Limitations of next generation $0\nu\beta\beta$ germanium experiments: The Good, the Bad and the Ugly

The good: Metallization

The bad: ^{210}Pb on surfaces,

And the ugly: ^{68}Ge

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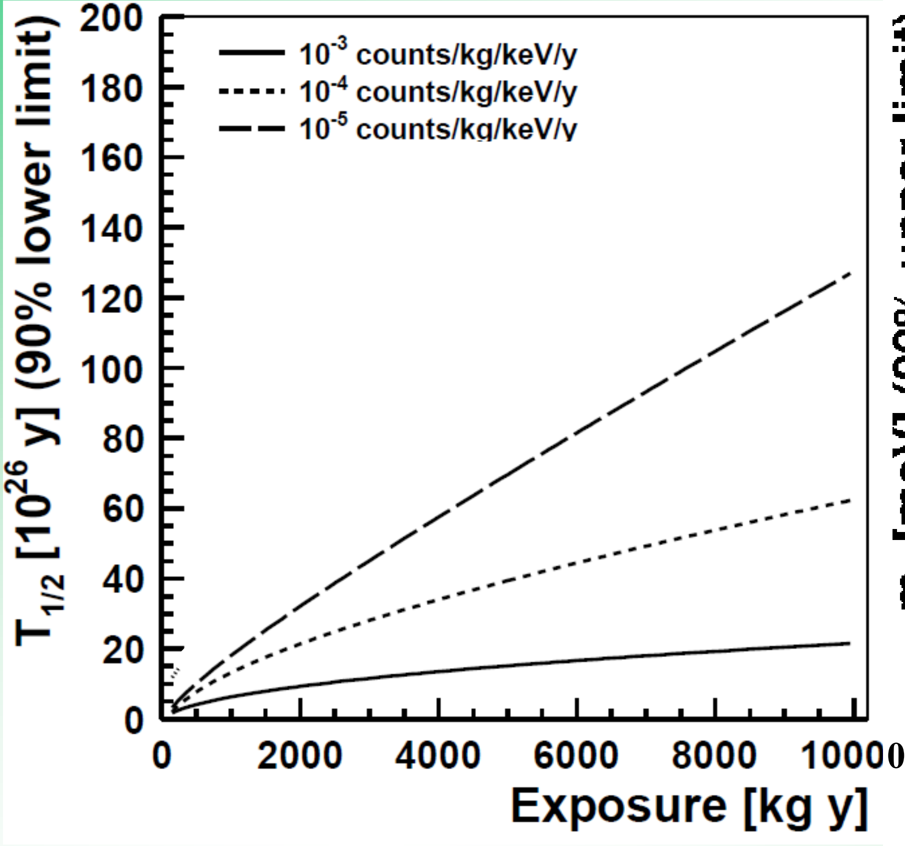
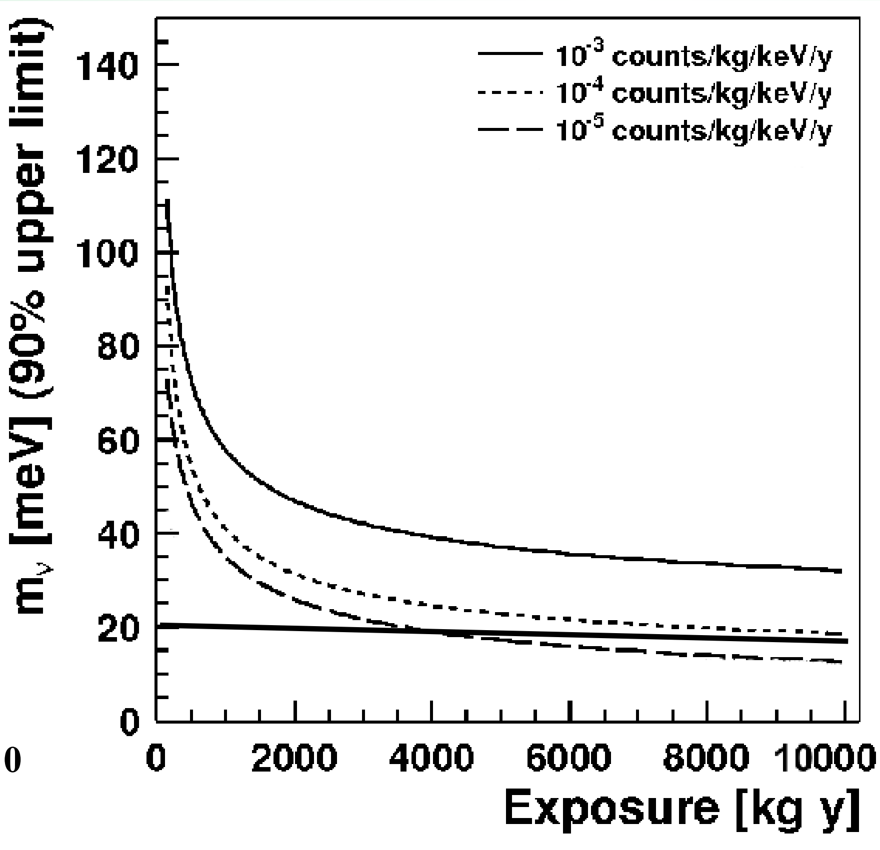
Ton Scale Required Background:





Ton scale experiment requires background of 10^{-5} cts/(kg keV y)

Limits calculated using ensemble test method from A. Caldwell, Kevin Kröninger, Phys.Rev.D 74 (2006) 092003

Aluminum as background

Aluminum: used for many useful things

Aluminum as background

Used to metallize HPGe detectors.

Example case:

Full metallization of HPGe type detector with 75 mm diameter and 70 mm height

$$2\cdot\pi\cdot 3.75\text{cm}\cdot 300\text{nm}\cdot 7\text{cm}\cdot 2.7\text{g/cm}^3$$

$$=$$

13.4mg

of aluminum on the outer surface

→**Primordials: ^{238}U - ^{232}Th**

→**Cosmogenics: ^{26}Al, ^{22}Na**

Aluminum as background

^{26}Al: β+ decay,

Q-value: 4 MeV,

$T_{1/2}$=7.4·10^{5} years

Can not be removed easily from bulk aluminium

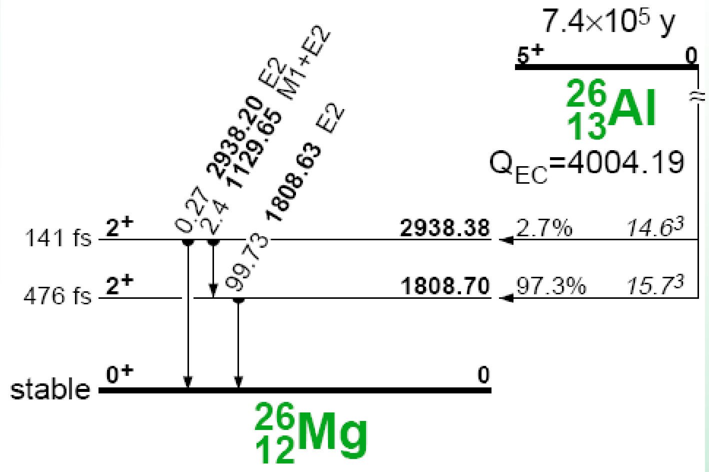
Can not wait for decay

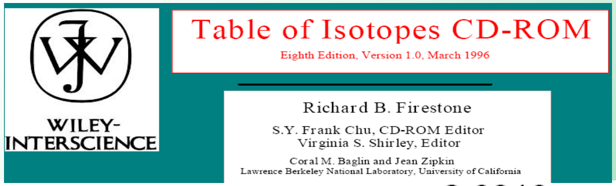
^{22}Na: Q-value: 2.84 MeV,

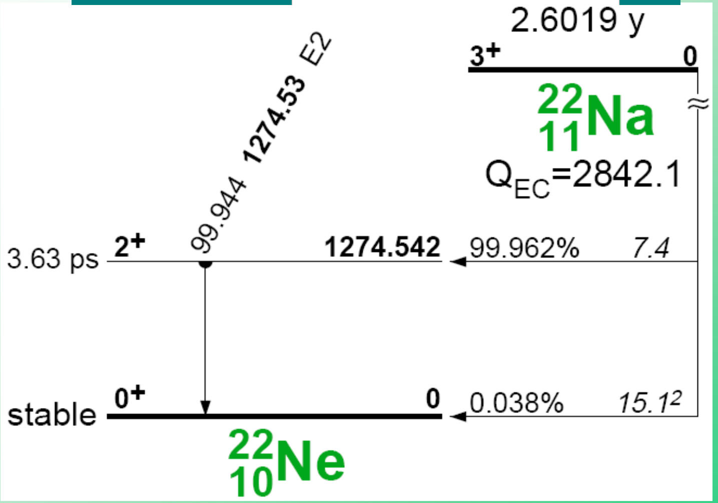
$T_{1/2}$=2.6 years

Easily produced if at sea level

Can wait for decay

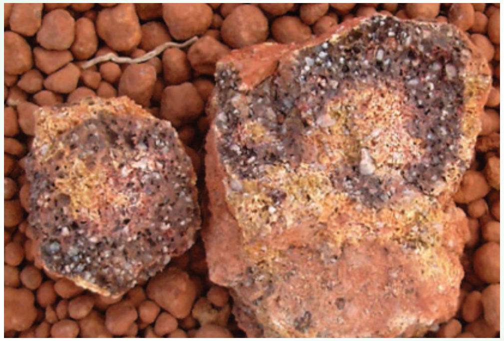






Aluminum as background

Aluminum is refined from Bauxite.



Bauxite mines:

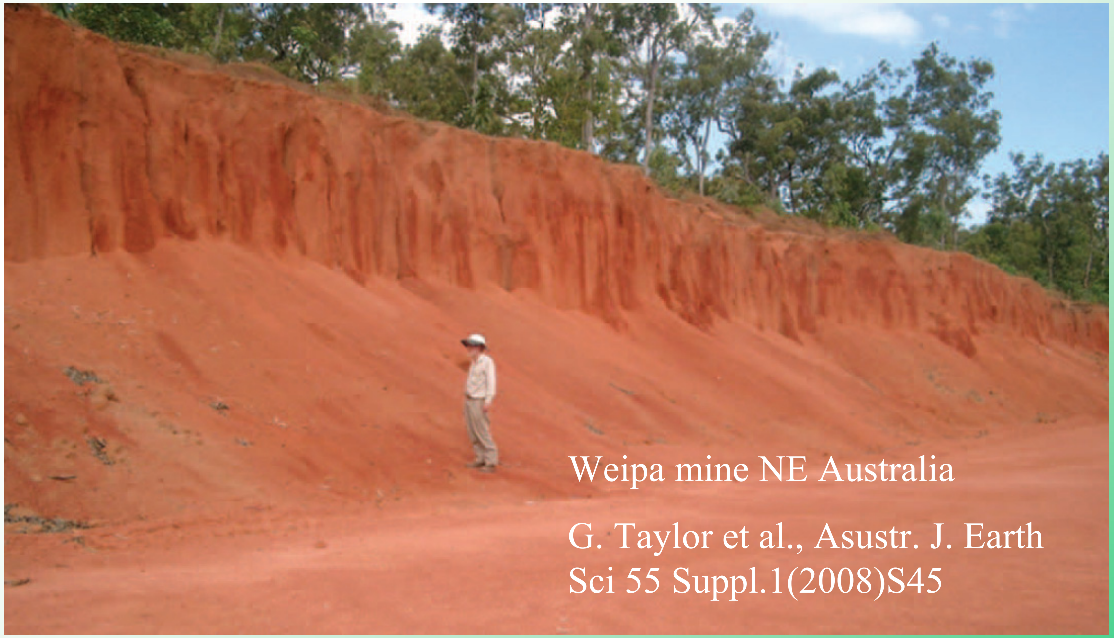
mainly open pits

Top soil overburden: < 1m

Layer thickness: 2m – 4m

Deposits formed by weathering

→Rested on surface since its formation



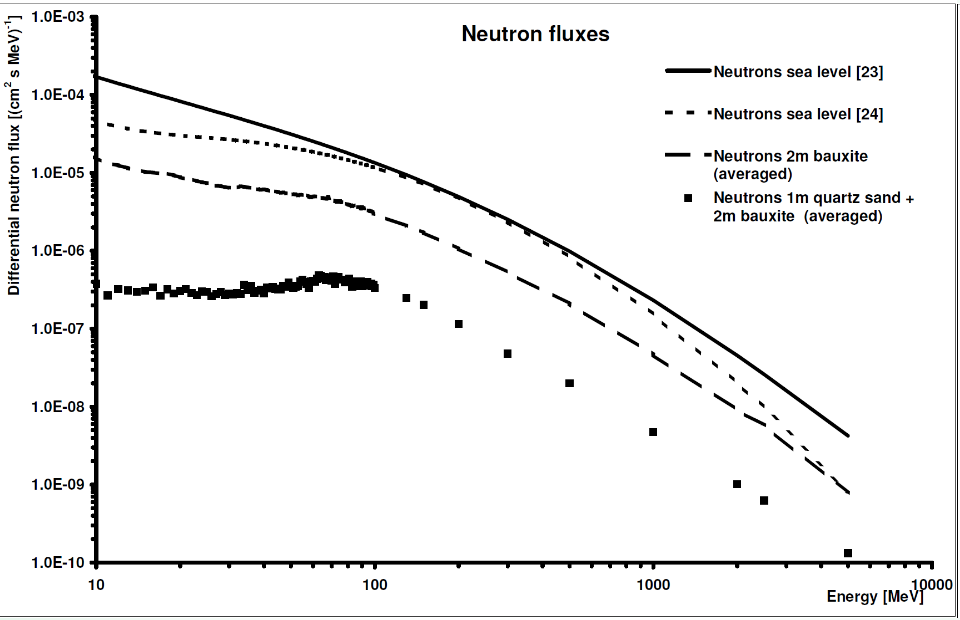
Weipa mine NE Australia

G. Taylor et al., Asustr. J. Earth Sci 55 Suppl.1(2008)S45

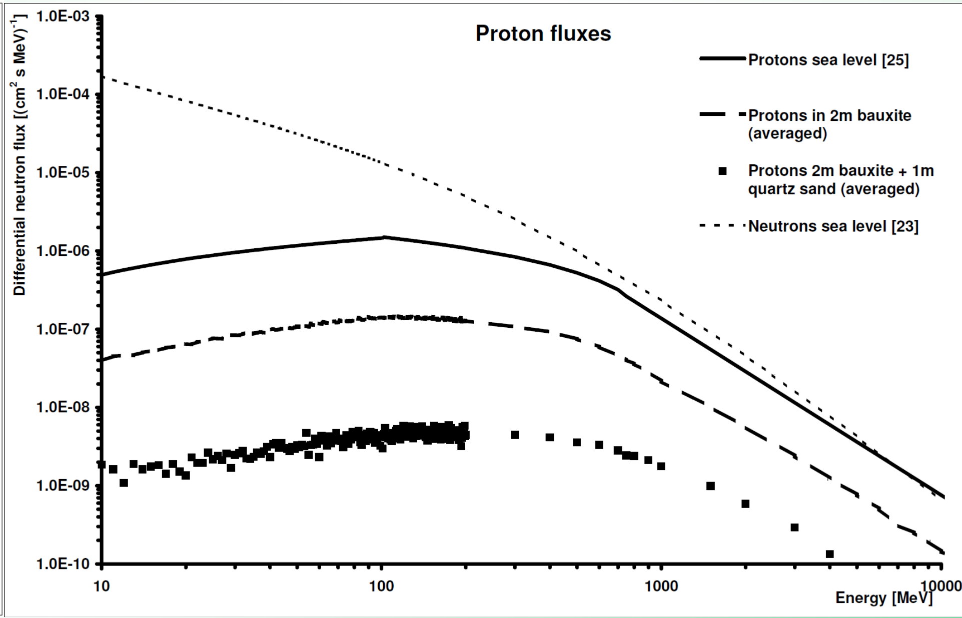
→ Assume full exposure to cosmic rays since millions of years

Aluminum as background

Secondary neutron flux



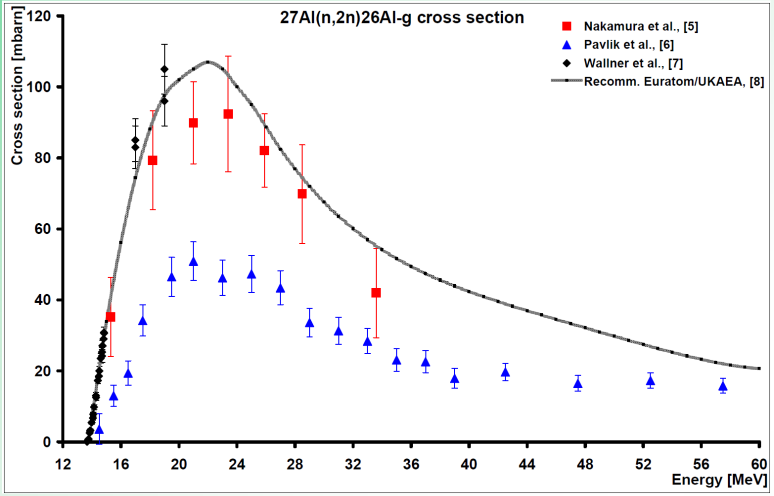
Secondary proton flux

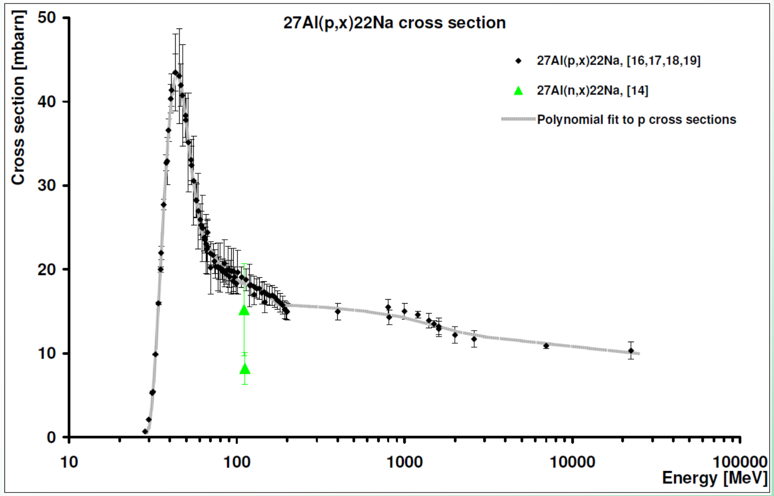


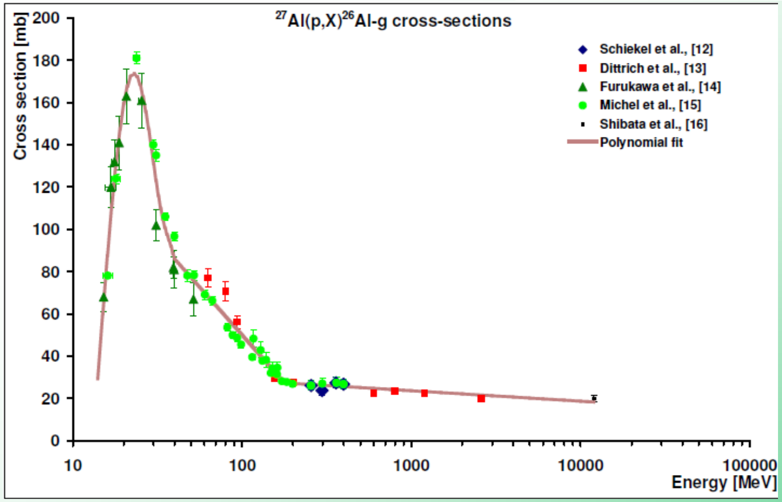
at sea level, New York, averaged over 2m bauxite layer and avereaged in a 2m bauxite layer under 1m soil:

Aluminum as background

Excitation functions for ^{26}Al and 22Na



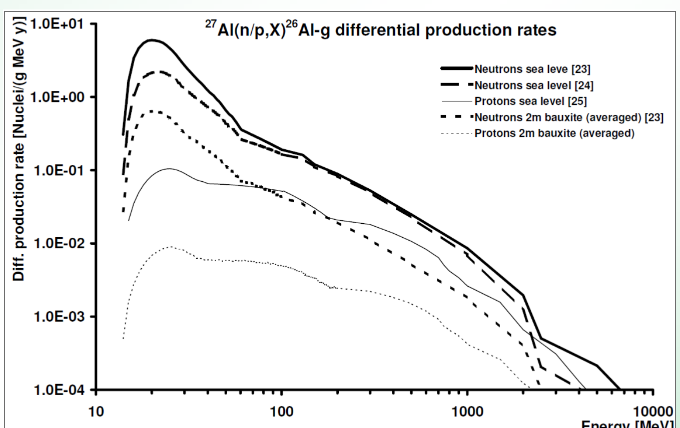


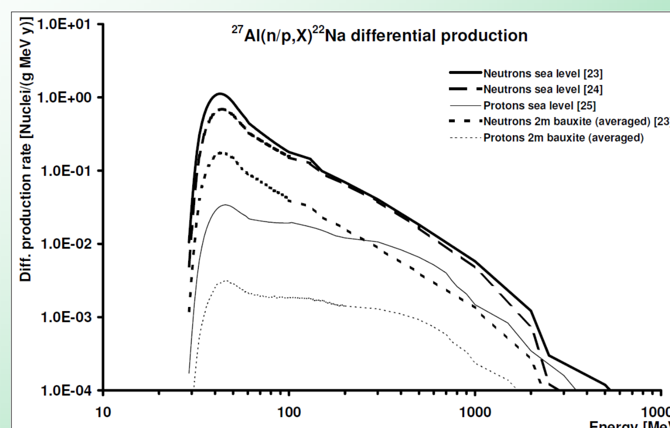


Aluminum as background

Expectations from naive calculations

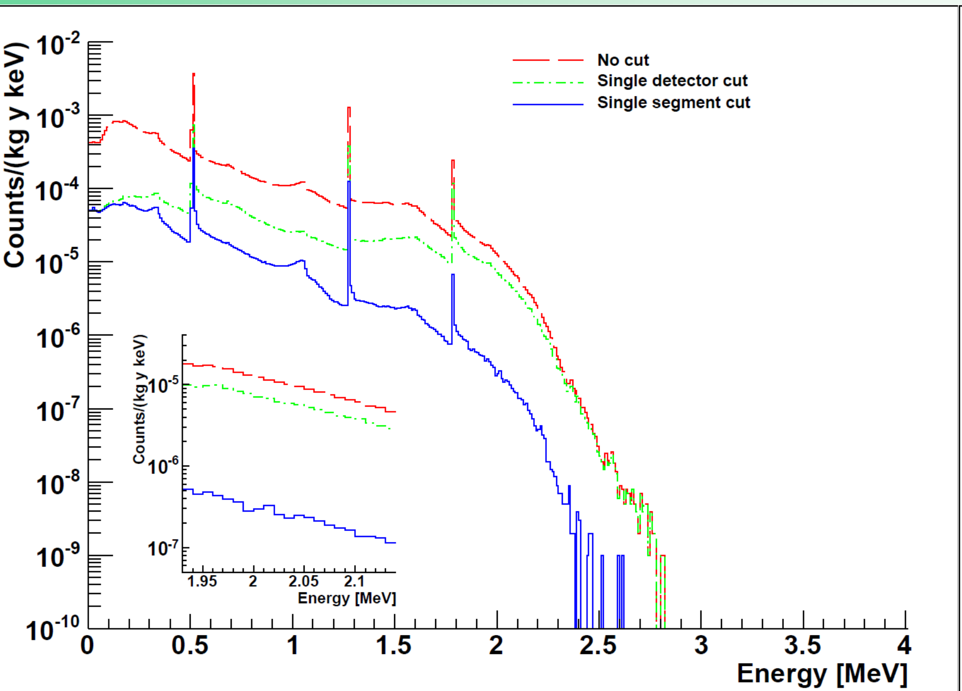
	^{26}Al [(g y)$^{-1}$]	^{26}Al [mBq/kg]	^{22}Na [(g y)$^{-1}$]	^{22}Na [mBq/kg]
n [surface Ziegler]	142	4.5	56	1.8
n [surface Gordon]	80	2.5	43	1.3
n[2m self absorption]	21	0.67	11	0.4
n[1m soil 2m self abs.]	1.4	0.04	1.0	0.03
p [surface]	17	0.54	8.7	0.1
n + p in 2m bauxite	23	0.74		
Sea level, half equilibrium			32	1.0

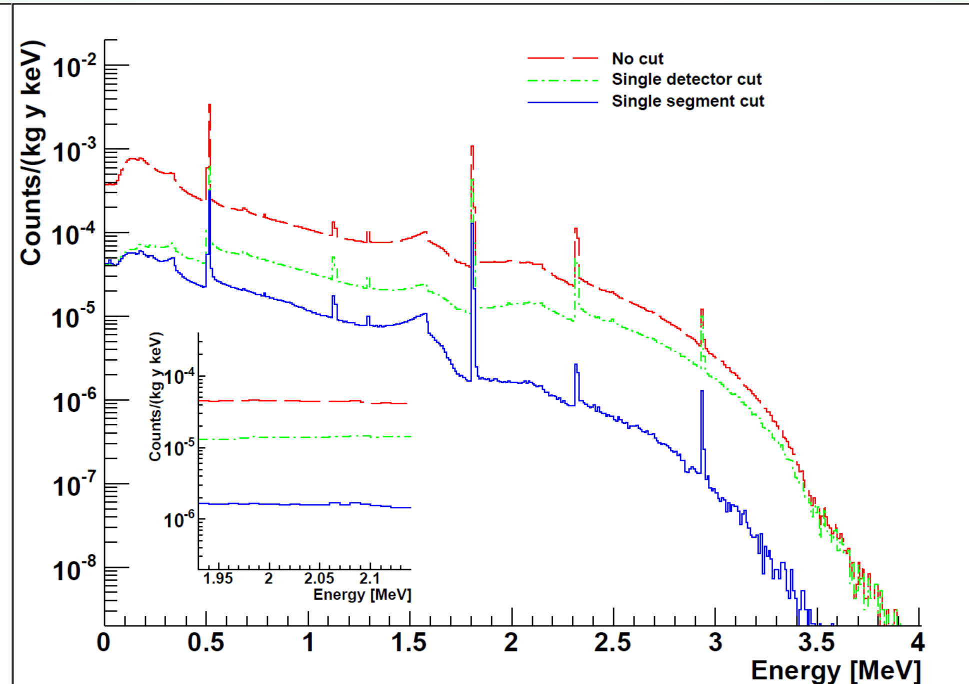




Aluminum as background

MC of ^{26}Al and ^{22}Na (1.0 mBq/kg)



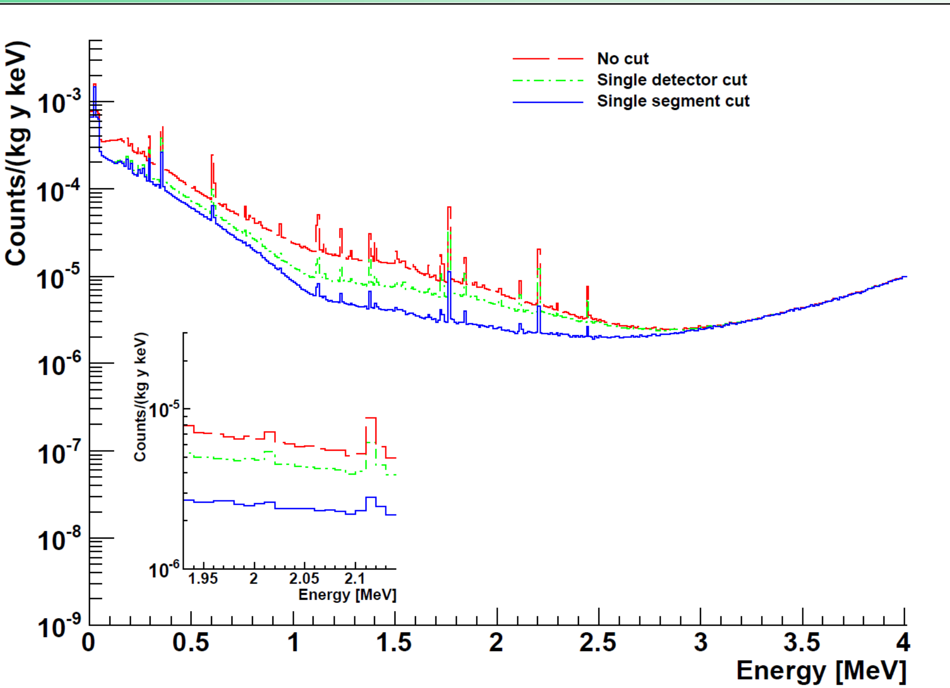


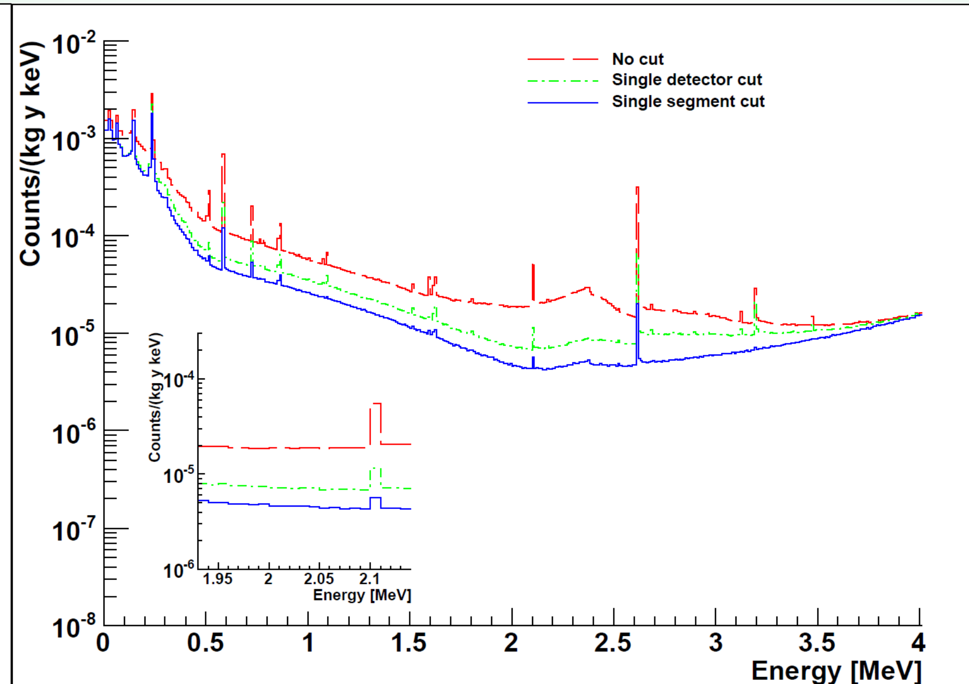
→Relevant background contribution for ton scale experiment even for activity ten times less than naïve expectation!

10^{-6} cts/(kg y keV) → Have to limit ^{26}Al activity to 0.6 mBq/kg
^{22}Na activity to 2mBq/kg

Aluminum as background

MC of ^{226}Ra and ^{228}Th (1.0 mBq/kg)





→Relevant background contribution for ton scale experiment even for activity ten times less than naïve expectation!

10^{-6} cts/(kg y keV) → Have to limit ^{226}Ra activity to 0.4 mBq/kg
^{228}Th activity to 0.2mBq/kg

Aluminum as background

Measurements of ULB Aluminium:
Activities in mBq/kg

Sample	^{26}Al	^{22}Na	^{226}Ra	^{228}Th	^{40}K
Kryal, Hydro Aluminium, UTH 1	0.6 ± 0.3	0.7 ± 0.3	< 0.38	<1.9	<21
Kryal, VAW, UTH 0.25	< 0.15	< 0.26	<0.28	<0.58	<22
Highpural, VAW	< 0.45	< 0.37	<3.7	47 ± 5	<5.5
ULB I [6]	0.2 ± 0.1	< 0.32	<0.7	3.8 ± 0.7	4.9 ± 1.8
ULB II [5]	$0.38^{+0.19}_{-0.14}$	< 0.18	0.27 ± 0.19	1.4 ± 0.2	$1.1^{+0.2}_{-0.1}$

^{26}Al and ^{22}Na found in ULB aluminum!

Clean Aluminum does exist!

→HPGe measurements sensitive enough to select ^{26}Al and ^{22}Na and ^{232}Th "free" Aluminum

Aluminum as background

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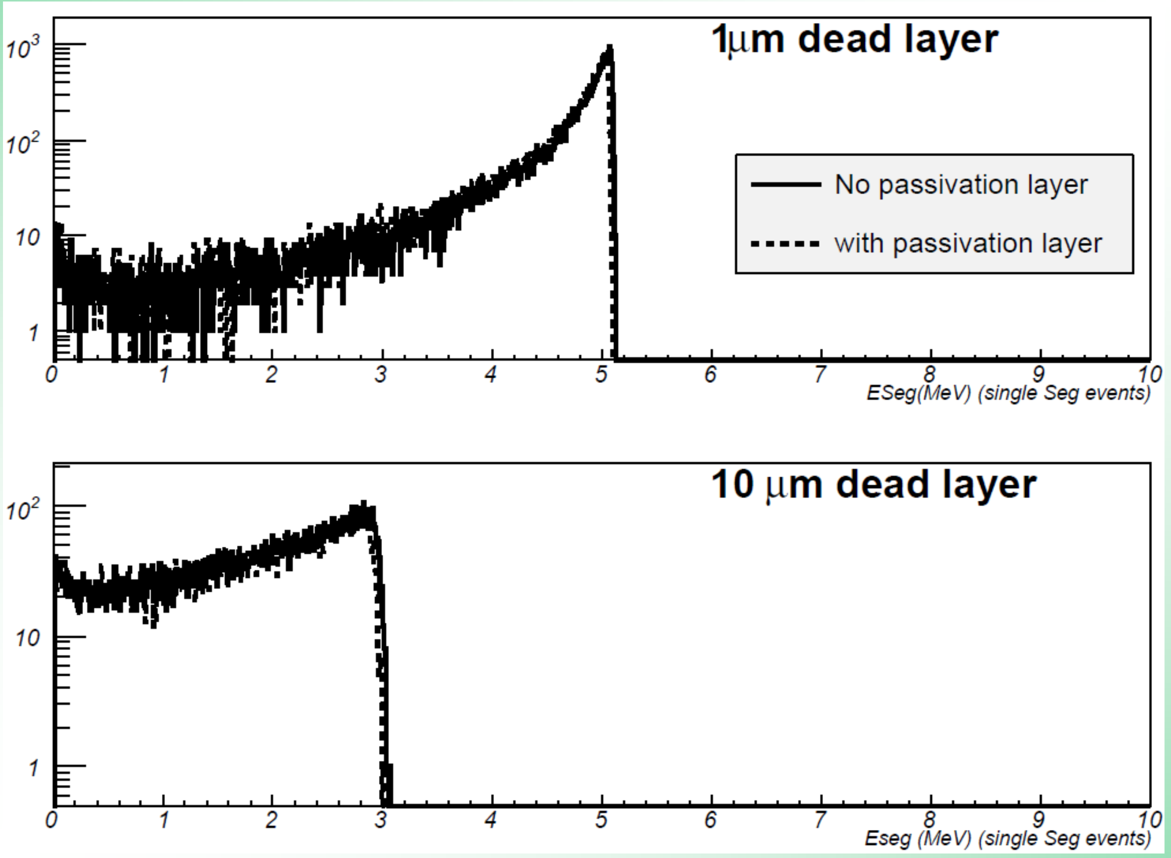
B. Majorovits et al. NIM A 647(2011)39

The Good

Contaminations on HPGe surfaces

^{210}Pb lead on surfaces with dead layer <20µm thickness

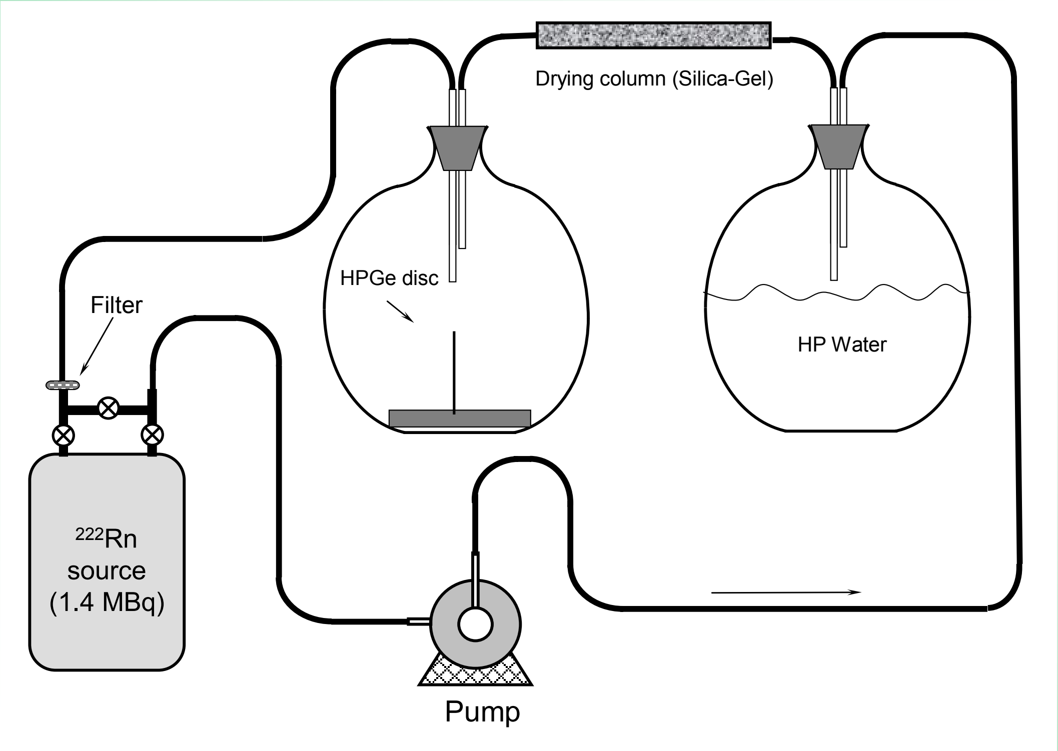


α contaminations (^{210}Pb, ^{210}Bi) seen in Heidelberg Moscow, Edelweiss, CDMS, GERDA experiments.
→ Investigation of surface treatment!

Contaminations on HPGe surfaces

Effect of etching : Removal and deposition efficiencies of ^{210}Pb and its daughters during etching of germanium

(in collaboration with G. Zuzel, MPI-K, M. Wojicik, Jagellonian Univ., Cracow and Canberra France, Lingolsheim, France):



1.4 MBq Rn (^{226}Ra) source

10 l gas volume in two excsicators

NPGe / HPGe discs and DI water exposed to ^{222}Rn source for 7 months at MPI-K in Heidelberg

Contaminations on HPGe surfaces

Clean HPGe disc etched in contaminated etching solution

Contaminated disc etched in clean etching solution

Samples were etched by Canberra France-Lingolsheim according to procedure of HPGe detector etching

Contaminations on HPGe surfaces

NPGe disc:

Isotope	Initial count rate [cpm]	Count rate after cleaning [cpm]	Reduction factor R
^{210}Pb	2.09 ± 0.12	–	–
	2.12 ± 0.21	< 0.02	> 106
^{210}Bi	40.7 ± 1.3	–	–
	46.1 ± 1.4	–	–
^{210}Po	50.0 ± 1.5	0.06 ± 0.02	833 ± 279
	47.0 ± 1.4	0.05 ± 0.02	940 ± 377

HPGe disc:

^{210}Pb	0.717 ± 0.011	< 0.001	> 717
^{210}Bi	14.70 ± 0.12	< 0.017	> 865
^{210}Po	11.88 ± 0.19	0.102 ± 0.006	117 ± 7

46.5 keV gamma with HPGe det :
1% est. efficiency

β - particles with Si det:
10% est. efficiency

α – particle with 4π Si det. system:
15% estimated efficiency

Measurements performed at Jagellonian University Cracow by M. Wojicik

Contaminations on HPGe surfaces

Deposition efficiencies on HPGe disc:

Isotope	Initial count rate [cpm]	Count rate after cleaning [cpm]	Count rate increase [cpm]	Number of nuclei on disc	Increase factor B_R
^{210}Pb	0.0163 ± 0.0009	0.023 ± 0.001	0.0066 ± 0.0013	$1.1 \cdot 10^7$	1.4
^{210}Bi	0.111 ± 0.006	0.217 ± 0.007	0.106 ± 0.009	7500	1.9
^{210}Po	0.064 ± 0.005	0.087 ± 0.006	0.023 ± 0.007	$1.7 \cdot 10^4$	1.4

Significant amount of ^{210}Pb, ^{210}Bi and ^{210}Po deposited on HPGe disc

HPGe measurement of ^{210}Pb concentration of DI water (upper limit): A < 20 Bq

Probability of plating onto HPGe from 100ml DI water:

^{210}Pb: > 1.2 %

^{210}Bi: > 1.2 %

^{210}Po: > 0.16 %

Accepted for publication in NIM A

Contaminations on HPGe surfaces

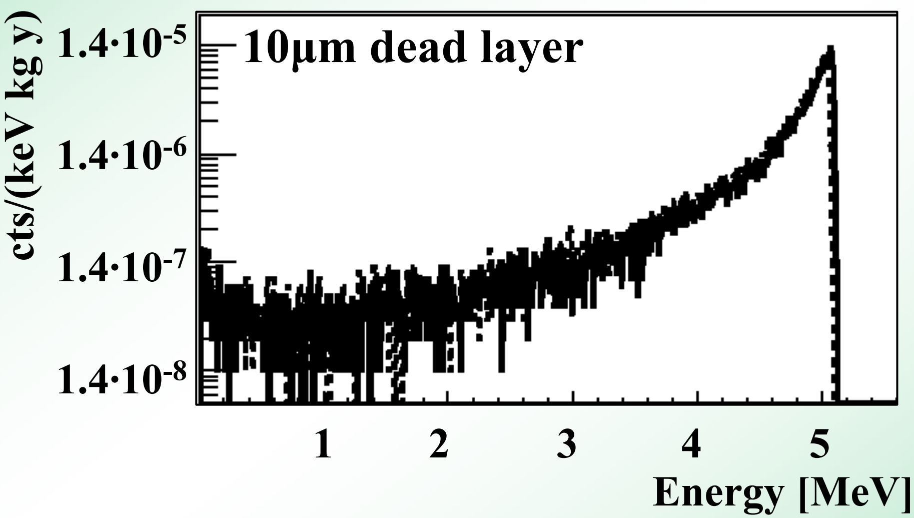
MC simulation: one ^{210}Pb nucleus on detector surface:

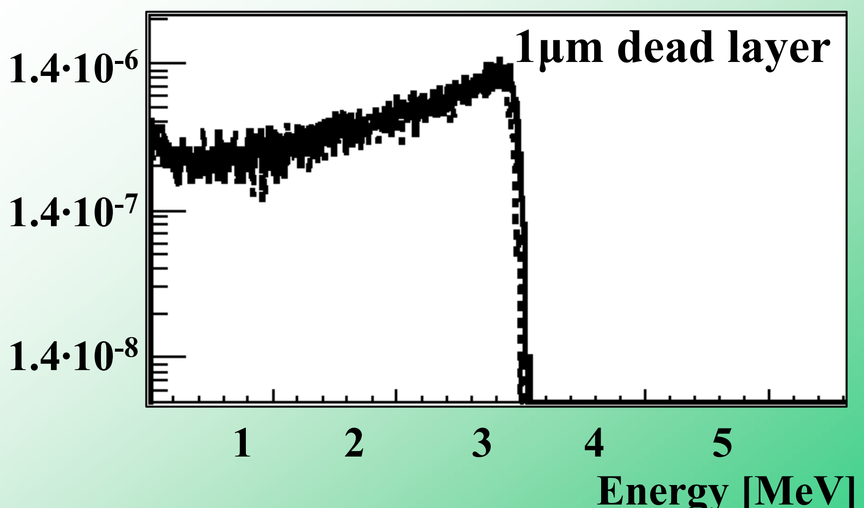
~10^{-7} cts/(kg y keV)

Allowed number of nuclei on active surface:
max. 10 → 0.01 nuclei per cm^2

in etchant (1.2% deposition eff.): ~850 ^{210}Pb nuclei ~10µBq/l!

→ ^{210}Pb Screening methods & Clean etchants needed





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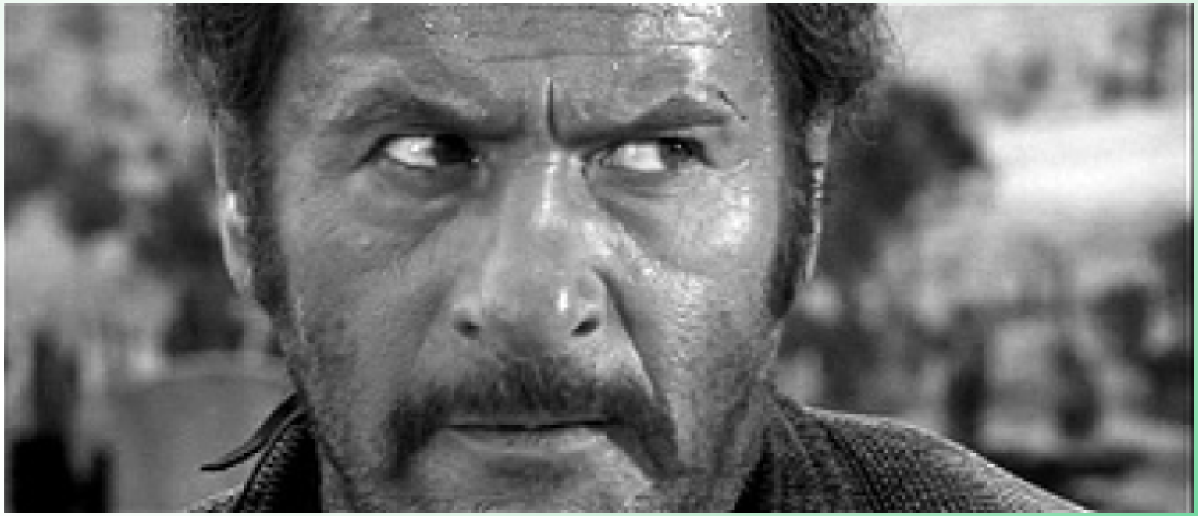
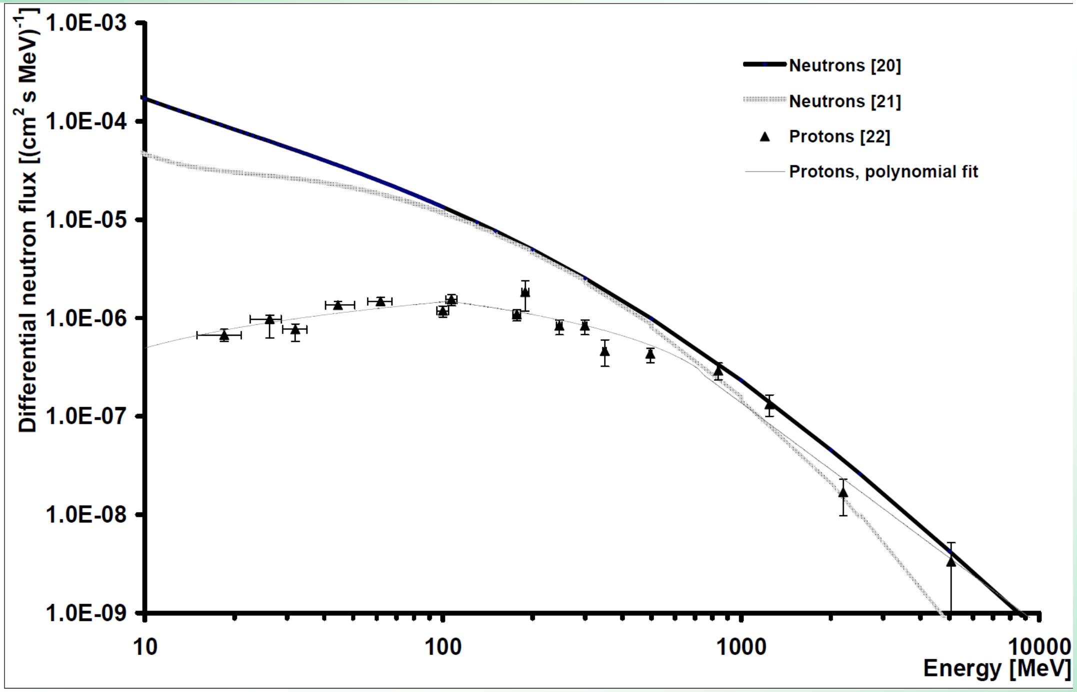


The Bad

Intrinsic HPGe contamination

Expected count rate due to ^{68}Ge in HPGe:
One ^{68}Ge nucleus per kg: $1.8 \cdot 10^{-5}$ cts/(kg y keV) [K. Kröninger, PhD]

→To keep the level below 10^{-6} cts/(kg y keV):
Roughly 55 ^{68}Ge nuclei per tonne allowed (0.055 per kg).



Production rates :

^{nat}Ge: 50 ^{68}Ge nuclei (kg day)$^{-1}$

^{enr}Ge: 7 ^{68}Ge nuclei (kg day)$^{-1}$

→ Max. 11 minutes above ground!

cosmogenic production of ^{60}Co and ^{68}Ge in germanium can be avoided by storage underground.

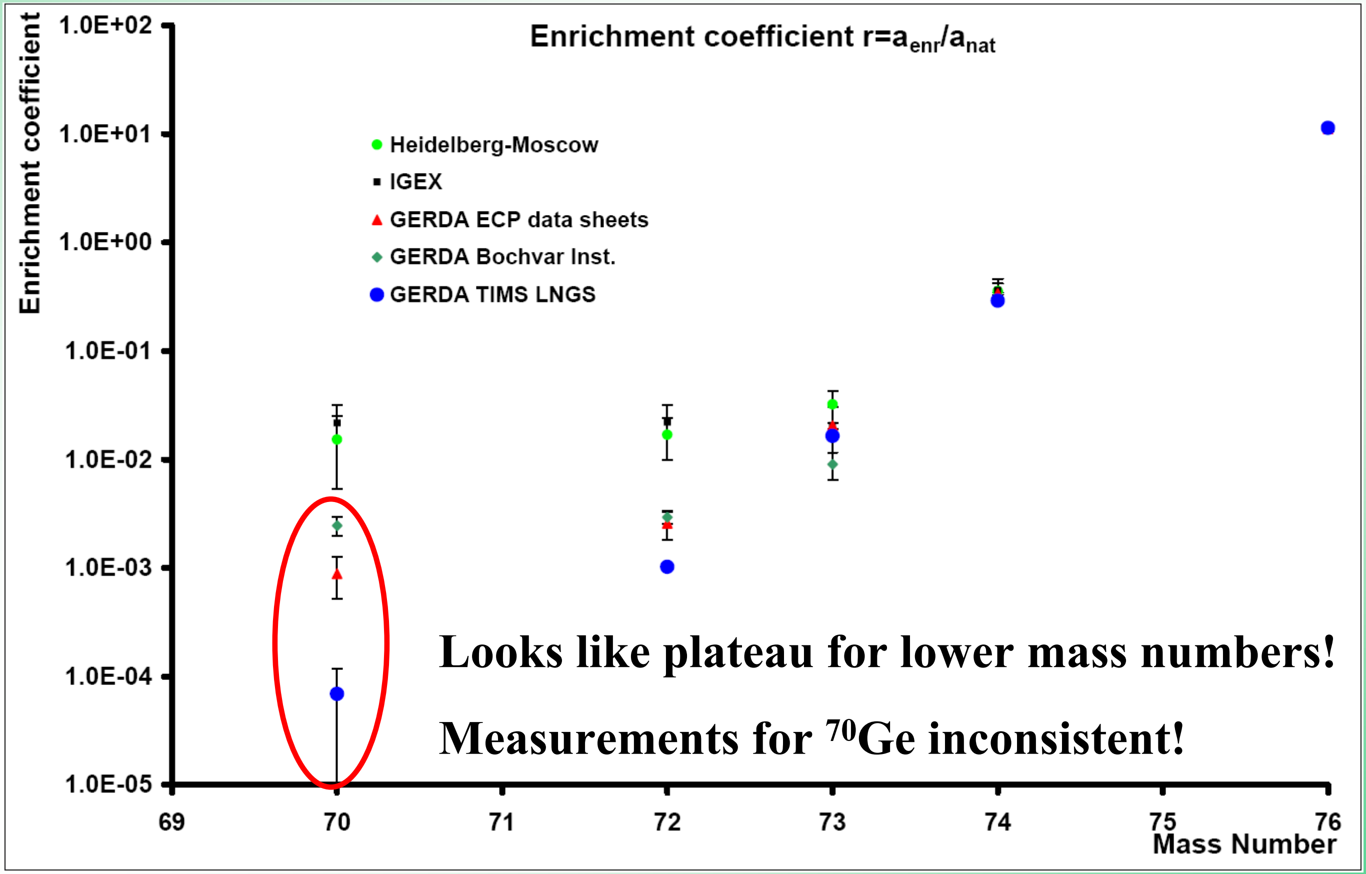
→ Enrichment underground!

Intrinsic HPGe contamination

In equilibrium in ^{nat}Ge: $2\cdot10^4$ ^{68}Ge nuclei/kg

Enrichment of germanium does deplete ^{68}Ge content.

But how efficiently?



Intrinsic HPGe contamination

Ratios of abundances natural to enriched materials:

Isotope	IGEX [73]	HdMo [51]	GERDA I [73]	GERDA II [52]	GERDA TIMS [74]	GERDA NAA [9]
^{76}Ge	10.9 ± 0.1	11.0 ± 0.4	11.2± 0.1	11.2 ± 0.1	11.4± 0.1	11.1 ± 0.1
^{74}Ge	0.362 ± 0.001	0.356 ± 0.006	0.334± 0.002	0.336 ± 0.008	0.290± 0.001	0.358 ± 0.002
^{73}Ge	$(2.1 \pm 0.1)\cdot 10^{-2}$	$(3.2 \pm 1.0)\cdot 10^{-2}$	$(9.0 \pm 0.1)\cdot 10^{-3}$	$(2.0 \pm 0.1)\cdot 10^{-2}$	$(1.64 \pm 0.03)\cdot 10^{-2}$	
^{72}Ge	$(2.20 \pm 0.04)\cdot 10^{-2}$	$(1.7 \pm 0.7)\cdot 10^{-2}$	$(2.93 \pm 0.03)\cdot 10^{-3}$	$(2.6 \pm 0.8)\cdot 10^{-3}$	$(1.02 \pm 0.04)\cdot 10^{-2}$	
^{70}Ge	$(2.16 \pm 0.05)\cdot 10^{-2}$	$(1.5 \pm 1.0)\cdot 10^{-2}$	$(2.45 \pm 0.02)\cdot 10^{-3}$	$(8.8 \pm 3.7)\cdot 10^{-4}$	$(6.9 \pm 0.5)\cdot 10^{-5}$	

Assume (!) deenrichment of ^{68}Ge of 10^{-4} (optimistic (?) for existing technology

→Expect two nuclei per kg enriched material

→Need to wait 5.18 half lives (3.84 years) to reach 0.055 nuclei/kg limit

→Need R&D on deenrichment of ^{68}Ge

The Ugly

Conclusions:

The Good 	**Metallization:**	**Significant background if not taken care of.** **Can be controlled via HPGe screening of aluminum.**
The Bad 	**Surfaces:**	**Need clean etchant. R&D for etchant screening!**
The Ugly 	**^{68}Ge:**	**Depletion efficiencies have to be studied and improved!**

It's a long way to the ton scale HP^{enr}Ge experiment

Donald Rumsfeld knew it all:

[Press Conference at NATO Headquarters, Brussels, Belgium, June 6, 2002]

“there are no "knowns." There are things we know that we know. There are known unknowns. That is to say there are things that we now know we don't know. But there are also unknown unknowns. There are things we do not know we don't know. “

	know	don’t know
know	^{26}Al, 2νββ, ...	Surface α-s, …
don’t know	???	Ton scale

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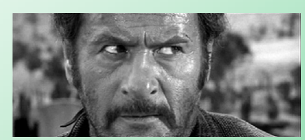
	know	don’t know
know	^{26}Al, 2νββ, …	Surface α-s, …
don’t know	0νββ	Ton scale

	know	don’t know
know		
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