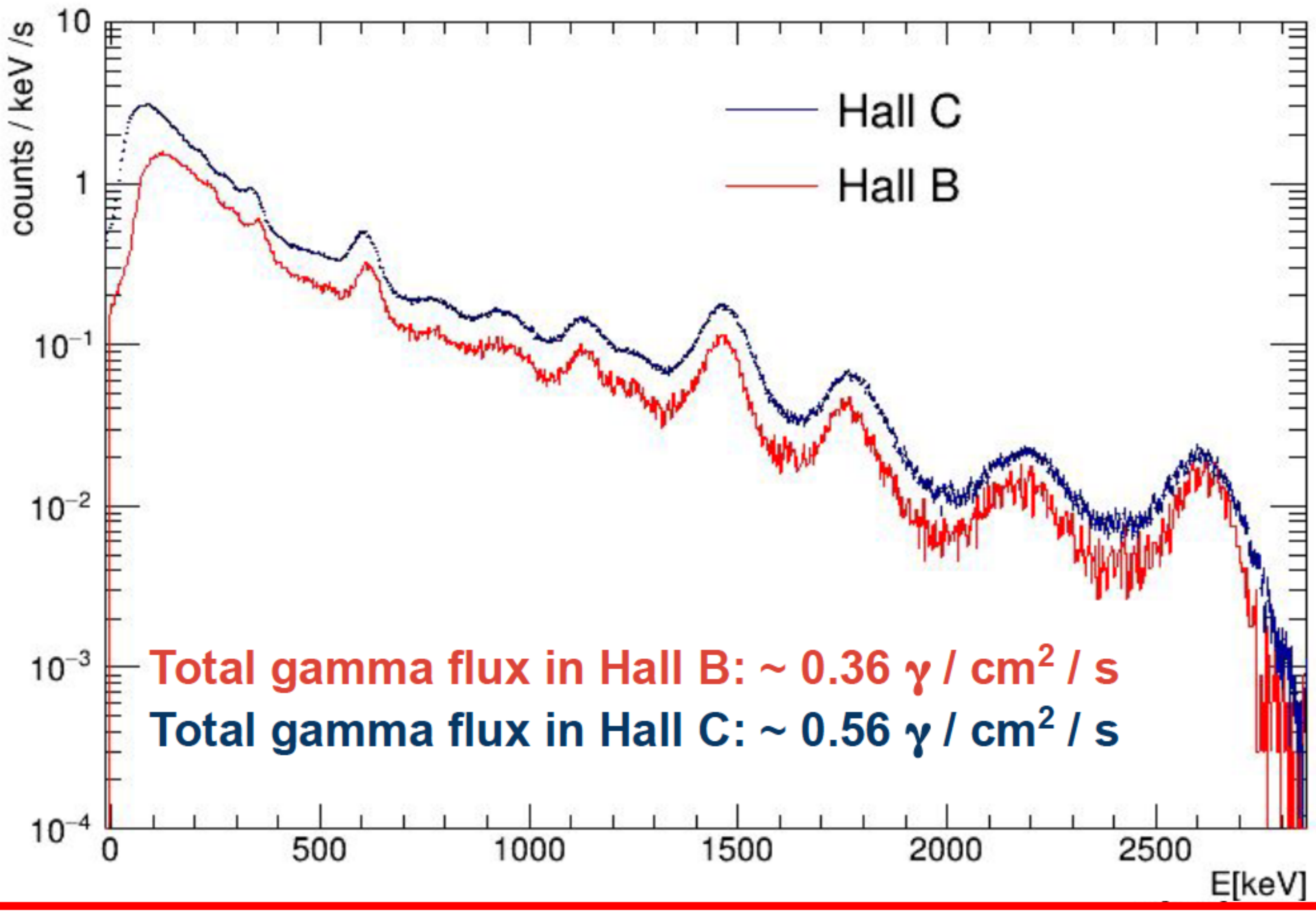
CYGNO-04 BKG Simulation

A summary of work done so far by Giulia et al

Vera, the daughter of Giulia was born on the **29th** of **November**

All the best to her and family

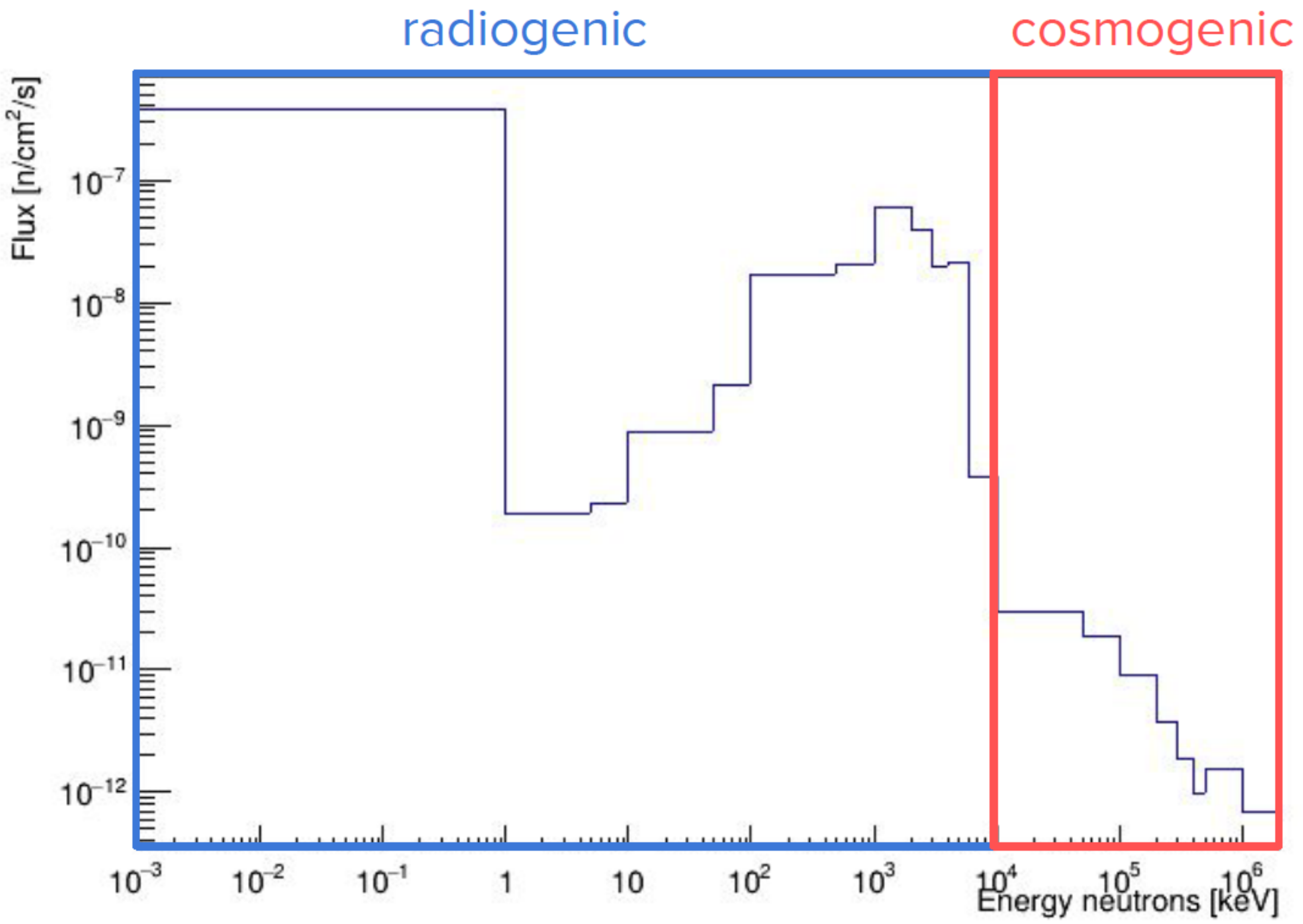
Ambient gammas



- Gammas mostly from K, U chain and Th chain
- Spectrum measured by SABRE collaboration(*)
- used as input for CYGNO simulations
- The shape is “hall-invariant” while the total flux is not.
- We’ll use the RM1-NaI for a direct measurement of the flux in hall-F

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

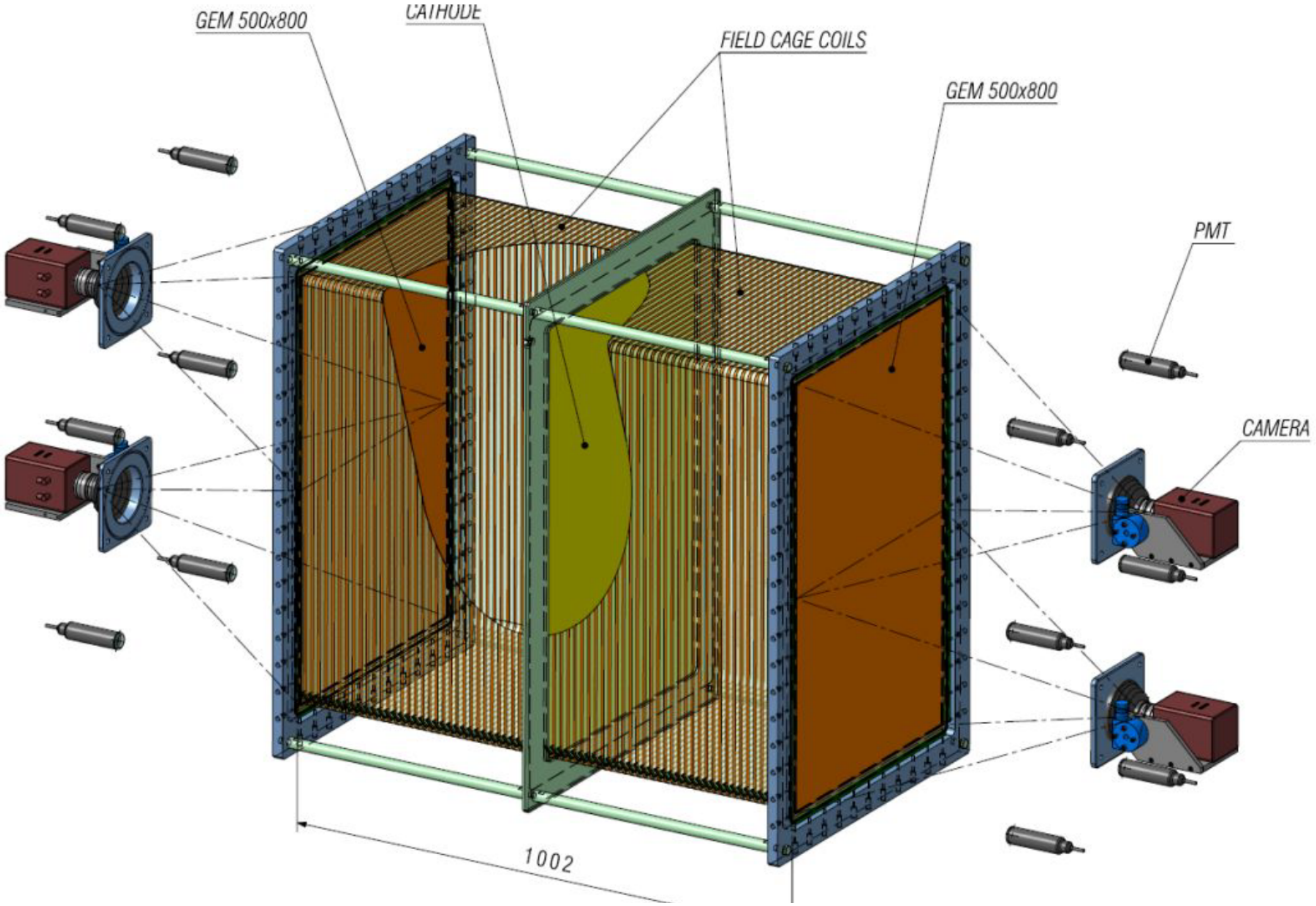
Belli/Arneodo (radiogenic, E<10 MeV)

and Hime (cosmogenic E>10 MeV)

Radioactivity of materials

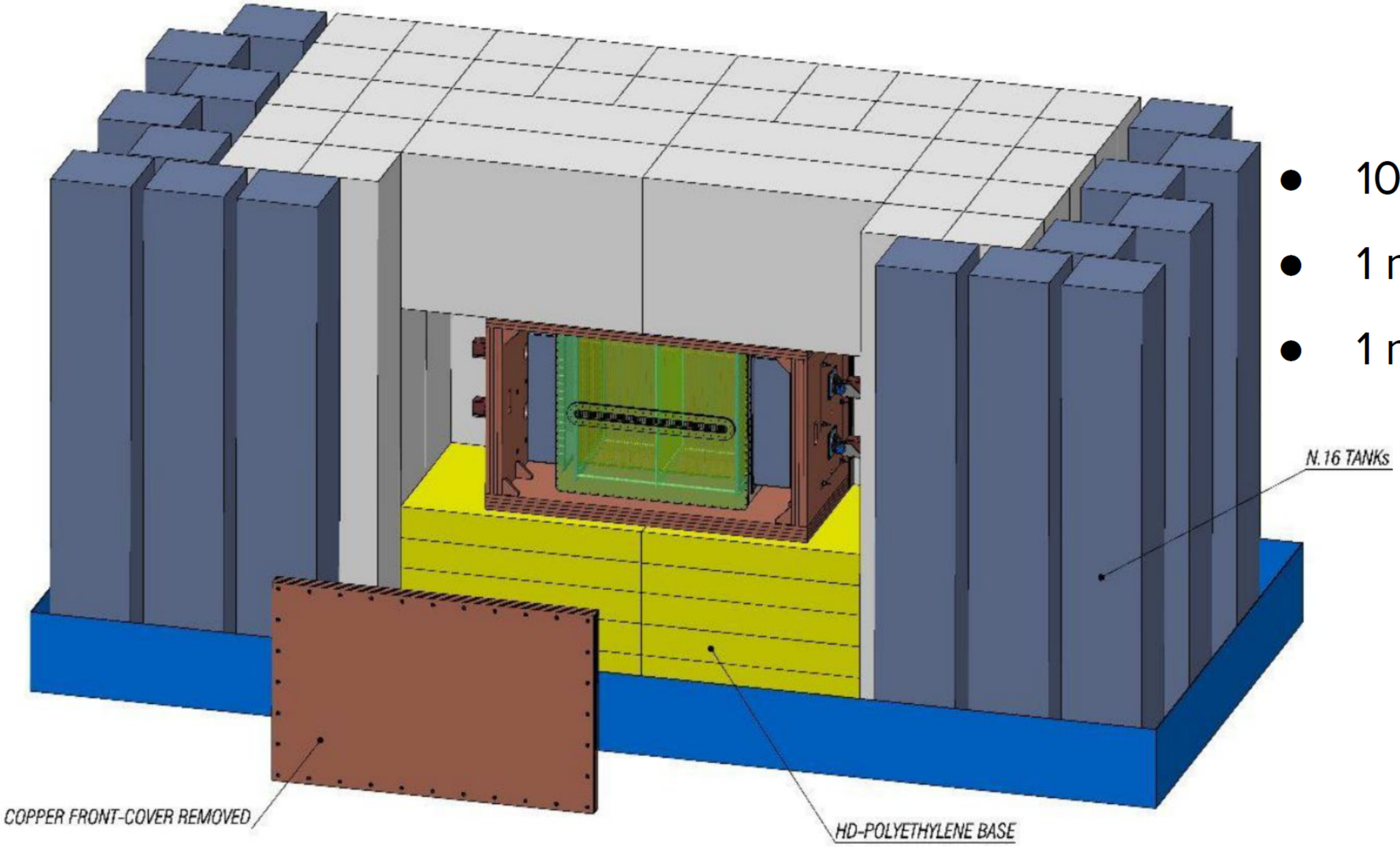
- natural radioactivity: U, Th and K of all material was evaluated on the basis of:
  - the direct measurements performed by Mathias;
  - radiopurity DB for the material we haven’t yet tested;
- to be done:
  - radon
  - ^{14}C decay in the gas mxiture

CYGNO-04 design



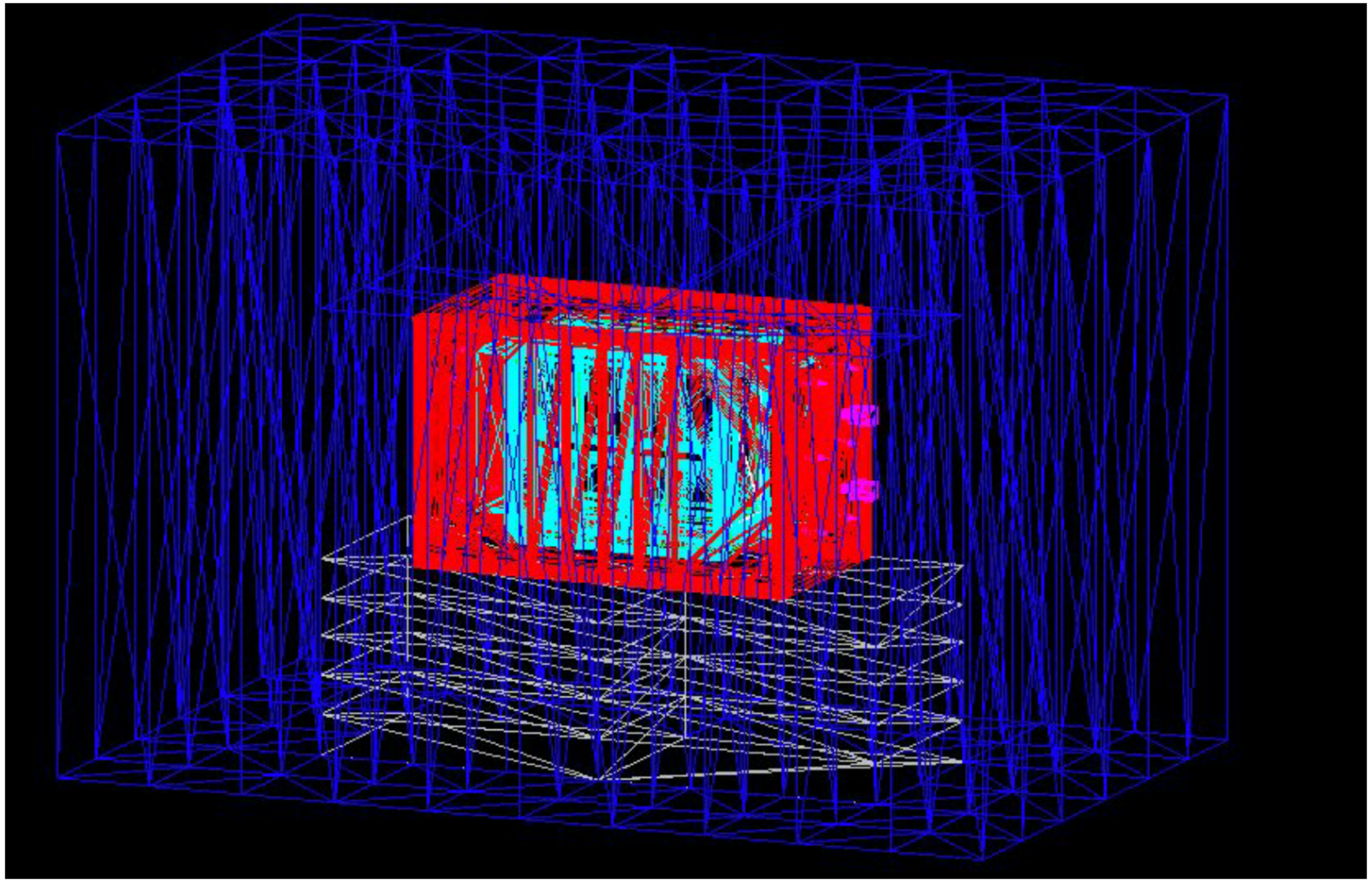
- $0.5 \times 0.8 \times 1\ m^3$ sensitive volume ($0.4\ m^3$)
- $He:CF_4$ gas mixture
- Central cathode
- 2 drift regions of 50 cm each
- 2 x triple-GEM stack
- 2 x 2 cameras on each side, framing $50 \times 80\ cm^2$ area

CYGNO-04 shielding design



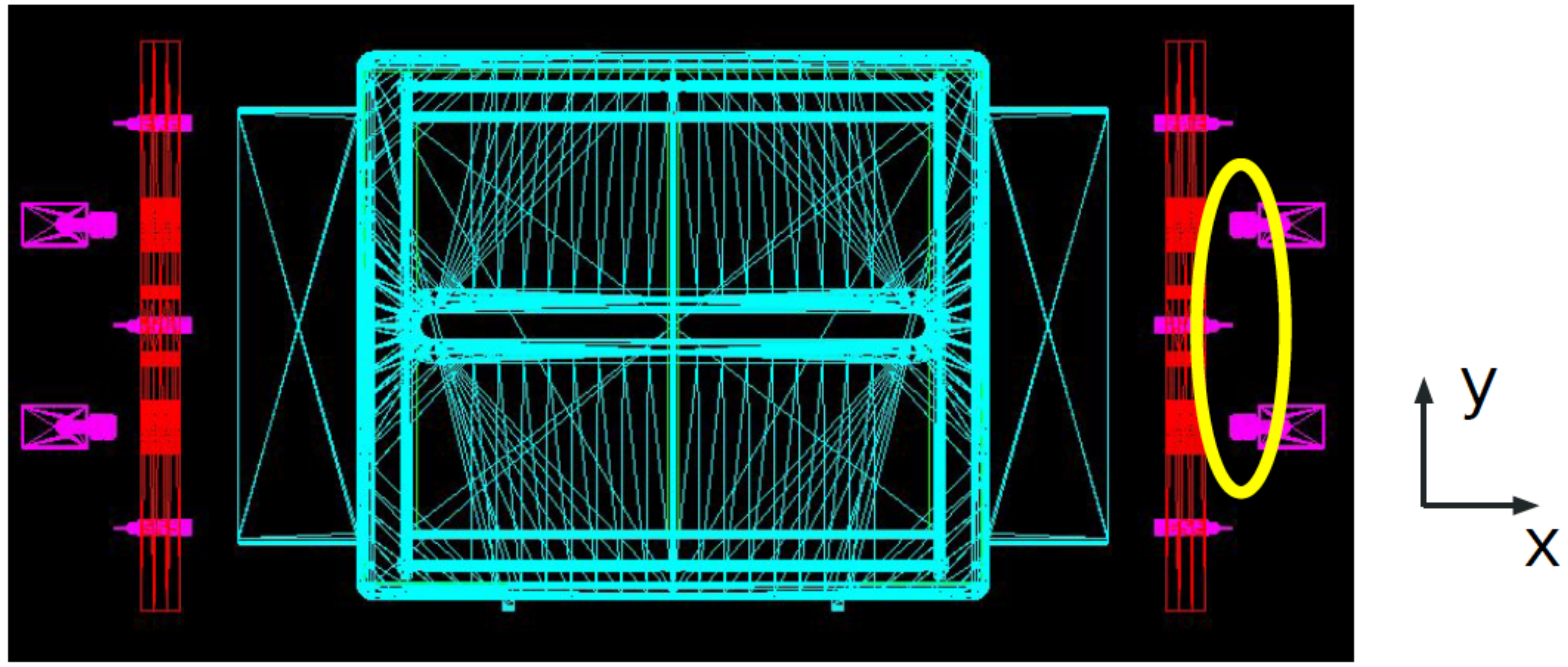
- 10 cm copper on all sides
- 1 m water on sides and top
- 1 m PE on the base

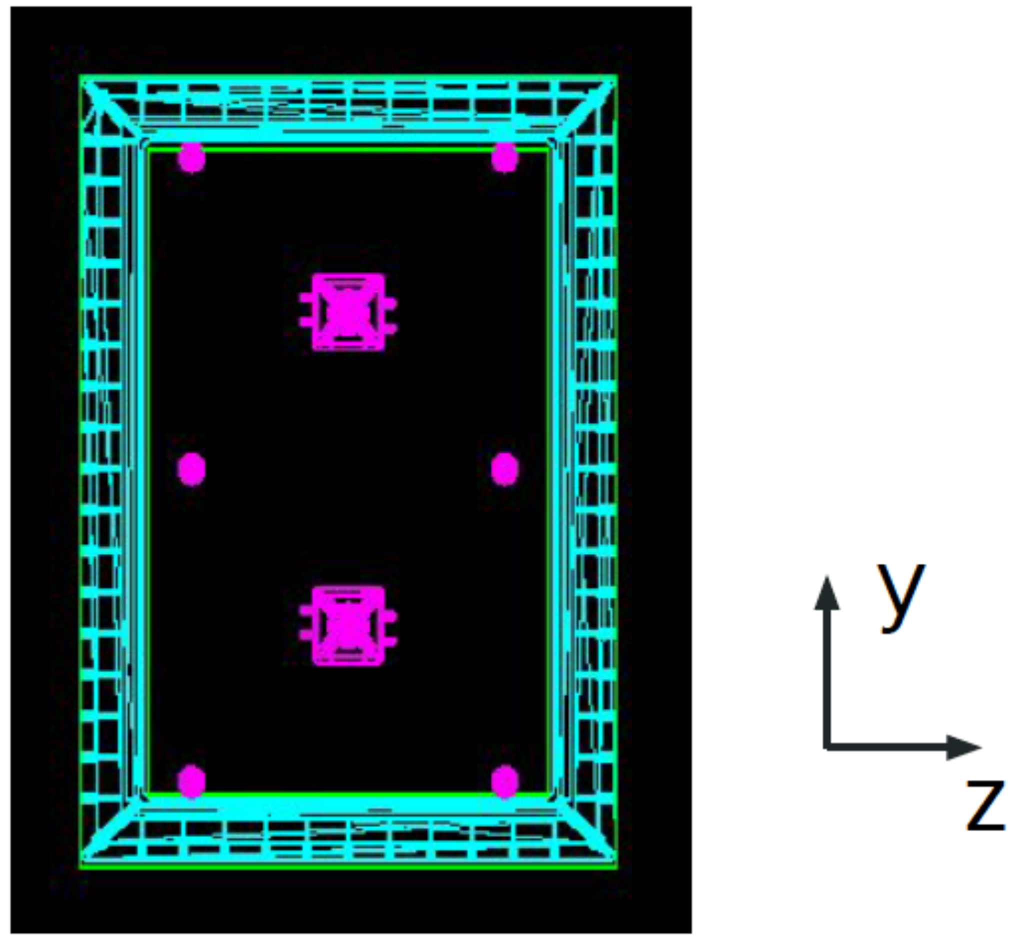
Geometry implemented in Geant4

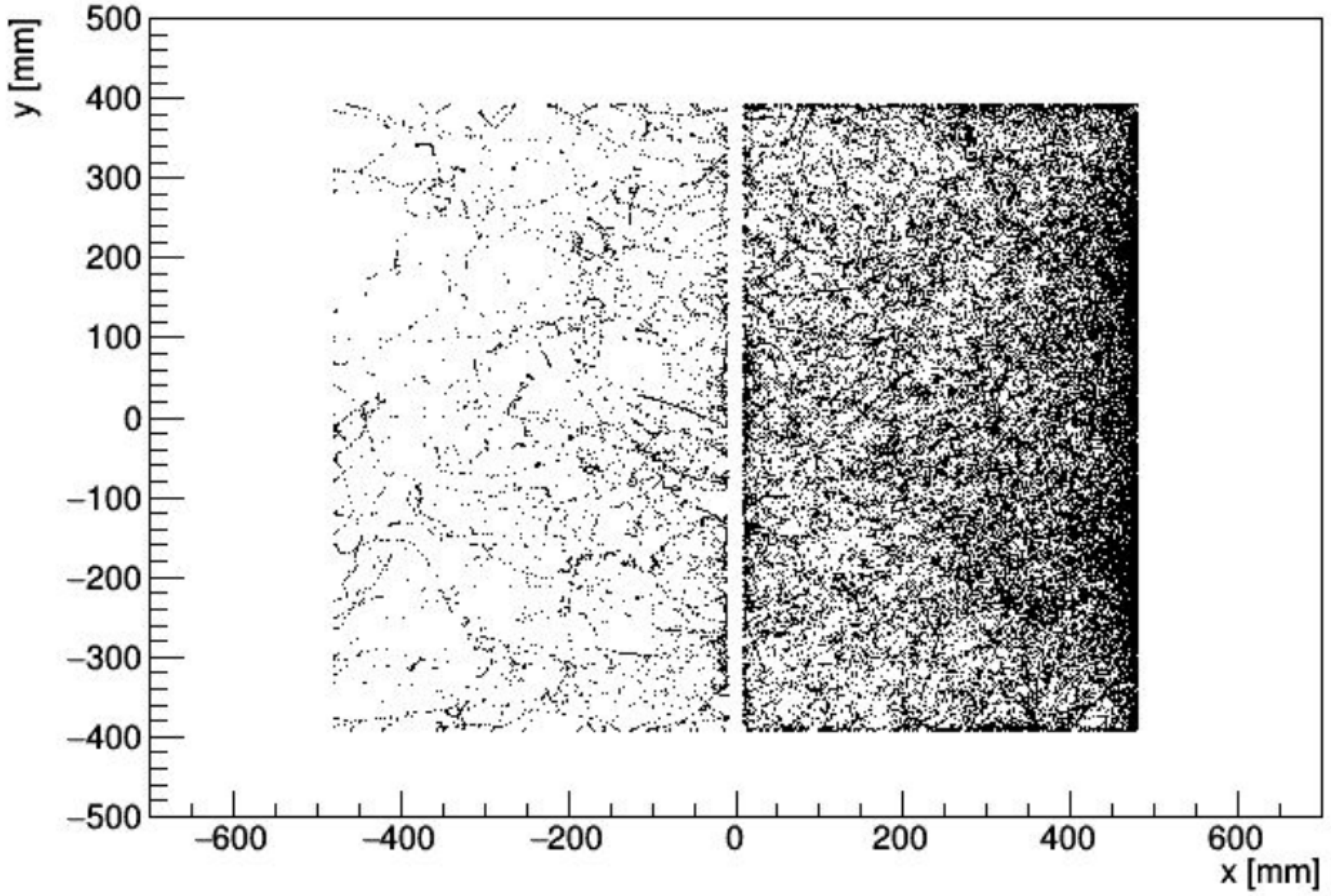


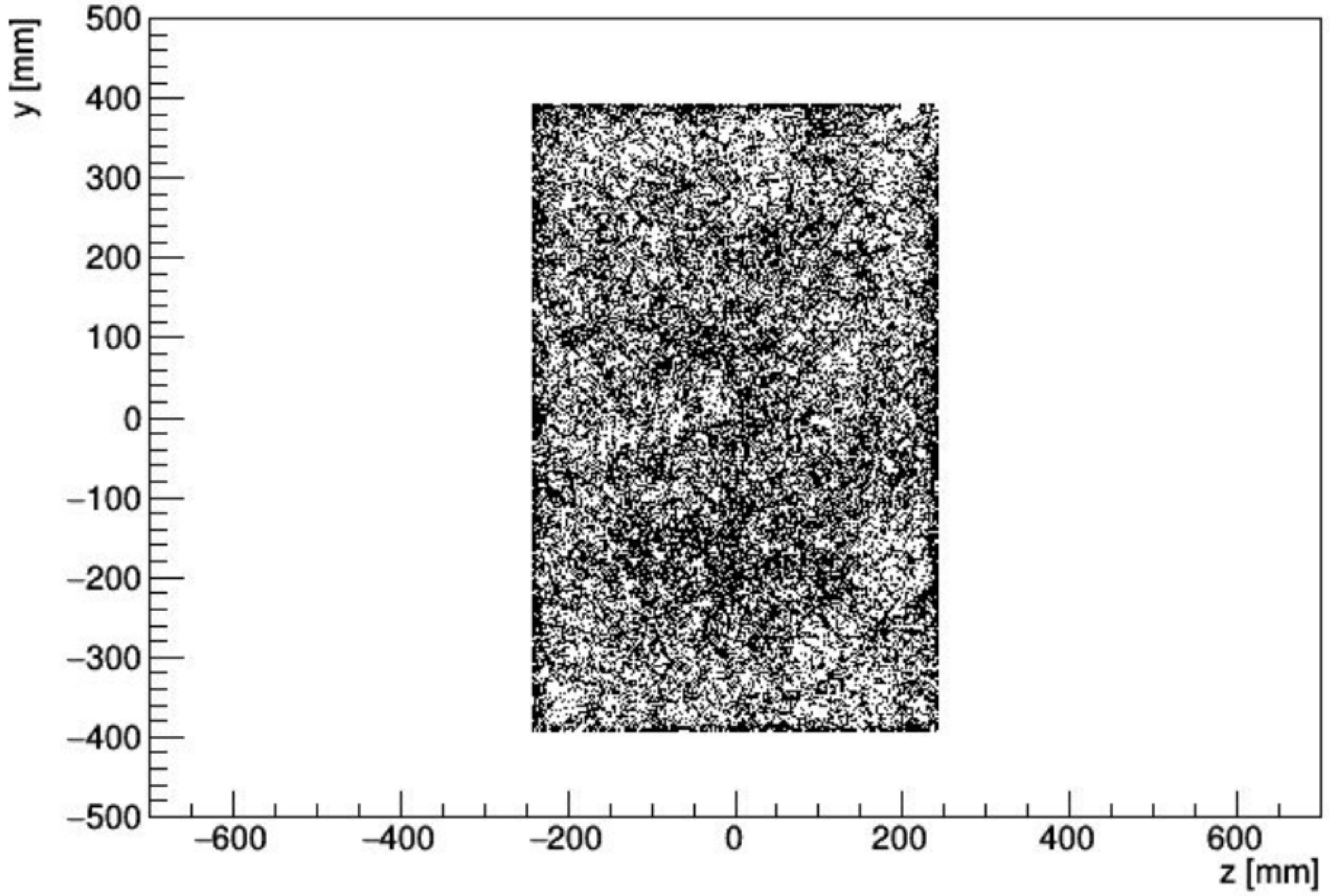
Github repository: https://github.com/CYGNUS-RD/CYGNO-MC/tree/cygno_04

Simulation of radioactivity from camera lenses (right)







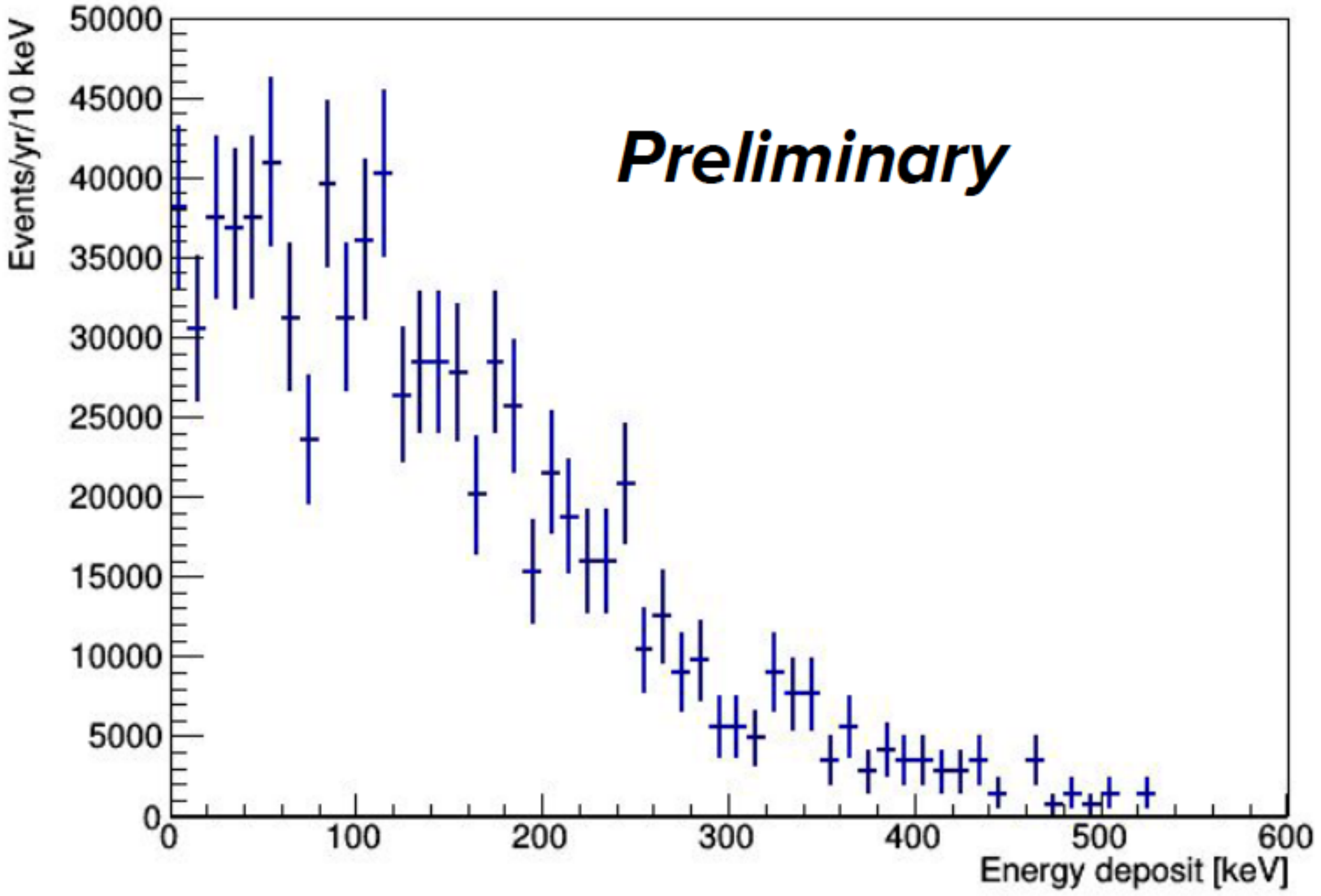


Expected rate from camera lenses

about 10% below 20 keV

- ^{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
```

GEANT4 simulation foresees **1.38 10^5** events/year from the lens below 20 keV

Expected rates from rescaling 1 m^3

GEM (Laubenst	Limit/Meas	evt/yr 1-20 keV	NR/yr 1-20 keV	ER/yr 1-20 keV	Ref	Comments
238U	M	4.07E+04	6.53E+02	4.01E+04	Laubenstein @LNGS	
232Th	L	8.99E+03	1.34E+02	8.85E+03	Laubenstein @LNGS	
235U	L	1.05E+04	1.33E+02	1.04E+04	Laubenstein @LNGS	
40K	L	3.23E+04	0.00E+00	3.23E+04	Laubenstein @LNGS	
60Co	L	2.59E+02	0.00E+00	2.59E+02	Laubenstein @LNGS	
GEM tot		**9.32E+04**	**9.20E+02**	**9.23E+04**		
GEM (only meas.)		**4.07E+04**	**6.53E+02**	**4.01E+04**		
Acrylic Box (Laubenstein)		**evt/yr 1-20 keV**	**NR/yr 1-20 keV**	**ER/yr 1-20 keV**		NR not simulated
238U	L	3.21E+04	0.00E+00	3.21E+04	Laubenstein @LNGS	
232Th	L	5.47E+04	1.77E+03	5.30E+04	Laubenstein @LNGS	
40K	L	2.04E+04	0.00E+00	2.04E+04	Laubenstein @LNGS	
Acrylic Box tot		**1.07E+05**	1.77E+03	**1.05E+05**		
Acrylic Box (only meas)		**0.00E+00**	0.00E+00	**0.00E+00**		
Camera Body (no shield)		**evt/yr 1-20 keV**	**NR/yr 1-20 keV**	**ER/yr 1-20 keV**		Hamamatsu, orca-flash4.0, only gamma emitters
238U	M	1.15E+05		1.15E+05	Laubenstein @L	only gamma emitters
232Th	M	1.93E+05		1.93E+05	Laubenstein @L	only gamma emitters
235U	M	0.00E+00		0.00E+00	Laubenstein @L	not simulated
40K	M	6.22E+03		6.22E+03	Laubenstein @LNGS	
60Co	L	6.05E+02		6.05E+02	Laubenstein @LNGS	
137Cs	M	2.14E+03		2.14E+03	Laubenstein @LNGS	
Camera Body tot (no shield)		**3.16E+05**		**3.16E+05**		
Camera Body only meas. (no sh		**3.16E+05**		**3.16E+05**		

Expected rates from rescaling 1 m^3

Camera Lens (glass)		evt/yr 1-20 keV	NR/yr 1-20 keV	ER/yr 1-20 keV		Hamamatsu, orca-flash4.0, s
238U	M	1.93E+04	0.00E+00	1.93E+04	Laubenstein @LNGS	
232Th	M	4.61E+04	0.00E+00	4.61E+04	Laubenstein @LNGS	
235U	M	1.46E+03	0.00E+00	1.46E+03	Laubenstein @LNGS	
40K	M	2.80E+04	0.00E+00	2.80E+04	Laubenstein @LNGS	
60Co	L	4.15E+02	0.00E+00	4.15E+02	Laubenstein @LNGS	
138La	M	1.06E+04	0.00E+00	1.06E+04	Laubenstein @LNGS	
137Cs	L	9.99E+01	0.00E+00	9.99E+01	Laubenstein @LNGS	
Camera Lens tot (shield)		**1.06E+05**	**0.00E+00**	**1.06E+05**		
Camera Lens only meas. (shield		**1.05E+05**	**0.00E+00**	**1.05E+05**		
GEM (T-REX)	**Limit/Meas**	**evt/yr 1-20 keV**	**NR/yr 1-20 keV**	**ER/yr 1-20 keV**		**Comments**
238U	L	1.77E+04	2.84E+02	1.74E+04	TREX: https://link.springer.com/content/pdf/10	
232Th	M	3.36E+03	5.02E+01	3.31E+03	TREX: https://link.springer.com/content/pdf/10	
235U	M	2.00E+04	2.52E+02	1.97E+04	TREX: https://link.springer.com/content/pdf/10	
40K	M	6.09E+03	0.00E+00	6.09E+03	TREX: https://link.springer.com/content/pdf/10	
60Co	L	8.64E+01	0.00E+00	8.64E+01	TREX: https://link.springer.com/content/pdf/10	
137Cs	L	1.91E+04	1.88E+02	1.89E+04	TREX: https://link.springer.com/content/pdf/10	
GEM tot		**6.63E+04**	**7.75E+02**	**6.55E+04**		
GEM (only meas.)		**2.94E+04**	**3.03E+02**	**2.91E+04**		
Acrylic Box (SNO)		**evt/yr 1-20 keV**	**NR/yr 1-20 keV**	**ER/yr 1-20 keV**		NR not simulated, activities f
238U	L	2.71E+03	0.00E+00	2.71E+03	SNO: https://www.radiopurity.org/rp/rp/_design	
232Th	L	6.92E+02	2.24E+01	6.70E+02	SNO: https://www.radiopurity.org/rp/rp/_design	
40K	L	4.16E+01	0.00E+00	4.16E+01	SNO: https://www.radiopurity.org/rp/rp/_design	
Acrylic Box tot		**3.45E+03**	**2.24E+01**	**3.42E+03**		
Acrylic Box (only meas)		**0.00E+00**	**0.00E+00**	**0.00E+00**		

20% lower than GEANT4

Expected rates from rescaling 1 m^3

Camera Lens (fused silica)		evt/yr 1-20 keV	NR/yr 1-20 keV	ER/yr 1-20 keV		Hamamatsu, orca-flash4.0, Haereus Suprasil https://www.rad
238U	M	1.24E+00	0.00E+00	1.24E+00	Haereus Supras	only gamma emitters
232Th	M	5.20E+00	0.00E+00	5.20E+00	Haereus Supras	only gamma emitters
235U	M	0.00E+00	0.00E+00	0.00E+00	Haereus Supras	not simulated
40K	M	1.68E-01	0.00E+00	1.68E-01	Haereus Suprasil: https://www.radiopurity.org/rp/rp/_design/persephone/index	
60Co	L	0.00E+00	0.00E+00	0.00E+00	Haereus Supras	not simulated
138La	M	0.00E+00	0.00E+00	0.00E+00	Haereus Suprasil: https://www.radiopurity.org/rp/rp/_design/persephone/index	
137Cs	L	0.00E+00	0.00E+00	0.00E+00	Haereus Suprasil: https://www.radiopurity.org/rp/rp/_design/persephone/index	
Camera Lens tot (shield)		**6.60E+00**	**0.00E+00**	**6.60E+00**		
Camera Lens only meas. (shielc		**6.60E+00**	**0.00E+00**	**6.60E+00**		
Cathode (Loomba)		**evt/yr 1-20 keV**	**NR/yr 1-20 keV**	**ER/yr 1-20 keV**		
238U	M	4.51E-02	5.01E-04	4.46E-02	Loomba https://arxiv.org/pdf/1502.03535.pdf	
232Th	L	0.00E+00	0.00E+00	0.00E+00	Loomba https://arxiv.org/pdf/1502.03535.pdf	
40K	L	0.00E+00	0.00E+00	0.00E+00	Loomba https://arxiv.org/pdf/1502.03535.pdf	
60Co	L	0.00E+00	0.00E+00	0.00E+00	Loomba https://arxiv.org/pdf/1502.03535.pdf	
137Cs	L	0.00E+00	0.00E+00	0.00E+00	Loomba https://arxiv.org/pdf/1502.03535.pdf	
Cathode tot		**4.51E-02**	**5.01E-04**	**4.46E-02**		
Cathode only meas.		**4.51E-02**	**5.01E-04**	**4.46E-02**		

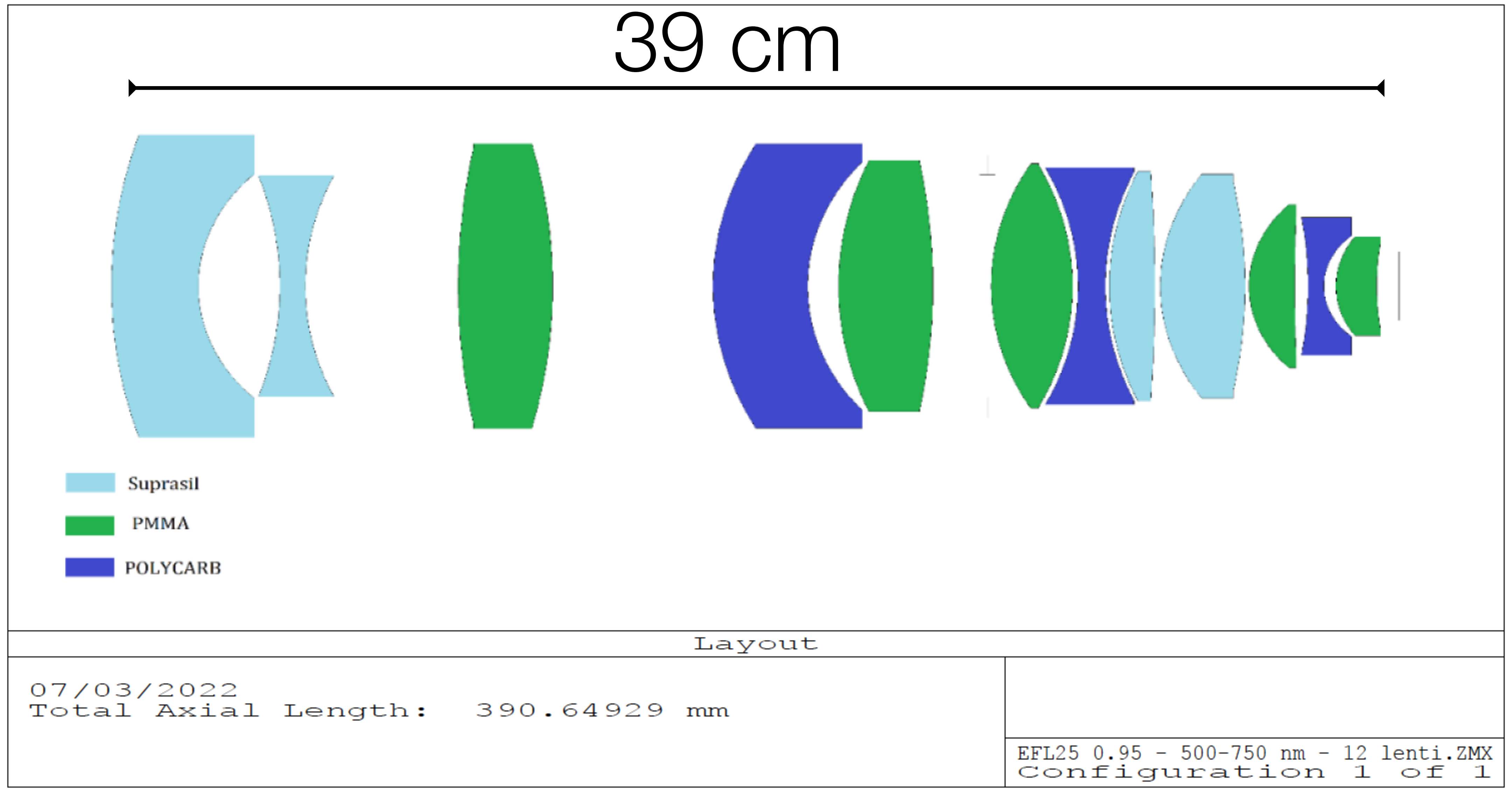
Expected rates from rescaling 1 m^3

	CYGNO-04		
Summary Table	**NR/yr 1-20 keV**	**ER/yr 1-20 keV**	**Reference**
GEM (LNGS)	9.20E+02	9.23E+04	Laubenstein@LNGS
GEM (TREX)	7.75E+02	6.55E+04	T-REX GEM
AcrylicBox (LNGS)	1.77E+03	1.05E+05	Laubenstein@LNGS
AcrylicBox (SNO)	2.24E+01	3.42E+03	SNO acrylic
CameraBody (no shield)		6.32E+05	Laubenstein@LNGS
CameraBody (with Cu shield)		8.81E+04	Laubenstein@LNGS
CameraLens (LNGS)	0.00E+00	1.06E+05	Laubenstein@LNGS
CameraLens fused silica		6.60E+00	Haereus "Suprasil"
Cathode (Cu)	1.69E-01	7.18E+01	T-REX copper
Cathode (Loomba)	5.46E-04	4.86E-02	Loomba
Field Cage (Cu)	2.99E-01	3.96E+02	T-REX copper
Field Cage (Kentaro)	1.02E+01	3.32E+03	Kentaro
External Gamma	0.00E+00	6.85E+03	SABRE gamma flux @LNGS
External Neutrons	7.50E+00	3.41E+00	CUORE n flux @LNGS
Total (LNGS)	**2.70E+03**	**3.99E+05**	
Total (low rad)	**8.05E+02**	**1.64E+05**	

- GEM (even the clean ones), cameras and lens are the main sources of internal radioactivity;
- PMMA we should use a clean one;
- Need to add: PMT, field cage, resistors, capacitors, screws…

The optics situation: the lens

- The commercial lens currently used in LIME is expected to be very “radioactive”;
- We are investigating with the Lobre company the possibility of realising a custom lens based on Suprasil, a very “clean” crystal;
- A positive feasibility study was financed last year with this final proposal



- Use of 3 different low radioactive materials should will provide the requested optical performance

	Requisito	Prestazione teorica
WD	600 mm	600 mm
Apertura	0.95	0.947
Materiali	Suprasil, PMMA, Policarbonato.	Suprasil, PMMA, Policarbonato
EFL	25 mm	24.93 mm
Risoluzione	Non specificato	~50 lp/mm adeguato a sensore
Requisito rispettato	Requisito modificato	Requisito non rispettato

The optics situation: the lens

- We just sent an order for:
  - detailed numerical analysis of the mechanical tolerances required for the realization of a lens with the following specifications:
  - samples of the materials (PC, PMMA, and Fused Silica) for a radioactivity check, which will be carried out directly by INFN;
  - fabrication of two lenses (one in PC and one in PMMA) in their final definition, to verify the feasibility of the manufacturing methodology of some plastic lenses.
- If all results are satisfying in 2024 we will realise the first complete prototype that is expected to have very low radioactivity contents

The optics situation: the camera

- In past with the help of Matthias we measured the radioactivity of all parts of a BSI camera.

piece #	description	piece	Ra228 from Th232 [Bq]	Th228 from Th232 [Bq]	Ra226 from U238 [Bq]	Th234 from U238 [Bq]	Pa234m from U238 [Bq]	K40 [Bq]	U235 [Bq]	Cs 137 [Bq]
1	CMOS sensor	1	0.0052	0.0053	0.0068	0.011	0.007	3.5	0.00091	0.00042
2	sensor frame	1	0.113	0.111	0.08	0.29	0.14	0.08	0.006	0.00086
3	sensor frame holder	1	0.007	0.016	0.0046	0.5	0.26	0.08	0.015	0.001
4	peltier cooler	1	0.00036	0.00024	0.00017	0.012	0.021	0.0026	0.0002	0.000054
5	electronic board	1	0.208	0.202	0.187	0.16	0.25	0.24	0.009	0.002
6	electronic board	1	0.248	0.229	0.335	0.12	0.2	0.19	0.0075	0.0025
7	electronic board	1	0.0679	0.0639	0.0552	0.053	0.1	0.053	0.0017	0.00047
8	electronic board	1	0.104	0.1	0.072	0.12	0.266	0.07	0.002	0.0011
9	cooling fan	1	0.07	0.0687	0.0558	0.1	0.2	1.4	0.0013	0.0011
10	metal supports	1	0.0012	0.0007	0.00031	0.024	0.036	0.0052	0.00074	0.0004
11	plastic support	1	0.0048	0.002	0.0024	0.08	0.16	0.1	0.004	0.00085
12	metal support	1	0.01	0.0067	0.003	0.8	1.1	0.015	0.039	0.0015
13	plastic objective support	1	0.006	0.0073	0.003	1.6	1.2	0.02	0.052	0.00093
14	camera case	1	0.0028	0.013	0.001	0.24	0.2	0.01	0.008	0.00031
15	camera objective case	1	0.0025	0.028	0.001	0.36	0.33	0.012	0.013	0.00029
16	sensor plastic frame	1	0.0004	0.00025	0.00011	0.0011	0.0081	0.0025	0.0004	0.00008
17	glass window	1	0.00033	0.00022	0.0002	0.0023	0.0016	0.006	0.0002	0.00024
18	plastic o-ring	1	0.001	0.001	0.00043	0.027	0.06	0.0032	0.001	0.00013
19	plastic o-rings	1	0.0011	0.00041	0.00049	0.0059	0.02	0.0043	0.00027	0.00009
20	Total		0.85359	0.85572	0.80851	4.5063	4.5597	5.7938	0.16222	0.014324
21										

The main part radioactivity seems to come from parts that could be, in principle, replaced with clean ones (supports, fans);

the sensor itself is responsible for 4 Bq of Potassium;

the sensor, without cover glass is responsible for 10 mBq

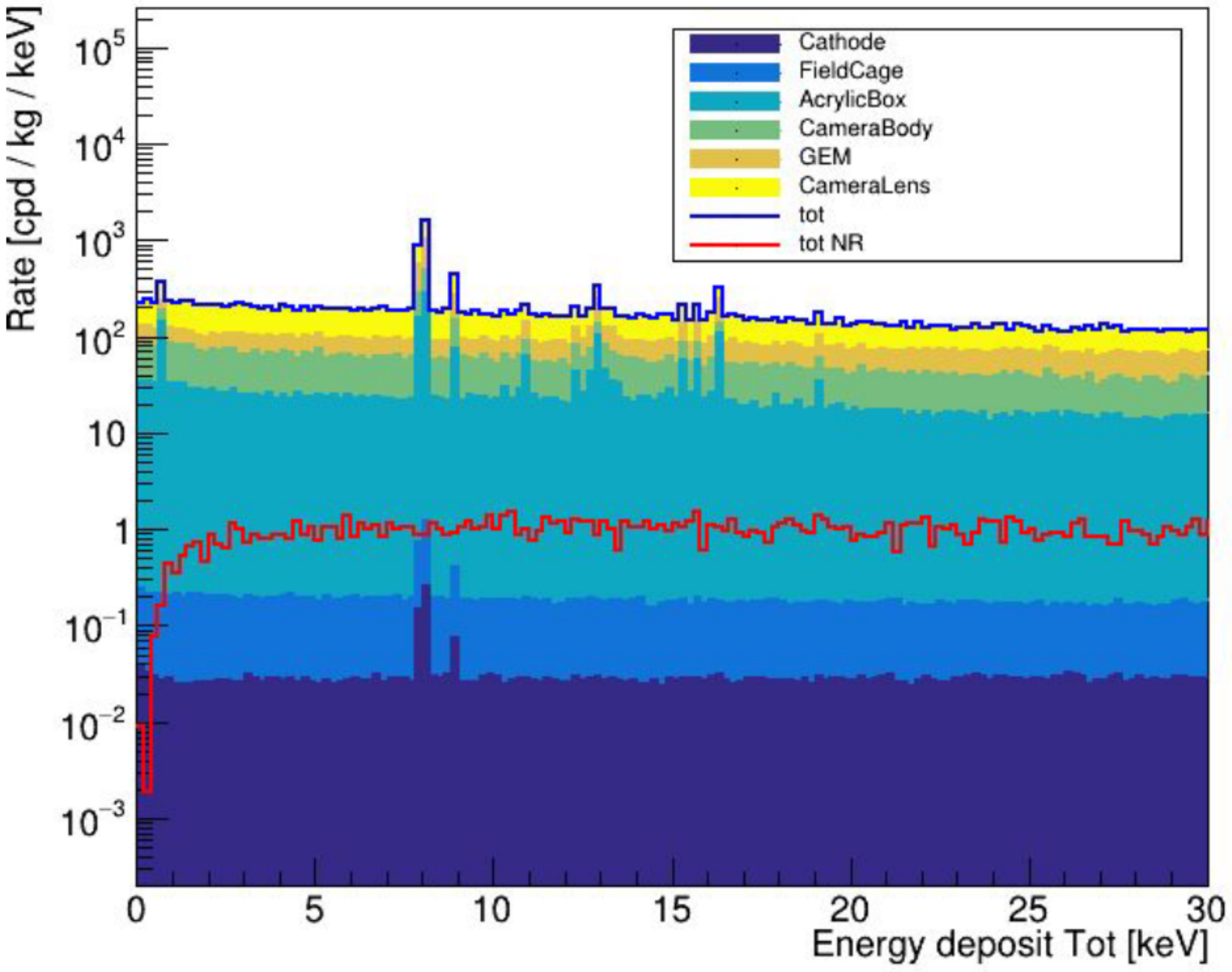
The optics situation: the lens

- In past we compared the performance and the radioactivity of different cameras

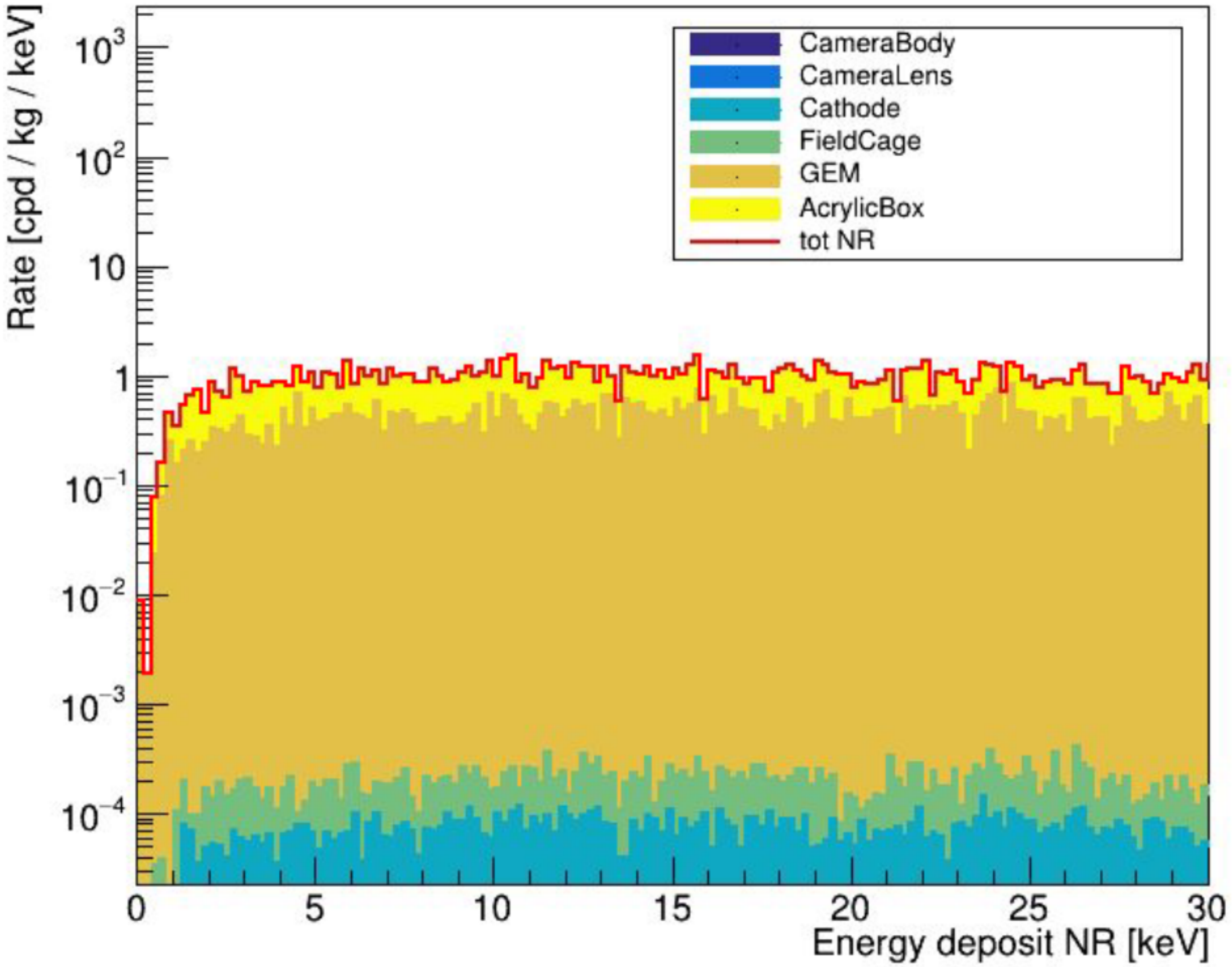
Camera	^{228}Ra	^{226}Th	^{226}Ra	^{234}Pa	^{40}K	Tot
Hamamatsu Orca Flash	2.1	2.1	1.9	7.0	1.9	15
Sensor Orca Flash	1.0	1.0	1.1	1.1	4.3	8.5
BSI	1.3	1.8	1.0	6.0	3.7	13.8
Hamamatsu Orca Quest	2.4	4.0	1.8	6.6	4.5	19.3

- Although a fused silica cover tile, the Orca Quest has a quite high ^{40}K contribution;
- Next step, is to provide a suprasil cover to BSI company;

Expected rates from rescaling 1 m^3



- to be rescaled

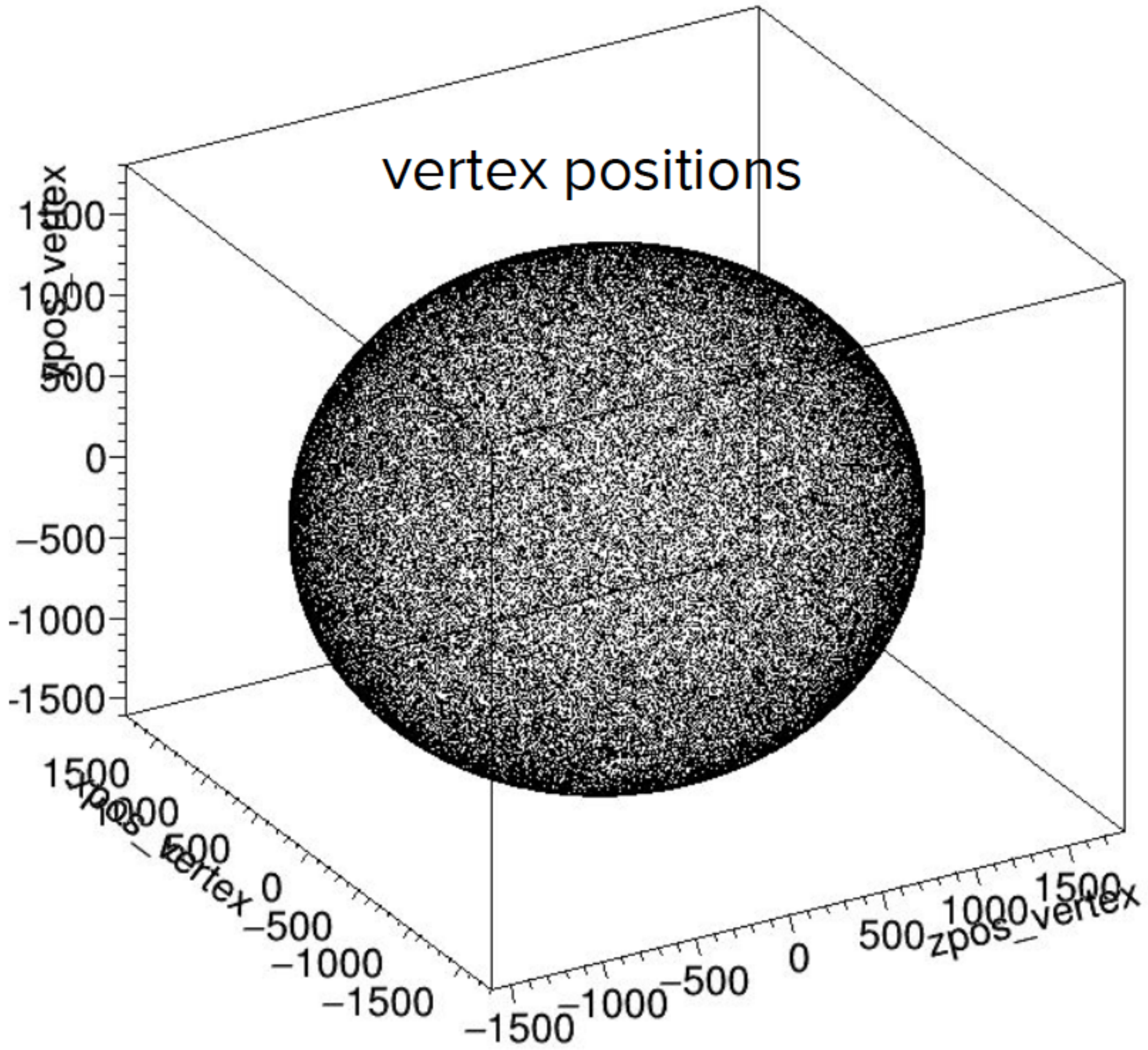


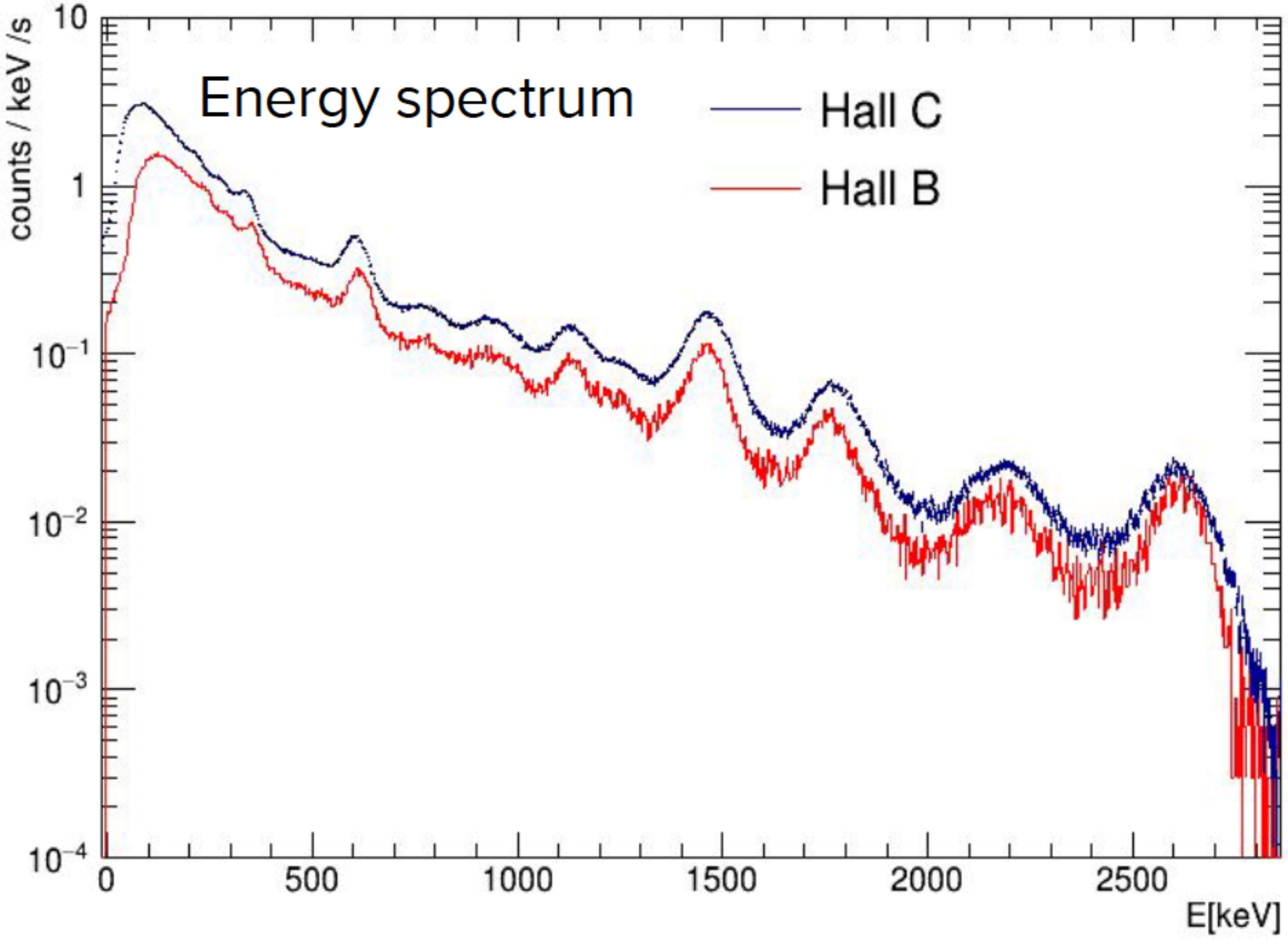
- to be rescaled

- GEM (even the clean ones), cameras and lens are the main contributors to internal radioactivity;
- Need to add: PMT, field cage, resistors, capacitors, screws.

External gamma simulation

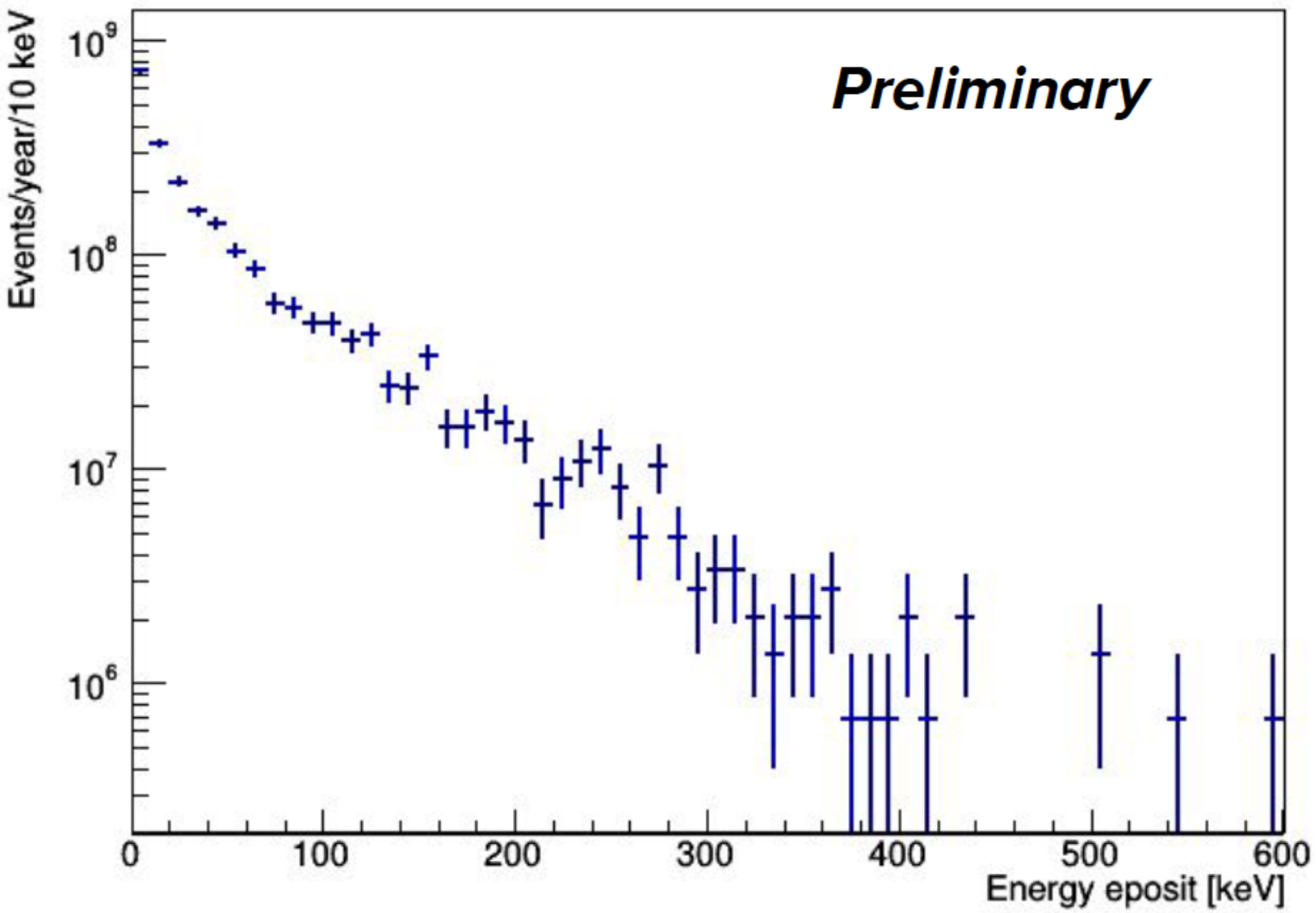
- Simulate gammas from a spherical surface containing the setup
- Energy distribution from gamma measurements at LNGS with NaI detector



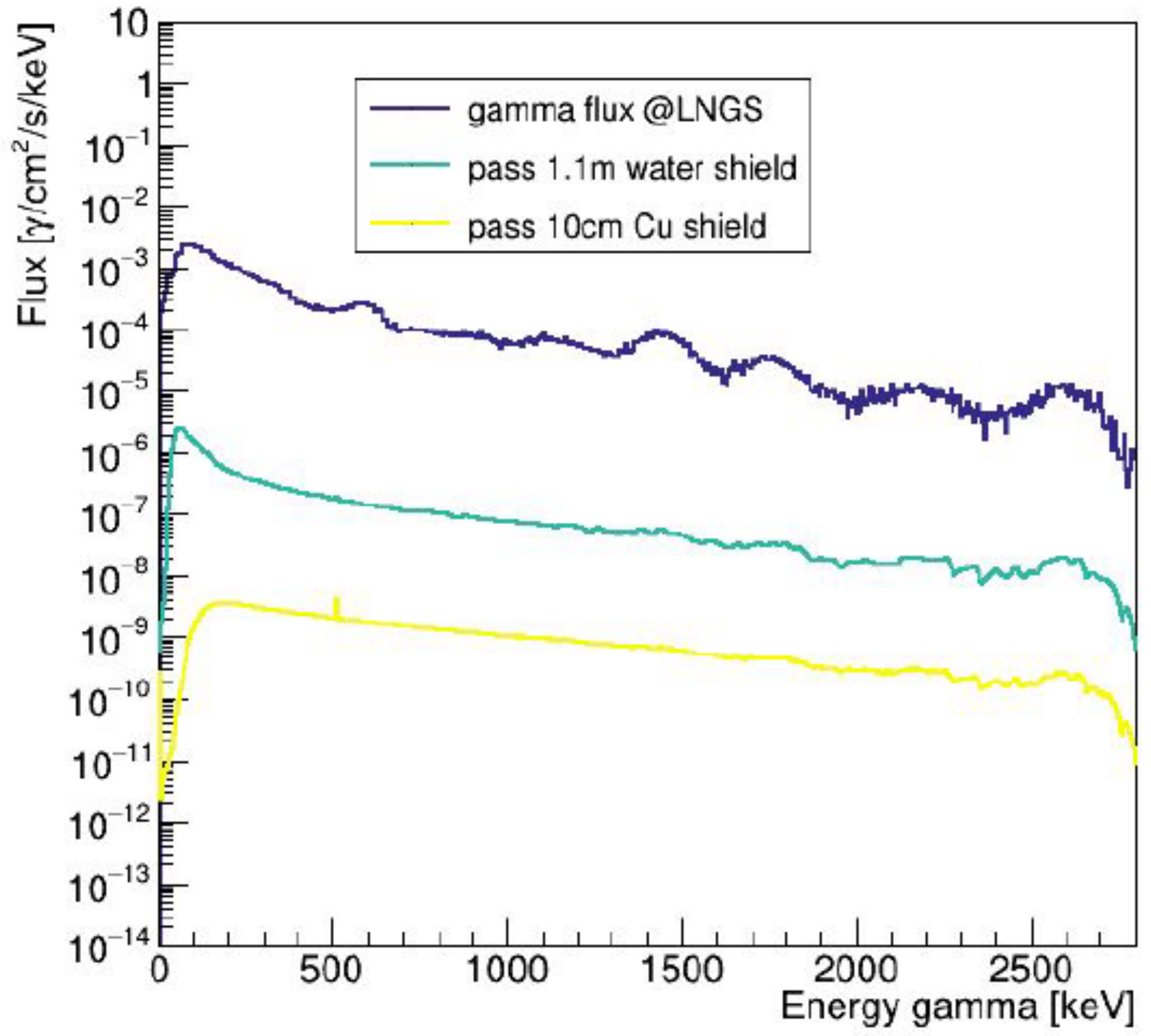


Rate from external gammas

- 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**

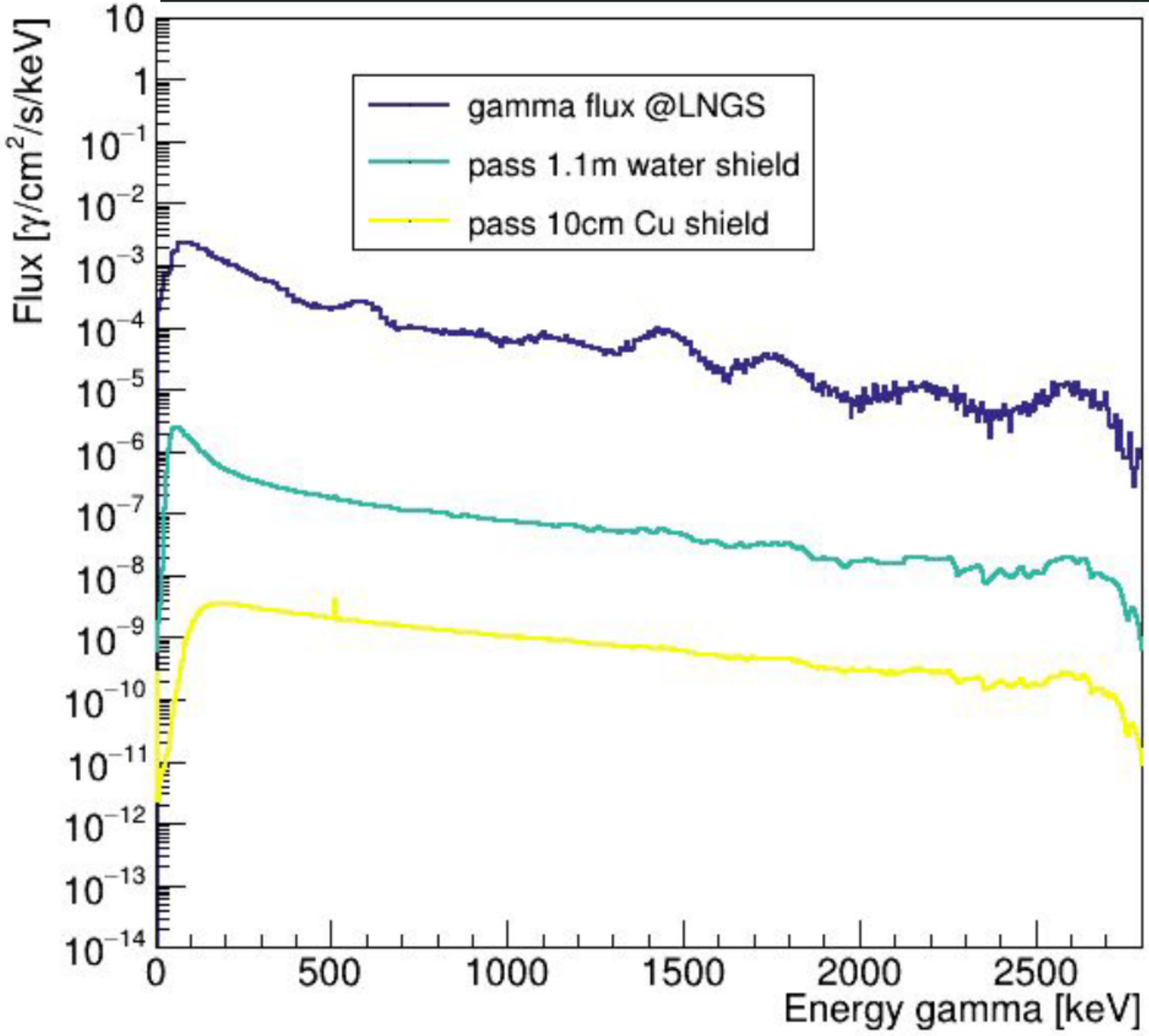


Average gamma flux attenuation of
1 m water + 10 cm Cu → ~5 x 10^{-6}

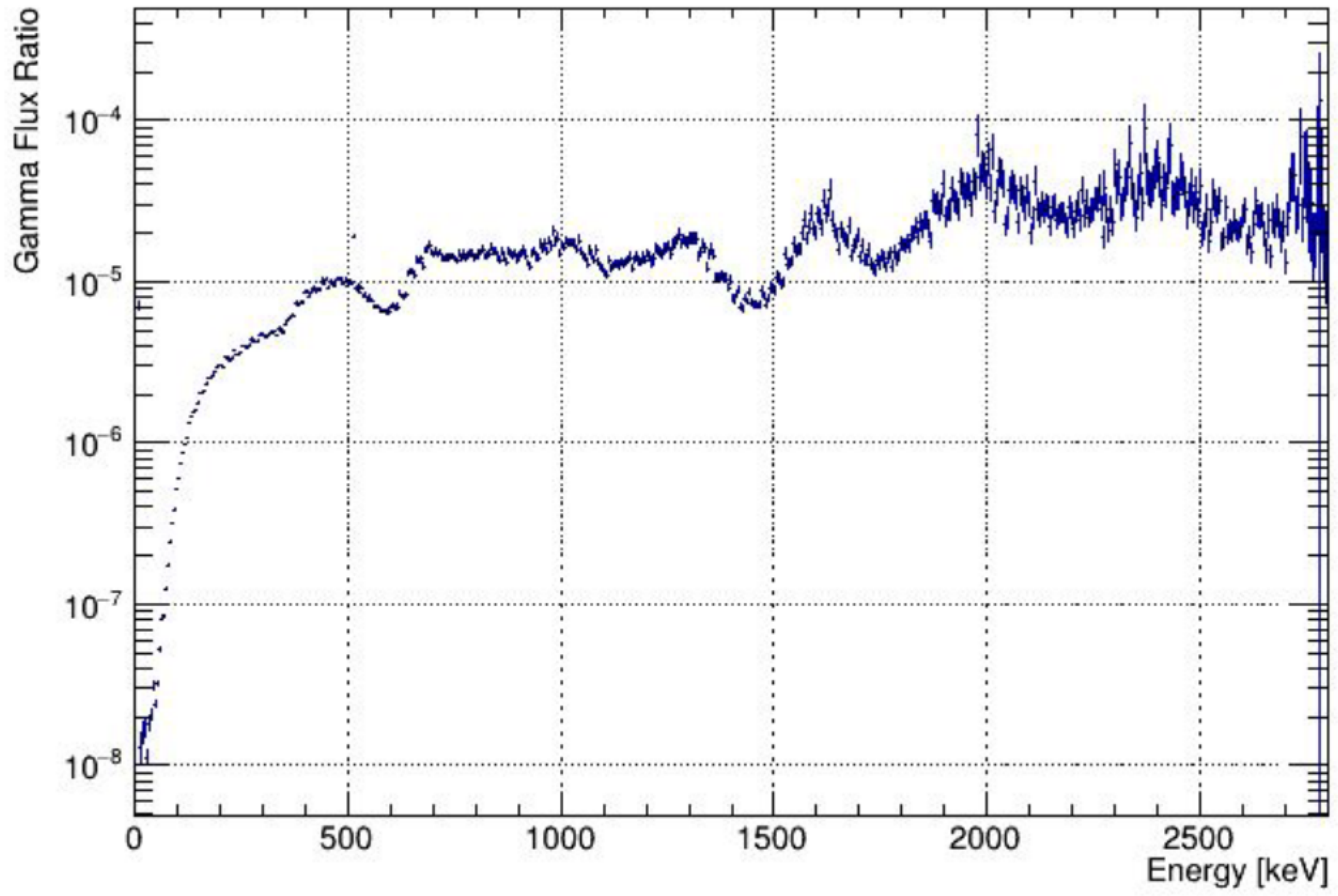


Gamma flux

gamma flux entering shield: 2.4x10^{-6} cm^{-2}s^{-1}



110 cm water shield
+ 10 cm copper shield



Conclusion

- GEANT simulation of CYGNO-04 to be concluded:
  - external bkg simulated;
  - internal bkg just started (lenses);
- Evaluation performed by properly rescaling gas and materials from the 1 m^3 simulation seems anyway a good reference to indicate main contributors;
- To reach a complete understanding all contributions should be taken into account with the inclusion of missing details of the detectors;
- Once the digitization is stable, we should use it too