Luminescent TeO_2 bolometers

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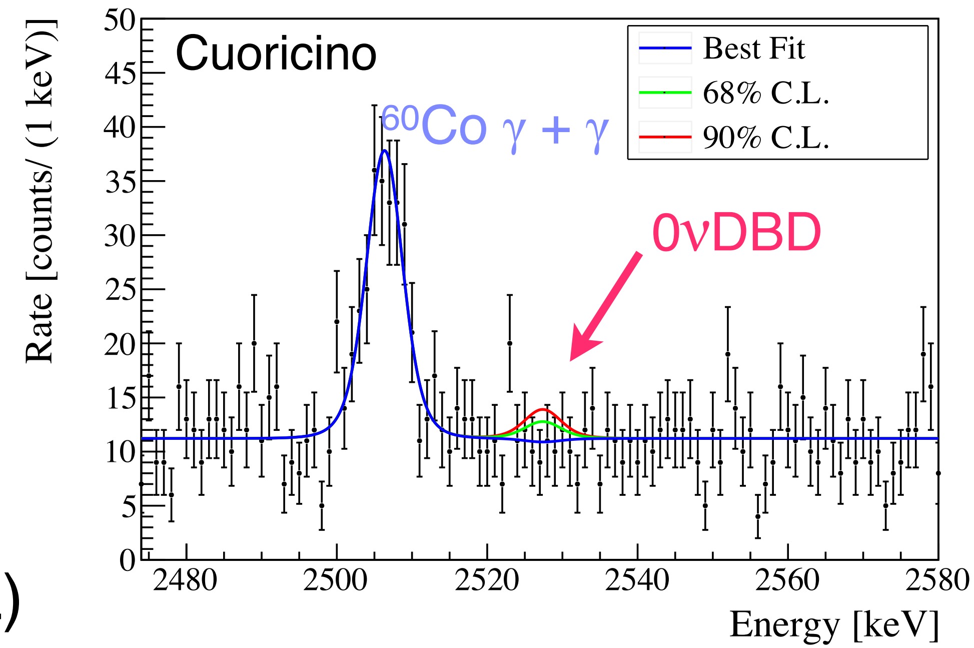
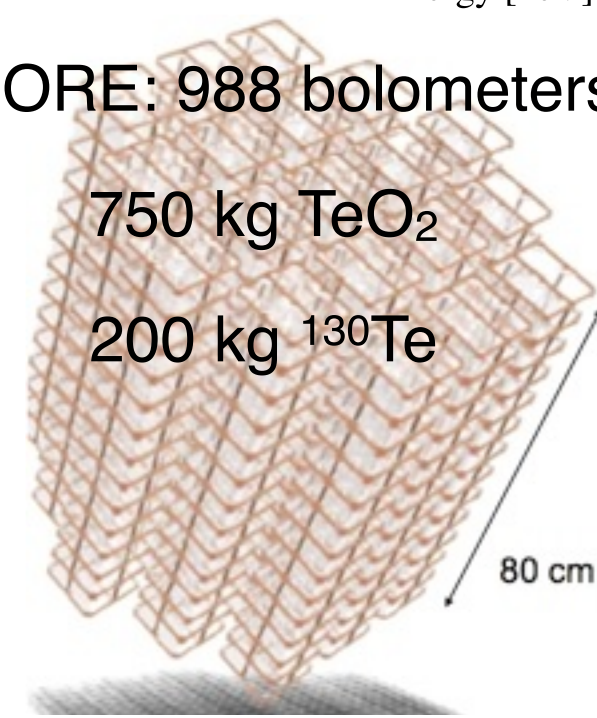
CUORE - @LNGS

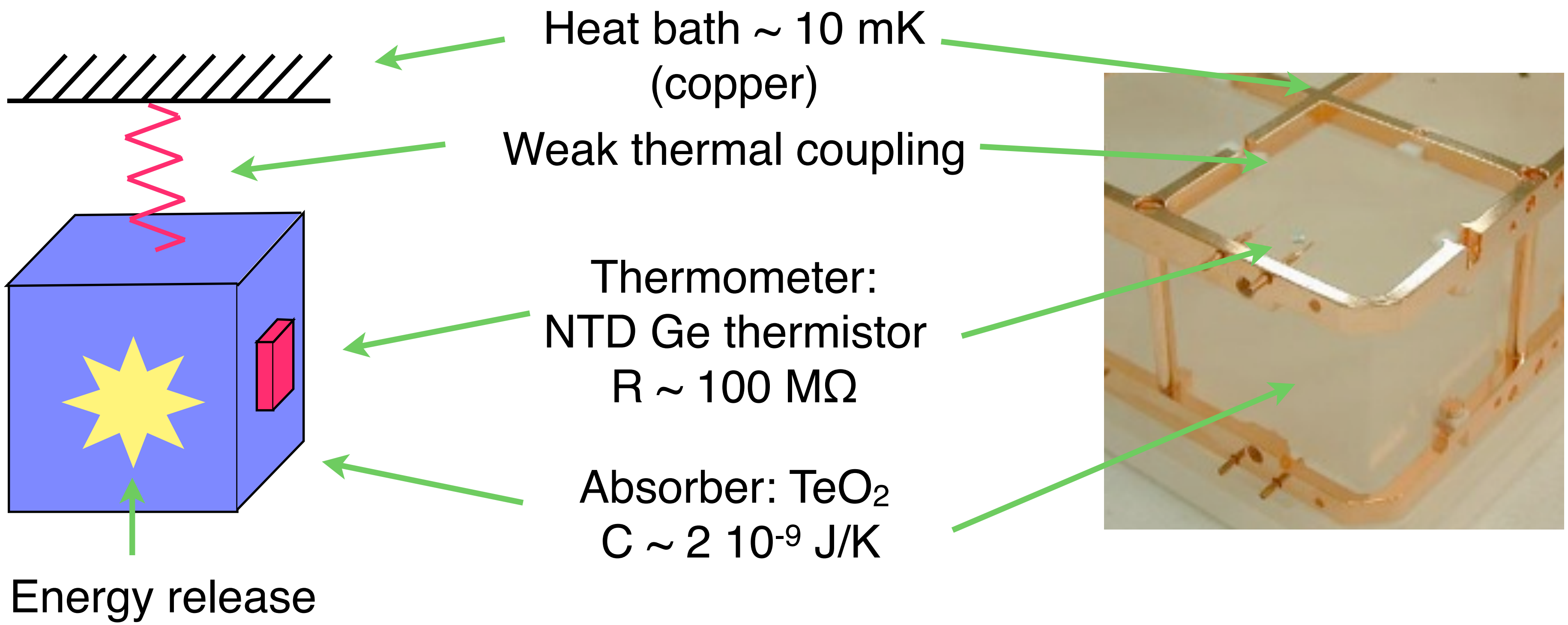
- ${}^{nat}TeO_2$ bolometers (34% ${}^{130}Te$), 750g each (ΔE = 5 keV FWHM)
- Past: Cuoricino
  - 62 bolometers
    11 kg (${}^{130}Te$) × 2 years,
    Bkg: 0.16 cpy/keV/kg
  - $T^{0\nu}_{1/2} > 2.8\times10^{24}$ years (90% CL)
    $\langle m_{\beta\beta}\rangle < 300\sim700$ meV
- Future: Cuore (data taking in 2015)
  - Expected bkg: 0.01~0.04 cpy/keV/kg
  - Exp. $T^{0\nu}_{1/2} > 1.6\times10^{26}$ years @68% CL
    $\langle m_{\beta\beta}\rangle < 40\sim94$ meV
- Present: Cuore-0, a CUORE-like tower
  - same mass of Cuoricino.





Bolometers

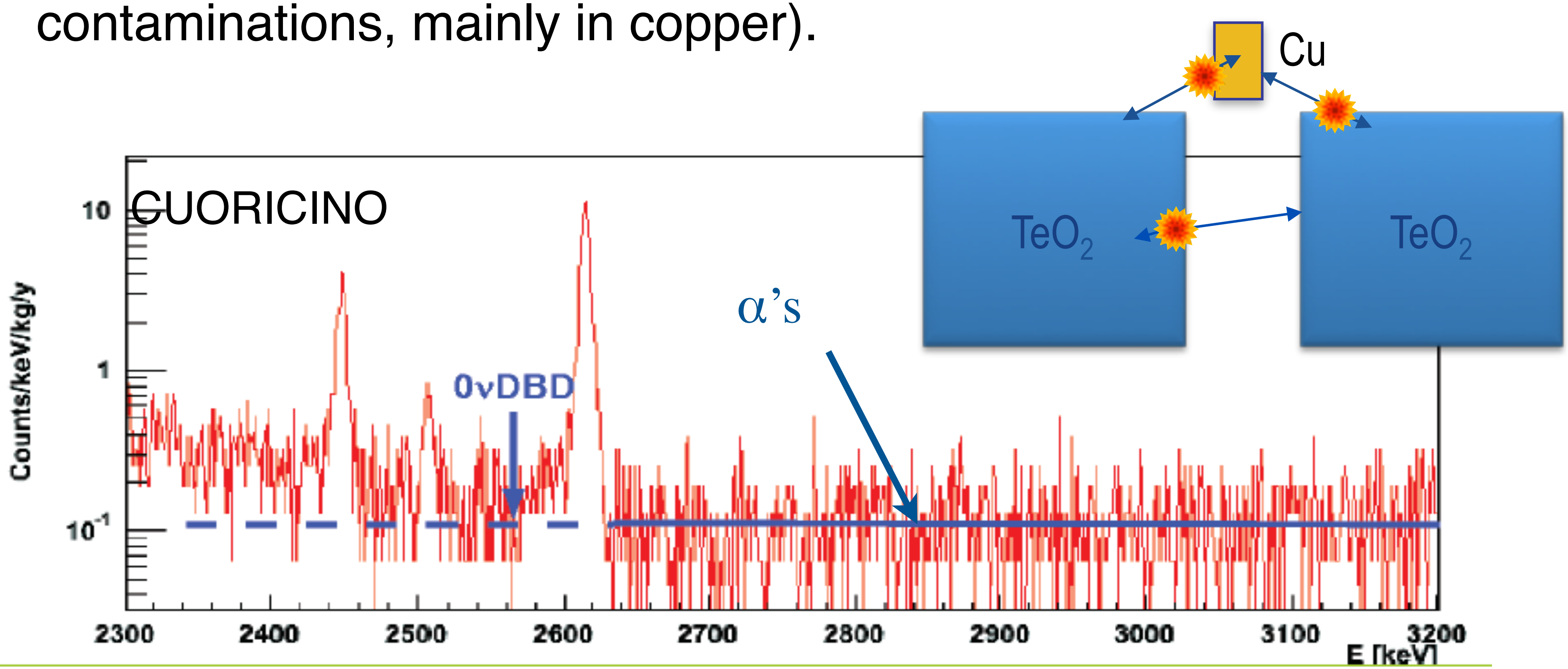
- Particle energy converted into phonons → temperature variation.
- 0νDBD source embedded in crystals.
- Low crystal heat capacitance and low base temperature to see small temperature variations → $\Delta T \sim E/C$



- Detector response in this configuration: ~ 0.1 mK / MeV
- Resolution @0νDBD ~ 5 keV FWHM

CUORE: the α nightmare

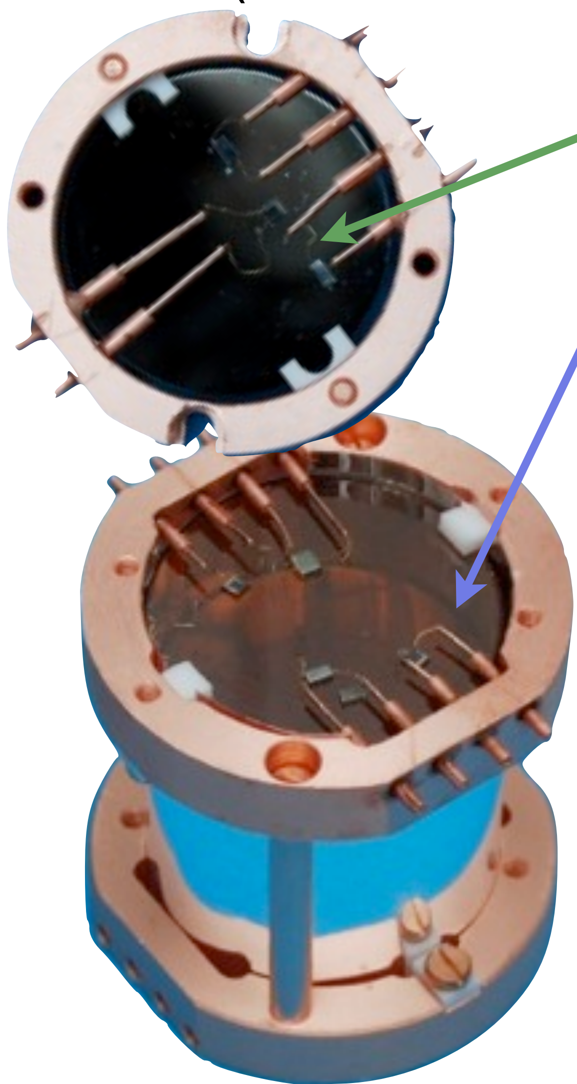
- MC: the background in CUORICINO is due to degraded α particles which release only a part of their energy in the detector (surface contaminations, mainly in copper).



- TeO_2 bolometers, per se, do not allow to discriminate β and α particles.
  - α bkg partially reduced by cleaning the detector parts.

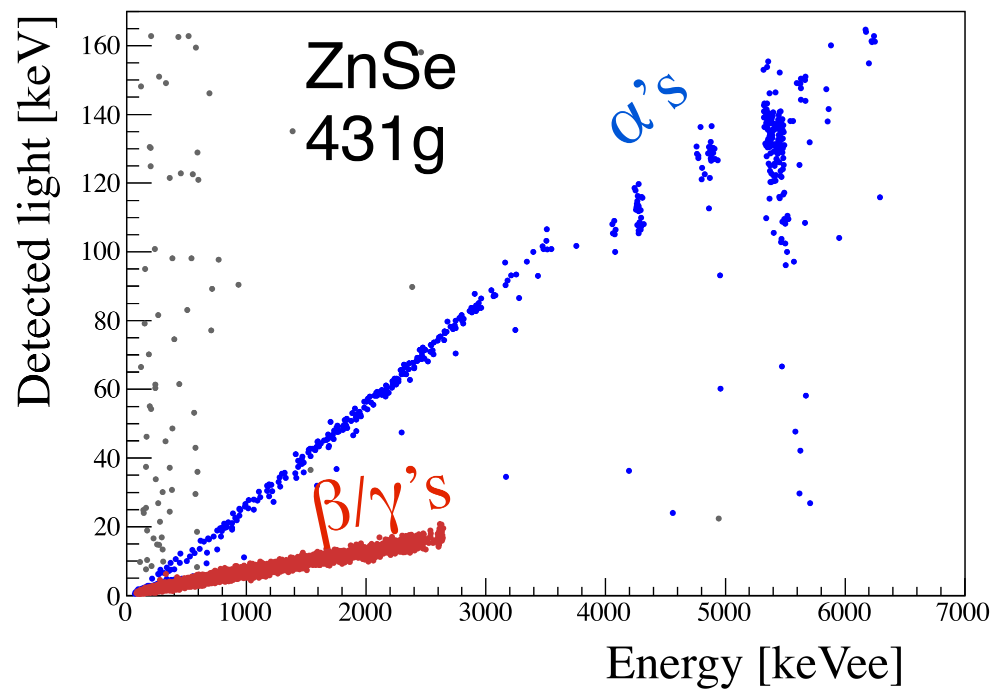
LUCIFER - @LNGS

- Scintillating bolometers to discriminate the α background, enriched in ^{82}Se or ^{100}Mo.
  - Target: define the technology for a ZERO background (<1 count/ton/year), ~1-ton isotope experiment after CUORE.



Light detector: Ge bolometer

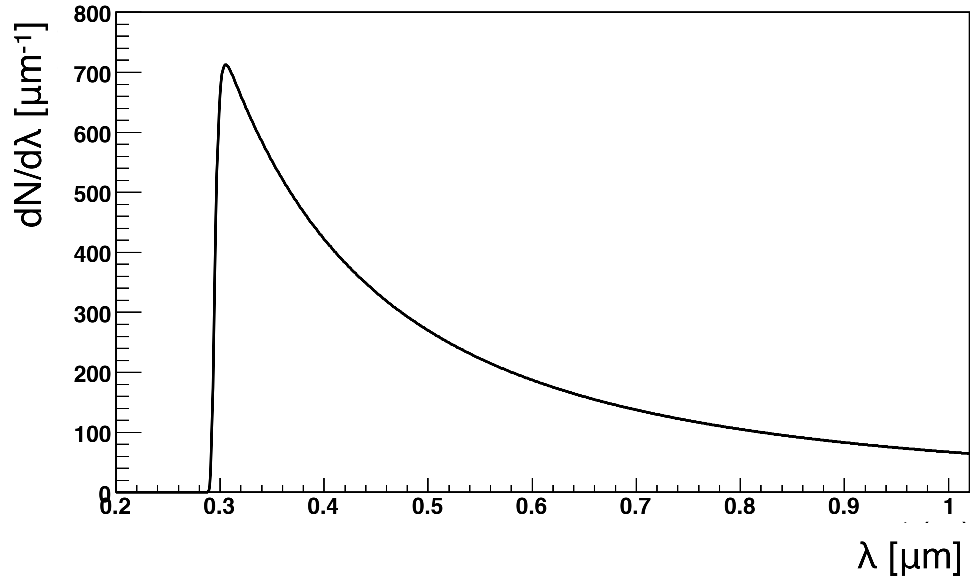
Absorber bolometer: $Zn^{82}Se$ or $Zn^{100}MoO_4$



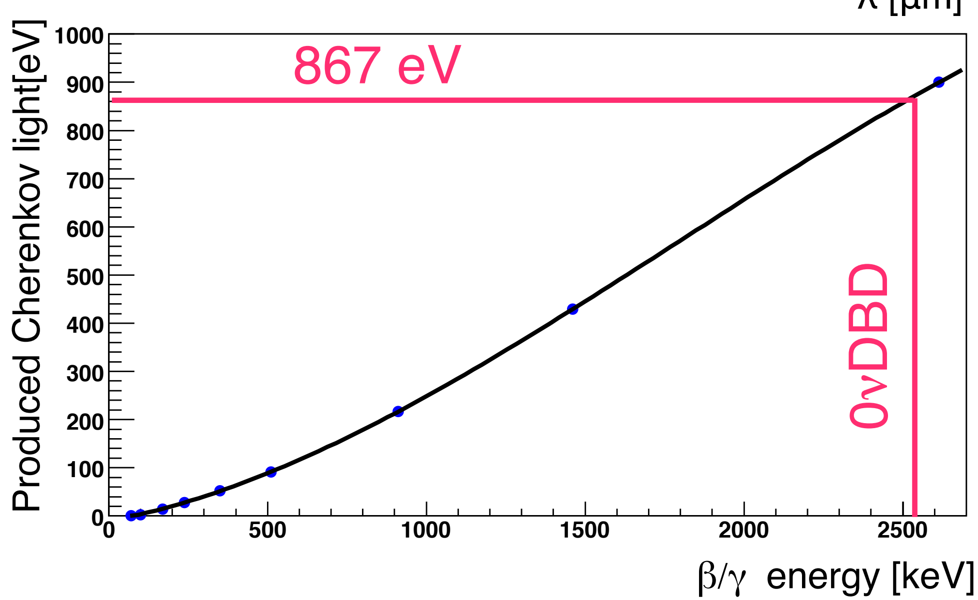
Cherenkov light in TeO_2

TeO_2 does not scintillate, however MeV β's emit Cherenkov light, unlike α's [T. Tabarelli de Fatis, Eur. Phys. J. C 65 (2010) 359].

Simulated Cherenkov emission spectrum from 1.5 MeV γ in TeO_2 at low temperatures.



Simulated emitted Cherenkov light as a function of β/γ energy.



First test: 117g TeO_2:Sm crystal

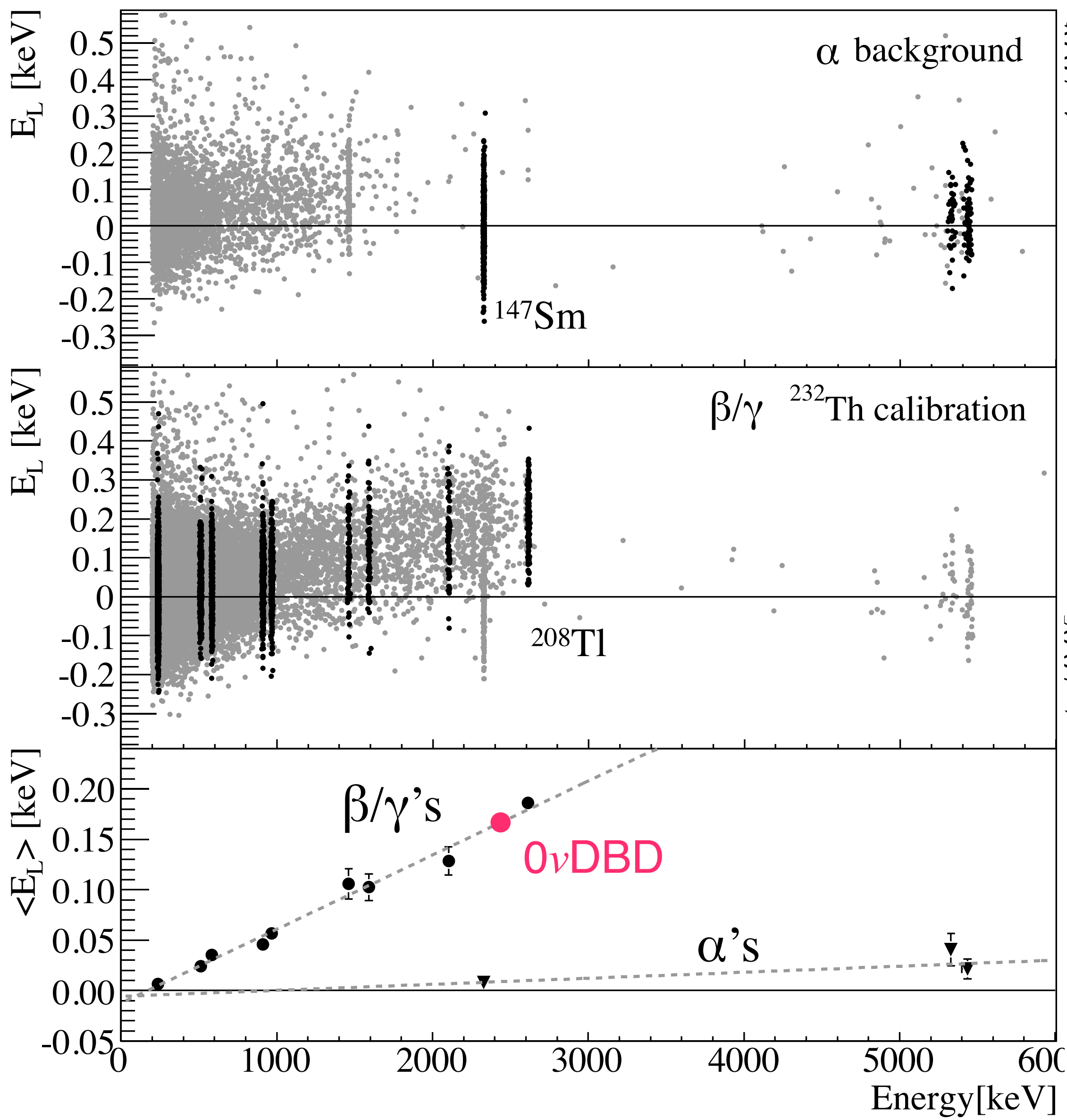
TeO_2:Sm (30 ppb ^{nat}Sm)
3.0x2.4x2.8 cm^3
116.65 g

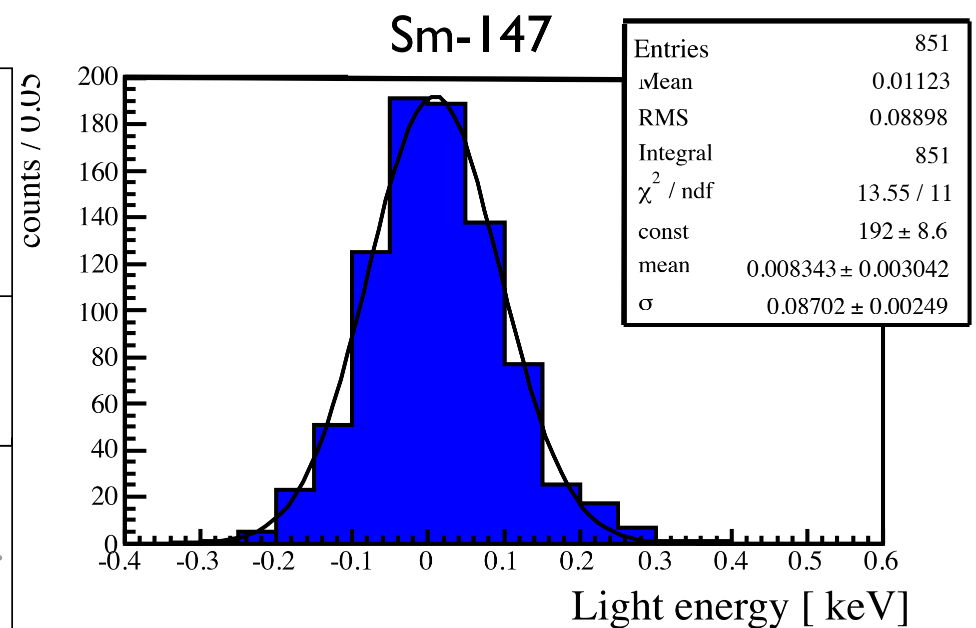
VM2002
reflecting foil

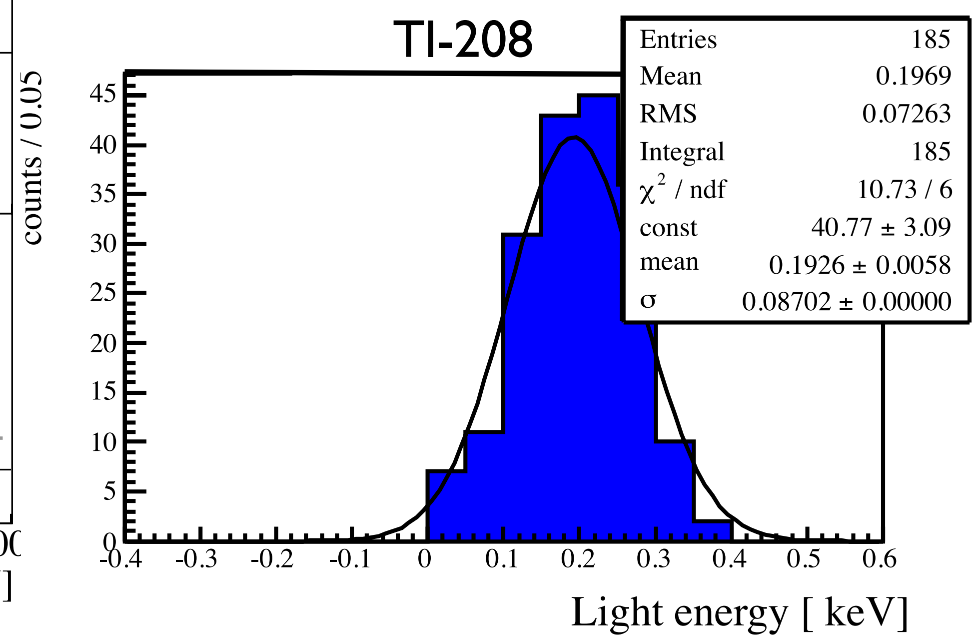
Light detector of pure Ge
66 mm diameter, 1mm thick.

117g TeO_2:Sm results

JINST 6 (2011) P10005
Astropart. Phys. 35 (2012) 558

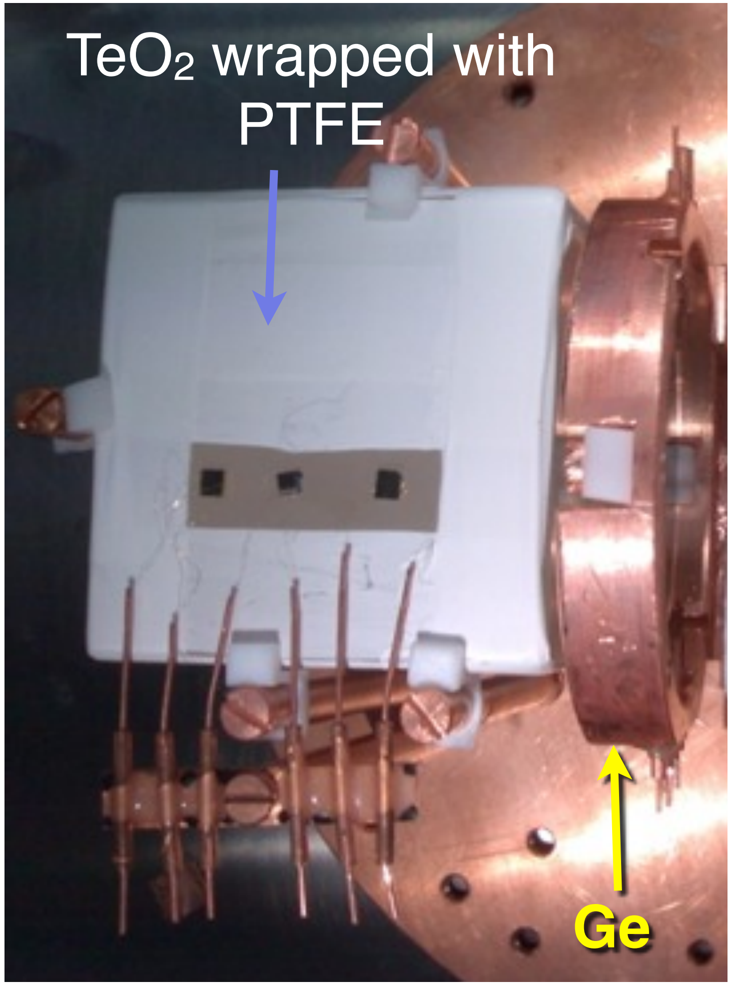


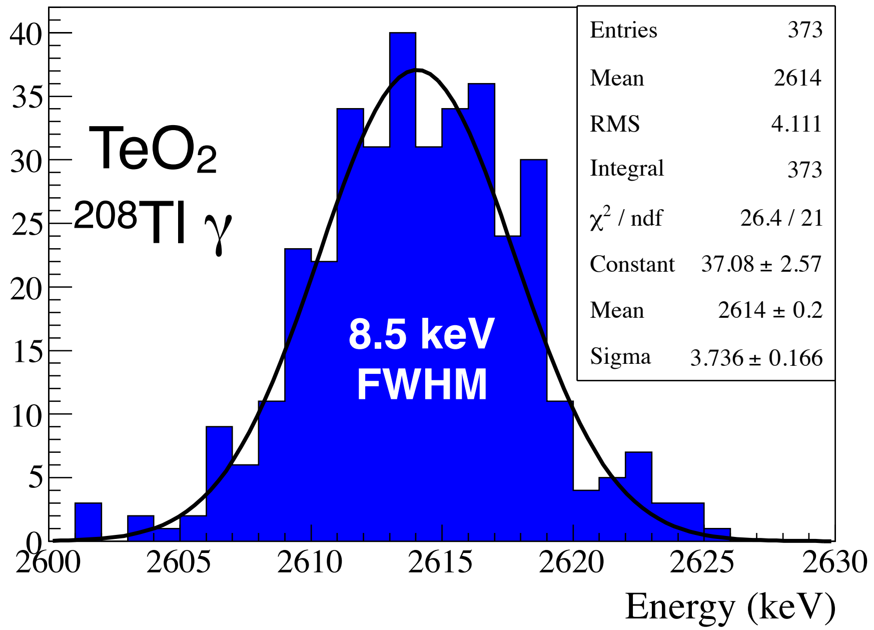


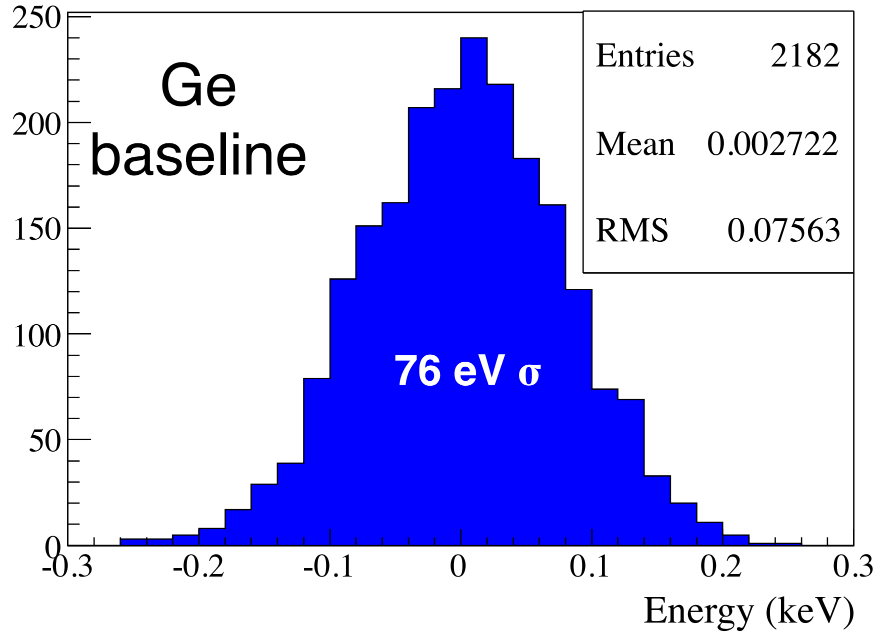


β/γ's light yield: 73 eV/MeV ⟶ 171 eV @2.527 MeV

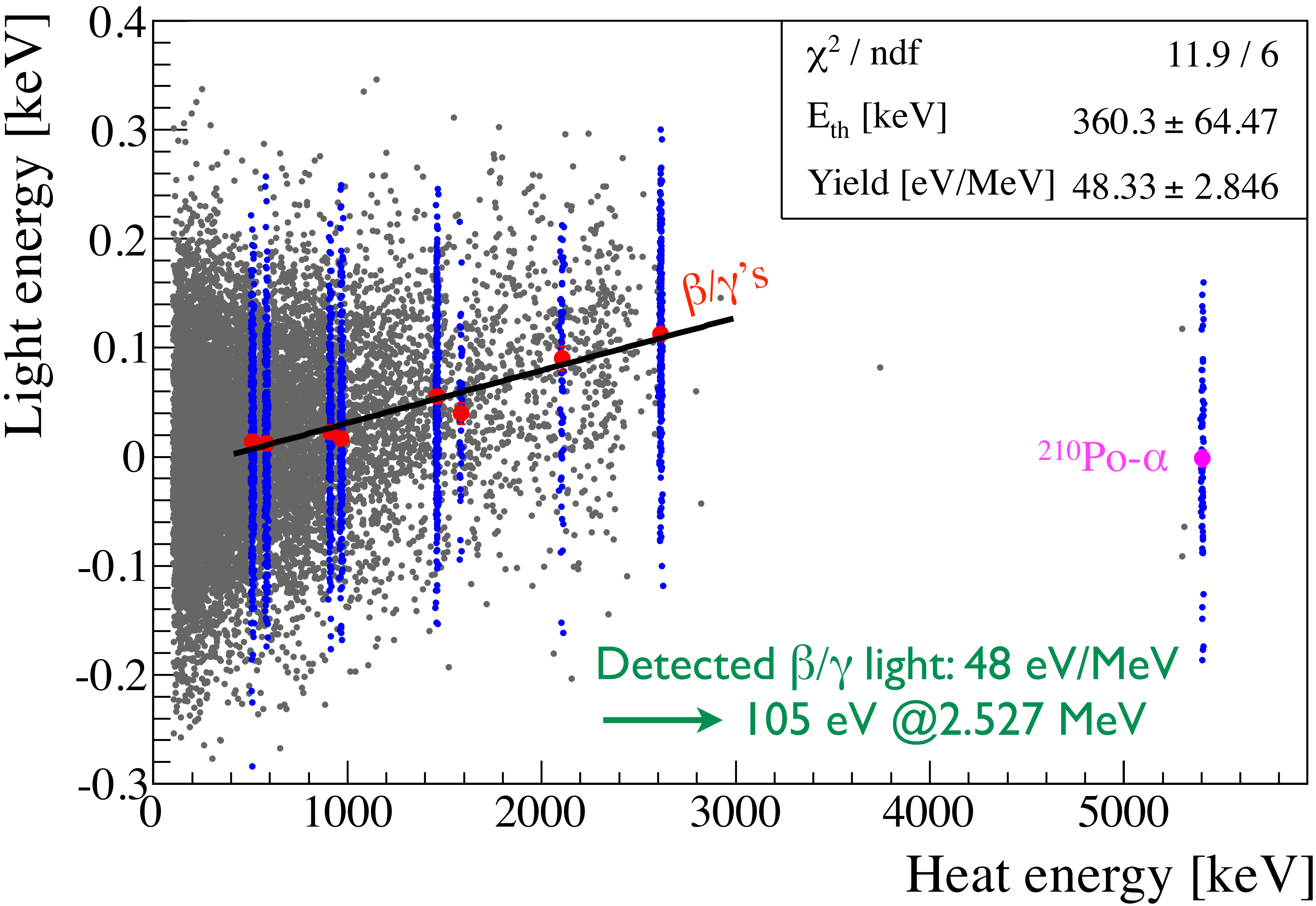
CUORE crystal (5x5x5 cm³)



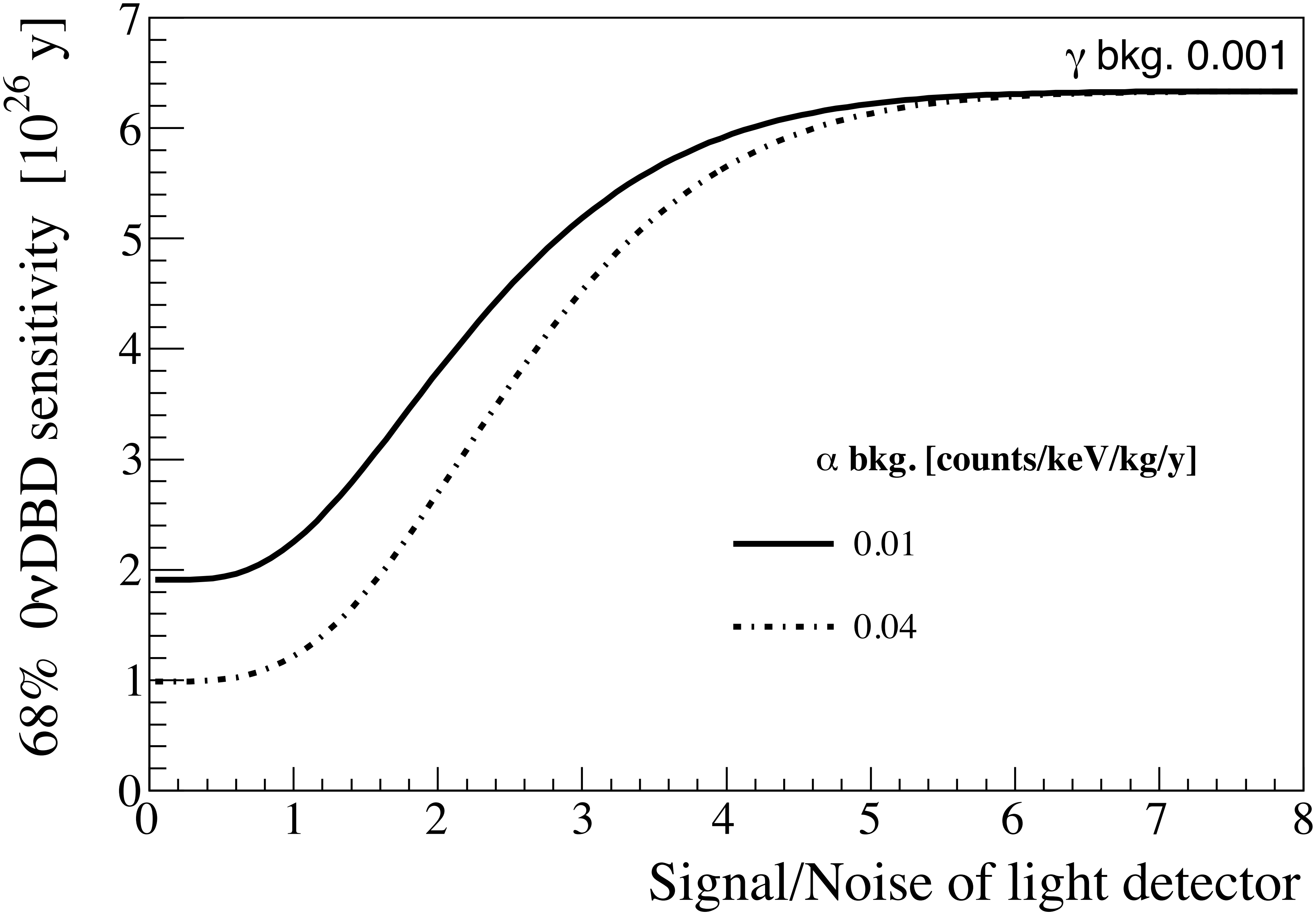




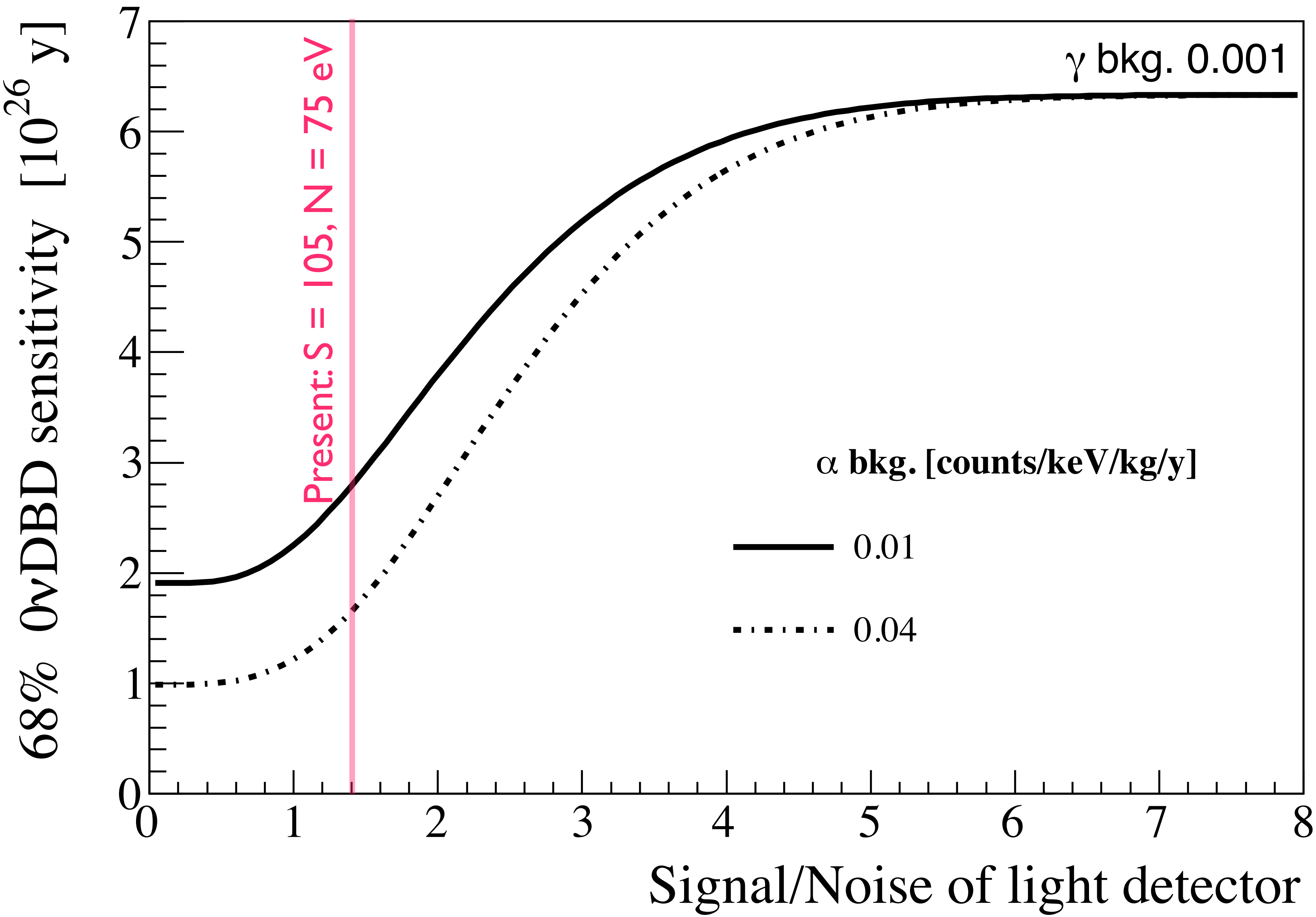
CUORE crystal (5x5x5 cm^3)



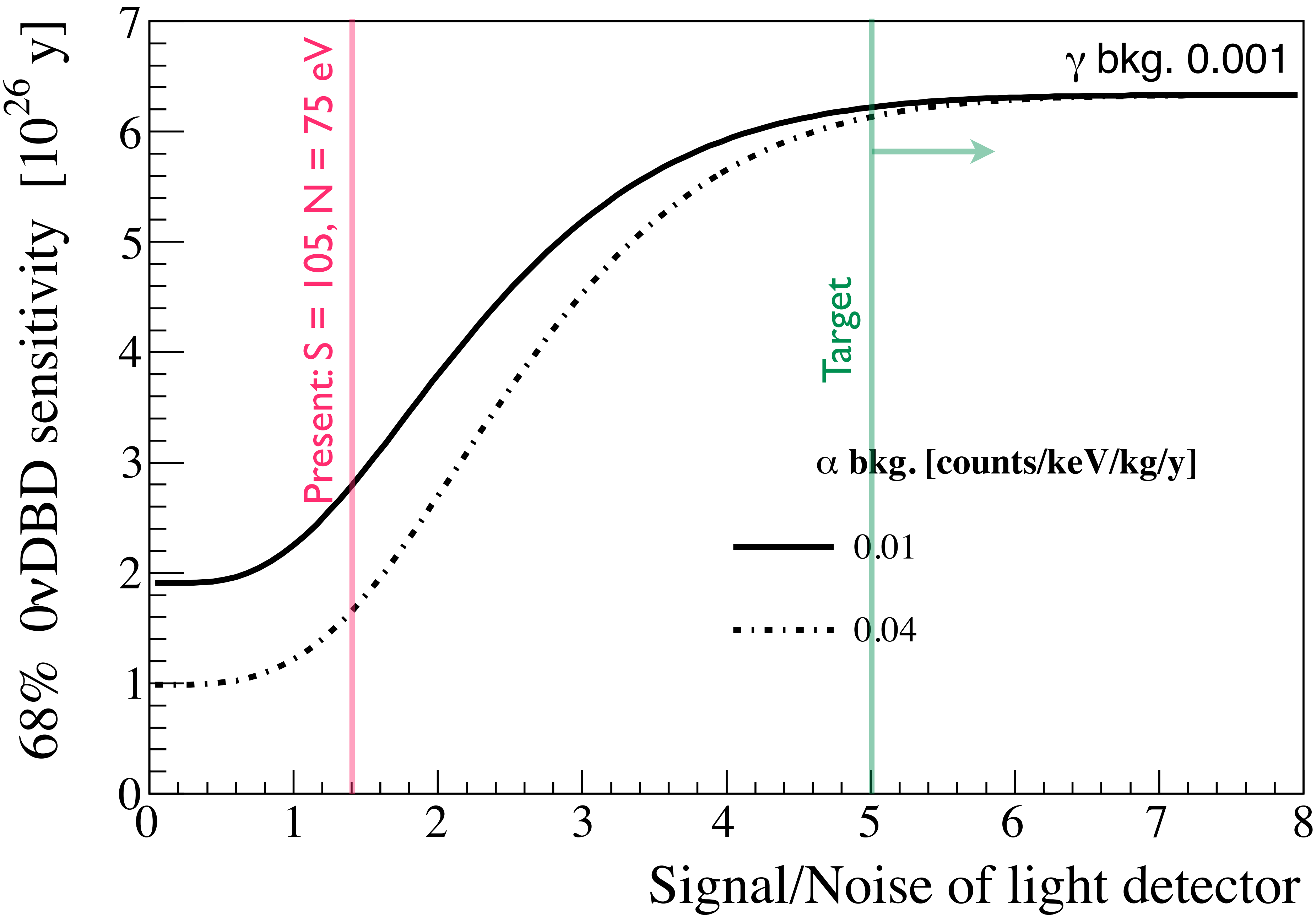
CUORE with Cherenkov



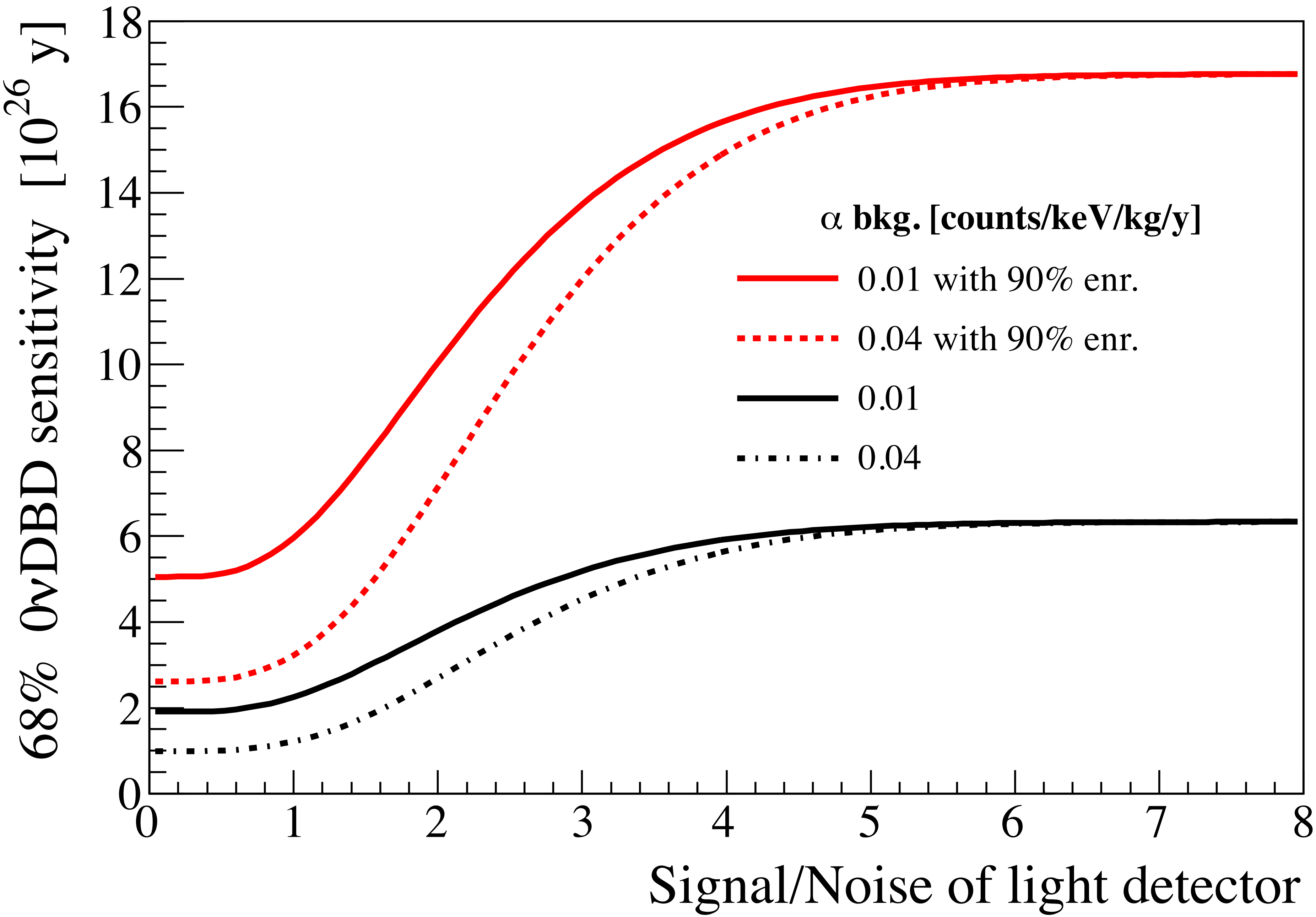
CUORE with Cherenkov



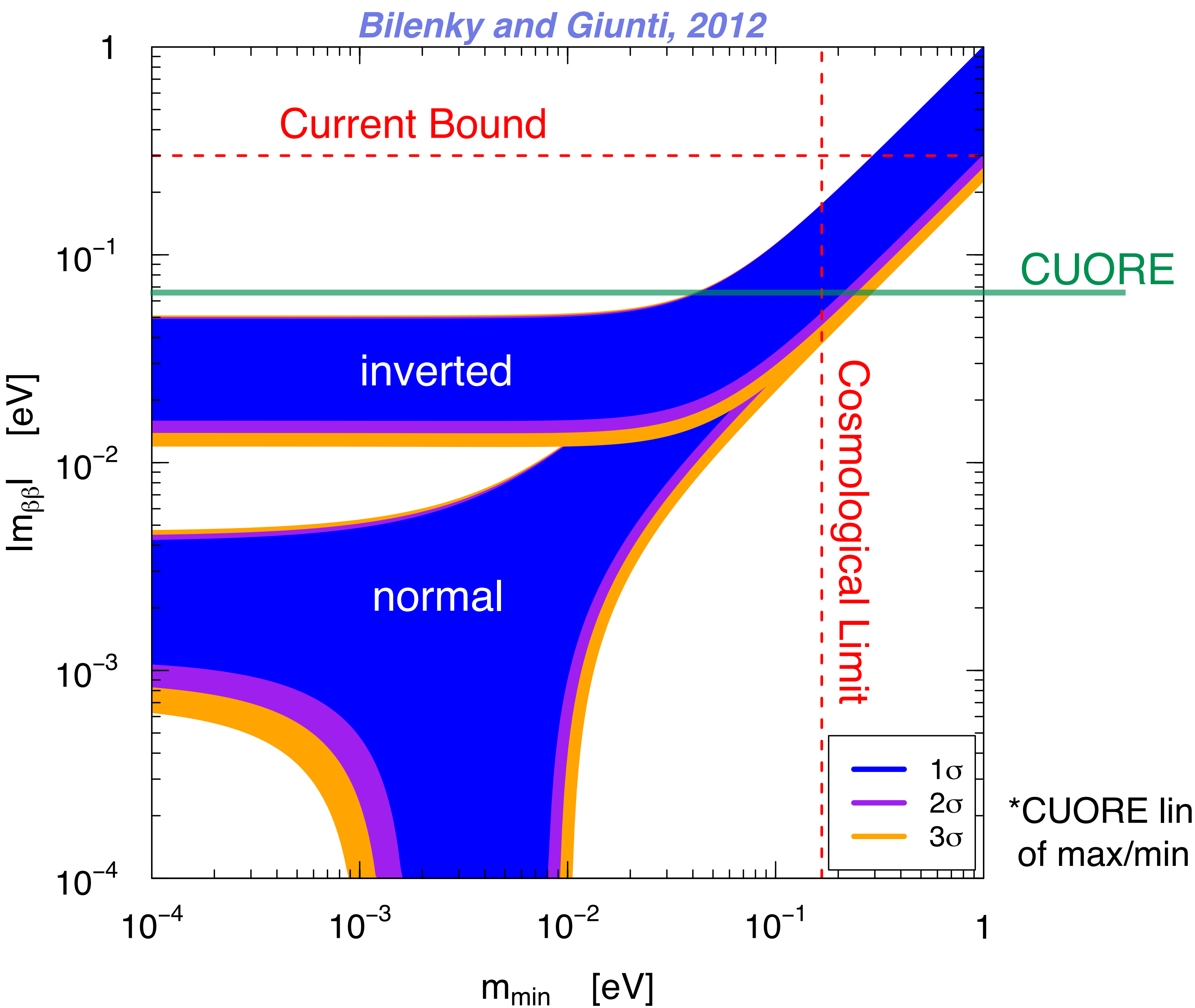
CUORE with Cherenkov



...and with ^{130}Te enrichment

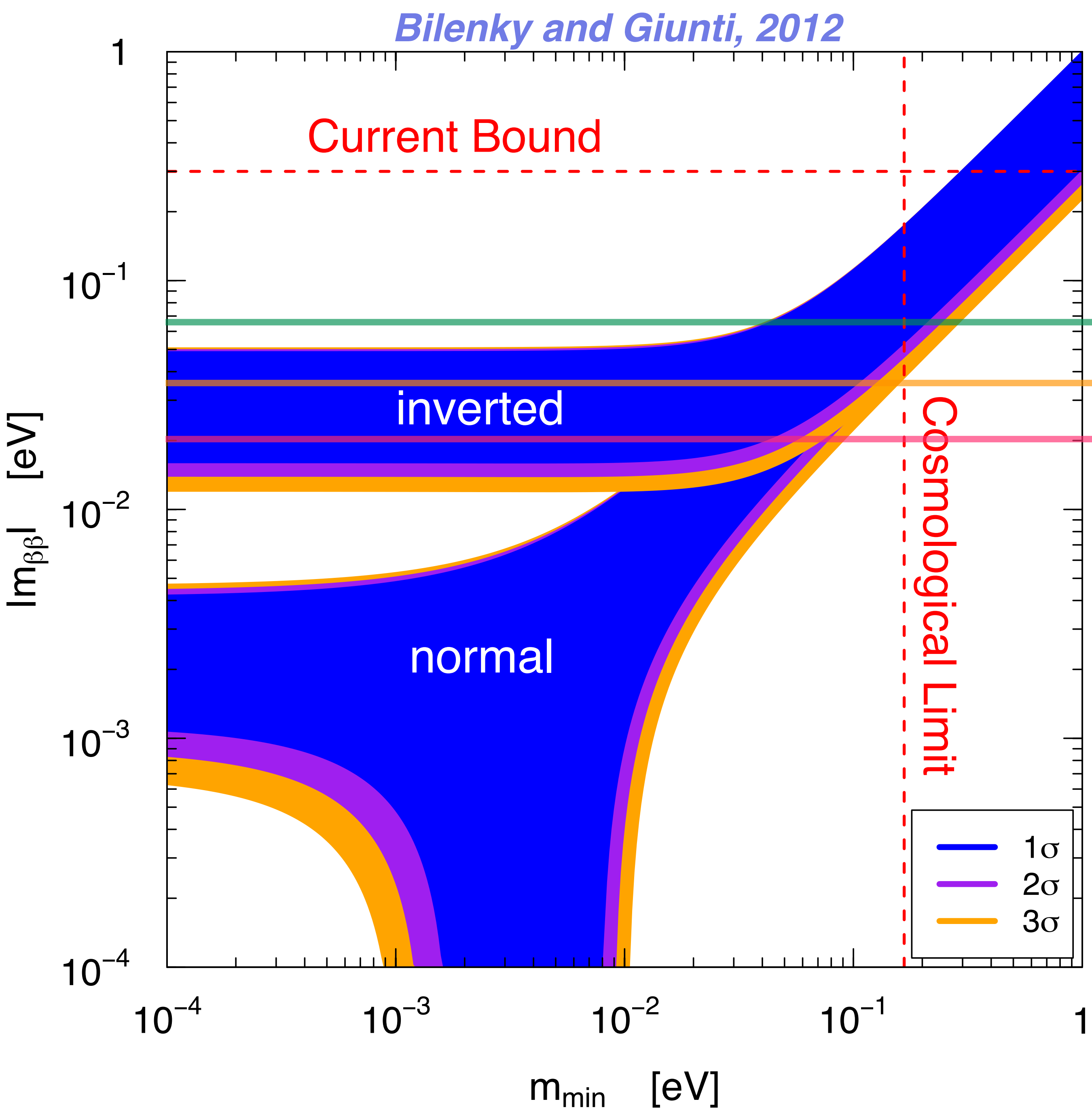


Sensitivity to ν Majorana mass



*CUORE lines indicate average of max/min ^{130}Te NME.

Sensitivity to ν Majorana mass



*CUORE lines indicate average of max/min ^{130}Te NME.

Requirement:

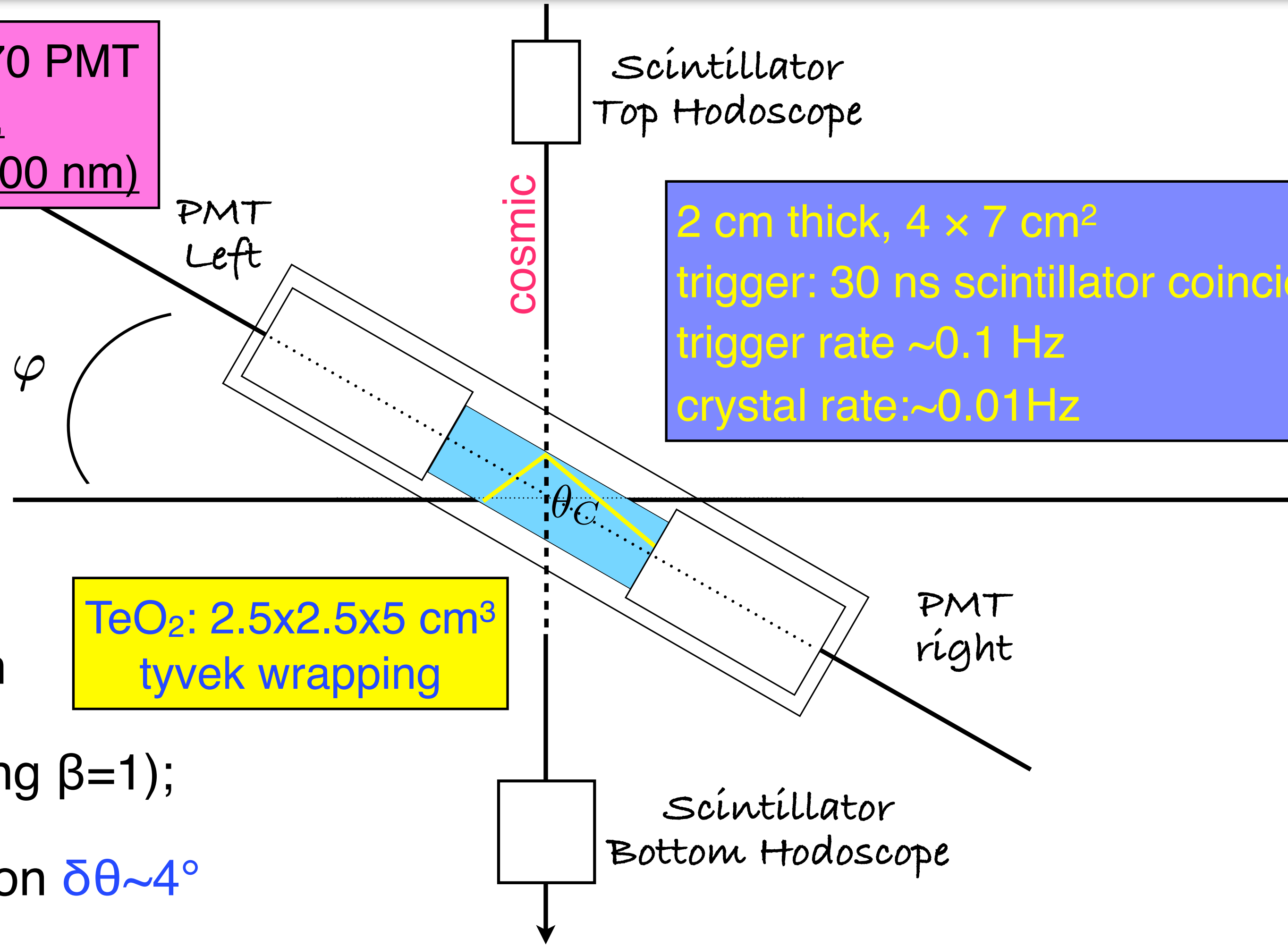
Signal/Noise $\gtrsim 5$

Light collection

- The signal detected in bolometric tests is 100 eV, against 870 predicted.
- To investigate the source of losses and the signal specs we built a setup for studies at room temperature in Rome.
  - First target: determine that the light we detect is effectively due to Cherenkov emission, not to scintillation...

Room temperature setup

Photonis XP2970 PMT
fast(~ns),
UV sensitive(>200 nm)



2 cm thick, 4 × 7 cm^2
trigger: 30 ns scintillator coincidence
trigger rate ~0.1 Hz
crystal rate:~0.01Hz

TeO_2: 2.5x2.5x5 cm^3
tyvek wrapping

- $\cos\vartheta_C = 1/(\beta n)$
  - n=2.64 at 340µm
  - $\vartheta_C = 68°$ (assuming β=1);
- Chromatic dispersion $\delta\theta \sim 4°$

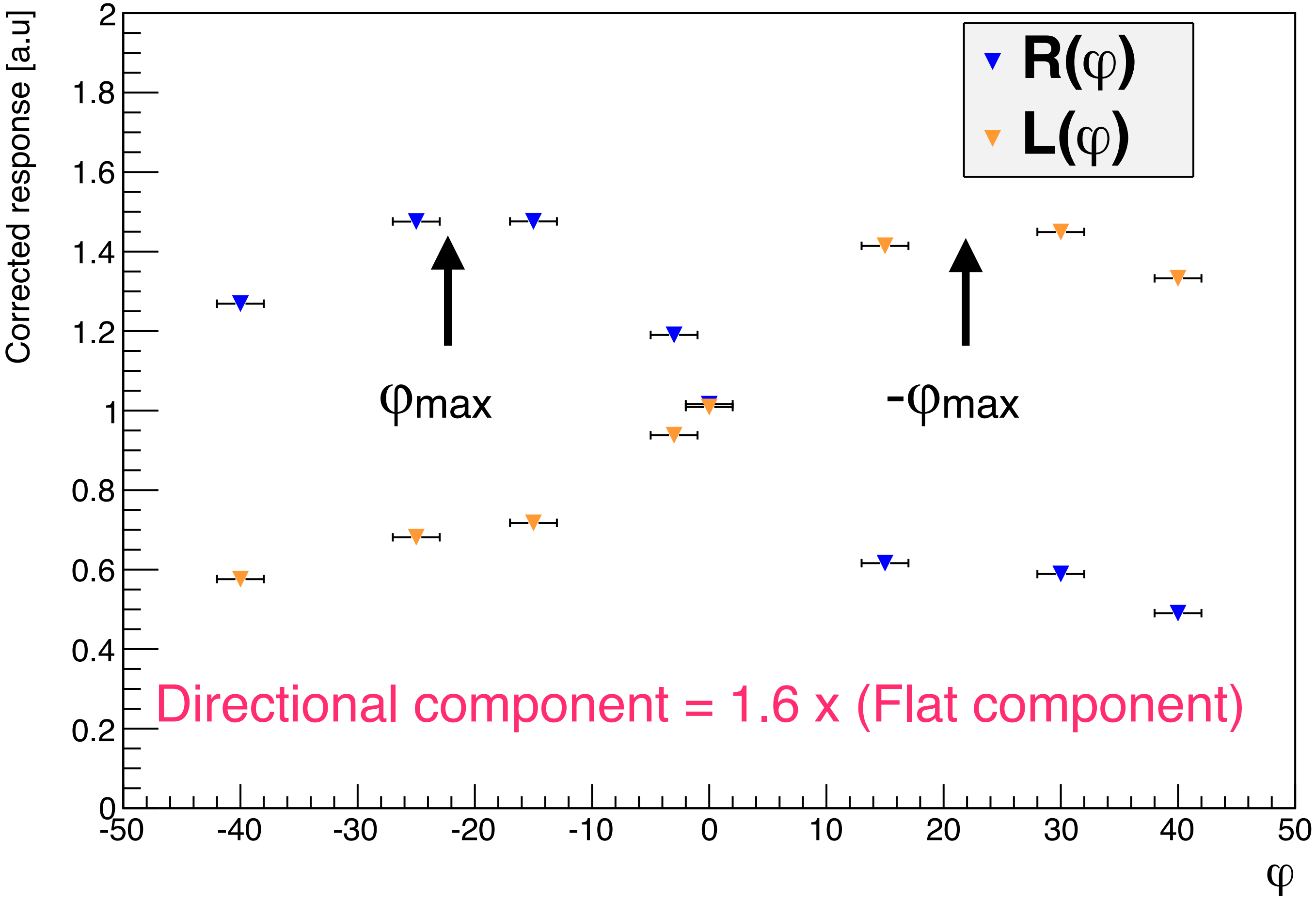
$$\bar{L}(\varphi) = \frac{\alpha}{\cos\varphi}(A_L + B_L(\varphi))$$

$$\bar{R}(\varphi) = \frac{\beta}{\cos\varphi}(A_R + B_R(\varphi))$$

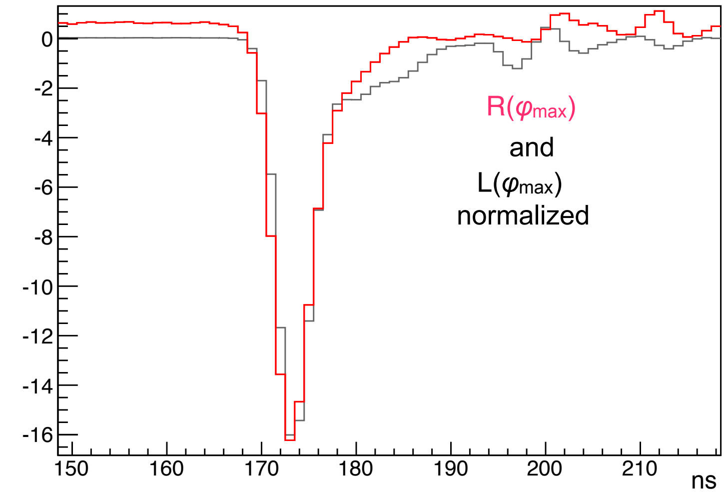
***A*: dependent from the angle:** Directional Cherenkov light.

***B*: independent from the angle.** Could be scintillation or Cherenkov light diffused.

Light direction and shape



Directional and flat component shapes are identical:



- Next steps:
  - Study the wavelength spectrum.
  - Study light collection with different reflector configurations.

Requirement:

Signal/Noise $\gtrsim$ 5

Light detectors

- S/N>5: if Signal ~100 eV ⟶ Noise ~ 20 eV σ
- Noise of Ge bolometers: 75-150 eV σ
  - Poor reproducibility: detectors used so far (70-80 eV σ) were selected among a large sample.
  - Noise dominated by detector vibrations which induce temperature variations.
  - Several attempts to lower the noise failed.

Possible alternatives

- Ge bolometers with Luke Effect: polarization of the Ge disk with electric field.
  - Electron-hole pairs produced in interactions are boosted, inducing a higher phonon signal. Thermal noise does not see the electric field.
  - Technique under investigation at Orsay and at LNGS.
- Transition Edge Sensors (TES): superconducting phonon sensors.
  - Sensitive to athermal phonons, insensitive to vibrations.
  - Technique proved in CRESST, but low reproducibility.
- Kinetic Inductance Detectors (KID): superconducting phonon sensors below the transition phase.
  - High reproducibility, but technique to be proved.

Working group

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Conclusions

- The detection of the Cherenkov light in TeO_2 bolometers could improve the CUORE performances by a factor 3-6.
  - Combined with 90% ^{130}Te enrichment, CUORE could cover the inverted hierarchy of neutrino masses.
- We detected the light, but we are still far from the required performances: light detector Signal/Noise > 5. At present:
  - Signal ~ 100 eV
  - Noise ~ 75 eV
- Studies to increase the Signal by increasing the light collection are being pursued.
- New low-noise light detectors are being considered.