Sources of background and their suppression illustrated by experiments on neutrino properties at LNGS

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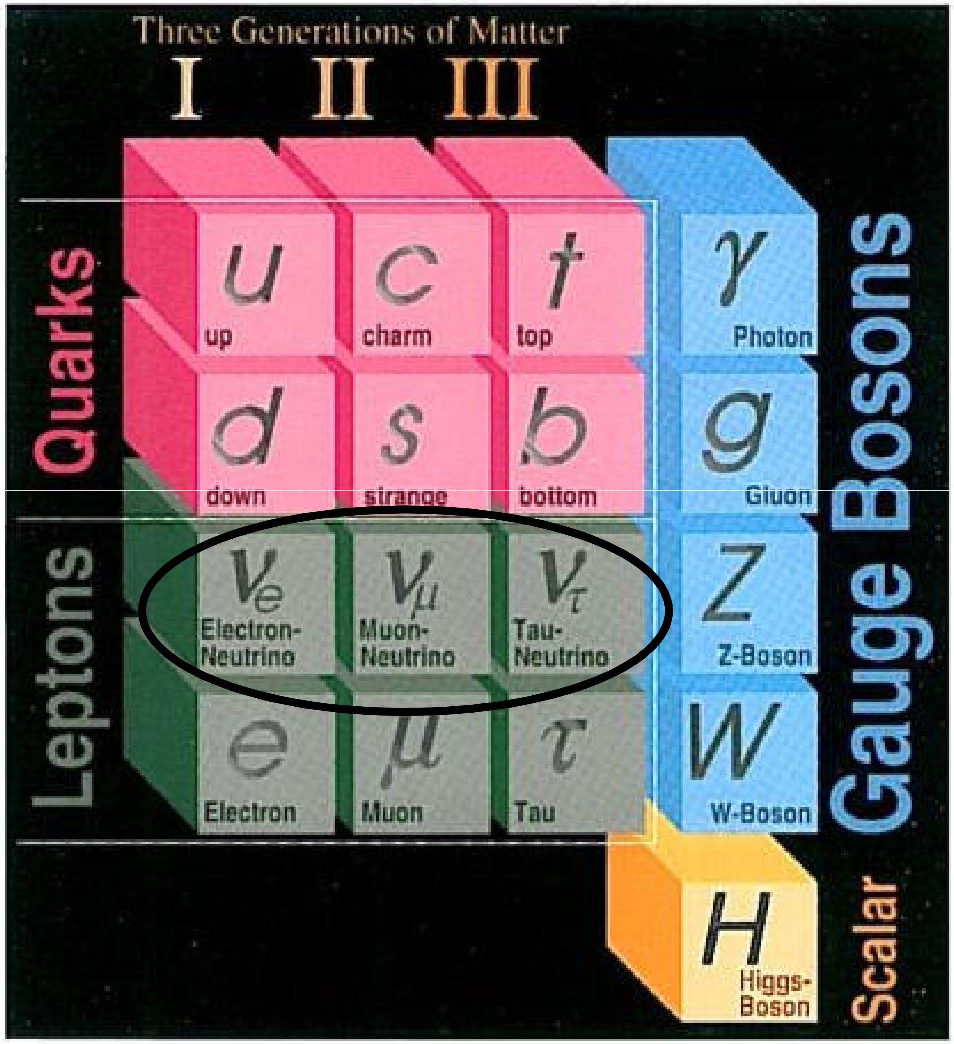
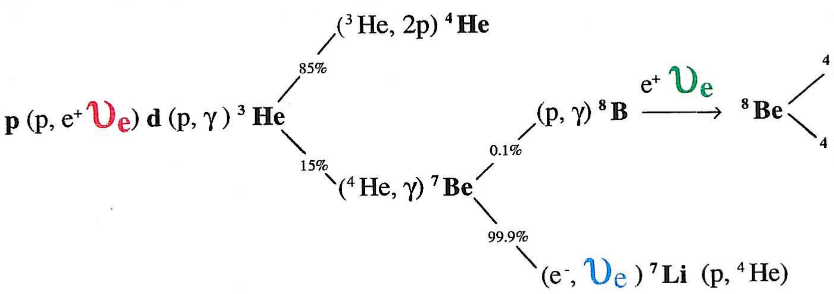
- neutrino properties via ☉ν's and ββ experiments
- sources of background
- germanium spectroscopy
- proportional counter of Davis type
- radioactive rare gases in BOREXINO
- from Heidelberg-Moscow to GERDA
- conclusion and future development

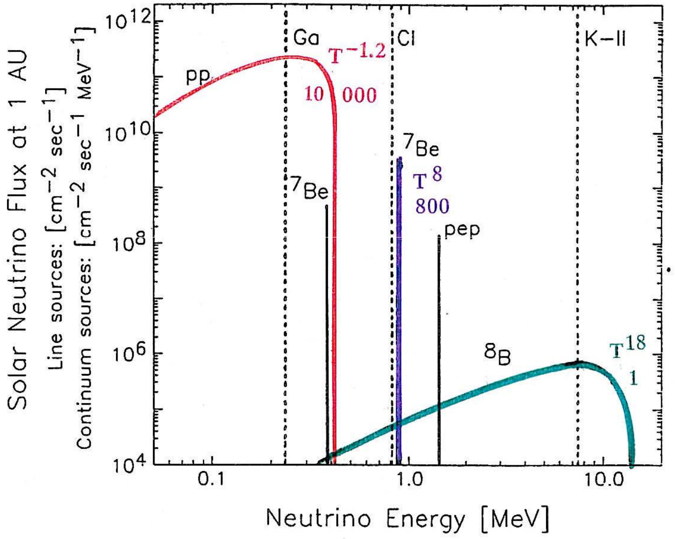
thanks to the colleagues of the Collaborations:
GALLEX/GNO, HEIDELBERG MOSCOW, BOREXINO, GERDA
special thanks to Matthias Laubenstein, LNGS

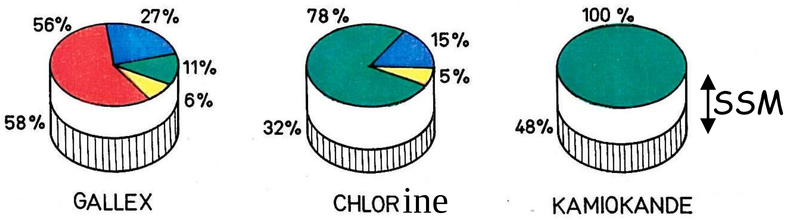
the elementary particles of the Standard Model of particle physics

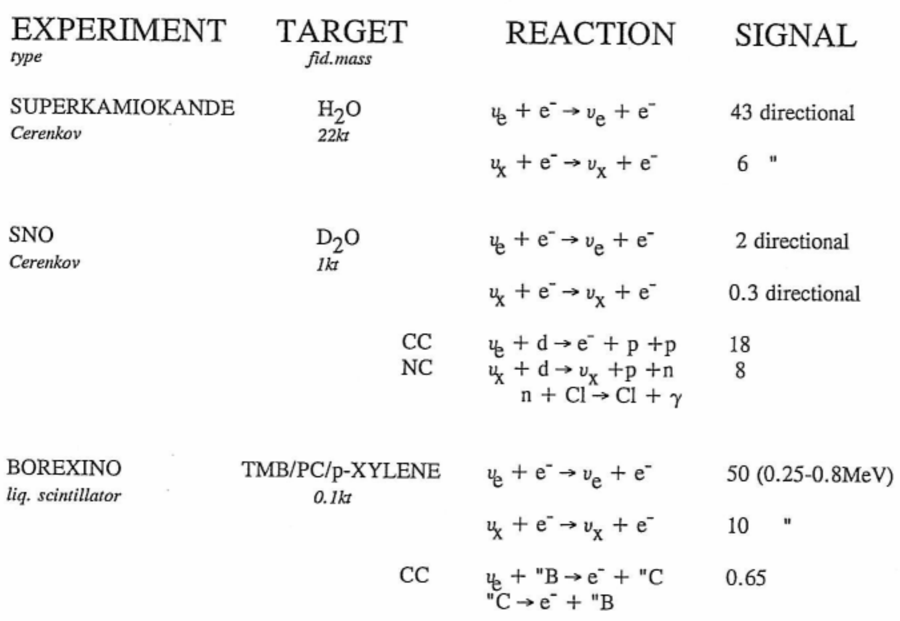


solar neutrino pp-cycle









EXPERIMENT *type*	TARGET *fid.mass*		REACTION	SIGNAL
SUPERKAMIOKANDE *Cerenkov*	H_2O *22kt*		$\nu_e + e^- \rightarrow \nu_e + e^-$	43 directional
			$\nu_x + e^- \rightarrow \nu_x + e^-$	6 "
SNO *Cerenkov*	D_2O *1kt*		$\nu_e + e^- \rightarrow \nu_e + e^-$	2 directional
			$\nu_x + e^- \rightarrow \nu_x + e^-$	0.3 directional
		CC	$\nu_e + d \rightarrow e^- + p + p$	18
		NC	$\nu_x + d \rightarrow \nu_x + p + n$ $n + Cl \rightarrow Cl + \gamma$	8
BOREXINO *liq. scintillator*	TMB/PC/p-XYLENE *0.1kt*		$\nu_e + e^- \rightarrow \nu_e + e^-$	50 (0.25-0.8MeV)
			$\nu_x + e^- \rightarrow \nu_x + e^-$	10 "
		CC	$\nu_e + "B \rightarrow e^- + "C$ $"C \rightarrow e^- + "B$	0.65

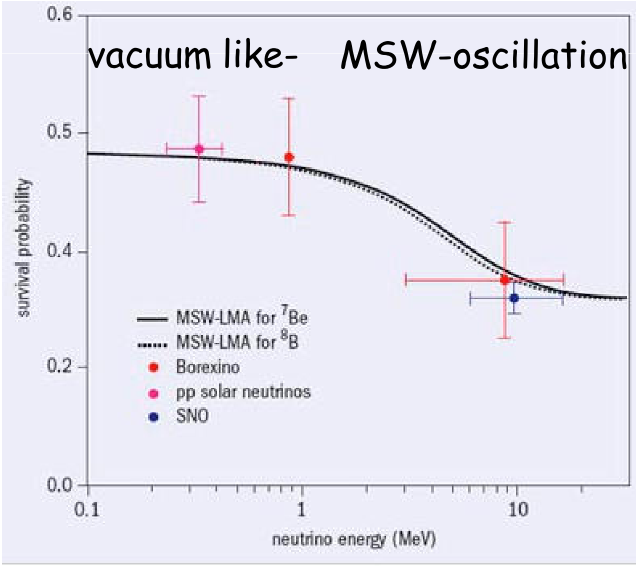
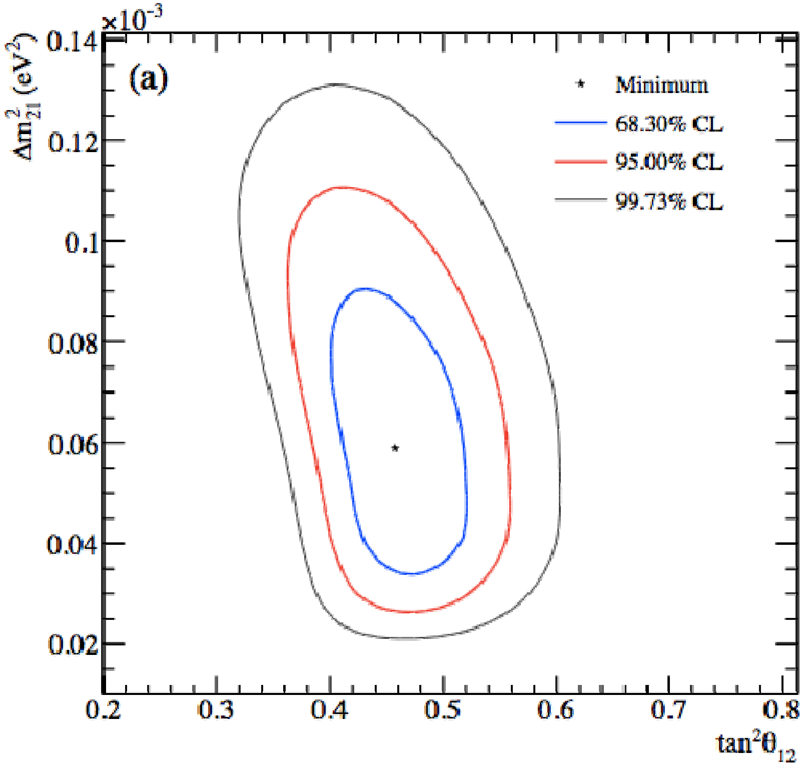


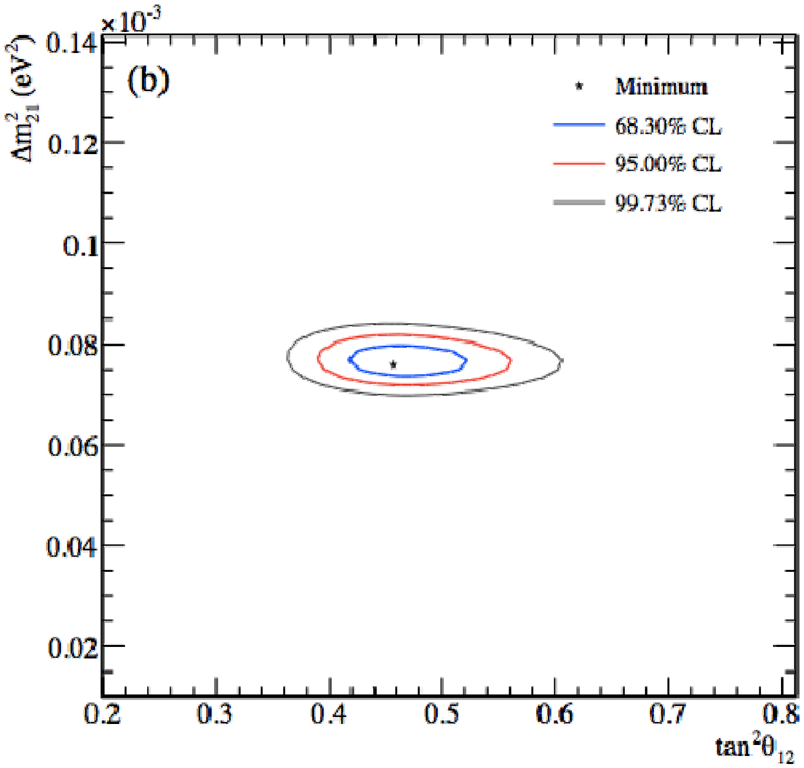
Fig. 3. Survival probability at Earth for electron solar neutrinos as a function of energy. The two Borexino measurements are shown together with the SNO result and the value predicted for pp neutrinos.

2 flavor

All solar



Solar + KamLAND



$$\theta_{12} = 34.06\,^{+1.16}_{-0.84}$$

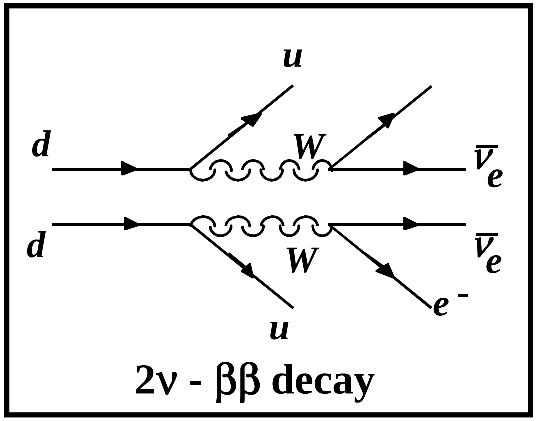
$$\Delta m^2_{21} = 7.59\,^{+0.20}_{-0.21} \times 10^{-5}\ \mathrm{eV}^2$$

ν = Majorana or Dirac particle ? **absolute mass scale, hierarchy?**

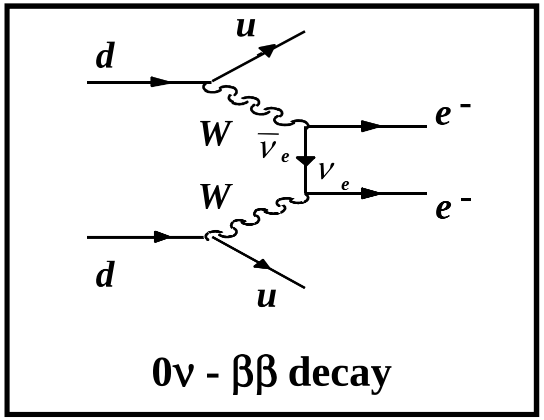
double beta decay

$\beta\beta(2\nu)$: $2n \rightarrow 2p + 2e^- + 2\bar{\nu}_e$

$\beta\beta(0\nu)$: $2n \rightarrow 2p + 2e^-$

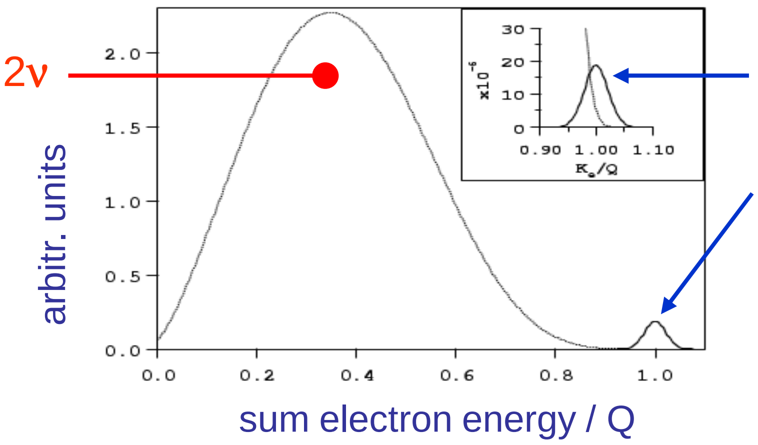


2ν - ββ decay



0ν - ββ decay

ΔL = 2 process



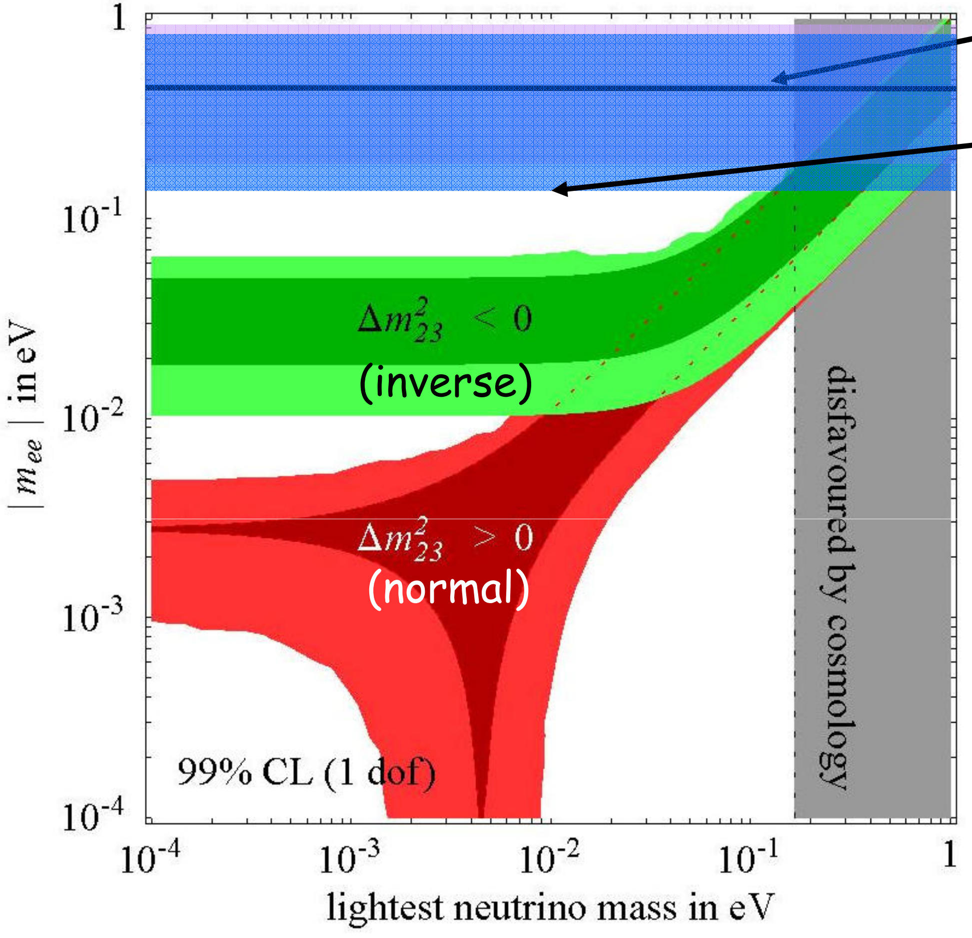
neutrinoless ββ peak

$$\Rightarrow T^{0\nu}_{1/2} \propto \langle m_\nu \rangle^{-2}$$

$$\langle m_\nu \rangle \propto (a)^{-1/2} (b\Delta E/Mt)^{1/4}$$

Q_β = 2.039 MeV for ^{76}Ge
2.529 MeV for ^{130}Te

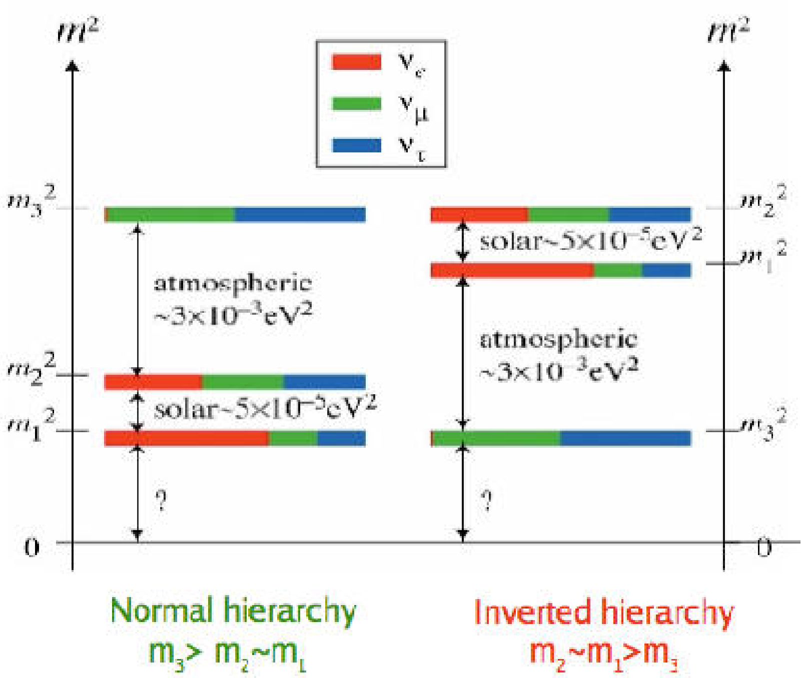
m_{ee} dependance on absolute mass scale and Θ_{13}



KK-HM evidence *(best value 0.44 eV)*

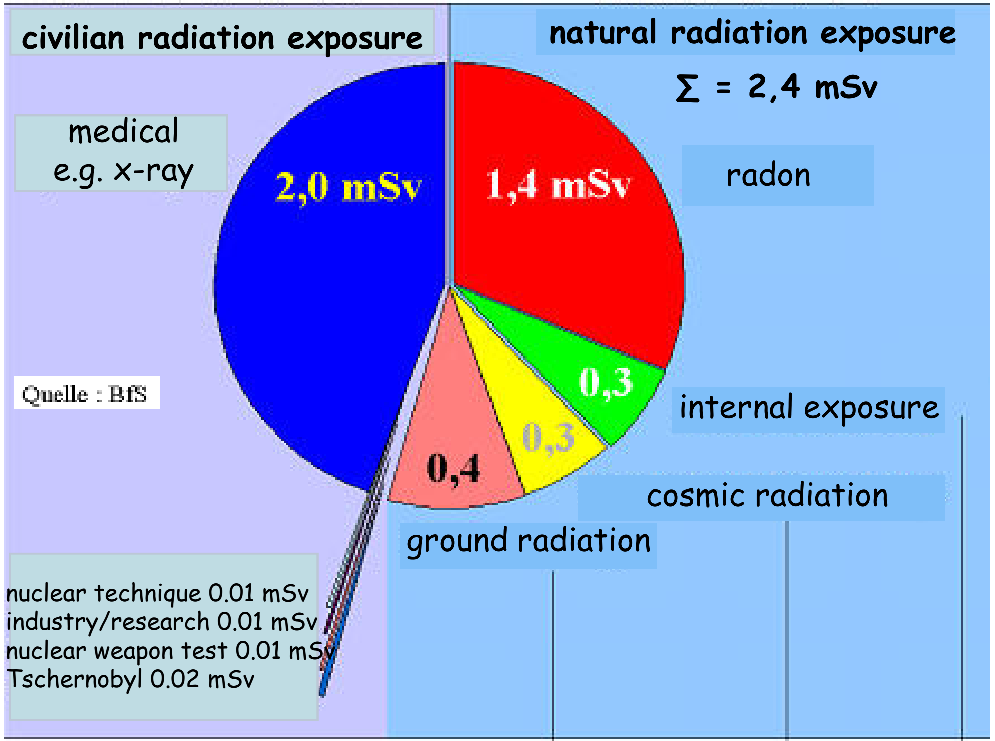
Cuoricino limit *(with the same NME <0.41 eV)*

F.Feruglio, A. Strumia, F. Vissani, NPB 659



background sources

average annual radiation
exposure in Germany
(total: 4.5 mSv)



Borexino scintillator

concentration
- ≈ 4×10^{-13} fraction ←
- ≈ 6×10^{-13} fraction ←

28 pBq/kg

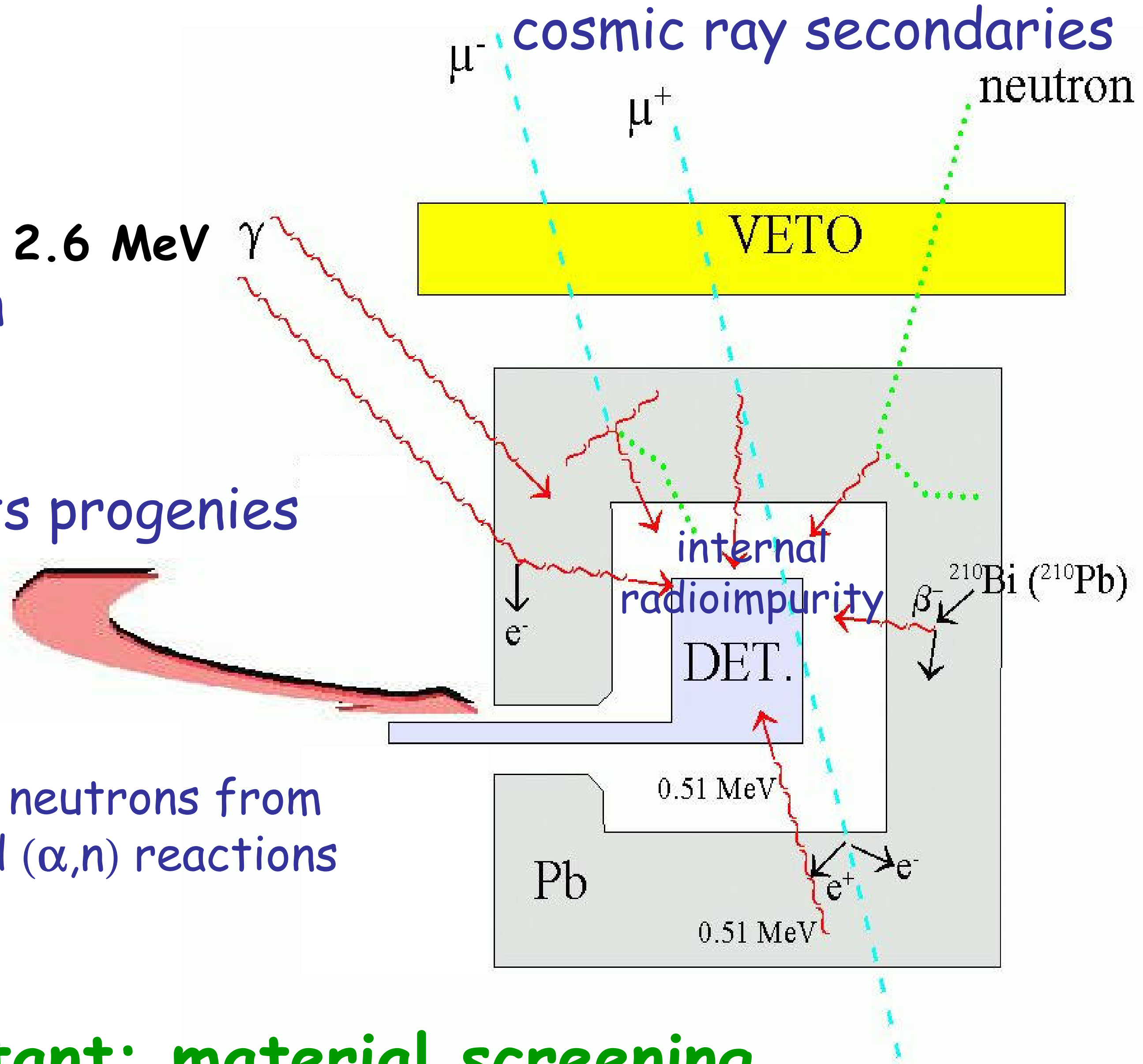
e.g. in 300 t ca 100 bis 200 µg soil

e.g. 1 kg soil
850 Bq ^{40}K
44 Bq ^{232}Th
36 Bq ^{238}U

at flight
altitude
ca x150

e.g. about
60 Bq/kg ^{40}K

background components in Ge spectrometry



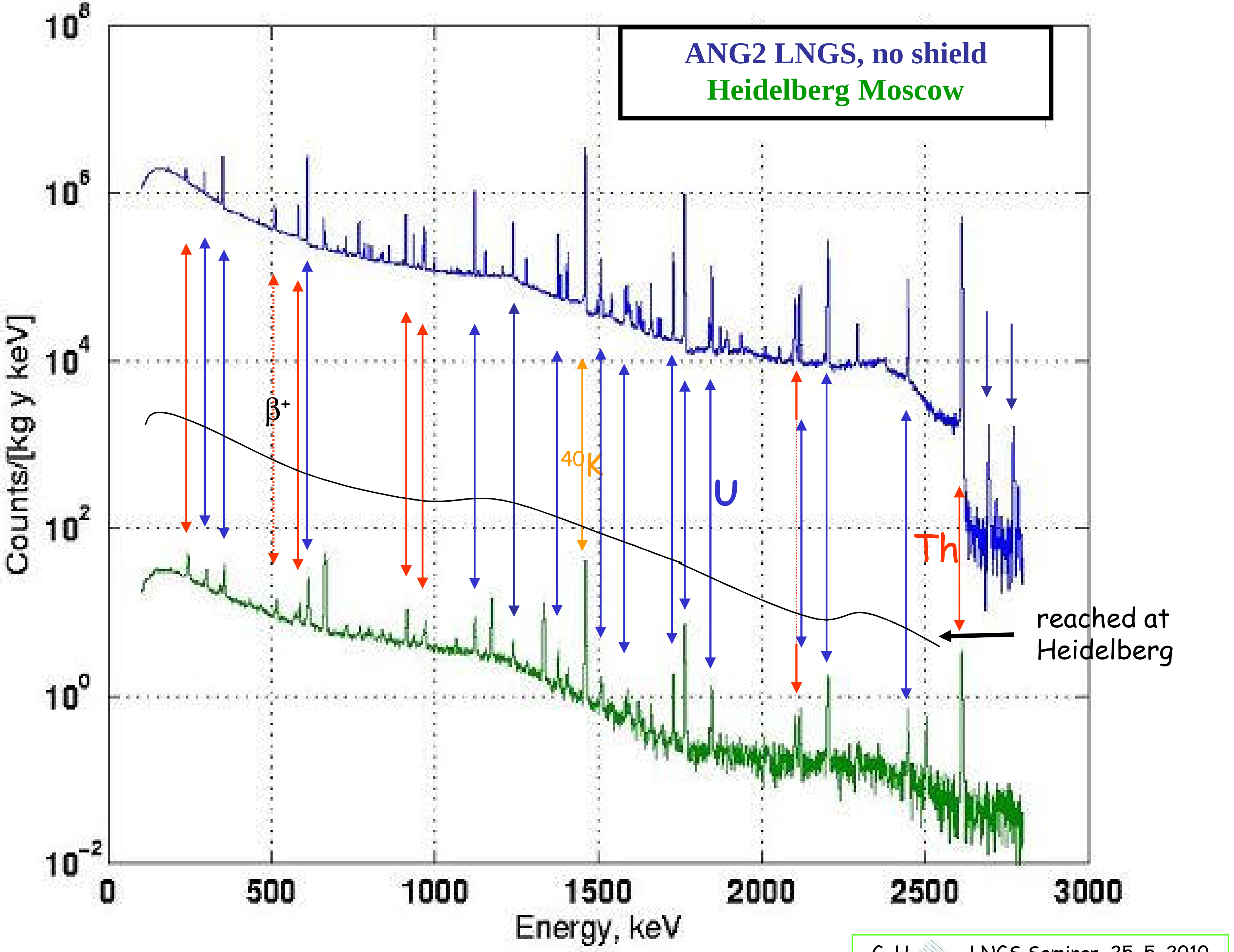
cosmic ray secondaries

external gamma radiation

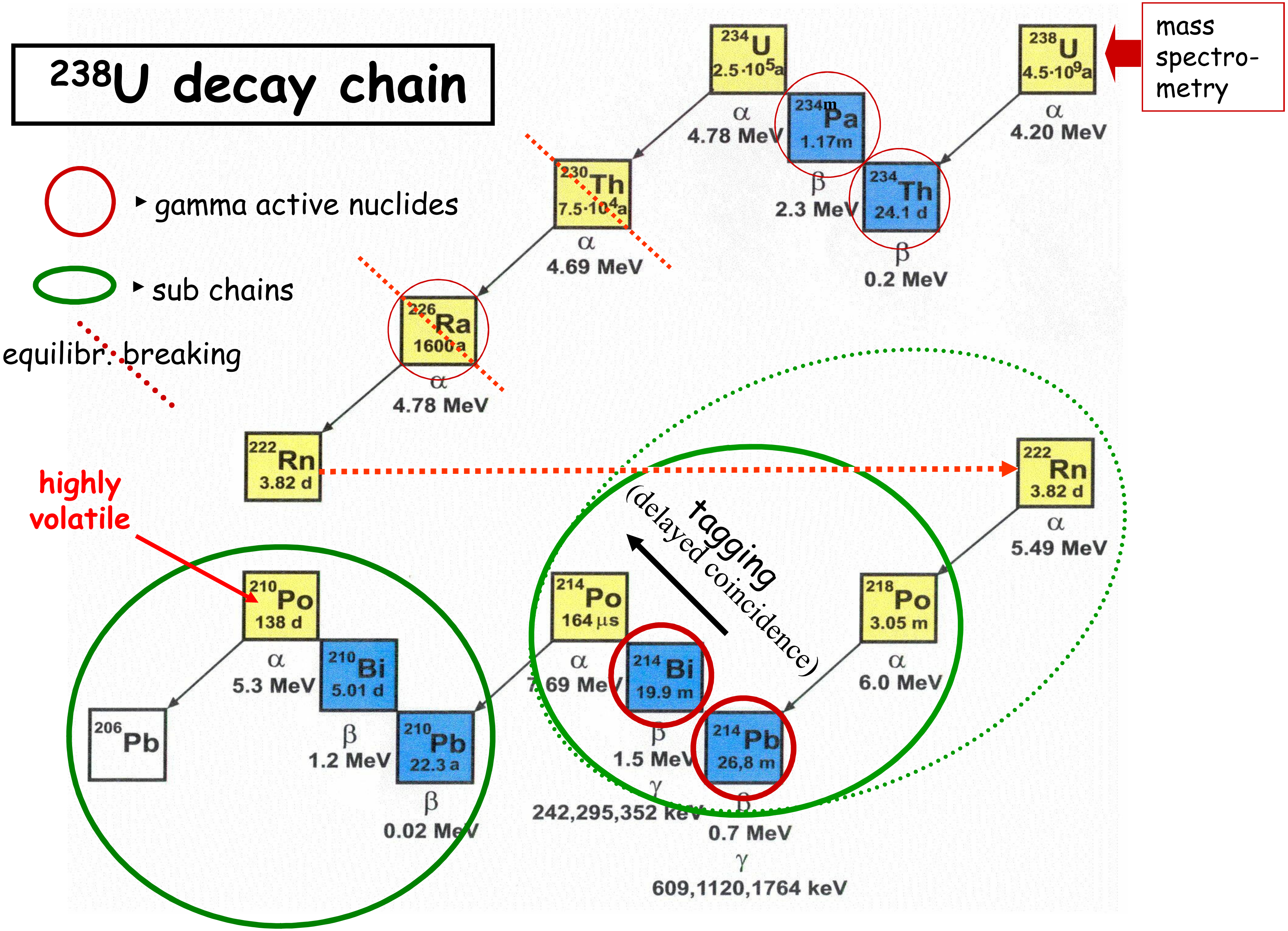
Rn and its progenies

primordial neutrons from fission and (α,n) reactions

most important: material screening


ANG2 LNGS, no shield
Heidelberg Moscow
β+
40K
U
Th
reached at Heidelberg
Counts/[kg y keV]
Energy, keV
10^6
10^6
10^4
10^2
10^0
10^-2
0
500
1000
1500
2000
2500
3000

^{238}U decay chain



- gamma active nuclides
- sub chains

equilibr. breaking

mass spectro-metry

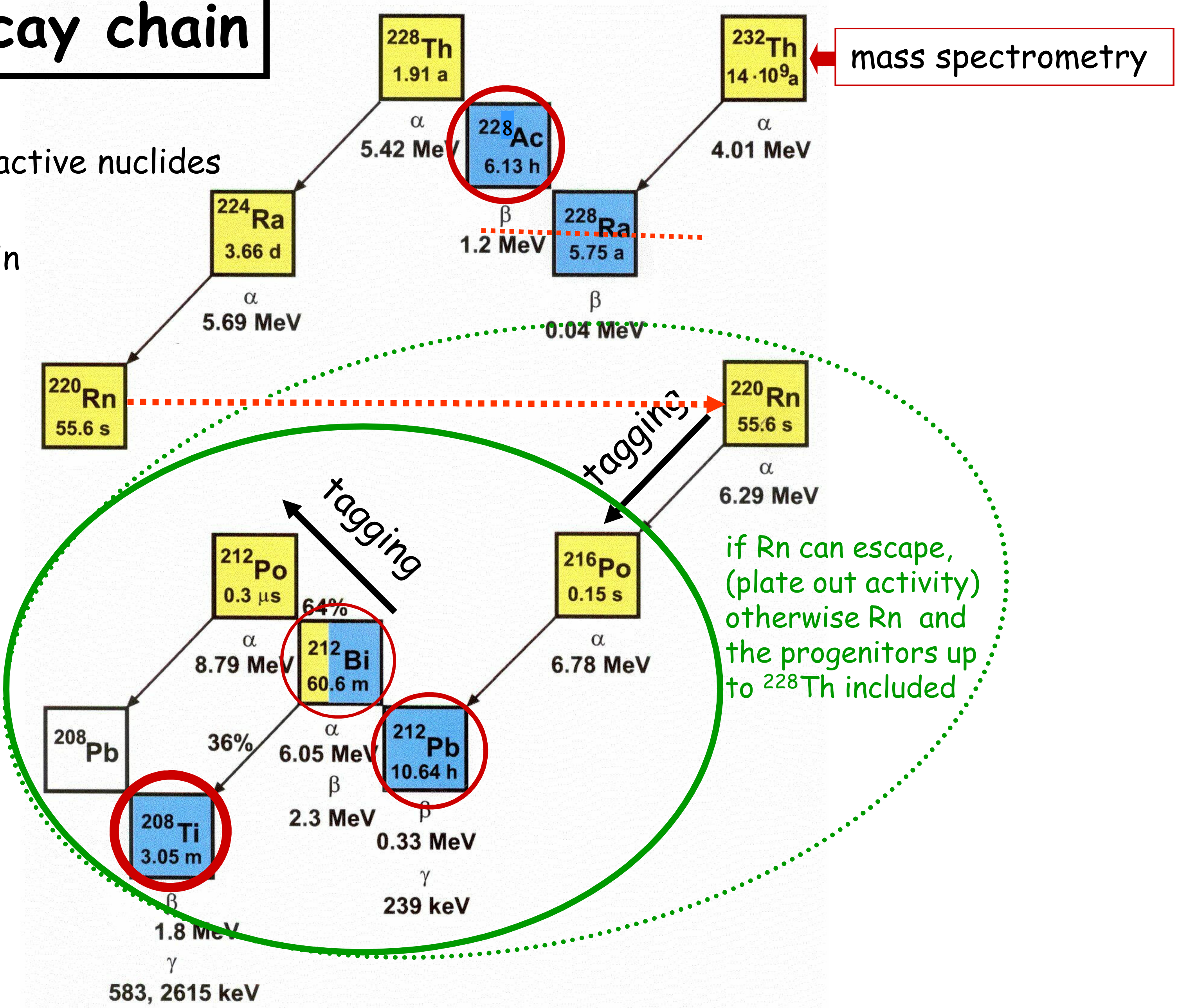
highly volatile

tagging (delayed coincidence)

^{232}Th decay chain

- ○ gamma active nuclides
- ⬭ sub chain

equilibr. breaking



mass spectrometry

tagging

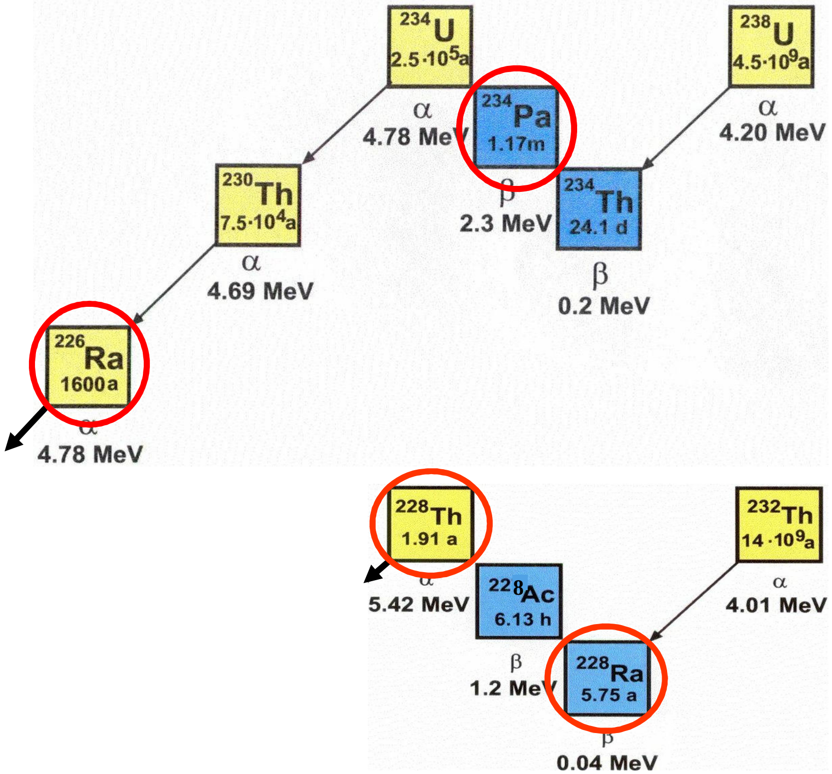
tagging

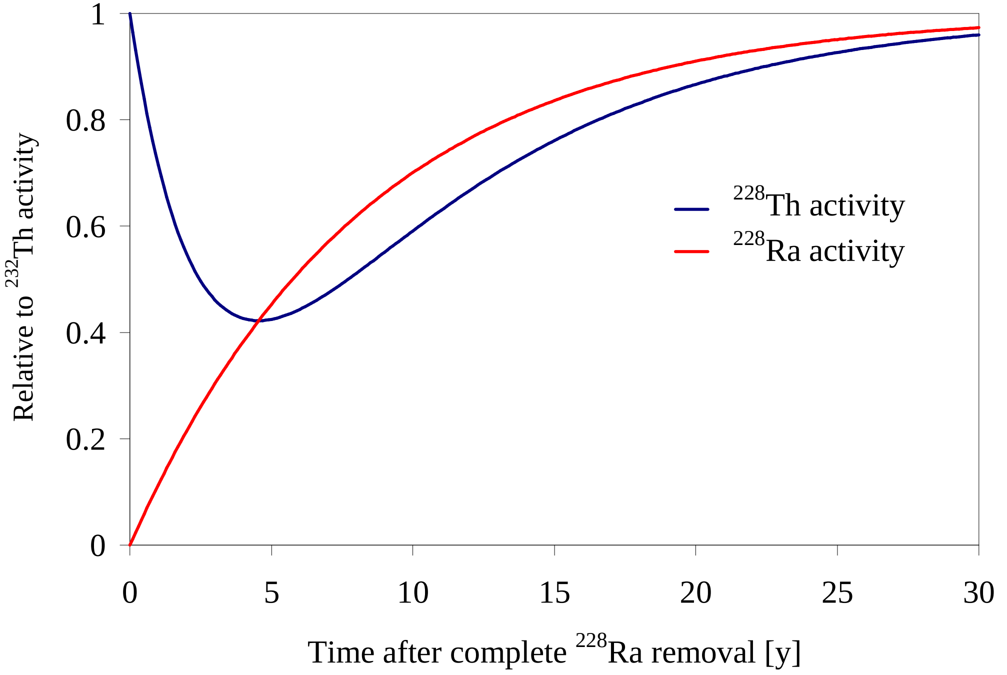
if Rn can escape, (plate out activity) otherwise Rn and the progenitors up to ^{228}Th included

disequilibrium in natural decay chains

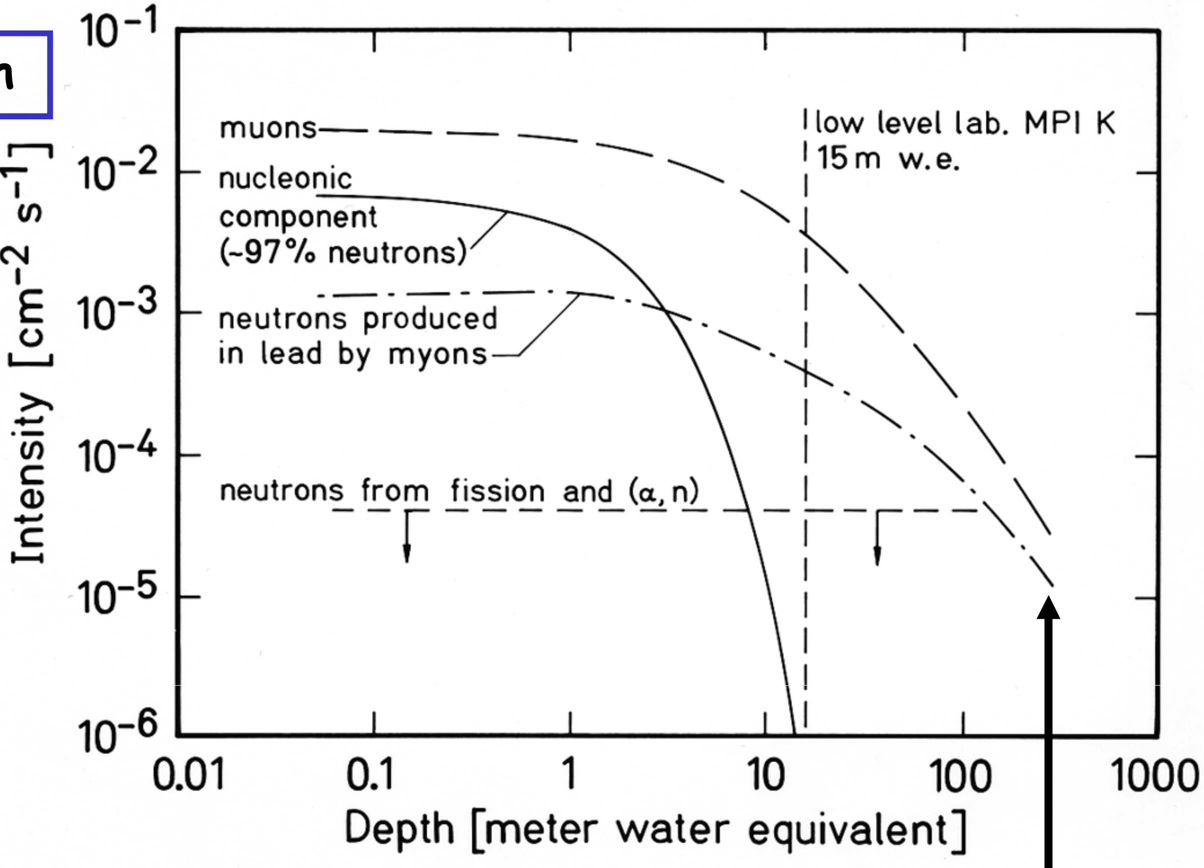
sample	**primordial radionuclides [mBq/kg] and ratios**					
	^{234m}Pa	^{226}Ra	^{234m}Pa/^{226}Ra	^{228}Th	^{228}Ra	^{228}Th/^{228}Ra
old ship steel	5.7[a]±1.4	0.15±0.02	38±11	0.46±0.07	0.47±0.05	0.98±0.18
G5	54[c]±16	1.0±0.6	54±36	1.5±0.2	1.0±0.5	1.5±0.77
GALLEX steel	16±4	0.19±0.05	84±31	≤ 0.50, ≤ 0.021*	≤ 0.15	

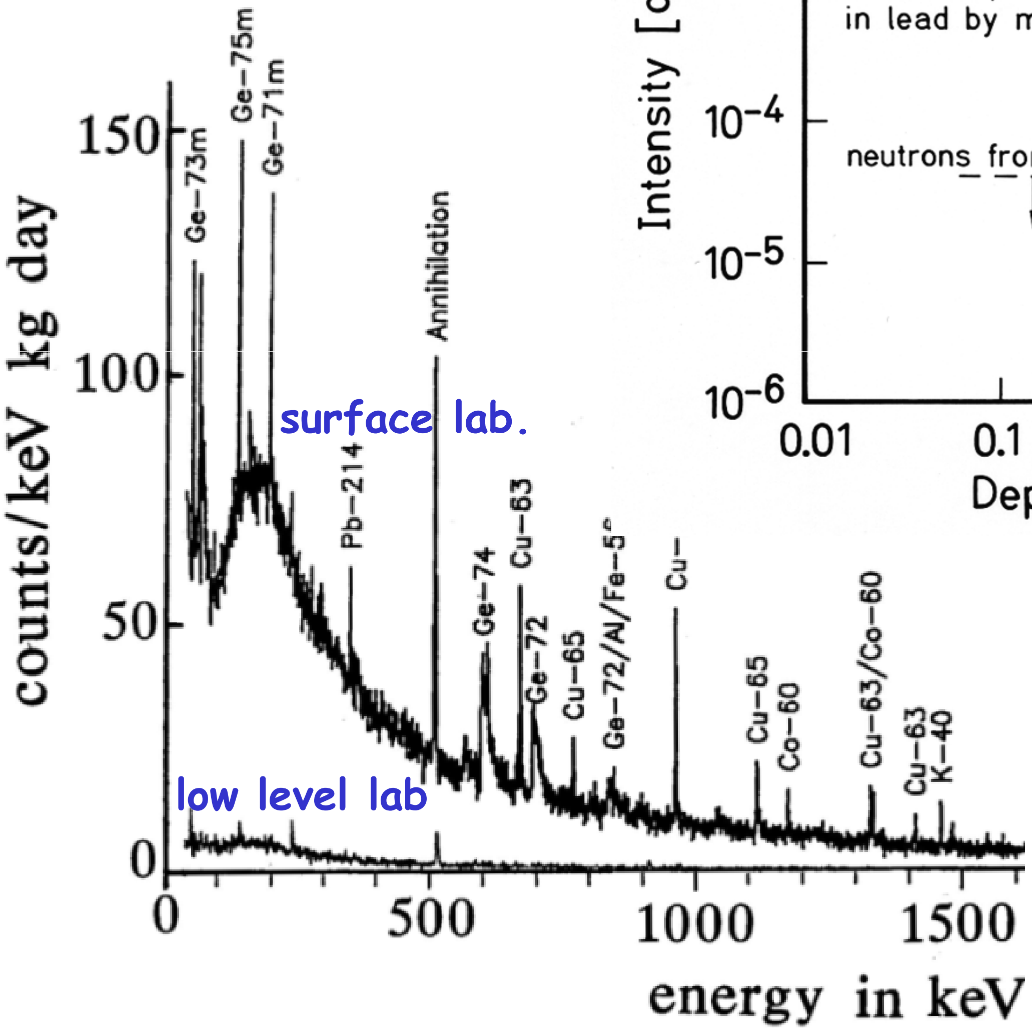
*** including the 2.615 MeV line**





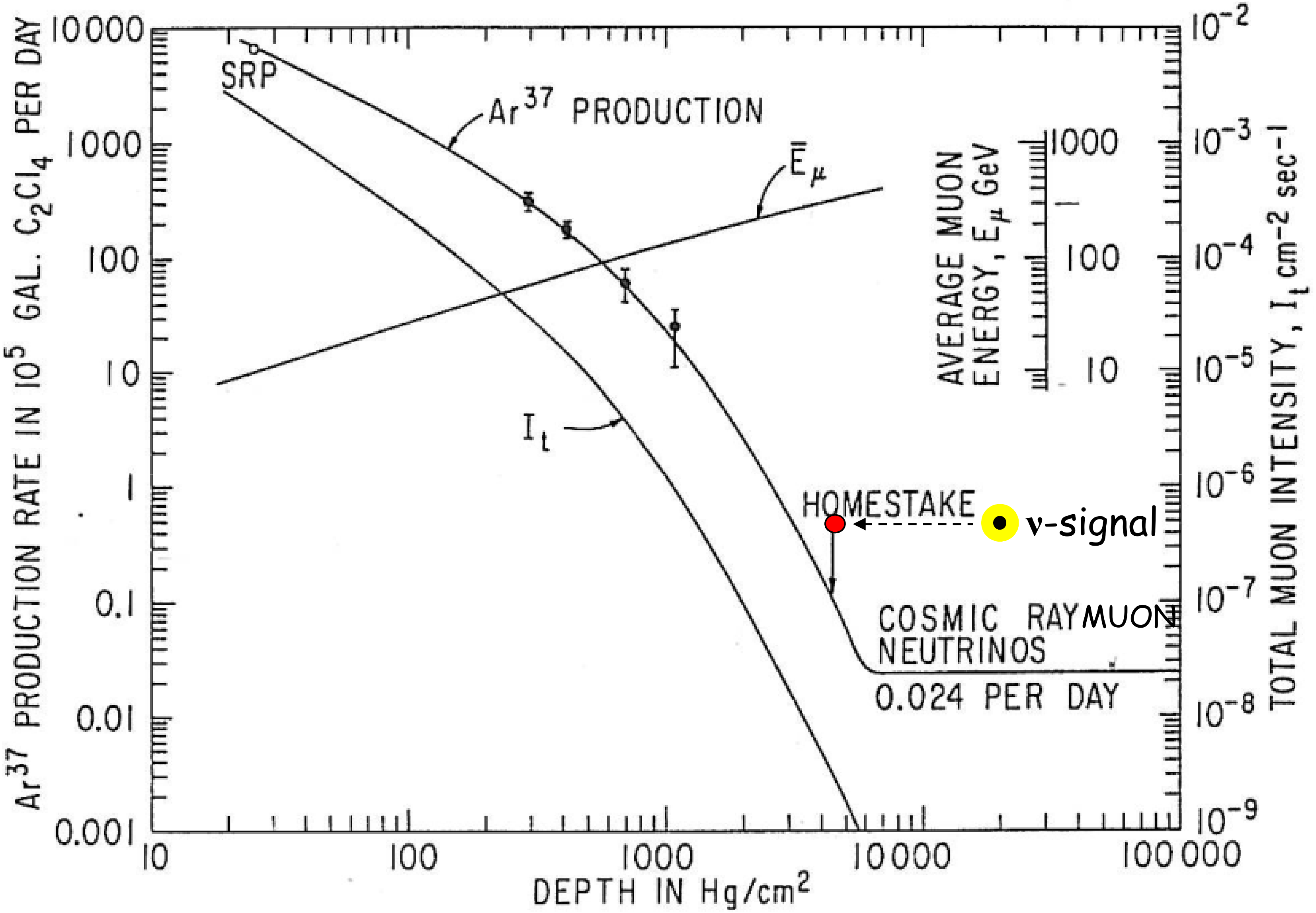
surface versus shallow depth





shield configuration to reduce neutrons under study at Heidelberg

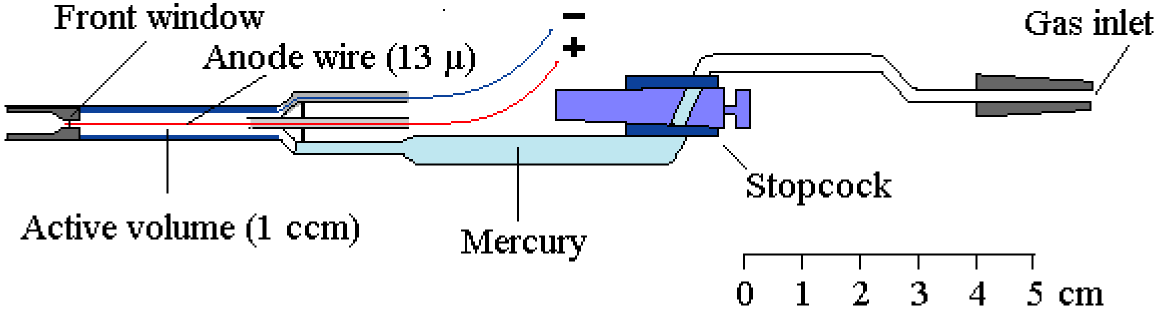
cosmic ray muon background reaction rate

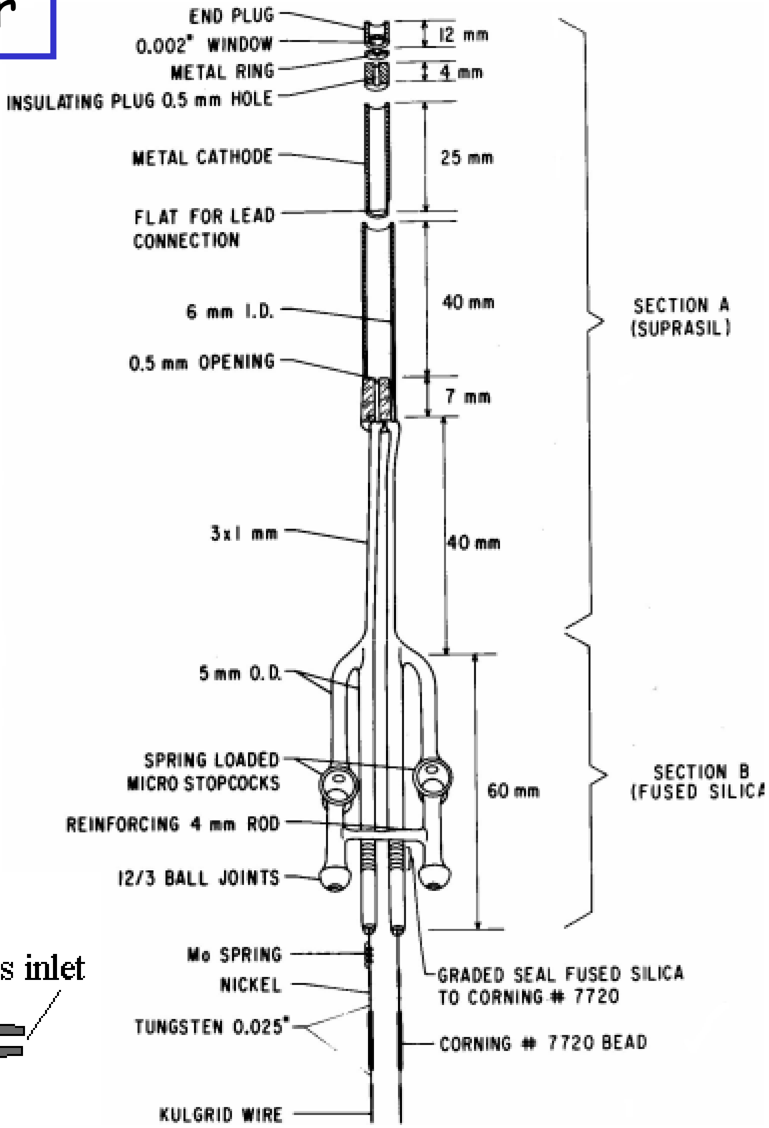


R. Davis Jr., Proc. Informal Conf. on Status of Solar Neutrino Research BNL 50879 (1978)1-54

Raymond Davis type proportional counter

HD-II proportional counter





....Raymond Davis Jr. ...I.J.Nucl.Med. Biol. 3 (1976), fast neutron dose requirement for...

Estimation of skeletal calcium in humans by exhaled ^{37}Ar measurement

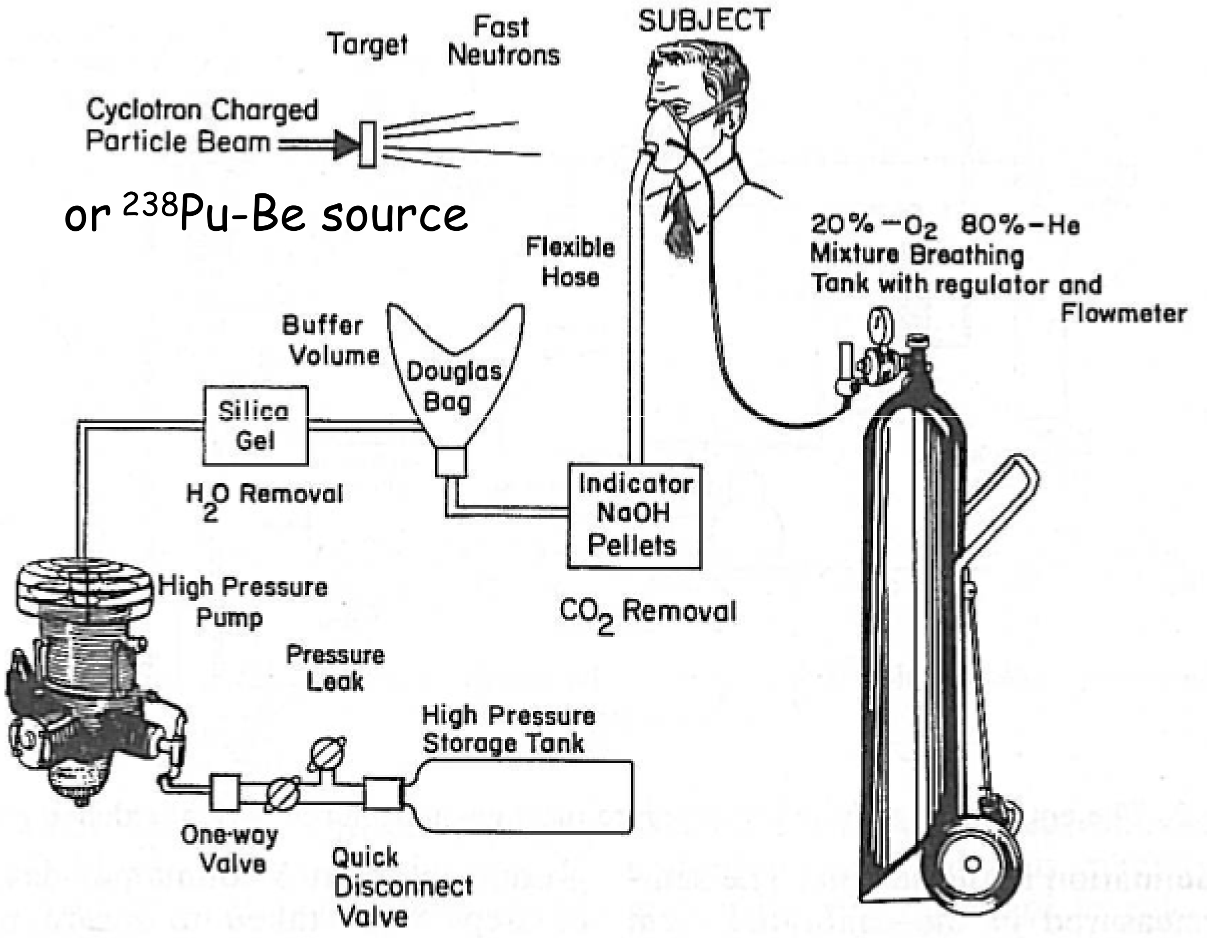


FIG. 1. The apparatus for collection and storage of respiratory exhaled gases.

or ^{238}Pu-Be source

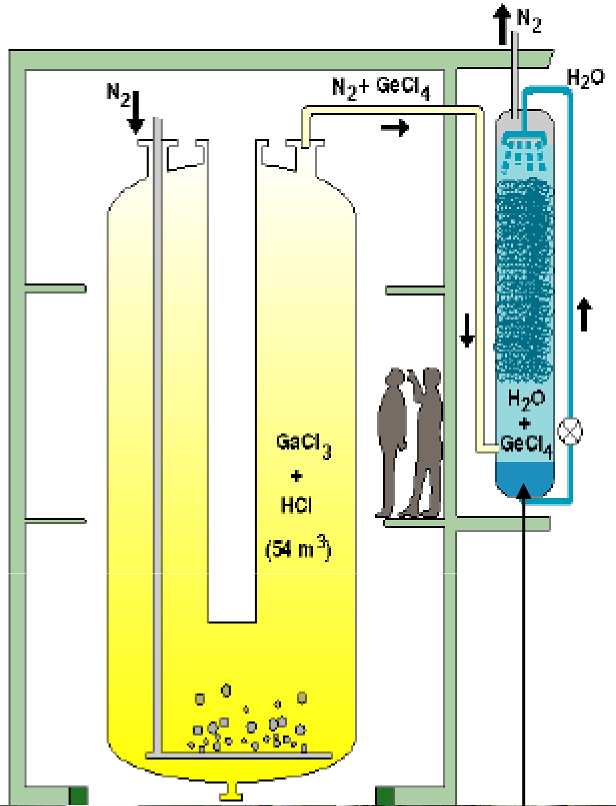
to investigate patients with metabolic bone desease

reaction: ^{40}Ca(n,α)^{37}Ar

½ h irradiation, 3 h collection

result : 10 mrad (≈ 0.1 mSv) sufficient for 1% counting error

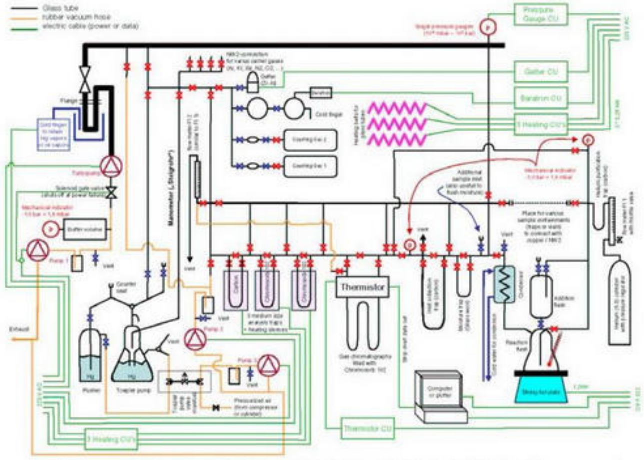
GALLEX/GNO-Sonnenneutrino-Detektor



(Extraktionen: 65 von 1991-1997/58 von 1998-2003)

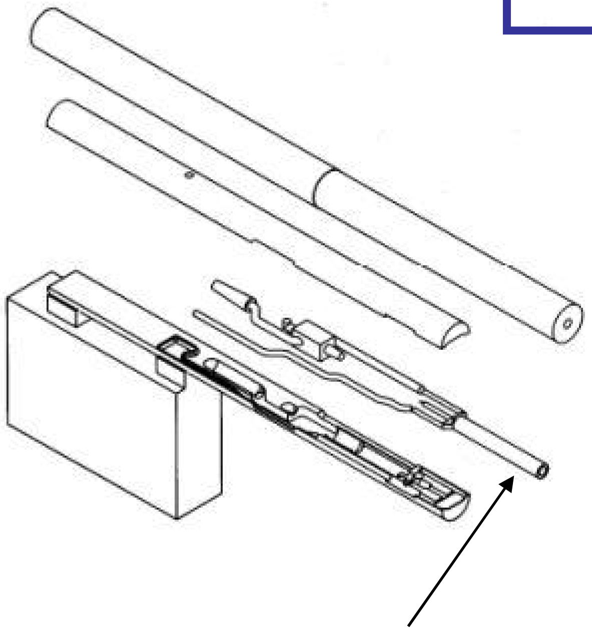
$$\boxed{\nu_e + {}^{71}Ga \rightarrow {}^{71}Ge + e^-}$$

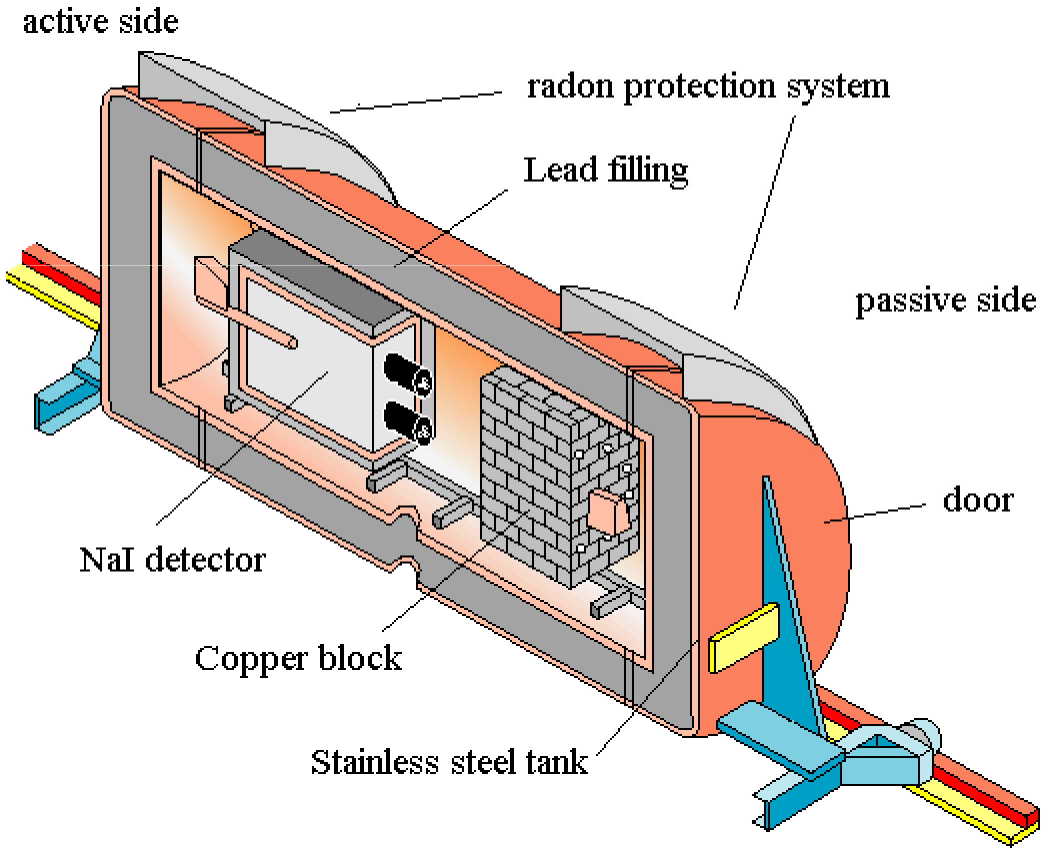
Detektor:	30.3 t Ga als $GaCl_3$ – HCl – Lösung (Gesamtgewicht 105 t)
Exponierung:	für 3 bis 4 Wochen
Extraktion:	Zugabe von 1 mg normalem Ge, wegen HCl-Überschuss → $GeCl_4$, spülen mit 2000 m^3 N_2
Umwandlung:	$GeCl_4 + NaBH_4 \rightarrow GeH_4$
Nachweis:	GeH_4 mit Xe in ein Proportional-Zählrohr (~1 cm^3) füllen, Messen der Elektronen und Röntgenstrahlen vom ^{71}Ge–Zerfall



counter filling line

GALLEX/GNO shielding tank

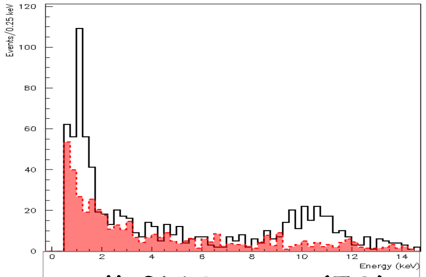




composition of background for Fe cathode counters in Pb/Cu shield at LNGS

Source	Activity or flux at the position of the proportional counter	Count rate > 0.5 keV [cpd]
External sources		
Muons	3×10^{-8} cm^{-2} s^{-1}	0.005
Neutrons	$<10^{-6}$ cm^{-2} s^{-1}	< 0.001
Gamma rays	$<10^{-6}$ cm^{-2} s^{-1}	< 0.02
Rn + progenies	< 0.5 Bq m^{-3}	< 0.006
K, Th, U in copper of the shielding material	< 2, 1, 1 mBq/kg	< 0.02
Internal sources		
K in quartz	0.04 mBq/kg	0.0001
Th in quartz	< 0.01 mBq/kg	< 0.0002
U in quartz	< 1.2 mBq/kg	< 0.03
^{60}Co in iron cathode	< 7 mBq/kg	< 0.02
K in iron cathode	0.06 mBq/kg	0.001
^{226}Ra in iron cathode	< 3 mBq/kg	< 0.2
Th in iron cathode	< 0.3 mBq/kg	< 0.017
U in iron cathode	< 0.4 mBq/kg	< 0.03
Tritium in counting gas	6 TU	0.023
^{85}Kr in counting gas	< 0.12 Bq m^{-3}	< 0.01
Sum		< 0.39

Fe powder screened



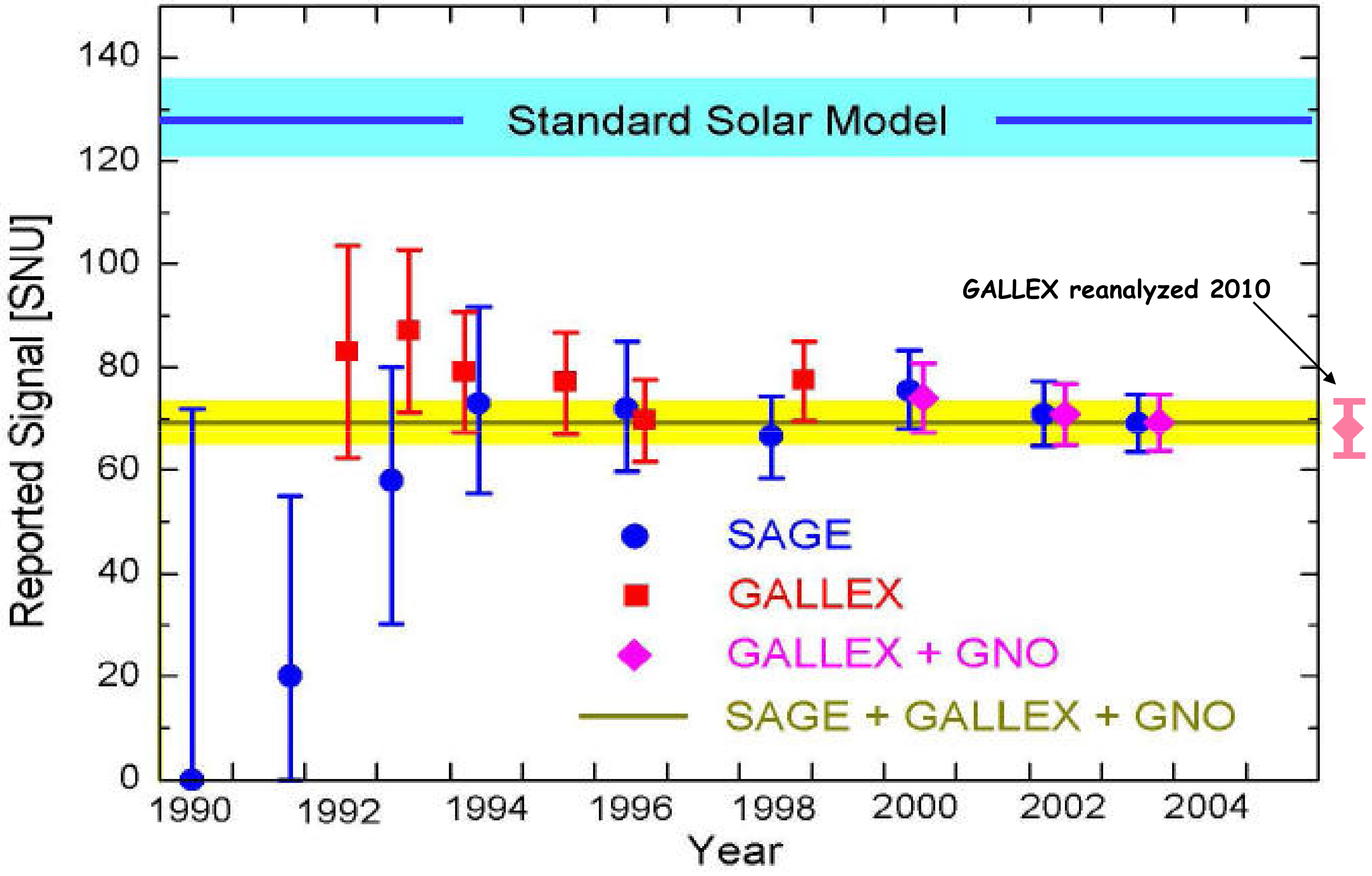
All GNO runs (58) recorded during the first 50 days

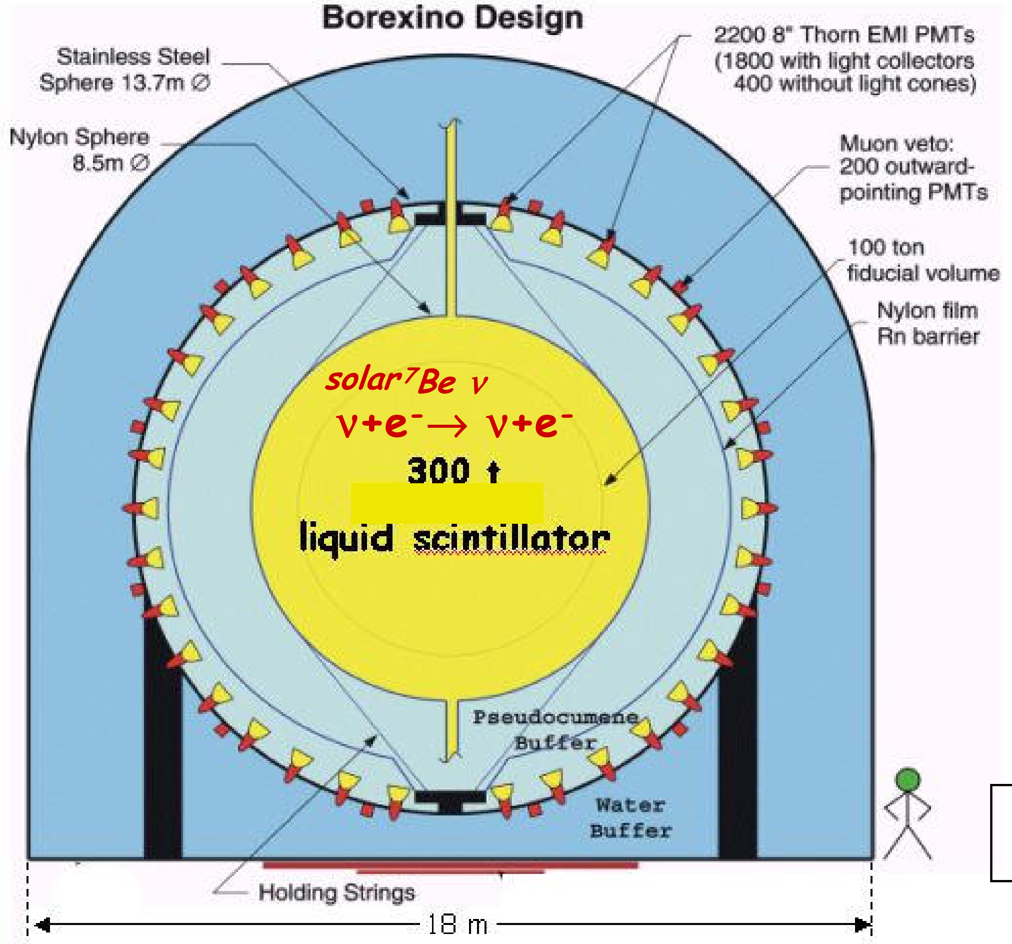
Background rates for counters used in GNO (0.5 keV ≤ E ≤ 15 keV) : 0.45
(8 with Fe cathode and 12 with Si cathode)

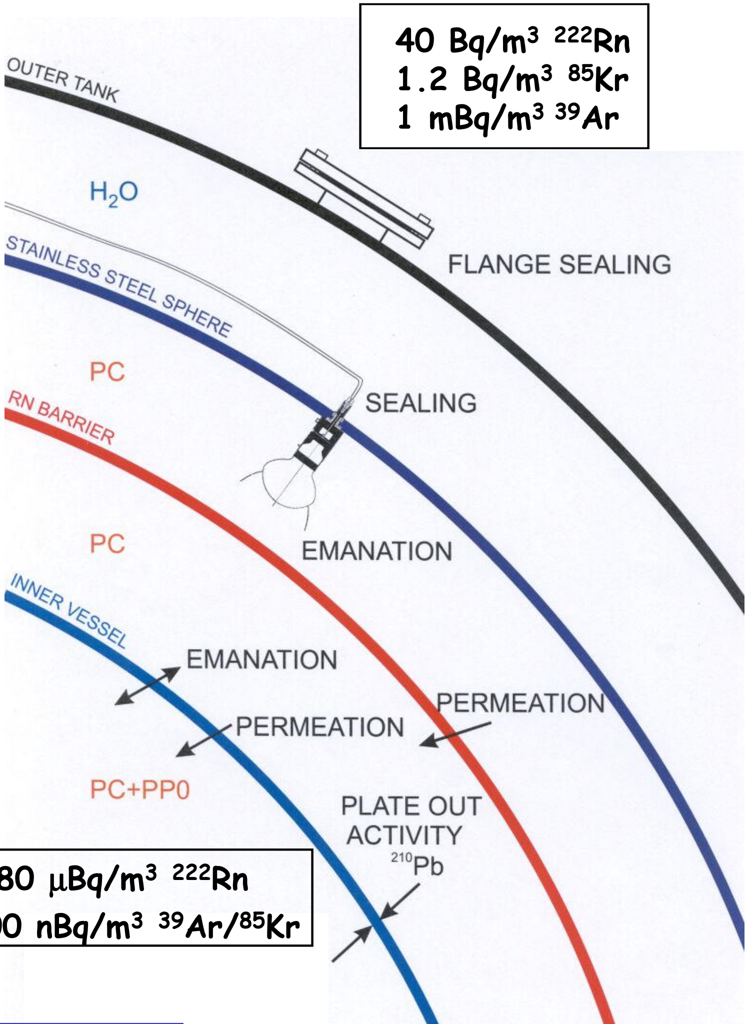
some contamination introduced during assembly (glassblowing)

With pulse shape discrimination [counts/d]	
L-window fast	K-window fast
0.040	0.025

Result of GALLEX/GNO and SAGE gallium solar neutrino experiments







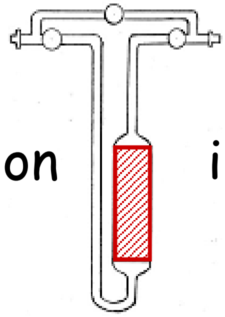
40 Bq/m^3 ^{222}Rn
1.2 Bq/m^3 ^{85}Kr
1 mBq/m^3 ^{39}Ar

80 μBq/m^3 ^{222}Rn
100 nBq/m^3 ^{39}Ar/^{85}Kr

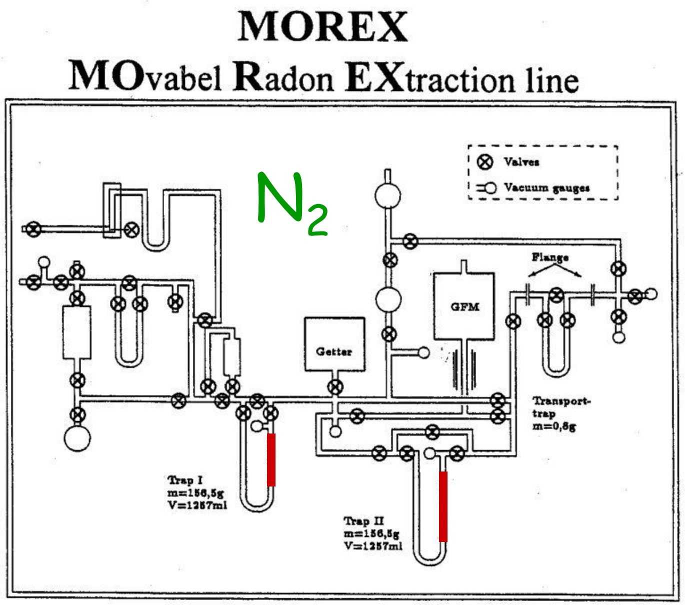
Commitment of Heidelberg:

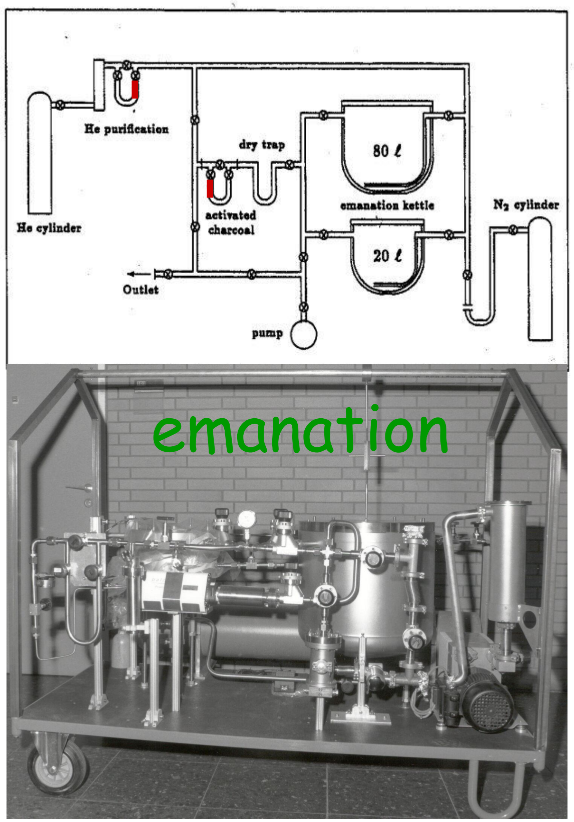
- develop methods to detect noble gas radionuclides and ^{226}Ra (via ^{222}Rn) at the μBq level
- screen (also γ counting) relevant materials and subsystems at that level
- provide nitrogen for scintillator purification at the required level

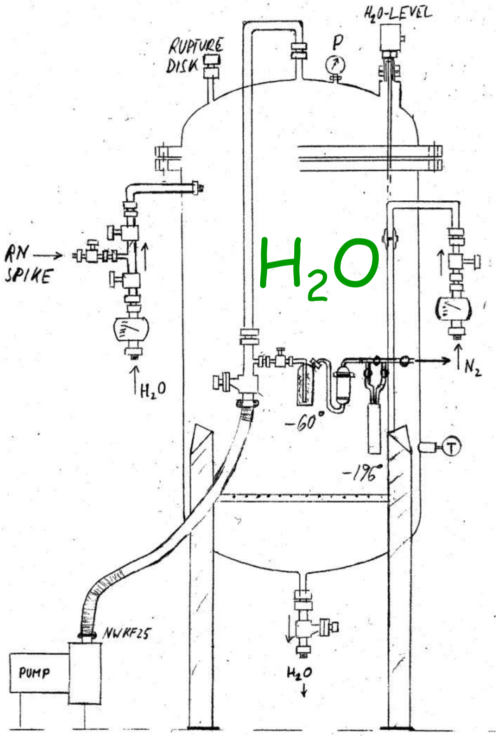
^{222}Rn screening at the μ**Bq** level



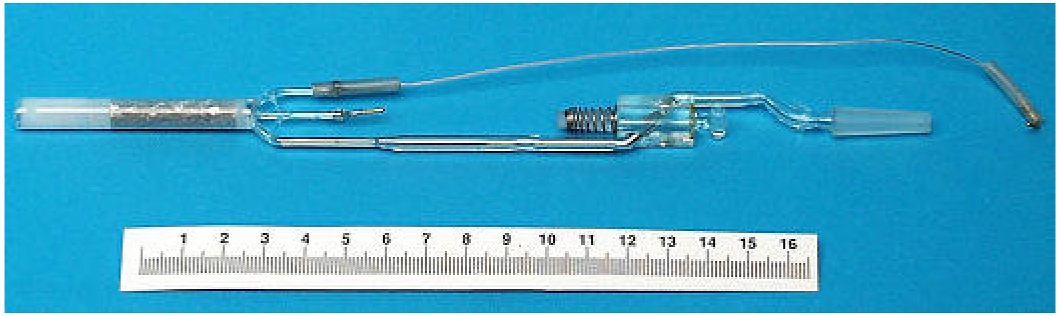
concentration of Rn in charcoal traps → proportional counting







^{222}Rn (^{226}Ra) assay with proportional counting



Ray Davis Jr.
type
miniture
counter

efficiency for internal counting (> 15 keV): 148 %

background: 0.2 – 2 counts per day

⇒ about **30 µBq** ^{222}Rn easily detectable (monitoring)

Extract Rn from large quatities of water, nitrogen and as an emanation signal of subsystems of BOREXINO

Reached sensitivities:

H_2O: 1 mBq Ra/m^3
0.1 mBq/Rn/m^3

nitrogen: 0.5 µBq/m^3

surface emanation 0.5 µBq/m^2

Emanation measurements under dry and wet conditions

^{226}Ra contamination of steel and nylon foil measured by ^{222}Rn emanation

sample	*surface concentration (μ Bq/m^2)*	*bulk concentration (μBq/kg)*
steel foil (untreated) (71 m^2)	**10 ± 1**	**640 ± 210^a**
after rinsing with H_2O	**5 ± 1**	
N_2 sparging column (280 m^2)	**8 ± 1**	
Sniamid/Capron foil (0.1 mm, 208 m^2)	**3 ± 1**	**100 ± 20^b ●**
Sniamid nylon (0.125 mm,130 m^2)	**≤ 0.8**	**$\leq 21^b$**

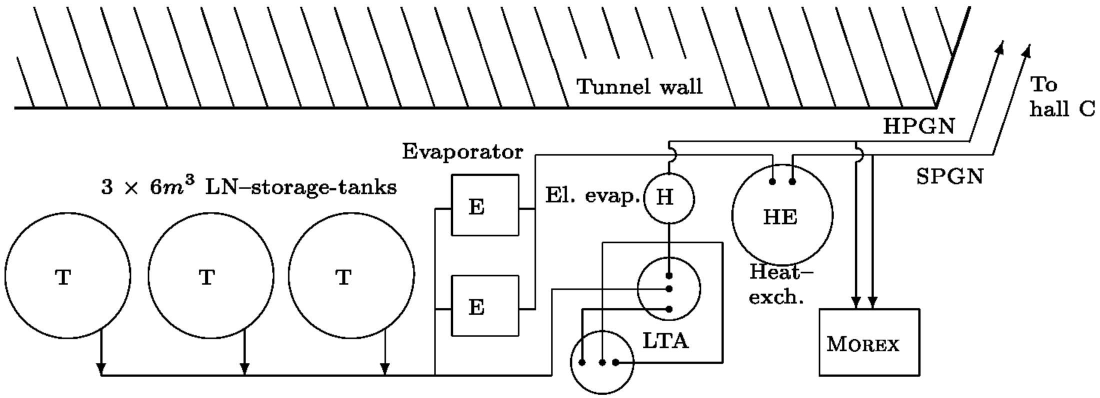
Grzegorz Zusel

[a] measured by Ge γ spectroscopy (expected emanation rate by α-recoil: 0.2 μBq/m^2)
[b] measured via ^{222}Rn emanation under wet condition (enhanced permeability)

● **corresponds to ~ 8 ppt U-equivalent - but ~ 2.5 ppt U measured with ICP-MS** ⇒

secular disequilibrium between U and Ra

Nitrogen plant of BOREXINO



activity in nitrogen [µBq/kg]

nitrogen sample	^{39}*Ar* a)	^{85}*Kr* a)	^{222}*Rn* b)
regular purity	12	41	40
charcoal purified	12	31	0.4
Charcoal purified liq.extr.			< 0.3
Linde Worms (7.0)	0.017	0.07	1
SOL Mantua (7.0)	0.006	0.04	
Westfalen Hörstel (6.0)	0.0006	0.06	
required	0.4	0.14	6
air	~1.1x10^{4}	~1.2x10^{6}	~1x10^{7}

a) **measured by rare-gas MS; 1 ppm Ar = 1.19 µBq/kg; 1 ppt Kr = 1.03µBq/kg**

b) **measured by concentration and proportional counting**

SOL LN$_2$-tank @ MPIK

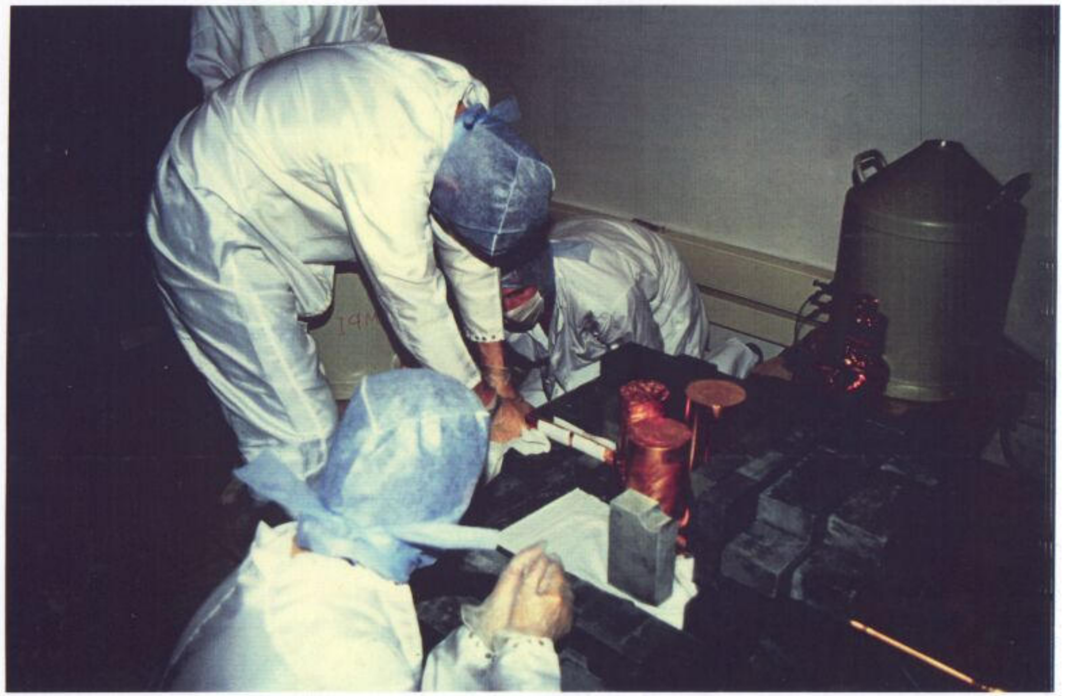
Acknowledgements for Ra/Rn, Ar and Kr measurements:

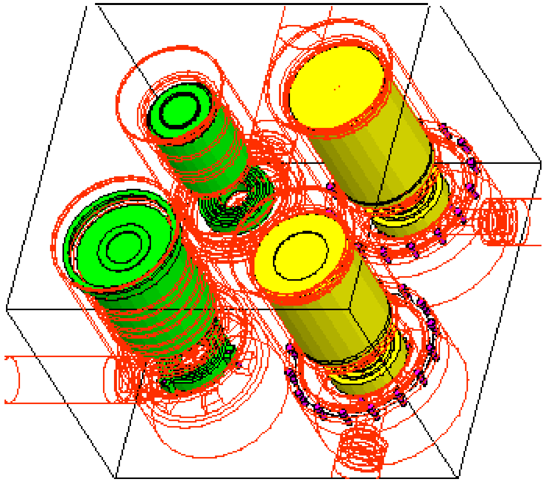
LNGS: M. Balata, L. Ioanucci, M. Laubenstein, C. Salvo

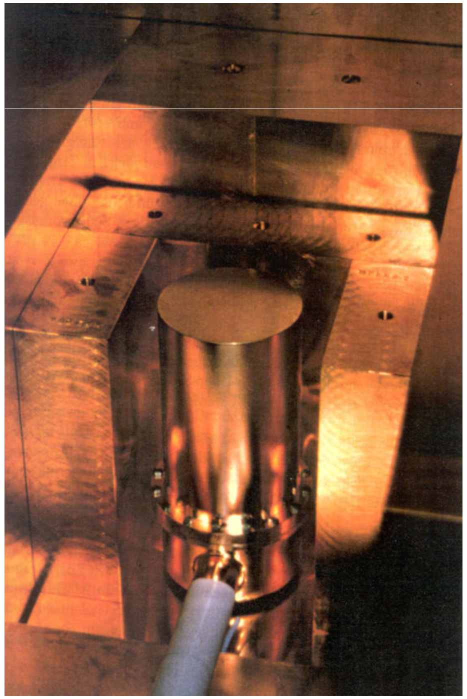
Heidelberg: C. Buck, B. Freudiger, H. Simgen, W. Rau, Y. Zakharov

Krakow: G. Zuzel, M.Wojcik

Heidelberg-Moscow double beta decay experiment





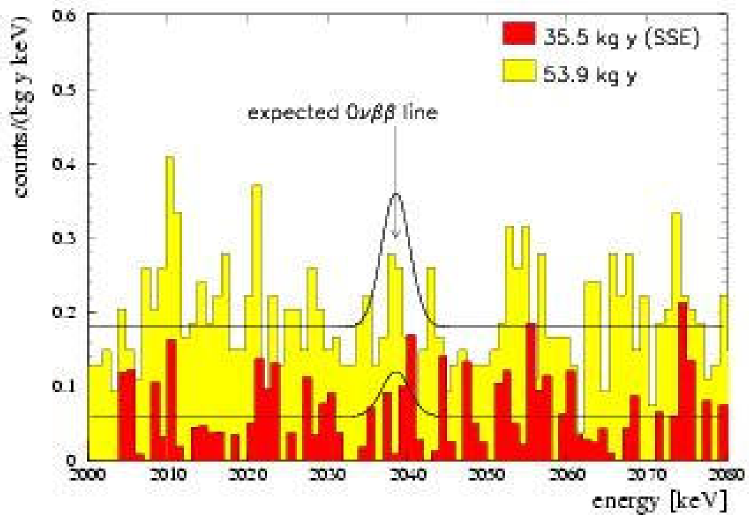


5 enriched Germanium diodes (86% in ^{76}Ge, normal 7.44%)

Shield made of:

20 cm regular Pb
20 cm Pb with 0.2 ^{210}Pb Bq/kg Pb
10 cm borated PE
Rn protection casing
cosmic veto

Result of Heidelberg-Moscow experiment



1990-2000 Gran Sasso Underground Laboratory

total mass = 10,9 kg

FWHM = 3,85 keV

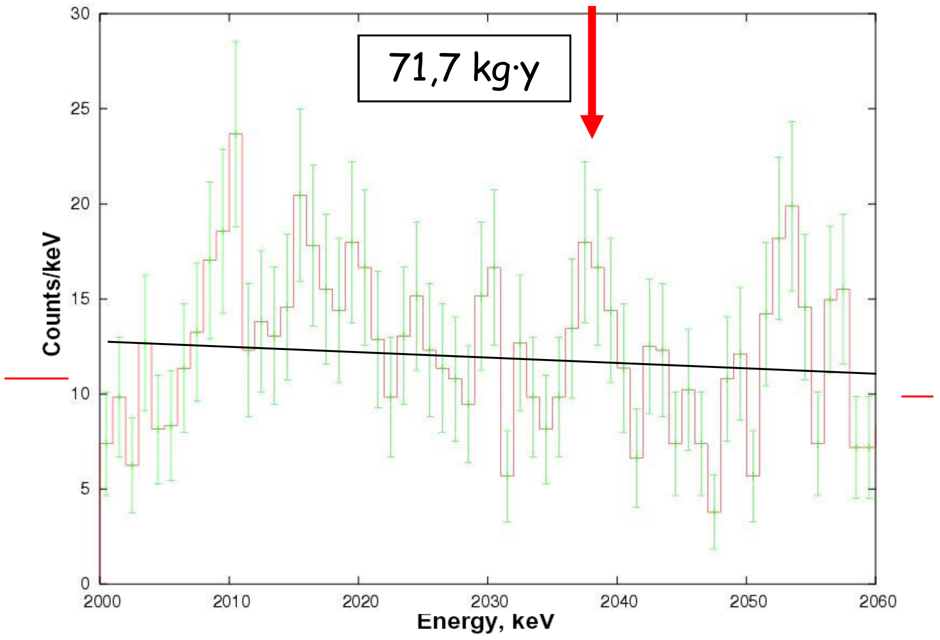
N_{Bkg}
0,19 counts y^{-1} kg^{-1} keV^{-1}
0,06 counts y^{-1} kg^{-1} keV^{-1} (SSE)

$$T^{0\nu}_{1/2} > 1.9\ 10^{25}\ \mathrm{y}\ (90\%\ \mathrm{C.L.})$$

$$< m_\nu > \ < 0.3 - 1.0\ \mathrm{eV}$$

Klapdor-Kleingrothaus et al. Eur Phys. J. 12 (2001) 147

Q_{bb}=2039 keV

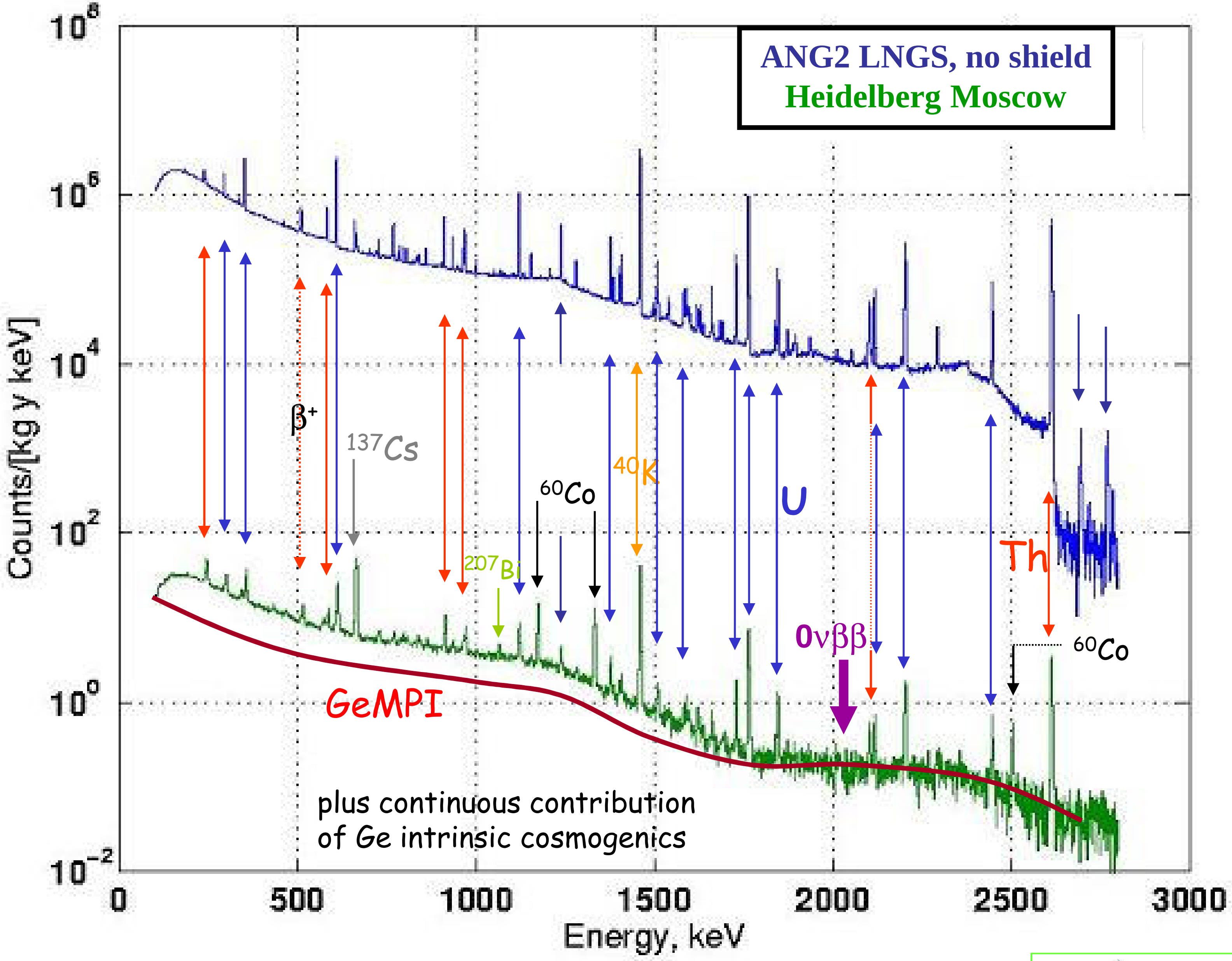


Evidence!!??

H. V. Klapdohr Kleingrothhaus and I. V. Krivosheina Modern Physics LetterA 21 (2006) 1547-1566

by application of two independent background suppression methods:
6 σ effect

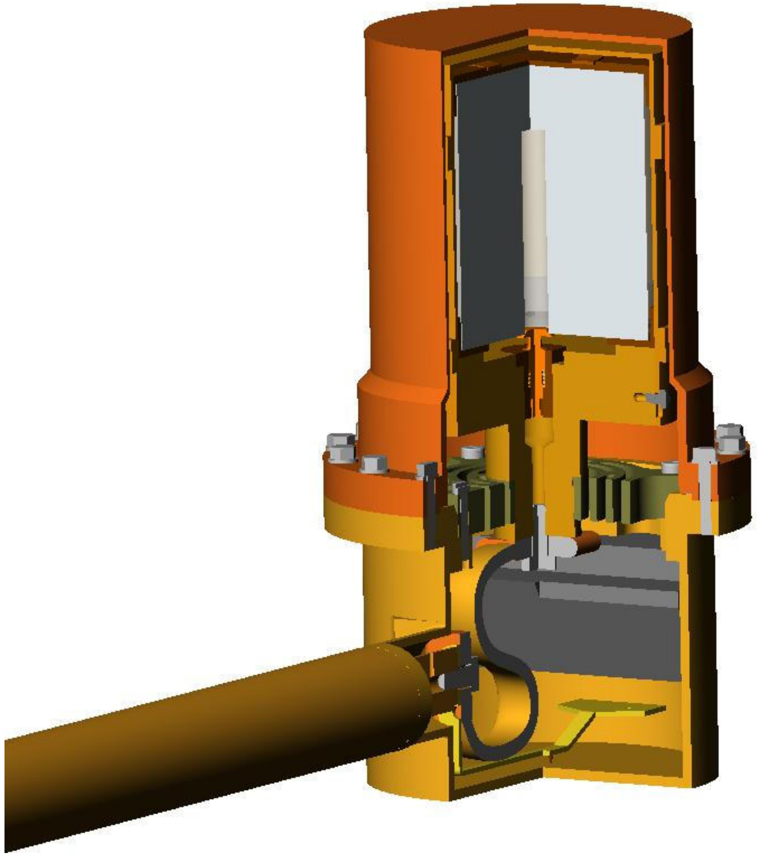
$$T_{1/2} = 2.23^{+0.44}_{-0.31} \times 10^{25}\ \mathrm{y}$$

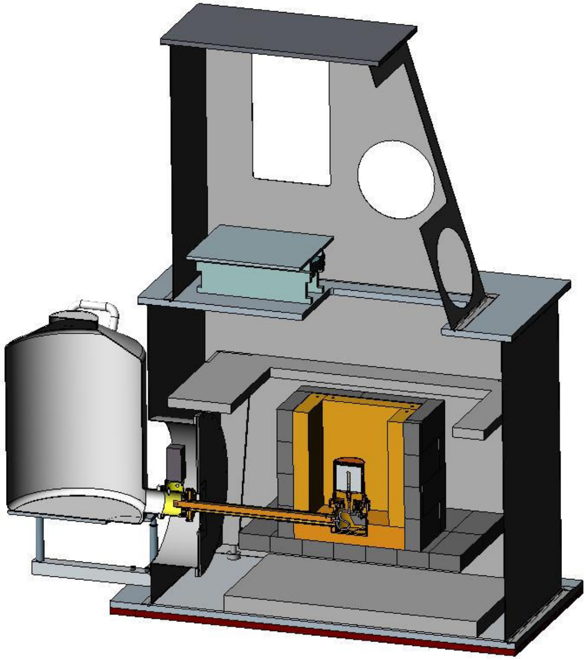


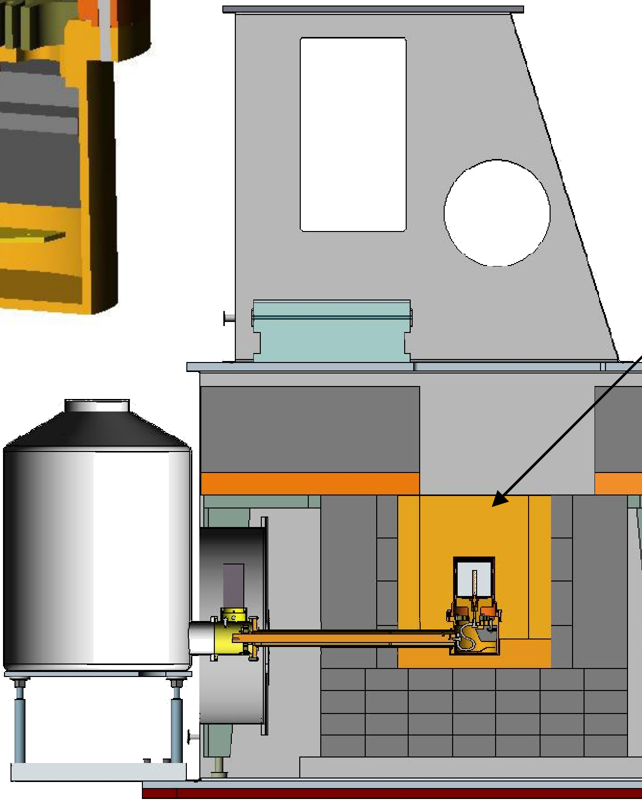
plus continuous contribution
of Ge intrinsic cosmogenics

GeMPI

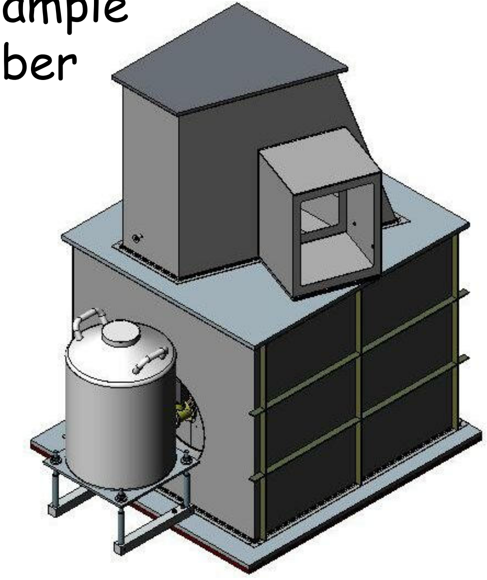
Ge spectrometer
of MPI at LNGS
since 1997







15 l sample chamber



Cu (NOSV) measurement with GeMPI

Cosmogenic* and primordial concentrations in Cu

radionuclide	halflife	activity [µBq/kg]	
cosmogenic		exposed	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 y	2100 ± 190	< 10
^{54}Mn	312.15 d	215 ± 21	
^{59}Fe	44.5 d	455 ± 120	
^{46}Sc	83.79 y	53 ± 18	
^{48}V	15.97 d	110 ± 37	
primordial			
^{226}Ra (U)	1600 y	< 35	< 16
^{228}Th (Th)	1.91 y	< 20	< 19
^{40}K	1.277×10^9 y	< 120	< 88

* saturation activity scaled after exposure at LNGS surface for 270 d

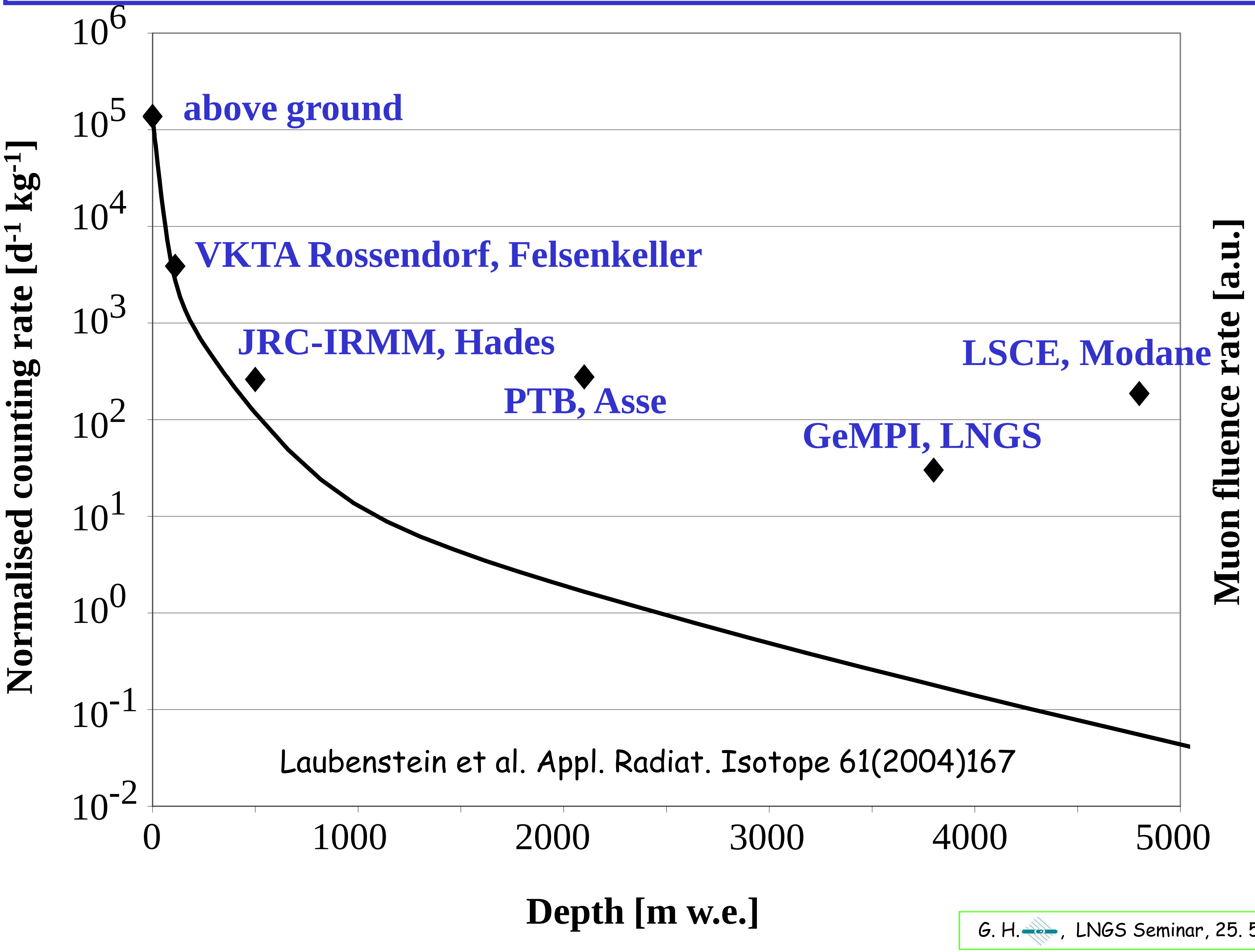
activity = PR/2.1 × $(1-e^{-\lambda t})$

⇨ ≤ 37 days of exposure

Measurement of lead with GeMPI

lead sample	weight	time	**specific activity [µBq/kg]**				
	[kg]	[d]	**^{226}Ra**	**^{228}Th**	**^{40}K**	**^{207}Bi**	**^{210}Pb**
DowRun	144.6	101.7	**< 29**	**< 22**	**440 ± 140**	**98 ± 24**	**$(2.7 \pm 0.4) \times 10^{7}$**
Boliden	144.3	75.0	**< 46**	**< 31**	**460 ± 170**	**< 13**	**$(2.3 \pm 0.4) \times 10^{7}$**
roman	22.1	37.2	**< 45**	**< 72**	**< 270**	**< 19**	**$< 1.3 \times 10^{6}$**
	bolometric measurement: Allesandrello et al. NIM B142 (1998) 163						**$< 4 \times 10^{3}$**

integral backgound rate of Ge spectrometer (Cellar-labs) as a function of muon flux



Laubenstein et al. Appl. Radiat. Isotope 61(2004)167

contamination of Cu [µBq/kg]
simulated for HDM detectors and measured

	^{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

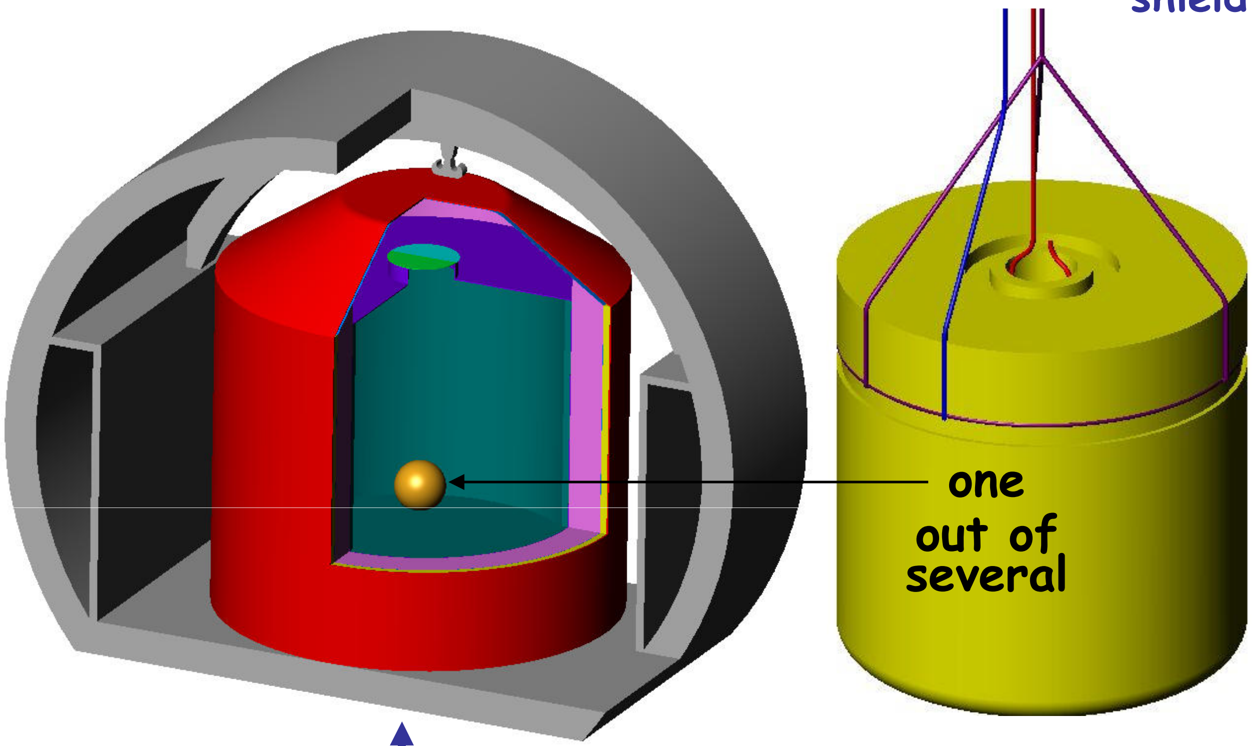
* 127 kg

M C simulation
Ch.Doerr,Uni HD
2002

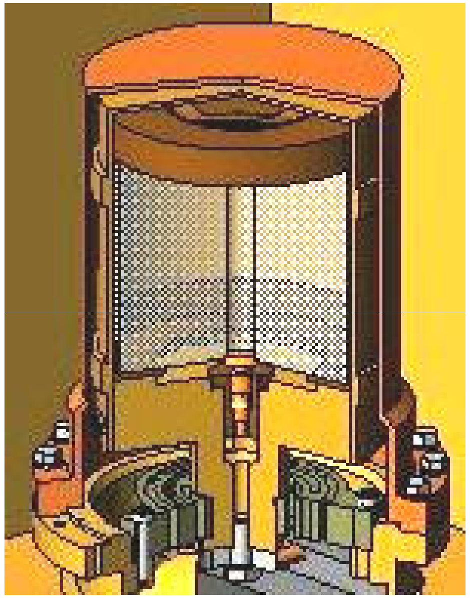
surface
contamination

naked Ge-crystals deployed in liquid nitrogen or argon

(cooling medium, insulator and shield against external radiation)



conventional detector crystal gladding

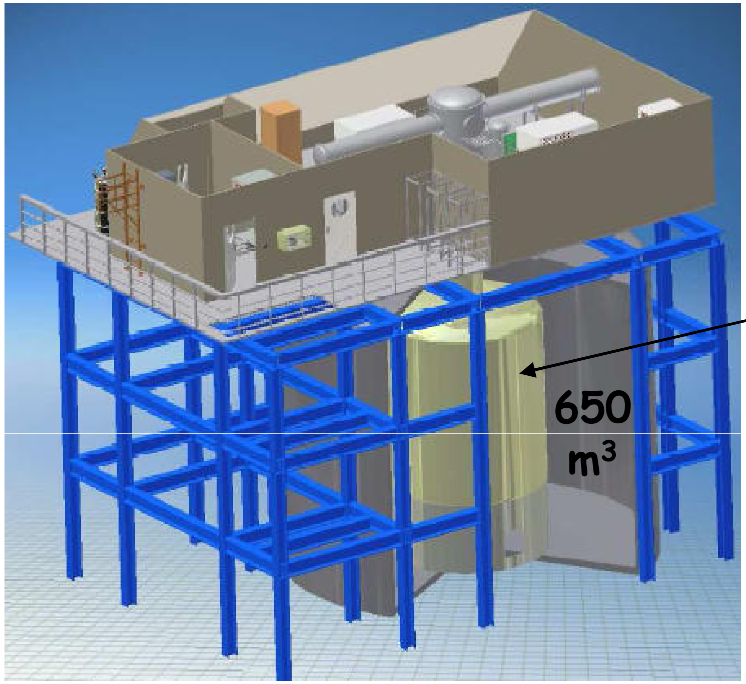


reduction of contact and gladding material:
about factor 7000 in mass, 200 in surface

not enough space at LNGS for full shielding by liquid N_2/Ar

GERDA

GERmanium **D**etector **A**rray for the search of neutrinoless double beta decay of ^{76}Ge



superinsulated stainless
steel cryostat with
internal Cu shield

low radioactivity stainless steel
(^{228}Th ≤ 5 mBq/kg)

Collaboration:

INFN LNGS, Assergi, Italy
JINR Dubna, Russia
IKTP Univ, Dresden, Germany
MPIK, Heidelberg, Germany
Univ. Köln, Germany
Jagiellonian University, Krakow, Poland
Univ. di Milano Bicocca e INFN, Milano, Italy
INR, Moscow, Russia
TEP Physics, Moscow, Russia
Kurchatov Institute, Moscow, Russia
MPI Physik, München, Germany
Univ. di Padova e INFN, Padova, Italy
Univ. Tübingen, Germany
Univ. Zürich, Switzerland

Spokesperson: Stefan Schönert, MPIK Heidelberg

Stainless steel measured for GERDA cryo tank

Steel 457.1			**Activity [mBq/kg]**							
sample			**primordial radionuclides**						**man made**	
heat **kg**	**#**	**plate** **hours**	^{226}Ra	^{234m}Pa	^{235}U	^{228}Th	^{228}Ra	^{40}K	^{137}Cs	^{60}Co
495243 54.75	G1	362891-1 76.6	≤ 1.3	≤ 94	≤ 2.6	≤ 0.2	≤ 2.6	≤ 2.8	0.77 ± 0.43	45.0 ± 2.1
494257 54.74	G2	347128-2 470	≤ 0.24	≤ 12	≤ 0.63	≤ 0.11	≤ 0.86	≤ 0.93	≤ 0.16	14.0 ± 0.1
494257 61,33	G6	347106-2 115.1	≤ 0.35	≤ 38	≤ 1.5	≤ 0.27	≤ 1.1	≤ 1.1	≤ 0.39	13.0 ± 0.6
T506095 57.6	G3	50609522 74.5	≤ 0.74	≤ 45	≤ 1.5	≤ 0.41	≤ 1.0	≤ 1.1	≤ 0.26	13.8 ± 0.7
255455 52.86	G4	68558 88.7	≤ 13	≤ 41	≤1.9	5.1 ± 0.5	≤ 3.0	≤ 1.7	≤ 0.36	20 ± 1
254533 53.15	G5	56754 230.4	1.0 ± 0.6	54 ± 16	2.5 ± 1.5	1.5 ± 0.2	1.0 ± 0.5	≤ 0.81	≤ 0.1	18.3 ± 0.7
255772 55,0	G7	71459 144.5	3.9 ± 1.6	≤ 56	≤ 3.9	5.2 ± 0.5	1.9 ± 1.0	≤ 1.7	≤ 0.6	42.1 ± 1.9

Cosmic ray induced isotopes in stainless steel (FeCrNiMo) measured for GERDA

Steel 457.1	activity [mBq/kg]					
sample	cosmogenic radionuclide					
$T_{1/2}$ →	^{7}Be 53.3 d	^{54}Mn 312.2 d	^{58}Co 70.9 d	^{56}Co 77.3 d	^{46}Sc 83.8 d	^{48}V 16.0 d
Production → channels	spallation	^{56}Fe(n,p2n) (μ^-,v2n)	^{60}Ni(n,p2n) (μ^-,v2n) ^{58}Ni(n,p)	^{58}Ni(n,p2n) (μ^-,v2n)	^{48}Ti(n,p2n) (μ^-,v2n) spallation on Fe	^{50}Cr(n,p2n) (μ^-,v2n) spallation on Fe
G1	≤ 3.9	1.3±0.4	0.67±0.34	≤ 0.32	≤ 0.35	0.30±0.11
G2	≤ 3.0	1.5±0.1	0.99±0.12	0.17±0.06	0.24±0.06	0.36±0.07
G3	≤ 5.7	0.92±0.24	0.56±0.23	≤ 0.62	≤ 0.54	0.27±0.11
G4	9.6±2.9	2.0±0.3	0.71±0.26	≤ 0.71	≤ 0.67	0.31±0.13
G5	4.8±1.7	1.7±0.2	0.69±0.16	0.28±0.10	0.47±0.14	0.22±0.09
G6	13.6±2.5	1.4±0.2	0.59±0.20	≤ 0.42	≤ 0.31	0.40±0.12
G7	≤ 5.9	1.6±0.3	0.54±0.27	≤ 0.6	0.61±0.26	0.39±0.13
P.Rate *sea level* [(10^3 sec)$^{-1}$ kg^{-1}]	*4.5±0.7*	*2.7±0.3*	*0.6±0.09*	*0.24±0.04*	*0.22±0.04*	*0.4±0.04*

3.2 mBq/kg (Heusser, 1994)

^{51}Cr: *2.0±0.7* ^{52}Mn: *0.35 ± 0.25* ^{56}Ni: *0.17 ± 0.05* [mBq/kg]

^{60}Co before: **11.1±0.5** after: **11.5±0.6** [Bq/kg]

irradiation time

← 327 d at sea level

underground than exposed for 314 d at LNGS surface (≈ 907 g/cm2)

≈ 200 d

≈ 600 d

all others are compatible with saturation

34.6 ± 5.3 measured at Heidelberg 63 days earlier

⇨ ^{7}Be not produced in cito, but contamination from filtration dust (up to 40 kBq/kg, Wershofen PTB)

← normalized to sea level (× 0.42)

GERDA phase I and II

Phase I: use 5 Heidelberg-Moscow and 3 IGEX detectors

estimated background: 0.01 Counts/(kg keV y) @ 2040 *keV*

exposure: 15 kg years

aim: is to confirm/refute claim

Phase II: plus 20 kg enriched material

envisioned Background: 0.001 Counts/(kg keV y) @ 2040 *keV*

exposure: 100 kg y

discovery potential to $T_{1/2} \approx 5 \cdot 10^{25}$ yrs,

limit setting to $1.5 \cdot 10^{26}$ yrs.

requires better suppression of cosmogenic ^{60}Co and ^{68}Ge in Ge crystals

discrimination of Multi Site Events (MSE) (e.g. Compton bgd.) from Single Site Events (SSE) (e.g. $0\nu\beta\beta$) by:

a) segmentation of germanium detectors
b) pulse shape analysis with BEGe-like (point contact) germanium detectors
c) detection of scintillation light of liquid argon sourrounding the crystal (beeing studied with LARGE)

Conclusion and future developments

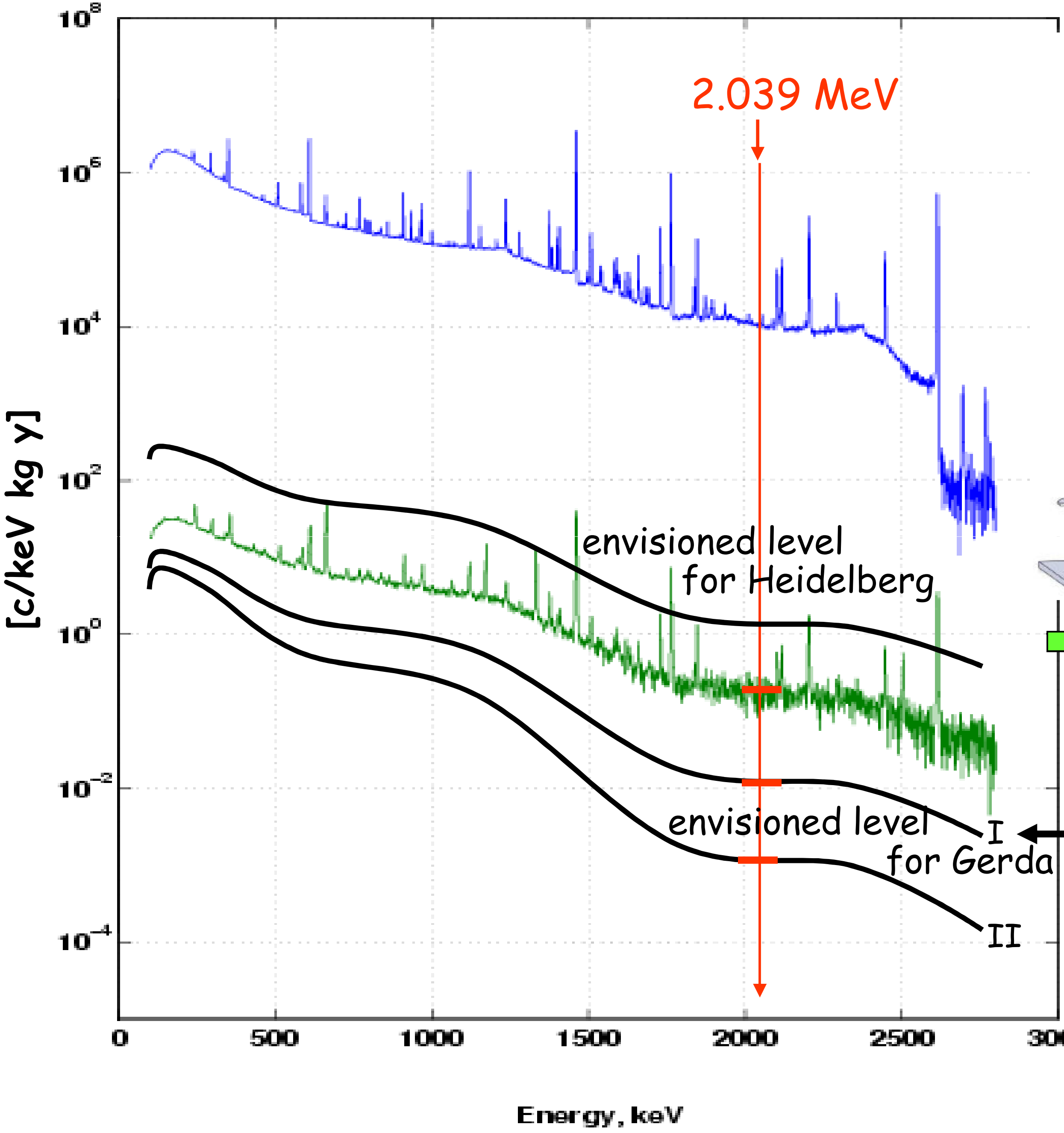
- highly sensitive Ra/Rn assay by Rn counting with miniature proportional counters
  - well suited for surface contamination studies (^{226}Ra typical contamination indicator)
  - applicable for assay of radioactive noble gases in liquid rare gas experiments
- Ge spectroscopy very powerful screening tool, also to control secular equilibrium
- hopeful development in 'clean' stainless steel production by electric arc melting

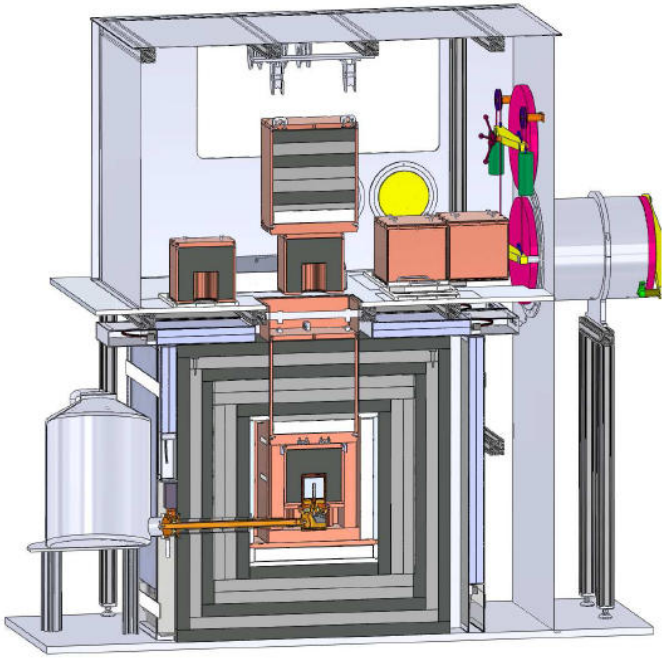
future needs:

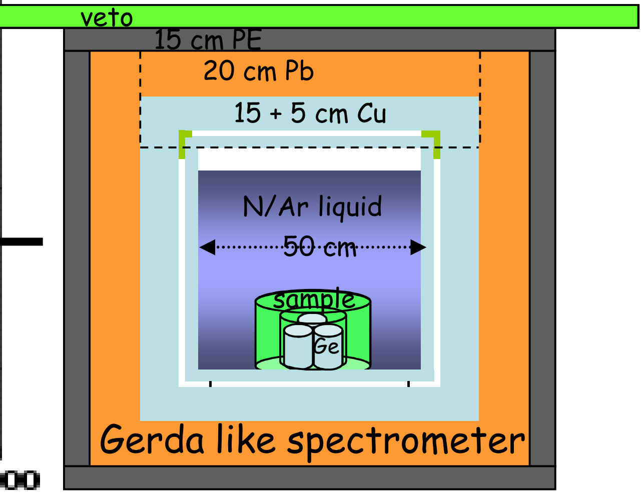
- study behavior of ^{210}Po, develop screening methods (liquid scintillation ?)
- systematic study of surface contamination
- upgrade Ge spectroscopy

GIOVE

Germanium **I**nner **O**uter **VE**to







assume ^{228}Th in Cu ≤ 5µBq/kg