CYGNO-30 Background Simulation

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Introduction

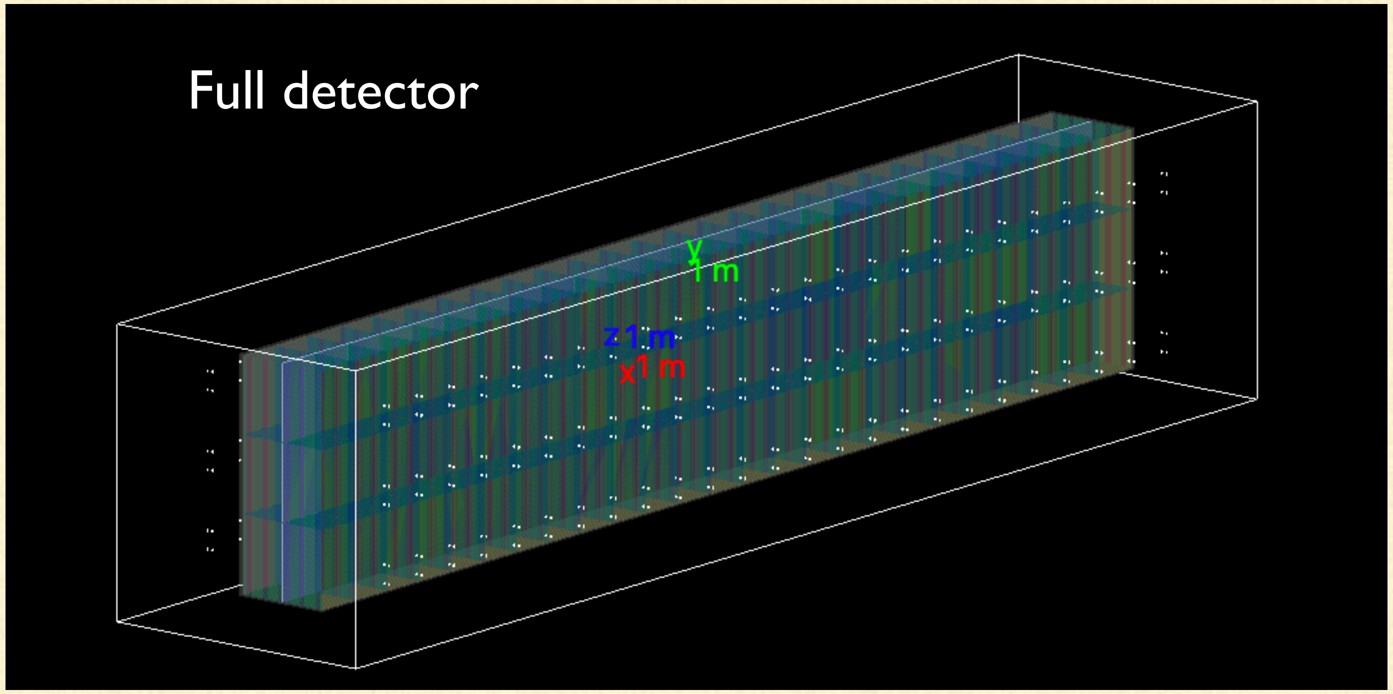
- Simulation done to study the gamma background in the CYGNO 30 detector
  - Background for dark matter searches (misidentification at low energy)
  - Background for the solar neutrino physics case

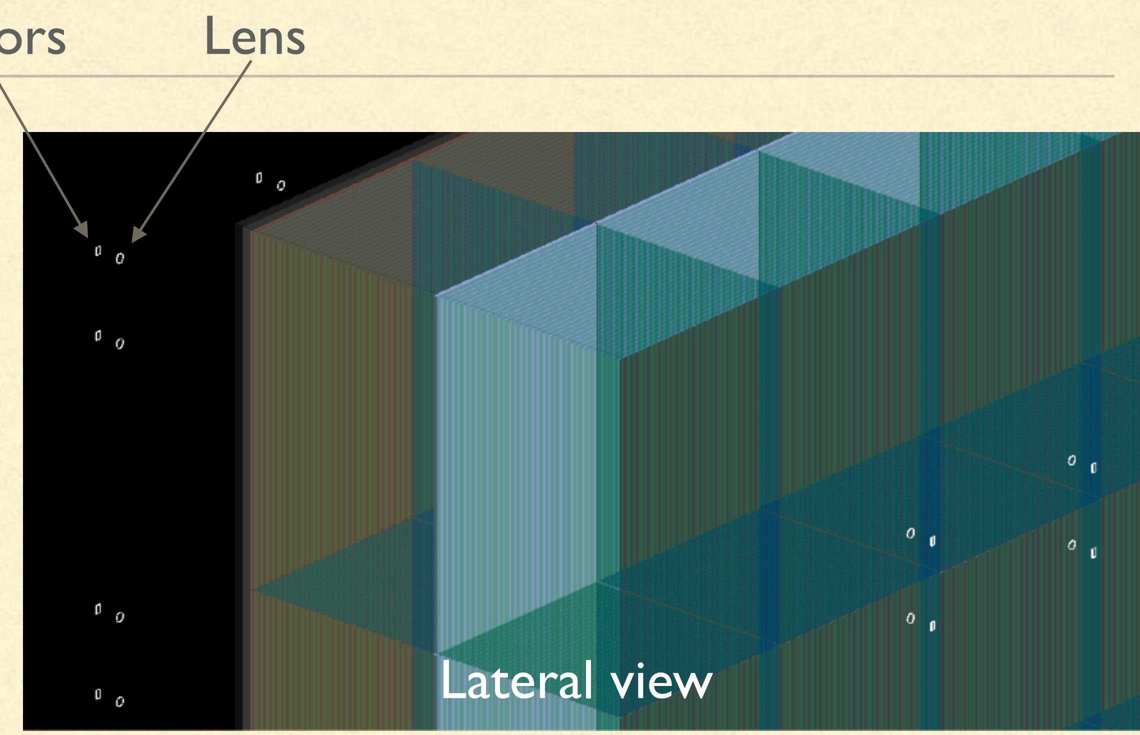
- CYGNO 30 (for current knowledge) will consist of 3x25 CYGNO 04 modules.

- All the modules are adjacent and enclosed in a common PMMA vessel

- CYGNO 30 will be realized in with ultrapure materials:
  - Every detector component → Most radiopure material used up to now employed

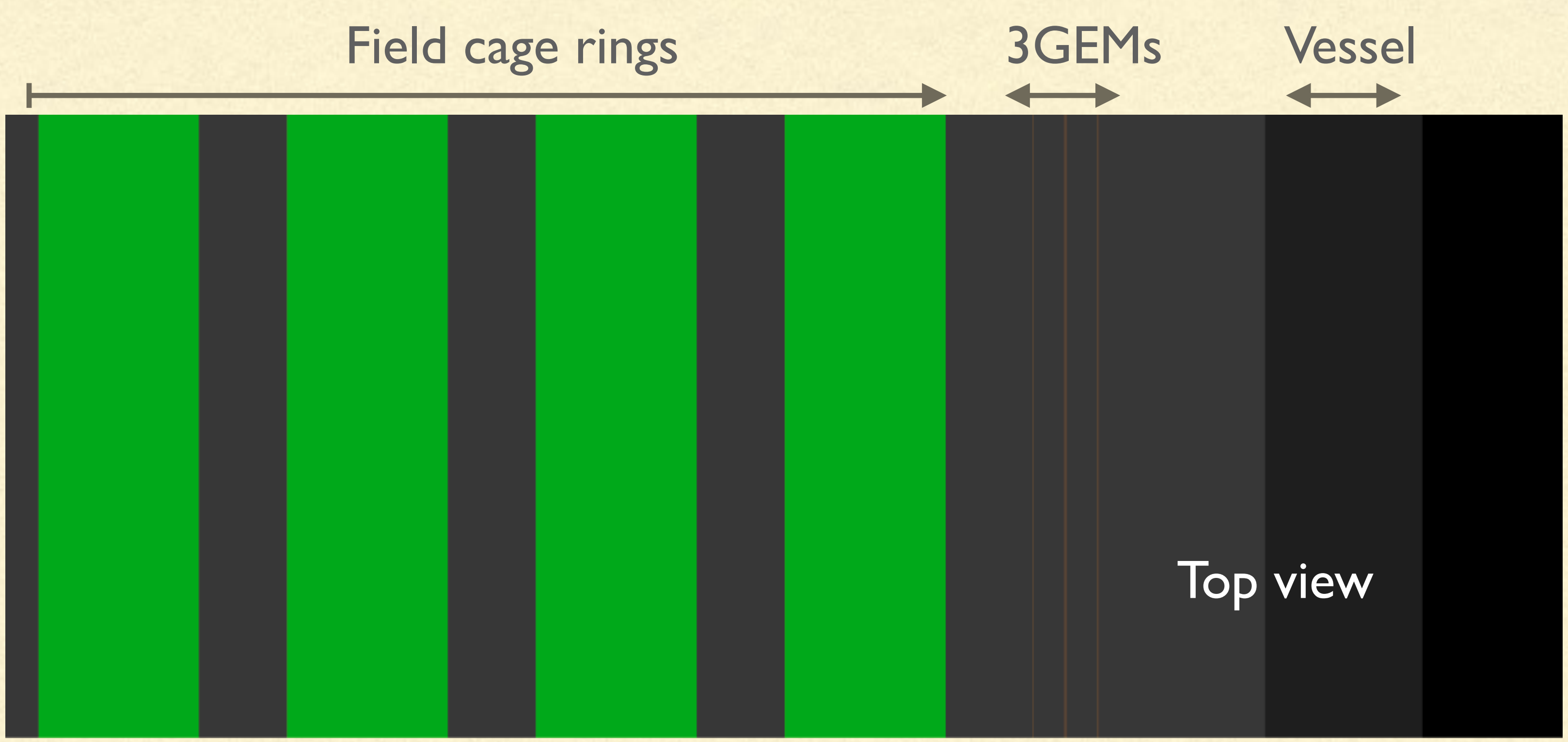
Detector geometry





Detector sizes

Cathodes	50 cm x 80 cm x 1 *cm*
Rings inner	50 cm x 80 cm x 1 cm + 2 mm thickness
Rings spacer	Such that 32 rings fit equidistantly in 50 cm lenght
GEMs	50cm x 80cm x 60 μm
GEMs spacing	2 mm thickness
Vessel	1 cm with respect to the detector + 1 cm thickness
Lens	1 cm Ø x 2 mm 57.7 cm from the GEMs
Sensors	10mm x 18mm x 1 mm 6 cm distance from Lens



Material radioactivity level

- Taken from the spreadsheet

GEM	Reference	Limit/Me	Activity (Bq/kg)	mass (kg)	Ngen	t_eq (year)
U238	TREX https://link.sp	L	1.32E-02	0.008025	1.00E+06	2.98E+02
Th232	TREX https://link.sp	M	5.45E-03	0.008025	1.00E+06	7.25E+02
U235	TREX https://link.sp	M	2.80E-02	0.008025	1.00E+06	1.41E+02
K40	TREX https://link.sp	M	6.31E-02	0.008025	1.00E+07	6.26E+02
Co60	TREX https://link.sp	L	2.34E-03	0.008025	1.00E+07	1.69E+04
Cs137	TREX https://link.sp	L	1.56E-03	0.008025	1.00E+07	2.54E+04

Camera Lens (fused	Reference	Limit/Me	Activity (Bq/kg)	mass (kg)	Ngen	t_eq (year)
U238	Haereus Suprasil: http	M	1.23E-04	3.843	3.00E+07	2.01E+03
Th232	Haereus Suprasil: http	M	4.07E-05	3.843	3.00E+07	6.09E+03
K40	Haereus Suprasil: http	M	3.10E-04	3.843	3.00E+07	8.00E+02

Acrylic	Reference	Limit/Me	Activity (Bq/kg)	mass (kg)	Ngen
U238	SNO: https://www.radi	L	2.96E-04	2.01E+02	1.00E+07
Th232	SNO: https://www.radi	L	5.69E-05	2.01E+02	1.00E+07
K40	SNO: https://www.radi	L	7.12E-05	2.01E+02	1.00E+07

Copper Field Cage	Reference	Limit/Me	Activity (Bq/kg)	mass (kg)	Ngen	t_eq (year)
238U	Cu from TREX: https://	L	1.20E-05	42.4915	5.00E+06	3.11E+02
232Th	Cu from TREX: https://	L	4.10E-06	42.4915	5.00E+06	9.10E+02
40K	Cu from TREX: https://	M	6.10E-05	42.4915	5.00E+06	6.12E+01
60Co	Cu from TREX: https://	L	2.40E-04	42.4915	5.00E+06	1.55E+01
137Cs	Cu from TREX: https://	L	2.90E-04	42.4915	5.00E+06	1.29E+01

DRIFT aluminum cathode

Loomba Cathode	Reference	Limit/Me	Activity (Bq/kg)	mass (kg)	Ngen	t_eq (year)
238U	https://arxiv.org/pdf/1	M	9.01E-01	0.00125	5.00E+05	1.41E+01
234U	https://arxiv.org/pdf/1	M	4.07E-05	0.00125	5.00E+05	3.11E+05

Cathode made by the same material of the field cage given the high U content

Sensors

This column for val

	C11440-52U, board only	PRIME-BSI EXPRESS, Teledyne	orca-flash4.0, model C11440-22CU	Thorlabs Quantalux	PRIME-BSI EXPRESS, Teledyne - CMOS from unassembled camera	PRIME-BSI EXPRESS, Teledyne - CMOS without glass
Th-232						
Ra-228	1.03	1.3	2.1	0.26	5.20E-03	2.00E-03
Th-228	1.06	1.8	2.1	0.63	5.30E-03	1.80E-03
U-238						
Ra-226	1.15	1	1.8	0.21	6.80E-03	2.83E-03
Pa-234m	1.1	6	7	3	0.007	<15 mBq
U235	0.06	0.27	0.4	0.12	0.00091	<0.29 mBq
K-40	4.3	3.6	1.9	1.2	3.50E+00	9.00E-03
Cs-137	7	<32 mBq	0.09	<2.3 mBq	0.00042	<0.24 mBq
Co-60	<1.2 mBq	<17 mBq	<0.012 mBq	<5.5 mBq		

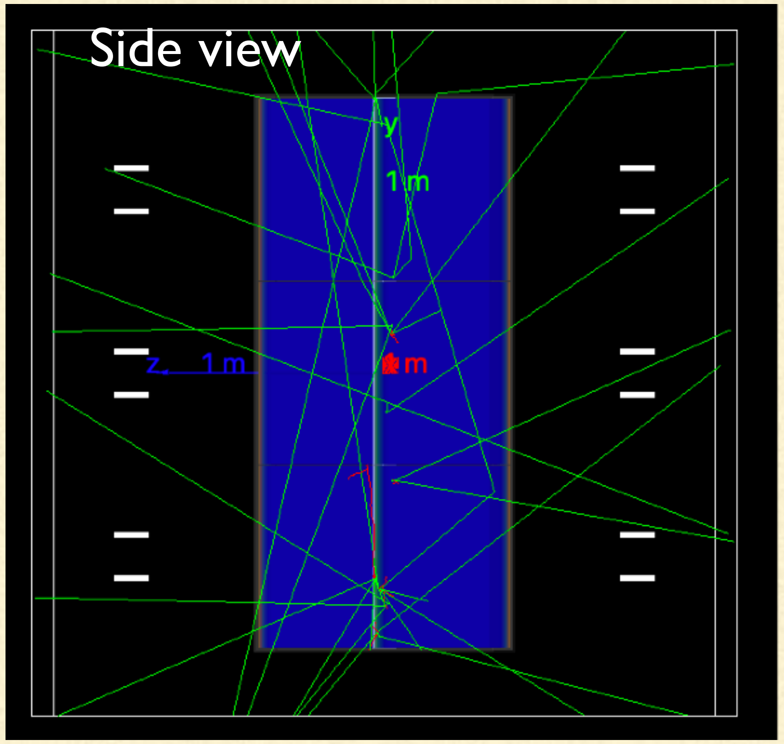
Radioactive decay simulation

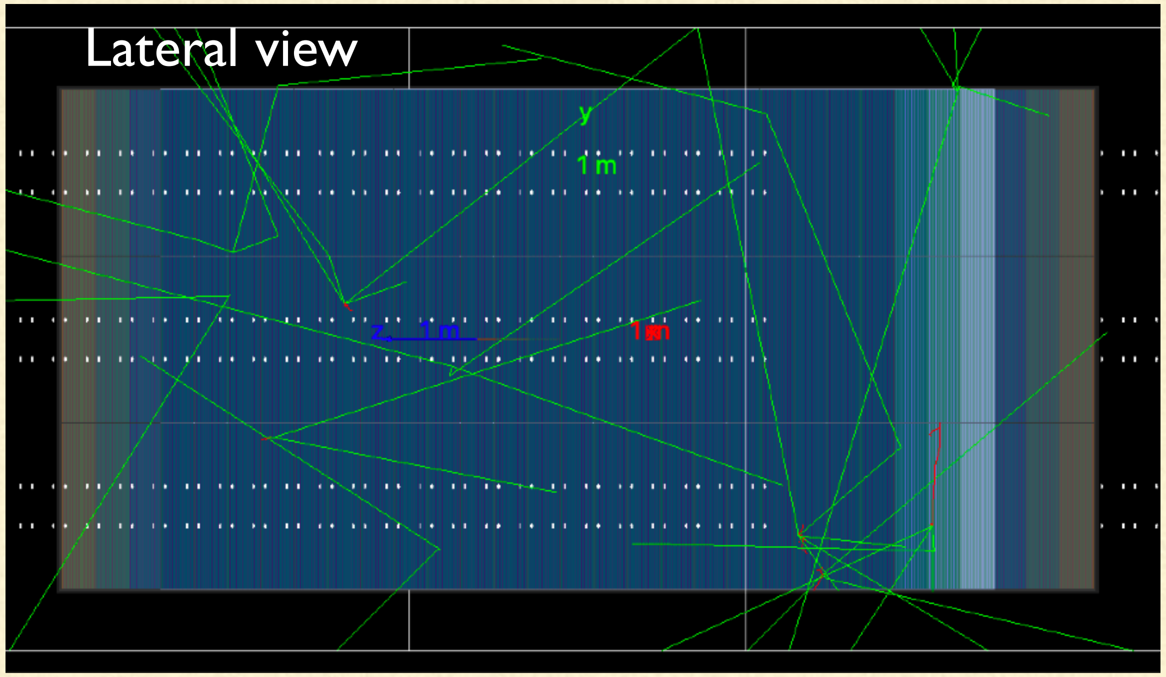
- Physics list used: FTFP_BERT_HP: for “radiation protection and shielding application”

- For every detector element (GEMs, Cathodes, Rings, ecc…):
  - For every contaminant (U238,U235,K40, ecc…):

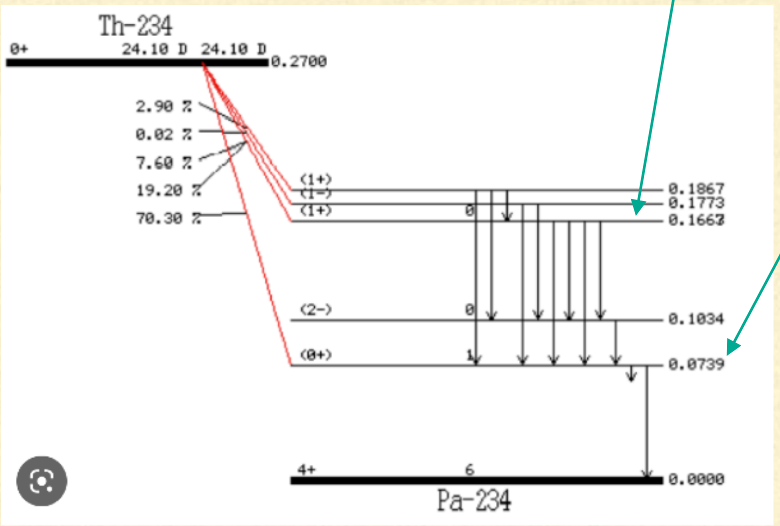
- N iteration of:
  1. Extraction of a random detector element (GEM_34, GEM_75)
  2. Extraction of a random point on the element volume
  3. Simulation of the whole decay chain of the element, taking into account also atomic excited states

Example of 10 U238 simulated on Cathodes






```
G4WT0 >     End of event. Decay chain: U238 ---> Th234 ---> Pa234[166.300X] ---> Pa234[73.920X] ---> U234 ---
> Th230[53.227] ---> Th230 ---> Ra226 ---> Rn222 ---> Po218 ---> Pb214 ---> Bi214[295.223] ---> Bi214[53.228] ---
> Bi214 ---> Po214[2192.537] ---> Po214[609.316] ---> Po214 ---> Pb210 ---> Bi210[46.539] ---> Bi210 ---> Po210 ---
> Pb206
```

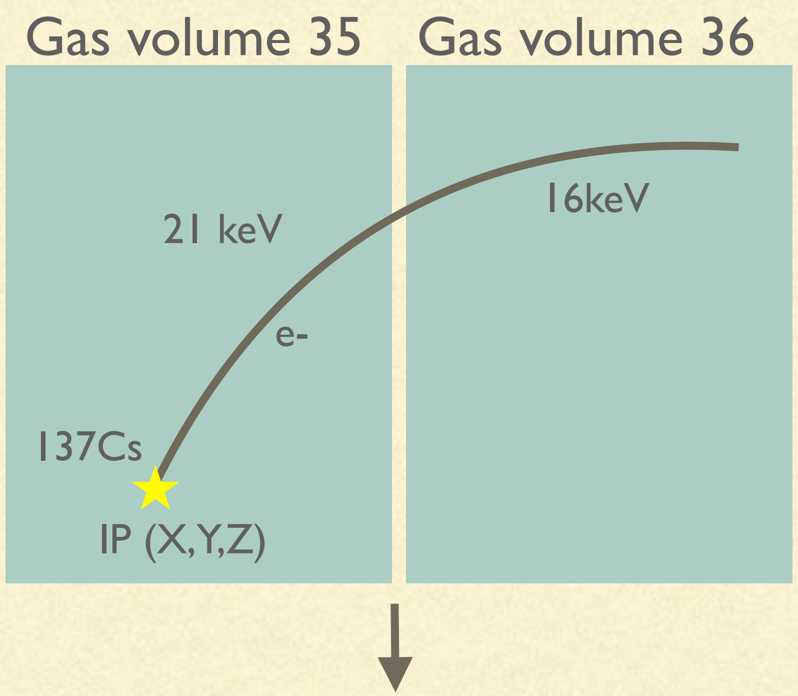


Summary of 10 U238 decays

```
          Bi210:      10  Emean =  84.95 meV   ( 81.11 meV --> 115.8 meV)    mean life = 7.231 d
   Bi210[46.539]:     10  Emean =  17.16 meV   ( 1.775 meV --> 36.23 meV)
          Bi214:      10  Emean =  214.2 meV   ( 97.88 meV --> 310.7 meV)    mean life = 28.71 min
  Bi214[295.223]:      6  Emean =  1.426 eV    ( 418.5 meV --> 2.137 eV )
  Bi214[351.932]:      4  Emean =  1.042 eV    ( 834.8 meV --> 1.235 eV )
   Bi214[53.228]:      4  Emean =  221.7 meV   ( 146.9 meV --> 445.9 meV)
          Pa234:       1  Emean =  130.2 meV   ( 130.2 meV --> 130.2 meV)    mean life = 9.666 h
 Pa234[166.300X]:      3  Emean =  93.88 meV   ( 63.62 meV --> 149.4 meV)
  Pa234[73.920X]:     10  Emean =    199 meV   ( 56.26 meV --> 445.3 meV)    mean life = 1.672 min
          Pb206:      10  Emean =  103.1 keV   ( 103.1 keV --> 103.1 keV)    stable
          Pb210:      10  Emean =  146.7 keV   ( 146.7 keV --> 146.7 keV)    mean life = 32.05 y
          Pb214:      10  Emean =  112.3 keV   ( 112.3 keV --> 112.3 keV)    mean life = 39.04 min
          Po210:      10  Emean =  3.484 eV    ( 1.935 eV  --> 4.935 eV )    mean life = 199.6 d
          Po214:      10  Emean =  4.375 eV    ( 931.4 meV --> 15.03 eV )    mean life = 237 us
 Po214[1377.678]:      1  Emean =  9.393 eV    ( 9.393 eV  --> 9.393 eV )
 Po214[1415.495]:      1  Emean =   1.24 eV    ( 1.24 eV  --> 1.24 eV )
 Po214[1729.609]:      3  Emean =  4.752 eV    ( 3.948 eV  --> 5.639 eV )
 Po214[1764.515]:      2  Emean =  3.551 eV    ( 1.188 eV  --> 5.913 eV )
 Po214[2118.533]:      1  Emean =  2.994 eV    ( 2.994 eV  --> 2.994 eV )
 Po214[2192.537]:      1  Emean =  2.916 eV    ( 2.916 eV  --> 2.916 eV )
 Po214[2293.358]:      1  Emean =  1.846 eV    ( 1.846 eV  --> 1.846 eV )
 Po214[2447.702]:      1  Emean =  837.8 meV   ( 837.8 meV --> 837.8 meV)
  Po214[609.316]:      6  Emean =  3.802 eV    ( 1.481 eV  --> 7.115 eV )
          Po218:      10  Emean =  100.9 keV   ( 100.9 keV --> 100.9 keV)    mean life = 4.469 min
          Ra226:      10  Emean =  49.83 keV   ( 125.1 meV --> 83.04 keV)    mean life = 2310 y
   Ra226[67.670]:      4  Emean =  81.86 keV   ( 81.86 keV --> 81.86 keV)
          Rn222:      10  Emean =   86.3 keV   ( 86.3 keV --> 86.3 keV)    mean life = 5.516 d
          Th230:      10  Emean =  49.88 keV   ( 82.6 meV --> 83.13 keV)    mean life = 1.089e+05 y
   Th230[53.227]:      4  Emean =  82.21 keV   ( 82.21 keV --> 82.21 keV)
          Th234:      10  Emean =  35.91 keV   ( 72.03 meV --> 71.83 keV)    mean life = 34.77 d
   Th234[49.550]:      5  Emean =  70.99 keV   ( 70.99 keV --> 70.99 keV)
           U234:      10  Emean =  9.435 eV    ( 420.6 meV --> 15.02 eV )    mean life = 3.544e+05 y
  U234[1496.111]:      1  Emean =  290.5 meV   ( 290.5 meV --> 290.5 meV)
  U234[1723.402]:      1  Emean =  645.6 meV   ( 645.6 meV --> 645.6 meV)
   U234[926.720]:      1  Emean =  743.7 meV   ( 743.7 meV --> 743.7 meV)
           U238:      10  Emean =      0 eV    ( 0 eV  --> 0 eV )    mean life = 6.45e+09 y
          alpha:      80  Emean =  5.357 MeV   ( 4.149 MeV --> 7.687 MeV)    stable
      anti_nu_e:      60  Emean =  610.5 keV   ( 2.83 keV --> 2.145 MeV)    stable
             e-:    7815  Emean =  4.735 keV   ( 0.000169 meV --> 2.067 MeV)    stable
          gamma:      44  Emean =  539.1 keV   ( 2.726 keV --> 2.448 MeV)    stable
```

Spectra production and normalization

- Given the computational time of the chain simulations, for every detector elements:
  - 1.000.000 primary nuclides decays have been generated for U238, U235, Th232
  - 10.000.000 primary nuclides decays have been generated for K40, Co60, Cs137
- For each particle entering the gas volume the information saved are:
  - Particle name
  - Total energy deposit in the single volume
  - The number of the volume in which the energy is deposited
  - The primary nucleus
  - X, Y, Z of the vertex



37 keV electron in the final spectrum

- Final spectra produced taking into account we can reconstruct the total energy of the electron and the impact point

- Each histogram scaled by the quantity:

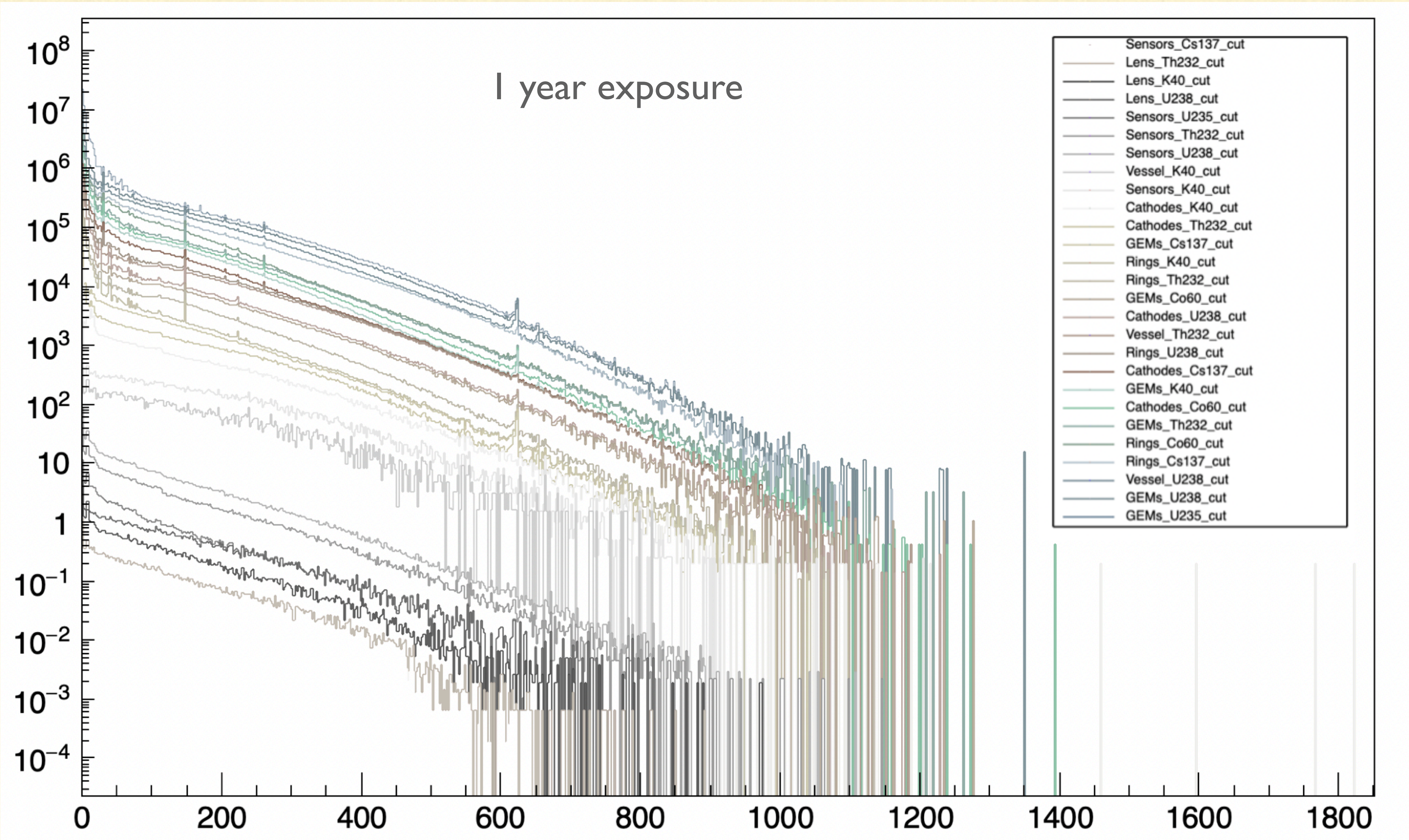
$$N = \frac{1}{N_{ev}} \cdot A\left[\frac{dec}{s \cdot kg}\right] \cdot M[kg] \cdot 3.15 \cdot 10^{7}\left[\frac{s}{y}\right]$$

- N_{ev} is the number of events
- A is the activity of the element
- M is the total mass of the detector component

```
{"Cathodes",809.7}, {"GEMs",18.75}, {"Lens",0.4995},
{"Rings",1114.74}, {"Sensors",0.1392}, {"Vessel",1102.24}
```

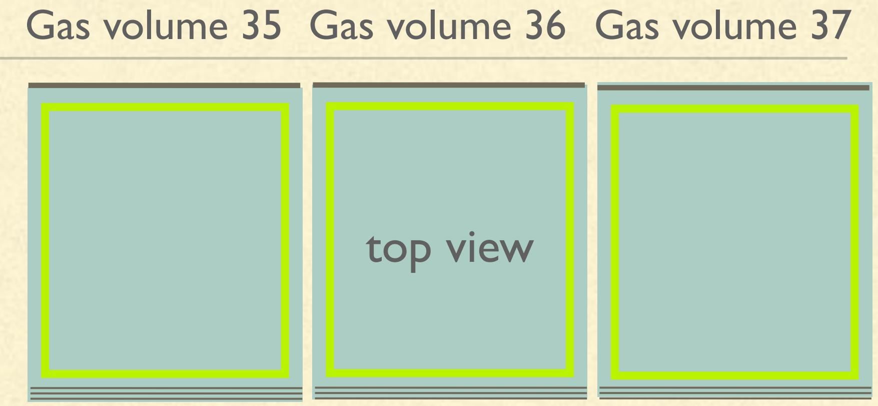
- List of each component total mass in Kg

Final gamma spectrum

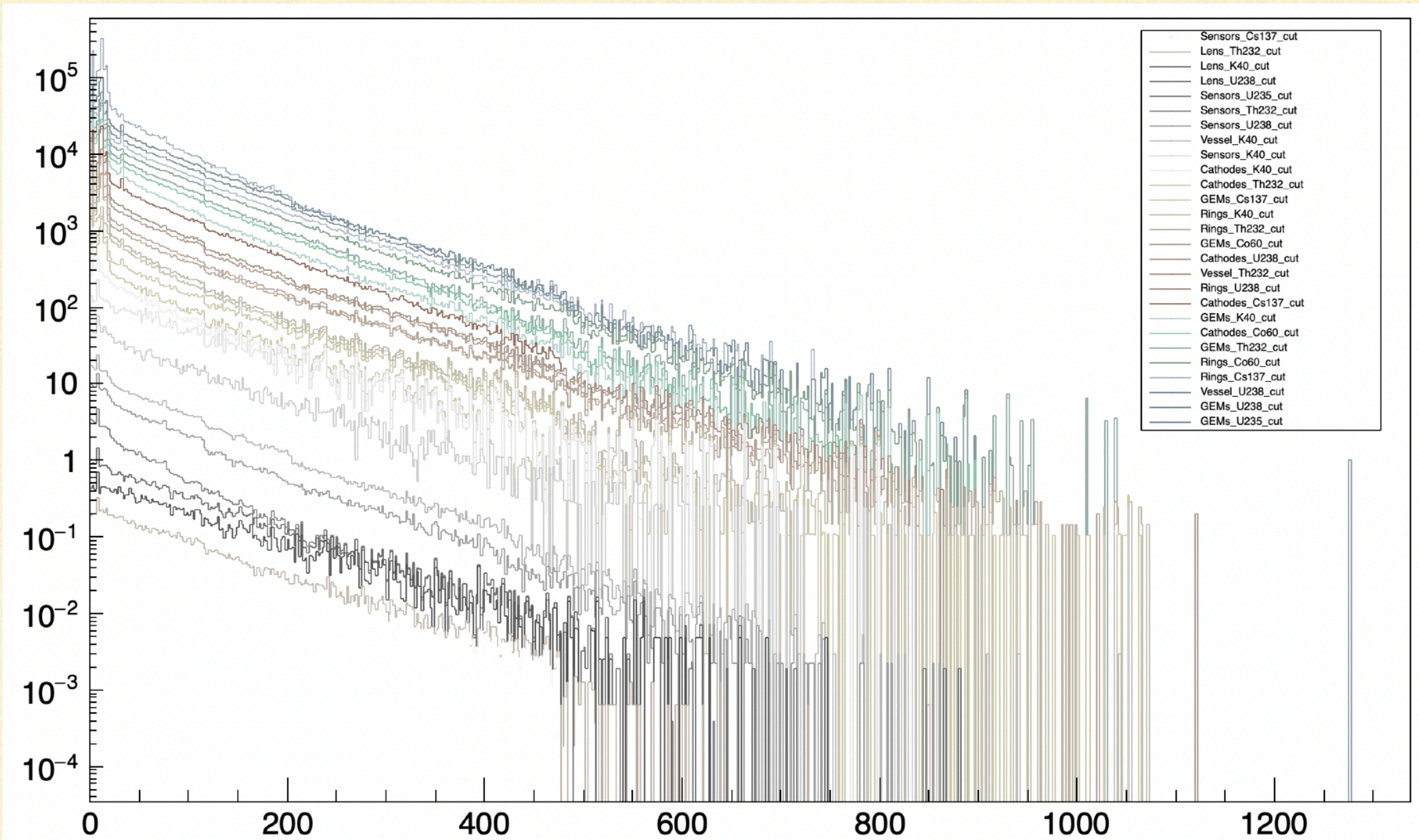


Full range: $9{,}85 \cdot 10^7\ ev/y$ 1-20keV: $6{,}09 \cdot 10^7\ ev/y$ 10-250keV: $4{,}59 \cdot 10^7\ ev/y$

Final gamma spectrum with fiducial cuts



- 3cm x 3cm cut on the GEM plane
- 5 cm from GEM and Cathode along z



Full range: $2{,}40 \cdot 10^6\ ev/y$ 1-20keV: $1{,}34 \cdot 10^6\ ev/y$ 10-250keV: $1{,}82 \cdot 10^6\ ev/y$

Component with highest contribution

No cuts

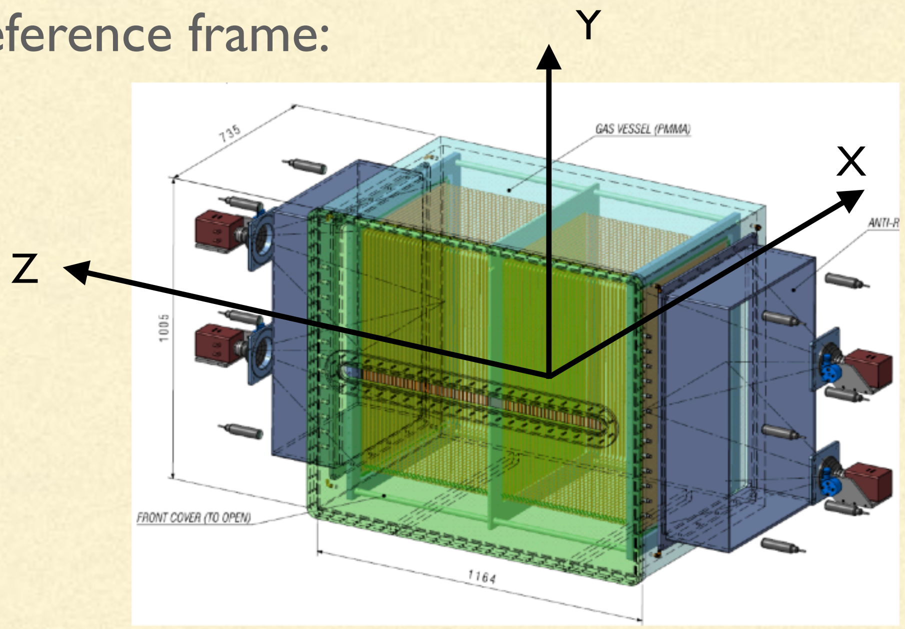
```
Cathodes_Co60  2.01417e+06  Cathodes_Cs137  2.81963e+06  Cathodes_K40  469016  Cathodes_Th232  420831
Cathodes_U238  1.54696e+06  GEMs_Co60  177299  GEMs_Cs137  129157  GEMs_K40  6.14066e+06
GEMs_Th232  4.50413e+06  GEMs_U235  4.58431e+07  GEMs_U238  1.46709e+07  Lens_K40  45.0426
Lens_Th232  12.2703  Lens_U238  33.3739  Rings_Co60  5.03953e+06  Rings_Cs137  7.83959e+06
Rings_K40  1.36895e+06  Rings_Th232  1.00345e+06  Rings_U238  3.73395e+06  Sensors_Cs137  8.82239
Sensors_K40  13551.3  Sensors_Th232  409.117  Sensors_U235  67.3543  Sensors_U238  487.388
Vessel_K40  18275.9  Vessel_Th232  108546  Vessel_U238  732698
```

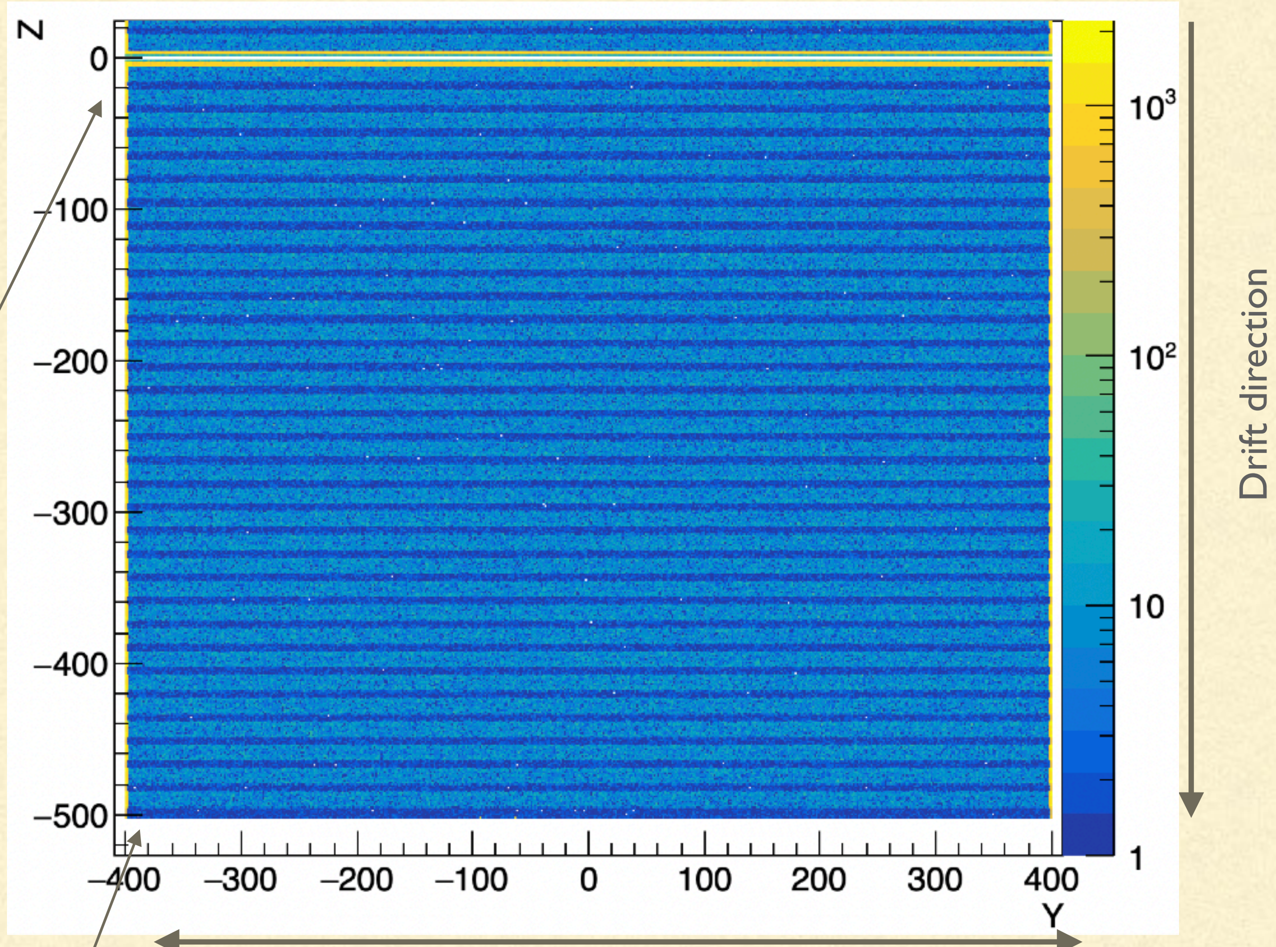
Cuts

```
Cathodes_Co60_cut  104888
Cathodes_Cs137_cut  87402  Cathodes_K40_cut  4574.1  Cathodes_Th232_cut  6504.43  Cathodes_U238_cut  19549.7
GEMs_Co60_cut  17728.1  GEMs_Cs137_cut  7701.26  GEMs_K40_cut  90203.1  GEMs_Th232_cut  116145
GEMs_U235_cut  1.06274e+06  GEMs_U238_cut  298142  Lens_K40_cut  14.1271  Lens_Th232_cut  5.86942
Lens_U238_cut  16.4283  Rings_Co60_cut  139757  Rings_Cs137_cut  149890  Rings_K40_cut  12686.6
Rings_Th232_cut  15185.4  Rings_U238_cut  47713.7  Sensors_Cs137_cut  4.75606  Sensors_K40_cut  4277.43
Sensors_Th232_cut  196.248  Sensors_U235_cut  45.5946  Sensors_U238_cut  236.636  Vessel_K40_cut  1586.43
Vessel_Th232_cut  37692  Vessel_U238_cut  183979
```

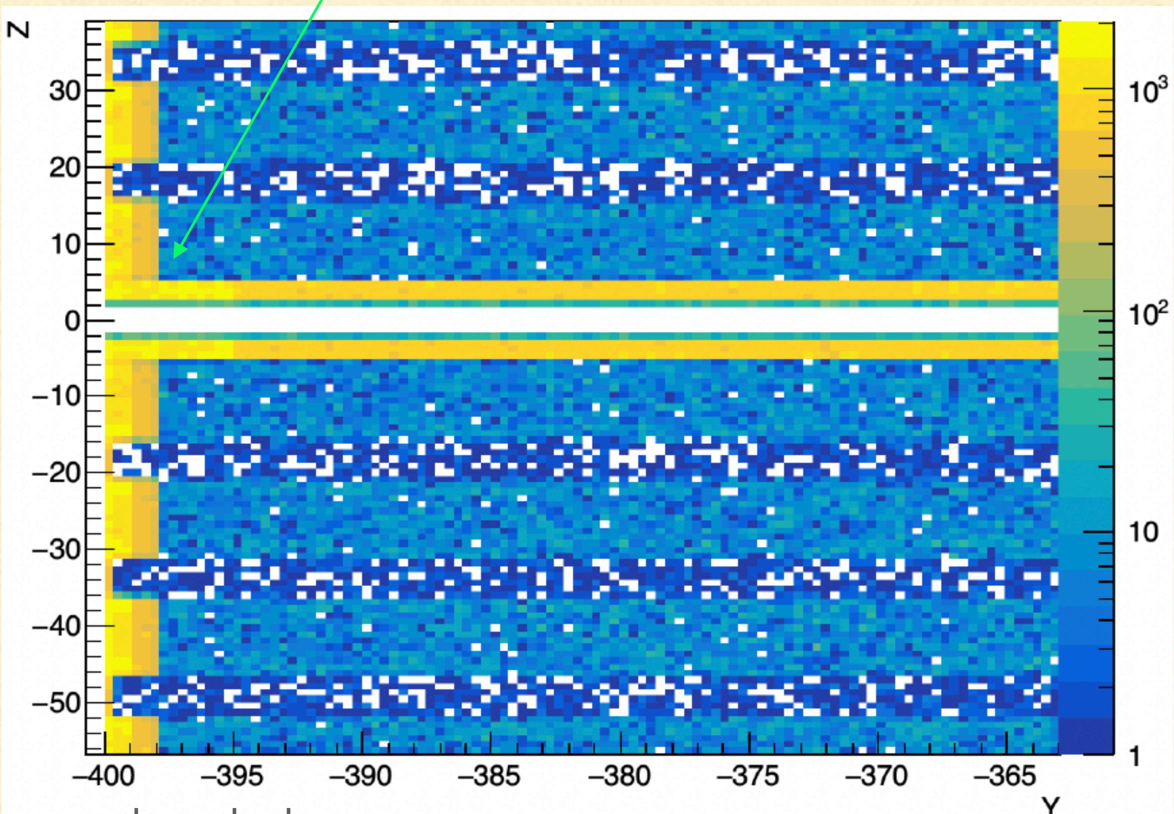
Y-Z Event distribution

- Reference frame:

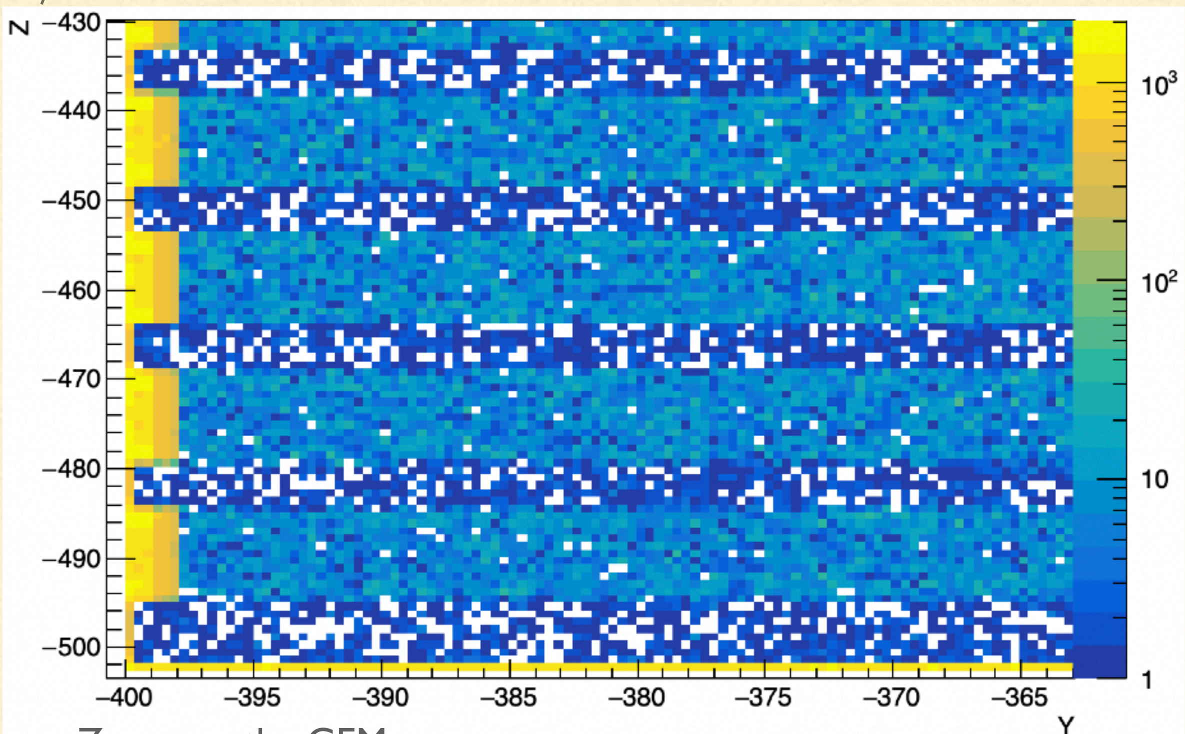




Beta and very low energy gamma with very samall λ (see Ca and Ti)



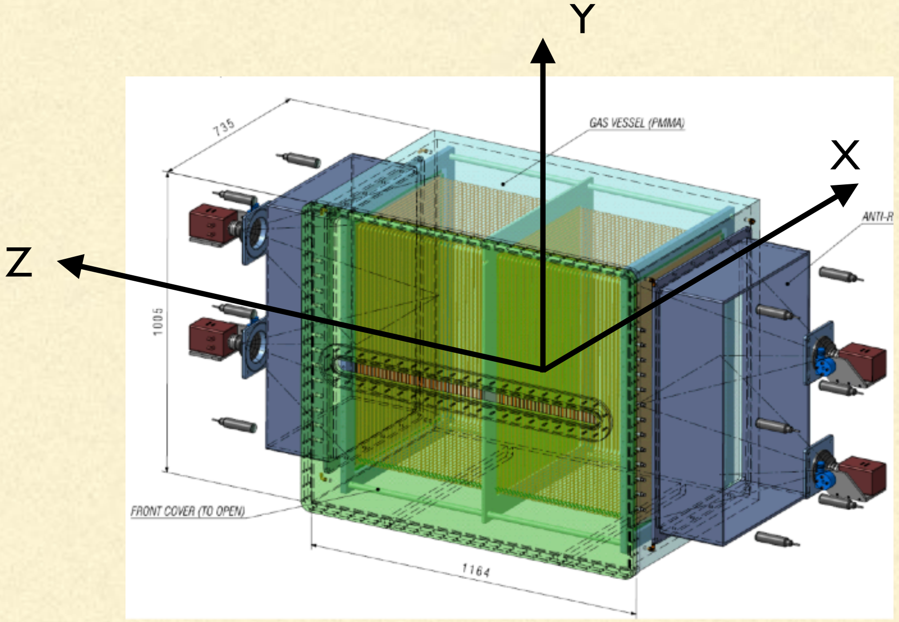
Zoom on the cathode corner

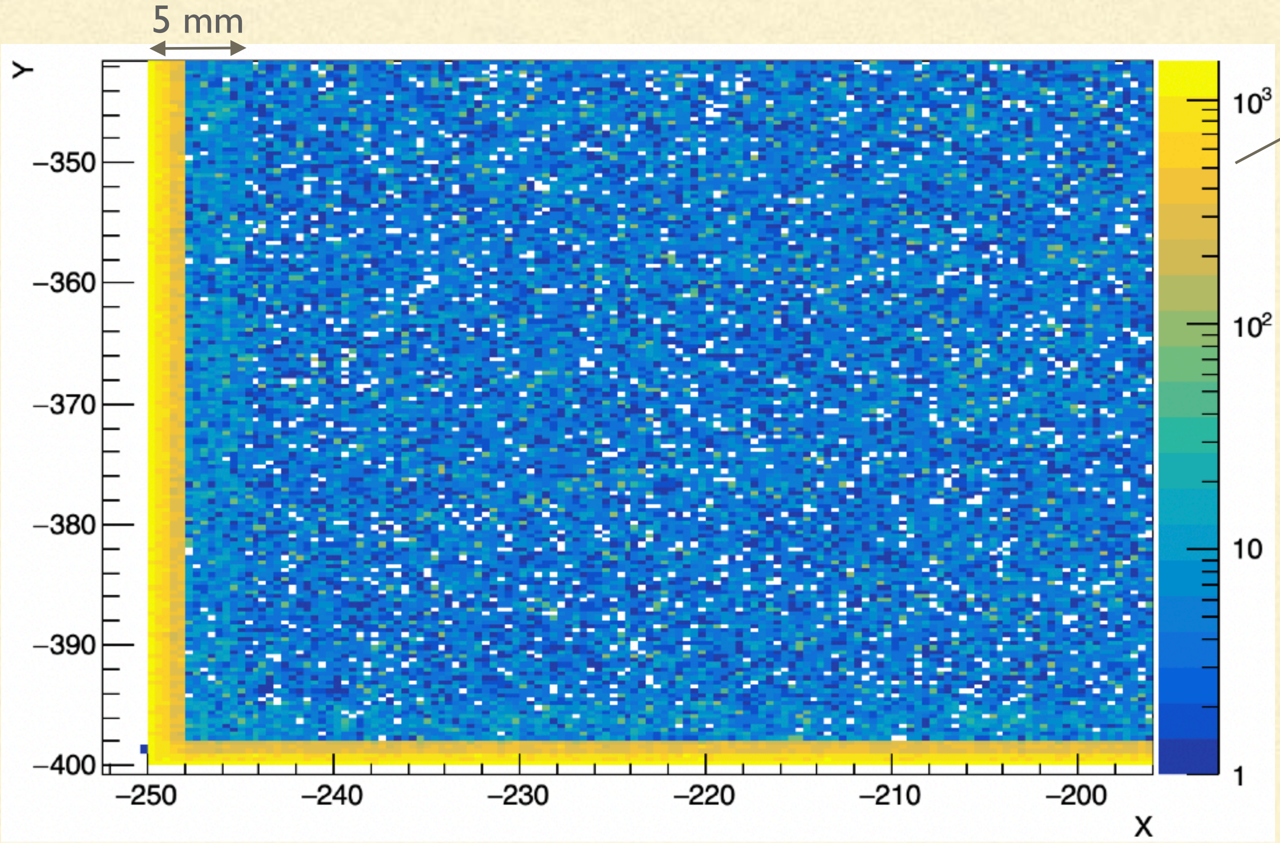


Zoom on the GEM corner

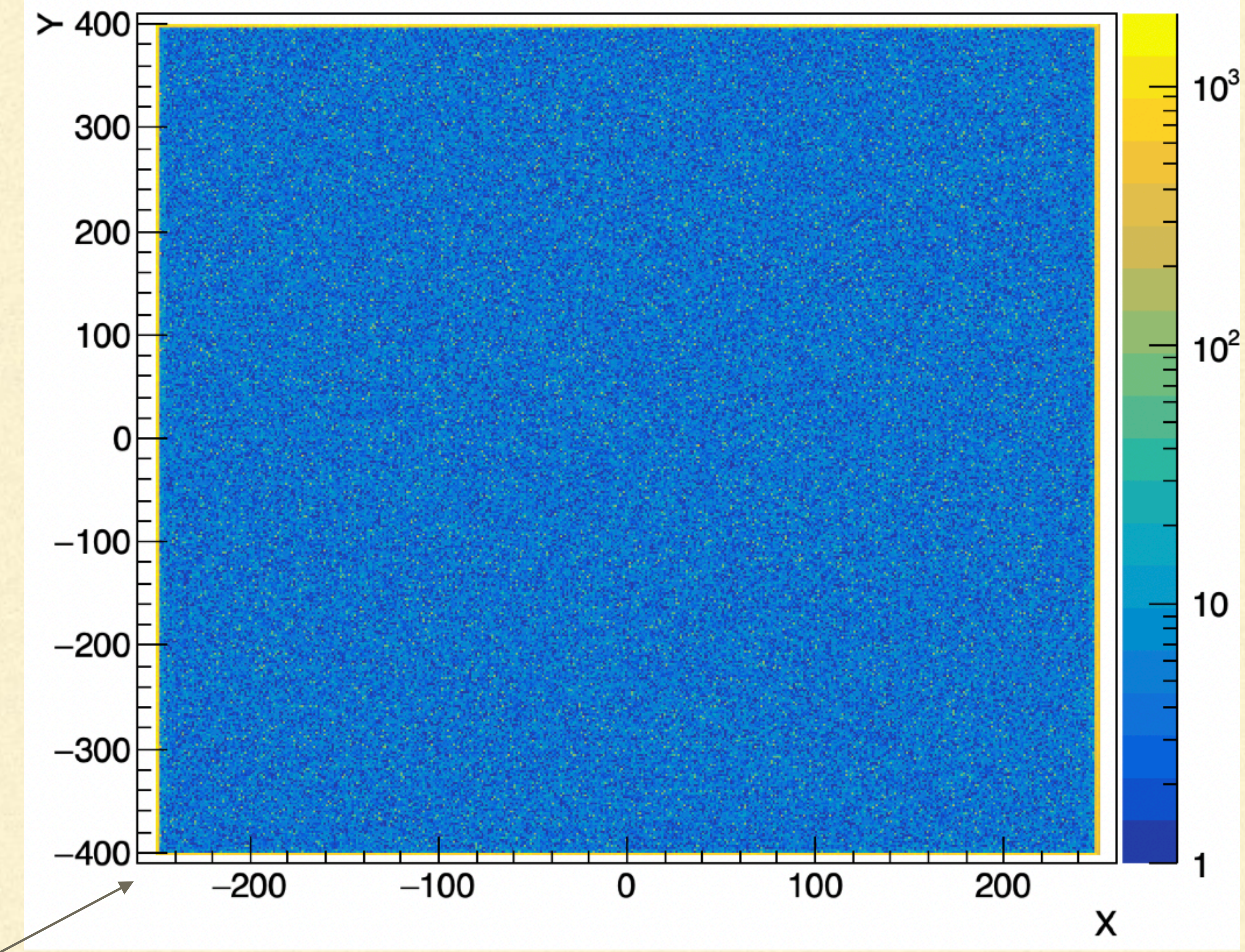
X-Y Event distribution

- Reference frame:





Zoom on the bottom left corner



- No trend in #events observed in the central region of the sensitive volume
- Some small anisotropy close to the border in X-Y is present
- Optimal cut seems to be
  - 5mm in XY
  - 4 mm from Cath.s and 1 mm from GEMs

Conclusions

- The gamma background of CYGNO 30 has been studied supposing to build the detector with the most pure material used up to now and the current future geometry
- The total spectrum have been produced and show a rate of electron recoil due to gamma of $2 \cdot 10^6$ events/y in the full energy range.
- The most critical components of the detector are mainly the GEMs, followed by the rings and the vessel
- The interaction point studies suggest a fiducial cut of 5 mm in the X-Y plane, 4 mm from Cath, and 1 mm from GEM
- Additional cut would reduce linearly the amount of signal and bkg (?). Most optimized cut (?)
- For the future study the NID geomety:
  - Same diffusion level of 50 cm ED with 1.5 m NID → cubic detector geometry