Vinča Institute of Nuclear Sciences,
Belgrade, Serbia, 13-15 November, 2012

European Commission

Gamma-ray Spectrometry

Low background and cosmic rays

Mikael Hult, PhD,

EC-JRC-IRMM, Retieseweg 111, 2440 Geel, Belgium

Mikael.hult@ec.europa.eu

1. **Primordial** **(Here since the formation of the earth)**

2. **Anthropogenic** **(man-made)**

3. **Cosmogenic** **(Induced by cosmic rays)**

European Commission

1. Primordial radionuclides

(natural, existing since the formation of the earth)

Earth is about 4.5·10^{9} years

^{238}U, $T_{½}$= 4.5·10^{9} years
^{235}U, $T_{½}$= 0.7·10^{9} years
^{232}Th, $T_{½}$= 14·10^{9} years
^{40}K, $T_{½}$= 1.3·10^{9} years

Less common ones

La-138, Rb-87, Sm-147, Lu-176, Re-187

Decays to

radium-226, radon-222,

polonium-210, lead-210 etc.

2. Anthropogenic (man-made)

Fission products: ^{137}Cs, ^{134}Cs,^{85}Kr, ^{125}Sb, …..

Activation products: ^{60}Co, ^{41}Ar, ….

Normally no problem for background, but after Chernobyl many (also new) detectors were contaminated

Note: always difficult with pure beta emitters; ^{90}Sr, ^{3}H

3. Cosmogenic

#	target	reaction	Produced radionuclide	γ-ray energy	$T_{1/2}$	Side reaction
9	^{59}Co	(n,p)	^{59}Fe	1099; 1291	44.53 d	(μ^-,0n)
10	^{60}Ni	(n,p)	^{60}Co	1173.2; 1332.5	5.271 y	
13	^{63}Cu	(n,4p6n)	^{54}Mn	834.84; 840.8^c	312.3 d	(μ^-,3p5n)
14	^{63}Cu	(n,2p5n)	^{57}Co	122.1; 136.5; 143.6^c	271.79 d	(μ^-,p4n)
15	^{63}Cu	(n,2p4n)	^{58}Co	810.8; 817.9^c	70.86 d	(μ^-,p3n)
16	^{63}Cu	(n,α)	^{60}Co	1173.2; 1332.5	5.271 y	
17	^{65}Cu	(n,γ)	^{66*}Cu	186.0		
18	^{65}Cu	(n,n’)	^{65*}Cu	1115.5; 1481.7		
19	^{70}Ge	(n,γ)	^{71m}Ge	23.5;174.9; 198.3	22 ms	72Ge(n,2n)
20	^{70}Ge	(n,γ)	^{71}Ge	10.37	11.34 d	
21	^{70}Ge	(n,3n)	^{68}Ge	10.37	271 d	
22	^{70}Ge	(n,2p4n)	^{65}Zn	1125.2	244.3 d	(μ^-,p4n)
23	^{72}Ge	(n,γ)	^{73m}Ge	13.3; 53.4; 66.7	0.5 s	74Ge(n,2n)
24	^{72}Ge	(n,n’)	^{72*}Ge	691.0^b; 834^b		

Many reactions in Cu ! (and Ge)

In Ge: ^{68}Ge, ^{57}Co, ^{58}Co, ^{60}Co, ^{65}Zn, ^{54}Mn, ^{63}Ni,^{55}Fe

Main background sources – in a practical classification scheme

⇒ Radon

⇒ Laboratory environment except radon (i.e. radioactivity and neutrons from fission and (a,n) reactions in surrounding materials)

⇒ Directly induced by cosmic rays

⇒ Indirectly induced by cosmic rays (Activation of Ge-crystal, cryostat and shield)

⇒ Radioimpurities in detector and shield

Important to identify location of background sources

⇒ Enables improvement (=reduction) of background

⇒ Enables improved design for future detector systems

Ways to quantify importance of background sources

1) Radon – monitor Rn-concentration and the background simultaneously. Extrapolate to zero Rn concentration to see count rate from other sources

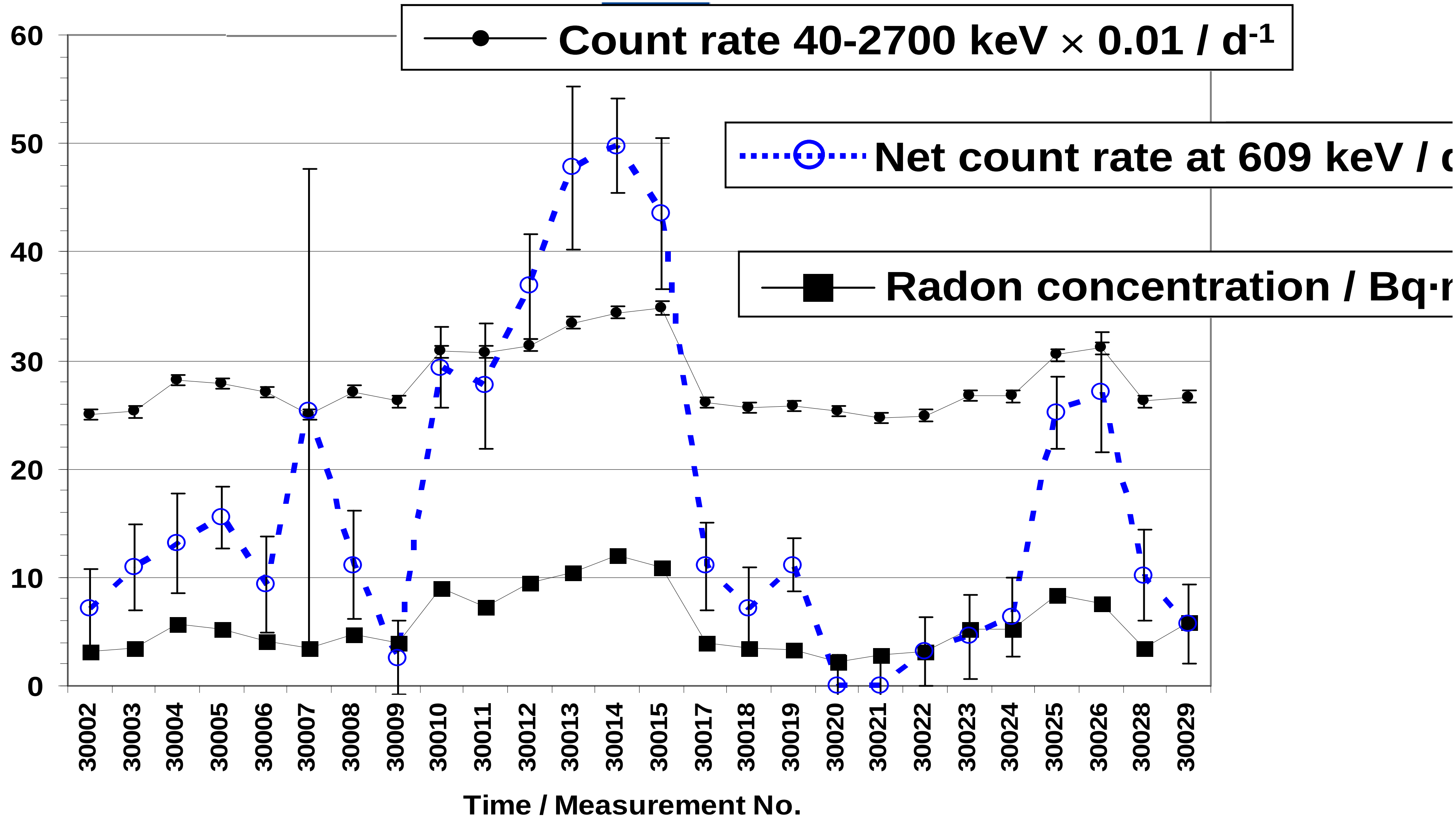
2) Radioimpurities in shield and detector – Cover endcap with a very pure material (Hg) and compare the difference in count rate

3) Environment – Vary the shield thickness (both lead and borated paraffin)- very cumbersome!!

4) Activation – Note count rate of activation peaks from crystal (e.g. Zn-65 at 1115+8.3 keV) and make simulations to find total count rate.

5) Muons - Correlate the background changes with changes in cosmic ray flux (see e.g. the Kiel neutron monitor on internet) or use a muon detector

……..


Count rate 40-2700 keV × 0.01 / d-1
Net count rate at 609 keV / c
Radon concentration / Bq·r
60
50
40
30
20
10
0
30002
30003
30004
30005
30006
30007
30008
30009
30010
30011
30012
30013
30014
30015
30017
30018
30019
30020
30021
30022
30023
30024
30025
30026
30028
30029
Time / Measurement No.

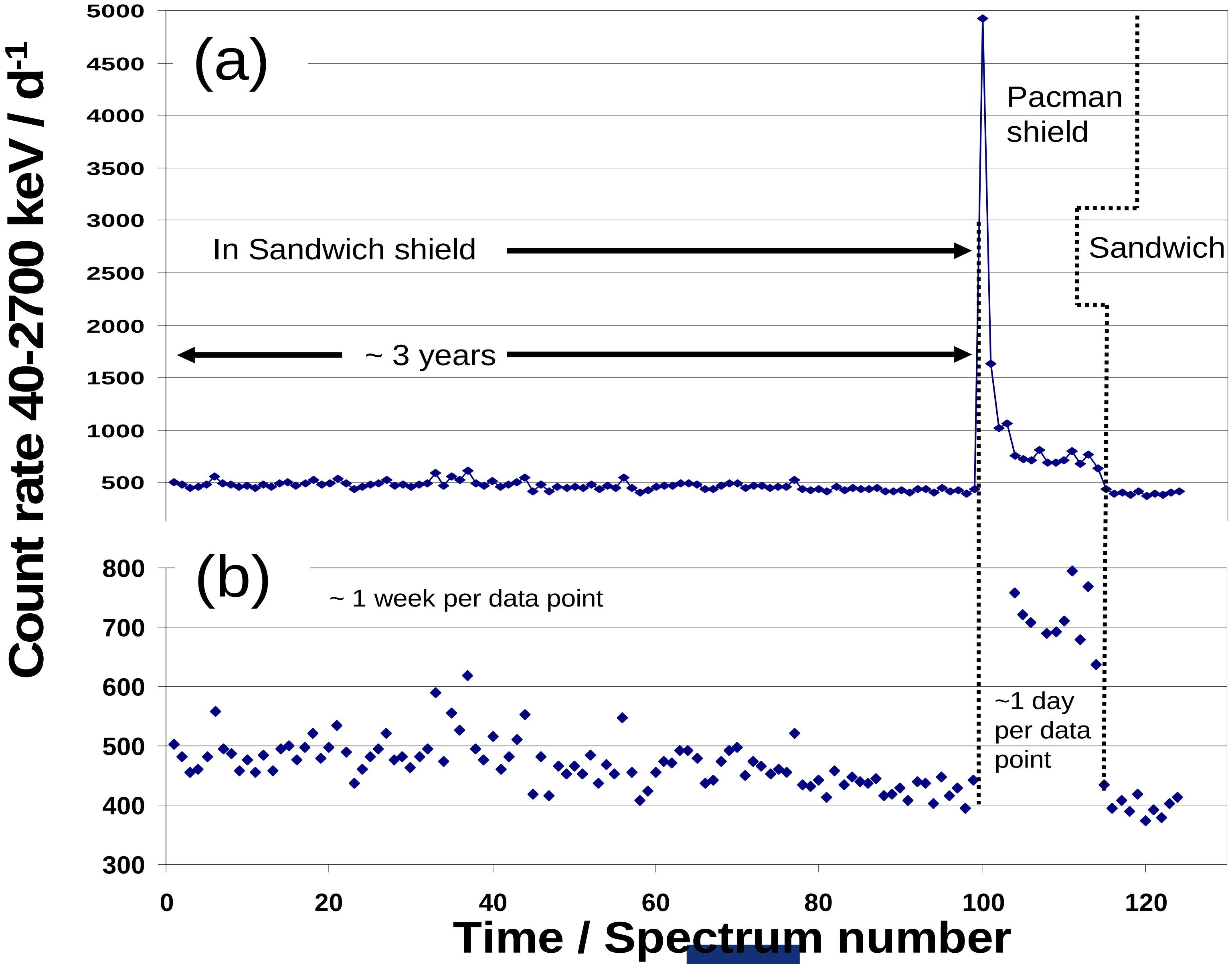
Other ways to understand background

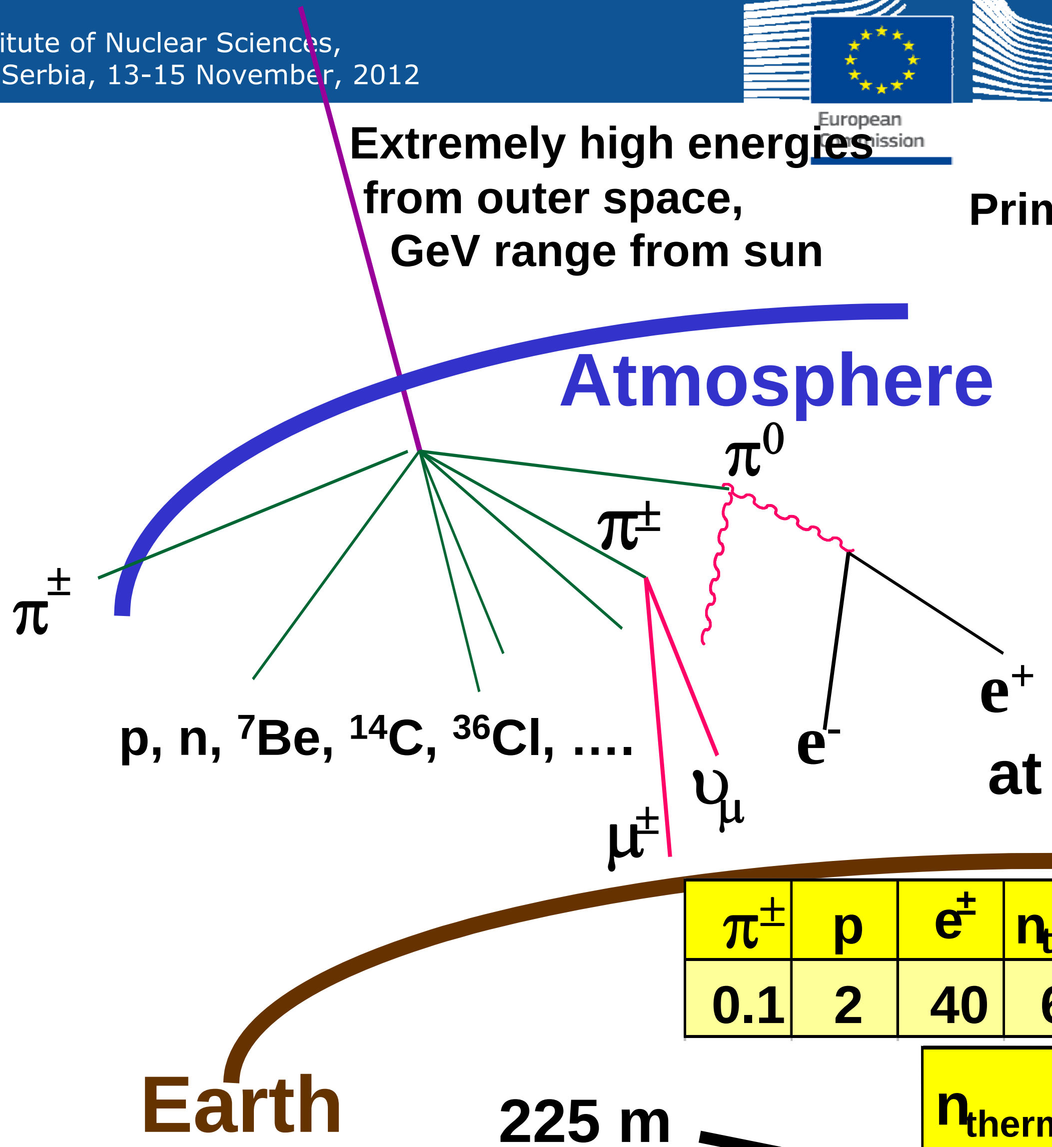
- Keep a log of the background – both background peaks and certain intervals
- Measure background in different shields – a good way to understand if a shield is bad or the detector is bad. (if background is good, then both must be good)

Quite cumbersome and time consuming. Moving lead and detectors, re-doing calibrations,….

Unless there are special lead shields that allow easy removal of detectors ………

Detector Ge-7 – ExRa (p-type w thin deadlayer), 90% rel eff. Inverted cryostat





Primary cosmic ray: 10^3 m^{-2} s^{-1}

9 % α

90 % p

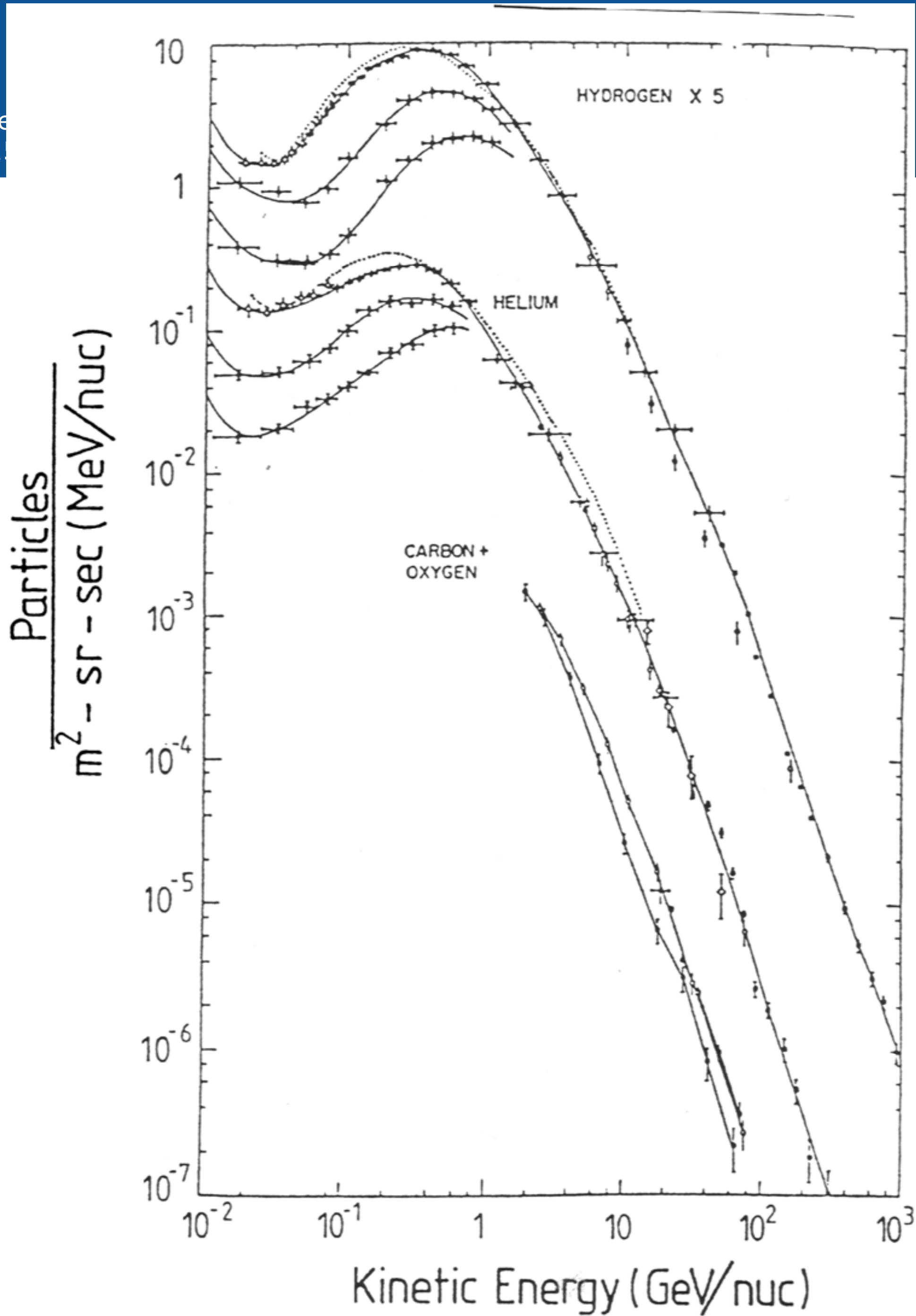
1 % heavier nuclei (up to Fe)

at surface (m^{-2}s^{-1})

$\pi^\pm$	p	$e^\pm$	n_{therm}	n_{fast}	$\mu^\pm$	υ
0.1	2	40	60	200	200	10^{11}

225 m underground (m^{-2}s^{-1})

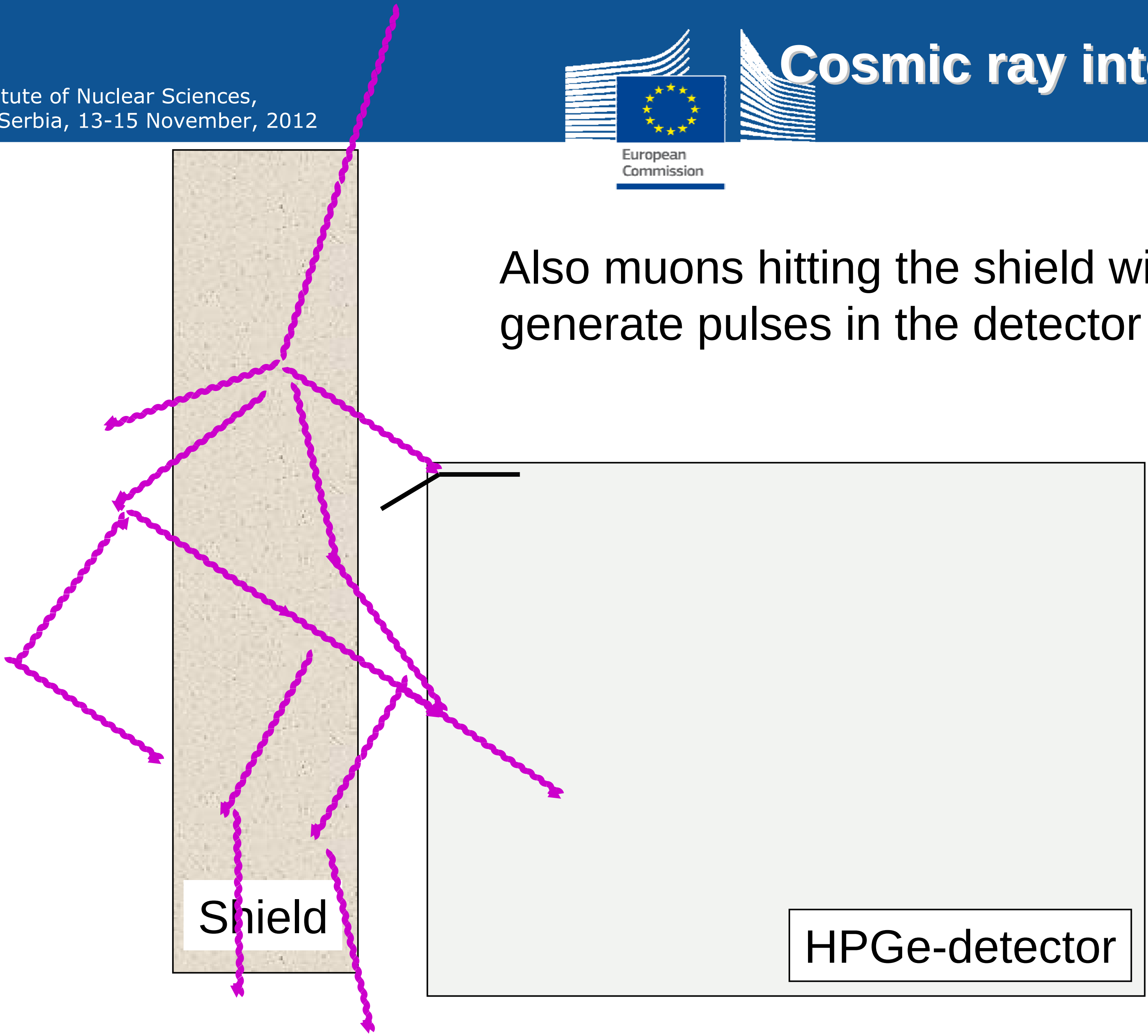
n_{therm}	n_{fast}	$\mu^\pm$	υ
<2	<2	0.1	10^{11}



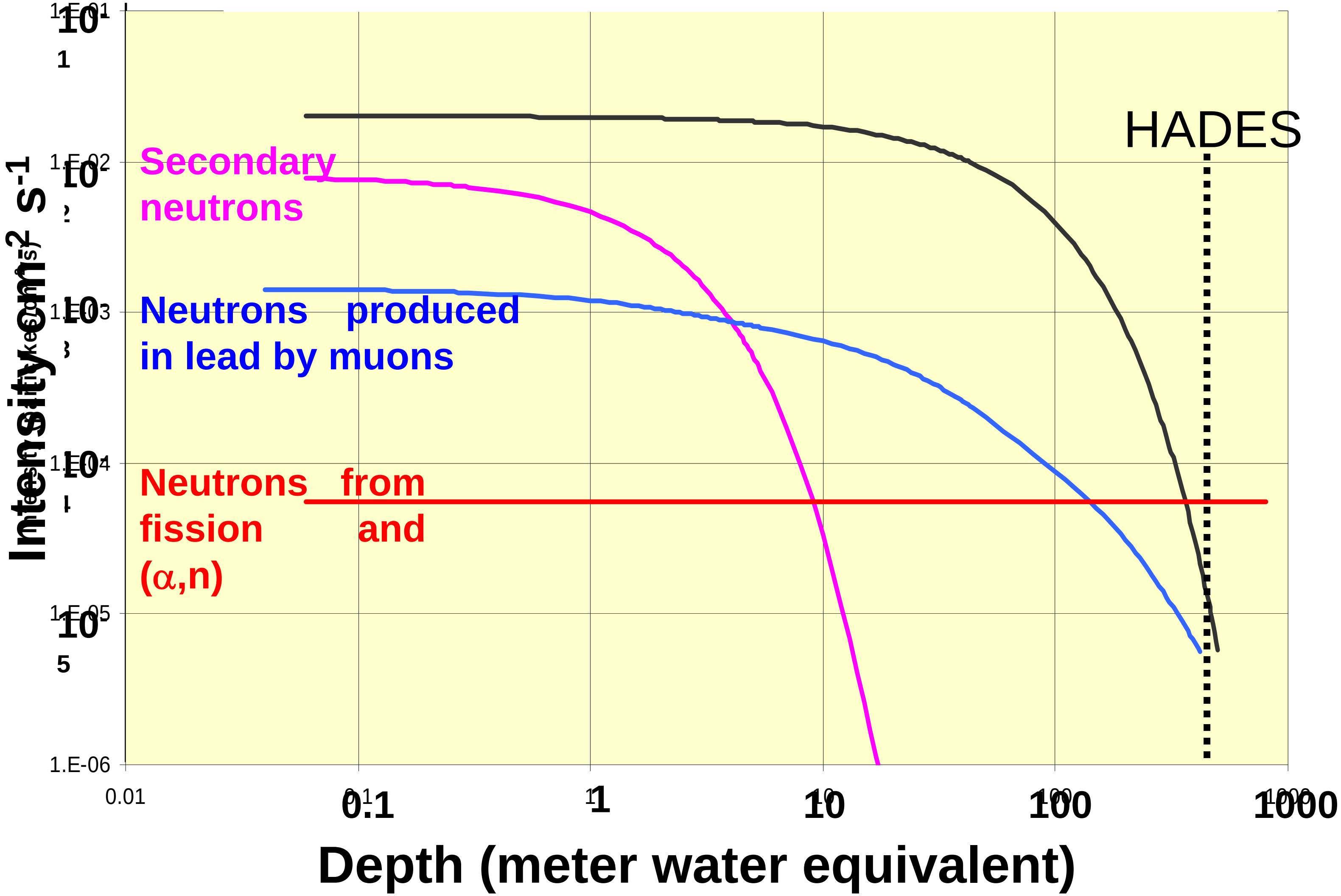
Cosmic rays have VERY high energies. Energies up to 10^{20} eV have been measured

Cosmic ray interactions

Also muons hitting the shield will generate pulses in the detector

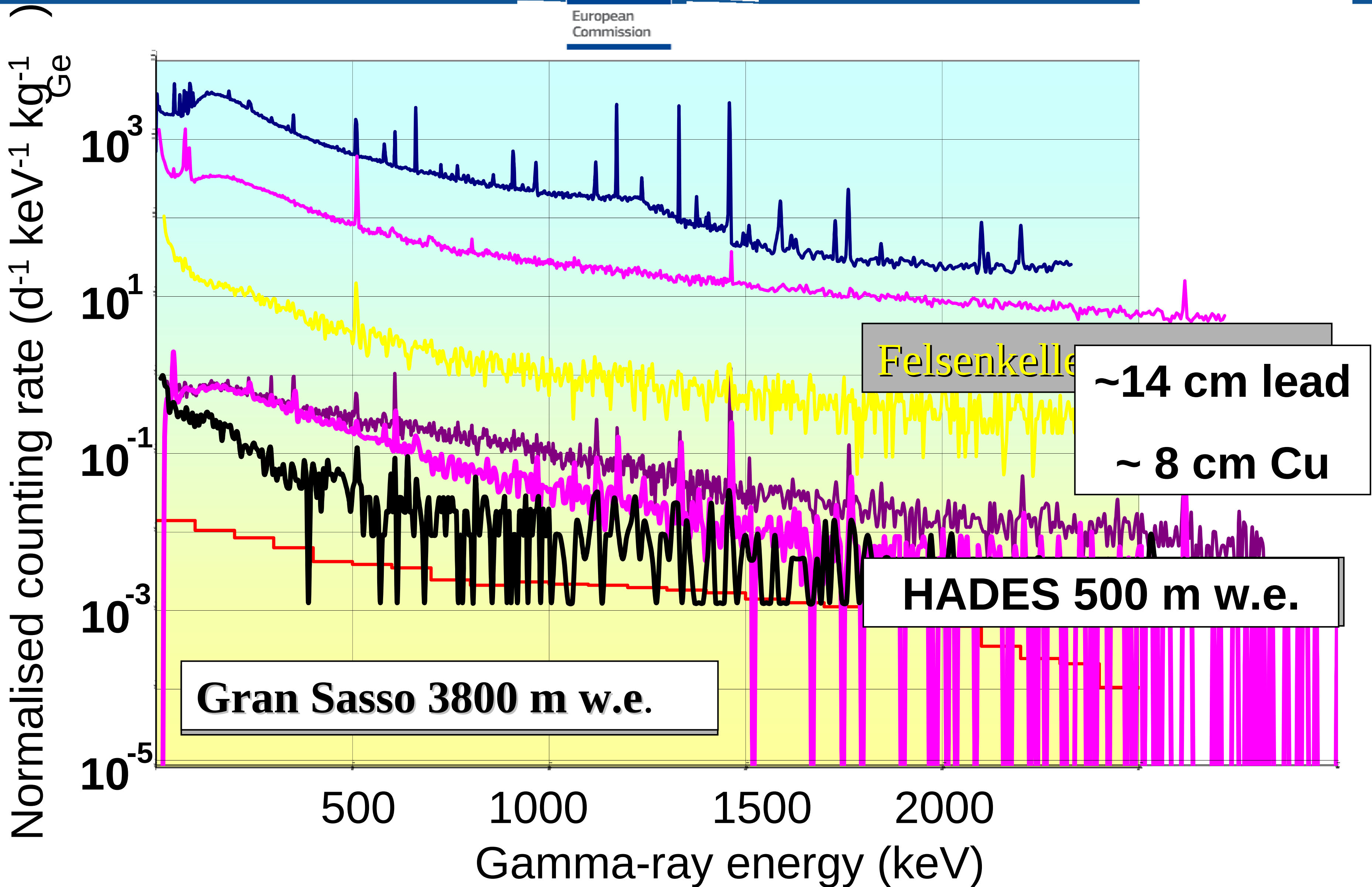


Attenuation of radiation in earth's crust



No air transport of a low background detector!!

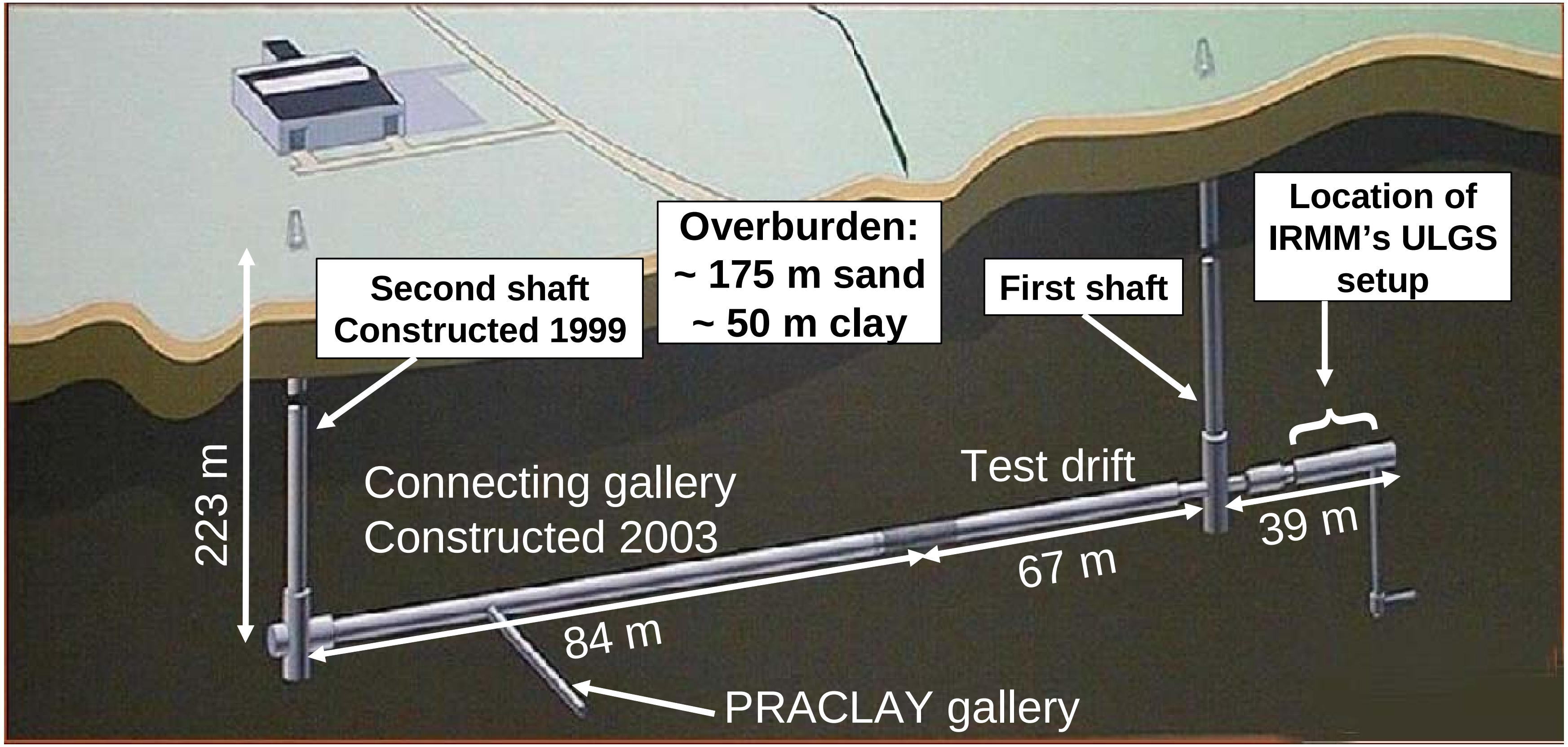
Gamma-ray background spectrum



European Commission

HADES = High Activity Disposal Experimental Site

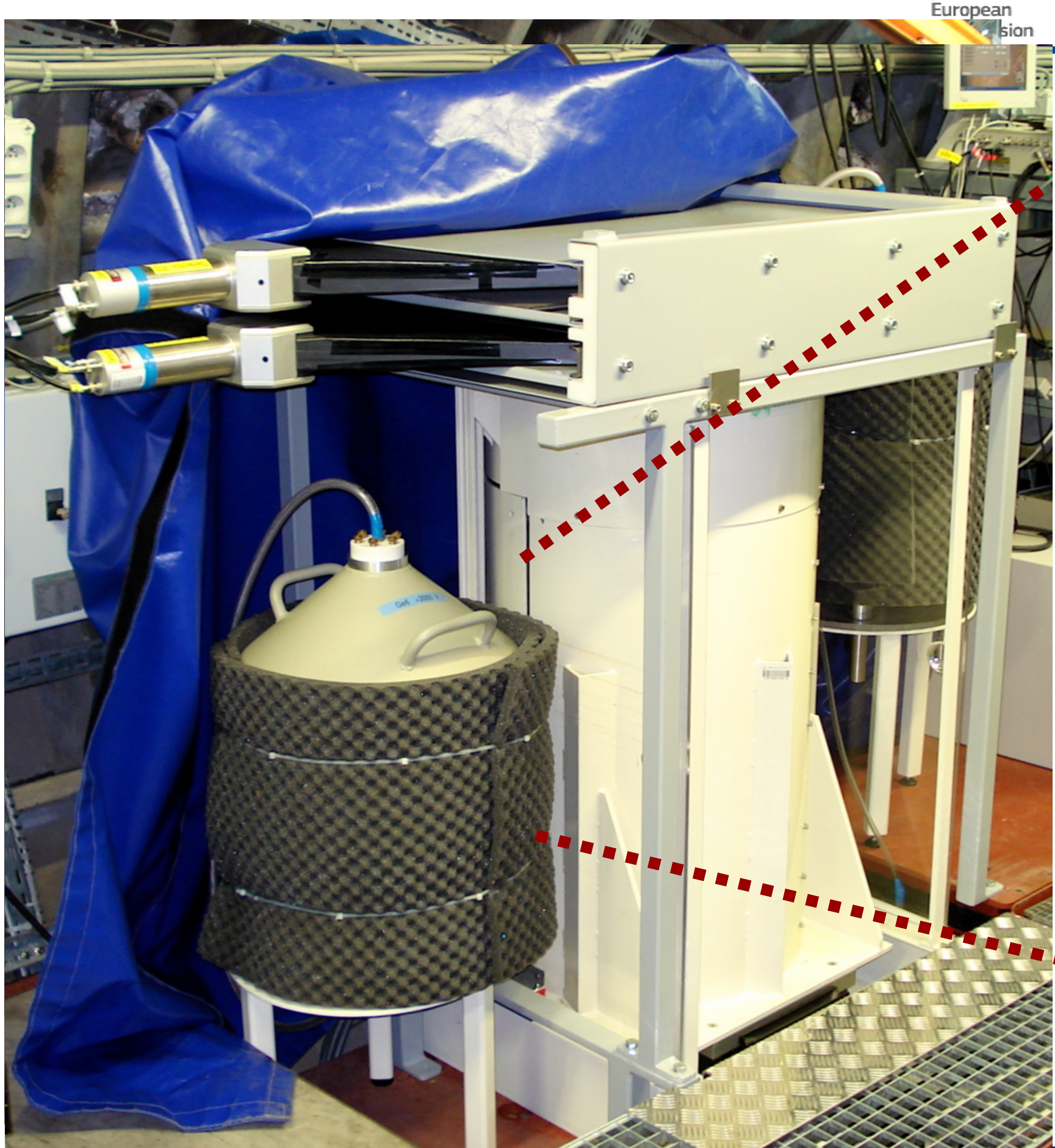
Located at SCK•CEN, Mol, Belgium, operated by EURIDICE

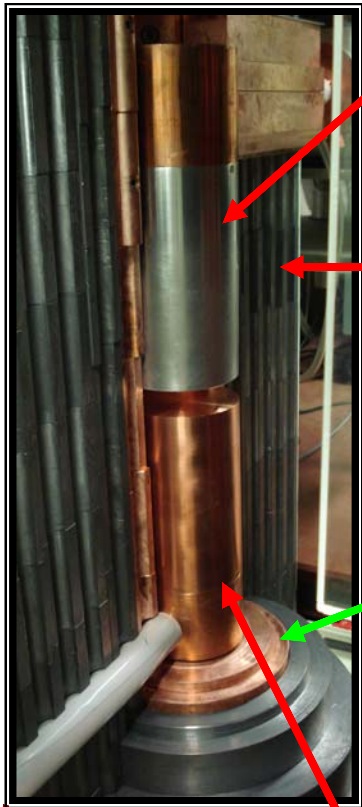



AIR
LUCHT
BRGM

The Sandwich Spectrometer

Increased solid angle





Ge-7

Pb shield = radiopure lead, 4 cm, 2.5 Bq/kg

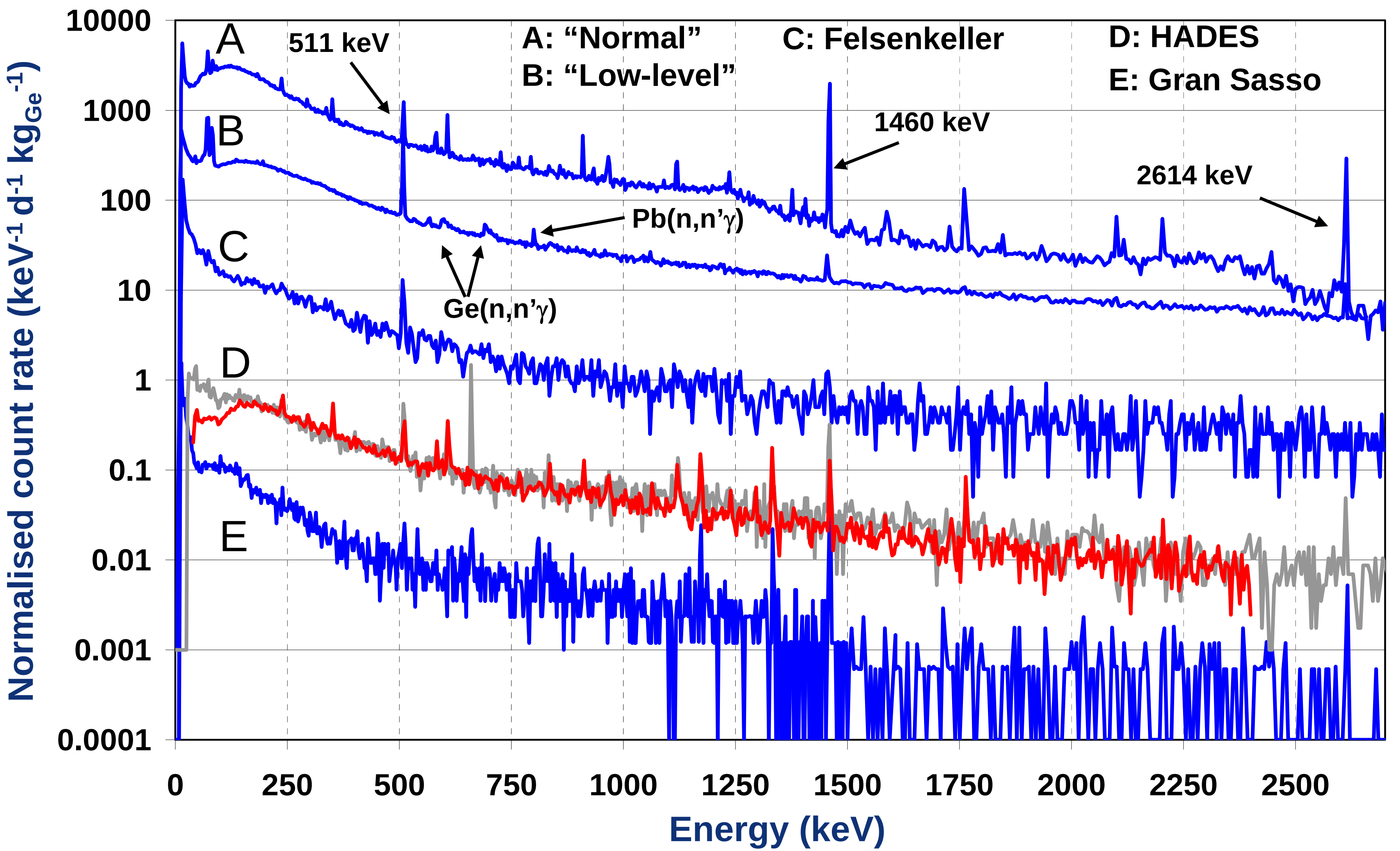
+14.5 cm lead, 20 Bq/kg

Cu lining = radiopure copper, 3.5 cm

Ge-6

Detector mass ~ 1.9 kg each

Background Comparison – Gamma-ray spectrometry



Extra benefits underground

Possibility to use thick lead shield (no increase of background after 15 cm)

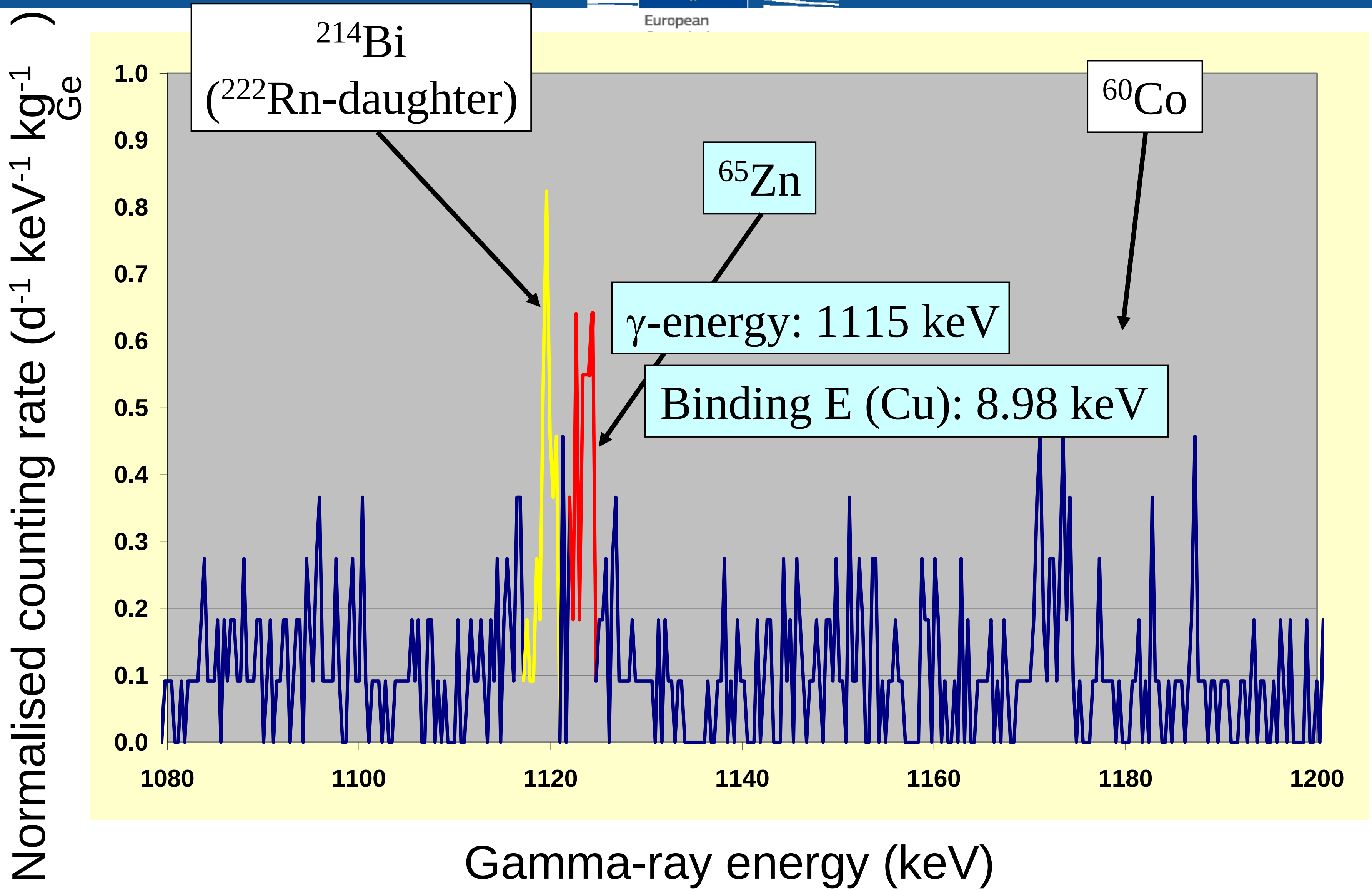
Possibility to use thick Cu shield as lining => not necessary with the best (most expensive) lead

No activation of Ge

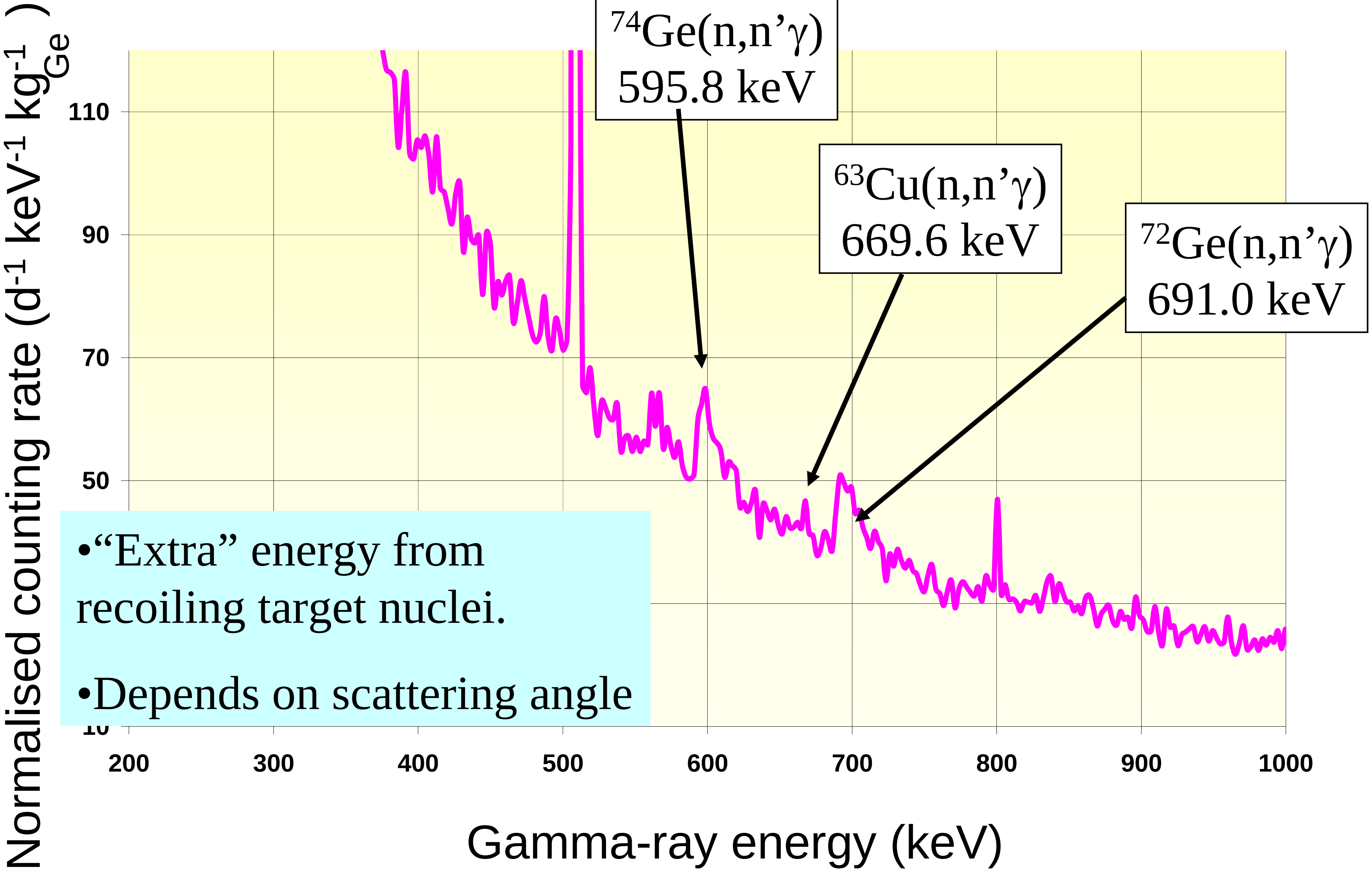
What is underground?

Depth (m w.e.)	Idiom	Characteristics
< 10	Not underground or above ground	• The soft component (e, e+, photons) is strongly reduced but still plays a part. • Very little reduction of muon flux and neutron induced by muons. • Muon shields are useful.
10 – 100	Shallow underground	• The soft component of the cosmic ray has vanished. • The muon flux is reduced a factor of 5-50, but Muon shields are useful. • There is still a significant flux of neutrons produced by muons (reduction of factor 2-10). • The activation of crystal and shield are still important factors.
100 – 1000	Semi deep underground	• Cosmogenic activation can be neglected. • A slight improvement can be obtained by discriminating against muons. • The neutron flux is dominated by (α,n) sources
> 1000	Deep underground	• The influence of the cosmic rays can be neglected. • The only source for neutrons are (α,n) reactions.

Source: Hult et al. Acta Chimica Slovenica, 2006.


^{214}Bi
(^{222}Rn-daughter)
^{60}Co
^{65}Zn
γ-energy: 1115 keV
Binding E (Cu): 8.98 keV
Normalised counting rate (d^{-1} keV^{-1} kg$^{-1}_{Ge}$)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1080
1100
1120
1140
1160
1180
1200
Gamma-ray energy (keV)

Weird triangular peaks



- "Extra" energy from recoiling target nuclei.
- Depends on scattering angle

European Commission

Other tricky peaks

^{58}Co

811 keV (γ-ray) + 7 keV (bind.E) = 818 keV

1460.8 keV

From ^{40}K, BUT also a peak at 1459.2 keV from ^{228}Ac (Pγ = 1.06% or 0.83%) => take care to quantify ^{40}K if there is a relatively high amount of ^{232}Th/^{228}Ra in the sample.

661.7 keV

^{137}Cs BUT also 1173-511 keV.

Other tricky peaks:

^{222}Rn-daughters

Background subtraction tricky if the Rn-concentration changes with time. Advice: Flush with N_2 and wait some time to start measurement.

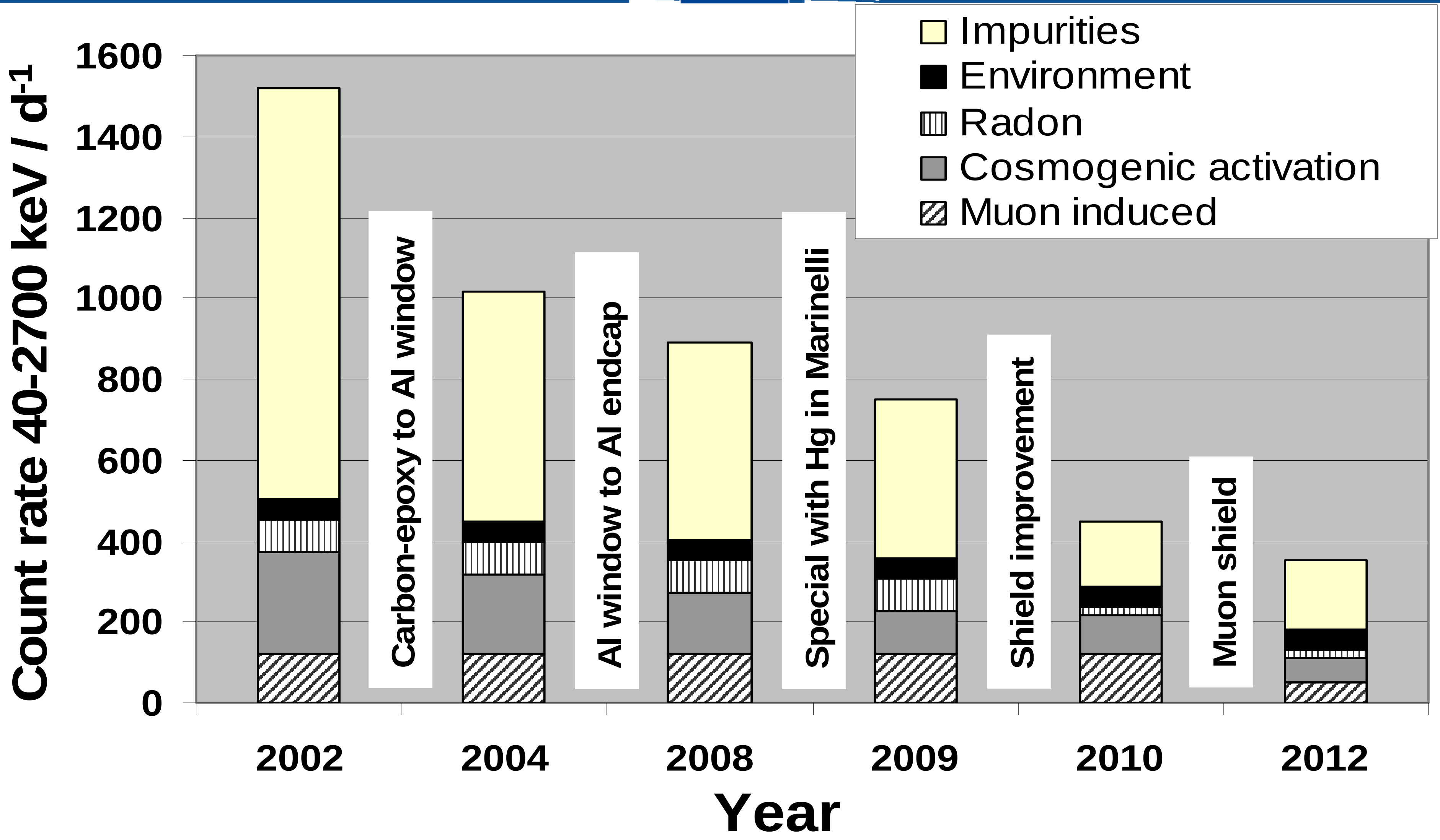
1293.6 keV

From ^{41}Ar produced in nuclear reactors.

^{40}K in big massive samples

The background subtraction could be incorrect since the sample will shield the detector from radioactivity in the shield

Detector Ge-5 – Background evolution



$$MDA \propto \frac{\sqrt{CR_{Bkg}}}{\sqrt{t_m}} \cdot \frac{1}{\varepsilon}$$

MDA = Minimum Detectable Activity (Bq)
CR_{Bkg}= Background Count Rate (s^{-1})
t_m = Measurement time (s)
ε = detection efficiency

$$MDA \propto \frac{\sqrt{CR_{Bkg}}}{\sqrt{t_m}} \cdot \frac{1}{\varepsilon}$$

ε: Increasing detector size will also increase background

ε: Increasing sample size may also increase background

t_m : "only" scales with square root

∴

It is worth while spending efforts to reduce background in order to obtain better MDAs

How long measurement time can you afford?

1 mBq ~ decay per hour
1 μBq ~ decay per week

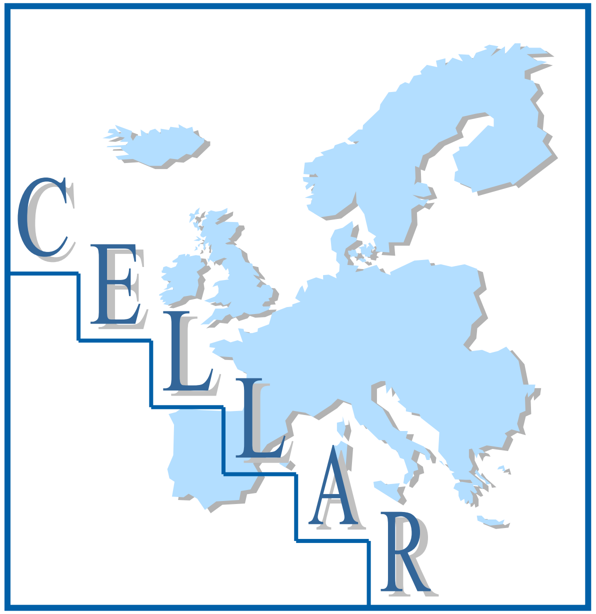
⇒To carry out big projects and measurement of numerous samples, <u>networking is essential</u>

Collaboration of European Low-level underground LAboRatories

CELLAR

European Commission

Collaboration of European Low-level underground LAboRatories



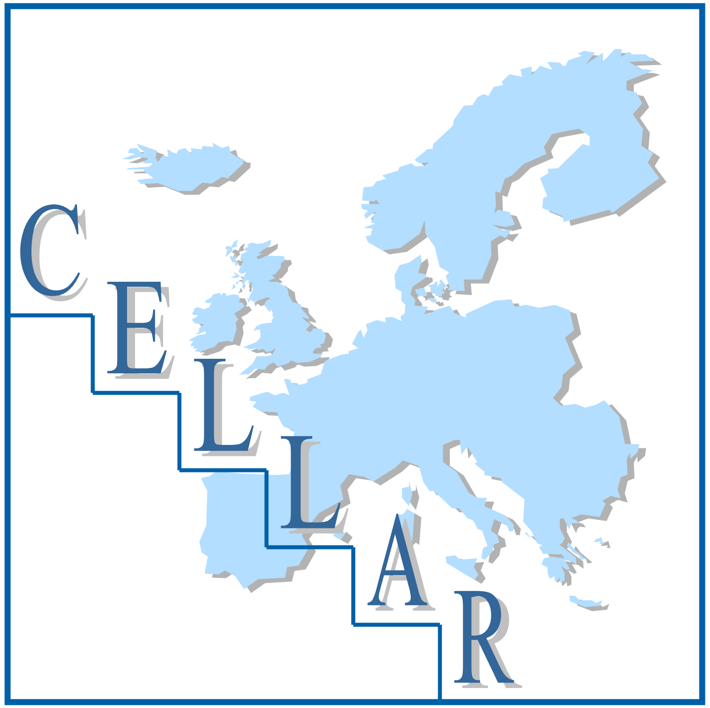
Mission: **To promote higher quality and sensitivity in ultra low-level radioactivity measurements for the improvement of crisis management, environment, health and consumer protection standards of Europe.**

CELLAR-labs

European Commission

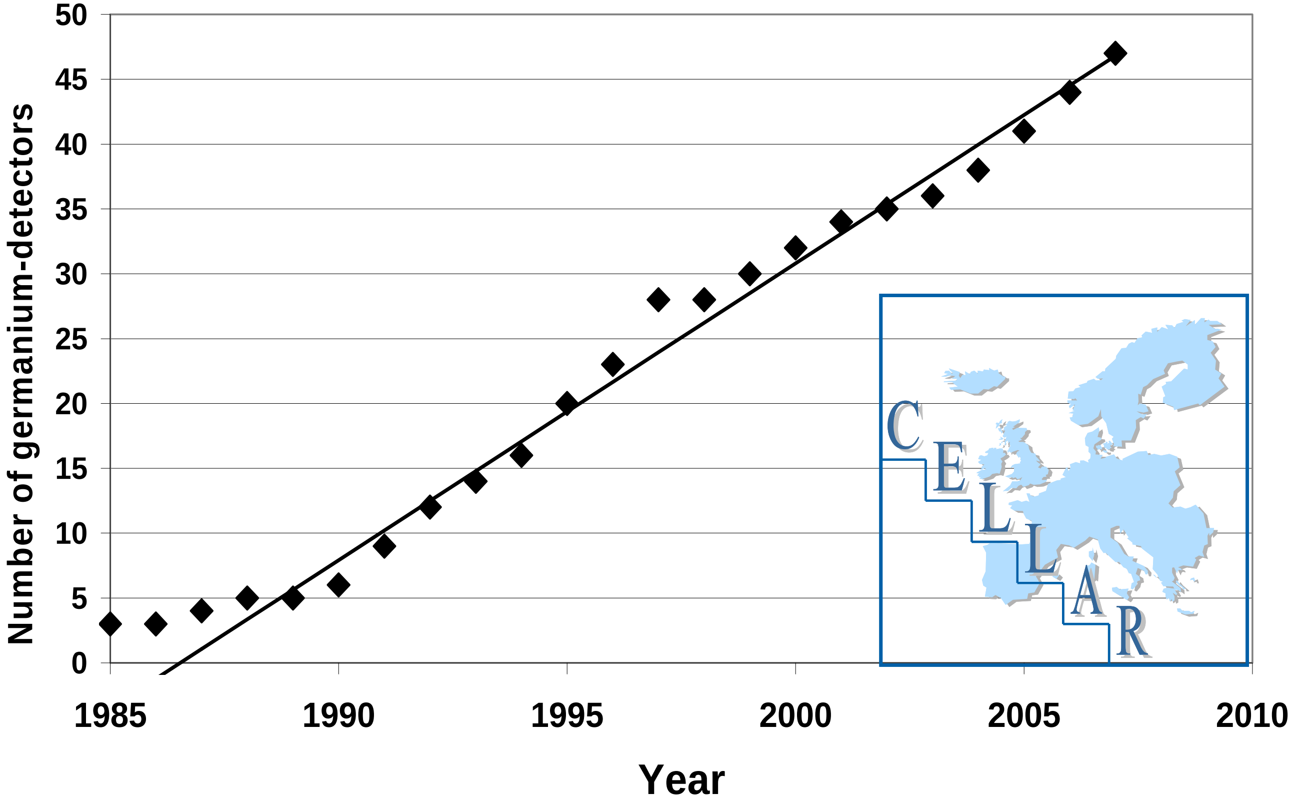
- Modane - France (-2200 m)
- Gran Sasso - Italy (-1700 m)
- Asse/PTB - Germany (-415 m)
- HADES – EU/Belgium (-225 m)
- Unirea, Romania (-208 m)
- University of Iceland (-165 m)
- Baradello Hill, Italy (- 100 m)
- Ferrière (LEGOS)-France (-80 m)
- Felsenkeller - Germany (-50 m)
- CAVE – Monaco (-15 m)
- MPI-Heidelberg - Germany (-10 m)

+ associated partners
e.g. Solotvina salt mine (Ukraine)

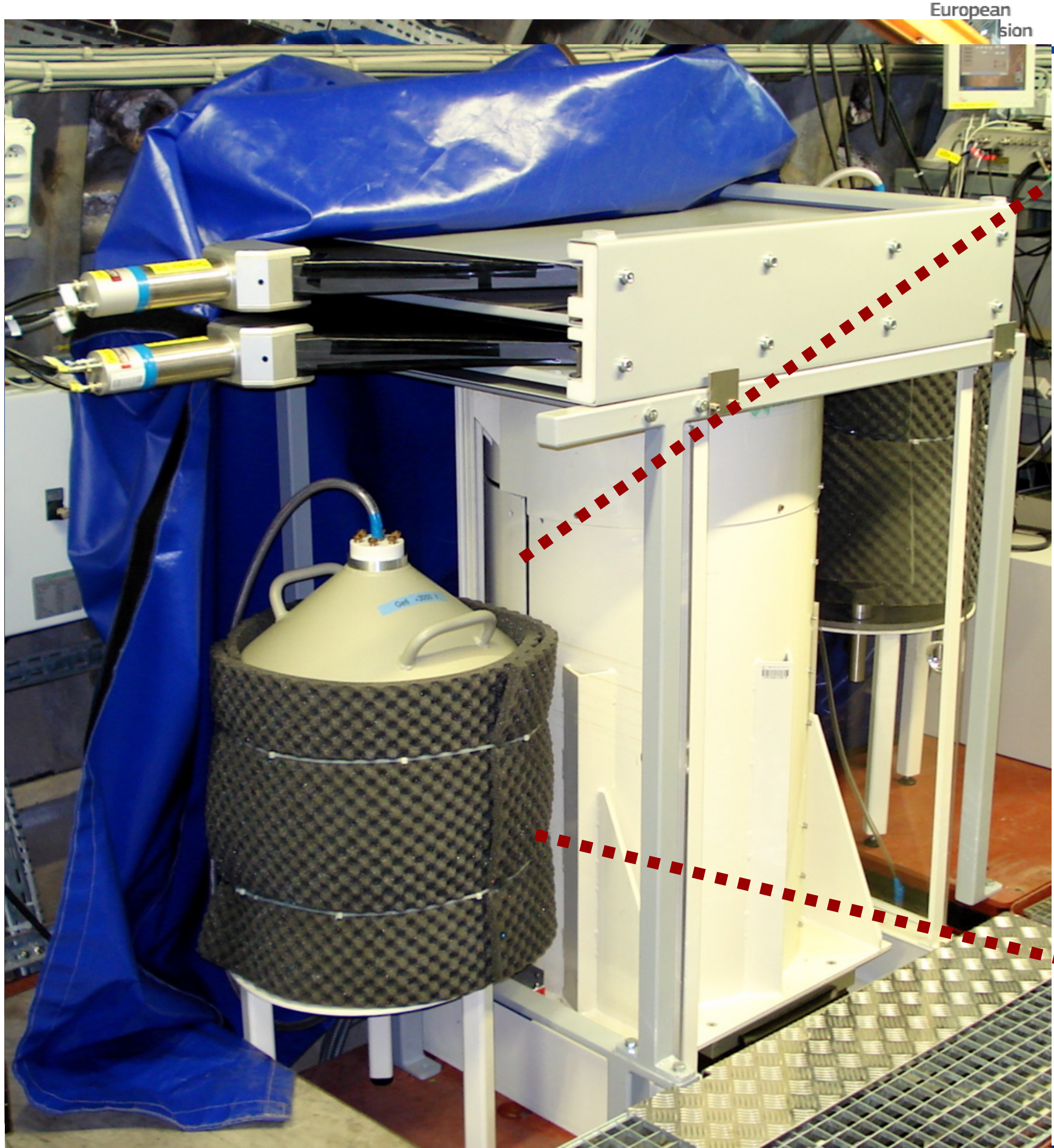


Not all partner institutes are in the list!

…a growing field of science, engineering and metrology



Increased solid angle



Ge-7

Pb shield = radiopure lead, 4 cm, 2.5 Bq/kg

+14.5 cm lead, 20 Bq/kg

Cu lining = radiopure copper, 3.5 cm

Ge-6

Detector mass ~ 1.9 kg each

Not always necessary for obtaining the lowest detection limits

Much better control of background components than above ground $\Rightarrow$ more robust measurements $\Rightarrow$ Important for better QC of reference samples.

Thank you for your attention!