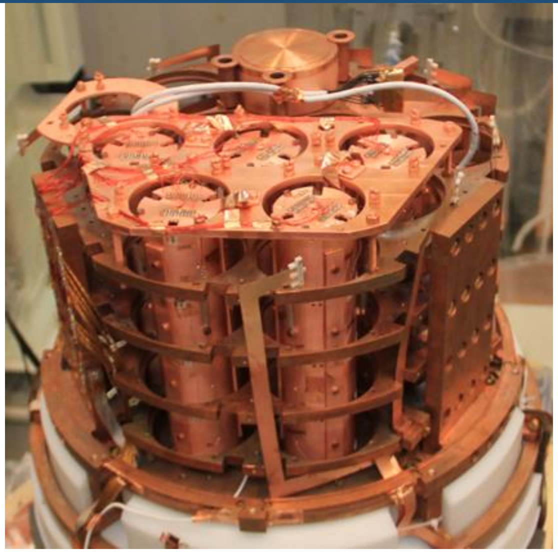
Screening activities with HPGe detectors

Pia Loaiza

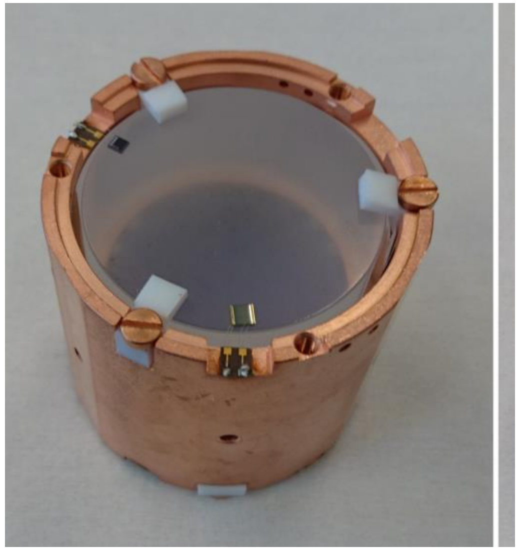
GDR DUPhy, June 1st, 2021

Fighting the background : How?

Dark matter



2β0ν



Background reduction

- Active discrimination
- Passively by:
  - Purification techniques
  - Cleaning
  - Screening

Passive background reduction

Background reduction is the key for a successful and a strong impact experiment

The Nobel Prize in Physics 2015

© Nobel Media AB. Photo: A. Mahmoud

Takaaki Kajita

Prize share: 1/2

© Nobel Media AB. Photo: A. Mahmoud

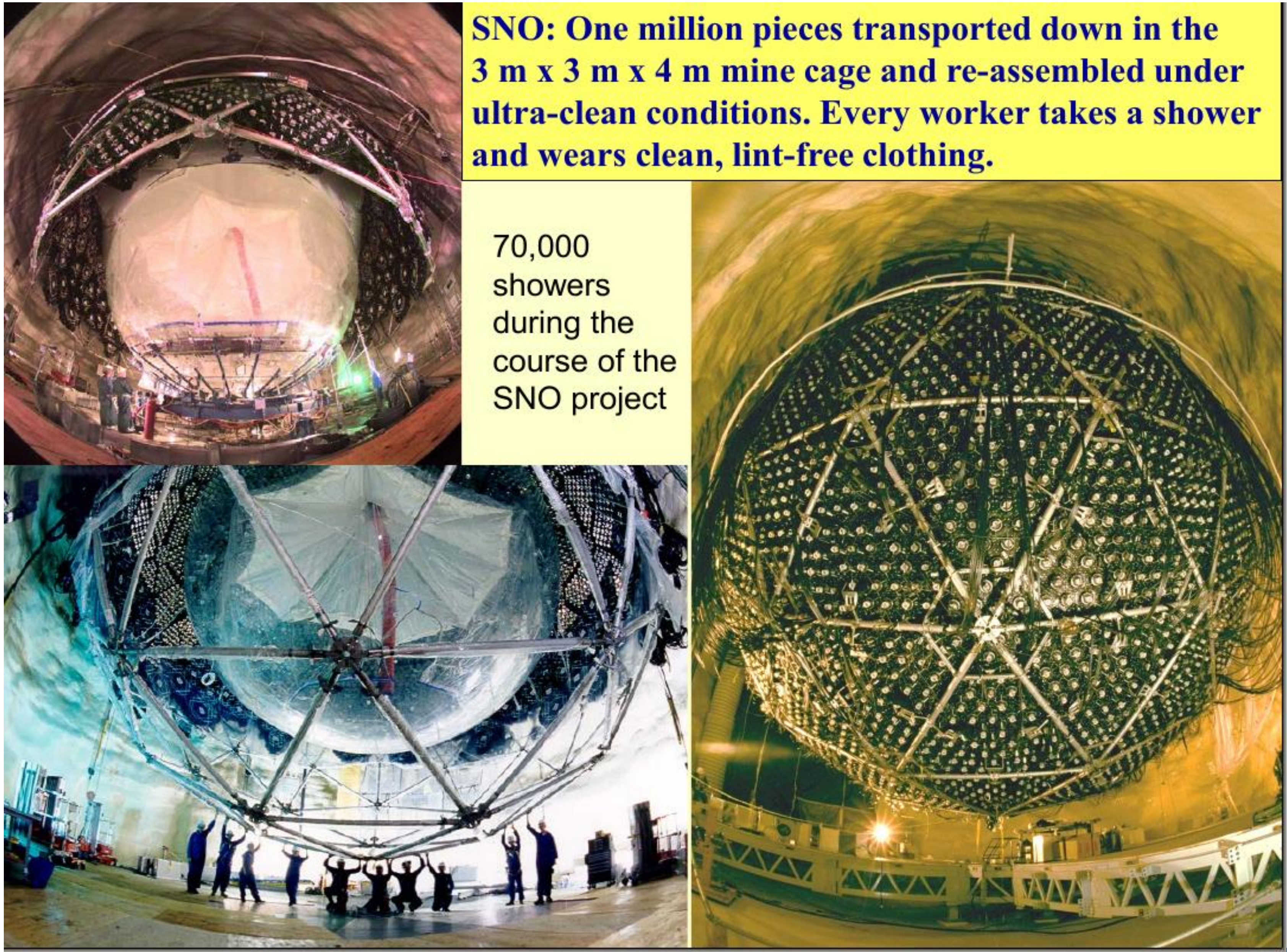
Arthur B. McDonald

Prize share: 1/2

"*We were very careful in terms of radioactivity [...] You start with U and Th, which are the main elements that create radioactive problems for us, they are about a part in a million in the rock and in the middle [of the detector], it was less than a part in* 10^{15}*, so one radioactive decay per ton of water. So the people that developed the radioactivity control systems did a tremendous job to get this project a success*".

Art McDonald, 'The Sudbury Neutrino Observatory: Observation of flavor change for solar neutrinos'. Nobel lecture prize lecture, Dec. 8, 2015

Cleaning



"You see that everybody on this picture is wearing lint-free clothing. The cleanless aspect of this project was tremendous. We had a million pieces, and by the time we were finished we had less mine dust in the entire structure than you could pileup in your thumb-nail, less than a gram, and this was essential for us to do this experiment".

Art McDonald, 'The Sudbury Neutrino Observatory: Observation of flavor change for solar neutrinos'. Nobel lecture prize lecture, Dec. 8, 2015

Measuring U/Th Content

Ex-situ

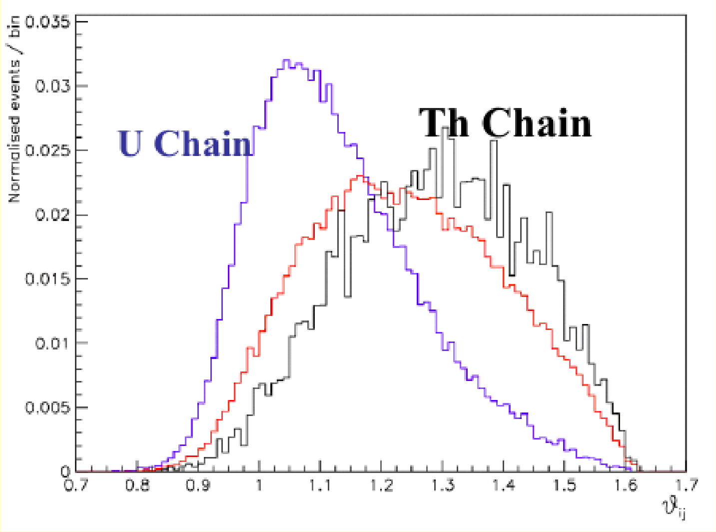
- **Ion exchange (^{224}Ra, ^{226}Ra)**
- **Membrane Degassing (^{222}Rn)**

count daughter product decays

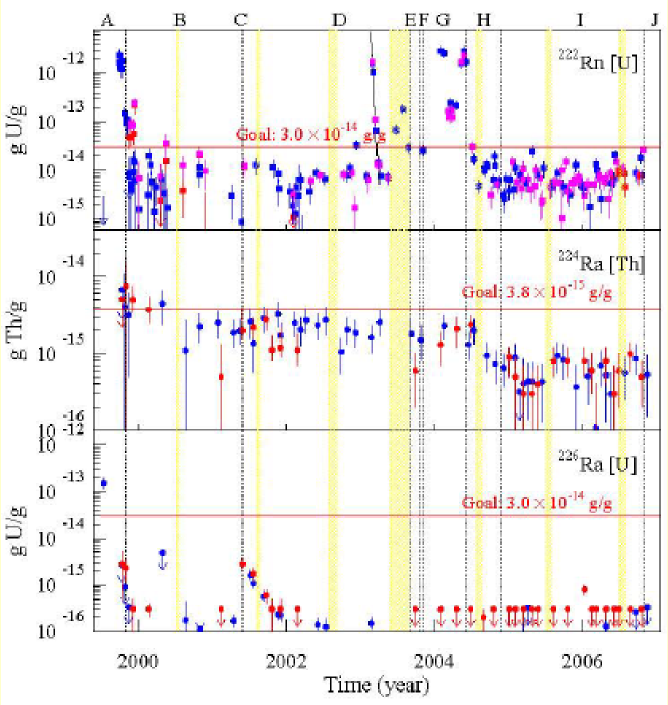
In-situ

- **Low energy data analysis**
- **Separate U and Th Chains**

Using Event isotropy



Isotropy

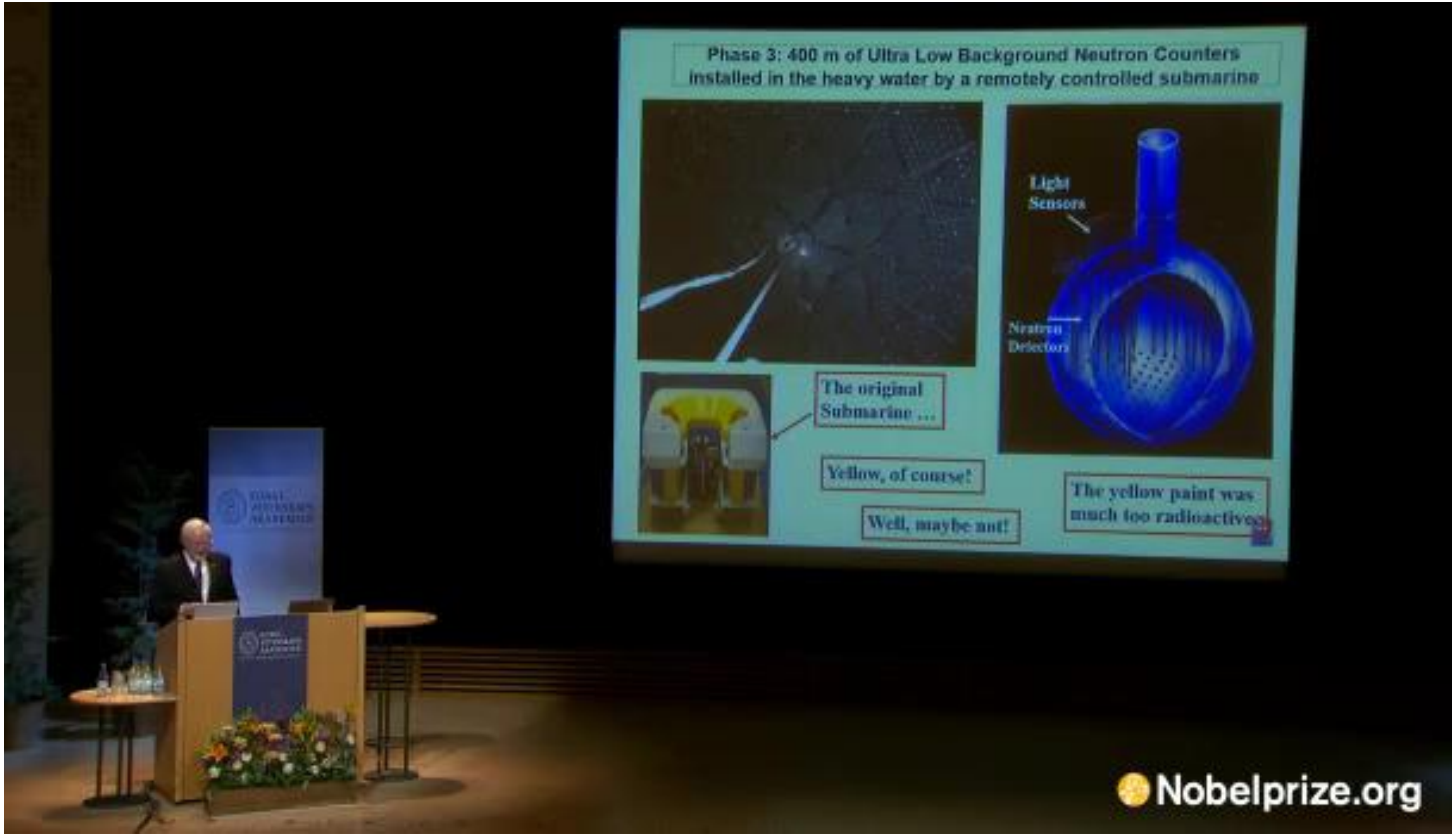


Numbers of background neutrons from gamma rays breaking apart deuterium are measured to be 3 times smaller than the signal. Uncertainty from this is less than 10% of the neutrino measurement.

"*We also did a tremendous amount of work to be sure that the number of gamma's that could produce neutrons simply from radioactivity were low enough. Through all the experiment we had set a goal of how much radioactivity we would have from Radon gas in the water from Radium, and you can see that all along the project we had met our goals. We were able to ensure that the number of events were a factor 3 smaller than the signal.*".

Art McDonald, 'The Sudbury Neutrino Observatory: Observation of flavor change for solar neutrinos'. Nobel lecture prize lecture, Dec. 8, 2015

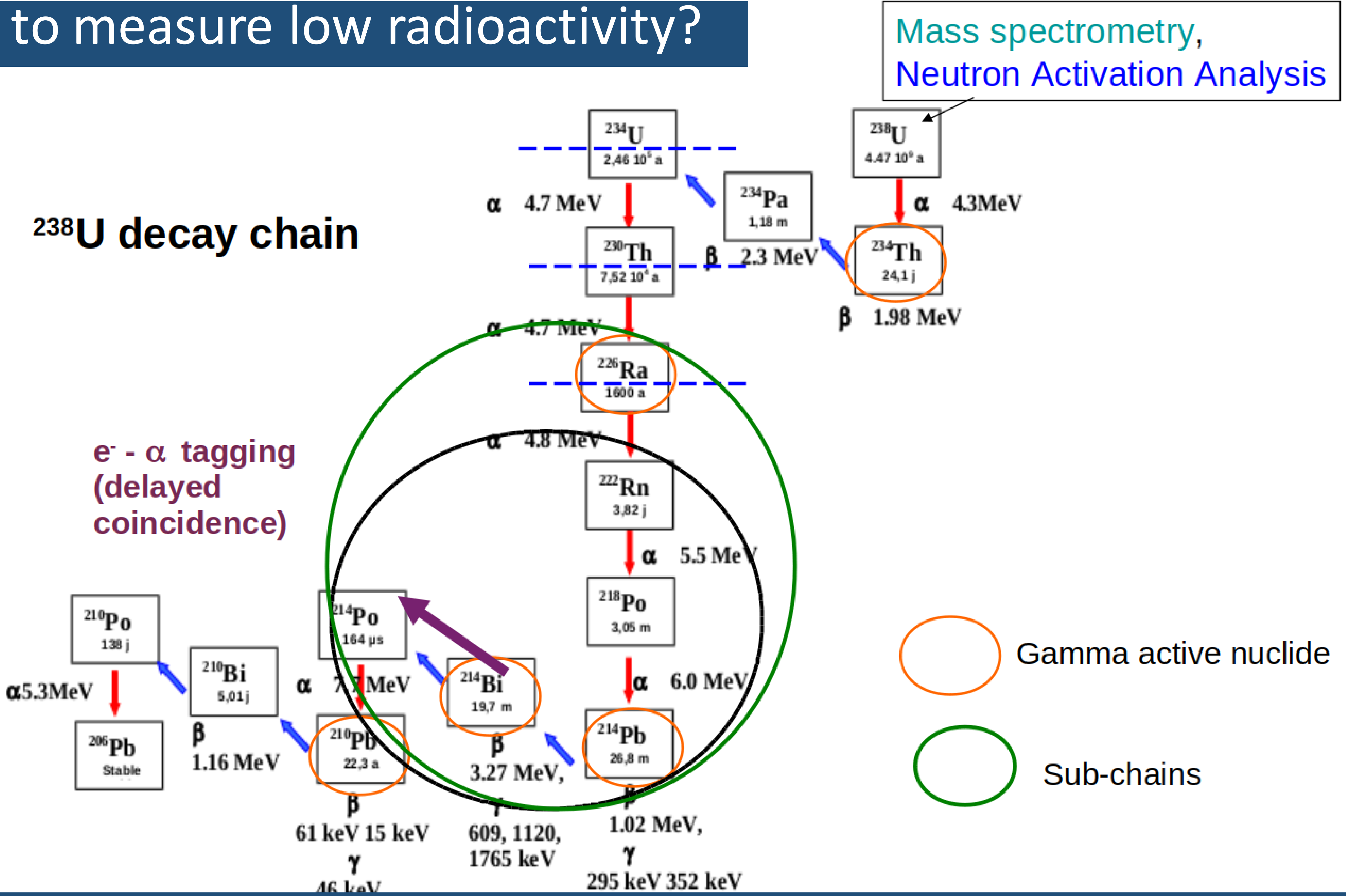
More about screening



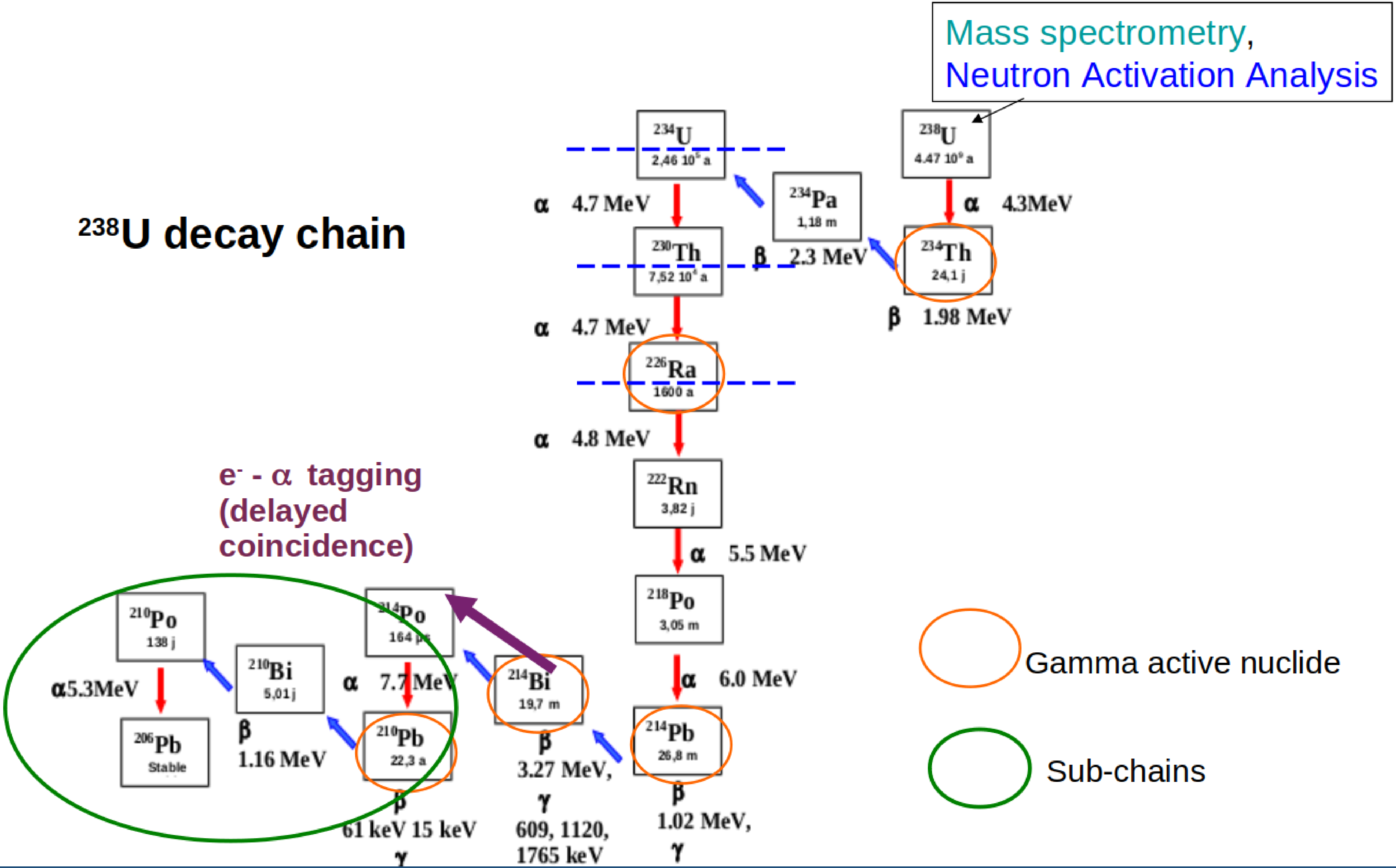
"But, as an indication of how you do go through some difficulties in this experiment and have to modify things mid-range, you can see how the submarine used to install them [the neutron counters] ended up looking like. This is how it looked like when we first design it. I mean, if you are going to build a submarine, what colour would you pick it? Of course, a yellow submarine. Except that particular yellow paint was very radioactive and we had to scrub it all off and have a very mundane submarine in order to do our work"

Art McDonald. Nobel lecture prize lecture, Dec. 8, 2015

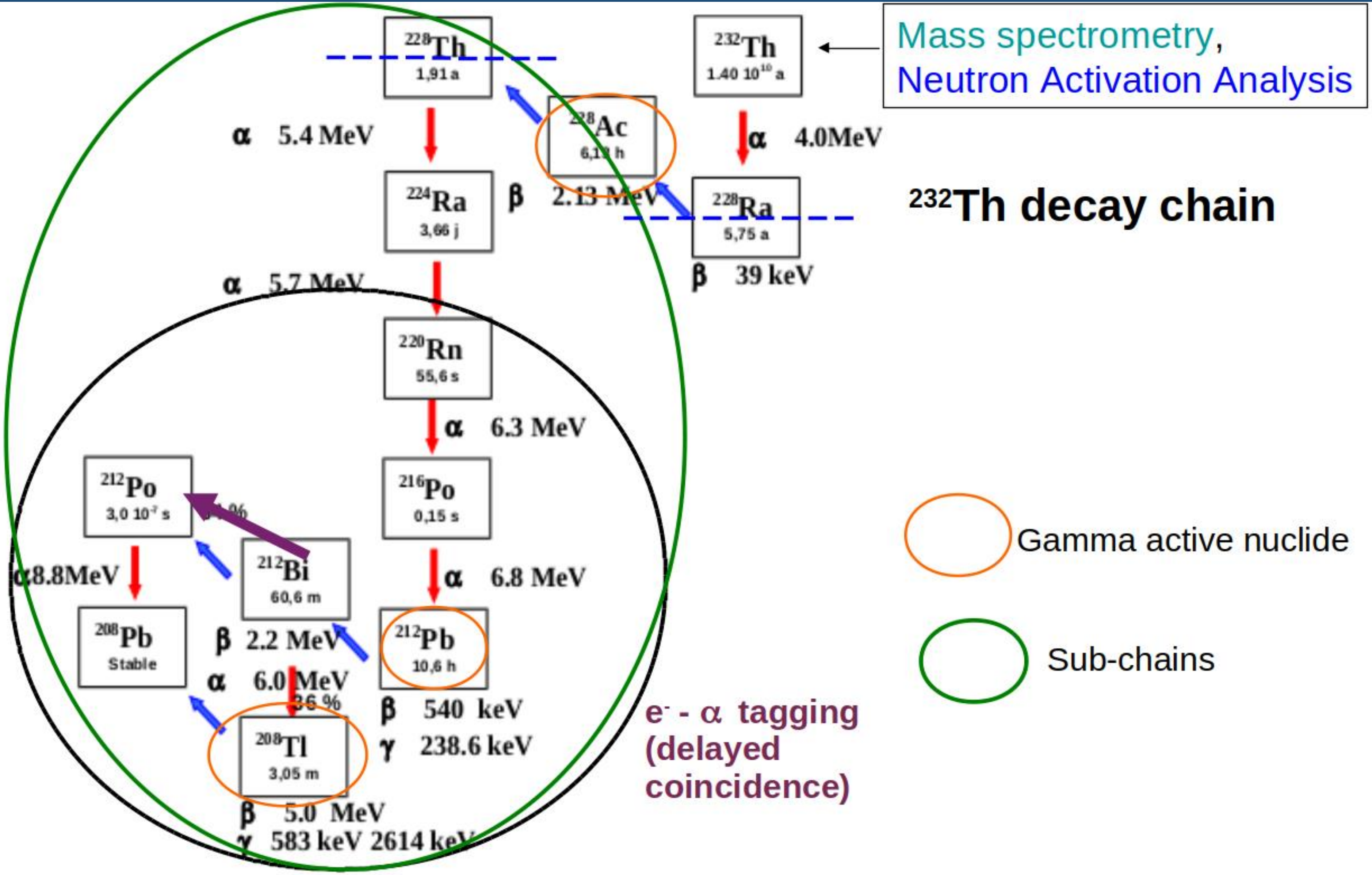
How to measure low radioactivity?



^{238}U decay chain



Th chain



228Th 1,91 a
α 5.4 MeV
224Ra 3,66 j
α 5.7 MeV
220Rn 55,6 s
α 6.3 MeV
216Po 0,15 s
α 6.8 MeV
212Pb 10,6 h
β 540 keV
γ 238.6 keV
212Bi 60,6 m
β 2.2 MeV
α 6.0 MeV
36 %
212Po 3,0 10⁻⁷ s
α8.8MeV
208Pb Stable
208Tl 3,05 m
β 5.0 MeV
γ 583 keV 2614 keV
228Ac
β 2.13 MeV
232Th 1.40 10¹⁰ a
α 4.0MeV
228Ra 5,75 a
β 39 keV
Mass spectrometry,
Neutron Activation Analysis
232Th decay chain
Gamma active nuclide
Sub-chains
e⁻ - α tagging (delayed coincidence)

Gamma-ray spectrometry in France - IRSN

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

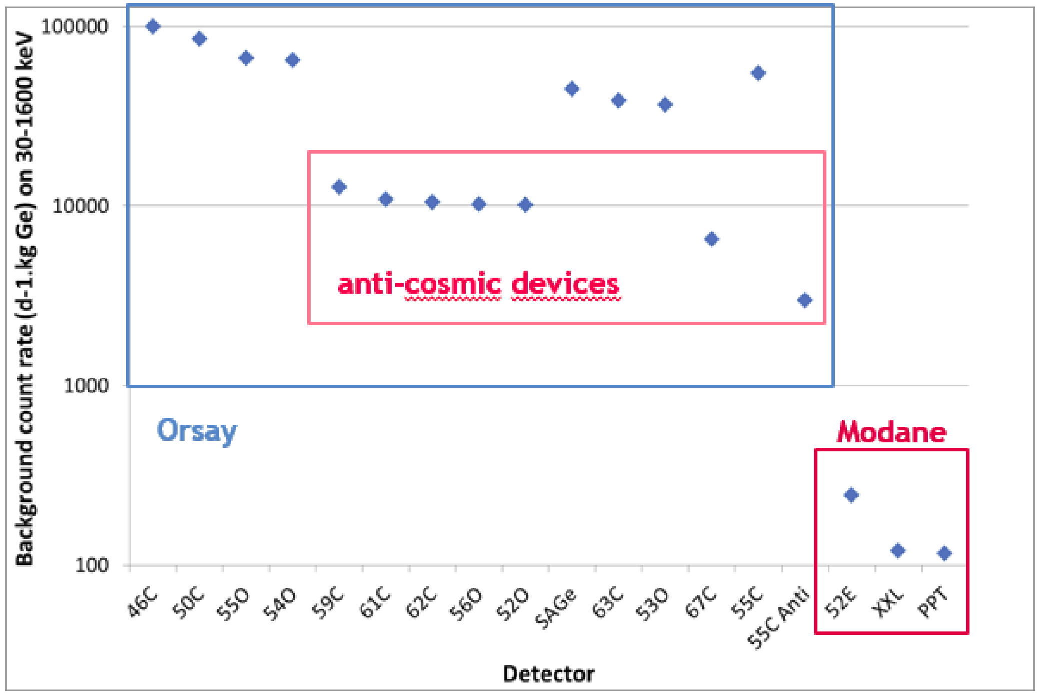
LMRE
Laboratoire de métrologie de la radioactivité dans l'environnement

- Environmental monitoring
- Radioecology studies
- Emergency preparedness

HPGe detectors in Orsay : the inner layer of the shielding covering the walls can be seen

DETECTORS

- 19 HPGe in Orsay (10 m.w.e)
- 3 HPGe in Modane



Gamma-ray spectrometry in France - LNHB

Laboratoire National Henri Becquerel
(Laboratoire National de Métrologie et d'Essais/CEA)

- Provide standard radioactive sources
- Determine photon emission probabilities of radionuclides
- Control of the purity of radioactive solutions

Vue de l'intérieur de la cellule

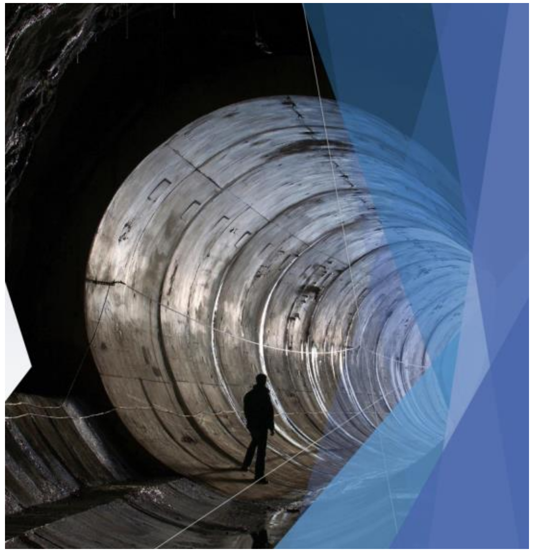
DETECTORS

- Several detectors above ground
- 1 HPGe under 65 cm earth + 75 cm of baryte concrete
- Active veto: plastic scintillators coupled to PMTs, with an electronics specially developed at LNHB (Applied Radiation and Isotopes, 109, 425 (2015))
- Shielding: Lead FA – Cadmium alloy – Lead TFA - Copper

Gamma-ray spectrometry in France - LAFARA

LAFARA :LAboratoire de mesure des FAibles RAdioactivités
LEGOS-Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (CNRS/UP/CNES/IRD)/Observatoire Midi-Pyrenées

LAFARA is located in the French Pyrénées, in the tunnel of Ferrières (Ariège), ~ 215 m.w.e



https://lafara.obs-mip.fr/

- Environmental samples for environmental sciences
- Water, sediments, sands

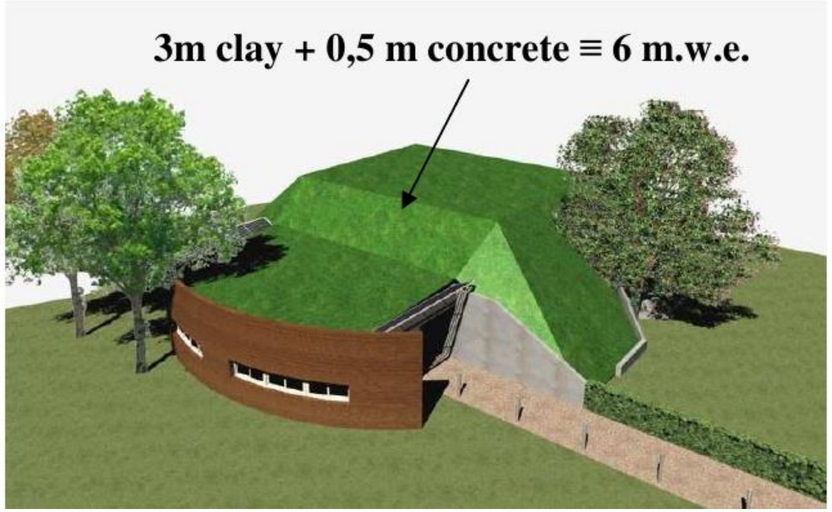
DETECTORS

- 5 HPGe (built with selected low radioactive materials)
- Electric cooling system
- Robotic autosampler

Gamma-ray spectrometry in France : CENBG

CENBG
Centre d'Études Nucléaires de Bordeaux-Gradignan

PRISNA
Plate-forme Régionale Interdisciplinaire de Spectrométrie Nucléaire en Aquitaine



- Archeological applications
- Fight againts frauds

DETECTORS

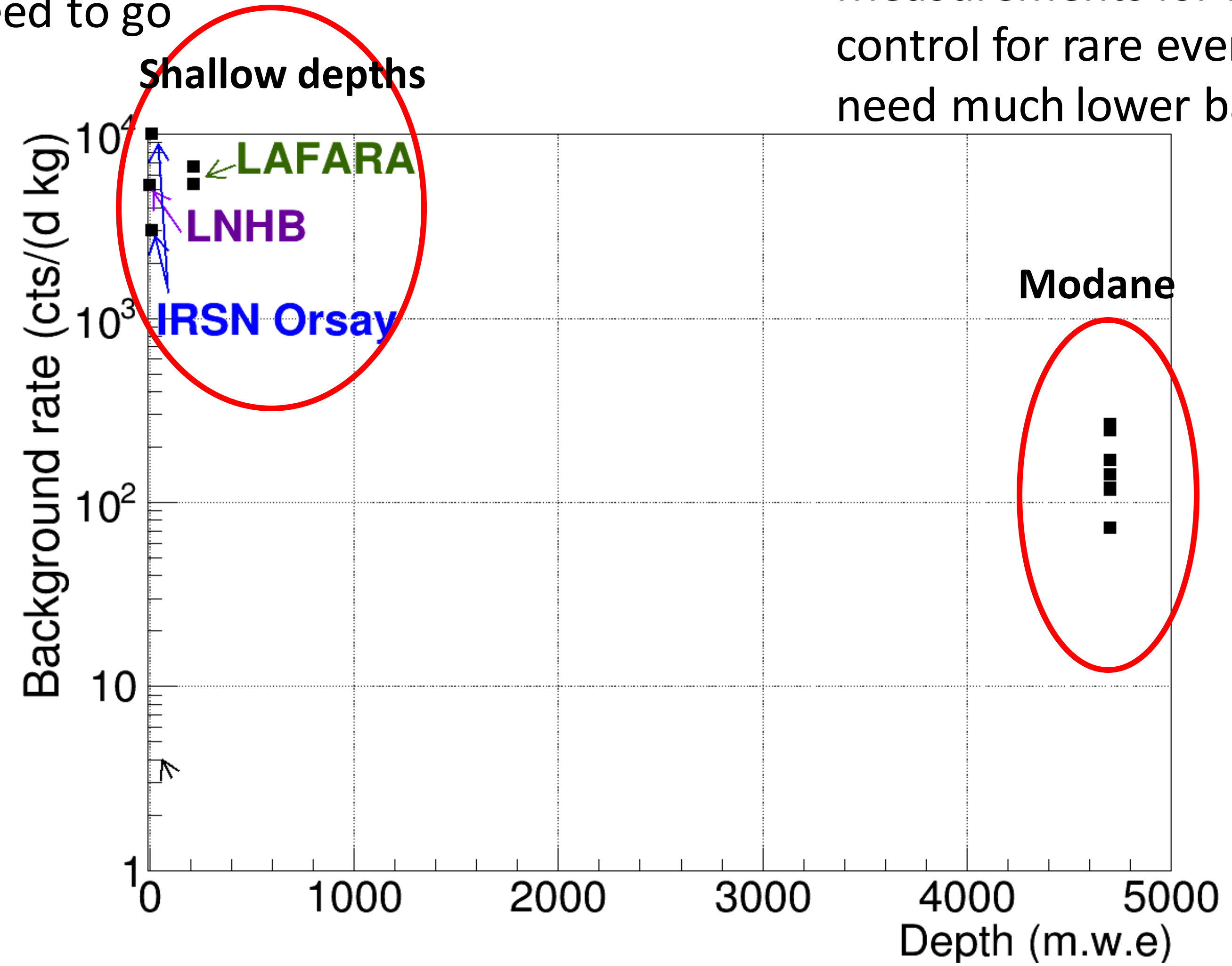
- 3 HPGe
- Sensitivities ~ 50 mBq/kg

- Pionering work in France on the development of low background HPGe detectors by Philippe and Françoise Hubert starting in 1990's
- Two HPGe's for the NEMO experiment installed at LSM

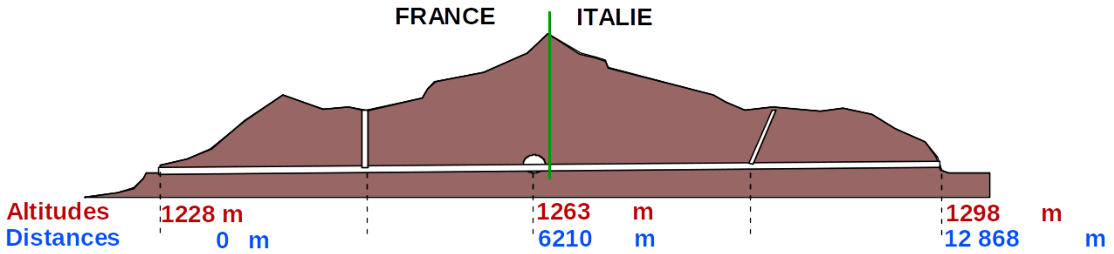
Background vs depth of some HPGe's in France

Measurements for environmental sciences, environmental control, metrology do not need to go deep underground

Measurements for background control for rare event searches do need much lower backgrounds



Gamma-ray spectrometry in France : LSM



- 4800 m.w.e

- 5 operating HPGe's belonging to French institutions for background control in rare event searches

Detector	type	Owner	Application
Mafalda	BEGe (planar)	LSM	Material selection
Obelix	coaxial, 3 kg	JINR/CTU/LSM	Material selection/ Nuclear physics
Gentiane	coaxial, 1 kg	Edelweiss	Material selection
Iris	coaxial, 2 kg	CENBG (SuperNemo)	Material selection
Jasmin	coaxial, 2 kg	CENBG (SuperNemo)	Material selection

Sensitivity in gamma-ray spectrometry

$$DETECTION\ LIMIT \sim \frac{1}{\varepsilon \cdot M \cdot P_\gamma}\sqrt{\frac{B \cdot \Delta E}{t}}$$

ε=efficiency

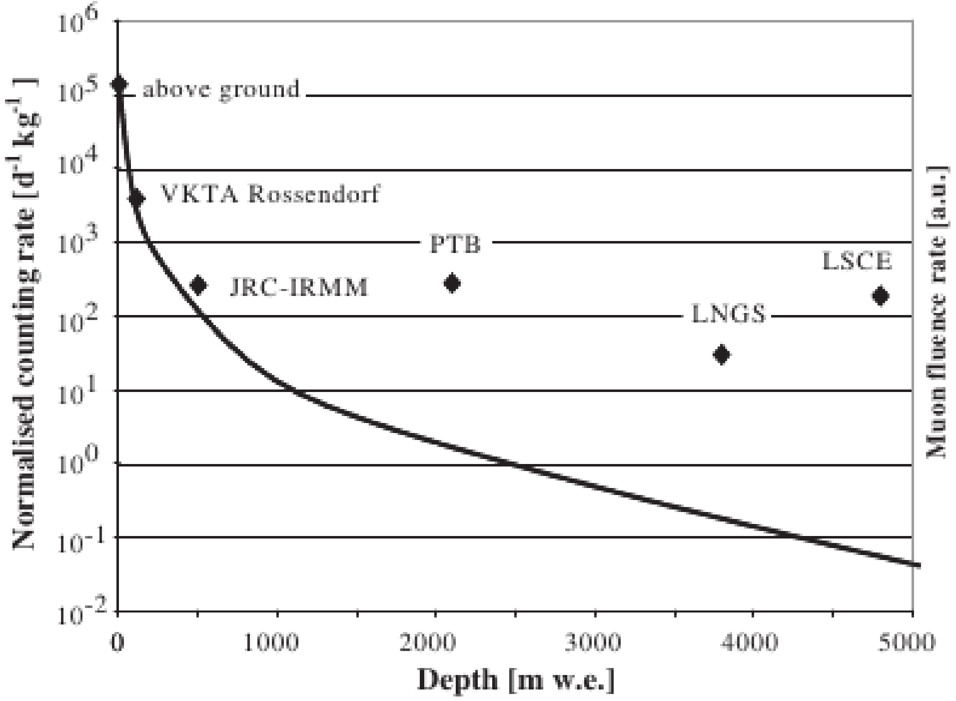
M: Source mass

t: Measuring time

B: Background

ΔE: Energy resolution

P_γ=Probability of emission



M. Laubenstein et al, Appl. Rad. Isot. 61, 167 (2004)

The muon background is playing a role for depths above 500 m.w.e. Below 500 m.w.e, the HPGe intrinsic background becomes dominant.

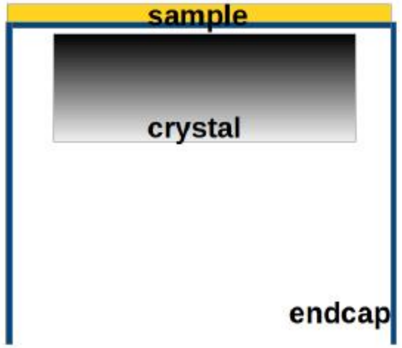
Low background gamma-ray spectrometry

Sensitivity improvement is achieved by reducing the intrinsic background:

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

Low background HPGe developed at LSM

Mafalda, planar:



Ge crystal:

- h= 30 mm
- diam= 80 mm
- mass=0.8 kg

\+ no dead layer

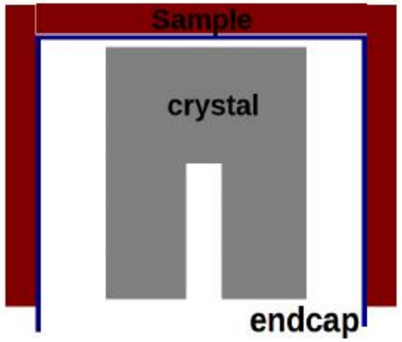
\+ improved energy resolution

\- modest sample masses

→ low energies 20 keV$<E_\gamma<\sim$ 600 keV (backgrounds relevant to dark matter)

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

Obelix, coaxial:



Ge crystal:

- h= 90 mm
- diam= 94 mm
- mass=3.0 kg

\+ higher efficiency for high energies

\+ large sample masses

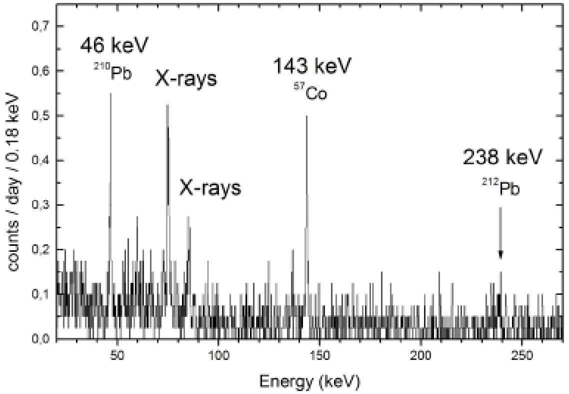
\- dead layer

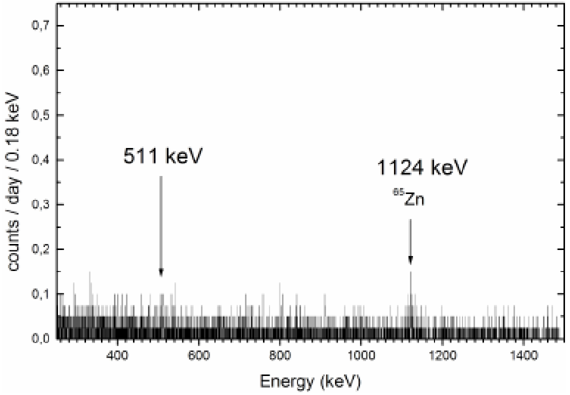
→ 'high' energies 100 keV$<E_\gamma<$ 3000 keV (backgrounds relevant to $2\beta0\nu$)

HPGe at LSM : intrinsic backgrounds

MAFALDA:

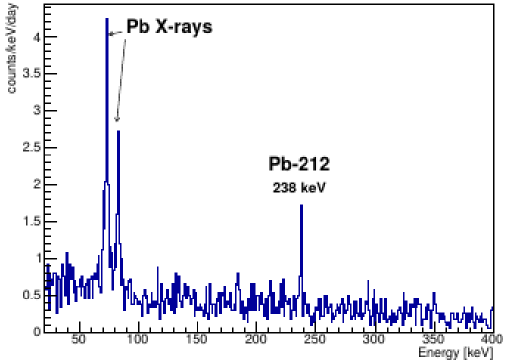
Energy resolution: 890 eV at 122 keV

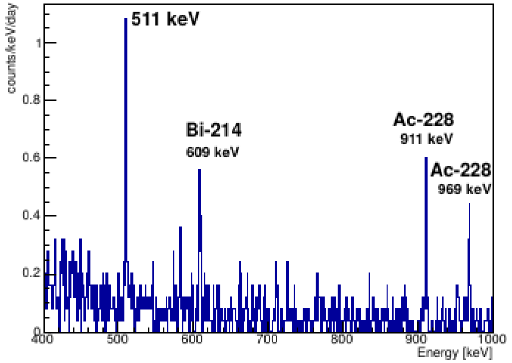




OBELIX:

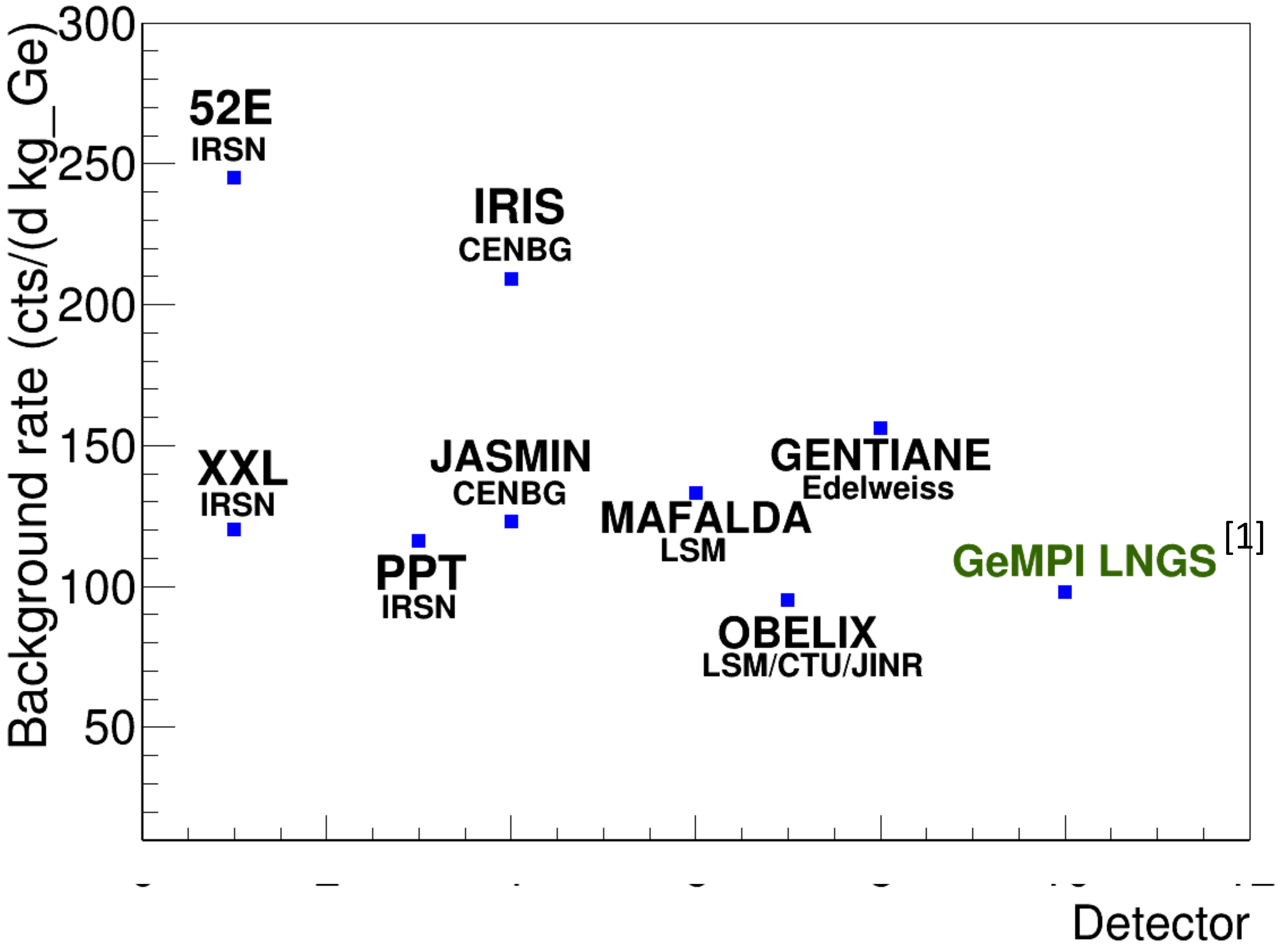
Energy resolution: 1200 eV at 122 keV





Background counting rate for single lines $\sim$ 1 count/day
Integral counting rate [20 - 1500] keV: 140 counts/day (Mafalda),
[40-3000]keV: 209 counts/day (Obelix)

Backgrounds of HPGe's at LSM



[1] H. Neder, G. Heusser, M. Laubenstein, Applied Radiation and Isotopes **53**, 191 (2000)

Sensitivities – where do we stand?

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	665	-	-	0.65 ± 0.08	0.30 ± 0.07
Jasmin (Coaxial)	Glue	2500	768			< 0.14	< 0.17
GeMPI2 [1] (Coaxial)	Copper	125000	2412			< 0.016	< 0.012

Low energies
46 keV, 63 keV, 92 keV

Higher energies
200 keV < E < 3000 keV

[1] M. Laubenstein et al,
Applied Radiation and Isoptopes 61, 167 (2004)

- For about 1 month measurement and $\mathcal{O}$(kg) $\rightarrow$ present sensitivities $\sim$ 100 μBq/kg - 500 μBq/kg in ^{226}Ra and ^{228}Th
- Best sensitivities can reach 20 μBq/kg in ^{226}Ra and ^{228}Th

Summary

- Background reduction is the key for a successful and a strong impact experiment

- Screening is essential for the passive background reduction

- Many activities in France with HPGe's:
- Environmental control
- Environmental science
- Background control for dark matter and double beta experiments

- Low background HPGe's at LSM among the most sensitive in the world

Avec mes remerciements:

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My apologies if someone has not been mentioned in this talk. If so, the reason is nothing than my lack of knowledge.