Compton spectra reconstruction

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LUXE simulation meeting

LUXE

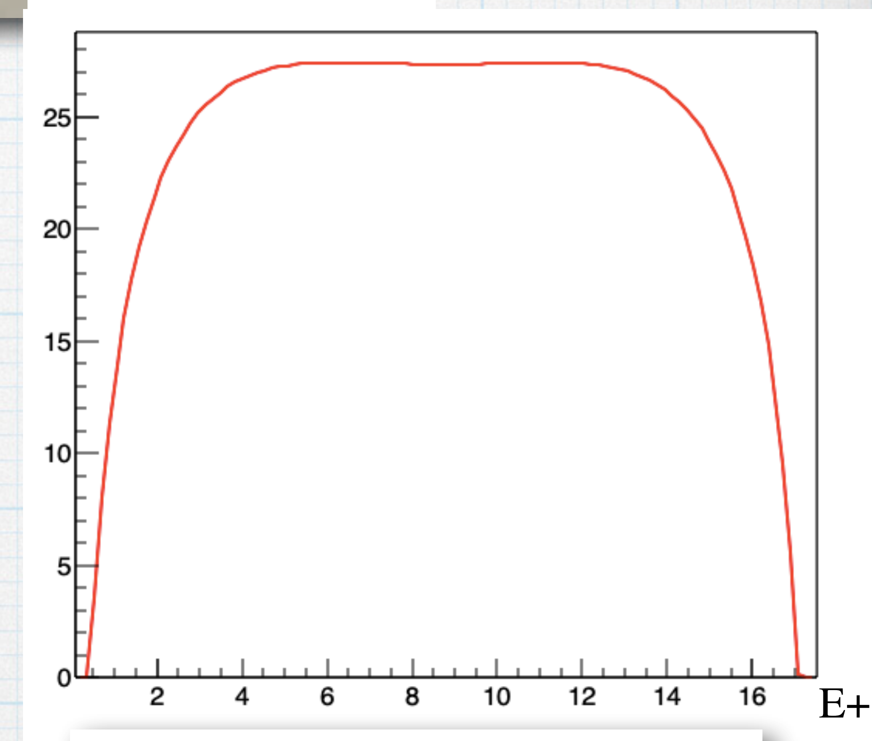
Photon spectra reconstruction using Bethe-Heitler pair spectrum

The classical Bethe-Heitler formula (H.Bethe, W.Heitler, Proc.Roy.Soc.A146 (34)83)

$$\Phi(E_0)\,dE_0 = \frac{Z^2}{137}\left(\frac{e^2}{mc^2}\right)^2 4\,\frac{E_{0+}{}^2E_+{}^2 + \frac{2}{3}E_0E_+}{(h\nu)^3}\,dE_0\left(\log\frac{2E_0E_+}{h\nu mc^2} - \frac{1}{2}\right).$$

energies involved are large compared with mc^2

$\Phi(E+, E_0=E\gamma)$



$\sigma(E\gamma, Ee) = \Phi(E\gamma, Ee)*N_a$ N_a - Number of atoms

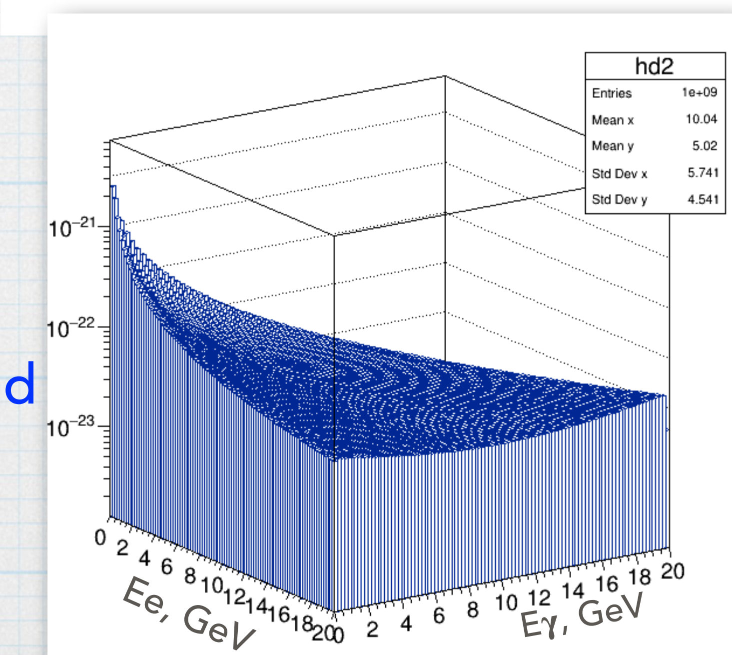
- Photon spectra $g(E\gamma)$ can be reconstructed by fitting

  $N(Ee) = \int \sigma(E\gamma, Ee)\, g(E\gamma)\, dE\gamma$

  Where N(Ee) positron/electron spectra measured in detector after the conversion.

- Since $\sigma(E\gamma, Ee)$ depends on number of scatters N_a defined by the thickness of the target the approach can be tested by using the thickness as fit parameter

- Used Bethe-Heitler class from Geant4, with corrections and extended for various effects (the screening, the pair creation in the field of atomic electrons, correction to the Born approximation, the LPM suppression mechanism, etc.) to calculate differential cross-section



True electron/photon spectra

4764BX out of 5000 BX at the laser intensity xi = 0.3 for 16.5 GeV electron beam

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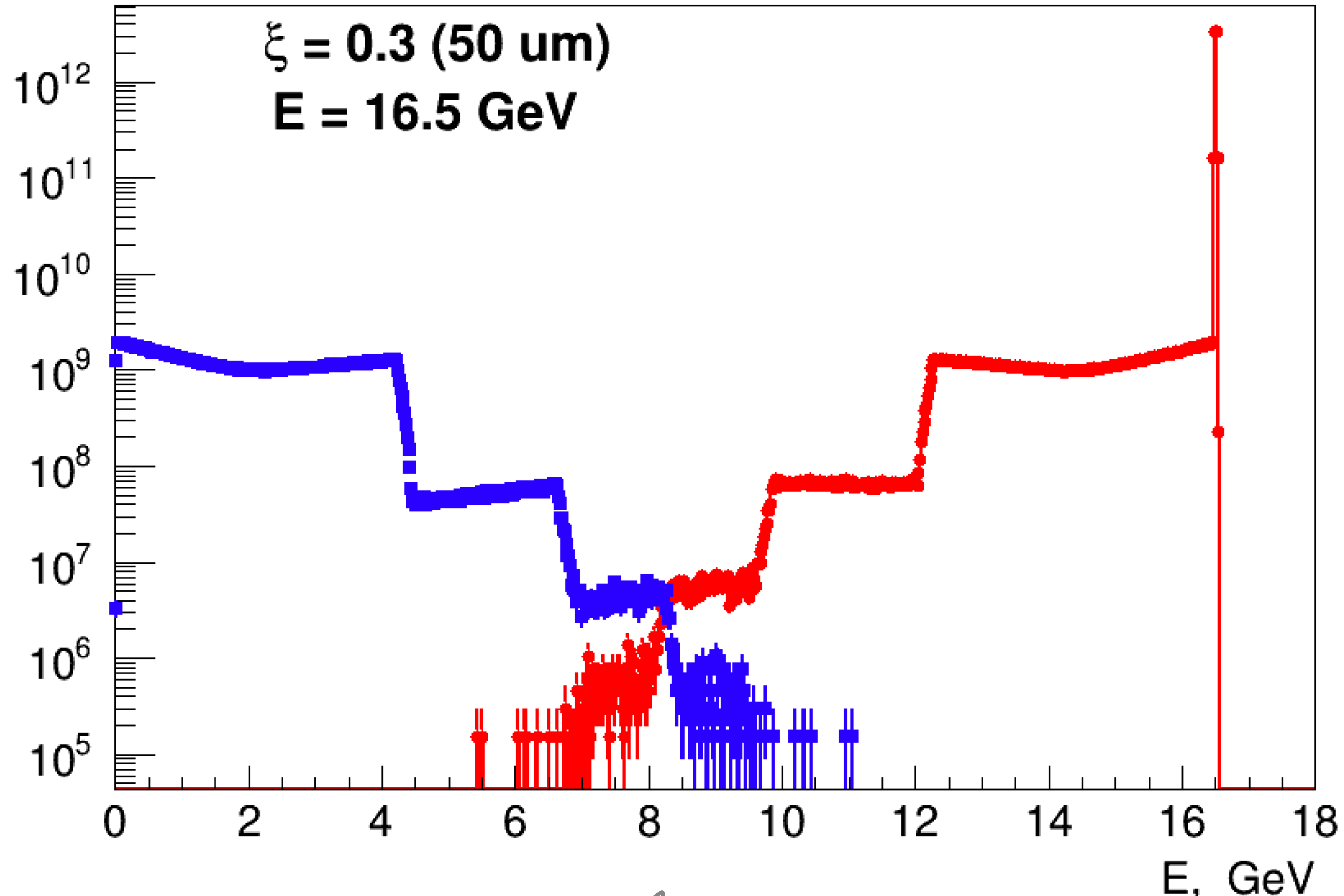
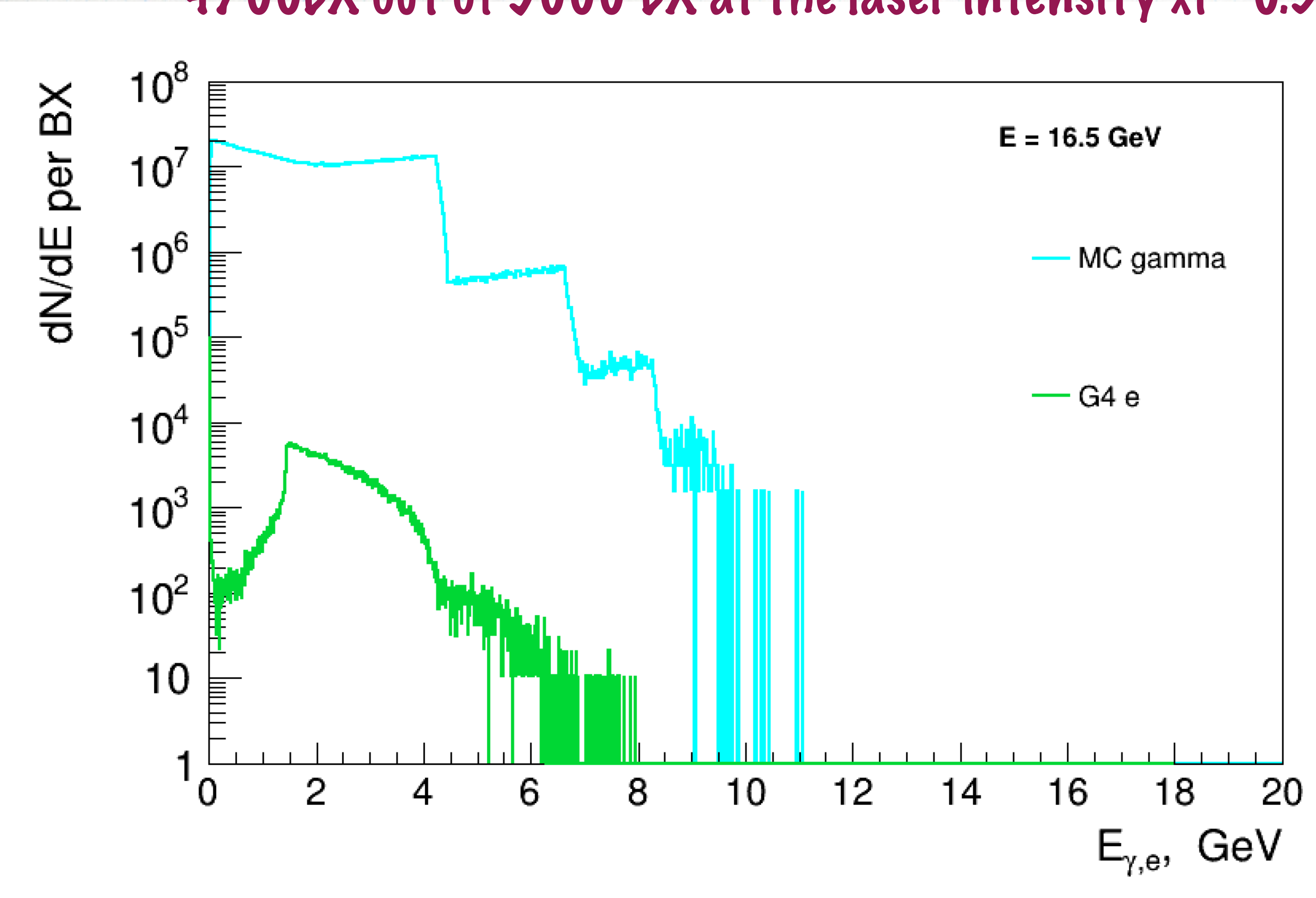
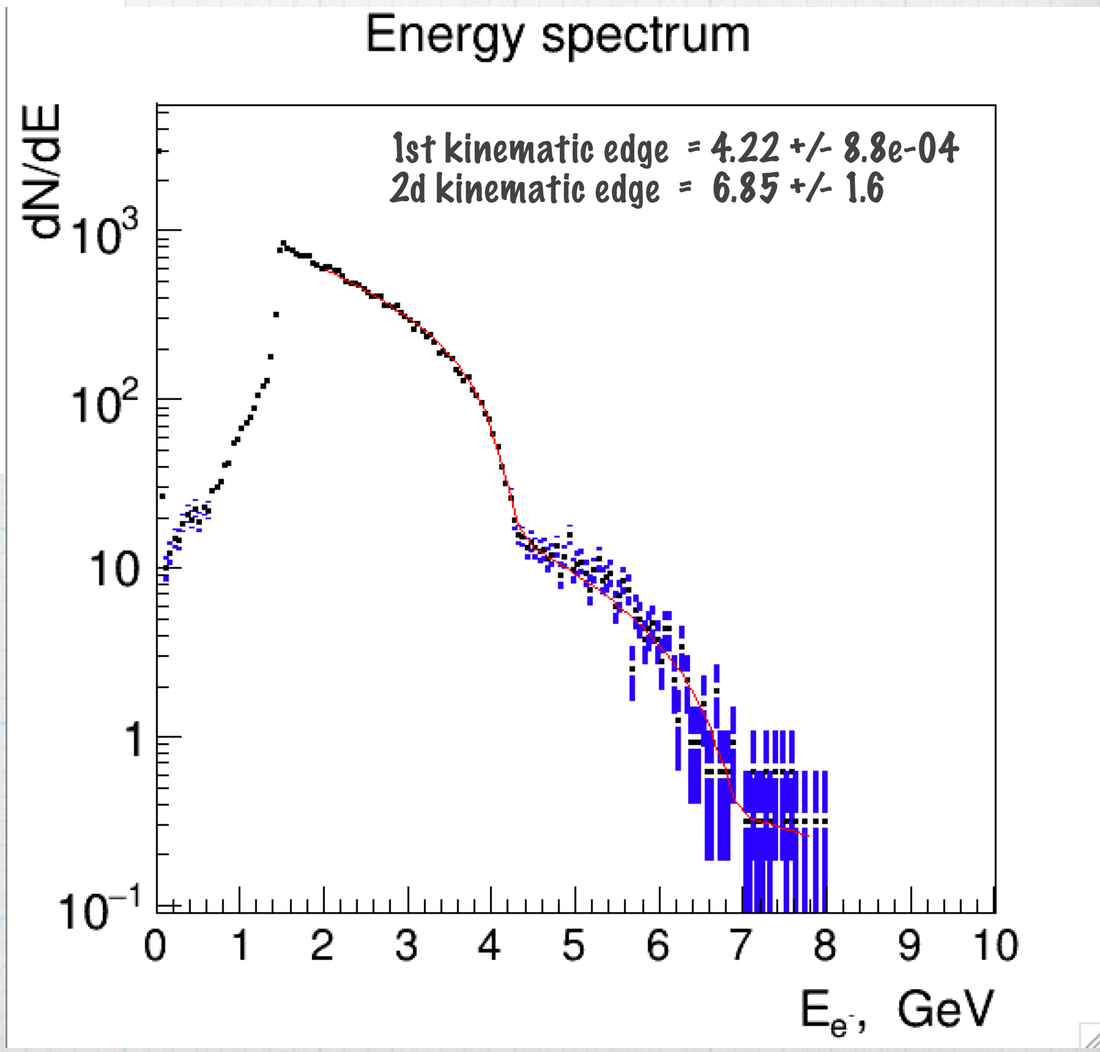


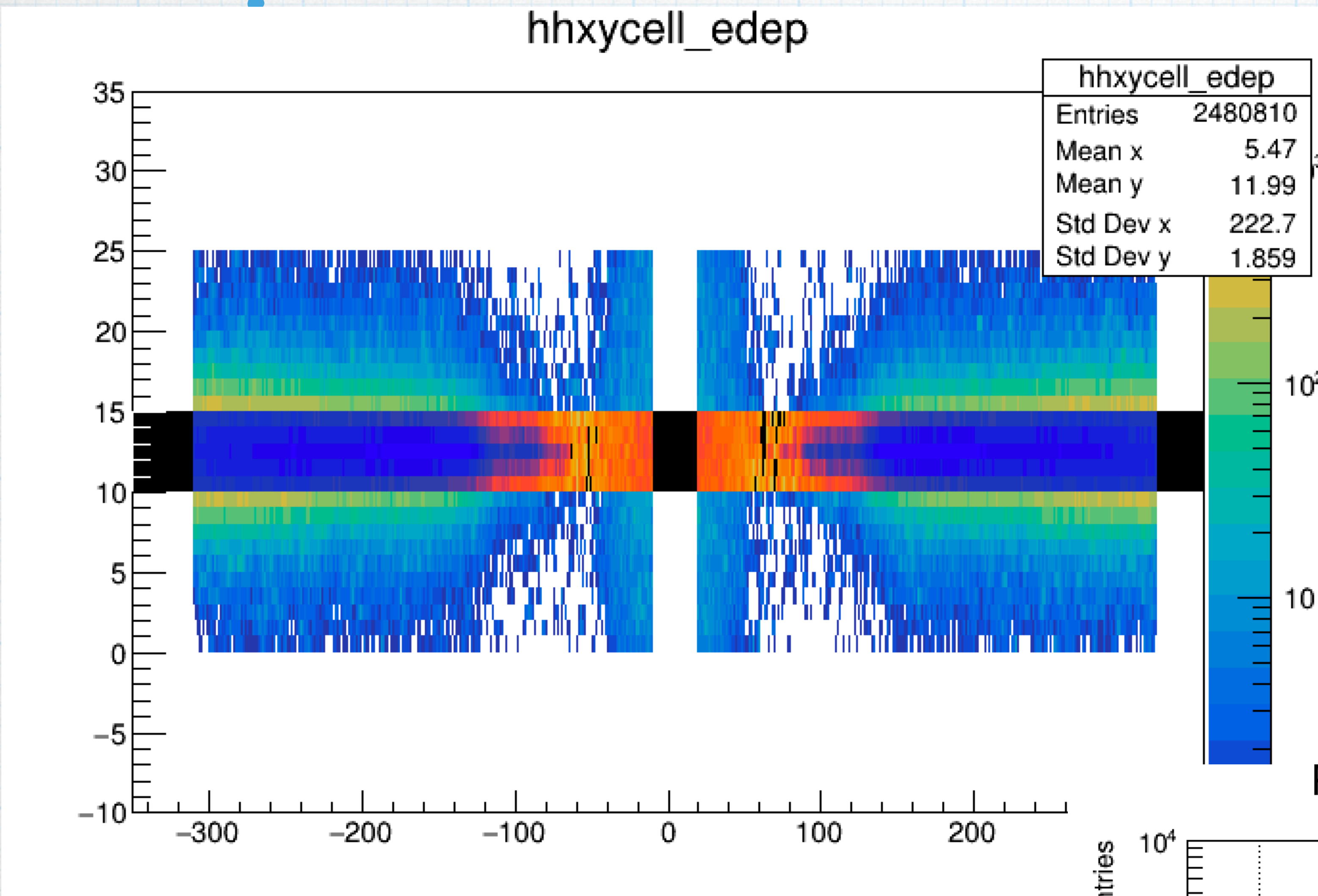
Spectra MC vs G4

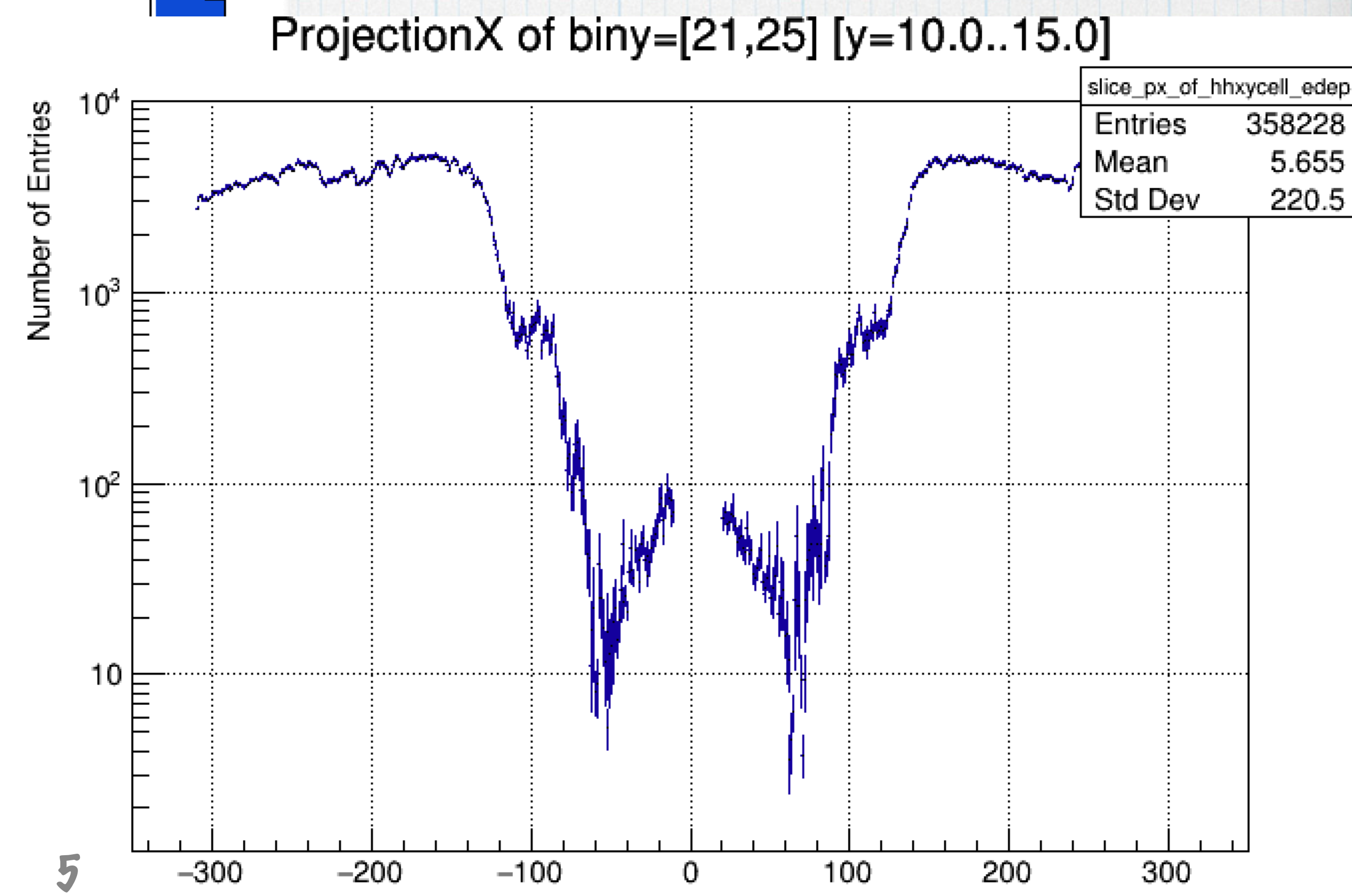
~4700BX out of 5000 BX at the laser intensity xi = 0.3 for 16.5 GeV electron beam



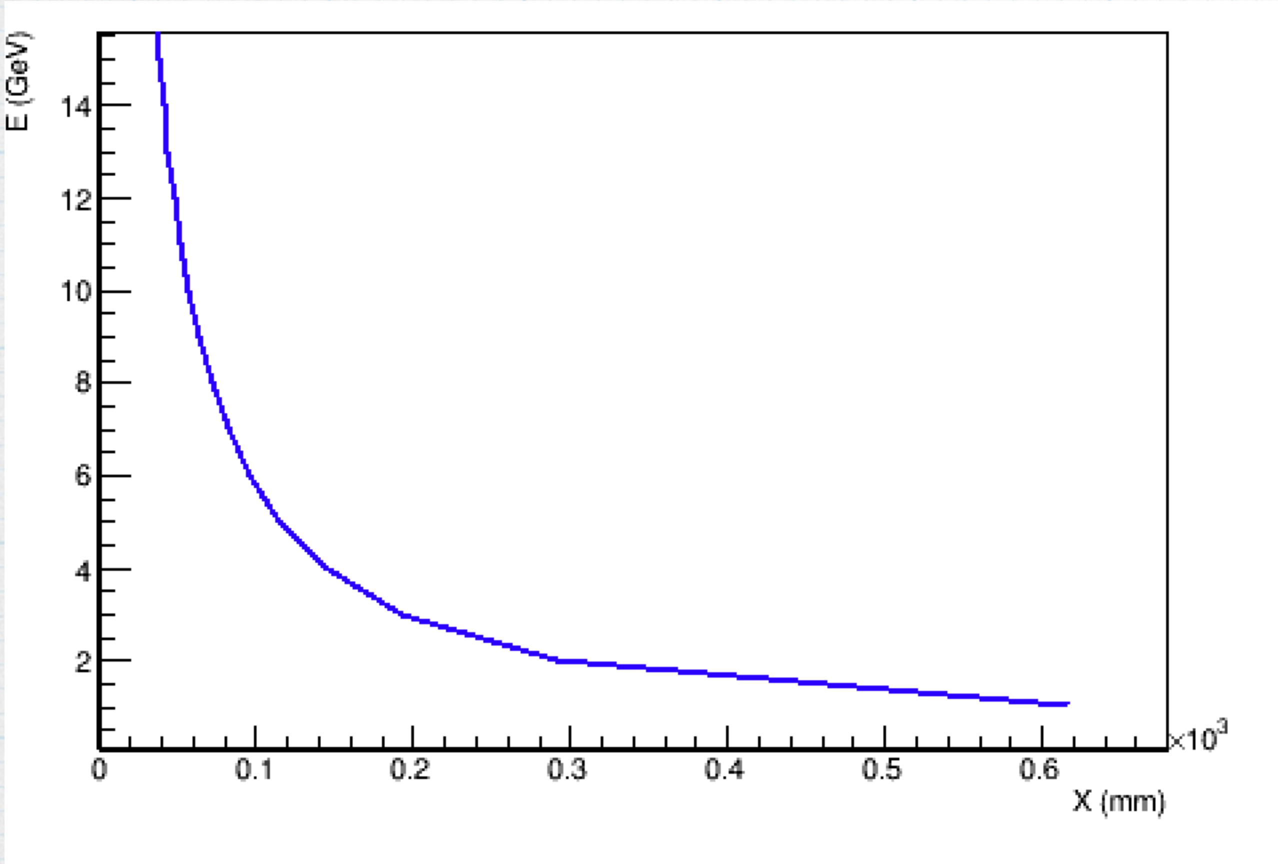


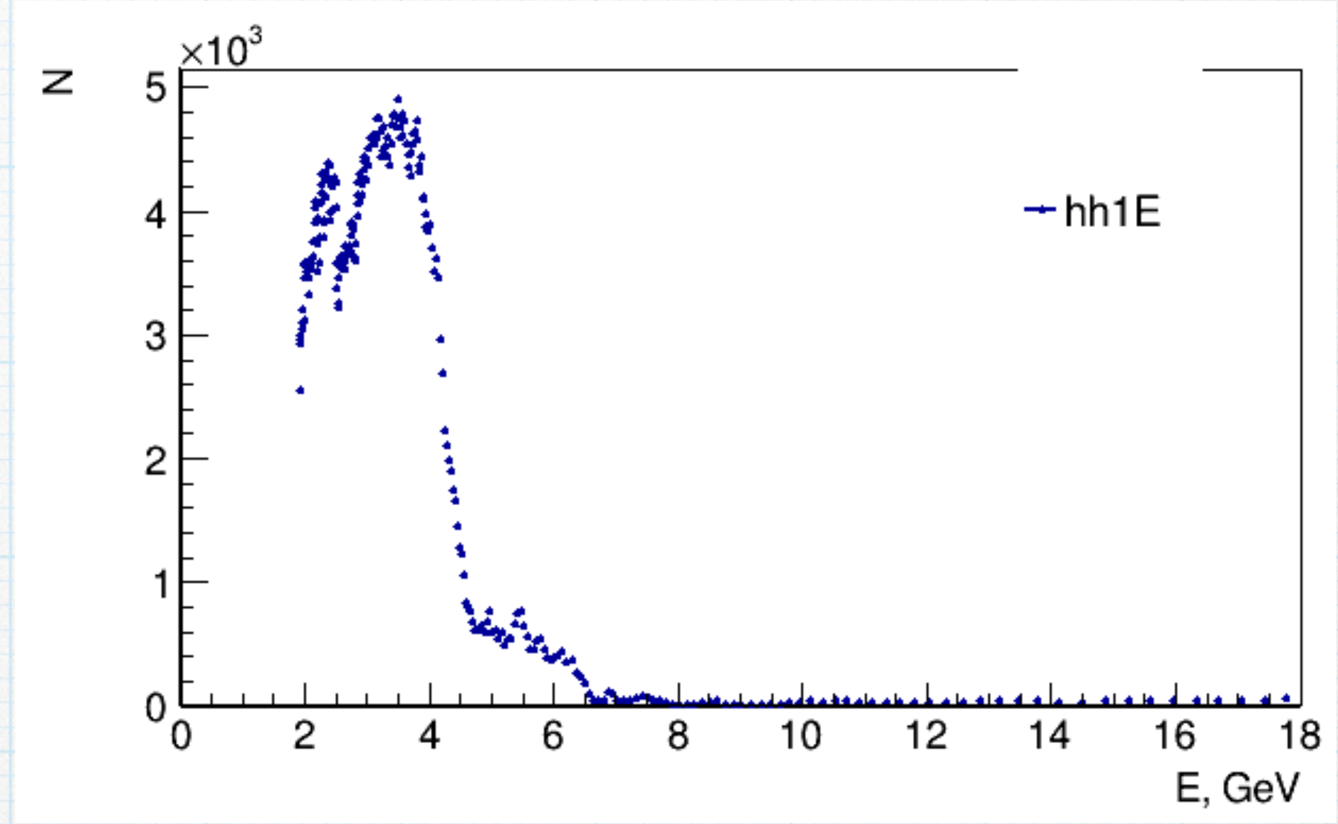
Spectra reconstruction for the LYSO case

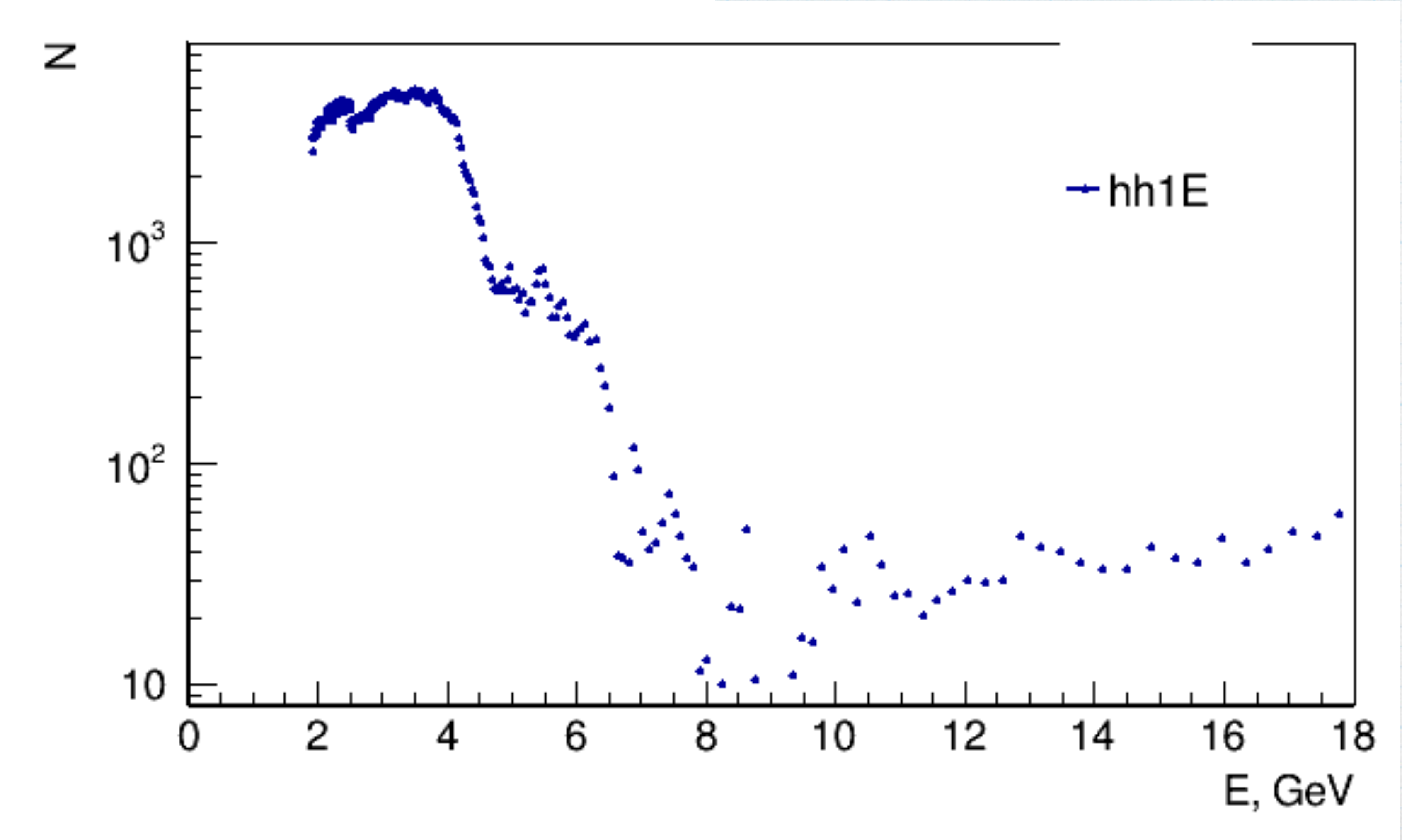




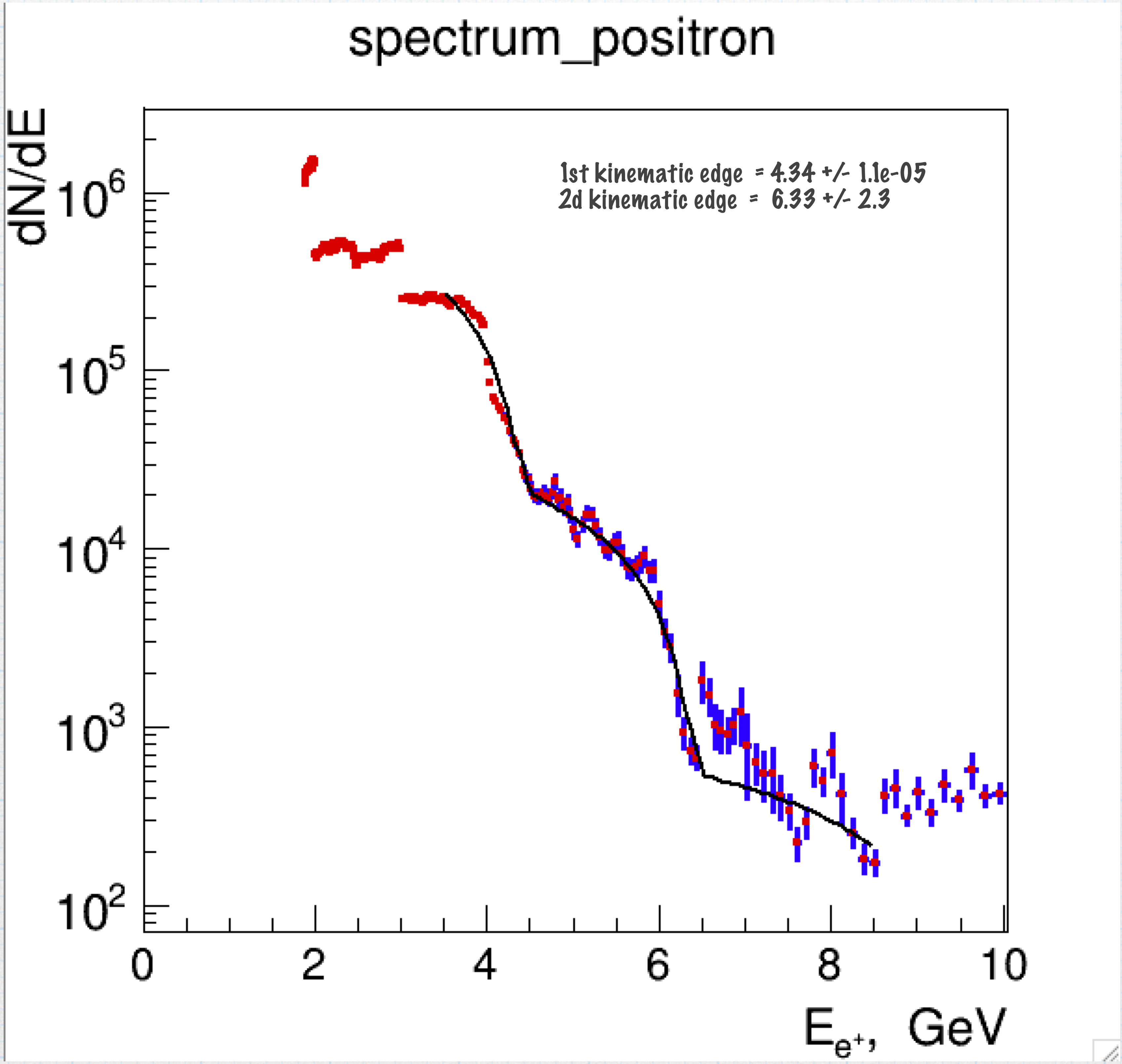
Spectra reconstruction for the LYSO case

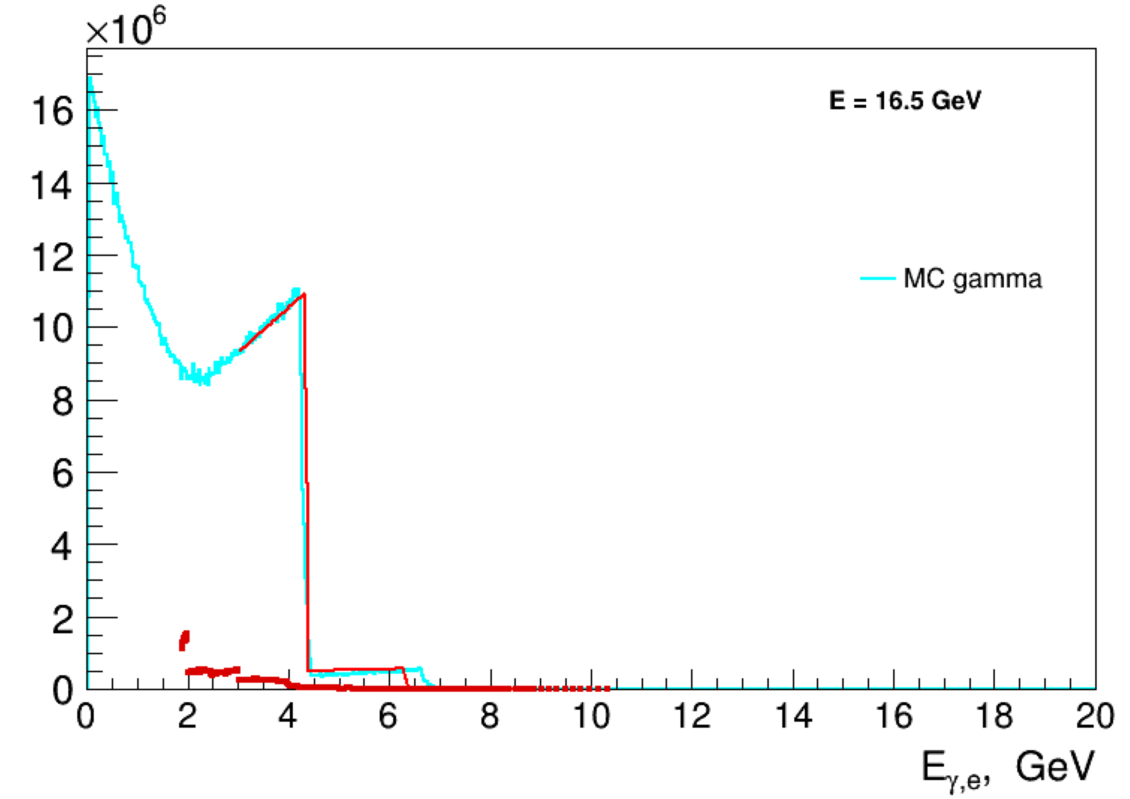


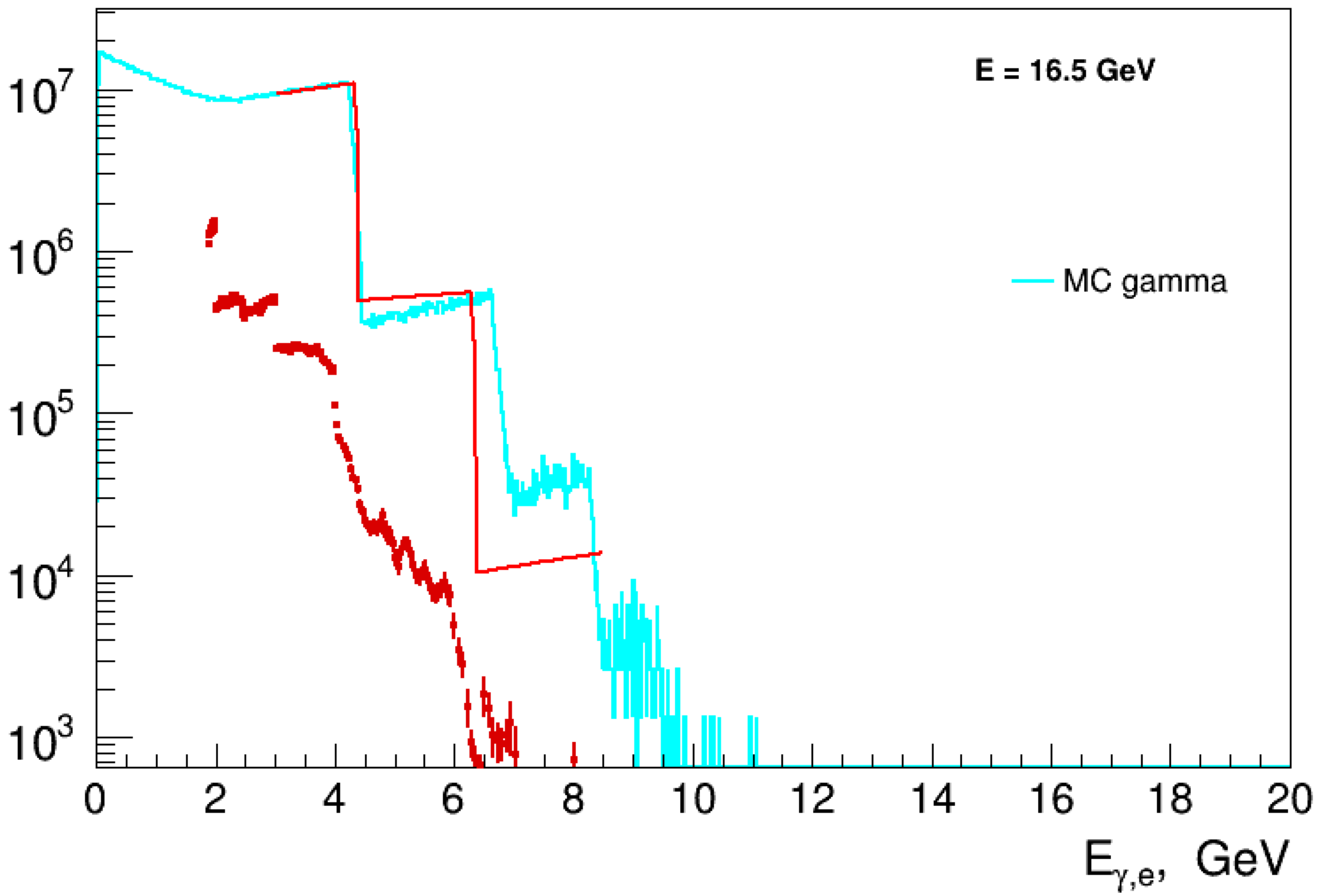




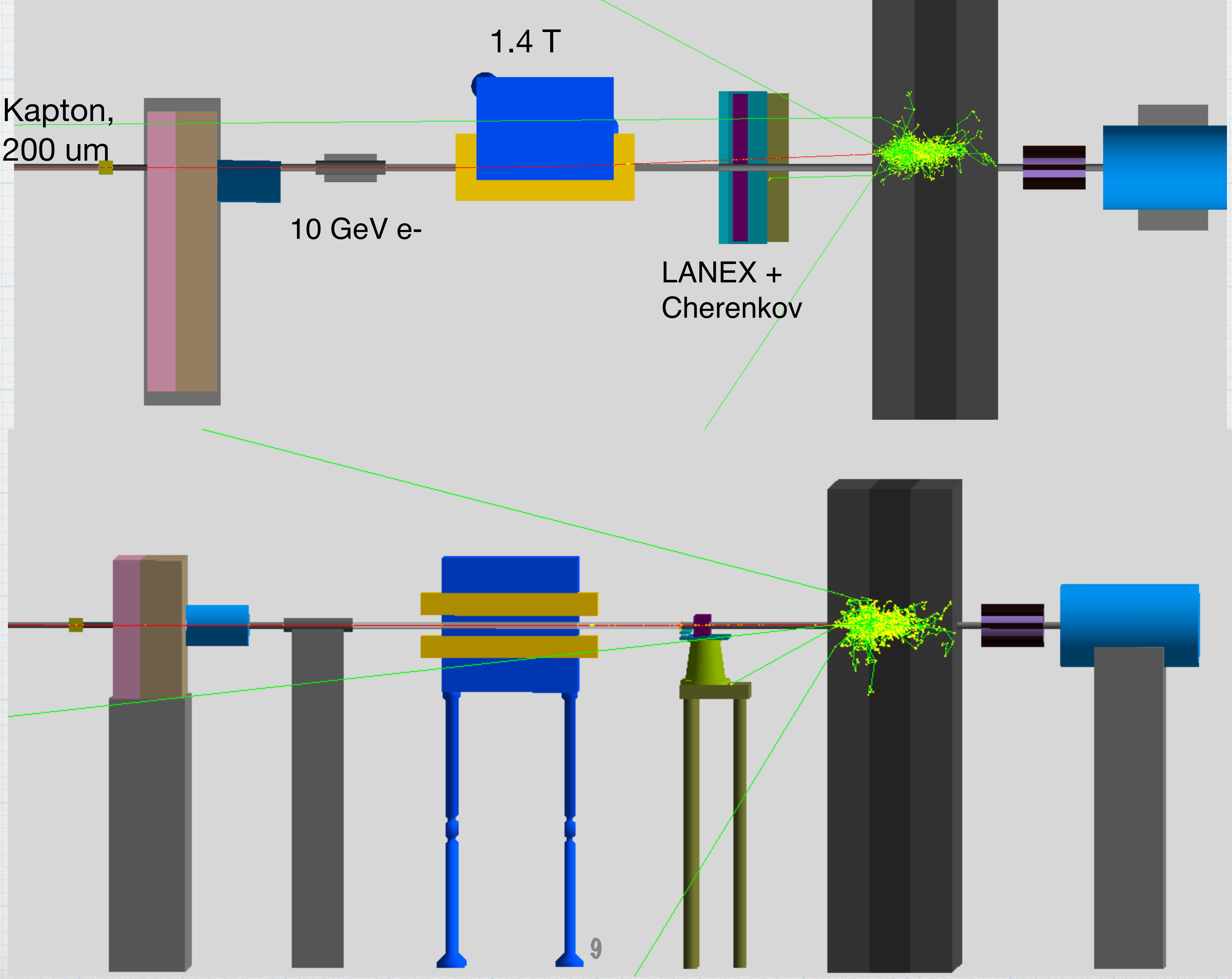
Kinematic edges reconstruction

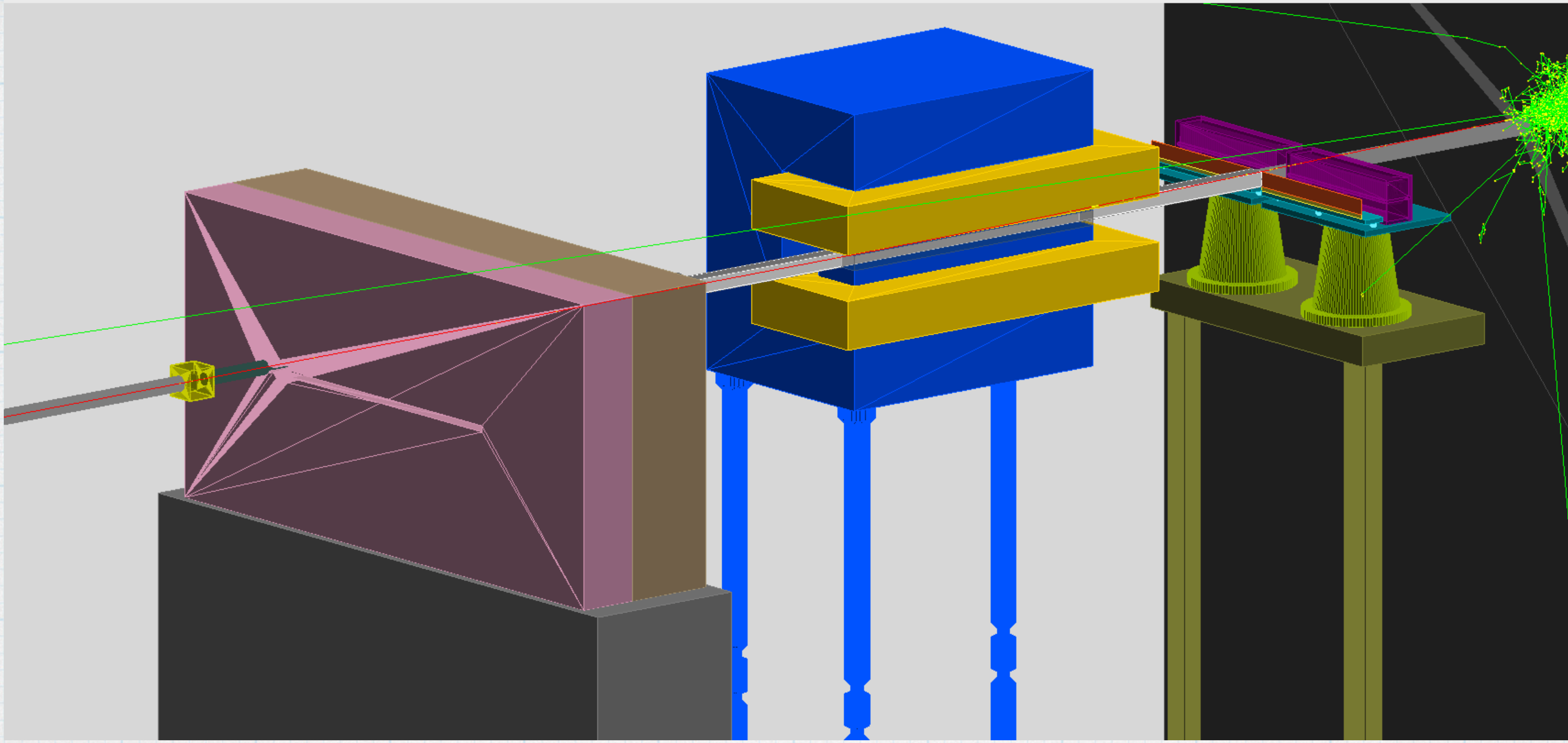


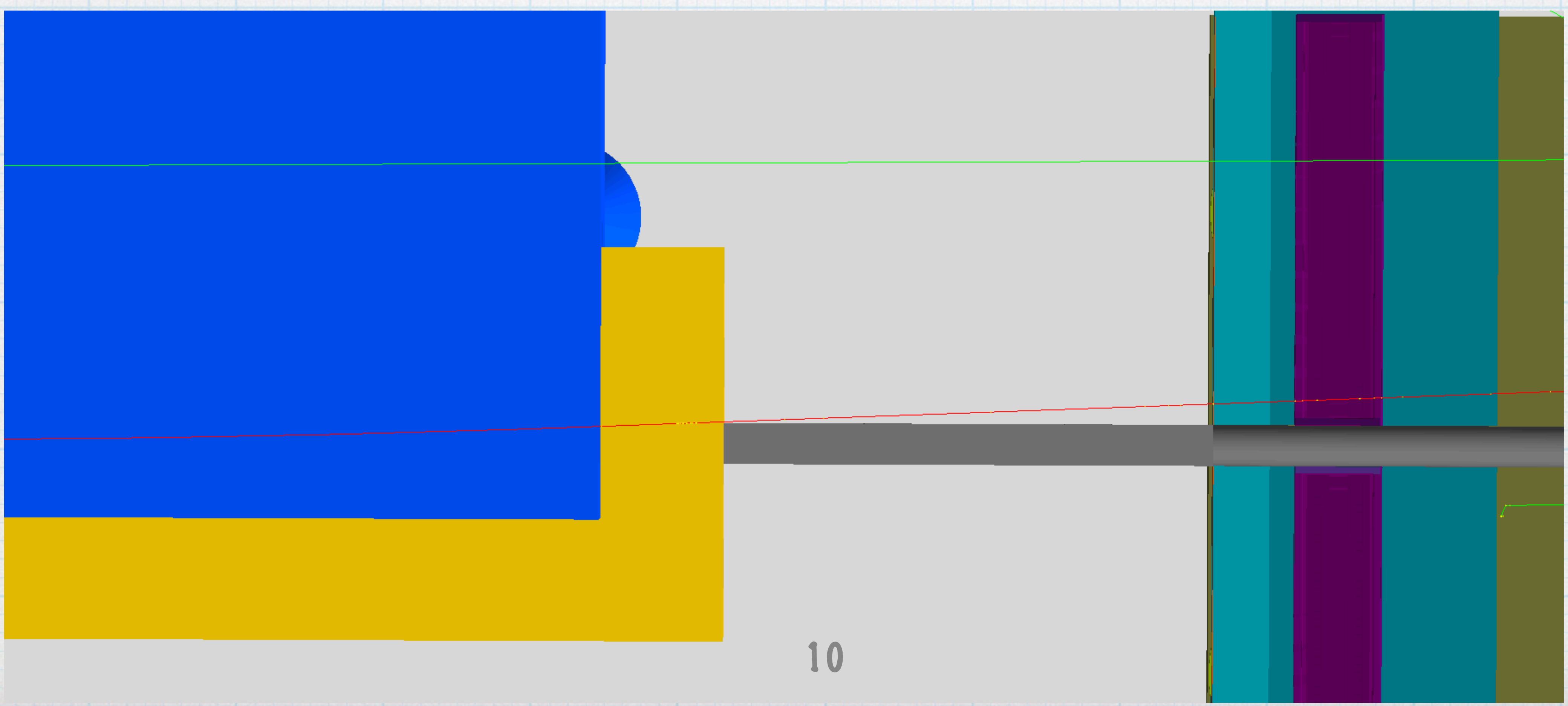

×10^6
E = 16.5 GeV
MC gamma
16
14
12
10
8
6
4
2
0
0 2 4 6 8 10 12 14 16 18 20
E_γ,e, GeV


E = 16.5 GeV
MC gamma
10^7
10^6
10^5
10^4
10^3
0 2 4 6 8 10 12 14 16 18 20
E_γ,e, GeV

Updated FDS setup with pipe







Summary

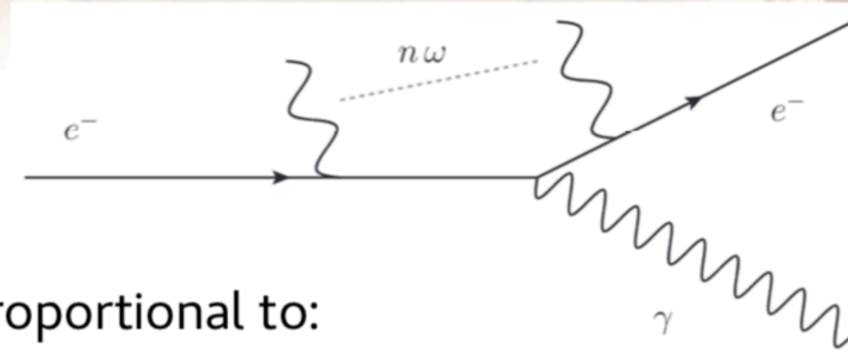
* The performance of FDS setup with beam pipe from the target to Compton detectors was studied

* **First glimpse at the reconstruction in LYSO**

Back up

High Intensity Compton Scattering

$$e^- + n\omega \rightarrow e^- + \gamma$$



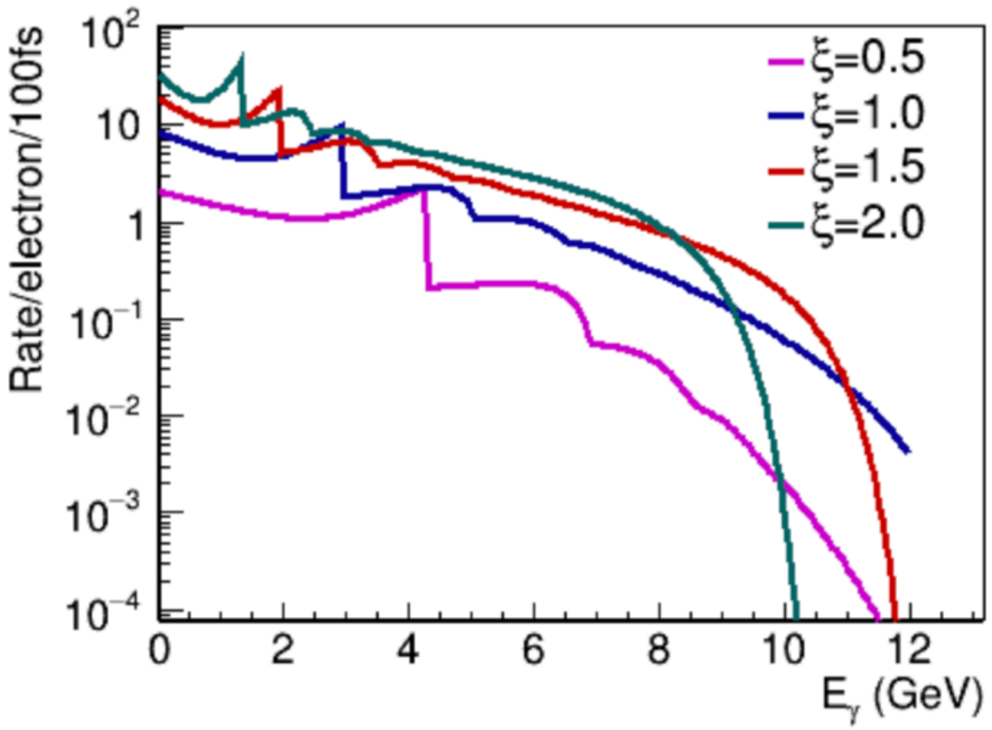
The rate of High Intensity Compton Scattering (HICS) is proportional to:

$$\sum_{\mathrm{n}} \delta^{(4)}\left[p_{\mathrm{i}} + k\frac{\xi^3}{2\chi_{\mathrm{i}}} + nk - p_{\mathrm{f}} - k\frac{\xi^3}{2\chi_{\mathrm{f}}} - k_{\mathrm{f}}\right]$$

Momentum conservation is a sum over external field photon contributions, *nk*

Even for *n=0* there is an irreducible contribution:

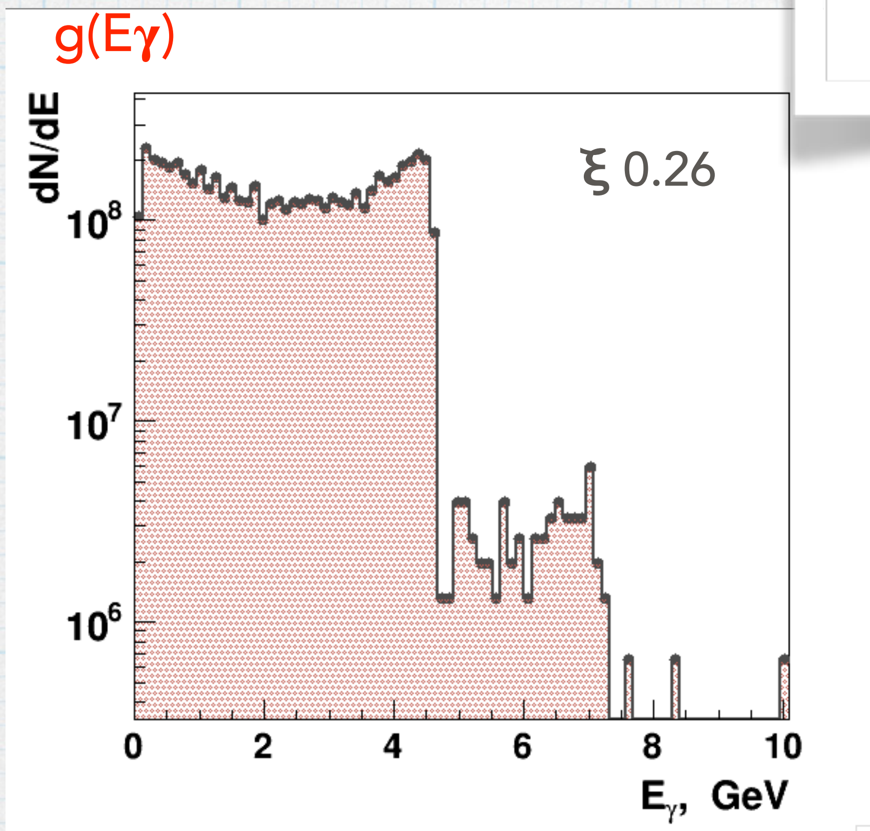
$$p_{\mathrm{i}} + k\frac{\xi^3}{2\chi_{\mathrm{i}}} \rightarrow p_{\mathrm{i}}^2 = m^2(1+\xi^2)$$

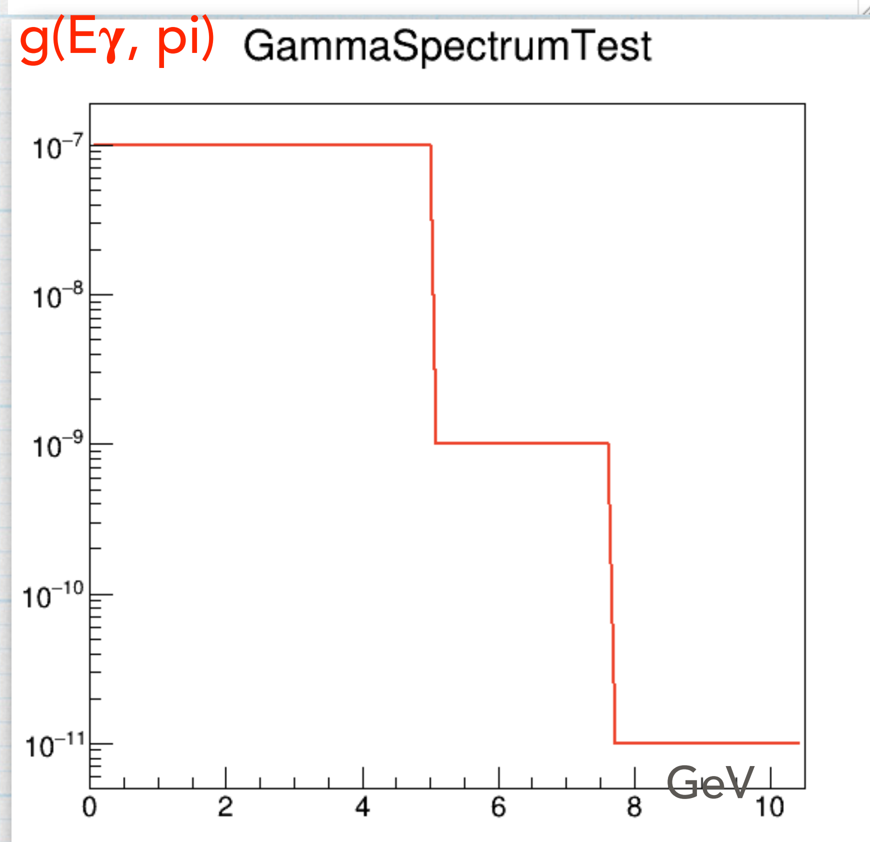


- Strong field leads to increase in electron rest mass.
- Observation of Compton edge shift.

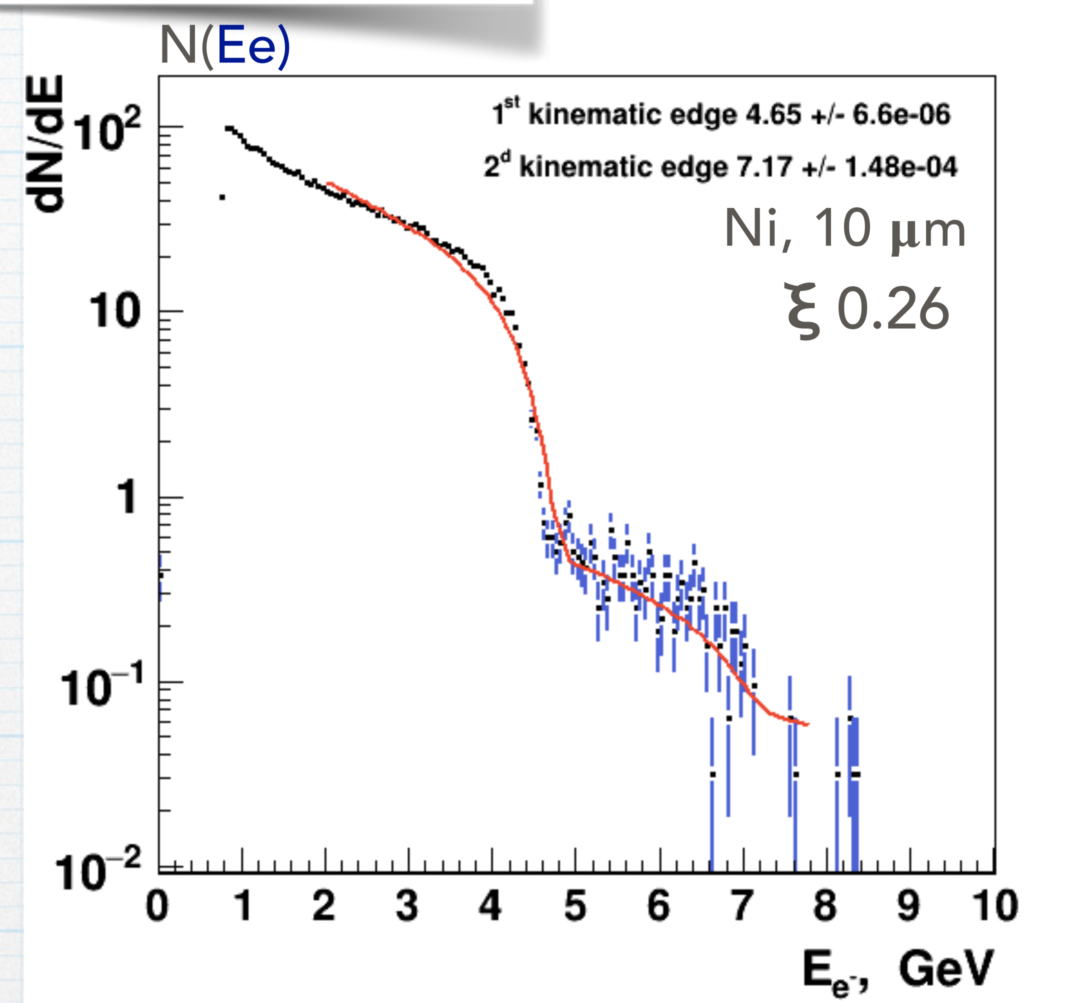
Kinematic edges with accurate pair spectrum

$$f(E_e)=\int \sigma(E_\gamma, E_e)\,g(E_\gamma)\,dE_\gamma$$





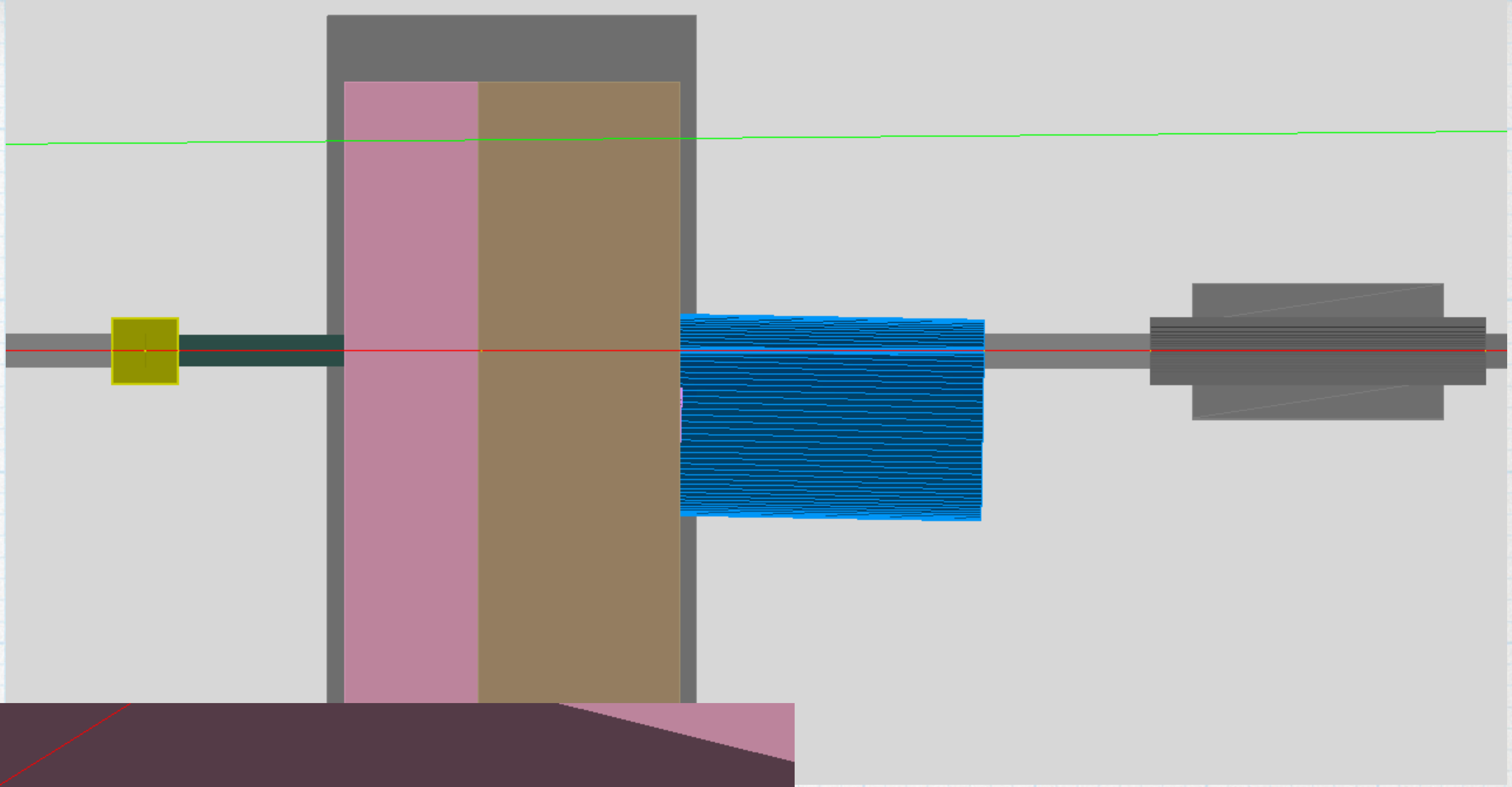
The single-particle spectrum obtained in GEANT4 is compared to a **model spectrum** calculated by convolving the trial **photon spectrum** with the **Bethe-Heitler cross section**

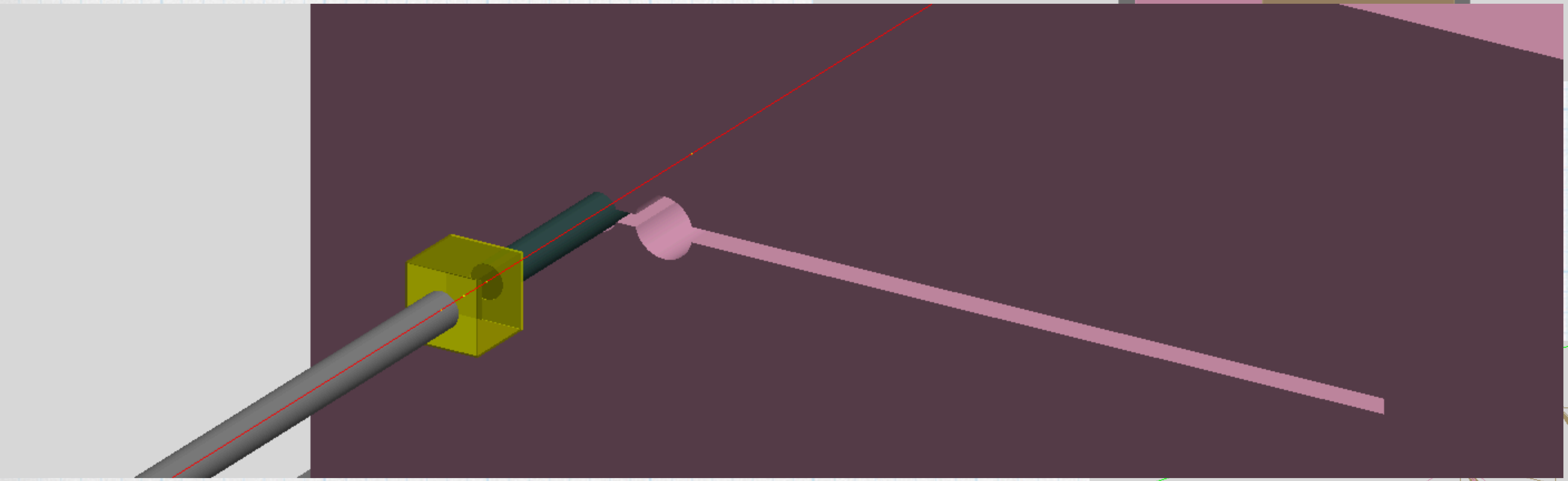


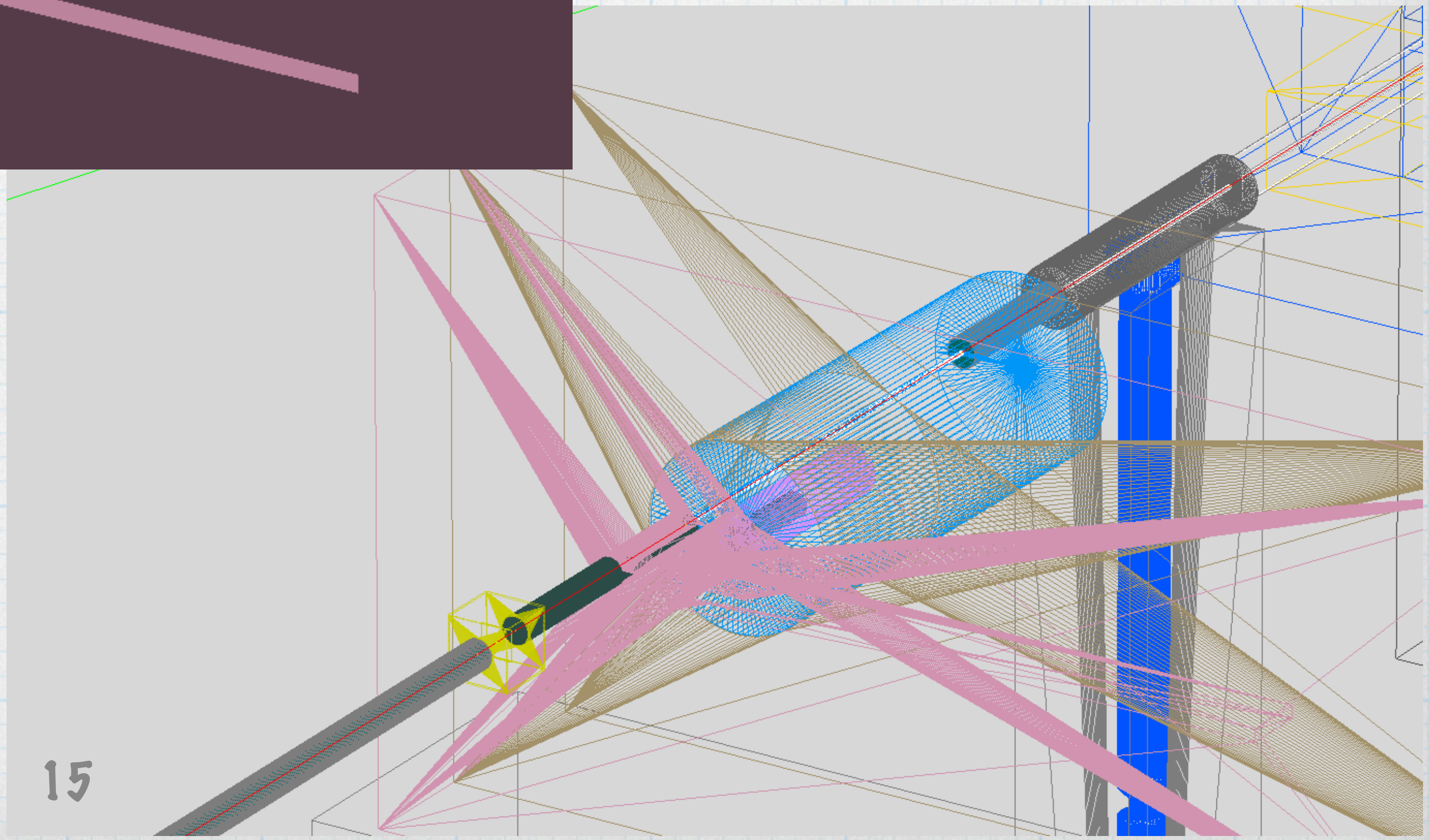
$$\int \sigma(E_\gamma, E_e)\,g(E_\gamma,p1,p2)\,dE_\gamma$$

fitting allows finding **the kinematic edges** quite well

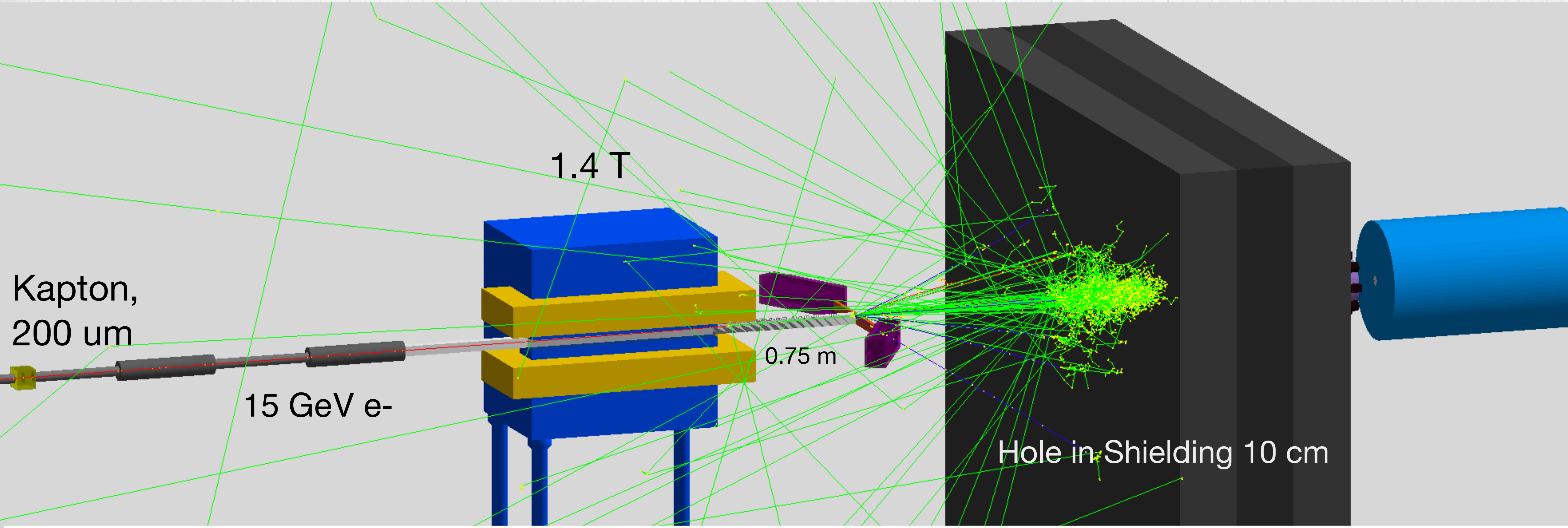
Beam pipe through the electron shielding







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	$w_0 = 8.0\mu$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	1.94	0.78	0.31	0.15
peak SQED χ (16.5 GeV)	0.9	0.79	0.69	0.61	0.55	0.34	0.138	0.055	0.028
JETI40 e-laser 16.5 GeV	10000	1000	1000	1000	1000	1000	500	5000	500

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

All studies were performed with 5000 BX at the laser intensity xi = 0.3 for 16.5 GeV electron beam

Spectra MC vs G4

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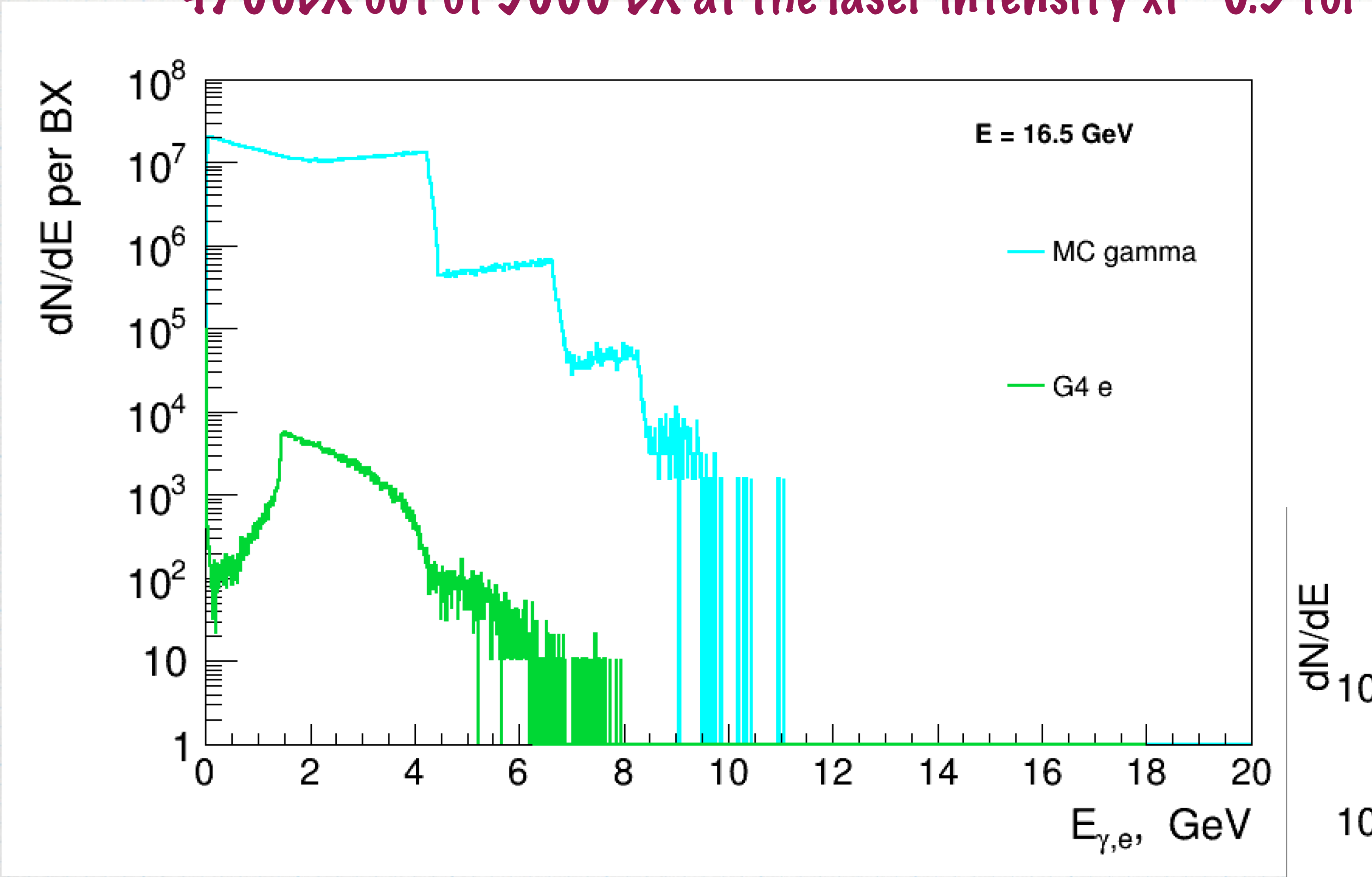
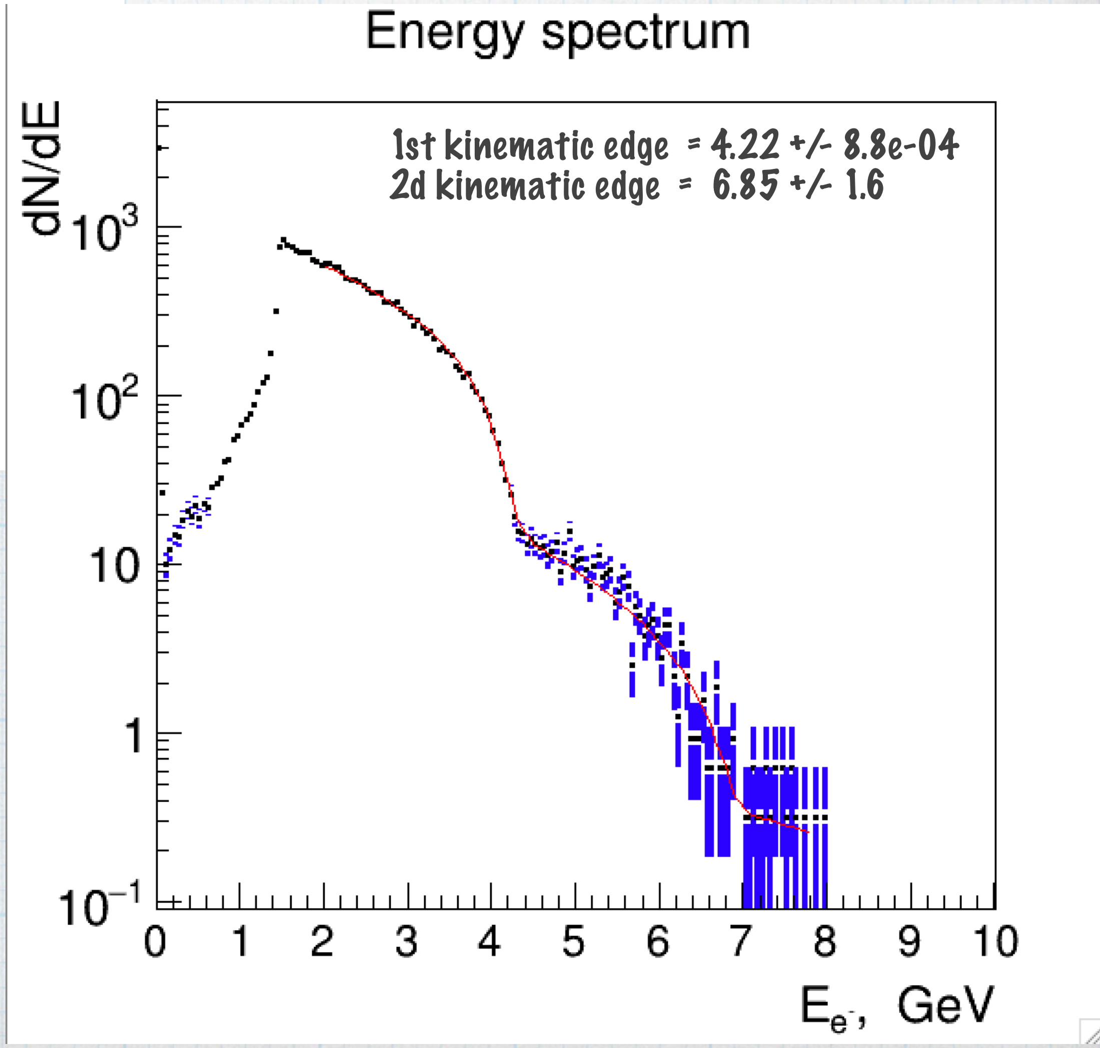
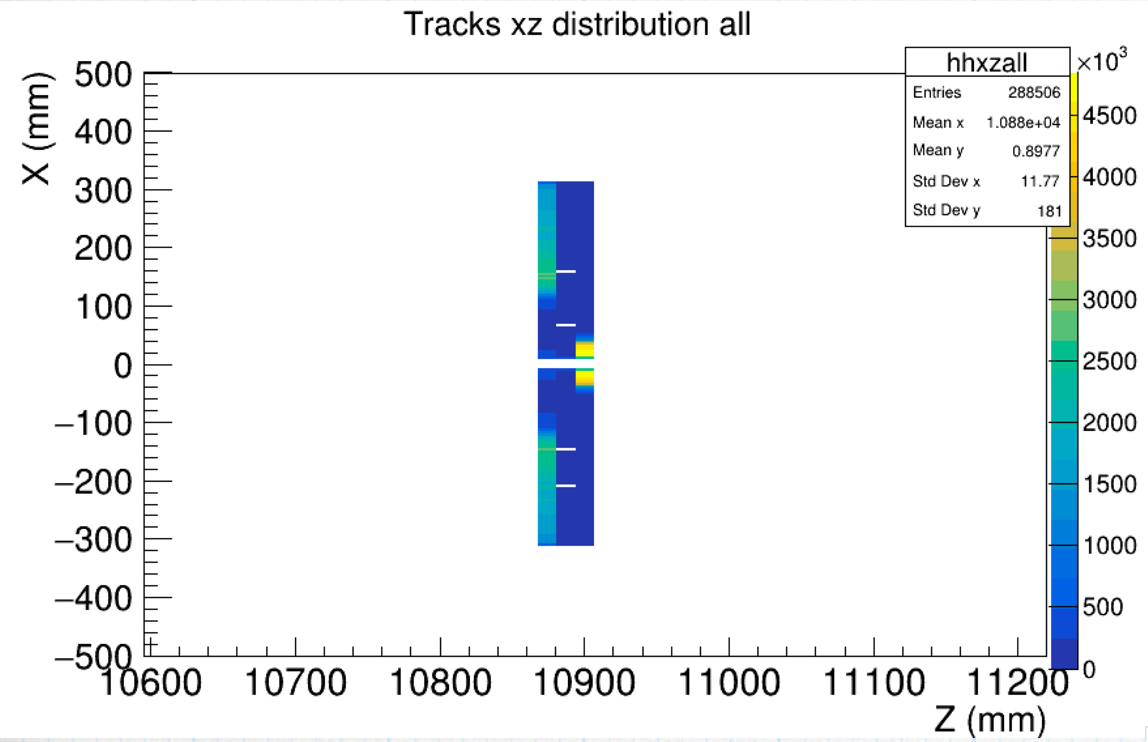
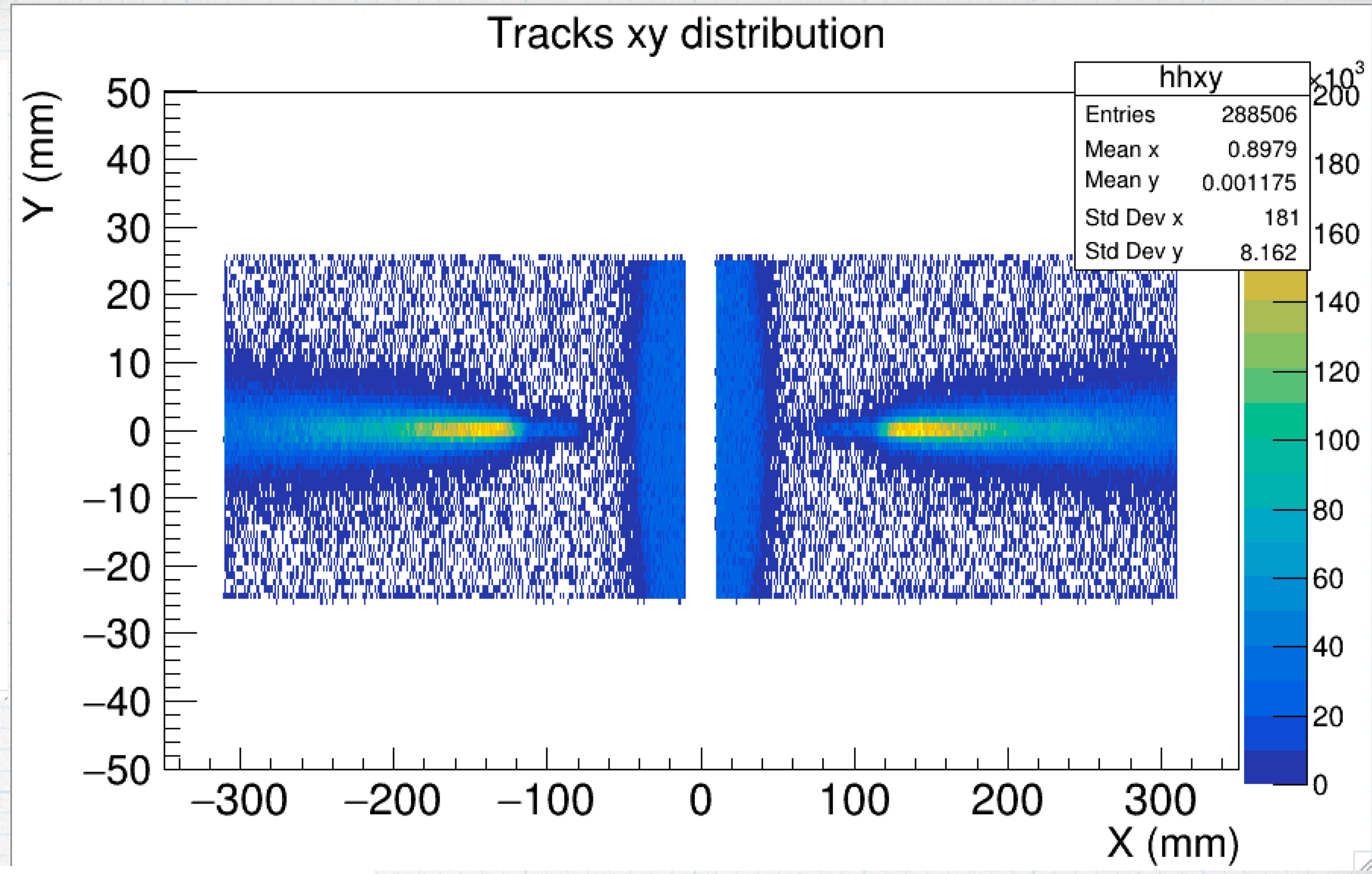
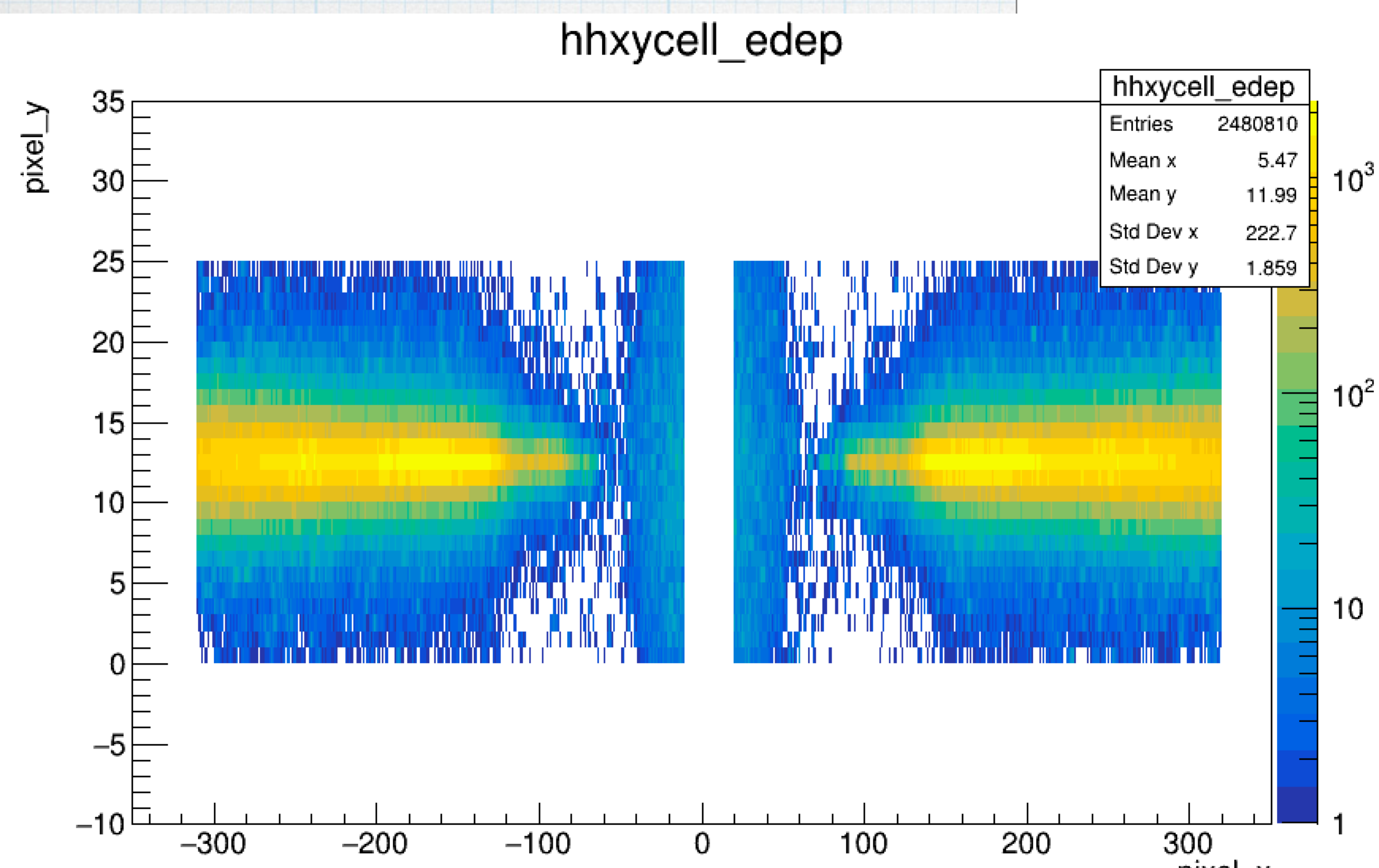
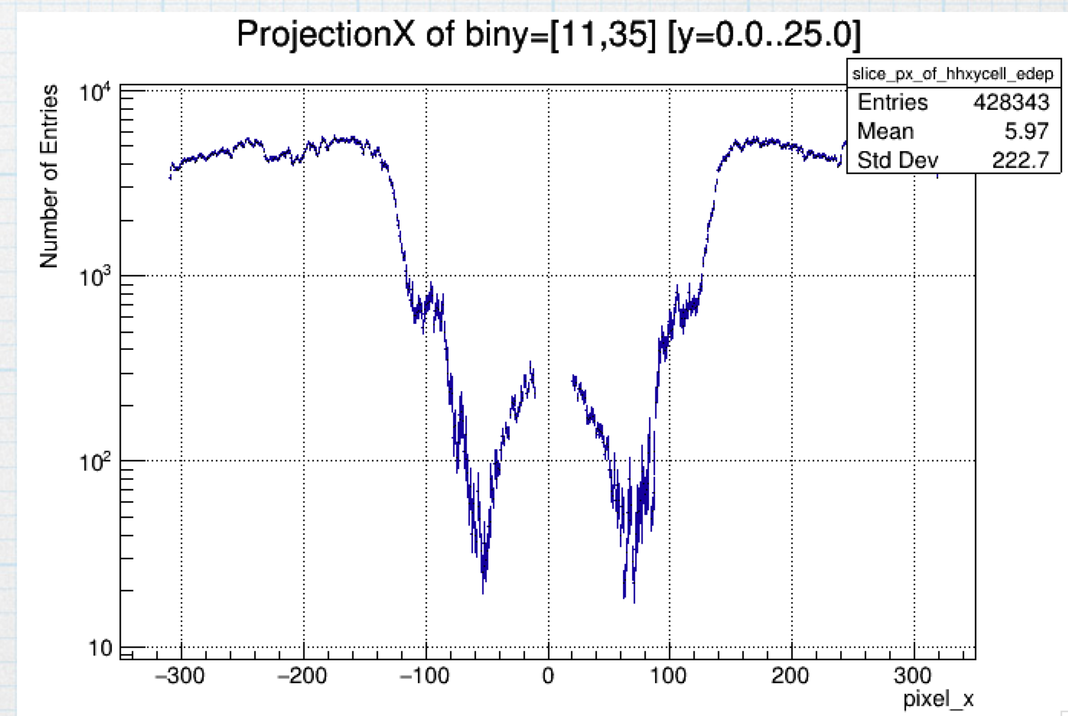





Tracks xz distribution all
hhxzall
Entries 288506
Mean x 1.088e+04
Mean y 0.8977
Std Dev x 11.77
Std Dev y 181
X (mm)
Z (mm)
×10^3


Tracks xy distribution
hhxy
Entries 288506
Mean x 0.8979
Mean y 0.001175
Std Dev x 181
Std Dev y 8.162
Y (mm)
X (mm)
×10^3

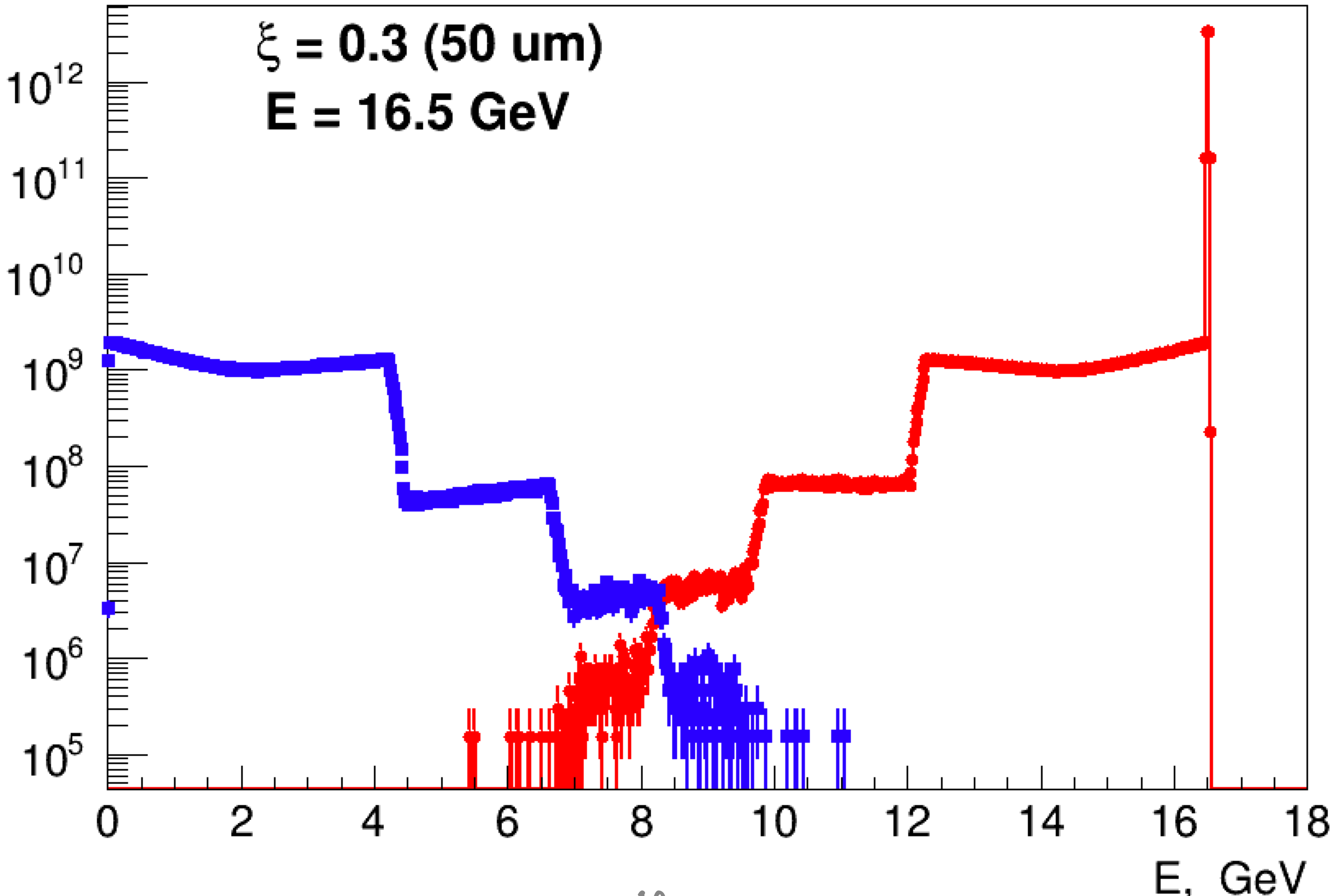

hhxycell_edep
hhxycell_edep
Entries 2480810
Mean x 5.47
Mean y 11.99
Std Dev x 222.7
Std Dev y 1.859
pixel_y
pixel_x


ProjectionX of biny=[11,35] [y=0.0..25.0]
slice_px_of_hhxycell_edep
Entries 428343
Mean 5.97
Std Dev 222.7
Number of Entries
pixel_x

True electron/photon spectra

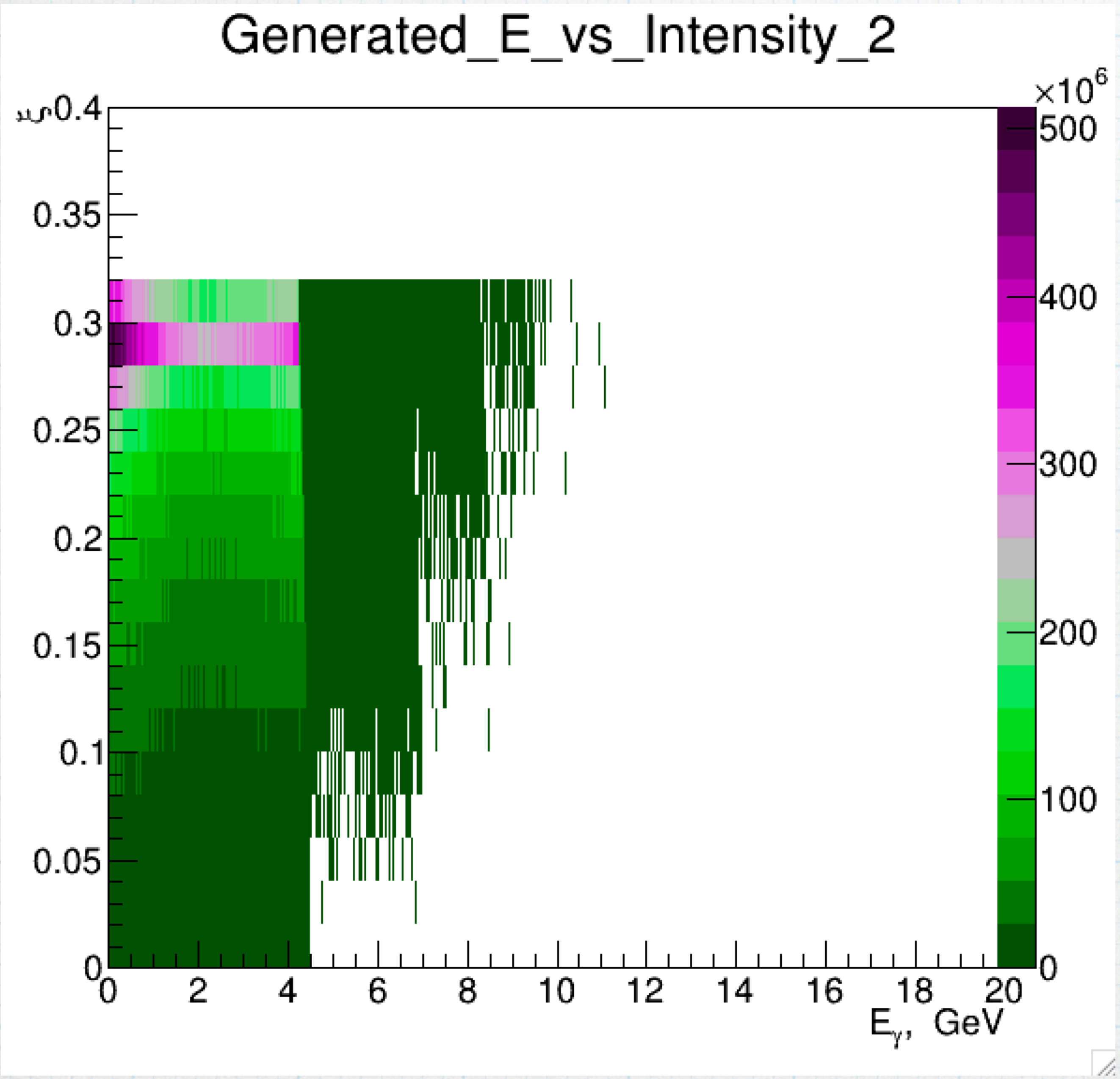
4764BX out of 5000 BX at the laser intensity xi = 0.3 for 16.5 GeV electron beam

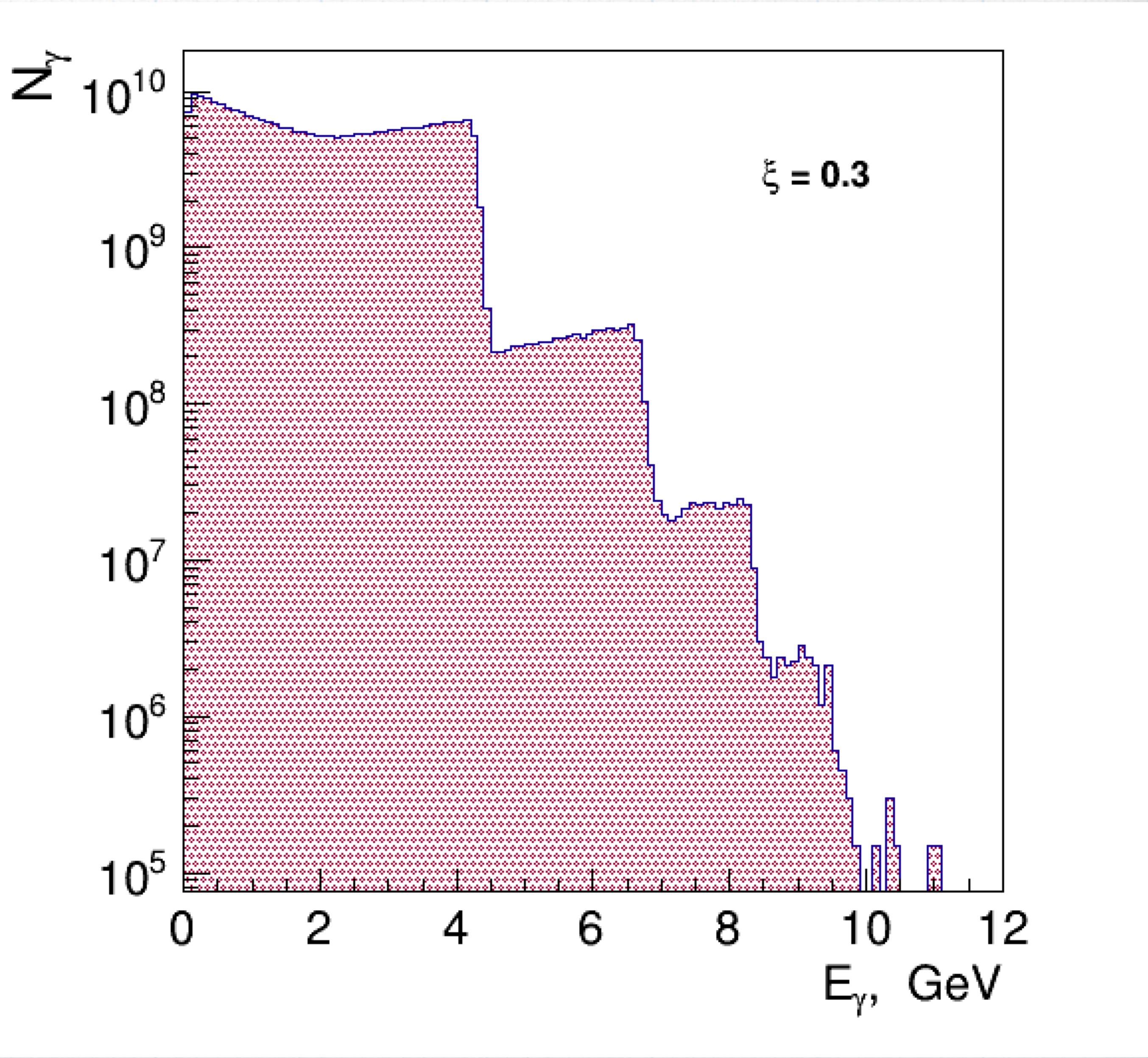
(~5% of files have NaN so they are ignored)



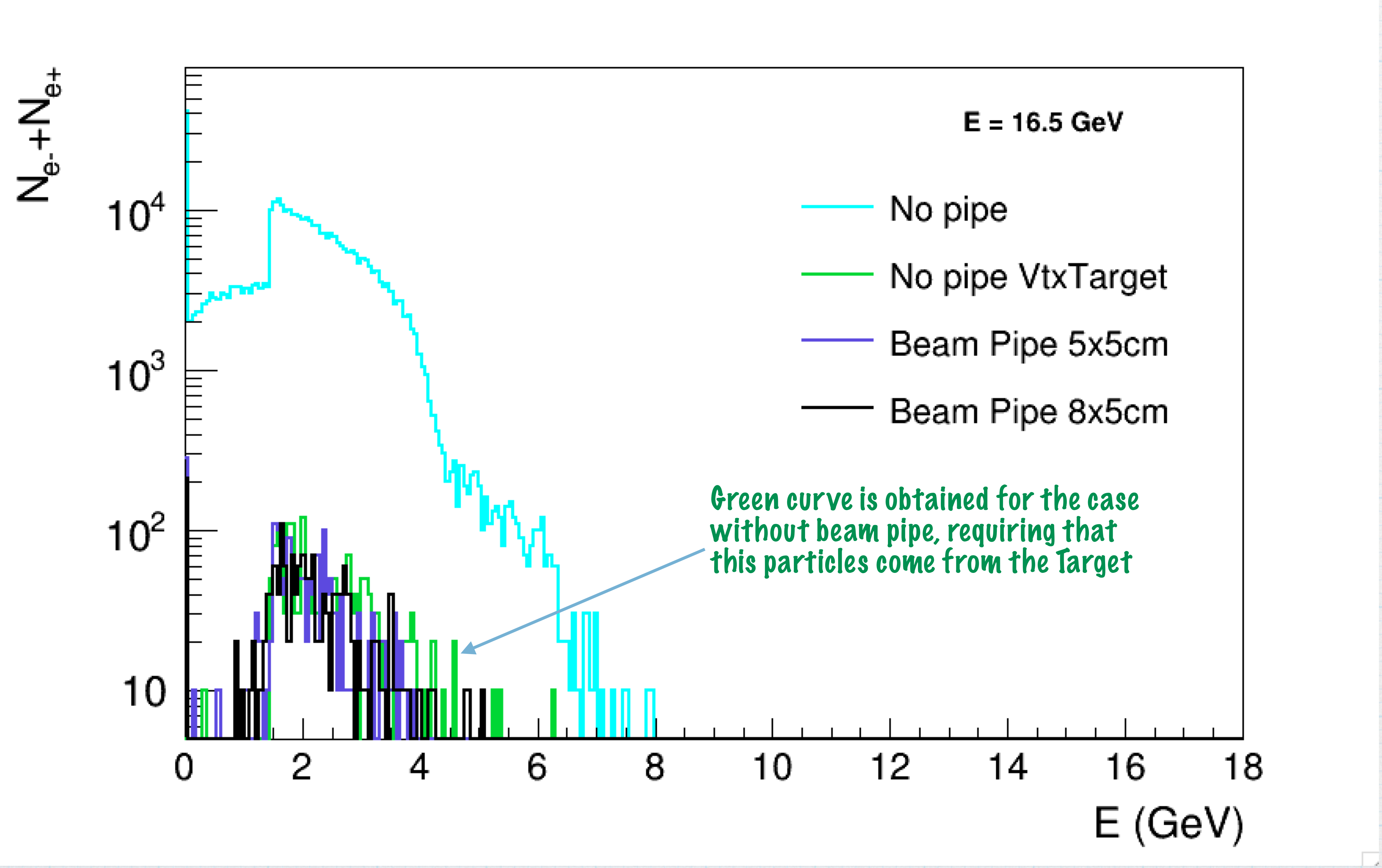
ξ vs photon energy in MC

5000 BX at the laser intensity xi = 0.3 for 16.5 GeV electron beam



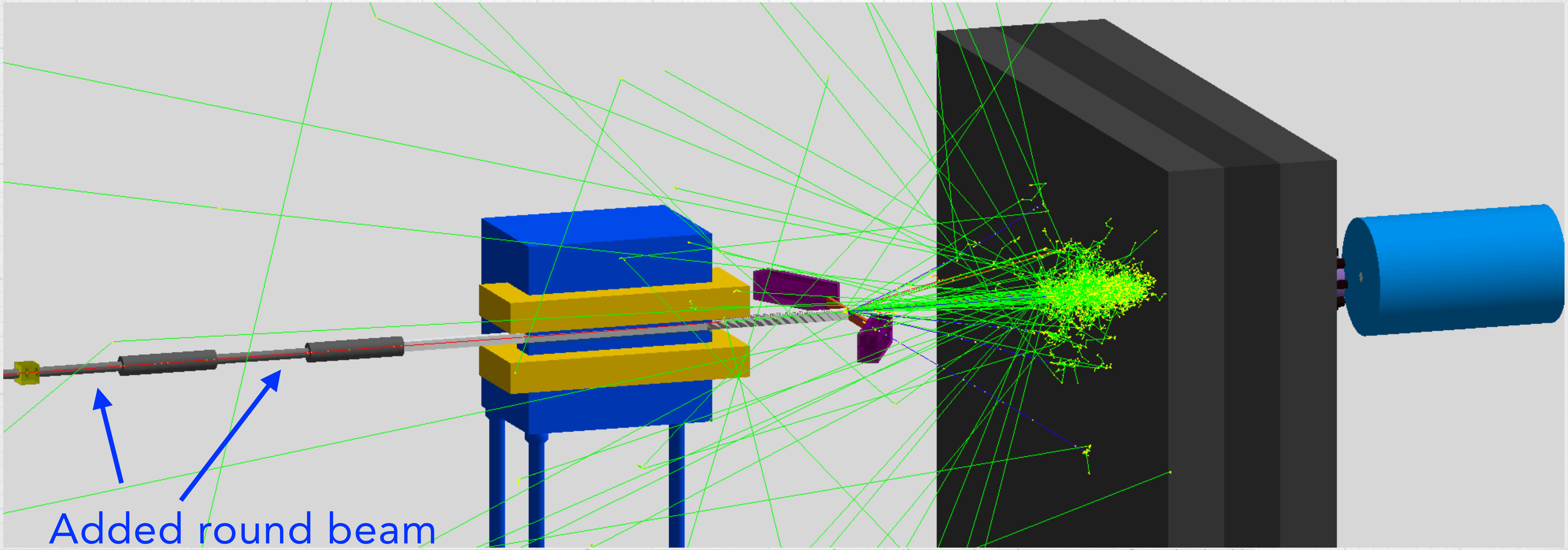


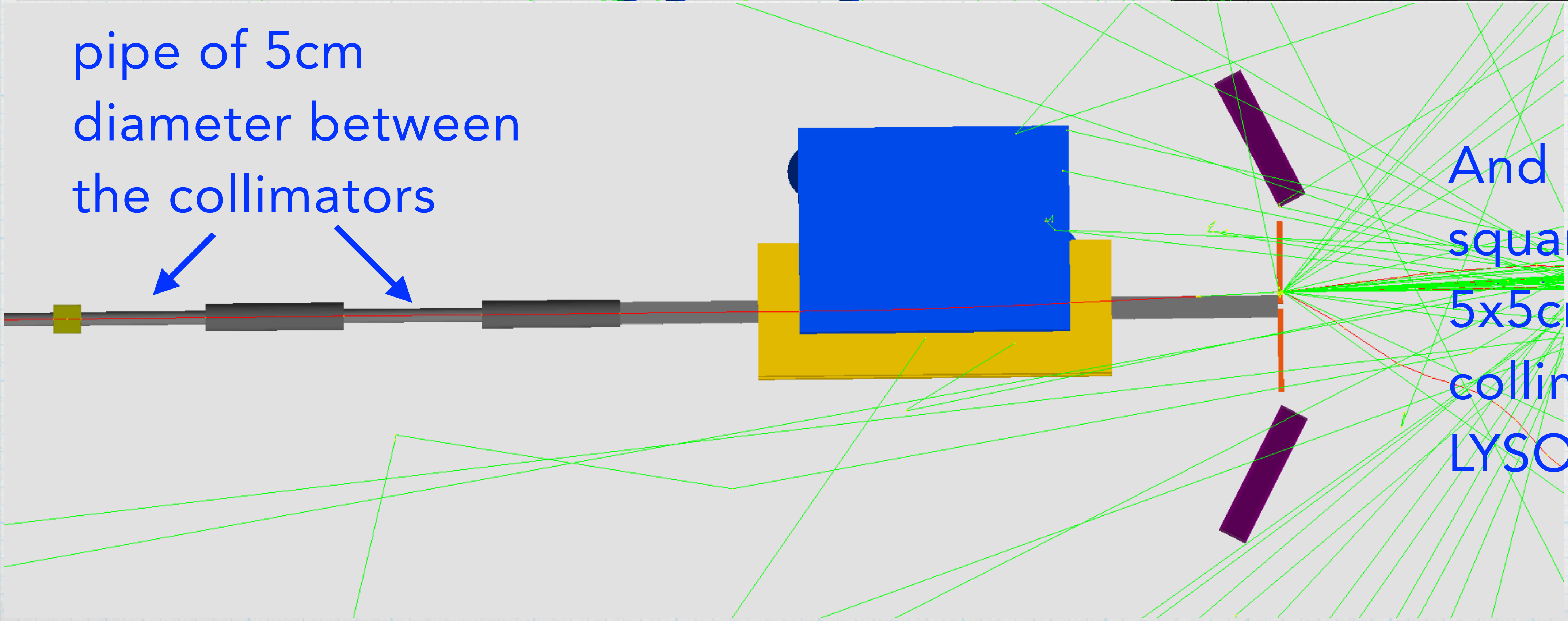
Spectra



Without beam pipe we measure in Compton detectors a lot e-/e+ pairs that were created in the air.
Only 4% e-/e+ are generated in the Target

Setup with the beam pipe

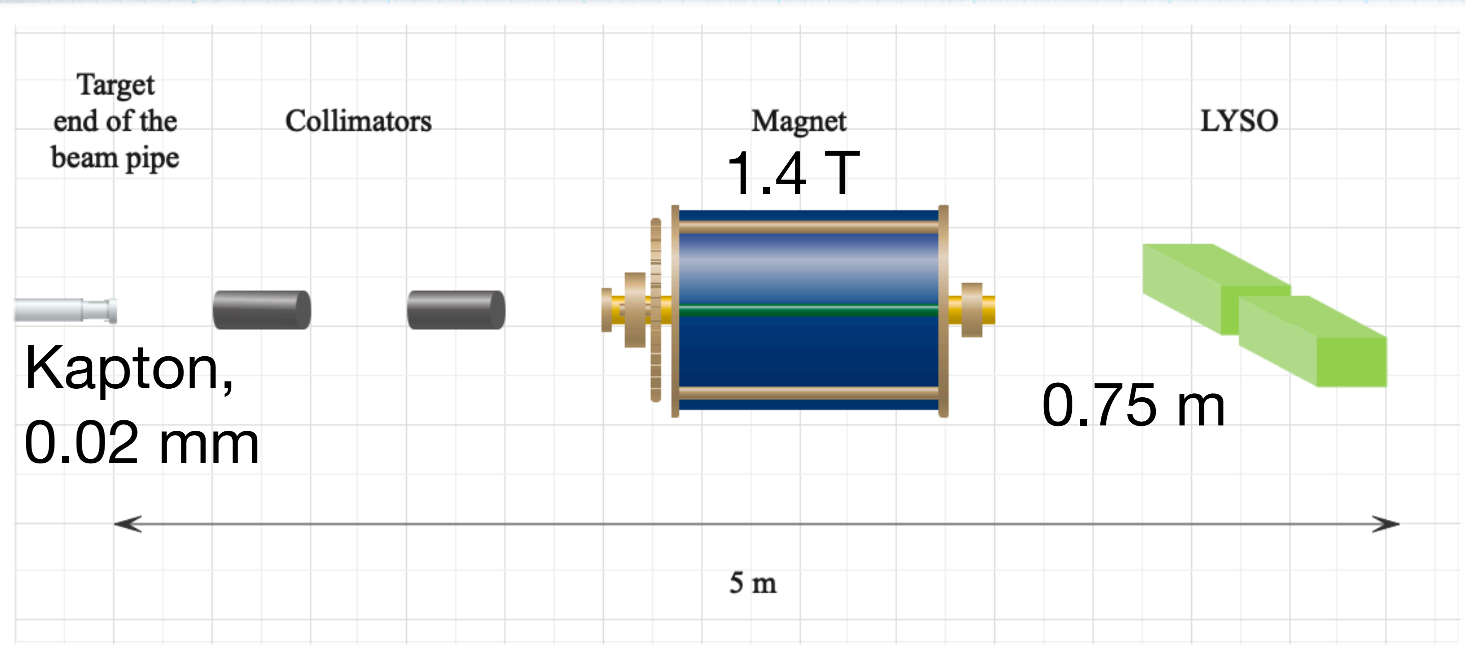


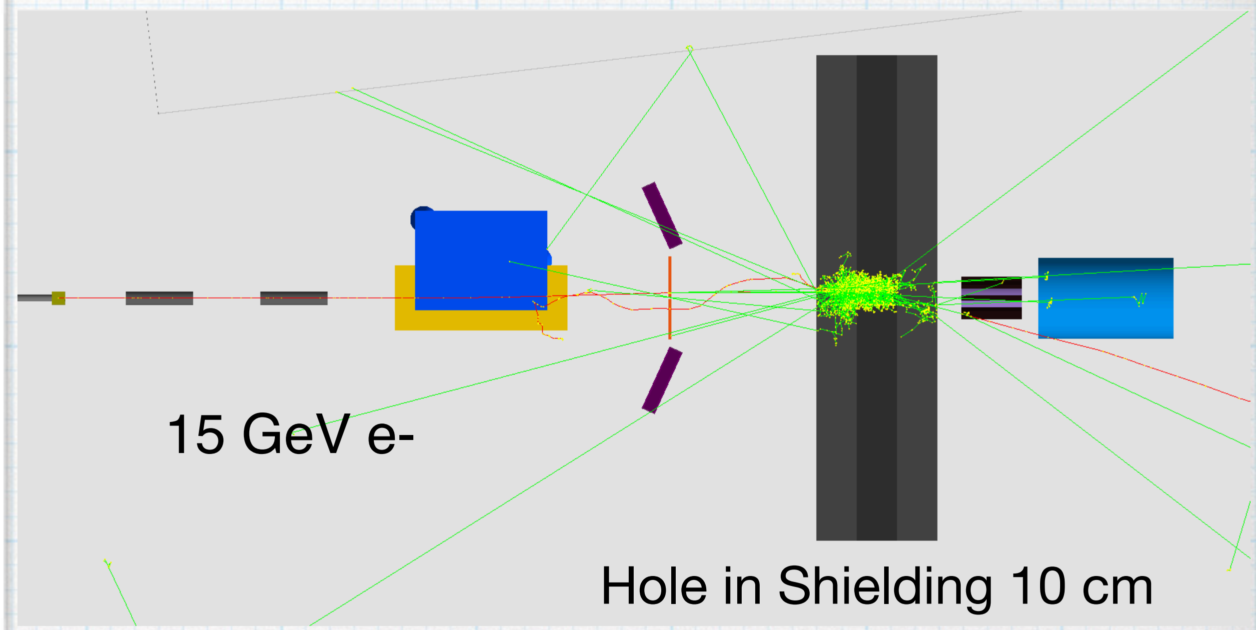


Added round beam pipe of 5cm diameter between the collimators

And beam pipe w/ square Xsection of 5x5cm (8x5cm) from collimators to the LYSO detectors

FDS with LYSO calorimeters





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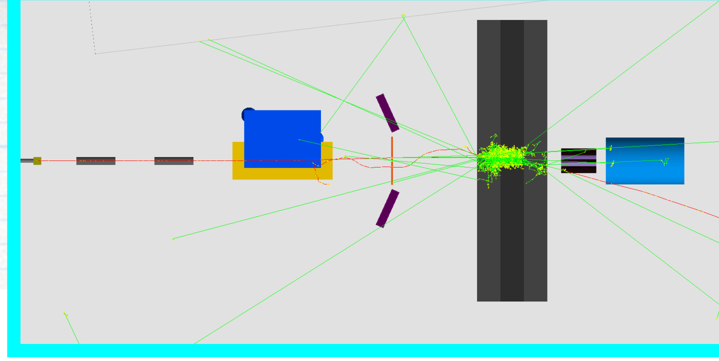
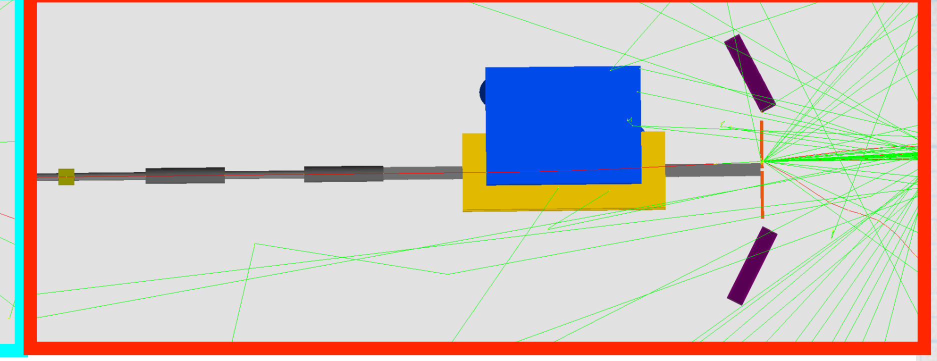
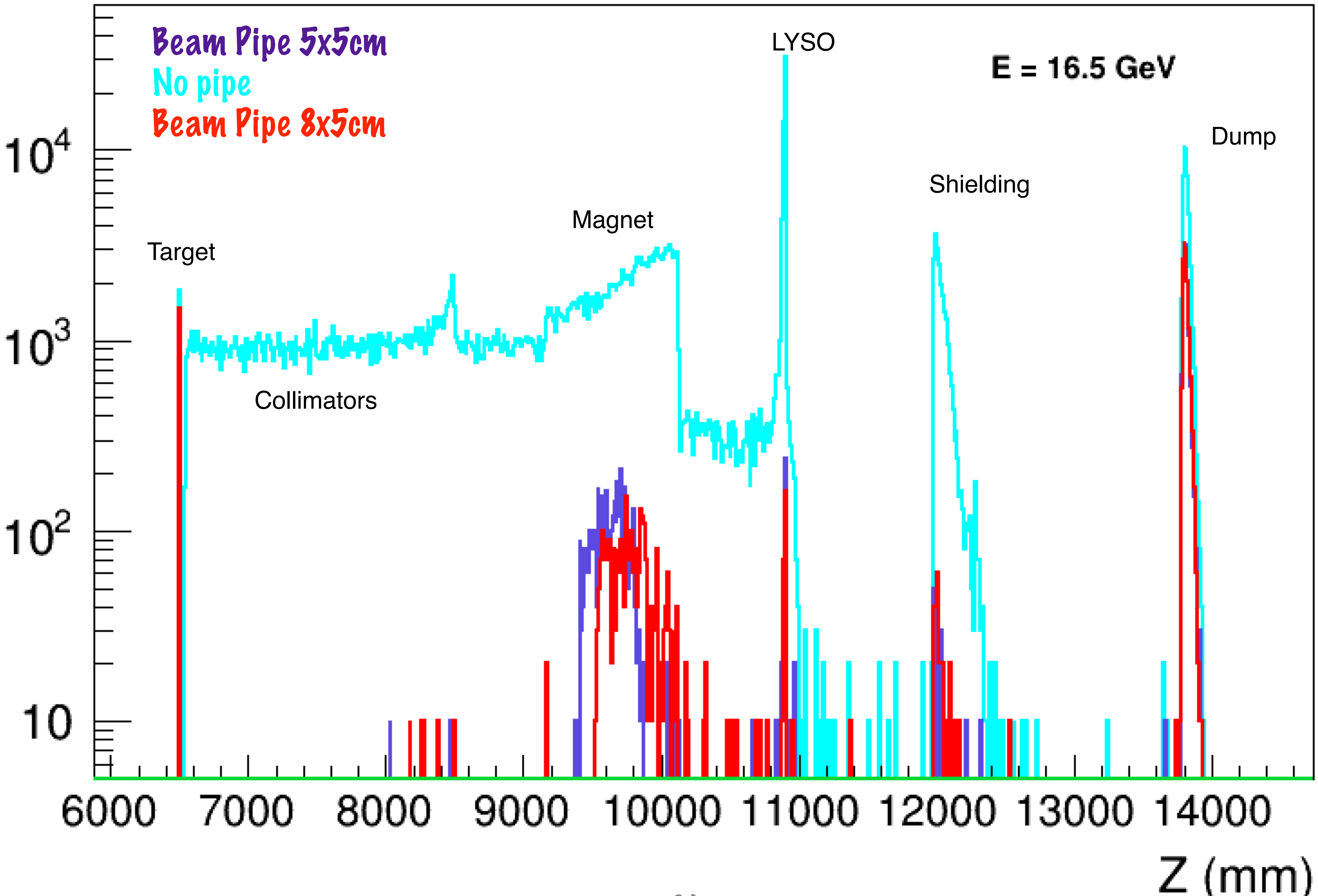
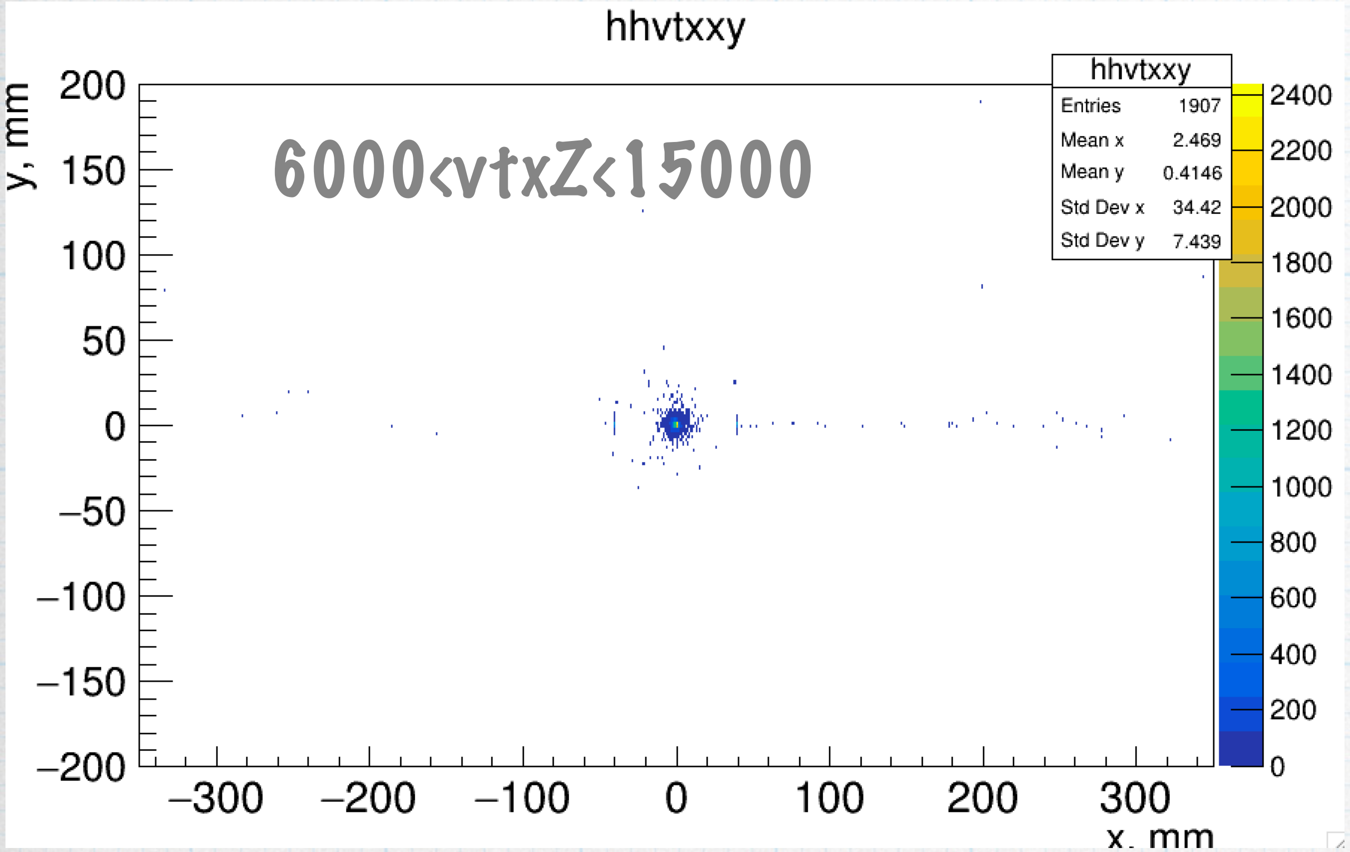
Vertex z



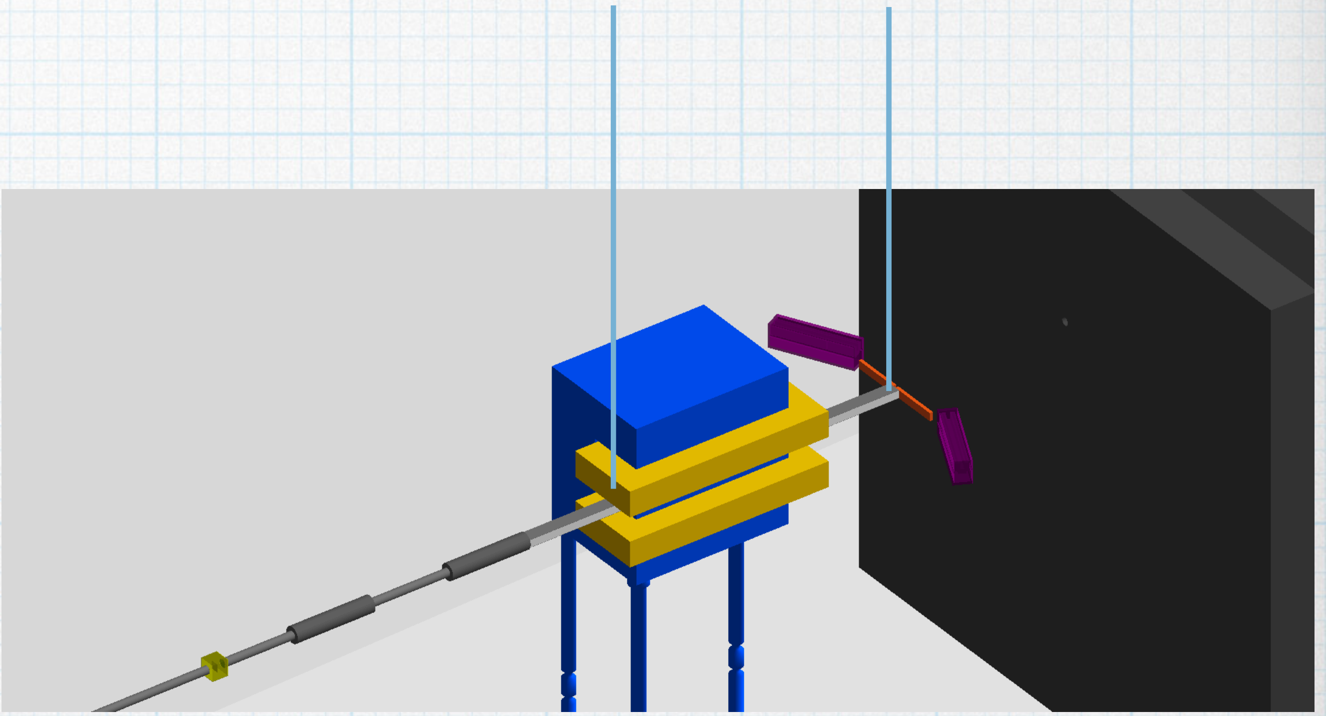


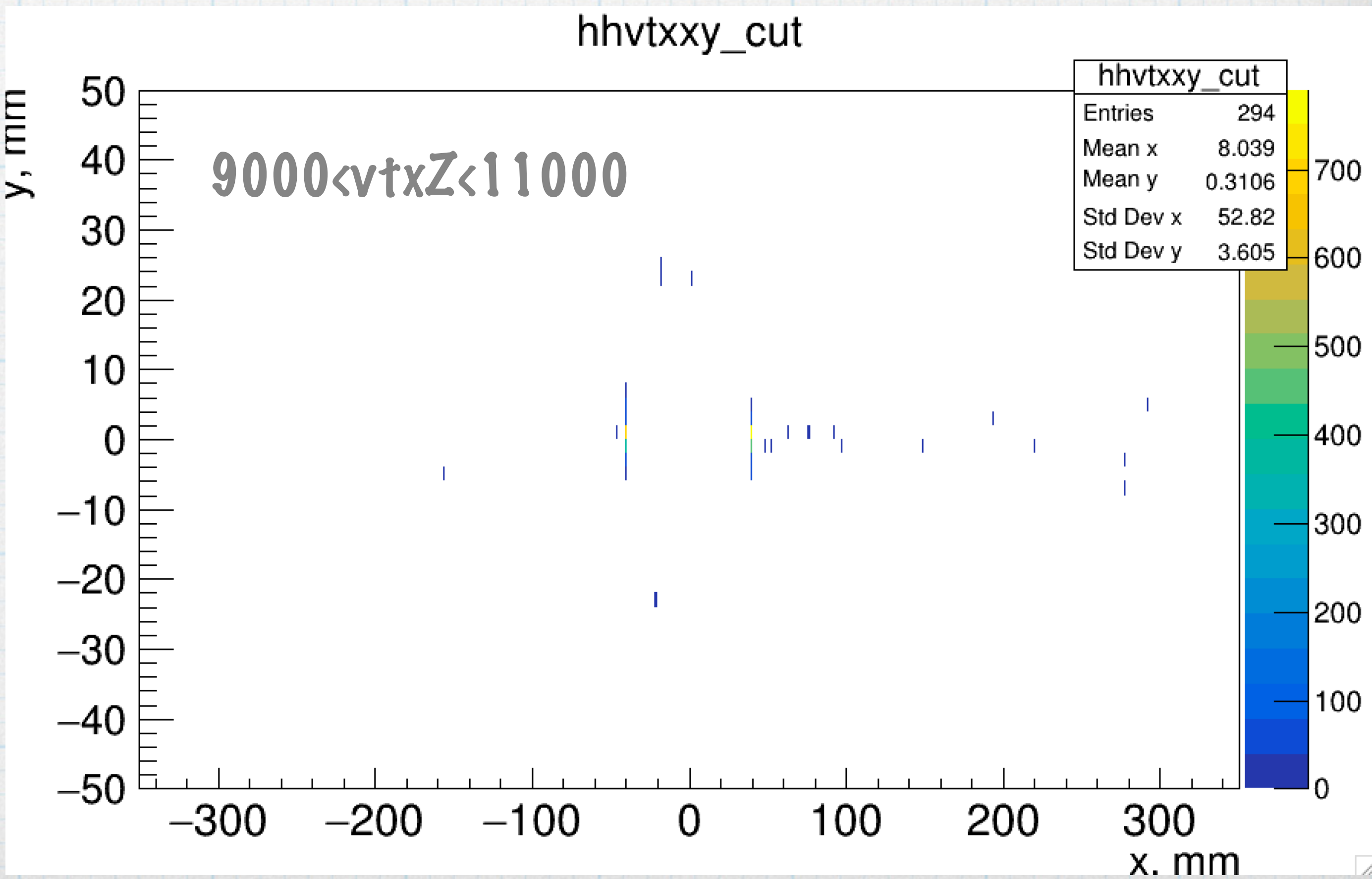

Beam Pipe 5x5cm
No pipe
Beam Pipe 8x5cm
E = 16.5 GeV
Target
Collimators
Magnet
LYSO
Shielding
Dump
10
10^2
10^3
10^4
6000 7000 8000 9000 10000 11000 12000 13000 14000
Z (mm)

Vertex x-y, beam pipe 8x5

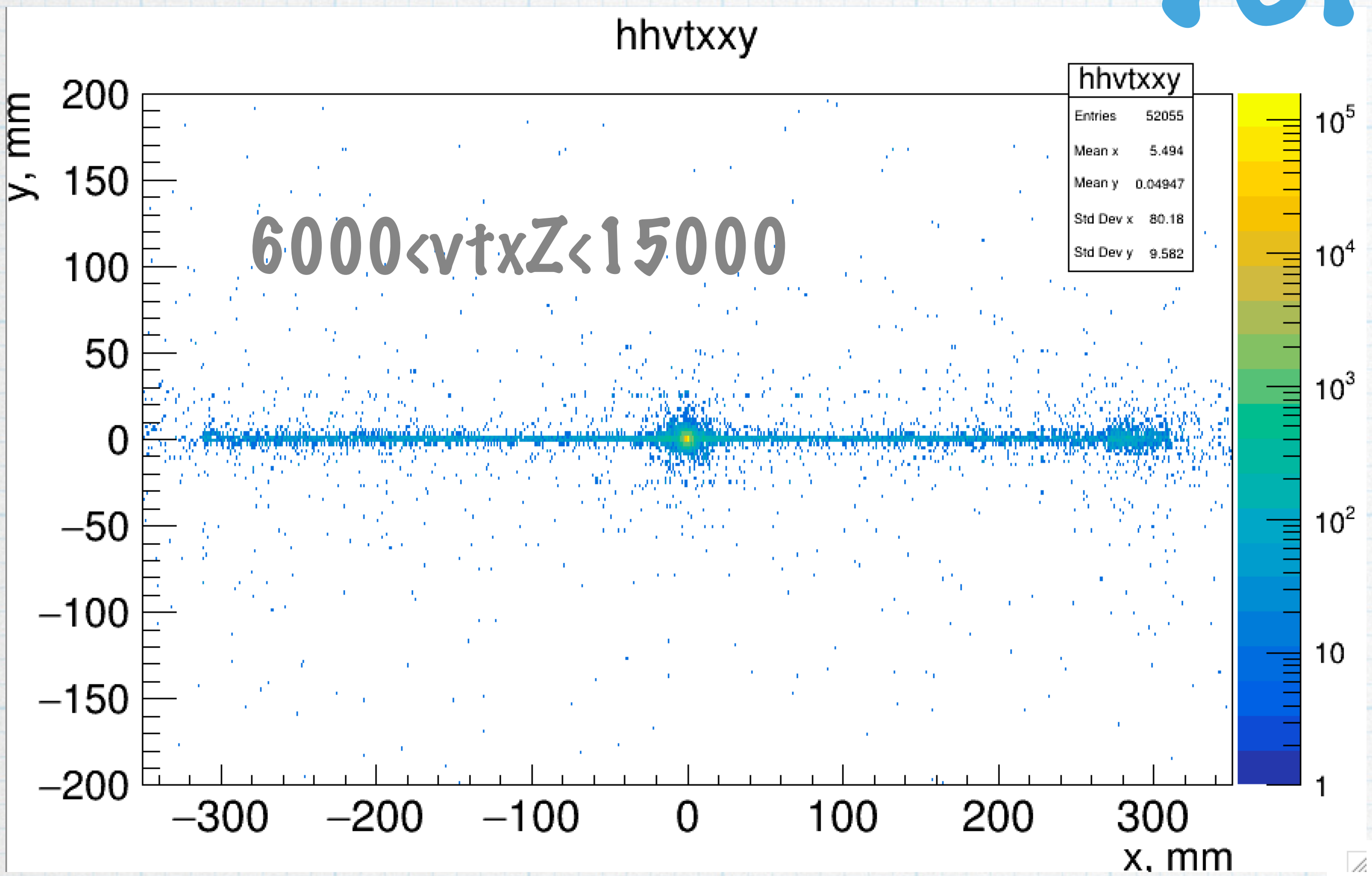


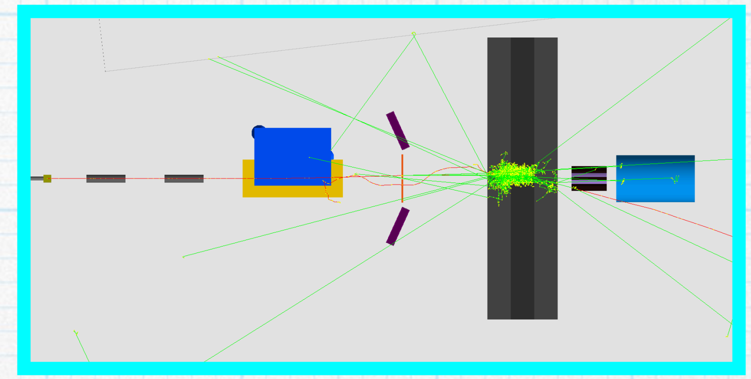
9000 mm - 11000mm

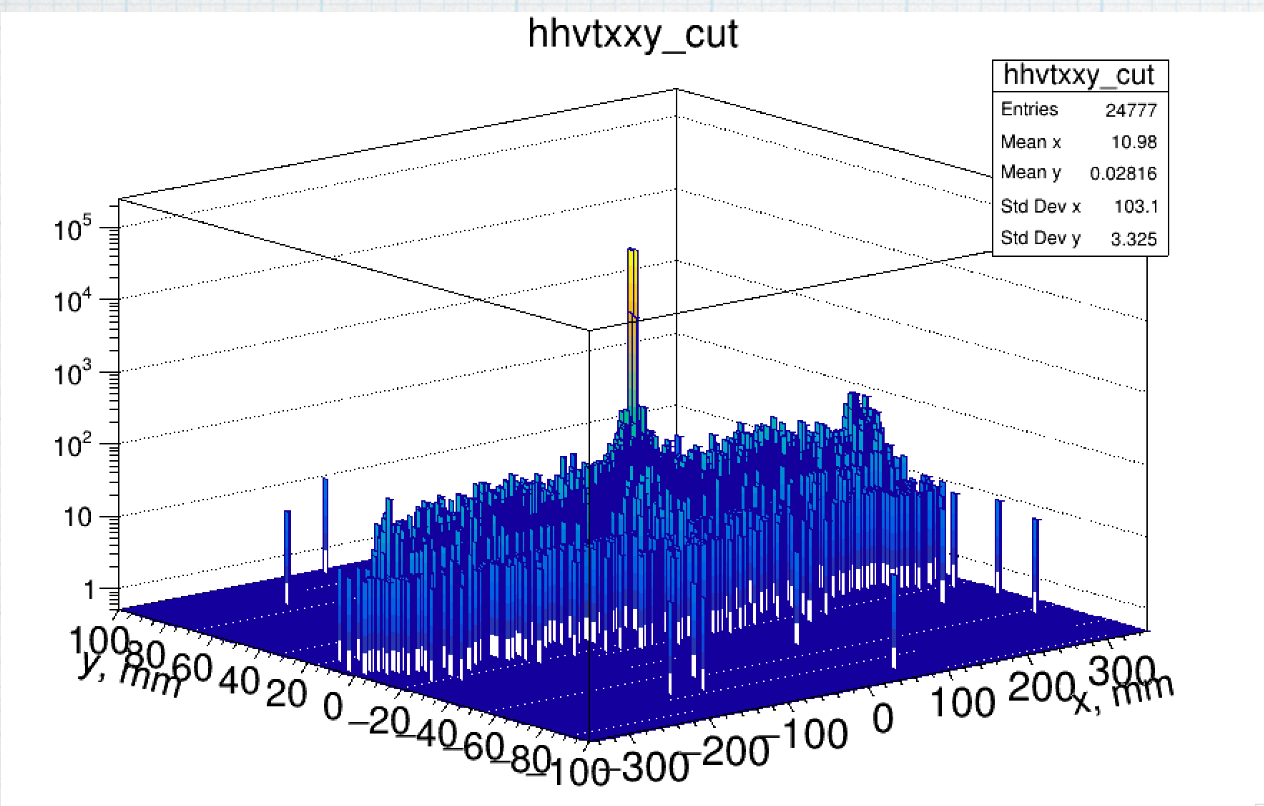


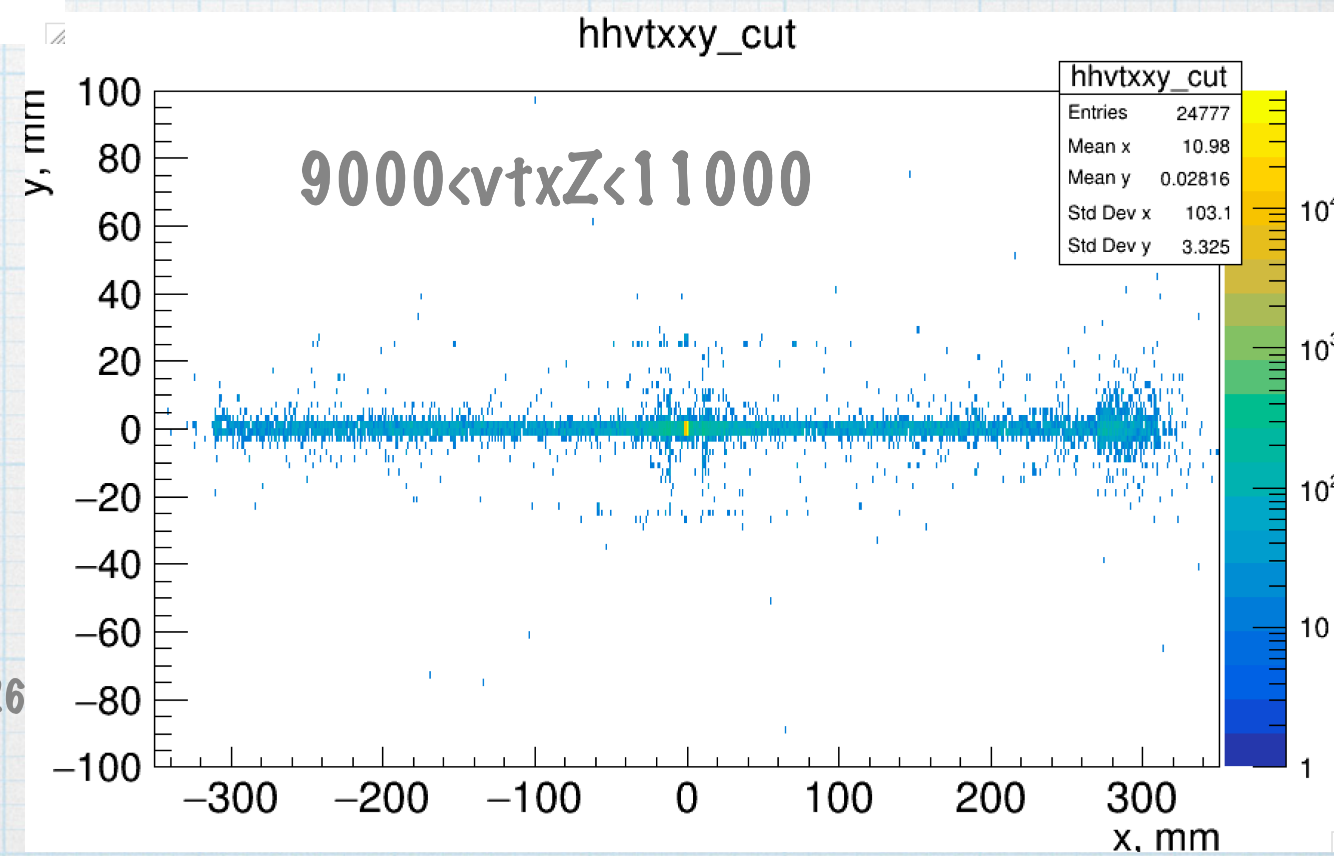


Vertex x-y, no pipe

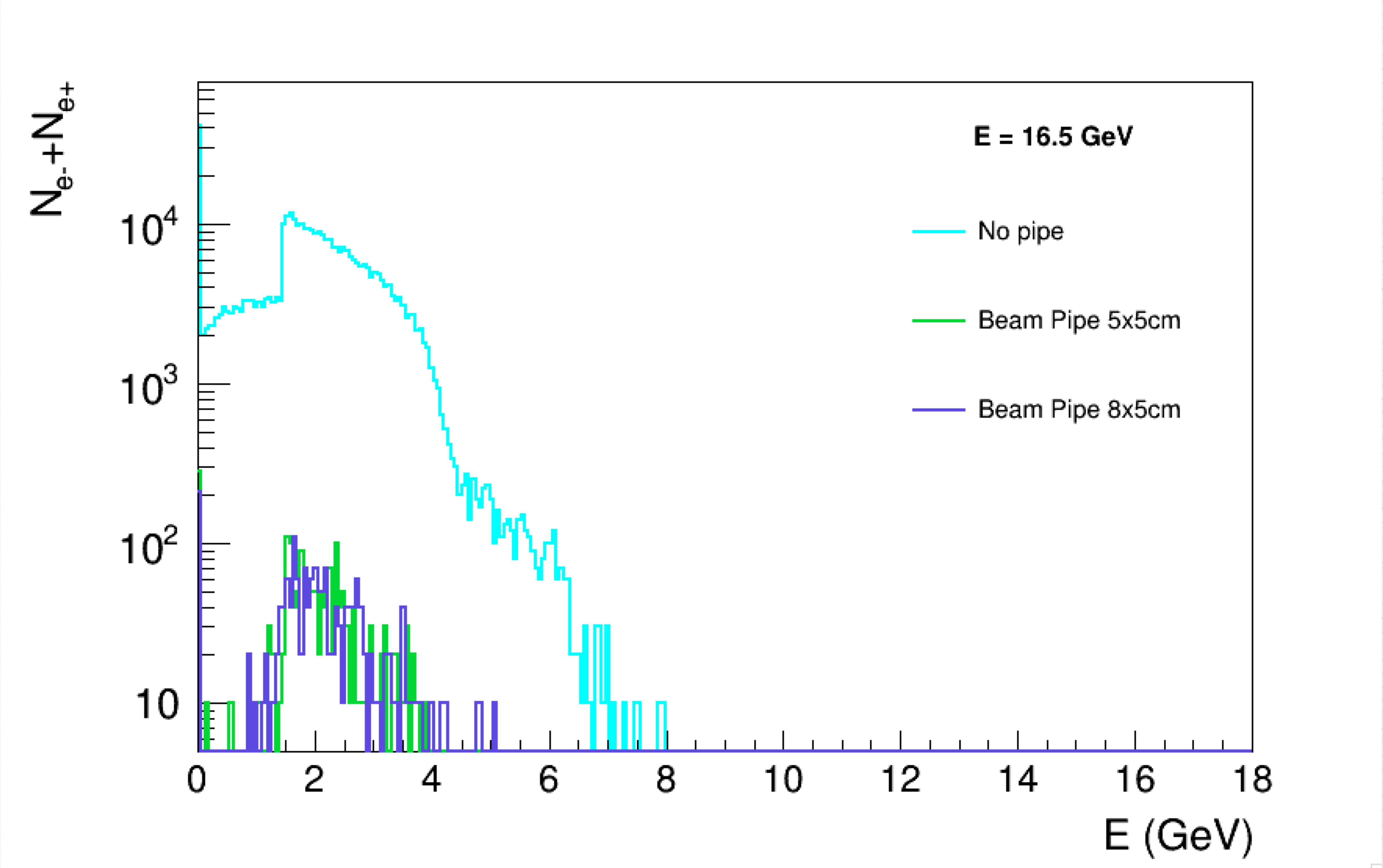








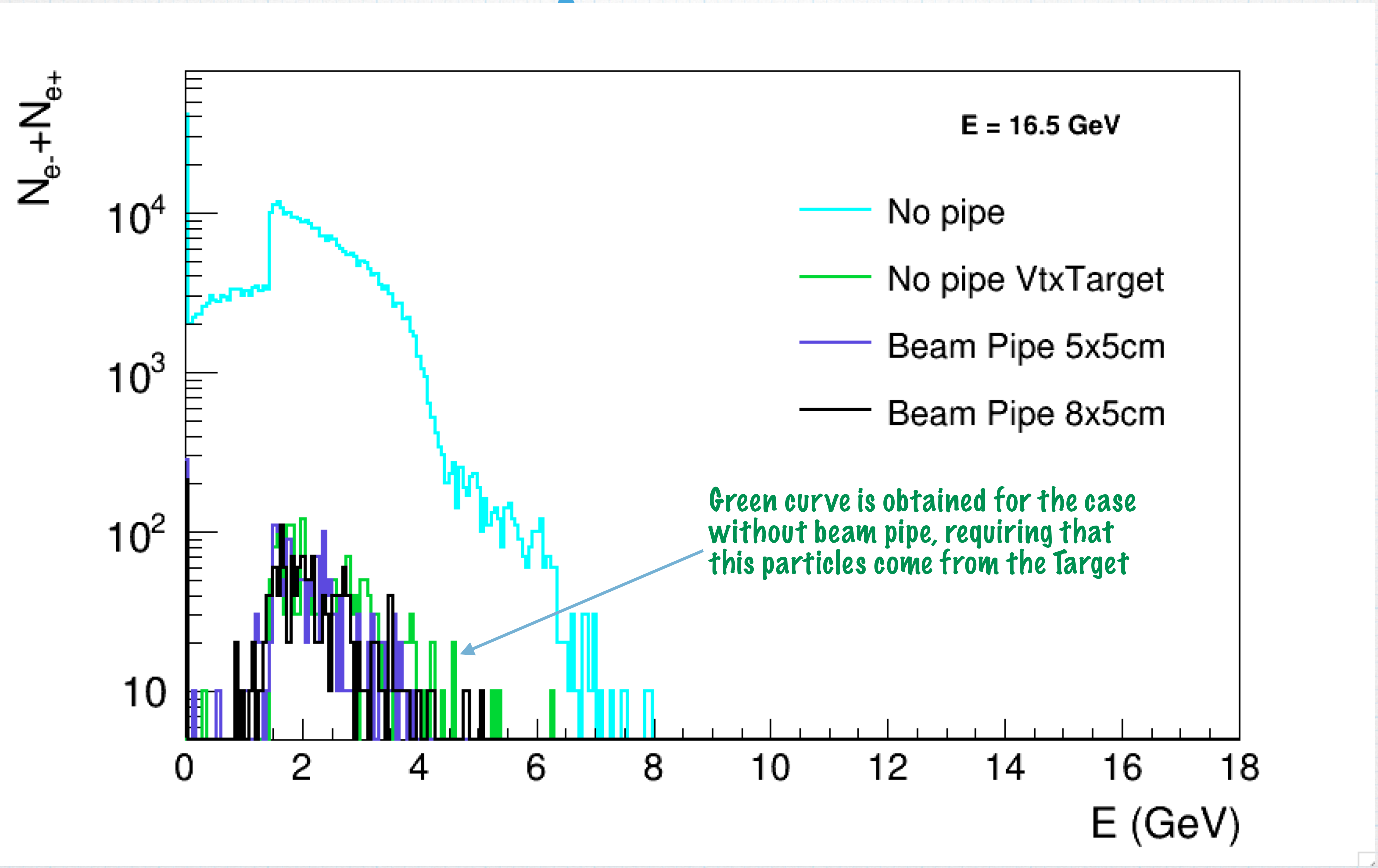
Spectra



Without beam pipe we measure in Compton detectors a lot e-/e+ pairs that were created in the air.
Only 4% e-/e+ come from the Target

As the laser intensity is low (xi =0.3), to reconstruct spectra we need more statistics.

Spectra



Without beam pipe we measure in Compton detectors a lot e-/e+ pairs that were created in the air.
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Summary

* The performance of FDS setup was compared with and without beam pipe from the target to Compton detectors

* Number of particles per BX hitting LYSO detector is 25 higher without beam pipe

* Big hole in the Shielding creates substantial background occupancy in LISO detectors.

* All extra particles are generated in the air. Number of particles generated in the target is identical.

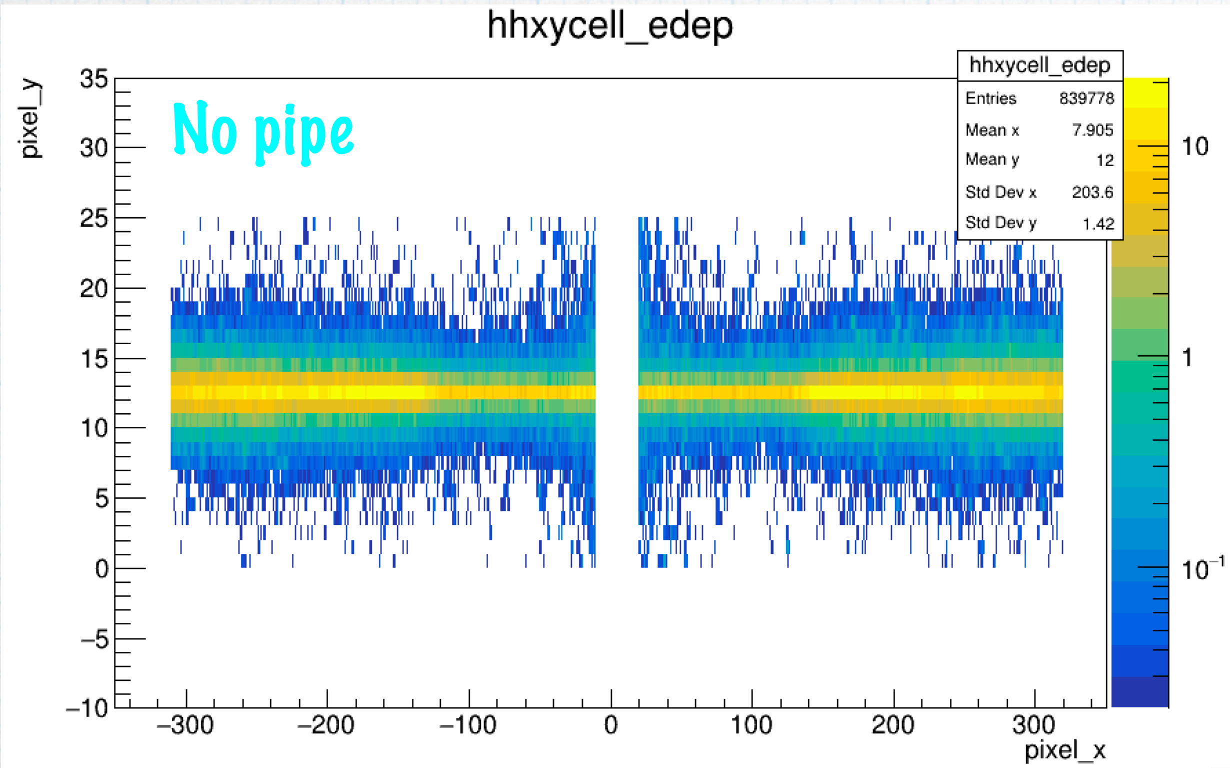
* In the air the vertexes are distributed almost uniformly all the way from the target to the detectors in case of no pipe.

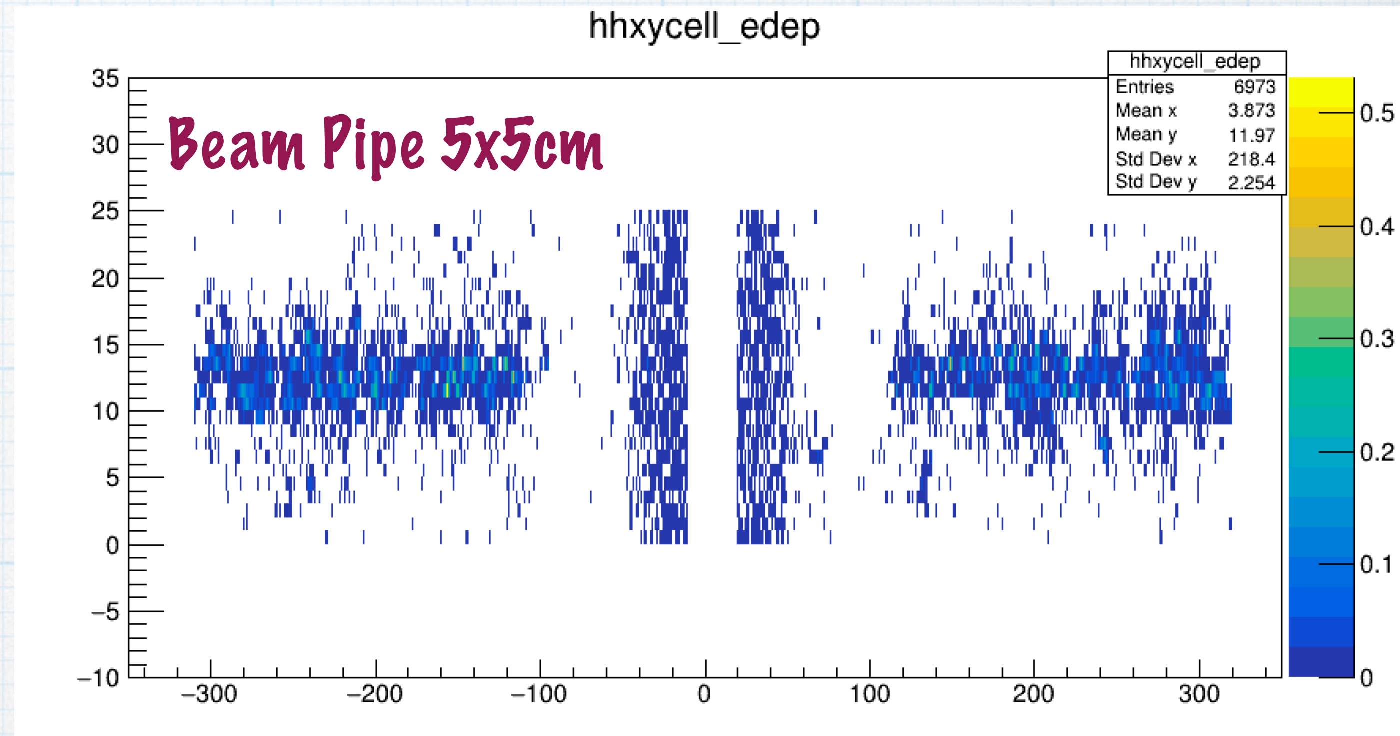
* As the laser intensity is low (xi =0.3), to reconstruct spectra we need more statistics. Asked Anthony to produce more; he runs now 1000BX

Deposited energy per cell

GeV per BX

- laser intensity $\xi = 0.32$





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.**

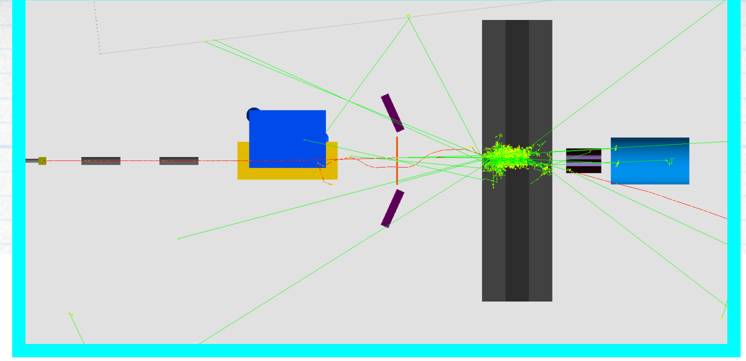
To convert it to Gy, convert it to J: ~1.6e-9J and then divide it to the mass of crystals in kg. Gy= J/kg

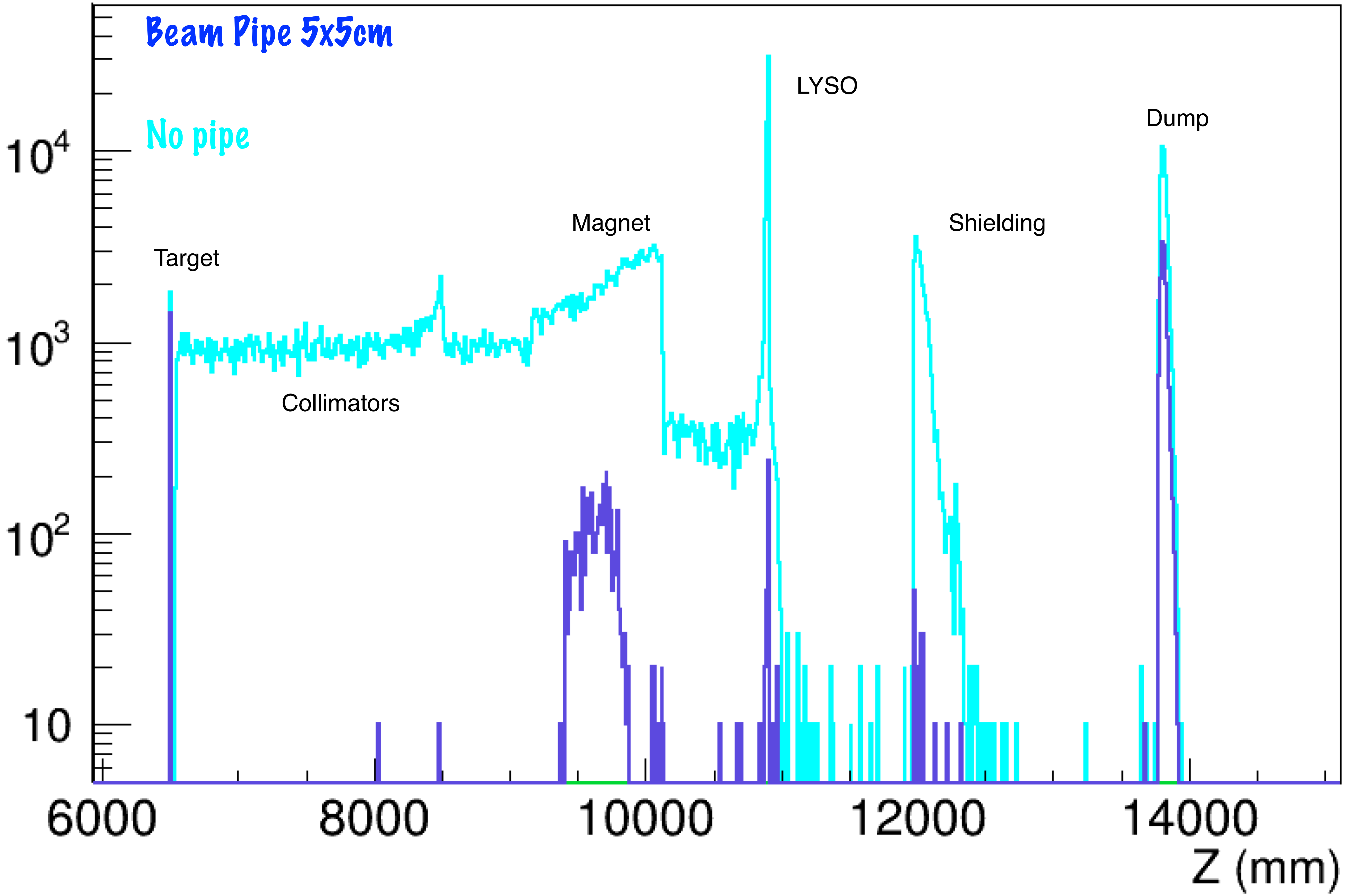
The density is 7.1 g/cm3, volume 0.1*0.2*2 = 0.04 cm3. Mass 7.1*0.04 = 0.284g.

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




Beam Pipe 5x5cm
No pipe
Target
Collimators
Magnet
LYSO
Shielding
Dump
10
10^2
10^3
10^4
6000
8000
10000
12000
14000
Z (mm)