

# The Laser Und XFEL Experiment at DESY: Physics opportunities and recent prospects

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*on behalf of LUXE Collaboration*

MoriondEW24. La Thuile, 28/03/24

TDR: <https://arxiv.org/abs/2308.00515>

CDR: <https://arxiv.org/abs/2102.02032>

# LUXE



HELMHOLTZ



## LUXE in a nutshell

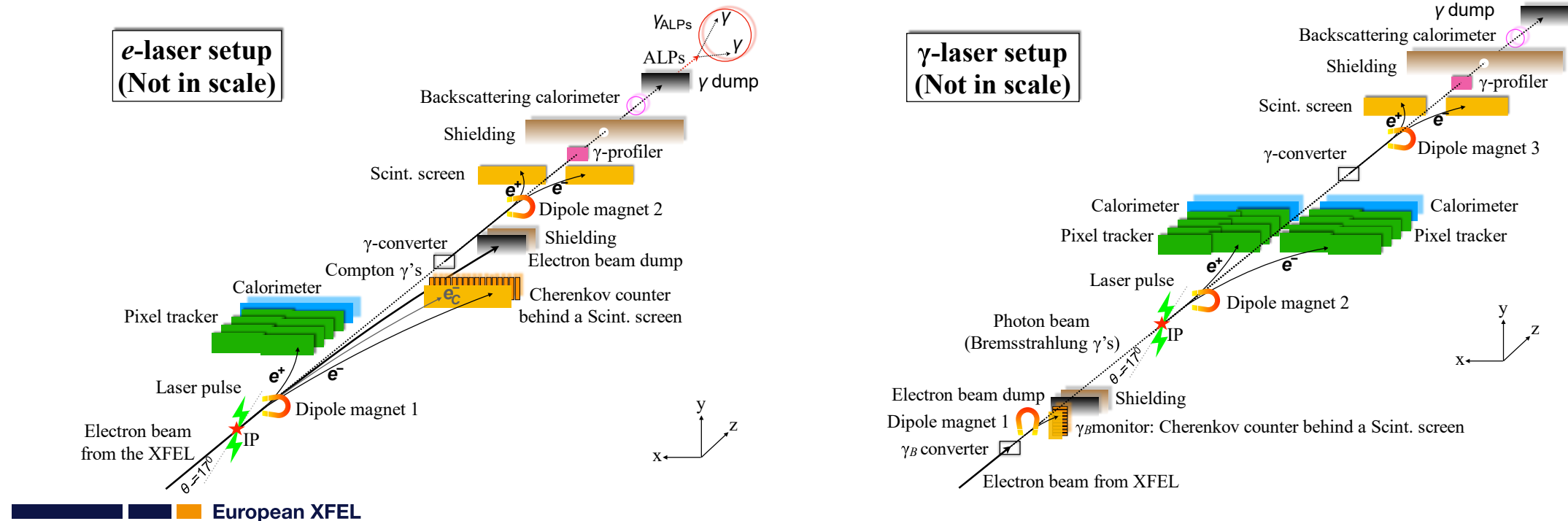
- LUXE is an experiment at DESY to perform precision measurements of the transition into the non-linear regime of strong field quantum electrodynamics (SFQED), and to search for new particles beyond the Standard Model coupling to photons.



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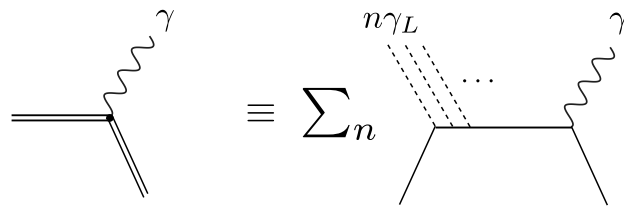
■ 16.5GeV  $e^-$  from Eu.XFEL collisions with a 40-350TW laser beam,  
(collaboration of HEP and laser physics communities)



## LUXE physics opportunities

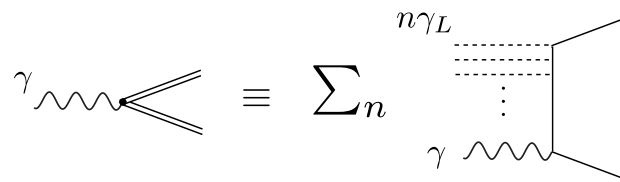
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- 16.5GeV  $e^-$  from EuXFEL collisions with a 40-350TW laser beam
- probing the onset of SFQED with the processes:



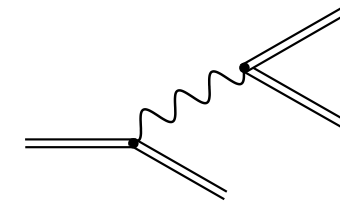
$$e^\pm + n \gamma_L \rightarrow e^\pm + \gamma$$

Nonlinear inverse Compton



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

Nonlinear Breit-Wheeler



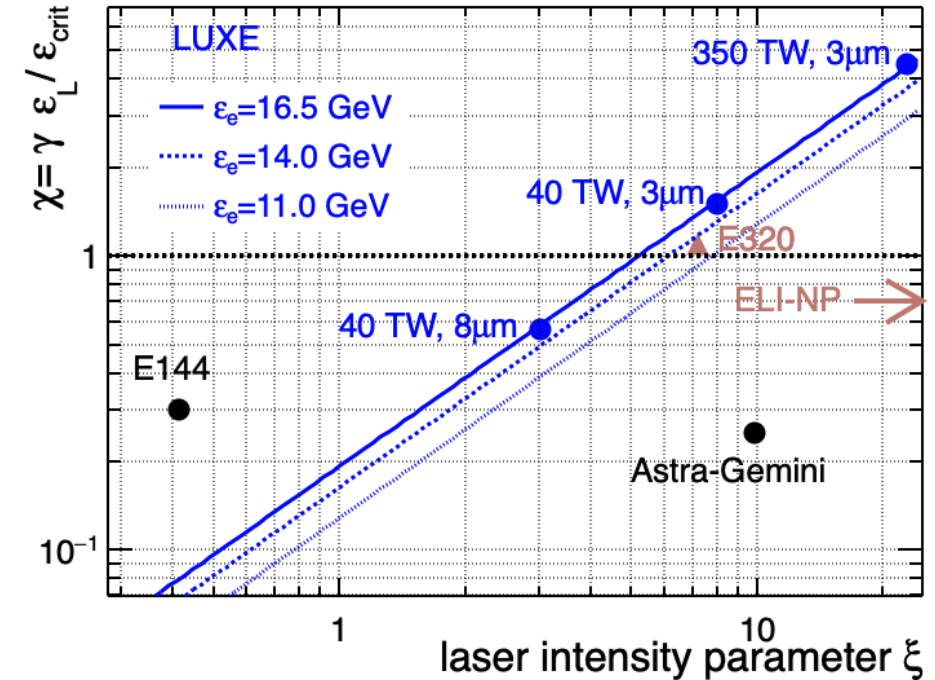
$$e^\pm + n \gamma_L \rightarrow e^\pm + \gamma$$

$$\gamma + n' \gamma_L \rightarrow e^+ + e^-$$

Nonlinear Trident

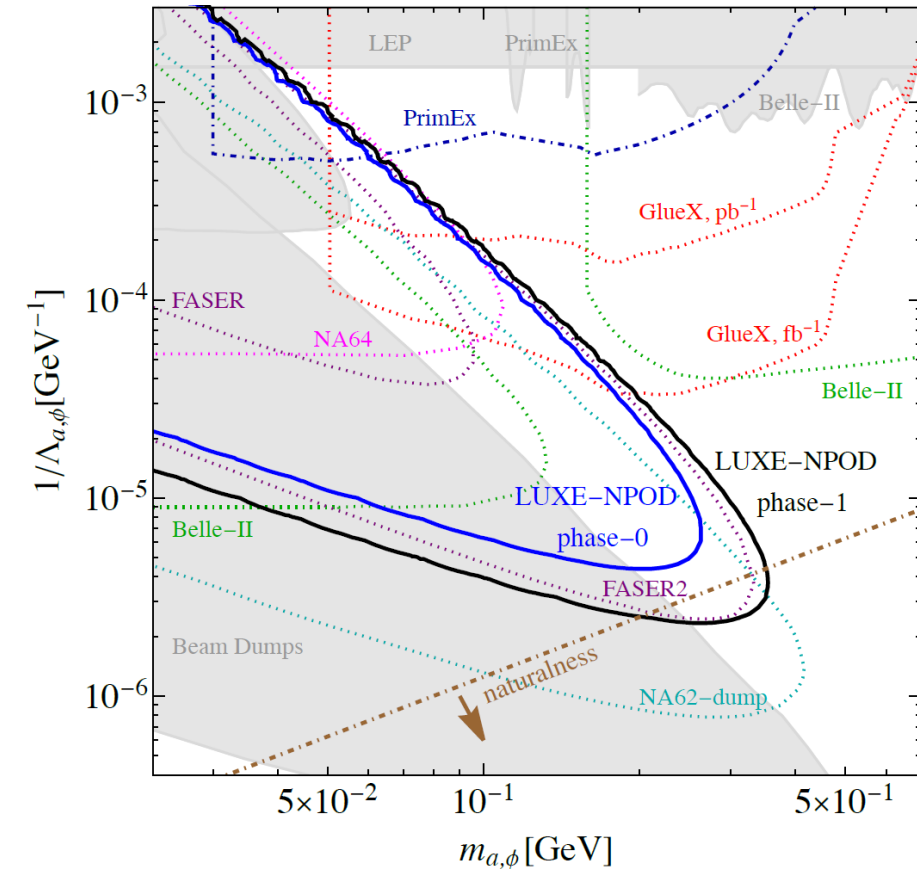
## LUXE key features and challenges

- Collaboration of *particle* and *laser* physics communities
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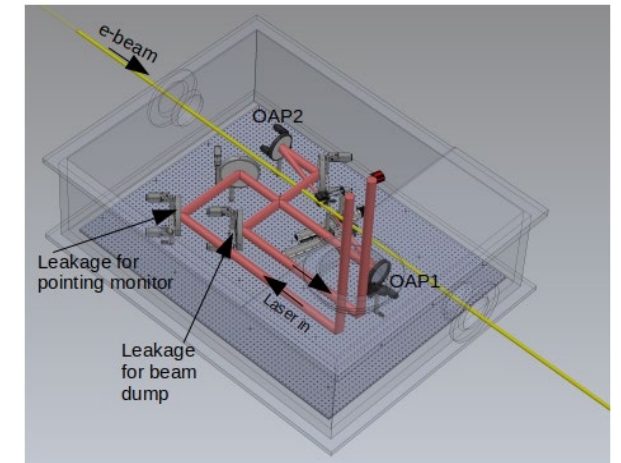
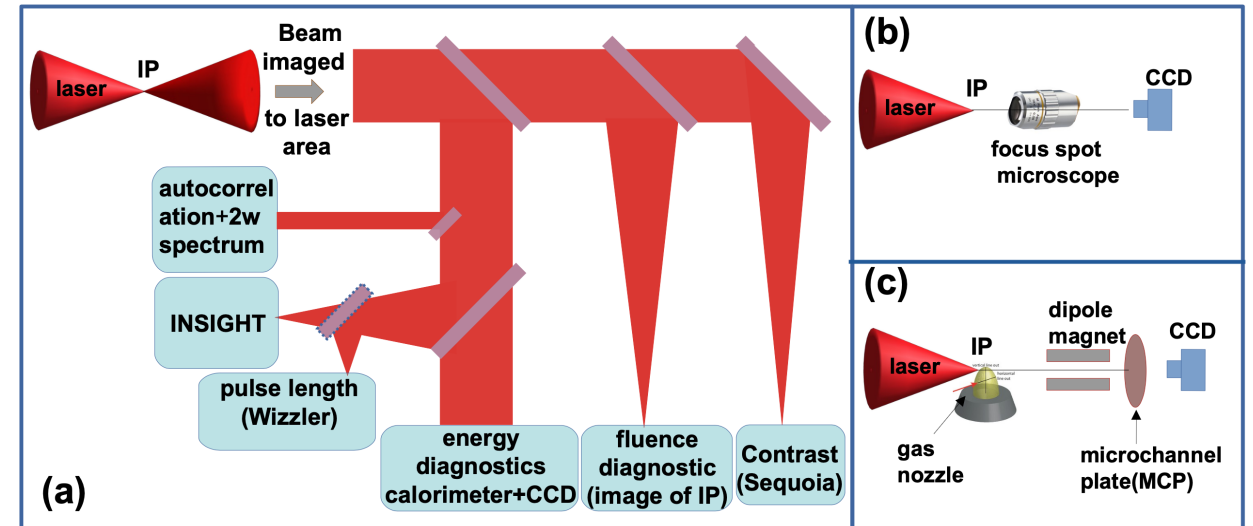


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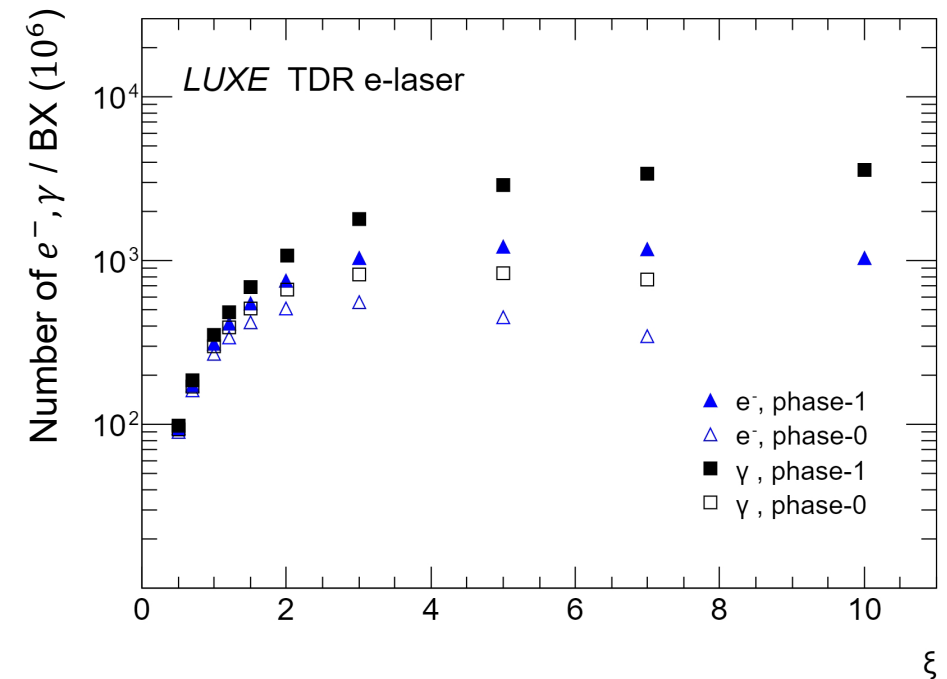


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- Wide range of particle production rates (from  $10^{-2}e^+$  to  $10^9 \gamma$  per event), high fluxes and precision physics (detector)





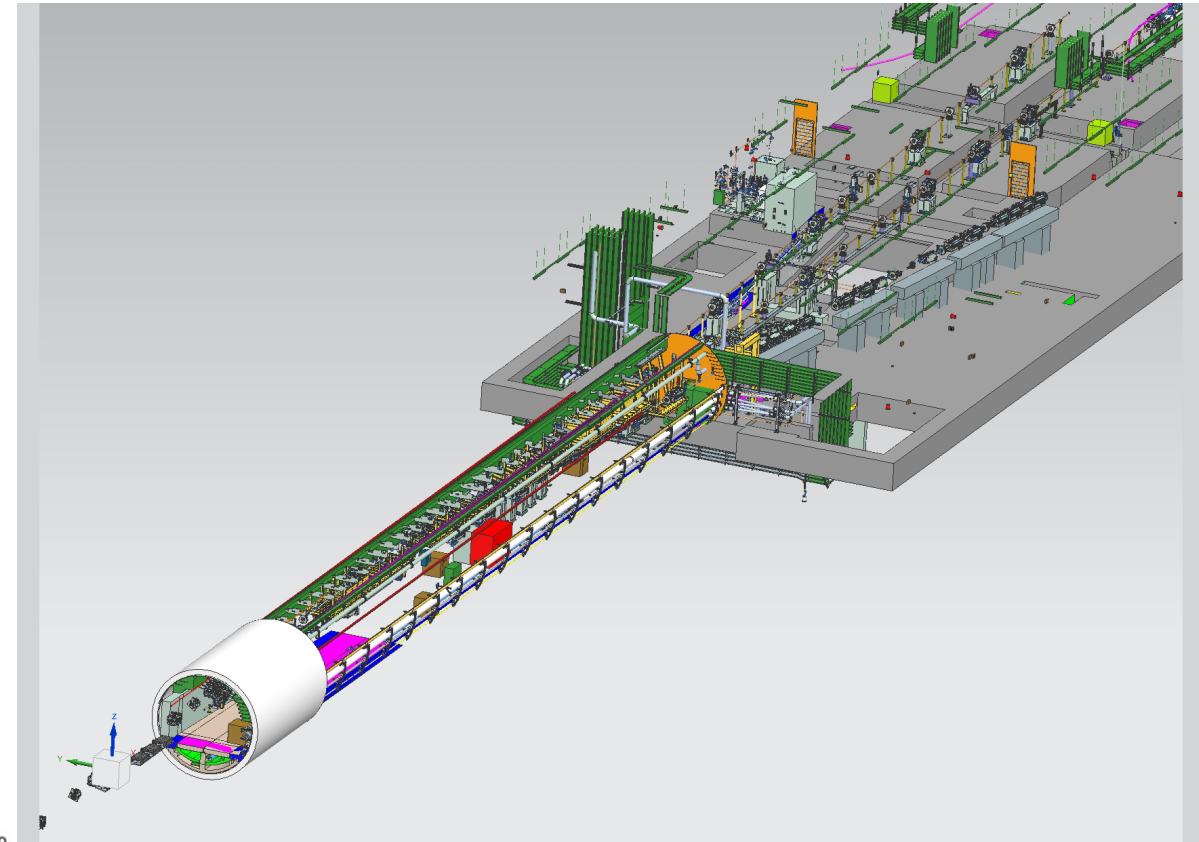
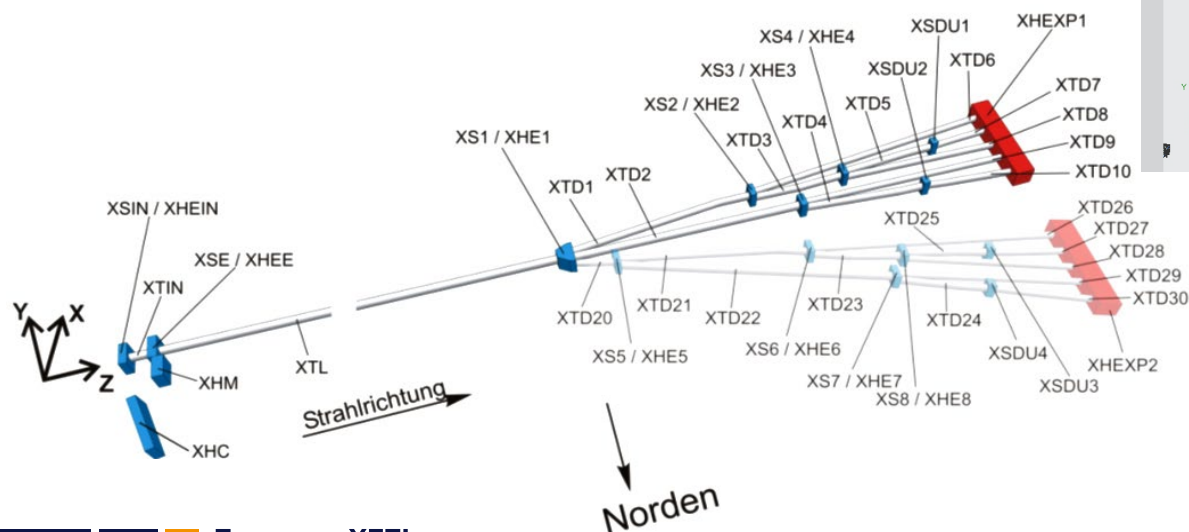


# Recent prospects

## Project update. Beam-line & laser

### Summary

- Preparation of **TD20** extraction beamline critical to meet **2025 XFEL shutdown**.
- Finalization of TD20 in shorter shutdowns.
- LUXE installation staggered in shorter shutdowns ahead of 2025, after TD20.



- Beam delivered to SASE1 and quality investigated already by Stuart Walker
- LUXE laser installed at ground level always accessible in new building sharing spaces with ASPECT.
- First experiment on JETI40 in 2021.

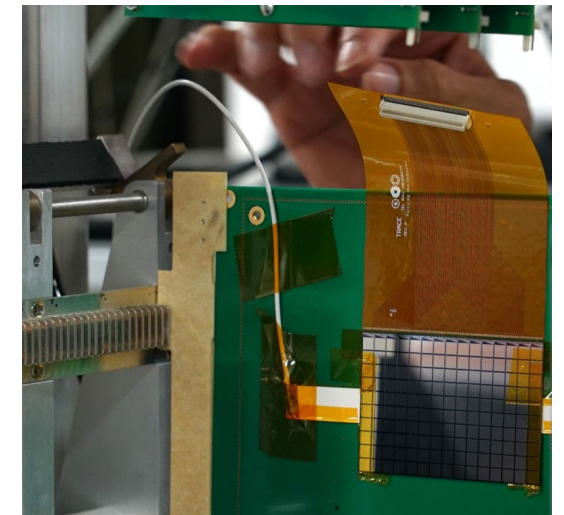
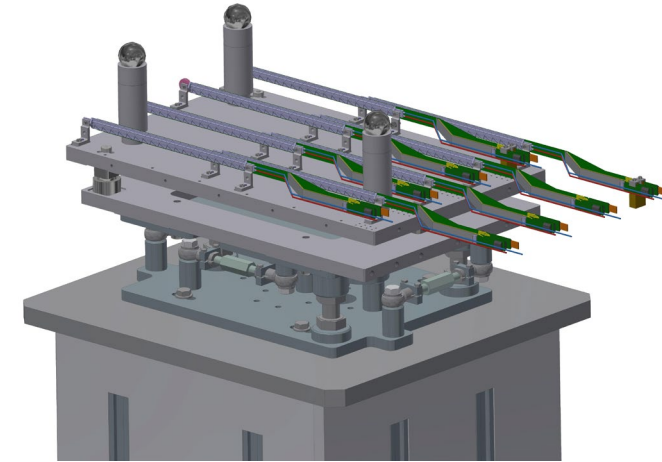
# Detectors

## Tracker

- Lots of progress in mechanics, hardware, daq software and track reconstruction.
- Allpix2, Geant4 (TDR) and Key4hep software frameworks (DD4hep, EDM4hep).
- Workgroup well organized and workload distributed over tasks and multiple people.
- Test beam end '23 at WIS, early '24 at DESY.

## E-Calorimeter

- Large group of people: workloads spread over simulations, hardware development, reconstruction.
- From design to prototype phase now. Mechanics include geodesy survey balls for alignment.
- Stack of single ECAL-P module will be tested at DESY and CERN. From test → calibration data.
- Fully assembled ECAL-P will be tested at DESY. Key components tested. Mechanics, sensor and ASICs for the full assembled calorimeter on the way.



# Detectors

## Cherenkov detector

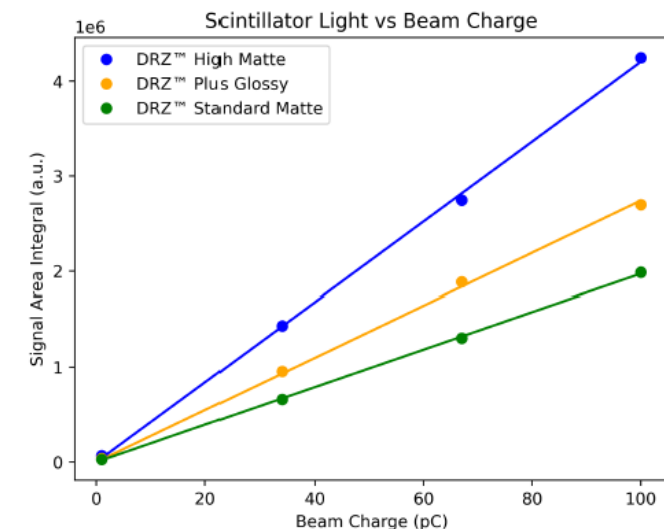
- Small workgroup. Minor updates in design and improved simulation efforts.
- Test beam at ARES with 150MeV 1-100pC/bunch 10Hz electron beam in July '23 with SiPM.
- Outlook: dose evaluation; calibration roadmap with led pulser; from 4 to 32 straw prototype.

## Gamma spectrometer

- Calibration strategy with thin-foil.
- EMP and dose may require longer imaging distance or fibre bundle.
- Tested experimentally at Apollon with LWFA-driven bremsstrahlung source up to GeV-photons.

## Bremsstrahlung and IP screens

- Scintillator** screen is GadOx with 545nm peak emission, radiation-hard with noticeable efficiency change at  $10^8$  Gy.
- Linear **response (ARES TB)** and 'No scint. Saturation expected up to 350pC/bunch'.



Light yield vs beam charge for different types of scintillator screens. Linear fit based on the datapoints is shown.

# Simulation, Software, DAQ and Computing

## ■ GEANT4 model, FullSim and FastSim

## ■ FLUKA simulation

## ■ EDM dd4hep migration

- Proposal to migrate the simulation to dd4hep;
- and to use a standardized data format for the various detectors (Event Data Model EDM4hep).

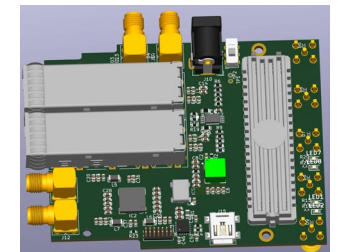
## ■ LUXE Control System and DAQ-related hardware

- Input for the 'LUXE Control System' LCS: two modes *baseline* and *enhanced*
- **LTU** (luxe timing unit) delivers triggers via **optical**-fibre fanout → custom optical to electric required.
- Connection to XFEL and laser needs more work.

## ■ DAQ software

- No final decision between EUDAQ2 and DOOCS.

## ■ NPOD and beyond





# Thank you!

backup slides



# LUXE Physics. What is 'strong field'?

## ■ LUXE main aims are

- Measure the interaction of real photons with electrons/positrons at field-strengths where the coupling becomes non-perturbative
- Make precision measurements of the transition between perturbative to non-perturbative regime of QED
- Use strong-field QED processes to design a sensitive search for BSM particles coupling to the photons

## ■ What is 'strong field'?

- QED constants lead to a natural EM field one can build, called the Schwinger field

$$\mathcal{E}_{\text{cr}} \equiv \frac{m^2 c^3}{e\hbar} \approx 1.32 \times 10^{18} \text{ V/cm}$$

- However, in the rest frame of a boosted high-energy probe charge, the EM field strength which it is subjected is boosted by the Lorentz factor  $\gamma$  to  $\mathcal{E}_* = \gamma \mathcal{E} (1 + \cos\theta)$  with  $\theta$  the collision angle (which for LUXE is 17.5 deg)

## LUXE Physics. QED in strong EM fields

- QED in intense EM fields can arise in
  - Gravitational collapse of black holes, where astrophysical pair creation can occur;
  - The propagation of cosmic rays;
  - The magnetosphere of strongly magnetised neutron stars;
  - Beam-beam collisions at future high-energy lepton colliders;
  - In heavy-ions collisions, e.g. where Coulomb field around nuclei (typically  $Z > 137$ ) is strong
- What separates strong-field QED from regular QED?
  - The dimensionless charge-field coupling, which in plane wave EM backgrounds is described by the *classical non-linearity parameter*

$$\xi = \frac{e \mathcal{E} \lambda_e}{\hbar \omega_L}$$

work of the EM field over a (reduced) Compton wavelength  
in units of  
the background EM field photon energy

- The  $\xi$  quantifies how many laser photons interact with the charge in each QED process, with the probability of interaction with  $n$  background photons scaling as  $\xi^{2n}$
- In weak-fields probabilities of QED processes scale as  $\sim \xi^2$  ( $n=1$ )



## LUXE Physics. Non-linearity parameters

- Classical non-linearity parameter

$$\xi \equiv \frac{e \mathcal{E}_L}{m_e \omega_L}$$

- Quantum non-linearity parameter

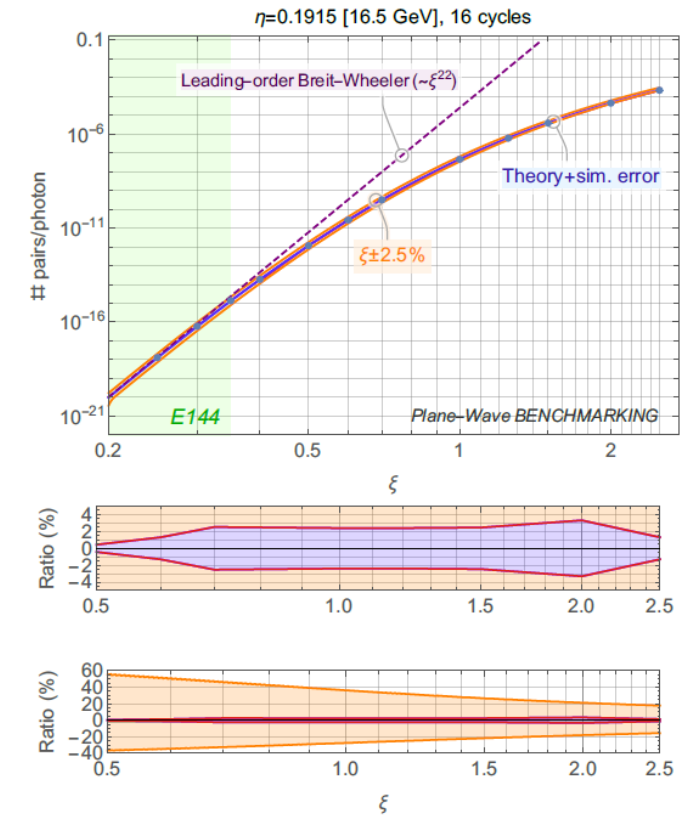
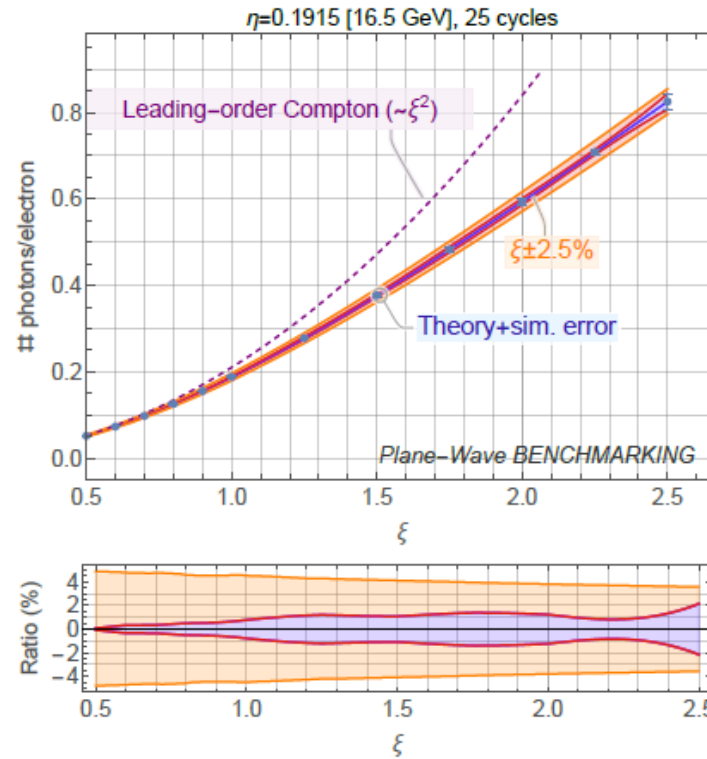
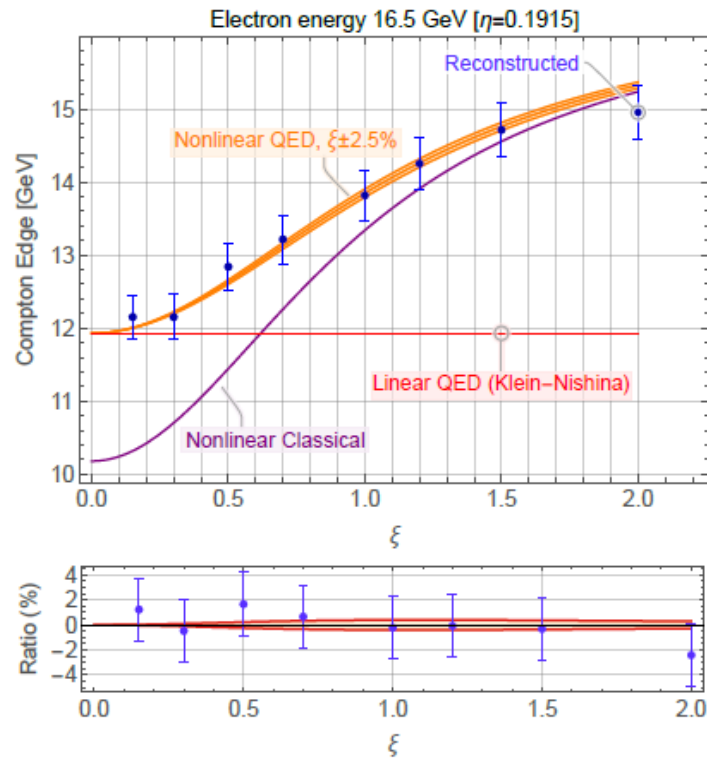
$$\chi \equiv \frac{E_*}{\mathcal{E}_{cr}} = \frac{e \hbar}{m_e^3 c^4} \sqrt{-(p_\mu F^{\mu\nu})^2}$$

$$E_* = \gamma_* \mathcal{E}_L (1 + \cos\theta)$$

$$\mathcal{E}_{cr} = \frac{m_e^2 c^3}{e \hbar} \simeq 1.32 \cdot 10^{18} \text{ V/m}$$

- How many laser photons interact with the charge in each QED process, with the probability of interaction with  $n$  background photons scaling as  $\xi^{2n}$ . *How much energy has been transferred from a classical field to a probe charge.*
- Energy transferred from the laser pulse to a probe electron over a reduced electron Compton wavelength, in units of the electron rest energy. *It quantifies the amount of electron recoil in the interaction.*

# LUXE Physics. Deviations from weak field QED



e-laser

$\gamma$ -laser

# LUXE new physics scenarios

- LUXE (phase-1) is expected to reach the sensitivity required to probe the edge of the parameter space of natural models of axion-like-particles (ALPs) and scalars, by using an optical and solid beam dump and an EM calorimeter.

