CYGNO simulations

Gianluca Cavoto, Giulia D’Imperio, Flavio Di Clemente

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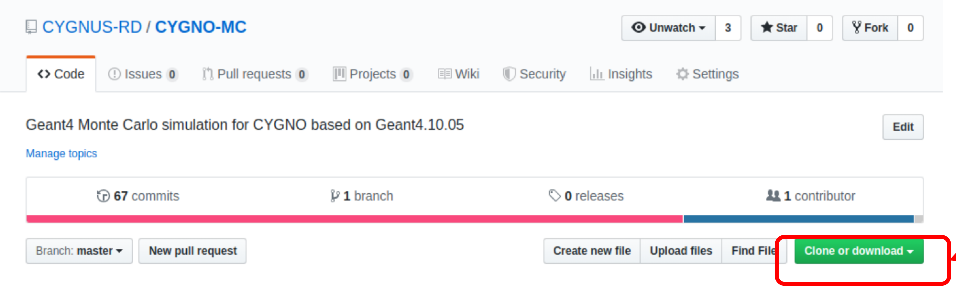
GEANT4 simulation repository

The simulation code is available in a repository in the CYGNUS-RD organization on github
https://github.com/CYGNUS-RD/CYGNO-MC

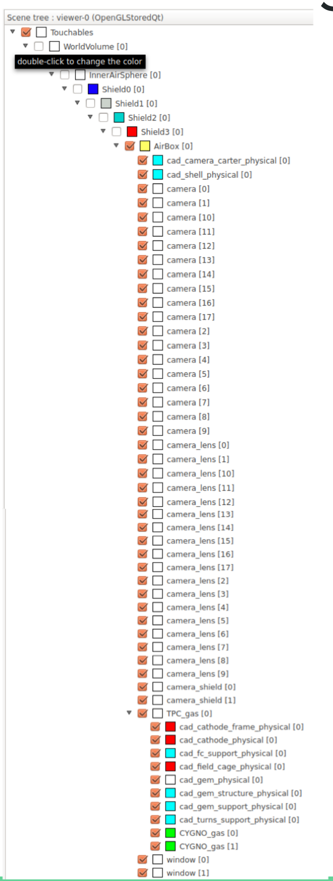
- need github account (free) and membership of CYGNUS-RD (contact Emanuele Di Marco)
- then we can add collaborators to CYGNO-MC repository with read and/or write permissions
- instructions to setup and run the code are available in the README file in the repository

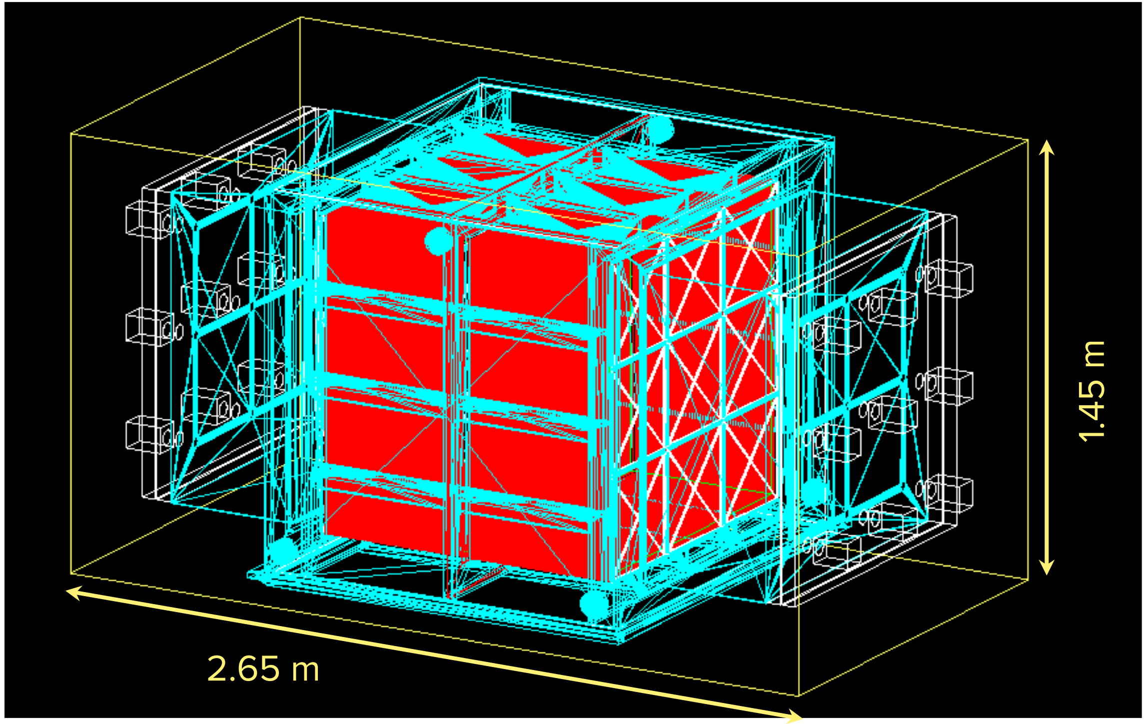


to clone the repository
on your working area

Working area:
- for simple tests, can be run in local
- pre-requisites ROOT, GEANT4, CadMesh (all open source and free software)
- for MC production Roma group is working on Roma3 cluster `ui7-01.roma3.infn.it`
- working area @LNGS farm?

Simulation geometry





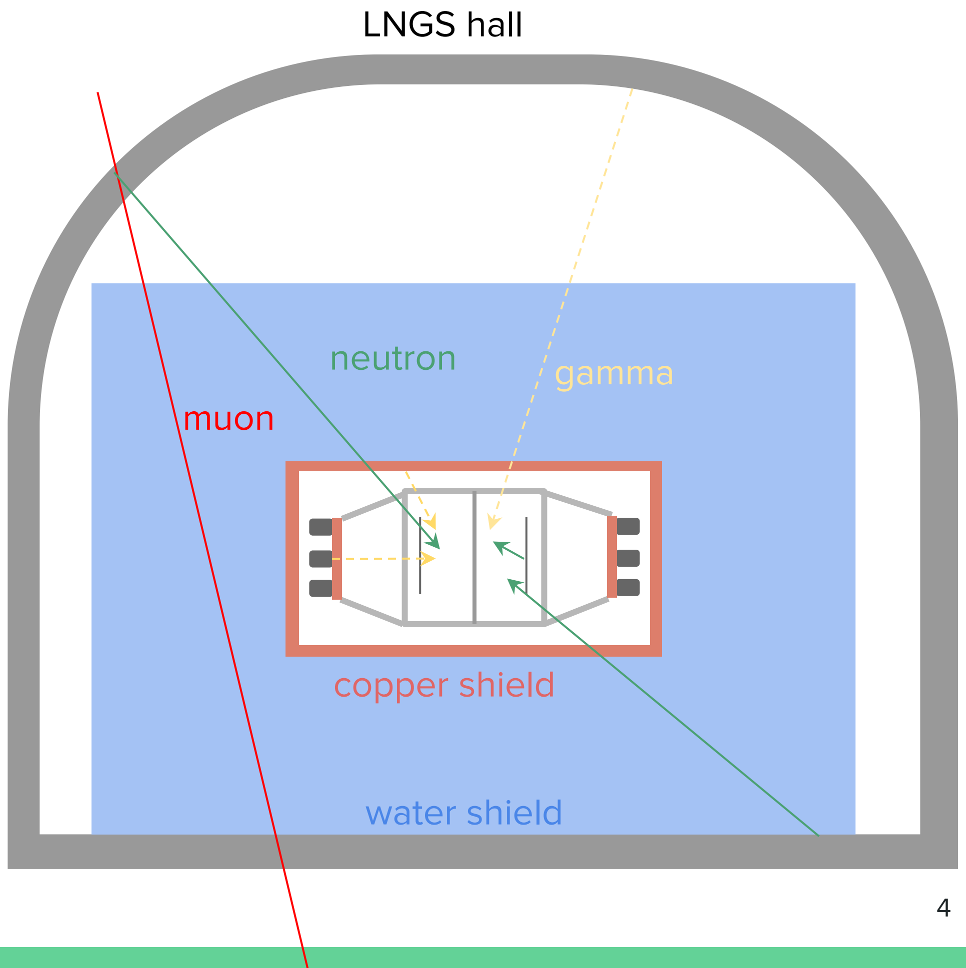
Background components

- Ambient neutrons/gammas
  (origin: outside setup, mostly rock)

- "Radiogenic" neutrons/gammas
  (origin: materials in setup)

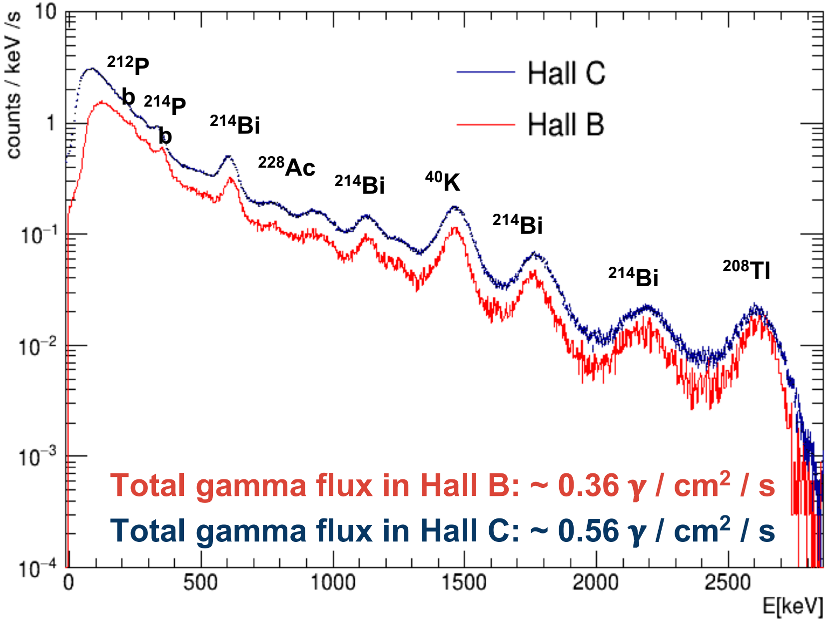
- Cosmogenic neutrons
  (origin: muon interactions)

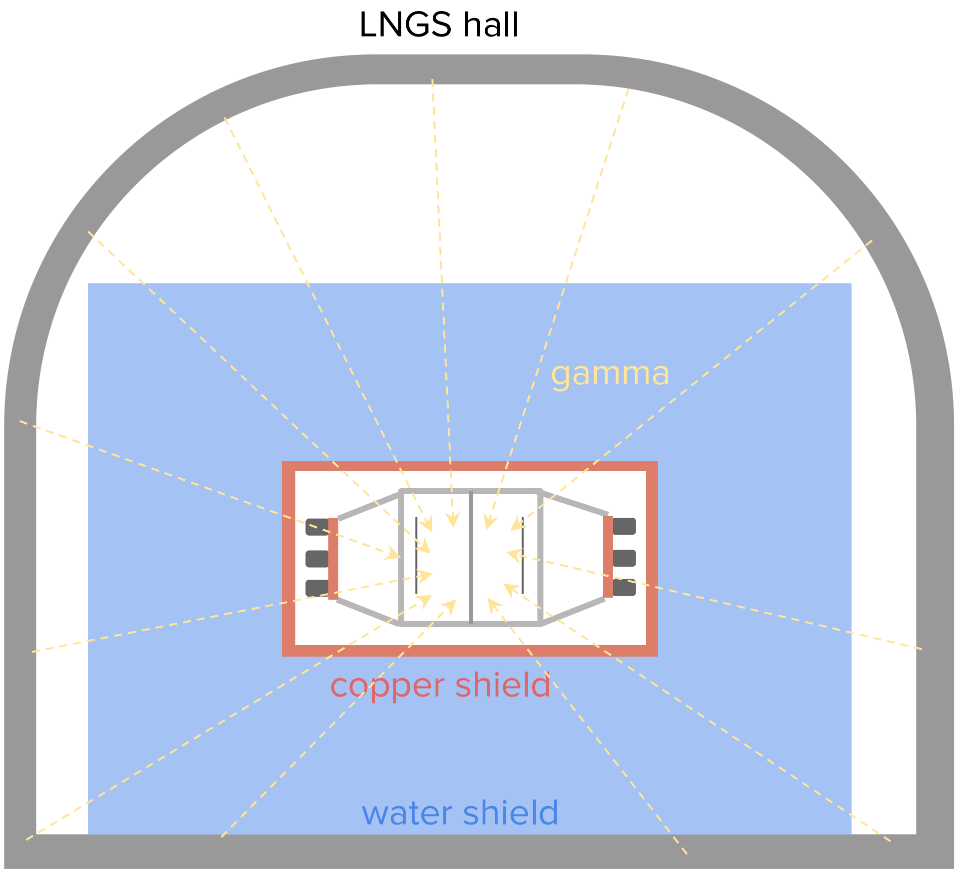
➔ in this presentation focus on
ambient gammas



External gamma flux

- Gammas mostlly from **K, U** chain and **Th** chain
- Spectrum measured by SABRE collaboration(*)
- used as input for CYGNO simulations





(*) in agreement with H. Wulandari et al. Astroparticle Physics 22 (2004) 313–322

Shielding study

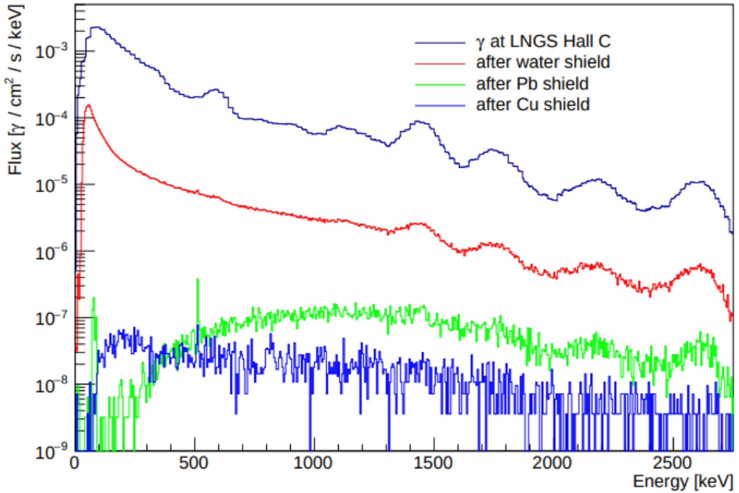
Goals:

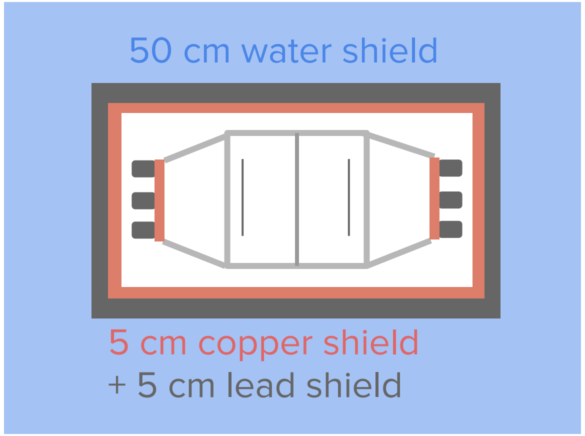
- Reduce ambient gamma/neutron background below the gamma/neutron background due to unavoidable radioactive contaminations of the setup materials, including the shielding itself (i.e. below the ‘radiogenic‘ flux)

- Total electron recoil background (ER) should be < 10^4 events/year in the low energy region [0-20] keV
  ➜ Bkg < 1 event/year, with ER rejection of 10^4 at low energy

Shield option 1: 50 cm water + 5 cm Pb + 5 cm Cu

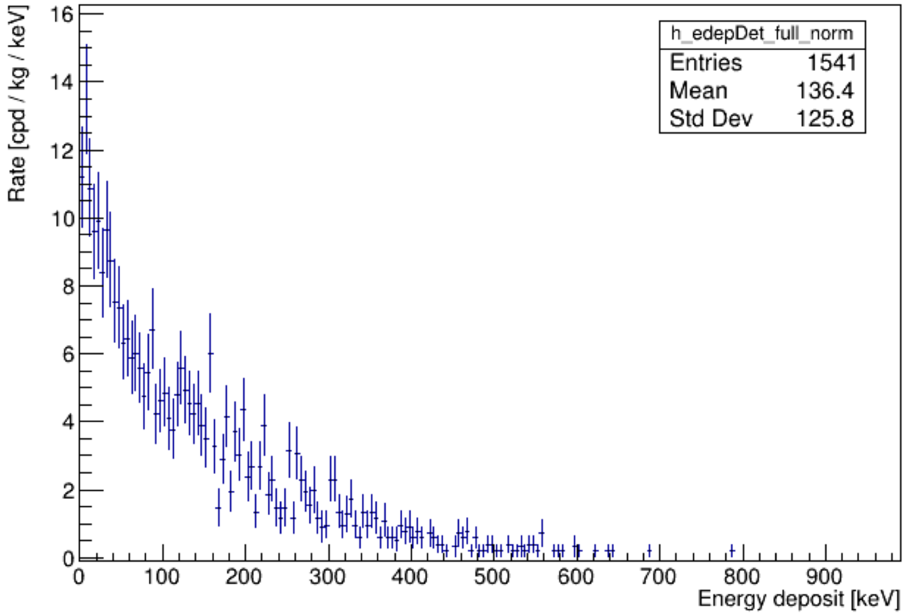
Gamma Flux entering outermost shield 0.56 $cm^{-2}\ s^{-1}$
Gamma Flux after 50 cm water shield 0.019 $cm^{-2}\ s^{-1}$
Gamma Flux after 5 cm Pb shield 0.00016 $cm^{-2}\ s^{-1}$
Gamma Flux after 5 cm Cu shield 4.3 10^{-5} $cm^{-2}\ s^{-1}$





Background from ambient gamma

Number of events in [0-20] keV : 11.3   cpd/kg/keV
Number of events in [0-20] keV : 1.32 10^5 evts/yr



- Goal total background < 10^4 evts/year
- **Need more effective shielding**

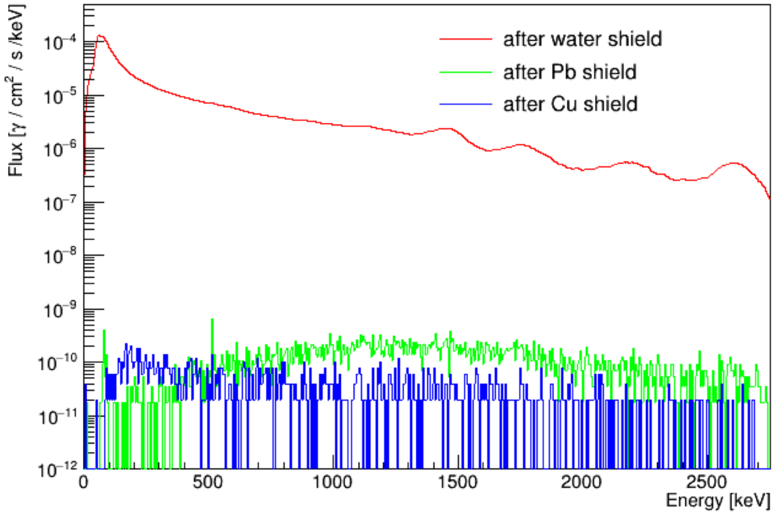
50 cm water + 5 cm Pb + 5 cm Cu

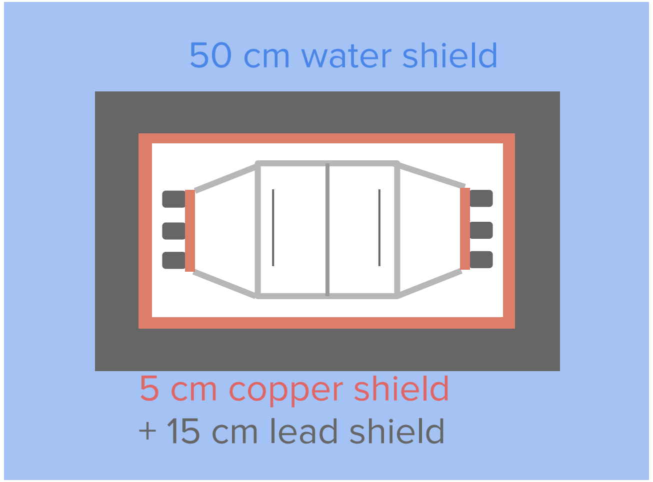
Volume	Material	Thickness [cm]	Mass [kg]	*Cost [keuro]
Shield1	Water	50	16e3	-
Shield2	Pb	5	12e3	60
Shield3	Cu	5	8.7e3	217.5

* assuming Pb ~5 euro/kg, Cu 25 euro/kg

Shield option 2: 50 cm water + 15 cm Pb + 5 cm Cu

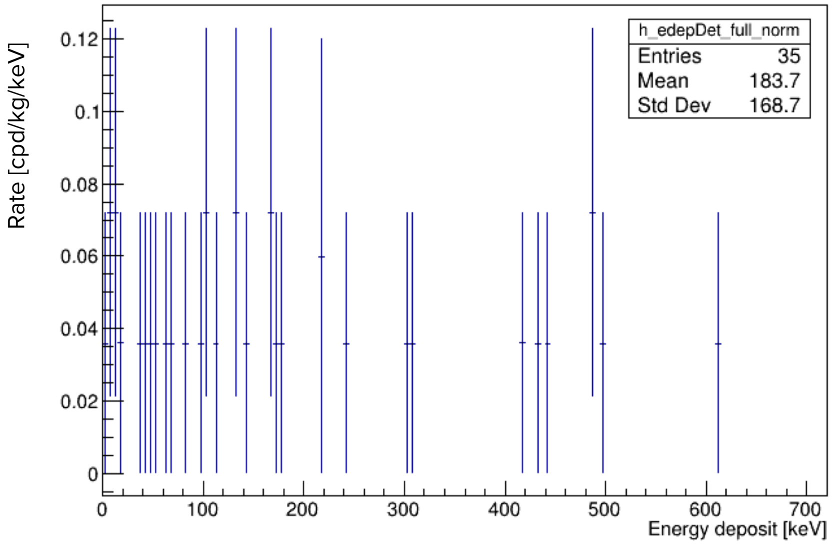
Gamma Flux entering outermost shield 0.56 cm^{-1} s^{-1}
Gamma Flux after 50 cm water shield 0.019 cm^{-1} s^{-1}
Gamma Flux after 20 cm Pb shield 3.2 10^{-7} cm^{-1} s^{-1}
Gamma Flux after 5 cm Cu shield 1.4 10^{-7} cm^{-1} s^{-1}





Background from ambient gamma

Number of events in [0-20] keV : 0.054 cpd/kg/keV
Number of events in [0-20] keV : **630 evts / yr**



- Goal total background < 10^4 evt/yr
- with 15 cm Pb ➜ **~10^3 evt/yr**

50 cm water + 15 cm Pb + 5 cm Cu

Volume	Material	Thickness [cm]	Mass [kg]	*Cost [keuro]
Shield1	Water	50	16e3	-
Shield2	Pb	15	42e3	210
Shield3	Cu	5	9e3	225

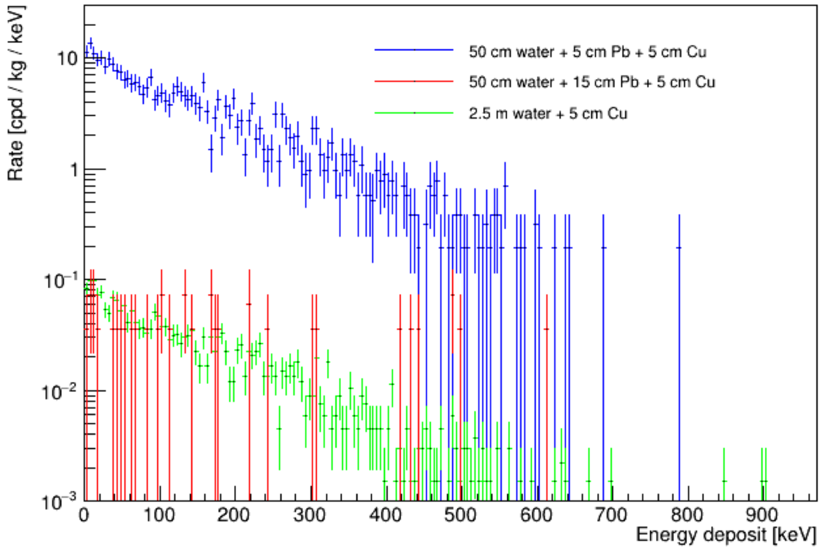
* assuming Pb ~5 euro/kg, Cu 25 euro/kg

Shield option 3: 250 cm water + 5 cm Cu

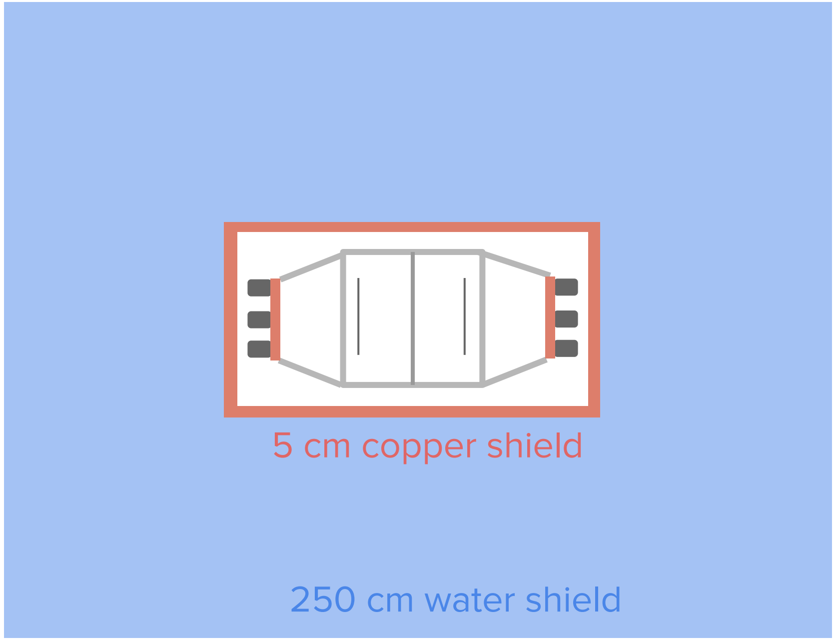
Energy deposit in CYGNO detector:

- Events in [0-20] keV : 0.086 cpd/kg/keV
- Events in [0-20] keV : **1015 evts / yr**

Comparison of expected rate in CYGNO for shield options 1-2-3



- negligible cost of primary material (water)
- cost of infrastructure (tanks, etc.) = ?



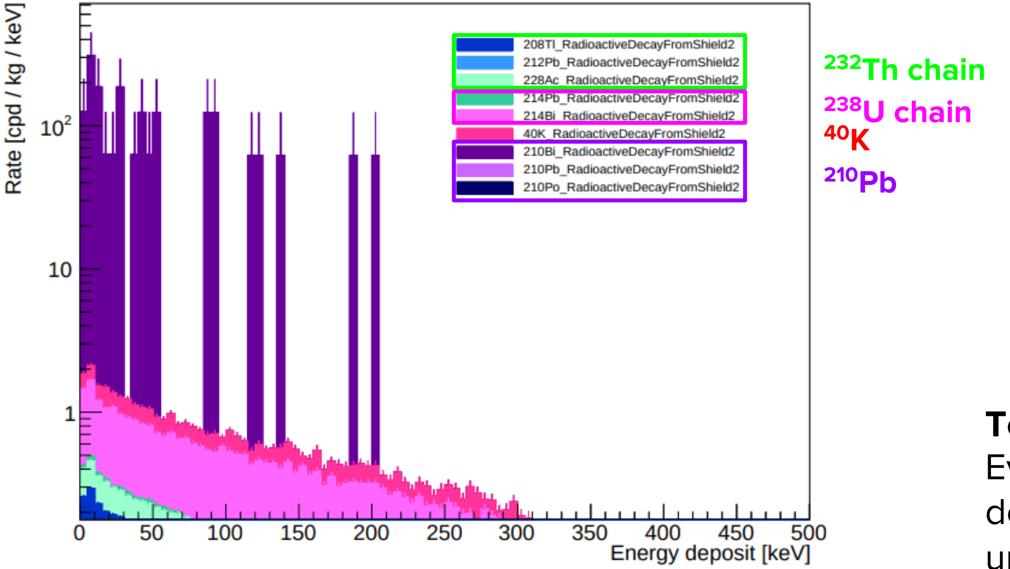
Lead shield radioactivity

- The highest background contribution from lead is ^{210}Pb
- ^{210}Pb is not in equilibrium with ^{238}U decay chain
- half life of ^{210}Pb is quite long (22 years)
- ^{210}Pb daughters have shorter half life, therefore they are in equilibrium with ^{210}Pb
- commercial lead has typically several 100 Bq/kg of ^{210}Pb. OPERA lead available at LNGS has 80 Bq/kg, CUORE roman Pb has <4 mBq/Kg activity
- ^{210}Pb ➔ 100% BR beta decay with q-value 63.5 keV
- **^{210}Bi** ➔ 100% BR beta decay with q-value 1162.1 keV
  ➔ **bremsstrahlung gives significant contribution to bkg**
- ^{210}Po ➔ 100% BR alpha q-value 5407.4 keV

$T_{1/2}$	Isotope	E_α(MeV)	I (%)	Activity
$4.468 \cdot 10^9\,y$	^{238}U			
	$\downarrow \alpha$	4.18	99.9	A0
$24.1\,d$	^{234}Th			
	$\downarrow \beta$			
$1.17\,m$	^{234m}Pa			
	$\downarrow \beta$			
$2.455 \cdot 10^5\,y$	^{234}U			
	$\downarrow \alpha$	4.75	99.8	A1
$7.538 \cdot 10^4\,y$	^{230}Th			
	$\downarrow \alpha$	4.66	99.7	A2
$1600\,y$	^{226}Ra			
	$\downarrow \alpha$	4.78	94.4	A3
$3.8\,d$	^{222}Rn			
	$\downarrow \alpha$	5.49	99.9	A3
$3.10\,m$	^{218}Po			
	$\downarrow \alpha$	6.00	99.9	A3
$26.8\,m$	^{214}Pb			
	$\downarrow \beta$			
$19.9\,m$	^{214}Bi			
	$\downarrow \beta$			
$164.3\mu\,s$(*)	^{214}Po			
	$\downarrow \alpha$	7.69	99.9	A3
$22.3\,y$	^{210}Pb			
	$\downarrow \beta$			
$5.01\,d$	^{210}Bi			
	$\downarrow \beta$			
$138.4\,d$	^{210}Po			
	$\downarrow \alpha$	5.30	100	A4
Stable	^{206}Pb			

Background from 5 cm lead shield

- Energy deposit in CYGNO detector from lead shield radioactivity
- assume ^{210}Pb of OPERA lead
- U, Th, K activities from T-REX paper (arxiv 1812.04519)
- shielding option 1 (50 cm water + 5 cm Pb + 5 cm Cu)



	Activity [mBq/kg]	Rate [cts/yr]
^{238}U	0.33	11.2 10^3
^{210}Pb	10^5	1.97 10^6
^{232}Th	0.10	4.51 10^3
^{40}K	1.2	4.6 10^3

Total rate 2 10^6 cts/yr

Even a 5 cm-thick shield of lead for 1 m^3 detector gives a large background, unless using archaeological lead.

Summary

- We have studied several shielding options for CYGNO
- Attempt to take into account **physics** and **cost**, also total **size** of the detector could be an issue
- Need material with high Z to have effective rejection of gamma with a compact shielding (high dE/dx)
- Pb is a good gamma shield but radioactive, non-radioactive option very expensive
- Cu is a good gamma shield, not radioactive but very expensive
- Water is less effective but not radioactive and not expensive. Increasing the shielding size up to 2.5 m of water + 5 cm copper, a sufficient rejection of ambient gamma can be achieved.

Scalability to CYGNO 30 m^3

- For **CYGNO 30 m^3** we expect ~300 higher background from ambient gamma
  - flux scales with surface L^2 (x 10)
  - probability of interaction in gas scales with mass (x 30)

- To maintain the same rate we calculated the thickness of the water shielding using the mass attenuation (μ/ρ) factor @1 MeV from https://physics.nist.gov/PhysRefData/XrayMassCoef/ComTab/water.html
  and the formula
  $I/I_o = \exp[-(\mu/\rho)x]$. with $x = \rho t$ ρ is the density and t the thickness

- The **thickness of water** needed for a 300 higher rejection factor of ambient gammas is **340 cm**