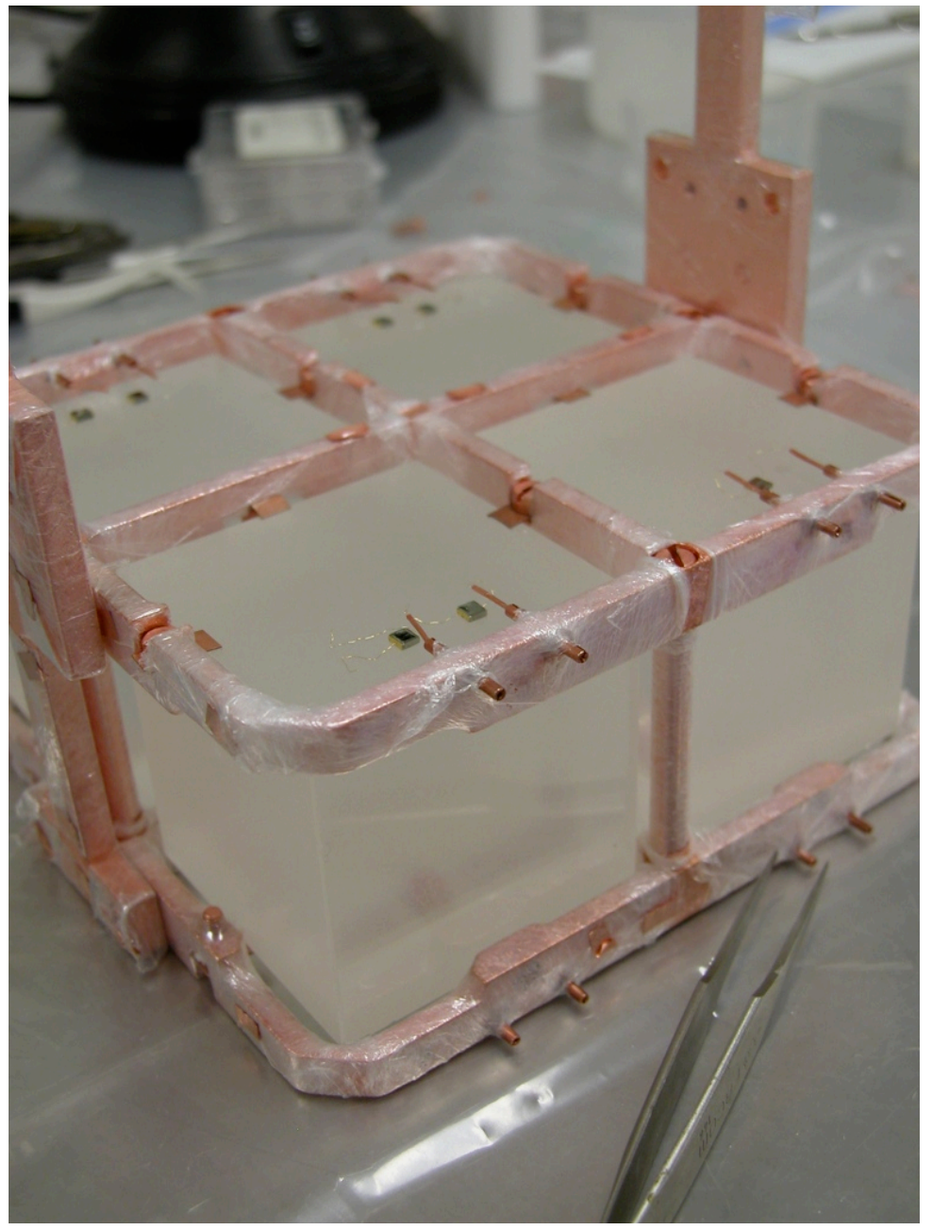
LS veto for large arrays of macro bolometers

Paolo Gorla
INFN Roma Tor Vergata



Outline

- Thermal detectors
- The problem of background from surfaces
- Surface alpha tagging: the ABSURD project
- Future plans

Bolometric Detectors

- Thermal detectors have a crucial role in Rare Events particle physics:
  - Extremely good energy res and low energy threshold
  - Large mass (~ton scale) detectors are on the way

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- CDMS
- CRESST
- EDELWEISS
- EUREKA
- ROSEBUD

0ν Double Beta Decay

- AMoRE
- CUORE
- Lucifer

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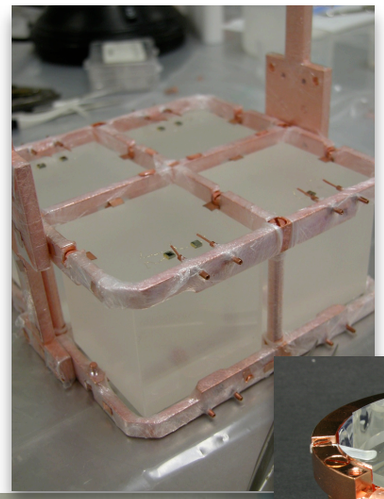

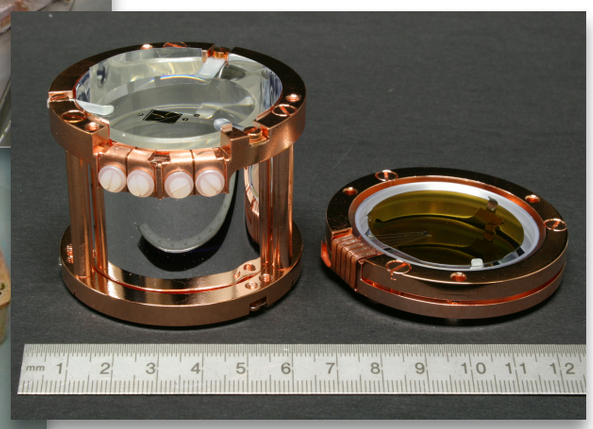

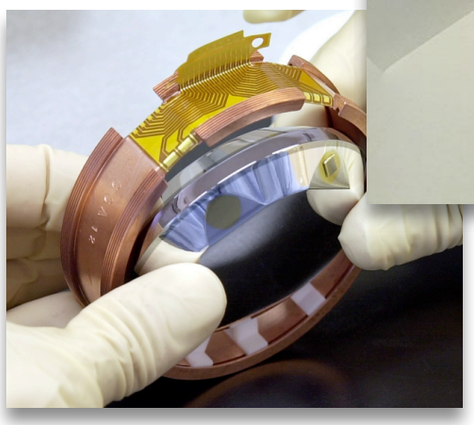

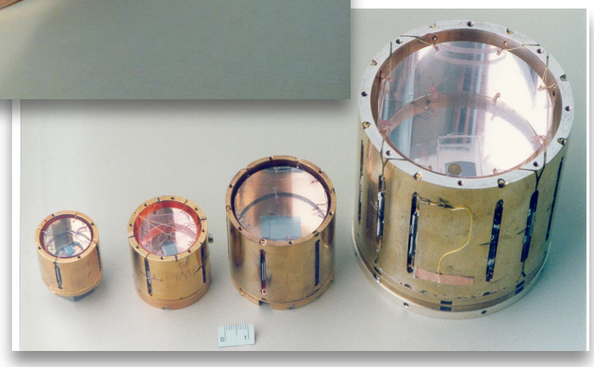

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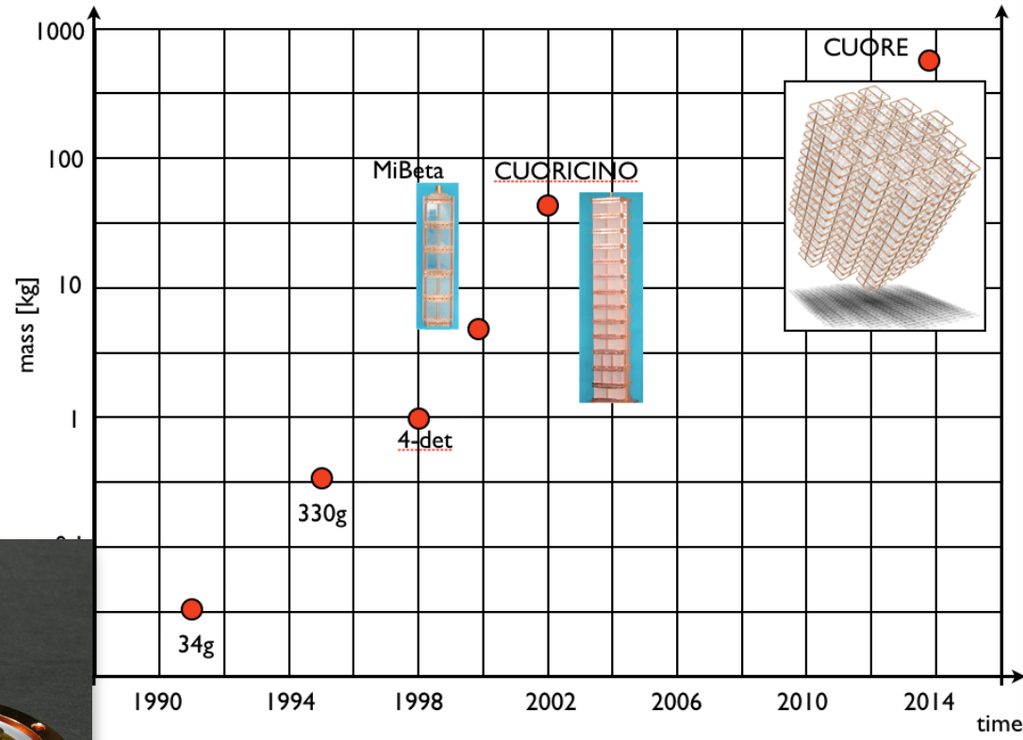

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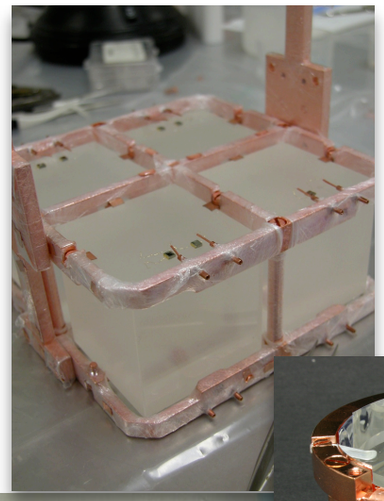

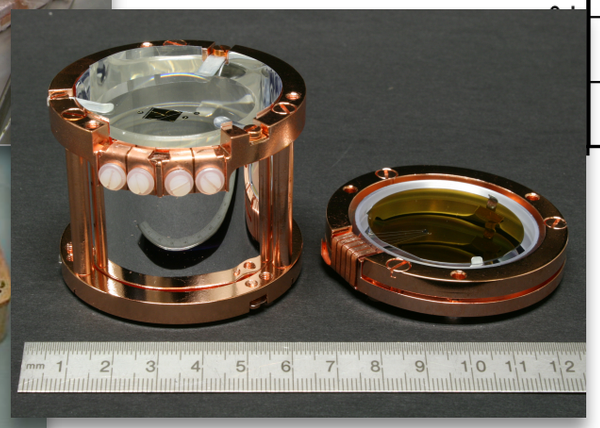

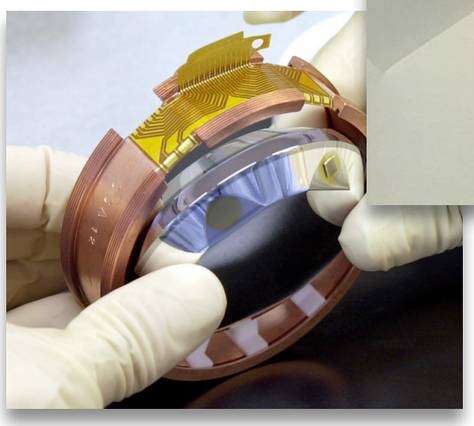

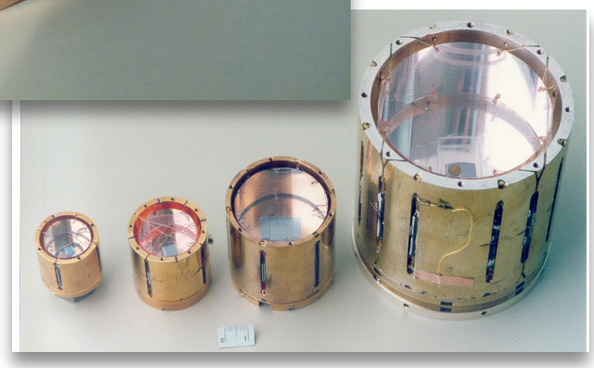

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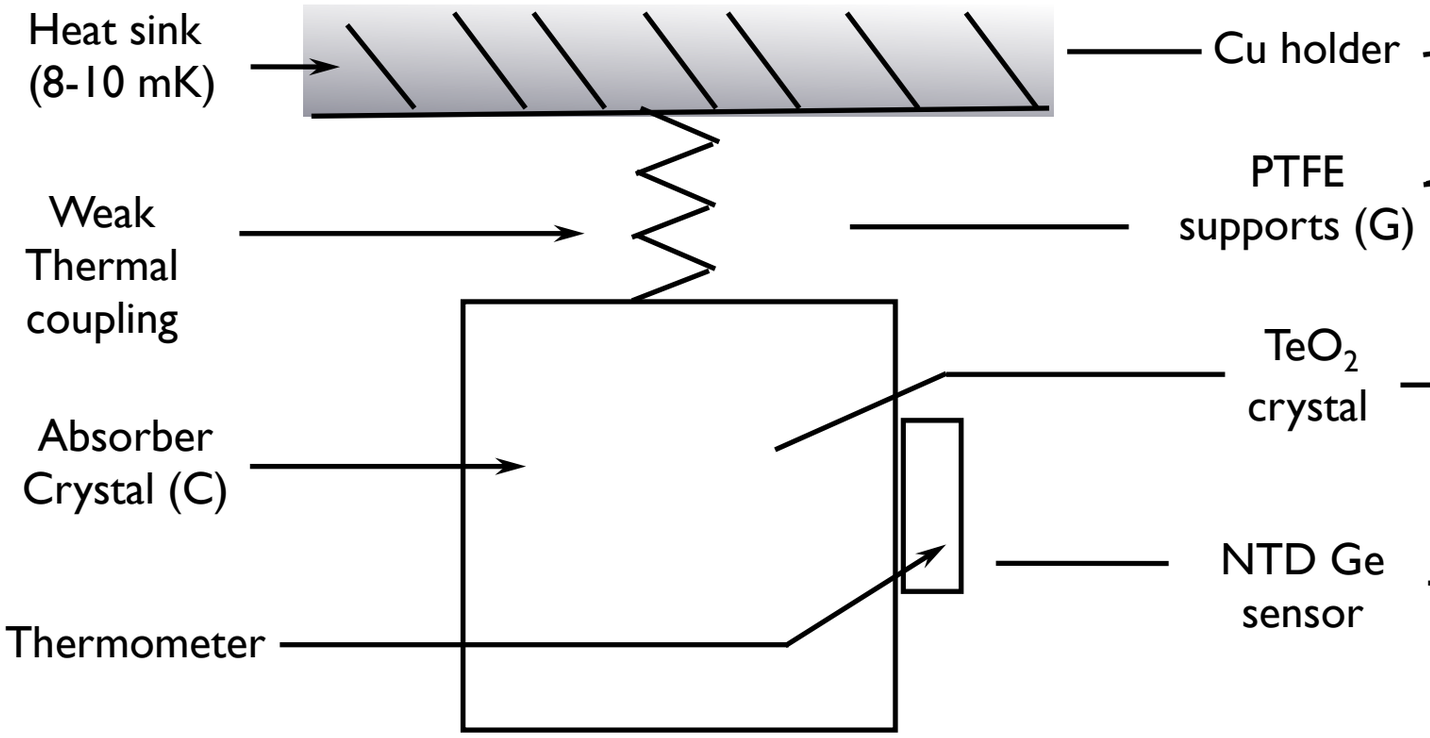
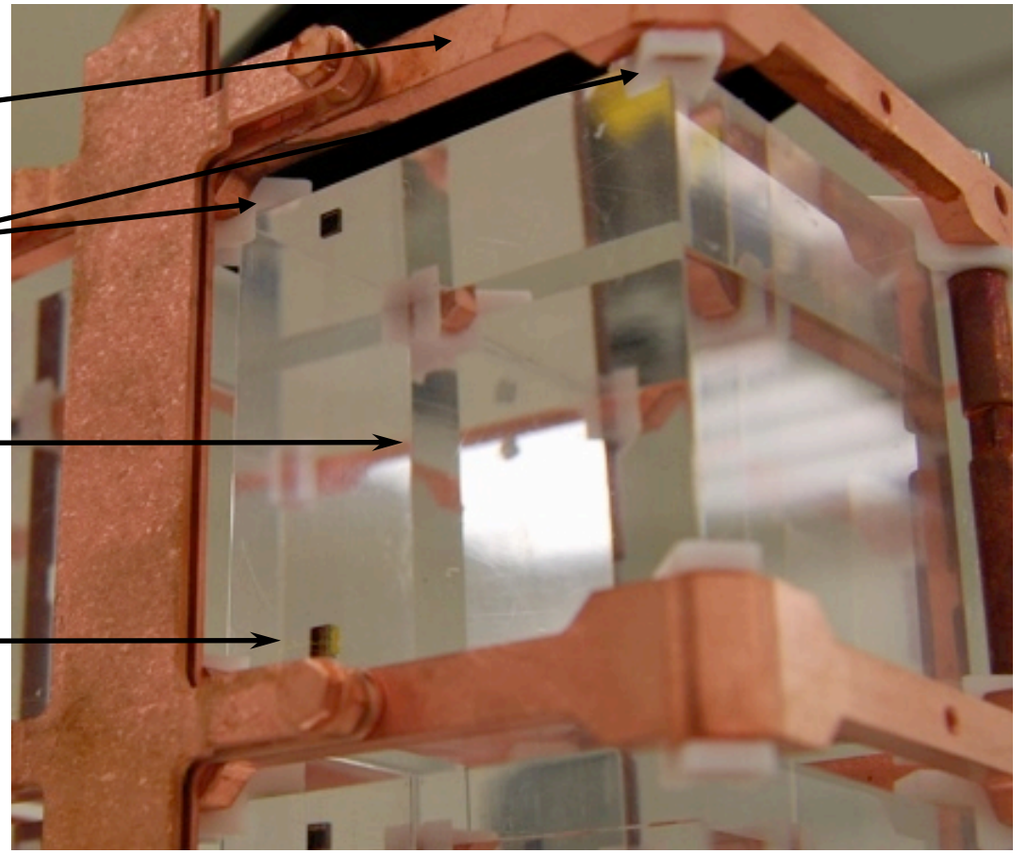
Working principle: the CUORE TeO_2 bolometers





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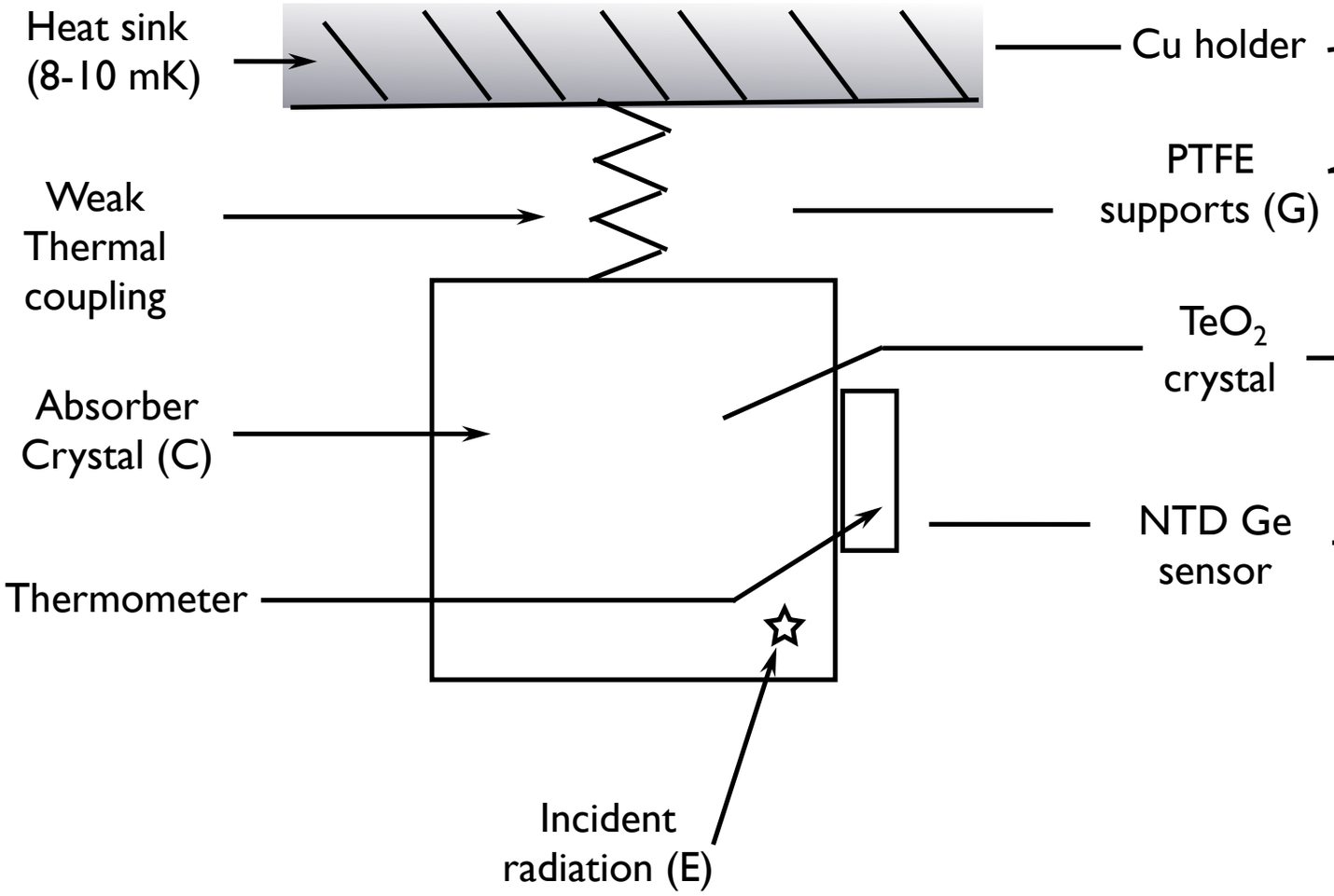
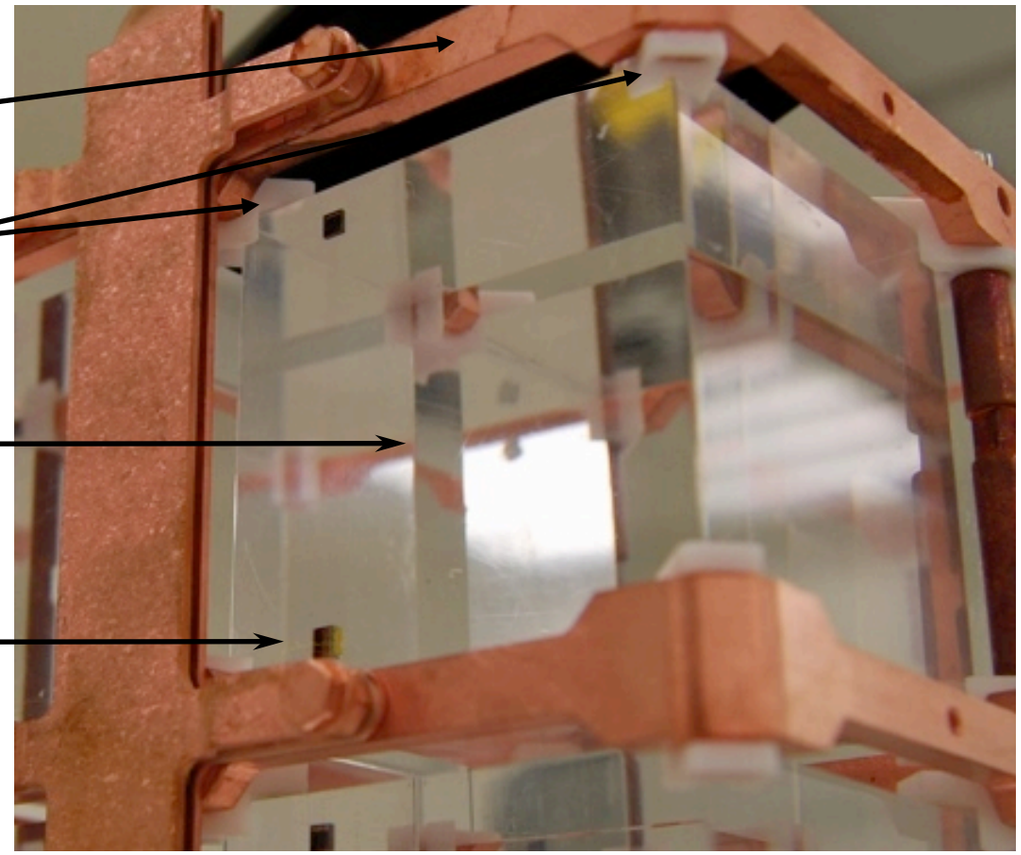
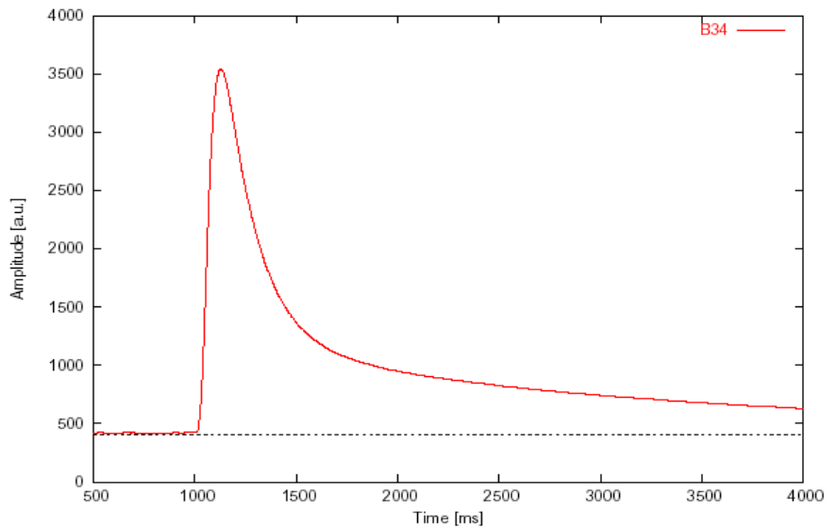




$$\Delta T = \frac{E}{C}$$

$$\tau = \frac{C}{G}$$



Absorber crystal: TeO2
- M = 750 g
- C = 2x10-9 J/K
- ΔT = 0.1 mK/MeV
- τ ~1 sec

Sensor: NTD Ge thermistor
- $R = R_0 \exp(T_0/T)^{1/2}$
- R_0 = 1 Ω, T_0 = 3-4 K
- R = 100 MΩ
- ΔR = 3 MΩ/MeV, ΔV = 0.3 mV/MeV

Dark Matter

Goal: direct detection of WIMPs via scattering on a nucleus

→ signature: nuclear recoil

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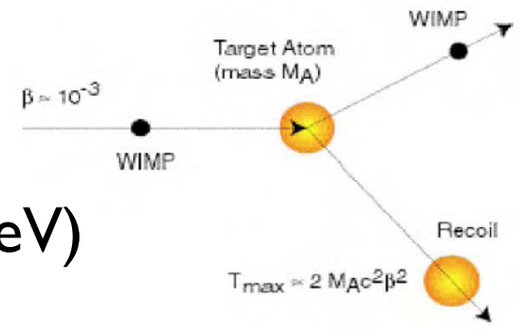
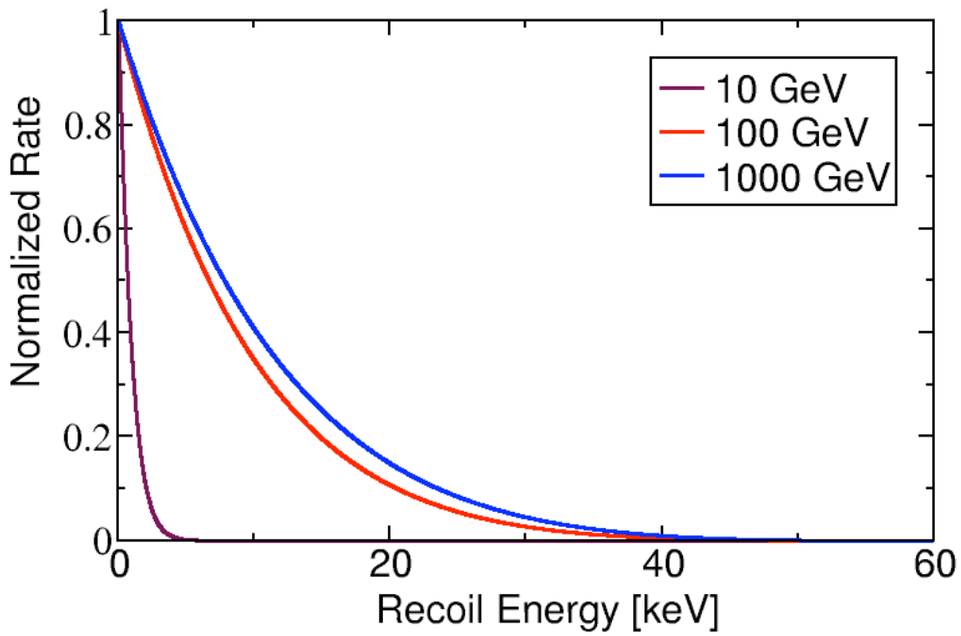
  - Very low energies: <O(10 keV)
  - Low rates: < O(1 kg^{-1} y^{-1})





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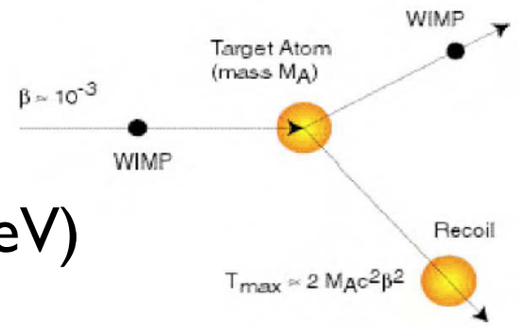
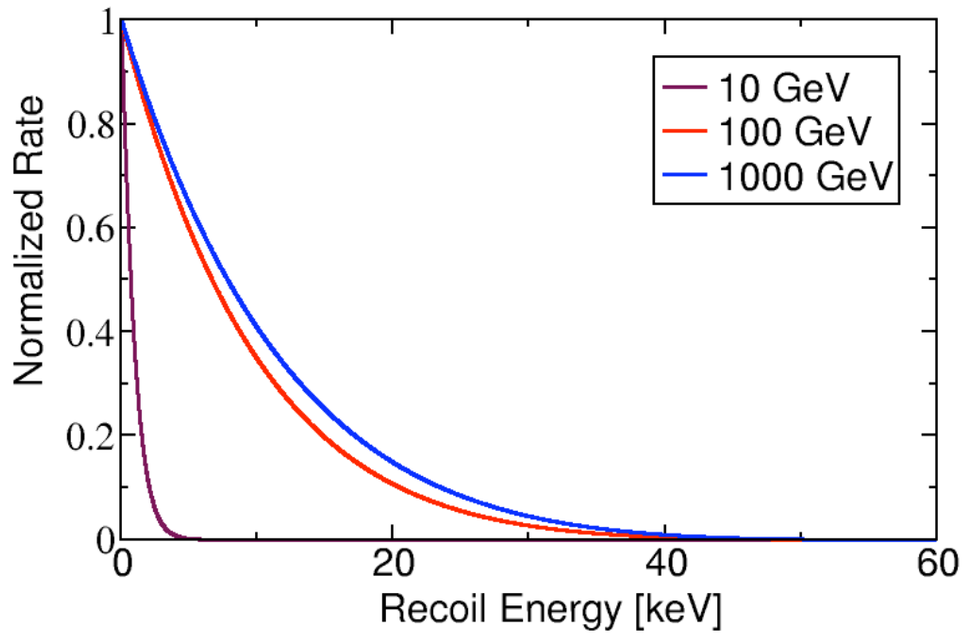
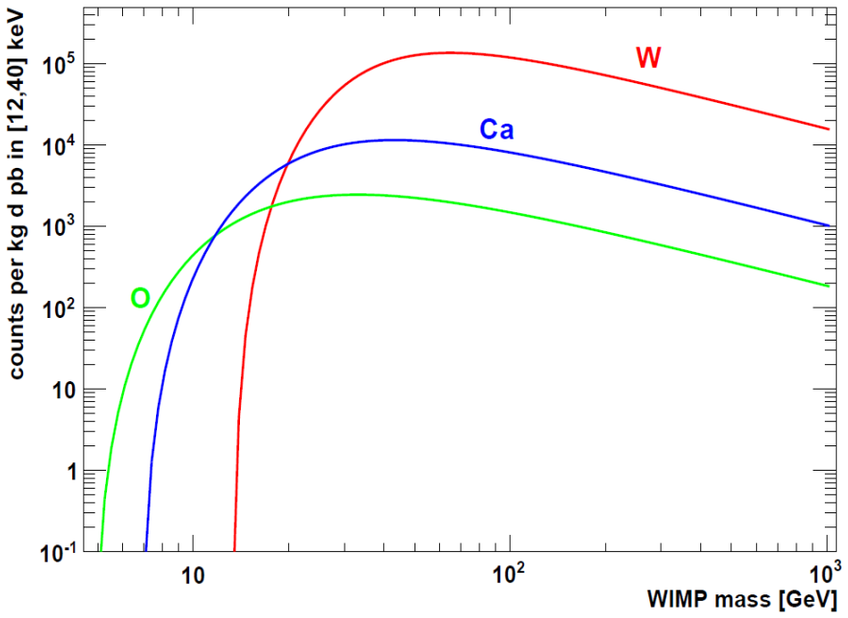




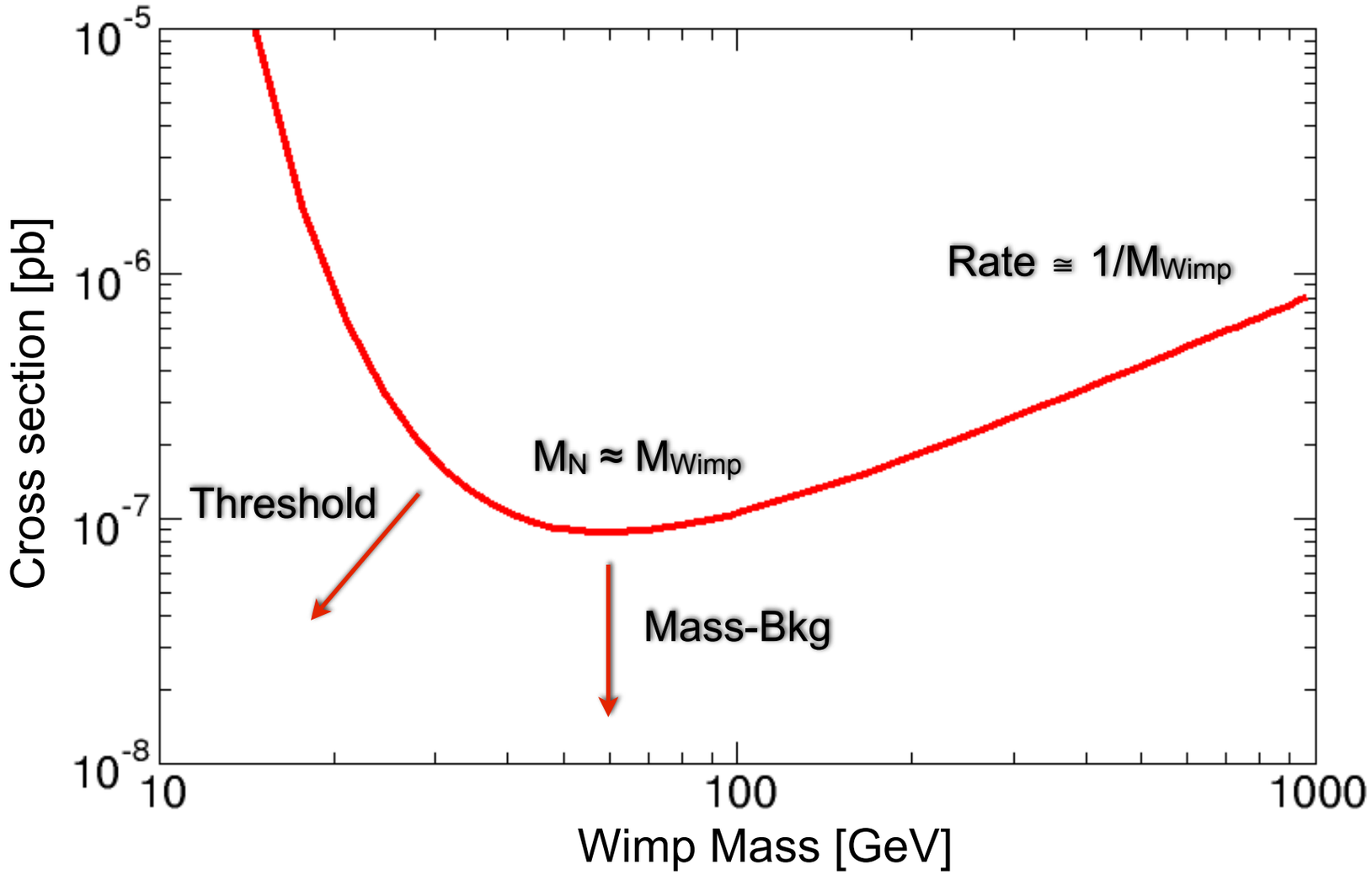
- Challenges:
  - Very low energies: <O(10 keV)
  - Low rates: < O(1 kg^{-1} y^{-1})

- Coherent scattering
  - $\sigma \propto A^2$: scattering in $CaWO_4$ dominated by W
  - light WIMPs (m_X< 20 GeV): W becomes negligible



CRESST

DM sensitivity



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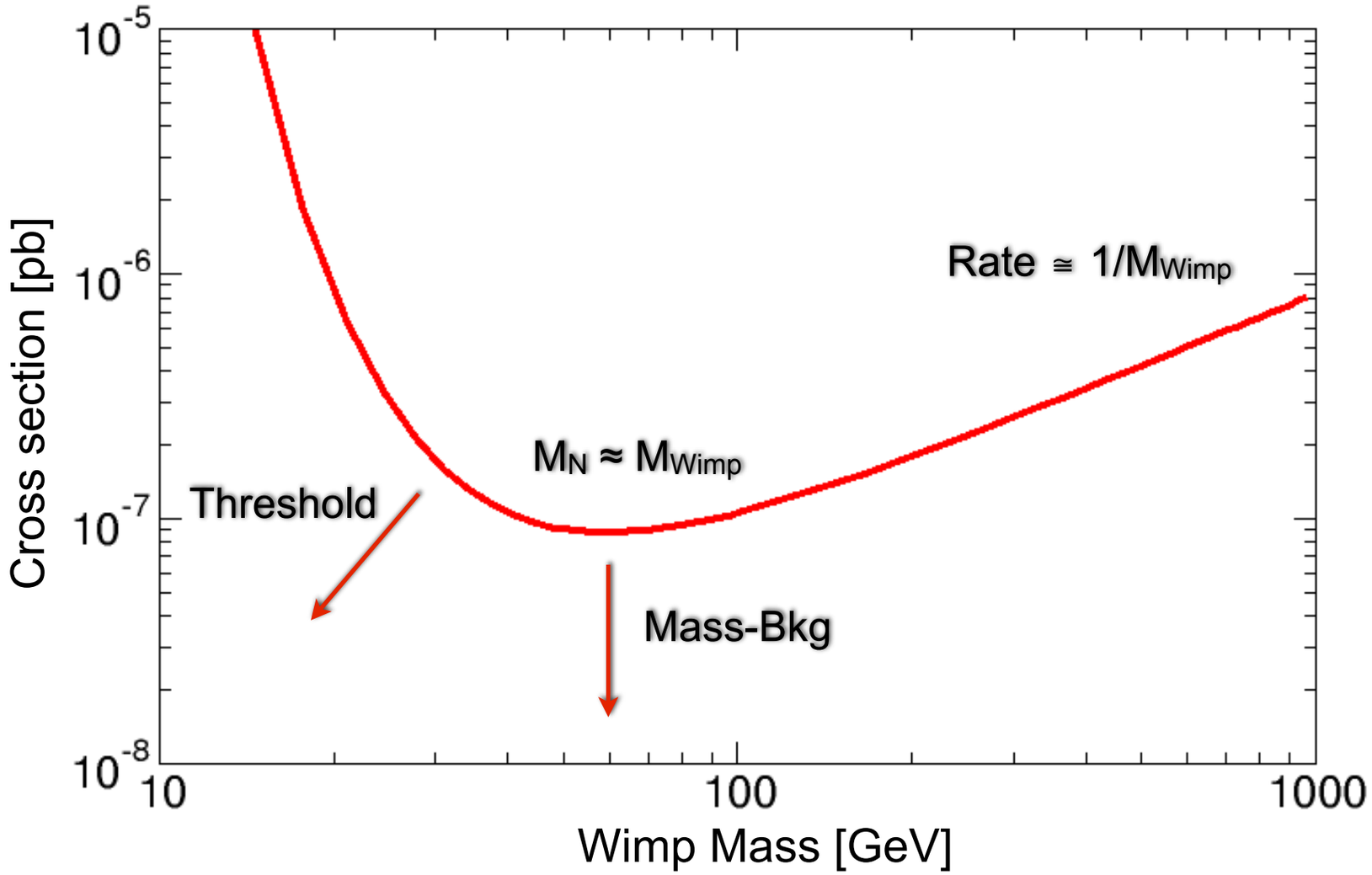
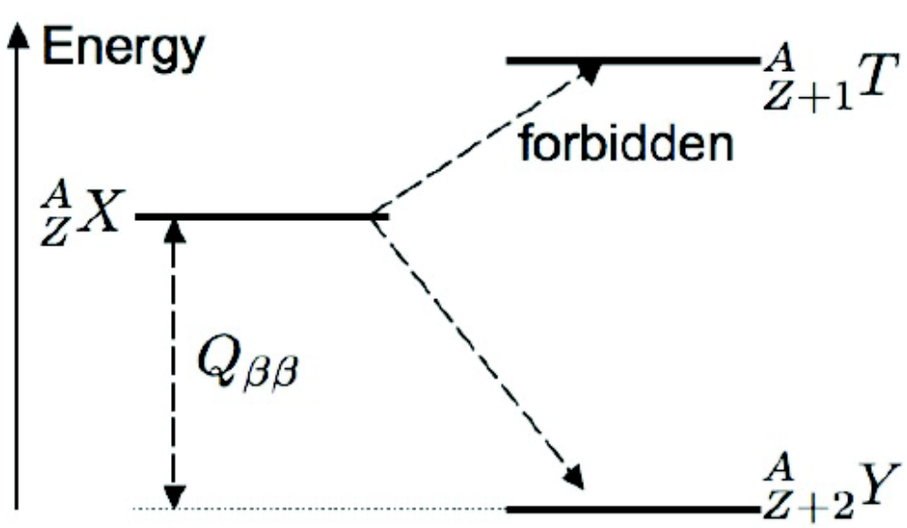
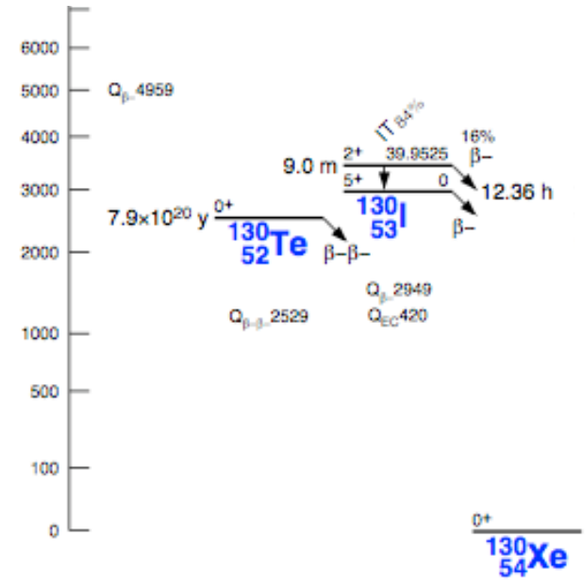


- Ideal experiment
  - Low bkg
  - Low threshold
  - Possibility of choosing target nucleus (multiple target nuclei)

Double Beta Decay (I)

2ν-DBD (M.Goeppert-Mayer, 1935) is an extremely rare second order process allowed by SM. It take place when both the parent and the daughter nuclei are more bound than the intermediate one (or the transition on the intermediate one is strongly suppressed). Because of the pairing term, such a condition is fulfilled in nature for a number of even-even nuclei.





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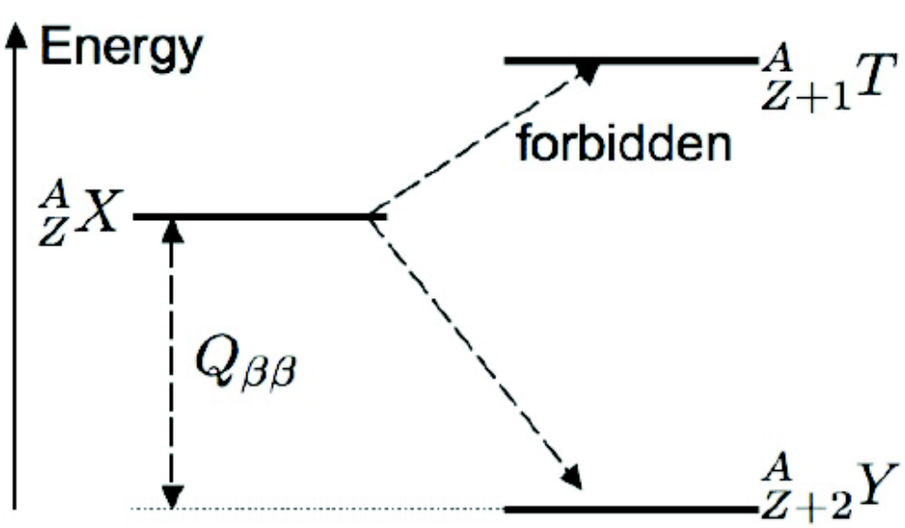
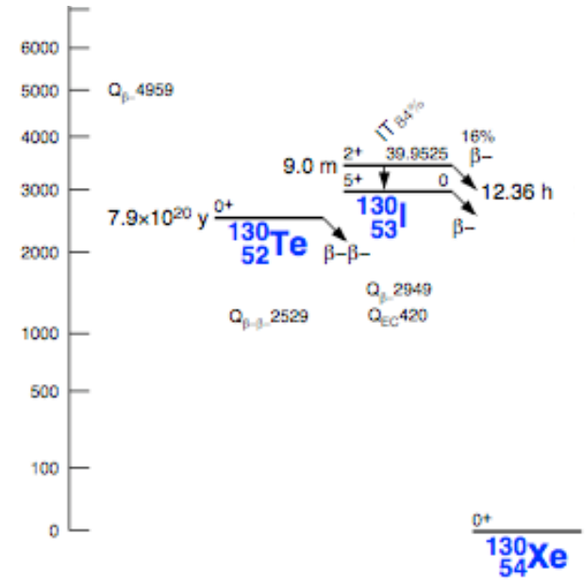
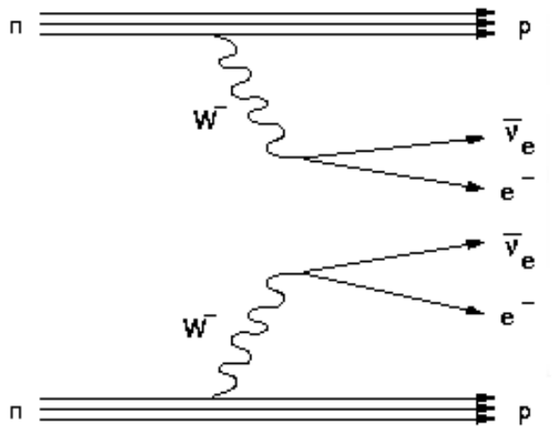




2ν-DBD: (A,Z) → (A,Z+2) + 2e⁻ + 2ν



- Extremely rare second order process allowed by SM
- Observed for several nuclei
- Process: $\tau^{0\nu} \sim 10^{19}$-10^{21} y

Double Beta Decay (II)

0ν-DBD (W.H.Furry, 1939) is a lepton number violating (ΔL=2), not allowed by the Standard Model. The 0νDBD can occur only if two requirements are satisfied: i) the neutrino has to be a Majorana particle, and ii) the neutrino has to have a non-vanishing mass.

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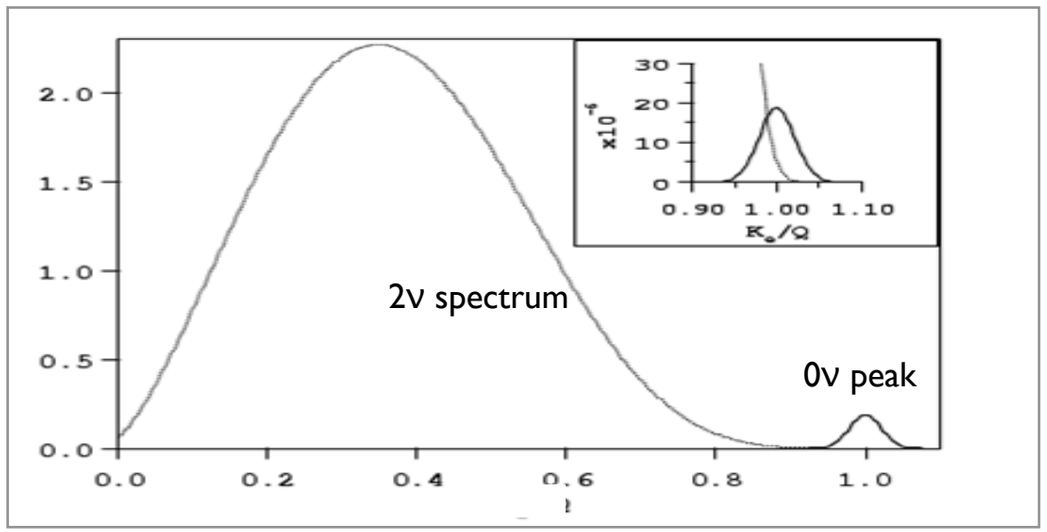
If 0ν-DBD is observed: neutrino is a Majorana particle and m_ν is measured

Schetcher, Valle Phys. Rev. D25 2951 1982

For $2e^-$ sum energy, expected signature is a peak with $E \equiv Q_{\beta\beta}$



Double Beta Decay (III)

$$(T^{0\nu}_{1/2})^{-1} = G(z,Q)|M|^2\langle m_\nu\rangle^2$$

Atomic physic:
phase space term
$O(Q^5)$

Nuclear physic:
nuclear matrix elements
(big uncertainties!)

Particle physics:
neutrino mass
(neutrino propagator)

$$|<m_\nu>| = |\ m_1|U_{e1}|^2 + m_2|U_{e2}|^2 e^{i\alpha} + m_3|U_{e3}|^2 e^{i\beta}\ |$$

Majorana phases

Parameterizing $m_2 = \sqrt{\Delta m^2_{sol} + m_1^2}$

$m_3 = \sqrt{\Delta m^2_{atm} + m_1^2}$ → $|<m_\nu>| = f(m_1)$

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Majorana phases

Parameterizing

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$$m_3 = \sqrt{\Delta m^2_{atm} + m_1^2}$$

$$\Rightarrow \quad |\langle m_\nu\rangle| = f(m_1)$$

Measuring 0ν-DBD it is a unique tool to measure m_ν and the ν mass the hierarchy

Sensitivity (I)

Half-life corresponding to the maximum signal n_B that could be hidden by the background fluctuations at a given statistical C.L.

$$S_{0\nu} \propto i.a. \cdot \sqrt{\frac{M \cdot T}{\Gamma \cdot b}}$$

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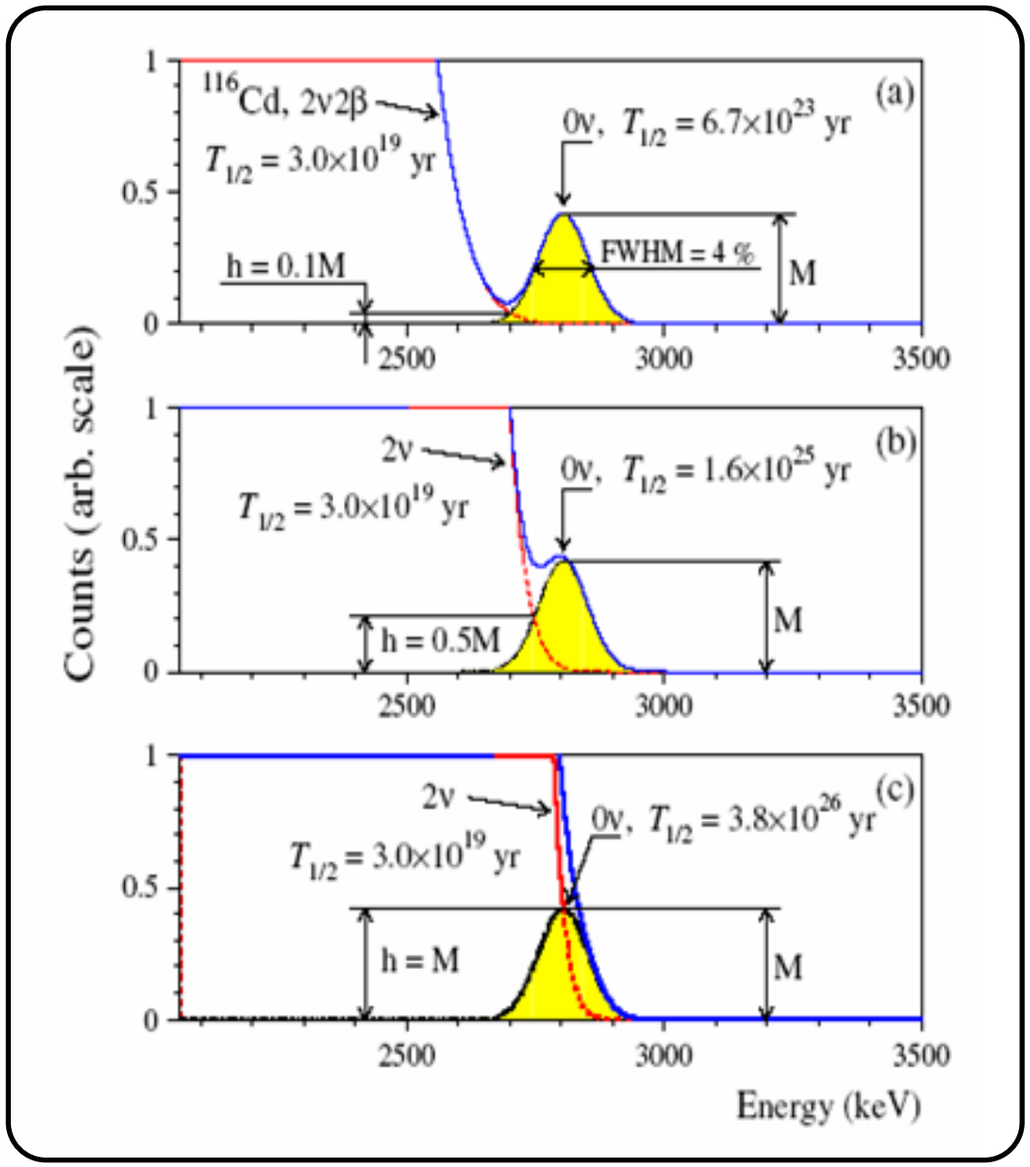
Background: currently this is the ONLY tunable parameter to push sensitivities of order of magnitudes.

Sensitivity (II): discovery potential

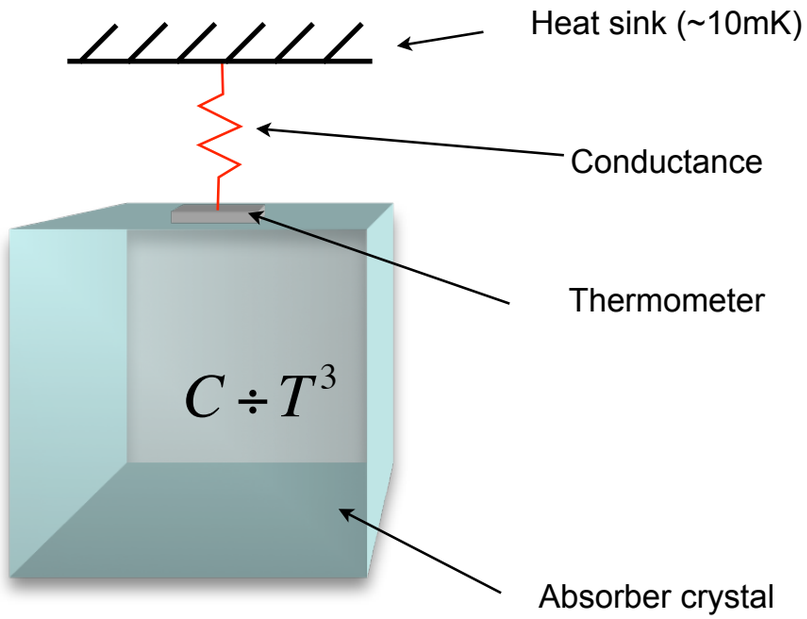


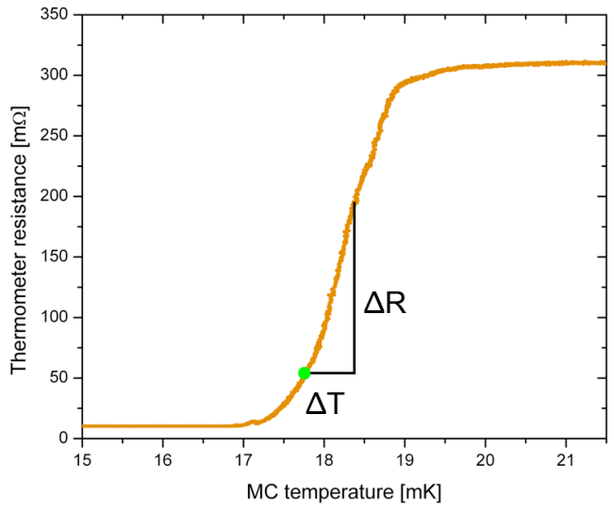
Yu.G. Zdesenko, F.A. Danevich and V.I. Tretyak
J.Phys. G: Nucl. Part. Phys. 30 (2004) 971

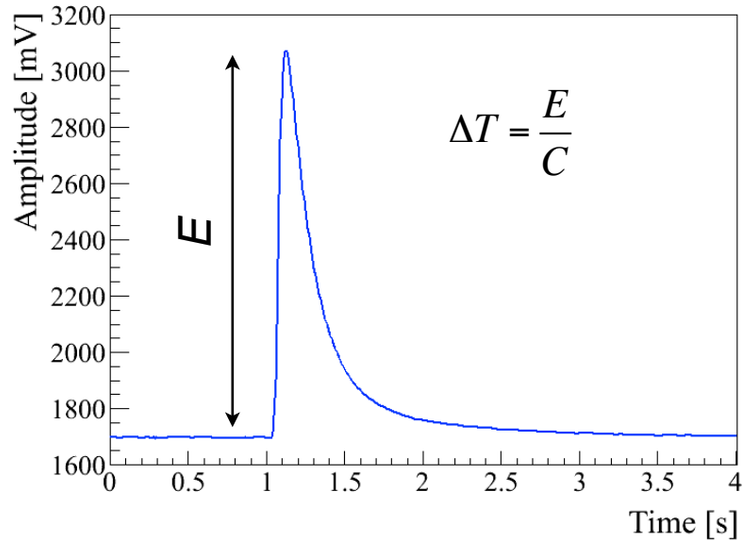
2νDBD is an unavoidable background for any 0νDBD (neutrino tagging?).

Energy resolution is a crucial parameter for any experiment aiming to measure 0νDBD and not just increasing the sensitivity on the not observed process.

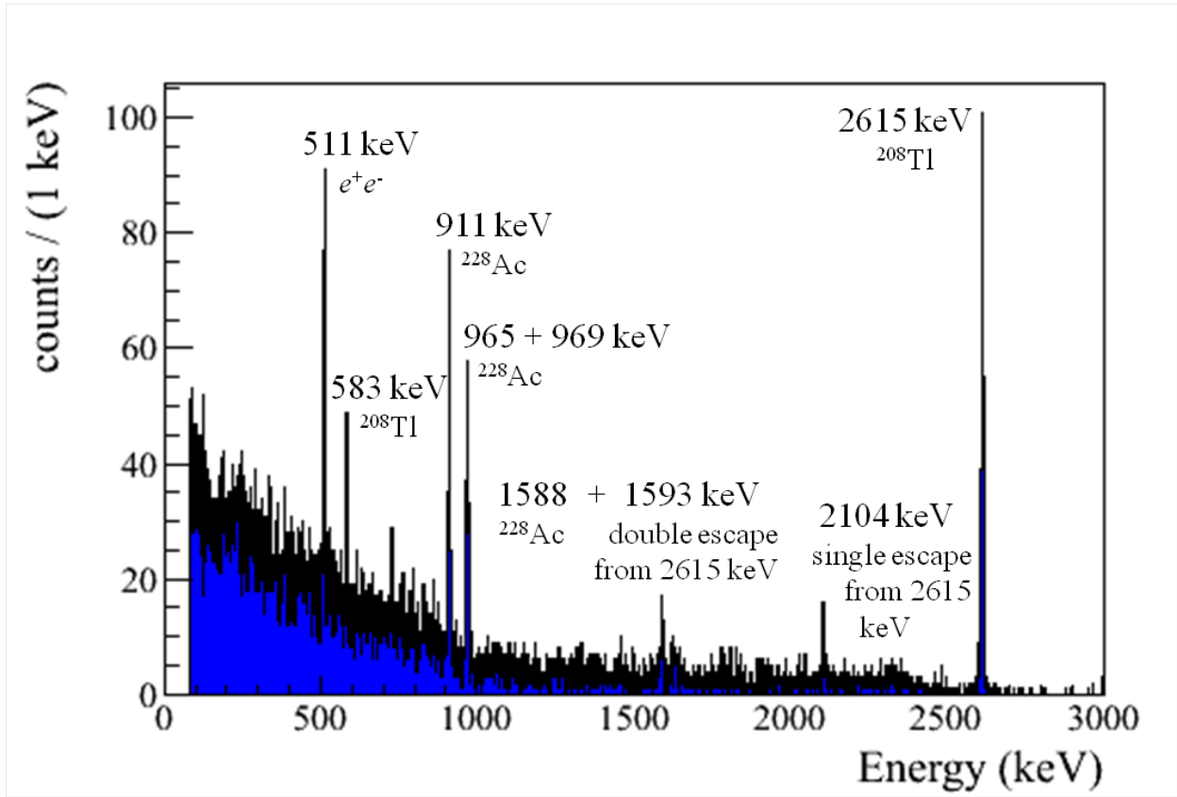
Thermal detectors: summary (I)







Advantages:



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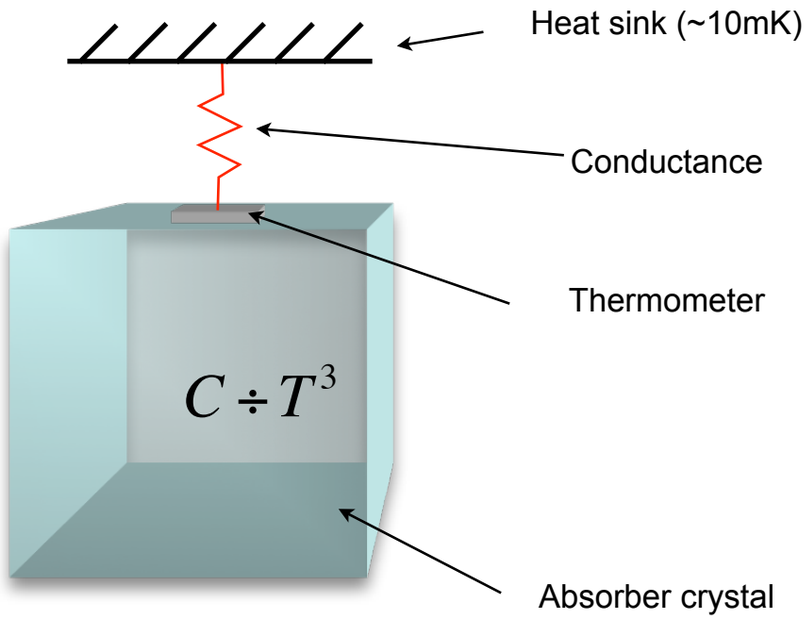
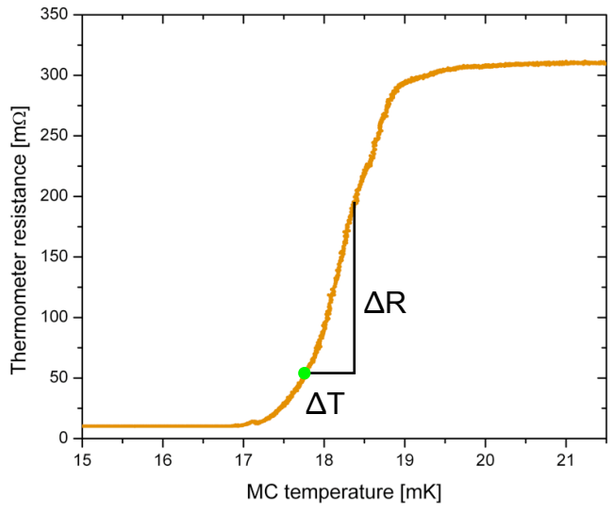
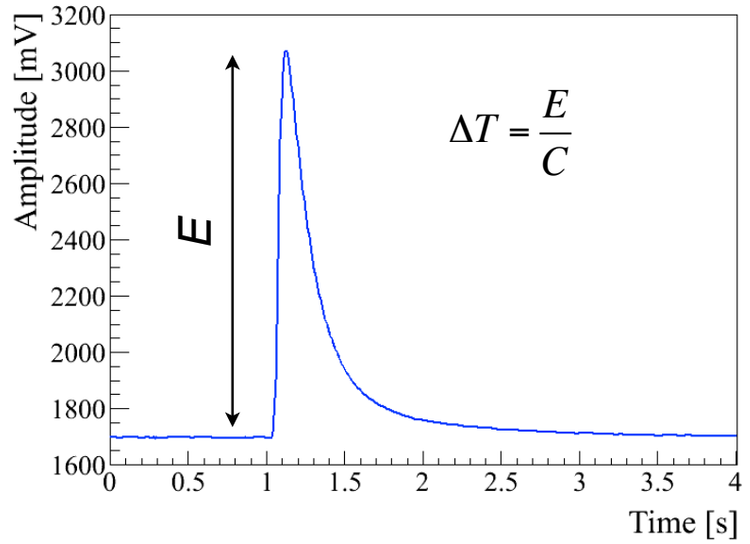
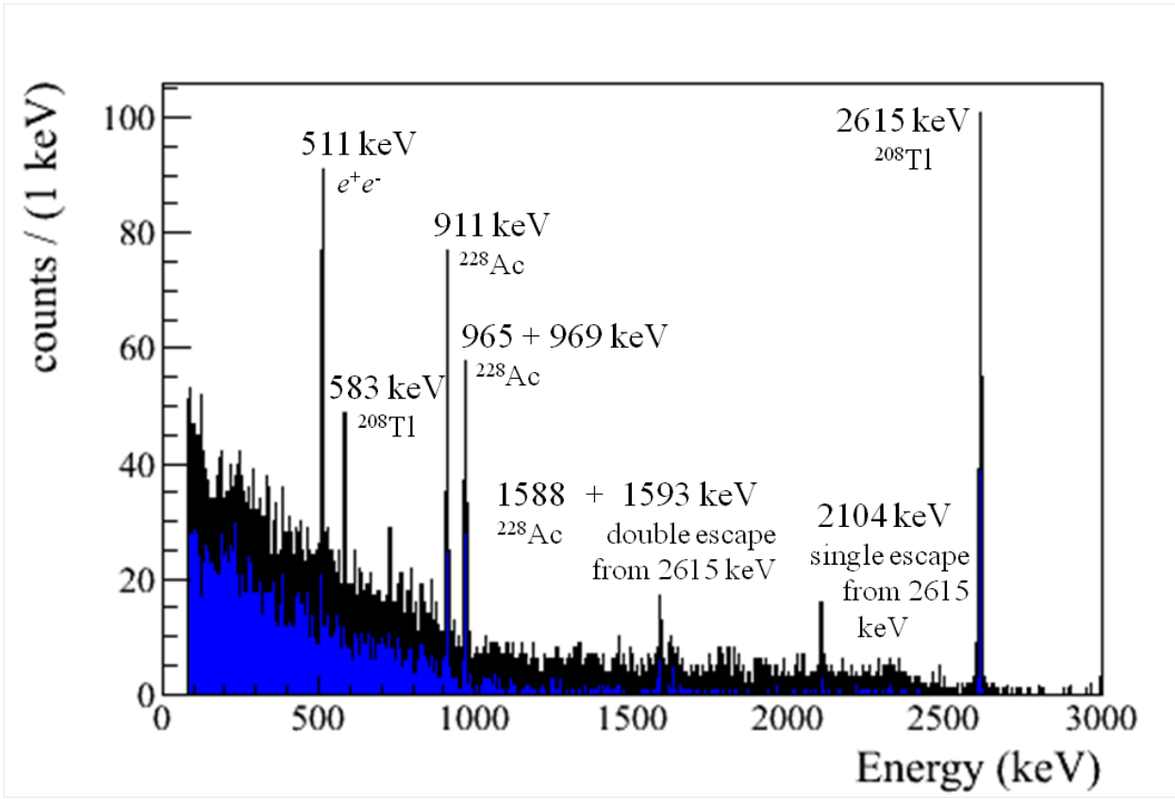






Advantages:

- Wide choice of materials: TeO_2, $CaWO_4$, Ge, Si, $Al2O_3$, $CaMoO_4$, BGO, etc. (low C at working T)



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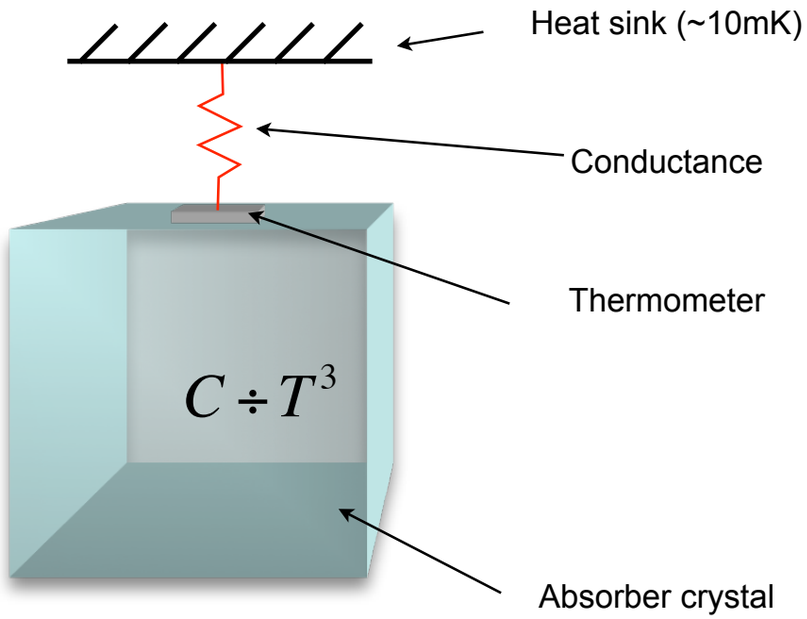

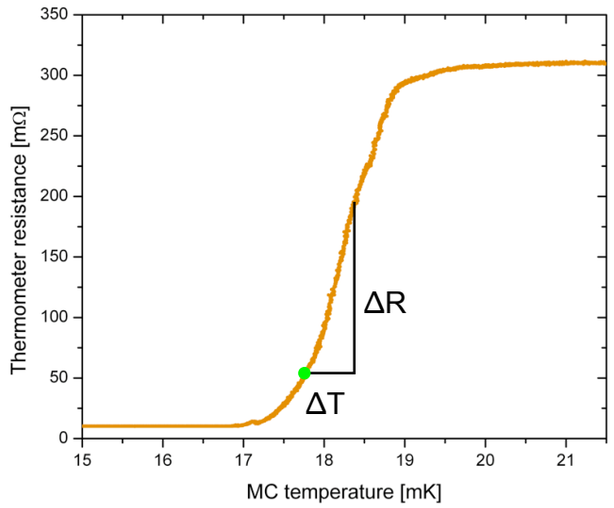

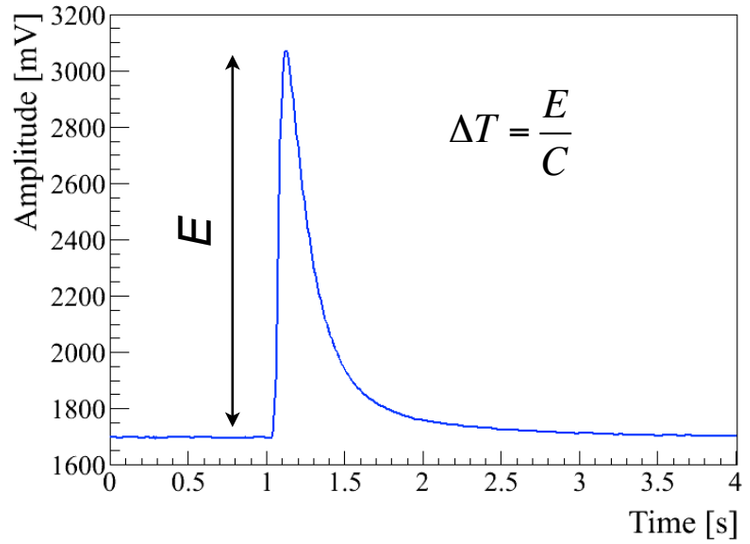

Advantages:

- Wide choice of materials: TeO_2, $CaWO_4$, Ge, Si, $Al2O_3$, $CaMoO_4$, BGO, etc. (low C at working T)
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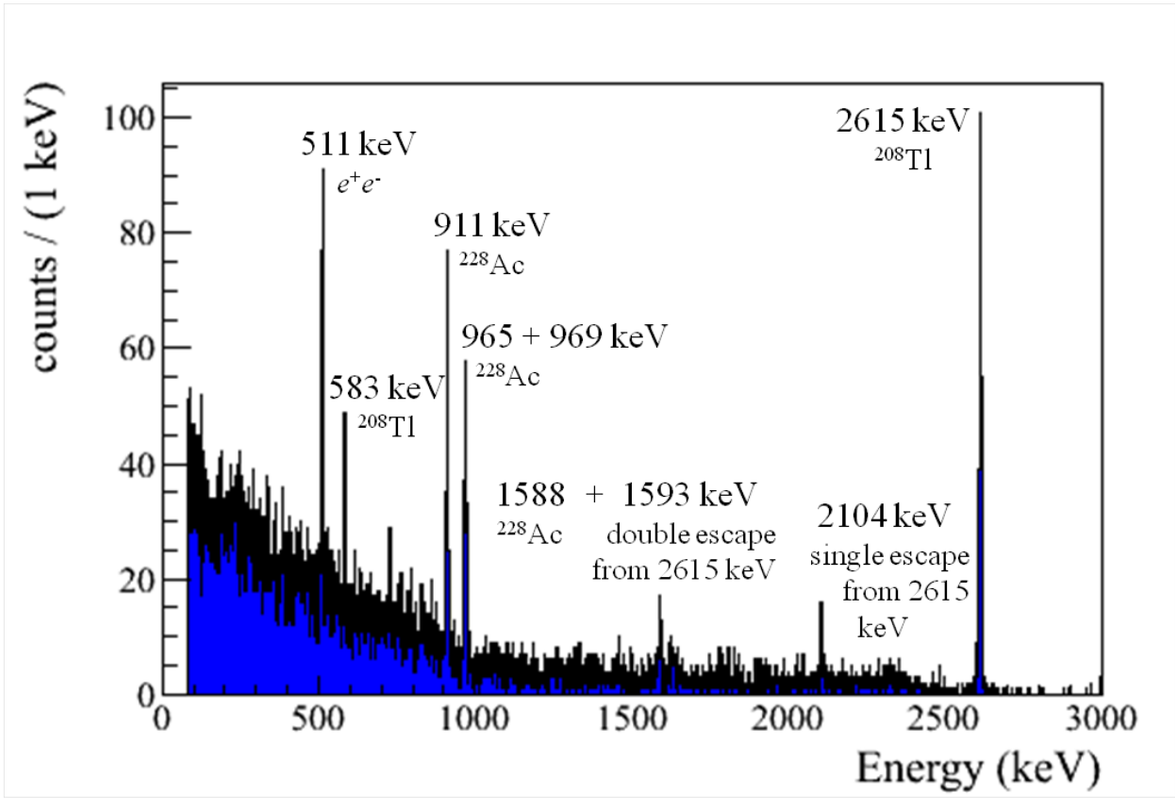
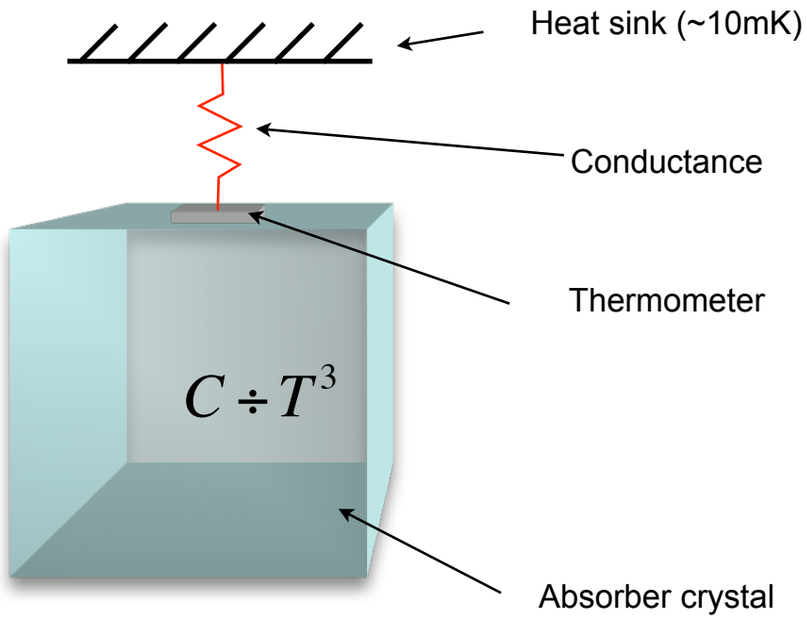
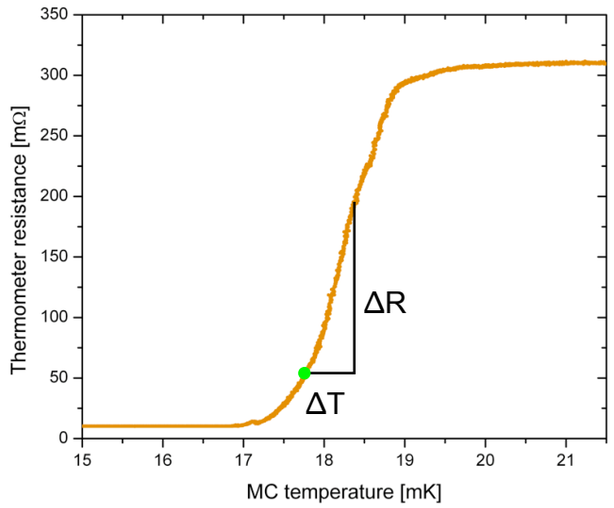
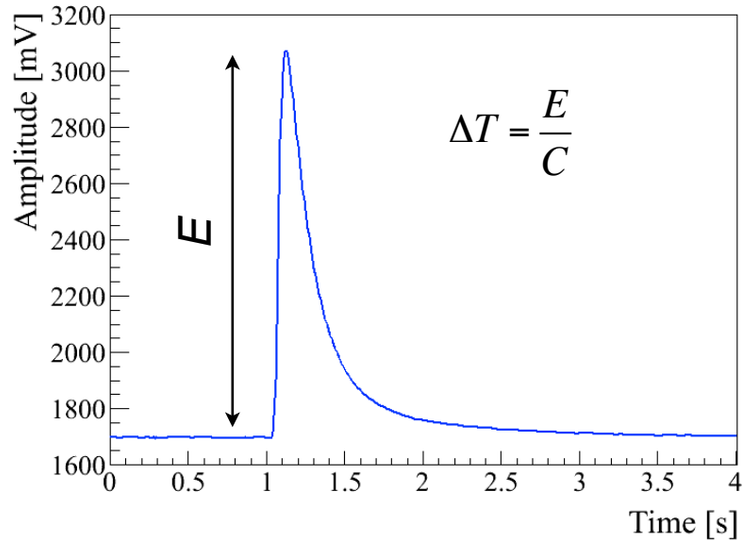


Thermal detectors: summary (I)







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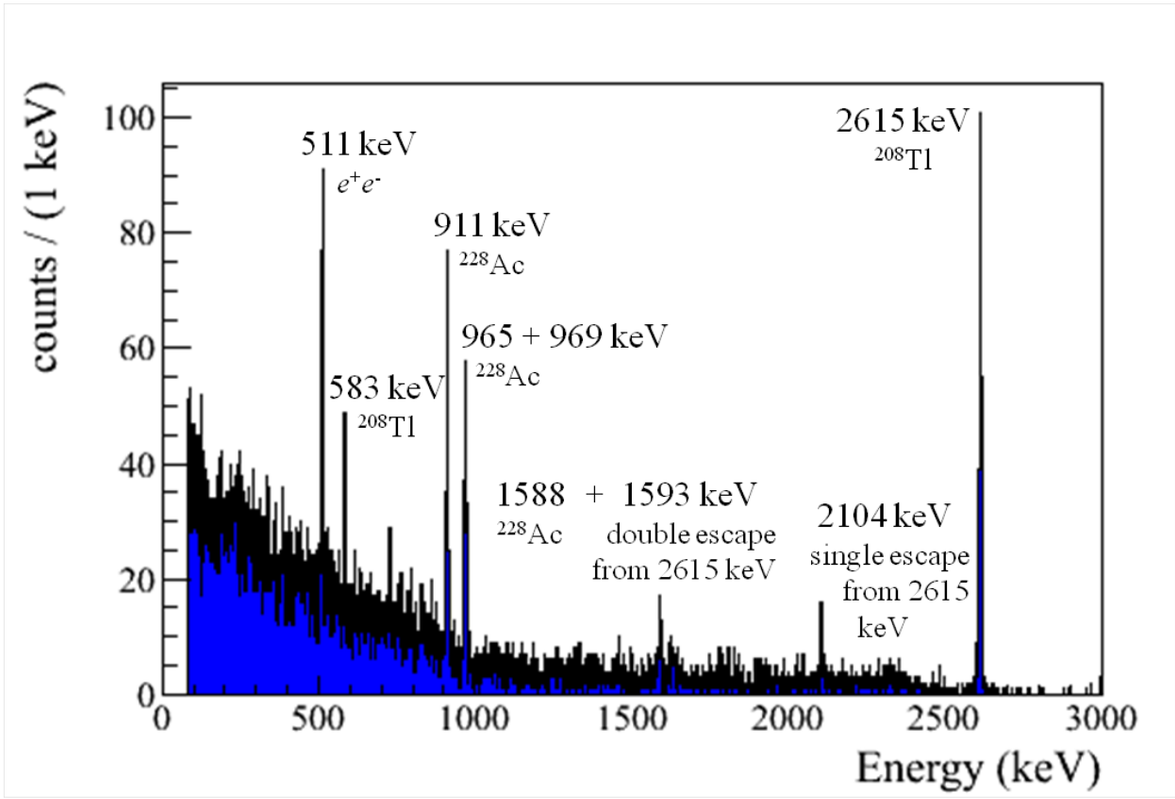
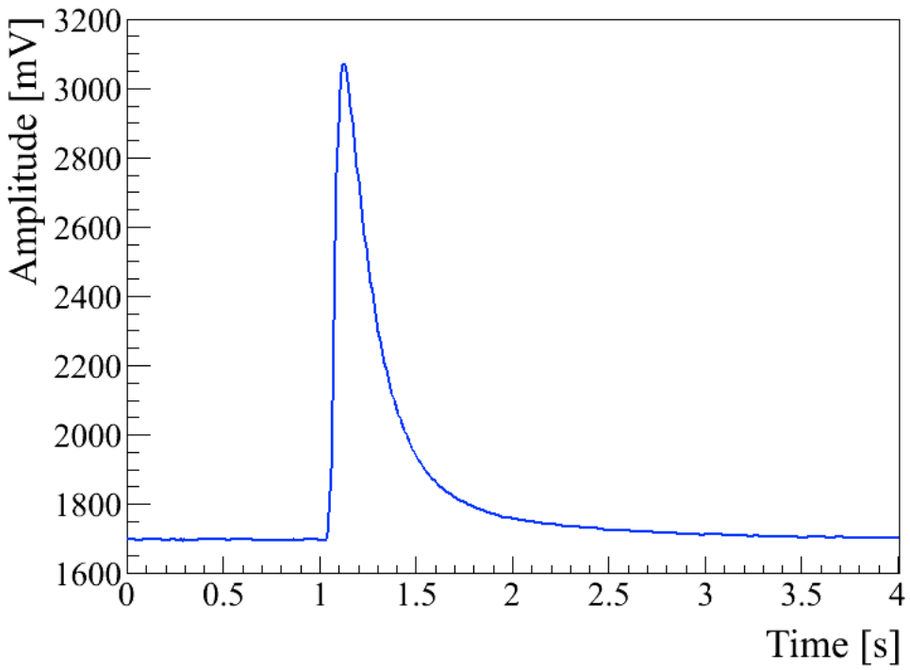
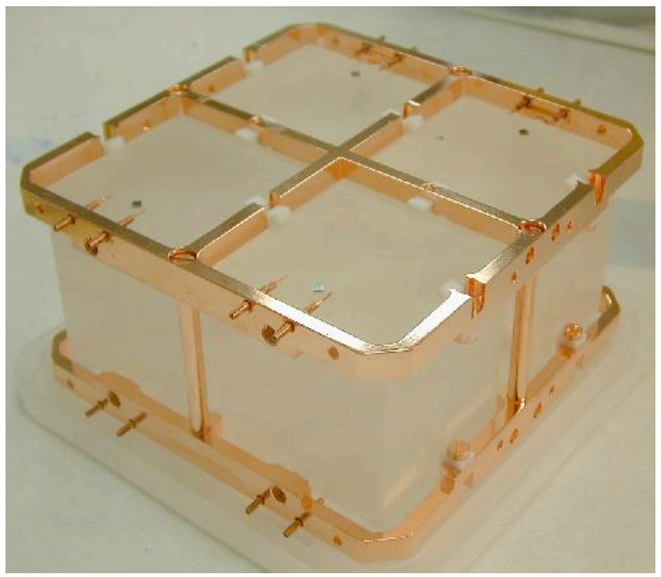
- Detector response independent from the radiation (calorimeters)



Thermal detectors: summary (II)

Disadvantages:

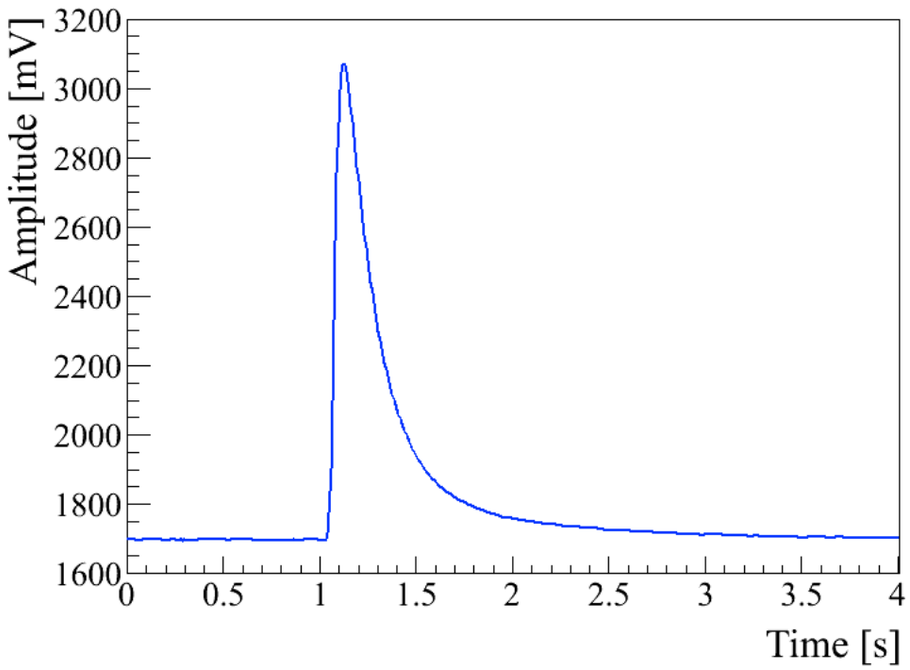


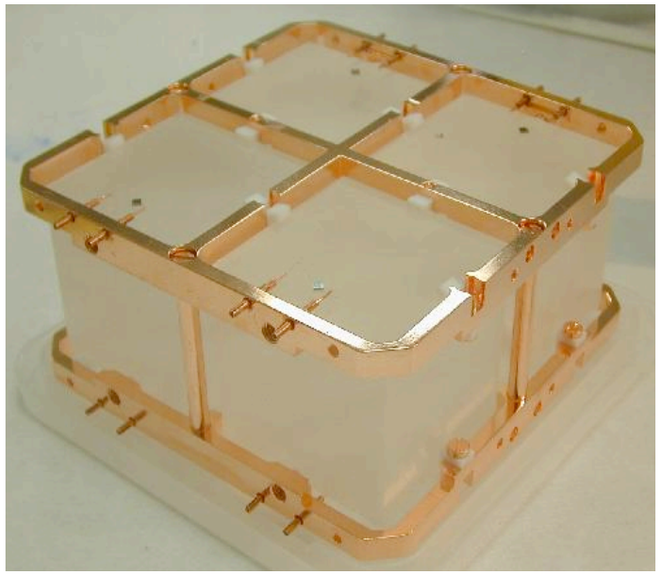


Thermal detectors: summary (II)

Disadvantages:

- Difficult to operate (dilution refrigerators)





Thermal detectors: summary (II)

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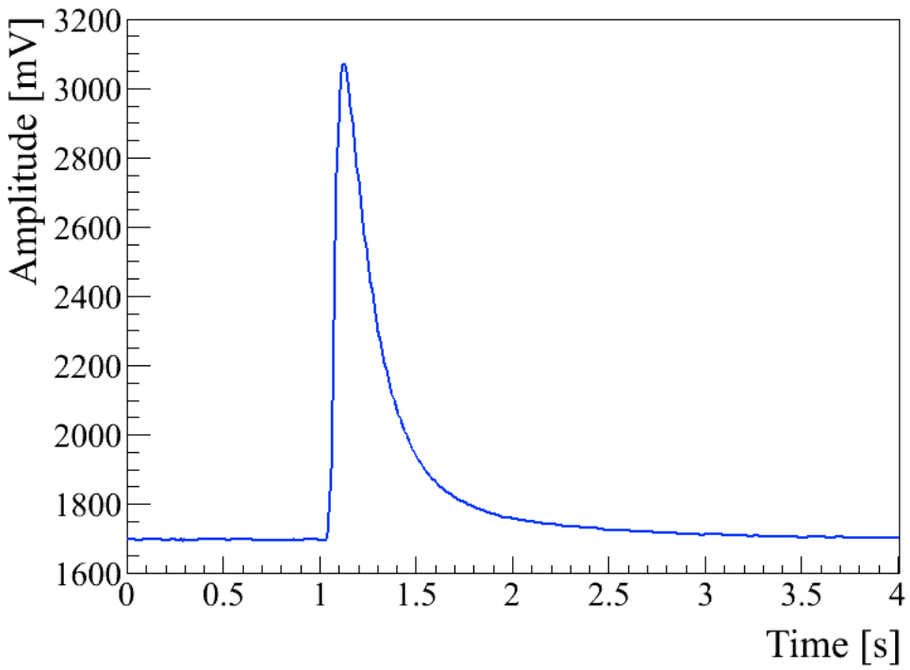
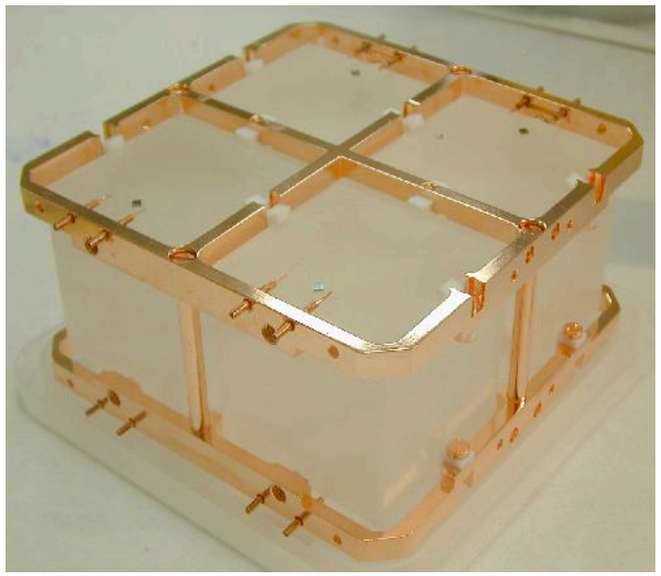
- Very slow response: thermal detectors with mass greater than ~1 g can operate only underground





Thermal detectors: summary (II)

Disadvantages:

- Difficult to operate (dilution refrigerators)
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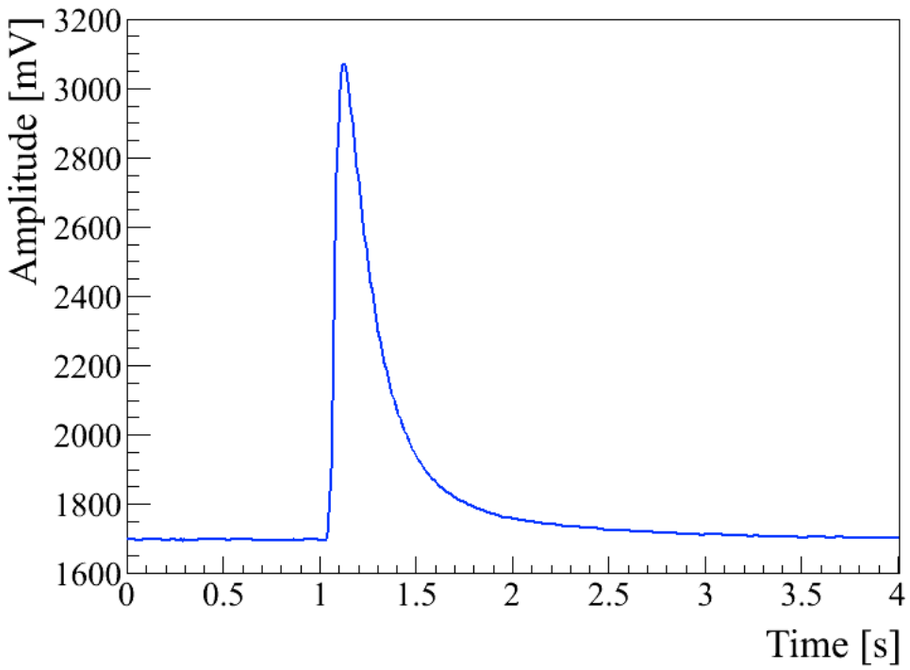
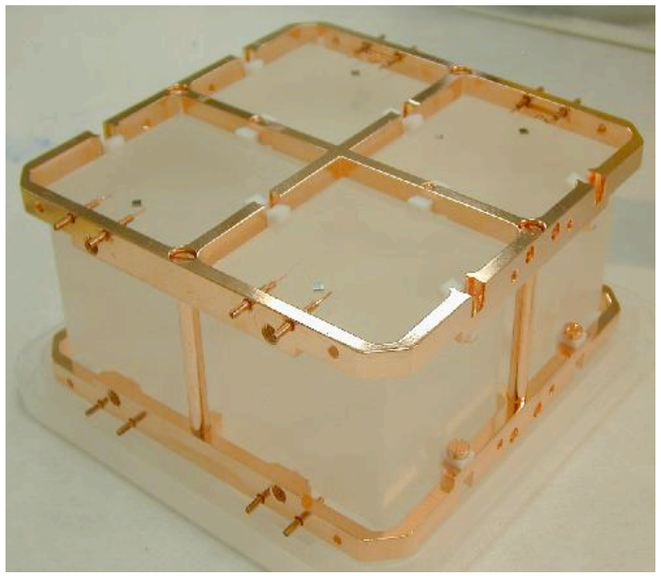
- Operated in vacuum and with no dead layers: exposed to bkg from surface contaminations

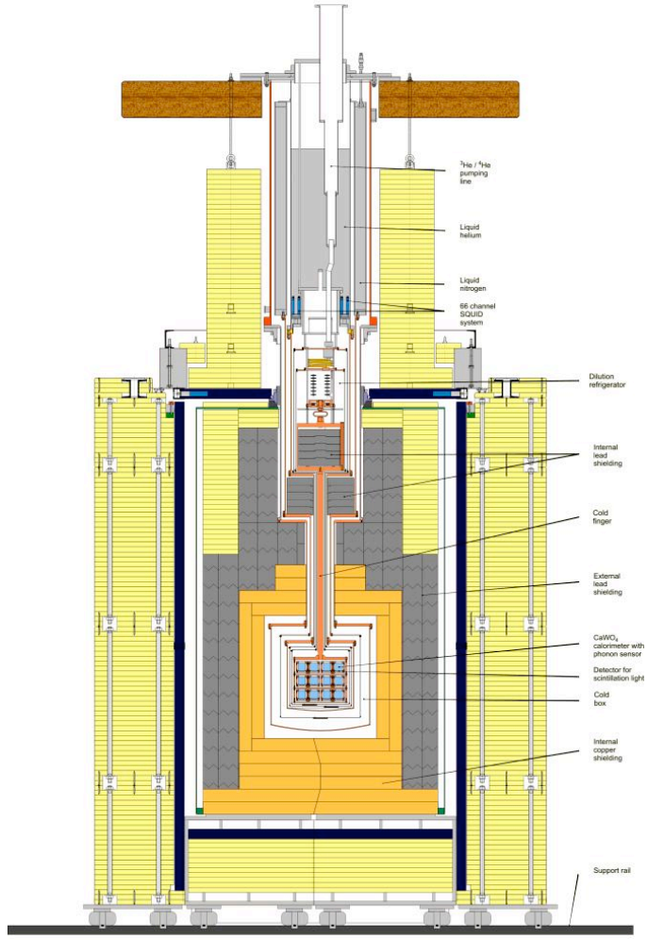


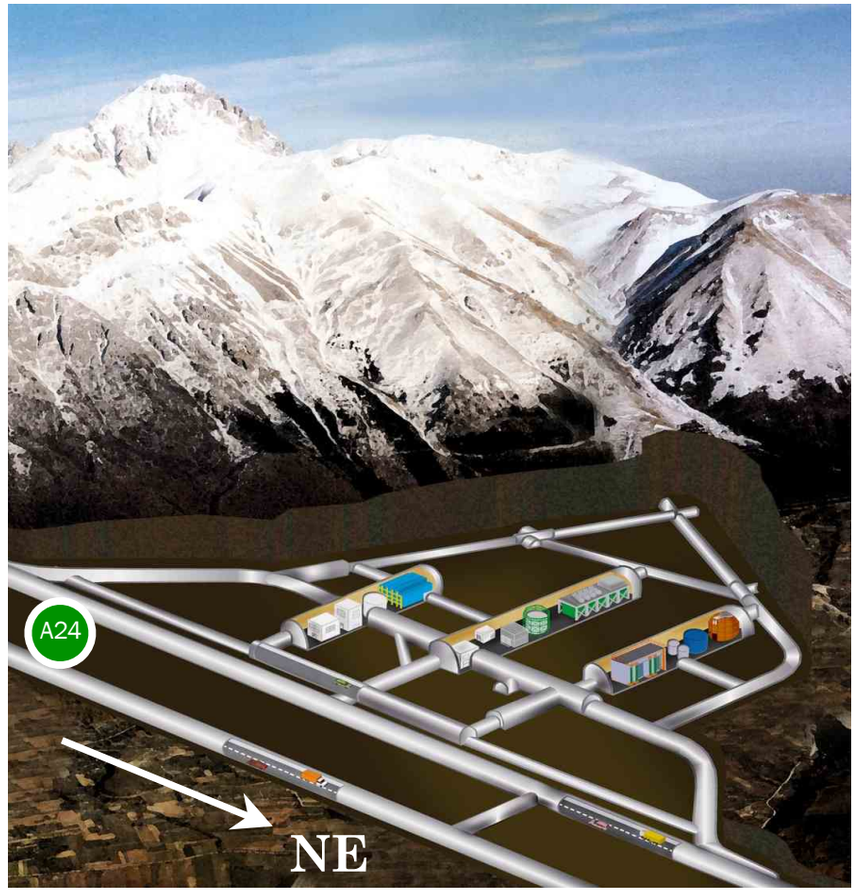


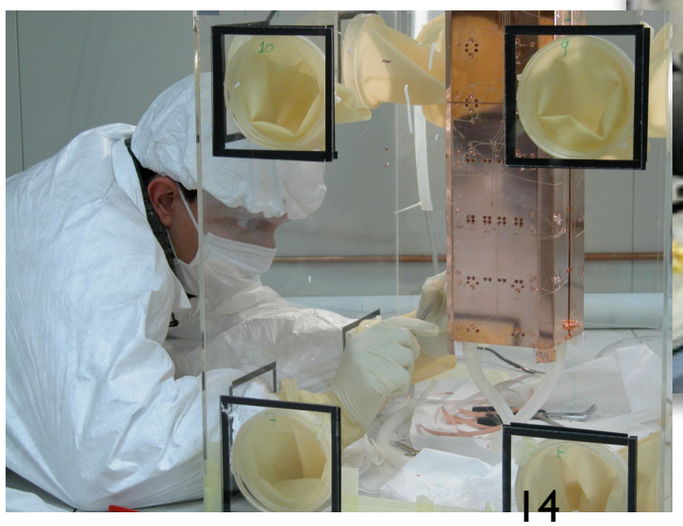
Background reduction

- Cosmic rays:
  - Underground labs
  - Vetos

- Radioactivity
  - Material selection
    - HPGe
    - NAA
    - ICPMS
- Clean Room
- Controlled atmosphere
- Shielding
- Active discrimination?







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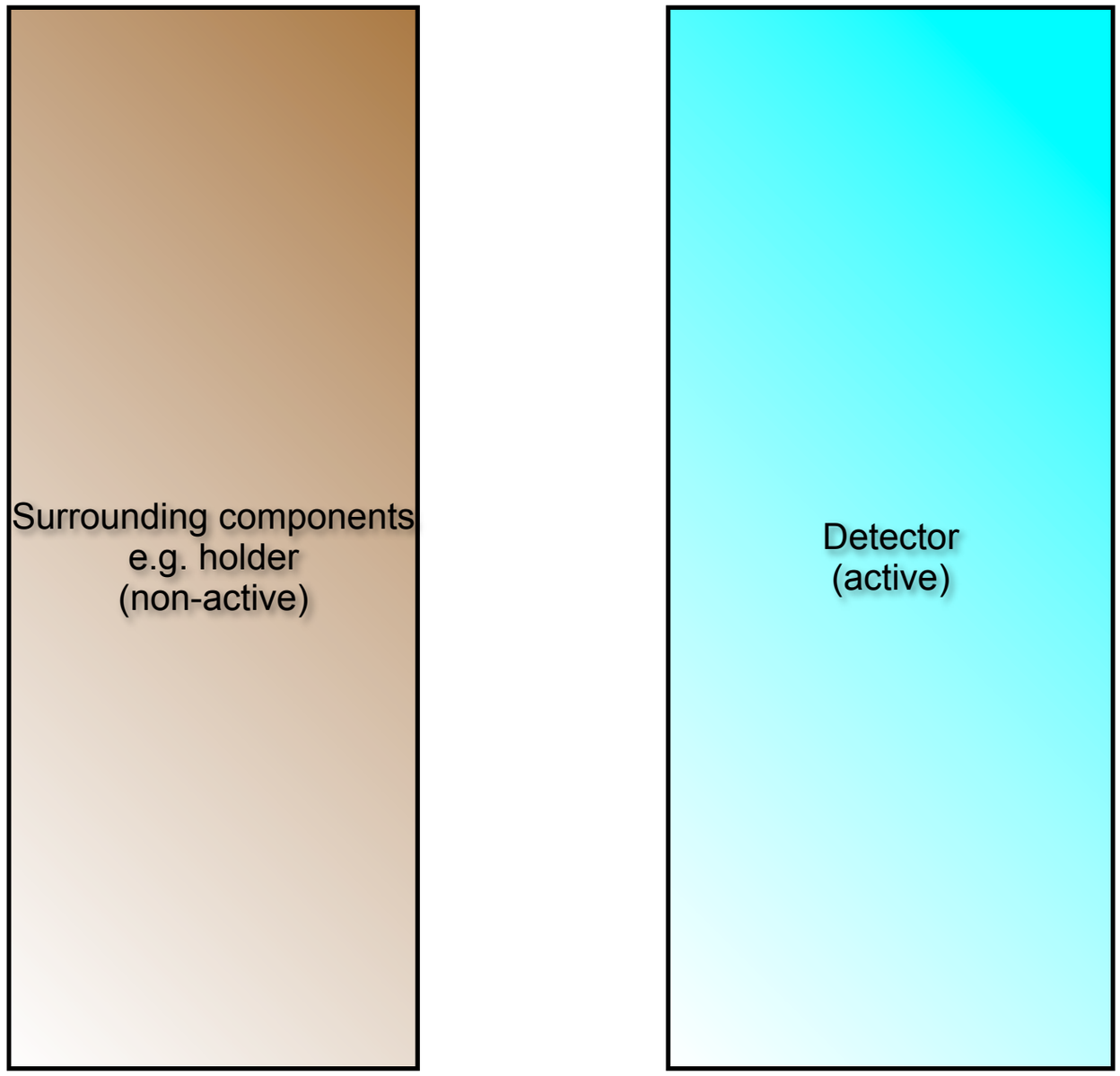

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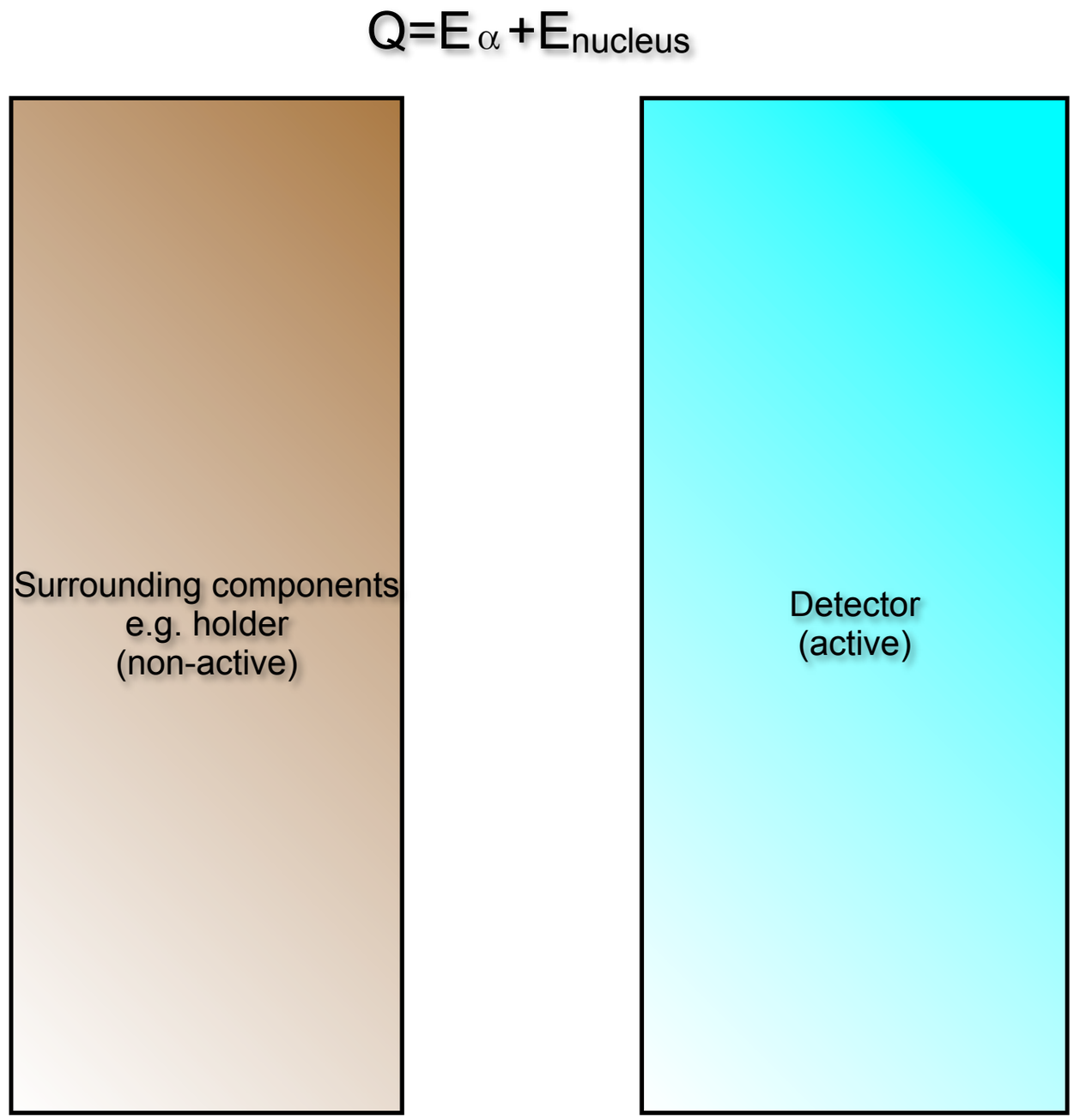

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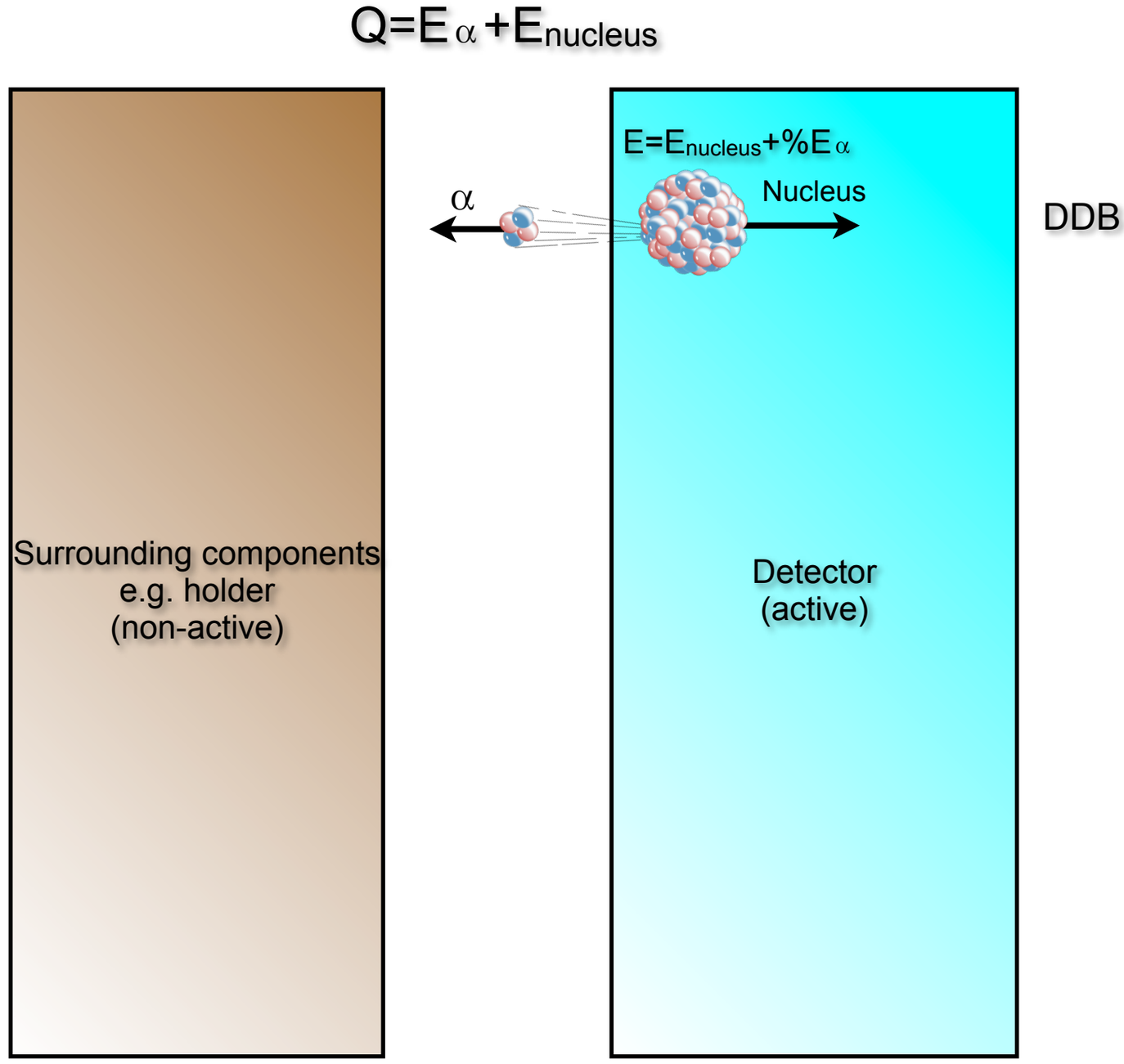

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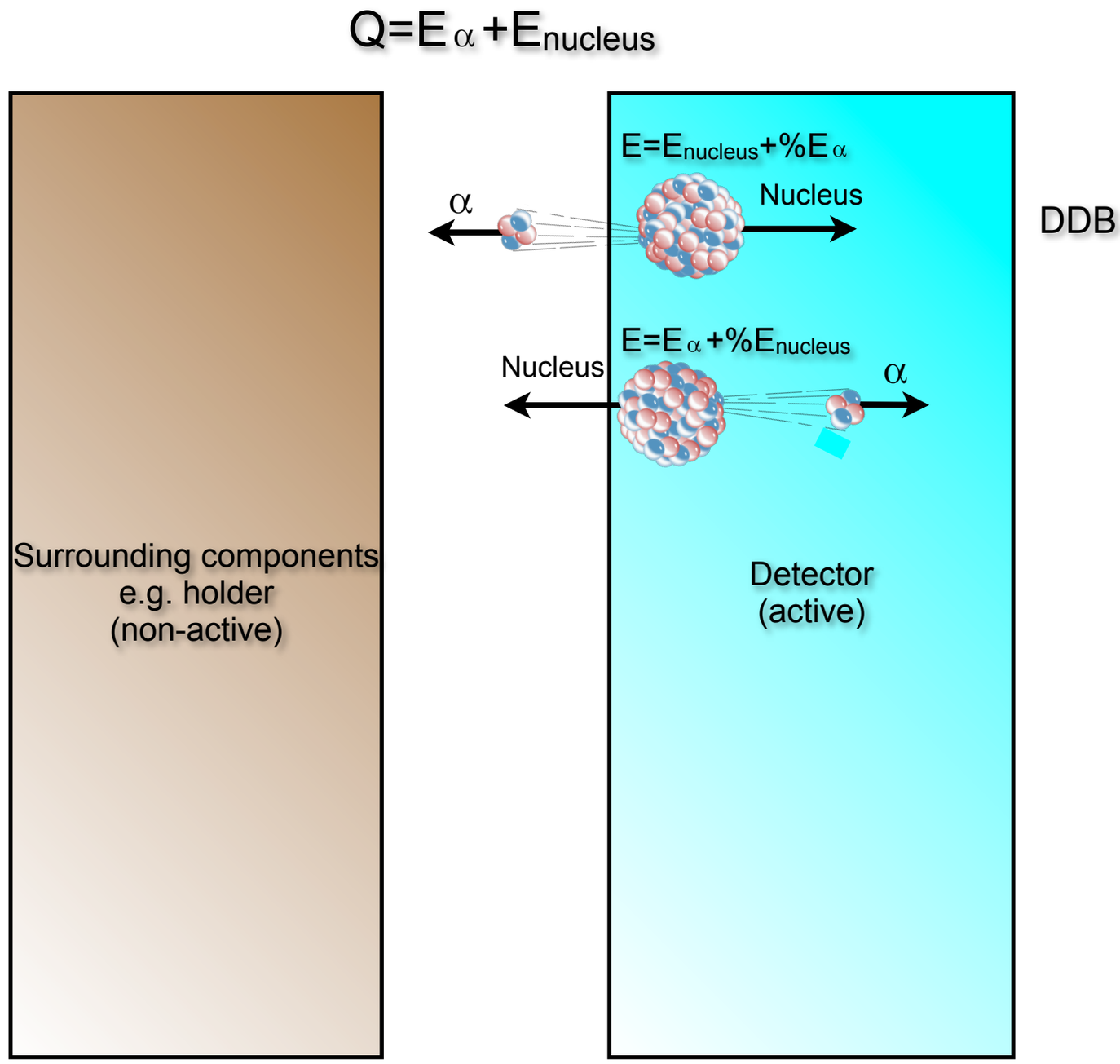

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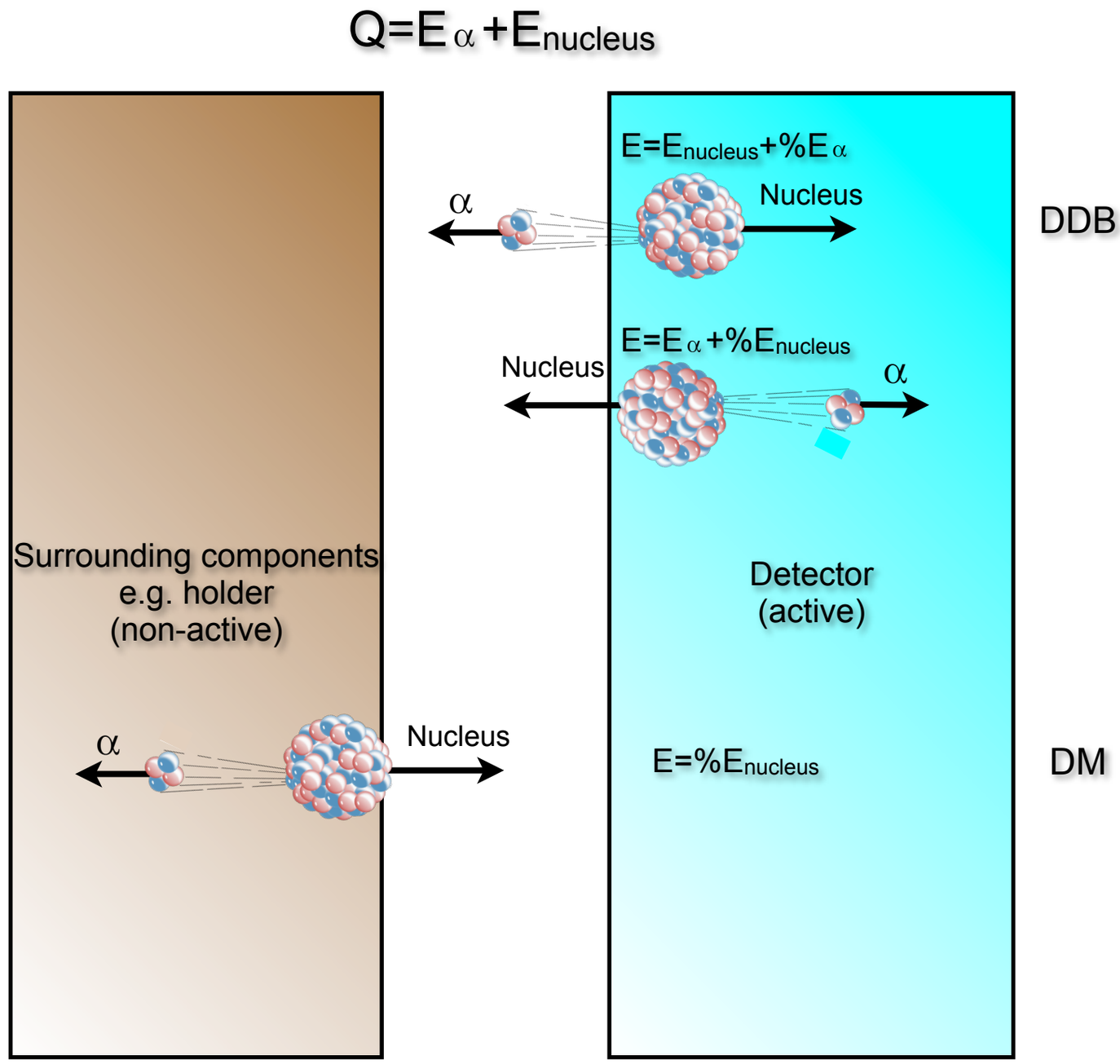

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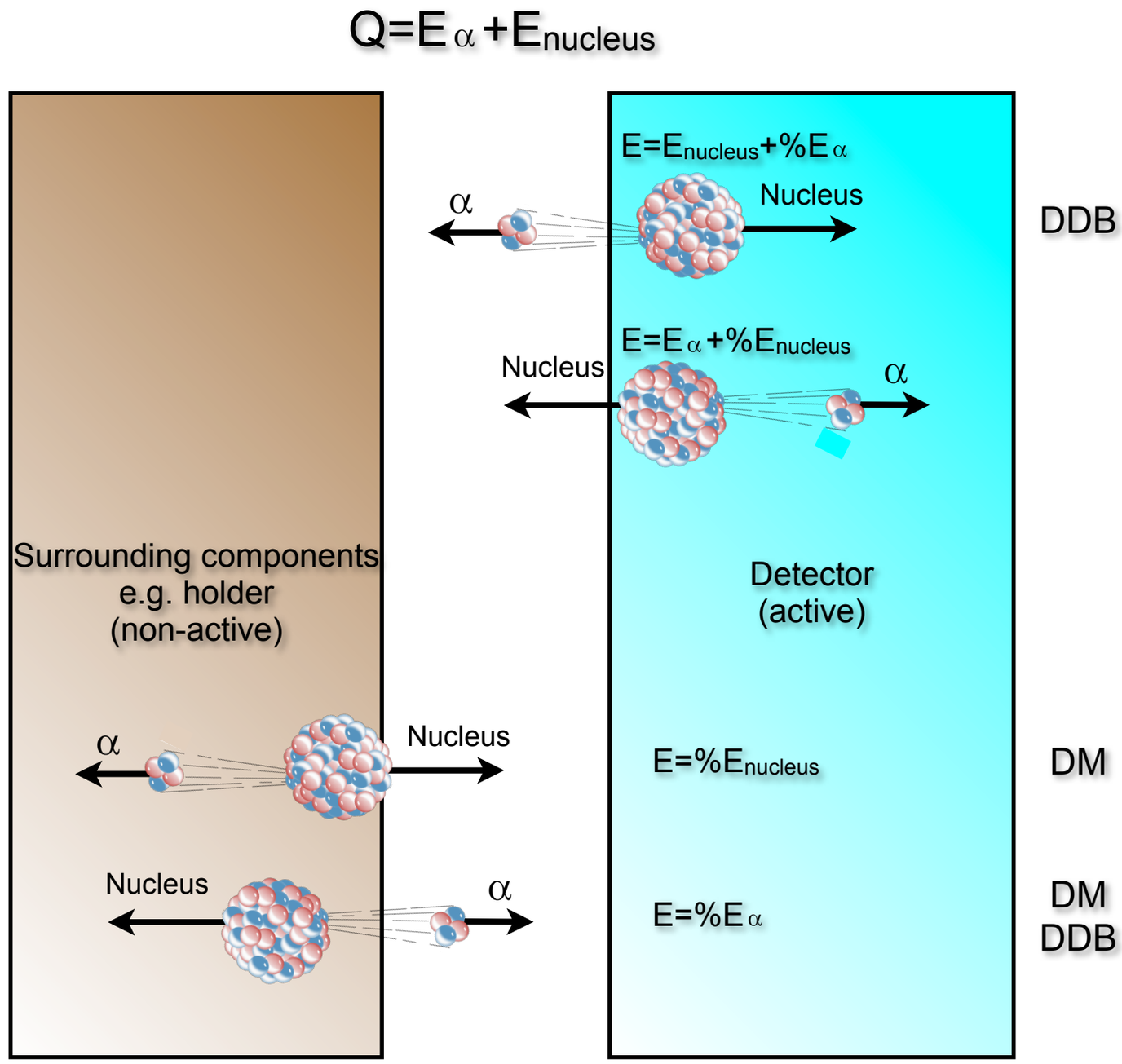

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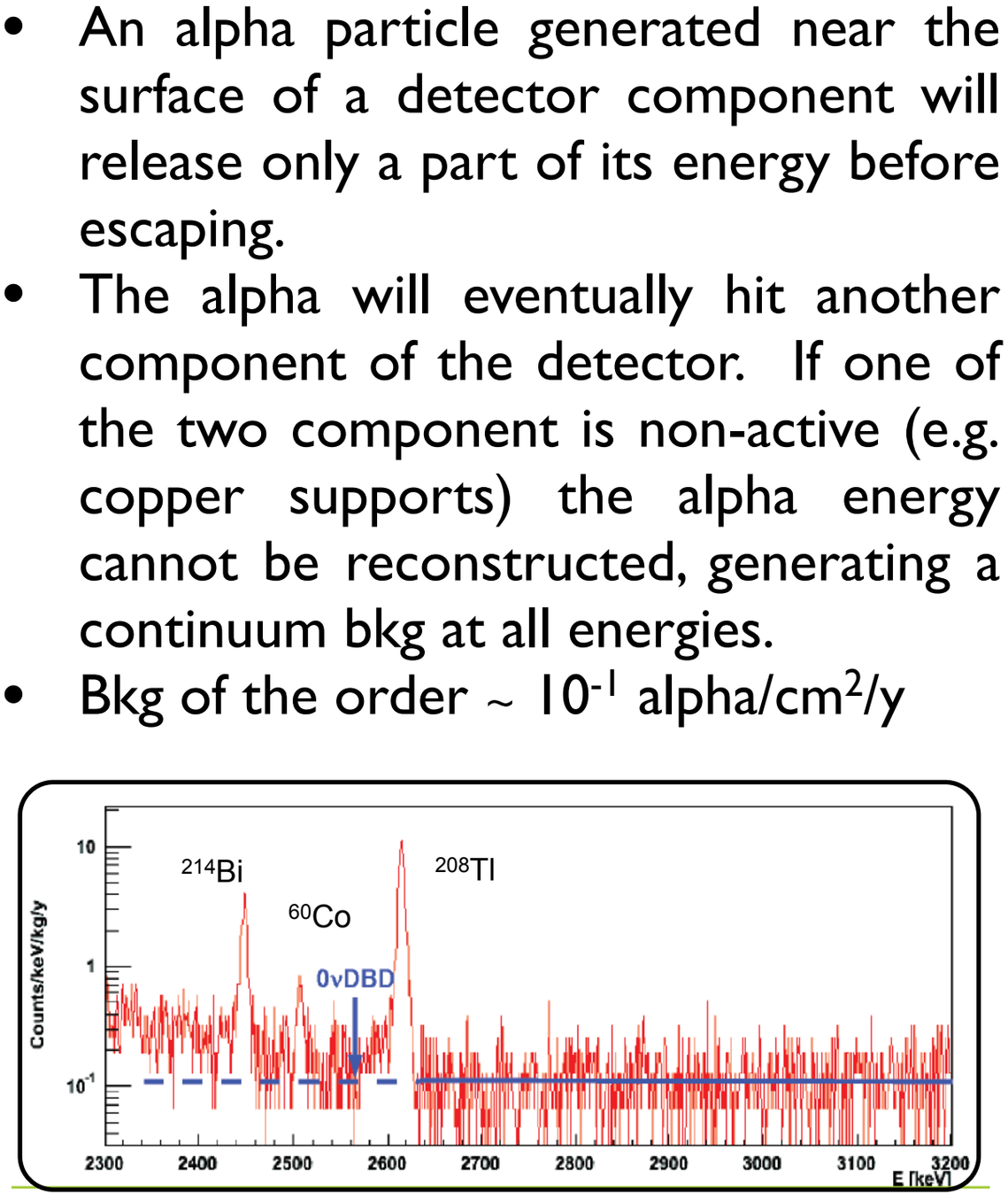
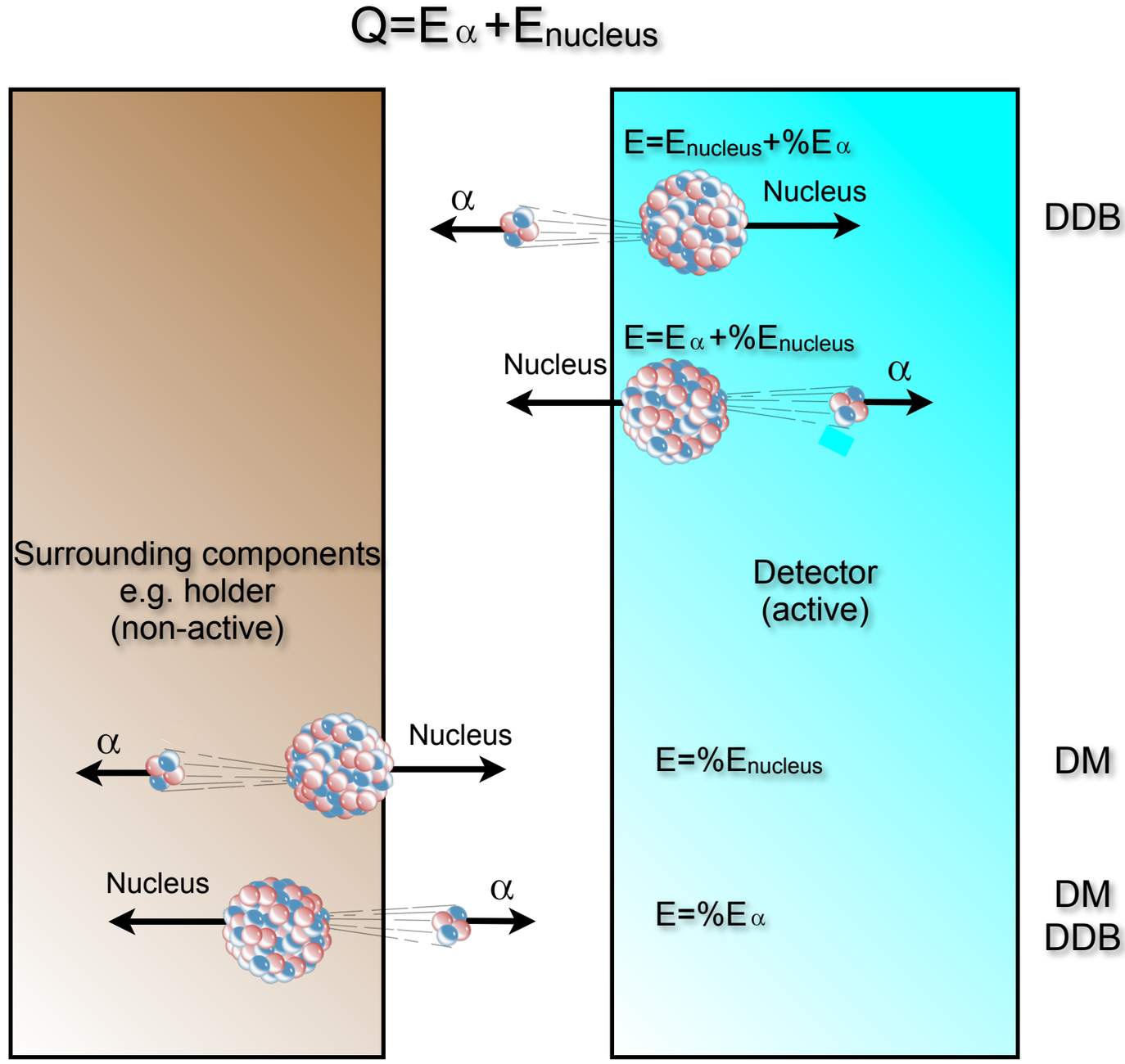
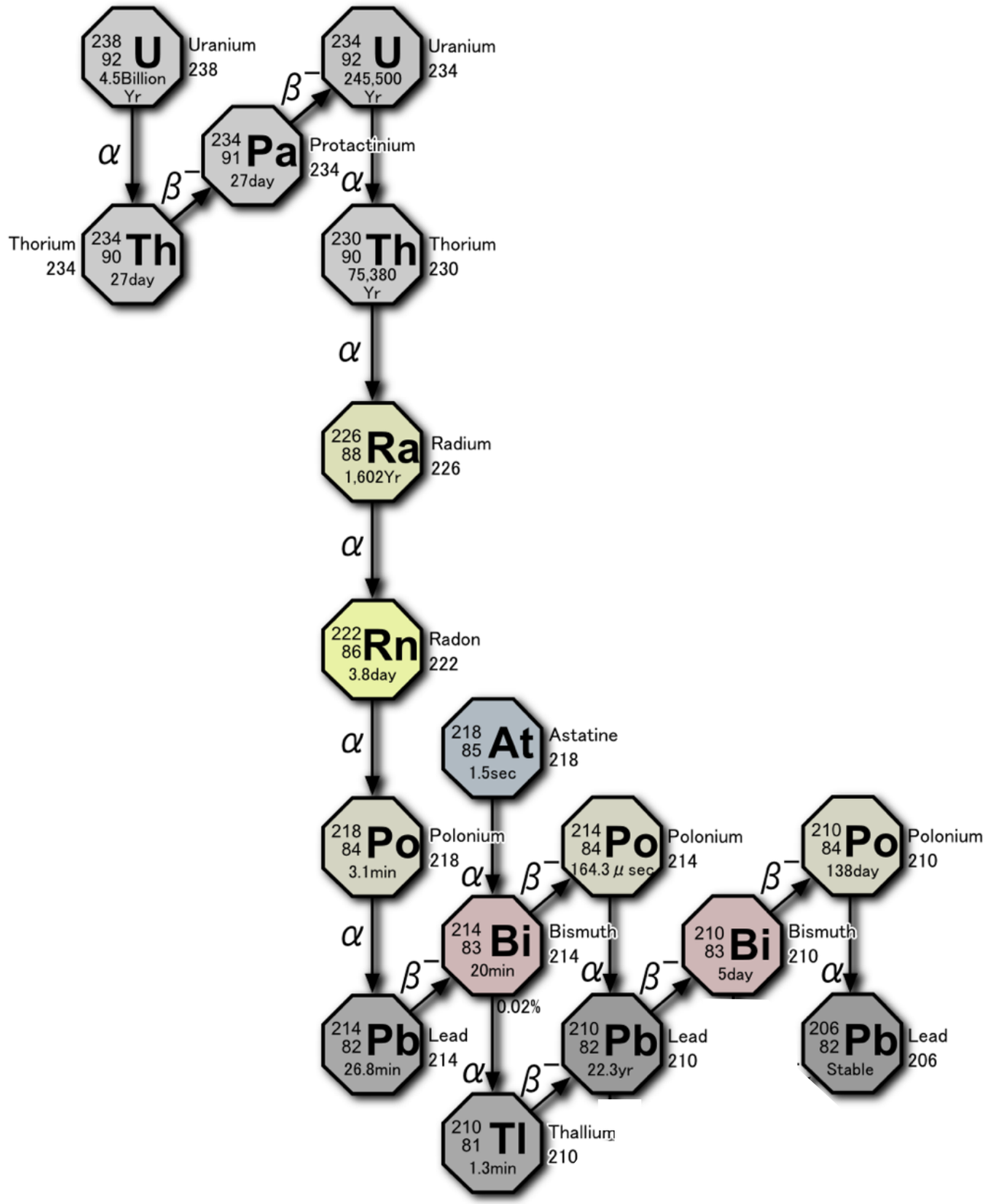




Surface background from ^{210}Pb



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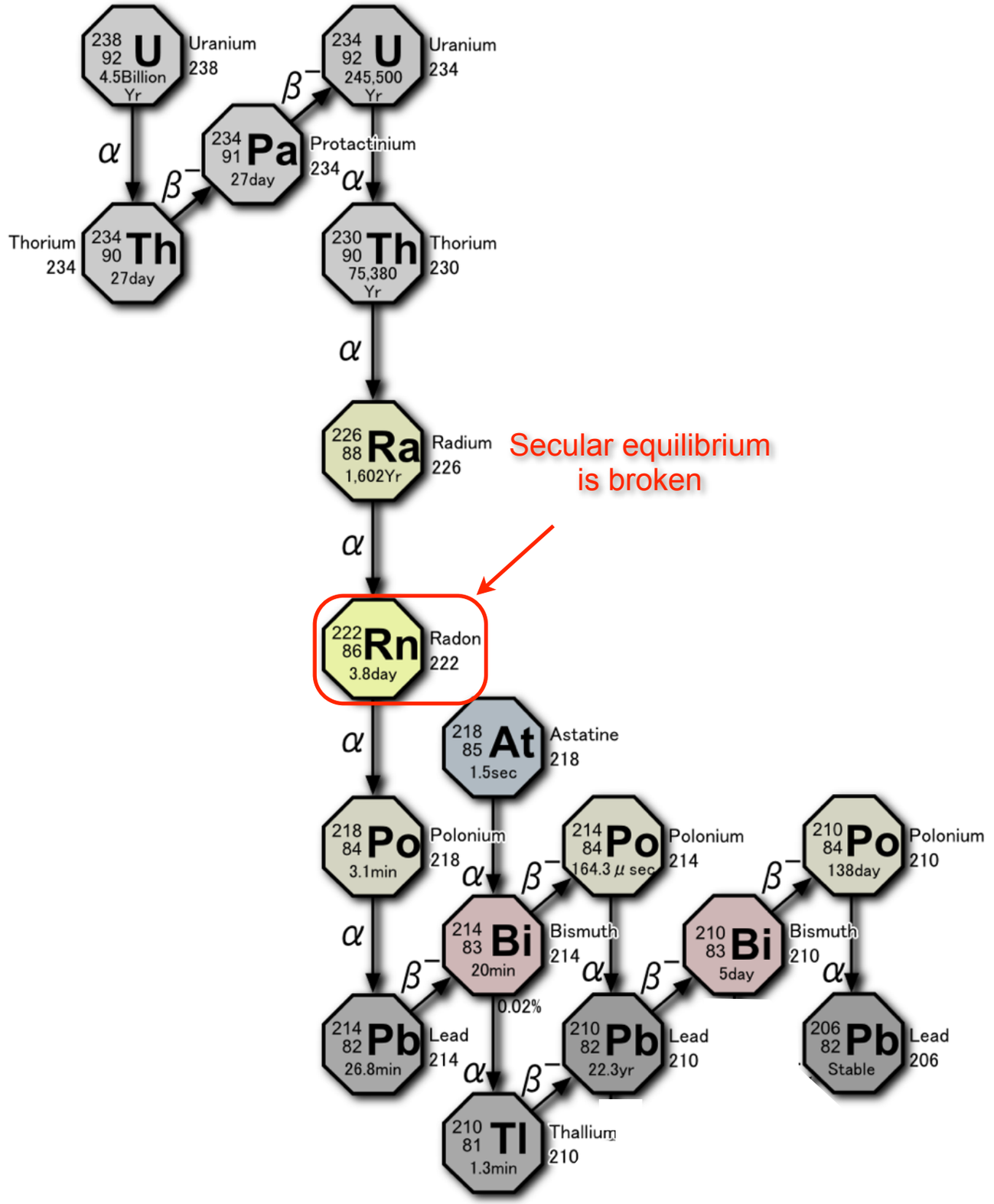

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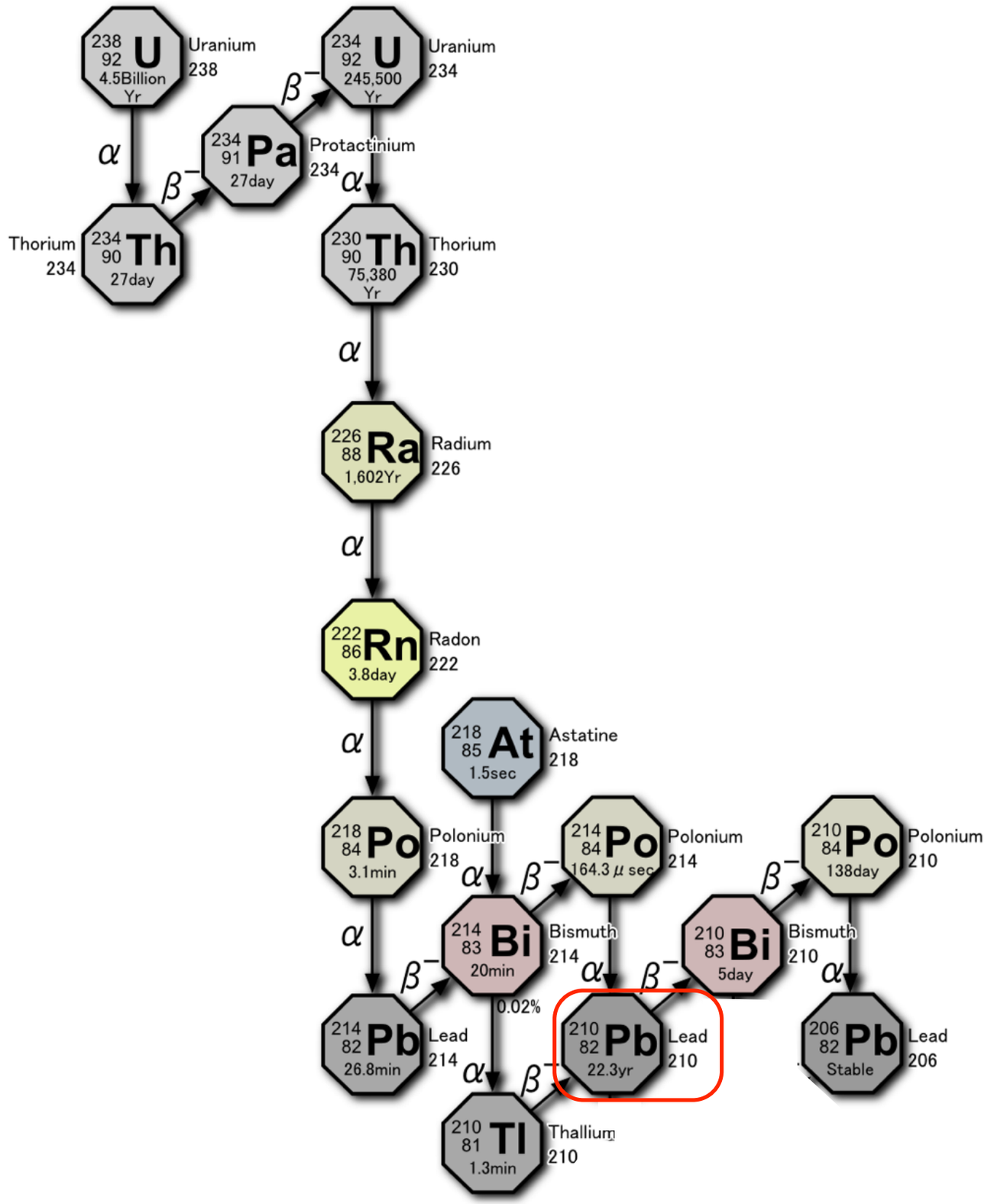

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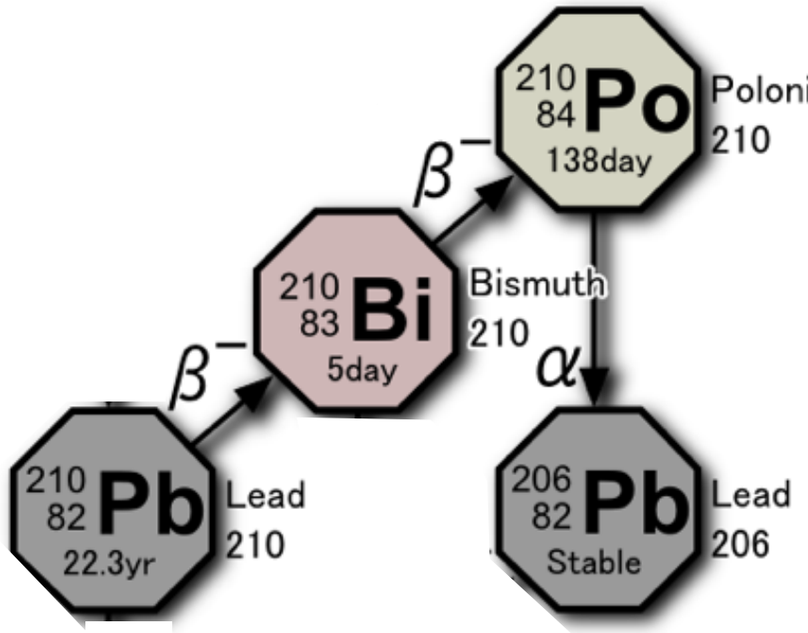

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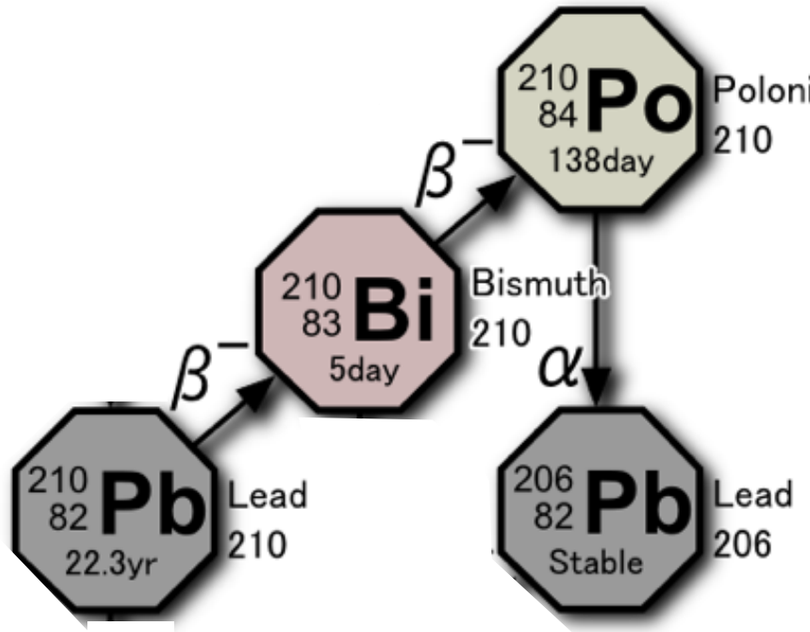

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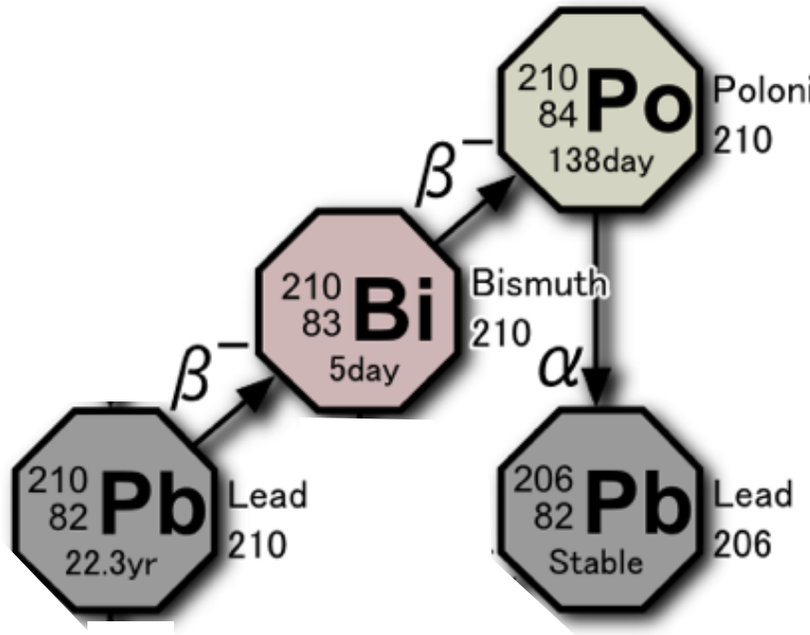

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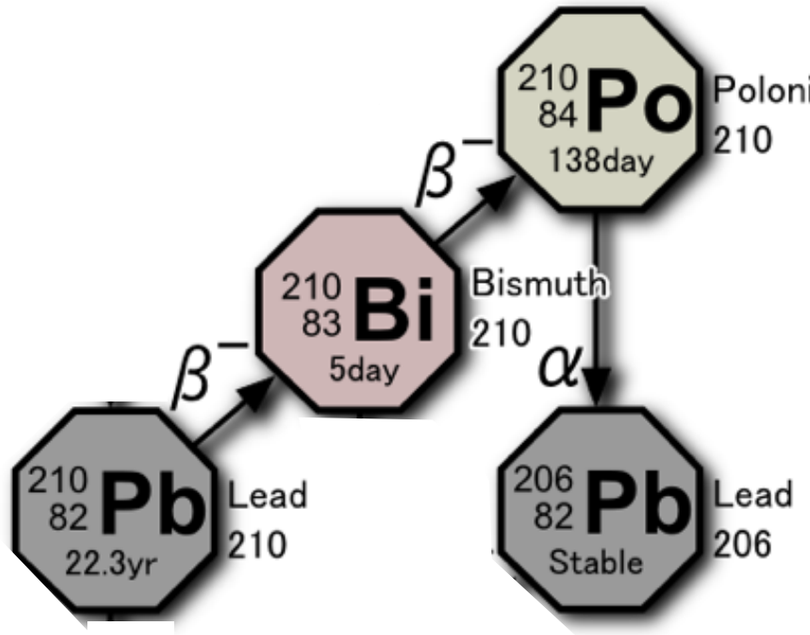

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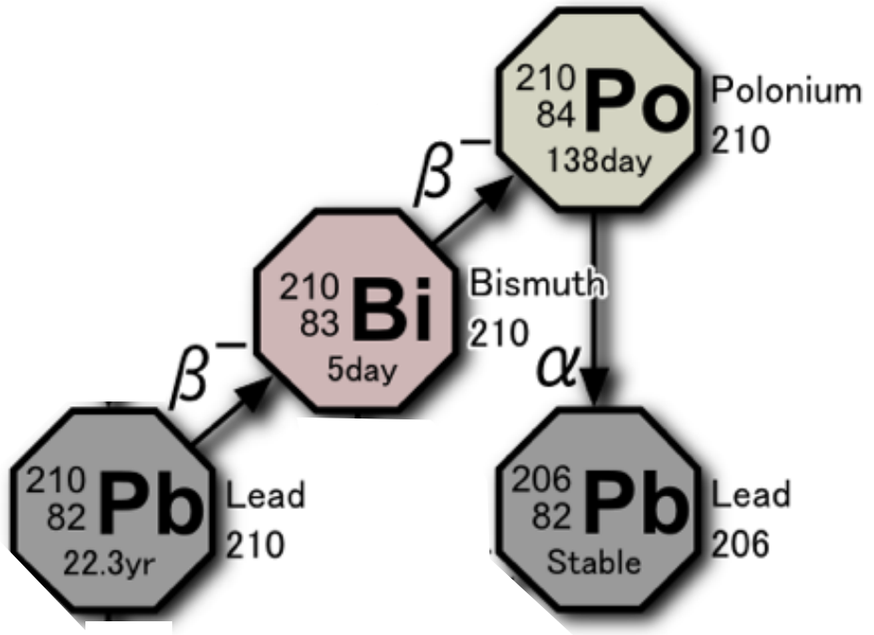

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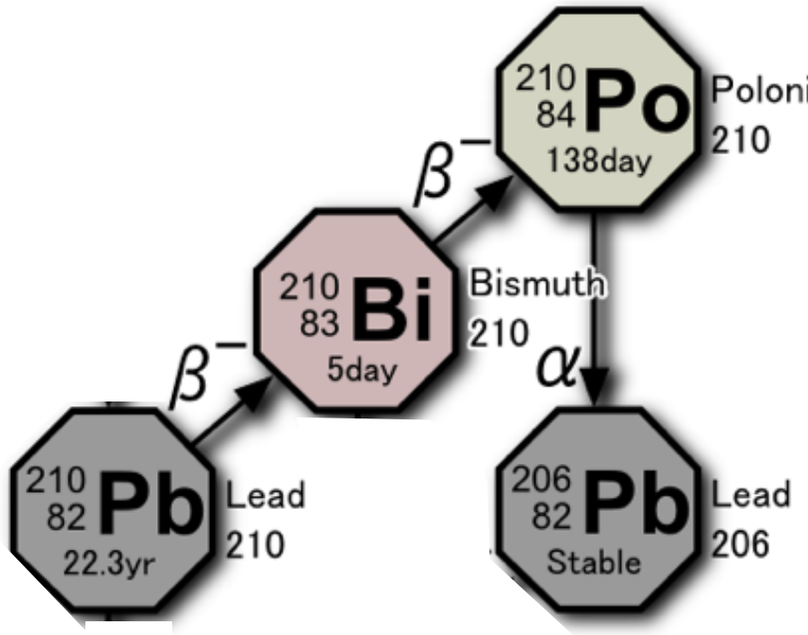

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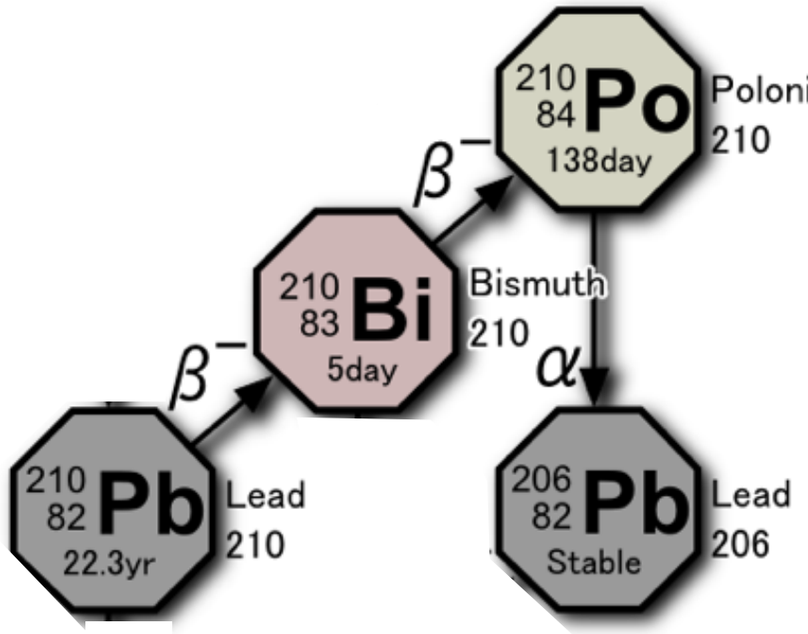

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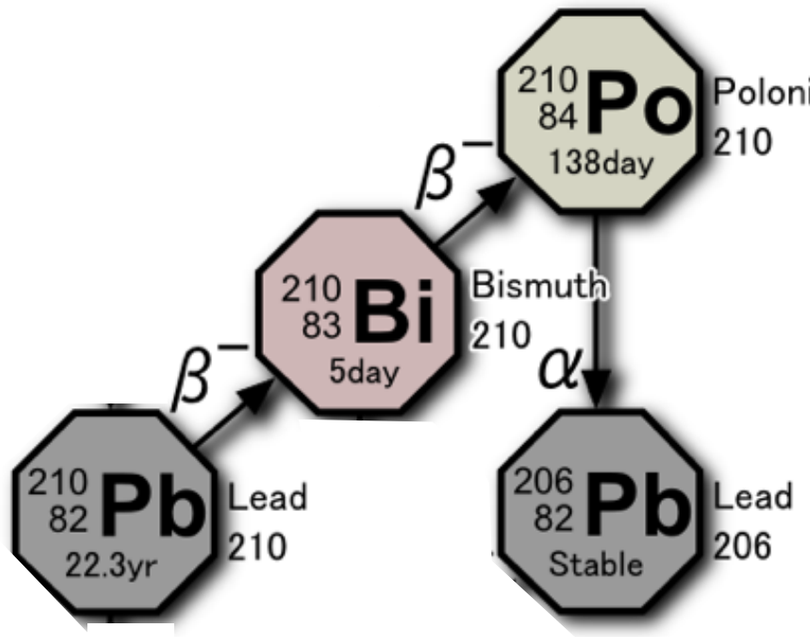

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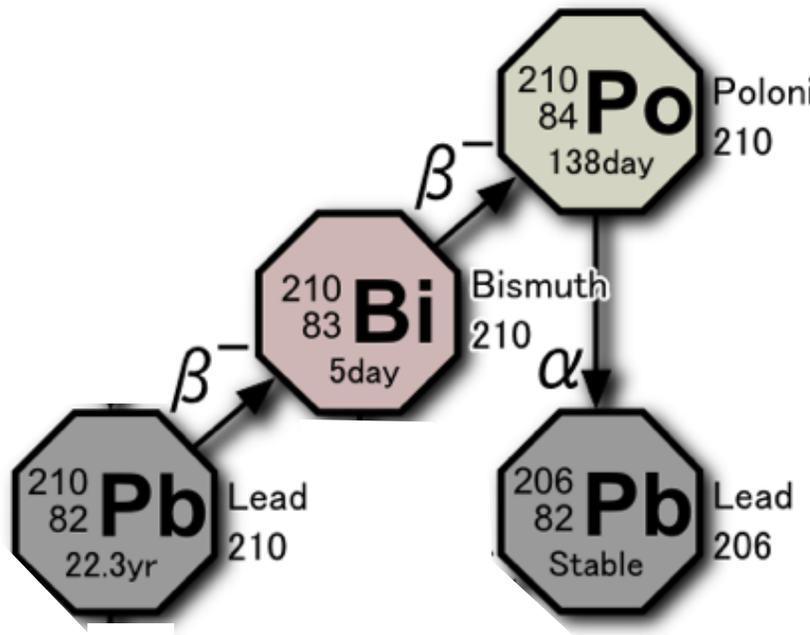

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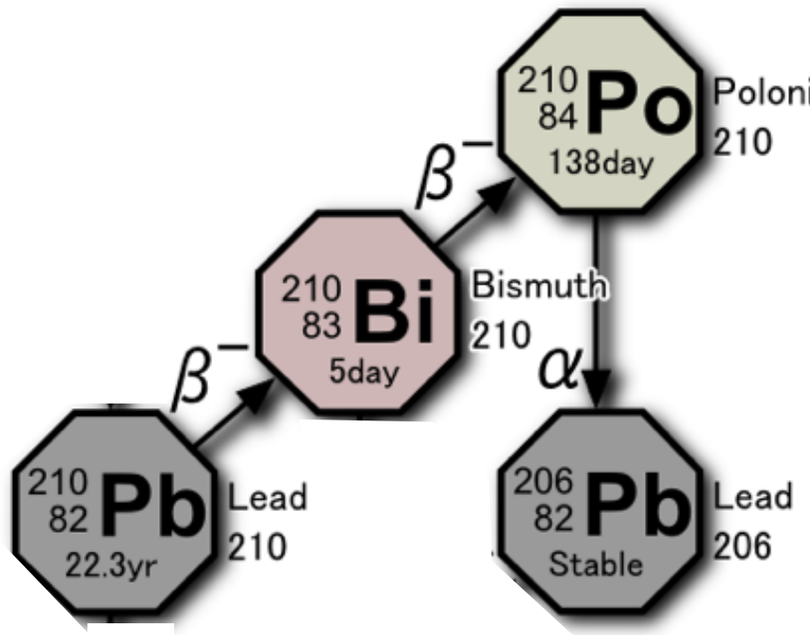

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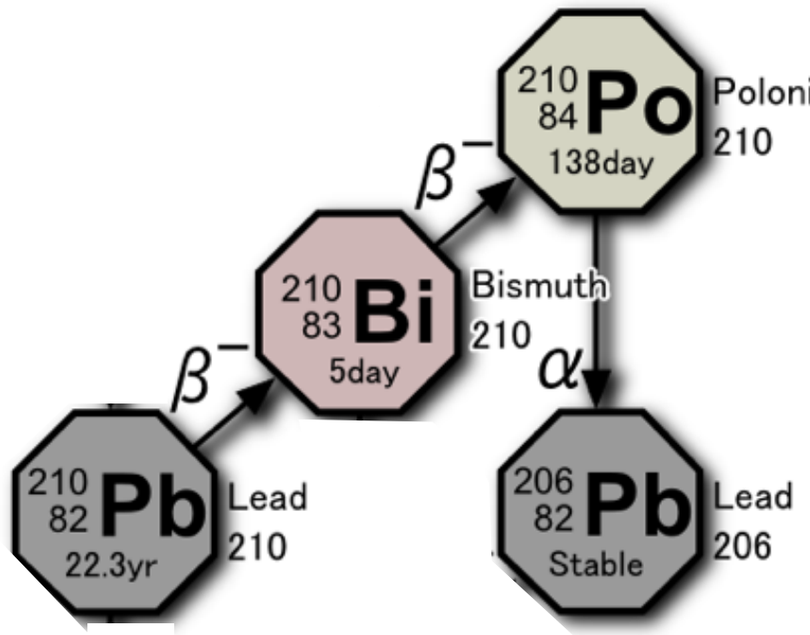
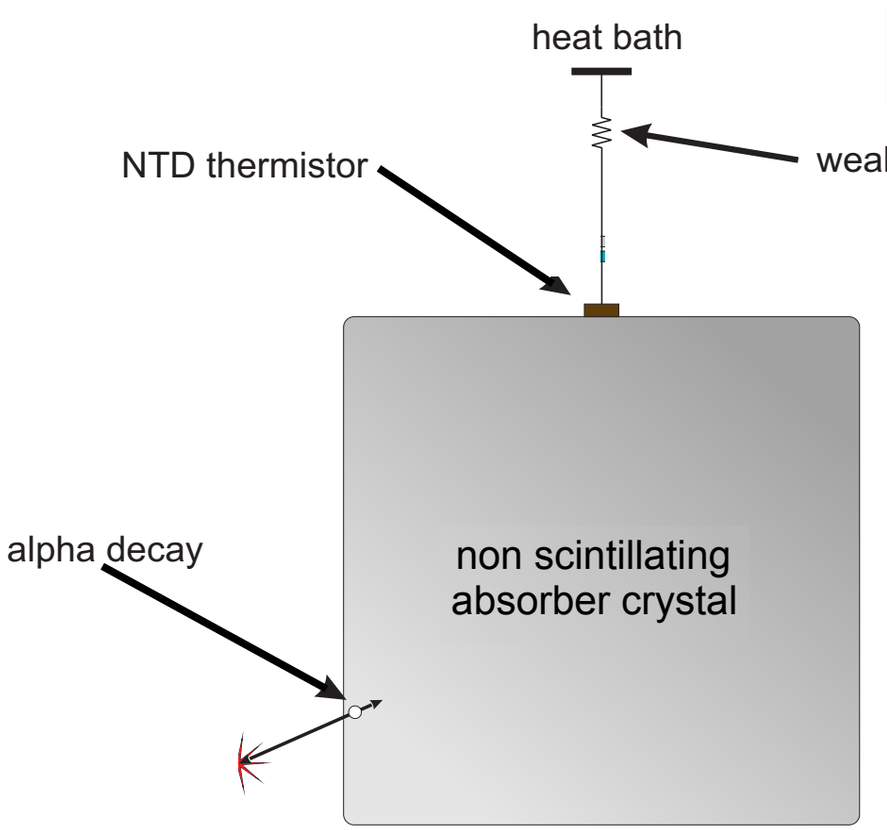


- No technique is sensitive enough!!
- This makes very hard to validate and compare passive shielding techniques

ABSURD: A Background SUrface Rejection Detector

Grant recently approved and funded by INFN



arxiv:1103.5296

Idea based on the CRESST experience

Pure bolometric detectors, measuring only the heat signal, cannot discriminate radiation type nor surface events.

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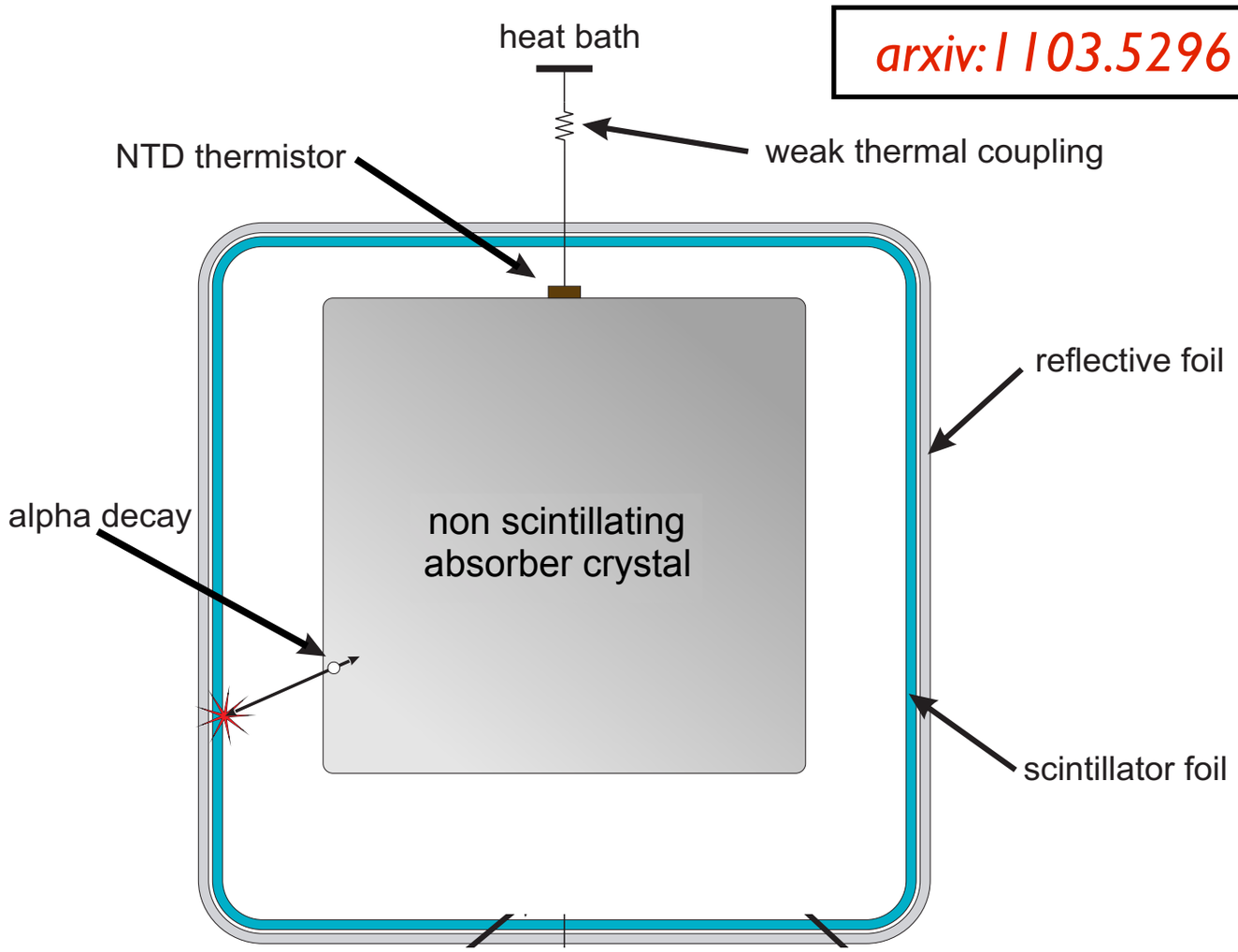

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The proposed solution consists in surrounding the bolometer with an active material. Using a scintillating foil (detached from the crystal) and adding a light detector a surface events rejection is possible.
Surface events, releasing part of their energy in the scintillating foil, will produce a photon signal that can be used to tag coincidence thermal pulses on the main detector.

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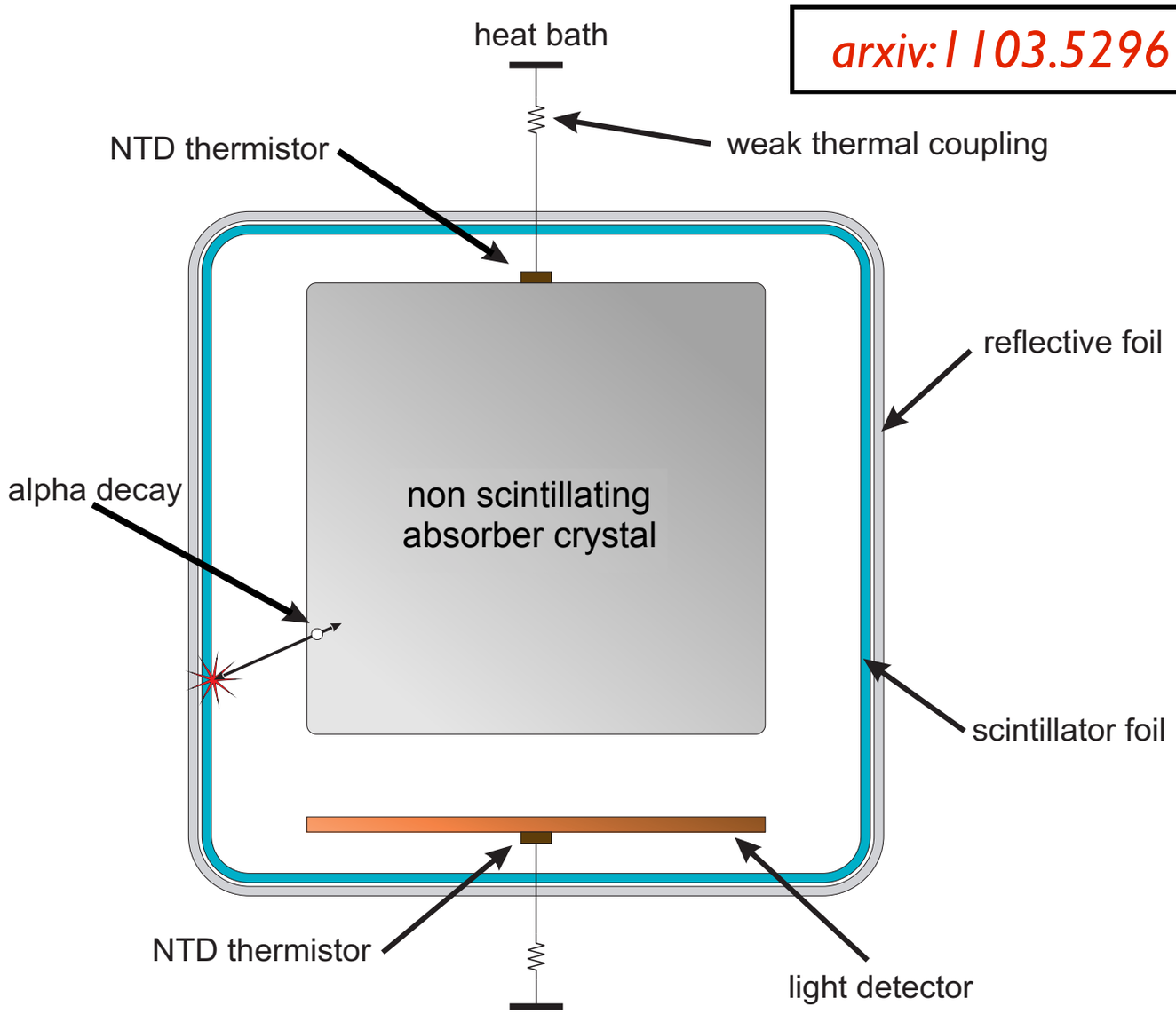

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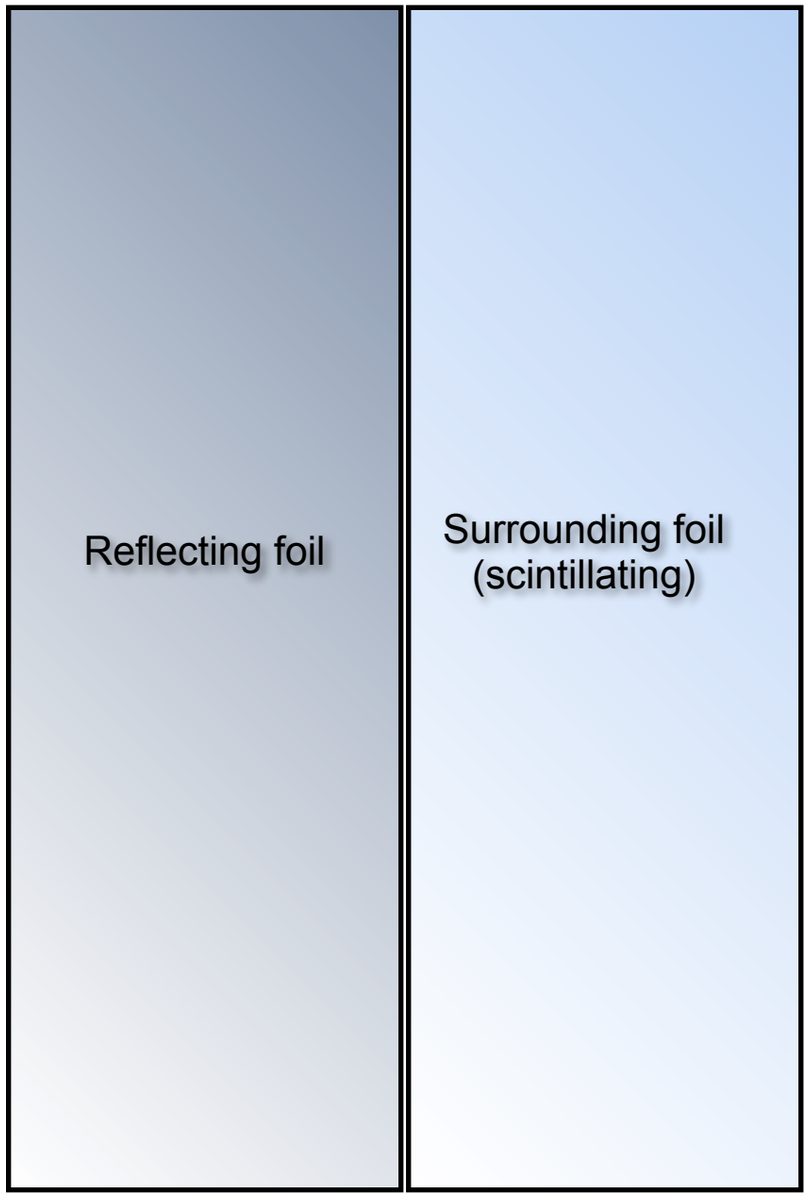
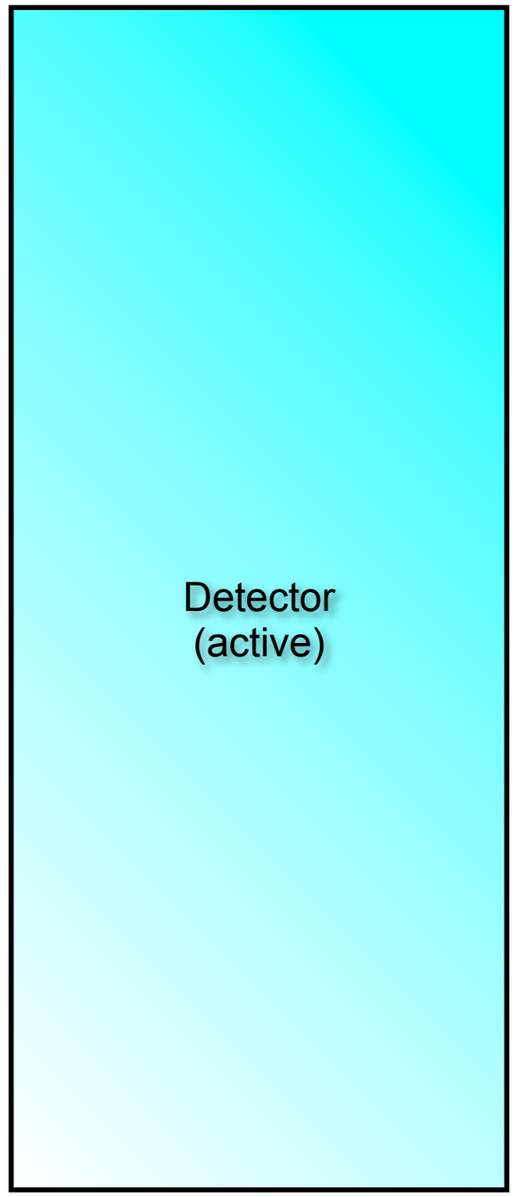
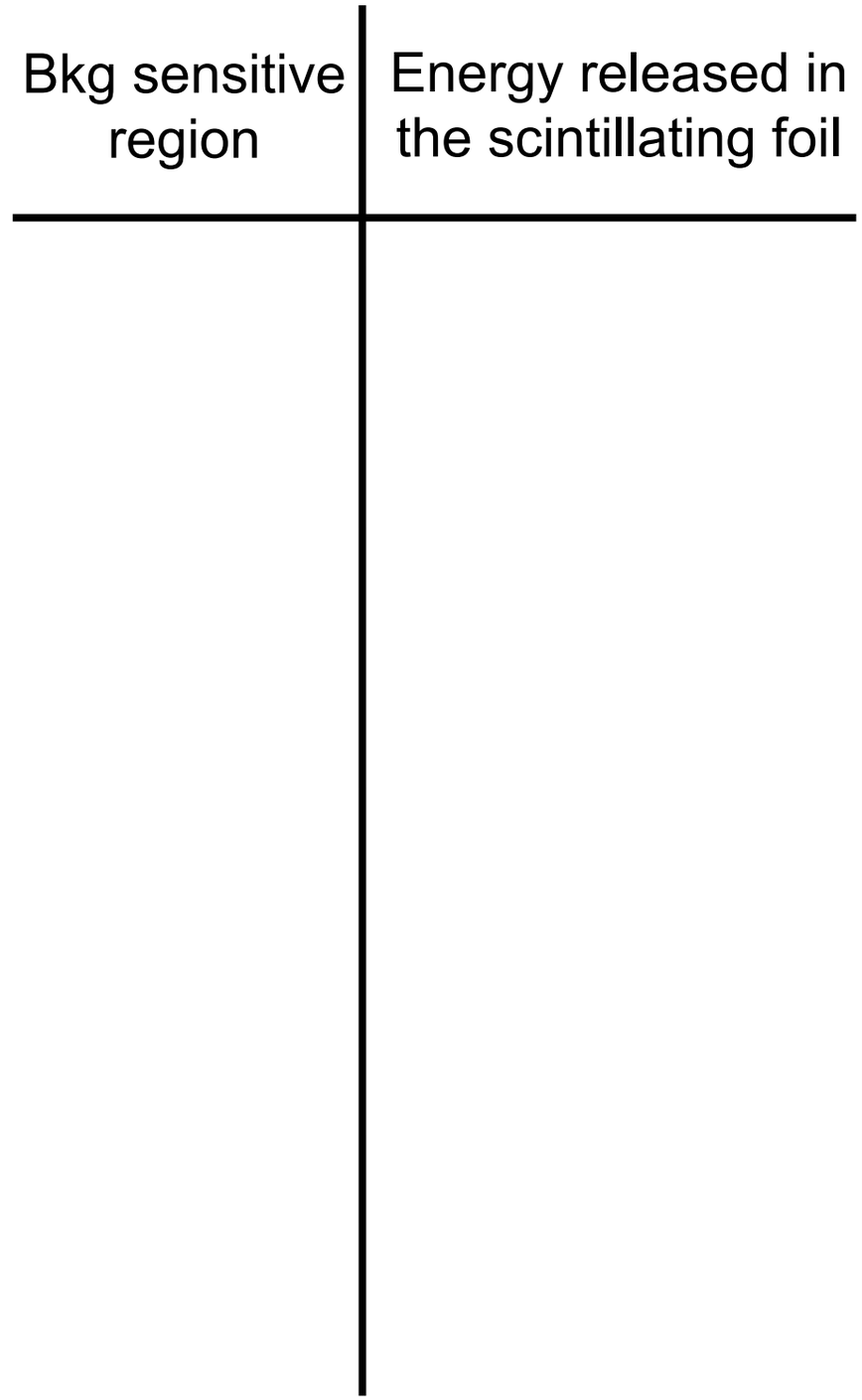
The light detector, suitable for operating at ~10 mK, is a bolometer itself (low heat capacity) and needs a very low energy threshold to clearly detect hundreds of eV light signals.

The energy signal

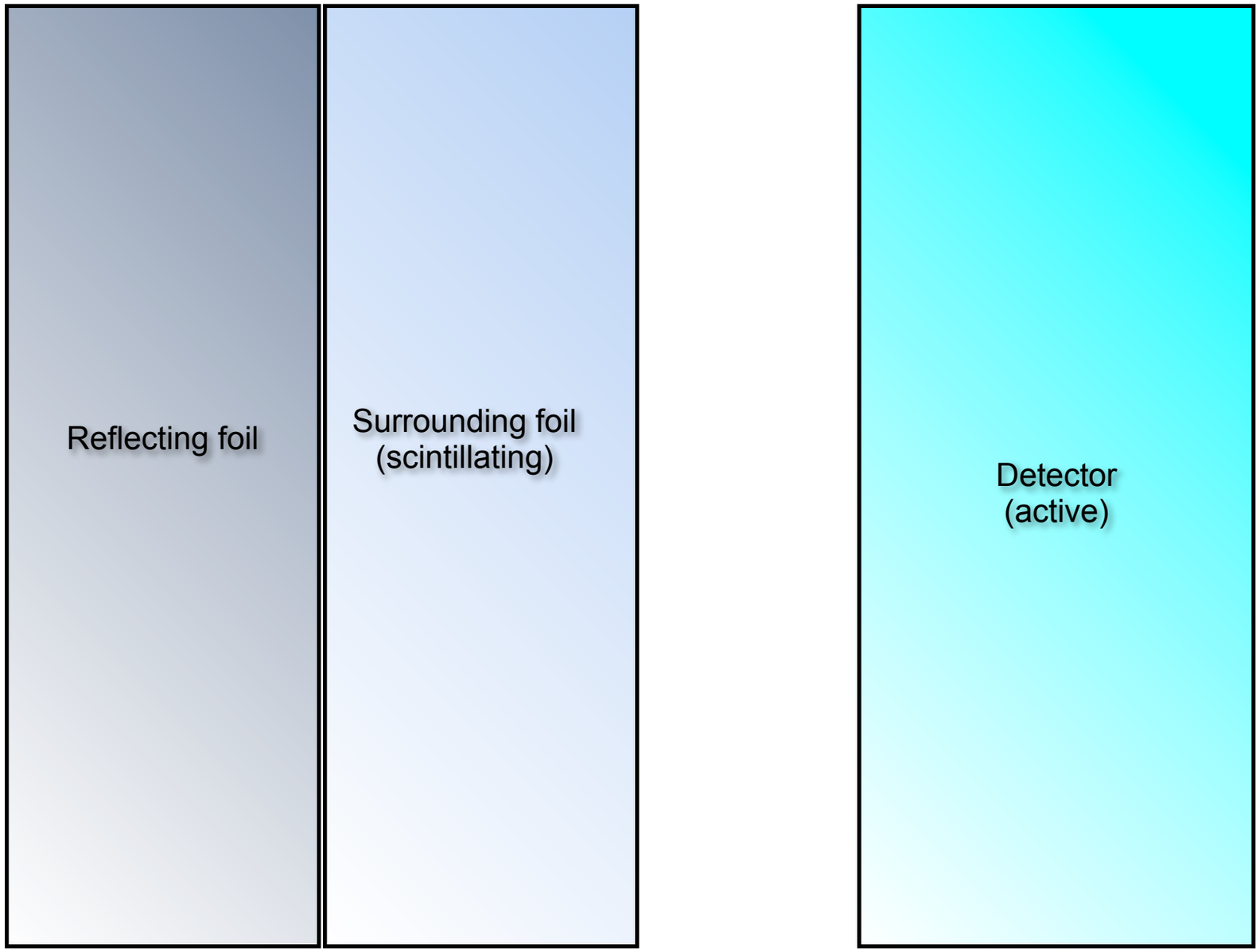






The energy signal

$Q = E_\alpha + E_{nucleus} = 5.4$ MeV (^{210}Po)



Bkg sensitive region	Energy released in the scintillating foil

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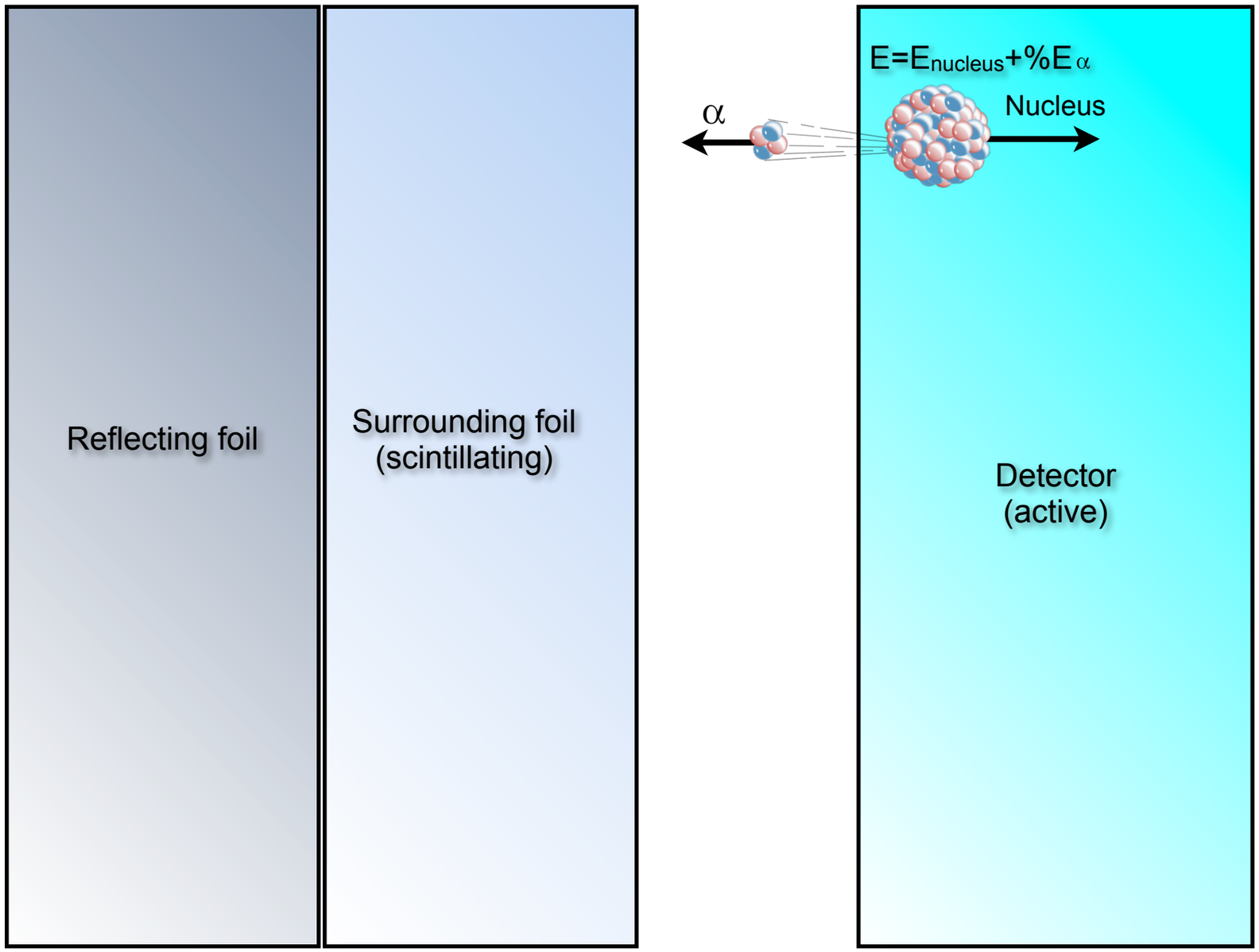

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DDB	2-3 MeV	3.4-2.4 MeV

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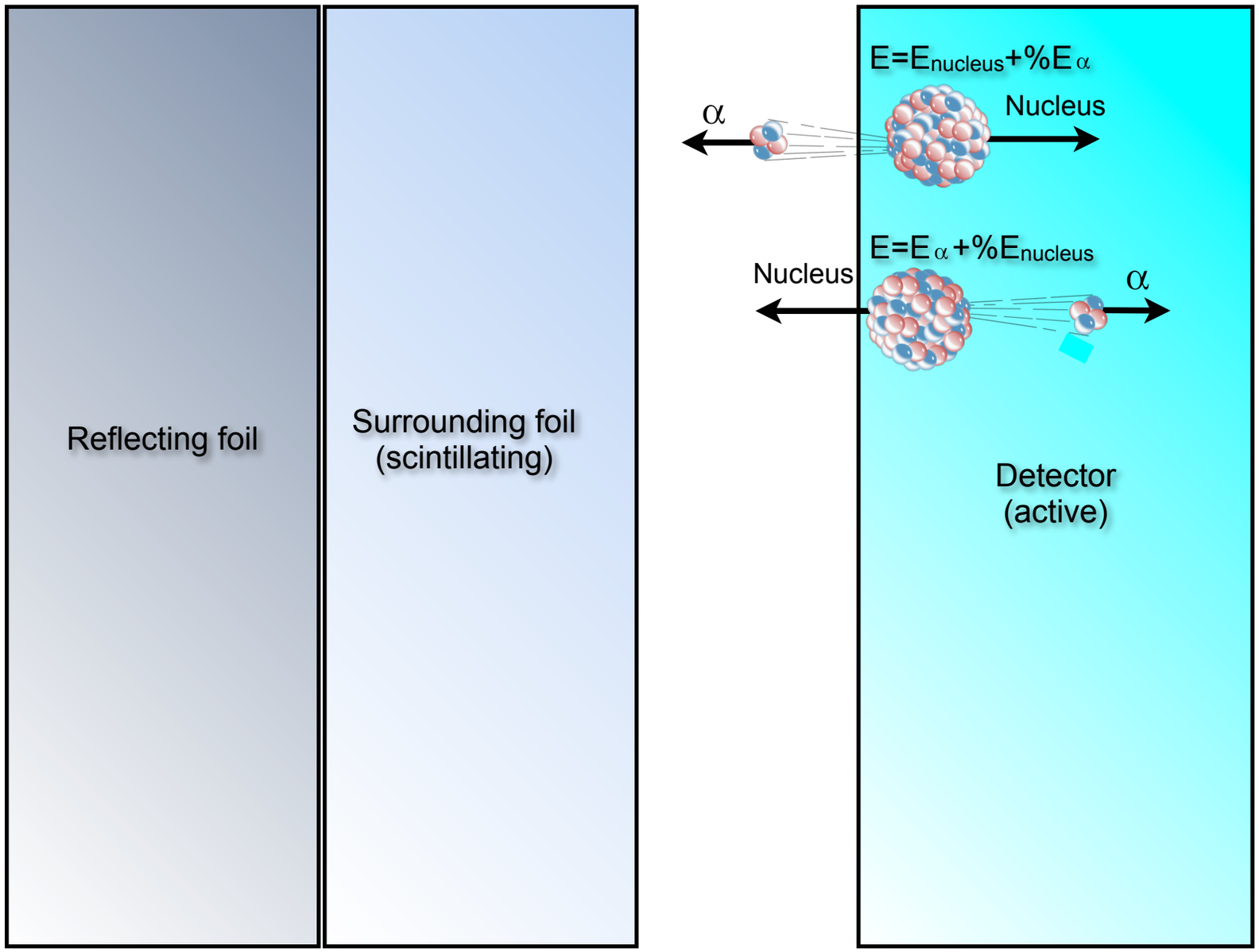

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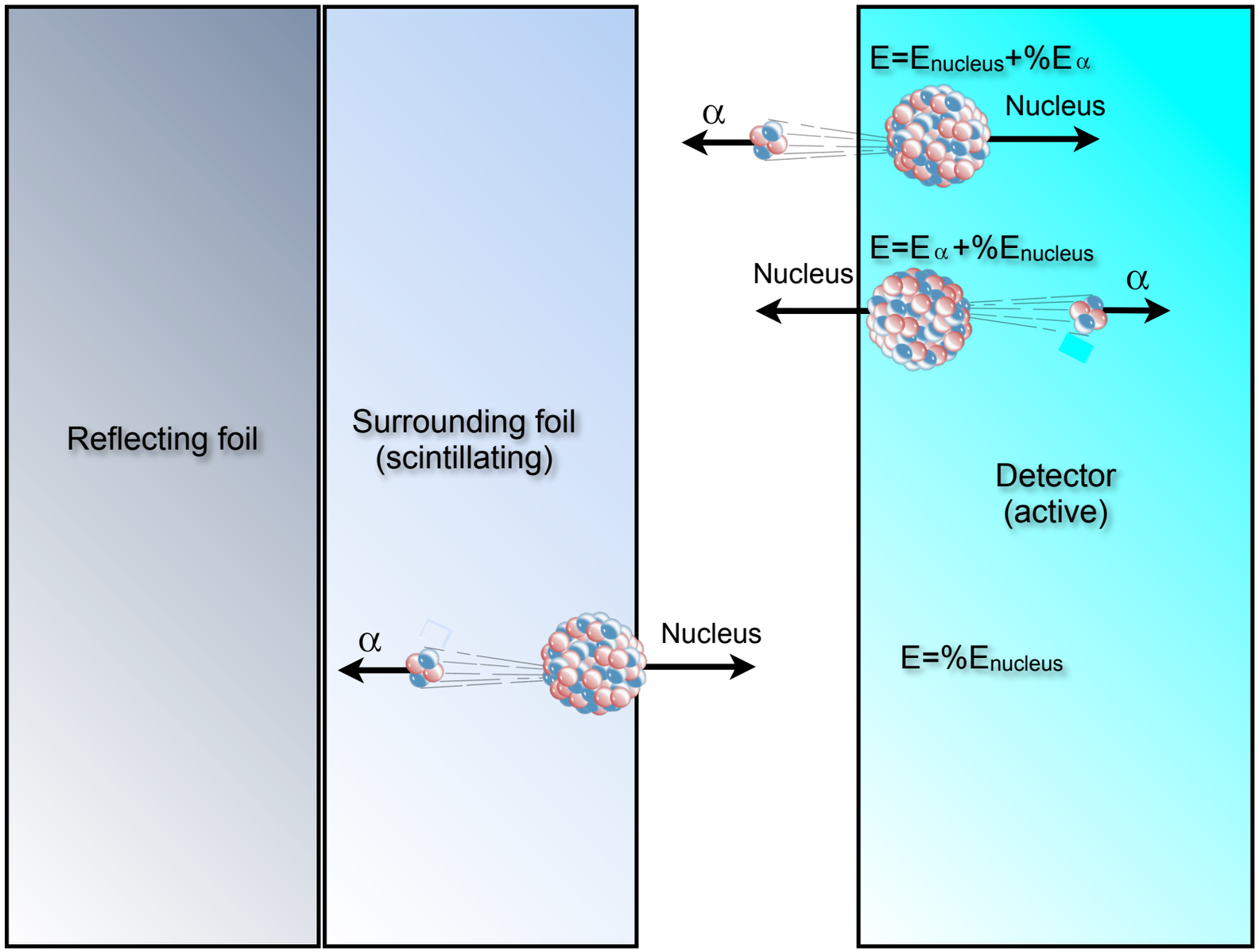

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DDB	2-3 MeV	3.4-2.4 MeV
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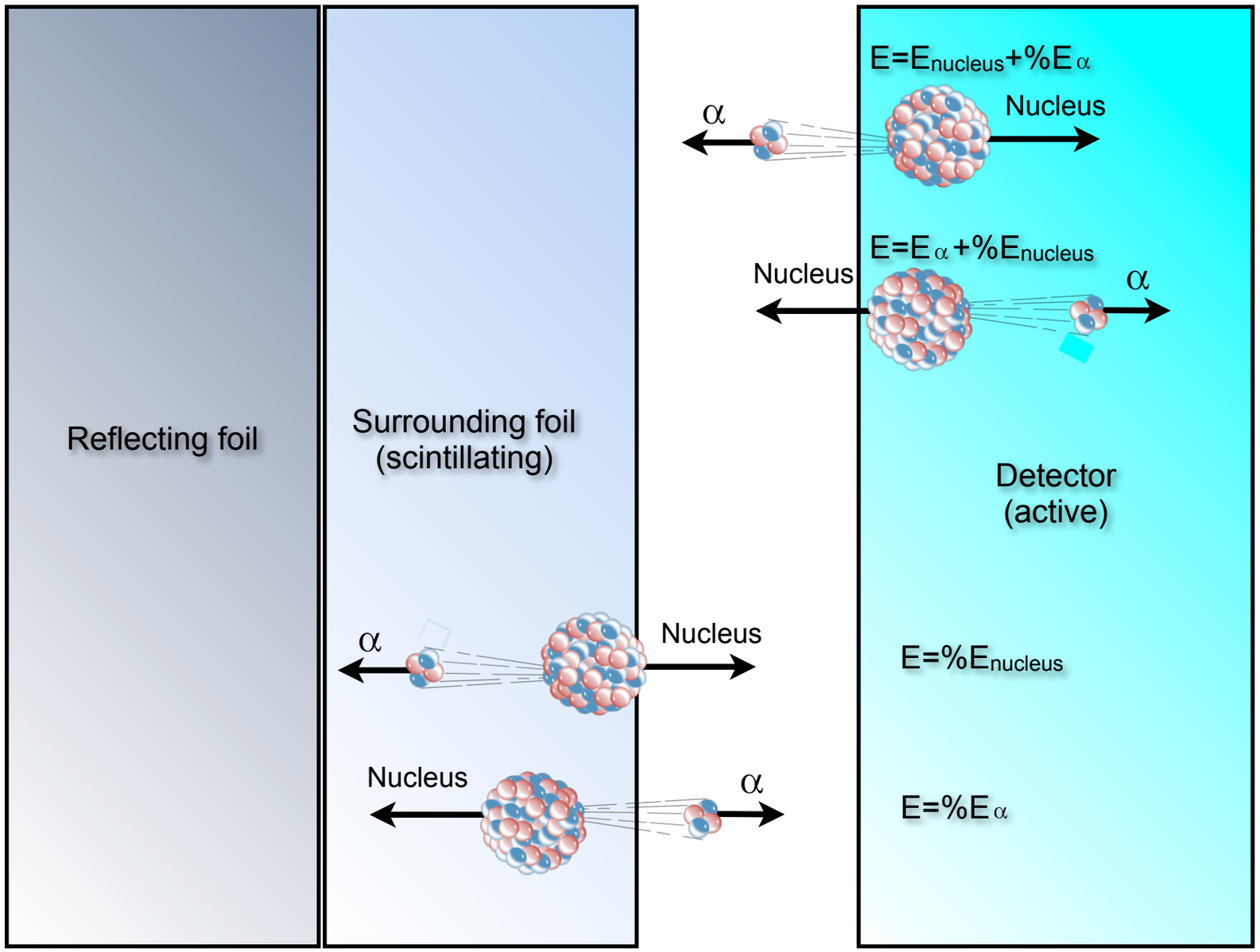

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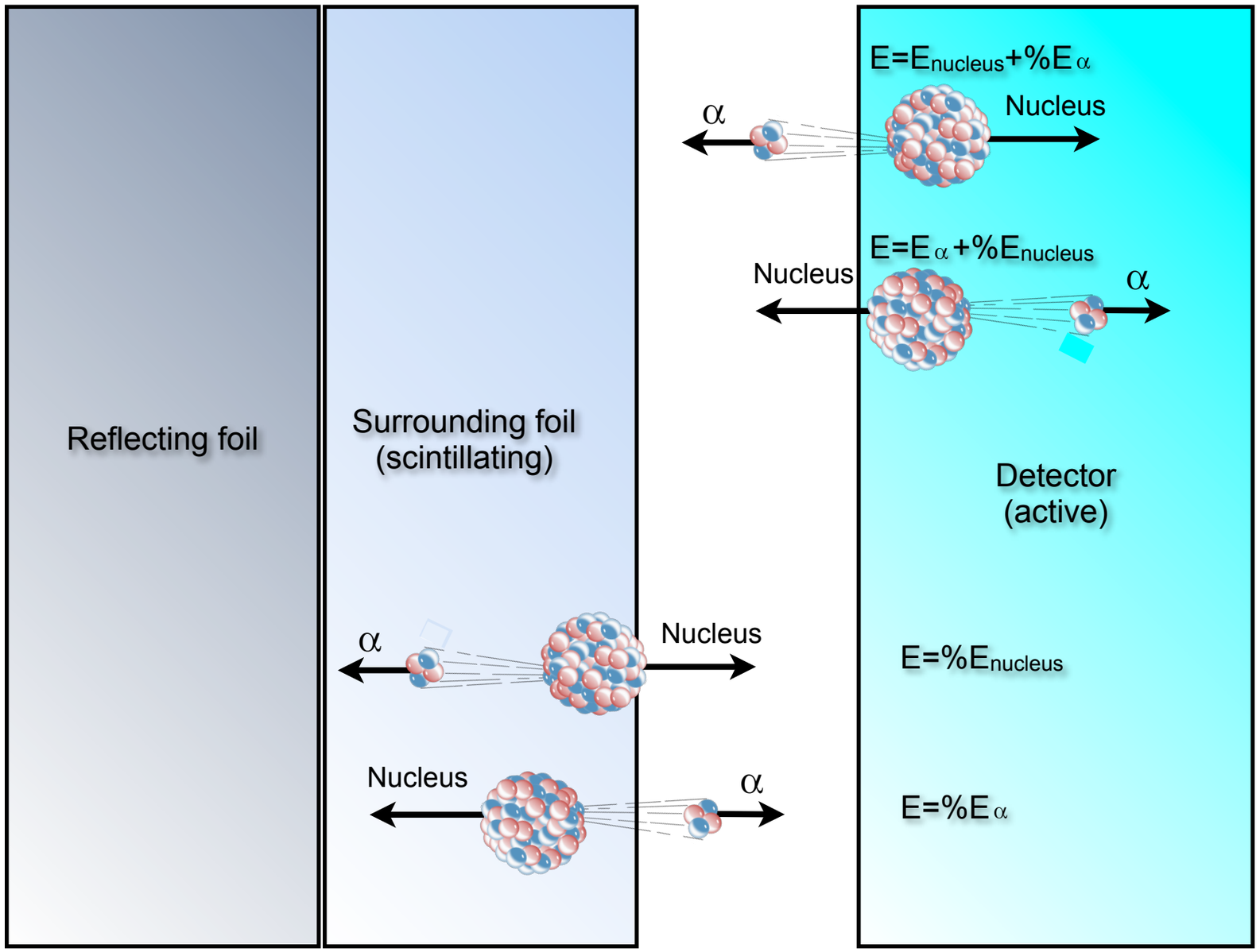

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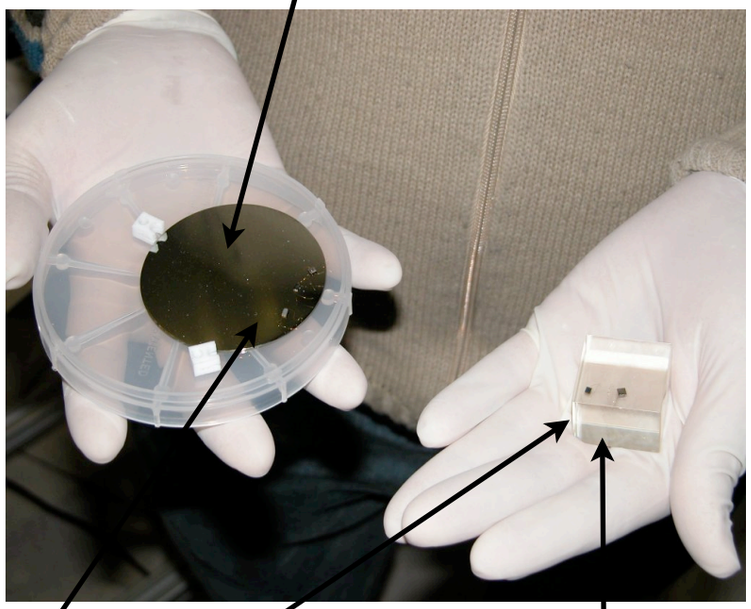
The balance between light collection/energy threshold of the light detector and the light emission of the s.f. must be such that a 1.5 MeV alpha can be detected lowest alpha sources ~ 4 MeV.

The light detector



Thermal light detector:

- Standard bolometric light detector have typical threshold ~ 300-500 eV (e.g Lucifer,)
- It is possible (using TES e SQUID) reach thresholds below 100 eV (e.g. CRESST)
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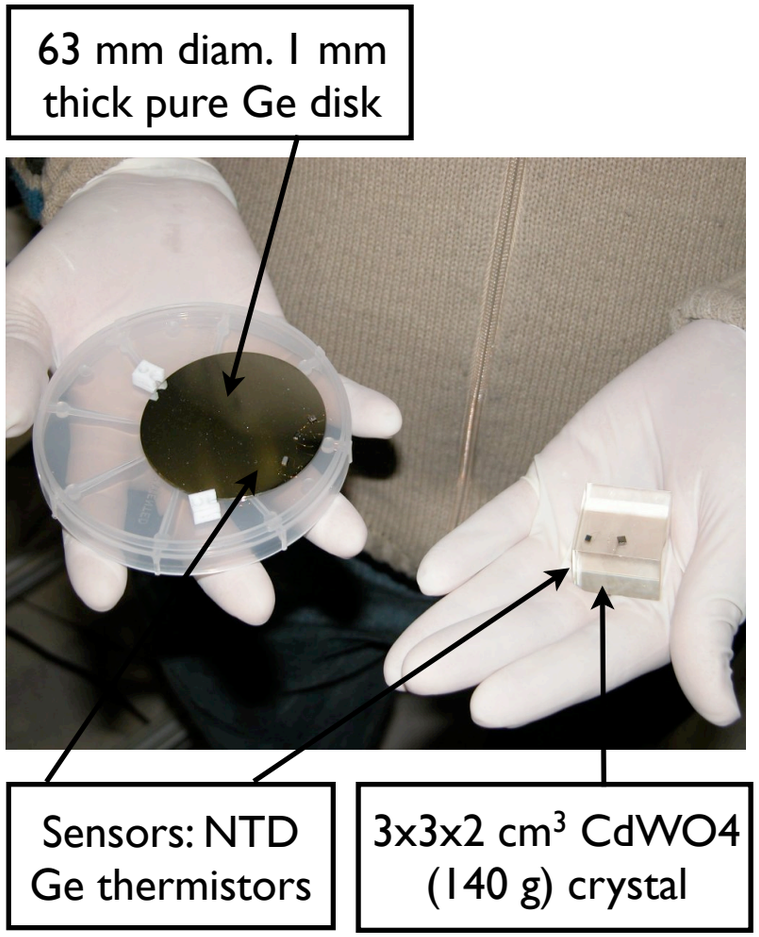

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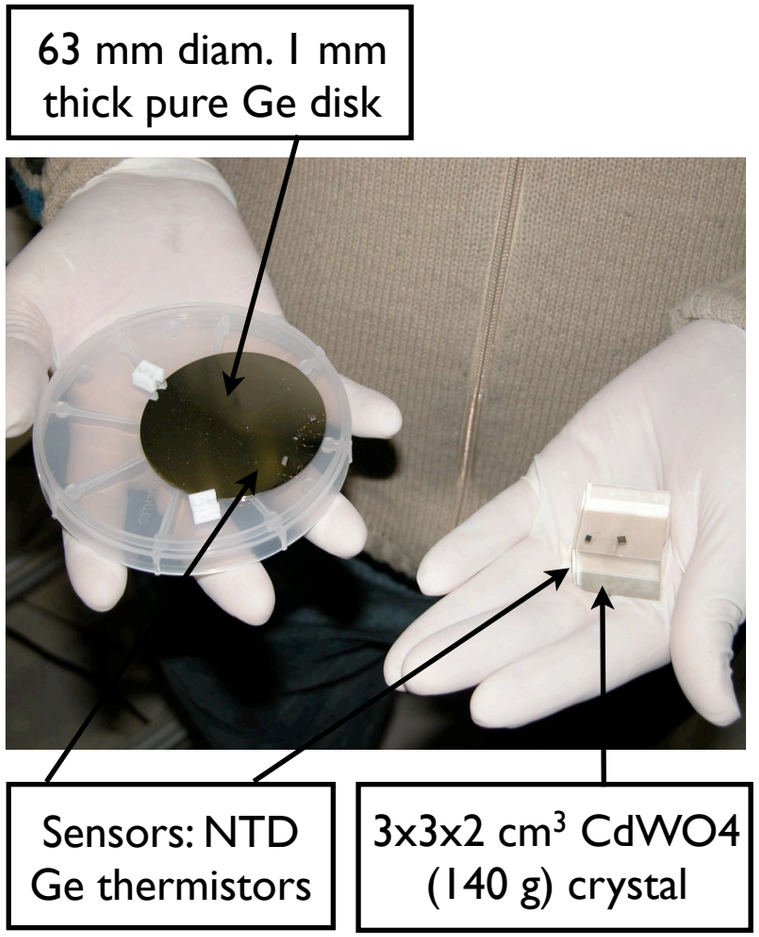

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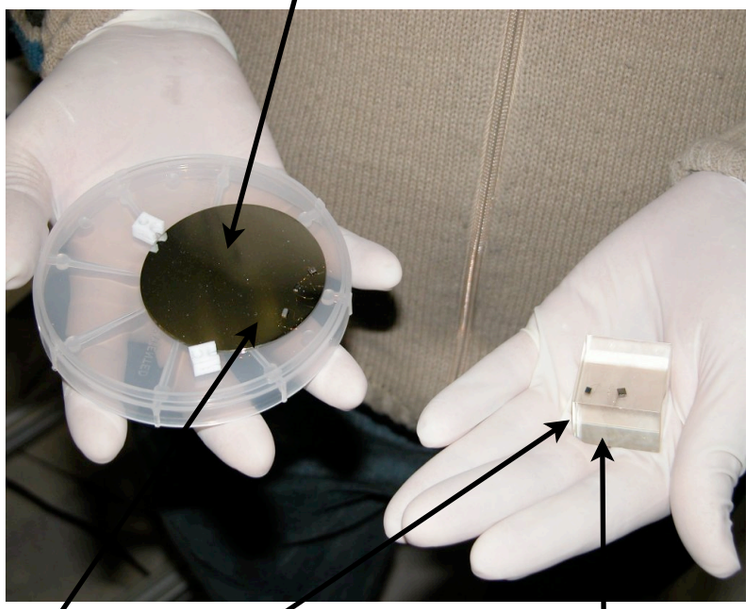

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Goal: a scintillating foil that produce enough light so that the collected light is > 300-500 eV

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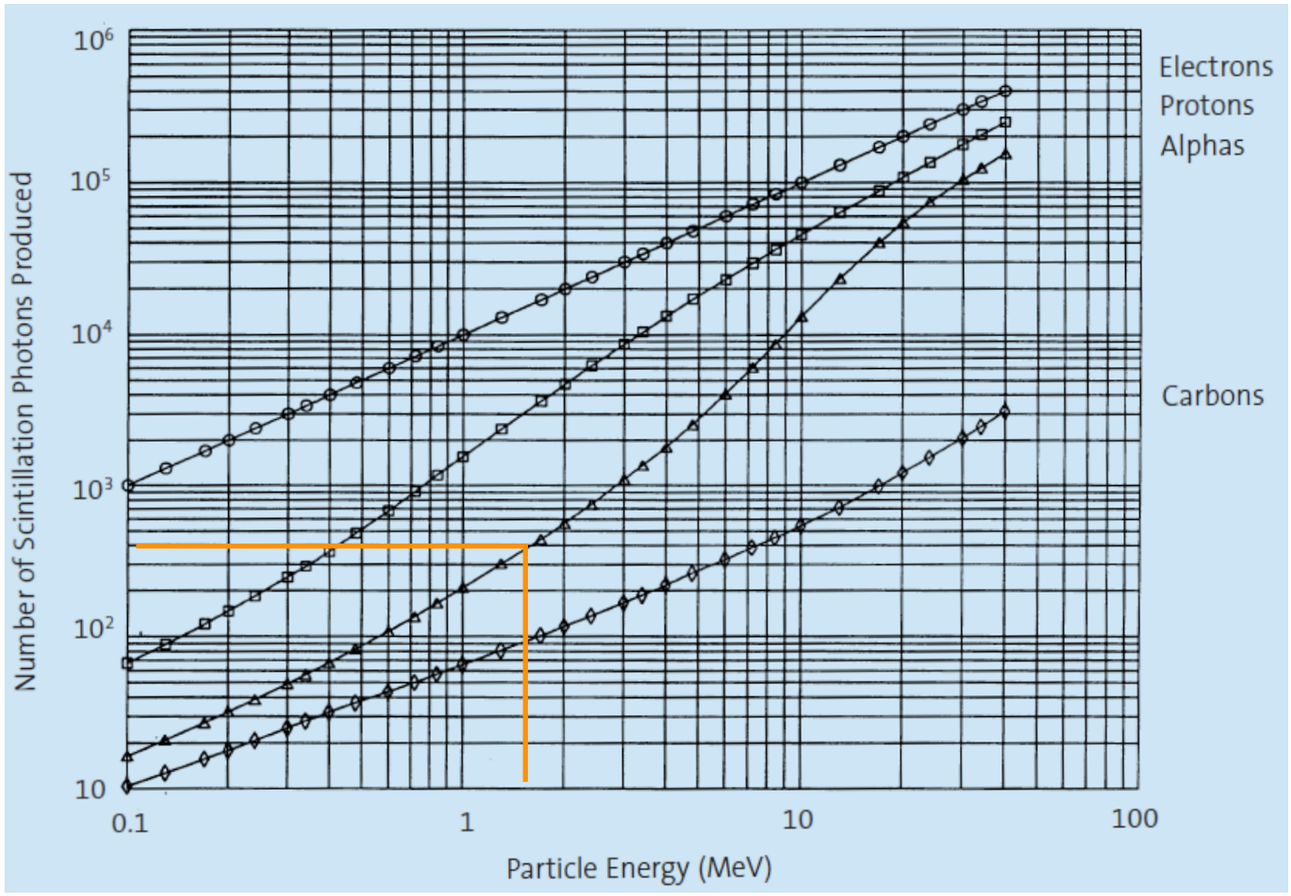

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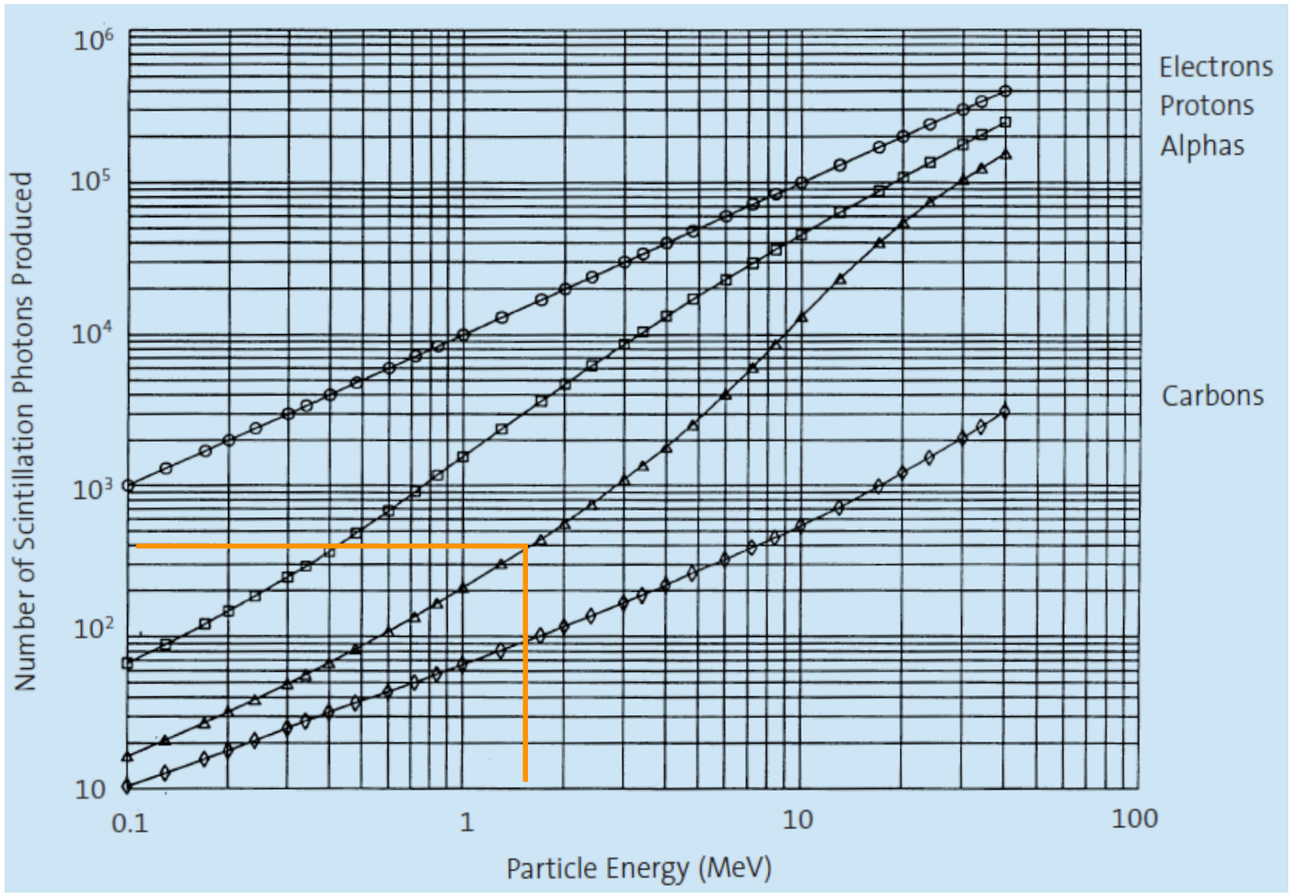

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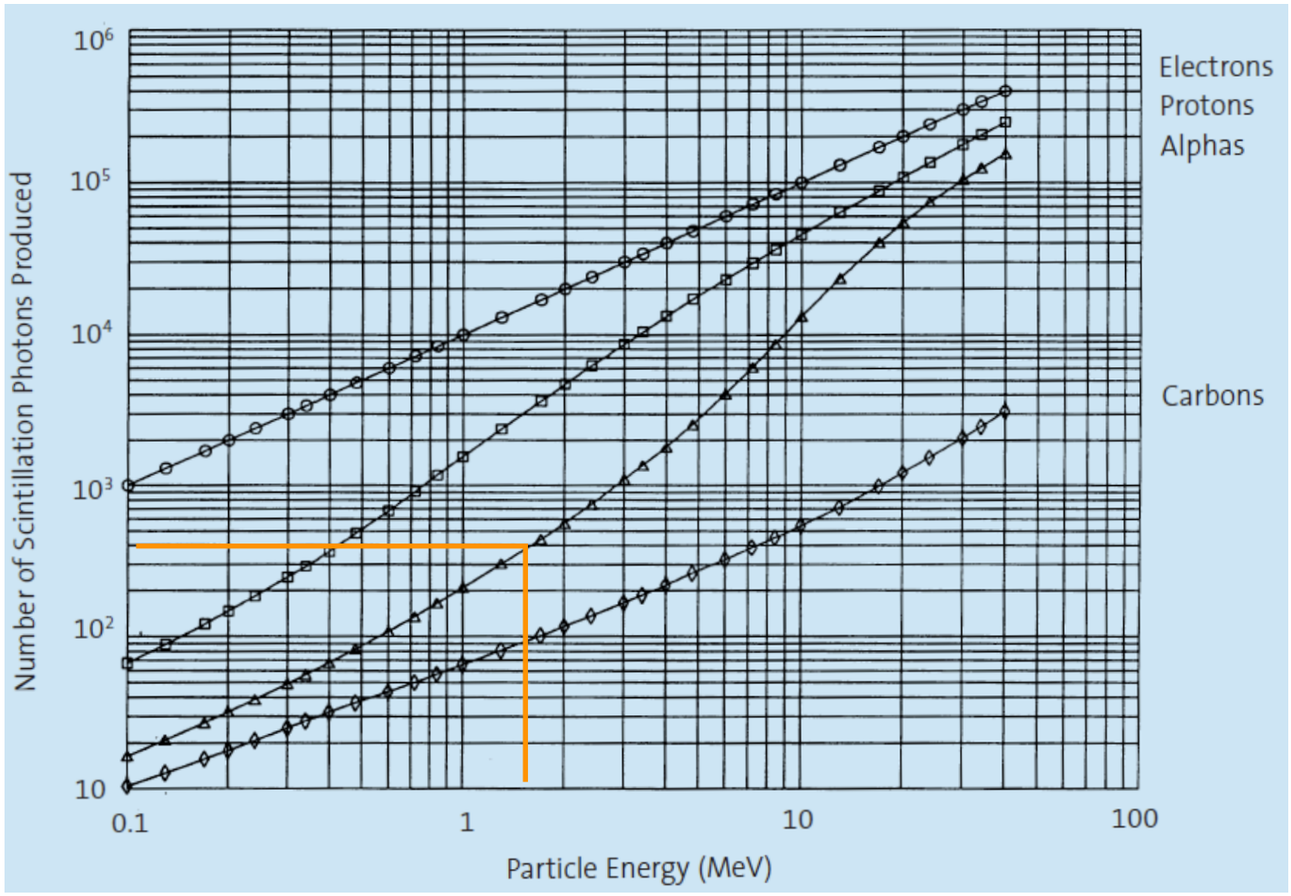

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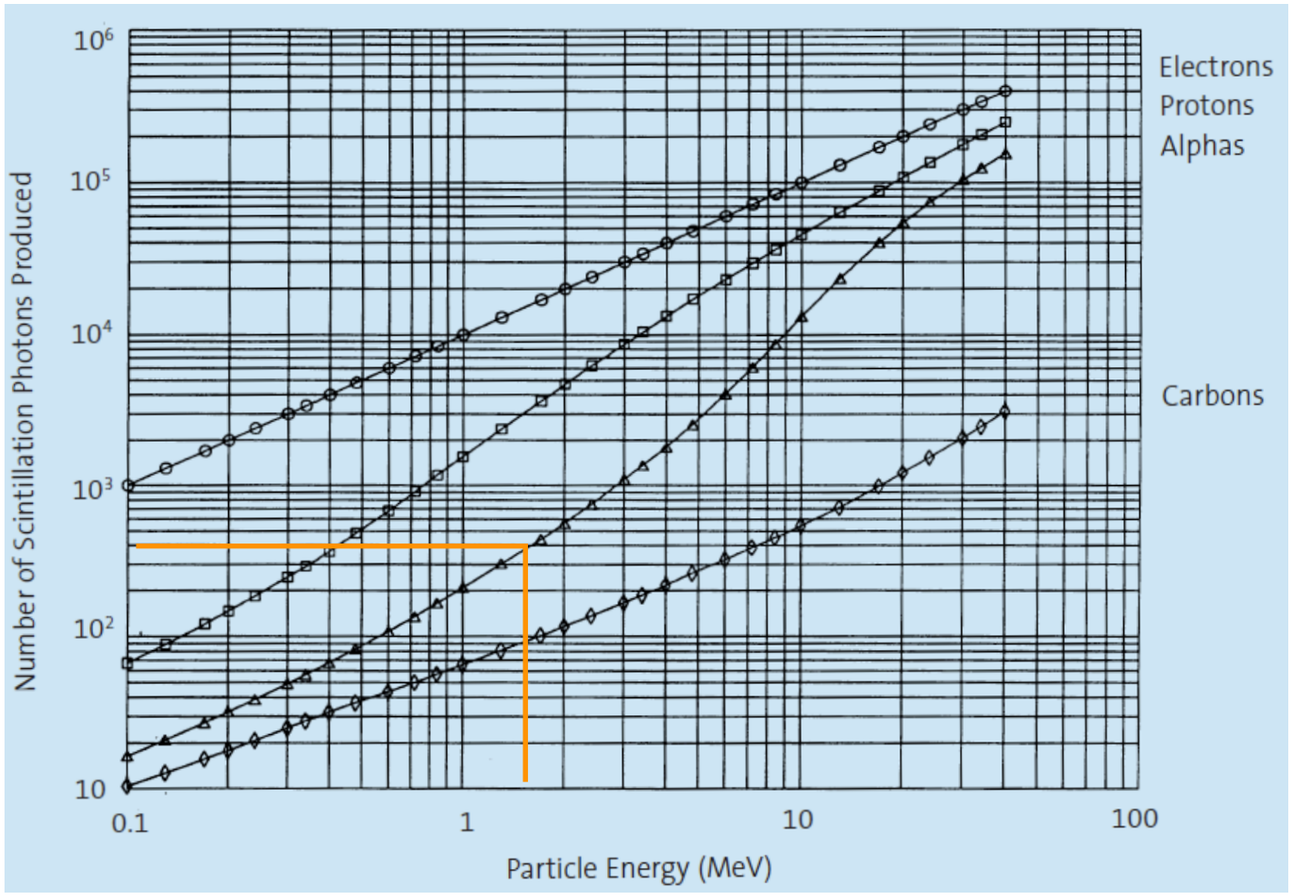

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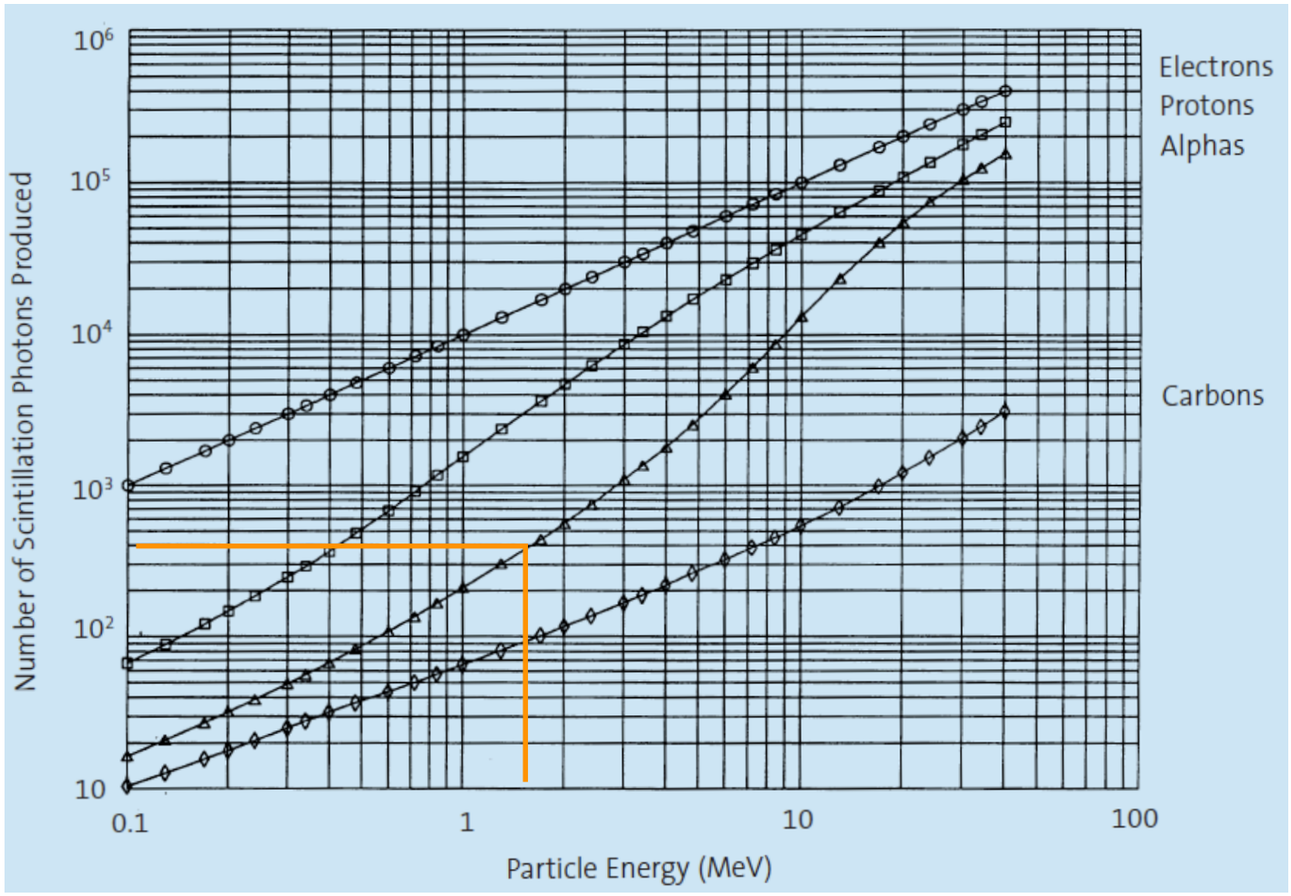

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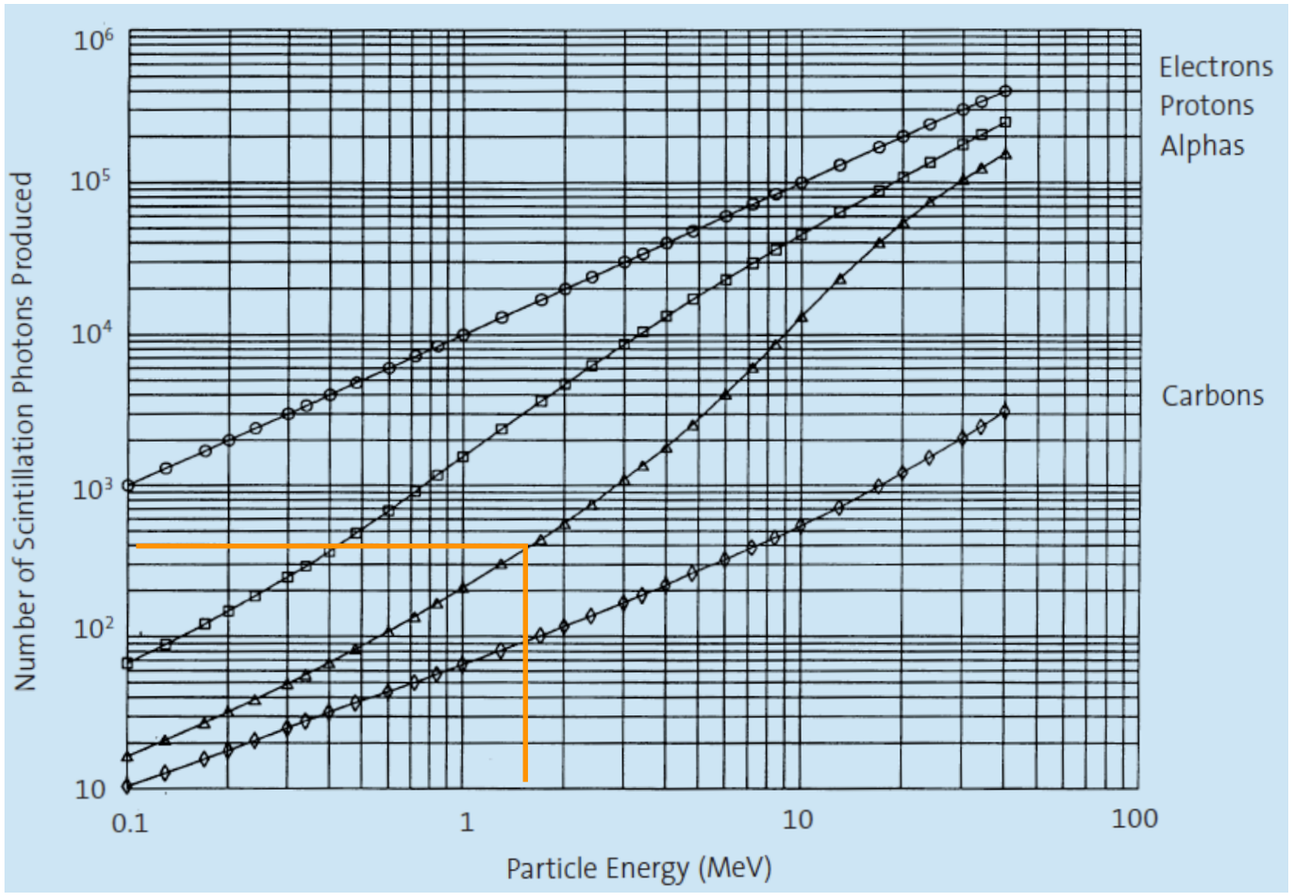

Collaboration with BNL (M.Yeh group): test of different polymers (3M THV), different scintillators (LAB, PPO,...), and different deposition techniques (spin coating...)

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