STELLA - The L.N.G.S. low background facility

Dr. Matthias Laubenstein
Laboratori Nazionali del Gran Sasso
ITALY

IAPS @ Gran Sasso - Particle & Astroparticle Physics Spring Event
May 7th - 8th, 2015

Introduction

- Many fundamental experiments aim to detect very weak signals. They have to fight against background of different origin.
  - cosmic radiation
  - particles of nuclear decays
  - intrinsic natural radioactivity

↓

low background α and γ spectroscopy @ L.N.G.S.

STELLA = SubTErranean Low Level Assay

Germanium spectroscopy

Comparison of Radio-assay techniques

for primordial U/Th decay chains and K

	suited for
Ge-spectroscopy	γ emitting nuclides
Rn emanation assay	^{226}Ra, ^{228}Th
neutron activation	primordial parents
liquid scintillation counting	α,β emitting nuclides
mass spectrometry (ICP-MS; AMS)	primordial parents
graphite furnace AAS	primordial parents
Röntgen Excitation Analysis	primordial parents
α spectroscopy	^{210}Po, α emitting nuclides

difficult to compare because each method has its special application

method	suited for	sensitivity for U/Th
Ge-spectroscopy*	γ emitting nuclides	10-100 μBq/kg
Rn emanation assay	^{226}Ra, ^{228}Th	0.1-10 μBq/kg
neutron activation	primordial parents	0. 01 μBq/kg
liquid scintillation counting	α,β emitting nuclides	1 mBq/kg
mass spectrometry (ICP-MS; AMS)	primordial parents	1-100 μBq/kg
graphite furnace AAS	primordial parents	1-1000 μBq/kg
Röntgen Excitation Analysis	primordial parents	10 mBq/kg
α spectroscopy	^{210}Po, α emitting nuclides	1 mBq/kg

* Needs counting times from several weeks to several months

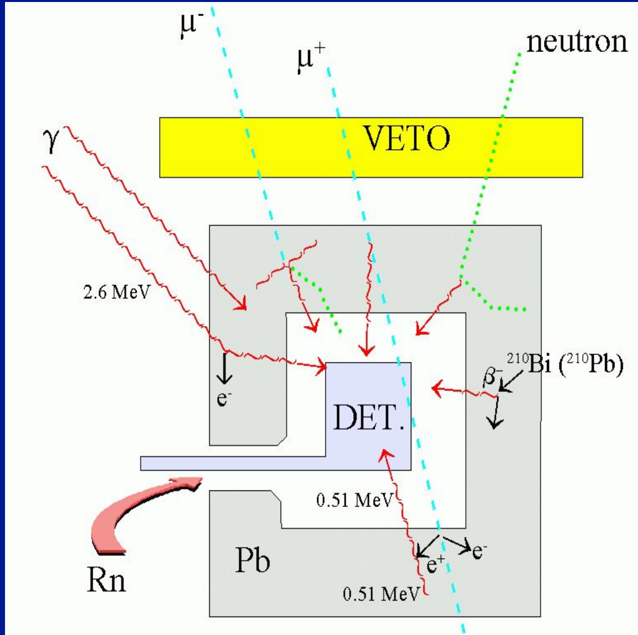
Best see Borexino Collaboration, Arpesella, C. et al., Measurements of extremely low radioactivity levels in Borexino, Astrop. Phys. 18 (2002) 1-25

Ultra Low-level Gamma Spectrometry

i.e. low-level γ-spectrometry with additional background reduction by using active shields, material selection and/or underground laboratories

Background components in Ge spectrometry

- external gamma radiation (2.6 MeV ^{208}Tl, {up to 3.2 MeV ^{214}Bi})
- radio-impurities close to crystal (primordial, anthropogenic)
- Rn and its progenies
- cosmic rays (neutrons, muon and activation)
- neutrons from fission and (α,n) reactions



by courtesy of Dr. G. Heusser

most important: material screening U/Th chains and K dominant from Bq/kg down to μBq/kg only reliably radiopure material - Cu – but mBq/kg cosmogenics besides Si, Ge, Au, Ag, Hg, (Pb – except ^{210}Pb)

improvements in iterative steps

Rock properties

radioactivity (in Bq kg^{-1}):

	Gran Sasso	M^{t} Blanc
^{232}Th	0.25-0.5	≈90
^{238}U	5	80-500
^{226}Ra	4.5	30-300
^{40}K	5-50	100-2000

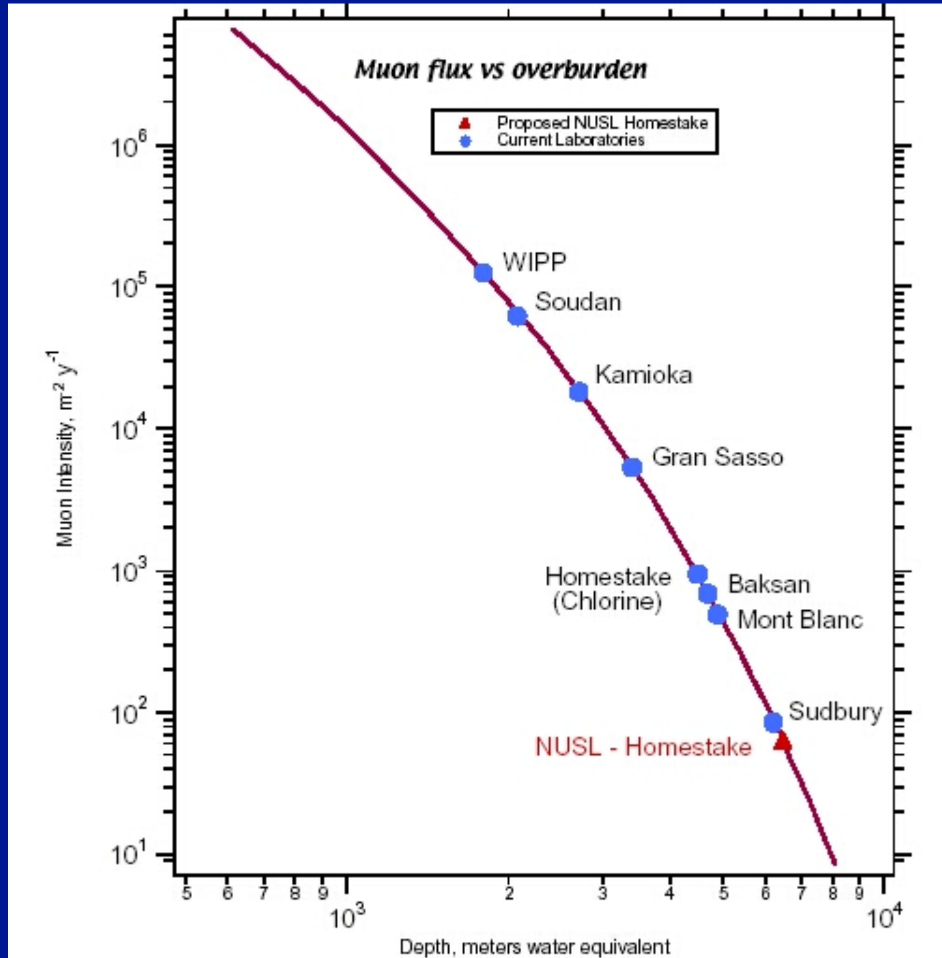
Muons

muon flux:

e.g. @ L.N.G.S.

$\approx 1\ \mu/(m^2 \cdot h)$, $E_\mu > 1$ TeV

(10^6 reduction with respect to surface)



Neutrons

<u>*neutron flux:*</u>

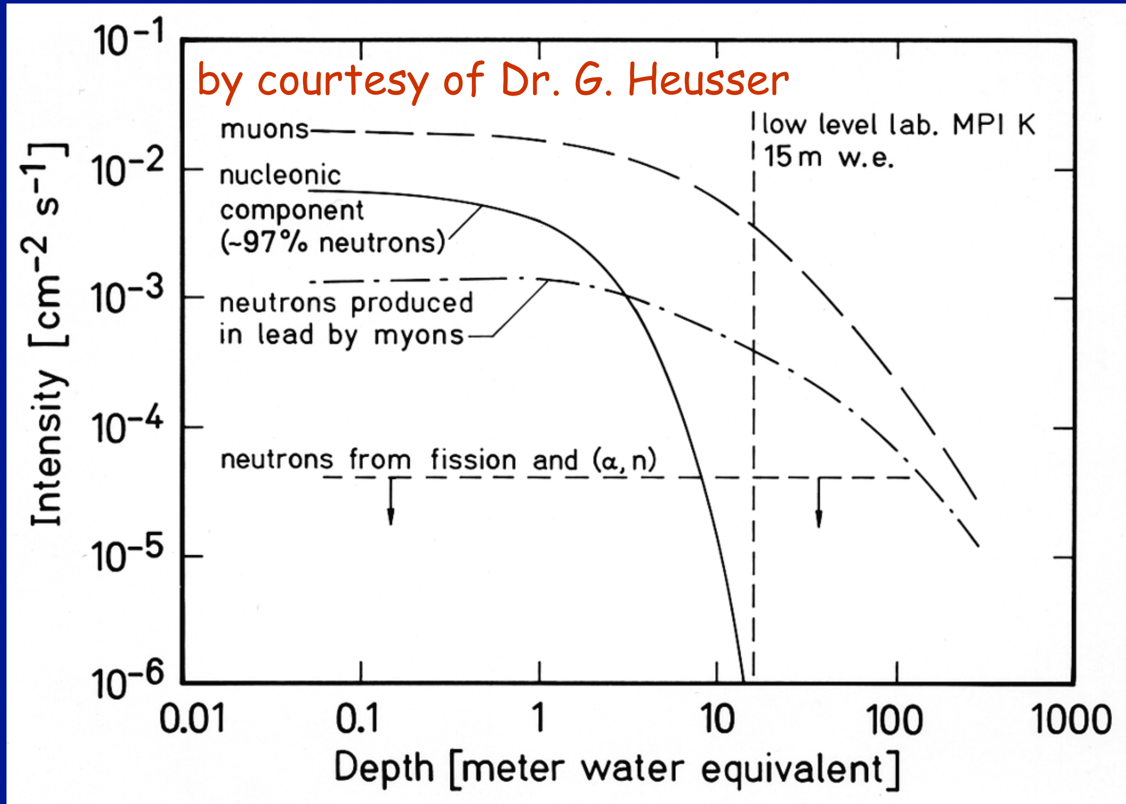
e.g. @ L.N.G.S.

fission and (α,n)

$\Phi_{th} \approx 3\times10^{-6}\ cm^{-2}\ s^{-1}$

$\Phi_{fc} < 0.3\times10^{-6}\ cm^{-2}\ s^{-1}$

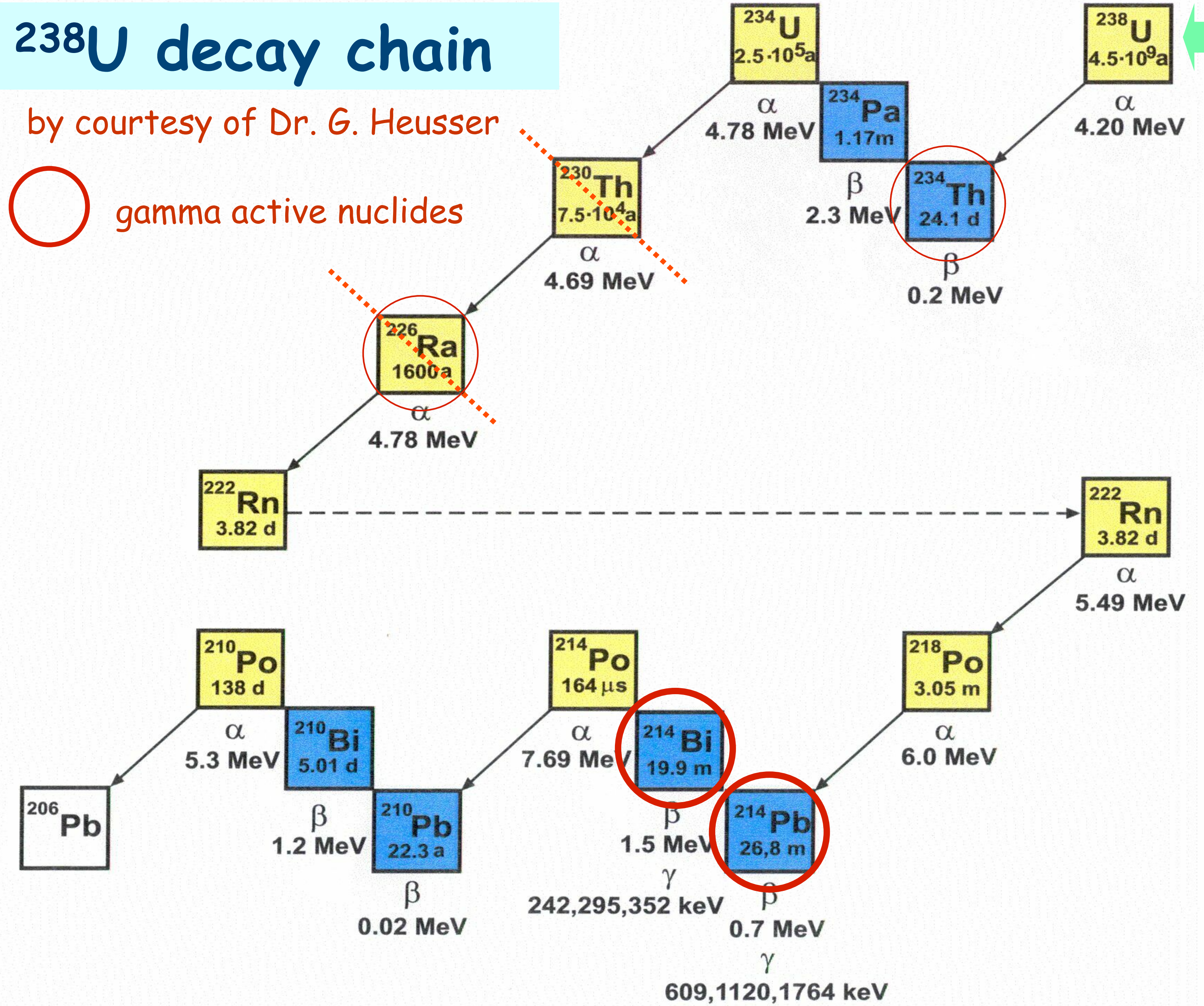
(10^3 reduction)



^{238}U decay chain

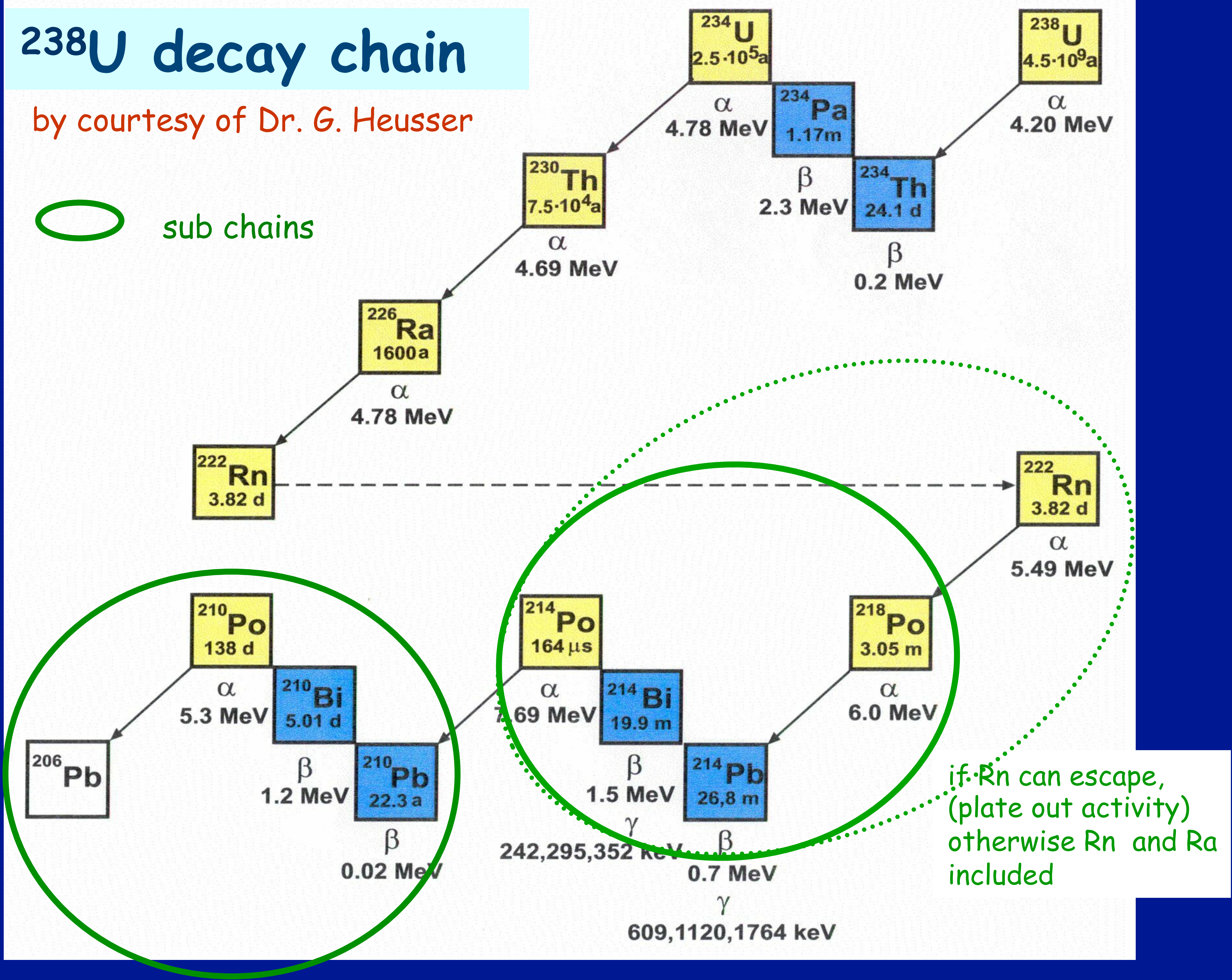
by courtesy of Dr. G. Heusser

gamma active nuclides



^{238}U decay chain

by courtesy of Dr. G. Heusser

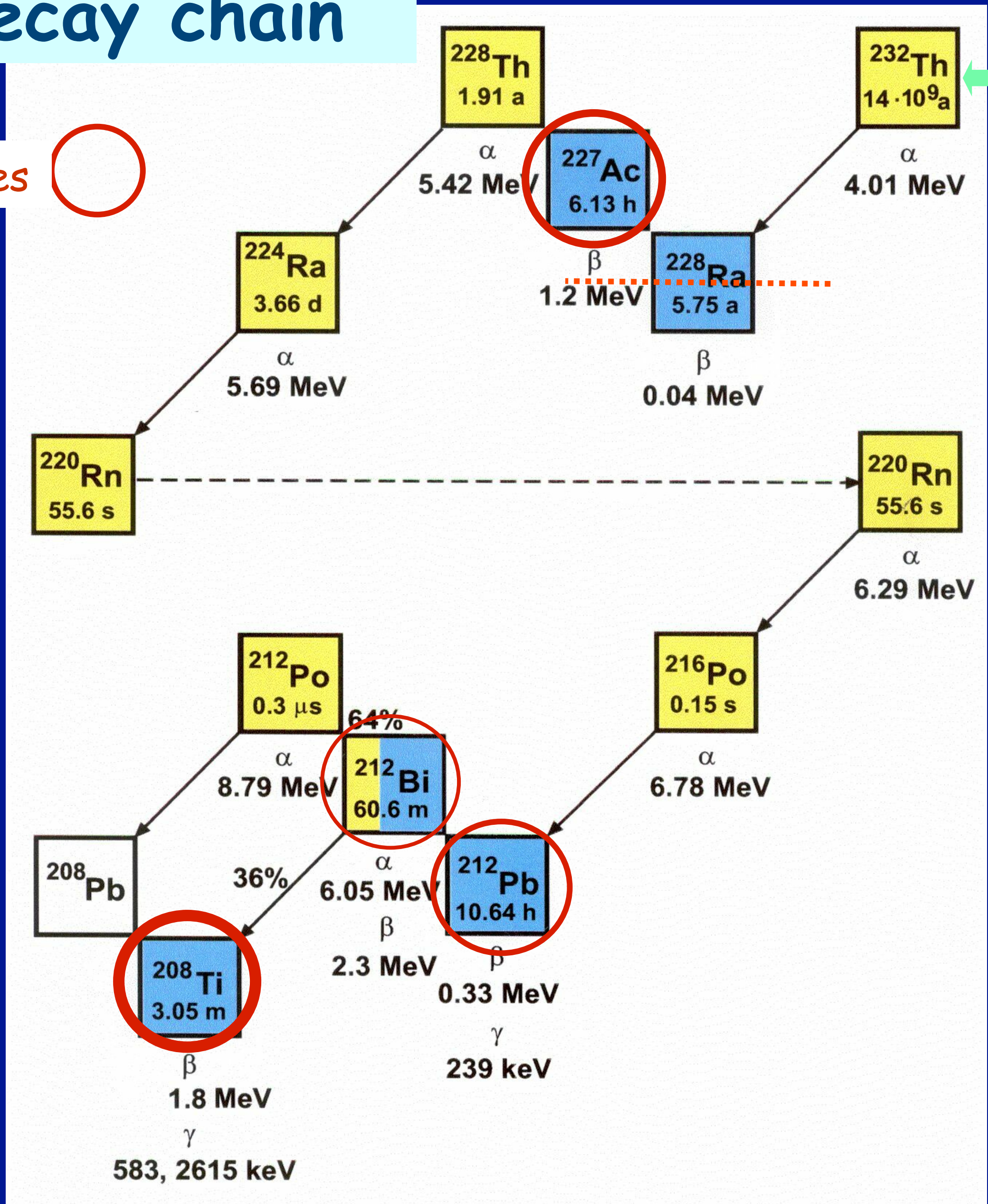


^{232}Th decay chain

by courtesy of Dr. G. Heusser

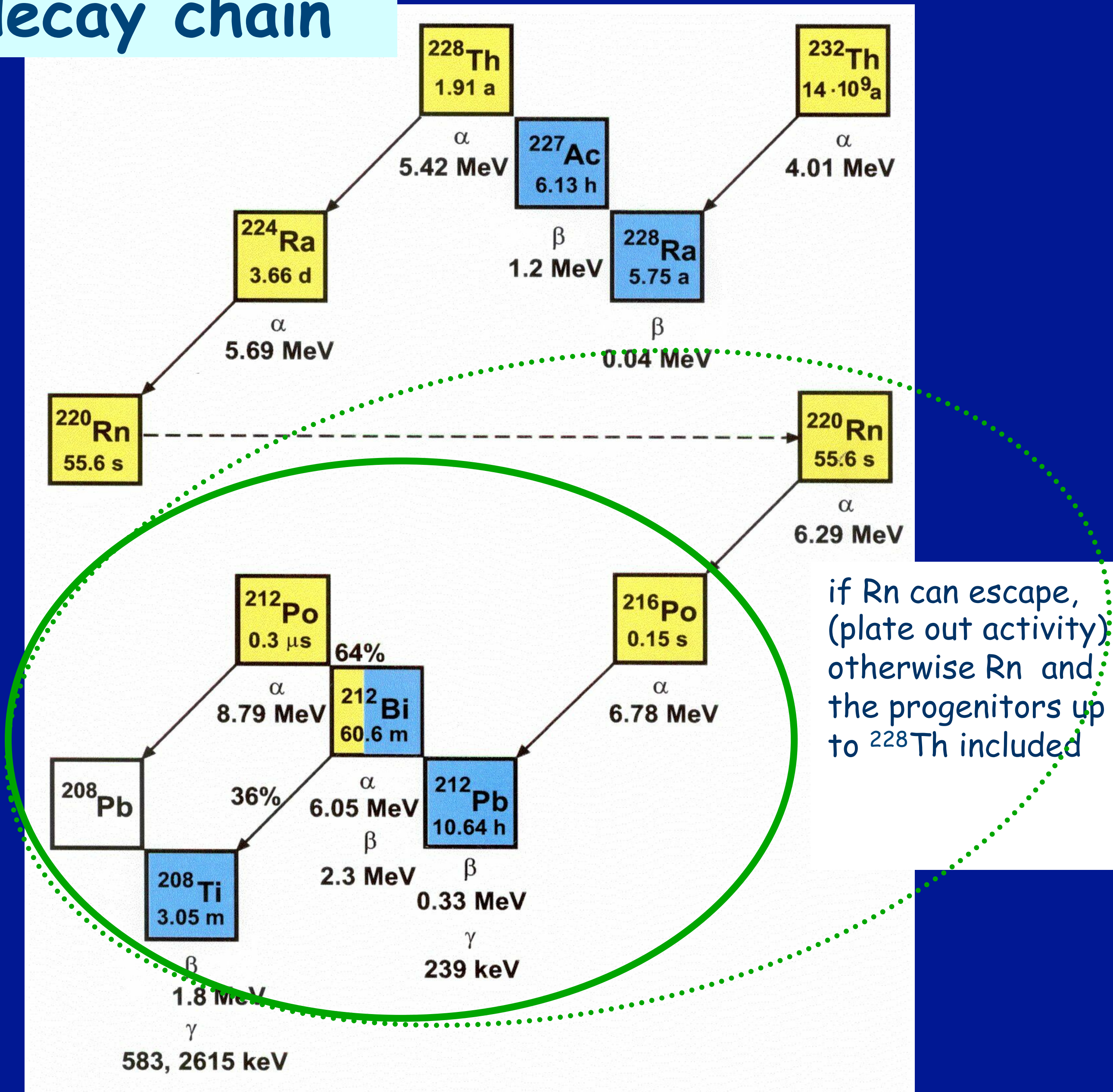
gamma active nuclides

mass spectrometry

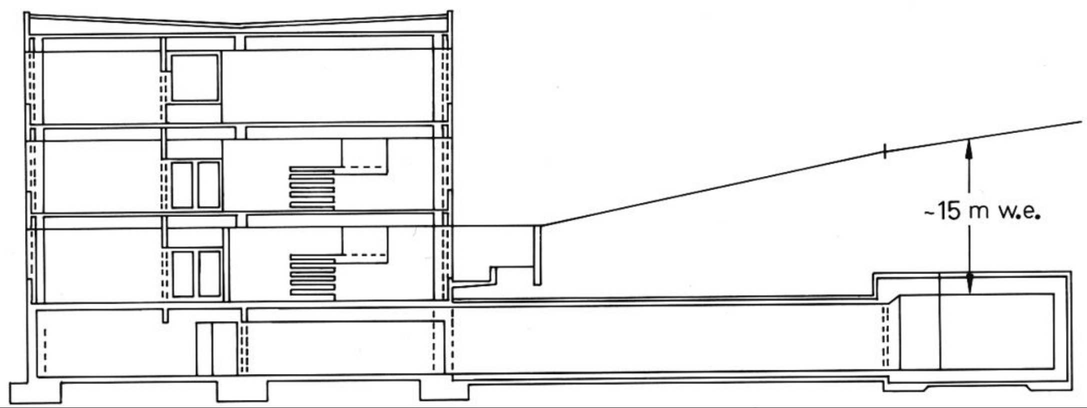


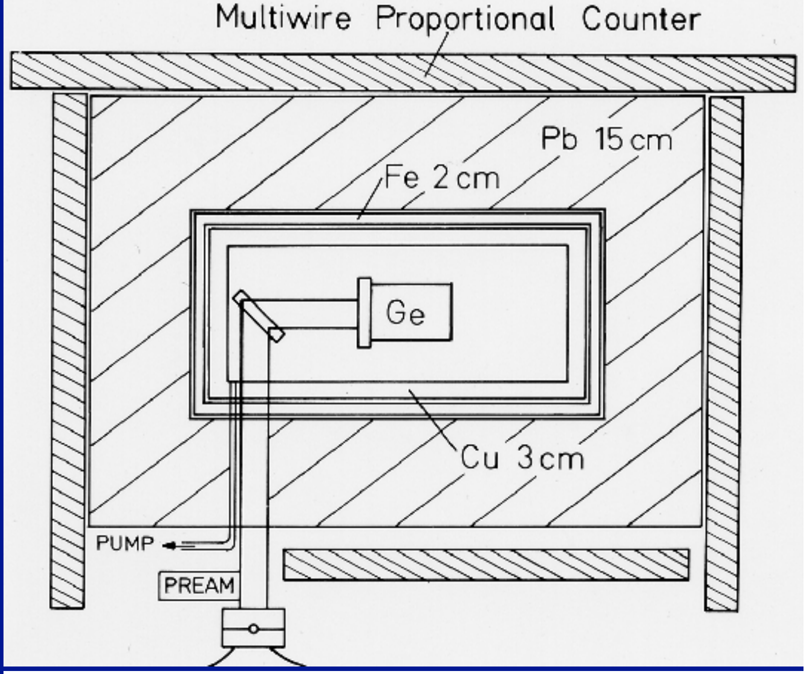
^{232}Th decay chain

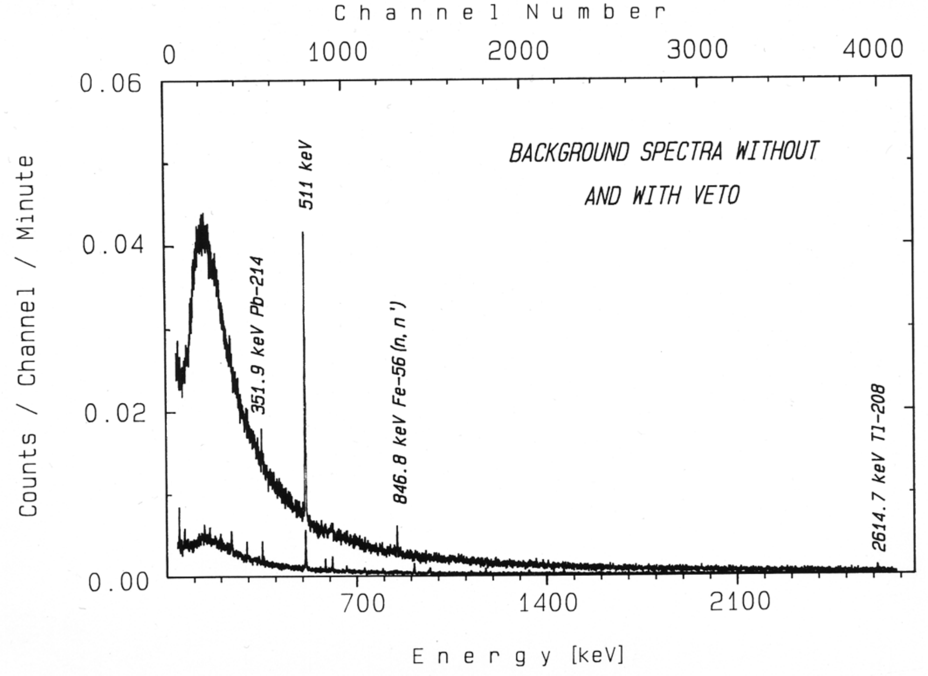
by courtesy of Dr. G. Heusser

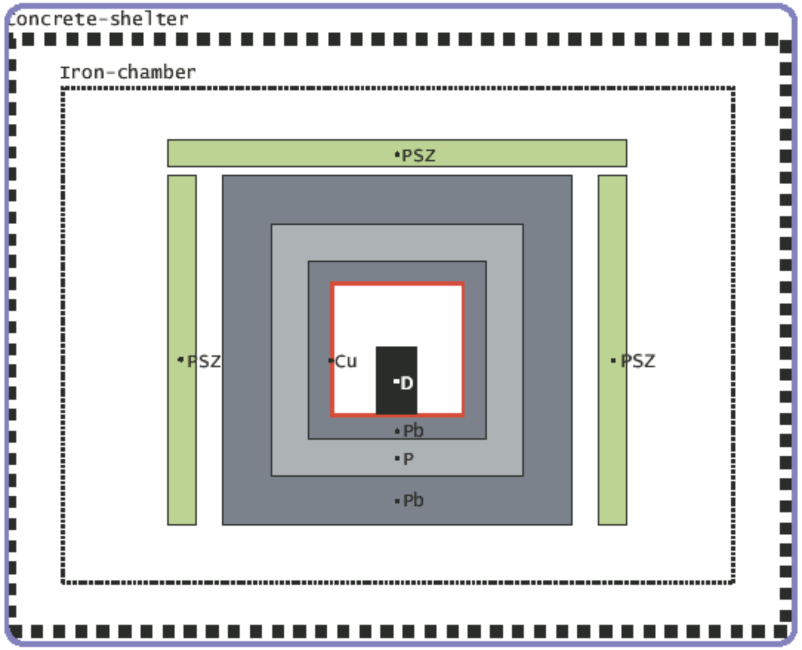


if Rn can escape, (plate out activity) otherwise Rn and the progenitors up to ^{228}Th included


~15 m w.e.

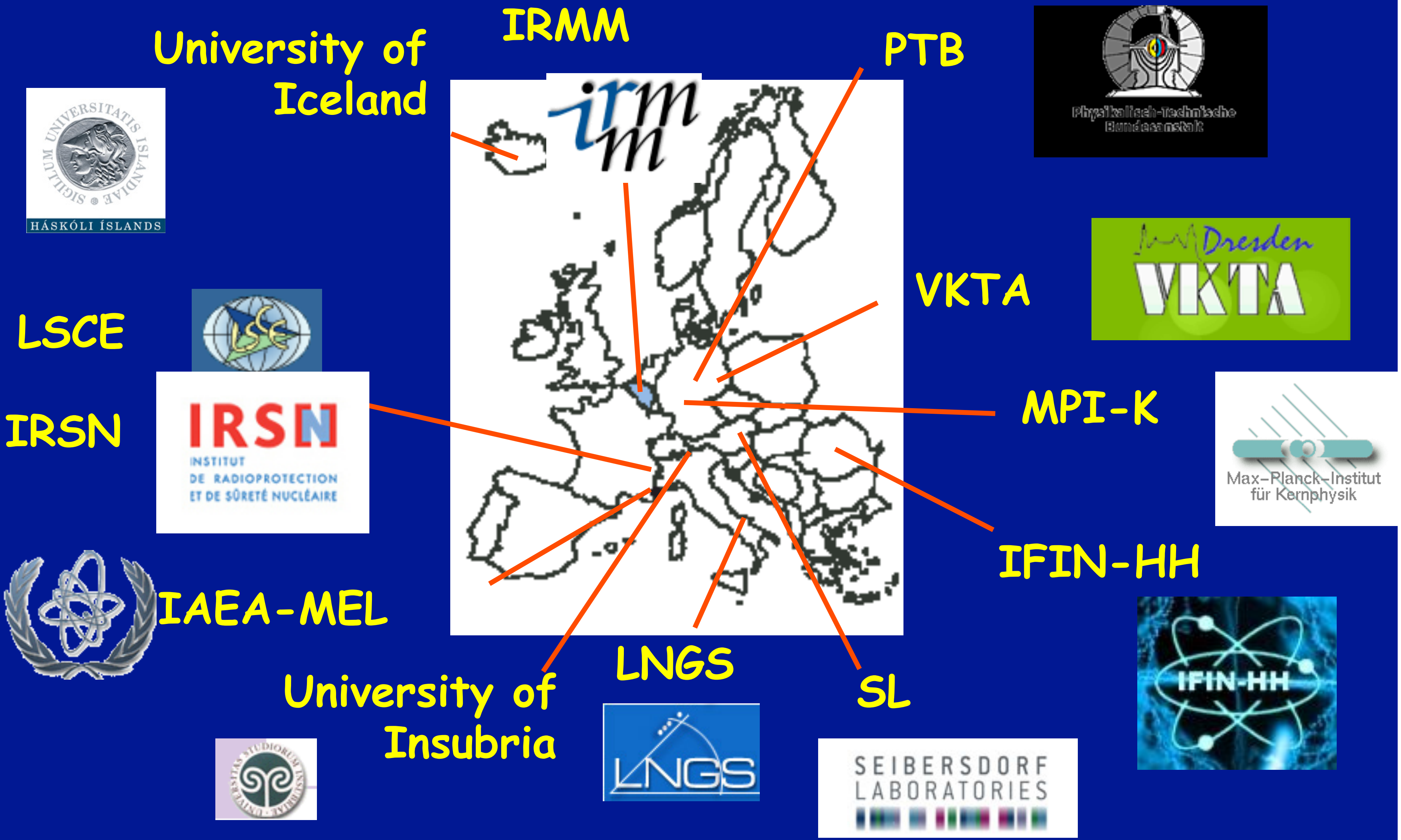

Multiwire Proportional Counter
Pb 15 cm
Fe 2 cm
Ge
Cu 3 cm
PUMP
PREAM


Channel Number
0
1000
2000
3000
4000
0.06
0.04
0.02
0.00
Counts / Channel / Minute
BACKGROUND SPECTRA WITHOUT
AND WITH VETO
511 keV
351.9 keV Pb-214
846.8 keV Fe-56(n,n')
2614.7 keV Tl-208
700
1400
2100
Energy [keV]


concrete-shelter
Iron-chamber
PSZ
PSZ
PSZ
Cu
D
Pb
P
Pb

CELLAR

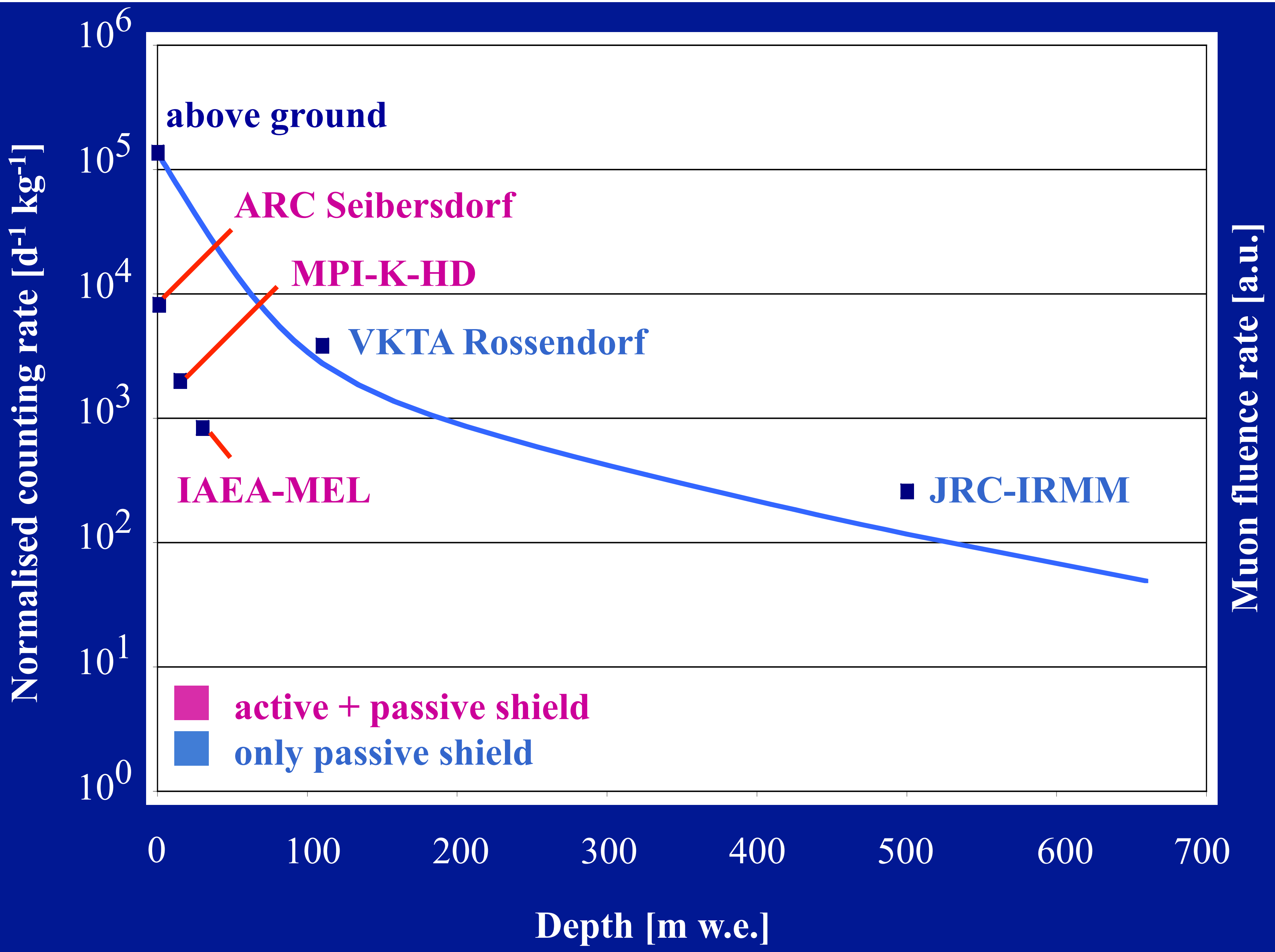
Collaboration of European Low-level underground LAboRatories


University of Iceland
HÁSKÓLI ÍSLANDS
IRMM
PTB
Physikalisch-Technische Bundesanstalt
LSCE
VKTA
Dresden
VKTA
IRSN
IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE
MPI-K
Max-Planck-Institut für Kernphysik
IFIN-HH
IFIN-HH
IAEA-MEL
University of Insubria
LNGS
LNGS
SL
SEIBERSDORF LABORATORIES

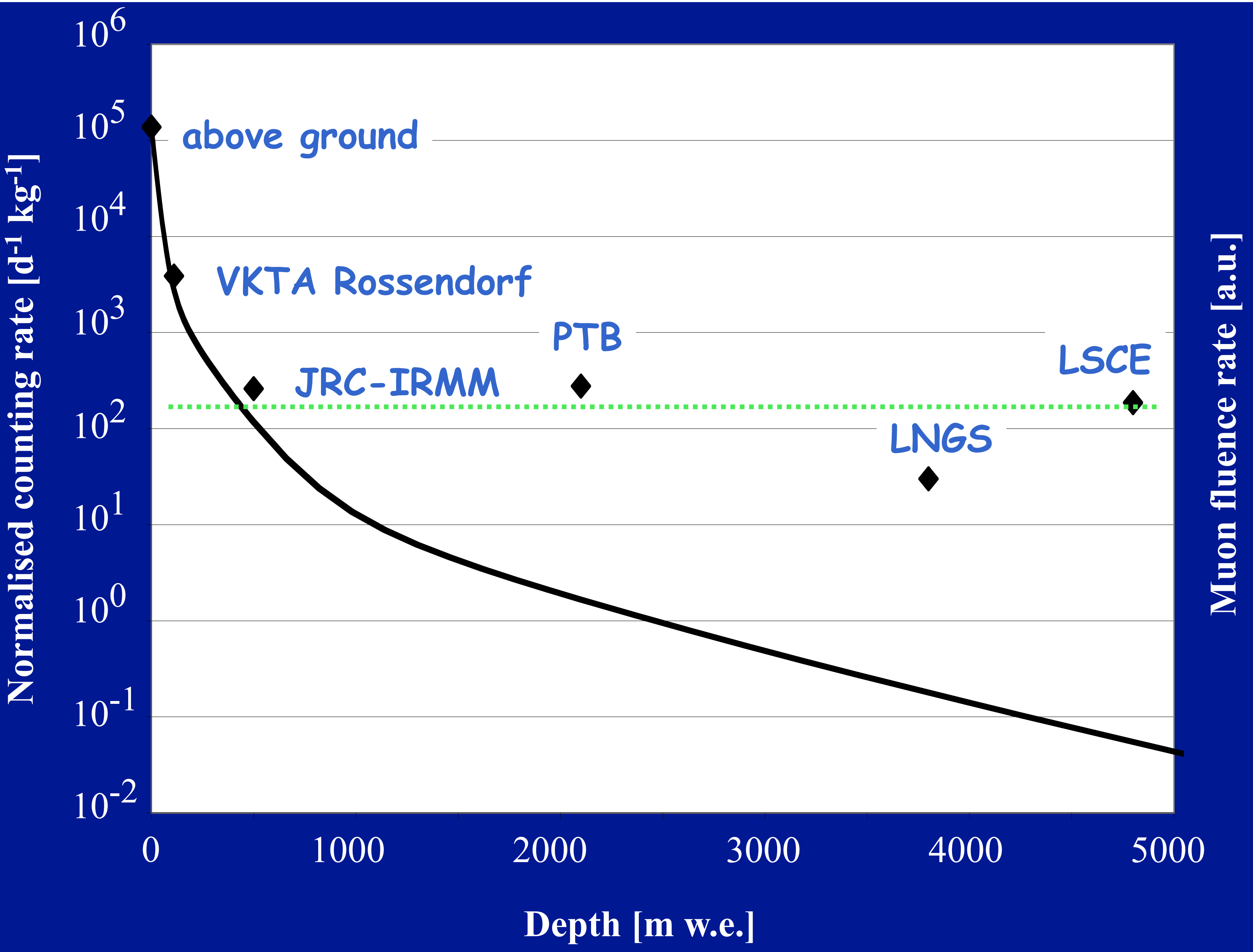
Some of the partner laboratories:

Seibersdorf Laboratories- Austria	(above ground, ~ 3 m w.e.)
MPI-Heidelberg - Germany	(~ 8 m ≅ 15 m w.e.)
IAEA-MEL - Monaco	(~ 14 m ≅ 30 m w.e.)
VKTA - Germany	(~ 50 m ≅ 110 m w.e.)
University of Iceland	(~ 165 m ≅ 350 m w.e.)
IRMM - EU - Belgium	(~ 225 m ≅ 500 m w.e.)
PTB - Germany	(~ 925 m ≅ 2100 m w.e.)
LNGS - Italy	(~ 1400 m ≅ 3800 m w.e.)
LSCE - France	(~ 1750 m ≅ 4800 m w.e.)

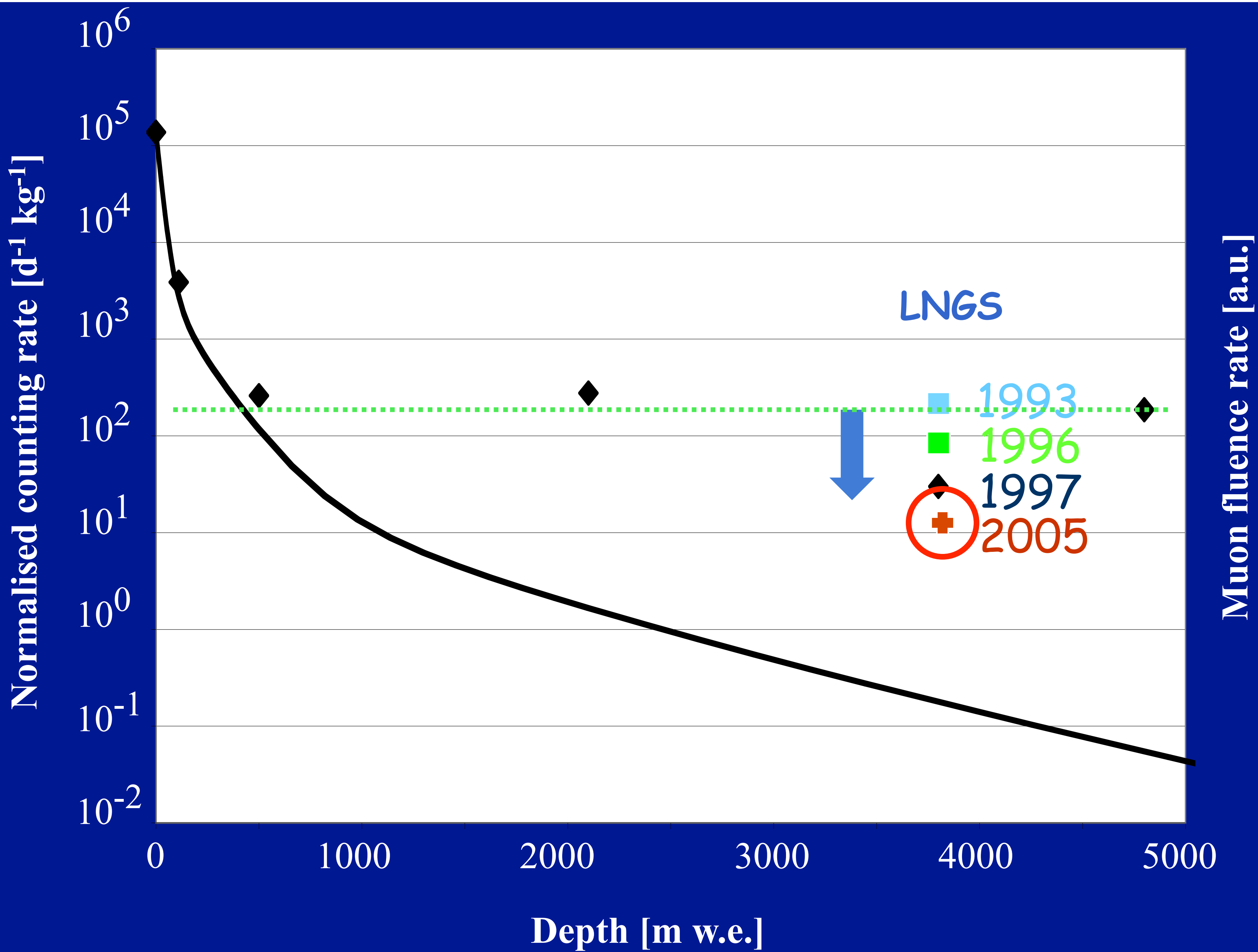
(m. w.e. = meter water equivalent, the height of water equivalent to that of the actual shielding material)

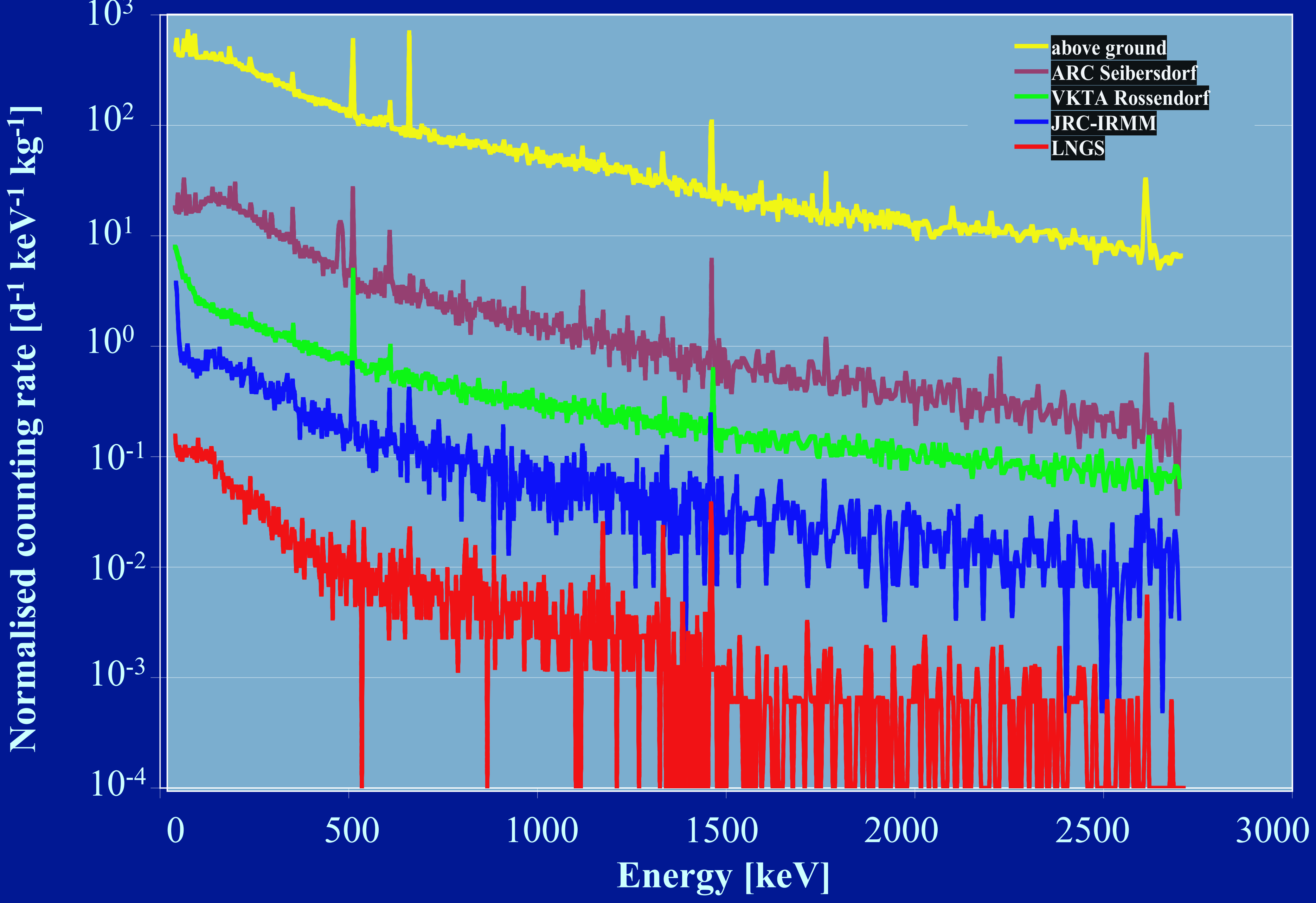


10^6
10^5
10^4
10^3
10^2
10^1
10^0
Normalised counting rate [d-1 kg-1]
above ground
ARC Seibersdorf
MPI-K-HD
VKTA Rossendorf
IAEA-MEL
JRC-IRMM
active + passive shield
only passive shield
0
100
200
300
400
500
600
700
Depth [m w.e.]
Muon fluence rate [a.u.]



10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
Normalised counting rate [d^{-1} kg^{-1}]
above ground
VKTA Rossendorf
PTB
JRC-IRMM
LSCE
LNGS
Muon fluence rate [a.u.]
0
1000
2000
3000
4000
5000
Depth [m w.e.]


10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
Normalised counting rate [d^-1 kg^-1]
0
1000
2000
3000
4000
5000
Depth [m w.e.]
Muon fluence rate [a.u.]
LNGS
1993
1996
1997
2005



above ground
ARC Seibersdorf
VKTA Rossendorf
JRC-IRMM
LNGS
Normalised counting rate [d-1 keV-1 kg-1]
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
0
500
1000
1500
2000
2500
3000
Energy [keV]

Background (peak) count rates [kg^{-1} y^{-1}]

Energy [keV]	GeMPI	HDM # 1-5
352 (U/Ra)	≤ 31	110 – 180
609 (U/Ra)	≤ 30	96 - 140
583 (Th)	≤ 23	18 – 42
2615 (Th)	17 ± 5	11 - 22
1461 (K)	90 ± 13	74 - 290
100-2730 keV	9760	12300

Contamination of Cu [μBq kg^{-1}]

	^{226}Ra (U)	^{228}Th (Th)	^{40}K
Cryostat of ANG1	168 ± 8	84 ± 7	236 ± 61
Cryostat of ANG2	91 ± 4	10 ± 3	78 ± 22
Cryostat of ANG3	105 ± 5	84 ± 5	927 ± 46
Cryostat of ANG4	115 ± 3	87 ± 4	199 ± 4
Cryostat of ANG5	100 ± 4	26 ± 4	1632 ± 49
measured by **GeMPI***	≤ 16	≤ 12	≤ 110

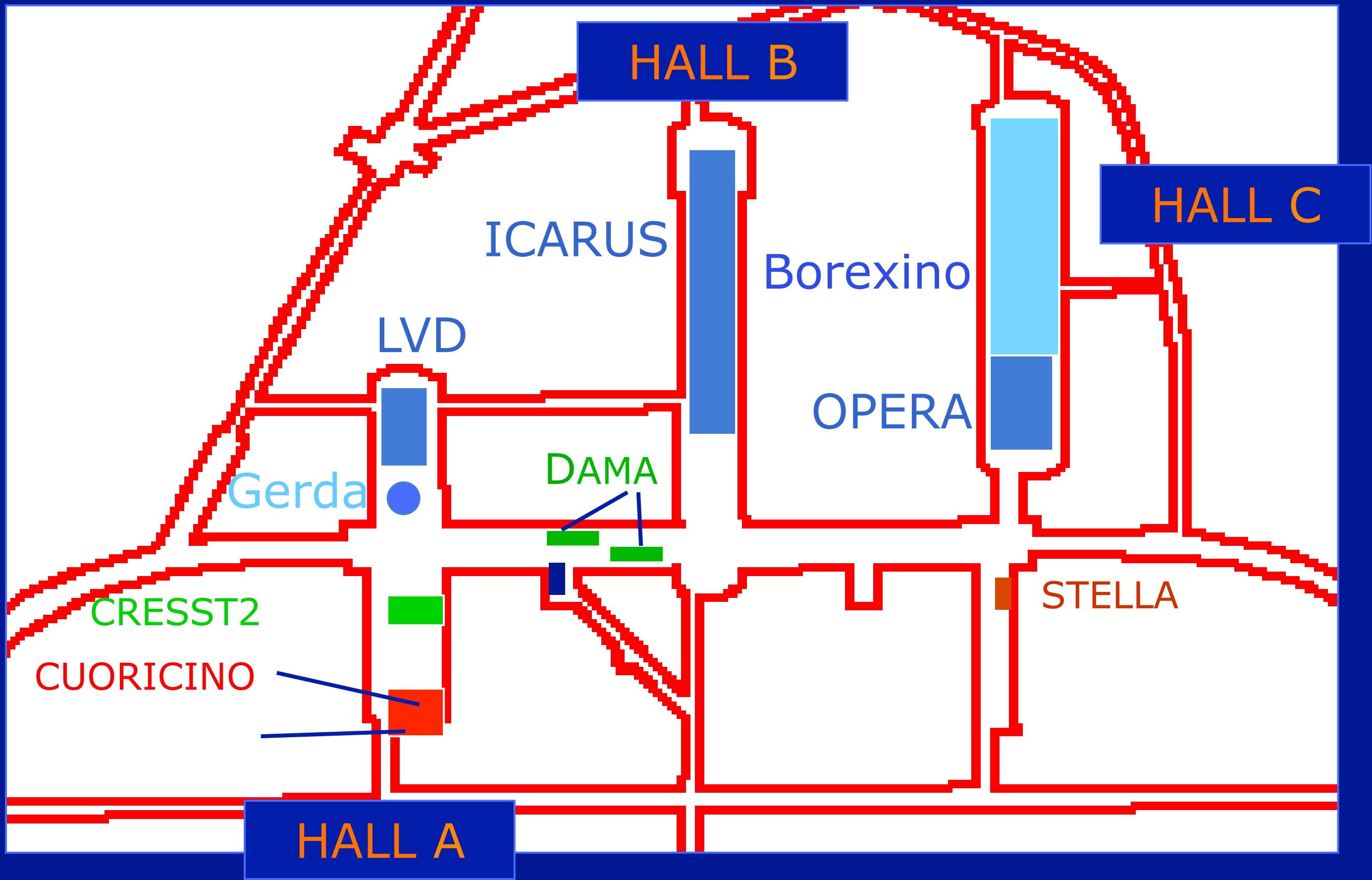
Monte Carlo simul.
Ch. Dörr,Uni HD
2002

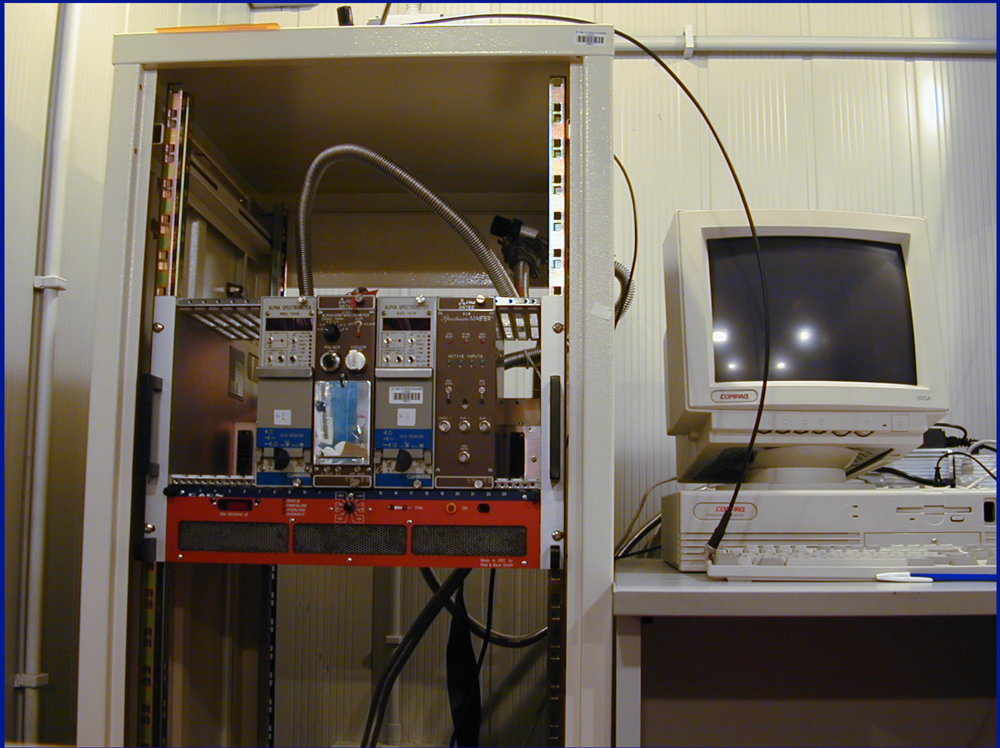
surface contamination

* 127 kg

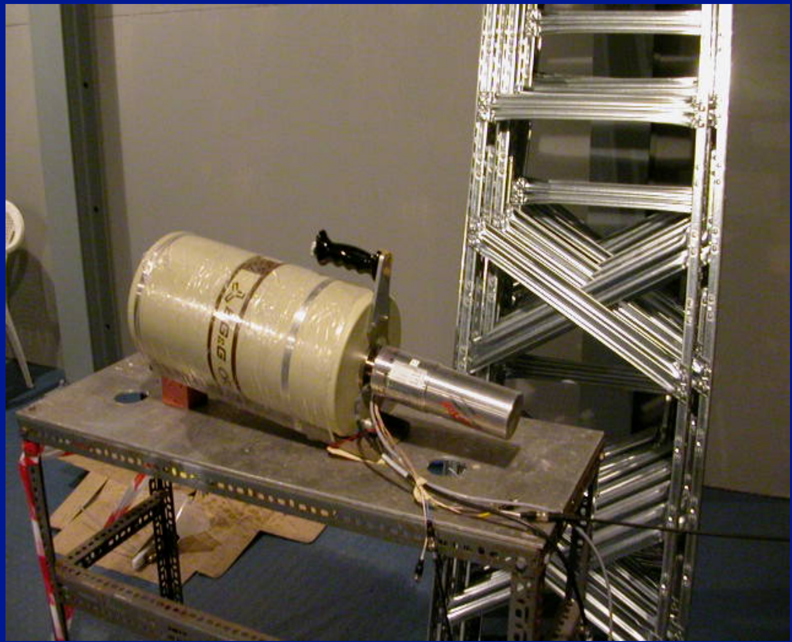
STELLA

Underground laboratories





portable
γ spectrometer



α spectroscopy

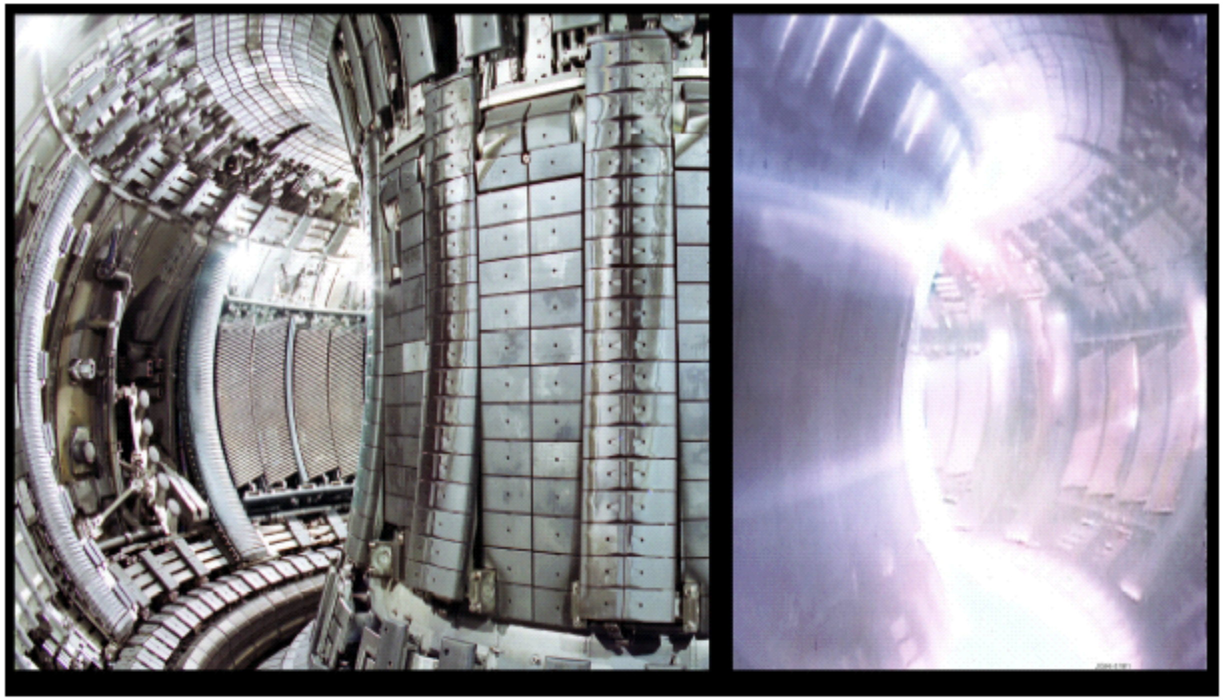

EG&G ORTEC

Activities - 1

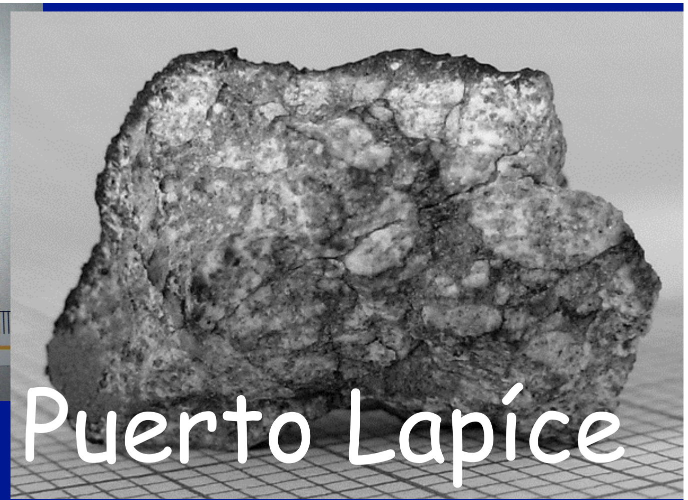
- material screening (GerDA, Borexino, CUORE, WArP, DoubleCHOOZ, Xenon)
- CELLAR: measurement of future Standard Reference Materials ("NIST Peruvian Soil, future SRM4355A") & samples from JET (Joint European Torus; fusion exp.)
- environmental radioactivity
- small fundamental physics research projects
- meteorite measurements

Use of activation technique to be able to determine the loss of charged particles from the plasma

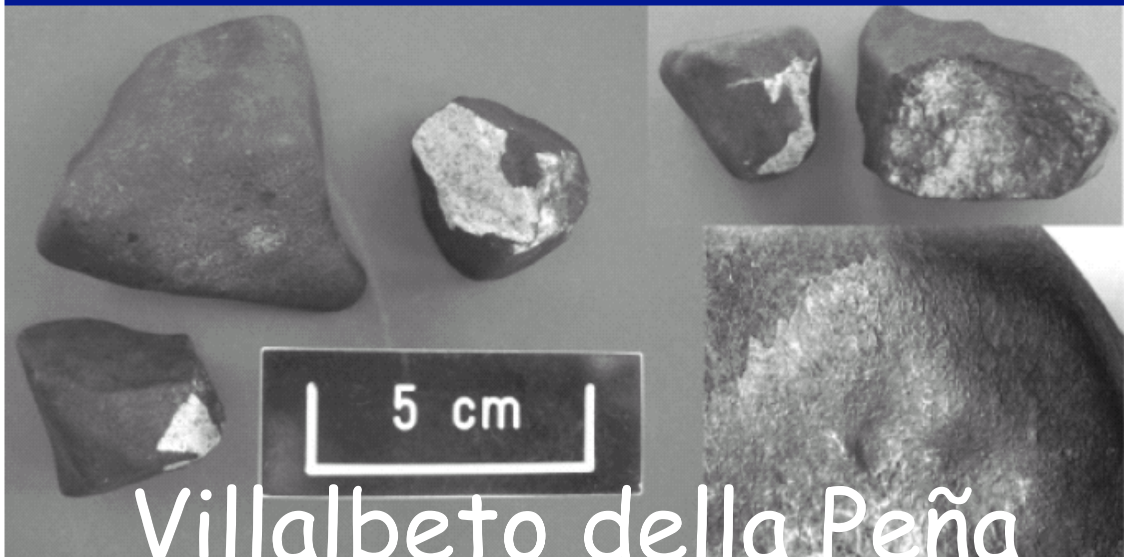
ULGS measurements : need low background due to **very low activity & small samples**.



- Analyse also short lived radionuclides like V-48 (16 d) and Sc-47 (3.4 d) and Cr-51 (28 d)
- Use 18 detectors (2 samples for one week on each detector)



MPS 44, Nr 2, 159-174 (2009)



MPS 40, Nr 6, 795-804 (2005)

Science 338, 1583-1587 (2012)

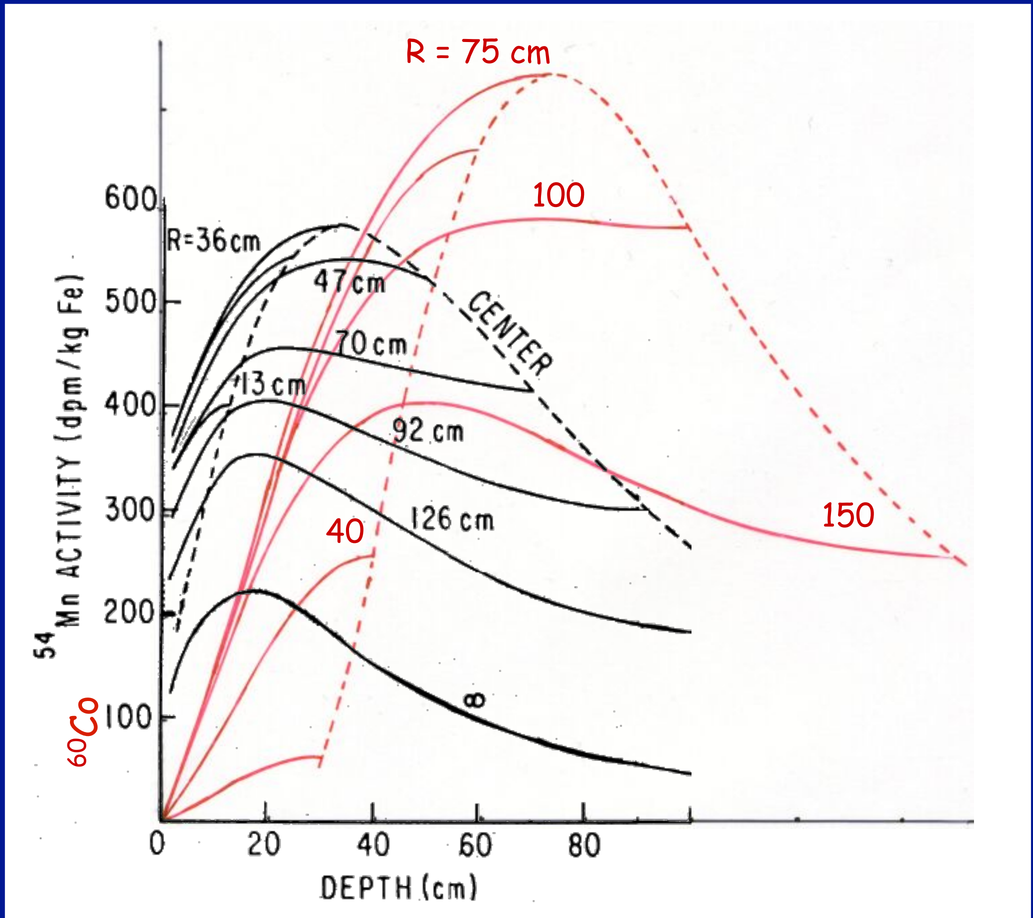
in meteorites

^{26}Al (7.16x10^5 a) β^+

^{22}Na (2.602 a) β^+

^{60}Co (5.27 a)

^{54}Mn (312.15 d)



Activities-2

As already mentioned not only γ spectroscopy is performed, but also studies on radon.

Average radon concentration in the experimental halls is in the range of (30-150) Bq m^{-3} with the ventilation working properly.

Continuous monitoring is performed with commercial radon monitors.

Moreover R&D on radioprotection equipment (bronchial dose meter) has been performed.

Physics measurements -1

- double EC in ^{136}Ce to excited levels of ^{136}Ba (Nucl. Phys. A 824 (2009) 101–114)

$$T_{1/2}(^{136}\text{Ce}, 2\varepsilon, 0\nu + 2\nu, 2392\,\text{keV}) > 2.4 \times 10^{15}\,\text{yr} \quad \text{at } 90\%\ \text{C.L.}$$

$$T_{1/2}(^{136}\text{Ce}, 2\varepsilon, 0\nu + 2\nu, 2400\,\text{keV}) > 4.1 \times 10^{15}\,\text{yr} \quad \text{at } 90\%\ \text{C.L.}$$

- 2β-decay of ^{104}Ru to excited level of ^{104}Pd (Eur. Phys. J. A 42 (2009) 171–177):

$$T_{1/2}^{2\beta^-\ (2\nu+0\nu)}(\text{g.s.} \rightarrow 556\,\text{keV}) \geq 3.5 \times 10^{19}\,\text{yr}.$$

Physics measurements - 2

- α decay $^{151}Eu \rightarrow ^{147}Pm$, E_{exc}=91.1 keV (Nucl. Instr. Meth. A572 (2007) 734–738):

  $T_{1/2} > 2.4 \times 10^{16}$ a (90% CL);

- β-decay of ^{115}In to $^{115}Sn^*$ (Nucl. Phys. A748 (2005) 333–347):

  $T_{1/2} > (3.73 \pm 0.98) \times 10^{20}$ a (90% CL);

- determination of $^3He(\alpha,\gamma)^7Be$ cross section at low energies (LUNA experiment) (Phys. Rev. C75, 035805 (2007))

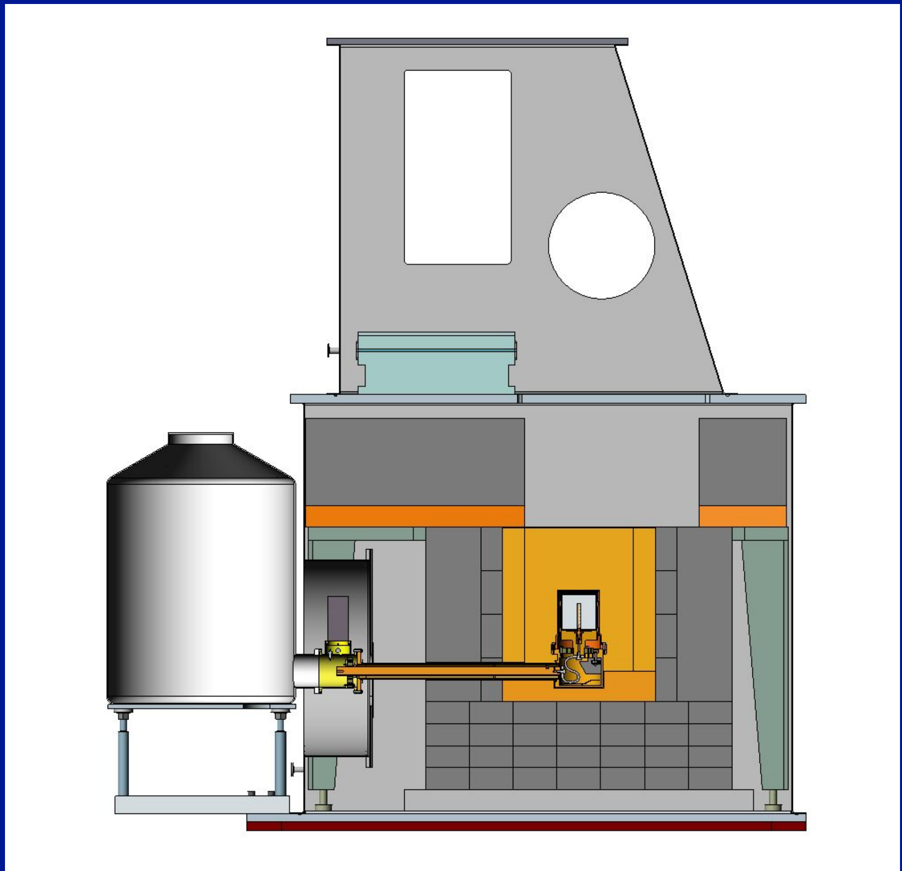
GeMPI

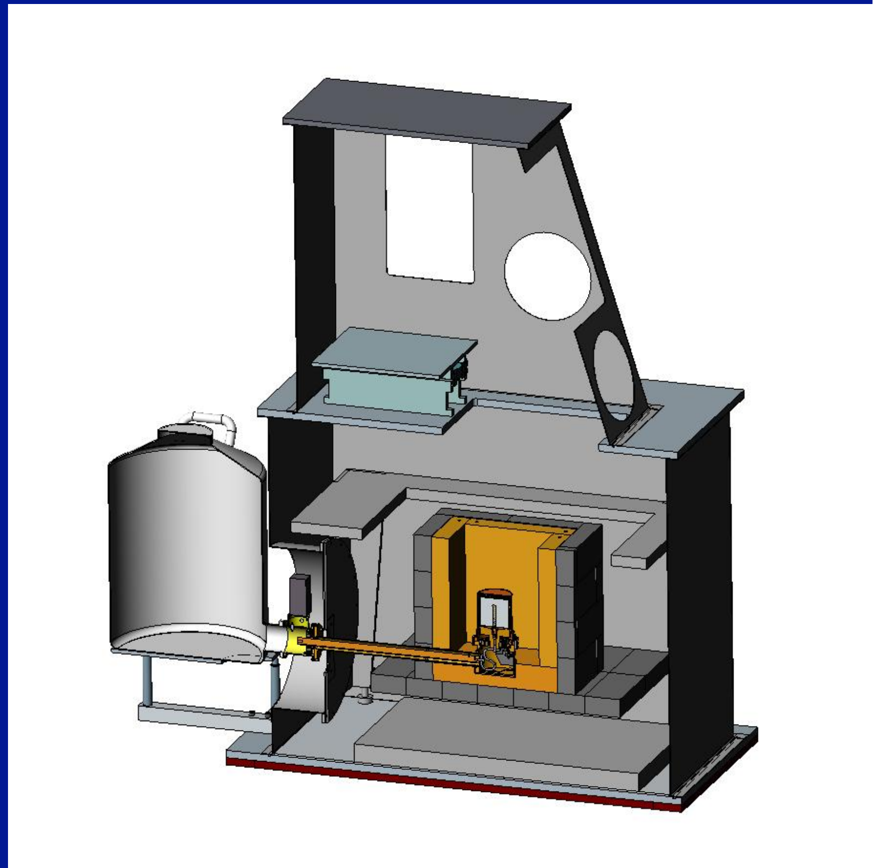
G. Heusser
B. Prokosch
H. Neder M. Laubenstein

Operated at

LNGS

(3800 m w.e.)

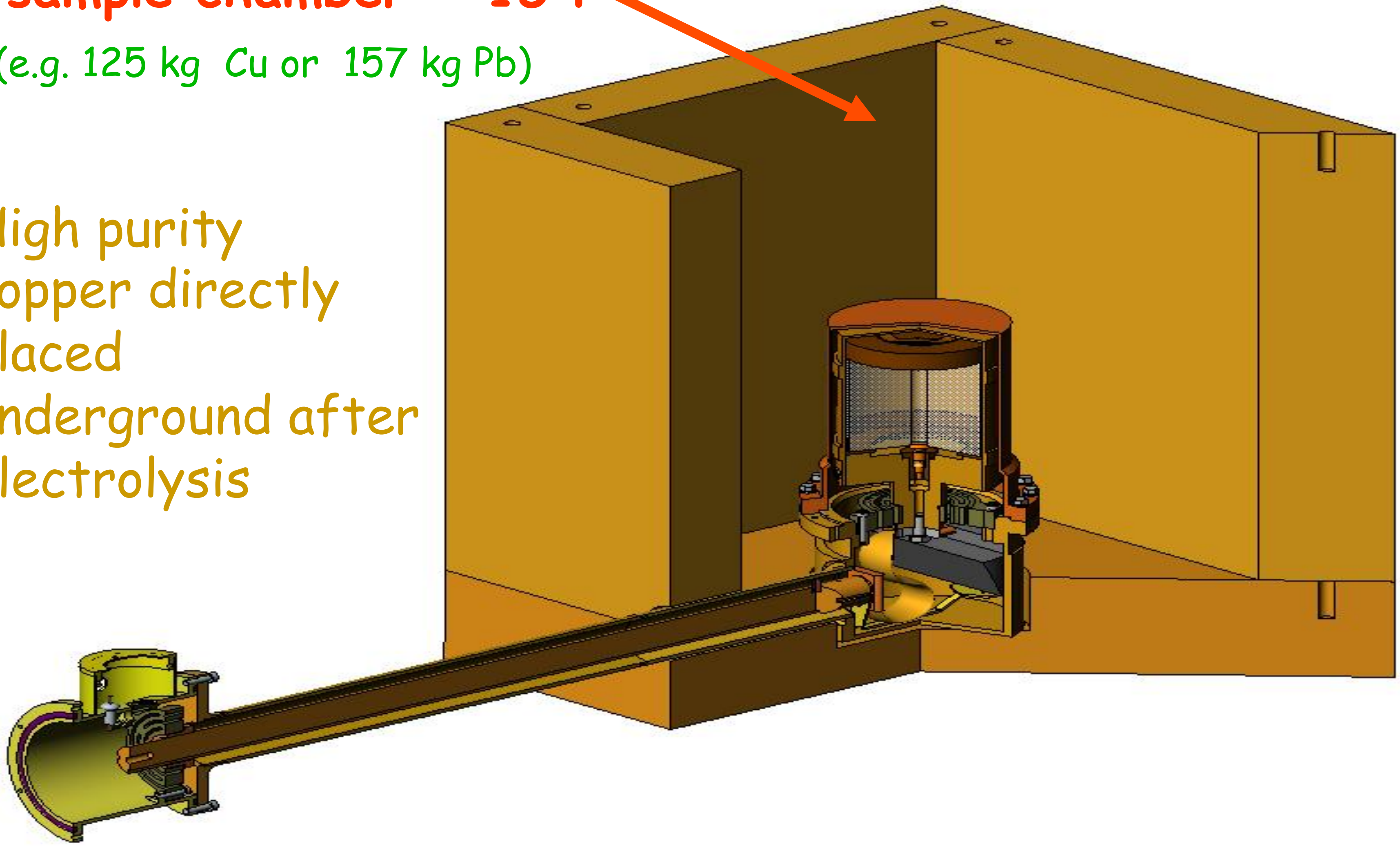




effective volume of sample chamber ~ 15 l

(e.g. 125 kg Cu or 157 kg Pb)

High purity copper directly placed underground after electrolysis



125 kg NOSV Cu for LENS measured with GeMPI

G. Heusser
M. Laubenstein

Cosmogenic* radioactivity concentrations in Cu

radionuclide cosmogenic	halflife	activity [μBq kg^{-1}] exposed (270 d)	unexposed
^{56}Co	77.31 d	230 ± 30	
^{57}Co	271.83 d	1800 ± 400	
^{58}Co	70.86 d	1650 ± 90	
^{60}Co	5.27 a	2100 ± 190	< 10
^{54}Mn	312.15 d	215 ± 21	
^{59}Fe	44.5 d	455 ± 120	
^{46}Sc	83.79 d	53 ± 18	
^{48}V	15.97 d	110 ± 40	

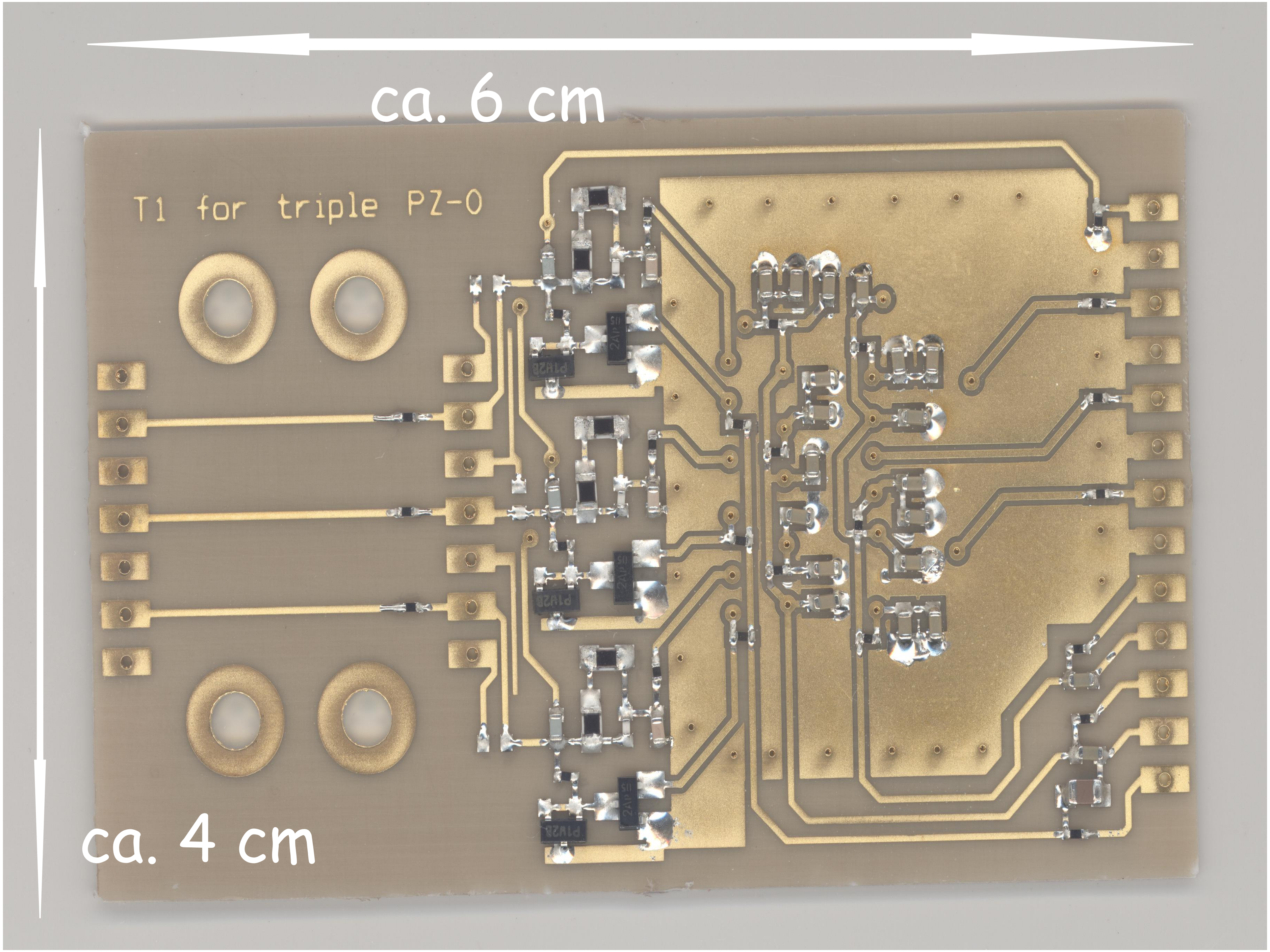
125 kg NOSV Cu for LENS measured with GeMPI

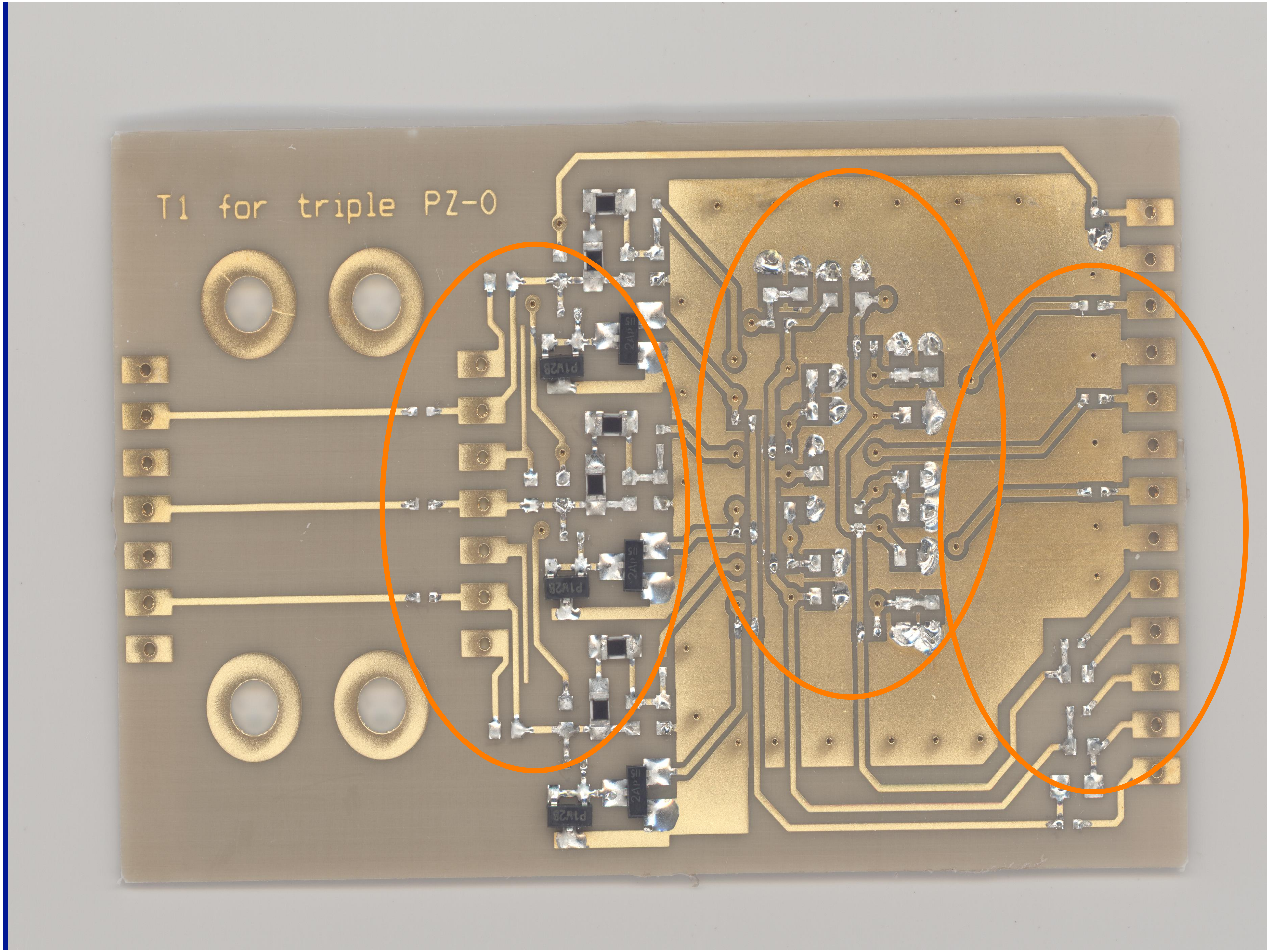
G. Heusser
M. Laubenstein

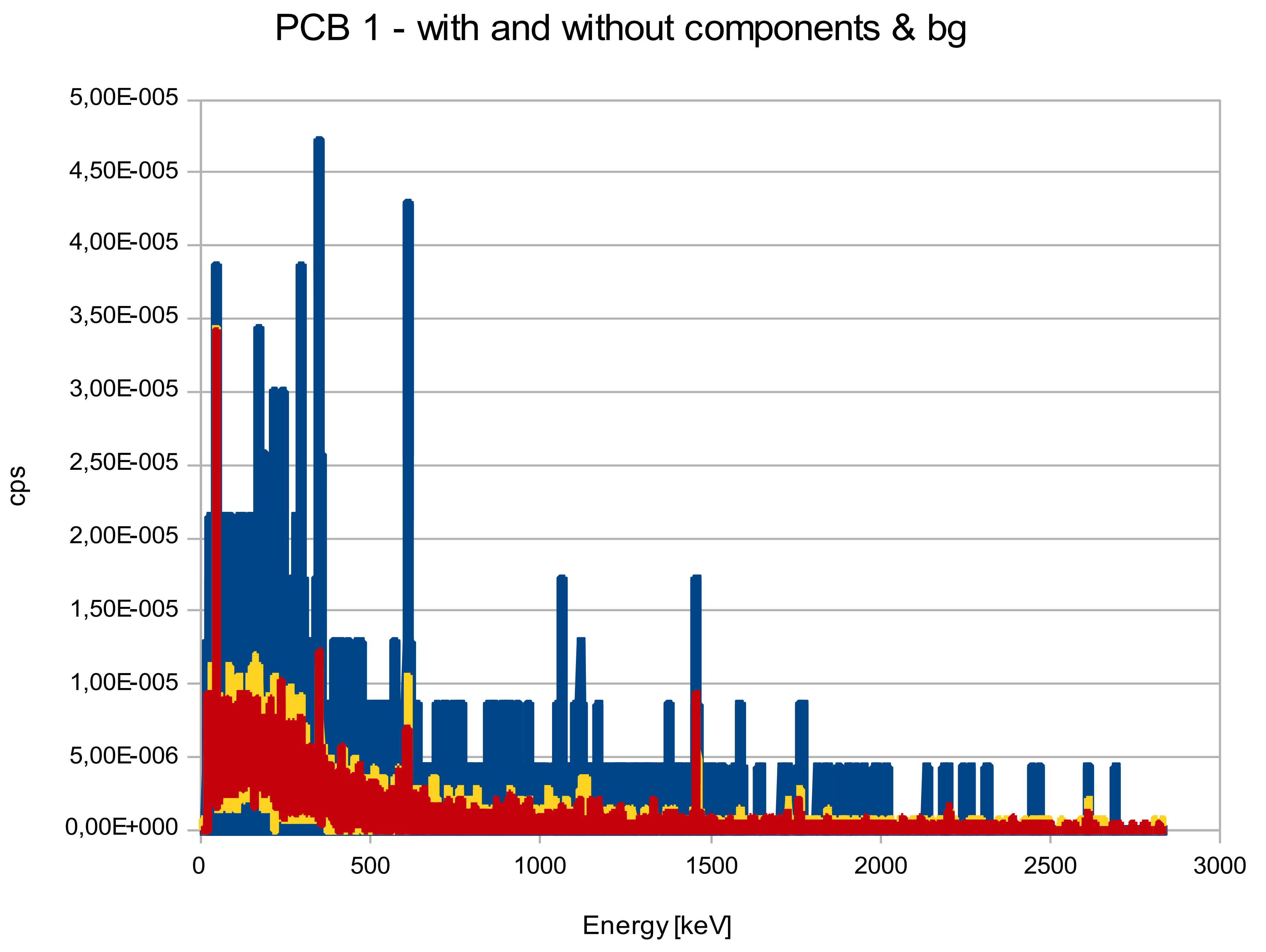
Primordial radioactivity concentrations in Cu

radionuclide	halflife	activity [μBq kg^{-1}] exposed (270 d)	activity [μBq kg^{-1}] unexposed
^{226}Ra (U)	1600 a	< 35	< 16
^{228}Th (Th)	1.91 a	< 20	< 19
^{40}K	1.277×10^{9} a	< 120	< 88


GeDSG


ca. 6 cm
T1 for triple PZ-0
ca. 4 cm


T1 for triple PZ-0



PCB 1 - with and without components & bg
5,00E-005
4,50E-005
4,00E-005
3,50E-005
3,00E-005
2,50E-005
2,00E-005
1,50E-005
1,00E-005
5,00E-006
0,00E+000
cps
0
500
1000
1500
2000
2500
3000
Energy [keV]

Conclusions

New research applications

- Particle Astrophysics (material and techniques applicable to DM search)
- Space Science (e.g. micro meteorites, Mars samples, cosmic activation products, comet tail samples)
- Atmospheric samples (short lived isotopes, radionuclide composition)
- Ocean samples (deep ocean water - ^{60}Fe)
- in general possible application of low background techniques to interdisciplinary fields

Further "necessary" Improvements - 1

- more sensitive screening techniques (< μBq/kg for ^{226}Ra) ⇒ use of today's (e.g. CTF) or tomorrow's (e.g. GERDA) most sensitive detectors for screening

- dedicated and highly sensitive screening and test techniques for measuring and monitoring *surface* contaminations

Further "necessary" Improvements - 2

- reorganization and optimization of existing screening facilities is necessary, because they are costly and measurement times can be rather lengthy

- harmonization of how to report data and intercomparison programs for ultra low-level measurement techniques further possible improvements:

- improved neutron shields
- improved material selection
- active shielding
- going deeper underground
- storage of freshly made construction materials underground
- multi-segmented crystals or multiple crystals
- collaboration with producers (e.g. depleted Ge, crystal growing, Cu electroforming underground)