the forward photon detector system

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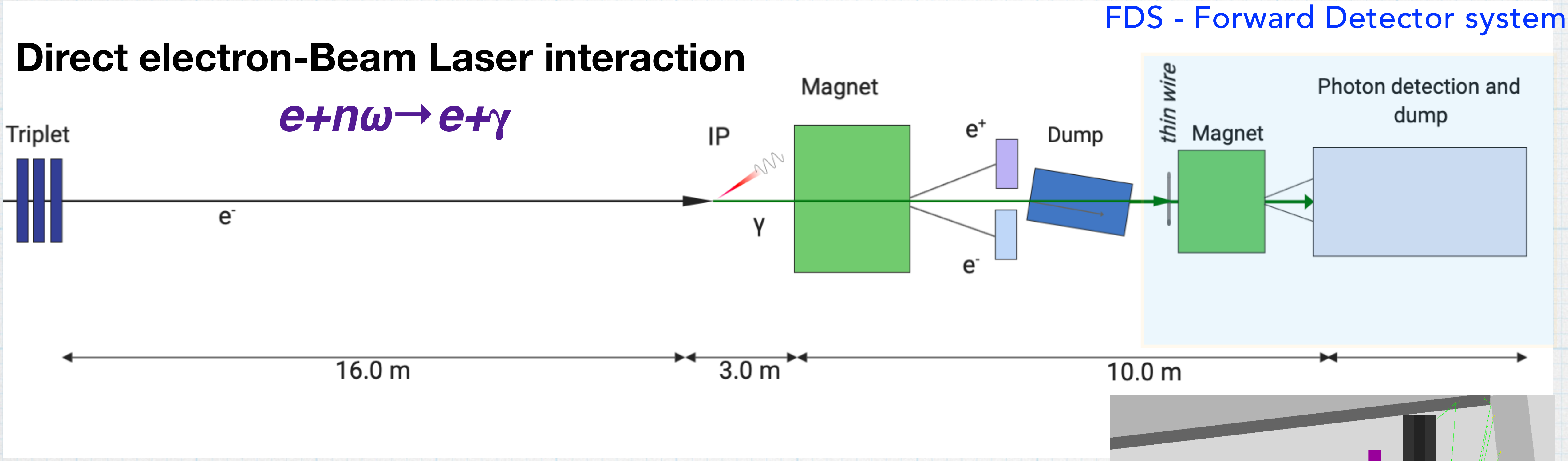
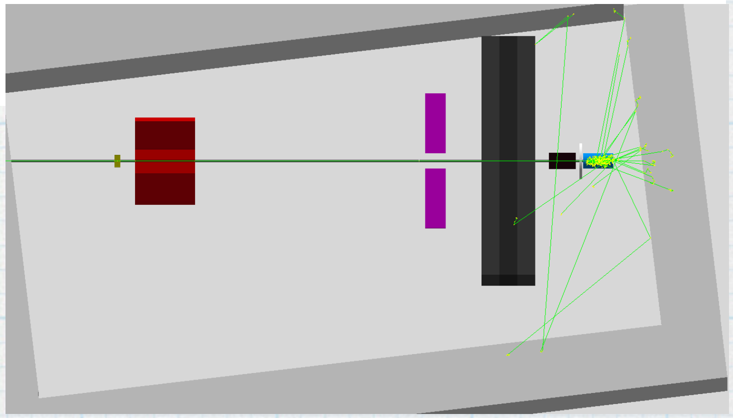
27/07/20

LUXE

Intro





Tasks at hand:

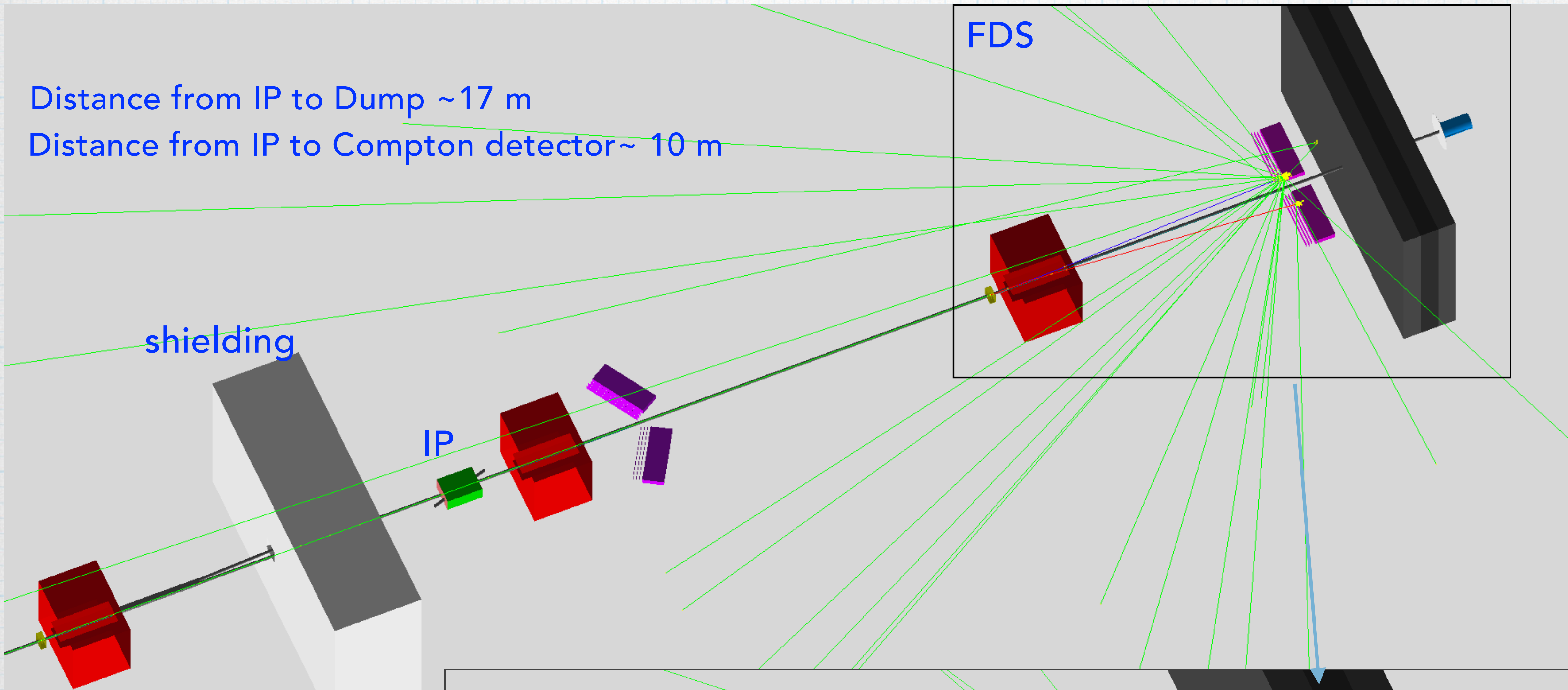
I measure HICS energy spectrum.

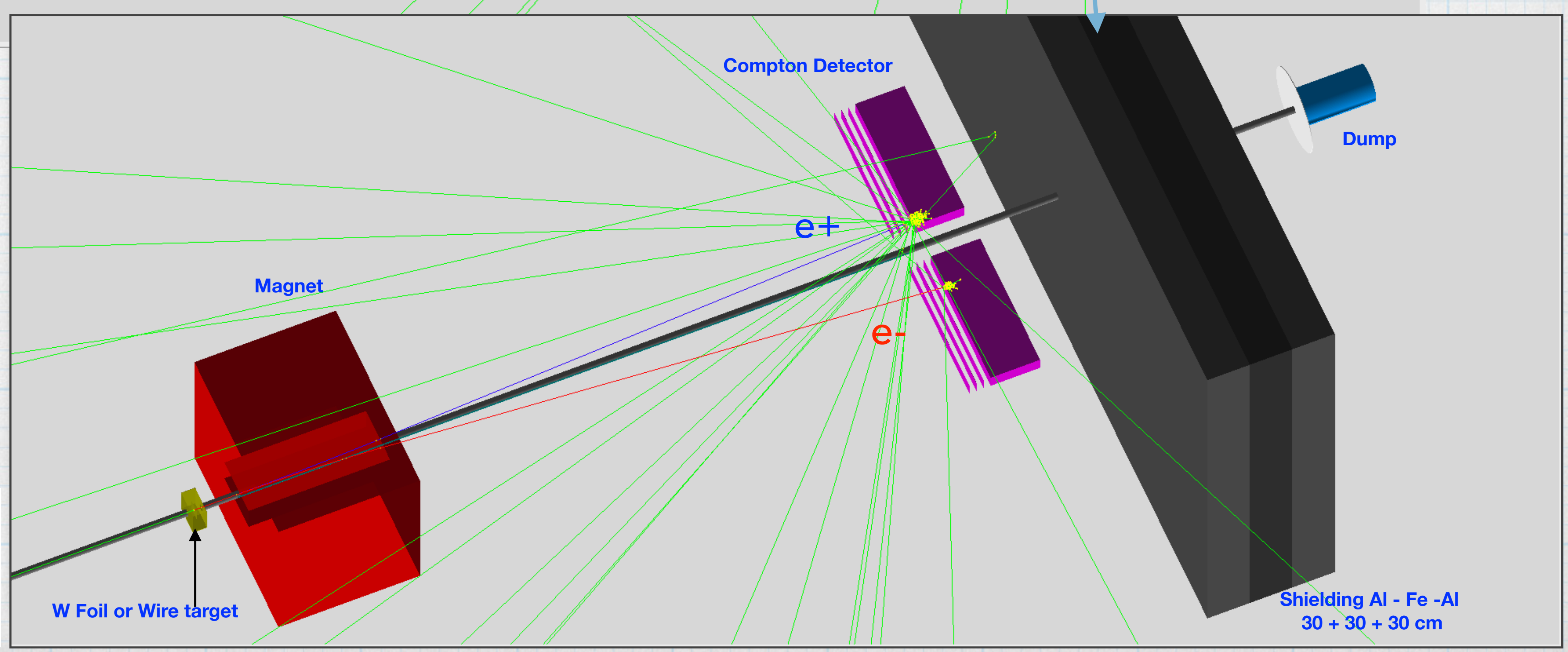
- Use low X0 target (~1e-6 X0) for gamma to electrons/positrons conversions followed by spectrometer;
- determine kinematic edges;
- detailed shape.

II measure absolute number of photons on event-by-event basis.

- Spectra normalisation;
- Be sensitive to angular distribution of HICS photons (if possible)

Experimental setup for using conversions in GEANT4



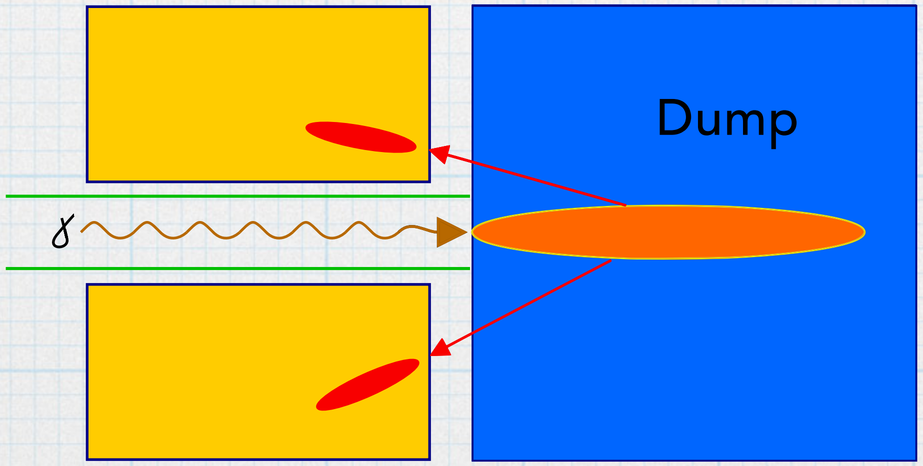


Thickness, μm	W, N_{e^-}	Ni, N_{e^-}
10	$3.8*10^3$	940
5	860	
1	32	25

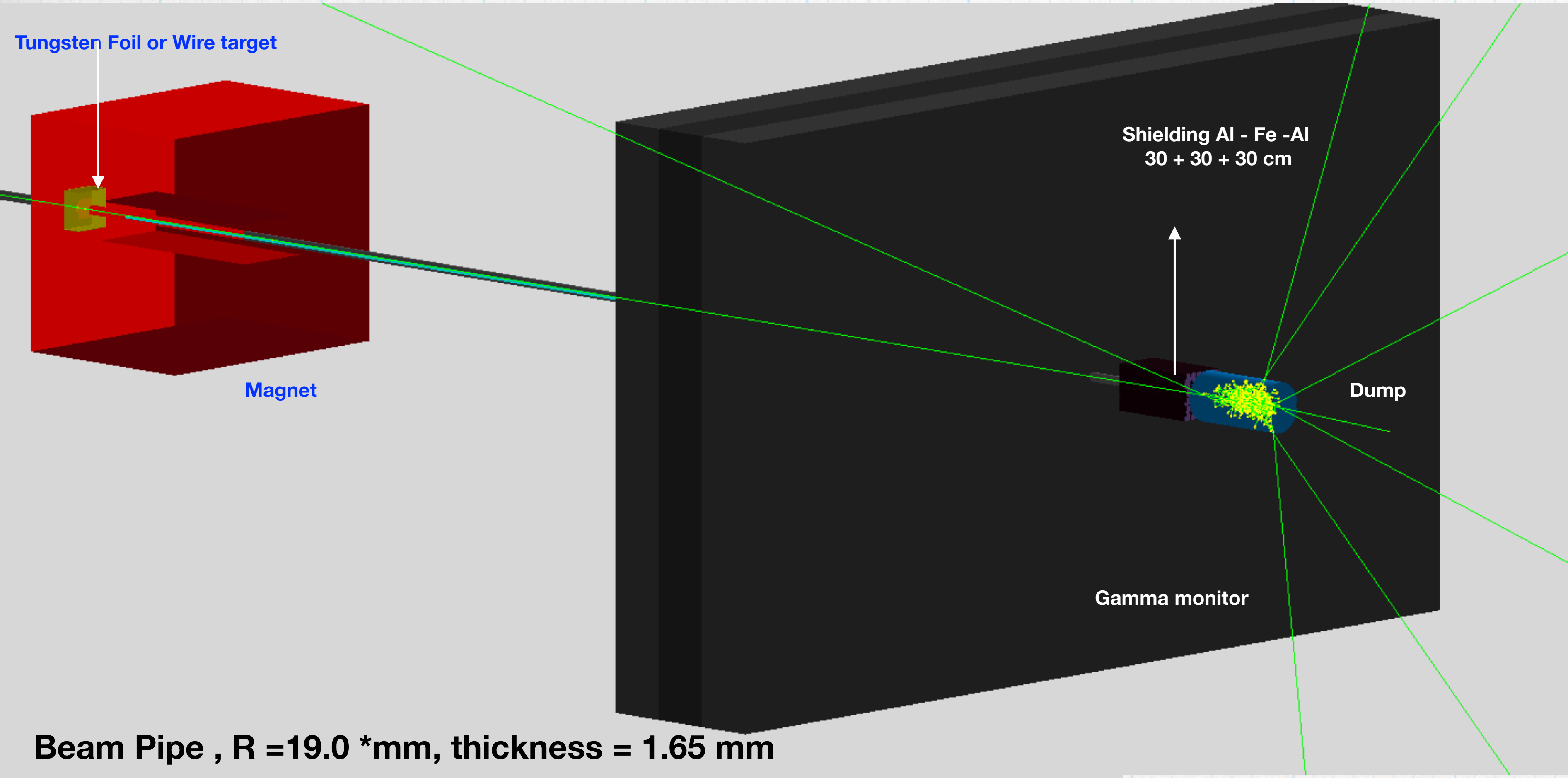
Rates For 6.0e9 electrons in BX w/ E= 17.5 GeV

Location	particle type	rate for ξ=2.6	rate for ξ=0.26
e– detector	e–, E <16 GeV	**5.9e+9**	**2.4e+07**
e+ detector	e+	**61.07**	**0.0**
Photon detector	γ	**2.4e+11**	**3.8e+07**
Photon detector	e+ and e–	**2.3e+07**	**4.2e+04**
Photon detector	e+ and e–	**5.8e+5**	**3.8e+03**

The Idea:

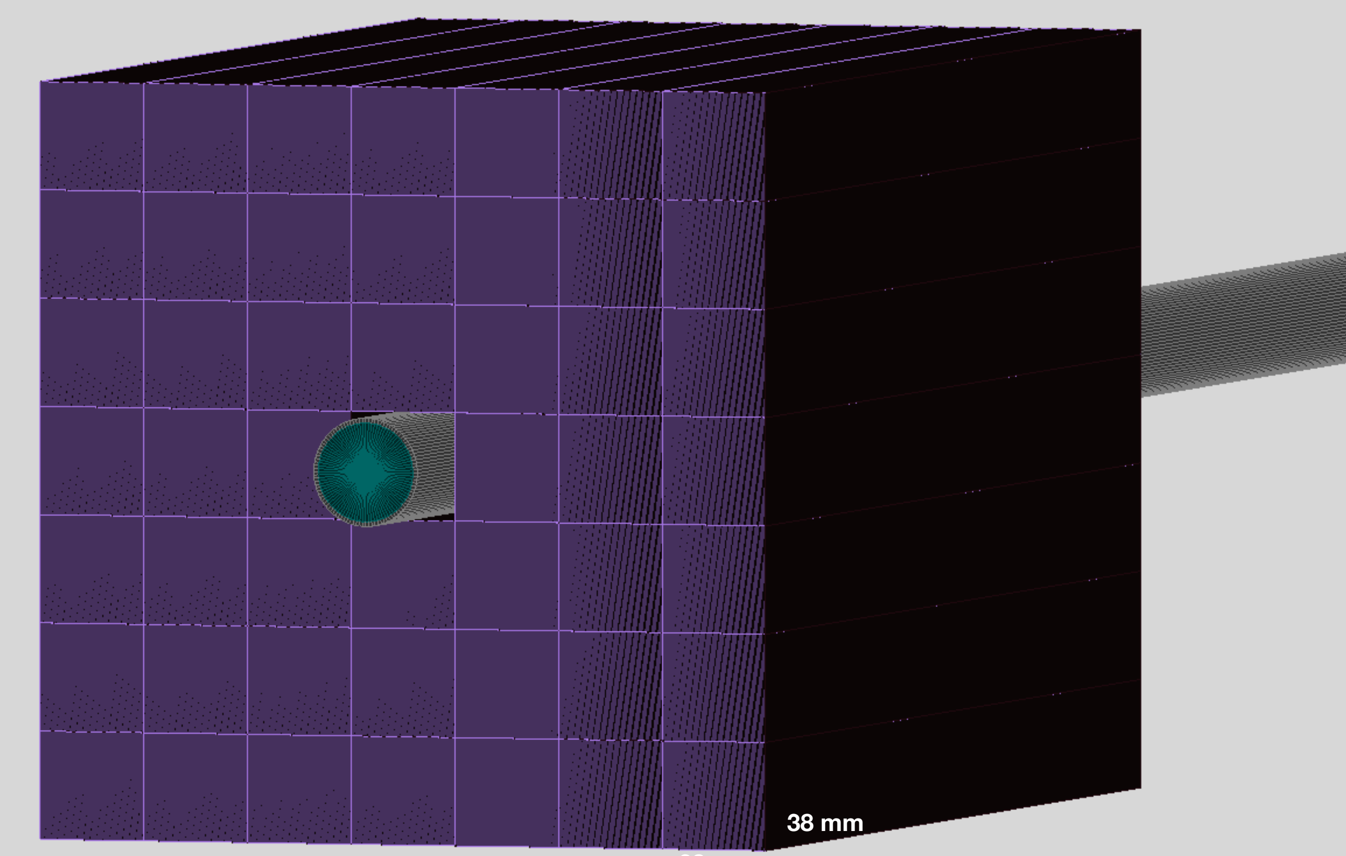


Gamma Monitor

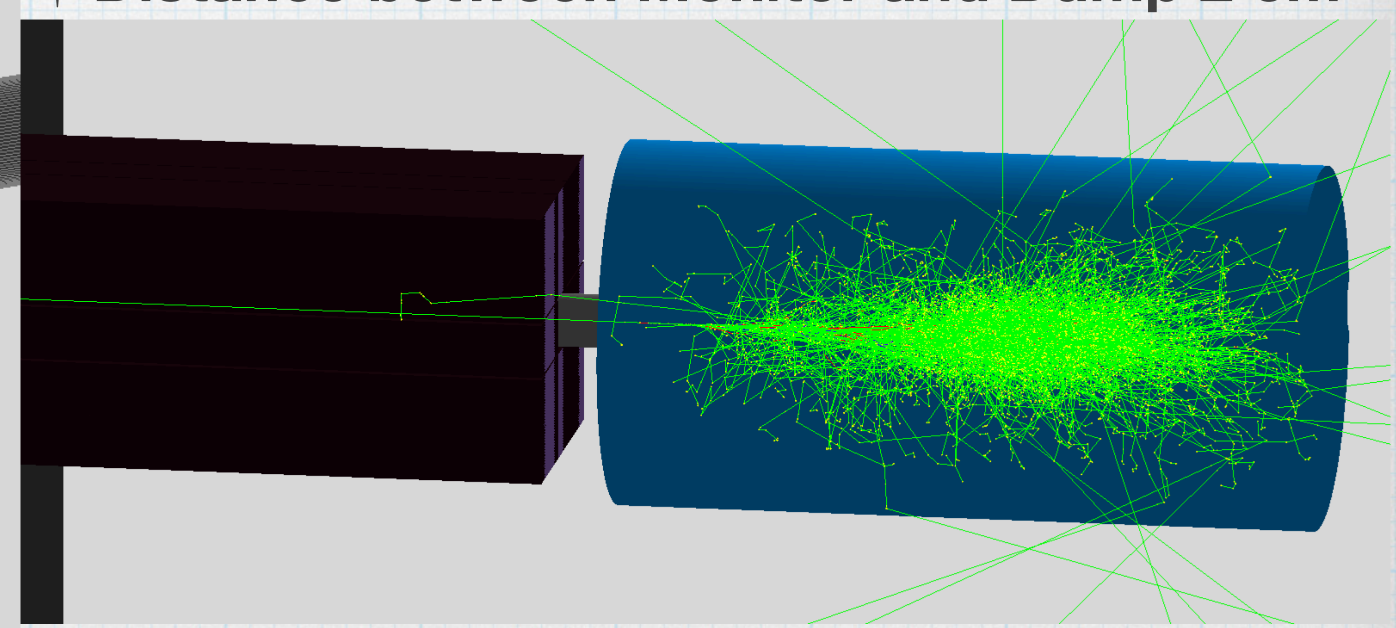


- The implementation of FDS in Luxe geometry with the LG Gamma Monitor made of new LG blocks in front of Al-Cu Dump,
- LG w/ measures 3.8 × 3.8 cm^2, length is 45 cm
- Wrapped with Aluminium foil of 0.016 mm (typical household foil; no account for air)

Beam Pipe , R =19.0 *mm, thickness = 1.65 mm

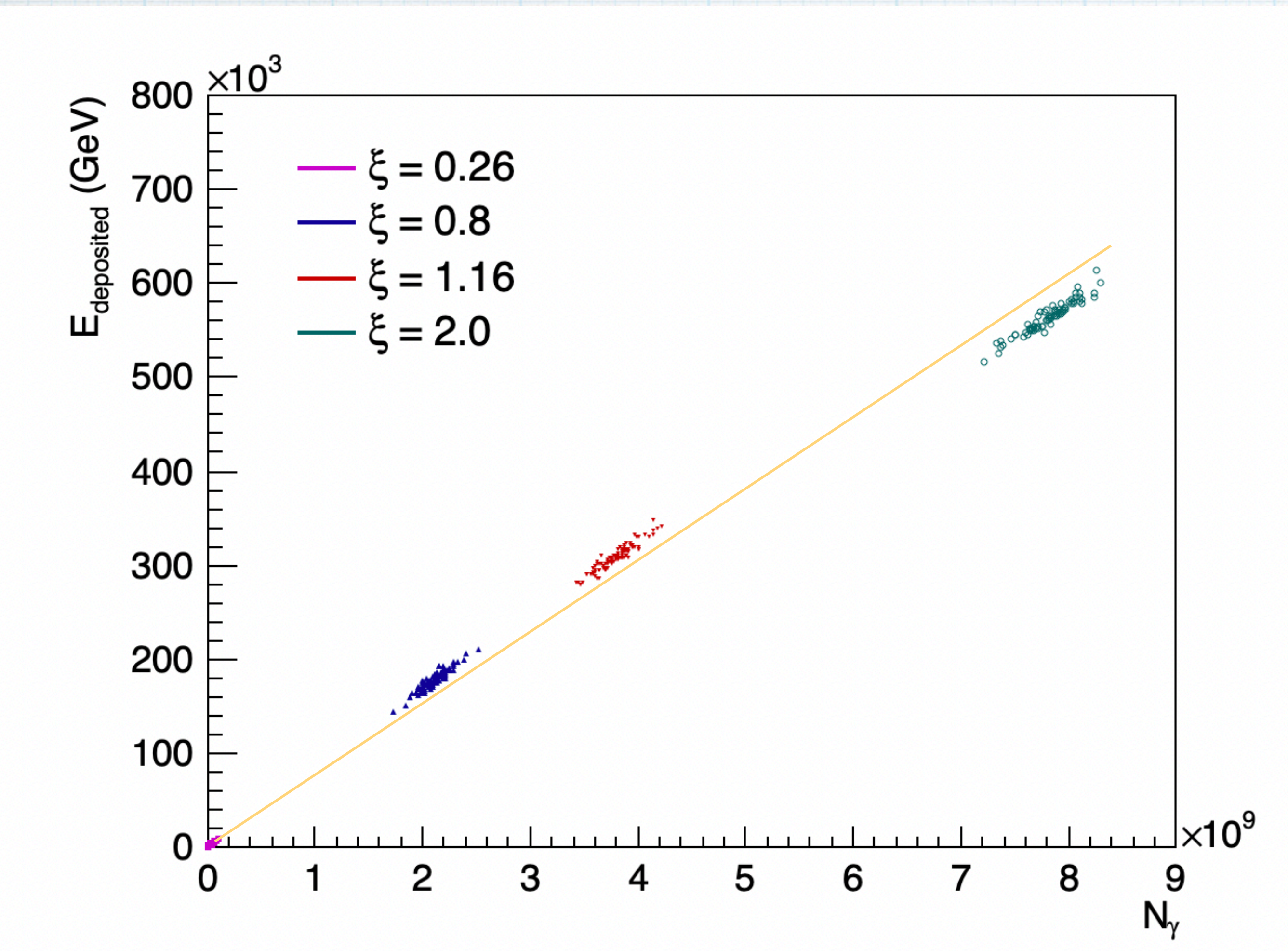


- Distance between Monitor and Dump 2 cm

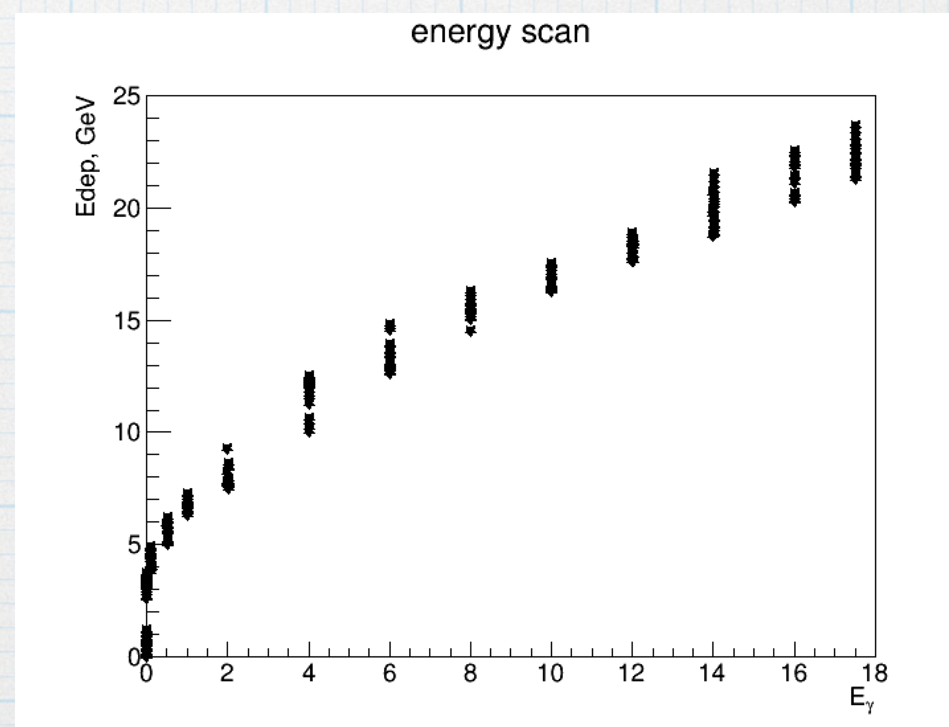


Simulation and Performance

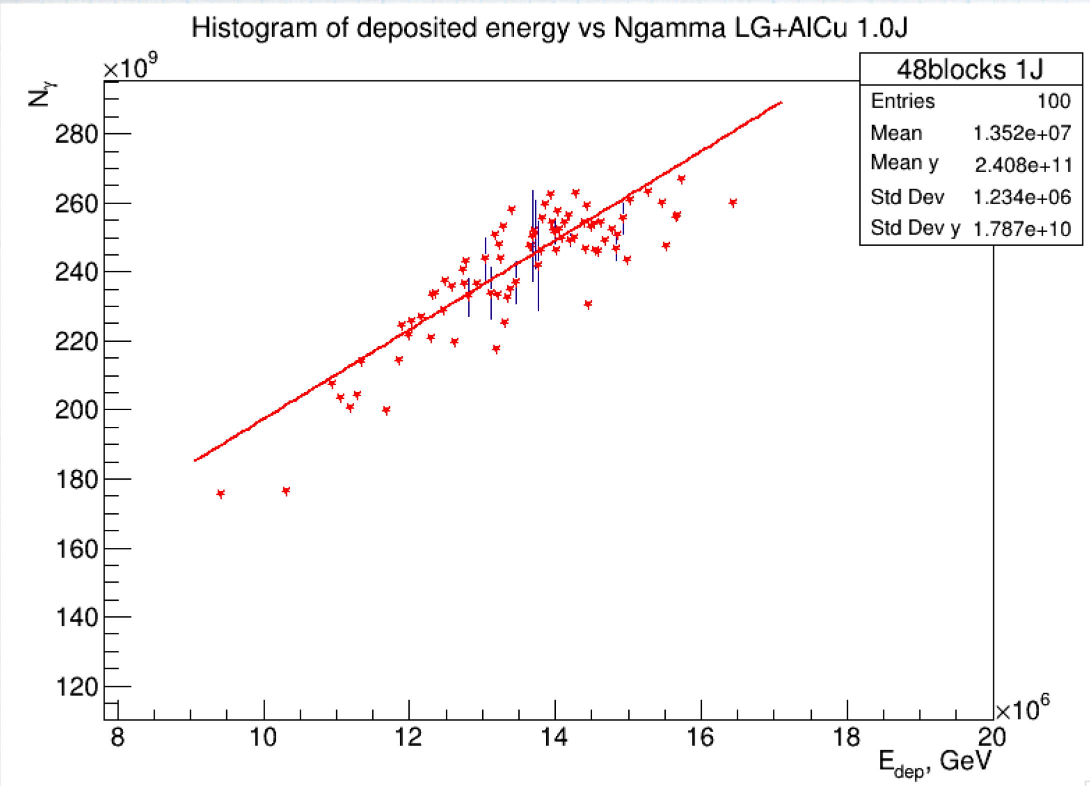
Deposited energy versus true number of photons. Each point is one BX



- The (almost) linear dependence of deposited energy on number of incoming photons in GM allows the usage of backscatters for monitoring the photon flux
- For small ξ the HICS spectrum is softer and soft photons produce less back-scatters. This is the reason of small deviation from linearity in Edep on Eγ dependence



Uncertainties estimation



N(E) number of photons

$$\Delta N = \frac{\partial N}{\partial E}\Delta E \quad \Rightarrow \quad \frac{\Delta N}{N} = \frac{1}{N}\frac{\partial N}{\partial E}\Delta E$$

$$\frac{\Delta N}{N} = \frac{1}{N}\frac{\partial N}{\partial E}\Delta E = 6.8*10^4 * 1.3 * 10^4 / 2.5 * 10^{11} = 3.5 * 10^{-3}$$

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****************************************
Minimizer is Linear
Chi2                      =      49.2879
NDf                       =           13
p0                        =  6.79976e+10    +/-    3.97264e+09
p1                        =      12940.5    +/-    282.483
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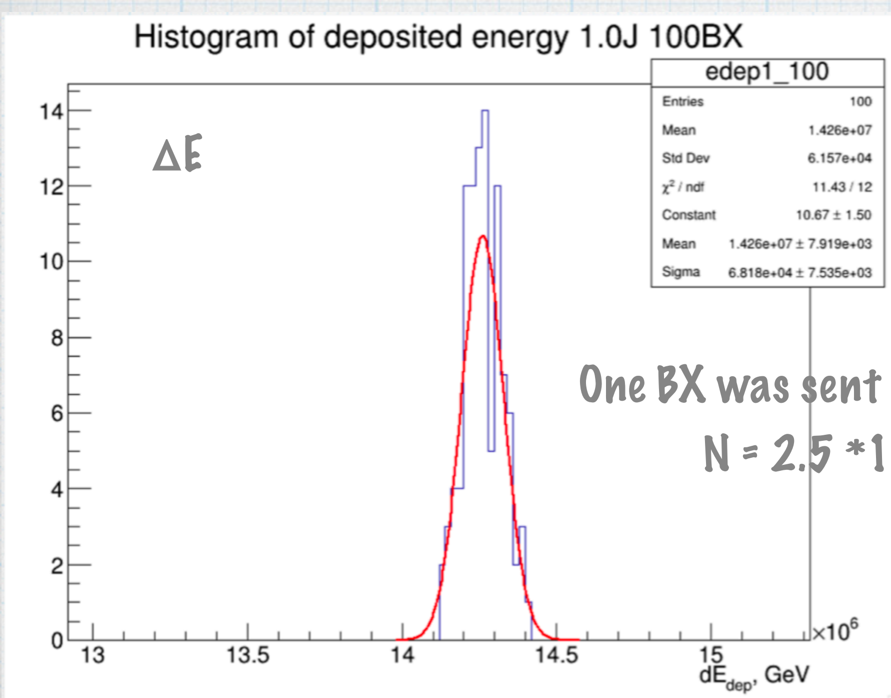
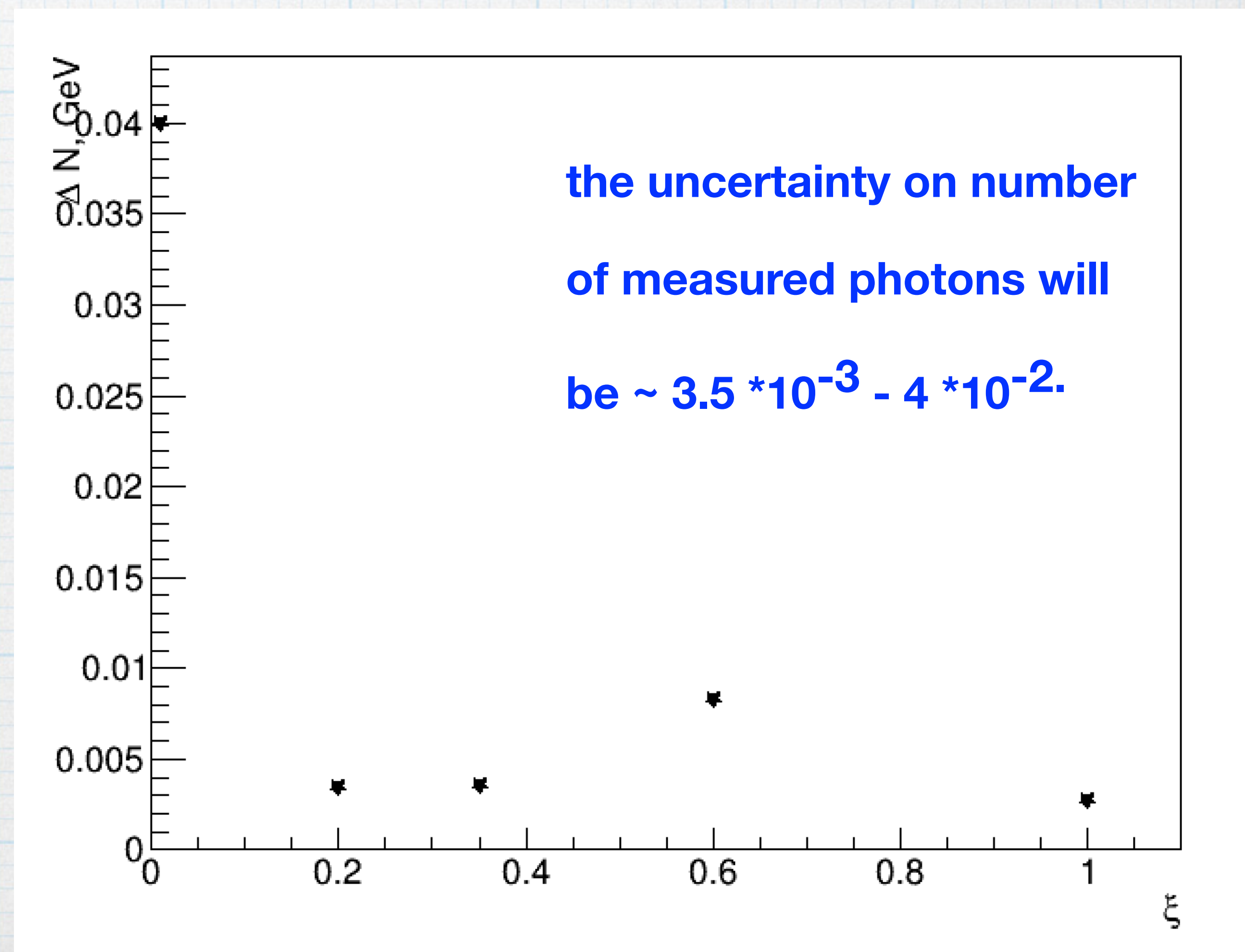
$\partial N/\partial E$



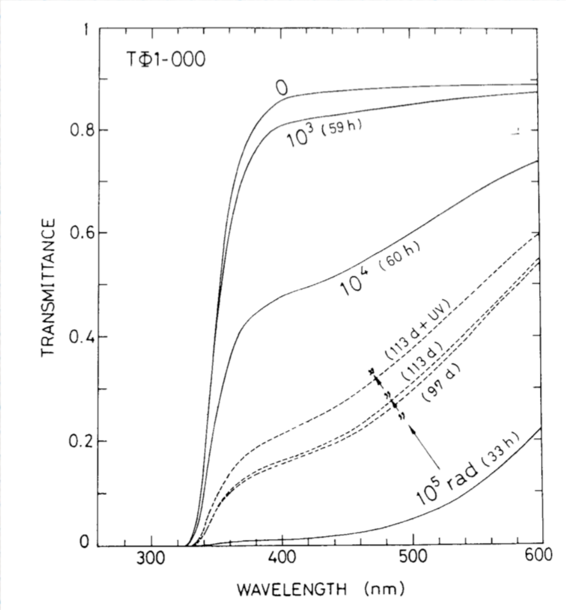
One BX was sent 100 times => $\Delta E = 6.8*10^4$

$N = 2.5 * 10^{11}$ $\partial N/\partial E = 12940$



the uncertainty on number of measured photons will be ~ $3.5 * 10^{-3}$ - $4 * 10^{-2}$.

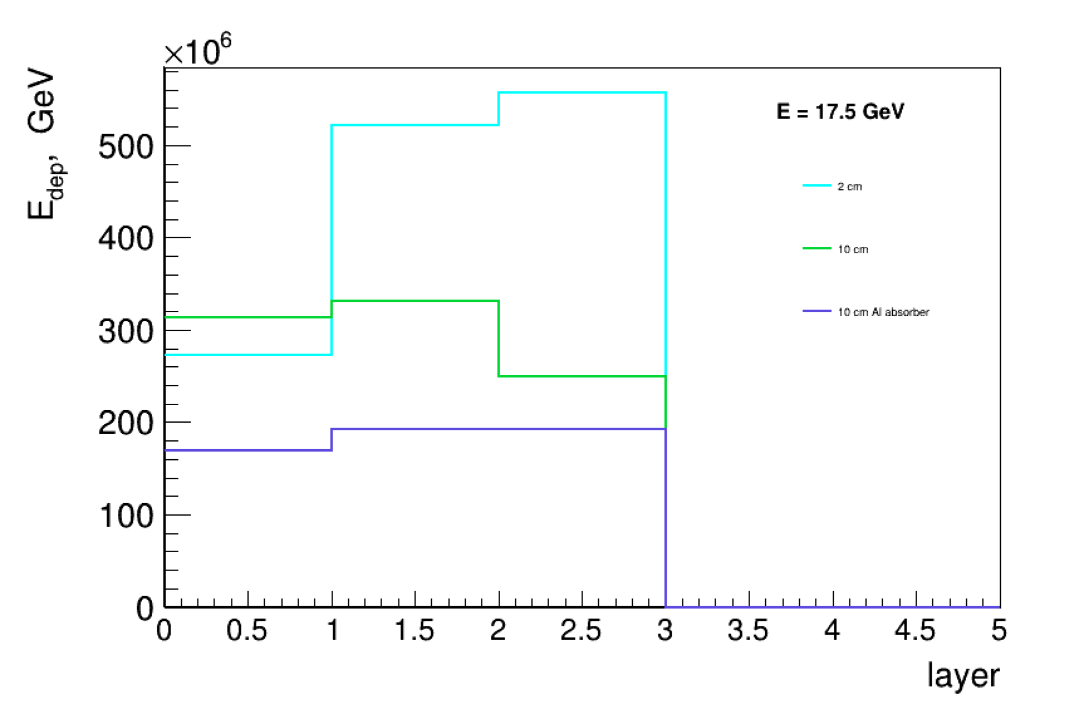
Degradation of the optical properties of the lead glass (TF1) by radiation

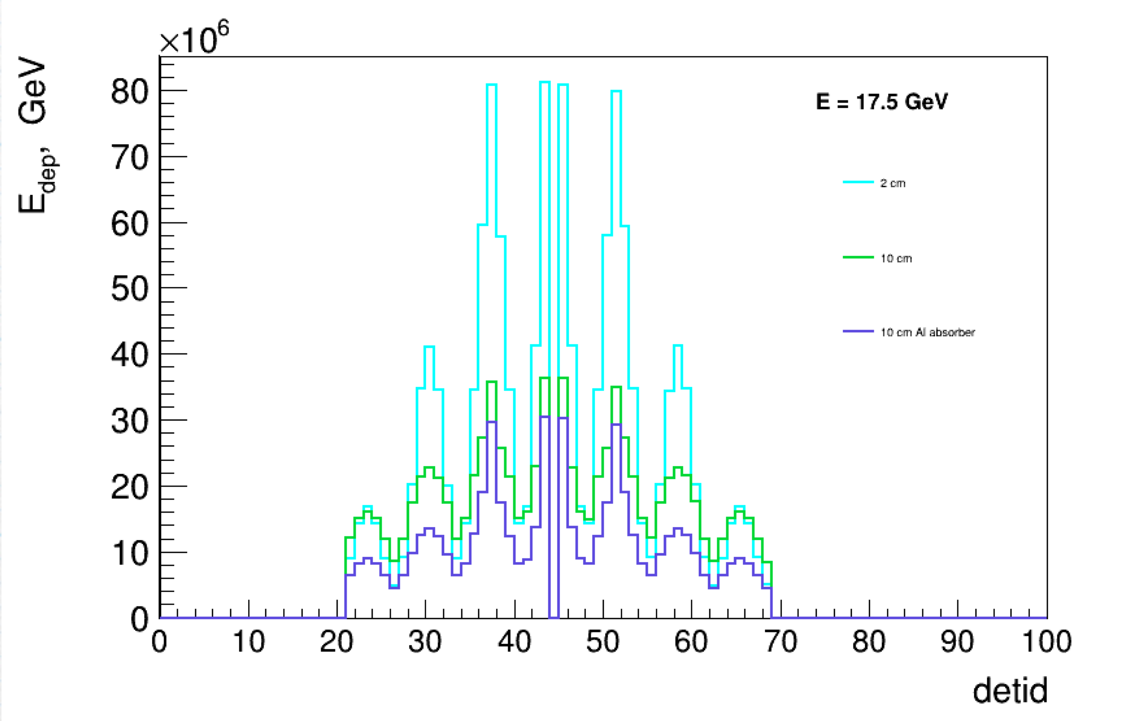


https://doi.org/10.1016/0168-9002(94)90990-3

If, we require the decrease of transmission over the detector depth of 45 cm to be less than 1/e, the tolerable accumulated dose should be about 10^4 rad for TF101 (~ (=> 5* 10^2 rad = 5Gy for TF1))

1rad= 0.01 Gy



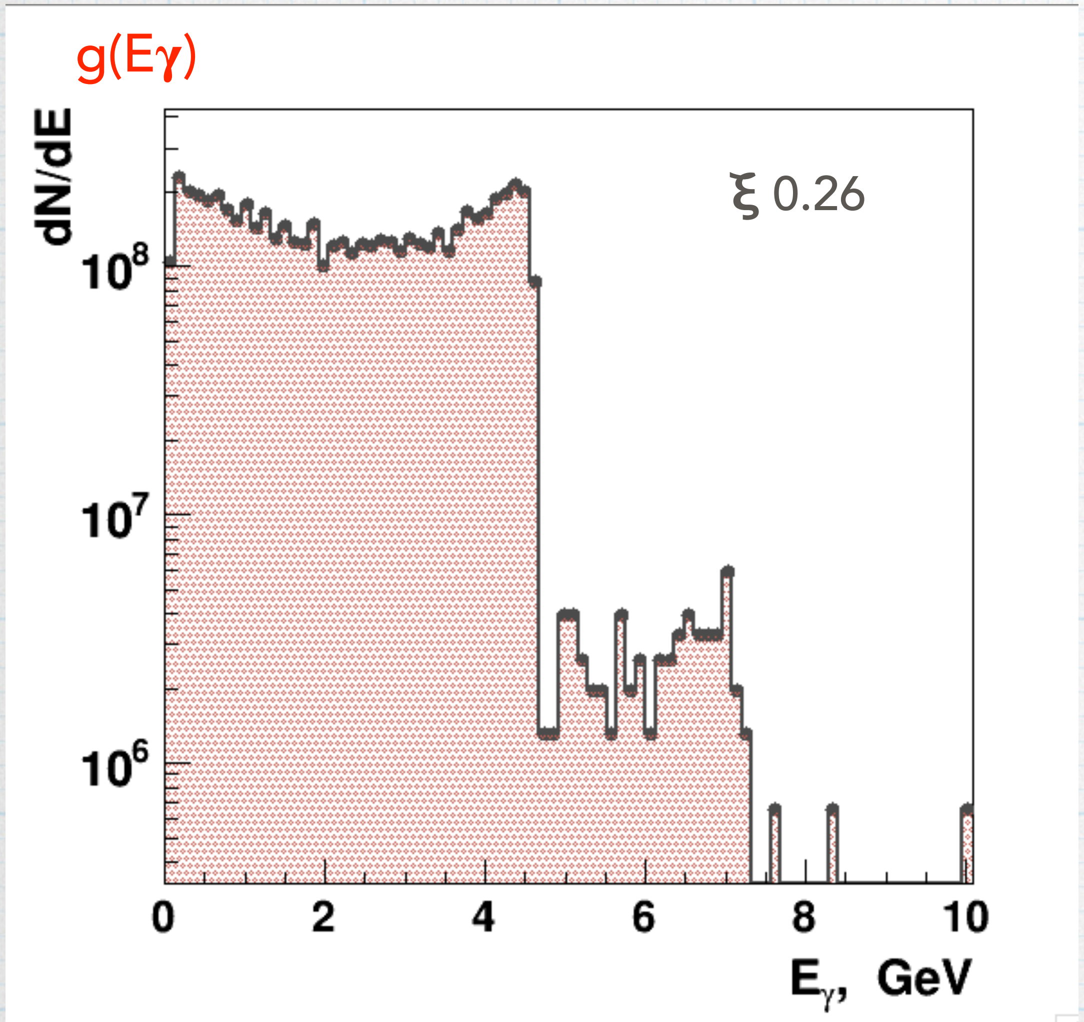


- **Moving further from the dump the deposit in inner layer twice less, which prolonged the usage of inner layer up to 7 hours**
- **Adding 4 cm Al absorber between dump and monitor prolongs up to 10 hours for the inner layer**

Kinematic edges with accurate pair spectrum

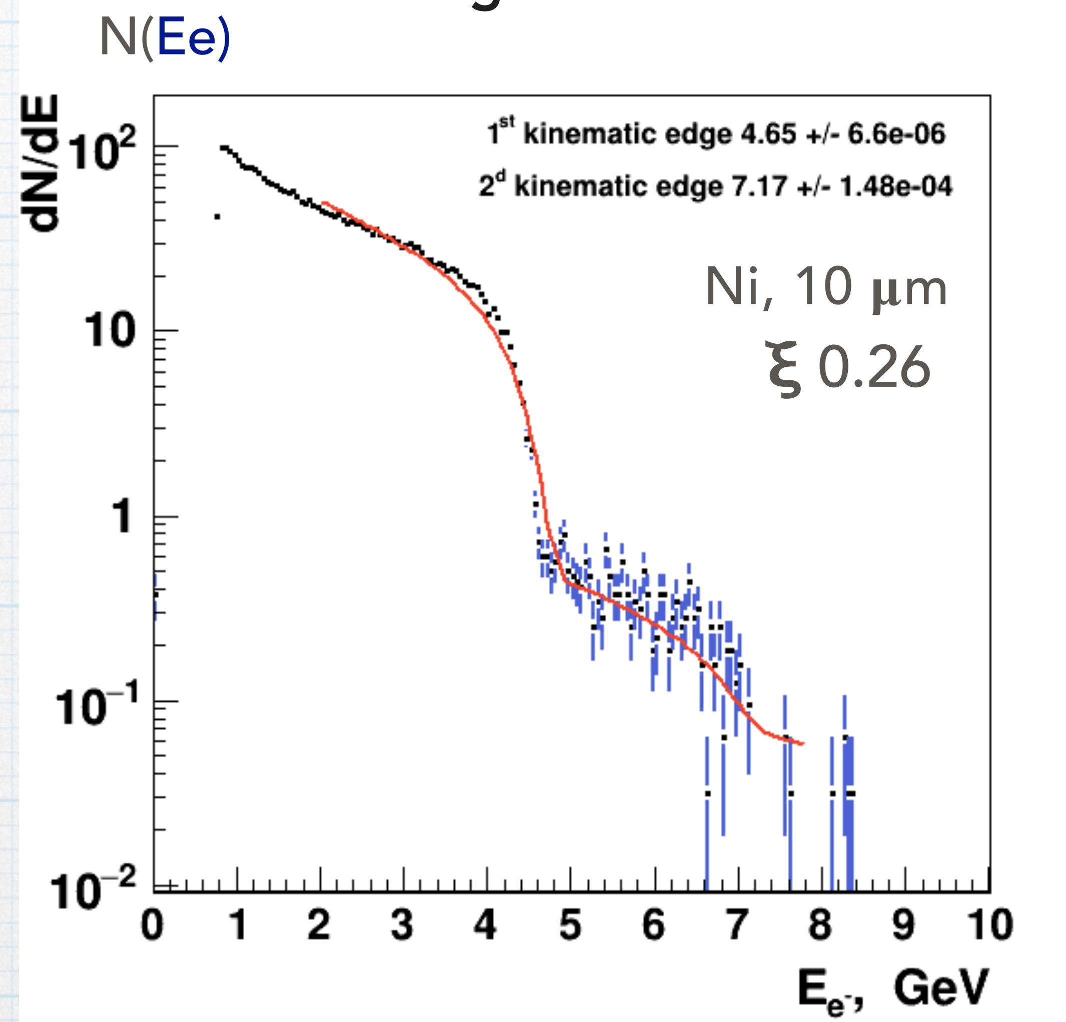
$$f(E_e)=\int \sigma(E_\gamma, E_e)\,g(E_\gamma)\,dE_\gamma$$

True MC photon spectrum generated by Anthony



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**

True electron spectrum generated in GEANT4



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

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

Summary

- ☑ Measuring total energy of back-scattering particles can be used to monitor the flow of incoming photons. Existing (@DESY 4free) lead glass blocks might be a good choice for the calorimeter.
- ☑ The estimated uncertainty on number of measured photons is ~ 10^{-3} - 10^{-2} in case of HICS.
- ☑ Can be used also for bremsstrahlung using the convolution of response function with the spectrum.
- ☑ If we consider the usage of existing (@DESY 4free) lead glass blocks the radiation degradation could be an issue but it could be mitigated.
- ☑ Performed GEANT4 simulations of HICS MC for 14 and 17.5 GeV electron beam and different laser intensity. Kinematic edges of HICS spectra can be well reconstructed (assuming an ideal detector) for relatively low laser intensities. E.g. ξ=0.26, n=1,2,3.
- ☑ Different materials and geometries for conversion target were studied. Number of pairs can be adjusted in wide range, down to ~10^2 to match a comfortable level of chosen detector technology.
- ☐ Degradation of optical properties studies
- ☐ Use more realistic LUXE geometry which has been partly implemented and consider specific (or different) detector techniques implementation.

Back up

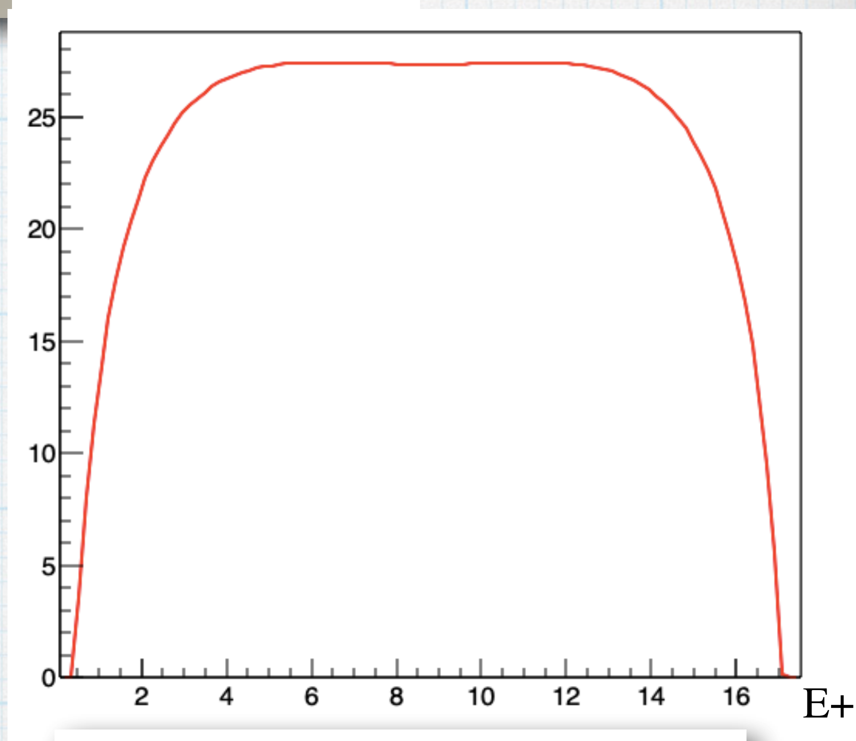
Photon spectra reconstruction using Bethe-Heitler pair spectrum

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

$$\Phi(E_0)\, dE_0 = \frac{Z^2}{137}\left(\frac{e^2}{mc^2}\right)^2 4\, \frac{E_{0+}{}^2 E_+{}^2 + \frac{2}{3} E_0 E_+}{(h\nu)^3}\, dE_0 \left(\log \frac{2E_0 E_+}{h\nu mc^2} - \frac{1}{2}\right).$$

energies involved are large compared with mc^2

$\Phi(E+, E_0=E\gamma)$



$\sigma(E\gamma, Ee) = \Phi(E\gamma,Ee)*N_a$ N_a - Number of atoms

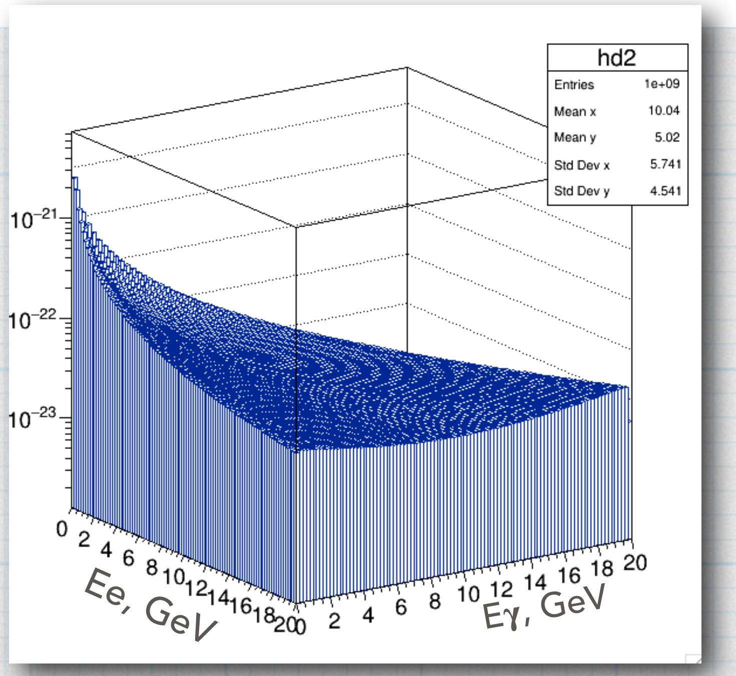
- Photon spectra $g(E\gamma)$ can be reconstructed by fitting

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

  Where N(Ee) positron/electron spectra measured in detector after the conversion.

- Since $\sigma(E\gamma, Ee)$ depends on number of scatters N_a defined by the thickness of the target the approach can be tested by using the thickness as fit parameter

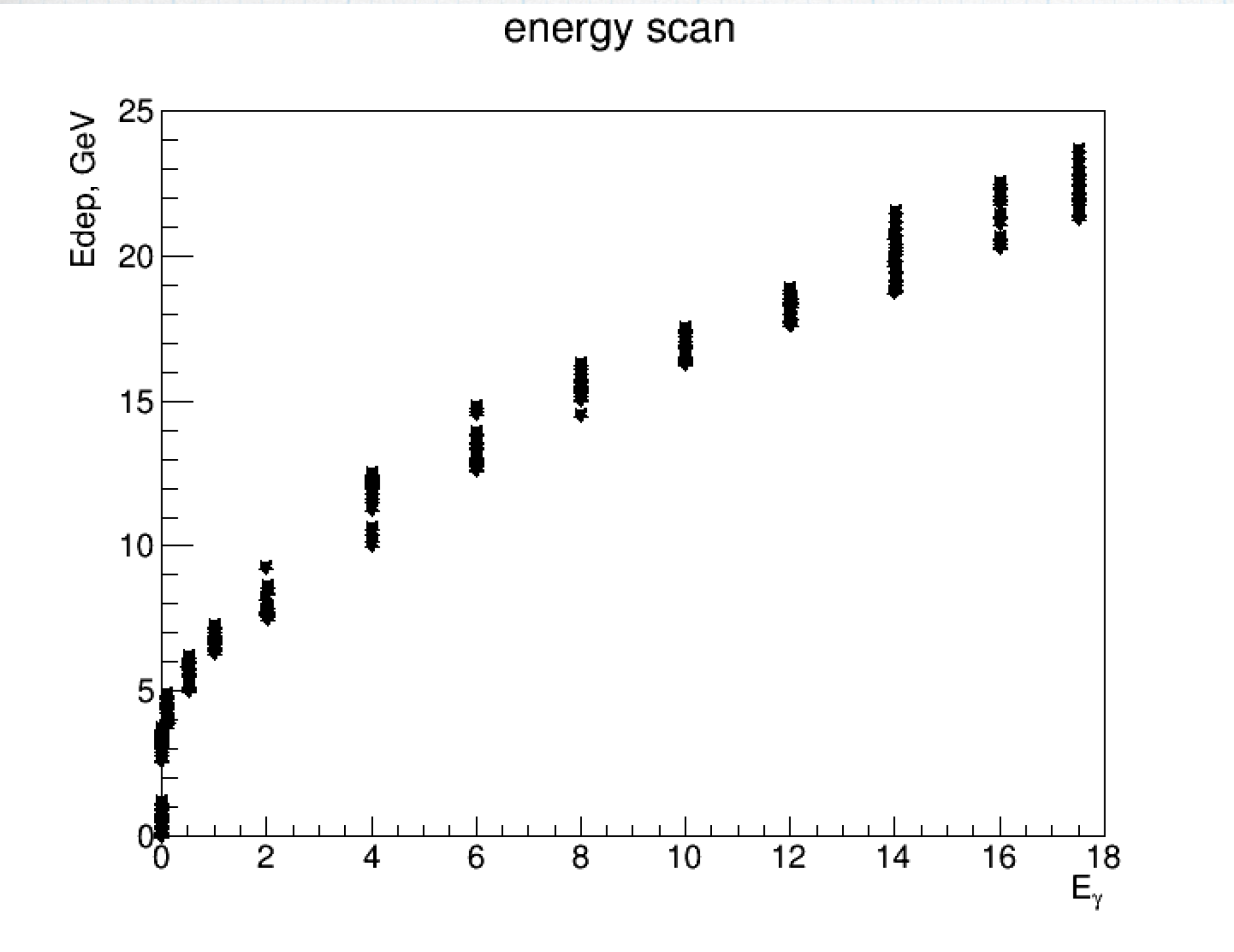
- Used Bethe-Heitler class from Geant4, with corrections and extended for various effects (the screening, the pair creation in the field of atomic electrons, correction to the Born approximation, the LPM suppression mechanism, etc.) to calculate differential cross-section

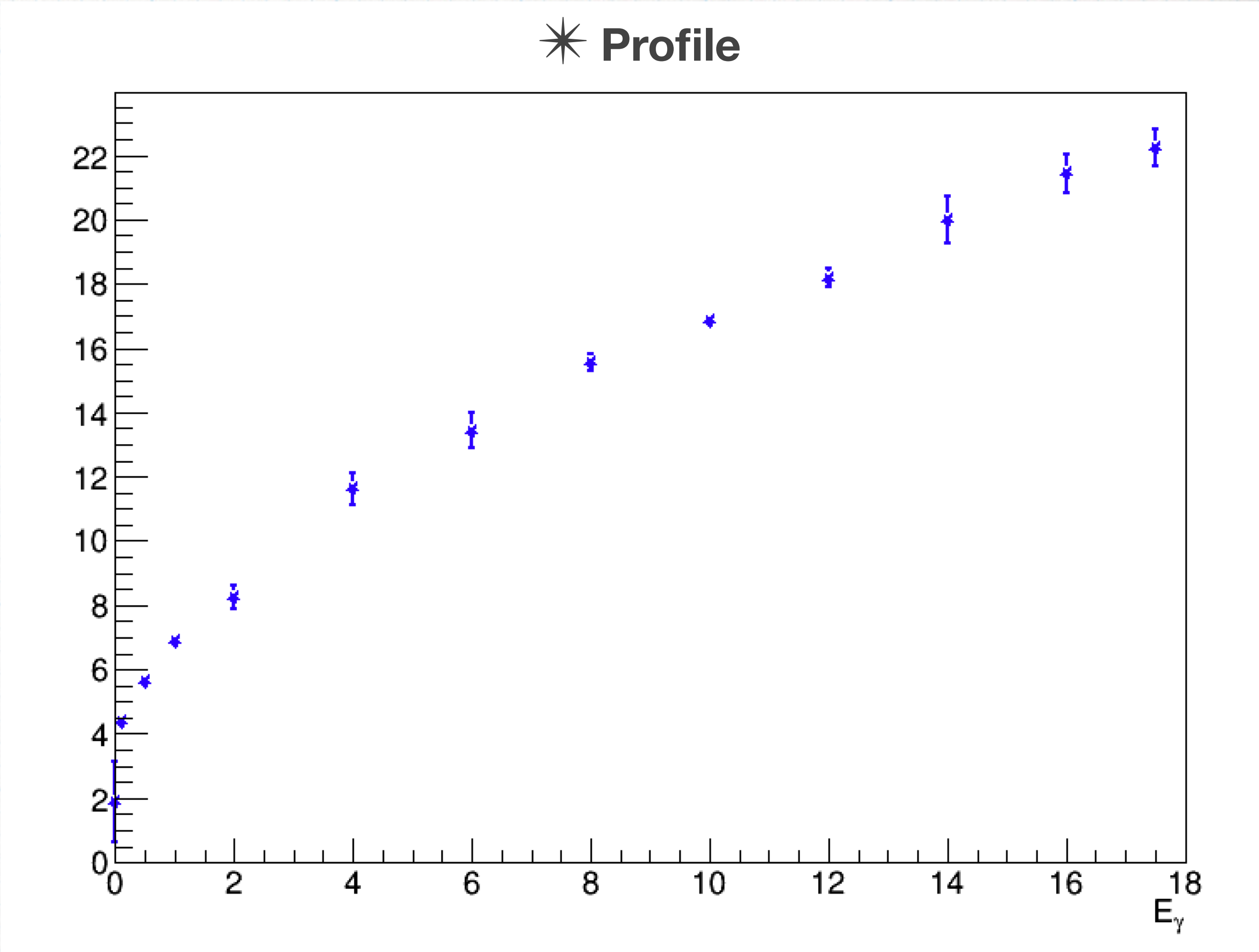


Energy dependence of deposited energy in Gamma monitor

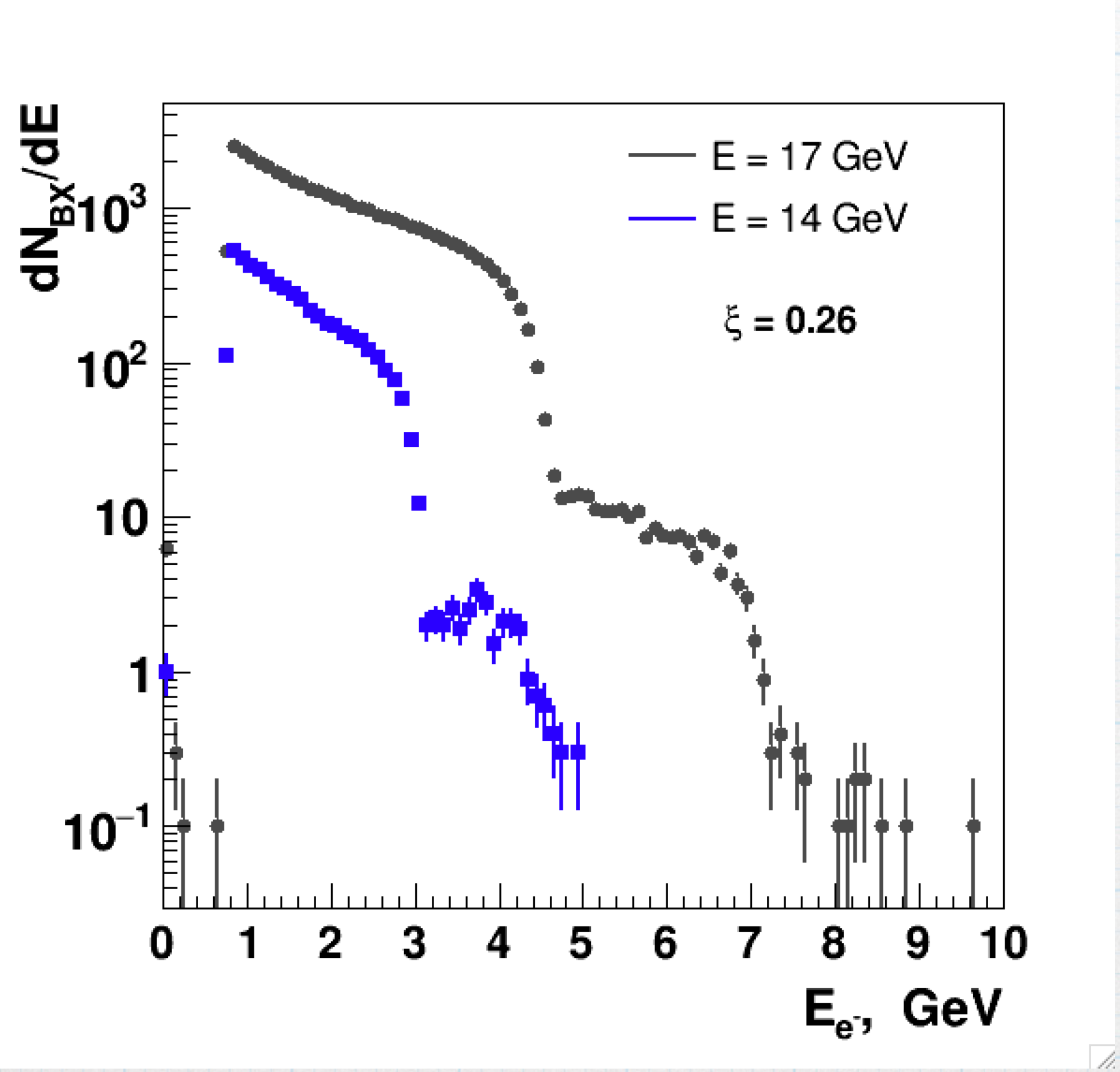
20 Runs* 100000 photons with mono energies: 1,2,4,6,8,10,12,14,16 and 17.5 GeV

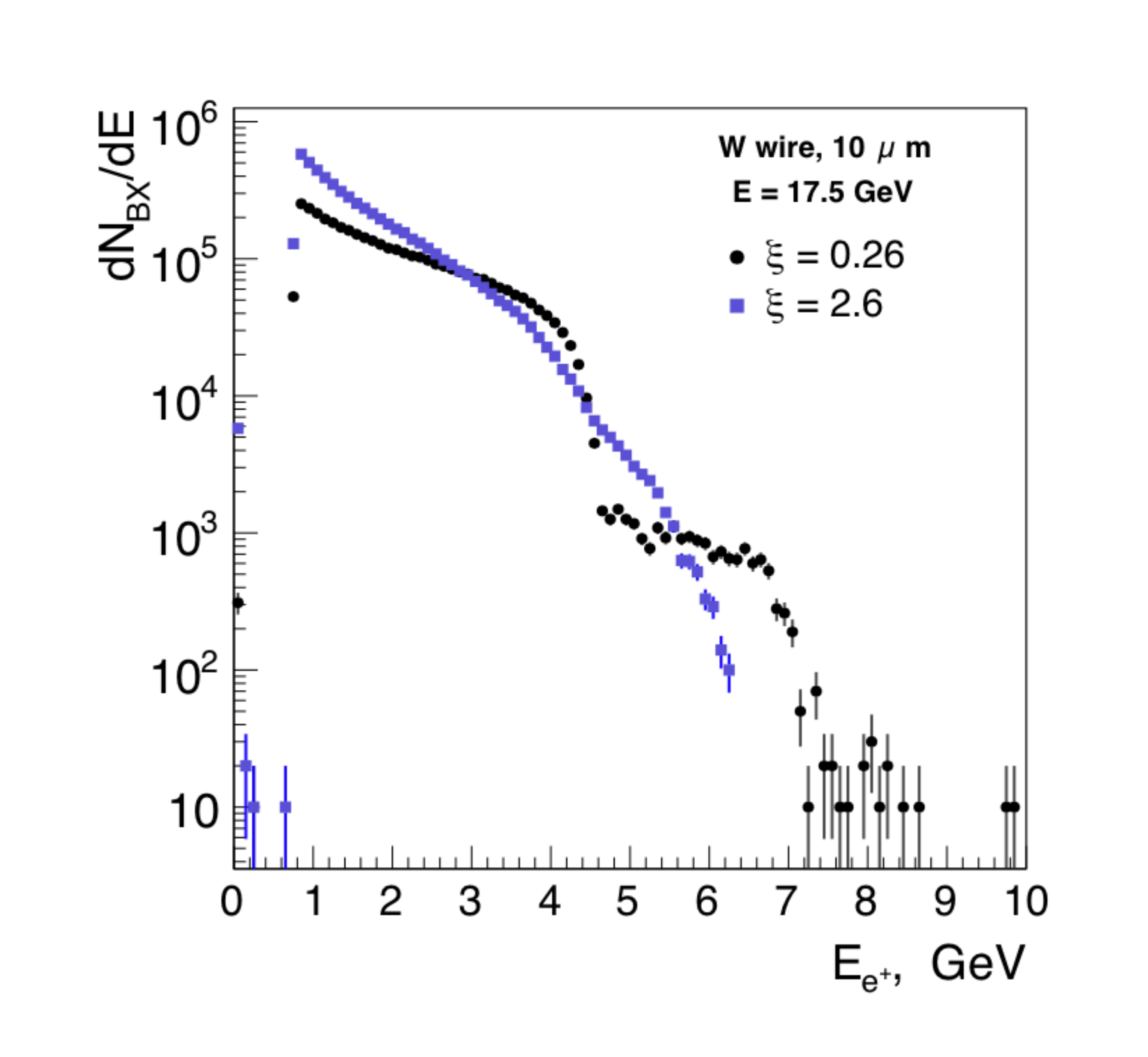
Added lower energies 0.0001, 0.1, 0.5 GeV





Photon spectra for E_γ =14 vs 17.5 GeV and ξ =0.26 vs 2.6

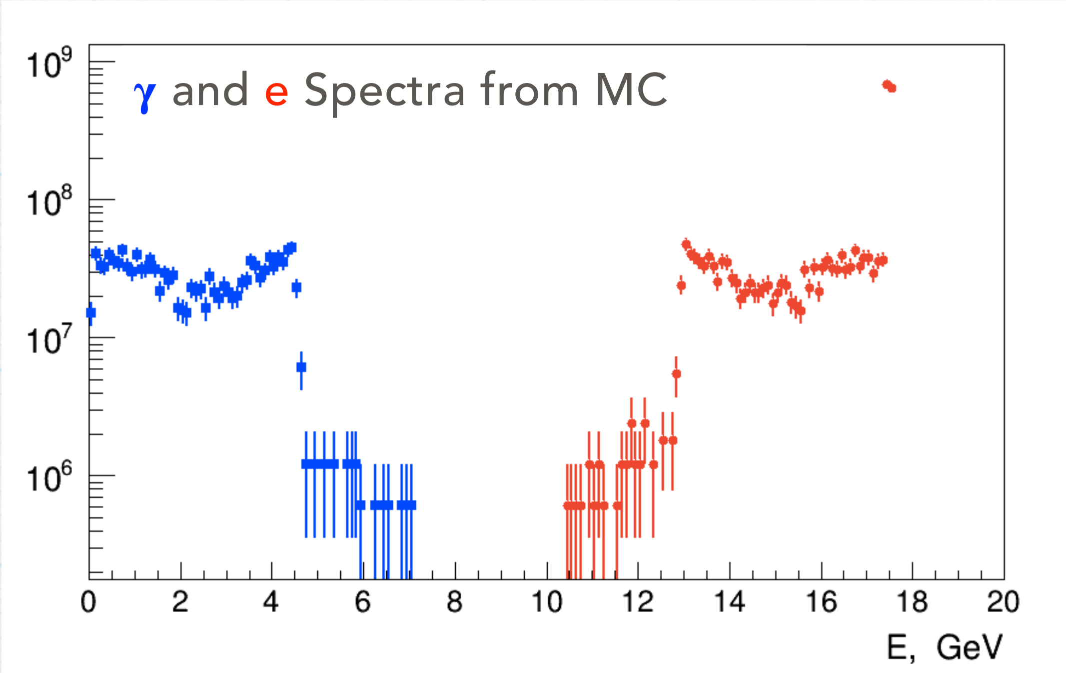




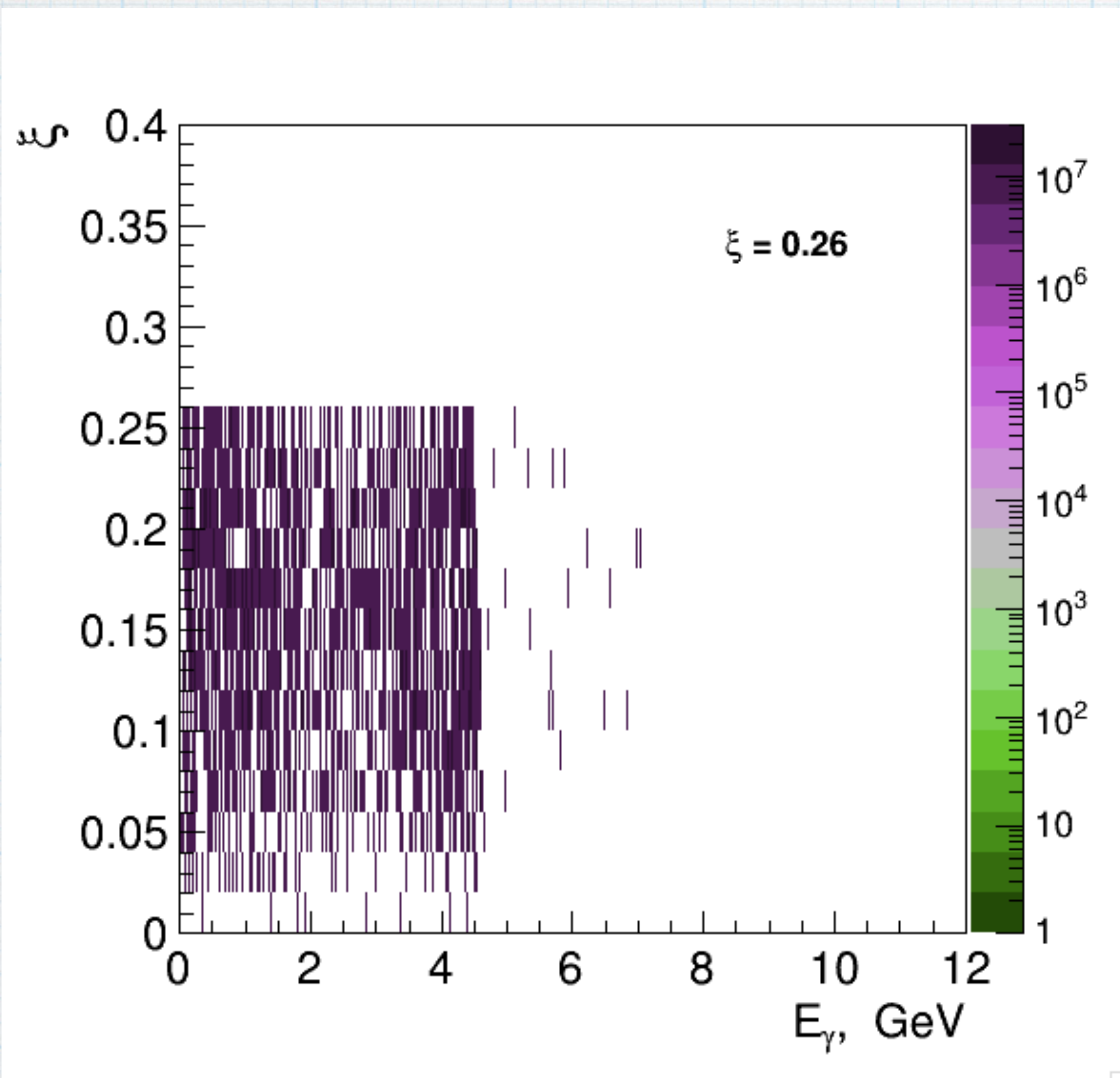
Peak ξ = 0.26 (0.01 J)

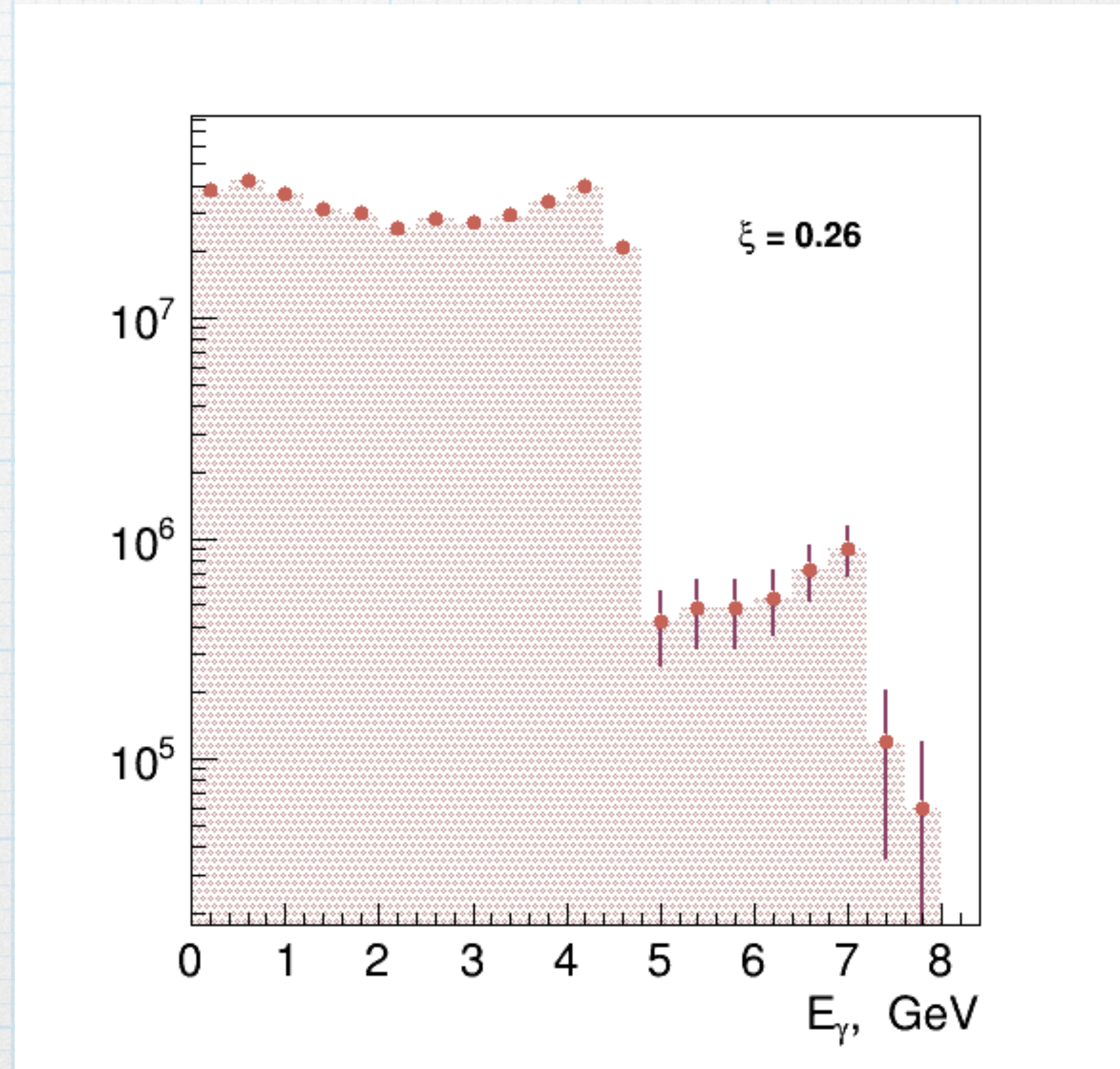
Eγ FROM MC Ee= 17.5 GeV

Peak ξ = 0.26



For 800 nm laser, 17.5 GeV electrons: Compton edge ~ 5.14 GeV
the first kinematic edge is shifted approximately by 200 MeV



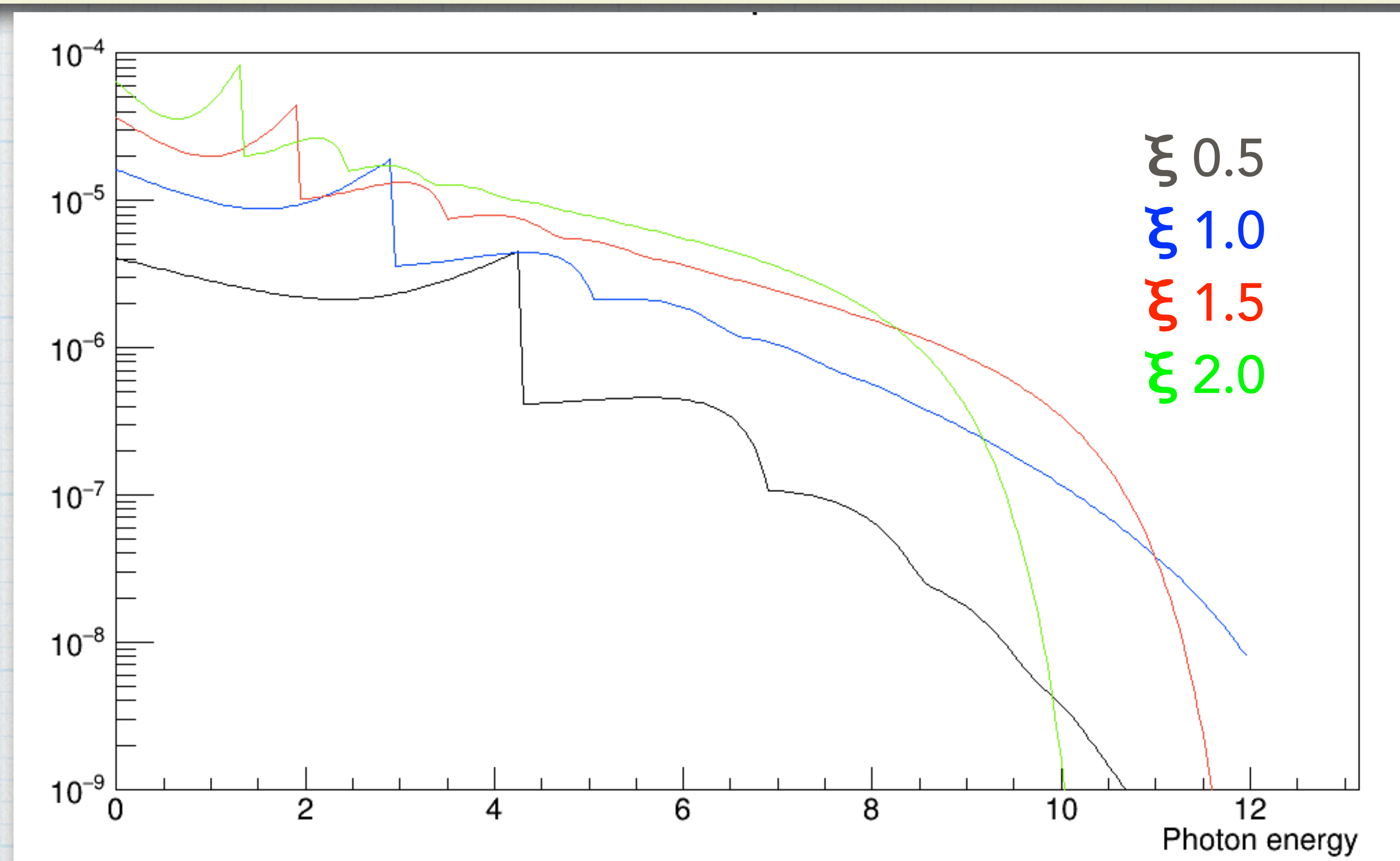


Test photon spectra reconstruction using HICS differential cross section

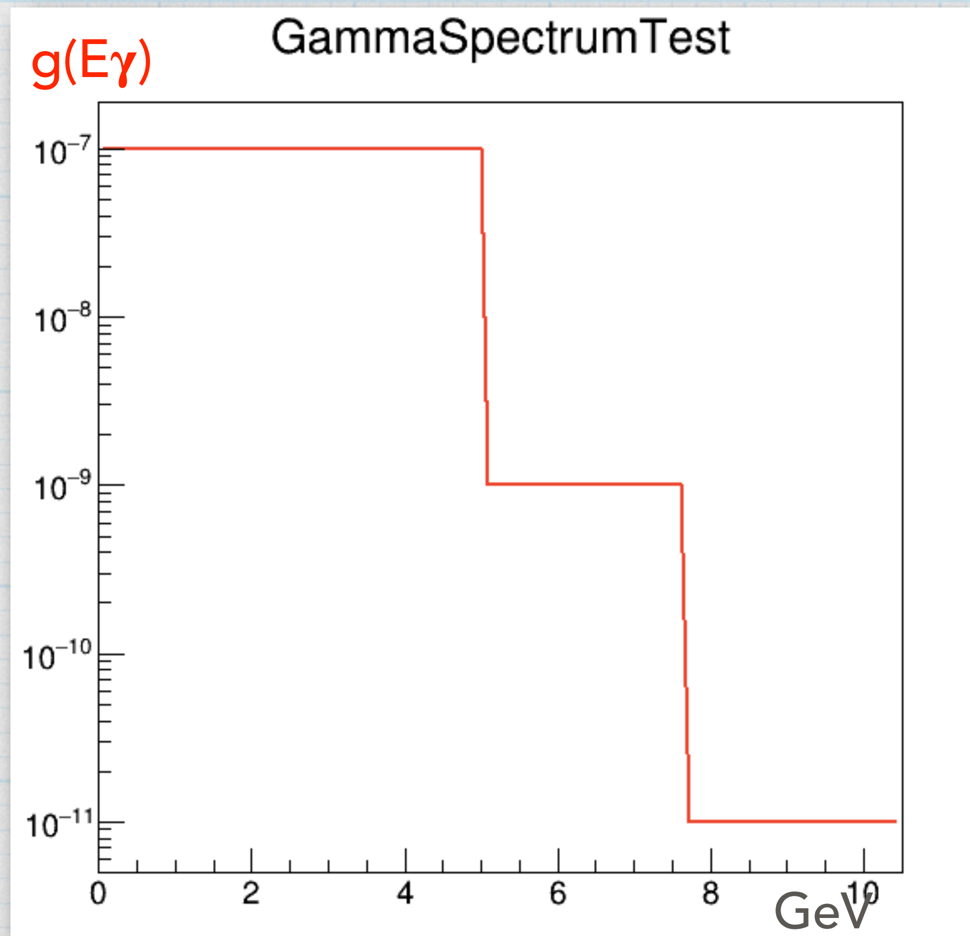
$$\Gamma_{\mathrm{HICS}} = -\frac{\alpha m^2}{\epsilon_{\mathrm{i}}} \sum_{n=1}^{\infty} \int_0^{u_n} \frac{du}{(1+u)^2} \left[\mathrm{J}_n^2(z_u) - \frac{\xi^2}{4} \frac{1+(1+u)^2}{1+u} \left(\mathrm{J}_{n+1}^2 + \mathrm{J}_{n\text{-}1}^2 - 2\,\mathrm{J}_n^2 \right) \right]$$

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

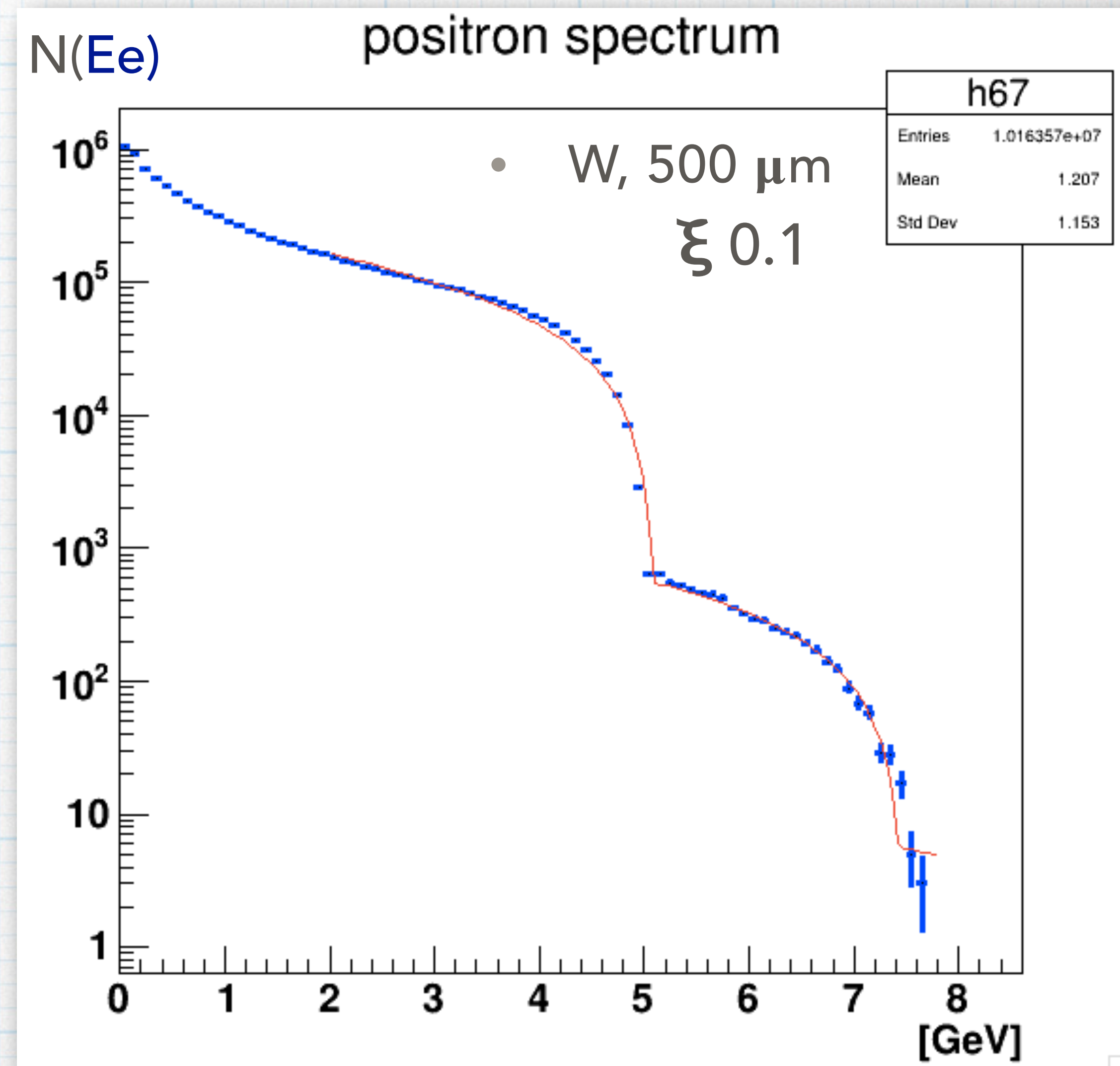
Increasing ξ increases the HICS rate, but suppresses the photon energy (the mass shift)



Kinematic edges and target thickness reconstruction



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
$3.5 \cdot 10^{-3}$	$3.2 \cdot 10^{-3}$
$5 \cdot 10^{-3}$	$4.6 \cdot 10^{-3}$
10^{-2}	$0.9 \cdot 10^{-2}$
$2 \cdot 10^{-2}$	$1.8 \cdot 10^{-2}$
$5 \cdot 10^{-2}$	$5.01 \cdot 10^{-2}$

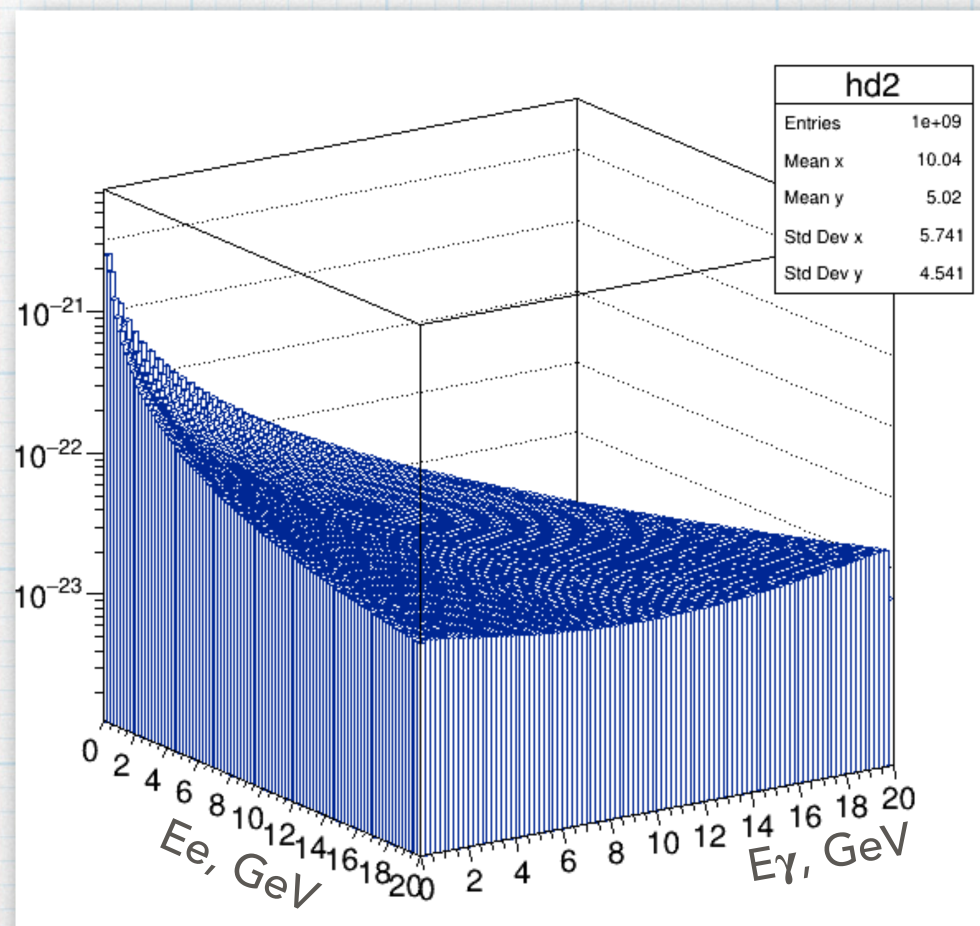
Using accurate pair spectrum

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

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

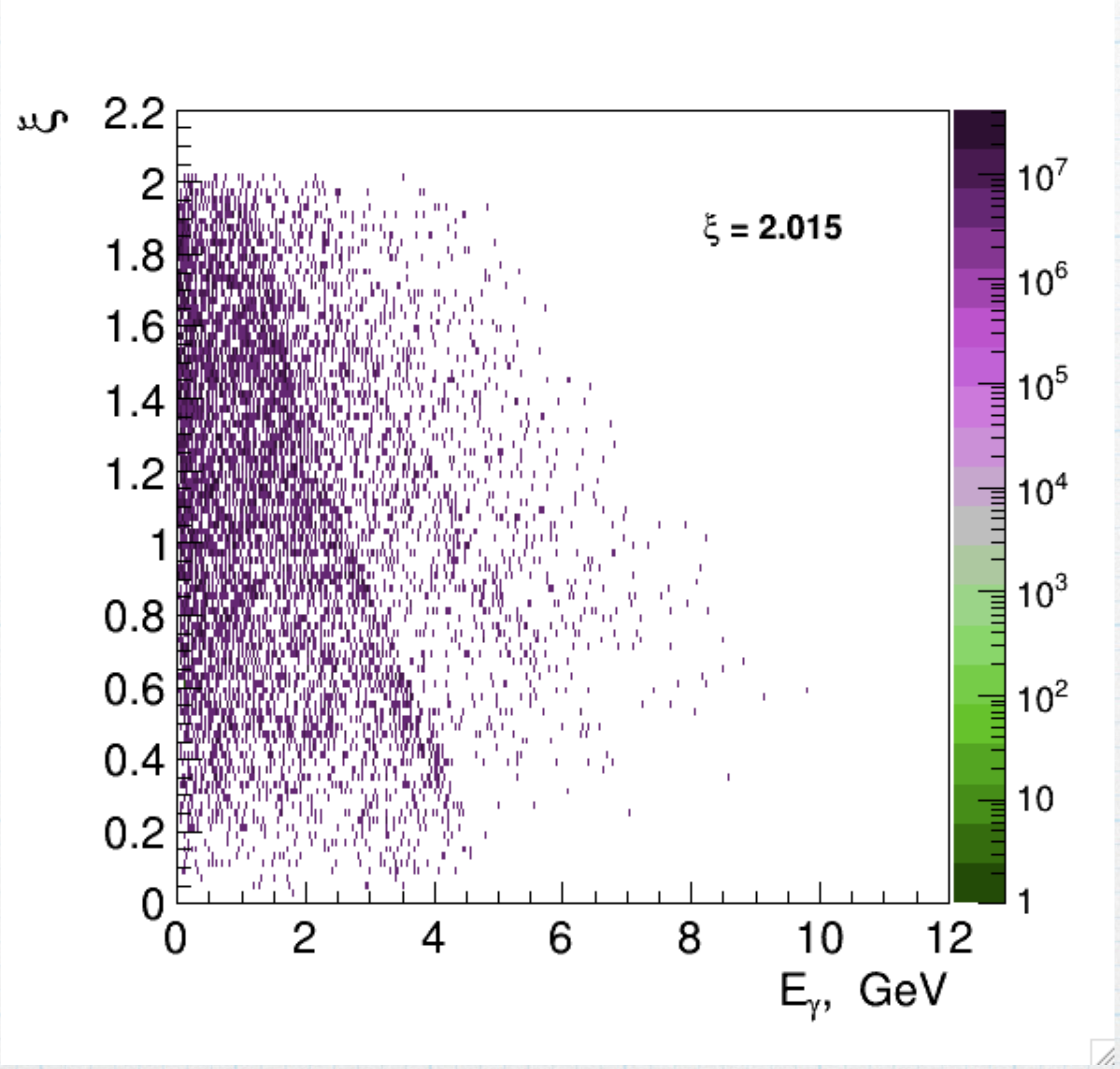
energies involved are large compared with mc^2

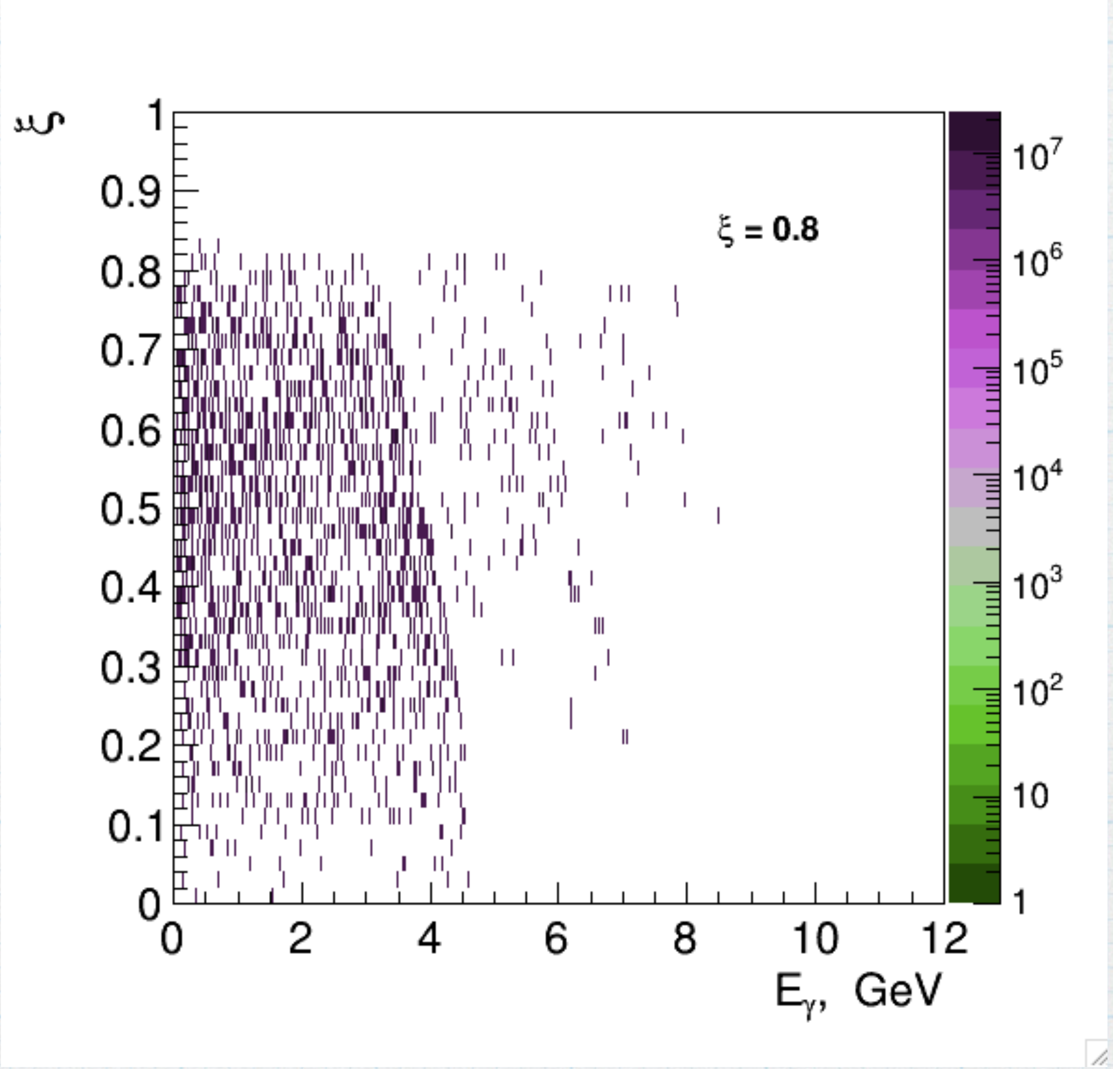
Corrected Bethe-Heitler cross-section from GEANT4 is currently used:



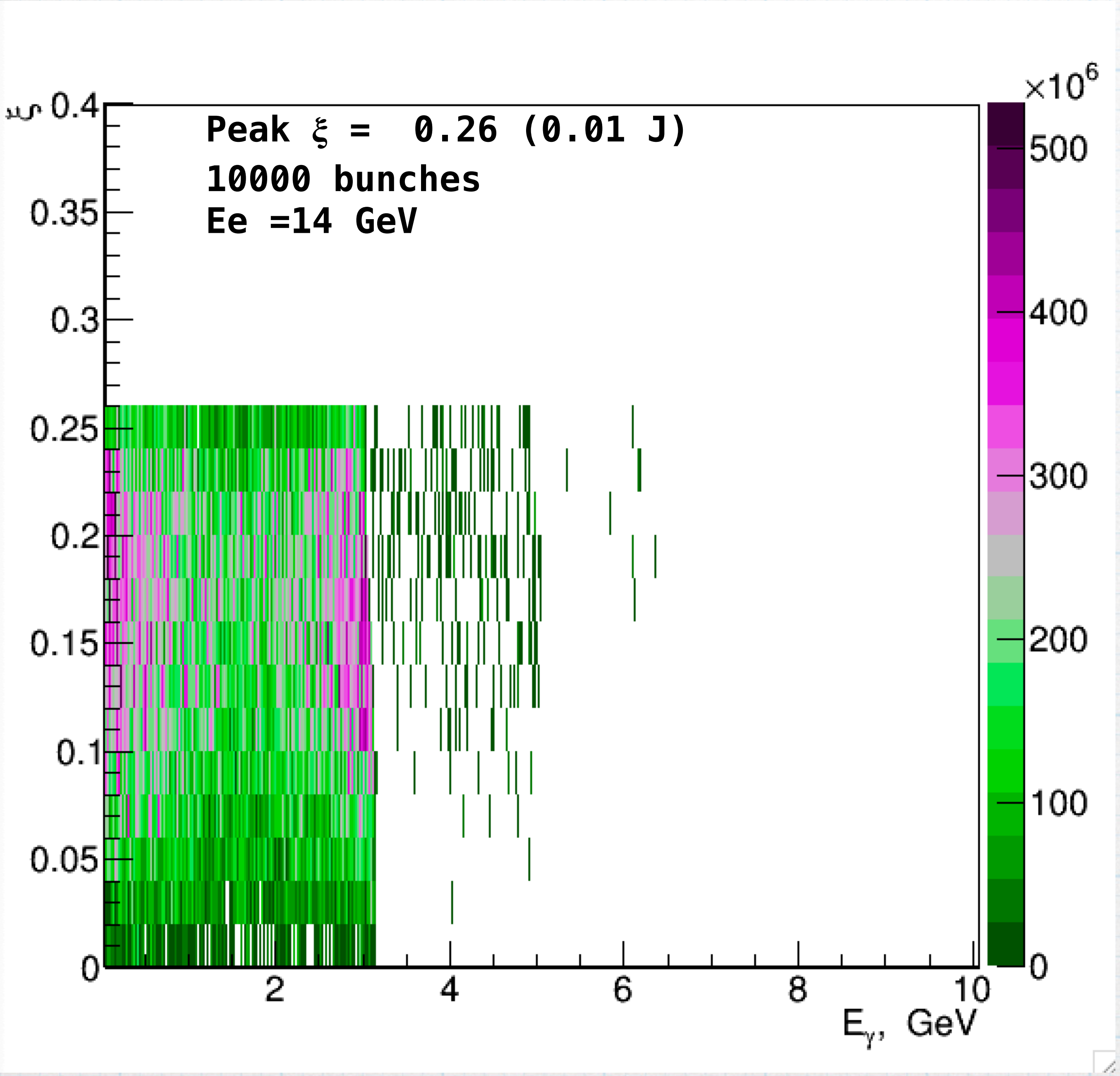
- Used Bethe-Heitler class from Geant4, with corrections and extended for various effects (the screening, the pair creation in the field of atomic electrons, correction to the Born approximation, the LPM suppression mechanism, etc.) to calculate differential cross-section

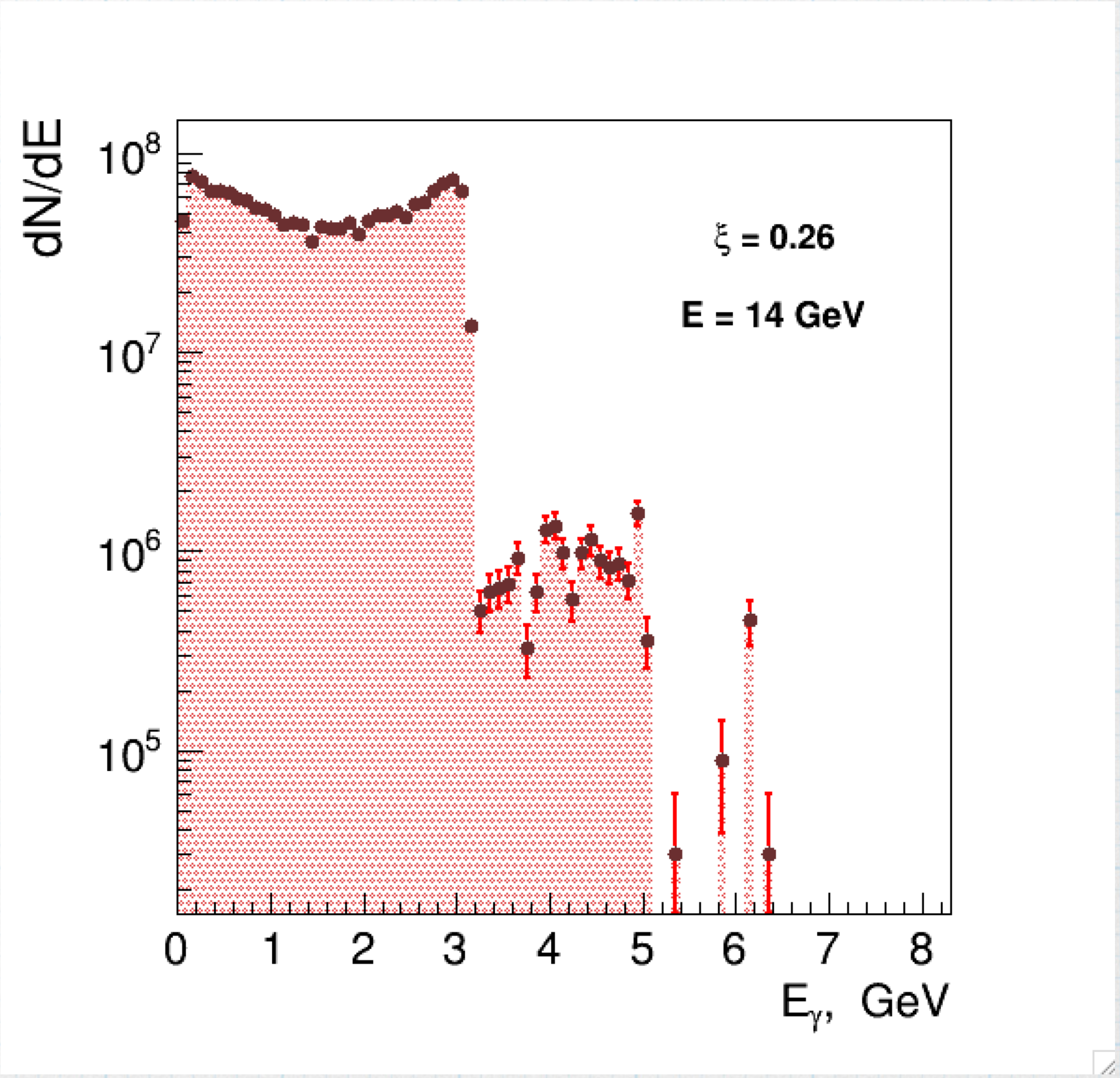
ξ vs E_γ FROM MC for E_γ= 17.5 GeV





ξ vs Eγ FROM MC for 14 GeV

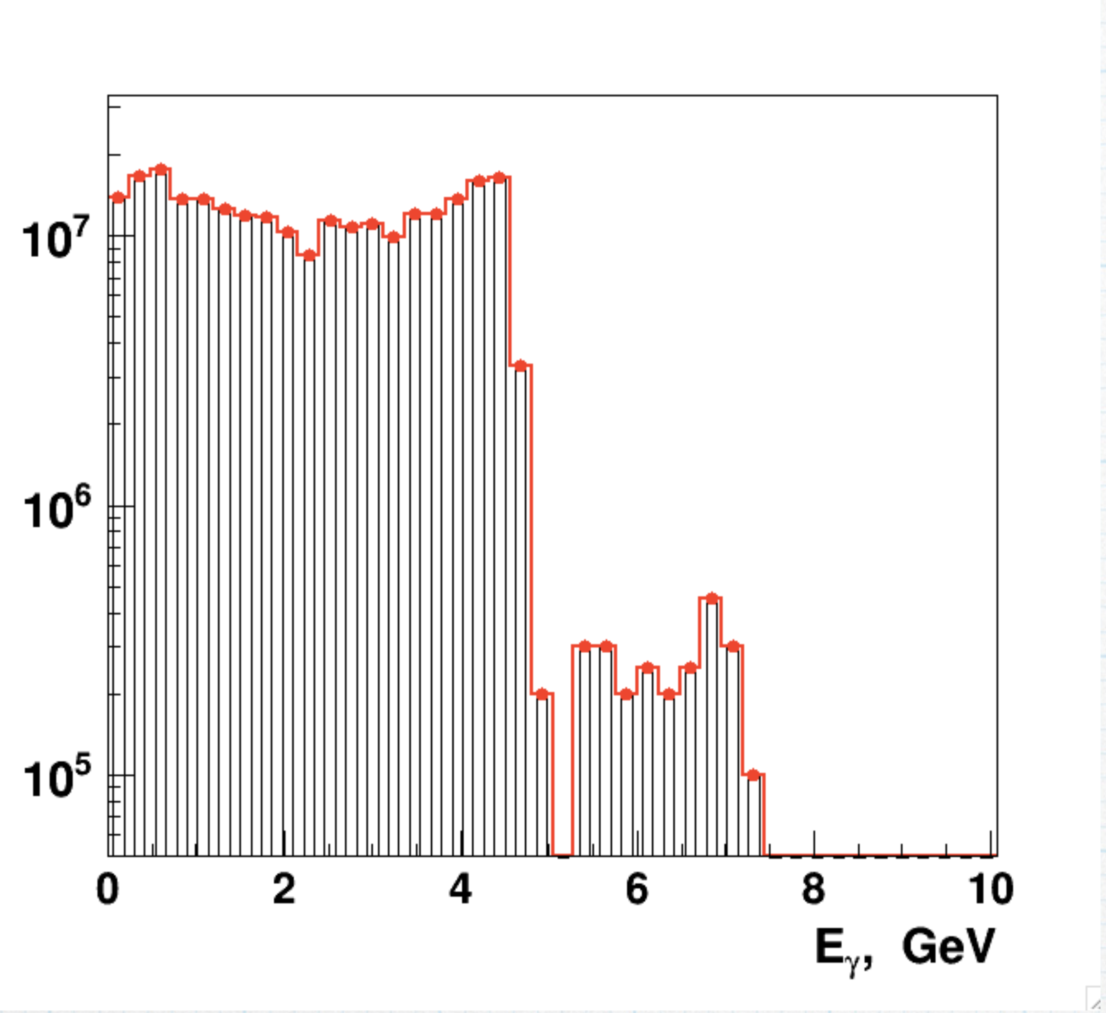


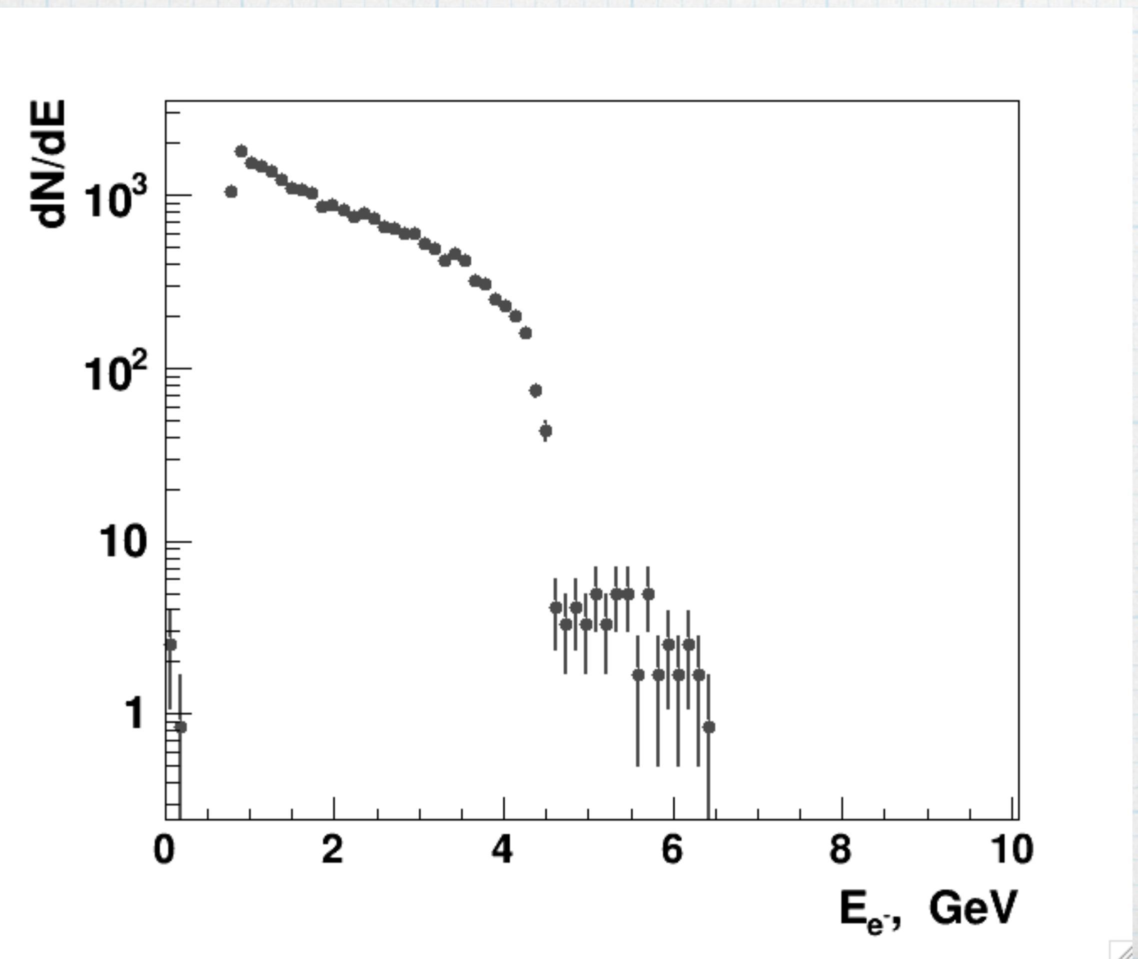


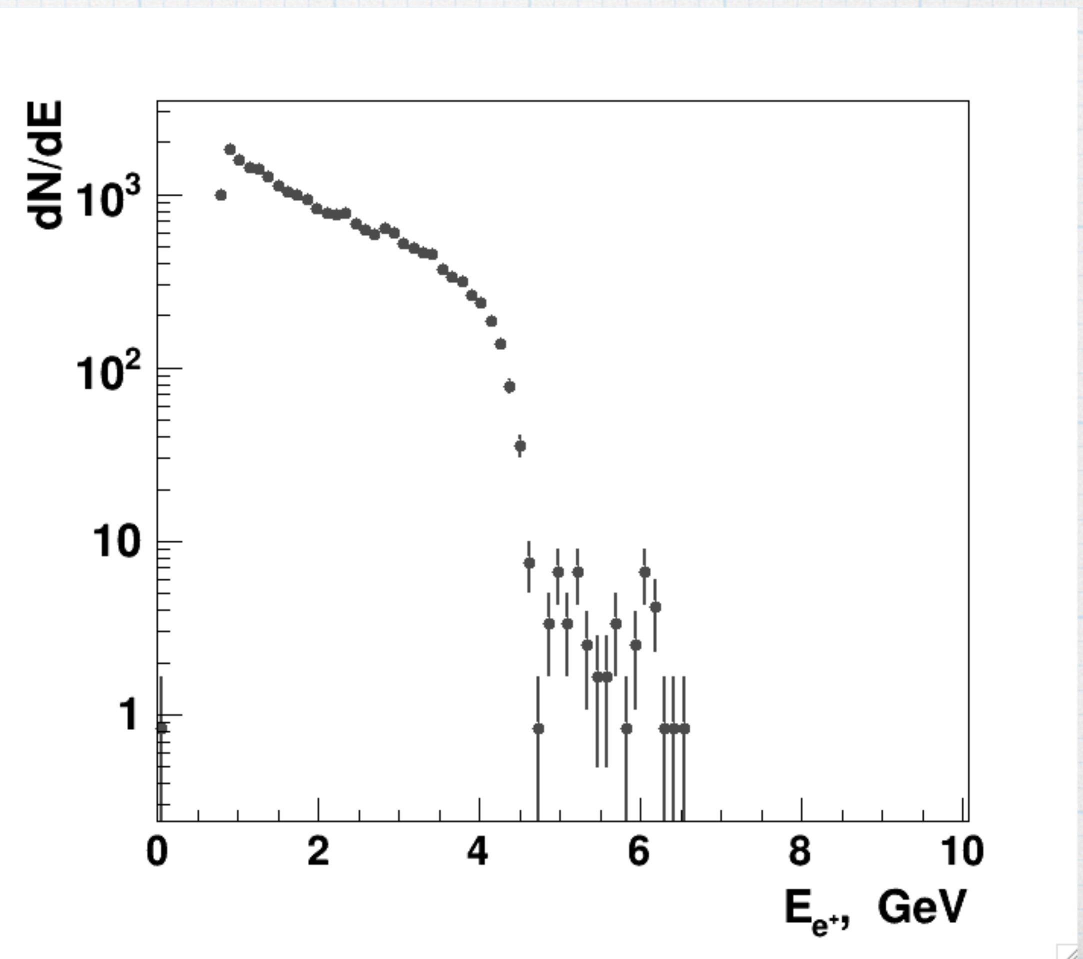
Geant4 simulation for the W wire converter

1000 BX

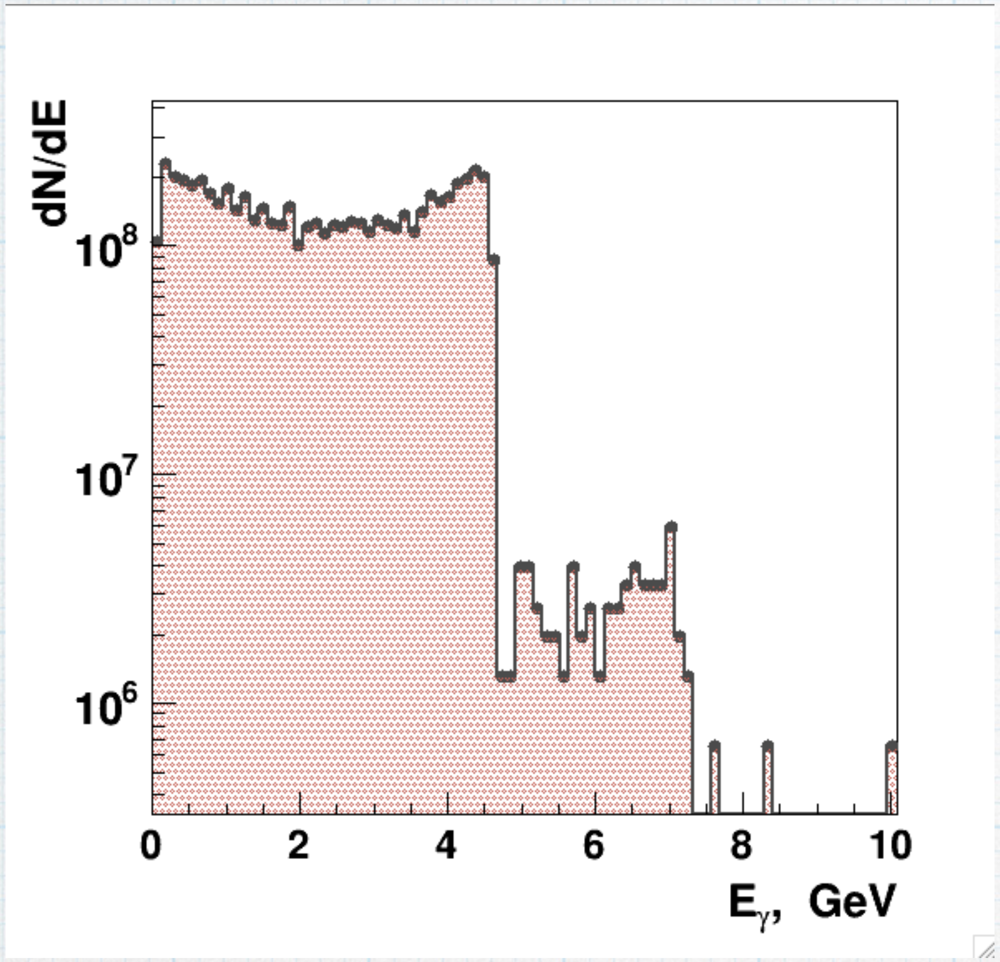
W thickness 10 um







Geant4 simulation for the Ni wire converter spectra



~63000 BX

Ni thickness 10 um