Background measurements underground

Nuclear Astrophysics at the Dresden Felsenkeller
Dresde, Germany, 26 – 28 June, 2017

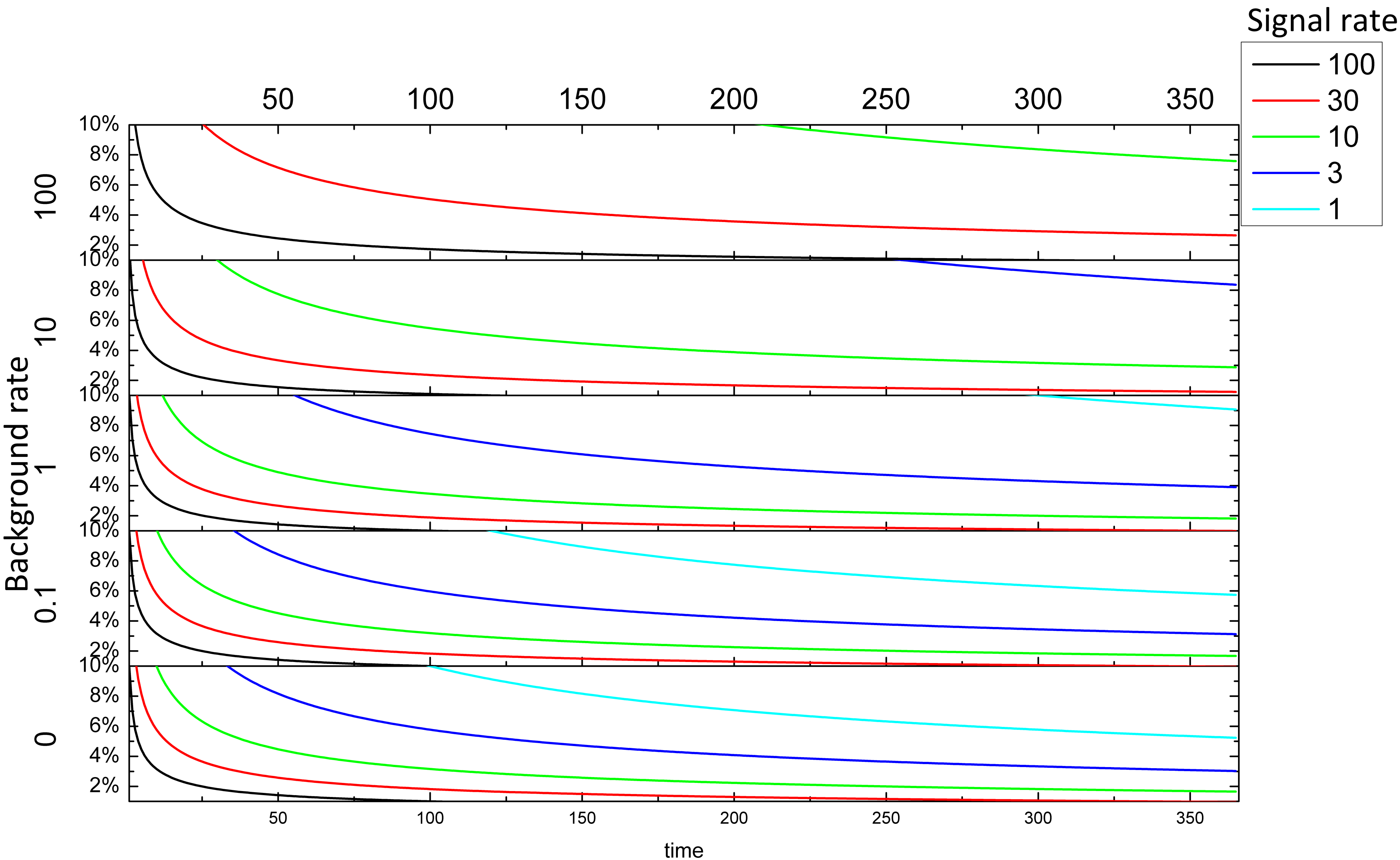
Tamás Szücs

Why to go underground, why are we concern the background?

Consider detected 10 events/day

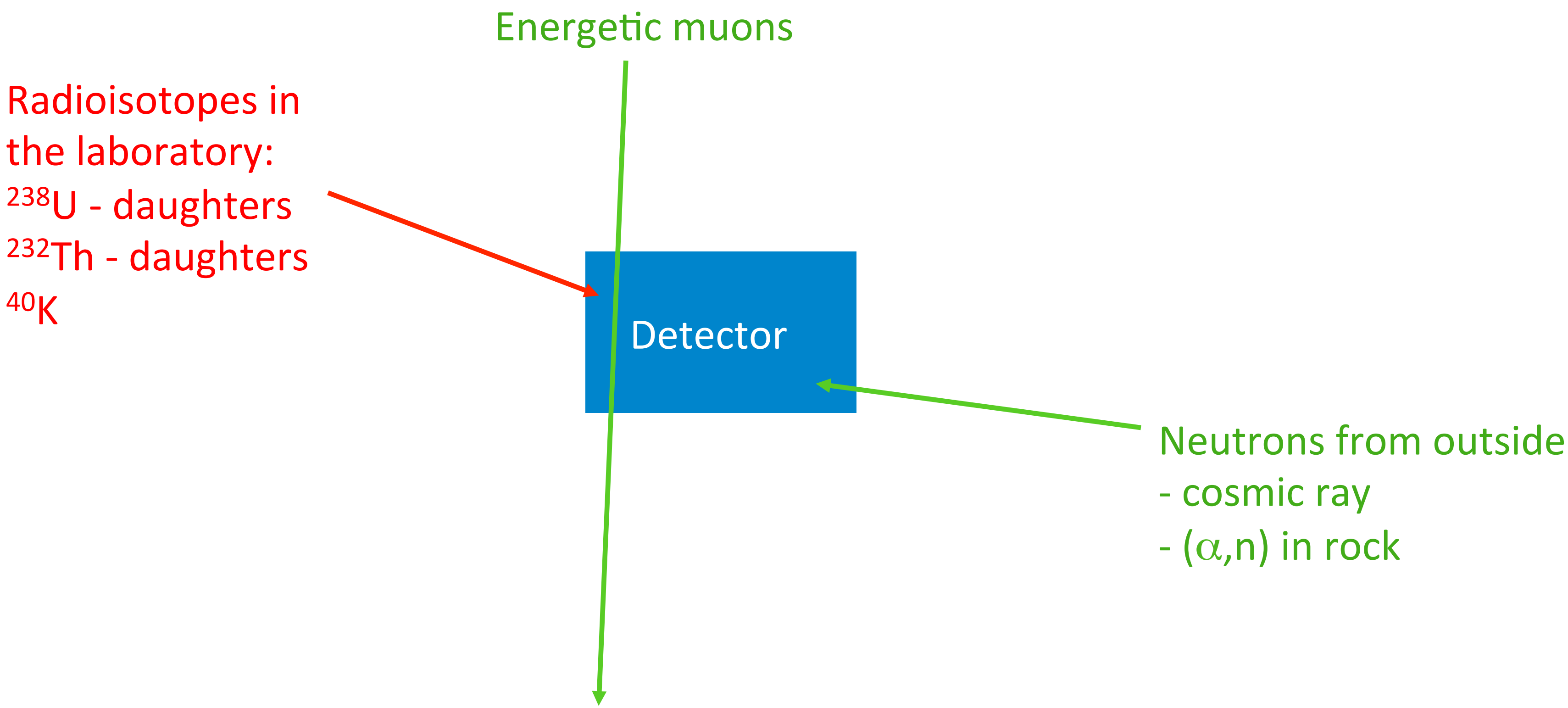
Background count rate (event / hour)	Time needed to reach 10% precision (days)	Time ratio of extra time needed respect to the no background situation
0	10	**0**
0.1	10.2	2%
0.5	11	10%
1	12	20%
10	30	3
20	50	5
50	110	11
100	210	210
200	410	40
500	1010	100
1000	2010	200

Why to go underground, why are we concern the background?



Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017

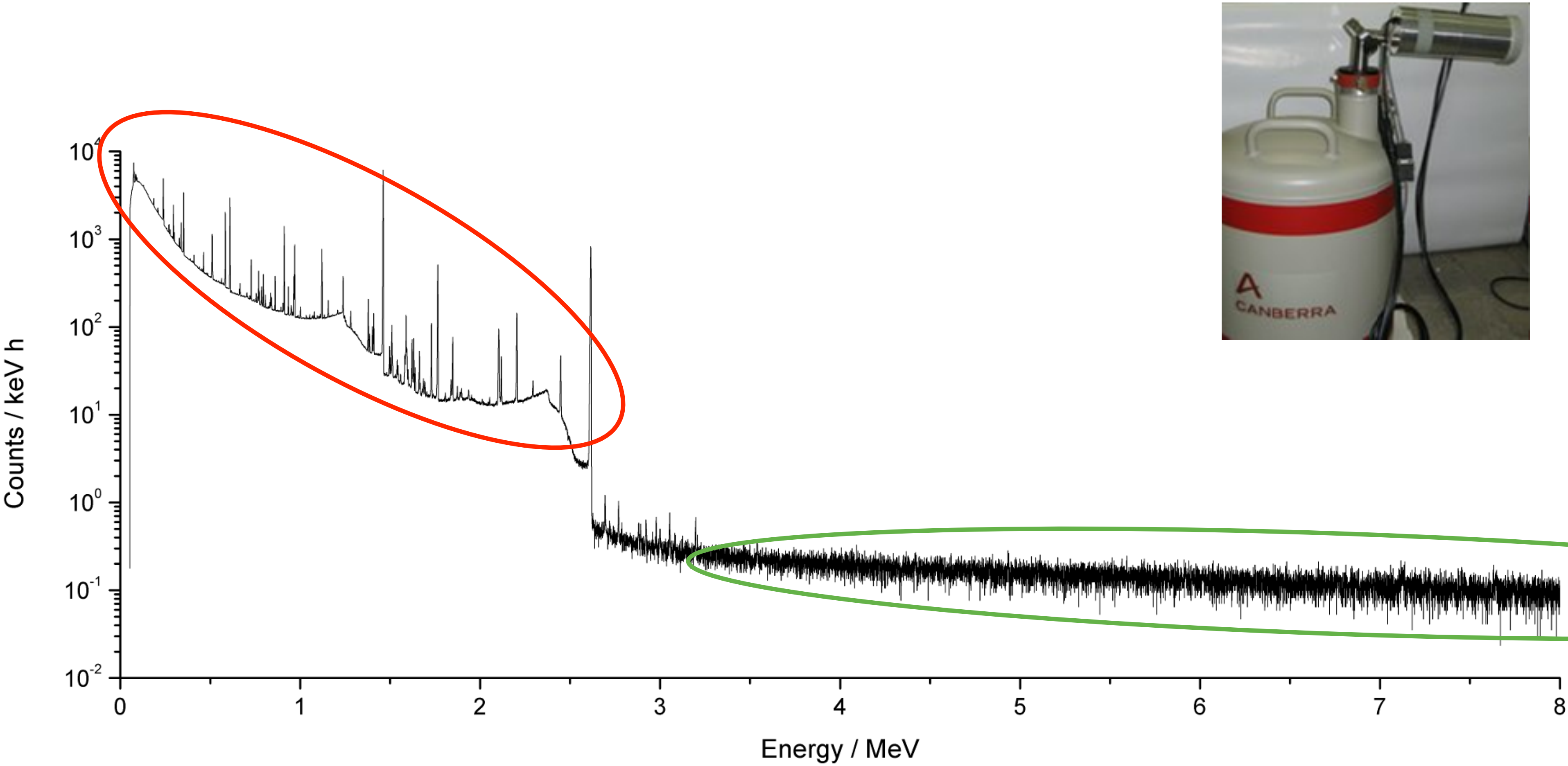
What contributes to the laboratory background?



Red: $E_\gamma < 3$ MeV

Green: $E_\gamma < 3$ MeV and $E_\gamma > 3$ MeV

Laboratory background at the Earth's surface



Natural radioisotopes

Cosmic-rays, mainly muons

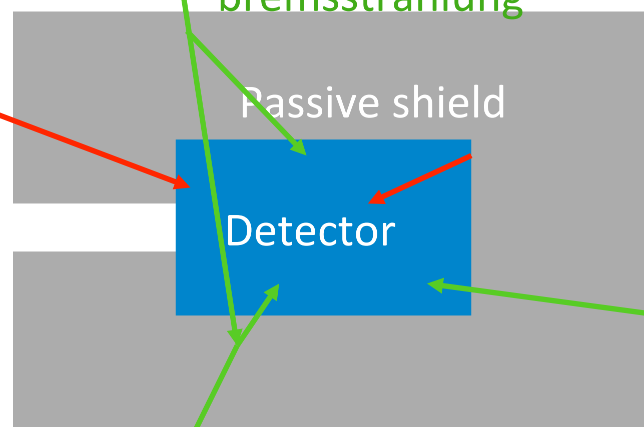
What contributes to the laboratory background?

Energetic muons

Secondary radiation:
electron-positrons;
bremsstrahlung

Radioisotopes in
the laboratory:
^{238}U - daughters
^{232}Th - daughters
^{40}K

Radioisotopes in
detector and shield:
^{238}U - daughters
^{232}Th - daughters
^{60}Co



Neutrons from outside:
- cosmic ray
- (α,n) in rock

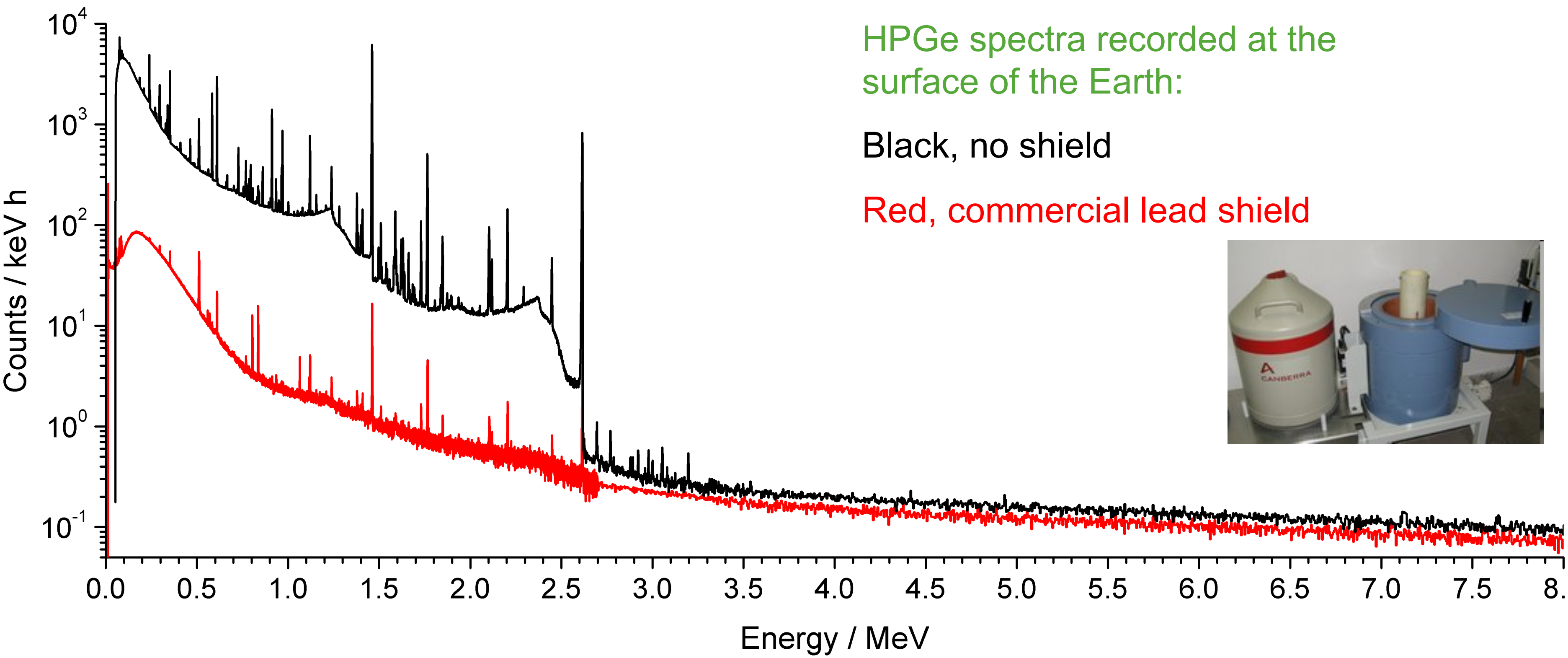
Neutrons created in the
passive shield or
laboratory walls by
muons (μ,n)

Red: $E_\gamma < 3$ MeV

Green: $E_\gamma < 3$ MeV and $E_\gamma > 3$ MeV

Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017

Laboratory background at the Earth's surface using passive shield



HPGe spectra recorded at the surface of the Earth:

Black, no shield

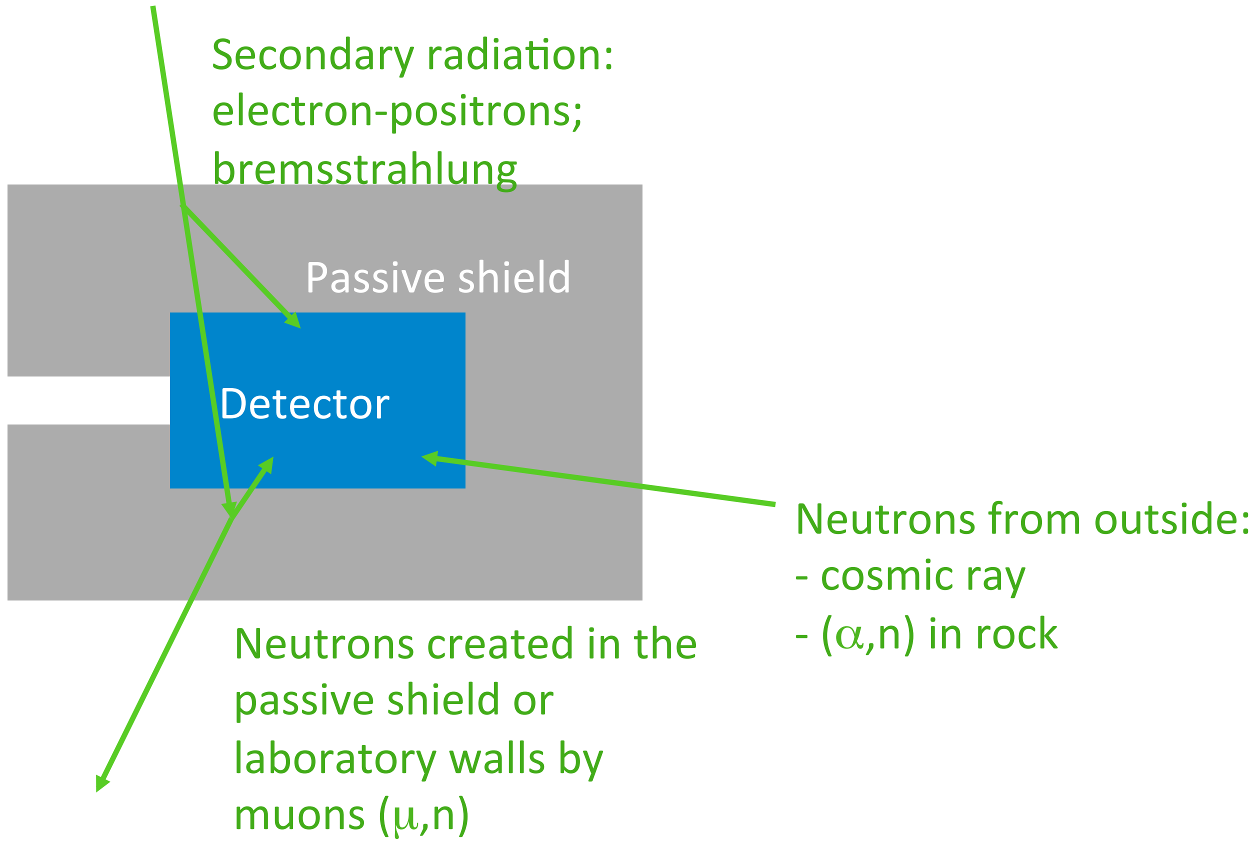
Red, commercial lead shield

Factor of 20 – 80 reduction at E_γ < 3 MeV

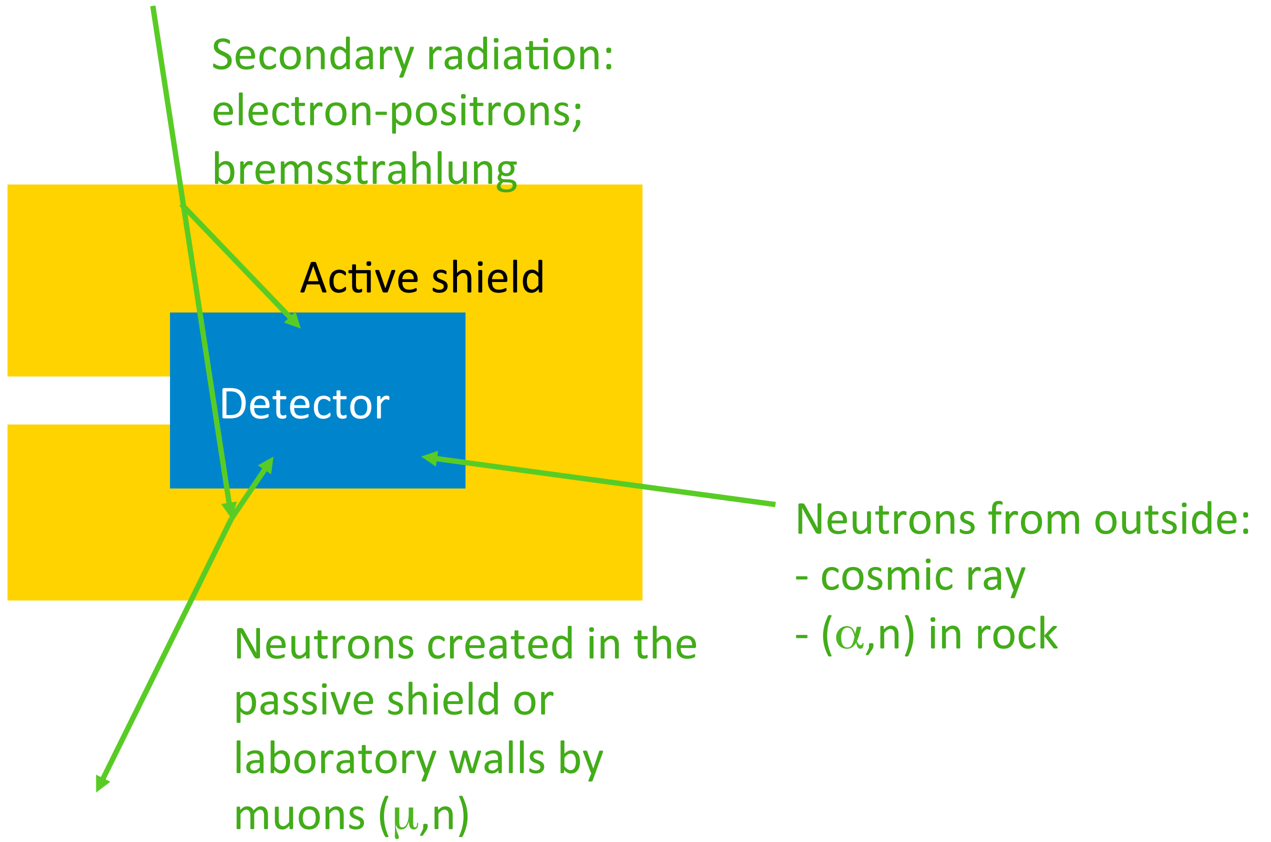
Lead does not do much at E_γ> 3 MeV.

Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017

What contributes to the laboratory background?



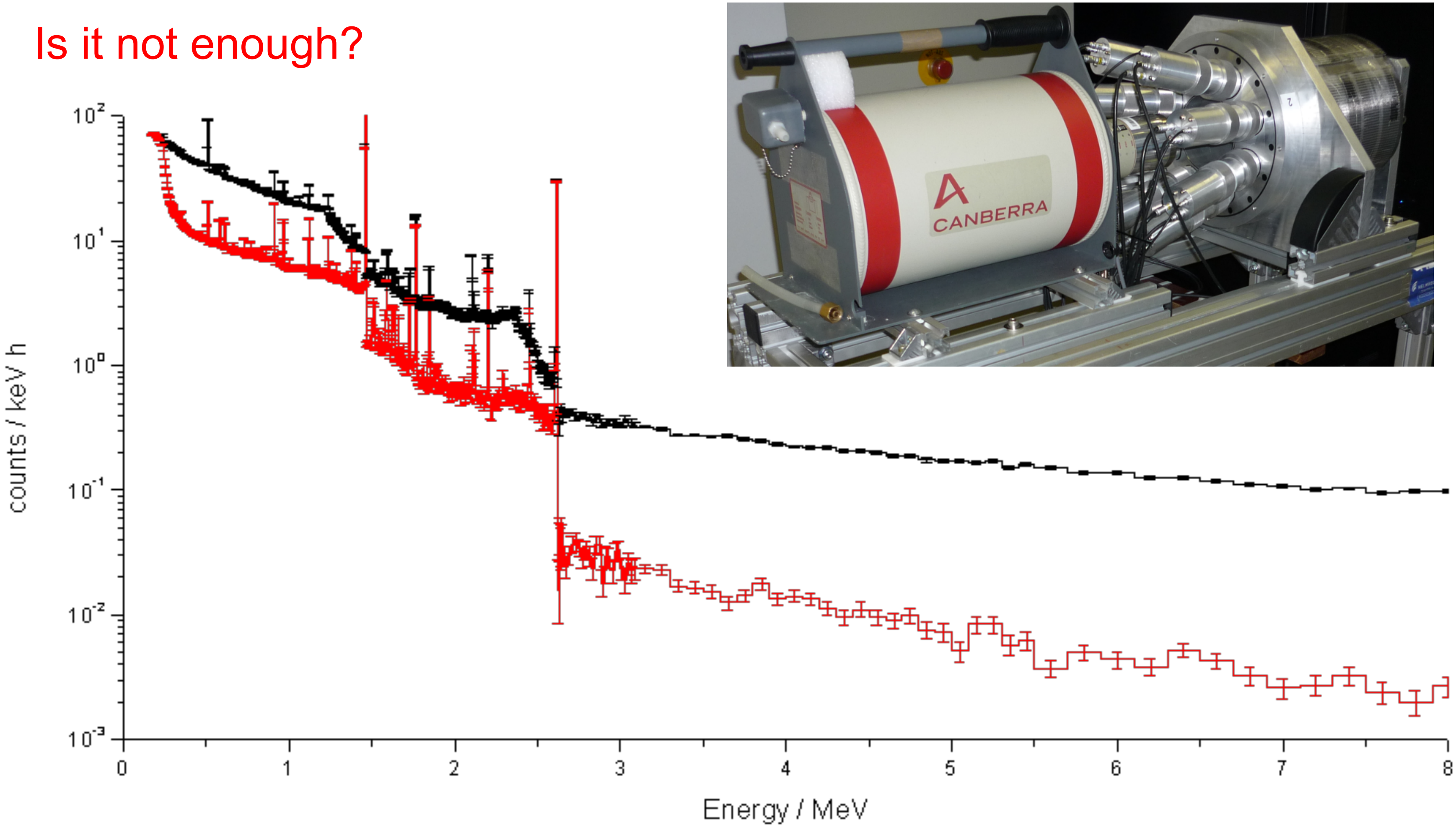
What contributes to the laboratory background?



Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017

Laboratory background at the Earth's surface using active shielding

Is it not enough?



Factor of 3 – 4 reduction at E_γ < 3 MeV

Factor of 10 – 1000 reduction at E_γ> 3 MeV

Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017

Is it enough?

Scenario	Reaction	E_G[keV]	σ [barn]	Detected events/ hour
AGB stars (80 MK)	$^{14}N(p,\gamma)^{15}O$	81	10^{-12}	10^{-4}

1 barn= 10^{-24} cm^2; assume 10^{16} h^{-1} beam, 10^{18} at/cm^2 target, 10^{-2} detection efficiency

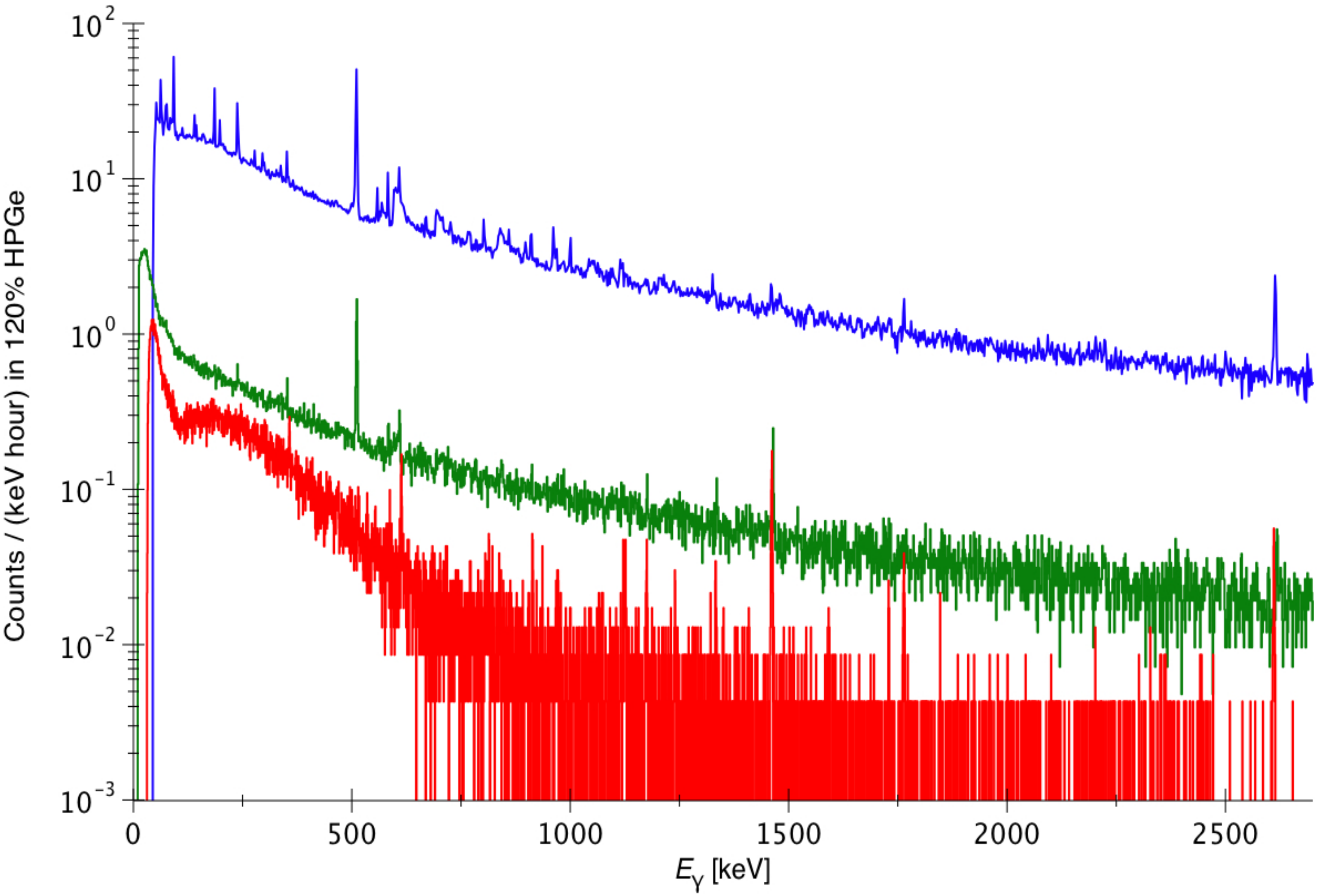
Without background, for 10% precision one need 100 counts. With this count rare it would take 115 years. This is practically impossible.

BUT approach as close as possible: Consider 100 times higher rate. (10^{-2} event/h)

	Background count rate (event / hour)	Time needed to reach 10% precision (years)
Without background	0	**1.1**
Typical overground settings with active shield	$2*10^{-2}$	5.7

Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017

Laboratory background for E_γ < 3 MeV



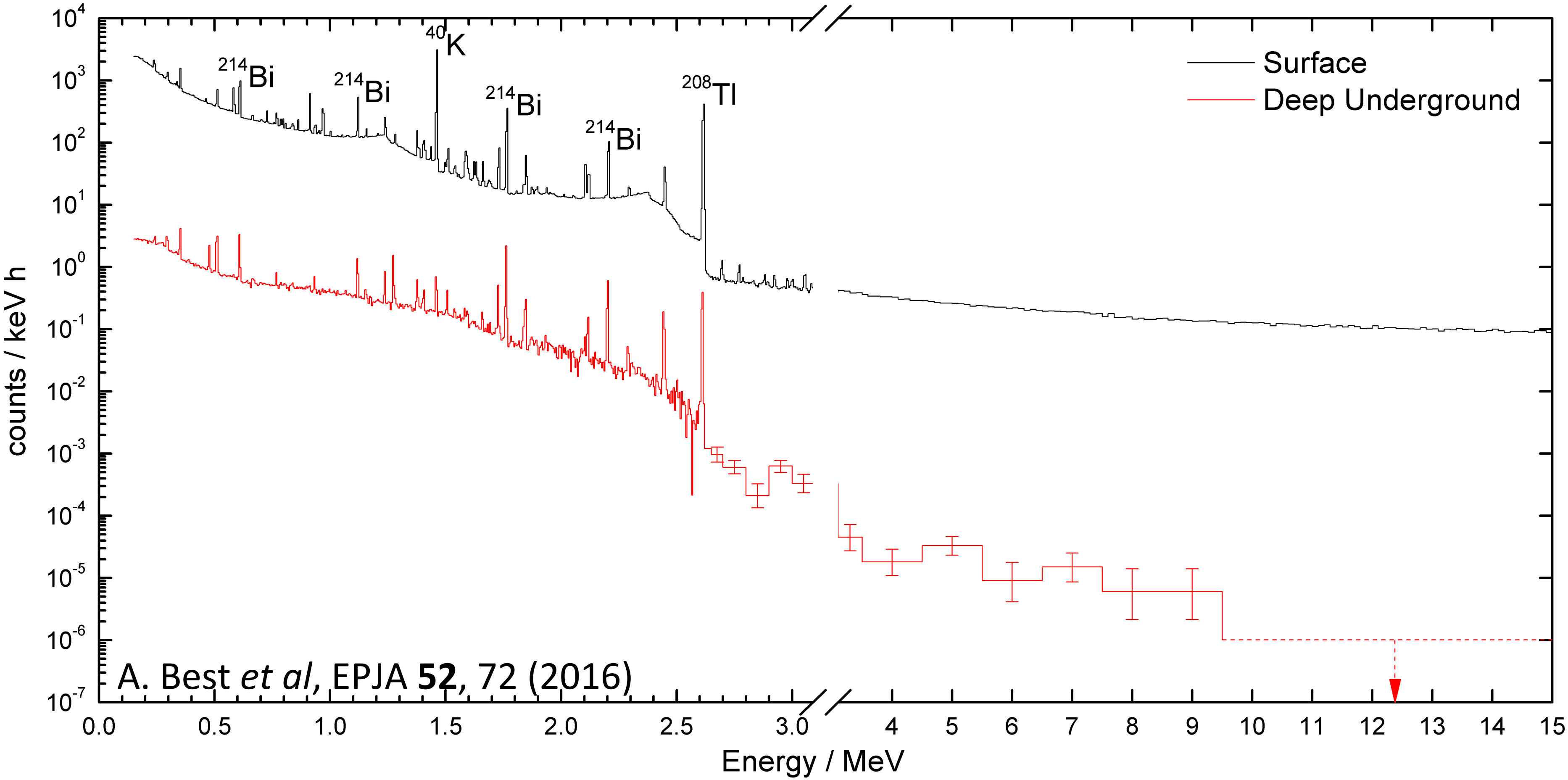
E_γ = 1.5 MeV

Earth's surface:
4 counts/hour

Shallow,
~110 mwe:
0.13 counts/hour

Deep underground,
~3800 mwe:
0.007 counts/hour

Laboratory background at deep underground



Factor of 100 – 1000 reduction at E_γ < 3 MeV

Factor of 10000 – 100000 reduction at E_γ> 3 MeV

Above 10 MeV practically empty background!

Why to go underground, an example

Scenario	Reaction	E_G[keV]	σ [barn]	Detected events/ hour
AGB stars (80 MK)	$^{14}N(p,\gamma)^{15}O$	81	10^{-12}	10^{-4}

1 barn= 10^{-24} cm^2; assume 10^{16} h^{-1} beam, 10^{18} at/cm^2 target, 10^{-2} detection efficiency

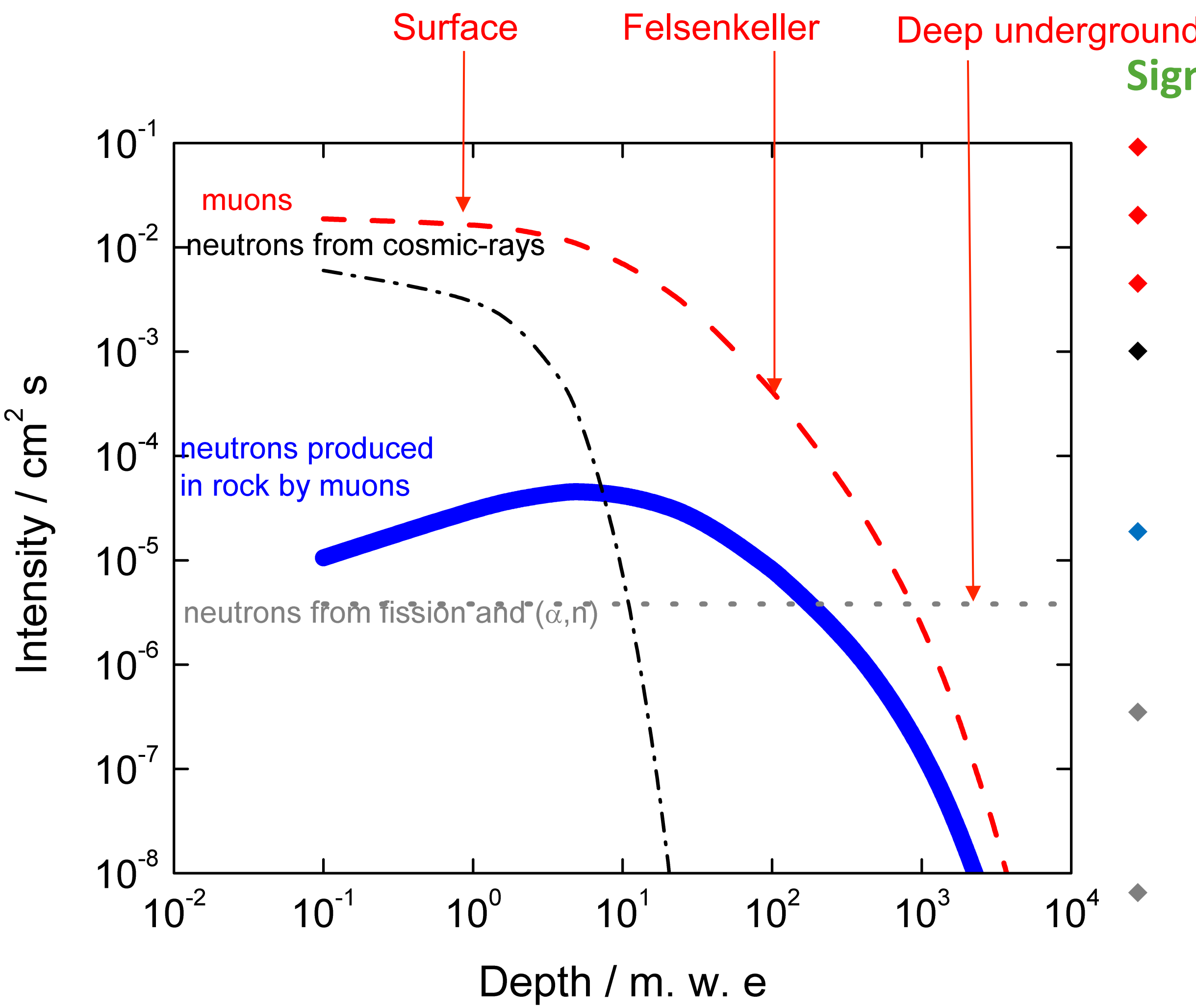
Without background, for 10% precision one need 100 counts. With this count rare it would take 115 years. This is practically impossible.

BUT approach as close as possible: Consider 100 times higher rate. (10^{-2} event/h)

	Background count rate (event / hour)	Time needed to reach 10% precision (years)
Without background	0	**1.1**
Typical overground settings with active shield	$2*10^{-2}$	5.7
Deep underground	$4*10^{-4}$	**1.2**

Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017

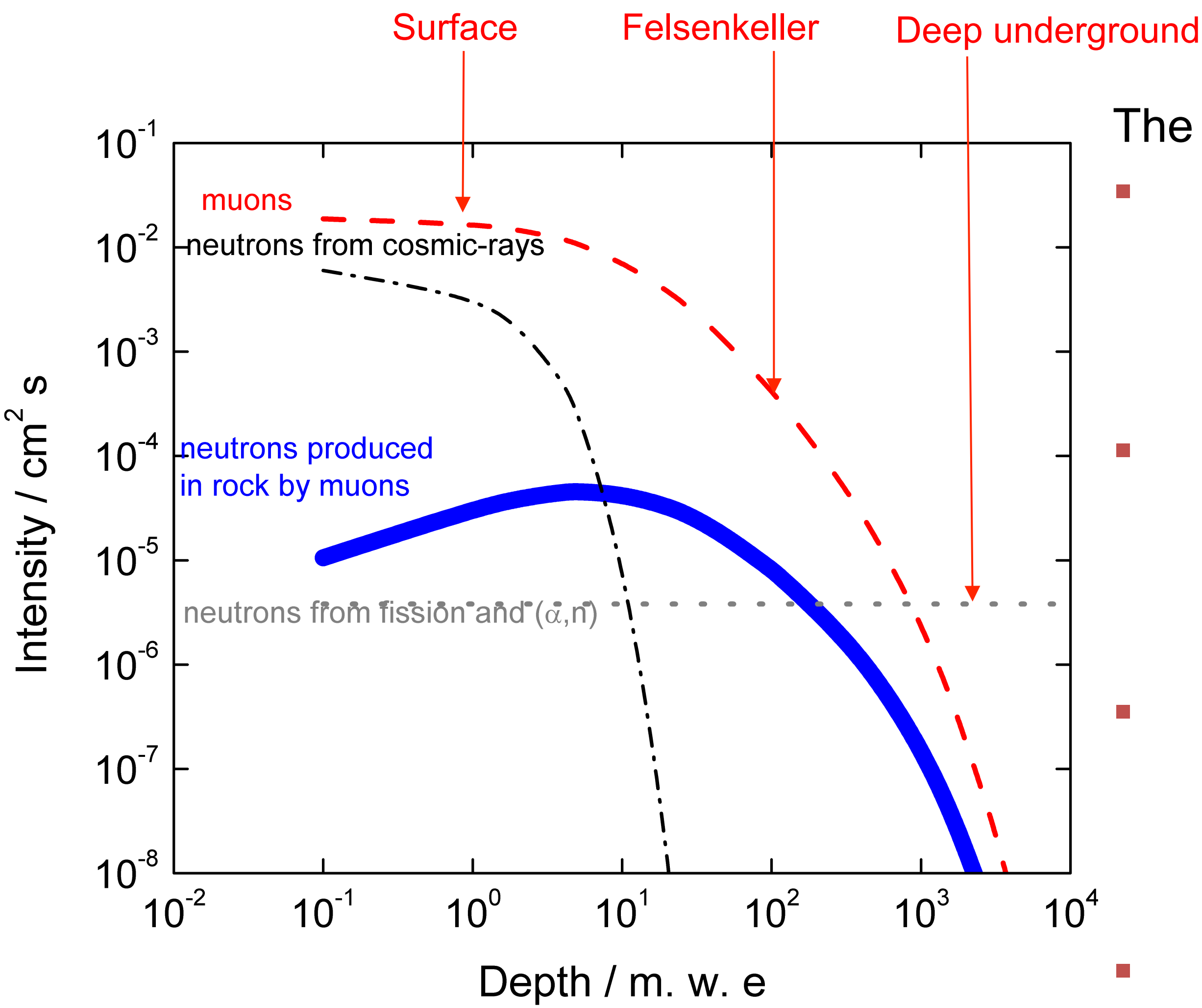
Attenuation of the laboratory background underground



Signals in a gamma detector

- Direct ionisation:
- continuous energy deposit
- up to 100MeV
- Inelastic scattering; continuous energy deposit of several tens of MeV
- Inelastic scattering; continuous energy deposit of several tens of MeV
- Neutrons up to max 5-8MeV but mainly thermalized neutrons
- Elastic, inelastic scattering, and nuclear reactions producing max. ~10MeV γ-rays

Attenuation of the laboratory background underground

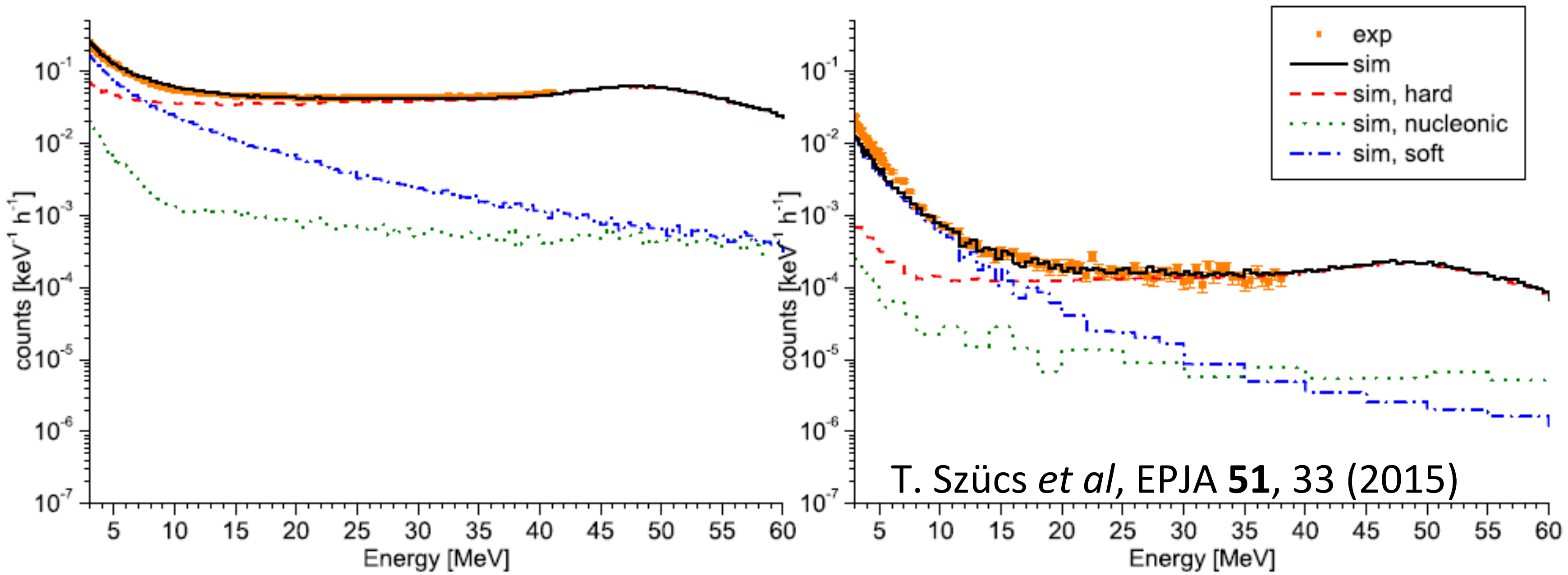


The issues are:

- Energy loss of passing muons in the detector
  → Active shield
- Interaction of cosmic-ray nucleons in the detector
  → 10m rock
- (α,n) neutrons from natural radioactivity in the walls
  → Passive shield
- Neutrons generated by muons
  → 500m rock

Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017

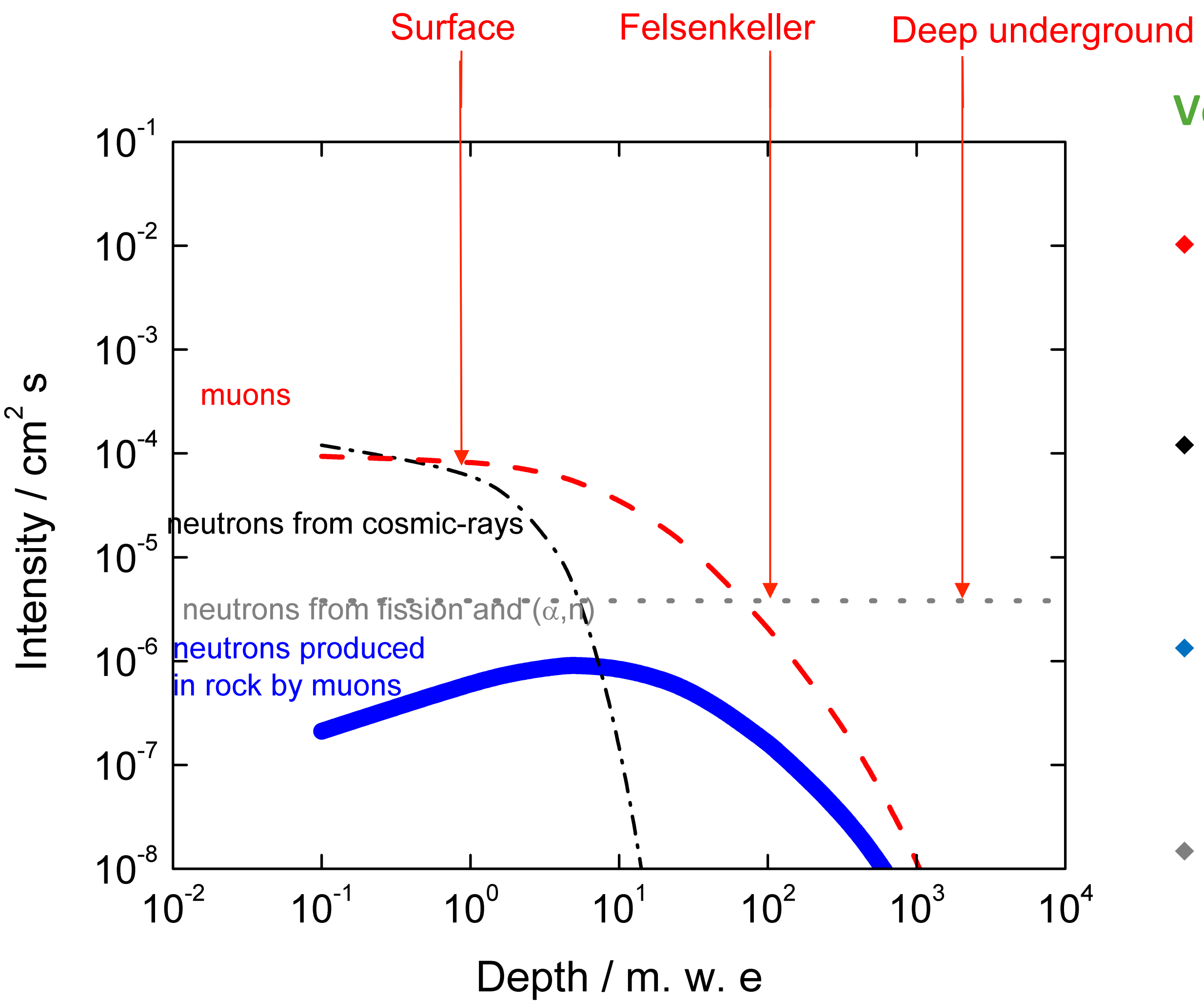
GEANT4 simulation of the signal of the cosmic-ray components in HPGe detectors



- Overground the soft component dominates below 10 MeV
- This component becomes negligible if a 15 cm thick lead shield is applied

Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017

What if active shielding is applied?



Veto factors

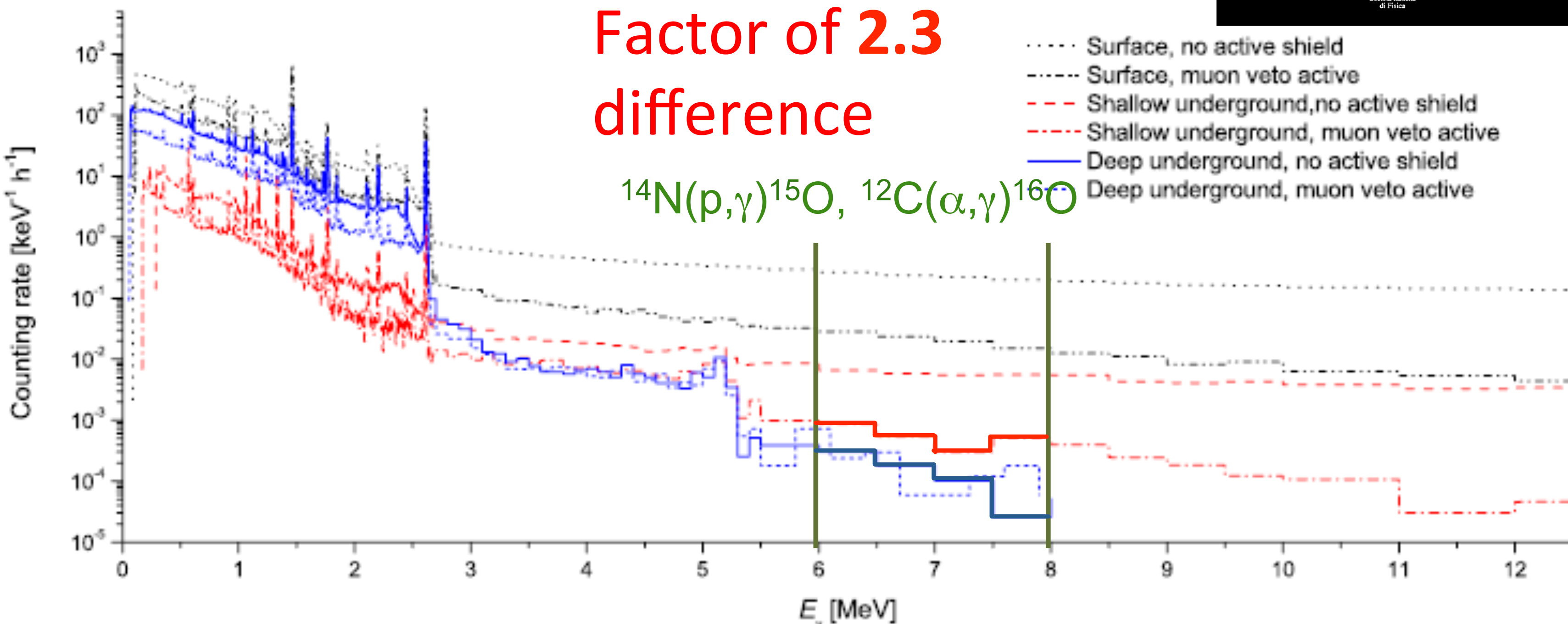
- 200-300
- 50-80
- 50-80
- No effect

Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017

Background, in a typical HPGe detector in the Felsenkeller (45 m)

- Combination of active veto and 45m of rock shielding gives a factor of 500 background reduction

- Final value close to deep-underground background
  T. Szücs *et al*, EPJA **48**, 8 (2012)

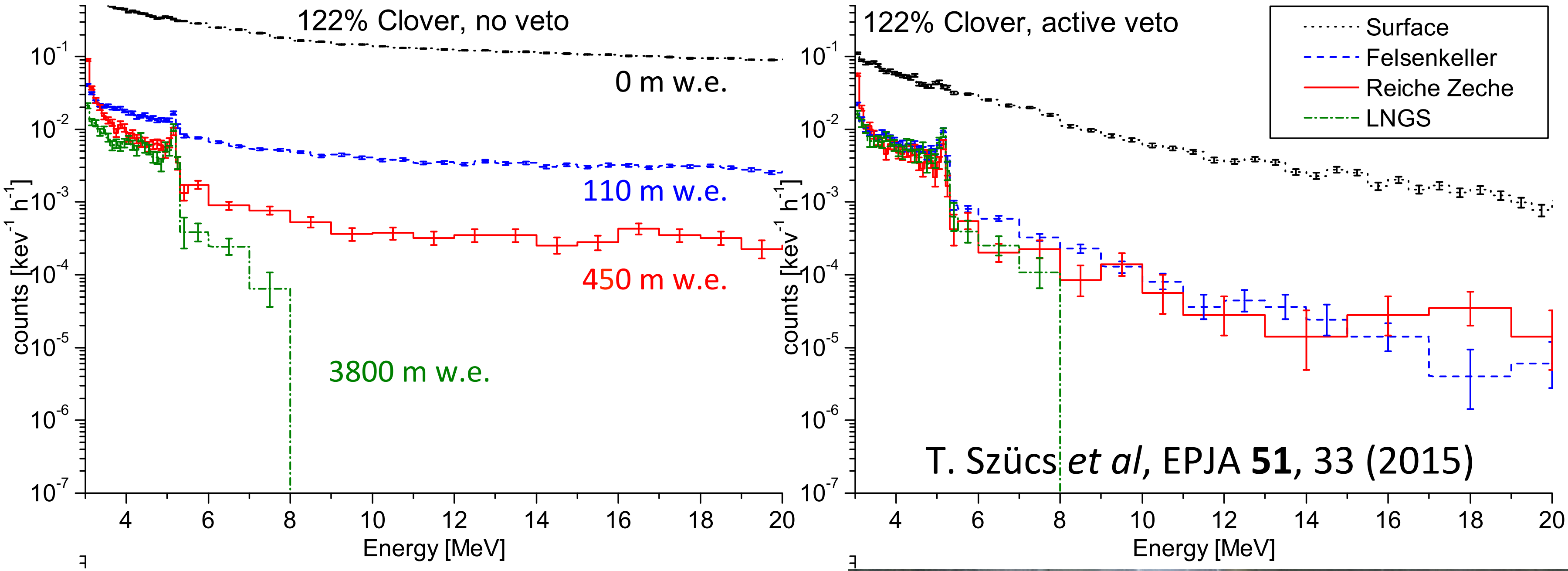


Reiche Zeche mine / Freiberg / Germany (Measurement at 150 m depth)

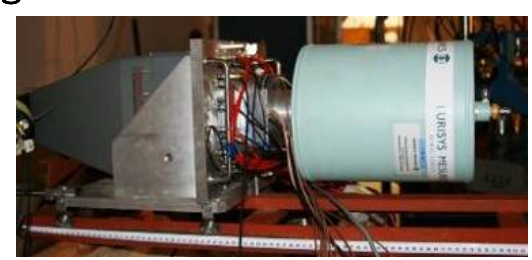
- Silver mine founded in 1168
- Recently a Teaching, Research and Visitor Mine
- TU Bergakademie Freiberg

Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017

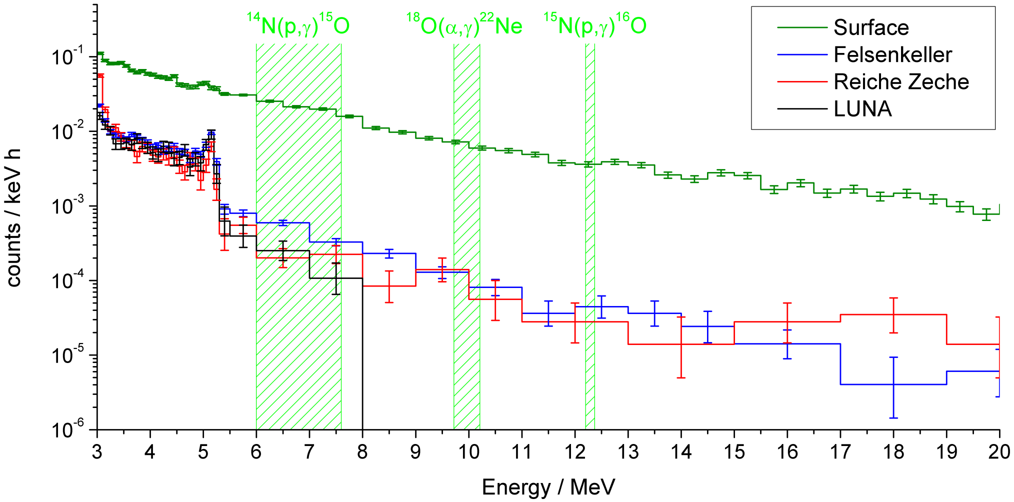
Background, in the same HPGe detector in Reiche Zeche (150 m)

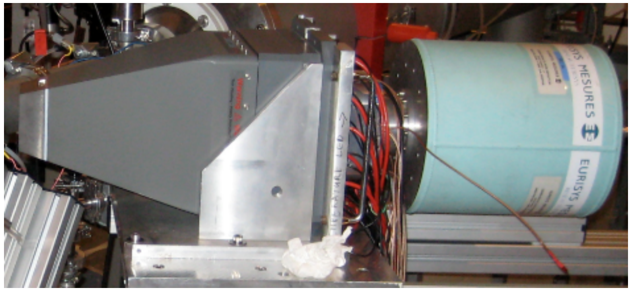


- One and the same HPGe detector (Eurisys Clover with active veto)
- At a depth of 150 m, the background rate at 6-8 MeV γ-ray energy is consistent with the deep underground one

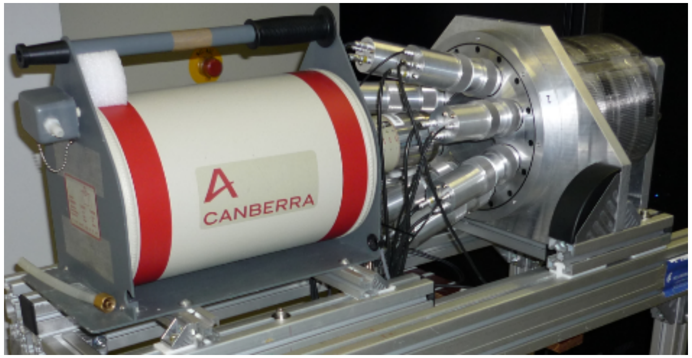


HPGe γ spectra recorded with active shielding

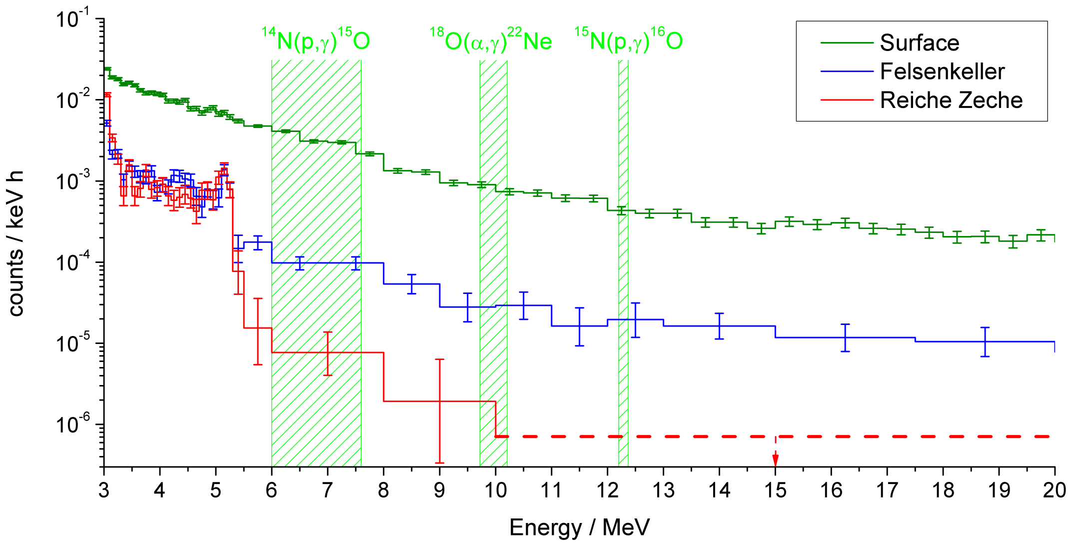




Clover:
- 122% relative efficiency
- ~1.1 cm thick pyramidal BGO



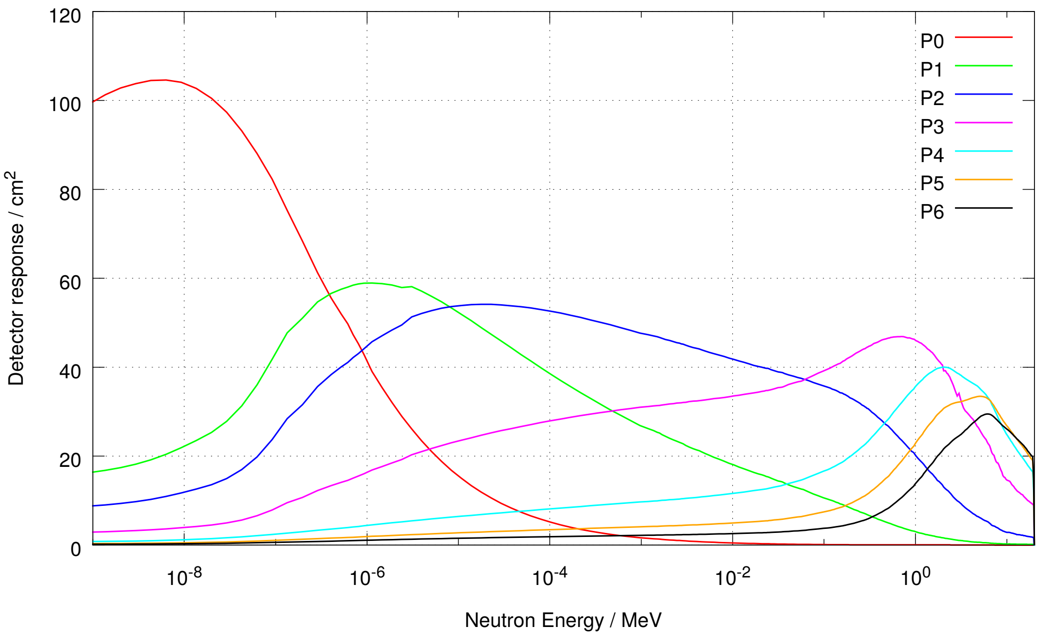
60% HPGe
- 60% relative efficiency
- ~3 cm thick cylindrical BGO

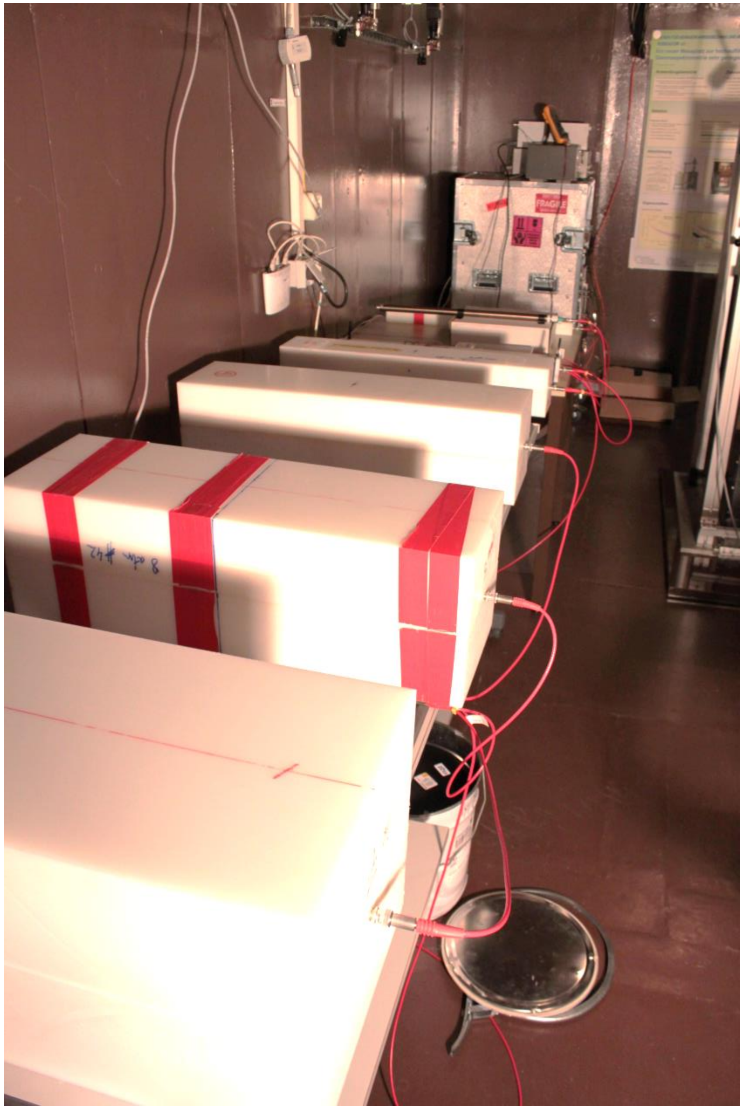


Neutron flux (Marcel Grieger, MSc work)

- ^{3}He counters inside polyethylene moderator blocks of various sizes

- Same setup previously used at Canfranc underground lab, Spain
  D. Jordan et al.,
  Astropart. Phys. 42, 1 (2013)

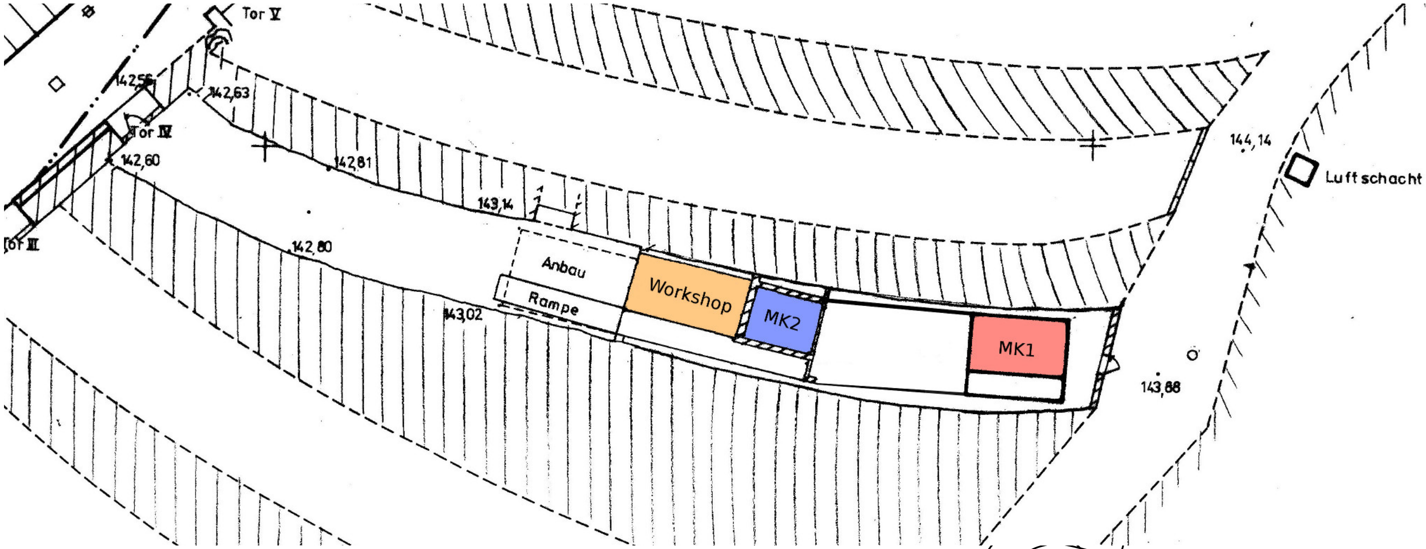




Neutron flux (Marcel Grieger, MSc work)

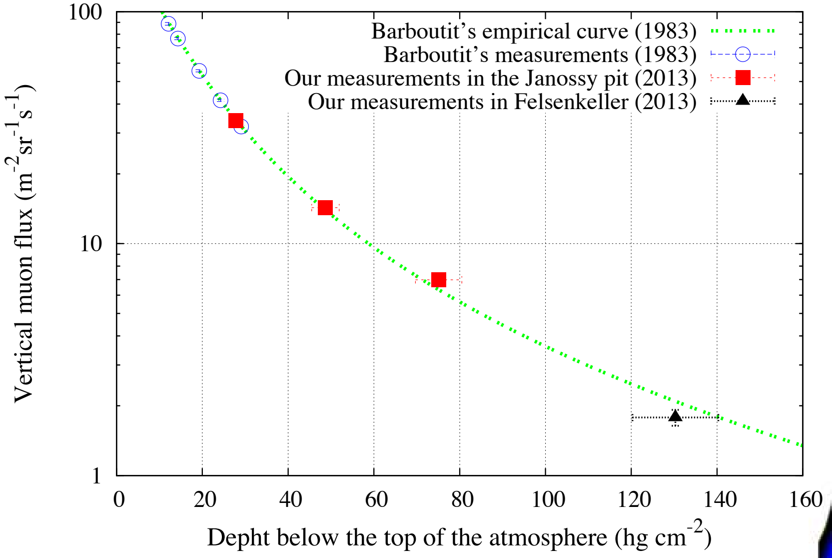
- Three different campaigns show consistent results
- Very different fluxes at three nearby sites (all in tunnel IV) with similar muon flux

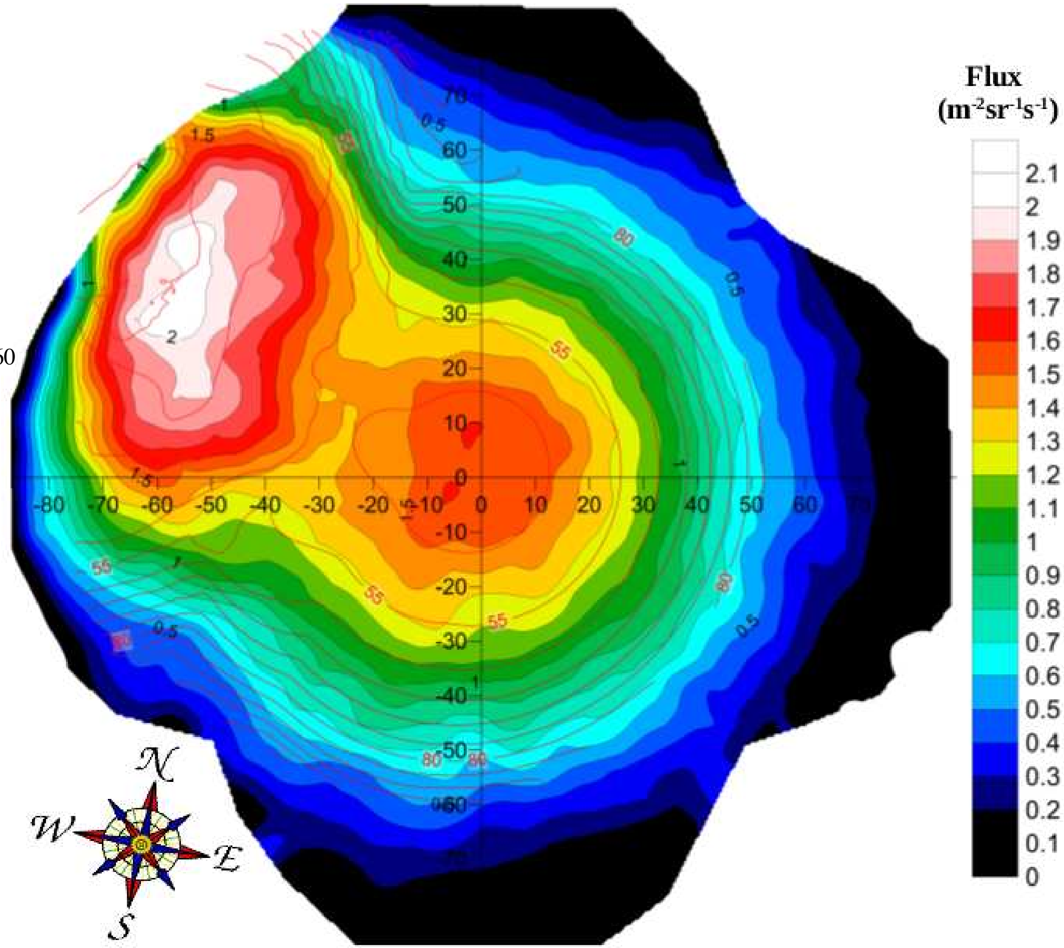
Site	Intergated flux [10^{-4} cm^{-2} s^{-1}]
Workshop	**2.1**
MK2 (Pb+Fe)	**4.6**
MK1 (rock)	**0.7**



Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017

Felsenkeller, muon flux measurement

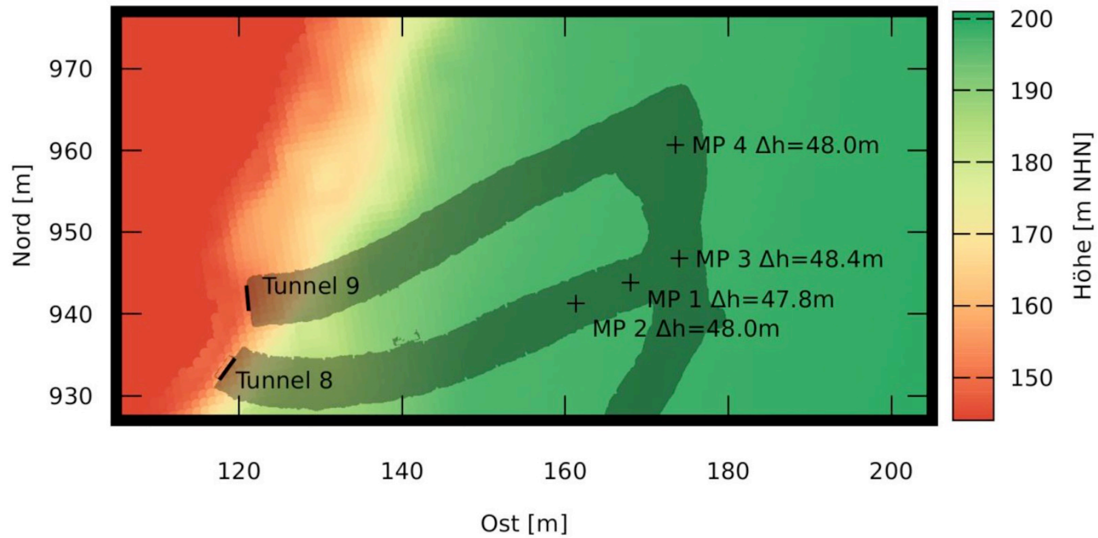


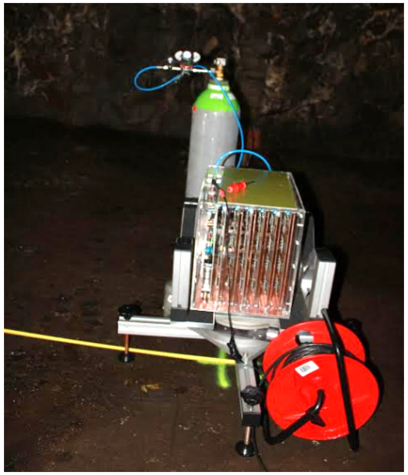


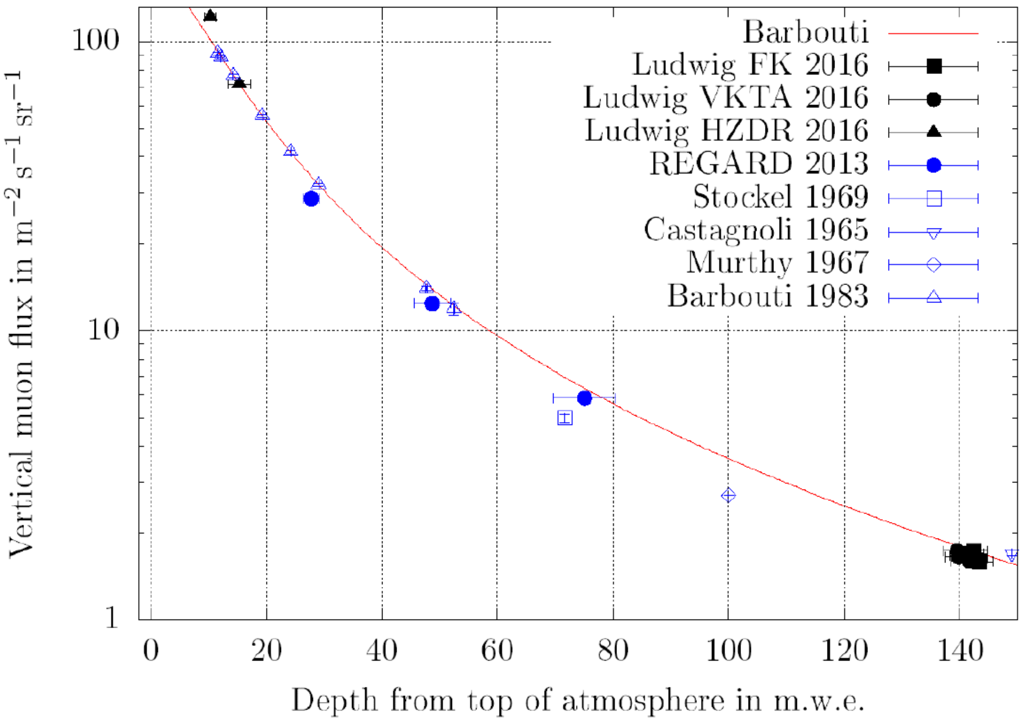
- Rock overburden 130 m.w.e., slightly higher than in the nearby existing low-activity lab (110 m.w.e.)

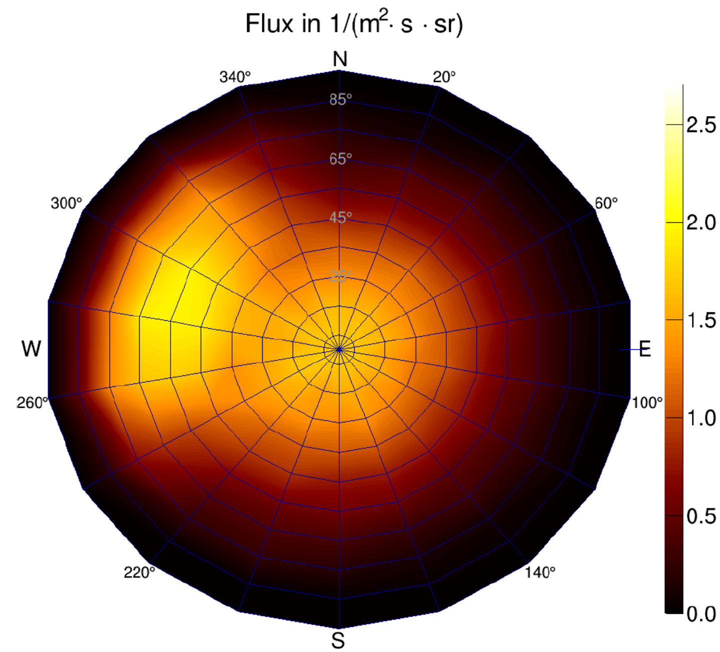
L. Oláh *et al*, J. Phys.: Conf. Ser. **665**, 012032 (2016)

Muon flux measurements (Felix Ludwig, MSc work)





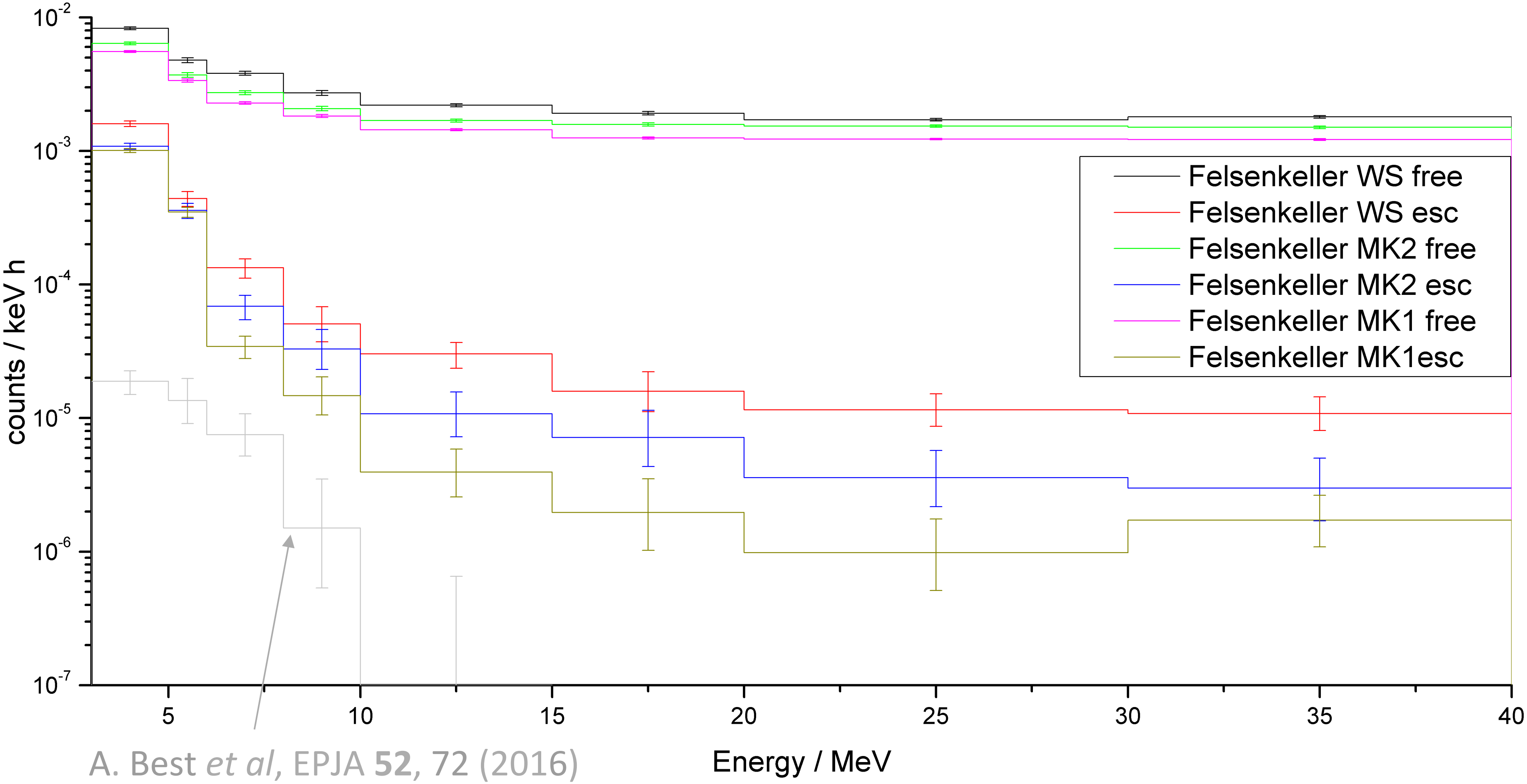




MTA atomki DEBRECEN
HZDR

Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017

60% HPGe @ Felsenkeller



A. Best *et al*, EPJA **52**, 72 (2016)
scaled for same Ge mass

Thank you for your attention!

Tamás Szücs | tszucs@atomki.mta.hu | Dresden, 24.-28.06.2017