INPUTS & REQUIREMENTS FOR THE FORWARD PHOTON DETECTOR SYSTEM

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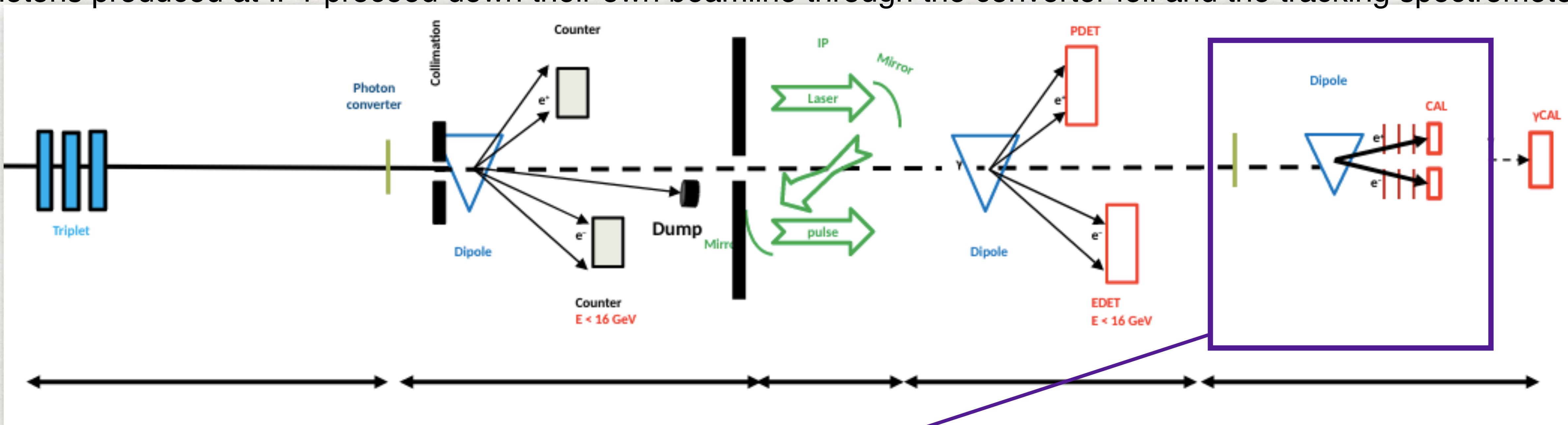
LUXE workshop

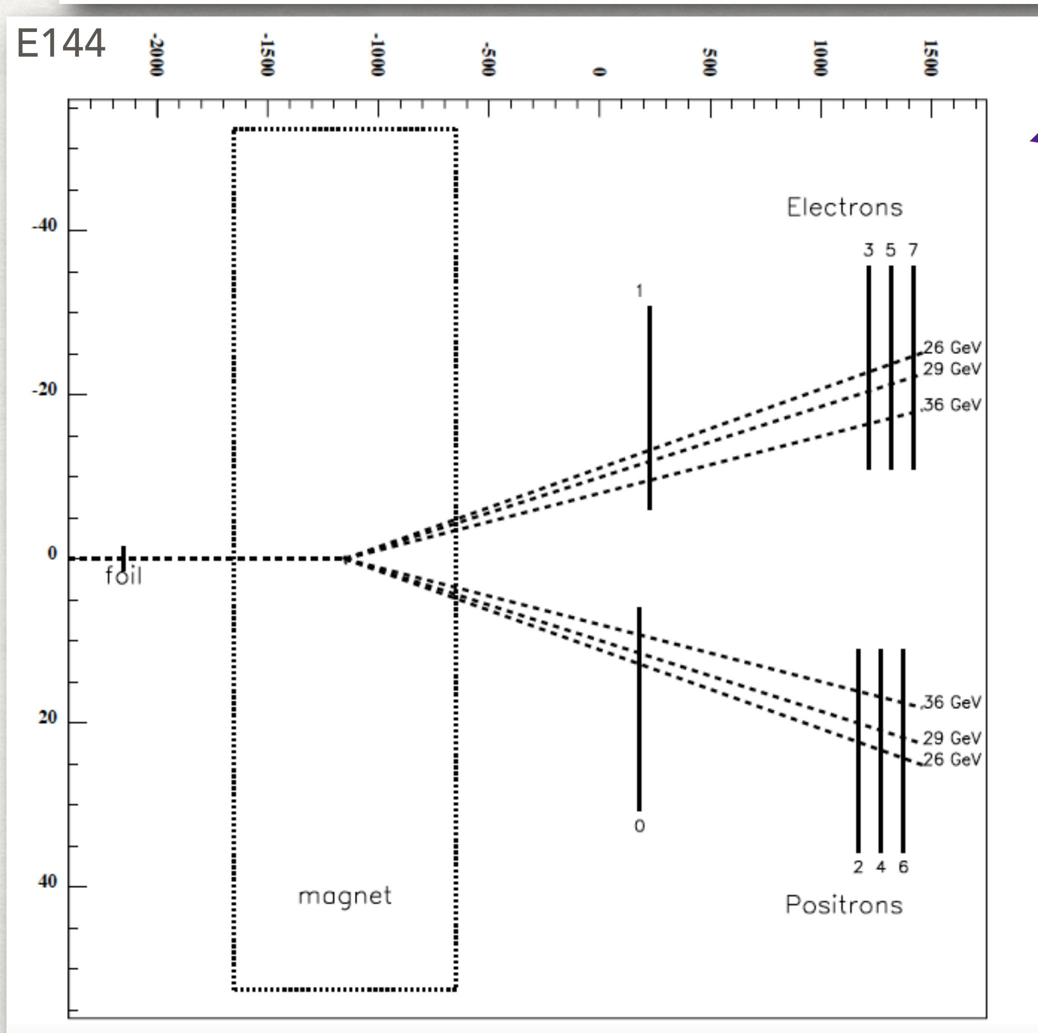
OUTLINE

- layout for FDS of the LUXE experiment
- HICS and the absolute number of forward photons
- method of study the photon-conversion data
- spectra from MC
- Geant4 simulation for the converter

LAYOUT FOR FDS OF THE LUXE EXPERIMENT

Photons produced at IP1 proceed down their own beamline through the converter foil and the tracking spectrometer





$$\begin{aligned} e + n\omega &\rightarrow e + \gamma \\ \gamma + n\omega &\rightarrow e^+ + e^-. \end{aligned}$$

- HICS -> Non-linear Compton
- BPPP -> monitor brem photons

The experiment should have the capability:

- to detect the presence of particles scattered at different orders of n
- to measure their overall rate
- to resolve the detailed shape of their spectra to some extent
- to correlate these measurements with an estimate of the intensity parameter

The observation of tracks created by photons above the n = 1 kinematic edge, which could not arise through multiple n = 1 scattering, could demonstrate unambiguously the non-linear Compton scattering process

PHOTONS FROM THEORETICAL CALCULATIONS

HICS DIFFERENTIAL TRANSITION PROBABILITY VS RADIATED PHOTON ENERGY

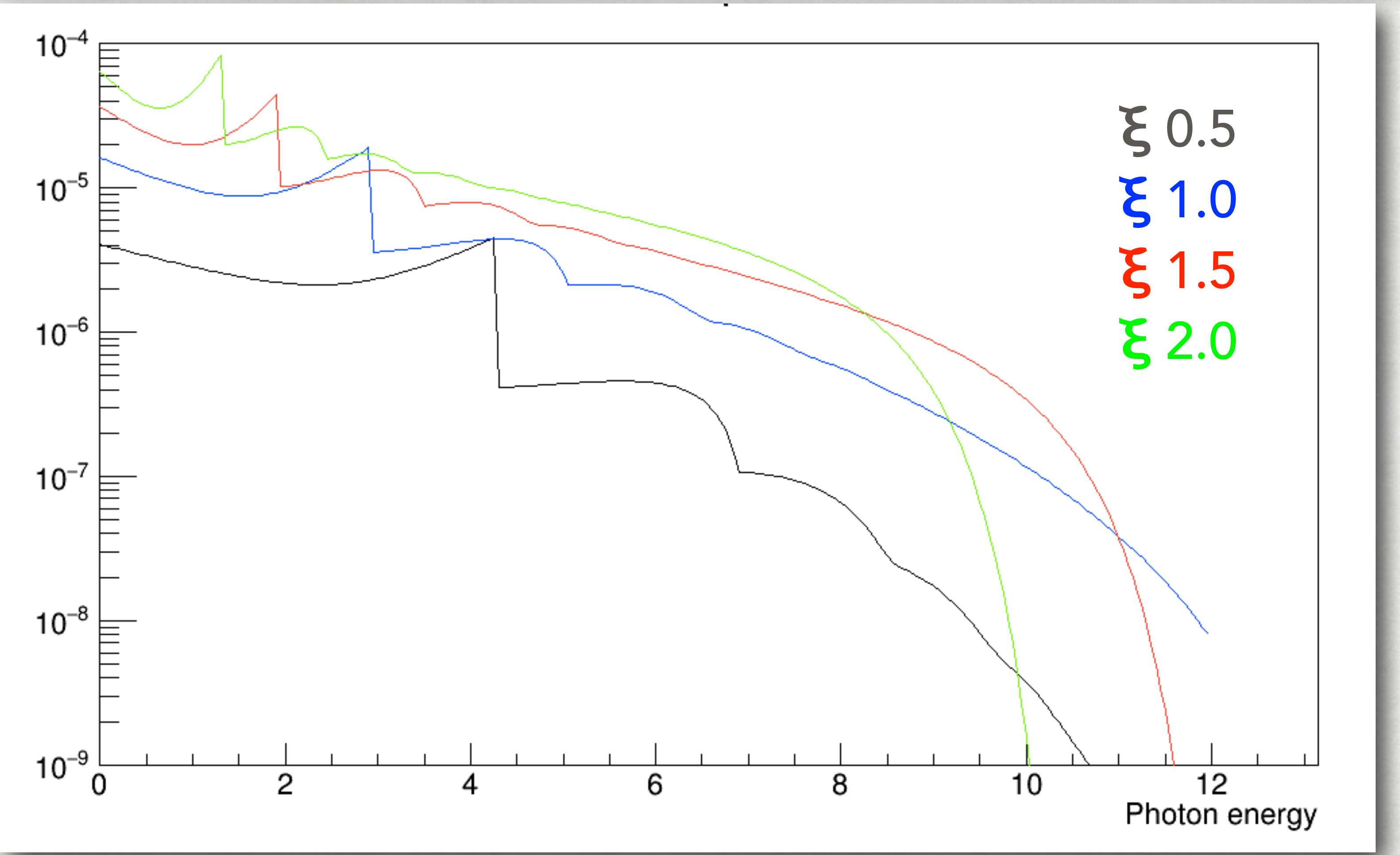
per initial particle per 100 fs 800 nm laser. 17.5 GeV initial electrons, 0.9*Pi crossing angle

data produced of HICS/IPW/circularly polarized with Mathematica by Anthony Hartin 4/2/2019

$$\Gamma_{\mathrm{HICS}} = -\frac{\alpha m^2}{\epsilon_{\mathrm{i}}} \sum_{n=1}^{\infty} \int_0^{u_n} \frac{du}{(1+u)^2} \left[\mathrm{J}_n^2(z_u) - \frac{\xi^2}{4} \frac{1+(1+u)^2}{1+u} \left(\mathrm{J}_{n+1}^2 + \mathrm{J}_{n-1}^2 - 2\,\mathrm{J}_n^2 \right) \right]$$

$$z_{\mathrm{u}} \equiv \frac{m^2 \xi \sqrt{1+\xi^2}}{k \cdot p_i} \left[u(u_n - u) \right]^{1/2}, \quad u_n \equiv \frac{2(k.p_i)\, n}{m^2(1+\xi^2)}, \quad \xi \equiv \frac{e|A|}{m}$$

Increasing ξ increases the HICS rate, but suppresses the photon energy (the mass shift)



ABSOLUTE NUMBER OF PHOTONS

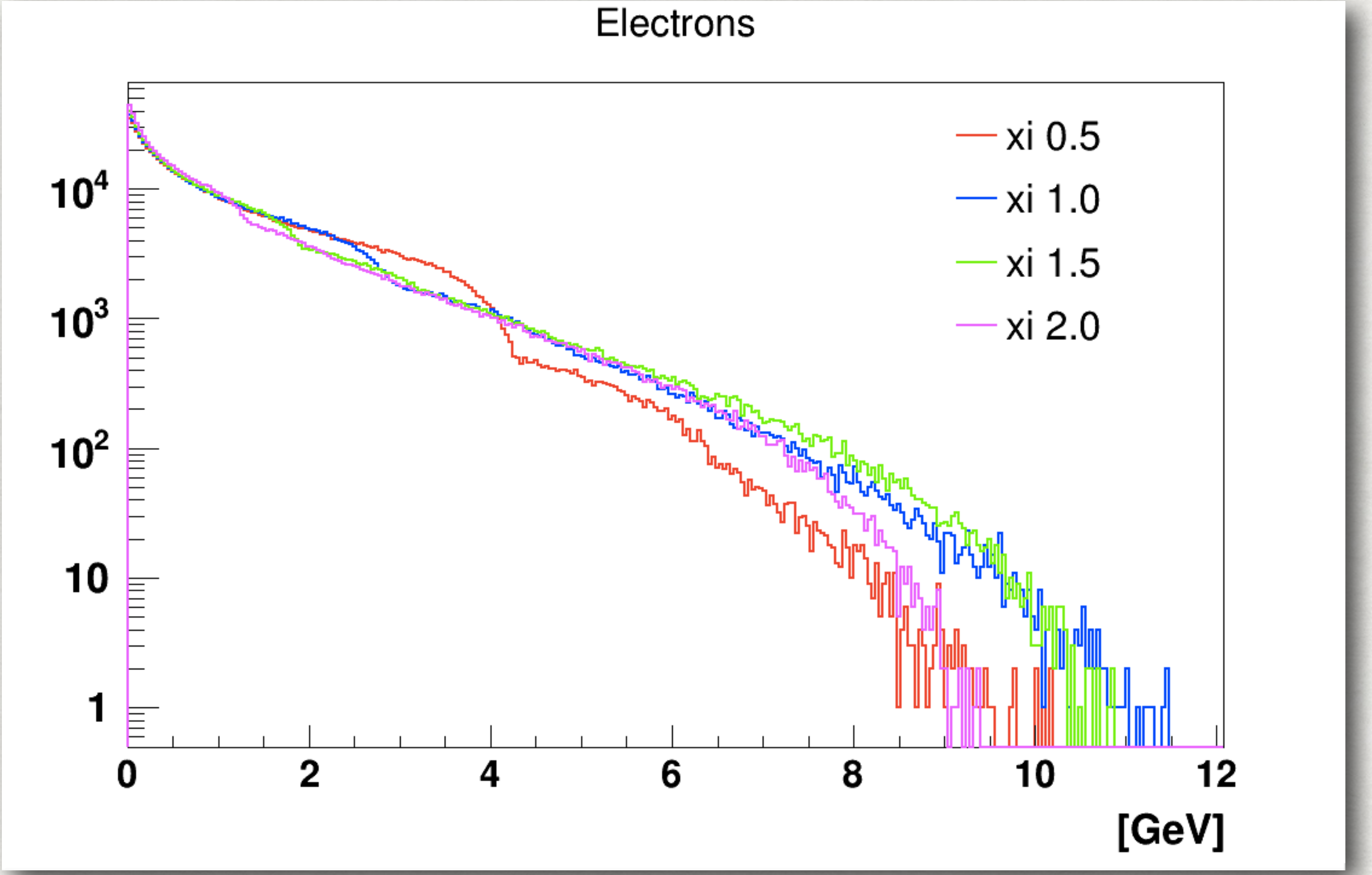
differential transition rate per electron per 100 fs.

multiply it by the number of electrons in the bunch (6.25e+09) and by the laser pulse duration (t=35 fs)

ξ	1e 35 fs (1BX)	Nγ
0.5	2.39	1.49255E+10
1	8.43	5.26758E+10
1.5	16.29	1.01825E+11
2	24.41	1.52579E+11

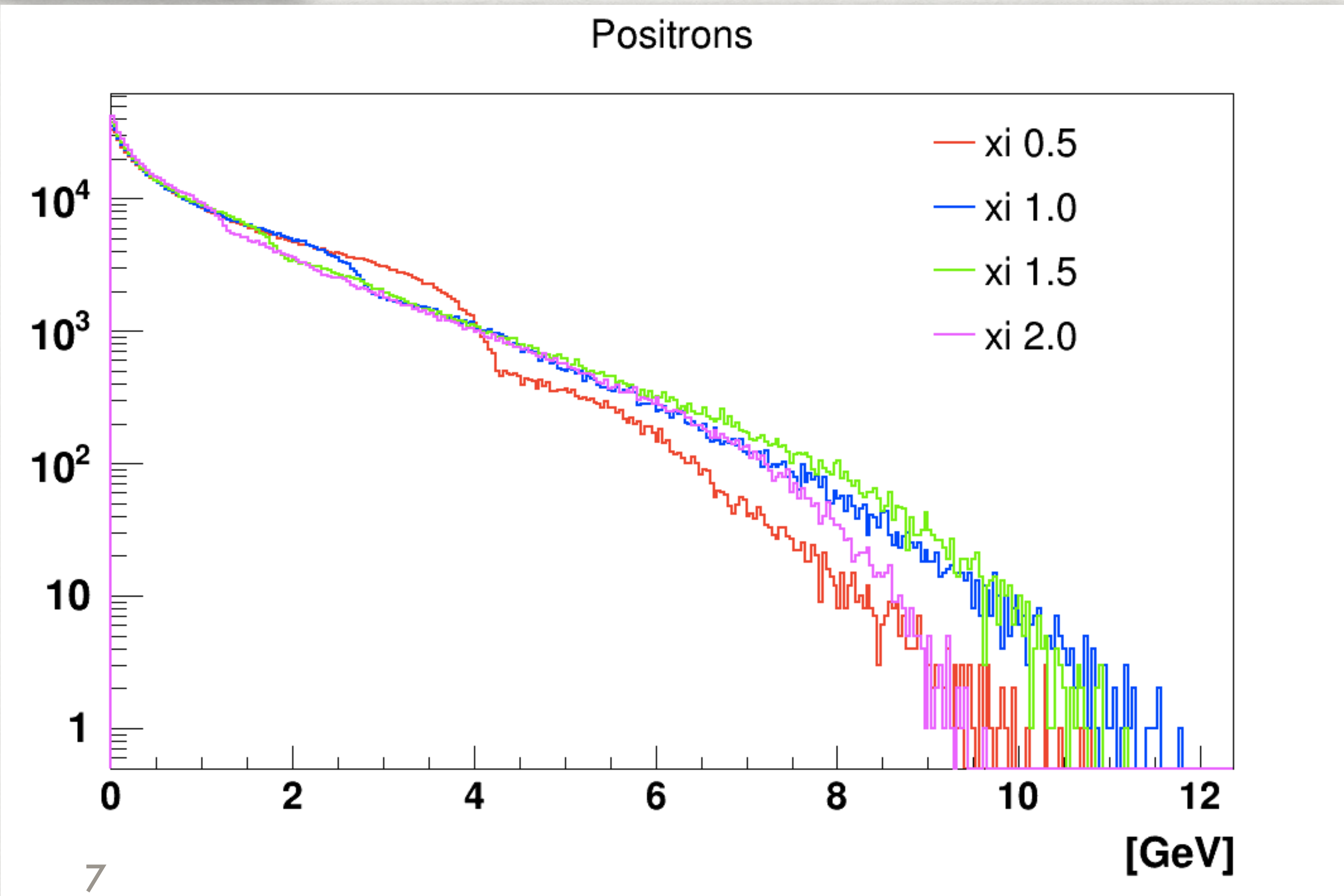
The transverse structure of the laser field is not taken into account in the data and it is assumed that the laser field is uniform in transverse direction and it is essentially the same for all electrons -> It could be accounted for in MC

If the target thickness is 1% of X0 at this laser intensities ~ 1E8-1E9 e+e- pairs would enter the pair spectrometer in each laser pulse

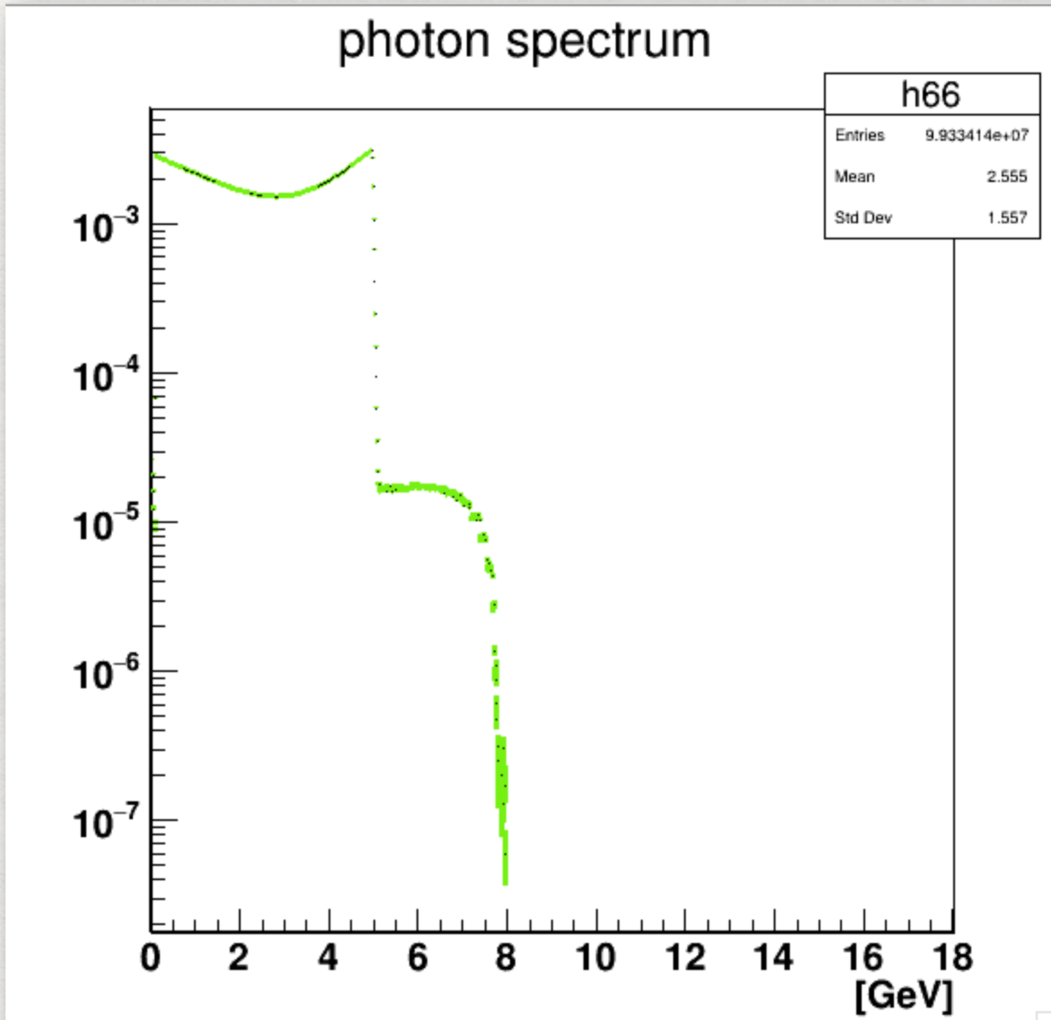


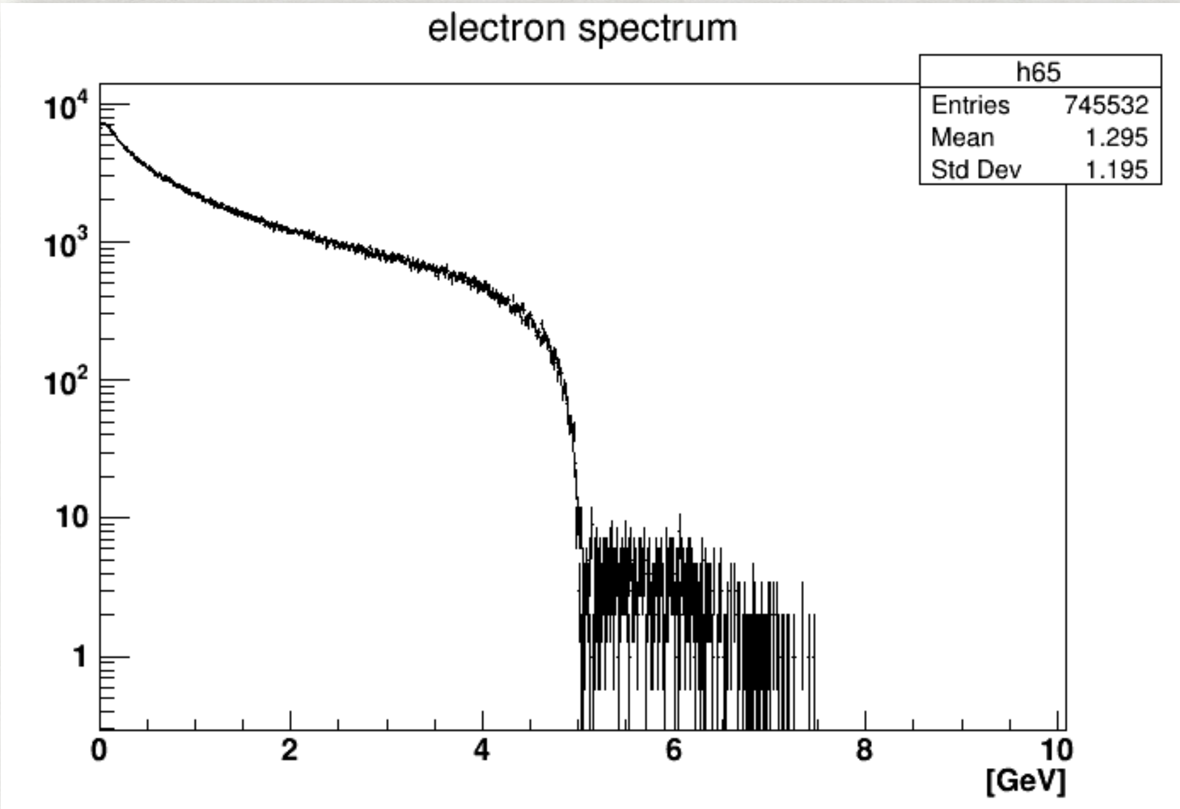
THE ELECTRON AND POSITRON SPECTRA FROM CONVERSION OF FORWARD PHOTONS INTO THE PAIRS FOR DIFFERENT ξ FROM GEANT4

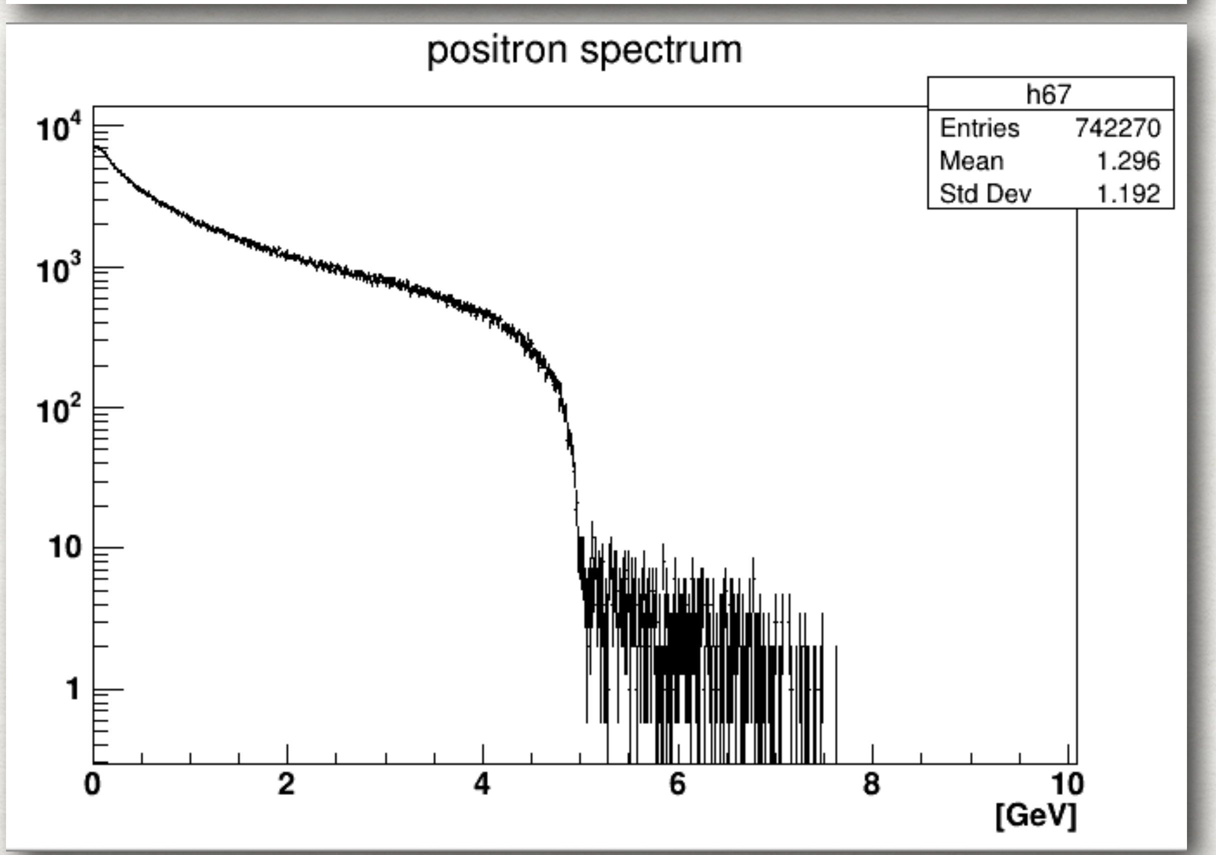
- target material - W
- thickness 35 um
- 1E8 photons



FORWARD PHOTONS IN GEANT4





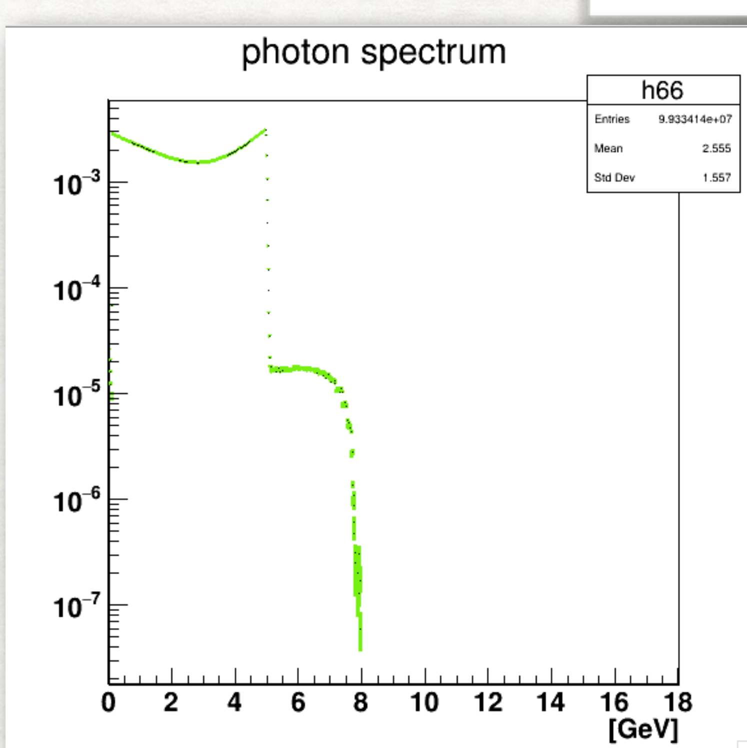


target: Tungsten foil, 0.35 um

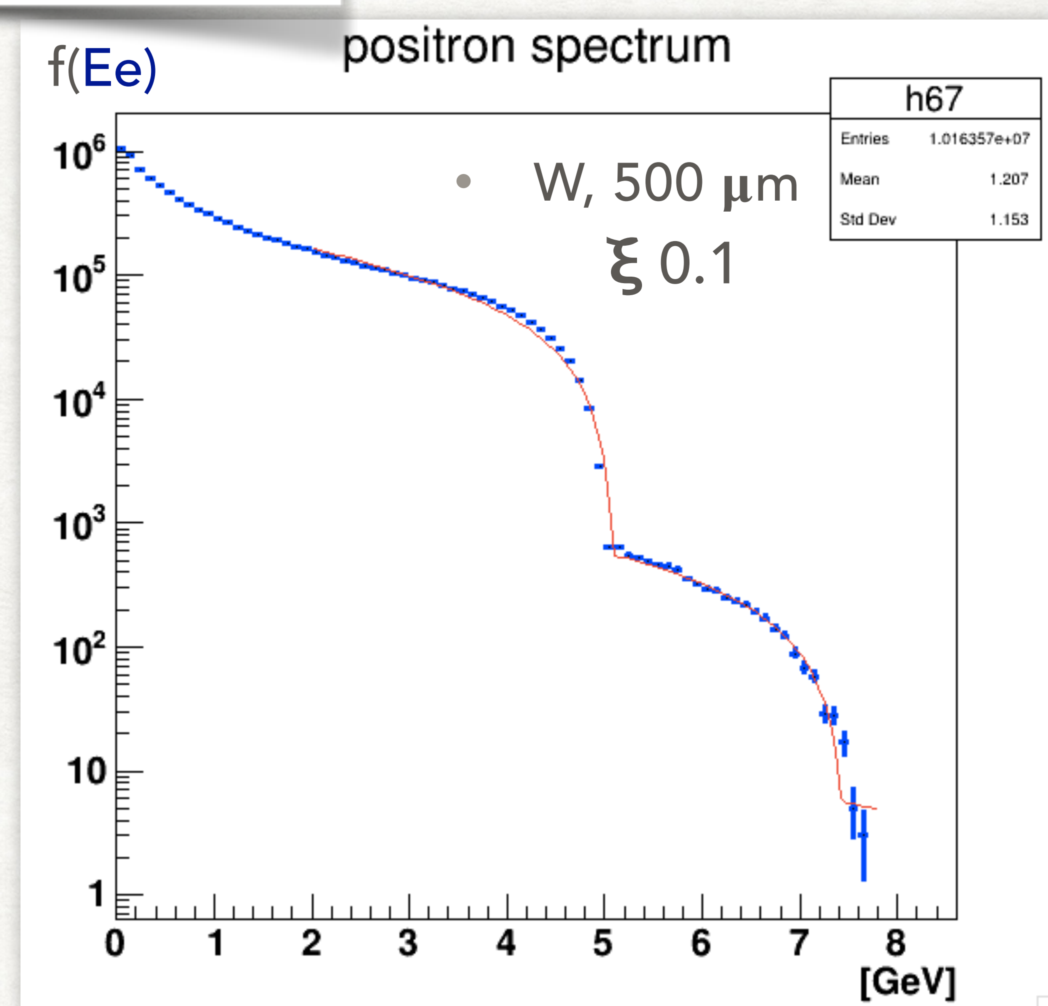
1e8 photons, $\xi = 0.5$

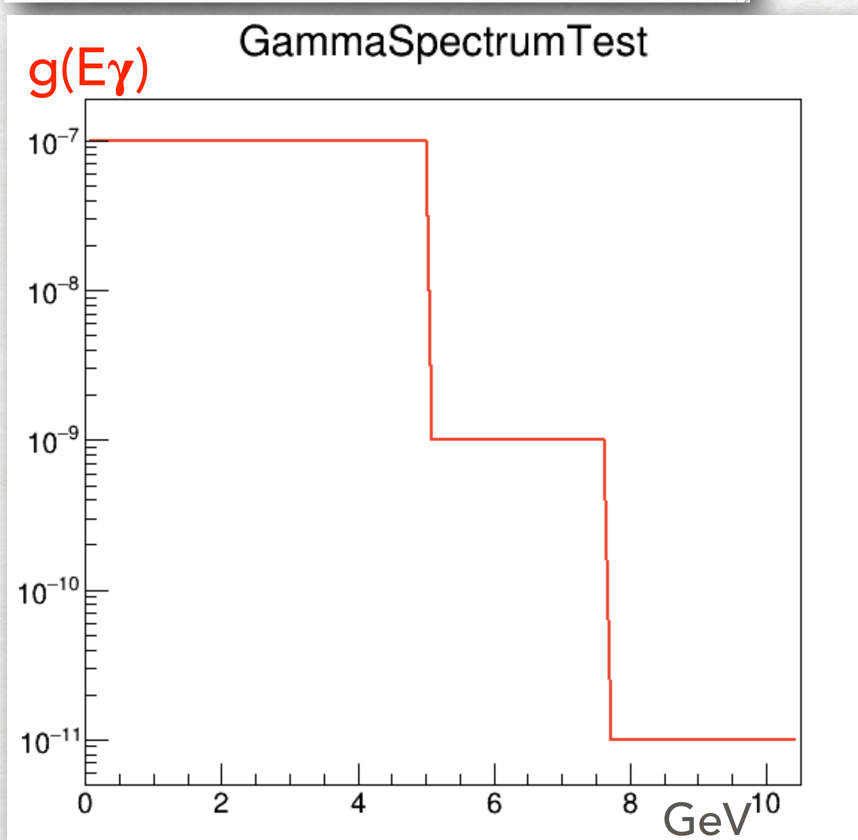
METHOD OF PHOTON SPECTRUM RESTORATION

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



The reconstructed single-particle momentum spectra is compared to a **model spectrum** calculated by convolving the **simulated photon spectrum** with the **Bethe-Heitler pair spectrum**



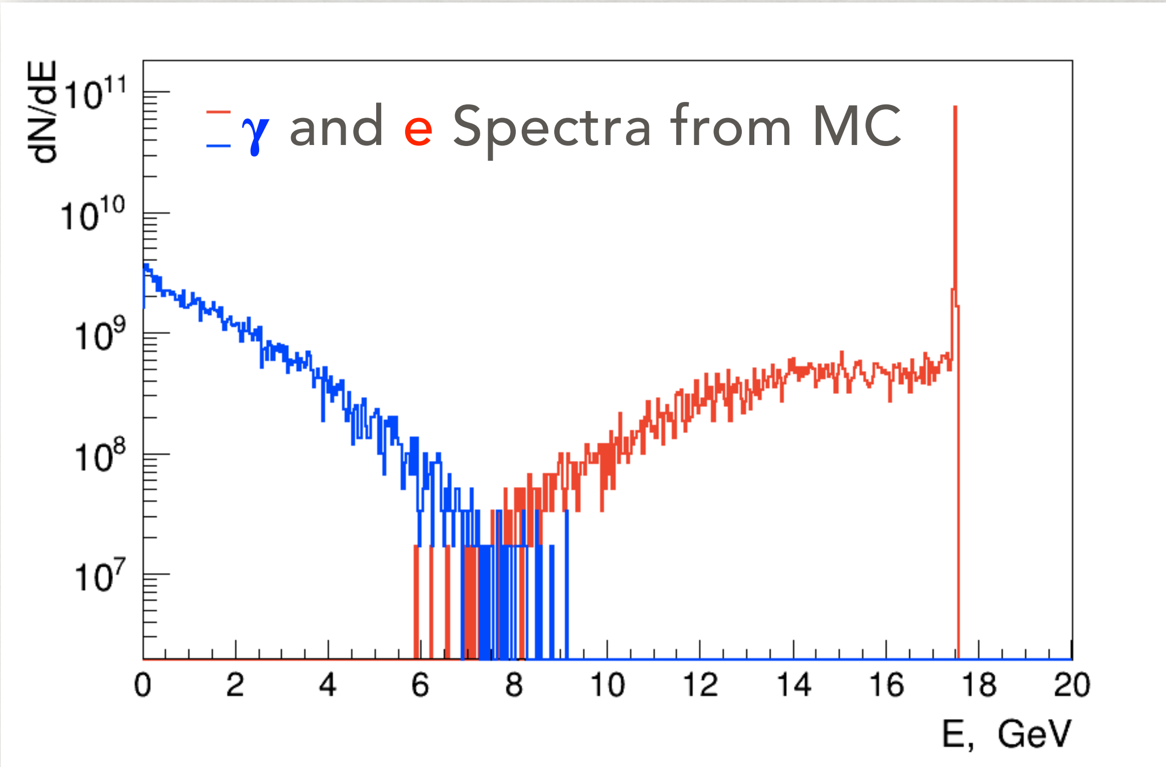


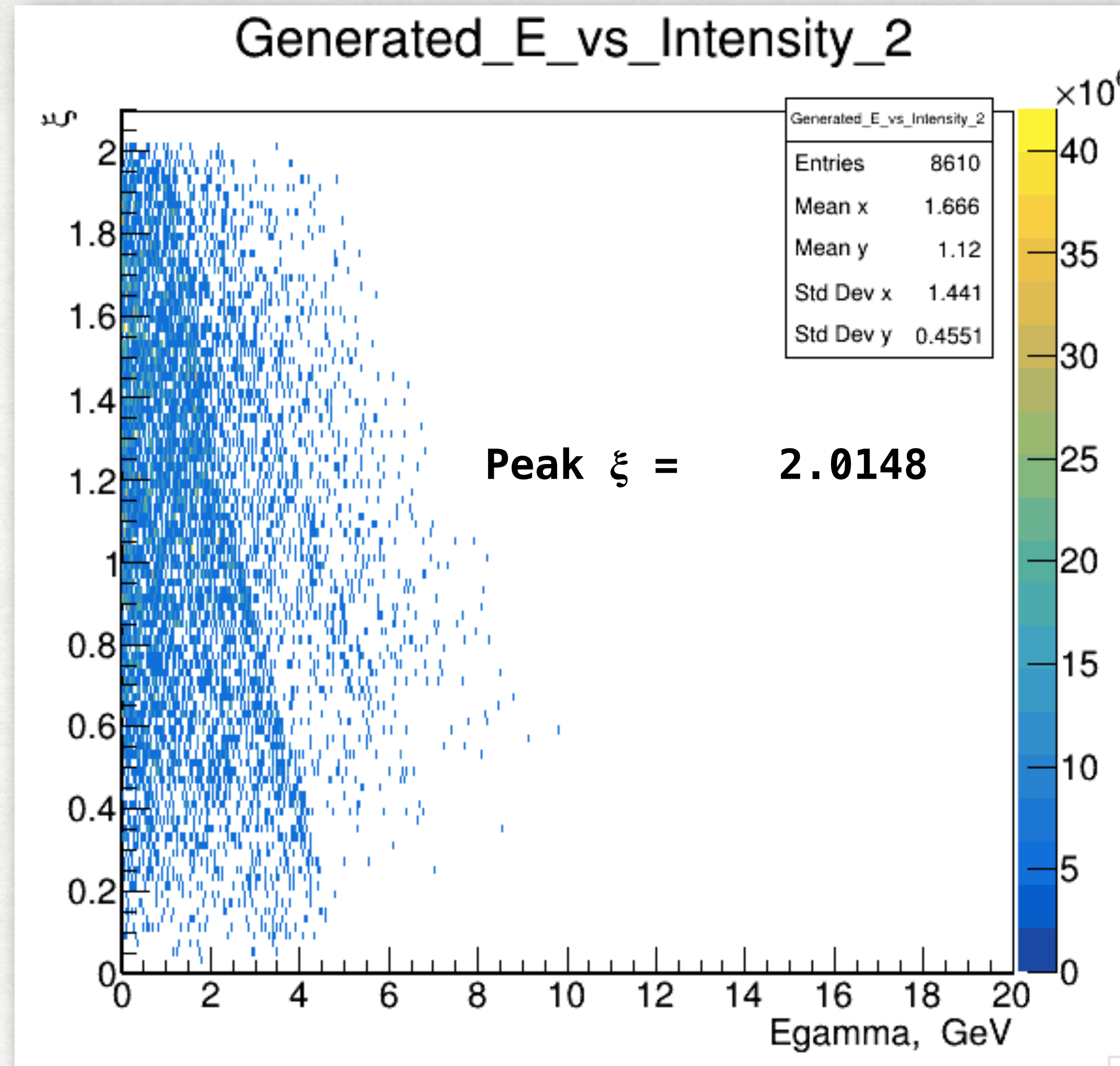
$$\int \sigma(E\gamma, Ee)g(E\gamma,p1,p2)dE\gamma$$

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

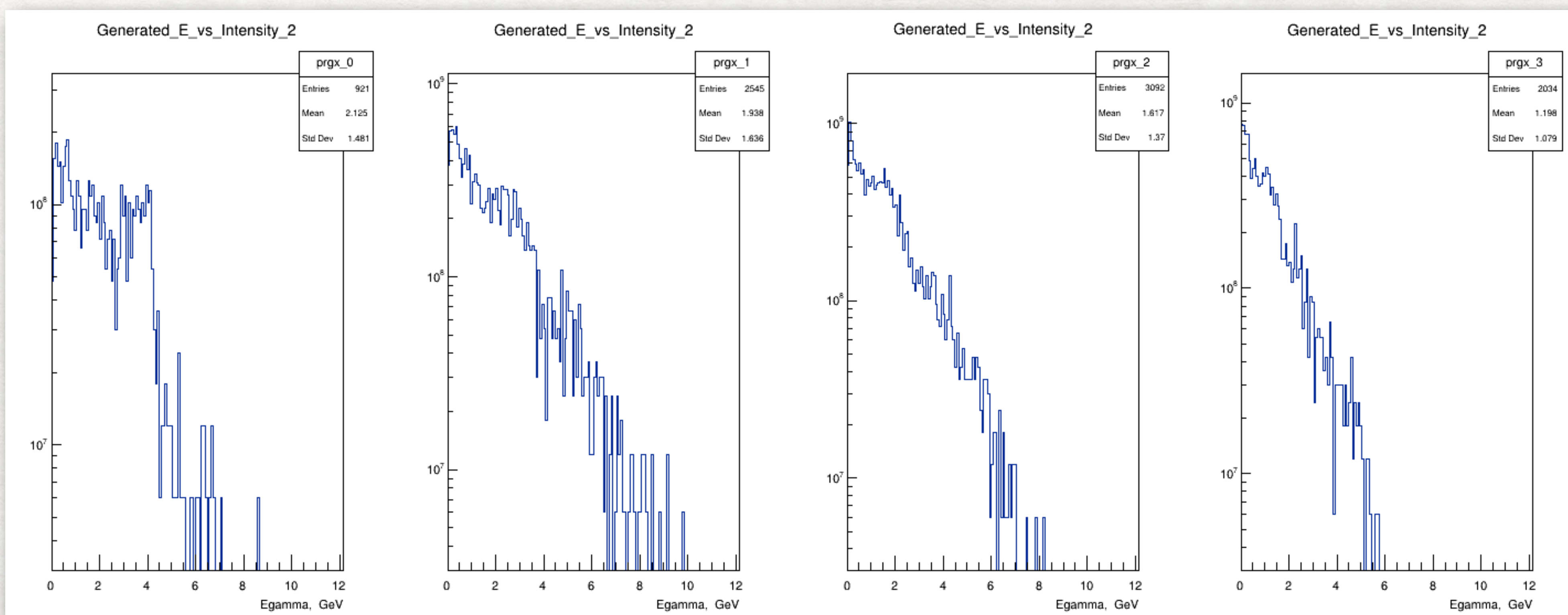
PHOTONS FROM MC

ξ VS EGAMMA FROM MC



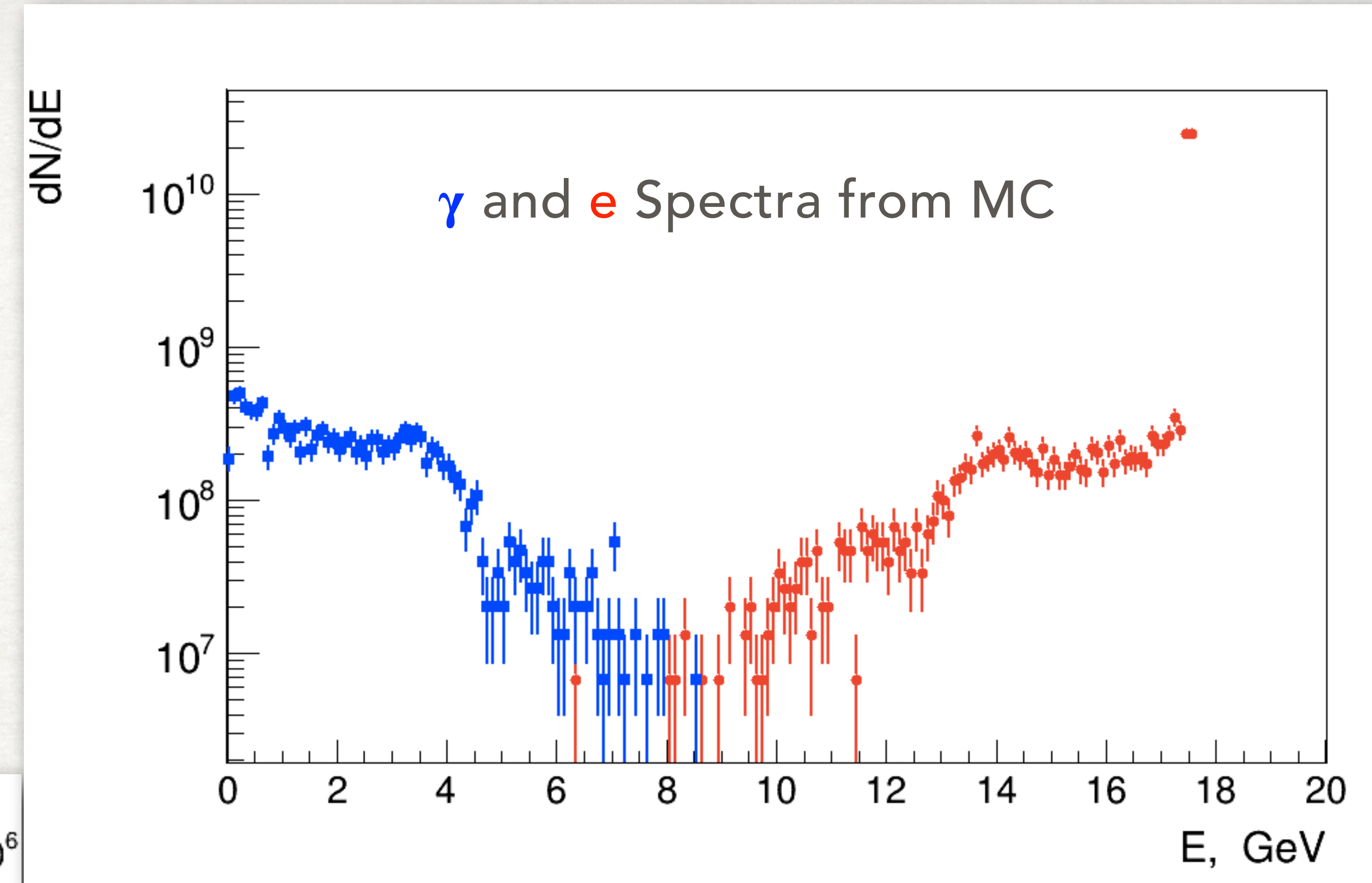


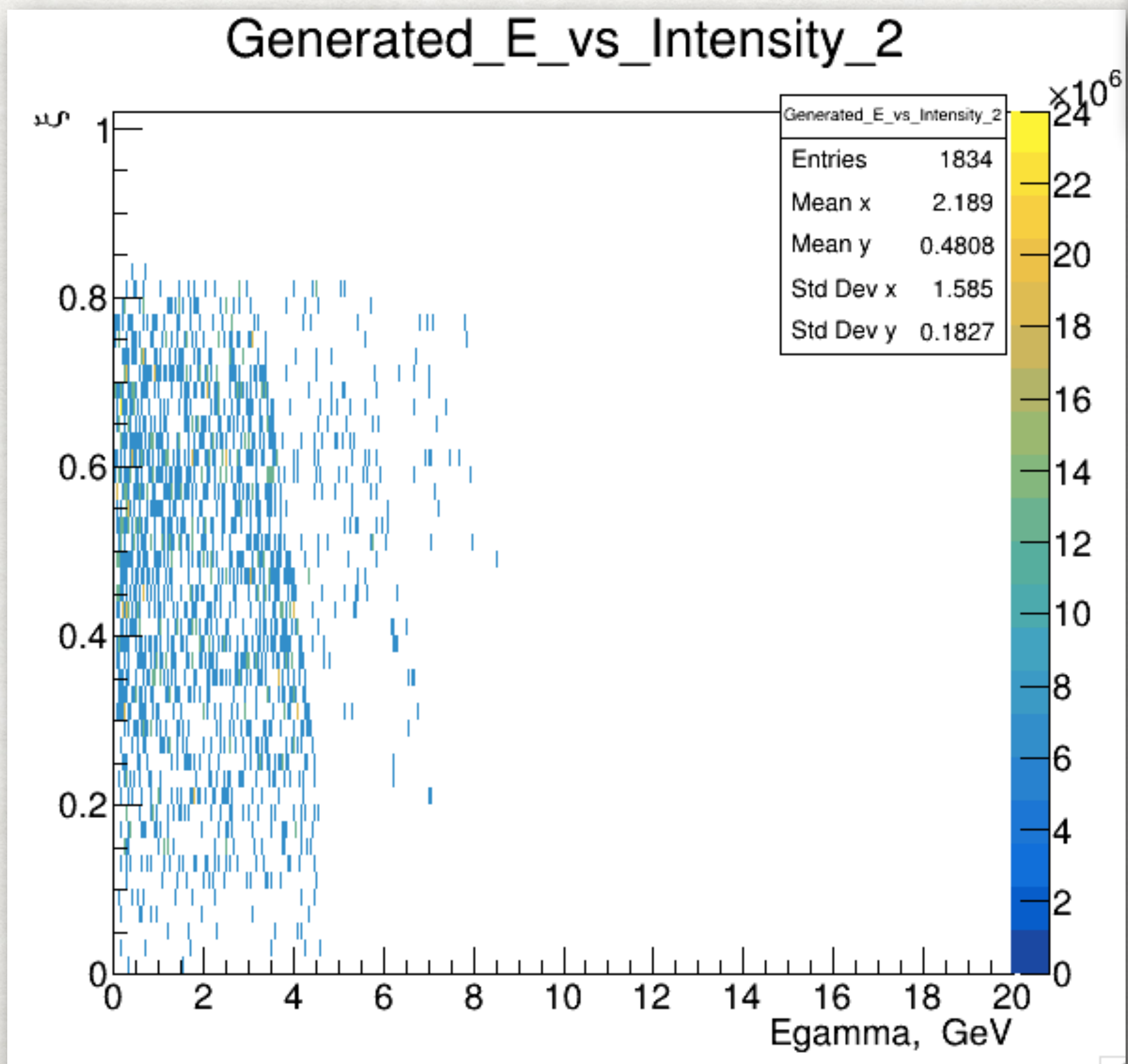
- Laser Intensity (ξ) is not uniform
- This makes the kinematic edges from different *n* not visible

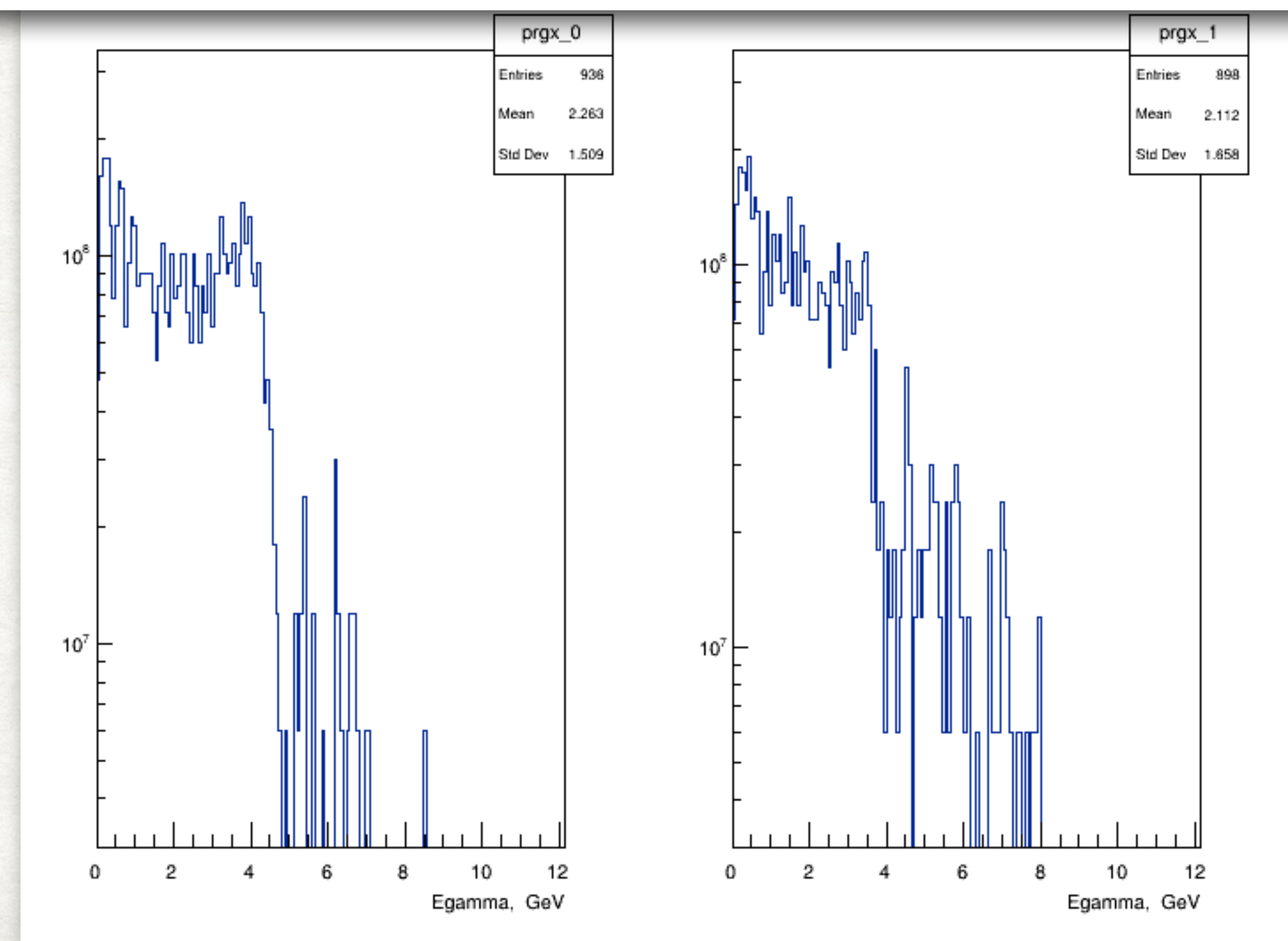


ξ VS EGAMMA FROM MC

Peak ξ = 0.8





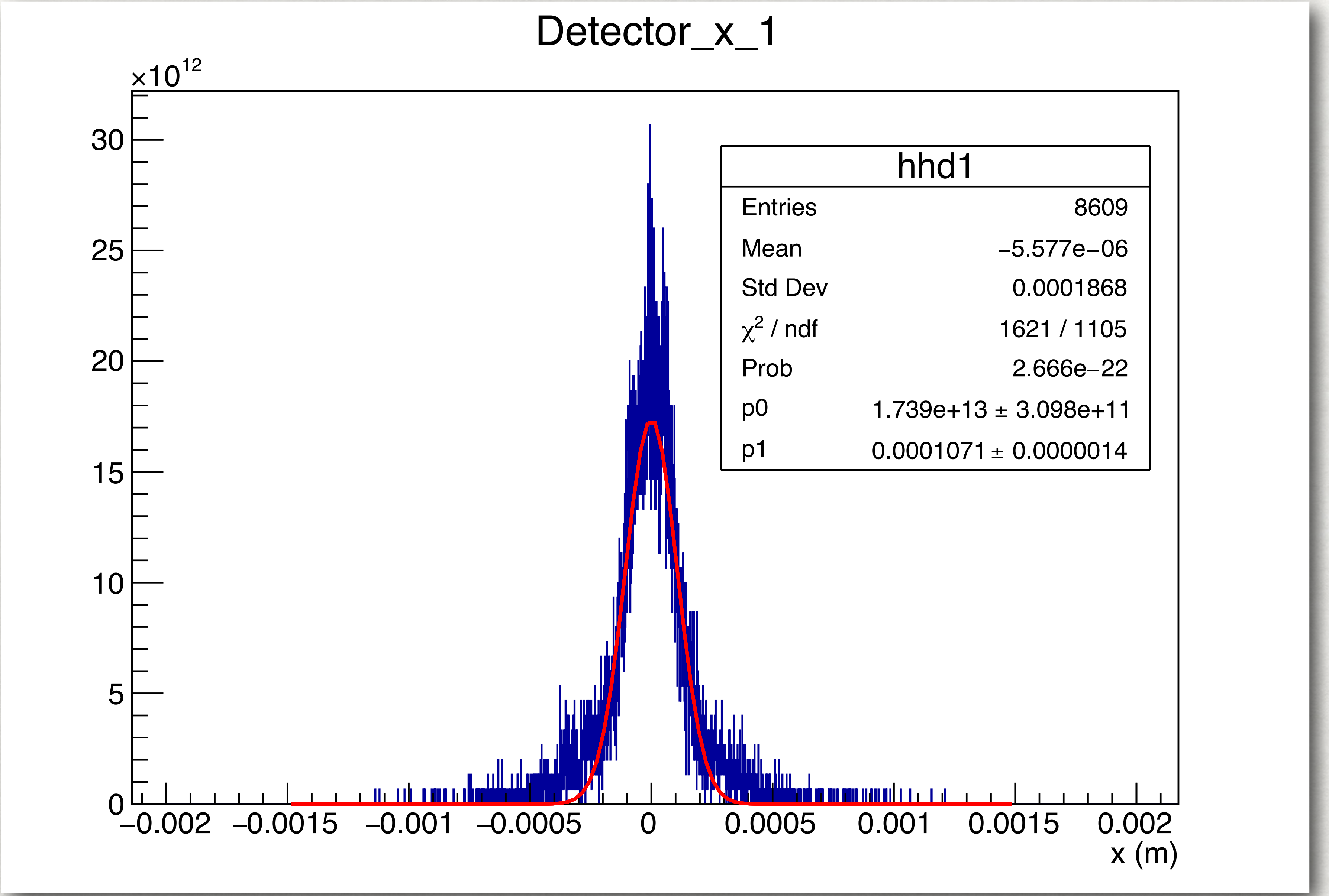


DETECTOR REQUIREMENTS

- Number of photons for HICS process for different xi (for 0.1 and 0.6) for nominal XFL beam (6.25e+09) gives 1e+10 and 5e+10 correspondingly
- CONSIDERING Number of particles (e- or e+) in detector to be ~ e+3
- Then the target is supposed to be~ e-6 X0
    - Jet Target
    - Thin Wire Target ~e-2 X0 which geometry makes angular selection
- It is possible to decrease the Nominal Number of e in a bunch to 6.0e+7 with special gun tuning

N OF PHOTONS FROM MC

- emulating the wire, detector on distance of **10m** from IP

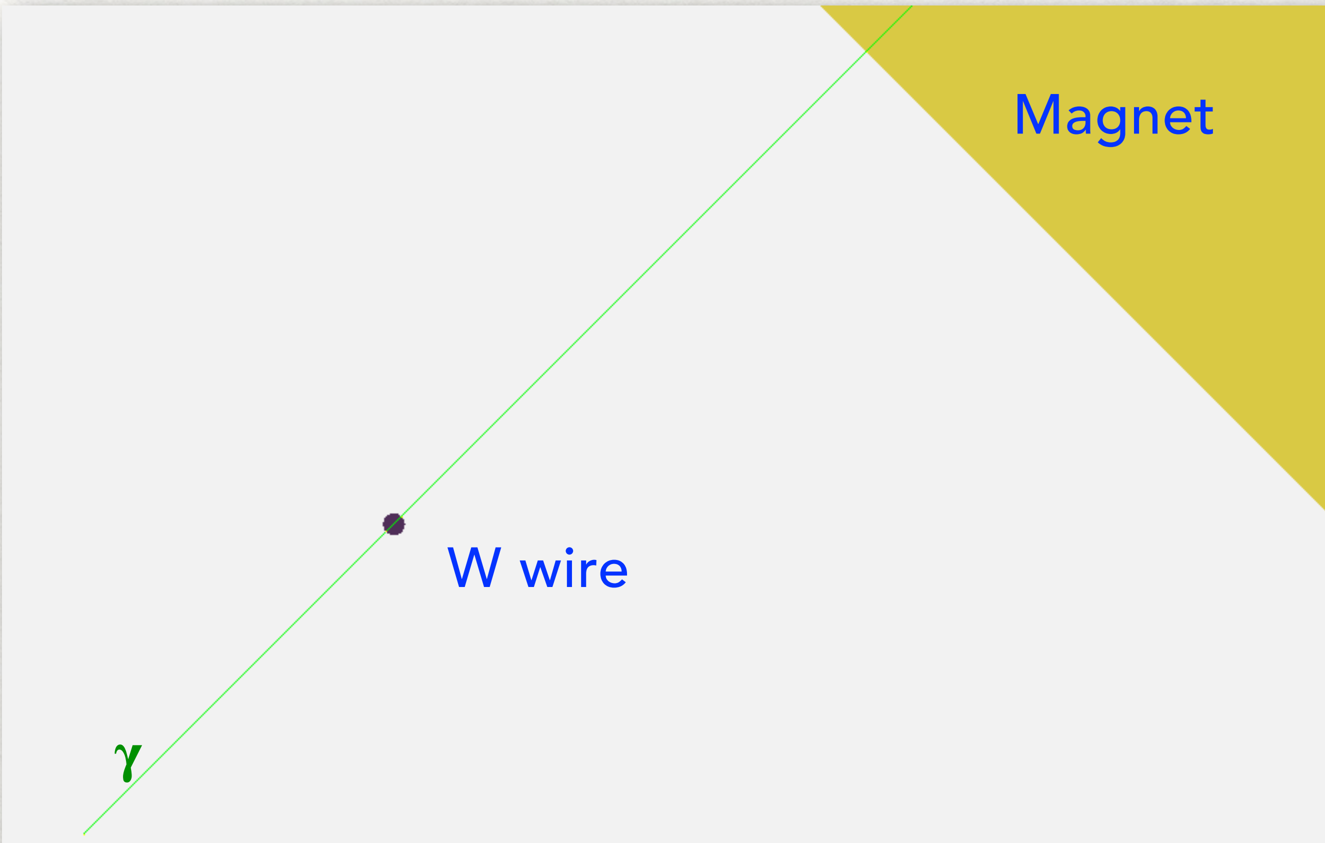


Integral(-5.0e-6, 5.0e-6)*0.003
(double) 521512 =5e+5

<-less but still a lot

Ngamma in case of foil			
ξ	1e 100 fs	1e 35 fs	Nγ
0.5	6.82	2.39	1.49255E+10
1	24.08	8.43	5.26758E+10
1.5	46.55	16.29	1.01825E+11
2	69.75	24.41	1.52579E+11

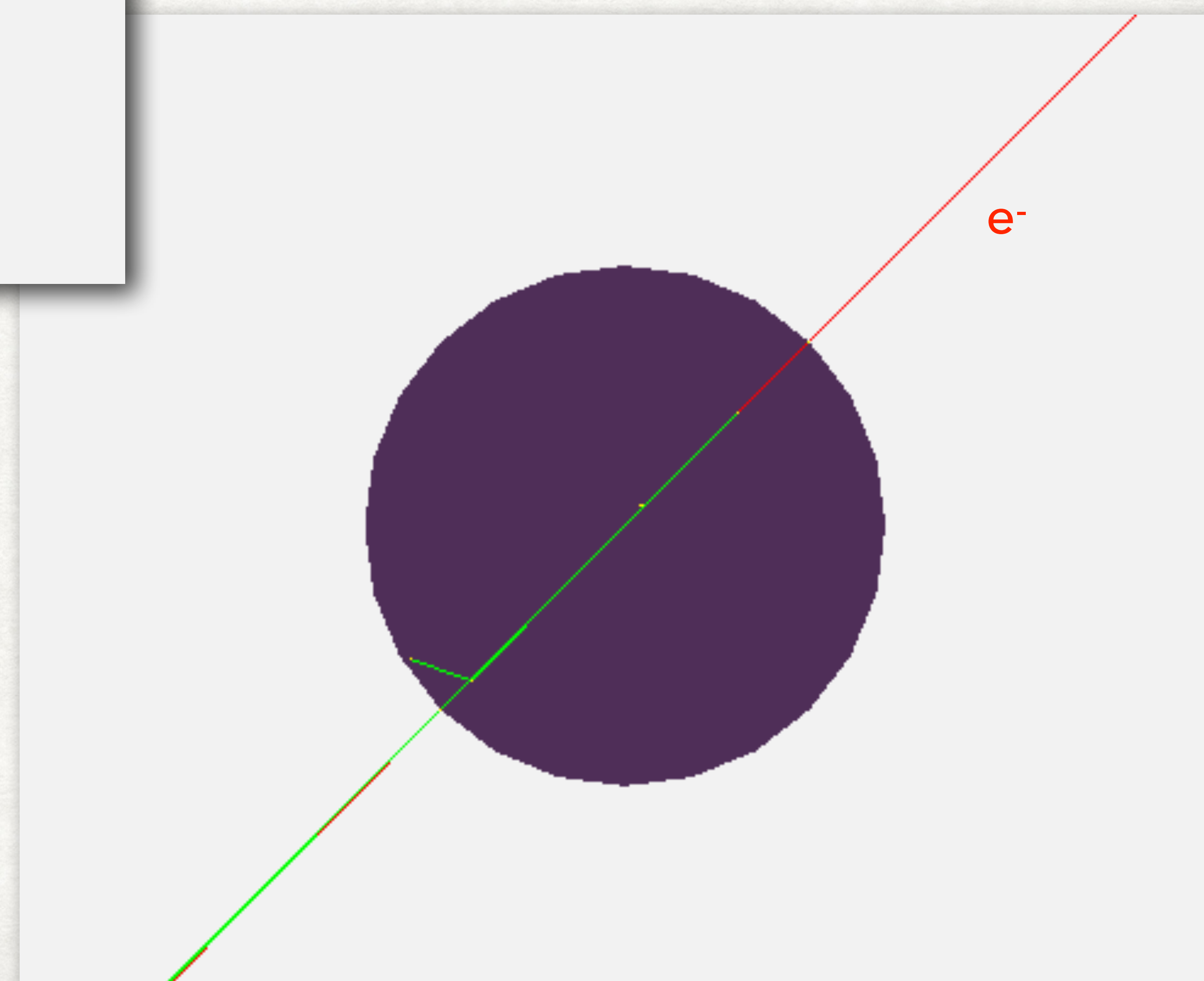
GEANT4 SIMULATION FOR THE WIRE CONVERTER



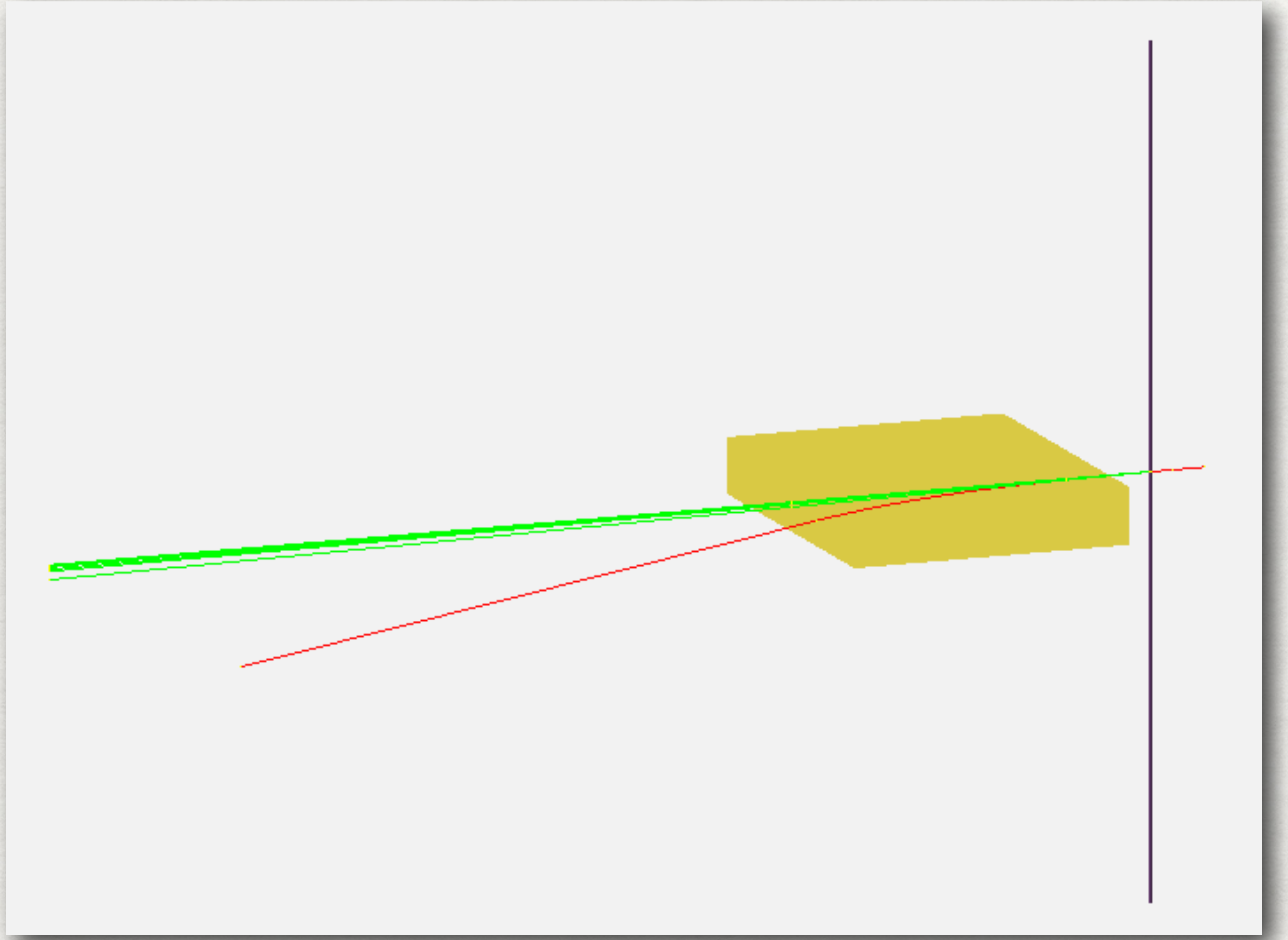
Magnet 1 T

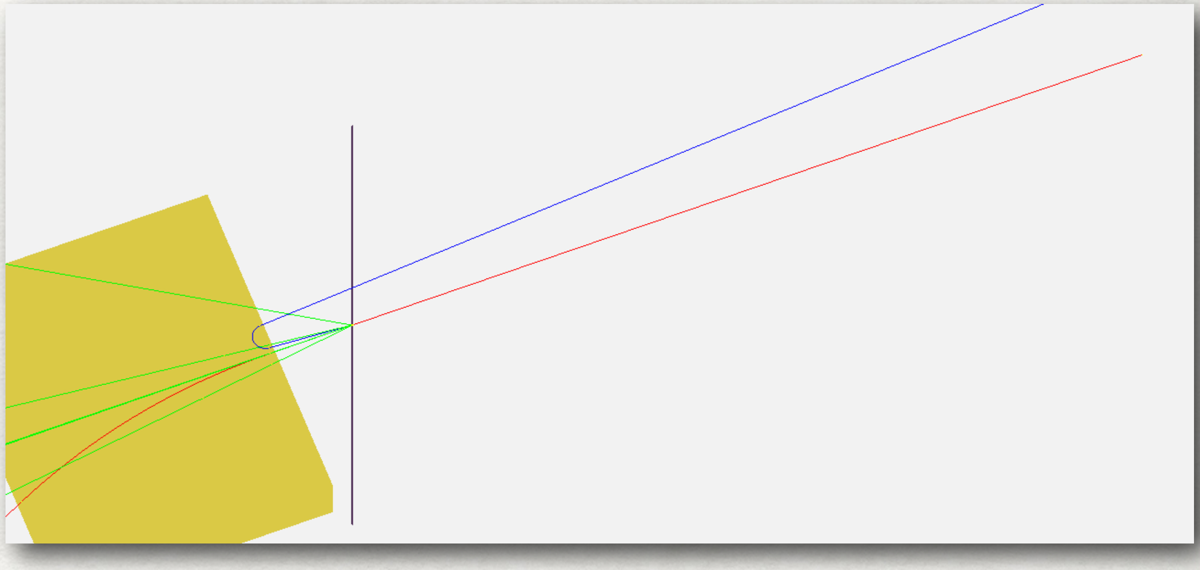
d from Target to Magnet 30 cm

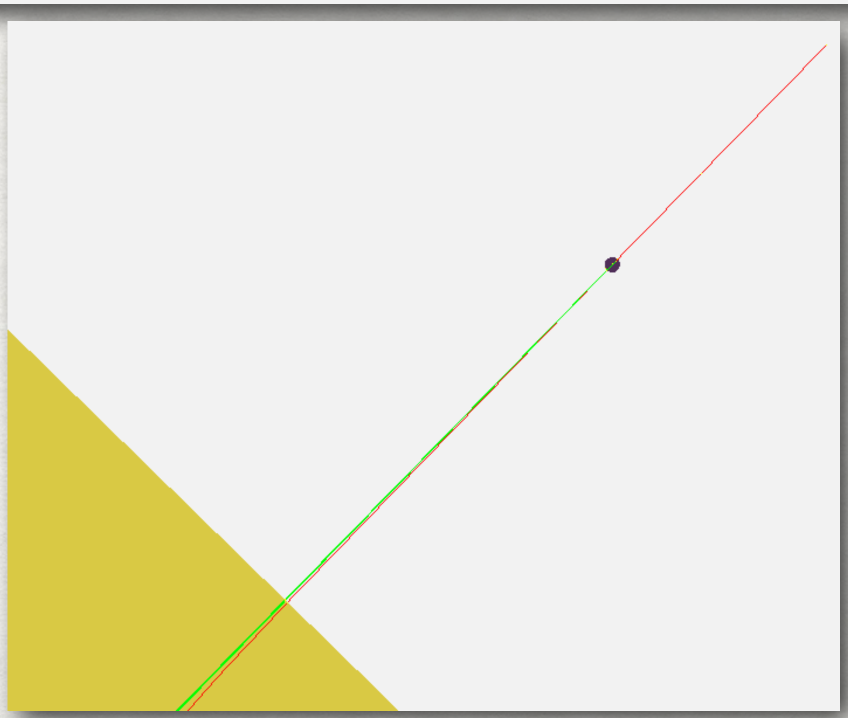
d from Source to Target 9.7 m

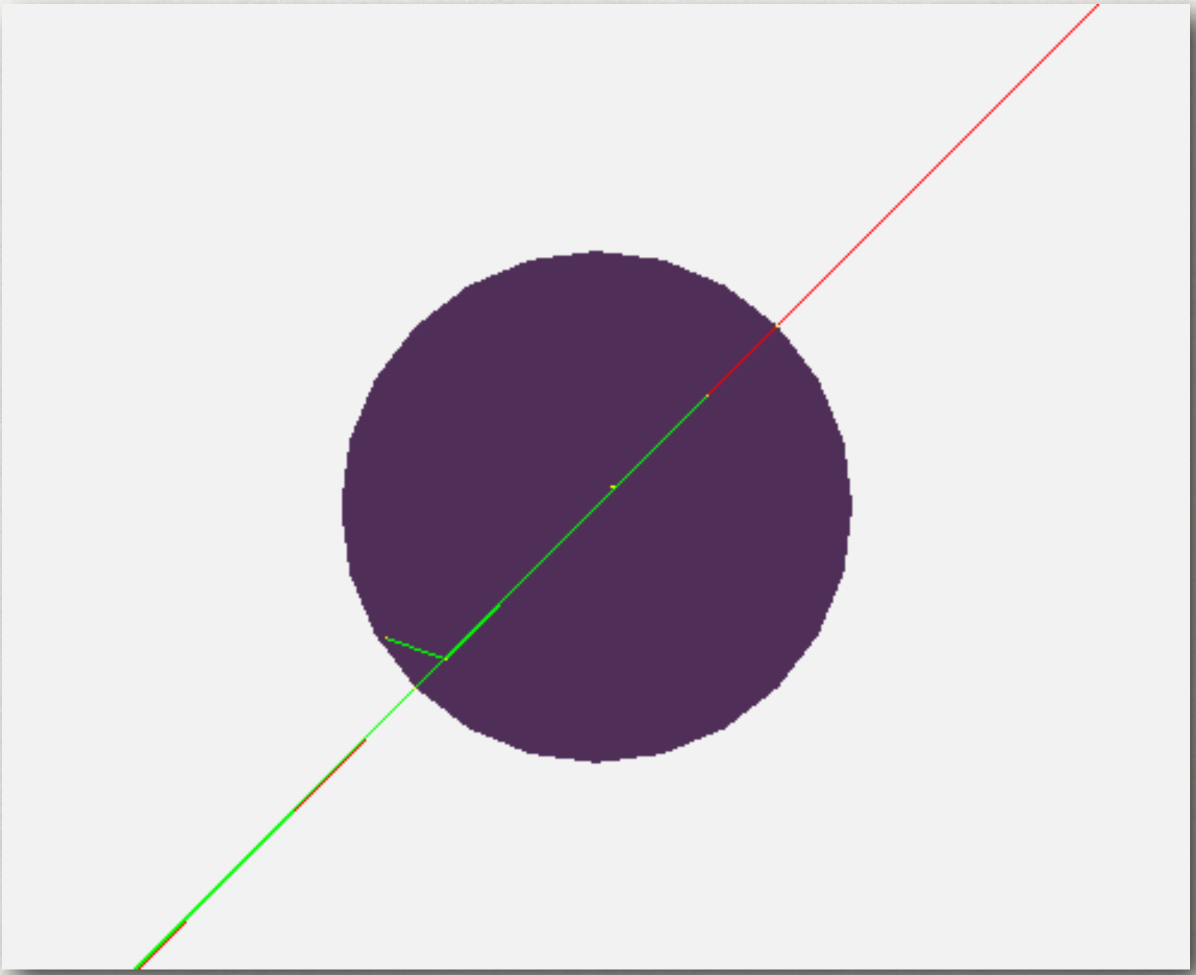


GEANT4 SIMULATION FOR THE WIRE CONVERTER





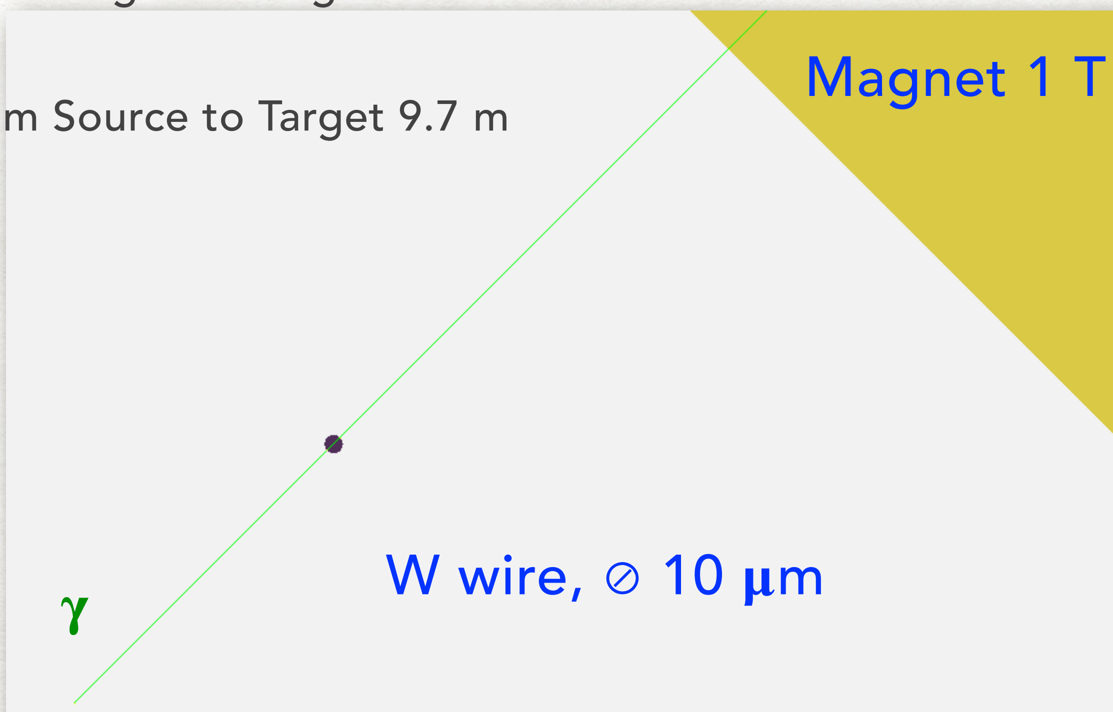


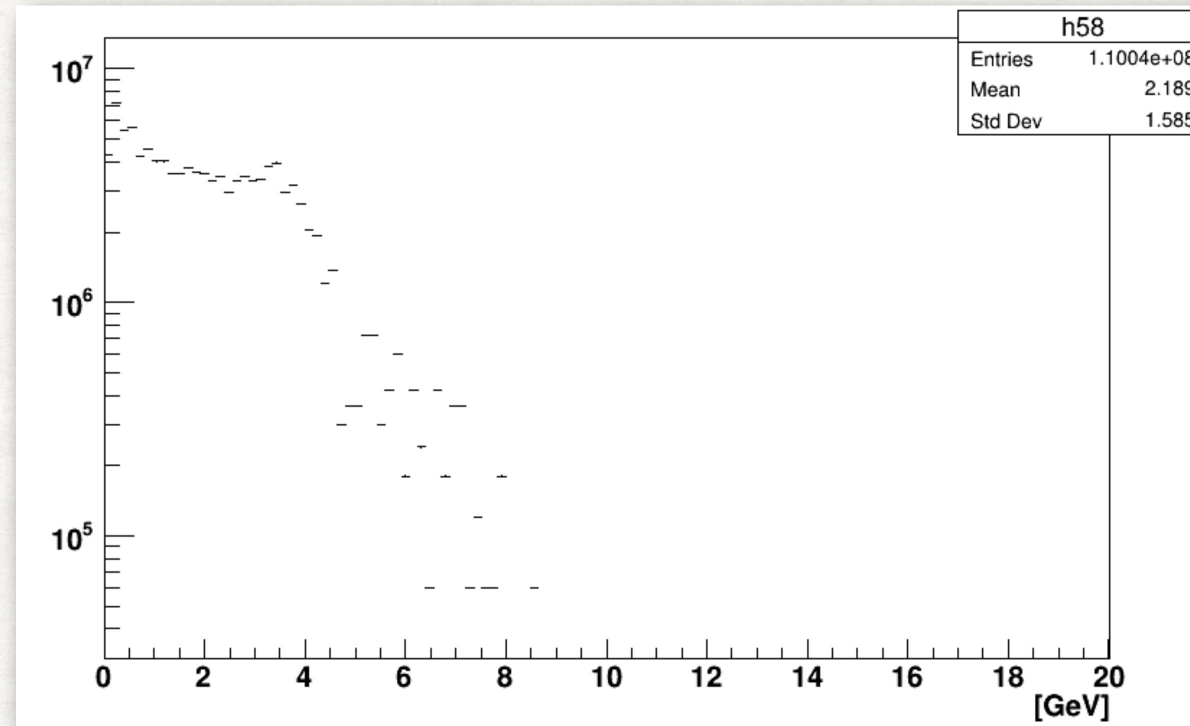


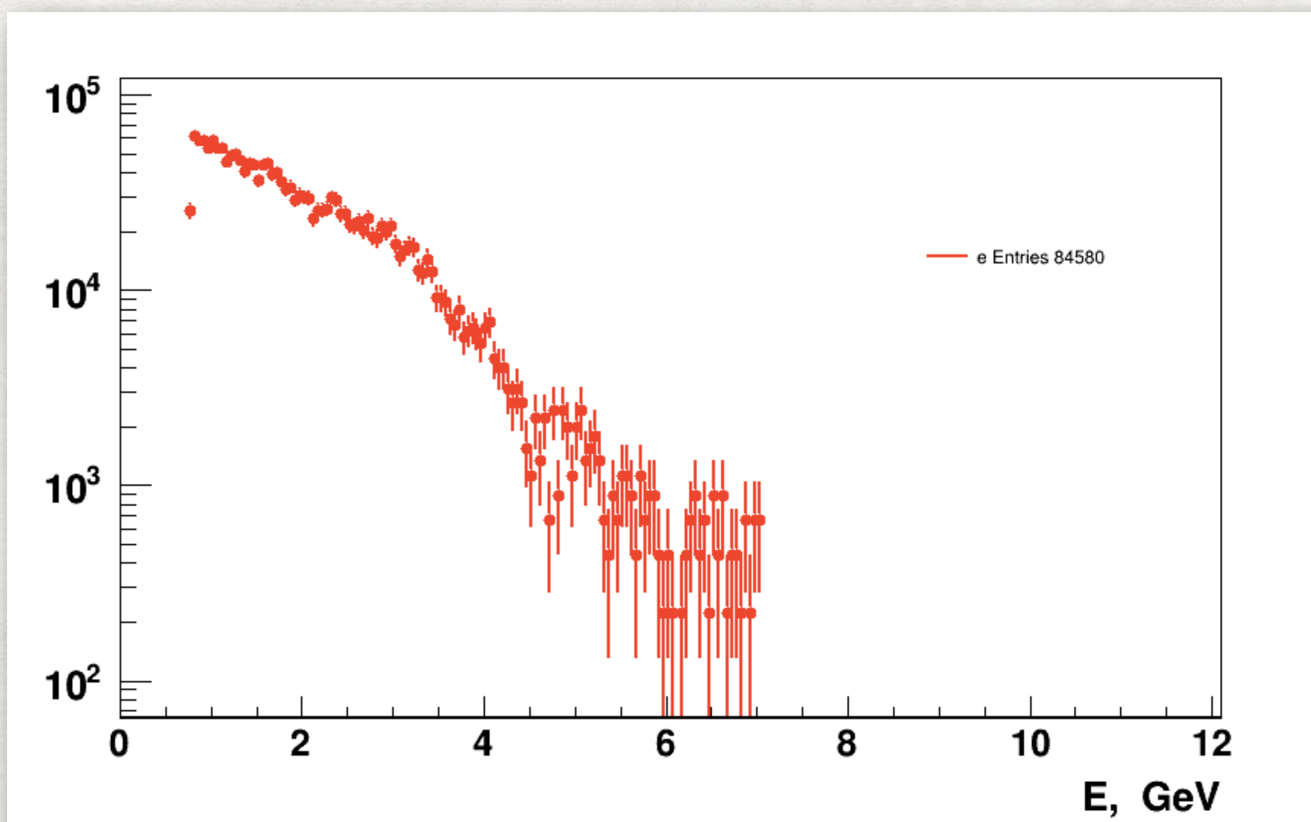
GEANT4 SIMULATION FOR THE WIRE CONVERTER

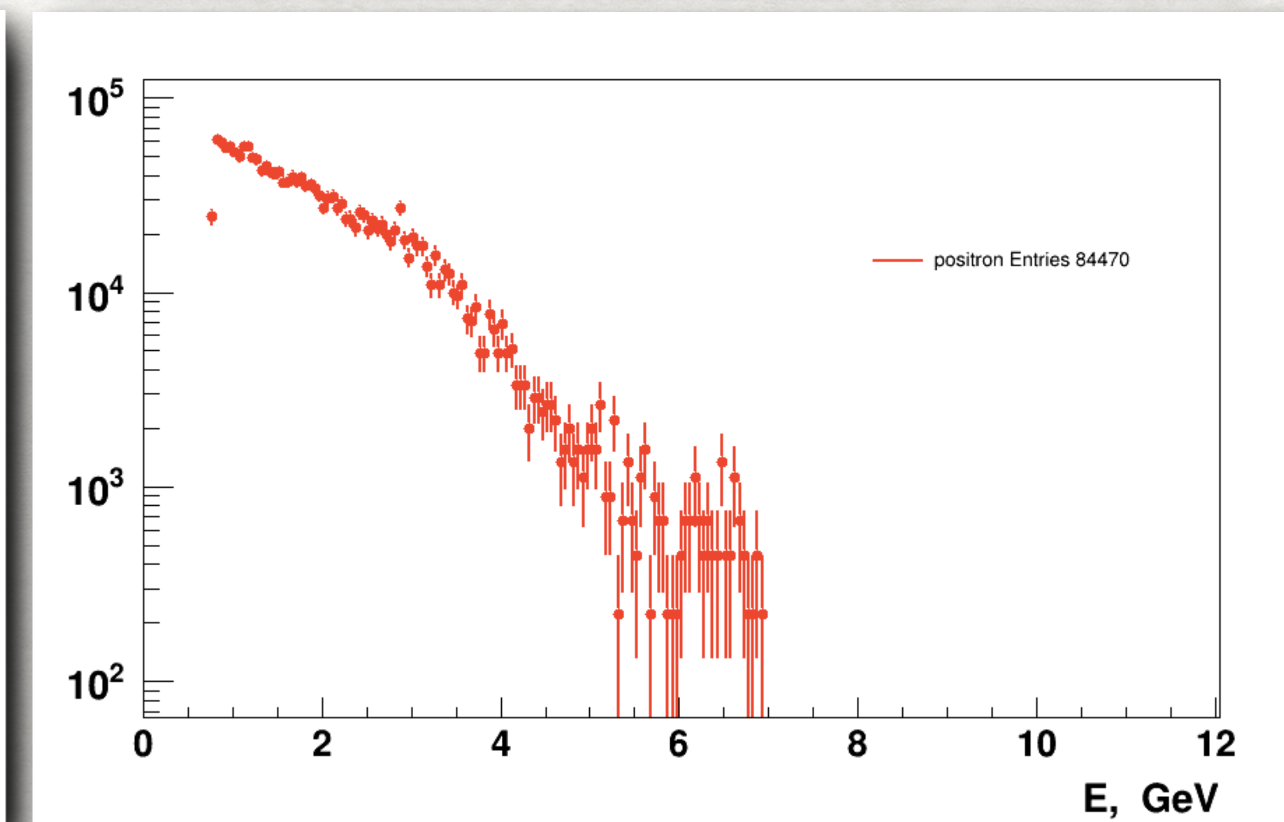
d from Target to Magnet 30 cm

d from Source to Target 9.7 m





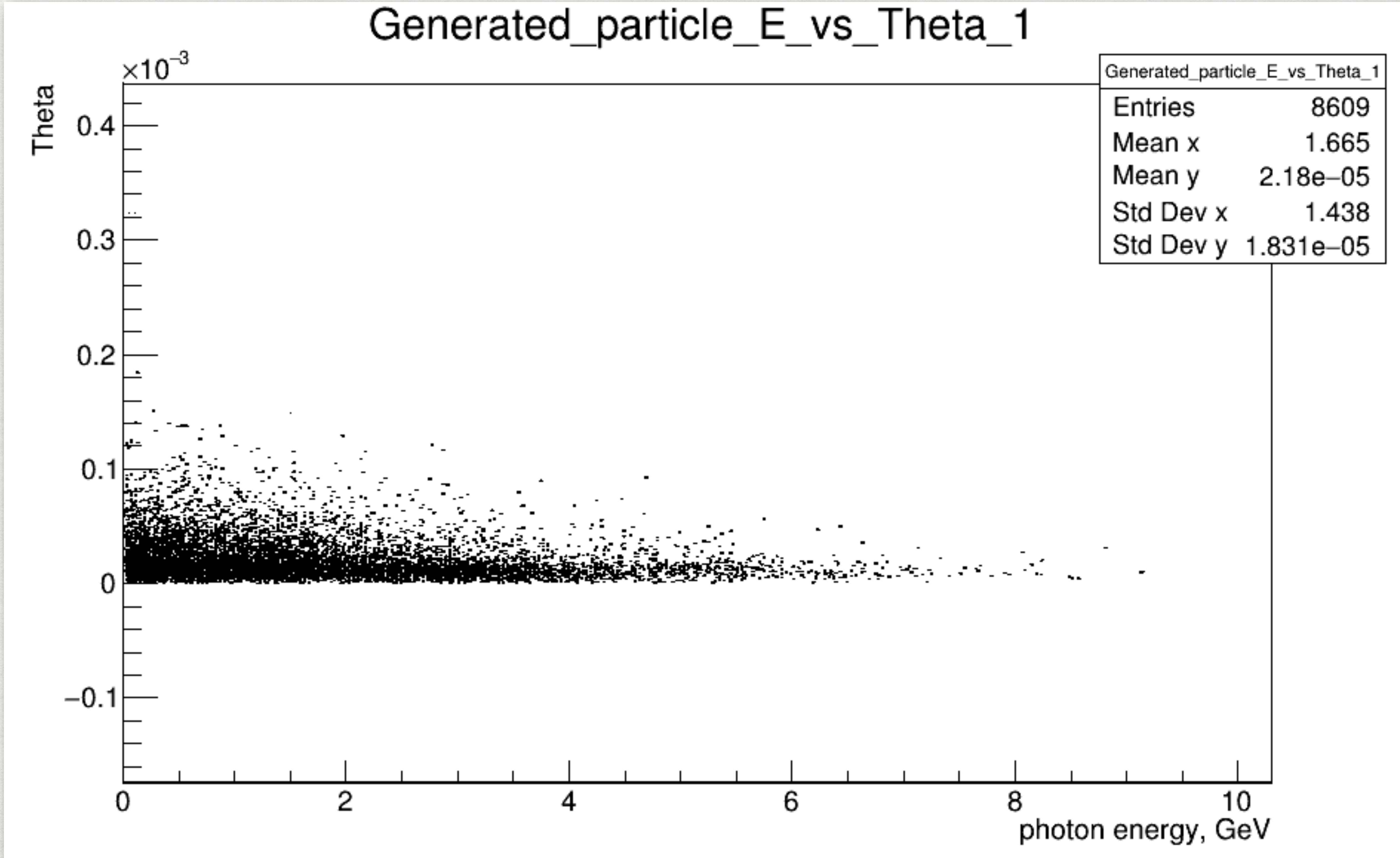




WHAT'S DONE & WHAT'S NEXT

- Estimated the absolute number of forward photons: from theory and MC+GEANT4 simulation: very high fluencies
- It is possible to restore the position of kinematic edges with good accuracy
- Non-uniform Laser Intensity (ξ) makes the kinematic edges from different n not visible, especially for high ξ
- Preliminary was studied the feasibility of usage W wire as converter target. For nominal XEFL beam the ξ =0.1 10 m from IP the number of e ~8e4.
    - for reduced intensity further could be reduced by tuning the XEFL gun this number will be ~e2-e3
    - also to go further from IP
    - to scan HICS photons in transverse plane with wire target
    - to study gas jet target

BACK UP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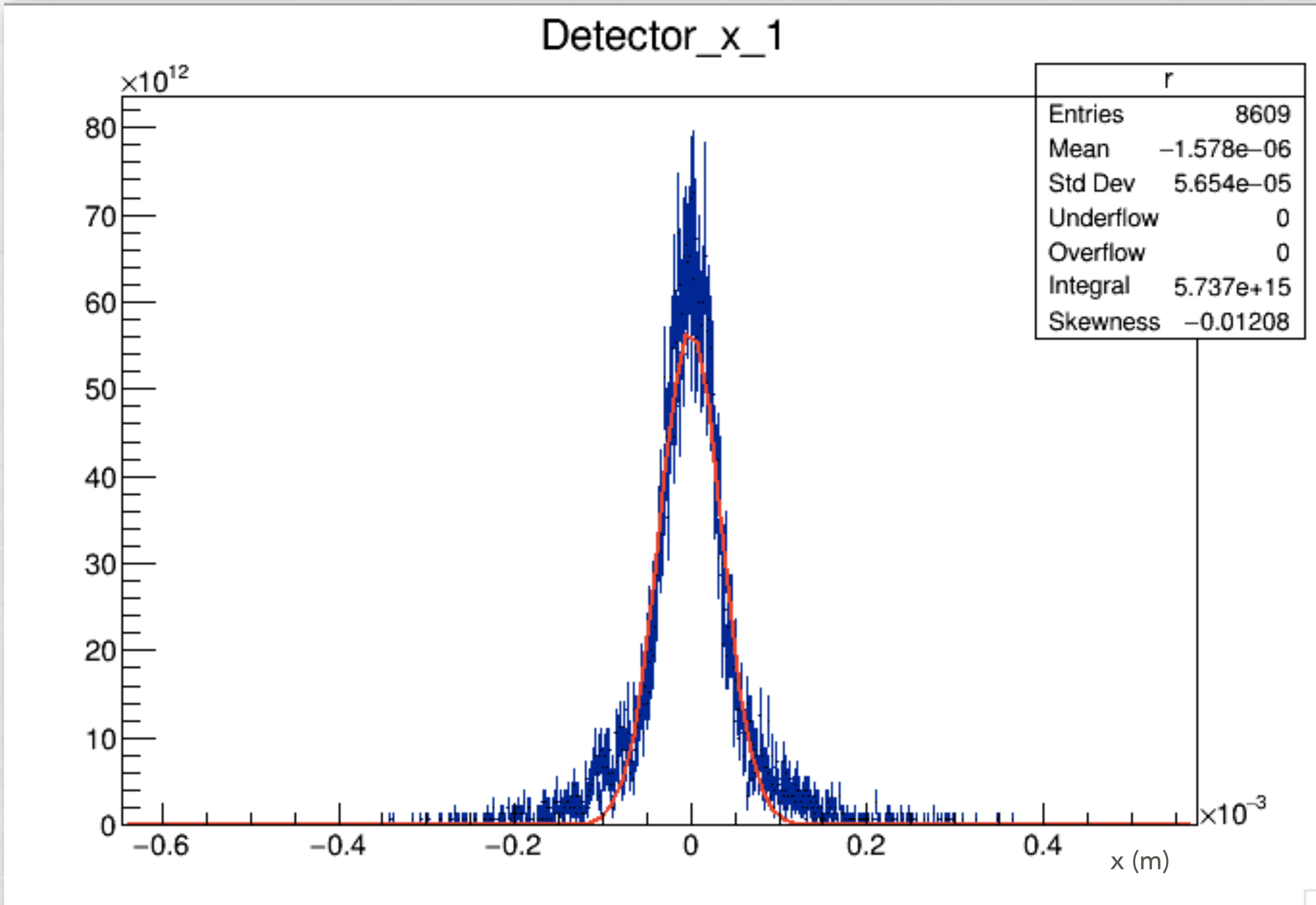
×10^-3
Theta
Generated_particle_E_vs_Theta_1
Entries 8609
Mean x 1.665
Mean y 2.18e−05
Std Dev x 1.438
Std Dev y 1.831e−05
0.4
0.3
0.2
0.1
0
−0.1
0
2
4
6
8
10
photon energy, GeV

N OF PHOTONS

- for W wire, detector on distance of **3m** from IP




```
Integral 5.7366667e+09
```

```
Integral(-0.5e-5,0.5e-5)
```
<- 10 um of W wire

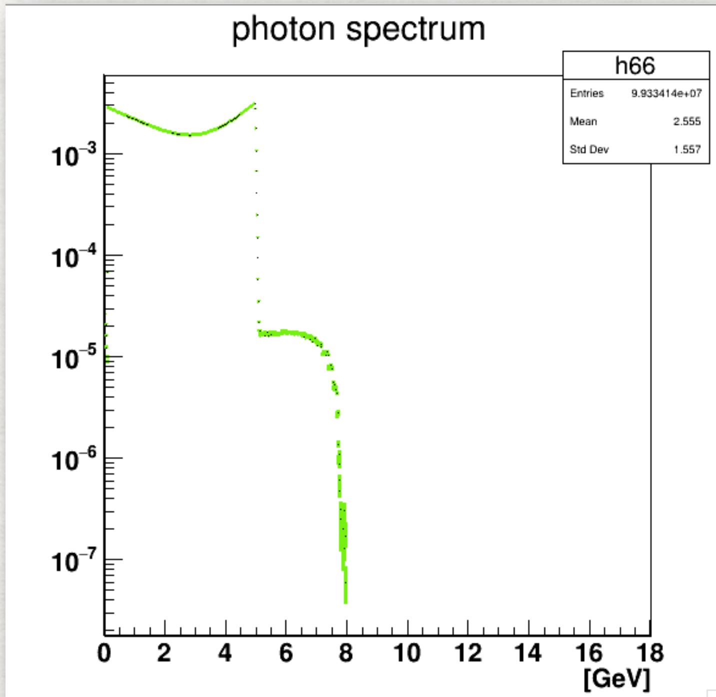
```
(double) 5.6544765e+08
Integral(-0.5e-5,0.5e-5)*0.003
```
<-0.3% X0

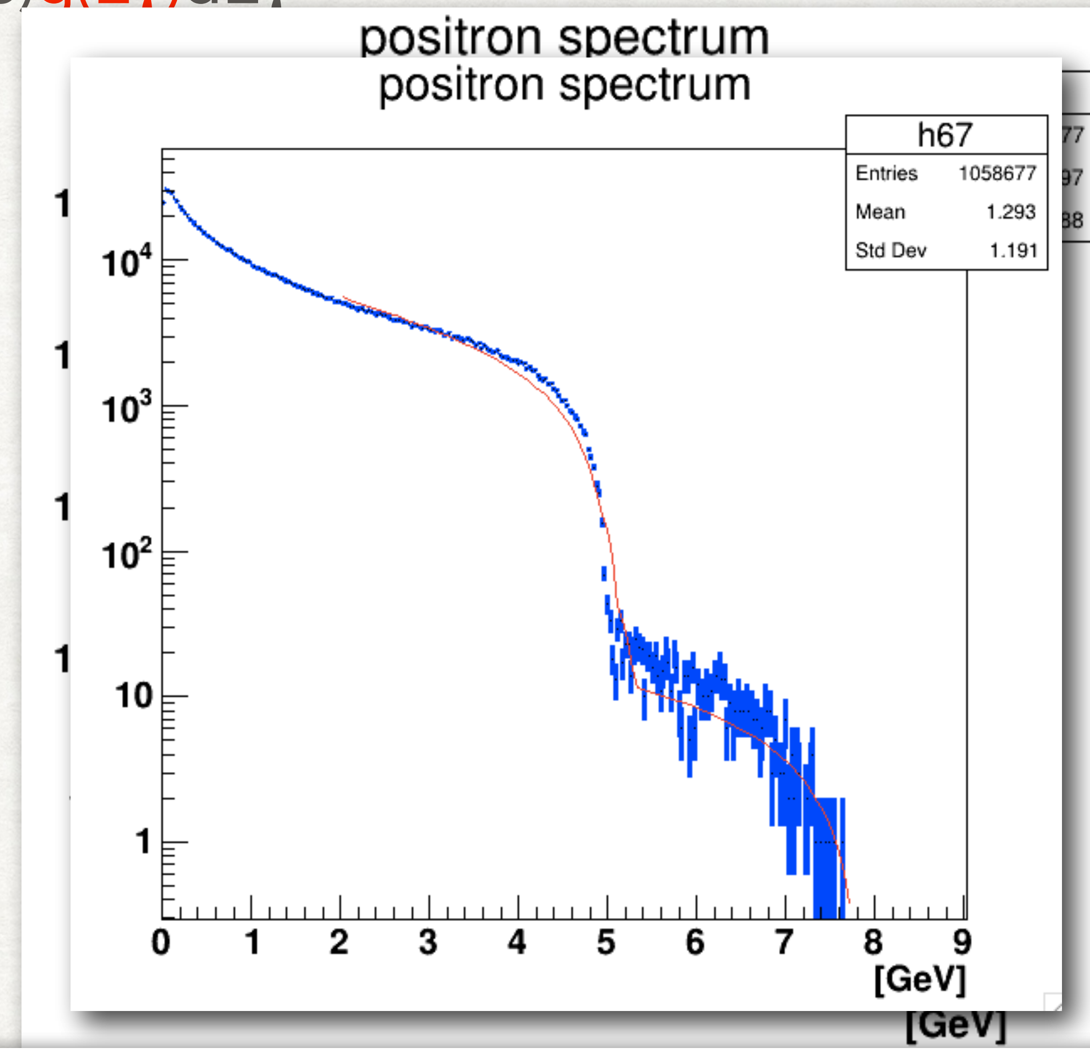
```
(double) 1696343.0 =2e+6
```
<-still a lot

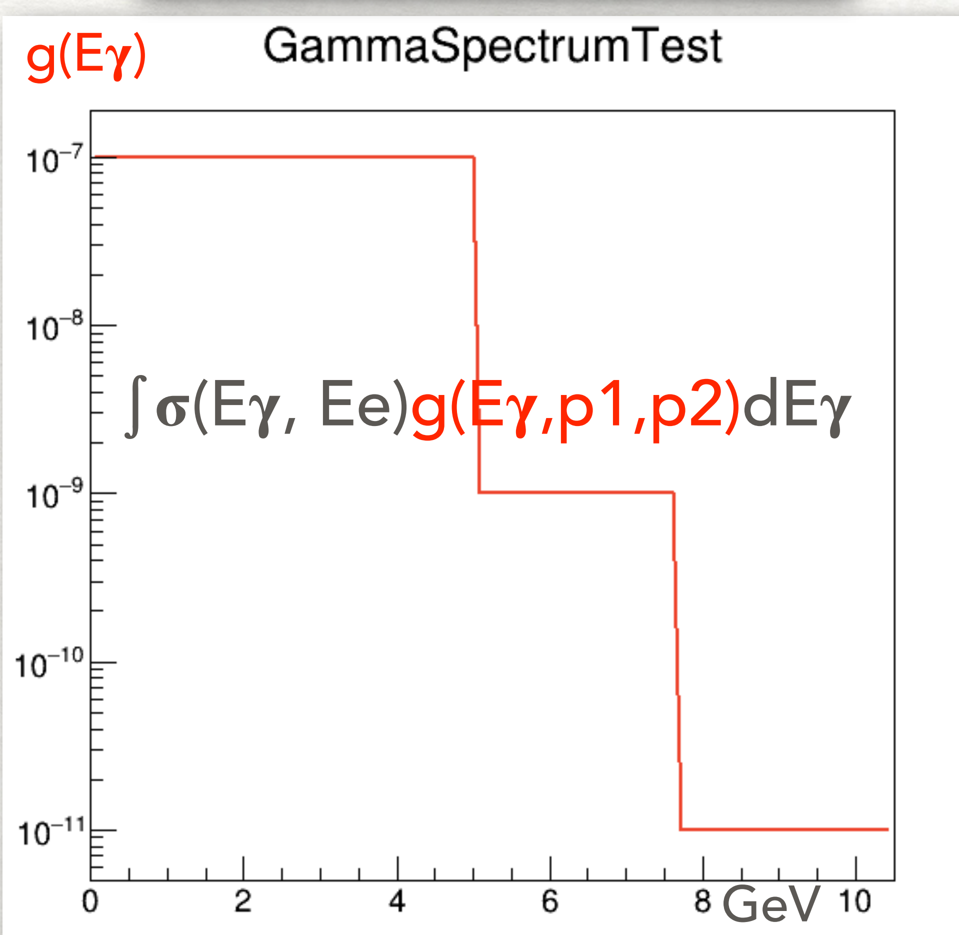
TESTING: COMPTON-LIKE

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

target material (W), its thickness 50 um








```
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  EXT PARAMETER                APPROXIMATE        STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  p0           0.00000e+00     fixed
   2  p1           2.83448e+06   5.52378e+03  -0.00000e+00   7.82770e-07
   3  p2           5.03009e+00   2.31482e+00   0.00000e+00  -1.91210e+03
   4  p3           0.00000e+00     fixed
   5  p4           1.28127e+04   5.88782e+02   0.00000e+00  -7.97467e-06
   6  p5           7.77573e+00   1.76479e+00  -0.00000e+00   3.62273e+02
   7  p6           1.00000e+00     fixed
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  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
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   3  p2           5.03009e+00     fixed
   4  p3           0.00000e+00     fixed
   5  p4           1.28143e+04   6.03570e+02   1.80570e+01   8.41417e-08
   6  p5           7.77573e+00     fixed
   7  p6           1.00000e+00     fixed
```
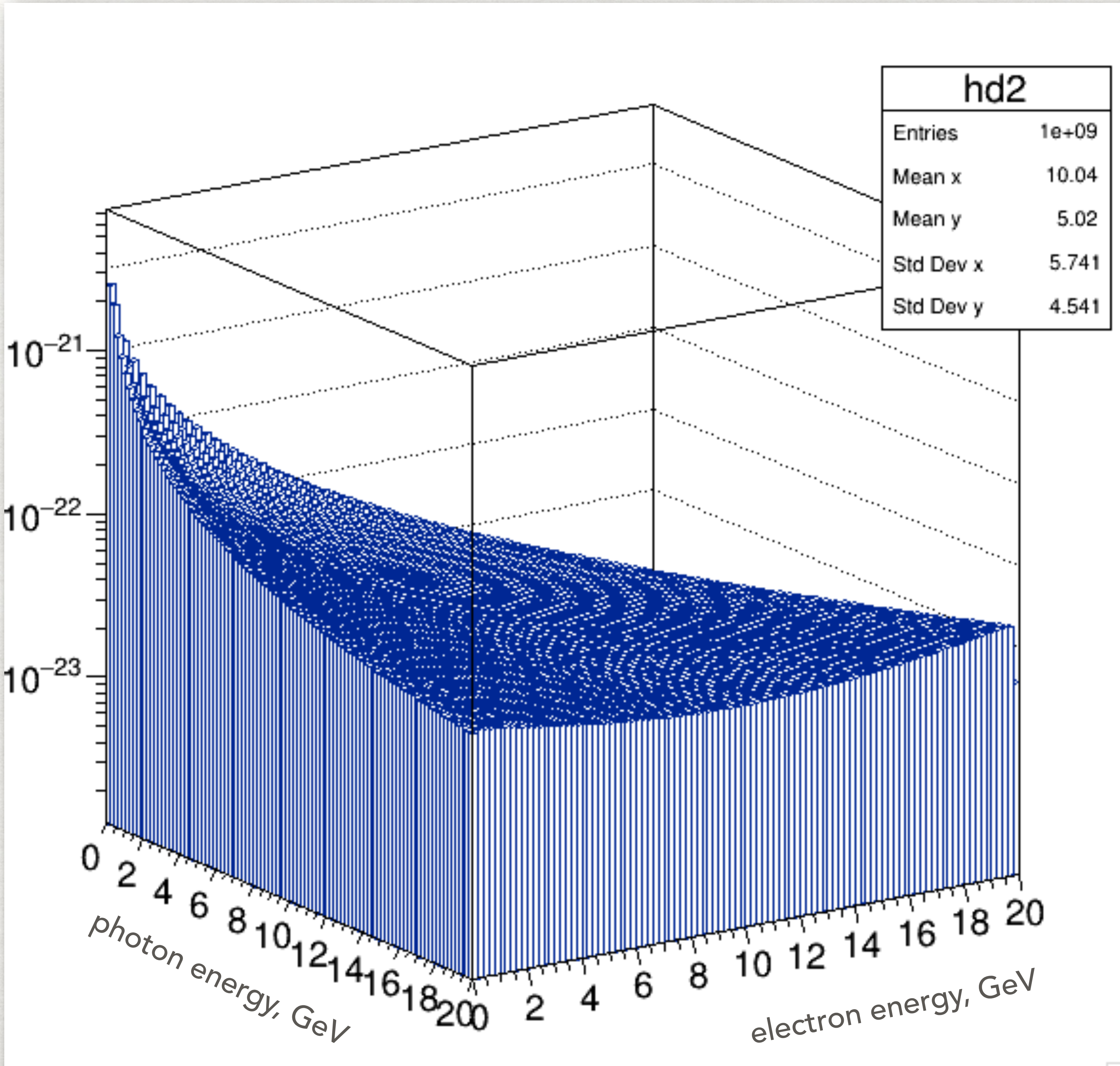
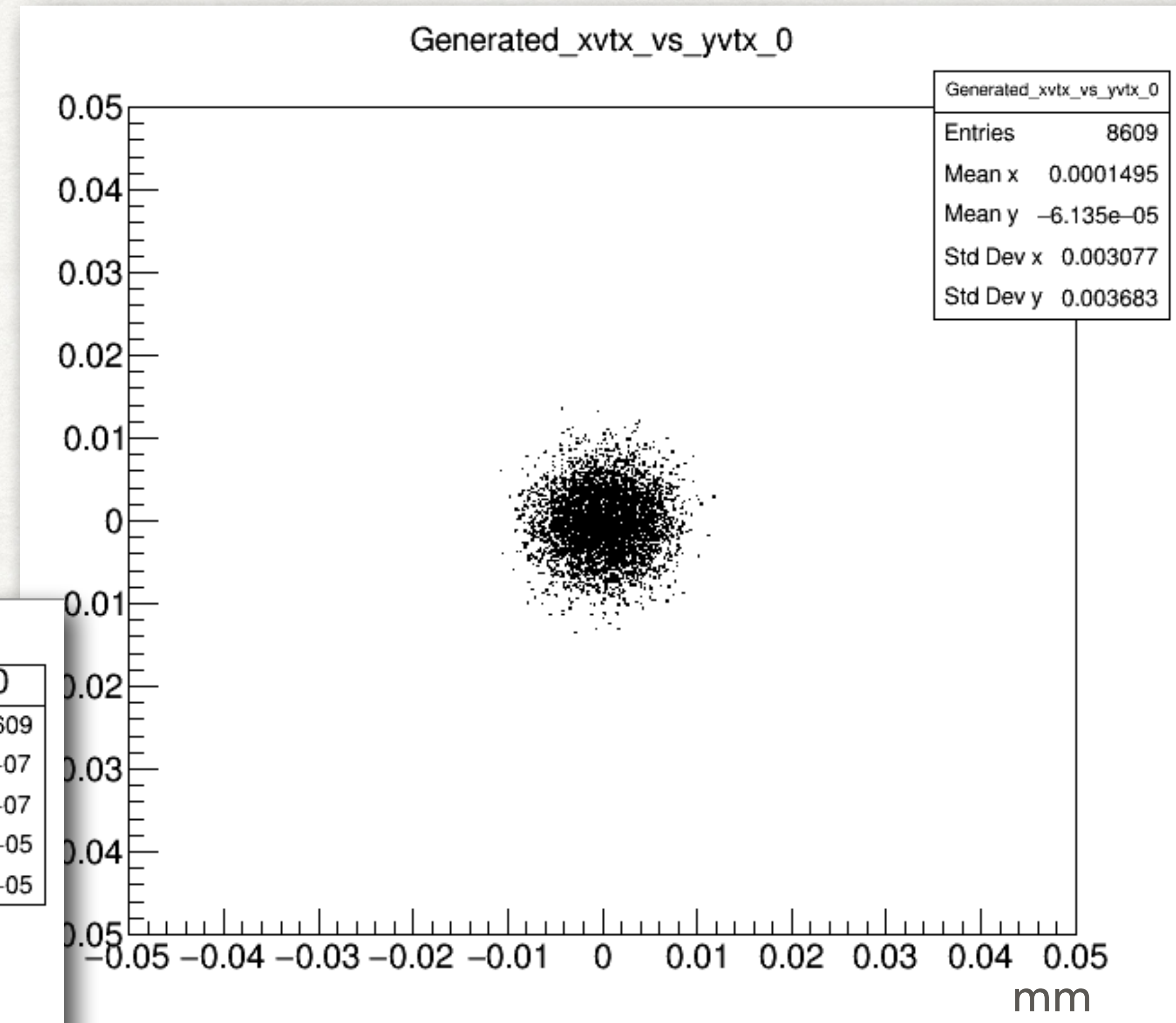

DIFFERENTIAL CROSS-SECTION FROM GEANT4

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Generated_xvtx_vs_yvtx_0
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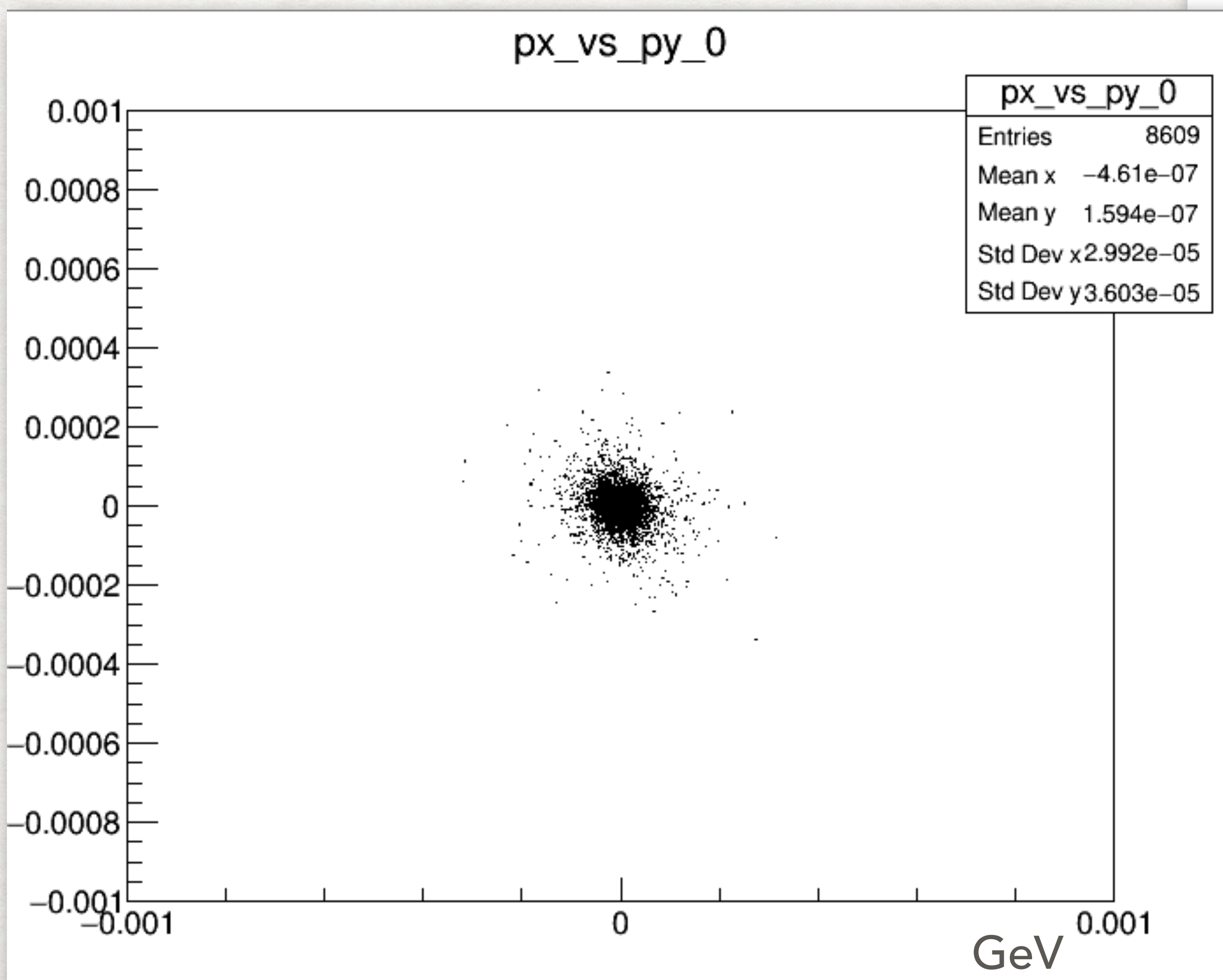
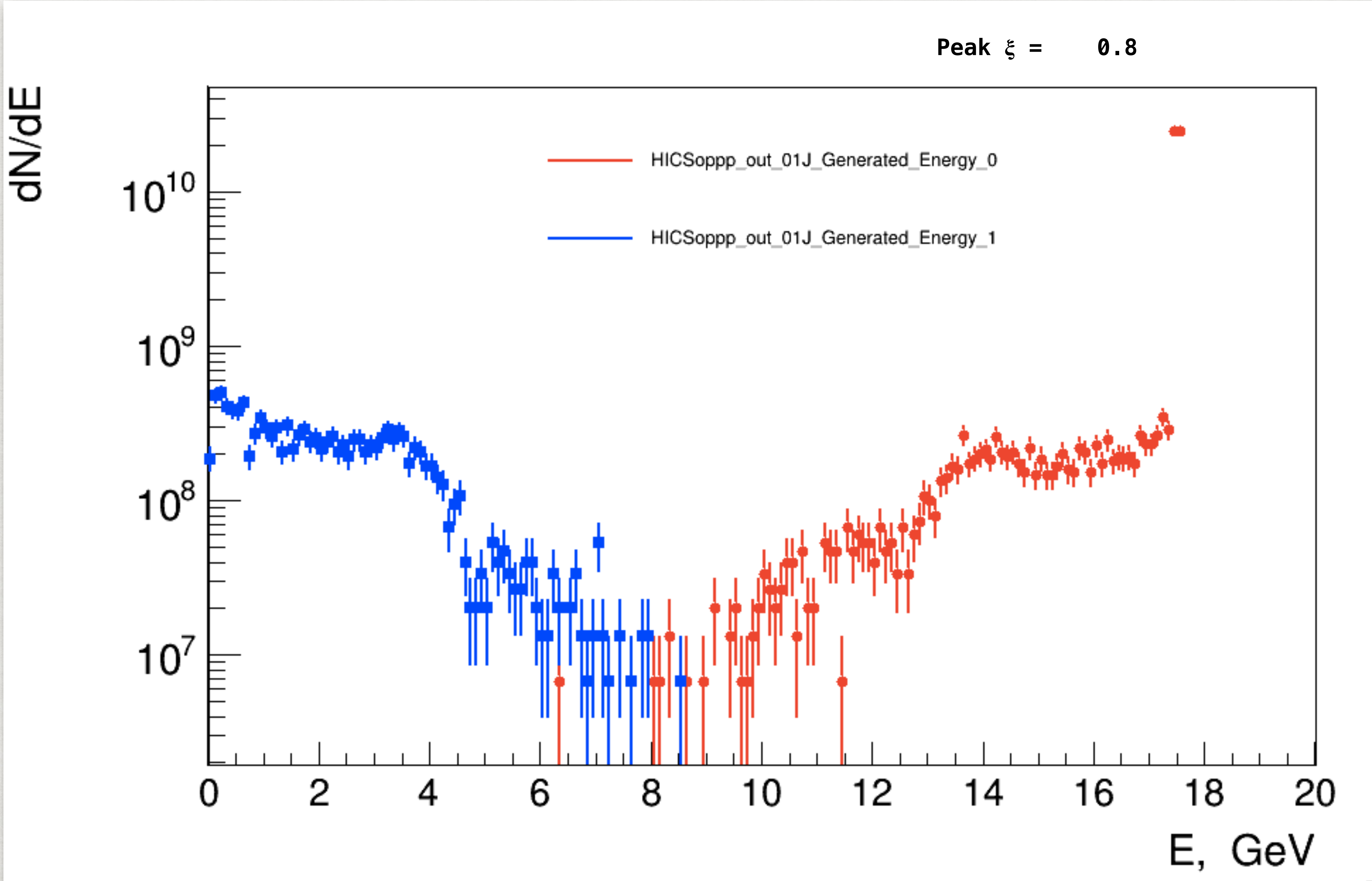
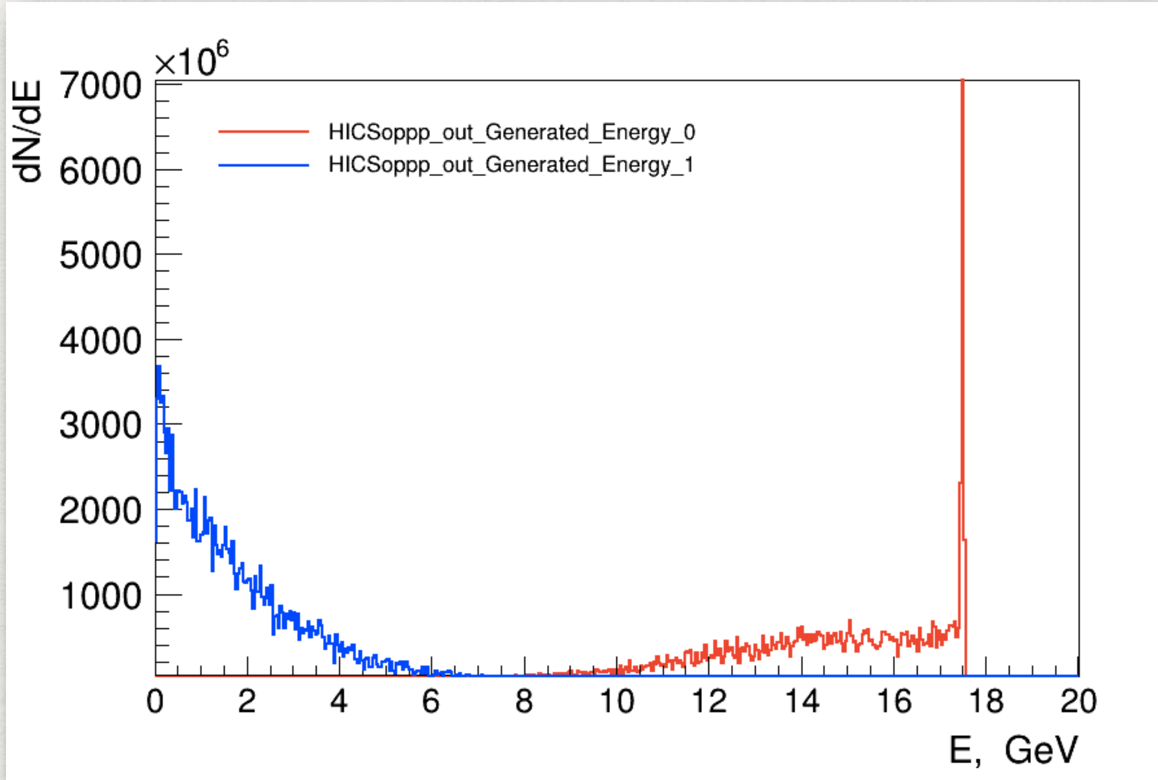
Mean y −6.135e−05
Std Dev x 0.003077
Std Dev y 0.003683
mm


px_vs_py_0
px_vs_py_0
Entries 8609
Mean x −4.61e−07
Mean y 1.594e−07
Std Dev x 2.992e−05
Std Dev y 3.603e−05
GeV

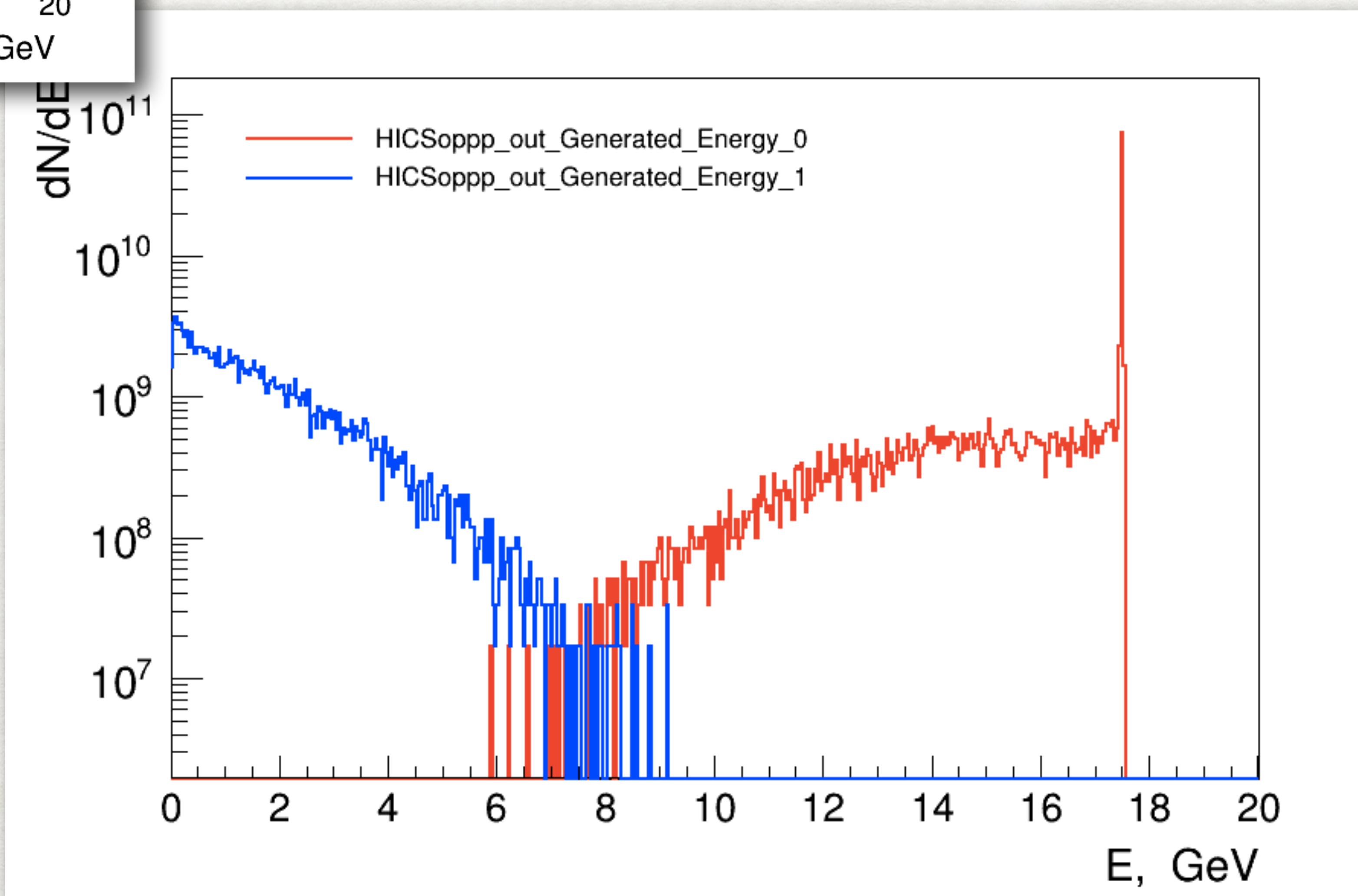
PHOTON AND ELECTRON SPECTRA FROM MC



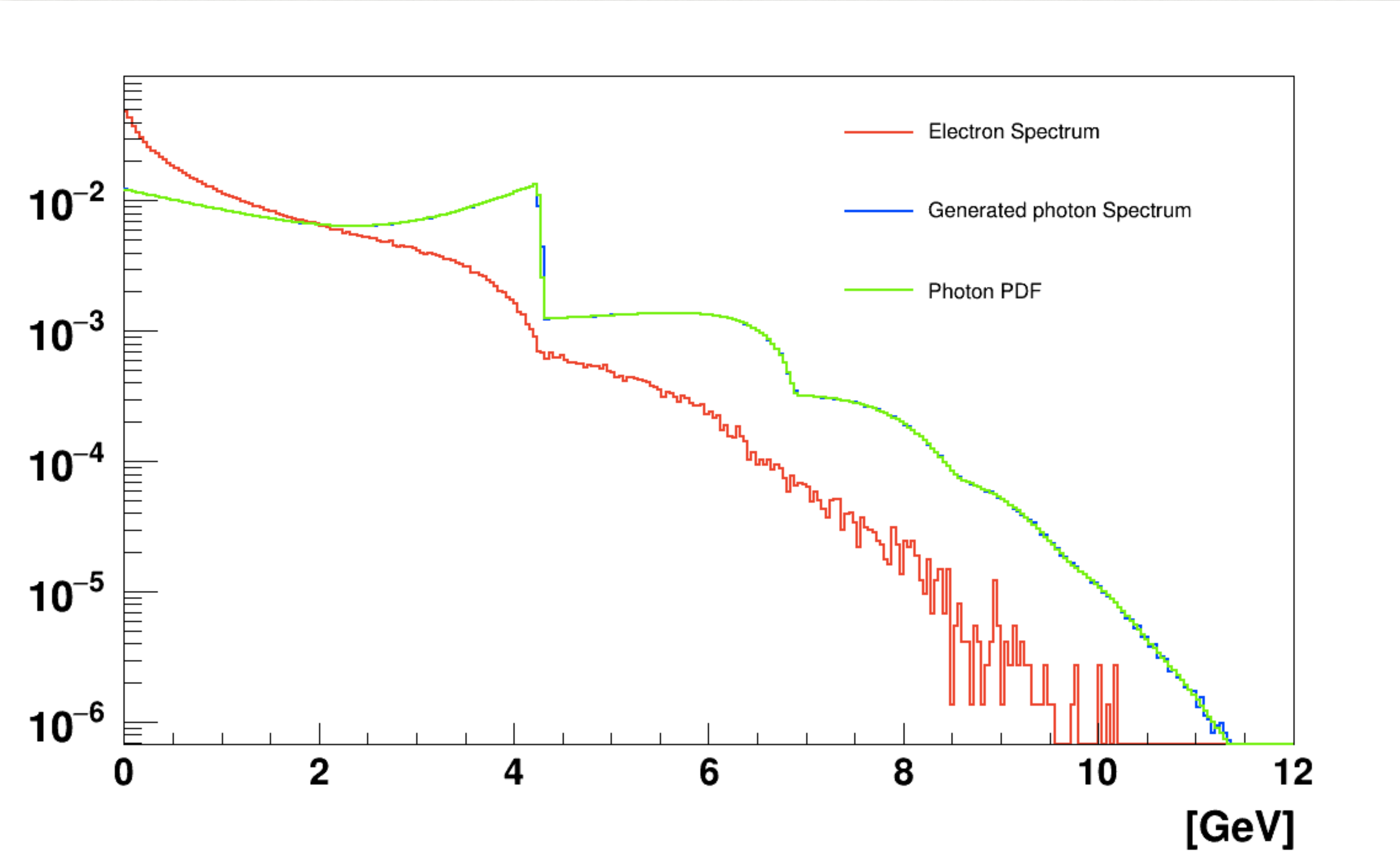
PHOTON AND ELECTRON SPECTRA FROM MC



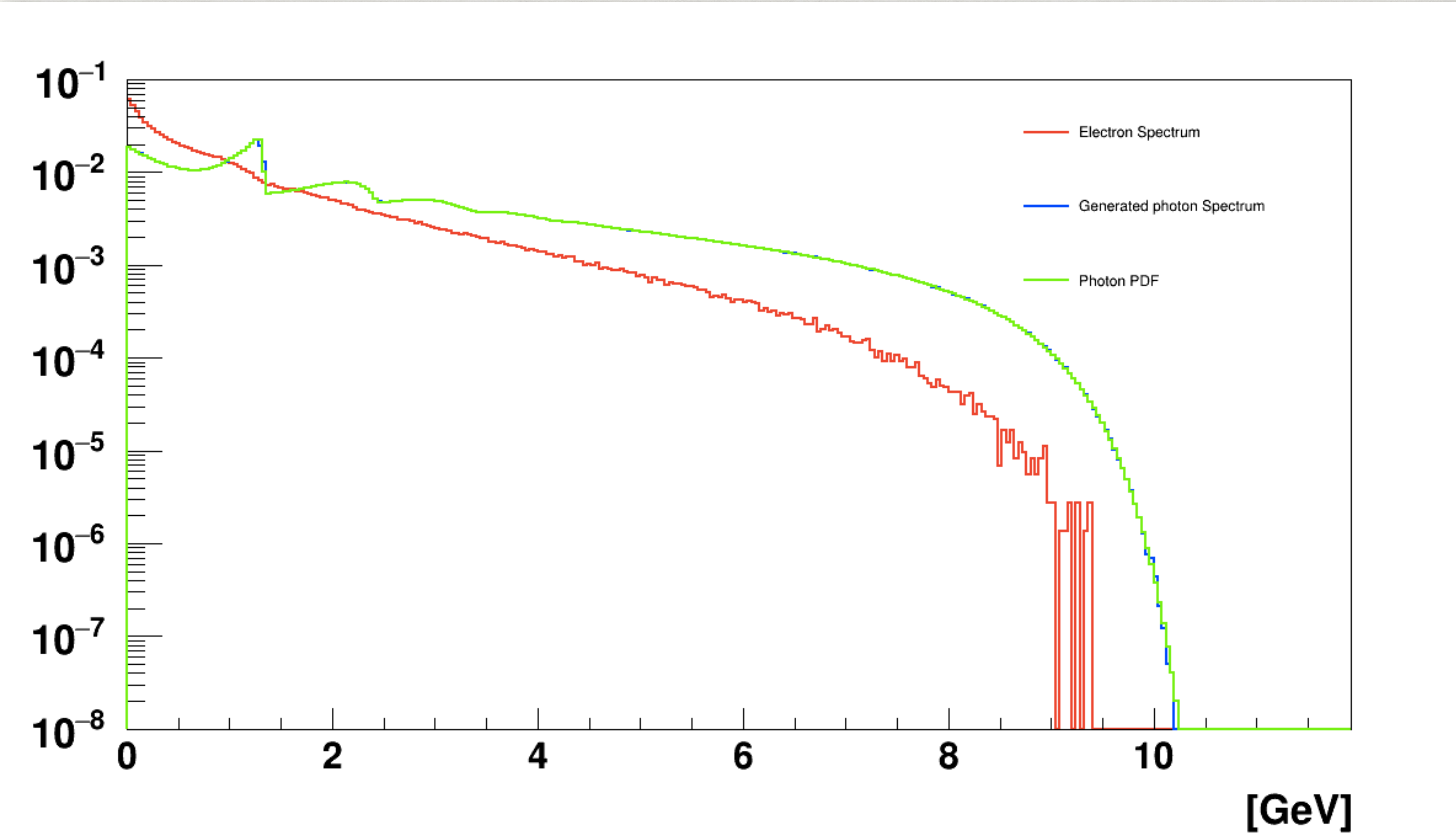
Peak xi = 2.0148



GAMMA AND ELECTRON SPECTRA FOR ξ=0.5



GAMMA AND ELECTRON SPECTRA FOR ξ=2.0



TOTAL X-SECTION

XCOM: Photon Cross Sections Database (The National Institute of Standards and Technology (NIST))

A web database which can be used to calculate photon cross sections for scattering, photoelectric absorption and pair production, as well as total attenuation coefficients, for any element, compound or mixture ($Z \leq 100$), at energies from 1 keV to 100 GeV.

G4BetheHeitlerModel from Geant4

total cross section per atom in GEANT4

E_γ = incident gamma energy, and $X = \ln(E_\gamma / m_e c^2)$

The total cross-section has been parameterised as :

$$\sigma(Z, E_\gamma) = Z(Z+1)\left[F_1(X) + F_2(X)\,Z + \frac{F_3(X)}{Z}\right]$$

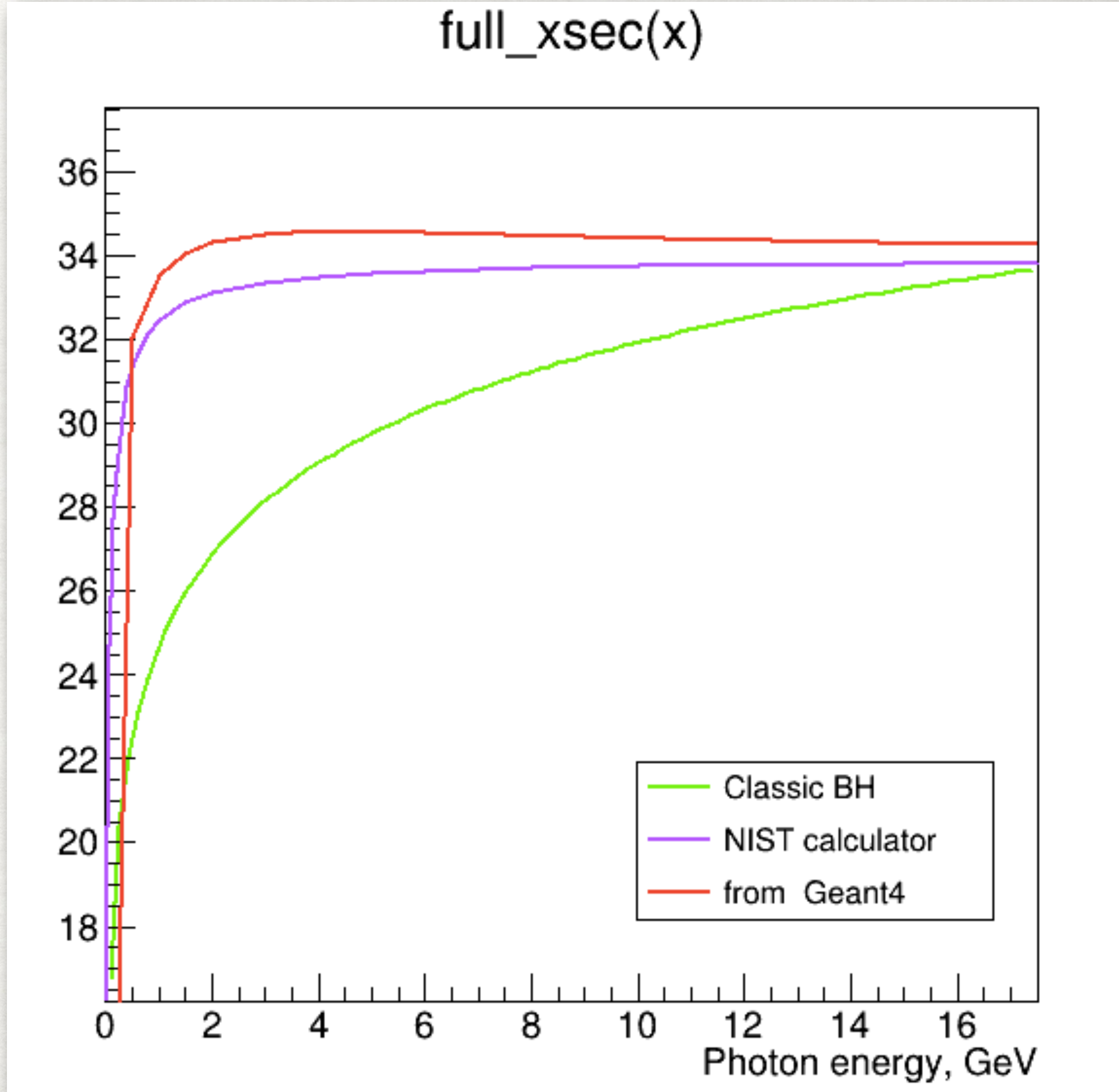
with :

$$\begin{aligned} F_1(X) &= a_0 + a_1 X + a_2 X^2 + a_3 X^3 + a_4 X^4 + a_5 X^5 \\ F_2(X) &= b_0 + b_1 X + b_2 X^2 + b_3 X^3 + b_4 X^4 + b_5 X^5 \\ F_3(X) &= c_0 + c_1 X + c_2 X^2 + c_3 X^3 + c_4 X^4 + c_5 X^5 \end{aligned}$$

The parameters a_i, b_i, c_i were fitted to the data [hubb80].

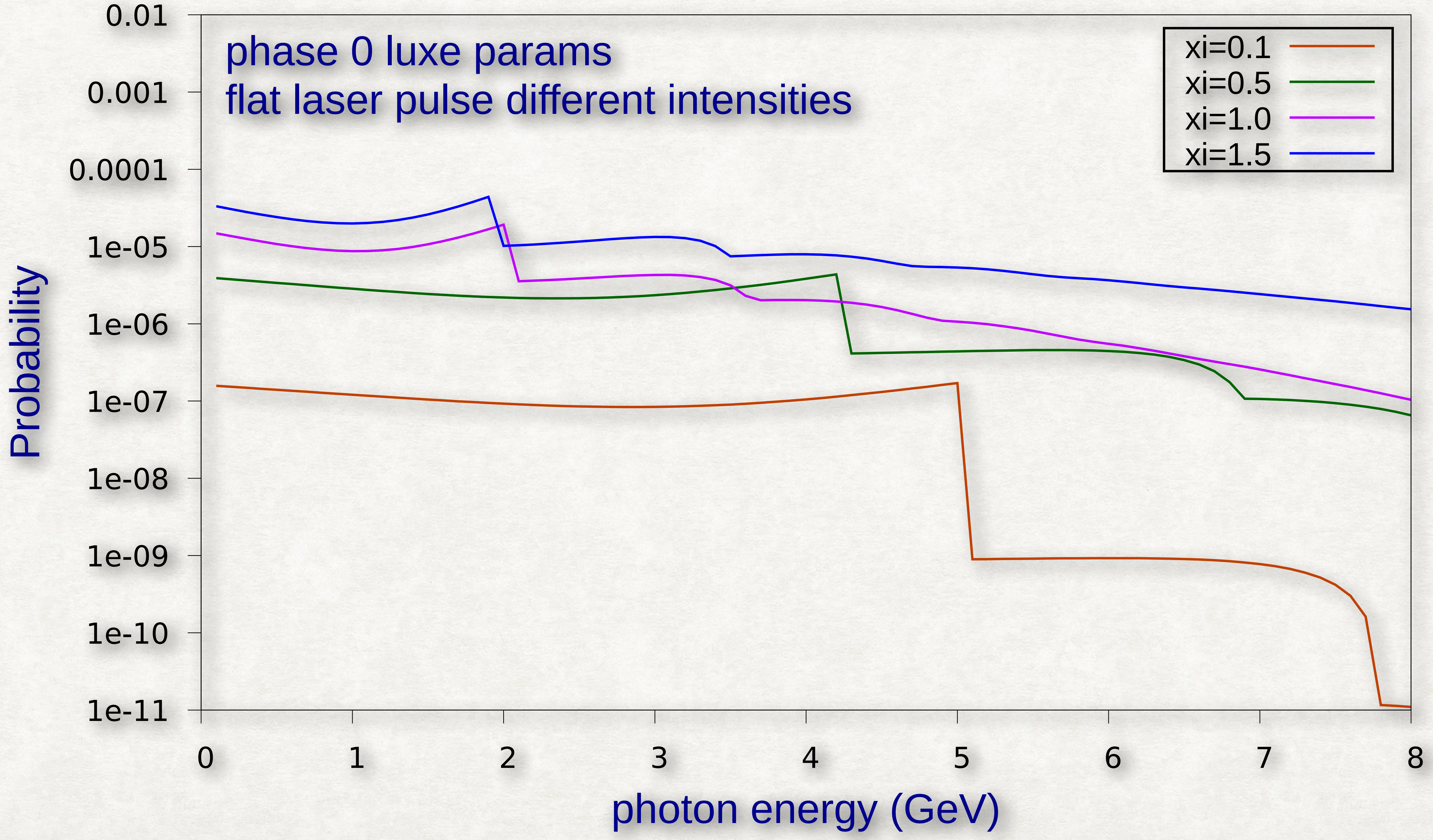
This parameterisation describes the data in the range :

$$\left.\begin{array}{c} 1 \leq Z \leq 100 \\ E_\gamma \in [1.5\ \text{MeV}, 100\ \text{GeV}] \end{array}\right\} \frac{\Delta\sigma}{\sigma} \leq 5\% \quad \text{with a mean value of} \approx 2.2\%$$

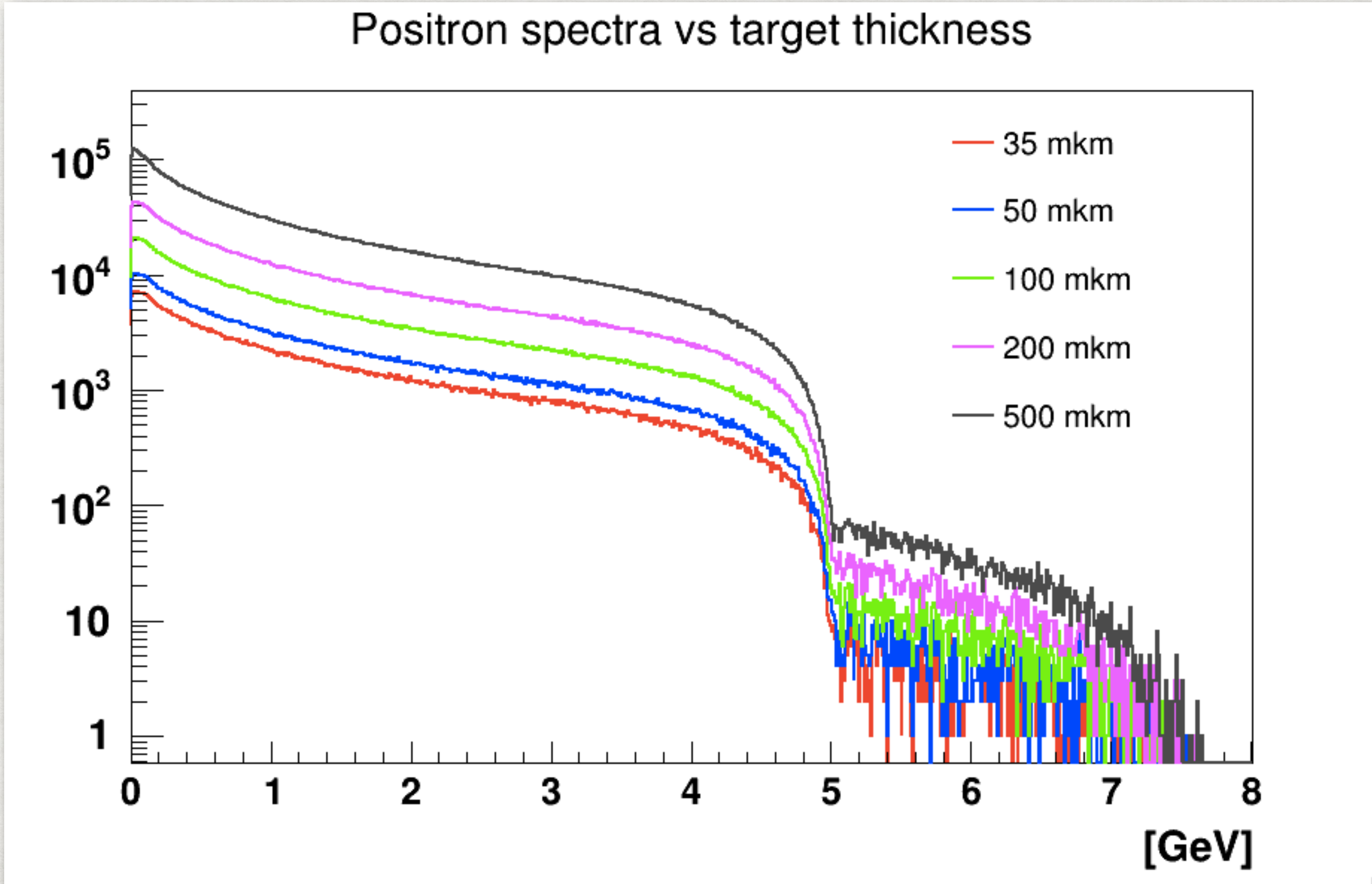


PHOTON SPECTRA VS LASER INTENSITIES

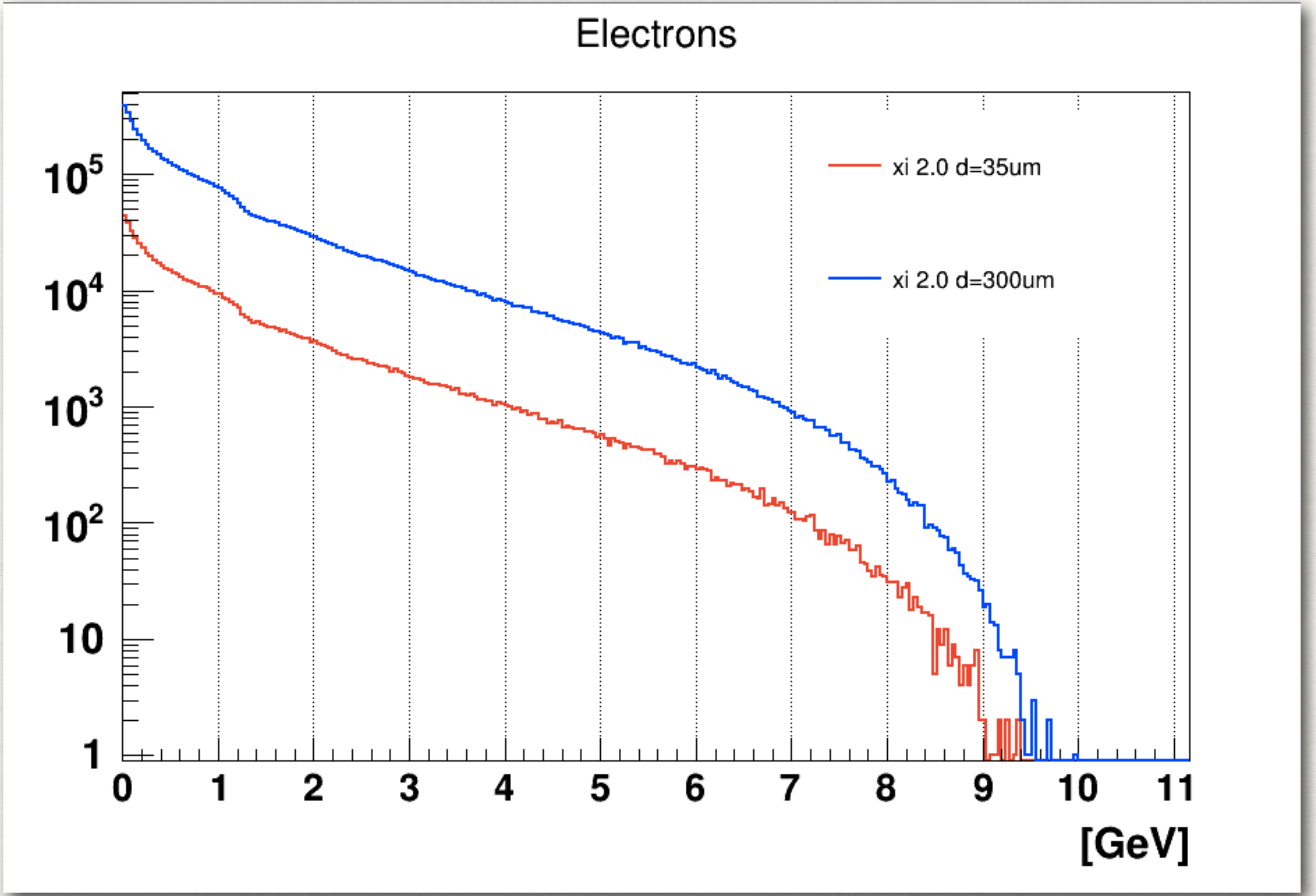
- plot from Anthony



POSITRON SPECTRA VS TARGET THICKNESS IN GEANT4



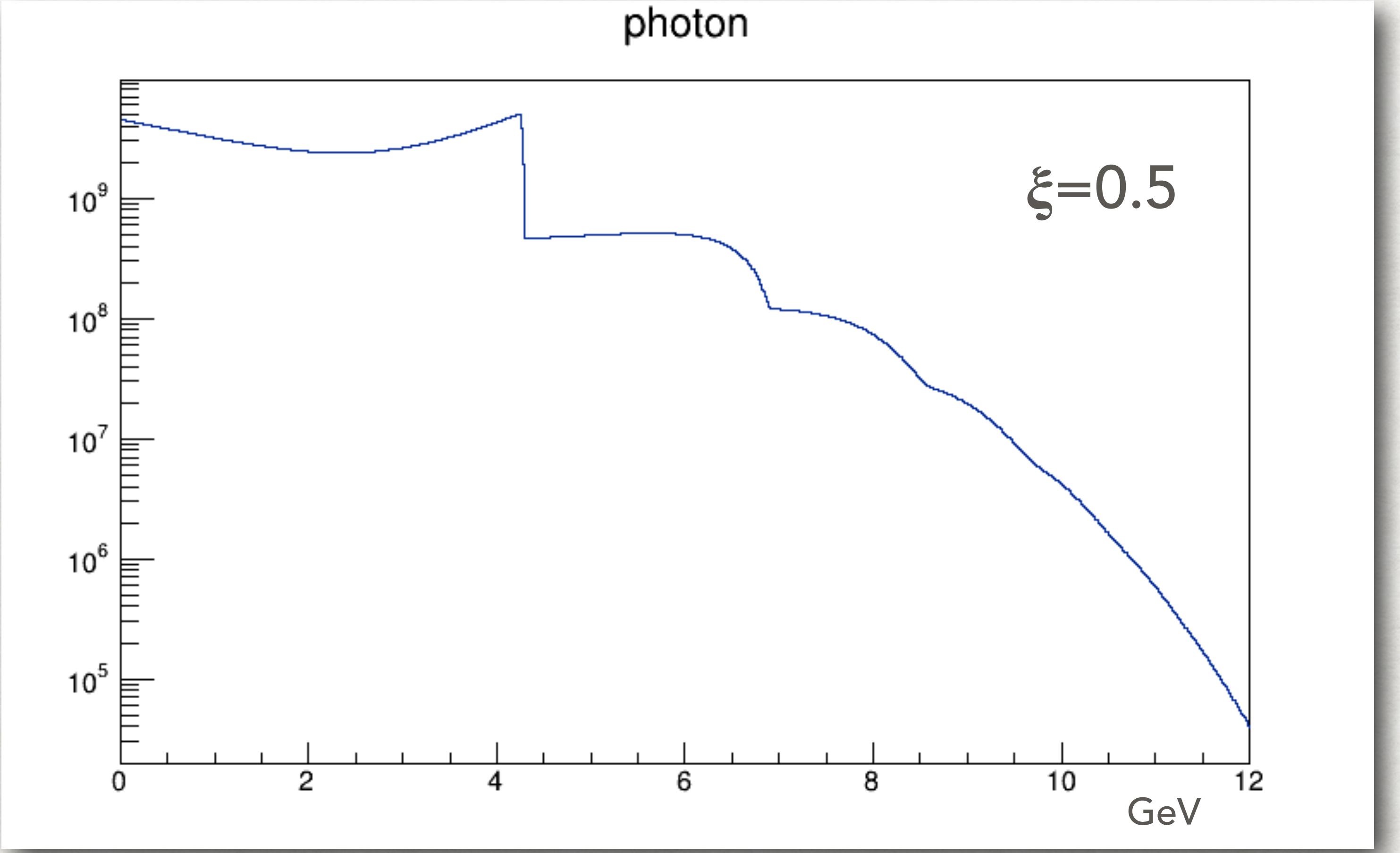
ELECTRON SPECTRA: 35 μ VS 300 μ



ABSOLUTE NUMBER OF PHOTONS

multiply the rate by the mass of the electron in eV, by 510998, then we will get differential transition rate per electron per 100 fs.

multiply it by the number of electrons in the bunch (6.25e+09) and by the laser pulse duration (t=35 fs) (t/ 100fs)

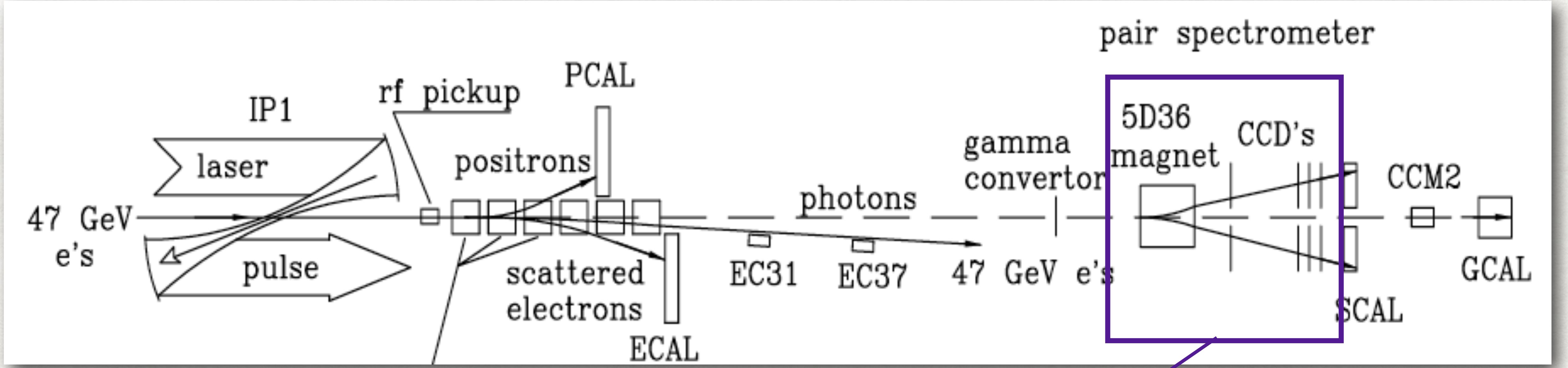


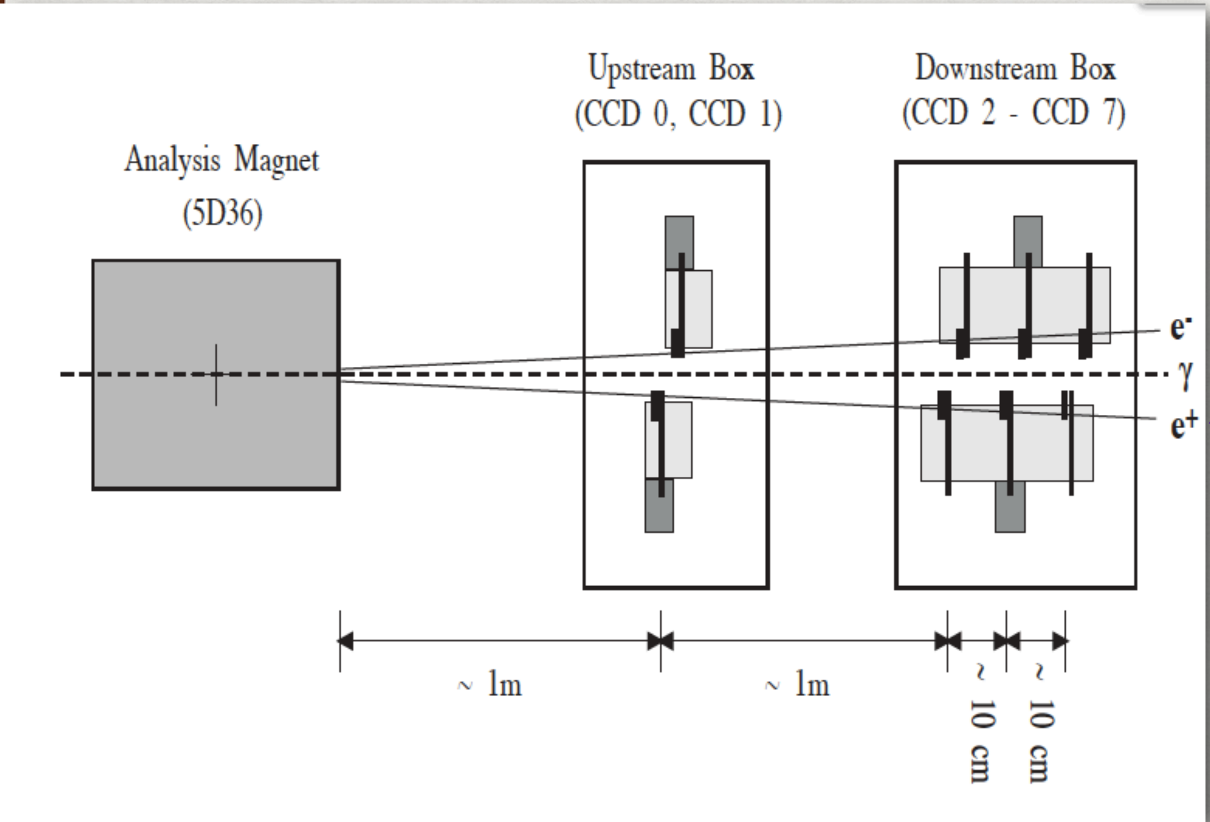
Integral:1.49255e+10

The transverse structure of the laser field is not taken into account in the data (and xi is Gauss max) and it is assumed that the laser field is uniform in transverse direction and it is essentially the same for all electrons

LAYOUT FOR THE E-144 EXPERIMENT

Photons produced at IP1 proceed down their own beamline through the converter foil and the tracking spectrometer





e-/e+ tracks were reconstructed using the 3 back planes of CCD's. All triplets of points from the back CCD planes of a given arm were tested to see if they fit a line intercepting a region near the center of the spectrometer magnet. This set of candidate tracks included many “fake" tracks from thermal noise, and combinatoric background of points from different particles.

No attempt was made to use the CCDs in the front plane of the spectrometer in this mode, since the high number of hits led to significant ambiguity in the projection from the back planes to the front.

CCD image sensors: pixel size 22.5*22.5 um

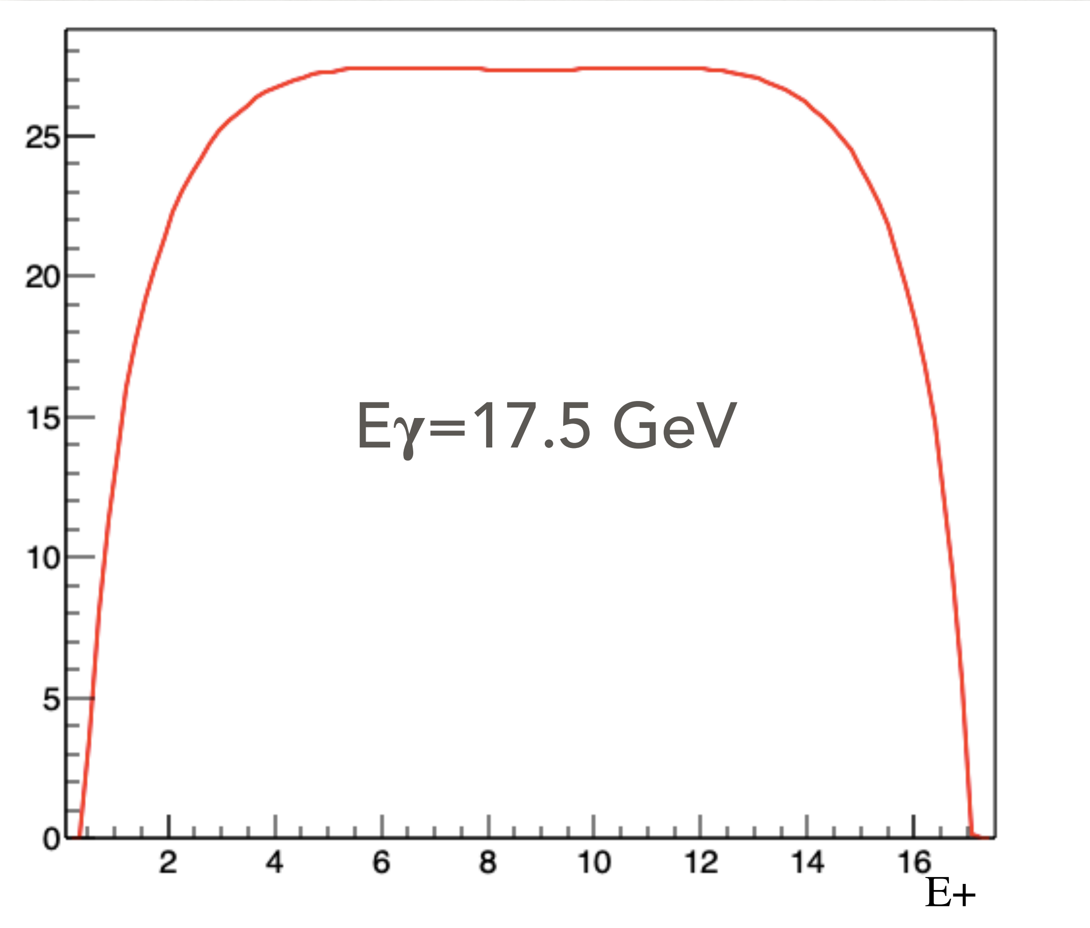
[EEV, 1242*1152].

THE CLASSICAL BETHE-HEITLER PAIR SPECTRUM

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

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

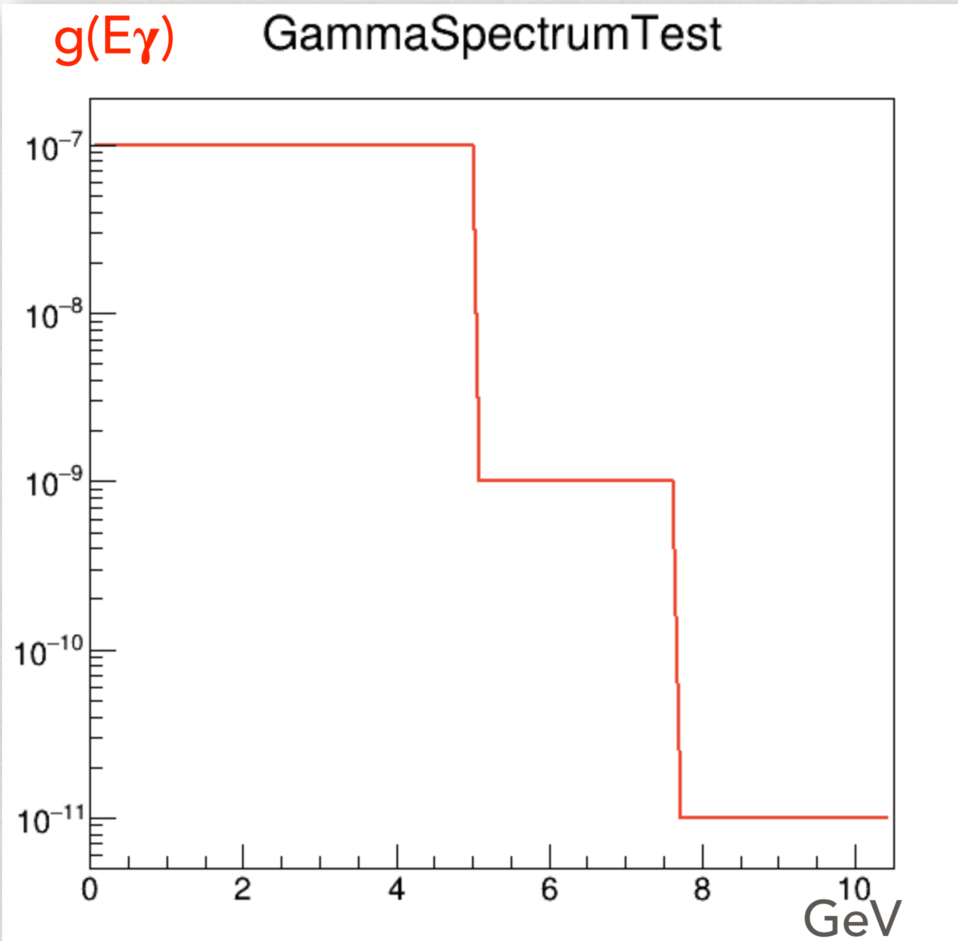
energies involved are large compared with mc^2

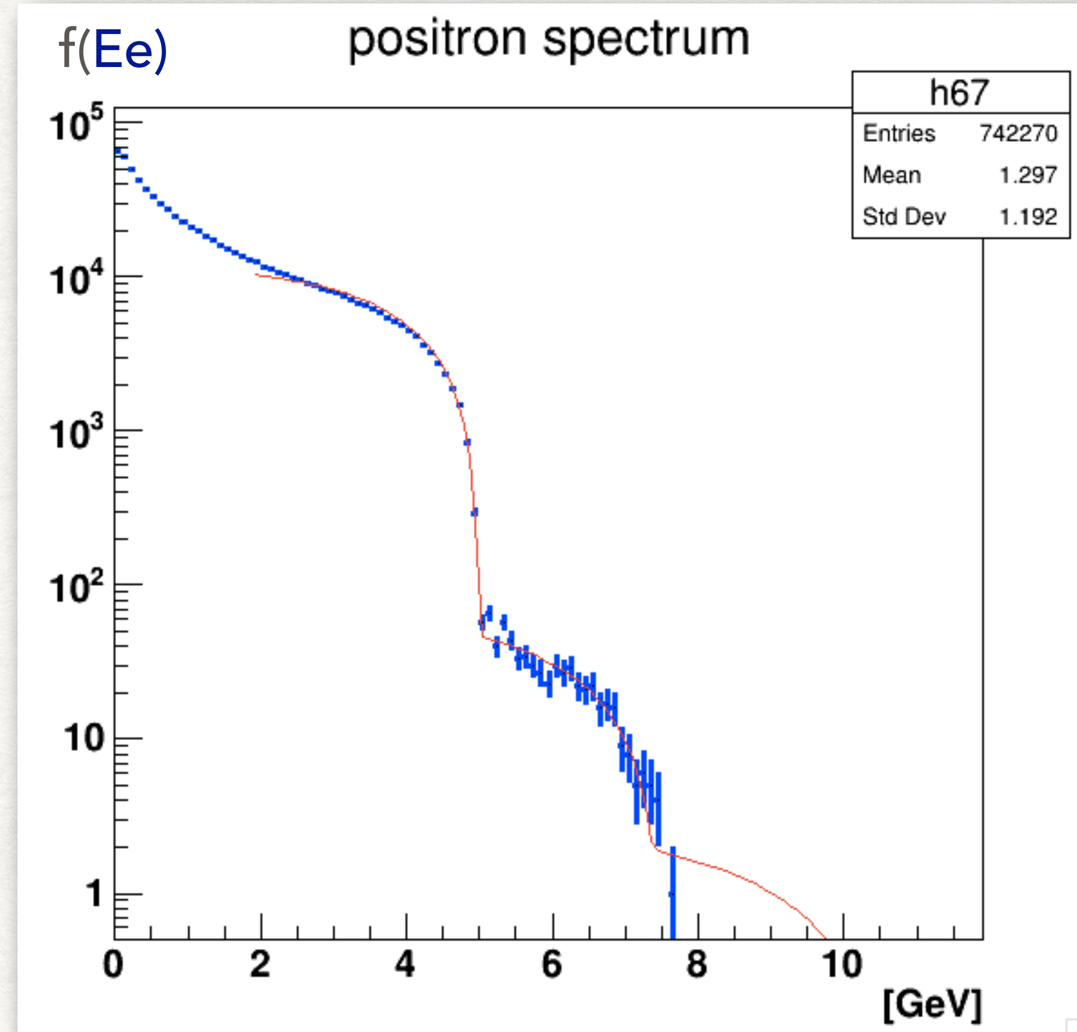


The idea - to check if any photon spectrum could be restored if we have the classical BH distribution and characteristic shapes of photon spectrum

TESTING: COMPTON-LIKE

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





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

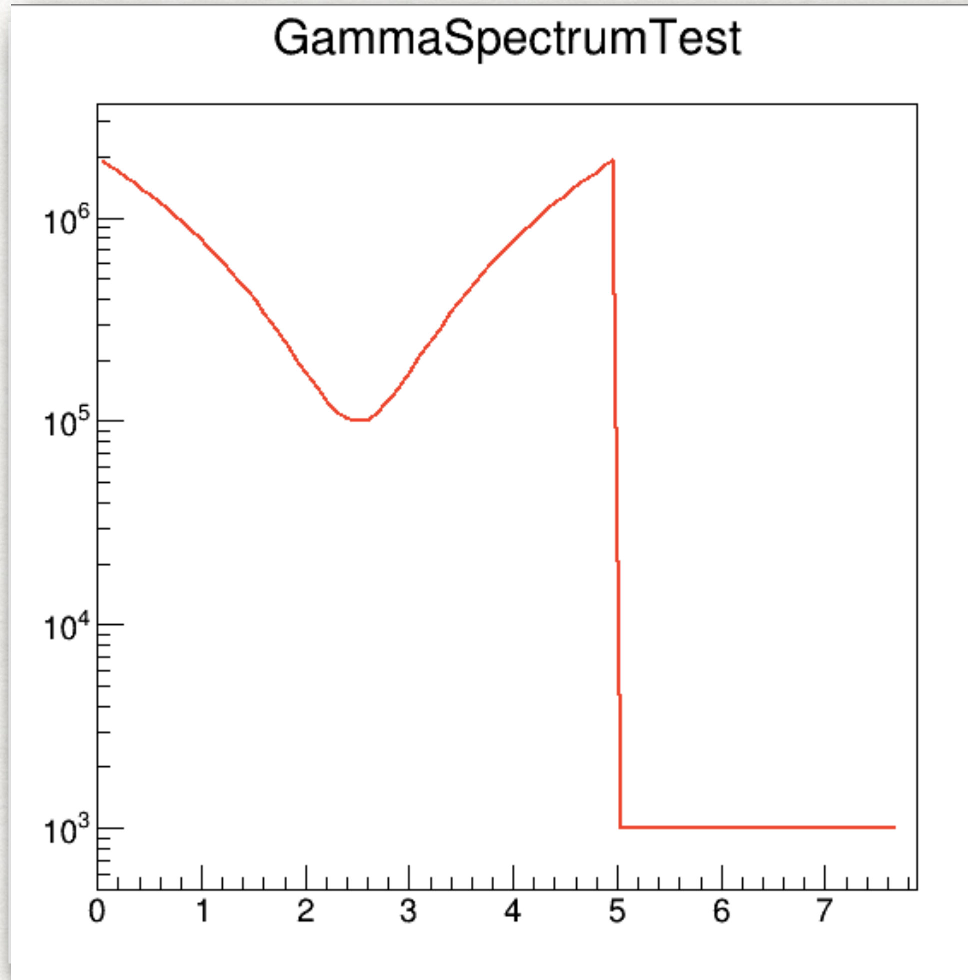
fitting allows finding the parameters quite well :

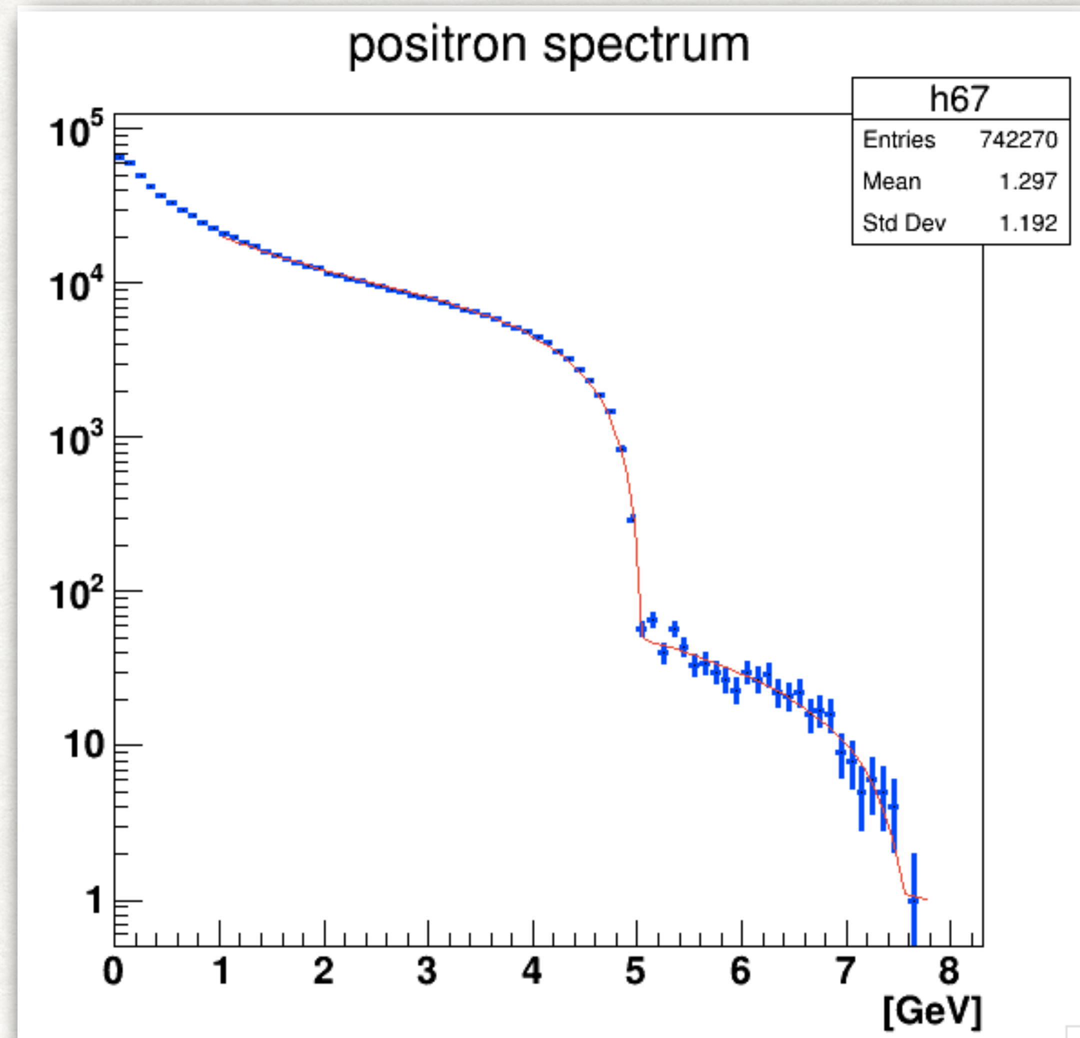
```
FCN=1309.19 FROM HESSE     STATUS=OK             39 CALLS          442 TOTAL
                    EDM=9.77144e-09    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                  STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  p0           0.00000e+00     fixed
  2  p1           3.71863e-05   1.18274e-07   7.47299e-08  -9.55179e+00
  3  p2           5.00872e+00   2.75457e-03   2.31805e-06   2.53148e-02
  4  p3           0.00000e+00     fixed
  5  p4           1.02419e-07   7.39607e-09   7.48765e-08** at limit **
  6  p5           7.38500e+00   8.55688e-02   1.42343e-05  -1.88485e-03
  7  p6           2.16581e-09   1.14383e-09   3.41734e-06   8.55195e-03
```

TESTING: COMPTON-LIKE

Ee=∫σ(Eγ, Ee)g(Eγ)dEγ

target material (W), its thickness 35 um





∫σ(Eγ, Ee)g(Eγ,p1,p2)dEγ

```
 FCN=145.218 FROM HESSE     STATUS=OK             56 CALLS        1207 TOTAL
                     EDM=4.92239e-08    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  p0           1.85584e+05   3.13357e+04   7.89176e-07  -3.96577e-02
   2  p1           9.96061e+05   9.50413e+05   2.45175e-06   1.51142e-03
   3  p2           5.03997e+00   3.58164e-03   2.97159e-07  -1.51967e-01
   4  p3           0.00000e+00     fixed
   5  p4           1.04141e+04   1.84485e+03   3.30306e-06   1.00640e-02
   6  p5           7.55555e+00   9.87041e-02   7.68131e-03  -5.14074e-04
   7  p6           2.78794e+02   2.50973e+02   1.60564e-05   7.45705e-05
   8  p7           2.31367e-03   3.84606e-04   3.67255e-07  -2.59769e+00
(Int_t) 0
```