INPUTS & REQUIREMENTS FOR THE FORWARD PHOTON DETECTOR SYSTEM

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LUXE workshop

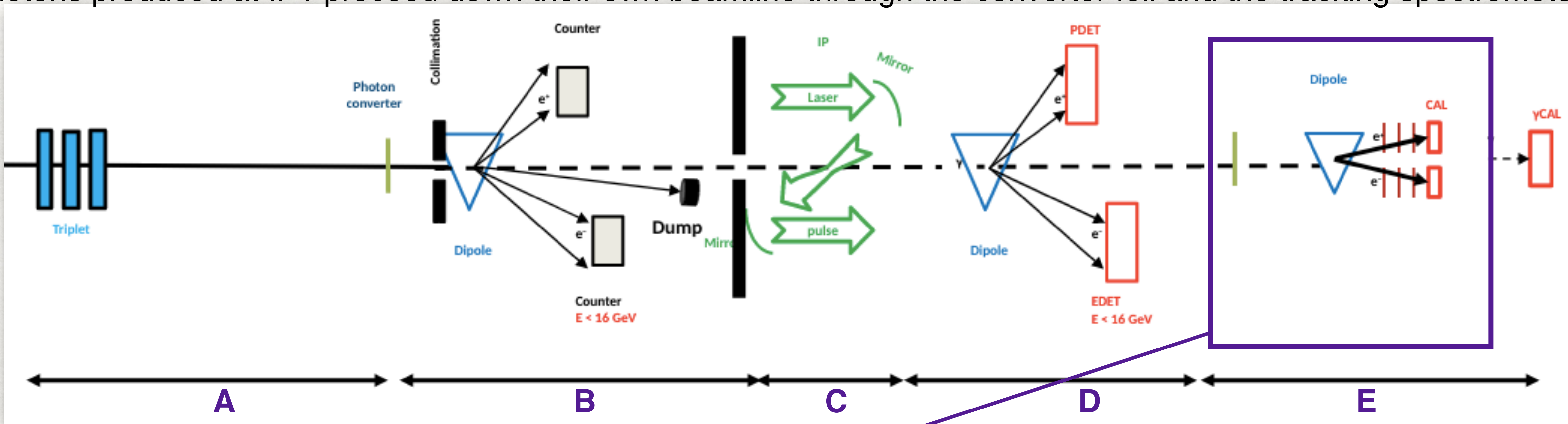
LUXE

OUTLINE

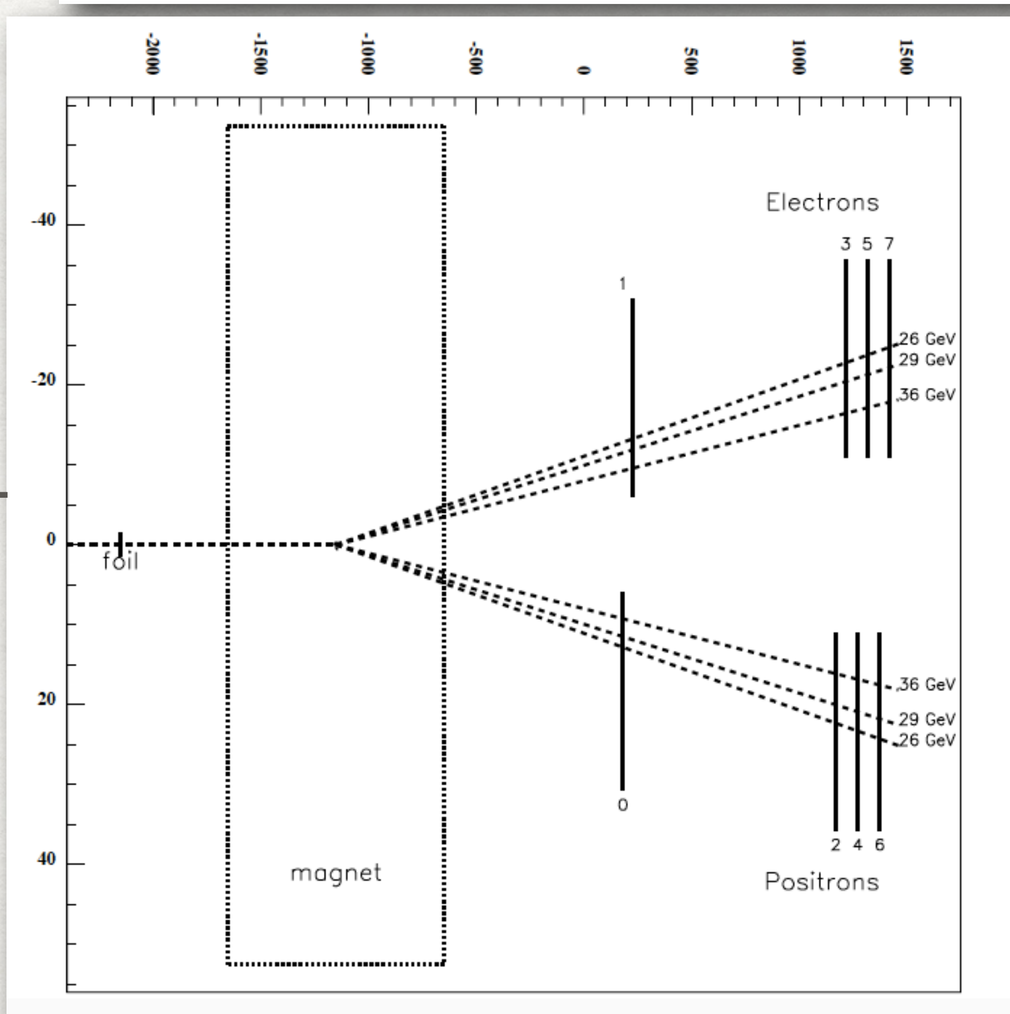
- layout for FDS of the LUXE experiment
- HICS and the absolute number of forward photons
- method to study the photon-conversion data
- spectra from MC
- Geant4 simulation for the converter

LAYOUT FOR FDS OF THE LUXE EXPERIMENT

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



E144 Experiment



- $e + n\omega \rightarrow e + \gamma$ **HICS ➔ Non-linear Compton**
- $\gamma + n\omega \rightarrow e^+ + e^-$ **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

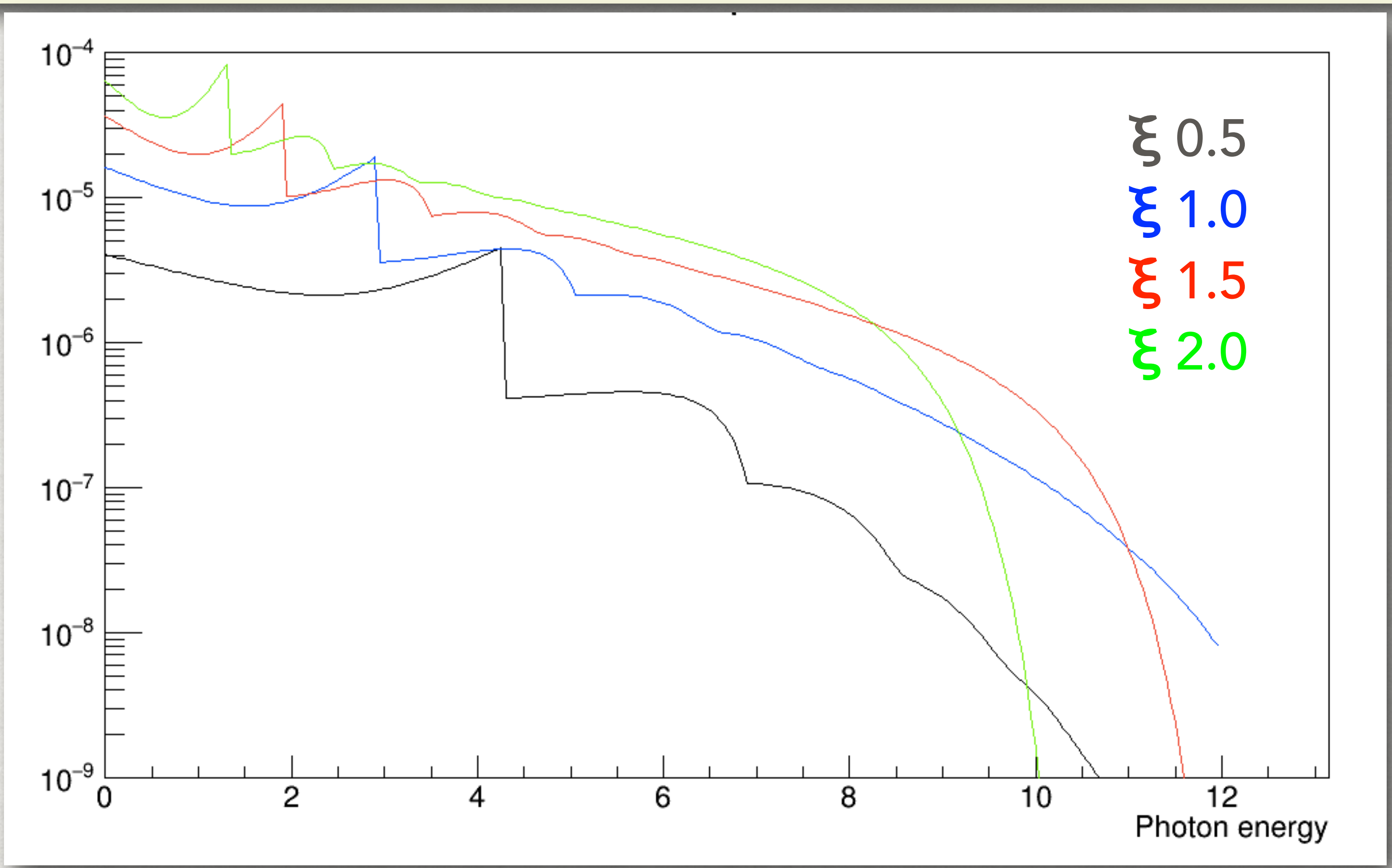
data produced of HICS/IPW/circularly polarized with Mathematica by Anthony Hartin

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

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

differential transition rate per electron per 100 fs.

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



ABSOLUTE NUMBER OF PHOTONS

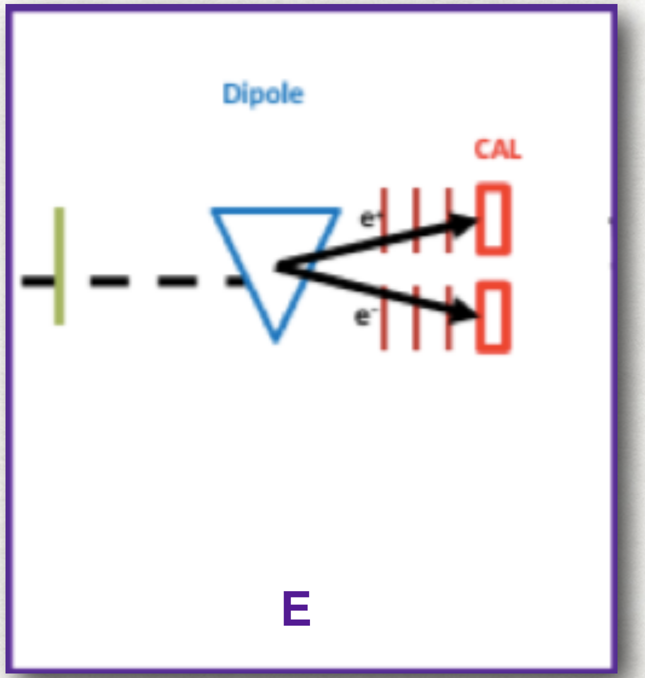
production rate for the electron bunch 6.25e+09 and laser pulse t=35 fs estimated from theoretical calculations

ξ	1e 35 fs (1BX)	$N\gamma$
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

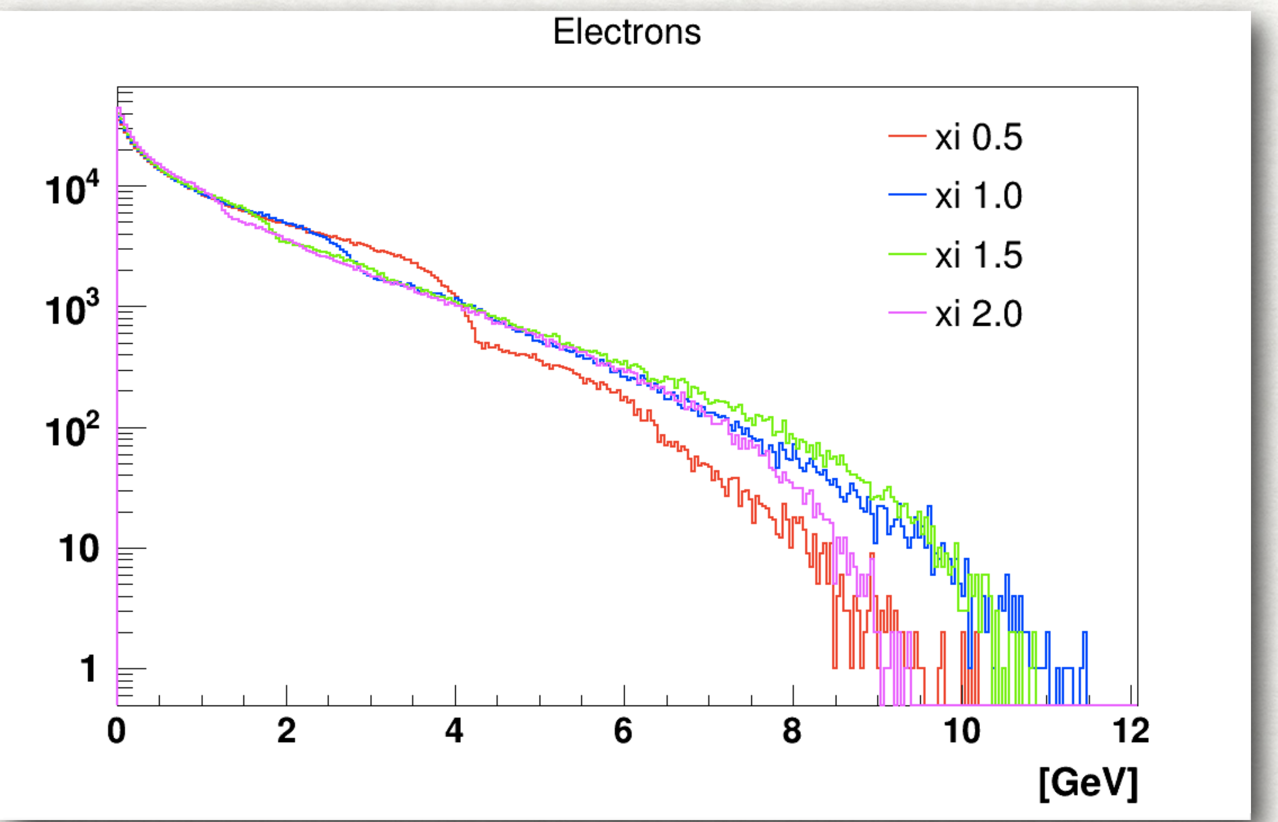
The transverse structure of the laser field is not taken into account in the data and it is assumed that the laser field is uniform in transverse plane and it is essentially the same for all electrons -> It could be accounted for in MC

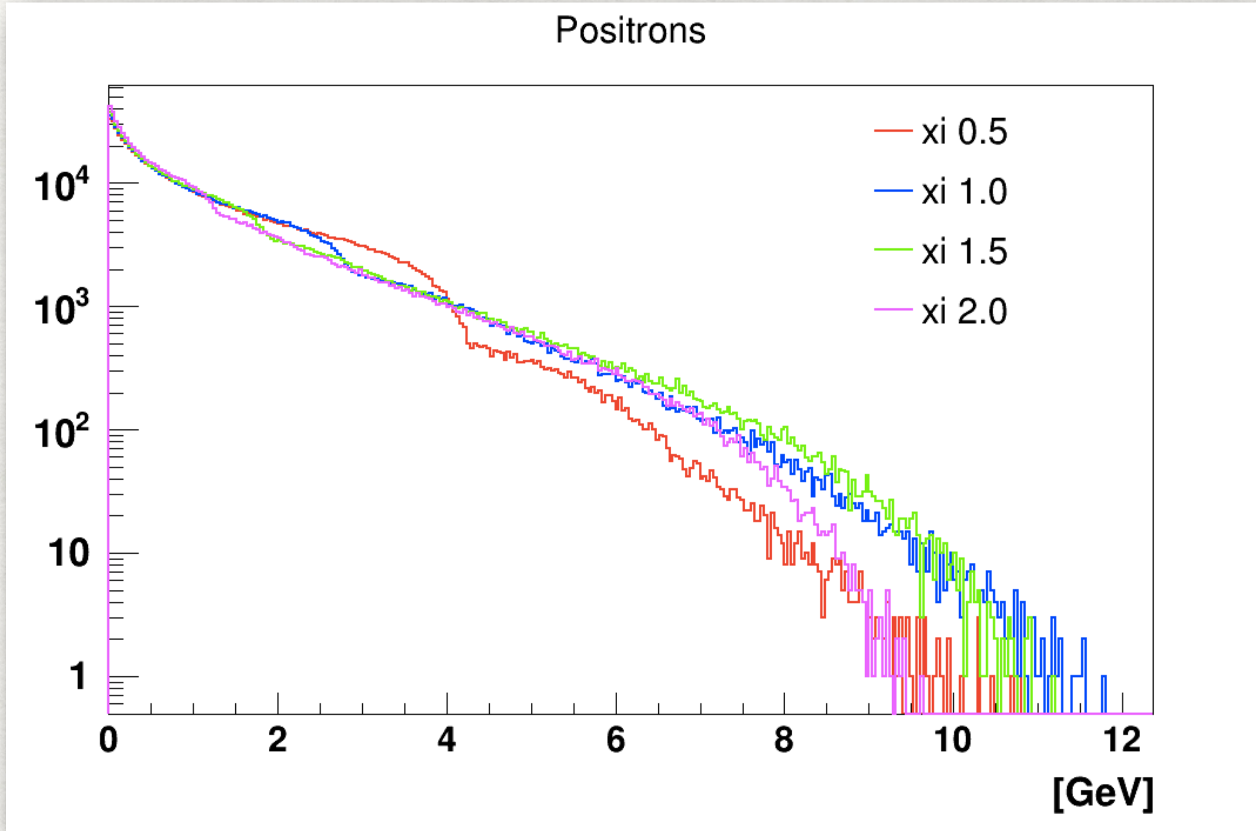
If the target thickness is 1% of X0 at this laser intensities ~ 1e8-1e9 e+e- pairs would enter the pair spectrometer in each laser pulse

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

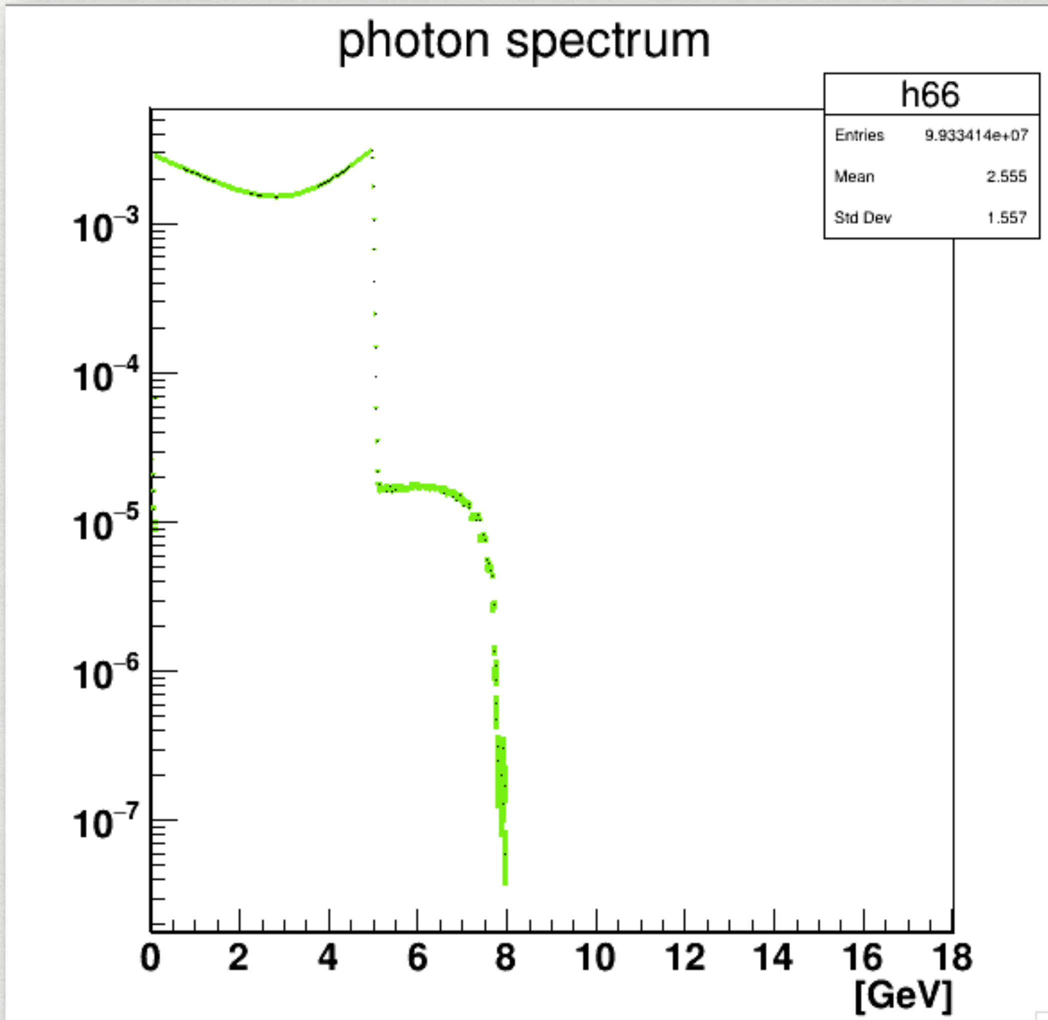


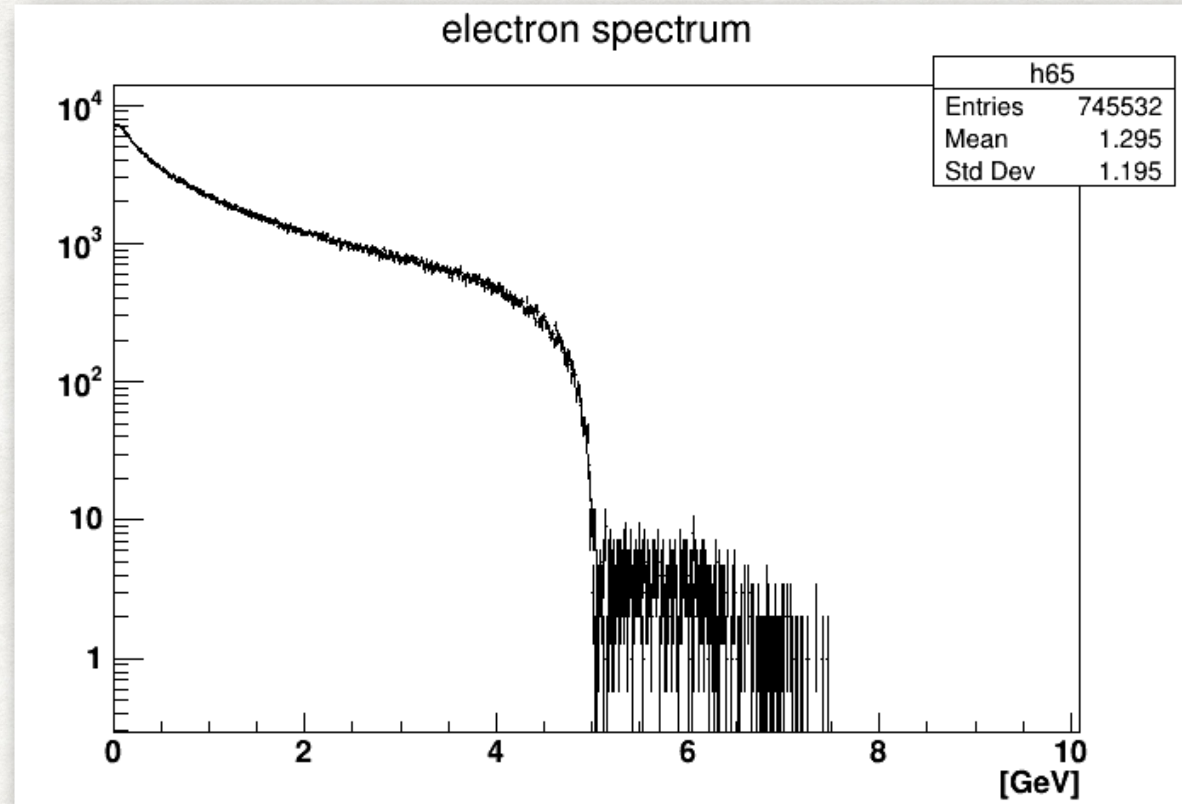
- target material - W foil
- thickness 35 um
- 1e8 photons

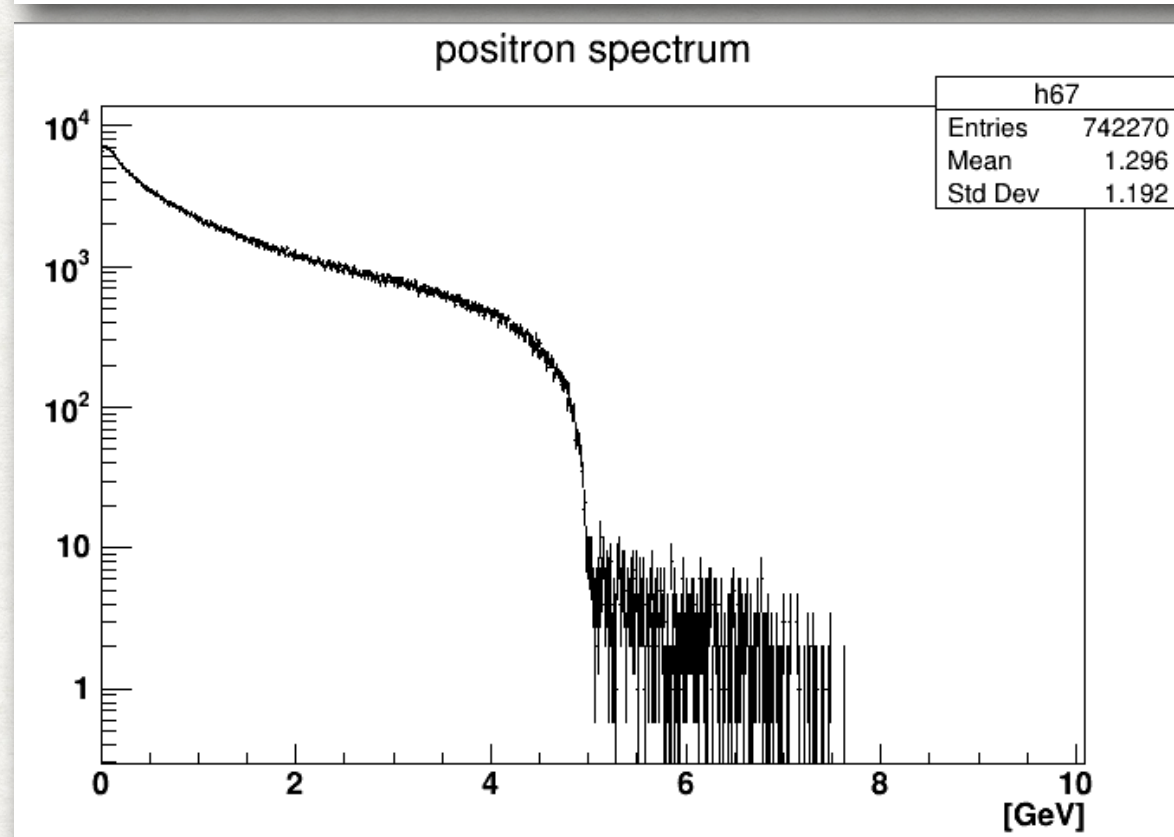




FORWARD PHOTONS IN GEANT4







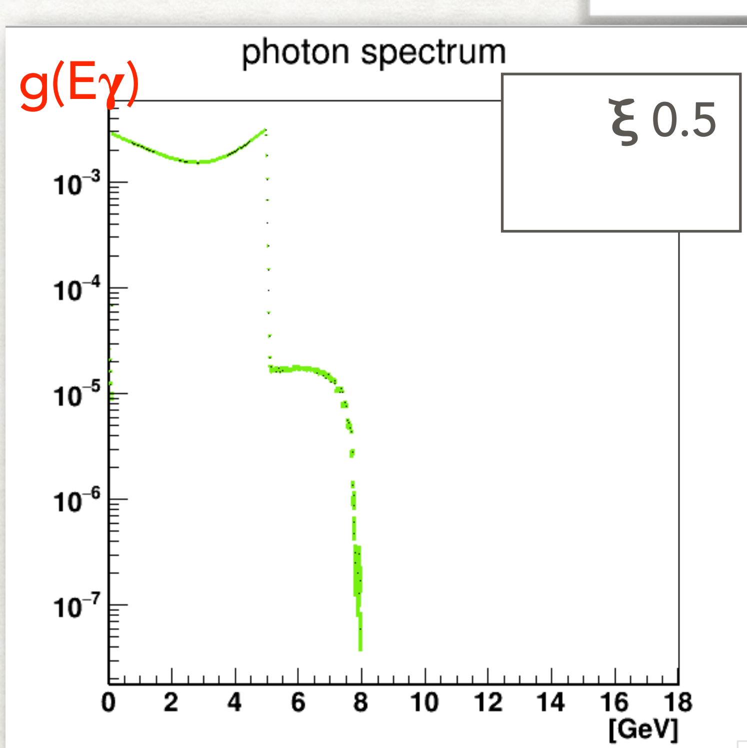
target: Tungsten foil, 0.35 um

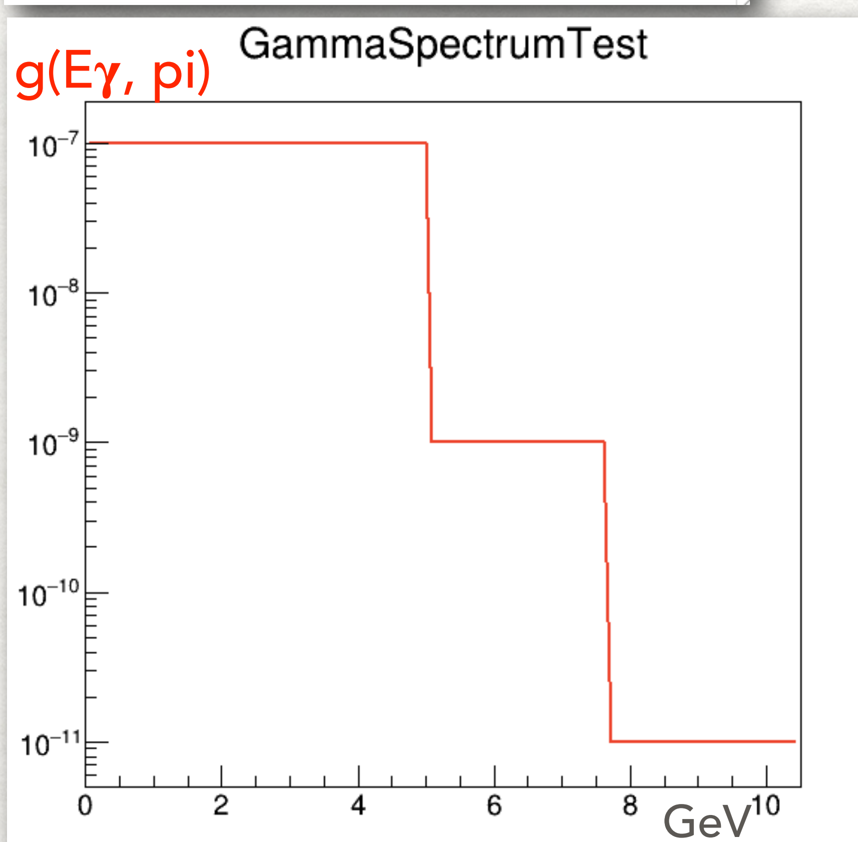
1e8 photons, ξ = 0.5

HUGE fluxes, for nominal beam ~ 1e+6
hard to measure energy of individual particles

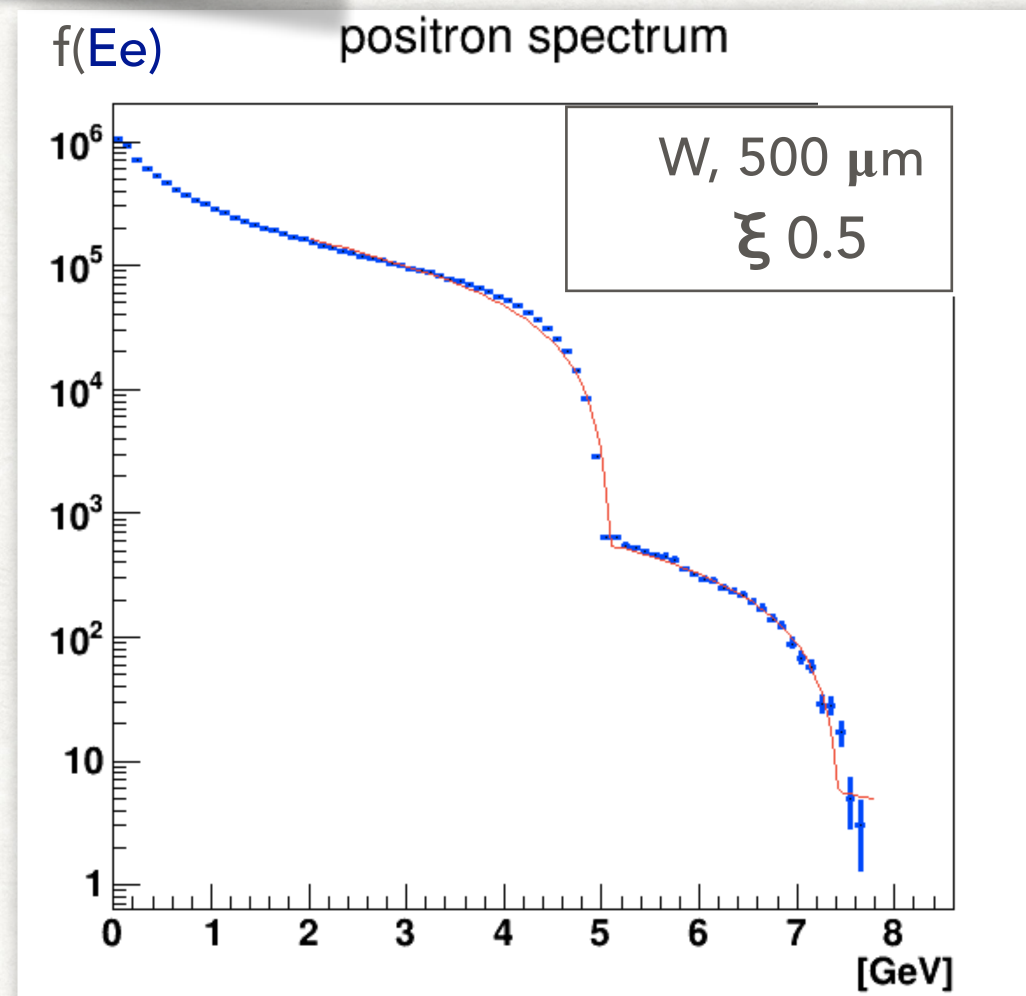
METHOD OF PHOTON SPECTRUM RESTORATION

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





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 **the kinematic edges** quite well

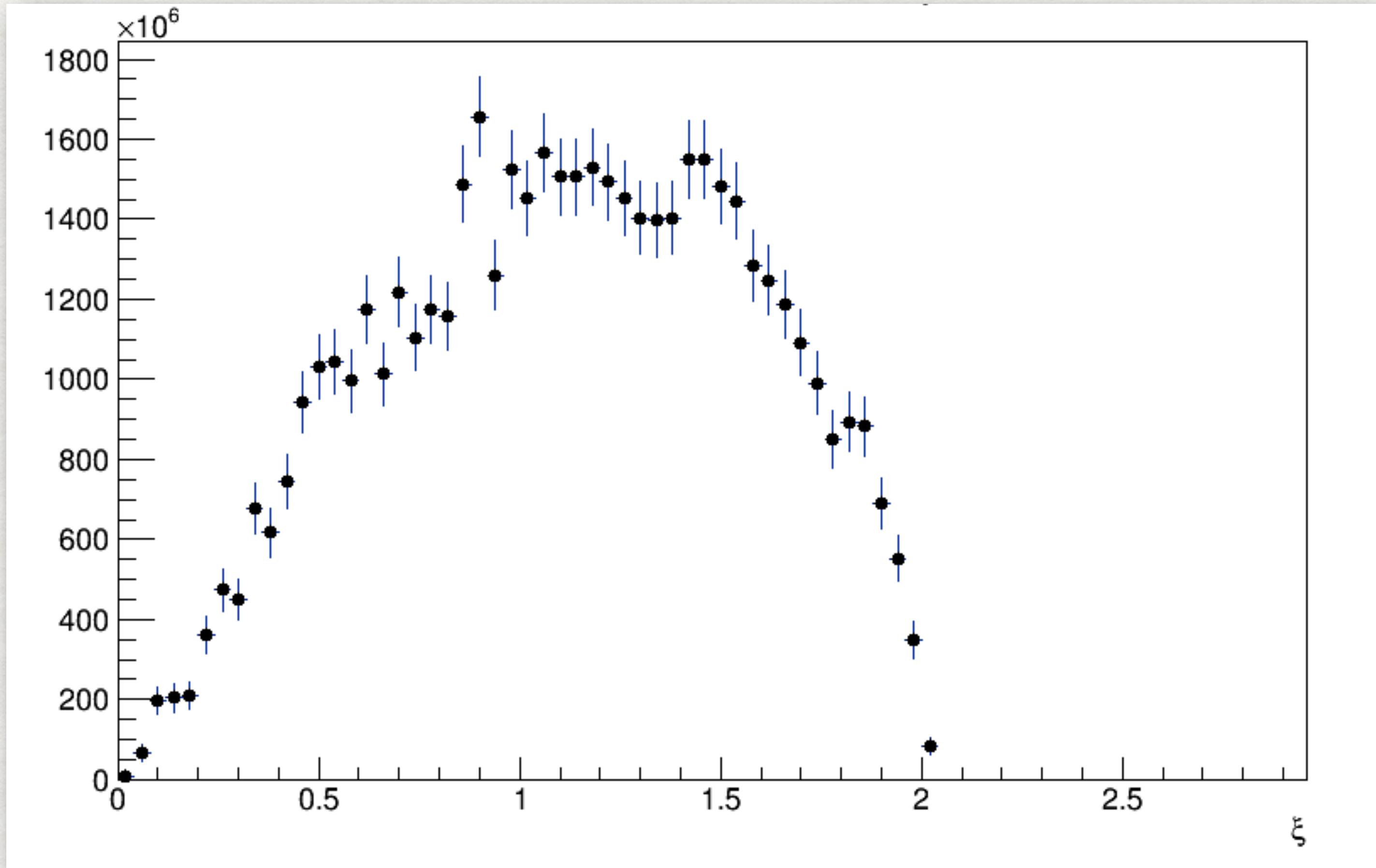
but this is done for the theoretical curve with uniform intensity

PHOTONS FROM MC

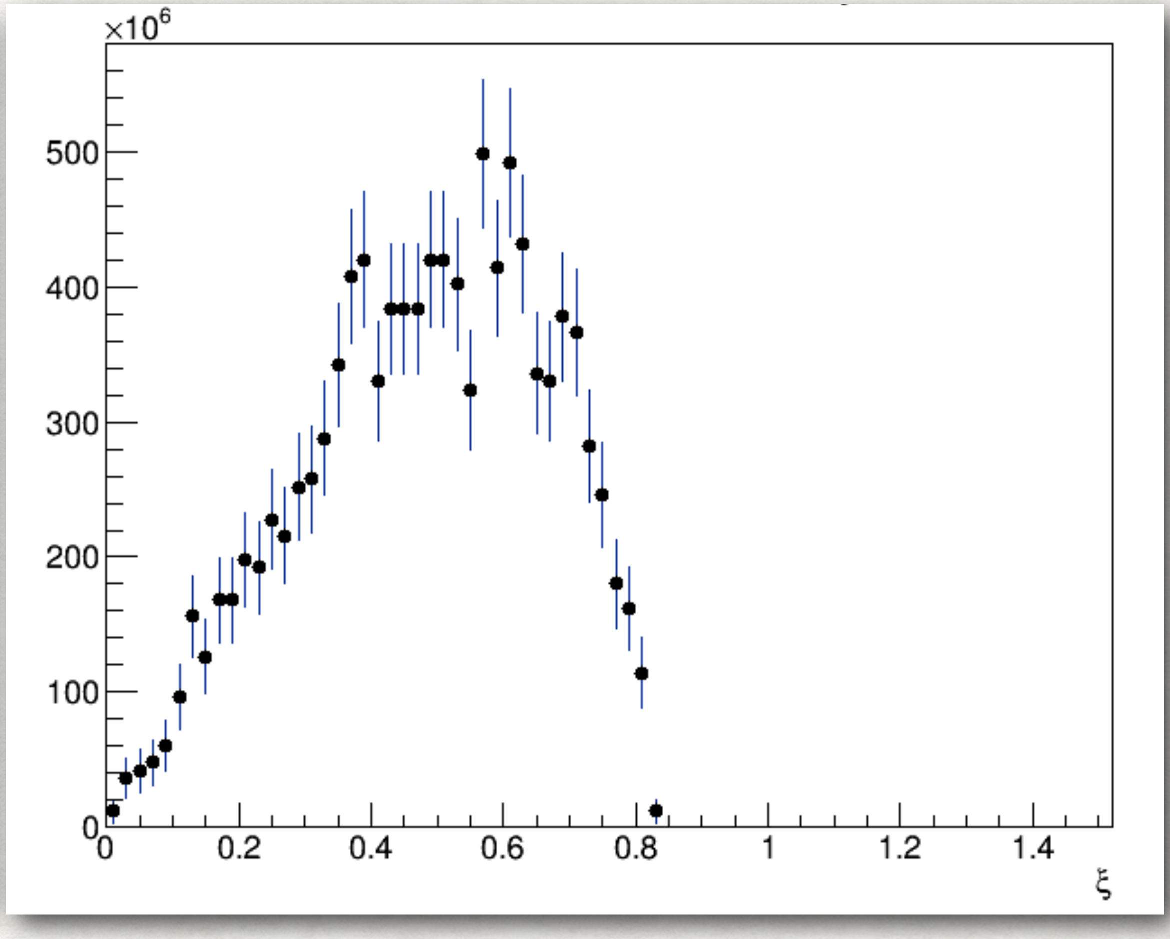
LASER INTENSITY

MC simulation provides information for ξ for each individual interaction

Peak ξ = 2.0148

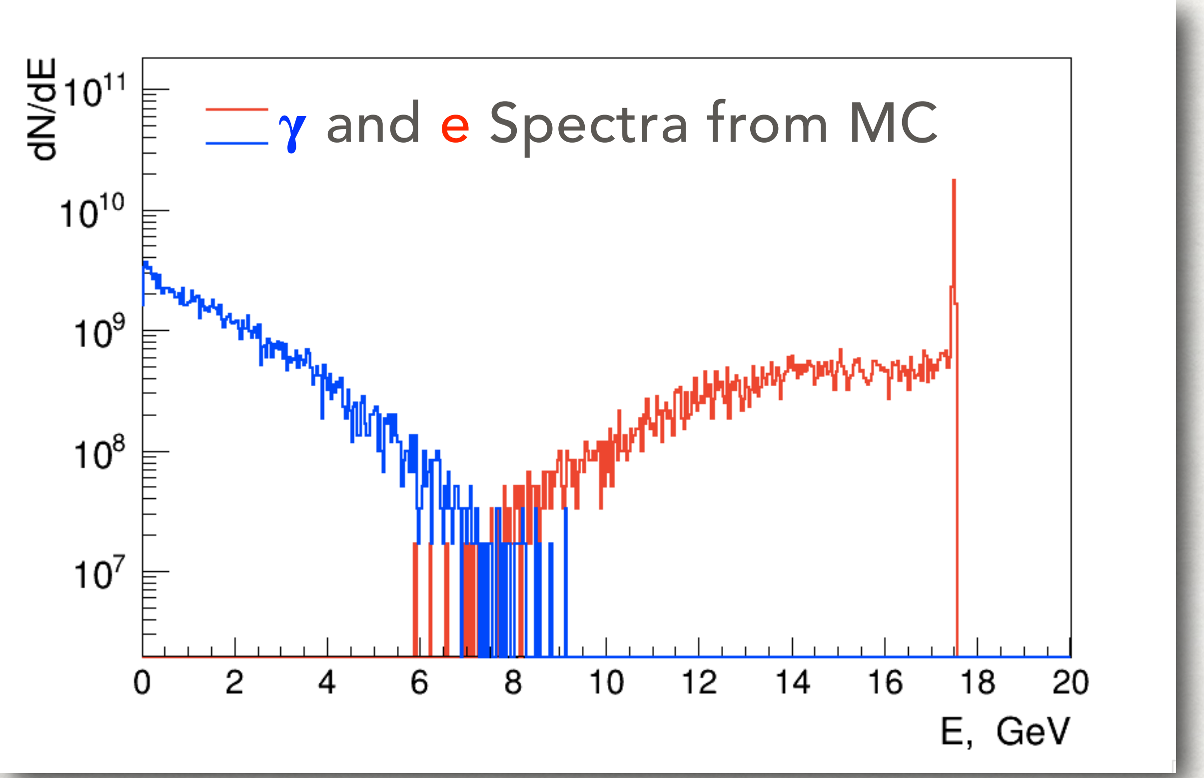


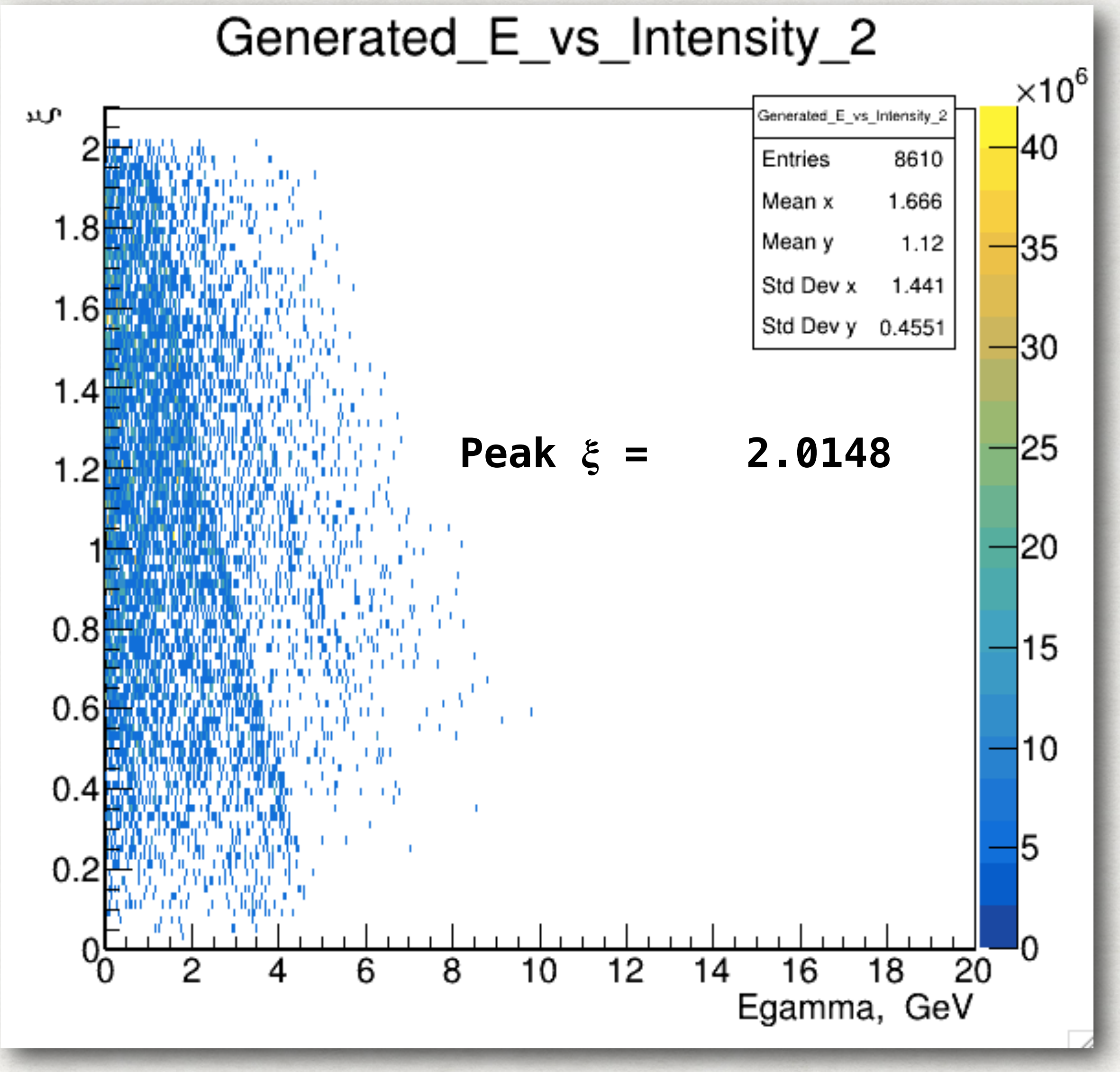
Peak ξ = 0.8



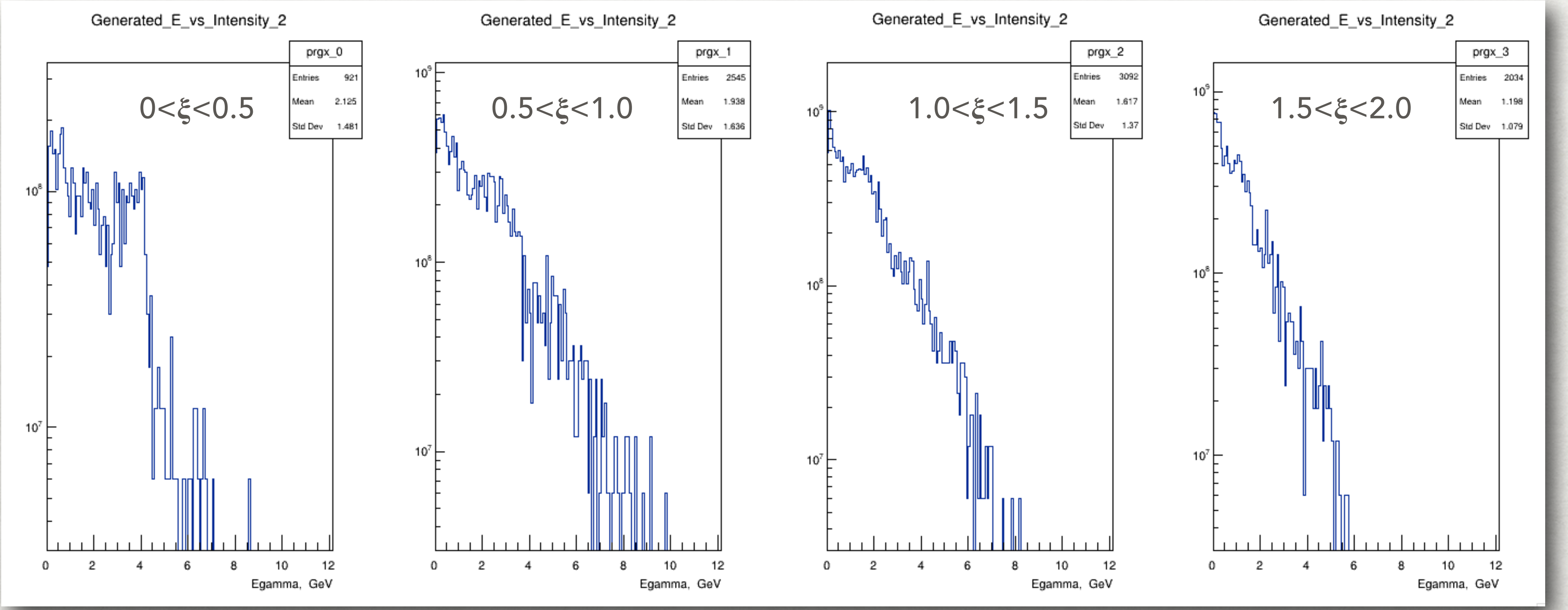
- Realistic simulation of laser pulse intensity distribution.
- The field is not the same across the laser pulse.

ξ VS Eγ FROM MC





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

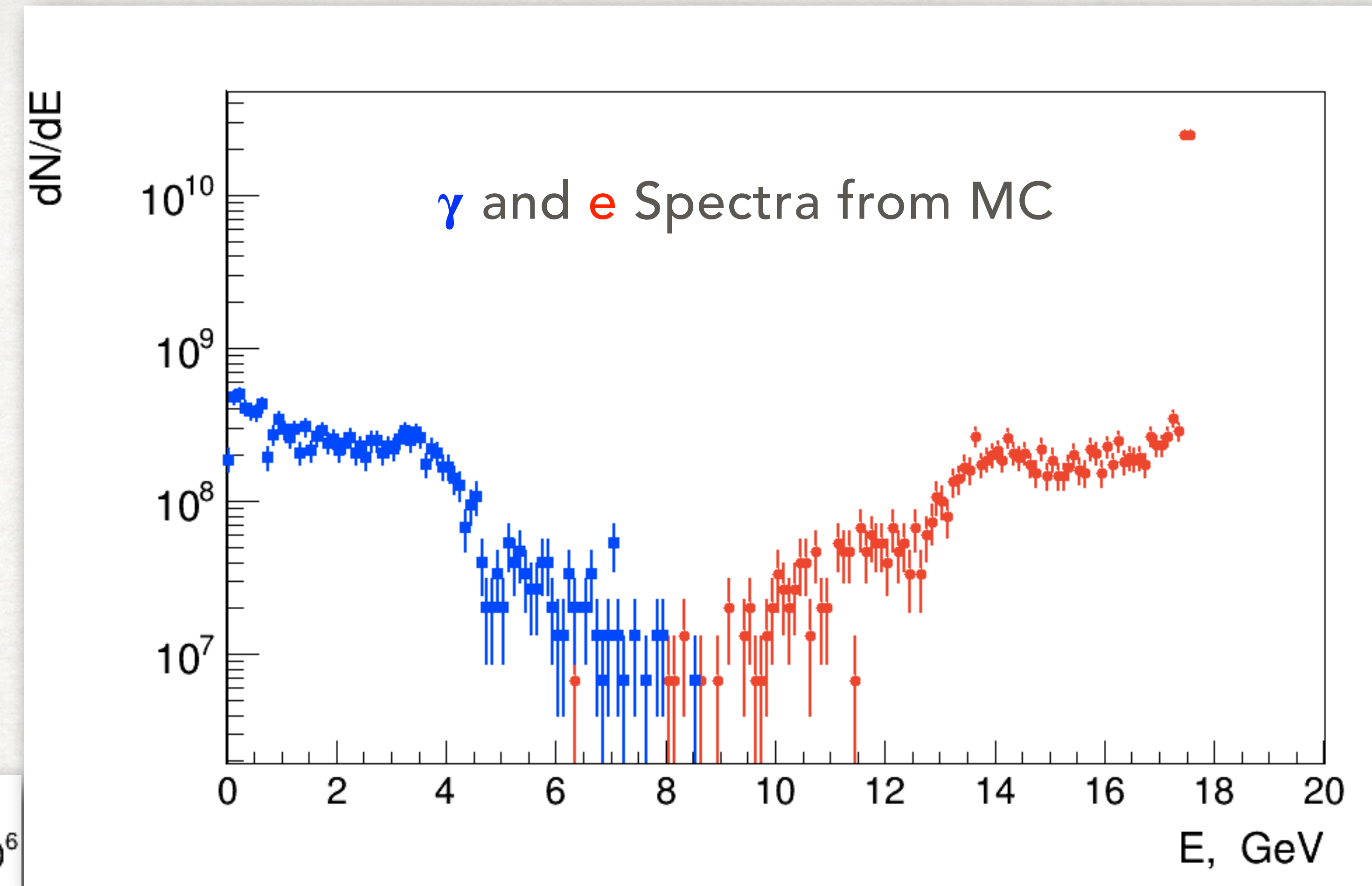


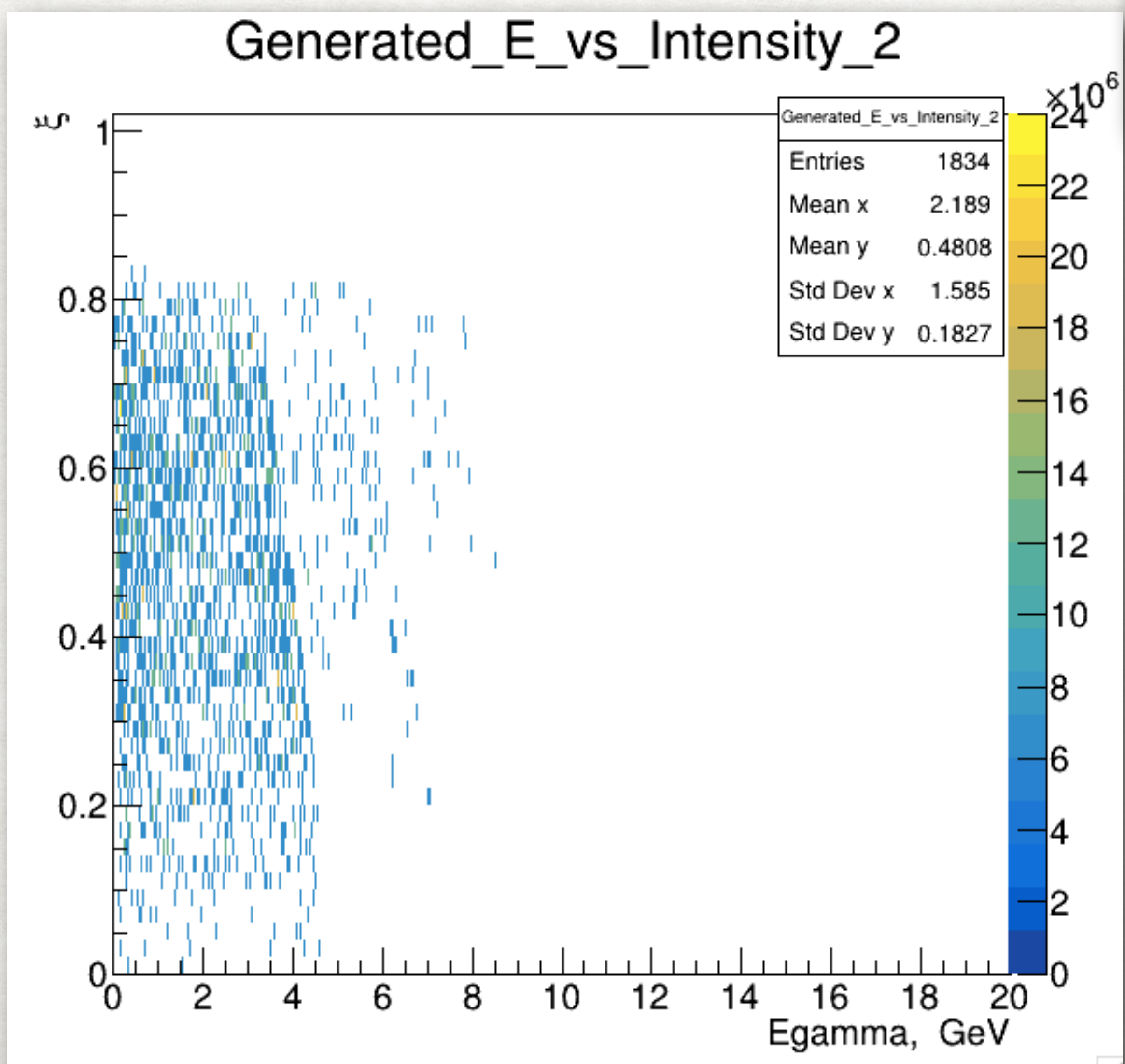
- ξ distribution might be reconstructed by fitting measured spectra w/ convolution of HICS xsection & ξ trial distribution

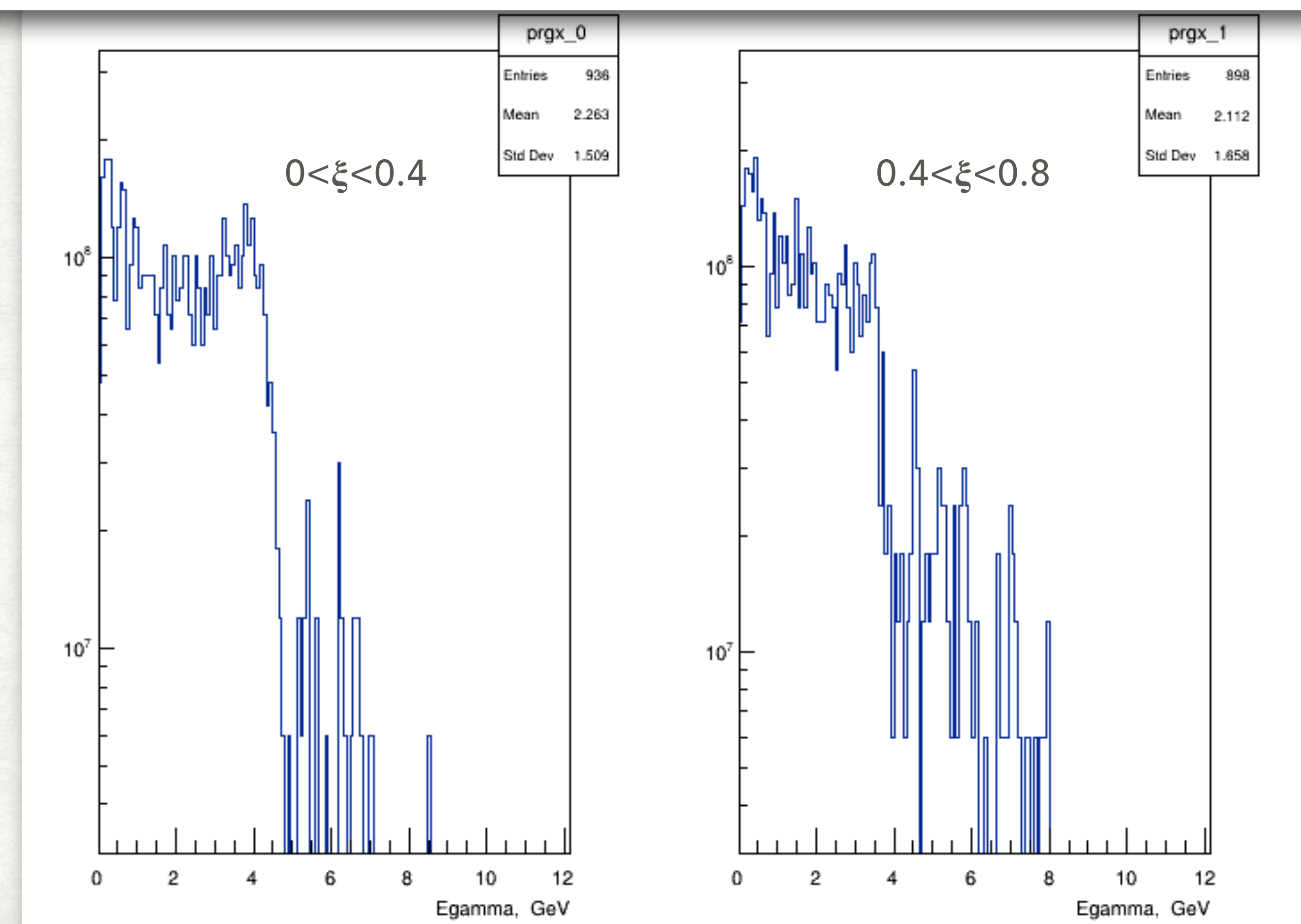
ξ VS Eγ FROM MC

Peak ξ = 0.8

The kinematic edges can be seen at the low intensity.







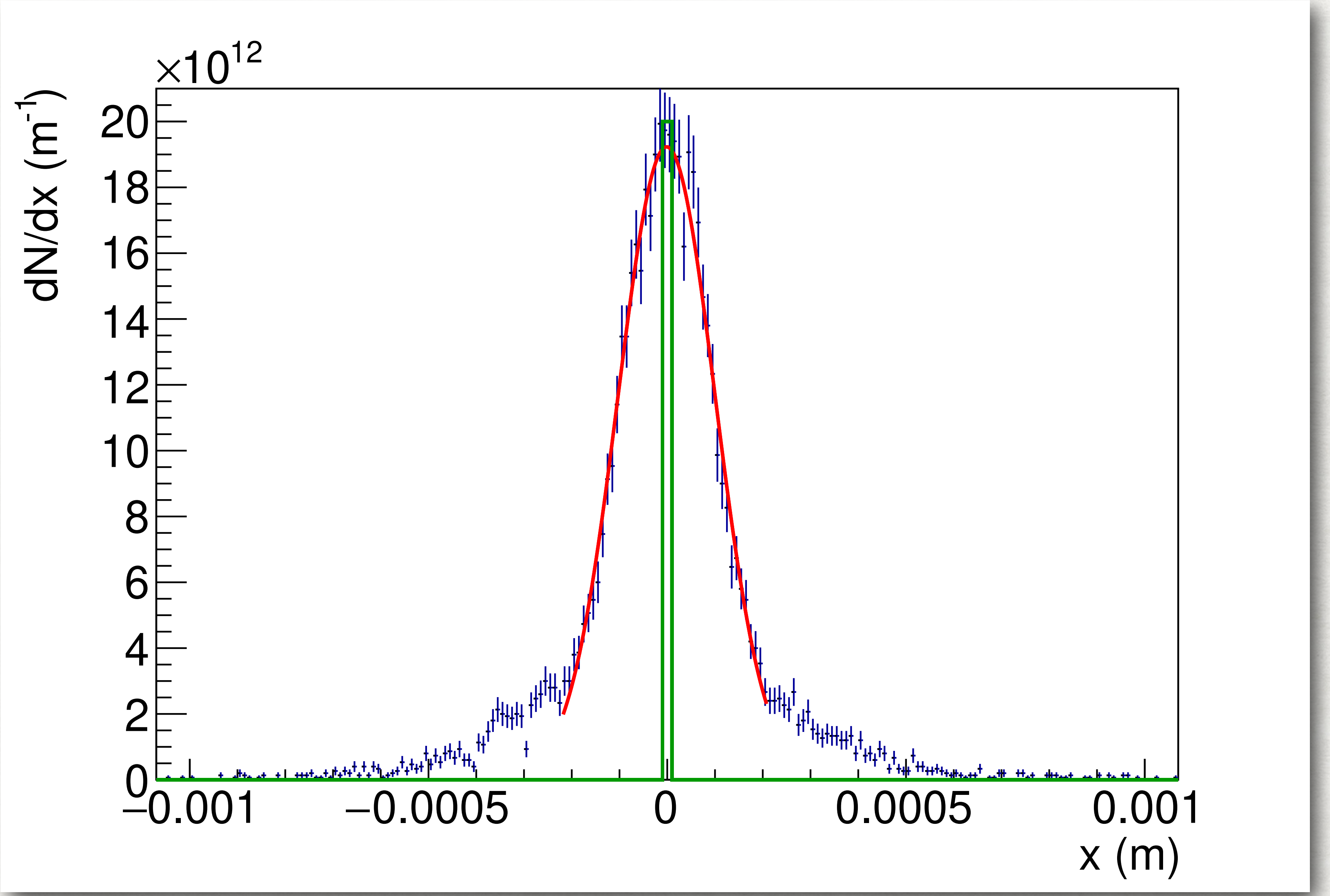
DETECTOR REQUIREMENTS

Tasks at hand → a) measure number of photons
b) measure energy spectrum

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

N OF PHOTONS FROM MC

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

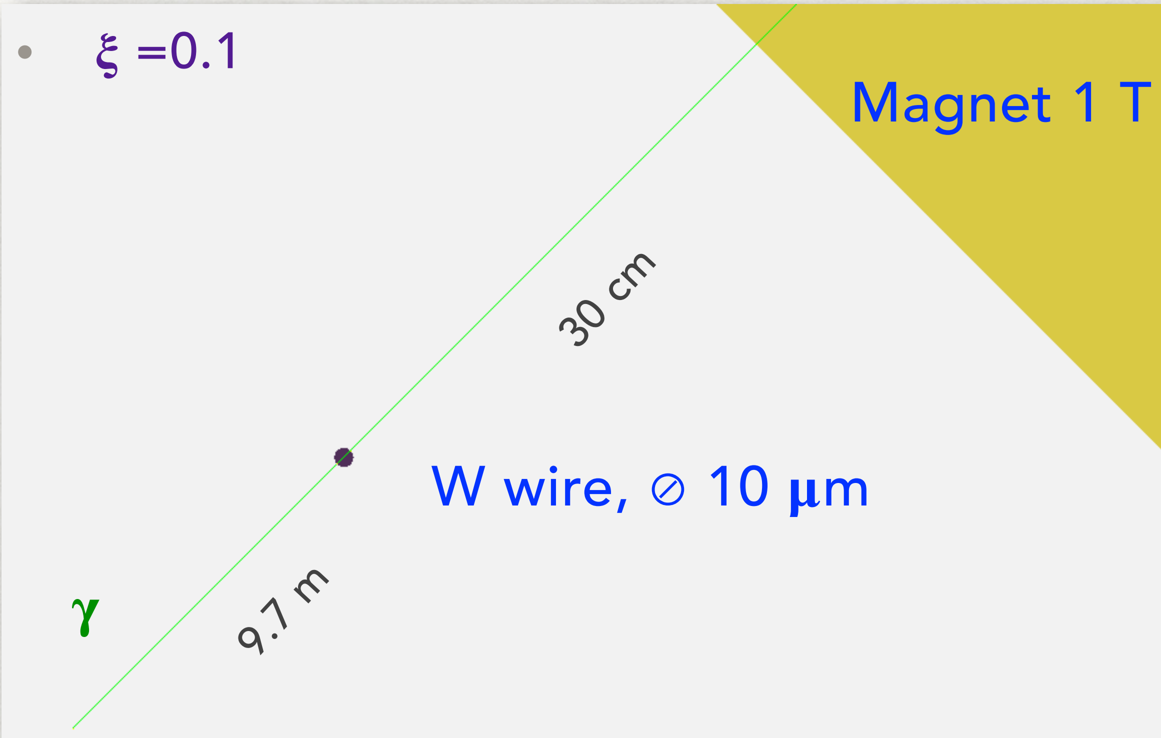


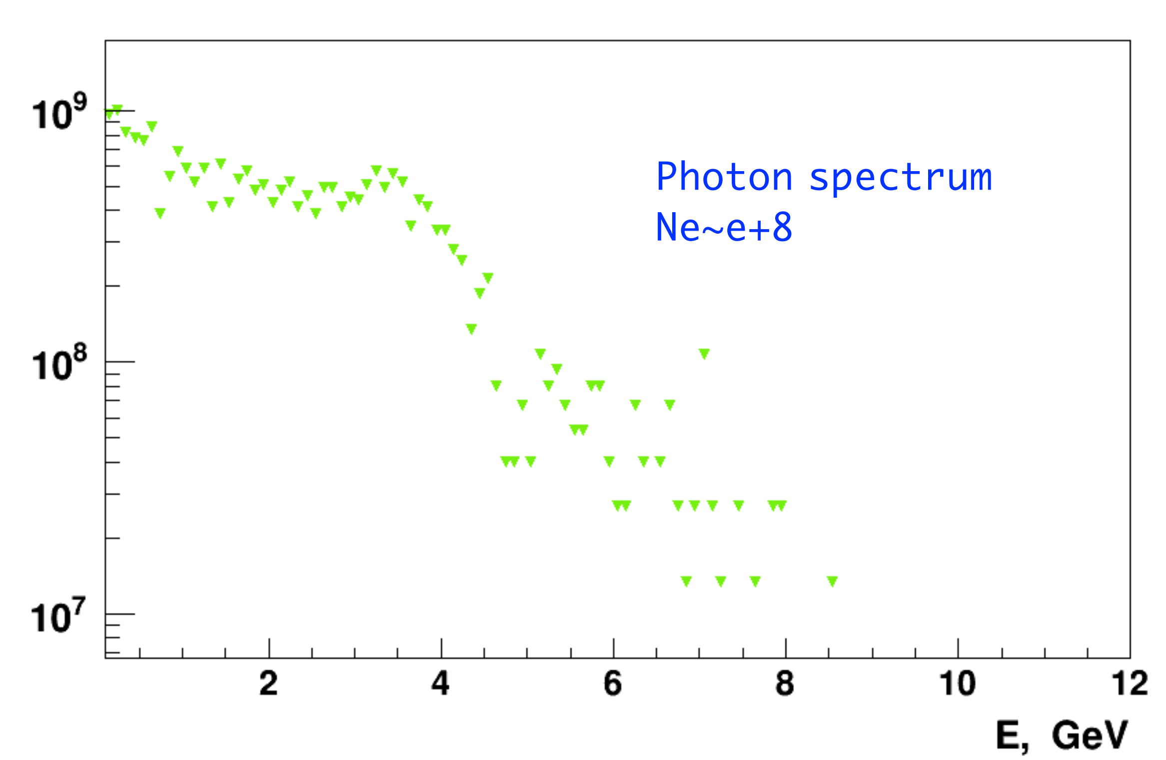
Ngamma in case of wire	
ξ	Nγ
0.1	5E+05

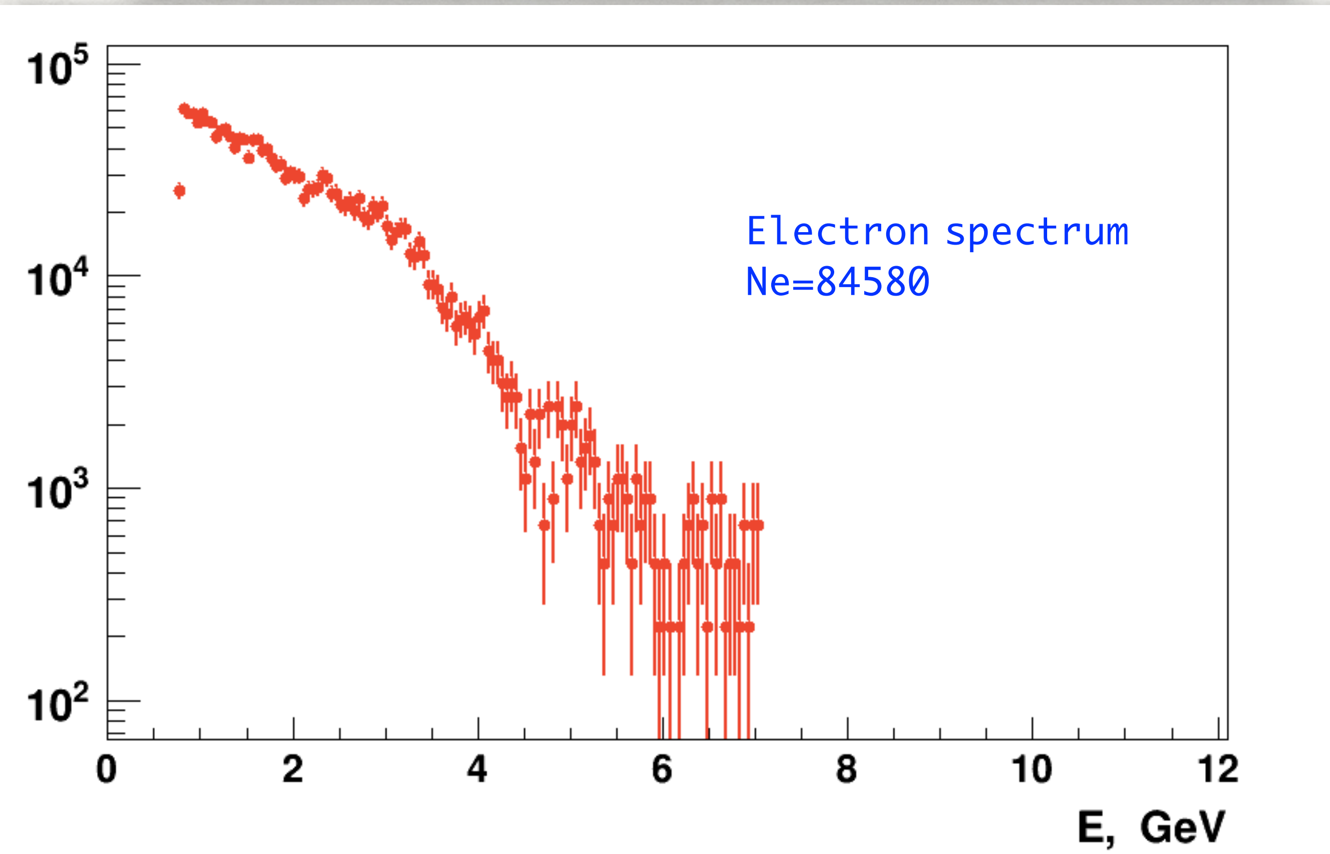
less but still a lot

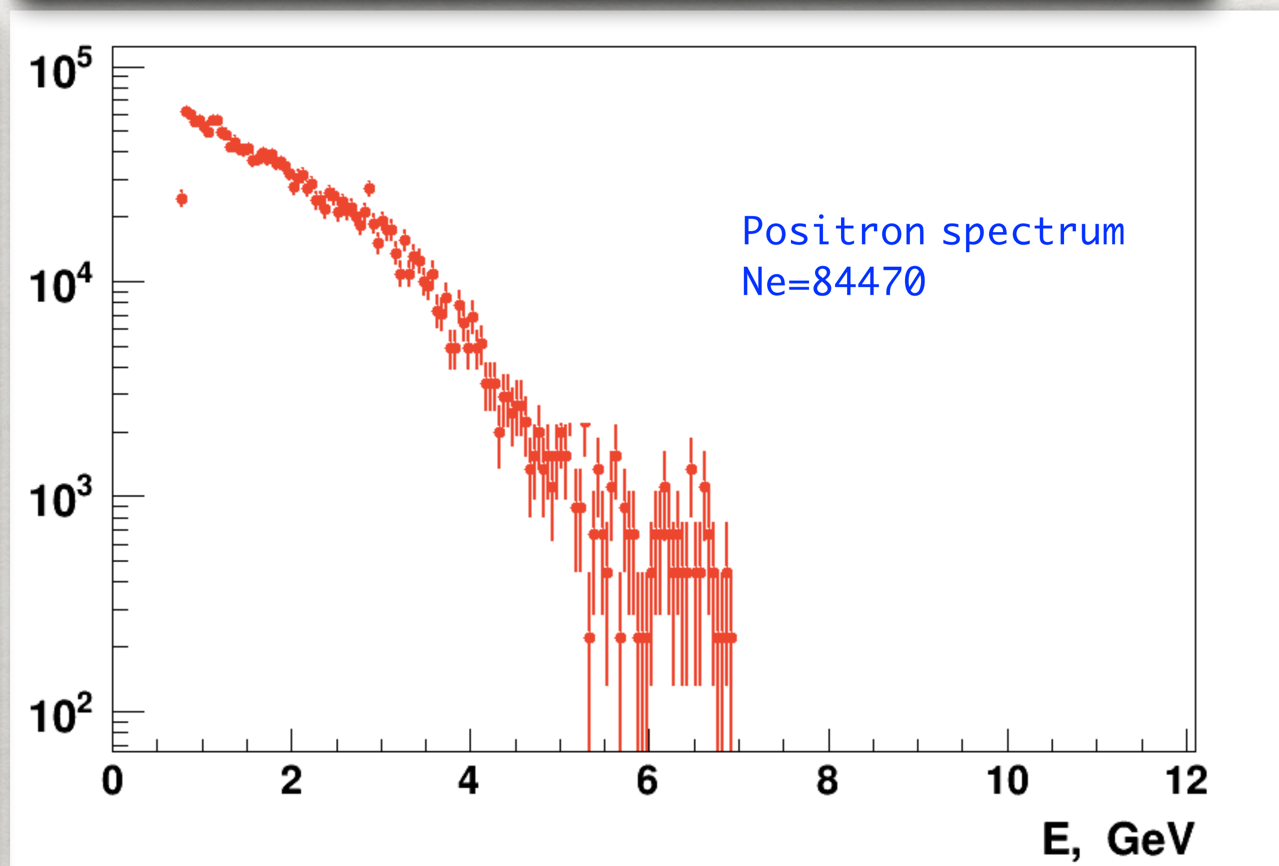
Ngamma in case of foil		
ξ	1e 35 fs (1BX)	Nγ
0.5	2.39	1.49255E+10
1	8.43	5.26758E+10
1.5	16.29	1.01825E+11
2	24.41	1.52579E+11

GEANT4 SIMULATION FOR THE WIRE CONVERTER







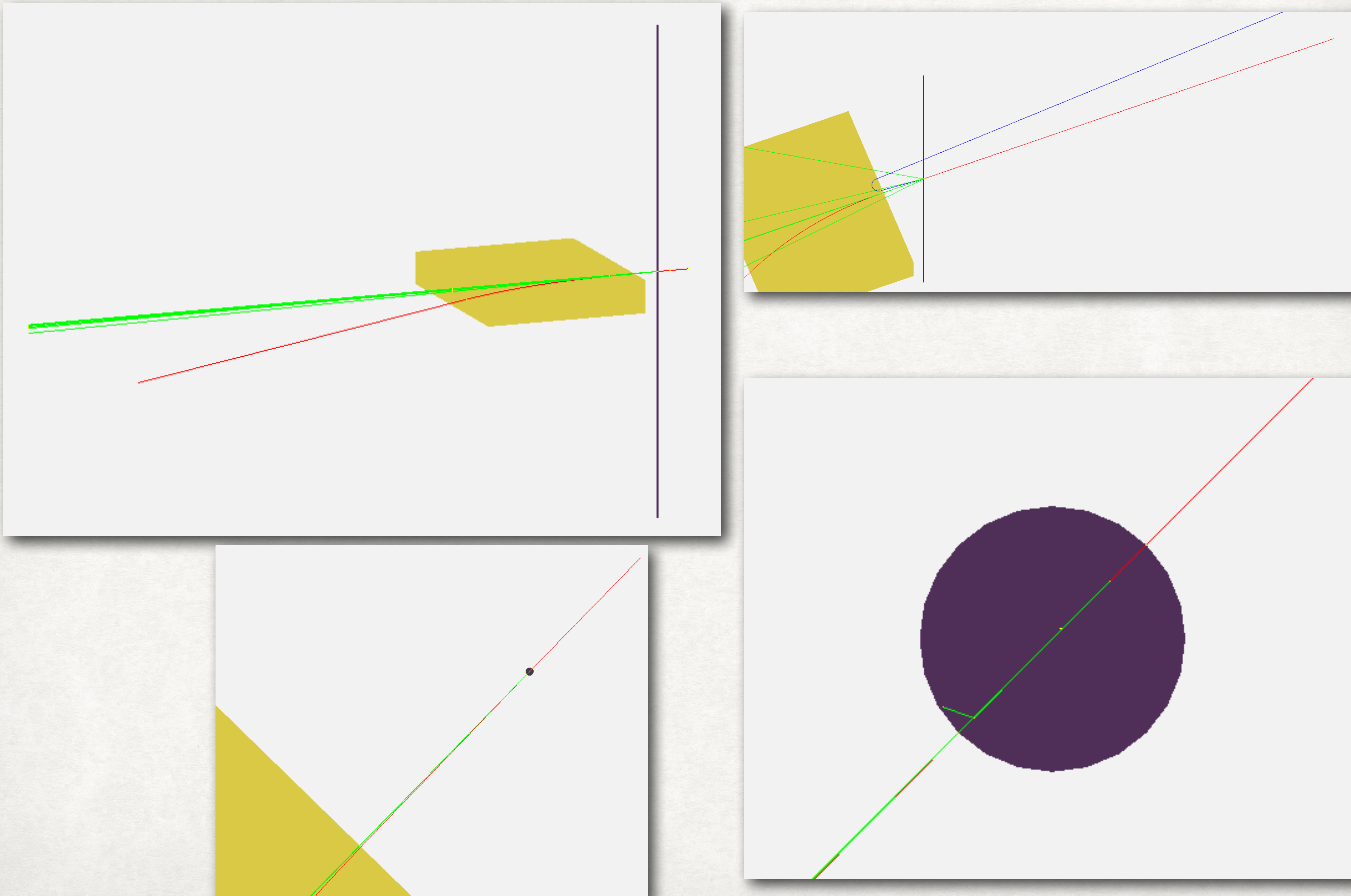


WHAT'S DONE & WHAT'S NEXT

- Estimated the absolute number of forward photons: from theory and MC+GEANT4 simulation: very high fluxes
- It is not trivial to restore the position of kinematic edges for n>1 for the real case scenario
- Non-uniform Laser Intensity (ξ) makes the kinematic edges from different *n* not visible, especially for high ξ
- Preliminary studies of the feasibility of usage W wire as converter target. For nominal XFEL beam the ξ =0.1, 10 m from IP, the number of e ~8e4.
  - this number will be ~1e2-1e3 for less intensive XFEL beam which is possible by tuning its gun;
  - to go further from IP
  - to study gas jet target
- for the BPPP monitoring the number of e+e- after the conversion for the wire is well manageable (~100).

BACK UP

GEANT4 SIMULATION FOR THE WIRE CONVERTER

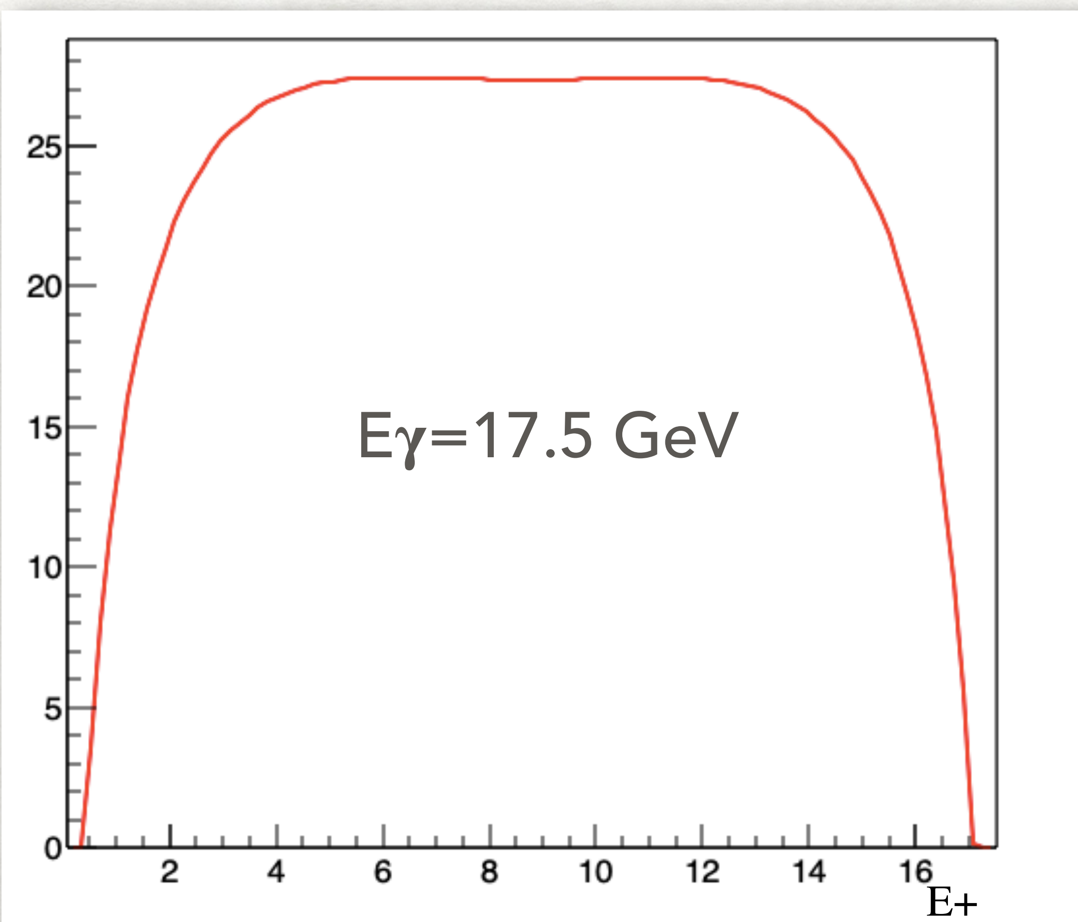


BETHE-HEITLER PAIR SPECTRUM

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 mc²



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