LUXE Experimental Conditions and Detector Design

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Outline

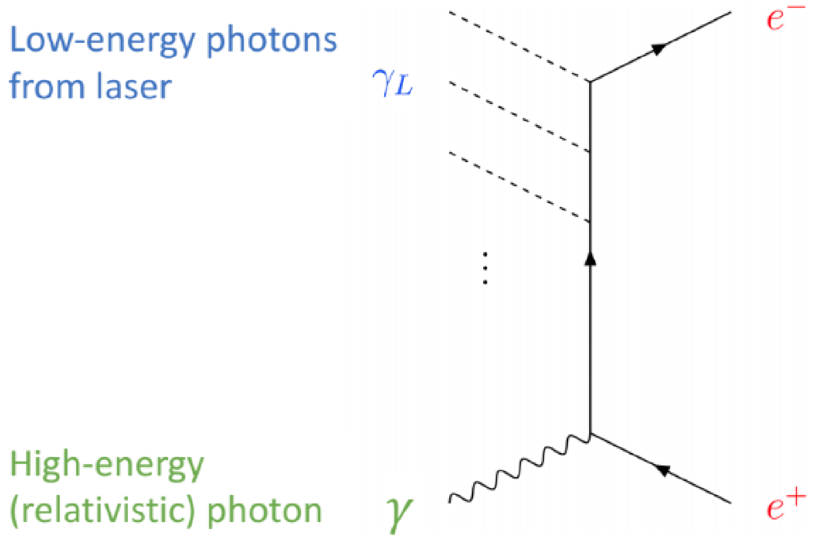
LUXE – **L**aser **U**nd **X**FEL **E**xpriment

- Introduction
- LUXE setup for bremsstrahlung photon pair production study
- Signal study in MC simulations
- Background estimation for different geometries

Laser-assisted pair production

$$\gamma + n\omega \rightarrow e^+ e^-$$

One photon pair production (OPPP) at ultra high intensity - non-perturbative physics



The rate of laser-assisted (OPPP) rate:

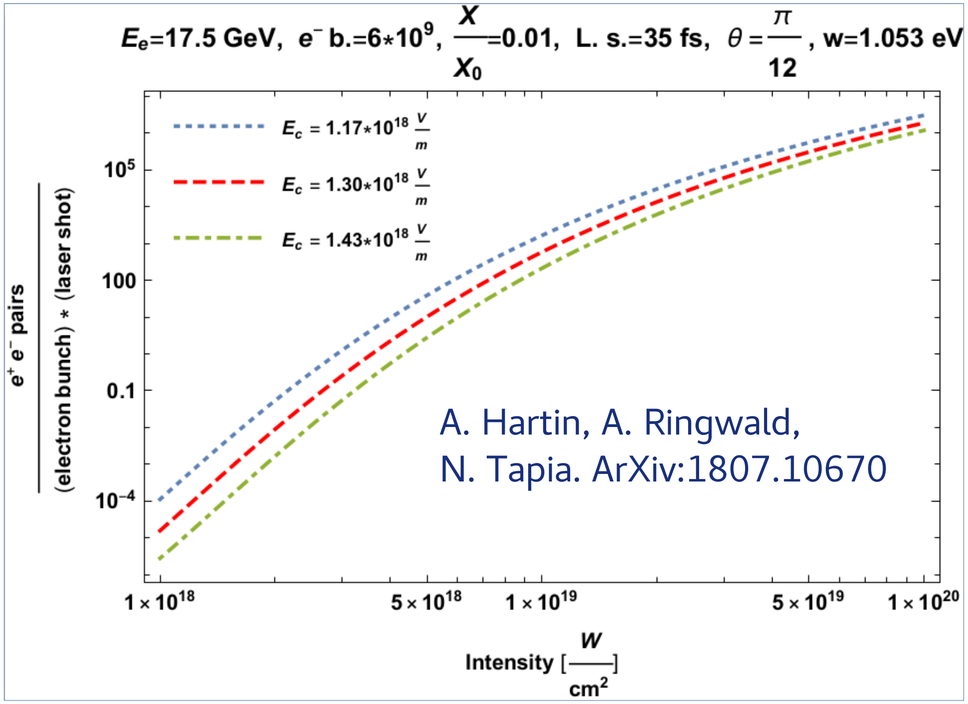
$$\Gamma_{\rm OPPP} = \frac{\alpha m_e^2}{4\,\omega_{\rm i}} F_\gamma(\xi, \chi_\gamma)$$

$$\xi \equiv \frac{e\,|\mathbf{E}|}{\omega m_e} = \frac{m_e}{\omega}\frac{|\mathbf{E}|}{\mathrm{E}_c}\,, \qquad \chi_\gamma \equiv \frac{k \cdot k_i}{m_e^2}\,\xi = (1+\cos\theta)\,\frac{\omega_i}{m_e}\frac{|\mathbf{E}|}{\mathrm{E}_c}$$

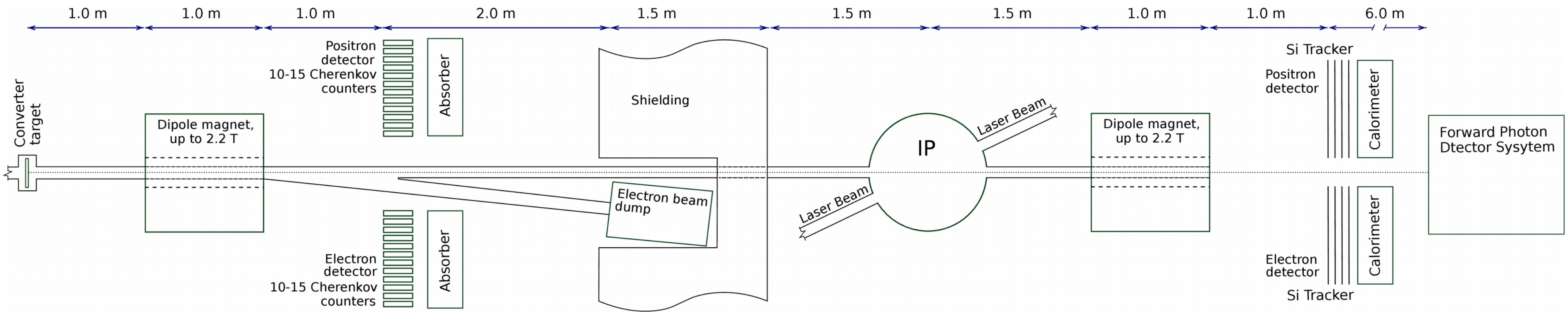
Use bremsstrahlung photons produced by XFEL beam hitting tungsten target.

$$\Gamma_{\rm BPPP} = \frac{\alpha\, m_e^2}{4}\int_0^{E_e}\frac{\mathrm{d}\omega_i}{\omega_{\rm i}}\frac{\mathrm{d}N_\gamma}{\mathrm{d}\omega_i}\,F_\gamma(\xi, \chi_\gamma(\omega_i))$$

$$\Gamma_{\rm BPPP} \rightarrow \frac{\alpha\, m_e^2}{E_e}\,\frac{9}{128}\sqrt{\frac{3}{2}}\,\chi_e^2\, e^{-\frac{8}{3\chi_e}\left(1-\frac{1}{15\xi^2}\right)}\,\frac{X}{X_0}$$



Photon-Photon collisions at LUXE



European XFEL beam for LUXE

Parameter	Value
Beam Energy [GeV]	up to 17.5
Bunch Charge [nC]	0.25–1.0
Number of bunches	1
Repetition Rate [Hz]	up to 10
Spotsize at the IP [μm]	5–20

e^- 1.26 – 6.25 x 10^9

Normalized emittance 1.4 mm mrad;

Laser parameters for different stages of LUXE

	30 TW, 8μm	**300 TW, 8μm**	**300 TW, 3μm**
Laser energy after compression (J)	0.9	9	9
Percentage of laser in focus (%)	40	40	40
Laser energy in focus (J)	0.36	3.6	3.6
Laser pulse duration (fs)	30	30	30
Laser focal spot FWHM (μm)	8	8	3
Peak intensity in focus (Wcm^{-2})	1.6×10^{19}	1.6×10^{20}	1.1×10^{21}
Dimensionless peak intensity, ξ	2	6.2	16
Laser repetition rate (Hz)	1	1	1
Electron-laser crossing angle (rad))	0.35	0.35	0.35

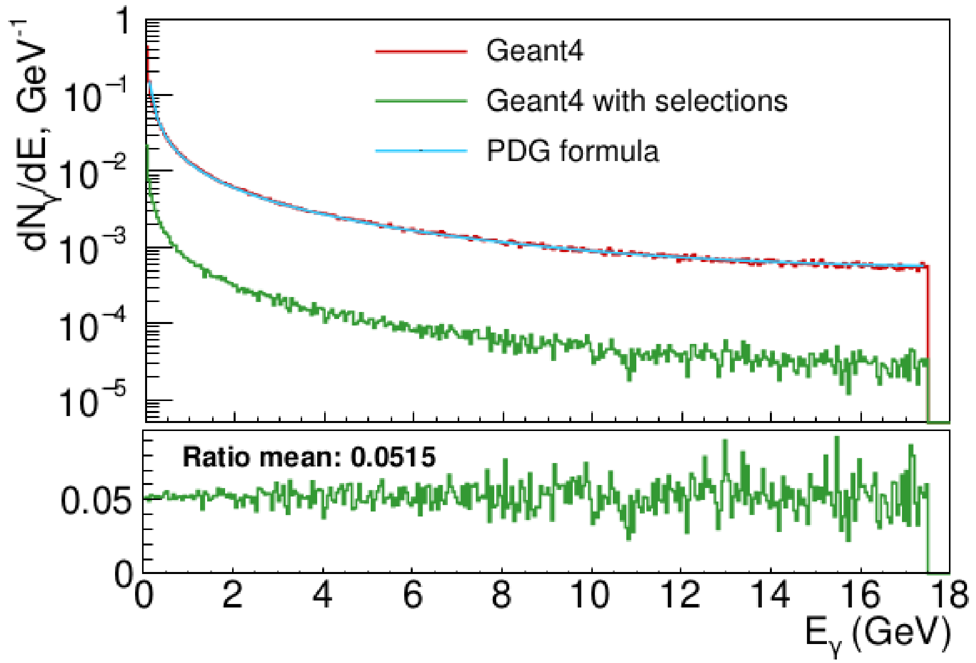
Bremsstrahlung production: Geant4 vs PDG formula

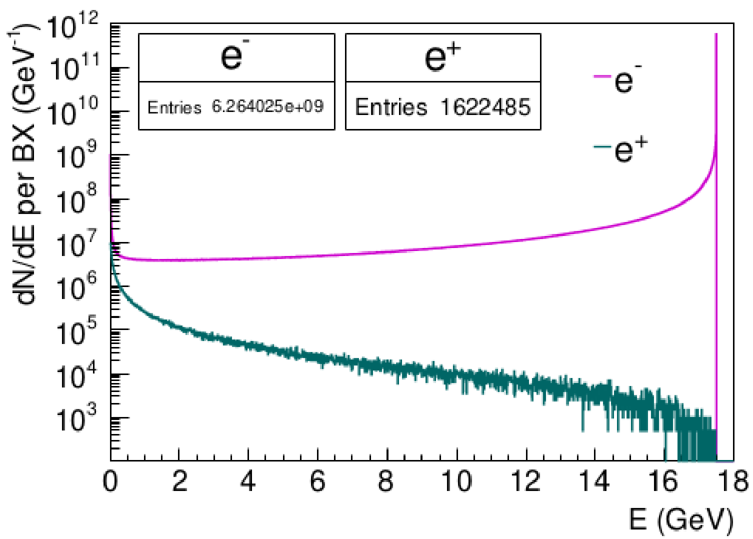
PDG recommended formula for thin targets for bremsstrahlung production:

$$\omega_i \frac{dN_\gamma}{d\omega_i} \approx \left[\frac{4}{3} - \frac{4}{3}\left(\frac{\omega_i}{E_e}\right) + \left(\frac{\omega_i}{E_e}\right)^2\right] \frac{X}{X_0}$$

It is used to calculate integral on slide 3 to get the pair production rate.

- The formula does not take into account angular distribution of bremsstrahlung photons
- Geant4 simulation:
  - accounts for laser beam transverse size
  - and thick targets to optimize the photon flux.





- Gaussian beam;
- Tungsten target 1%X0 (35um), 2m from IP;
- 10M electrons
- Two histograms are compared:
  - |x| < 1mm and |y| < 1mm;
  - |x| < 25um and |y| < 25um.

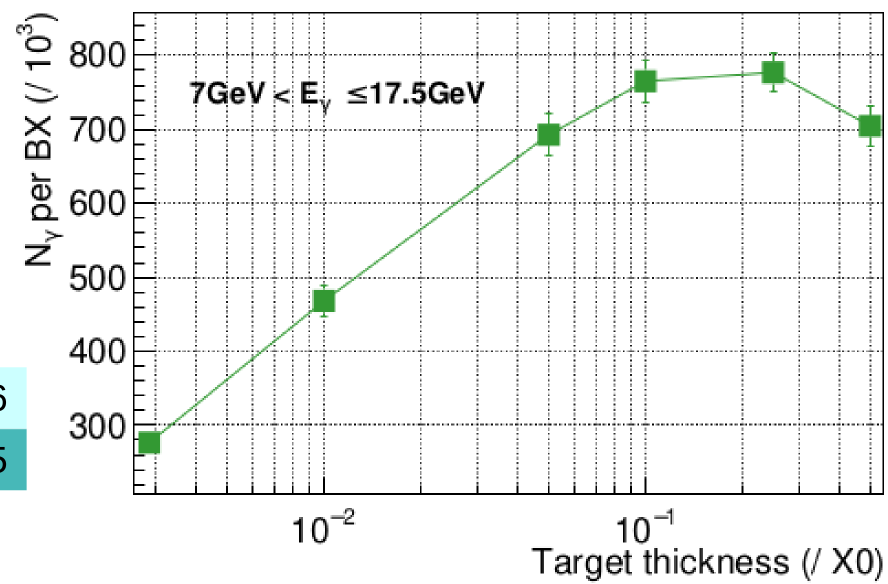
Geant4 simulation with different target thickness and different physics lists

- Gaussian beam, focused on IP;
- Tungsten target 1%X0 (35um) thickness
- 5 m from IP;
- 6.25 M electrons (BX/1000);
- Production cut: 1 µm.

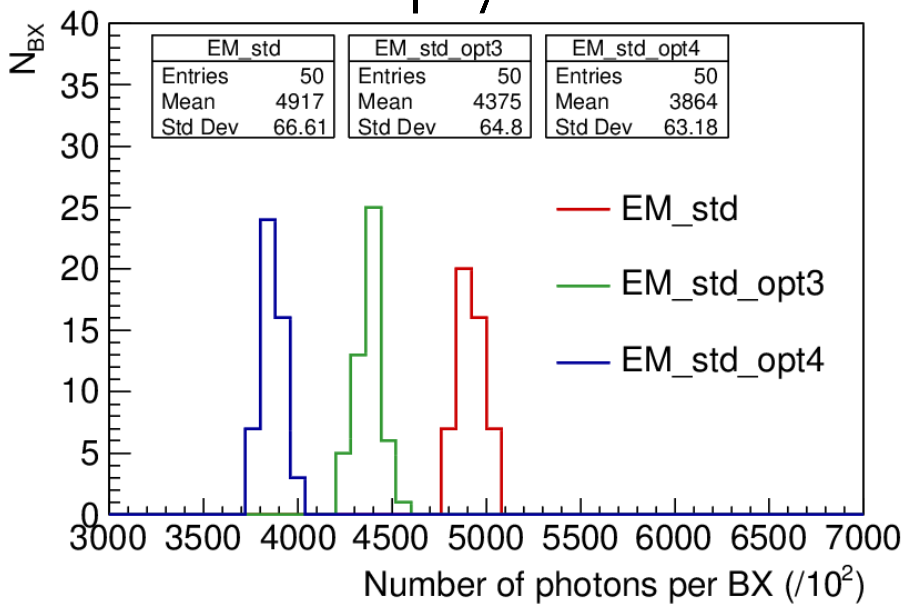
Number of photons inside |x|<25um and |y|<25um;

Nγ	4.91E+06
Nγ, E >7GeV	4.66E+05

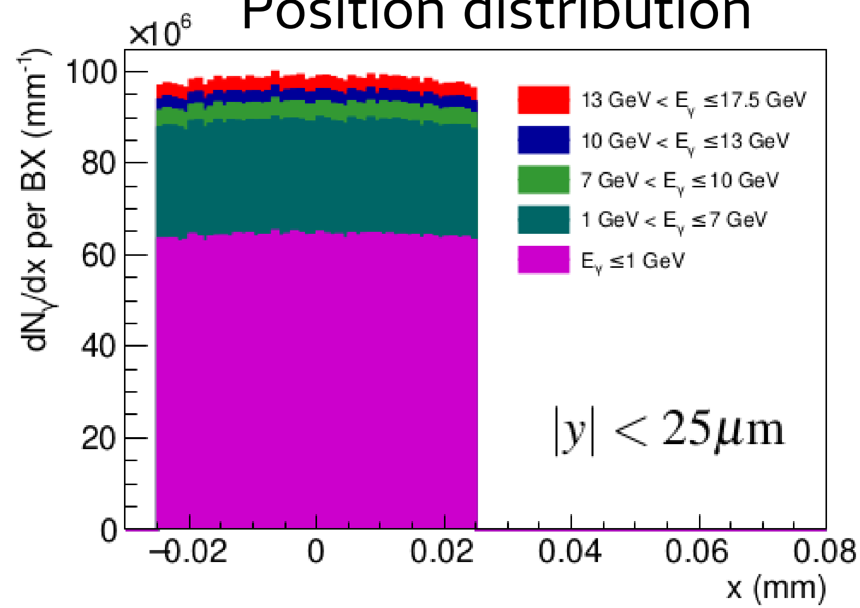
Different target thickness



Different physics lists

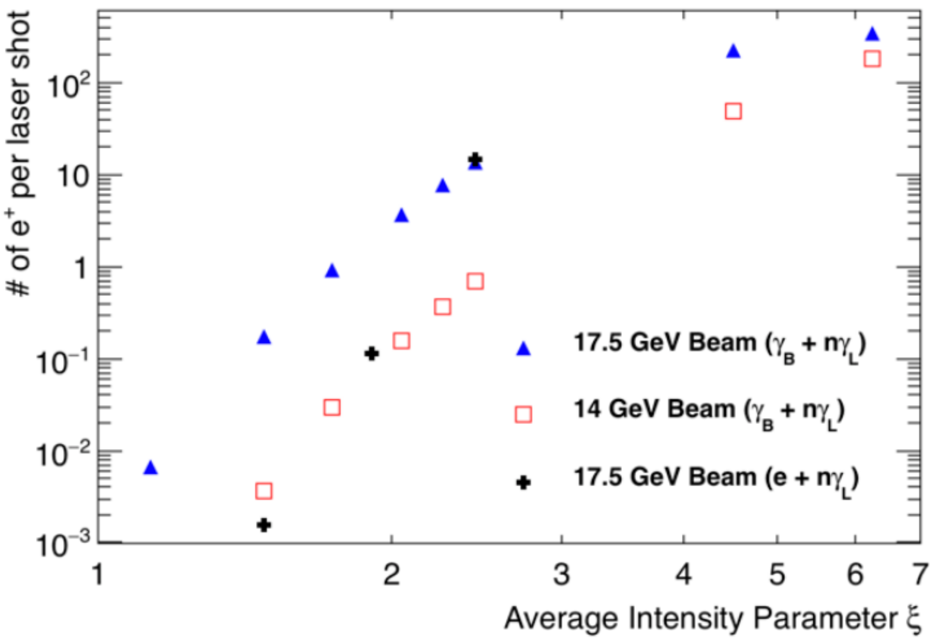


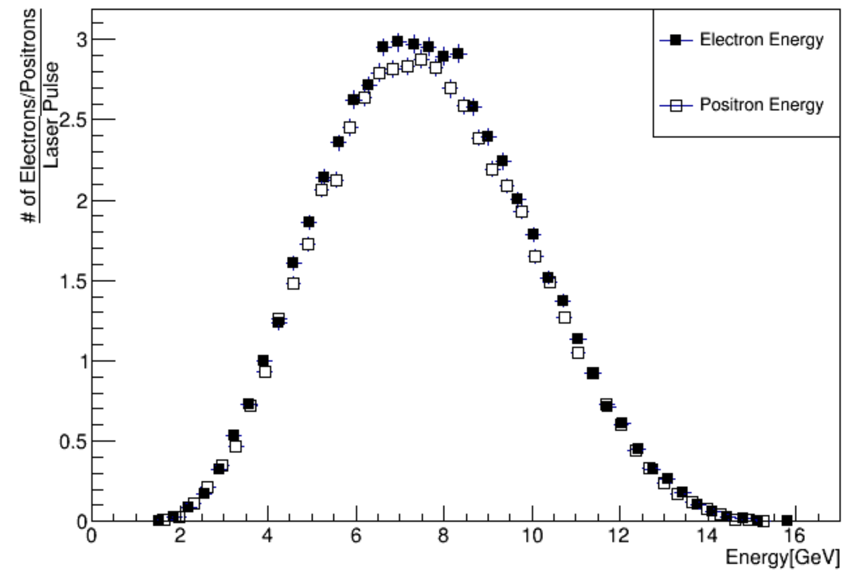
Position distribution



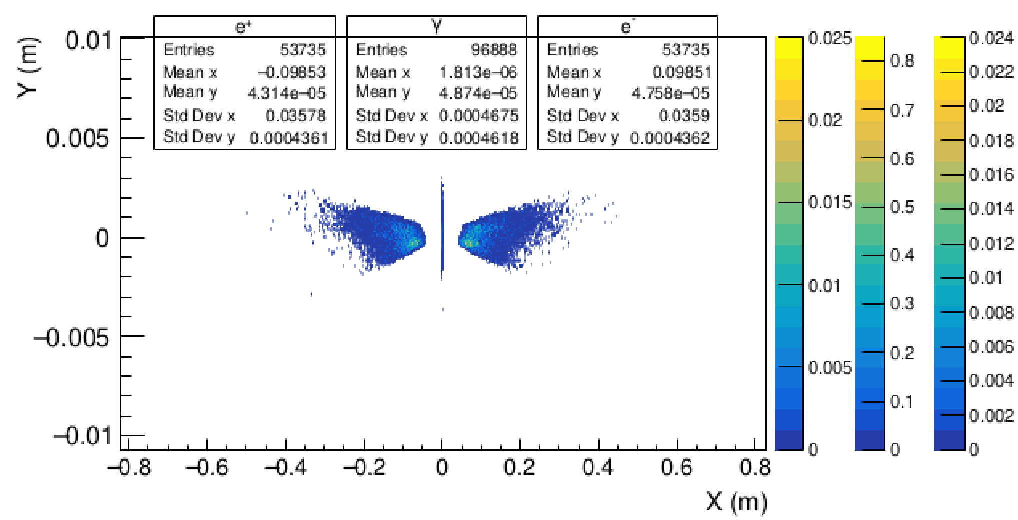
MC Simulation of Bremsstrahlung Pair Production

Rate of electron-positron pairs production as a function of laser intensity, MC simulation.





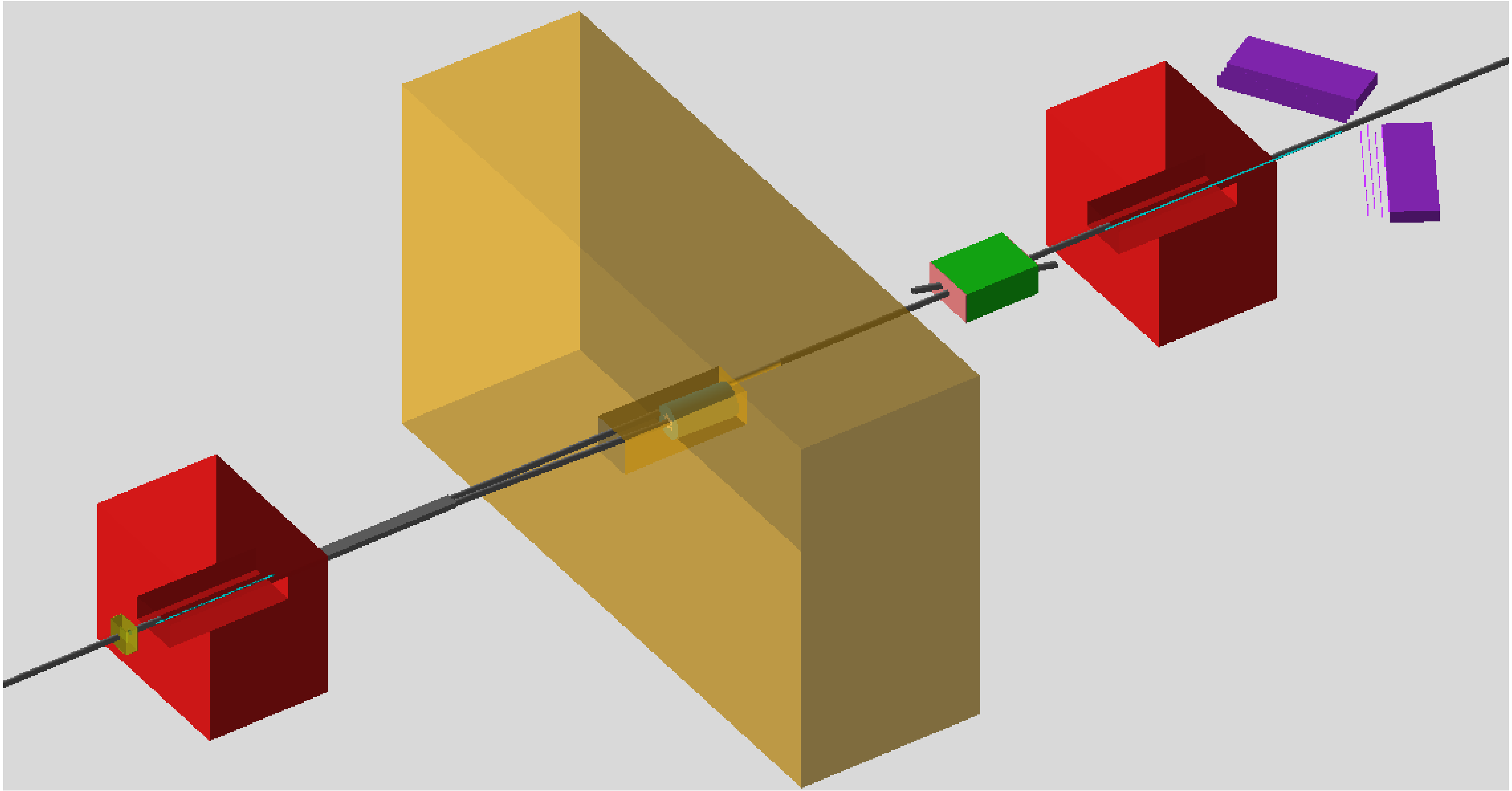
OPPP e-, e+ spectra



For different (limited) distances form the target to IP

$$N_\gamma(R) = \frac{R_0^2}{R^2} N_\gamma(R_0)$$

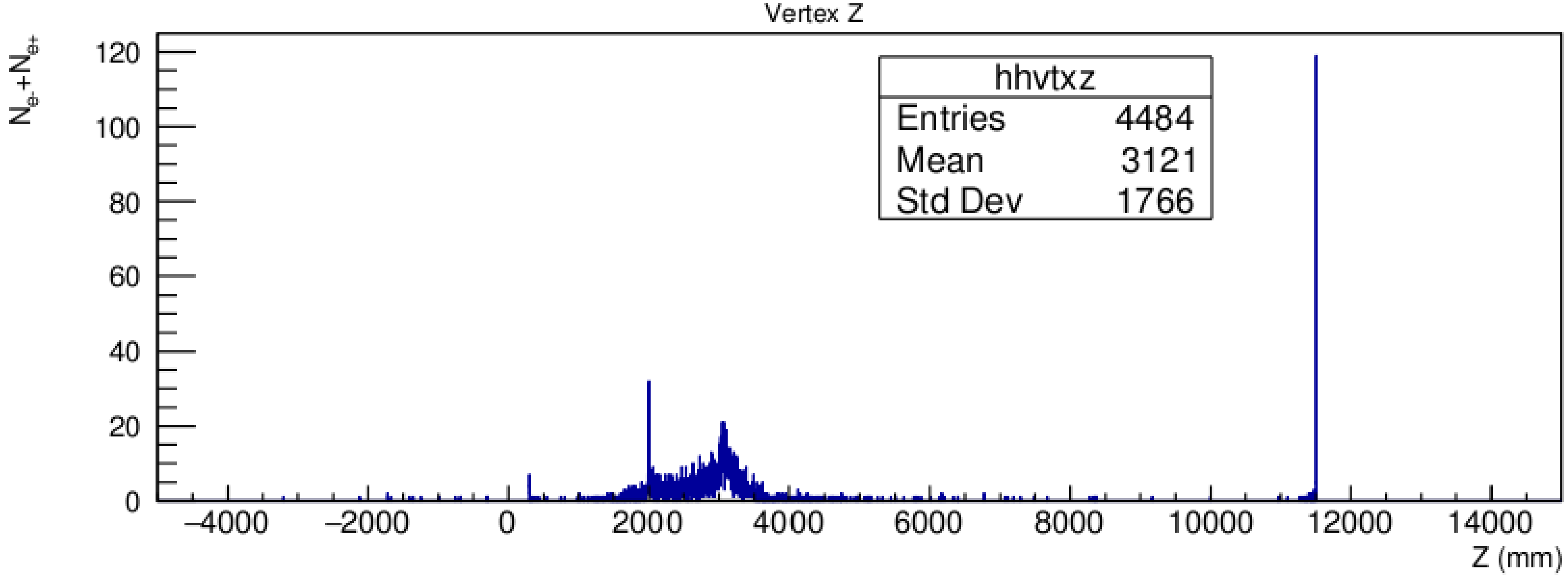
Background Study in Geant4

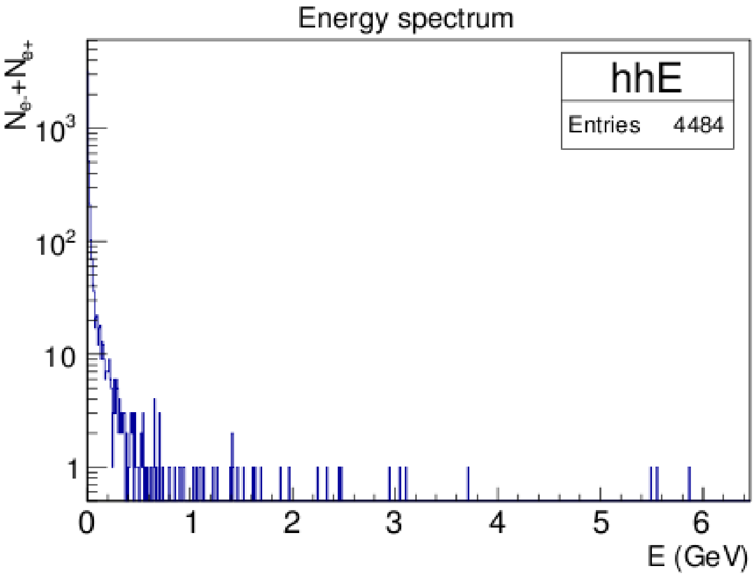


Distance from the bremsstrahlung target to IP is 7.25 m

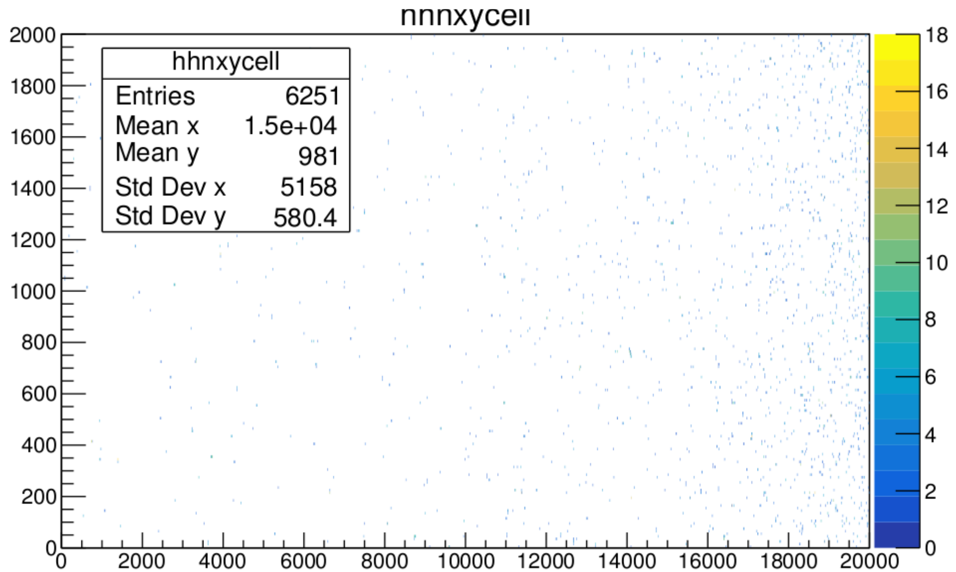
Background tracks

700M e- simulated





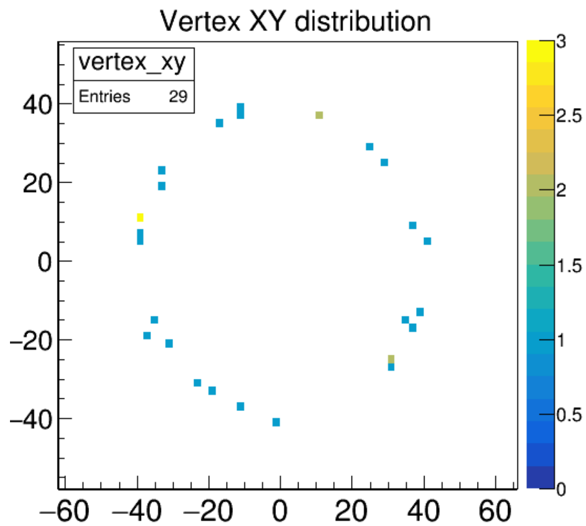
Occupancy in the first tracking plane

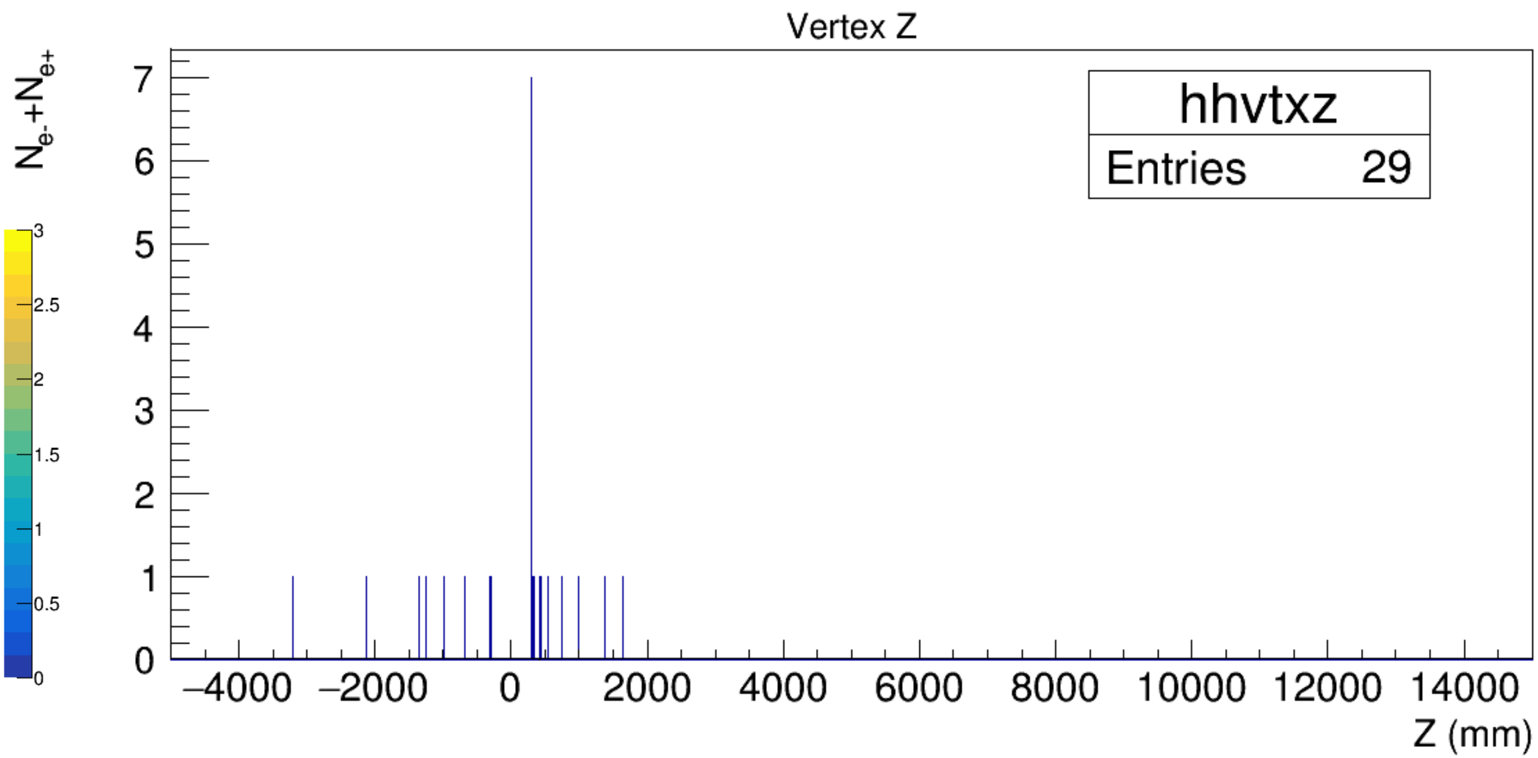


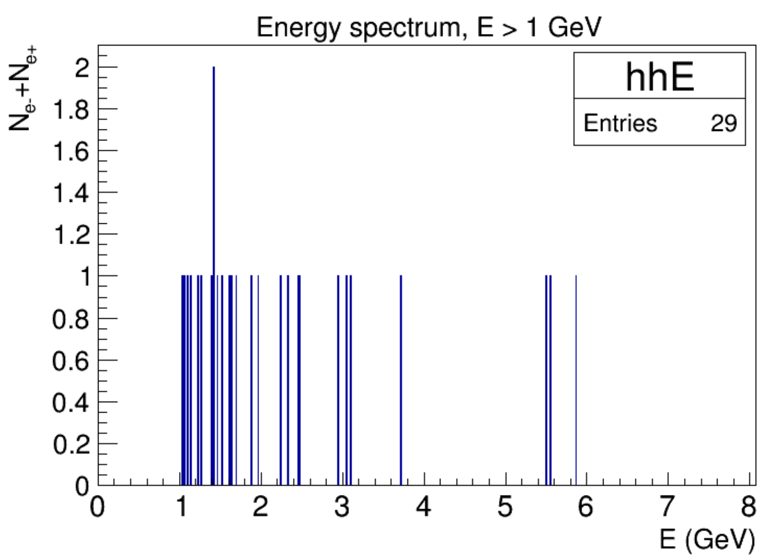
Background track with energy above 1 GeV

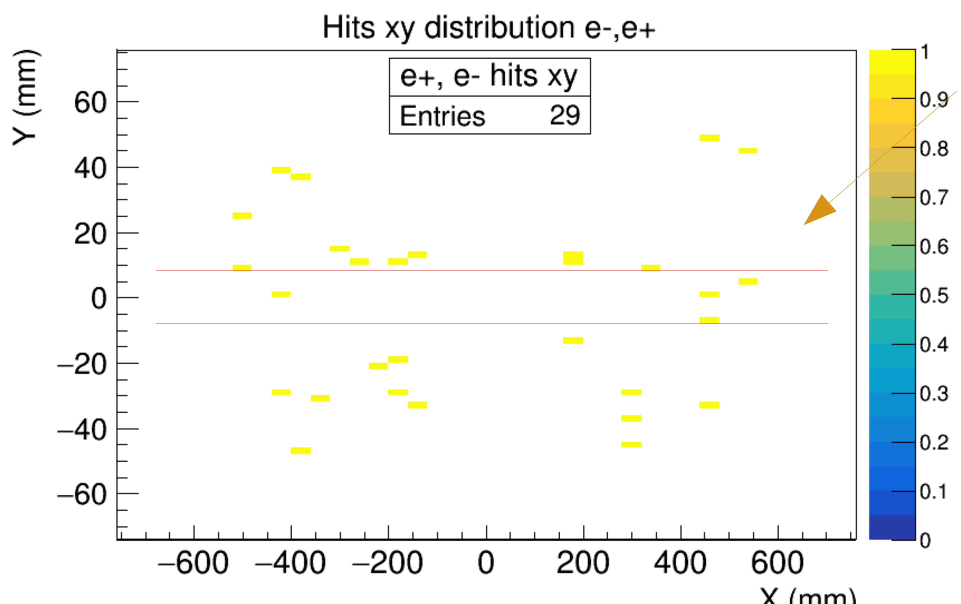
700M e- simulated

All particles produced in beam pipe
$\gamma \rightarrow e^+ + e^-$



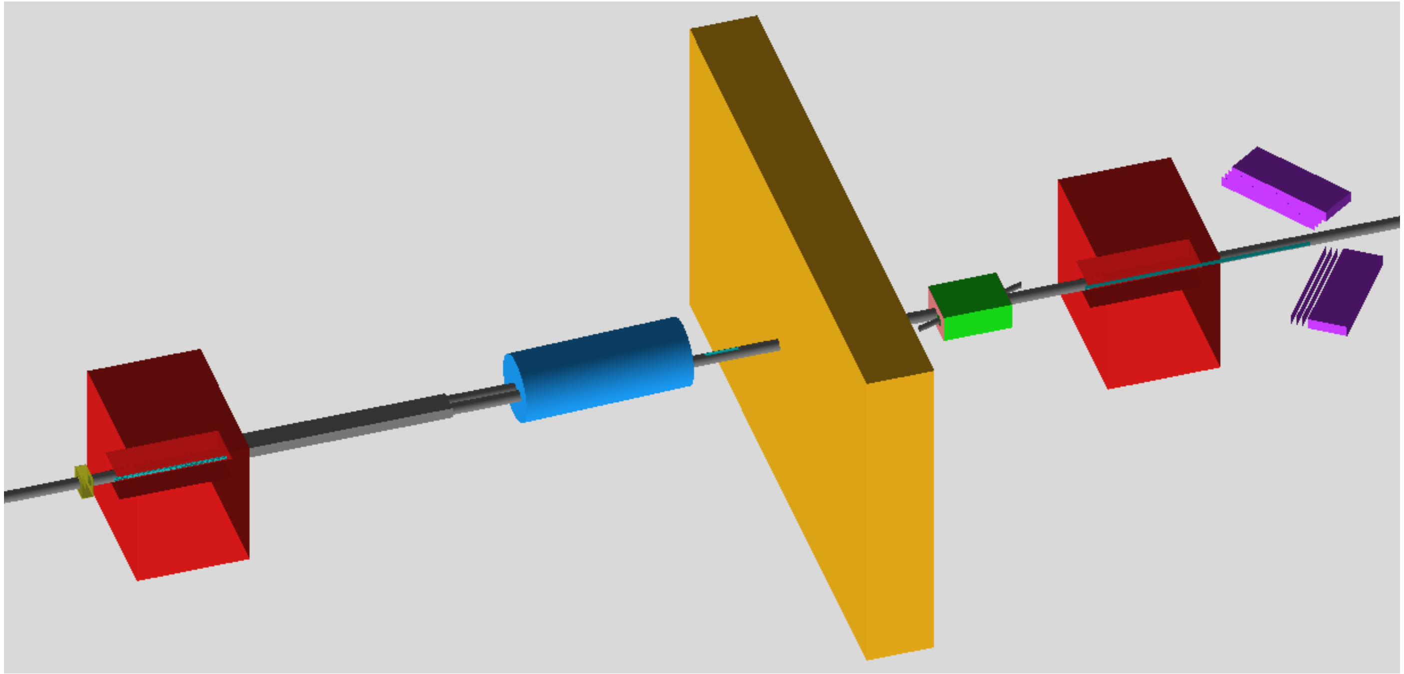


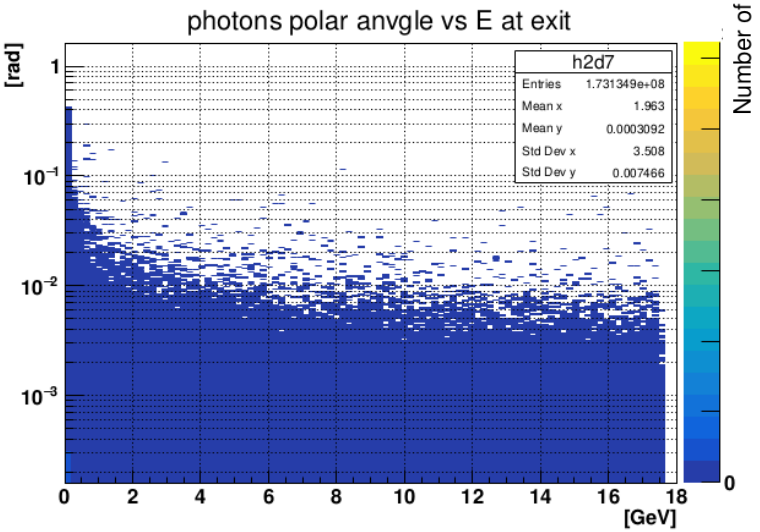


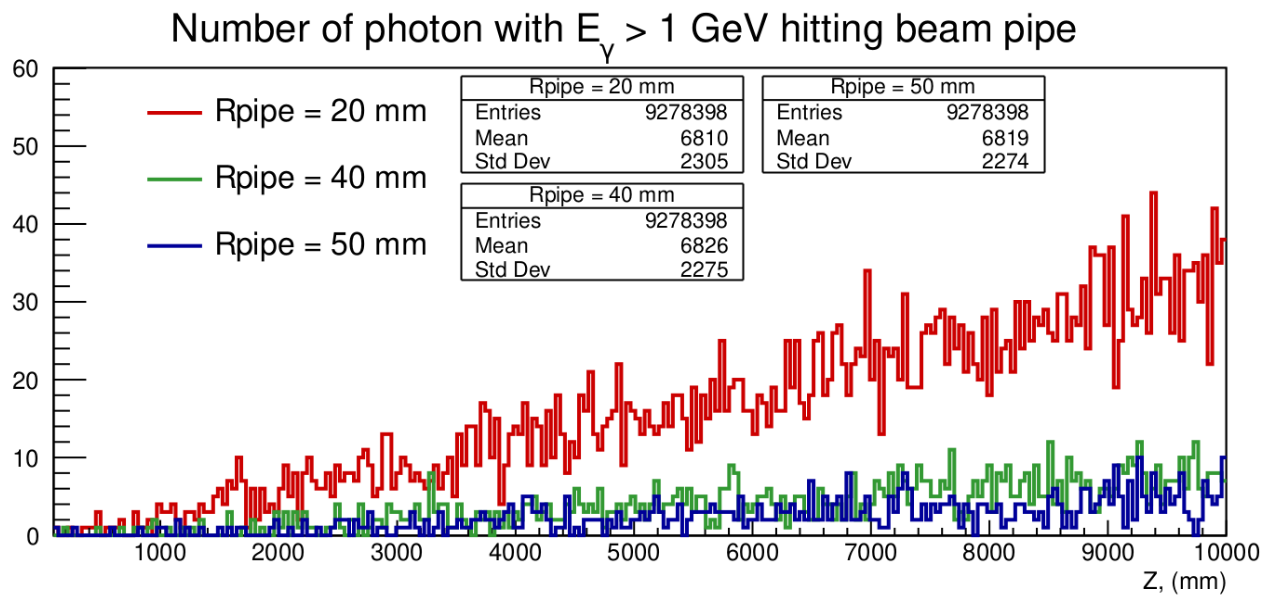


Cut on detector acceptance reduce it down to 4

Beam Pipe
D = 10 cm



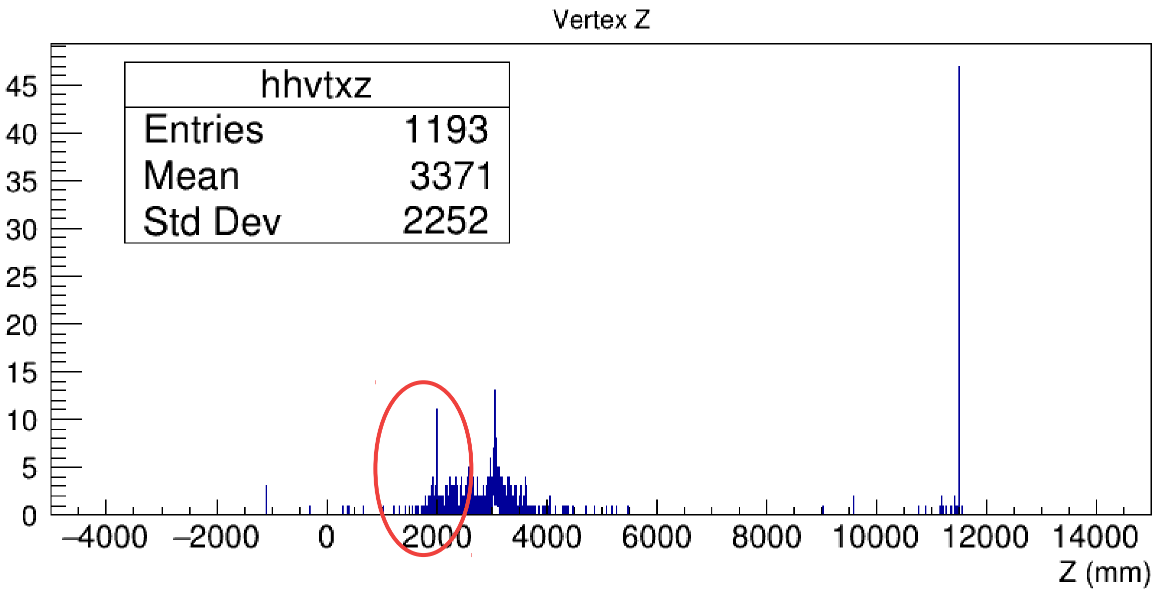


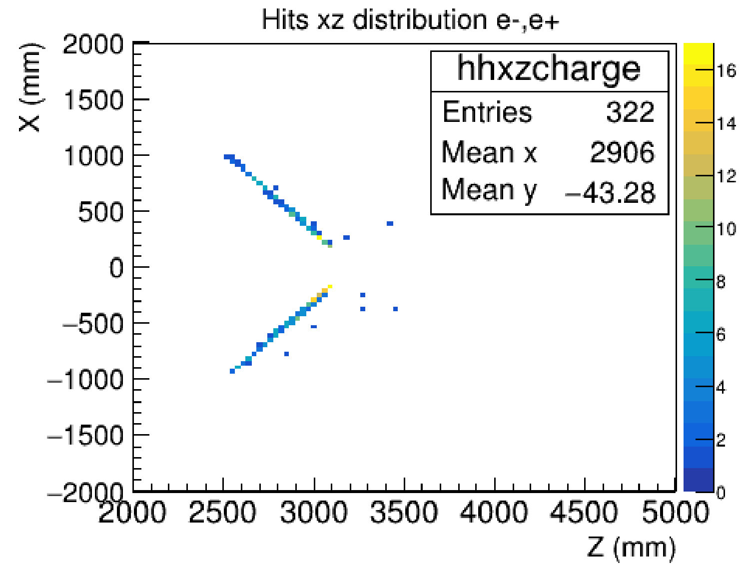


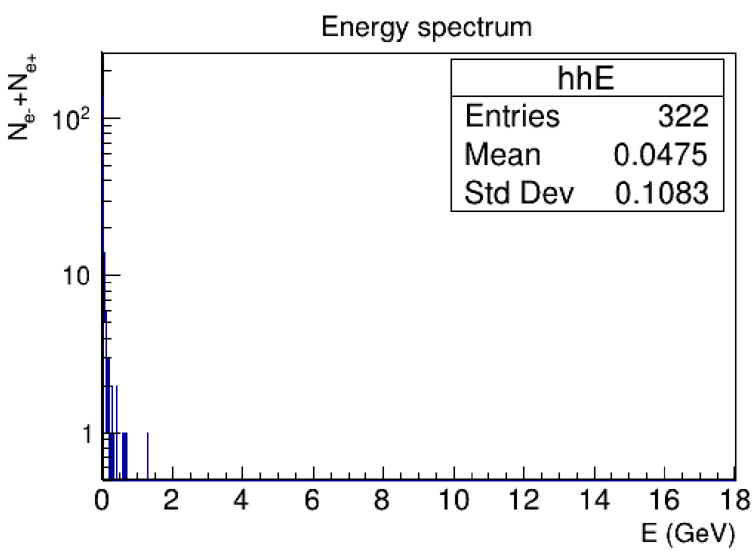
Beam Pipe D = 10 cm. Vertexes of the e+, e- tracks entering the detector volume.

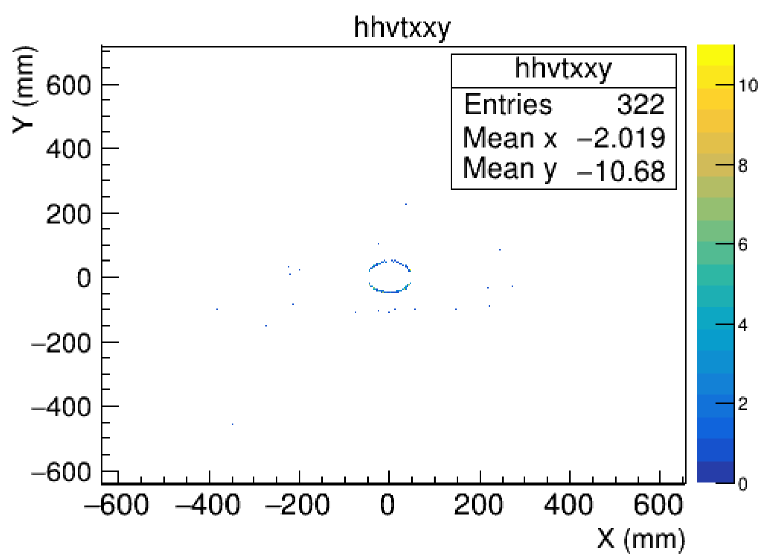
300M e-;

1m < Z < 2.5m; (Spectrometer magnet)





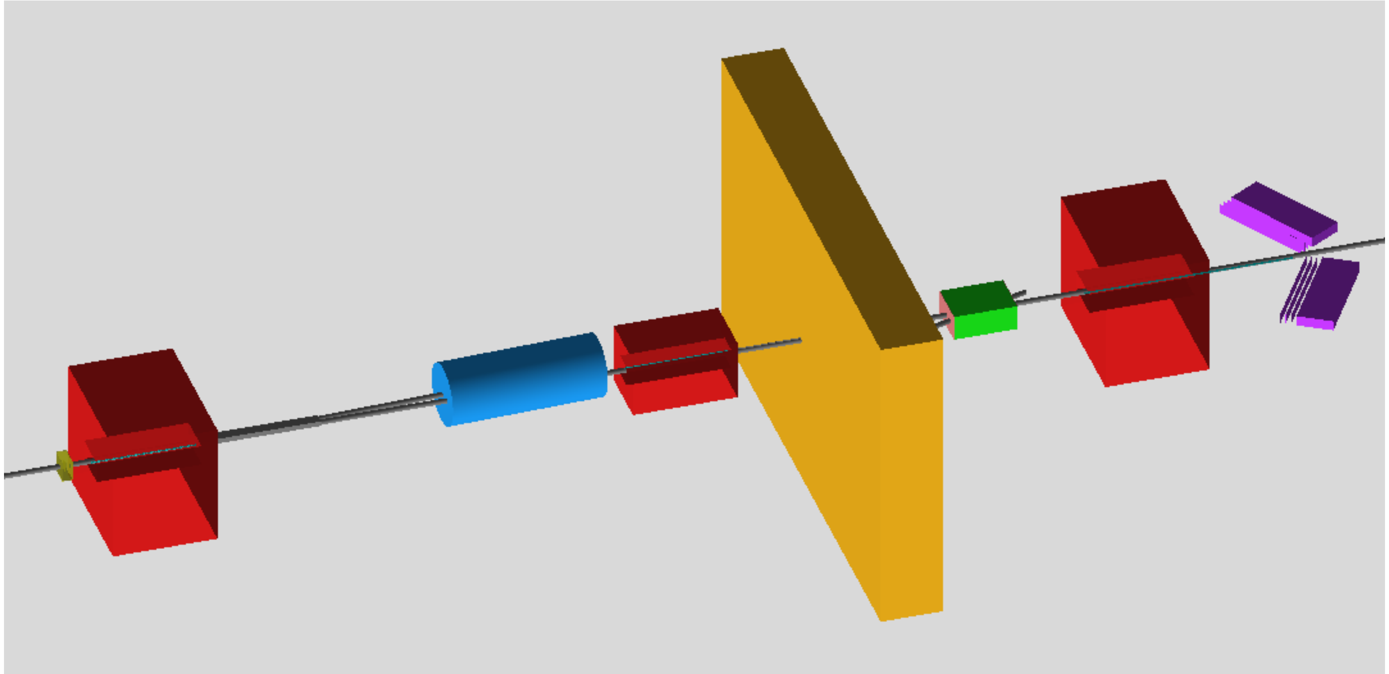




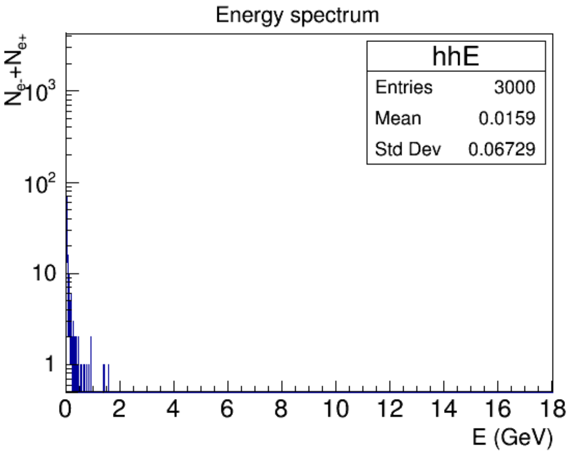
Geometry with a Magnet after the Beam Dump

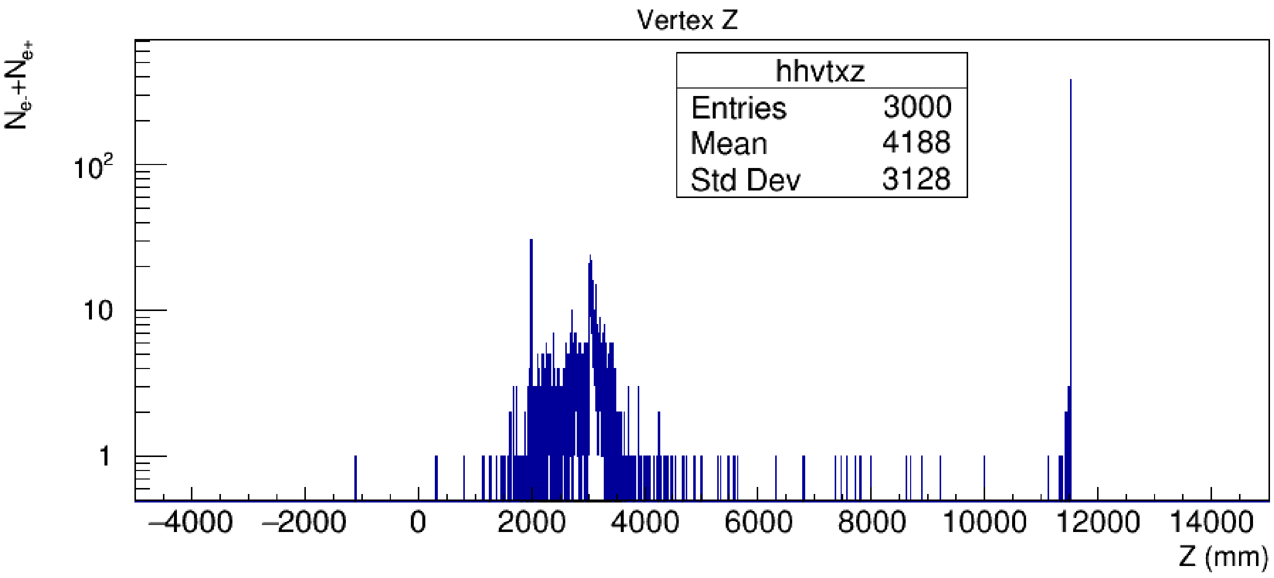
Magnet:
- Length: 1 m;
- Drift: 0.7 m;
- Field 1.4 T;
- y = 6.3 cm, for 8 GeV

Distance
Target – IP: 9 m.



1.678e9 e-





Summary

- The number of electron-positron pairs expected in collisions of bremsstrahlung photons with laser beam is in the range of 10^{-2} – 10^{2} per bunch crossing (depending on laser intensity);
- Lumical could provide complementary measurements of e+e- pairs;
- There is significant background in e+e- pairs detectors produced by low energy (below 1 GeV) particles. For different geometries it might range 5-20 cm^{-2}.
- Calorimeter would be an essential tool in rejecting the background.
- High position and energy resolution of the calorimeter is important for good performance.
- Continue study in more detailed and realistic geometry.

Back up

Strong field QFT

- In a presence of strong electromagnetic field, the virtual charges, start to separate.
- In the Schwinger limit, an electric field ($\varepsilon = 1.3 \times 10^{18}$ V/m) does the work equivalent to separating two electron rest masses over a Compton wavelength

$$\frac{h}{mc} e\,\varepsilon \geqslant mc^2$$

- Vacuum state becomes unstable and the field is predicted to induce vacuum pair production.

Fields reach the Schwinger limit:

- in relativistic heavy ion collisions;
- in an astrophysical setting near the surface of a magnetar;
- in strong gravitational field near a black hole.

High power laser facilities provide a possibility to study strong field QED in clean lab conditions.

LUXE intended to use EU.XFEL e- beam and high power laser to probe strong field QED

Electron and laser beam parameters

E_pulse, μJ	Crossing angle, rad	Laser σxy, μm	Laser σz, ps	N Electrons	Electron σx, mm	Electron σy, mm	Electron σz, ps
3.5*10^6	0.3	10	0.035	6.25E+09	0.005	0.005	0.08

- Laser wavelength = 800.00 nm (1.5498 eV);
- Circular polarized.