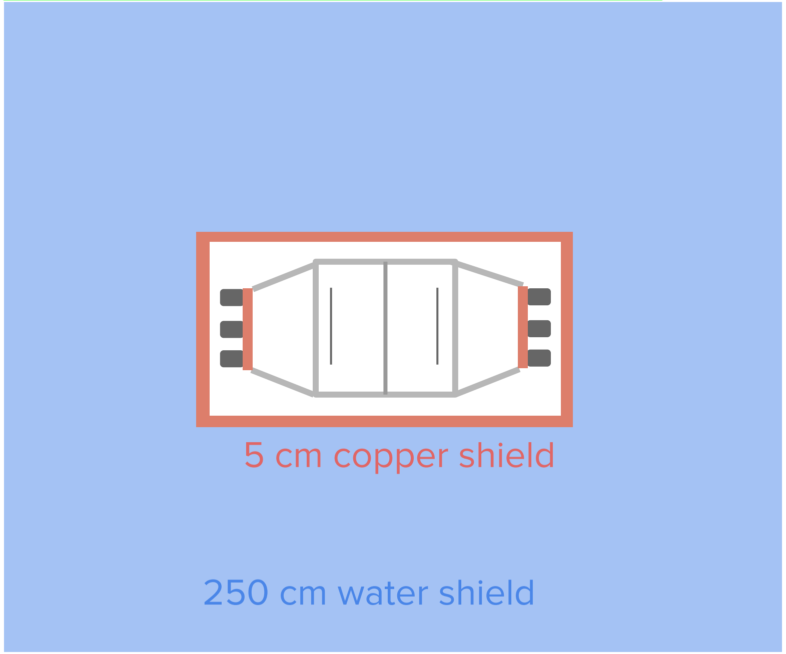
Shielding simulations update

Giulia D’Imperio

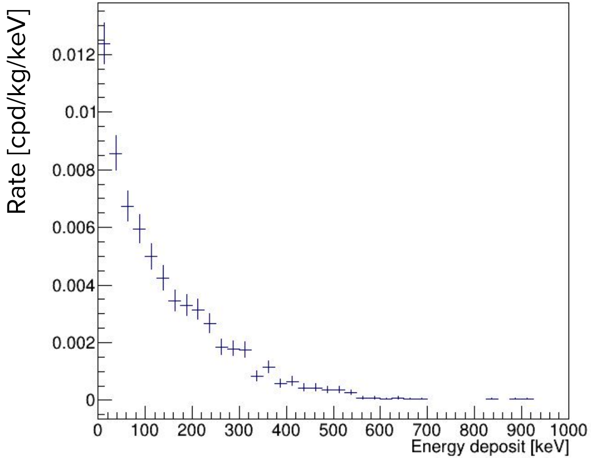
CYGNO simulation meeting 10/02/20

Gamma shielding option 2: external gamma

250 cm water + 5 cm Cu



Gamma Flux at LNGS 0.56 cm^{-1} s^{-1}
Gamma Flux after 2.5 m water shield 3.7 10^{-8} cm^{-1} s^{-1}
Gamma Flux after 5 cm Cu shield 3.7 10^{-9} cm^{-1} s^{-1}



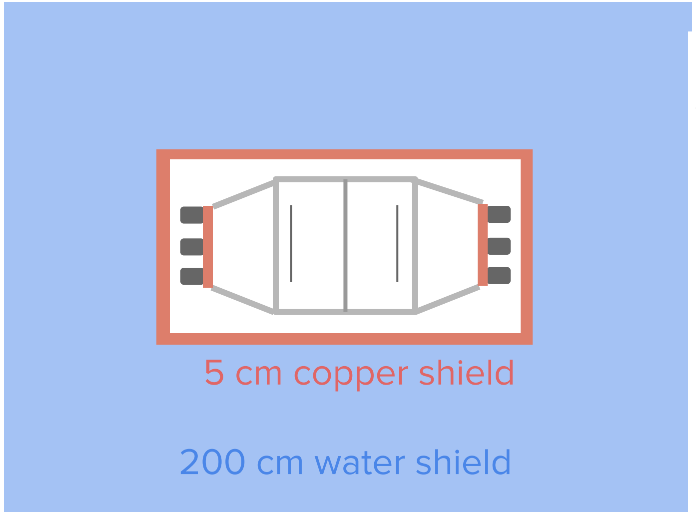
Note: fixed bug in previous analysis, this option is 1 order of magnitude more effective

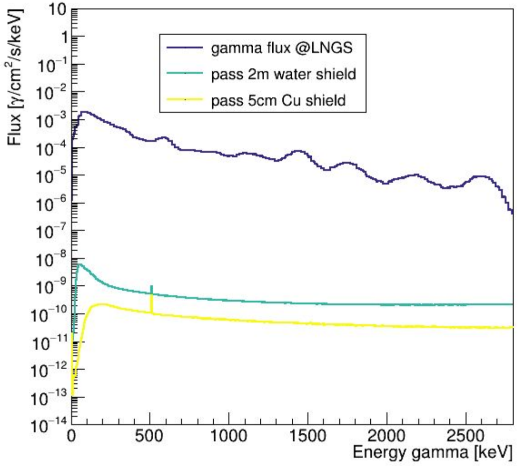
Rate [0-20] keV = 1.2 10^{-2} cpd/kg/keV ➜ **150 cts/yr** [0-20] keV in CYGNO detector

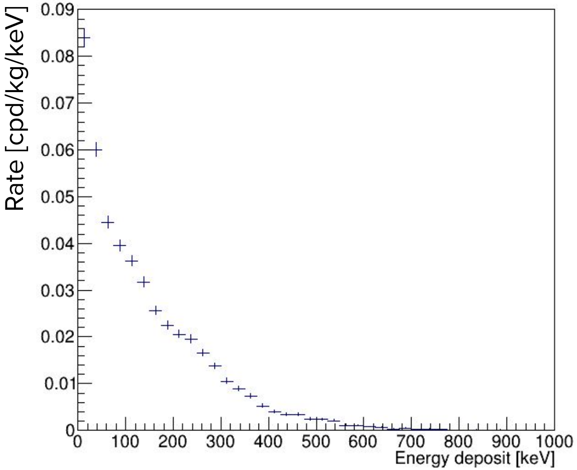
Decrease water shield to 2m: external gamma

200 cm water + 5 cm Cu

Gamma Flux at LNGS 0.56 $cm^{-1} s^{-1}$
Gamma Flux after 2 m water shield 1.4 10^{-6} $cm^{-1} s^{-1}$
Gamma Flux after 5 cm Cu shield 1.8 10^{-7} $cm^{-1} s^{-1}$





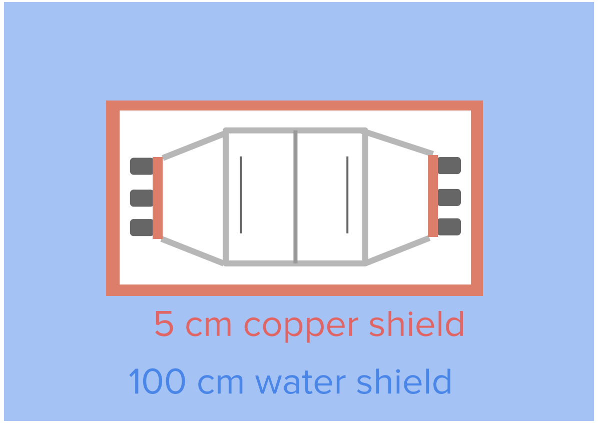


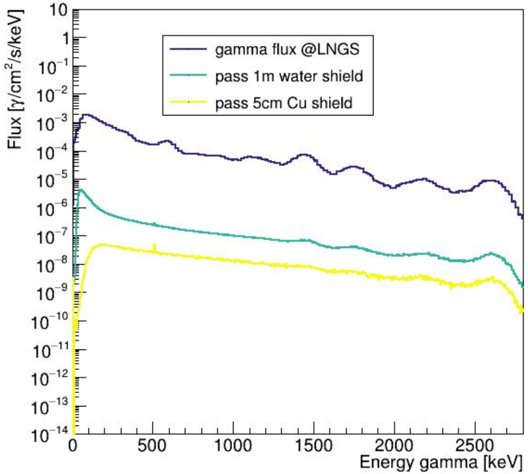
Rate [0-20] keV = 8.8 10^{-2} cpd/kg/keV → **10^3 cts/yr** [0-20] keV in CYGNO detector

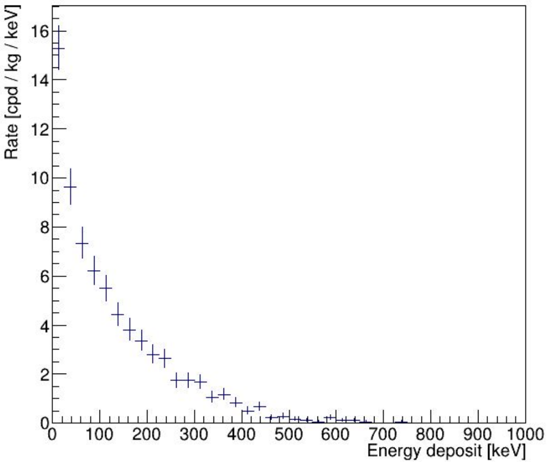
Decrease water shield to 1m: external gamma

100 cm water + 5 cm Cu

Gamma Flux at LNGS 0.56 cm^{-1} s^{-1}
Gamma Flux after 1 m water shield 6.1 10^{-4} cm^{-1} s^{-1}
Gamma Flux after 5 cm Cu shield 3.4 10^{-5} cm^{-1} s^{-1}





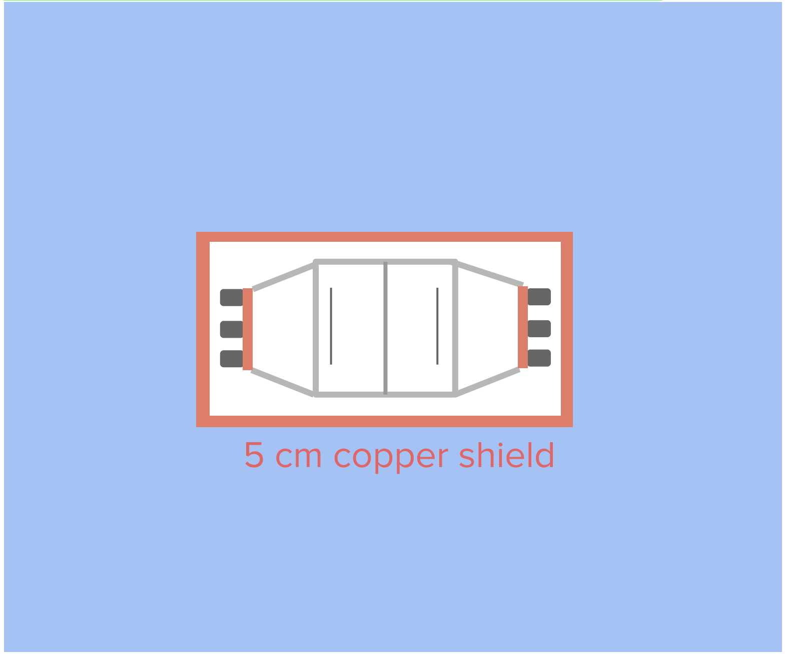


Rate [0-20] keV = 16 cpd/kg/keV ➔ **2 10^5 cts/yr** [0-20] keV in CYGNO detector

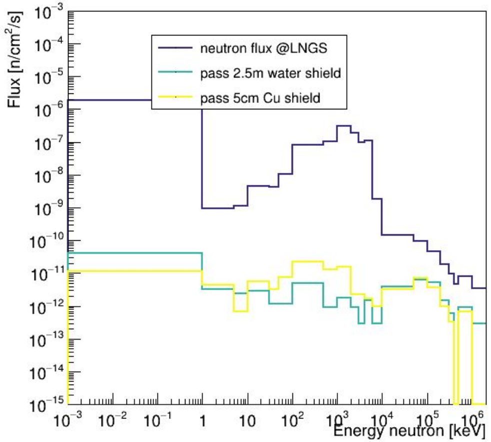
External neutrons and secondary gammas

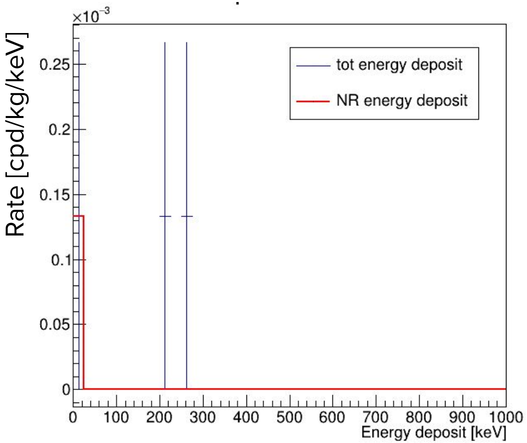
Gamma shielding option 2: external neutrons

250 cm water + 5 cm Cu



Neutron Flux @LNGS 2.7 10^{-7} cm^{-2} s^{-1}
Neutron Flux after water shield 6 10^{-11} cm^{-2} s^{-1}
Neutron Flux after Cu shield 1 10^{-10} cm^{-2} s^{-1}



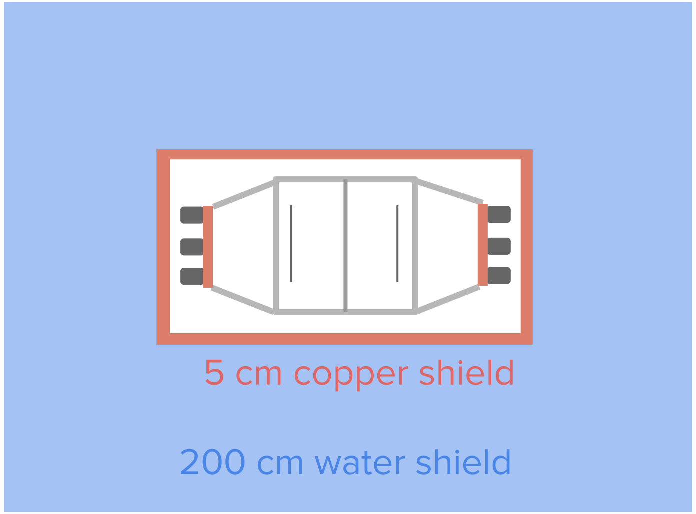


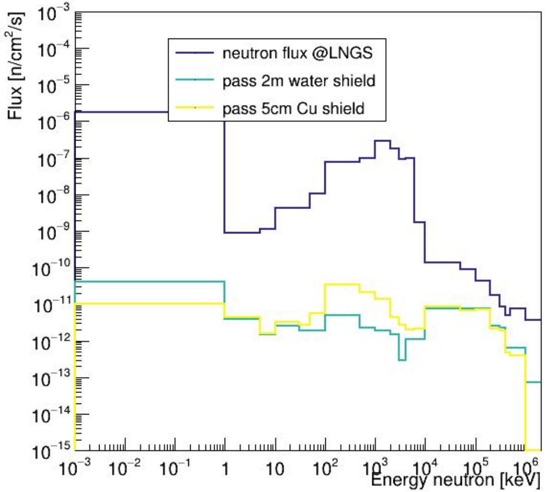
Low statistics, but probably negligible ER rate, **O(1) NR/year**

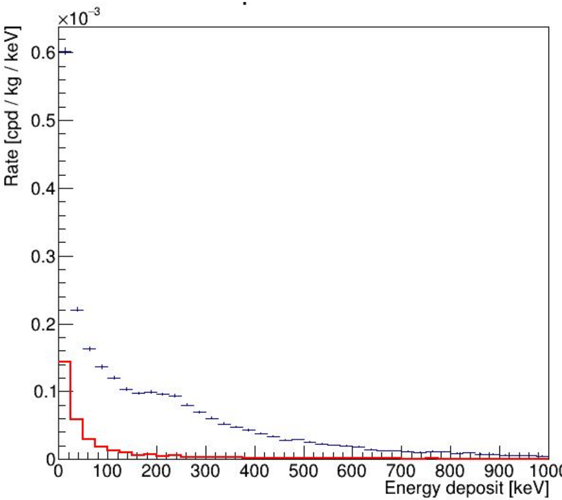
Decrease water shield to 2m: external neutrons

200 cm water + 5 cm Cu

Neutron Flux @LNGS 2.7 10^{-7} cm^{-2} s^{-1}
Neutron Flux after water shield 1.7 10^{-10} cm^{-2} s^{-1}
Neutron Flux after Cu shield 3 10^{-10} cm^{-2} s^{-1}





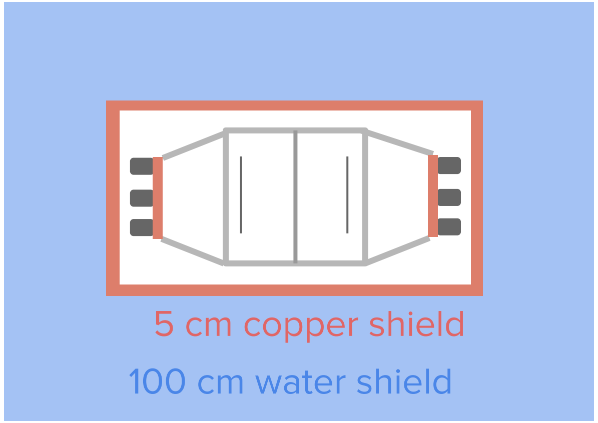


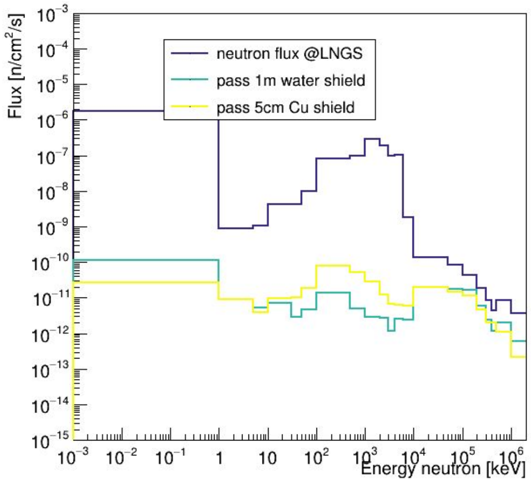
Rate [0-20] keV = 7.1 10^{-4} cpd/kg/keV → **8 cts/yr** [0-20] keV in CYGNO detector (**O(1) NR/year**)

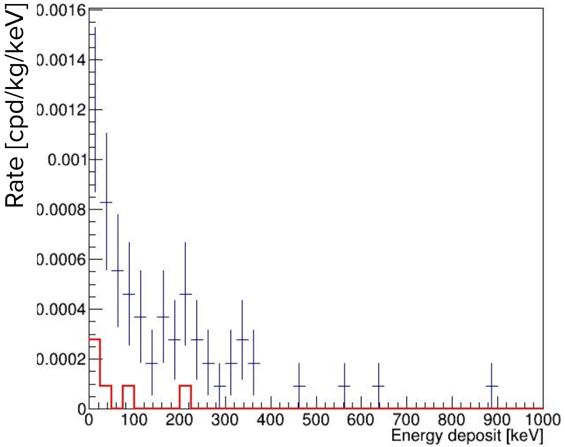
Decrease water shield to 1m: external neutrons

100 cm water + 5 cm Cu

Neutron Flux @LNGS 2.7 10^{-7} cm^{-2} s^{-1}
Neutron Flux after water shield 2.5 10^{-10} cm^{-2} s^{-1}
Neutron Flux after Cu shield 3 10^{-10} cm^{-2} s^{-1}



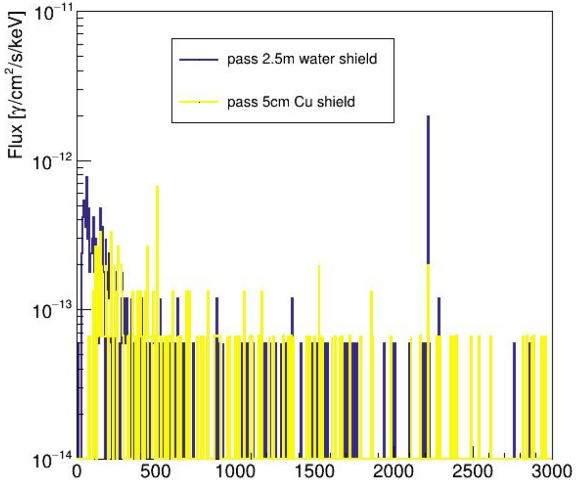




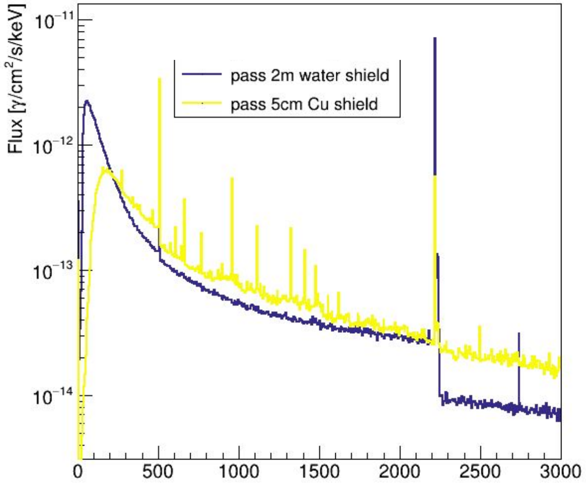
Rate [0-20] keV = 2 10^{-3} cpd/kg/keV ➔ **23 cts/yr** [0-20] keV in CYGNO detector (**O(1) NR/year**)

Secondary gammas

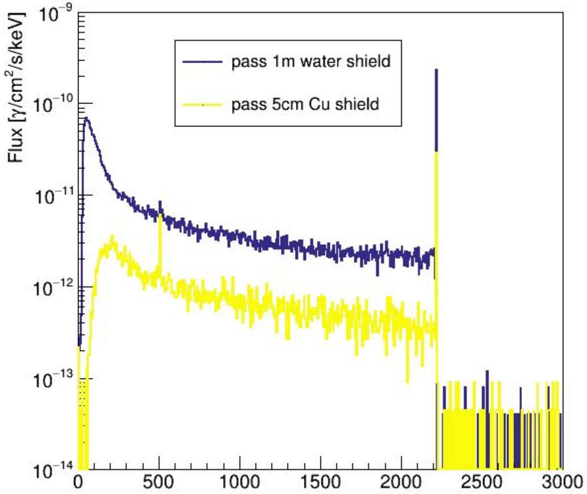
250 cm water + 5 cm Cu



200 cm water + 5 cm Cu

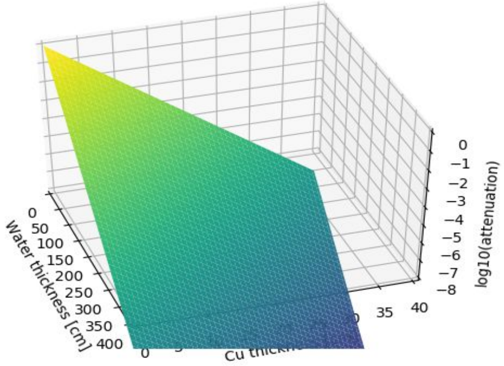


100 cm water + 5 cm Cu

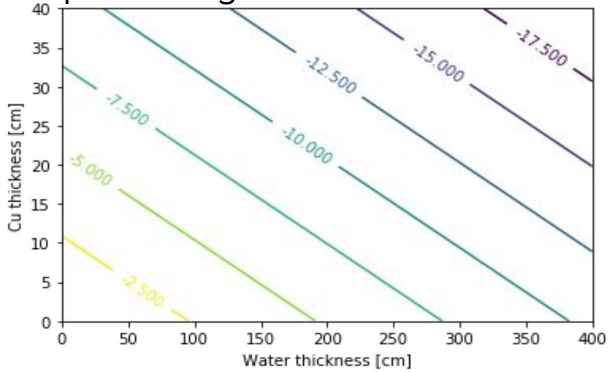


Summary

- **2.5 m water + 5 cm Cu:**
  - attenuation gamma: 10^{-8}
  - attenuation neutrons: 10^{-3}
  - total rate: 10^{2} cpy (tot), O(1) cpy NR
  - cost: 400 keuro (water) + 200 keuro (Cu)
- **2 m water + 5 cm Cu:**
  - attenuation gamma: 10^{-7}
  - attenuation neutrons: 10^{-3}
  - total rate: 10^{3} cpy (tot), O(1) cpy NR
  - cost: 250 keuro (water) + 200 keuro (Cu)
- **1 m water + 5 cm Cu:**
  - attenuation gamma: 10^{-4}
  - attenuation neutrons: 10^{-3}
  - total rate: 10^{5} cpy (tot), O(1) cpy NR
  - cost: 70 keuro (water) + 200 keuro (Cu)



Expected log10 attenuation factor

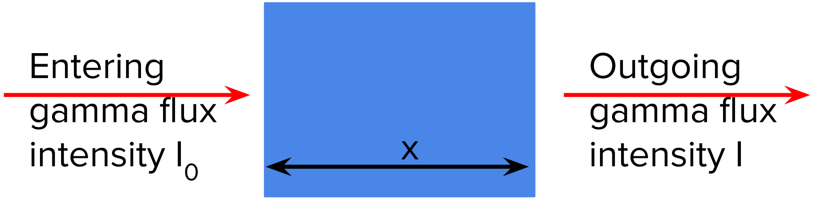


Backup

X-rays attenuation (rough calculation)

$$I/I_0 = \exp[-(\mu/\rho)x] \, .$$
$$\mu/\rho = x^{-1} \ln(I_0/I)$$

ρ material density
x=ρt “mass thickness”



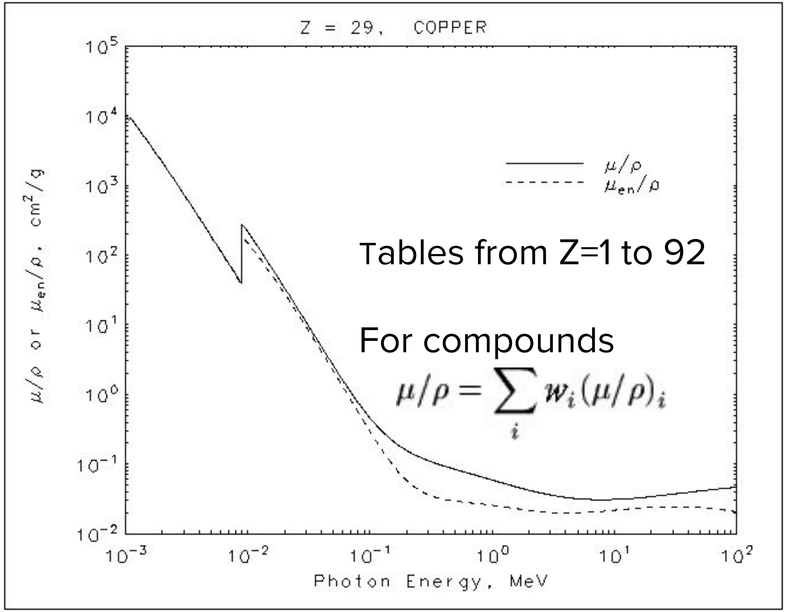
$$\mu/\rho = \sigma_{tot}/uA \, .$$

u = atomic mass unit
A = relative atomic mass
σ_{tot} is the total cross section

$$\sigma_{tot} = \sigma_{pe} + \sigma_{coh} + \sigma_{incoh} + \sigma_{pair} + \sigma_{trip} + \sigma_{ph.n.}$$

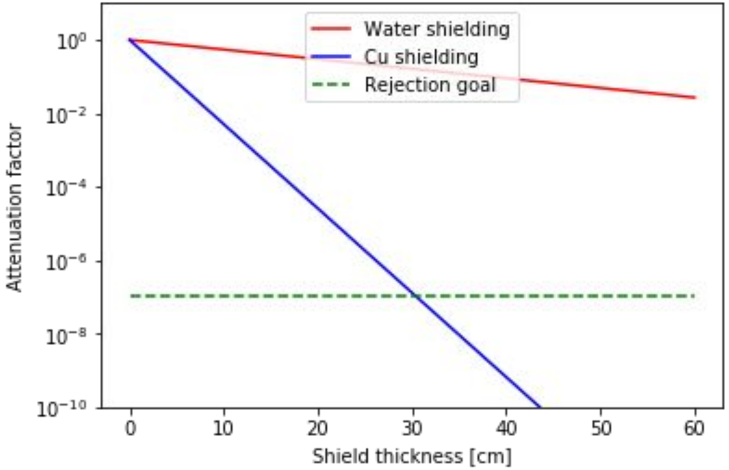
σ_{pe} atomic photoeffect xsec
σ_{coh} and σ_{incoh} coherent (Rayleigh) and incoherent (Compton) scattering xsec
σ_{pair} and σ_{trip} e+e- production xsec in the fields of the nucleus and of the atomic electrons
$\sigma_{ph.n.}$ photonuclear cross section

https://physics.nist.gov/PhysRefData/XrayMassCoef/chap2.html
https://physics.nist.gov/PhysRefData/XrayMassCoef/tab3.html



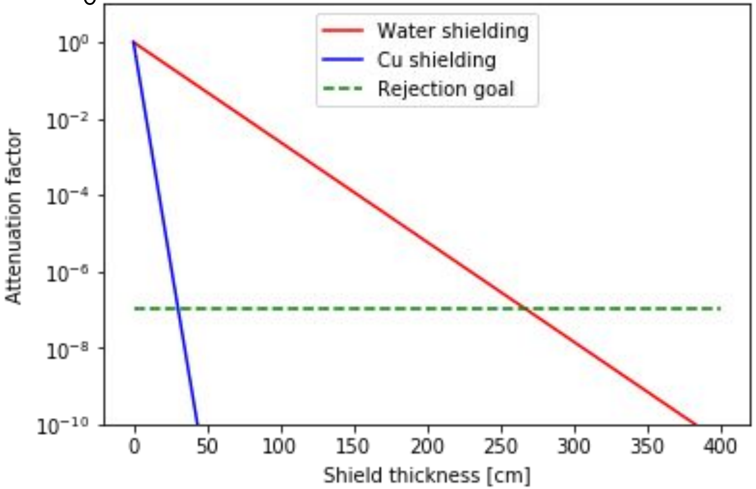
X-rays attenuation with Cu and water

I/I_0 attenuation vs thickness (1 MeV gamma)



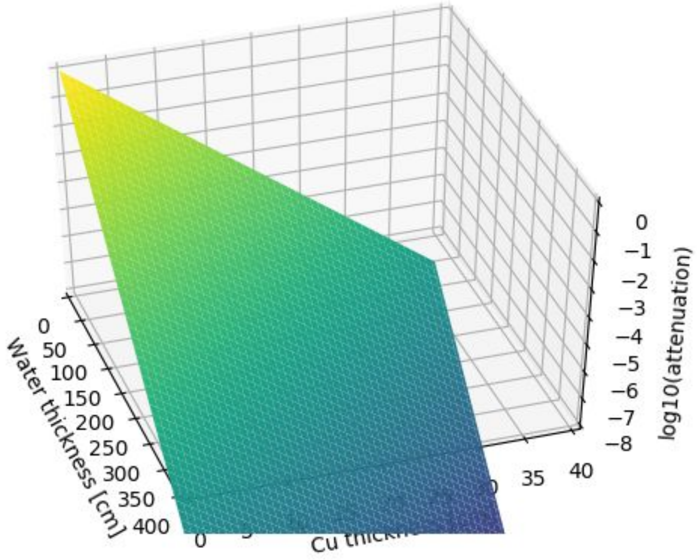
Shielding made of only copper gives an attenuation of 10^7 with thickness ~30 cm

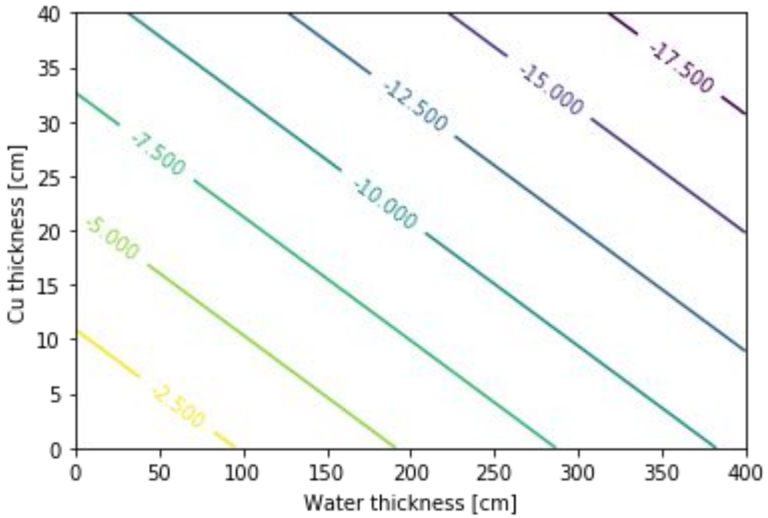
I/I_0 attenuation vs thickness (1 MeV gamma)



Shielding made of only water gives an attenuation of 10^7 with thickness ~270 cm

Combination of Cu + water

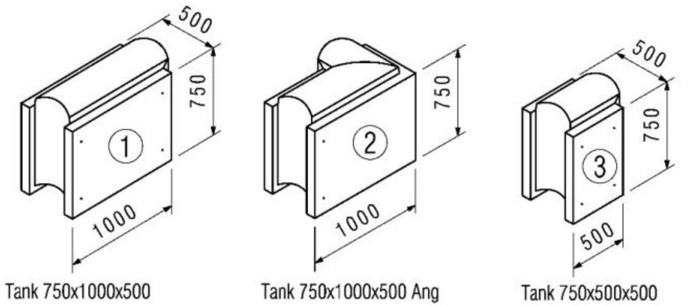


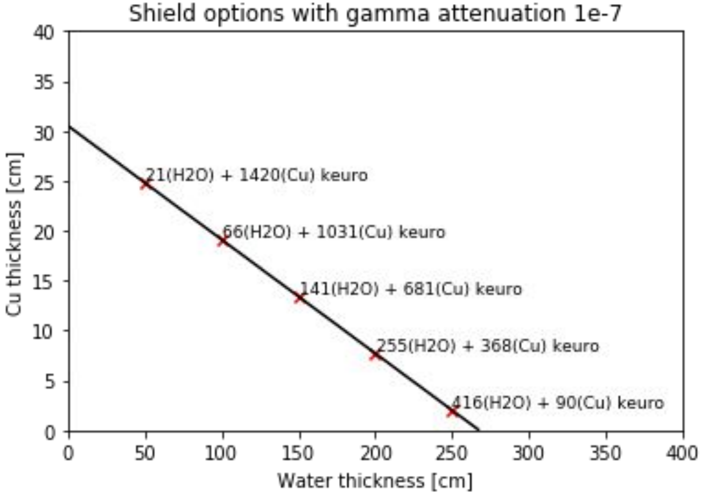


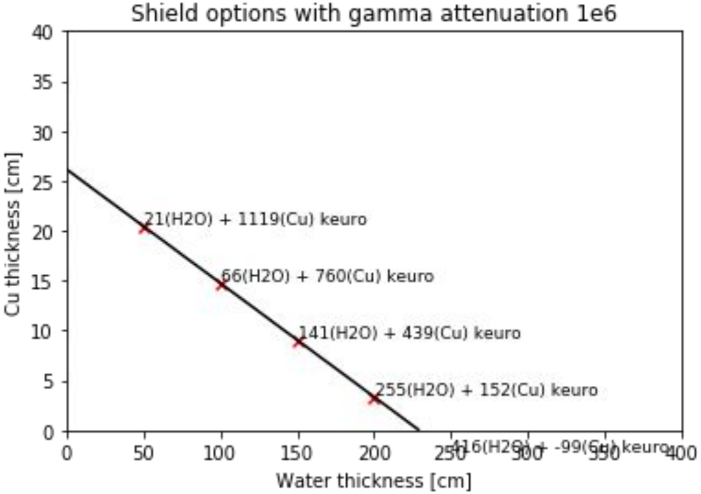
Cost optimization Cu + water

Assumptions:

- Cost of copper: 25 euro/kg
- Cost of water: ~500 euro/tank from Cesidio presentation (➜ ~1.3 euro/kg)





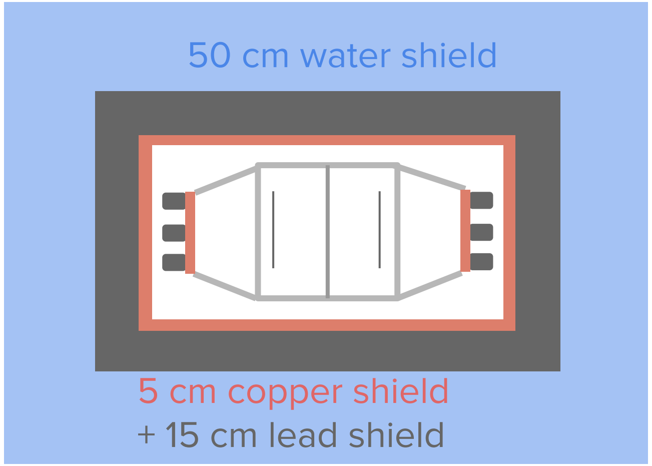


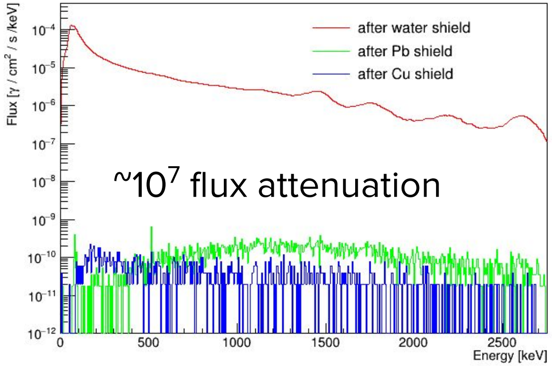
The Cu cost is significantly higher than water (also the modular option for water shielding), so the option with only 5 cm copper and 2-2.5 m water is the cheapest

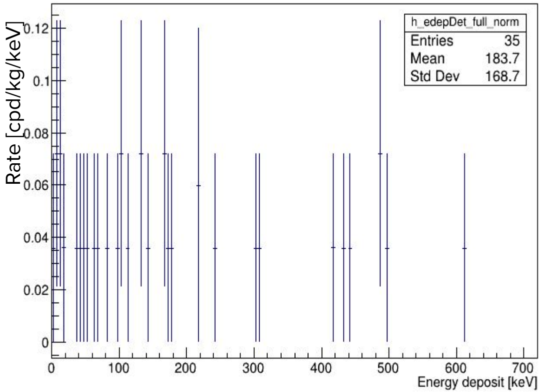
Shielding option 1: external gamma

50 cm water + 15 cm Pb + 5 cm Cu

Gamma Flux at LNGS 0.56 cm^{-1} s^{-1}
Gamma Flux after 50 cm water shield 0.019 cm^{-1} s^{-1}
Gamma Flux after 20 cm Pb shield 3.2 10^{-7} cm^{-1} s^{-1}
Gamma Flux after 5 cm Cu shield 1.4 10^{-7} cm^{-1} s^{-1}







Rate [0-20] keV = 0.054 cpd/kg/keV ➔ **630 cts/yr** [0-20] keV in CYGNO detector