Shielding Strategies

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Application of Germanium Detector in Fundamental Research
Tsinghua University Bejing, March 24 - 26, 20011

Introduction

Shielding against external background
- cosmics
- natural long-lived activities
- examples

Surface contamination

Intrinsic background

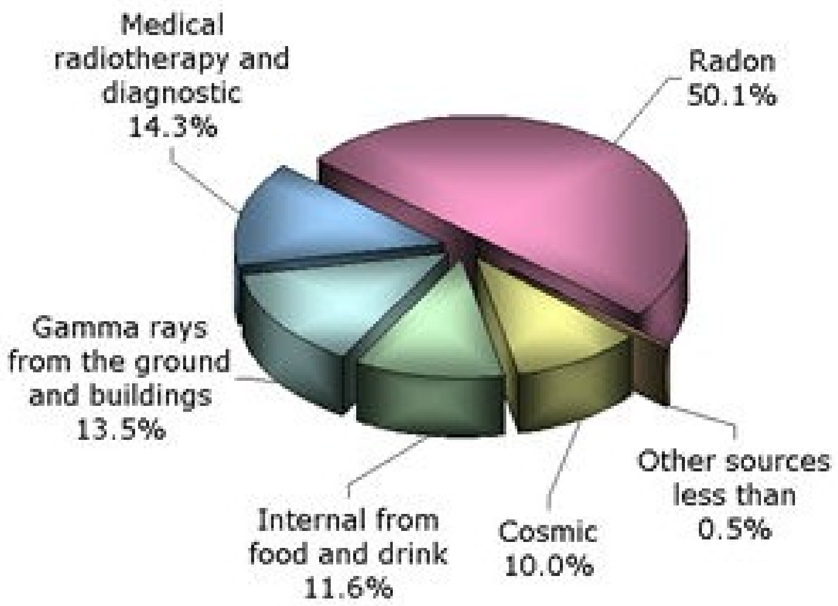
Ultimate designs?

Conclusion

passive shields

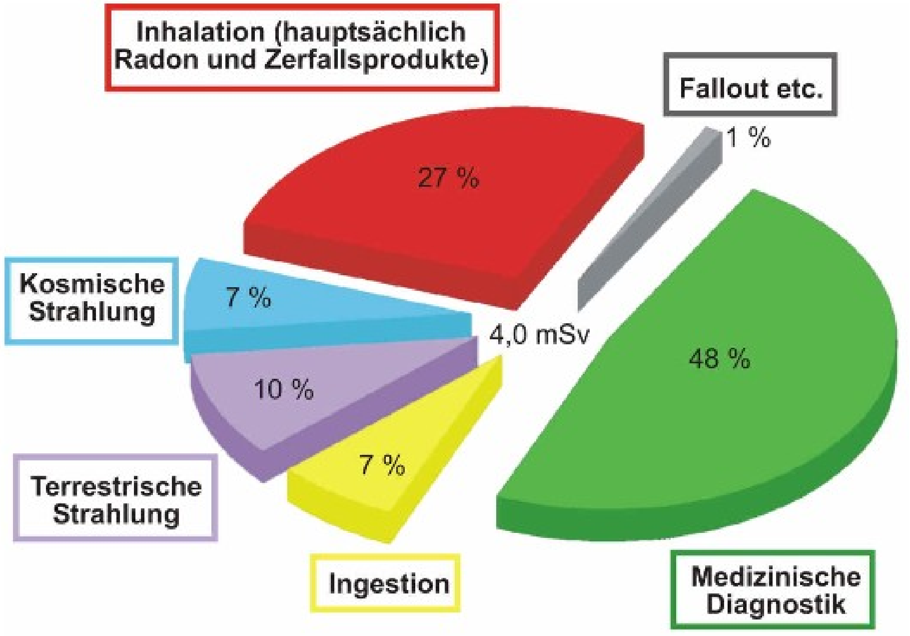
active shields

England



total: 2.6 mSv / a
(NPL-UK 2008)

Germany



(PTB-BMU 2003)

1mSv ~ 80 kBq

Ge-76

$$T_{1/2} = \frac{\ln 2 \cdot \mathbf{Natom} \cdot \text{time}}{\mathbf{Ndcy}} = \frac{5.47 \cdot 10^{24} \cdot (\text{mass / kg}) \cdot (\text{time / yrs})}{\mathbf{Ndcy}} \quad [\text{yrs}]$$

- 90% confidence limit (C.L.) in case of zero event (F.C.: **Ndcy**=2.44):

$T_{1/2}$ > 2.2 · 10^{24} (m / kg)·(t / yrs) [yrs]

► increase mass and time, too naïve:

2) sensitivity in case of background :

Ndcy ► $\sqrt{\mathbf{Nbgnd} + \mathbf{Ndcy}} \sim c\sqrt{b \cdot m \cdot t \cdot \Delta E}$

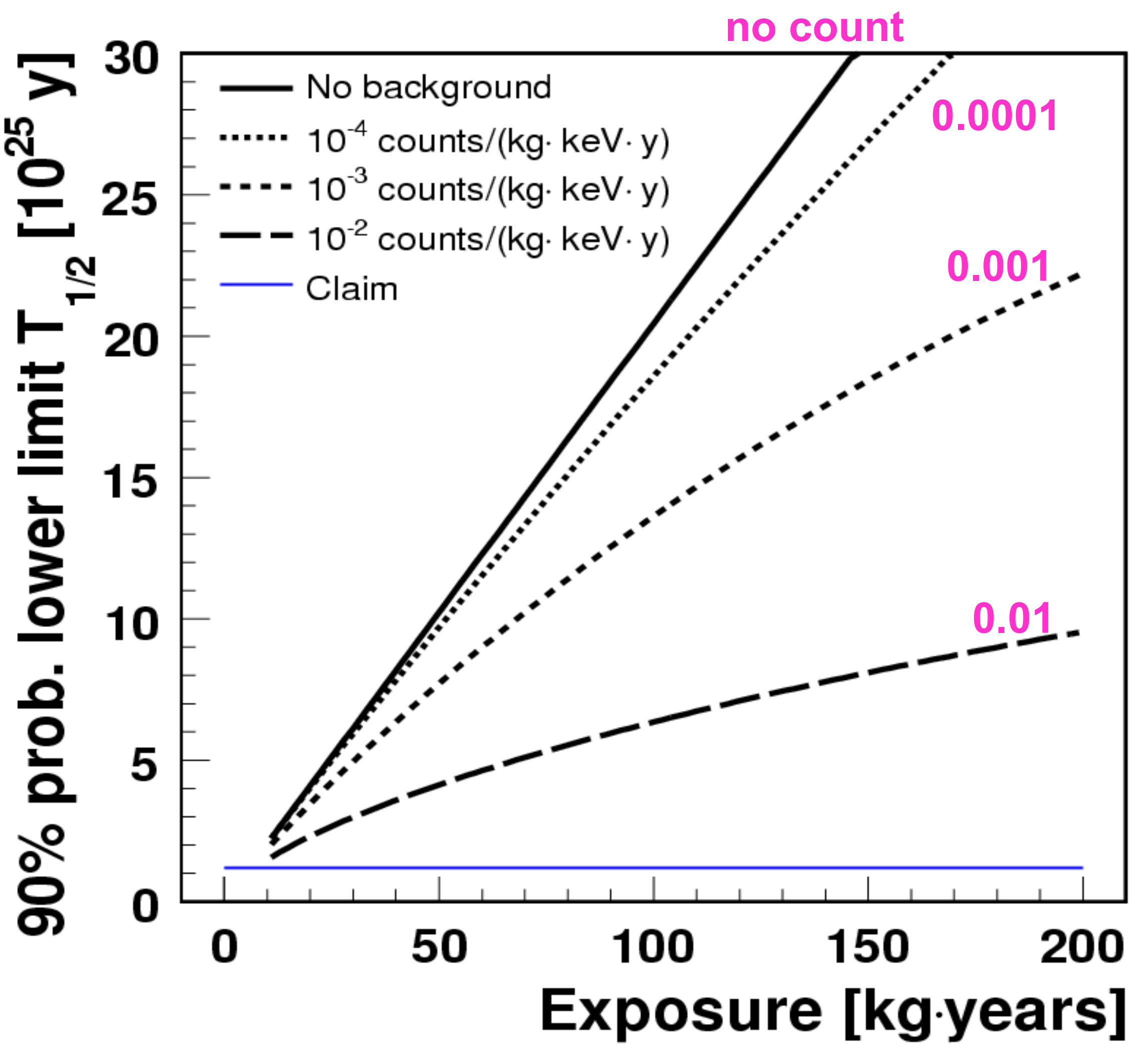
	Ge-76
b: background index in [cts/(kg·keV·yrs)]	0.1
ΔE: resolution [keV]	3.3

$T_{1/2}$ > const $\sqrt{(m \cdot t) / (B \cdot \Delta E)}$

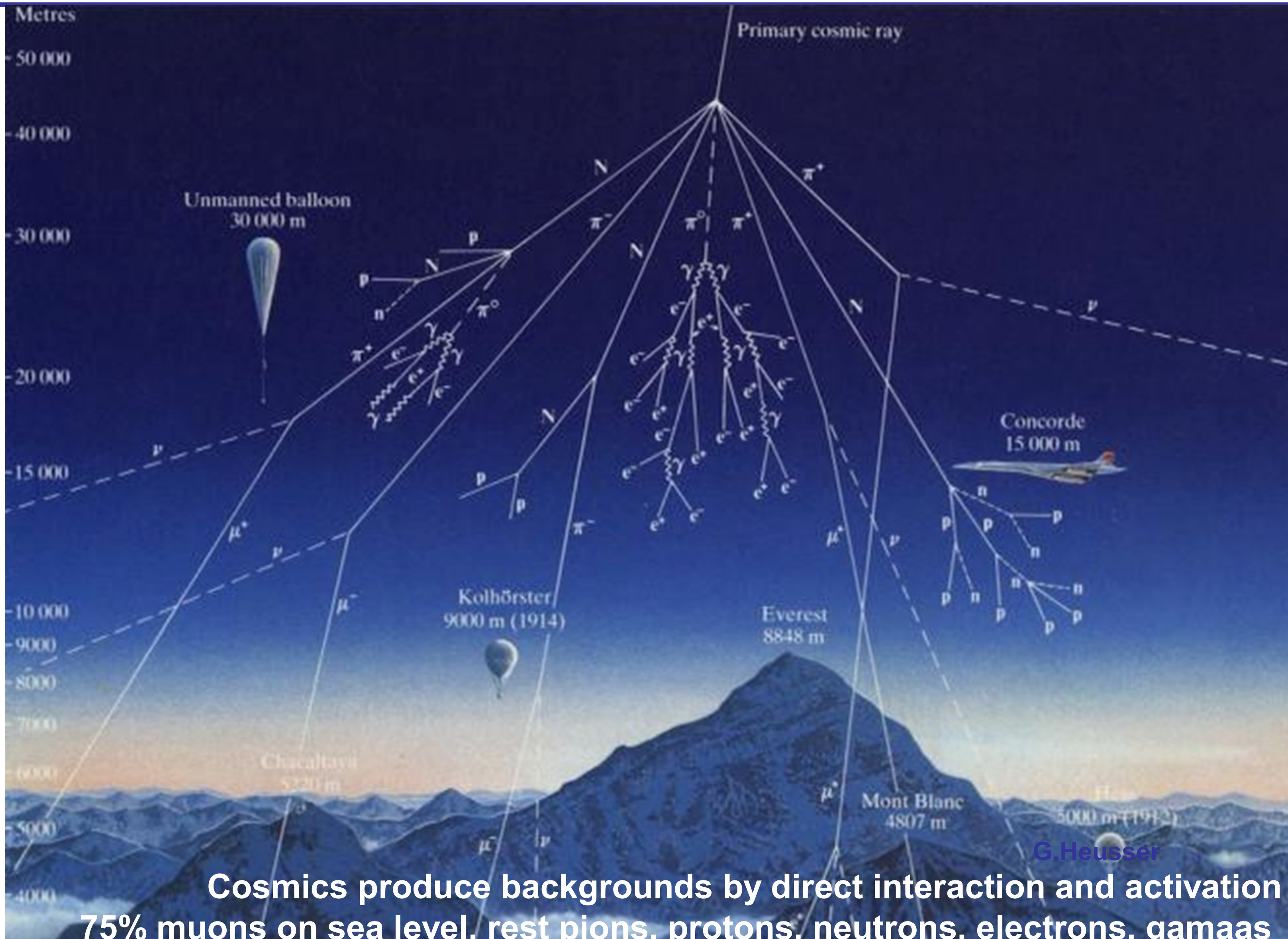
$$T^{0\nu}_{1/2}(n_\sigma) = \frac{4.16 \times 10^{26} y}{n_\sigma} \left(\frac{\varepsilon a}{W}\right) \sqrt{\frac{Mt}{b\Delta(E)}}$$

*RevModPhys 80(08)481

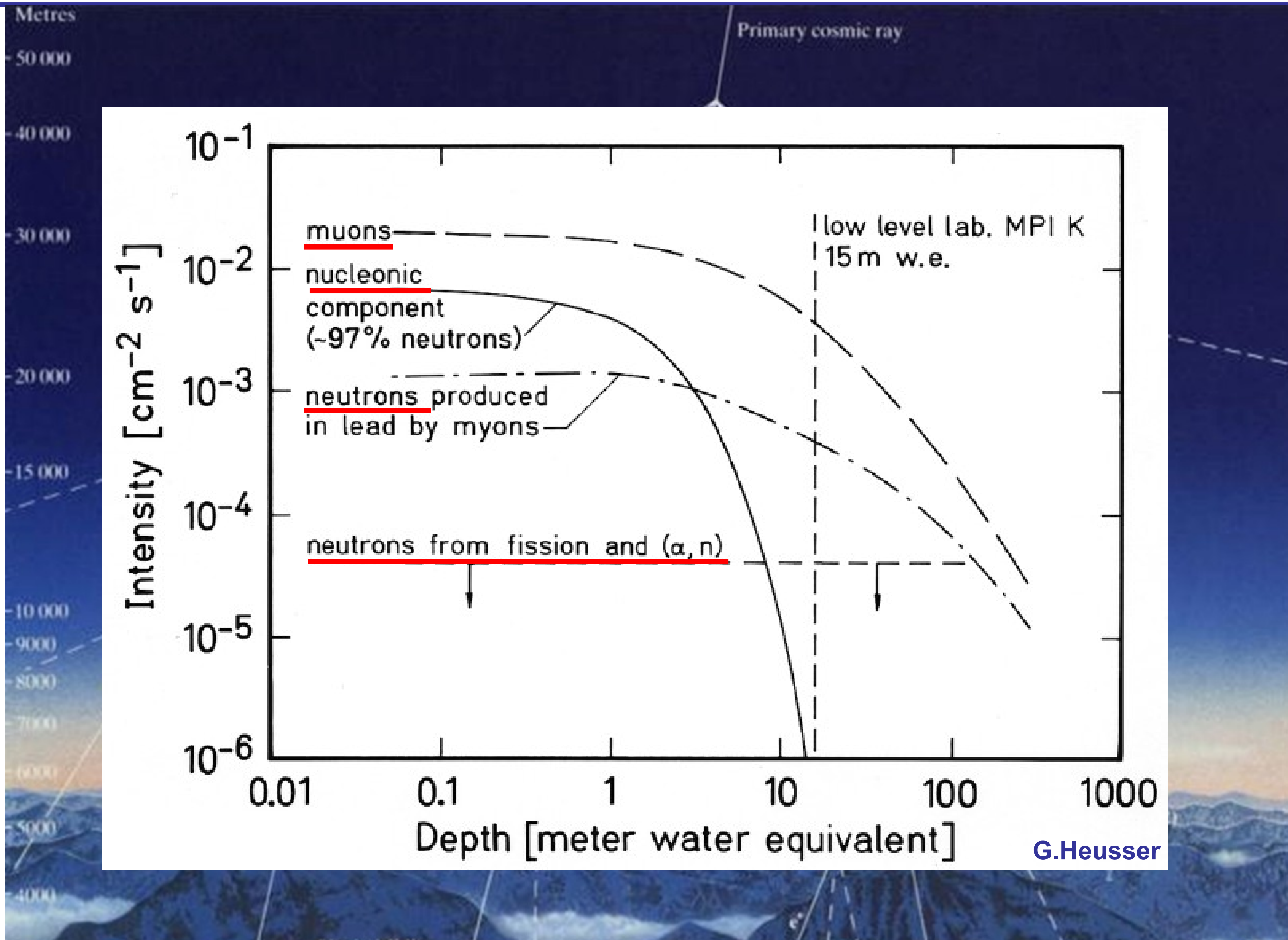
► reduce background index b ◄
► optimize energy resolution ΔE◄

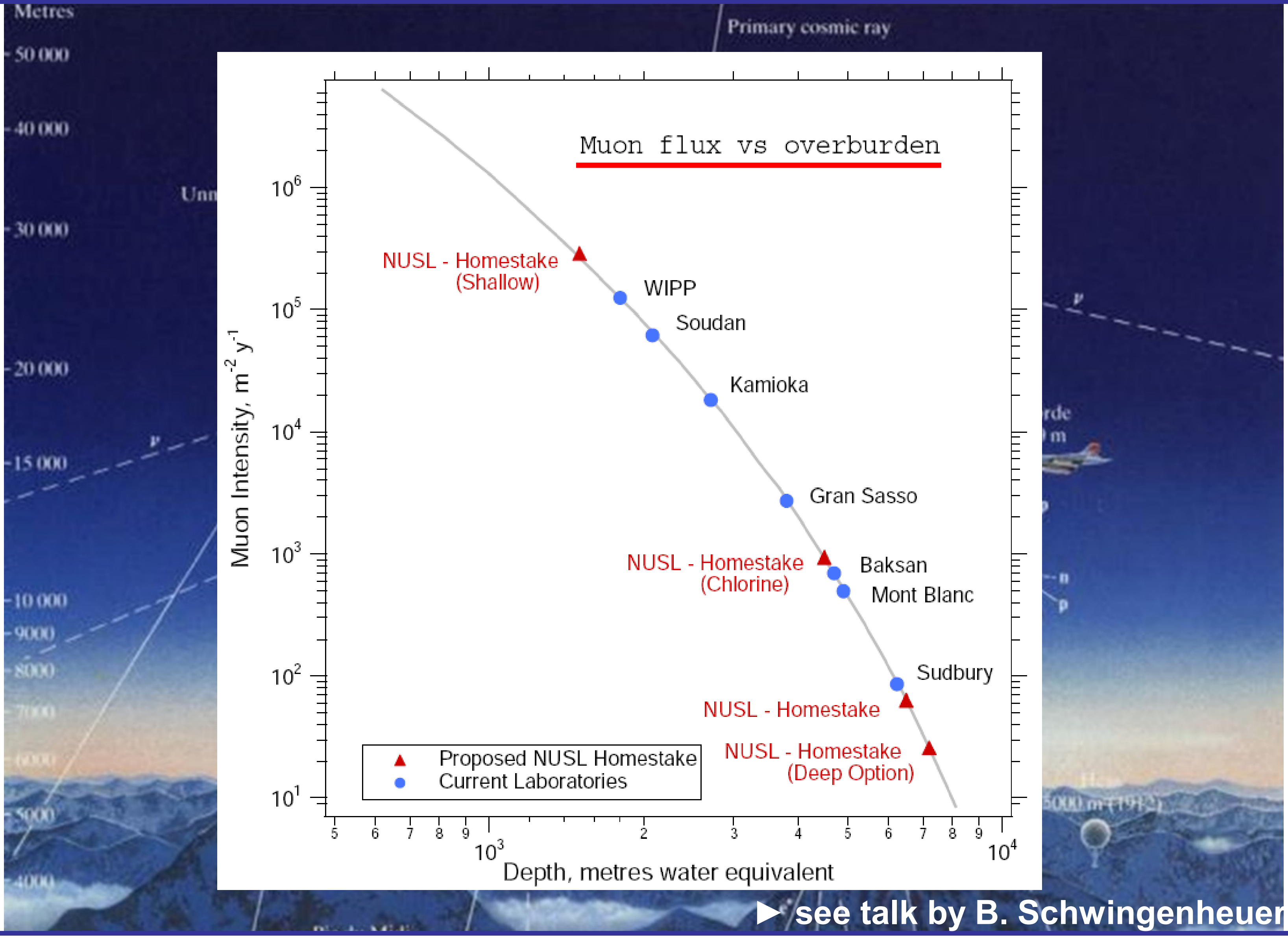


Caldwell & Kröninger, PRD74 (2006) 092003

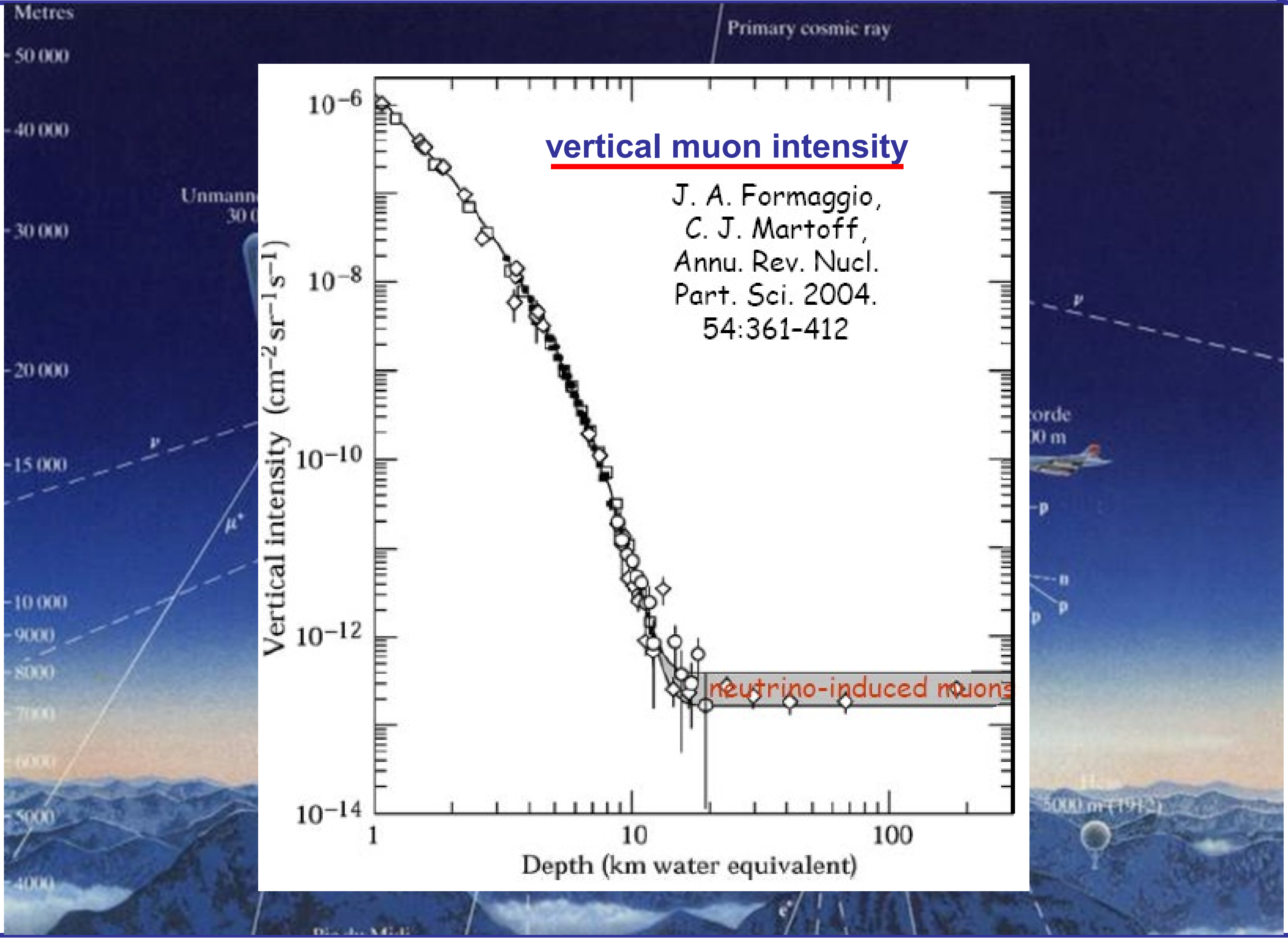


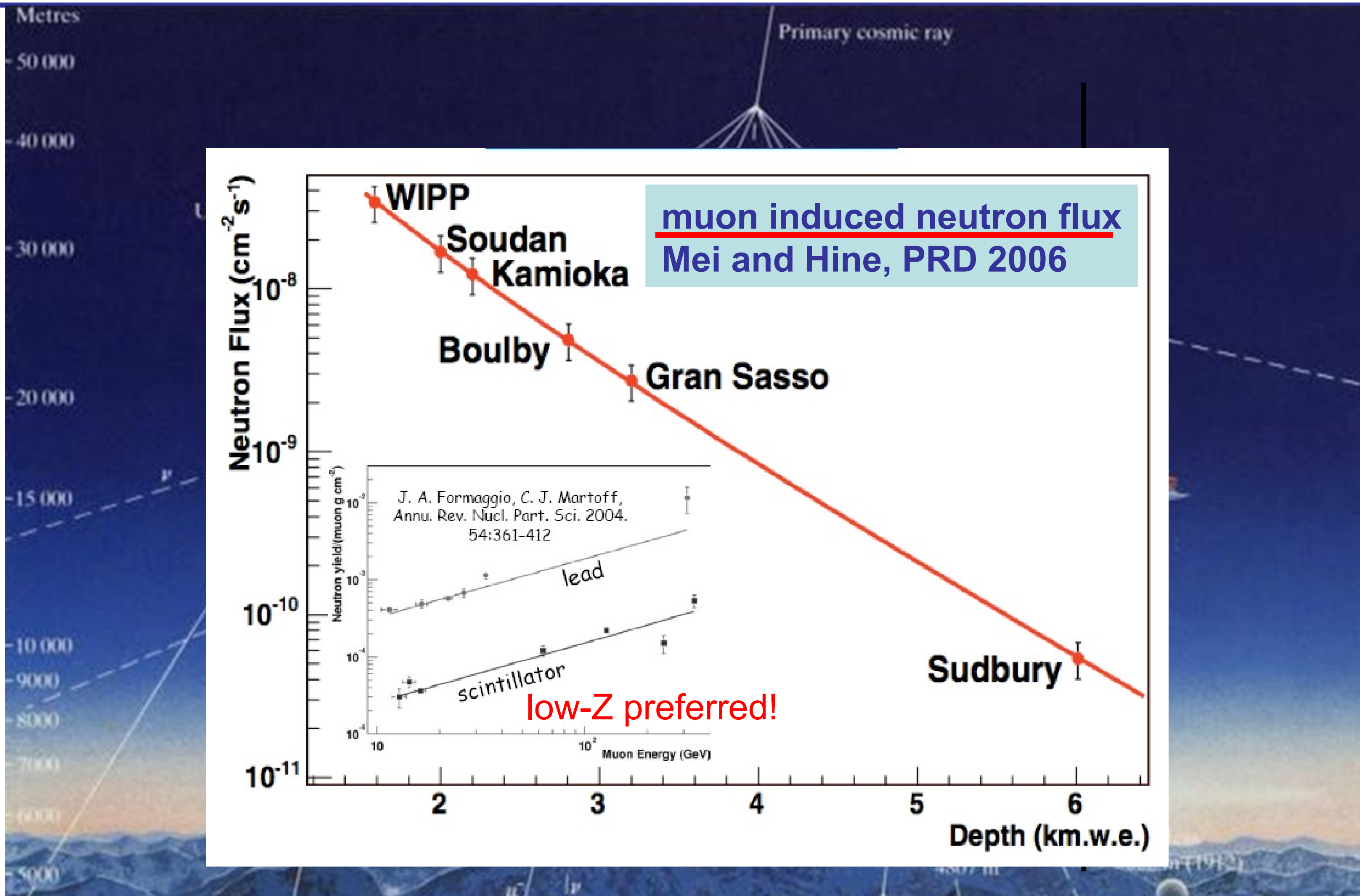
Cosmics produce backgrounds by direct interaction and activation
75% muons on sea level, rest pions, protons, neutrons, electrons, gamaas


Metres
50 000
40 000
30 000
20 000
15 000
10 000
9000
8000
7000
6000
5000
4000
Primary cosmic ray
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
Intensity [cm^{-2} s^{-1}]
muons
nucleonic
component
(~97% neutrons)
neutrons produced
in lead by myons
neutrons from fission and (α, n)
low level lab. MPI K
15 m w.e.
0.01
0.1
1
10
100
1000
Depth [meter water equivalent]
G.Heusser

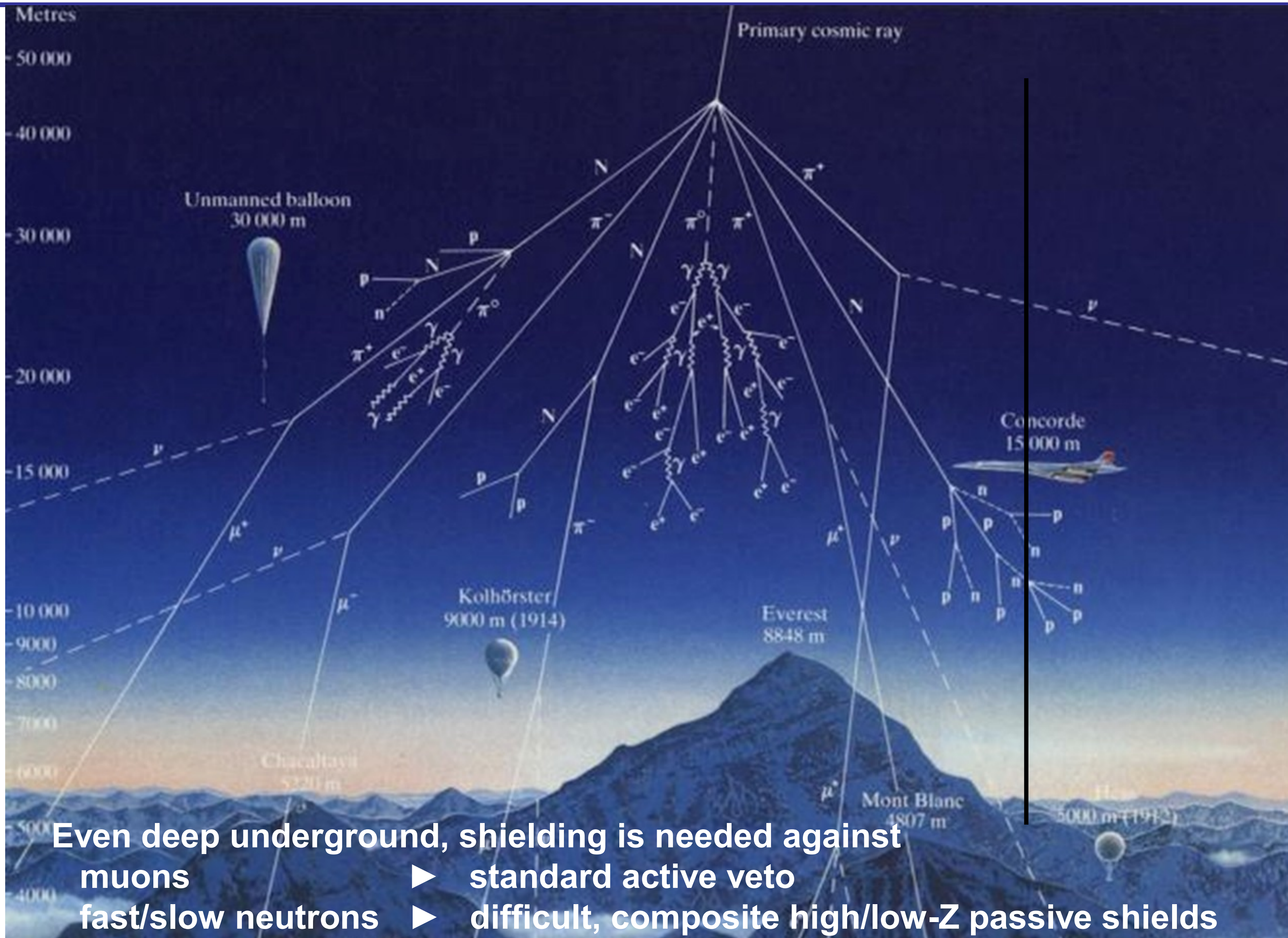


► see talk by B. Schwingenheuer


vertical muon intensity
J. A. Formaggio, C. J. Martoff, Annu. Rev. Nucl. Part. Sci. 2004. 54:361-412
neutrino-induced muons
Vertical intensity (cm^{-2}sr^{-1}s^{-1})
Depth (km water equivalent)
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
1
10
100
Metres
50 000
40 000
30 000
20 000
15 000
10 000
9000
8000
5000
4000
Primary cosmic ray

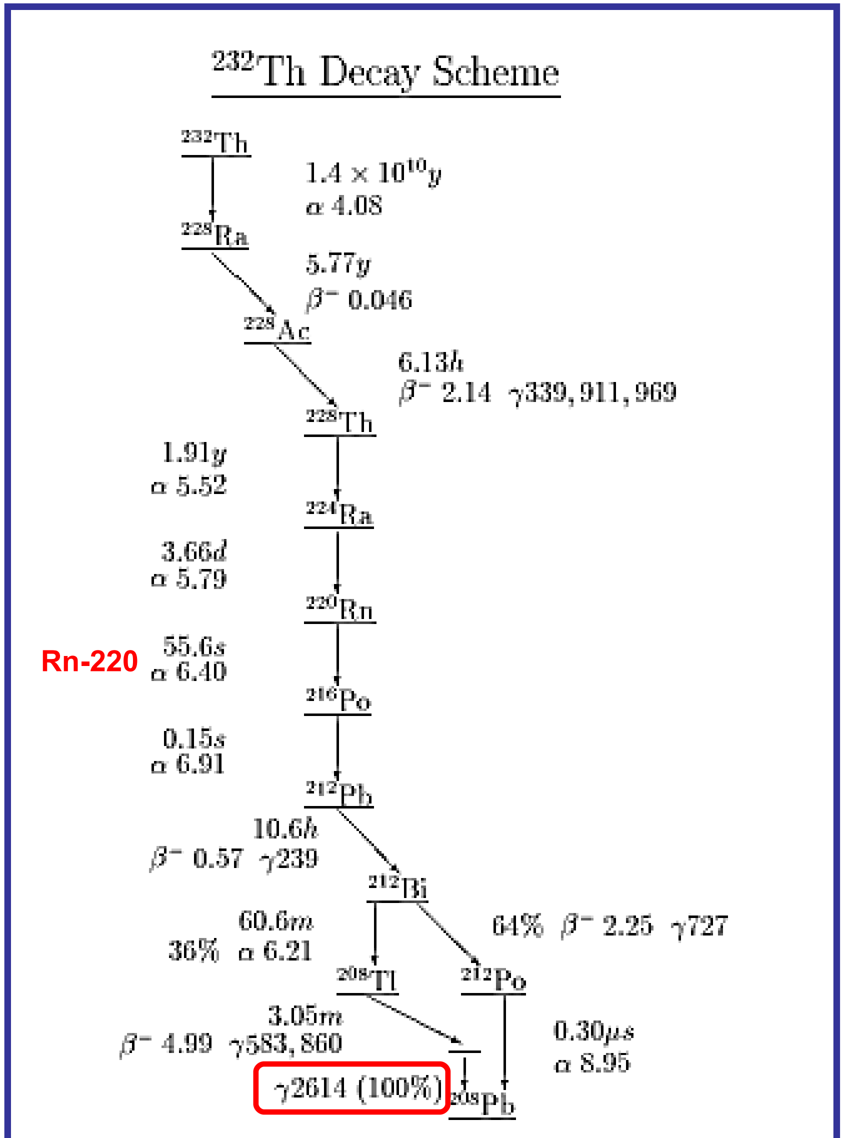


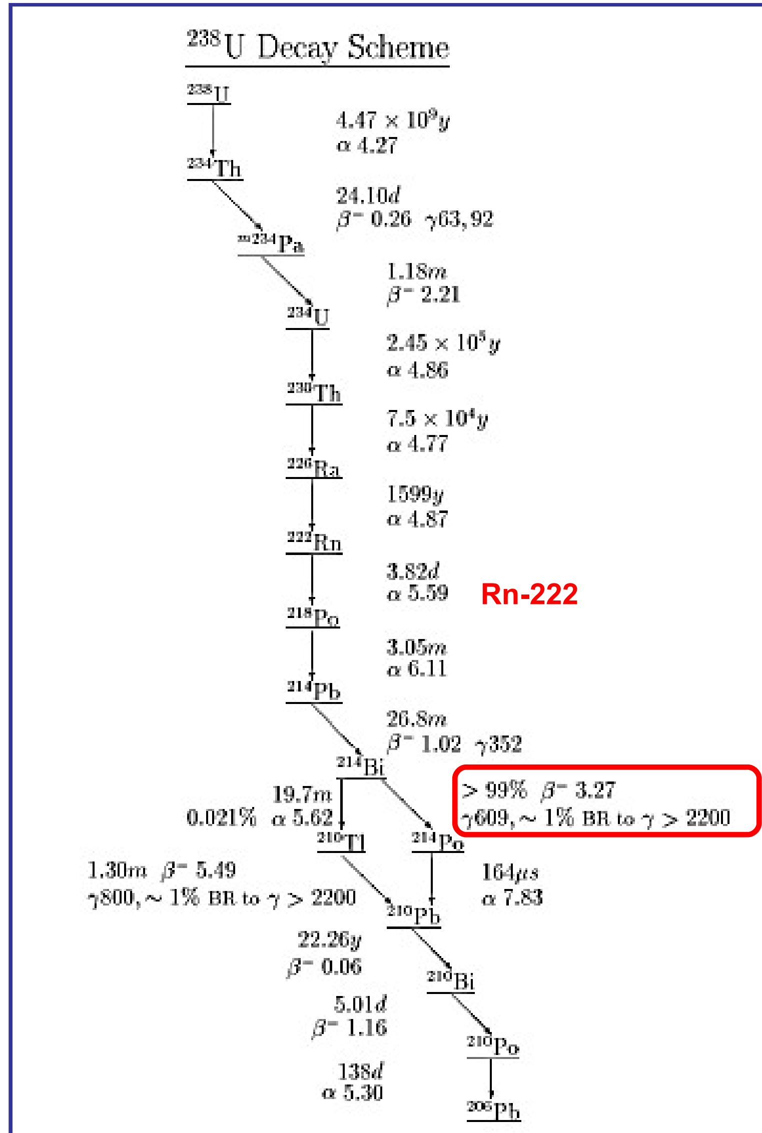
NB: Low energy neutrons are also produced by fission and (α,n) reactions!
Conflicting predictions for hard component spectrum, ► measure n-spectra



Even deep underground, shielding is needed against
- muons ► standard active veto
- fast/slow neutrons ► difficult, composite high/low-Z passive shields

natural long-lived activities





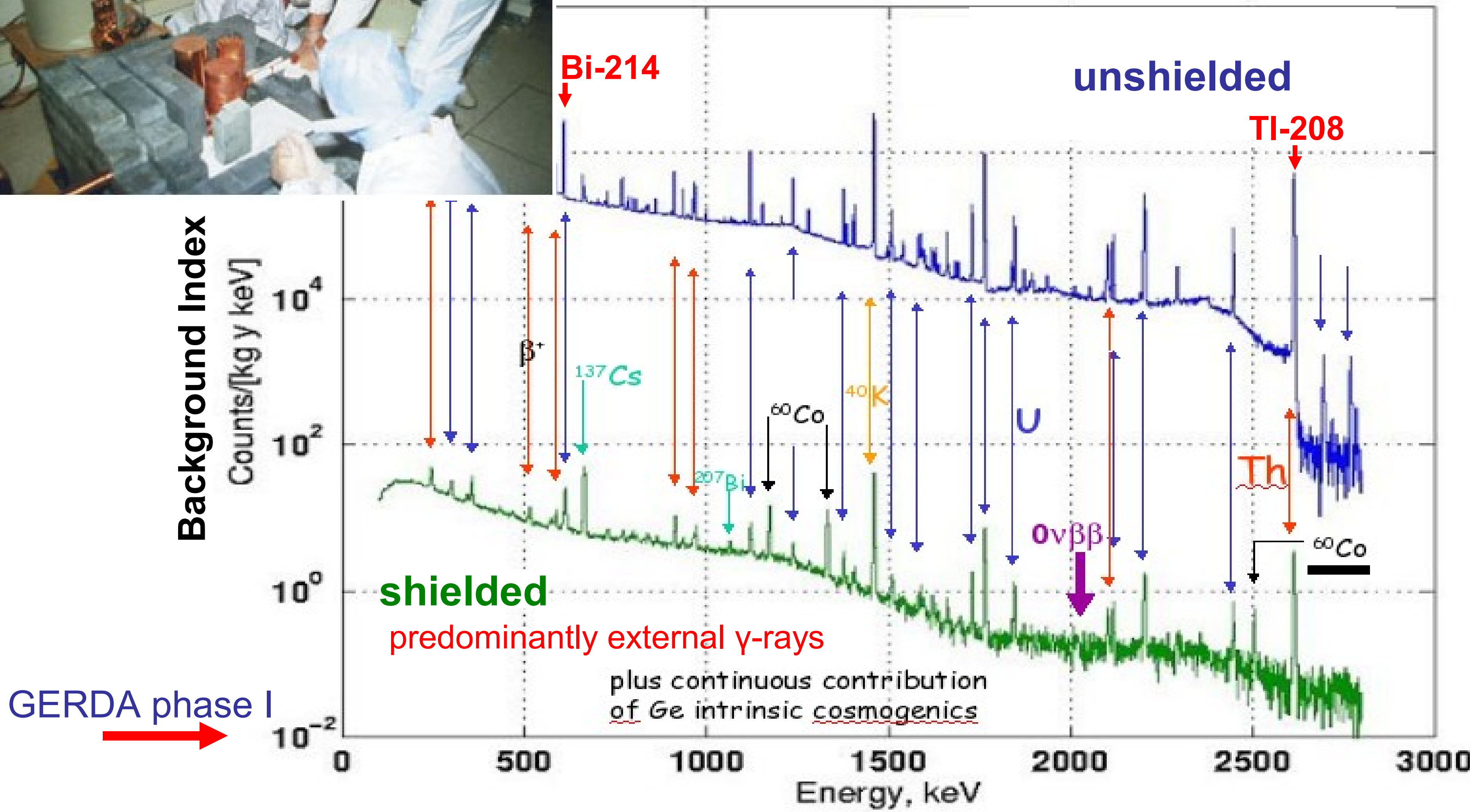
Rn-222 (Rn-220,-219):

- gaseous, highly volatile/penetrating!
  ~40 Bq/m^3 , in salt mines less
  (screen materials and setup)

- UHV tight experimental setup,
  (metal seals only)

background spectra

spectra measured at LNGS with Ge diode

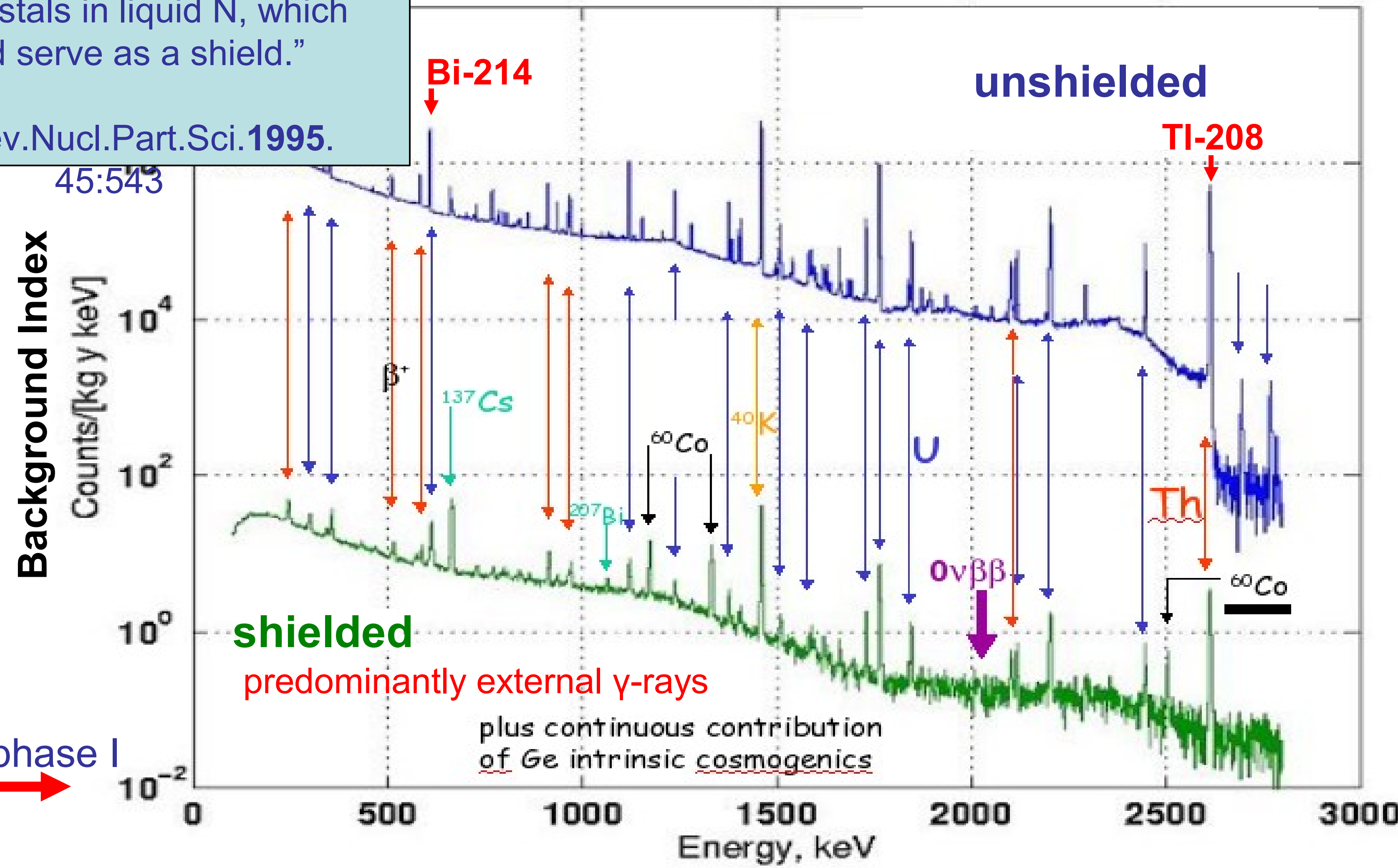


Gerd Heusser
:
“One option for background reduction is to immerse the almost bare crystals in liquid N, which would serve as a shield.”

Ann.Rev.Nucl.Part.Sci.**1995**.
45:543

background spectra

spectra measured at LNGS with Ge diode

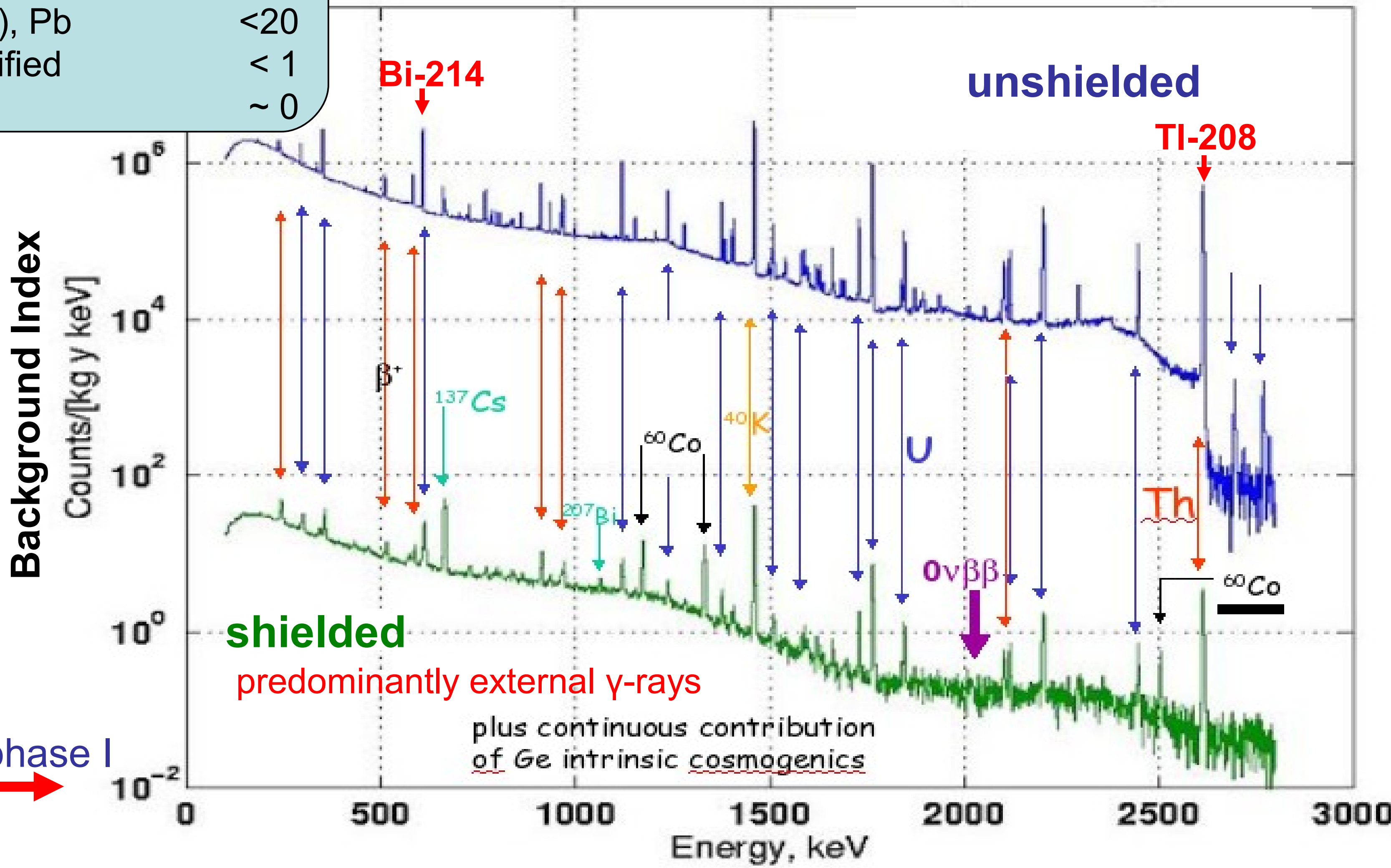


GERDA phase I

background spectra

Activity of Tl-208	(µBq/kg)
rock, concrete	3000000
stainless steel	~ 5000
Cu(NOSV), Pb	<20
water, purified	< 1
LN2, LAr	~ 0

spectra measured at LNGS with Ge diode

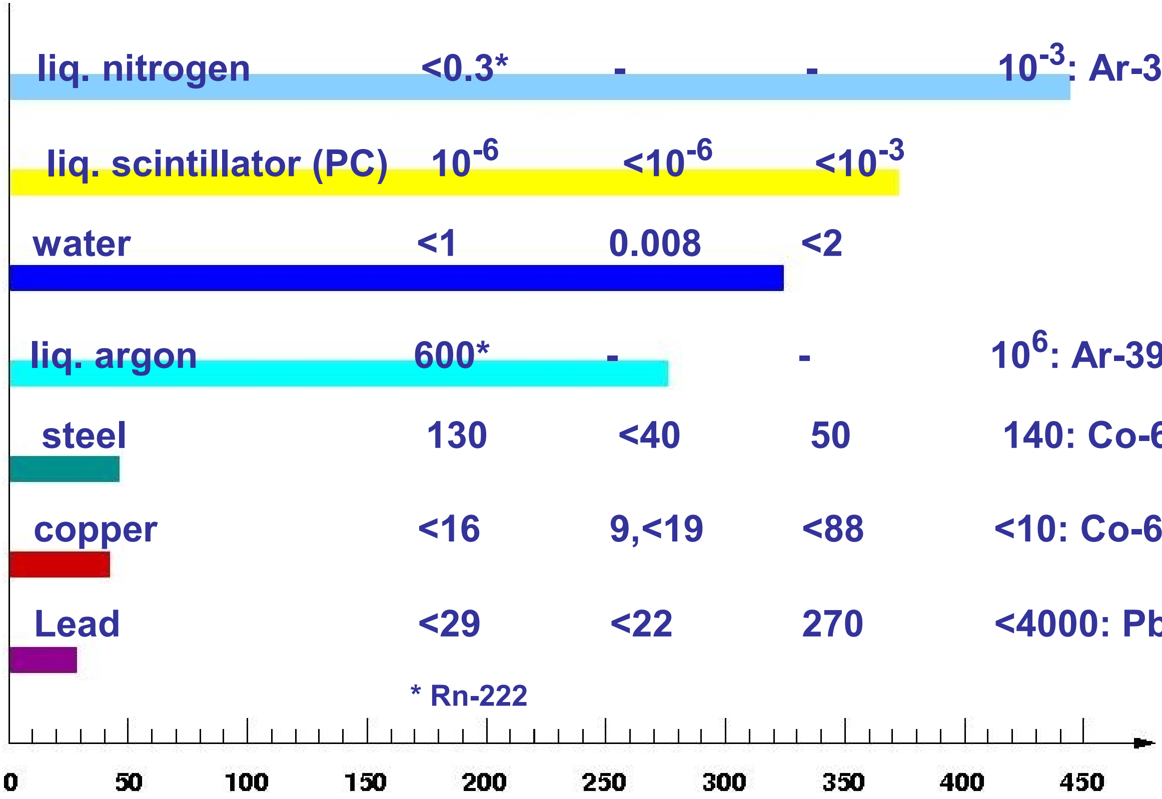


GERDA phase I

intrinsic contamination of shielding materials

Material	activity [µBq / kg]			
	Ra-226 (U)	Th-228	K-40	misc
liq. nitrogen	<0.3*	-	-	10^{-3}: Ar-39
liq. scintillator (PC)	10^{-6}	$<10^{-6}$	$<10^{-3}$	
water	<1	0.008	<2	
liq. argon	600*	-	-	10^{6}: Ar-39, ~150:Ar-42
steel	130	<40	50	140: Co-60
copper	<16	9,<19	<88	<10: Co-60
Lead	<29	<22	270	<4000: Pb-210

* Rn-222



Thickness for 10^{-6} attenuation of 2.61 MeV gamma rays [cm]

Data from G. Heusser , LNGS DBD workshop 2010

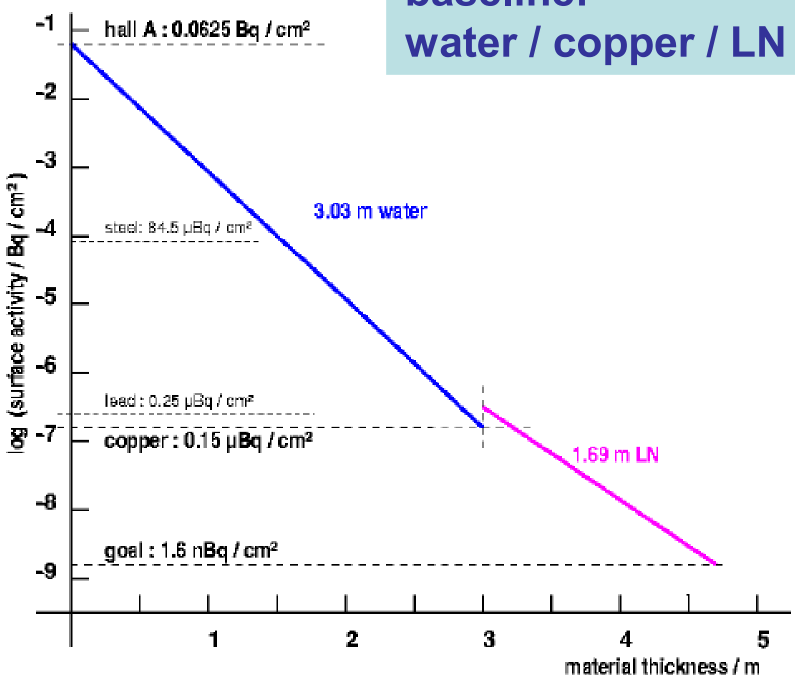
GERDA graded shield options

(none of them implemented!)

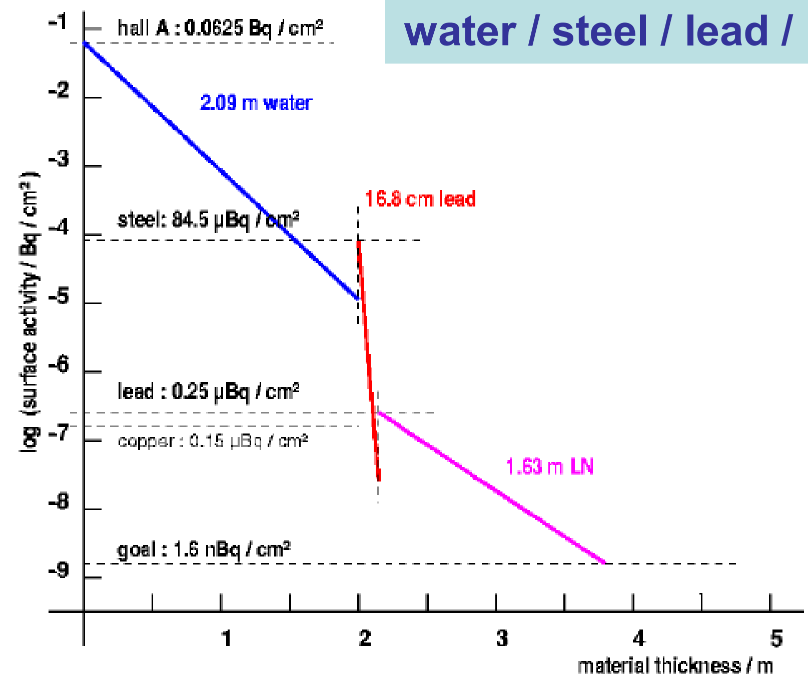
required attenuation factor $2.5 \cdot 10^{-8}$

log(surface activity for 2.6 MeV y) [Bq/cm2]

baseline:
water / copper / LN



alternative:
water / steel / lead / LN



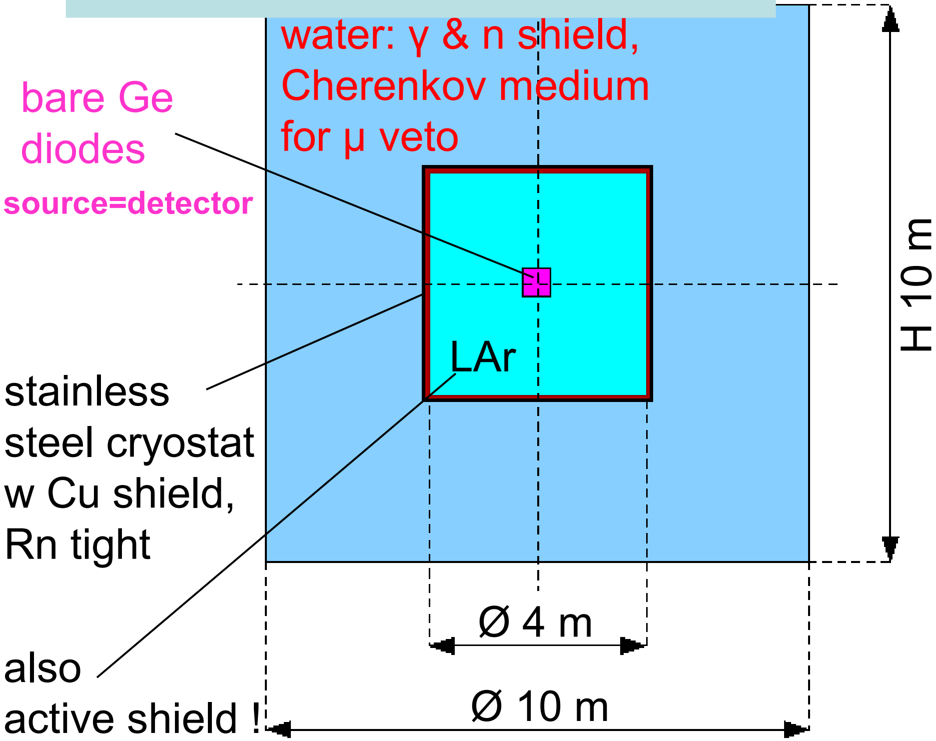
material thickness [m]

many possibilities to comply with constraints like feasibiliy, size, cost, …

generic external background shields

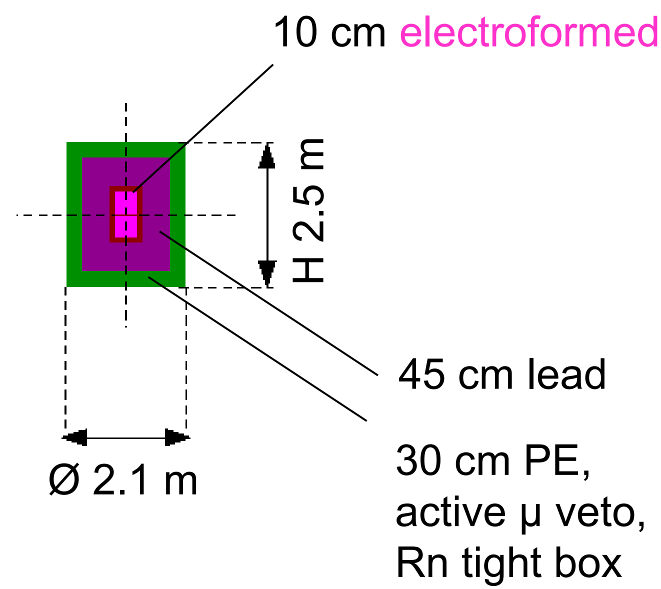
GERDA (low Z shield)

bare Ge diodes in high-purity LAr
< 1µBq/m³ STP Rn-222 (established)



Majorana (high Z shield; deep underground)

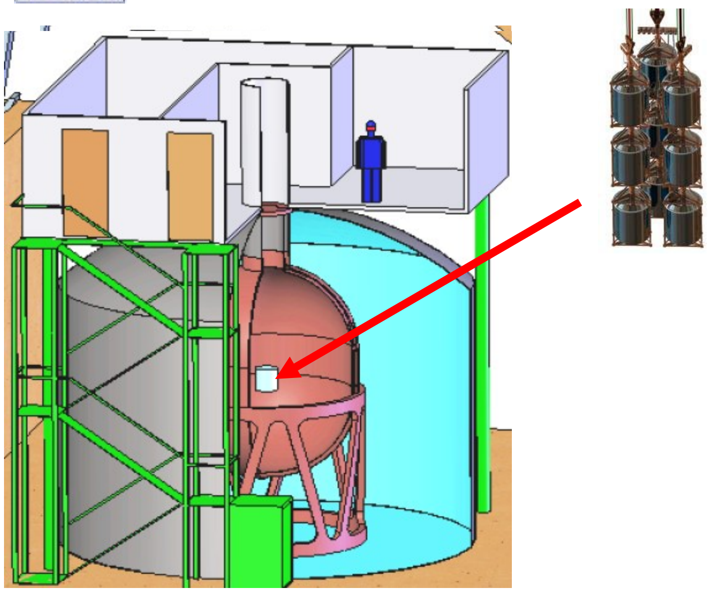
Ge diodes housed in vacuum cryostat,
ultra-high-purity electroformed Cu shield
< 1 µBq/kg Th-232 (not yet established)



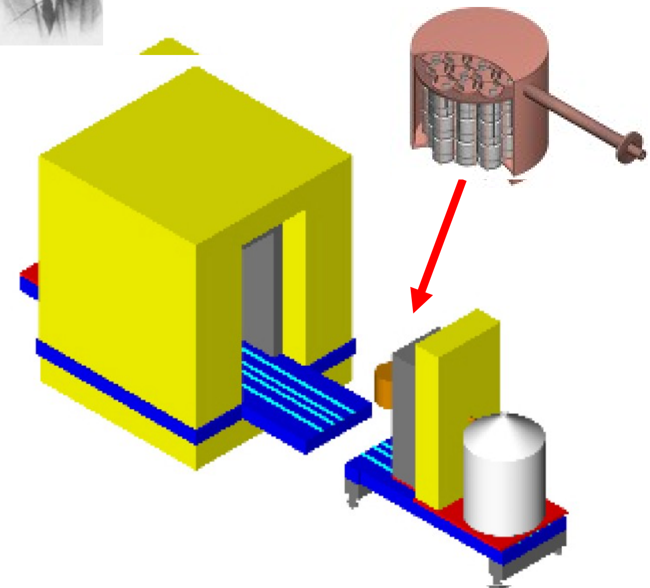
α(LAr) = 0.050/cm α(Cu) = 0.34/cm
α(H_2O) = 0.043/cm α(Pb) = 0.48/cm

examples GERDA & Majorana

GERDA



Majorana

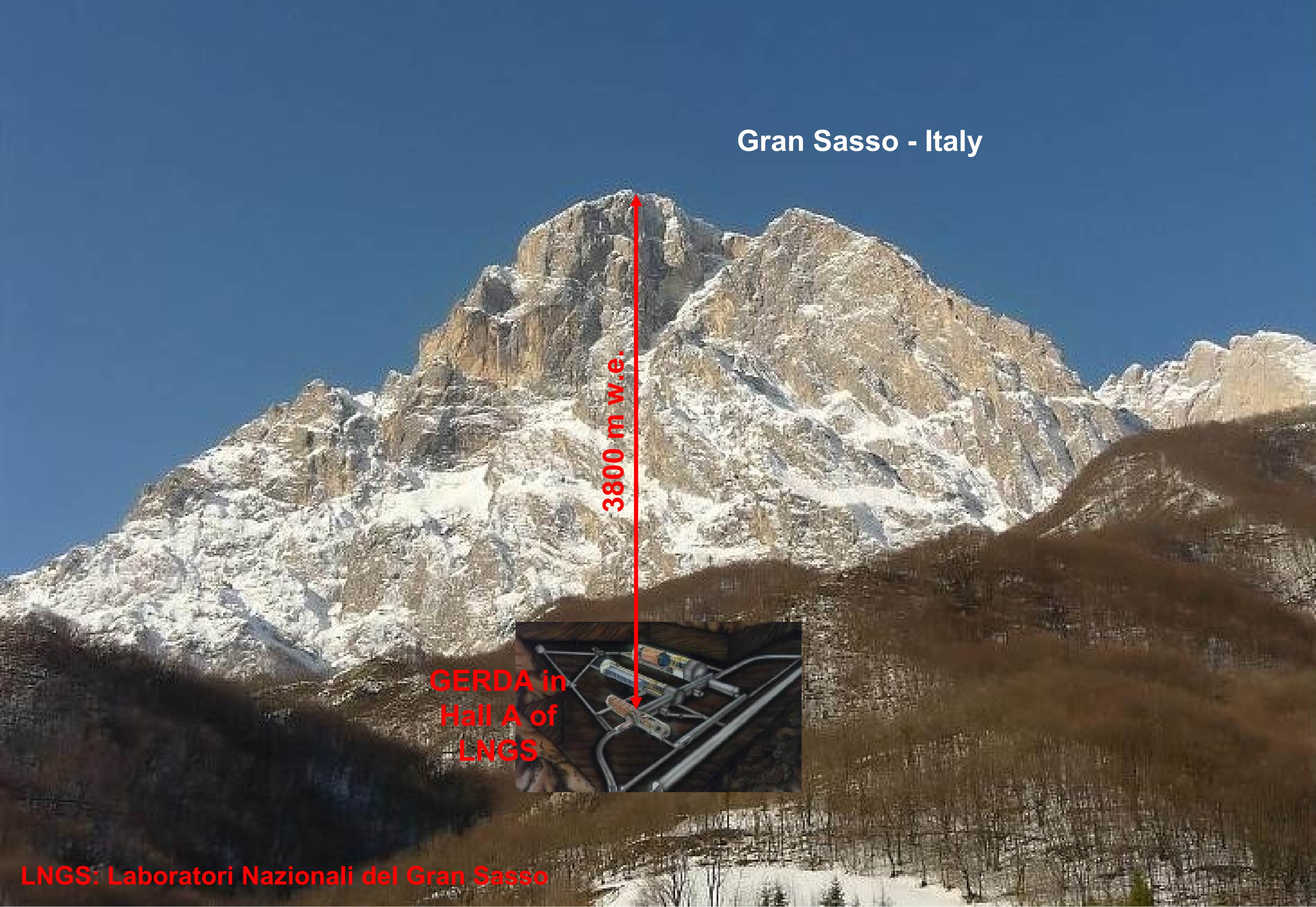


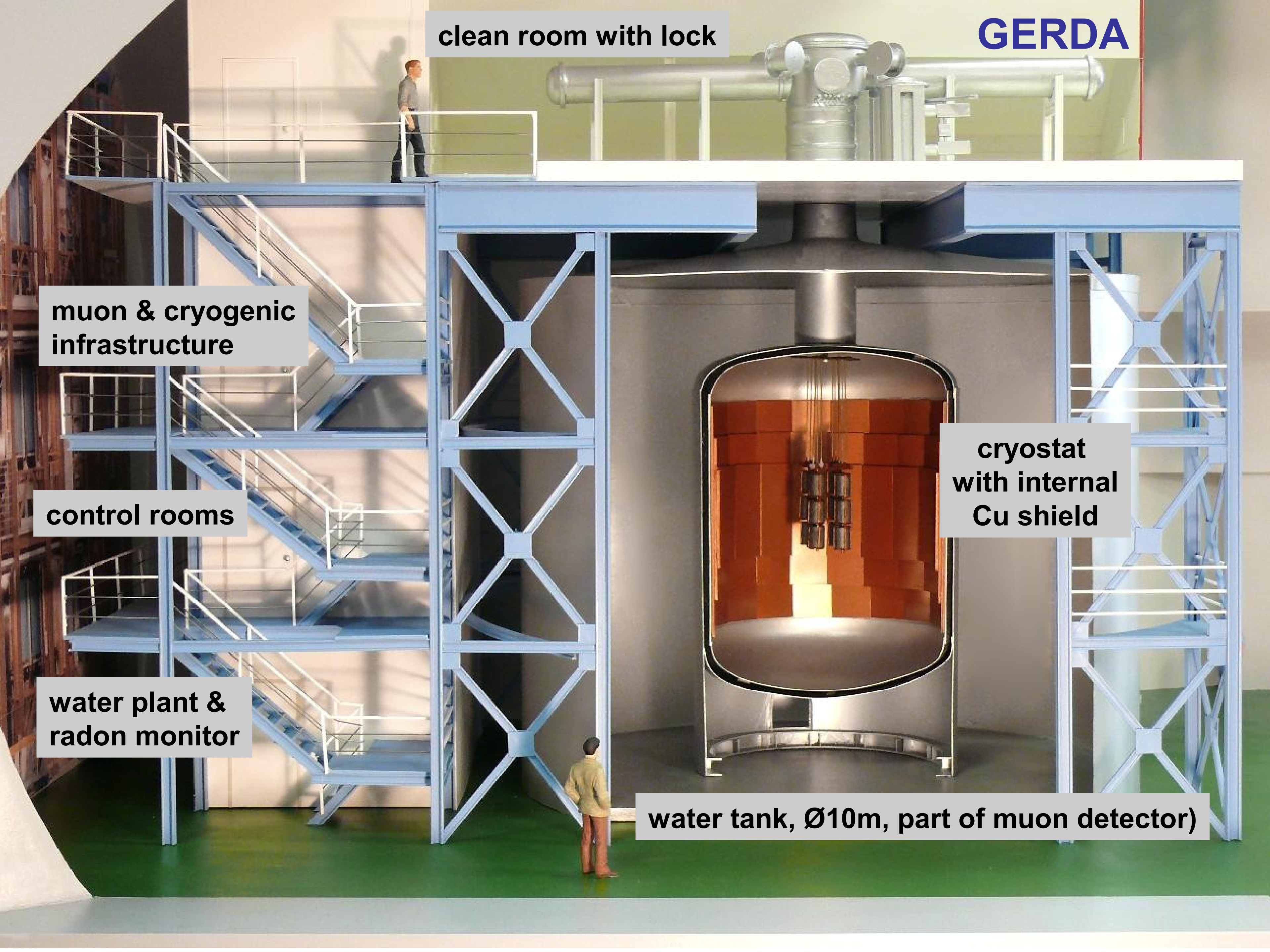
- ‘bare’ ^{enr}Ge array in liquid argon
- shield: high-purity liquid Argon / H_2O

- array(s) of ^{enr}Ge housed in high-purity

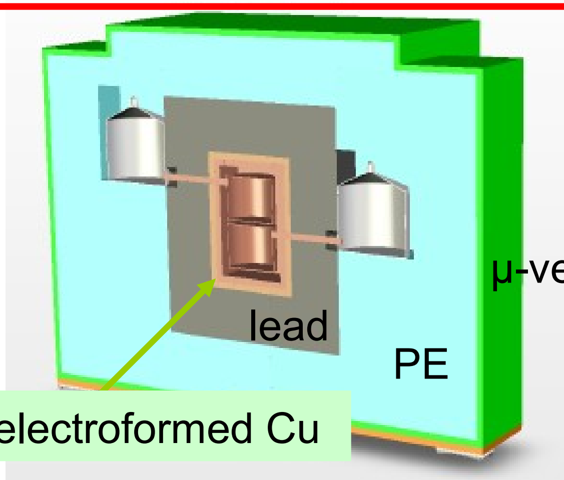
  electroformed copper cryostat
- shield: electroformed copper / lead

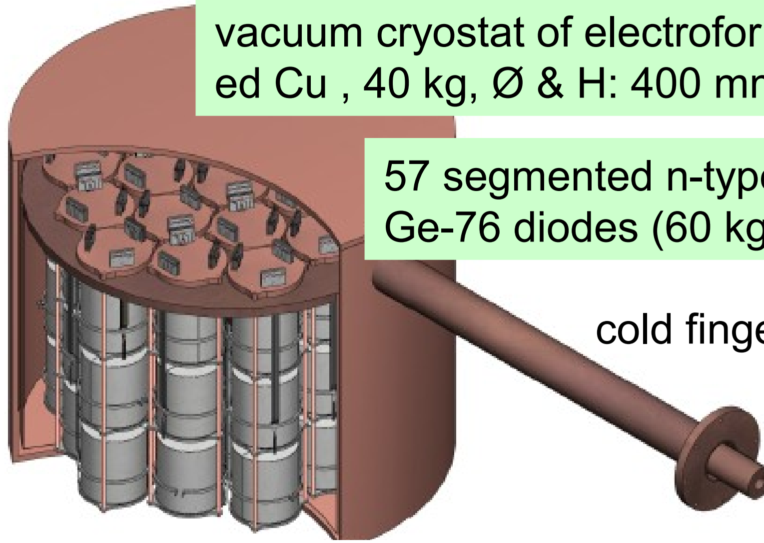
GERDA location

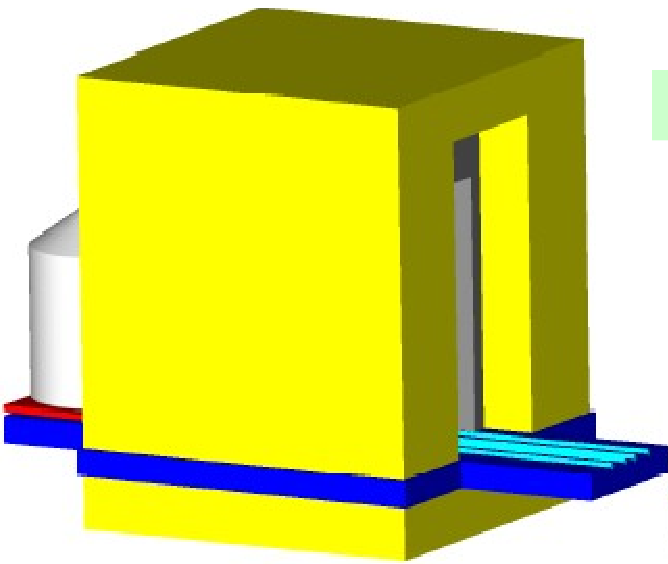


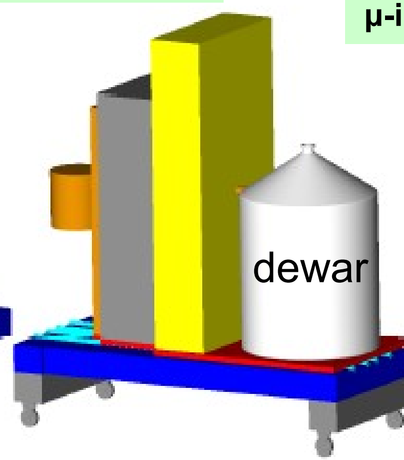

clean room with lock
GERDA
muon & cryogenic infrastructure
control rooms
water plant & radon monitor
cryostat with internal Cu shield
water tank, Ø10m, part of muon detector)

▲ 5000 m w.e. rock above ▲

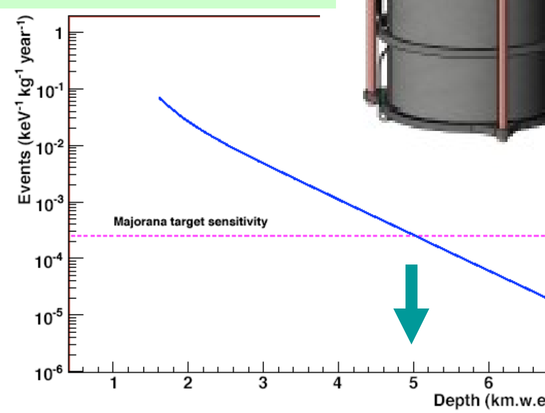




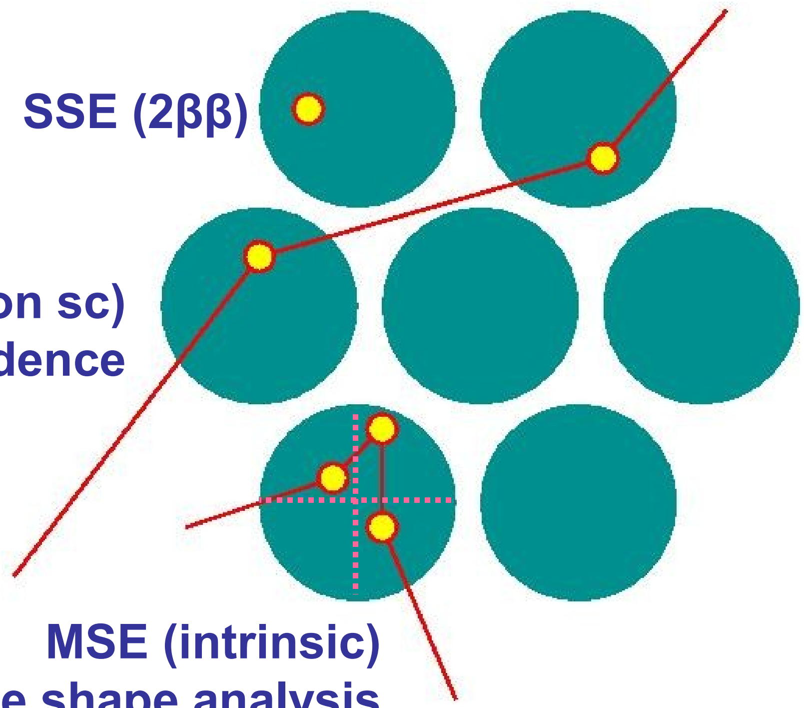




µ-induced events vs depth



discrimination of single / multi site events

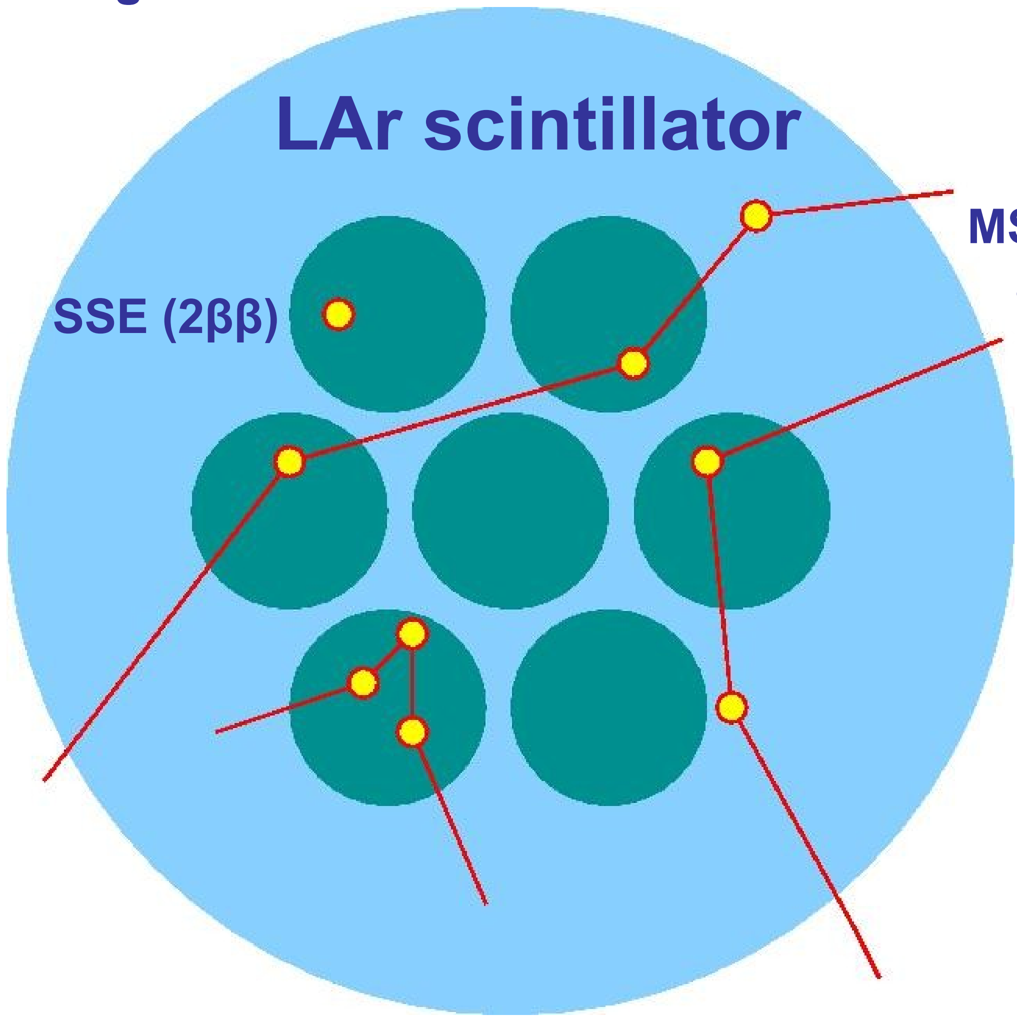


SSE (2ββ)

MSE (Compton sc)
anti-coincidence

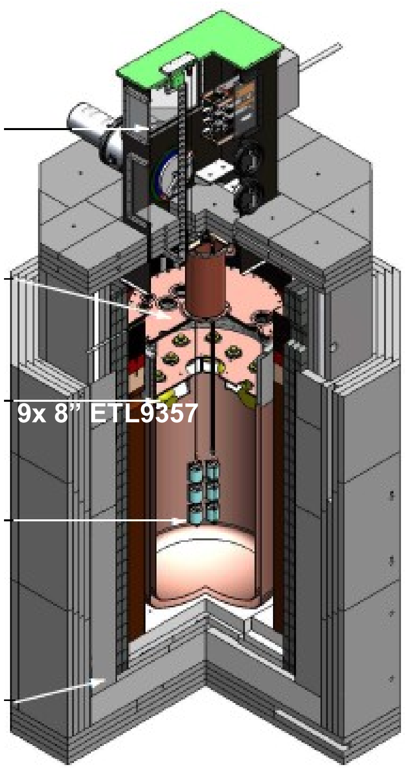
MSE (intrinsic)
pulse shape analysis
segmentation – anti-coincidence

discrimination of single / multi site events

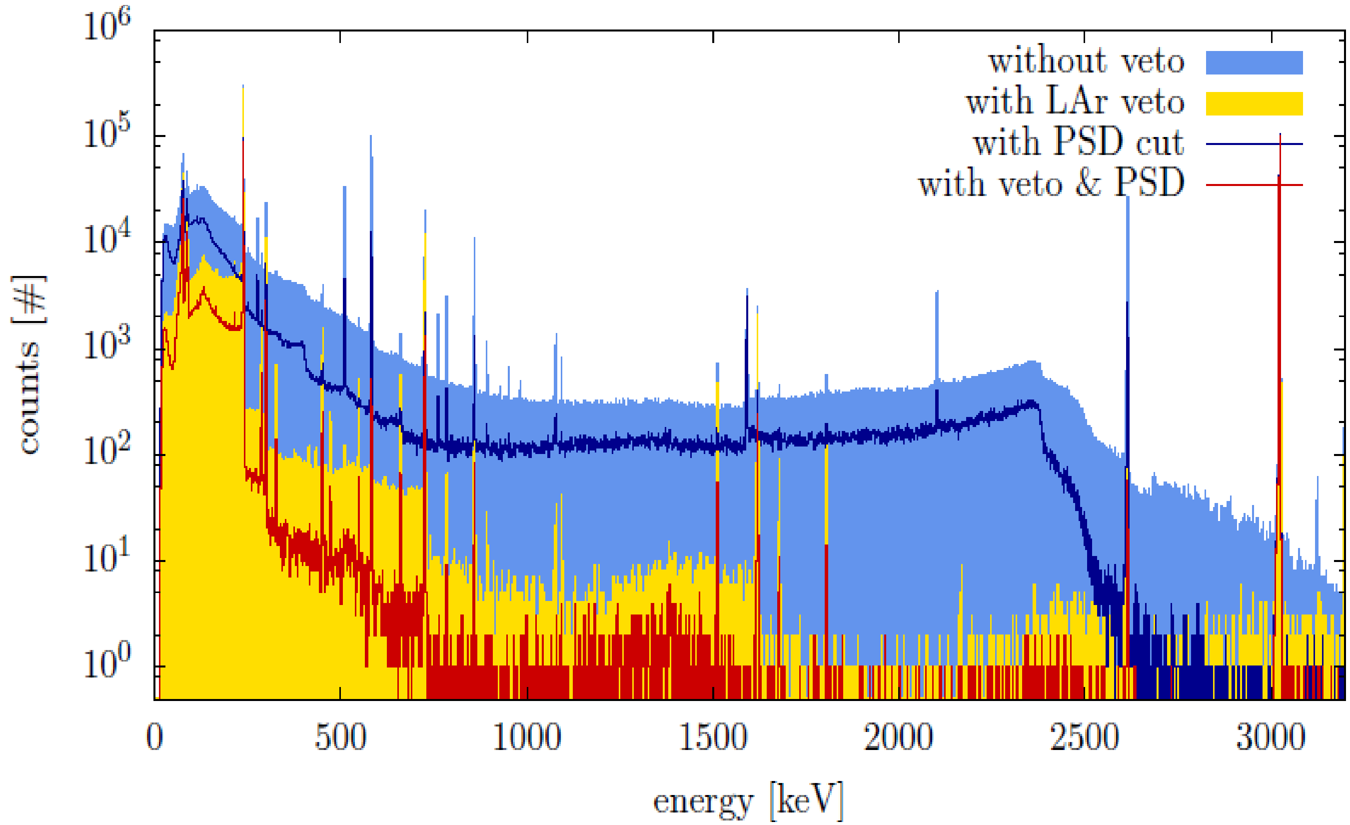


R&D liquid argon instrumentation

Low background GERDA-LArGe test facility @ LNGS:
Detection of coincident liquid argon scintillation light to discriminate background



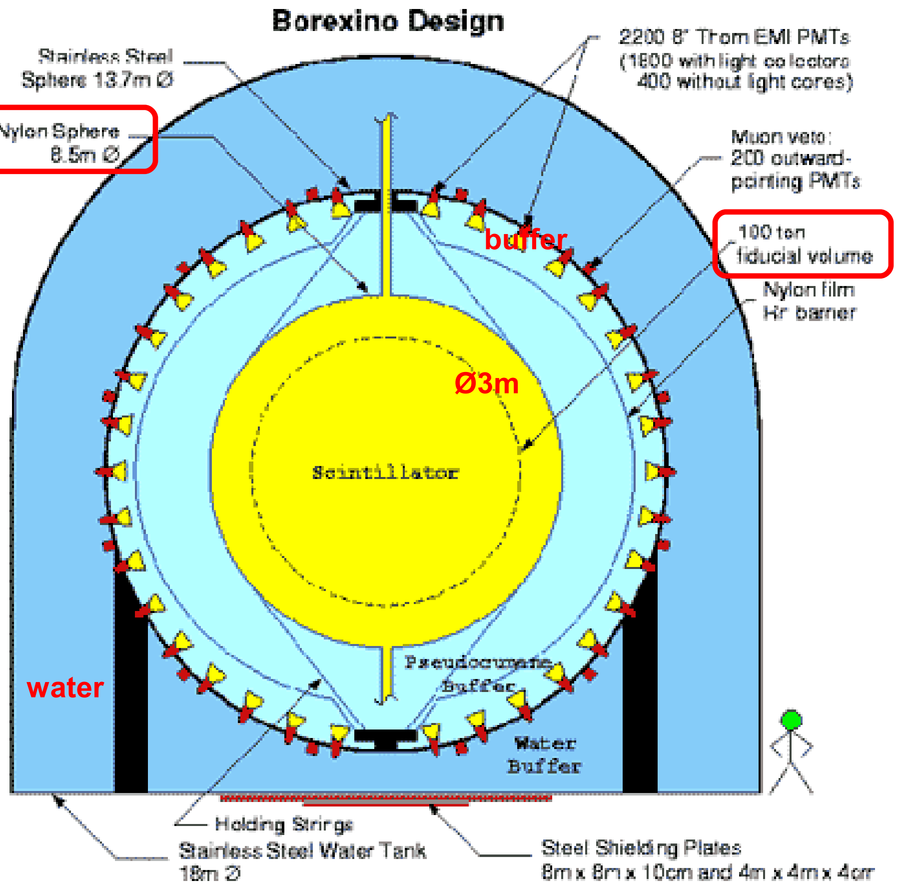
► see talk by D. Budjas



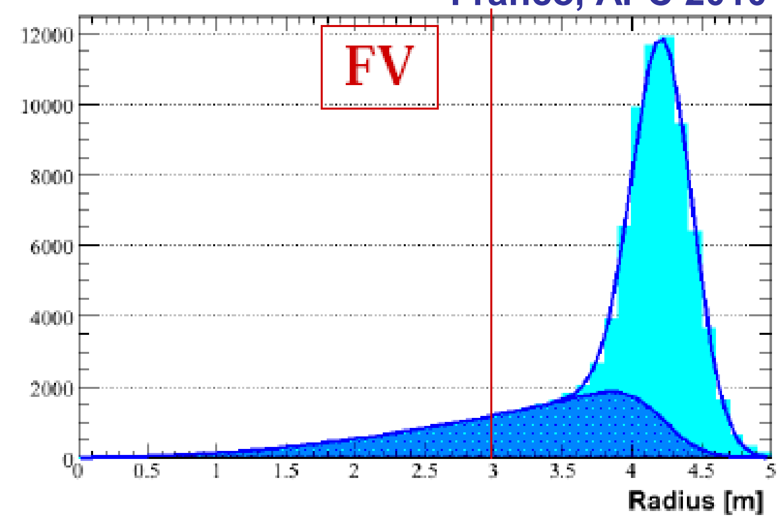
Operation of GERDA BEGe detector prototype in LArGe:
Measured suppression factor at $Q_{\beta\beta}$: ~$0.5 \cdot 10^4$ for
a near ^{228}Th calibration source (M. Heisel, PhD thesis, Heidelberg 2011)

Potential problem: Ar-42 decay to K-42 with Q_β(K-42)=3.5MeV

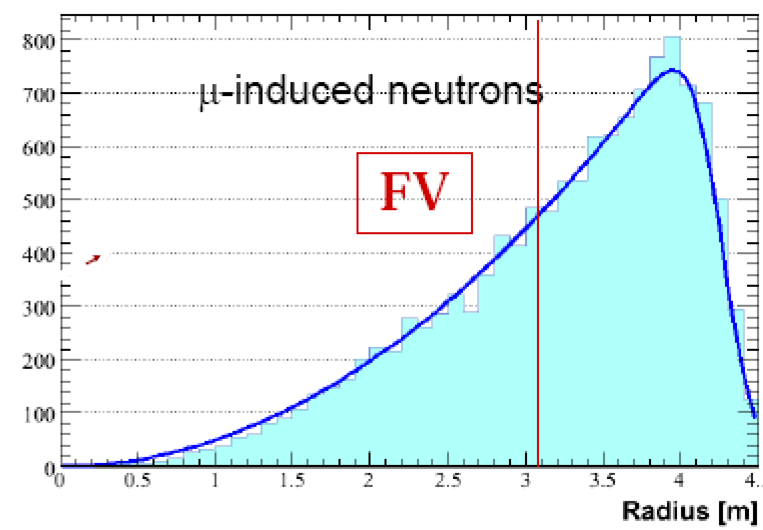
cleanliest place on/under earth !



Franco, APC 2010

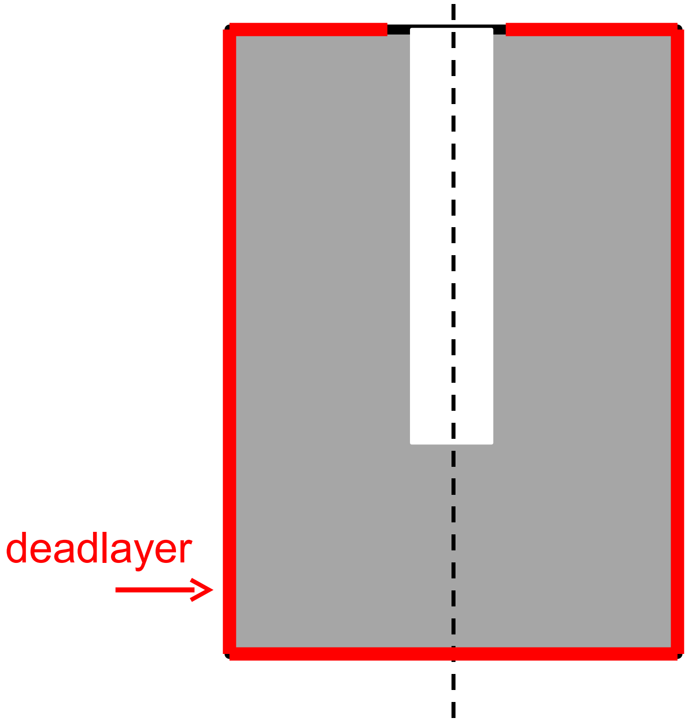


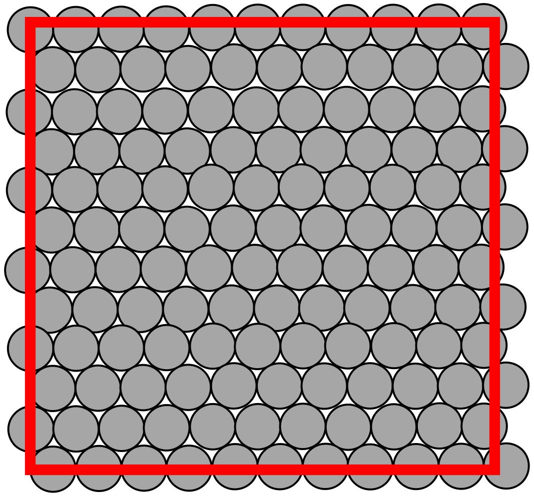
^{7}Be energy region (mainly ^{210}Po)



position sensitive ►►►►

Yes! **(trivial if position sensitive)**





Practical: p-type Ge diode with ~1mm thick Li-diffused contact, material loss ~6%
n-type ► ultrapure coating?!

Possible - but affordable?: 3d array of ~1000 Ge-diodes, material loss ~50%

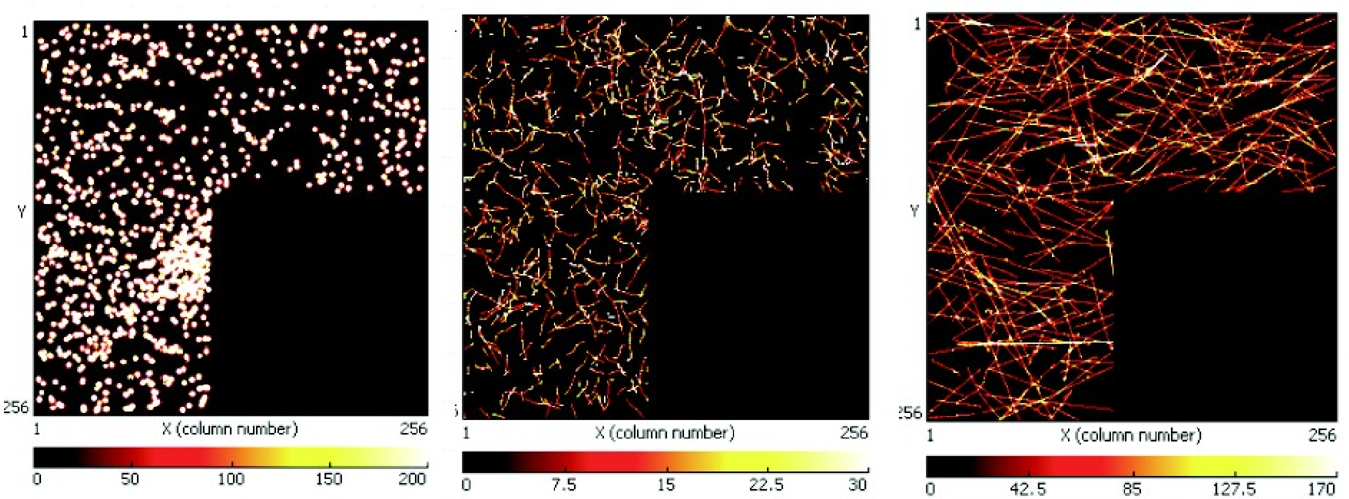
ultimate segmentation: pixelisation

Particle ID by tracking in pixel detector (TimePix: t=1mm, 1.4x1.4 cm2, 55µm pixel pitch)

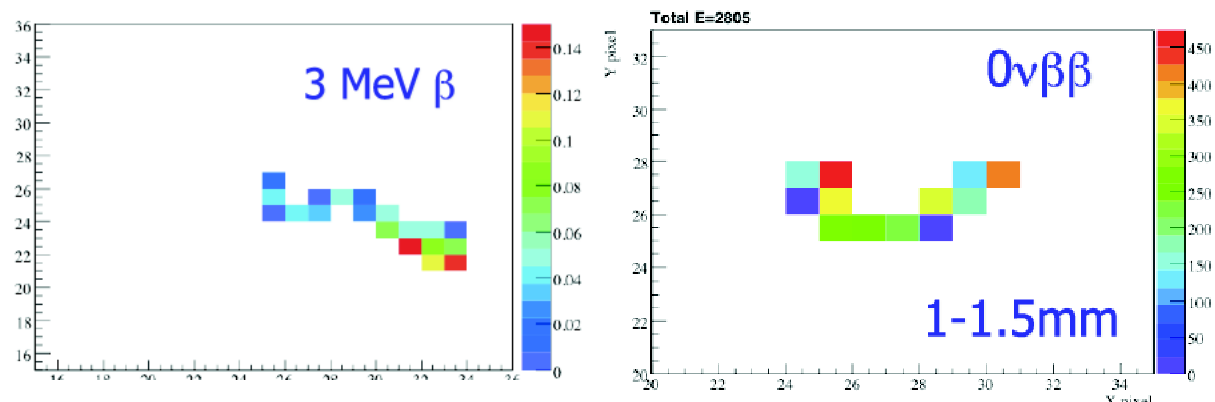
alpha — 1 pixel

beta, **muon** — connected pixels

gamma — disconnected pixels



Exploit topology!



K.Zuber taup09

Effective shielding is crucial for next generation of double beta decay experiments.

Both passive and active shields needed

Two competing concepts for passive shields (Majorana – GERDA) being realized

conventional high Z (Cu, Pb) graded shield with extra muon veto & neutron absorber
(How large are contaminations of electroformed copper?)
novel low Z (water, LN, LAr?) graded shield with integral muon veto & neutron absorber
(latter approach is much more demanding w.r.t. space, infrastructure, safety)

Adequate screening of all shielding materials/volumes essential; dto mounting material!

Promising R&D results for active veto – if LAr: use depleted argon?!

Transfer of concepts from other successful low counting experiments might be useful

fiducial volume
pixelisation
in-situ cleaning of shield & detector, (practical for Ge?)