CYGNO simulations

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GEANT4 simulation repository

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

- 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

CYGNUS-RD / CYGNO-MC		• Unwatch	1 ▼ 3 ★ Star 0 ∛ Fork 0	
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Geant4 Monte Carlo simulation for CY	GNO based on Geant4.10.05		Edit	
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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

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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 counts / keV /s 212P Hall C 214 D ²¹⁴Bi Hall B Ē ²²⁸Ac ²¹⁴Bi ⁴⁰K ²¹⁴Bi 10⁻¹ 208TI ²¹⁴Bi 10⁻² 10^{-3} Total gamma flux in Hall B: ~ 0.36 γ / cm² / s Total gamma flux in Hall C: ~ 0.56 γ / cm² / s 10-4 500 1000 1500 2000 2500 E[keV]



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

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 < 10⁴ events/year in the low energy region [0-20] keV
 - → Bkg < 1 event/year, with ER rejection of 10⁴ 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 : 1.32 10⁵ evts/yr



- Goal total background < 10⁴ 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 < 10⁴ evt/yr
- with 15 cm Pb → ~10³ 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.) = ?



250 cm water shield

Lead shield radioactivity

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

$T_{1/2}$	Isotope	$E_{\alpha}(\text{MeV})$	I (%)	Activity
$4.468\cdot 10^9y$	^{238}U			
24.1d	$\downarrow \alpha$ ^{234}Th	4.18	99.9	A0
1.17m	$^{\downarrow \rho}_{234m}Pa$			
$2.455\cdot 10^5y$	$\downarrow^{\beta}_{234}U$			
$7.538 \cdot 10^4 y$	$\downarrow \alpha$ ^{230}Th	4.75	99.8	A1
1600 %	$\downarrow \alpha$ 226 R_{α}	4.66	99.7	A2
1000 <i>y</i>	$\downarrow \alpha$	4.78	94.4	A3
3.8 d	$\downarrow \alpha$	5.49	99.9	A3
3.10m	^{218}Po $\downarrow \alpha$	6.00	99.9	A3
26.8m	²¹⁴ Pb			
19.9m	$^{\downarrow \rho}_{214}Bi$			
$164.3\mu s(*)$	$\downarrow^{\beta}_{214}Po$			
	$\downarrow \alpha$	7.69	99.9	A3
22.3 y	210Pb]
5.01d	$\downarrow^{\beta}_{210}Bi$			
138.4 d	$\downarrow^{\beta}_{210}Po$			
Stable	$\downarrow^{\alpha}_{206}Pb$	5.30	100	A4

Background from 5 cm lead shield

- Energy deposit in CYGNO detector from lead shield radioactivity
- assume ²¹⁰Pb 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 2 10⁶ cts/yr

Even a 5 cm-thick shield of lead for 1 m³ 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 m³

• For **CYGNO 30 m³** 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 <u>https://physics.nist.gov/PhysRefData/XrayMassCoef/ComTab/water.html</u> and the formula $I/I_o = \exp[-(\mu/\rho)x]$. with x = $\rho t - \rho$ is the density and t the thickness
- The thickness of water needed for a 300 higher rejection factor of ambient gammas is 340 cm