NON-LINEAR COMPTON STUDY IN THE LUXE EXPERIMENT

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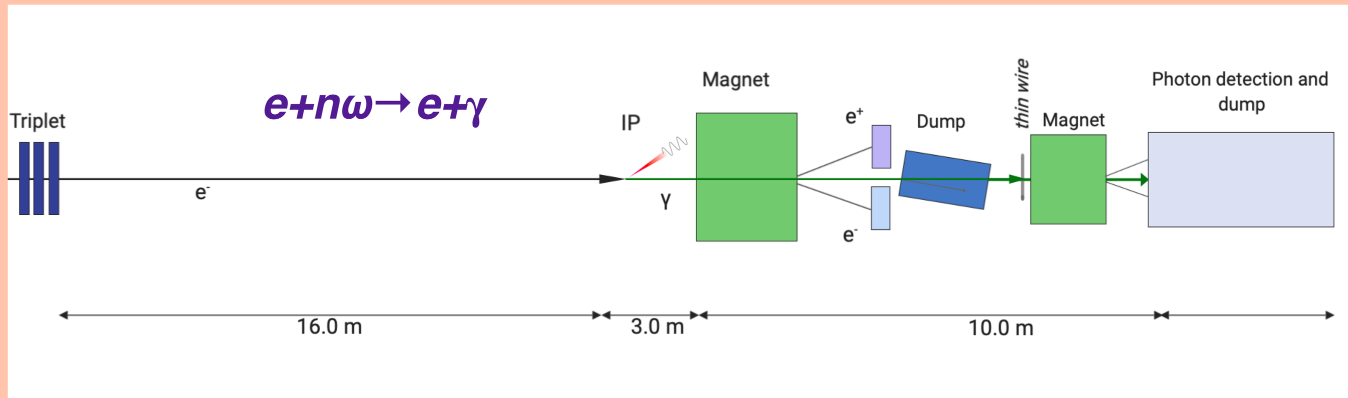
Introduction

The electron beam accelerator of the European XFEL, operated at DESY, is the highest energy electron beam currently operating world-wide. While it was designed for the purpose of photon science it is also ideally suited to study quantum physics in the strong-field regime. This is the goal of the LUXE experiment currently being designed by DESY accelerator, particle and laser physicists jointly with collaborators from Germany, Israel, Ukraine and UK.

LUXE

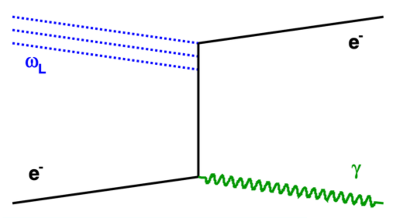
LUXE experiment will measure the non-linear Compton, often referred as High Intensity Compton scattering (HICS) and the two-step trident process in a new regime. In one of the modes, LUXE will collide the electron beam with the high-power laser pulse, comprising laser field $\mathcal{E}_L$ with frequency ω_L. With these measurements, the LUXE experiment will advance the field significantly compared to previous experiments.

LUXE SETUP for Direct electron-Beam Laser interaction

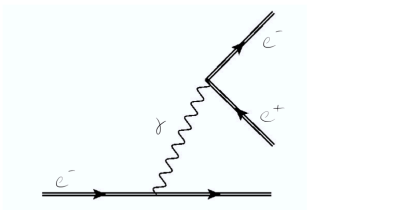


Main Processes of Interest

Direct electron-Beam Laser interaction:
$e^- + n\omega_L \rightarrow e^- + \gamma$

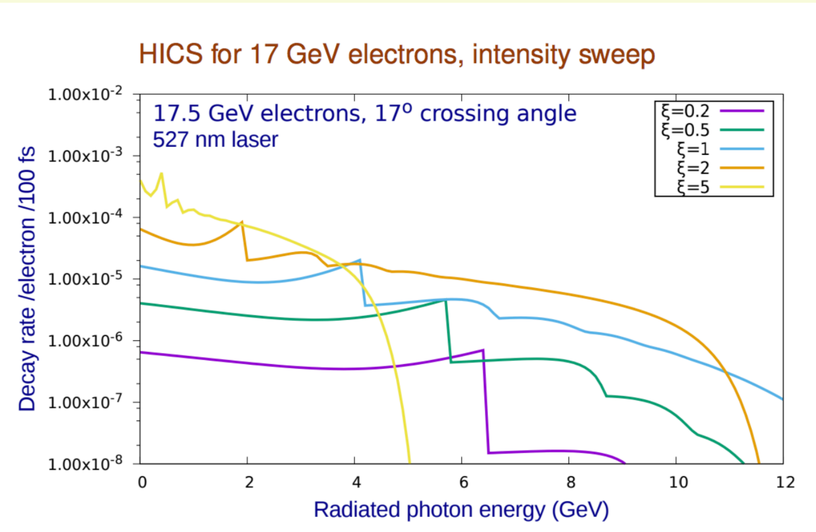


Leading order diagram for the laser stimulated trident process:



The trident process can either proceed in a quasi-instantaneous single step - "one-step trident" or via sequential subprocesses - "two-step" nonlinear Compton followed by nonlinear Breit-Wheeler (distinction is off-shell vs on-shell photon).

Non-Linear Compton Scattering from theoretical calculation and Monte Carlo (MC) simulations



A. Hartin (UCL)

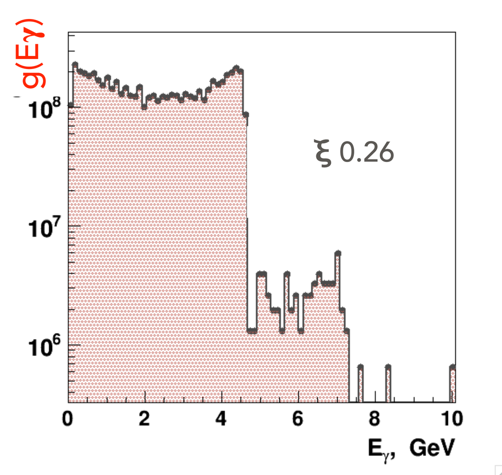
Increasing the laser intensity ξ

$$\xi^2 = 4\pi\alpha\left[\frac{\mathcal{E}_L}{\omega_L m_e}\right]^2$$

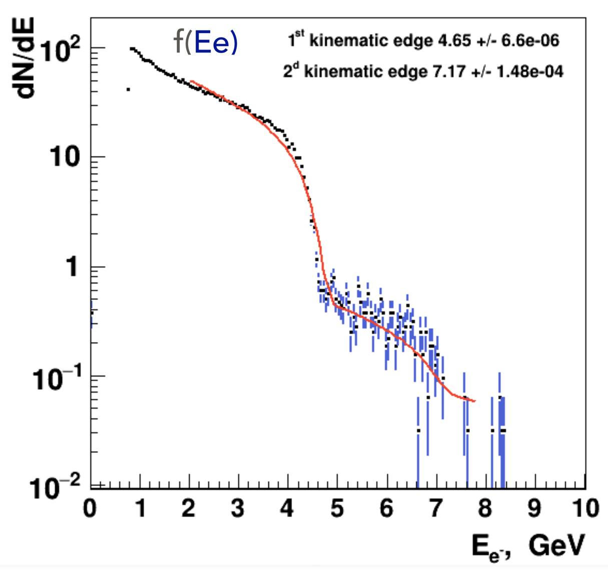
increases the HICS rate, but suppresses the photon energy (the mass shift)

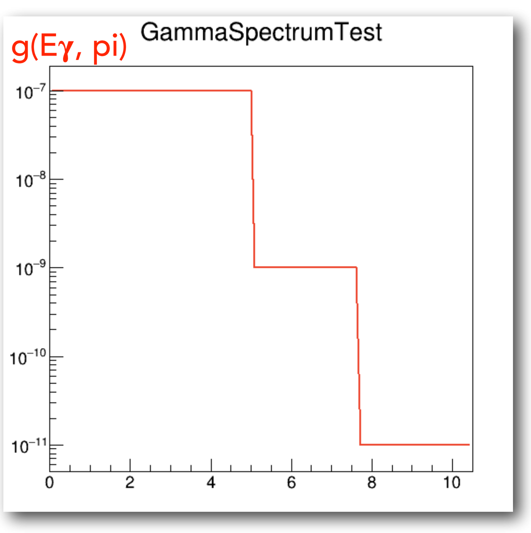
METHOD of photon spectrum restoration

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



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**

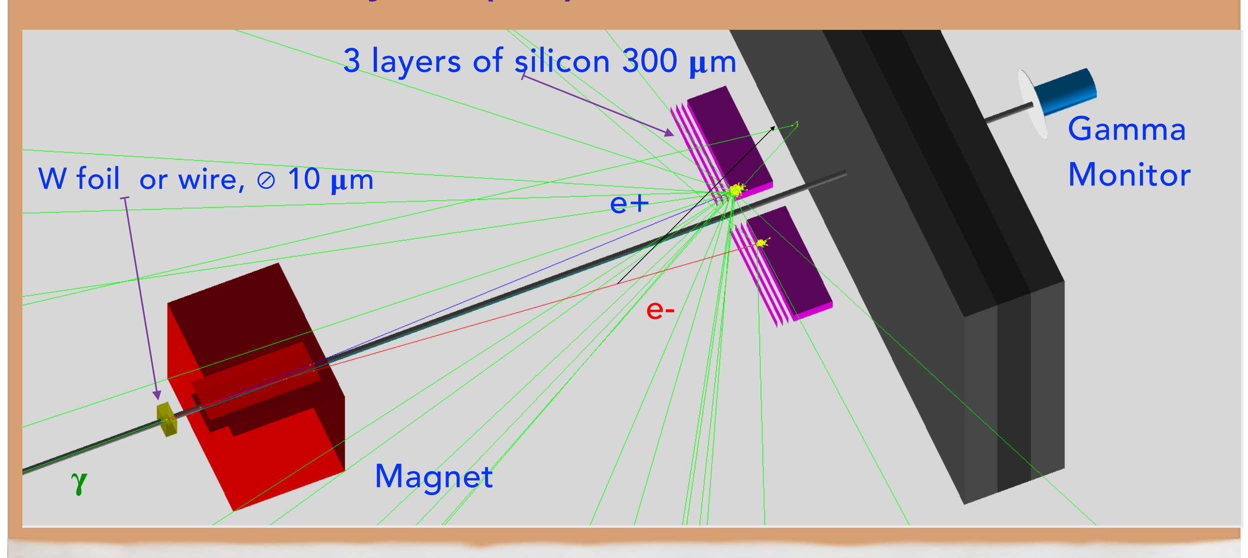




$$\int \sigma(E\gamma, E_e)\, g(E\gamma, p1, p2)\, dE\gamma$$

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

Forward Detector System (FDS) in GEANT4

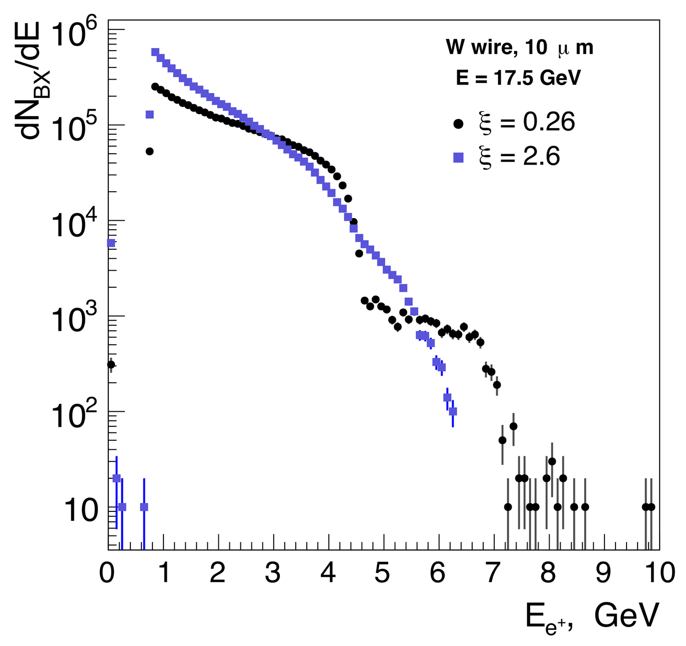


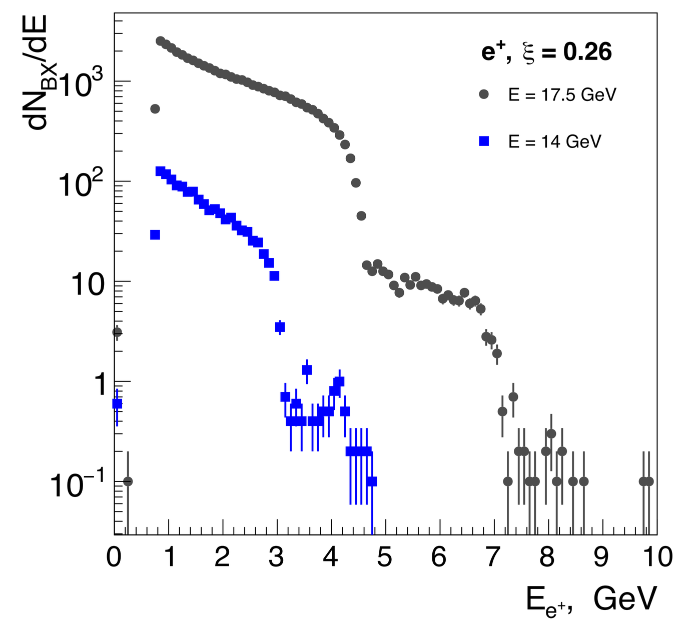
Rates for 6.0e9 electrons

Rates of particles for the e–laser setup. The two signal processes are the HICS (high intensity Compton Scattering) and the Trident process.

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 (trident)	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

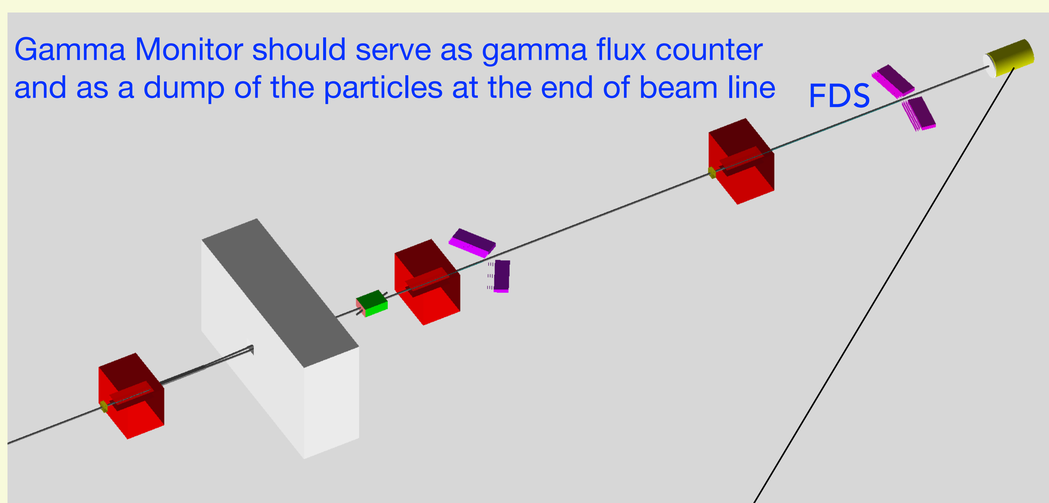
Positron spectra observed in detector in Geant4 simulation

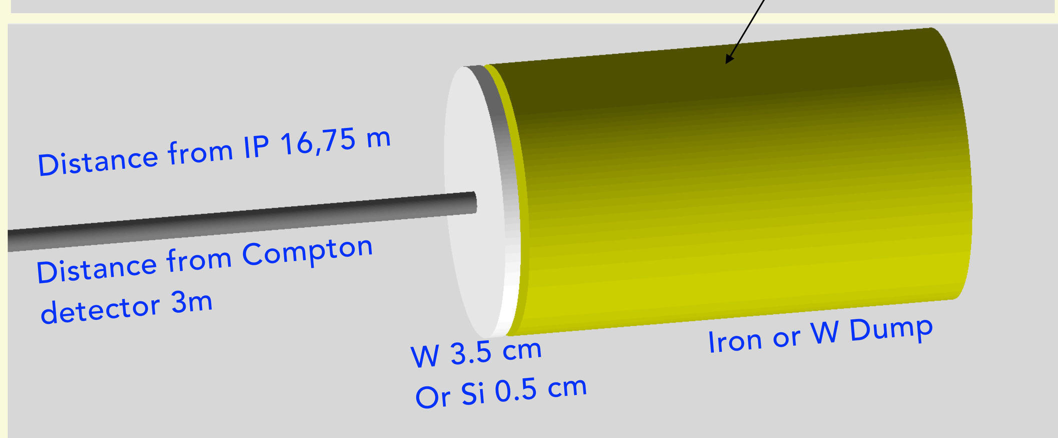


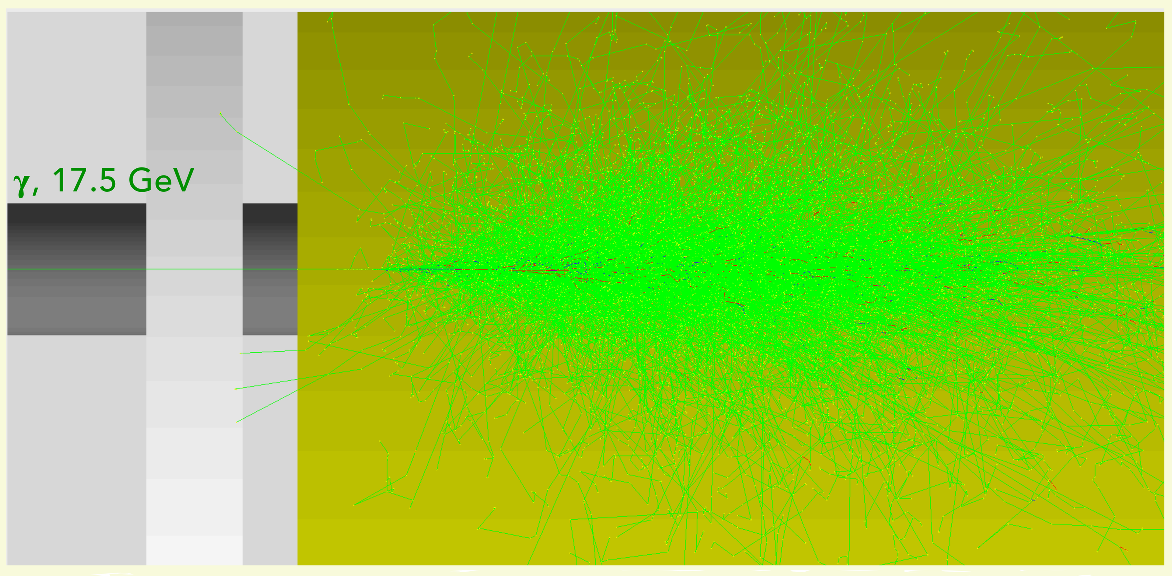


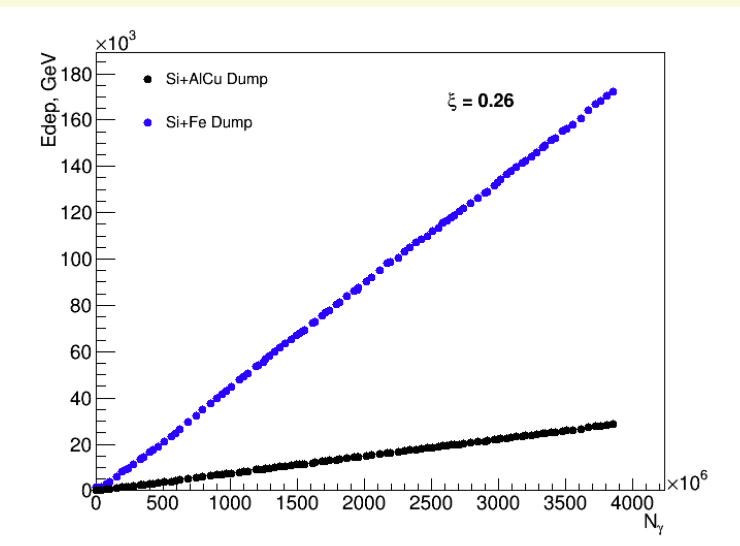
- Photon flux very high (>10^7 per BX)
- Thin wire target to convert photons to e+e- pairs
- Non-uniform Laser Intensity (ξ) smears the kinematic edges
- ✳ Compton edges observable in energy spectra
- ✳ For nominal XFEL beam: ξ =0.26, 10 m from IP the number of e ~3.8e3.

Gamma Monitor in Luxe setup









The linear dependence of deposited energy on number of incoming photons allows the usage of backscatters for estimating the photon flux

Summary

- **Forward Detector studies:**
  - The estimated absolute number of forward photons: from theory and MC+GEANT4 simulation: very high fluxes (>10^7 per bunch crossing)
  - The detector could be realised as target (wire, foil) and spectrometer+calorimeter.
  - It was preliminary studied in simulation the feasibility of Tungsten or Nickel wires (foils) as converter target. For nominal XEFL beam and ξ =0.26 at 10 m from IP, the expected number of e-e- pairs ranges 150-4000.
  - Demonstrated the possibility of reconstruction the HICS spectra and the positions of kinematic edges with good accuracy.
  - Non-uniform laser intensity distribution over the pulse blurs the kinematic edges in the spectra, especially for high ξ.
- **Gamma monitor studies:**
  - ✳ Gamma Monitor is studied in simple configuration in GEANT4 with Tungsten Calorimeter in front of the photon dump.
  - ✳ The linear dependence of deposited energy on number of incoming photons allows the usage of backscatters for counting the photon flux.
  - ✳ The energy spectrum of backscatters is below 1 GeV and for the vast majority is below critical energy for the most detector materials.
  - ✳ The background in Compton detector and Gamma Monitor needs to be studied.

References

1. Letter of Intent for the LUXE experiment: DESY-19-151; arXiv:1909.00860