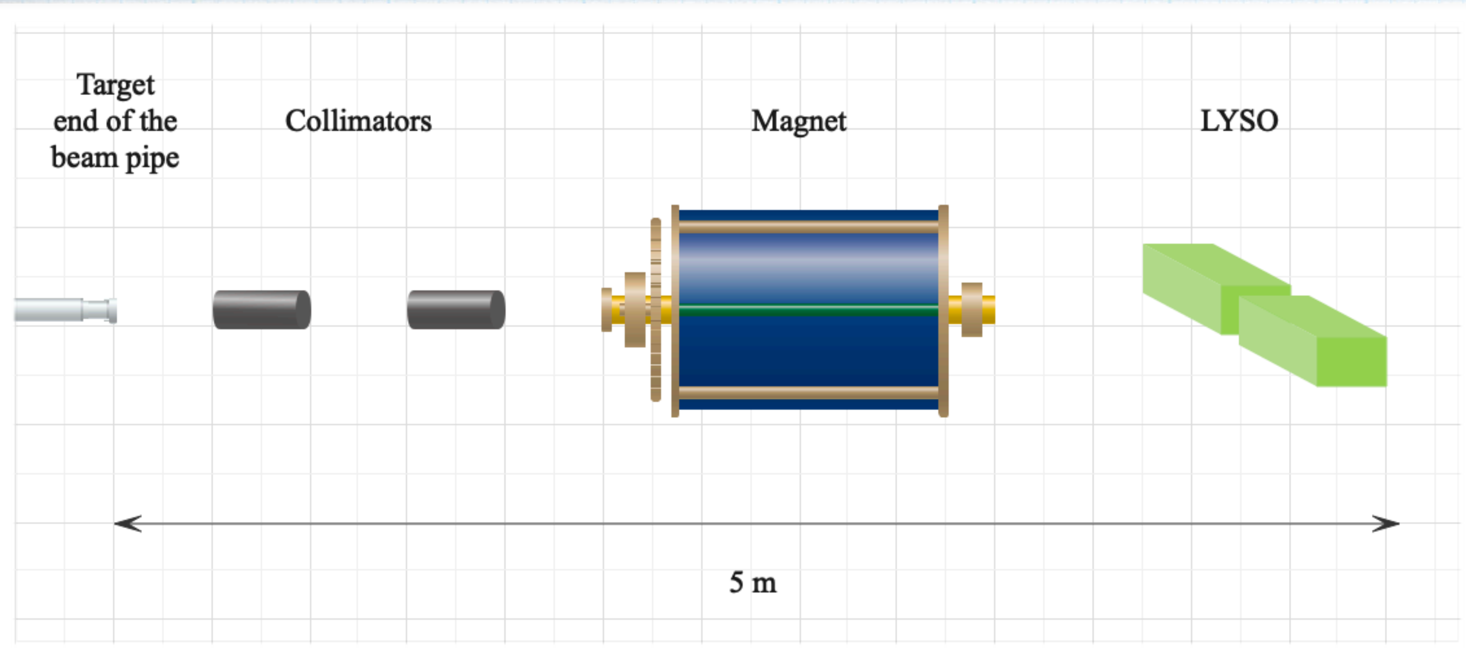
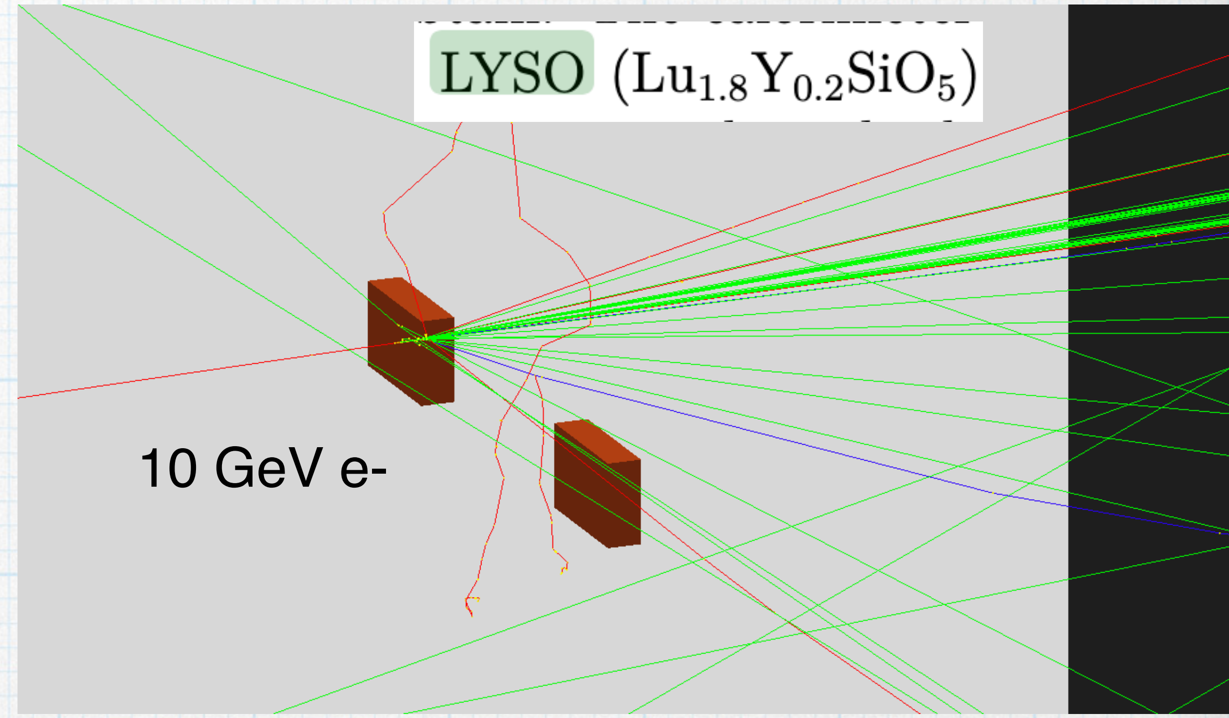
FDS performance

Borysova Maryna (KINR)
3/09/20
LUXE weekly technical meeting

LYSO calorimeters

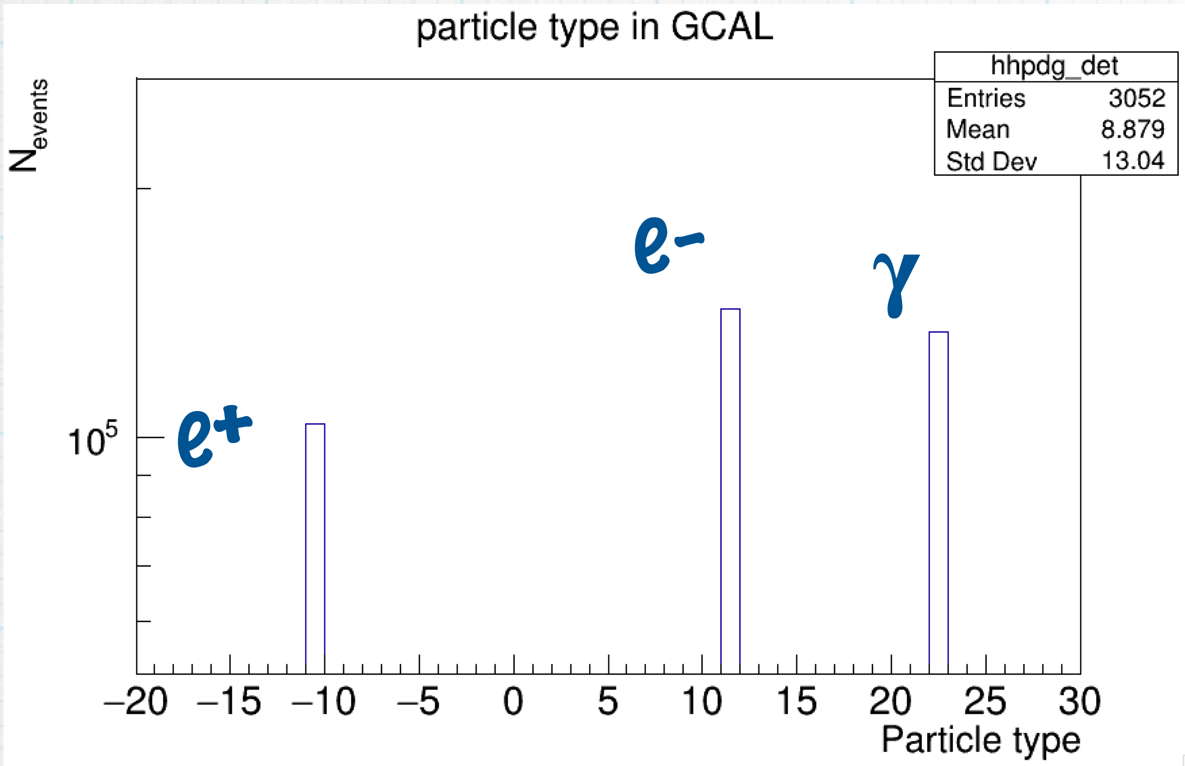


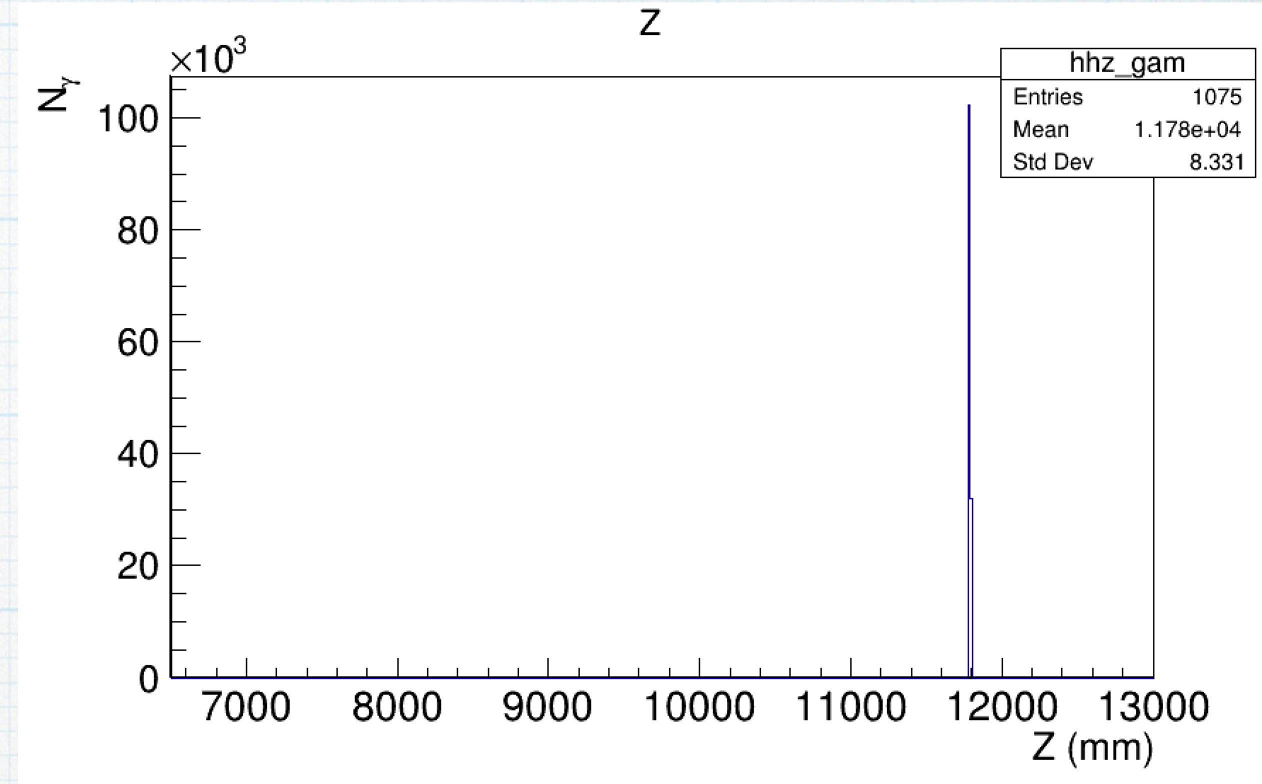


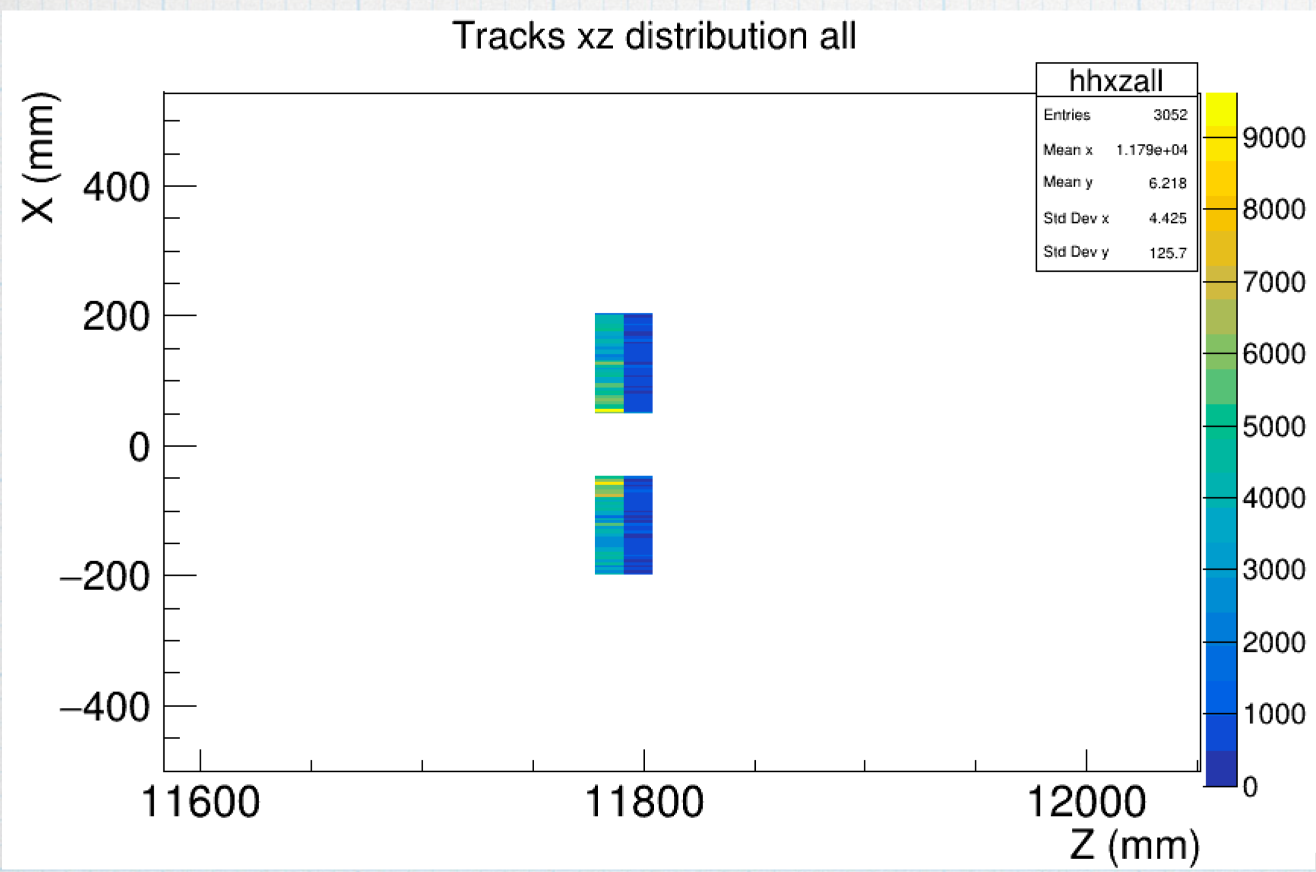
Aug 2020 Data Runs, bunch/pulse crossings completed

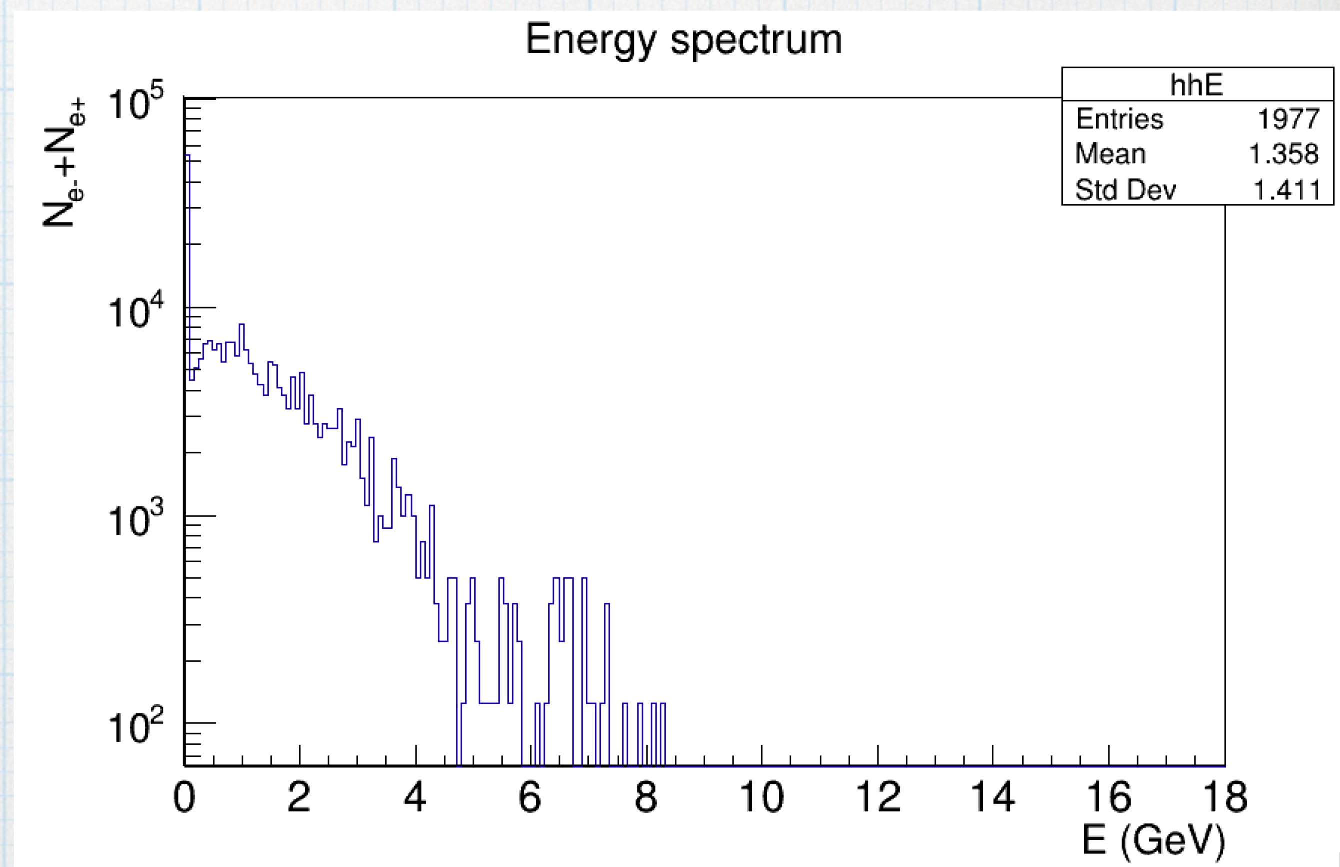
Experiment Config	$w_0 = 3\mu$m	$w_0 = 3.5\mu$m	$w_0 = 4.0\mu$m	$w_0 = 4.5\mu$m	$w_0 = 5.0\mu$m	$w_0 = 20.0\mu$m	$w_0 = 50.0\mu$m	$w_0 = 100.0\mu$m
peak SQED ξ	5.12	4.44	3.88	3.45	3.1	0.78	0.32	0.15
JETI40 e-laser 16.5 GeV	939	951	946	949	938	193	200	200
JETI40 e-laser 17.5 GeV	182	121	115	125	69			

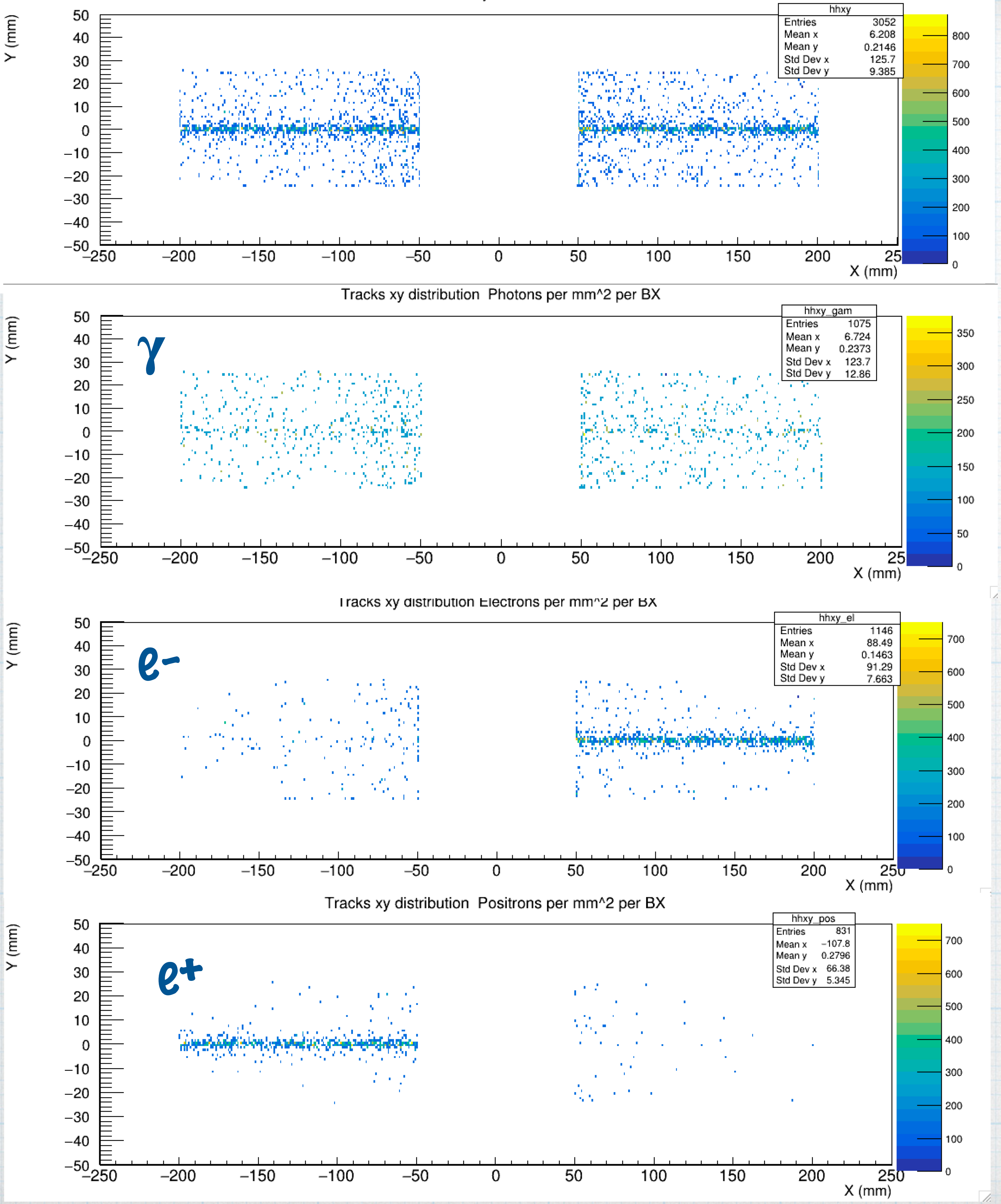
- The scintillators are modelled as a 15x5x2 cm (x:y:z) layer of lyso material
- The crystal (bin) size of the scintillators are 2 x 1 mm (finer segmentation in x; the deflection direction) giving 25 x 300 bins.


particle type in GCAL
hhpdg_det
Entries 3052
Mean 8.879
Std Dev 13.04
N_events
e+
e-
γ
Particle type

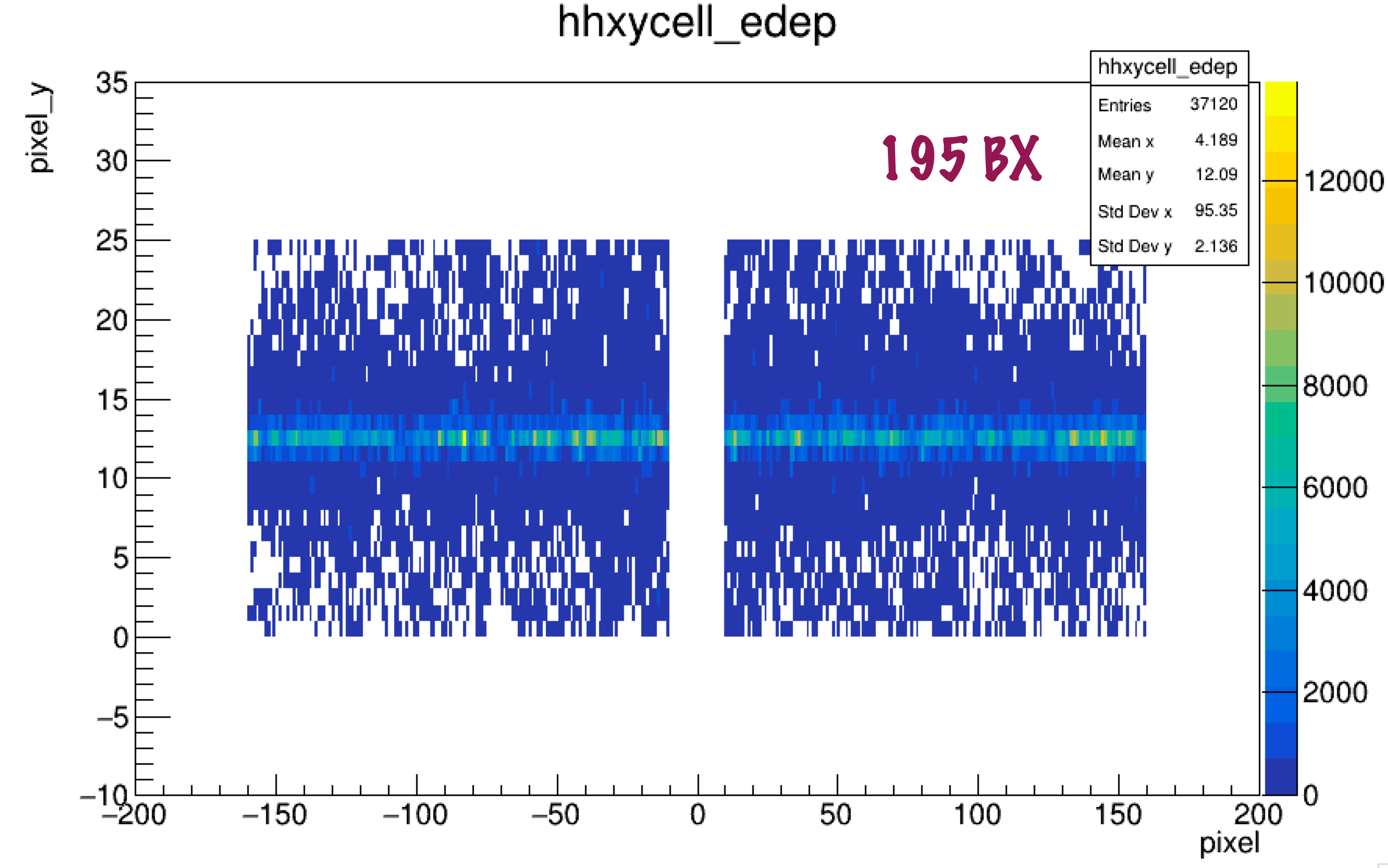

Z
hhz_gam
Entries 1075
Mean 1.178e+04
Std Dev 8.331
N_γ
×10^3
Z (mm)


Tracks xz distribution all
hhxzall
Entries 3052
Mean x 1.179e+04
Mean y 6.218
Std Dev x 4.425
Std Dev y 125.7
X (mm)
Z (mm)


Energy spectrum
hhE
Entries 1977
Mean 1.358
Std Dev 1.411
N_e- + N_e+
E (GeV)



Number of particles per BX per mm^2



Deposited energy per cell

- laser intensity $\xi = 0.15$

Compton MC2020 r for 1J (xi=0.15), 16.5 GeV electrons. G4: tungsten foil of 10 um as a target, magnet 1T and 1.5m distance from magnet to LYSO .

If we take distribution of deposited energy the values around maximum are ~61 GeV.

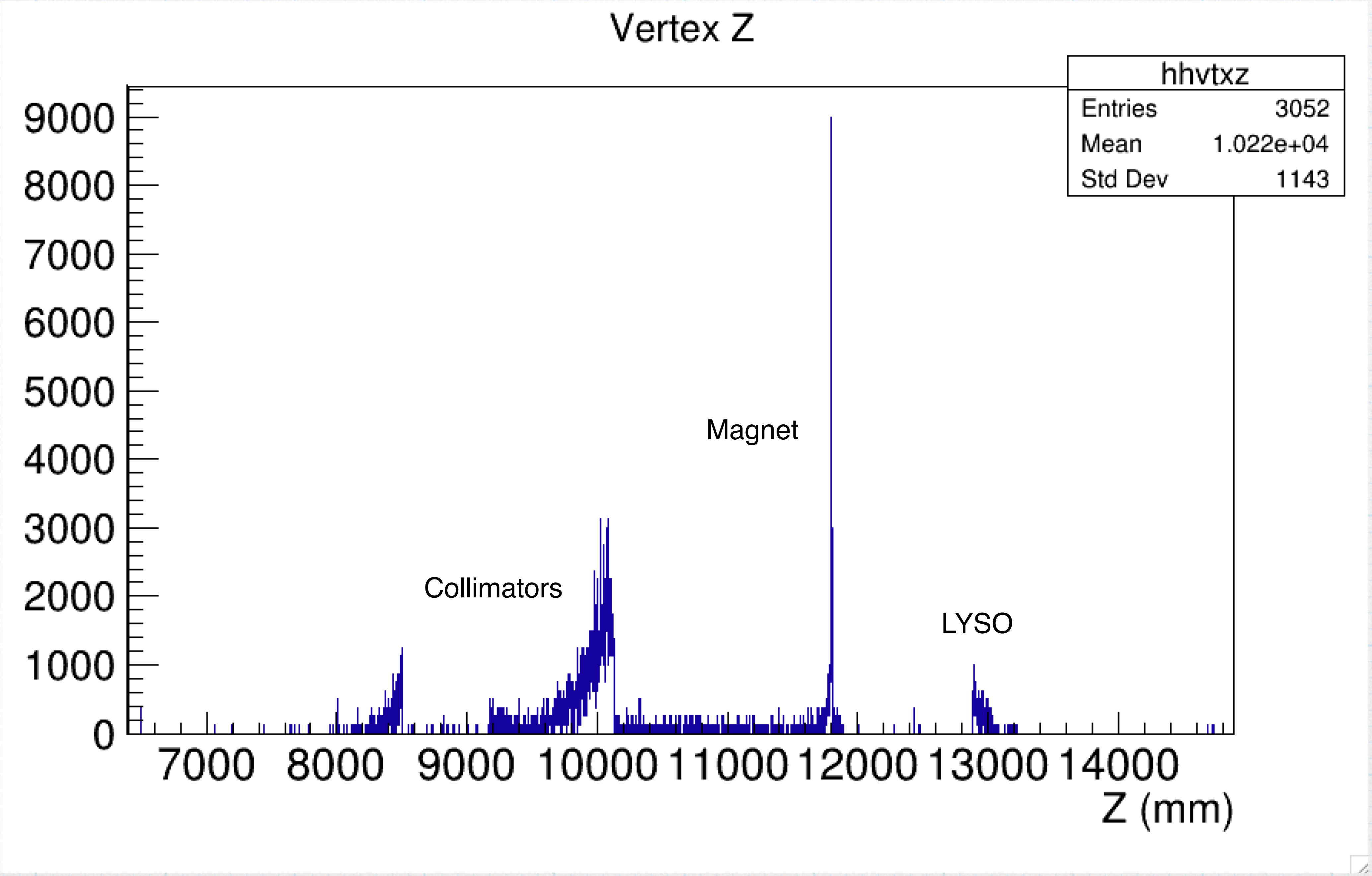
To convert it to Gy, convert it to J: ~5.7e-9J and then divide it to the mass of crystals in kg. Gy= J/kg

The density is 7.1 g/cm3, volume 0.1*0.2*2 = 0.04 cm3. Mass 7.1*0.04 = 0.284g.

Finally, 5.7e-9J/0.284e-3 = 3.4e-4 Gy per BX.

Assuming 1 Hz collisions rate we get the dose of 1000Gy in LYSO crystal in about 1000/3.4e-4 = 2.9e7s which is 335 days.

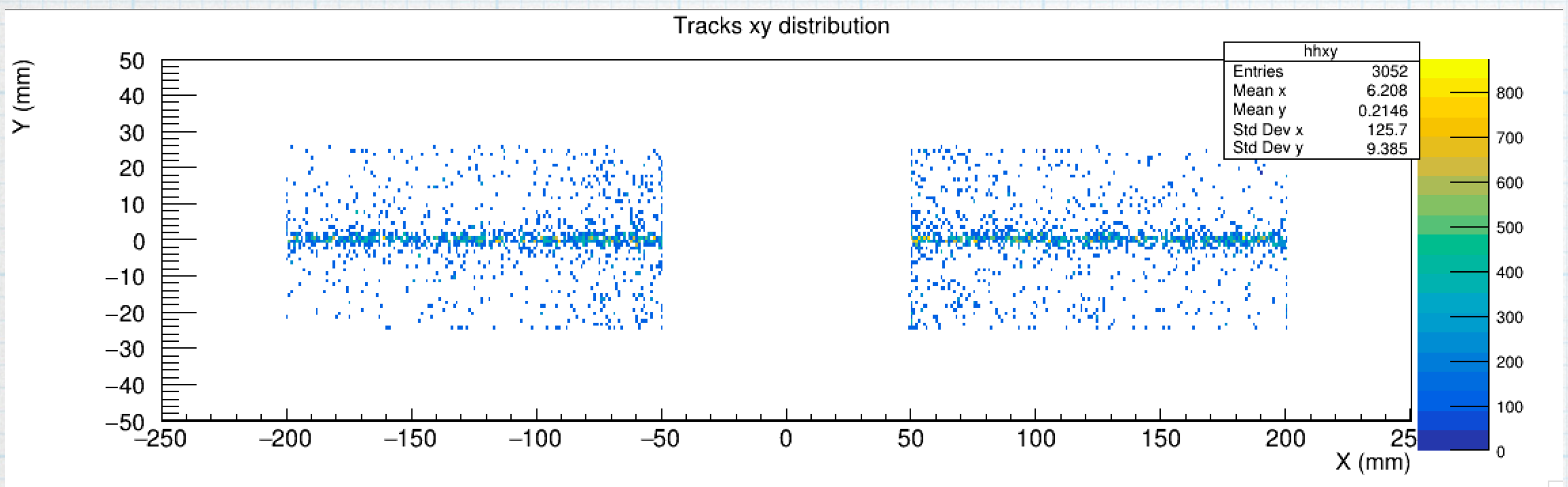
Vertices

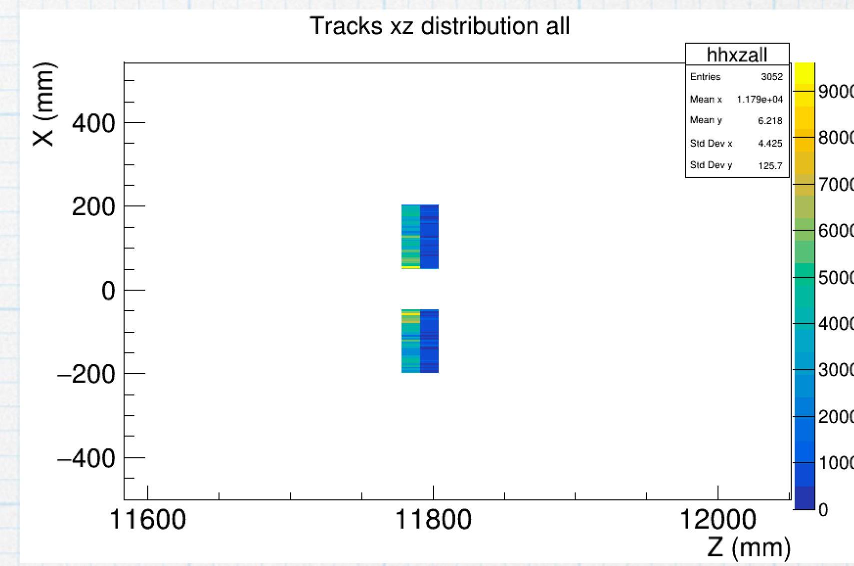


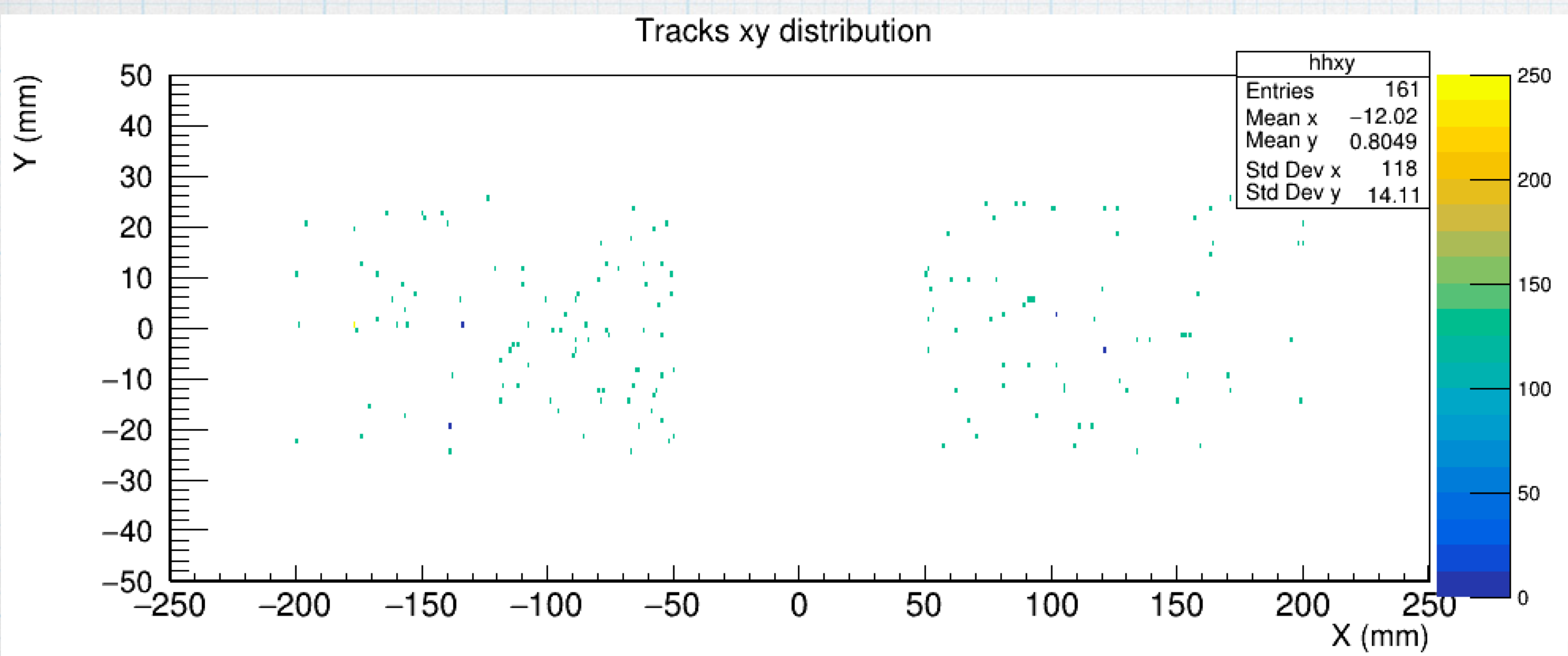
Vertex Z
hhvtxz
Entries 3052
Mean 1.022e+04
Std Dev 1143
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Magnet
Collimators
LYSO
7000 8000 9000 10000 11000 12000 13000 14000
Z (mm)

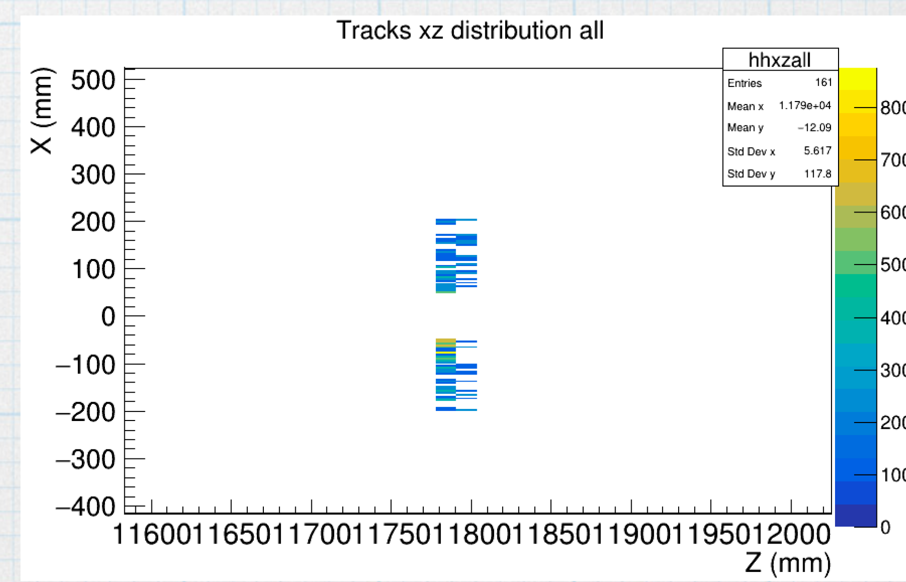
Air vs Vacuum

Number of particles per BX per mm^2

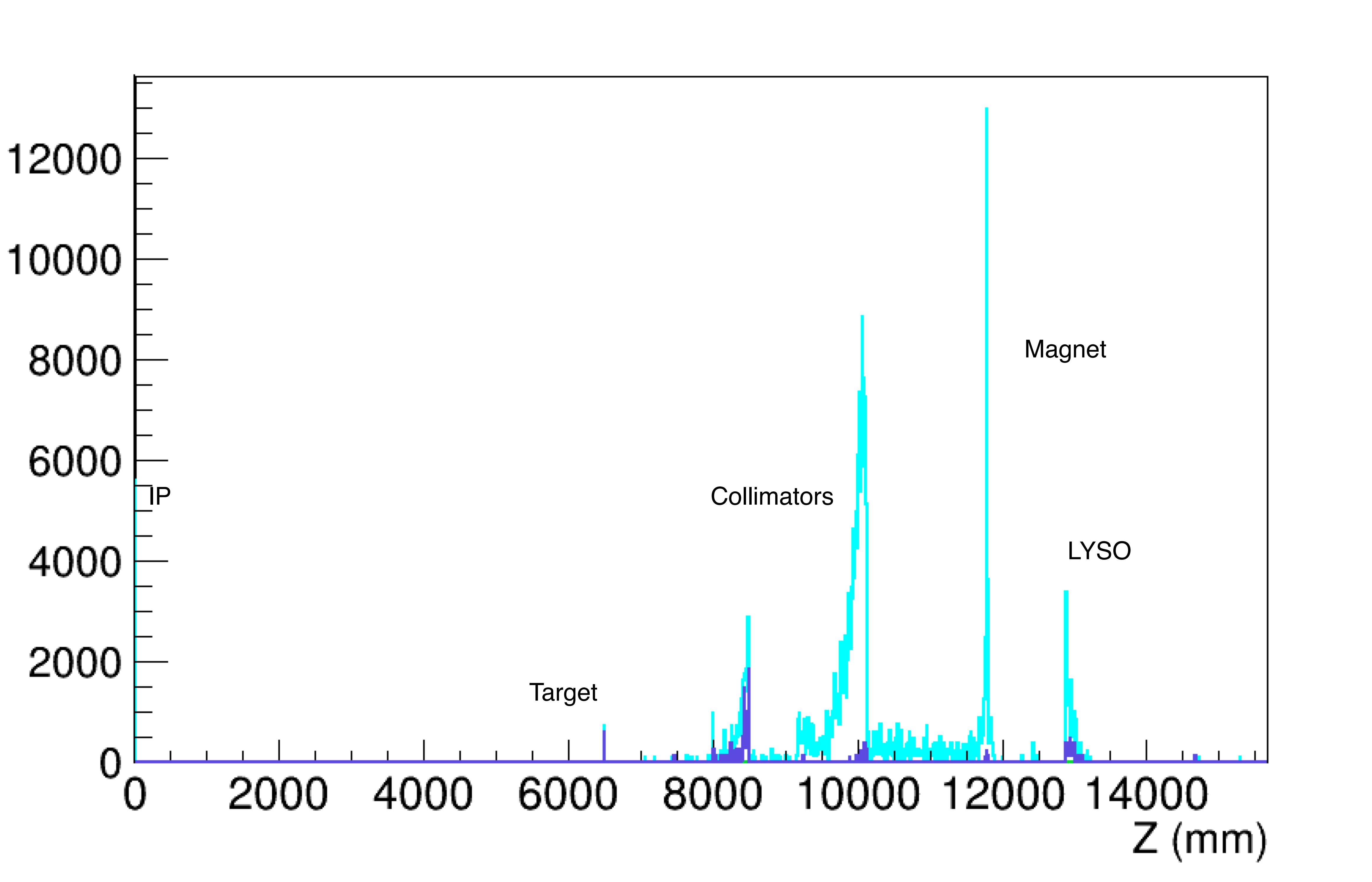




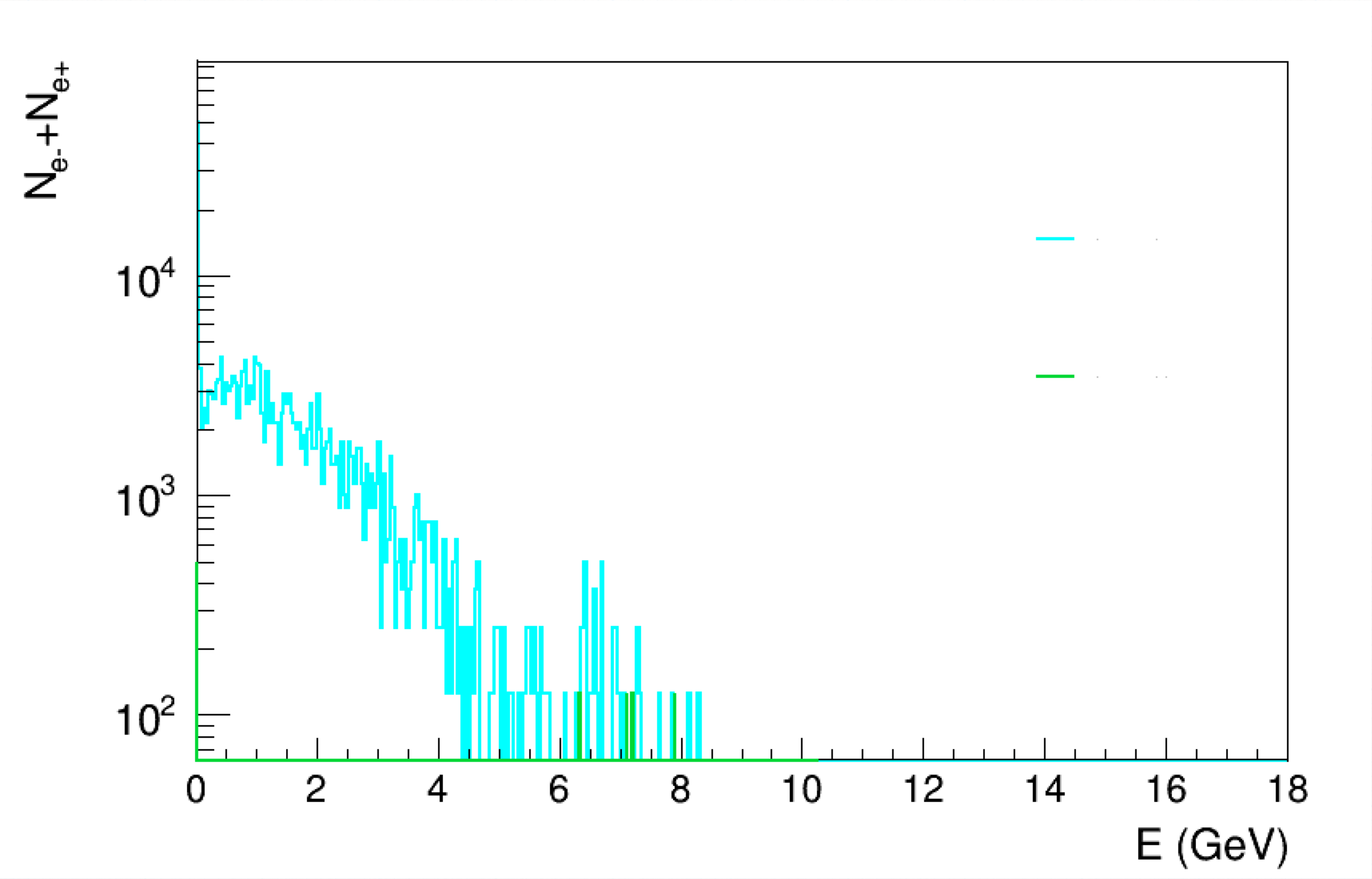




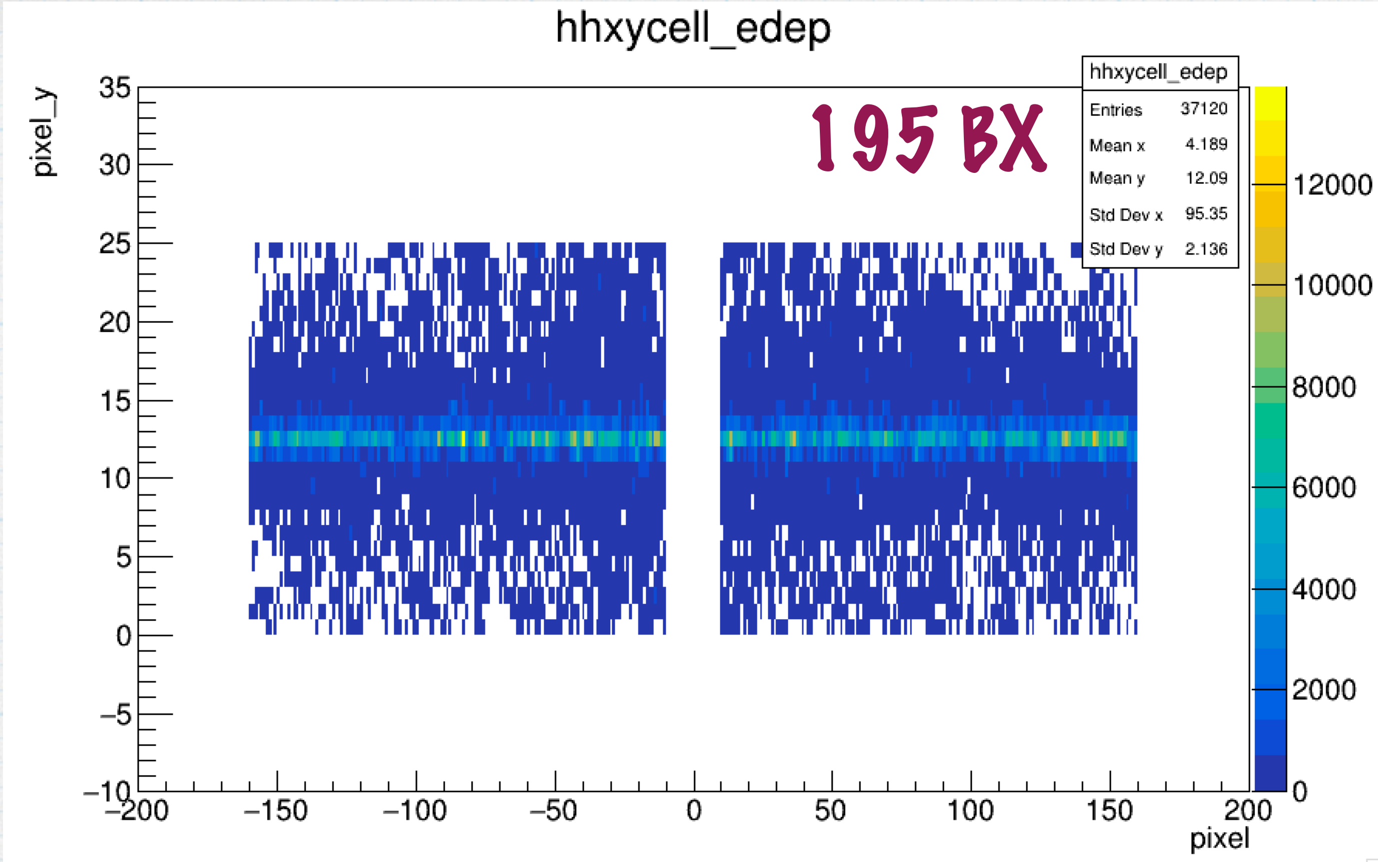
Vertices: Air vs Vacuum



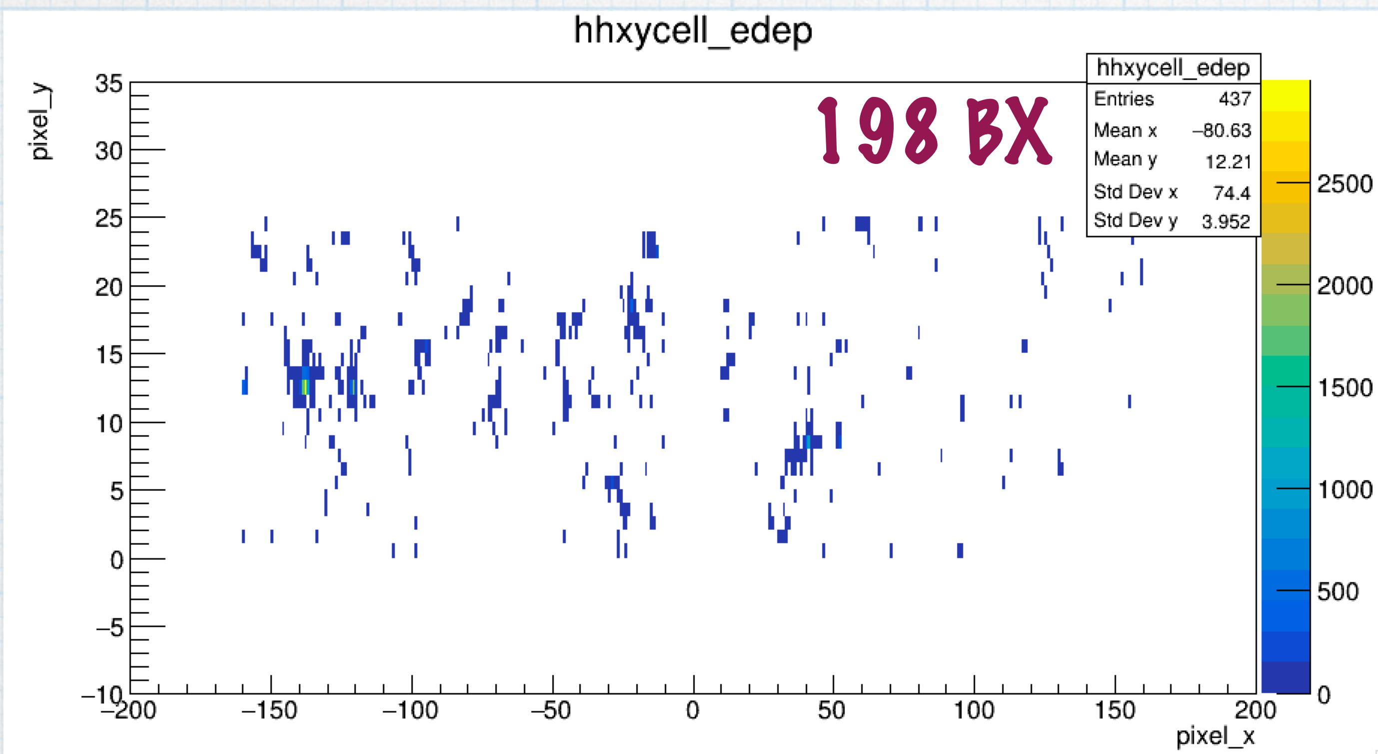
Air vs Vacuum



Deposited energy per cell: Air vs Vacuum



Edep (per 1 BX) =61.5 GeV

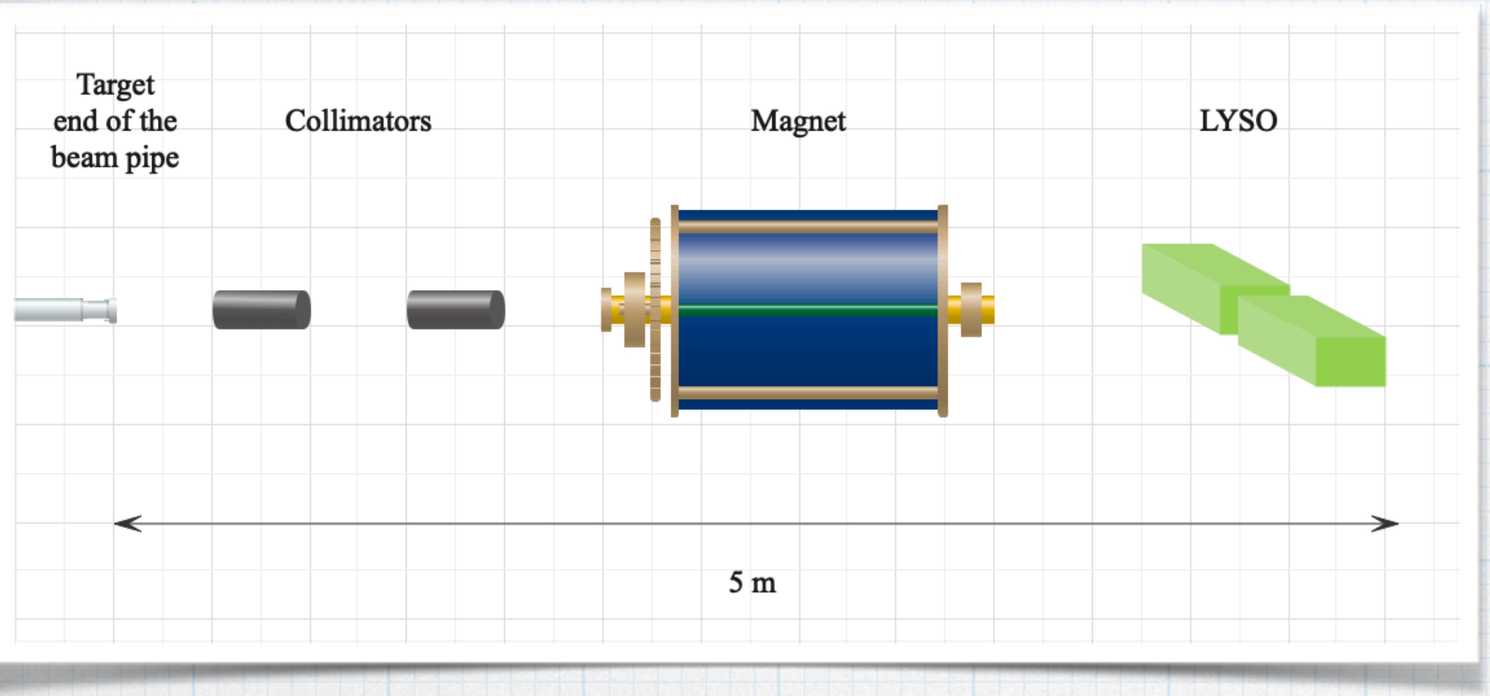


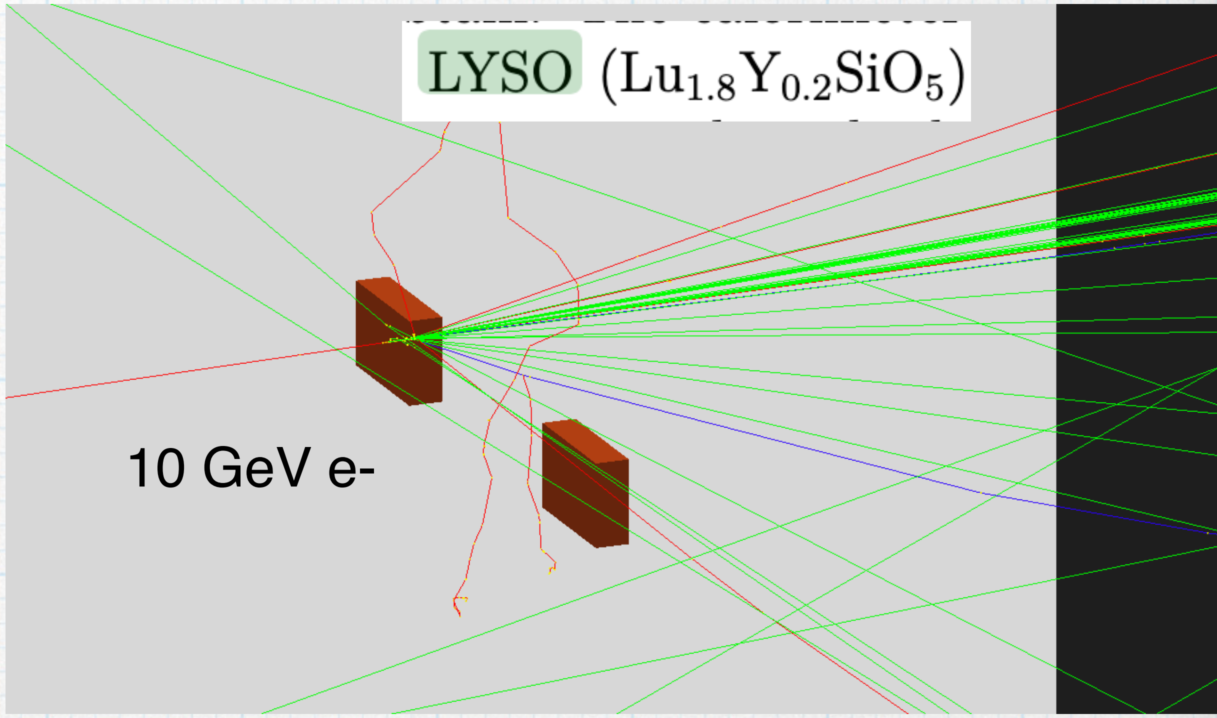
Edep (per 1 BX) =12.6 GeV

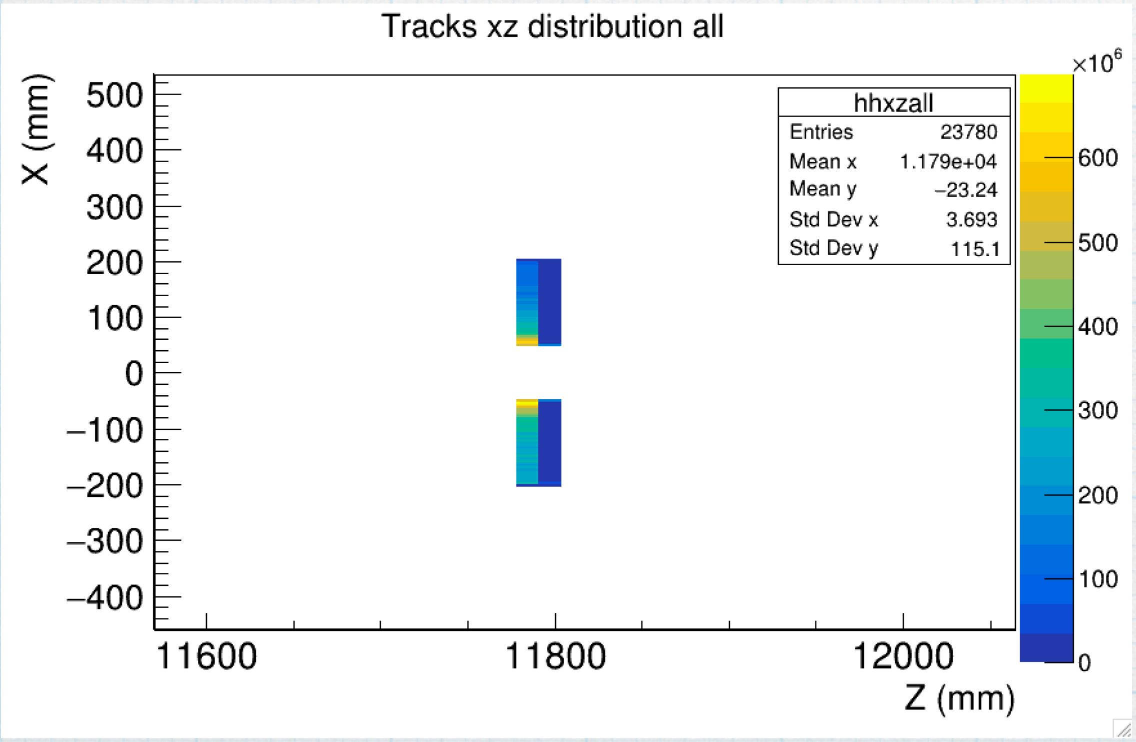
			5Gy		1000Gy	
Edep(1BX),GeV	Edep(1BX), J	Edep(1BX), J/(crystall) Gy	sec	hours	sec	days
61.53846153846	9.86E-09	3.47E-05	1.44E+05	40.01	2.88E+07	333.39
12.62626262626	2.02E-09	7.12E-06	7.02E+05	194.98	1.40E+08	1624.87

Back up

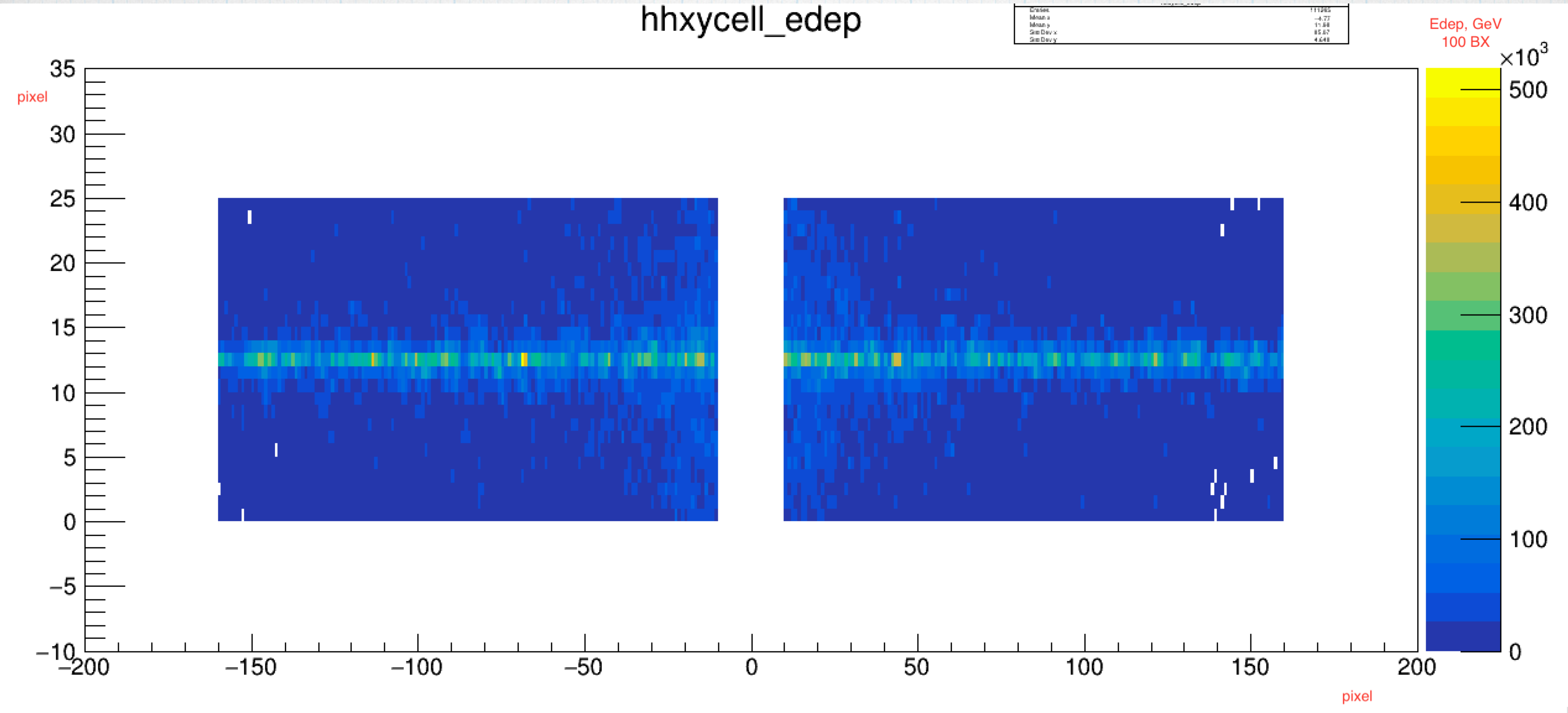
LYSO calorimeters







- The scintillators are modelled as a 15x5x2 cm (x:y:z) layer of lyso material
- The crystal (bin) size of the scintillators are 2 x 1 mm (finer segmentation in x; the deflection direction) giving 25 x 300 bins.



Compton MC2019 r for 1J (xi=2.6), 17.5 GeV electrons. G4: tungsten foil of 10 um as a target, magnet 1T and 1.5m distance from magnet to LYSO .

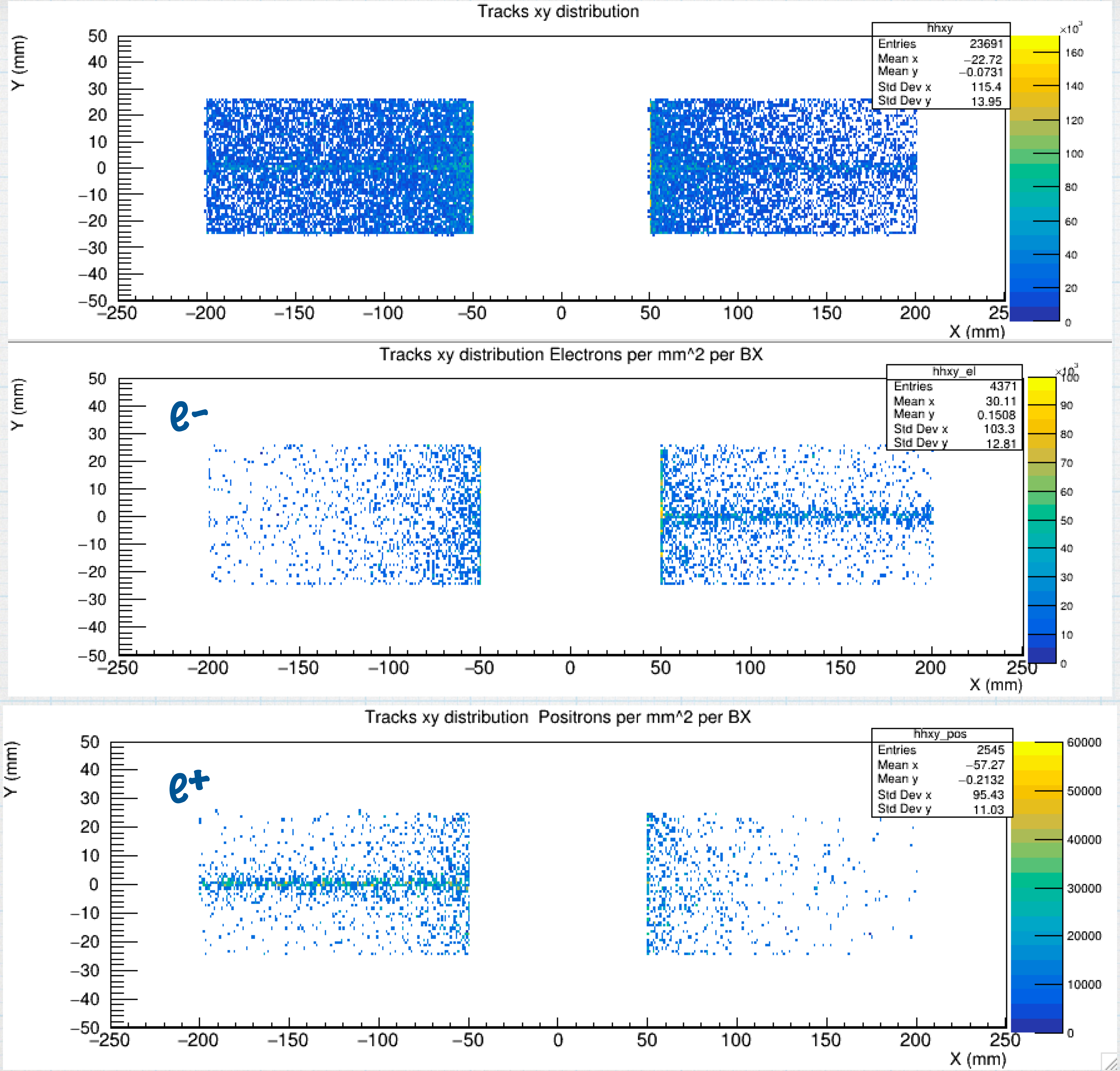
If we take distribution of deposited energy the values around maximum are ~5e3 GeV.

To convert it to Gy, convert it to J: ~8e-7 J and then divide it to the mass of crystals in kg. Gy= J/kg

The density is 7.1 g/cm3, volume 0.1*0.2*2 = 0.04 cm3. Mass 7.1*0.04 = 0.284g.

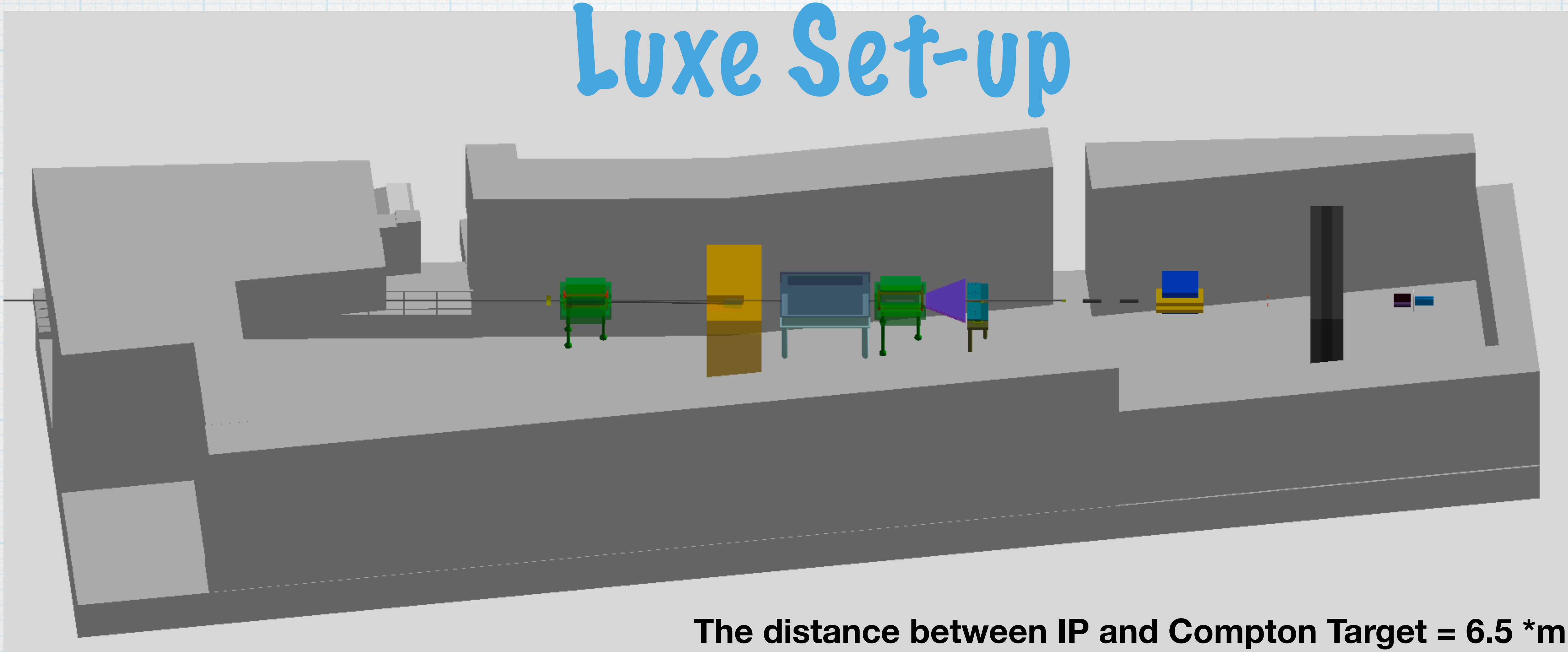
Finally 8e-7J/0.284e-3 = 2.8e-3 Gy per BX.

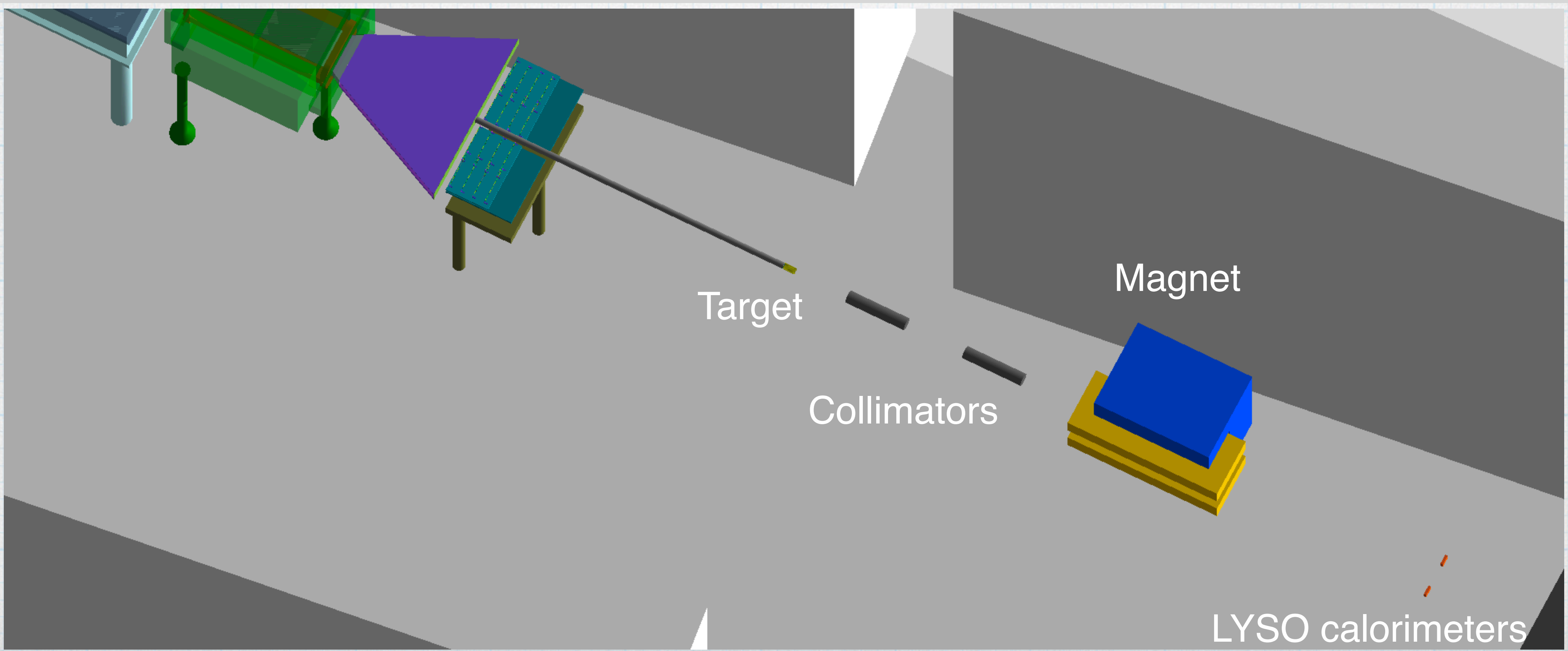
Assuming 1Hz collisions rate we get the dose of 1000Gy in LYSO crystal in about 1000/2.8e-3 = 3.6e6s which is 41,6 days.



Number of particles per BX per mm^2

Luxe Set-up

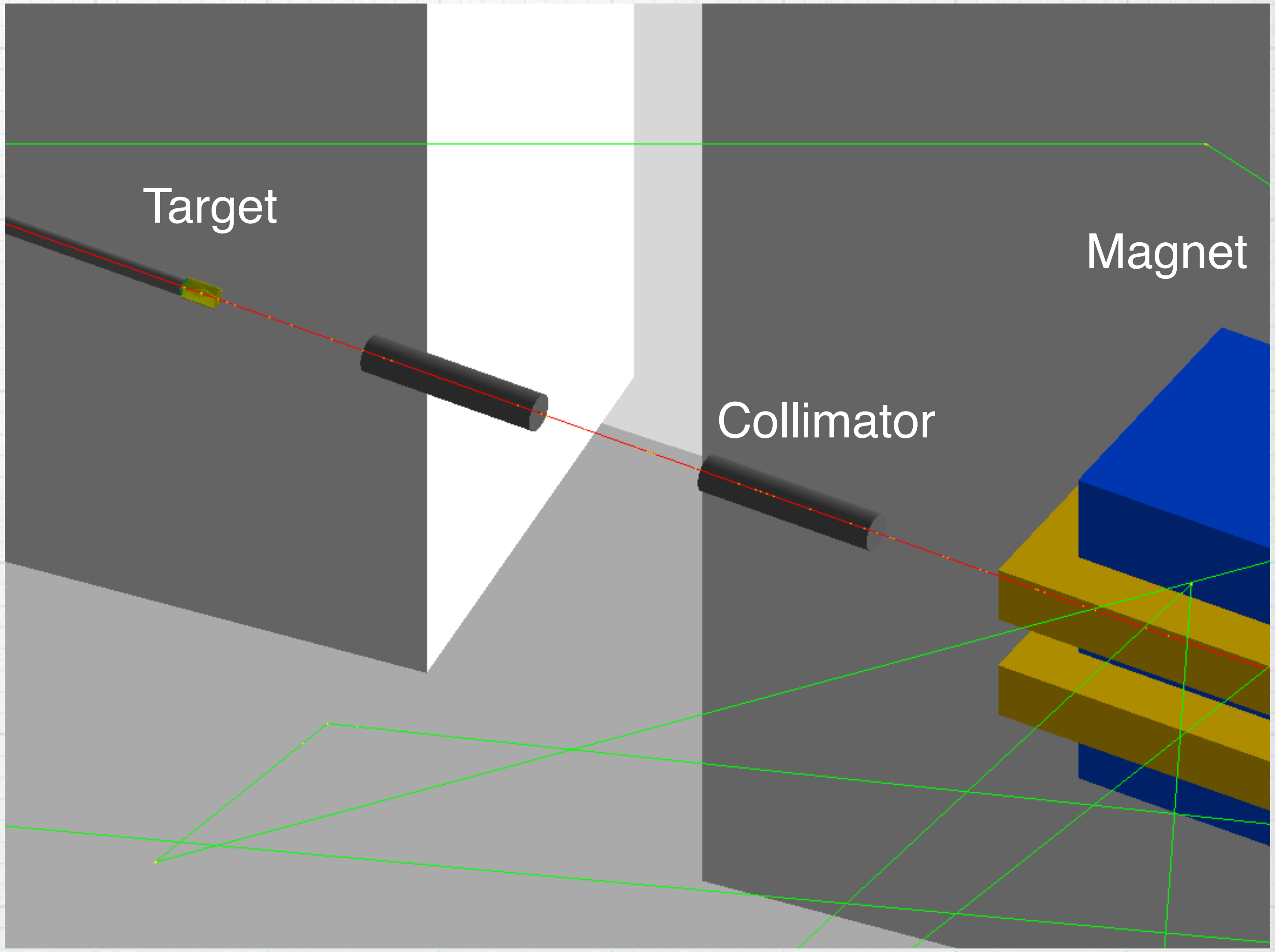

The distance between IP and Compton Target = 6.5 *m


Target
Magnet
Collimators
LYSO calorimeters

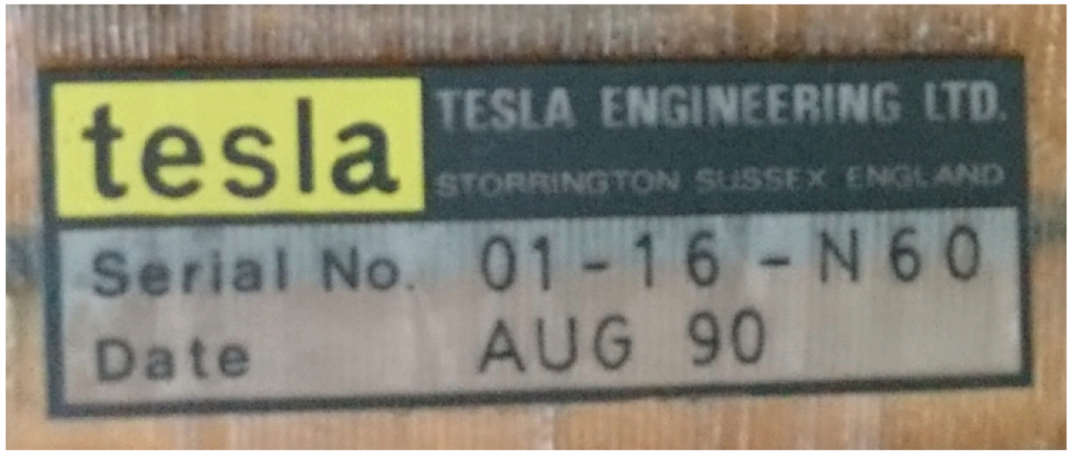
Specifications from FLUKA

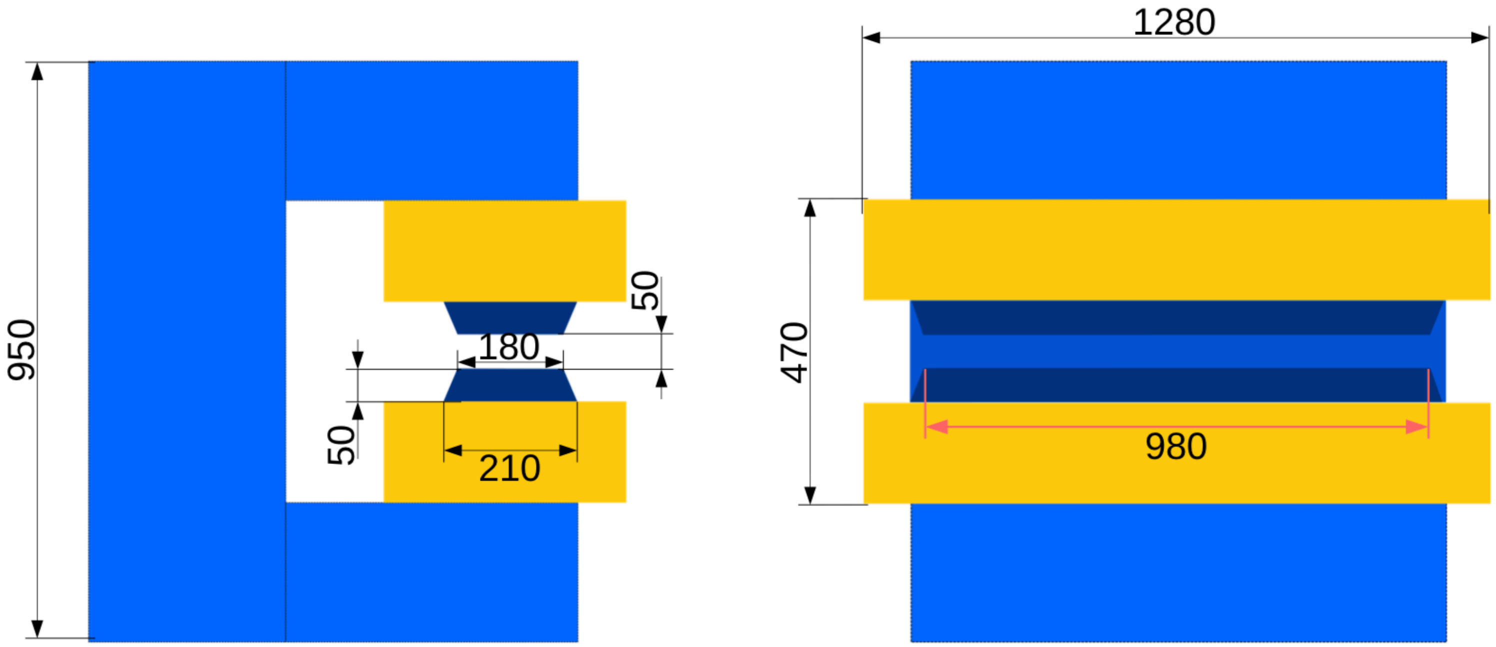
From Kyle:

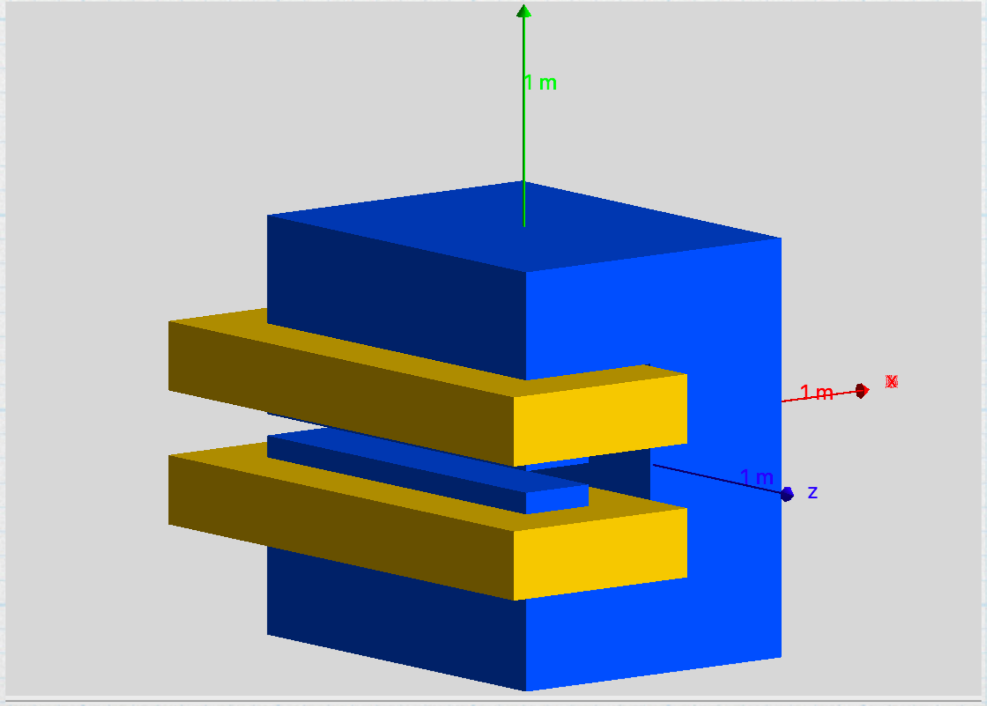
Technical Specifications	
Target	
Material	W
Thickness (z)	10 μm
Width (y)	20 cm
Height (x)	20 cm
Collimators	
Material	Pb
Length	50 cm
Inner Radius	0.4 cm
Outer Radius	5.0 cm
Separation	50 cm
Magnet	
Field Strength	Up to 1.4 T
Effective Length (z)	98 cm
Effective Width (y)	18 cm
Effective Height (x)	5 cm
Yoke Material	Fe
Coil Material	Cu (hollow; water cooled)
Total Length (z)	128 cm
Total Width (y)	73.75 cm
Total Height (x)	97 cm
Detector	
Material	LYSO Scintillator
Crystal Size	0.5 mm $\times$ 2 mm
Screen Size	30 cm $\times$ 10 cm

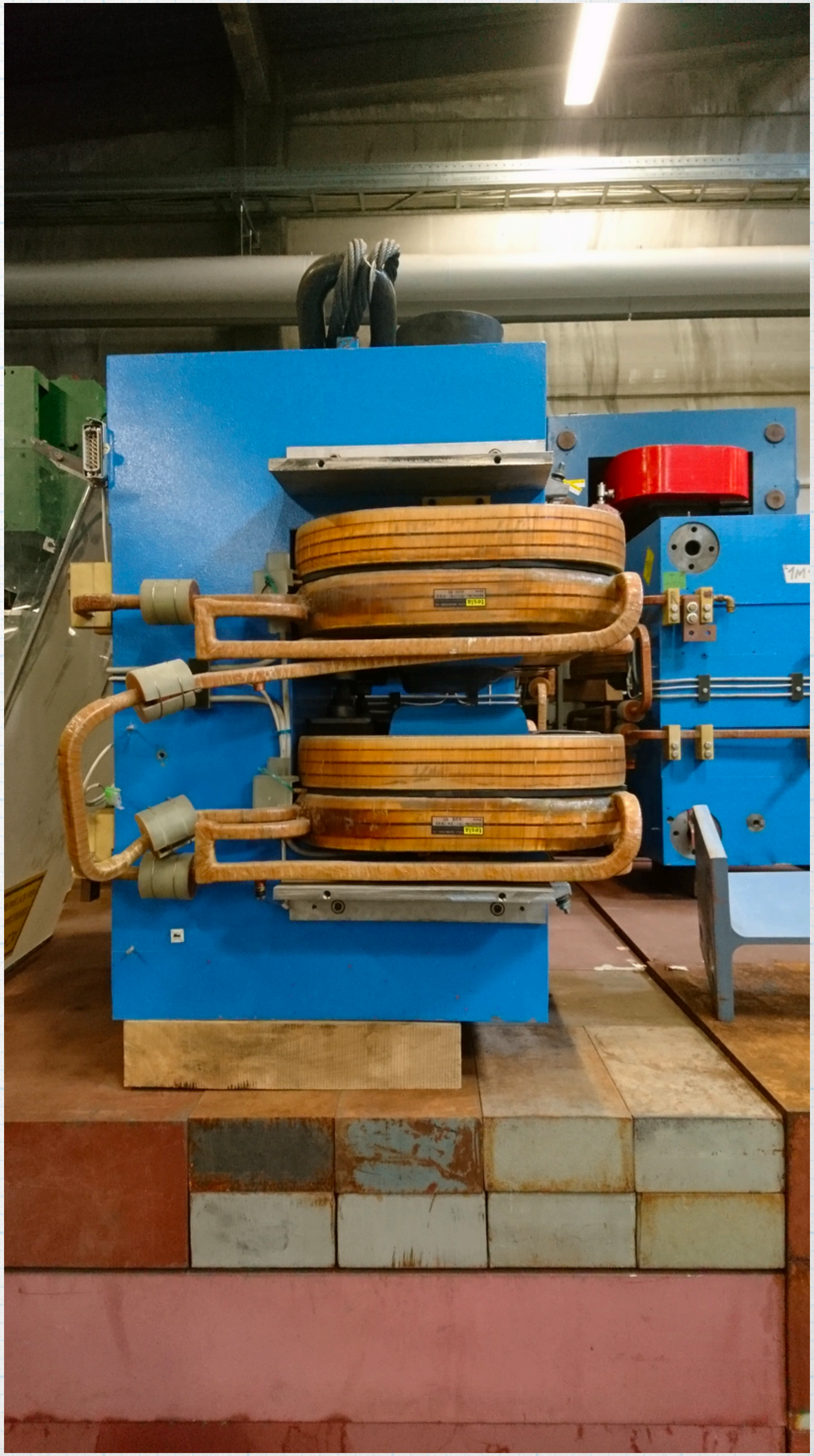


C-shape magnet



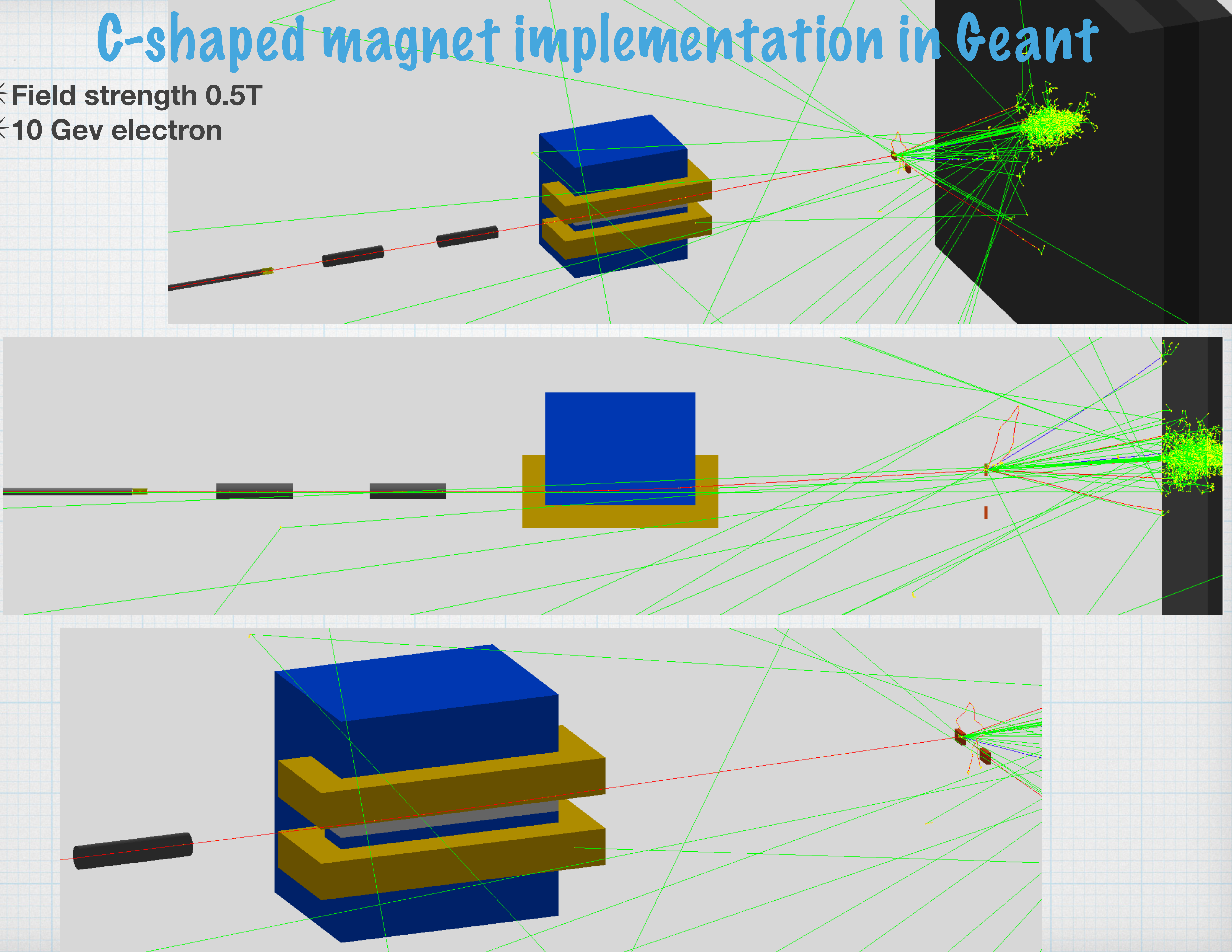




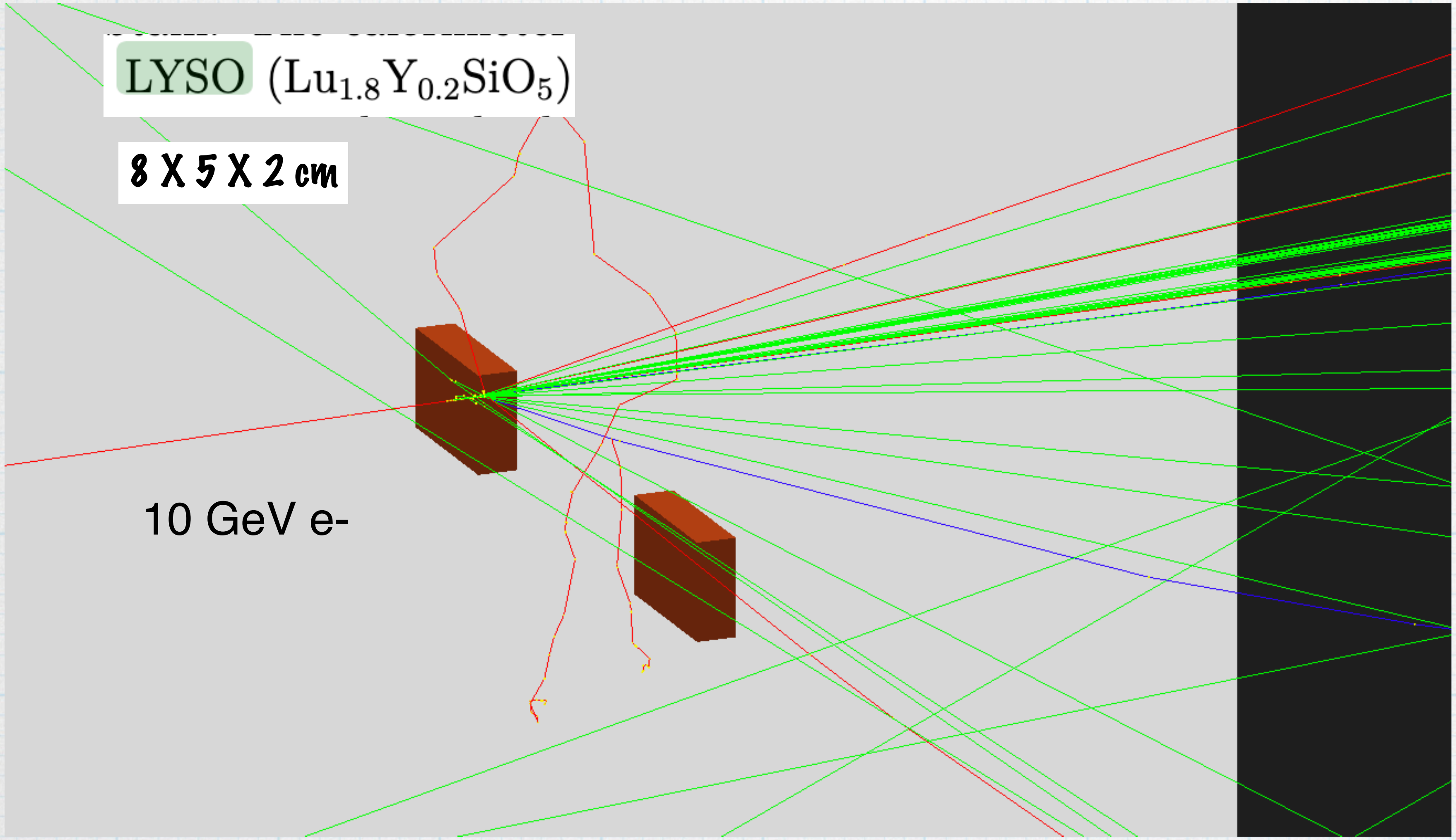


C-shaped magnet implementation in Geant

- Field strength 0.5T
- 10 Gev electron



LYSO calorimeters

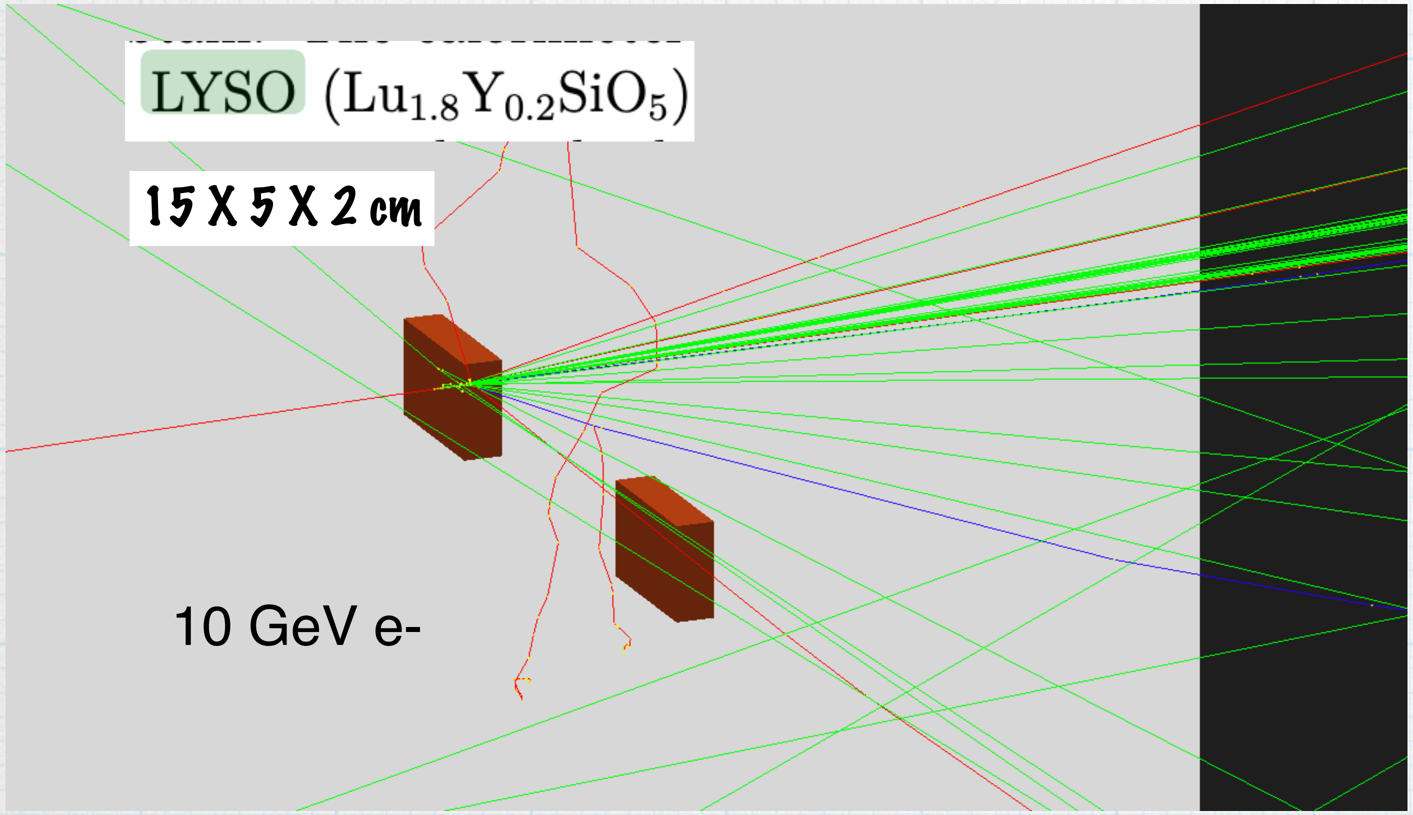


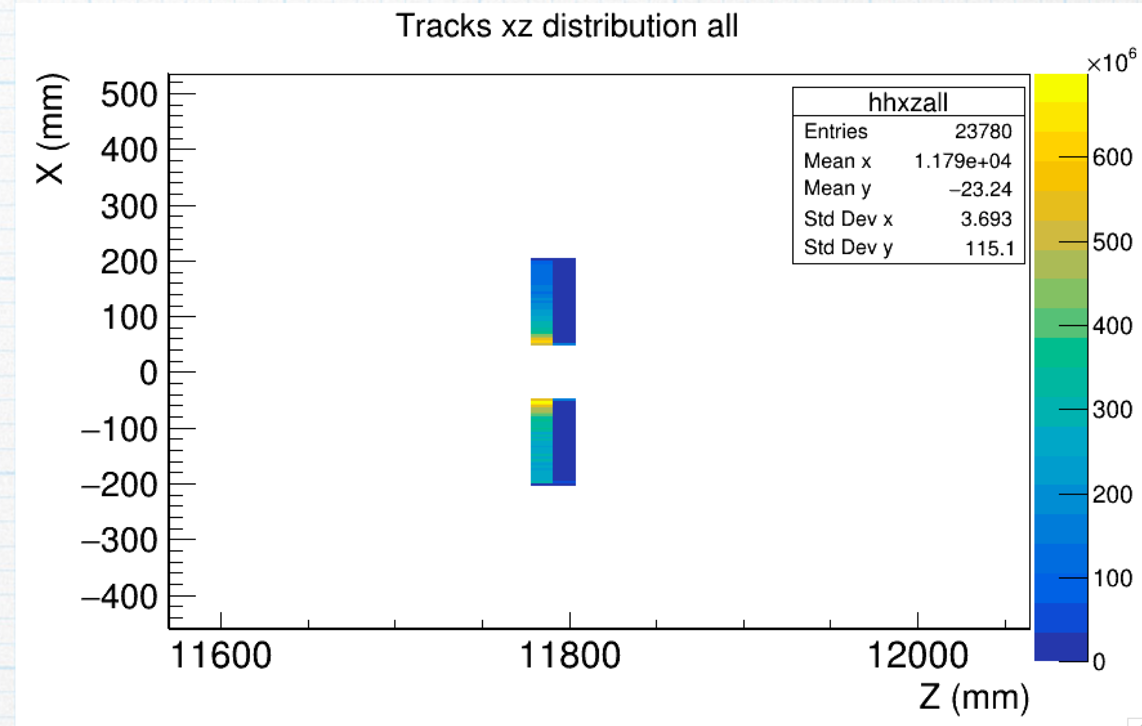
LYSO Ce scintilltion crystal, Cerium doped Lutetium Yttrium Silicate scintillation crystal, LYSO Ce scintillator crystal, 2 x 2 x 20mm

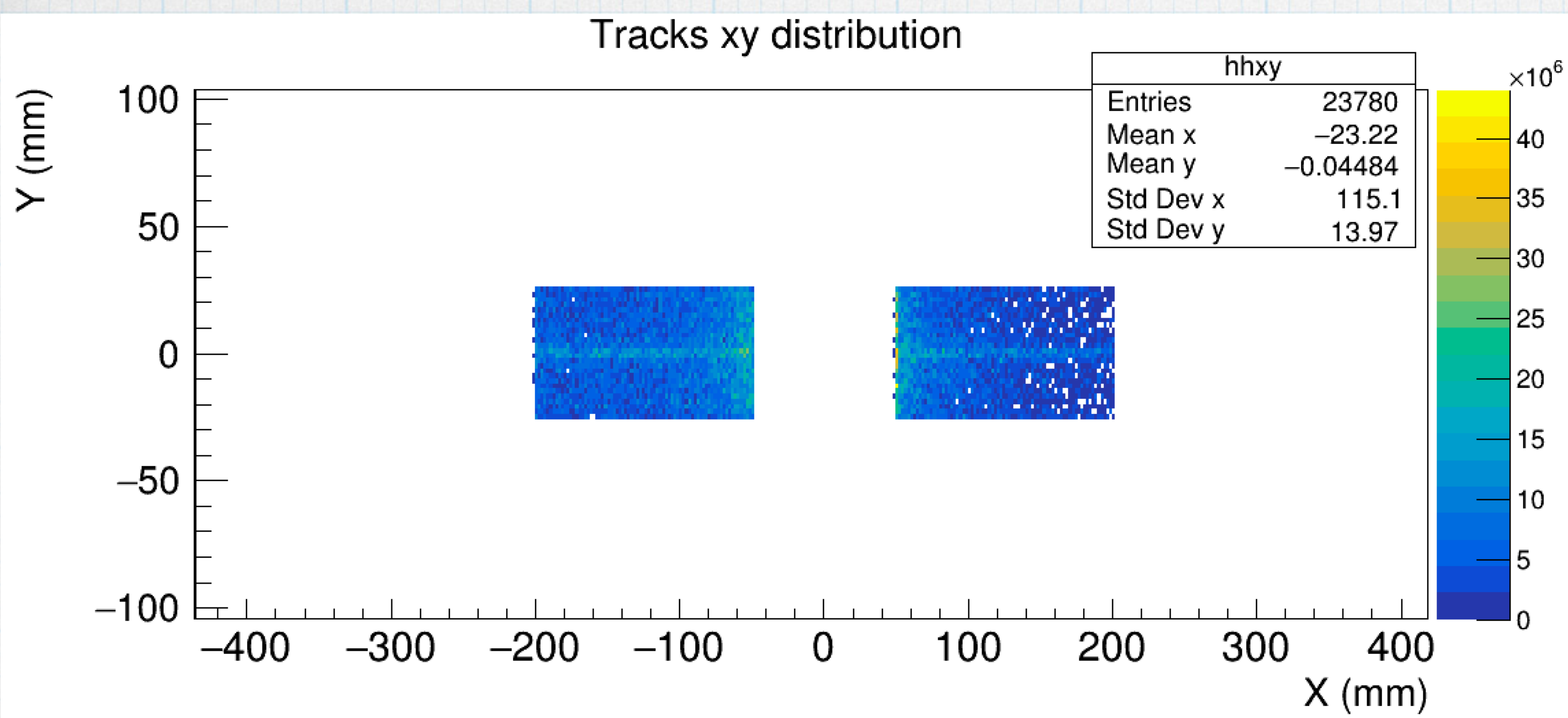
$39.00

- The scintillators are modelled as a 8x5x2 cm (x:y:z) layer of lyso material (a 5cm thick layer of kapton should be behind)
- the length in x is only 8cm to avoid the 'peaks' in electron, positron and photon density as these may overwhelm the scintillators.
- The crystal (bin) size of the scintillators are 2 x 1 mm (finer segmentation in x; the deflection direction) giving 25 x 80 bins.
- It's possible to increase this to 25 x 100 bins using 2 x 0.8 mm crystals.
- This is not completely finalised

LYSO calorimeters

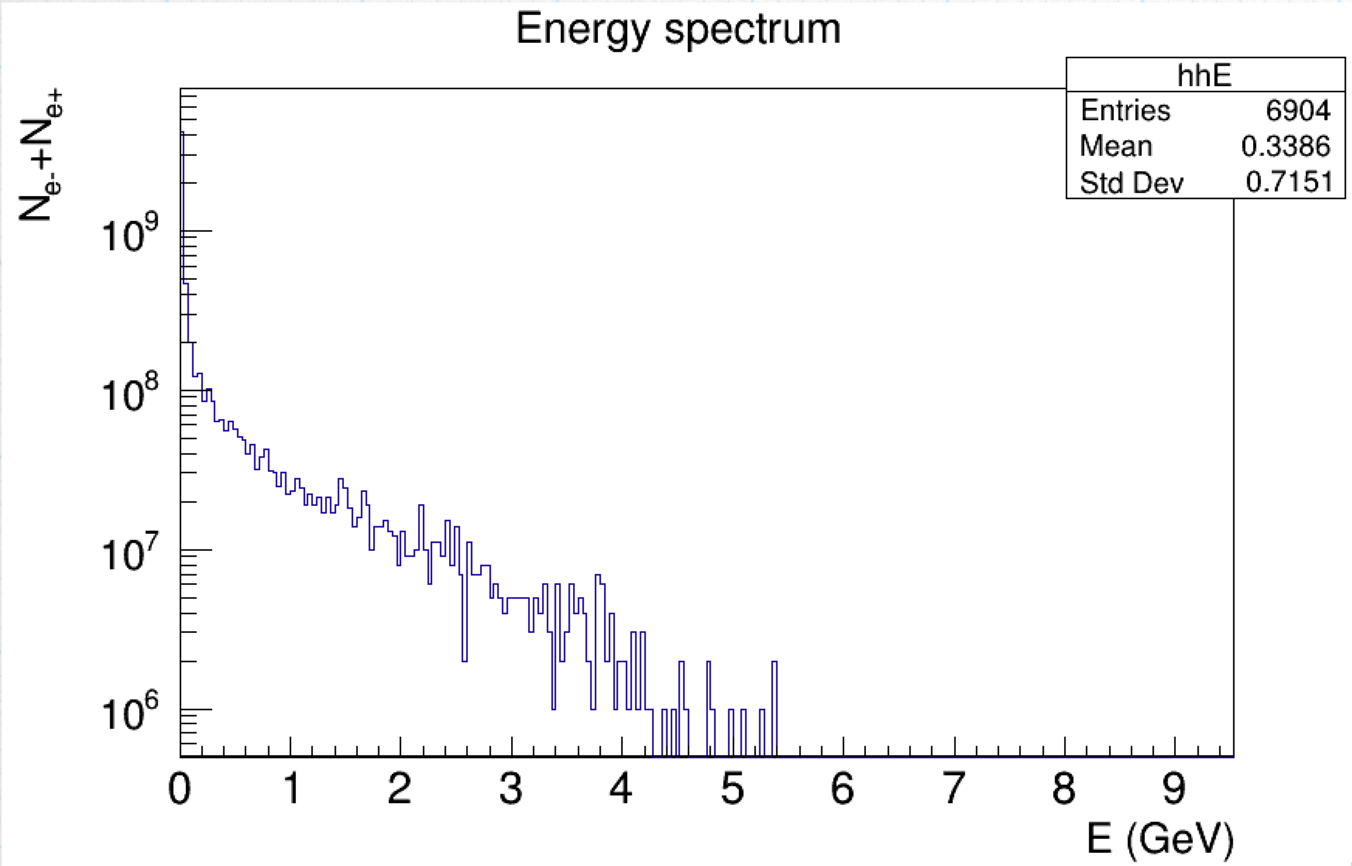


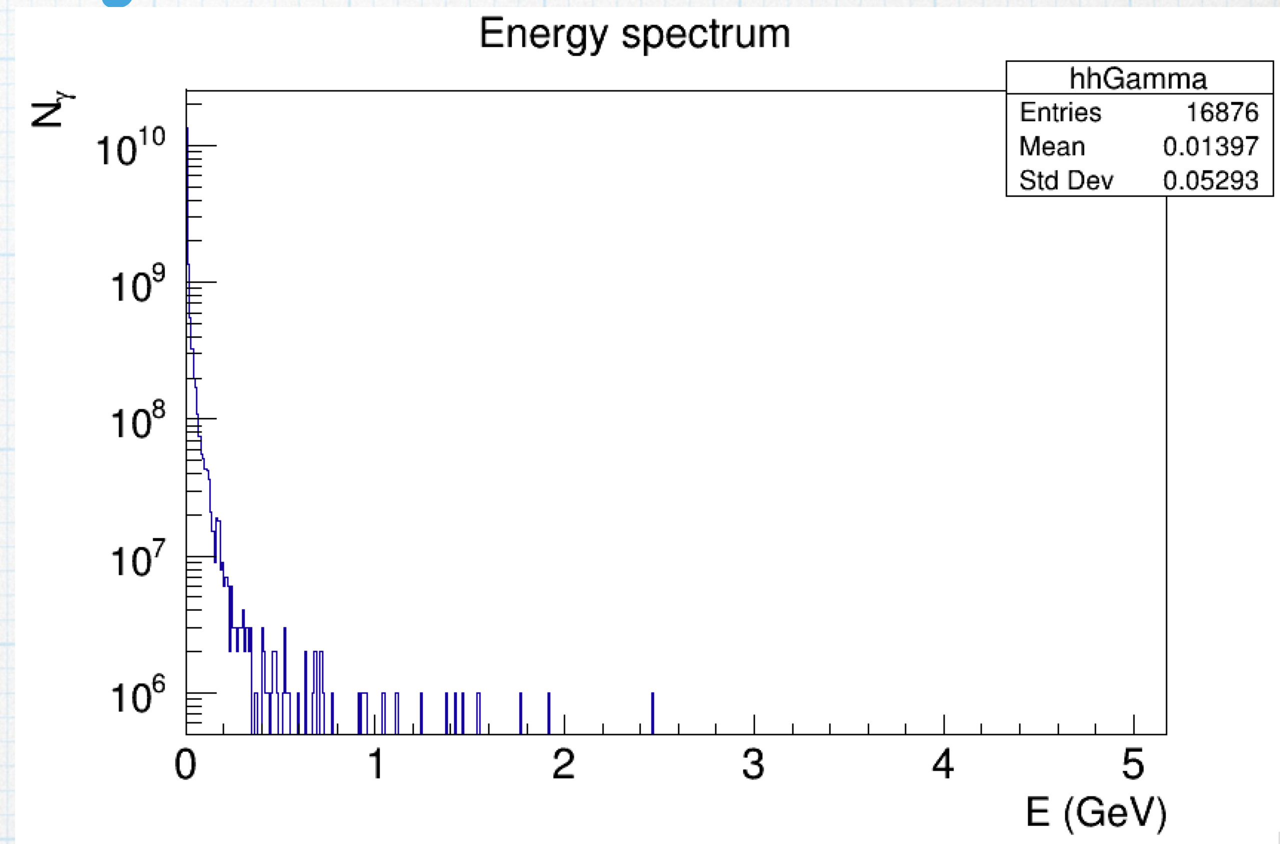


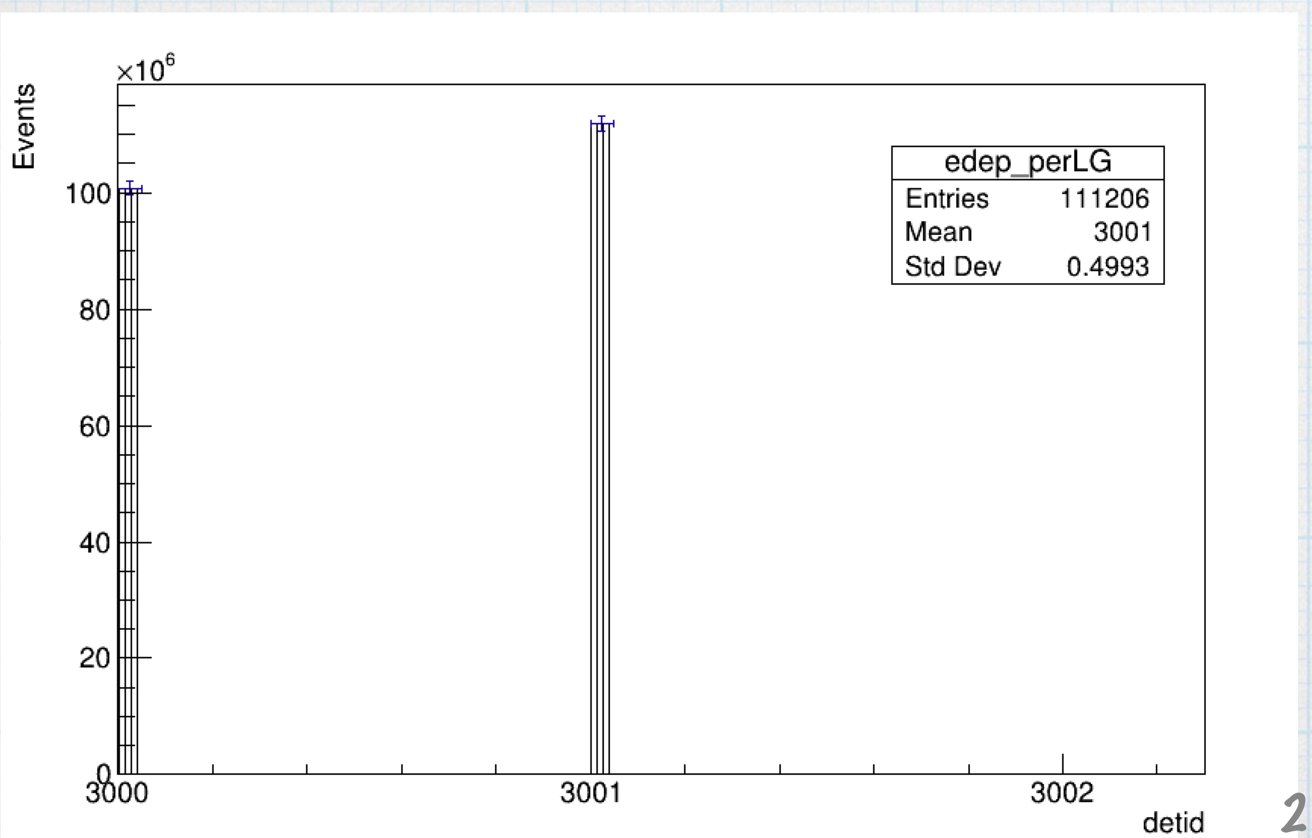


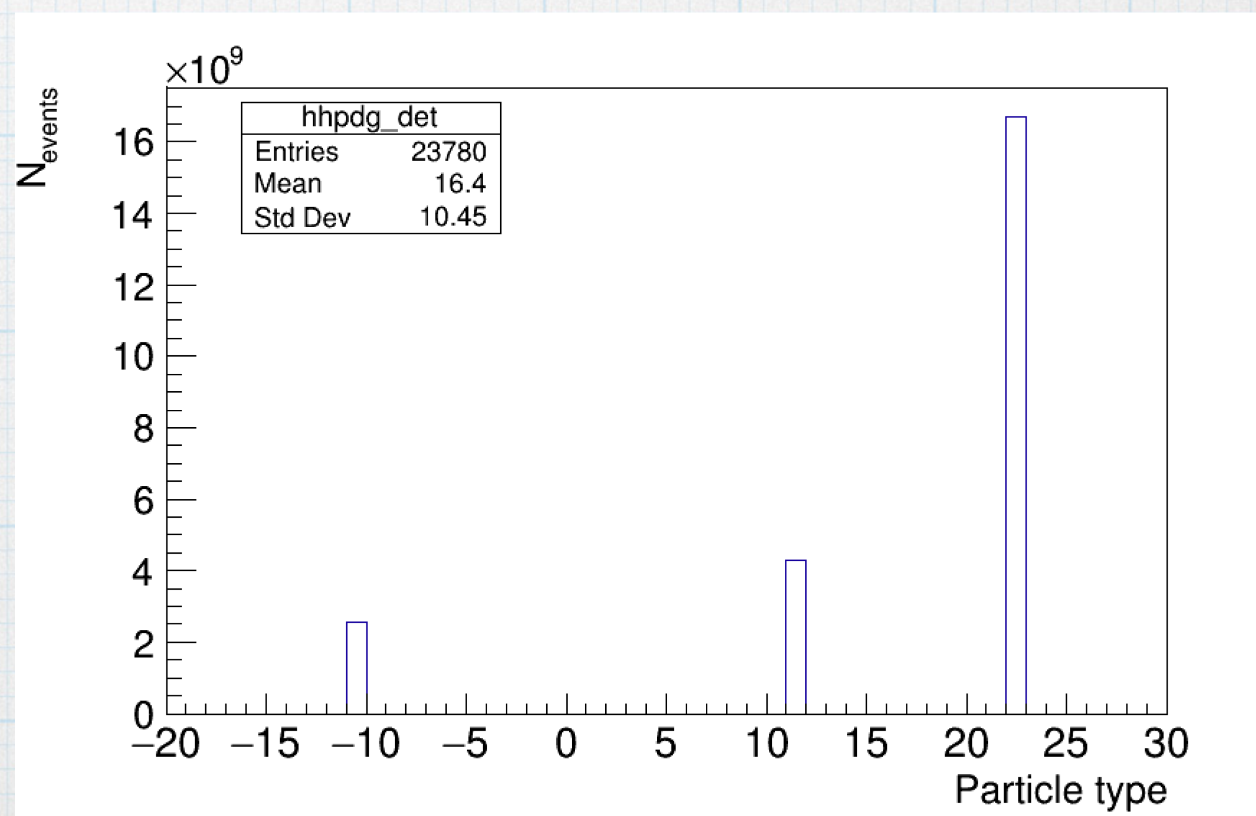
- ✳ The scintillators are modelled as a 15x5x2 cm (x:y:z) layer of lyso material
- ✳ The crystal (bin) size of the scintillators are 2 x 1 mm (finer segmentation in x; the deflection direction) giving 25 x 300 bins.

Control plots

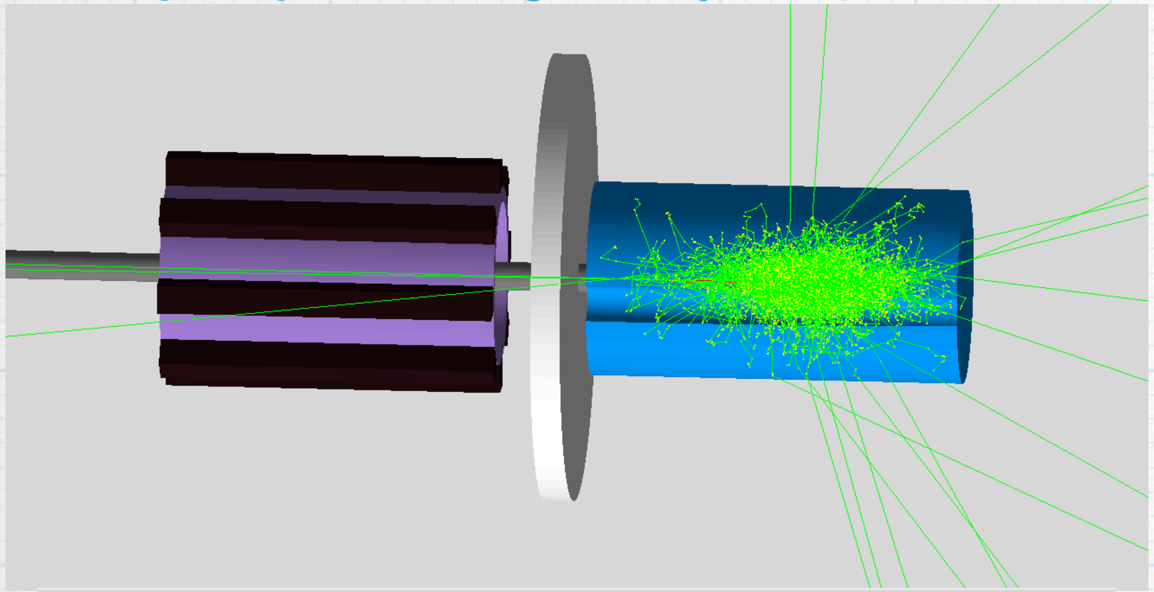






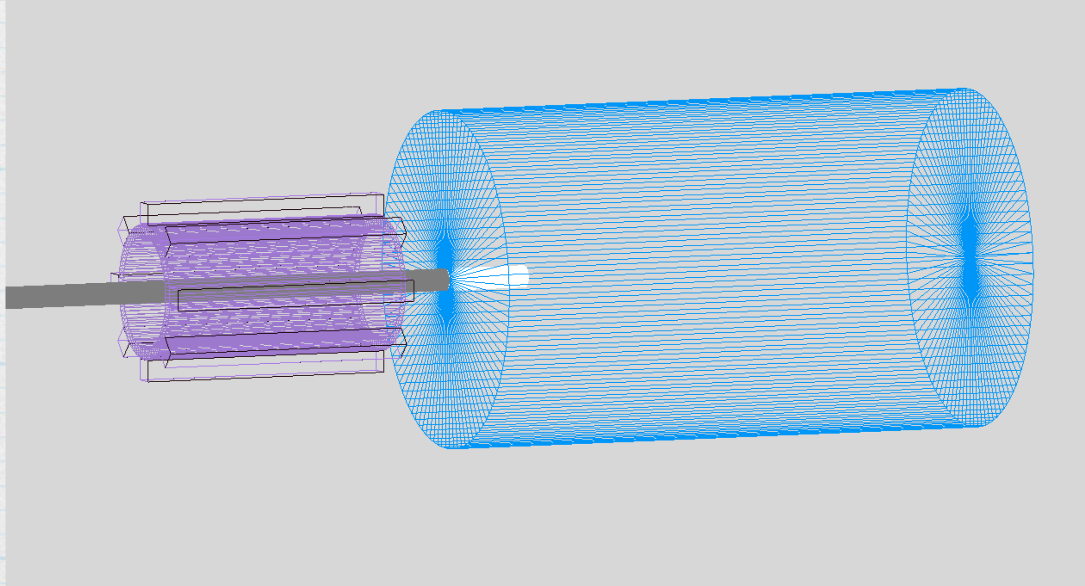


Gamma Monitor & BeamDump: new design

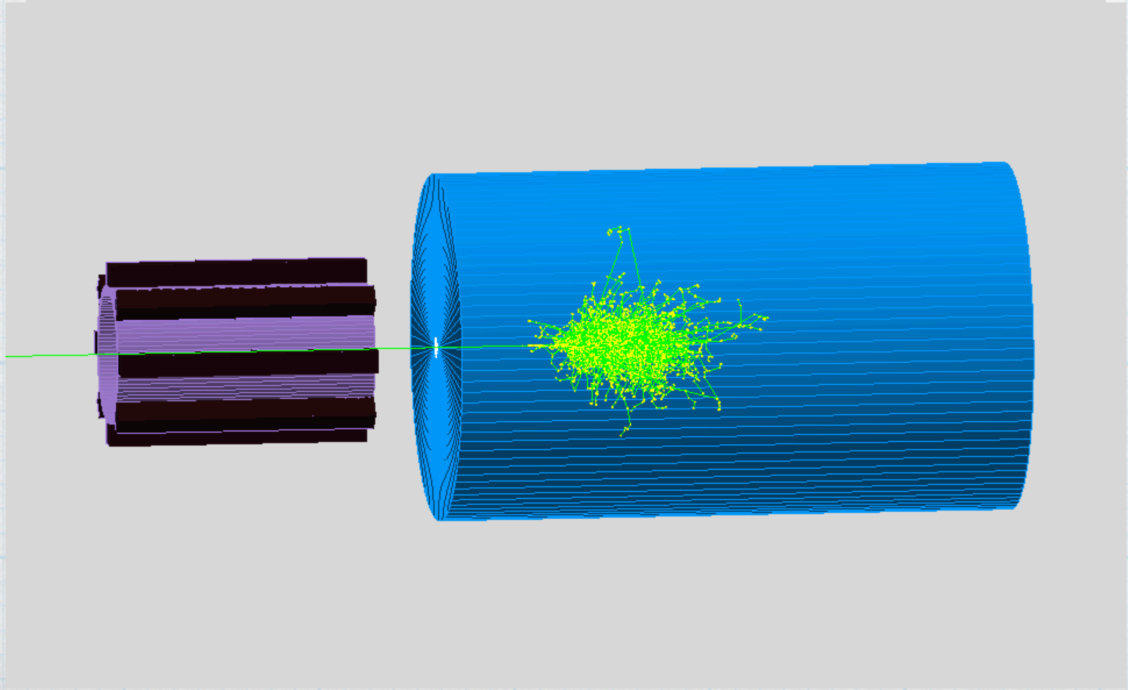


- Distance between Monitor and Dump 10 cm

  - Beam Pipe R 1.9 cm
  - Beam Dump: R=15 cm, L=50 cm; Insert AL 6.5 cm
  - Absorber Pb 4 cm
  - GM Support: No

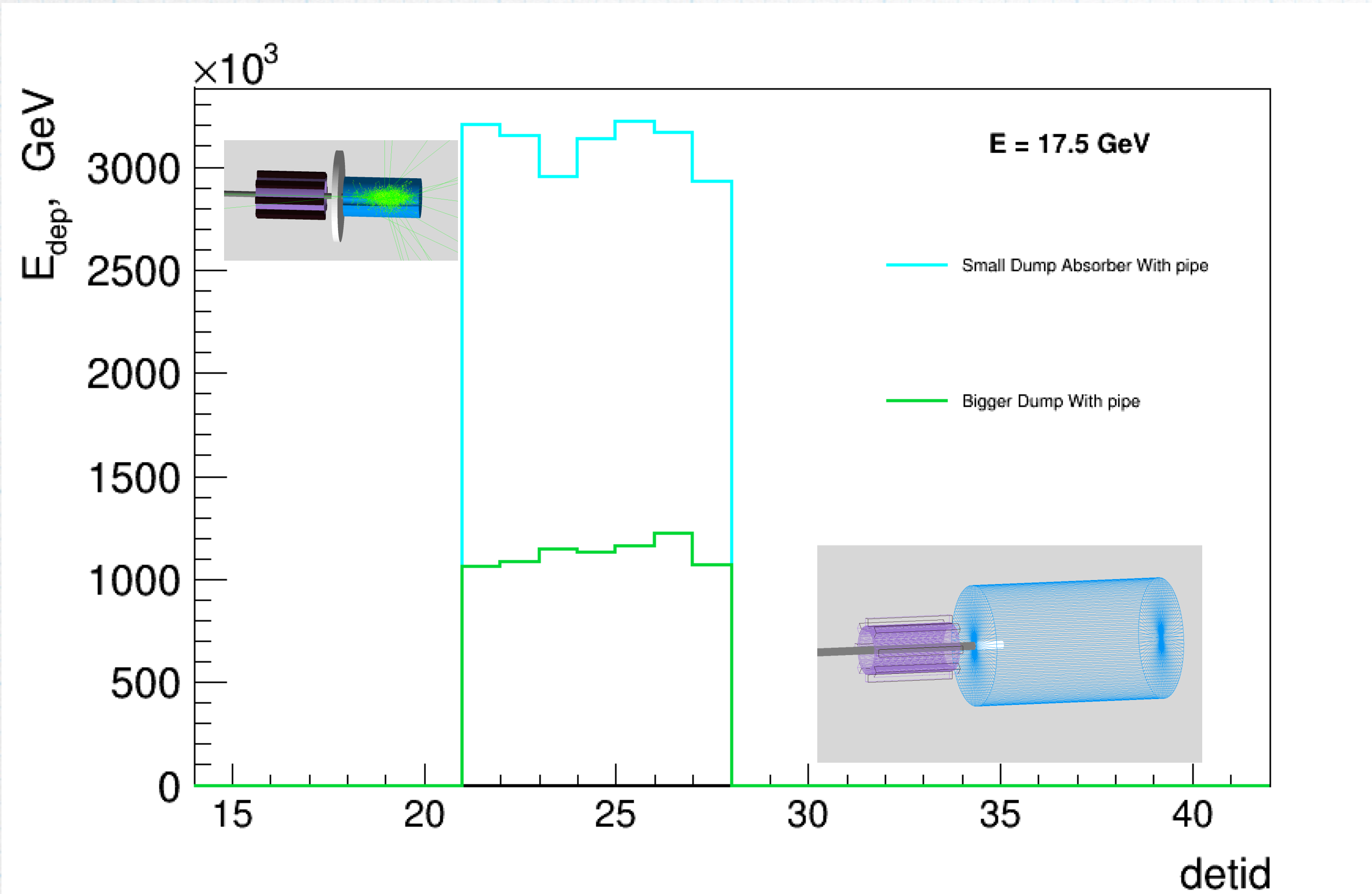


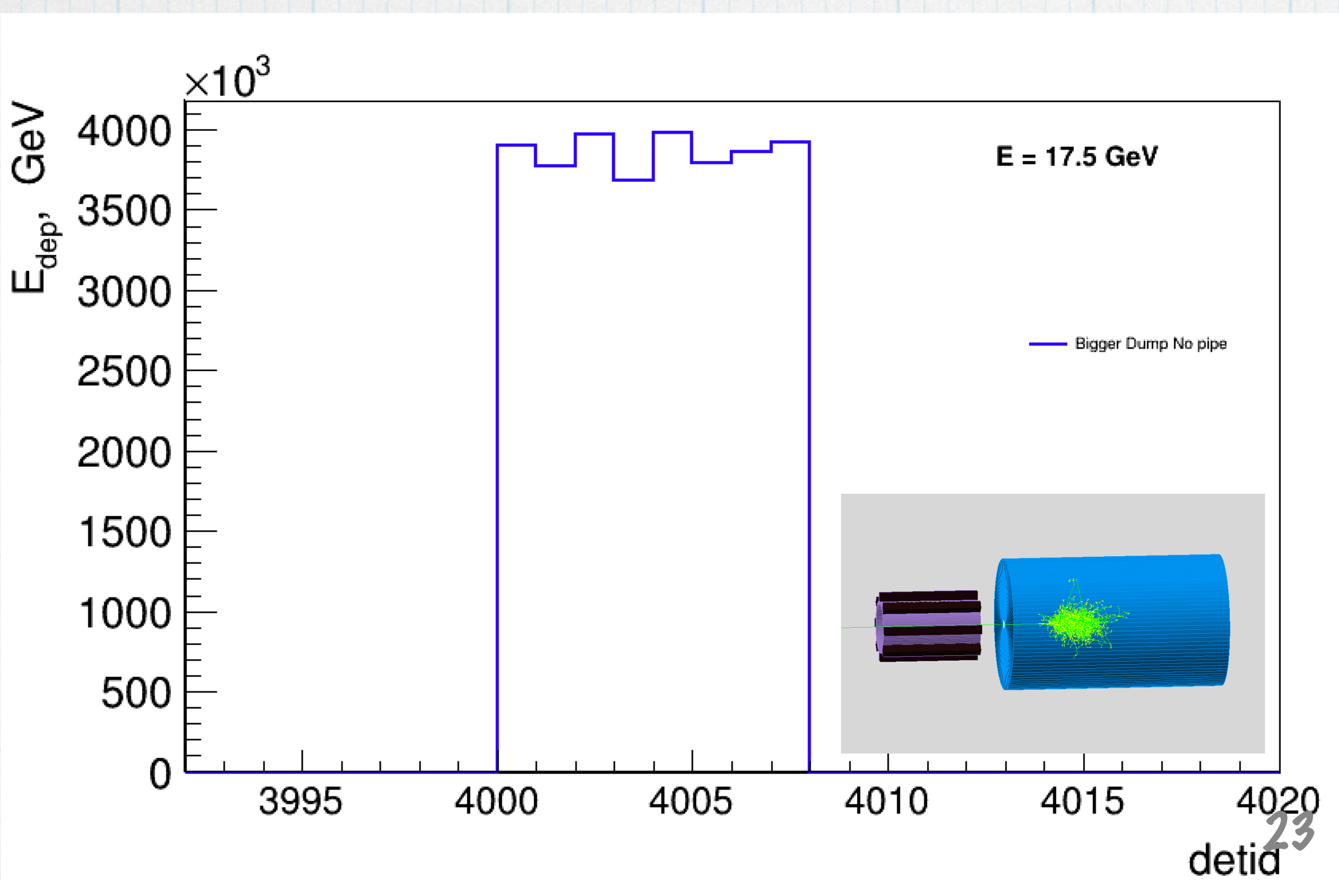
  - Beam Pipe R 1.9 cm
  - Beam Dump: R=30 cm, L=100 cm Insert Air, 1.9 cm, 15 cm length
  - GM Support: Stainless Steel of 1 cm thickness



  - No beam pipe
  - Beam Dump: R=30 cm, L=100 cm Insert Air, 1.9 cm
  - GM Support: Stainless Steel of 1 cm thickness

Performance

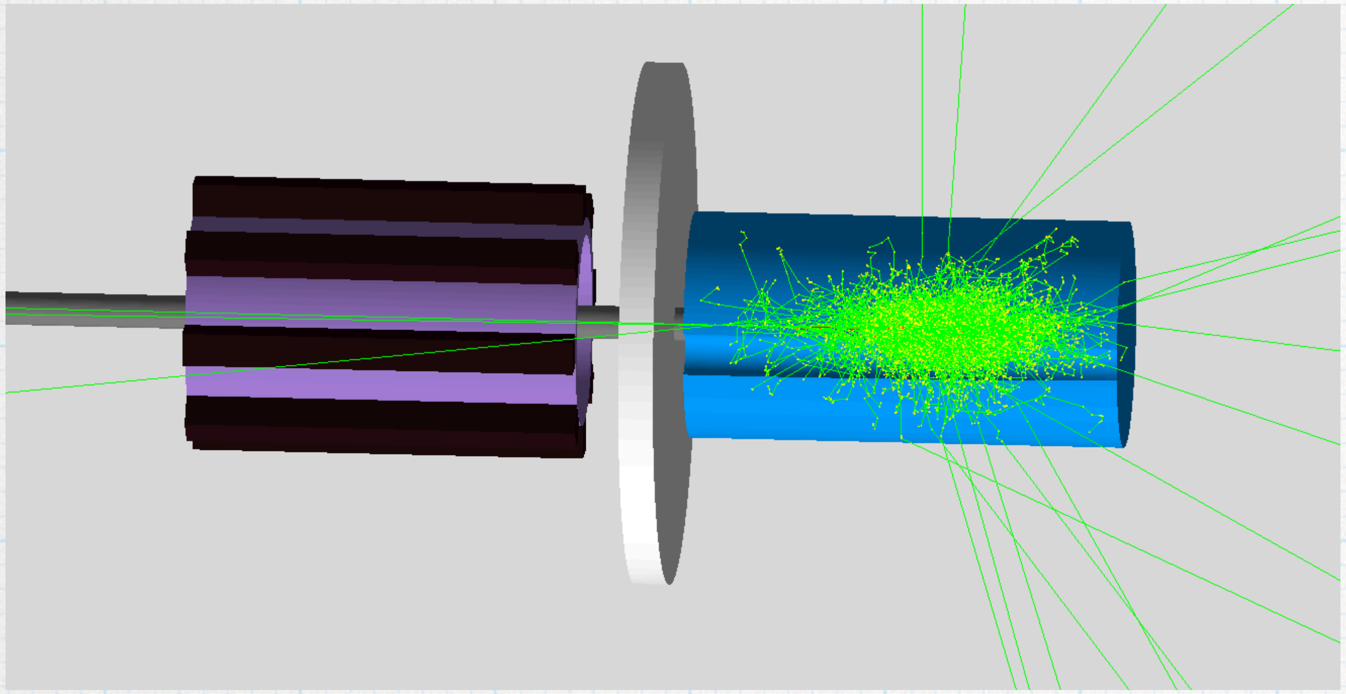




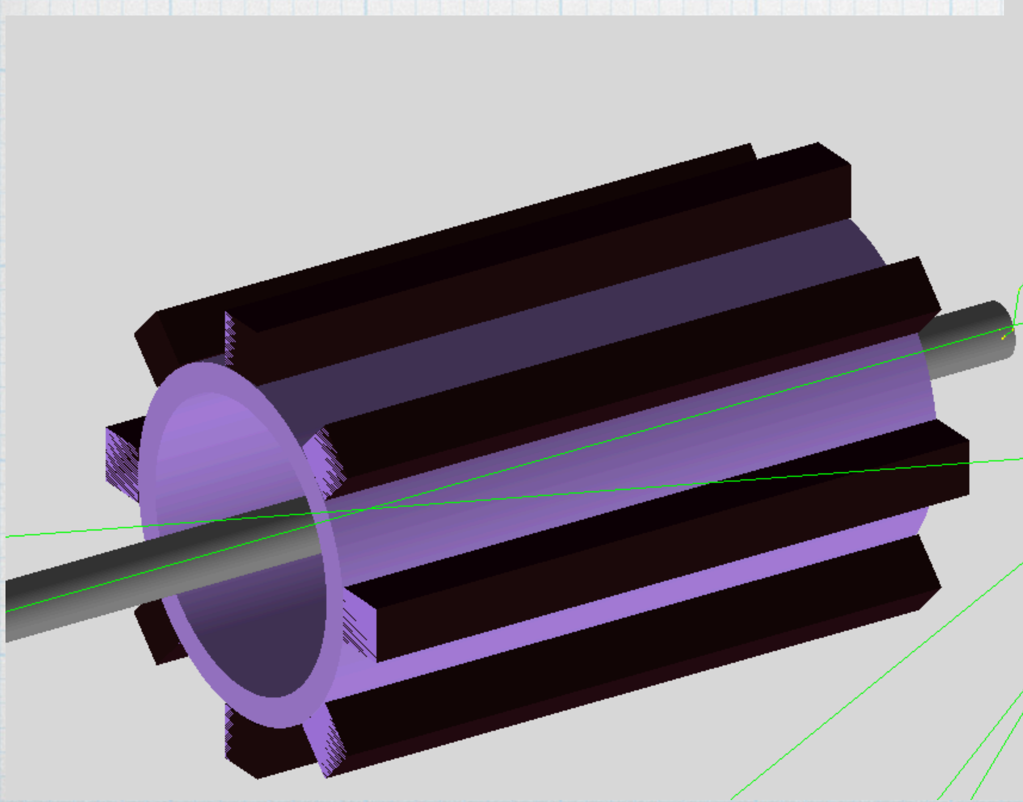
✴ 100 BX At high laser intensities ξ =2.6 (1J)

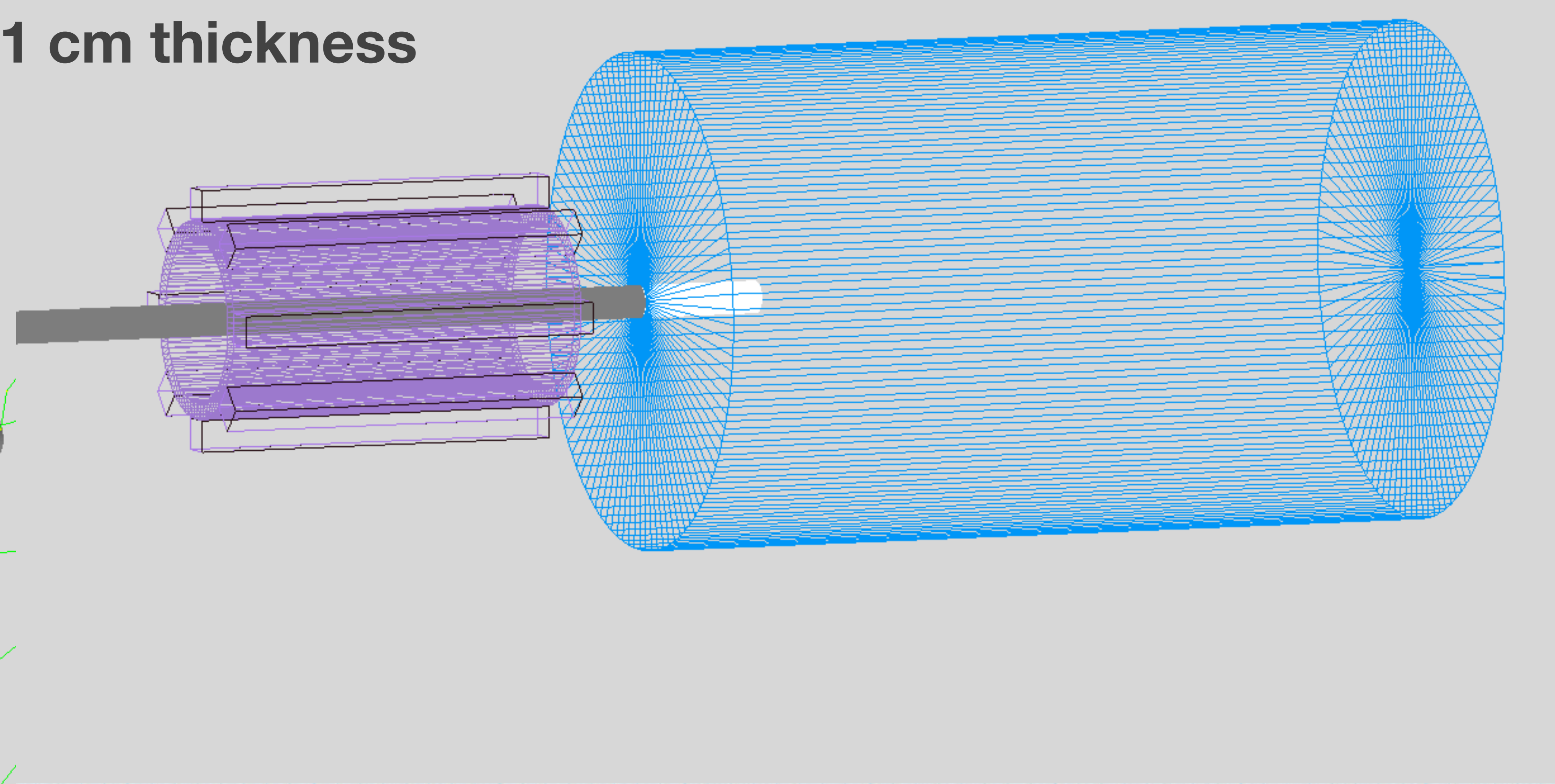
- Depending on exact chemical composition of LG blocks (TF1 Or TF101) max acceptable dose could be in the range of 5-100 Gy, which roughly means for
- 1st configuration 75-1500 hours
- 2nd Configuration 180-3600 hours
- 3d Configuration 59-1200 hours
- The environment is more harsh without beam pipe;
- The bigger hole in the dump could further improve the performance

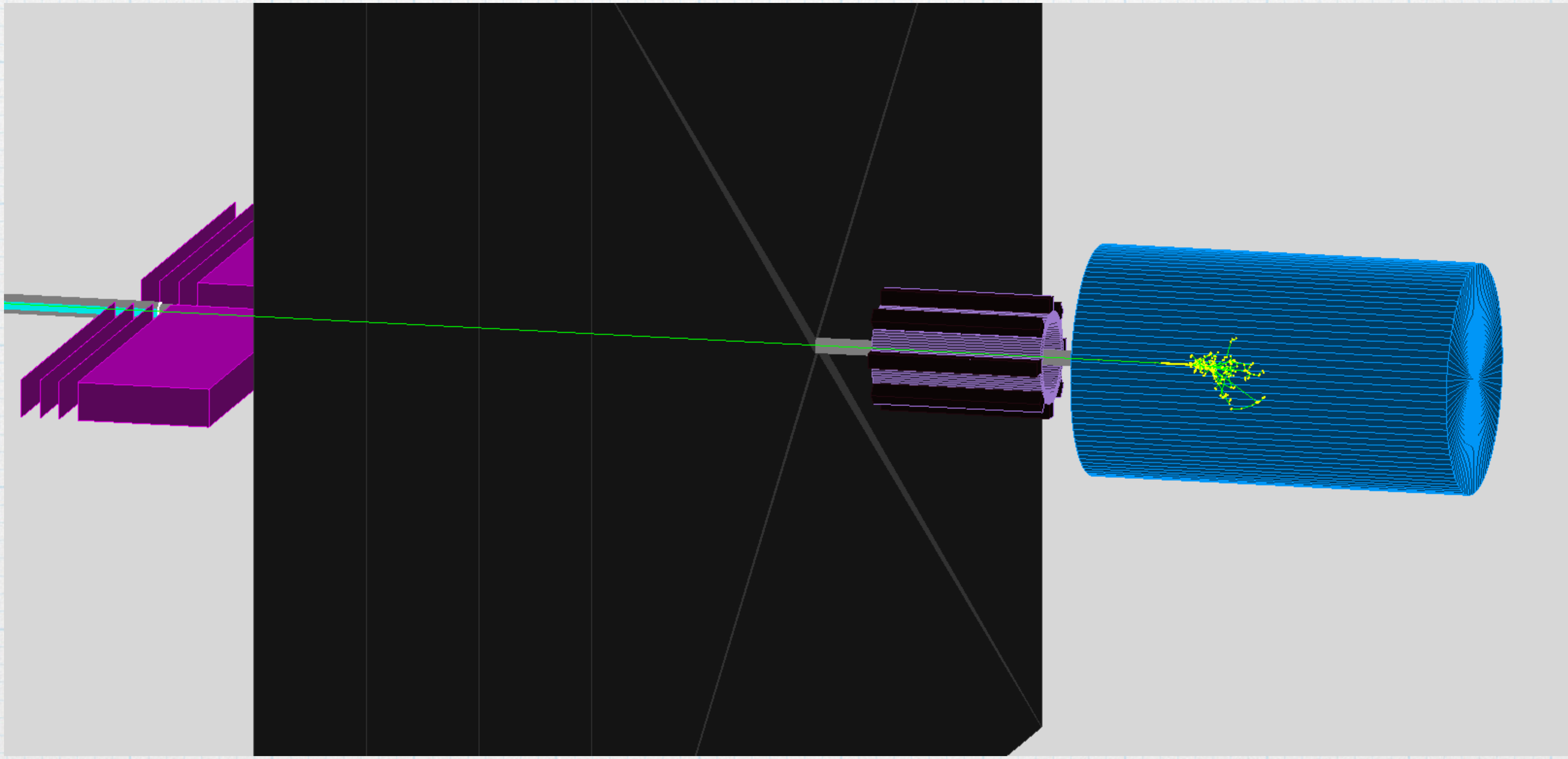
Gamma Monitor & BeamDump: new design



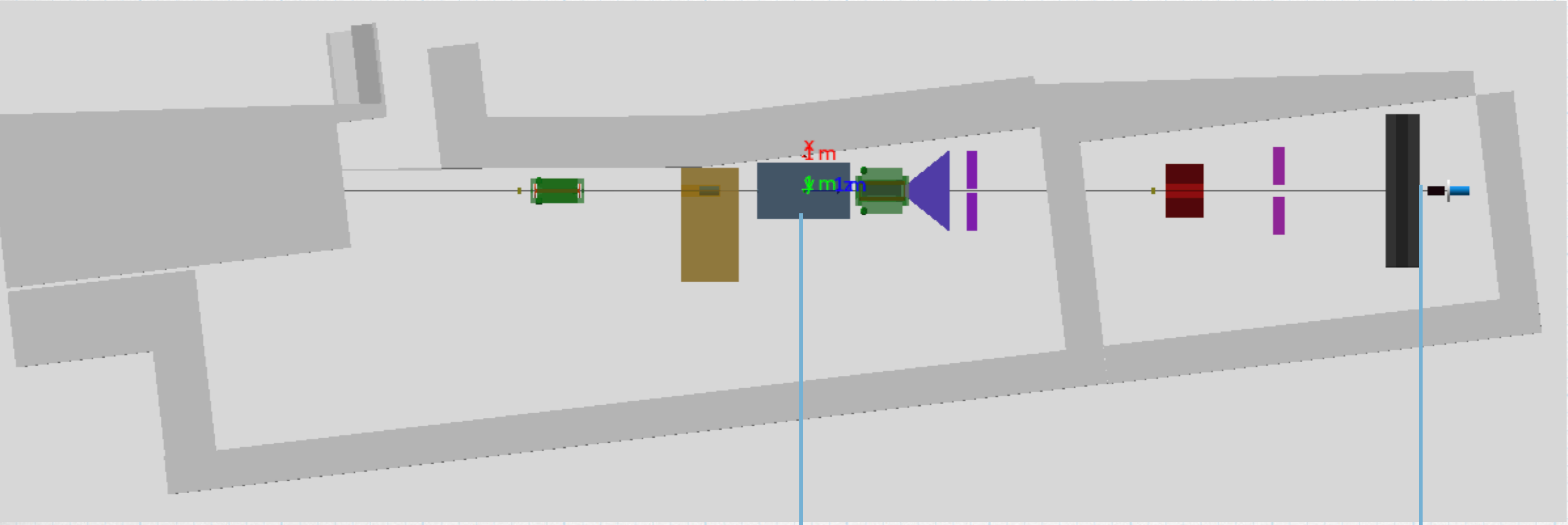
- The implementation of FDS in Luxe geometry with the LG Gamma Monitor made of new LG blocks in front of Cu Dump with a hole of 15 cm,
- LG w/ measures 3.8 × 3.8 cm^2, length is 45 cm
- Wrapped with Aluminium foil of 0.016 mm (typical household foil; no account for air)
- Distance between Monitor and Dump 10 cm
- Beam Dump: R=30 cm, L=100 cm
- GM Support: Stainless Steel of 1 cm thickness

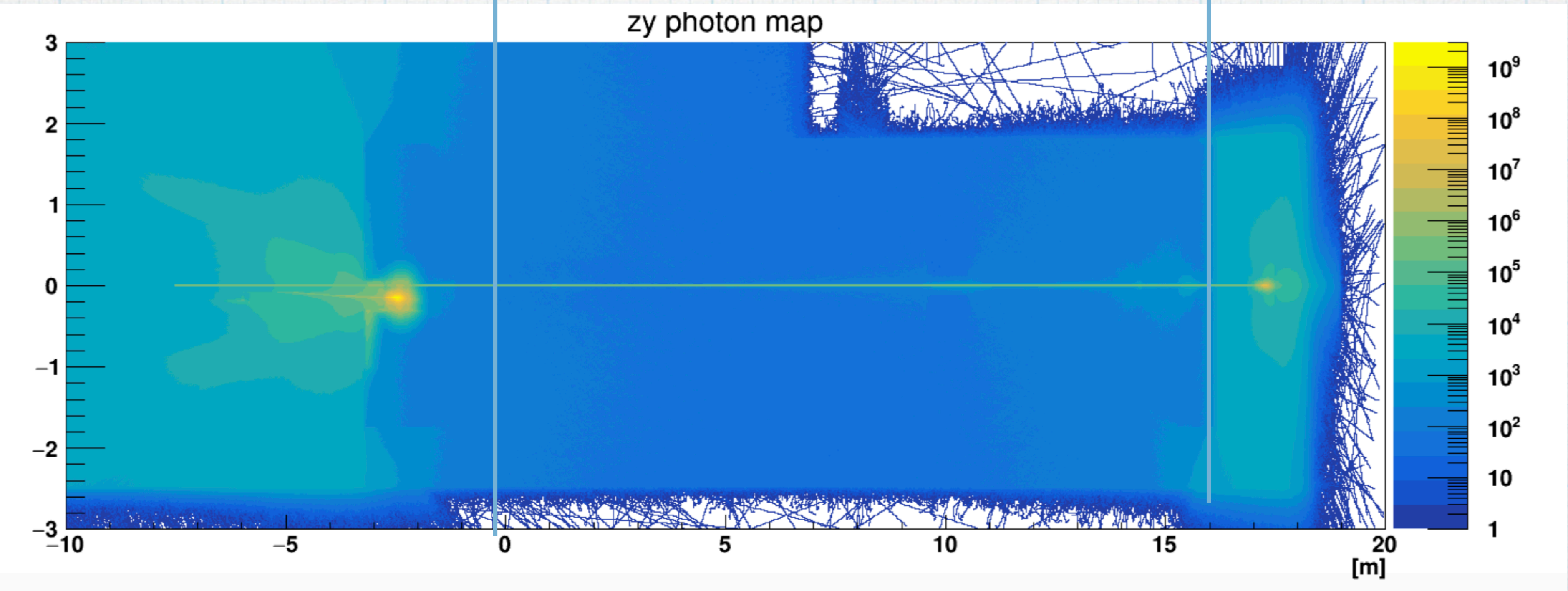




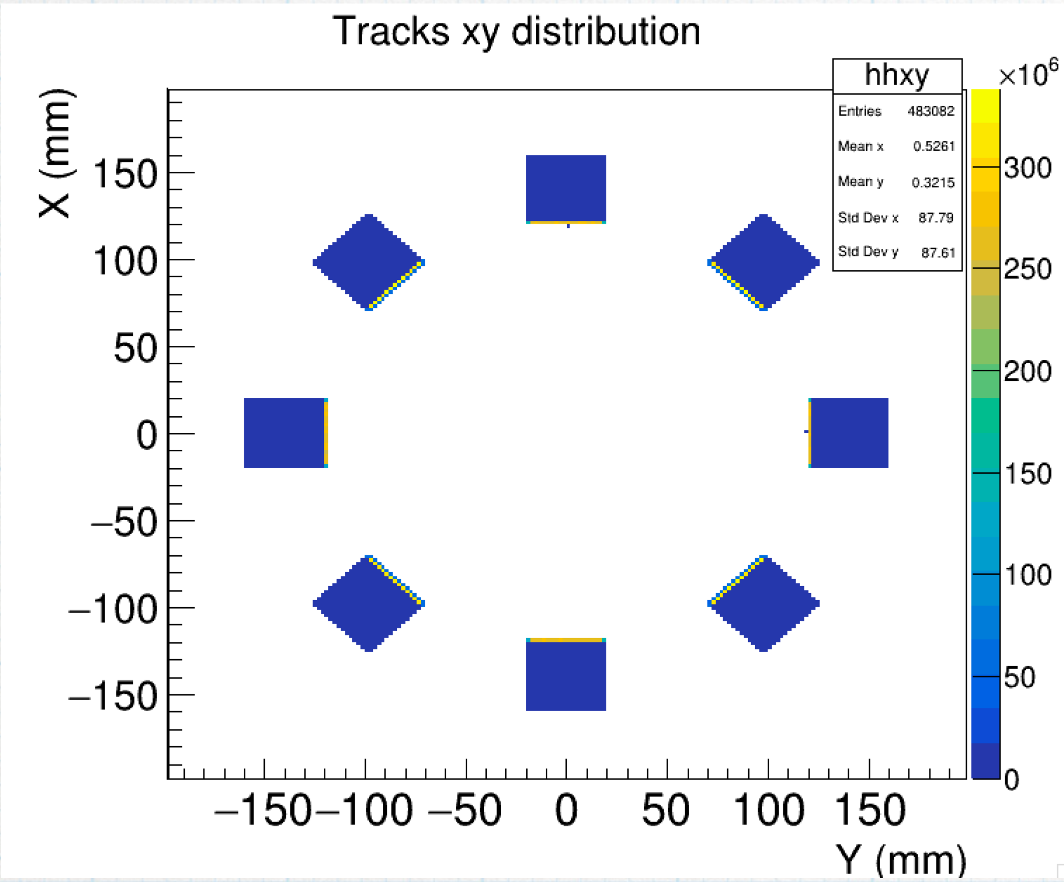


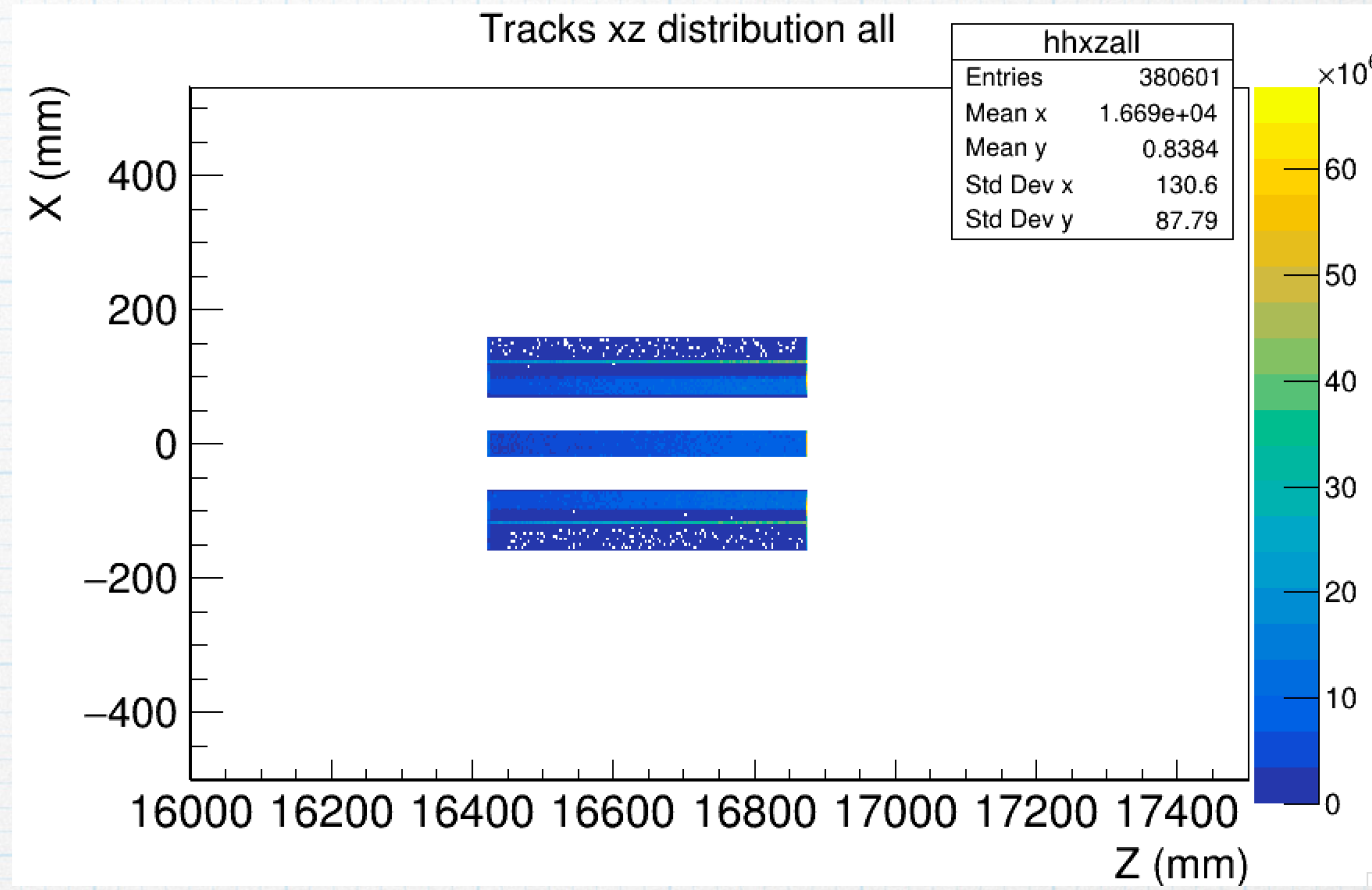
Photon fluxes in Geant 4 setup

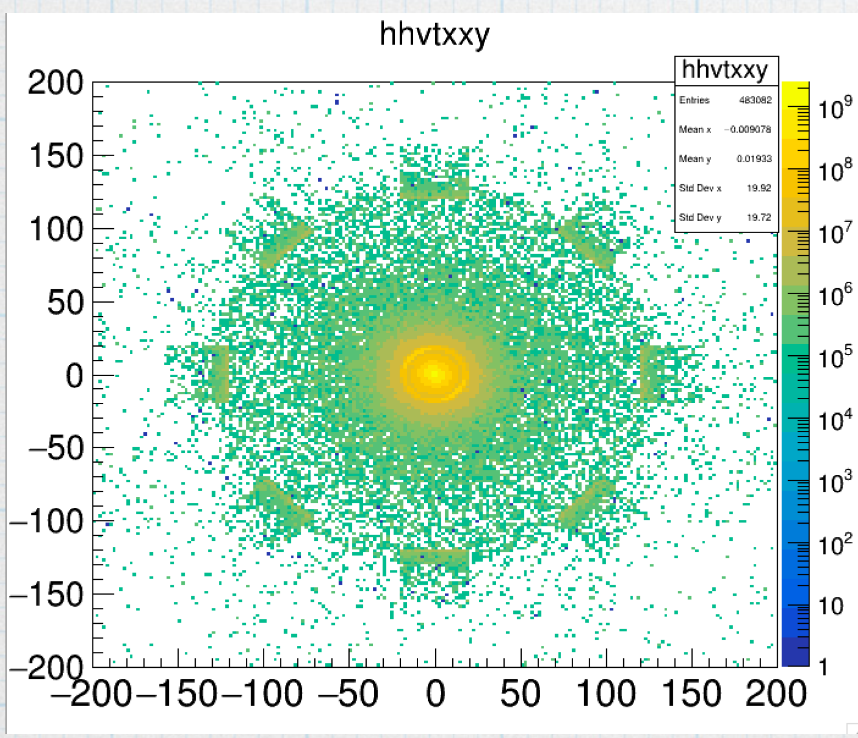


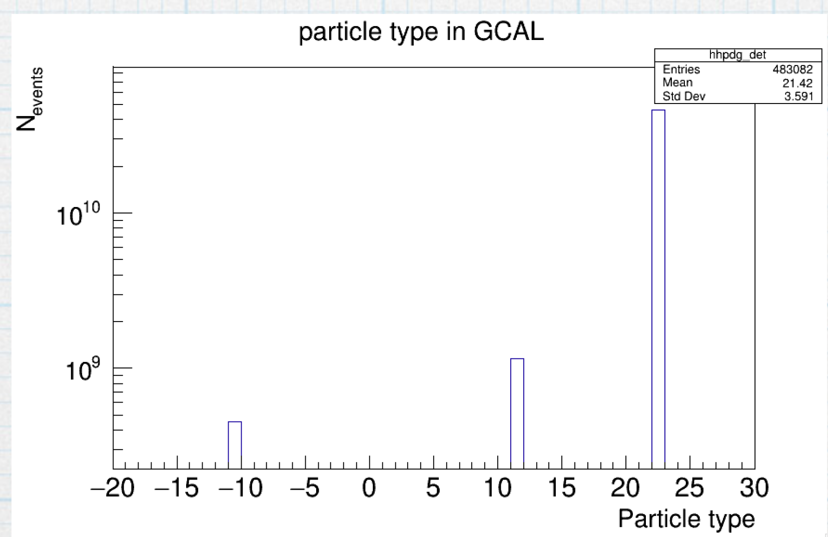


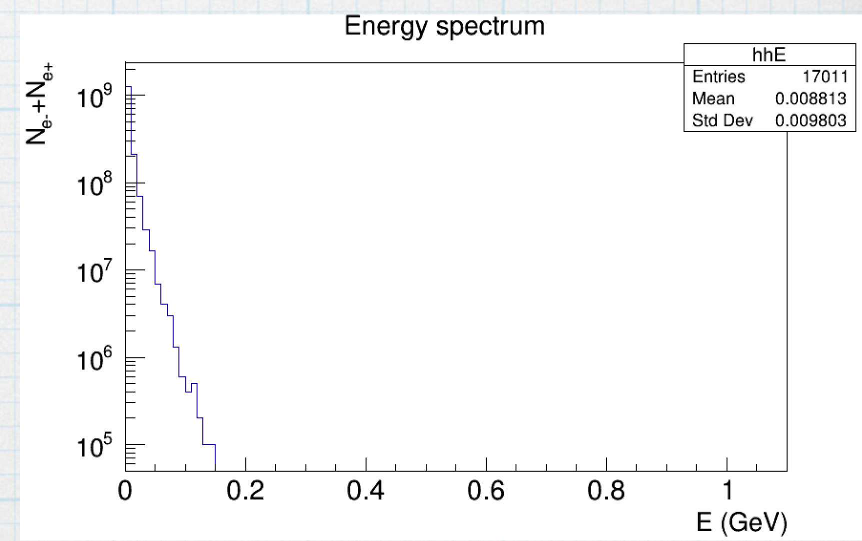
Simulation and Performance



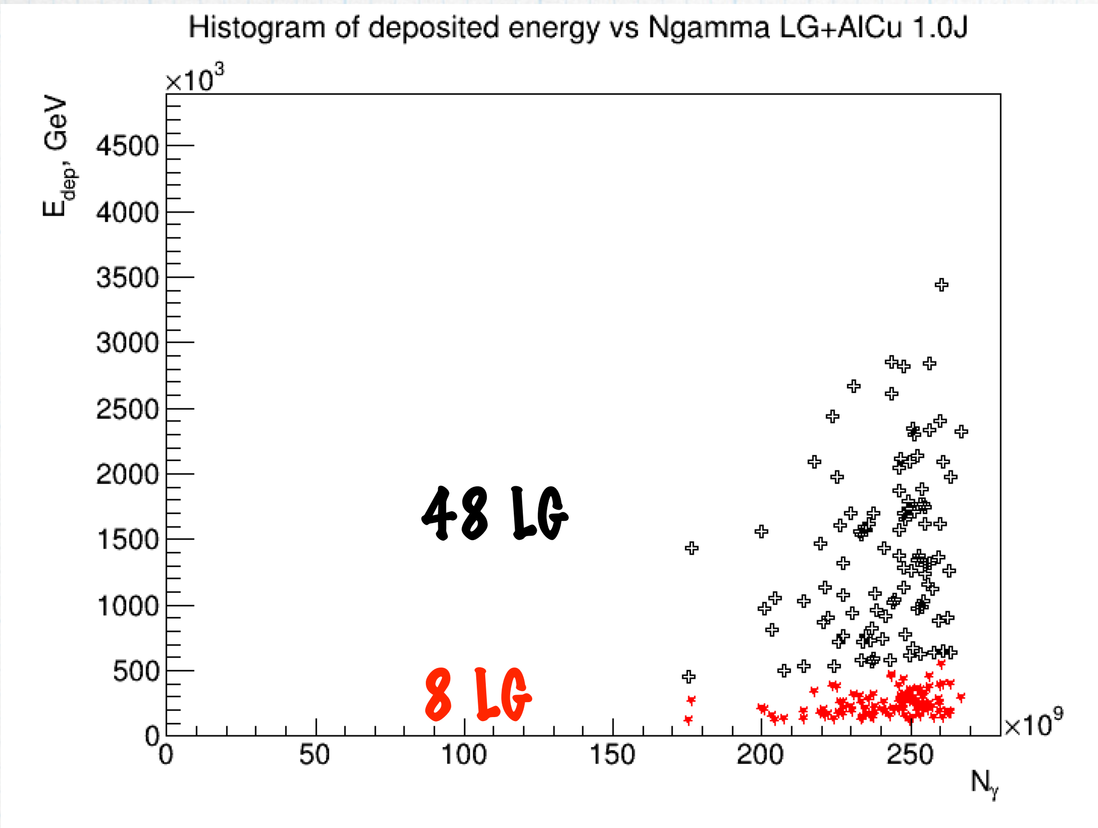


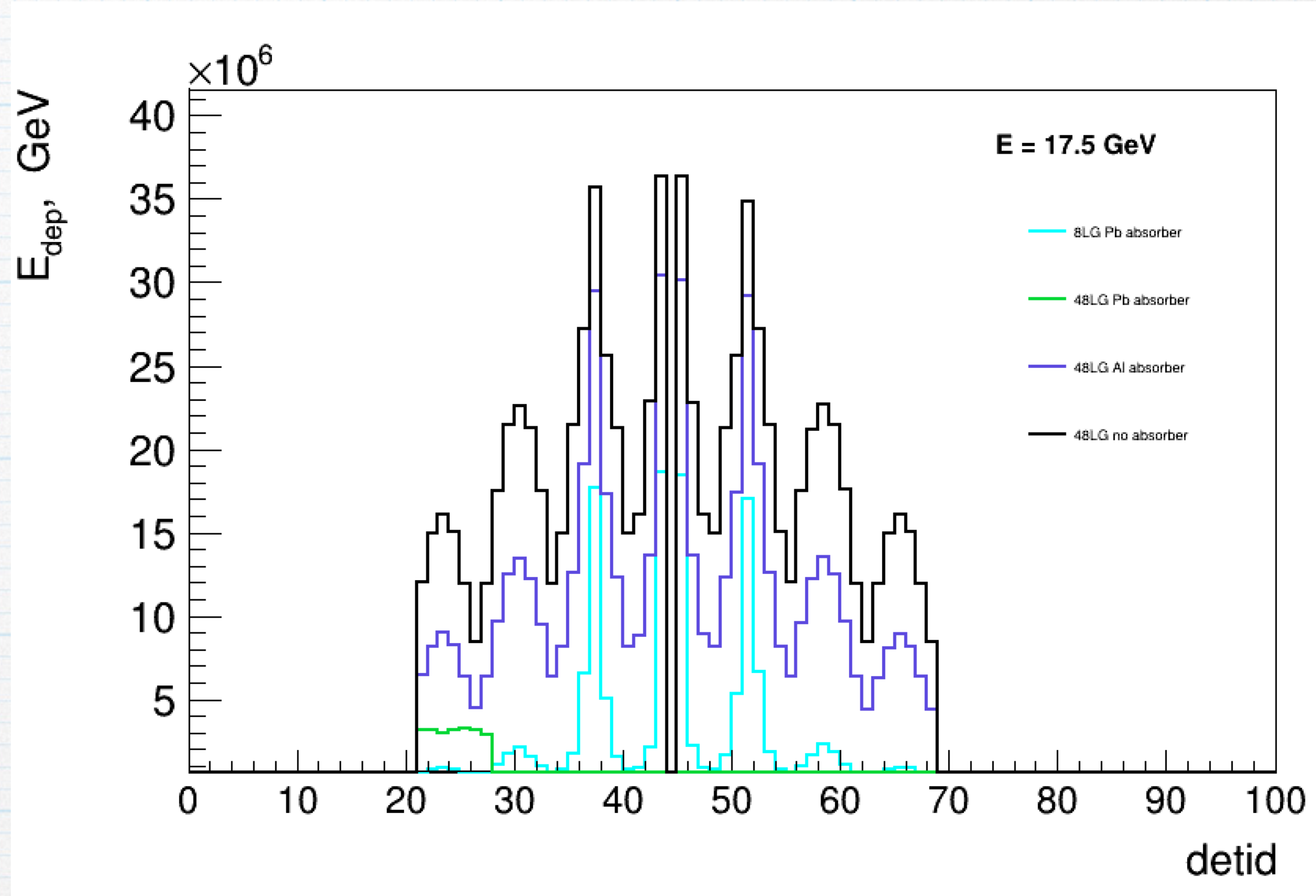


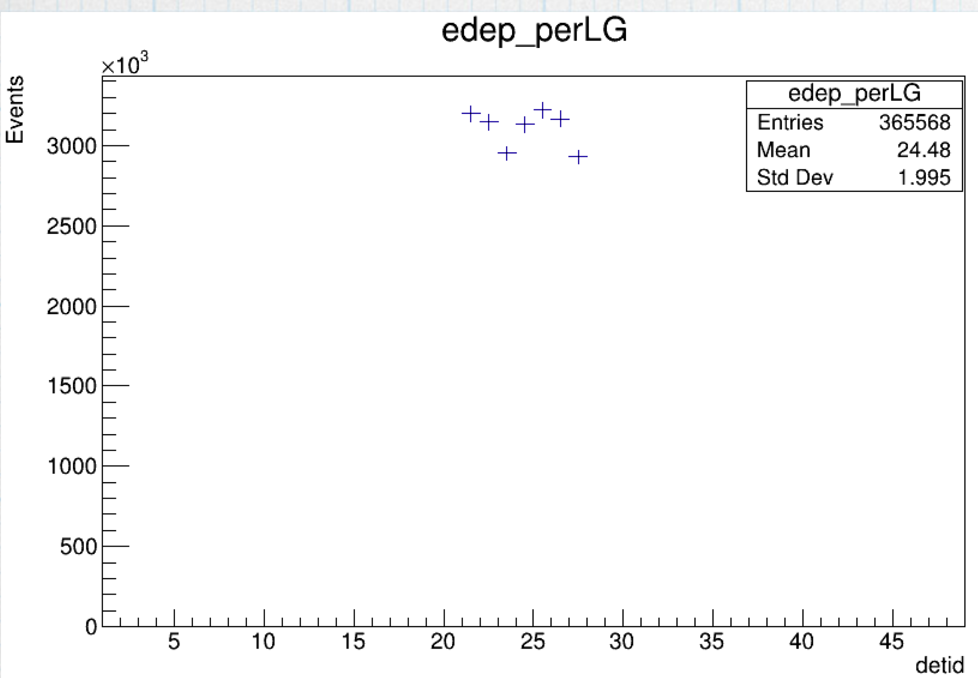




Simulation and Performance





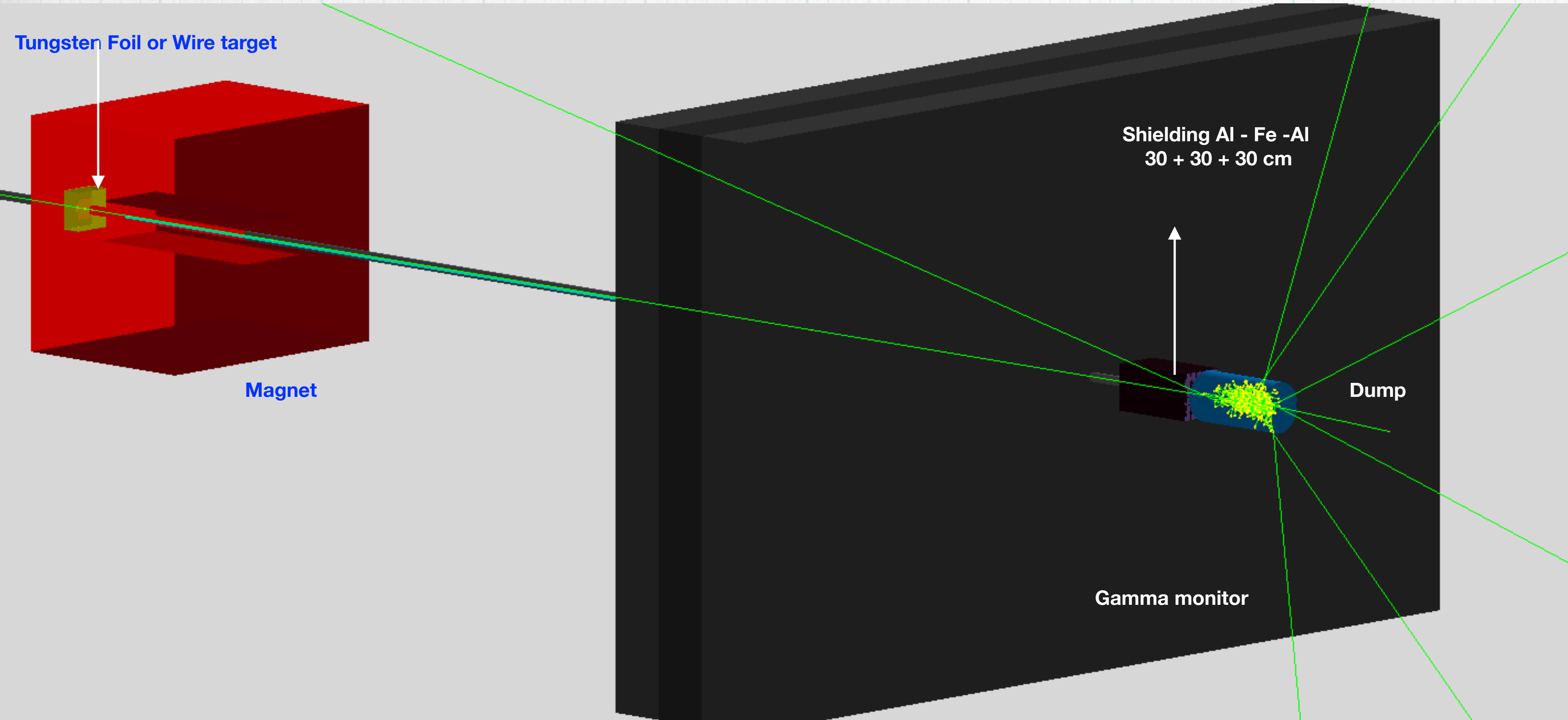


- Depending on exact chemical composition of LG blocks max acceptable dose could be in the range of 5-100 Gy, which roughly means 75-1500 hours of usage on a distance of 10 cm with lead absorber from the beam pipe.
- Air support was used; using the real support made from Al(?) could further improve the performance

Outcomes

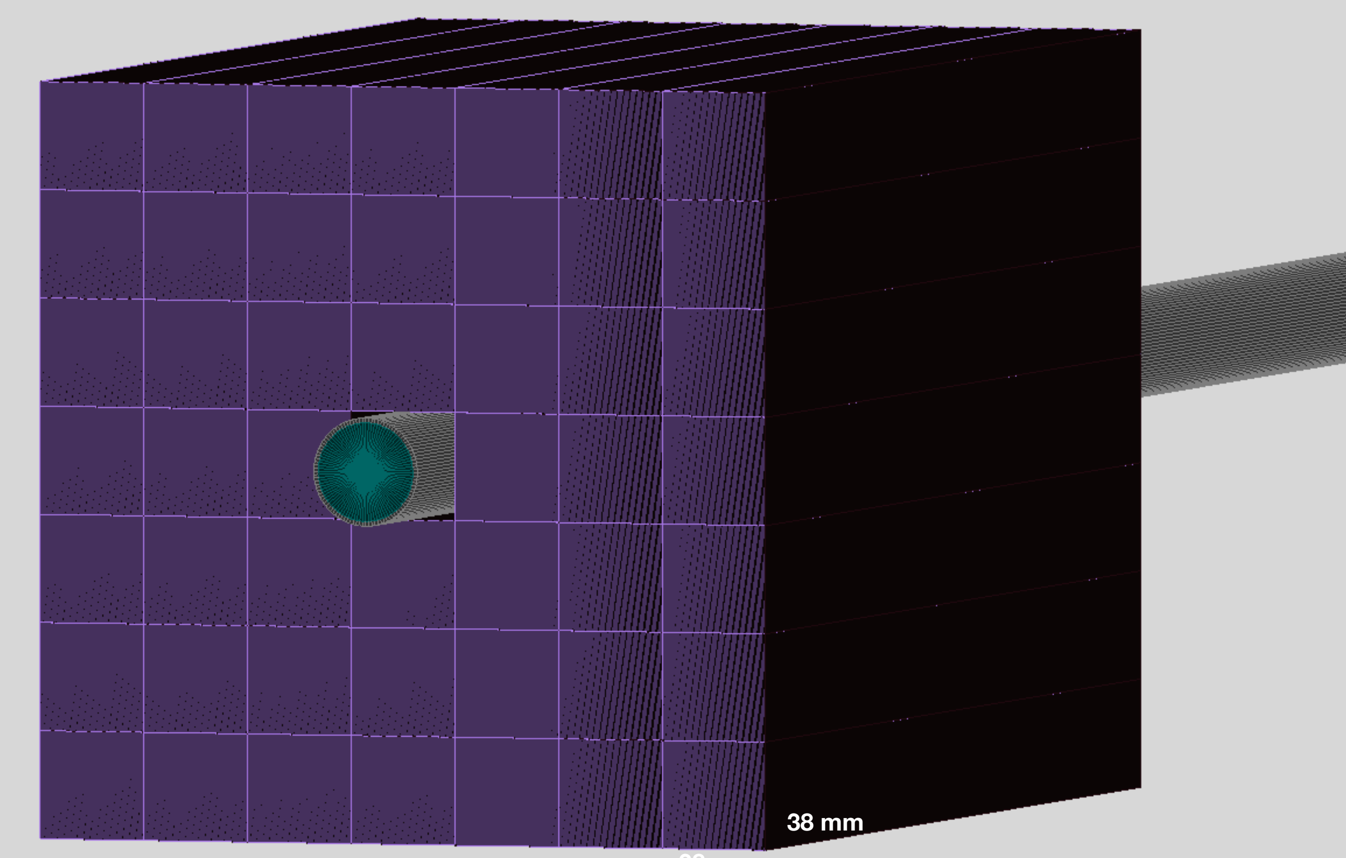
- Energy measured in GM of back-scattering particles is 4-6 orders of magnitude smaller than initial beam energy. Initial flux ~10^{12} GeV in GM depending on geometry ~10^{6}- 10^{8} GeV
- Considering the high energy deposit in the inner layer of the GM, it is reasonable to have only one layer with LG blocks placed around beam pipe in a circle.
  - Possible sensitivity to the beam asymmetry
  - Uniform radiation load
  - Several replacements sets of LG blocks (6*8 =48)
- Depending on exact chemical composition of LG blocks max acceptable dose could be in the range of 5-100 Gy, which roughly means 200-4000 hours of usage on a distance of 10 cm from the beam pipe.
- Considering the fact that no actual beam dump is foreseen and beam will be dumped into the wall, we can consider to design dump/reflector with needed properties

Gamma Monitor

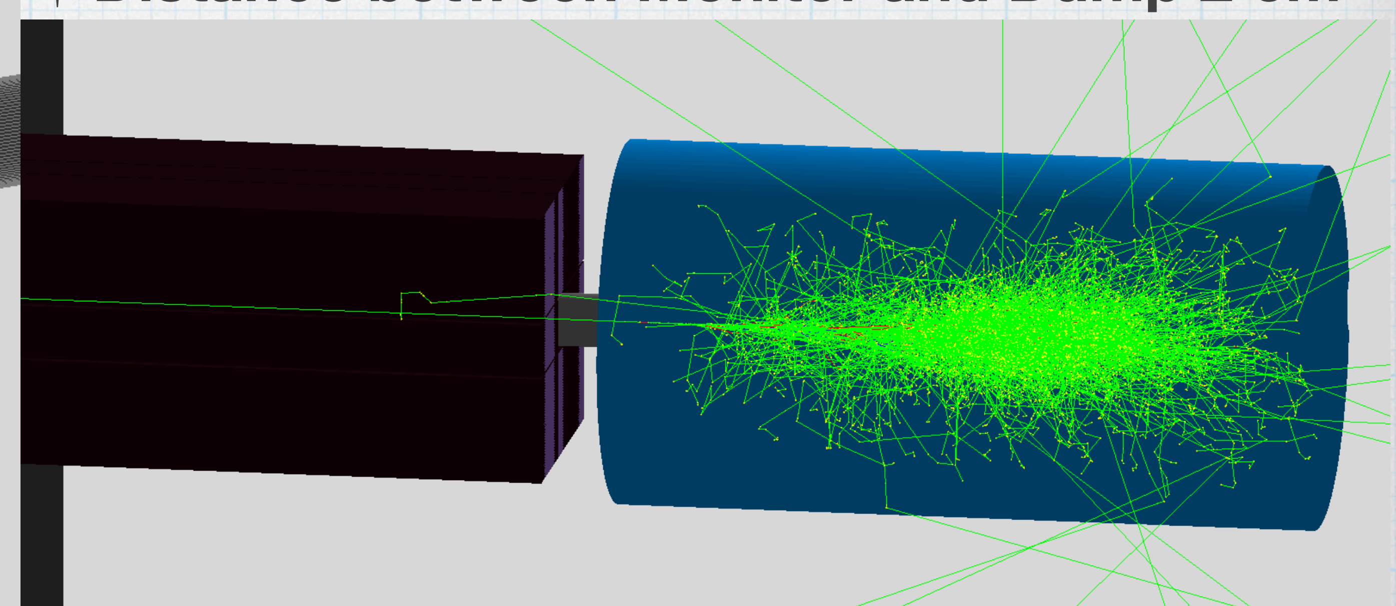


- The implementation of FDS in Luxe geometry with the LG Gamma Monitor made of new LG blocks in front of Al-Cu Dump,
- LG w/ measures 3.8 × 3.8 cm^2, length is 45 cm
- Wrapped with Aluminium foil of 0.016 mm (typical household foil; no account for air)

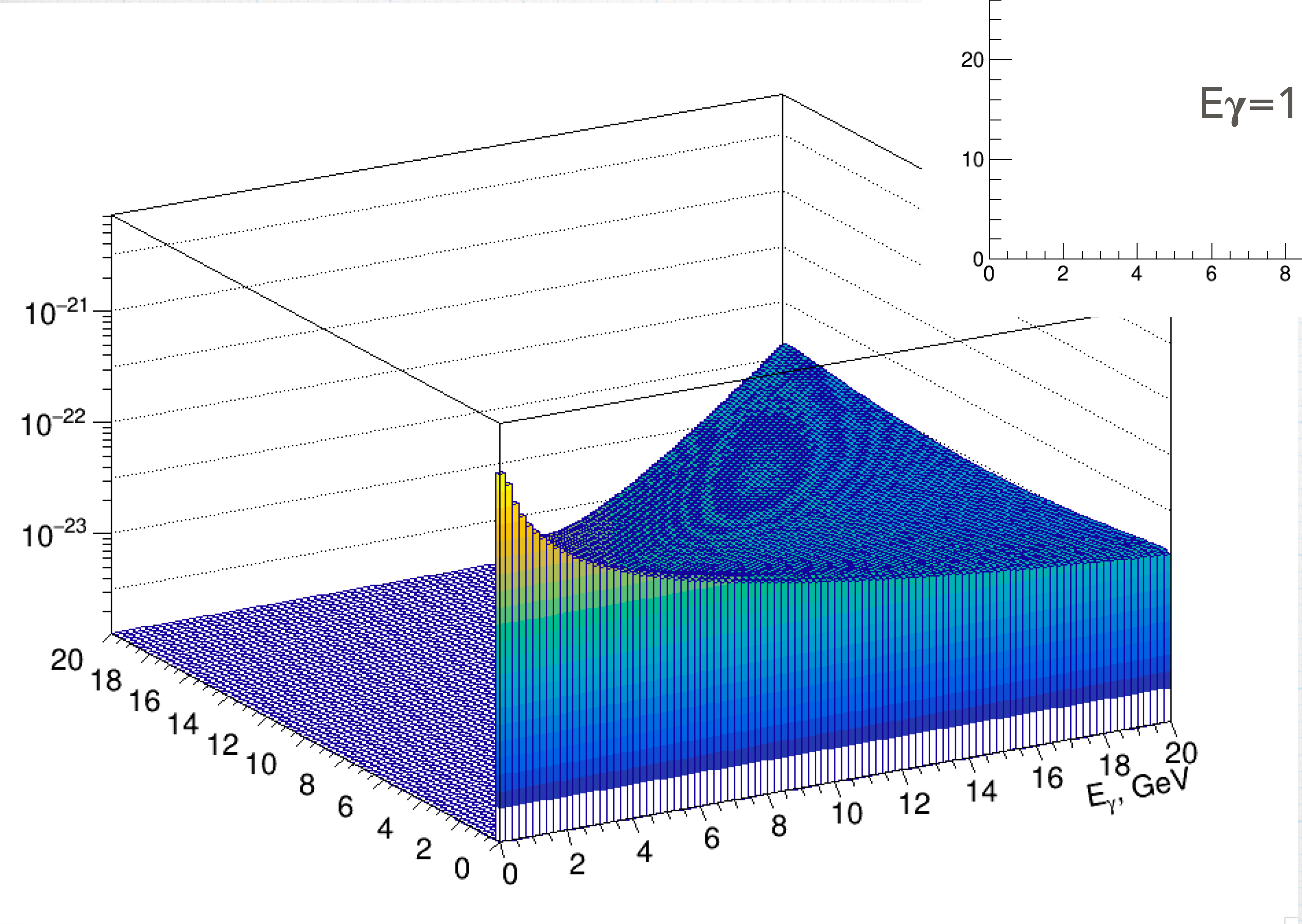
Beam Pipe , R =19.0 *mm, thickness = 1.65 mm

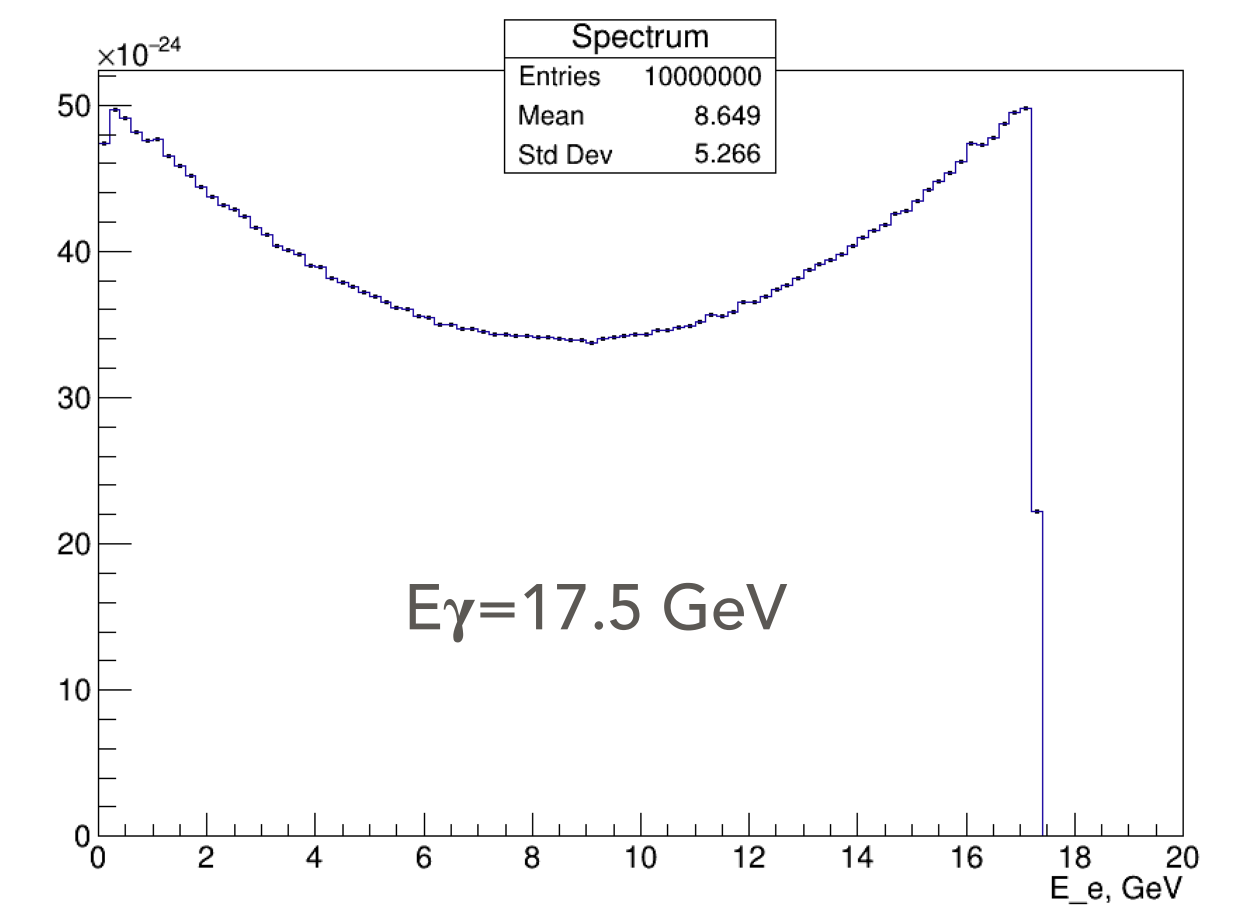


- Distance between Monitor and Dump 2 cm

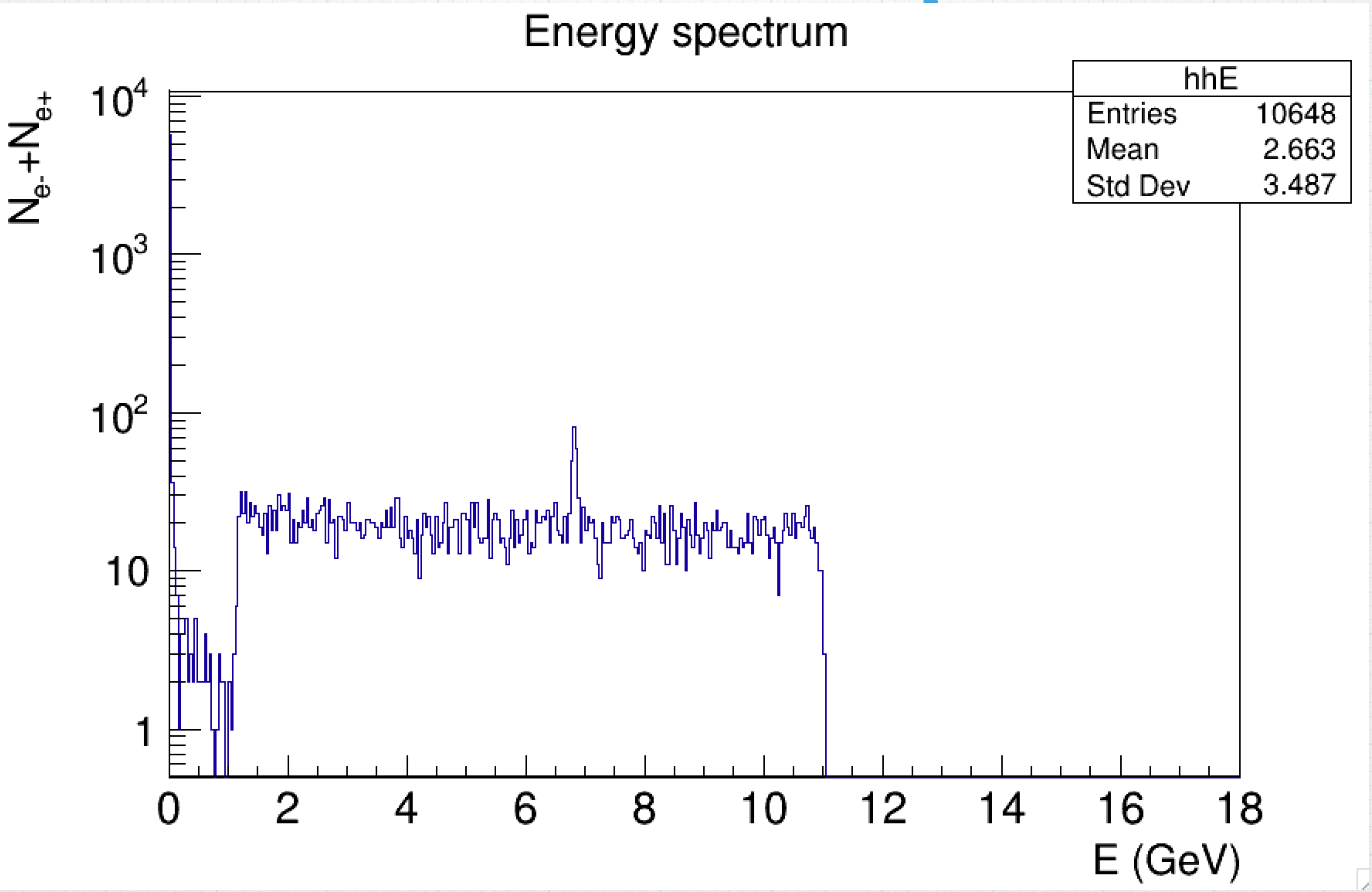


Photon spectrum from Geant4

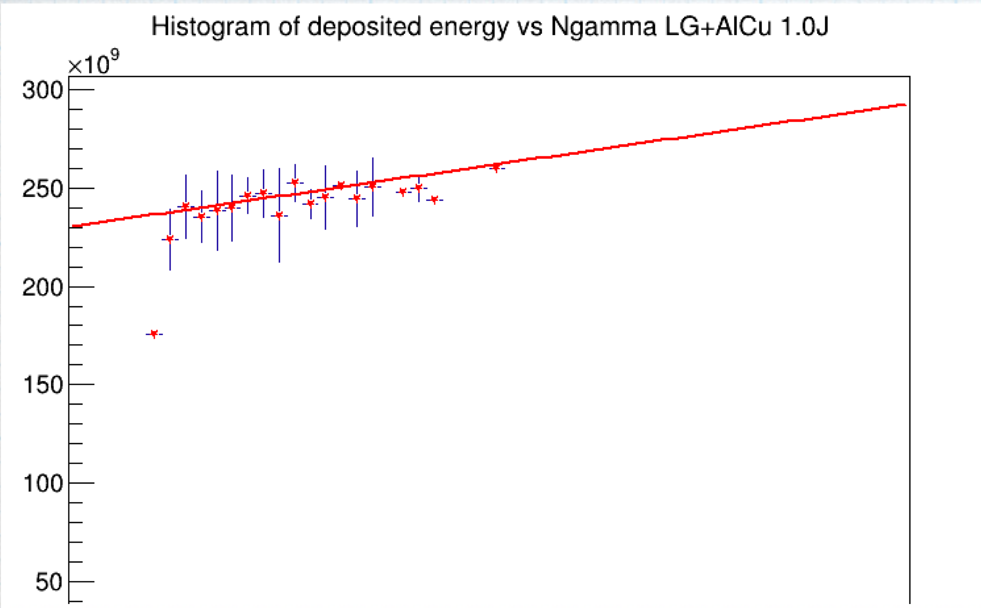




At the detector plane

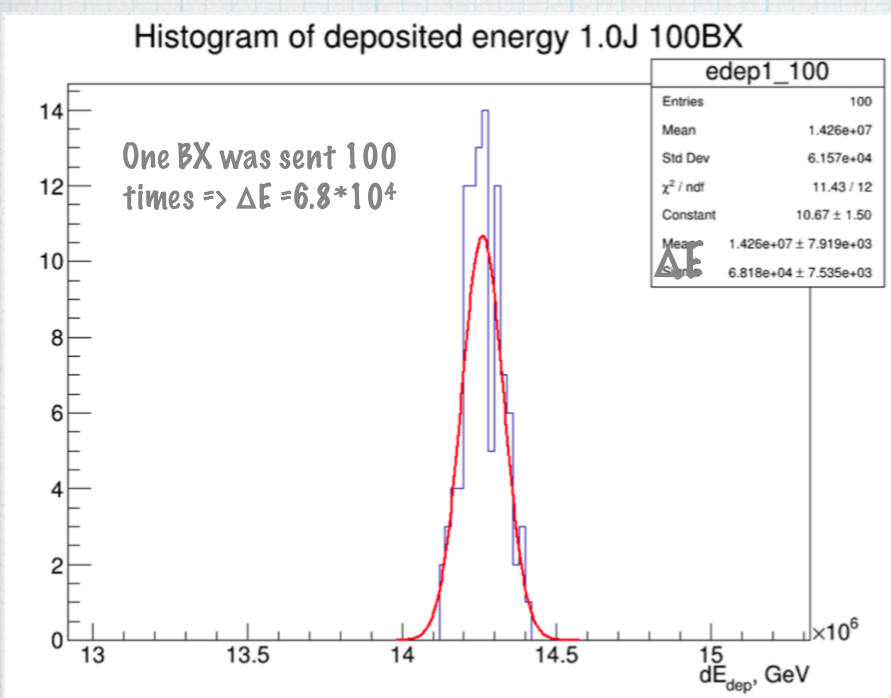


Uncertainties estimation




```
****************************************
Minimizer is Linear
Chi2                      =      4.02143
NDf                       =           13
p0                        =  2.30176e+11   +/-   9.80548e+09
p1                        =        57763   +/-   28404.7
```

```
Minimizer is Linear
Chi2                      =      49.2879
NDf                       =           13
p0                        =  6.79976e+10   +/-   3.97264e+09
p1              ∂N/∂E     =      12940.5   +/-   282.483
```

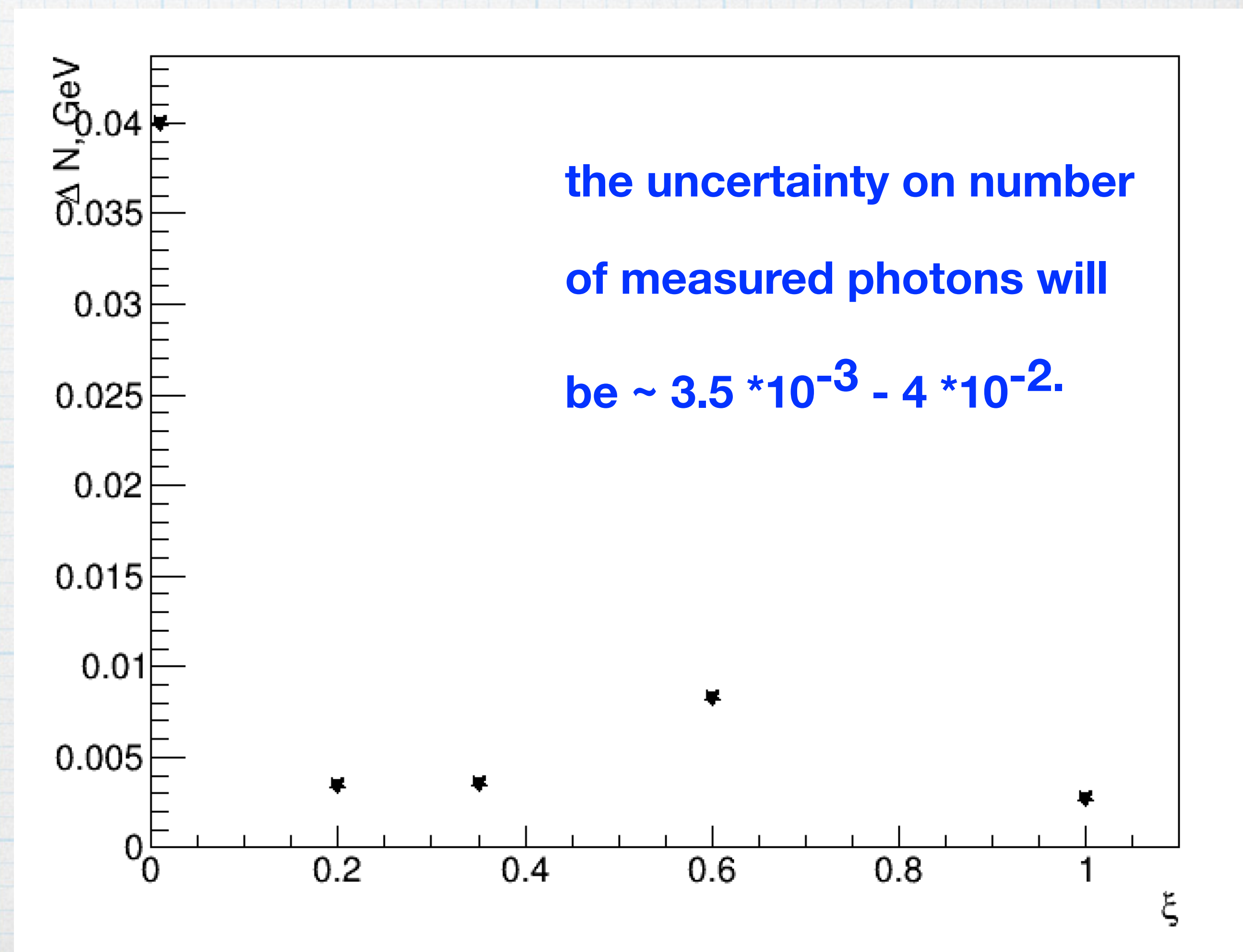


N(E) number of photons

$$\Delta N = \frac{\partial N}{\partial E}\Delta E \quad \Rightarrow \quad \frac{\Delta N}{N} = \frac{1}{N}\frac{\partial N}{\partial E}\Delta E$$

$N = 2.5 \cdot 10^{11}$ $\partial N/\partial E = 57763$

$$\frac{\Delta N}{N} = \frac{1}{N}\frac{\partial N}{\partial E}\Delta E = 6.8 \cdot 10^4 \cdot 1.3 \cdot 10^4 / 2.5 \cdot 10^{11} = 3.5 \cdot 10^{-3}$$

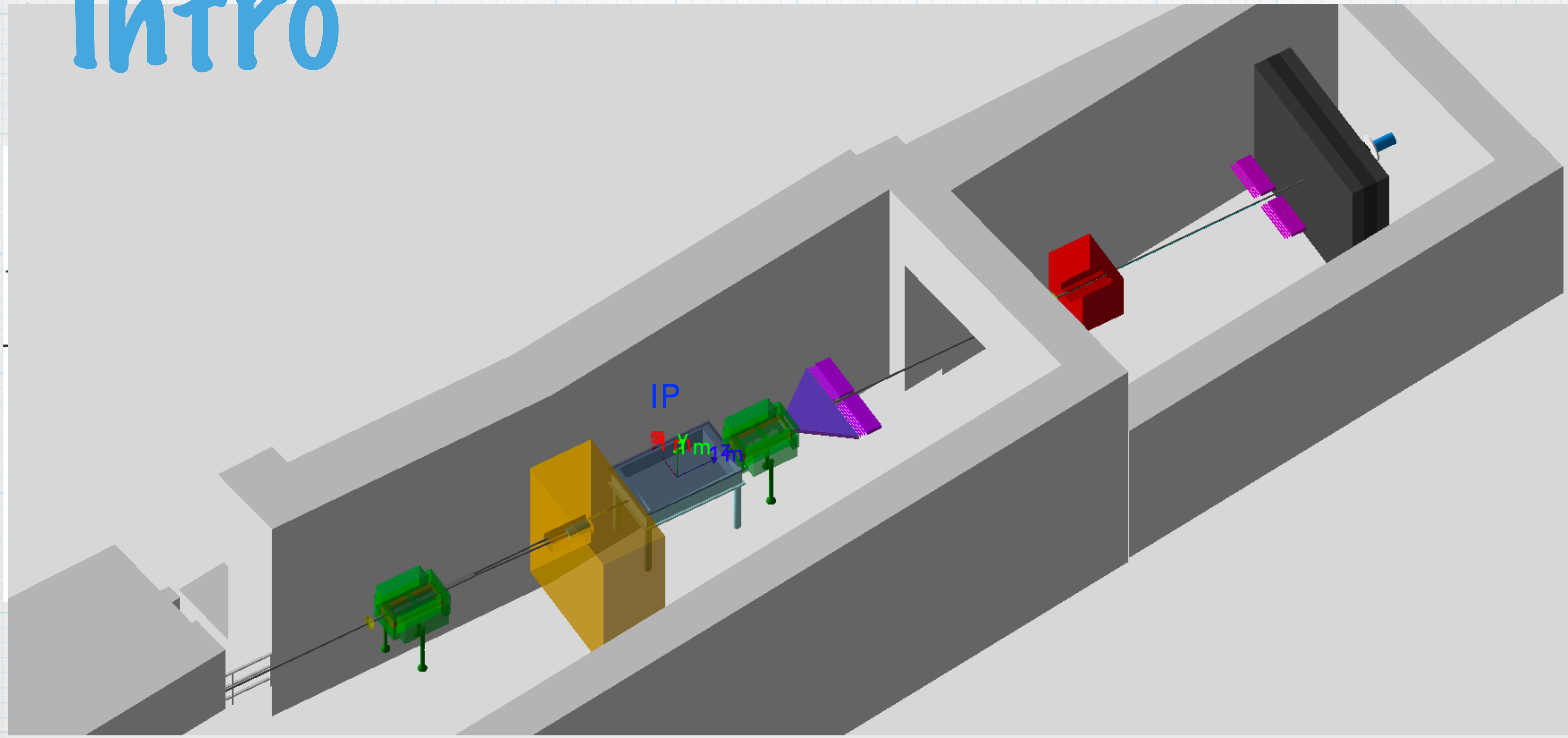


Outline

* Intro
* Experiment layout in GEANT4
* Simulation results
  - deposited energy on number of incoming photons
  - uncertainties estimation
  - degradation of optical properties studies

Intro

FDS - Forward Detector system



I measure HICS energy spectrum.

- Use low X0 target (~1e-6 X0) for gamma to electrons/positrons conversions followed by spectrometer;
- determine kinematic edges;
- detailed shape.

II measure absolute number of photons on event-by-event basis.

- Spectra normalisation;
- Be sensitive to angular distribution of HICS photons (if possible)

Inputs

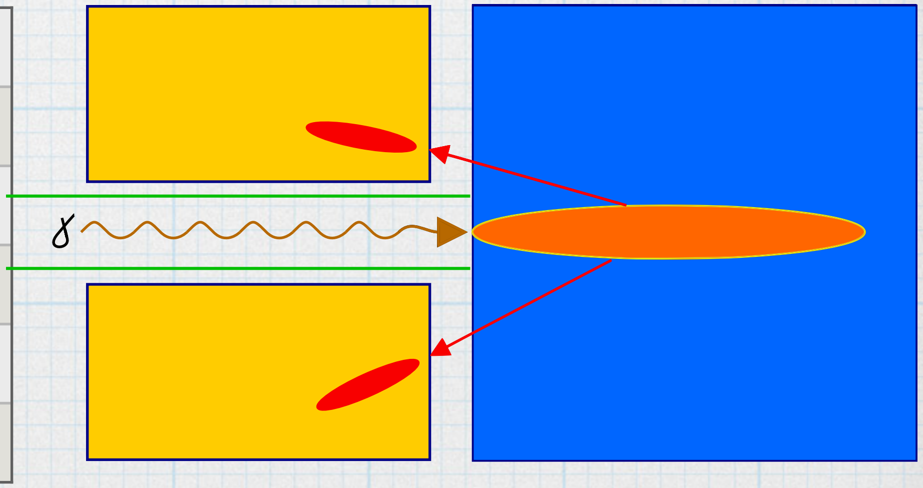
- MC for HICS + trident to model $e + n\omega \rightarrow e + \gamma$ process (A. Hartin)
- Ee = 14 and 17.5 GeV
- Different laser intensities ξ

J	ξ
0.01	0.26
0.1	0.82
0.2	1.16
0.35	1.54
0.6	2.02
1.0	2.6

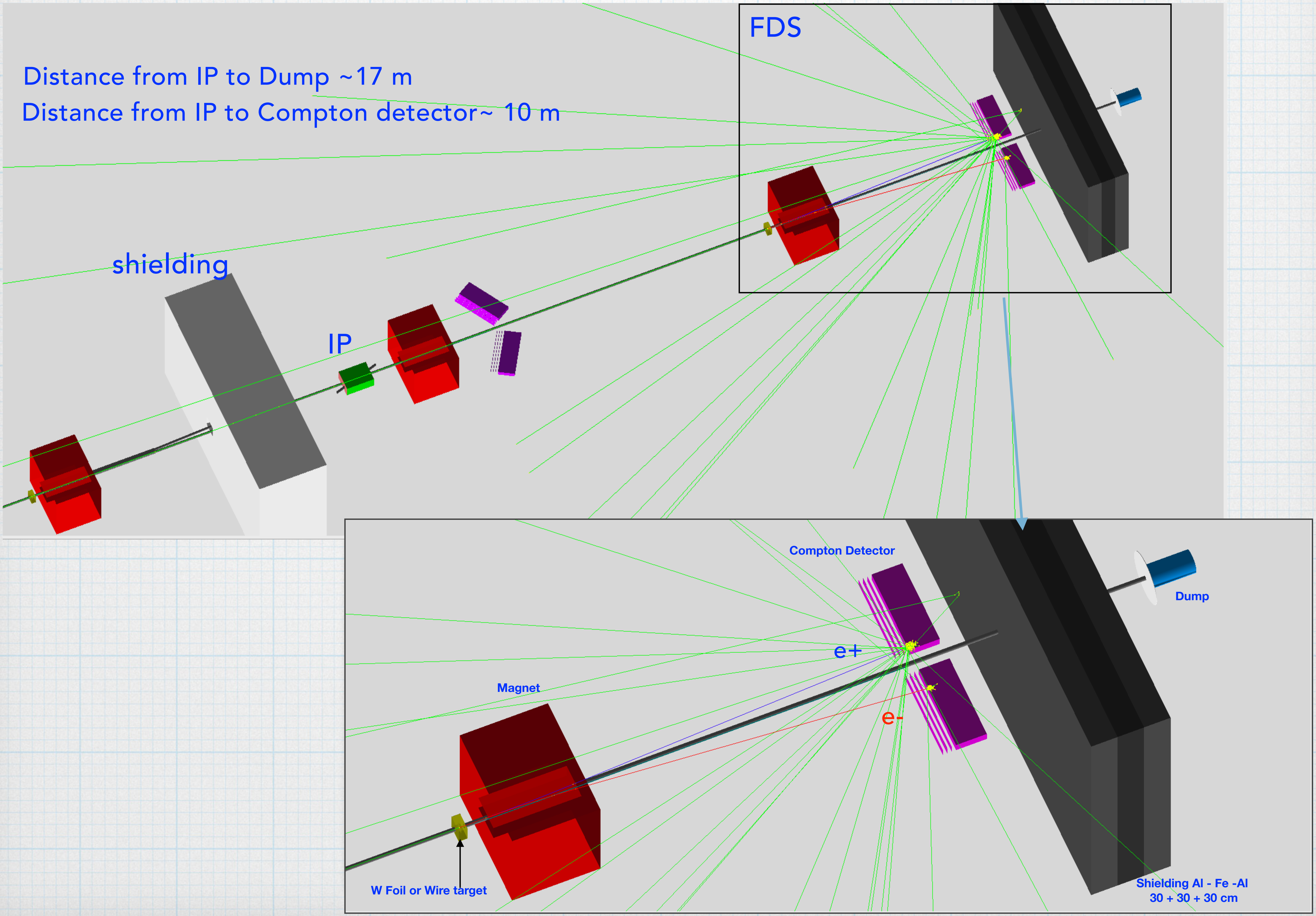
- the estimated rates of electrons, positrons and photons in the various detector regions for e-laser setup and Ee =17.5 GeV

Location	particle type	rate for ξ=2.6	rate for ξ=0.26
e– detector	e–, E <16 GeV	**5.9e+9**	**2.4e+07**
e+ detector	e+	**61.07**	**0.0**
Photon	γ	**2.4e+11**	**3.8e+07**
Photon	e+ and e–	**2.3e+07**	**4.2e+04**
Photon	e+ and e–	**5.8e+5**	**3.8e+03**

The Idea:



Experimental setup in GEANT4

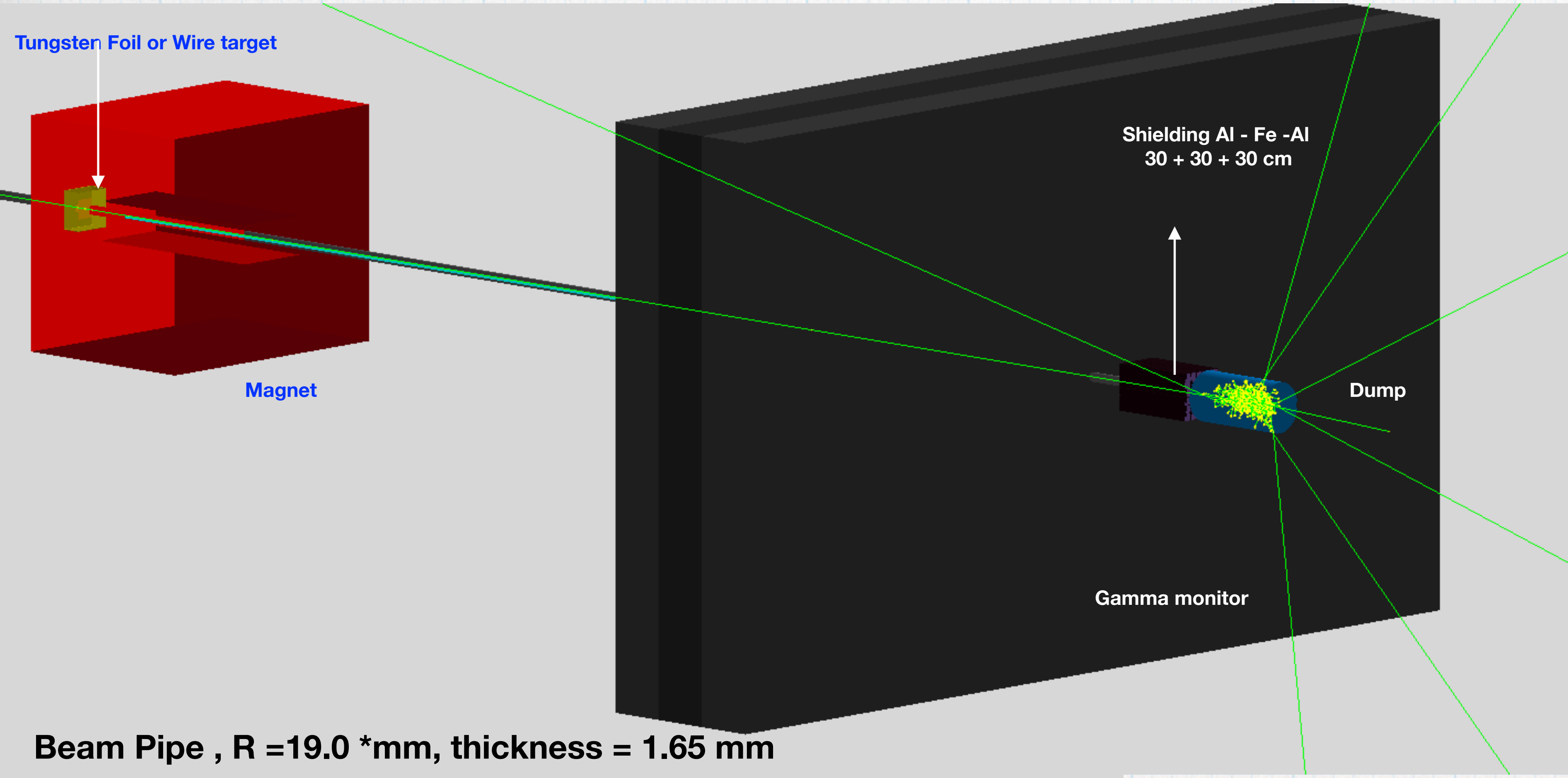


Lead glass blocks found in Hera West @DESY

- New TF-1 LG blocks! Not irradiated, w/ measures 3.8 × 3.8 cm^2, length is 45 cm , ~50
- Will give the possibility to determine precisely coordinates and energies

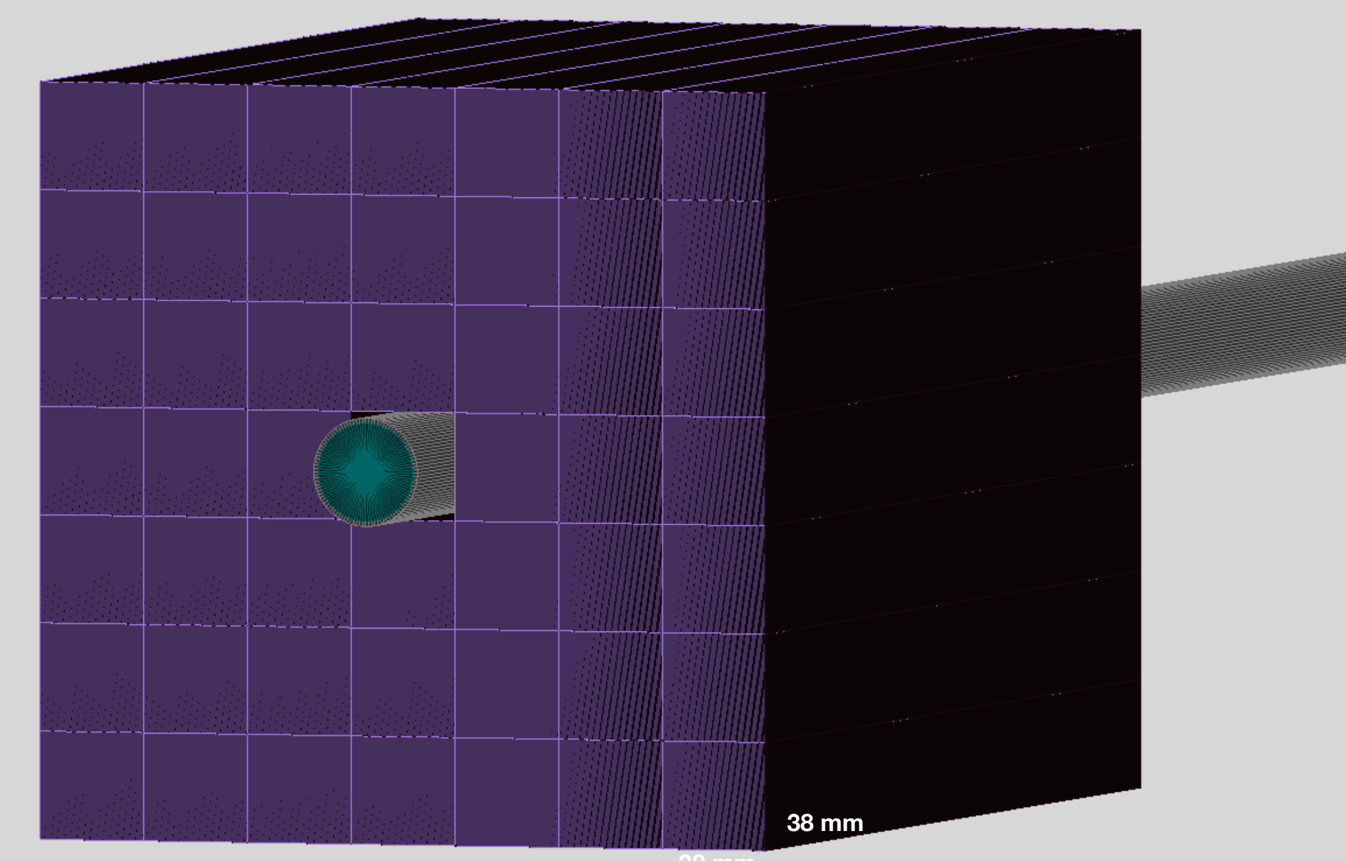
- Spare modules for GAMS found in Hera West thanks to Sergey Schuwalow
- There is a preliminary agreement to move it to the LUXE Lab

Gamma Monitor

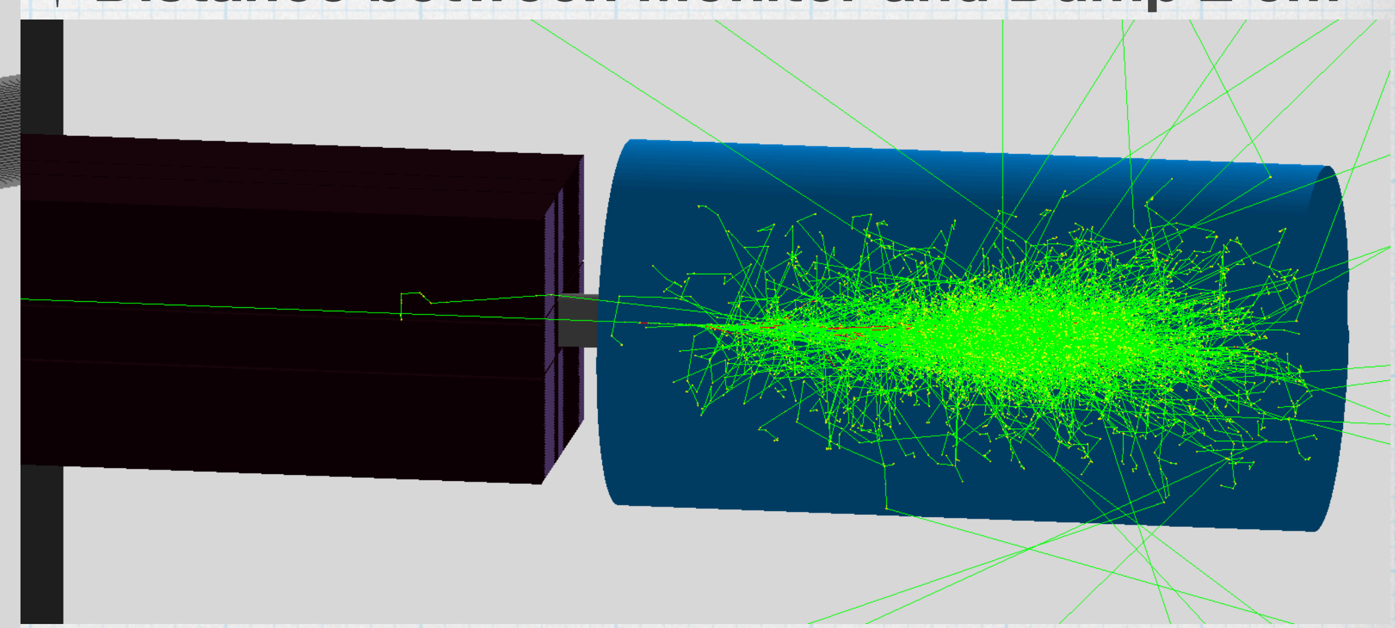


- The implementation of FDS in Luxe geometry with the LG Gamma Monitor made of new LG blocks in front of Al-Cu Dump,
- LG w/ measures 3.8 × 3.8 cm², length is 45 cm
- Wrapped with Aluminium foil of 0.016 mm (typical household foil; no account for air)

Beam Pipe , R =19.0 *mm, thickness = 1.65 mm

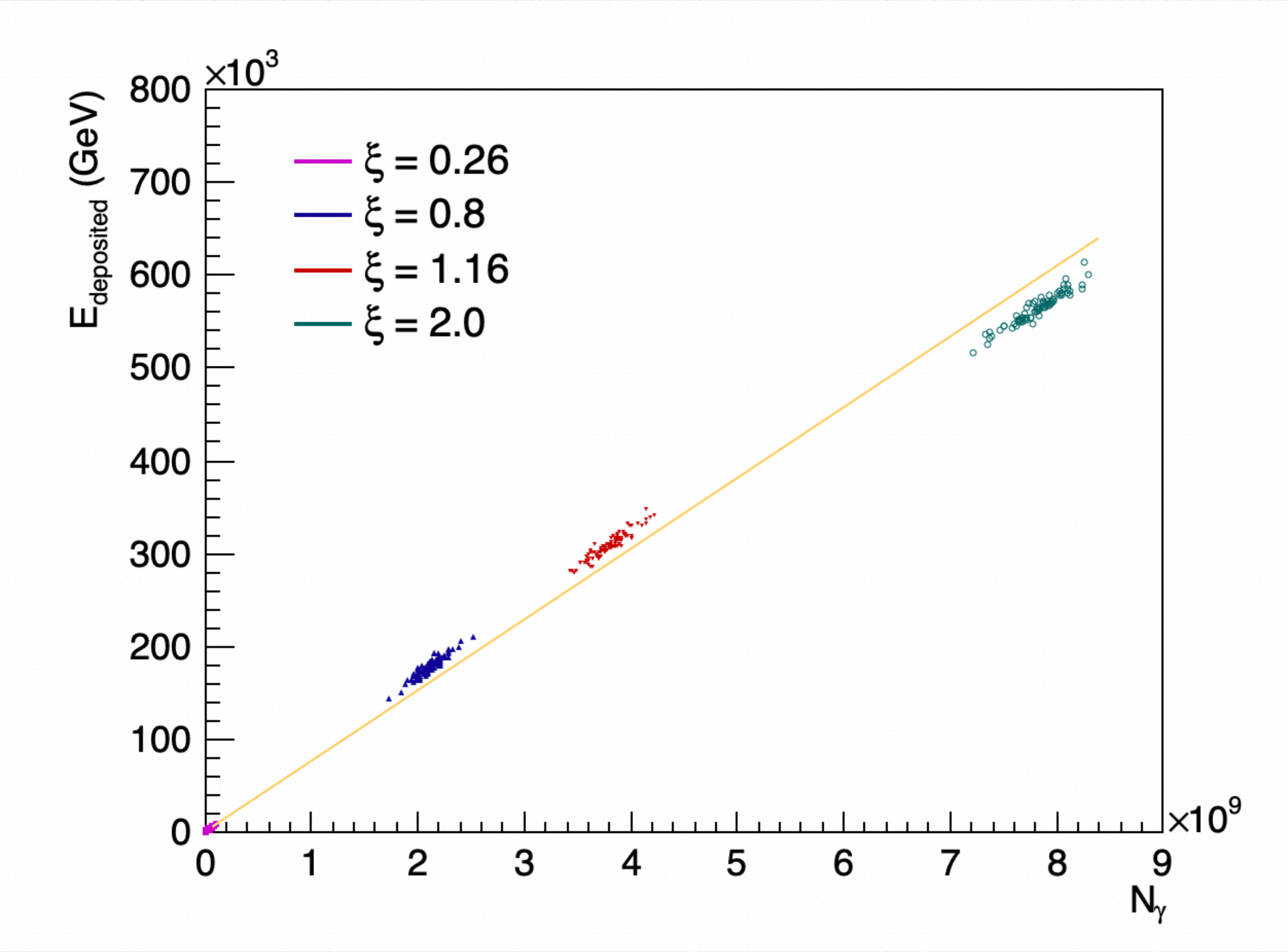


- Distance between Monitor and Dump 2 cm

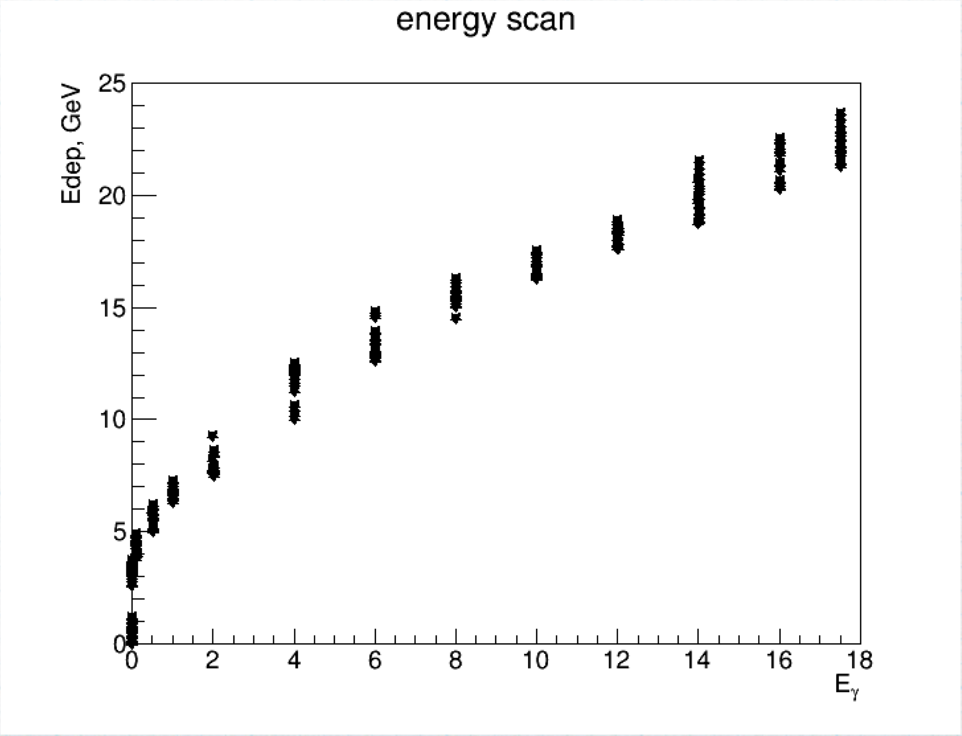


Simulation and Performance

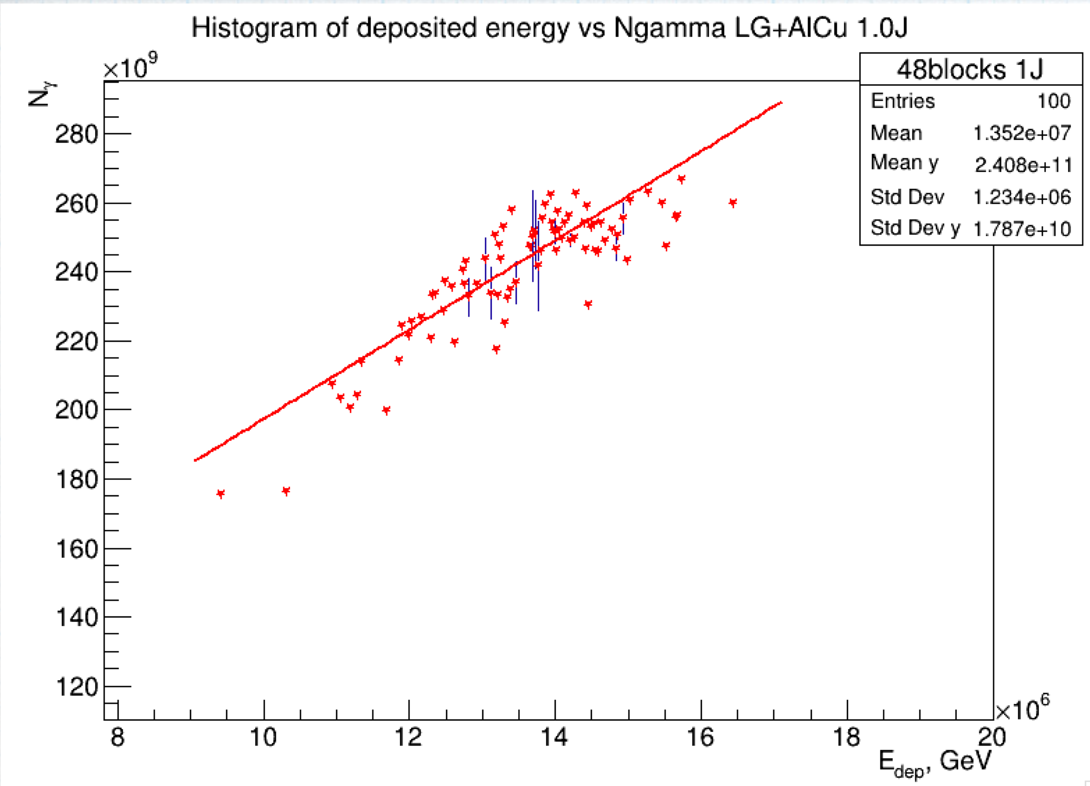
Deposited energy versus true number of photons. Each point is one BX



- The (almost) linear dependence of deposited energy on number of incoming photons in GM allows the usage of backscatters for monitoring the photon flux
- For small ξ the HICS spectrum is softer and soft photons produce less back-scatters. This is the reason of small deviation from linearity in Edep on Eγ dependence



Uncertainties estimation



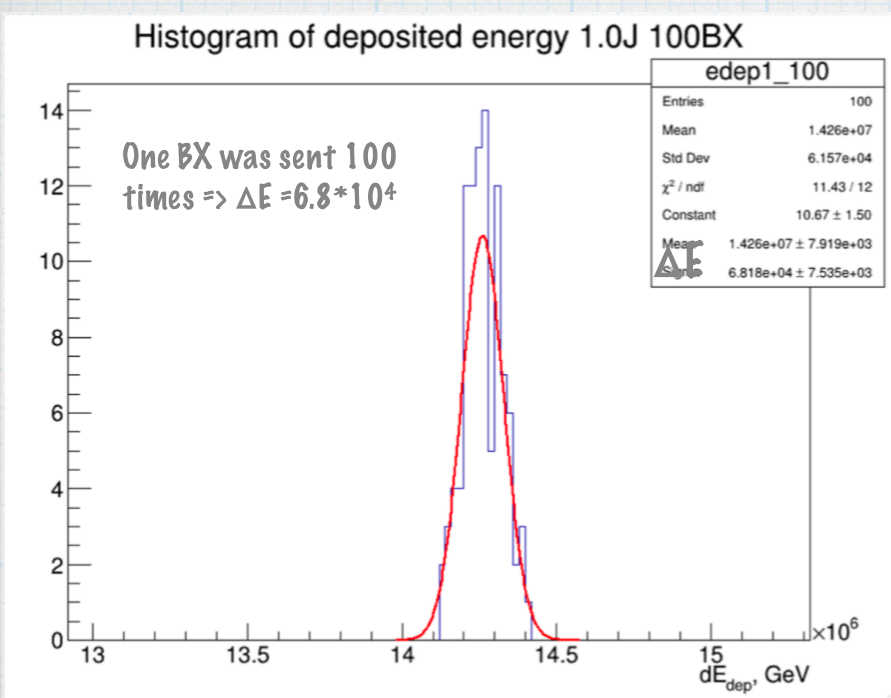
N(E) number of photons

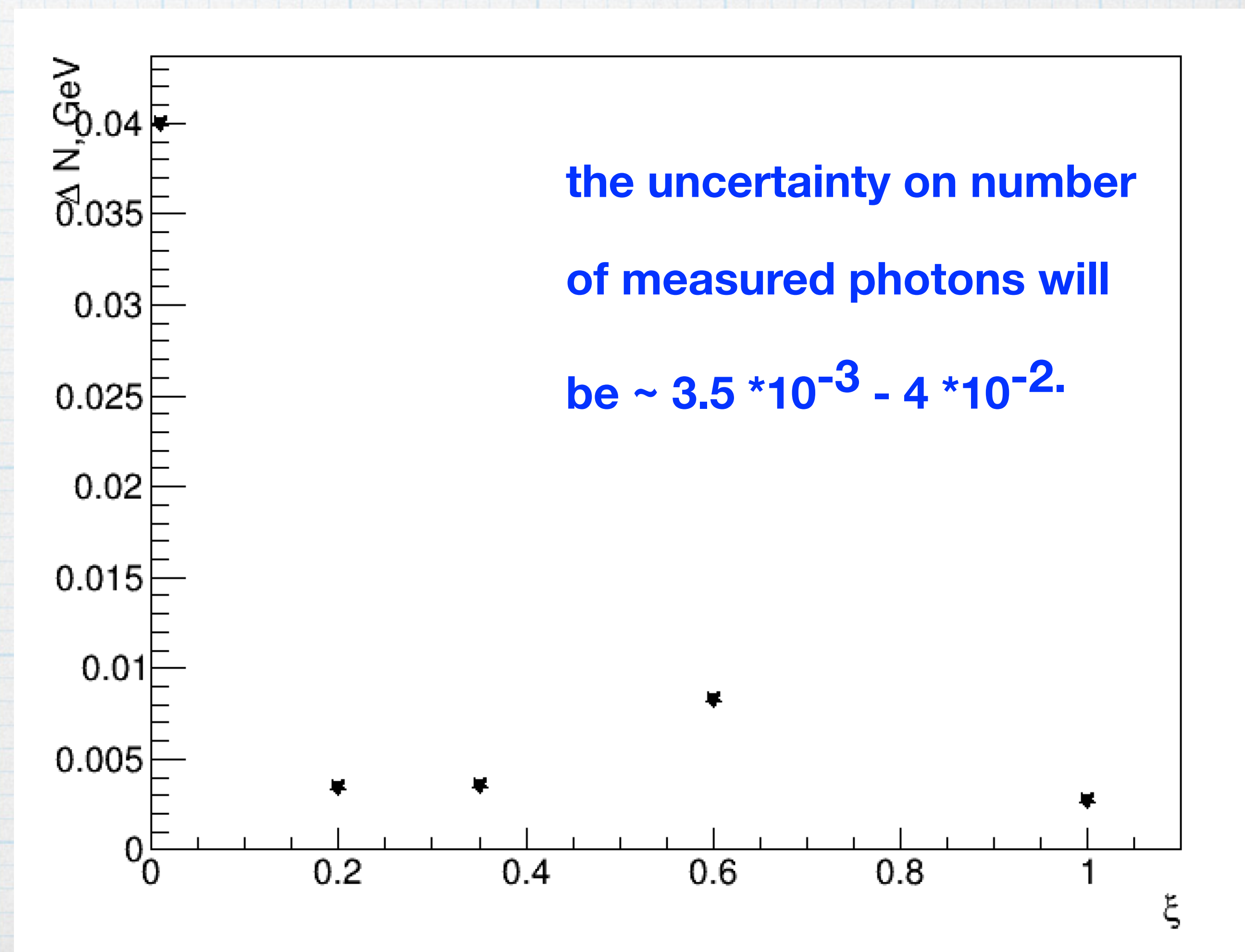
$$\Delta N = \frac{\partial N}{\partial E}\Delta E \Rightarrow \frac{\Delta N}{N} = \frac{1}{N}\frac{\partial N}{\partial E}\Delta E$$

$N = 2.5 * 10^{11}$ $\partial N/\partial E = 12940$

$$\frac{\Delta N}{N} = \frac{1}{N}\frac{\partial N}{\partial E}\Delta E = 6.8*10^4 * 1.3 * 10^4 / 2.5 * 10^{11} = 3.5 * 10^{-3}$$

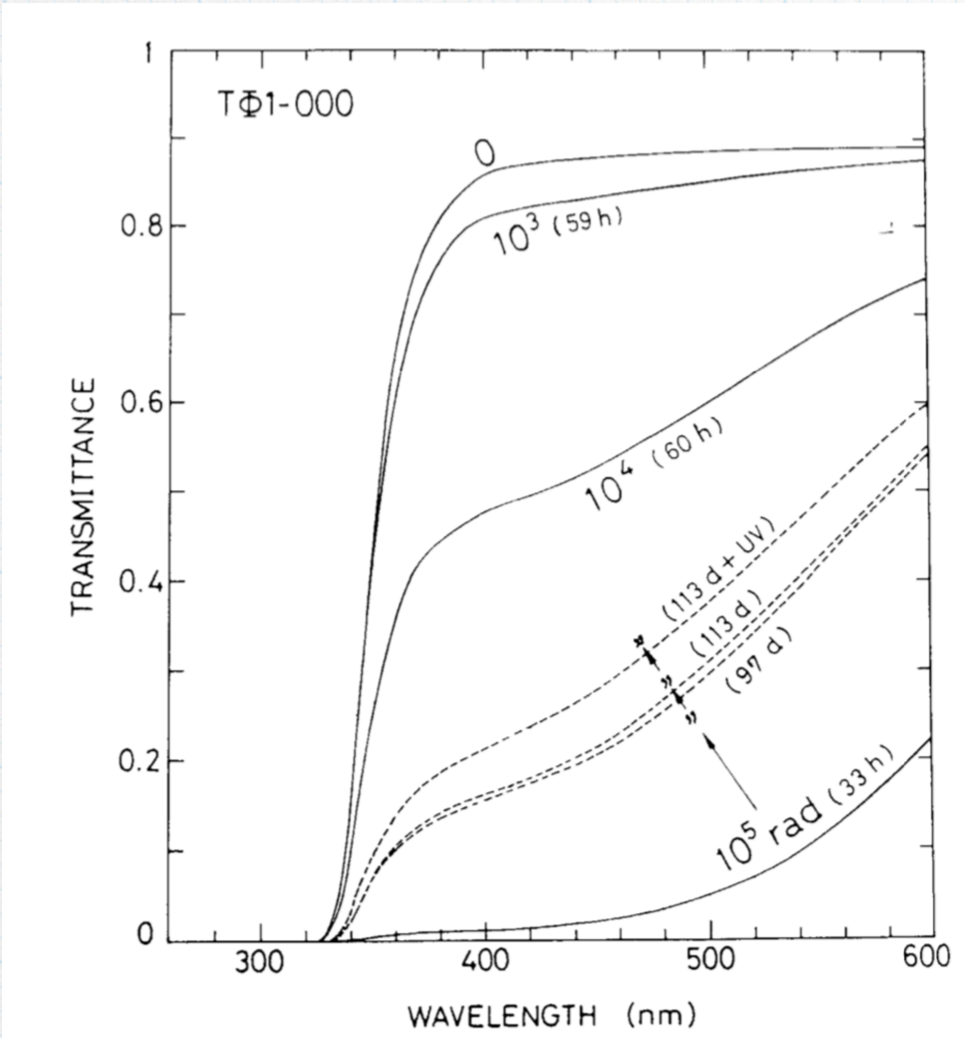
```
****************************************
Minimizer is Linear
Chi2                      =      49.2879
NDf                       =           13
p0                        =  6.79976e+10    +/-    3.97264e+09
p1               ∂N/∂E    =      12940.5    +/-    282.483
```

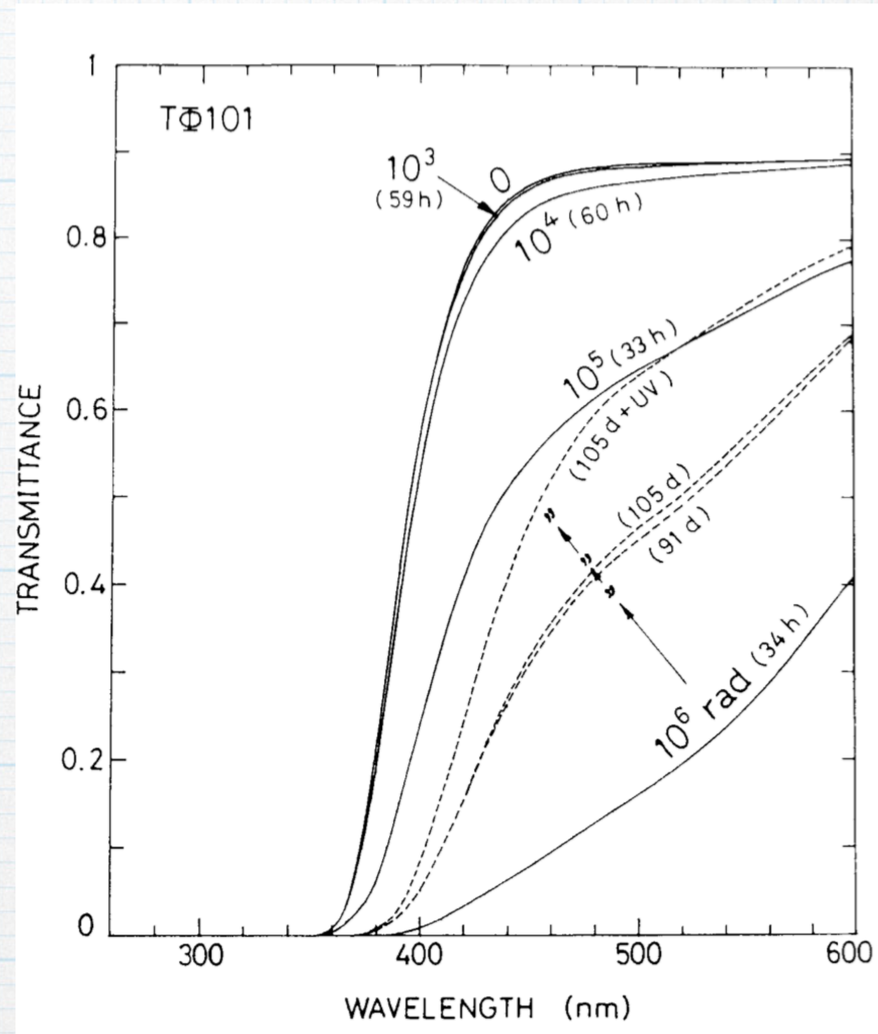




the uncertainty on number of measured photons will be ~ $3.5 * 10^{-3}$ - $4 * 10^{-2}$.

Degradation of the optical properties of the lead glass (TF1& TF101) by radiation





1rad= 0.01 Gy

TF101 - radiation hardened with addition of 0.2% cerium

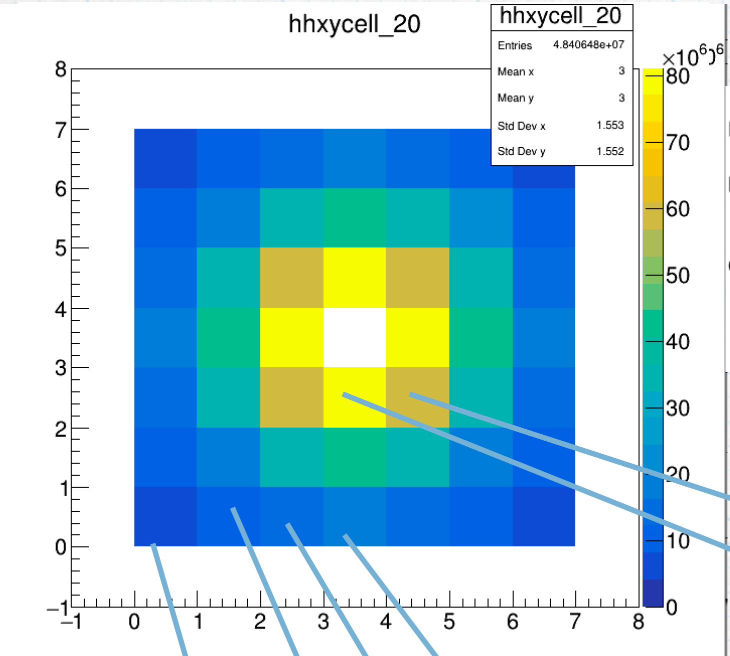
https://doi.org/10.1016/0168-9002(94)90990-3

If, we require the decrease of transmission over the detector depth of 45 cm LG block to be less than 1/e, the tolerable accumulated dose in TF101 should be about 10^4 rad = 100 Gy or a little higher.

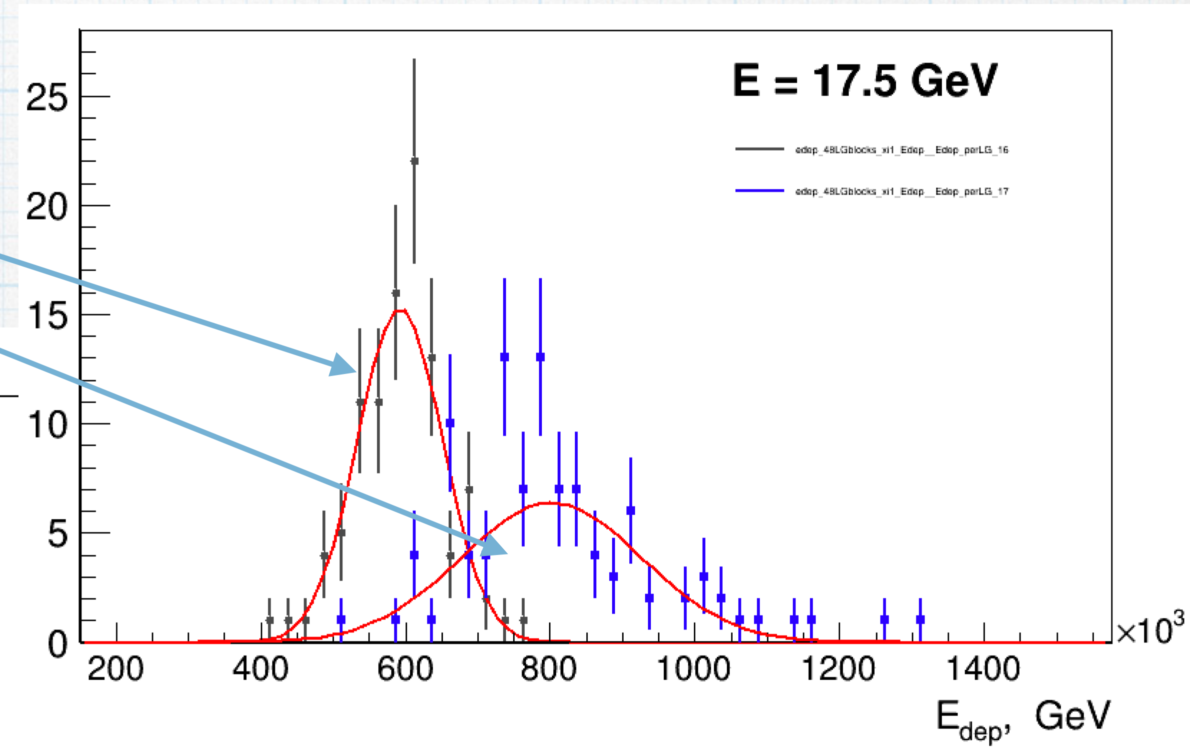
(=> 5* 10^2 rad = 5Gy In TF1)

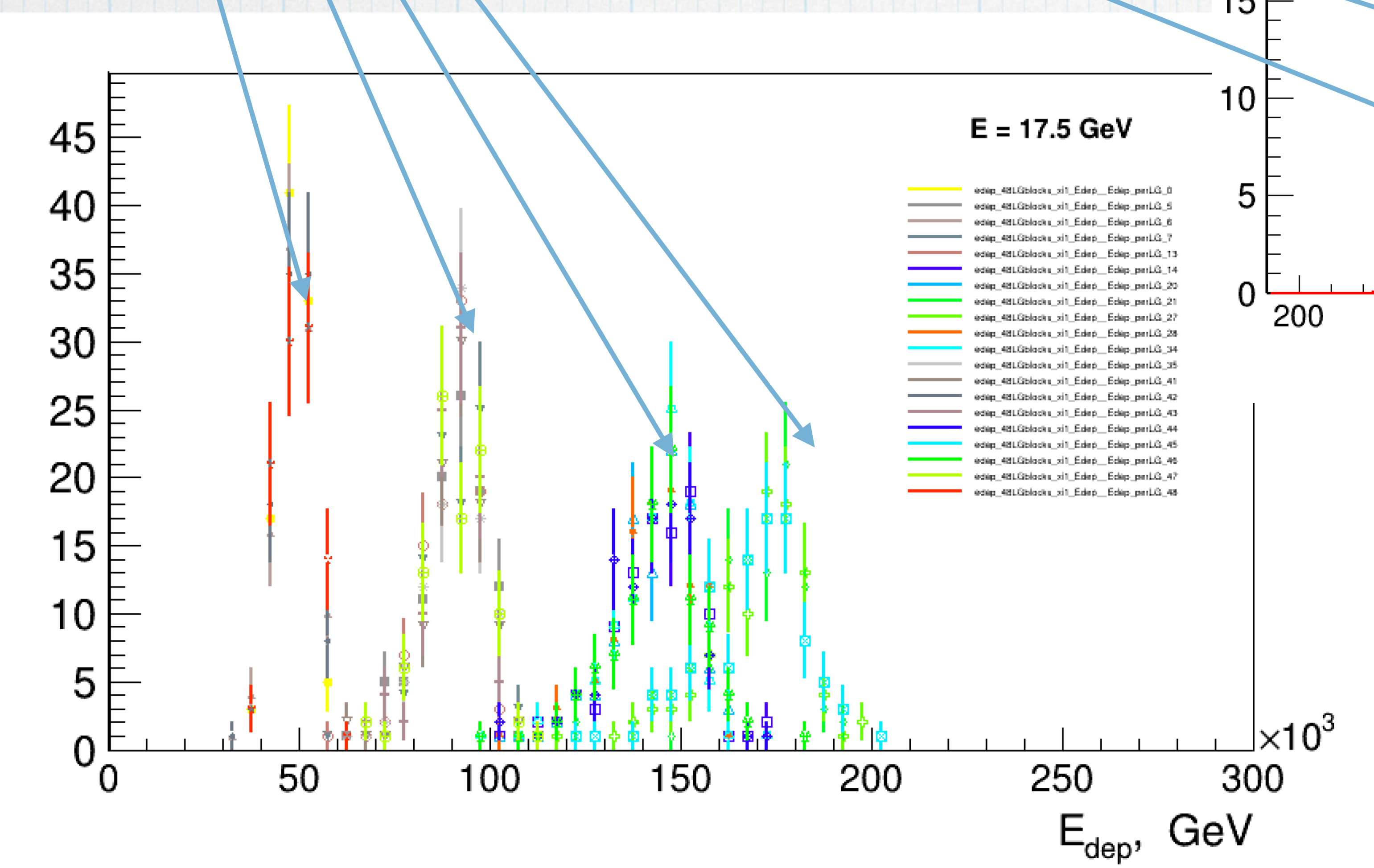
tolerable accumulated doses in the individual blocks

✴At high laser intensities ξ =2.6 (1J)



	Edep(100BX),GeV	Edep(1BX),GeV	Edep(1BX), J	Edep(1BX), J/kg (x0)=Gy	Edep(1BX), J/(2.5kg block)=Gy	Edep(1BX), Gy/sec(2.5kg block)	sec	hours
Inner layer	8.02E+07	8.02E+05	1.28E-04	9.22E-04	5.12E-05	5.12E-04	9.76E+03	2.71
	5.92E+07	5.92E+05	9.49E-05	6.81E-04	3.78E-05	3.78E-04	1.32E+04	3.67
Middle layer	4.40E+07	4.40E+05	7.05E-05	5.06E-04	2.81E-05	2.81E-04	1.78E+04	4.94
	3.50E+07	3.50E+05	5.61E-05	4.03E-04	2.24E-05	2.24E-04	2.24E+04	6.21
	2.00E+07	2.00E+05	3.21E-05	2.30E-04	1.28E-05	1.28E-04	3.91E+04	10.87
Outer layer		1.70E+05	2.72E-05	1.95E-04	1.08E-05	1.08E-04	4.61E+04	12.81
		1.44E+05	2.30E-05	1.65E-04	9.18E-06	9.18E-05	5.45E+04	15.13
		9.13E+04	1.46E-05	1.05E-04	5.83E-06	5.83E-05	8.57E+04	23.82
		4.86E+04	7.78E-06	5.59E-05	3.10E-06	3.10E-05	1.61E+05	44.76

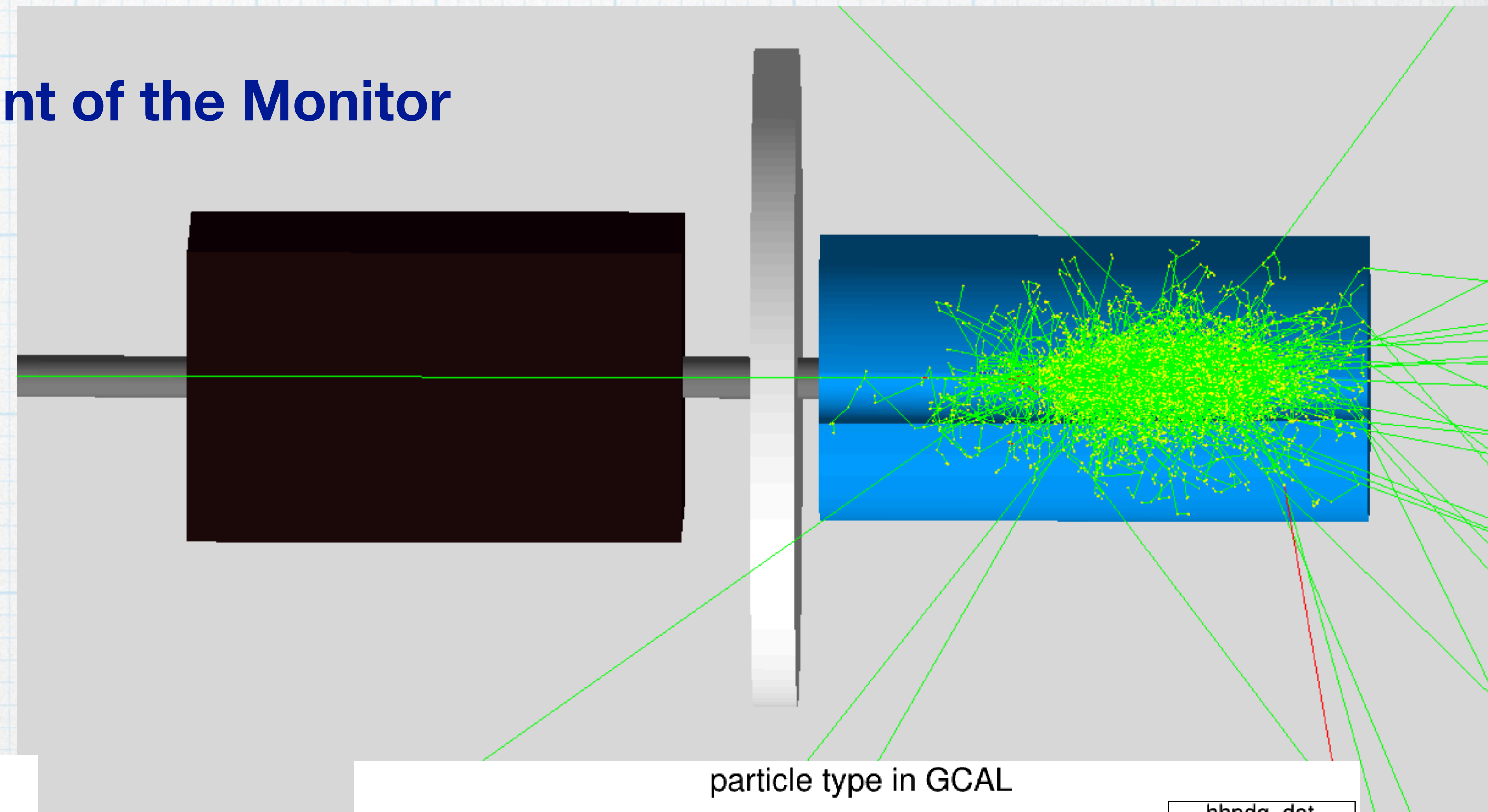


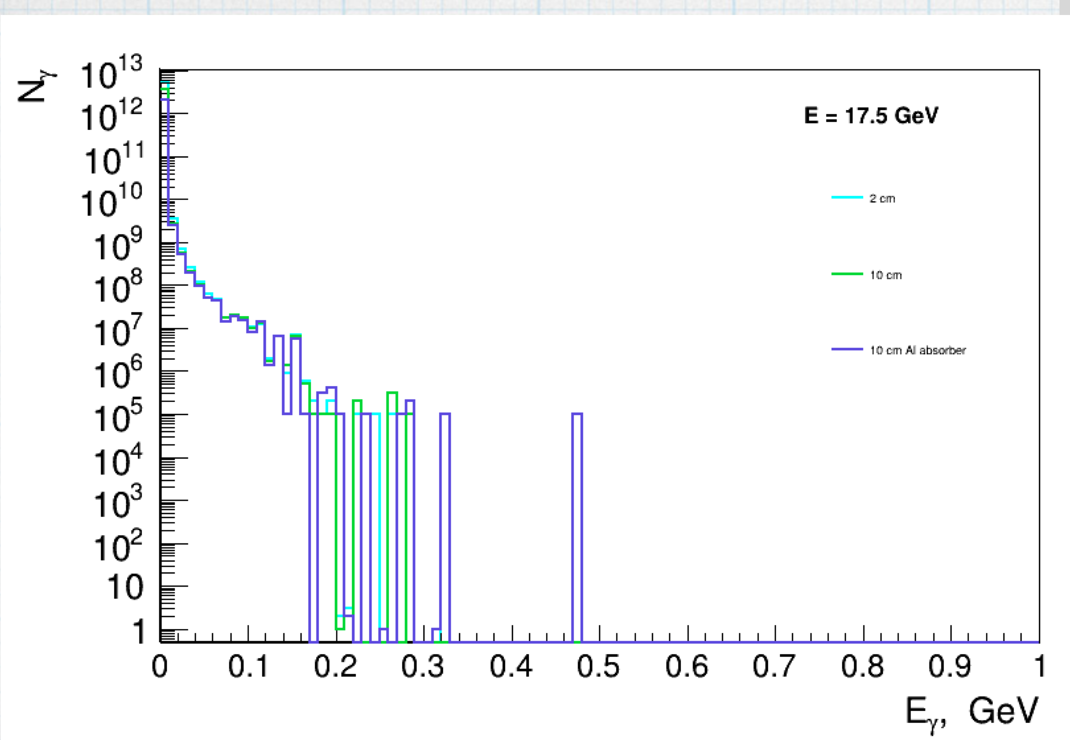


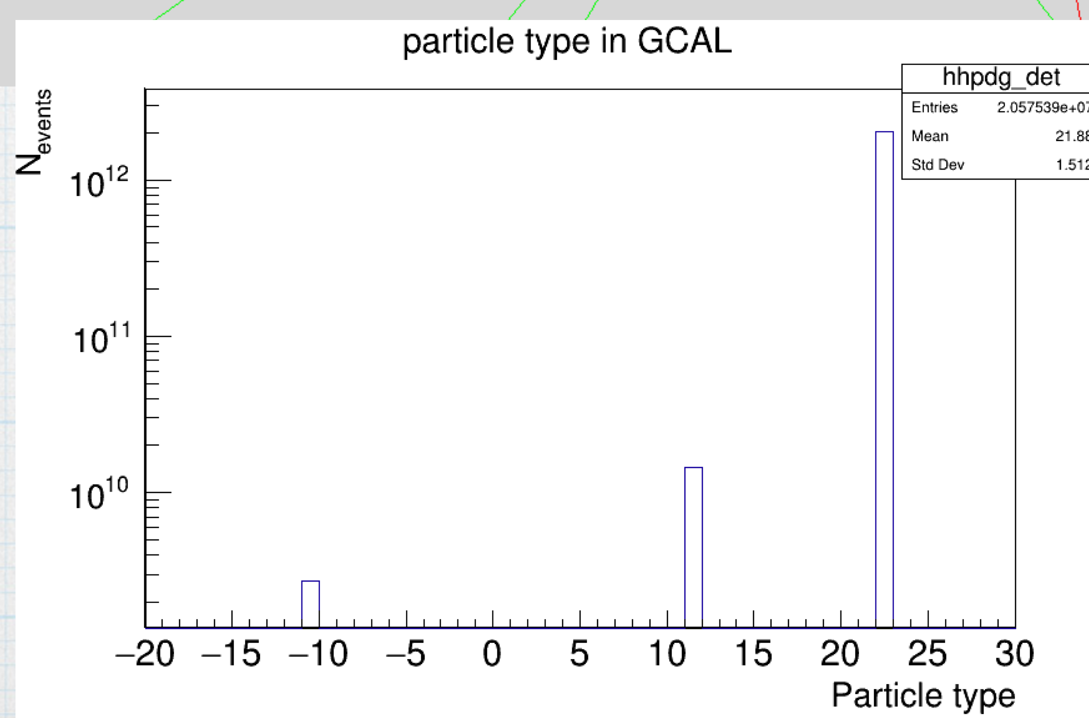
At 10 Hz rate the energy deposition accumulates the dose of 5 Gy in the whole TF1 block which ranges from 3 hours up to 45 hours

Adding absorber

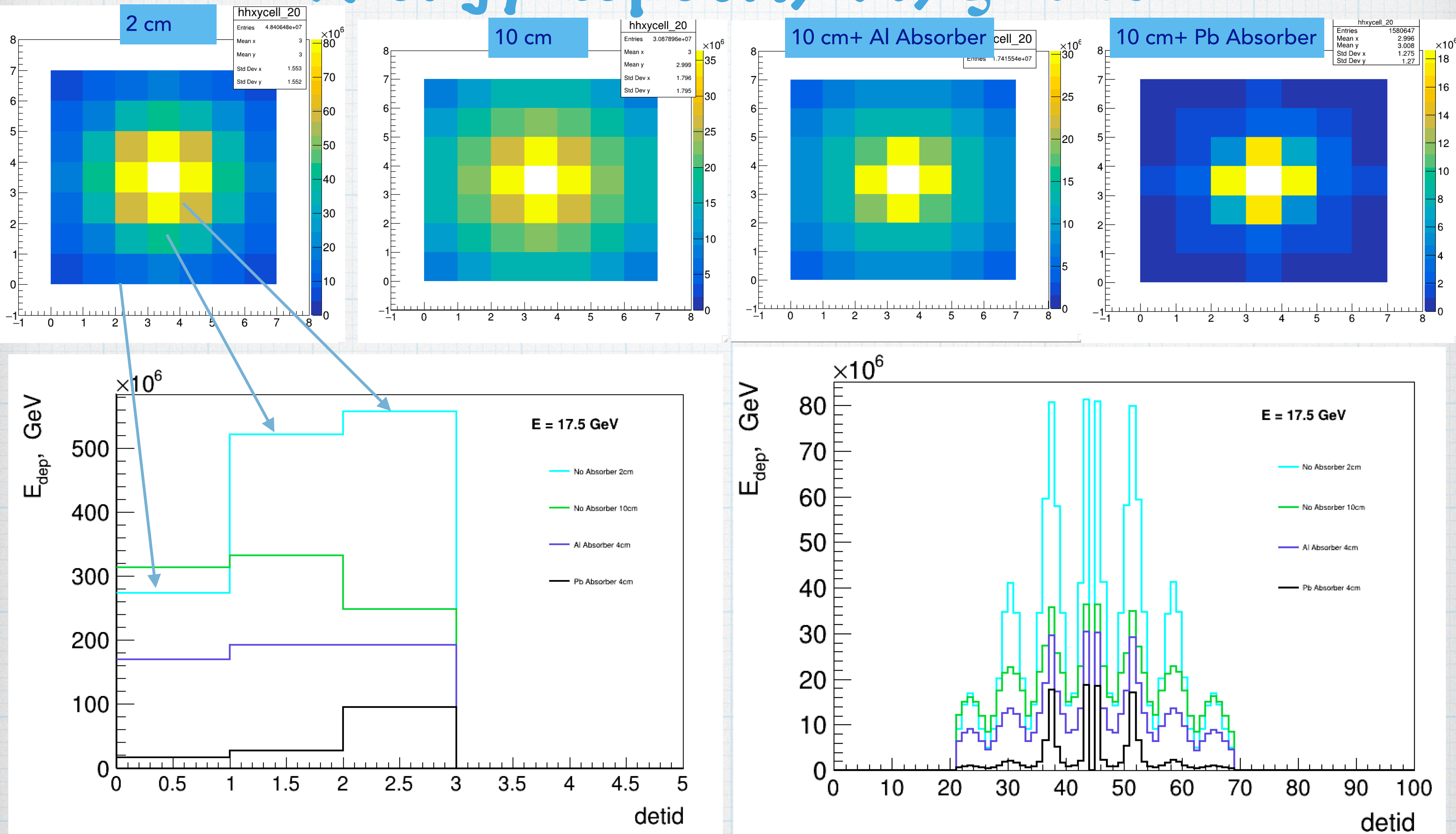
- 2Months ~1460 hours
- To try:
  - ✓ absorber (Al or Pb, 4 cm) in front of the Monitor







Energy deposit, 48, ξ =2.6



- ✴ **Moving further from the dump the deposit in inner layer twice less, which prolonged the usage of inner layer up to 7 hours**
- ✴ **Adding 4 cm Al absorber between dump and monitor prolongs up to 10 hours for the inner layer**

Summary

- ☑ Measuring total energy of back-scattering particles can be used to monitor the flow of incoming photons. Existing (@DESY 4free) lead glass blocks might be a good choice for the calorimeter.
- ☑ The estimated uncertainty on number of measured photons is ~ 10^{-3} - 10^{-2} in case of HICS.
- ☑ Can be used also for bremsstrahlung using the convolution of response function with the spectrum.
- ☑ If we consider the usage of existing (@DESY 4free) lead glass blocks the radiation degradation could be an issue but it could be mitigated.
- ☐ Degradation of optical properties studies
- ☐ Use more realistic LUXE geometry which has been partly implemented and consider specific (or different) detector techniques implementation.

Energy dependence of deposited energy in Gamma monitor

20 Runs* 100000 photons with mono energies: 1,2,4,6,8,10,12,14,16 and 17.5 GeV

Added lower energies 0.0001, 0.1, 0.5 GeV