Background simulations for CYGNO-04 detector

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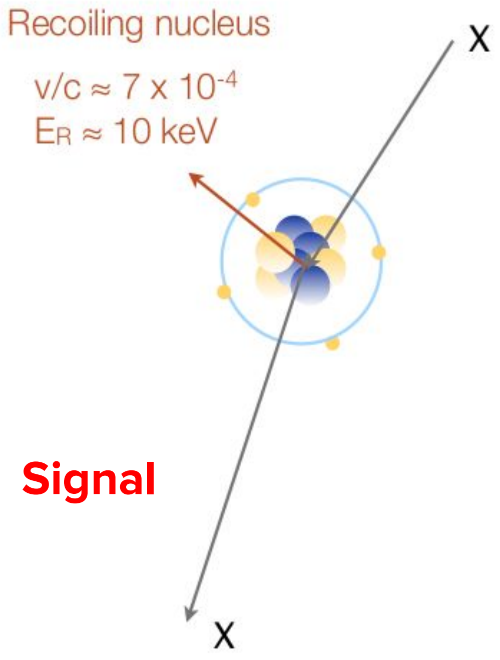
19-20/12/22
CYGNO Collaboration Meeting, Roma

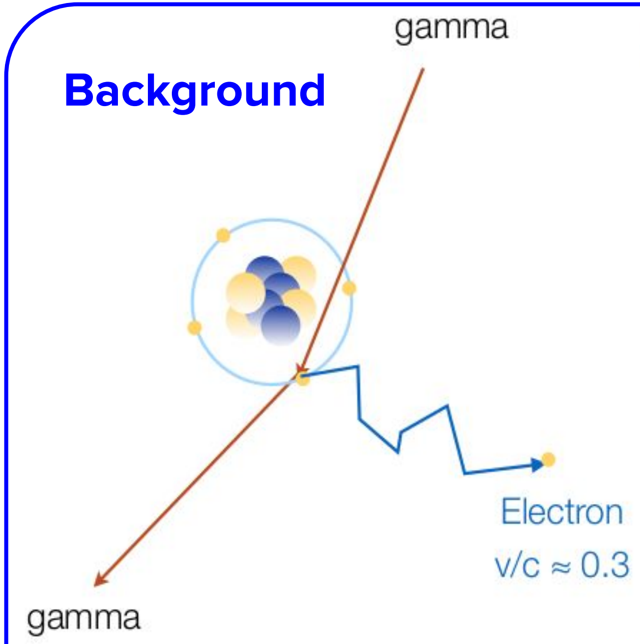
Signal and background events in dark matter search

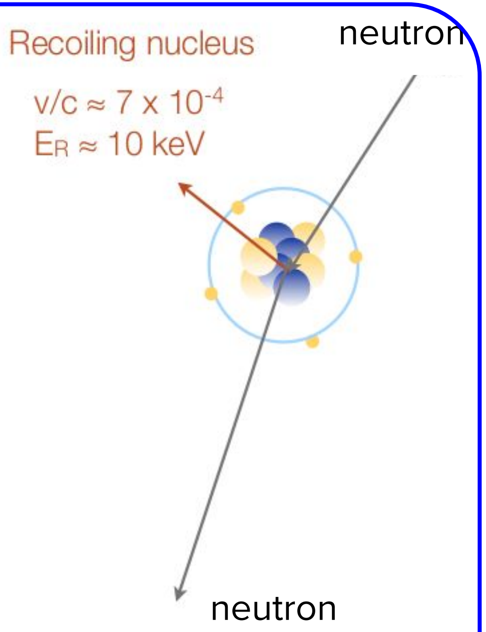


Signal

WIMPs produce
nuclear recoils (NR)

Background



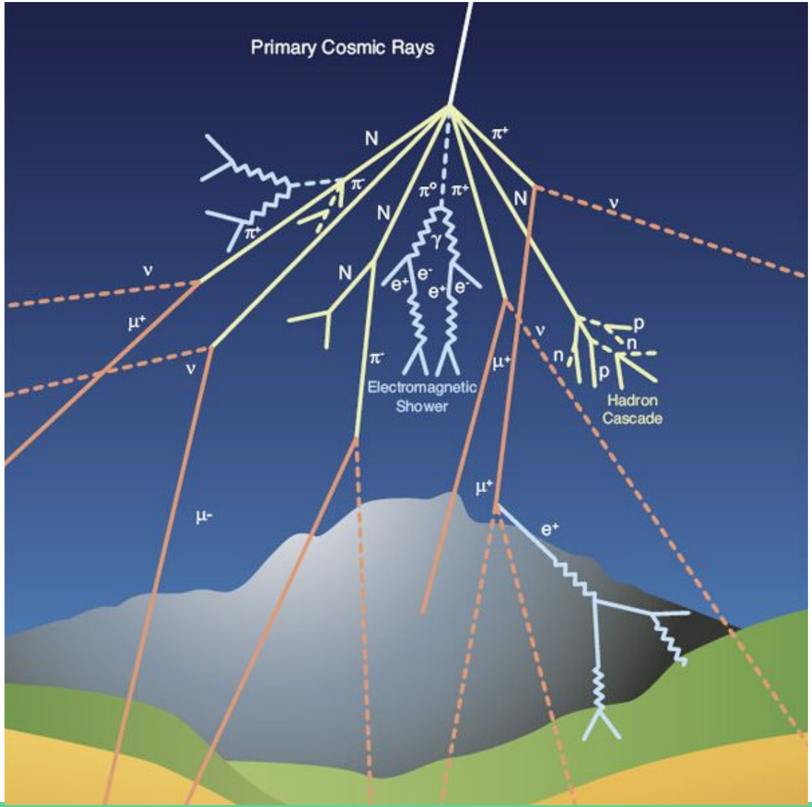


Most of the background from **electron recoils (ER)** caused by **β/γ events**

Neutrons produce **nuclear recoils (NR)** similar to WIMPs

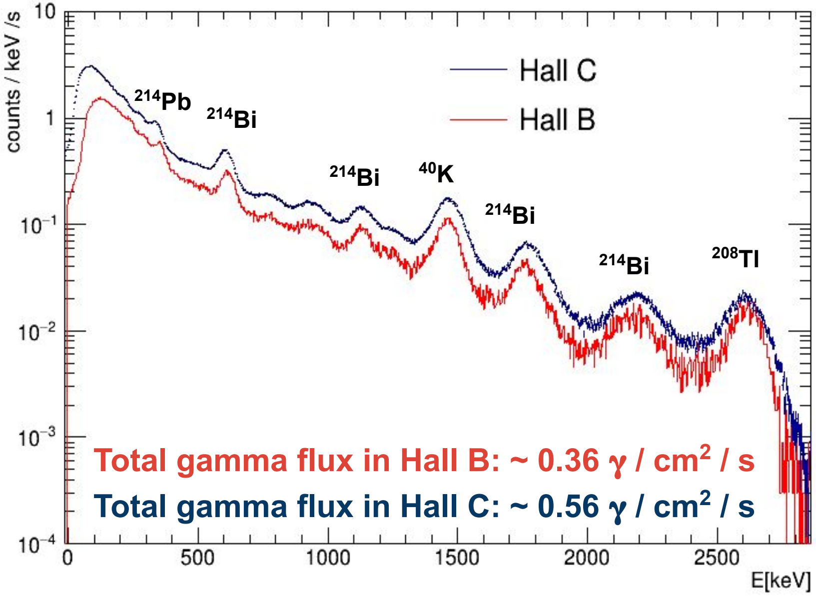
Background sources

1) Cosmic rays



2) Environmental radioactivity

Mainly potassium (K) uranium (U) and thorium (Th) and their daughters

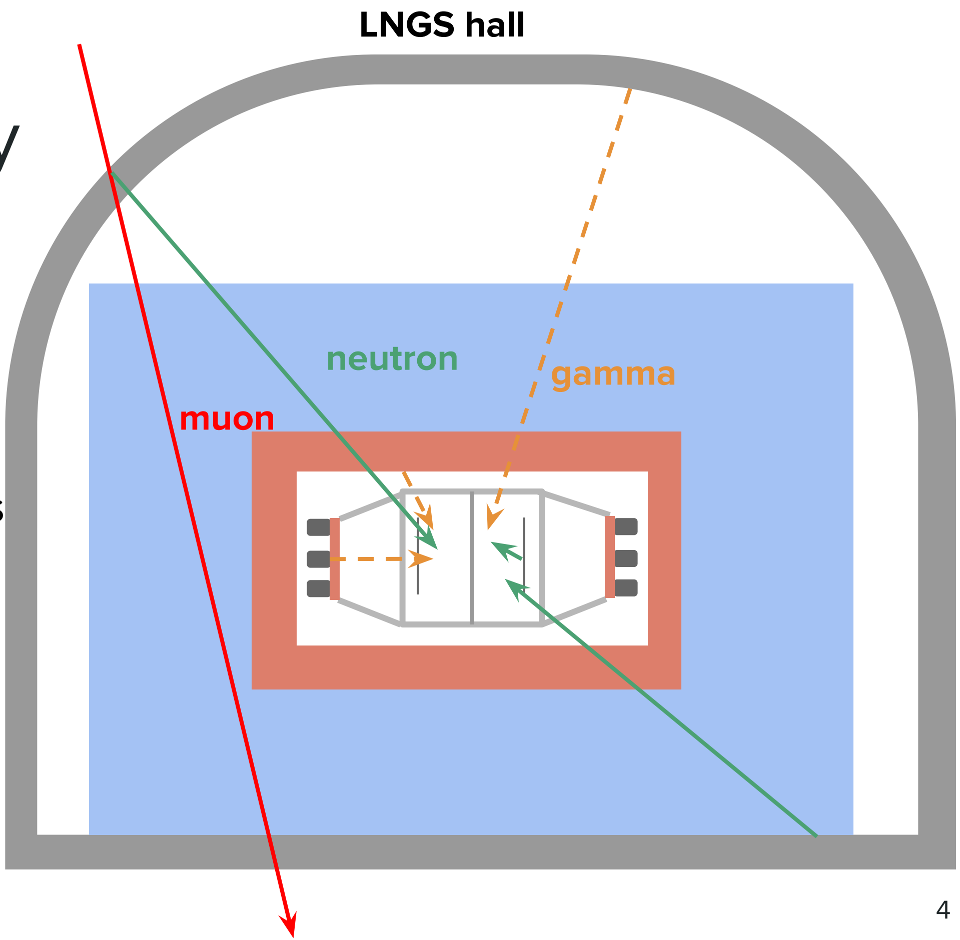


Background components in underground laboratory

- Internal radiogenic neutrons/gammas (origin: radioactivity of the materials in setup)

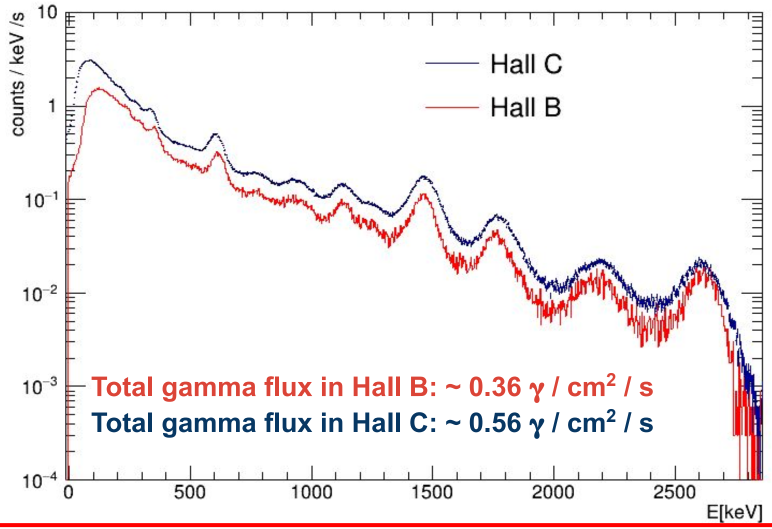
- External radiogenic neutrons/gammas (origin: radioactivity of rocks and concrete of the lab)

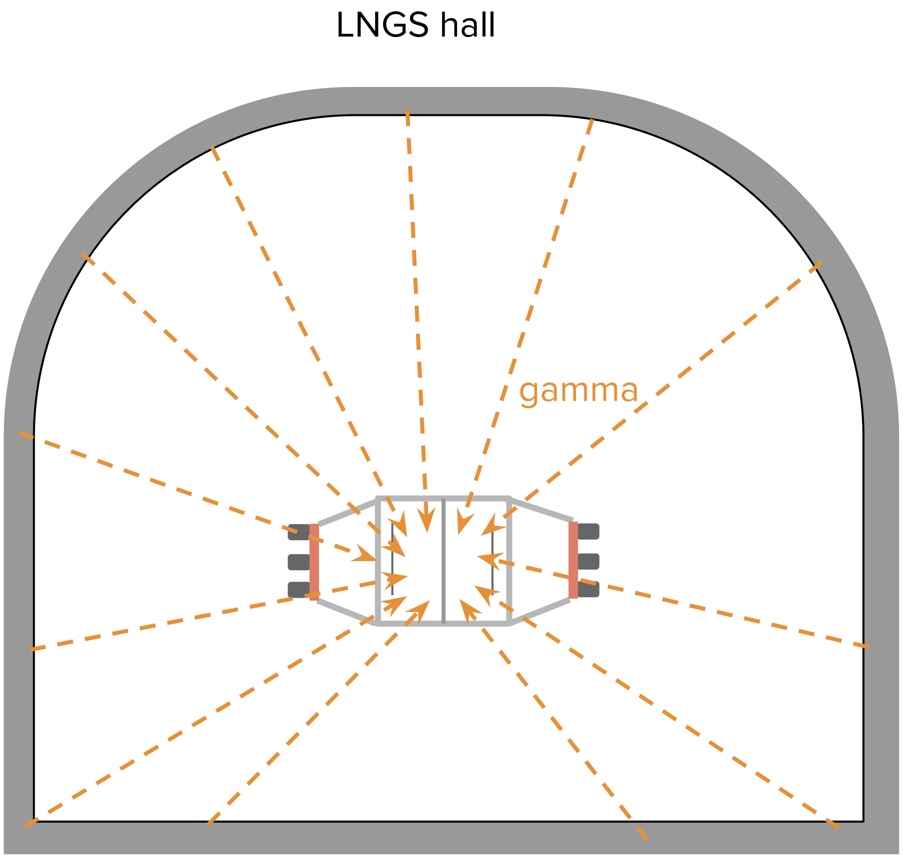
- External cosmogenic neutrons (origin: muon interactions)



Ambient gammas

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

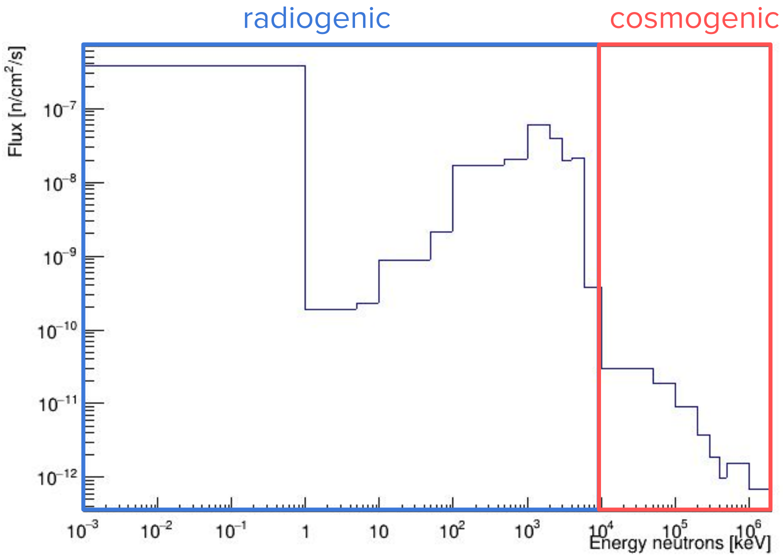


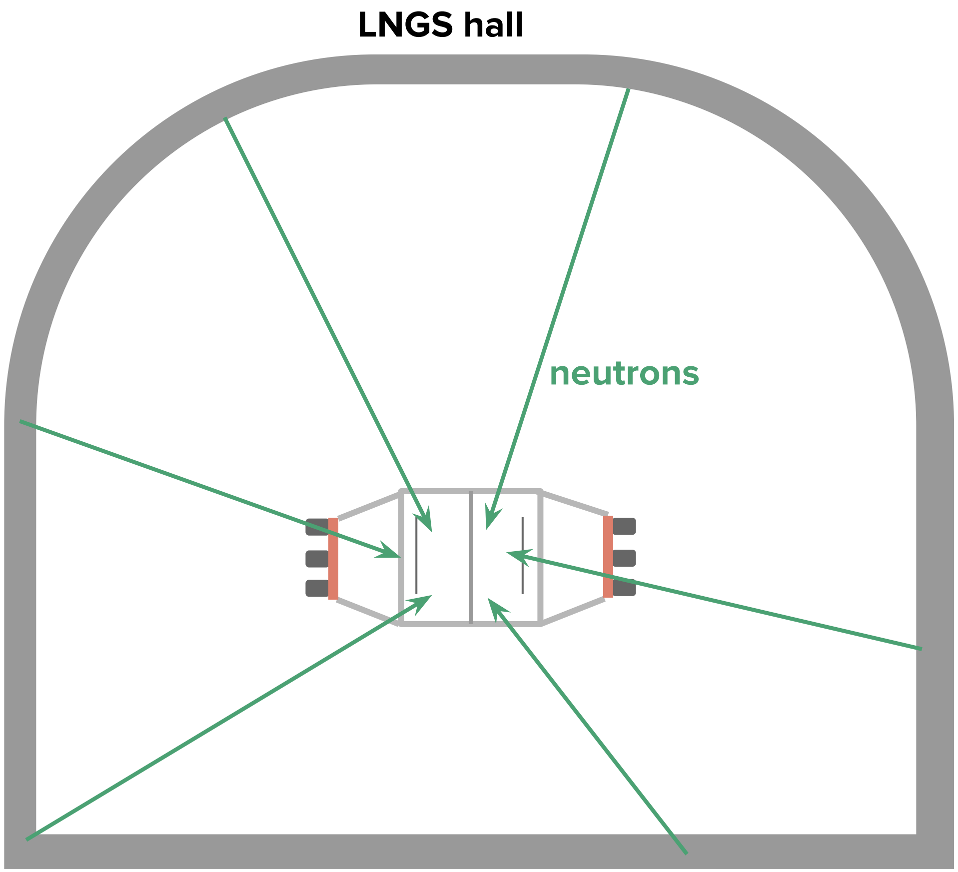


Without shield **O(10^9) evts/yr** in the CYGNO detector
→ need shielding with **attenuation power 10^{-5}-10^{-6}**

Ambient neutrons

- Ambient neutrons from radioactivity in the rock
- Spectrum from CUORE MC
  ➜ measurements Belli/Arneodo (radiogenic, E<10 MeV) and Hime (cosmogenic E>10 MeV)



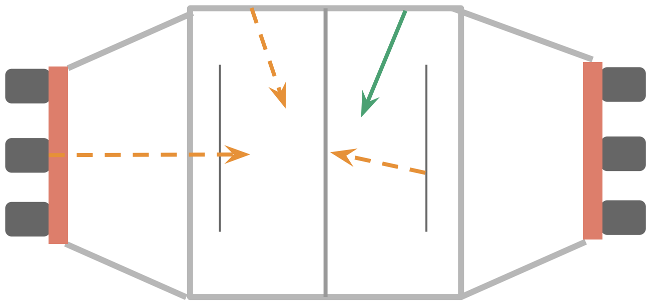


Radioactivity of materials

- natural radioactivity: U, Th and K
- radon
- cosmogenically activated isotopes

➔ usually the most worrisome backgrounds are internal (externals can be shielded)

➔ Careful evaluation of the material activities is important to predict the background



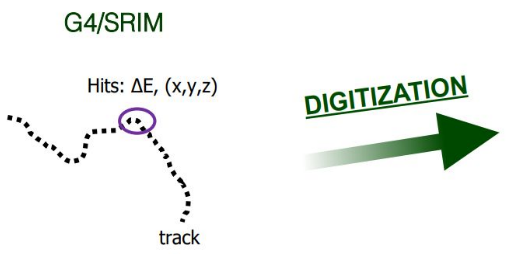
Simulation workflow

1. Interactions of ER/NR in the gas ➔ tracks (x,y,z,dE) **Geant4 (ER) / SRIM (NR)**

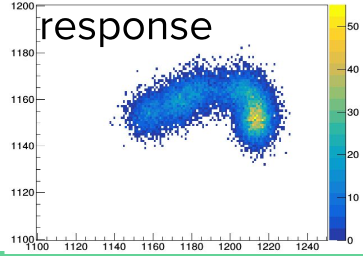
2. Calculate electron diffusion in CYGNO gas **Garfield**

3. Simulation of primary electrons + transport to the GEMS
4. Simulation of GEM multiplication with saturation effect
5. Simulation of light production
6. Simulation of the camera (geometry, sensor, noise)

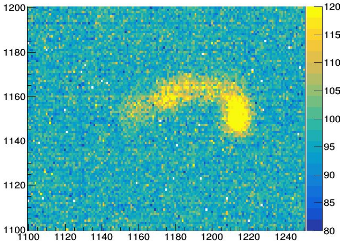
$\left.\right\}$ **detector simulation (digitization)**



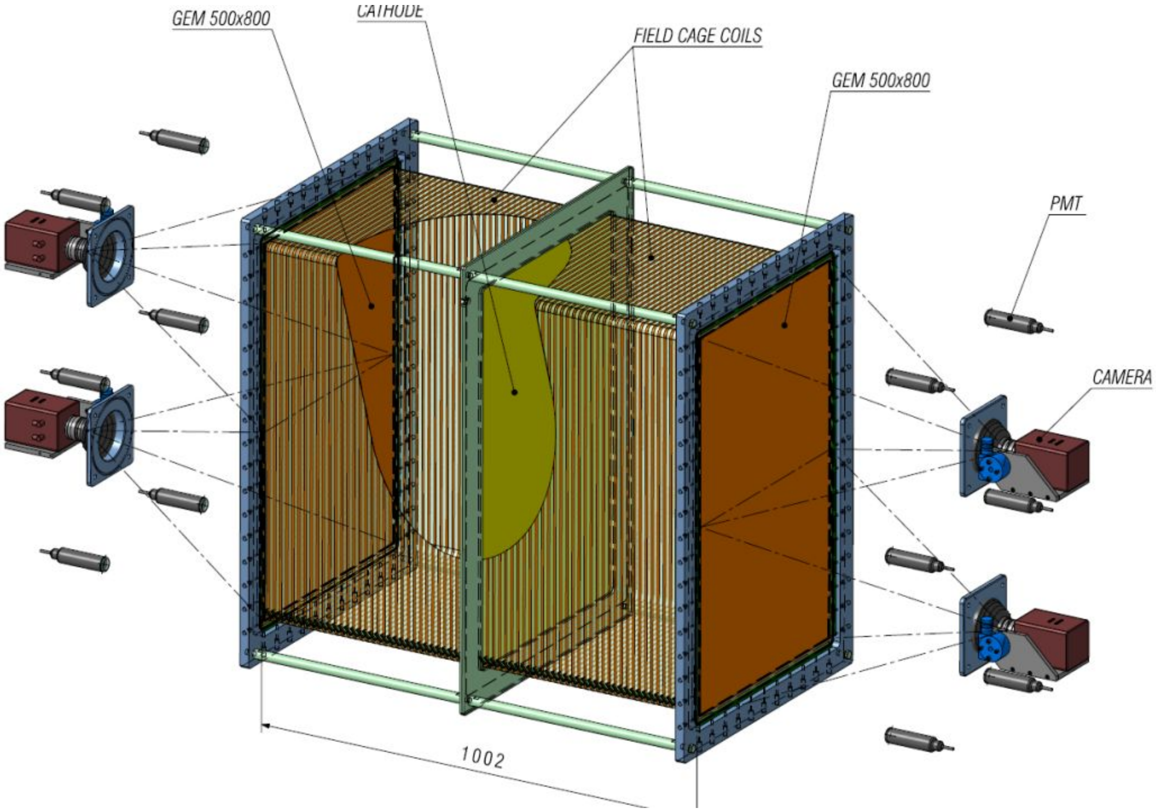
Detector response



Detector response + noise

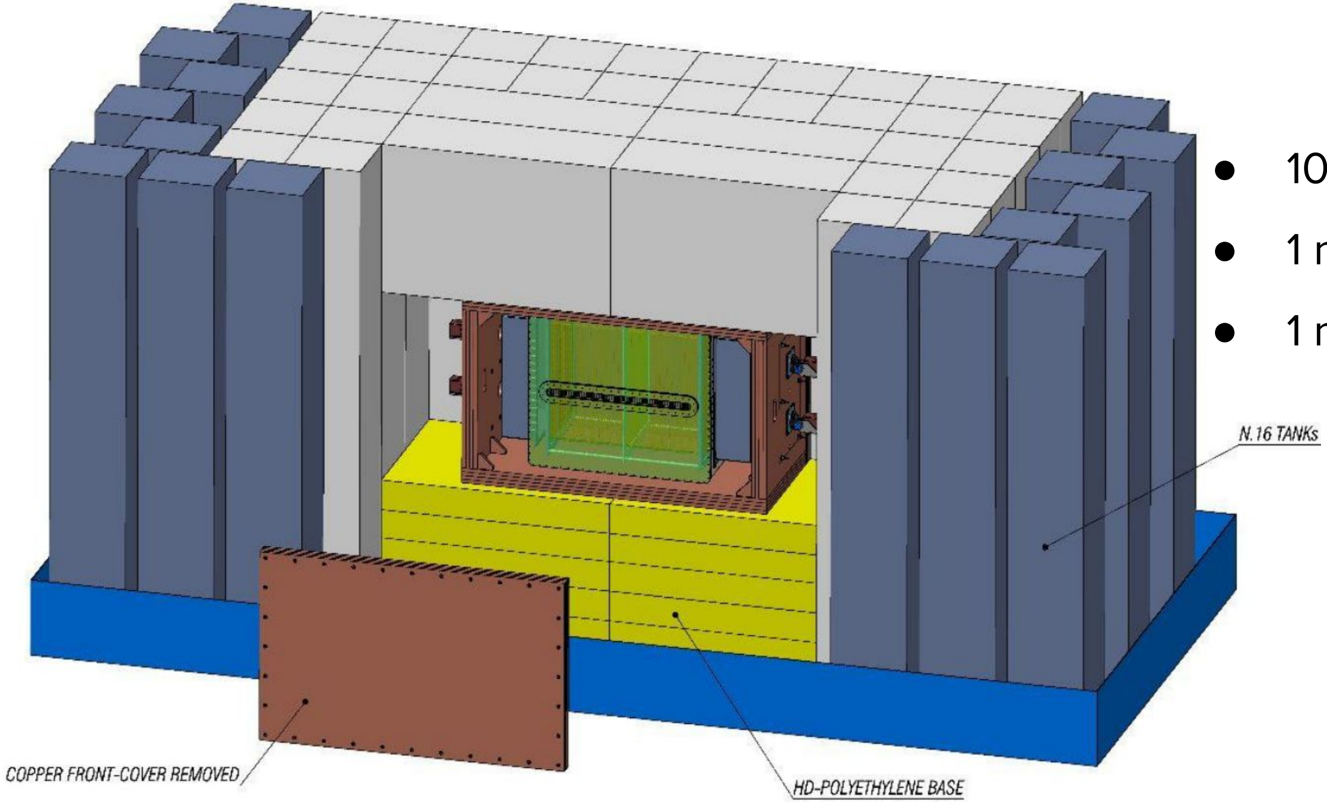


CYGNO-04 design



- $0.5 \times 0.8 \times 1\ m^3$ sensitive volume ($0.4\ m^3$)
- $He:CF_4$ gas mixture
- Central cathode
- 2 drift regions of 50 cm each
- 2 x triple-GEM stack
- 2 x 2 cameras on each side, framing $50 \times 80\ cm^2$ area

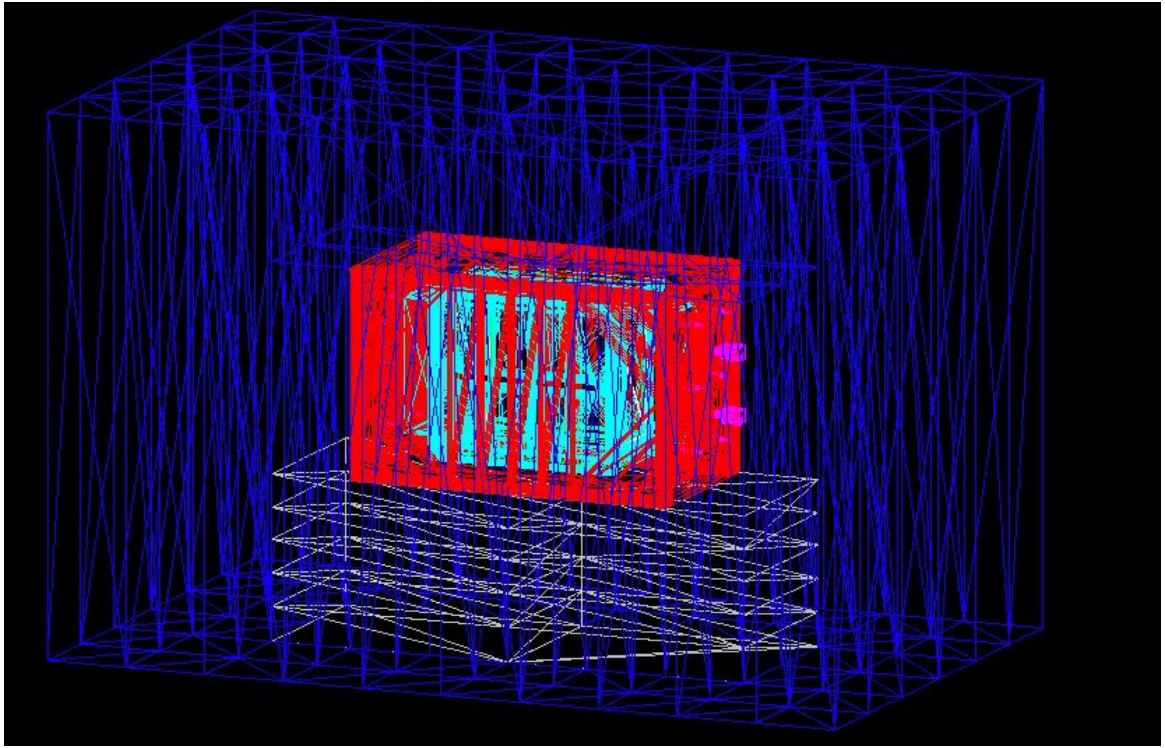
CYGNO-04 shielding design



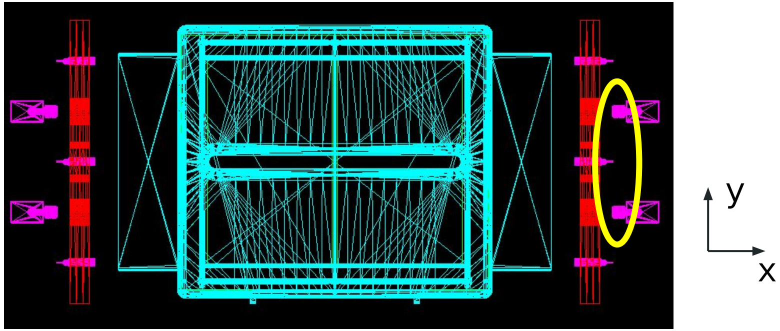
- 10 cm copper on all sides
- 1 m water on sides and top
- 1 m PE on the base

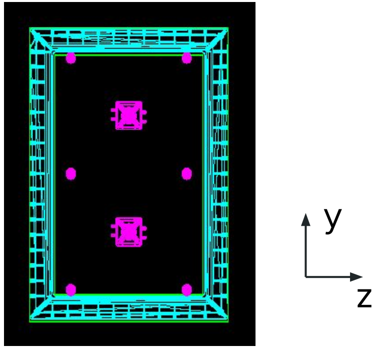
Geometry implemented in Geant4

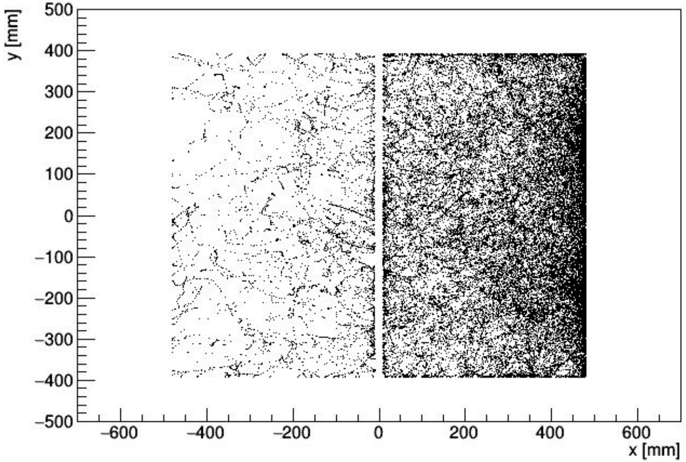
- Github repository: https://github.com/CYGNUS-RD/CYGNO-MC/tree/cygno_04

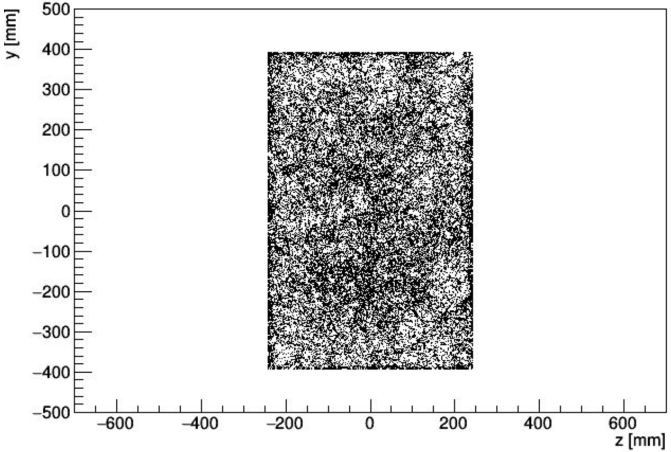


Simulation of radioactivity from camera lenses (right)



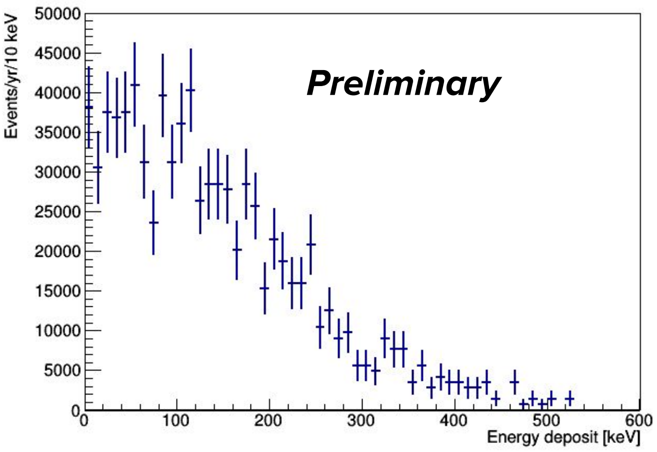






Expected rate from camera lenses

- ^{40}K events generated in camera lenses: 10^6
- Activity: 11 Bq/pc ➜ 4 lenses ➜ 44 Bq
- Events releasing energy in the gas: 1213 (99 in the 0-20 keV range)
- **Rate from ^{40}K**= N/ Ngen * activity = **1.7 (0.14) x 10^6 evts/yr**
  ➜ simulation to be done for all radioactive isotopes and all setup parts



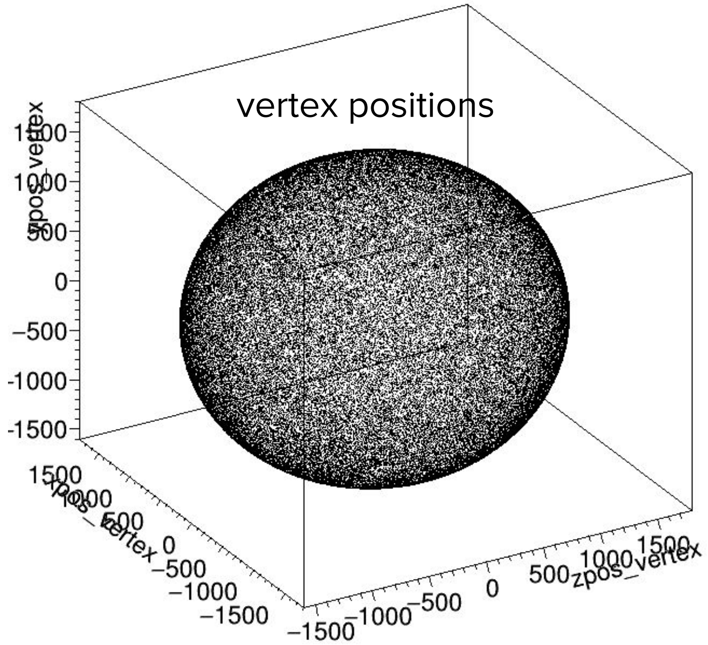
Radioactivity measurements with HPGe by Laubenstein

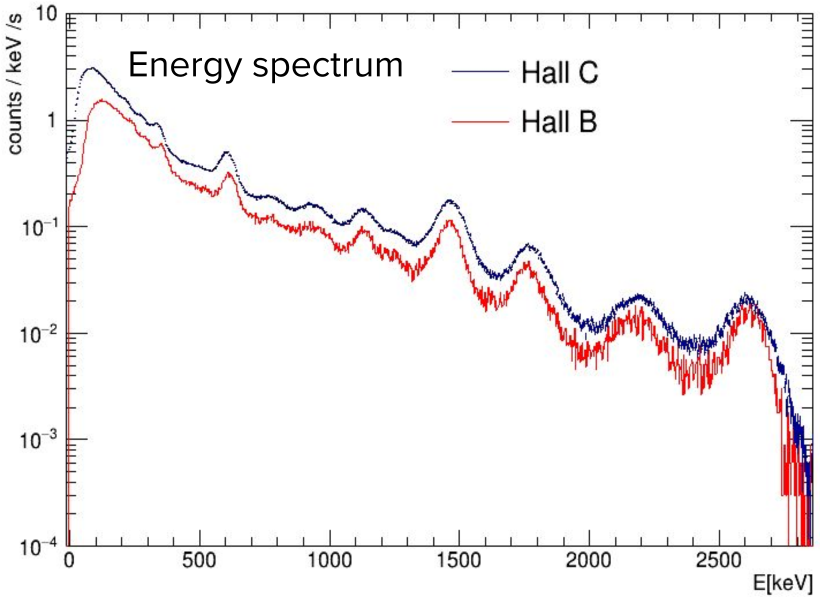
```
Th-232:
Ra-228: (0.077 +- 0.009) Bq/pc
Th-228: (0.078 +- 0.006) Bq/pc

U-238:
Ra-226          (0.41 +- 0.02) Bq/pc
Pa-234m (0.9 +- 0.3) Bq/pc

U-235:          (0.031 +- 0.008) Bq/pc

K-40:           (11 +- 1) Bq/pc

Cs-137: < 0.0057 Bq/pc

Co-60:          < 0.0099 Bq/pc
La-138: (0.52 +- 0.04) Bq/pc
```

Note: radioclean lenses made of fused silica or plastic could be 3-4 order of magnitude less radioactive

External gamma simulation

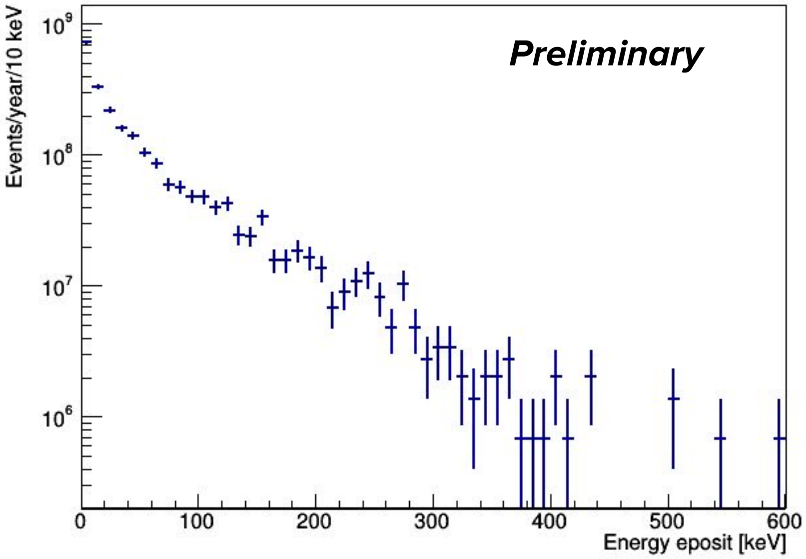
- Simulate gammas from a spherical surface containing the setup
- Energy distribution from gamma measurements at LNGS with NaI detector



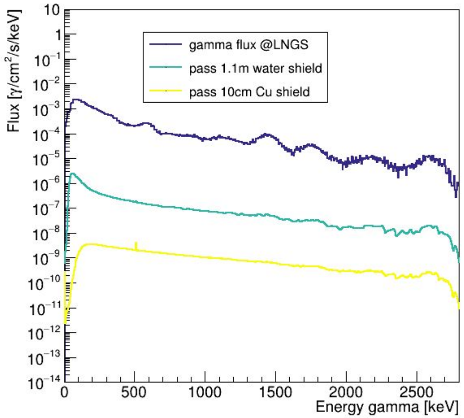


Rate from external gammas

- Gammas generated from surface: 10^7 events
- Flux at LNGS ~ 0.5 gamma/cm^2/s
- Events releasing energy in the gas: 3395 (1546 in the 0-20 keV range)
- **Rate from gammas (no shield)** = N/ Ngen * flux * surf = **2.3 (1.0) x 10^9 evts/yr**

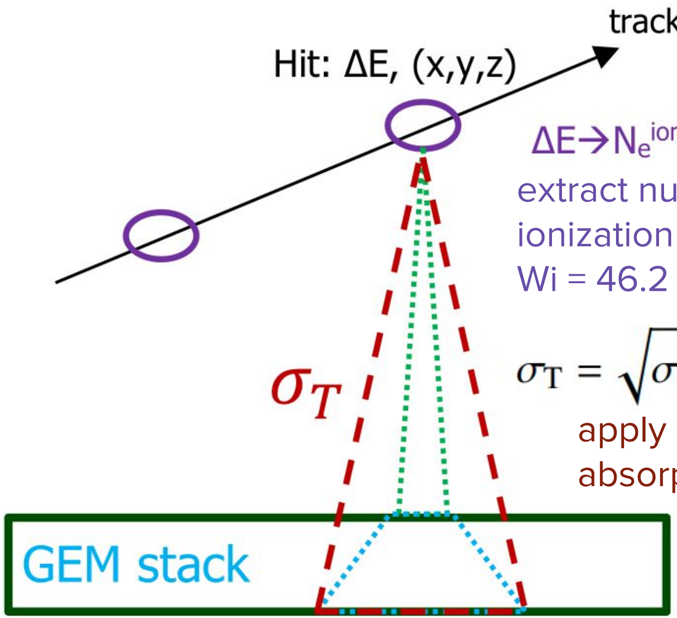


Average gamma flux attenuation of
1 m water + 10 cm Cu ➔ ~5 x 10^{-6}



Next step: detector simulation

Github repository: https://github.com/CYGNUS-RD/digitization



$\Delta E \rightarrow N_e^{ion} = \Delta E / W_i$

extract number of ionization electrons

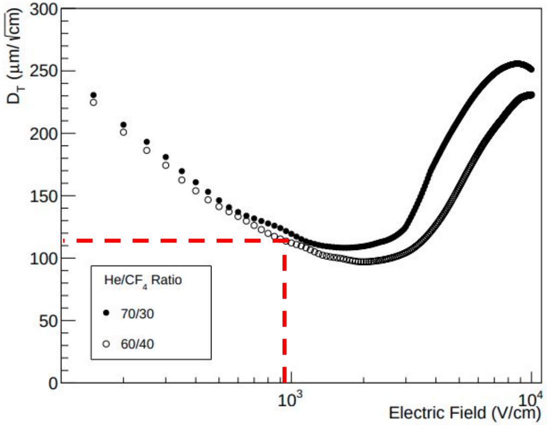
Wi = 46.2 eV

$$\sigma_T = \sqrt{\sigma_{T0}^2 \oplus D_T^2 \cdot z}$$

apply diffusion

absorption length = 1.4 m

Simulate electron multiplication & light production in GEM stack



$$D_T^{60/40} = 115 \ \frac{\mu m}{\sqrt{cm}}$$

$$\sigma_{T0}^{60/40} = (280 \pm 60)\ \mu m$$

For 930V/cm drift field

see talk by F. Petrucci

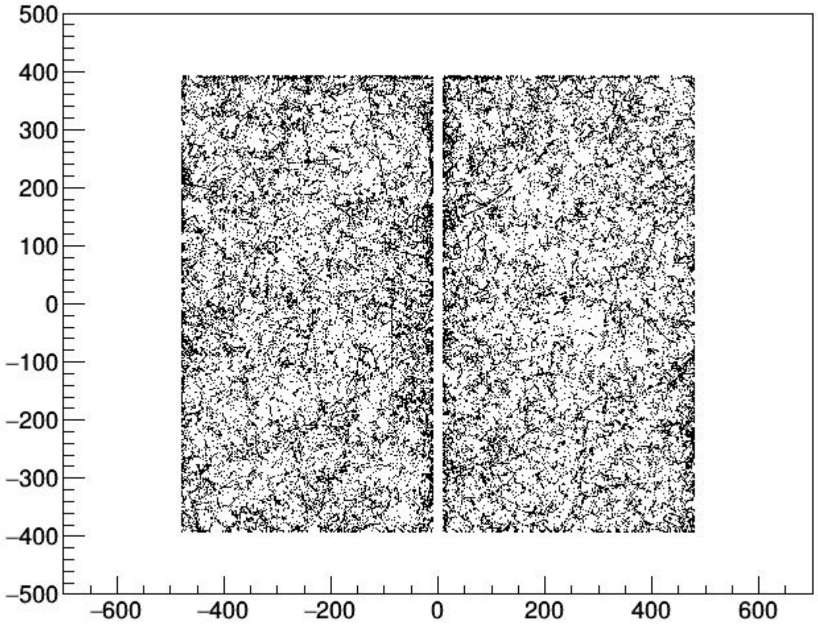
Summary

- Lesson from LIME: internal background will be likely dominated by GEMs and cameras (see Flaminia's talk on Monday)
  - need to optimize materials for low background experiments
  - radioactivity screening or CYGNO-04 materials very important
  - full simulations for CYGNO-04 in progress
- External gamma background estimation ~10^3-10^4 events/year with shielding made of water (1 m) and copper (10 cm)
  - full simulations in progress
- Nuclear recoils from background
  - small background but "irreducible" ➔ identical to NR from DM
  - study fiducialization techniques with simulation and LIME data
- Validation of MC with LIME data is very important
  - full simulation+reconstruction chain: interactions (Geant/SRIM), detector, reconstruction

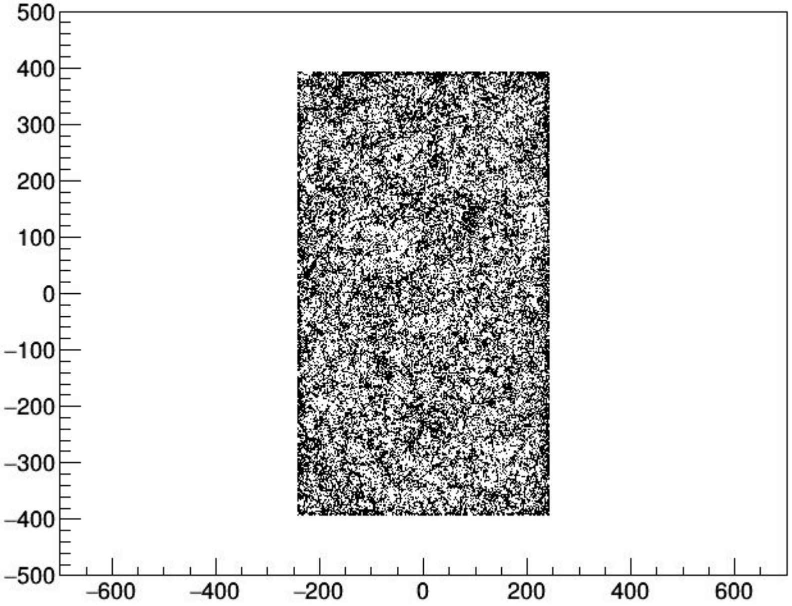
Extra slides

Simulation of external gammas

y[mm] vs x[mm]

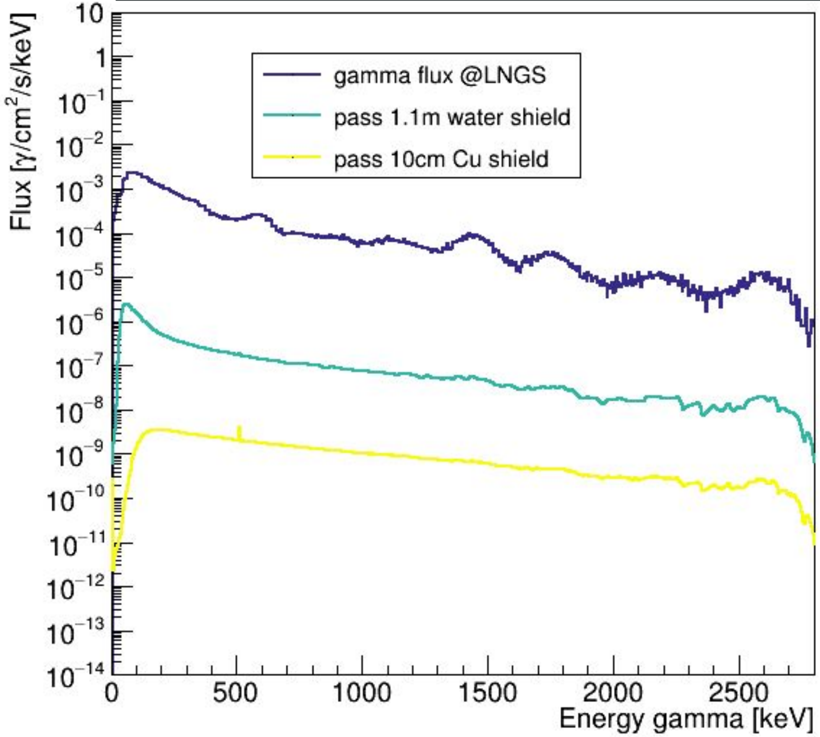


y[mm] vs z[mm]

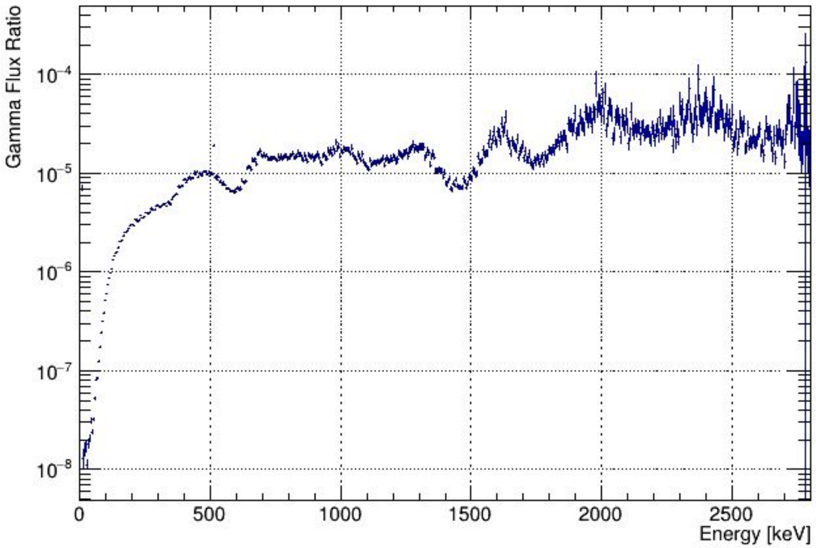


Gamma flux

gamma flux entering shield: 2.4×10^{-6} $cm^{-2}s^{-1}$



110 cm water shield
+ 10 cm copper shield



Summary of internal backgrounds (old calculations)

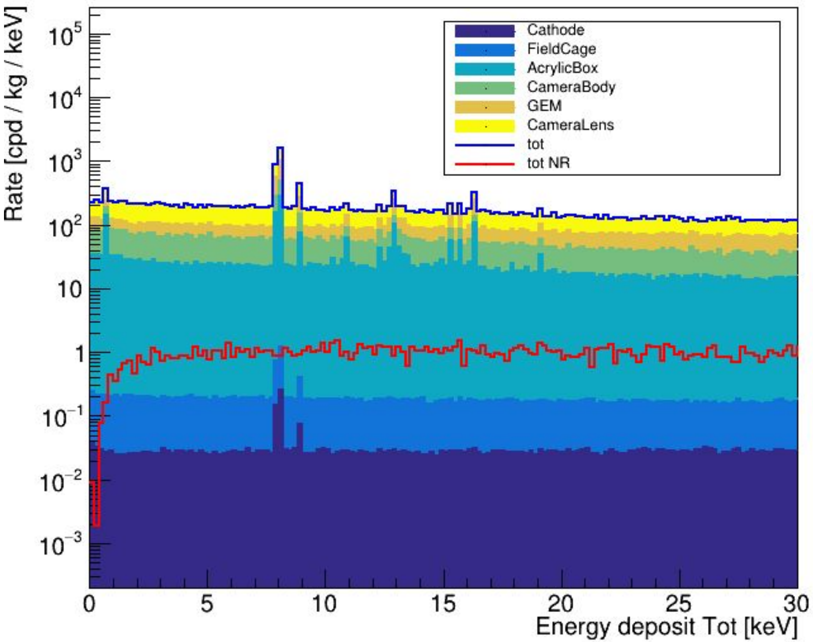
	CYGNO		CHINOTTO*		
Summary Table	**NR/yr 1-20 keV**	**ER/yr 1-20 keV**	**NR/yr 1-20 keV**	**ER/yr 1-20 keV**	**Reference**
GEM (LNGS)	5.07E+03	5.09E+05	1.00E+03	1.01E+05	Laubenstein@LNGS
GEM (TREX)	4.27E+03	3.61E+05	8.44E+02	7.14E+04	T-REX GEM
AcrylicBox (LNGS)	6.07E+03	3.61E+05	1.56E+03	9.32E+04	Laubenstein@LNGS
AcrylicBox (SNO)	7.67E+01	1.17E+04	1.98E+01	3.02E+03	SNO acrylic
CameraBody	0.00E+00	4.46E+05	0.00E+00	8.81E+04	Laubenstein@LNGS
CameraLens (LNGS)	0.00E+00	1.07E+06	0.00E+00	2.12E+05	Laubenstein@LNGS
CameraLens (fused silica)	0.00E+00	6.68E+01	0.00E+00	1.32E+01	Haereus "Suprasil"
Cathode (Cu)	8.58E-01	3.63E+02	1.69E-01	7.18E+01	T-REX copper
Field Cage (Cu)	1.51E+00	2.00E+03	2.99E-01	3.96E+02	T-REX copper
Total (LNGS)	**1.11E+04**	**2.39E+06**	**2.57E+03**	**4.94E+05**	
Total (low rad)	**4.35E+03**	**8.21E+05**	**8.64E+02**	**1.63E+05**	

- NR for the low-rad option mostly come from GEM ➔ could be reduced with fiducialization
- ER for the low-rad option mostly come from GEM and Camera body

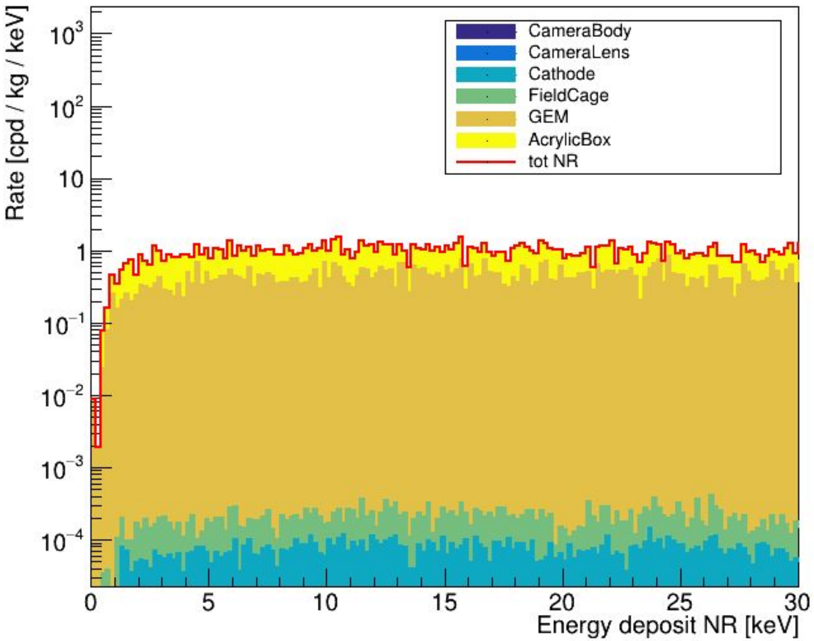
* Rates for CHINOTTO are obtained scaling from CYGNO-1m^3 numbers

Summary of internal backgrounds CYGNO-1m3 (old)

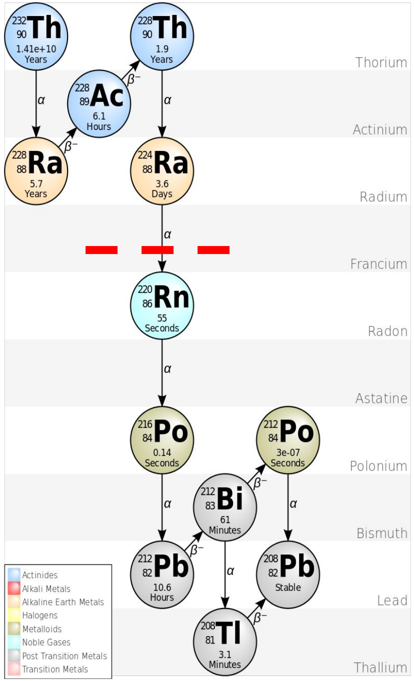
- **ER rate [1-20] keV = 2.3x10^{6} cts/yr**

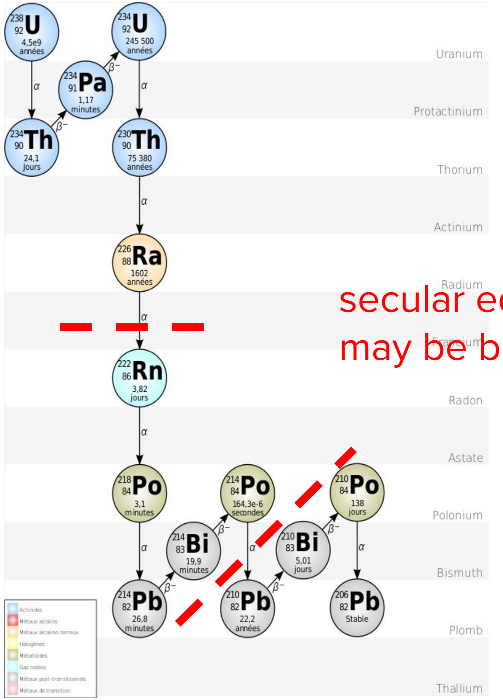


- **NR rate [1-20] keV = 1.1x10^{4} cts/yr**



Radioactive chains





secular equilibrium
may be broken