FORWARD PHOTONS

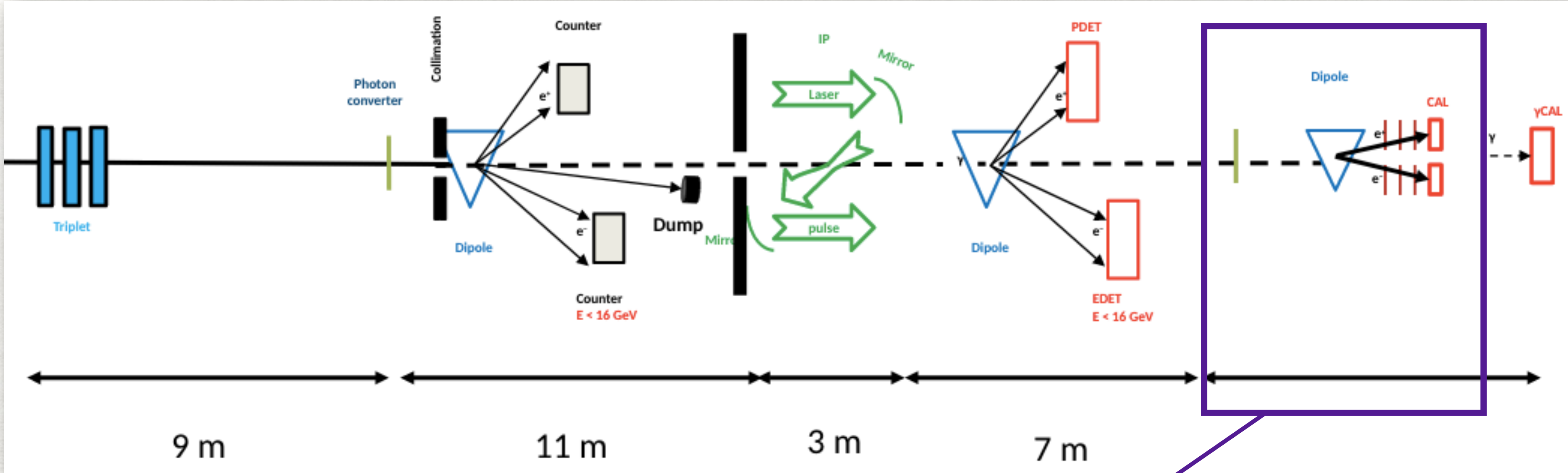
Borysova Maryna (KINR)

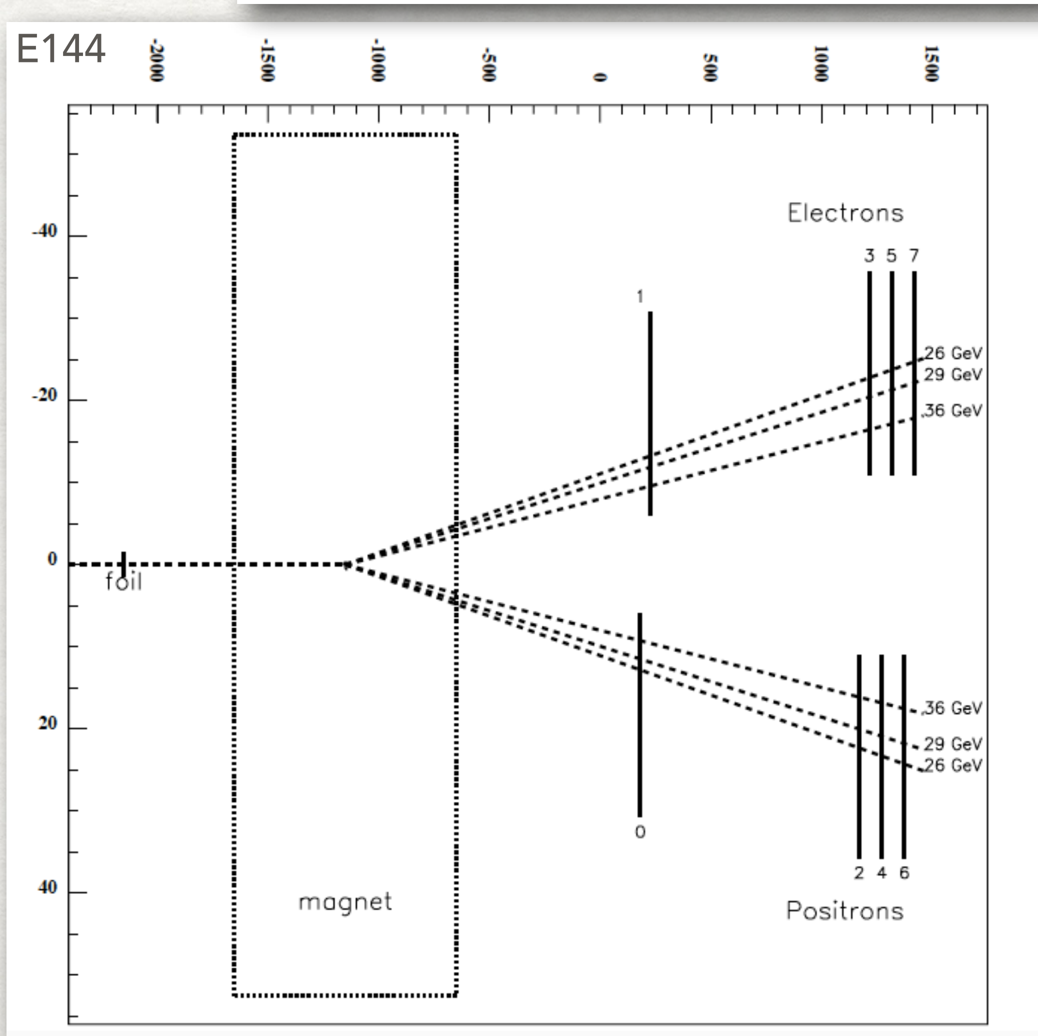
04/03/19

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





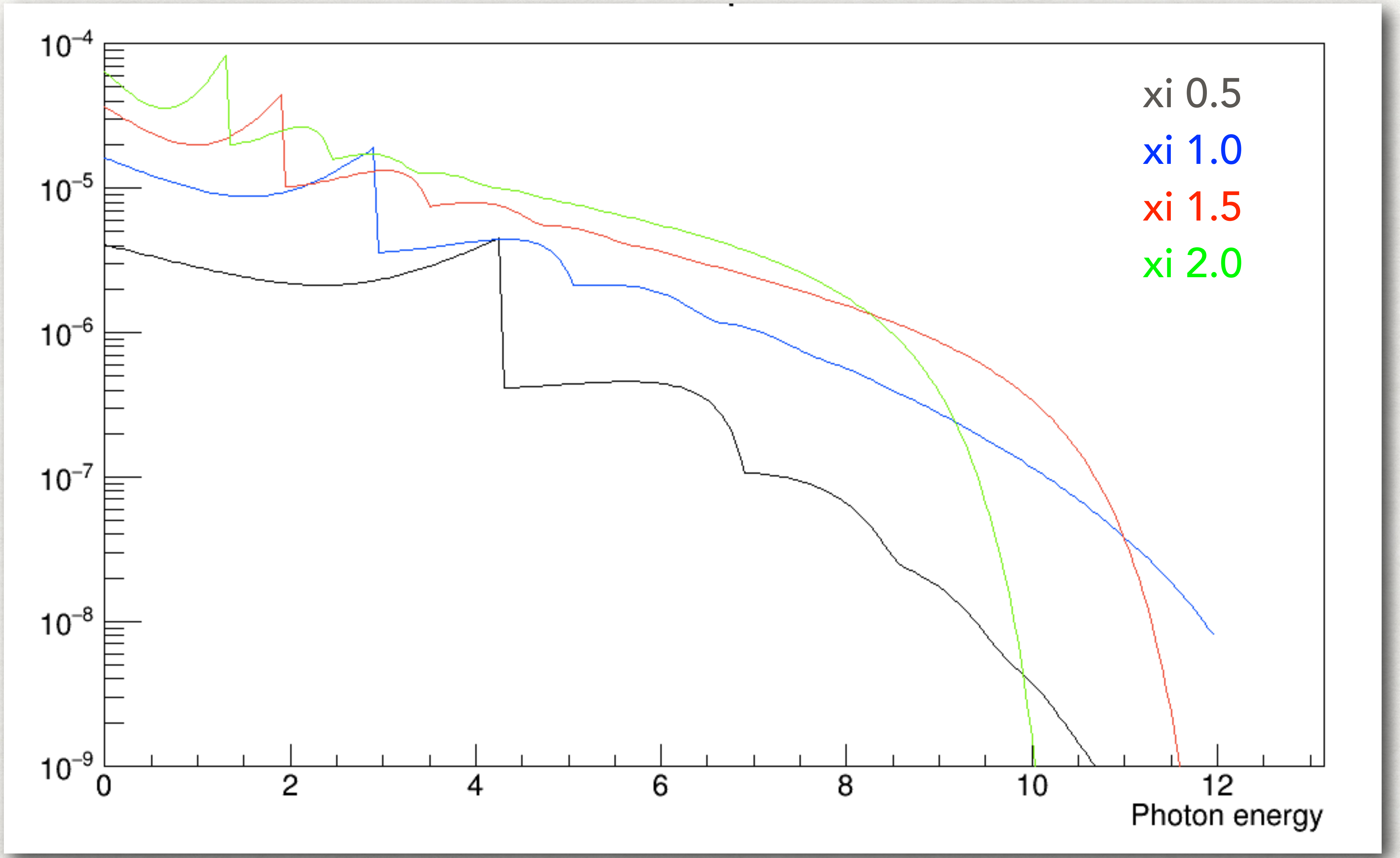
$$
\begin{aligned}
e + n\omega &\rightarrow e + \gamma \\
\gamma + n\omega &\rightarrow e^+ + e^-.
\end{aligned}
$$

- 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**

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

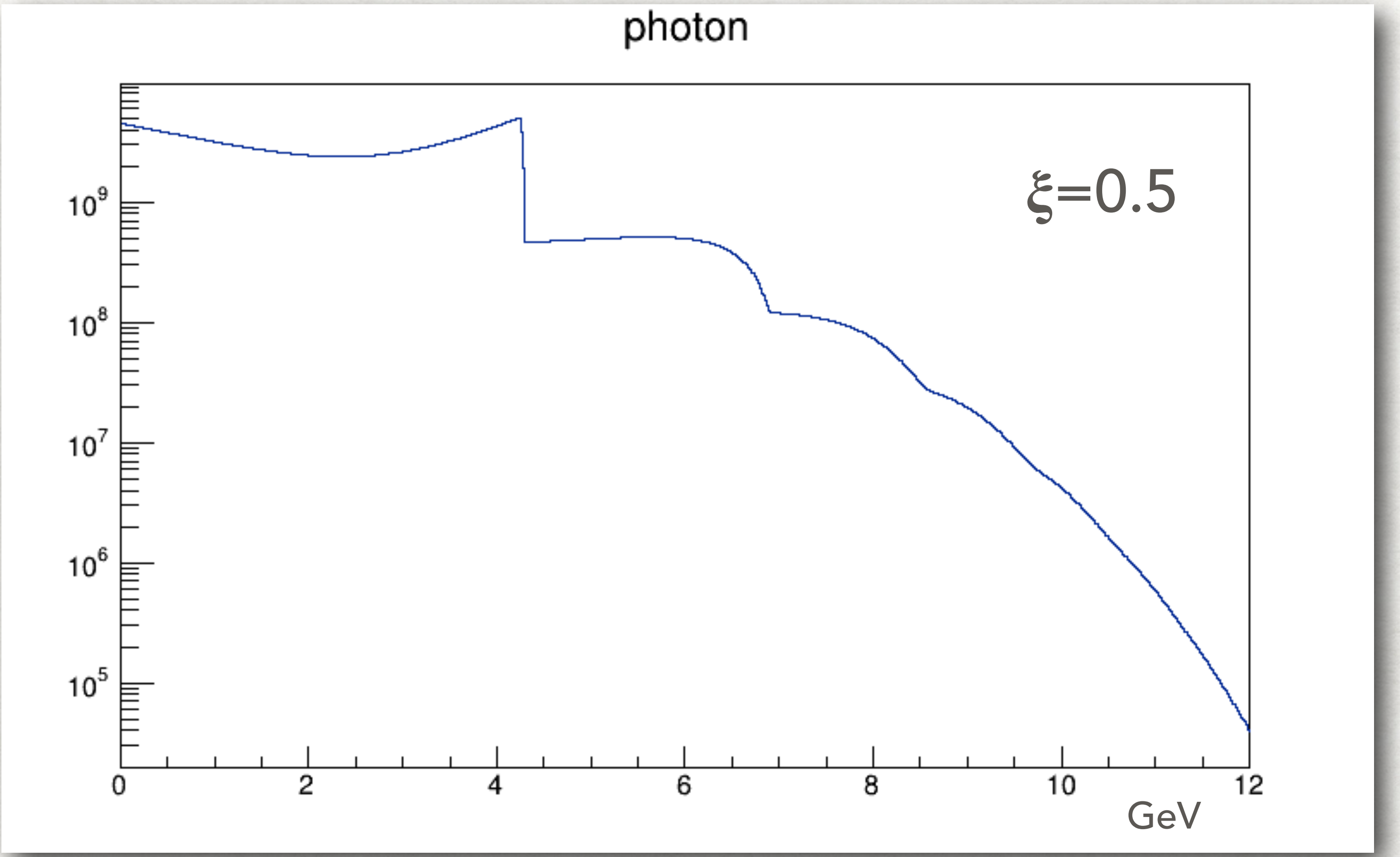
data produced of HICS/IPW/circularly polarized with Mathematica by Anthony Hartin 4/2/2019



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)	Nphoton
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

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 :

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

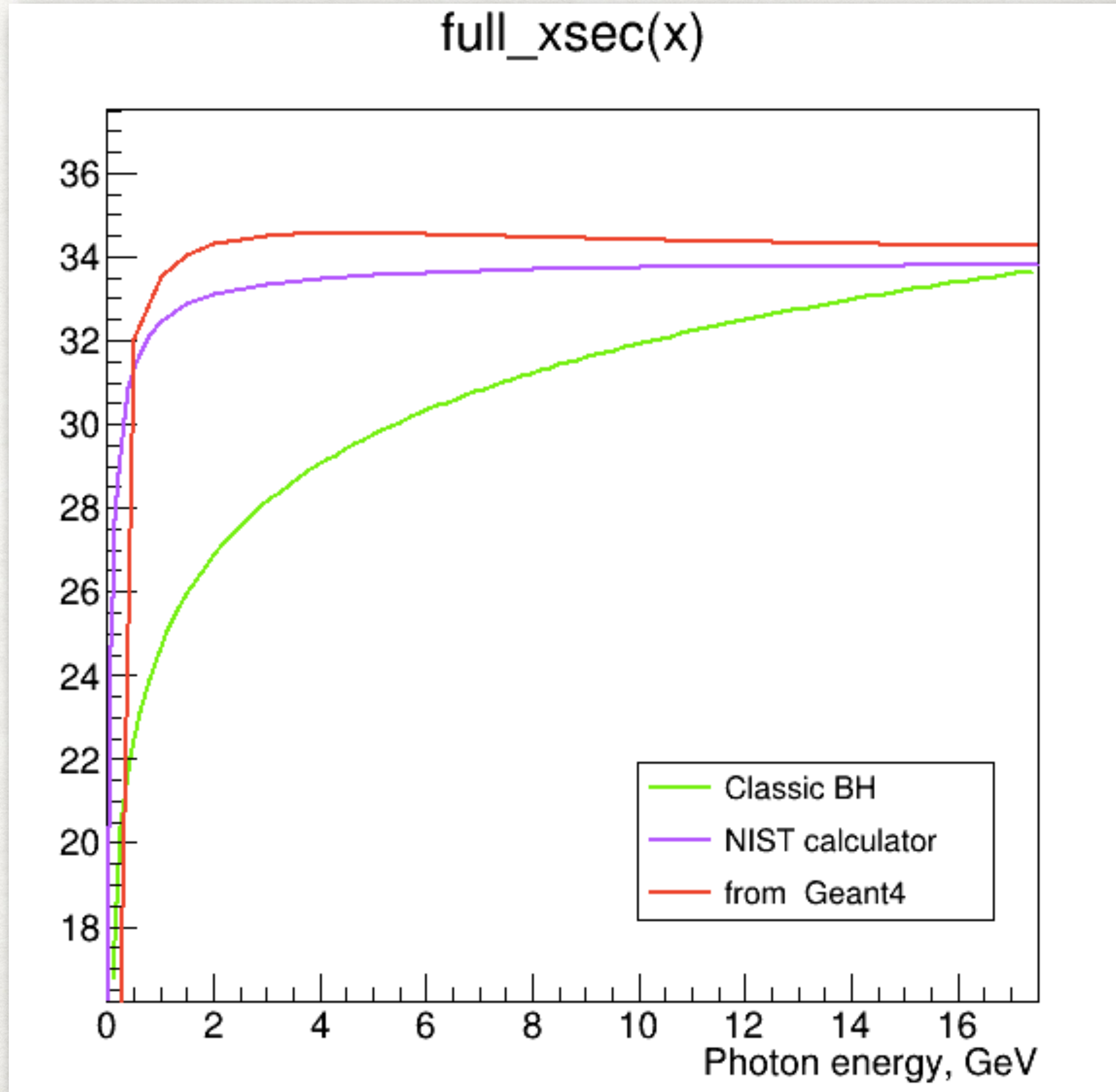
with :

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

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

This parameterisation describes the data in the range :

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



WHAT'S DONE & WHAT'S NEXT

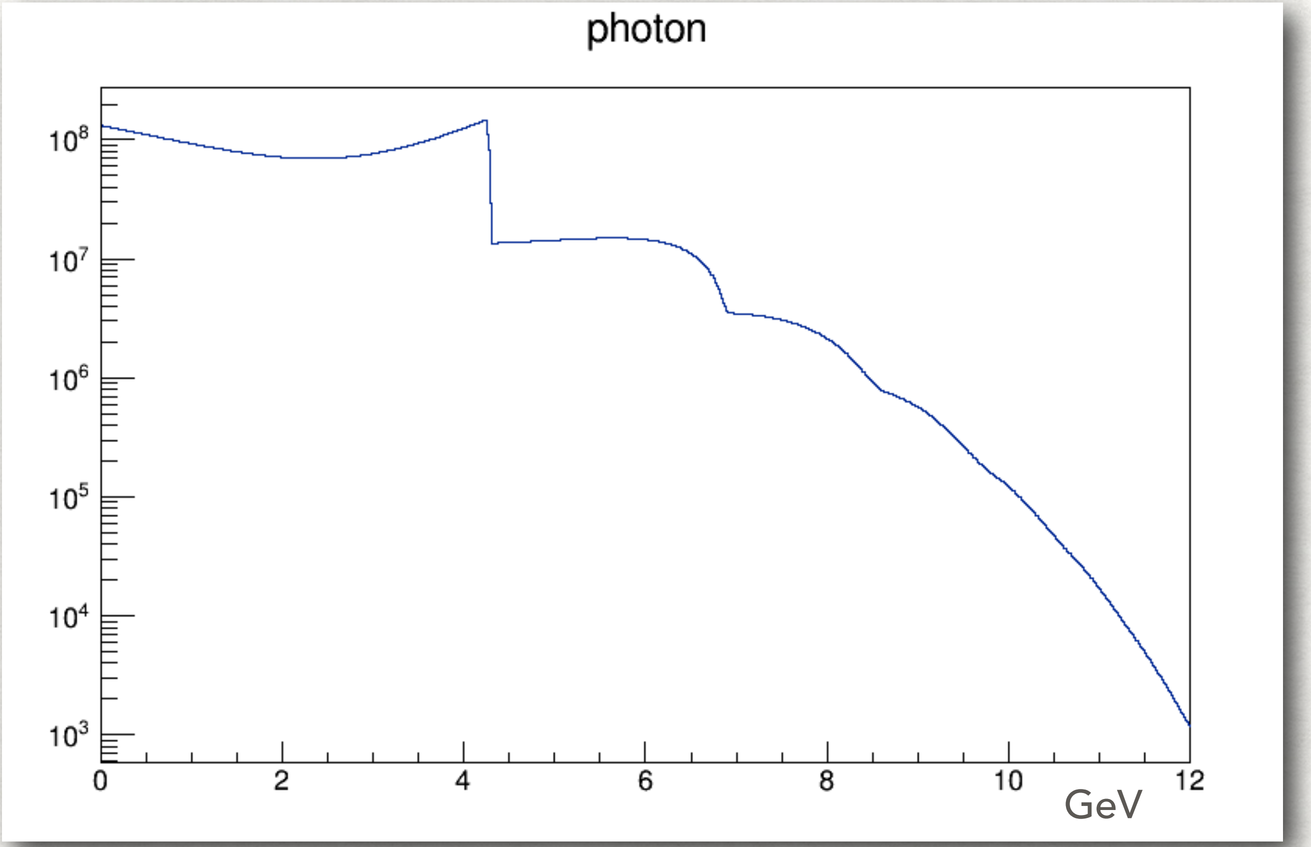
- estimated the absolute number of forward photons
- used Bethe-Heitler formula from Geant4 to calculate total cross-section per atom
- to use Bethe-Heitler class from Geant4, with corrections and extended for various effects (the screening, the pair creation in the field of atomic electrons, correction to the Born approximation, the LPM suppression mechanism, etc.) to calculate differential cross-section
- test if we could fit and find other parameters describing the process: target material (Z).

BACK UP

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.

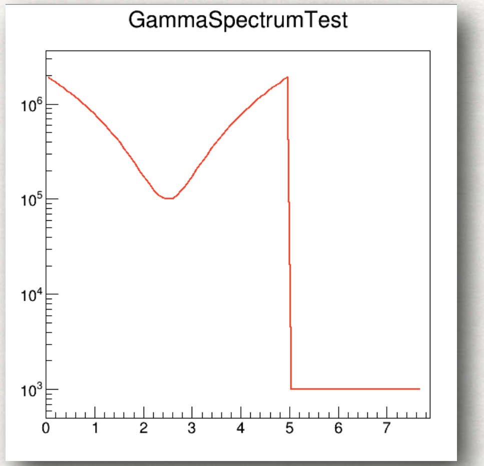
multiply it by the number of electrons in the bunch (6.25e+09) and by the laser pulse duration (35 ps) as it is seen by the electron (t * me/E / 100fs)

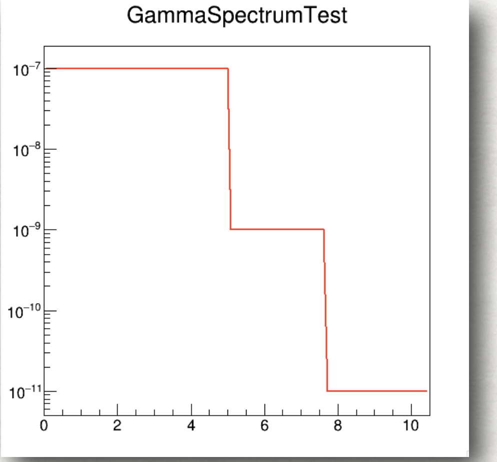


Integral:4.35822e+08

Does the transverse structure of the laser field is taken into account in the data (and xi is Gauss max) or it is assumed that the laser field is uniform in transverse direction and it is essentially the same for all electrons?

FITTED THICKNESS



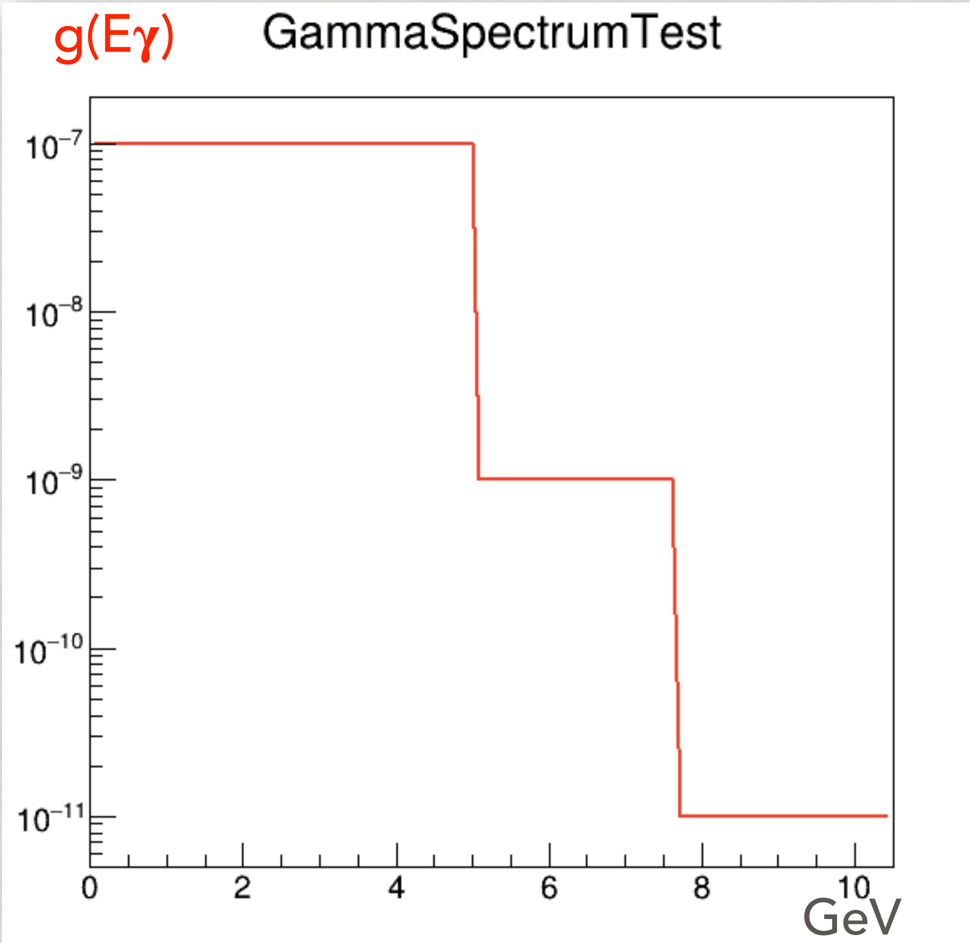


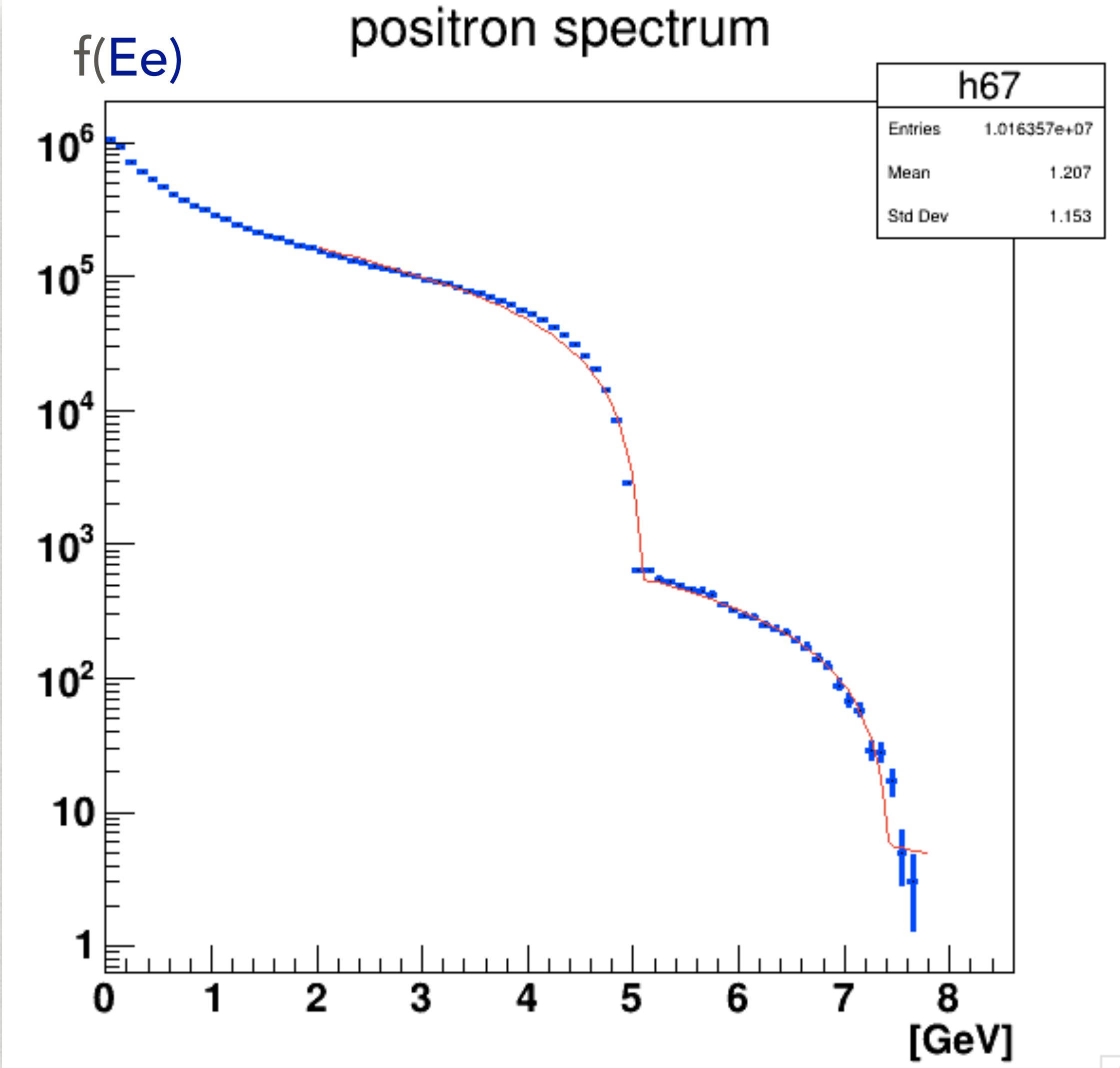
Thickness, cm	p[7] from the fit, cm	p[7] from the fit, cm
$3.5 * 10^{-3}$	$2.55 * 10^{-3}$	$3.2 * 10^{-3}$
$5 * 10^{-3}$	$5.17 * 10^{-3}$	$4.6 * 10^{-3}$
10^{-2}	$0.7 * 10^{-2}$	$0.9 * 10^{-2}$
$2 * 10^{-2}$	$1.8 * 10^{-2}$	$1.8 * 10^{-2}$
$5 * 10^{-2}$	$5.67 * 10^{-2}$	$5.01 * 10^{-2}$

TESTING: COMPTON-LIKE

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

target material (W), its thickness 500 um





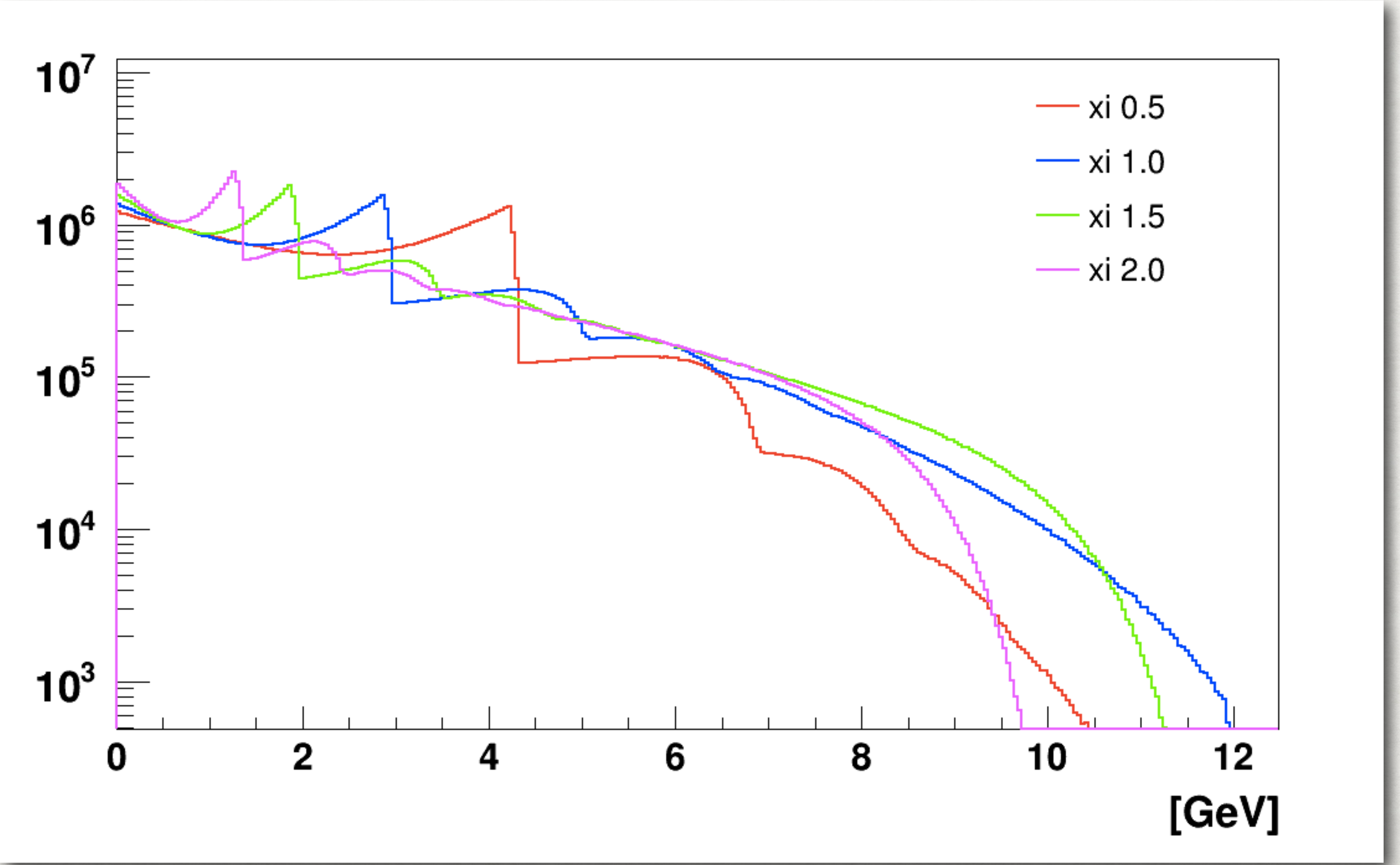
$\int \sigma(E\gamma, Ee) g(E\gamma, p1, p2) dE\gamma$

fitting allows finding the parameters quite well :

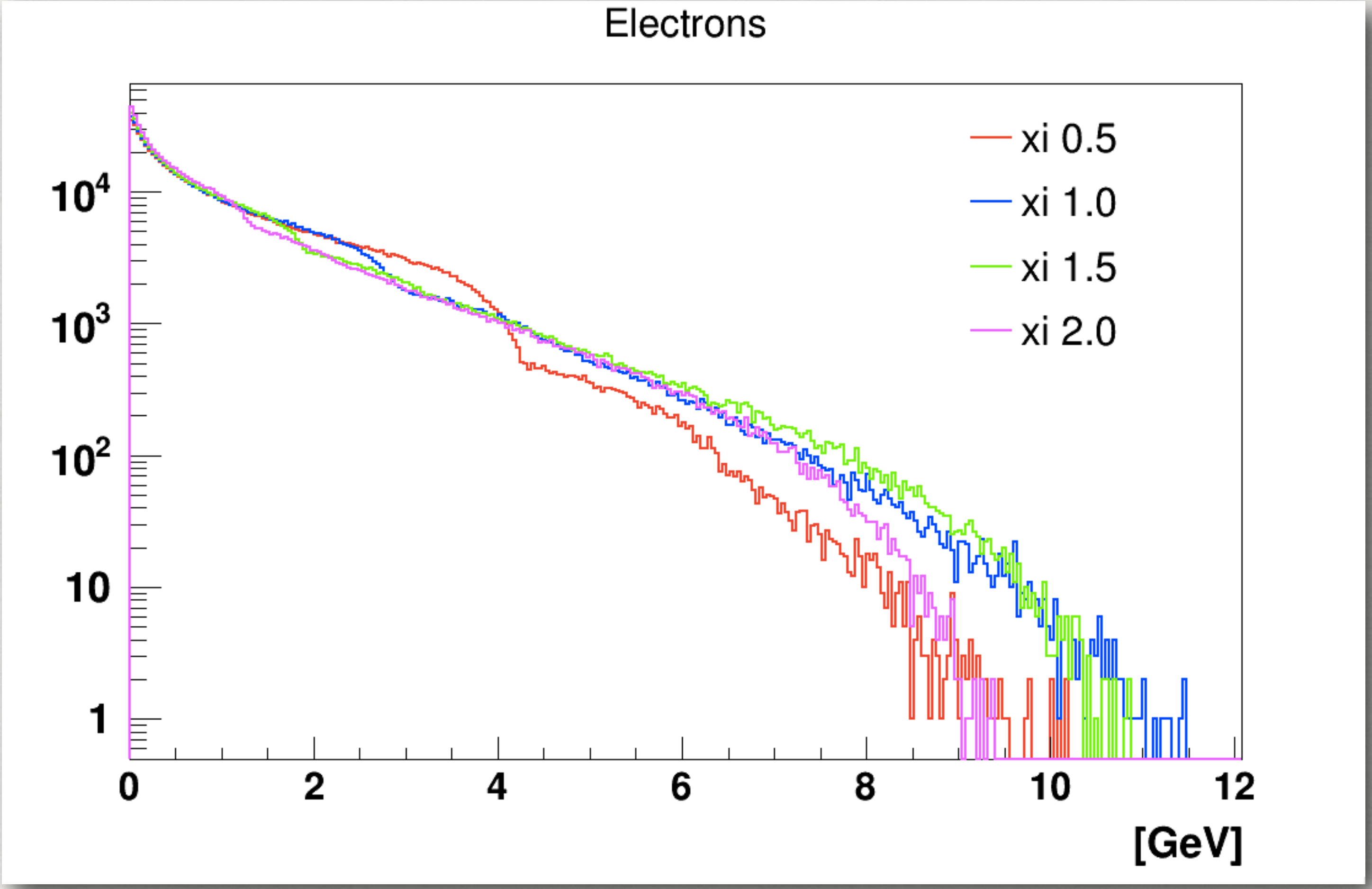
EXT NO.	PARAMETER NAME	VALUE	APPROXIMATE ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	0.00000e+00	fixed		
2	p1	8.10443e+05	7.55173e+03	4.54179e-07	8.91191e-01
3	p2	5.08073e+00	6.97488e-04	6.53706e-04	1.39541e-01
4	p3	0.00000e+00	fixed		
5	p4	5.78148e+03	1.25645e+02	4.35657e-07	-2.81589e-01
6	p5	7.43076e+00	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

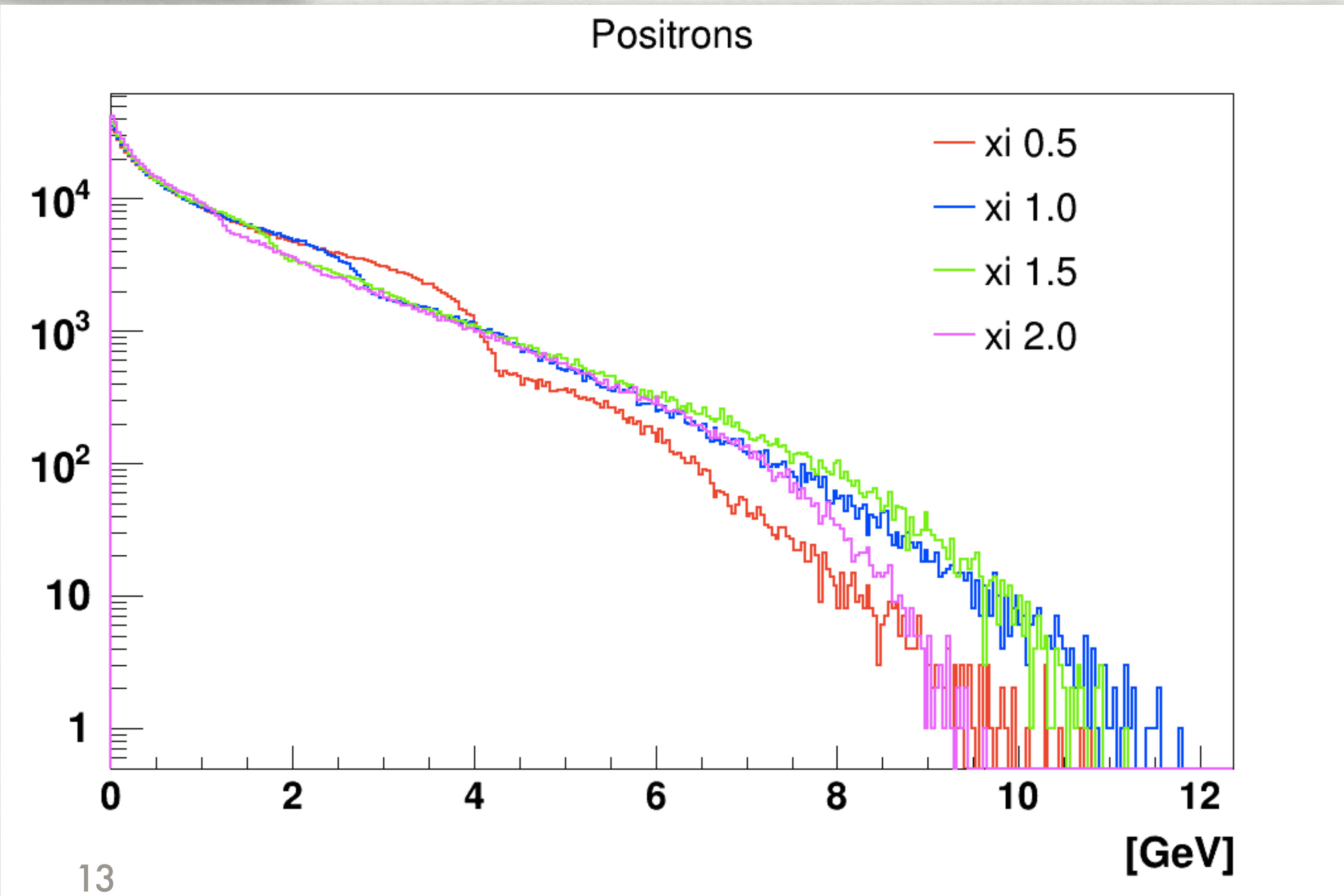
PHOTON SPECTRA FROM GEANT4

10E8 PHOTONS

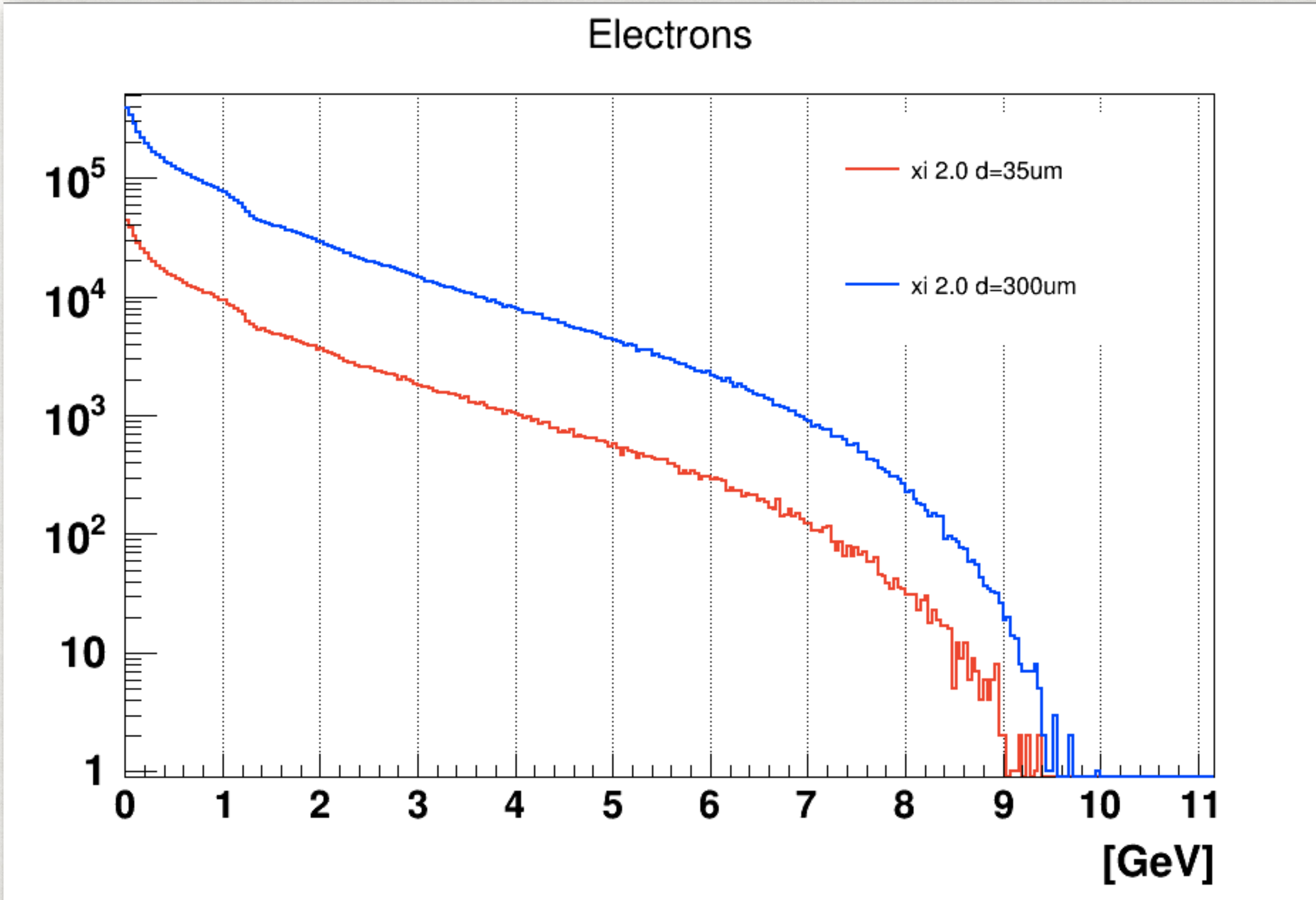


UNC

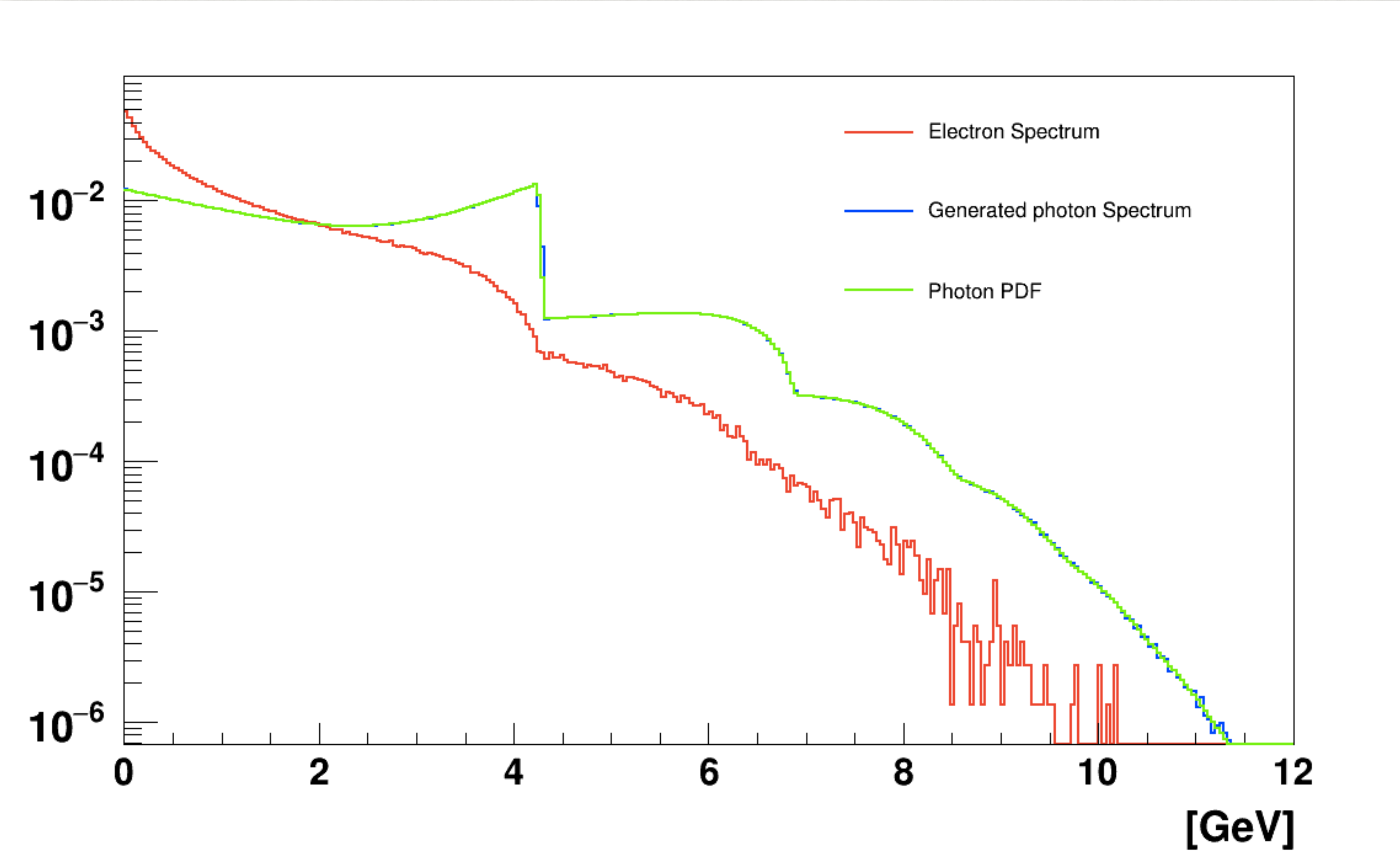

Electrons
xi 0.5
xi 1.0
xi 1.5
xi 2.0
10^4
10^3
10^2
10
1
0
2
4
6
8
10
12
[GeV]


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]

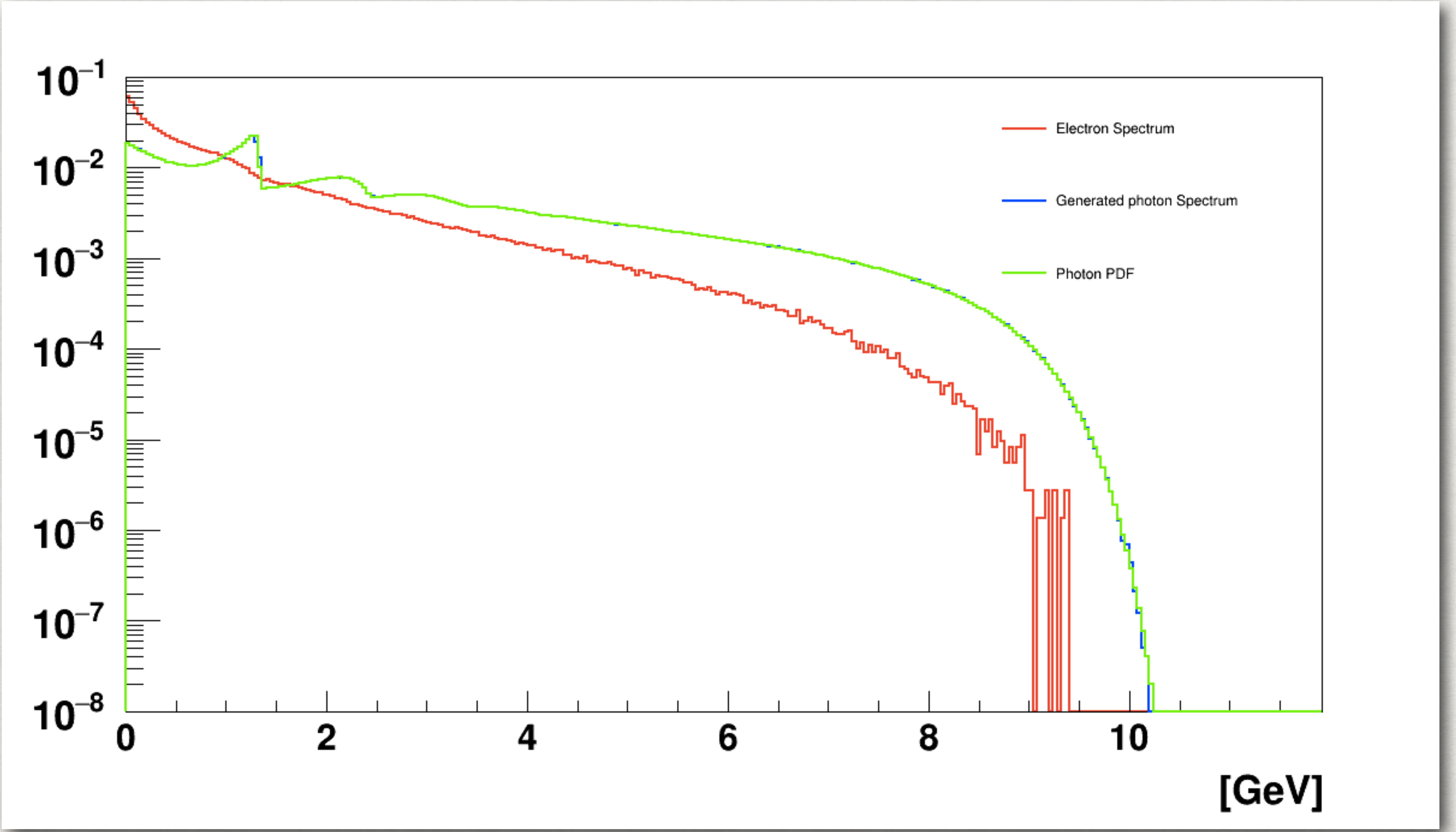
ELECTRON SPECTRA: 35 UM VS 300 UM



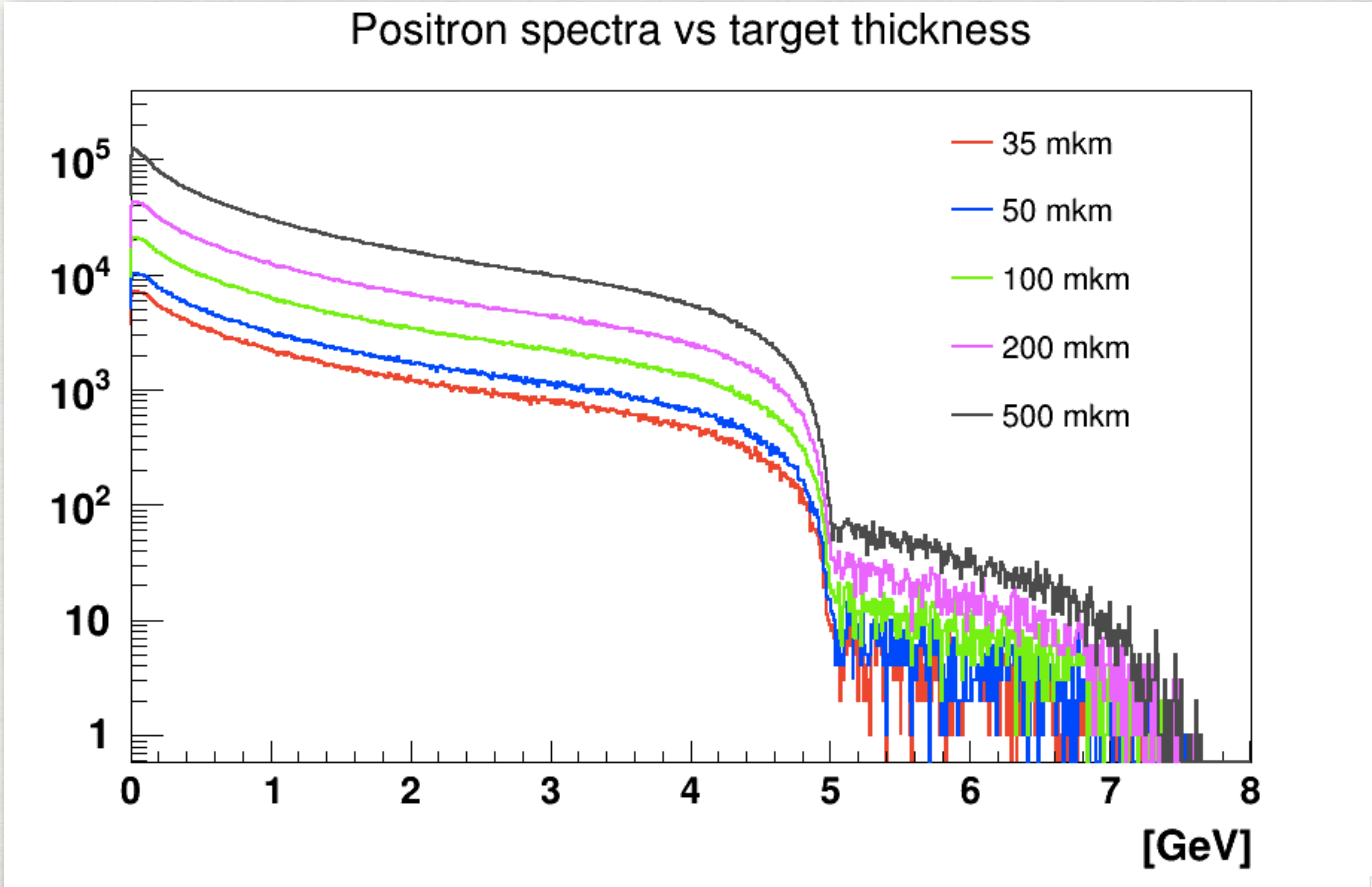
GAMMA AND ELECTRON SPECTRA FOR XI=0.5



GAMMA AND ELECTRON SPECTRA FOR XI=2.0



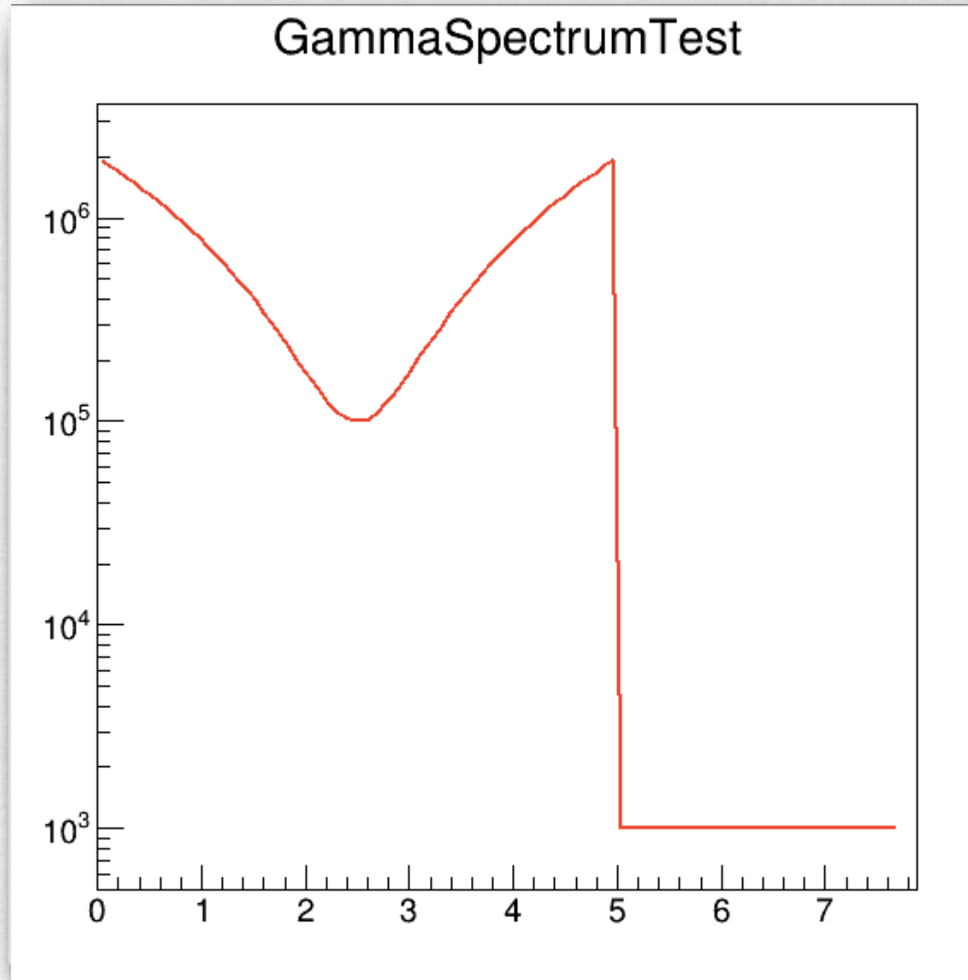
POSITRON SPECTRA VS TARGET THICKNESS IN GEANT4

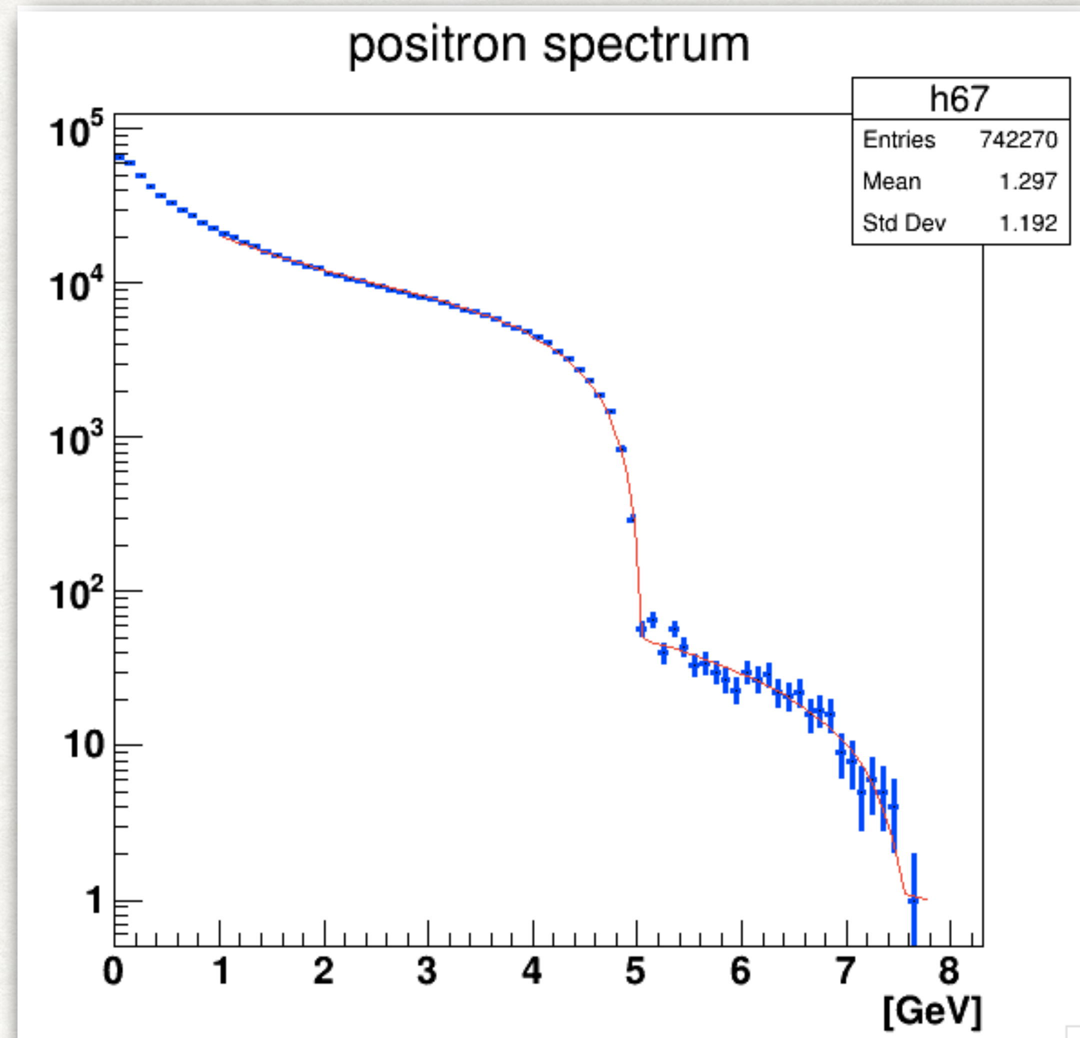


TESTING: COMPTON-LIKE

Ee=∫σ(Eγ, Ee)g(Eγ)dEγ

target material (W), its thickness 35 um





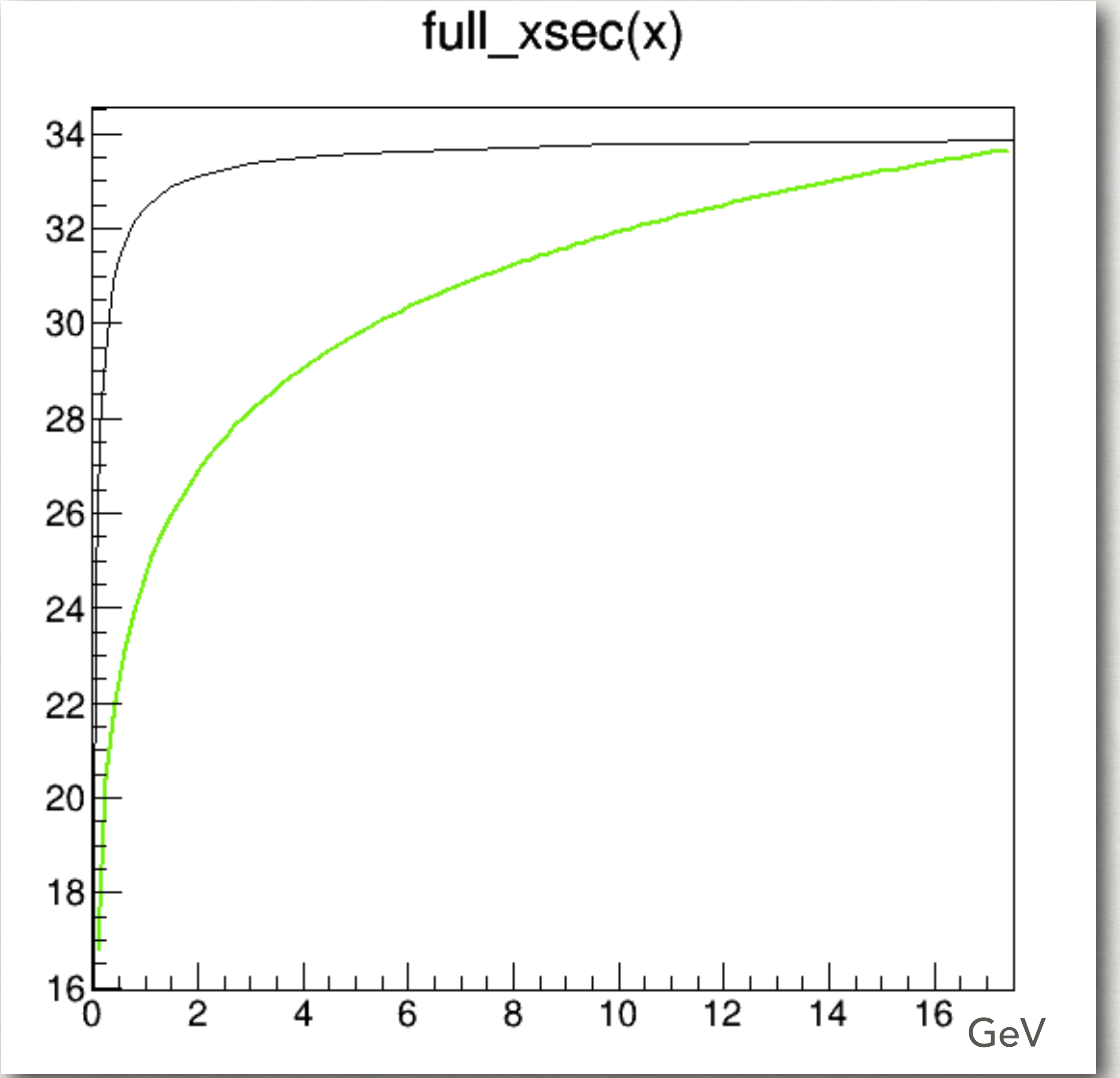
∫σ(Eγ, Ee)g(Eγ,p1,p2)dEγ

```
 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
```

TOTAL X-SECTION

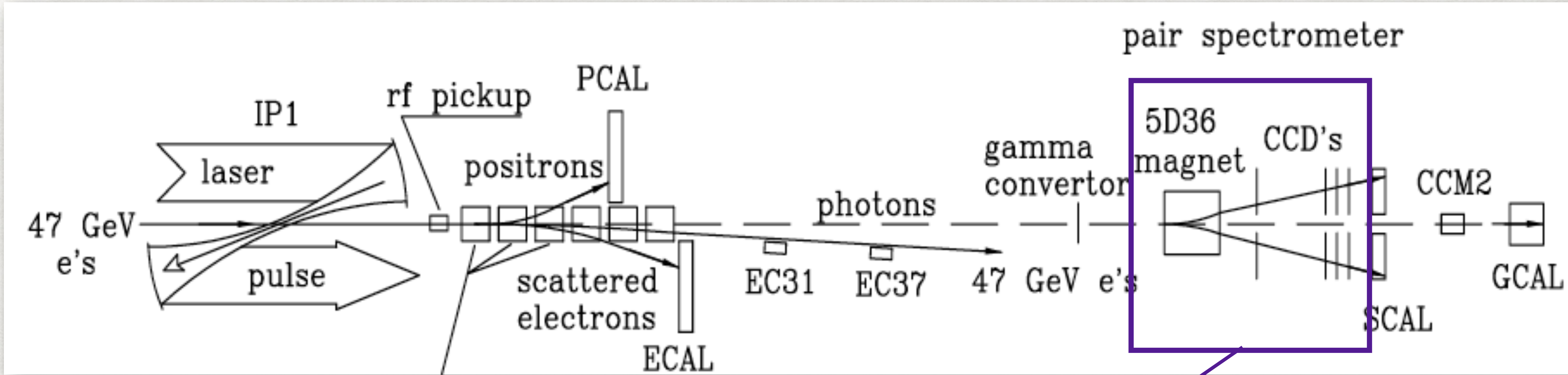
XCOM: Photon Cross Sections Database (The National Institute of Standards and Technology (NIST))

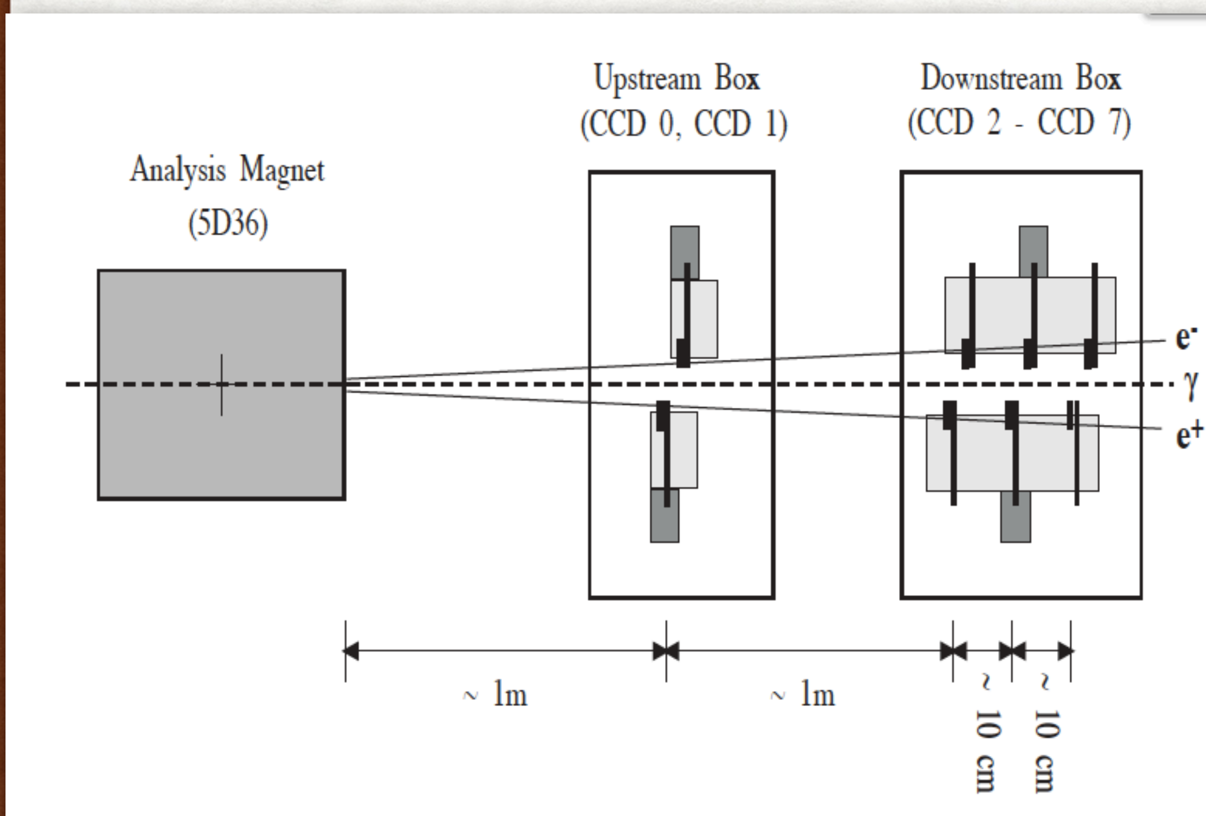
A web database which can be used to calculate photon cross sections for scattering, photoelectric absorption and pair production, as well as total attenuation coefficients, for any element, compound or mixture ($Z \leq 100$), at energies from 1 keV to 100 GeV.



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

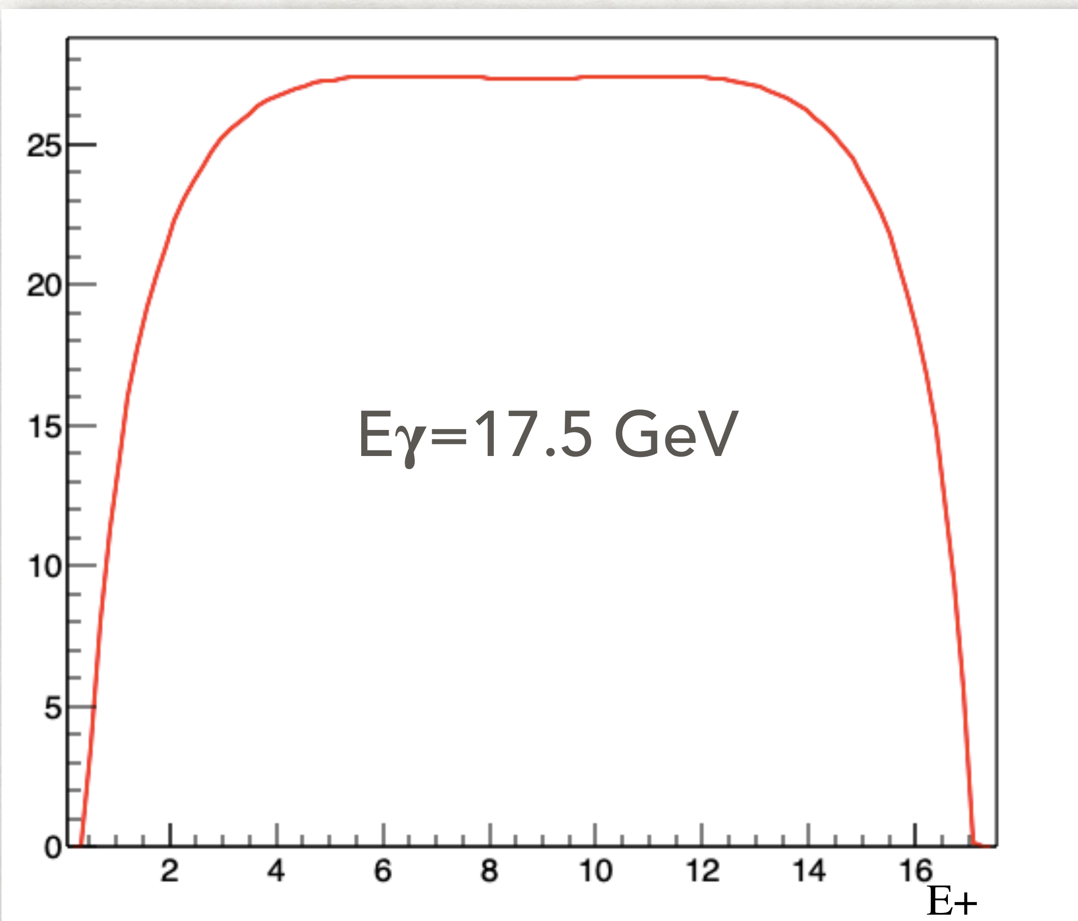
[EEV, 1242*1152].

THE CLASSICAL BETHE-HEITLER PAIR SPECTRUM

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

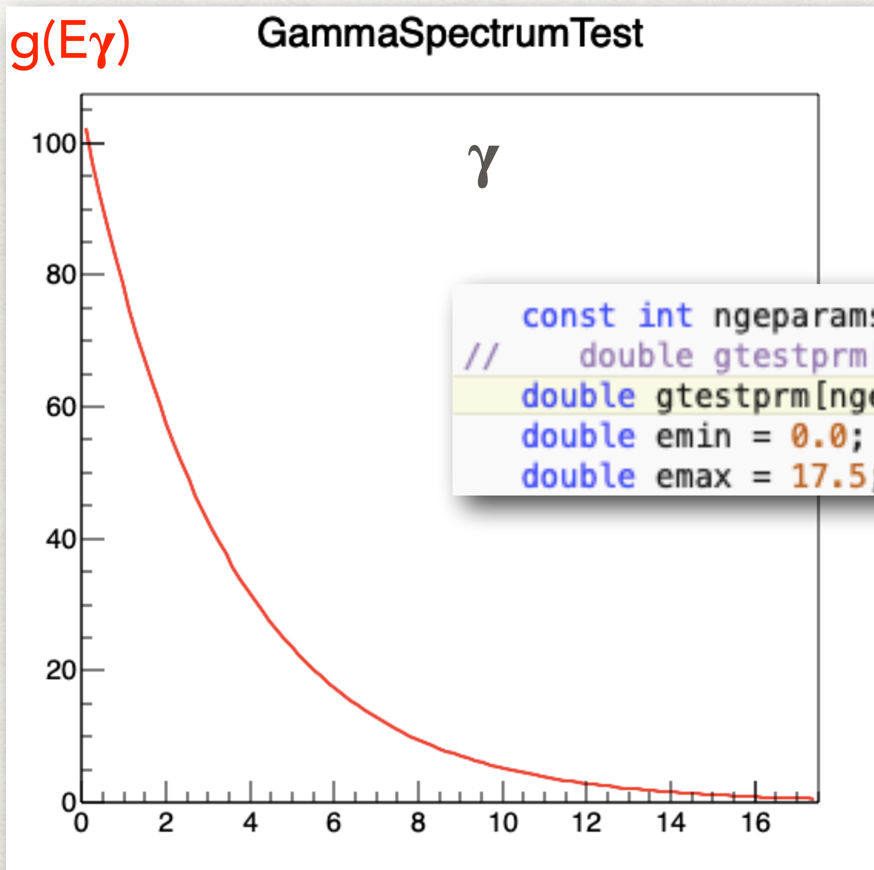
$$\Phi\,(E_0)\,dE_0 = \frac{Z^2}{137}\left(\frac{e^2}{mc^2}\right)^2 4\,\frac{E_0{}^2 + E_+{}^2 + \frac{2}{3}E_0E_+}{(h\nu)^3}\,dE_0\left(\log\frac{2E_0E_+}{h\nu mc^2} - \frac{1}{2}\right).$$

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

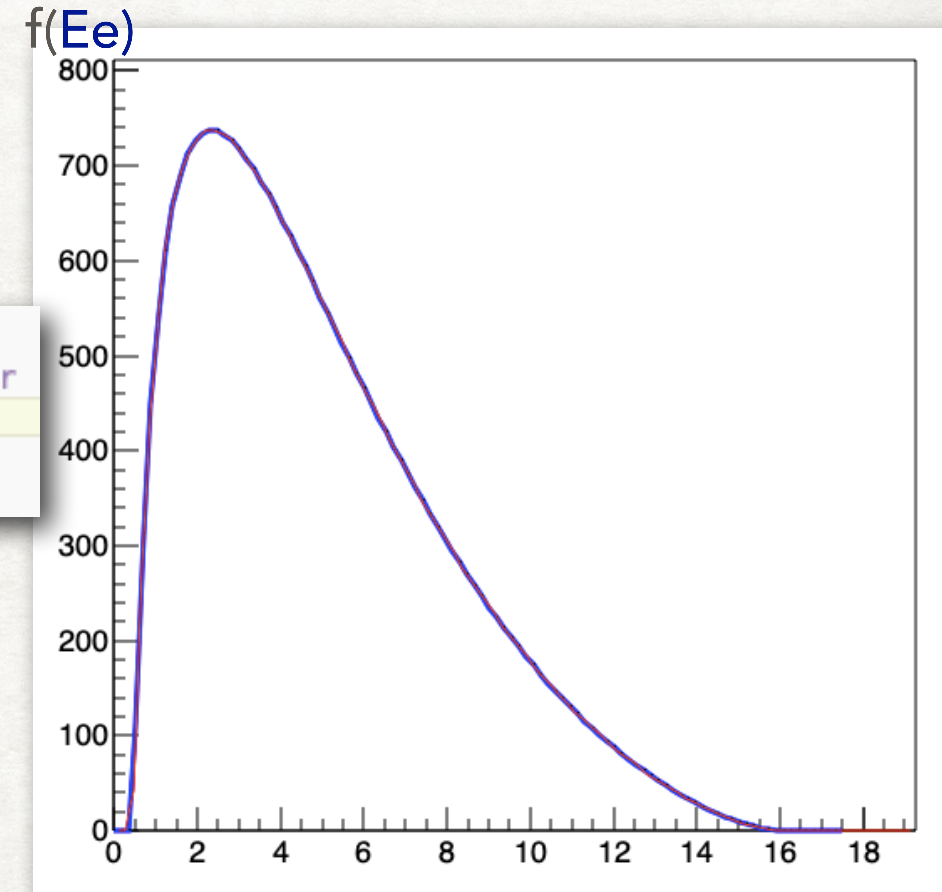
TESTING: EXPONENTIAL



BH

Ee=∫σ(Eγ, Ee)g(Eγ)dEγ

```
   const int ngeparams = 2;
//     double gtestprm[ngeparams] = {100.0, 17.5};  // linear
   double gtestprm[ngeparams] = {105.0, 0.3};    // exp
   double emin = 0.0;
   double emax = 17.5;
```

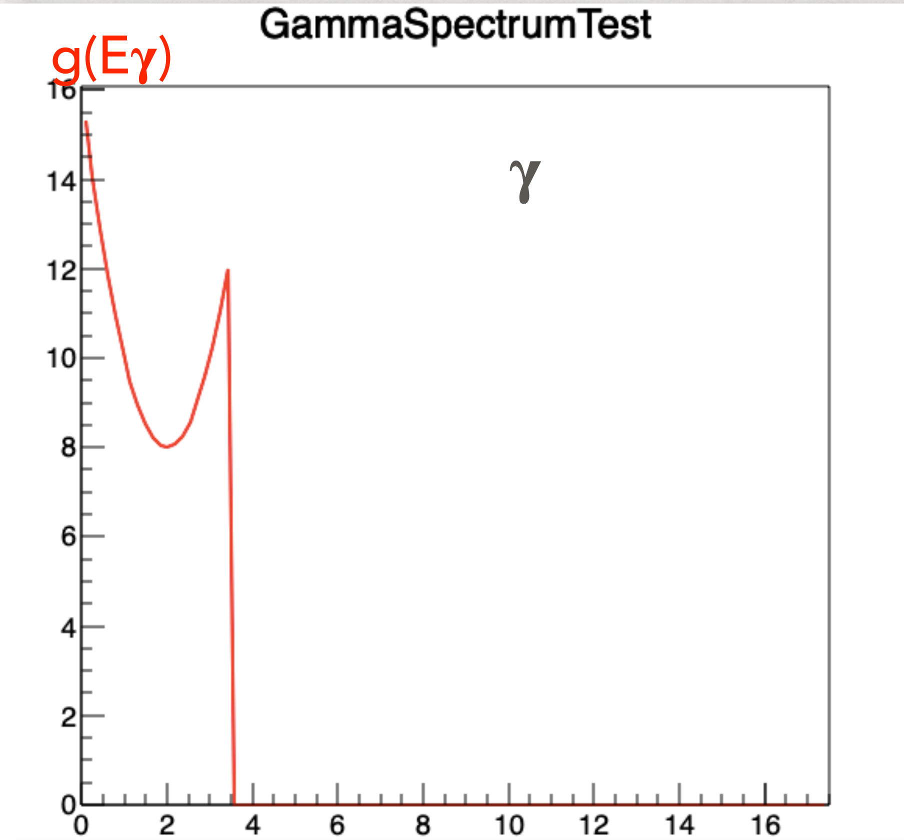


∫σ(Eγ, Ee)g(Eγ,p1,p2)dEγ

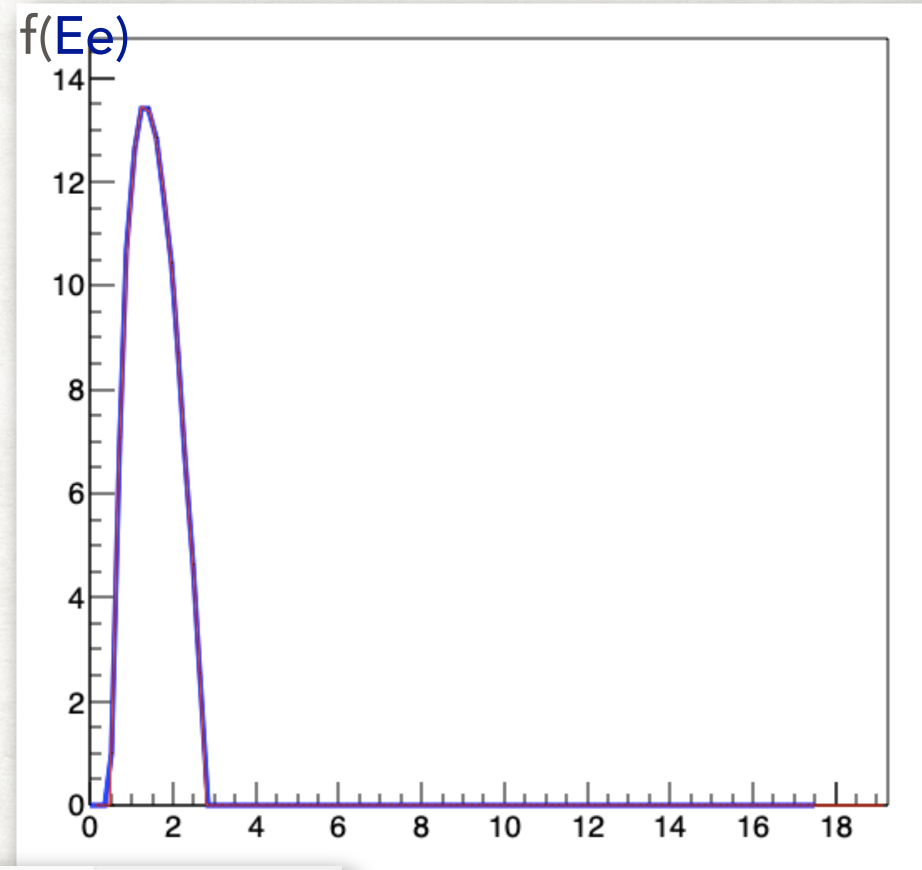
fitting allows finding the parameters with high precision

```
****************************************
Minimizer is Minuit / Migrad
Chi2                      =  8.52694e-11
NDf                       =           98
Edm                       =  1.70646e-10
NCalls                    =          167
p0                        =          105   +/-   1.72634e-07
p1                        =          0.3   +/-   1.73966e-10
```

TESTING: COMPTON-LIKE



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




```
//    double gtestprm[ngeparams] = {100.0, 17.5};  // linear
//    double gtestprm[ngeparams] = {105.0, 0.3};   // exp
   const int ngeparams = 3;    double gtestprm[ngeparams] = {2.0, 2.0, 8.0};  // parabola like Compton
```

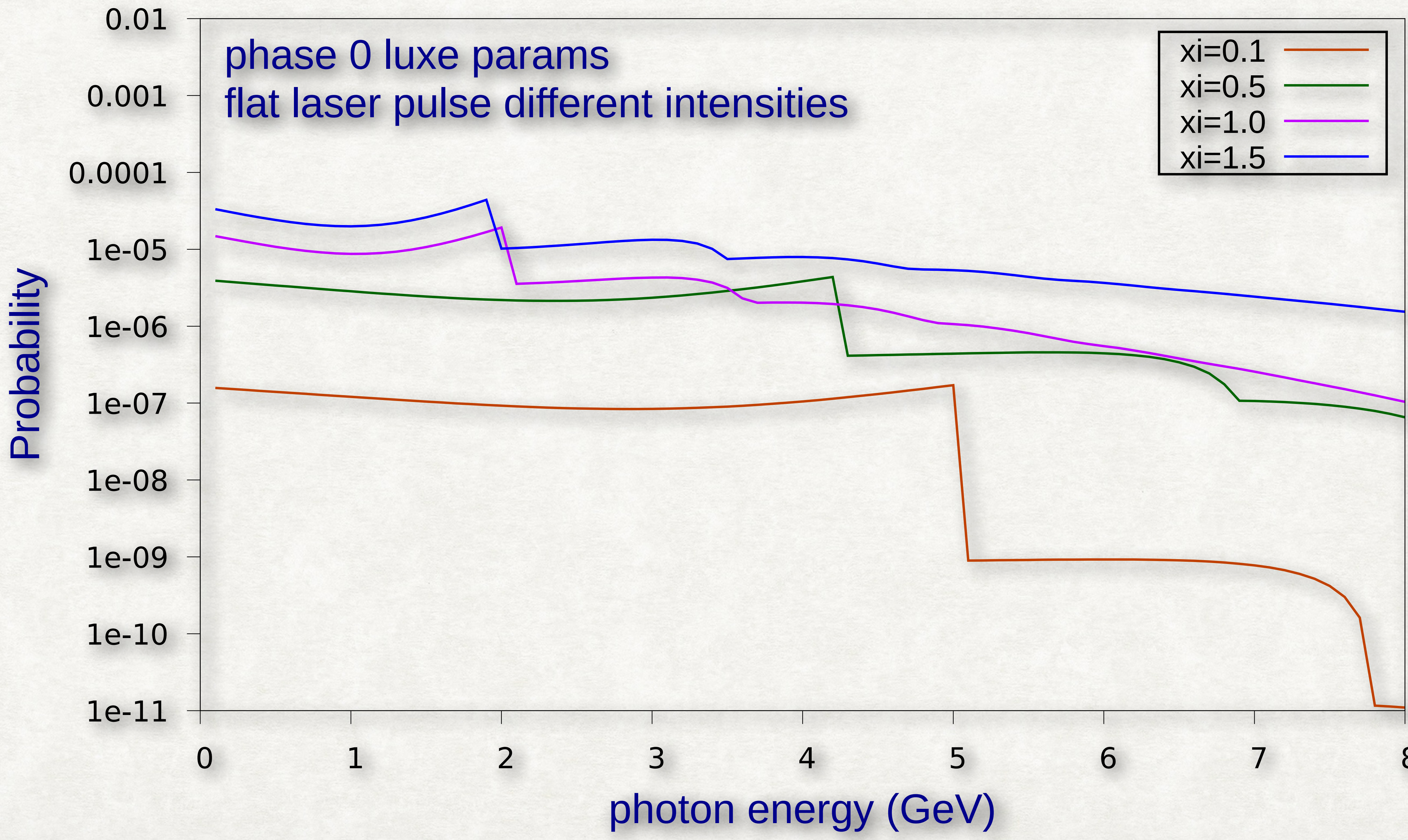
$$\int \sigma(E_\gamma, E_e)\, g(E_\gamma, p1, p2)\, dE_\gamma$$

fitting allows finding the parameters quite well :

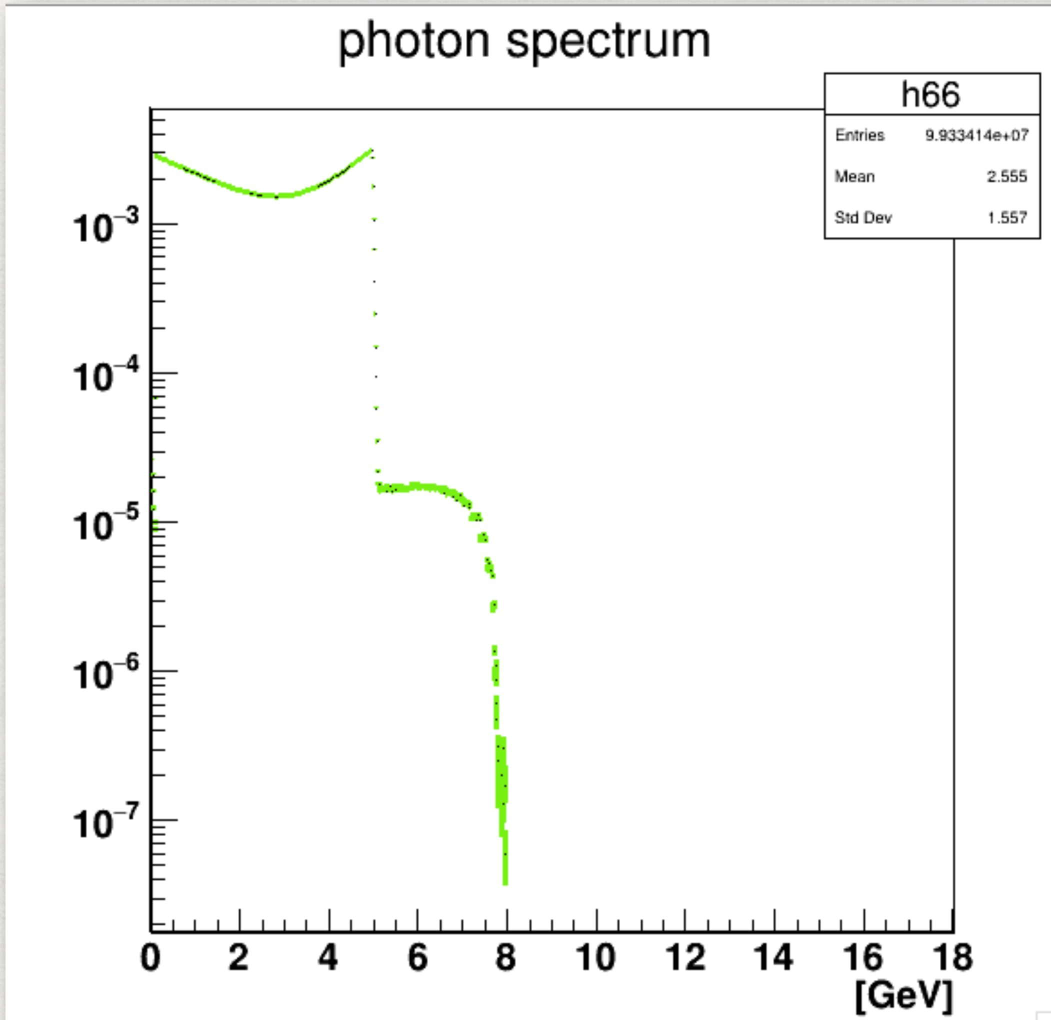
```
****************************************
Minimizer is Minuit / MigradImproved
Chi2                      =  5.92197e-07
NDf                       =           97
Edm                       =  1.27179e-06
NCalls                    =          342
p0                        =       1.9899   +/-   0.00109921
p1                        =      1.99569   +/-   0.000468708
p2                        =      7.99435   +/-   0.000639219
```

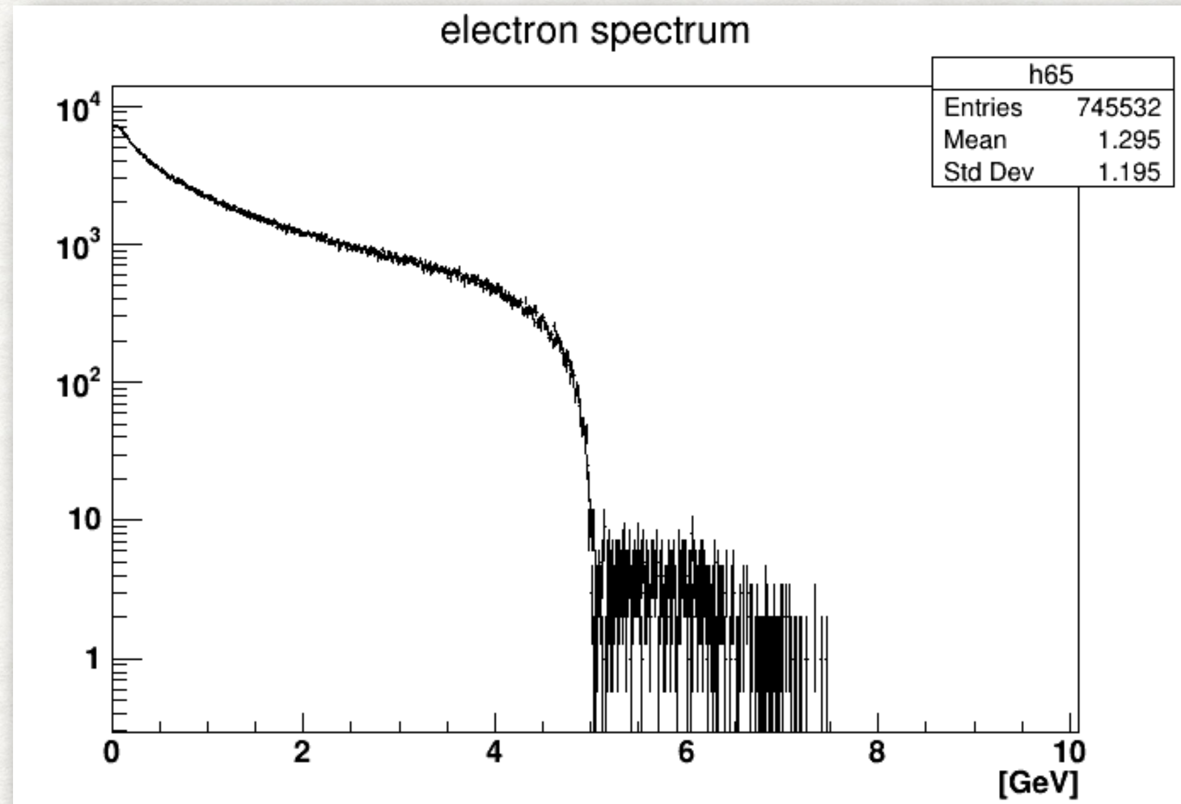
PHOTON SPECTRA VS LASER INTENSITIES

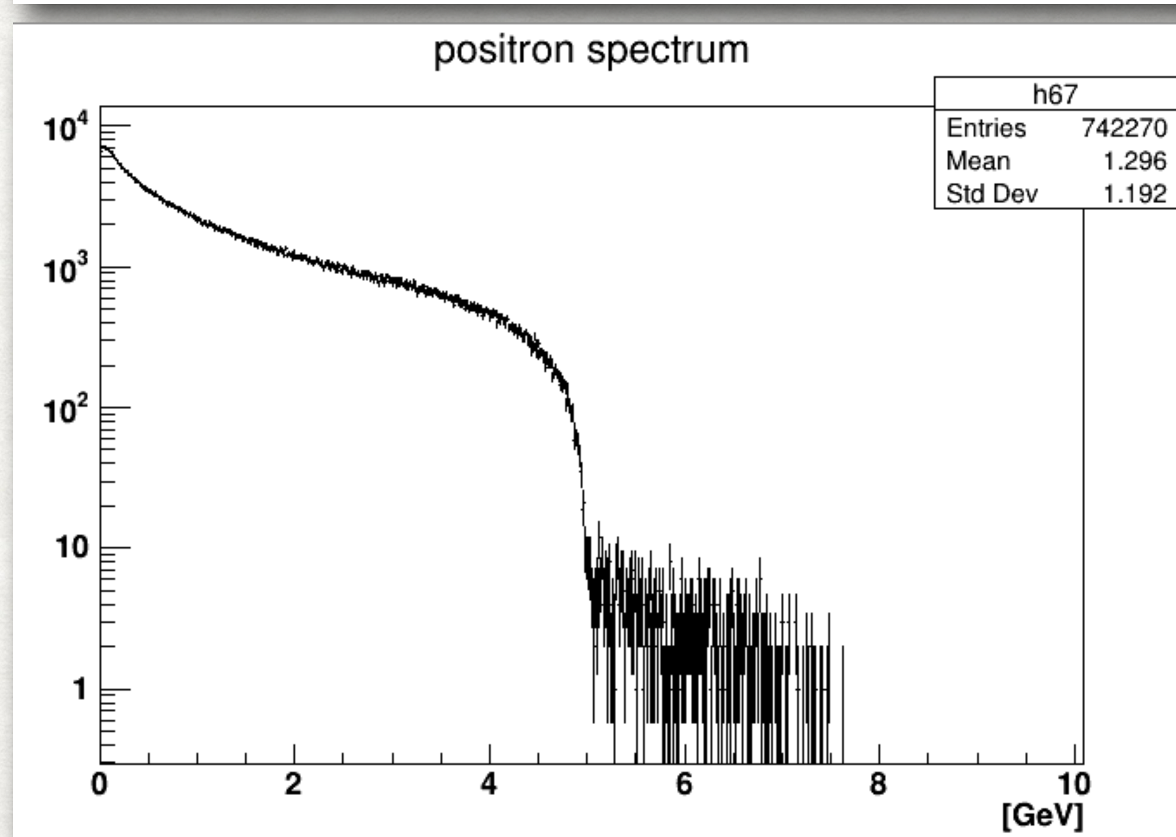
- plot from Anthony



FORWARD PHOTONS IN GEANT4



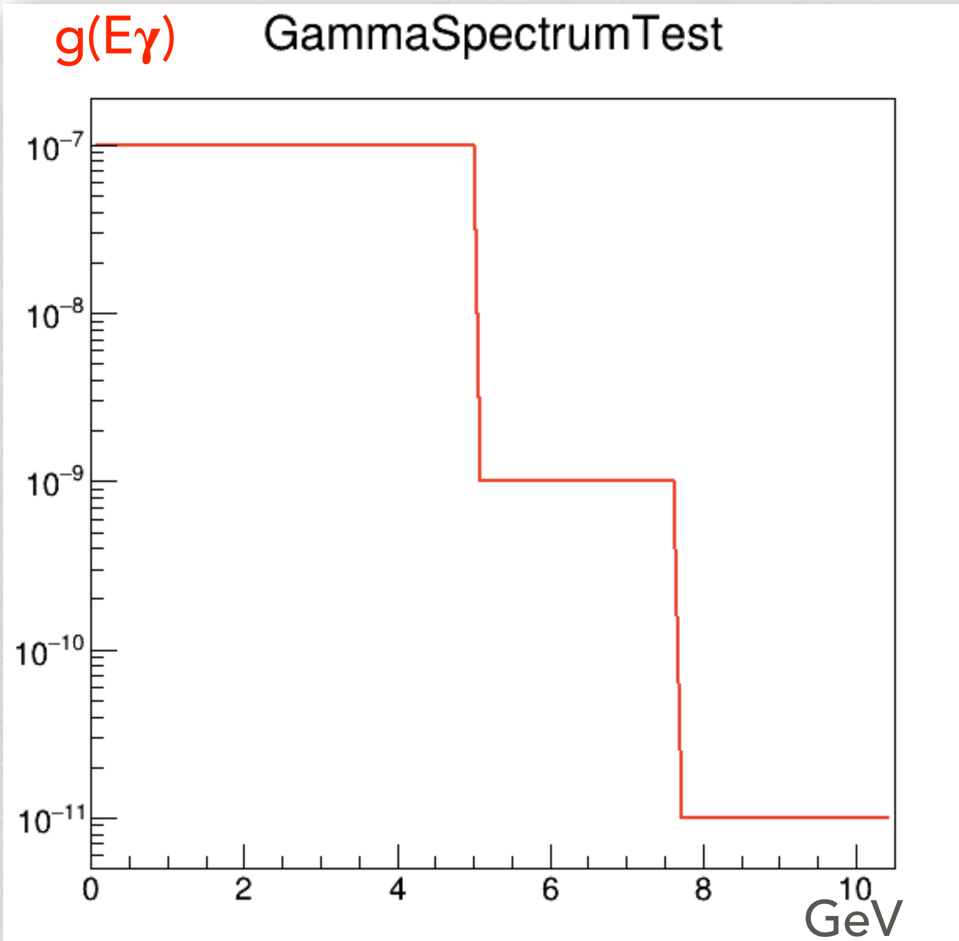


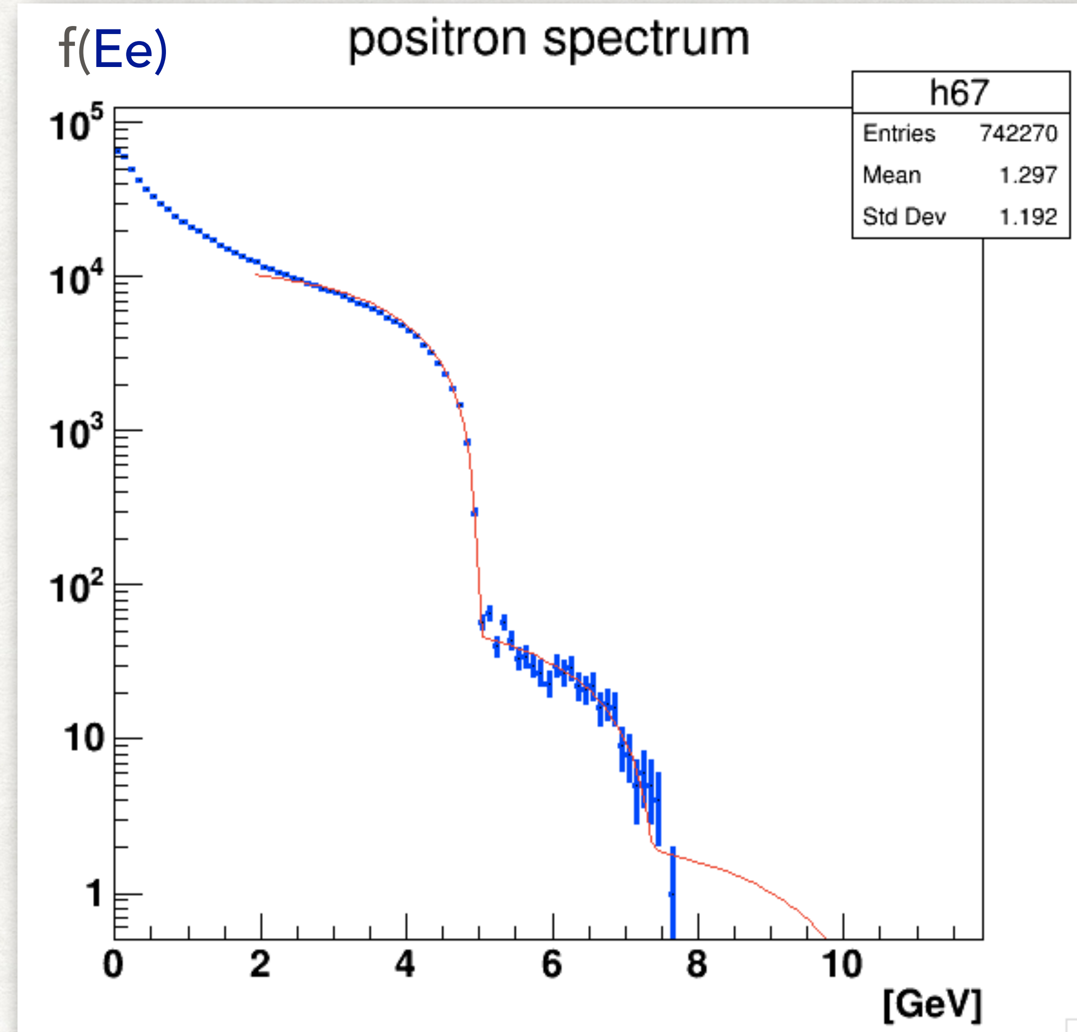


target: Tungsten, 0.35 um
1e8 photons

TESTING: COMPTON-LIKE

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





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

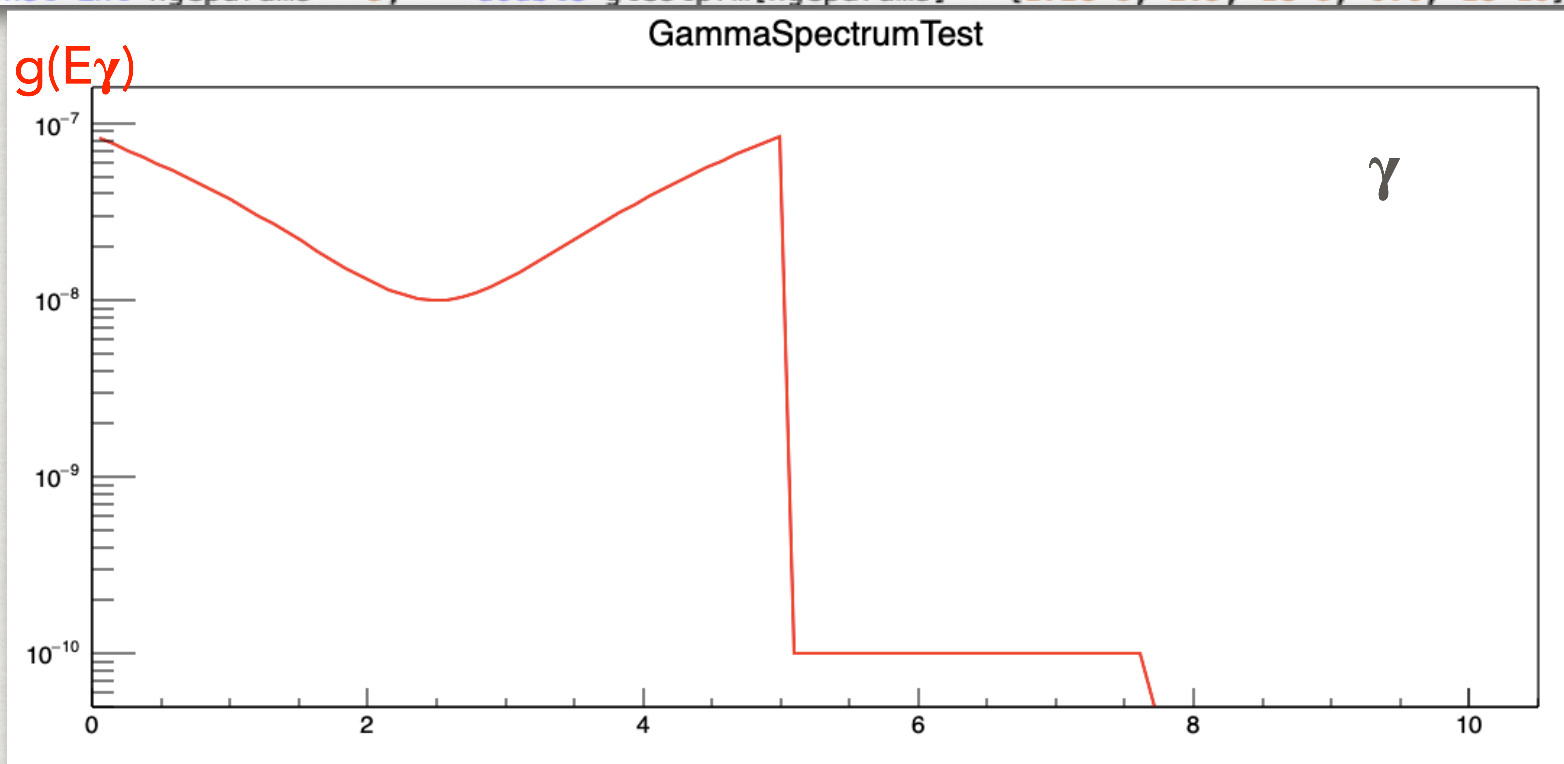
fitting allows finding the parameters quite well :

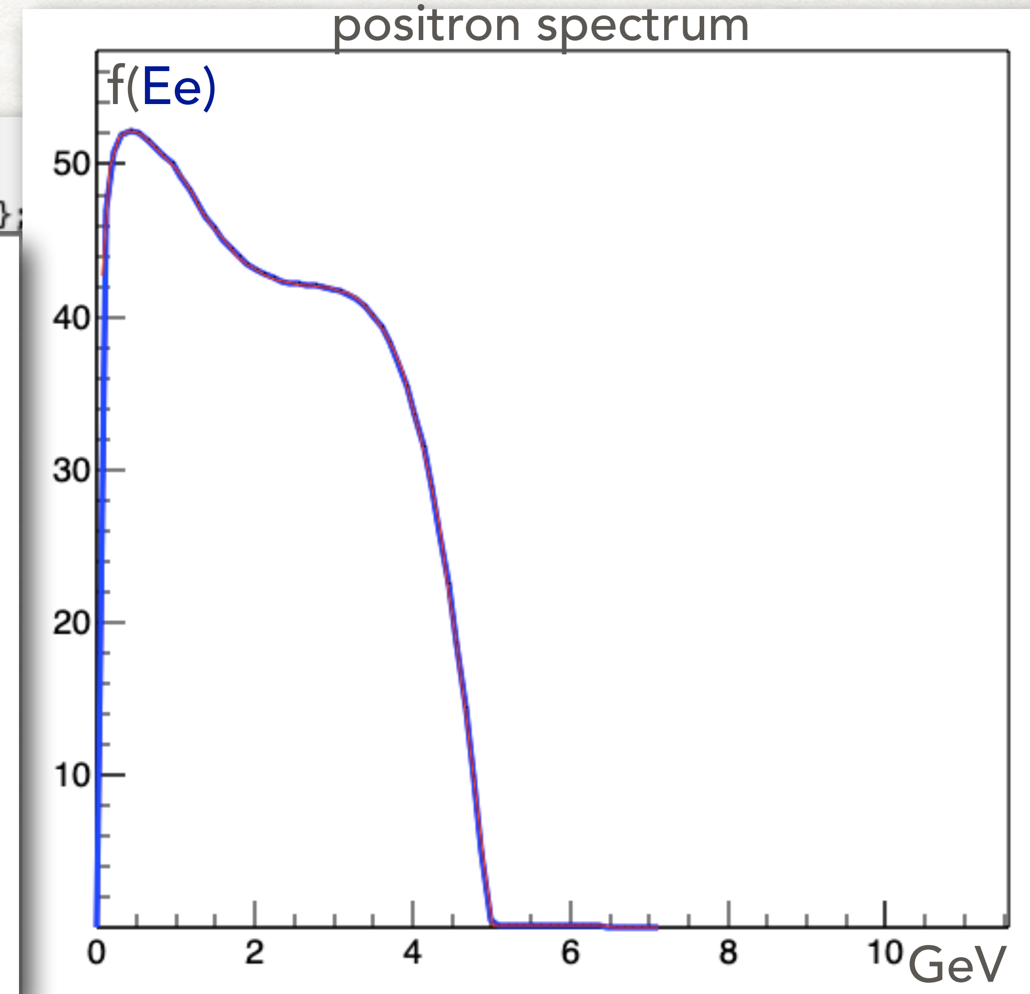
```
 FCN=1309.19 FROM HESSE     STATUS=OK             39 CALLS          442 TOTAL
                     EDM=9.77144e-09    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   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

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

```
    double gtestprm[ngeparams] = {100.0, 17.5};  // linear
    double gtestprm[ngeparams] = {105.0, 0.3};   // exp
const int ngeparams = 5;     double gtestprm[ngeparams] = {1.2e-8, 2.5, 1e-8, 0.0, 1e-10};
```





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

fitting allows finding the parameters quite well :

```
****************************************
Minimizer is Minuit / MigradImproved
Chi2                      =  6.09809e-07
NDf                       =           96
Edm                       =  1.21973e-06
NCalls                    =          404
p0                        =  1.20003e-08   +/-   6.73267e-14
p1                        =      2.50003   +/-   5.02686e-06
p2                        =  1.00002e-08   +/-   5.23111e-14
p3                        =            0                       (fixed)
p4                        =  9.99282e-11   +/-   1.04159e-14
```