Low background techniques

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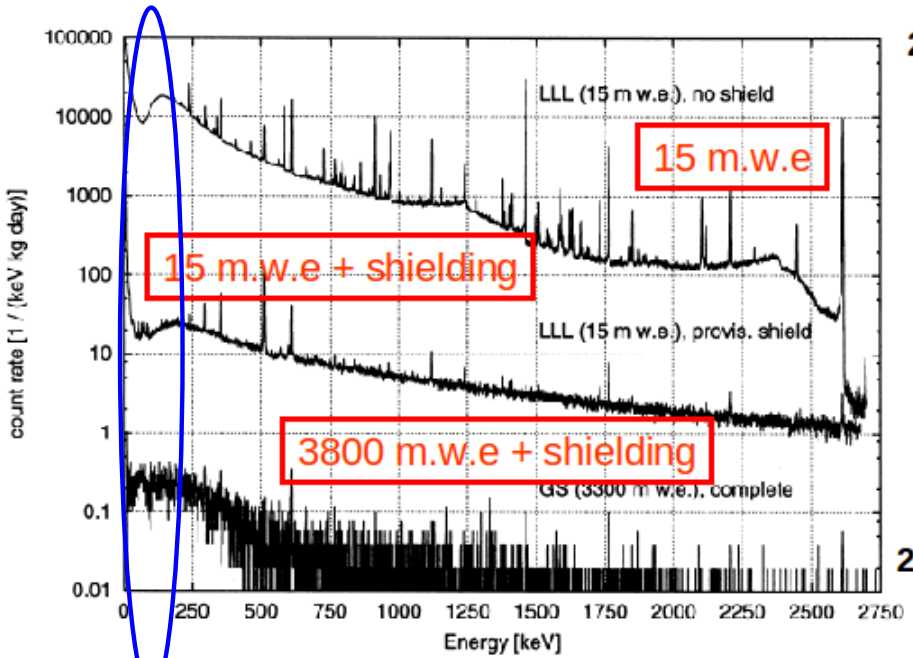
Background: Basics

Source	Reduction
Cosmic rays	Go underground
Natural radioactivity in rock + concrete (γ, β, n)	Shieldings
Radioactivity from materials in the detector construction	Material selection + Rejection

Light dark matter search in the low energy region ([0-50]keV) of natural radioactivity spectrum $\rightarrow$ CHALLENGING



2.10^6 muons/m² day on surface

26 muons/m² day at 3800 m.w.e

(Applied Rad and Isotopes 53 (2000) 191)

Radioactivity

Primordial : ^{238}U, ^{235}U, ^{232}Th decay chains and ^{40}K

Cosmogenic : ^{60}Co, ^{54}Mn, ...

Anthropogenic (man-made) ^{137}Cs, ^{241}Am, ...

Most used techniques for bulk radioactivity measurement

Technique	Sample Mass	Sensitivity for U/Th (mBq/kg)	Pros	Cons
ICPMS*	some mg	10^{-1} - 10^{-2}	High sensitivity small sample mass	Limited to the parent of U/Th chain
Neutron Activation Analysis	10 g to 1 kg	10^{-2} - 10^{-5}	Highest sensitivty	Limited to the parent of U/Th chain
Low background γ spectrometry	10 g to some kgs	1 - 10^{-1}	Analysis of (almost) all radionucleides in the chain	Less sensitive Limited to γ emitters

* Inductively Coupled Plasma Mass Spectroscopy

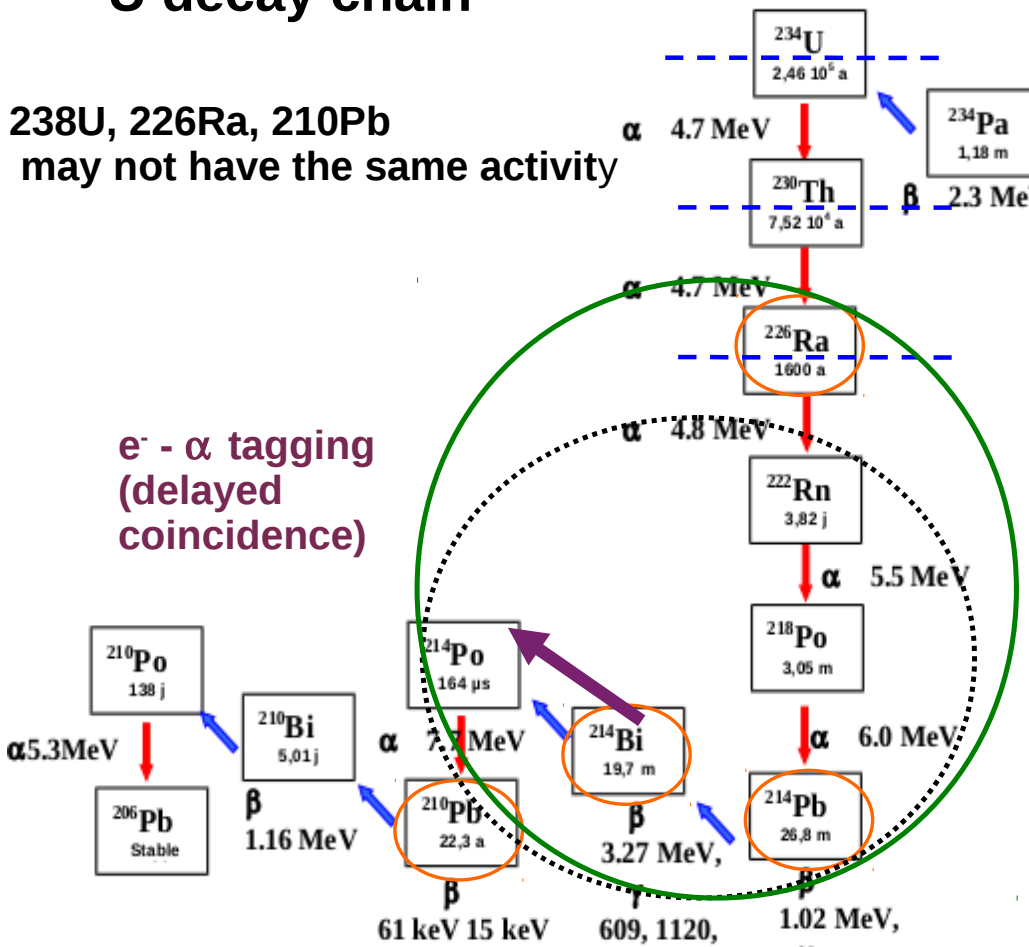
Low background gamma spectrometry is the only technique measuring several radionucldes in the same chain $\rightarrow$ allows to validate or not the secular equilibrium in the chain.

Secular equilibrium

As a result of physical or chemical processes during the fabrication of materials, secular equilibrium is rarely achieved, since radionuclides in the chain may be enhanced or depleted

^{238}U decay chain

238U, 226Ra, 210Pb may not have the same activity



Mass spectrometry, Neutron Activation Analysis

e⁻ - α tagging (delayed coincidence)

Gamma spectrometry :

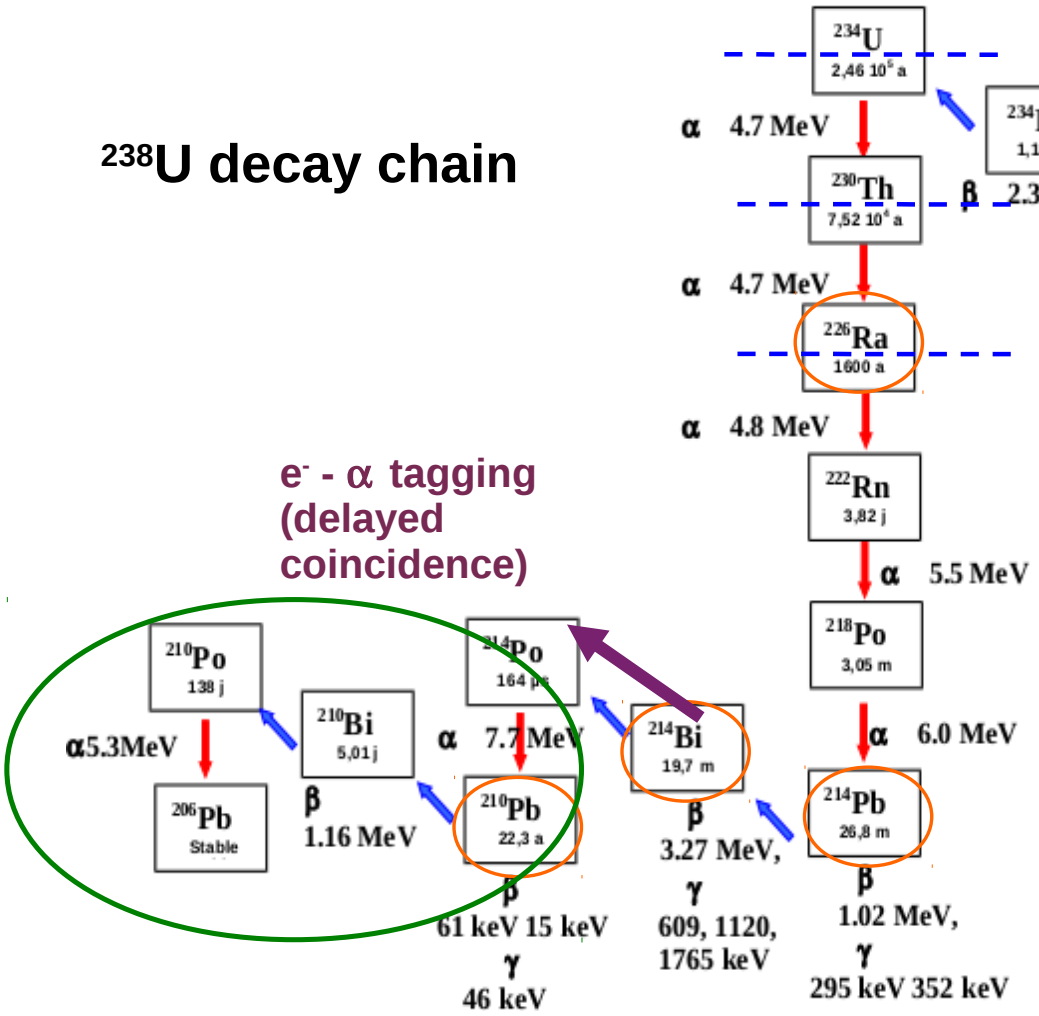
- Indirect measurement of 238-U via 234-Th
- Measure 226-Ra subchain via 214-Pb, 214-Bi

Gamma active nuclide

Sub-chains

How to measure? Uranium chain

^{238}U decay chain



Mass spectrometry, Neutron Activation Analysis

e$^-$ - α tagging (delayed coincidence)

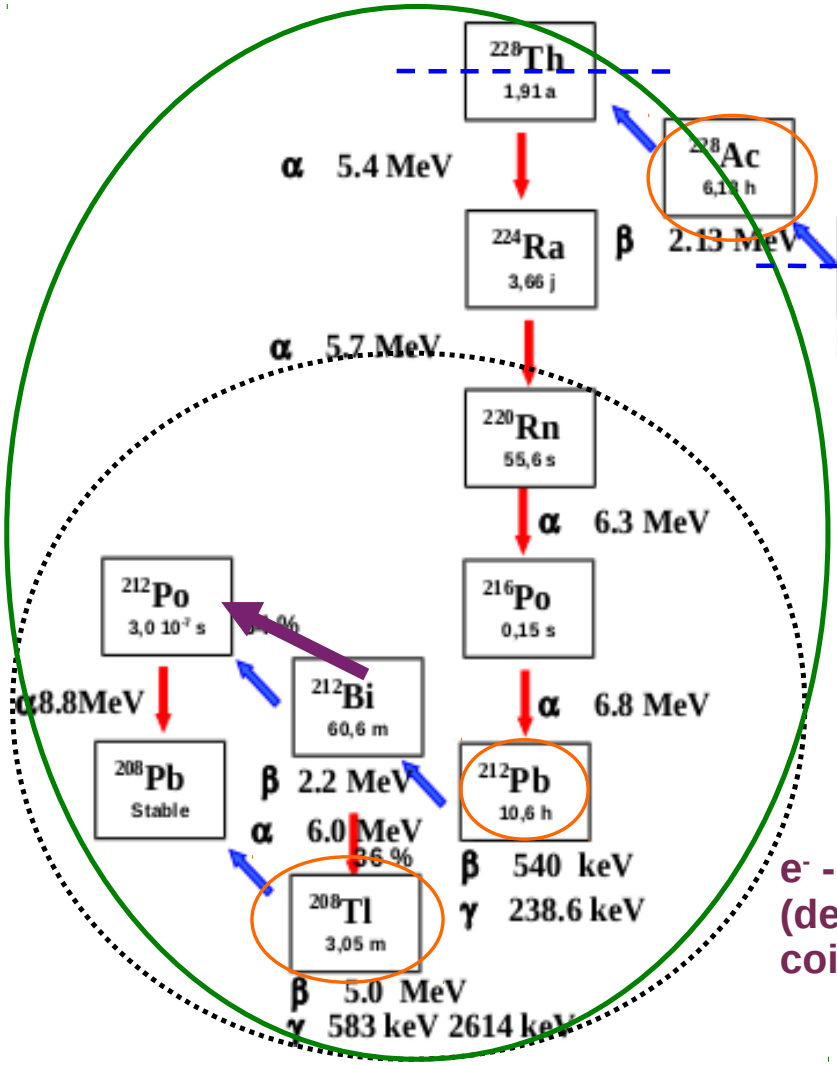
Gamma spectrometry :

Measures 210-Pb sub-chain via 210-Pb

Gamma active nuclide

Sub-chains

How to measure? Thorium chain



Mass spectrometry,
Neutron Activation Analysis

^{232}Th decay chain

Gamma spectrometry :

- Measures 228Ra via 228Ac
- Measures 228Th subchain via 212Pb and 208Tl

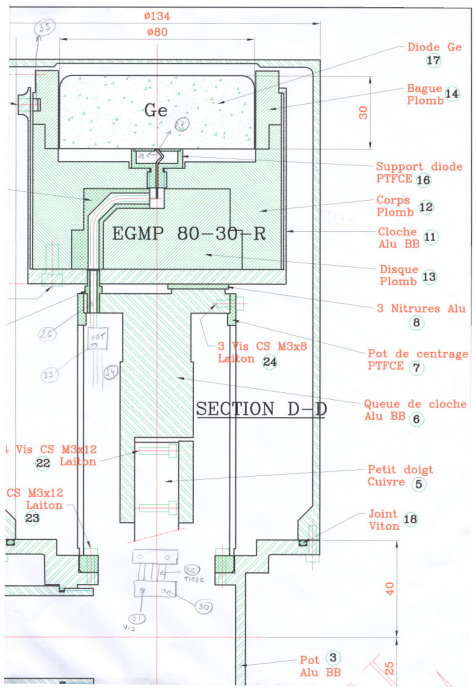
e^- - α tagging (delayed coincidence)

Gamma active nuclide

Sub-chains

Low background gamma-ray spectrometry

$$Det.Lim. = \frac{1}{\varepsilon \cdot M \cdot P_\gamma}\sqrt{\frac{B \cdot \Delta E}{t}}$$



ε=efficiency

M: Source mass

t: Measuring time

B: Background

ΔE: Energy resolution

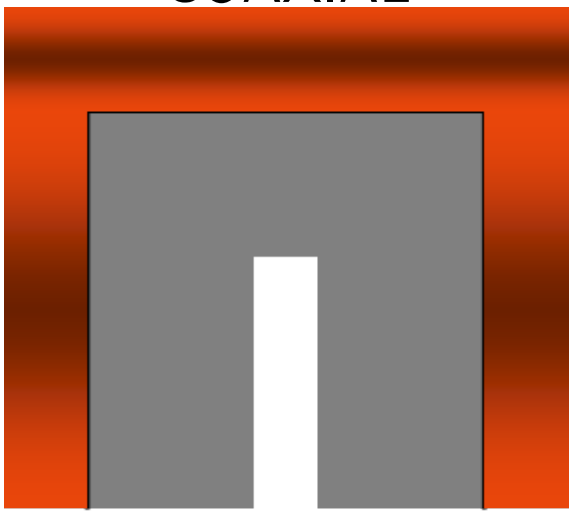
P_γ=Probability of emission

Sensitivity improvement by:

- **material selection of all components**
- **new configurations**
- **shielding improvements**

HPGe detector types

COAXIAL



+high sample mass
+high efficiency at high energies (i.e 2.7 MeV)
-less efficient for low energies

WELL

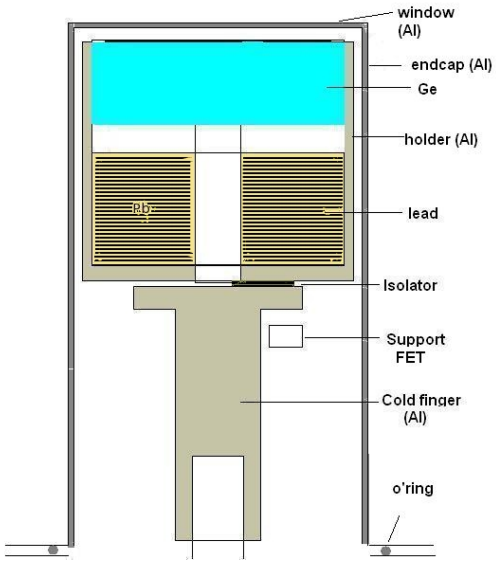
+high efficiency at all energies
-limited sample geometries

PLANAR

+high resolution at low E_γ
-middle sample masses

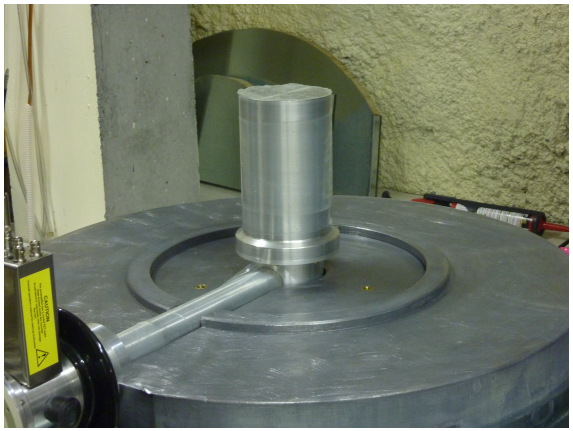
Developments

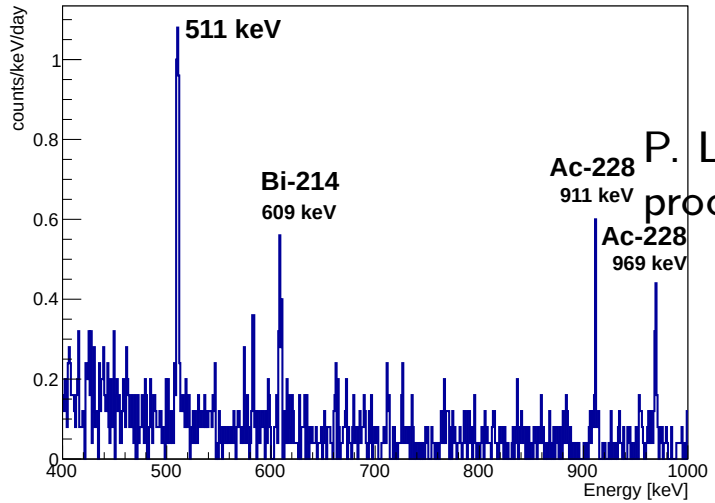
PLANAR HPGe at LSM, MAFALDA:



P. Loaiza et al, NIM*A* 634 (2011) 64

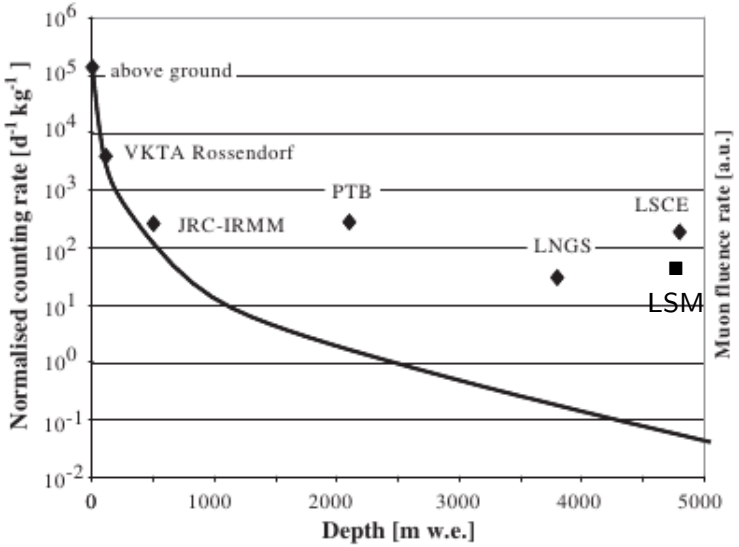
COAXIAL HPGe at LSM, OBELIX:





P. Loaiza et al, AIP Conf. proc. 1672 (1), 130002-1

Sensitivities



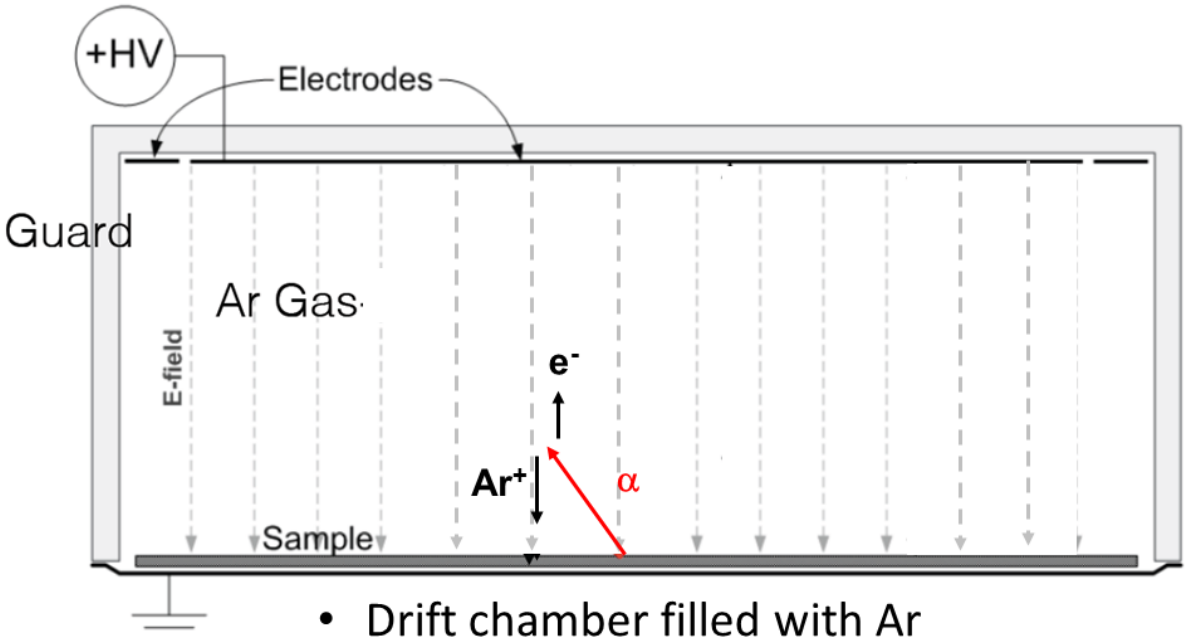
Detector	Material	Mass (g)	Time (h)	^{210}Pb (mBq/kg)	^{234}Th(^{238}U) (mBq/kg)	^{226}Ra (mBq/kg)	^{228}Th (mBq/kg)
Mafalda (Planar)	Aluminium	1025	132	< 9	<3	< 0.9	1.0±0.3
Obelix (Coaxial)	Polyethylene	3900	672	-	-	0.65 ± 0.08	0.30±0.07
GeMPI2 (Coaxial)	Copper	125000	2412	-	<7	<0.016	<0.012

Low energies: 46 keV, 63 keV, 92 keV

Higher energies: 200 keV < E < 3000 keV

- For about 1 month measurement and $\mathcal{O}$(kg) $\rightarrow$ present sensitivities $\sim$ 500 μBq/kg in ^{226}Ra and ^{228}Th
- Best sensitivities can reach 20 μBq/kg in ^{226}Ra and ^{228}Th

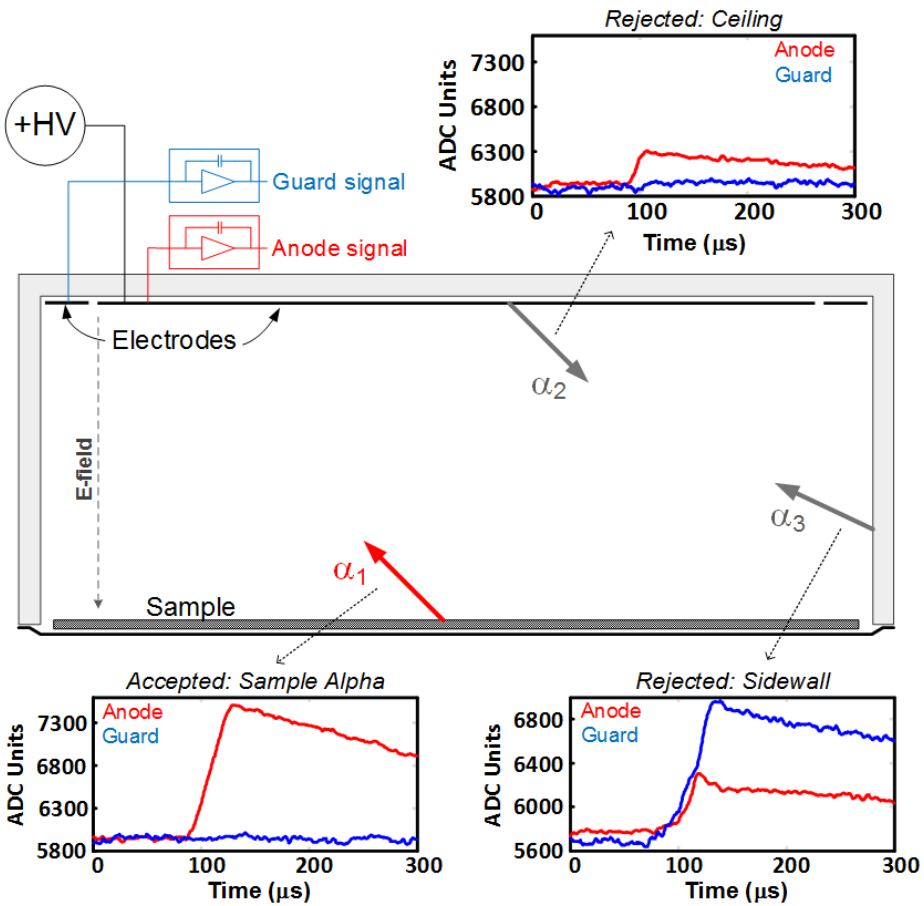
Surface radioactivity measurement by α/β detection: XIA's Alpha counter – UltraLo-1800



- Drift chamber filled with Ar
- Electrodes at +1kV

Images courtesy of www.xia.com/ultralo

XIA's Alpha counter – UltraLo-1800



Images courtesy of www.xia.com/ultralo

Alpha selection :

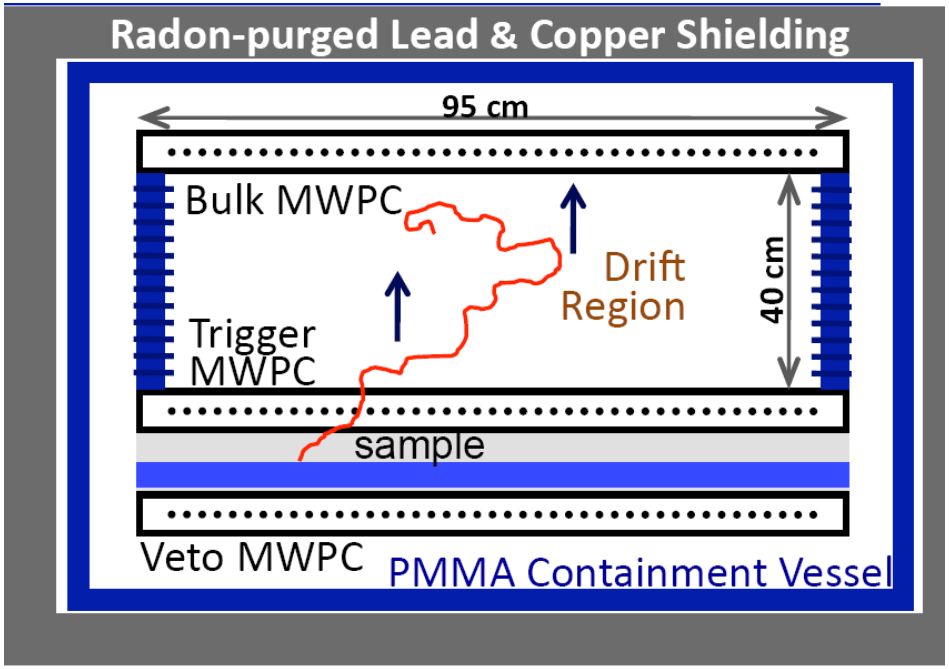
- $\geq$ 2 MeV
- Pulse shape discrimination of alphas from walls and ceiling
- Alphas from sample : no guard signal amplitude

Background :

- **Sea-level, unshielded**
  $\sim 10^{-3}$ α/cm^2/hr
- **Underground, shielded**
  $\sim 10^{-4}$ α /cm^2/hr

Total sample surface: 1800 or 707 cm^2

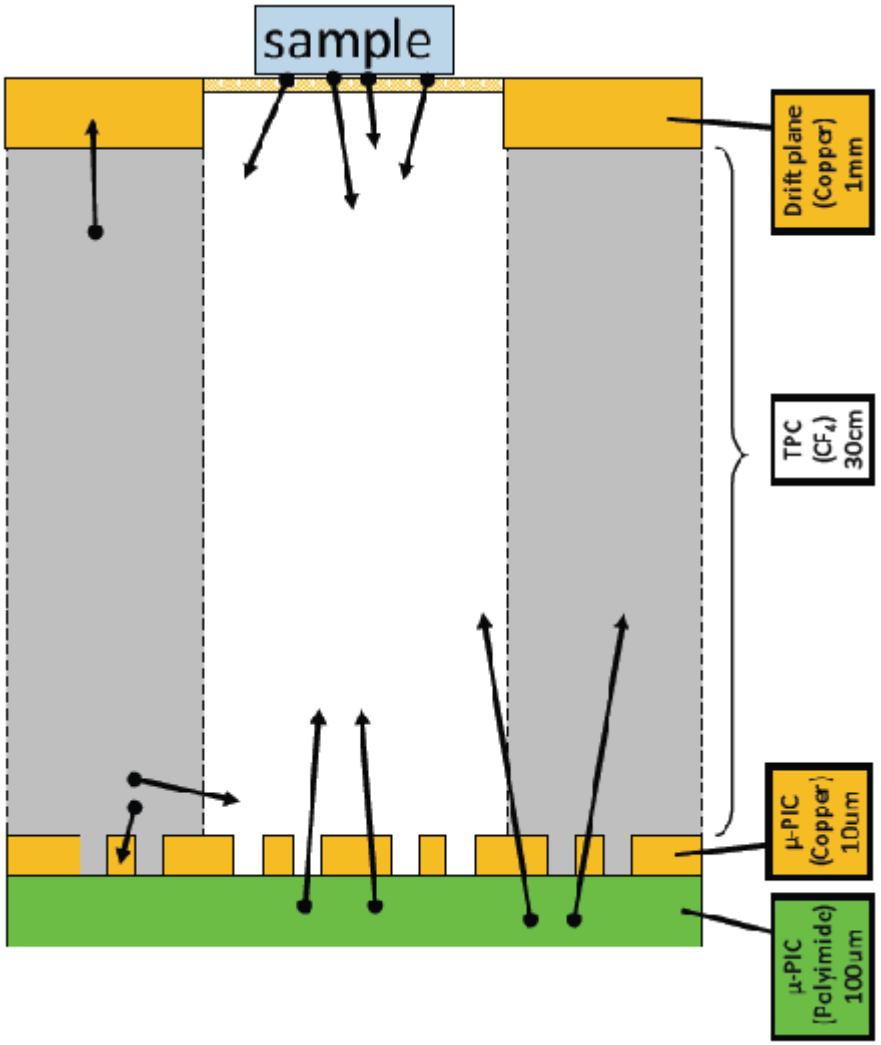
Beta cage



- Drift chamber with Multi-wire proportional counter
- Sample in the gas (Ne)
- A 'trigger' MWPC creates the trigger region
- Drift region contains all 200 keV e- and alphas
- A 'bulk' MWPC collects the charges

Total sample surface: 4500 cm^2

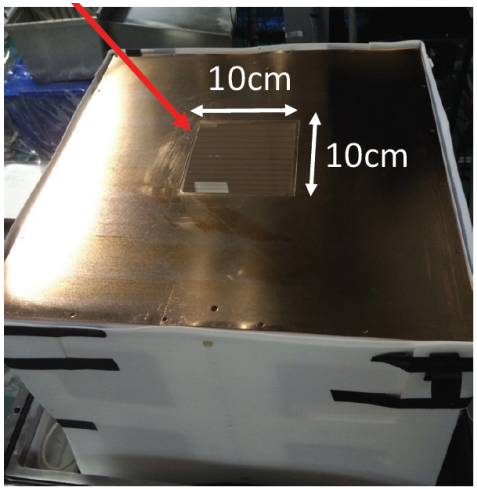
Surface alpha detector using μ-TPC



Developped by NEWAGE collaboration (direction-sensitive dark matter search)

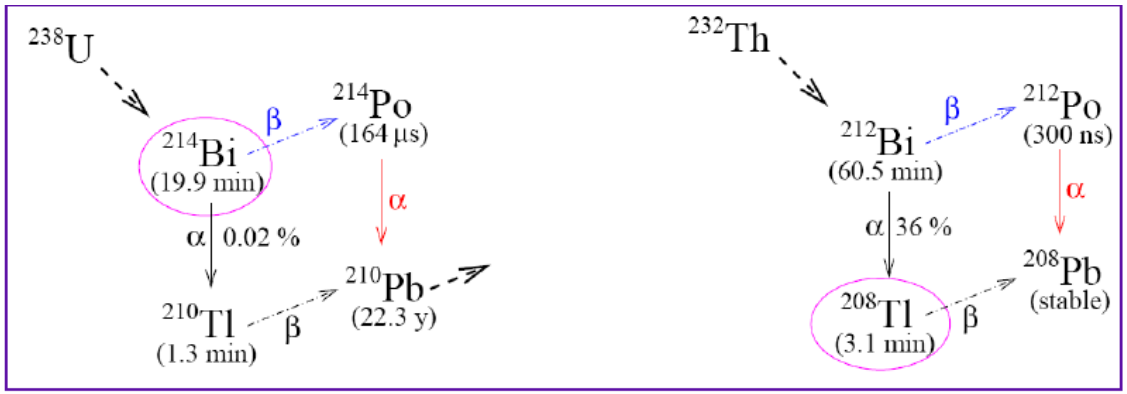
- Located at Kamioka mine
- Background (outside sample region): 0.119 ± 0.002 events/cm^2/h

Total sample surface: 10×10 cm^2

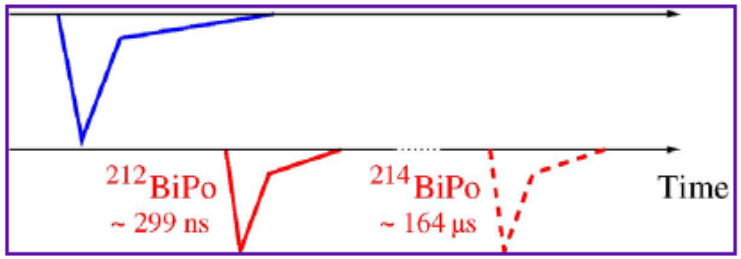


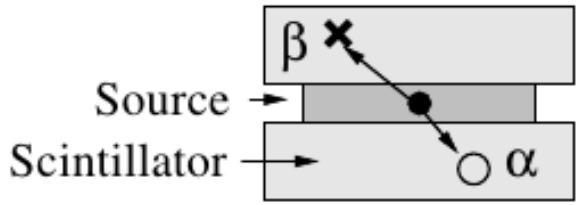
The BiPo-3 detector

Developped by the SuperNEMO collaboration to measure $\beta\beta$ source foils at the level of 2 μBq/kg for Tl-208



^{212}Bi and ^{214}Bi are measured by electron-alpha coincidence in the BiPo desintegration

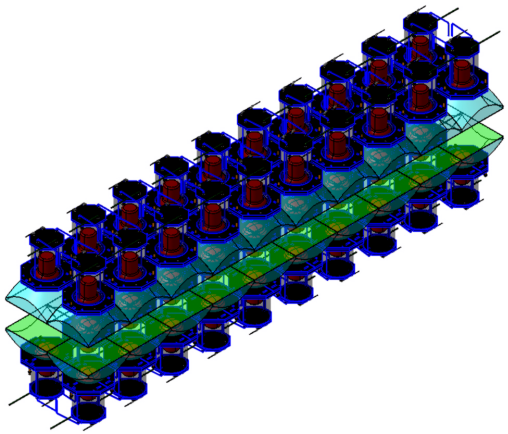


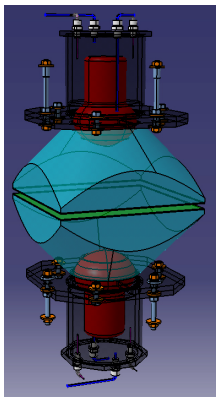


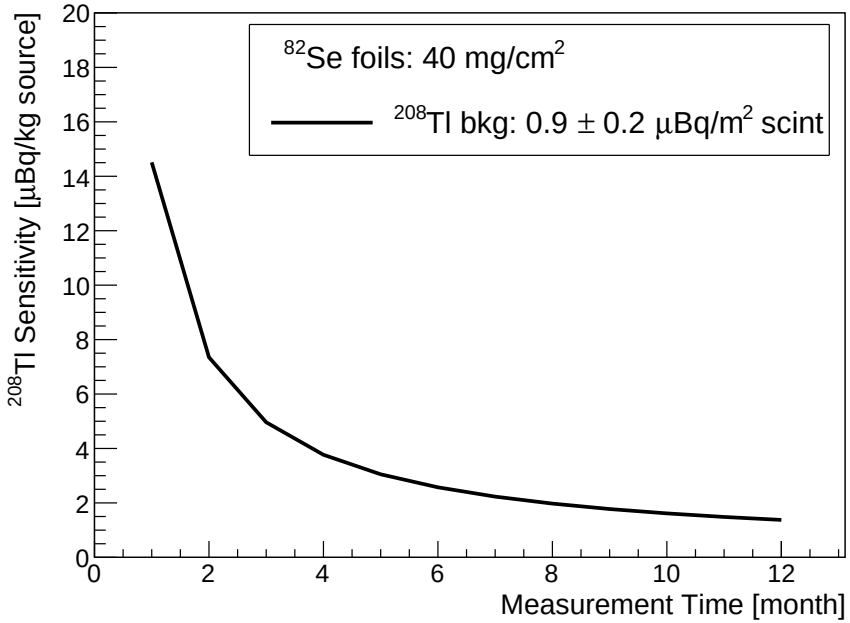
The sample is placed between two plastic scintillators coupled to low radioactive PMTs

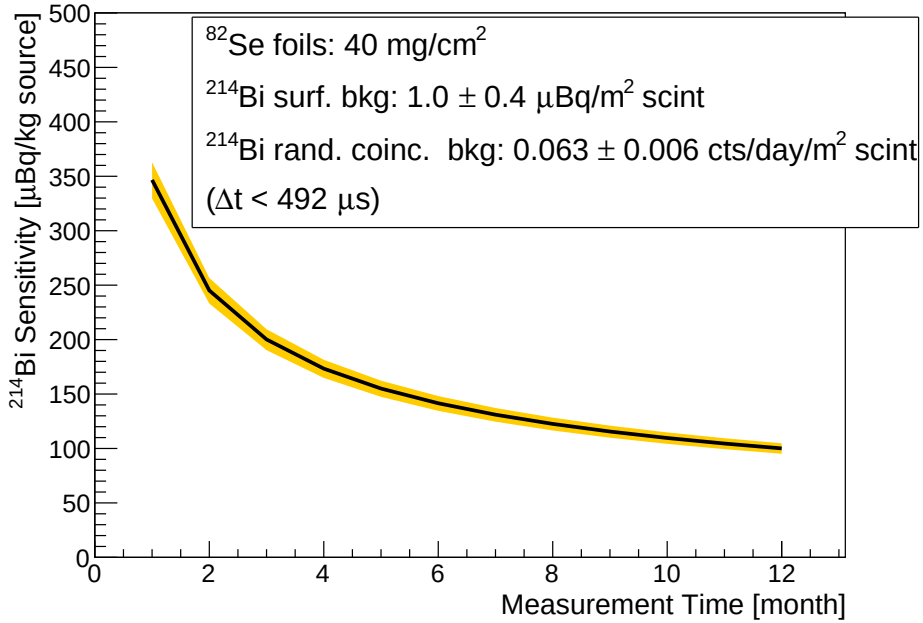
The BiPo-3 detector

Total surface=3.6 m^2









Conclusions

- ICPMS, γ spectrometry are complementary techniques for the assesment of bulk radioactivity
- Typical sensitivities for γ spectrometry are $\sim$ 500 μBq/kg in ^{226}Ra and ^{228}Th
- Surface radioactivity measurement: XIA's Alpha counter – UltraLo-1800, Background underground, shielded $\sim 10^{-4}$ α /cm^2/hr $\rightarrow$ Sensitivities $<$ 0.5 mBq/m^2 for ^{210}Po