STELLA: THE FACILITY FOR LOW BACKGROUND TECHNIQUES AT LNGS

STELLA = SubTErranean Low Level Assay

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CoEPP-CAASTRO Workshop
29, 30 September 2014
Melbourne, Australia

INTRODUCTION

Particle physics experiments searching for rare events such as neutrino interactions, neutrinoless double beta decay and dark matter, have to fight against background of different origin

- cosmic radiation → Experiments must be located underground/ underwater (ice)
- environmental background → Shielding, veto
- intrinsic natural radioactivity of the experimental setup → low-level background techniques and instrumentation

BACKGROUND SOURCES FOR AN UNDERGROUND SITE

- cosmic ray muons;
- neutrons (muon-induced, radioactivity-induced, fission)
- gammas;
- radon;

depth [km w. e.]

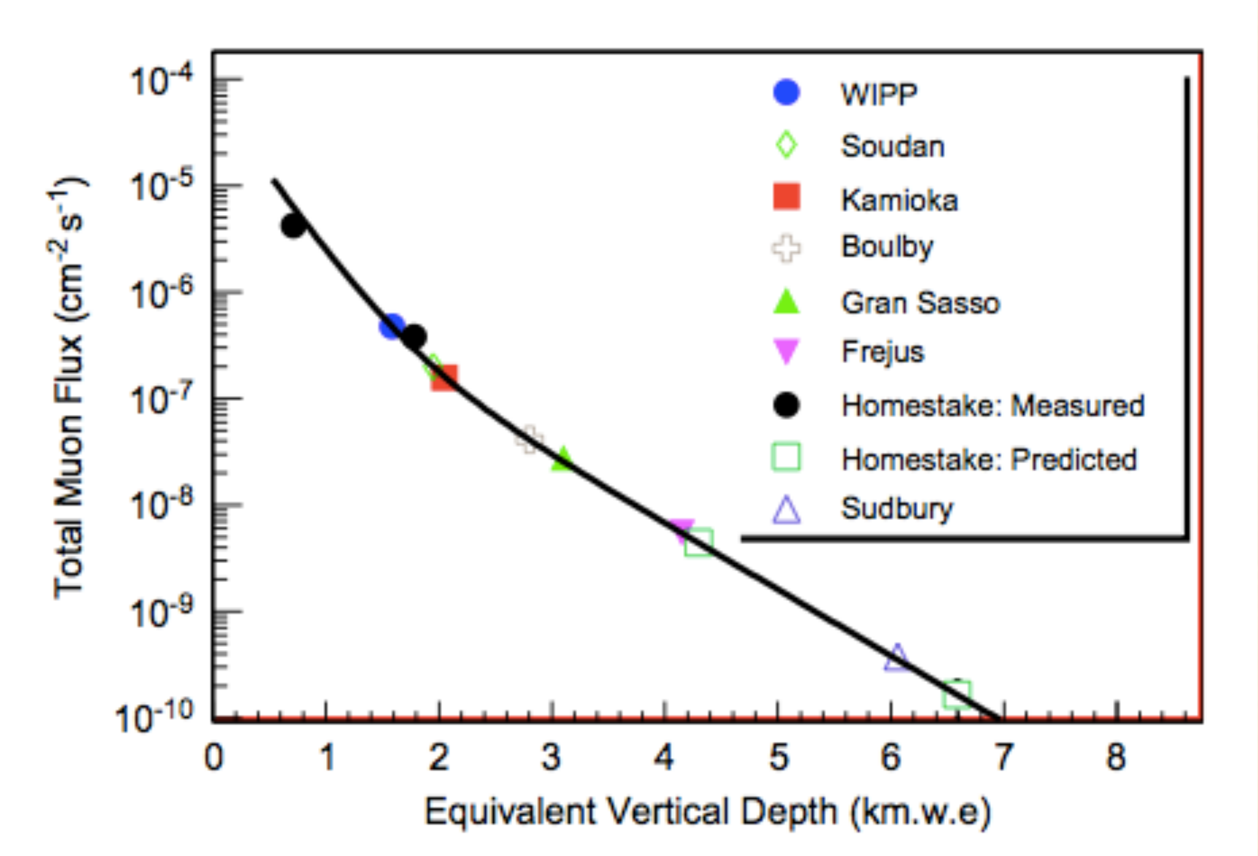
rock composition
geology

COSMIC RAY MUONS

D.-M. Mei, A. Hime, Phys. Rev. D 73 (2006) 053004, astro-ph/0512125

muon flux @ LNGS:

- measured by MACRO and LVD experiments
- 3.2×10^{-8} $\mu/(cm^2 \cdot s)$
- $E_\mu = 270$ GeV
- 10^6 reduction wrt surface



- the flux of high-energy muons induced by cosmic rays interactions decreases as depth increases while the angular dependence is due to the surface profile

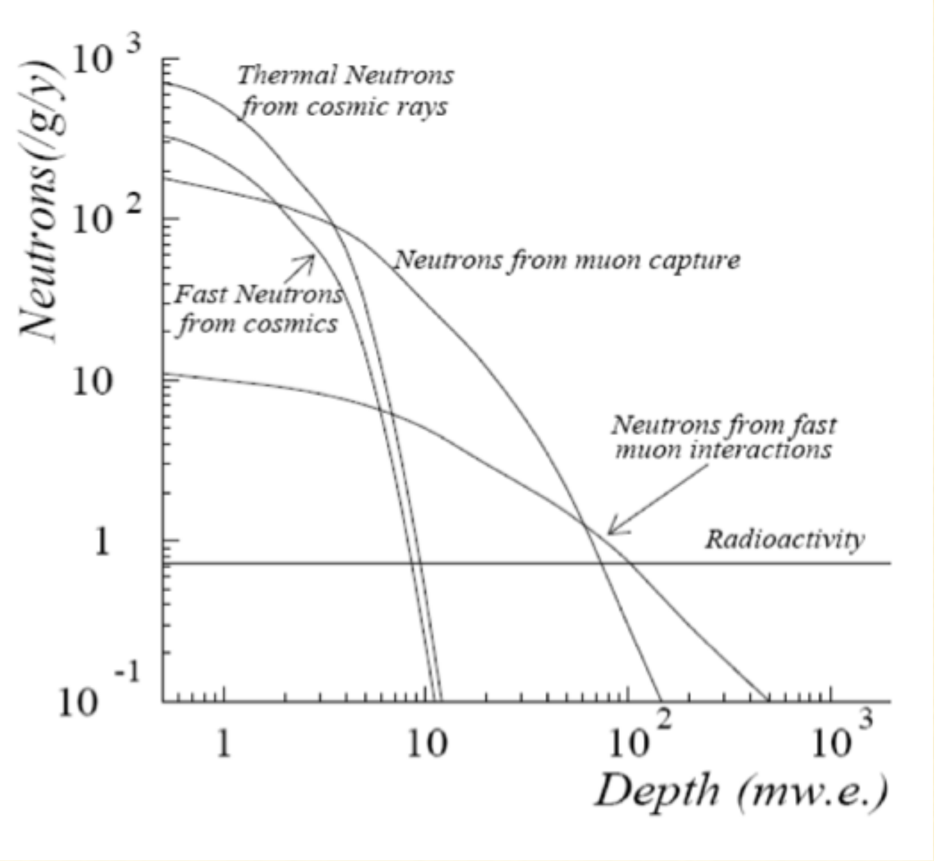
UNDERGROUND NEUTRONS

Underground neutron flux @ LNGS:

- ~ 3×10^{-6} n/s/cm^2 (< 10 MeV)

- low energy neutrons (from thermal to about 10 MeV) are generated by spontaneous fission (the most important source being U) and (α,n) processes due to interactions of α's from natural emitters with light target nuclei in the rock.

- Both contributions depend on the site and are independent on depth;

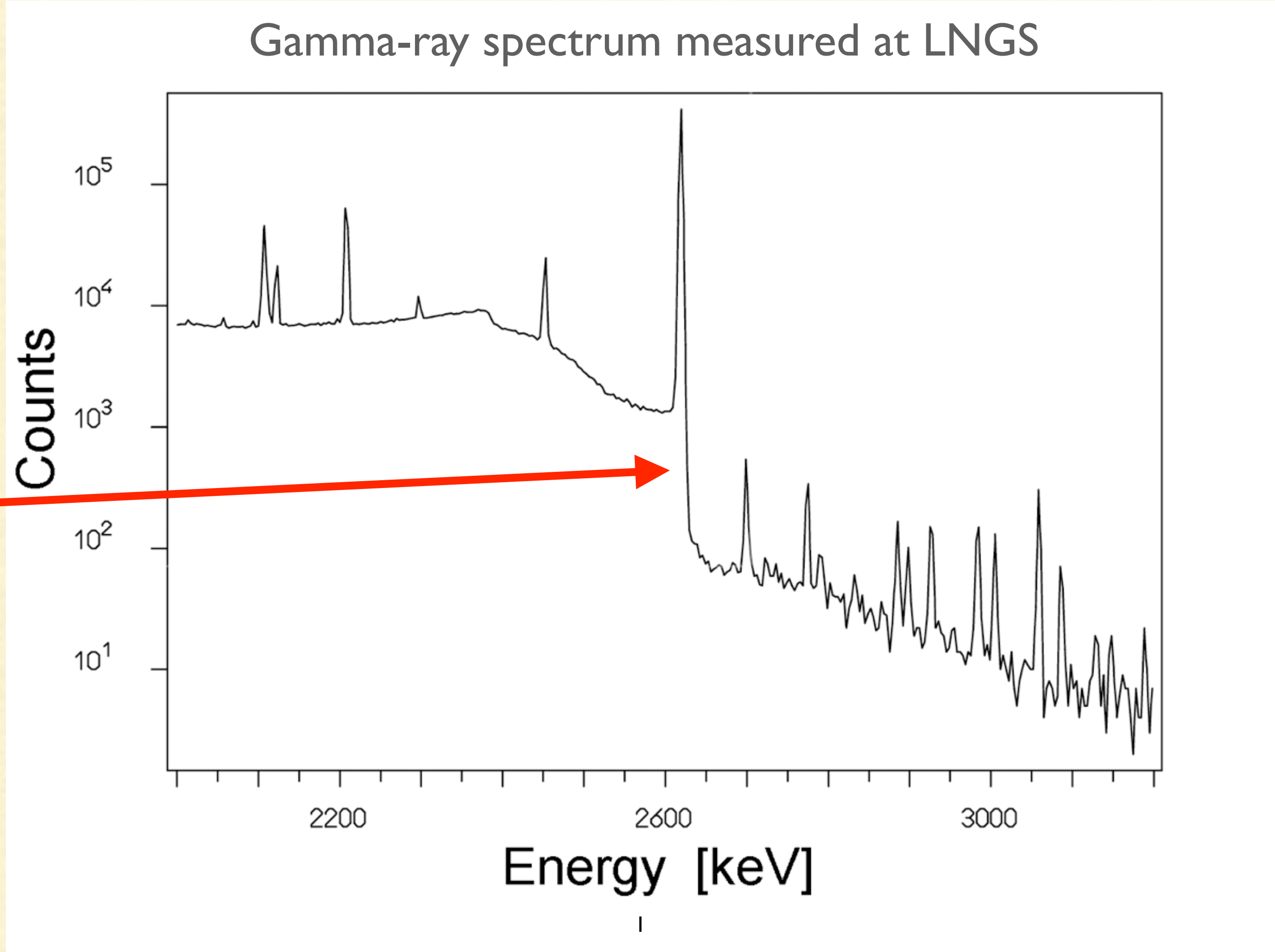


F. E. Gray, Nuclear Instruments and Methods in Physics Research A638 (2011) 63–66

- high energy neutrons (up to GeV) are generated by muon spallation processes. This contribution is related to the site depth. Can be estimated by simulations (3 orders of magnitude lower than environmental neutrons).

GAMMAS

- gammas from natural radioactivity of the rock: spectrum ends at the energy of the ^{208}Tl line from ^{232}Th decay chain (2614 keV);
- gammas from muons and neutrons interactions in the rock or other materials;



- concrete covering the walls of the experimental halls and other materials around the detector such as supports, shielding, electrical connections, etc… contribute to the radioactive background;

ROCK PROPERTIES

Gran Sasso rock consists mainly of $CaCO_3$ and $MgCO_3$, with a density of 2.71 ± 0.05 g/cm^3

	H	C	O	Na	Mg	Al	Si	P	S	K	Ca	Ti	Fe
Rock	-	11.88	47.91	-	5.58	1.03	1.27	-	-	1.03	30.29	-	-
Concrete	0.89	7.99	48.4	0.60	0.85	0.90	3.86	0.04	0.16	0.54	34.06	0.04	0.43

U/Th content in rock

	^{238}U (ppm)	^{232}Th (ppm)
Rock Hall A	6.80	2.167
Rock Hall B	0.42	0.062
Rock Hall C	0.66	0.066
Concrete	1.05	0.656

- radon concentration in the air depends on local geology, but increases in closed halls. This can only be attenuated by proper ventilation;

LOW BACKGROUND TECHNIQUES

Besides building the experiments in a deep underground site, extremely low-level background techniques and instrumentation are an essential requirement.

- Fundamental topics common to most experiments are:
  - selection of radiopure materials
  - techniques for shielding against environmental backgrounds - purification techniques
- This is the main motivation for a Low Background Techniques Laboratory

MATERIAL SCREENING: ASSESSING RADIOPURITY

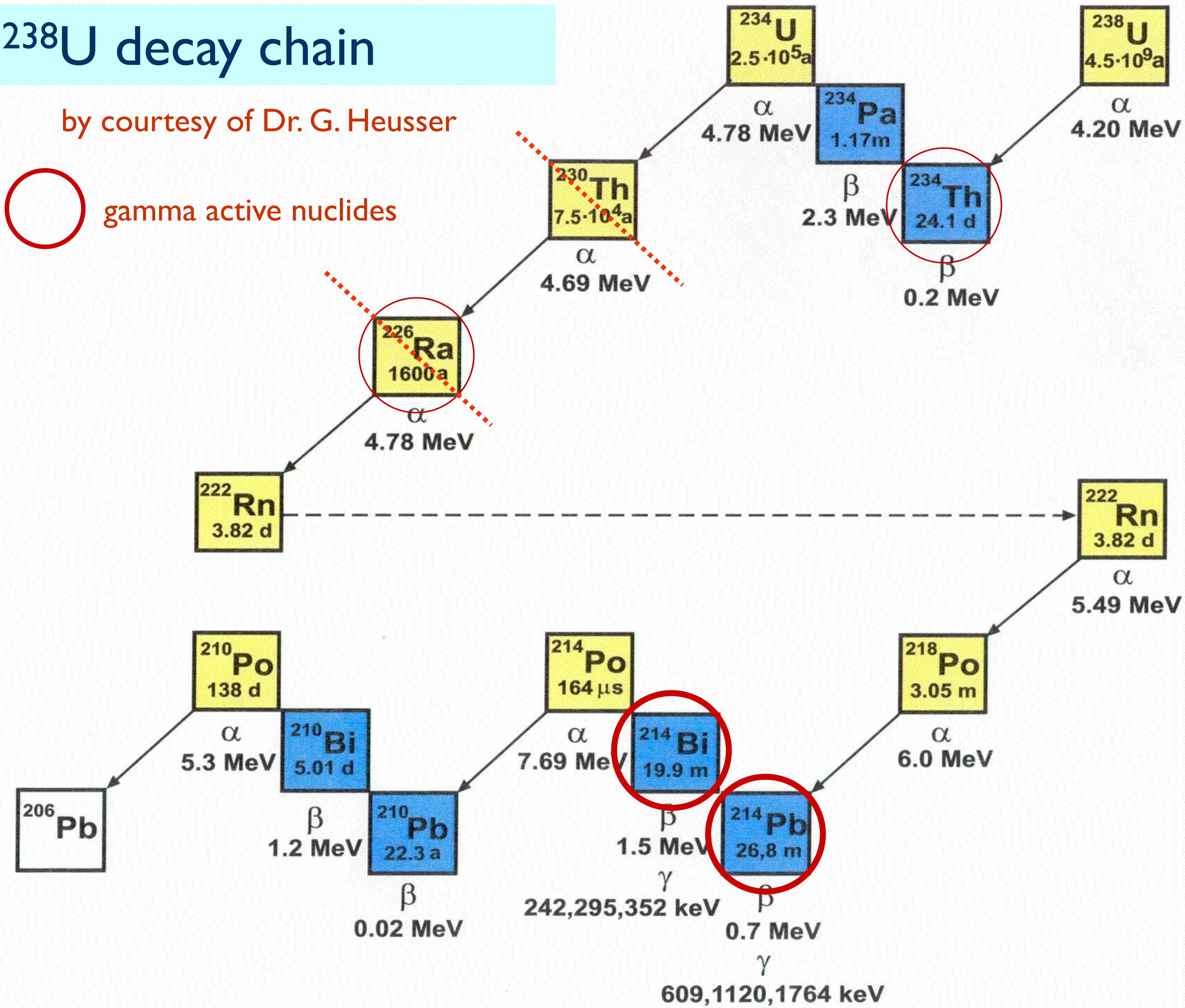
Main contaminations, common concern to all underground experiments:

- ^{238}U, ^{232}Th decay chains (naturally occurring)
- ^{40}K (naturally occurring)
- cosmogenic isotopes (produced by cosmogenic activation)
- Radon

^{238}U decay chain

by courtesy of Dr. G. Heusser

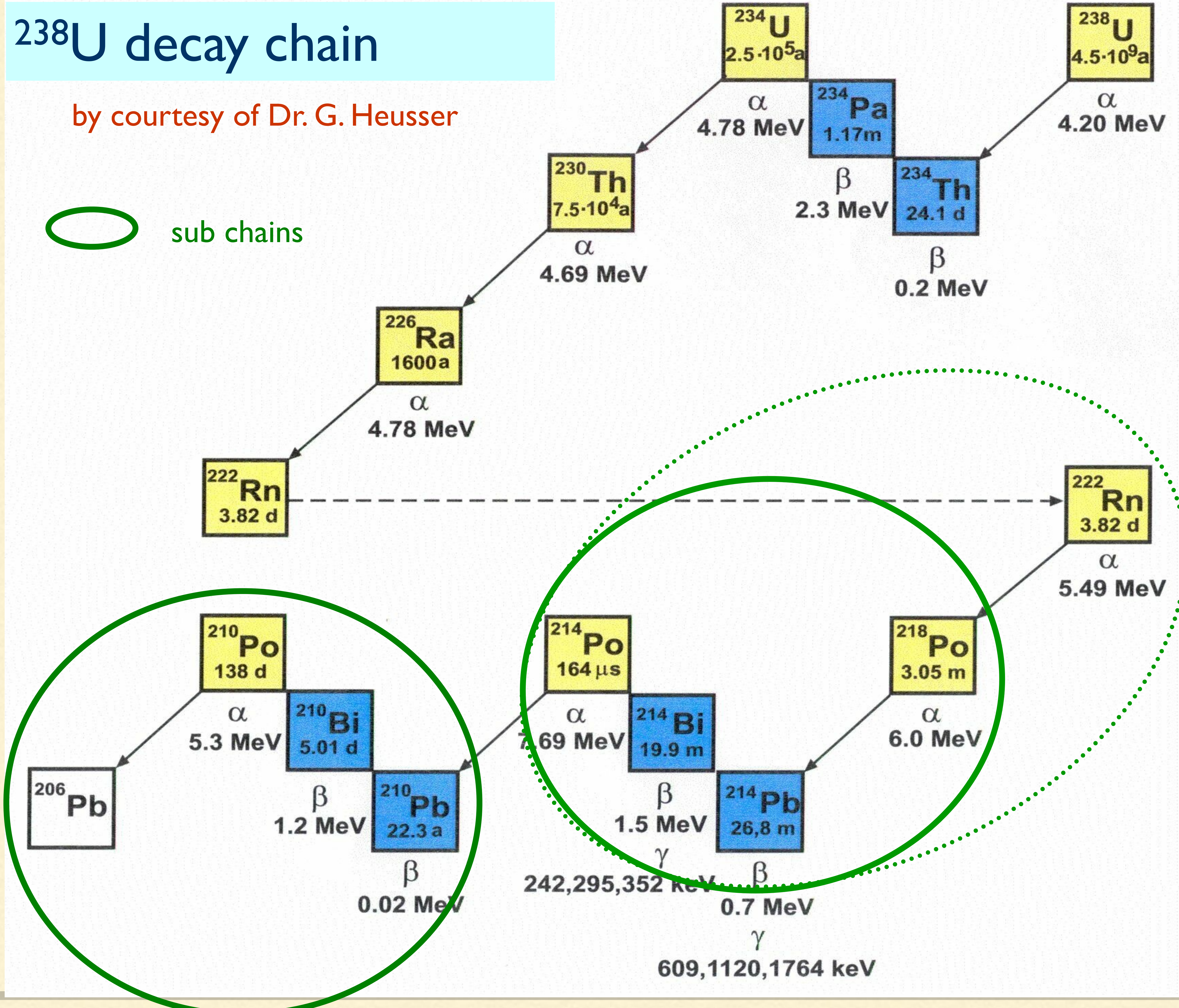
gamma active nuclides



^{238}U decay chain

by courtesy of Dr. G. Heusser

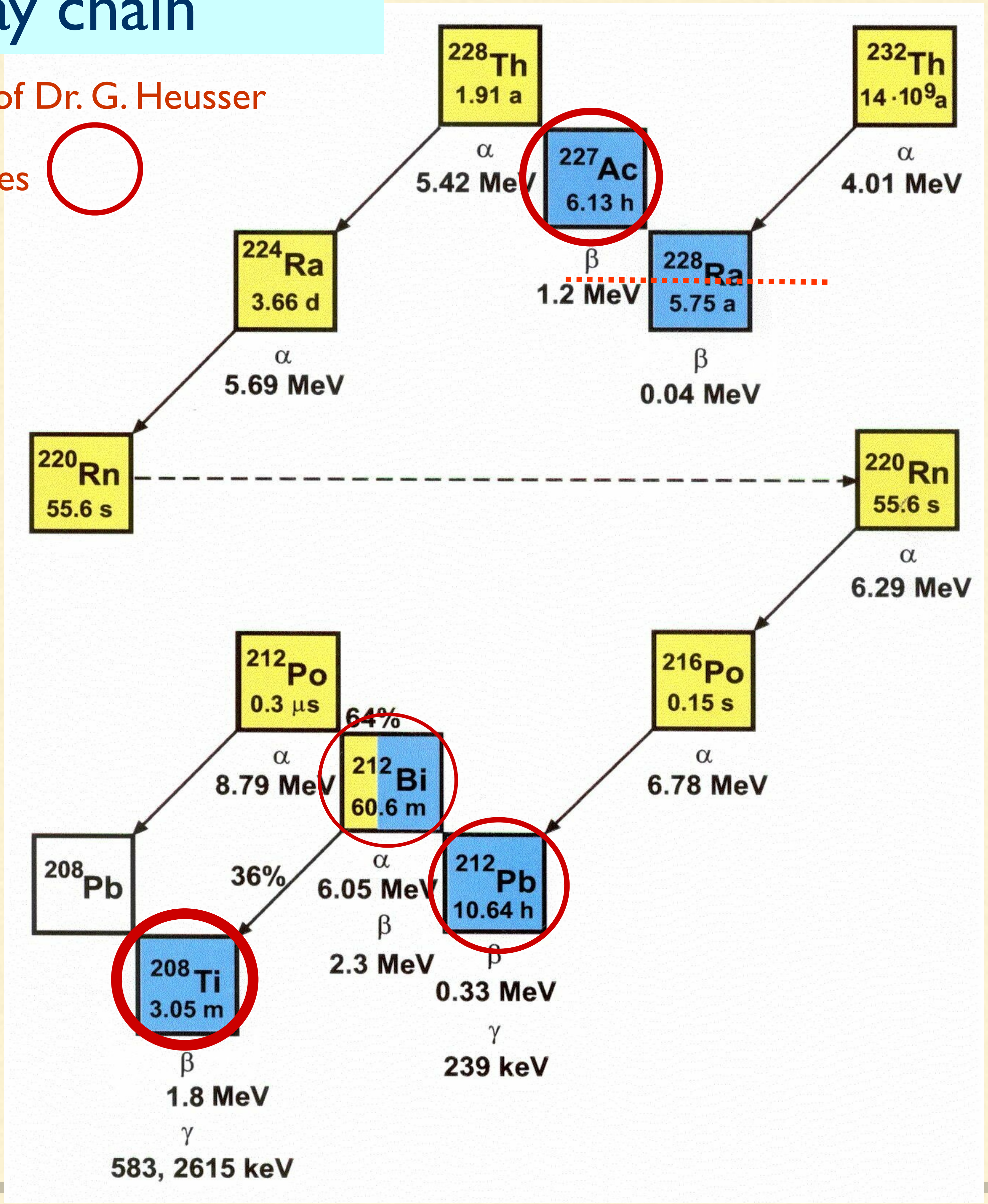
sub chains



^{232}Th decay chain

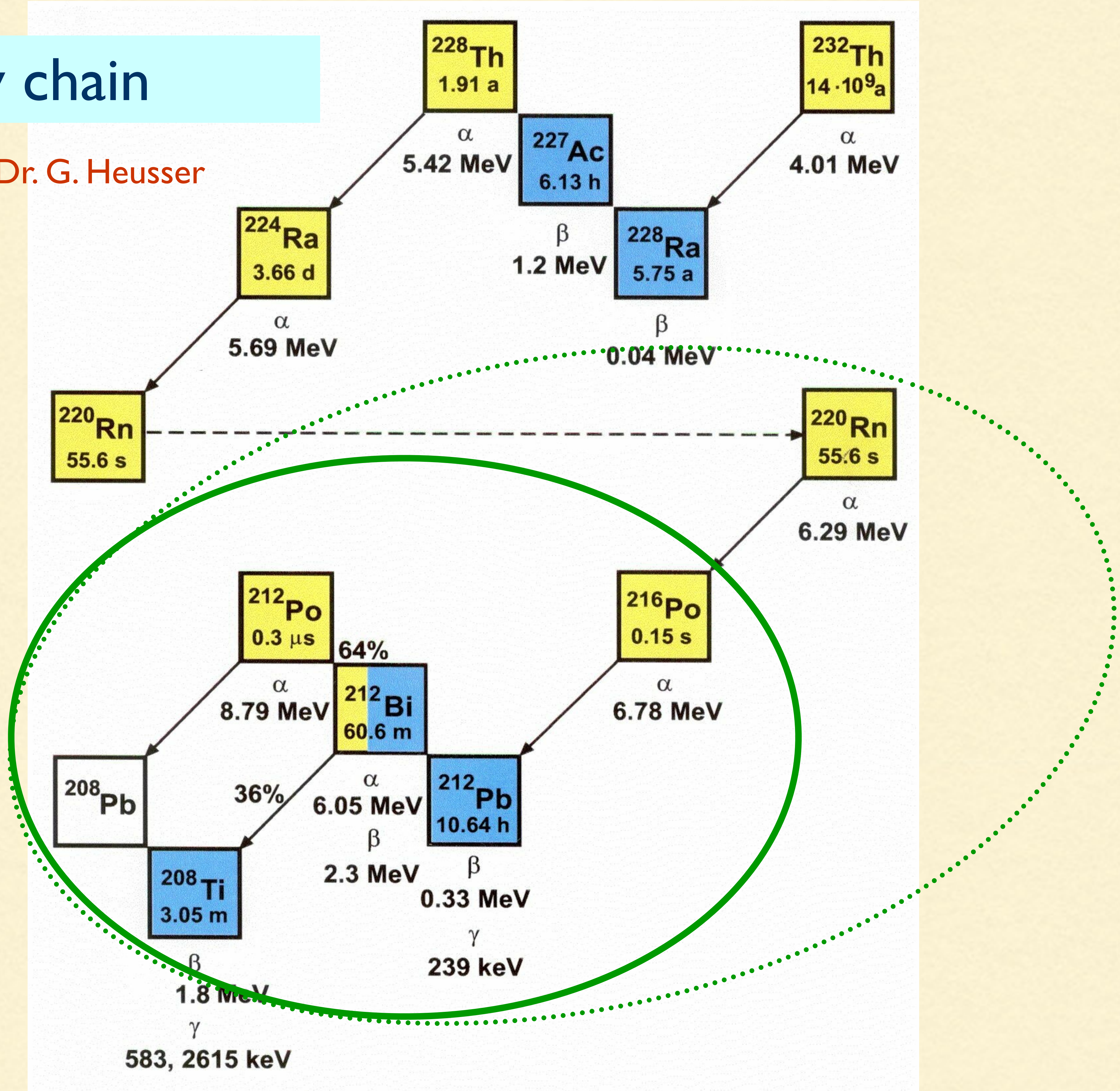
by courtesy of Dr. G. Heusser

gamma active nuclides



^{232}Th decay chain

by courtesy of Dr. G. Heusser



RADIOASSAY TECHNIQUES

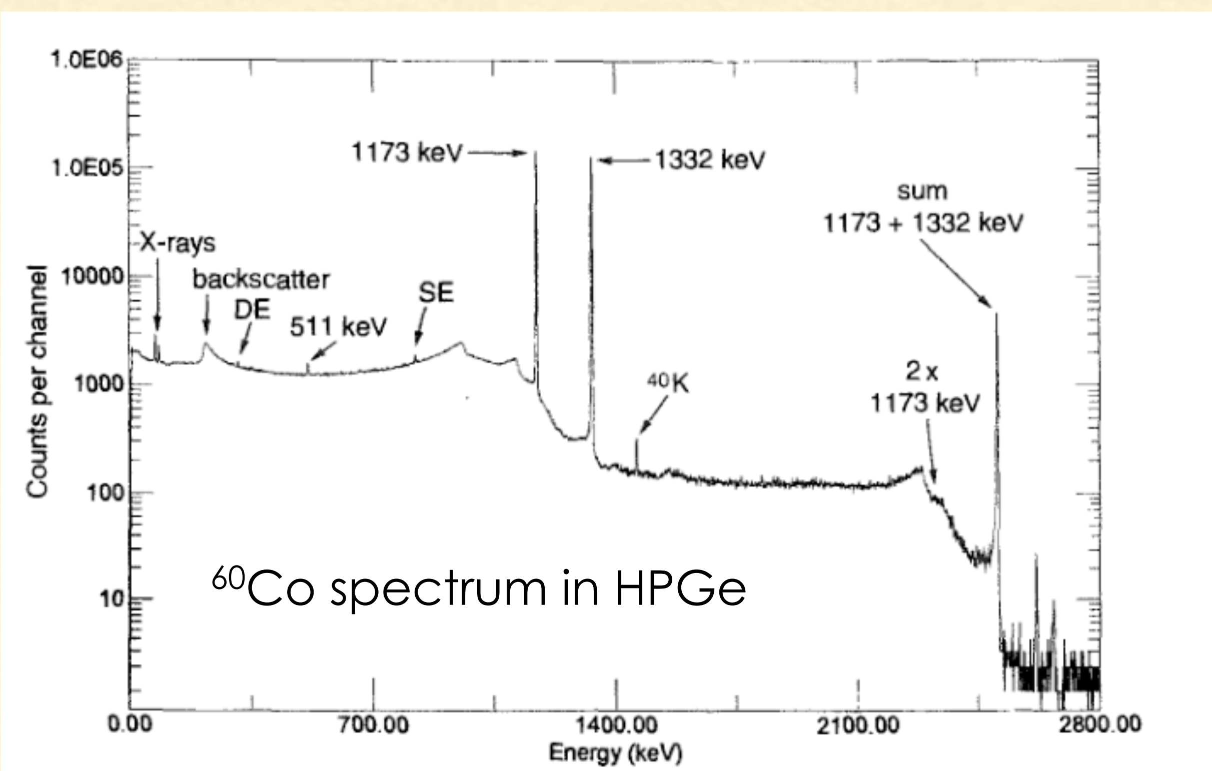
Ge-spectroscopy	gamma emitting nuclides	10-100 µBq/kg
Rn emanation assay	226	0.1-10 µBq/kg
neutron activation analysis	primordial parents	0.01 µBq/kg
liquid scintillation counting	alpha,beta emitting nuclides	1 mBq/kg
mass spectrometry (ICP-MS, AMS)	primordial parents	1-100 µBq/kg
AES + AAS analysis	primordial parents	1-1000 µBq/kg
X-Ray Fluorescence	primordial parents	10 mBq/kg
alpha spectroscopy	α emitting nuclides	1 mBq/kg

difficult to compare because each method has its special application

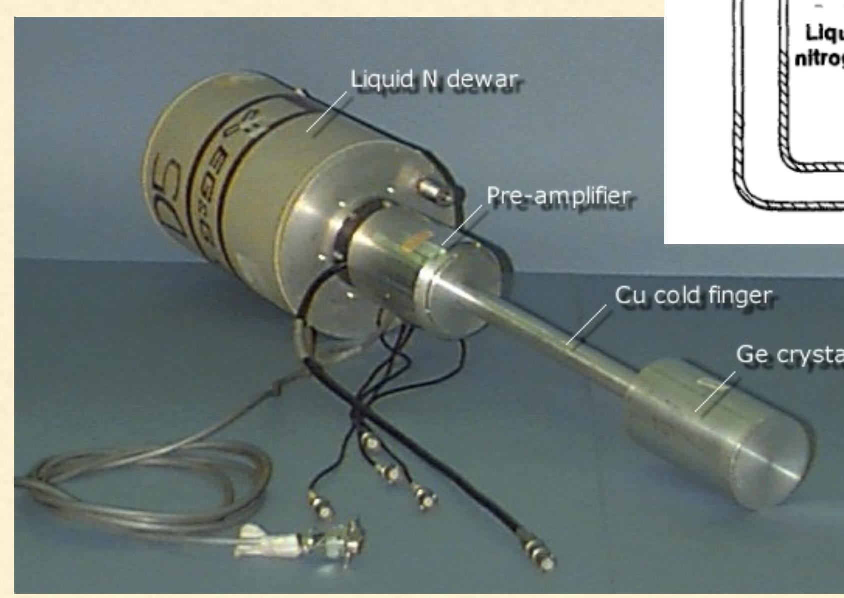
GE SPECTROSCOPY

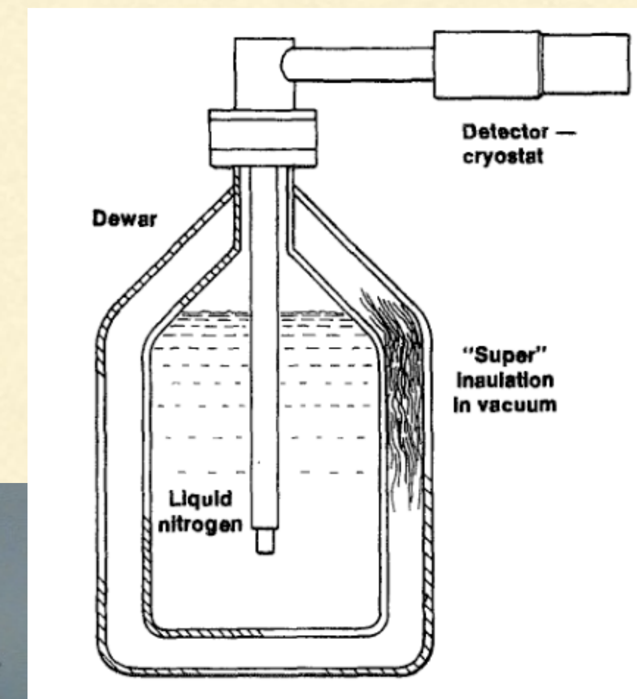
- High Purity germanium (HPGe) detectors
- sensitive to gammas
- excellent energy resolution over a broad energy region
- needs counting times from several weeks to several months

work @
LN temperature



^{60}Co spectrum in HPGe





STELLA - LOW LEVEL LAB

8 (+3) HPGe detectors working

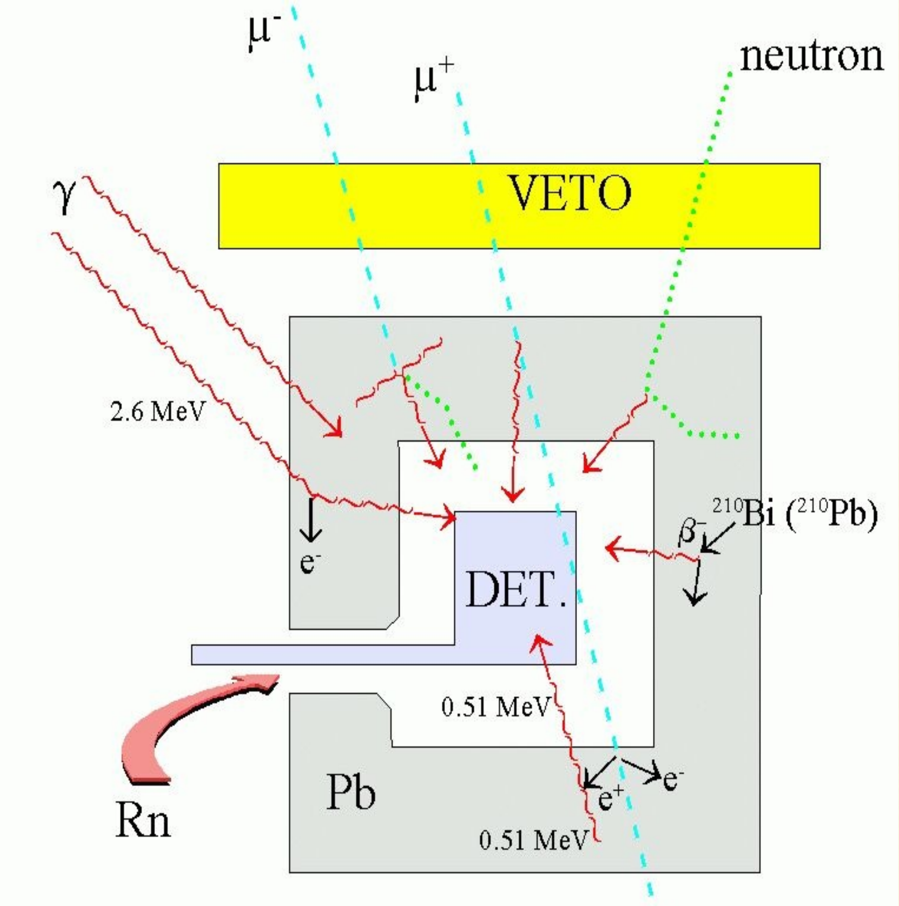
Shielding:
20 cm low activity lead
(^{210}Pb < 20 Bq/kg)
5 cm OFHC copper
5 cm acrylic and Cd foil on the bottom

Rn-suppression:
1 cm acrylic cover with continuous N2 flow

Material selection:
highly radiopure, (almost) no activation

BACKGROUND COMPONENTS IN GE SPECTROMETRY

- external gamma radiation (2.6 MeV)
- 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

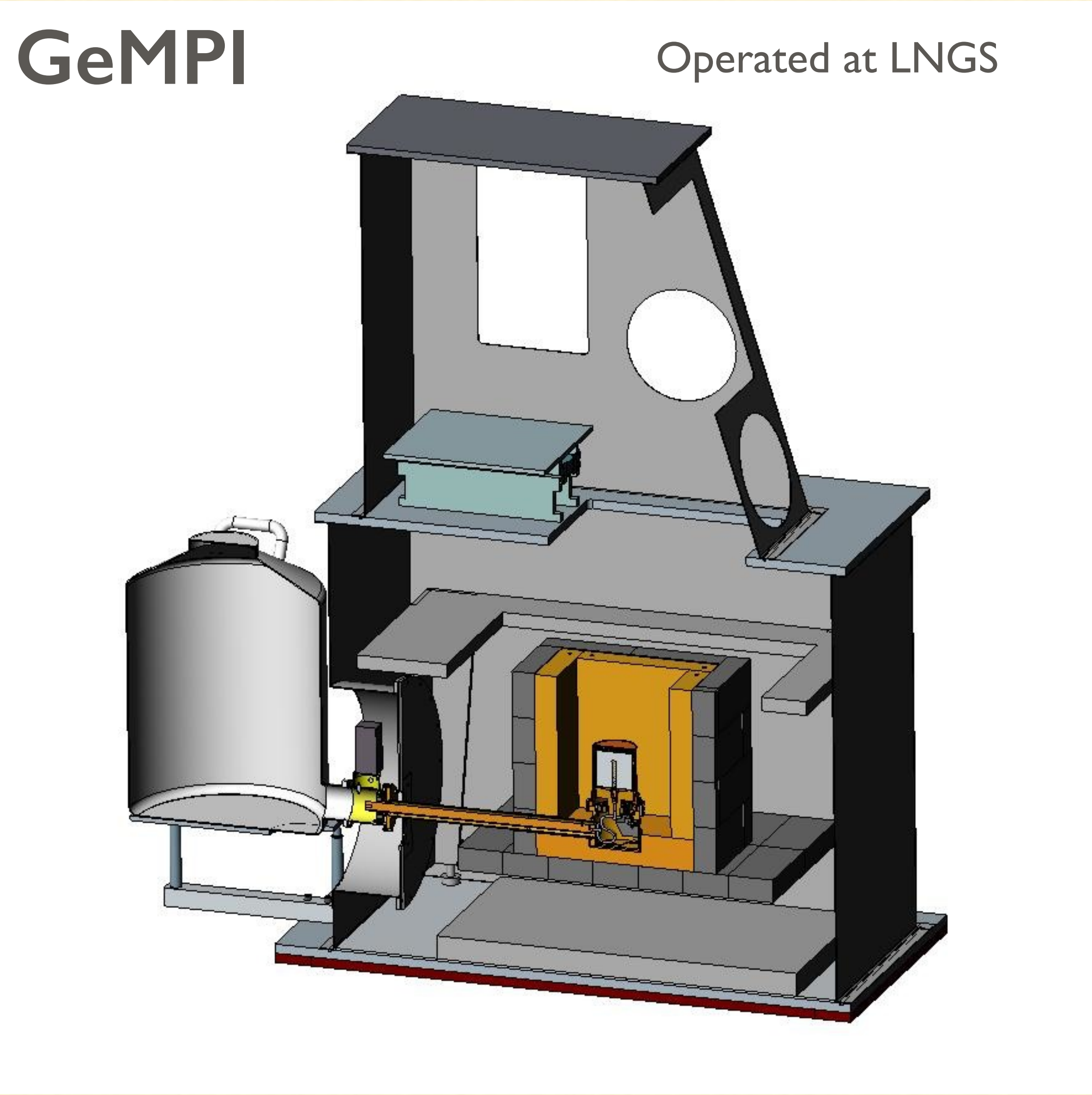
most important: material screening

U/Th chains and K dominant from Bq/kg down to μBq/kg
only reliably radiopure material - Cu – but mBq/kg cosmogenics

improvements in iterative steps

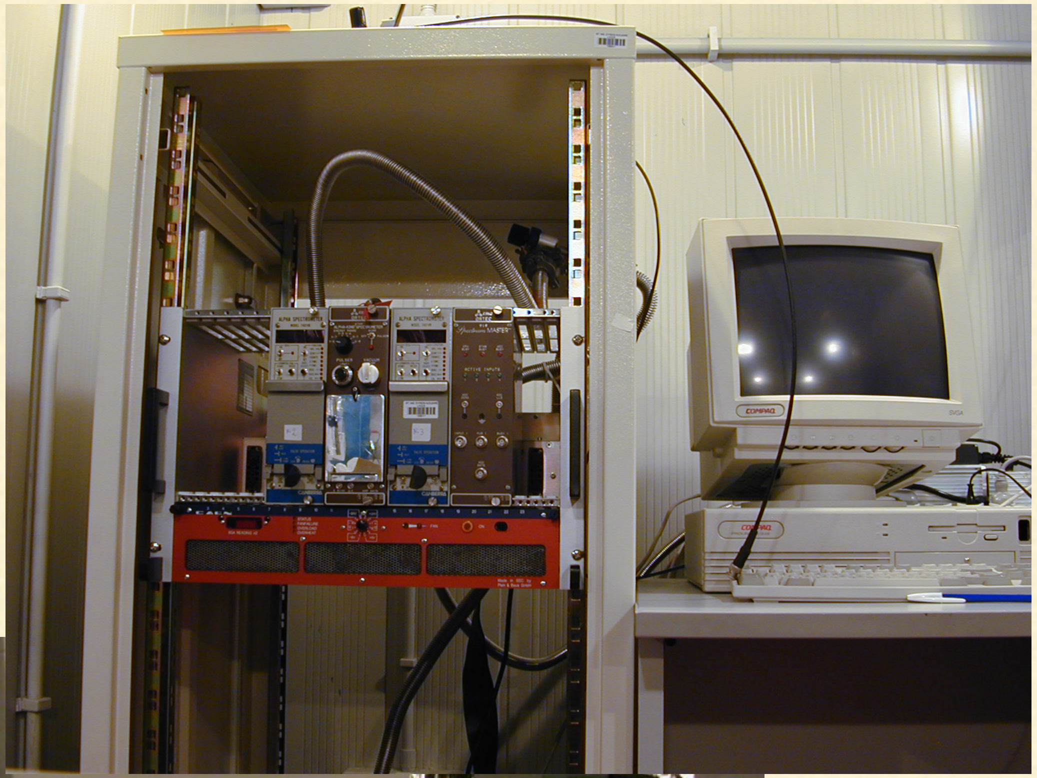
ULTRA LOW-LEVEL GAMMA SPECTROSCOPY

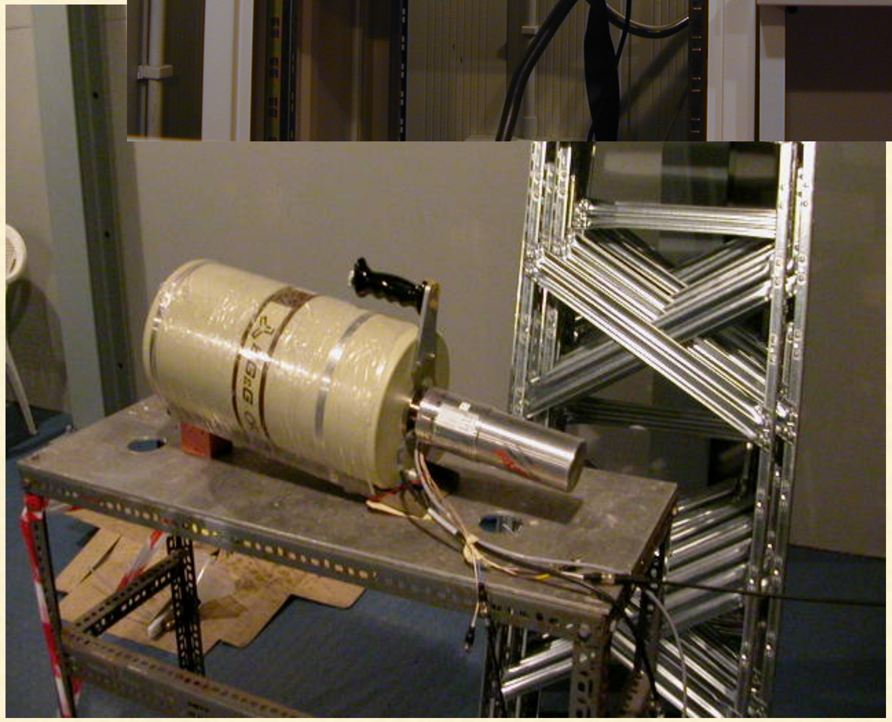
- low-level γ-spectroscopy with additional background reduction by using active shields, material selection and/or underground laboratories;
- Radon suppression, also during sample insertion is achieved by an air-lock system combined with an airtight steel casing around the shield, which is pressurised with nitrogen gas;
- large sample capacity of up to 15 l



OTHER TECHNIQUES

- alpha spectroscopy with silicon PIPS detectors
- alpha/beta spectroscopy with a liquid scintillation counter
- portable detectors





SPECIAL TECHNIQUES SERVICE

The Special Techniques service is in charge of the following activities:

- development of detection techniques for low-level radioactivity and rare nuclear processes;
- measurement of building and construction materials as regards their content of natural radioactivity;
- measurement of natural radioactivity in environmental samples;
- support to the experiments on usage and maintenance of vacuum systems, dilution refrigerators and helium liquefiers;

COLLABORATION WITH OTHER LNGS SERVICES

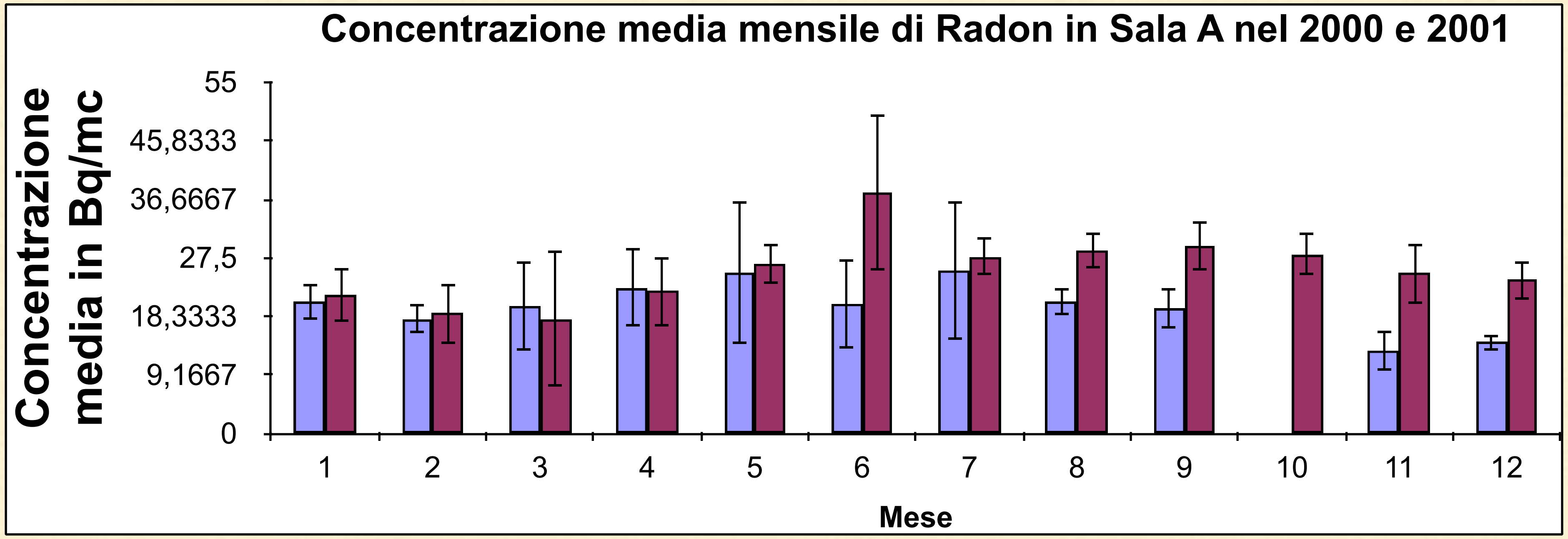
- Service for Safety Procedures (active radon monitoring in the underground laboratories in addition to passive routine monitoring)
- Radiation protection expert
- Chemical Service (collaboration for optimising the measurements results, synergy between ICP-MS and γ spectroscopy)

ACTIVITIES-1

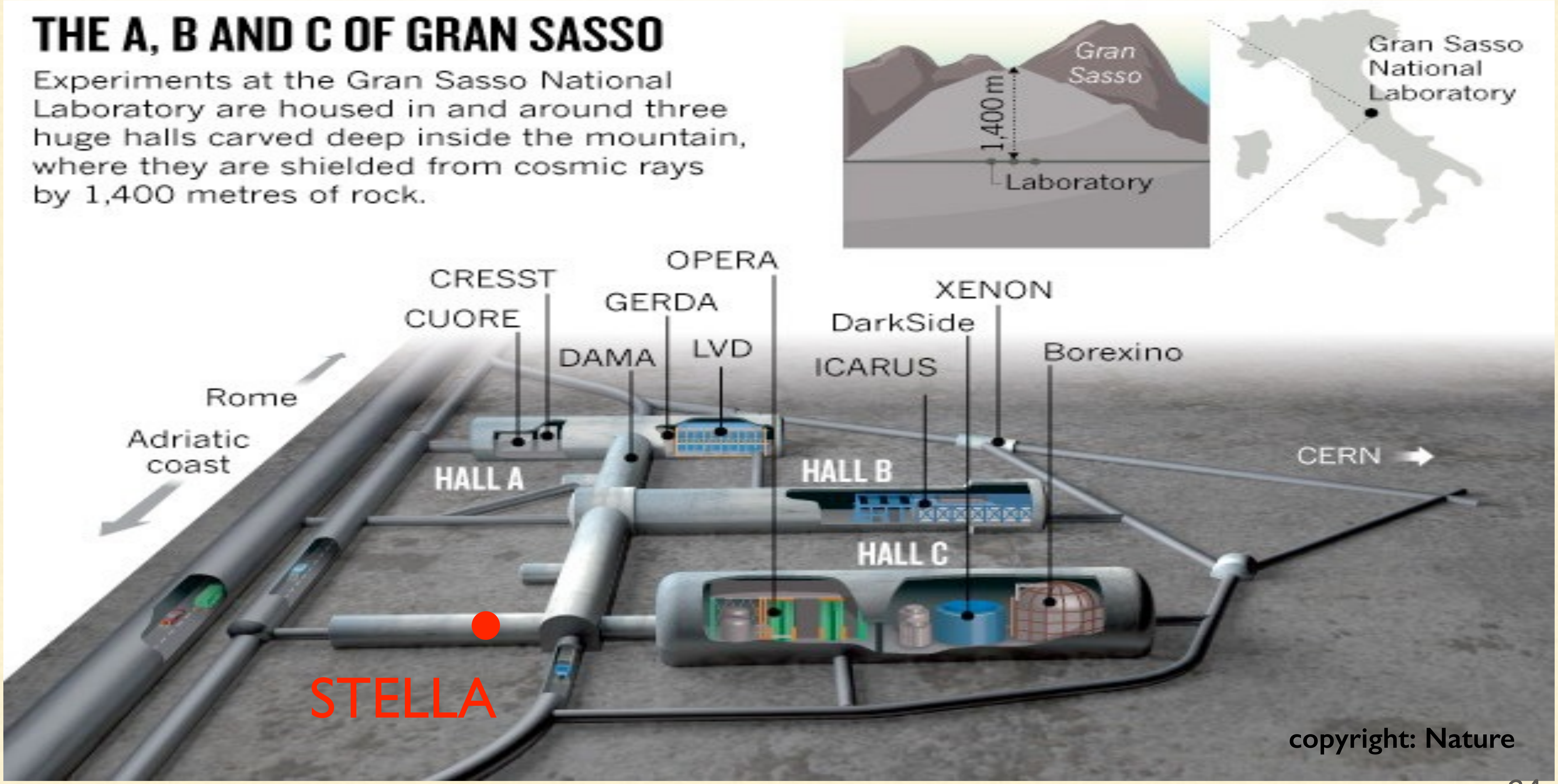
- material screening for LNGS experiments
- CELLAR (network of european low level underground laboratories) for measurement of future Standard Reference Materials ("NIST Peruvian Soil, future SRM4355A") & samples from JET (Joint European Torus; fusion exp.)
- environmental radioactivity (ERMES, Univ. AQ, Univ. FI)
- small fundamental physics research projects (ARMONIA, DAMA, KINR)
- meteorite measurements (Jesenice (Slovenia), Maribo (Denmark), Bunburra Rockhole (Australia), Carancas (Peru), Berduc (Argentina))

ACTIVITIES-2

- Continuous radon monitoring with commercial radon monitors.
- Average radon concentration in the experimental halls is in the range of (30-150) Bq/m^3 with the ventilation working properly.
- R&D on radioprotection equipment (bronchial dose meter)



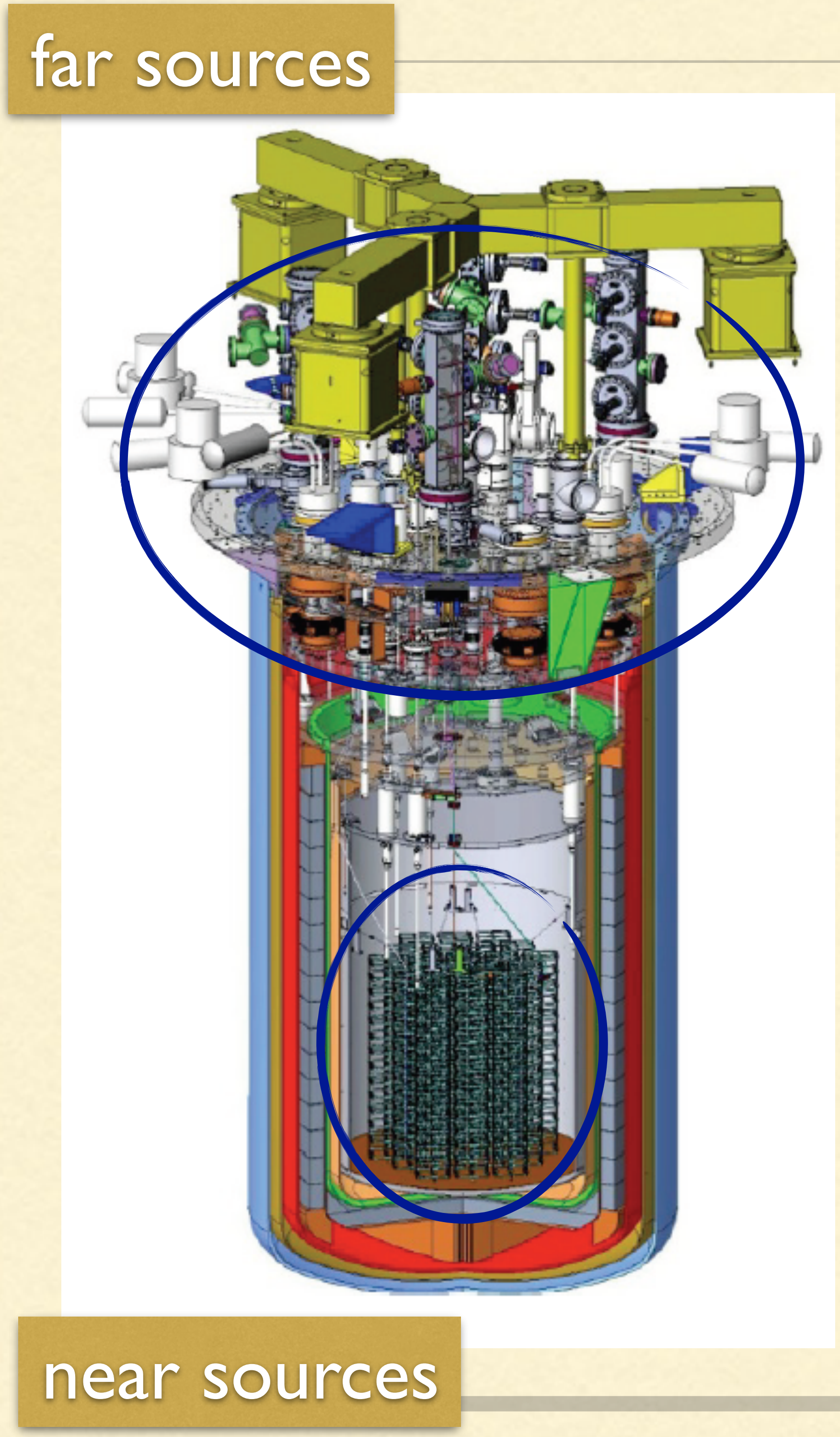
LOCATION OF STELLA



BACKGROUND BUDGET OF AN EXPERIMENT

- Experiments searching for rare events make extensive use of radio assay techniques to select radiopure materials.
- The results are very often upper limits for several reasons: sensitivity of the technique, purity of the samples, small parts to be tested, etc…
- Those values are used as input to MonteCarlo simulations to calculate the background budget of an experiment

AN EXAMPLE: CUORE



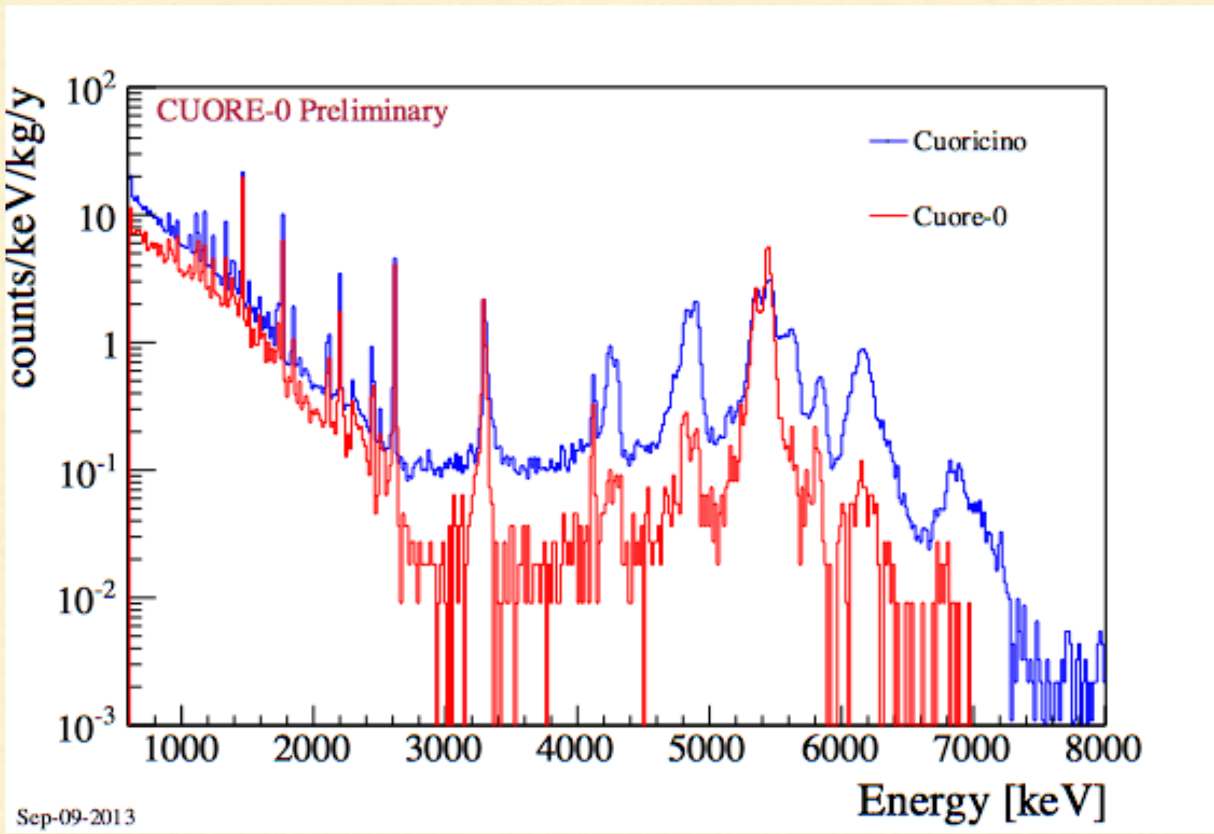
CUORE searches for neutrinoless double beta decay of ^{130}Te at LNGS with an array of 988 TeO_2 crystals operated as cryogenic bolometers (10 mK).

All of the materials used to assemble the experimental setup were tested for radio purity, in particular those parts in close proximity to the detectors

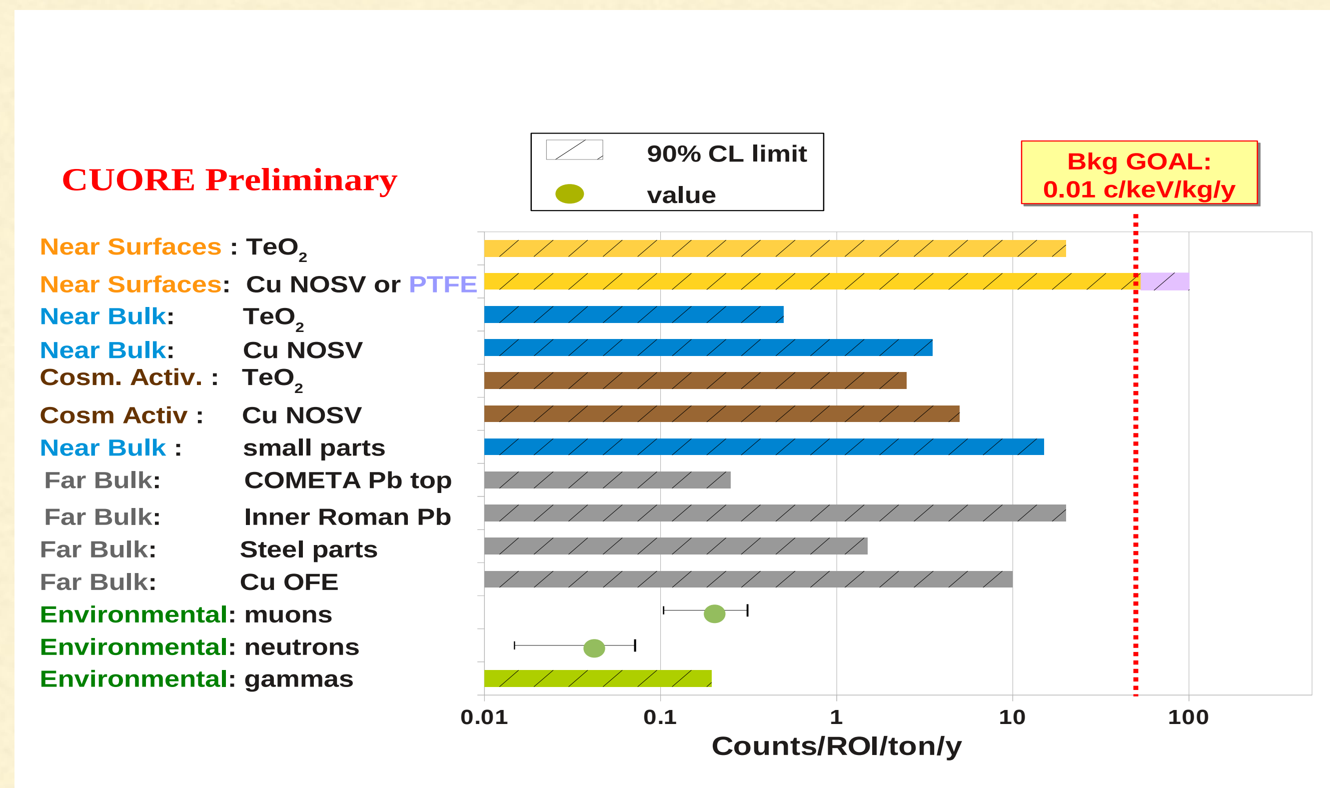
Bolometers are fully sensitive detectors (no dead layer): surface contaminations due to machining, cleaning and its exposure to ”contaminated” air, often exceed bulk ones and are particularly dangerous.

CUORE-0, a single CUORE tower, was assembled and it’s taking data since March 2013 at LNGS to demonstrated the validity of the CUORE tower assembly line and of the CUORE cleaning procedures.

CUORE BACKGROUND BUDGET



CUORE-0 demonstrated a reduction of the gamma and alpha background due to better radon control and surface treatment.



Only CUORE will tell us what the ultimate CUORE background index will be

FUTURE IMPROVEMENTS - 1

- Experiments need more sensitive screening techniques. One solution could be the use of today's or tomorrow's most sensitive detectors for screening;
- Experiments need dedicated and highly sensitive screening and test techniques for measuring and monitoring surface contaminations;

FUTURE IMPROVEMENTS - 2

- Re-organization 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.