LUXE A new experiment to study non-perturbative QED in electron-LASER and photon-LASER collisions

LUXE DESY.

LHCP 2021

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Quantum electrodynamics (QED) is the world's most precisely known (and tested) theory.

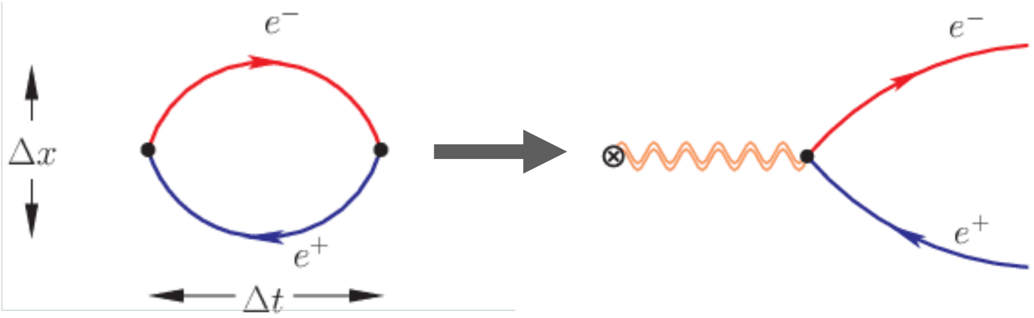
- Weak coupling allows for perturbative description

Vacuum polarisation increases coupling with energy.

- At high energies, the perturbative expansion fails
- The Schwinger limit $\varepsilon_{cr} = 1.32 \cdot 10^{18}$ V/m defines the strong-field regime of QED

Schwinger pair production

e^+e^- pairs are spontaneously created by field-induced tunnelling out of the vacuum

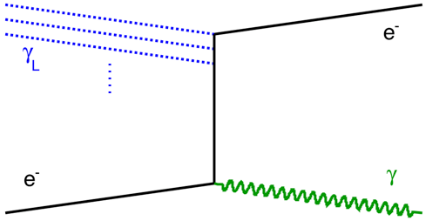


What happens if e^+, e^- or γ propagate in a very strong field?

High-intensity lasers (of frequency ω_L) can provide fields ε_L of 10^{14} V/m in the laboratory frame.

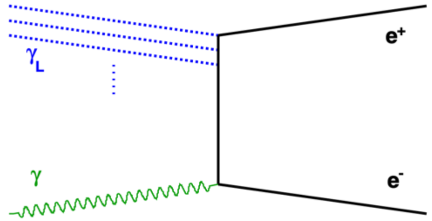
- The field strength will reach ε_{cr} for highly boosted electrons ($\gamma_e \sim 10^4$)

LUXE (Laser Und XFEL Experiment) will investigate the transition into the non-perturbative regime of QED for the first time.



Compton scattering

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



Breit-Wheeler pair production

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

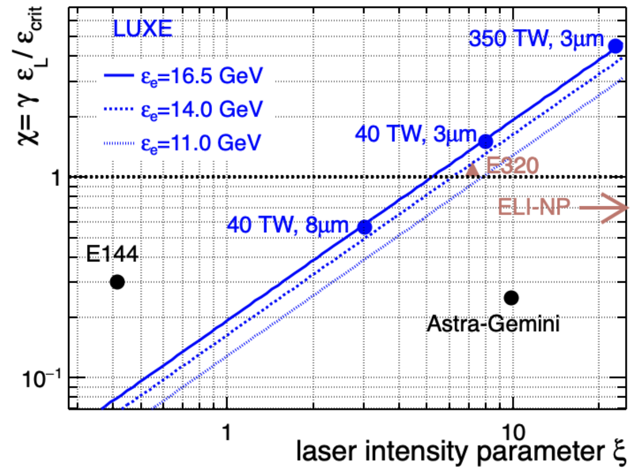
Key quantities.

Quantum parameter

$$\chi_\gamma = (1+\cos\theta)\frac{E_\gamma}{m_e}\frac{\varepsilon_L}{\varepsilon_{cr}}$$

Field intensity parameter

$$\xi = \sqrt{4\pi\alpha}\left(\frac{\varepsilon_L}{\omega_L m_e}\right) = \frac{m_e\varepsilon_L}{\omega_L\varepsilon_{cr}}$$



GOALS

References.

[1] LUXE CDR, arXiv: 2102.02032

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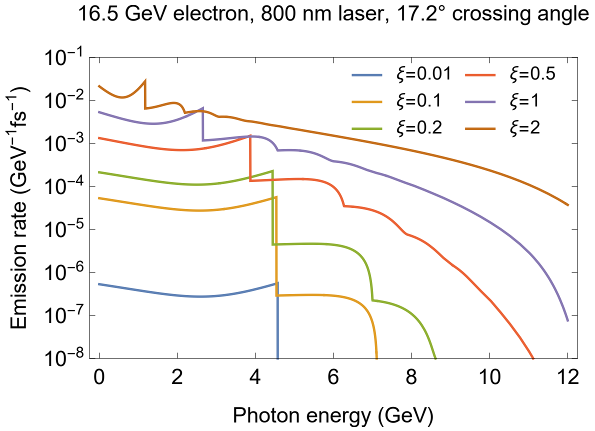
Nonlinear Compton scattering

Reconstruct Compton edge in electron (Scintillator and Cerenkov detector) or photon spectrum (Photon spectrometer)



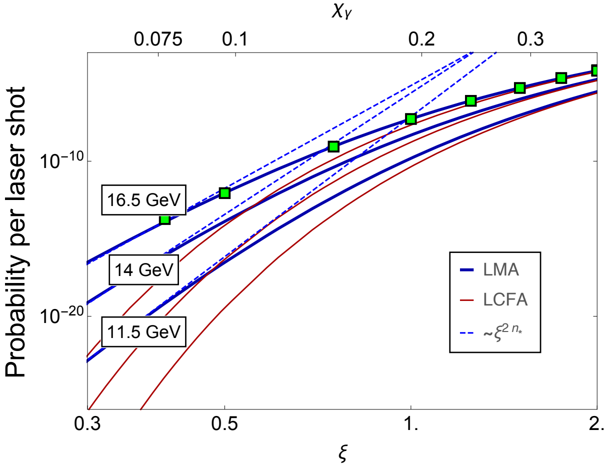
Compton edge red-shift proportional to the laser intensity.

- Can be interpreted as an effective rest mass shift

$$m_* = m_e\sqrt{1+\xi^2}$$

Nonlinear Breit-Wheeler

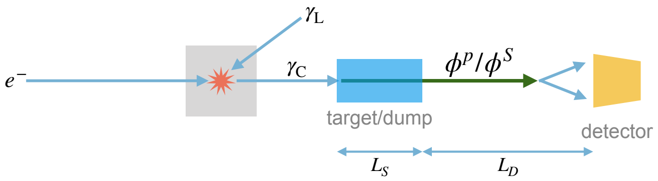
Measure positron rate with combined pixel tracking detector and EM calorimeter.



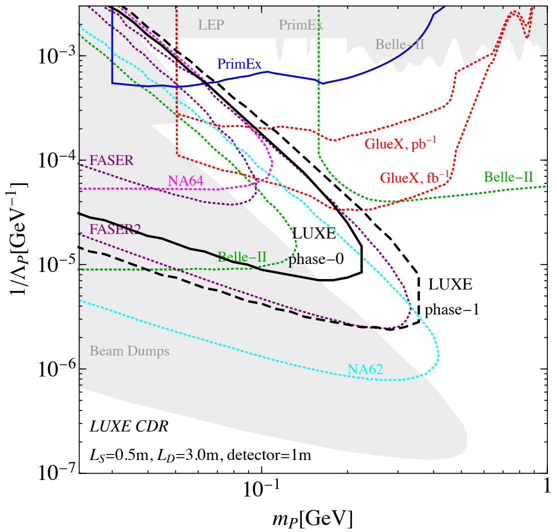
- $\xi < 1$: perturbative regime, rate follows power law
- $\xi \gg 1$: non-perturbative regime, departure from power law

Search for BSM physics

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



Sensitivity competitive with other ongoing and planned experiments.



DETECTORS

Measure fluxes and energy spectra of e^+, e^- and γ.
- Particle fluxes vary between ~0.01 (e^+) and 10^9 (e^-, γ) per laser shot

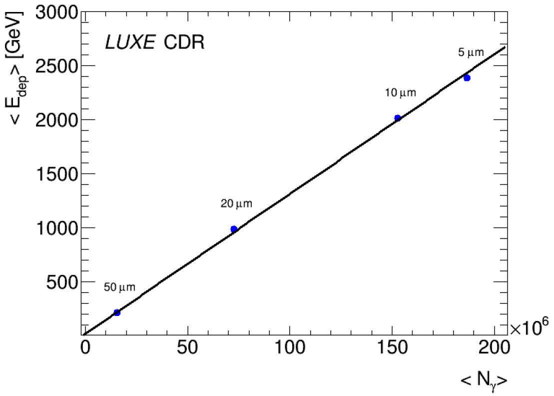
Expected e^+e^- rates
- e −laser 10^{-2} − 10^4 pairs
- γ −laser 10^{-3} − 1 pairs

Use different detector technologies!

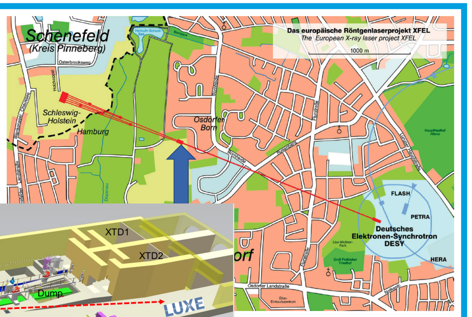
Complementary technologies will aid cross-calibration, understanding of systematics, etc.

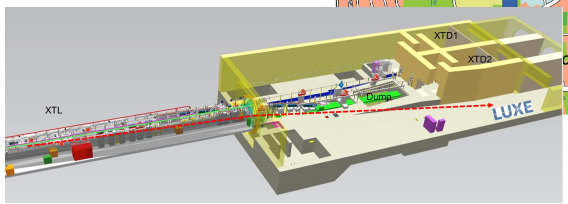
Photon detectors
- Measure up to 10^9 photons summing up to TeV energies.

Three systems:
- Gamma-ray spectrometer
- Gamma-ray profiler
- Gamma flux monitor

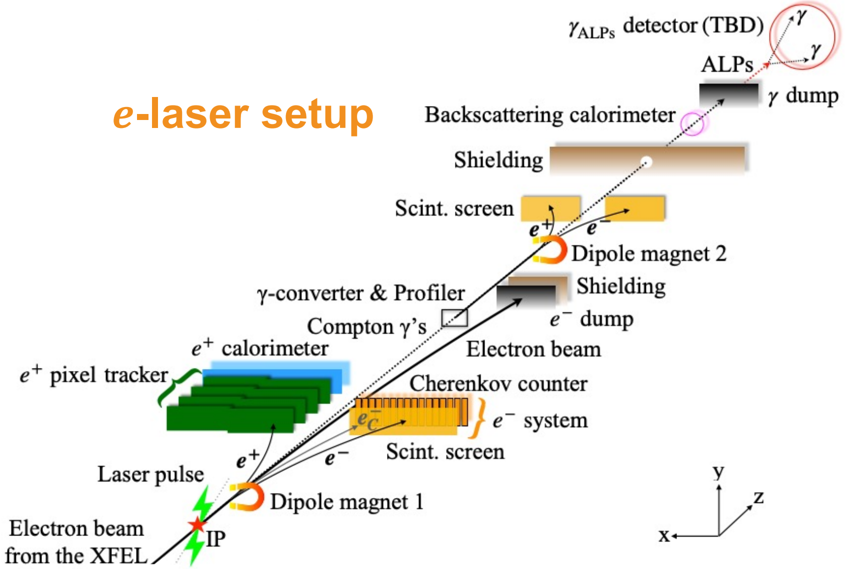


WHERE?
DESY and Eu.XFEL in Schenefeld & Hamburg Germany

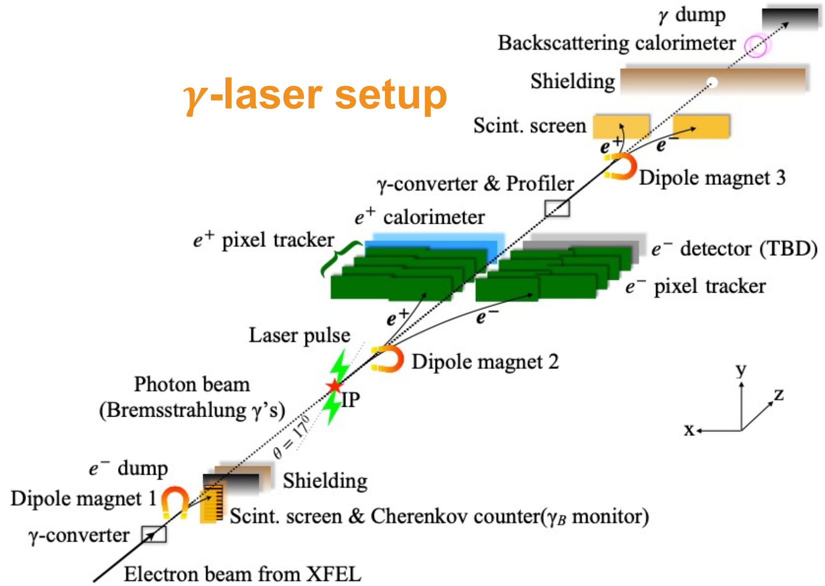




e-laser setup



γ-laser setup



BSM detectors
- Need ~zero background $\gamma\gamma$ events

A calorimeter to measure signal
- E > 0.5 GeV
- Pointing resolution of few cm
- Timing resolution of ~1 ns

Muon chambers for veto

LASERS

- Existing JETI40 (Jena) LASER will be used at the start ("phase-0")
- Exceptional shot-to-shot stability!

LUXE basic LASER parameters	
active medium	Ti:Sa
wavelength (energy)	800nm (1.55eV)
crossing angle	17.2°
pulse length	30fs
spot size	≥3µm
power	40TW / 350TW
peak intensity [10^{19} W/cm^2]	13.3 / 120

Electron detectors
- Need good background rejection and good linearity.

High-rate regions
- Cherenkov detector and scintillator screens

Low-rate regions
- Silicon pixel trackers and high granularity calorimeters