

# The Čerenkov effect in TeO<sub>2</sub> bolometers

Nicola Casali

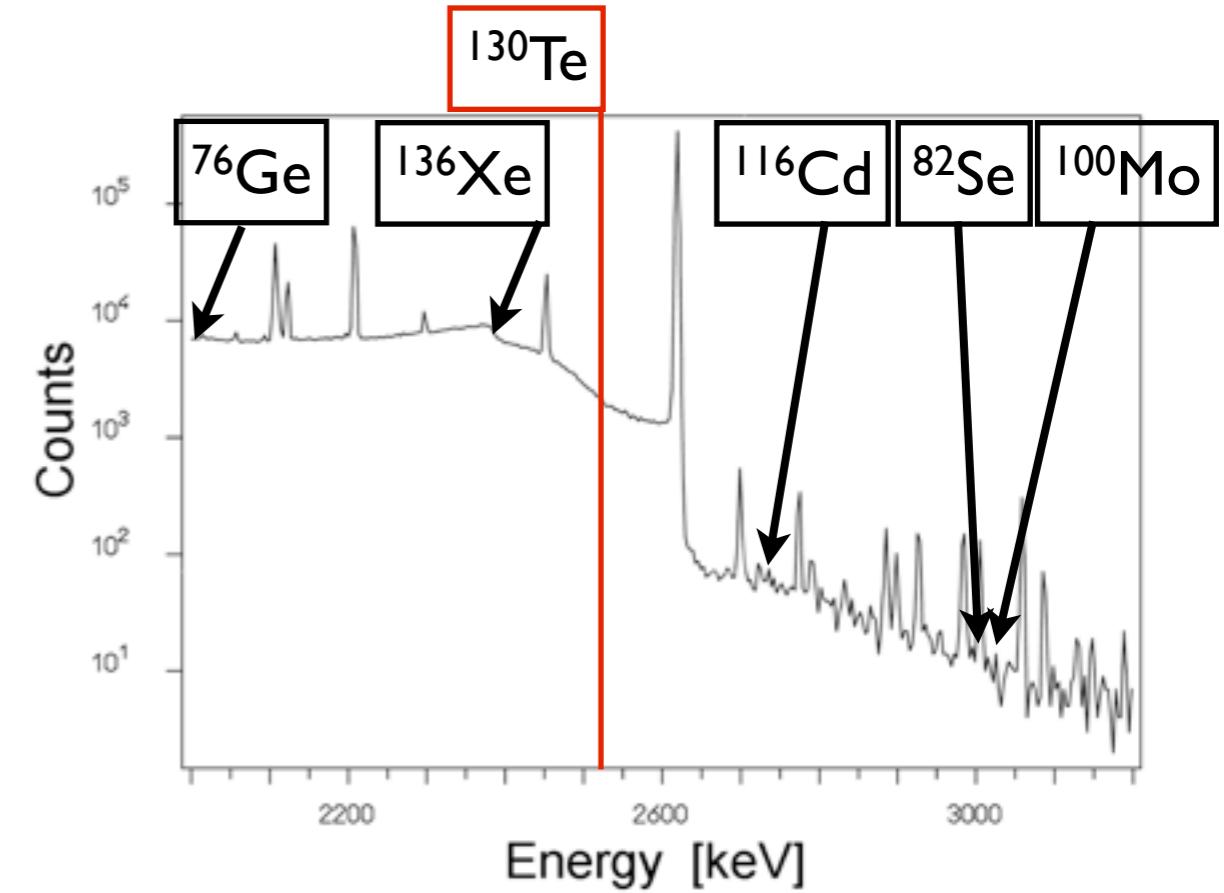
Third general meeting of the ISOTTA project  
18/12/2013

# Double beta decay with Tellurium

The sensitivity to the half-life of the neutrinoless double beta decay goes as:

$$S^{0\nu} \propto \frac{\text{I.A.}}{\text{bkg.}} \cdot \sqrt{\frac{\text{Mass} \cdot \text{livetime}}{\Delta E}}$$

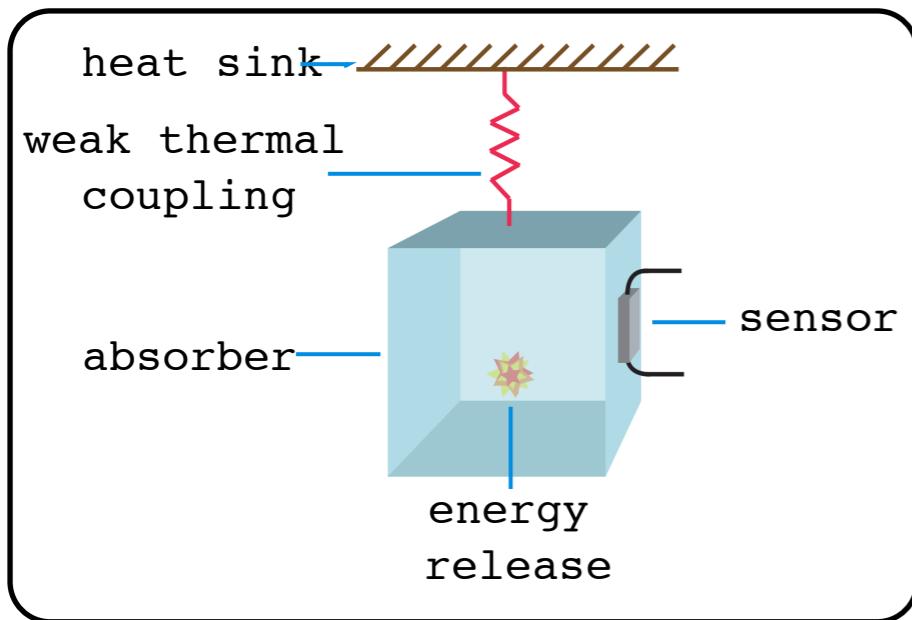
$\beta\beta$ Decay Reaction	Isotopic Abundance [atomic %]	Q-value [keV]
$^{48}\text{Ca} \rightarrow ^{48}\text{Ti}$	0.2	4274
$^{76}\text{Ge} \rightarrow ^{76}\text{Se}$	7.6	2039
$^{82}\text{Se} \rightarrow ^{82}\text{Kr}$	8.7	2996
$^{96}\text{Zr} \rightarrow ^{96}\text{Mo}$	2.8	3348
$^{100}\text{Mo} \rightarrow ^{100}\text{Ru}$	9.6	3034
$^{116}\text{Cd} \rightarrow ^{116}\text{Sn}$	7.5	2814
$^{124}\text{Sn} \rightarrow ^{124}\text{Te}$	5.8	2288
$^{128}\text{Te} \rightarrow ^{128}\text{Xe}$	31.8	866
$^{130}\text{Te} \rightarrow ^{130}\text{Xe}$	34.2	2528
$^{136}\text{Xe} \rightarrow ^{136}\text{Ba}$	8.9	2458
$^{150}\text{Nd} \rightarrow ^{150}\text{Sm}$	5.6	3368



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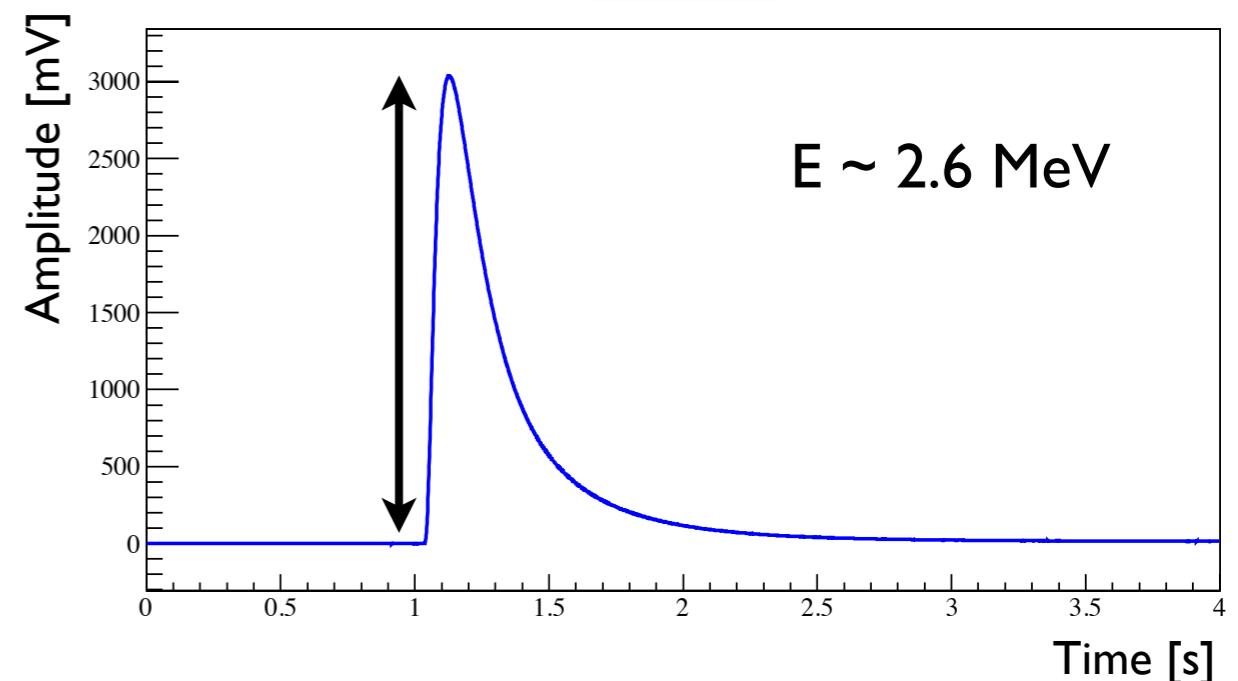
High energy resolution:  
5 keV FWHM @ 2.6 MeV

High scalability:  
possibility to assemble very large  
mass detector 100-1000 kg

Heat sink  $\Rightarrow \sim 10 \text{ mK}$

Absorber  $\Rightarrow \text{TeO}_2 \text{ crystal}$

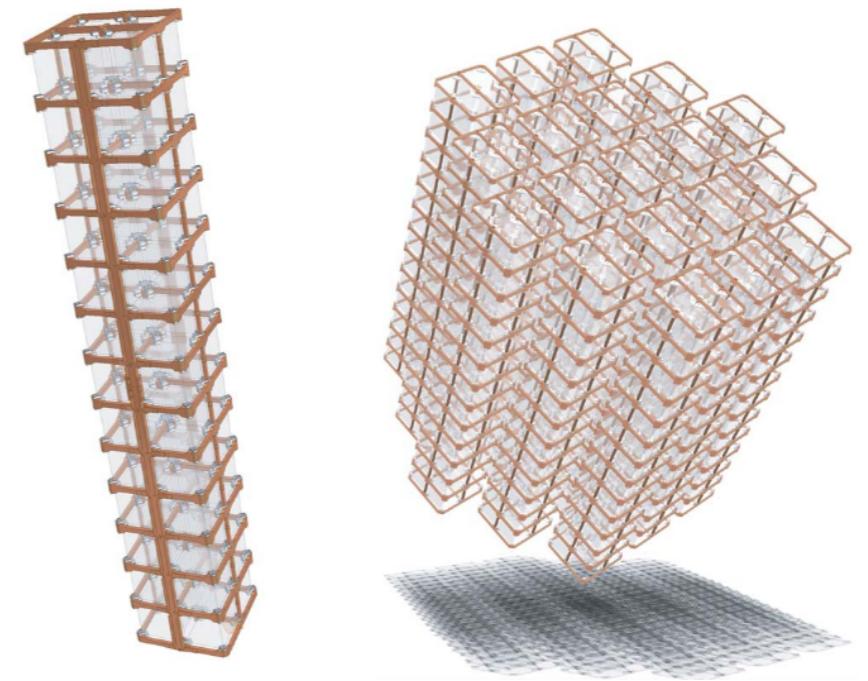
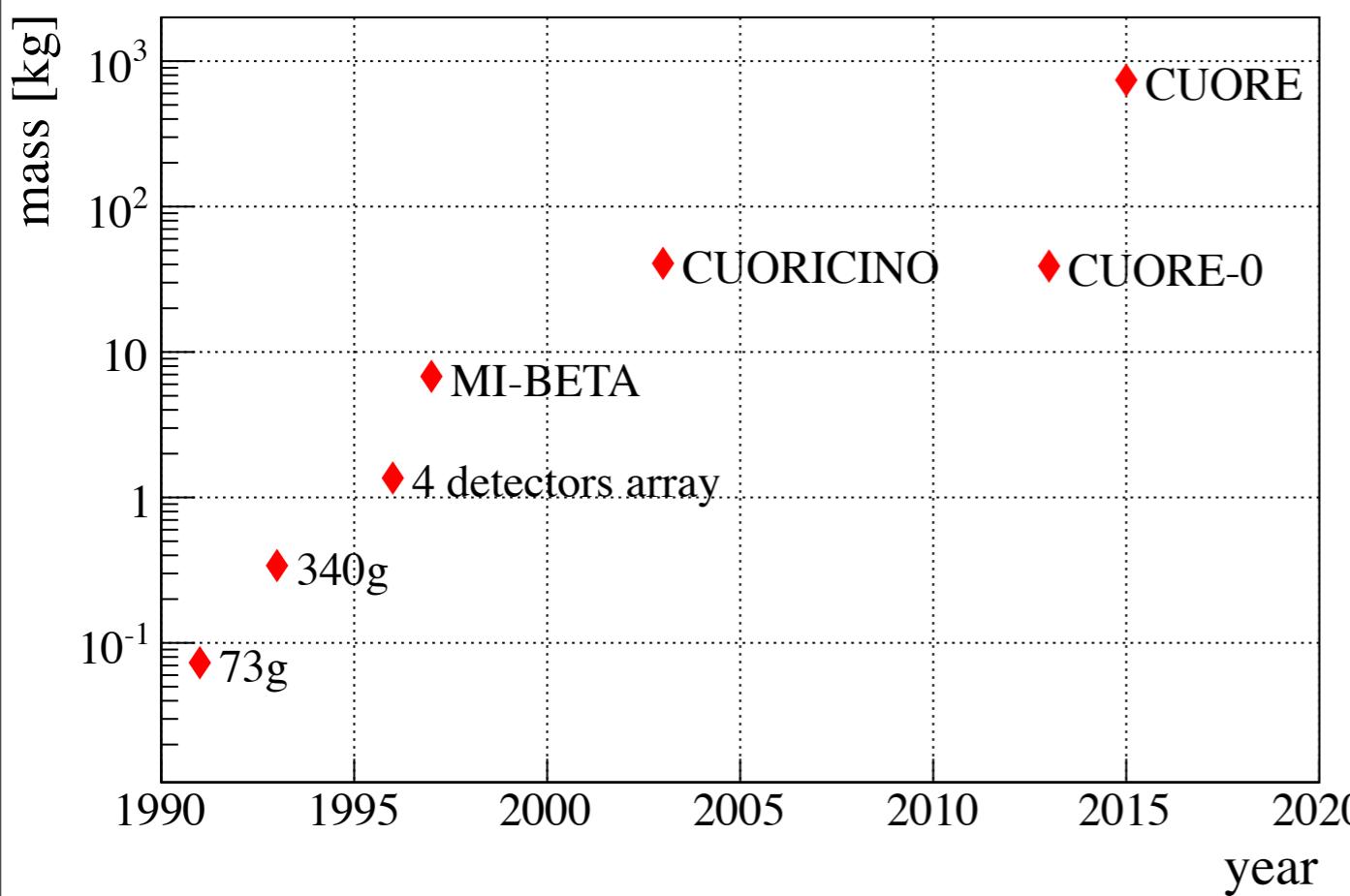
Sensor  $\Rightarrow \text{NTD-Ge thermistor with } R \sim 50 \text{ M}\Omega$



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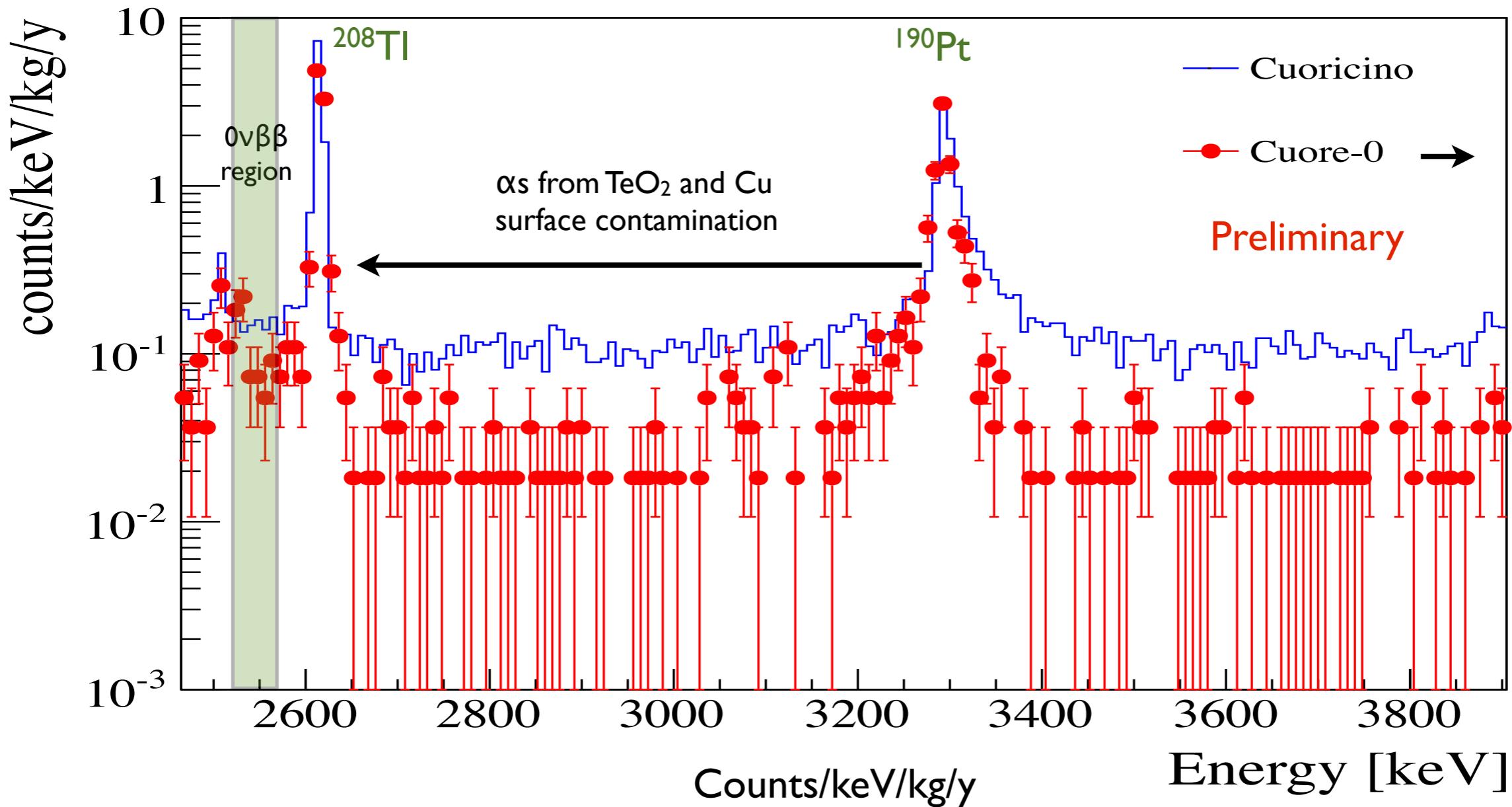


CUORE

988 bolometers 5x5x5 cm of TeO<sub>2</sub>

19 towers

# Continuous $\alpha$ background



	flat background $0\nu\beta\beta$	flat background 2.7-3.9 MeV	Efficiency
CUORICINO	$0.153 \pm 0.006$	$0.110 \pm 0.001$	$83 \pm 1$
CUORE-0	$0.074 \pm 0.012$	$0.019 \pm 0.002$	$78 \pm 1$

The cleaning procedure could not remove completely the surface contaminations

# $\alpha$ background rejection

Detection of the Čerenkov radiation

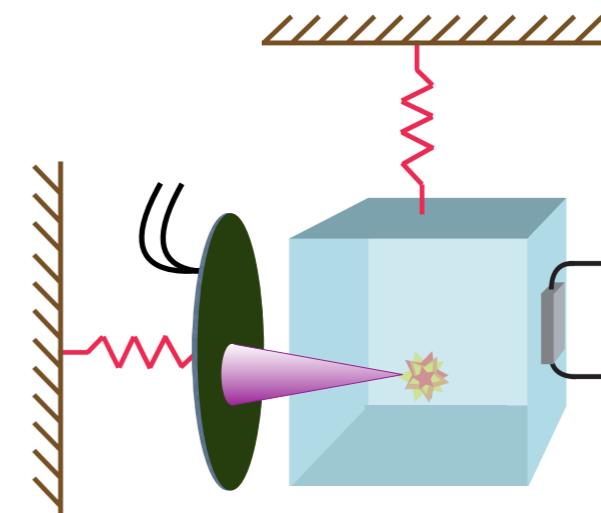
$$\beta n > 1 \quad \beta > \frac{1}{n} \approx 0.416$$

Čerenkov threshold	@ 2.5 MeV	Čerenkov energy
$E_{e^-} > 54 \text{ keV}$	Yes Čerenkov	~900 eV
$E_\alpha > 400 \text{ MeV}$	No Čerenkov	

Using a light detector is possible to detect the Čerenkov radiation and disentangle signal from background ([T. Tabarelli de Fatis, Eur. Phys. J. C 65 359, 2010](#)):

the light detector must work fine @ 10 mK, and not interfere with the bolometer

also the LD is a bolometer



# Čerenkov detectors

We performed various measurements using different geometrical configurations and reflective foils

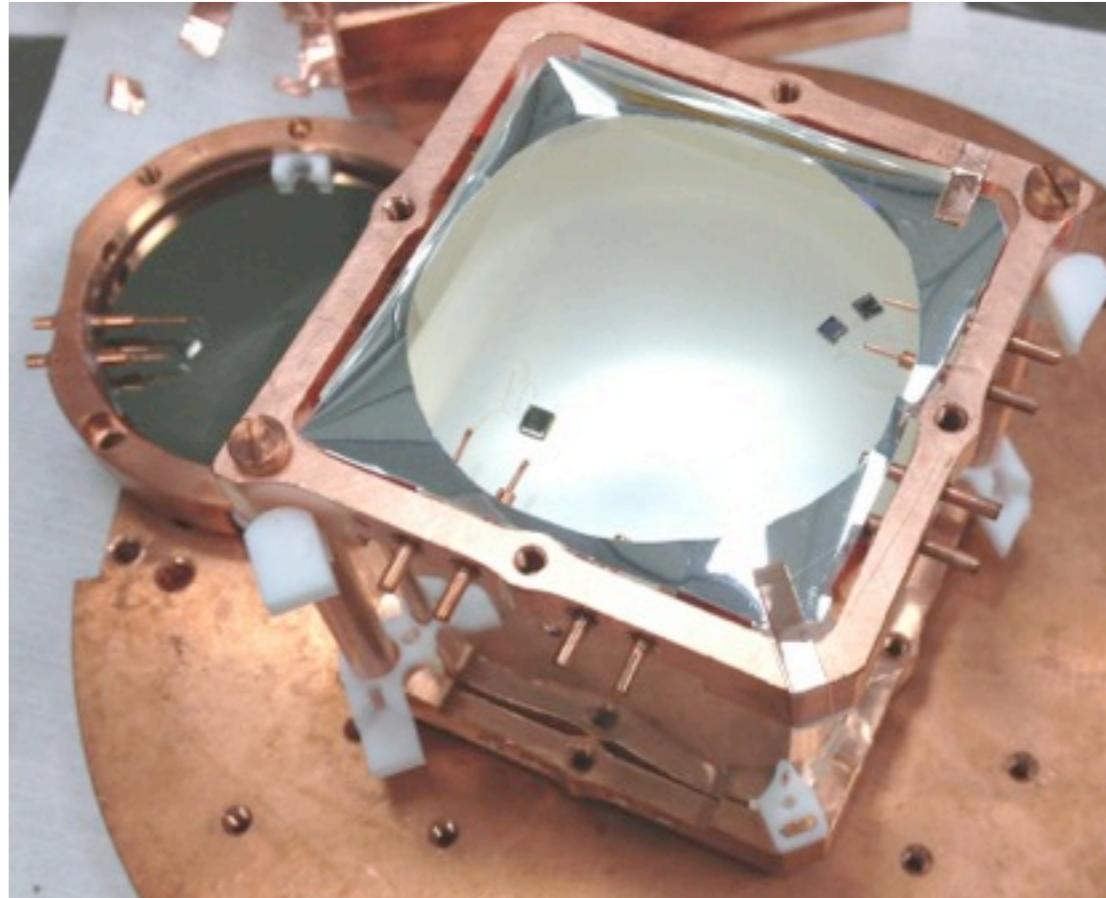
In this presentation I will show in detail the last one

TeO <sub>2</sub> crystal	Reflector	LD	Light detected [eV/MeV]	Light detected @ 2527 keV [eV]
750 g	PTFE 4 faces	Ge	25±3	52
750 g	PTFE	Ge	48±3	105
750 g	VM2002	Ge	43±2	97
750 g	VM2002 FULL	Ge	44±3	98

# The detector

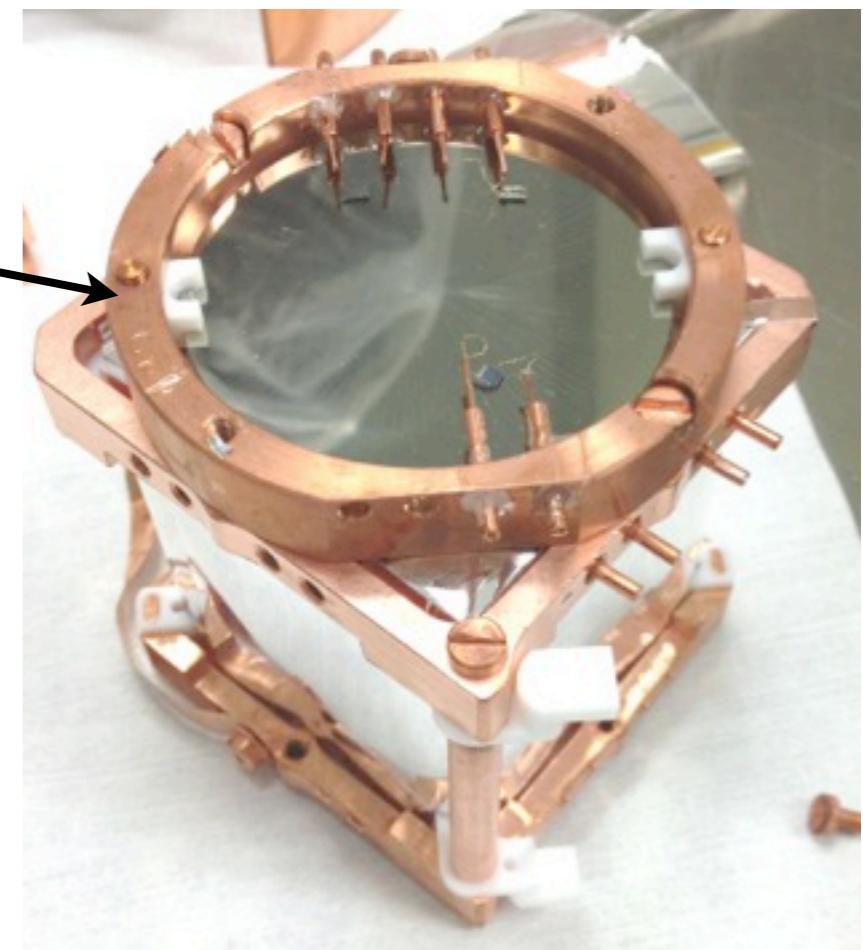
TeO<sub>2</sub> bolometer 5x5x5 cm,  
covered with VM2002  
reflective foil

Germanium bolometer  
(diameter 50 mm, thickness  
300 µm) working as light  
detector faced to the TeO<sub>2</sub>



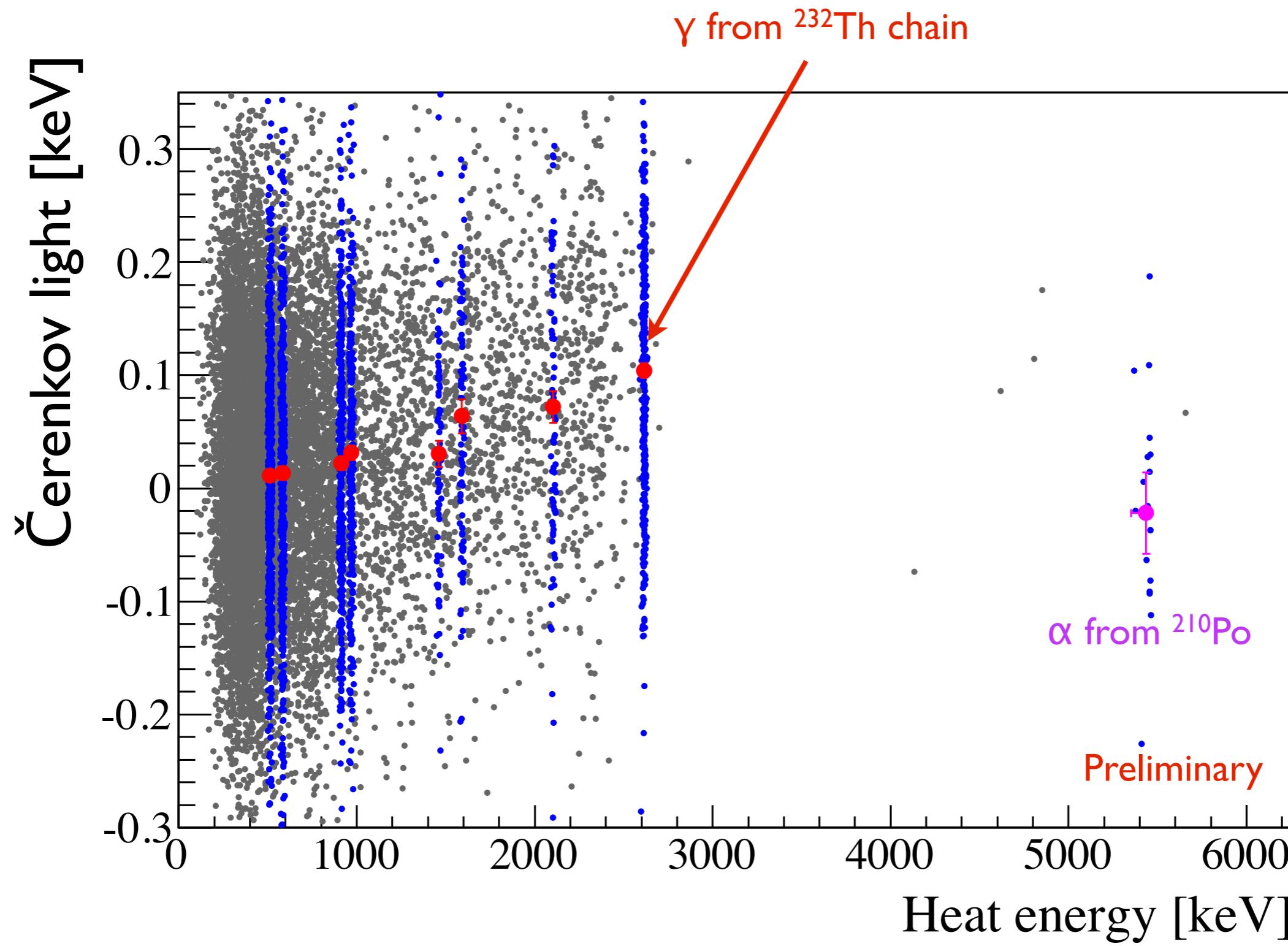
In the Hall C of the  
Laboratori Nazionali  
del Gran Sasso

8

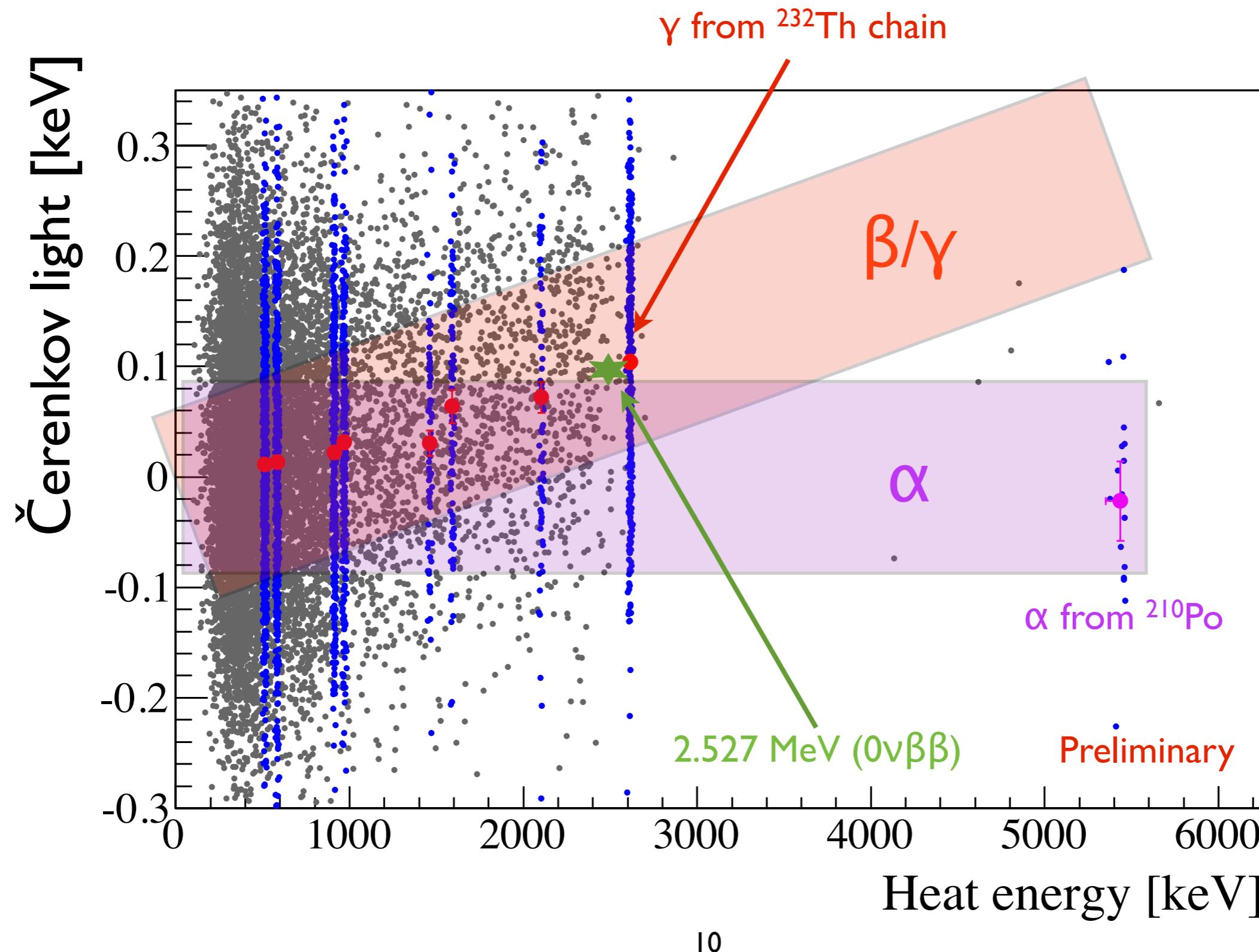


The germanium light  
detector was  
developed by the  
LUCIFER collaboration

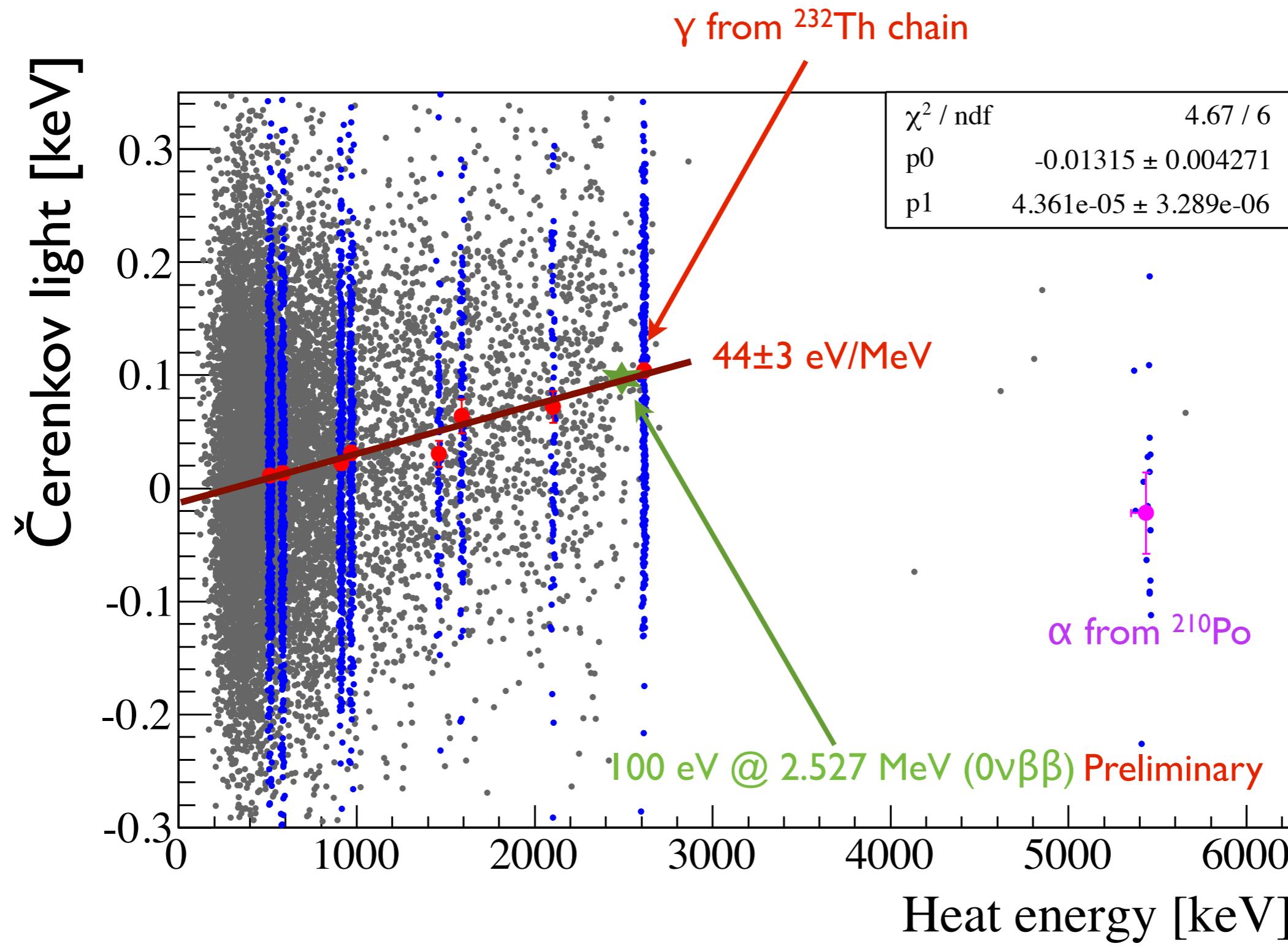
# Data results



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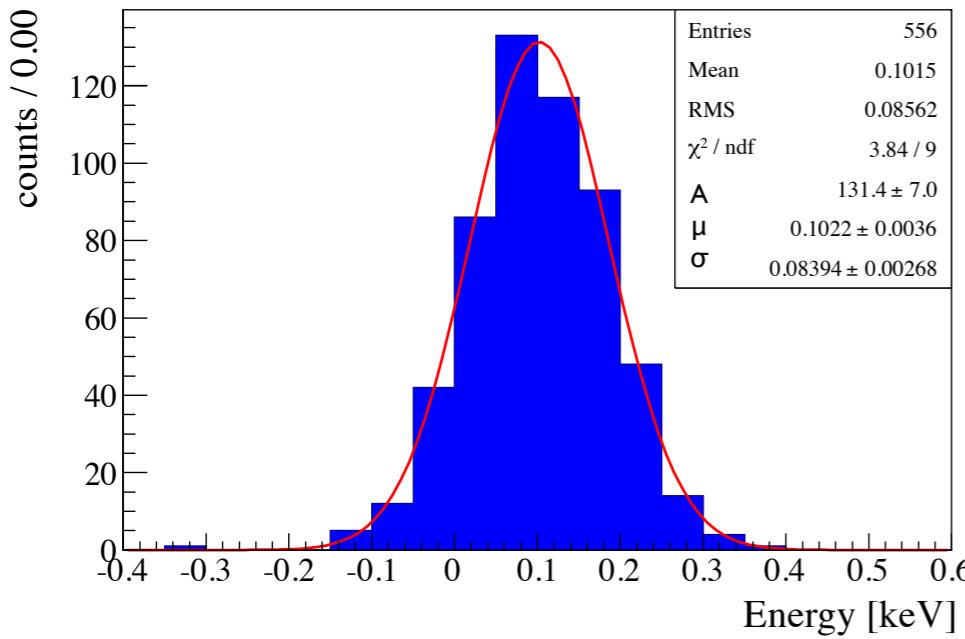


# Data results

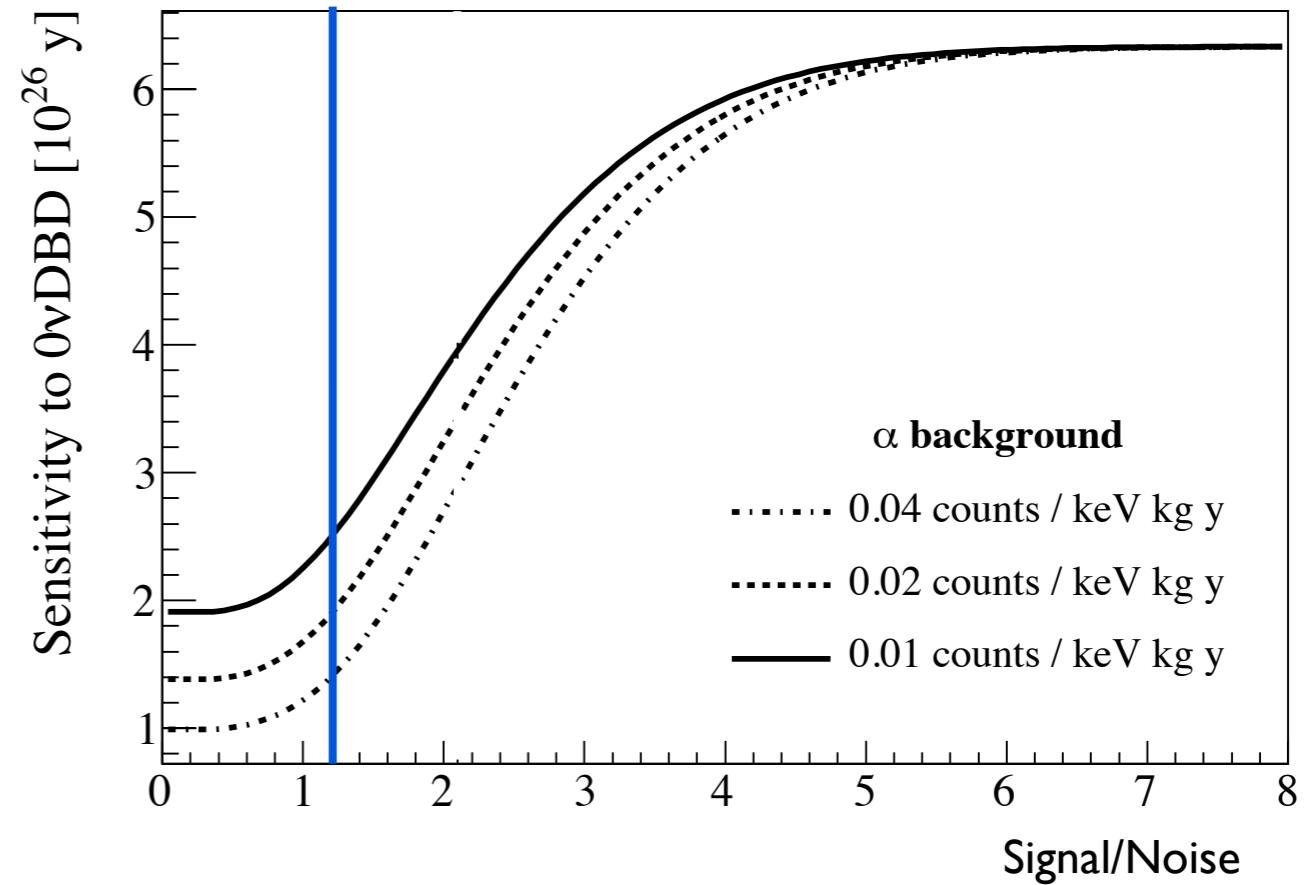
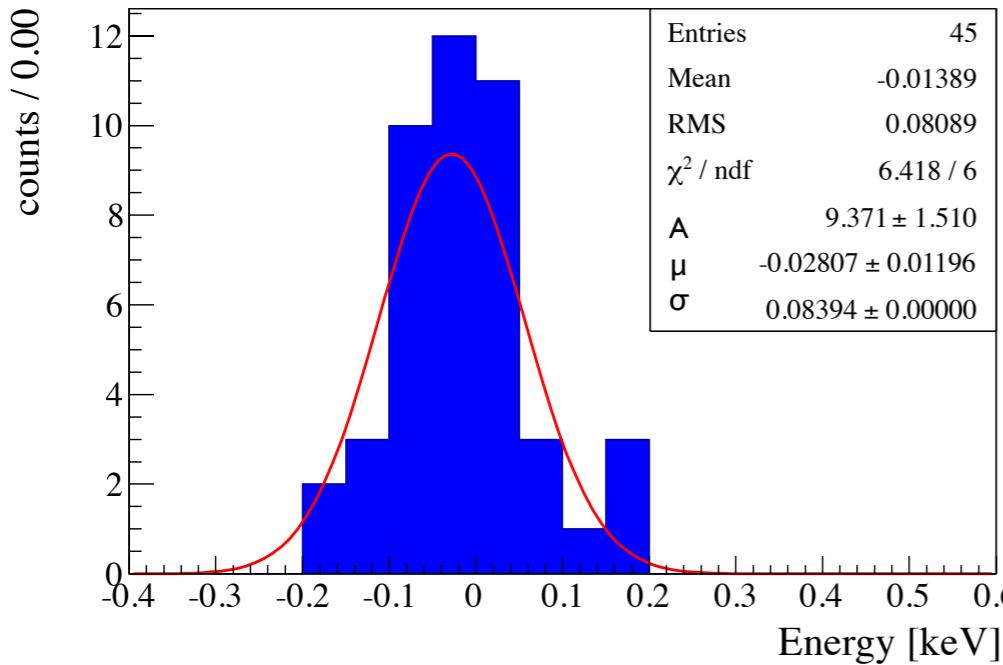


# The discrimination power

$^{208}\text{TI}$   $\gamma$  2615 keV



$^{210}\text{Po}$   $\alpha$  5400 keV



$$\frac{S}{N} = \frac{98 \text{ eV}}{84 \text{ eV}} = 1.2$$

The signal to noise ratio is too low to achieve a discrimination between signal and background

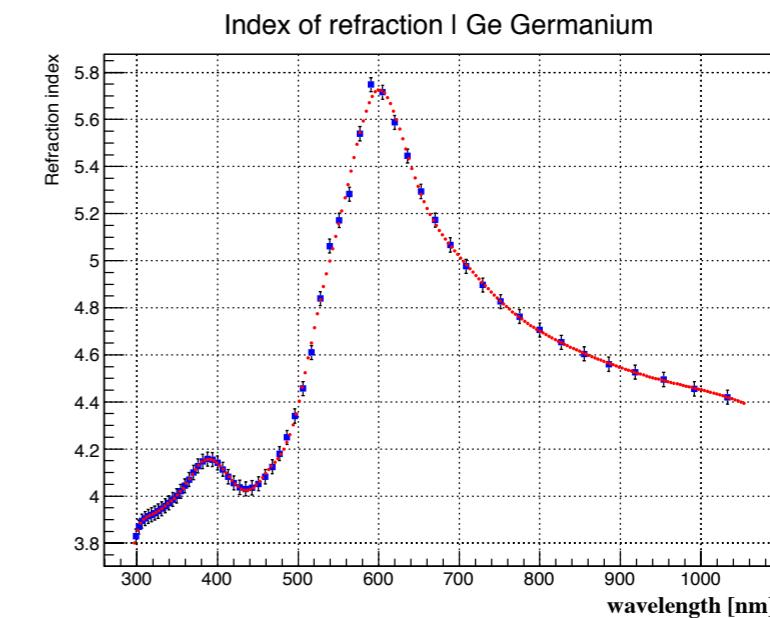
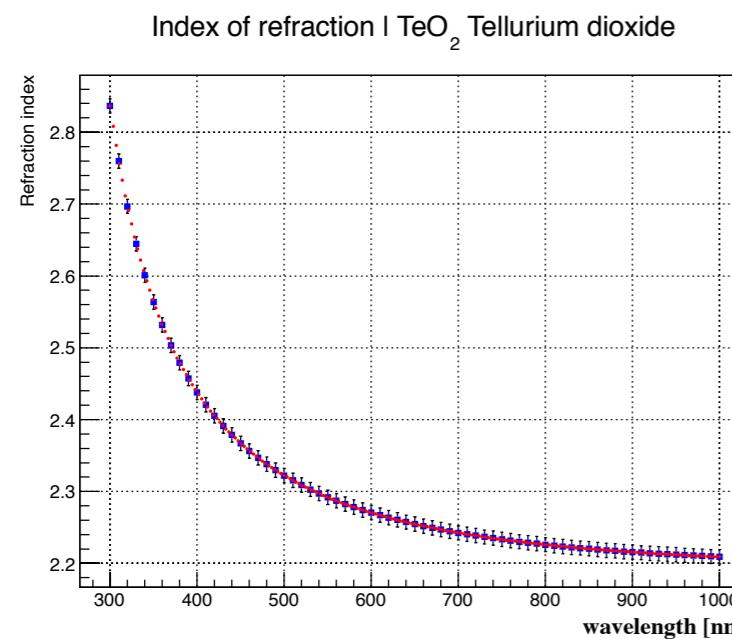
# Simulation: LITRANI

Why only 100 eV compared to the 900 eV expected?

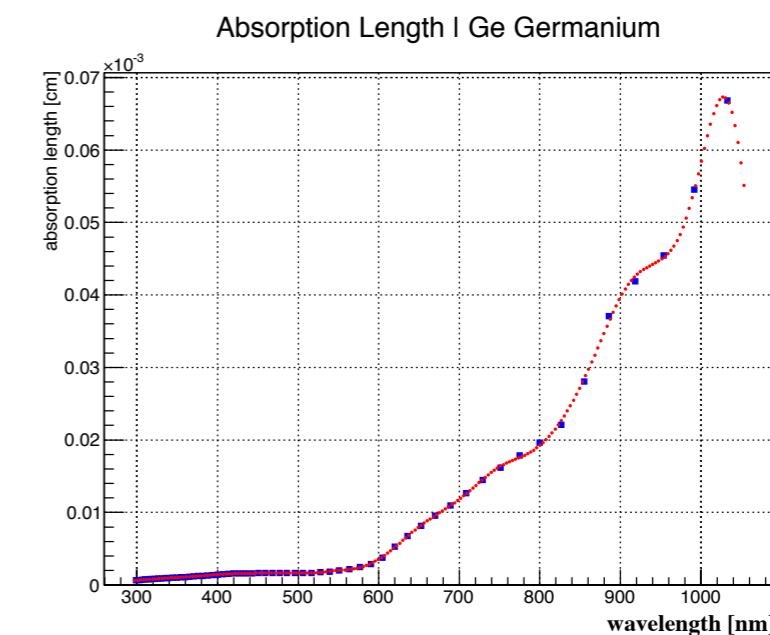
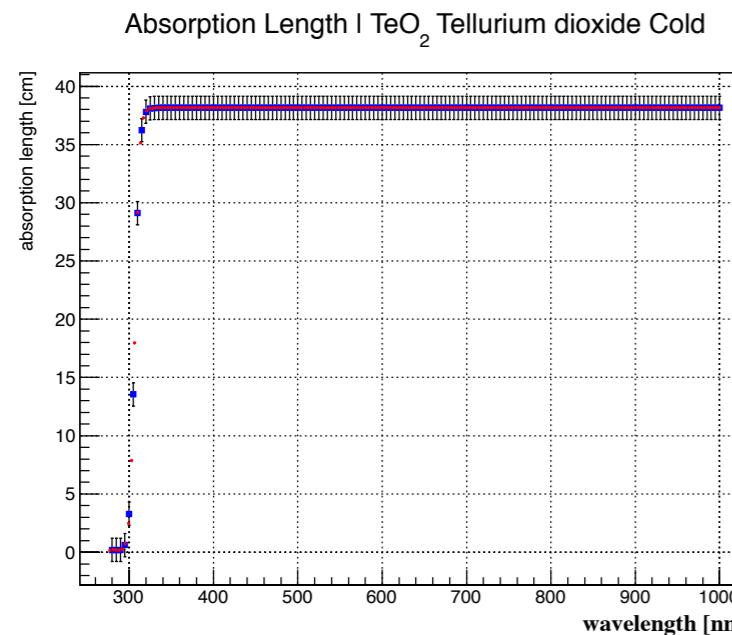
We performed a Monte Carlo simulation of the Čerenkov effect inside the experimental setup using the LITRANI software



All the optical properties of the materials must be known



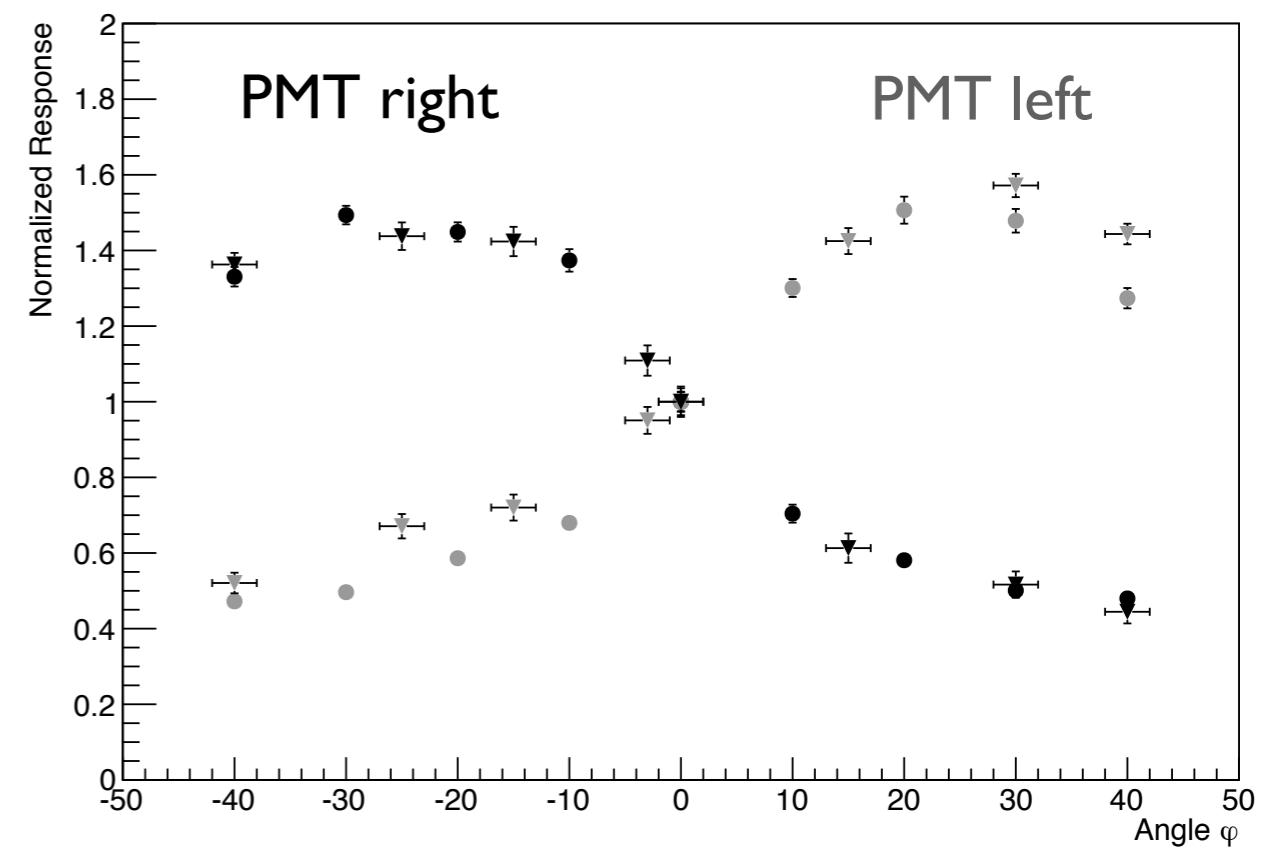
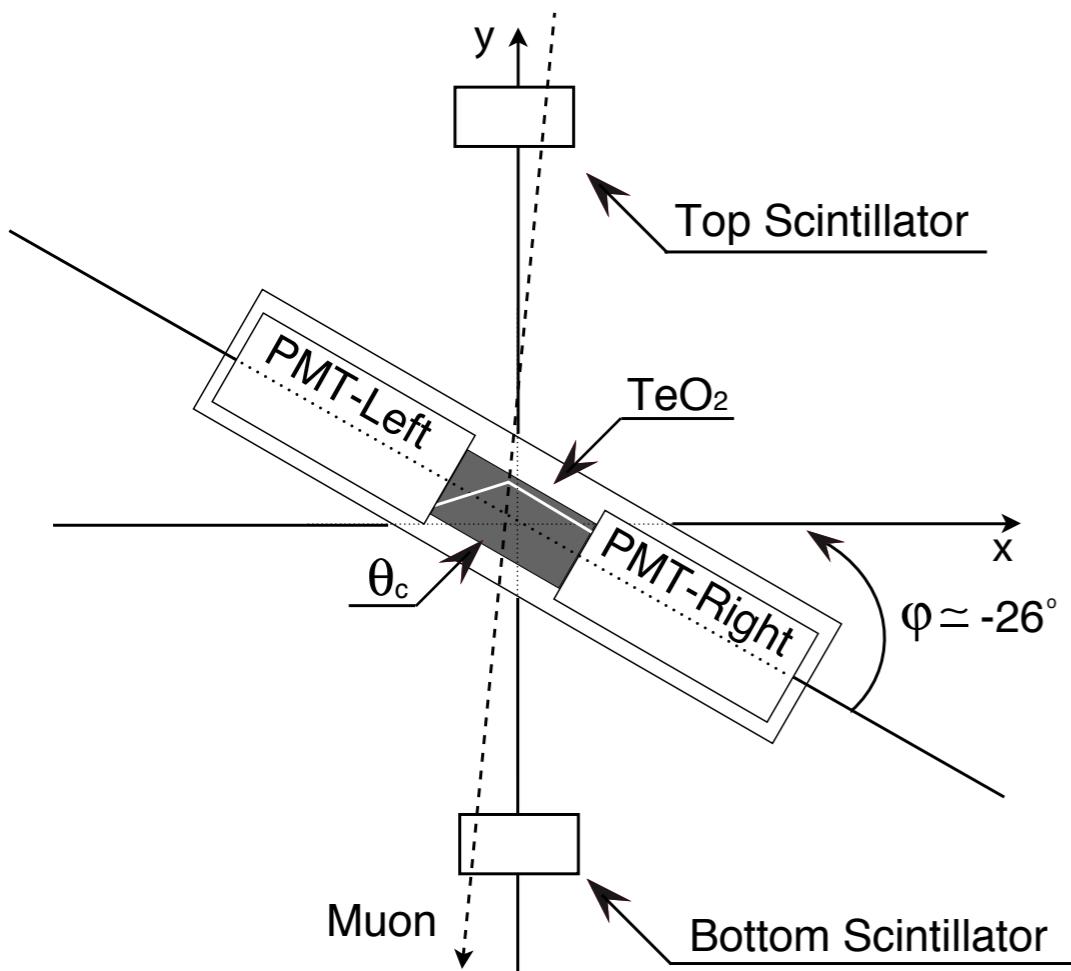
Refractive index



Absorption length

# Simulation: LITRANI

This Monte Carlo was tested with a room temperature measurement:  
The Čerenkov radiation emitted by  $\text{TeO}_2$  crystal when crossed by cosmic muons



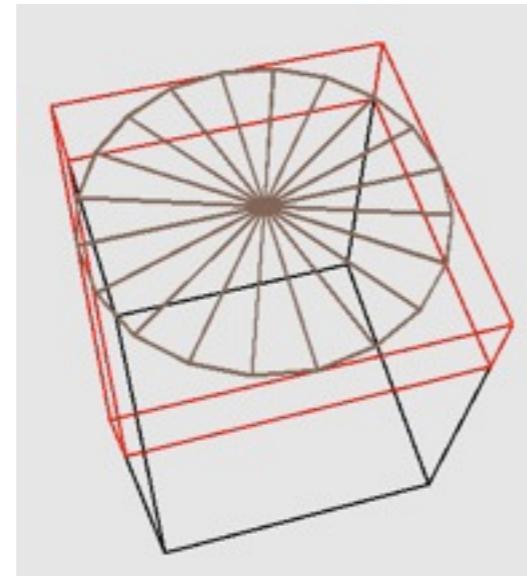
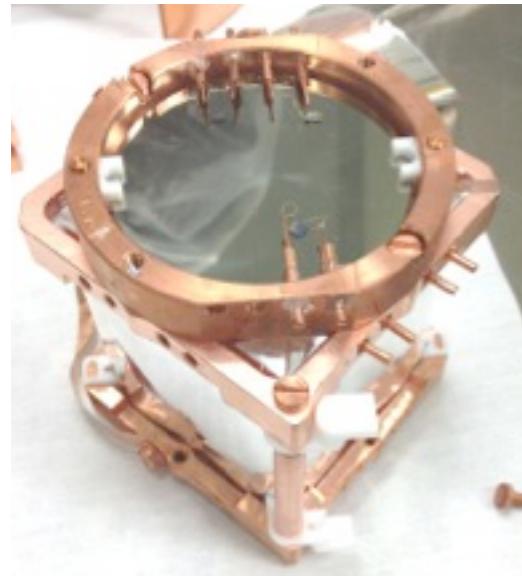
The simulation (●) well reproduce the data (▼)

N. Casali et al, NIMA55904 DOI: [10.1016/j.nima.2013.07.024](https://doi.org/10.1016/j.nima.2013.07.024)

F. Bellini et al, JINST 7 (2012) P11014 DOI: [10.1088/1748-0221/7/11/P11014](https://doi.org/10.1088/1748-0221/7/11/P11014)

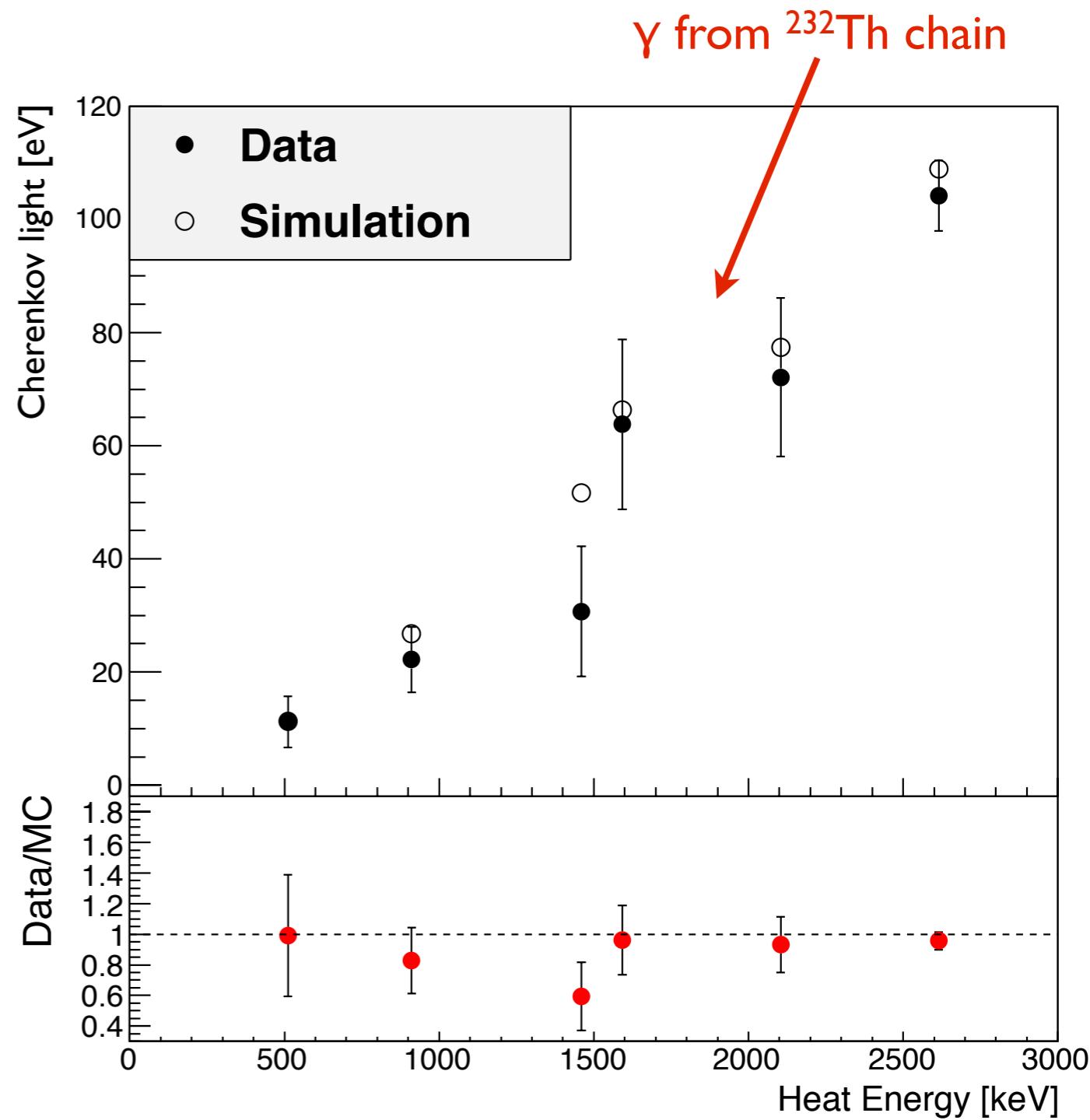
# Simulation: LITRANI

We reproduced the set-up in LITRANI:  
TeO<sub>2</sub> crystal + Reflective foil + Germanium  
and evaluate the average energy produced  
by the Čerenkov photons in  $\gamma$  interactions  
(emitted by <sup>232</sup>Th chain)



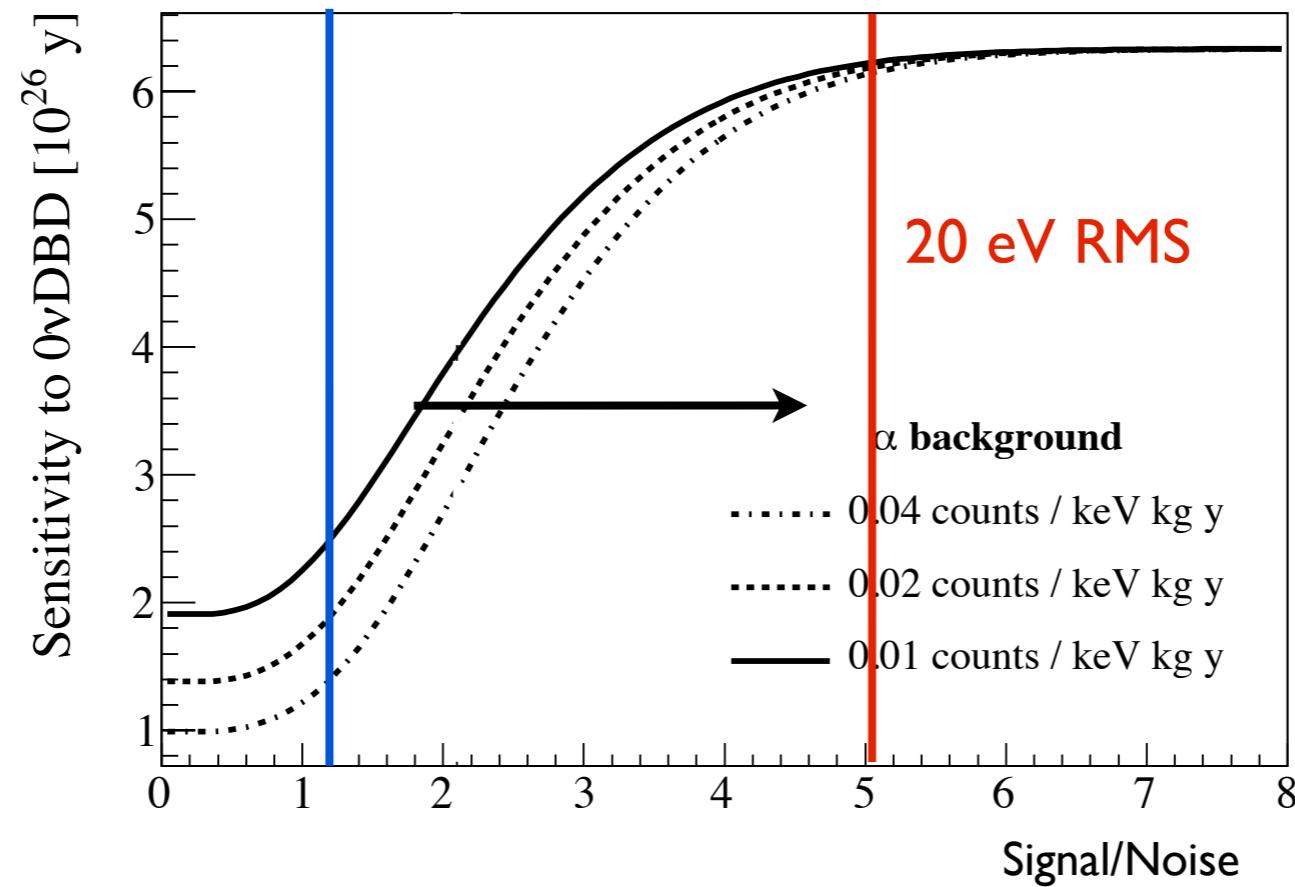
About the 85 % of Čerenkov photons are absorbed inside the the crystal

Only 15 % reach the germanium light detector



# Conclusions

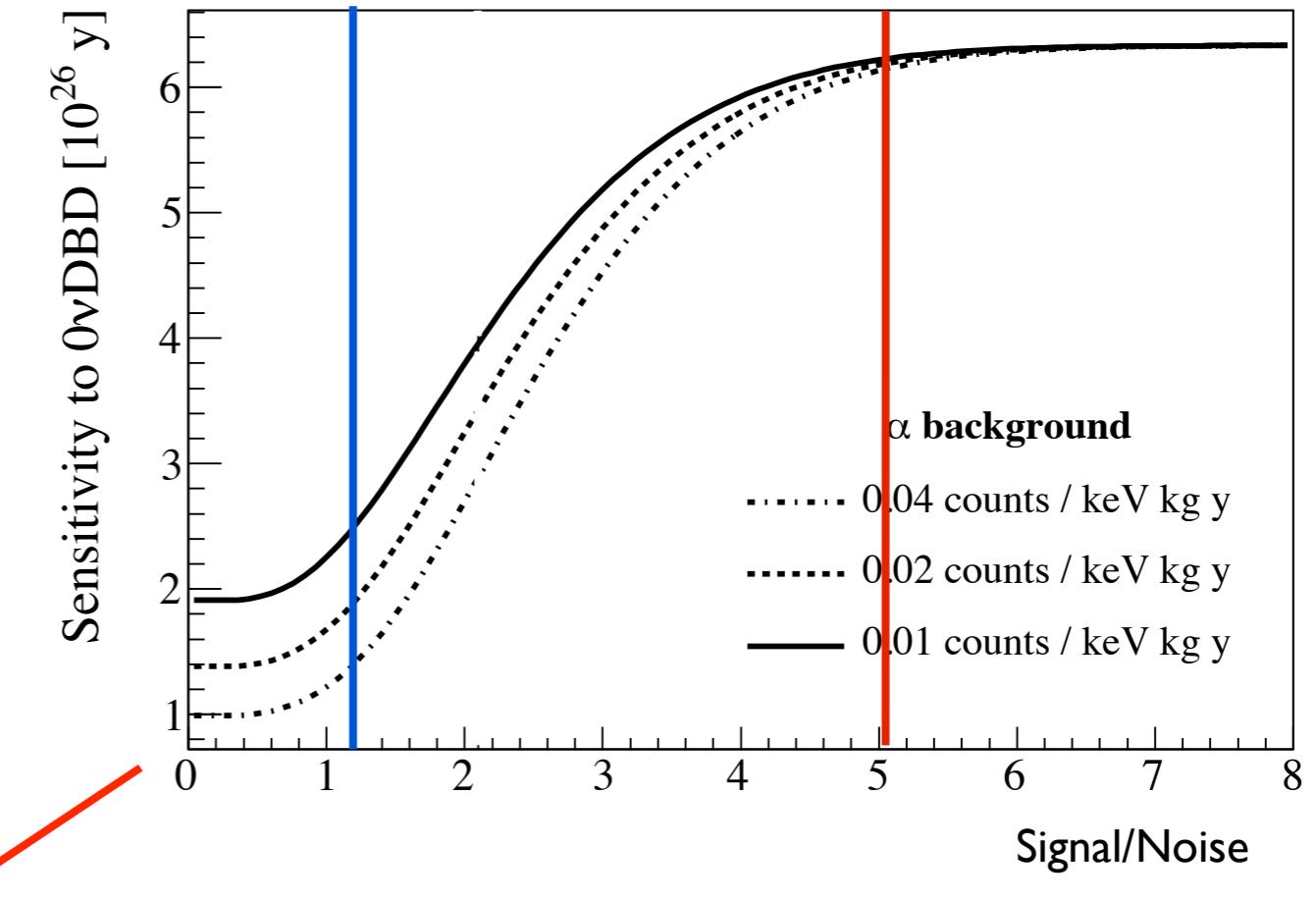
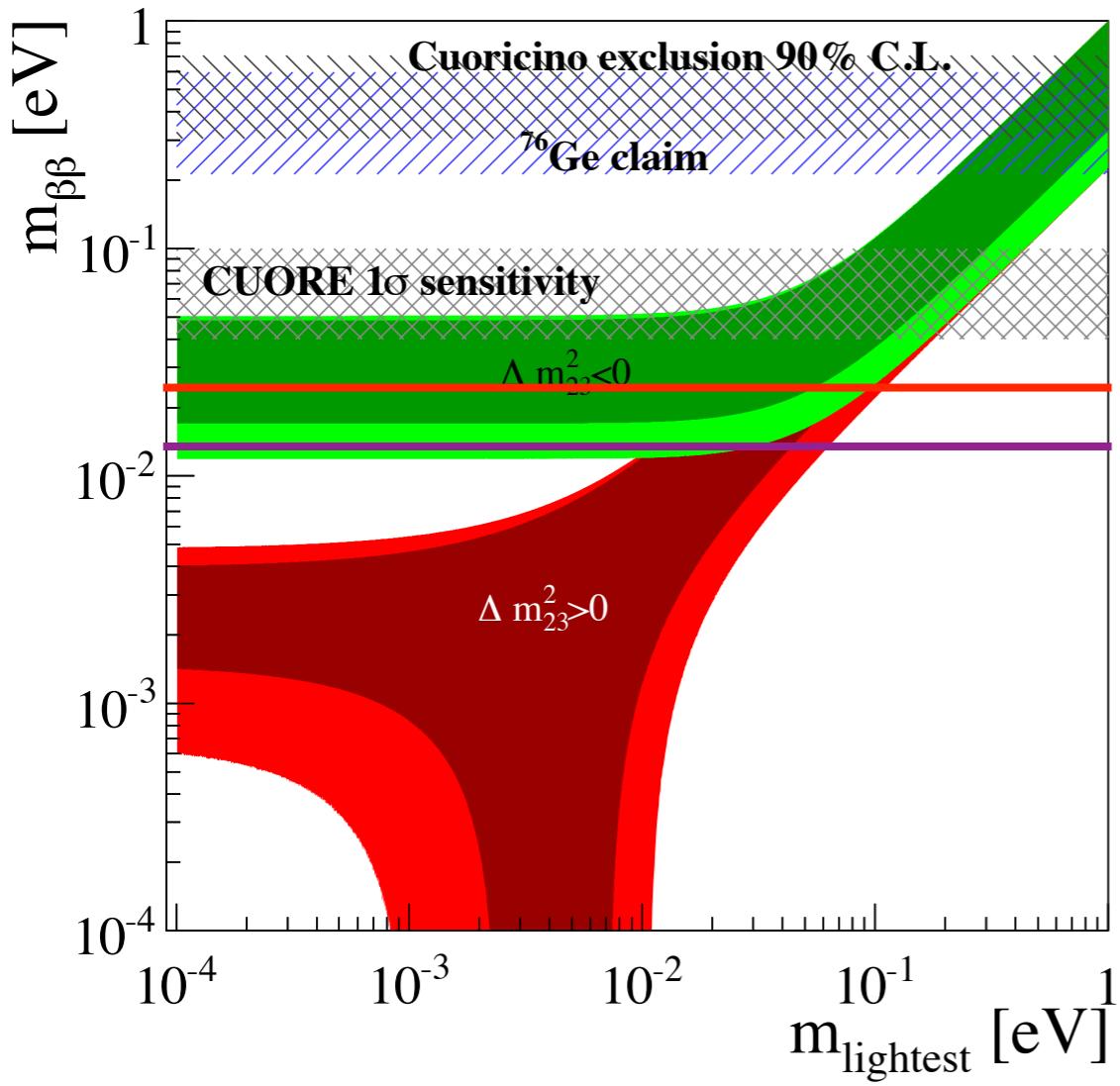
- Detecting the Čerenkov radiation is possible to disentangle  $\alpha$  from  $\beta/\gamma$  particles in  $\text{TeO}_2$  bolometer.
- The signal to noise ratio is too low to achieve an  $\alpha$  background rejection.
- The Monte Carlo simulation well reproduces the experimental data; proves also that to increase the signal to noise ratio we can only improve the baseline RMS of the light detectors.



BACKUP

# An inverted hierarchy explorer

$$S(T) = S^{CUORE} \epsilon_{\beta\gamma} \sqrt{\frac{B_\alpha + B_{\beta\gamma}}{\epsilon_\alpha B_\alpha + \epsilon_{\beta\gamma} B_{\beta\gamma}}}$$



95%  ${}^{130}\text{Te} \rightarrow T_{1/2}^{0\nu} \sim 15 \times 10^{26}$  years

$$\left[ T_{1/2}^{0\nu} \right]^{-1} = G_{0\nu} |M_{0\nu}|^2 \langle m_{\beta\beta} \rangle^2$$