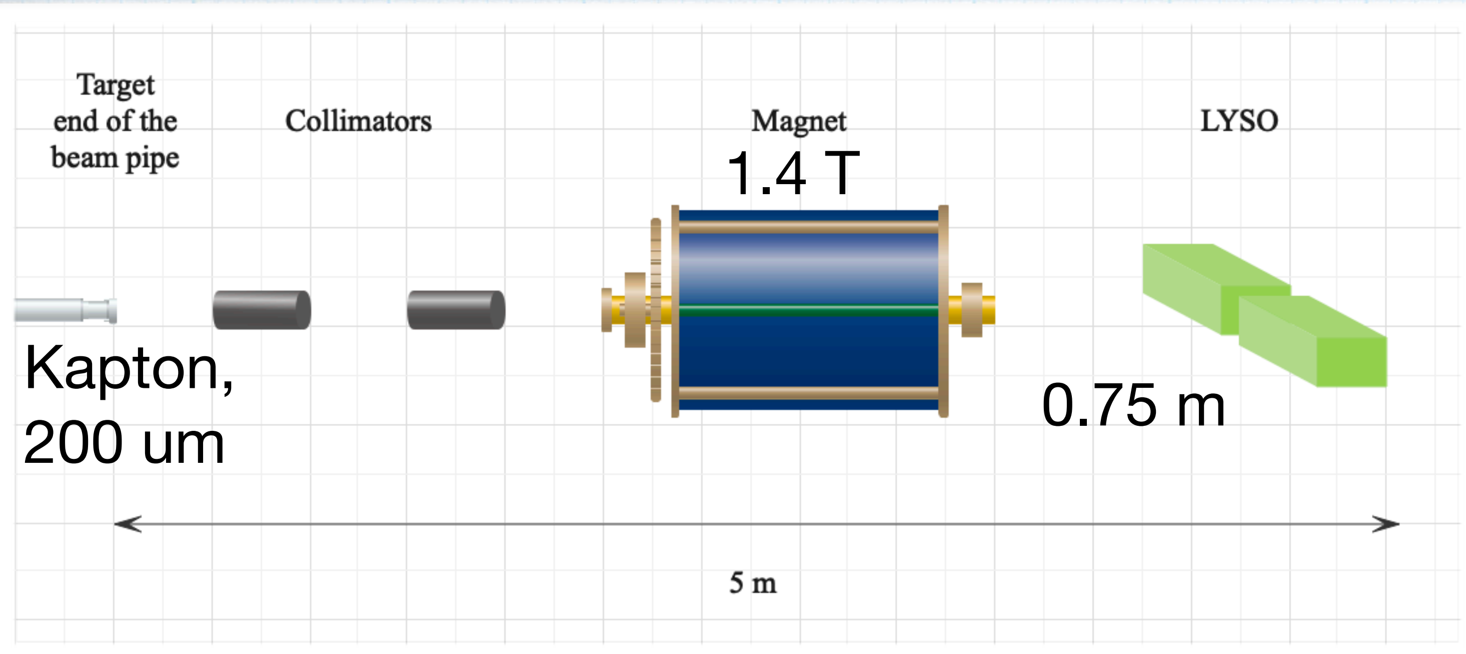
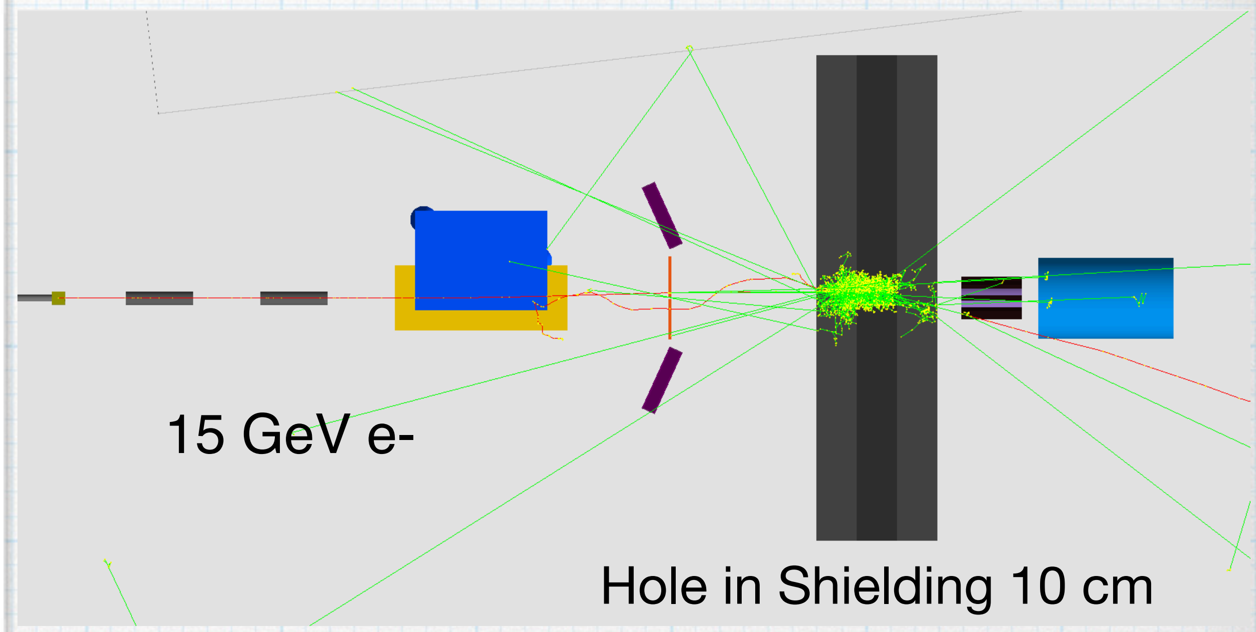
FDS performance

Borysova Maryna (KINR)
10/09/20
LUXE weekly technical meeting

LUXE

FDS with LYSO calorimeters



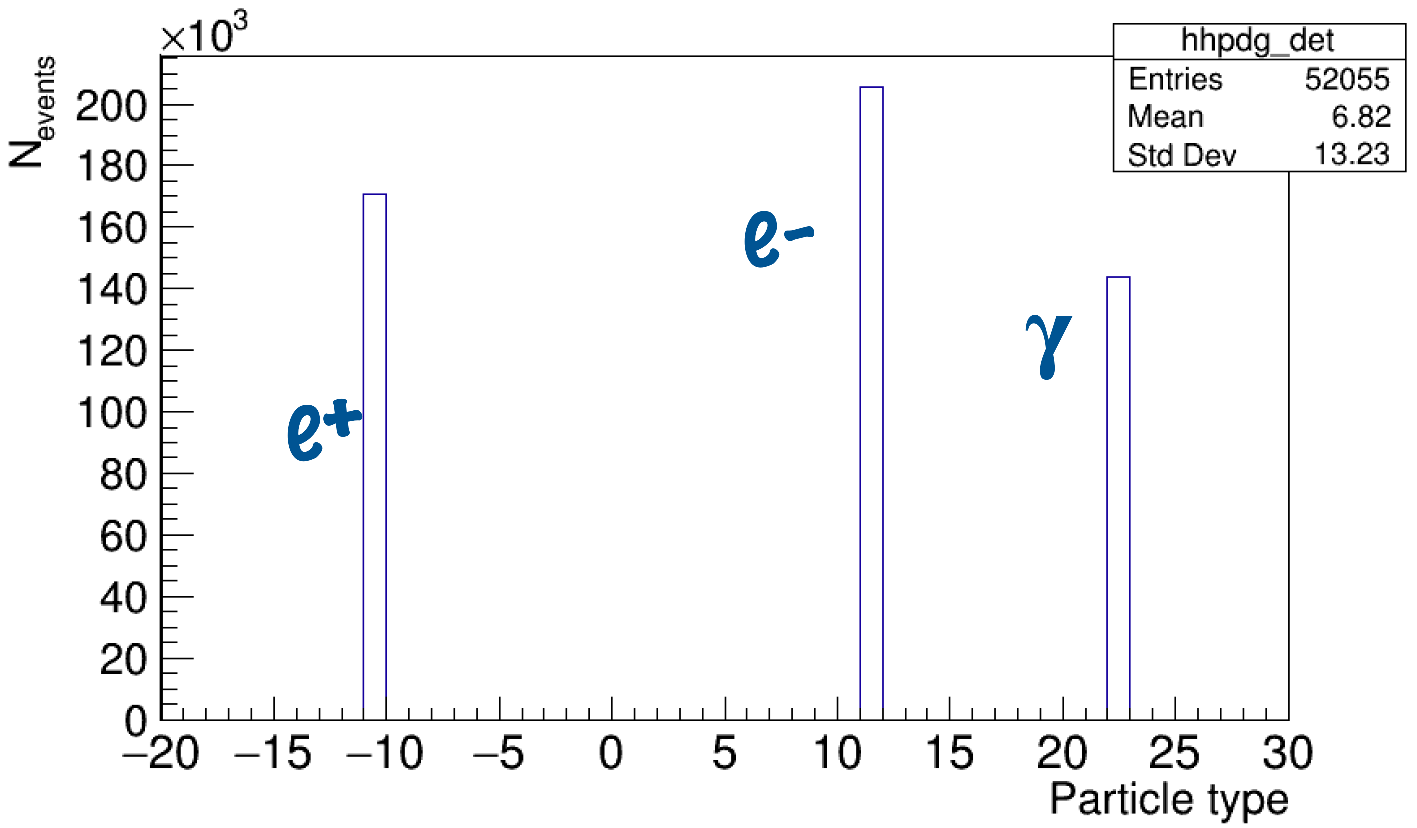


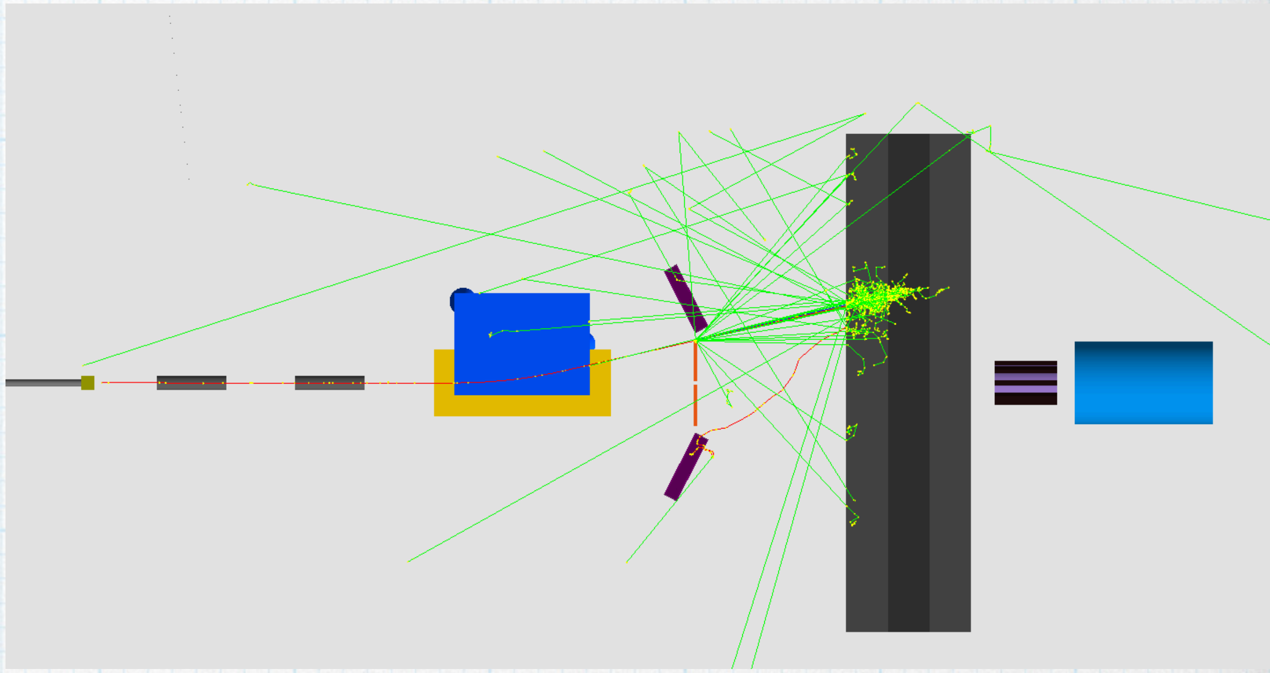
Aug 2020 Data Runs, bunch/pulse crossings completed

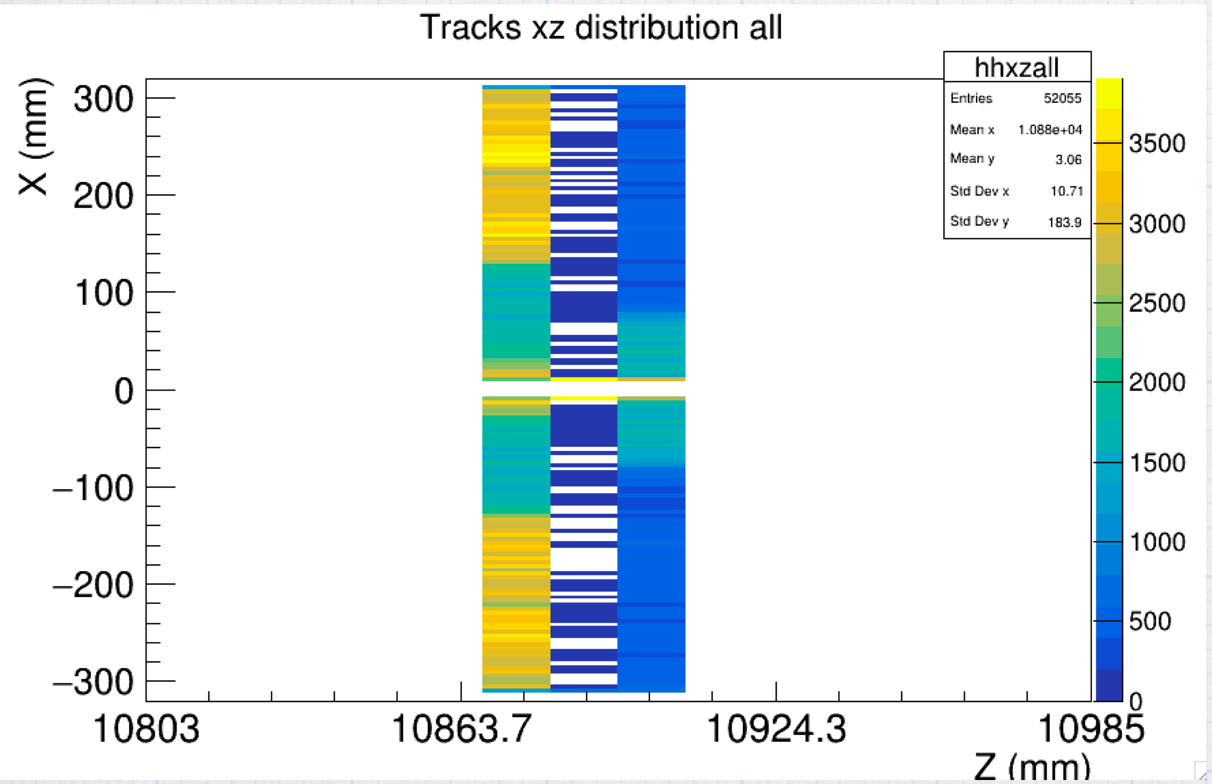
Experiment Config	$w_0 = 3\mu$m	$w_0 = 3.5\mu$m	$w_0 = 4.0\mu$m	$w_0 = 4.5\mu$m	$w_0 = 5.0\mu$m	$w_0 = 20.0\mu$m	$w_0 = 50.0\mu$m	$w_0 = 100.0\mu$m
peak SQED ξ	5.12	4.44	3.88	3.45	3.1	0.78	0.32	0.15
JETI40 e-laser 16.5 GeV	939	951	946	949	938	193	200	200
JETI40 e-laser 17.5 GeV	182	121	115	125	69			

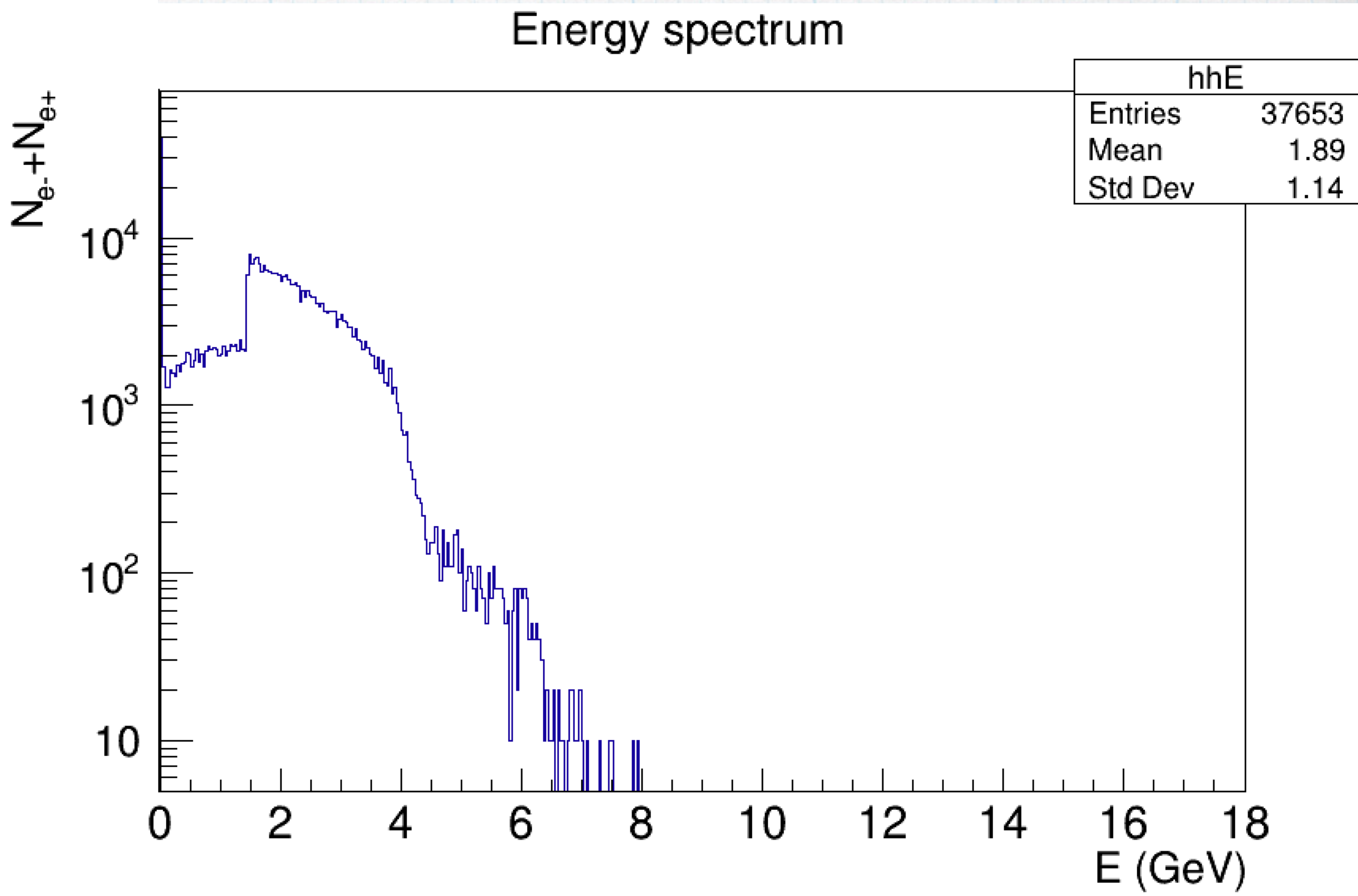
- The scintillators are modelled as a 15x5x2 cm (x:y:z) layer of lyso material
- The crystal (bin) size of the scintillators are 2 x 1 mm (finer segmentation in x; the deflection direction) giving 25 x 300 bins.

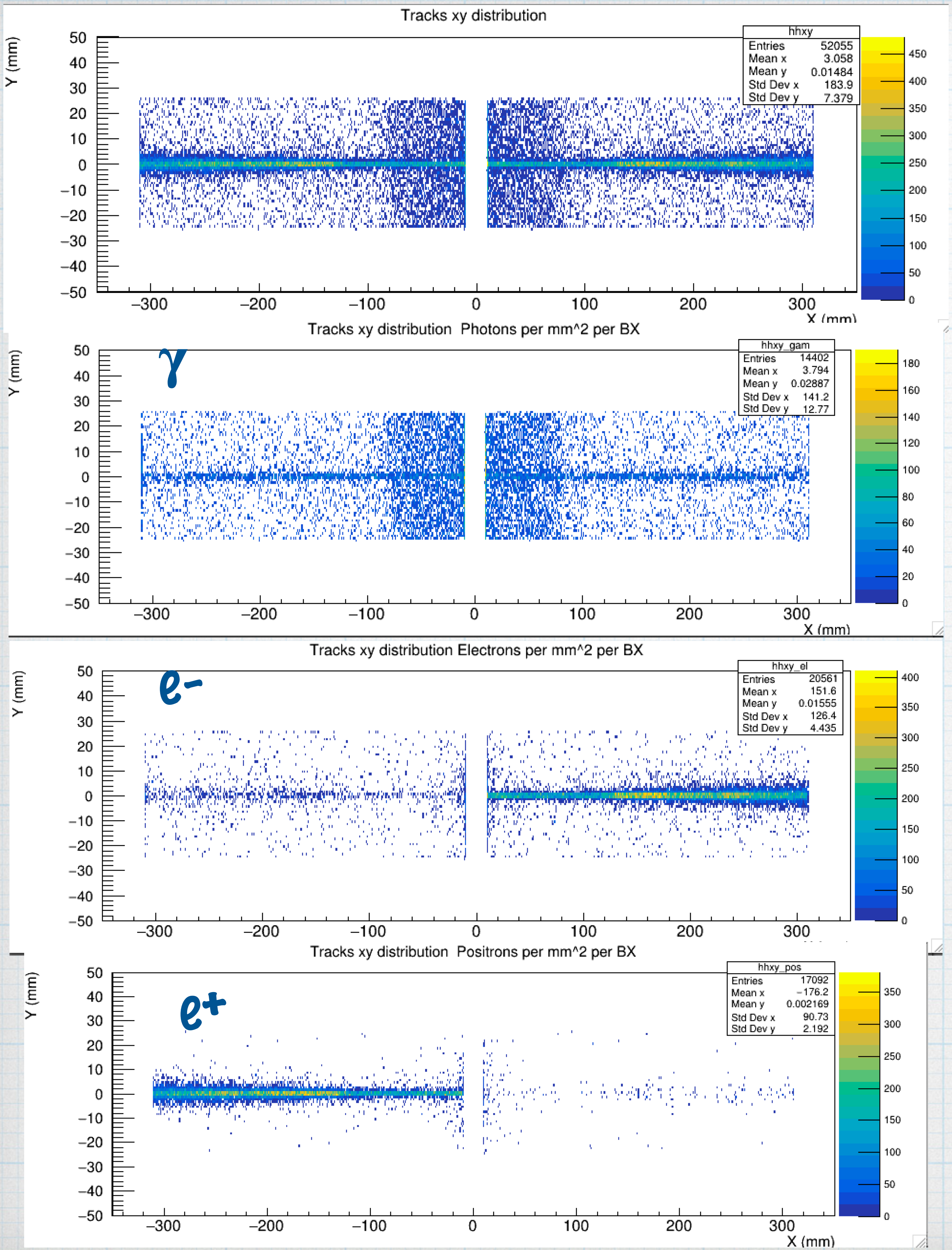
LYSO $(Lu_{1.8}Y_{0.2}SiO_5)$


hhpdg_det
Entries 52055
Mean 6.82
Std Dev 13.23
N_{events}
$\times10^3$
e+
e-
γ
Particle type



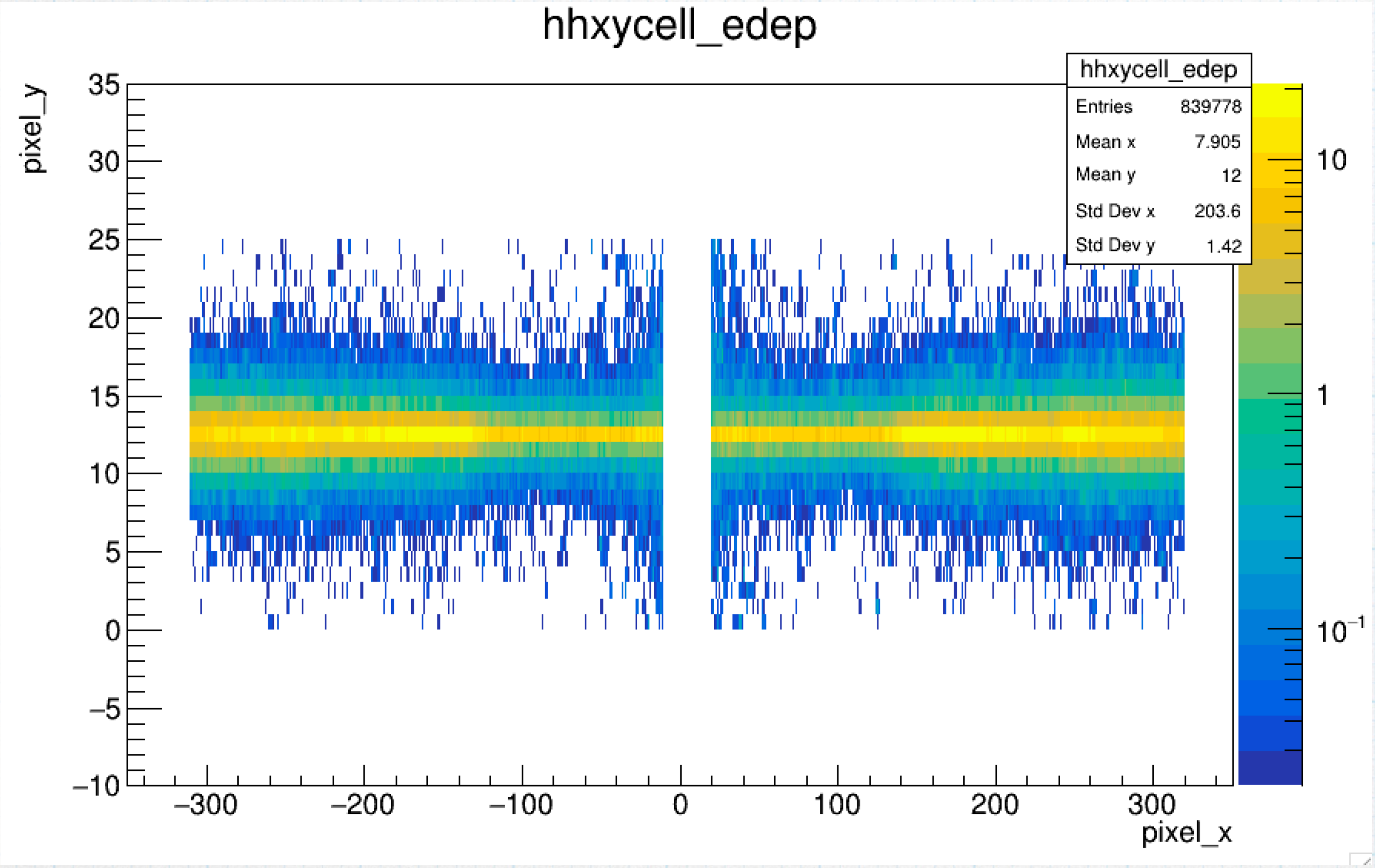

Tracks xz distribution all
hhxzall
Entries 52055
Mean x 1.088e+04
Mean y 3.06
Std Dev x 10.71
Std Dev y 183.9
X (mm)
Z (mm)


Energy spectrum
hhE
Entries 37653
Mean 1.89
Std Dev 1.14
$N_{e-}+N_{e+}$
E (GeV)



Number of particles per BX per mm^2

Deposited energy per cell



- laser intensity $\xi = 0.32$

GeV per BX

Compton MC2020 r for (xi=0.32), 16.5 GeV electrons. G4: Kapton foil of 20 um as a target, magnet 1.4T and 0.75m distance from magnet to LYSO .

If we take distribution of deposited energy the values around maximum are ~10 GeV.

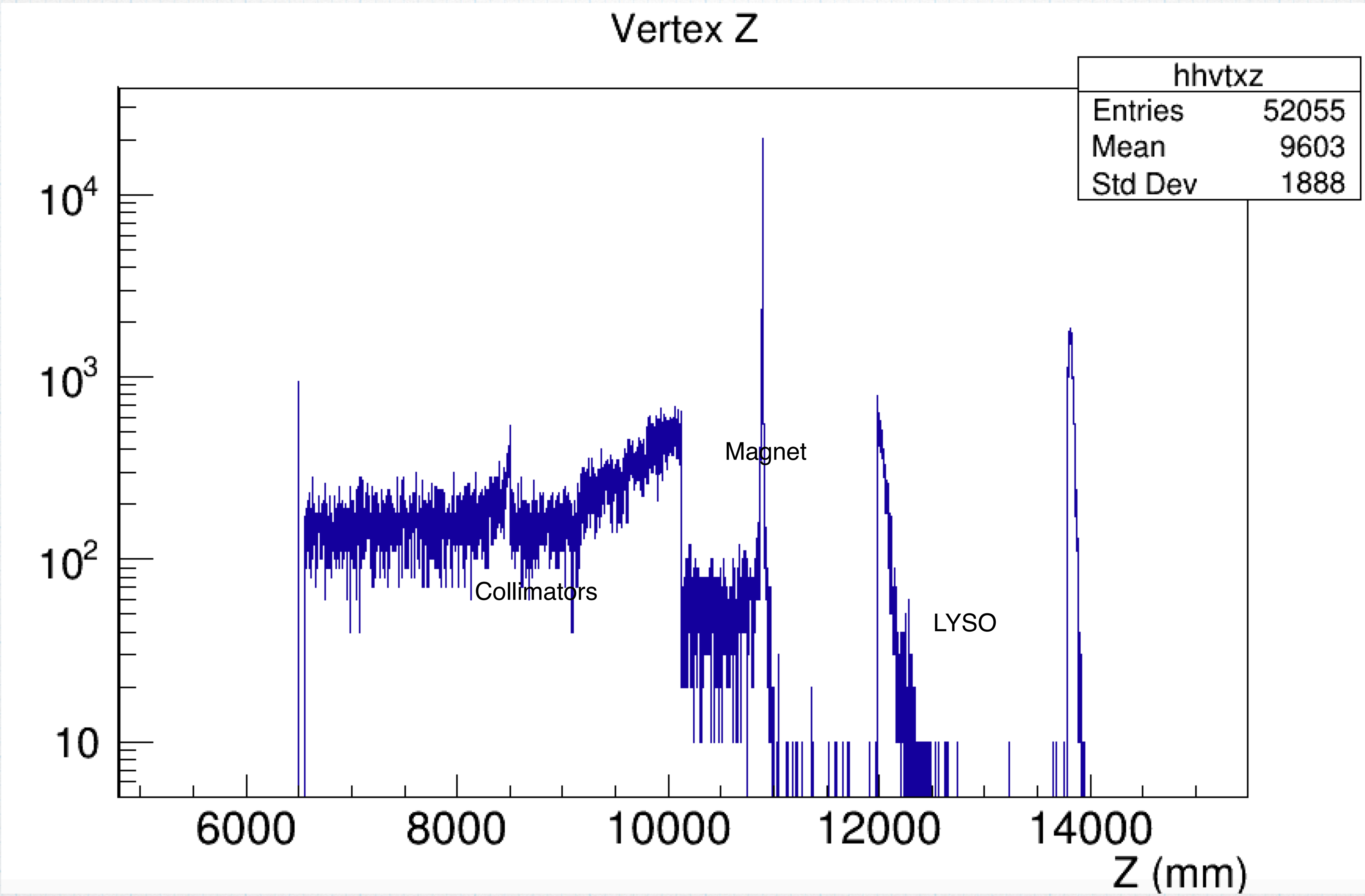
To convert it to Gy, convert it to J: ~1.6e-9J and then divide it to the mass of crystals in kg. Gy= J/kg

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

Finally, 5.6e-6 Gy per BX.

Assuming 1 Hz collisions rate we get the dose of 10 kGy in LYSO crystal in about 56 years.

Vertex z



Vertex Z
hhvtxz
Entries 52055
Mean 9603
Std Dev 1888
10^4
10^3
10^2
10
Magnet
Collimators
LYSO
6000
8000
10000
12000
14000
Z (mm)

Profiler

Just simple estimation for GADOX (LANEX)
let's take photon beam of 10^10 photons of 10 GeV. The total energy is 10^11 GeV which is 16J.

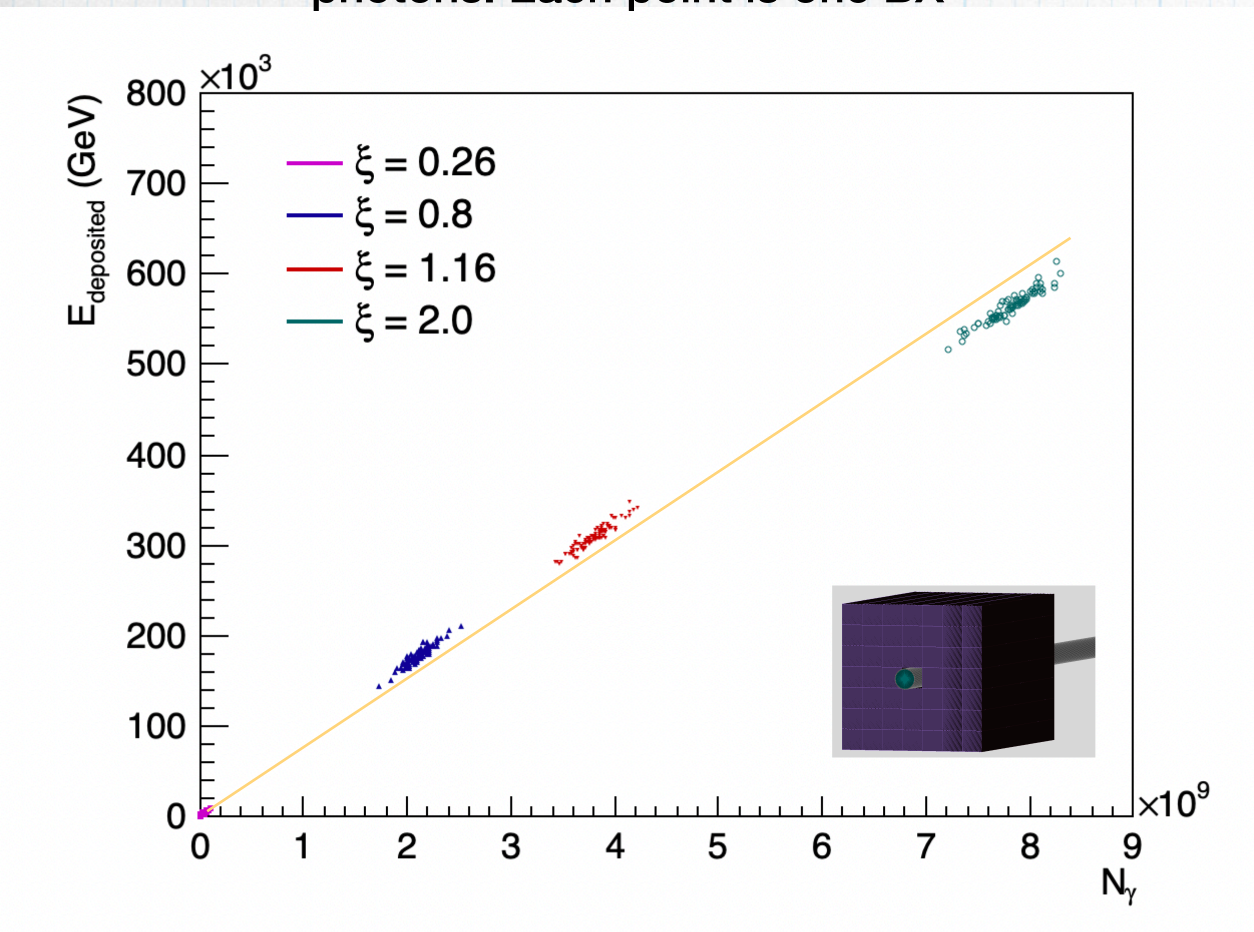
If we consider the transverse size of the beam to be 0,4 mm and profiler thickness 5 cm (3.6 X0) with density~ 6,7 g/cm^3 the mass of irradiated area will be 0,042 g.
Specific heat capacity of gadolinium is 0,23 J/g K. Assuming 10% energy absorption (for 3.6 X0) that volume will heat by 165 degrees in one BX.
In 10 sec at 1Hz it will probably reach the melting point.

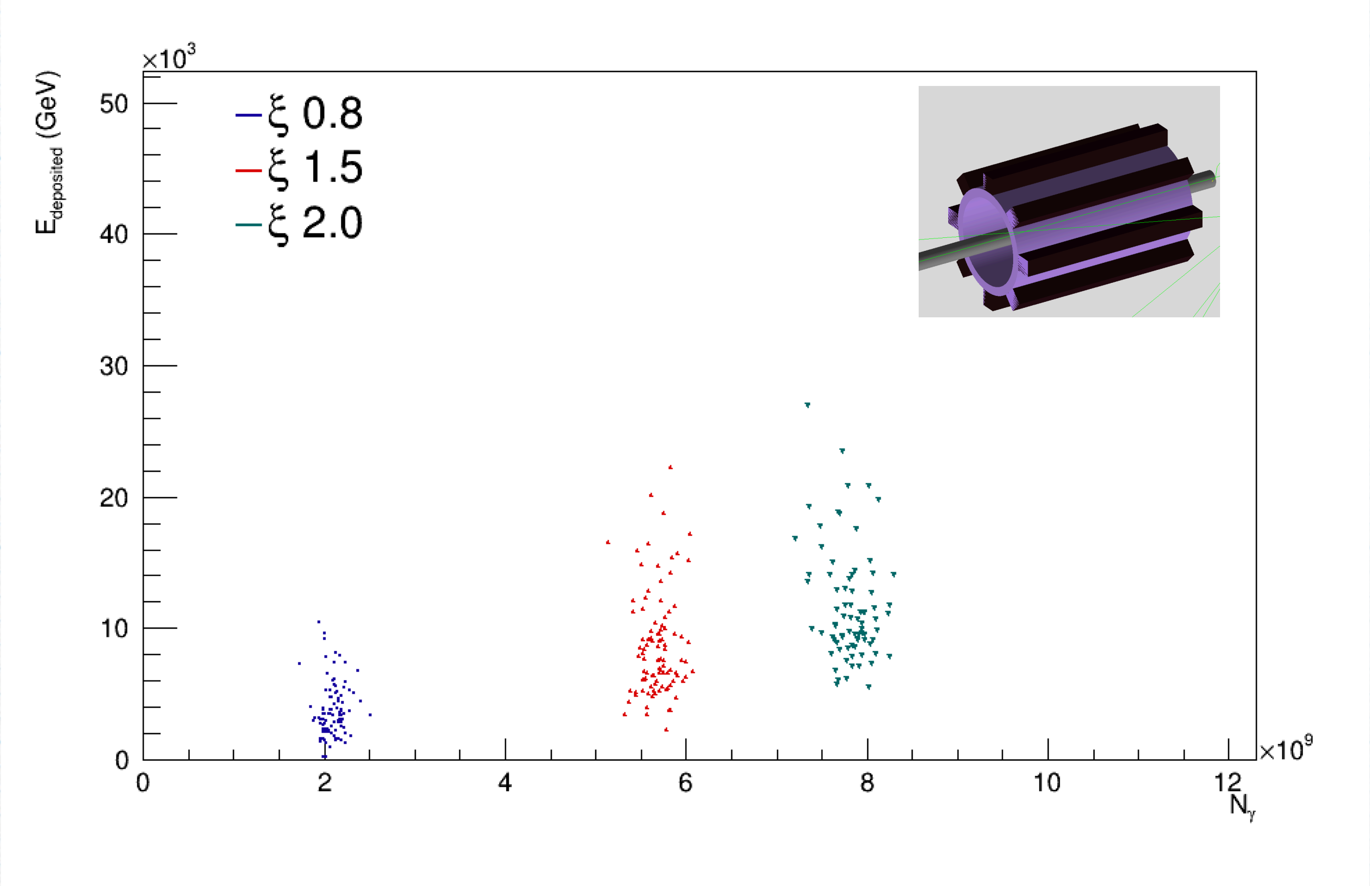
Of course I didn't account for heat dissipation, maybe the area of energy deposition will be wider and the constants for Gadox could be a bit different, but probably this won't work out: 5cm thick Gadox will burnt out in the center in seconds.
Lets forget the radiation damages...

Gamma Monitor

Simulation and Performance

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



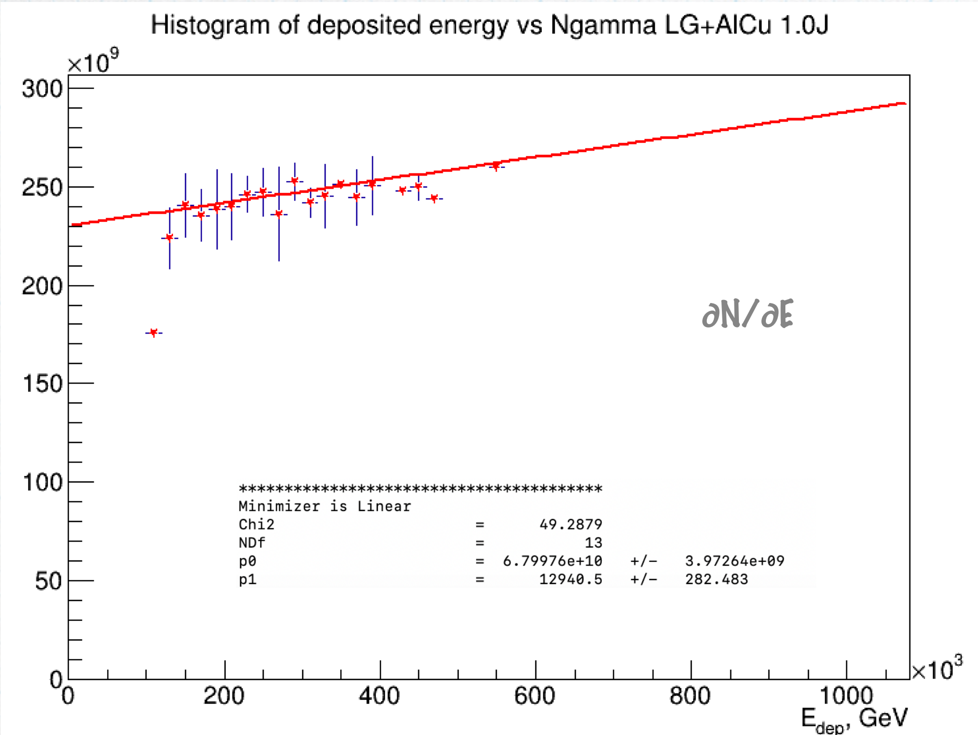


- The (almost) linear dependence of deposited energy on number of incoming photons in GM allows the usage of backscatters for monitoring the photon flux

Uncertainties estimation

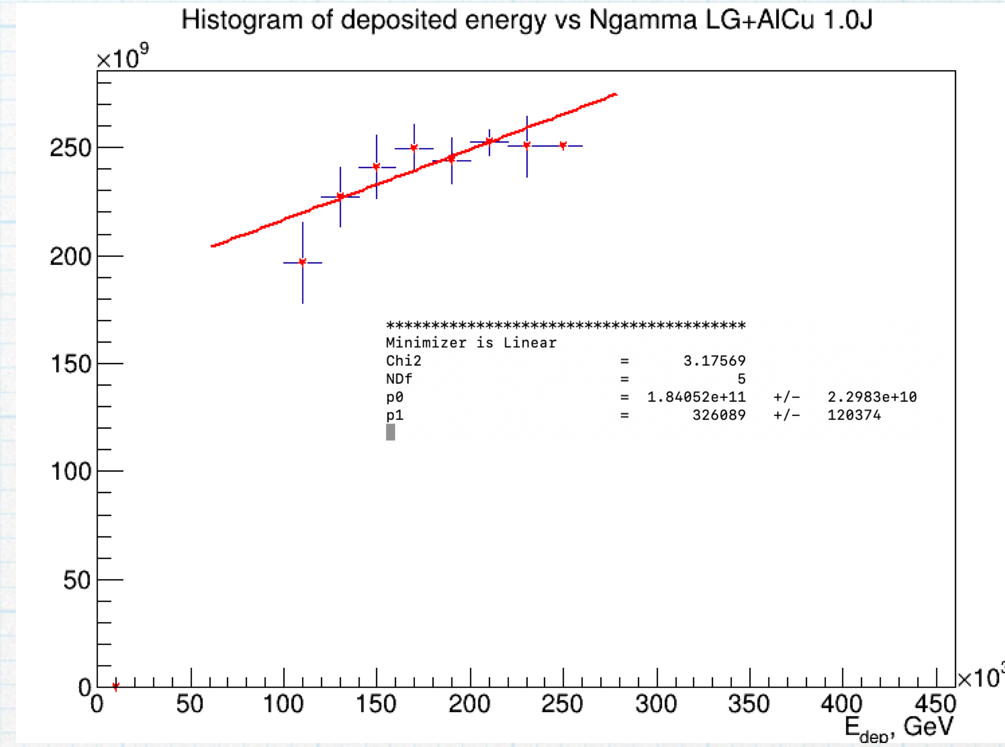
N(E) number of photons

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

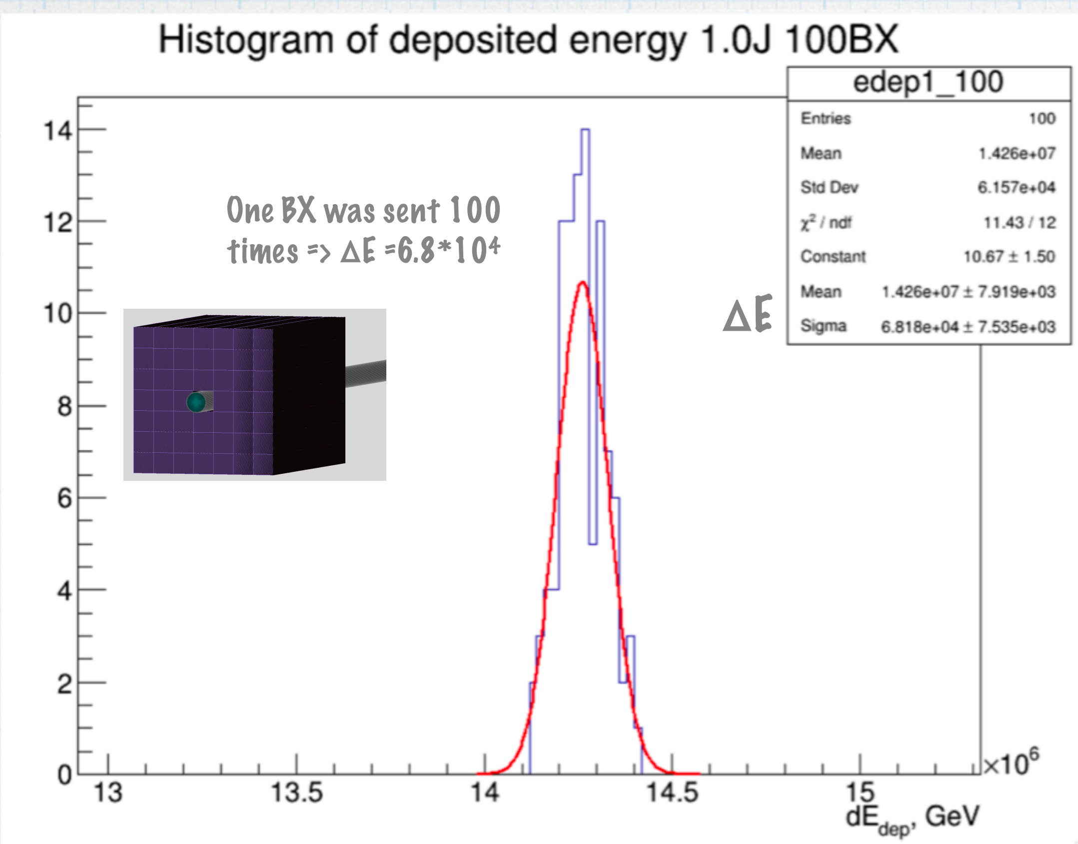


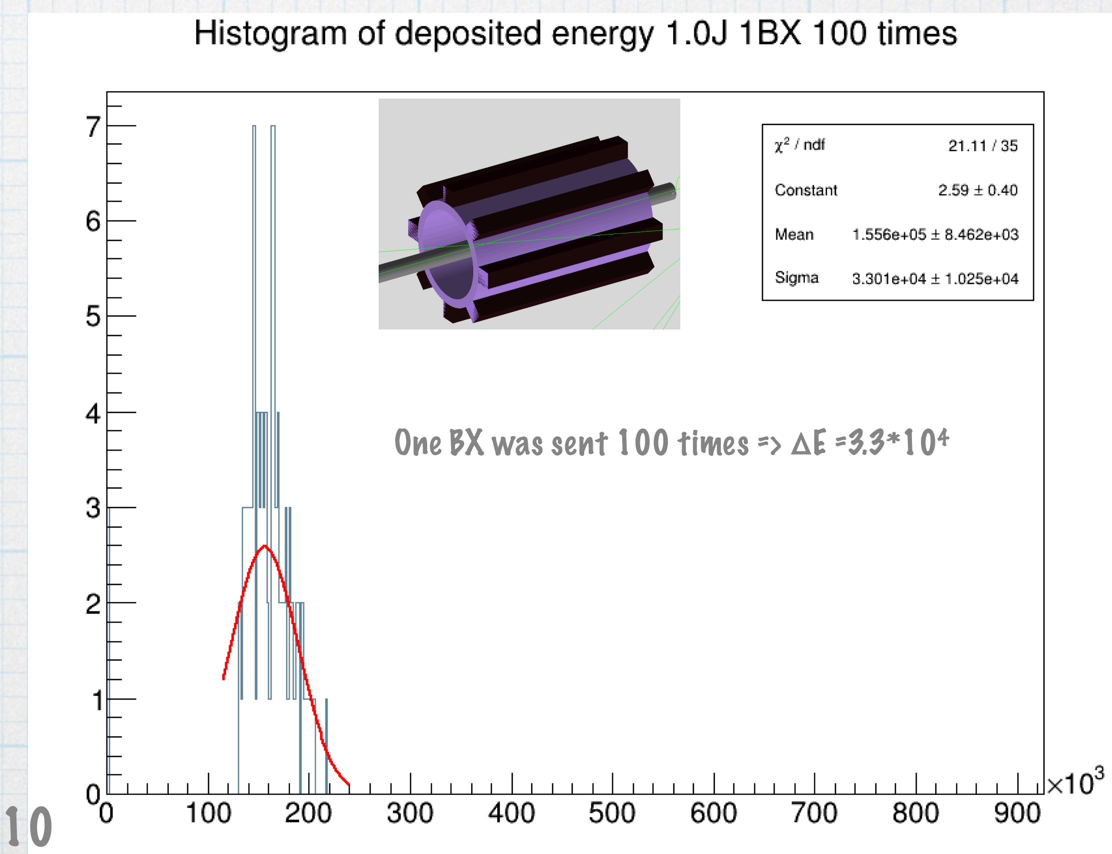
N = 2.5 *10^11 ∂N/∂E =57763

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



$\Delta N/N=3.3*10^4*3.3*10^5/2.5*10^{11} = 4.4*10^{-2}$





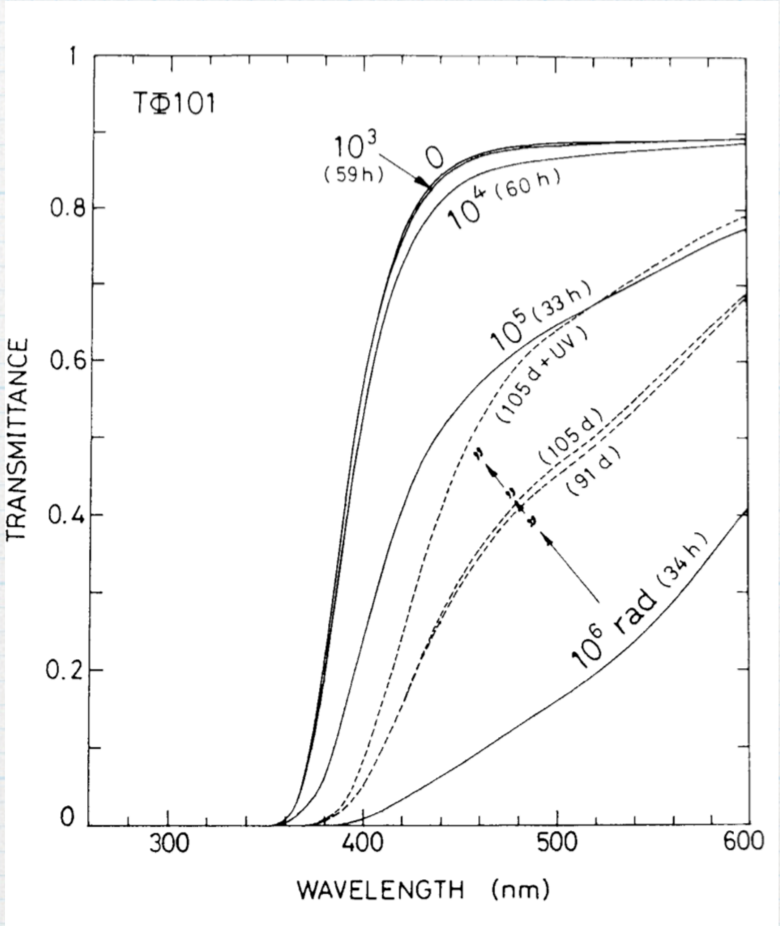
Radiation hardness

the lead glass crystals are of the best radiation hardness.
It was a plan to test them in HERA-B conditions, where they also had radiation hardness problem.
We need to test one crystal at the realistic conditions: measure transparency before and after irradiation which we could do later, I think.

So assuming that it is radiation hard type of the crystal then it makes sense to reverse to 7X7 geometry because it proves to be better in energy deposit linearity.
For the 8 blocks configuration the accuracy of photon counting drops as seen from recent results.

the radiation tolerance for 7X7 geometry is given:

Gamma Monitor 48		
	Accumulated 1 kGy, (days)	10 kGy, (days)
TF101	20% degradation	turns brown
Inner layer	226.0	2260.4
	305.9	3059.1
Middle layer	411.8	4118.0
	517.7	5177.0
	906.0	9059.7
Outer layer	1068.0	10680.2
	1261.2	12611.7
	1985.4	19853.7
	3730.6	37306.0

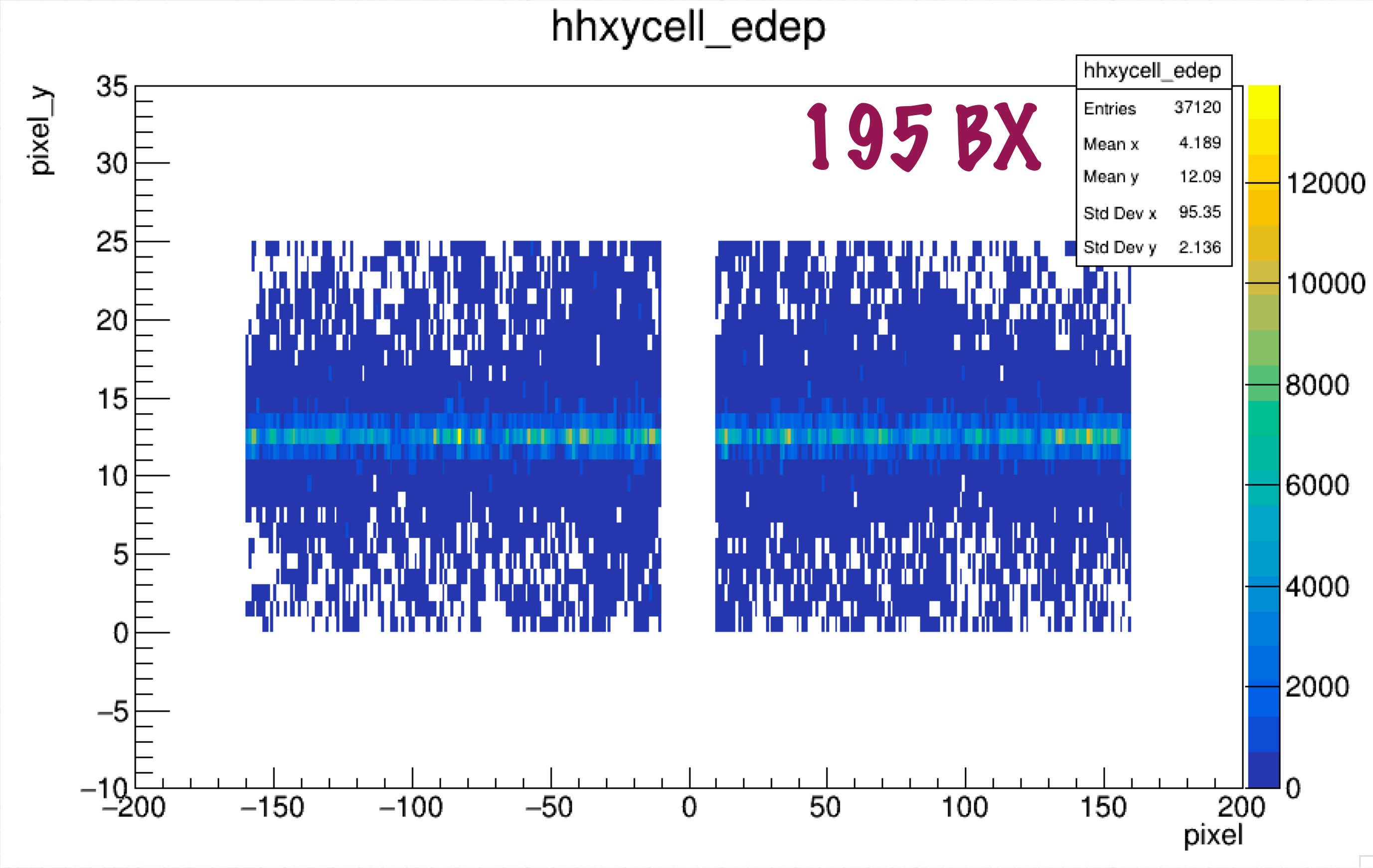


TF101 - radiation hardened with addition of 0.2% cerium

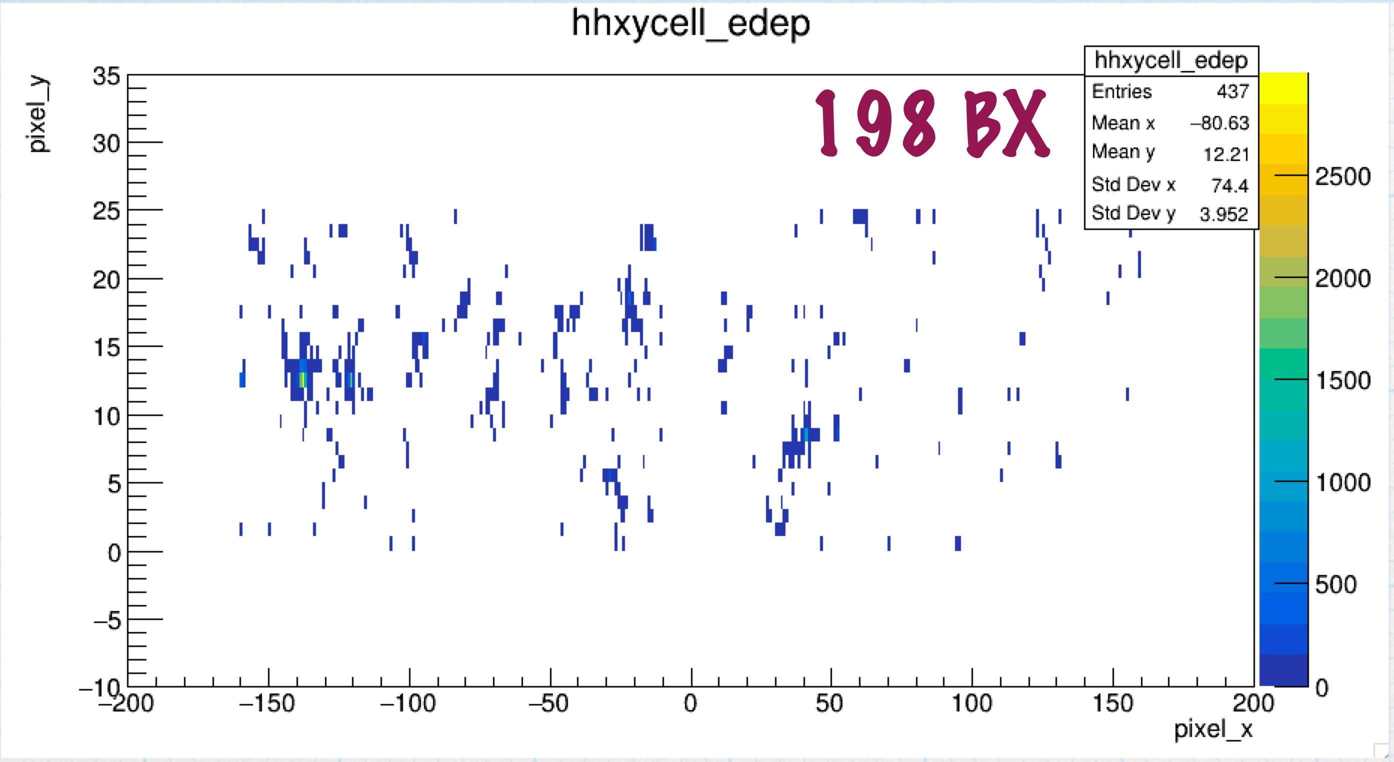
After 1 kGy full recovery is possible (with UV exposure); for 10 kGy - substantial damage

Back up

Deposited energy per cell: Air vs Vacuum



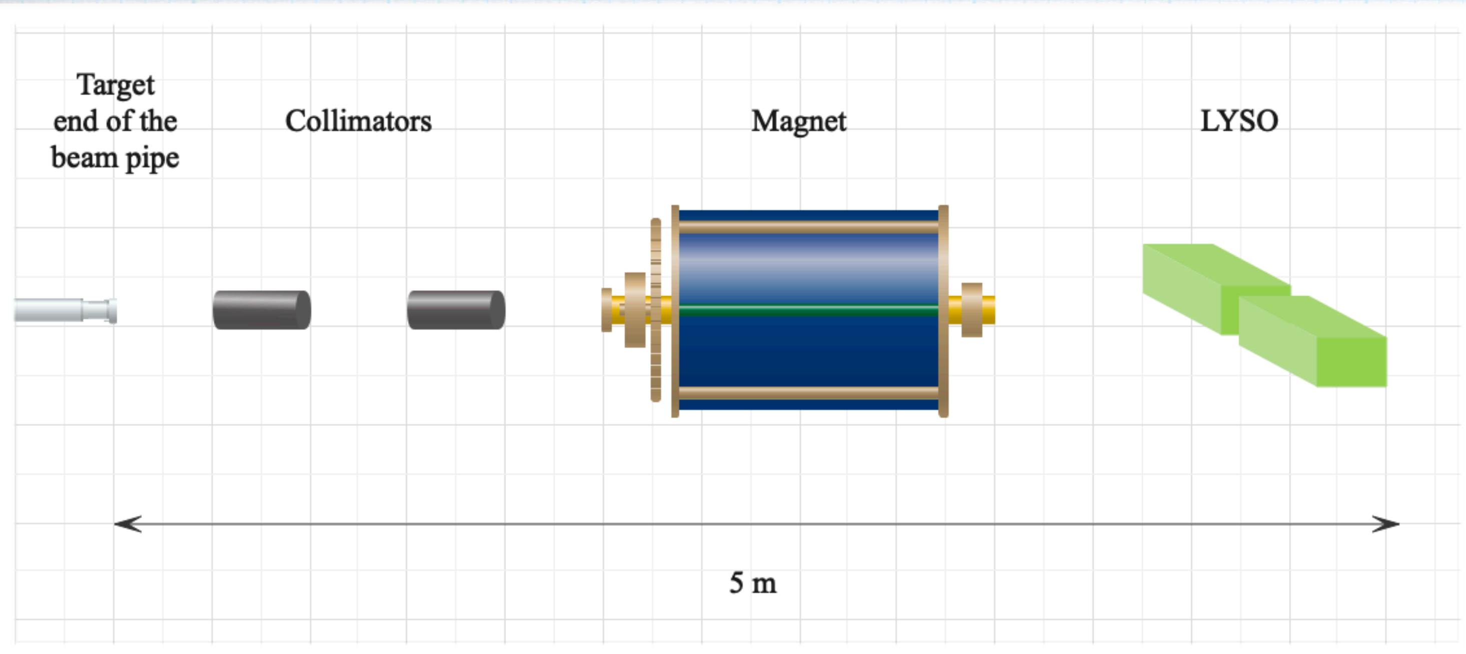
Edep (per 1 BX) =61.5 GeV

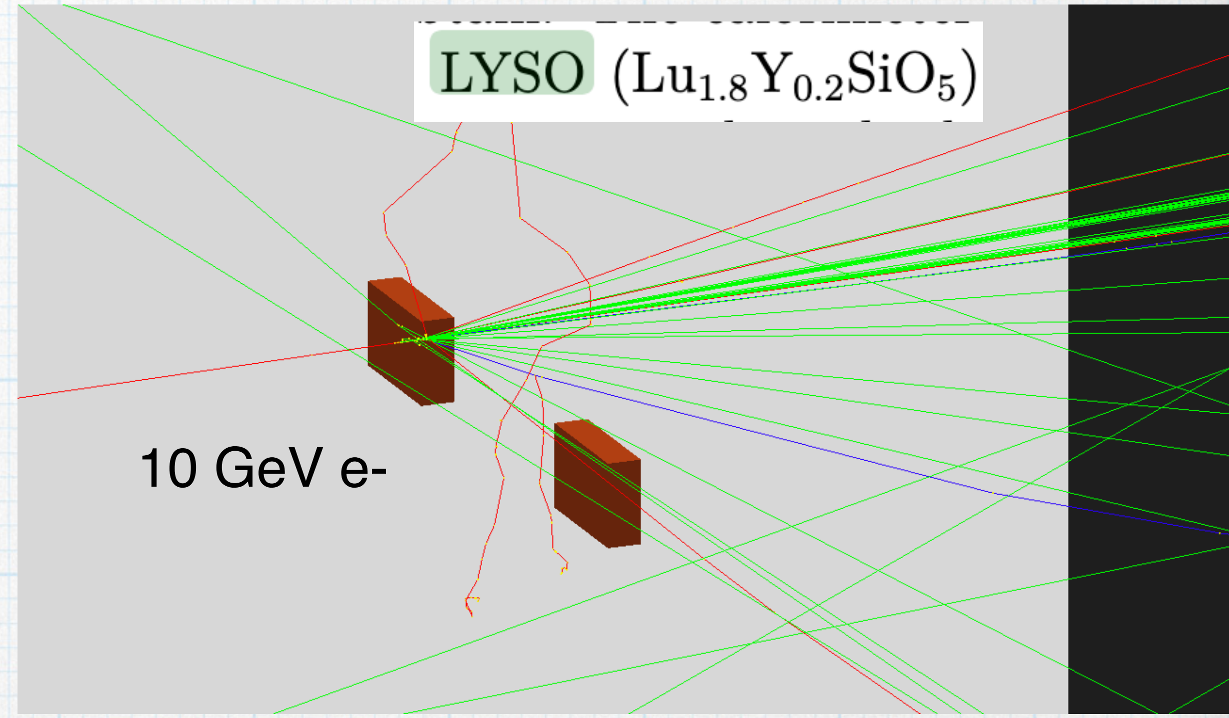


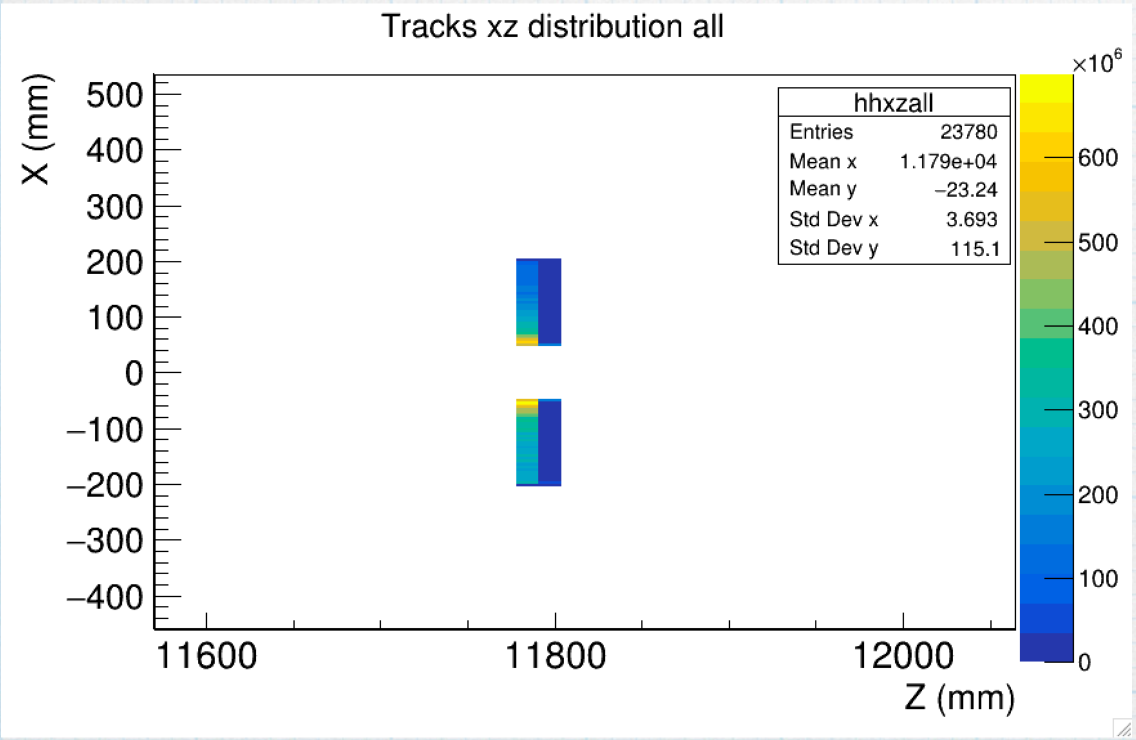
Edep (per 1 BX) =12.6 GeV

			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

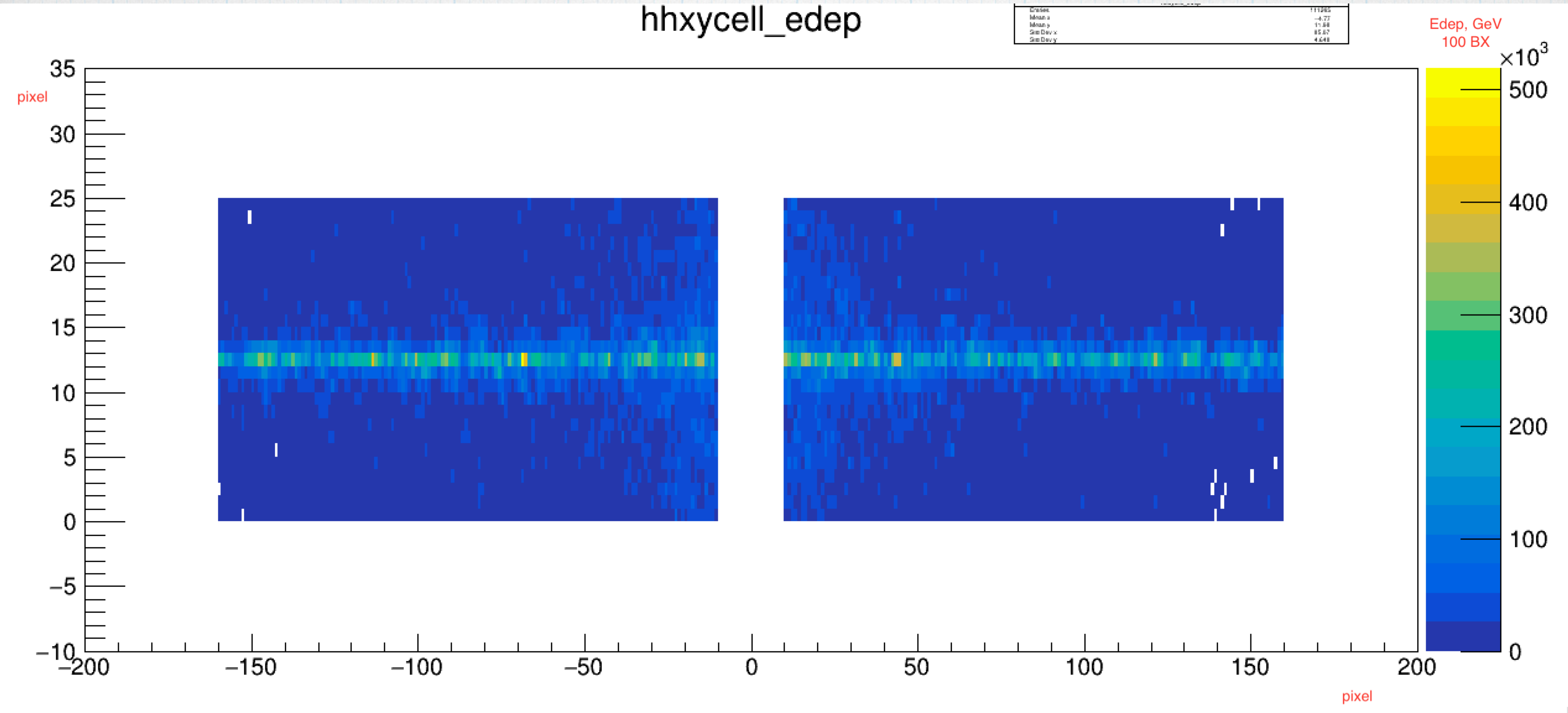
LYSO calorimeters







- ✳ 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 .

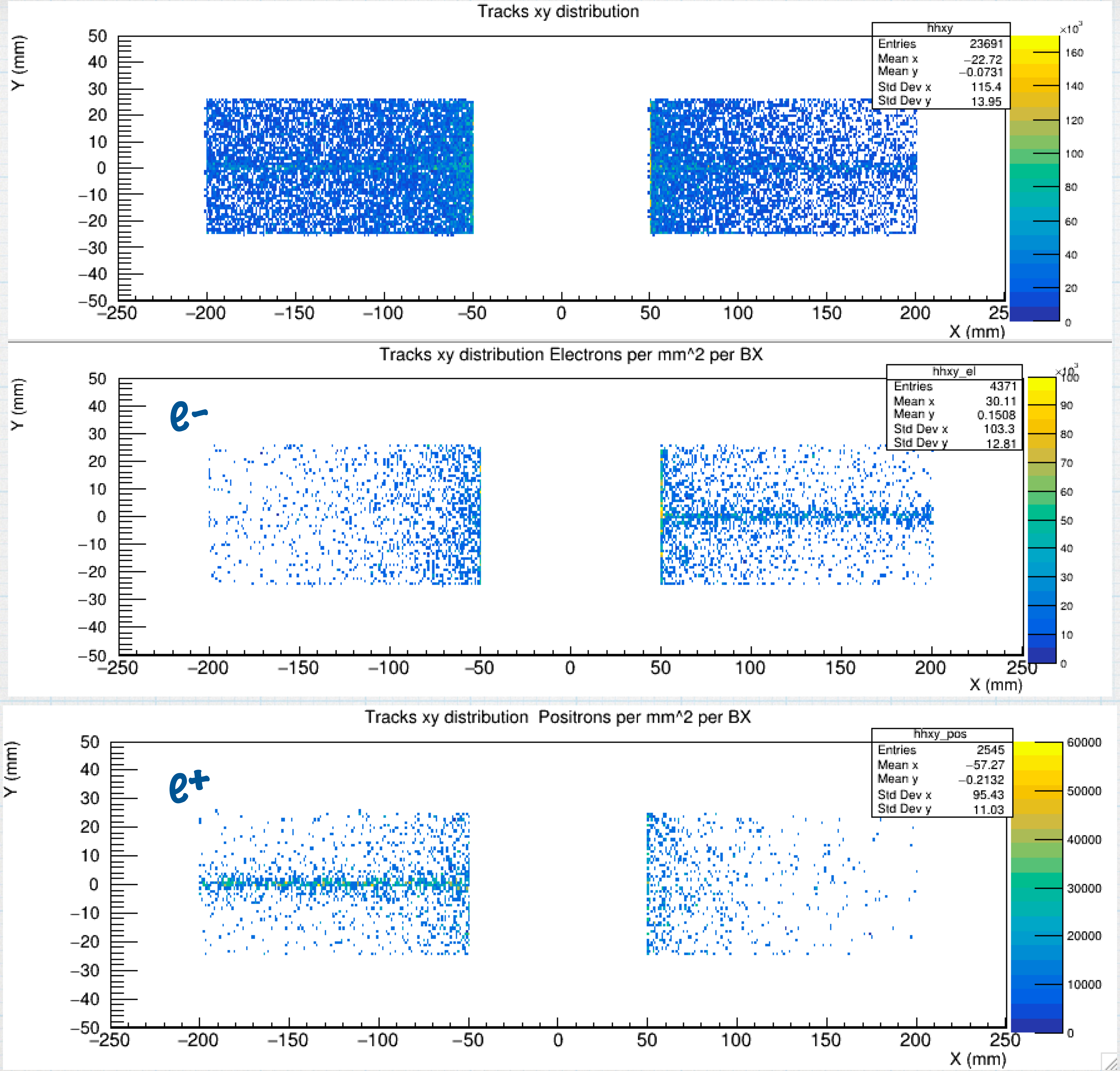
If we take distribution of deposited energy the values around maximum are ~5e3 GeV.

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.

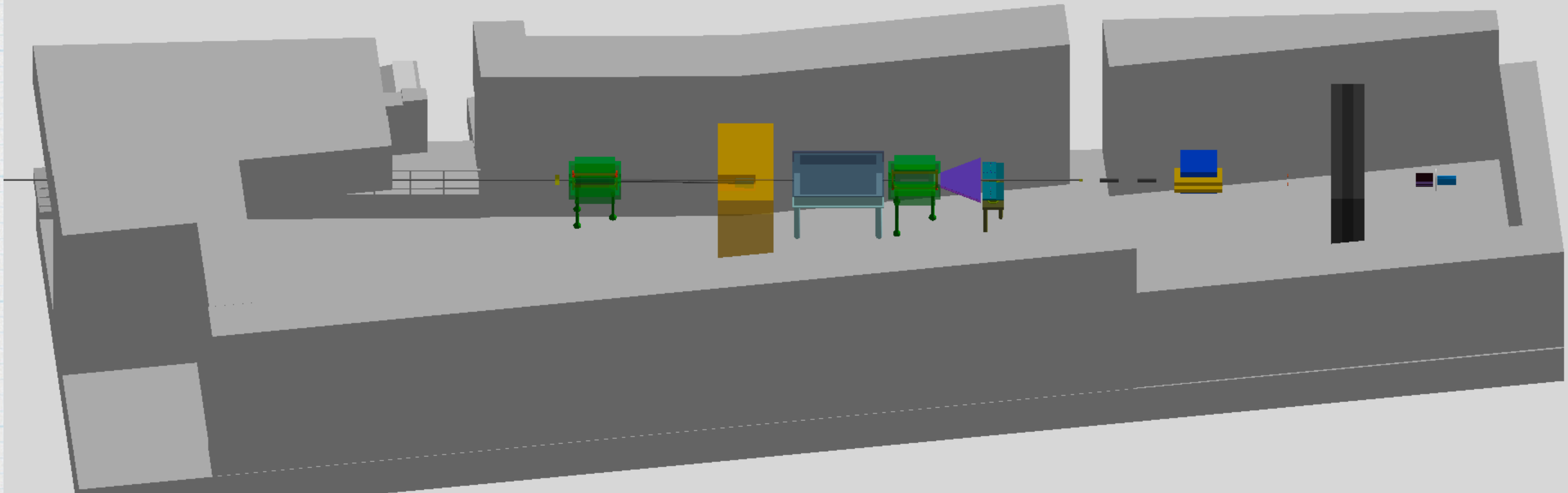
Finally 8e-7J/0.284e-3 = 2.8e-3 Gy per BX.

Assuming 1Hz collisions rate we get the dose of 10000Gy in LYSO crystal in about 1000/2.8e-3 = 3.6e6s which is 41,3 days.

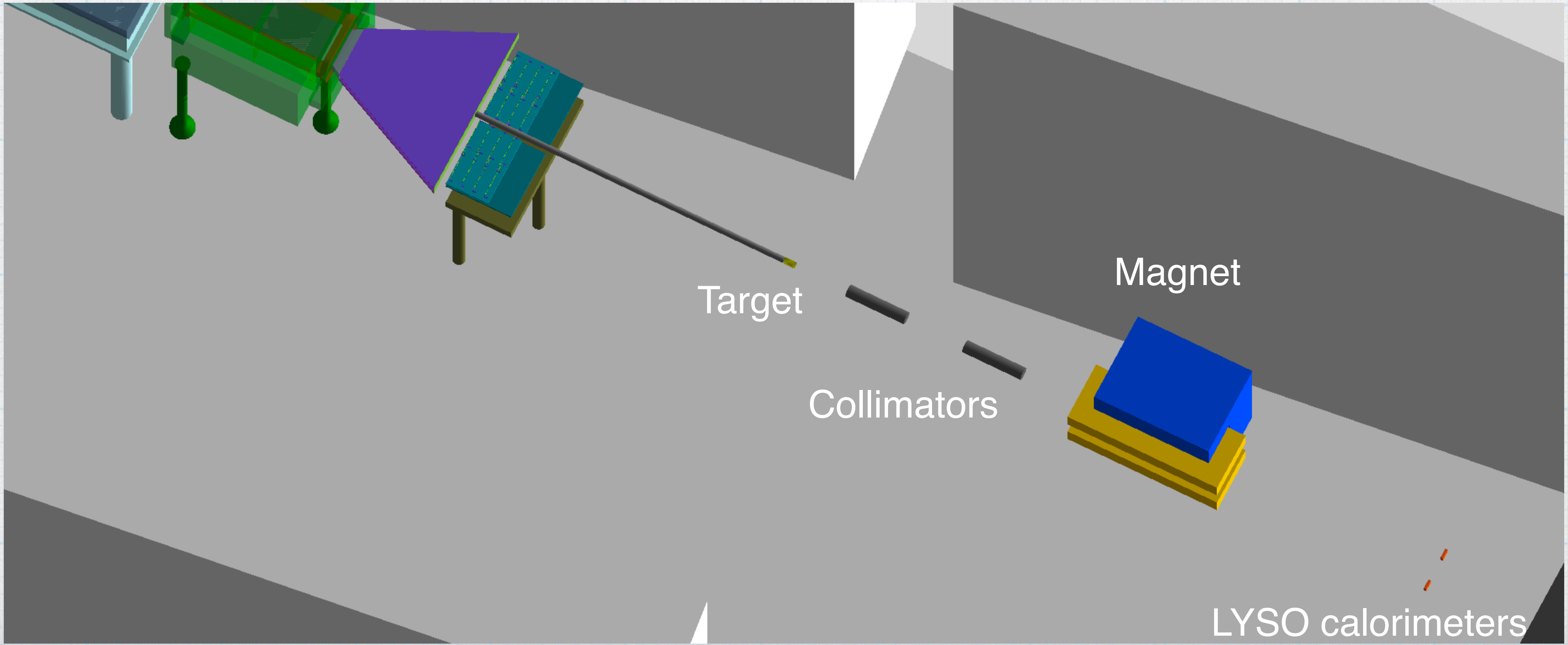


Number of particles per BX per mm^2

Luxe Set-up



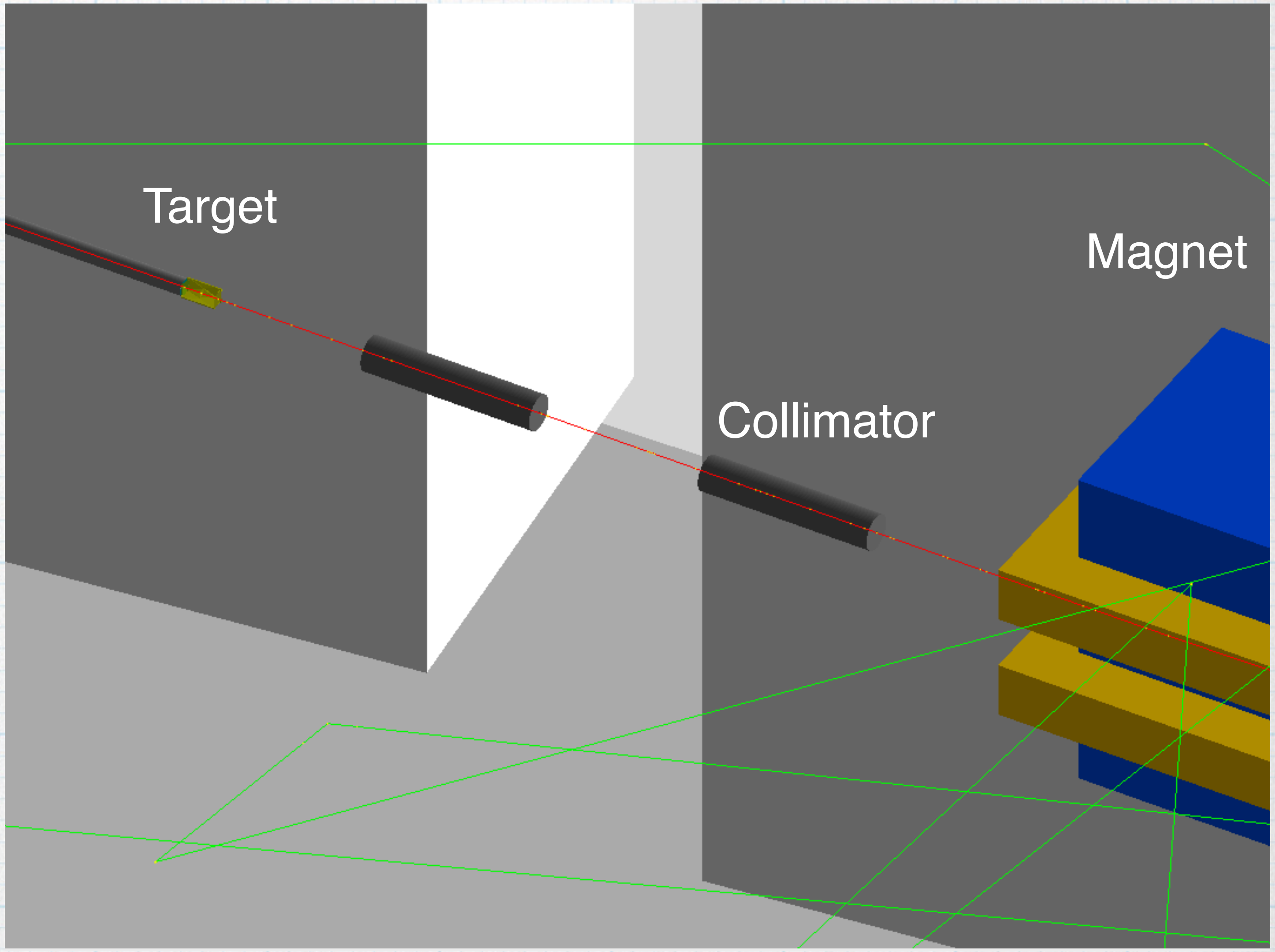
The distance between IP and Compton Target = 6.5 *m



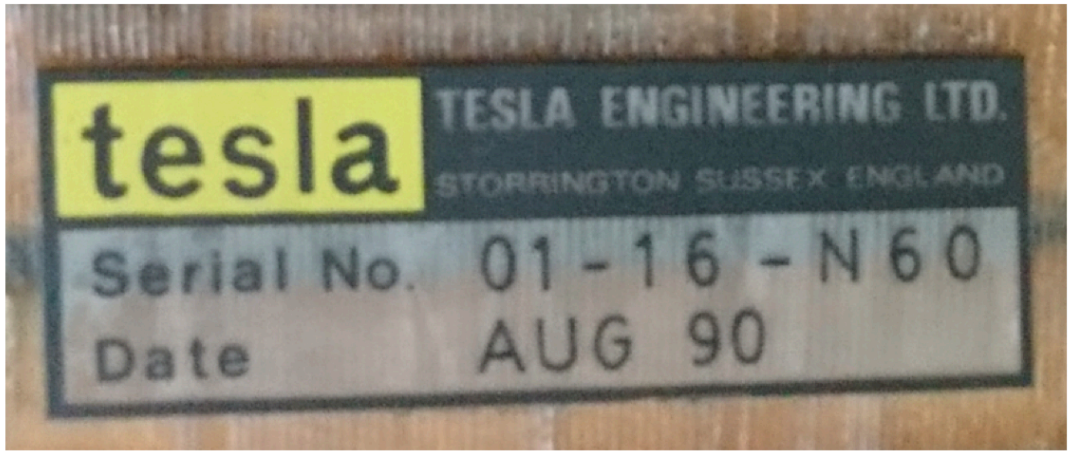
Specifications from FLUKA

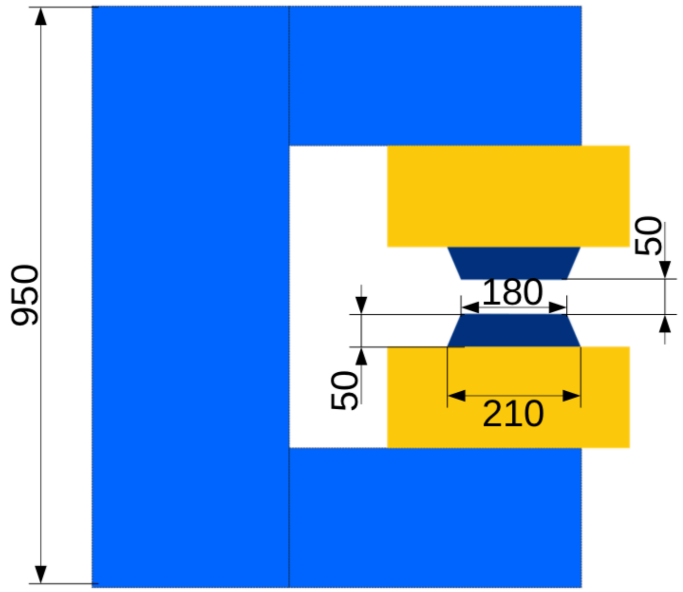
From Kyle:

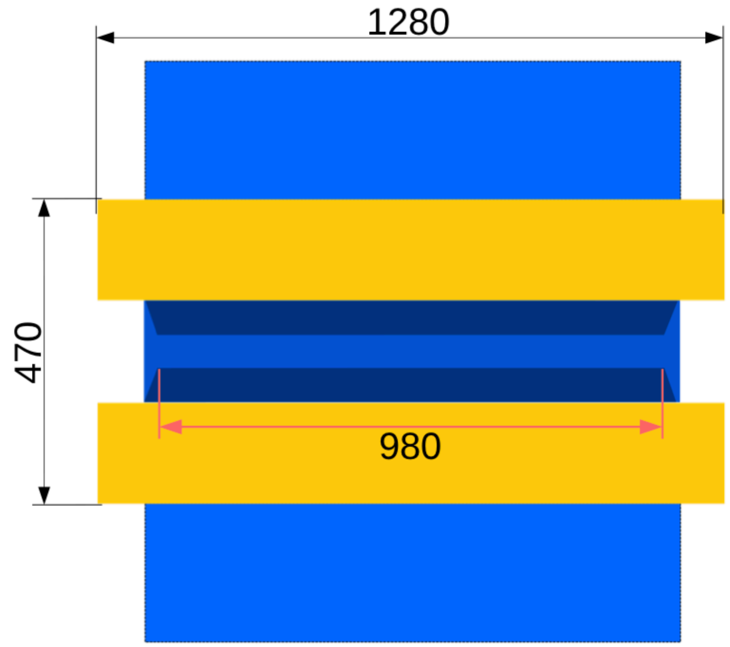
Technical Specifications	
Target	
Material	W
Thickness (z)	10 μm
Width (y)	20 cm
Height (x)	20 cm
Collimators	
Material	Pb
Length	50 cm
Inner Radius	0.4 cm
Outer Radius	5.0 cm
Separation	50 cm
Magnet	
Field Strength	Up to 1.4 T
Effective Length (z)	98 cm
Effective Width (y)	18 cm
Effective Height (x)	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

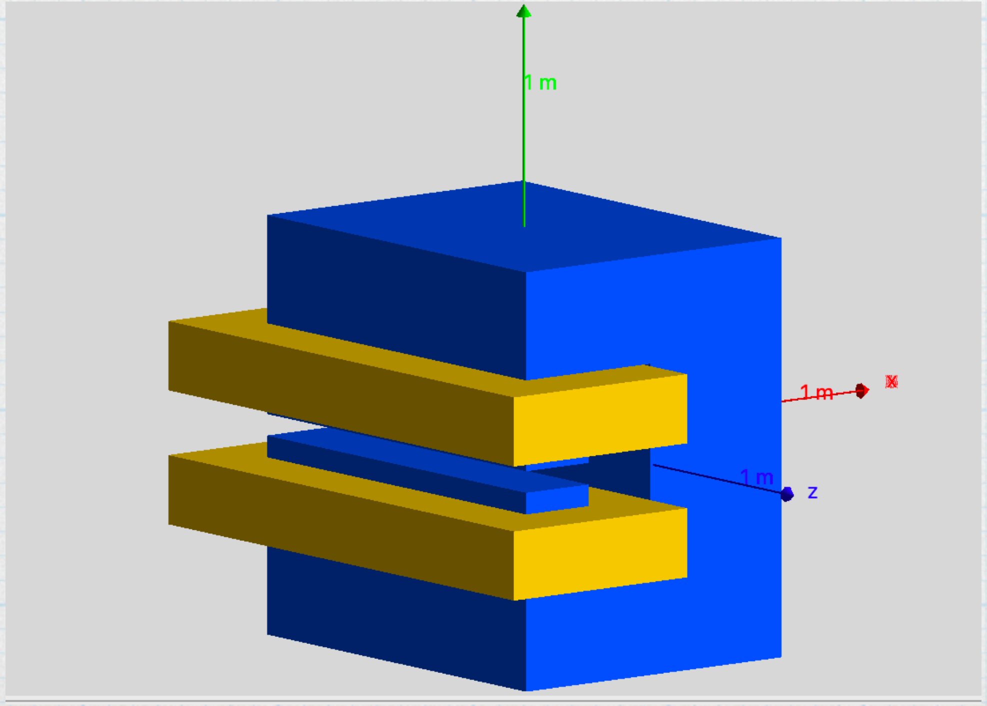


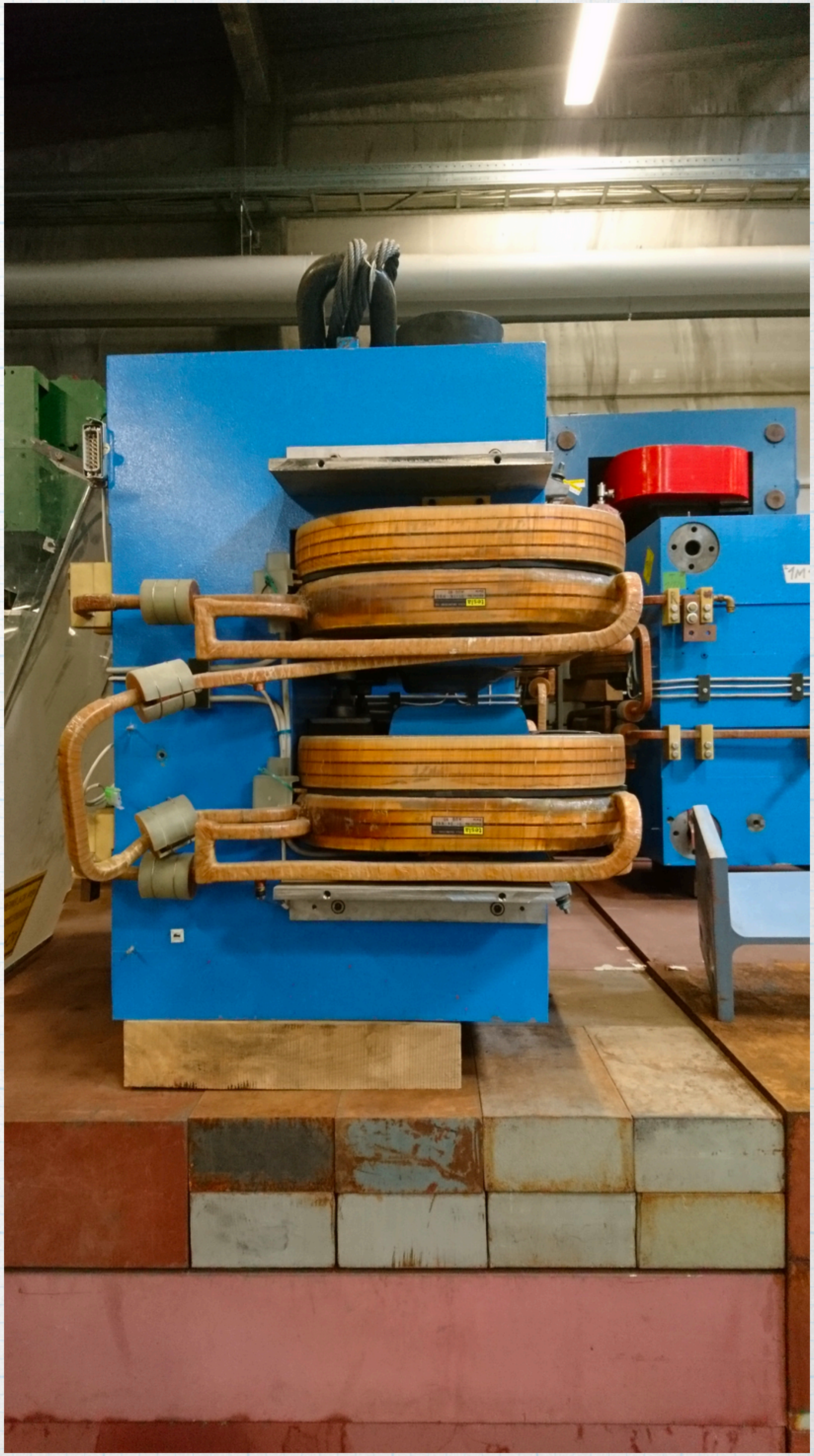
C-shape magnet





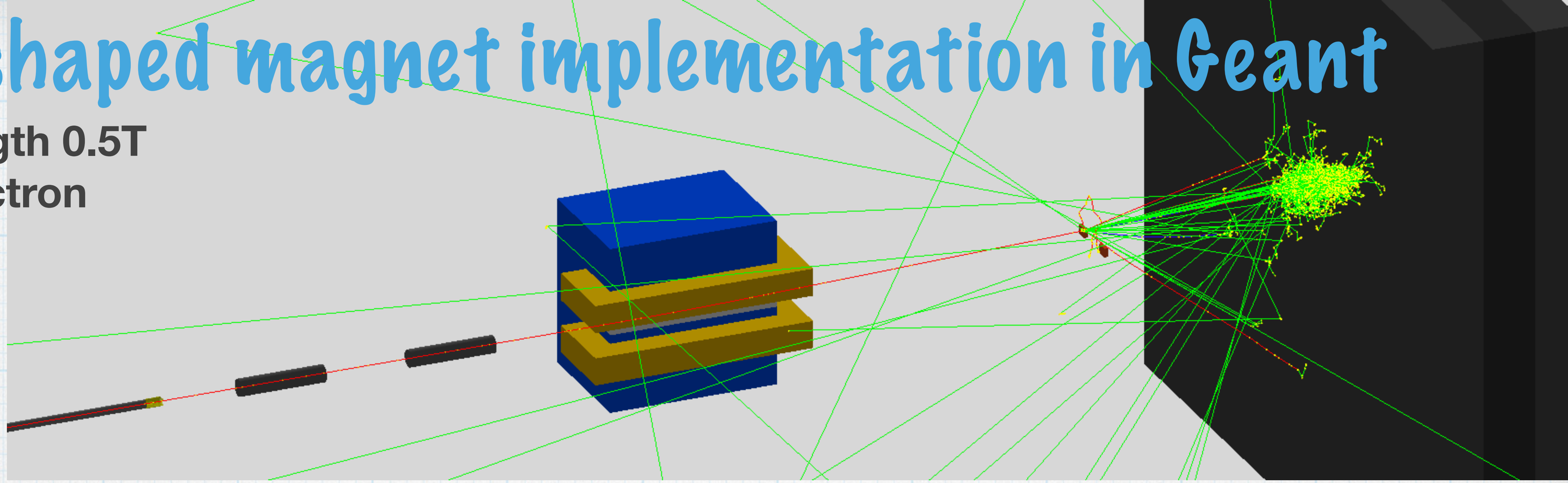


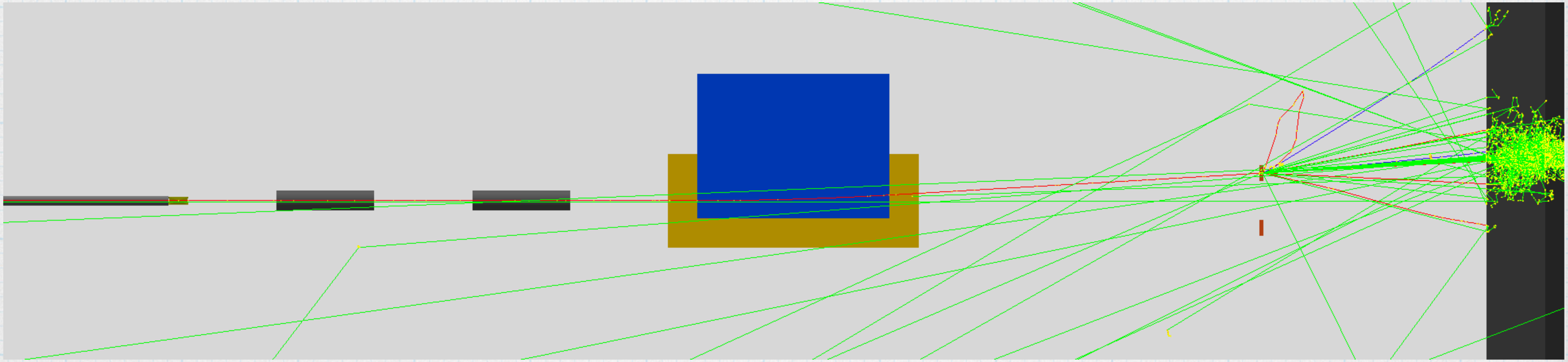


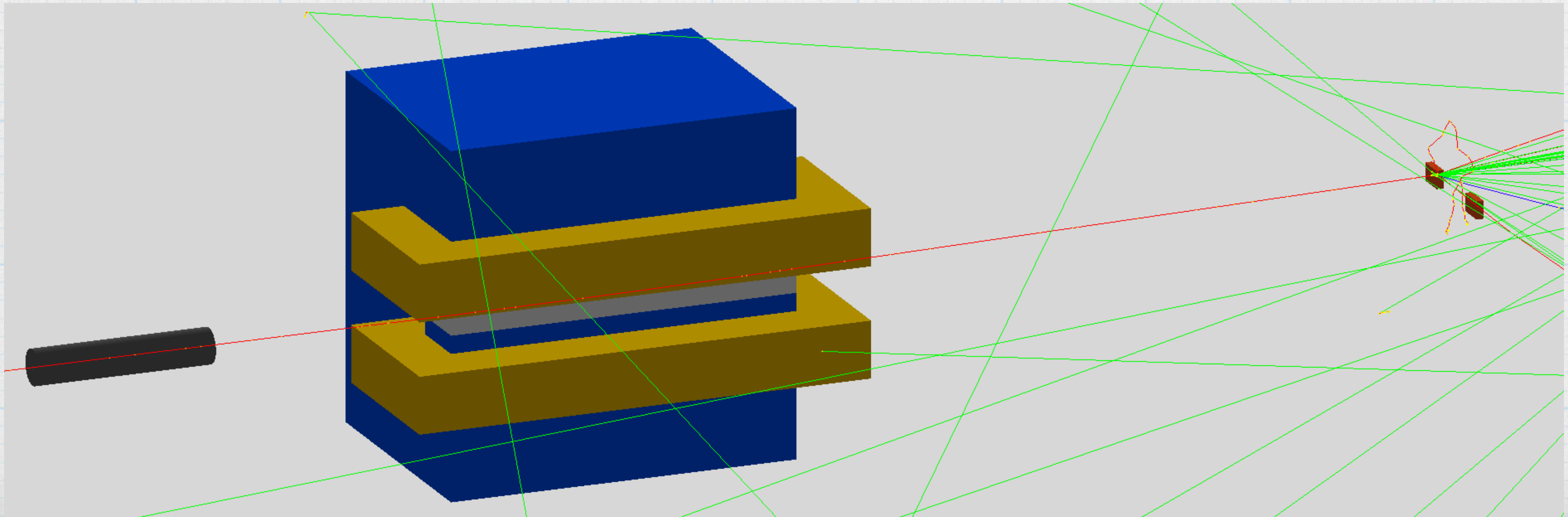


C-shaped magnet implementation in Geant

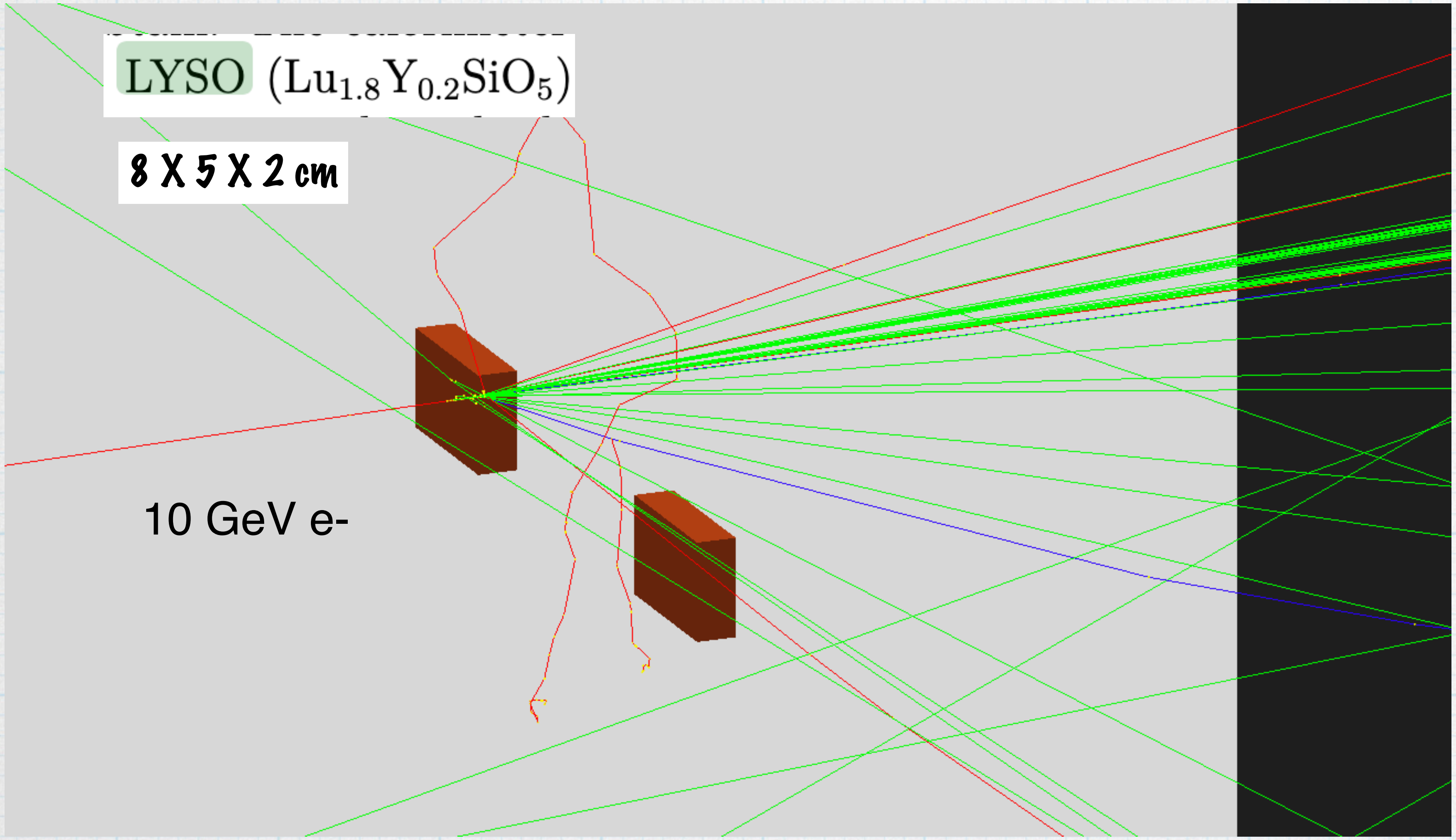
- Field strength 0.5T
- 10 Gev electron







LYSO calorimeters

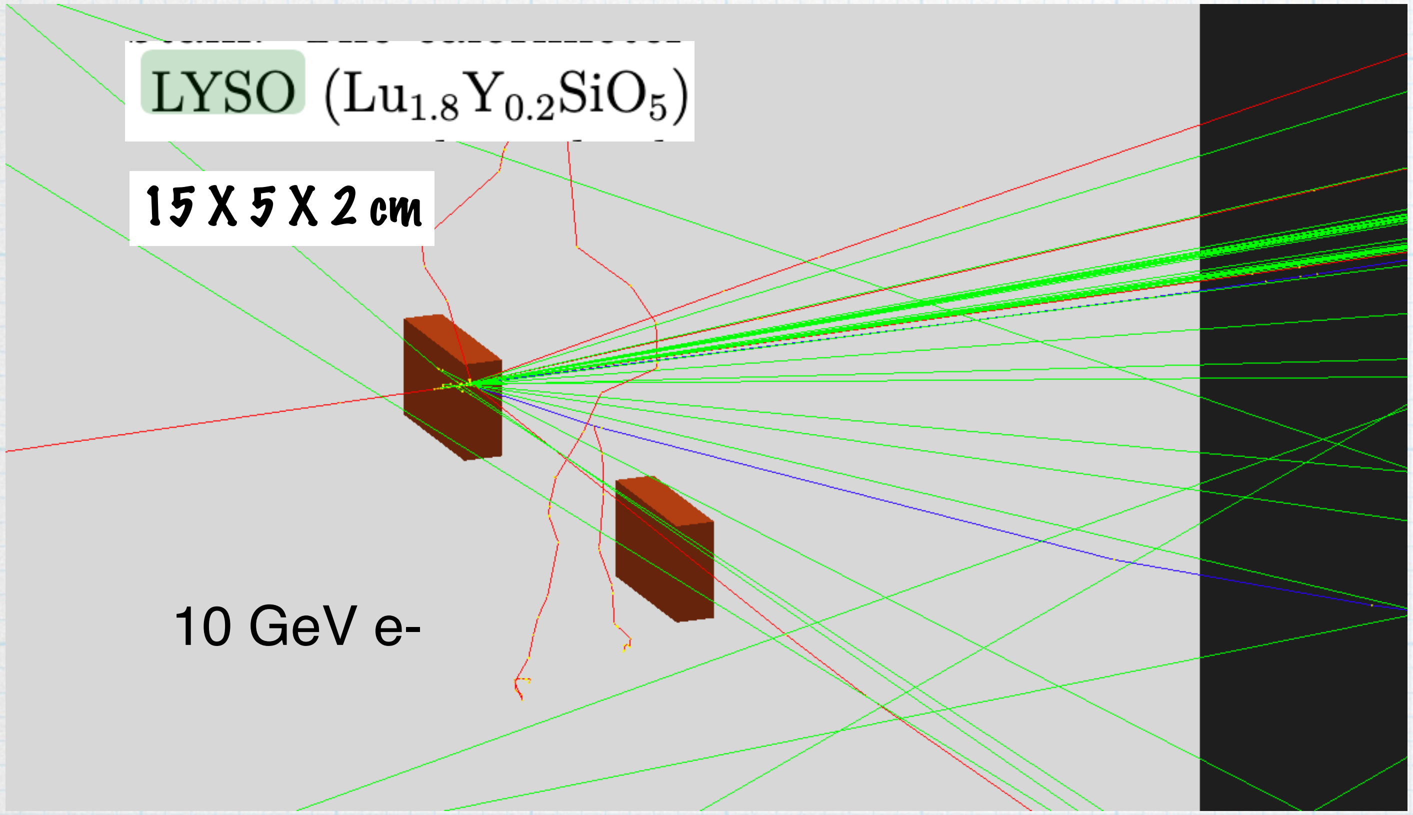


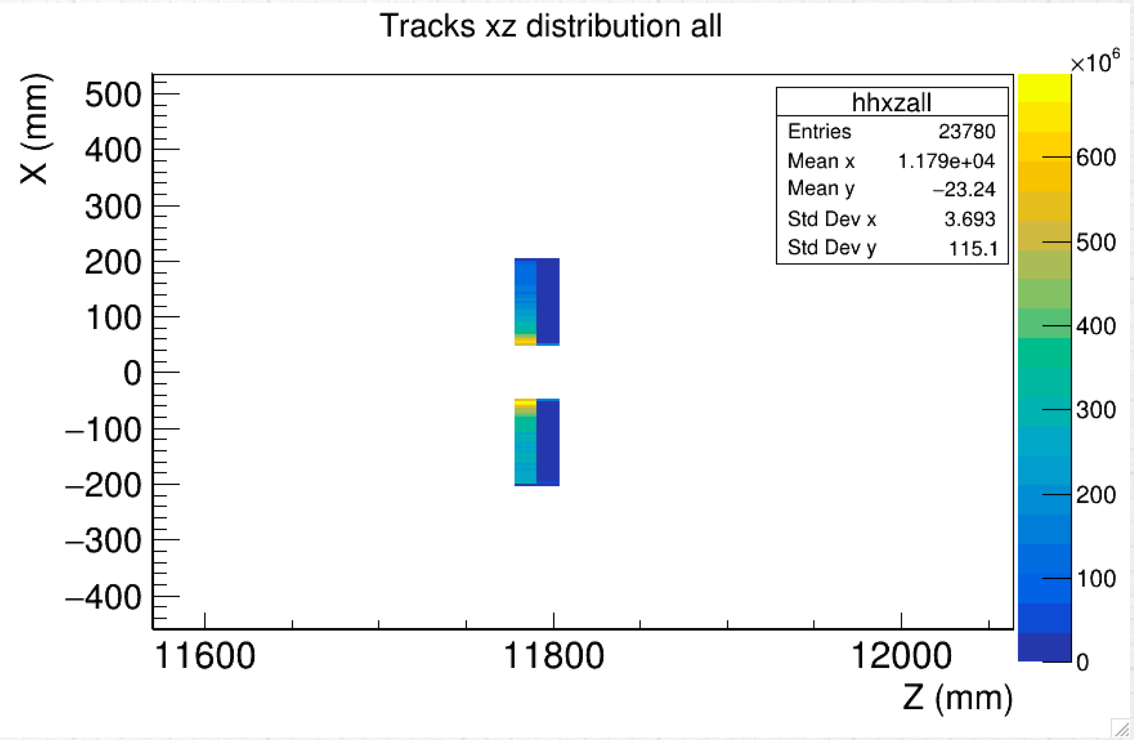
LYSO Ce scintilltion crystal, Cerium doped Lutetium Yttrium Silicate scintillation crystal, LYSO Ce scintillator crystal, 2 x 2 x 20mm

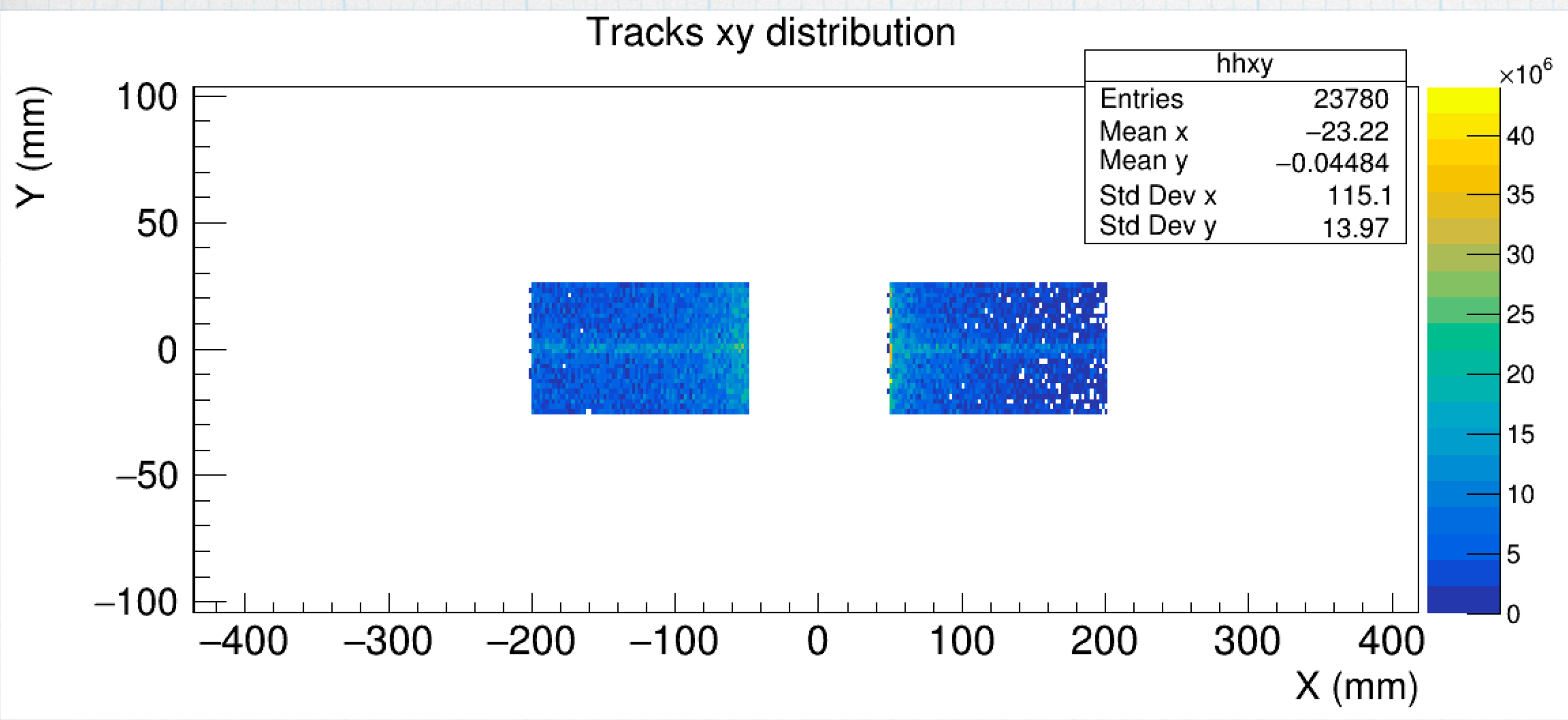
$39.00

- 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

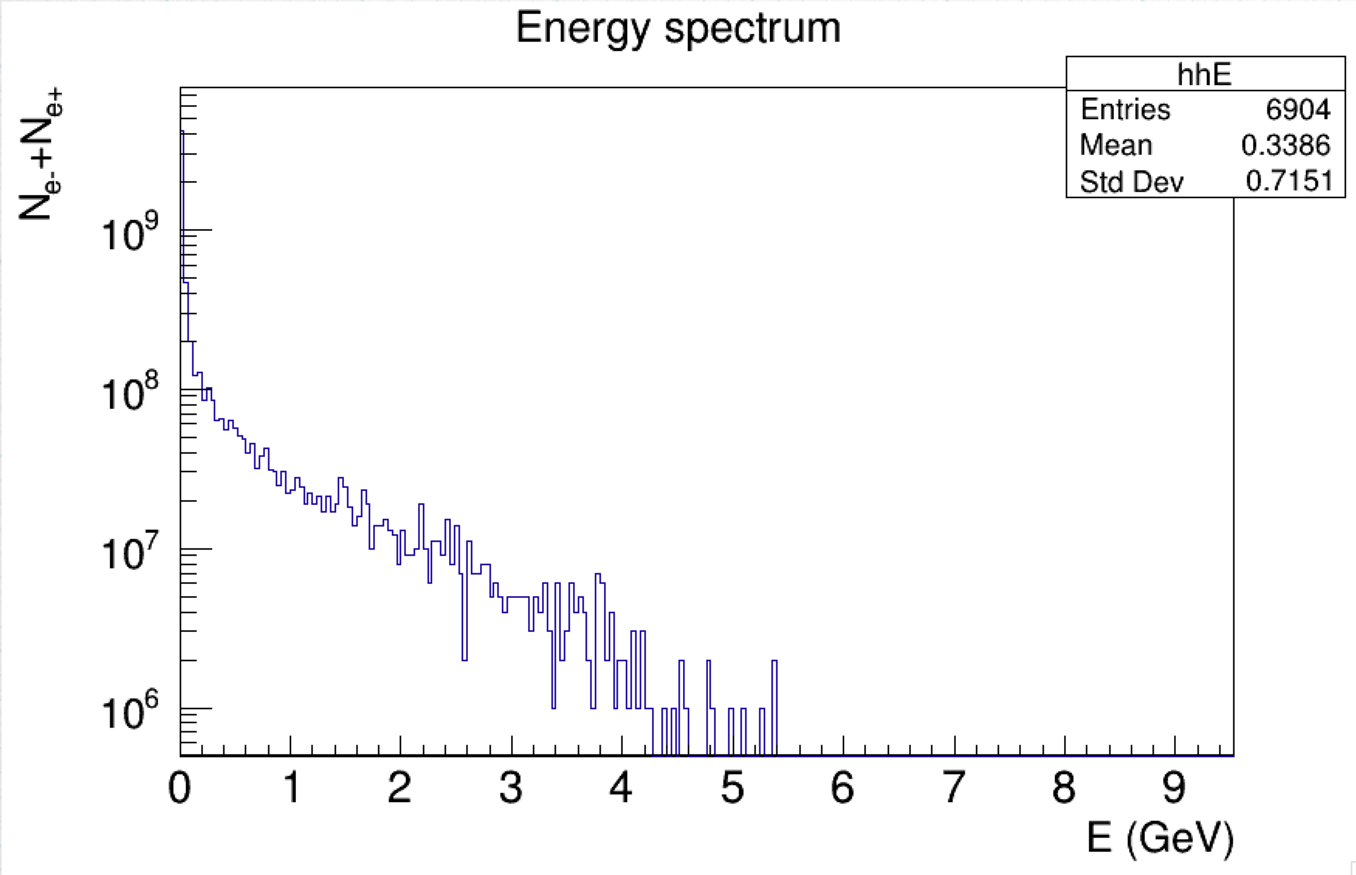


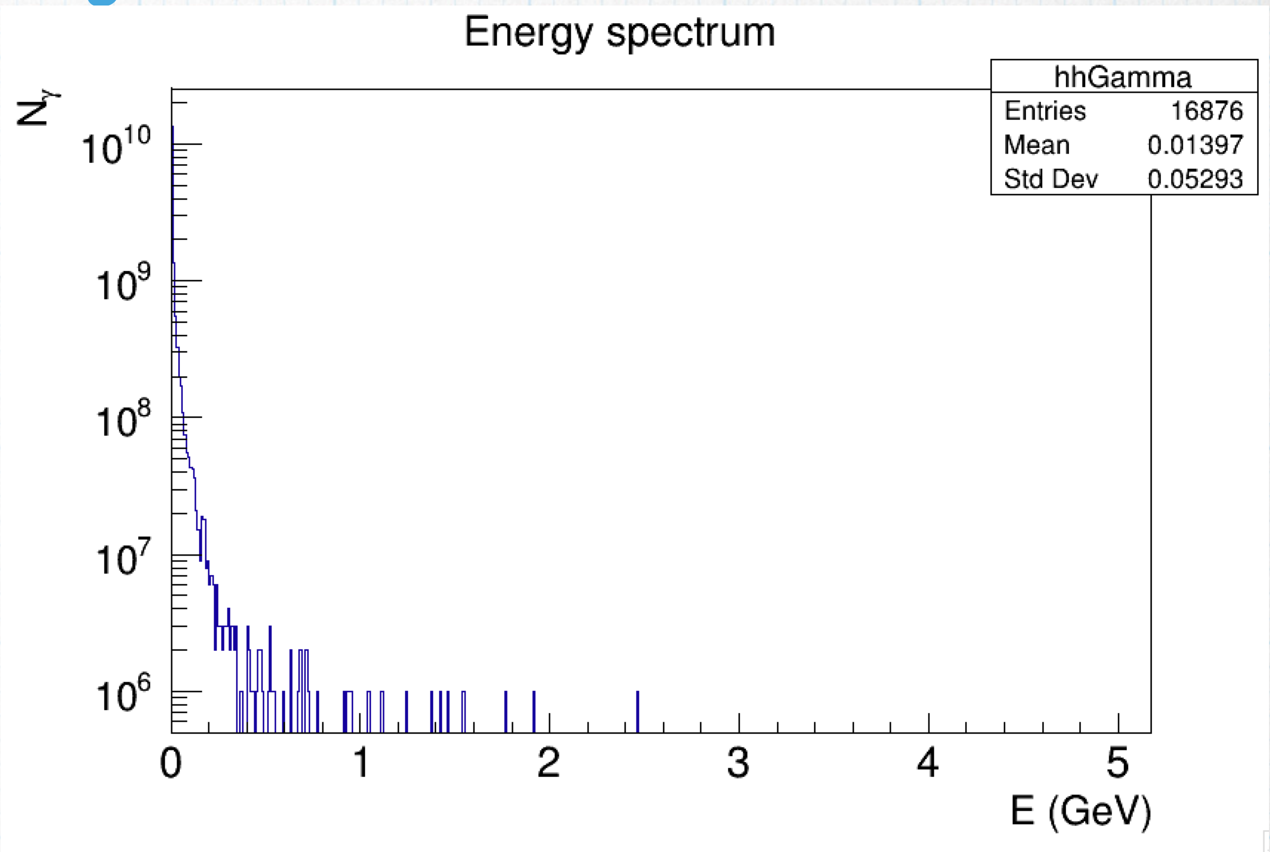


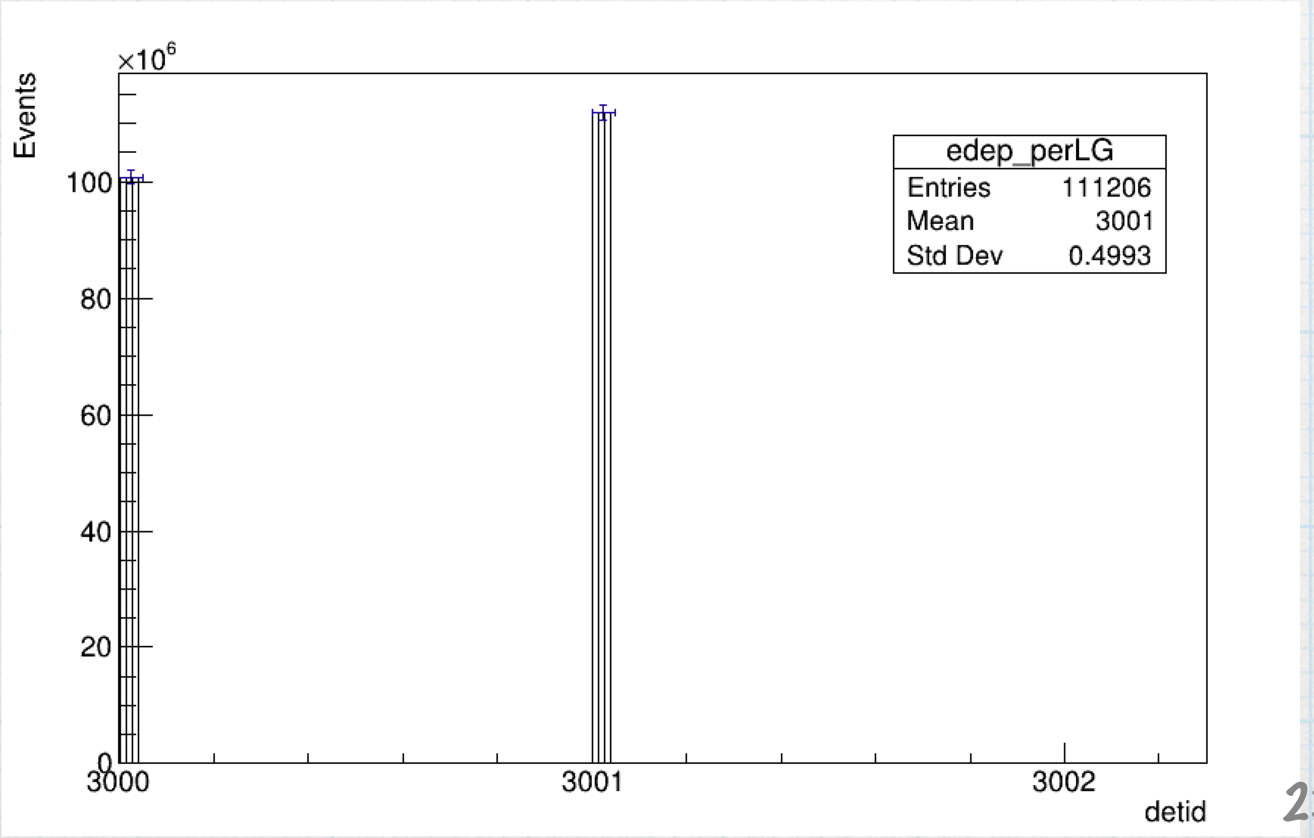


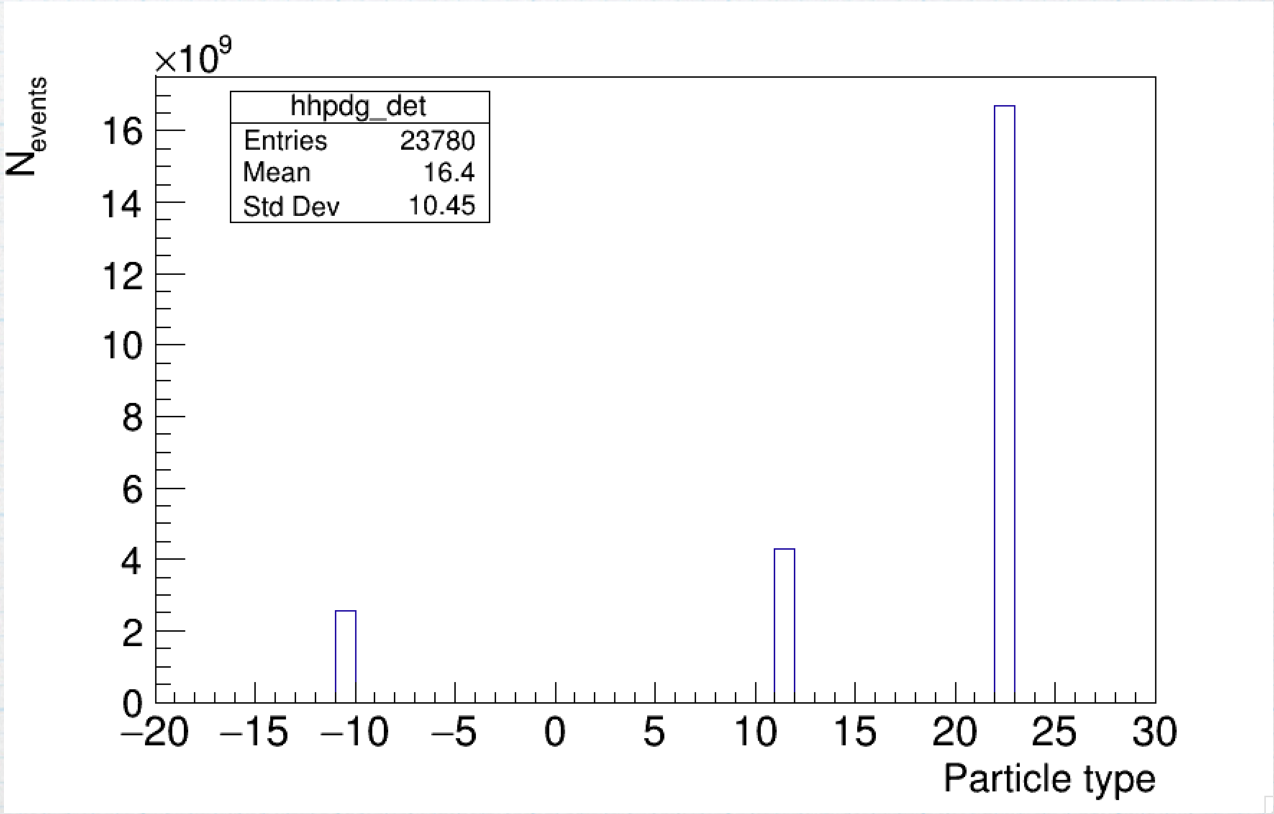
- The scintillators are modelled as a 15x5x2 cm (x:y:z) layer of lyso material
- The crystal (bin) size of the scintillators are 2 x 1 mm (finer segmentation in x; the deflection direction) giving 25 x 300 bins.

Control plots

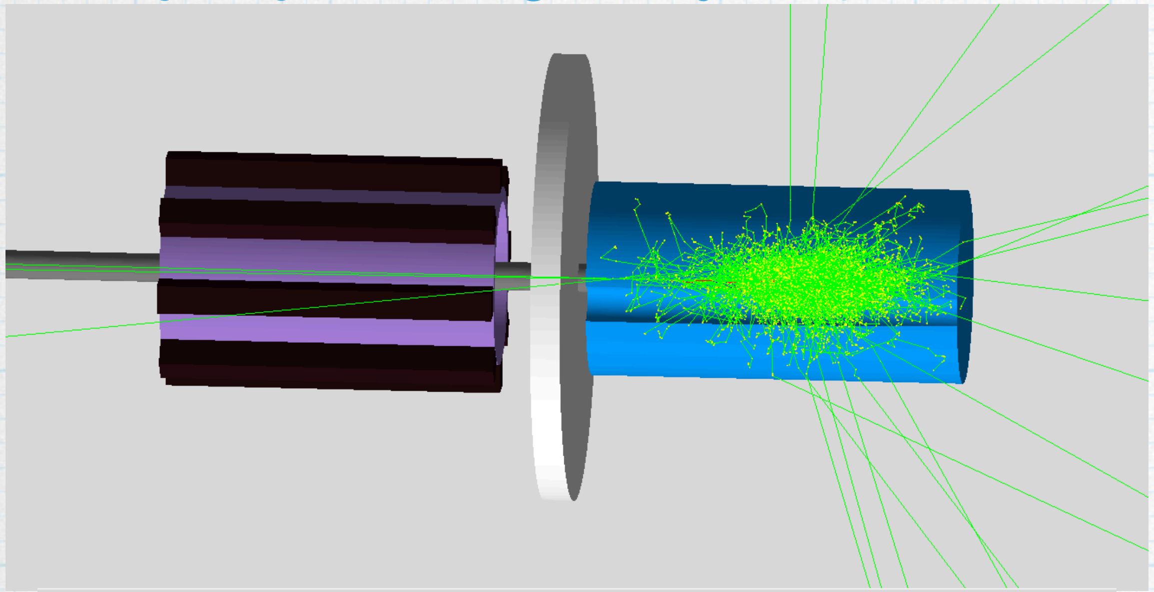






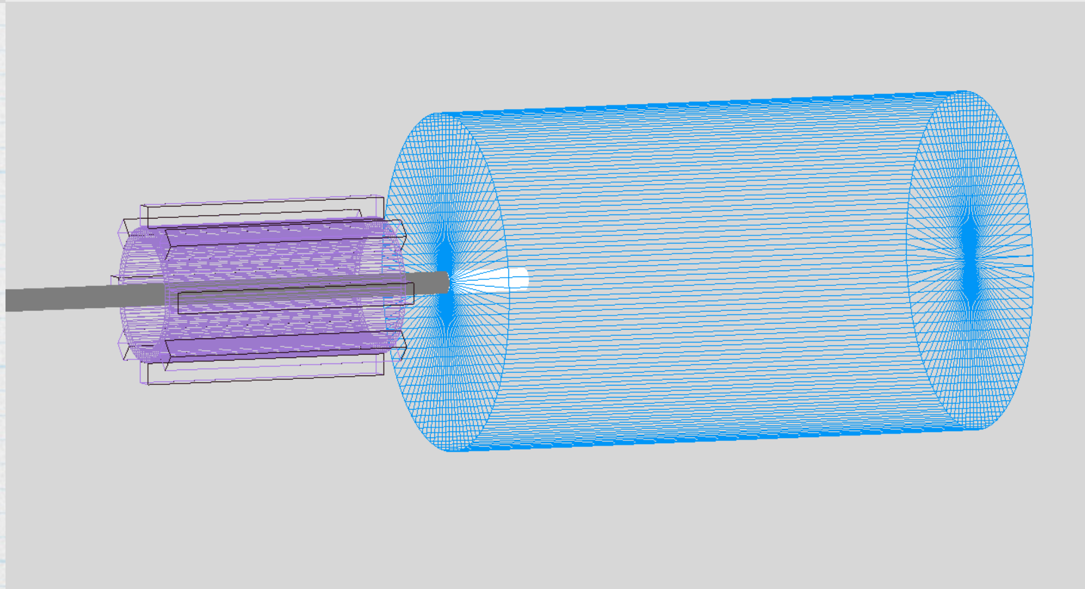


Gamma Monitor & BeamDump: new design

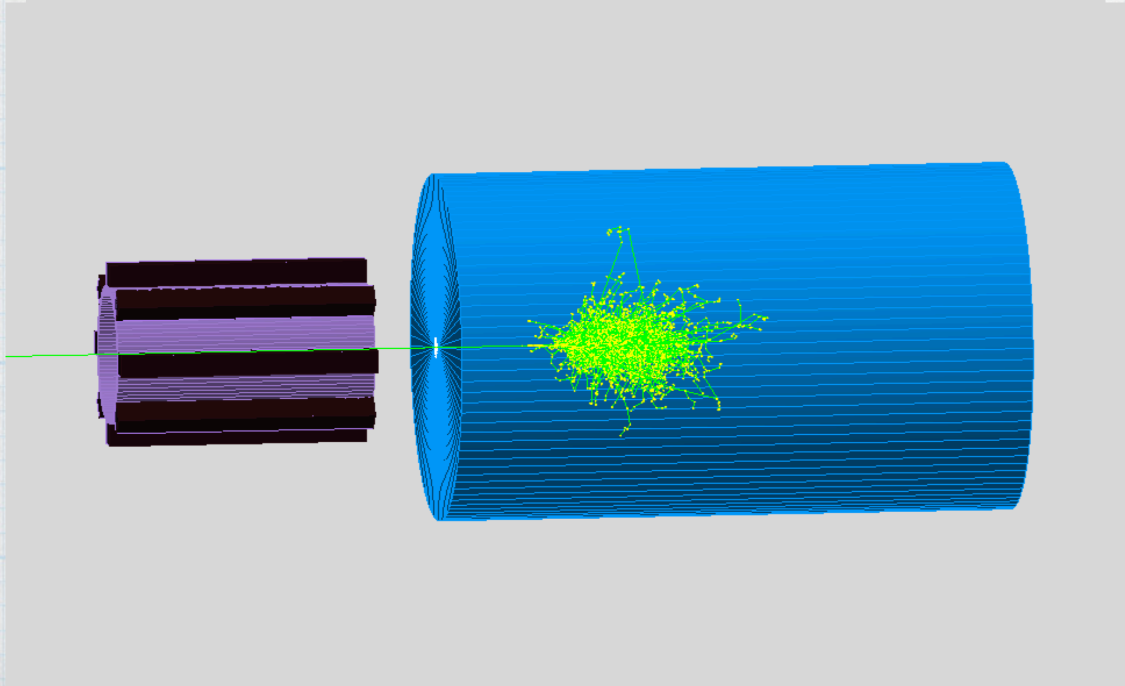


✳Distance between Monitor and Dump 10 cm

- ✳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



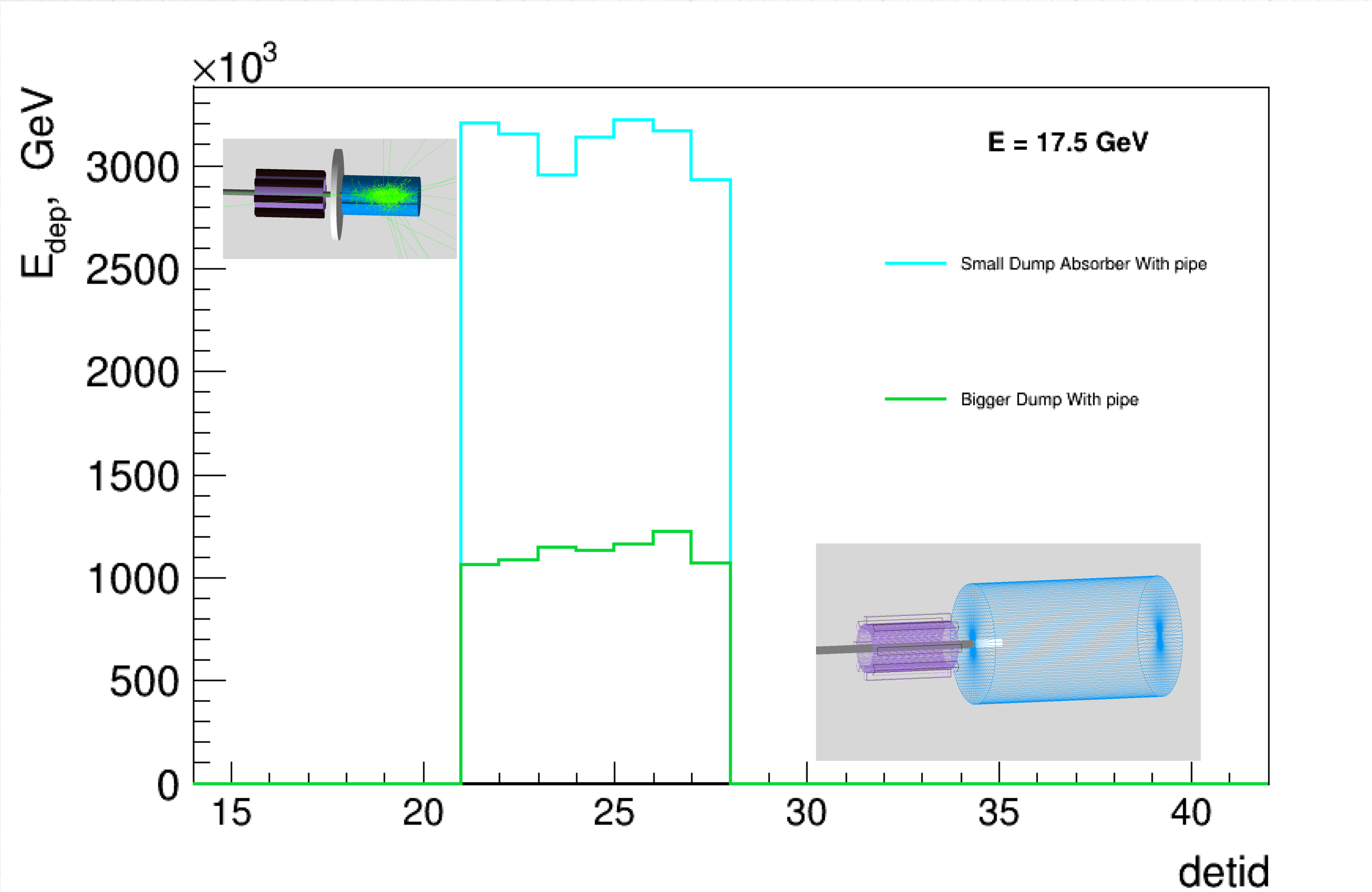
- ✳Beam Pipe R 1.9 cm
- ✳Beam Dump: R=30 cm, L=100 cm Insert Air, 1.9 cm, 15 cm length
- ✳GM Support: Stainless Steel of 1 cm thickness

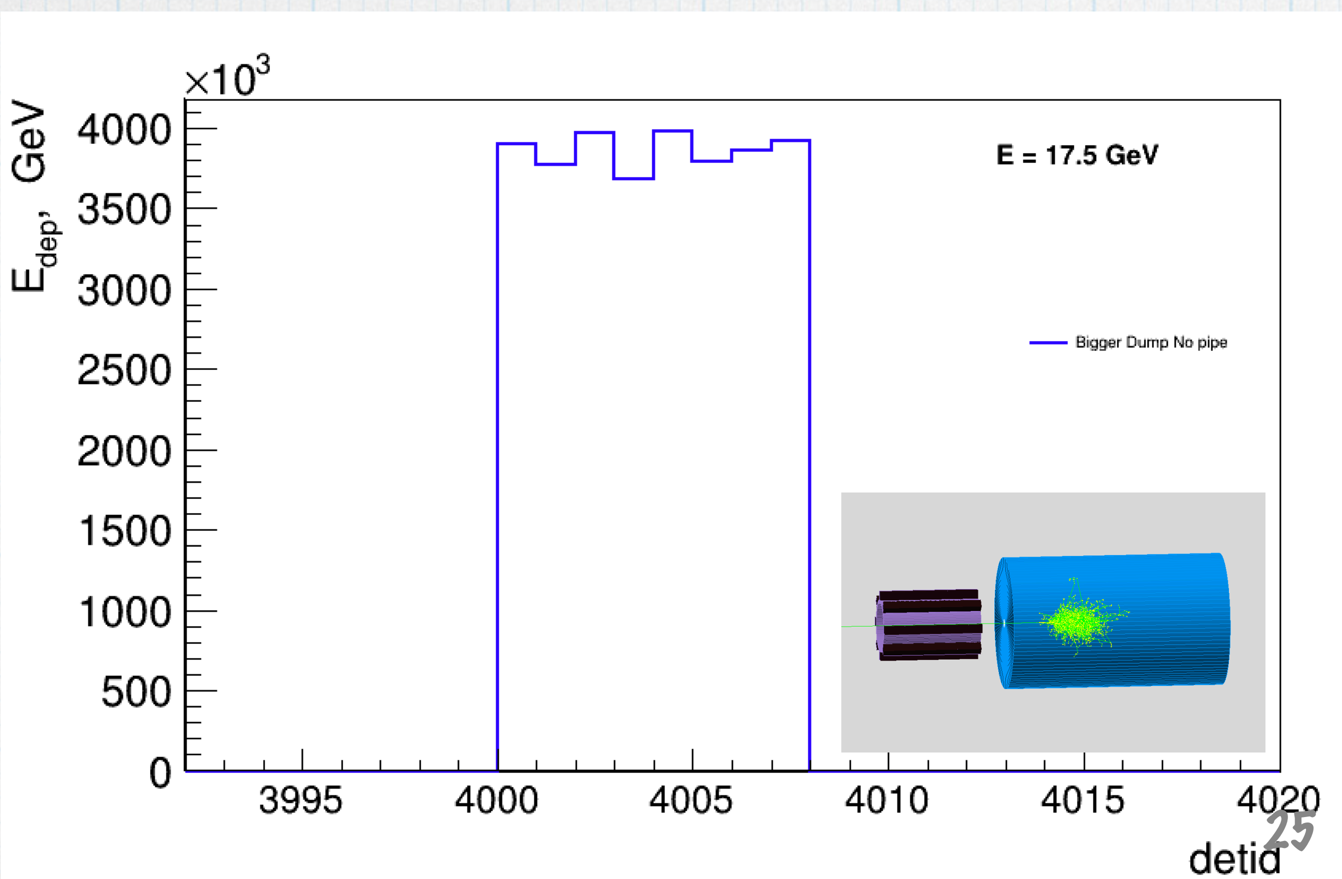


- ✳No beam pipe
- ✳Beam Dump: R=30 cm, L=100 cm Insert Air, 1.9 cm
- ✳GM Support: Stainless Steel of 1 cm thickness

Performance

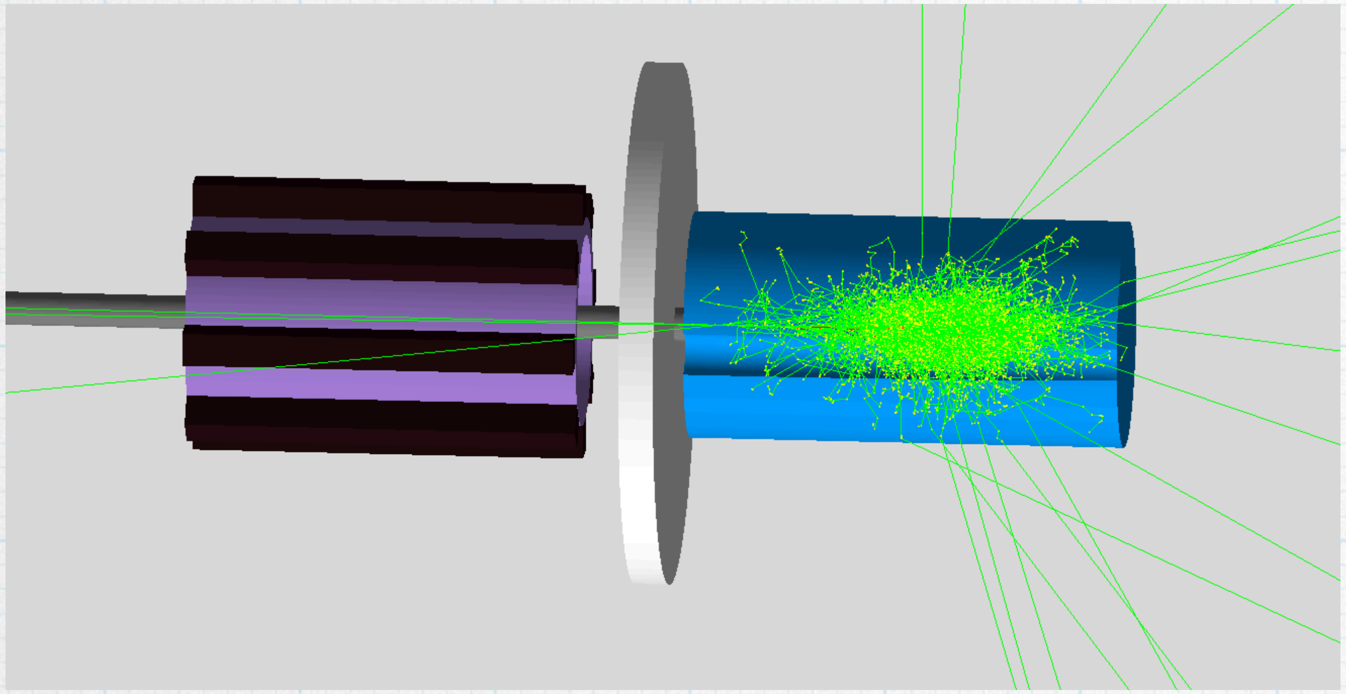
✶ 100 BX **At high laser intensities ξ =2.6 (1J)**



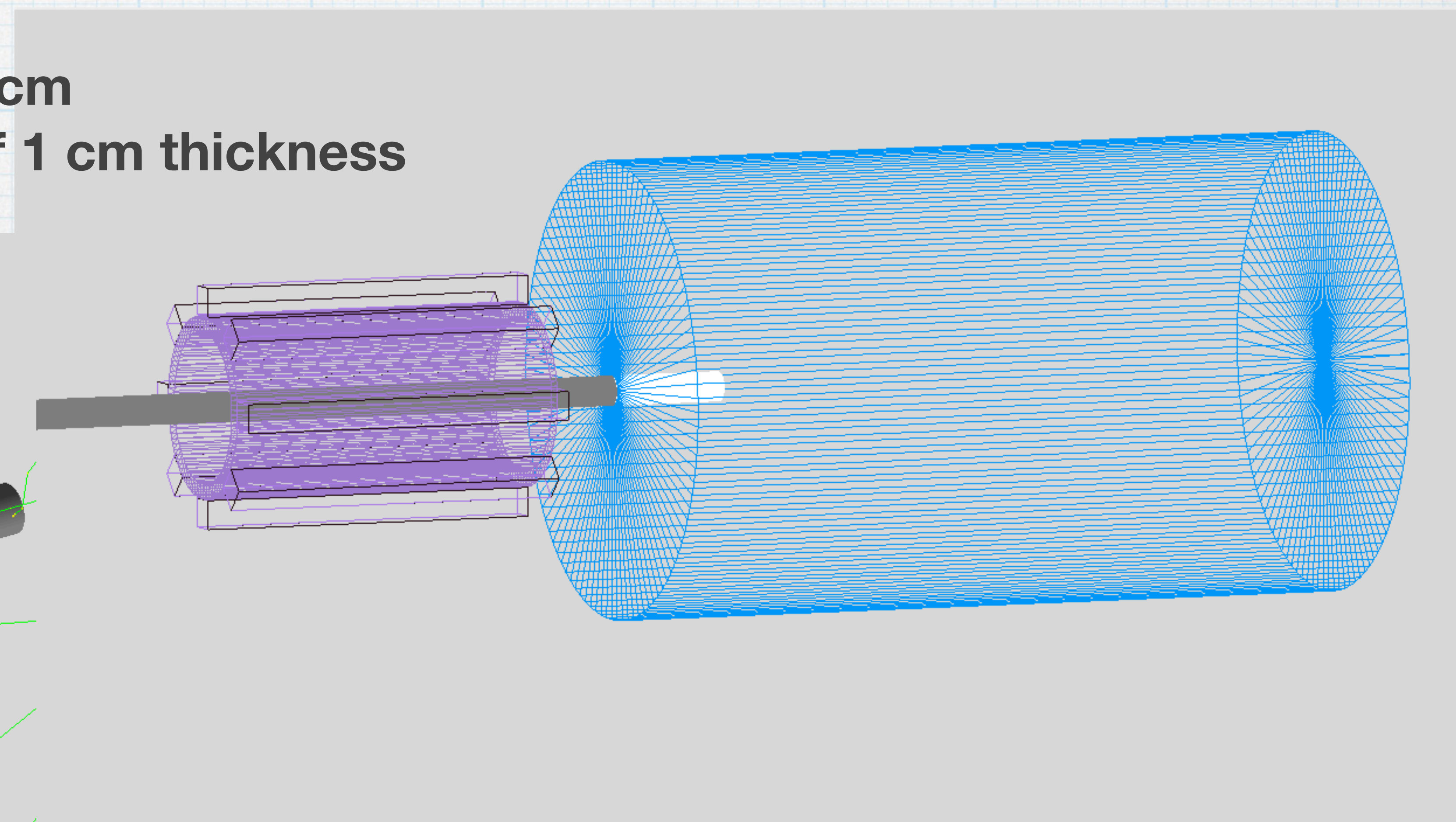


* Depending on exact chemical composition of LG blocks (TF1 Or TF101) max acceptable dose could be in the range of 5-100 Gy, which roughly means for
* Ist configuration 75-1500 hours
* 2nd Configuration 180-3600 hours
* 3d Configuration 59-1200 hours
* The environment is more harsh without beam pipe;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

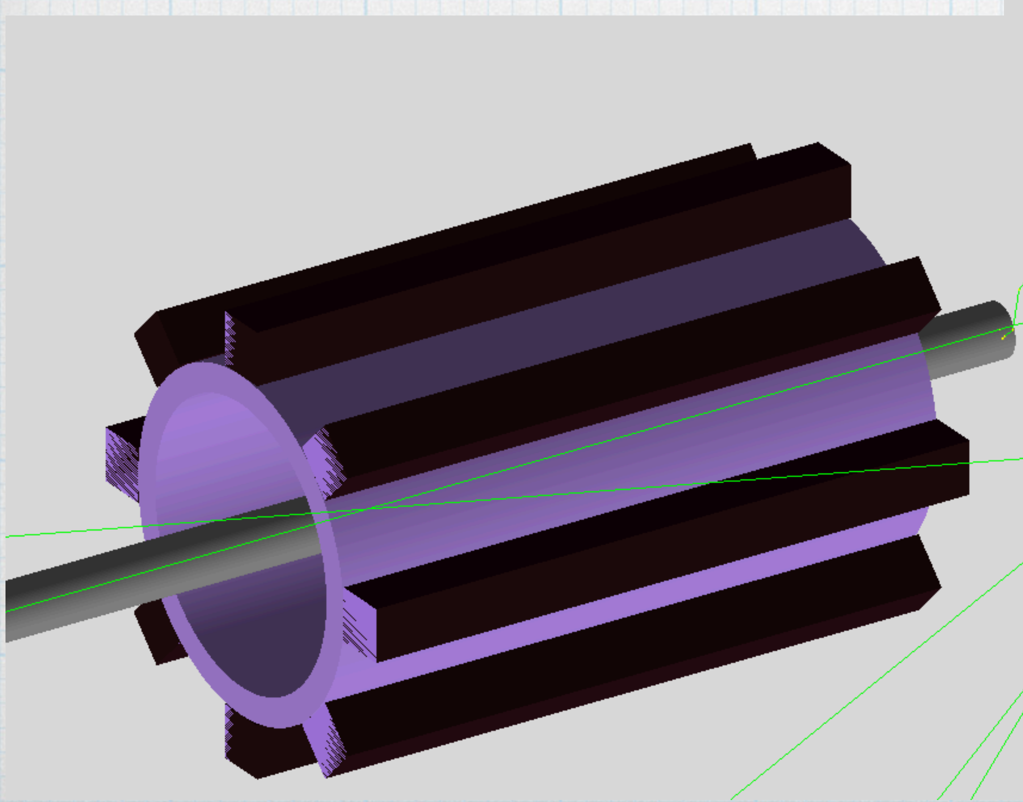
Gamma Monitor & BeamDump: new design

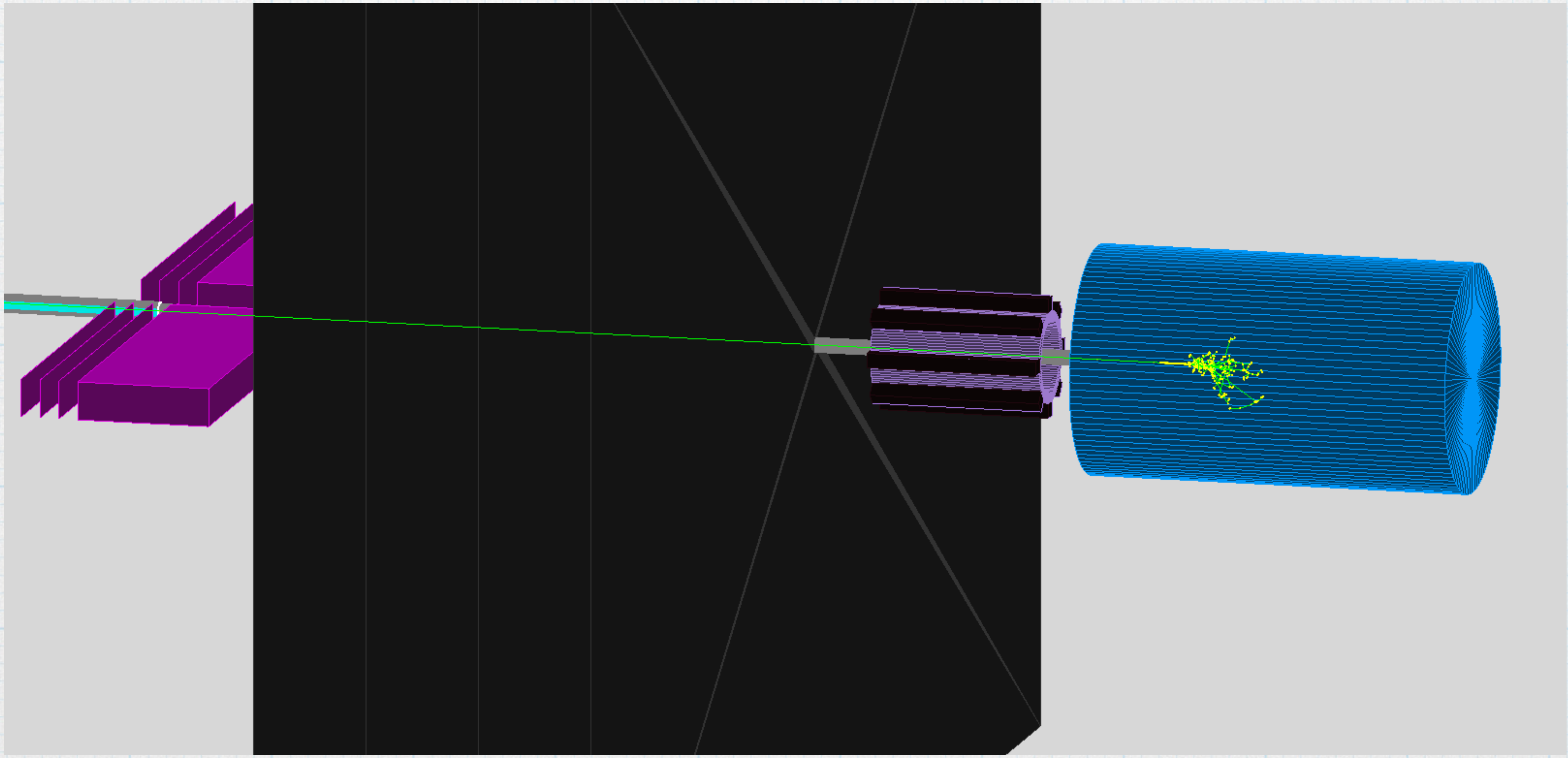


- ✷The implementation of FDS in Luxe geometry with the LG Gamma Monitor made of new LG blocks in front of Cu Dump with a hole of 15 cm,
- ✷LG w/ measures 3.8 × 3.8 cm^2, length is 45 cm
- ✷Wrapped with Aluminium foil of 0.016 mm (typical household foil; no account for air)
- ✷Distance between Monitor and Dump 10 cm

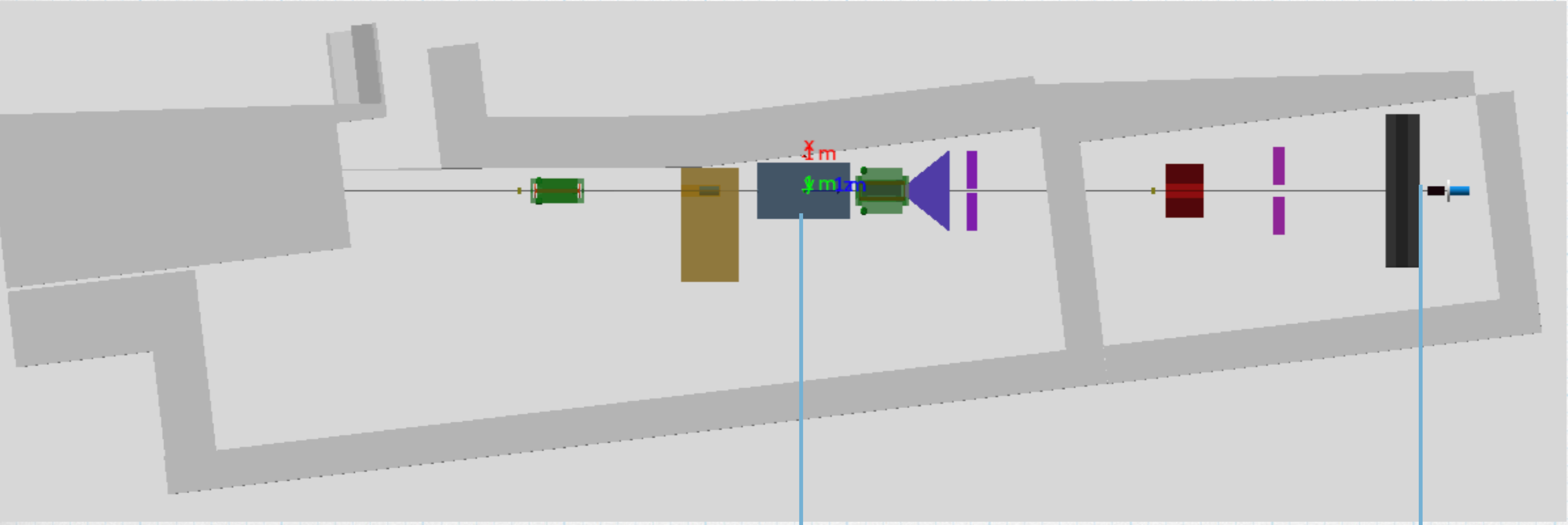


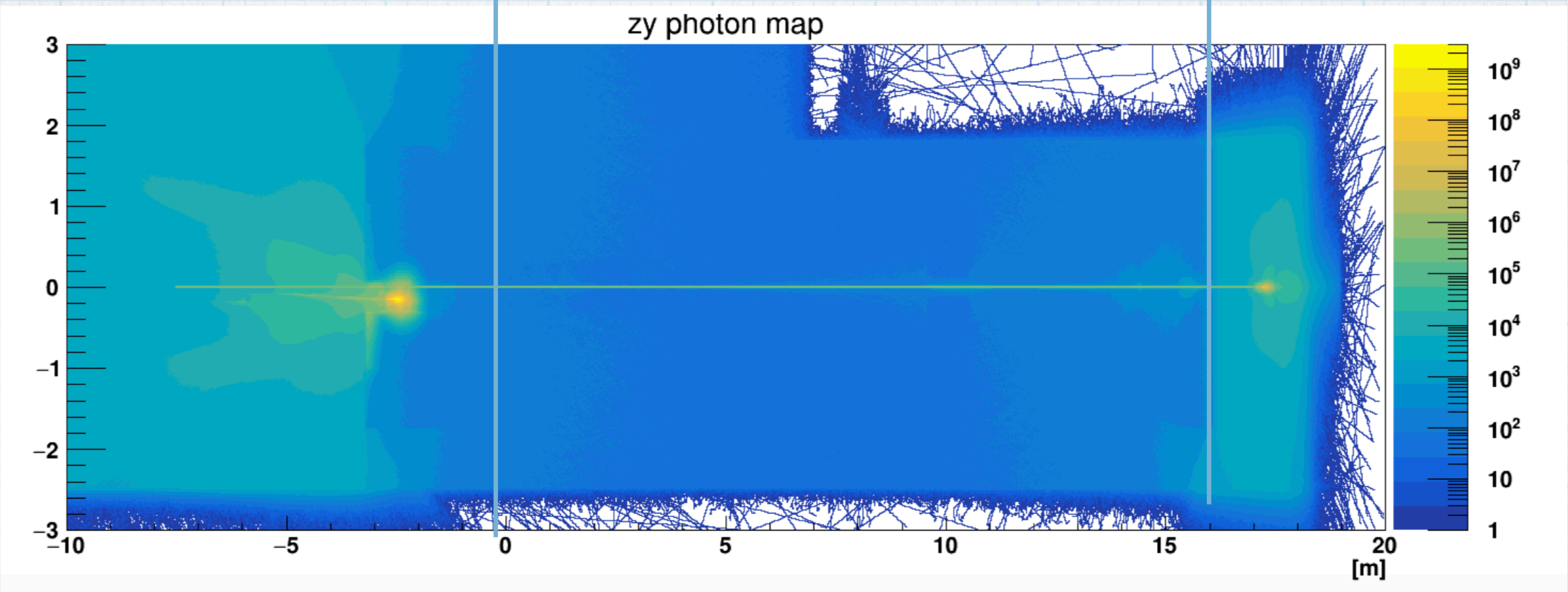
- ✷Beam Dump: R=30 cm, L=100 cm
- ✷GM Support: Stainless Steel of 1 cm thickness



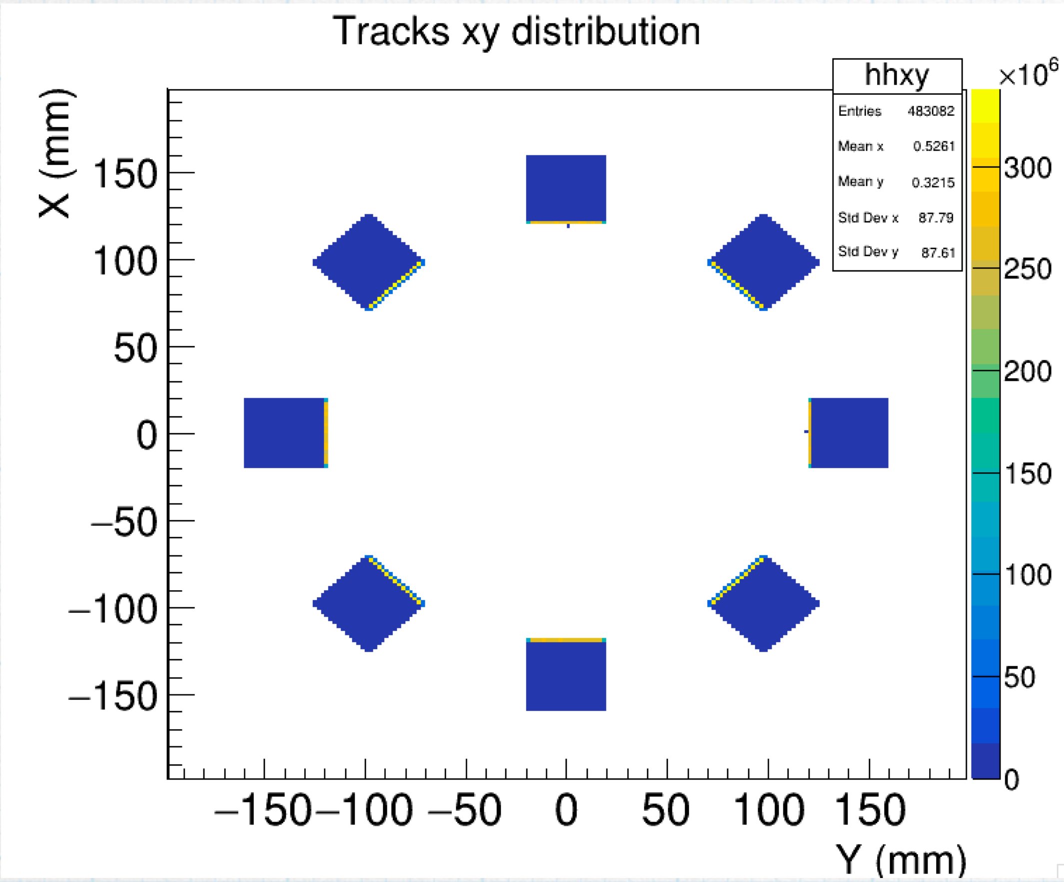


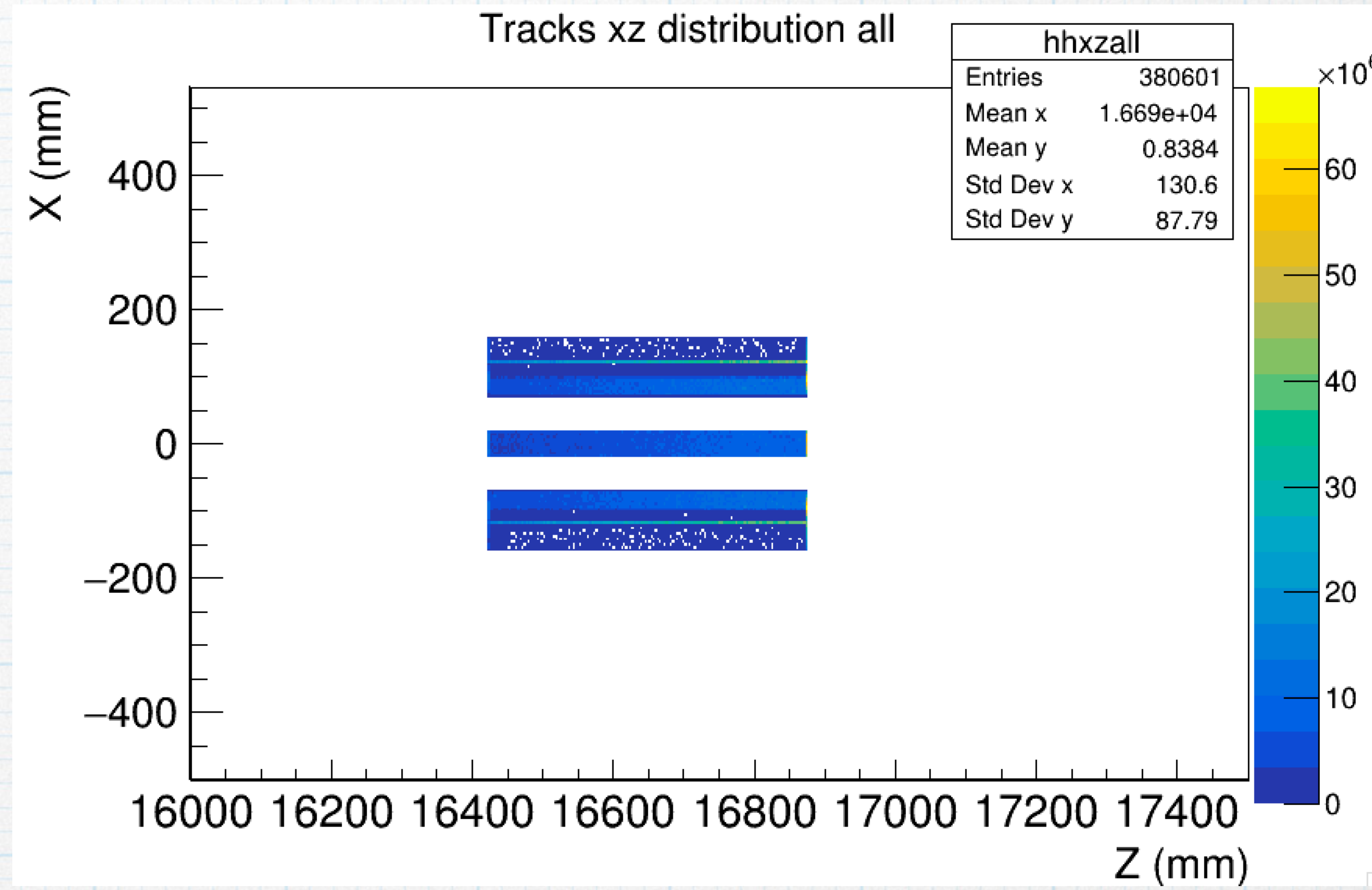
Photon fluxes in Geant 4 setup

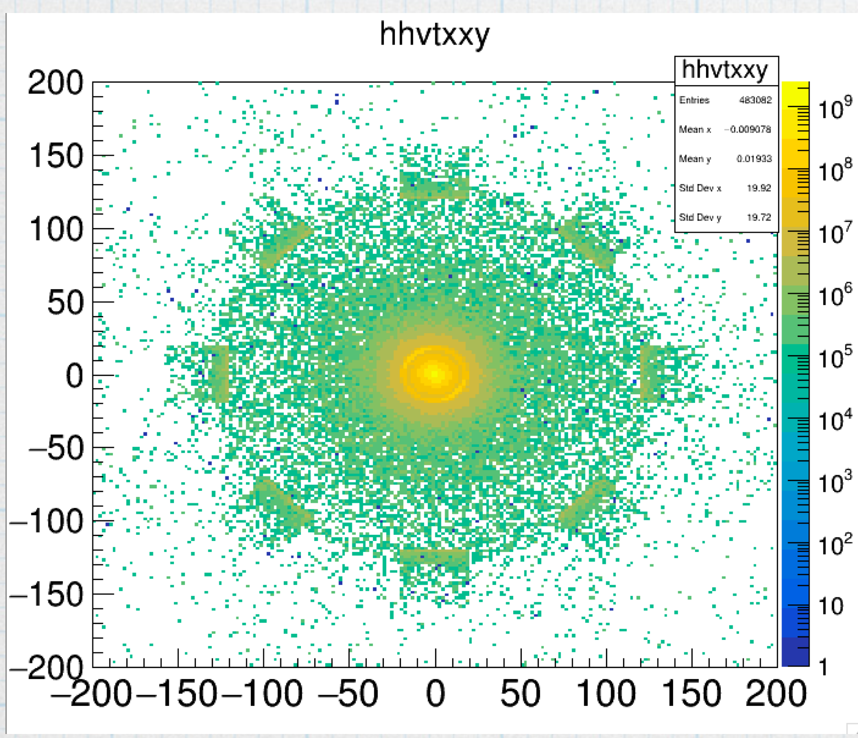


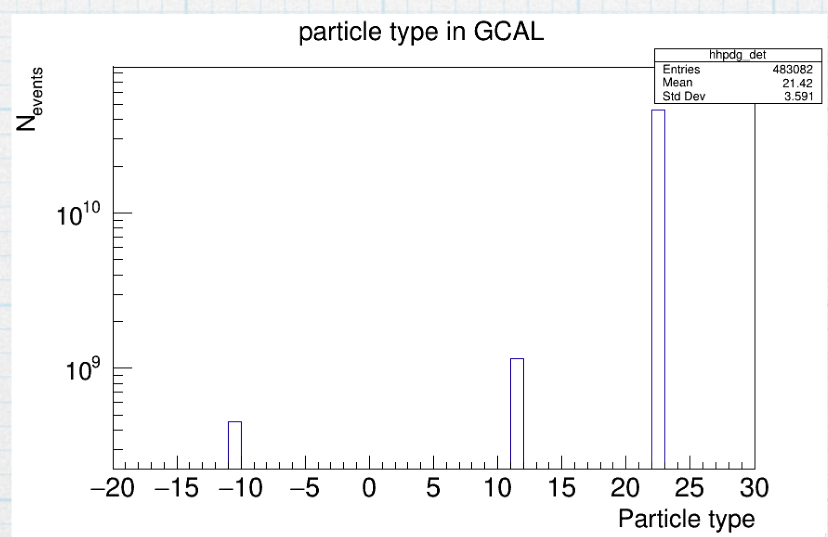


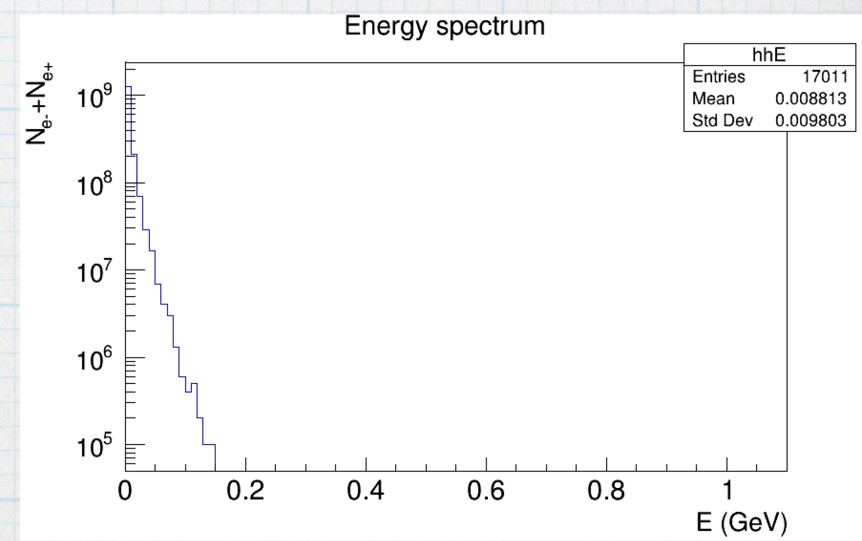
Simulation and Performance



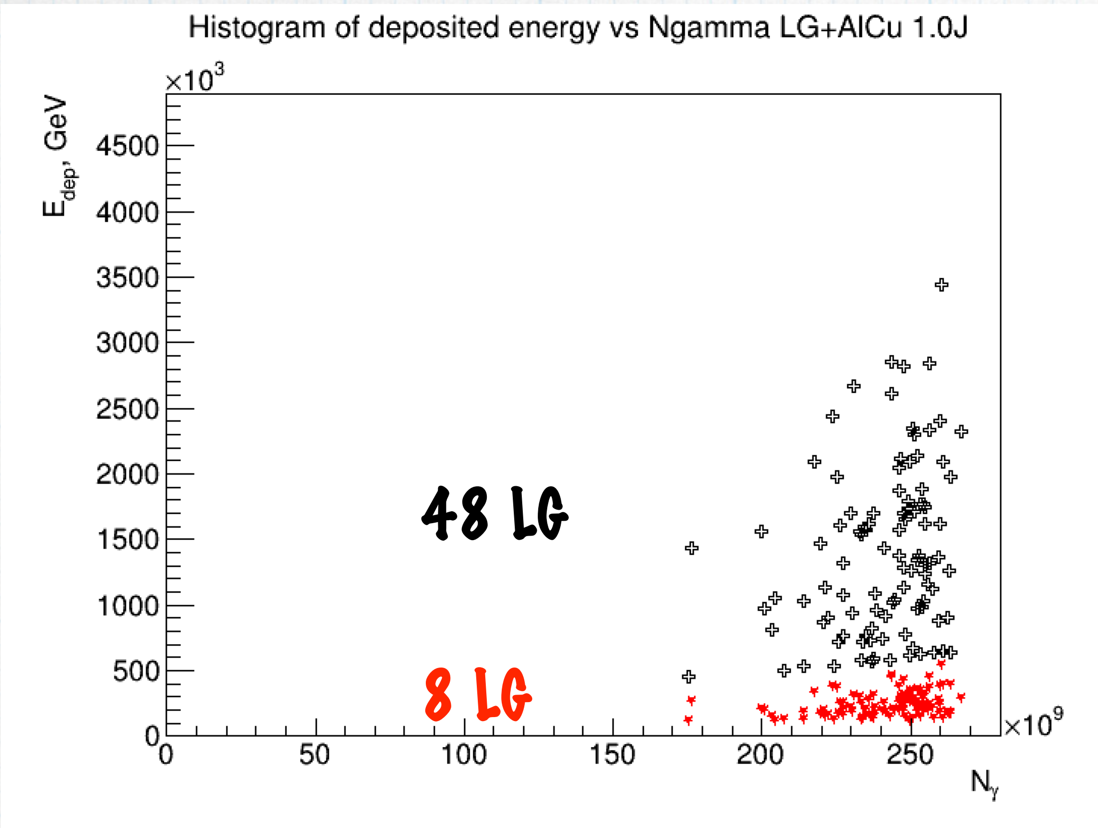


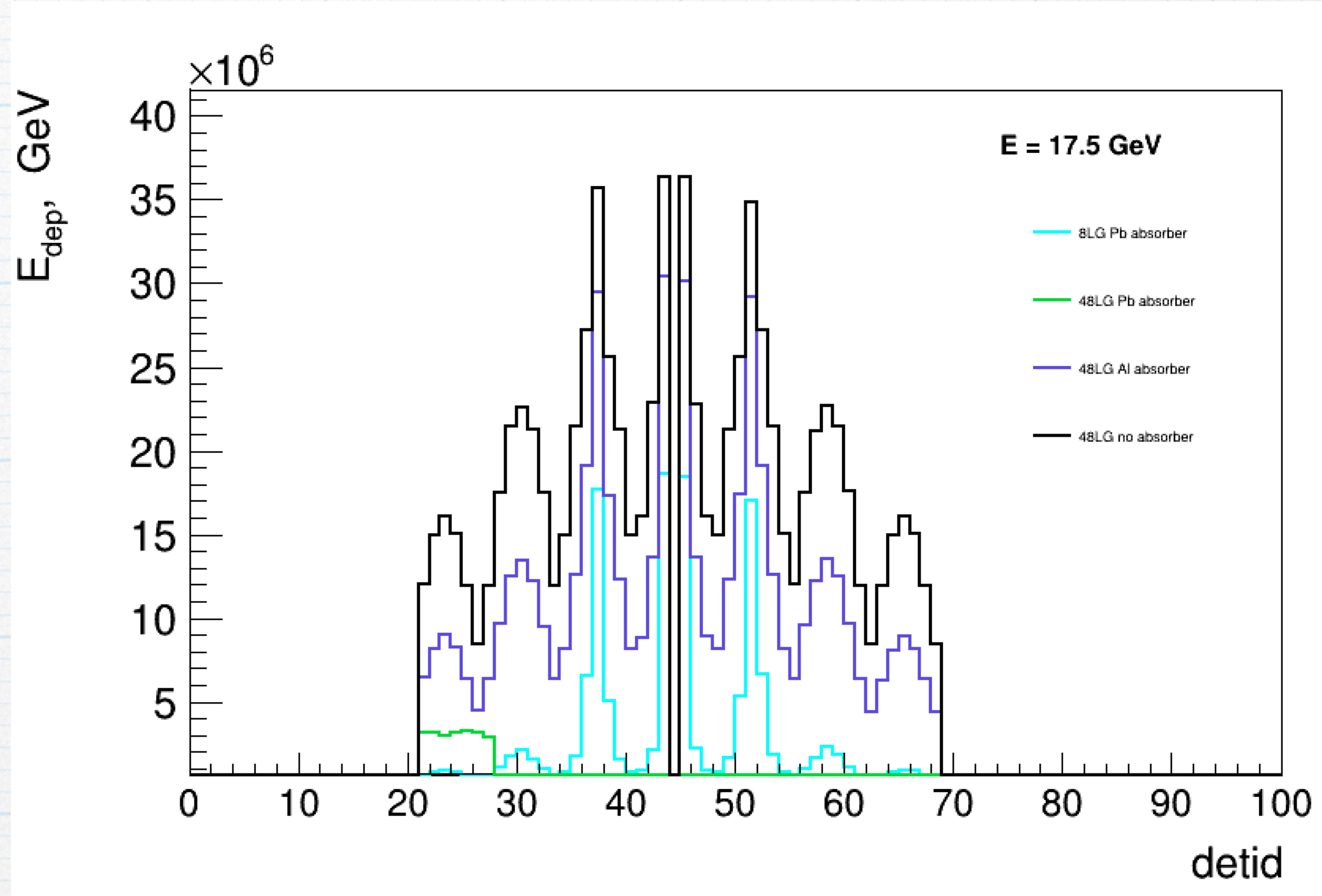


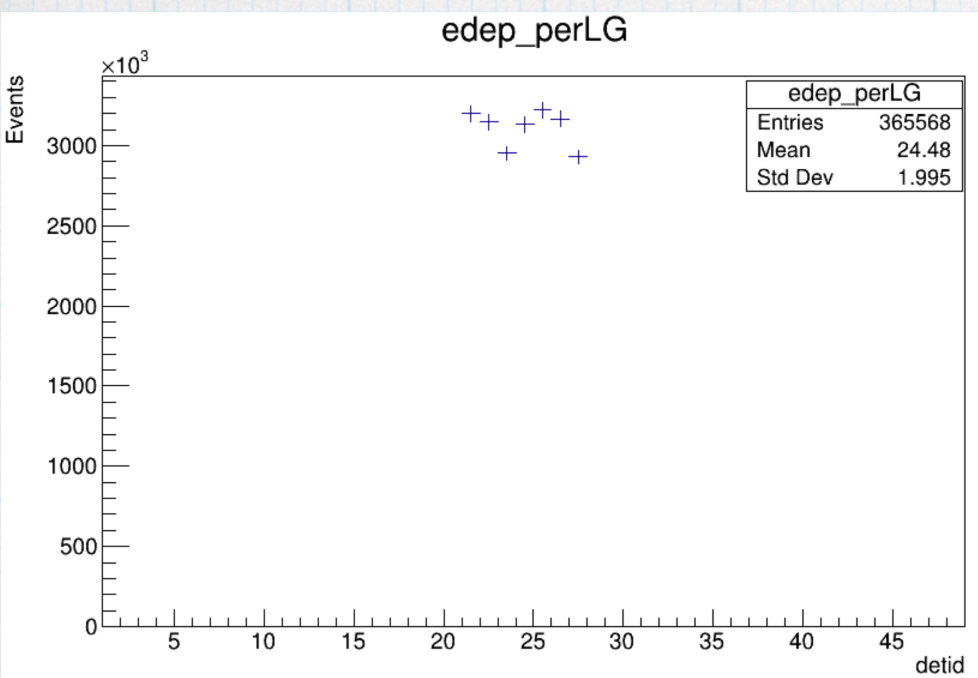




Simulation and Performance







* 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

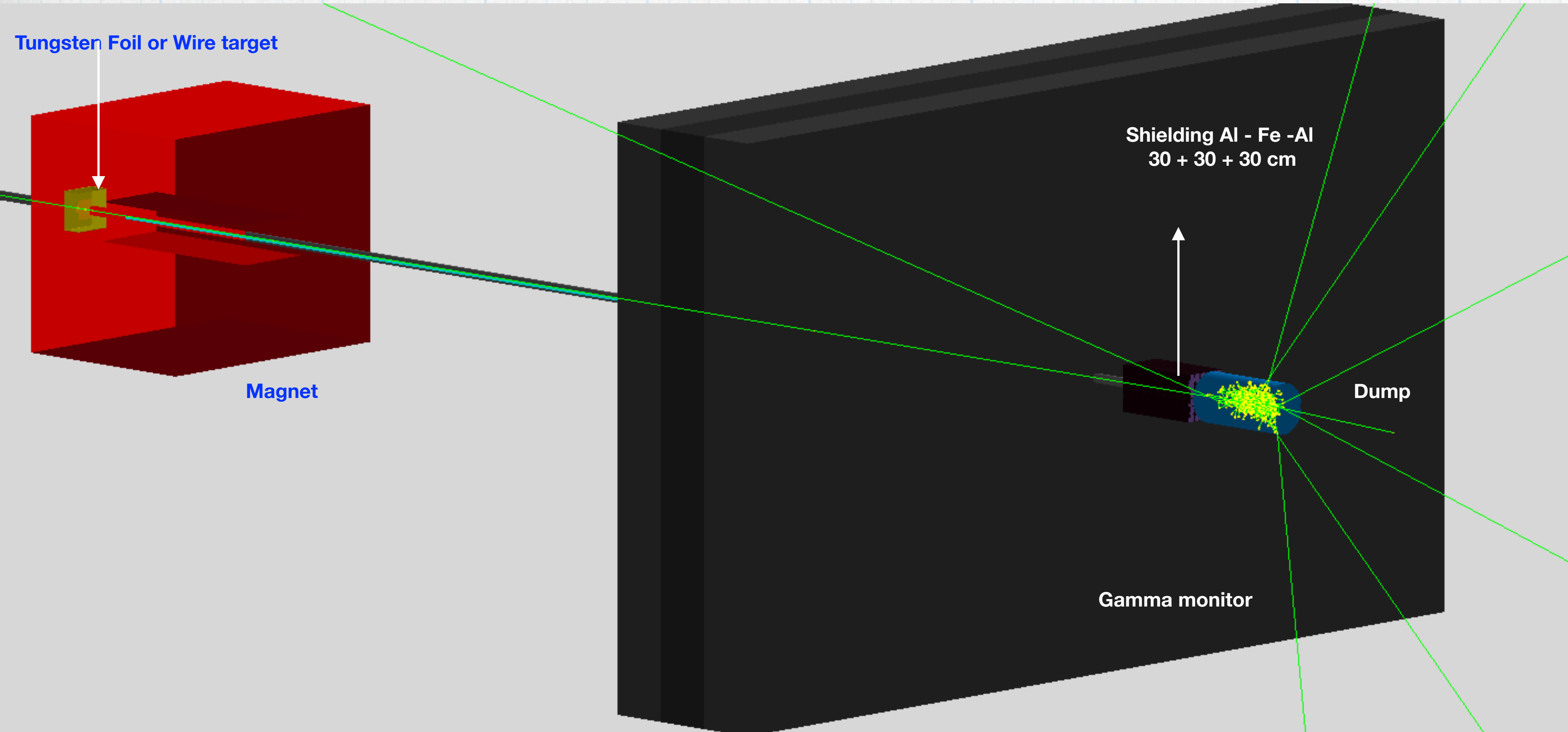
* Energy measured in GM of back-scattering particles is 4-6 orders of magnitude smaller than initial beam energy. Initial flux ~10^{12} GeV in GM depending on geometry ~10^{6}- 10^{8} GeV

* 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.

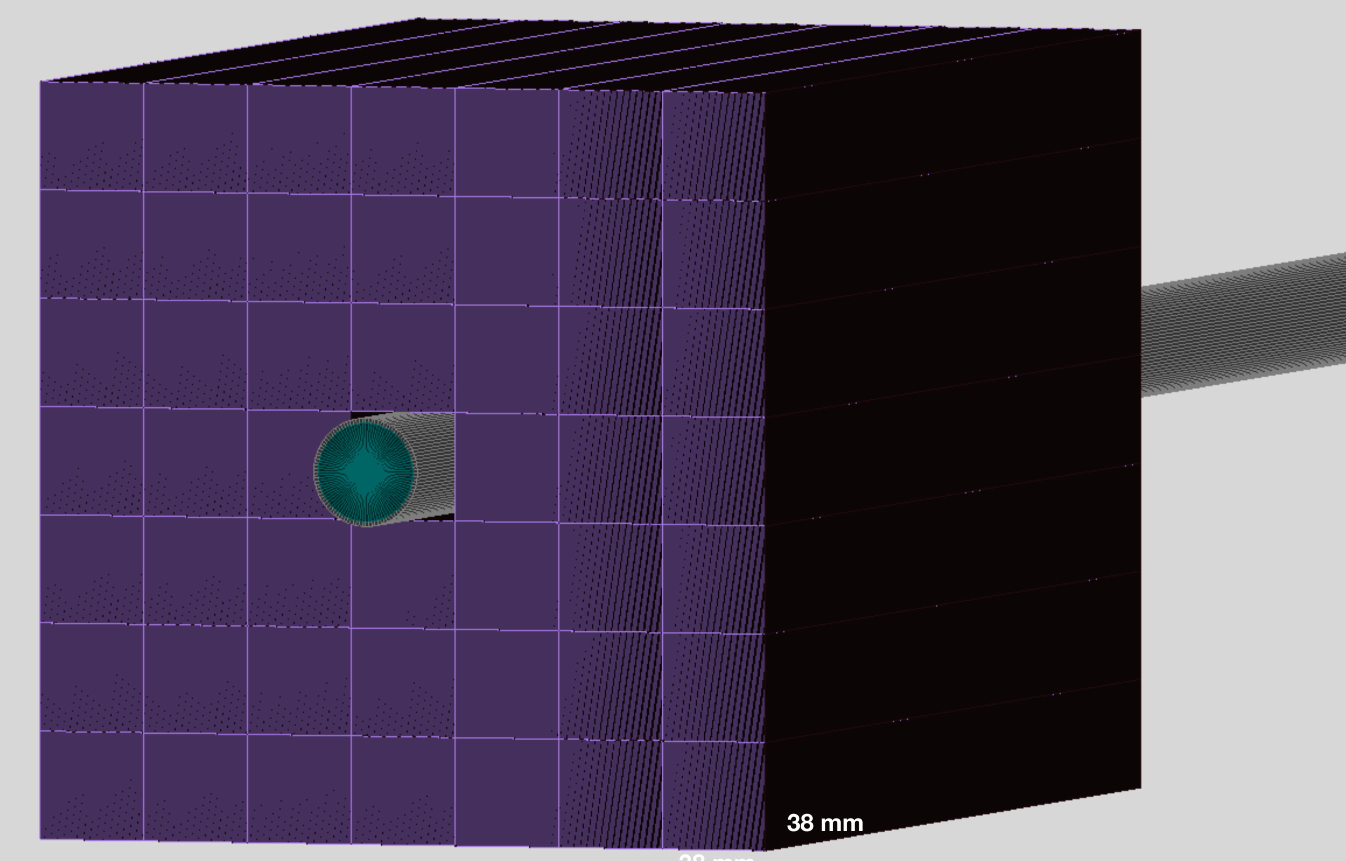
* Considering the fact that no actual beam dump is foreseen and beam will be dumped into the wall, we can consider to design dump/reflector with needed properties

Gamma Monitor

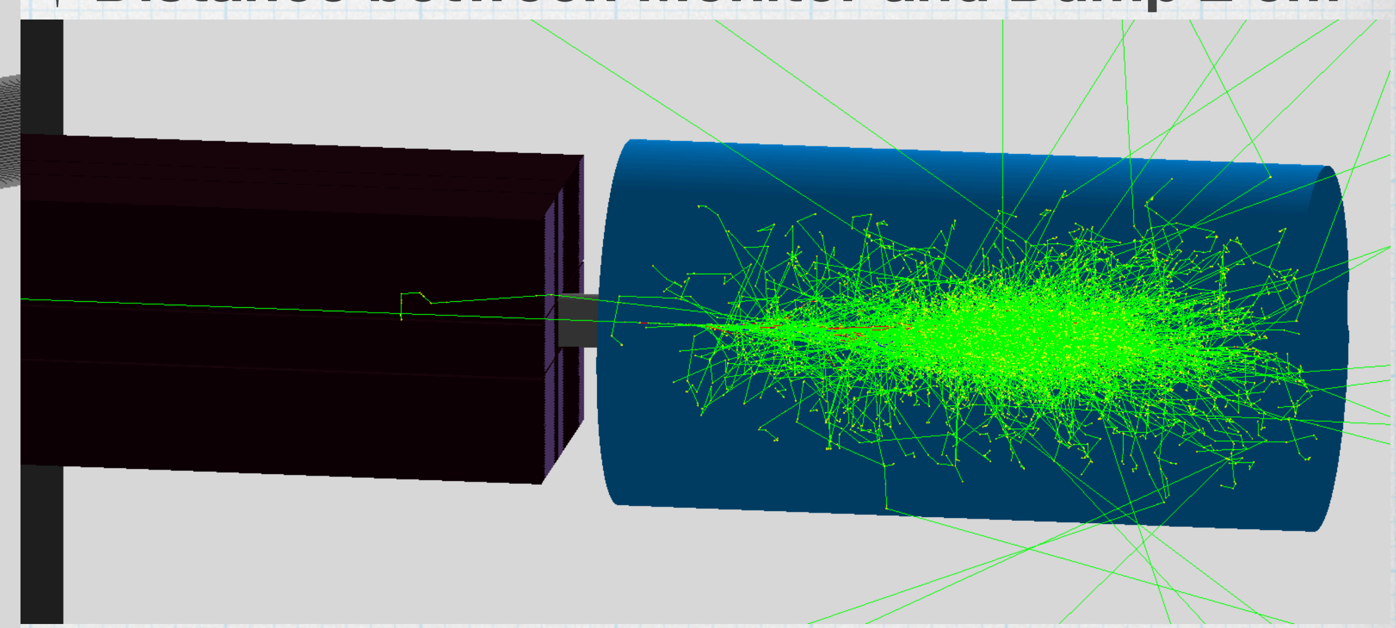


- The implementation of FDS in Luxe geometry with the LG Gamma Monitor made of new LG blocks in front of Al-Cu Dump,
- LG w/ measures 3.8 × 3.8 cm^2, length is 45 cm
- Wrapped with Aluminium foil of 0.016 mm (typical household foil; no account for air)

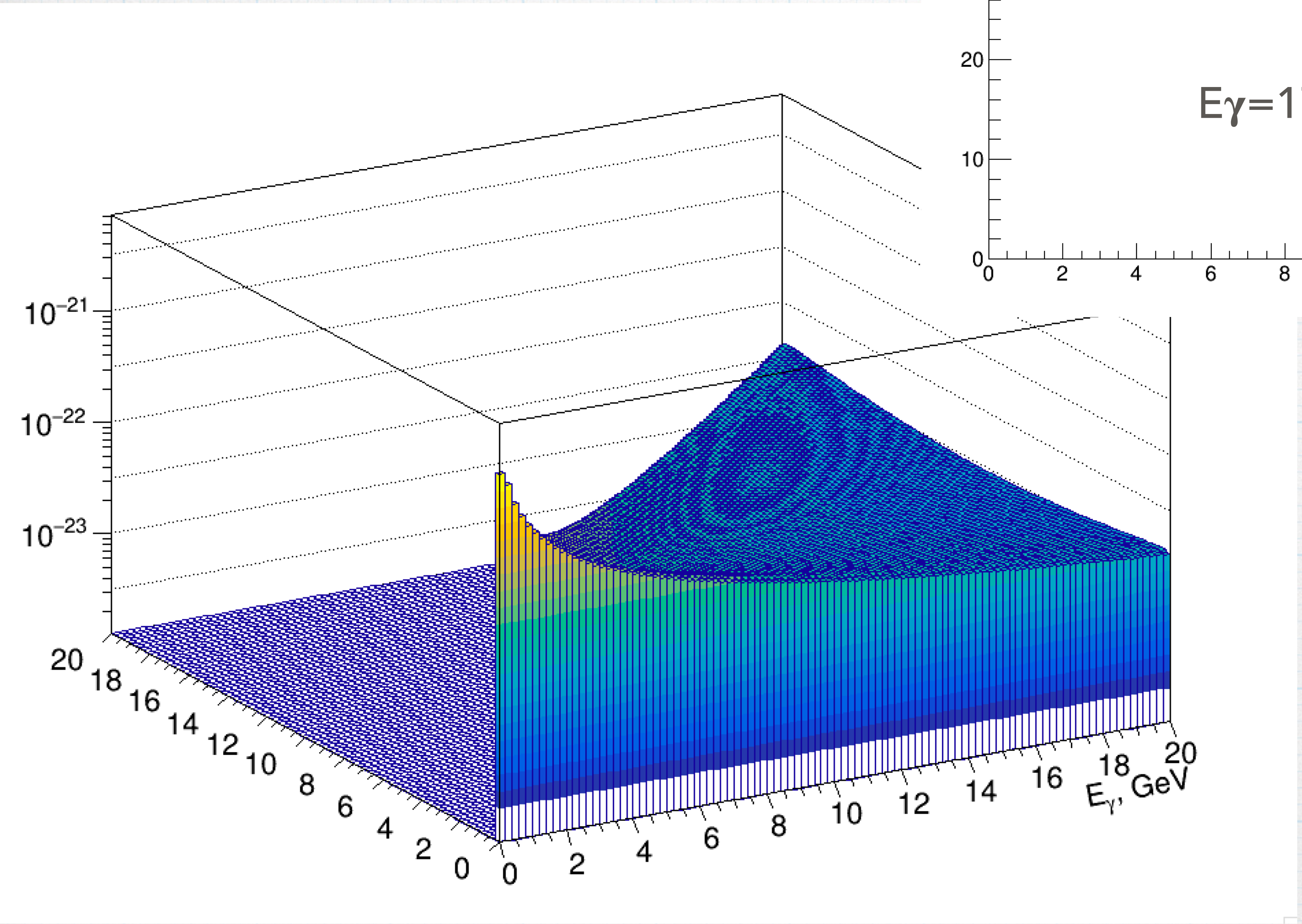
Beam Pipe , R =19.0 *mm, thickness = 1.65 mm

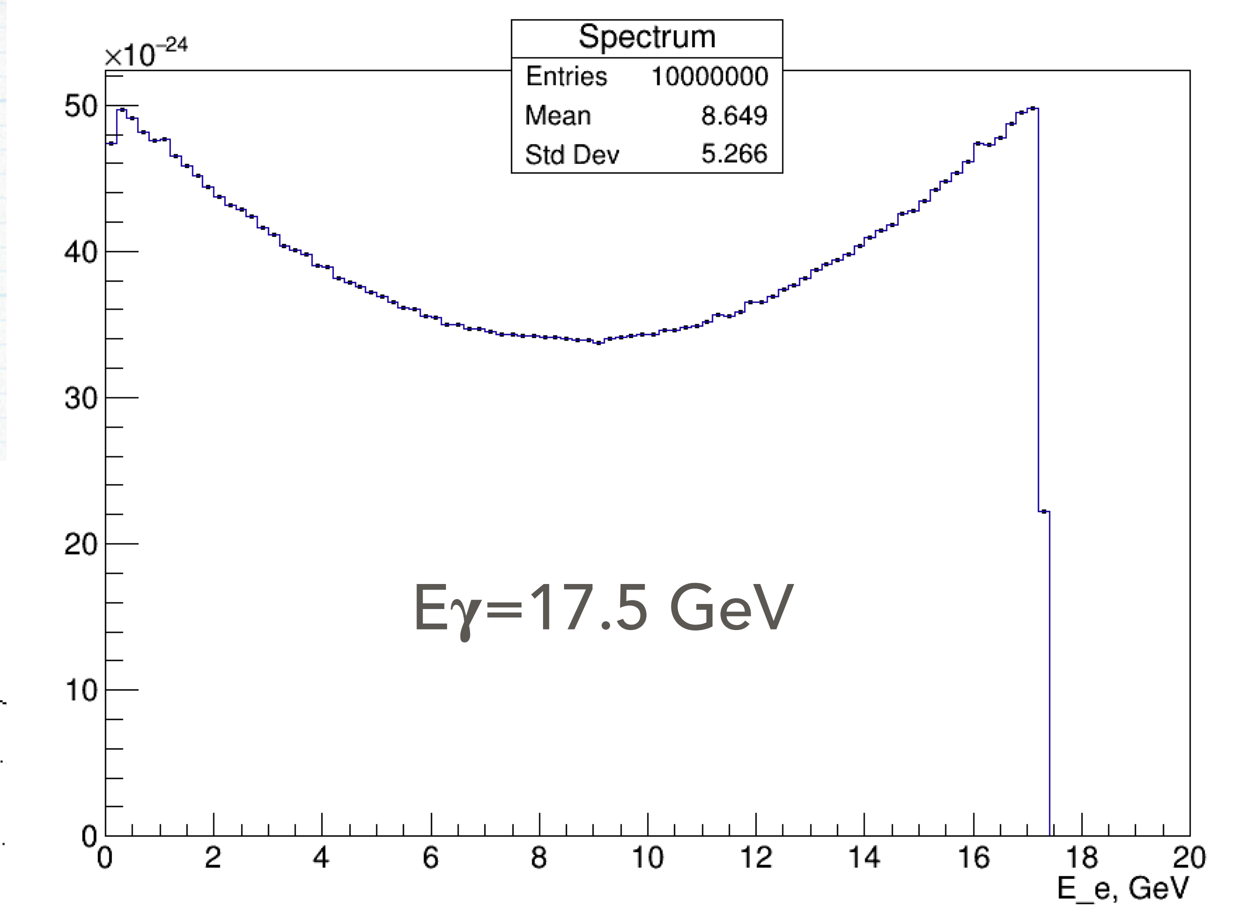


- Distance between Monitor and Dump 2 cm

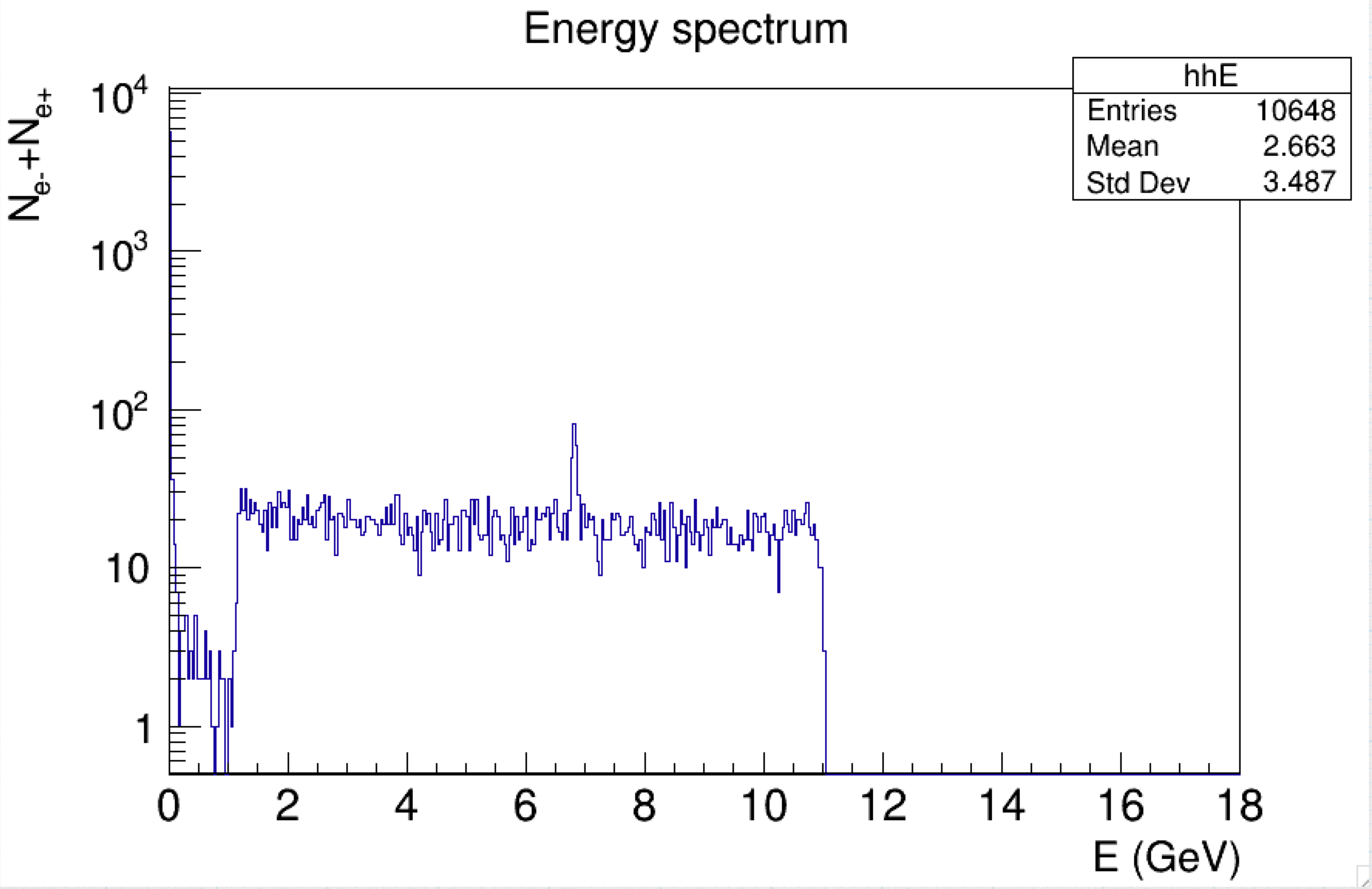


Photon spectrum from Geant4

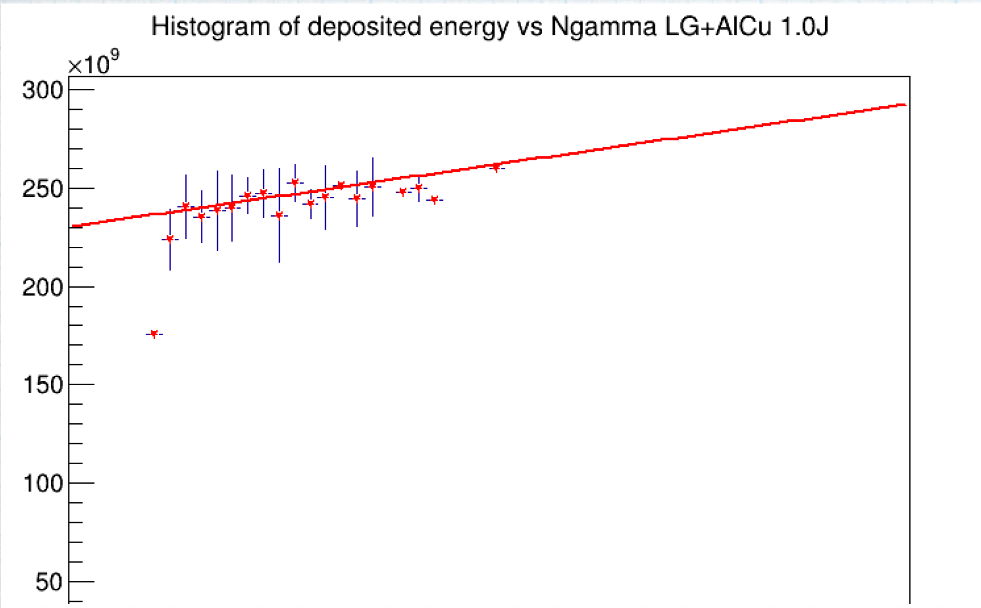




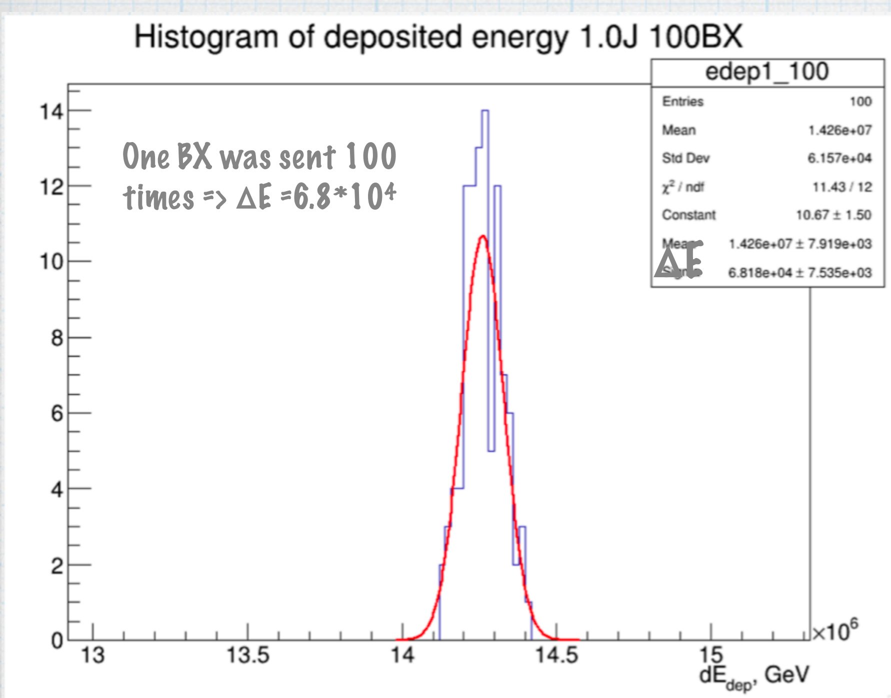
At the detector plane



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
```

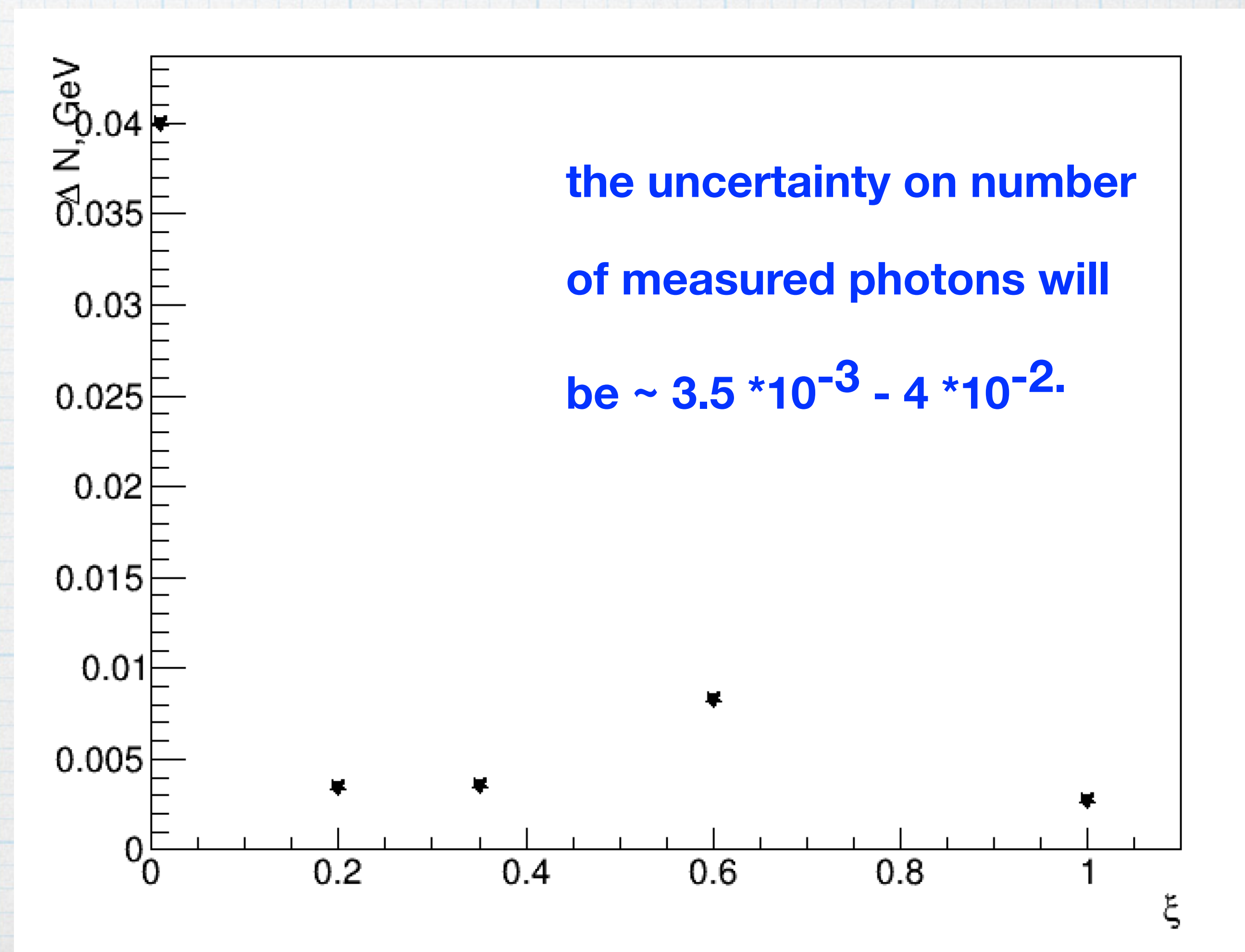


N(E) number of photons

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

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

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

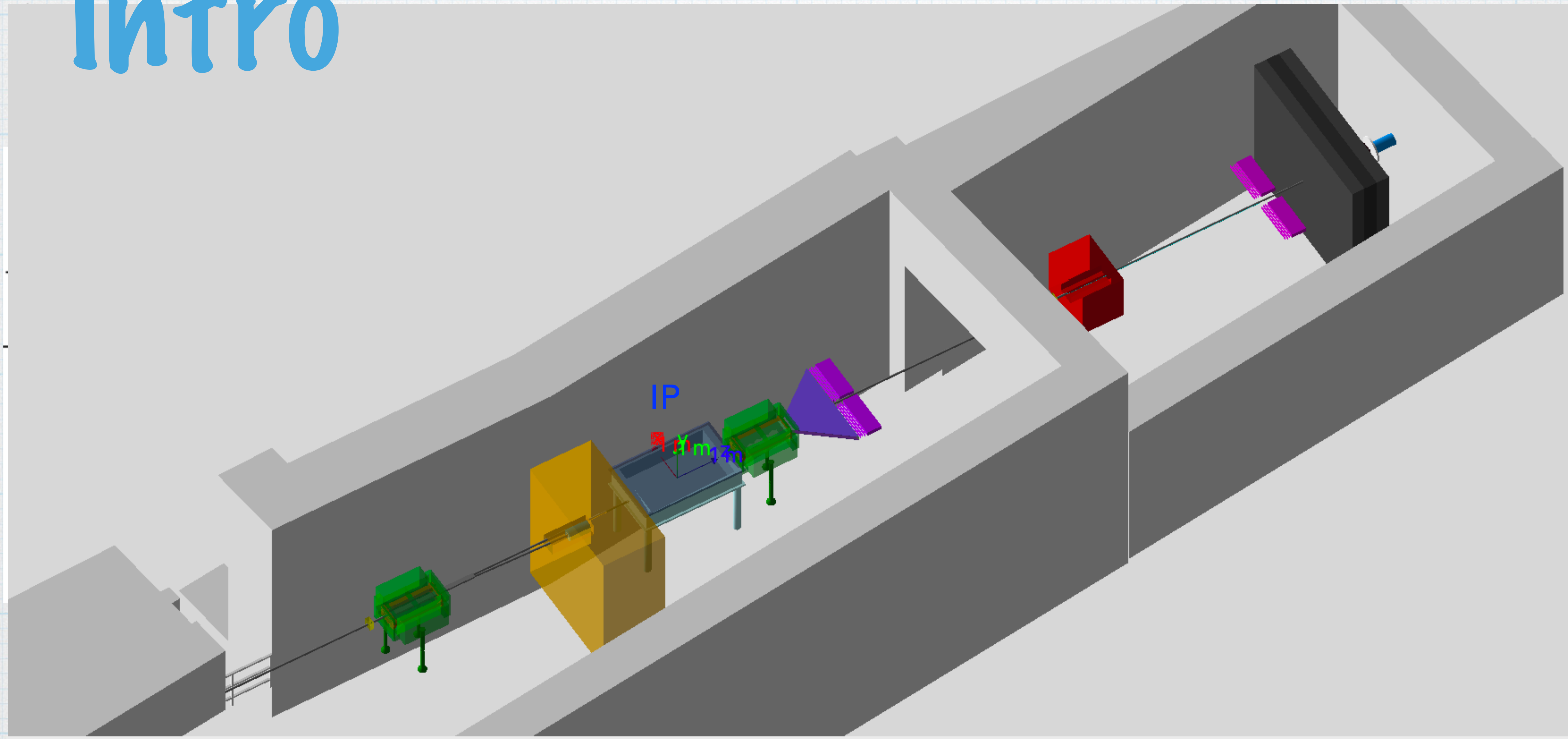


Outline

* 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

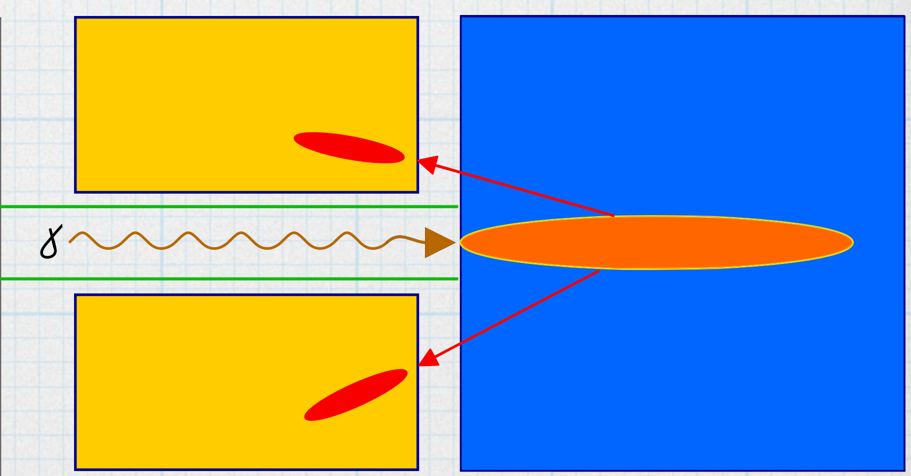
- MC for HICS + trident to model $e + n\omega \rightarrow e + \gamma$ process (A. Hartin)

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

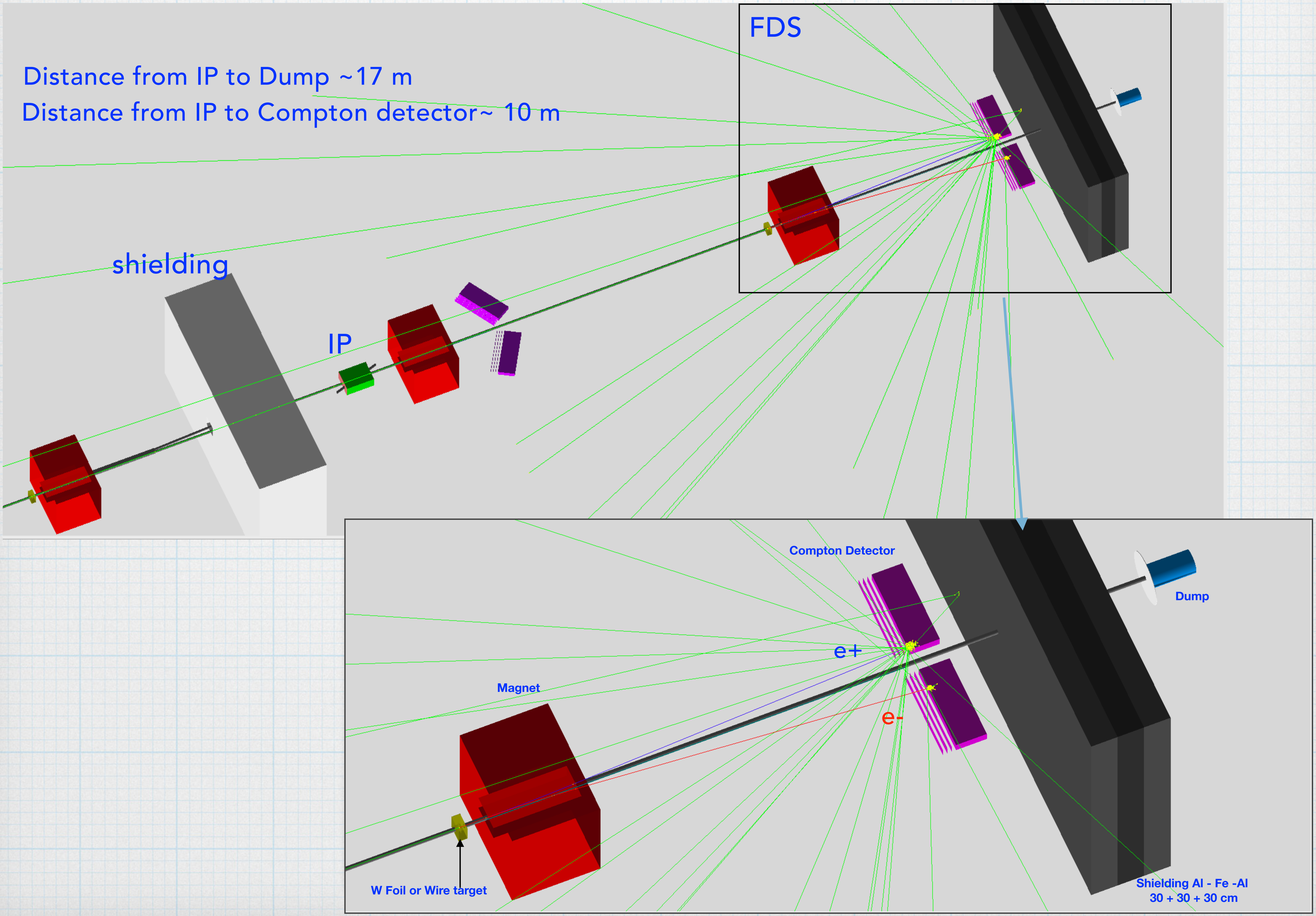
- Ee = 14 and 17.5 GeV
- Different laser intensities ξ
- the estimated rates of electrons, positrons and photons in the various detector regions for e-laser setup and Ee =17.5 GeV

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

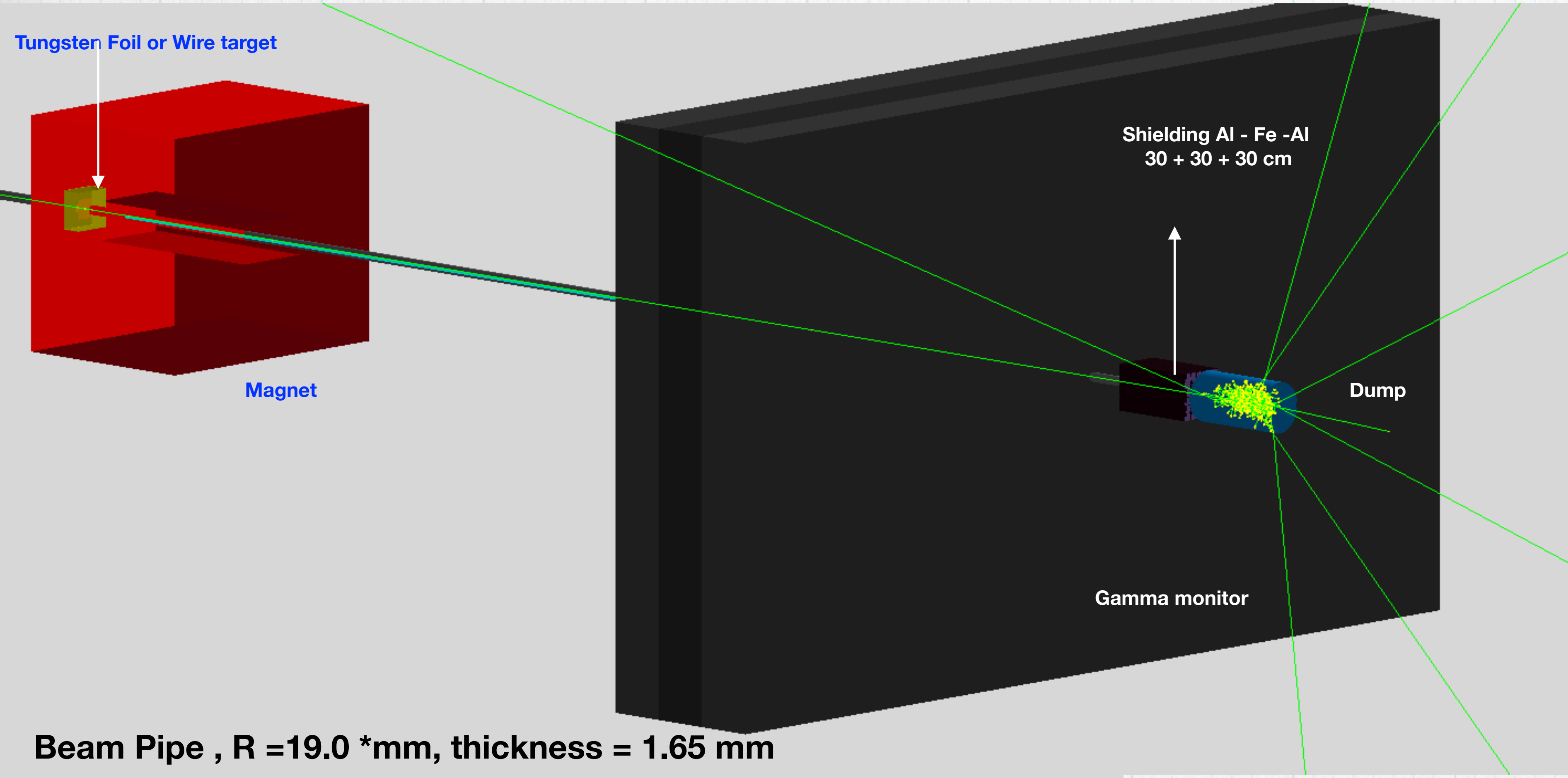


Lead glass blocks found in Hera West @DESY

- New TF-1 LG blocks! Not irradiated, w/ measures 3.8 × 3.8 cm², 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
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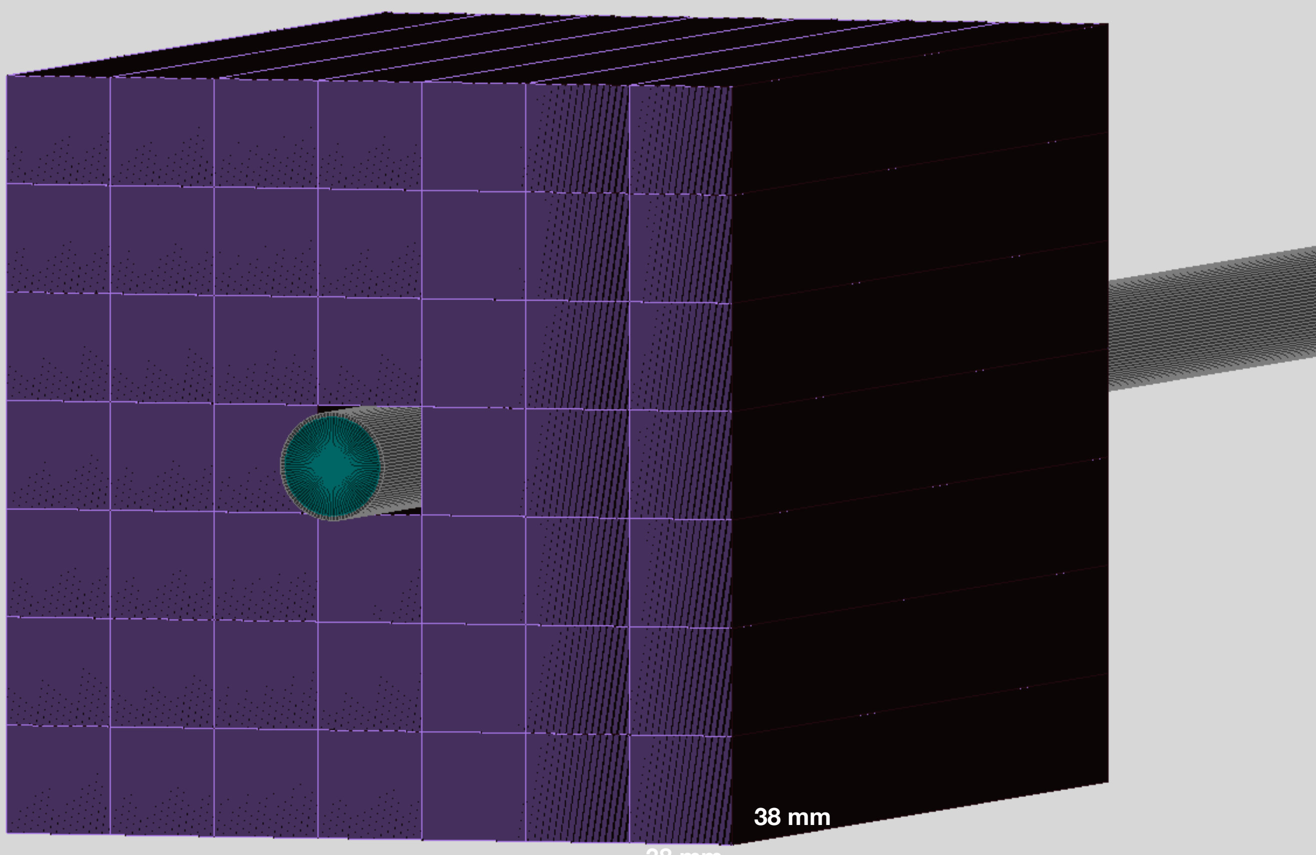
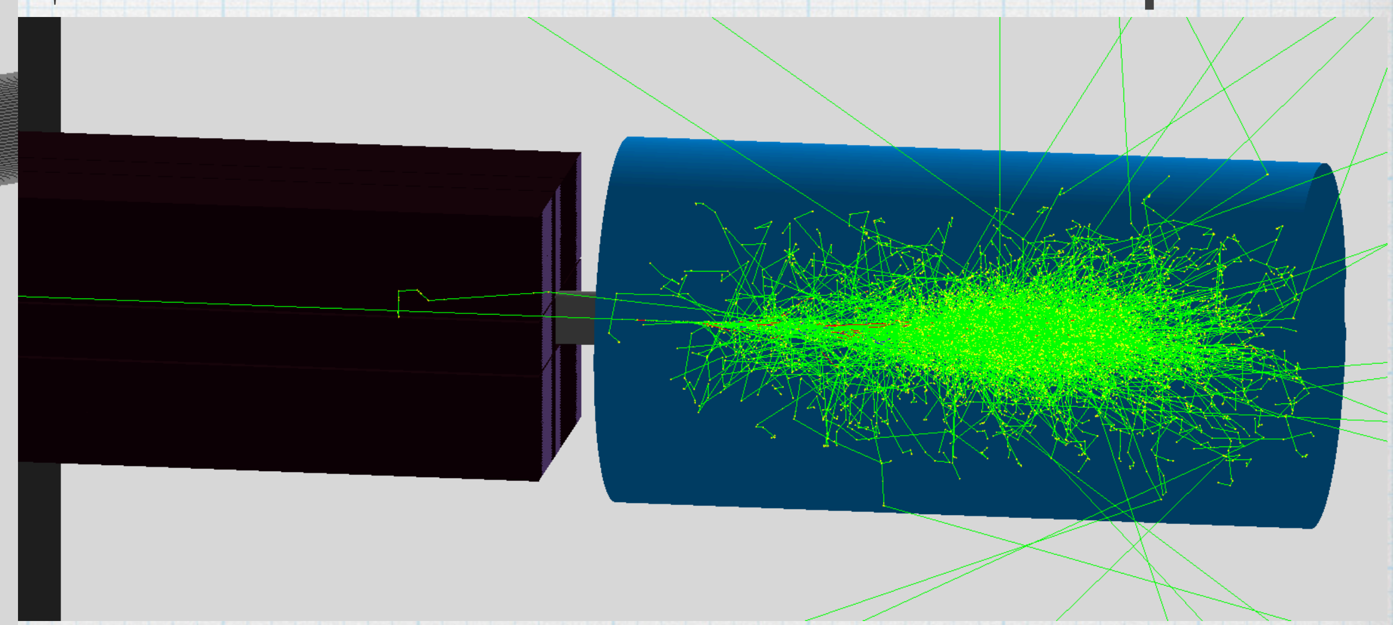
Beam Pipe , R =19.0 *mm, thickness = 1.65 mm

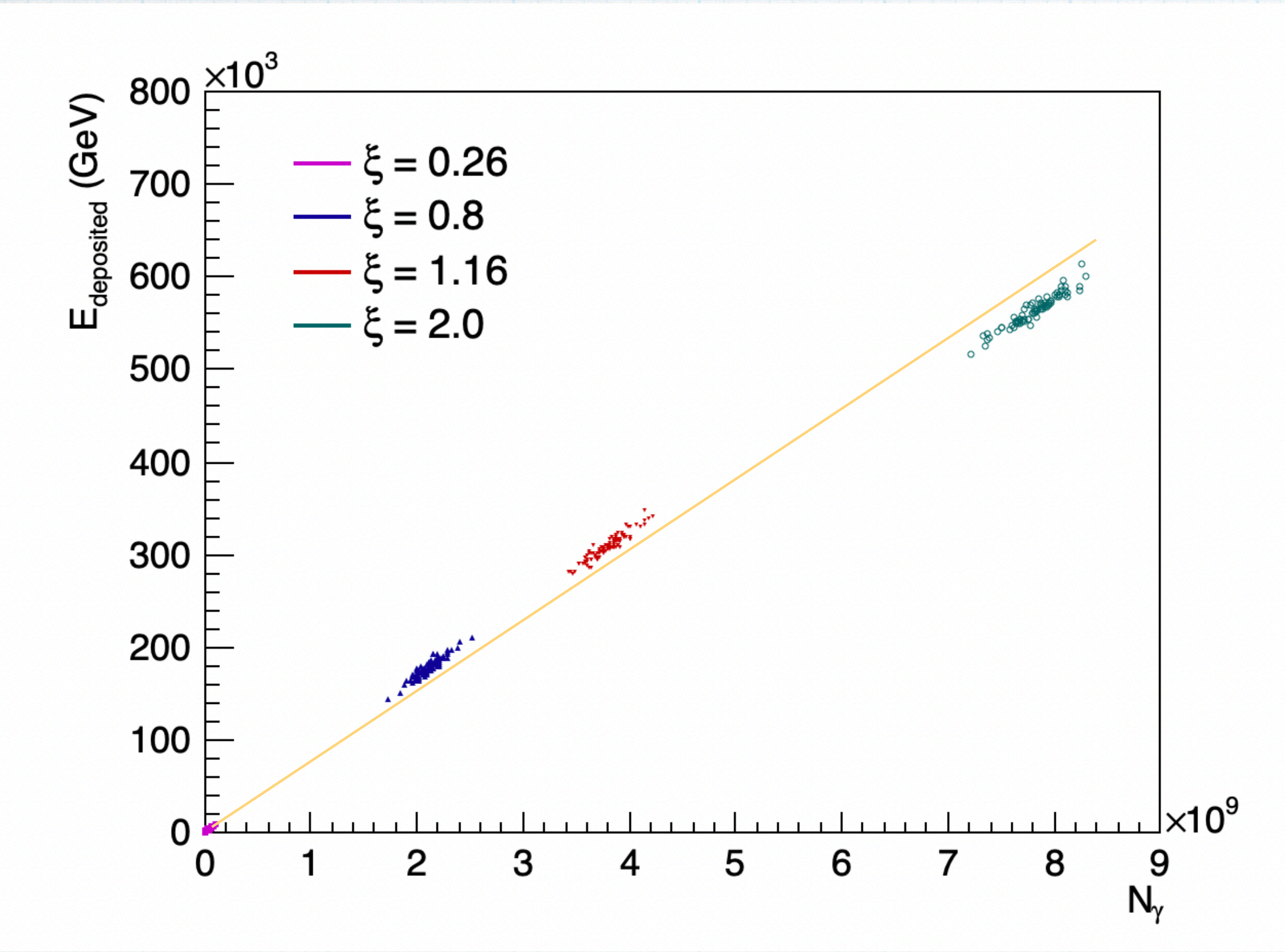


- Distance between Monitor and Dump 2 cm

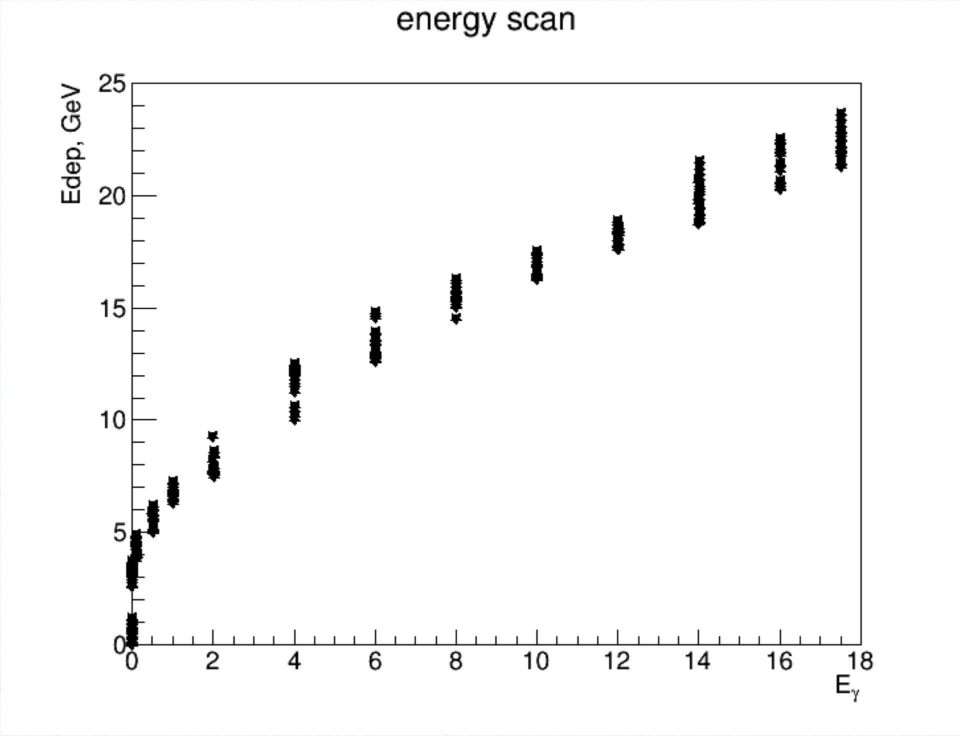


Simulation and Performance

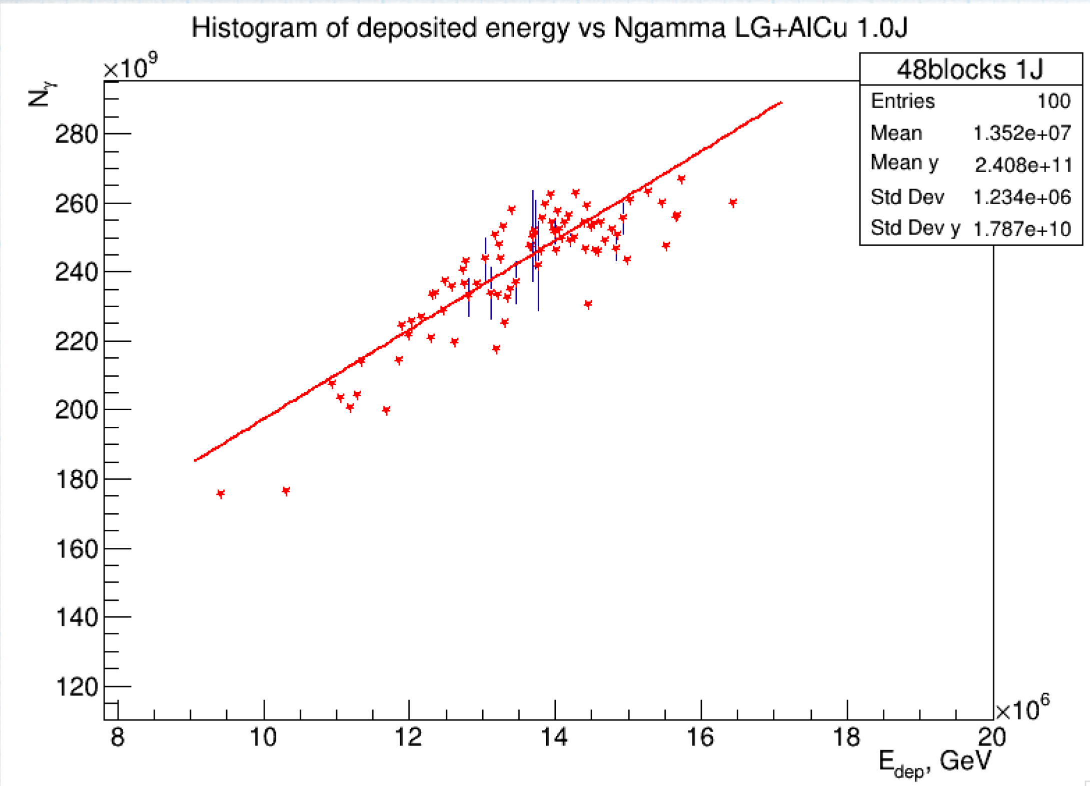
Deposited energy versus true number of photons. Each point is one BX



- 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



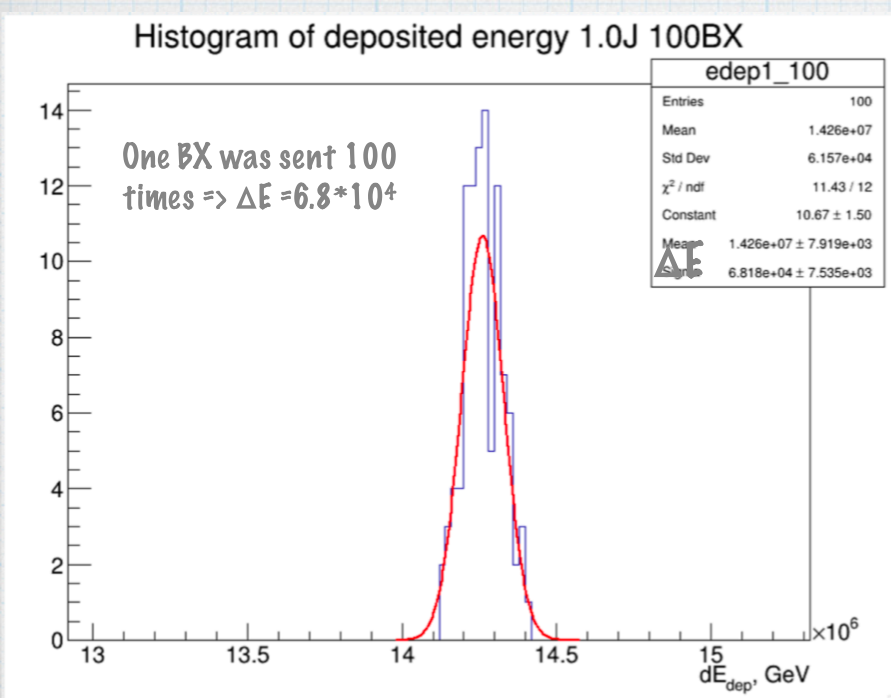
N(E) number of photons

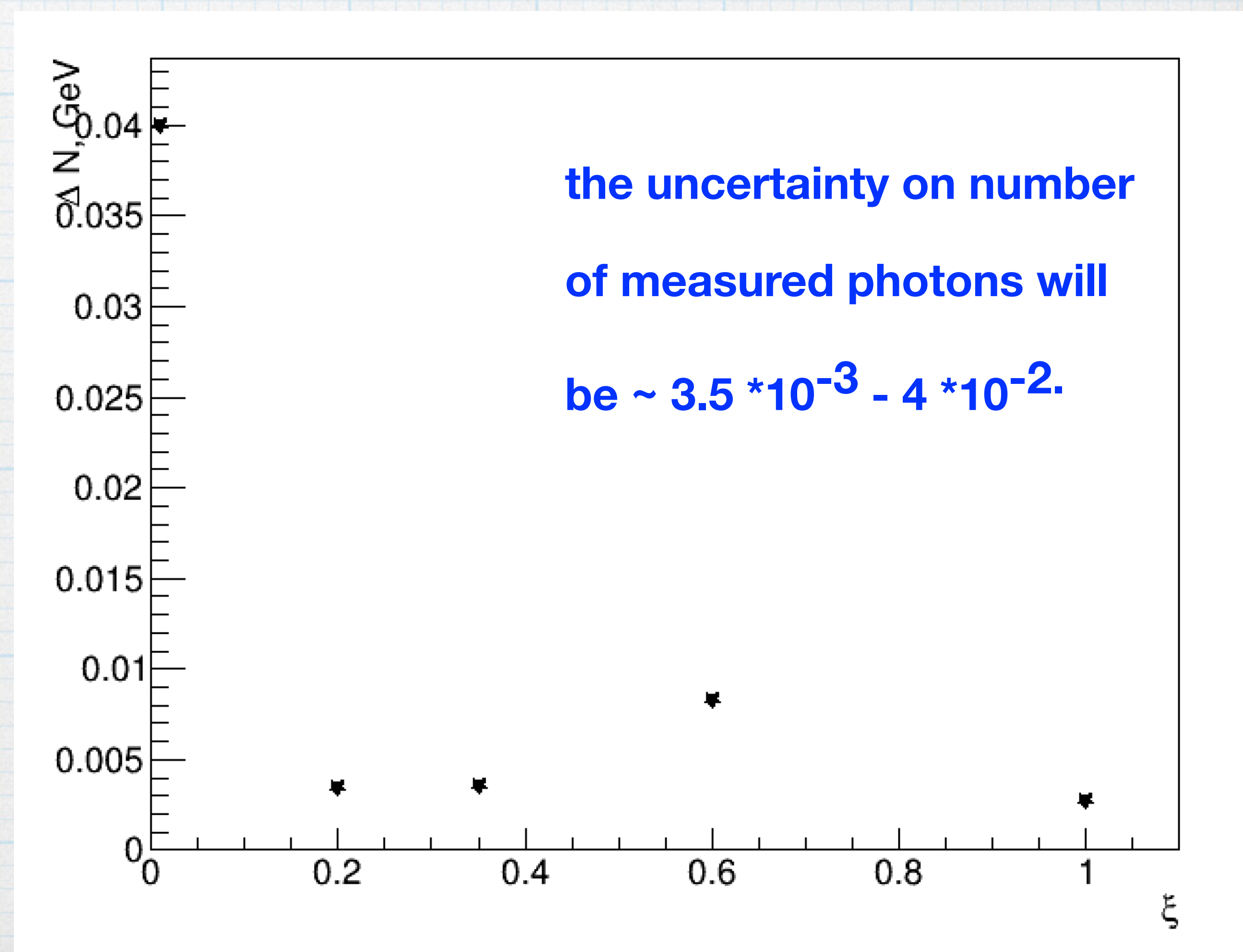
$$\Delta N = \frac{\partial N}{\partial E}\Delta E \quad \Rightarrow \quad \frac{\Delta N}{N} = \frac{1}{N}\frac{\partial N}{\partial E}\Delta E$$

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

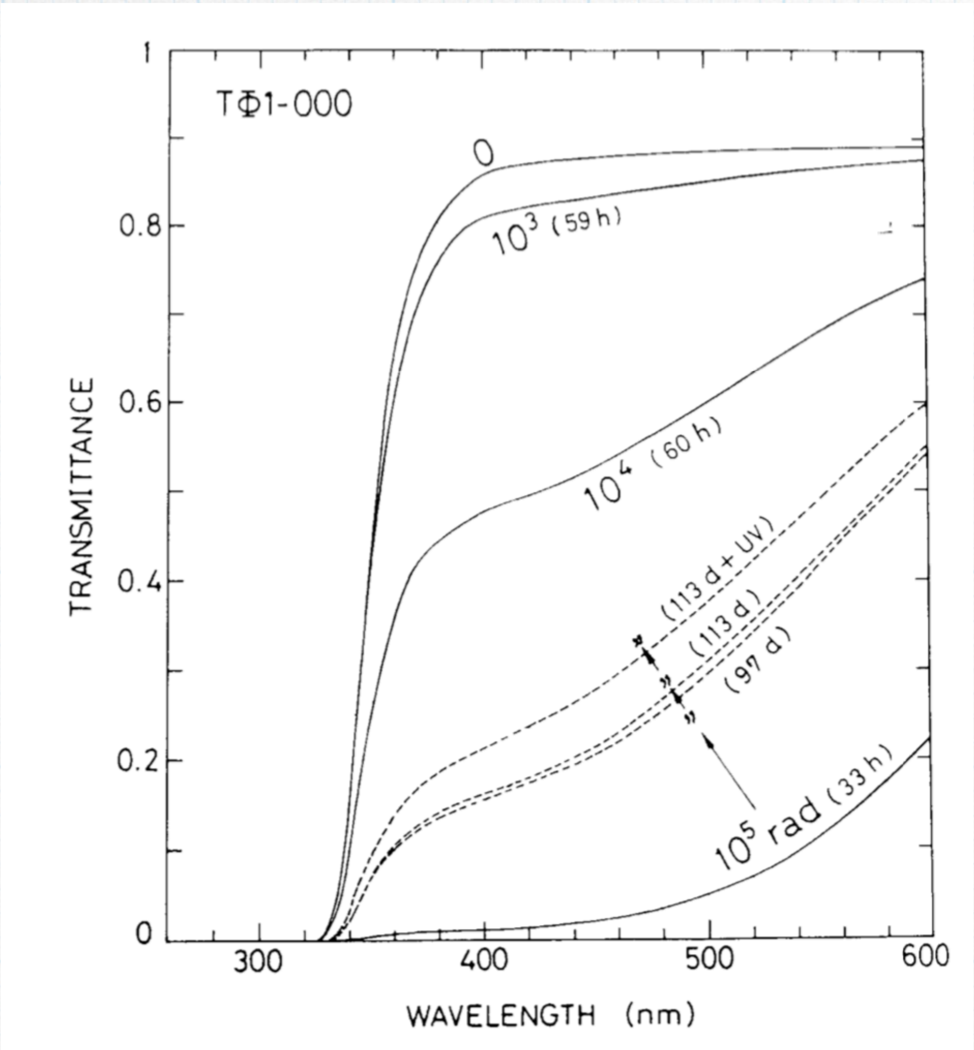
$$\frac{\Delta N}{N} = \frac{1}{N}\frac{\partial N}{\partial E}\Delta E = 6.8*10^4 * 1.3 * 10^4 / 2.5 * 10^{11} = 3.5 * 10^{-3}$$

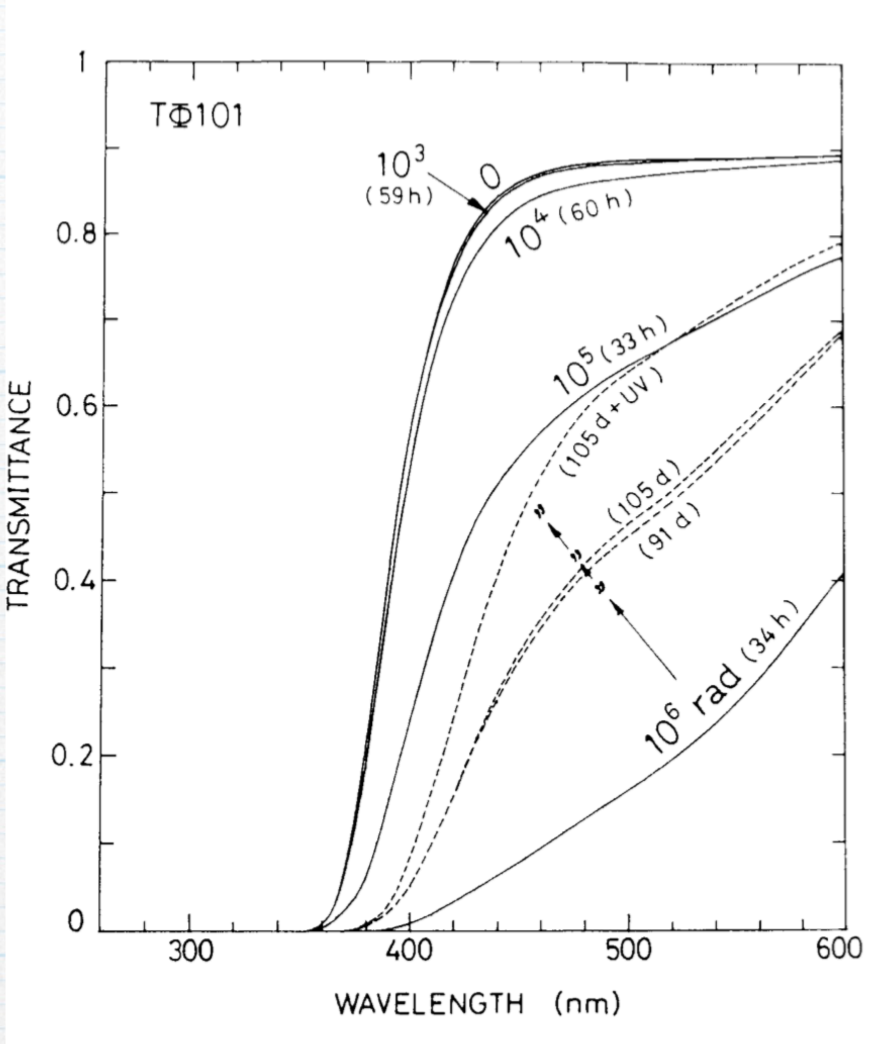
```
****************************************
Minimizer is Linear
Chi2                      =      49.2879
NDf                       =           13
p0                        =  6.79976e+10    +/-    3.97264e+09
p1              ∂N/∂E     =      12940.5    +/-    282.483
```





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





1rad= 0.01 Gy

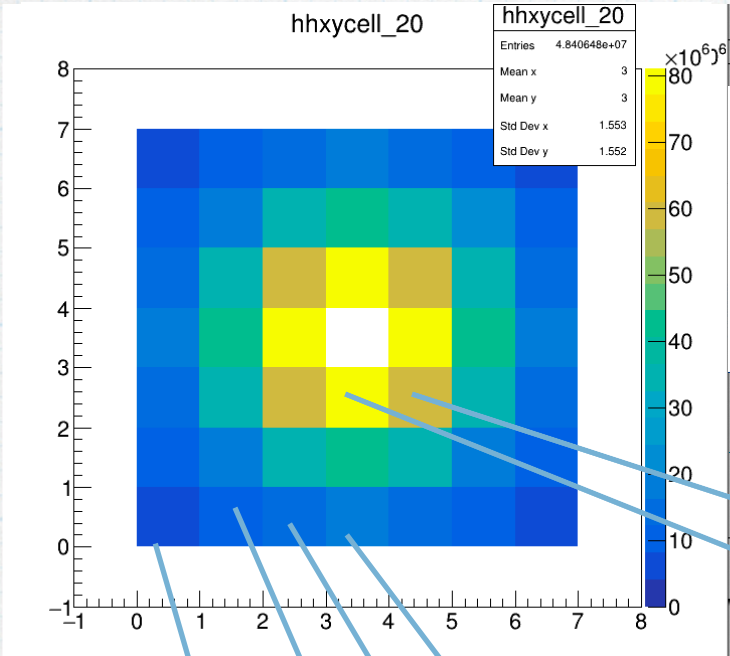
TF101 - radiation hardened with addition of 0.2% cerium

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.

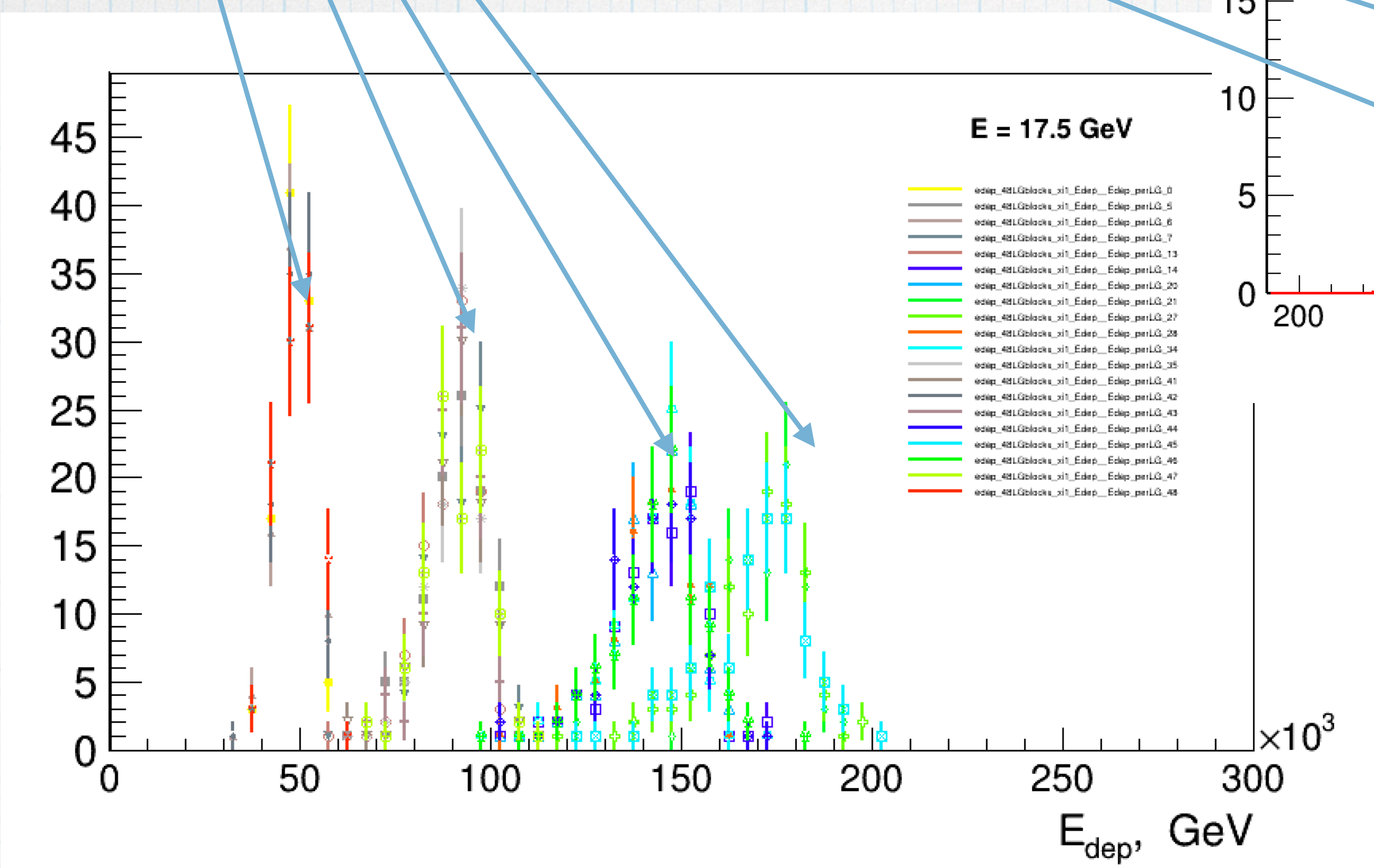
(=> 5* 10^2 rad = 5Gy In TF1)

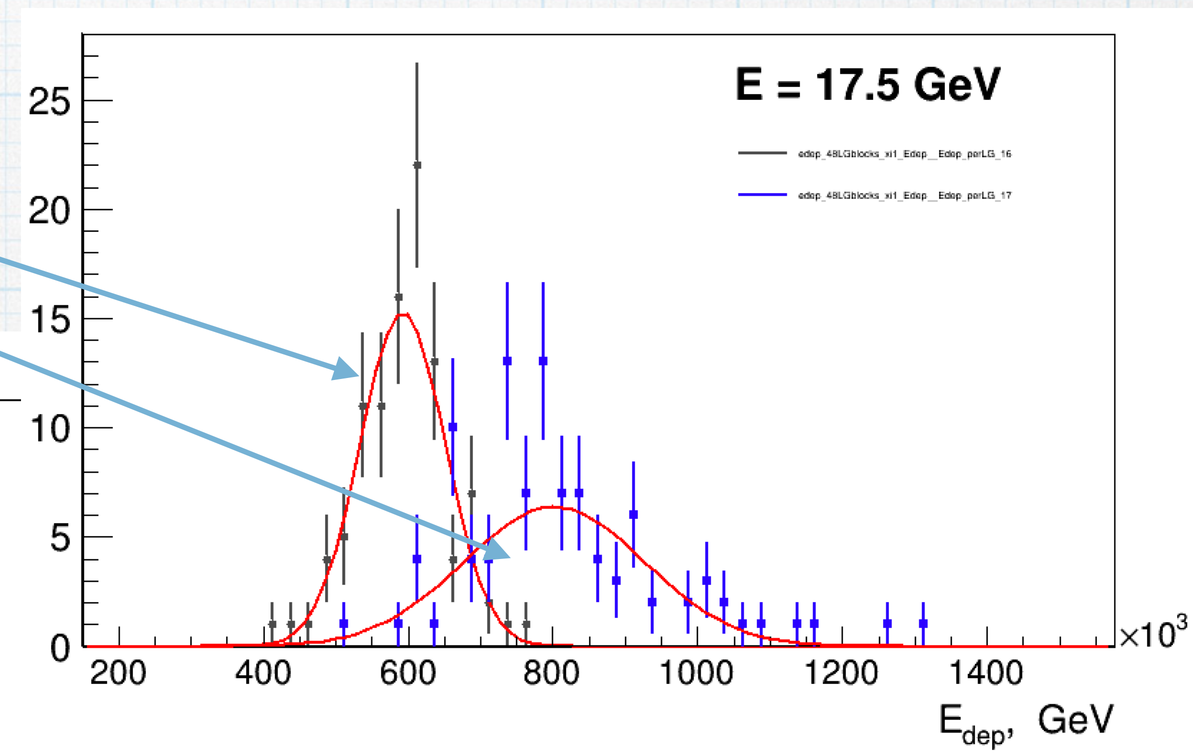
tolerable accumulated doses in the individual blocks



✶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

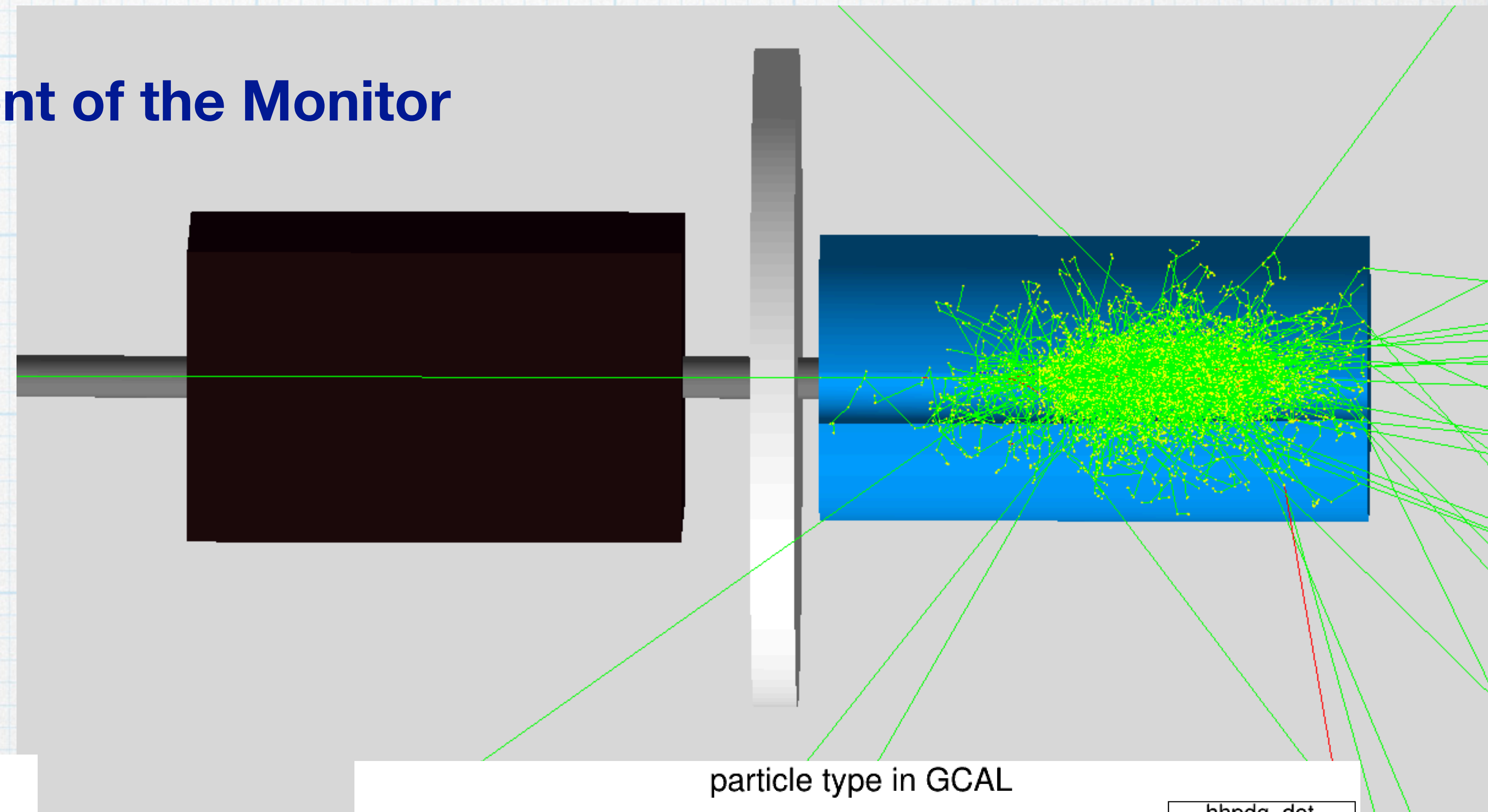


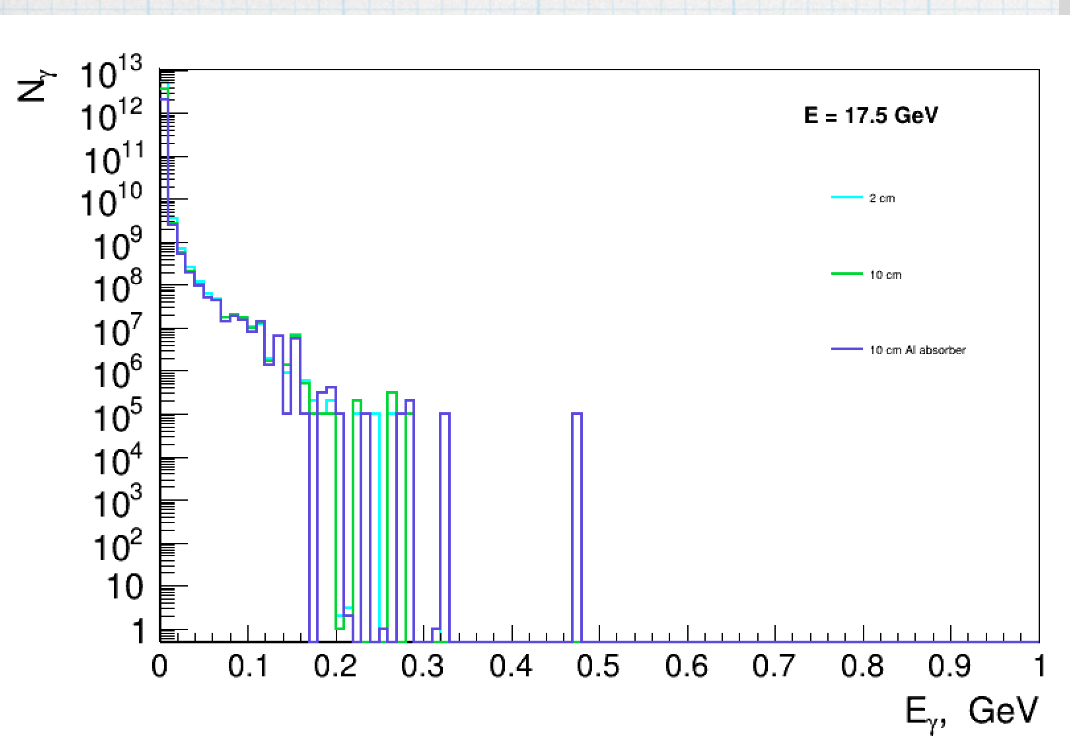


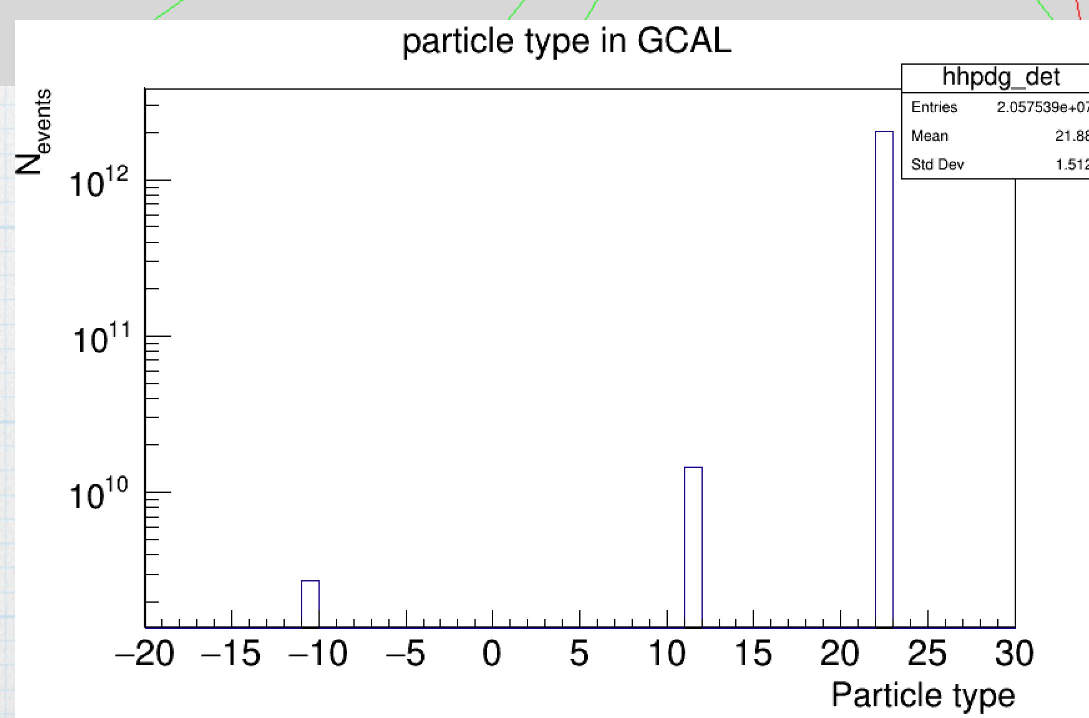
At 10 Hz rate the energy deposition accumulates the dose of 5 Gy in the whole TF1 block which ranges from 3 hours up to 45 hours

Adding absorber

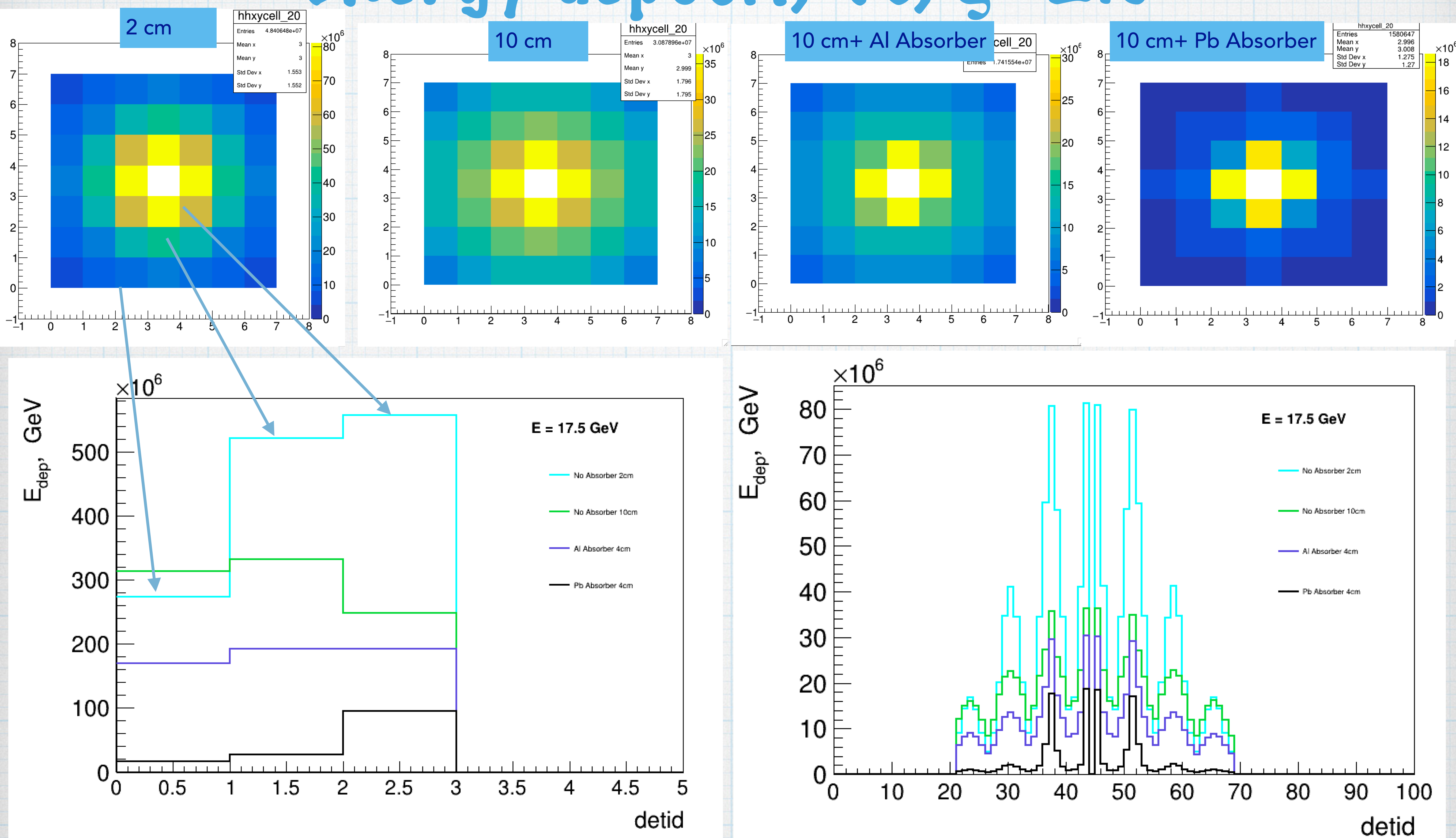
- ✳ 2Months ~1460 hours
- ✳ To try:
  - ✓ absorber (Al or Pb, 4 cm) in front of the Monitor







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

- [x] 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.

- [x] The estimated uncertainty on number of measured photons is ~ 10^{-3} - 10^{-2} in case of HICS.

- [x] Can be used also for bremsstrahlung using the convolution of response function with the spectrum.

- [x] 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