The future of $0\nu\beta\beta$

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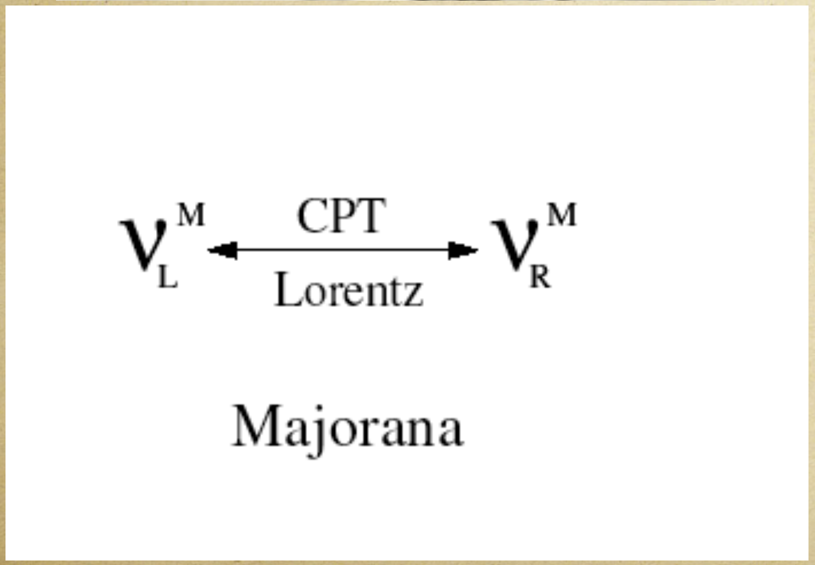
Majorana conjecture

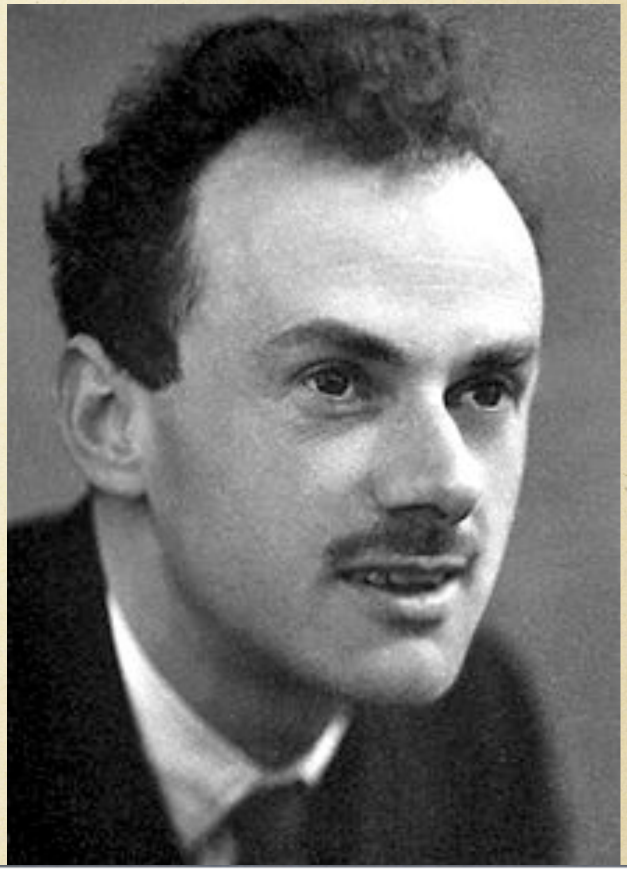
$$\nu = \bar{\nu}$$

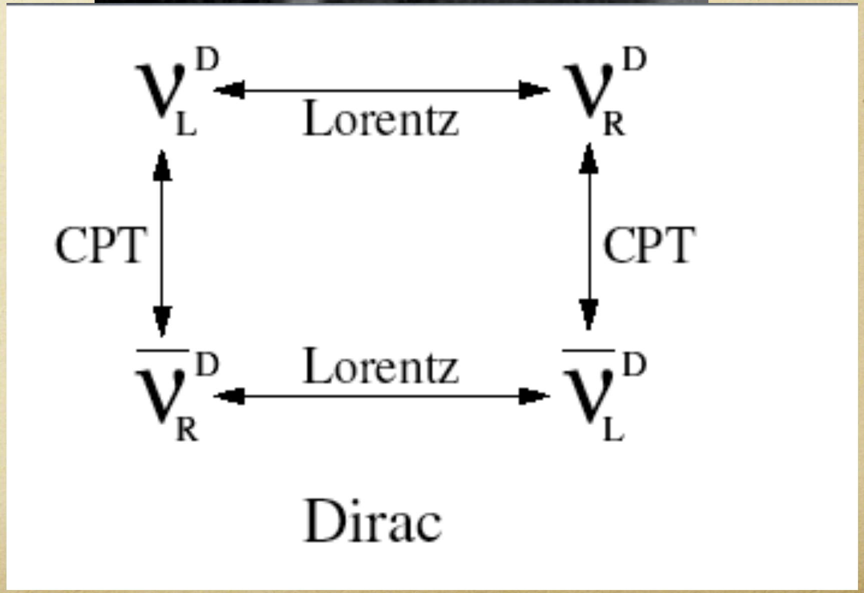
Main consequence :

Lepton Number Violation

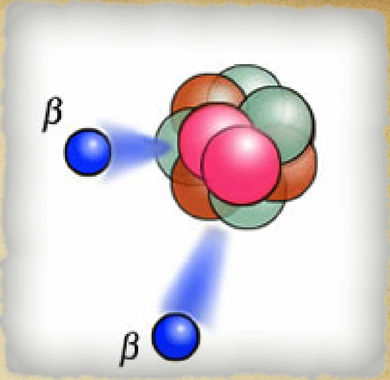
Majorana vs. Dirac

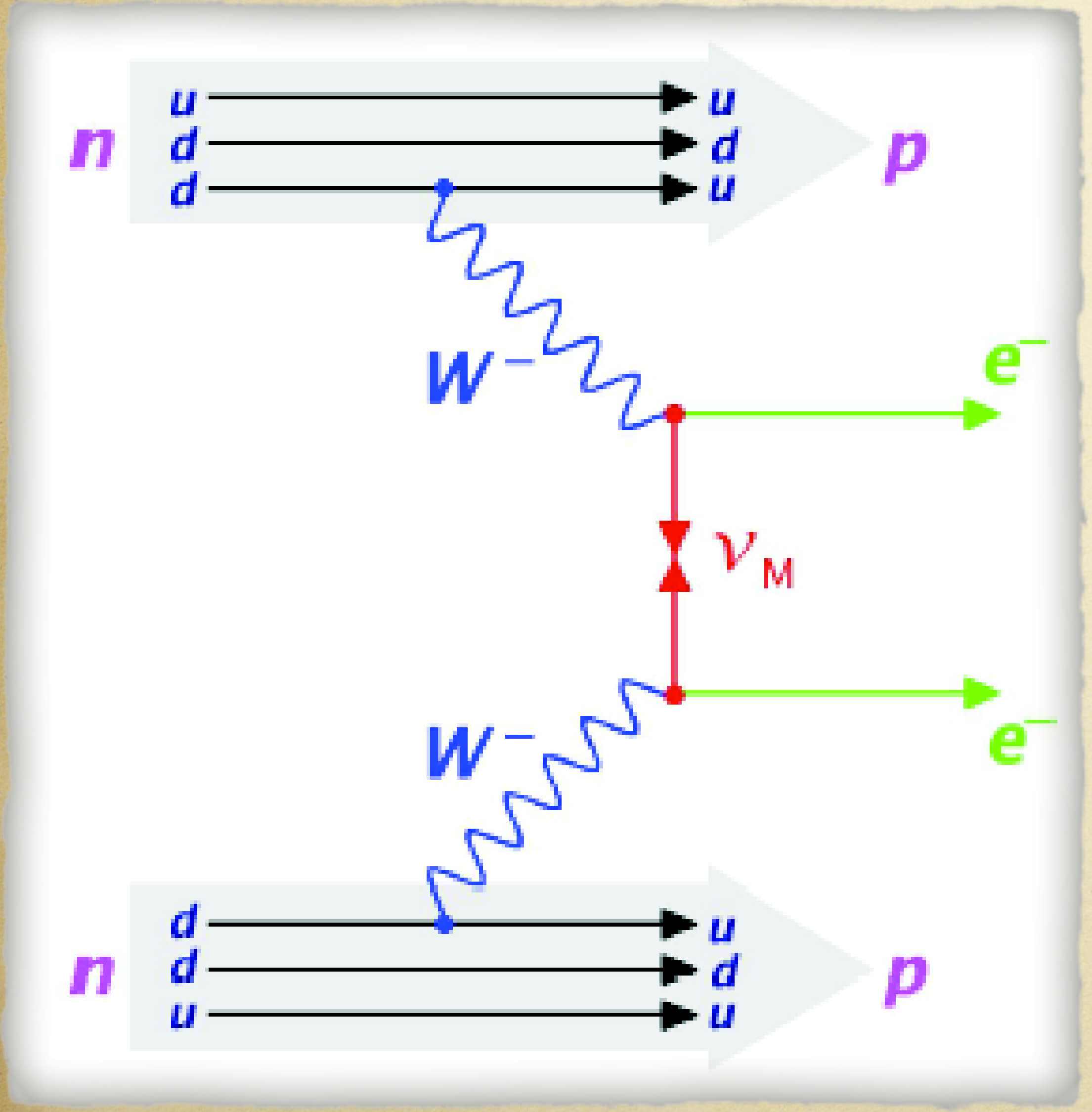






Neutrino-less DBD (0νββ)





Only if:

Majorana Neutrinos

If observed:

Proof of the Majorana nature of Neutrino

how patients should we be ?

parameter containing
the **physics**

$$1/\tau = G(Q,Z)\,|M_{nucl}|^2 \langle M_{\beta\beta} \rangle^2$$

what the **experimentalists**
try to measure

what the **nuclear theorists**
try to calculate

just on the back of the envelope

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

$C \sim 10^{-12}\ y^{-1}$, $m_e \sim 500$ keV, $m_{\beta\beta} \sim 10$ meV

$\tau_{1/2}^{0\nu} > 10^{26}$ y

[universe life $15\ 10^9$ y , Avogadro number $6\ 10^{23}$]

what are we looking at ?

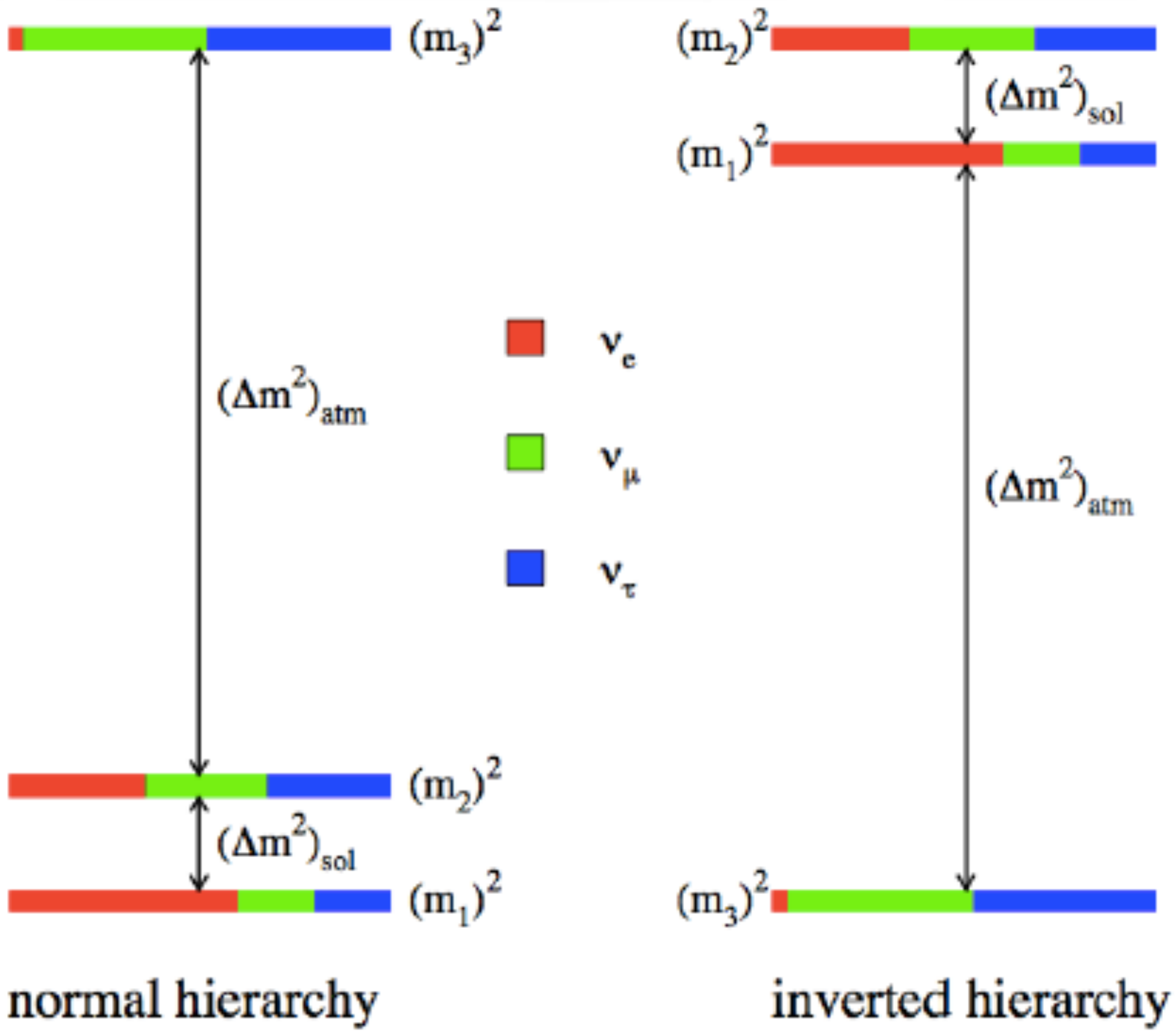
$$m_{\beta\beta} = \sum m_{\nu_k} U_{ek}^2 = \cos^2\theta_{13}(m_1 \cos^2\theta_{12} + m_2 e^{2i\alpha} \sin^2\theta_{12}) + m_3 e^{2i\beta} \sin^2\theta_{13}$$

The observable comes as a combination of the three neutrino masses, the mixing angles and the Majorana phases.

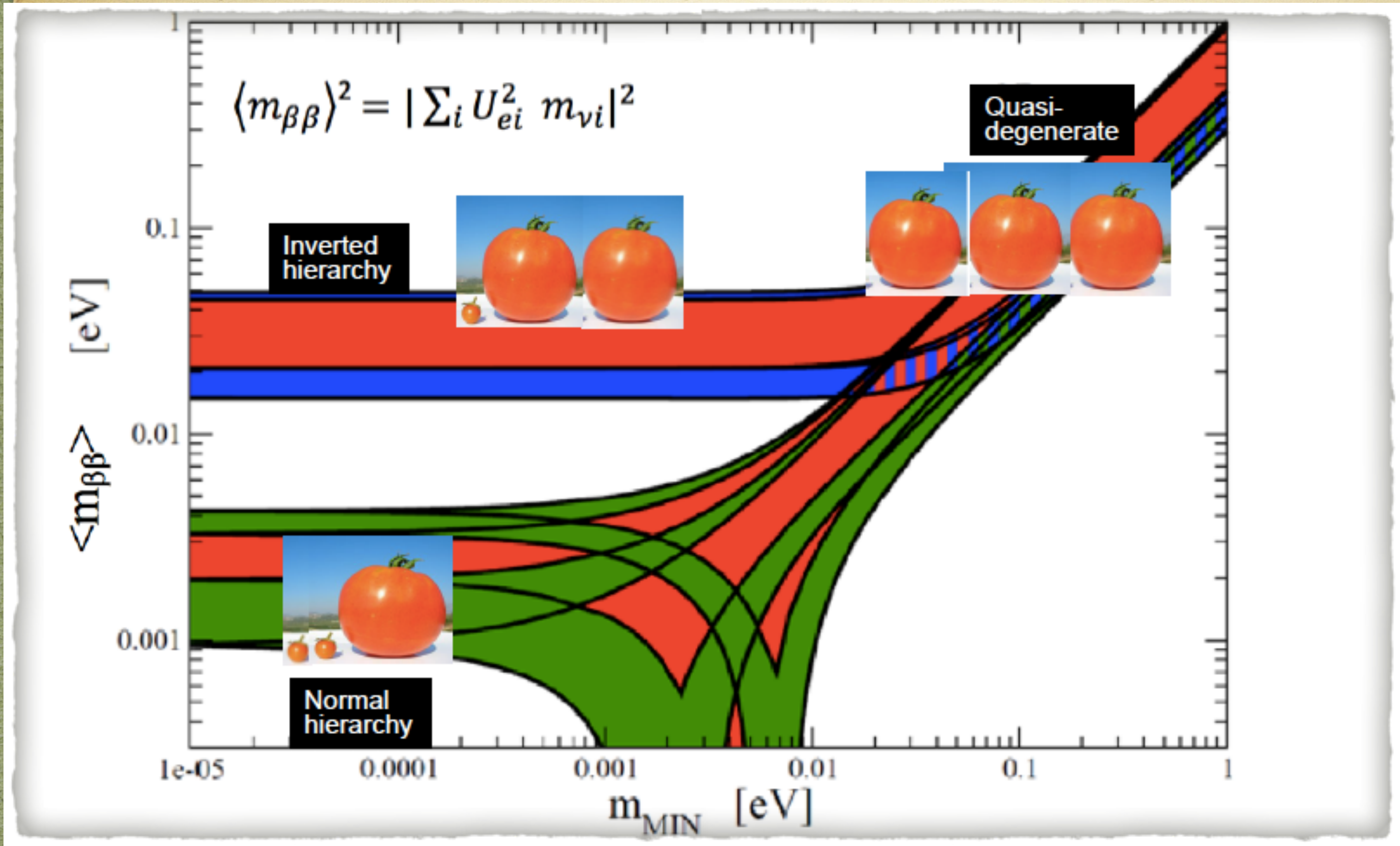
Let’s parameterize as a function of the known parameters

$$m_{\beta\beta} = f\,(U_{ek}, m_{lightest}, \delta m_{sol}, \Delta m_{atm})$$

Two possibilities:



the final result is :



The question is which, if any, part of this phase space can be attained by a realistic experiment

.

set a goal of exploring IH. Get down to 10-20 meV

The name of the game

expected number of ββ0ν events

detector mass
isotopic abundance
live time
efficiency

$$S = \frac{M \cdot N_A \cdot a}{W} \cdot \ln(2) \cdot \frac{t}{T^{0\nu}_{1/2}} \cdot \varepsilon$$

molecular mass
ββ0ν half-life

mean number of background counts around the Q-value

background rate in counts/keV/kg/y
energy resolution (detector FWHM)

$$B = b \cdot M \cdot \Delta E \cdot t$$

detector mass
live time

Sensitivity is S/√B

$$\text{Sensitivity} \quad \boxed{\propto K\sqrt{\frac{M\cdot t}{B\cdot\Delta E}}} \quad (\text{i.a.} \bullet \varepsilon)$$

$$m_{\beta\beta} \propto \sqrt{(1/\tau)}$$

which way ?

- increase abundance of the right isotope (linear)
- increase M a lot (square root)
- decrease B (ideally get to mythical zero background and get rid of the square root)
- get an extraordinary good energy resolution (remember we are talking of a signal of a few MeV but still gaining only by a square root)

brutal consideration

Sensitivity $\propto K \sqrt{\dfrac{M \cdot t}{B \cdot \Delta E}}$ (i.a. • ε)

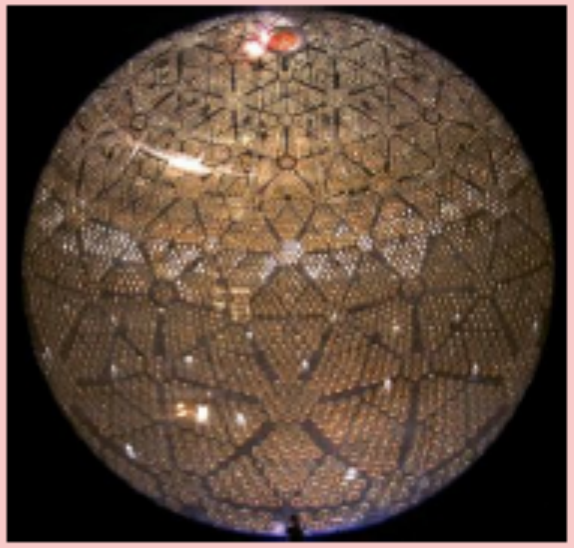
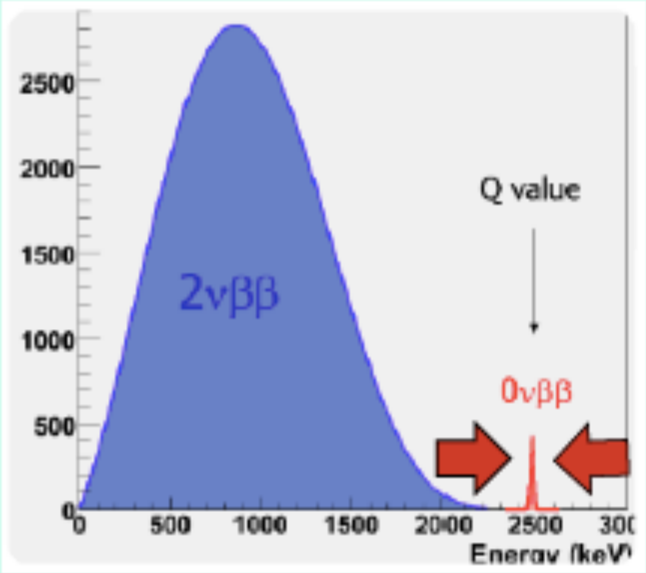
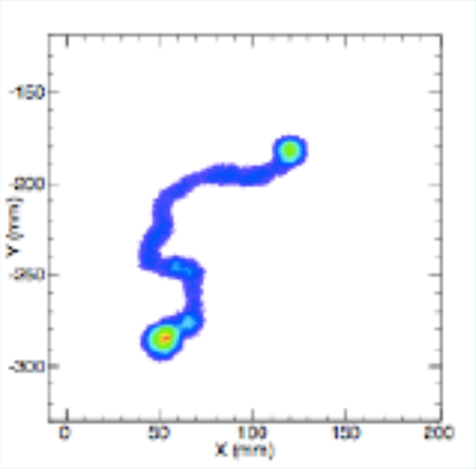
$m_{\beta\beta} \propto \sqrt{(1/\tau)}$

To get a factor 10 in $m_{\beta\beta}$ you have a choice :

M	100 Ton	instead of 1 Ton
t	500 y	instead of 5 y
ΔE	50 eV	instead of 5 keV

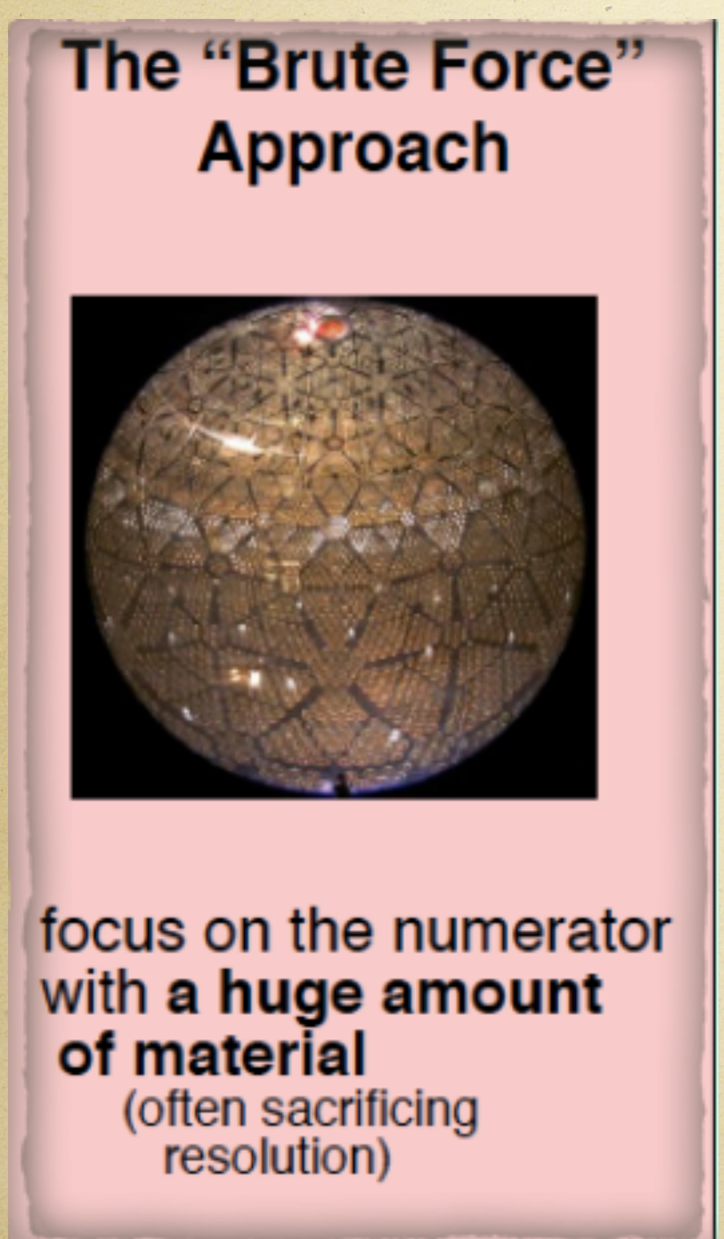
B	0.001	instead of 0.1

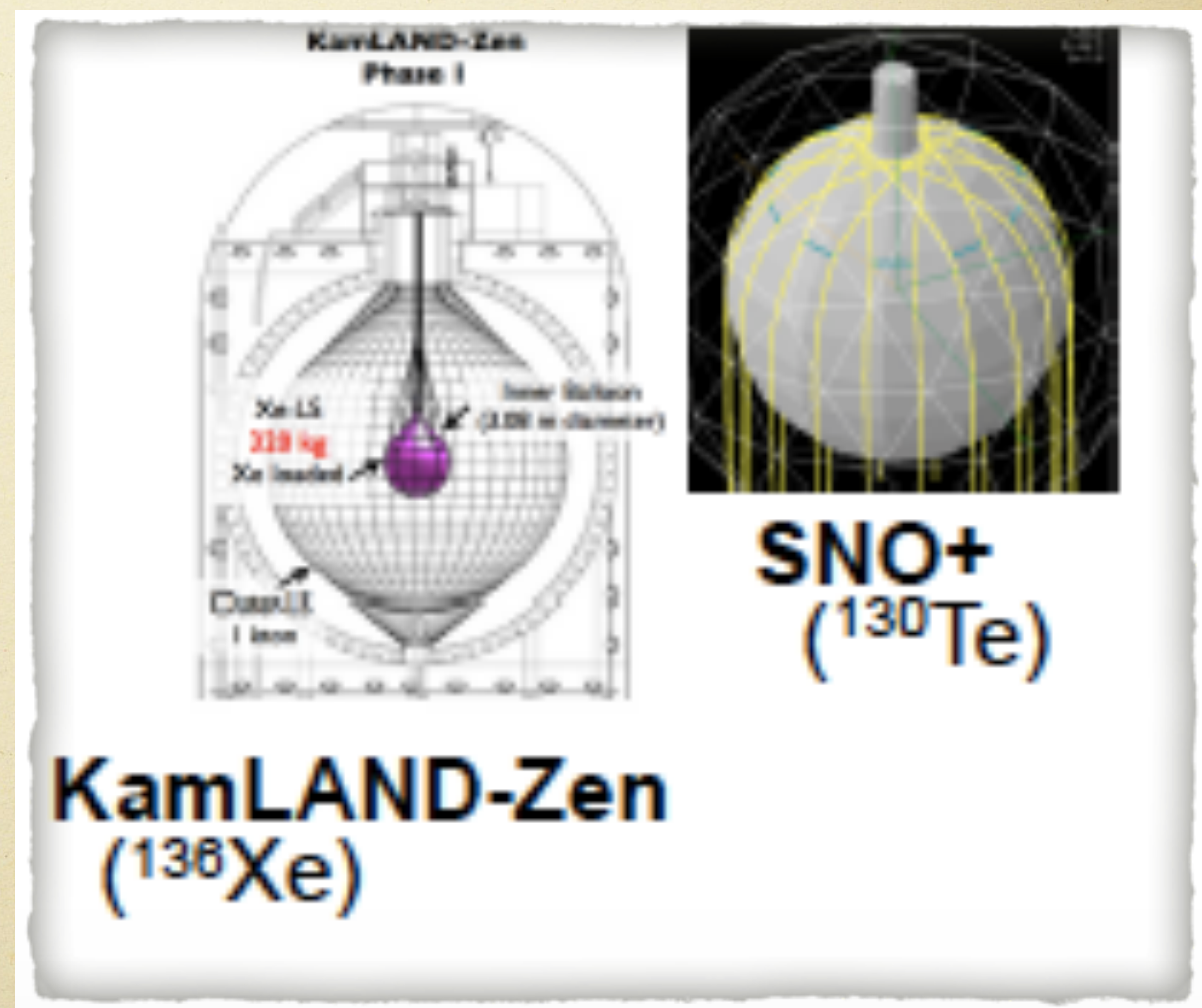
meaning :

The "Brute Force" Approach	The "Peak-Squeezer" Approach	The "Final-State Judgement" Approach
		
focus on the numerator with **a huge amount of material** (often sacrificing resolution)	focus on the denominator by **squeezing down ΔE** (various technologies)	try to make the background zero by **tracking or tagging**

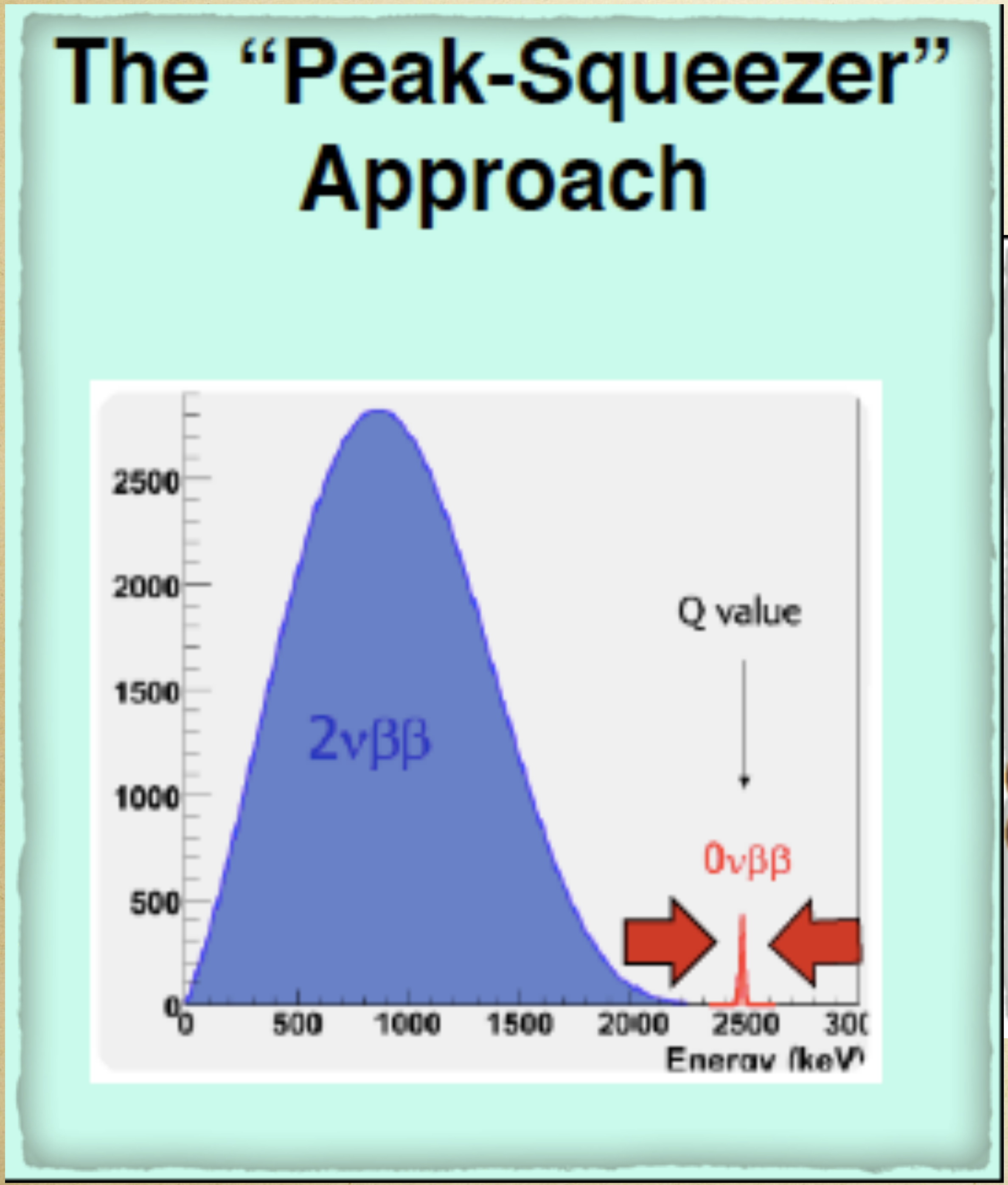
or better make the right cocktail of all of the above

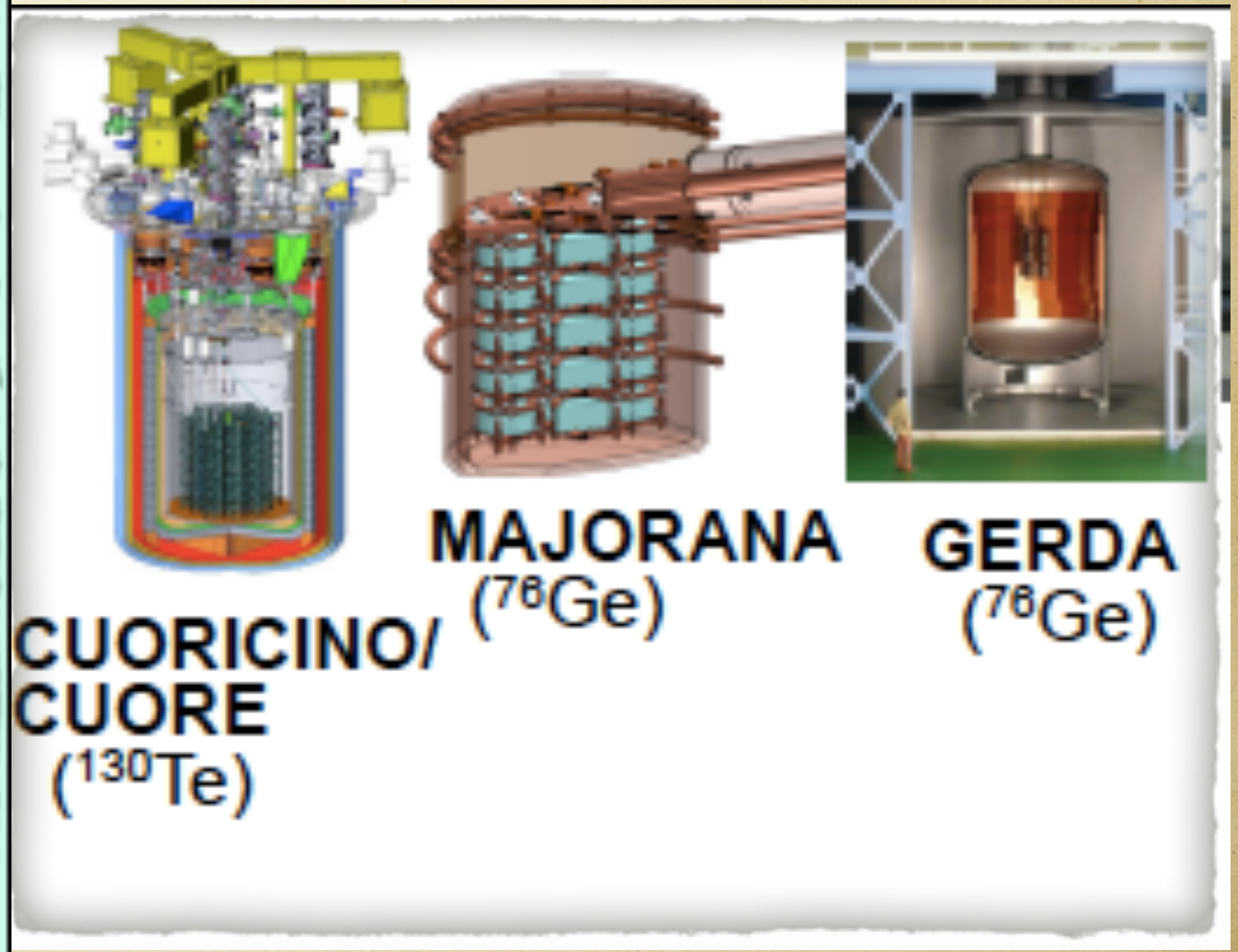
the state of the art: brute force



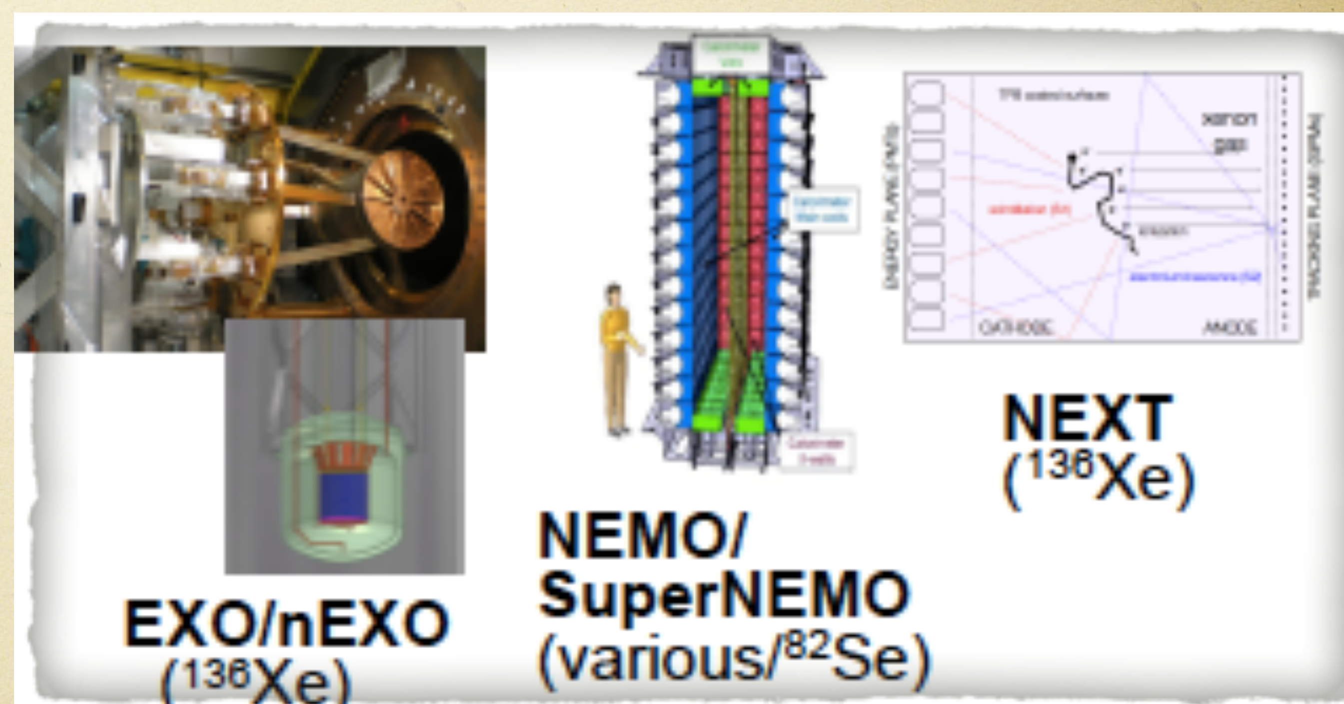


the state of the art: peak squeezer



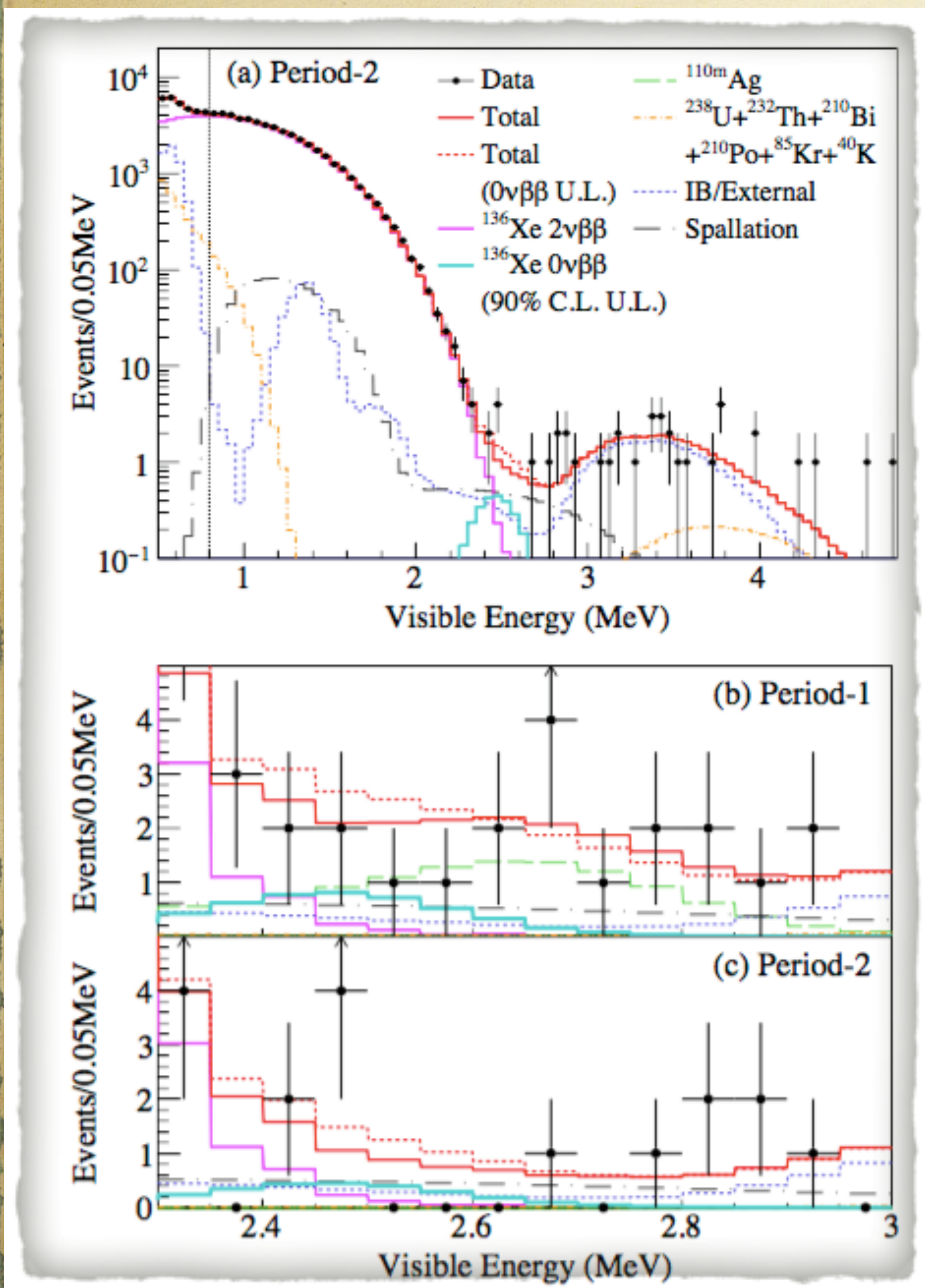


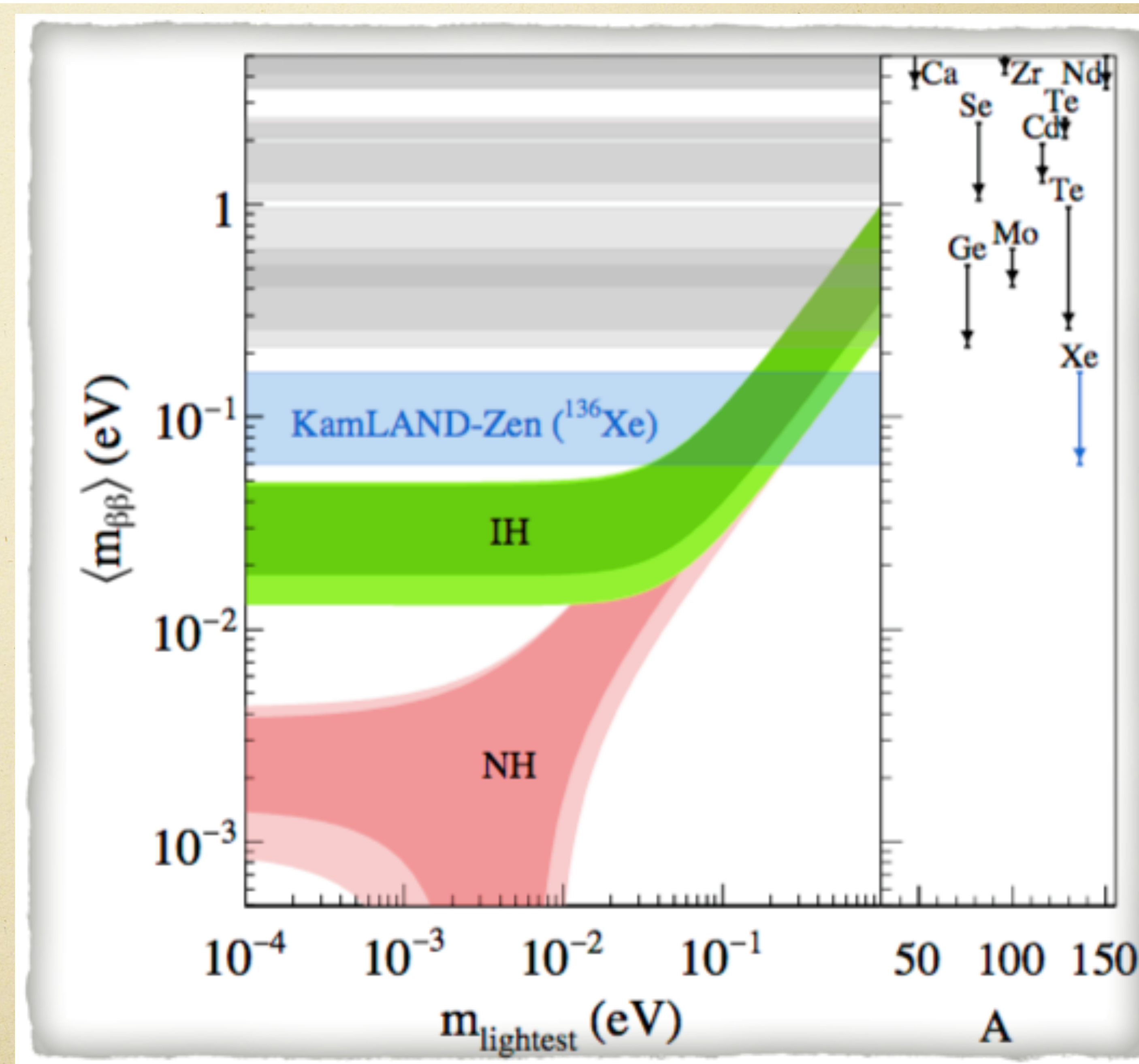
the state of the art: tracking



so far the winner is

Search for Majorana Neutrinos near the Inverted Mass Hierarchy region with KamLAND-Zen





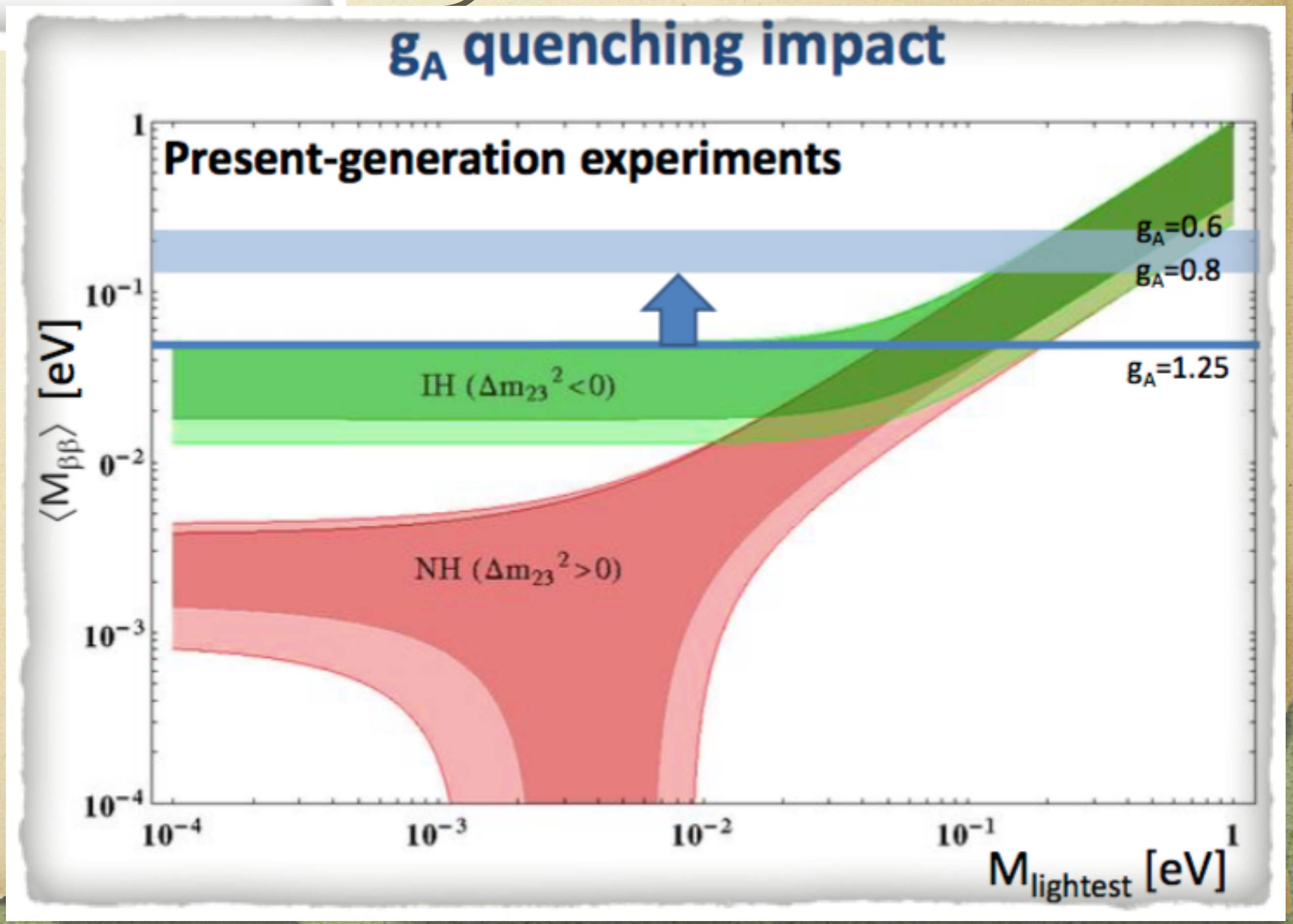
$$T^{0\nu}_{1/2} > 1.1 \times 10^{26}\ \text{yr (90\% C.L.)}$$

something worrisome

$$\mathcal{M} \equiv g_A^2\, \mathcal{M}_{0\nu} = g_A^2 \left(M_{GT}^{(0\nu)} - \left(\frac{g_V}{g_A}\right)^2 M_F^{(0\nu)} + M_T^{(0\nu)} \right)$$

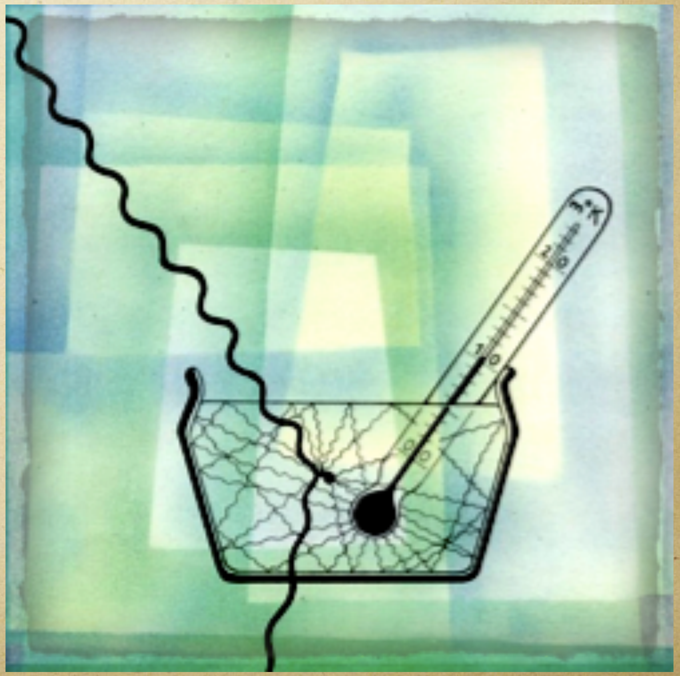
$$g_A = \begin{cases} g_{\text{nucleon}} & = 1.269 \\ g_{\text{quark}} & = 1 \\ g_{\text{phen.}} & = g_{\text{nucleon}} \cdot A^{-0.18} \end{cases}$$

$\left.\vphantom{\begin{cases}a\\b\\c\end{cases}}\right\}$ **2**νββ who knows ?



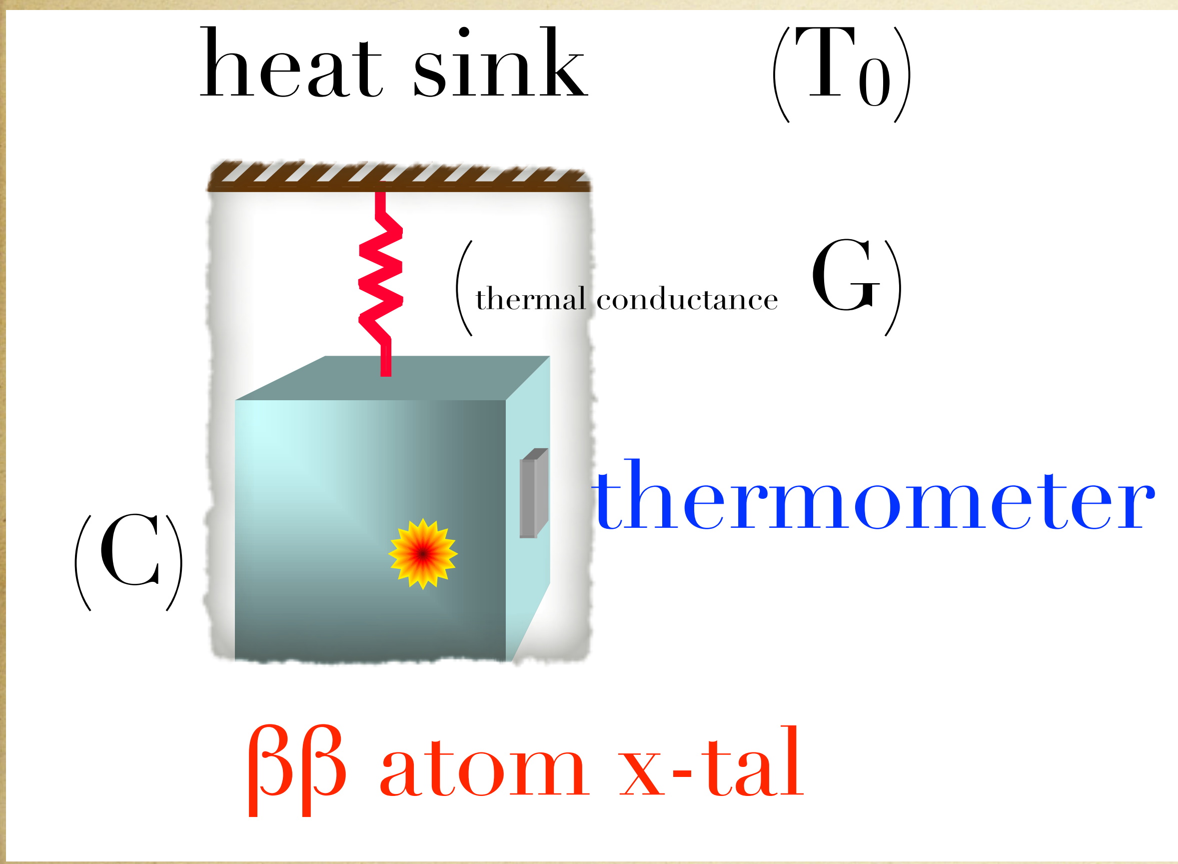
Bolometric technique as a competitor

- from MiBeta to CUORE via Cuoricino and Cuore-0
- Scintillating bolometers as an evolution toward Zero Background



(very) Low Temperature Calorimeter

A True Calorimeter



Basic Physics: $\Delta T = E/C$
(Energy release/ Thermal capacity)

Implication: Low C ⇒ Low T
Bonus: (almost) No limit to ΔE
($k_B T^2 C$)

Not for all apps : $\tau = C/G \sim 1s$

$$C(T) = \beta \frac{m}{M} \left(\frac{T}{\Theta_D} \right)^3$$

$$\Delta T(t) = \frac{\Delta E}{C} \exp\left(-\frac{t}{\tau} \right)$$

Why a bolometer

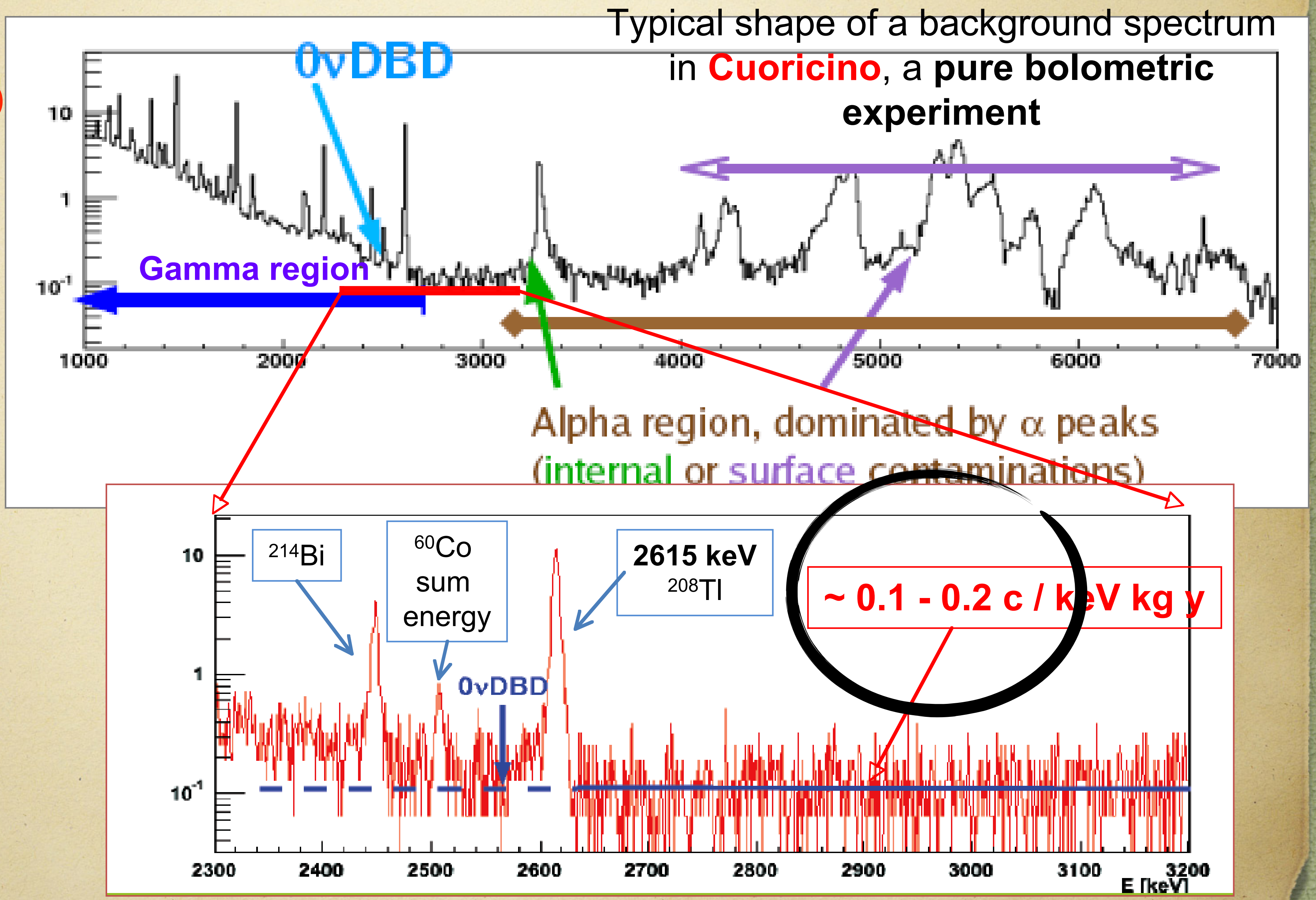
- M, t, B, ΔE are the parameters of the game
- t is irrelevant
- M is ‘easy’ with a calorimeter
- ΔE is a definite bonus
- B is what this part of the talk is mostly about

it is time to deal with the enemy: what is the background ?

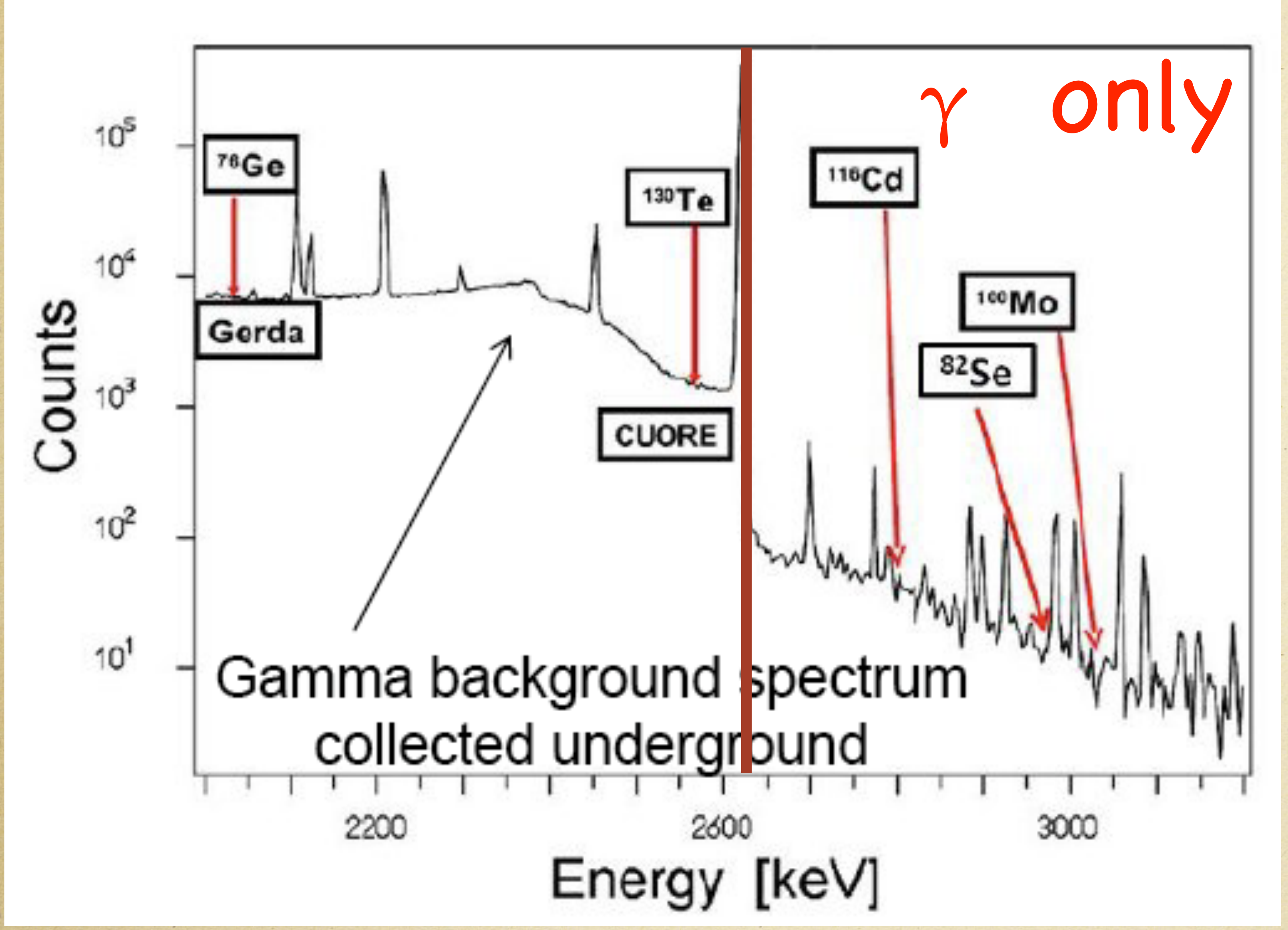
Cuoricino

b=0.18 ± 0.02 c/keV/kg/y

B is experiment dependent. Cuoricino as an example



we have two enemies then

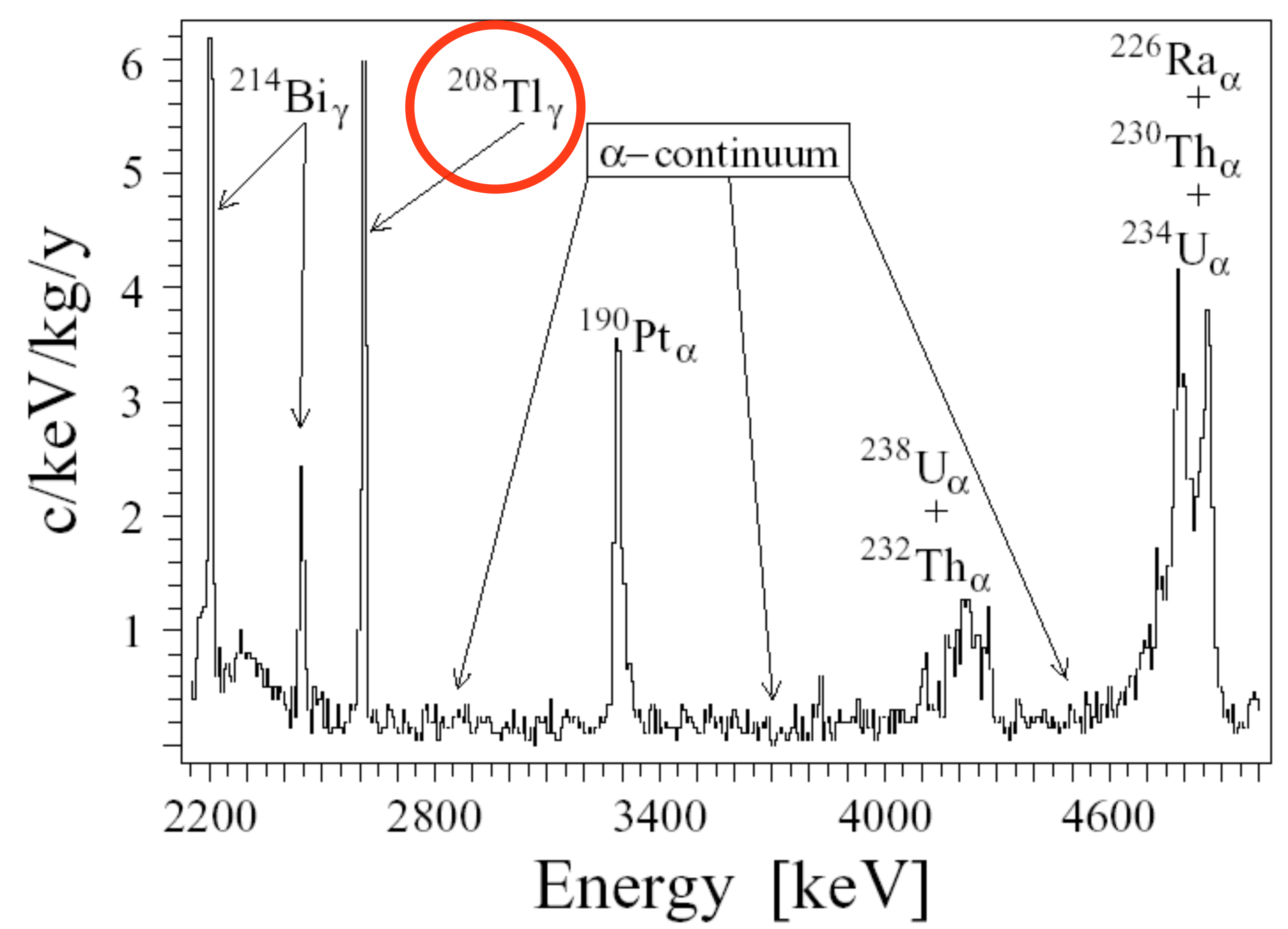


Photons

^{208}Tl is where photons start to disappear

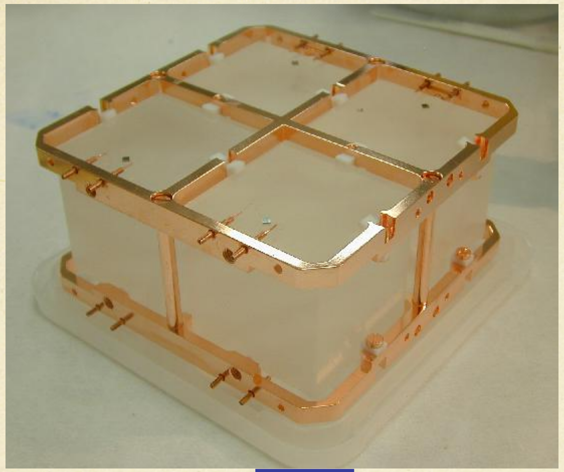
Keep it in mind !

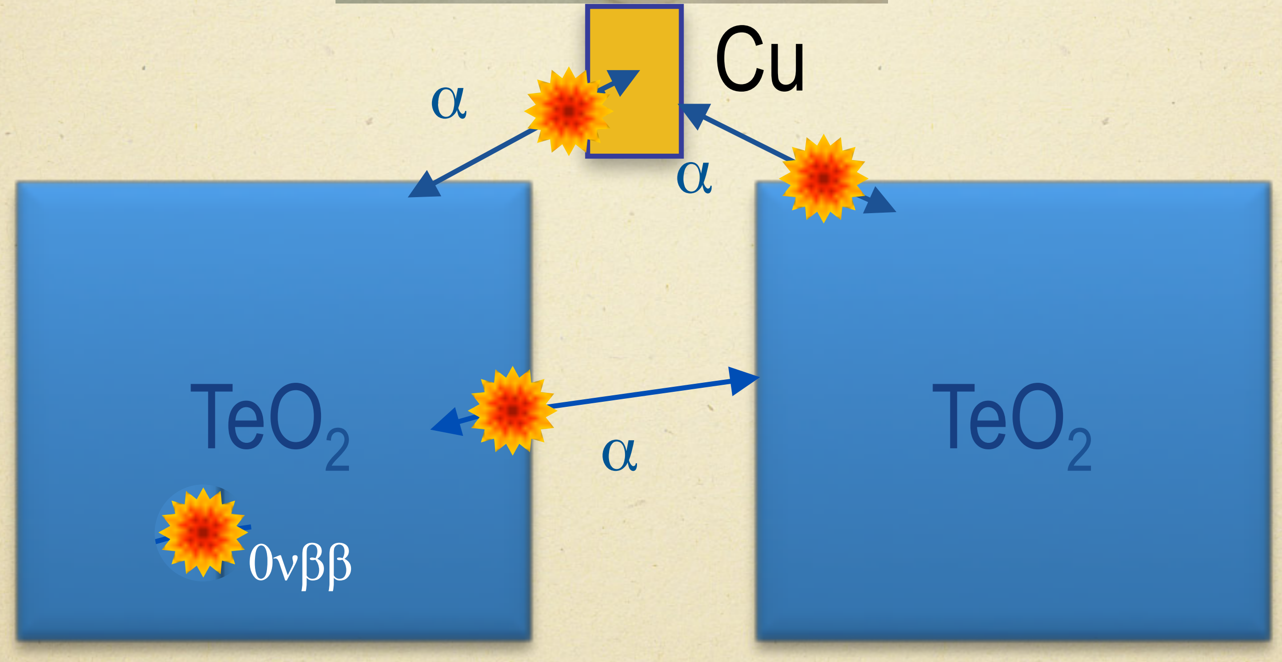
and…



the α land

the nasty α background





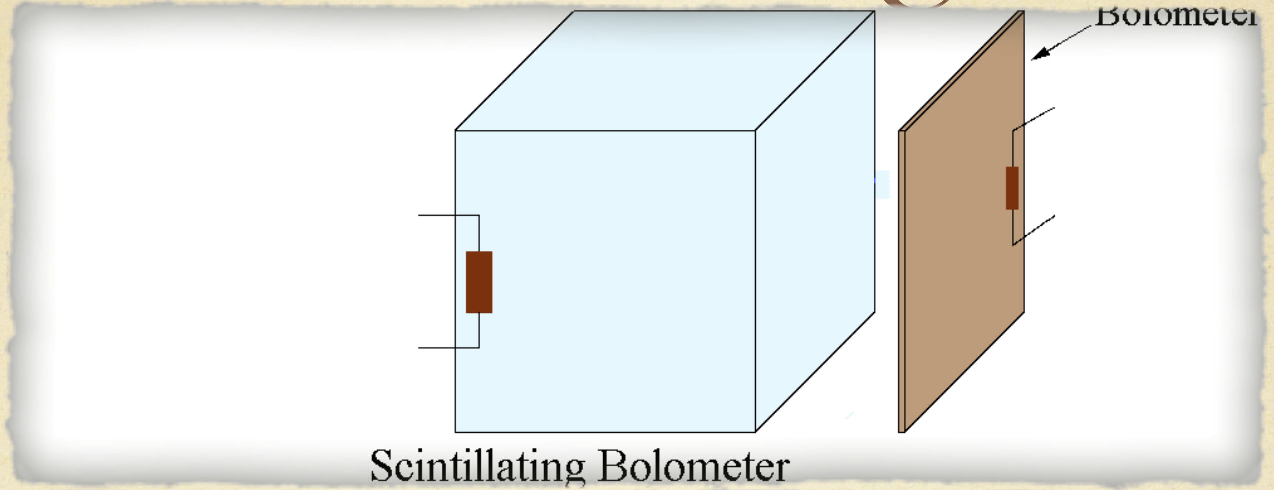
what is measured is part of the α energy
(if it were an internal emission…no problem !)
that induces a flat background

The LUCIFER concept

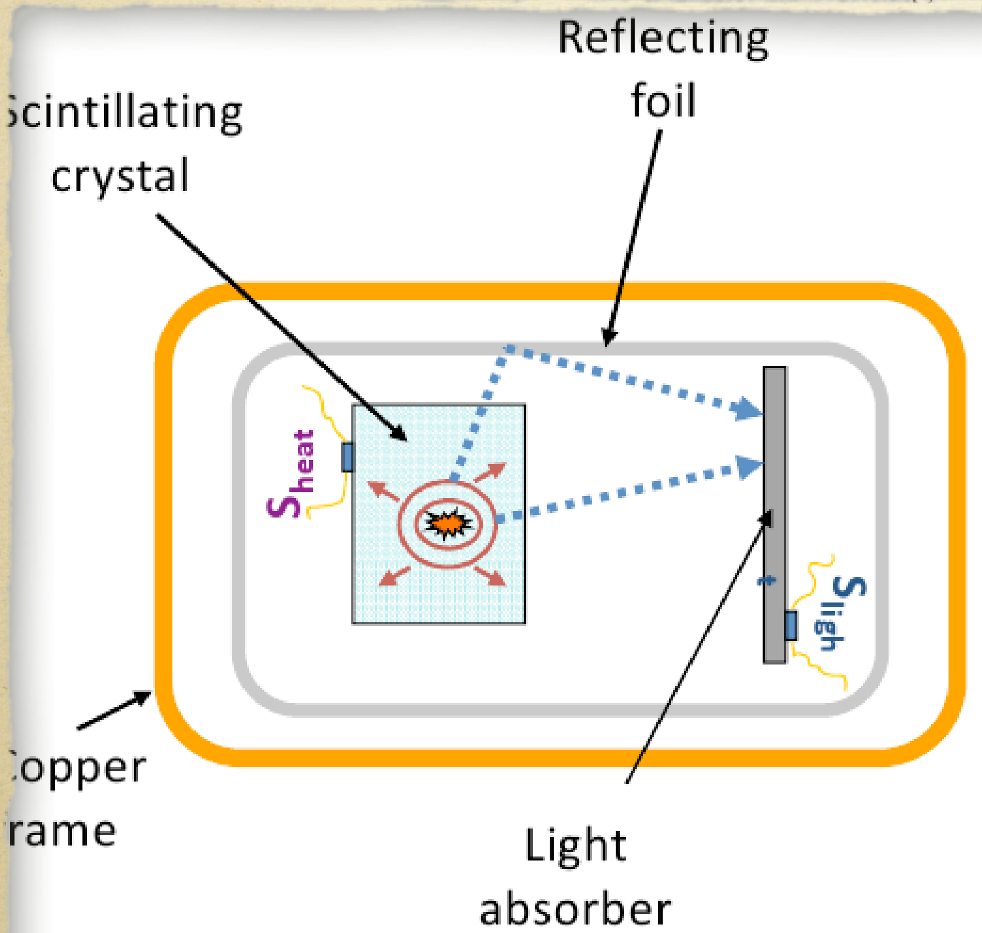
Lucifer is a Latin word (from the words *lucem ferre*), literally meaning "light-bearer", which in that language is used as a name for the dawn appearance of the planet Venus, heralding daylight.

Bringing light underground

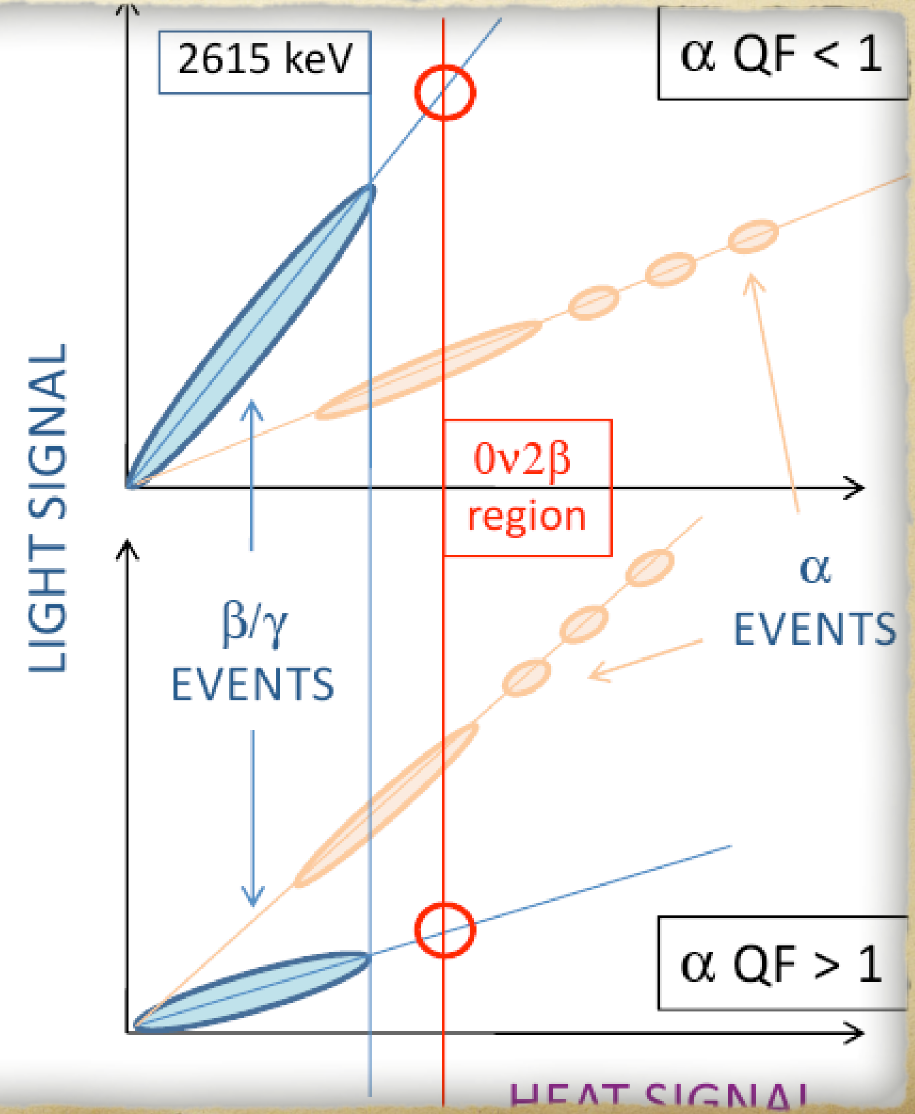
Heat & Light



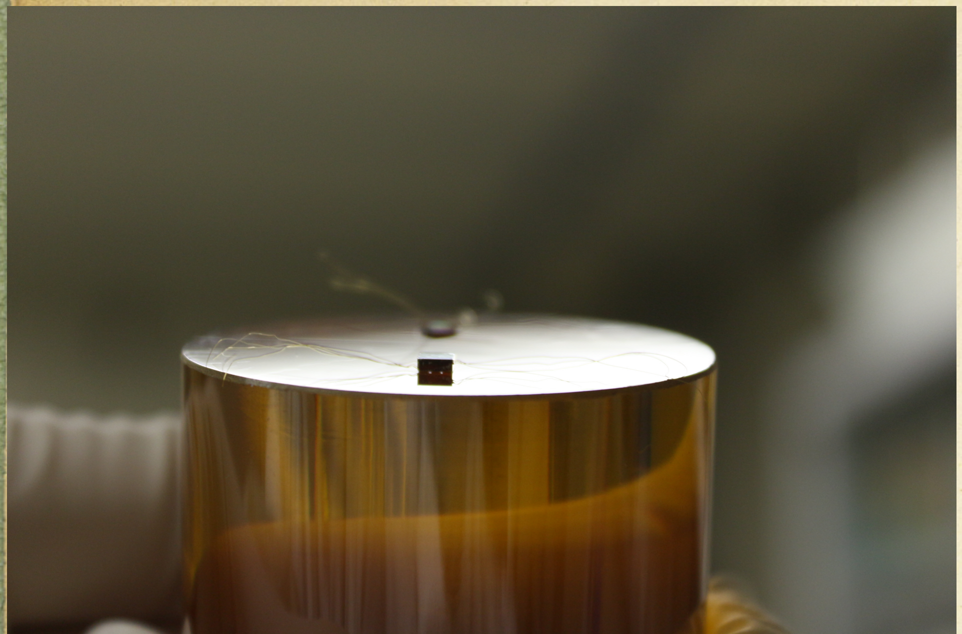
Bolometer
Scintillating Bolometer



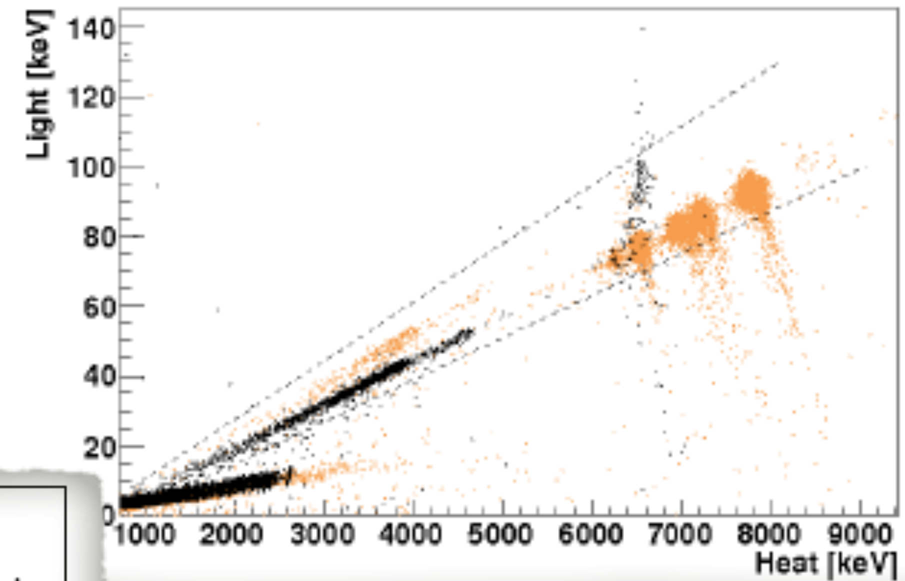
Reflecting foil
Scintillating crystal
S_{heat}
S_{light}
Copper frame
Light absorber

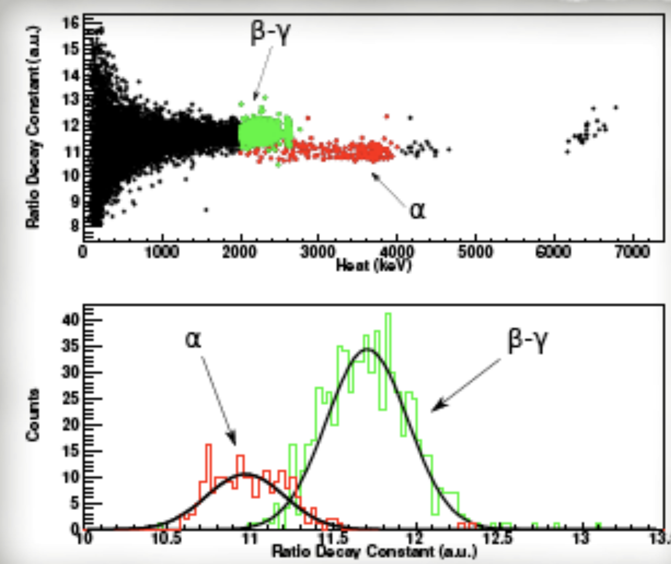


2615 keV
α QF < 1
0ν2β region
LIGHT SIGNAL
β/γ EVENTS
α EVENTS
α QF > 1
HEAT SIGNAL

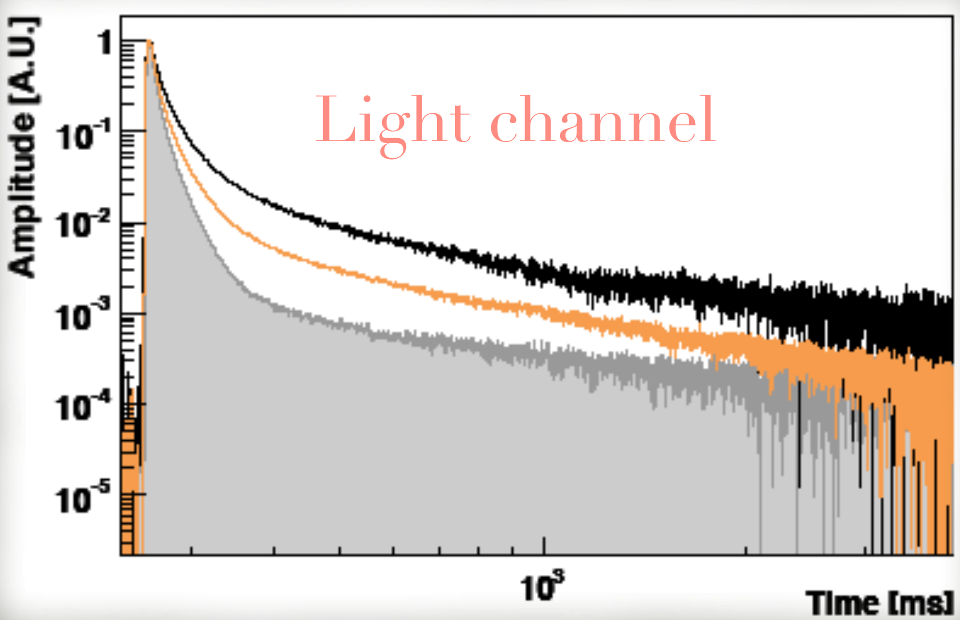


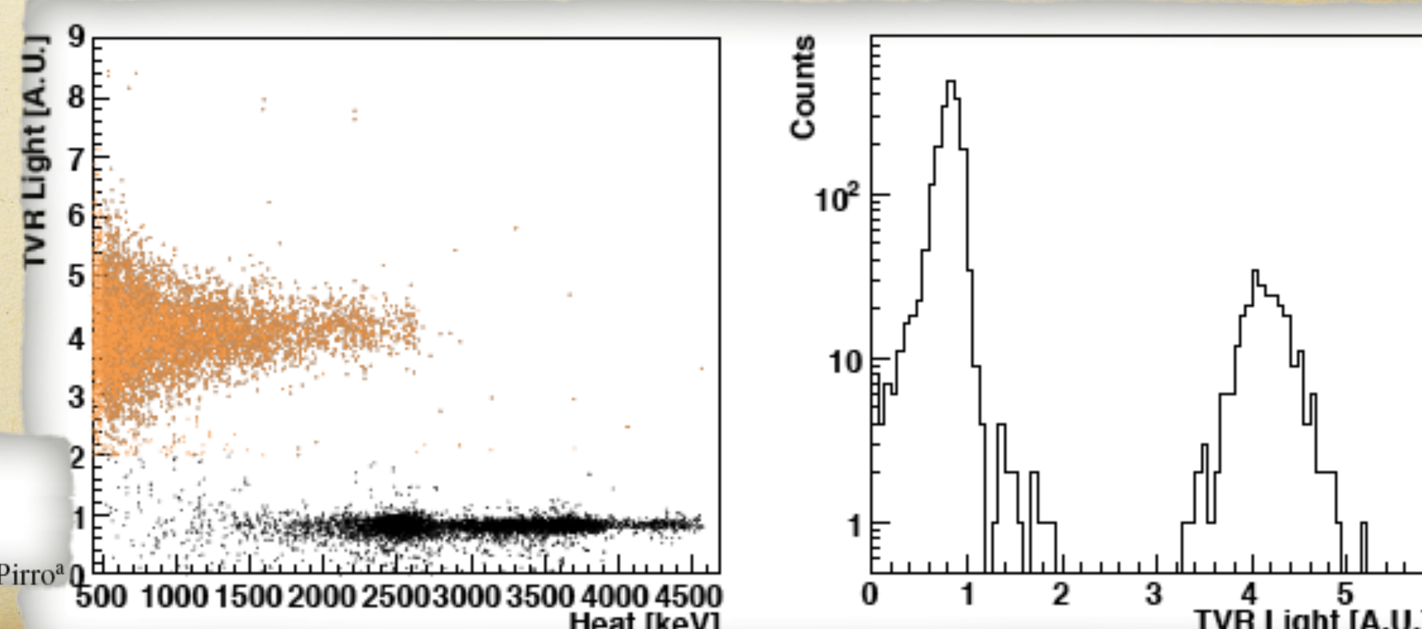
ZnSe





Heat channel





ZnSe scintillating bolometers for Double Beta Decay

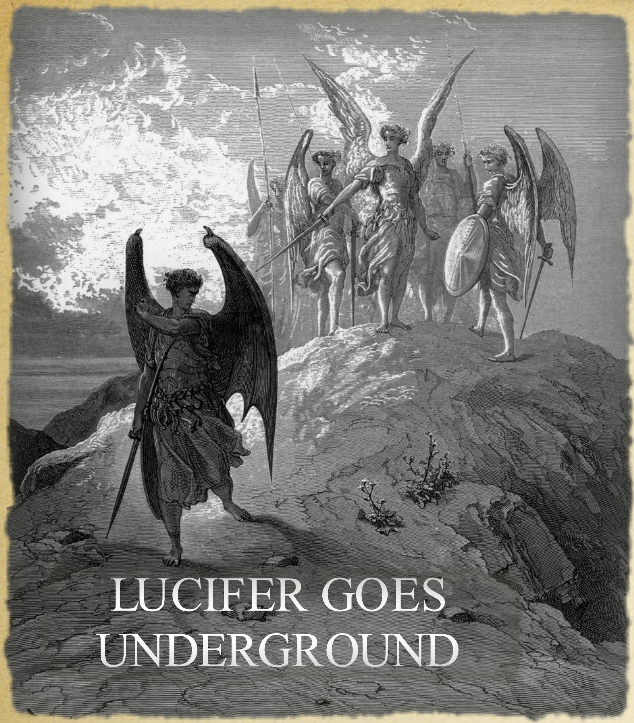
Astropart.Phys. 34 (2011) 344-353

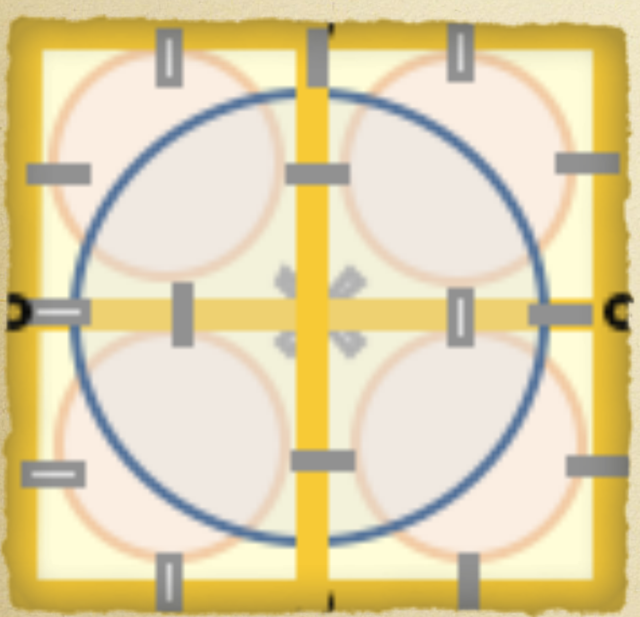
C. Arnaboldi[a], S. Capelli[b,a], O. Cremonesi[a], L. Gironi[b,a], M. Pavan[b,a], G. Pessina[a], S. Pirro[a]

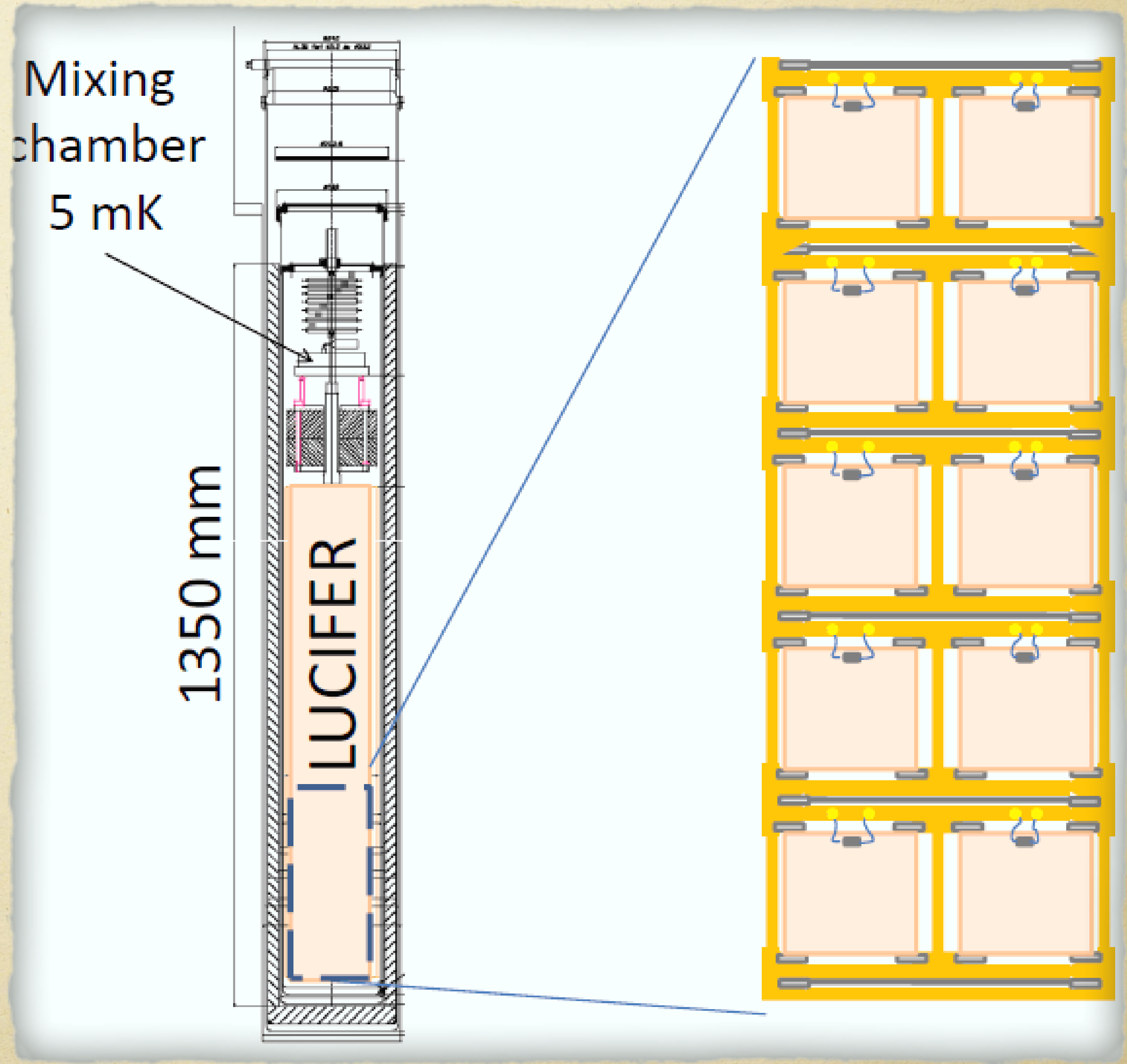
LUCIFER demonstrator

Low-background **U**nderground **C**ryogenic **I**nstallation **F**or **E**lusive **R**ates

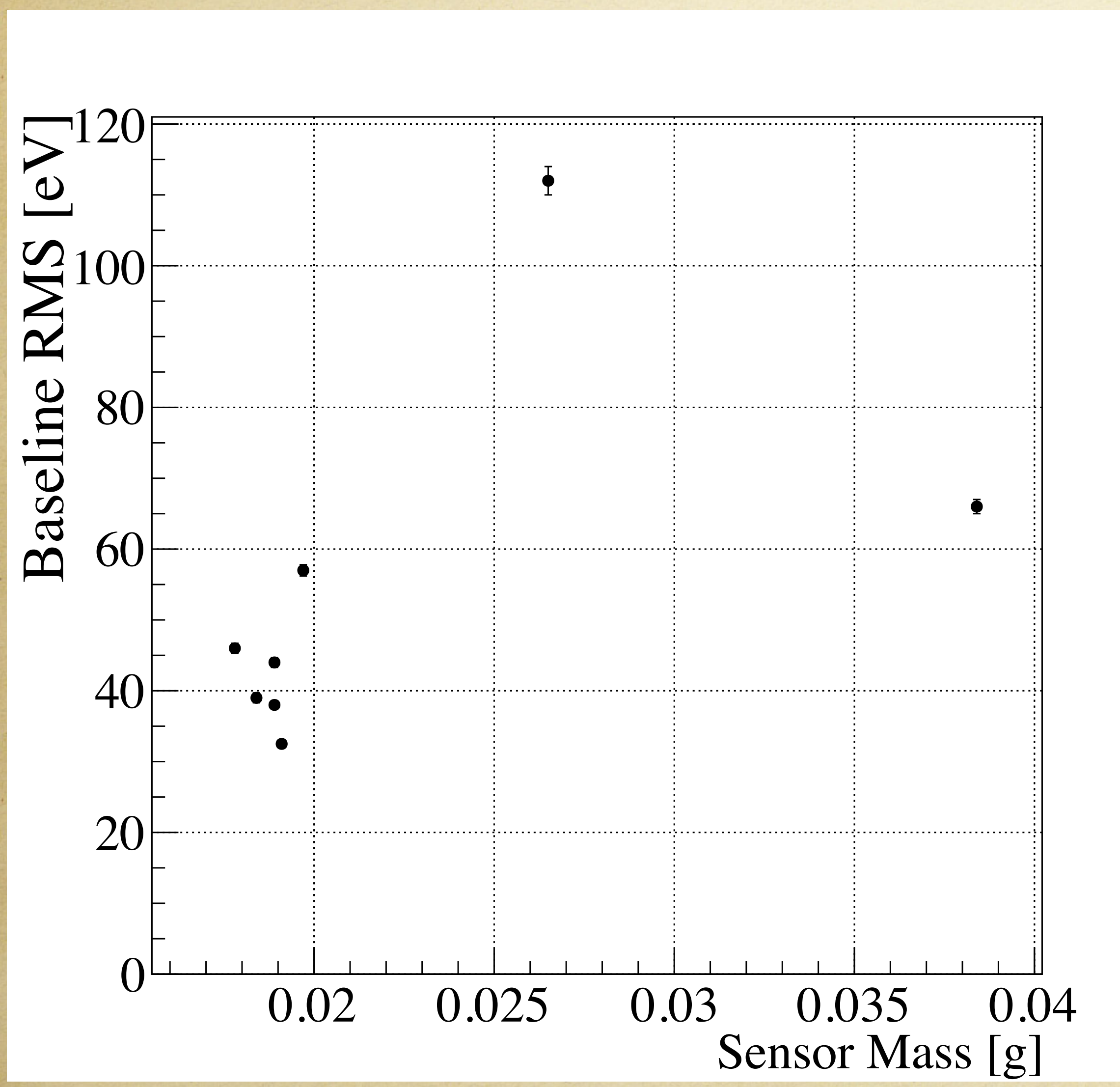
ERC-2009-AdG 247115

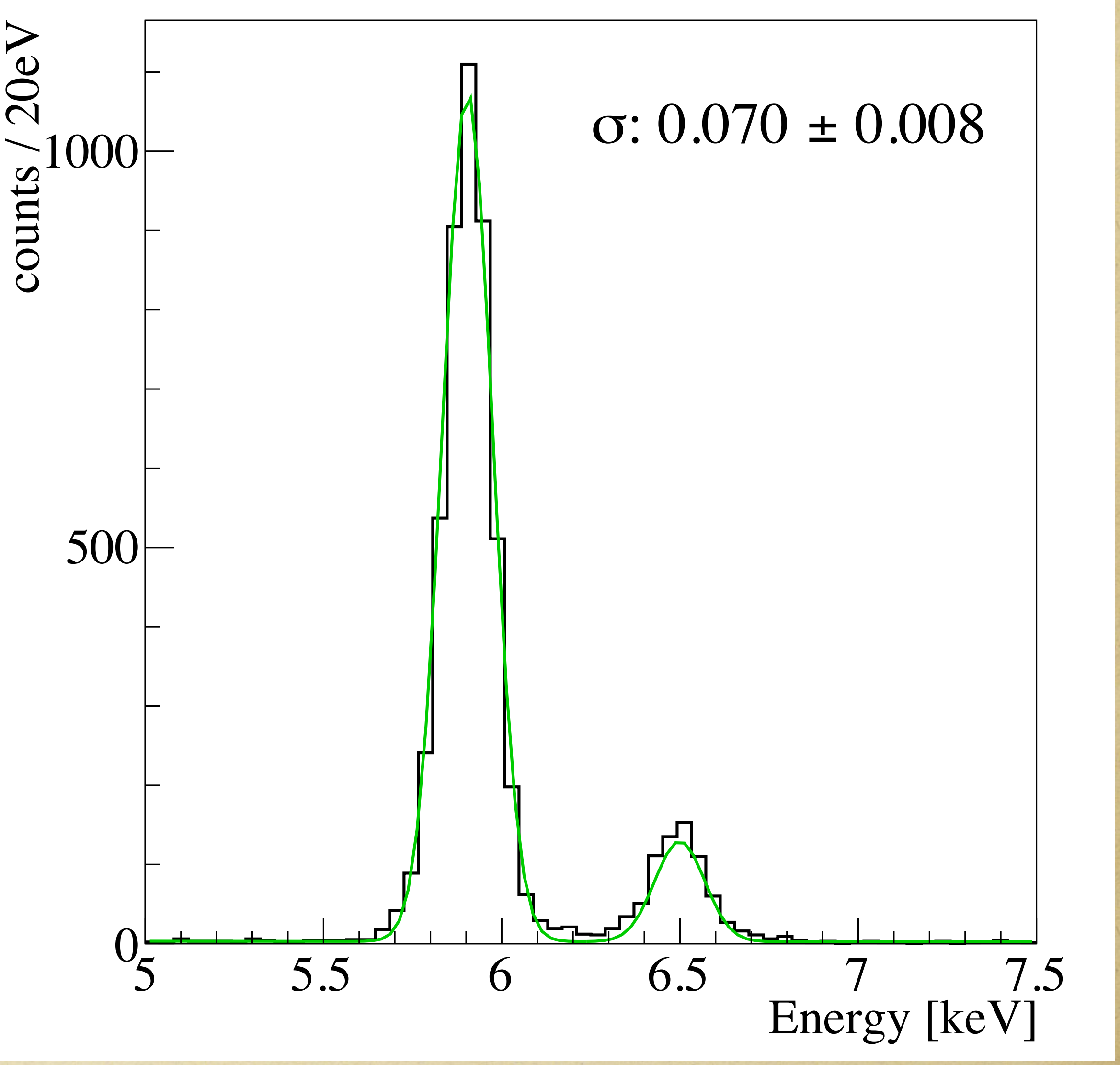






with spectacular L.D.





goals

- assess background (has to be lower than 10^{-3})
- decide amongst ZnSe, ZnMo or LiMo
- project lifetime and mass limits to a realistic 1 Ton experiment that
- should be able to span the entire inverted hierarchy

if you want to know all… pls. read:

http://arxiv.org/pdf/1601.07512.pdf

Neutrinoless double beta decay: 2015 review

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(Dated: January 28, 2016)

The discovery of neutrino masses through the observation of oscillations boosted the importance of neutrinoless double beta decay ($0\nu\beta\beta$). In this paper, we review the main features of this process, underlining its key role both from the experimental and theoretical point of view. In particular, we contextualize the $0\nu\beta\beta$ in the panorama of lepton-number violating processes, also assessing some possible particle physics mechanisms mediating the process. Since the $0\nu\beta\beta$ existence is correlated with neutrino masses, we also review the state-of-art of the theoretical understanding of neutrino masses. In the final part, the status of current $0\nu\beta\beta$ experiments is presented and the prospects for the future hunt for $0\nu\beta\beta$ are discussed. Also, experimental data coming from cosmological surveys are considered and their impact on $0\nu\beta\beta$ expectations is examined.

Conclusions

- Neutrino Physics is one of the leading field in HEP today
- Dirac or Majorana nature of neutrino mass is a fundamental question that needs to be answered at (almost) all cost(s)
- Neutrino-less DBD might possibly be the sole chance to give a measure of neutrino mass
- The second generation experiments might not be enough to win.
- We have to prepare for third generation. Toward 0 background.