INPUTS & REQUIREMENTS FOR THE FORWARD PHOTON DETECTOR SYSTEM

Borysova Maryna (KINR)

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LUXE weekly technical meetings

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
  - Metal Micro-strip Detector?
- It is possible to decrease the nominal number of e- in a bunch down to 6.0e+7 with special gun tuning

METAL MICRO-STRIP DETECTOR AS A TARGET ?

MMD is a ~1.0 μm thick semi-transparent radiation hard micro-strip detector designed (KINR) for non-destructive online beam profile monitoring

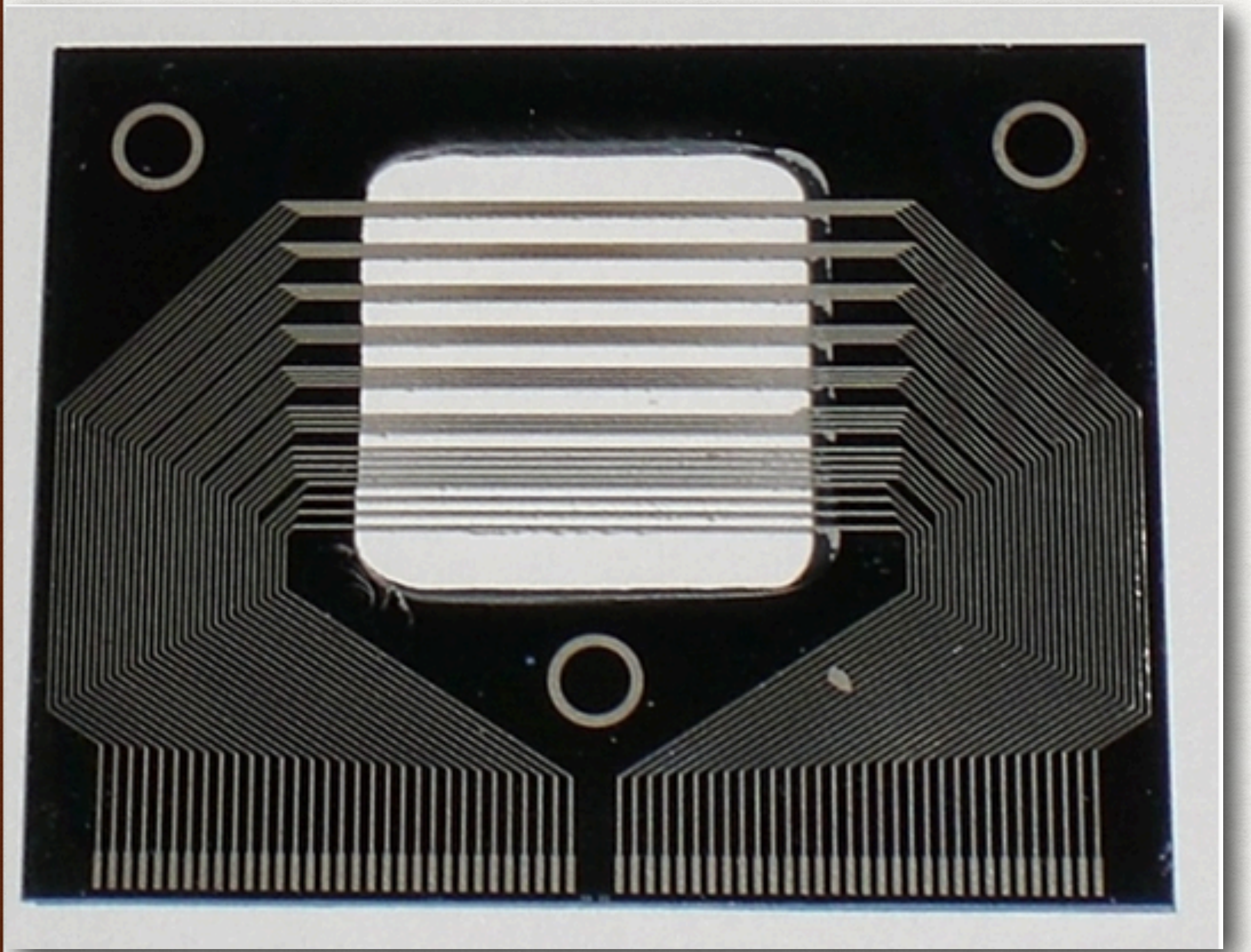


Photo of the MMD with variable pitch (8 groups of strips with pitch varying from 3 to 300 μm)

The current technology allows for production of the thin (~1 μm) Ni-strips with a pitch of ~ few μm, providing high position resolution.

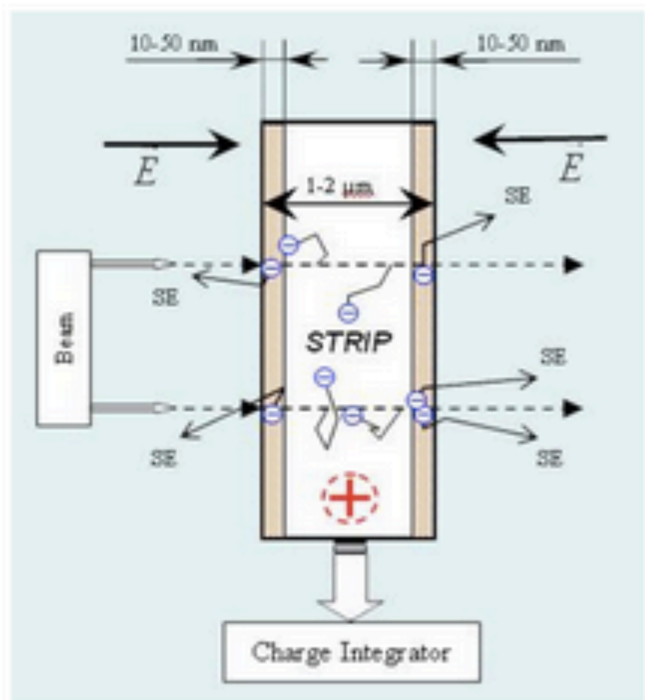
MMD advantages are:

- extremely low thickness of sensor (~ 1 μm) unreachable in other types of micro-detectors;
- high radiation resistance (>100 MGy);
- transparency for charged particle beams (transmittance up to 90%) allows for including MMD into a feedback system for focusing and stabilization of a beam;
- low operational voltage (20 V);
- high spatial resolution (5…25 μm);
- unique, well-developed production technology;
- commercially available read-out hardware and software;

METAL MICRO-STRIP DETECTOR AS A TARGET ?

MMD is a ~1.0 μm thick radiation hard micro-strip detector designed (KINR) for non-destructive online beam profile monitoring

Secondary Electron Emission from the metal surface can be measured and provide information about flux



Signal – positive charge created by the electron emission under the impinging particles.

Conversion factor – electrons/particle: ranges from 0.1 (for MIP) to few hundreds (for the fast Heavy Ion)

Noise – thermoelectric emission, r/f pickup, fluctuation of the leakage current, … Determined by the connecting cable and readout electronics: ENC: (100 – 500) electrons

Thickness – 1 μm (transparent, non-destructive device for the measured beam)

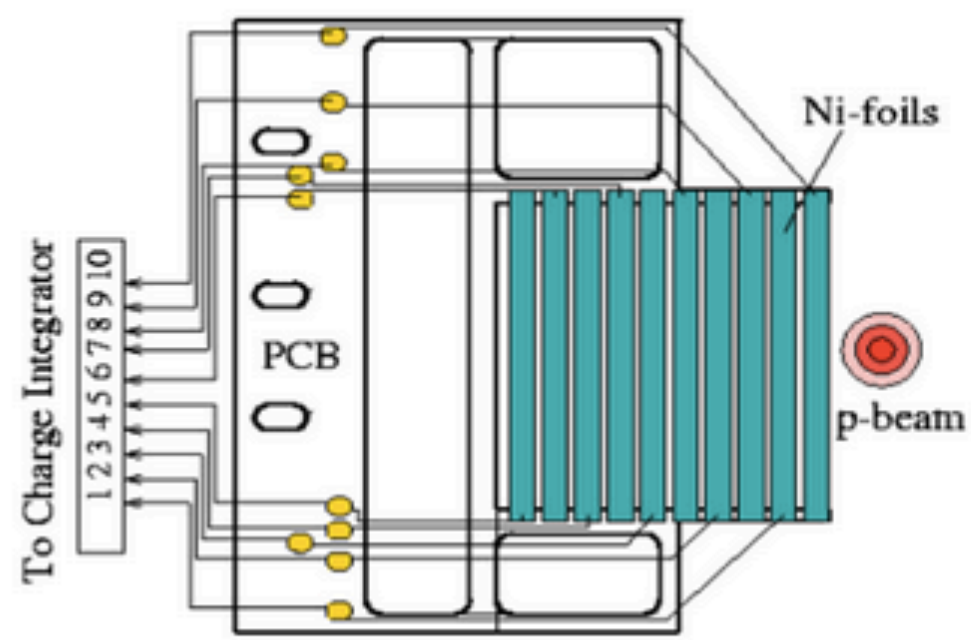
Position resolution – up to 10 μm

This technology works with x-rays, protons and other ion beams!

Radiation hardness - more than 100 MGy

Stable operation at X-ray intensity - up to 10^{16} photons·s^{-1}·mm^{-2}

Stable operation at proton beam intensity - up to 10^{10} protons·s^{-1}·mm^{-2}



Low operation voltage (20 V)

Average Power and Radiation Heat:

ABSORBER: W, 35UM FOIL

$$I_{ave}(q_t, \nu_t) := q_t \cdot \nu_t$$

$$P_{ave}(q_t, \nu_t, d) := E_{specmin} \cdot \rho \cdot d \cdot \frac{I_{ave}(q_t, \nu_t)}{e}$$

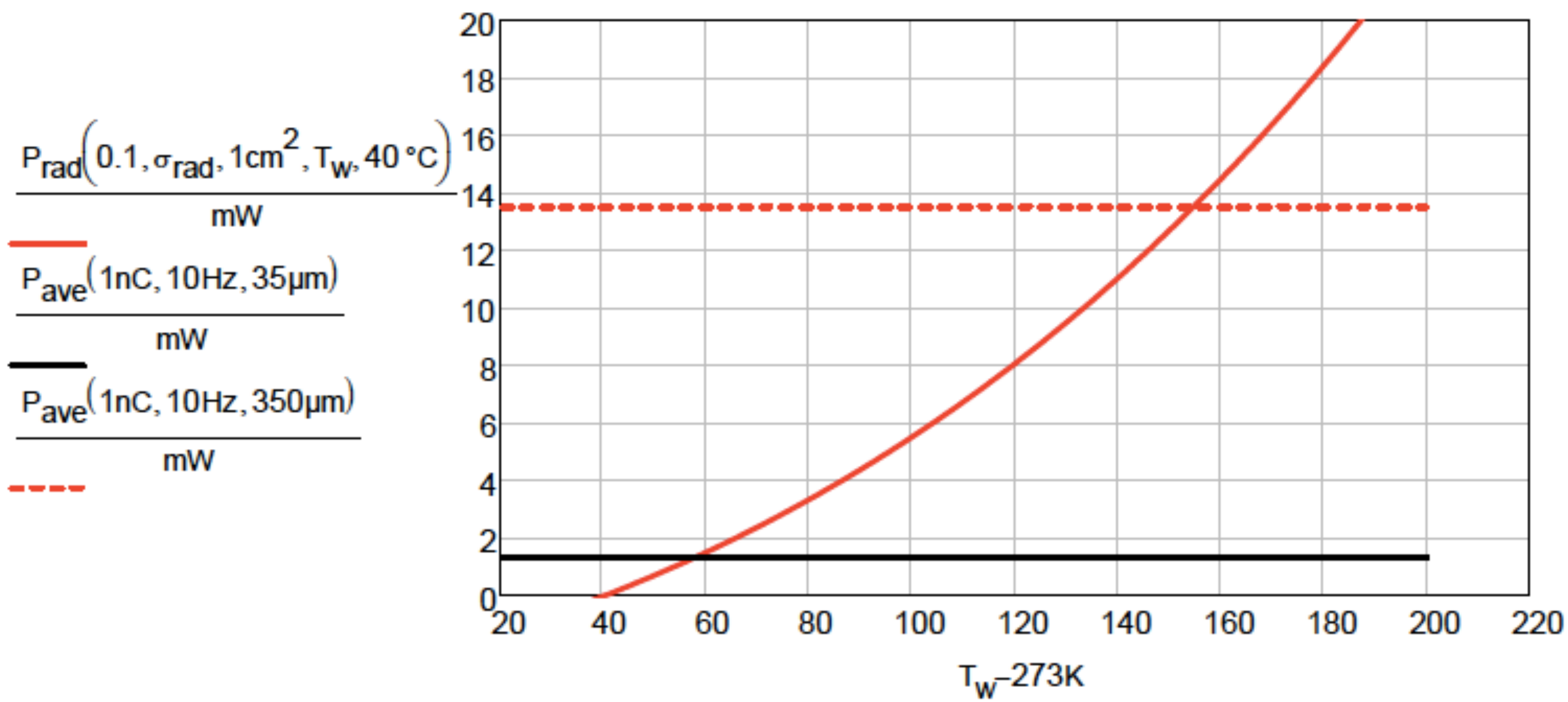
average power introduced by the beam

$$P_{ave}(1nC, 10Hz, 35\mu m) = 1.351 \cdot mW$$

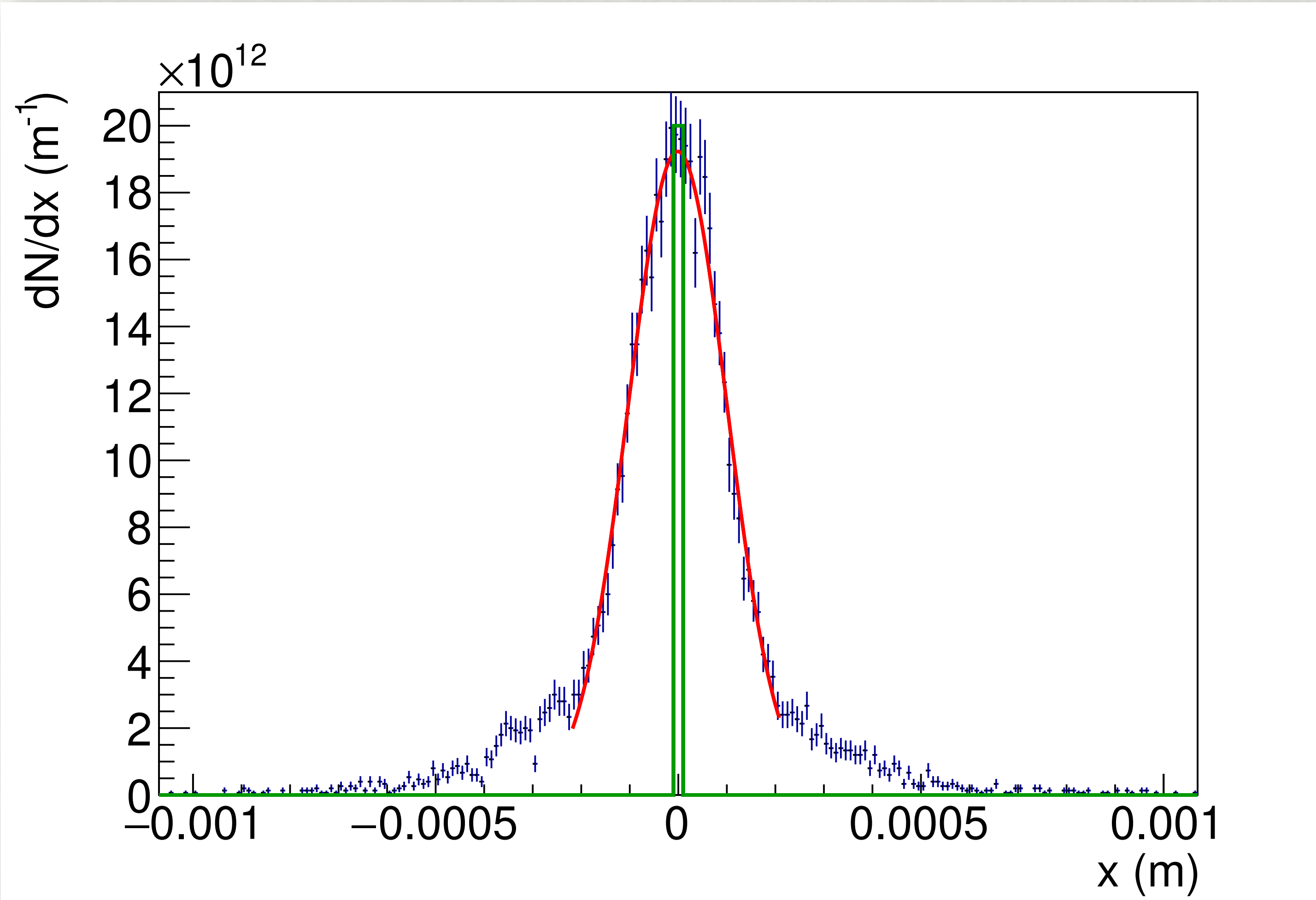
$$\sigma_{rad} := 5.67 \cdot 10^{-8} \cdot \frac{W}{m^2 \cdot K^4}$$

$$P_{rad}(\varepsilon_W, \sigma_{rad}, A_W, T_W, T_{amb}) := \varepsilon_W \cdot \sigma_{rad} \cdot A_W \cdot \left(T_W^{\,4} - T_{amb}^{\,4}\right)$$

$$T_W := 20\,°C, 21\,°C .. 200\,°C$$



TOTAL ENERGY DEPOSIT



$$\Delta T(r) = \frac{dQ}{\rho c_p dV}$$

$T_{MELTING}$ =1726K FOR NI
TOTAL ENERGY DEPOSIT PER ABSORBER PER EVENT:
FOR NI WIRE, ⊘ 1 μM, ΔT ~10^{-8} K

	NI, 1UM	W, 1UM	NI, 10UM
BEAM	E_{DEP},EV	E_{DEP},EV	E_{DEP},EV
MONO	0.05	0.39	5.92
MC	$4*10^{-4}$	$9.5*10^{-3}$	

NI, 10UM	E_{DEP},EV	E_{DEP},EV
MONO, WIRE	5.9	
MC, FOIL		5.92

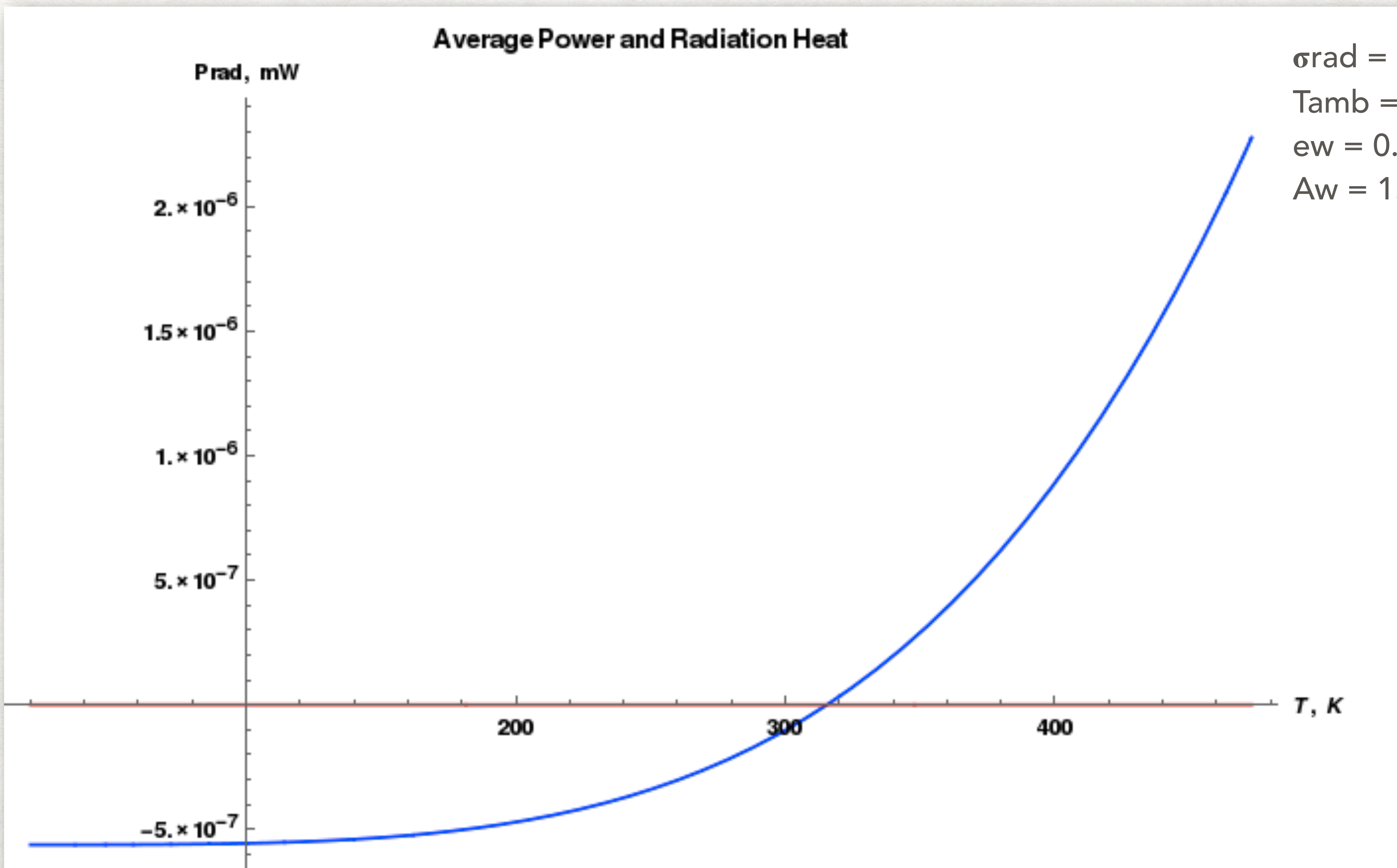
AVERAGE POWER AND RADIATION HEAT

Pave(qt ,vt ,d)=dE/dx*ρ*d*Ngamma*vt

dE/dx= 4.125*10^-7 MeV*cm^2/g (* Mono beam 5.86*10^-05 MeV*cm^2/g*)
Ngamma = 4.8*10^6
Pave(Ngamma, 10Hz ,1 μm) =2.8*10^-12 mW

ABSORBER: NI, 1UM WIRE

$$P_{rad}(\varepsilon_w, \sigma_{rad}, A_w, T_w, T_{amb}) := \varepsilon_w \cdot \sigma_{rad} \cdot A_w \cdot \left(T_w^4 - T_{amb}^4\right)$$



σrad = 5.67*10^-8 (*W/m^2*K^4*)
Tamb = 315.5(*K*)
ew = 0.1
Aw = 1.0*10^-4 (*m^2*)

WHAT'S DONE & WHAT'S NEXT

- Preliminary studies of the feasibility of usage Ni wire as converter target. For nominal XFEL beam the ξ =0.1, 10 m from IP, the number of ~1e2-1e3.
- the beam dissipated power in 1μm thick Ni-foil can be easily extracted via radiation.When the wire has about 1e-4 m^2 in area with >0.1 absorption coeff, its temperature will stay at 40°C in an ambient vacuum system of 40°C chamber temperature.
- To study SEE in Geant4

BACK UP

PHOTONS FROM MC

Instantaneous Hetas and tolerable Limit:

ABSORBER: W, 35UM FOIL

$Q_{spec}(T1, T2) := c_V \cdot (T2 - T1)$

$Q_{spec}(20\,°C, T_{melt}) = 450.24 \cdot \frac{J}{g}$

$tol\Delta T_{inst} := (1 - \nu) \cdot \frac{\sigma_{02}}{\alpha \cdot E}$

$tol\Delta T_{inst} = 180.282\,K$

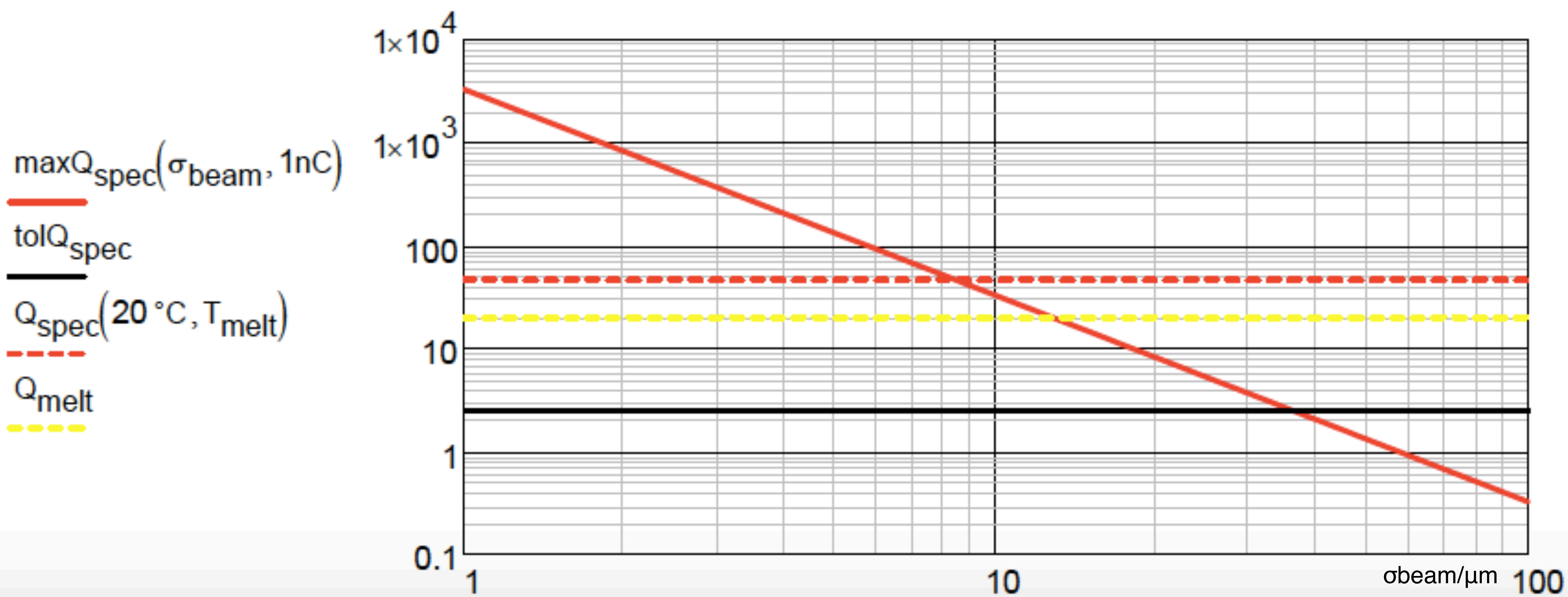
$tolQ_{spec} := c_V \cdot tol\Delta T_{inst}$

$tolQ_{spec} = 24.158 \cdot \frac{J}{g}$

$maxQ_{spec}(\sigma_{beam}, q_t) := E_{specmin} \cdot \frac{q_t}{e} \cdot \frac{1}{2\pi \cdot \sigma_{beam}{}^2}$

$maxQ_{spec}(10\mu m, 1nC) = 318.31 \cdot \frac{J}{g}$

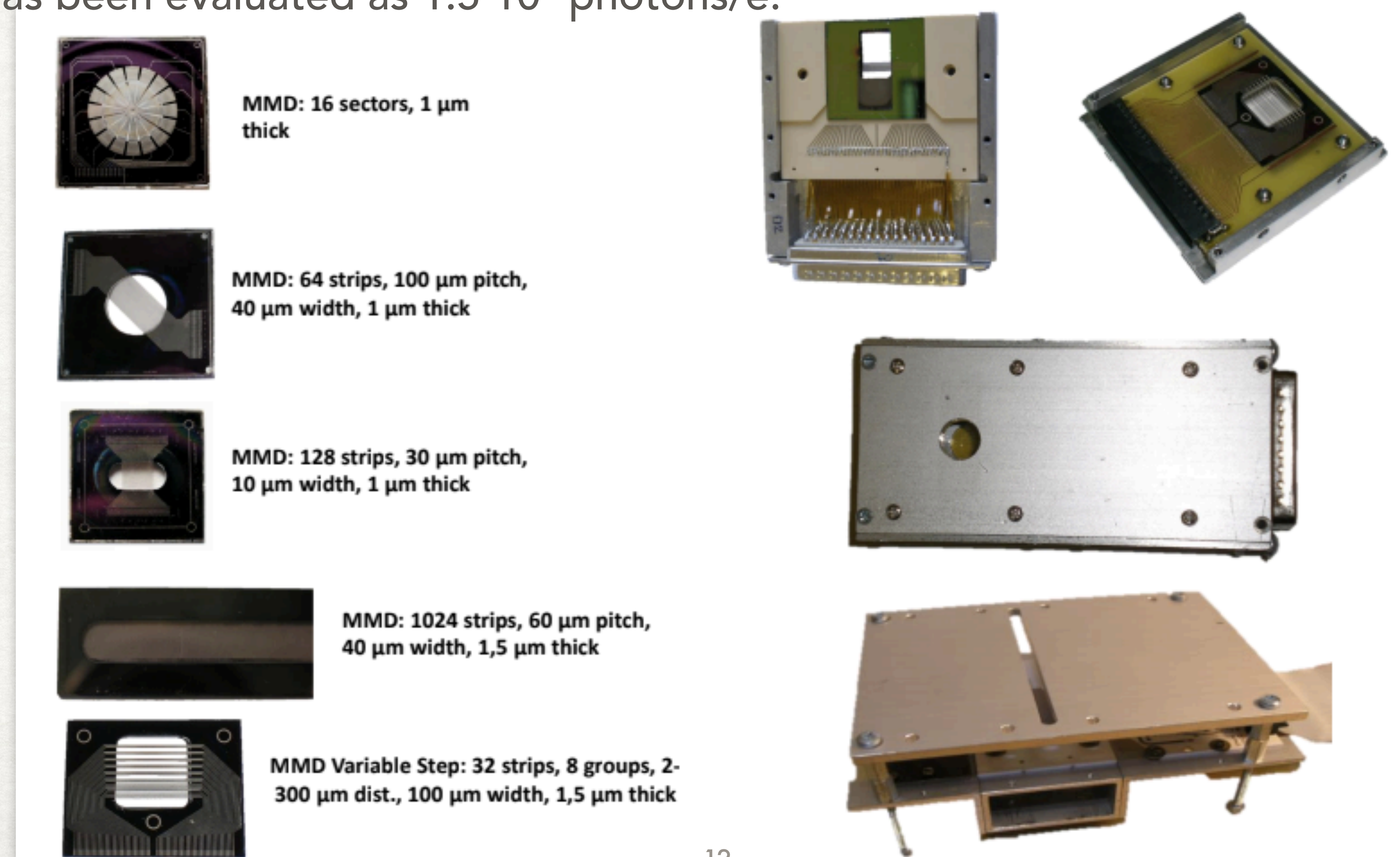
$\sigma_{beam} := 1\mu m, 2\mu m .. 100\mu m$



TESTS

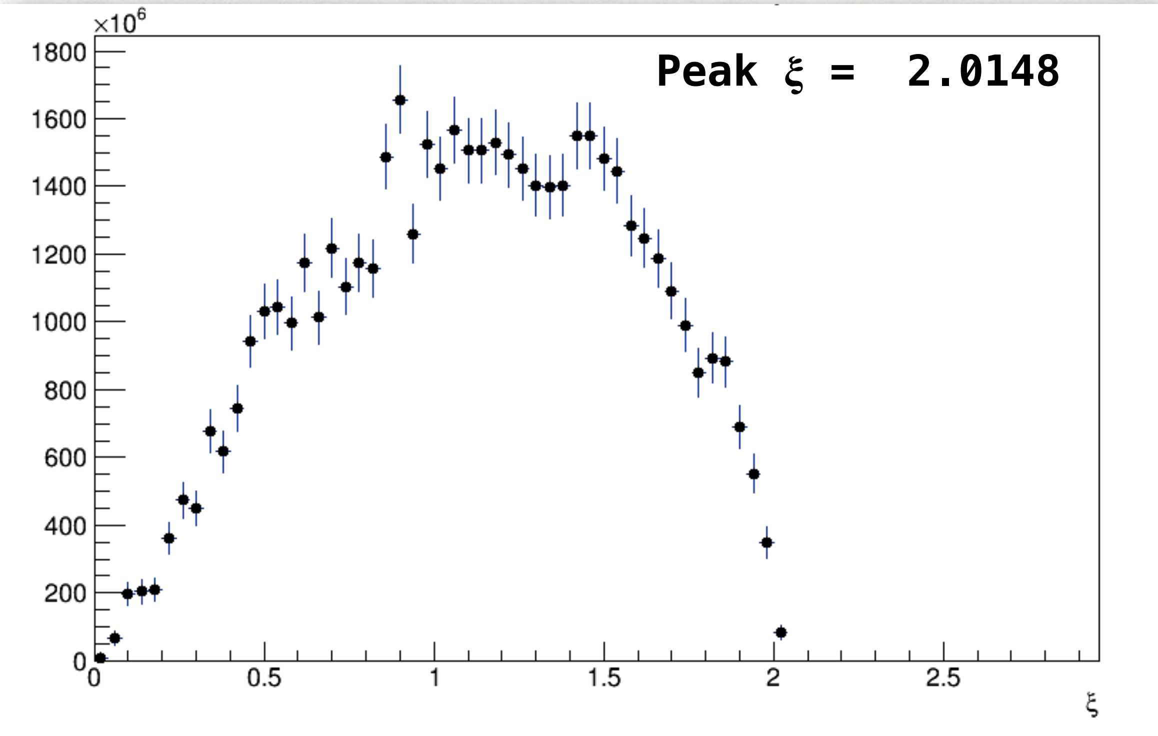
32 MeV alpha-particles beam at Tandem generator for single events upset studies of the BEETLE chip (MPIfK, Heidelberg)

The MMD was applied successfully for the X-rays beam profile monitoring at HASYLAB (DESY, Hamburg) [4]. MMD (32 Ni strips, 70 μm pitch, 2 μm thickness) has been introduced into the 15 keV X-ray beam ($4.5 \cdot 10^{14}$ photons/second/mm2). The conversion factor has been evaluated as $1.5 \cdot 10^{4}$ photons/e.

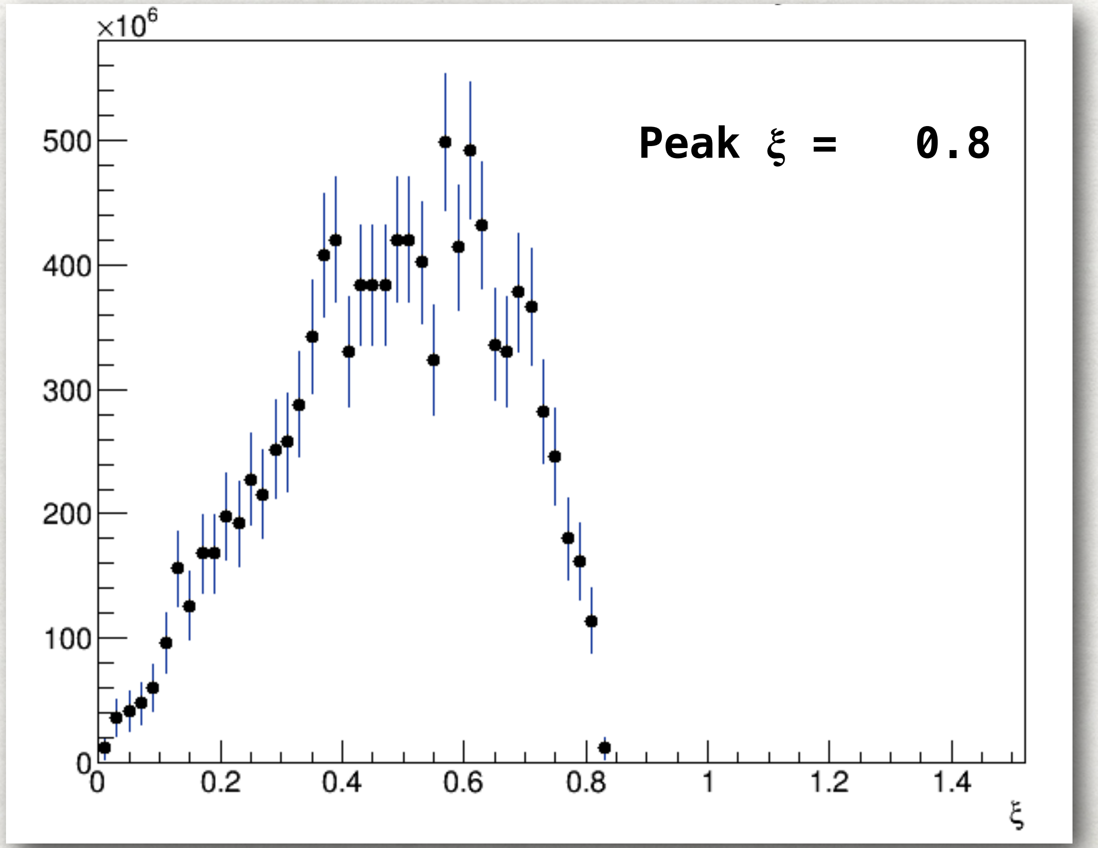


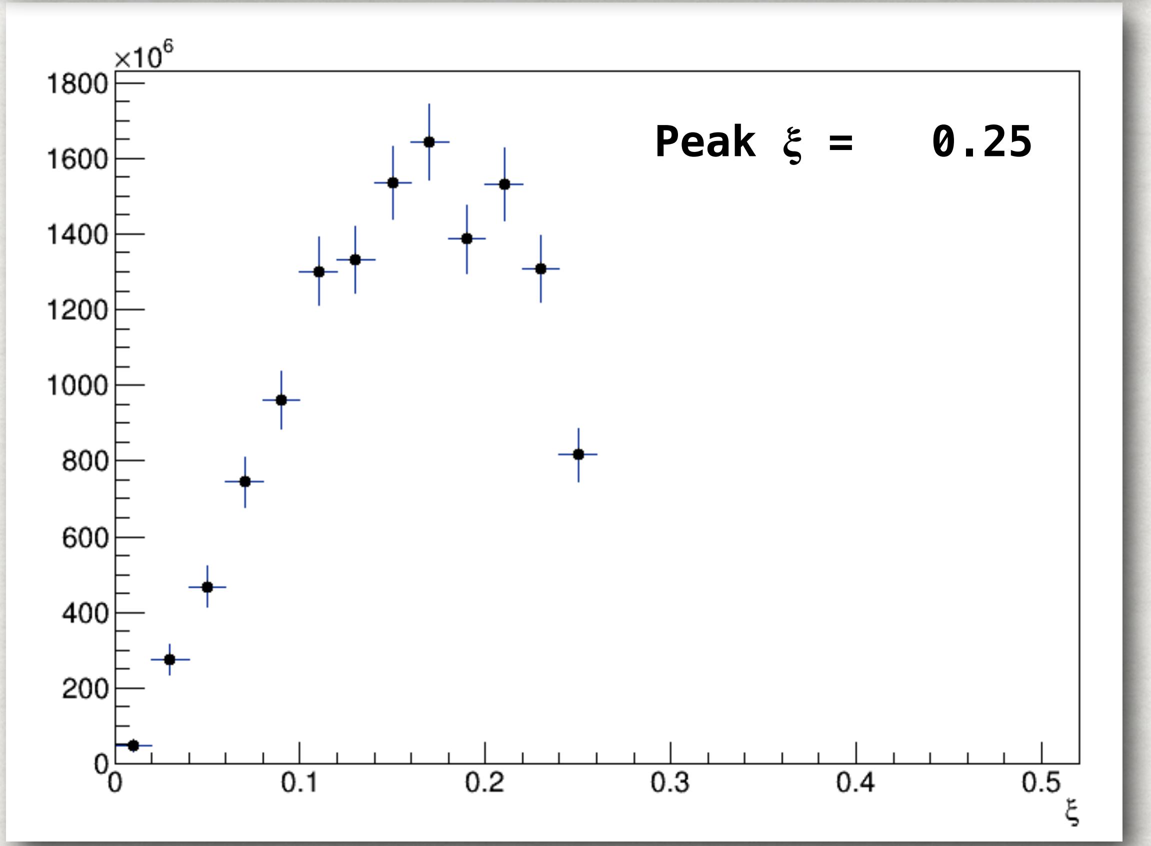
LASER INTENSITY

MC simulation provides information for ξ for each individual interaction

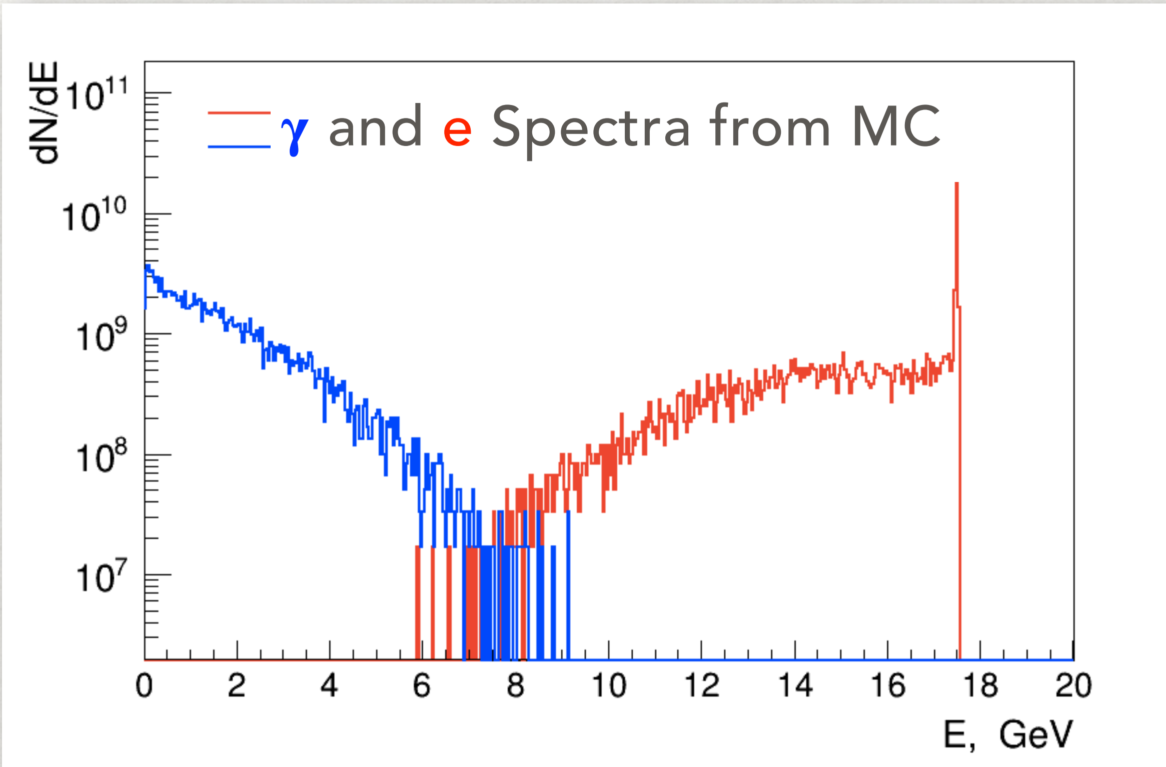


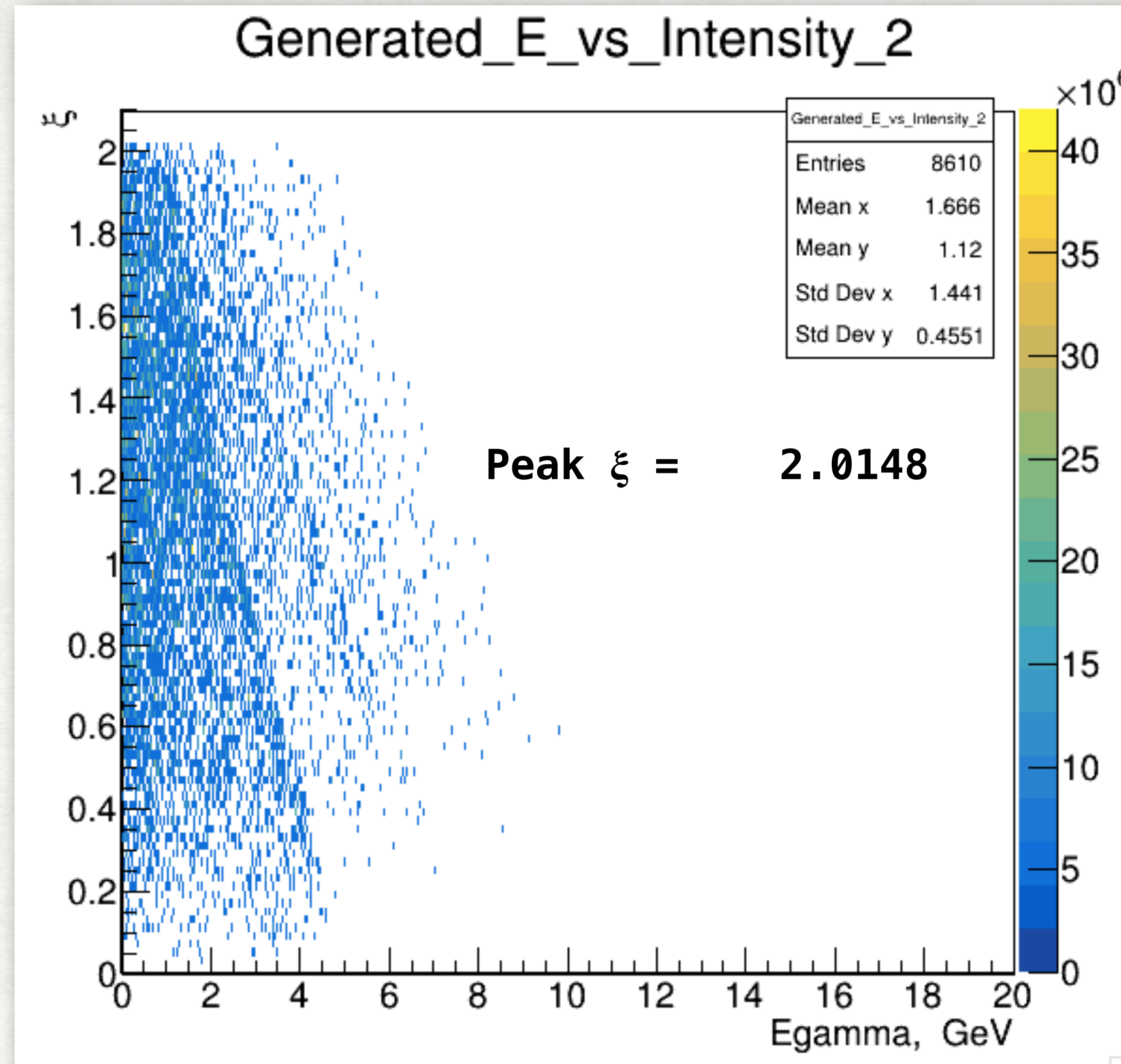
- Realistic simulation of laser pulse intensity distribution.
- The field is not the same across the laser pulse.



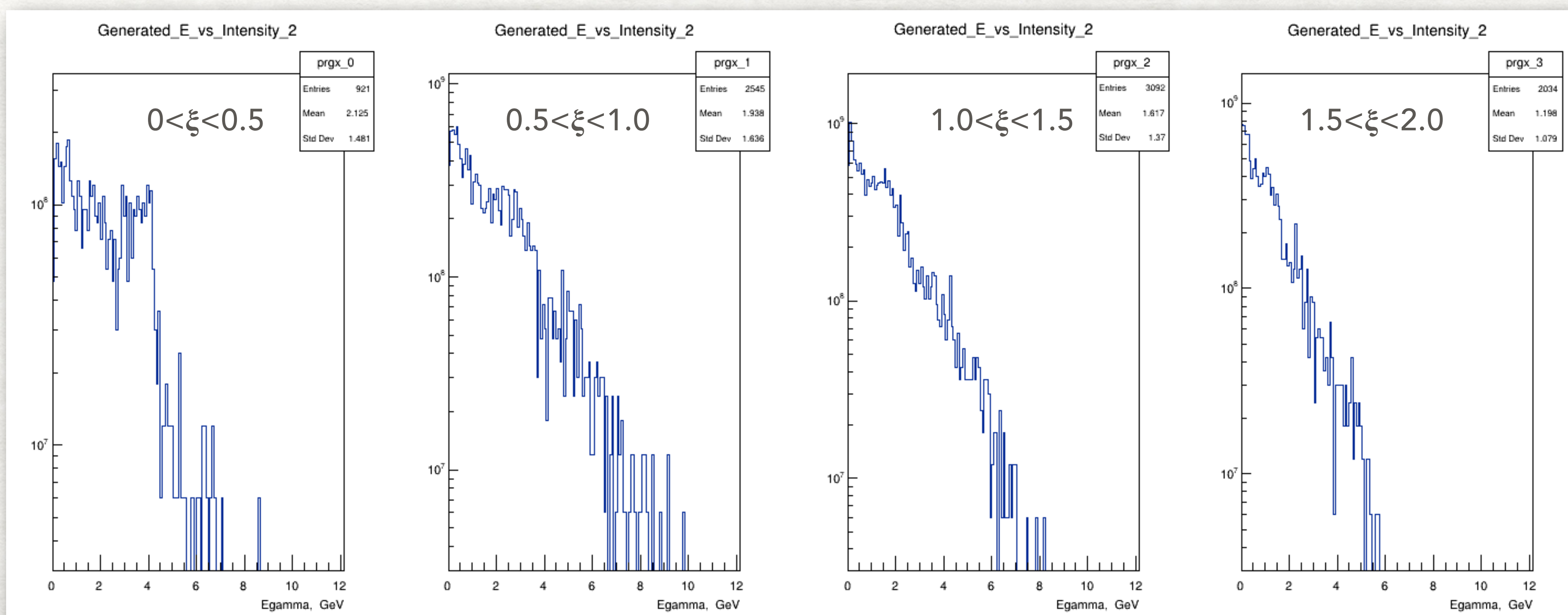


ξ VS Eγ FROM MC





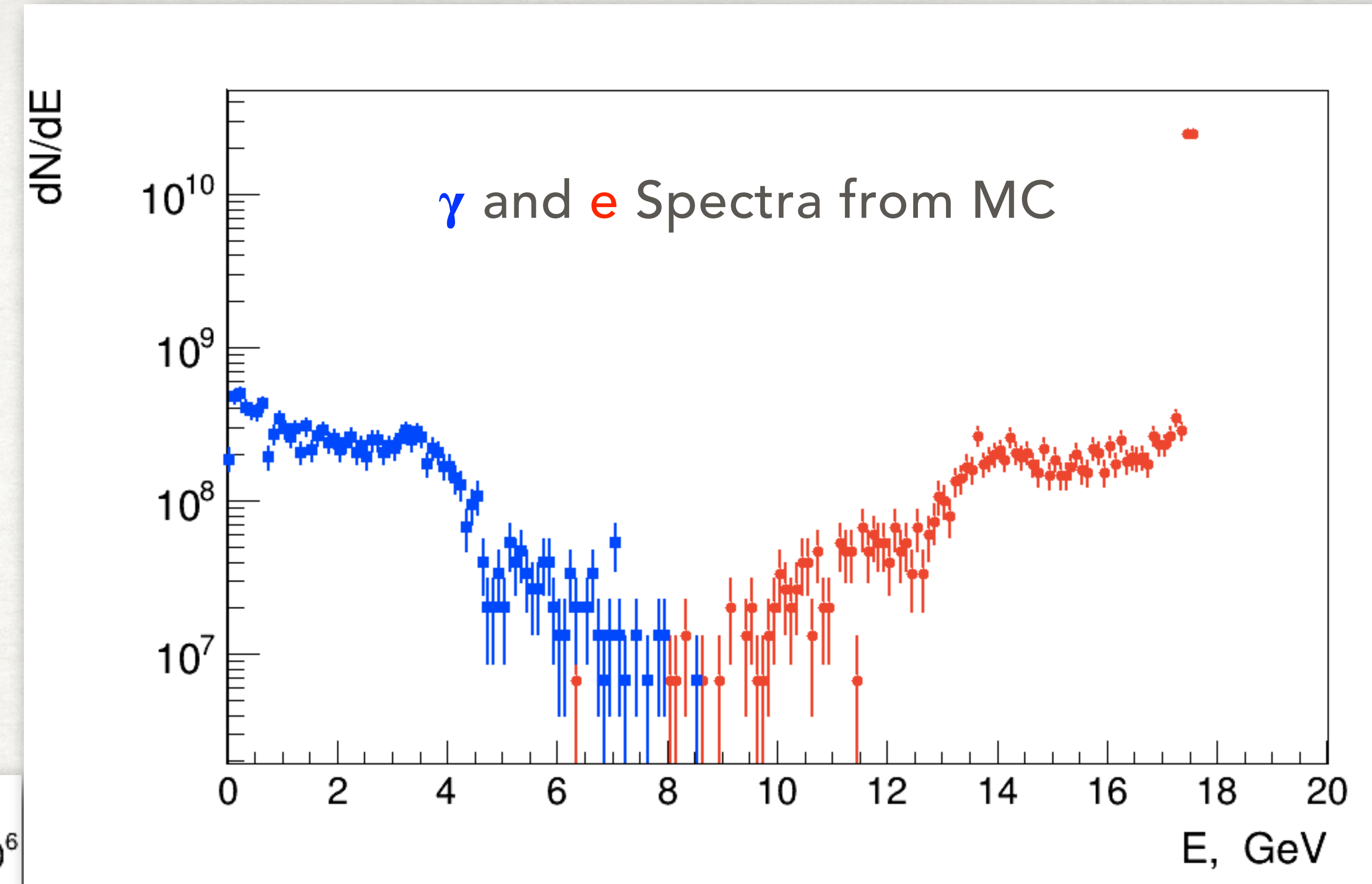
- Laser Intensity (ξ) is not uniform
- This makes the kinematic edges from different *n* not visible
- ξ distribution might be reconstructed by fitting measured spectra w/ convolution of HICS xsection & ξ trial distribution

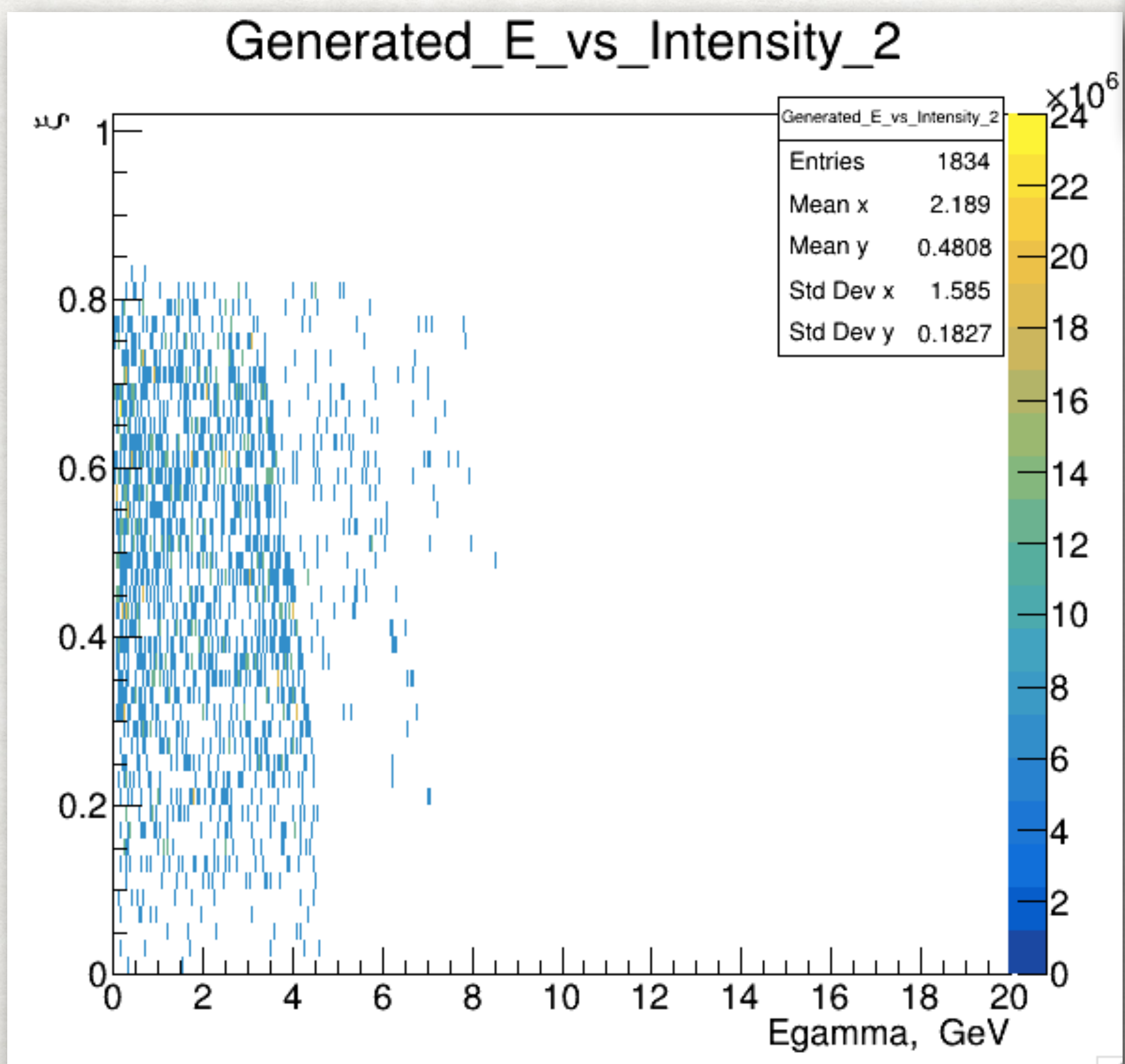


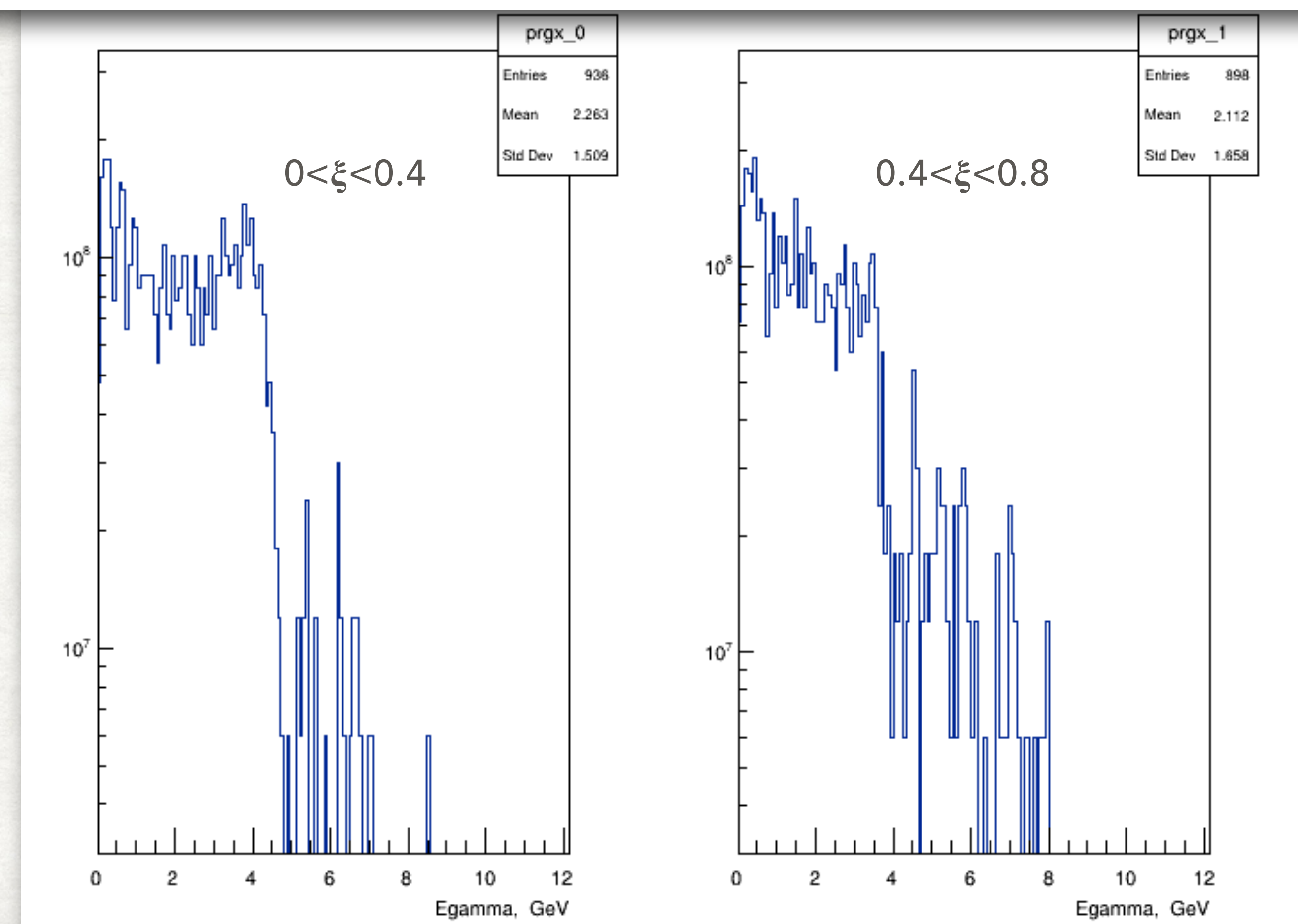
ξ VS Eγ FROM MC

Peak ξ = 0.8

The kinematic edges can be seen at the low intensity.



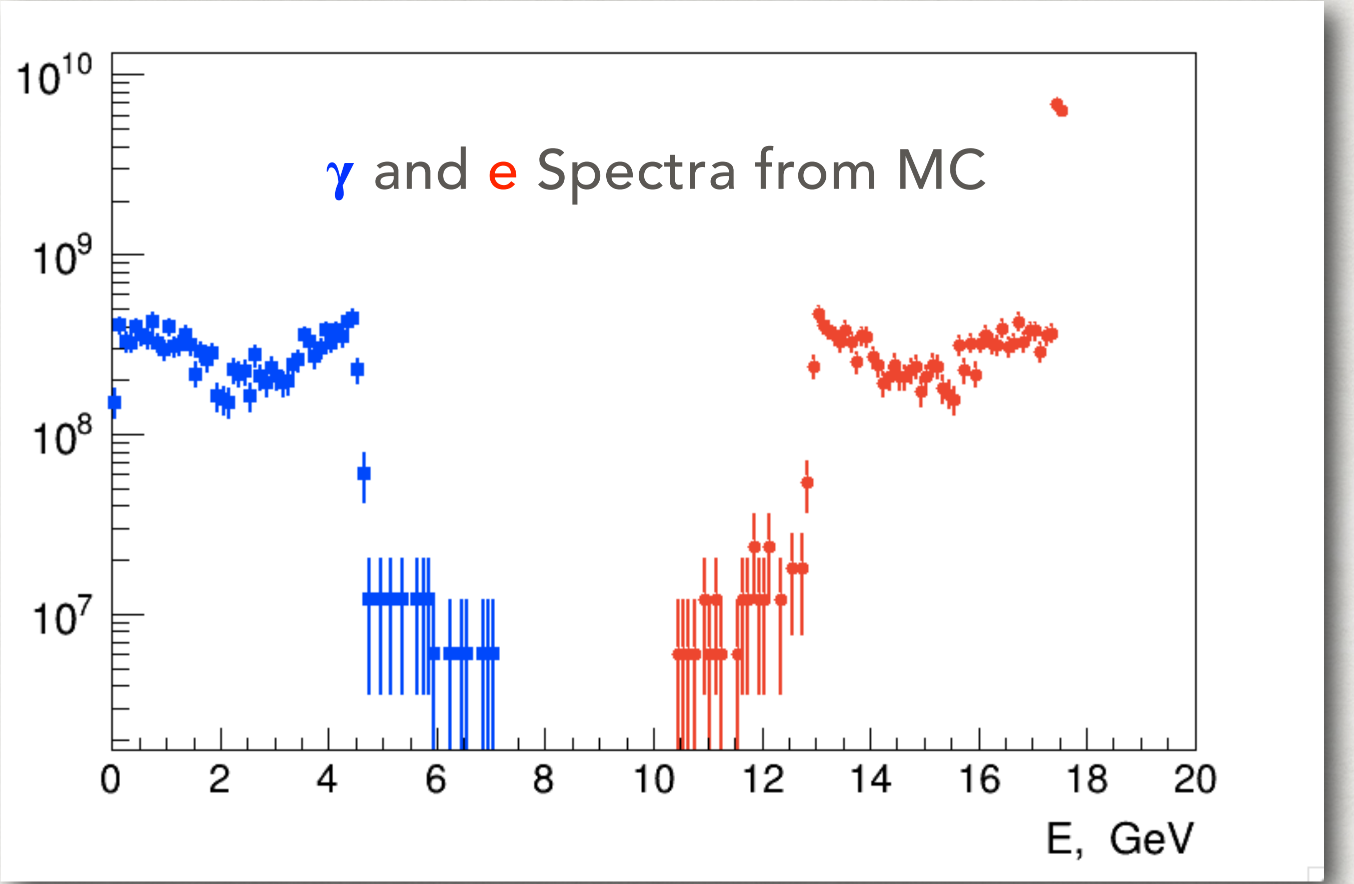


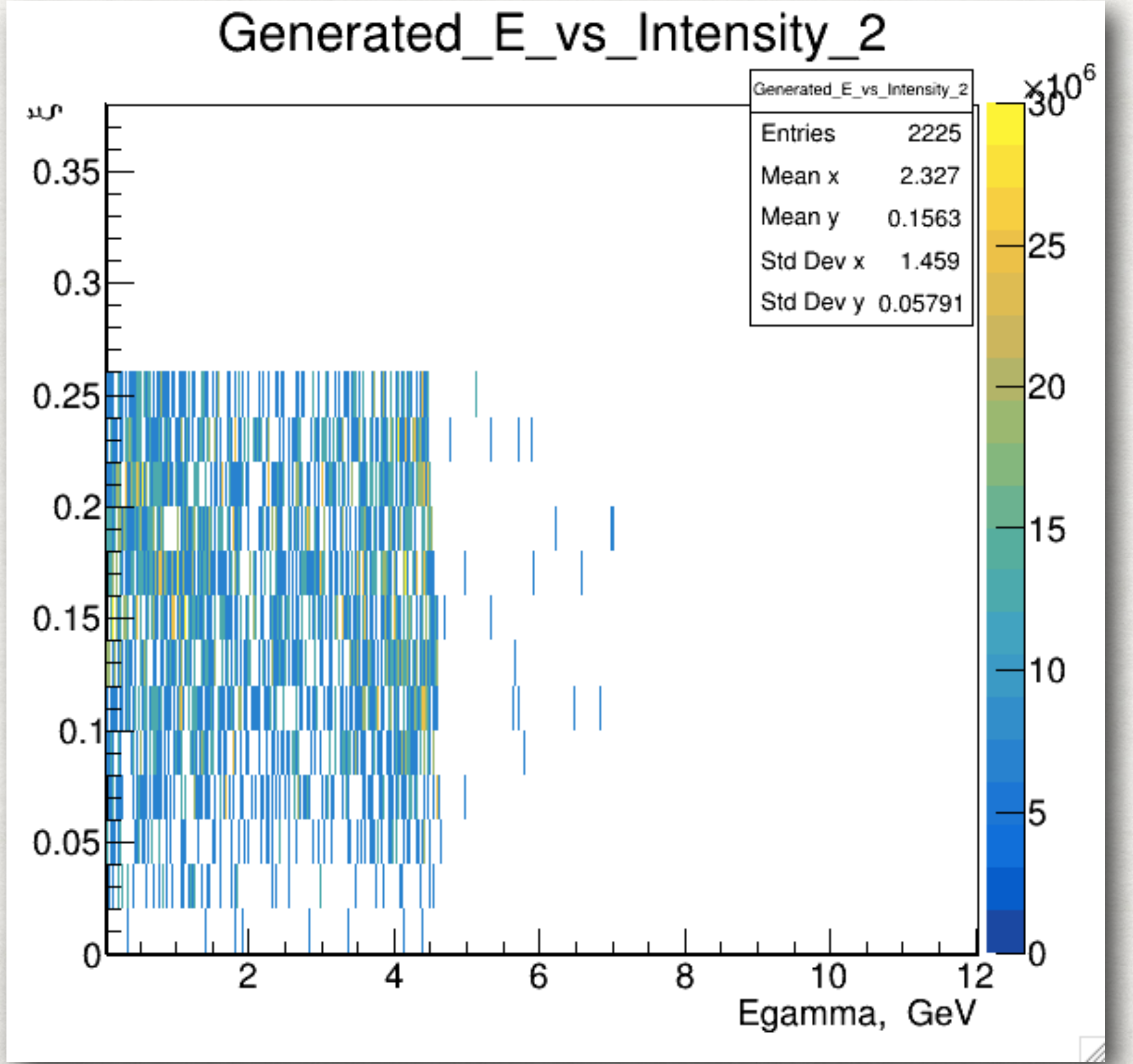


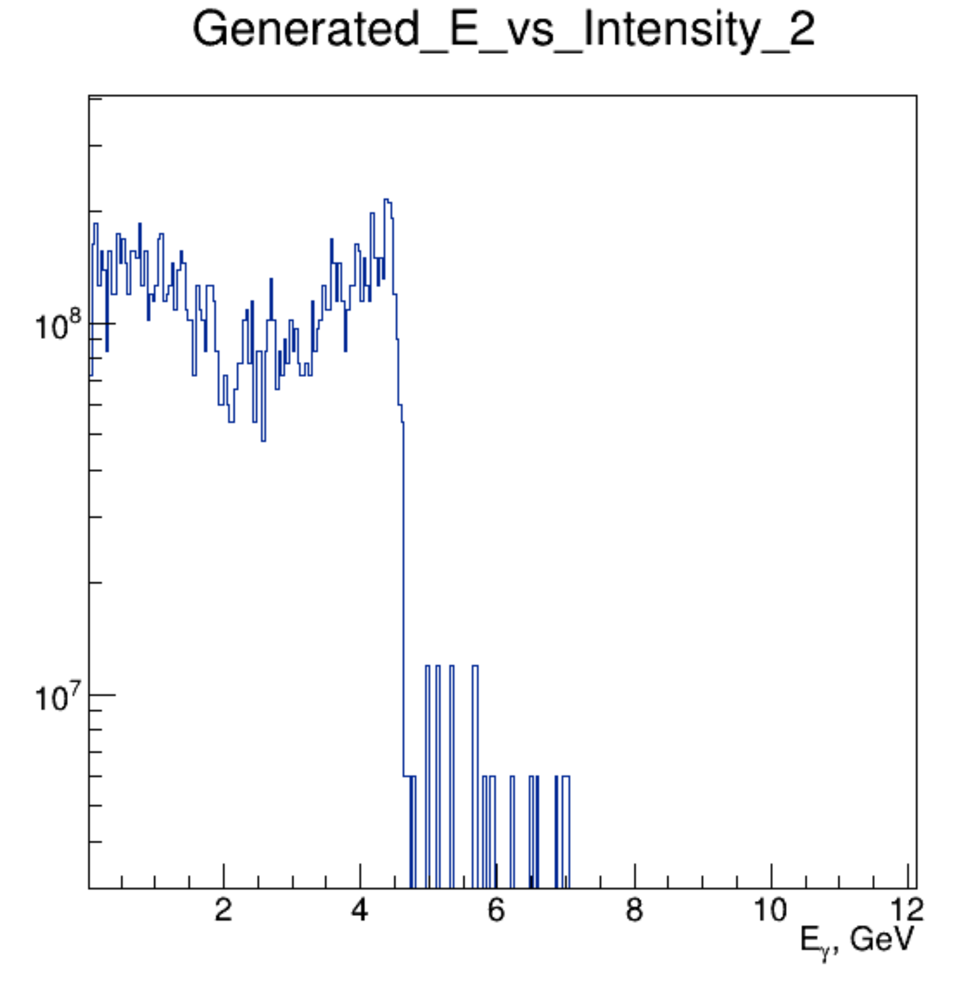
ξ VS Eγ FROM MC

Peak ξ = 0.25
0.01 J

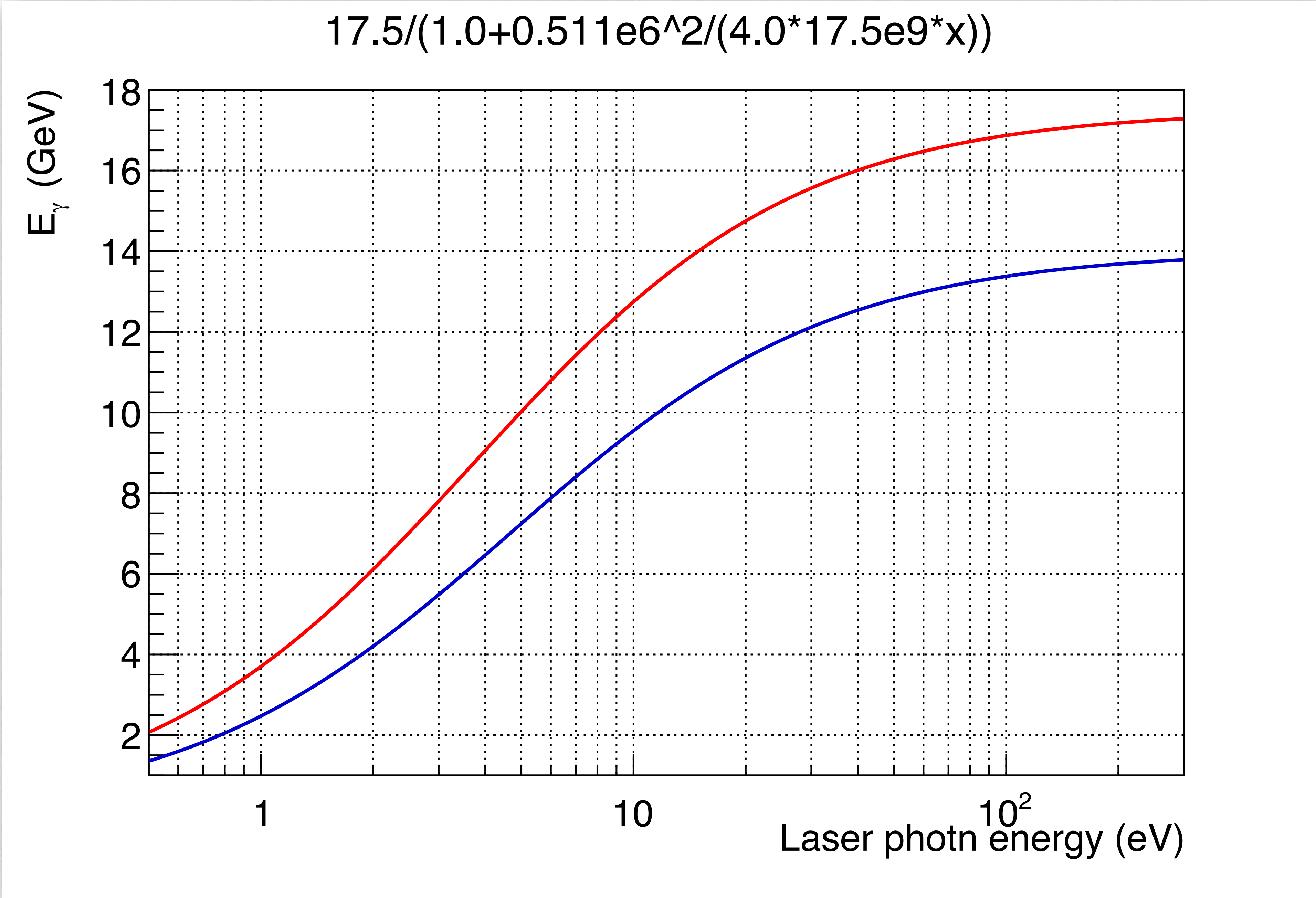
The first kinematic edge is seen very profoundly but higher n are not seen at all







COMPTON EDGE FROM CALCULATIONS



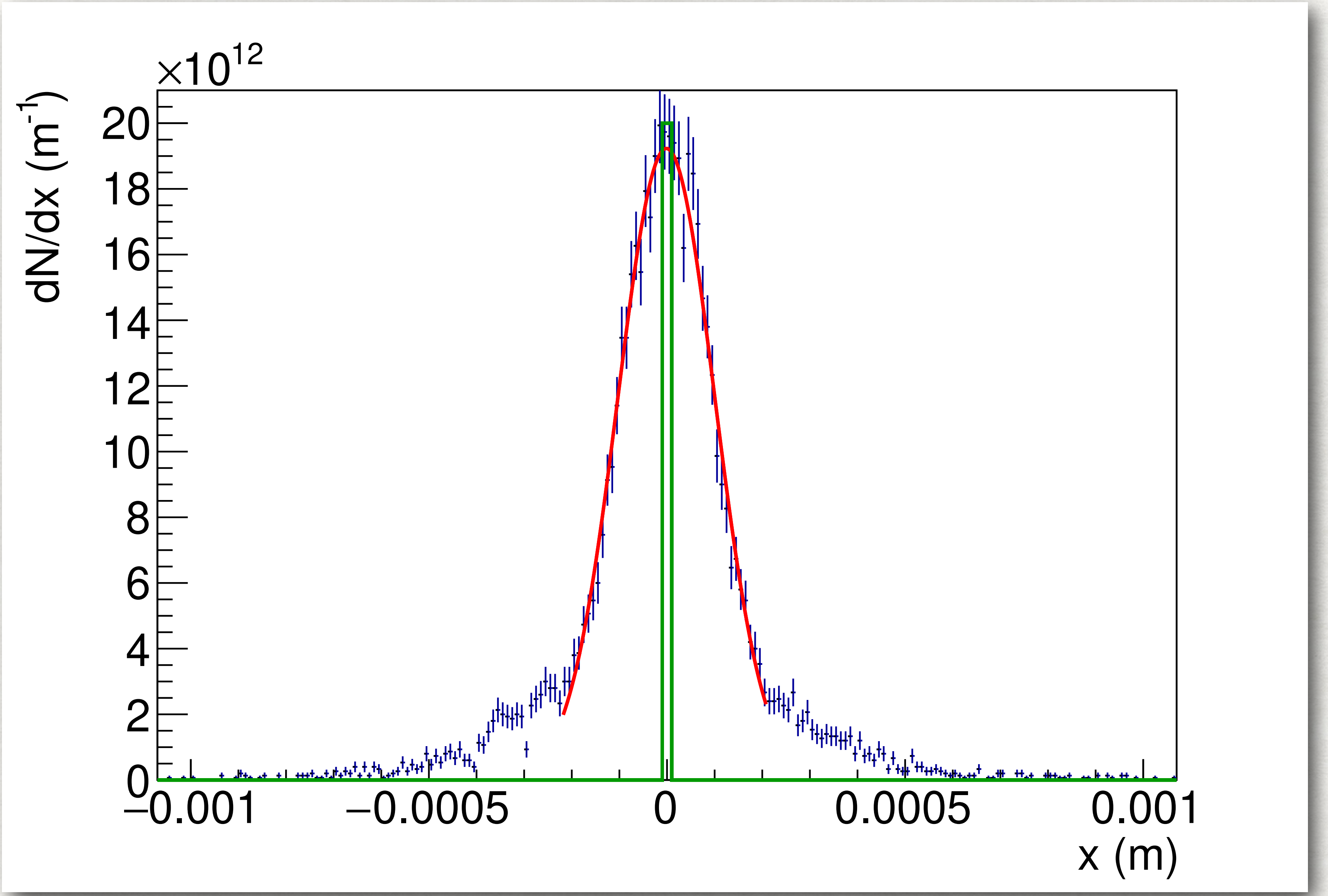
For 800nm laser: Copmton edge ~ 5.137019 GEV

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).

N OF PHOTONS FROM MC

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

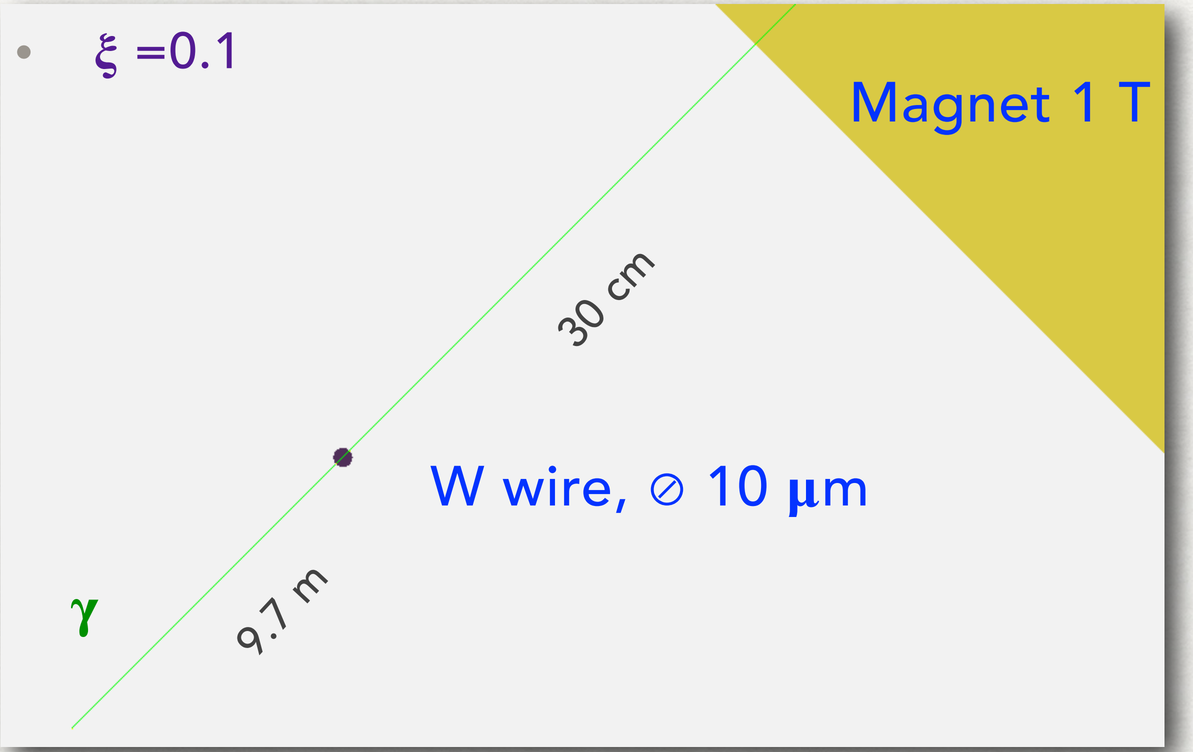


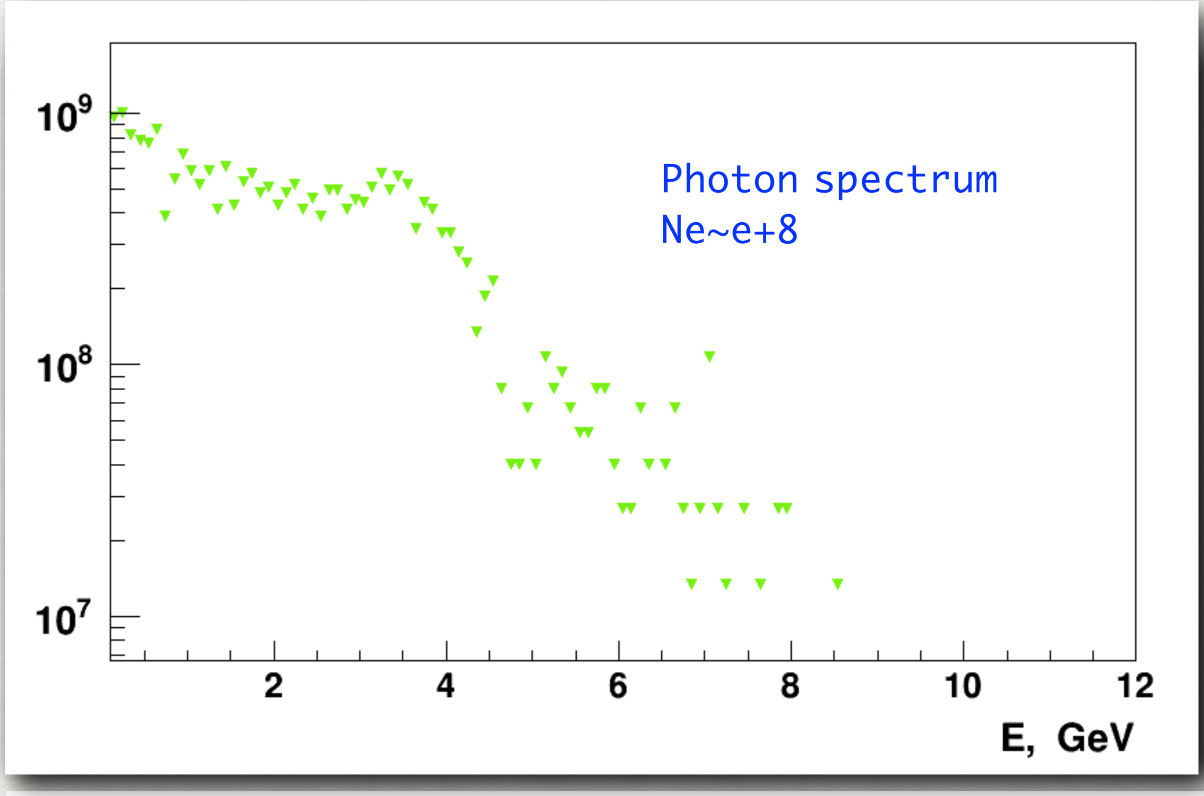
Ngamma in case of wire	
ξ	Nγ
0.1	5E+05

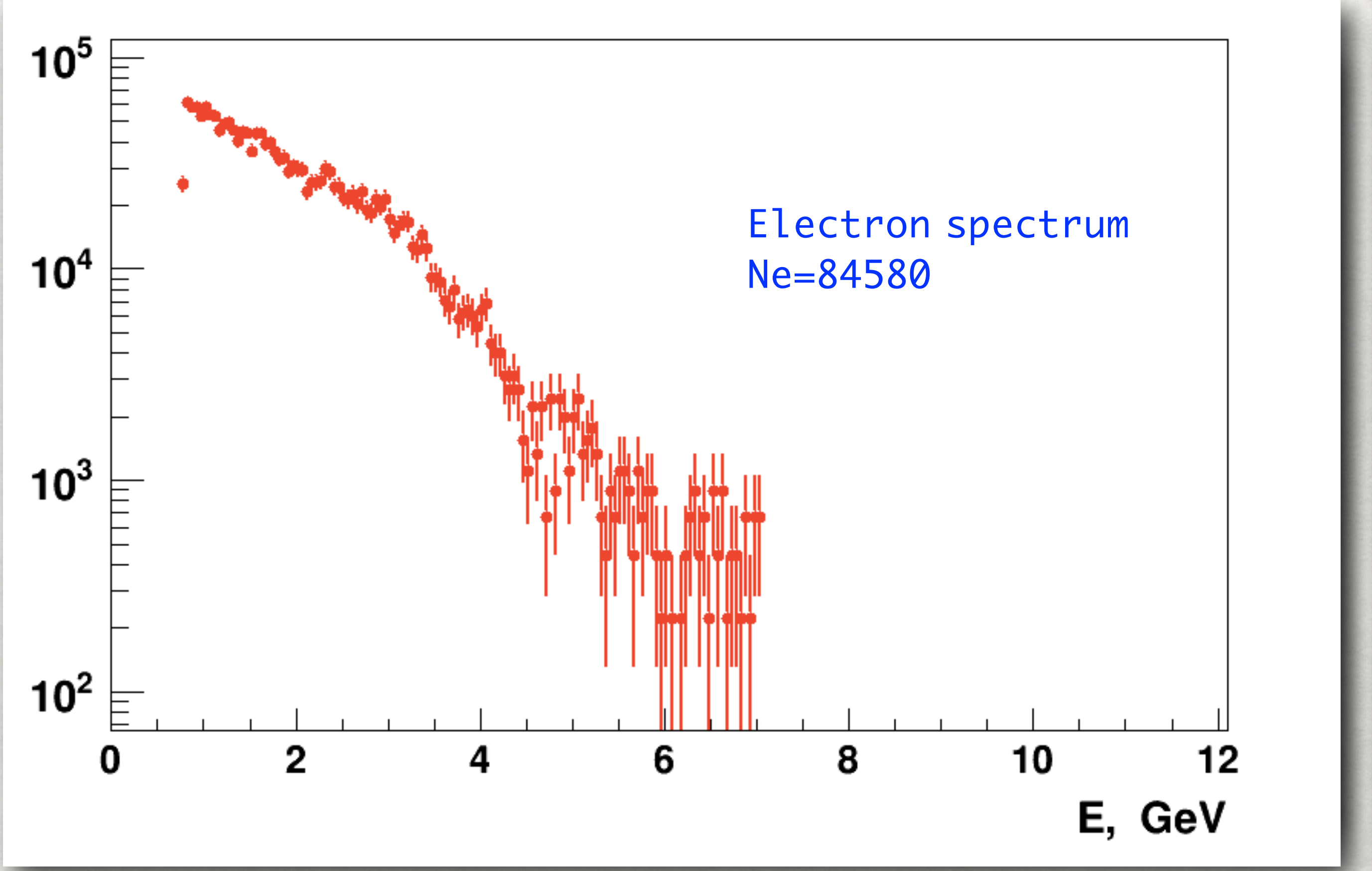
less but still a lot

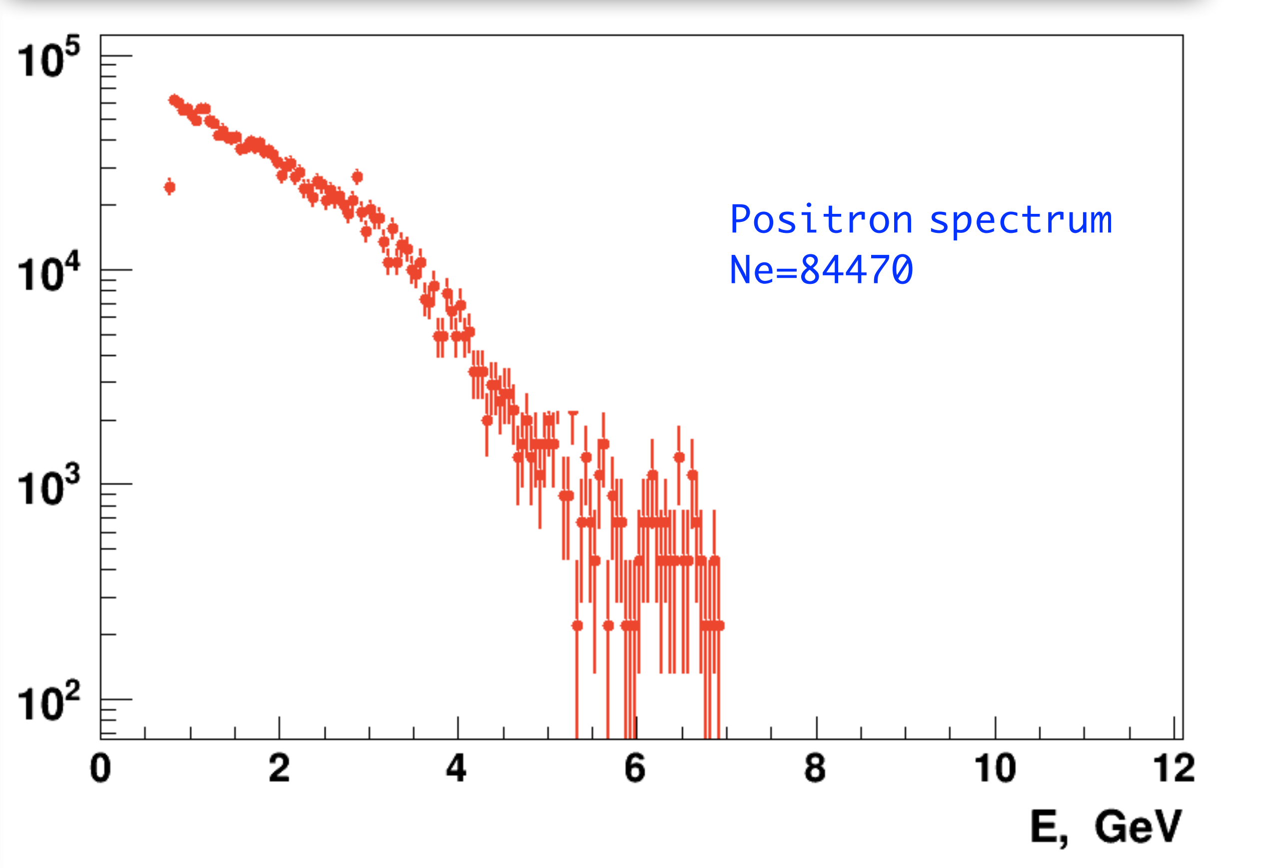
Ngamma in case of foil		
ξ	1e 35 fs (1BX)	Nγ
0.5	2.39	1.49255E+10
1	8.43	5.26758E+10
1.5	16.29	1.01825E+11
2	24.41	1.52579E+11

GEANT4 SIMULATION FOR THE WIRE CONVERTER

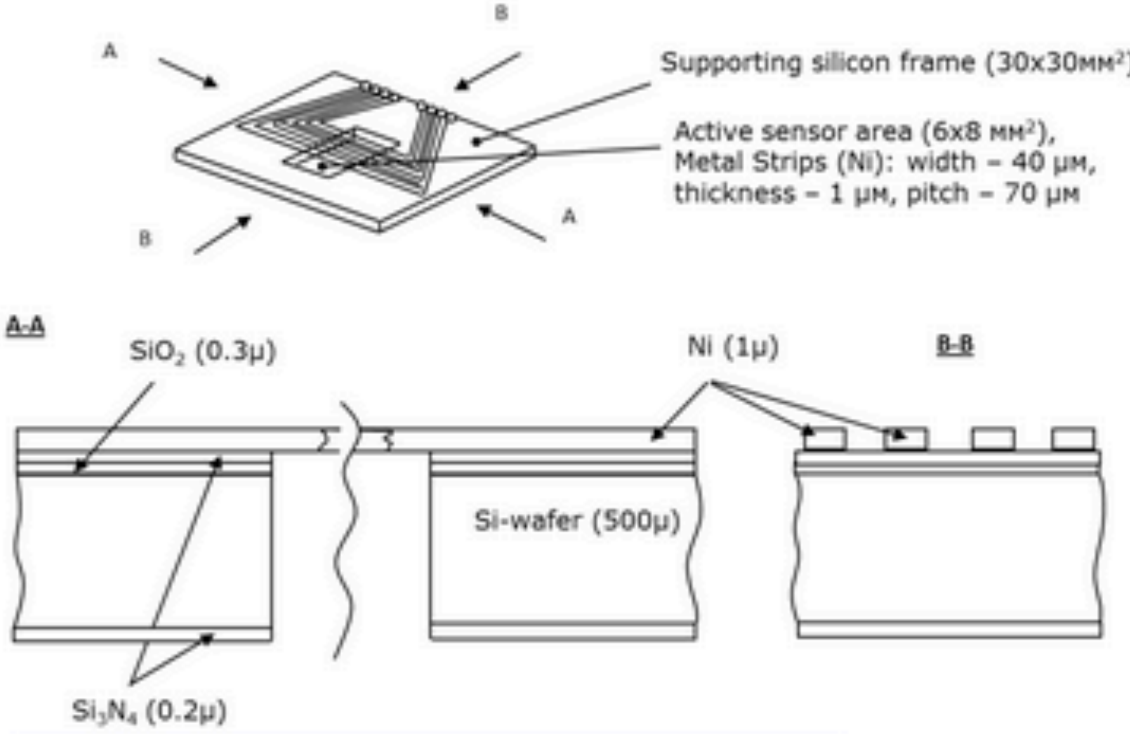


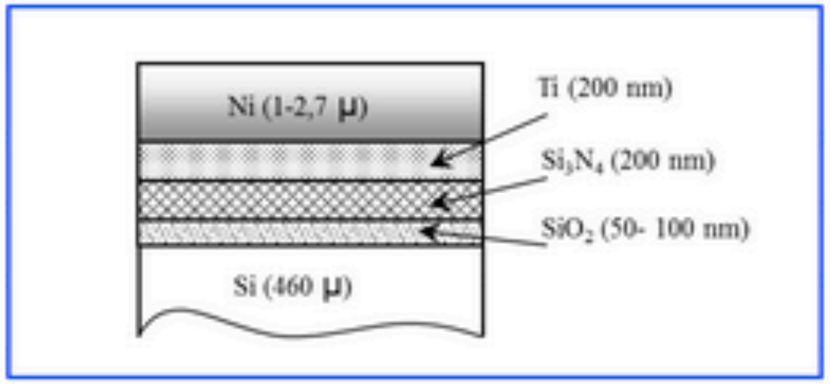


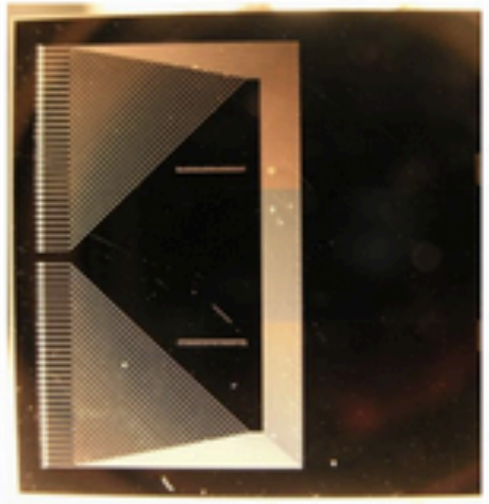


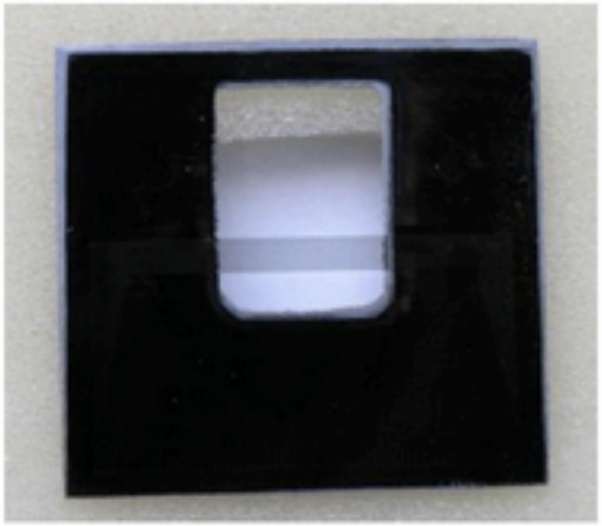


Production technology









PRODUCTION TECHNOLOGY

The sensors were prepared by means of microelectronics technology and plasma-chemistry etching. Nickel layers served as films for the photo-lithography shaping of the strip pattern as well as contacting lines and pads. From the back side of the sensor a window was created for the plasma-chemistry etching. The KINR plasma-chemical reactor with variable ion energy has been used.

The strips were bonded to the ceramics based pitch adapter and connected by a flexible kapton isolated cable to the 50-pin connector.

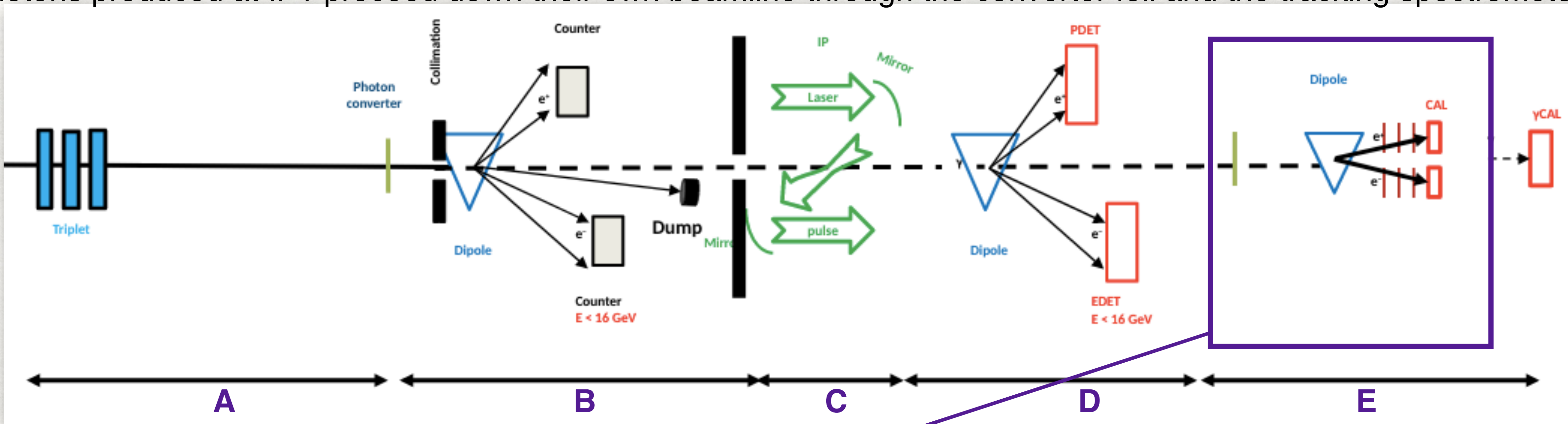
Metal strip sensor is the only object interacting with the radiation beam in the working area

OUTLINE

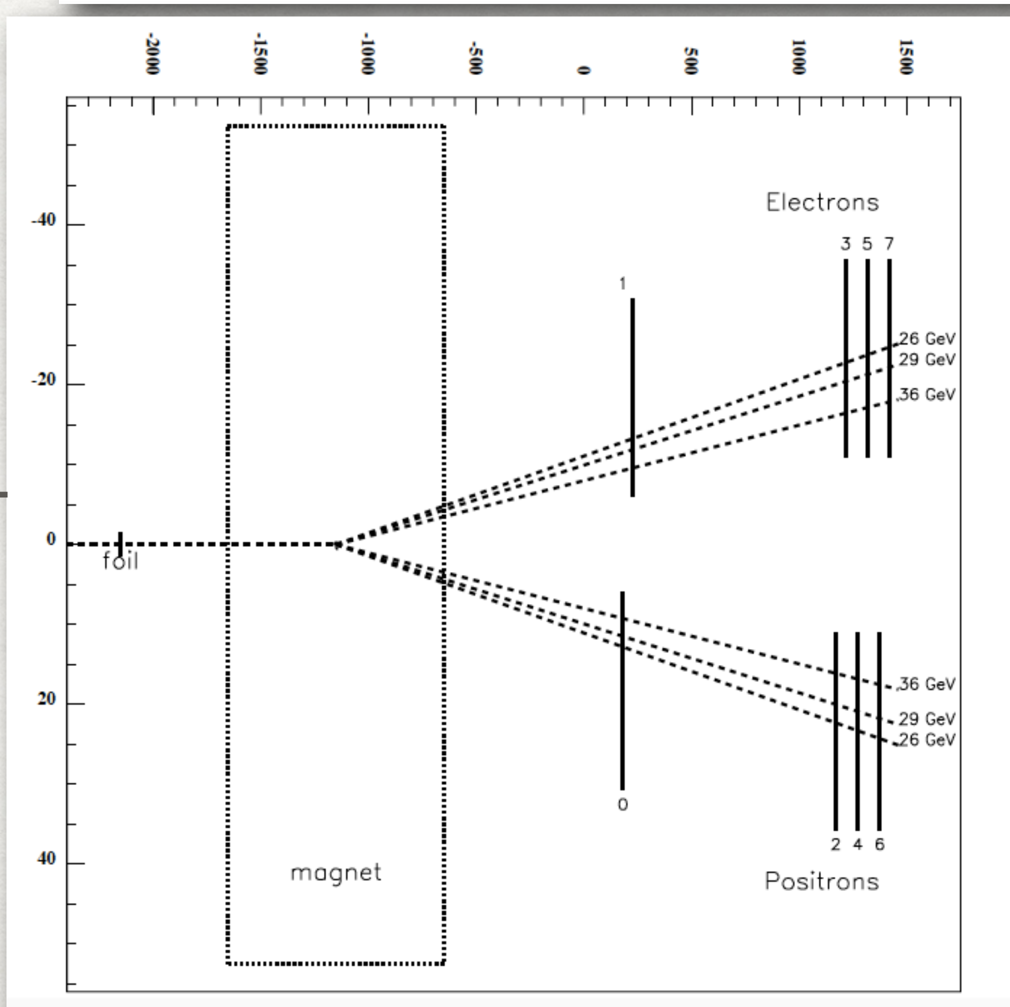
- layout for FDS of the LUXE experiment
- HICS and the absolute number of forward photons
- method to study the photon-conversion data
- spectra from MC
- Geant4 simulation for the converter

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 + nω → e + γ*** **HICS → Non-linear Compton**
- ***γ + nω → 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

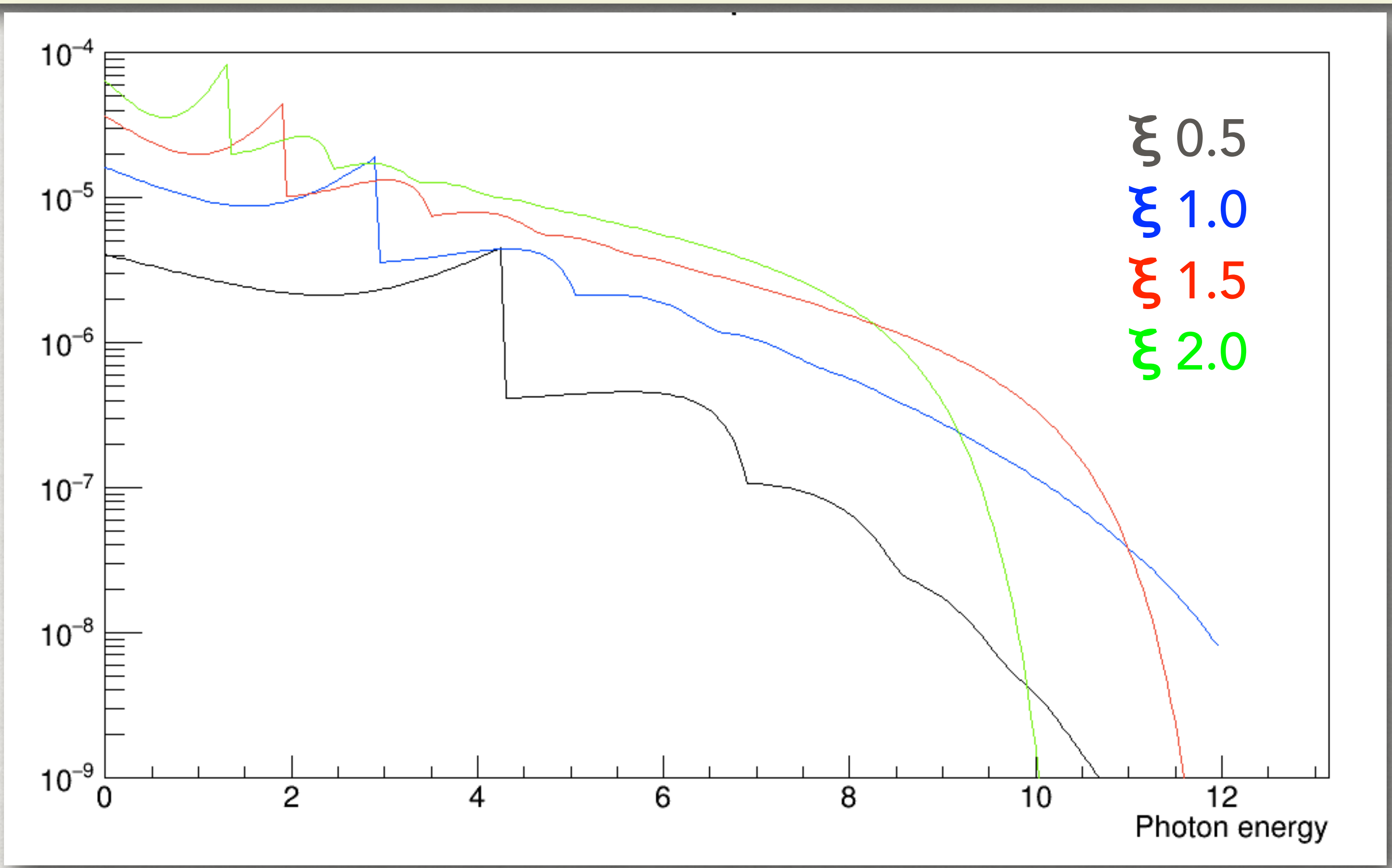
data produced of HICS/IPW/circularly polarized with Mathematica by Anthony Hartin

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

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

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

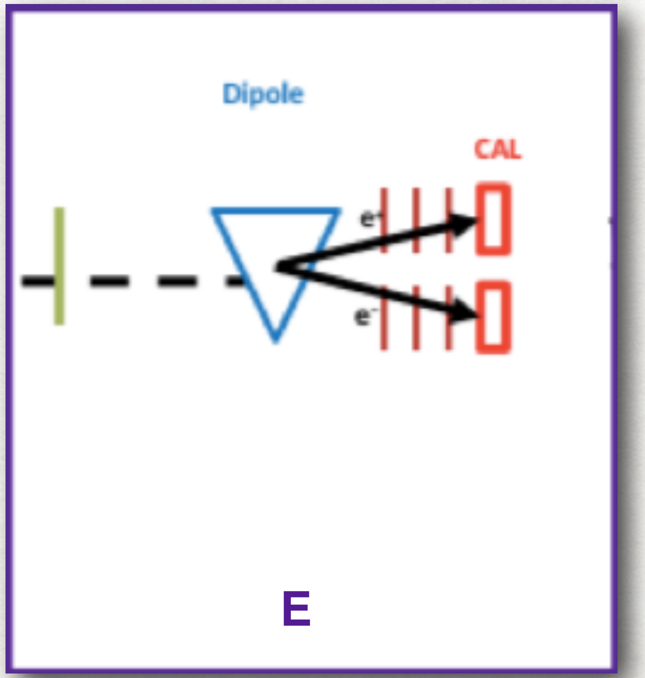
production rate for the electron bunch 6.25e+09 and laser pulse t=35 fs estimated from theoretical calculations

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

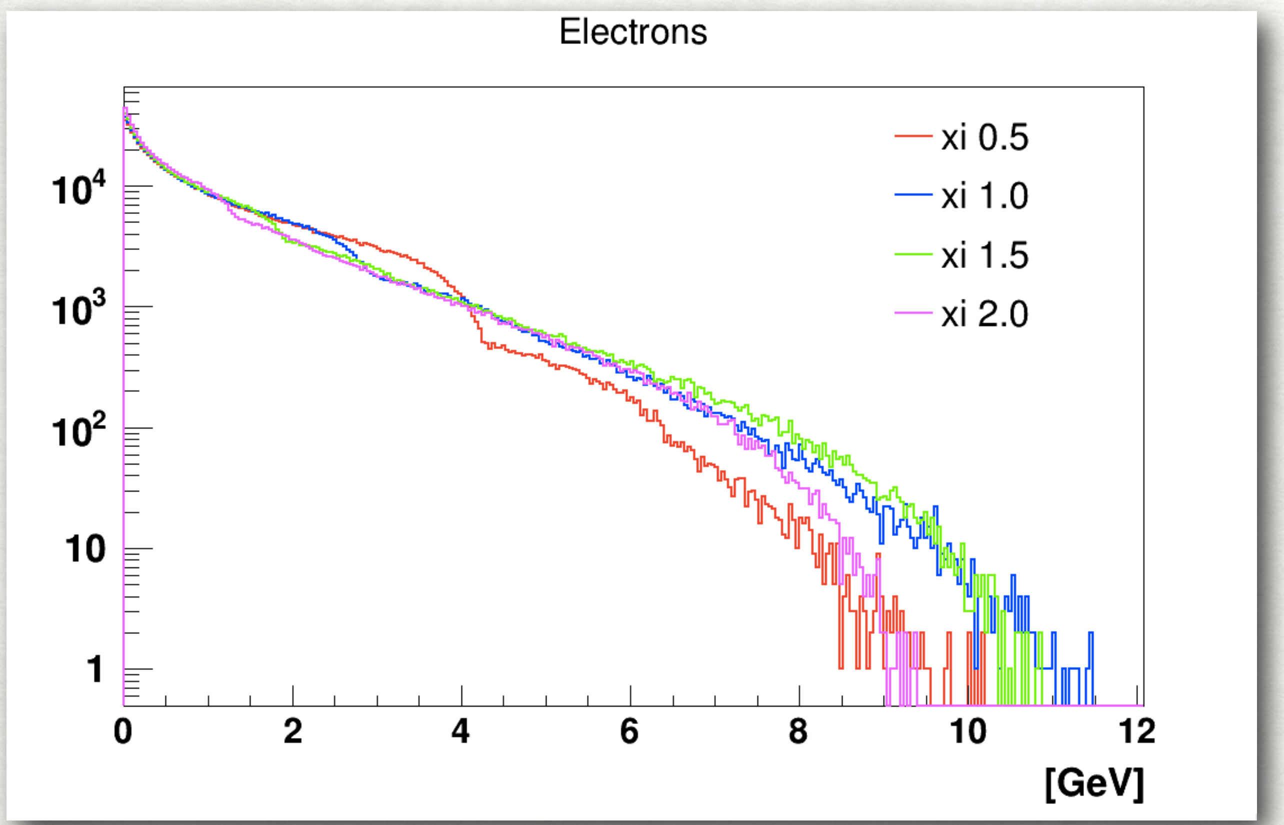
The transverse structure of the laser field is not taken into account in the data and it is assumed that the laser field is uniform in transverse plane and it is essentially the same for all electrons -> It could be accounted for in MC

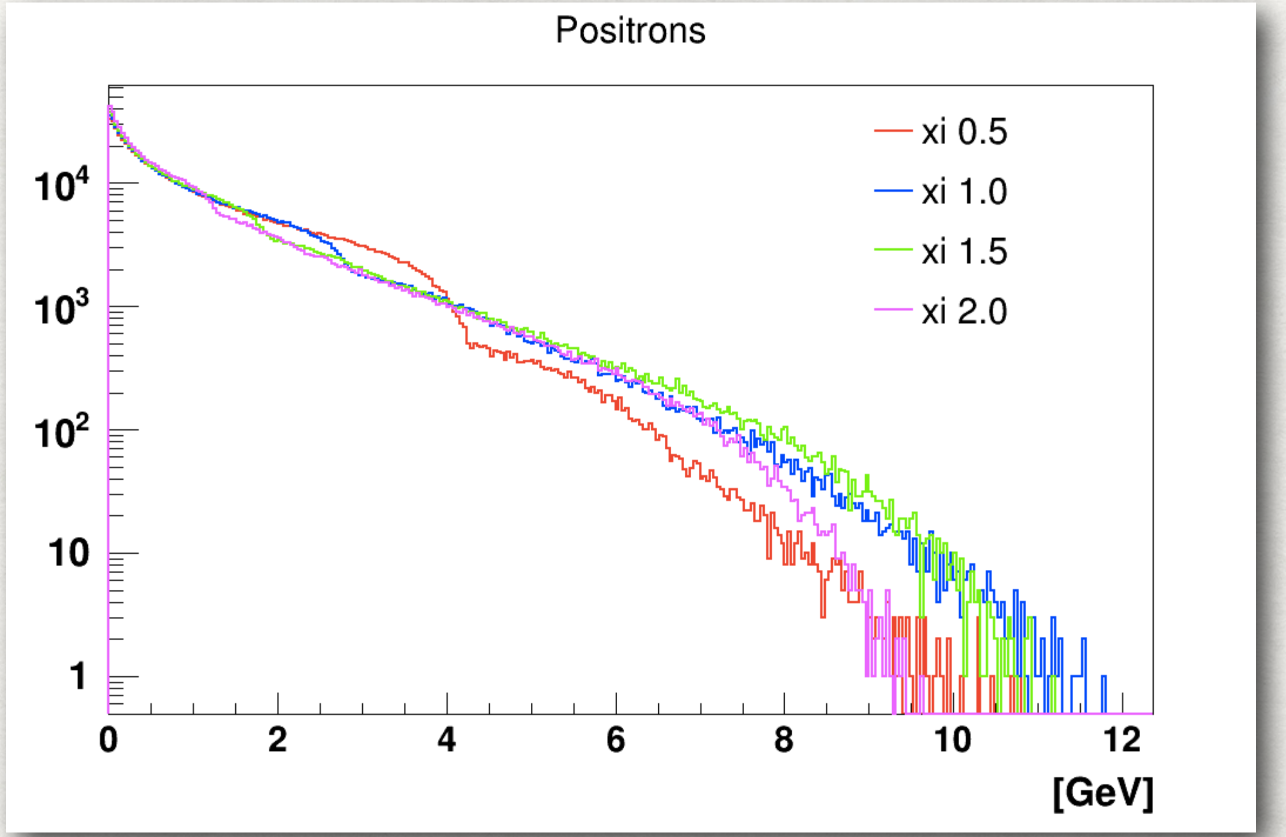
If the target thickness is 1% of X0 at this laser intensities ~ 1e8-1e9 e+e- pairs would enter the pair spectrometer in each laser pulse

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

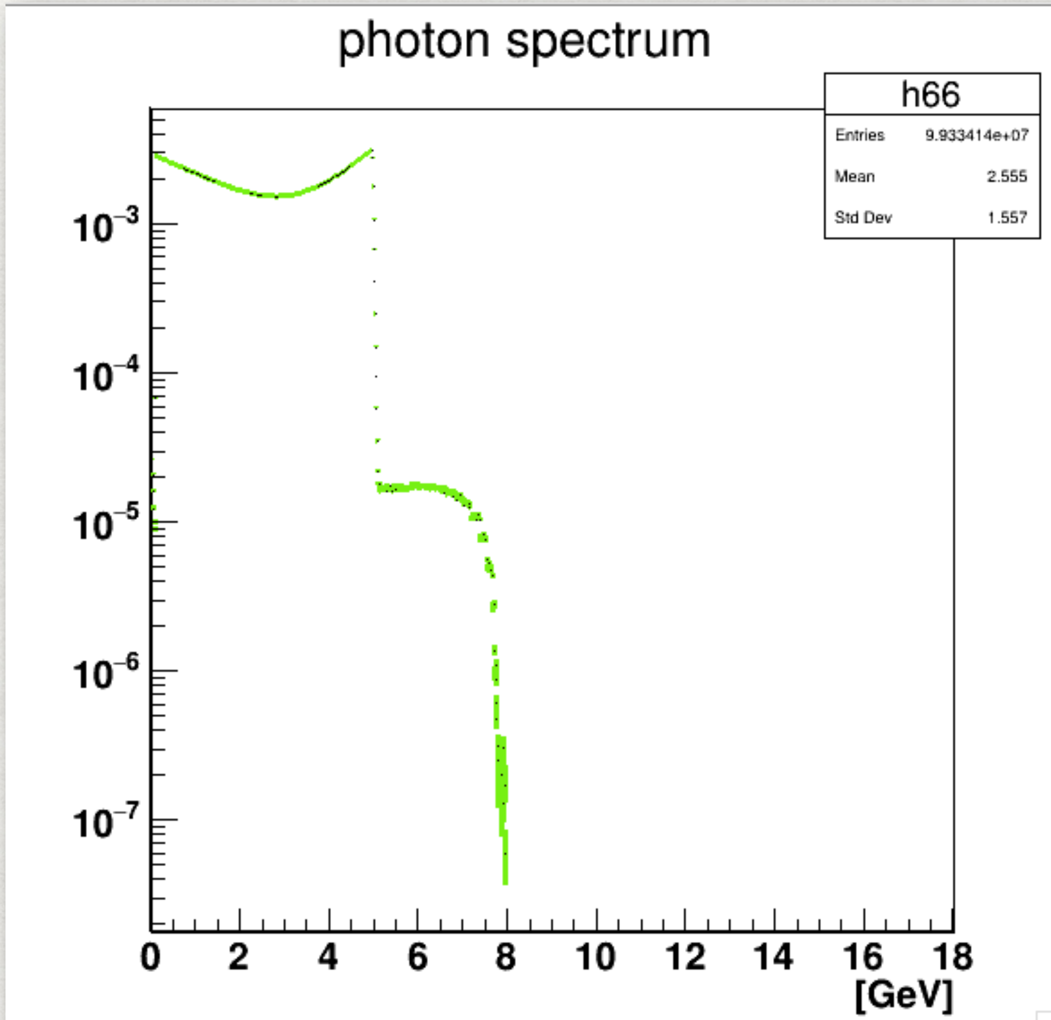


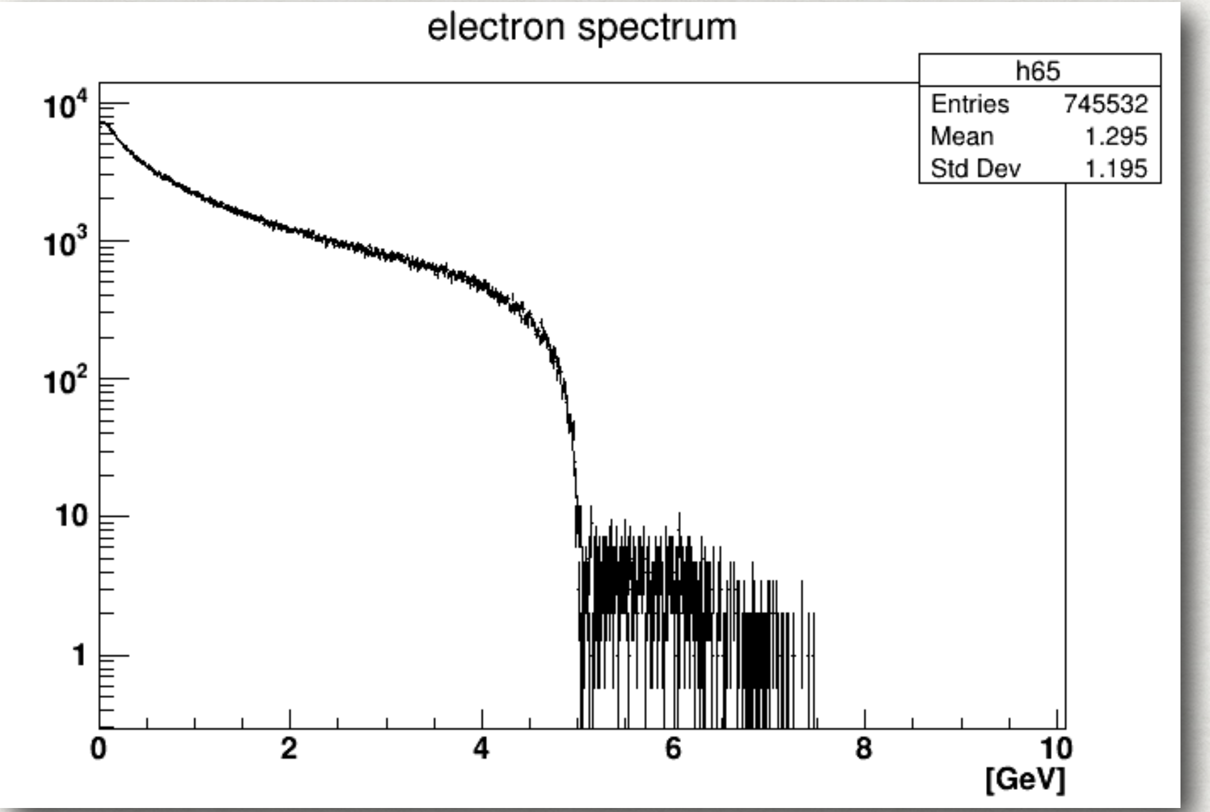
- target material - W foil
- thickness 35 um
- 1e8 photons

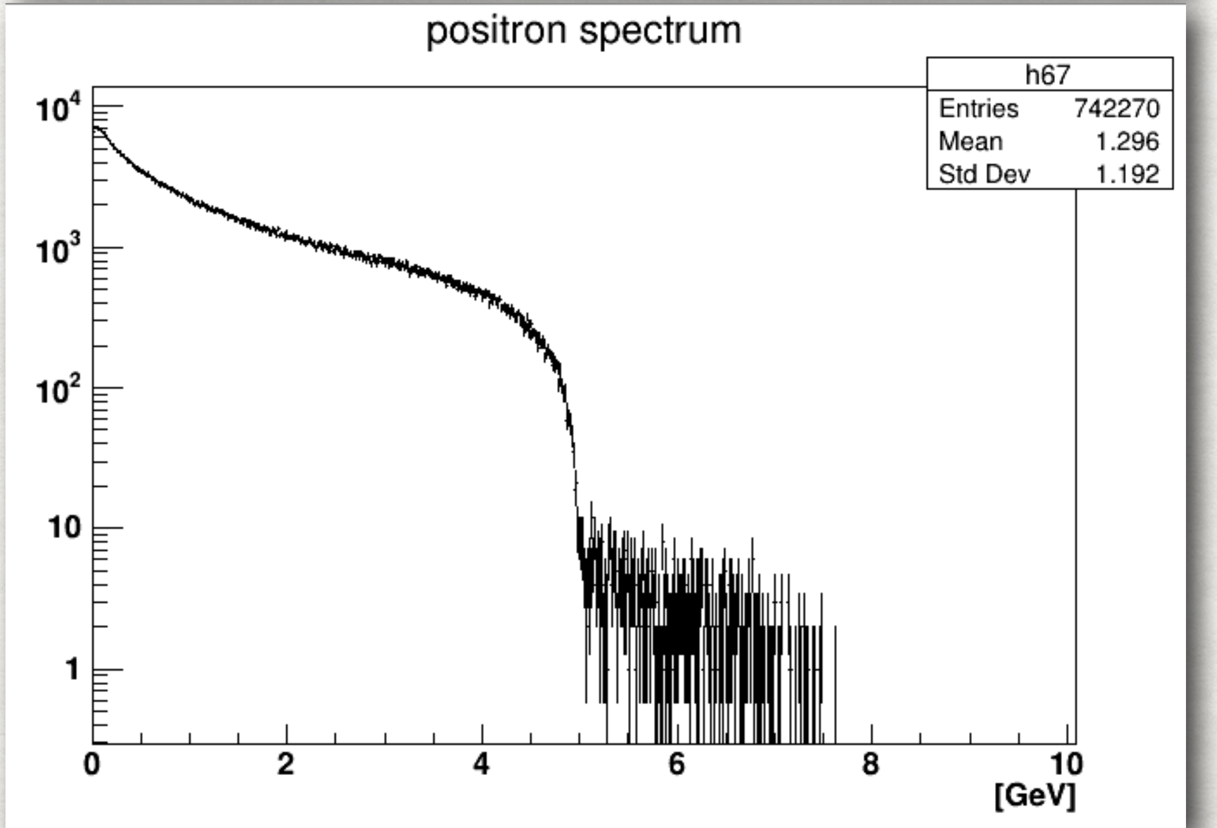




FORWARD PHOTONS IN GEANT4





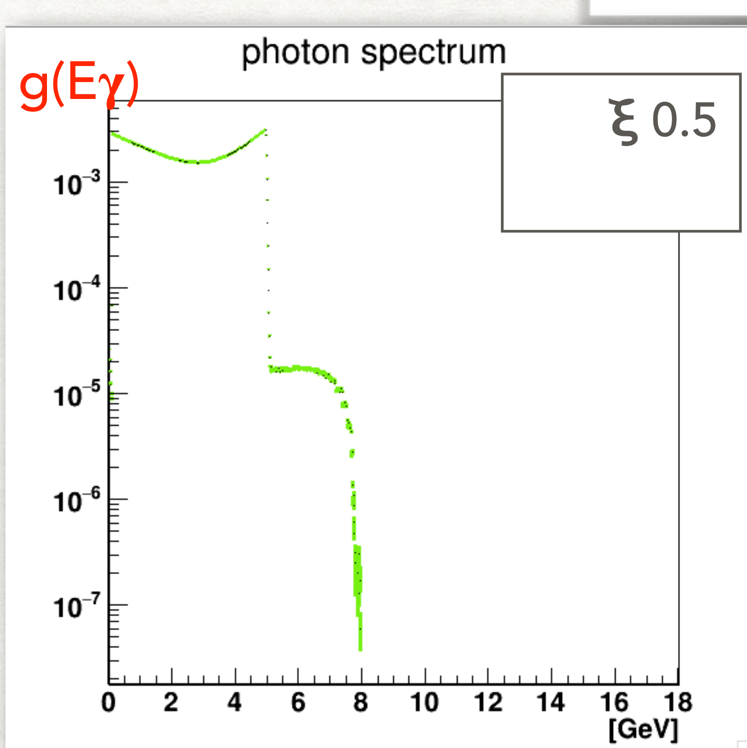


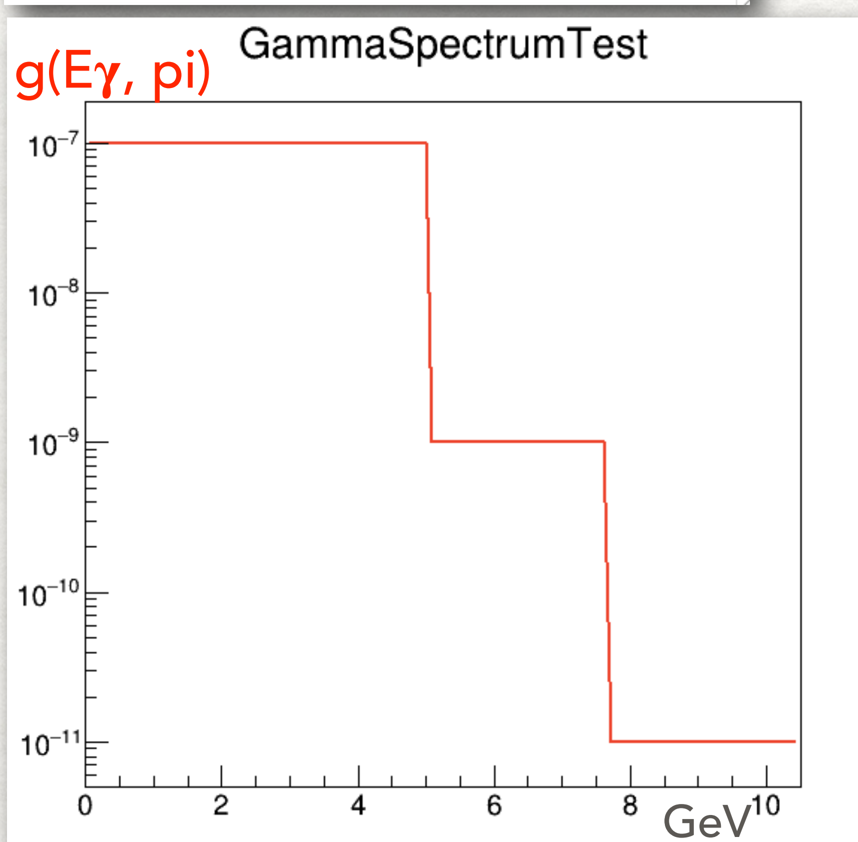
target: Tungsten foil, 0.35 um
1e8 photons, ξ = 0.5

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

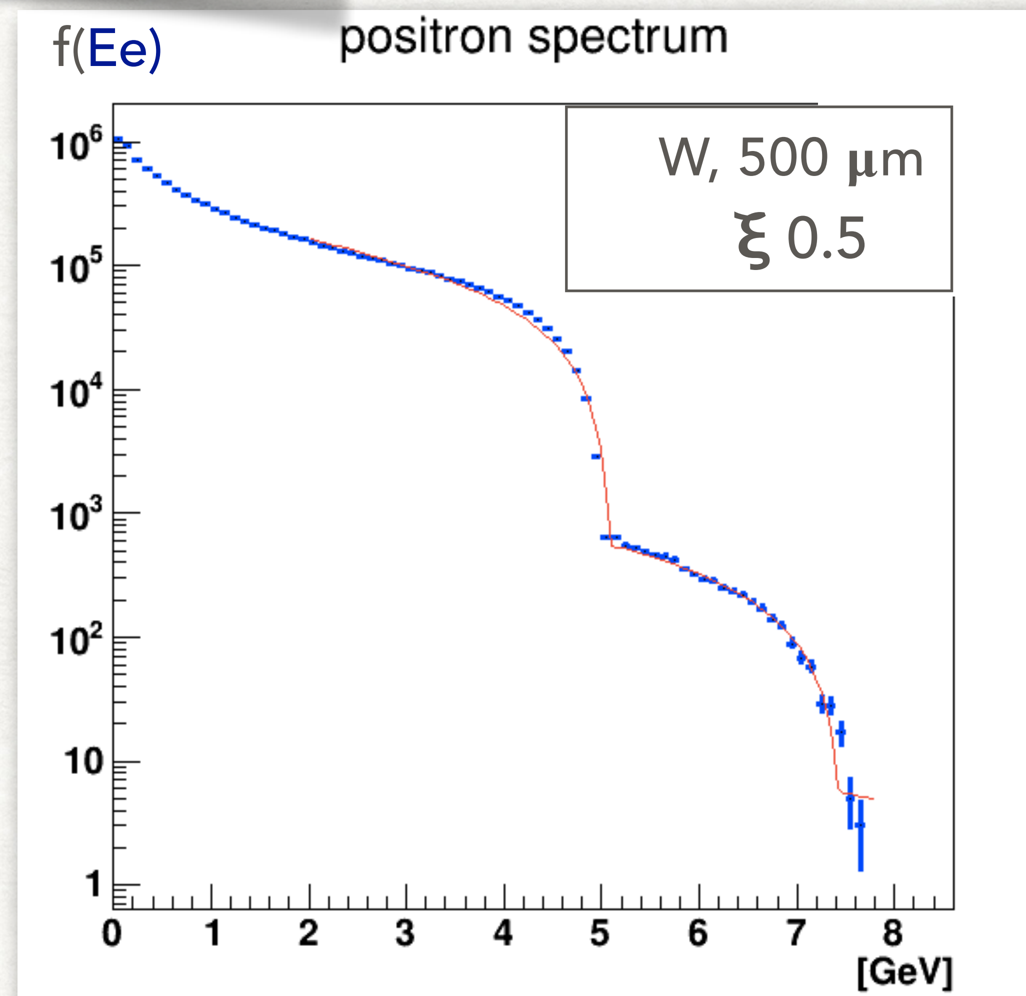
METHOD OF PHOTON SPECTRUM RESTORATION

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





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**

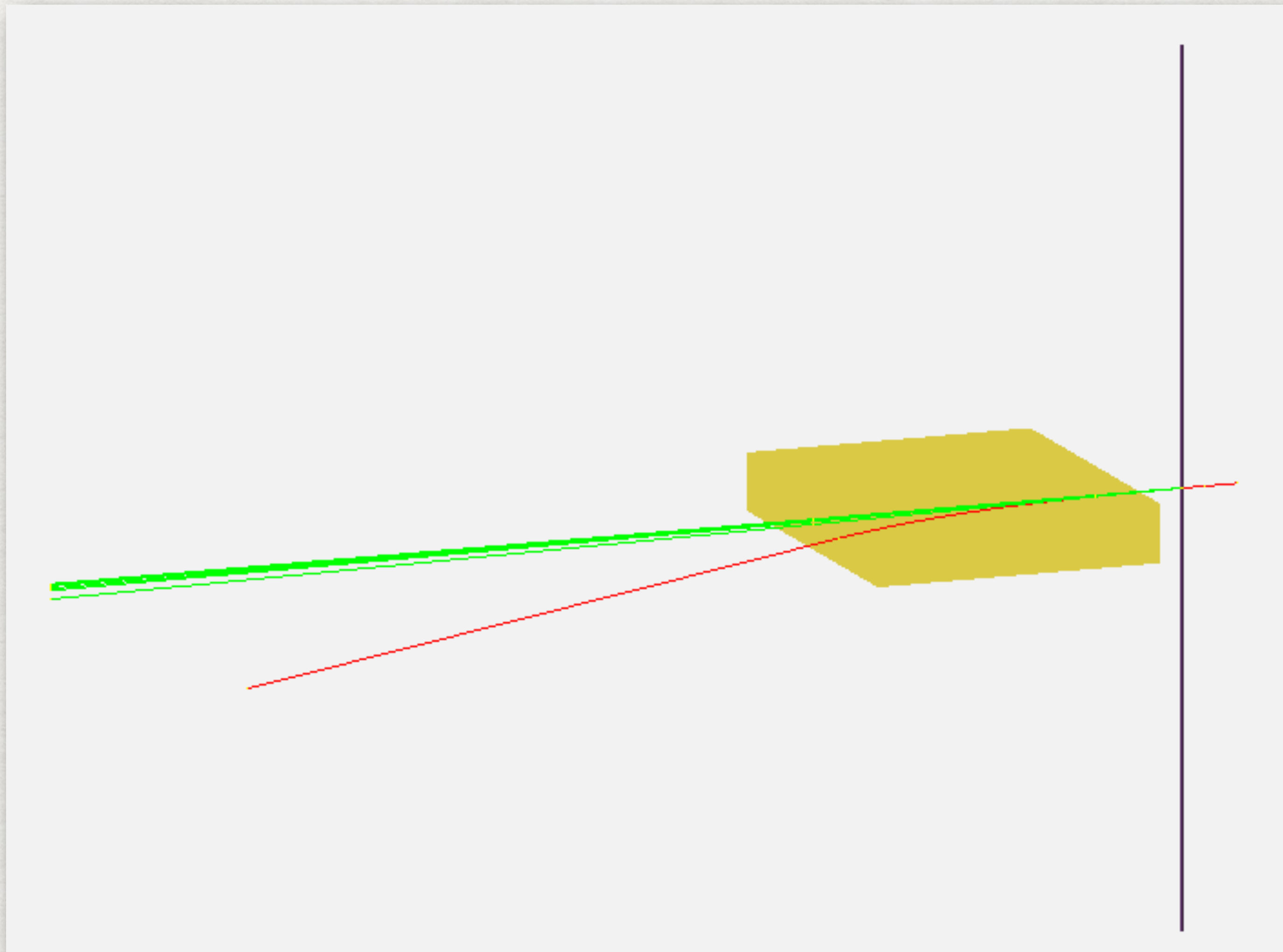


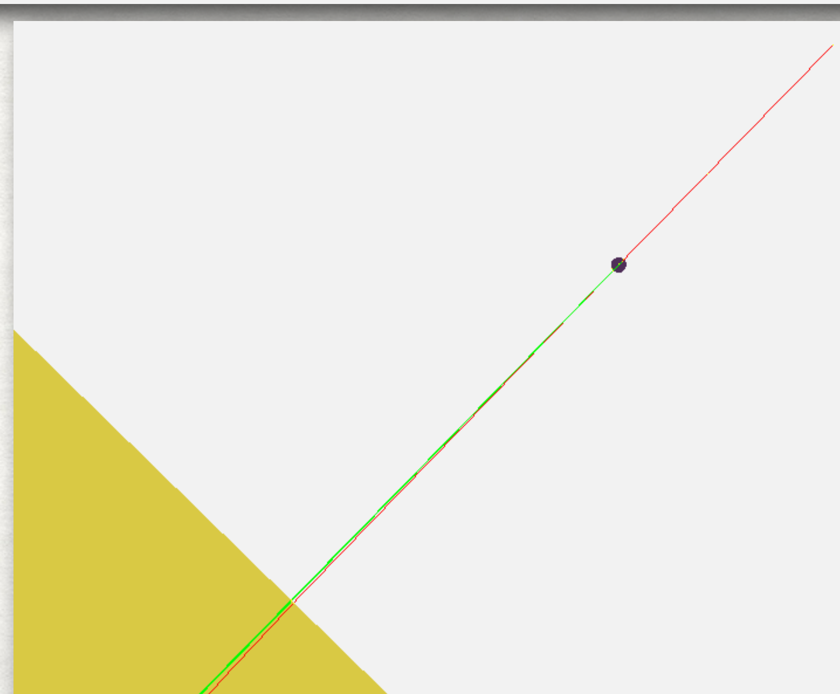
$$\int \sigma(E_\gamma, E_e)\, g(E_\gamma, p1, p2)\, dE_\gamma$$

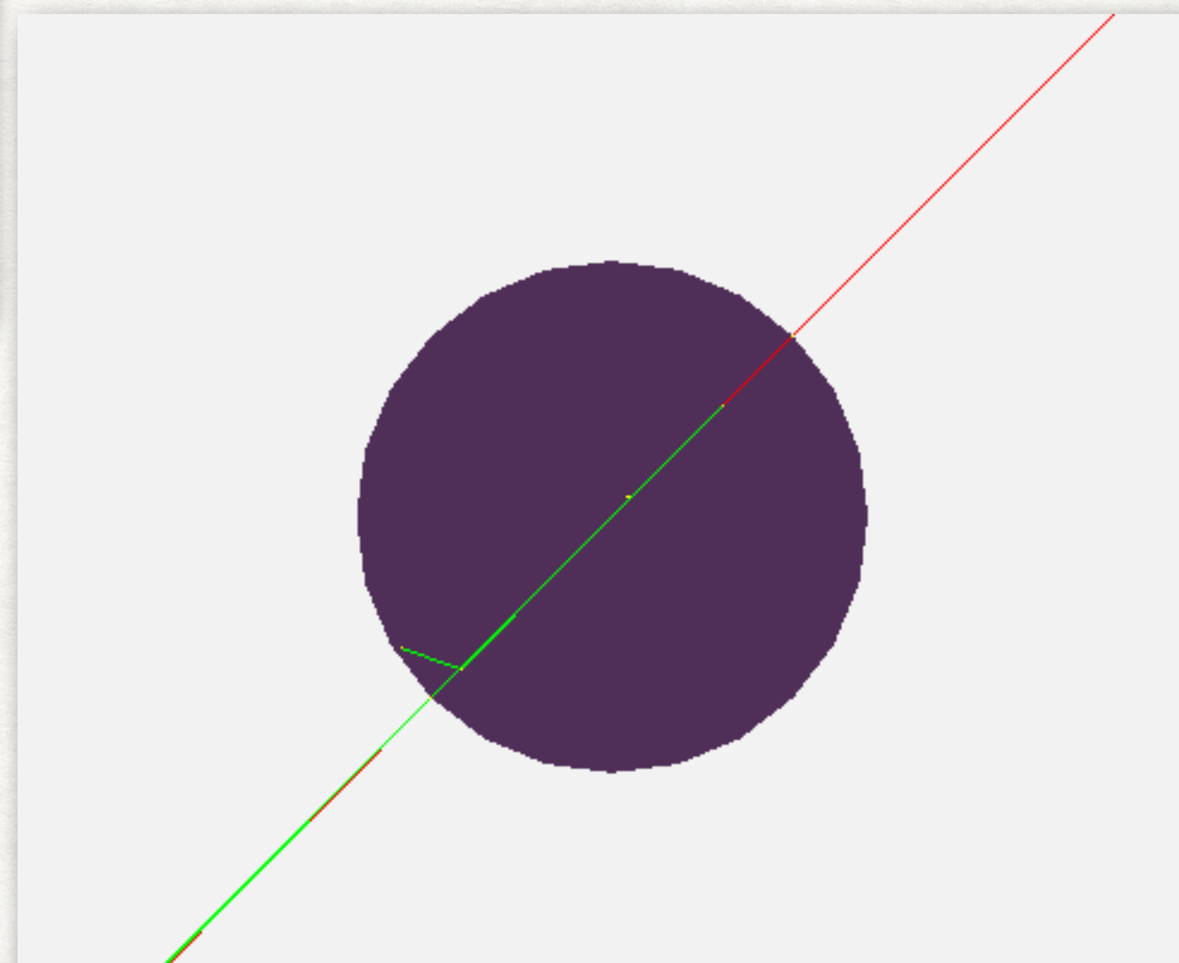
fitting allows finding the **the kinematic edges** quite well

but this is done for the theoretical curve with uniform intensity

GEANT4 SIMULATION FOR THE WIRE CONVERTER





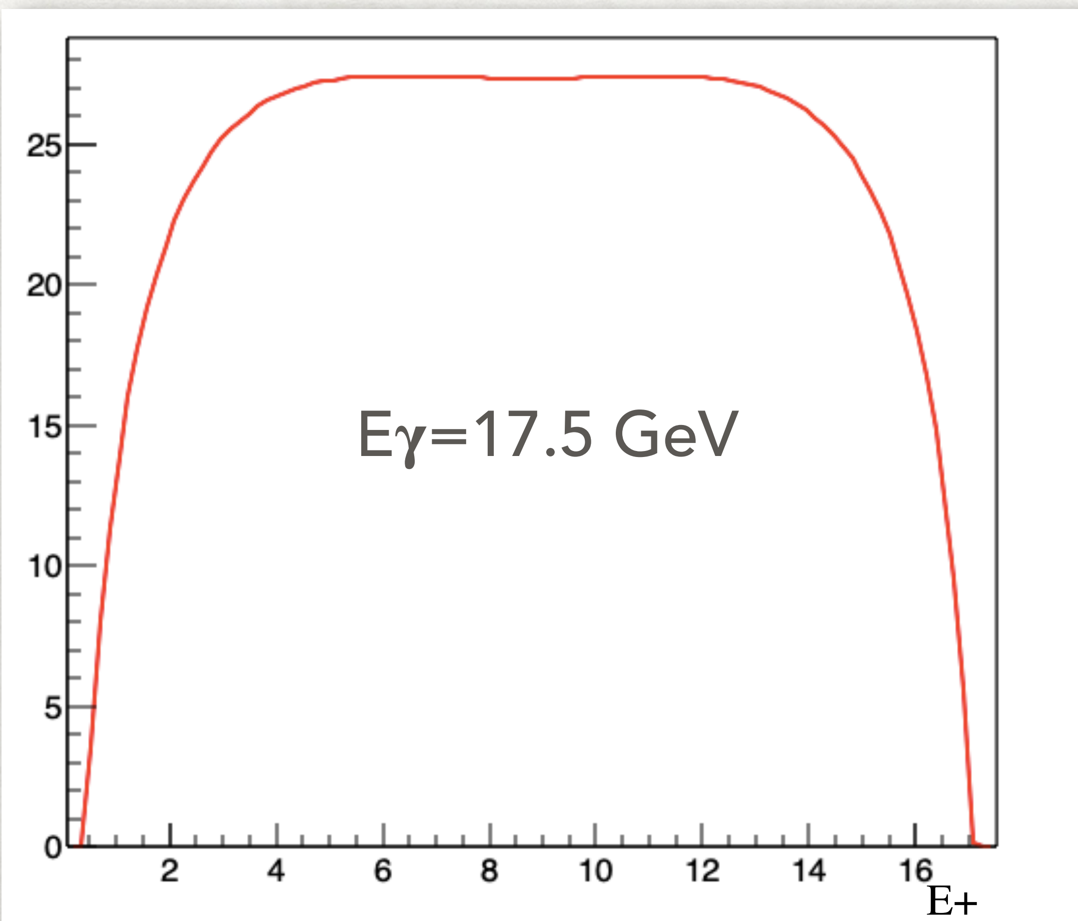


BETHE-HEITLER PAIR SPECTRUM

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 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