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

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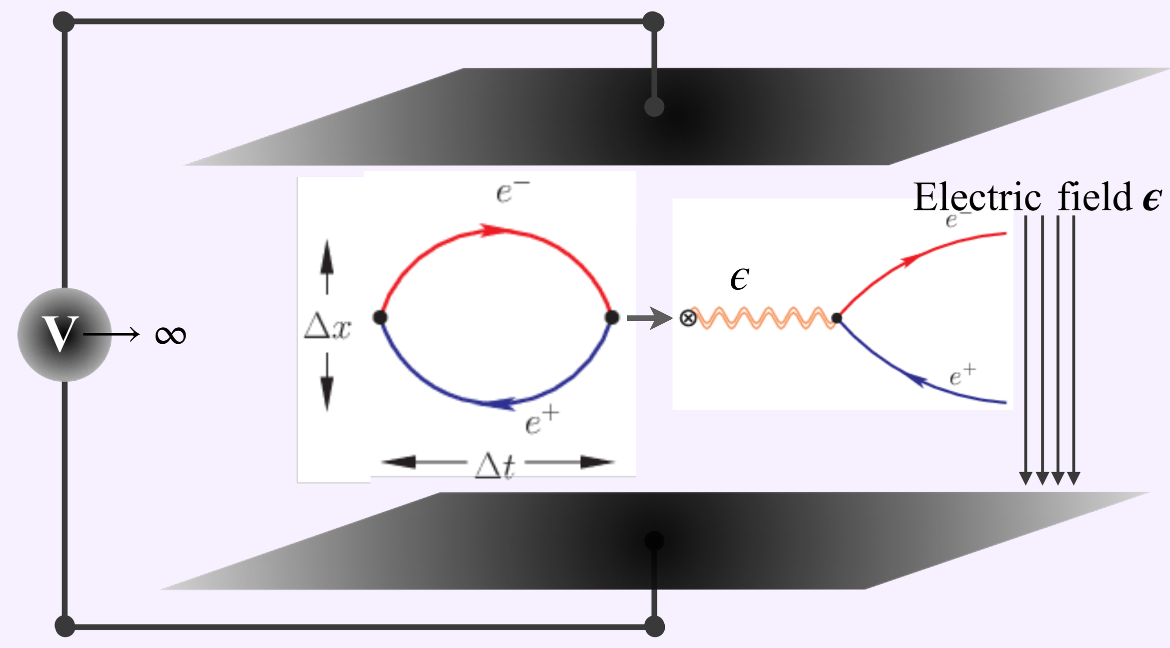
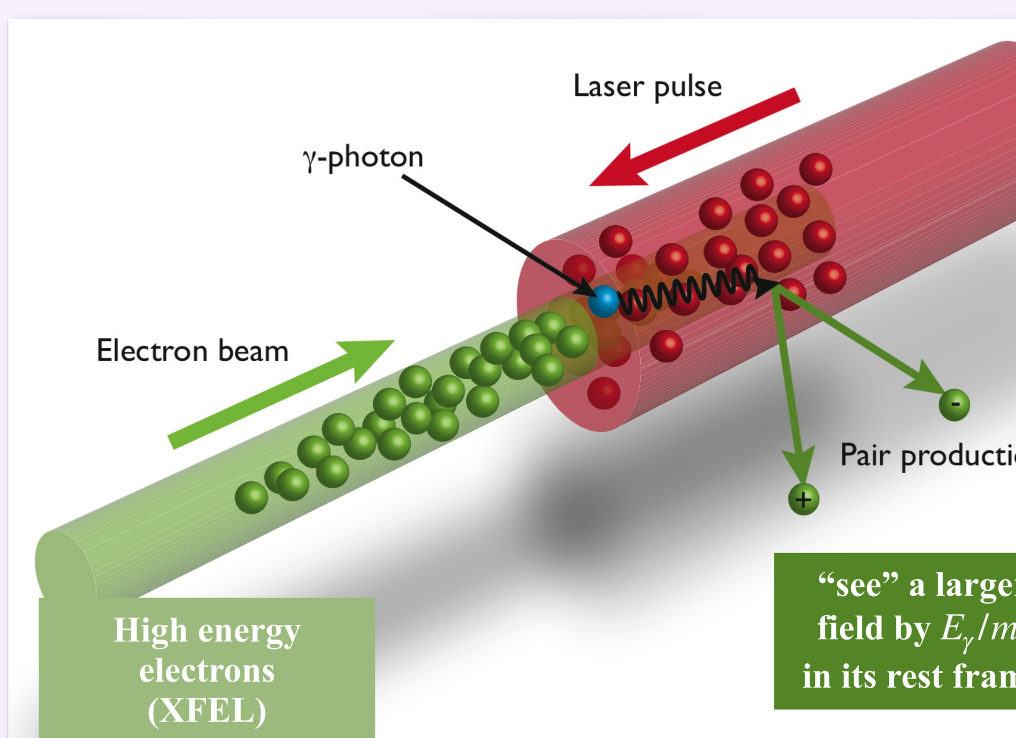
Introduction

✦Perturbative QED with small background field is well-understood, but there is **much less understanding of QED in the regime of strong fields**.
✦For very strong field, QED perturbation theory breaks down and becomes non-perturbative.
✦At the Schwinger critical field: $\epsilon_{\text{crit}} = m_e^2c^3/e\hbar \simeq 1.32 \cdot 10^{18}$ V/m, vacuum breaks down and electron and positron pairs are produced spontaneously.
  ✦ϵ_{crit} not achievable in terrestrial laboratories unless **use of lasers** - in certain rest frames the field of lasers can be enhanced by the system's boost.
  ✦First experiment to try this: E144 @ SLAC in 1990s - reached ~$\epsilon_{\text{crit}}/4$.
  ✦Present-day experiments (e.g. E320, Astra-Gemini) and planned (e.g. ELI-NP).
  ✦Propose to do this using European XFEL electron beam and high power laser: **LUXE experiment** based at DESY, Germany.
✦LUXE will study **non-perturbative and non-linear QED phenomena in the strong field regime** (in the transition region near and above ϵ_{crit}) in electron/photon beam and high power laser collisions.



LUXE Experiment



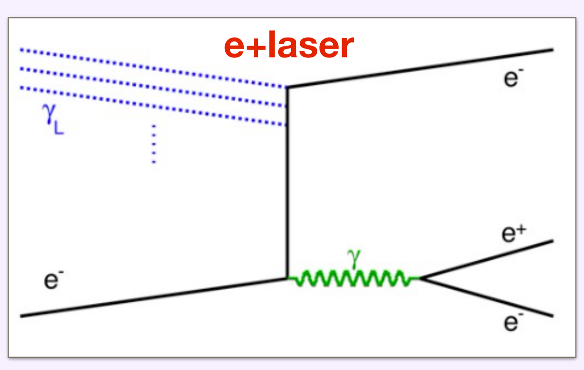
✦**High-power laser**
  ✦**Phase 0: laser power 40 TW (1.3×10^{20} W/cm^2)**
  ✦**Phase 1: laser power 350 TW (1.2×10^{21} W/cm^2)**
✦**Wavelength 800 nm**
✦**Repetition rate ~1 Hz**

✦E_e **up to 16.5 GeV,** N_e **= 1.5x10⁹ e⁻/bunch**
✦**LUXE uses one out of 2700 bunches per train**
✦**Repetition rate 10 Hz.**

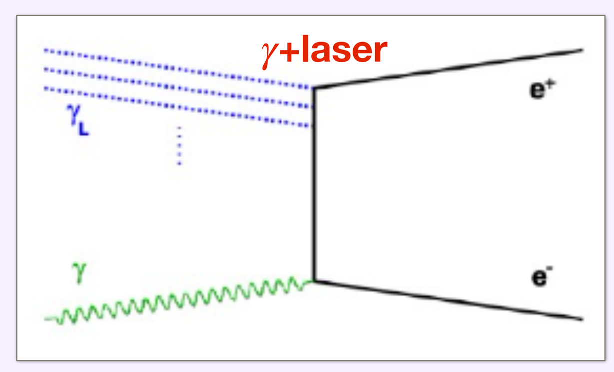
✦LUXE will run in electron (e^-) + laser (γ_L) mode where it will study the physics process of **non-linear Compton scattering.**

✦The **non-linear trident process** where the non-linear Compton scattering is followed by a pair production will also be studied.

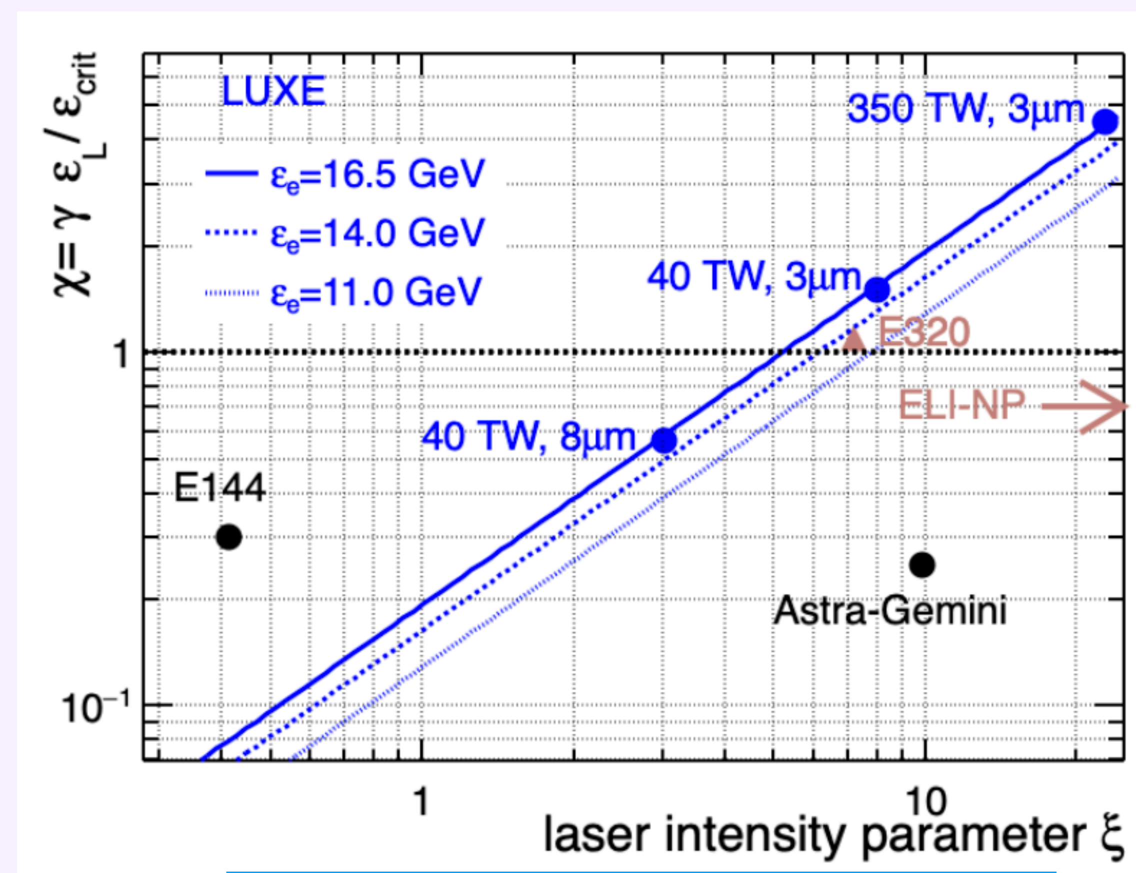
✦It will run in photon (γ) + laser mode to study the **non-linear Breit-Wheeler** process.
✦The signal rate varies from 10^{-2} to 10^9 per bunch crossing.



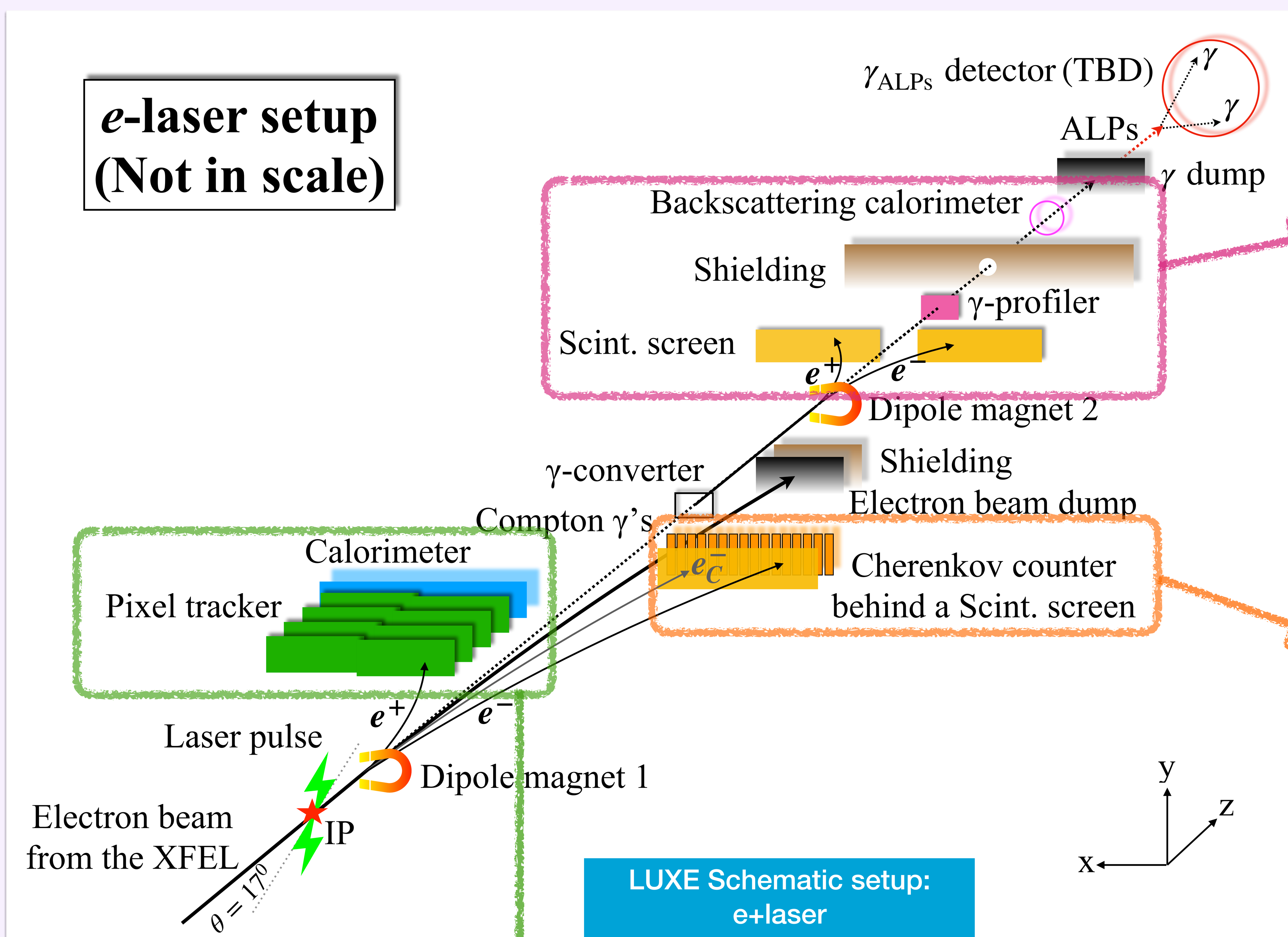
Non-linear Compton scattering, followed by pair production: $e^- + n\gamma_L \to e^- + \gamma, \gamma \to e^+ + e^-$



Non-linear Breit-Wheeler: $\gamma_L + \gamma \to e^+ + e^-$



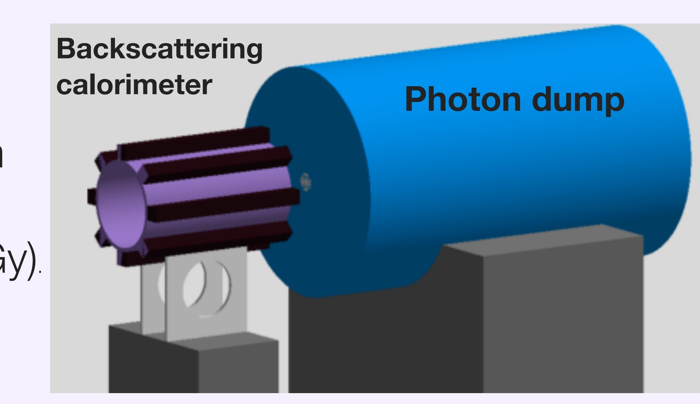
Laser intensity parameter: $\xi \propto \epsilon/\epsilon_{\text{crit}}$.
Quantum parameter: $\chi_{e,\gamma} \propto (E_{e,\gamma}/m_e)\xi$,
Perturbative when $\xi \ll 1$



LUXE Schematic setup: e+laser

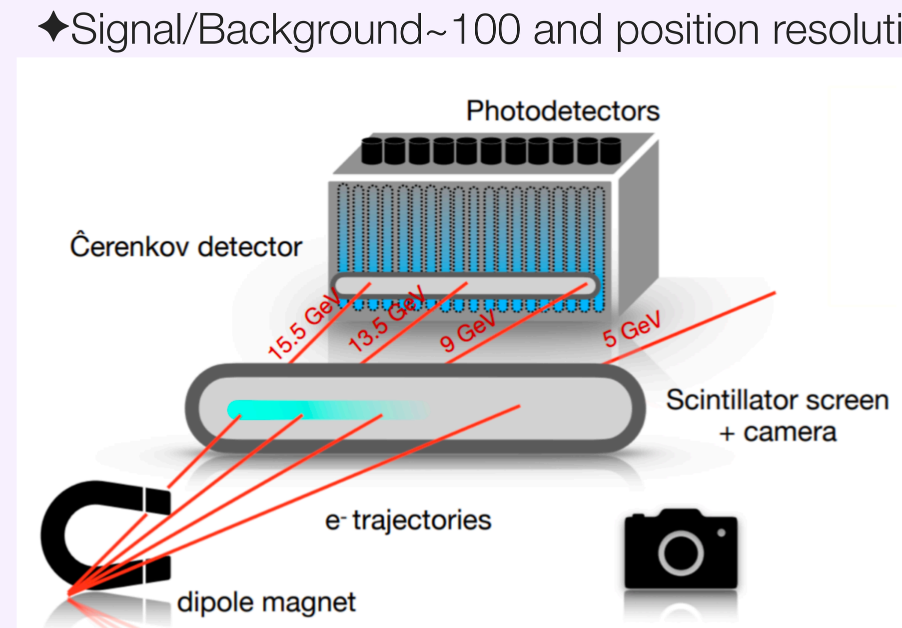
Photon detection system

✦High number of photons ~ 10^9.
✦Tungsten converter target (10 µm) generates 10^4-10^5 e^+/e^- pairs.
✦Spectrometer:
  ✦LANEX (Tb-doped Gadolinium Oxysulfide) scintillator screen in addition to CCD cameras (for e^+/e^-).
✦Gamma beam profiler:
  ✦Sapphire strips sensors (2x2 cm^2, 100 µm thickness, 100 µm strip pitch).
  ✦Very radiation hard material (up to 100 MGy).
✦Backscattering calorimeter to measure flux.
  ✦Consists of 8 lead glass blocks around beam axis with radius ~17 cm.
  ✦Almost linear dependence between the energy deposited and the number of incident photons.



Electron detection system

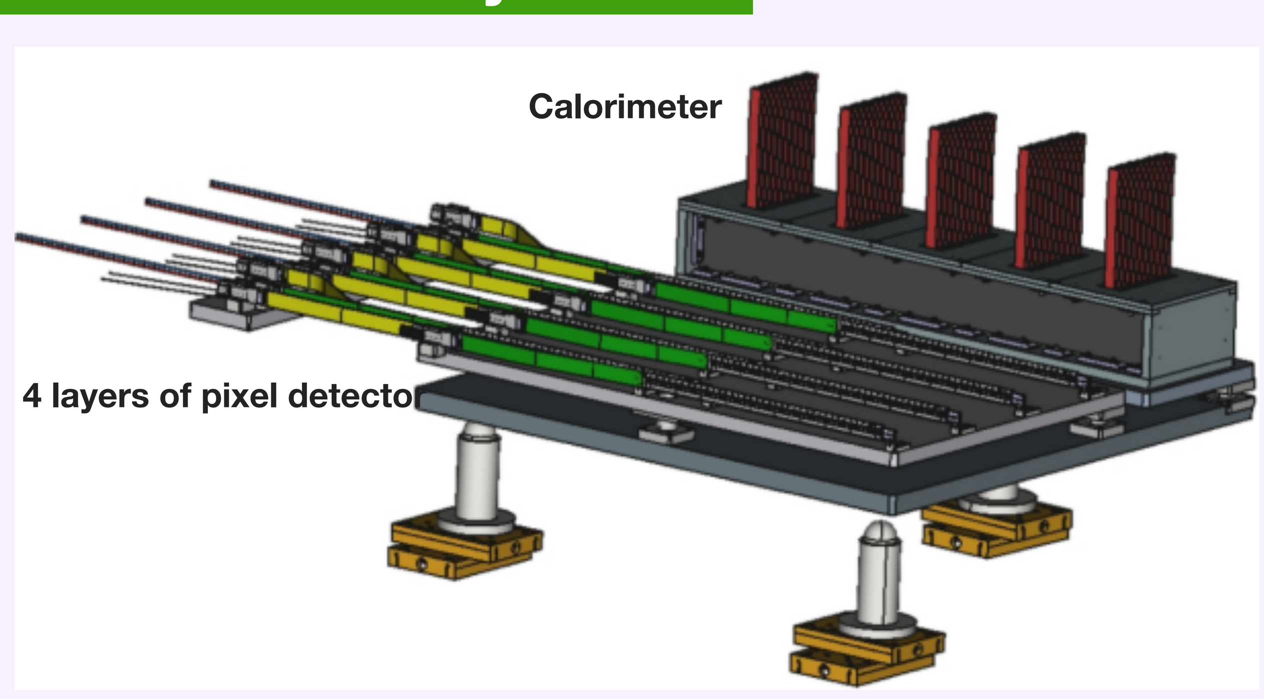
✦Very high event rate: up to 10^9 electrons.
✦Scintillator screen:
  ✦Tb-doped Gadolinium Oxysulfide, radiation hard (up to 10 MGy).
  ✦Imaging is done with CMOS camera.
  ✦Signal/Background~100 and position resolution $\mathcal{O}(100\ \mu\text{m})$ (at ~50 MeV).



✦Cherenkov detector:
  ✦Consists of reflective straw tube channels filled with air as an active medium.
  ✦Signal/Background > 1000.
  ✦Cherenkov threshold of 20 MeV.

Positron detection system

✦Pixel tracker:
  ✦Four layers of ALPIDE sensors.
  ✦Developed by ALICE for the phase 1 upgrade.
  ✦Pixel size of 27×29 µm^2 with a spatial resolution of 5 µm.
  ✦Able to tolerate an ionization doze of 2.7 Mrad.



✦Calorimeter:
  ✦20 layers of 3.5 mm thick tungsten absorber plates (20 X_0).
  ✦Sensor planes placed in a 1 mm gap between absorber plates
    ✦Silicon wafers of 320 µm thickness.
    ✦Each sensor has a surface of 7.56×5.19 cm^2 and consists of 150 pads.

Summary

✦The LUXE experiment will explore strong field non-perturbative QED predictions with the help of using the European XFEL electron beam and high power laser.
✦All the detectors are designed keeping in mind the rate measurements: from 10^{-2} to 10^9 per bunch crossing.
✦The experiment received a stage 1 critical approval from the DESY management.
✦Installation is foreseen in 2025 and data taking period from 2026.

References

1. Abramowicz, H., Acosta, U., Altarelli, M. *et al.* Conceptual design report for the LUXE experiment. *Eur. Phys. J. Spec. Top.* **230,** 2445–2560 (2021). https://doi.org/10.1140/epjs/s11734-021-00249-z

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