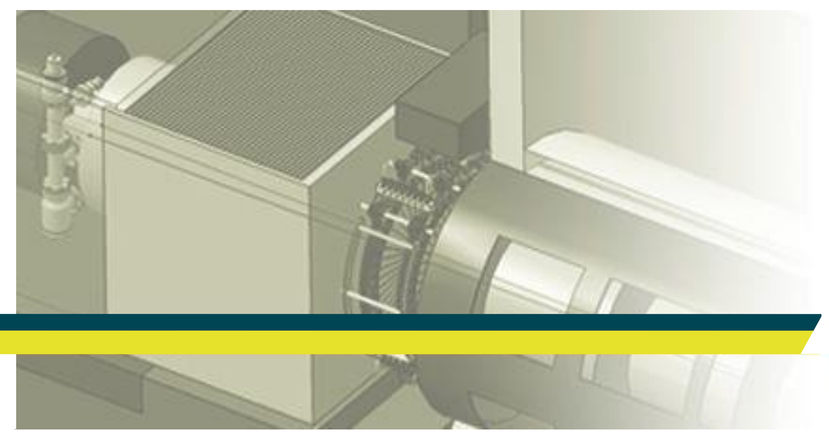
Detector Challenges of the strong-field QED experiment LUXE at the European XFEL



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on behalf of the LUXE and FCAL Collaborations

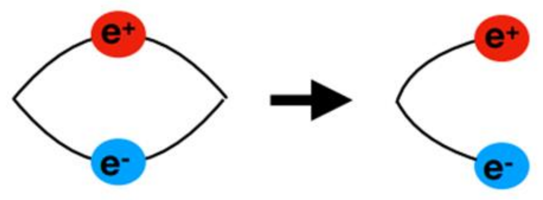
Introduction

- ❑ **Quantum electrodynamics (QED) is the world's most precisely known (and tested) theory.**
- ❑ **LUXE will study non-perturbative and non-linear QED phenomena in the strong-field regime.**
- ❑ **Vacuum boils if field large enough to create real pairs:**

"critical fiels" = work field over $\lambda_{Compton} > 2m_e$

- ❑ **More details on LUXE physics:**
  LUXE CDR: Eur.Phys.J.ST 230 (2021) 11, 2445-2560
  LUXE website: https://luxe.desy.de

QED becomes non-perturbative above Schwinger-Limit!



$E_{field} < 2m_e$ $\qquad$ $E_{field} > 2m_e$

$$E_{field} = \frac{\varepsilon e}{m_e}$$

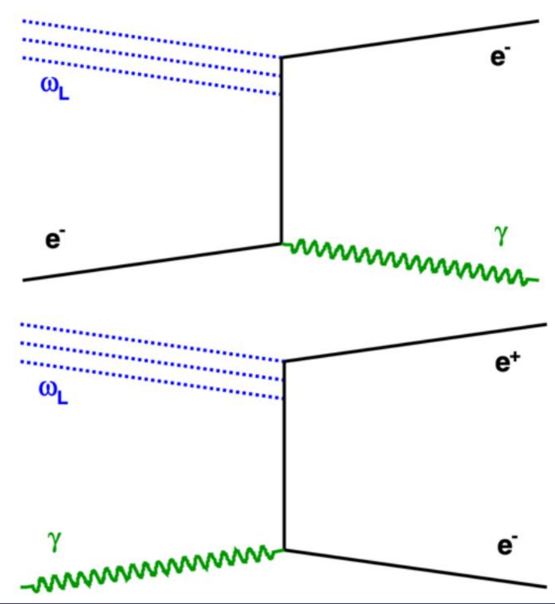
Schwinger-Limit:

$$\varepsilon_{crit} = \frac{m_e^2 c^3}{\hbar e}$$

e.g. for electrical field:

$$\varepsilon_{crit} \cong 1.32 \cdot 10^{18}\, V/m$$

Main processes of interest in LUXE

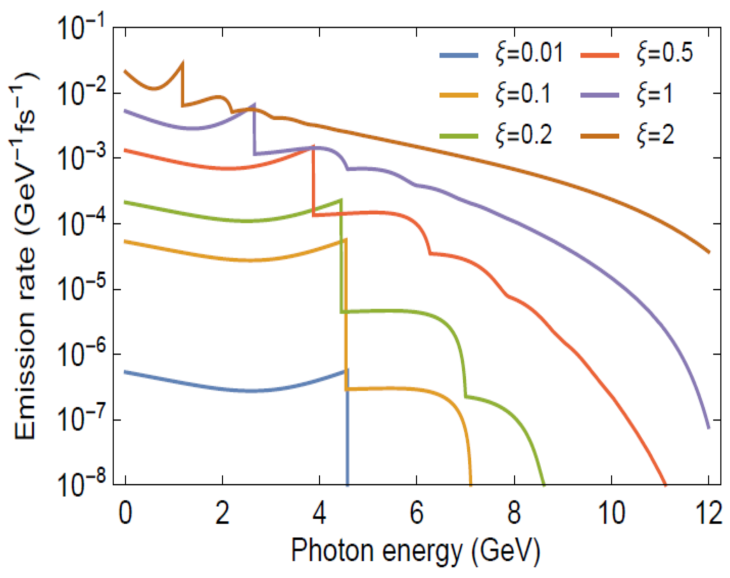


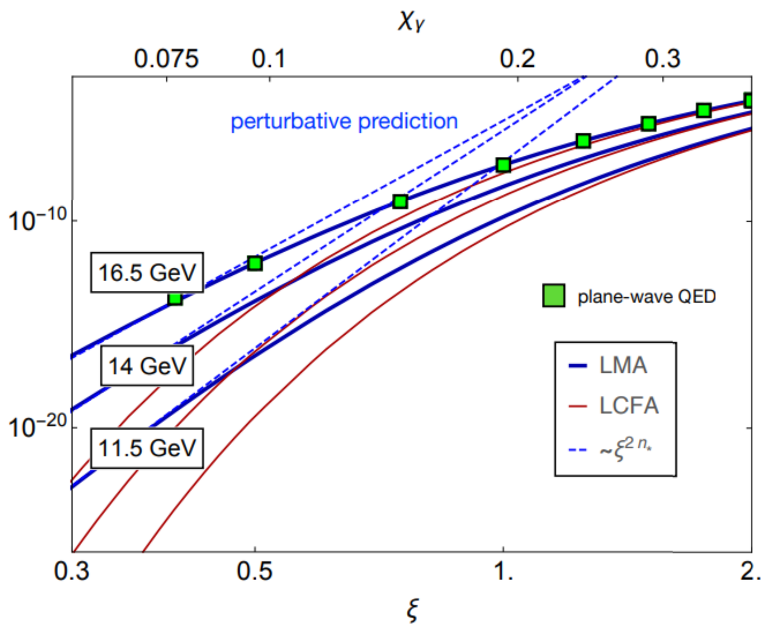
Goals

❑ **Non-linear Compton scattering and Breit-Wheeler pair production:**

Reconstruct Compton edge in electron (Scintillator or Cherenkov detector) or photon spectrum (Photon spectrometer);

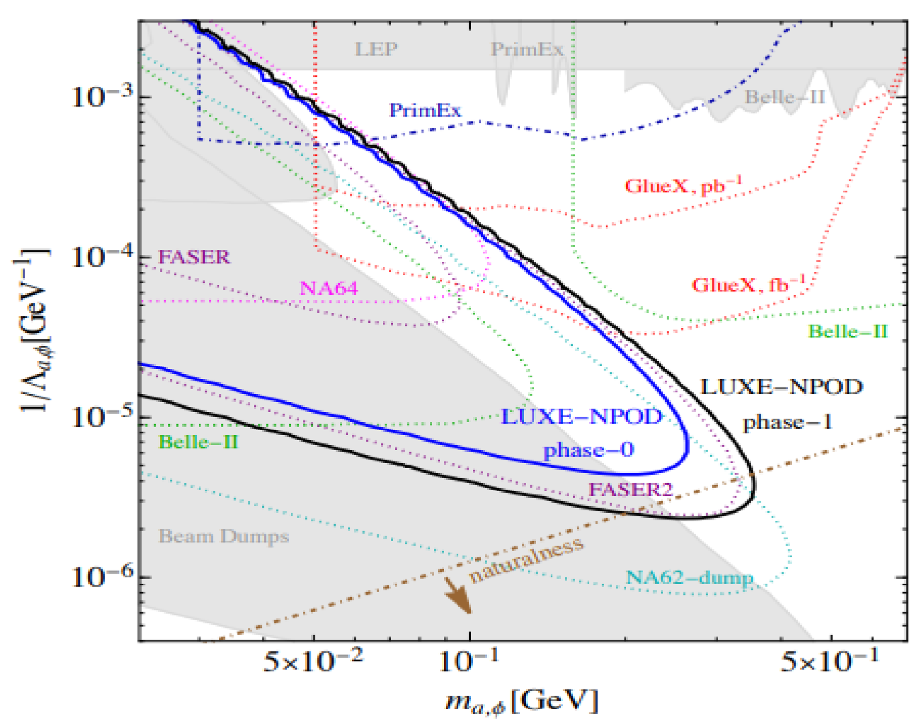
Measure positron rate with combined pixel tracking detector and EM calorimeter.





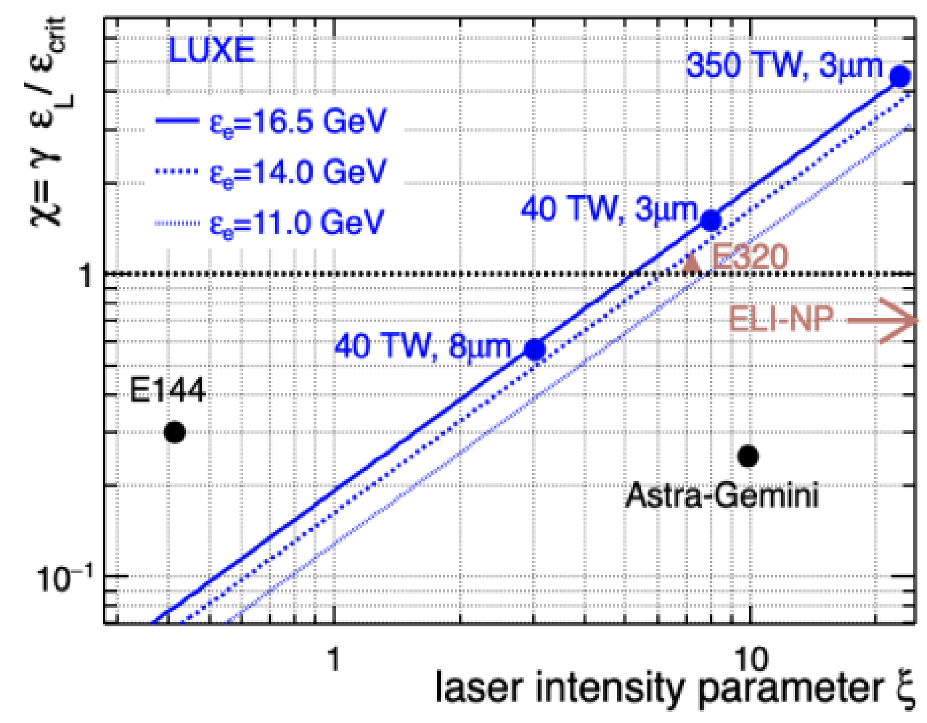
❑ **Search for BSM physics:**

The high-intensity photon beam can be used to search for (pseudo-) scalars or milli-charged particles ((mCPs)) in beam-dump.



❑ **LUXE in Strong-Field QED space parameters:**

- First set-up to enter $\xi > 1$ and $\chi > 1$ regime!
- Directly study collisions between LASER and real GeV photons.



Detectors

European XFEL electron beam:

- Energy 16.5 GeV @ 10 Hz (possible 10 GeV and 14 GeV).
- LUXE uses one out of 2700 bunches per train.
- Collide 1 Hz with laser and 9 Hz for background measurements.
- Normalized emittance 1.4 mm mrad.

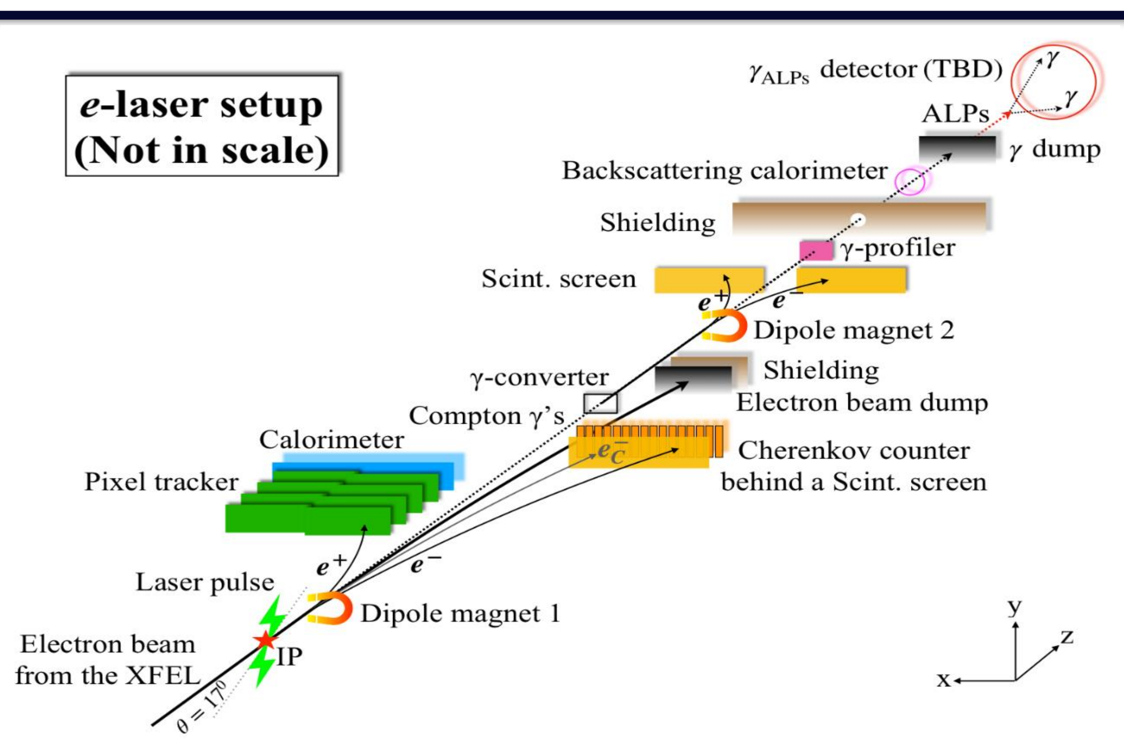
Laser:

- Laser wavelength = 800.00 nm (1.5498 eV).
- Repetition rate ~1 Hz.
- Power:
  - ✓ Phase 0: 40 TW, focal spot size: 3 or 8 μm (ξ = 7.9).
  - ✓ Phase 1: 350 TW, focal spot size: 3 μm (ξ = 23.6).

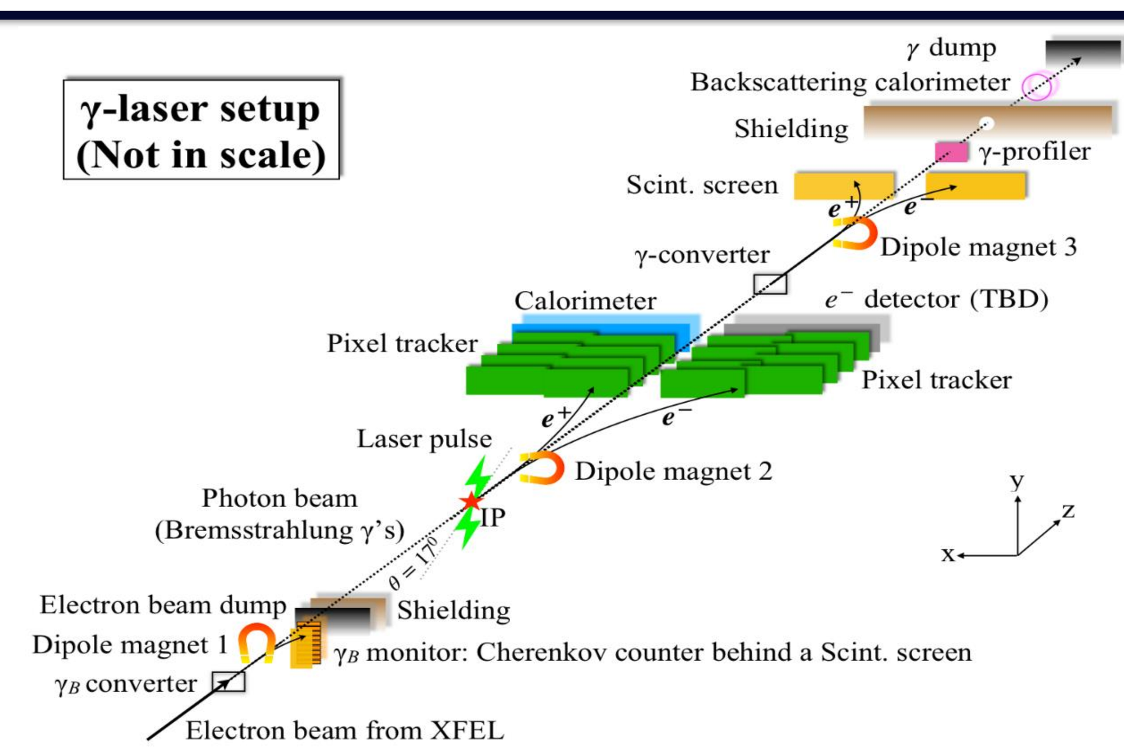
Use different detector technologies!!!

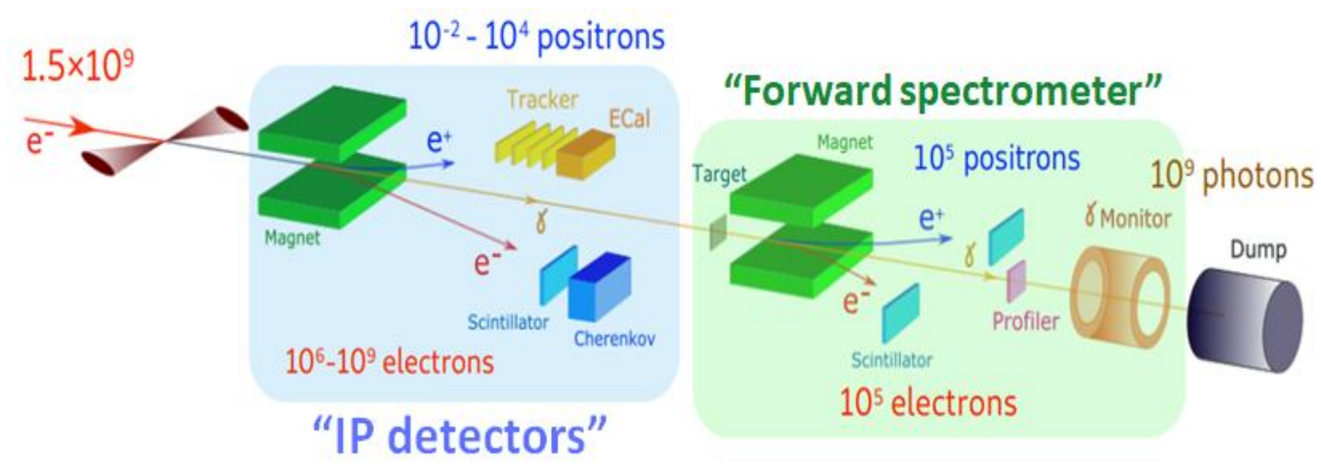
- ❑ Measure fluxes and energy spectra of e^+, e^- and γ.
- ❑ Particles fluxes vary between ~ 10^{-2} (e^+) and 10^9 (e^-, γ) per laser shot.

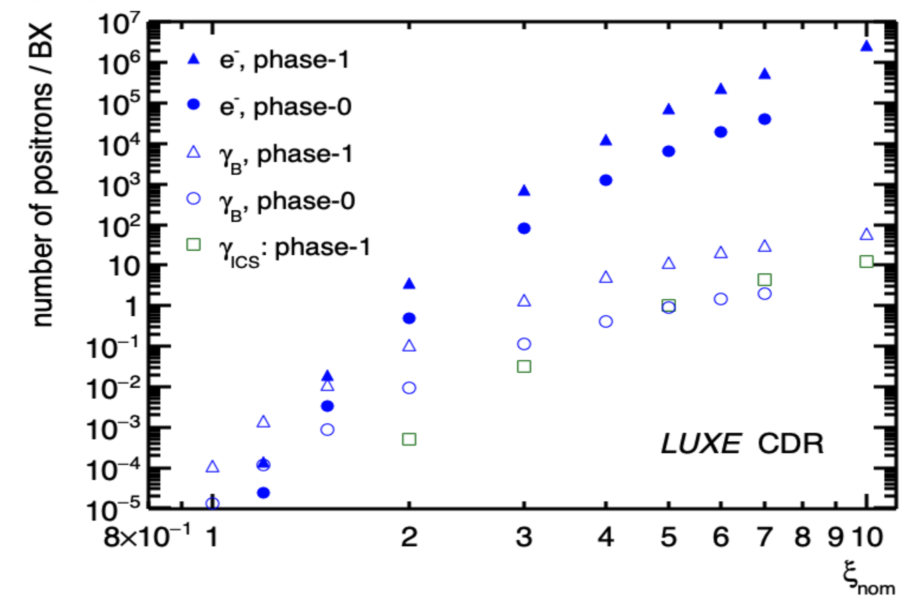
e-laser setup (Not in scale)



γ-laser setup (Not in scale)







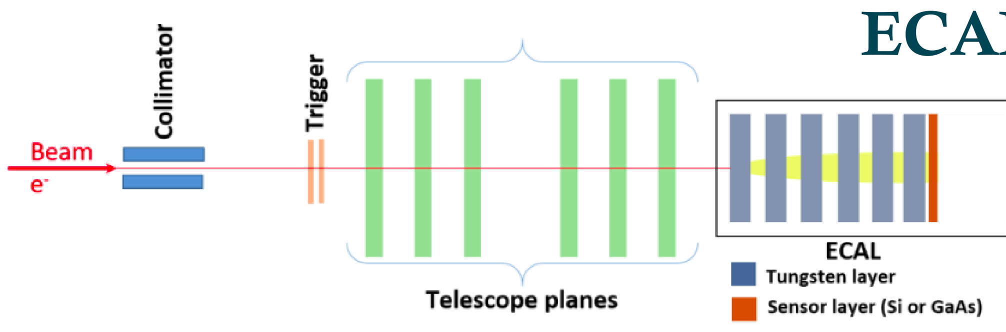
FLAME - LumiCal new readout:

- ❑ **FLAME** is a **System on Chip (SoC)** solution.
- ❑ **130 nm CMOS** technology.
- ❑ 32 mix-mode channels per ASIC.
- ❑ Each channel contains FE+10 bit ADC.
- ❑ Followed by high speed data link.
- ❑ Online data processing:
  - ❑ Pedestal, CM subtraction.
  - ❑ Pulse detection.
  - ❑ Deconvolution.
  - ❑ ToA and amplitude reconstruction.

LUXE ECAL design:

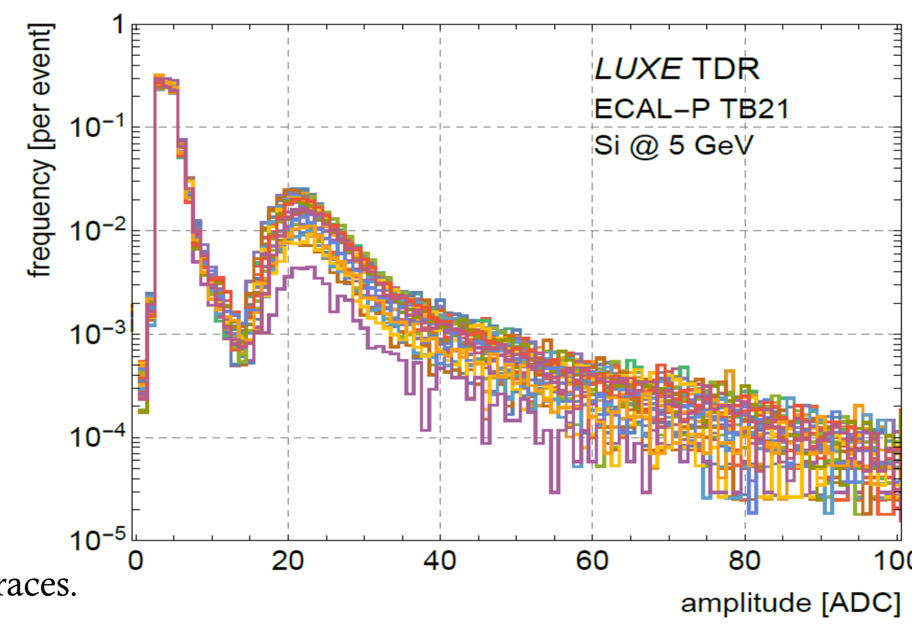
- ❑ High granularity EM calorimeter.
- ❑ Sampling calorimeter with 20 W absorber plates.
- ❑ Silicon or GaAs sensors (5x5 cm² pads) installed in 1 mm gap between absorber plates.
- ❑ Small Moliére radius, high spatial resolution of local energy deposits.
- ❑ The fiducial volume: 53 × 5.2 × 9 cm³ .

ECAL Calorimeter – 1st beamtest @ DESY



Test beam infrastructure @ DESY-II:

- Electron beam 1 - 5 GeV energy.
- 6 ALPIDE telescope planes.
- DUT (ECAL calorimeter):
  - FLAME ASIC.
  - Si (320μm) sensor or GaAs (500μm) sensor with traces.



Conclusions & Future Work

- ❑ The LUXE experiment will explore strong-field QED using European XFEL and high power laser.
- ❑ The calorimeter is designed to measure the number of positrons per bunch crossing in a wide range.
- ❑ ECAL will be a compact EM calorimeter with high granularity.
- ❑ LUXE is a new experiment designed to test a strong field QED predictions in a region never explored before in clean environments.
- ❑ Parasitically: search for BSM physics (axion-like particles (ALPs) or millicharged particles (mCPs) produced in dump).
- ❑ The experiment received a stage 0 critical approval (CD0) from the DESY management.
- ❑ Installation is foreseen in 2025, the data taking for phase-0 will be in 2025 and 2026, Upgrade to phase-1 laser at 2026.

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