Measuring the neutrino mass

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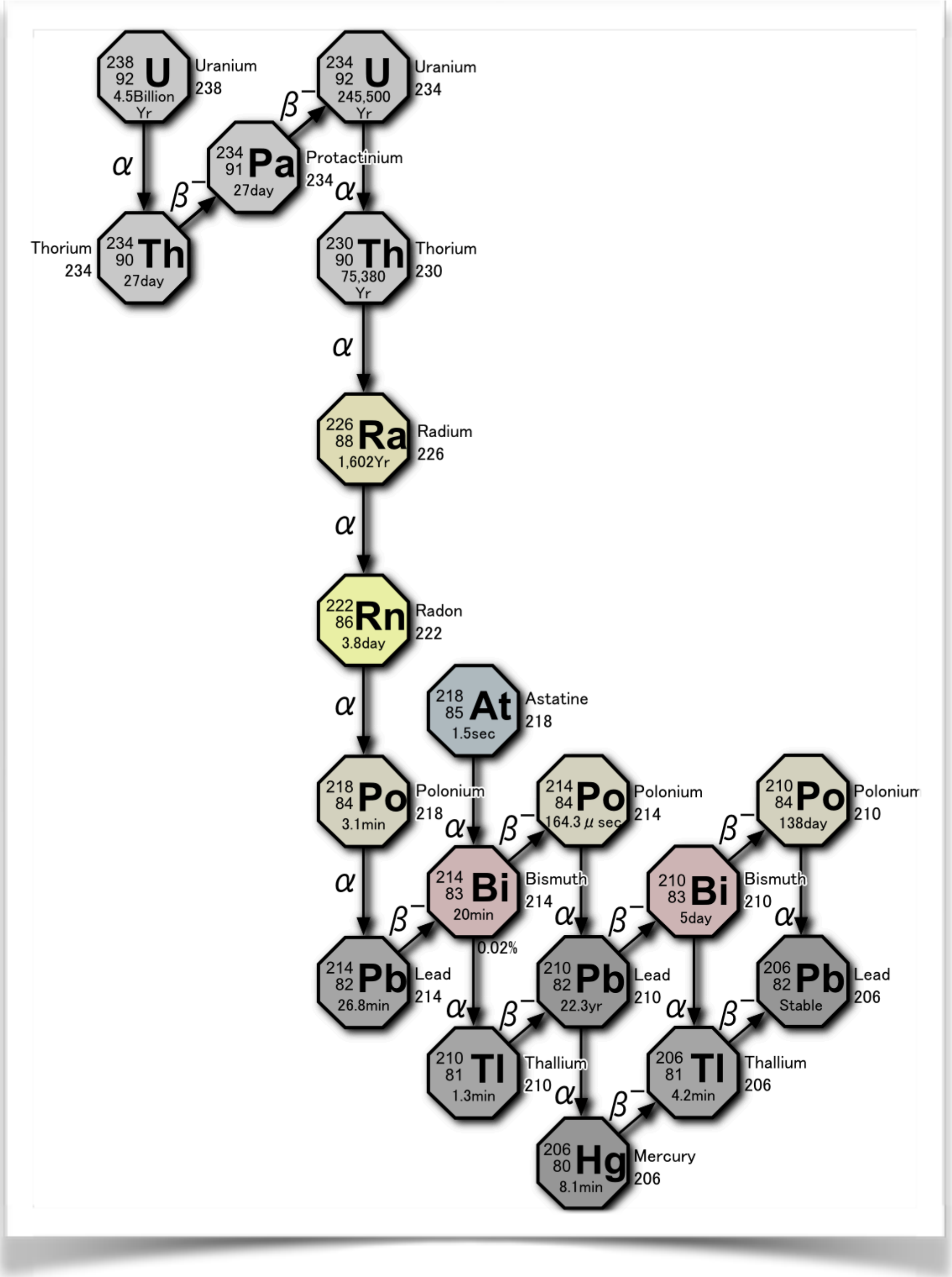
Lecture 3

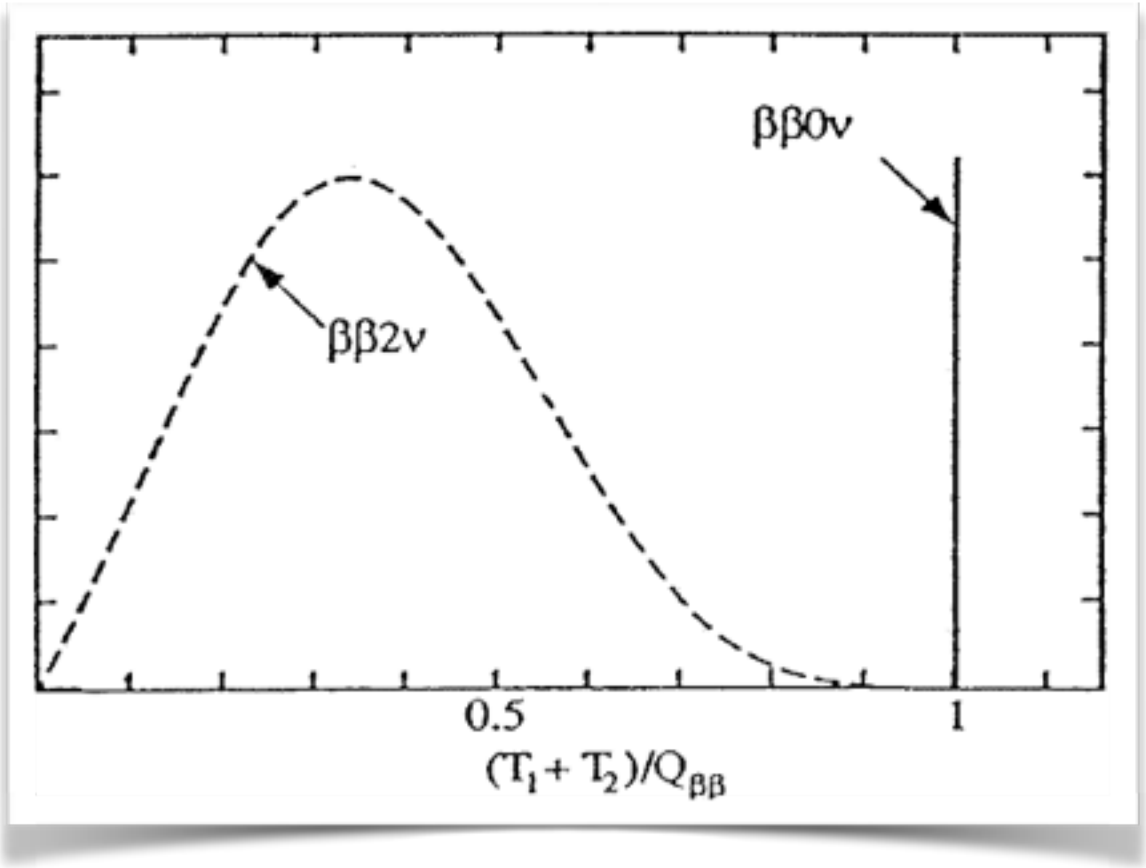
Experimental challenges

Why ββ0ν experiments are difficult



- Earth is a very radioactive planet. There are about 3 grams o U-238 and 9 grams of Th-232 per ton of rock around us.
- This is an intrinsic activity of the order of 60 Bq/kg of U-238 and 90 Bq/kg of Th-232.
- The lifetime of U-238 is of the order of 10^9 y and that of Th-232 10^{10} y. We want to explore lifetimes of of the order of 10^{26} -10^{27} y.
- The problem is much harder than finding a needle in a haystack

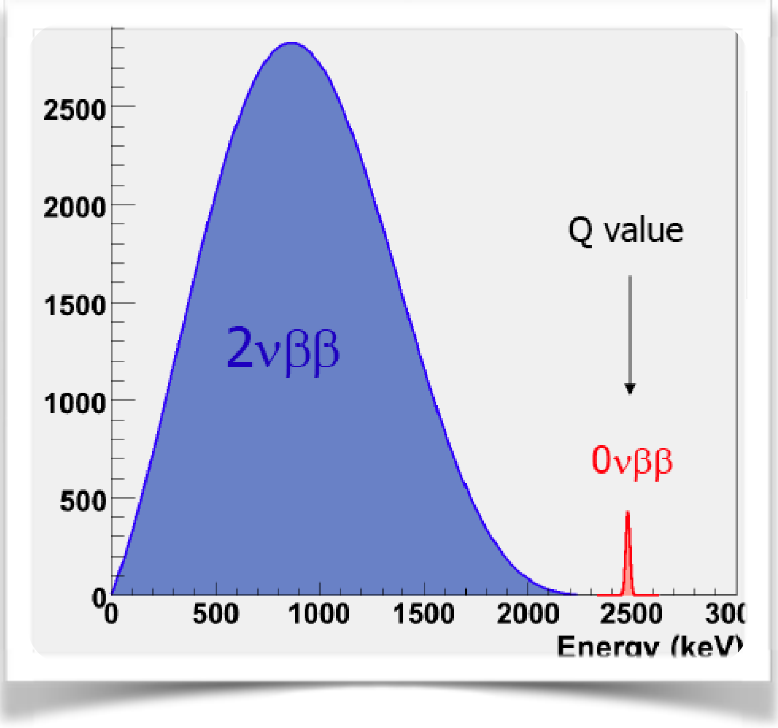
Measuring ββ0ν in an ideal experiment

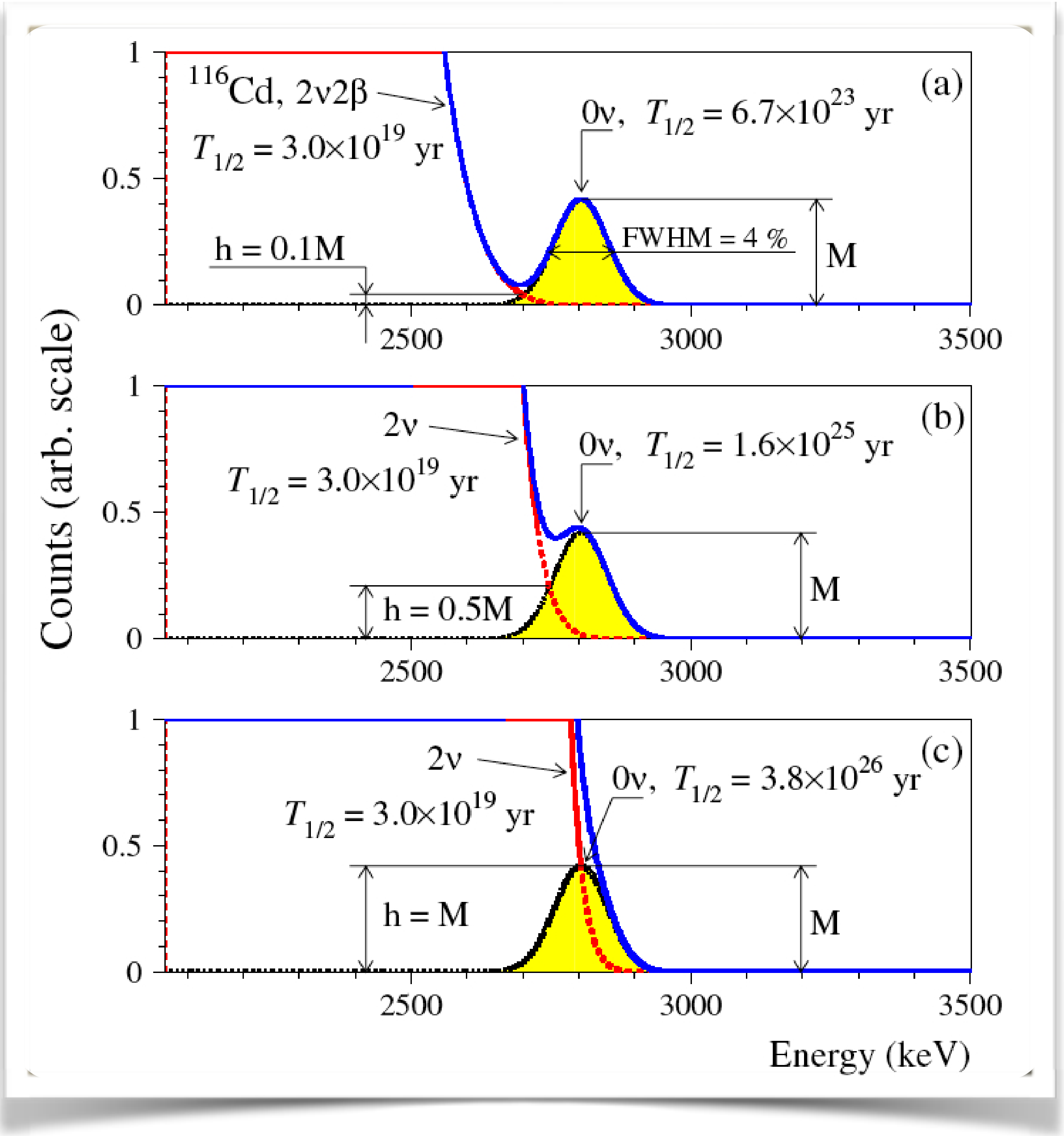


- Get yourself a detector with perfect energy resolution
- Measure the energy of the emitted electrons and select those with (T1+T2)/Q = 1
- Count the number of events and calculate the corresponding half-life.
- In Xe-136, a perfect detector of 1ton observes 3 events for a lifetime of 10^{27} y (~20 meV).
- Improvement with $\sqrt{T}$ but if you must subtract background then $\sqrt[4]{T}$

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q,Z)\ |M^{0\nu}|^2\ m^2_{\beta\beta}$$

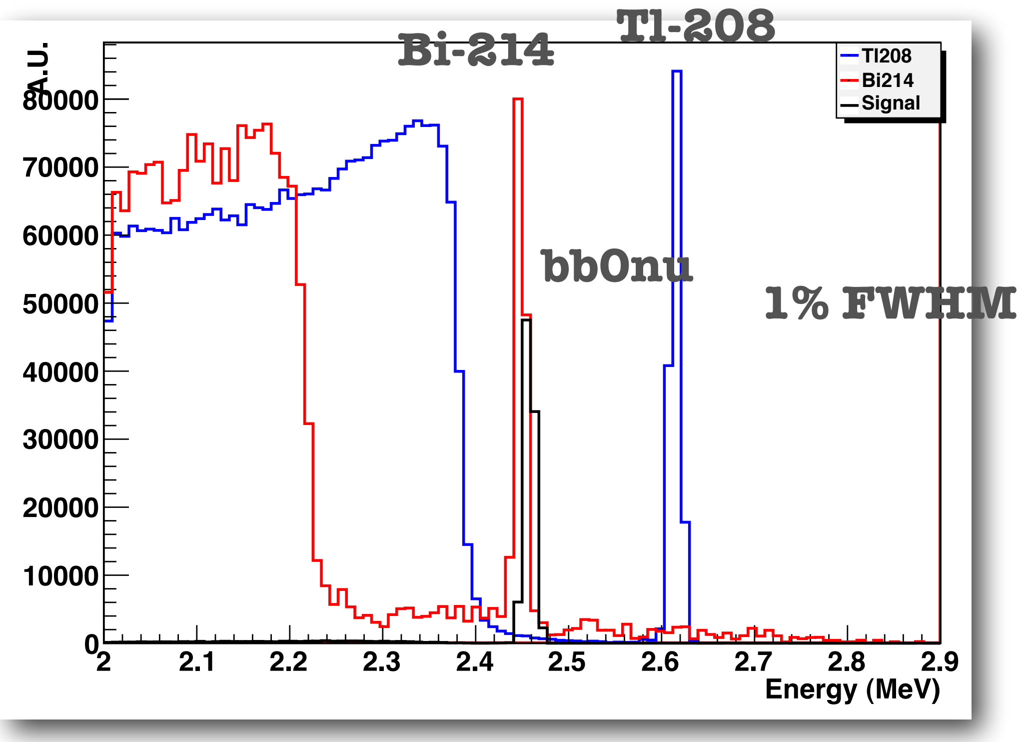
Why energy resolution?

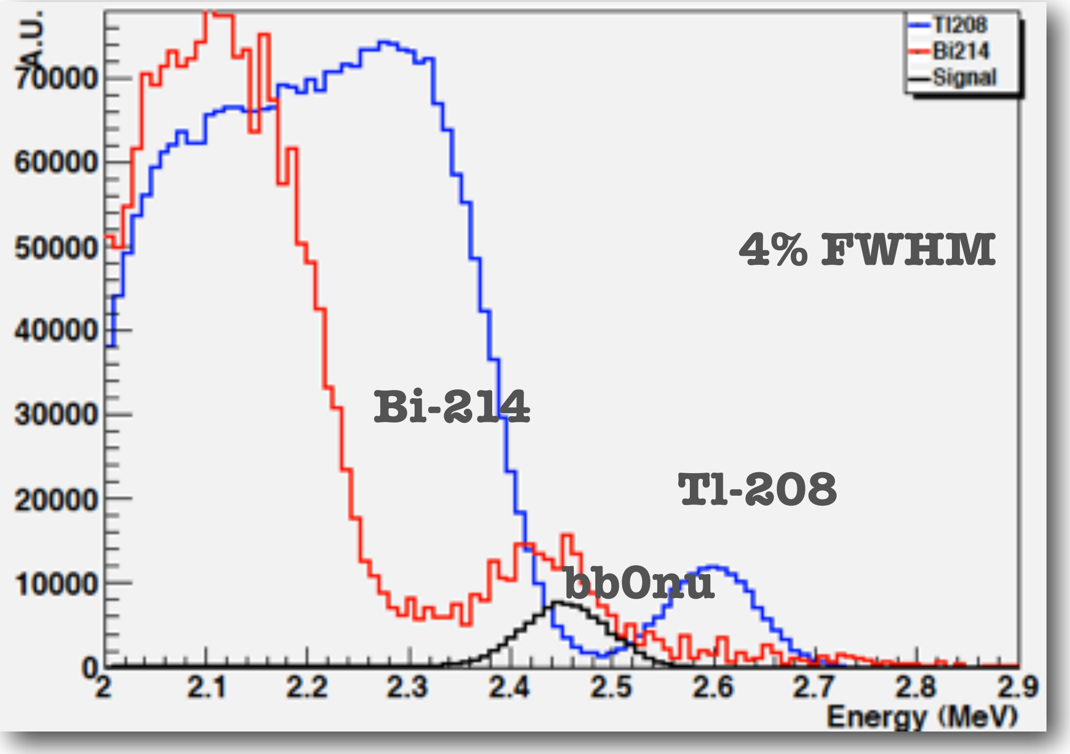




- Even in the absence of other backgrounds, must separate ββ2ν from ββ0ν
- As the energy resolution worsens this becomes more difficult and limits, eventually the sensitivity.

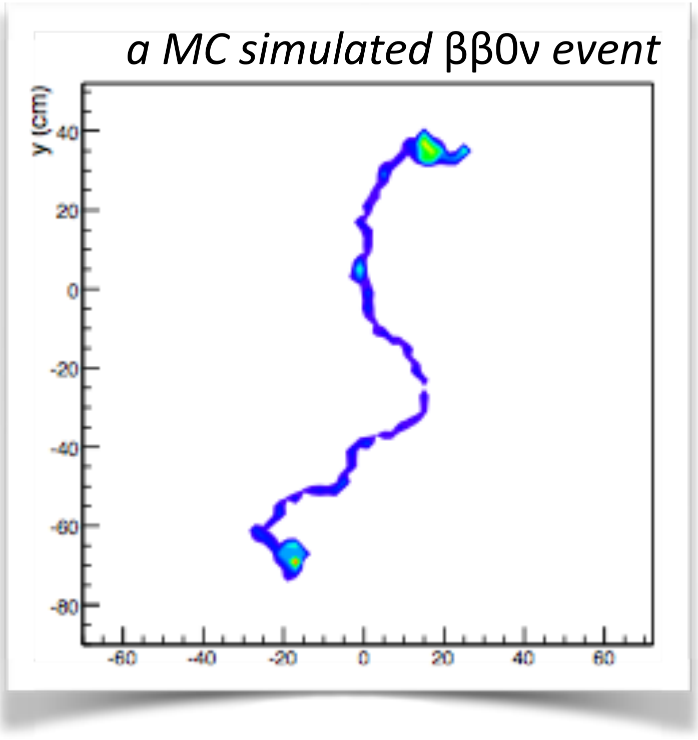
Why energy resolution?

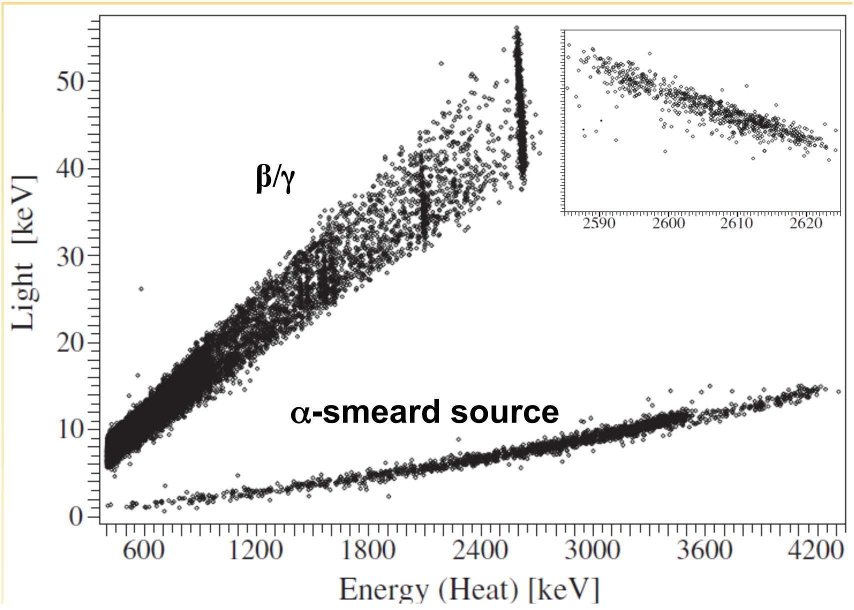


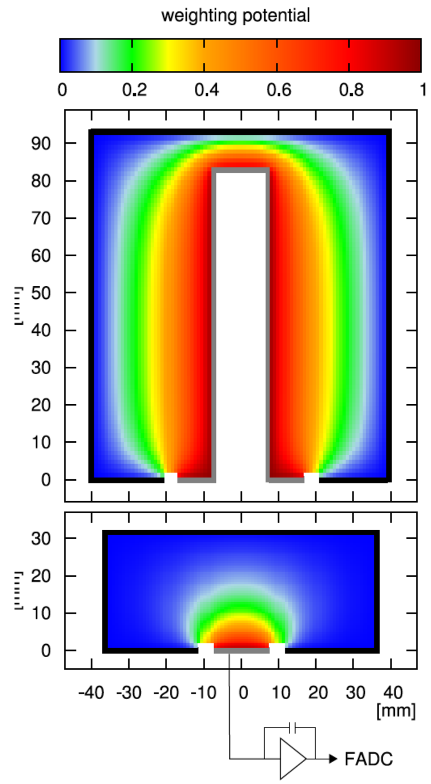


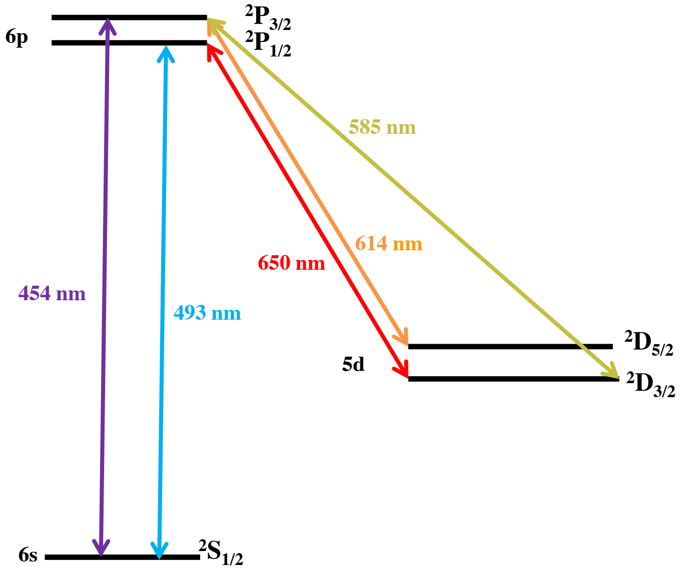
- Leading radioactive backgrounds for Xenon.
- Any resolution worse than 1% (FWHM) makes very difficult to separate signal from background.

Other handles


a MC simulated ββ0ν event

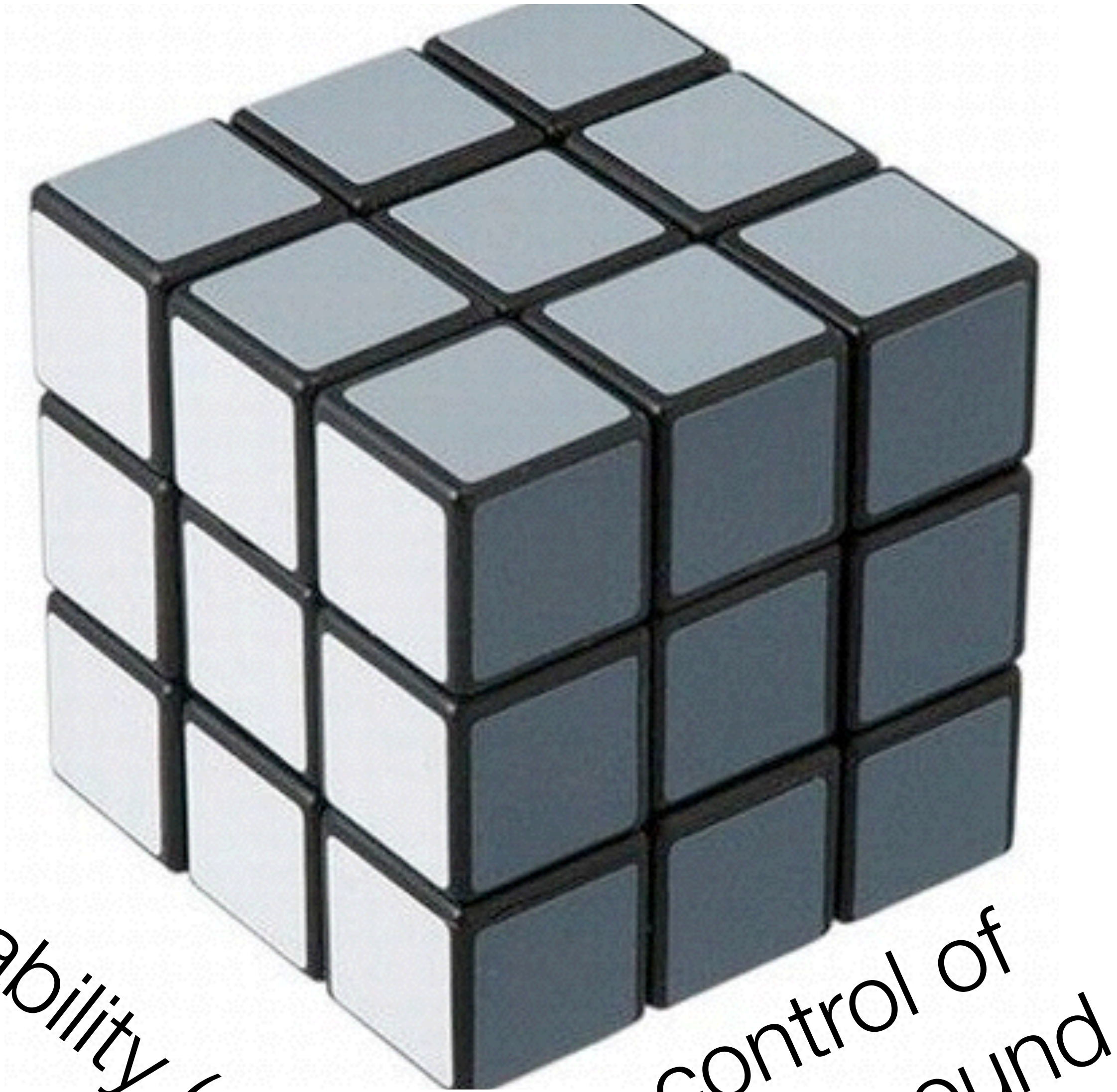






- Examples: tracking in NEMO, SupeNEMO, NEXT.
- PSD in Ge detectors (Gerda)
- Scintillation bolometers (Lucifer/Lumineux)
- BaTagging (EXO, NEXT)

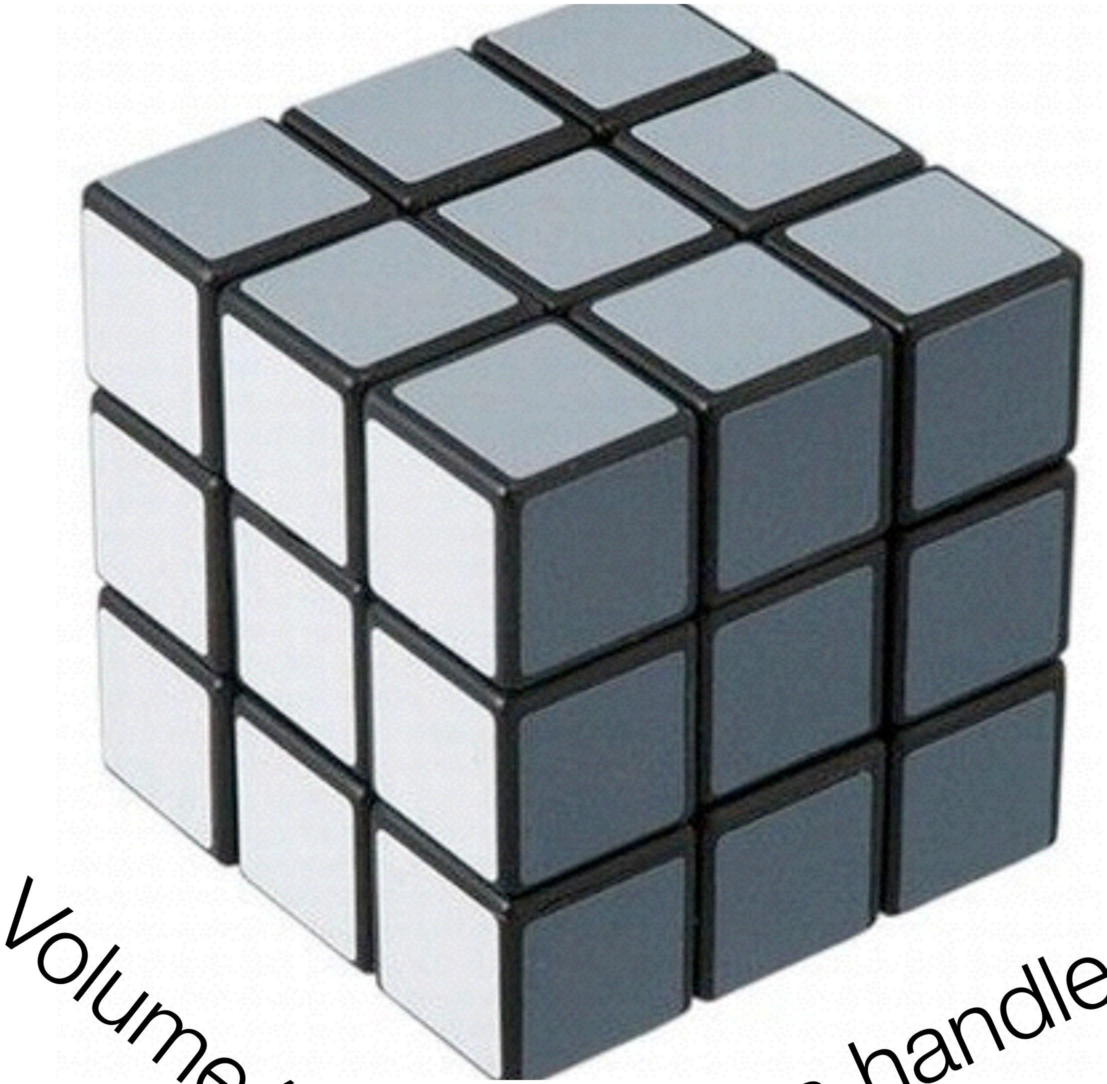
The experiment’s Rubik cube



radio-purity

scalability (mass, cost)

control of background

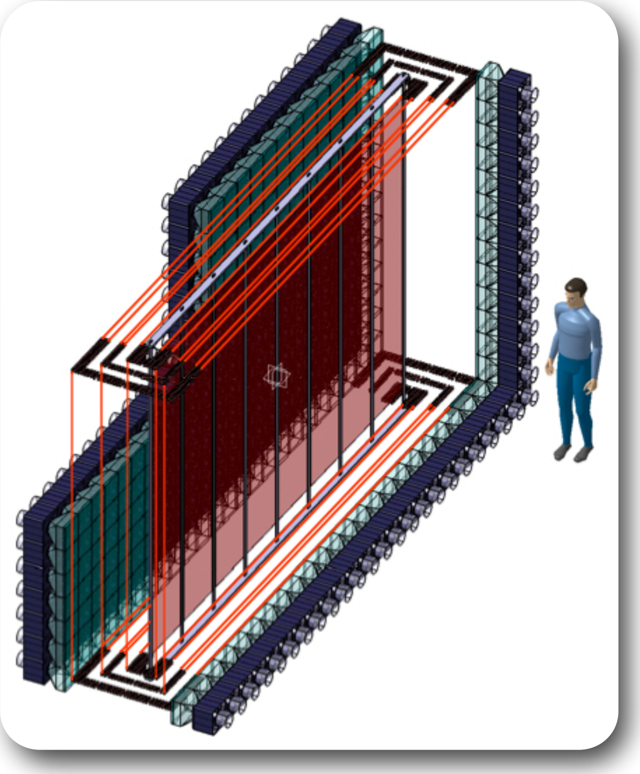


Resolution

Volume/Surface

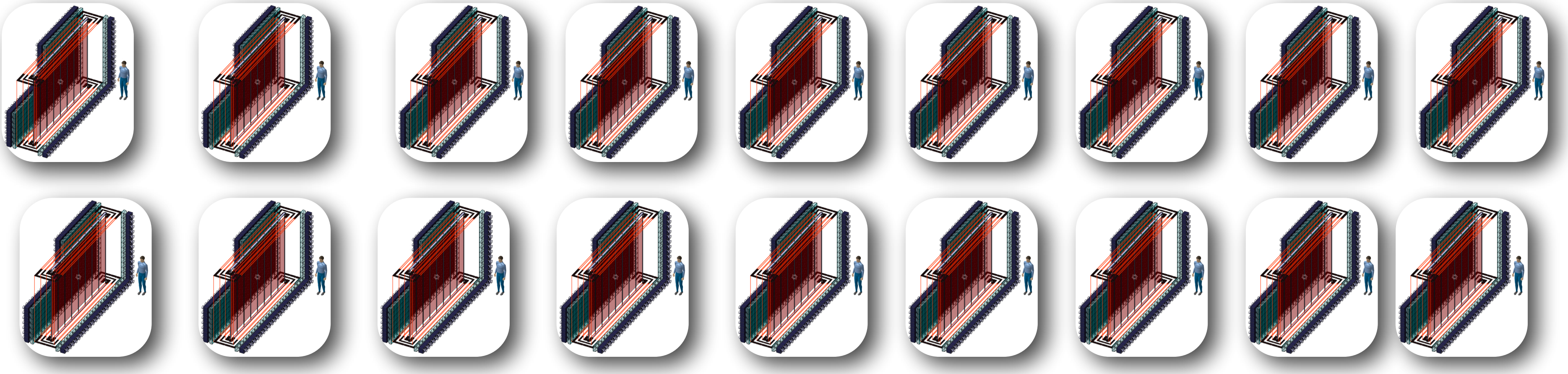
extra handles

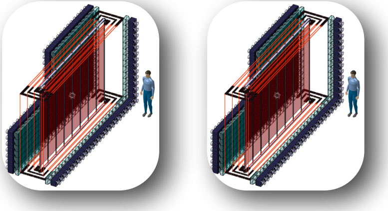
Scalability (source ≠ detector)



- Super-Nemo proposal: Target in a thin sheet surrounded by a tracker and a calorimeter.
- Mass of the sheet ~5 kg.
- Volume of detector ~10 m^3

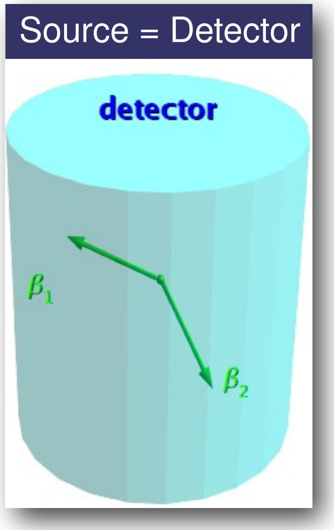
- 100 kg of target require 20 modules.
- No economy of scale → S/N (and sensor coverage) does not improve when increasing mass.

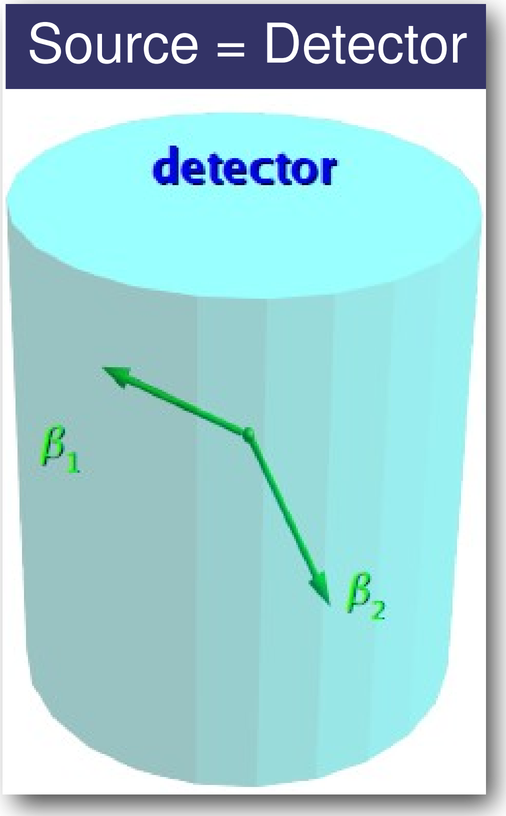


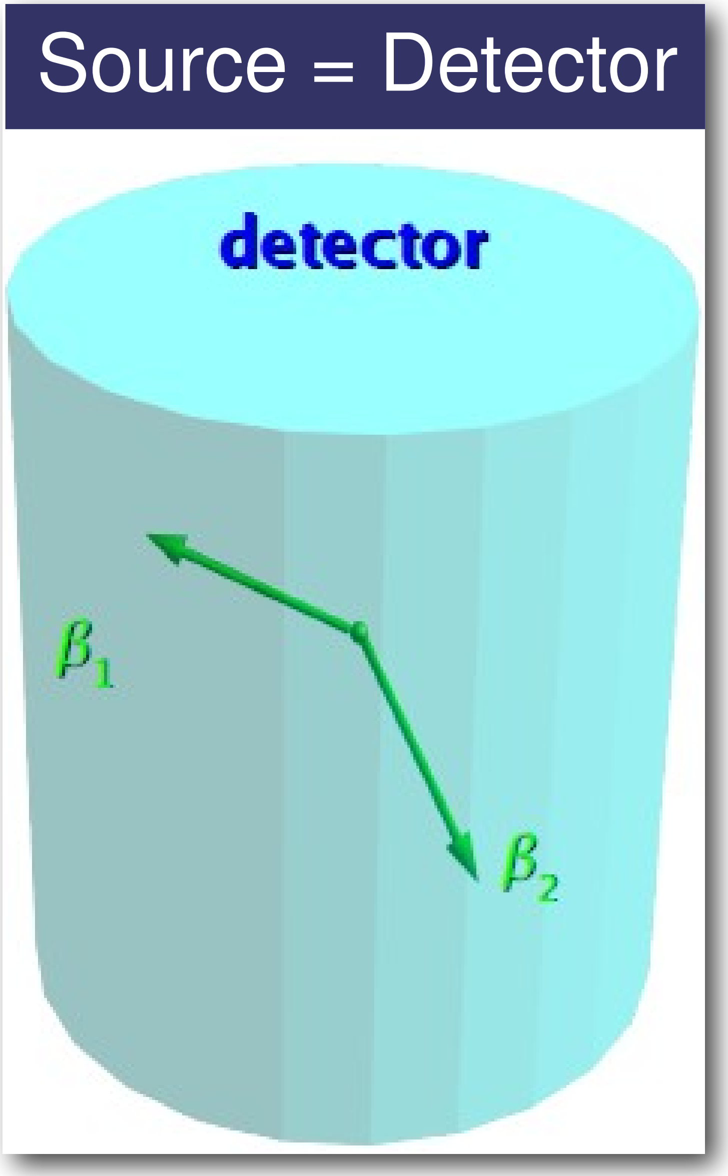


= **100 kg ?!**

Scalability (Source = detector)



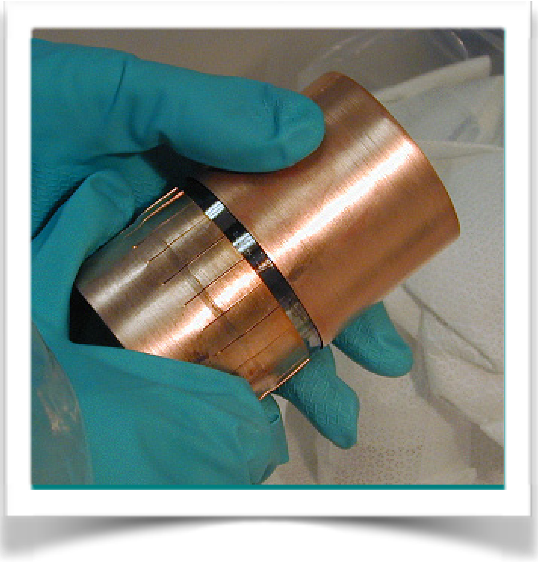




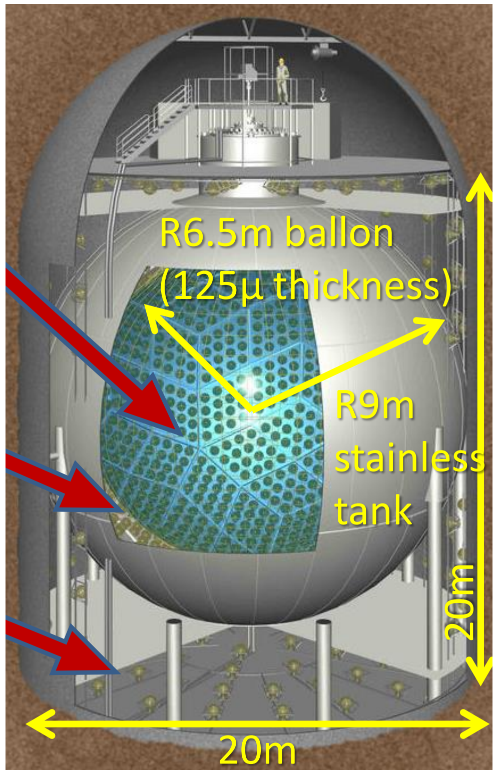
Economy of scale

- Homogenous detectors (such as TPCs): L→Lx2 -> V (Mass) →V(Mass)x 8
- S/N (and detector coverage) improve with L.

Radiopurity



- Build everything out of extremely radiopure materials.
- Solide state apparatus (GERDA, CUORE), display very low activities in detector material in the range of μBq/kg.



- TPCs (EXO, NEXT), have larger radioactive budget, due to their sensors (PMTs, APDs, SiPMs), but their ability to define a fiducial region away from surfaces, eliminates a whole class of backgrounds (α particles).
- In Super-NEMO the signal is constrained to come from the target, but the background also accumulates in the target and α particle background is relevant.
- LS calorimeters are capable of self-shielding from most backgrounds.

The signal and the noise

Signal

Period

$$N_{0\nu} = \frac{a \cdot N_A}{m_A} \frac{\log 2}{T^{0\nu}_{1/2}} \epsilon \cdot M \cdot t$$

$$T^{-1}_{1/2} \propto a \cdot \epsilon \cdot \sqrt{\frac{Mt}{\Delta E \cdot B}}$$

Background

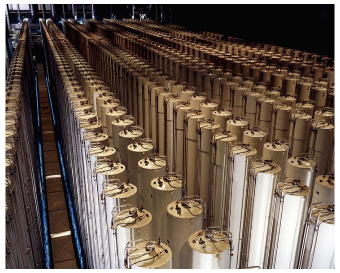
$$N_{bkg} = M \cdot t \cdot B \cdot E$$

- The background depends on the exposure (Mt) and on the product ΔExB. The signal depends on Mt.
- Increasing Mt without decreasing ΔExB implies that the background grows at the same rate of the signal, and therefore the sensitivity to the period only increases with the √Mt and the sensitivity to mββ only increases with $(MT)^{1/4}$
- Thus, a Golden Law: every time that you increase the mass by a factor α you must reduce the background by the same factor.

Building the perfect ββ0v experiment

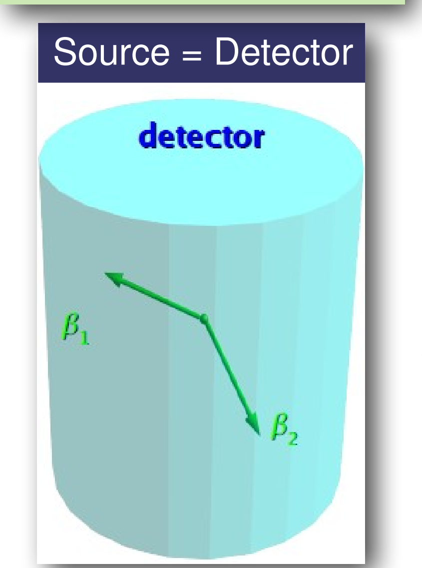
$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{Mt}{\Delta E \cdot B}}$$

Isotope



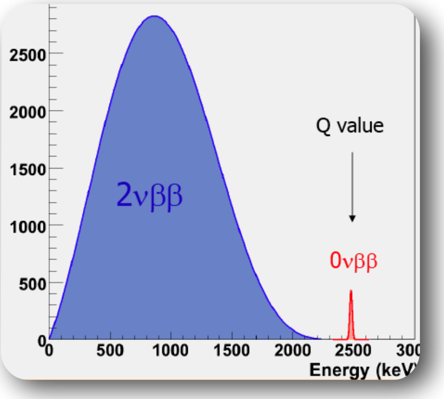
Find an isotope with large Q, no long lived radioactive isotopes, easy to procure and cheap.

Scalability



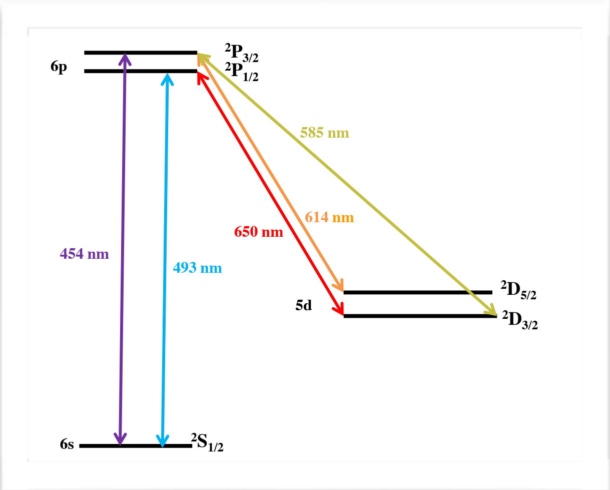
Build a detector with no dead areas, and economy of scale

ΔE



Build a detector with the best possible resolution

Background



Detector provides extra handles to reduce background