FORWARD PHOTONS

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07/03/19

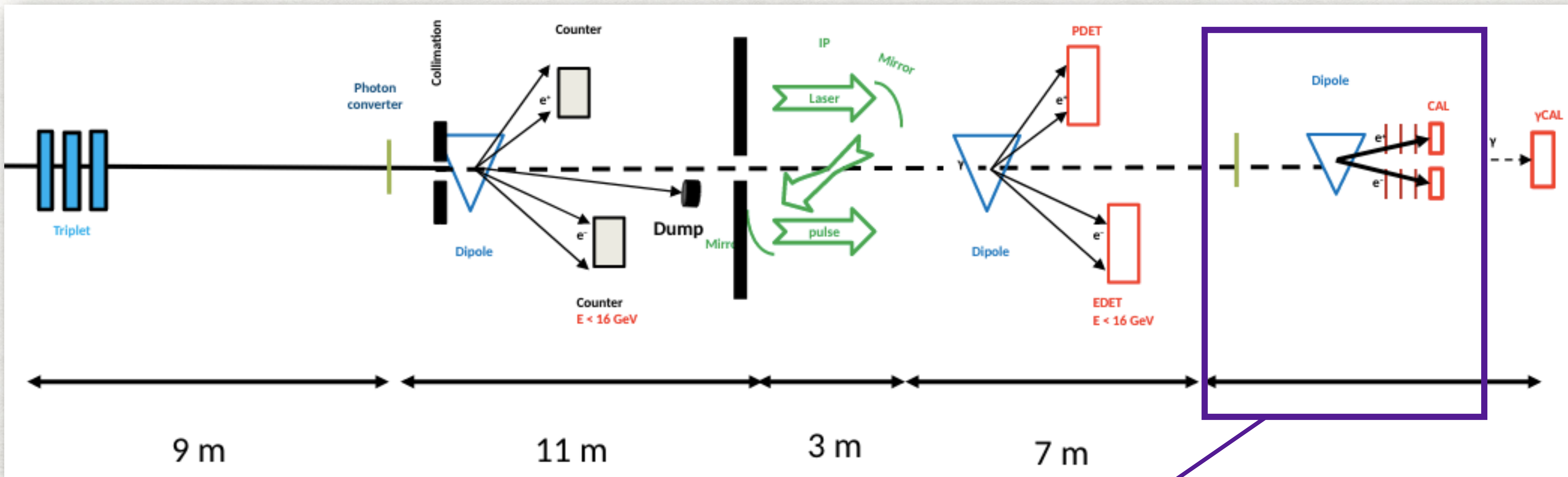
LUXE monthly meeting

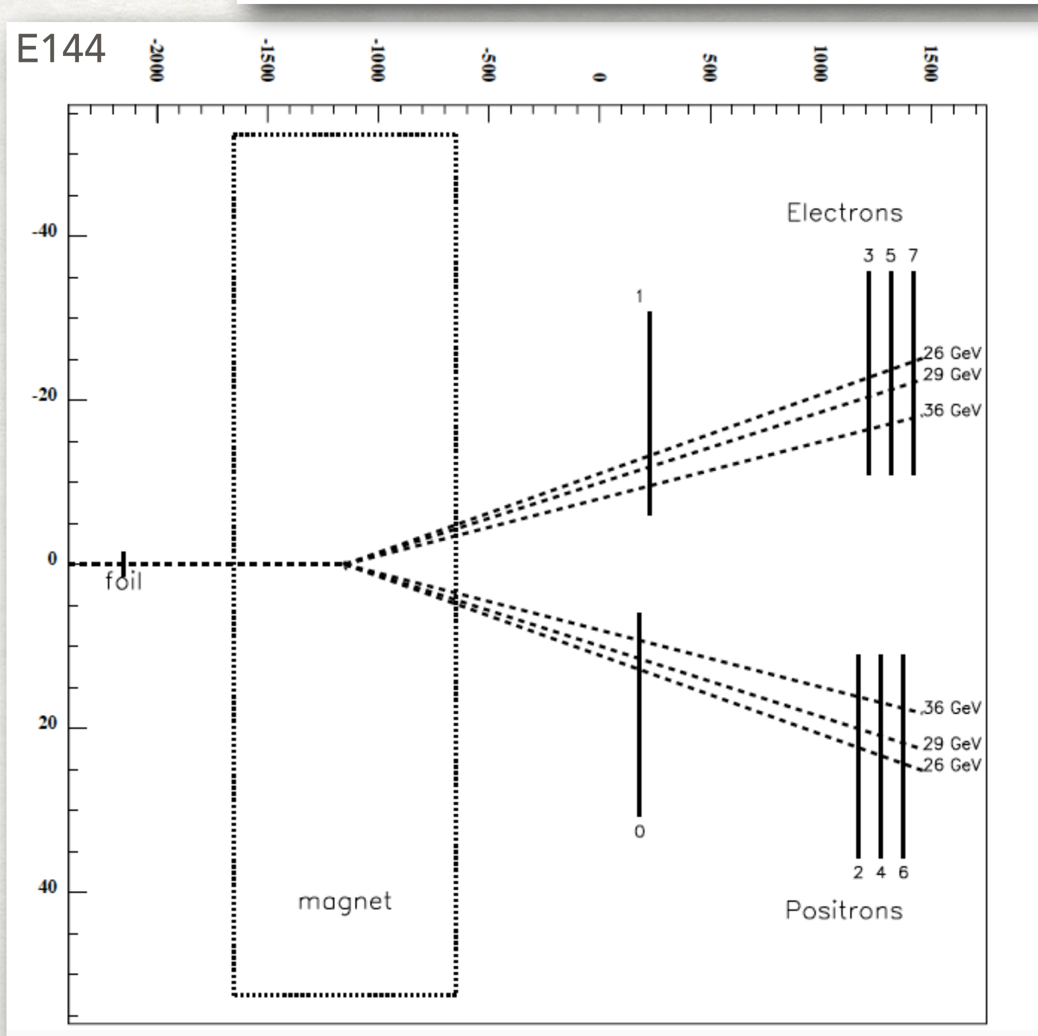
OUTLINE

- layout for FDS of the LUXE experiment
- HICS and the absolute number of forward photons
- method of study the photon-conversion data; test if we could fit and find other parameters describing the process: target thickness
- total cross-section calculation

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 experiment has the capability to detect the presence of particles scattered at different orders n, to measure their overall rate, to resolve the detailed shape of their spectra to some extent, and 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

HICS DIFFERENTIAL TRANSITION PROBABILITY VS RADIATED PHOTON ENERGY

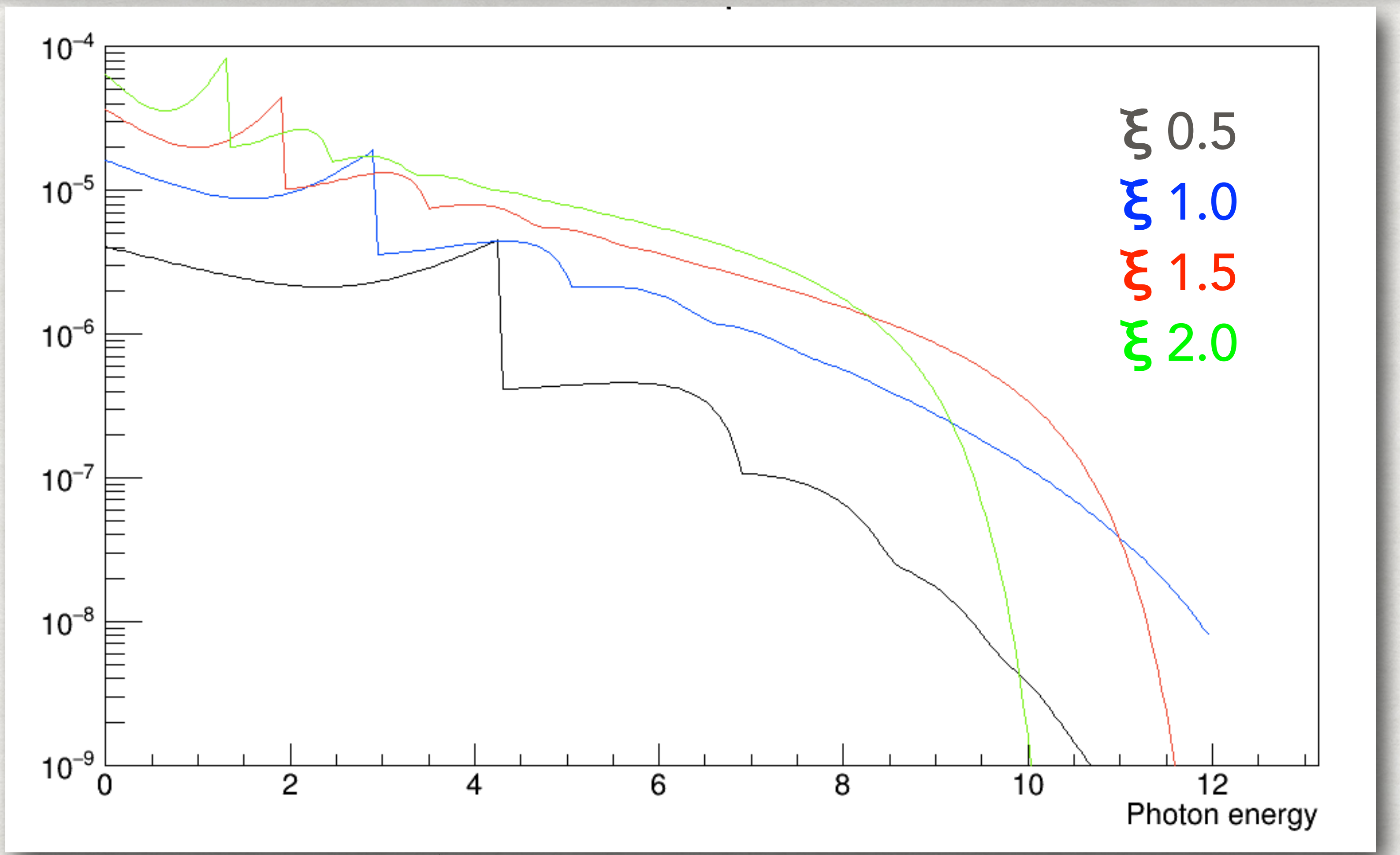
per initial particle per 100 fs 800 nm laser. 17.5 GeV initial electrons, 0.9*Pi crossing angle

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

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

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

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



ABSOLUTE NUMBER OF PHOTONS

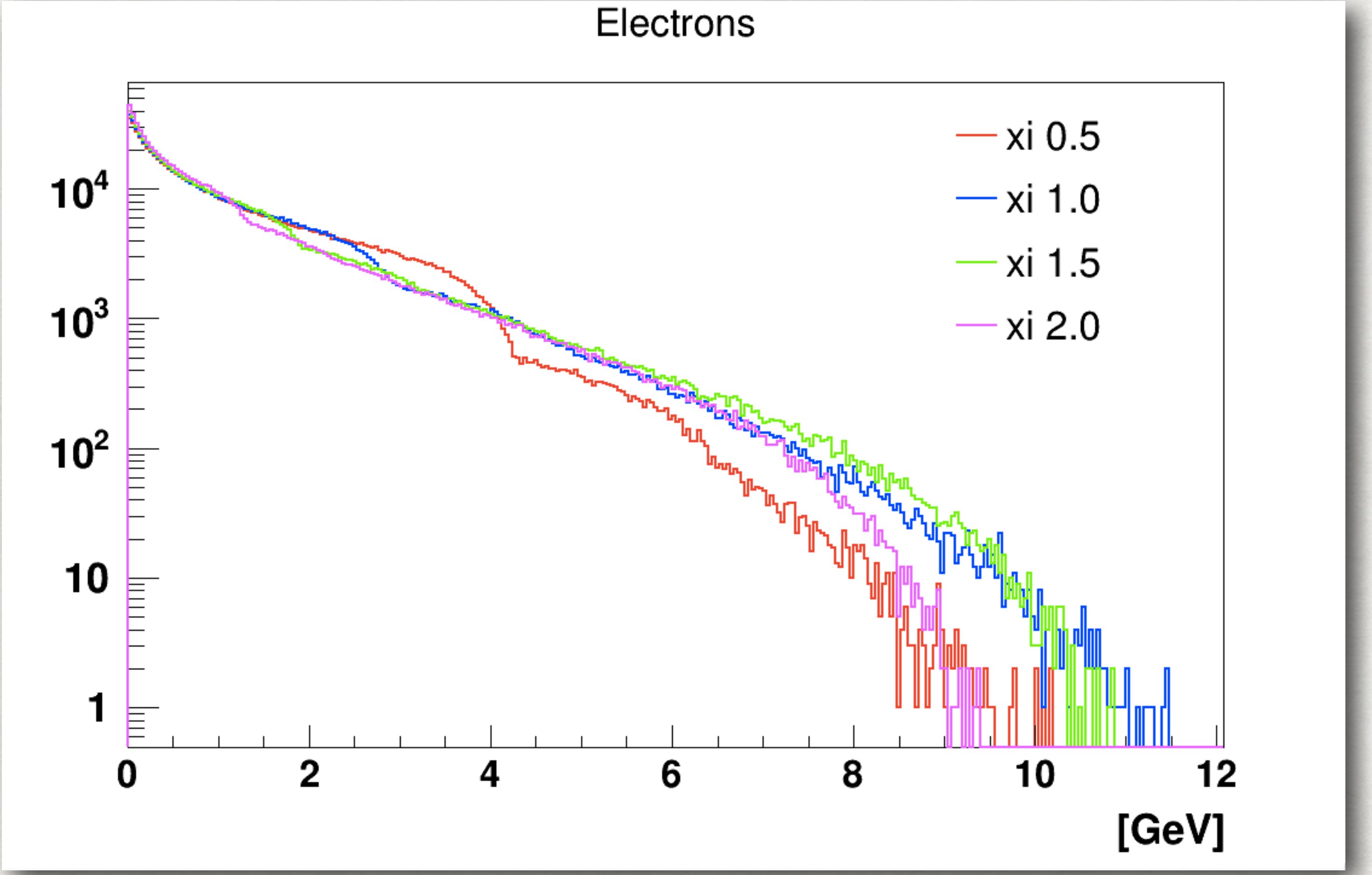
differential transition rate per electron per 100 fs.

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

ξ	1e 100 fs	1e 35 fs (1BX)	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

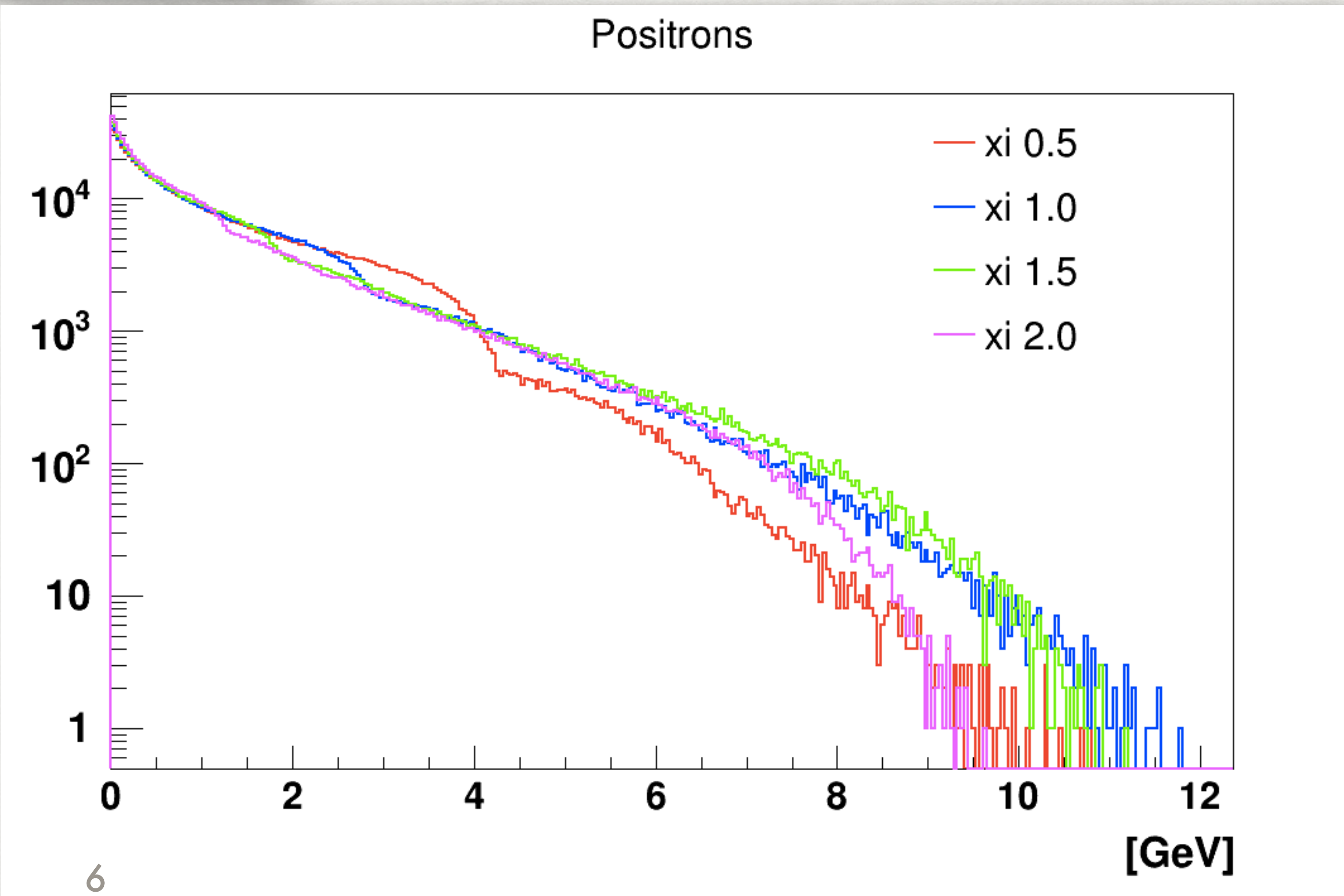
The transverse structure of the laser field is not taken into account in the data and it is assumed that the laser field is uniform in transverse direction and it is essentially the same for all electrons -> It could be accounted for in MC

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



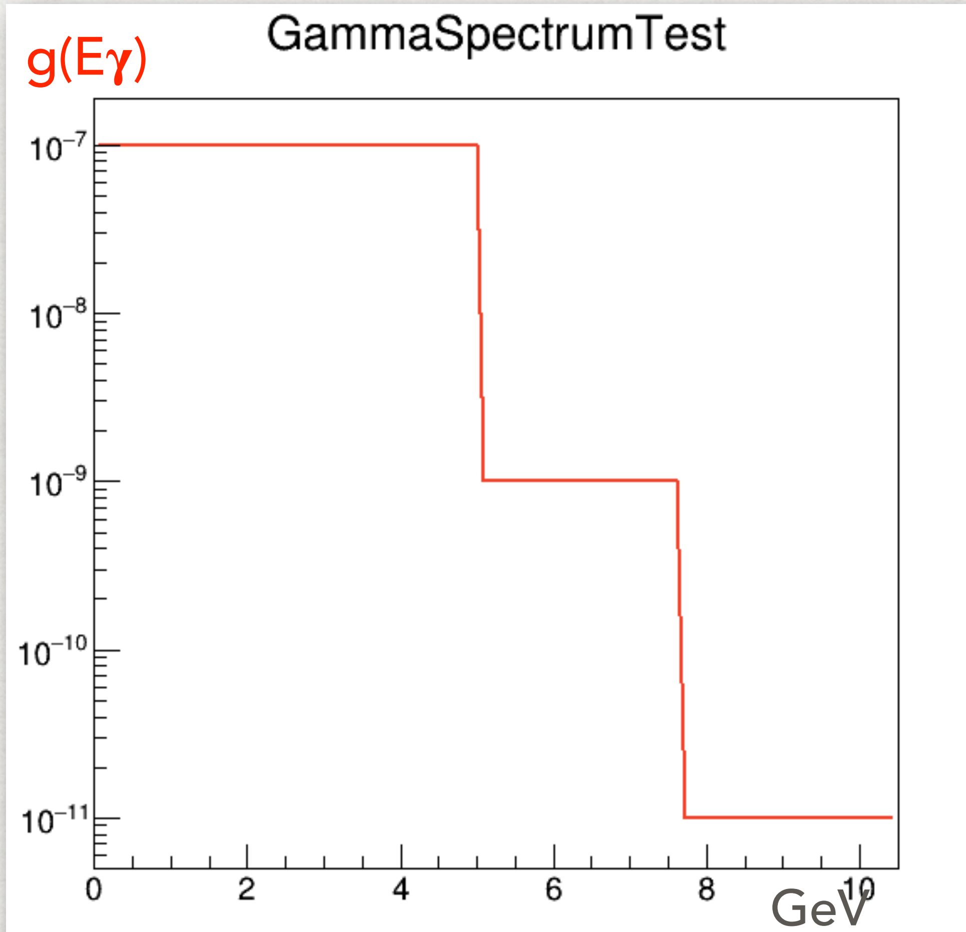
THE ELECTRON AND POSITRON SPECTRA FROM CONVERSION OF FORWARD PHOTONS INTO THE PAIRS FOR DIFFERENT ξ FROM GEANT4

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

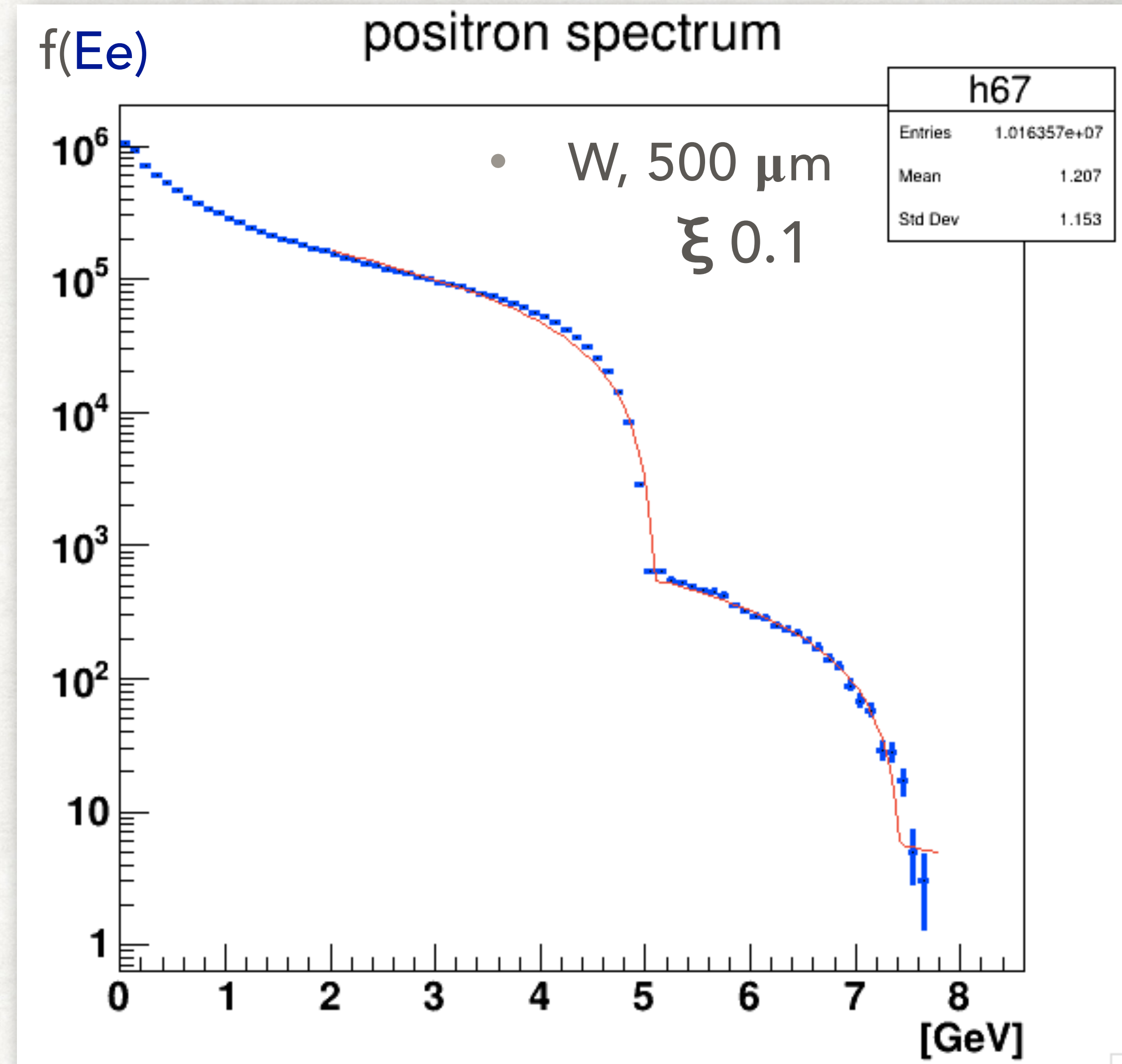


METHOD OF PHOTON SPECTRUM RESTORATION

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



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**



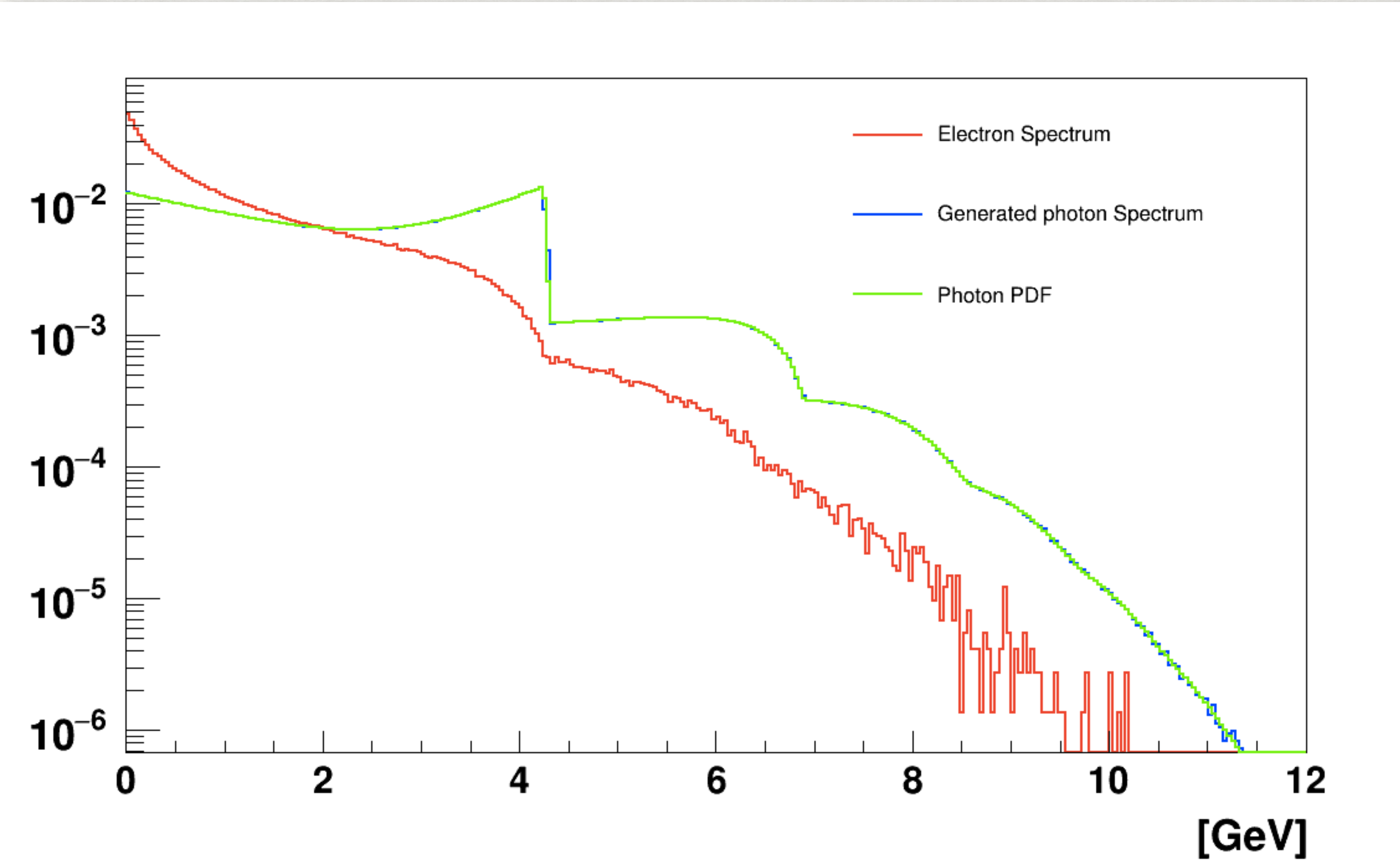
$$\int \sigma(E\gamma, Ee)\,g(E\gamma,p1,p2)\,dE\gamma$$

fitting allows finding the parameters quite well :

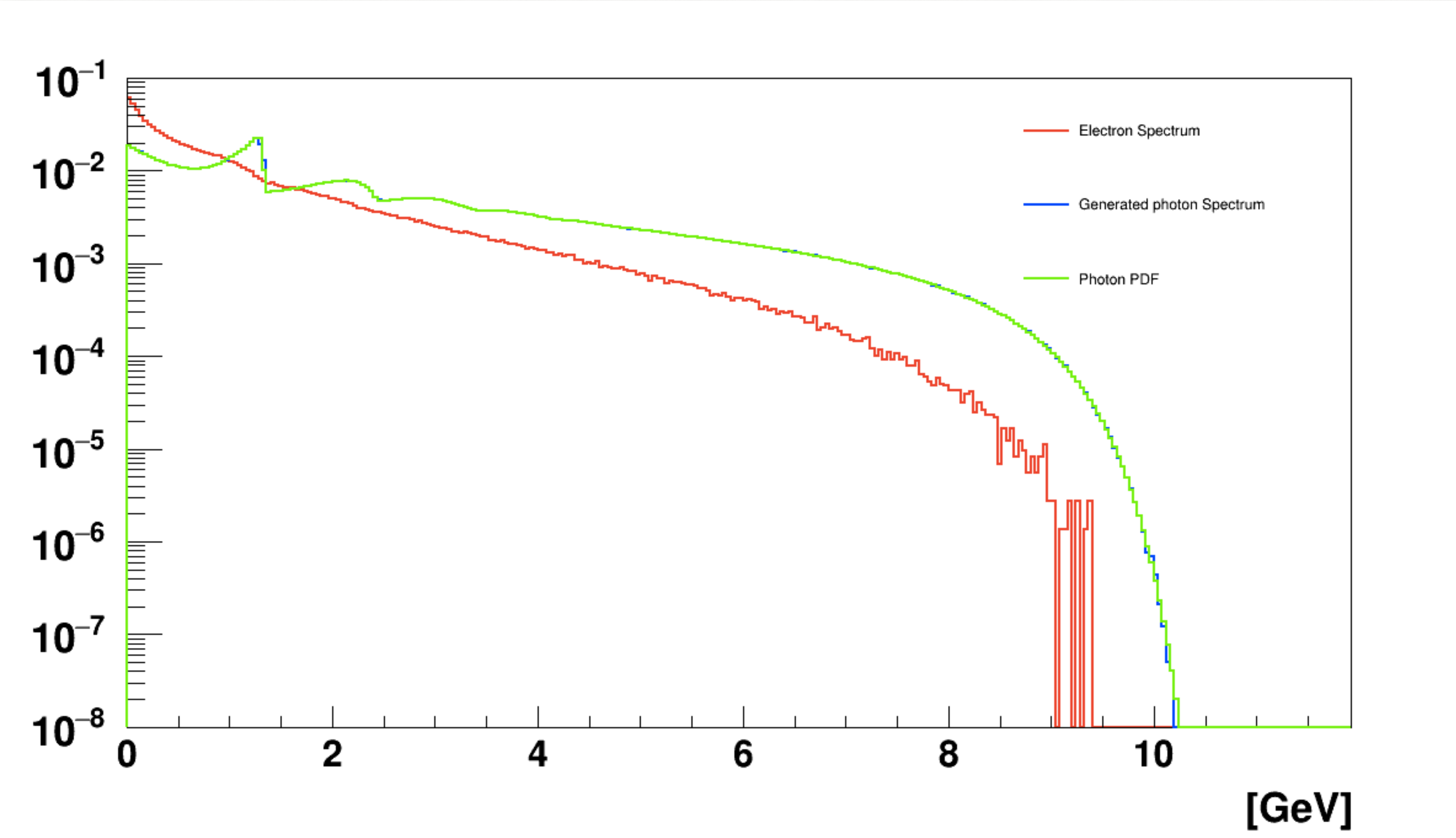
EXT NO.	PARAMETER NAME	VALUE	APPROXIMATE ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	0.00000e+00	fixed		
2	p1	8.10443e+05	7.55173e+03	4.54179e-07	8.91191e-01
3	p2	5.08073e+00	6.97488e-04	6.53706e-04	1.39541e-01
4	p3	0.00000e+00	fixed		
5	p4	5.78148e+03	1.25645e+02	4.35657e-07	-2.81589e-01
6	p5	7.43076e+00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

Thickness, cm	p[7] from the fit, cm
3.5×10^{-3}	3.2×10^{-3}
5×10^{-3}	4.6×10^{-3}
10^{-2}	0.9×10^{-2}
2×10^{-2}	1.8×10^{-2}
5×10^{-2}	5.01×10^{-2}

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 :

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

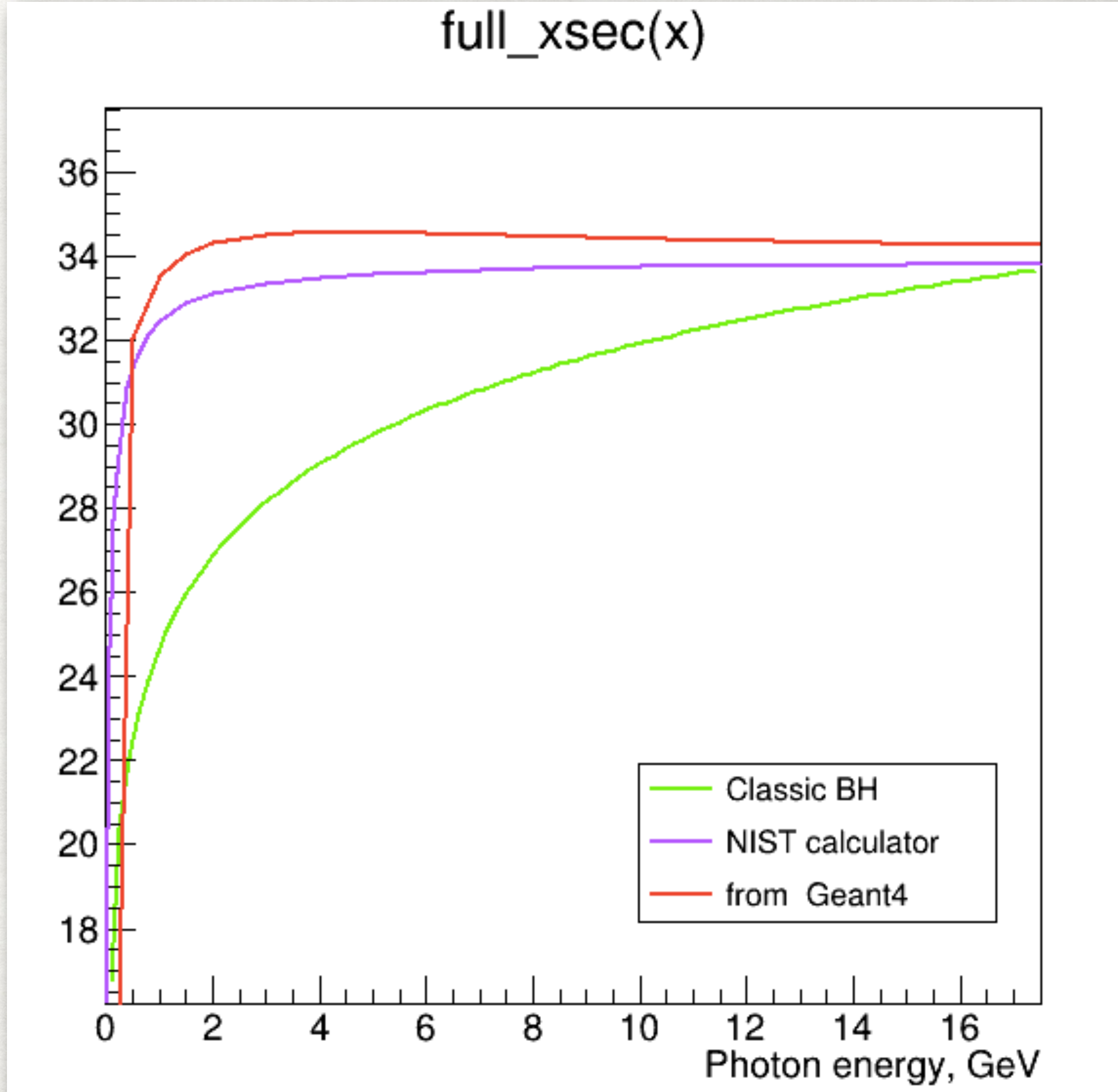
with :

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

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

This parameterisation describes the data in the range :

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



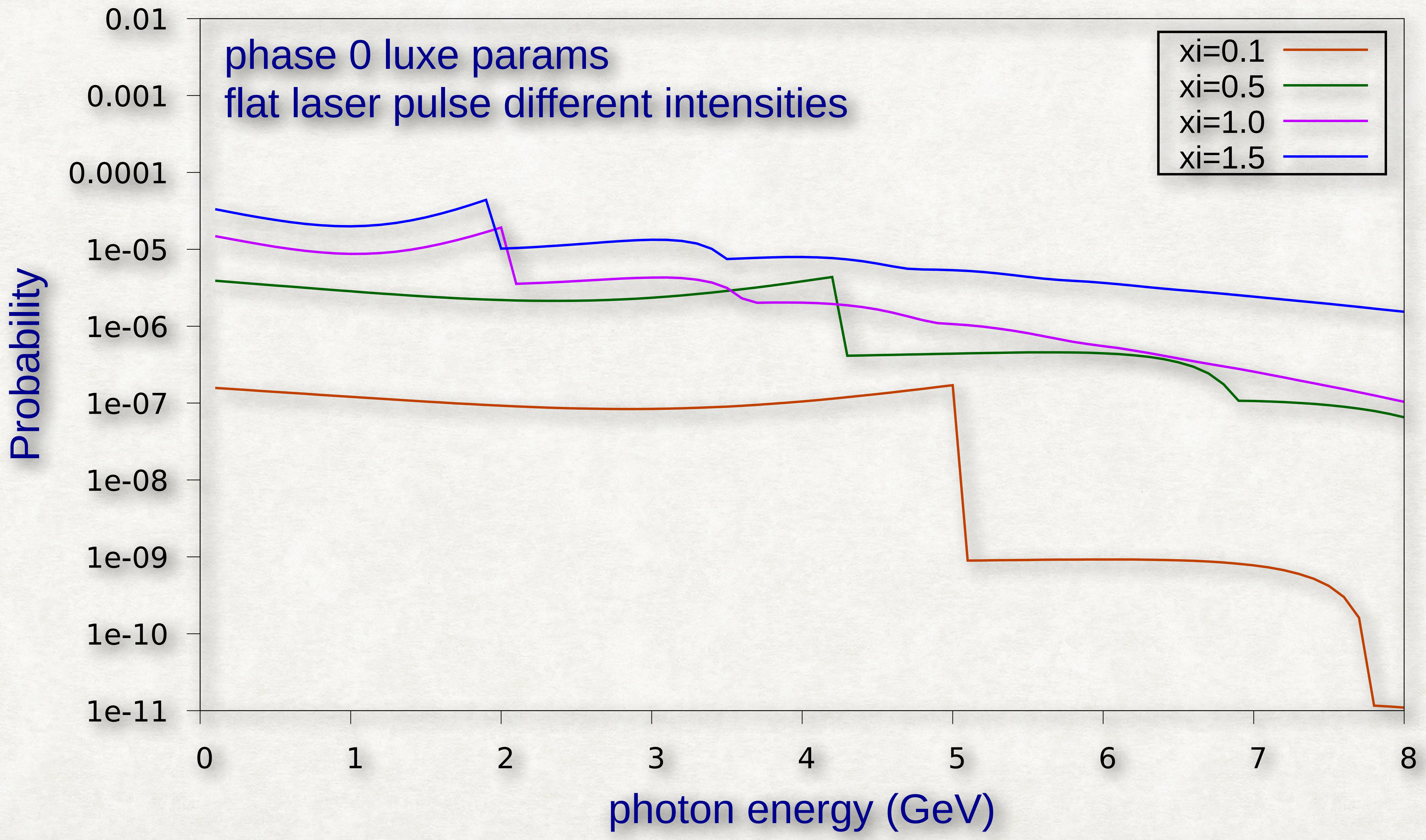
WHAT'S DONE & WHAT'S NEXT

- estimated the absolute number of forward photons
- used Bethe-Heitler formula from Geant4 to calculate total cross-section per atom
- tested the dependence on target thickness.
- 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).

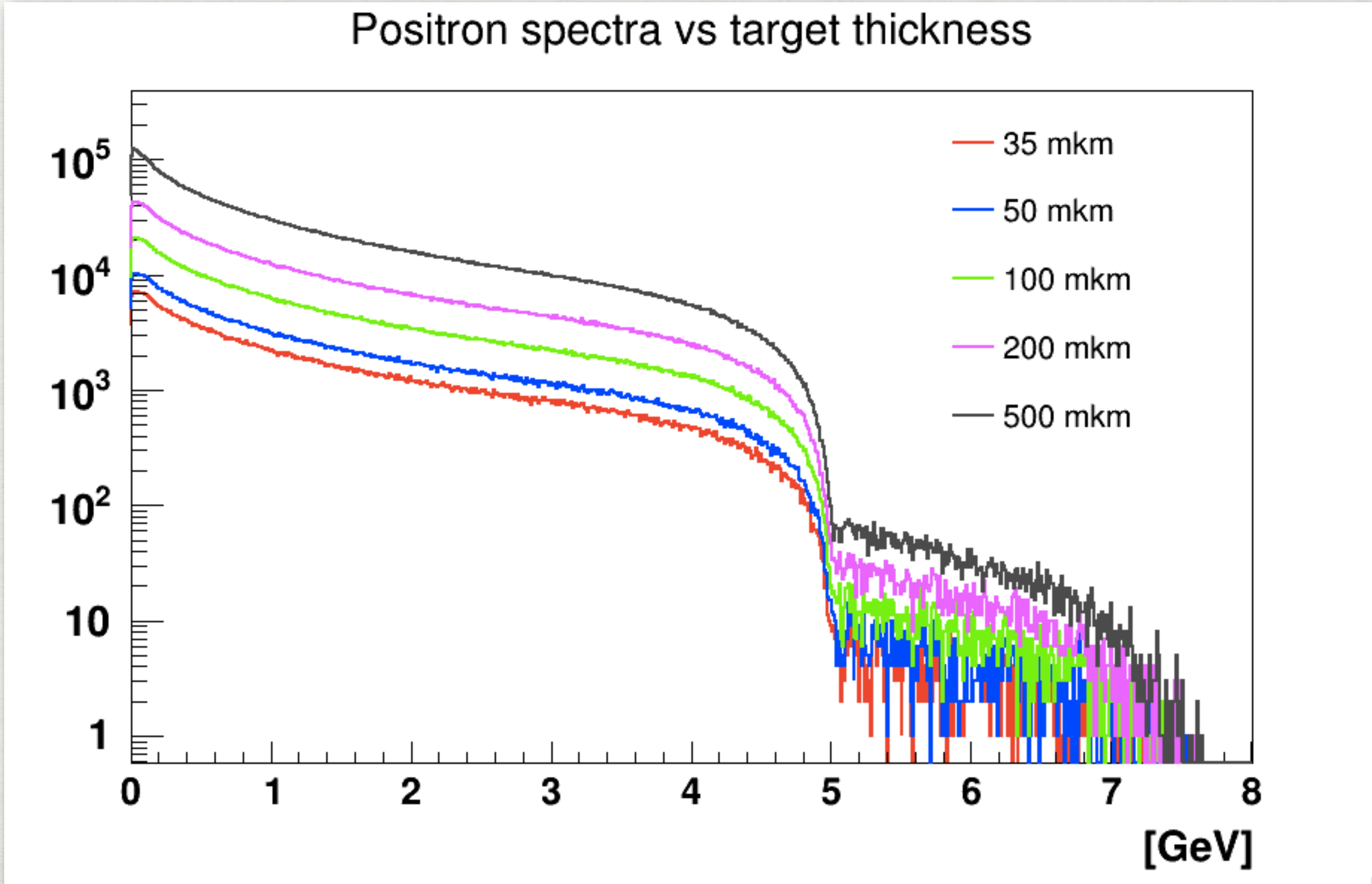
BACK UP

PHOTON SPECTRA VS LASER INTENSITIES

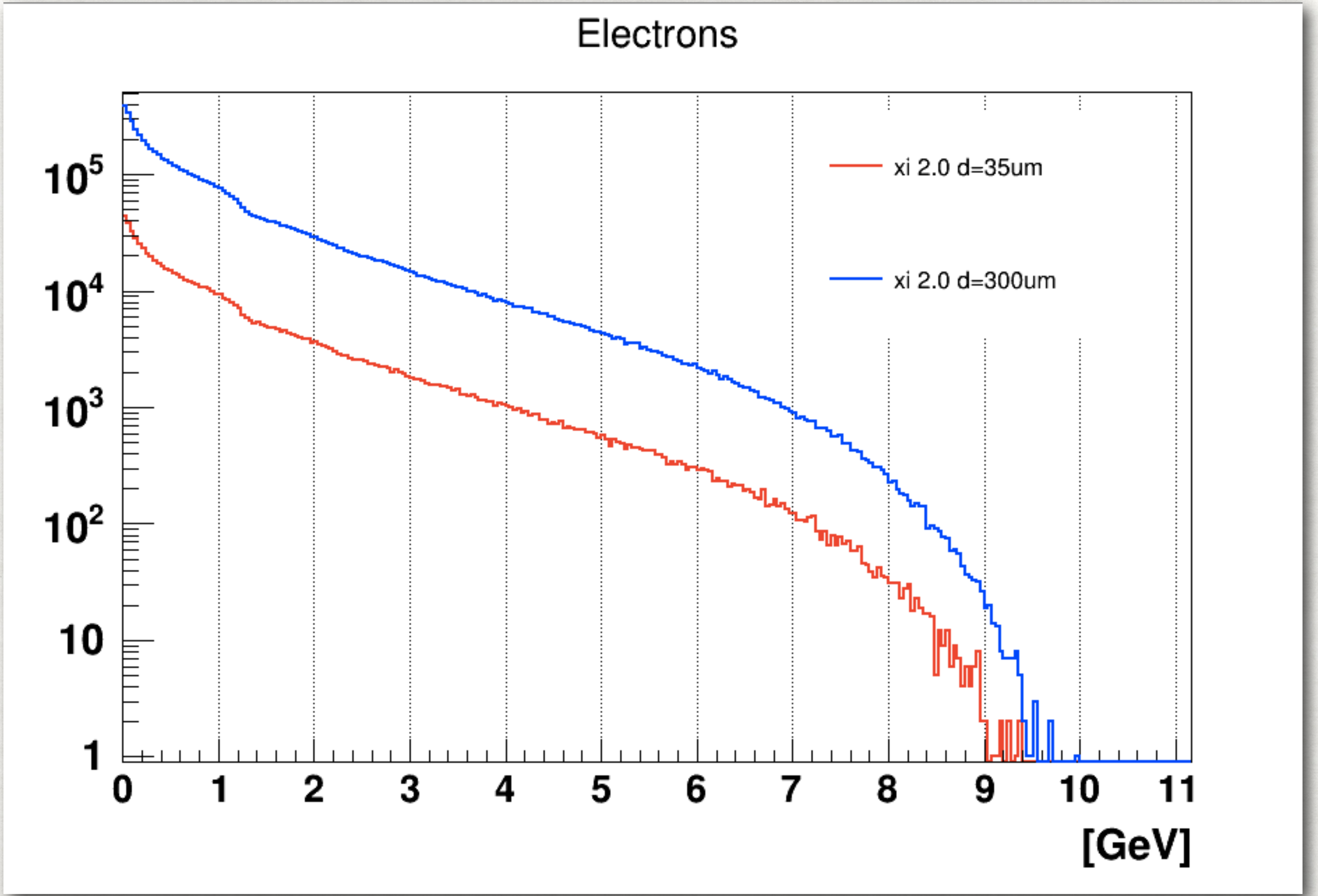
- plot from Anthony



POSITRON SPECTRA VS TARGET THICKNESS IN GEANT4



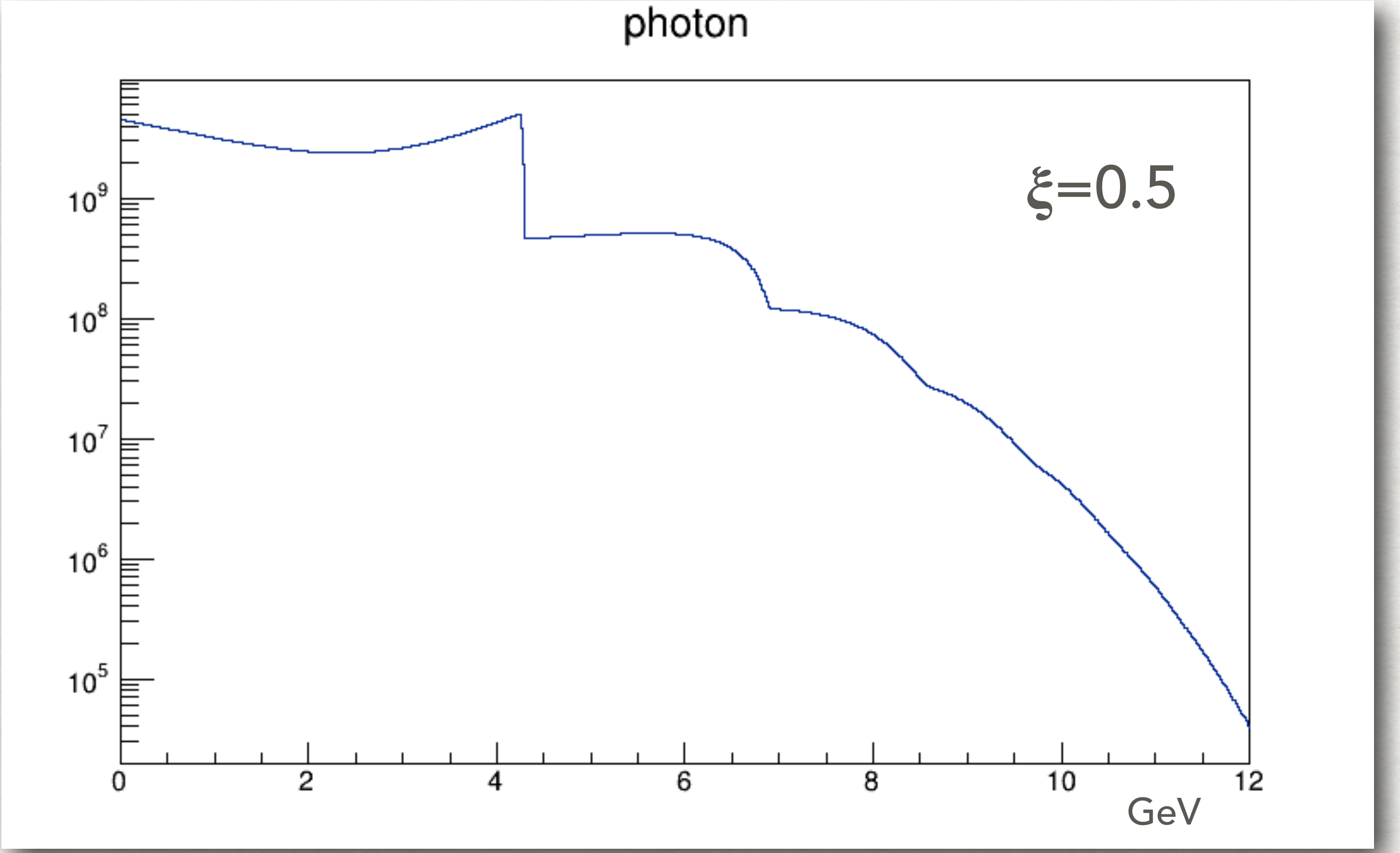
ELECTRON SPECTRA: 35 μ VS 300 μ



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)

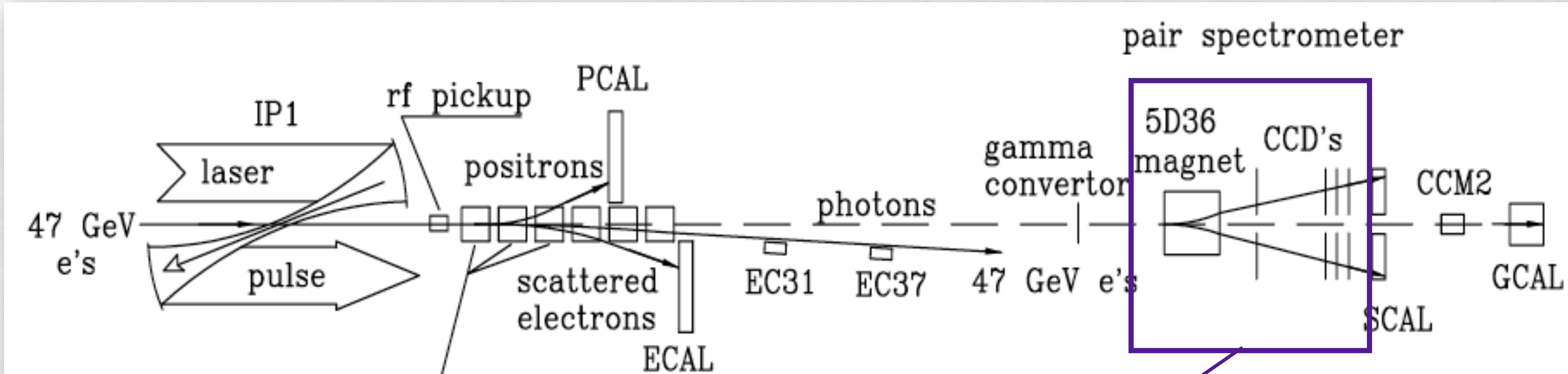


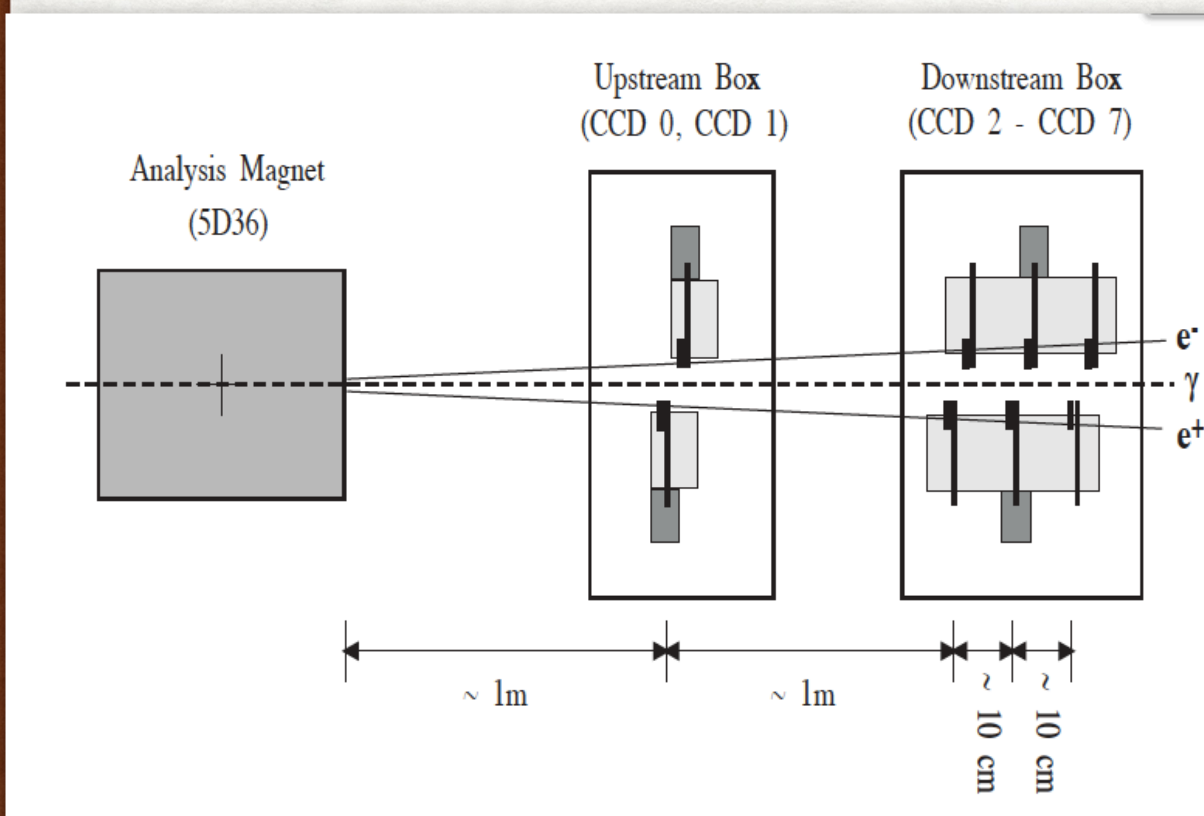
Integral:1.49255e+10

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

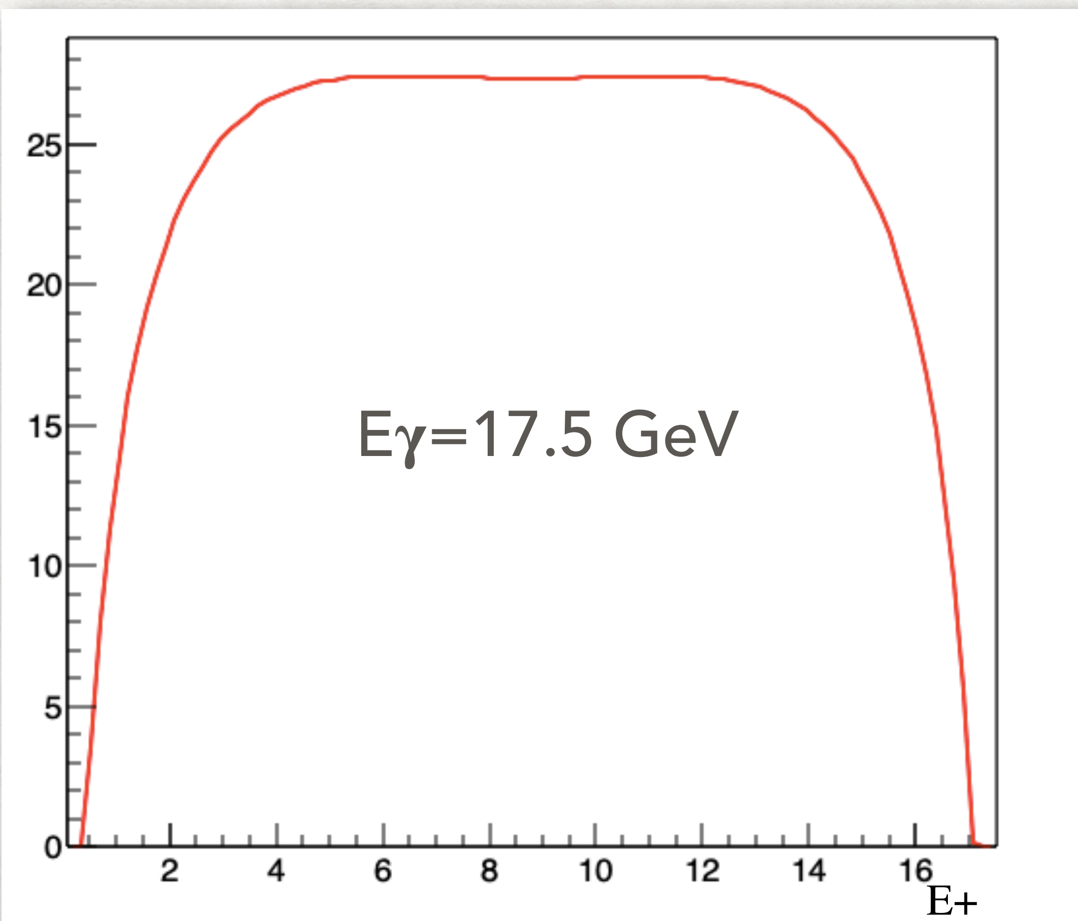
[EEV, 1242*1152].

THE CLASSICAL BETHE-HEITLER PAIR SPECTRUM

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

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

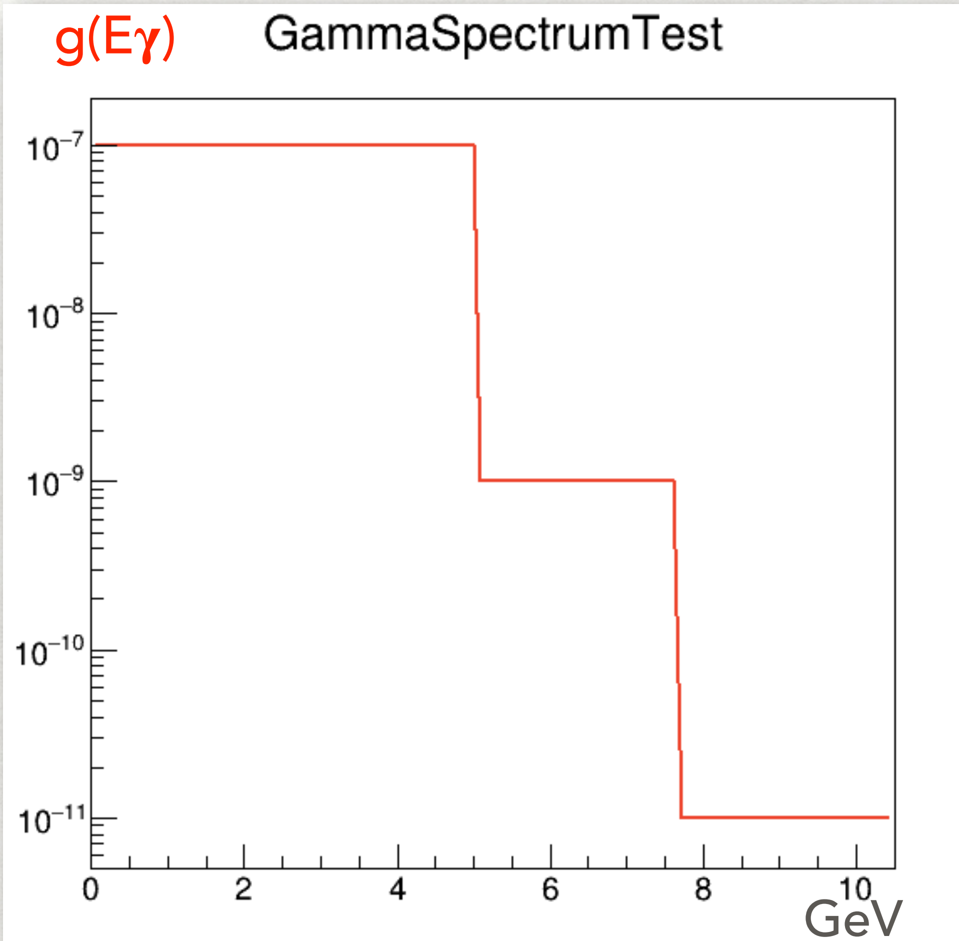
energies involved are large compared with mc^2

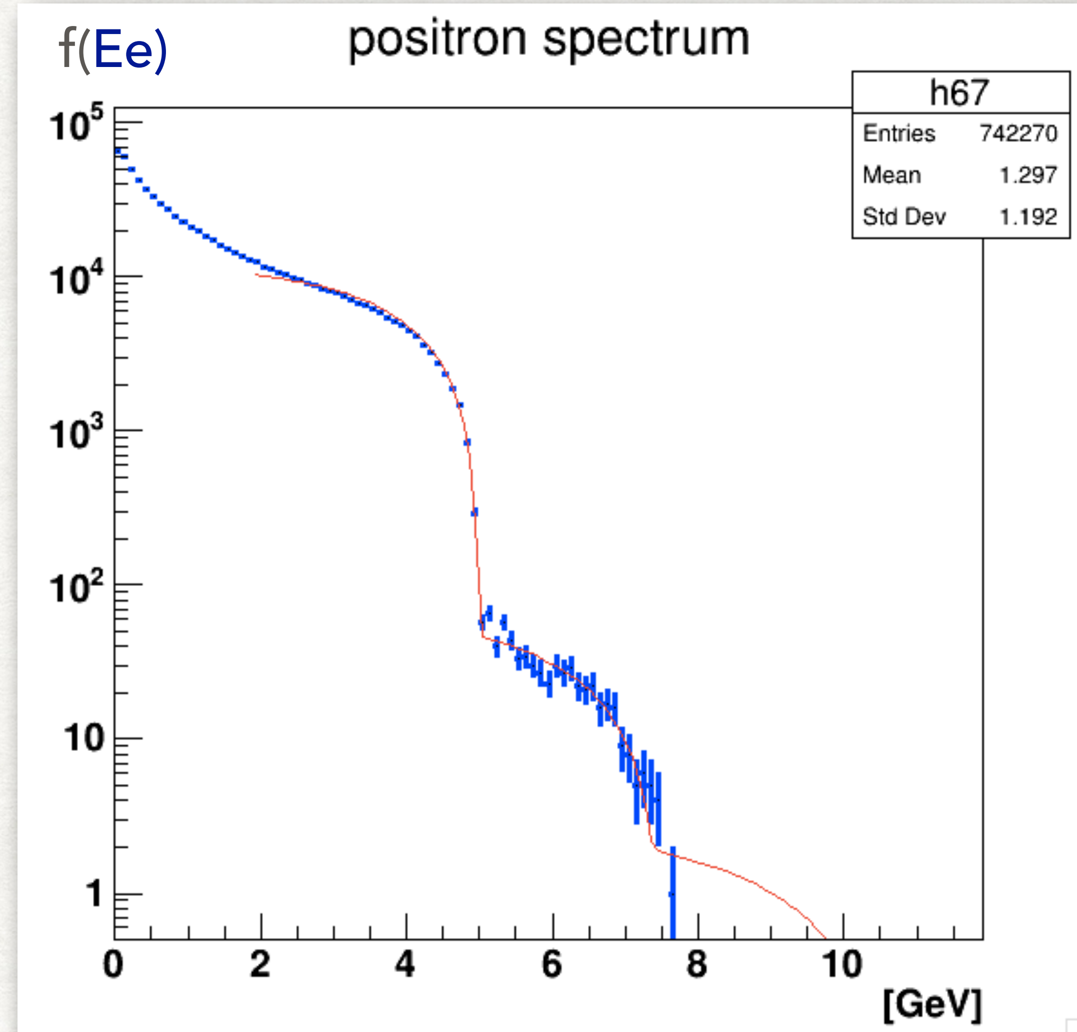


The idea - to check if any photon spectrum could be restored if we have the classical BH distribution and characteristic shapes of photon spectrum

TESTING: COMPTON-LIKE

Ee=∫σ(Eγ, Ee)g(Eγ)dEγ





∫σ(Eγ, Ee)g(Eγ,p1,p2)dEγ

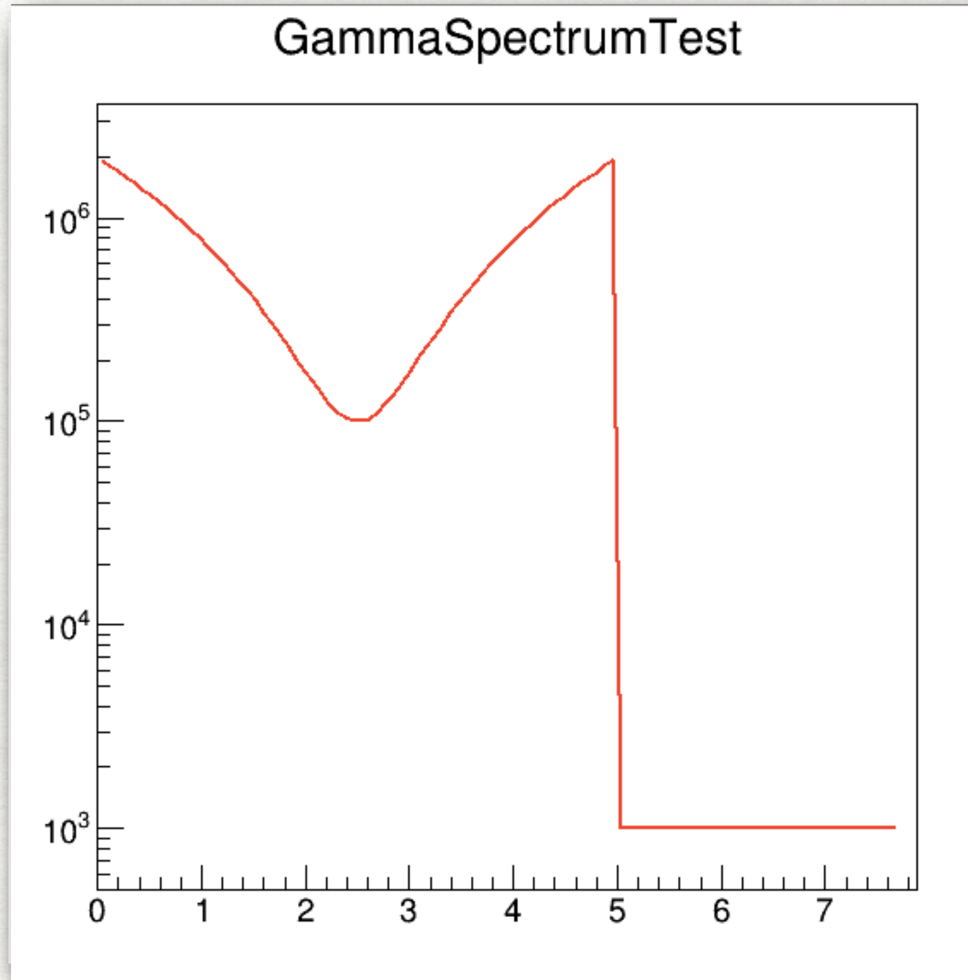
fitting allows finding the parameters quite well :

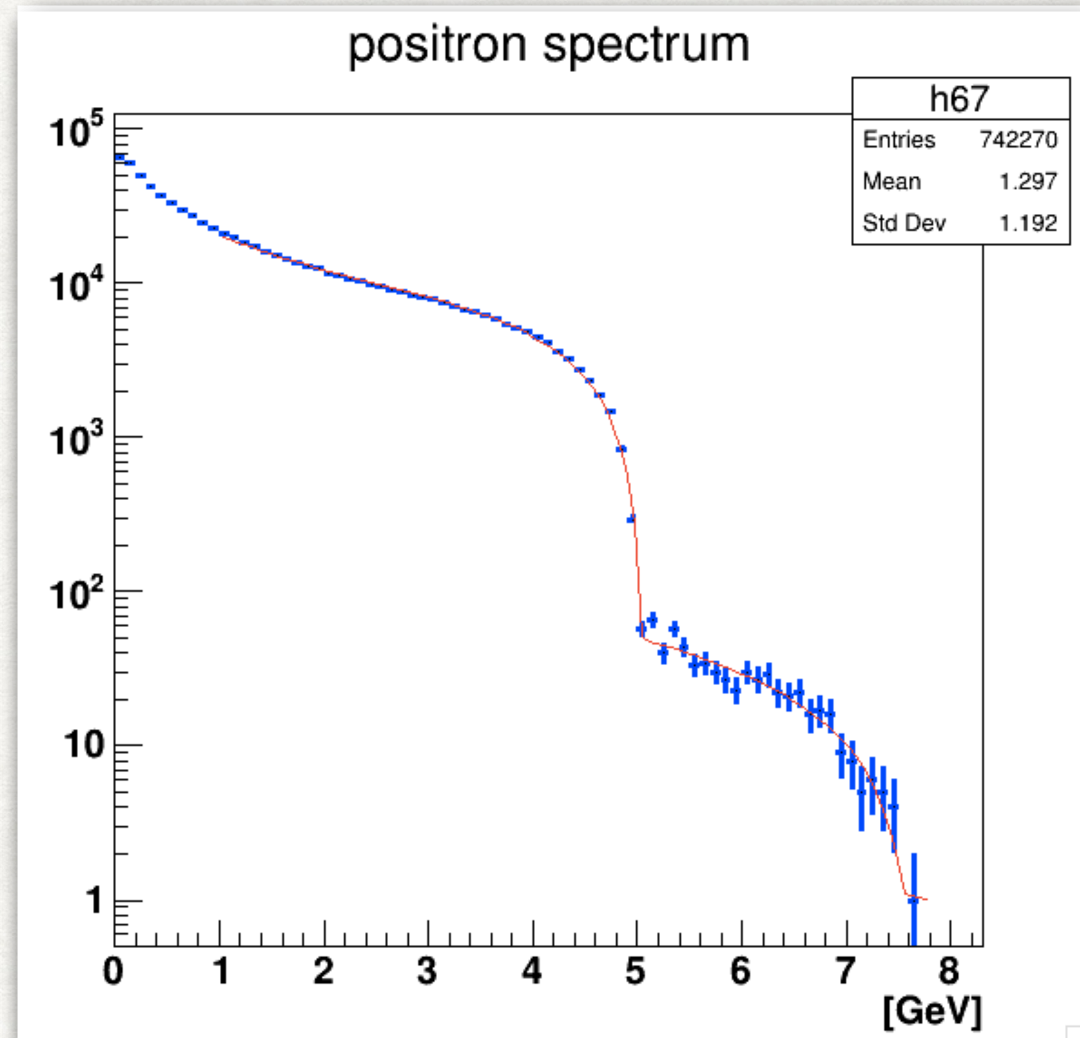
```
FCN=1309.19 FROM HESSE     STATUS=OK            39 CALLS          442 TOTAL
                    EDM=9.77144e-09    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  p0           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 NO.	PARAMETER NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
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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