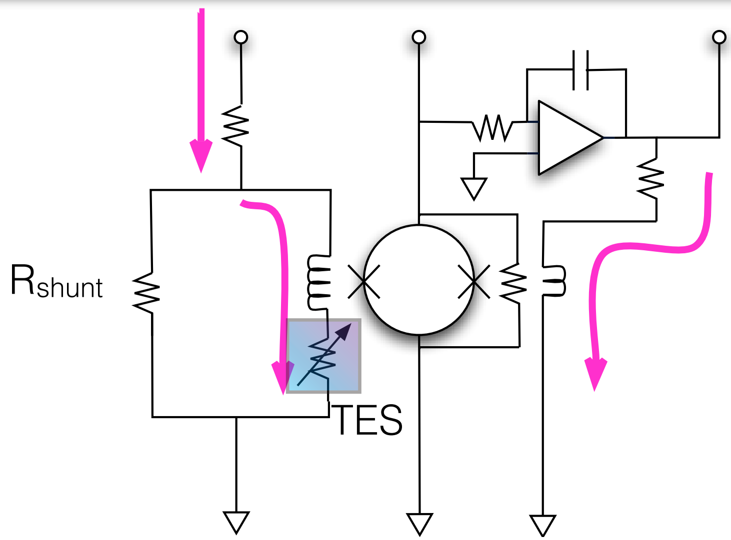


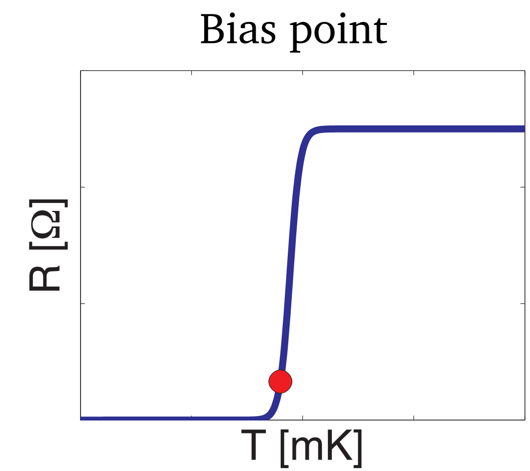
Silicon wafer + NTD on 6g TeO_2



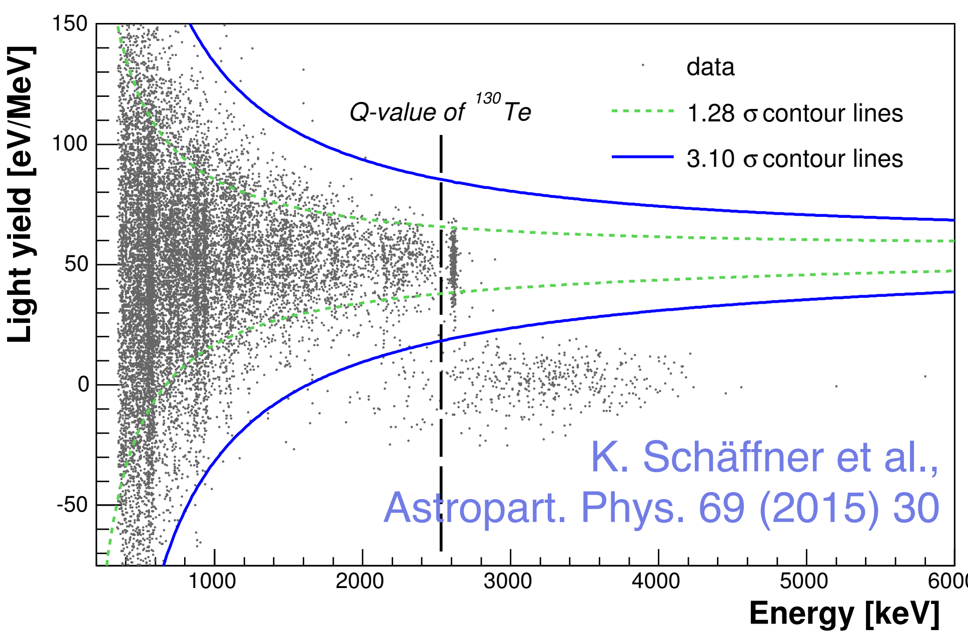
Light detectors: TES sensor



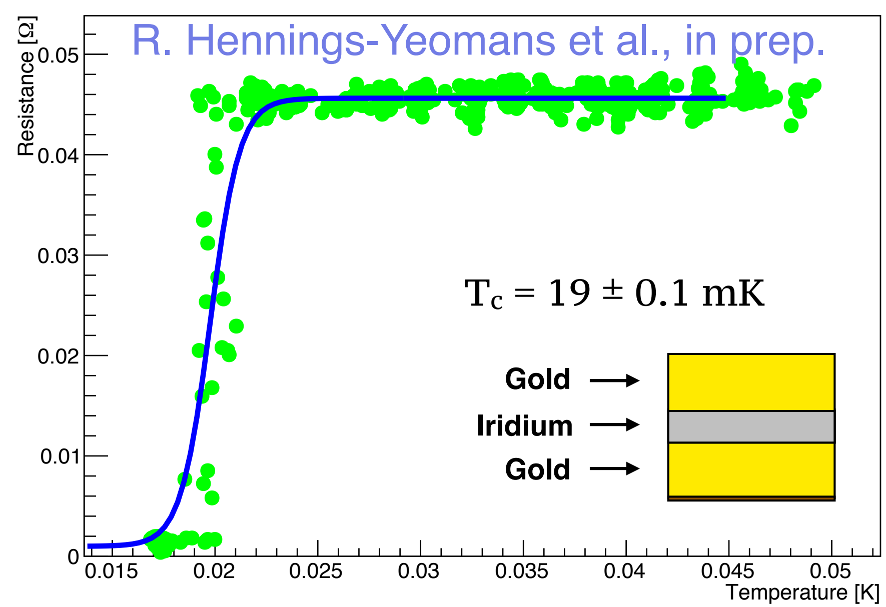




Sapphire wafer + W-TES on 285 g TeO_2



Ir/Au/Ir rilayer TES



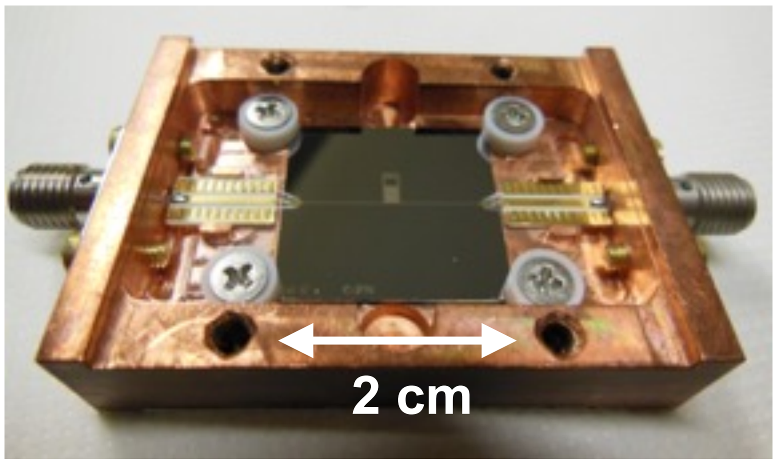
Need to develop a 1000 channel readout of SQUIDs

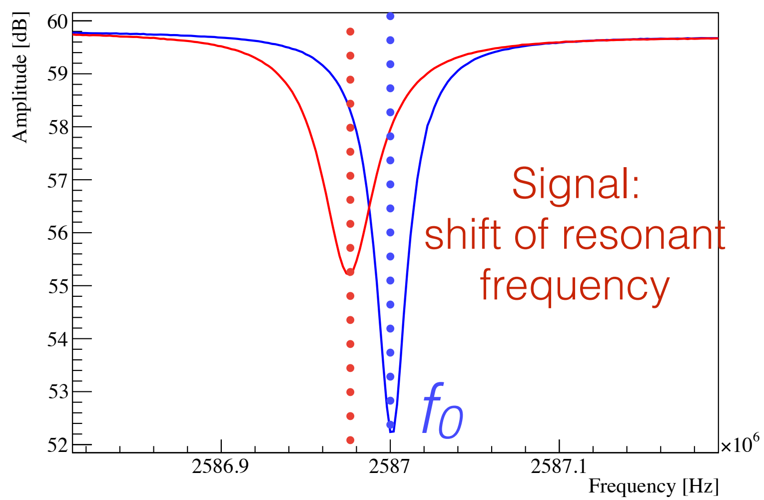
Light detectors: MKID sensor

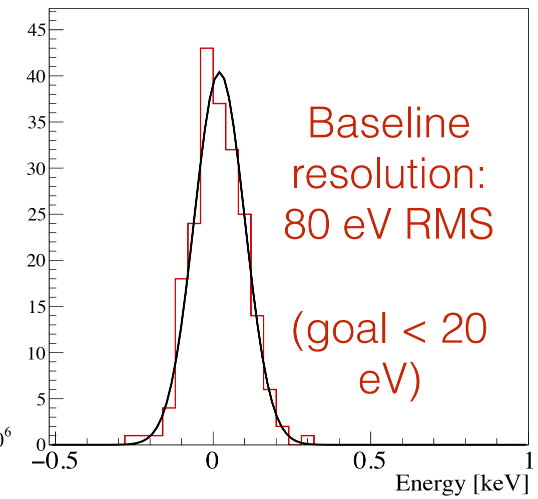
Microwave Kinetic Inductance Detector (MKID).
high scalability and multiplexing, no microphonic noise.

- **Phase I** - completed: single pixel, high-Q (1.5×10^5) Aluminum resonator.

F. Bellini, et al. arXiv:1606.04565







- **Phase II** - ongoing: test more sensitive superconductors (TiAl, TiN and Ti +TiN). Goal: 20 eV RMS resolution. TiAl preliminary: 55 eV RMS.

- **Phase III** - 2017-18: test at LNGS with TeO_2 bolometers.

$^{130}TeO_2$: Pilot experiment

- Select light detector technology: scalability, reproducibility and compatibility with CUORE infrastructure.
- Plan for an array of enriched $^{130}TeO_2$ bolometers in 2018.
- Preliminary results from two 435 g enriched crystals produced at SICCAS (CUORE crystals producer):

D.R Artusa, et al, arXiv:1610.03513

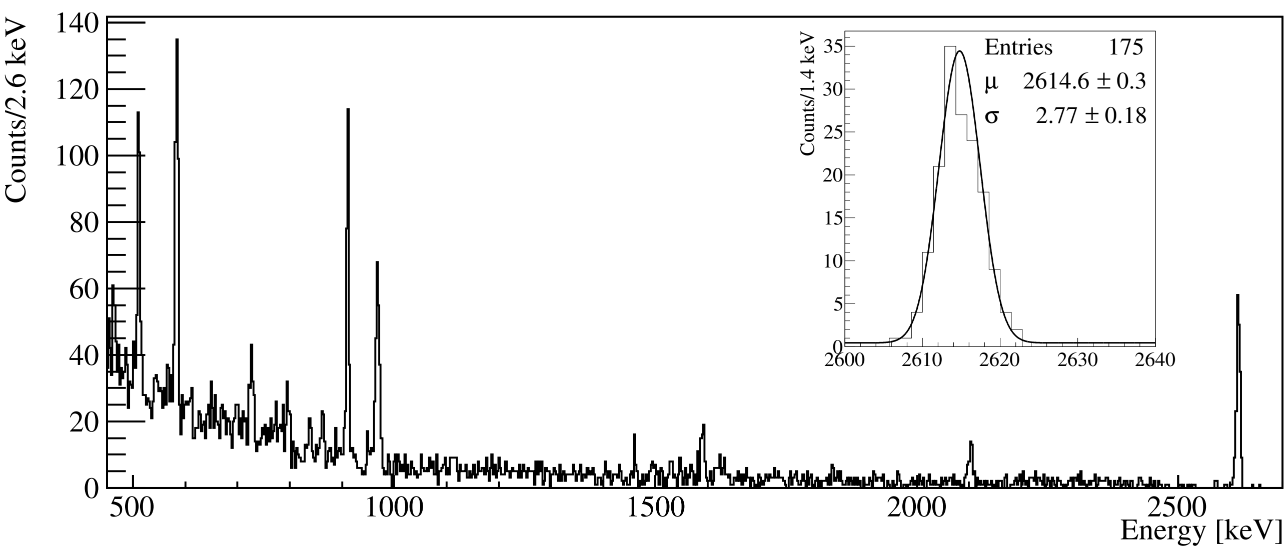
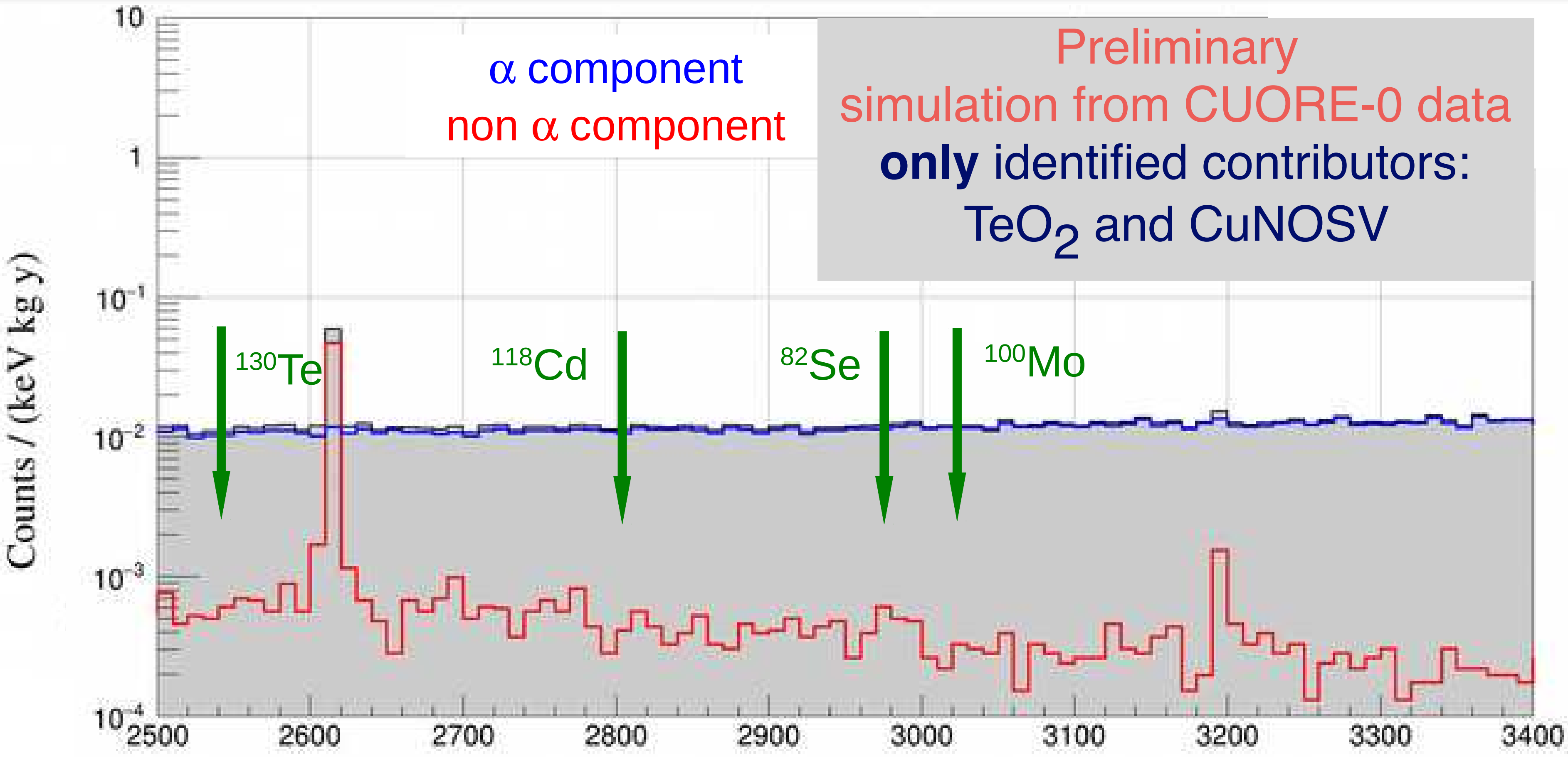


Table 4: Activity of trace contaminations belonging to ^{232}Th and ^{238}U chains for the two crystals. The total collected statistic is 663.8 hours for $^{130}TeO_2$-1 and 505.8 hours for $^{130}TeO_2$-2. Limits at 90 % C.L. See text for more details.

Chain	Nuclide	$^{130}TeO_2$-1 [μBq/kg]	$^{130}TeO_2$-2 [μBq/kg]
^{232}Th	^{232}Th	<4.3	<4.8
	^{228}Th	<2.3	<3.1
^{238}U	^{238}U	7.7 ± 2.7	15.1 ± 4.4
	^{234}U	<6.3	<5
	^{230}Th	<5.7	<3.8
	^{226}Ra	<2.3	<3.1
	^{210}Po	3795 ± 60	6076 ± 88

Backgrounds other than αs



- Need CUPID-0 ($Zn^{82}Se$) and CUORE data to confirm simulations.
- Anyhow, non-α background must be reduced by more than 10x
  - Need the development of technologies to measure contaminations of candidate materials for detector and cryostat (Copper, teflon…).
  - Need a muon veto

Conclusions

- CUPID aims at completely covering the inverted hierarchy of ν mass.
- 3 Pilot experiments:
  - 2016 - $Zn^{82}Se$, start of data taking end of the year.
  - 2017 - $Li_2{}^{100}MoO_4$
  - 2018 - $^{130}TeO_2$
- Selection of the best technology for CUPID.
- CUPID will start after CUORE, so after 2022-2023.

We are open to collaborations, contact us!