Neutron background in the water tank scenario

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Neutron background

^{76}Ge 0νββ signal window → 2039 ± 5 keV

→ any β radioactive isotope with Q ≥ 2039 keV is a potential source of background

→ many such isotopes can be produced by neutron activation of Ge isotopes in GERDA detectors while in operation

Aims:

1) identify the "dangerous isotopes"
2) perform the simulations of neutron transport using **LCS** (**MCNP**) for simplified GERDA geometry (LN_2 + water)
3) include neck into geometry
4) estimate the ^{77}Ge activity in crystals
5) do the same for LAr scenario → see my next talk ...

Dangerous isotopes

e.g. $^{76}Ge(n,\gamma)^{77}Ge(\beta^-)^{77}As^*(\gamma)$ Q_β = 2702 keV with $E_\beta + E_\gamma \geq$ 2039 keV

Nuclide	Reaction	Decay	*Q*-value [keV]	Half-life
^{77}Ge	(n,γ)	β^-	2702	11.3 h
^{76}Ga	(n,p)	β^-	7010	32.6 s
^{75}Ga	(n,pn)	β^-	3392	126 s
^{75}Zn	(n,2p)	β^-	6000	10.2 s
^{74}Ga	(n,p2n)	β^-	5370	8.12 m
^{74}Zn	(n,2pn)	β^-	2340	96 s
^{73}Zn	(n,α)	β^-	4290	6.6 s
^{69}Ge	(n,8n)	β^+,EC	2227	39.05 h
^{68}Ga	(n,p8n)	β^+,EC	2921	9.49 h
...	...	...	...	...

Decay chains multiply the rate, e.g. $^{75}Zn(\beta^-)^{75}Ga(\beta^-)^{75}Ge$

Production reactions

A) Spallation reactions

– threshold reactions – few MeV up to several tens of MeV
– threshold higher when more particles produced, e.g. $^{76}Ge(n,8n)^{68}Ga$

– typically no cross sections available, codes not reliable

B) Neutron capture reactions → ^{77}Ge

– no threshold – reaction occurs at all energies

– cross sections below 20 MeV available

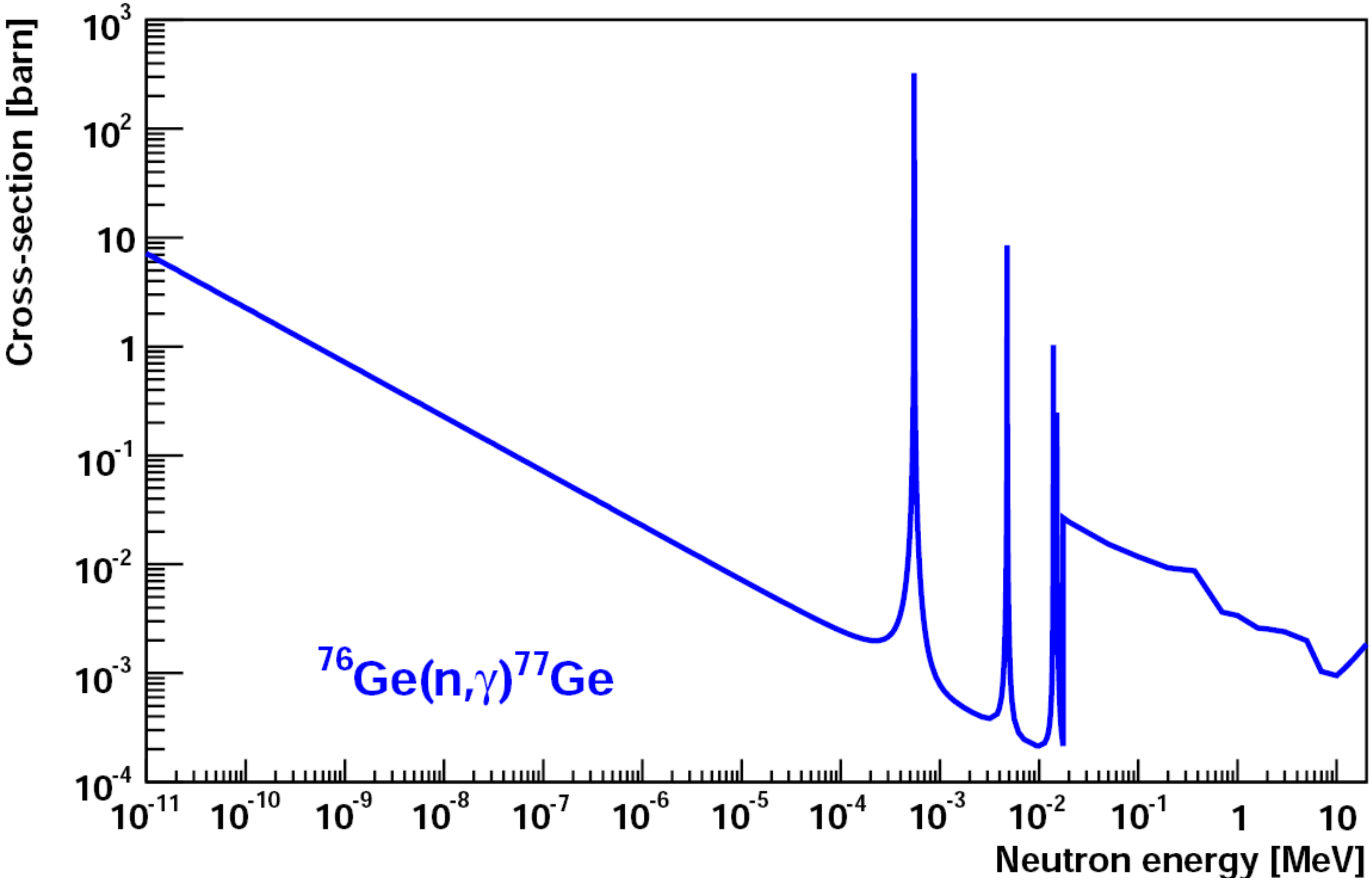
REALLY DANGEROUS

C) Inelastic scattering

– excitation of Ge nucleus to energy above 2039 keV

– neutron with energy equal to excitation energy (or higher) necessary

^{77}Ge excitation function

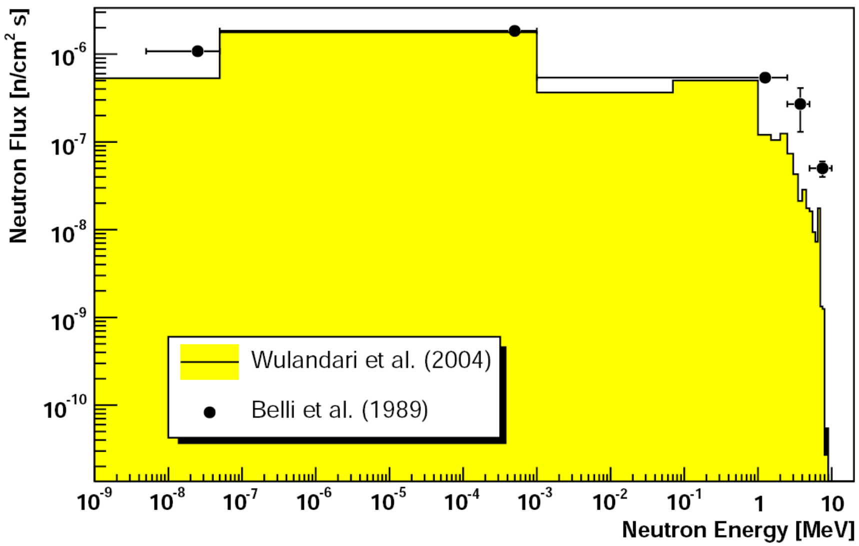


Neutron sources

Primordial: (α,n) + fission

- measured in Hall A
- low energies – up to 10 MeV
- high fluxes

  $\approx$ 5 x 10^3 neutrons cm^{-2} y^{-1} total

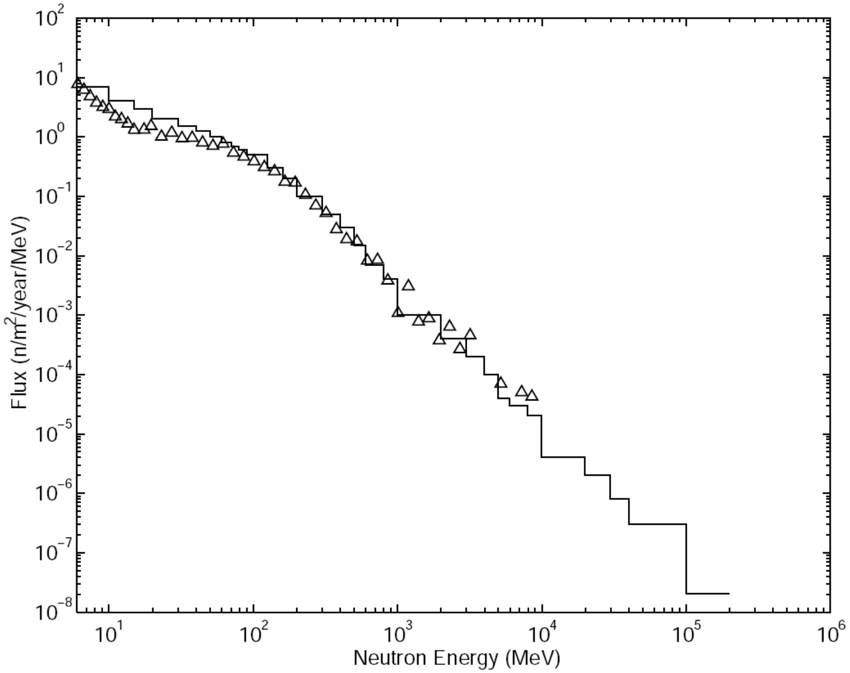


Muon induced:

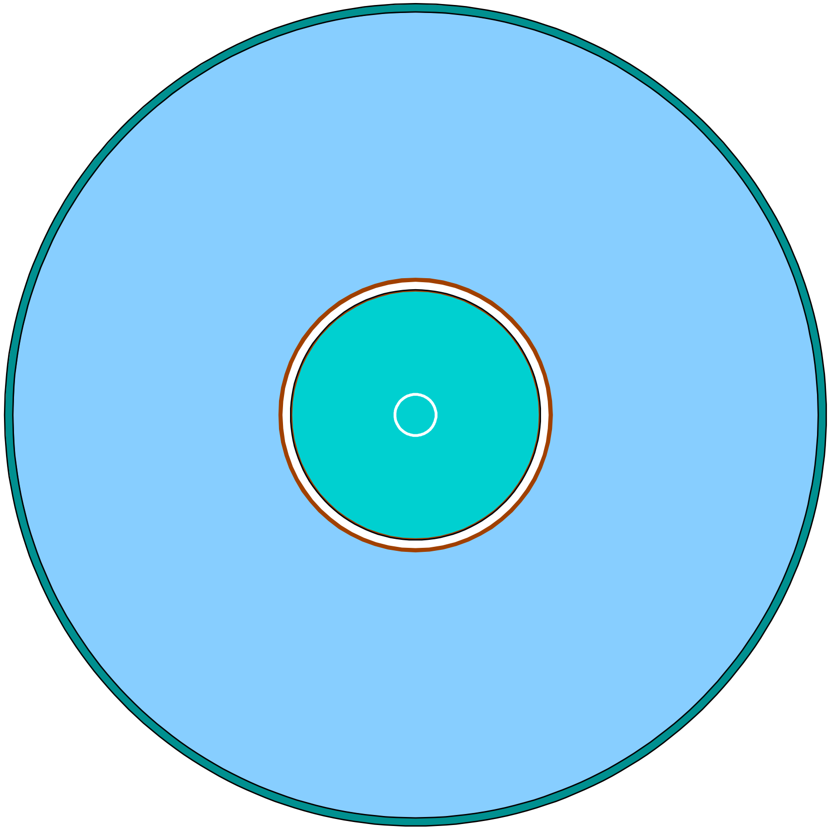
- no measurements
- high energies – up to few GeV
- low fluxes

  $\approx$ 10^{-2} neutrons cm^{-2} y^{-1} total

  (Dementyev et al. 1999, Wulandari et al. 2994)



Simulated geometry



Spherical shells

Radius [cm]	Material
800–500	Air
500–490	Stainless Steel
490–167	Water
167–162	Copper
162–152	Vacuum
152–150	Copper
150–0	LN_2

– Simulated neutron transport inside the setup using LCS

– Calculated neutron spectrum inside the sphere in the center with $R = 25$ cm

Neutron fluxes in crystal area

Primordial incident neutrons:

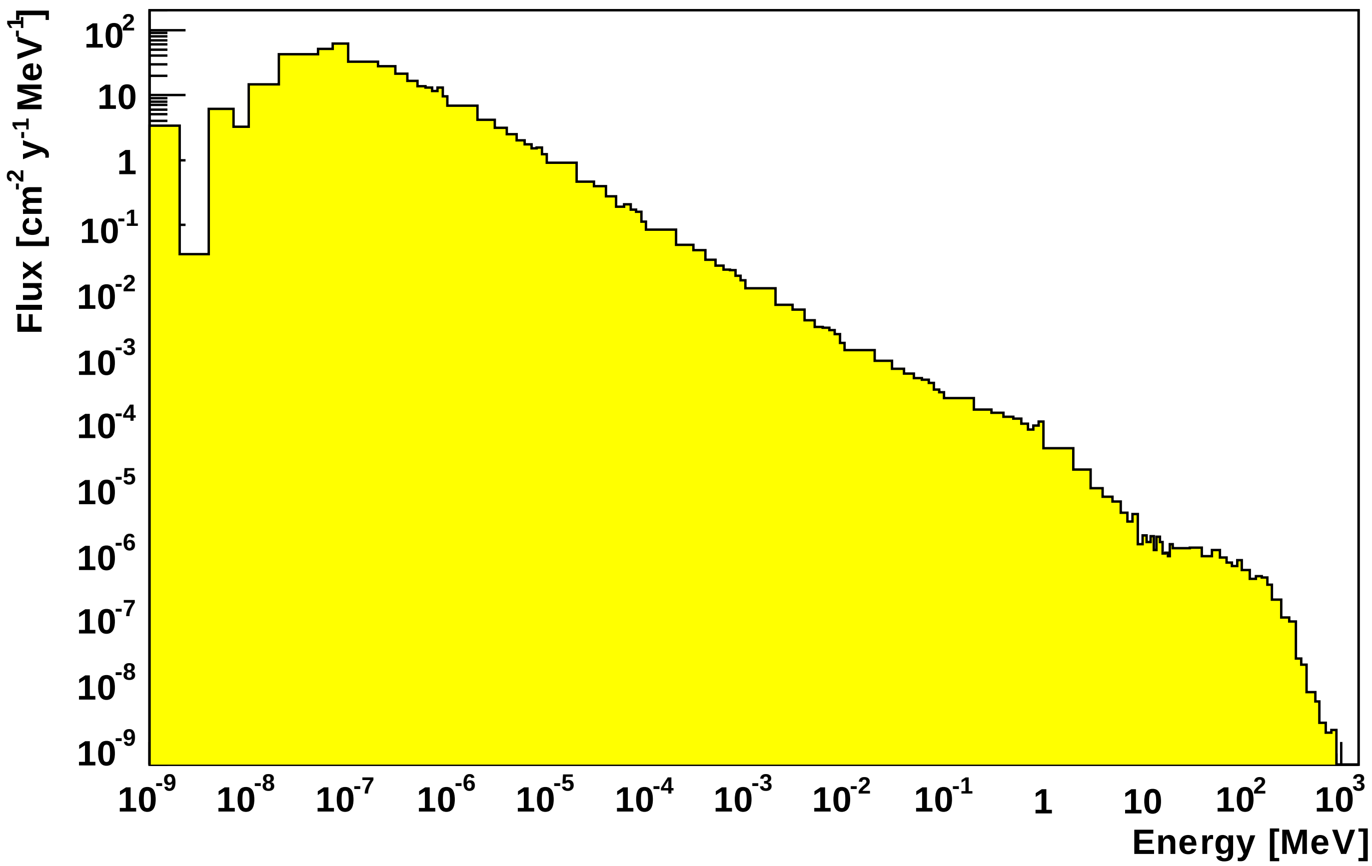
- generated 10^9 neutrons → corresponding to ≈ 2.5 years of irradiation
- no neutrons observed in crystal area
- not even in the surrounding nitrogen

Water shield stops all primordial neutrons

Muon induced incident neutrons:

- neutrons in crystal area for incident neutron energies > 40 MeV
- energetic incident neutrons produce large showers in outer stainless steel wall of the water tank

Neutron fluxes in crystal area (contd.)



Total flux:

5.2×10^{-4} cm^{-2} y^{-1}

≈

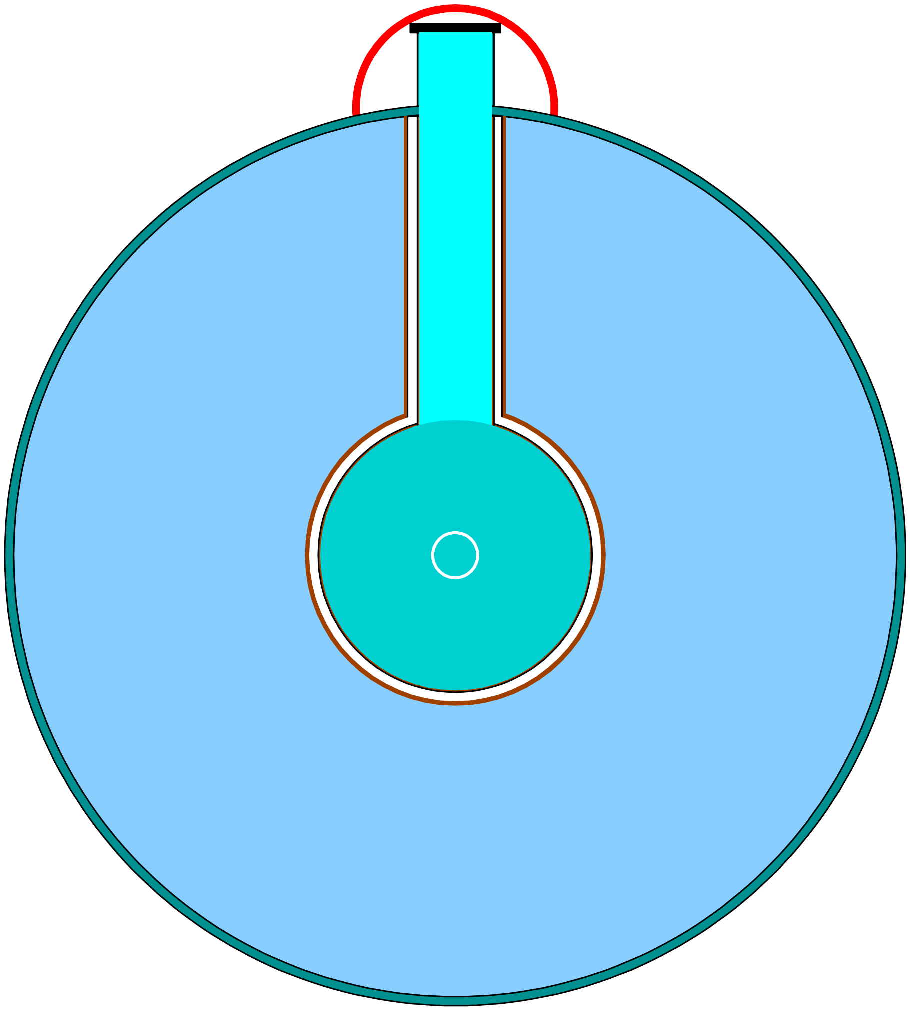
4 y^{-1} in Ge area

^{77}Ge production rate:

$$P(^{77}Ge) = N(^{76}Ge)\int_0^{\infty} J(E)\,s(E)\,dE$$

***P* (^{77}Ge) = 1.2 x 10^{-5} atoms kg^{-1} y^{-1}**

Geometry with neck - only primordials



- cylindrical neck with: $R = 40$ cm filled with N_2 gas
- hight above tank: 80 cm
- Lead cover: 15 cm thick

Primordial neutrons generated around the neck entrance

+ setup with neck half filled with LN_2
+ setup with PE shield around the neck entrance

Results for neck scenario

	Total neutron flux $[cm^{-2}\ y^{-1}]$	$[y^{-1}]$	**P (^{77}Ge) $[kg^{-1}\ y^{-1}]$**
no neck	0	0	**0**
empty neck	2.1×10^{-3}	16	**9×10^{-5}**
half filled neck	10^{-4}	0.8	**5.6×10^{-7}**
empty neck 25 cm PE	0	0	**0**

Summary

→ Water shield can stop all primordial neutrons

→ ^{77}Ge production by muon induced neutrons in rock is well below the GERDA sensitivity

→ Neck irradiation with primordial neutrons doesn't look too bad

BUT!

→ differences to the real design:

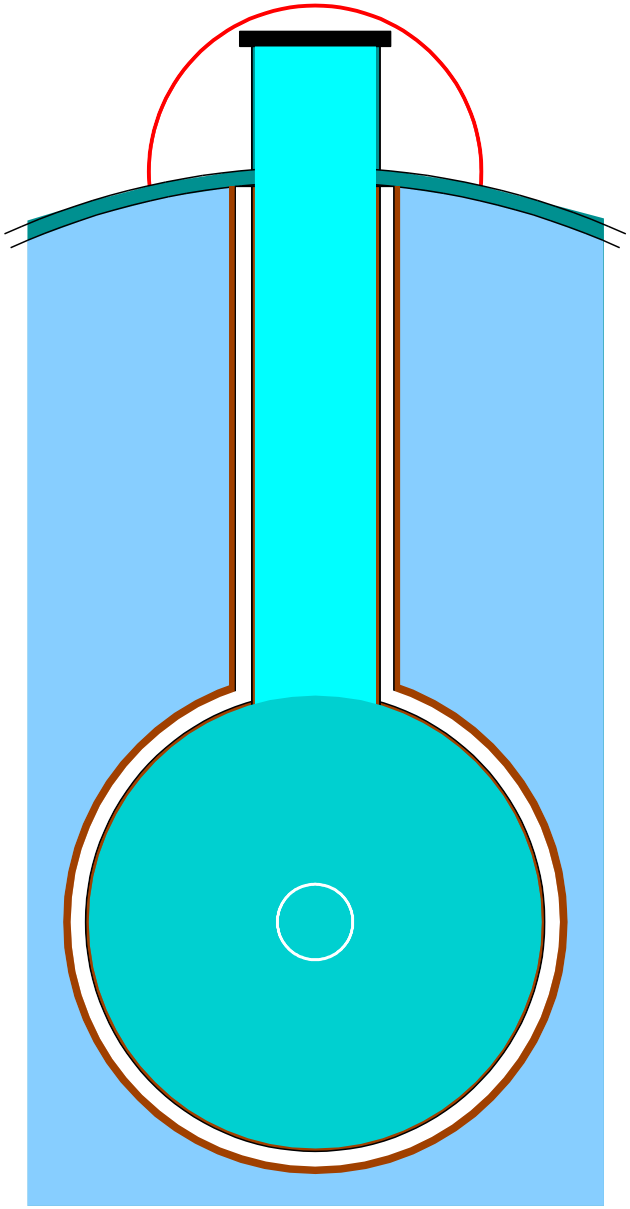
- water shield 50 cm thicker: **reality WORSE** → less moderation
- outer stainless steel too thick: **reality BETTER** → smaller showers
- copper walls too thick: **reality WORSE** → less absorption

Simulation setup is too optimistic

– originally only meant for **LCS** – **MaGe** cross-check

Good start but more needs to be done → **MaGe**

A few "neck" remarks



1) neck is no problem for primordials and LN_2

2) situation worse for LAr
   → as you will see in my next talk

3) most μ induced neutrons going downward
   → high energy neutrons hit the thick Lead shield (or any high-Z-material above) and create huge neutron showers going down the neck towards the crystals
   → these you cannot shield with PE around the neck
   → has not yet been simulated