Electron Detection System Working Group Update

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LUXE Steering Board Meeting, 28th of May, 2025

EDS Working Group Update

EDS@E320 Article in DESY Particle Physics Annual Report

LUXE electron detection system goes overseas

...to make quantum electrodynamics strong again

A small team of young researchers from the LUXE collaboration at DESY went to the USA in 2024 to develop and test a novel type of detector for studies of strong-field quantum electrodynamics. This detector is designed to measure the energy spectra of electrons interacting with a high-intensity laser pulse. Following initial test and commissioning measurements, the team could successfully observe the effects of the non-linear Compton process in their detection system. These measurements pave the way for future developments in the LUXE experiment at DESY.

LUXE is a planned experiment at DESY that will collide electrons from the European XFEL X-ray free-electron laser with a high-intensity laser pulse [1, 2]. The main goal is to precisely test the transition from perturbative to non-perturbative quantum electrodynamics (QED). One important detection system that is being developed at DESY is the electron detection system (EDS). To test it in a comparable environment, the DESY team visited the existing strong-field QED experiment E-320 at the FACET-II accelerator at the SLAC National Accelerator Laboratory in Menlo Park, USA [3].

Strong-field QED is an emerging part of quantum electrodynamics that involves strong or high-intensity fields [4]. It is relevant to our fundamental understanding of light–matter and light–light interactions. It finds application in astrophysics, plasma physics, the interaction of charged particles with crystals and future high-energy lepton colliders. The theory can be precisely tested by colliding a high-energy electron beam with a high-intensity laser pulse. The two main effects that can be observed are the non-linear Compton process and non-linear Breit–Wheeler pair production. In the former, an electron scatters off many photons of the laser pulse simultaneously, thereby radiating new, high-energy photons. In the latter, such a high-energy photon interacts with many laser photons, producing an electron–positron pair, the lightest matter–antimatter pair.

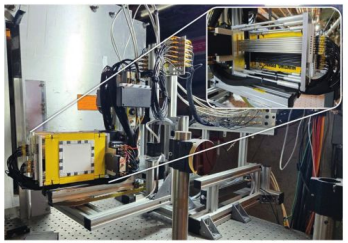

Figure 1
LUXE EDS prototype at the FACET-II accelerator at SLAC. The scintillating screen is surrounded by a yellow frame. The inset shows a view of the Cherenkov straws from the rear side.

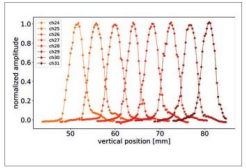

Figure 2
Signal measured with the Cherenkov straws of the EDS as a function of the vertical position, showing the signal in some straws (ch24 – ch31) when the detector is moved through a millimetre-sized beam.

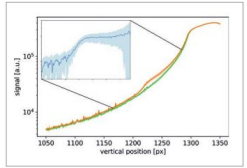

Figure 3
Signal measured with the scintillating screen of the EDS as a function of the vertical position, which is proportional to the particle energy. It shows the signal without electron–laser collisions (green) and with collisions (orange) as well as the difference between the two, which is only sensitive to the contribution from the Compton process (blue).

The main goal of the EDS is to measure the electron energy spectrum originating from the strong-field interaction. After the interaction, a dipole magnet spatially separates the different energies. A position-sensitive charge measurement provides the spectral information. The LUXE EDS is a dual detector system (Fig. 1). Electrons passing the screen (surrounded by the yellow frame in the image) produce light via the scintillation process. This light is detected with a CMOS camera. Behind the screen are straw detectors (shown from the back in the inset). Electrons passing through the straws produce via the Cherenkov process, which is detected with silicon photomultipliers.

The DESY team made two research visits to SLAC in 2024. The first visit, in May and June, served to get to know the facility, install the detector and perform the first commissioning measurements. During the second research visit, in October and November, the team installed an upgraded detector designed from the lessons learned during the first research visit. New detector components were added, and others were rearranged. The new system was then commissioned and calibrated. Finally, the team could test interesting strong-field physics in a three-night-long experiment session.

The LUXE team commissioned the detection system with a millimetre-sized beam by moving the detector vertically through the beam, which corresponds to the direction of the energy dispersion. Figure 2 shows the normalised amplitude of a few signals in the Cherenkov straw detector. The shape of the signal emerges from the convolution of the beam and the straw profiles.

Collisions of the electron beam and laser pulse were eventually recorded in the final measurement shift. Figure 3 shows an example of such a measurement. When the monoenergetic electron beam collides with the laser, some electrons lose some of their energy in the non-linear Compton process to produce high-energy photons. This leads to the edge-like structure in the electron spectrum.

The tests of the EDS prototype at the E-320 experiment at SLAC showed that this novel type of detector can measure the electron energy spectrum in the environment of a strong-field QED experiment. The next steps towards an EDS at the LUXE experiment involve a thorough analysis of all the data and a mechanical and electronic upgrade to meet LUXE's specific needs.

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References:

[1] https://luxe.desy.de/
[2] LUXE Collaboration, Eur. Phys. J. Spec. Top. 233, 1709–1974 (2024)
[3] D. Ries , S. Meuren, 2024 FACET-II PAC & User Meeting (2024)
[4] A. Fedotov et al., Phys. Rep. 1010, 1138 (2023)

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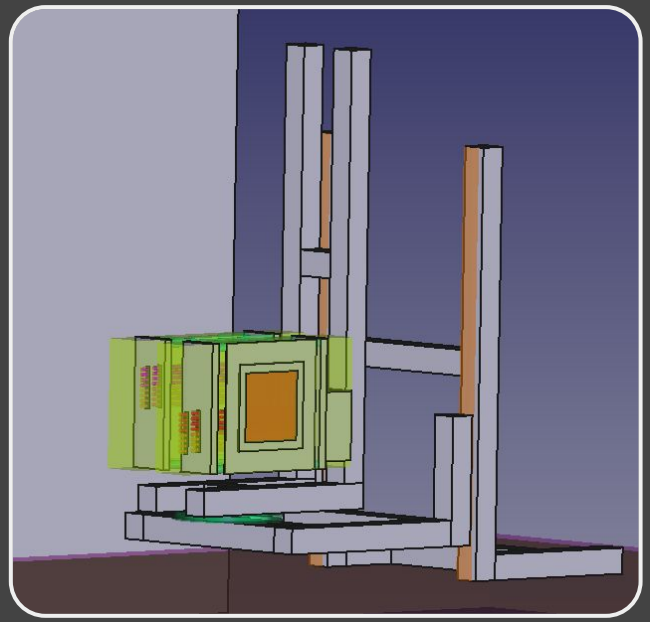

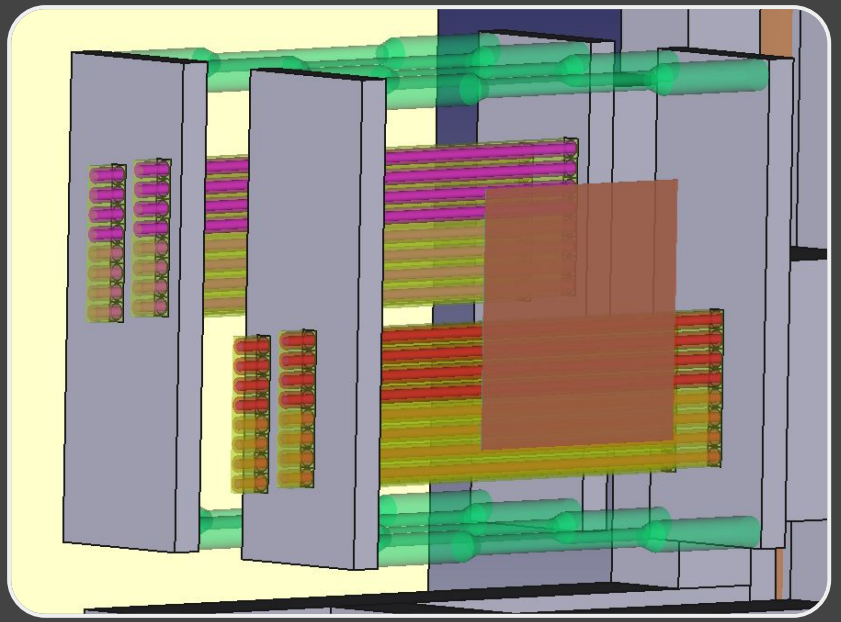

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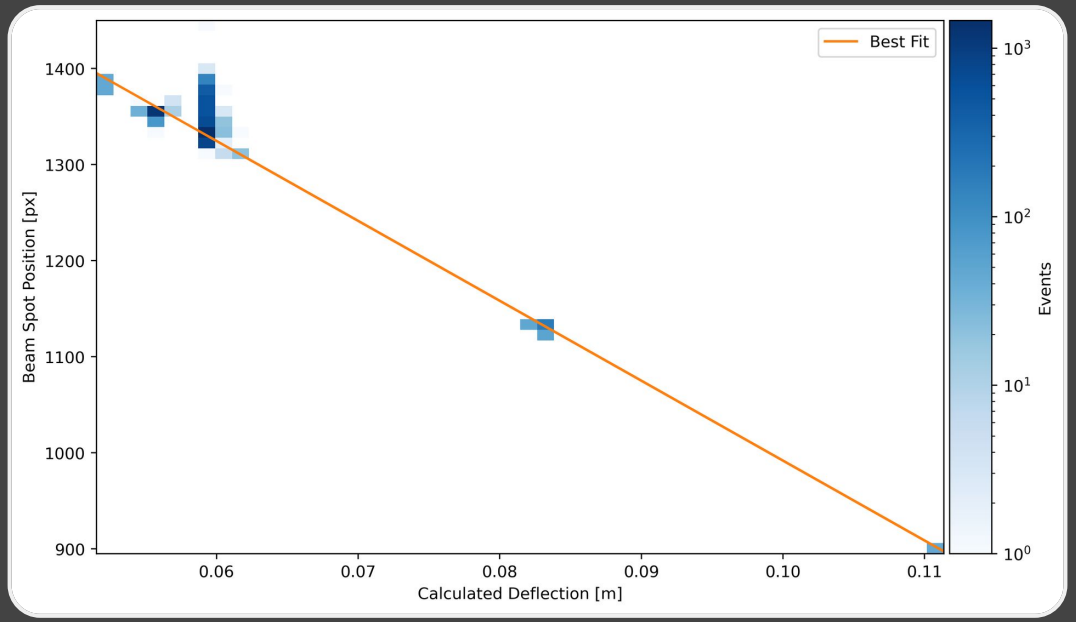
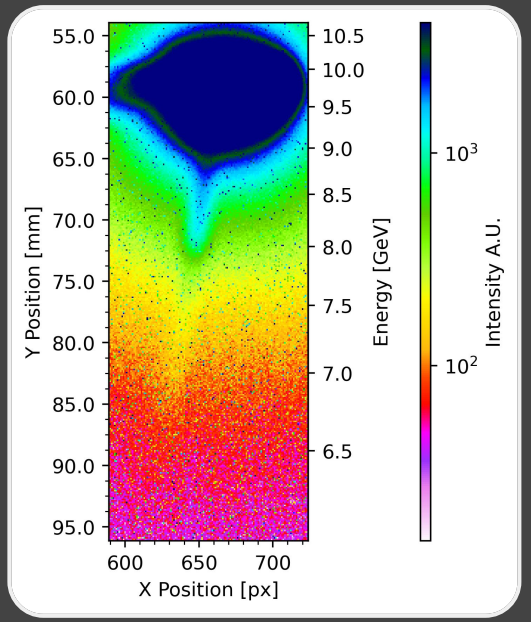
Updated Energy Calibration





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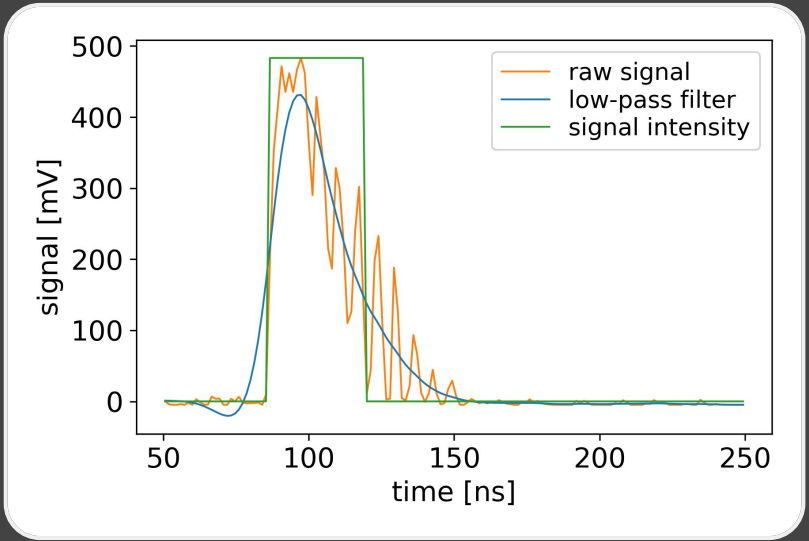
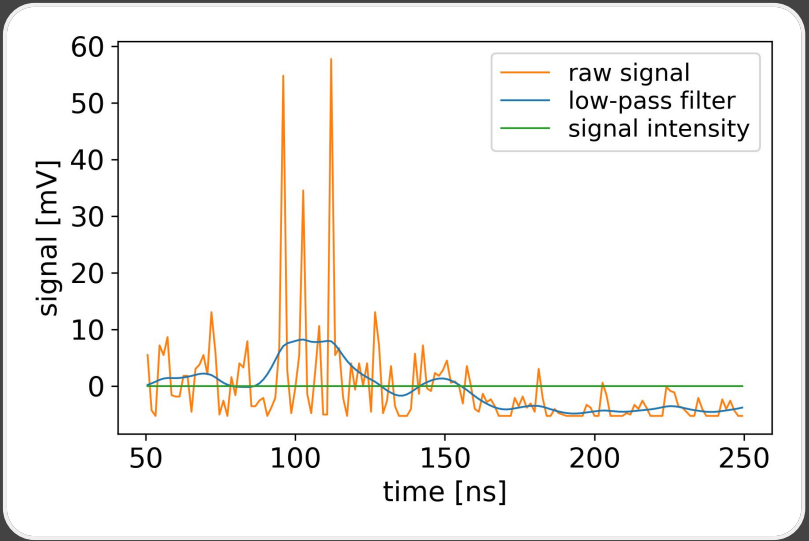
SiPM Noise Processing





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New LED Pulser for Calibration