FORWARD PHOTONS

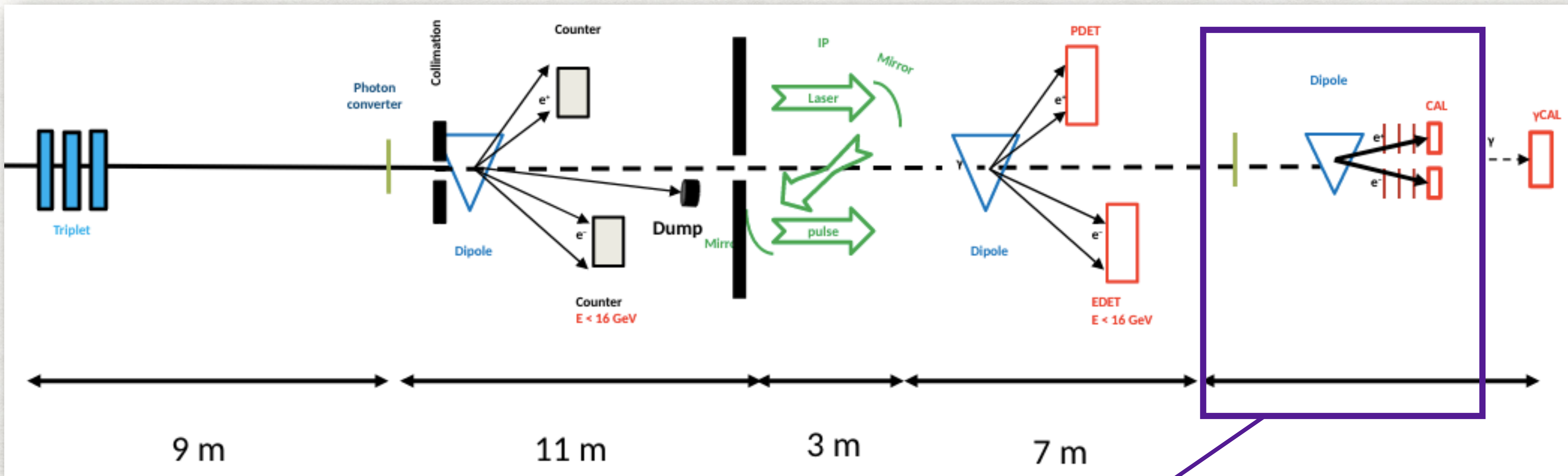
Borysova Maryna (KINR)

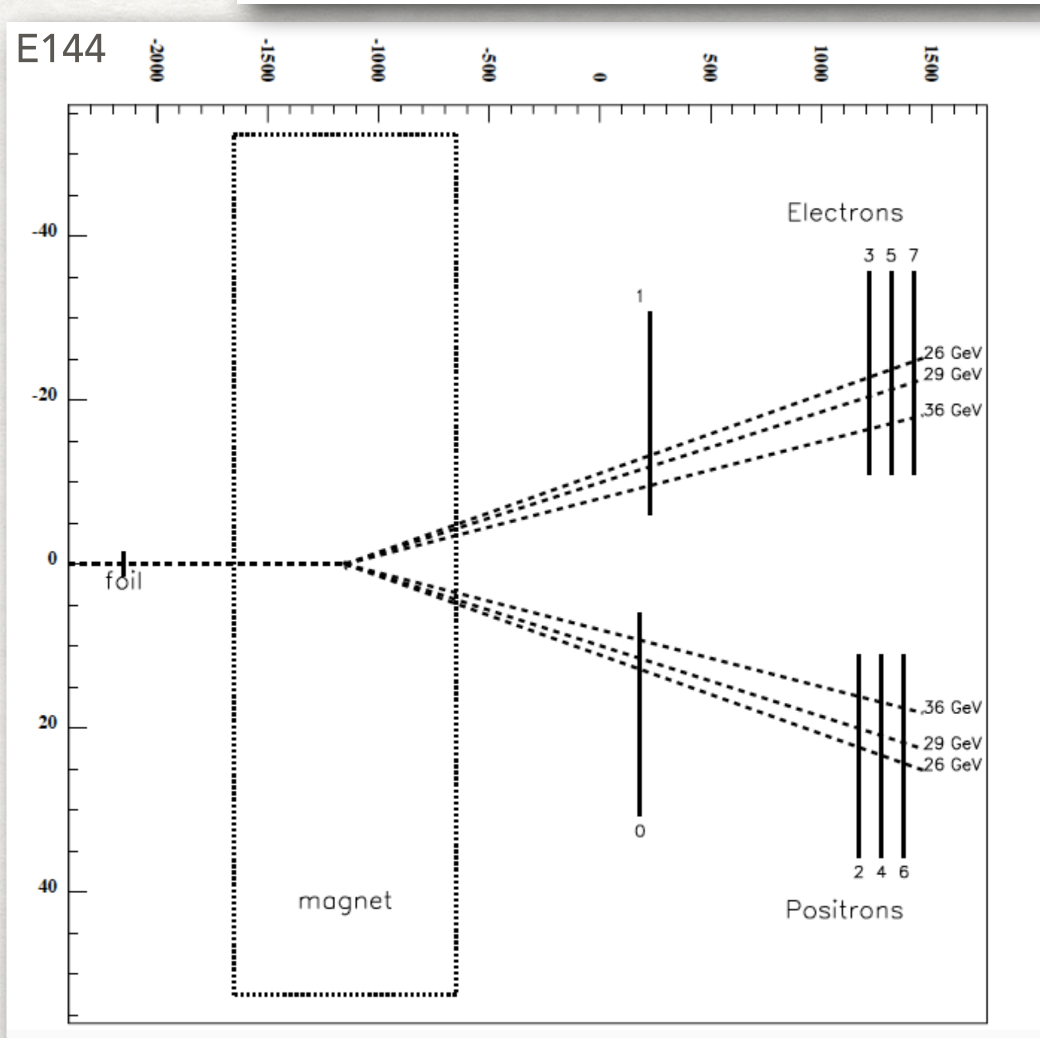
01/04/19

LUXE weekly meeting

LAYOUT FOR FDS OF THE LUXE EXPERIMENT

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



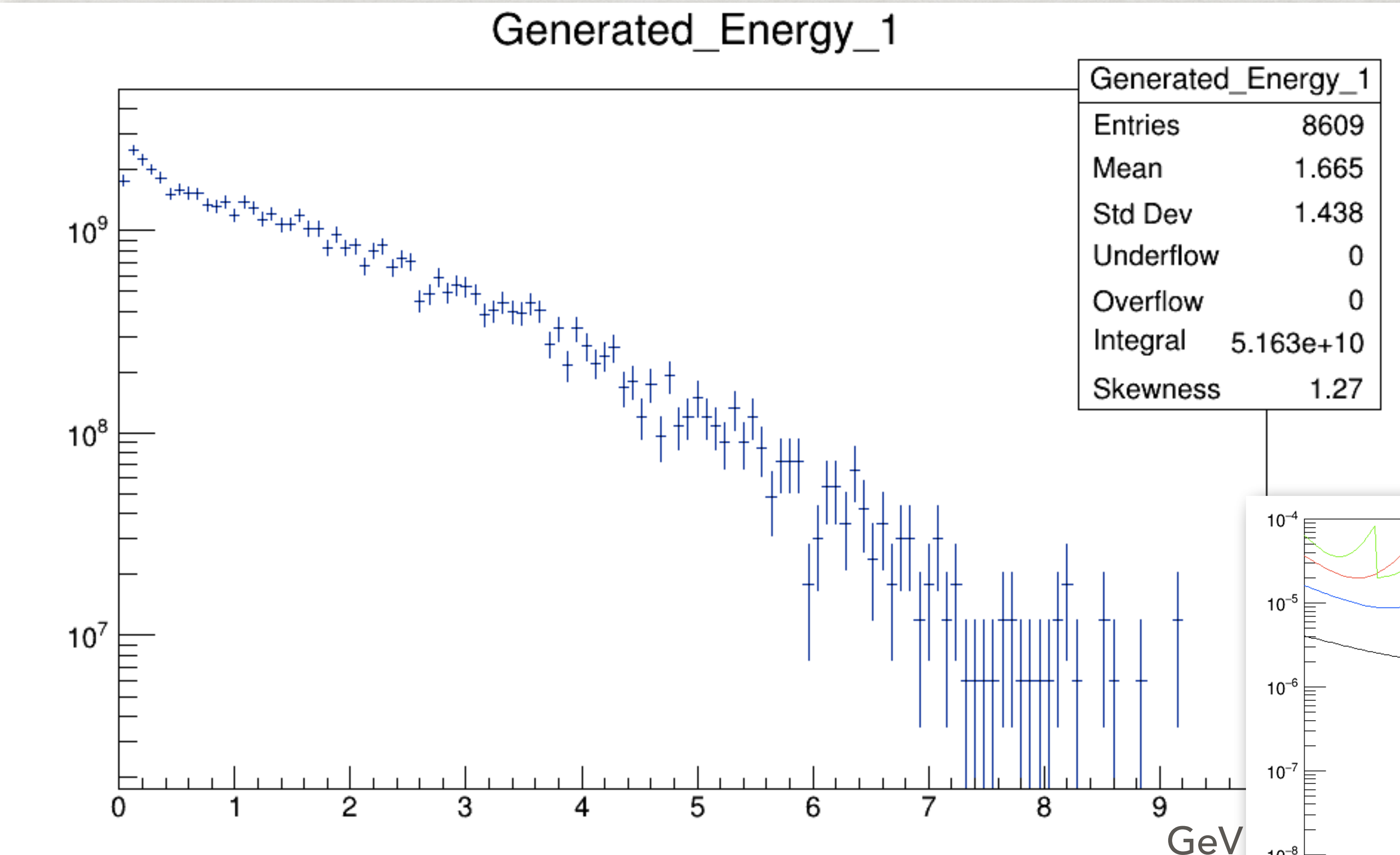


$$
\begin{array}{rcl}
e + n\omega & \rightarrow & e + \gamma \\
\gamma + n\omega & \rightarrow & e^{+} + e^{-}.
\end{array}
$$

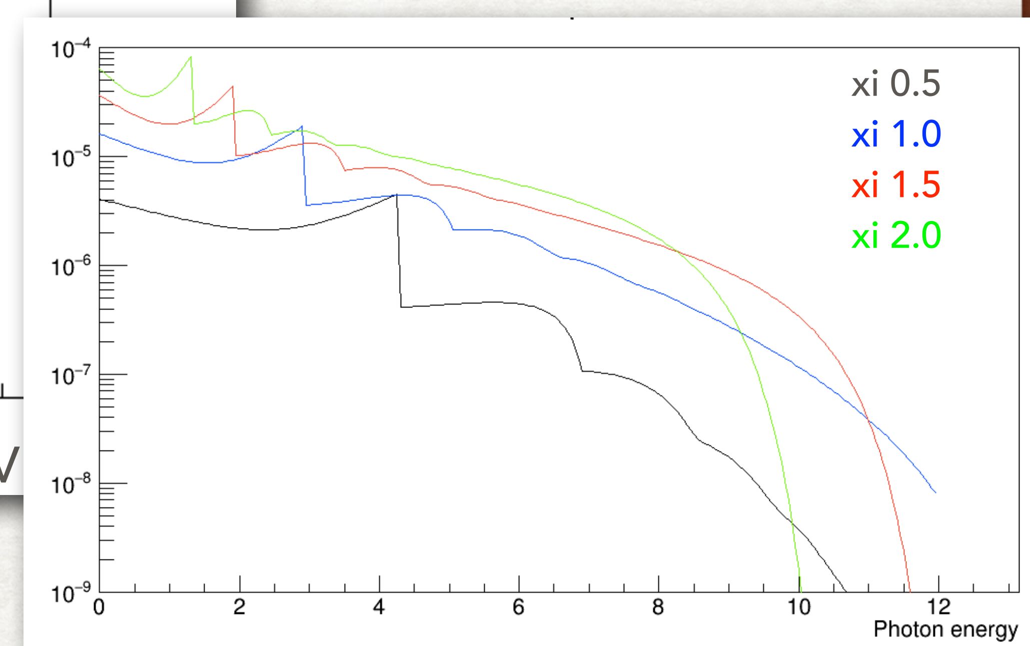
- The data from the two arms of the spectrometer are analyzed independently
- The reconstructed single-particle momentum spectra is compared to a **model spectrum** calculated by convolving the **simulated photon spectrum** with the **Bethe-Heitler pair spectrum**

MC HICS + OPPP WITH PRIMARY ELECTRONS

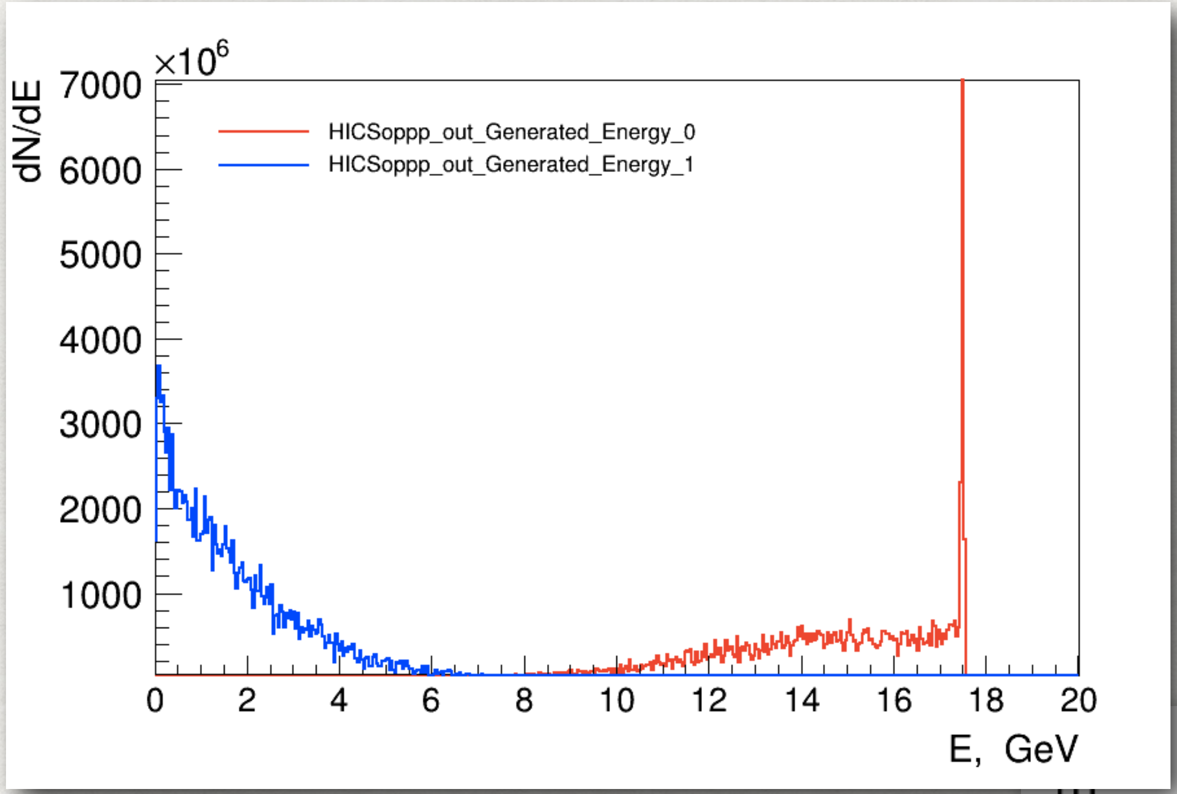
```
#  Electron energy =  17.5000 +/-  1.00% GeV,  Sigma_xyz =( 5.00    5.00   24.00 microns),
   Emit_xy =     1.40    1.40 mm mrad
#  Laser Intensity =    17.14 x10^18 W/cm^2,  Wavelength = 800.00 nm,  pulse length = 35.00 fs,
   spot size =   100.00 micron^2
#  Peak xi =    2.0148,  chi_e =    0.3785
```



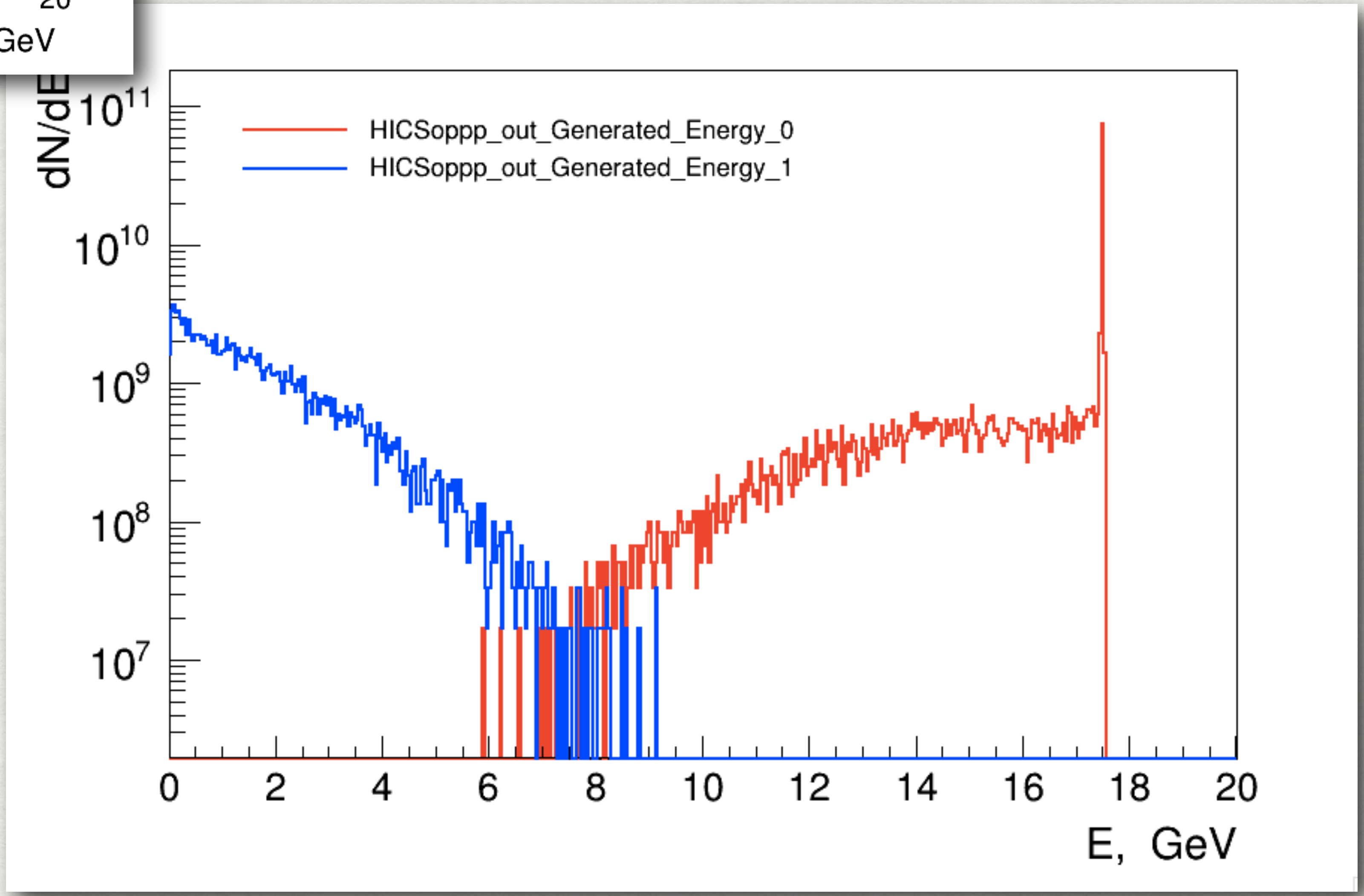
MC smears out the steps because the intensity is varying throughout the gaussian pulse



PHOTON AND ELECTRON SPECTRA

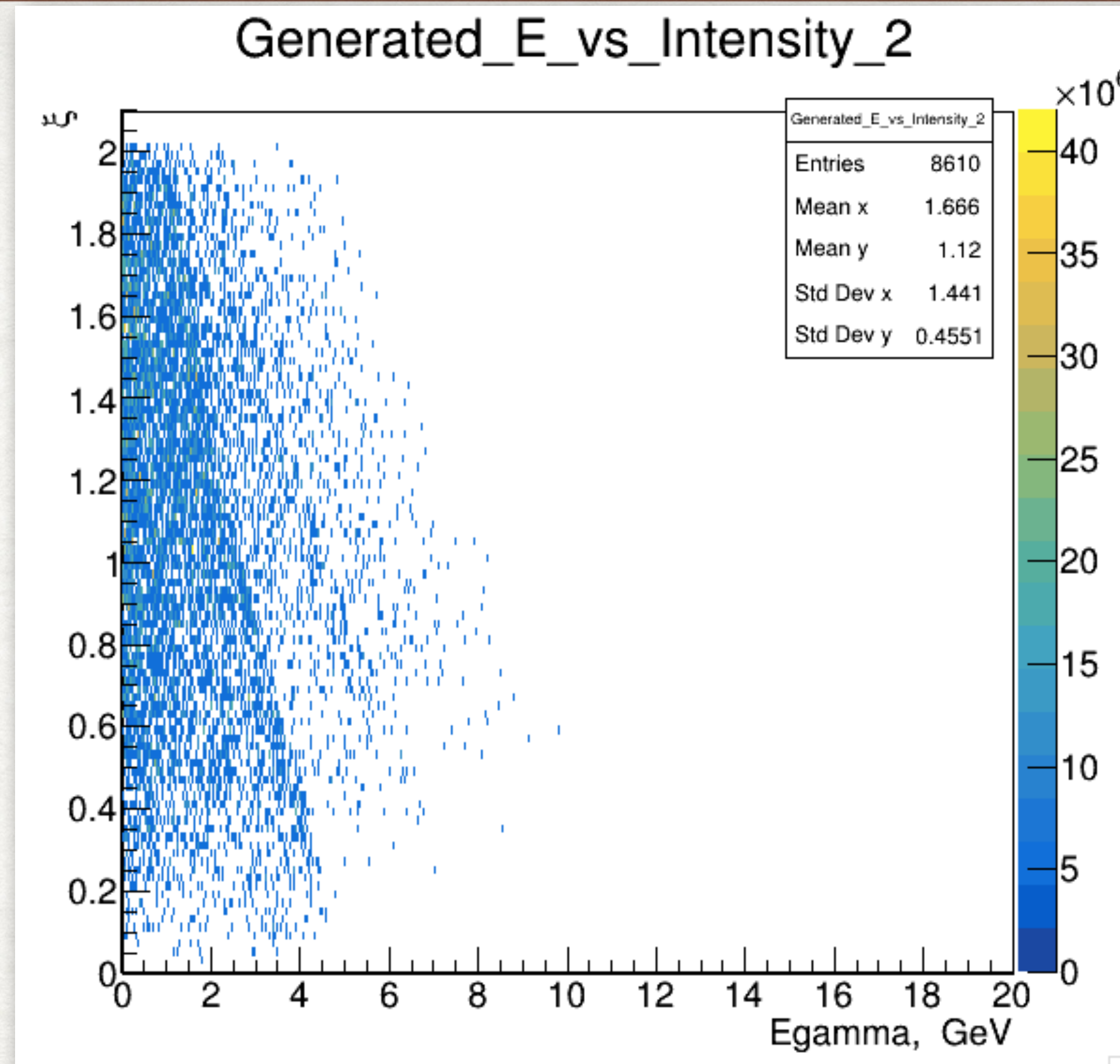


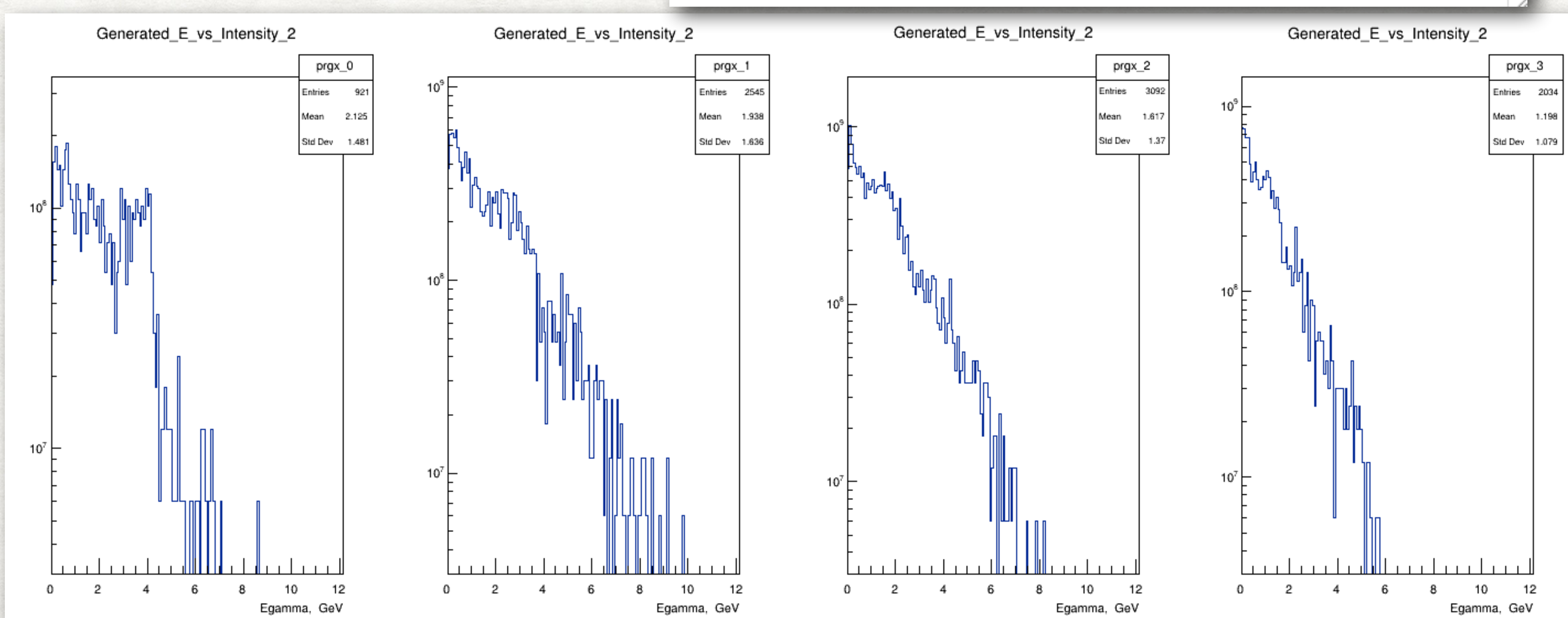
Peak xi = 2.0148



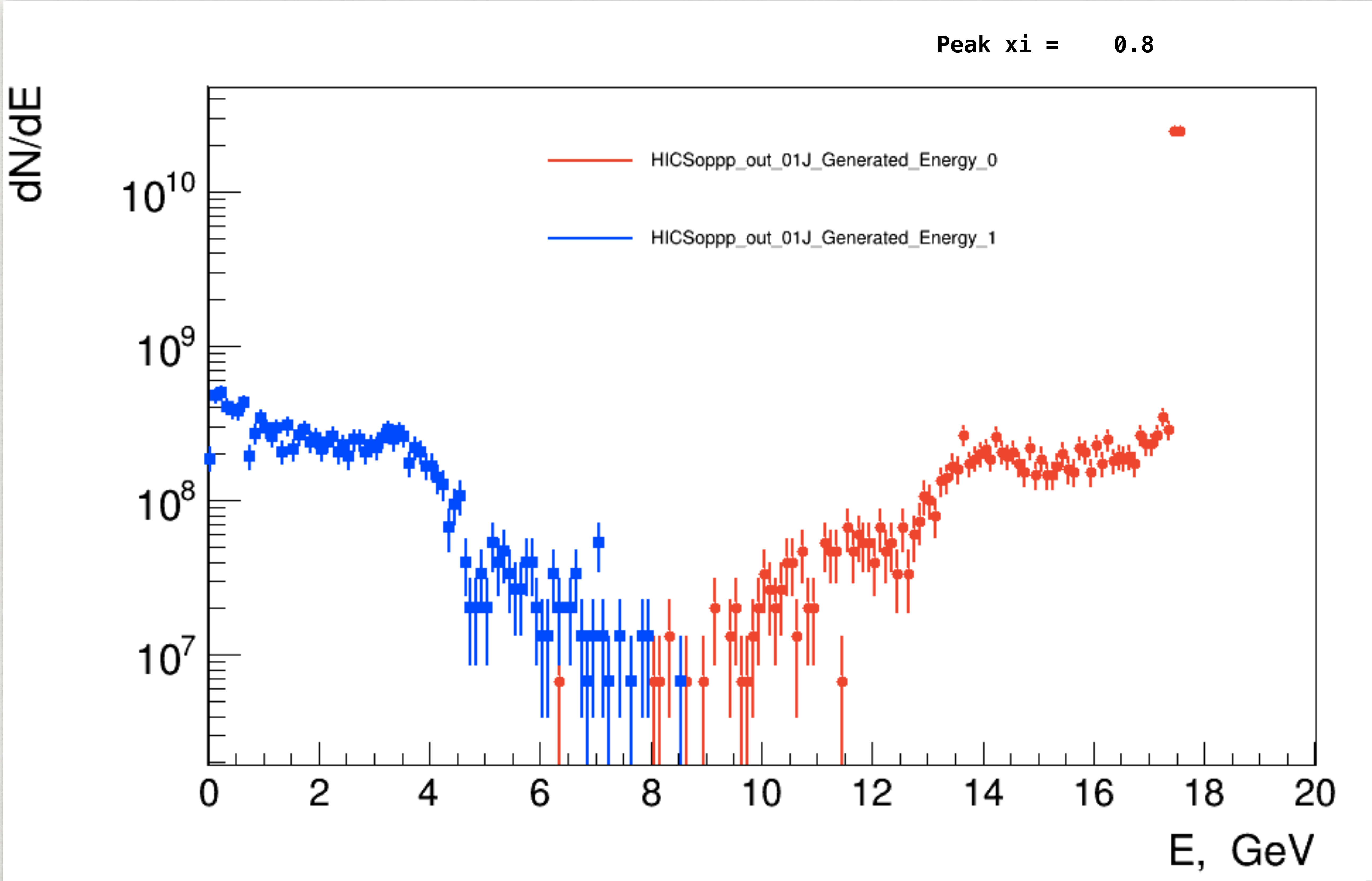
XI VS EGAMMA

Peak xi = 2.0148



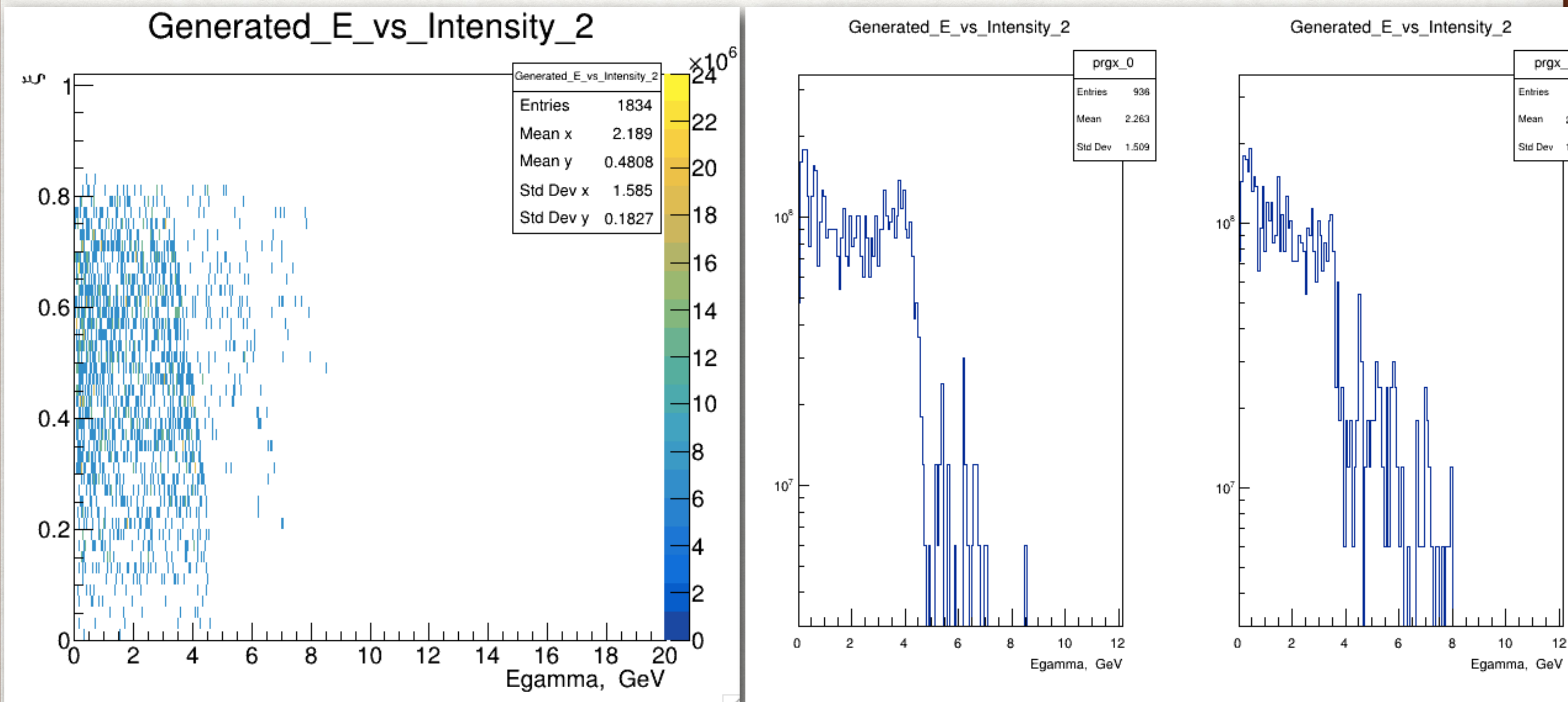


PHOTON AND ELECTRON SPECTRA

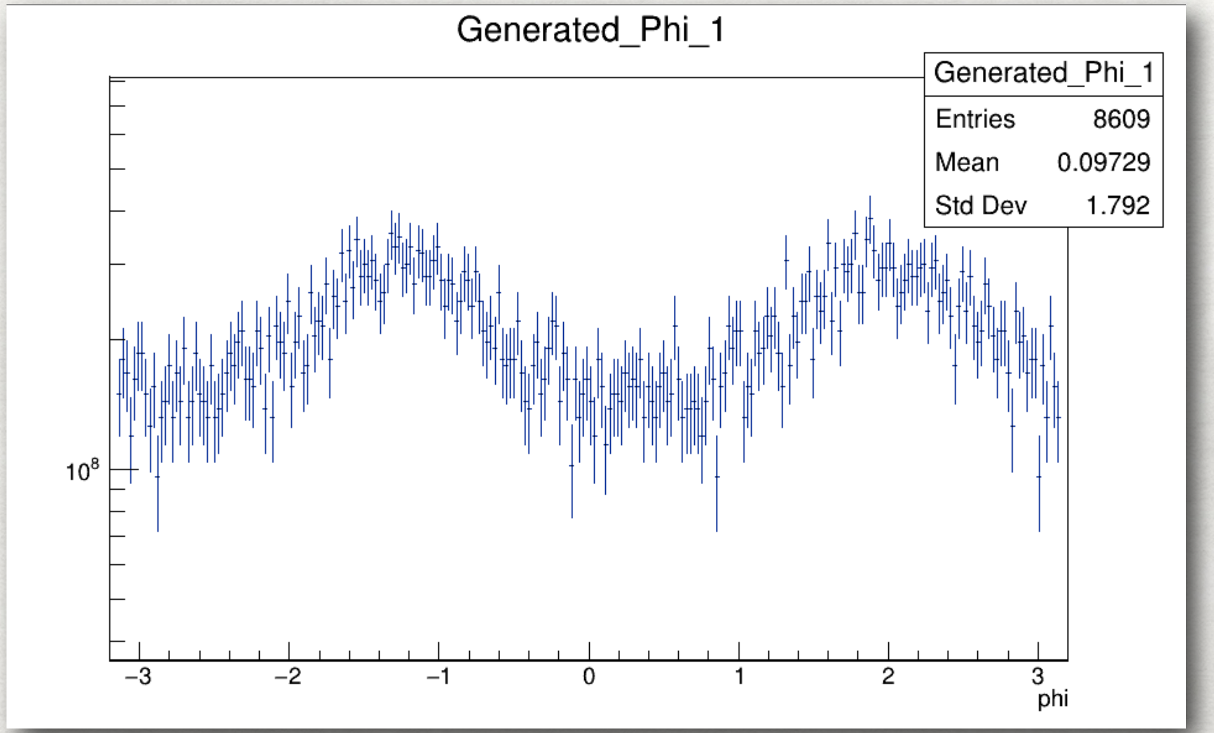


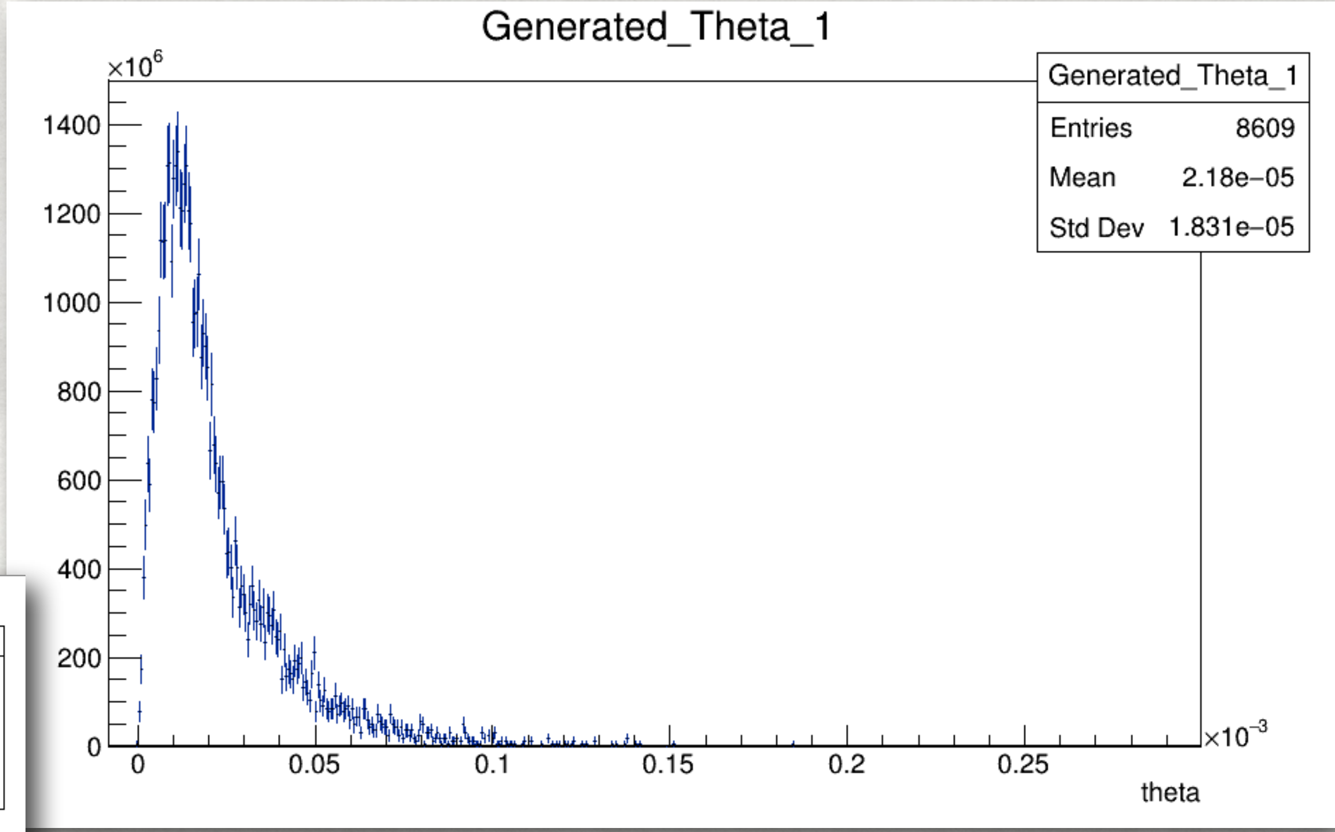
XI VS EGAMMA

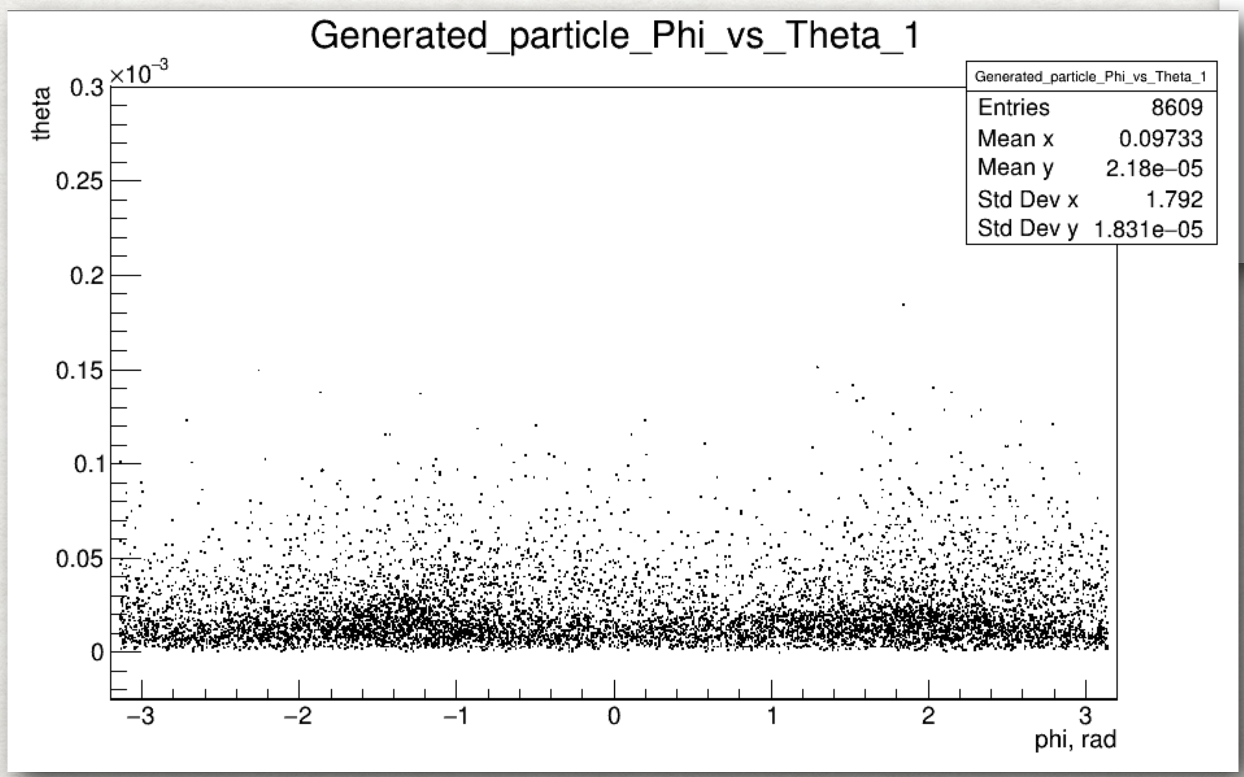
Peak xi = 0.8

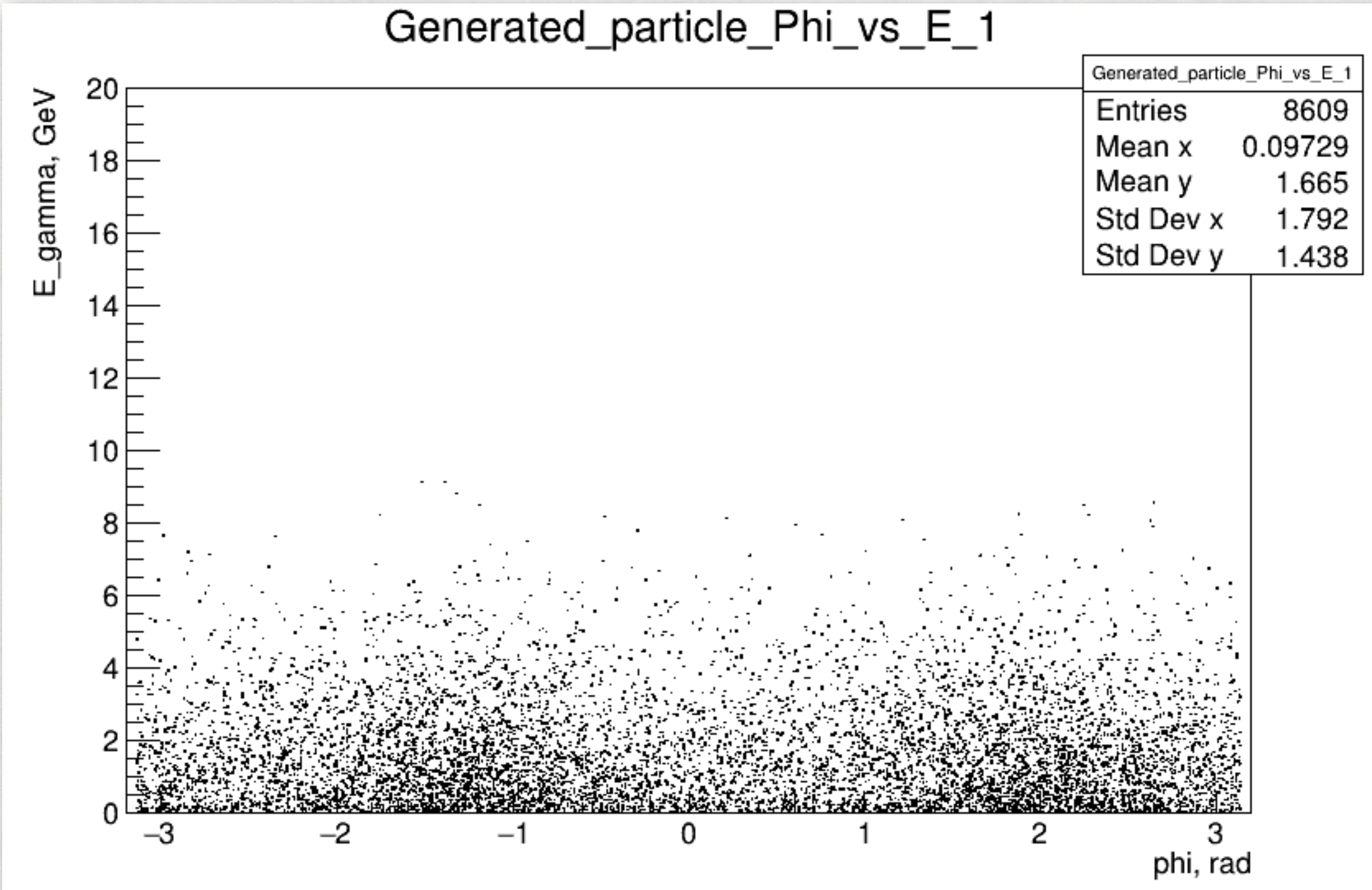


PHOTON DEPENDENCE ON ANGLES

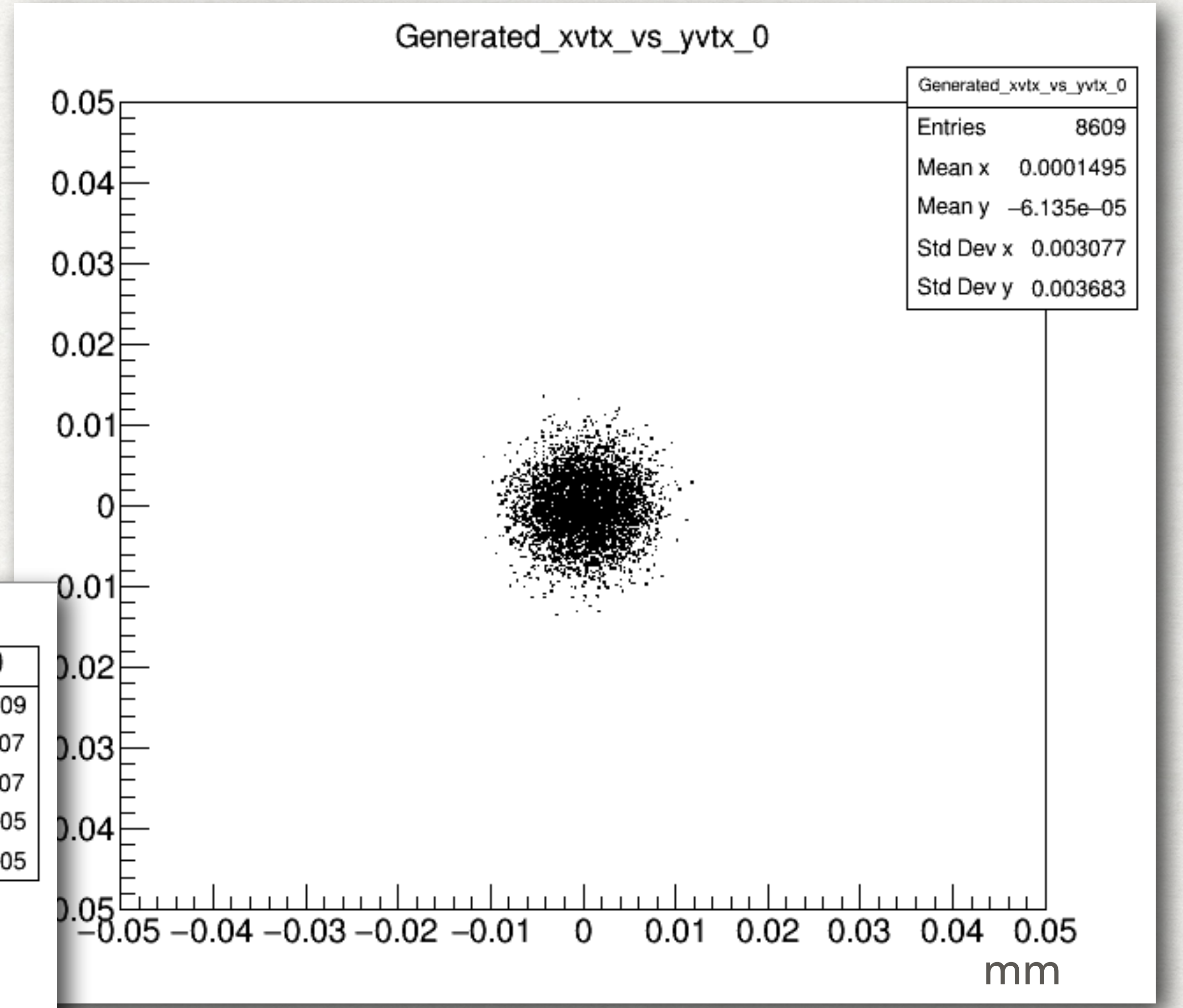








Generated_particle_Phi_vs_E_1
Generated_particle_Phi_vs_E_1
Entries 8609
Mean x 0.09729
Mean y 1.665
Std Dev x 1.792
Std Dev y 1.438
E_gamma, GeV
20
18
16
14
12
10
8
6
4
2
0
−3
−2
−1
0
1
2
3
phi, rad


Generated_xvtx_vs_yvtx_0
Generated_xvtx_vs_yvtx_0
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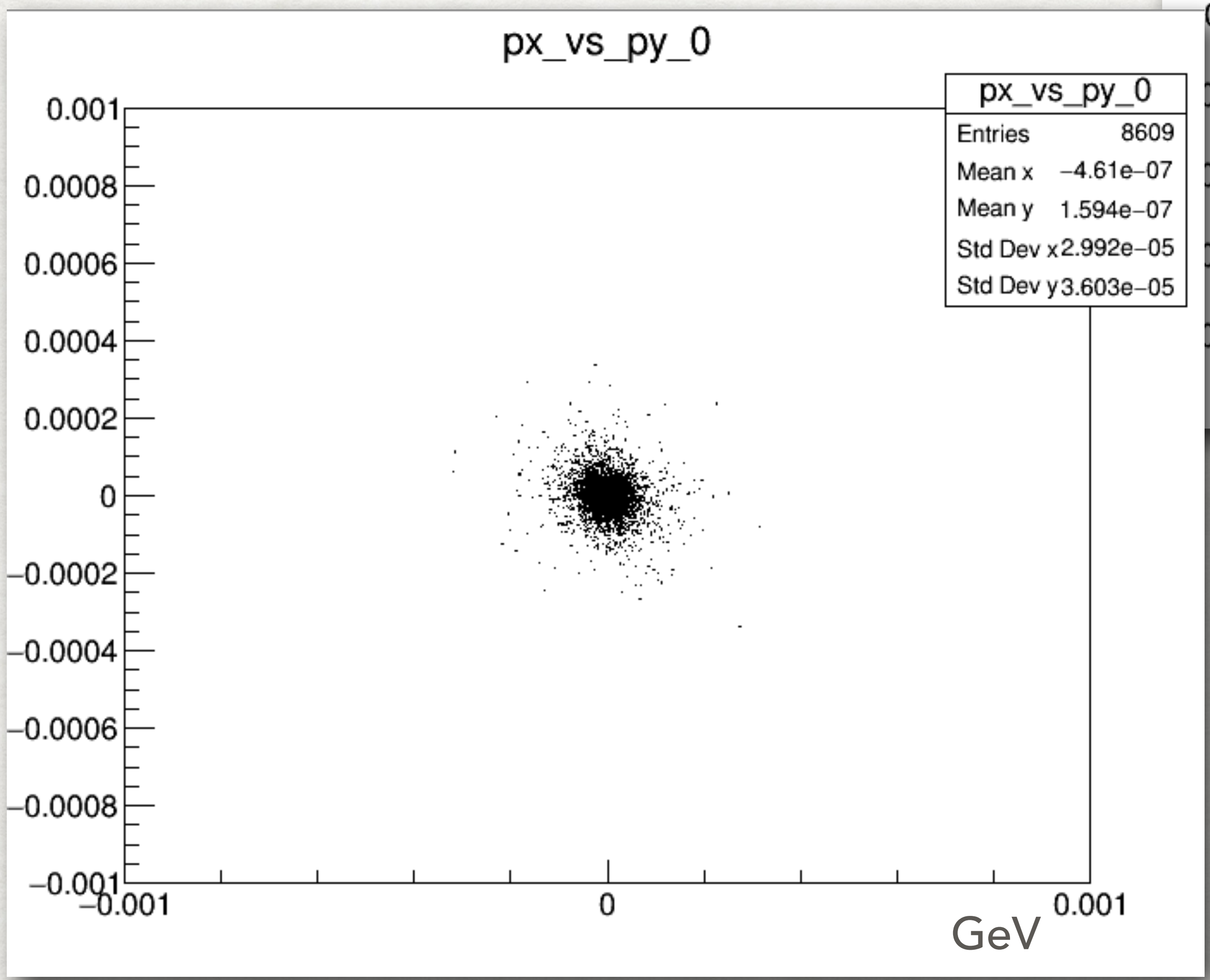
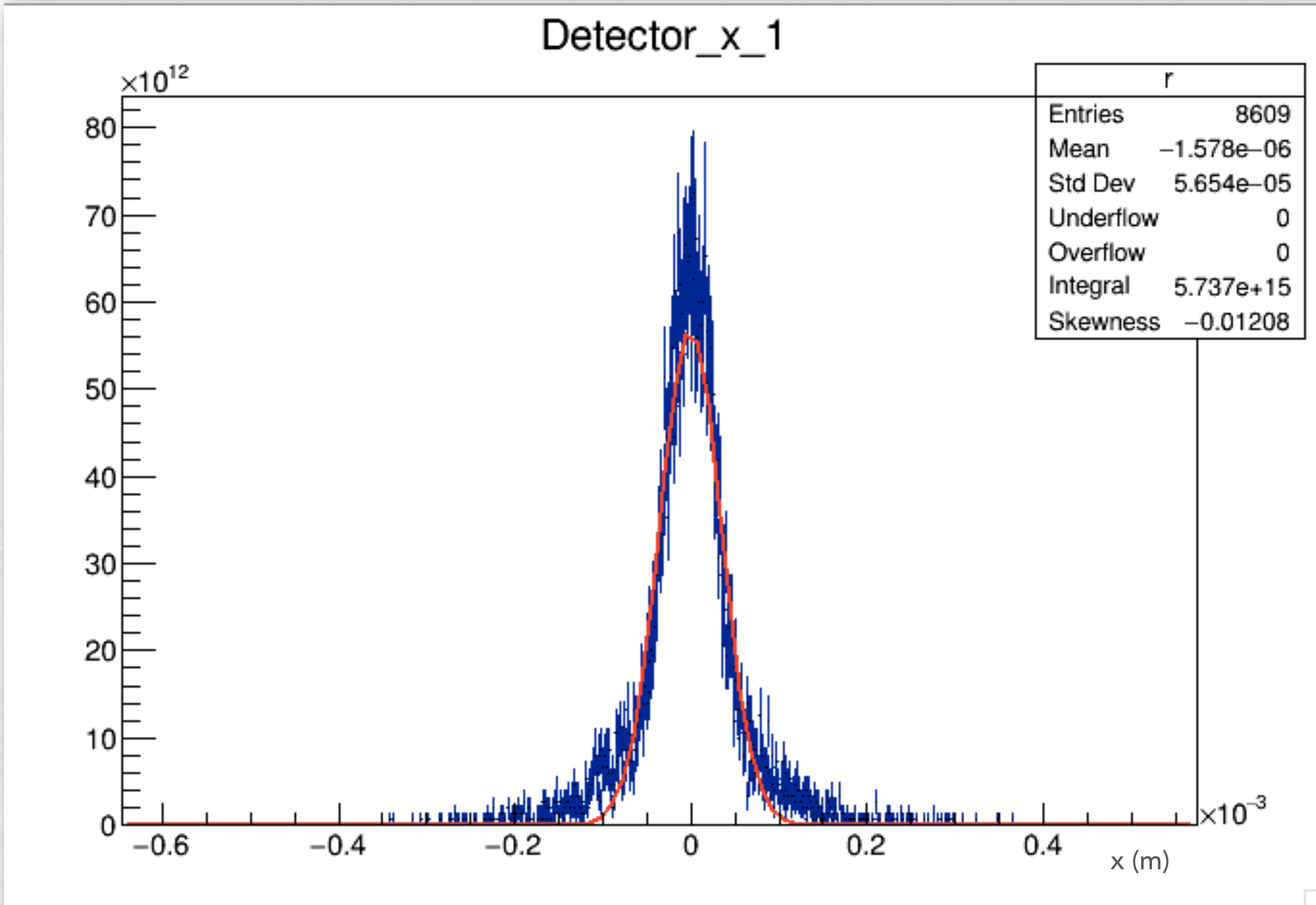
Mean x 0.0001495
Mean y −6.135e−05
Std Dev x 0.003077
Std Dev y 0.003683
mm


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

N OF PHOTONS

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

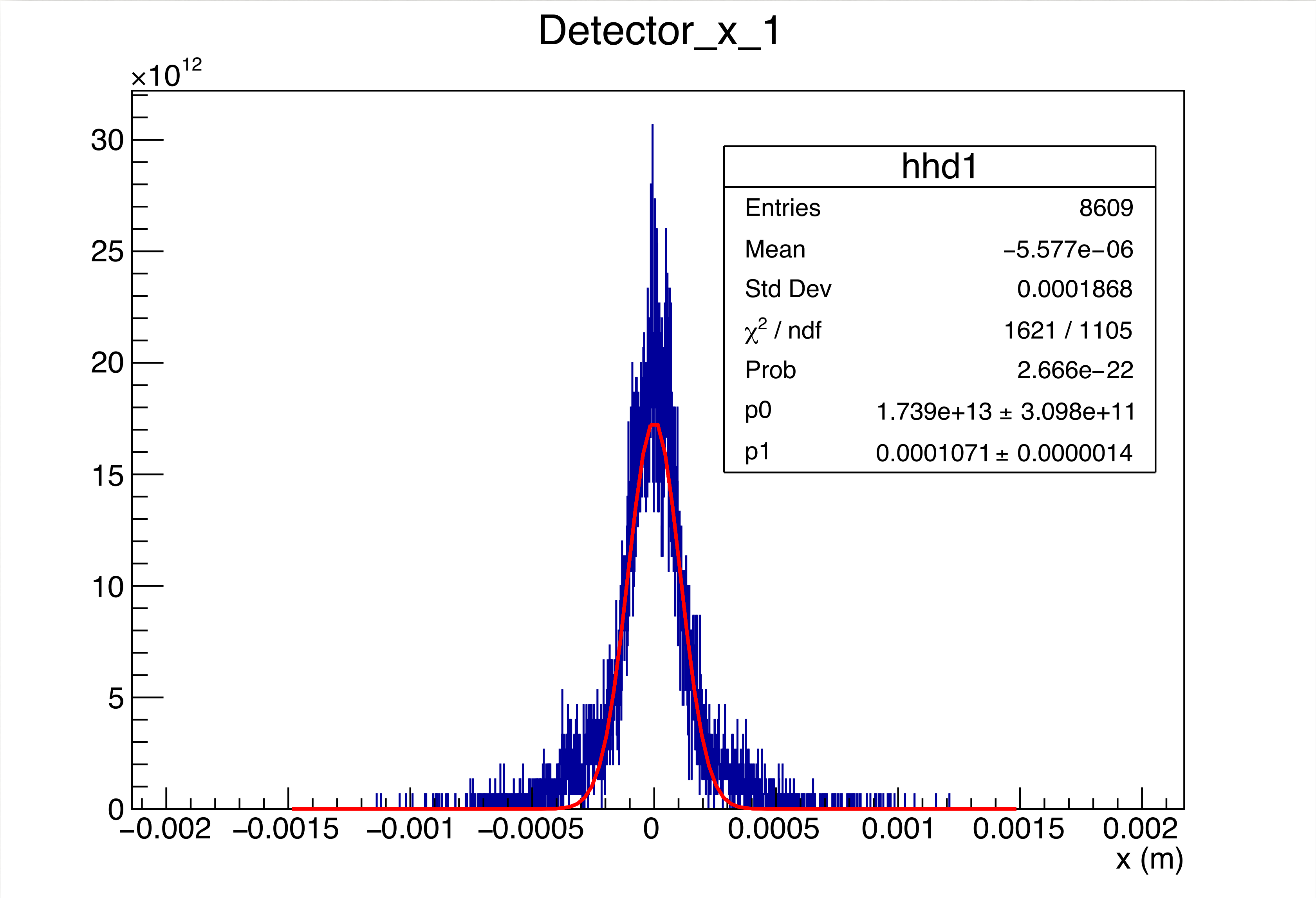



```
Integral 5.7366667e+09
```

```
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

N OF PHOTONS

- for W wire, detector on distance of 10m from IP



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

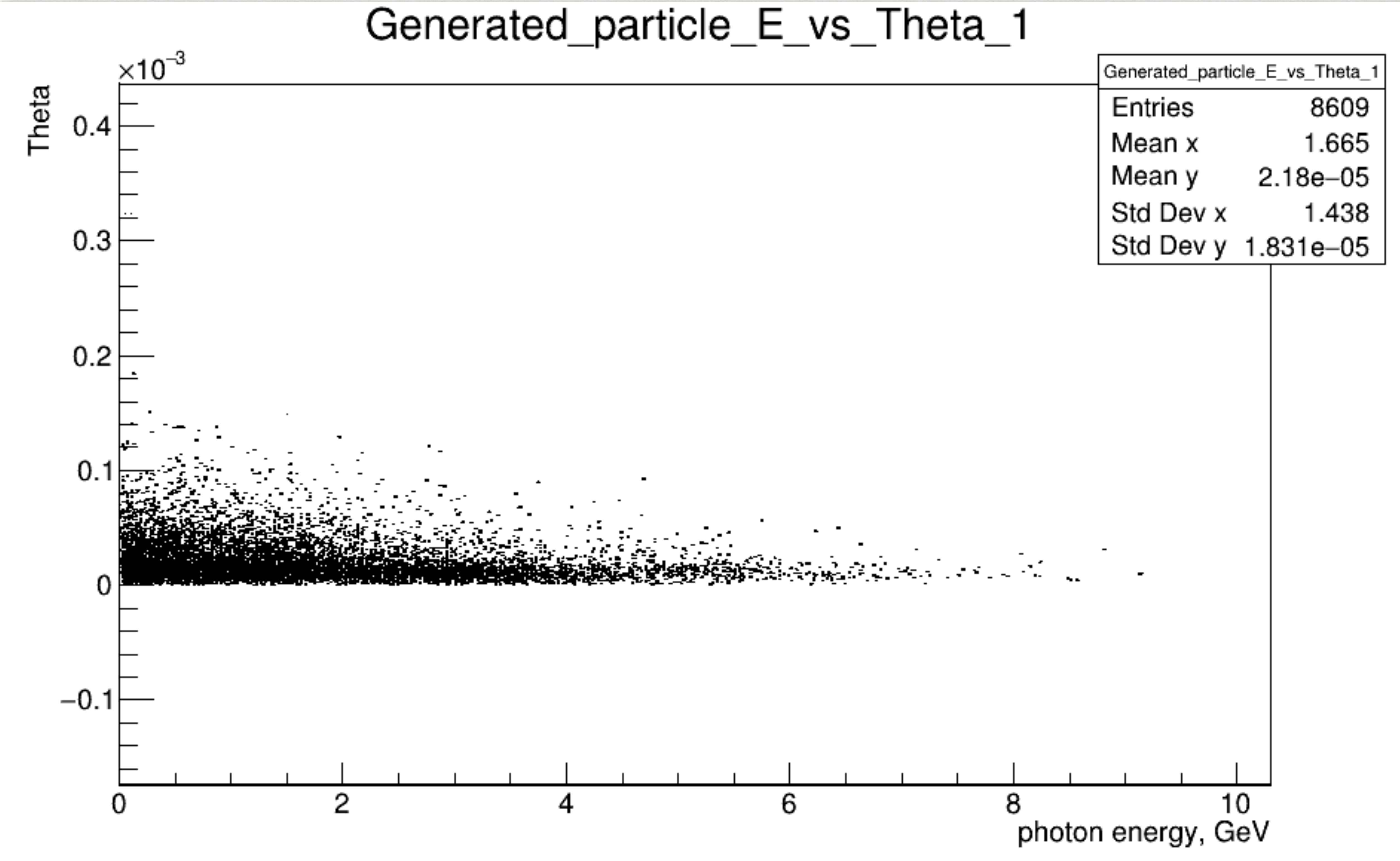
<-less but still a lot

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

WHAT'S DONE & WHAT'S NEXT

- first glance @ MC for HICS + OPPP with primary electrons: No structure is seen in photon spectrum
- Control plots for the process
- Estimation of number of photons in case of wire

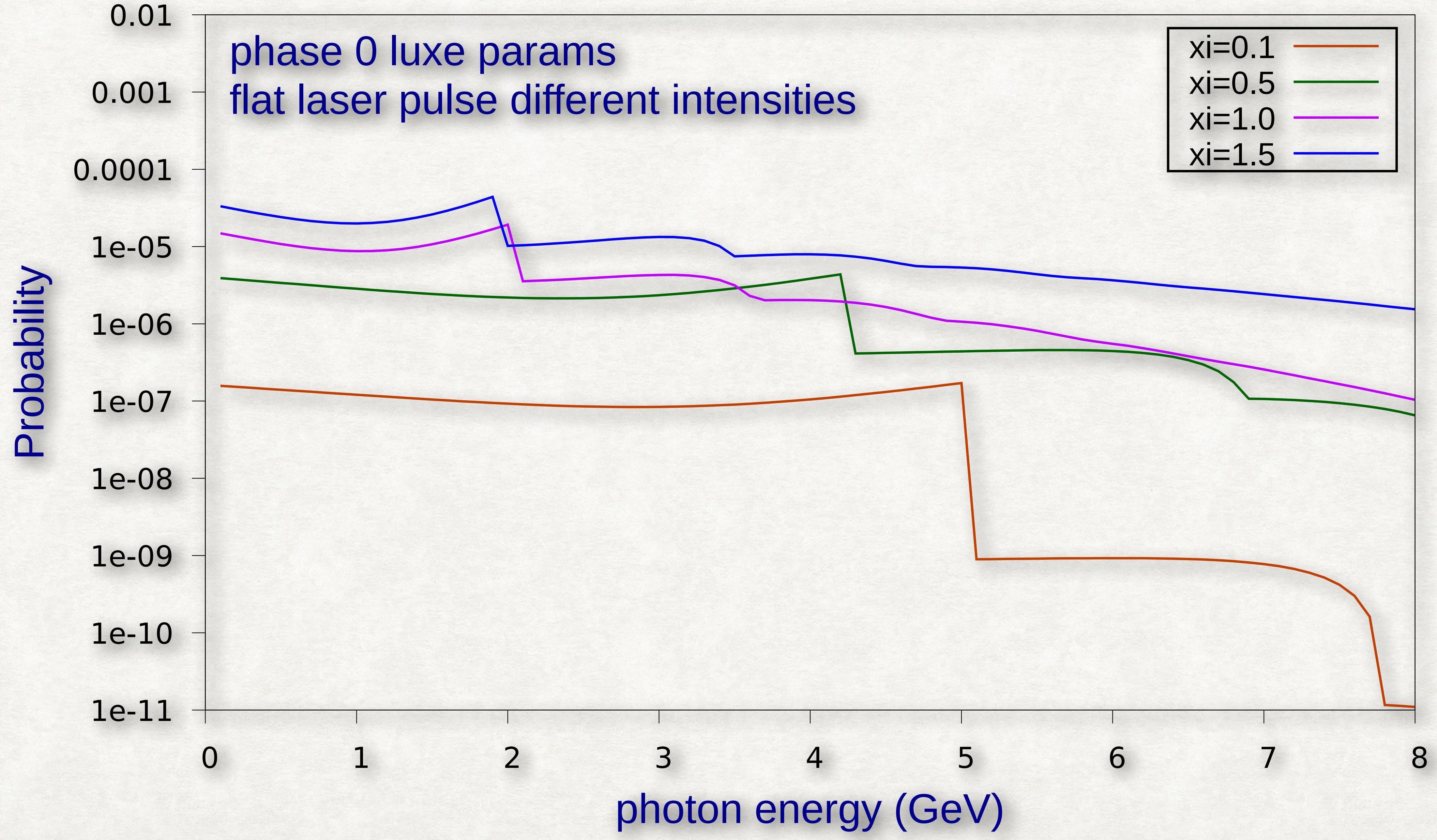
BACK UP



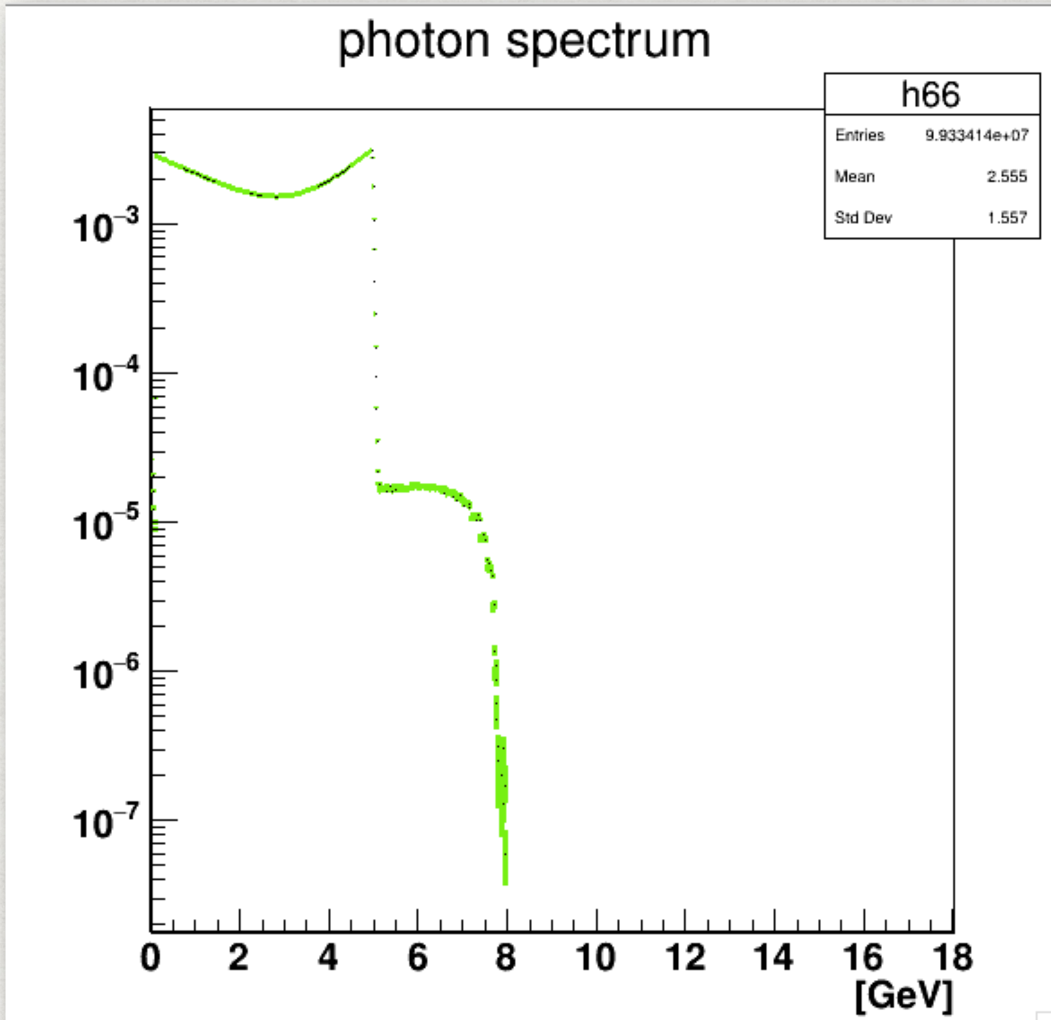
Generated_particle_E_vs_Theta_1
×10^-3
Theta
0.4
0.3
0.2
0.1
0
−0.1
0
2
4
6
8
10
photon energy, GeV
Generated_particle_E_vs_Theta_1
Entries 8609
Mean x 1.665
Mean y 2.18e−05
Std Dev x 1.438
Std Dev y 1.831e−05

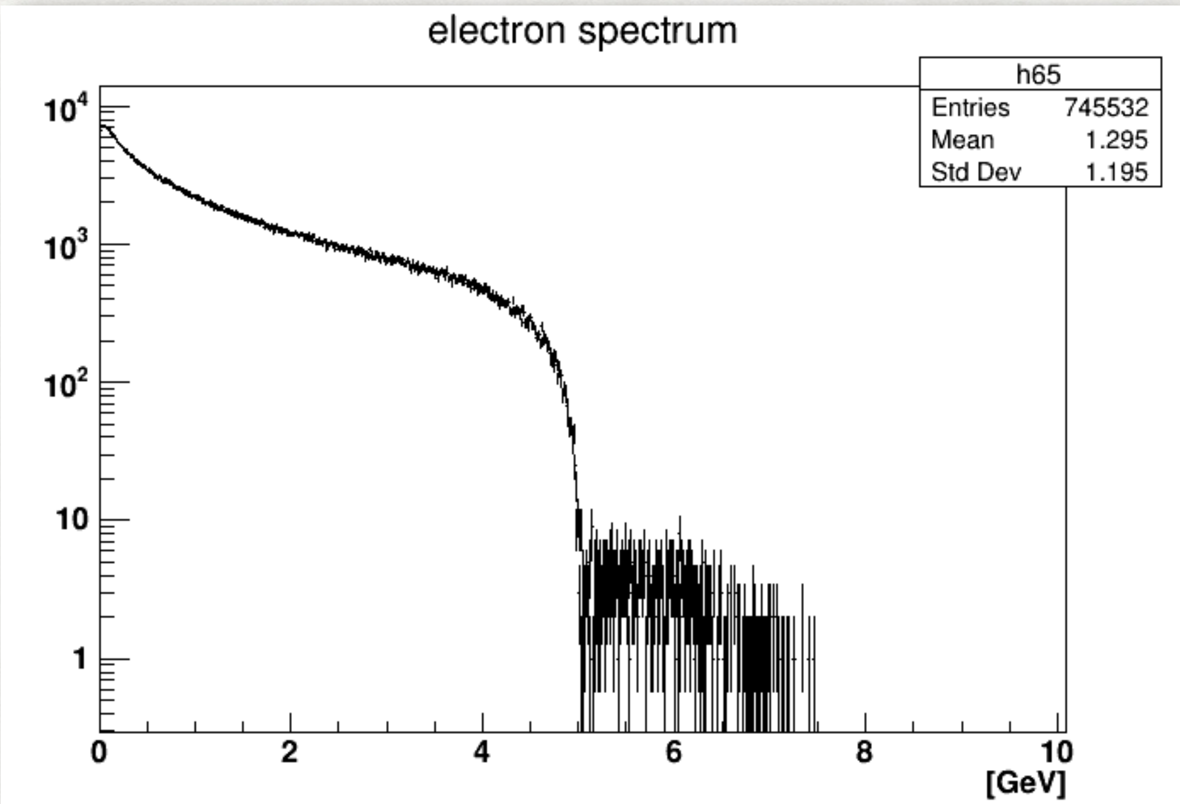
PHOTON SPECTRA VS LASER INTENSITIES

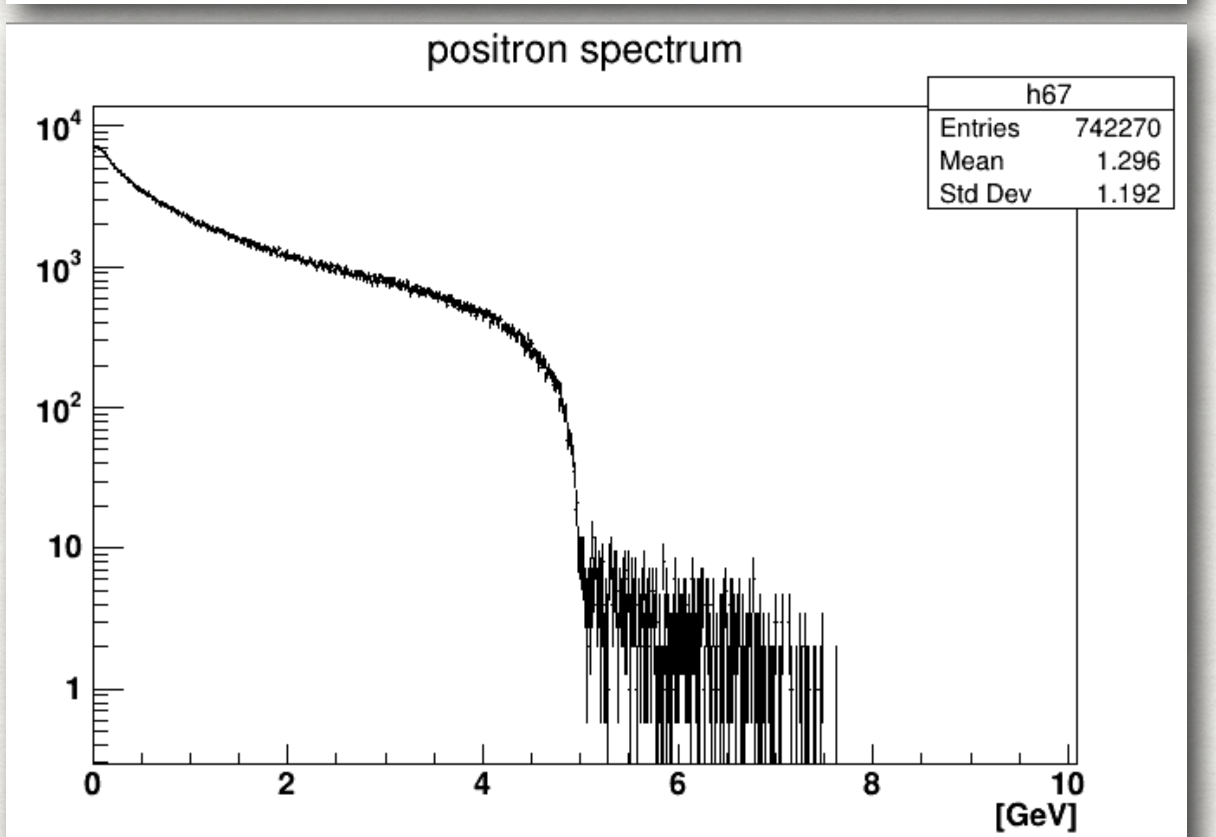
- plot from Anthony



FORWARD PHOTONS IN GEANT4

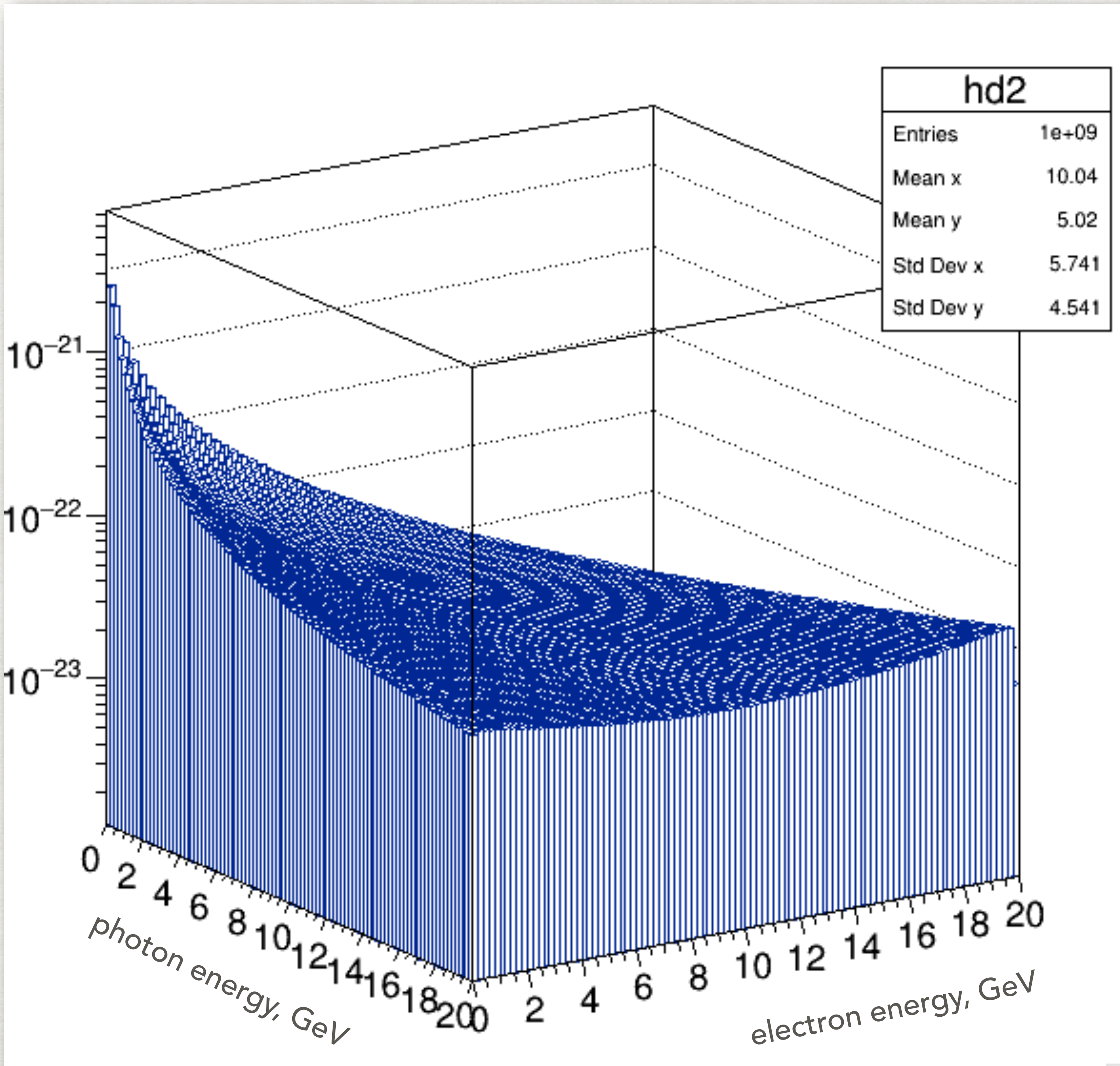






target: Tungsten, 0.35 um
1e8 photons

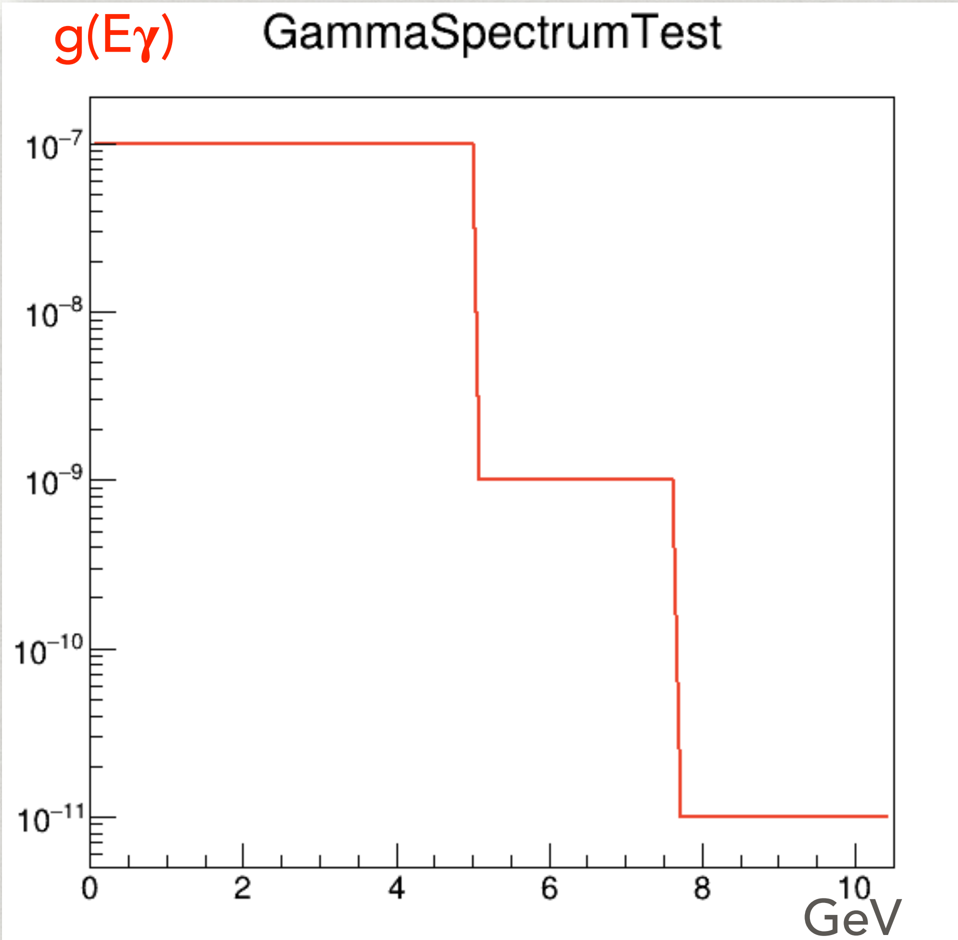
DIFFERENTIAL CROSS-SECTION FROM GEANT4

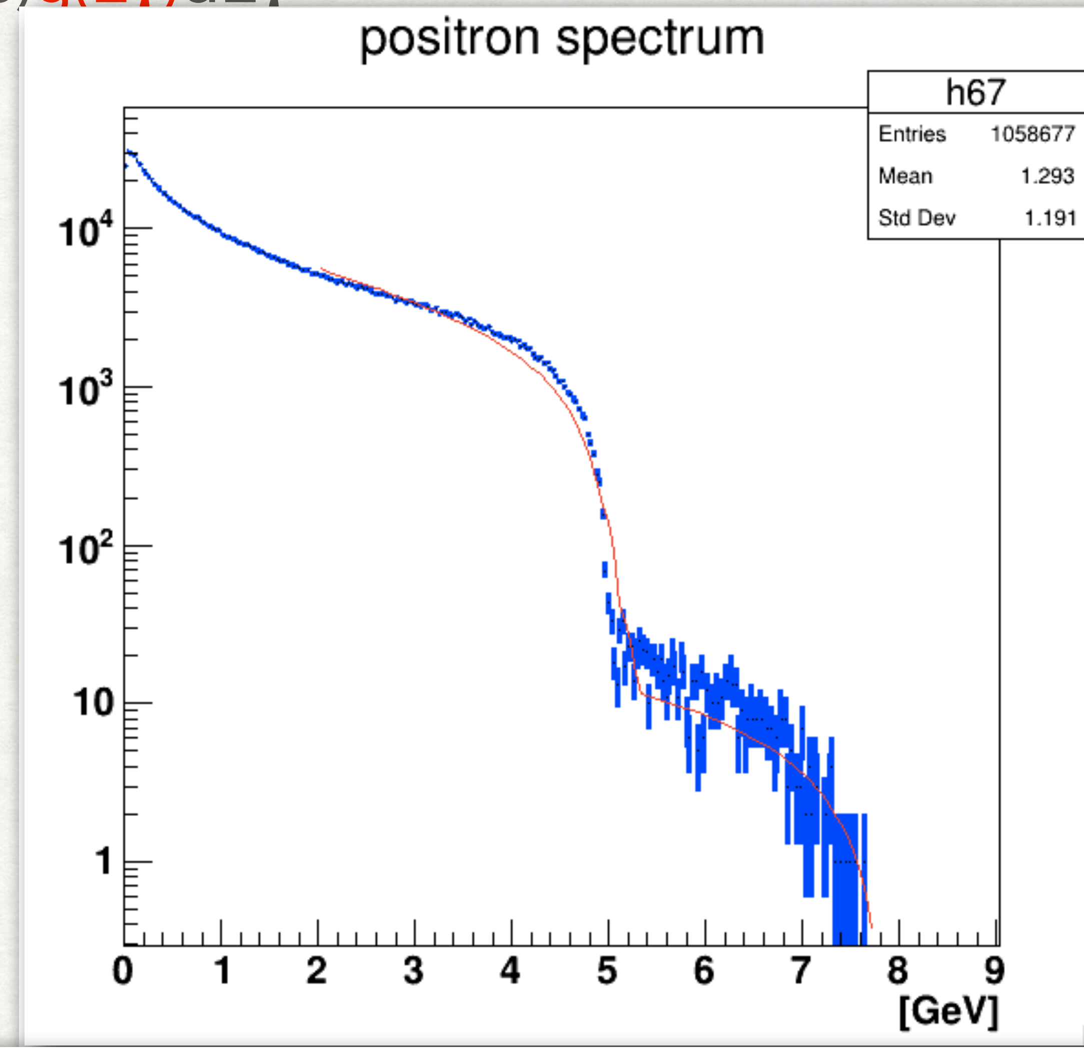


TESTING: COMPTON-LIKE

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

target material (W), its thickness 50 um





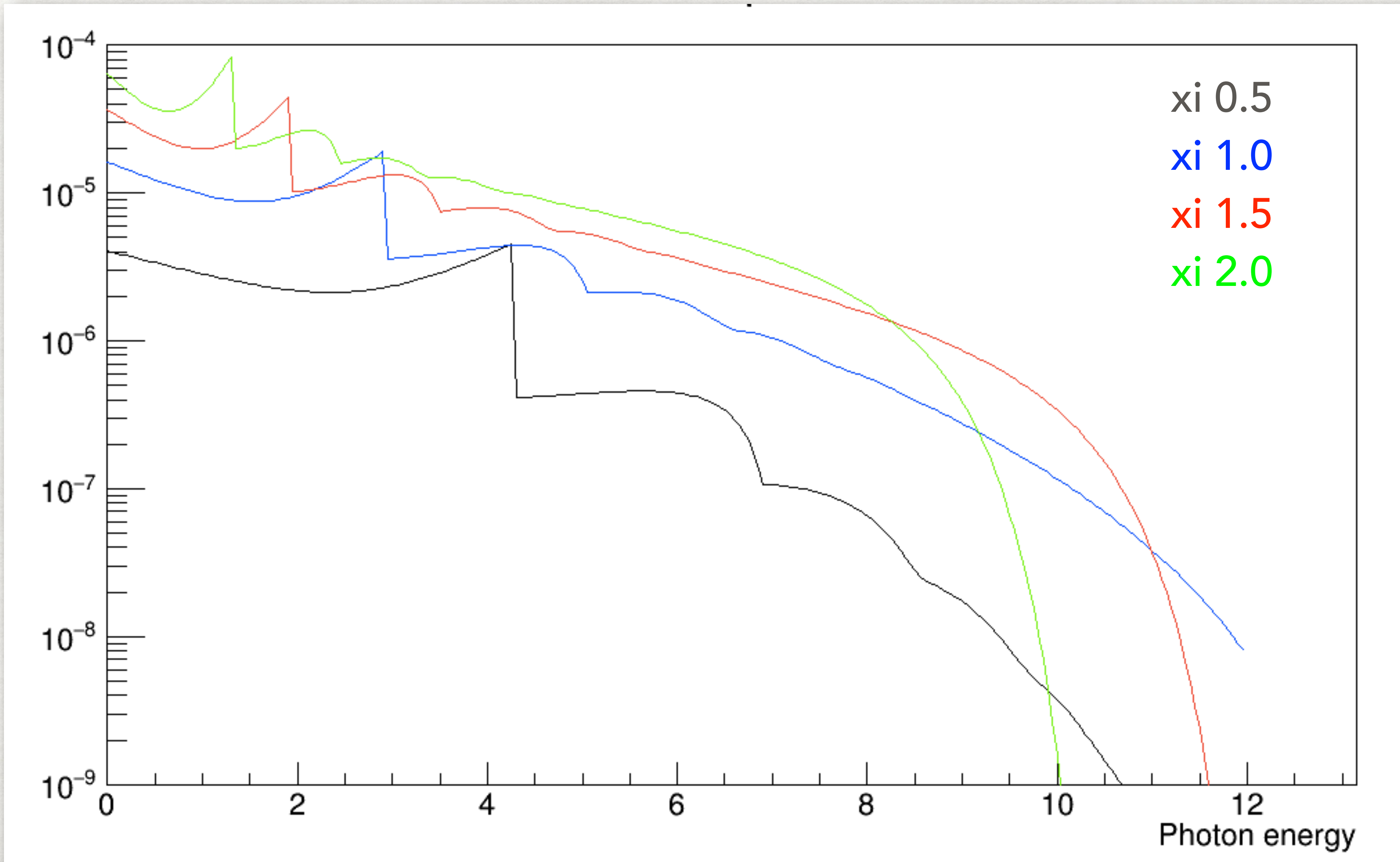
$$\int \sigma(E_\gamma, E_e) g(E_\gamma, p1, p2) dE_\gamma$$

```
FCN=3847.23 FROM MIGRAD    STATUS=FAILED        586 CALLS         587 TOTAL
                    EDM=0.00146922    STRATEGY= 1  ERROR MATRIX UNCERTAINTY   1.3 per cent
 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
FCN=3847.23 FROM MIGRAD    STATUS=CONVERGED      20 CALLS          21 TOTAL
                    EDM=2.48743e-09    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  p0          0.00000e+00     fixed
  2  p1          2.83446e+06   5.64367e+03   1.21997e+02   9.80448e-09
  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
```

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

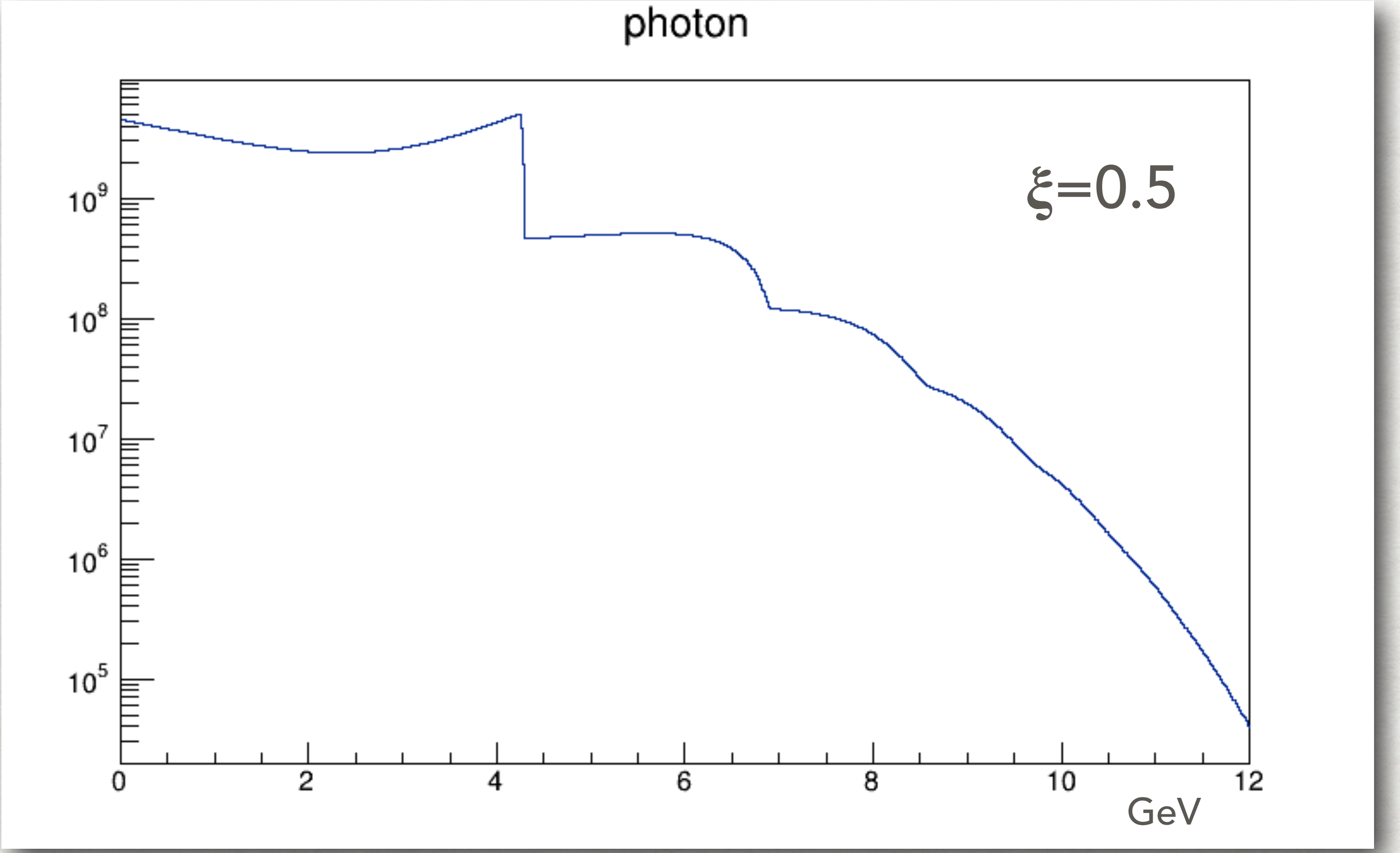
data produced of HICS/IPW/circularly polarized with Mathematica by Anthony Hartin 4/2/2019



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

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)

ξ	1e 100 fs	1e 35 fs (1BX)	$N\gamma$
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

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

ABSOLUTE NUMBER OF PHOTONS W/ ENERGY CUT

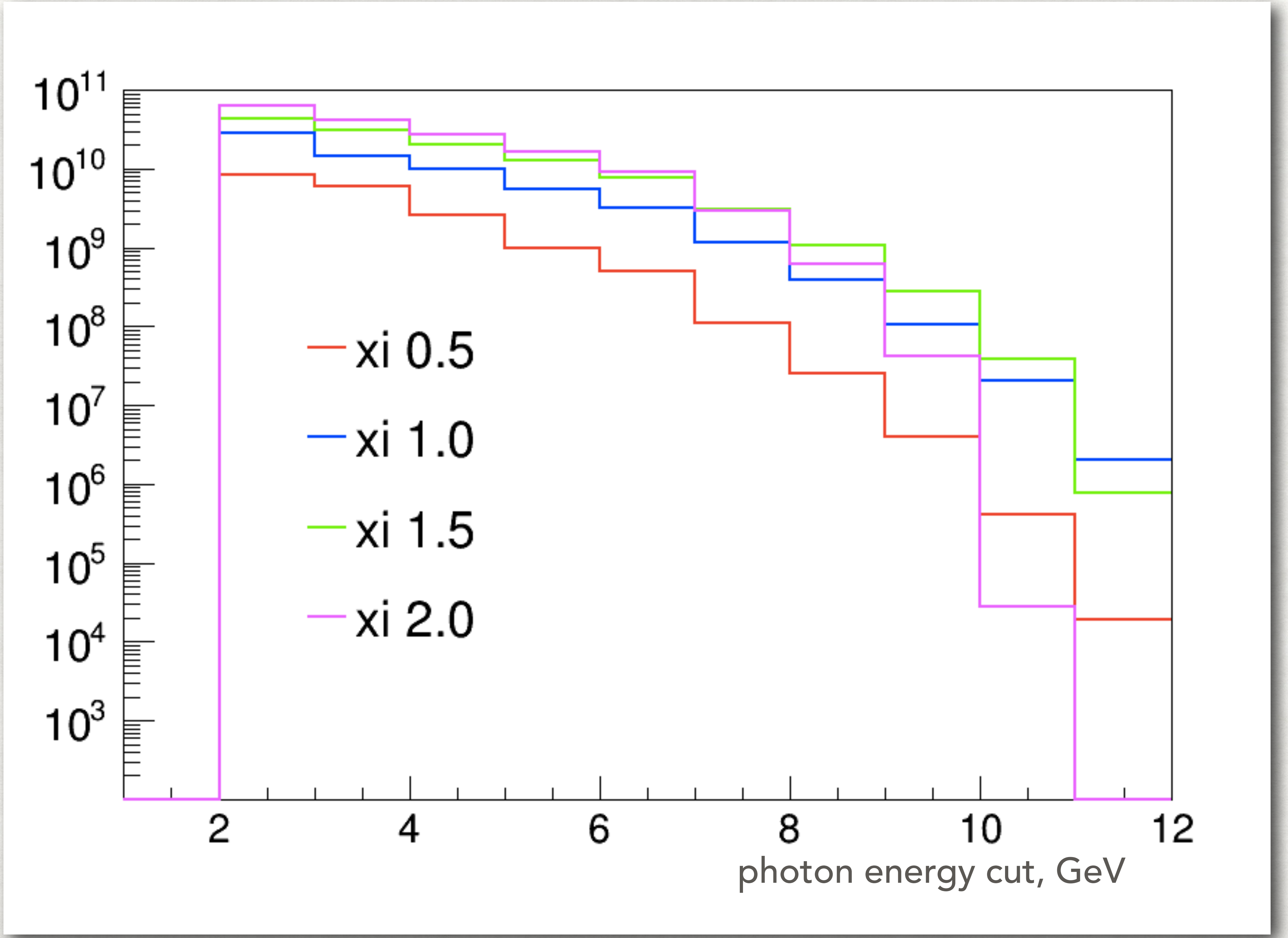
multiply the rate by the mass of the electron in eV, by 510998, then we will get differential transition rate per electron per 100 fs.

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

ξ	$N\gamma$	$N\gamma$, $E\gamma$>6.0 Gev	$N\gamma$, $E\gamma$>4.0 Gev	$N\gamma$, $E\gamma$>3.0 Gev	$N\gamma$, $E\gamma$>2.0 Gev
0.5	1.49255E+10	4.94882E+08			
1	5.26758E+10	3.16064E+09	1.00437E+10		
1.5	1.01825E+11	7.71401E+09		3.09275E+10	
2	1.52579E+11	9.25216E+09			6.44808E+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

NUMBER OF PHOTONS W/ ENERGY CUT



TUNGSTEN WIRE AS A TARGET

Mouse over to zoom in

Tungsten wolfram fine wire 0.01mm 0.02mm 0.03mm 0.04mm 0.05mm 0.1mm 0.15mm 0.2mm 0.3mm 0.4mm 0.5mm 1mm for scopes and transits

★★★★★ 5.0 (4 votes) | 9 orders

Price: US $69.99 / piece

Bulk Price

Diameter: 0.01mm X 10000m | 0.02mm X 2m | 0.03mm X 2m | 0.04mm X 2m | 0.05mm X 2m | 0.1mm X 2m | 0.15mm X 2m | 0.2mm X 2m | 0.3mm X 2m | 0.4mm X 2m | 0.5mm X 2m | 1mm X 2m | 1.5mm X 2m

Shipping: **Free Shipping to Germany via AliExpress Standard Shipping**

Estimated Delivery Time: 23 days

Quantity: – 1 + piece (4997 pieces available)

Total Price: **US $69.99**

Buy Now | Add to Cart | ♡ 20

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 :

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

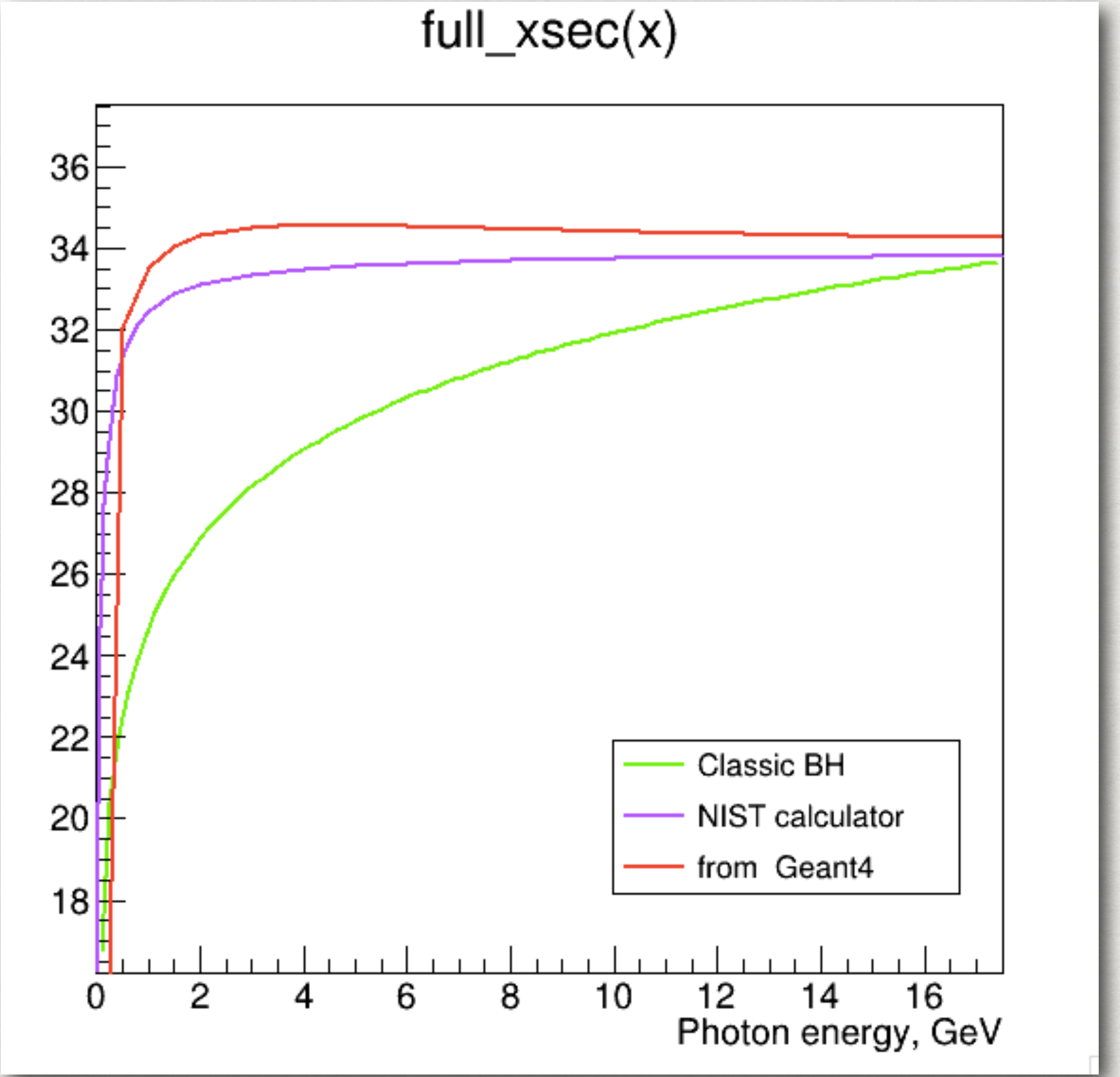
with :

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

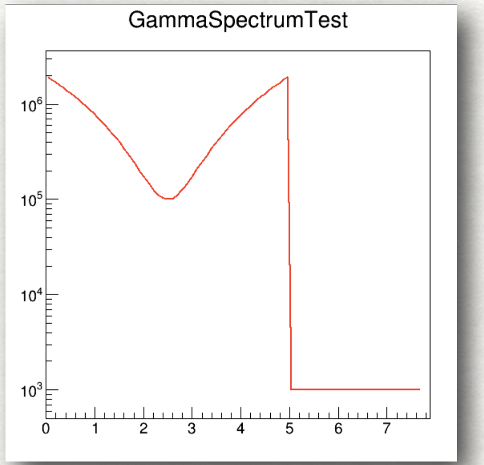
The parameters a_i, b_i, c_i were fitted to the data [hubb80].

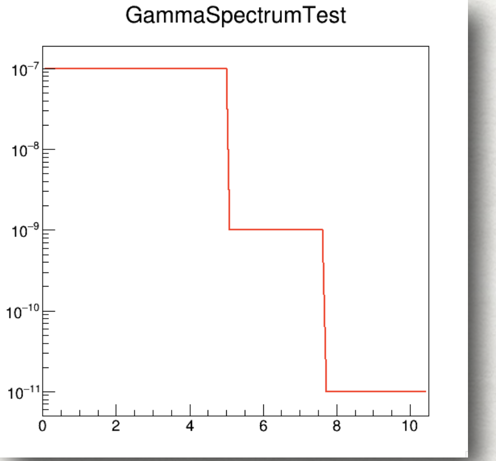
This parameterisation describes the data in the range :

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



FITTED THICKNESS



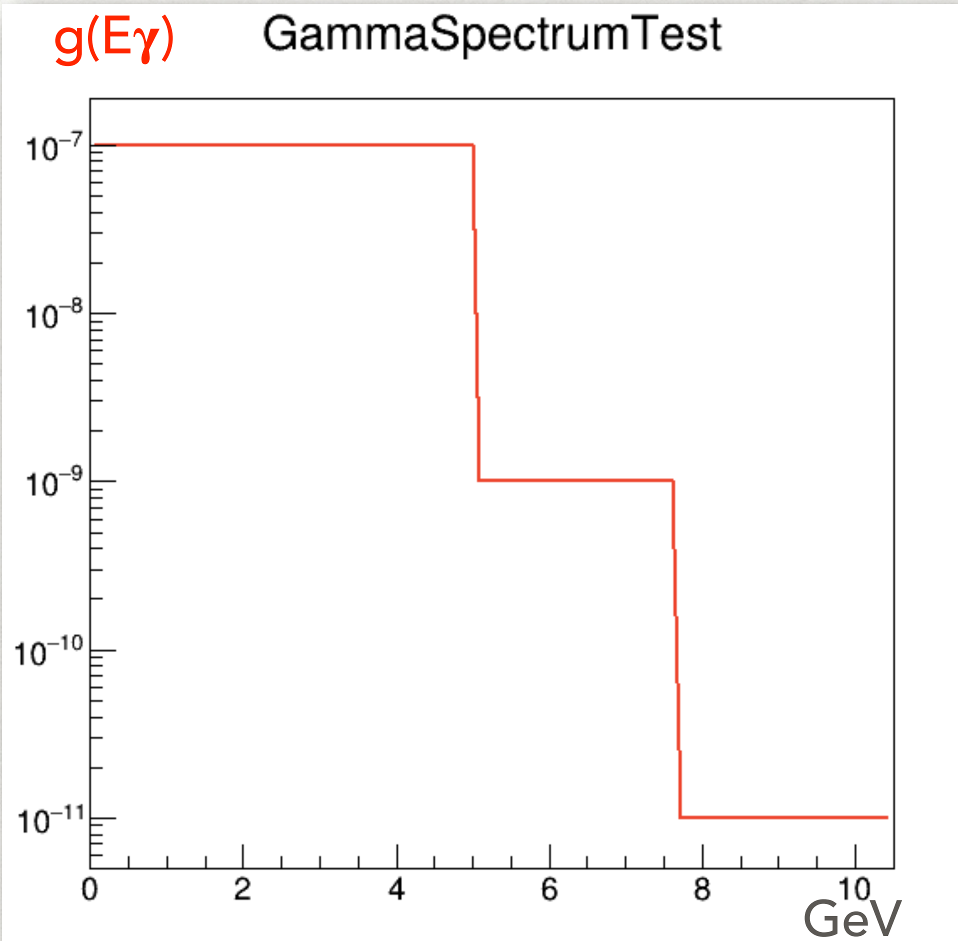


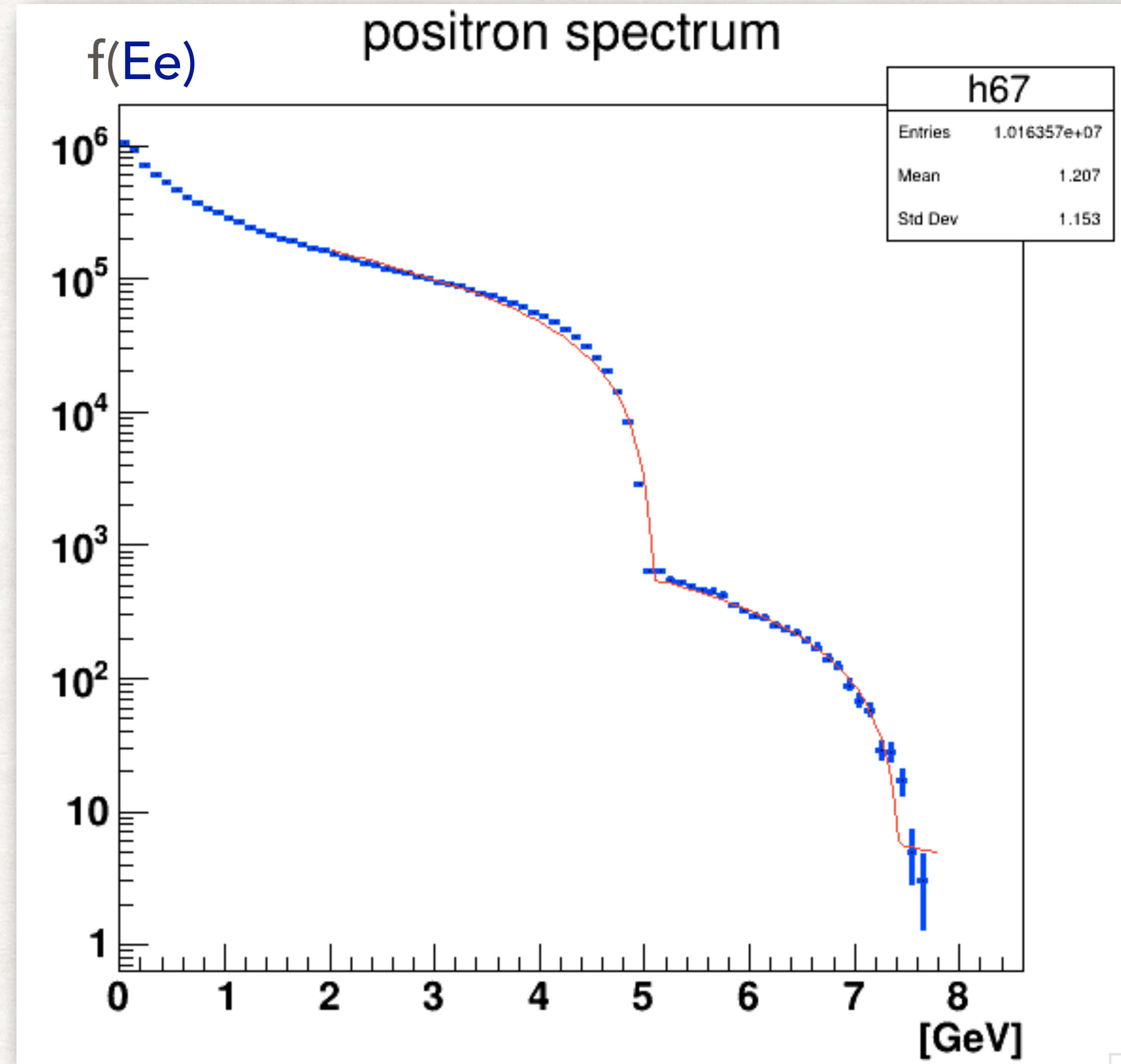
Thickness, cm	p[7] from the fit, cm	p[7] from the fit, cm
$3.5 * 10^{-3}$	$2.55 * 10^{-3}$	$3.2 * 10^{-3}$
$5 * 10^{-3}$	$5.17 * 10^{-3}$	$4.6 * 10^{-3}$
10^{-2}	$0.7 * 10^{-2}$	$0.9 * 10^{-2}$
$2 * 10^{-2}$	$1.8 * 10^{-2}$	$1.8 * 10^{-2}$
$5 * 10^{-2}$	$5.67 * 10^{-2}$	$5.01 * 10^{-2}$

TESTING: COMPTON-LIKE

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

target material (W), its thickness 500 um





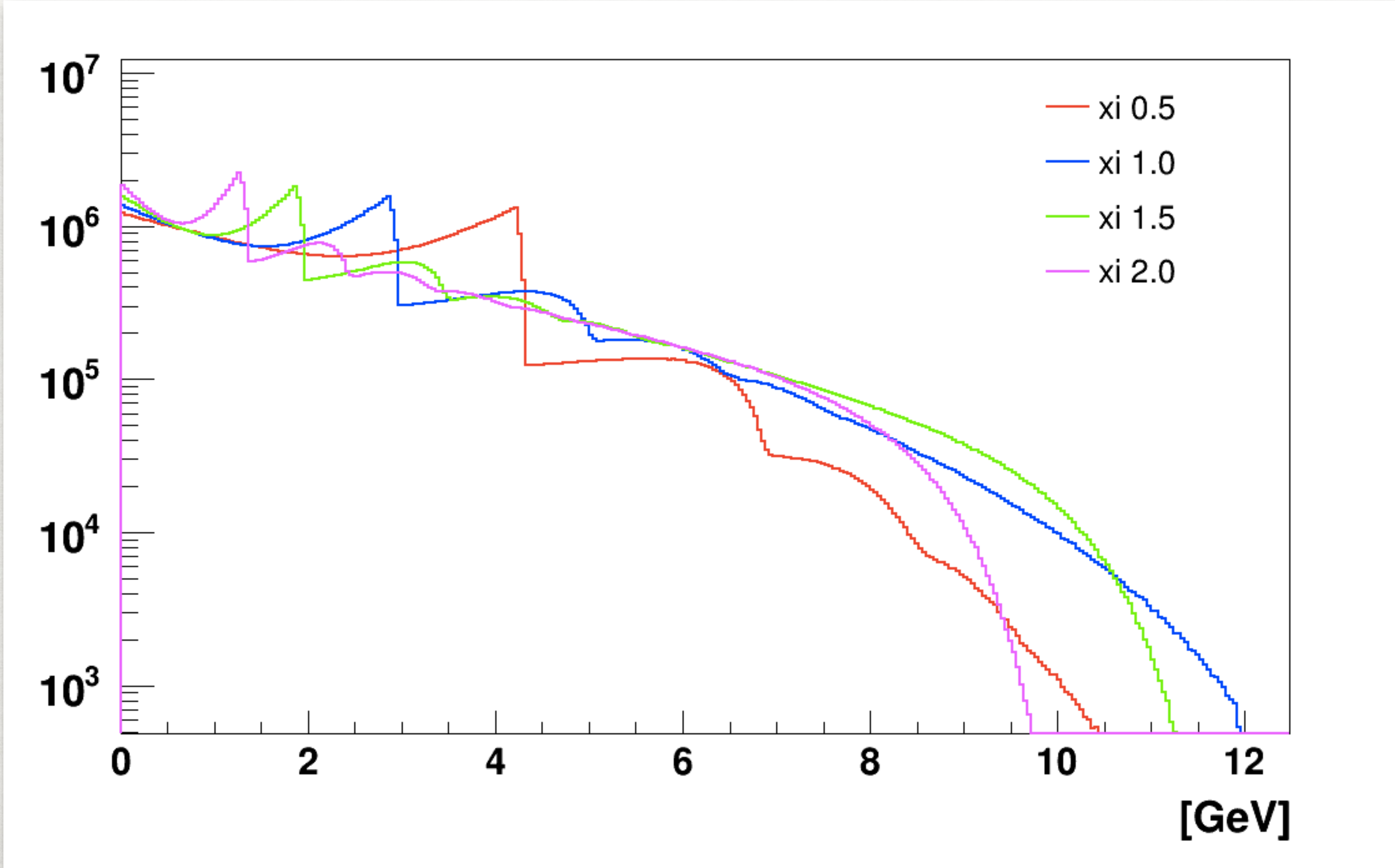
$\int \sigma(E\gamma, Ee)\, g(E\gamma, p1, p2)\, dE\gamma$

fitting allows finding the parameters quite well :

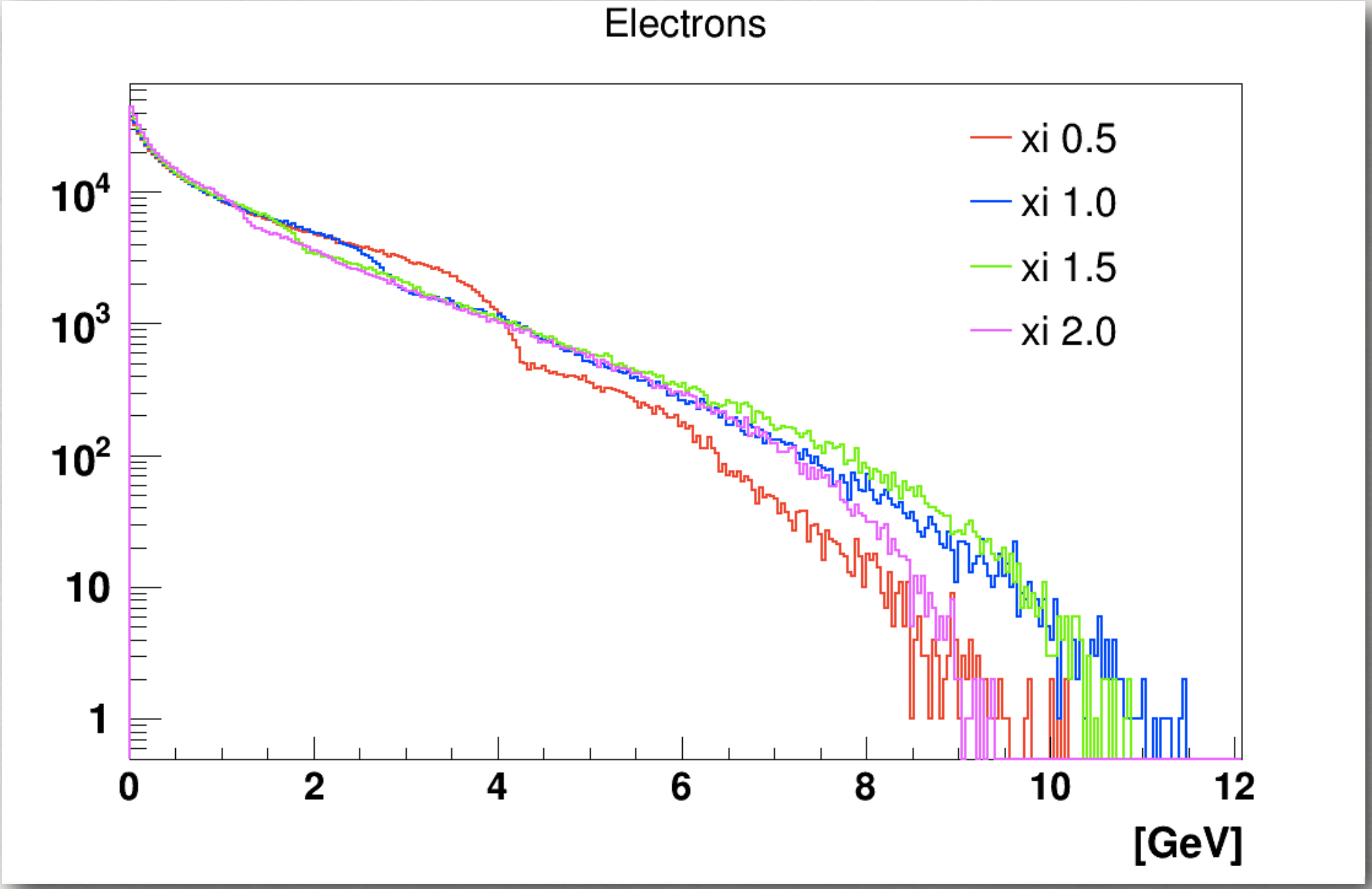
EXT NO.	PARAMETER NAME	VALUE	APPROXIMATE ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	0.00000e+00	fixed		
2	p1	8.10443e+05	7.55173e+03	4.54179e-07	8.91191e-01
3	p2	5.08073e+00	6.97488e-04	6.53706e-04	1.39541e-01
4	p3	0.00000e+00	fixed		
5	p4	5.78148e+03	1.25645e+02	4.35657e-07	-2.81589e-01
6	p5	7.43076e+00	2.04060e-02	2.03632e-02	-4.17430e-02
7	p6	6.14838e+01	1.53063e+01	2.48844e-05	-8.82892e-03
8	p7	5.01104e-02	4.66919e-04	3.40724e-07	3.39522e+00

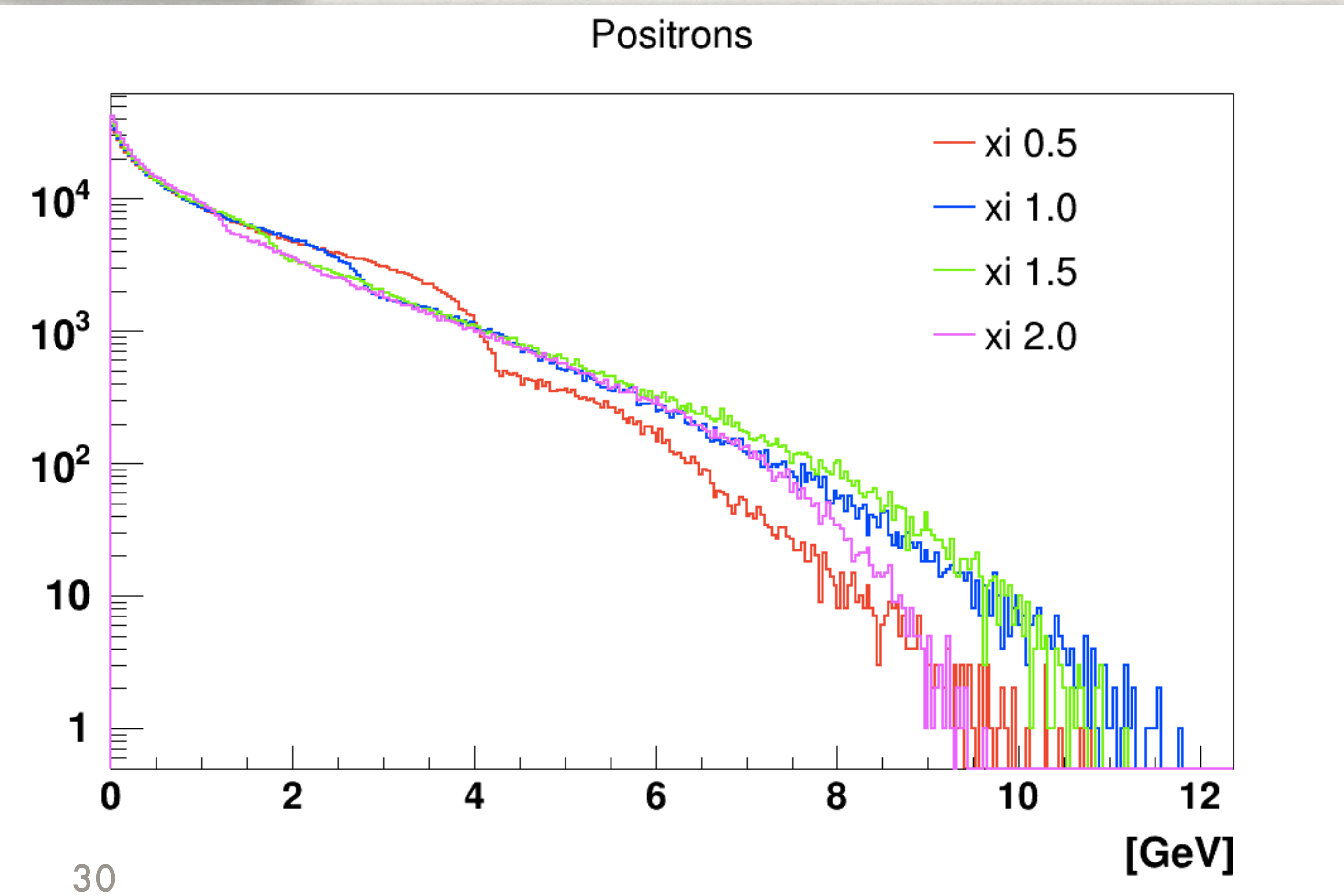
PHOTON SPECTRA FROM GEANT4

10E8 PHOTONS

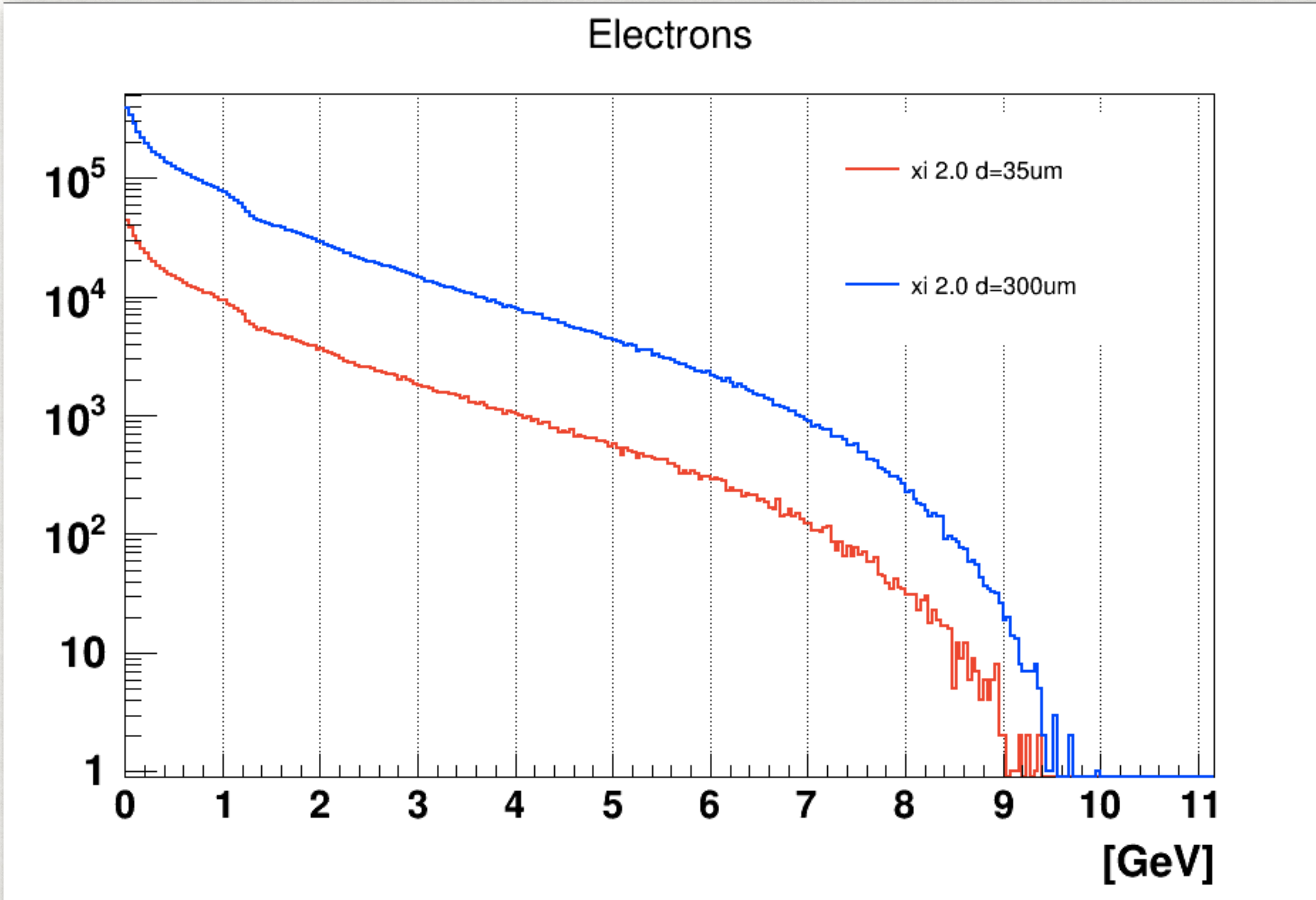


UNC

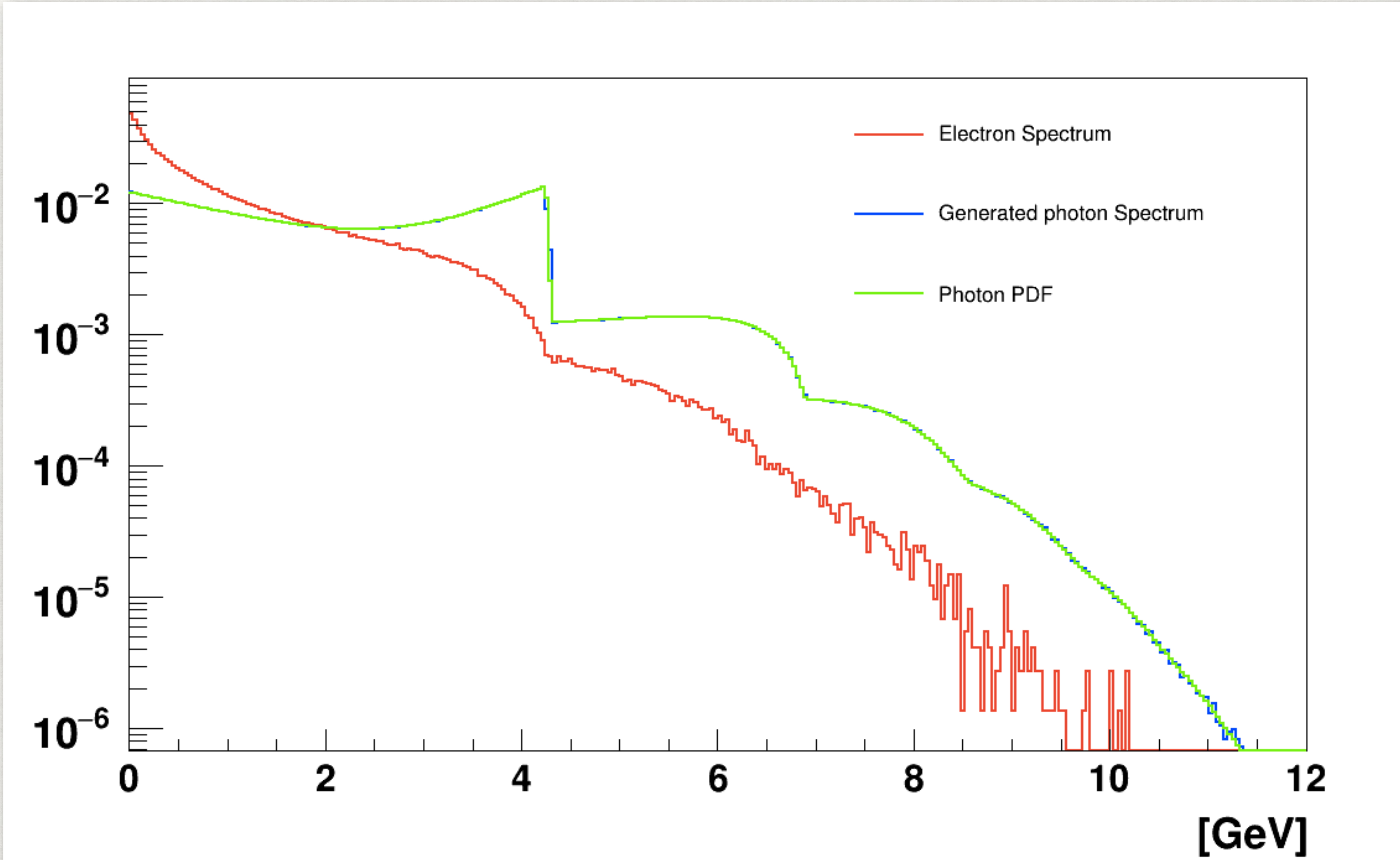

Electrons
xi 0.5
xi 1.0
xi 1.5
xi 2.0
10^4
10^3
10^2
10
1
0
2
4
6
8
10
12
[GeV]


Positrons
xi 0.5
xi 1.0
xi 1.5
xi 2.0
10^4
10^3
10^2
10
1
0
2
4
6
8
10
12
[GeV]

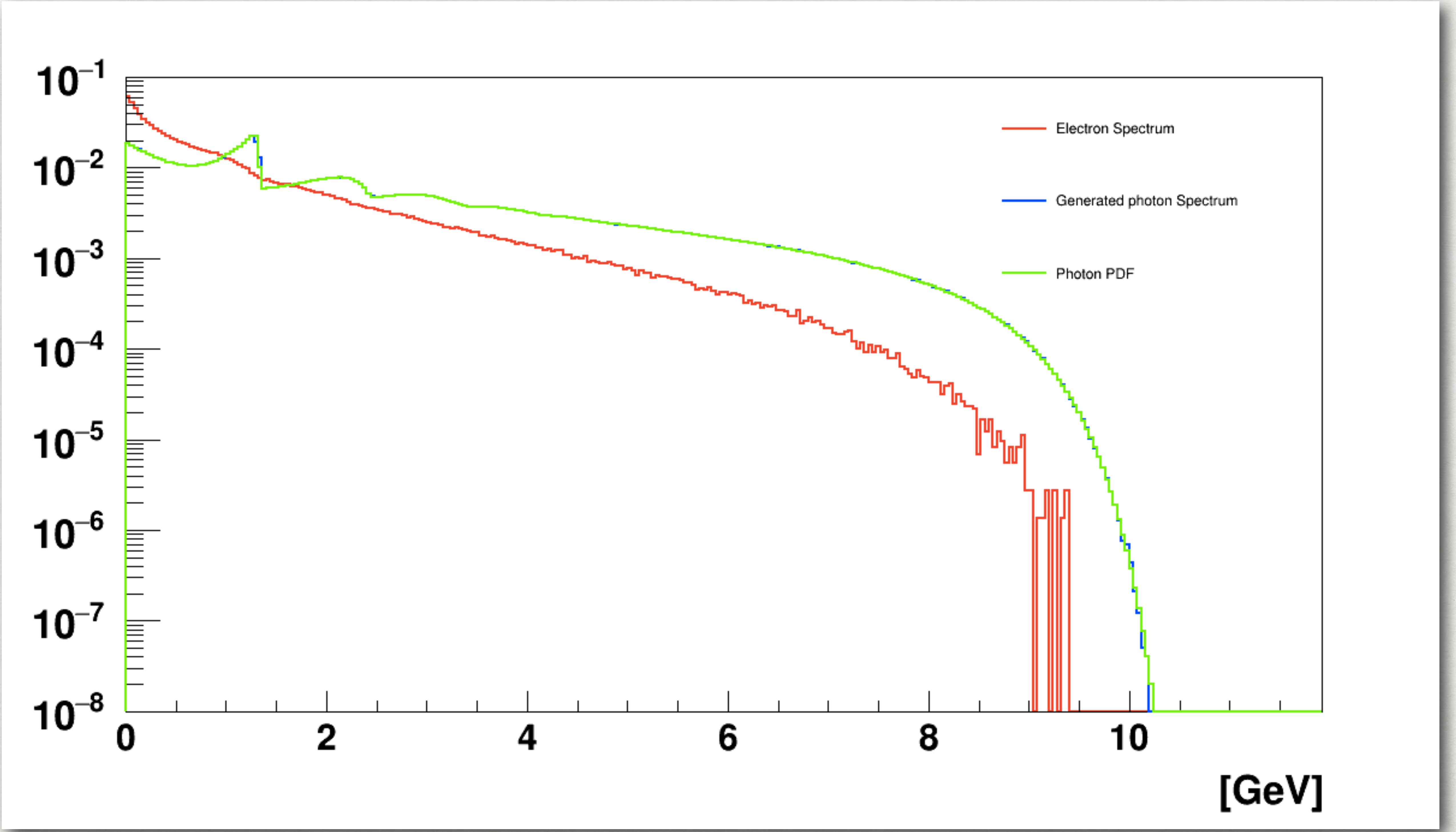
ELECTRON SPECTRA: 35 UM VS 300 UM



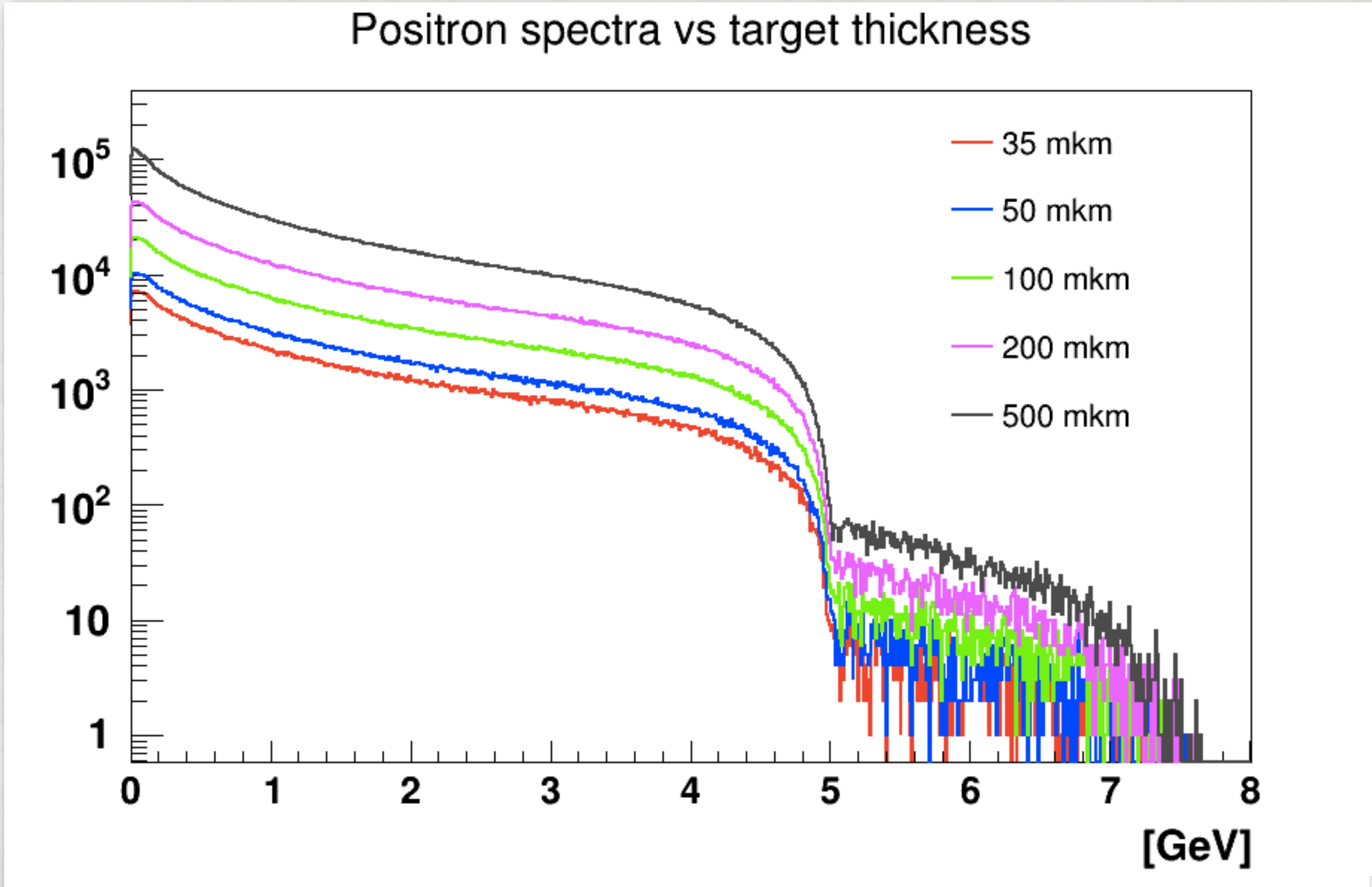
GAMMA AND ELECTRON SPECTRA FOR XI=0.5



GAMMA AND ELECTRON SPECTRA FOR XI=2.0



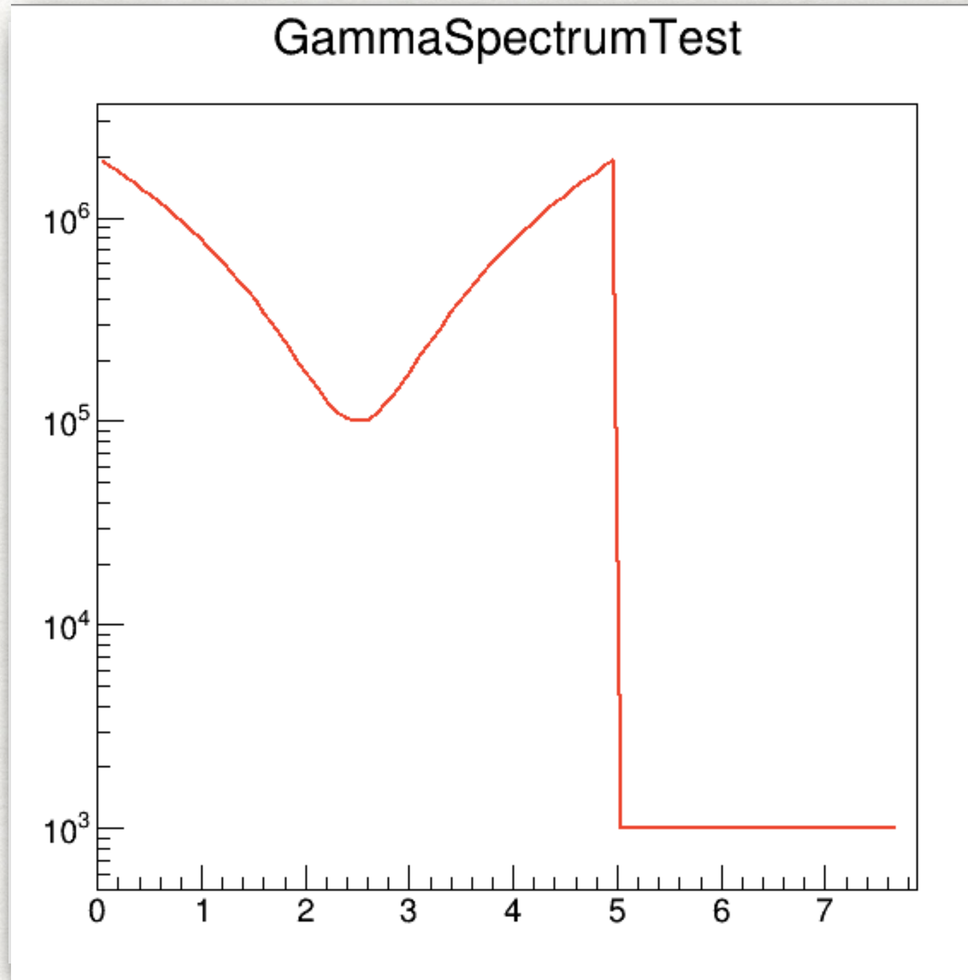
POSITRON SPECTRA VS TARGET THICKNESS IN GEANT4

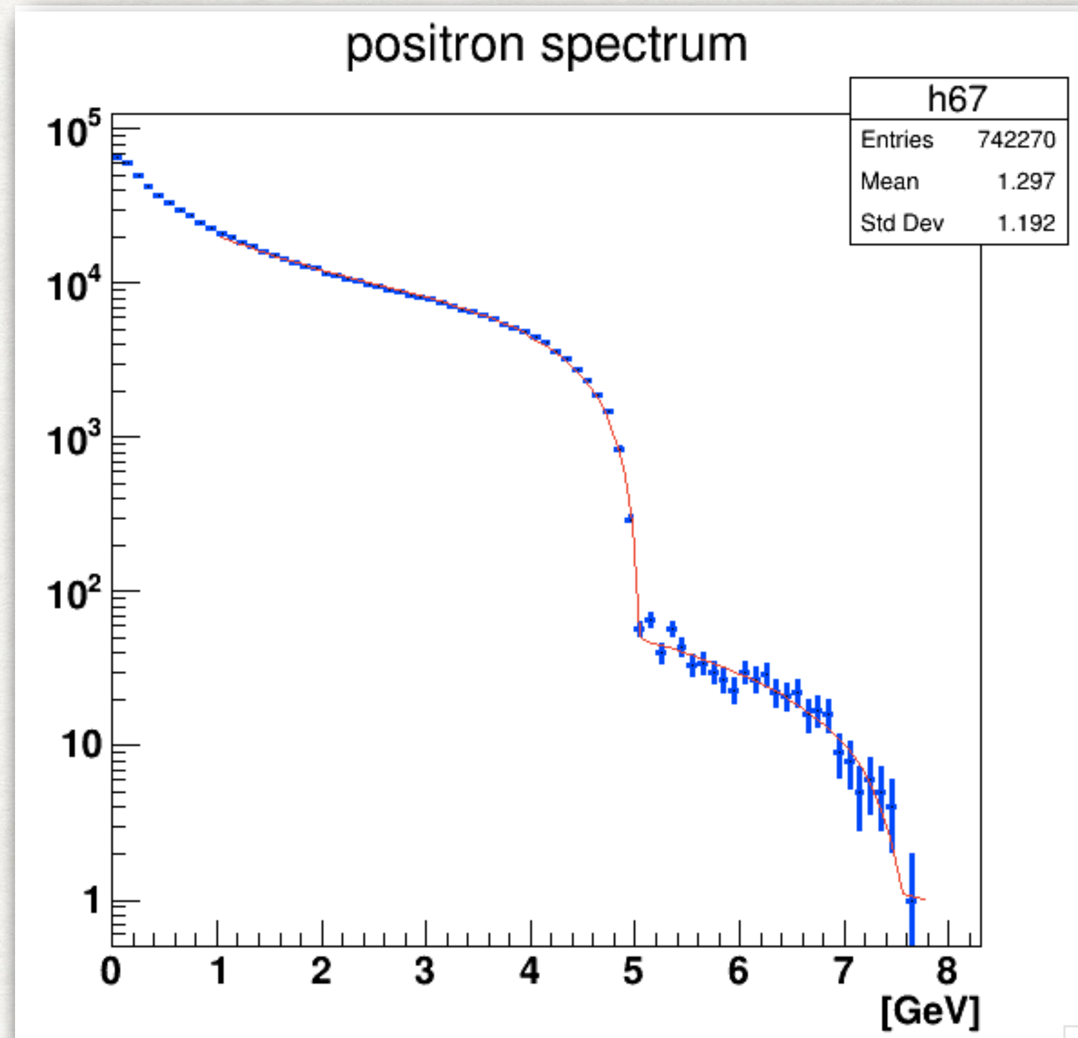


TESTING: COMPTON-LIKE

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

target material (W), its thickness 35 um



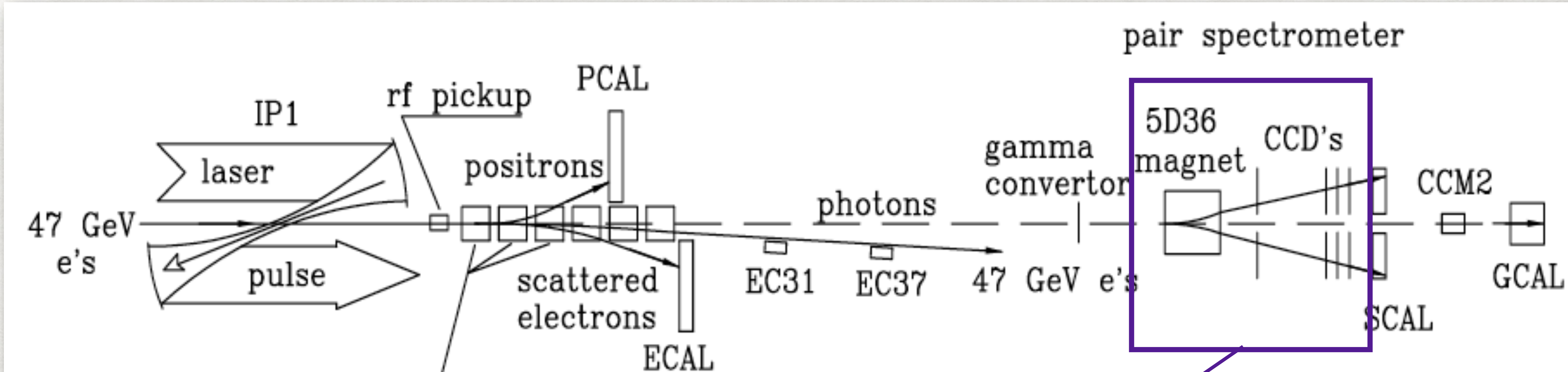


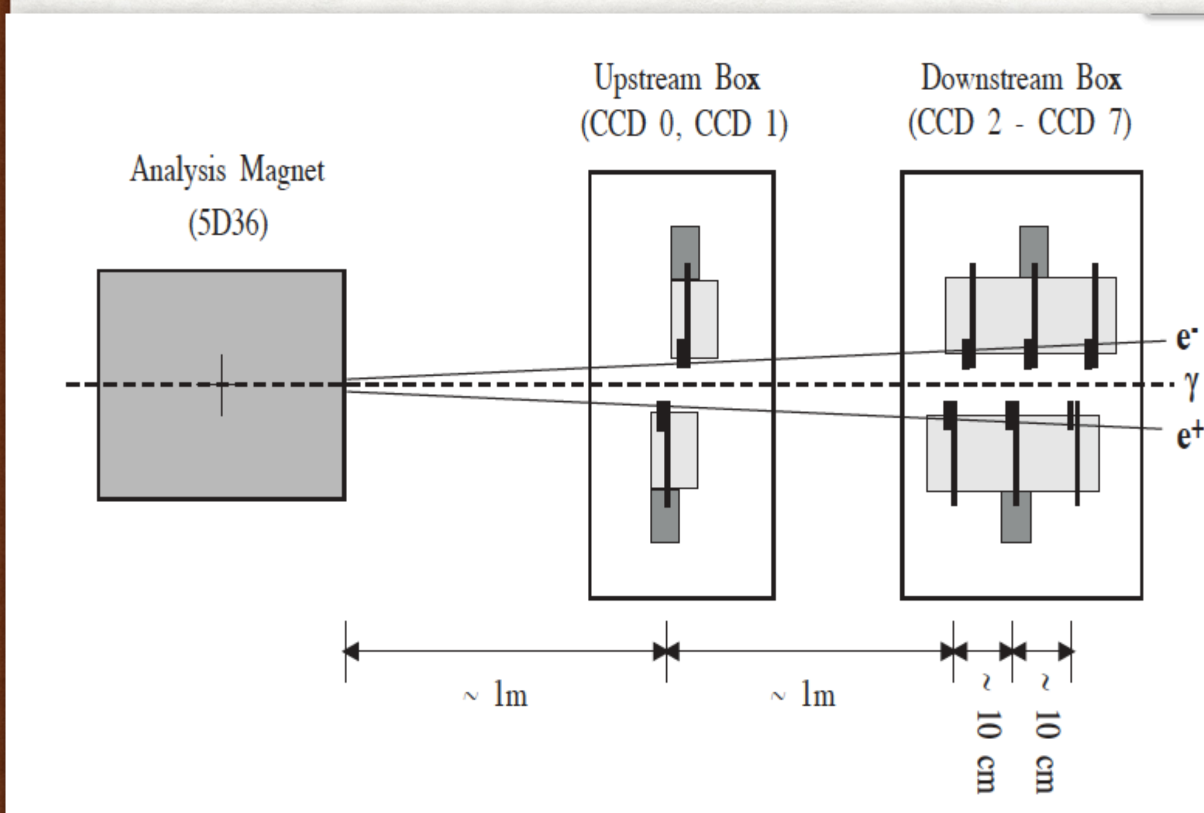
$\int \sigma(E\gamma, Ee)g(E\gamma,p1,p2)dE\gamma$

```
 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
```

LAYOUT FOR THE E-144 EXPERIMENT

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





CCD image sensors: pixel size 22.5*22.5 um

[EEV, 1242*1152].

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.

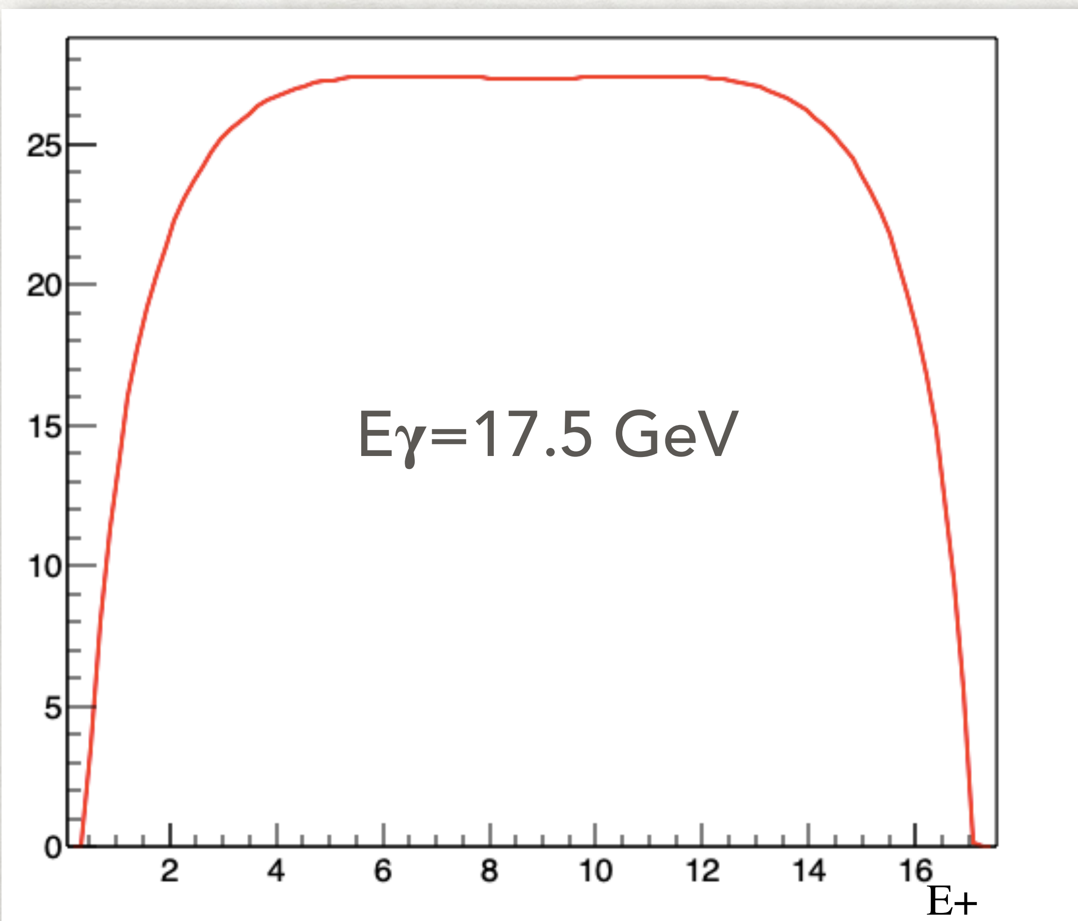
No attempt was made to use the CCDs in the front plane of the spectrometer in this mode, since the high number of hits led to significant ambiguity in the projection from the back planes to the front.

THE CLASSICAL BETHE-HEITLER PAIR SPECTRUM

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

$$\Phi\,(\mathrm{E}_0)\,d\mathrm{E}_0 = \frac{Z^2}{137}\left(\frac{e^2}{mc^2}\right)^2 4\,\frac{\mathrm{E}_{0+}{}^{2}\mathrm{E}_{+}{}^{2} + \frac{2}{3}\mathrm{E}_0\mathrm{E}_+}{(h\nu)^3}\,d\mathrm{E}_0\left(\log\frac{2\mathrm{E}_0\mathrm{E}_+}{h\nu mc^2} - \frac{1}{2}\right).$$

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

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 :

$$\begin{aligned} F_1(X) &= a_0 + a_1X + a_2X^2 + a_3X^3 + a_4X^4 + a_5X^5 \\ F_2(X) &= b_0 + b_1X + b_2X^2 + b_3X^3 + b_4X^4 + b_5X^5 \\ F_3(X) &= c_0 + c_1X + c_2X^2 + c_3X^3 + c_4X^4 + c_5X^5 \end{aligned}$$

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

This parameterisation describes the data in the range :

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