Non-perturbative QED at LUXE and prospects for future e^+- e^- colliders

Ruth Jacobs (DESY), for the LUXE collaboration

LCWS 2024, The University of Tokyo
10th July 2024

HELMHOLTZ

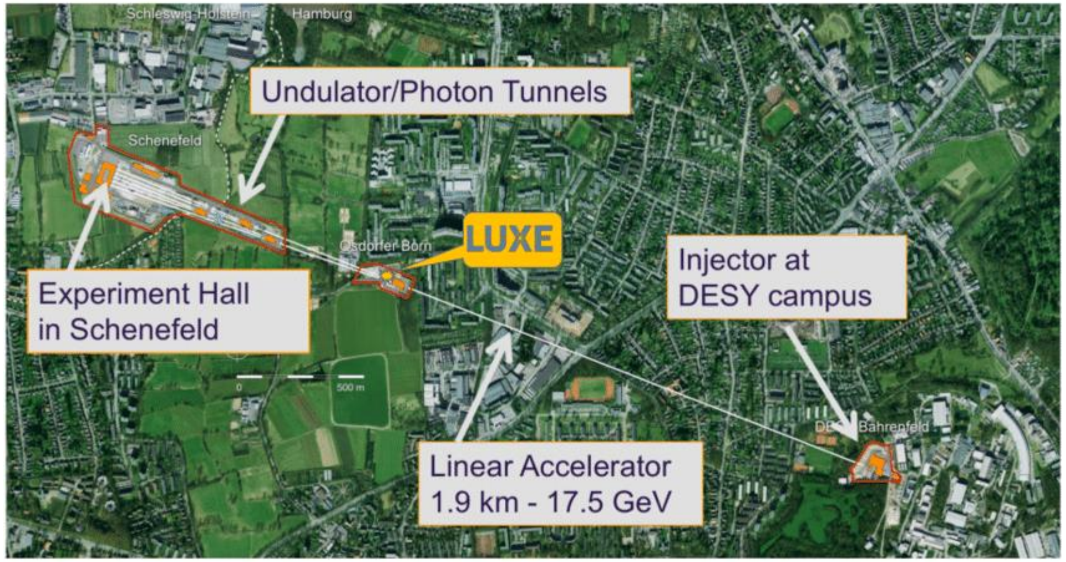
DESY.

Overview

LUXE
LASER Und XFEL Experiment

What is the LUXE experiment?

- proposed new experiment at DESY Hamburg & Eu.XFEL
- collisions between XFEL electron beam and high-intensity laser
  → probe (strong-field) QED in uncharted regime
- New physics search with optical beam dump experiment (NPOD)
- synergy between particle, accelerator and laser physics



What will be covered in today's talk?

1) What is strong-field QED and why is it interesting (for linear e^+/e^- colliders)?

2) What does LUXE add compared to previous and current SFQED/beam dump experiments?

3) What could be prospects for a LUXE-like experiment at a future e^+/e^- collider?

More physics beyond collider at future LC:
Sakaki-san‘s talk in Monday plenary

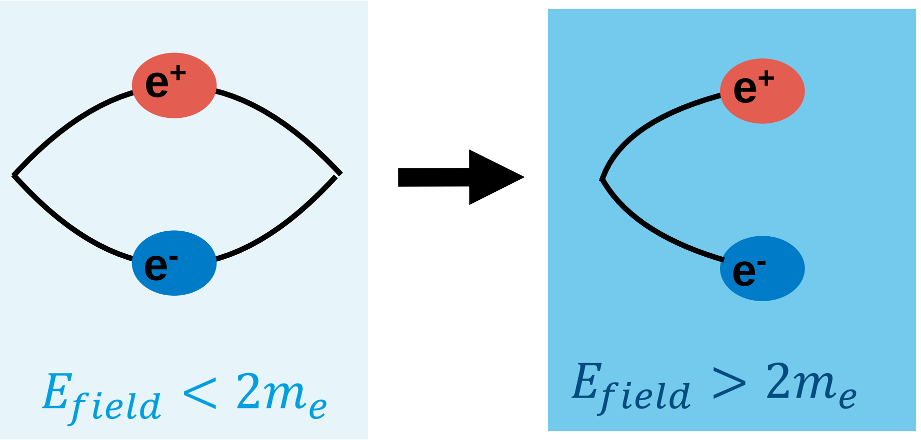
Strong-Field QED (SFQED)

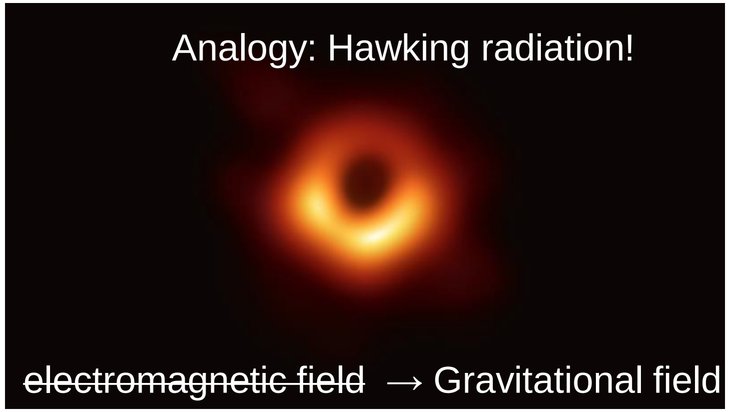
SFQED Review paper: A. Fedotov et al, 2203.00019 [arXiv:hep-ph]

- QED is one of the most well-tested theories in physics → based on perturbative calculations
- LUXE will probe QED in non-perturbative strong-field regime
- strong external field: work by field over Compton wavelength > rest mass of virtual particle
  → Schwinger-Limit
- Schwinger critical field: $\mathcal{E}_{cr} = \frac{m_e^2 c^3}{e\hbar}$ (e.g. for electrical field: $\mathcal{E}_{cr} = 1.32 \cdot 10^{18}\, V/m$)

Field energy:

$$E_{field} = \frac{e\mathcal{E}}{m_e}$$



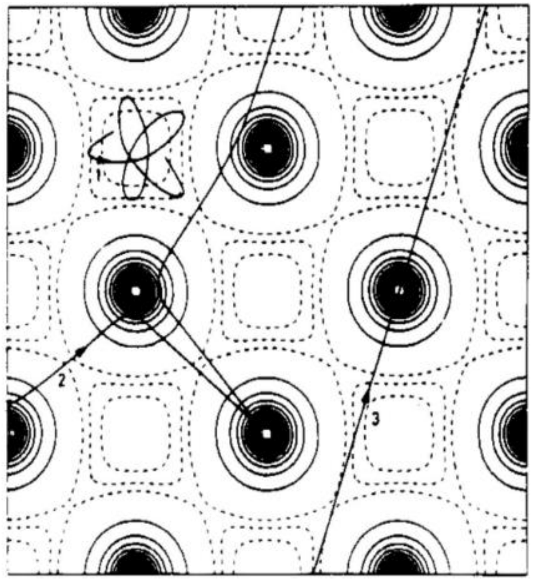


- Schwinger effect: creation of e^+e^- pair from vacuum in constant field
  → existing fields orders of magnitude too small compared to $\mathcal{E}_{cr}$, effect unobservable… but:

Non-linear quantum effects accessible in fields below $\mathcal{E}_{cr}$ with relativistic probe particles
→ fields $\mathcal{O}(\mathcal{E}_{cr})$ in particle rest frame!

Creating strong fields in the laboratory

NA63: 10.1103/PhysRevD.108.052013

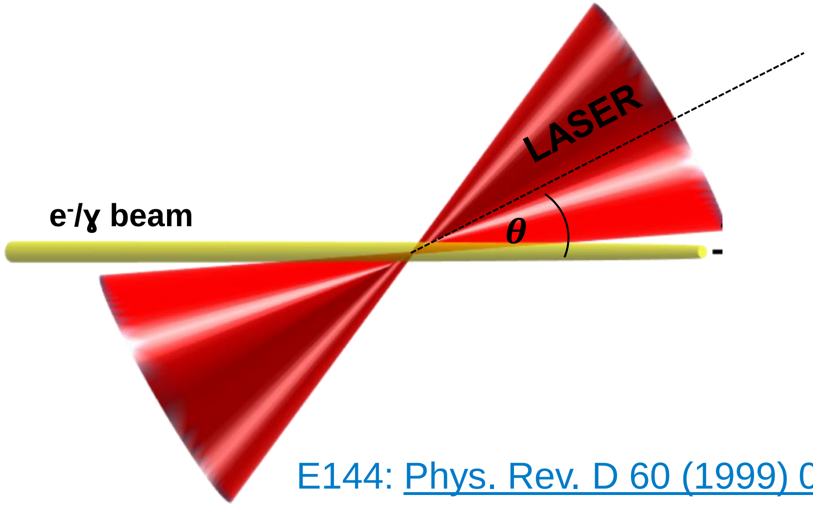


1) Solid state fixed-target experiments (e.g. NA63)

- Highly relativistic electrons impinging on crystalline target
- Crystal: EM field of ~10^{11} V/m
  → reach Schwinger limit in probe electron rest frame
- Observed multiple SF-QED processes at critical field

2) Laser – particle beam collisions (LUXE, E320, E144)

- High-intensity optical laser pulse colliding with GeV particle beam (e^-, γ)
- Lorentz-boosted EM field in particle rest frame: $\mathcal{E}^* = \gamma \mathcal{E}_L (1 + cos\theta)$
- Collisions with secondary GeV photon beam possible (LUXE)
- „Clean lab conditions“: no dependence on solid-state dynamics



E144: Phys. Rev. D 60 (1999) 092004
E320: HILAS-2022-HF4B.6
LUXE: arXiv:2308.00515

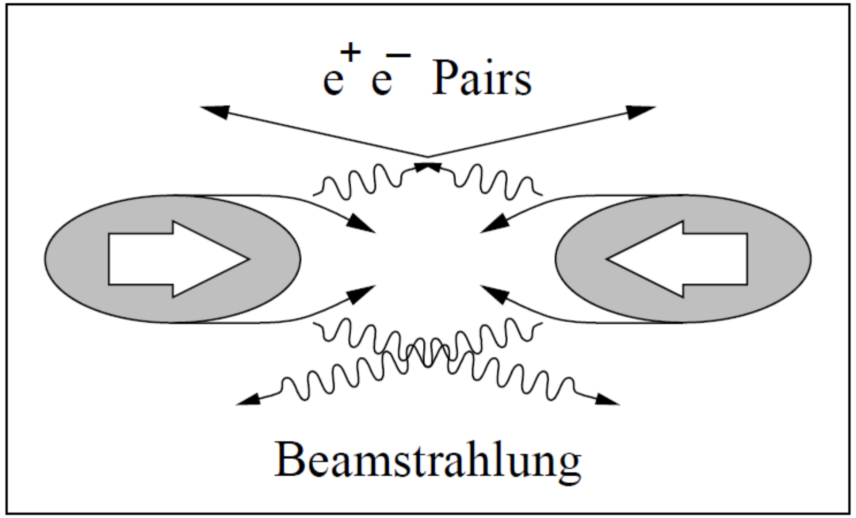
Creating strong fields in the laboratory

Source: Thesis A. Vogel (2008)

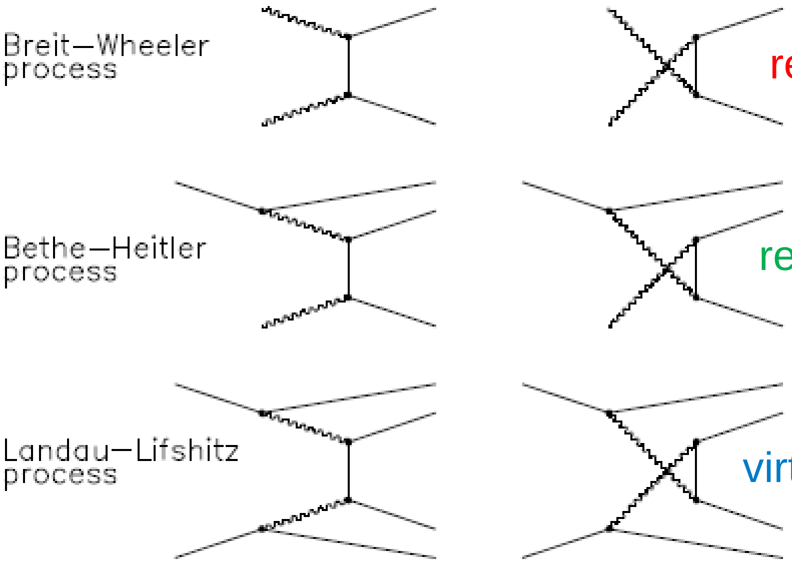
3) Beam-beam interactions (linear colliders)

- Schwinger critical field reached in collision of dense e+/e- bunches
  → aided by particle boost
- Pinch effect: - particles in one bunch deflected by strong field of the other
  - deflection → Beamstrahlung photons
  - scattering of photons → pair production

→ Luminosity enhancement, beam energy spread, detector backgrounds



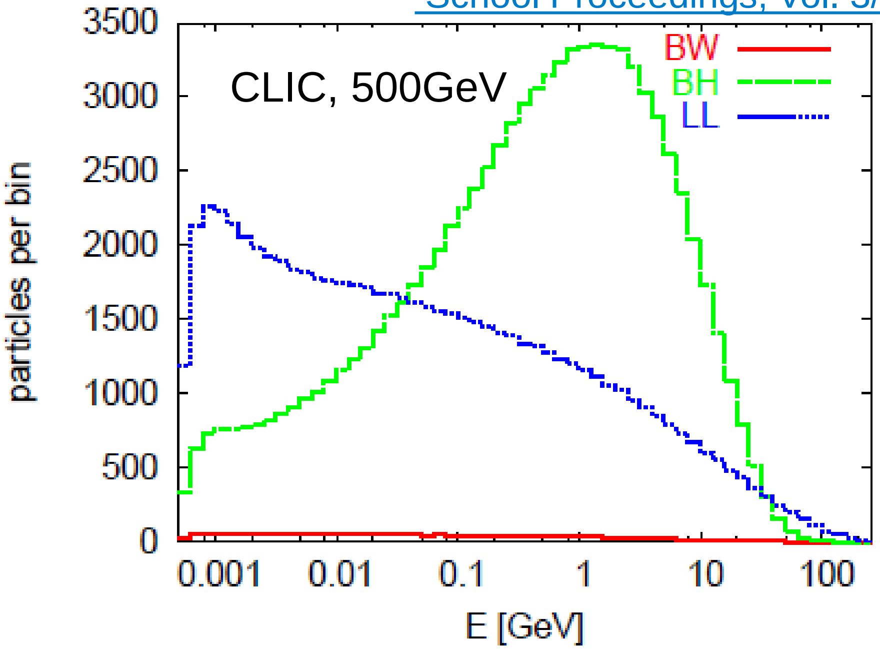
D. Schulte, CERN Yellow Reports: School Proceedings, Vol. 3/2017)



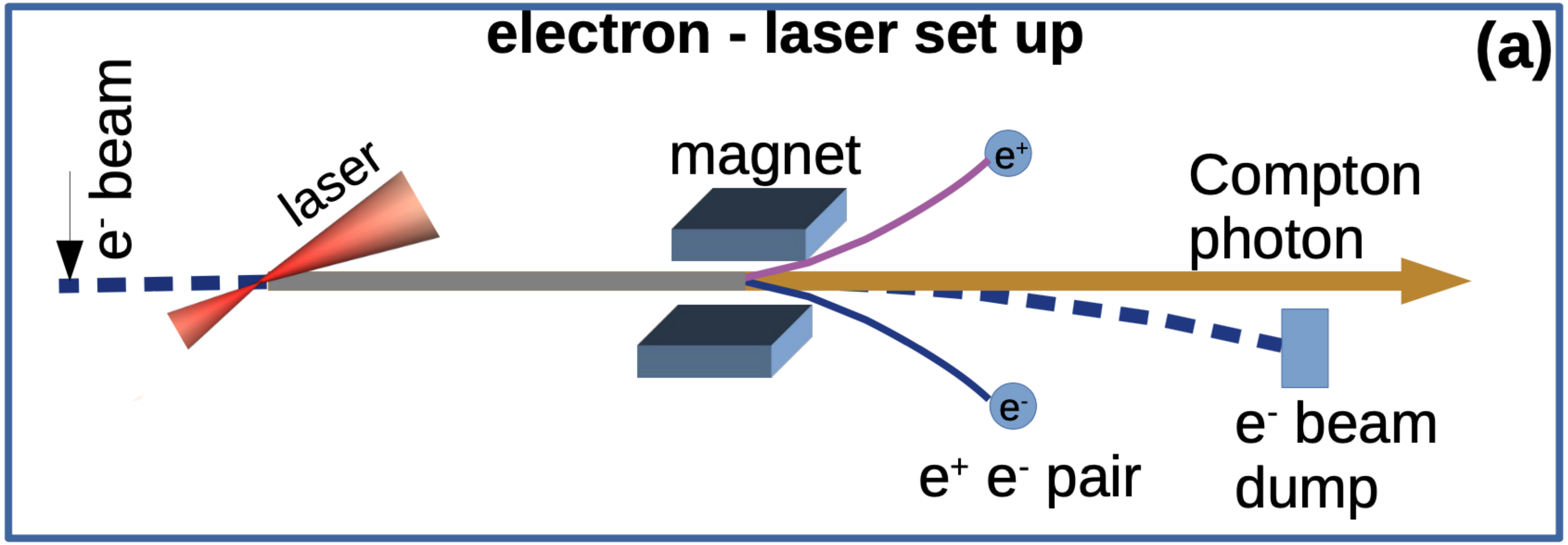
real + real (few %)

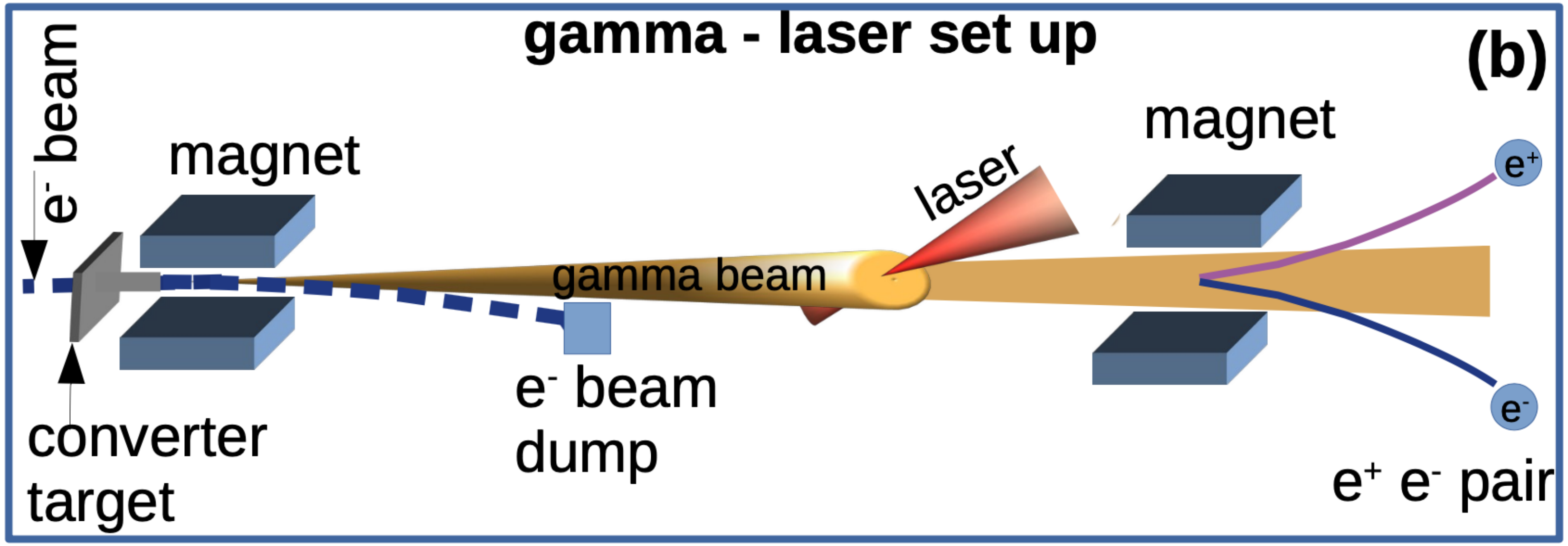
real + virtual (~1/3)

virtual + virtual (~2/3)

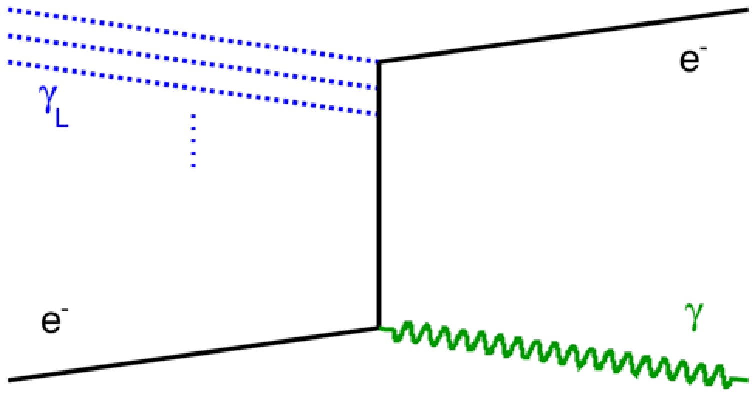


LUXE experimental setup(s)



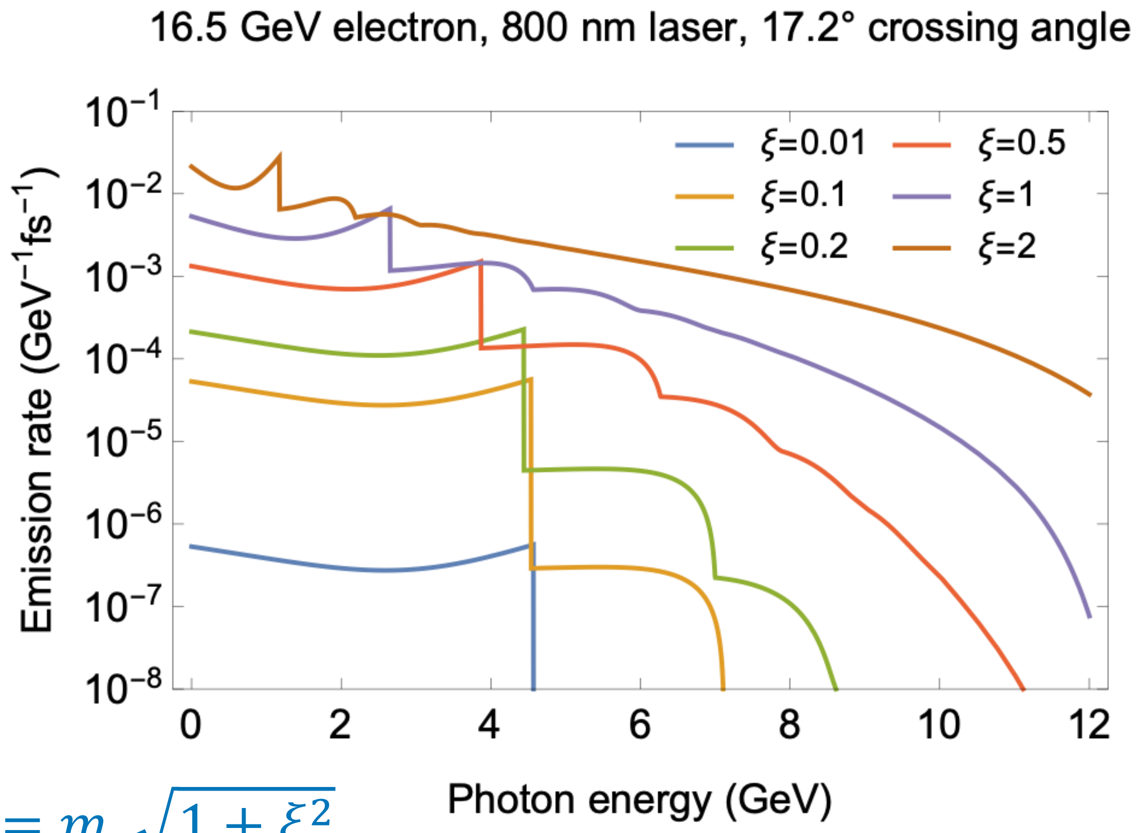


Non-linear Compton scattering



Non-linear Compton Scattering

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



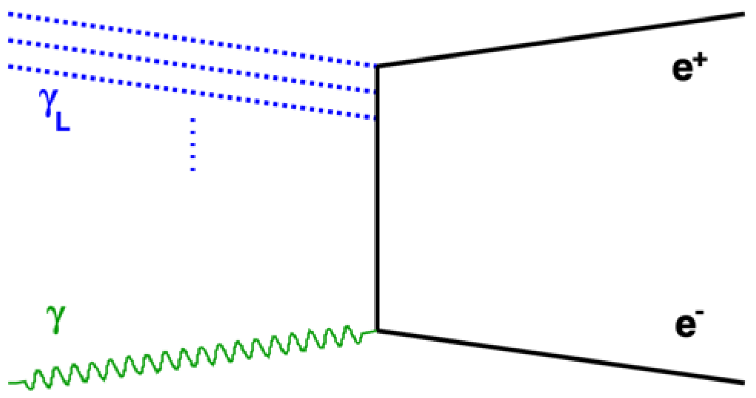
- in strong fields, electron obtains larger effective mass $m_* = m_e\sqrt{1+\xi^2}$
  →Compton edge shifts with laser intensity parameter ξ
  →n-th order harmonics (interaction with n laser photons)

- Note: Non-linear Compton scattering has a classical limit
  → deviation between non-linear QED and non-linear classical Compton: quantum non-linearity parameter χ

- Parameters ξ and χ determined by laser intensity and electron beam energy

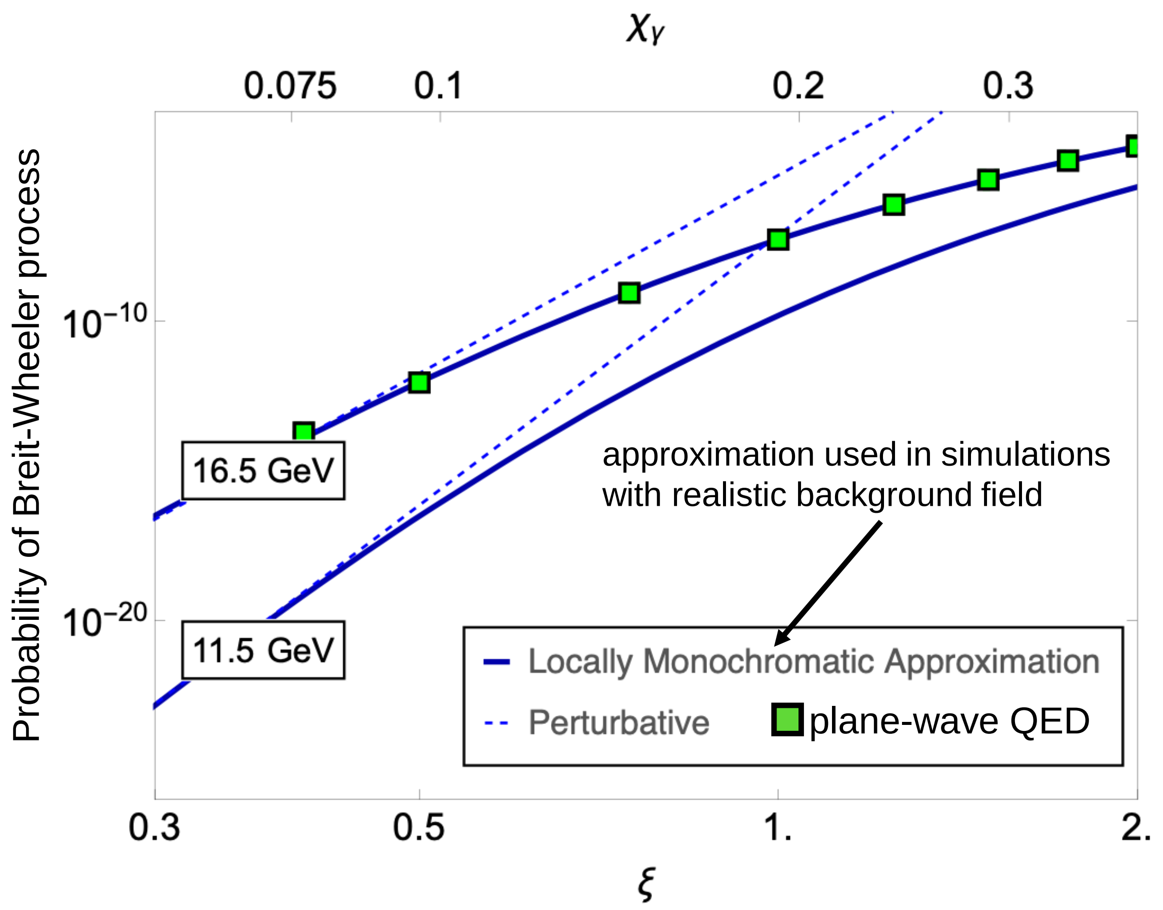
Different combinations of ξ and χ result in different types of non-linear behavior!

Breit-Wheeler pair production



(non-linear) Breit-Wheeler pair production

$\gamma_{C/sec} + n\gamma_L \rightarrow e^+ + e^-$



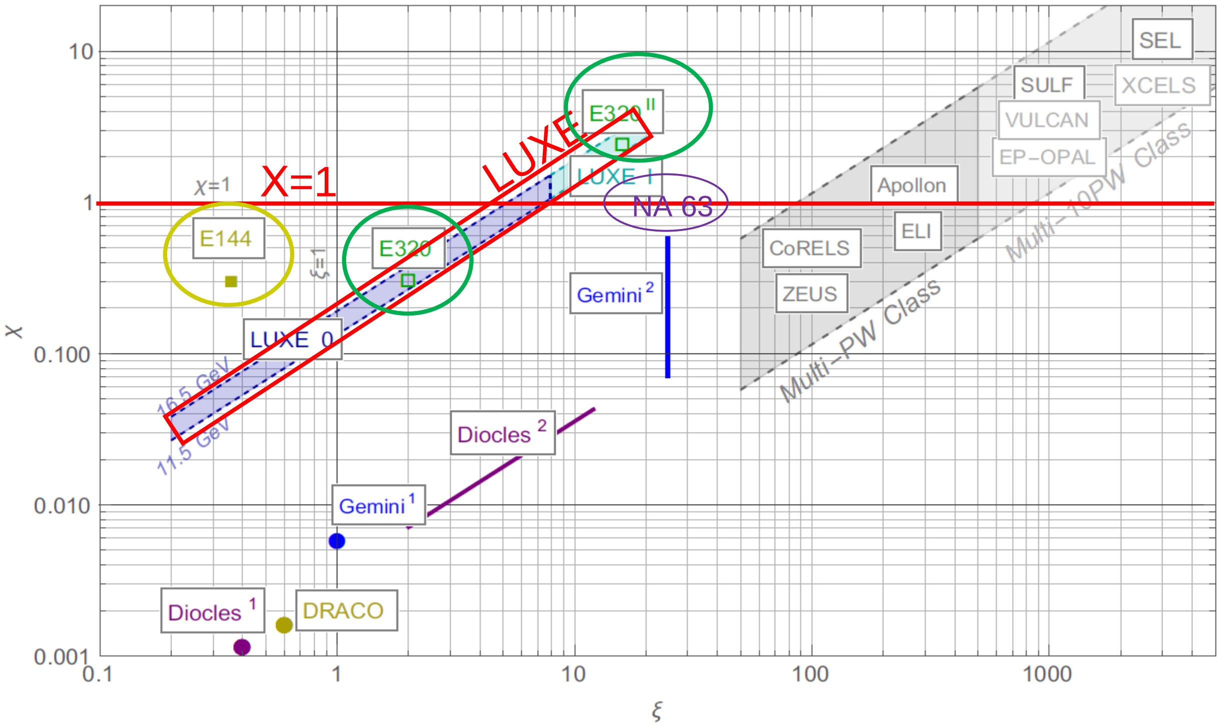
- initial photon from Compton scattering or secondary beam
- Note: this process has no classical limit (energy threshold)!
  → purely quantum, requires $\chi \sim \mathcal{O}(1)$!

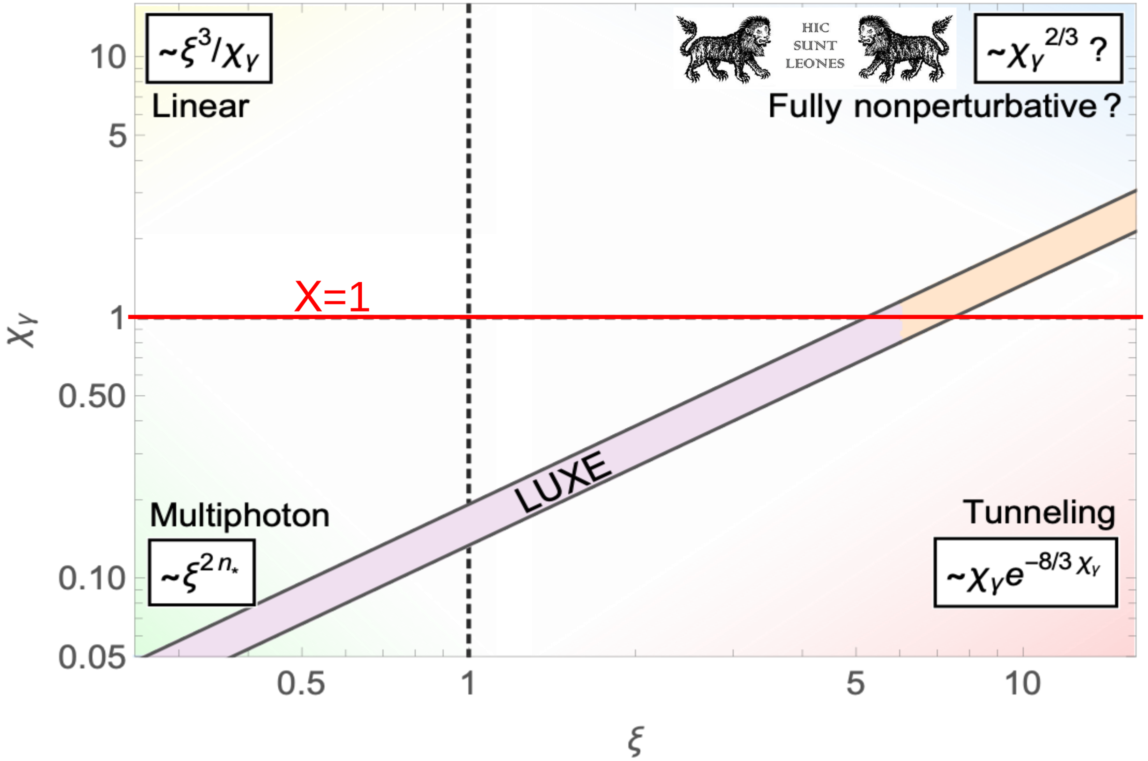
$\xi \ll 1$: $R_{e^+} \propto \xi^{2n} \propto I^n$ Perturbative regime → power law

$\xi \gg 1$: $R_{e^+} \propto \chi_\gamma \exp\left(-\frac{8}{3\chi_\gamma}\right)$ Non-perturbative regime → departure from power law

LUXE: first experiment to measure Breit-Wheeler pair production with real photons!

LUXE in Strong-Field QED Parameter Space





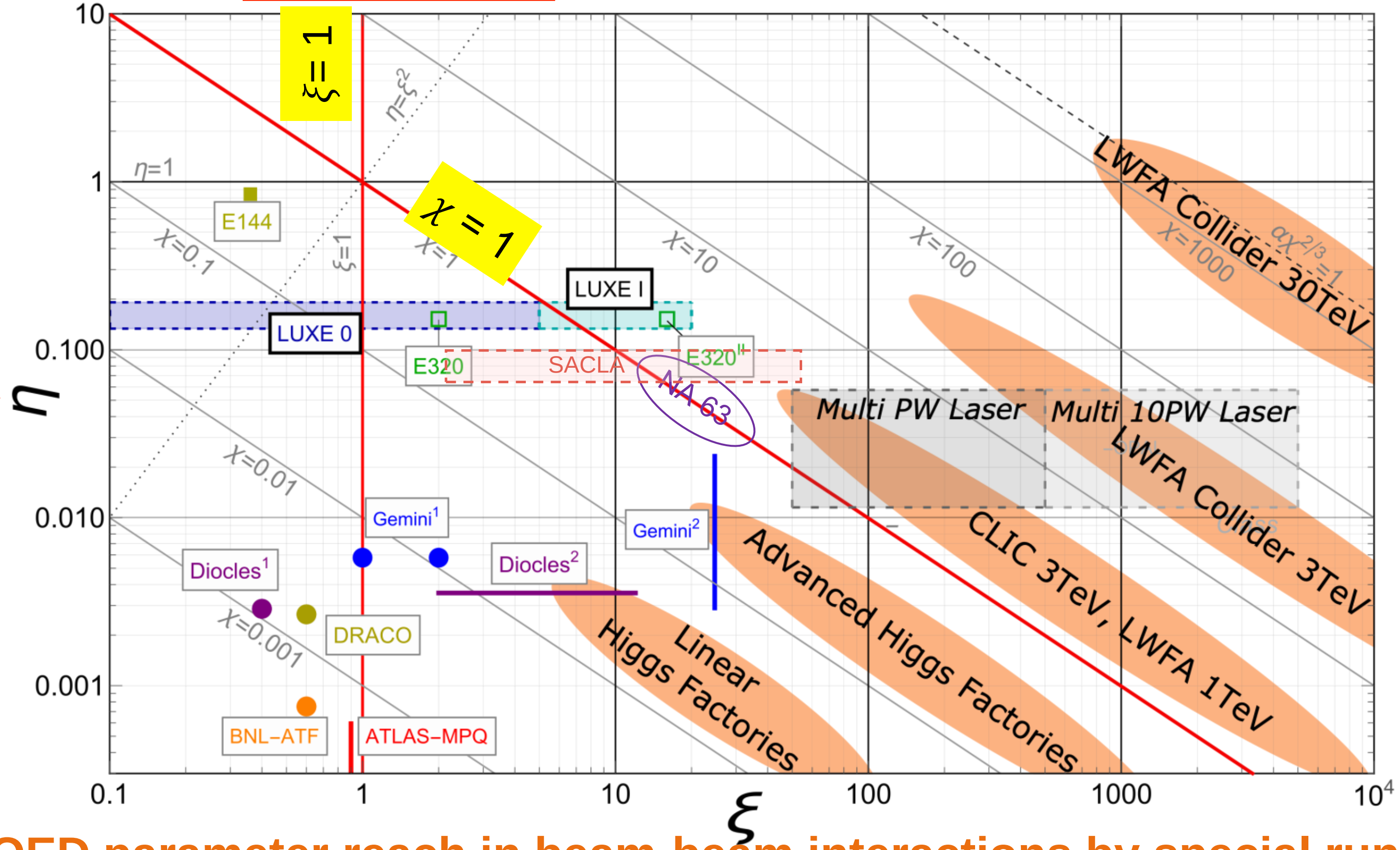
- experimental reach in SF QED parameter space (ξ, χ)
  → mainly determined by: particle beam energy, LASER intensity
- predecessor: E144 (SLAC e-laser collisions, 1990's) reached power-law regime, but not departure Phys. Rev. D 60 (1999) 092004
  → LUXE: three orders of magnitude more powerful laser
- contemporary: E320 (SLAC FACET-II e-laser collisions, operational) similar parameter reach as LUXE after upgrade
  → mode of experiment operation slighty different to LUXE HILAS-2022-HF4B.6
- LUXE unique ability: continuous high-statistics data-taking with variable laser spot size
  → precision mapping of SFQED parameter space in transition regime

Linear colliders in SFQED parameter space

J. List's talk (LCWS 2023)

- Quantum non-linearity parameter χ in collider context often called Υ, with average: $\Upsilon = \frac{2}{3}\frac{\langle E_c \rangle}{E_{\mathrm{beam}}} = \frac{5 r_e^2 \gamma N_e}{6 \alpha_e \sigma_z (\sigma_x^* + \sigma_y^*)}$
- "intensity parameter": ξ , or a_0 work by background field over a Compton wavelength
  - [arxiv:1807.06968] approximate bunch crossing with half-cycle laser of wavelength $\lambda = 4\sigma_z$
  - Peak a_0 (for round beams): $a_0 = \sqrt{\frac{2}{\pi^3}\frac{r_e}{\sigma_0} N}$

$\chi = \eta\xi$



Extend SFQED parameter reach in beam-beam interactions by special runs, maximizing Υ?

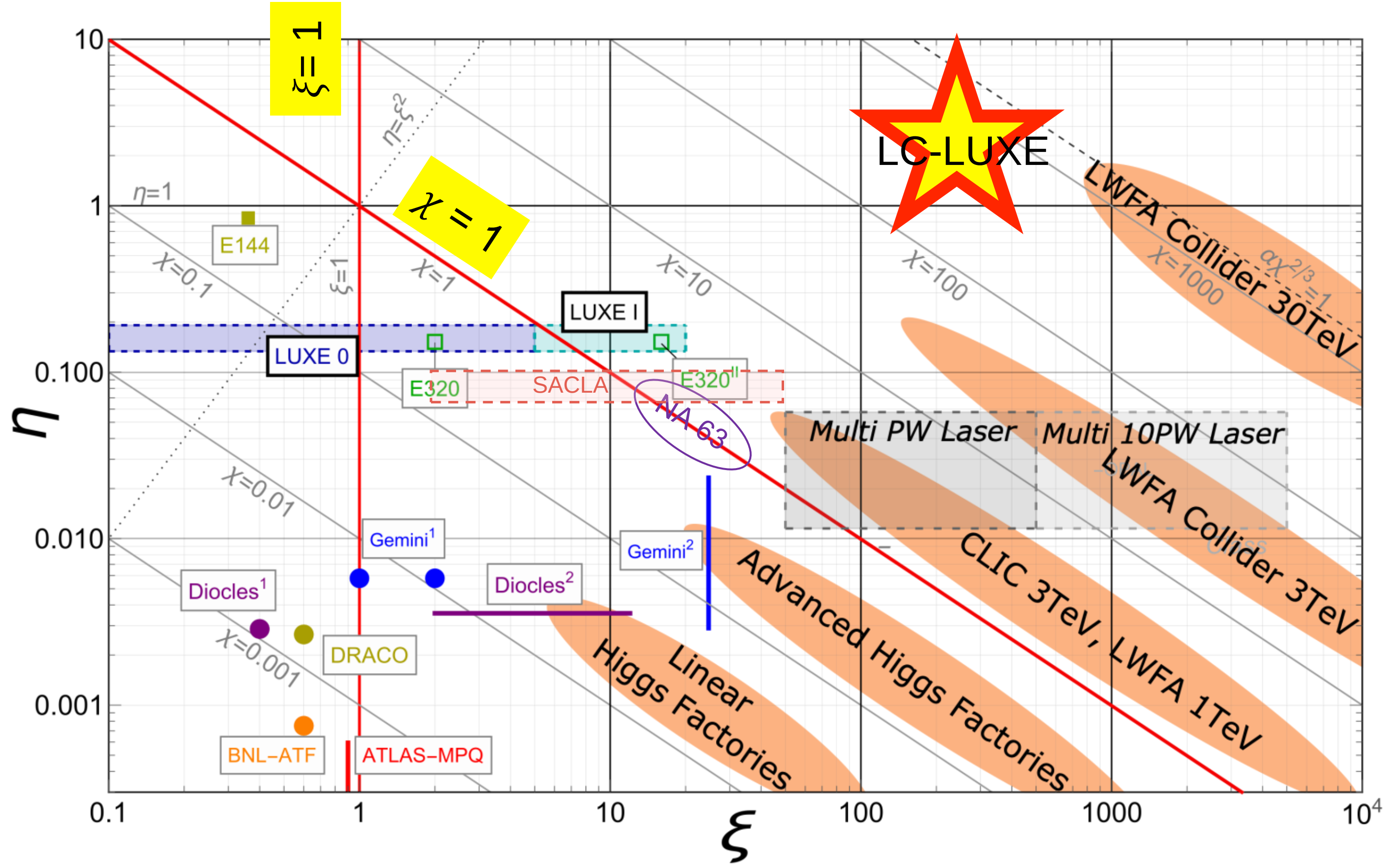
A LUXE-type experiment at a linear collider?

J. List's talk (LCWS 2023)

- SFQED experiments could be an interesting add-on to future collider facilities
  → e.g. extract few bunches from the main line and collide with a laser

- „LC-LUXE": LUXE-type experiment at ILC: e-beam energy 16.5 GeV (LUXE) → 125 GeV → 500 GeV
  → $\chi \cong 0.4 \rightarrow 30 \rightarrow 120$, future laser developments could improve further

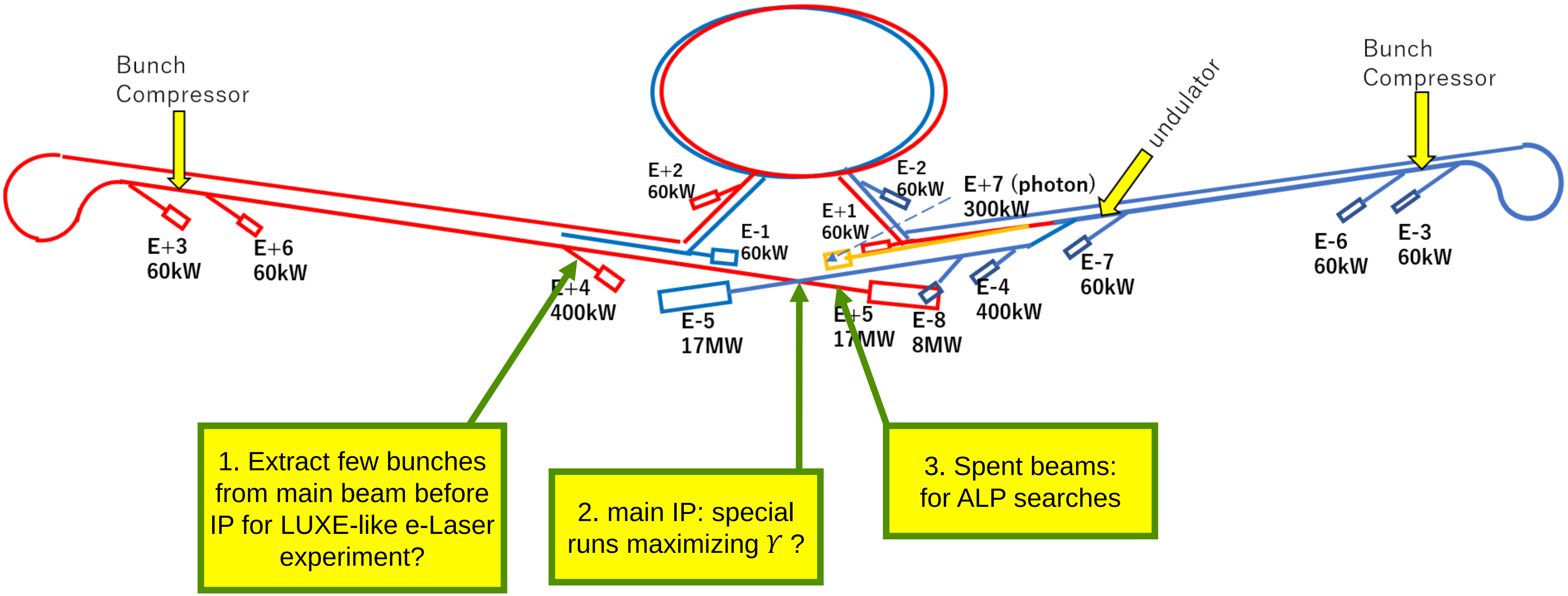
$$\chi = \eta\xi$$



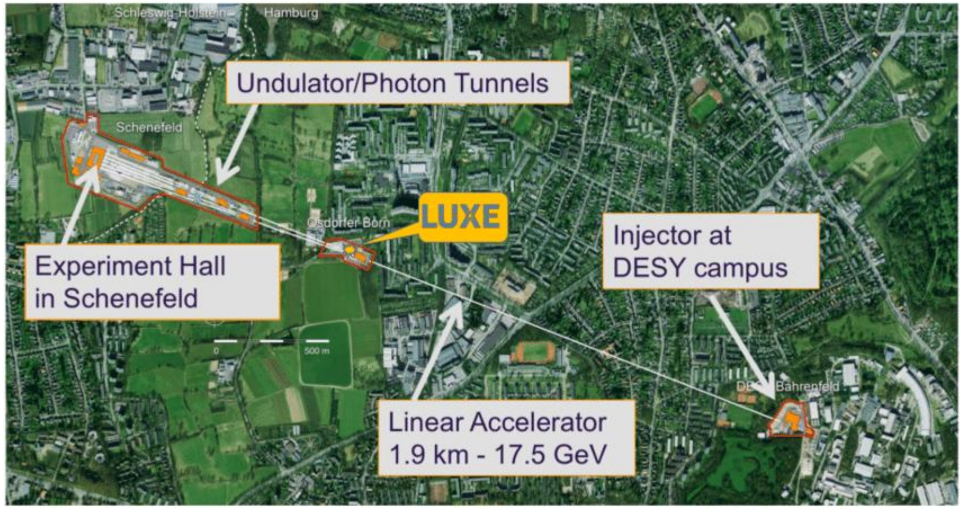
An LC-LUXE would enter the completely unknown fully non-perturbative regime!

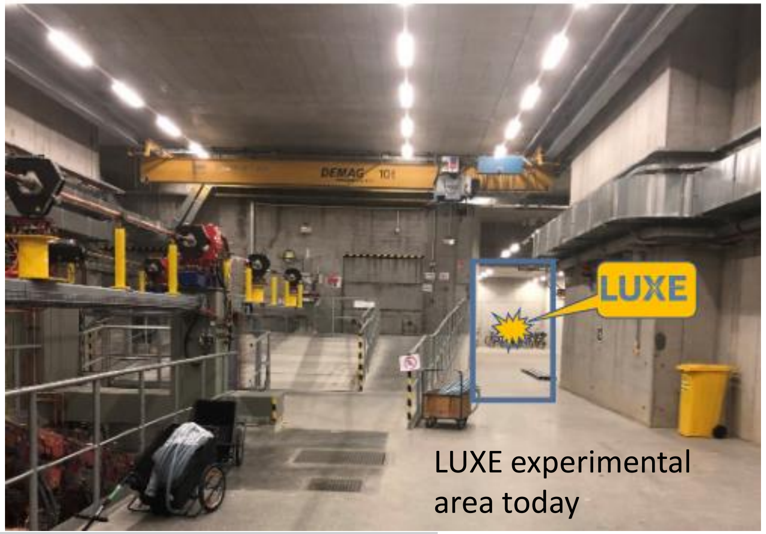
Where could SFQED be probed at a linear collider?

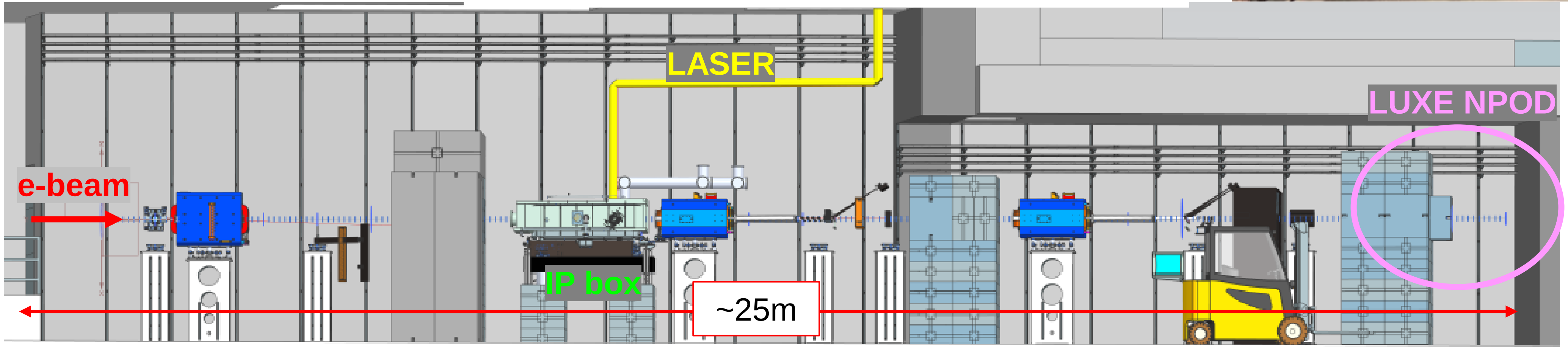
Example ILC



LUXE overview



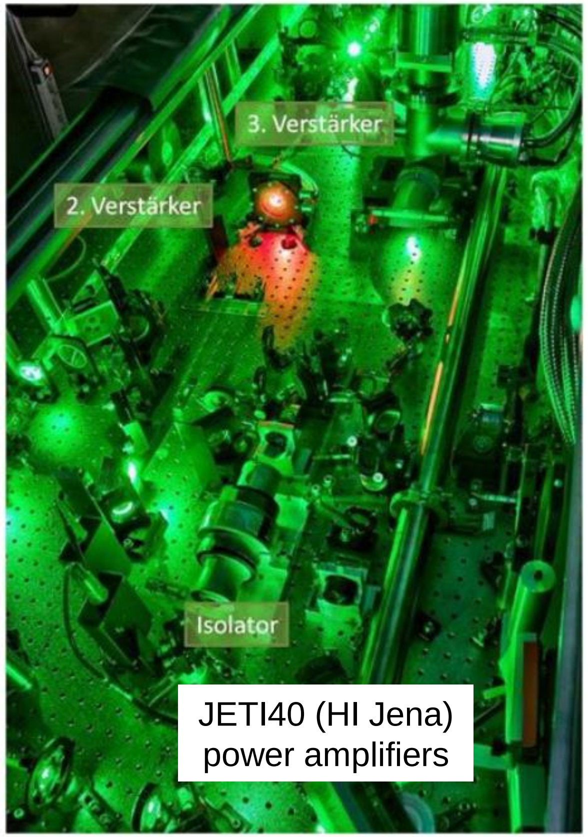




- LUXE uses high-quality 16.5 GeV Eu.XFEL electron beam before undulators
- Experiment location: Existing annex for future second Eu.XFEL fan(~2030's+) → Unique possibility to build and operate LUXE before that!
- Extract 1 bunch (out of 2700 bunches) per XFEL train for collision with laser

XFEL e^- Beam Properties important for LUXE	
Energy	16.5 GeV
#electrons/bunch	$1.5 \cdot 10^9$
repetition rate	10 Hz

The LUXE laser

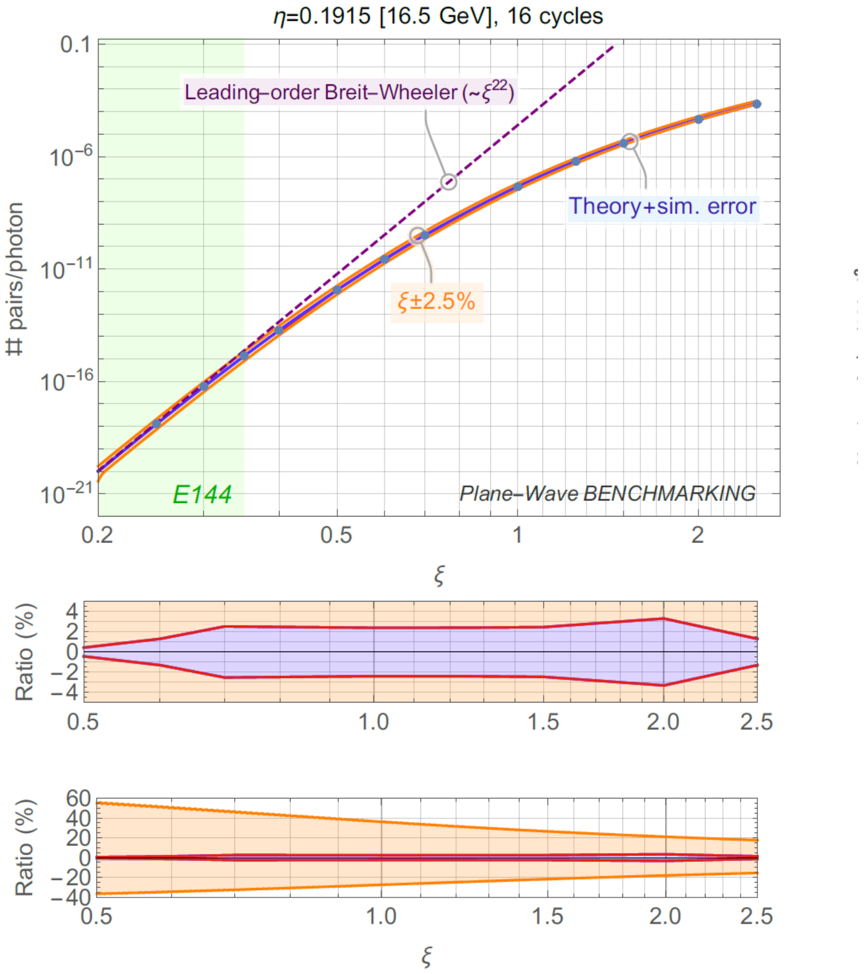


Laser intensity:

$$I = \frac{E_L}{\Delta t \pi d^2}$$

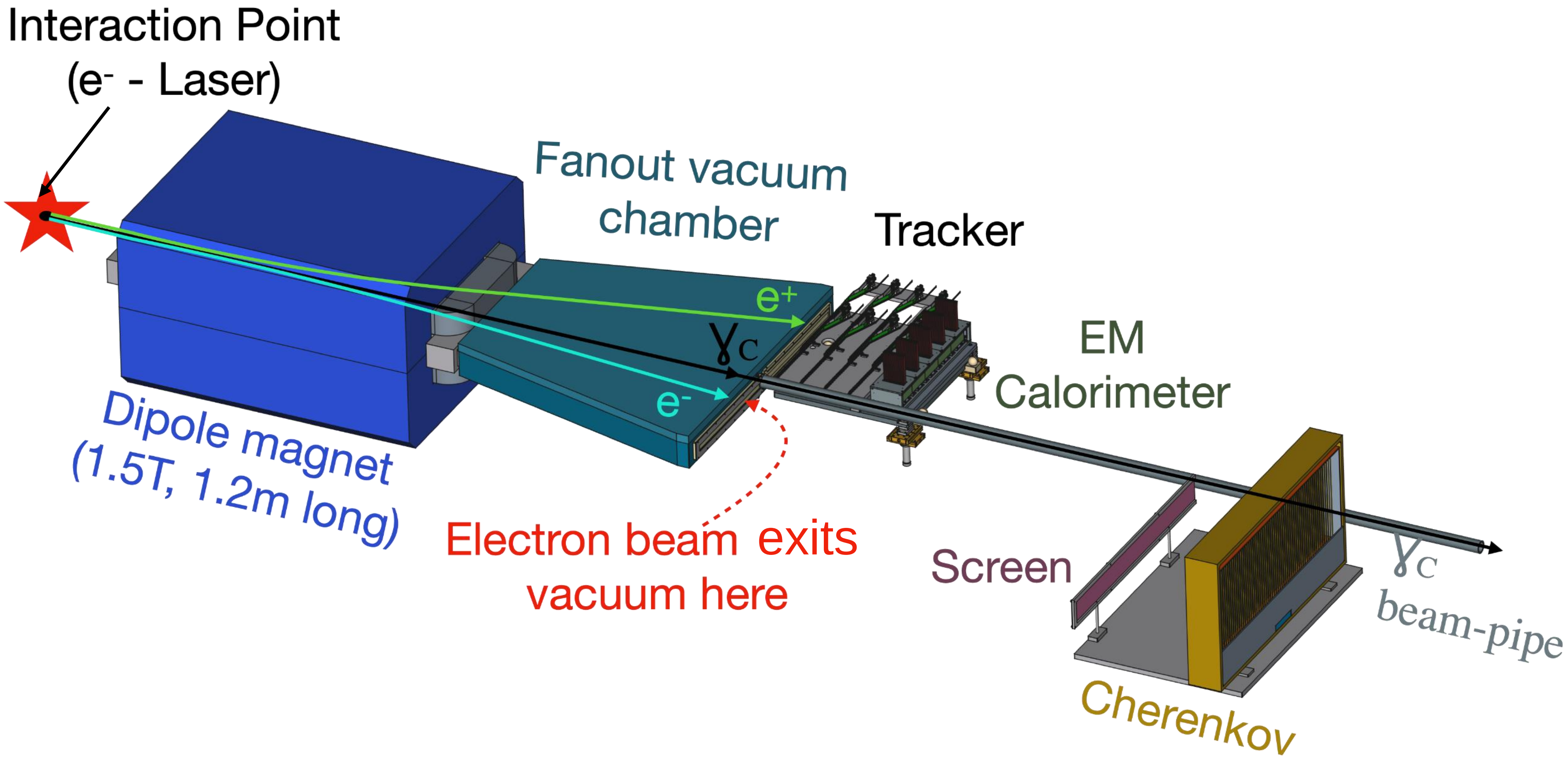
E_L: laser energy (J)
Δt: pulse length (s)
πd^2 : focus area (m^2)

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



- LUXE laser: TiSa (40TW, upgradeable to 350TW) → scan SFQED parameter space: vary laser spot size
- electron boost: current state-of-the-art in laser intensity is sufficient → need exceptional shot-by-shot stability
- LASER intensity uncertainty has a large impact on sensitivity → high-precision LASER diagnostics

LUXE IP Detectors



Two complementary detector technologies per measurement
→ cross-calibration, reduction of systematic uncertainties

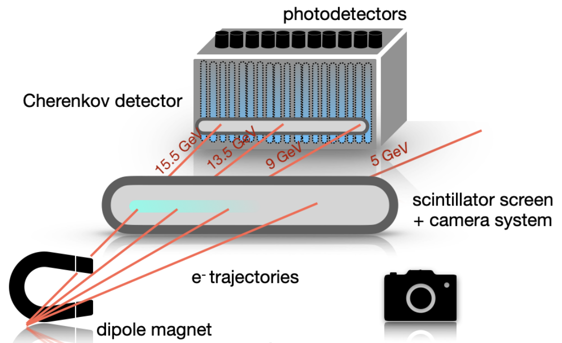
LUXE Particle Detectors

- e^+: Si pixel tracker,
  high-granularity Si-W calorimeter
  → high signal efficiency, momentum resolution

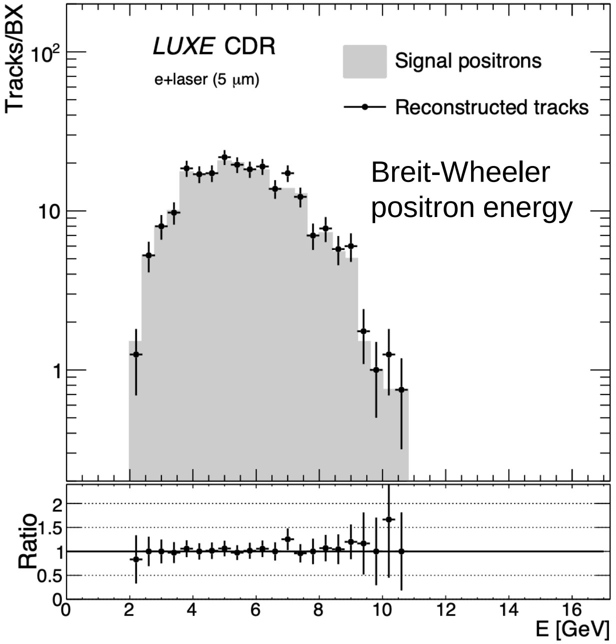
- e^-: scintillation screen & camera system,
  Cherenkov detectors
  → high rate tolerance, background rejection

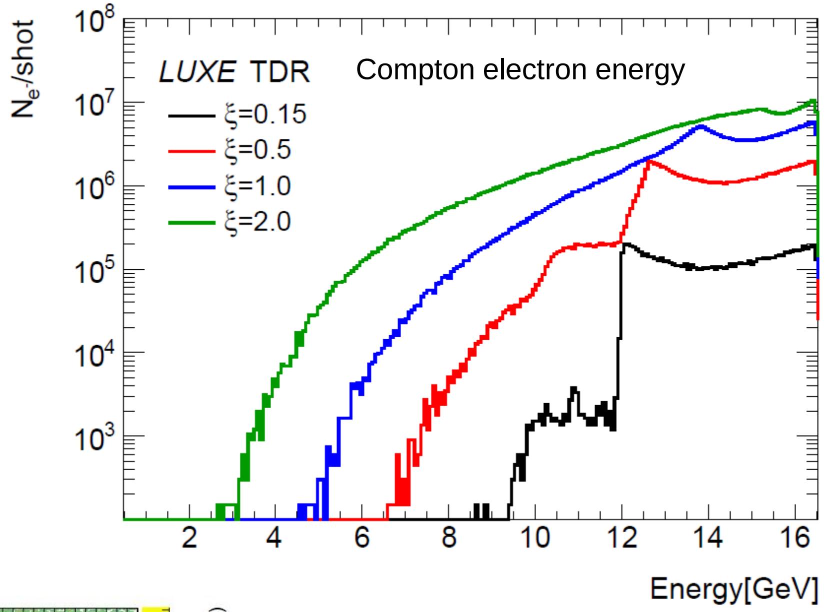
- γ: sapphire strip beam profiler,
  conversion spectrometer
  lead-glass flux monitors
  → complementary ξ measurement

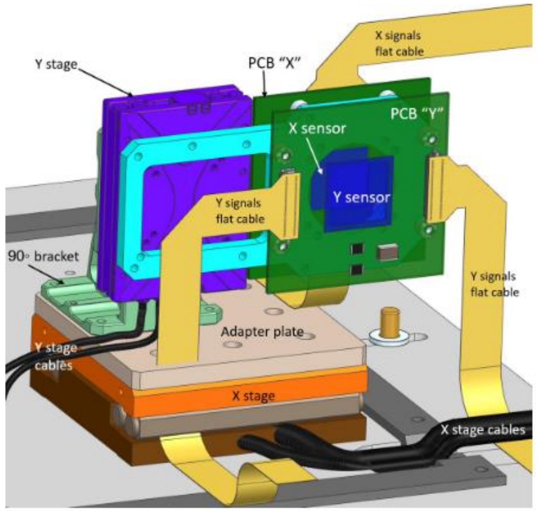
ALPIDE tracking detector stave



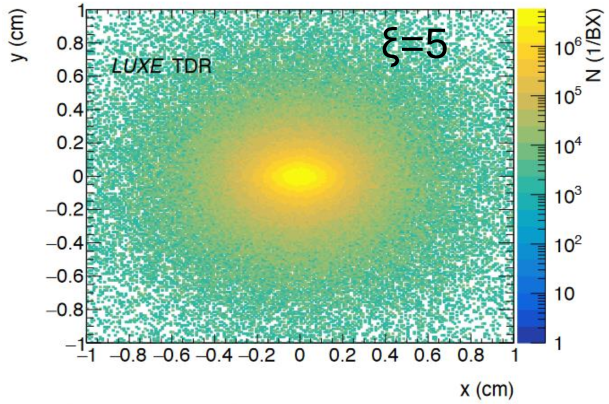
Electron spectrometer

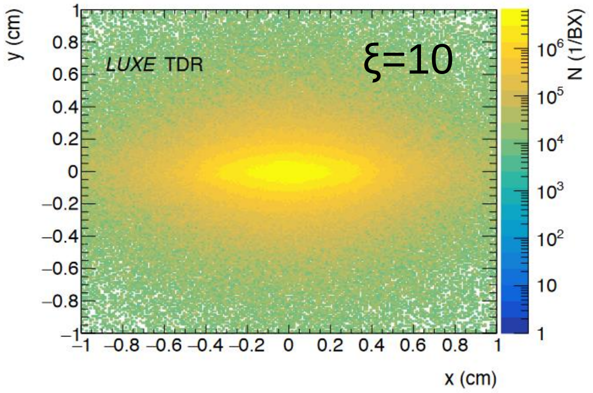






Gamma Beam Profiler



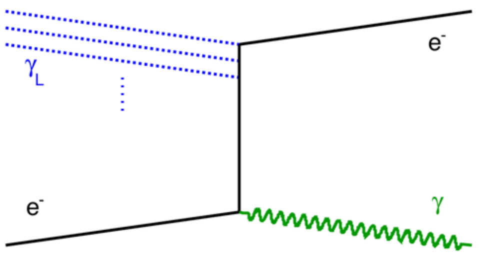


LUXE: interesting near-term application for new detector technologies

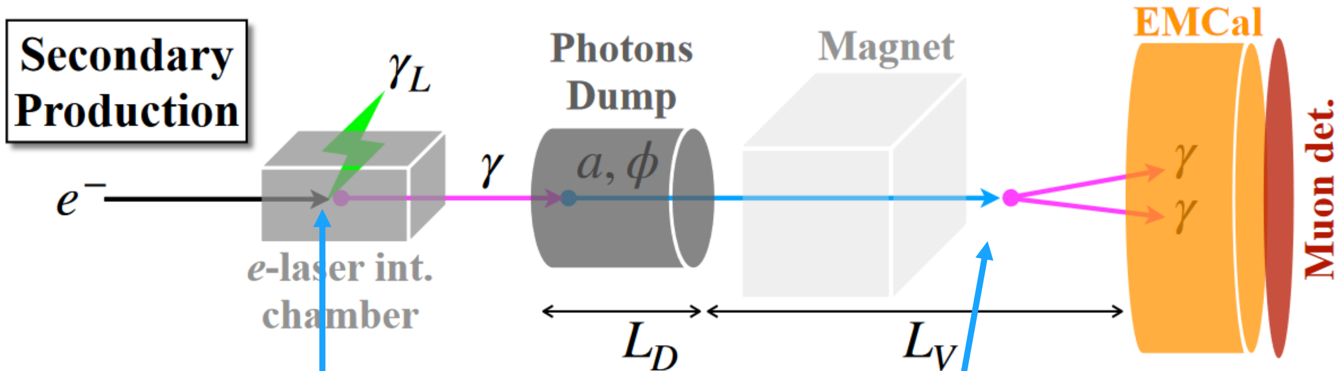
Phys. Rev. D 106, 115034

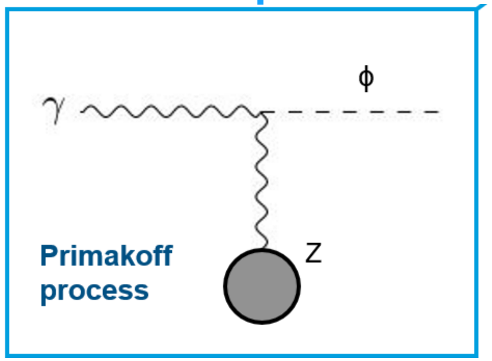
LUXE BSM Searches (LUXE-NPOD)

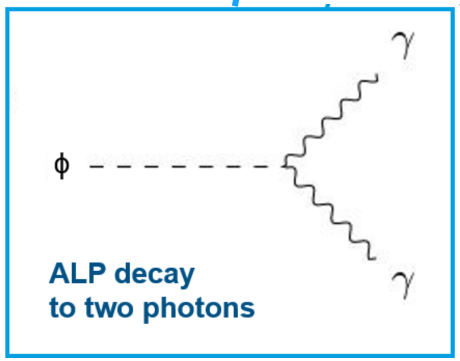
- LUXE will produce a high-intensity photon beam through Compton Scattering
  → produce e.g. axion-like (ALPs) in photon beam-dump
  → detect via new particle decay to two photons
- production of new particles also possible in primary electron/LASER interaction
- advantage of photon-on dump compared to electron-on dump: lower background
- conceptual design of photon detector with pointing capabilities ongoing
  → similar technologies applicable as e.g. in SHiP

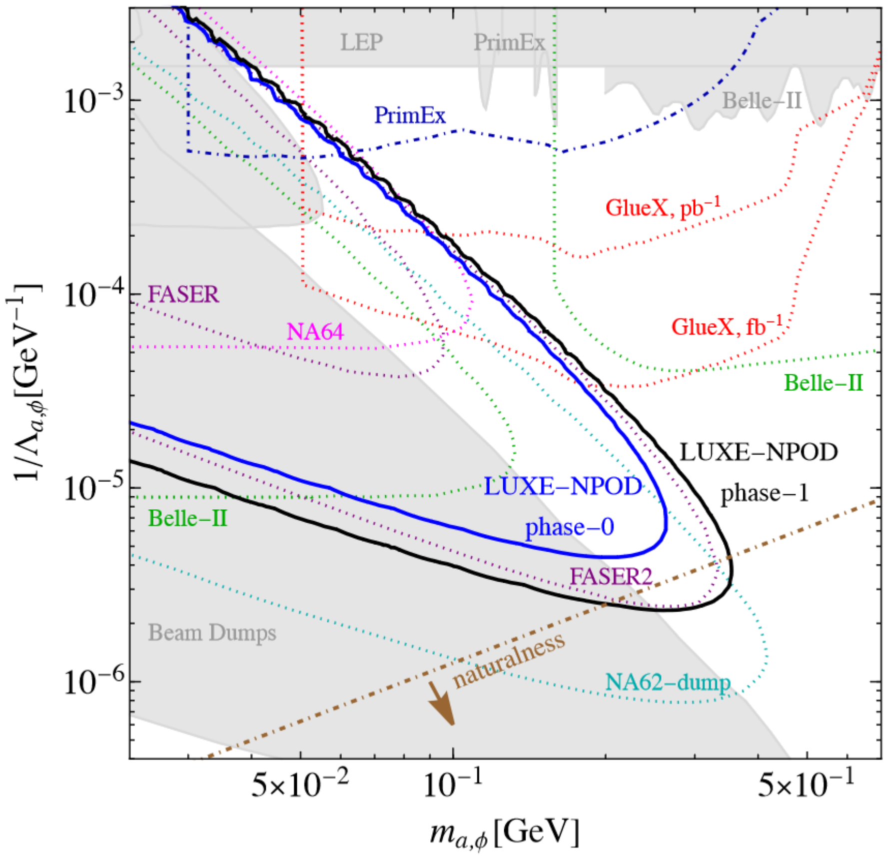


Non-linear Compton Scattering
$e^- + n\gamma_L \to e^- + \gamma_C$





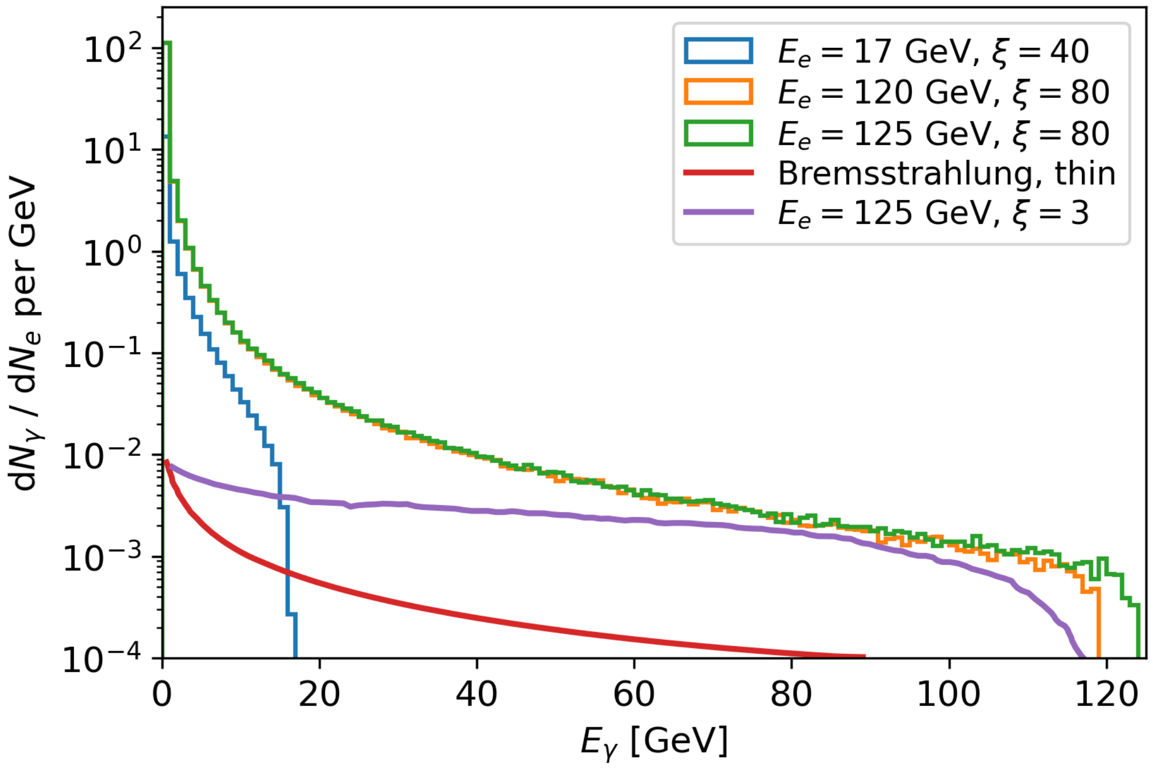


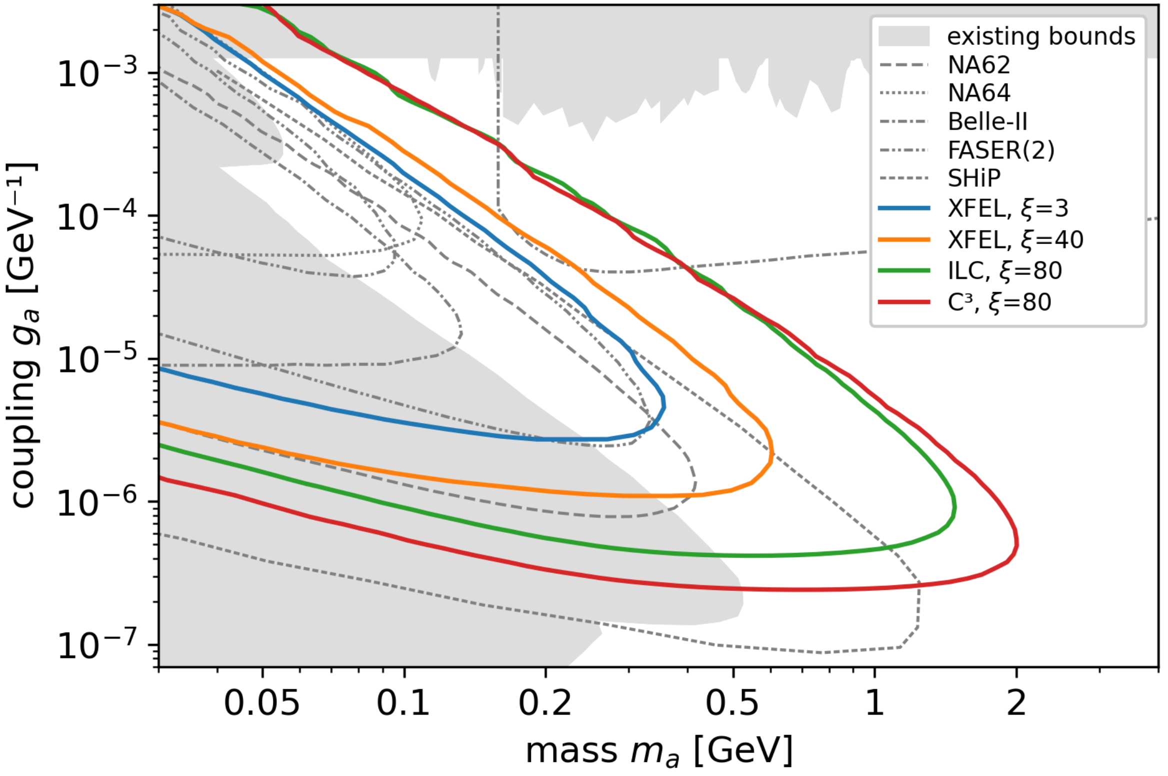


Prospects for NPOD at future facilities?

I. Schulthess
(see talk at ILC IDT WG3 meeting)

- Higher effective luminosity and higher beam energies allow for gain in ALP sensitivity
- Additional gain by optimizing the laser intensity parameter (goal: enhance rate of photons with $E_\gamma > 1$ GeV
- Significant extension in reach possible





Summary

LUXE: explore QED in uncharted regime with unprecedented precision

- probe transition from perturbative to non-perturbative QED
- LUXE-NPOD beam-dump experiment sensitive to sub-GeV ALPs
- approval at DESY & EuXFEL ongoing

LUXE and future (linear) e^+e^- colliders:

- SF-QED relevant for beam-beam interaction (could be studied in special high-Υ runs)
- LUXE-like e-beam-laser collision experiment at future linear collider could probe the fully non-perturbative regime
- LUXE detectors: testbed for new technologies e.g. for future colliders
- NPOD-like beam dump experiment has significantly extended reach in sensitivity

More documentation?

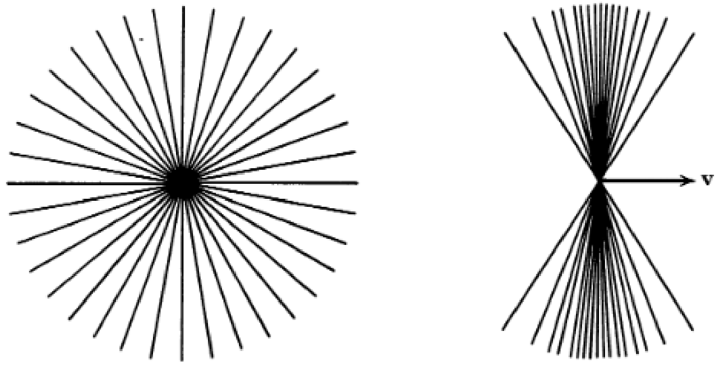
- LUXE TDR: https://arxiv.org/abs/2308.00515
- Website: https://luxe.desy.de

Backup

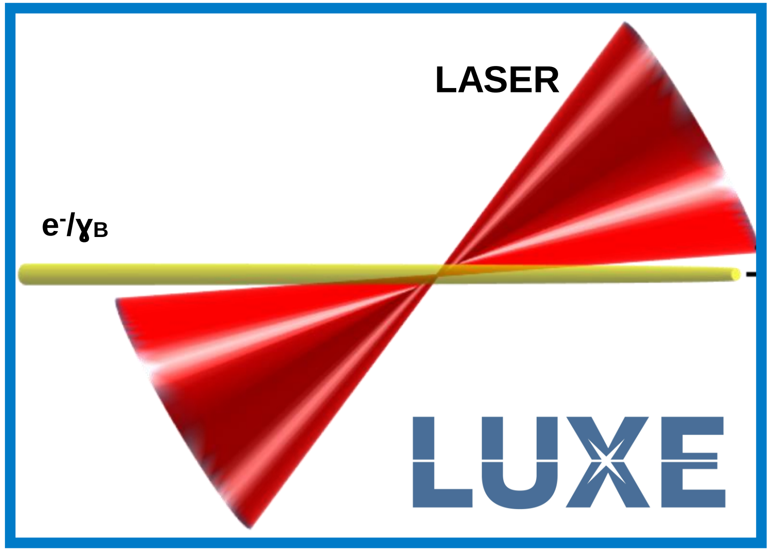
[Link](#) to QU lecture by Ben King
Review paper: A. Fedotov et al, 2203.00019 [arXiv:hep-ph]

SFQED with relativistic probes

- In the lab: reach fields at Schwinger limit in the rest frame of highly relativistic probe particles
  → LUXE: 16.5 GeV electrons + multi-TW optical LASER



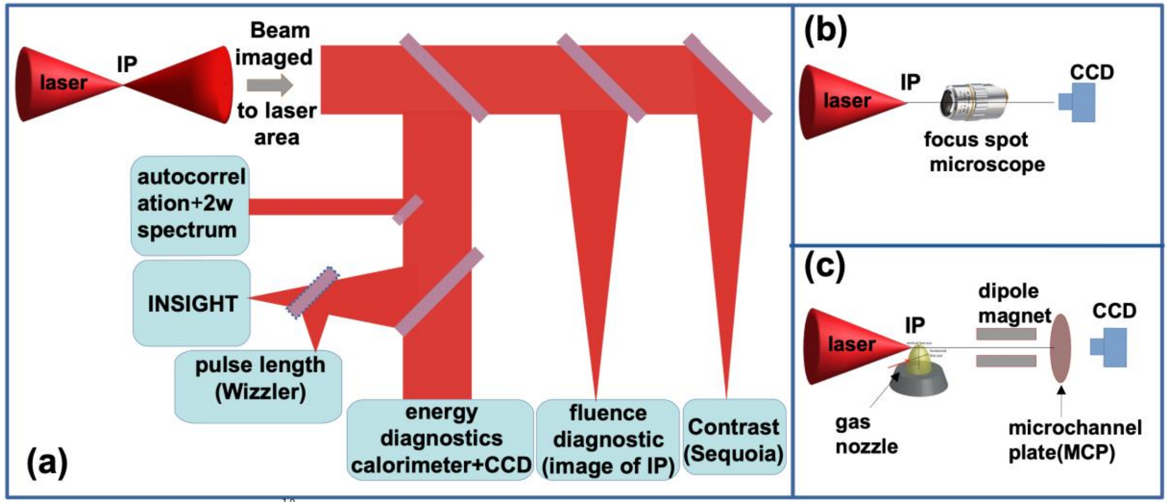
J. D. Jackson, *Classical Electrodynamics* 3rd. Edition

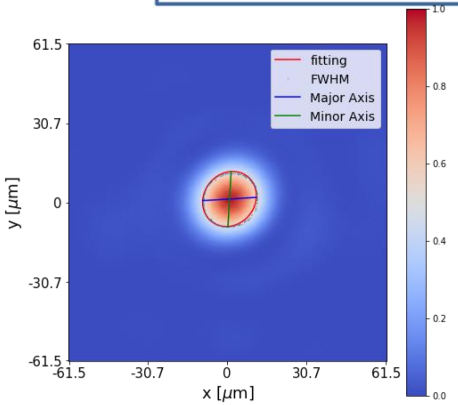


$$\mathcal{E}_{rest\ fr.} = \gamma \mathcal{E}_{lab\ fr.}$$

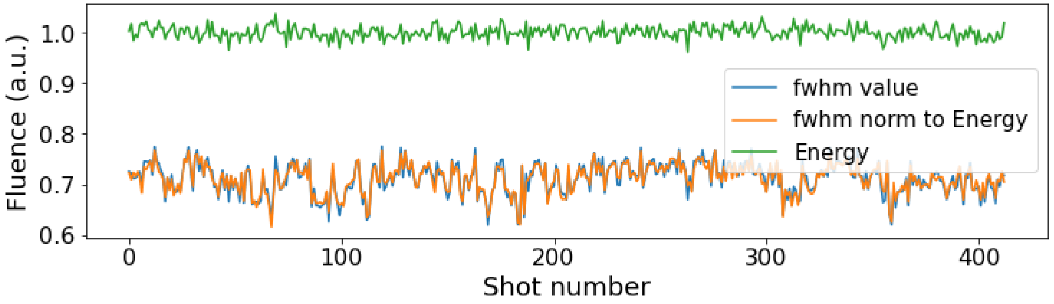
- Important consequence of having a relativistic probe:
  → any field background can be approximated as a plane wave

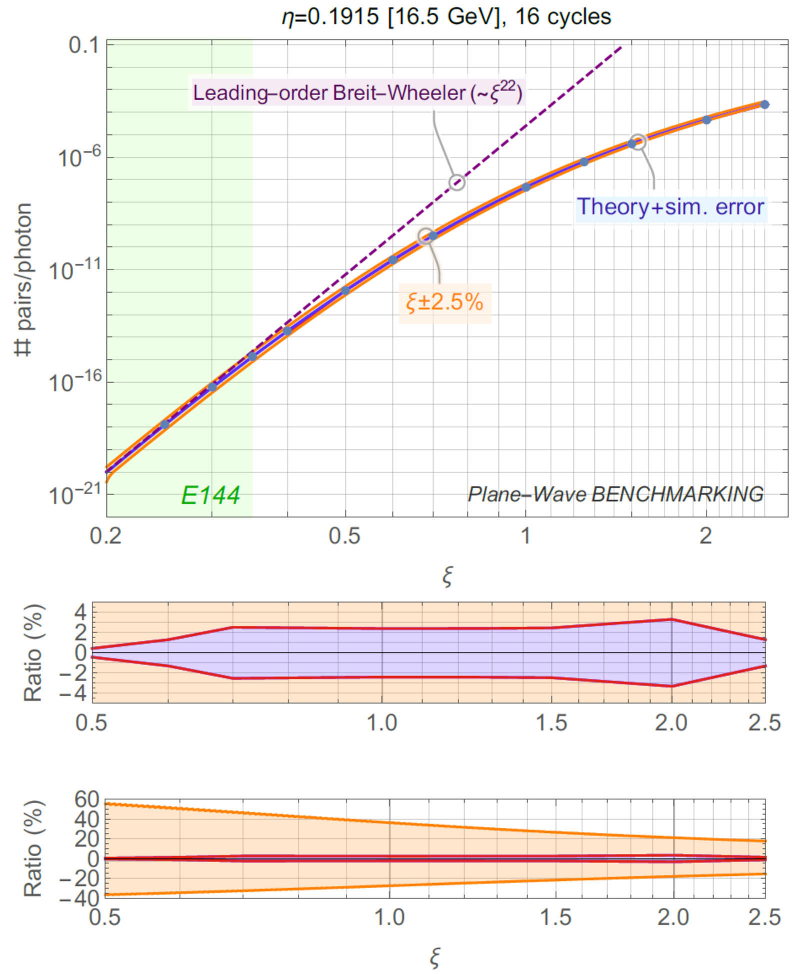
Laser Diagnostics





X. Huang (HI Jena)

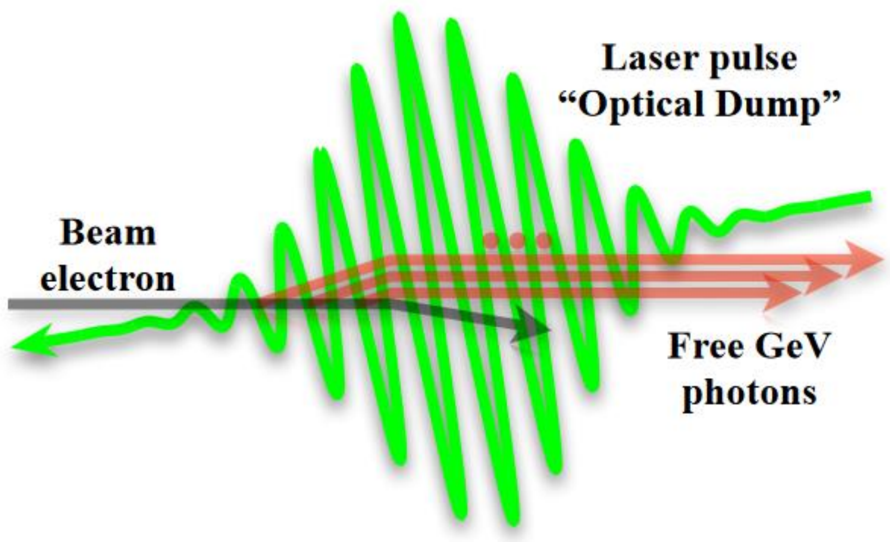




- LASER characterization quantities: energy, pulse length, spot size
  → many (partially redundant) measurements on re-imaged laser pulse
- LASER intensity uncertainty has a large impact on sensitivity!
- goal: ≤ 5% absolute uncertainty on LASER intensity, ≤ 1% shot-to-shot uncertainty
  → achievable with foreseen diagnostics suite

What is necessary to make a LUXE-NPOD experiment work?

Photon beam creation



Conditions for photon beam creation („time hierarchy“):

$$1/\omega_L \ll \tau_\gamma \lesssim t_L \ll \tau_{ee}$$

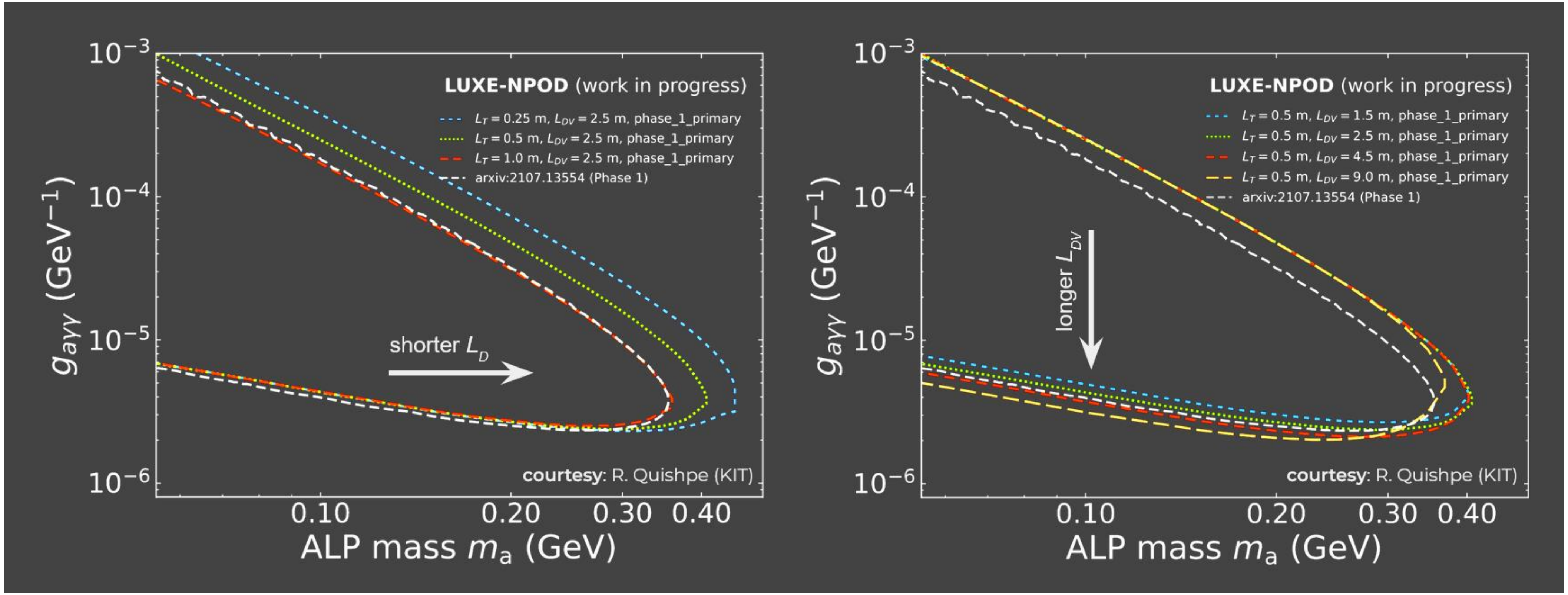
- Laser oscillation much faster than GeV radiation time-scale:
  →Laser can be treated as a background field
- γ radiation time-scale smaller than laser pulse length:
  → laser pulse is a thick target, electrons radiate most of their energy
  (LUXE NPOD: not the case, dump electrons off-axis)
- γ radiation time much shorter than pair-production time
  → photons free-streaming in laser pulse

What is necessary to make a LUXE-NPOD experiment work?

Dump and detector geometry optimization

Geometry considerations:

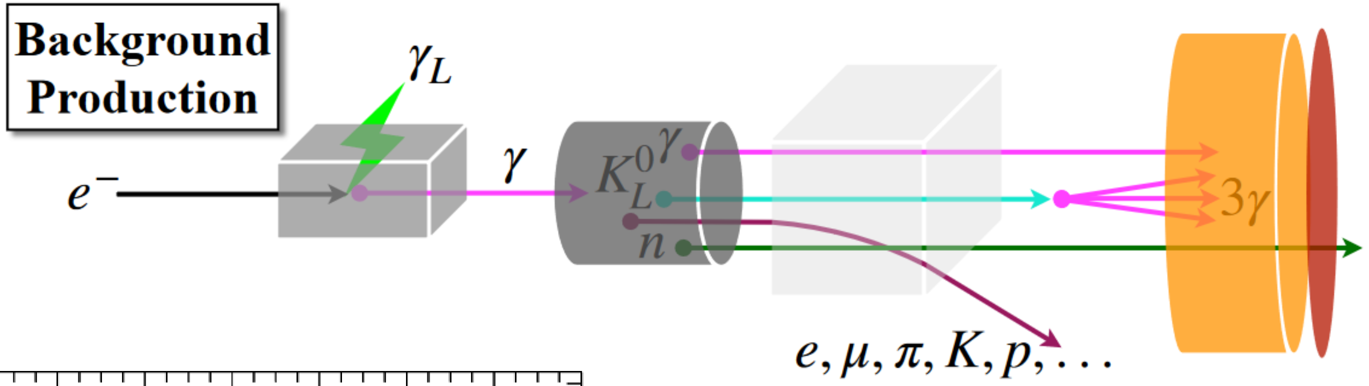
- Shorter dump: ALPS with larger couplings can escape the dump and decay in the decay volume
- Longer decay volume: ALPS with smaller couplings can decay in the decay volume

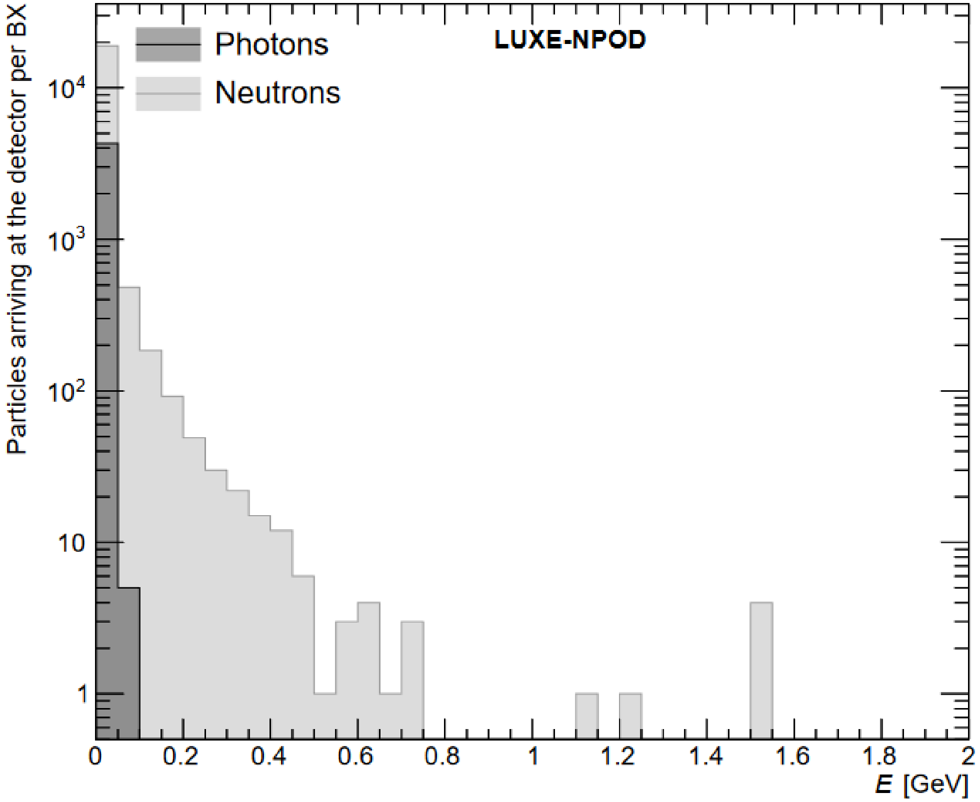


Phys. Rev. D 106, 115034

What is necessary to make a LUXE-NPOD experiment work?

Backgrounds

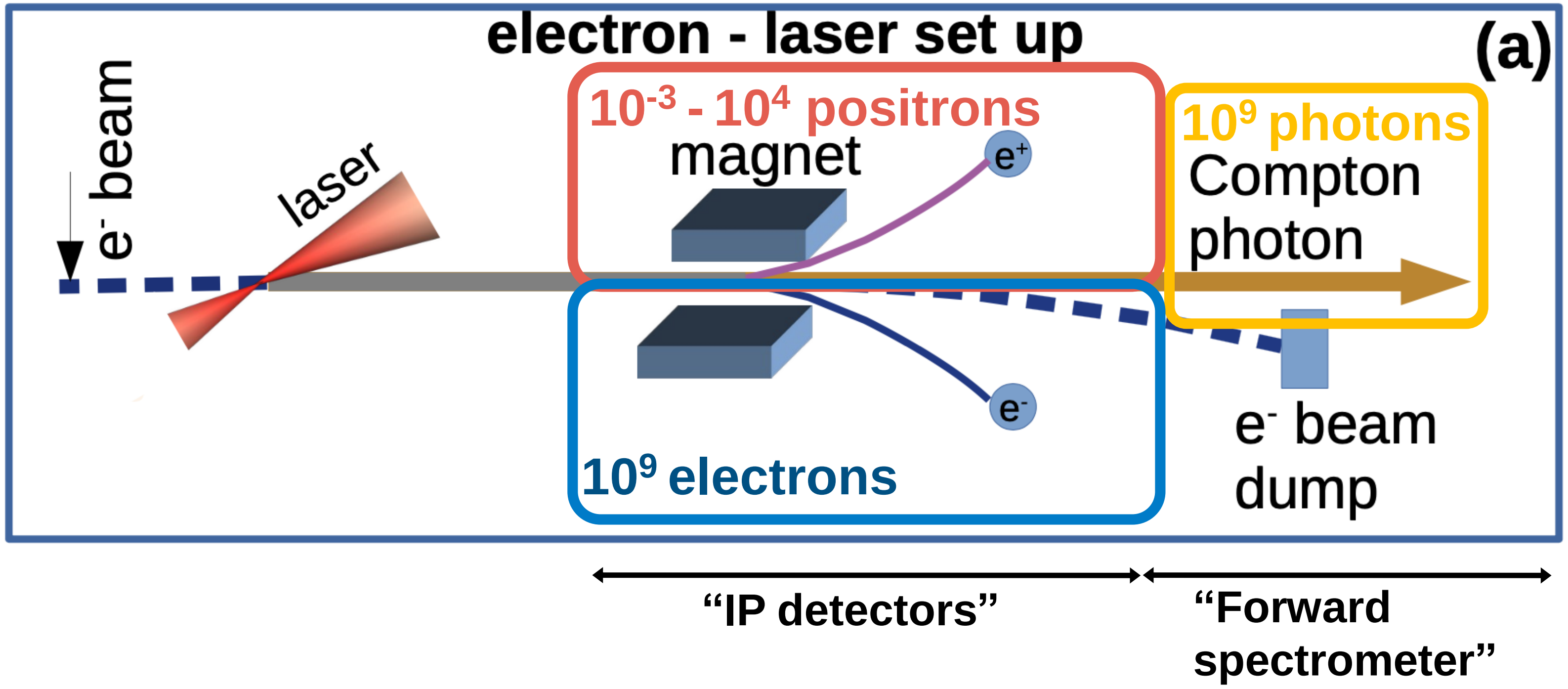




Background rejection:

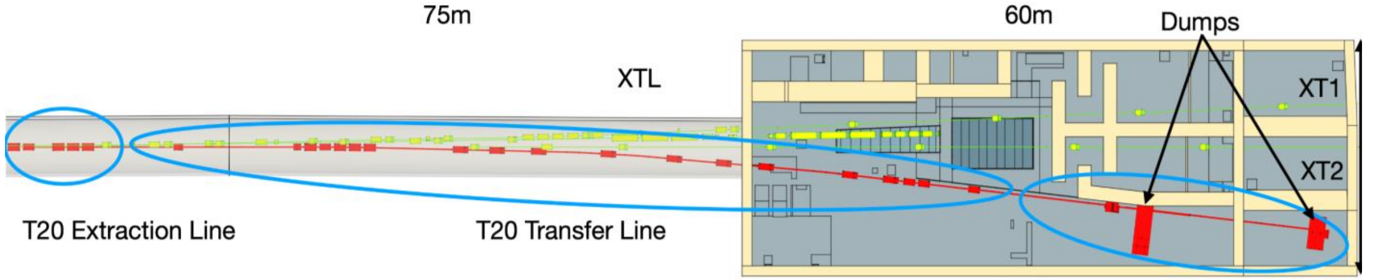
- Background Types: mis-identified neutrons, charged particles, real background photons
- Geant4 simulations for LUXE phase-1 with simplified detector configuration (W beam dump, L_D=1m, L_V=2.5m, R_V=1m)
- Photons: soft background
- Neutron background can be mitigated by energy cut E>0.5 GeV

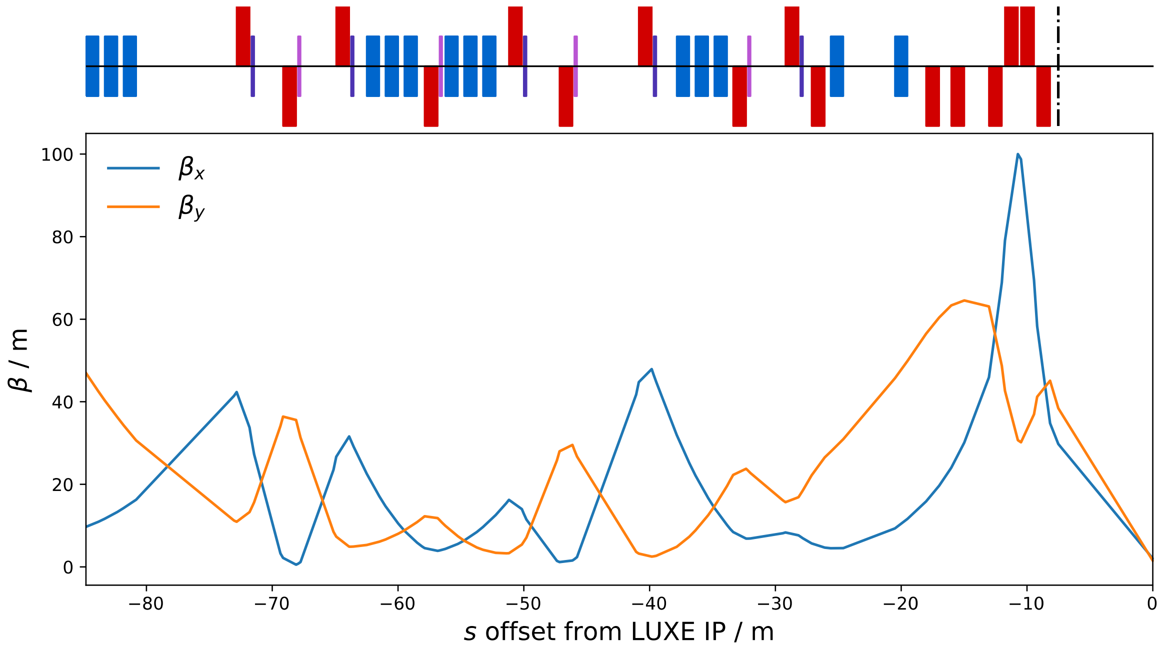
LUXE Particle Detectors

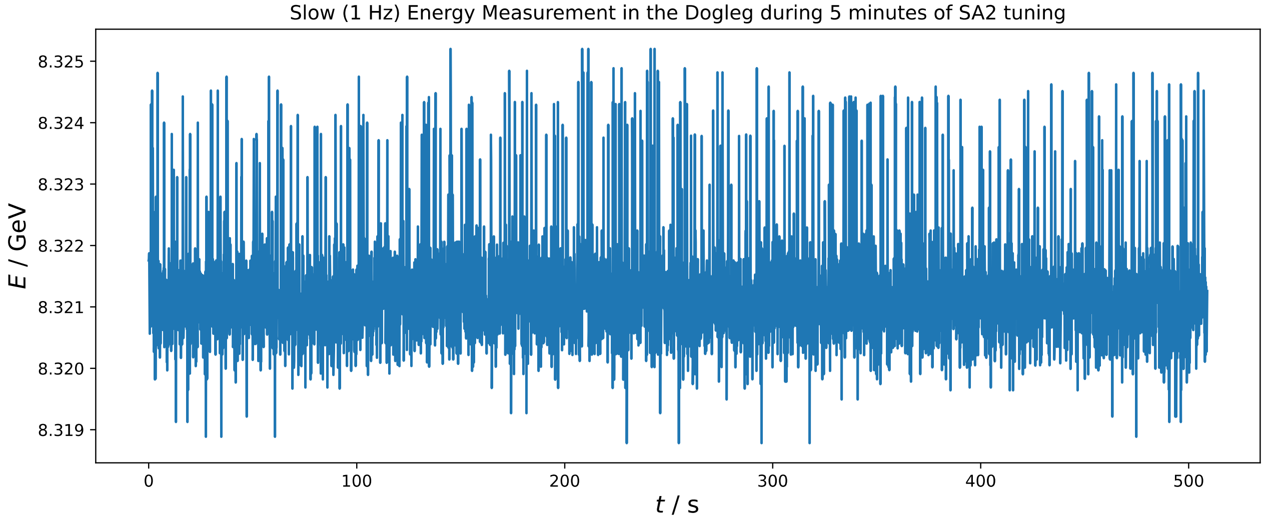


- goal: detection of electrons, positrons and photon fluxes and energy spectra
- particle fluxes vary between ~0.001 e^+ and 10^9 (e^- and ɣ) per laser shot!
- use technologies adapted to respective fluxes of signal and background

T20 electron beam extraction



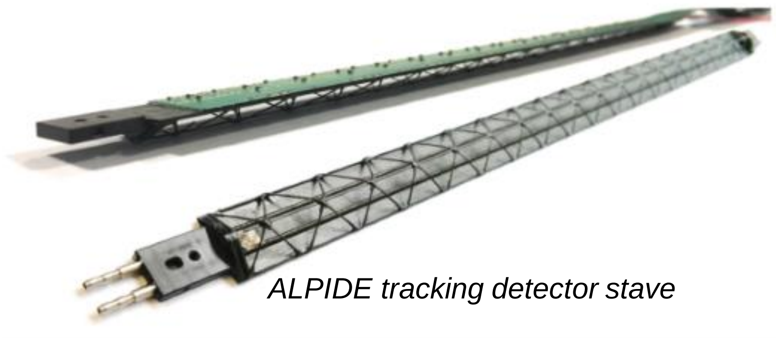




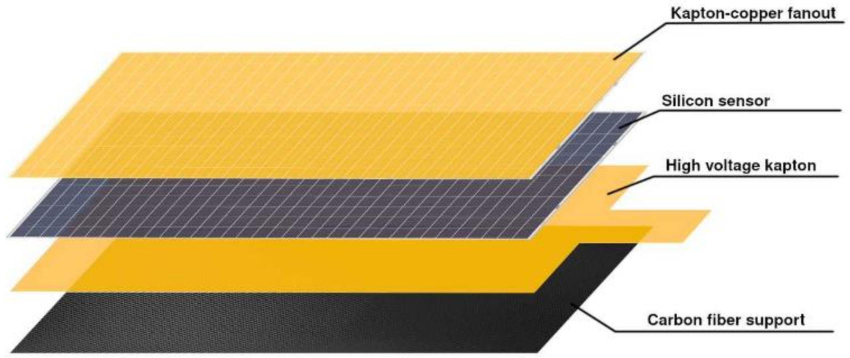
- Goal: kick out 1 bunch at angle -6.742° and transport to LUXE experimental area
- Lattice: Fast kicker magnet, Septa (asymmetric deflection magnets), Dipoles (deflection), Quadrupoles (focusing)
- Performance: - beam spot size: $\sigma_x = 9.3\mu m$, $\sigma_y = 8.1\mu m$
  - pulse size $130fs$
  - jitter parameters (measured): - shot-to-shot position variation: $1\mu m$
    - time-of-arrival jitter: $20fs$
    - energy variation: 0.01%

Beam properties after extraction line fulfil requirements for LUXE physics

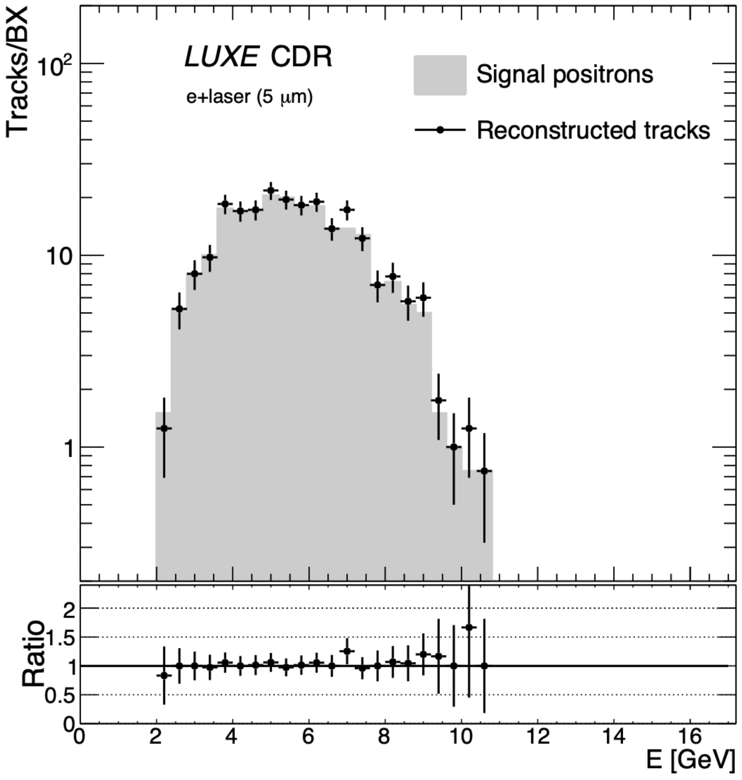
Positron Detection System



ALPIDE tracking detector stave



High-granularity ECAL layer



Silicon Pixel Tracker:

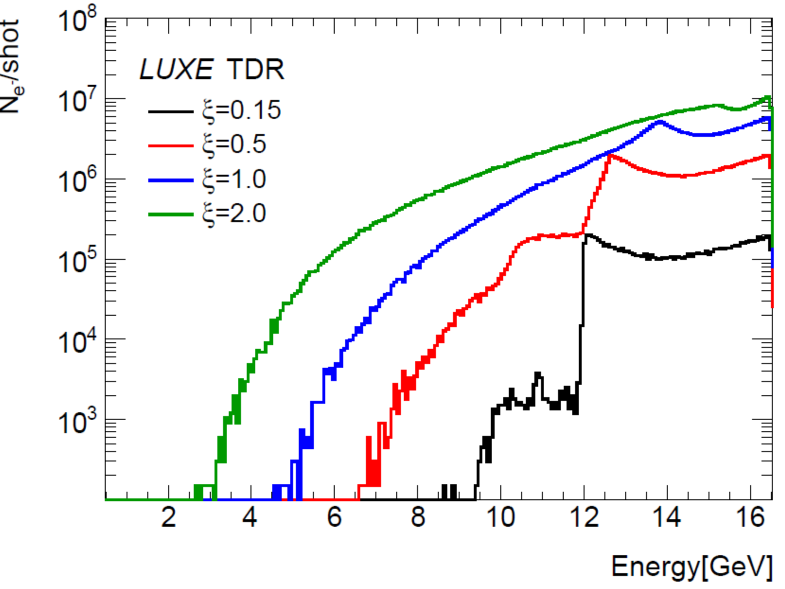
- four layers of ALPIDE silicon pixel sensors → developed for ALICE pixel tracker upgrade
- pitch size (27 x 29 μm), 5 μm resolution
- tracking: $\varepsilon > 98\%,\ \frac{\delta p}{p} \approx 0.3\%$
- very small background (<0.1 event / bunch crossing)

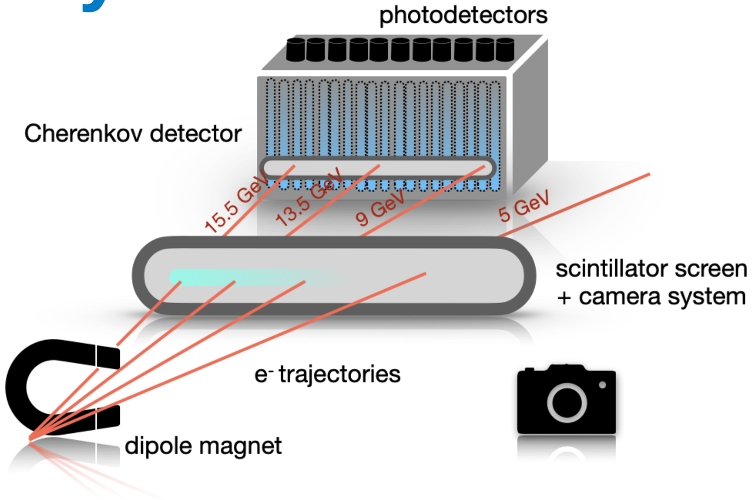
Si – W High-granularity Calorimeter:

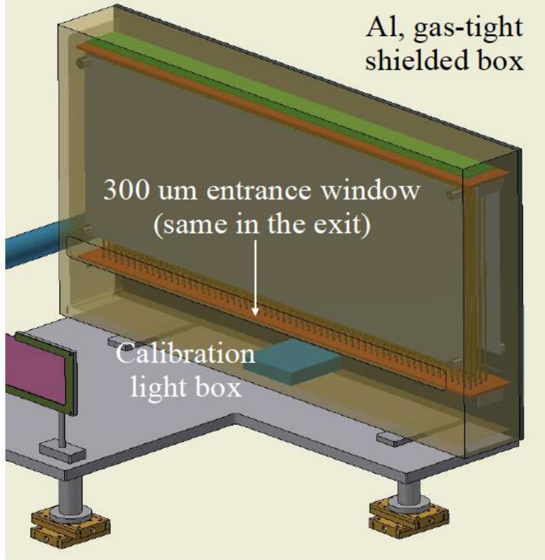
- 20-layer sampling calorimeter – high granularity: independent energy measurement through shower and position
- shower medium: 3.5mm Tungsten plates ($1X_0$), active medium: Silicon sensors ($5x5cm^2$, 320μm thick)
- read out by FLAME ASIC (developed for FCAL)

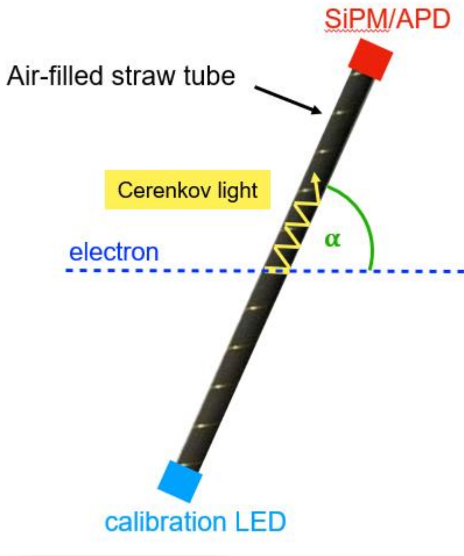
Positron detectors: High signal efficiency, high resolution!

Electron Detection System



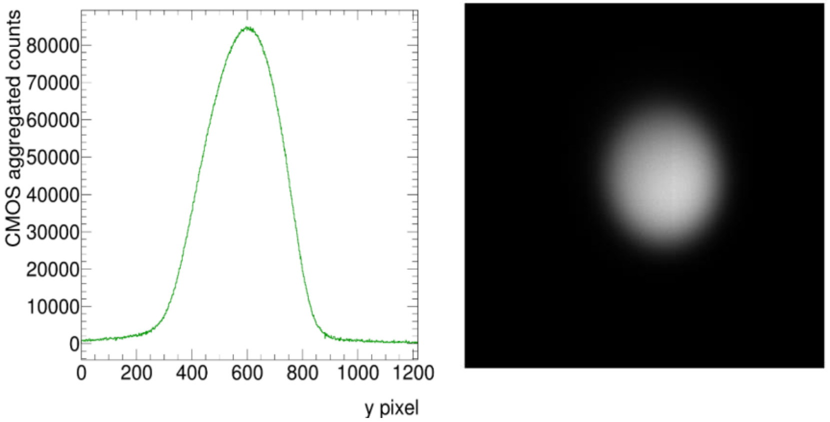






Scintillator screen (LANEX):

- camera takes pictures of scintillation light
- resolution of full system ~500μm



Beam spot imaged on Scint. Screen

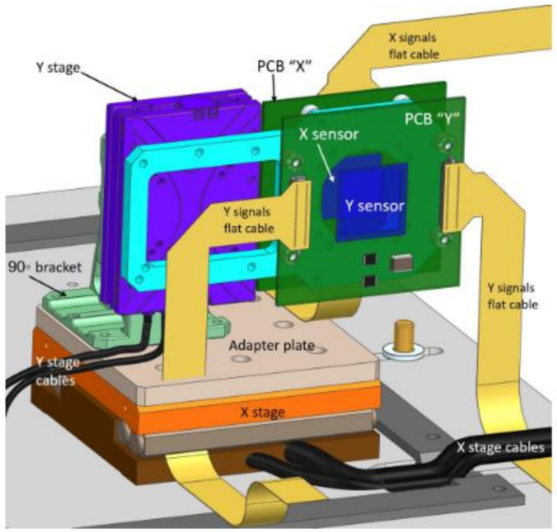

Straw prototype

Cerenkov detector:

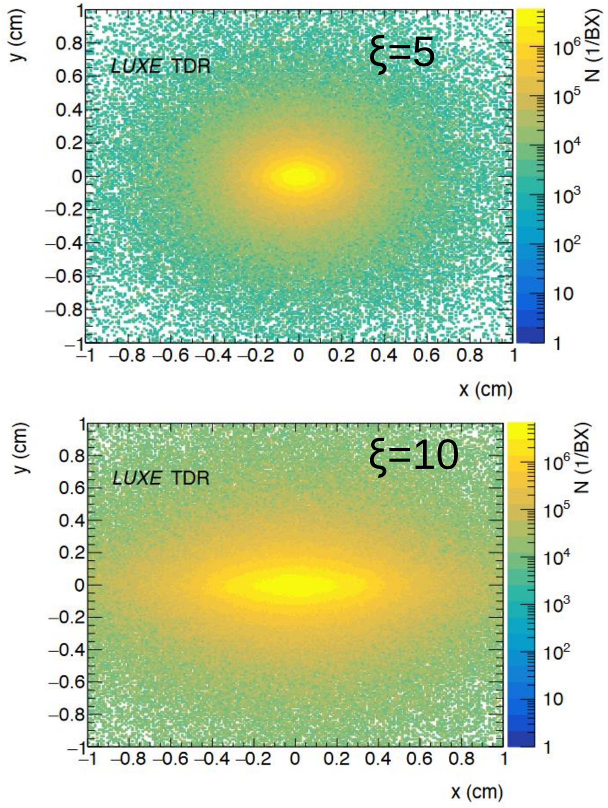
- finely segmented ($\emptyset = 4mm$) Air-filled channel (reflective tubes as light guides) → charged particles create Cherenkov light
- Active medium Air: low refractive index - reduce light yield, suppress backgrounds (Cherenkov threshold 20 MeV)

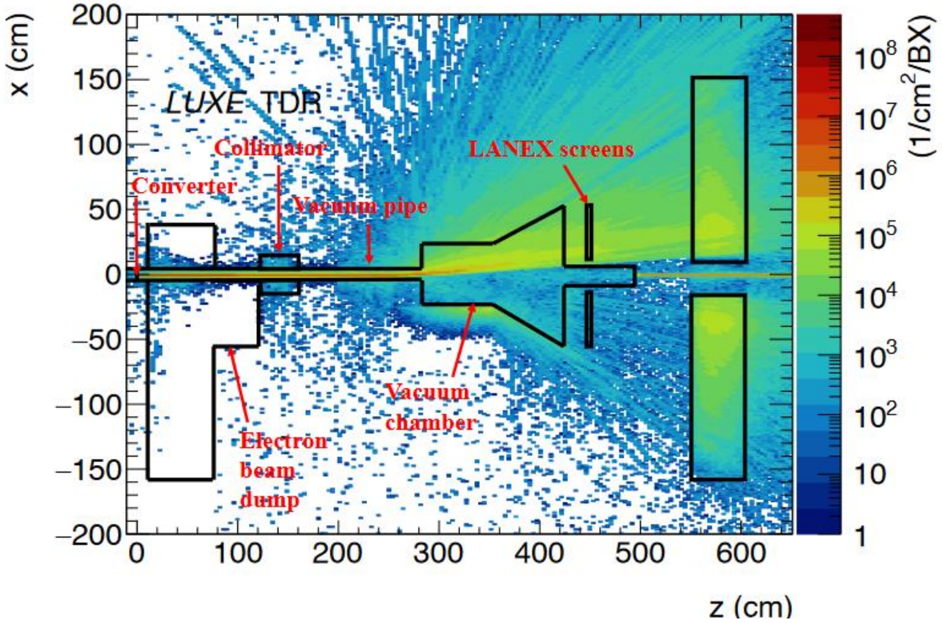
Electron detectors: High rate tolerance, large dynamic range!

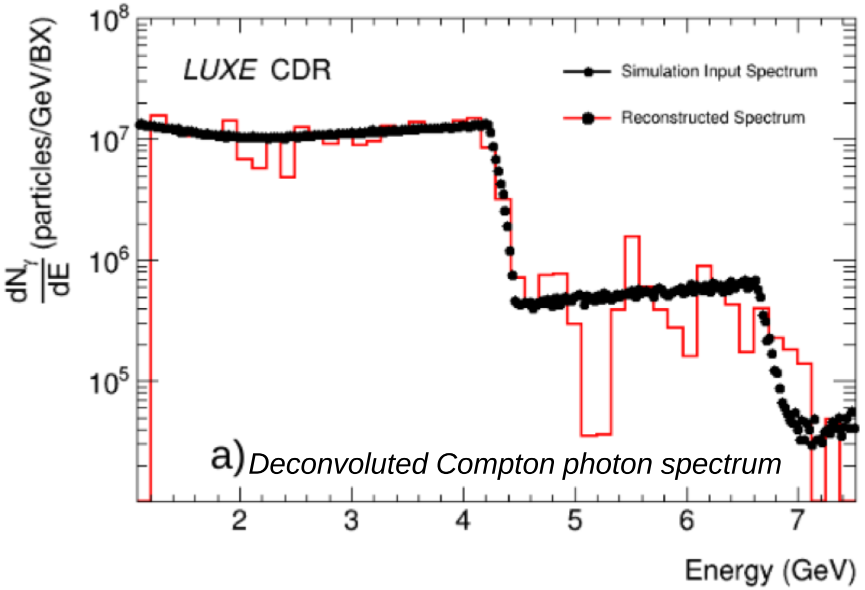
Photon Detection System



Gamma Beam Profiler





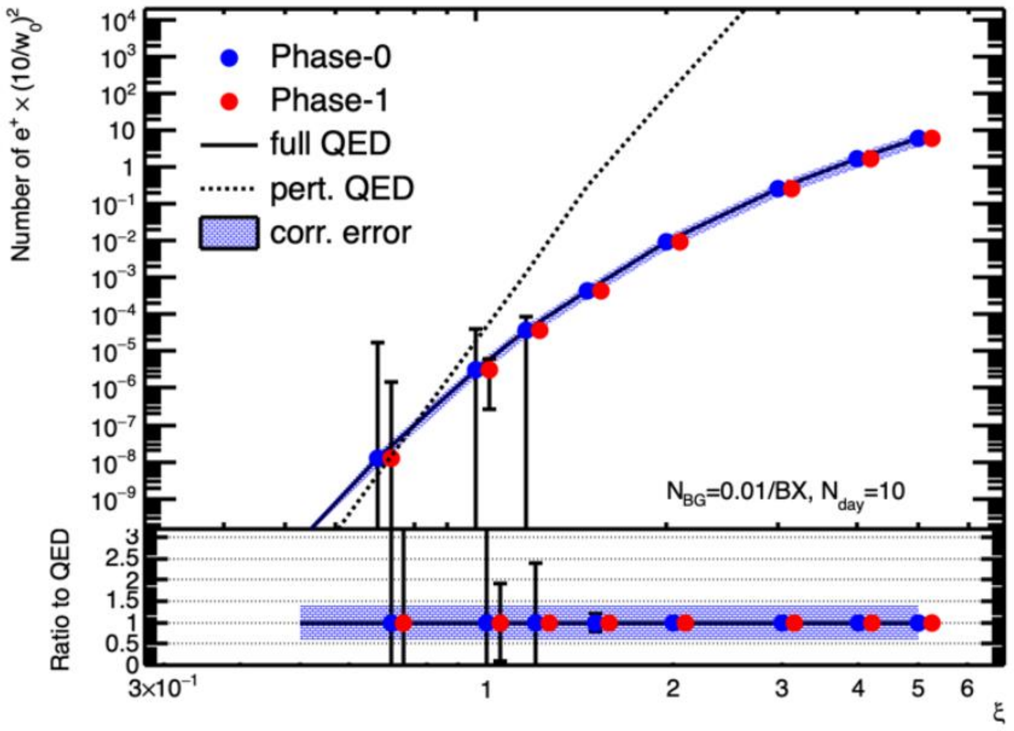


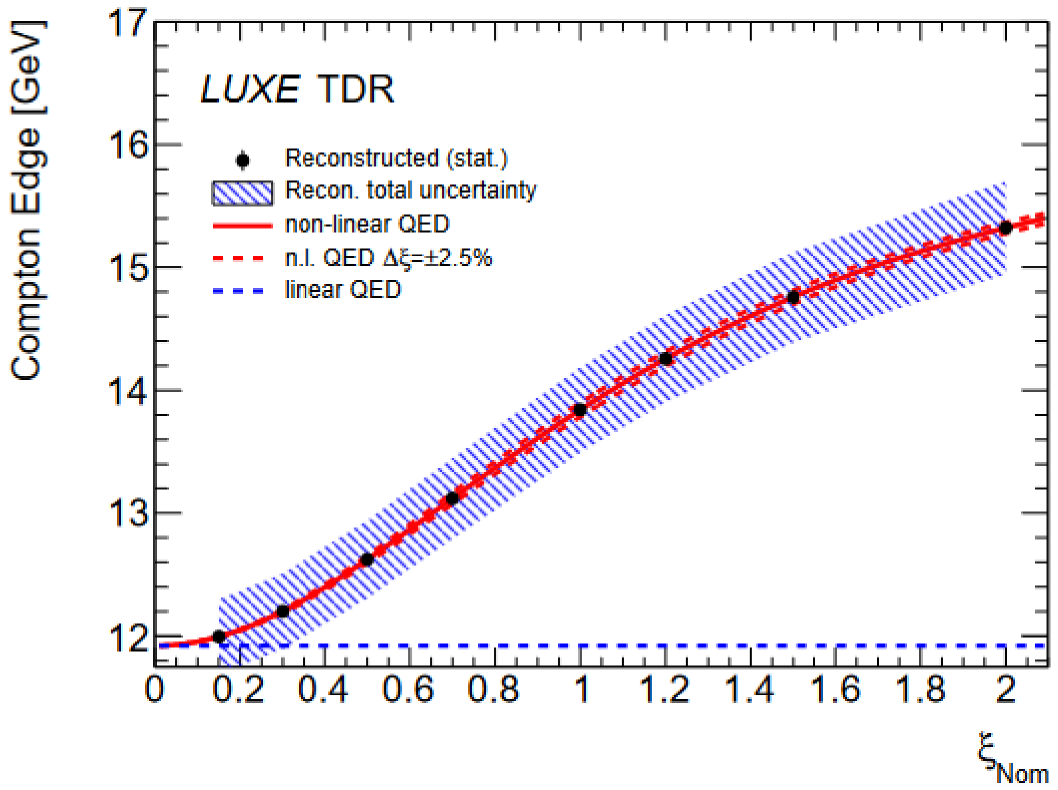
Gamma detector technologies:

- Gamma profiler (sapphire strips)
  → ɣ beam location and shape
  → precision measurement of Laser intensity
- Gamma spectrometer with scintillator screens behind converter
  → flux, energy spectrum ($\frac{\delta E}{E} < 2\%$)
- Gamma dump backscattering calorimeter → photon flux

Photon detectors: Precision measurement of ξ, complementary to Laser diagnostics

Expected Results





- Number of Breit-Wheeler pairs produced in photon-Laser collisions
- assuming 10dy of data-taking and 0.01 background events/ bunch crossing
- 40% correlated uncertainty to illustrate effect of uncertainty on ξ

- Compton edge position as function of ξ in electron-laser collisions
- assuming 1h data-taking, no background
- 2% correlated uncertainy to illustrate impact of energy resolution

SFQED parameters

Note:

$\mathcal{E}_L$: Laser field
$\mathcal{E}_{cr}$: Schwinger critical field

θ: Laser - probe crossing angle

ω_L: Laser frequency

$E_{e/\gamma}$: probe electron (photon) energy

Intensity parameter:

$$\xi = \sqrt{4\pi\alpha}\left(\frac{\mathcal{E}_L}{\omega_L m_e}\right) = \frac{m_e \mathcal{E}_L}{\omega_L \mathcal{E}_{cr}}$$

- measure of coupling between probe and Background (laser) field (also: square root of laser intensity)
- $\xi \geq 1$: non-perturbative regime

Quantum parameters:

$$\chi_e = (1+\cos\theta)\frac{E_e}{m_e}\frac{\mathcal{E}_L}{\mathcal{E}_{cr}}$$

$$\chi_\gamma = (1+\cos\theta)\frac{E_\gamma}{m_e}\frac{\mathcal{E}_L}{\mathcal{E}_{cr}}$$

- ratio of background laser field and Schwinger critical field
- $\chi \geq 1$: non-linear quantum effects become probable (e.g. pair production)

Energy Parameter

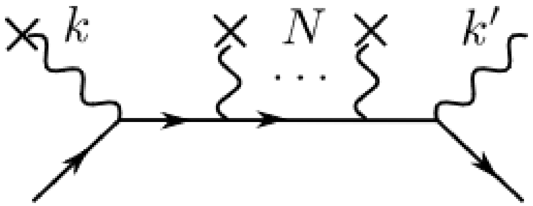
$$\eta = \frac{\chi}{\xi} = (1+\cos\theta)\frac{\omega_L E_{e/\gamma}}{{m_e}^2}$$

- (dimensionless) energy of collision between probe particle and background

Different combinations of ξ and χ result in different types of non-linear behavior!

Compton scattering in strong fields

- Consider Compton scattering in plane-wave background field: $A(x) = A_0 \sin(k \cdot x)$



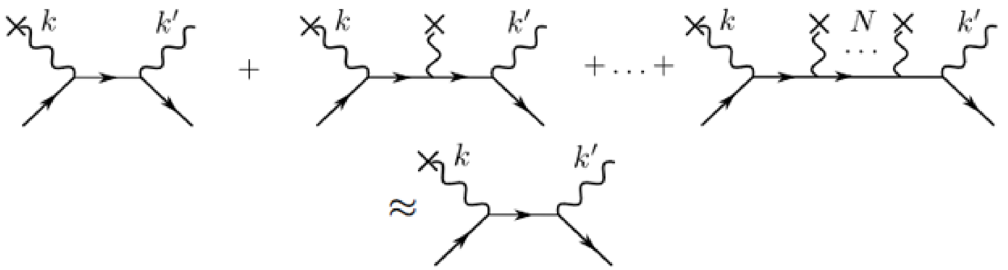
$+$ exchange diagram

fine structure constant

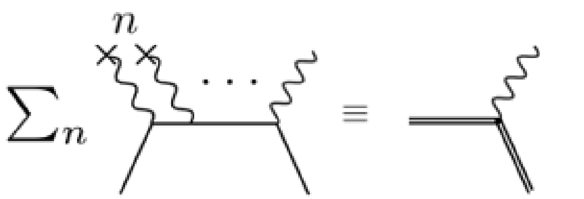
Probability $P \sim \alpha \left(\frac{eA_0}{m} \right)^{2N} = \alpha \xi^{2N}$

$$\xi = \frac{eA_0}{m}$$

'Classical nonlinearity / intensity parameter', ξ.



"weak" field $\xi < 1$



'Nonlinear' Compton scattering

strong field: $\xi \geq 1$

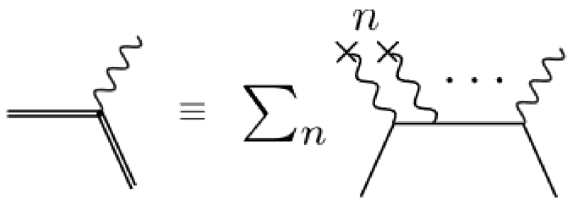
Strong field ($\xi \geq 1$): Need to take into account all order diagrams!

The Furry picture

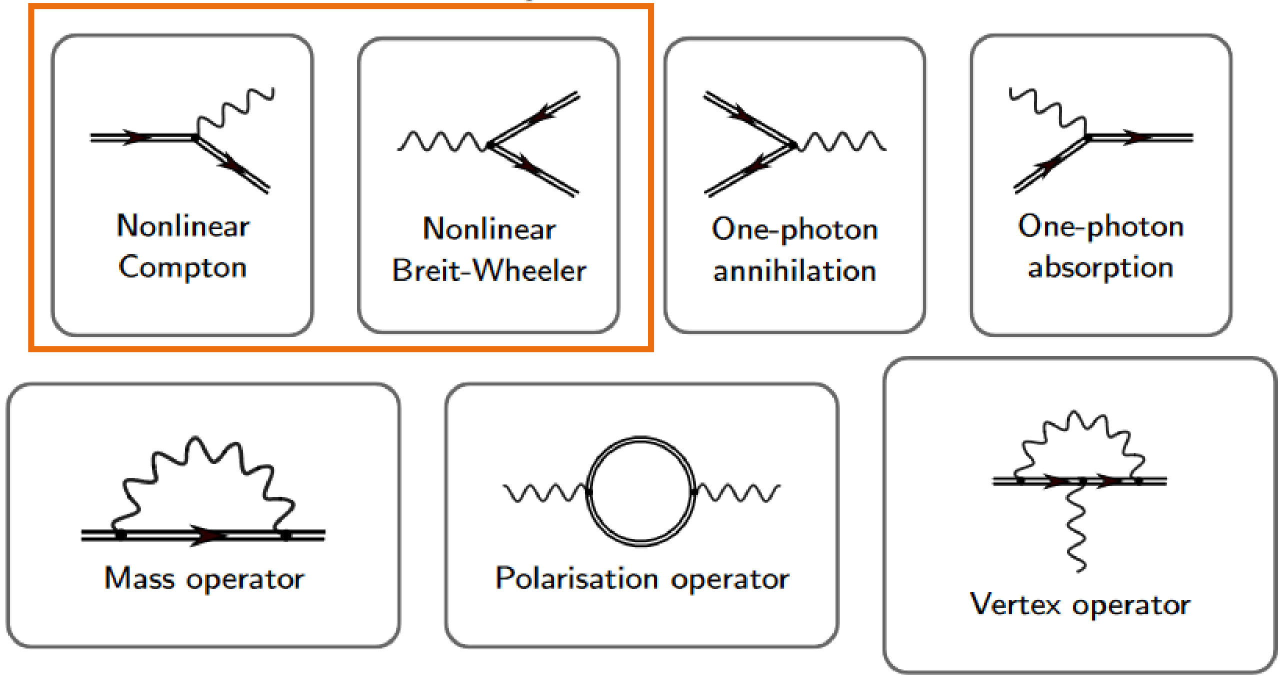
- How to do calculations? Solve equations of motion (Dirac equation) in field background
  → analytical solutions exist in plane wave background („Volkov wave functions“)

- derive Feynman rules for „dressed“ states („Furry expansion“)
  → treat background exactly, particle scattering perturbatively ($\alpha \ll 1$)

$$\mathcal{L} = \underbrace{-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \bar{\psi}\left(i\not{D} - m\right)\psi}_{\text{‘unperturbed’}} \underbrace{-e\bar{\psi}\not{A}\psi}_{\text{interaction}},$$



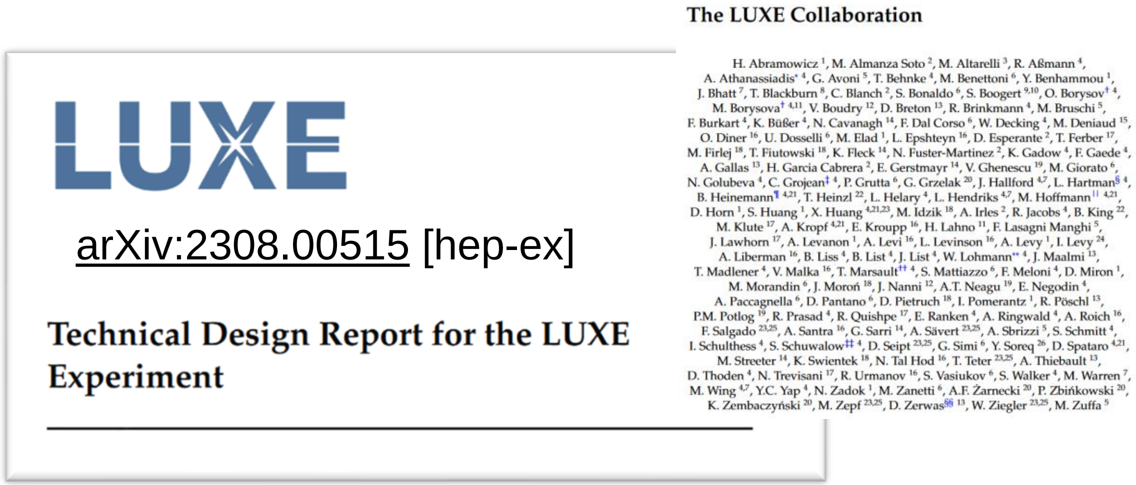
„dressed“ state



TDR: *EPJST.* **230**, 2445–2560 (2021)

LUXE Status & Planning

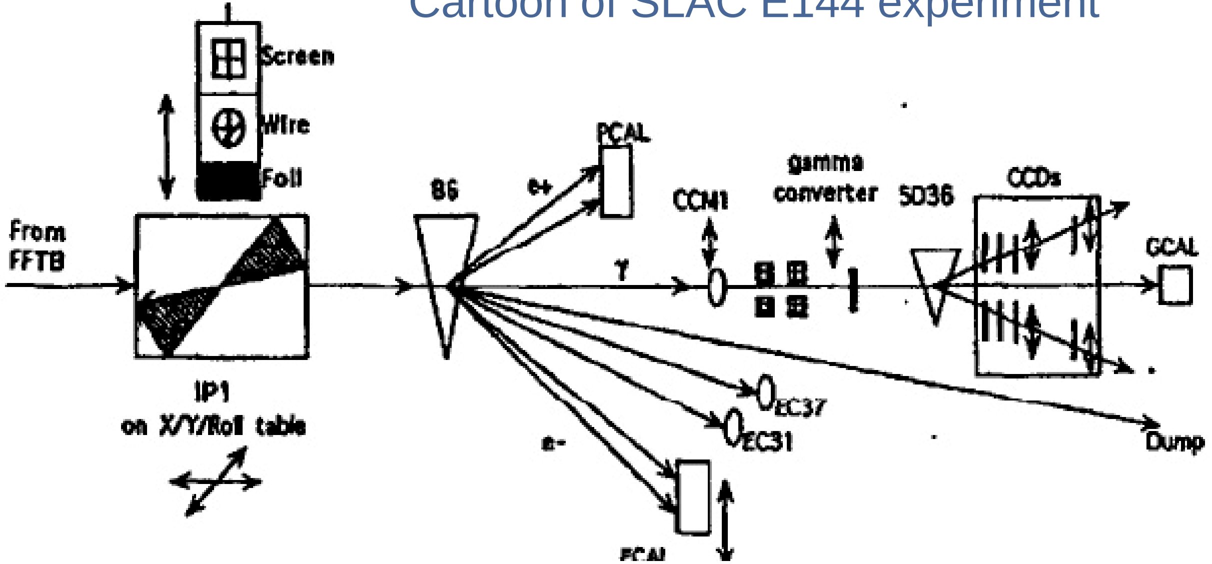
- LUXE initiated in 2017
- 2024: international collaboration with ~100 members
  → significant contributions by external partners
- Technical Design Report (TDR) released in 2023
- approval process at DESY and EuXFEL is progressing,
  → funding acquisition ongoing
- foresee staged construction in EuXFEL shutdowns
  → first phase-0 data-taking could start after 3-year
  construction period

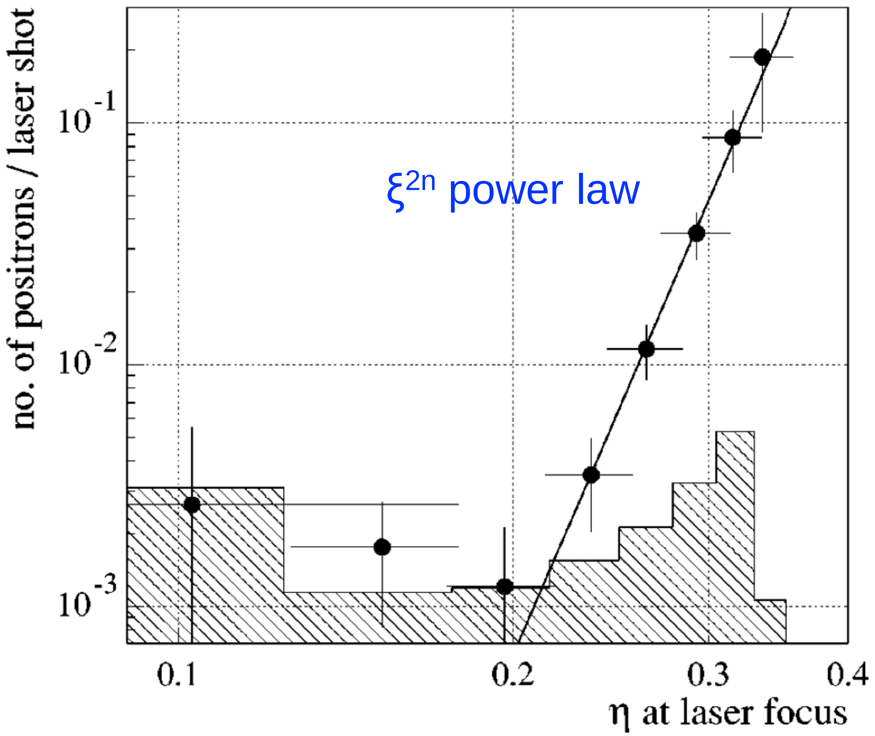


[Bamber et al. (SLAC 144) ‘99]

E144 experiment at SLAC

Cartoon of SLAC E144 experiment



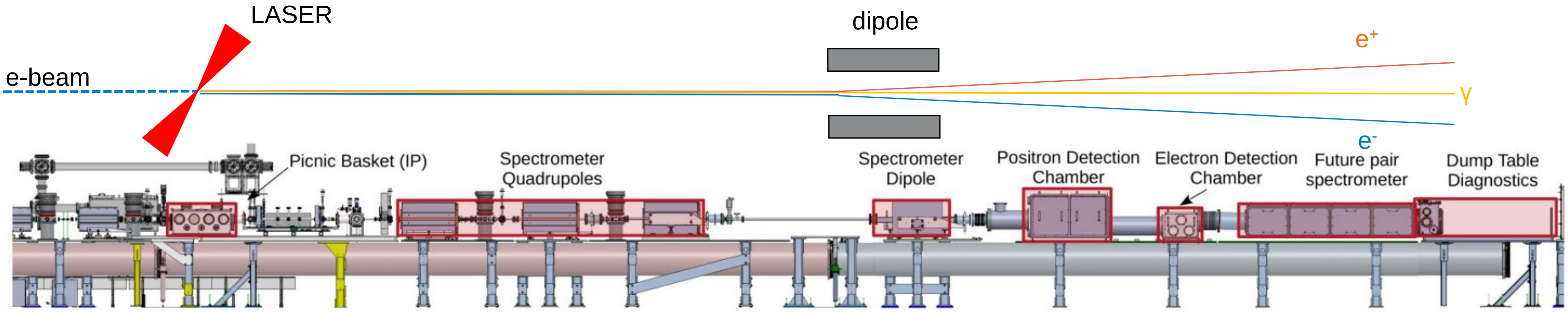


- E144: SLAC experiment in 1990’s using 46.6 GeV electron beam (e+LASER only!)
- reached $\chi \leq 0.25$, $\xi<0.4$
- observed process $e^- + n\gamma_L \rightarrow e^-\ e^+e^-$
- observed start of the ξ^{2n} power law, but not departure

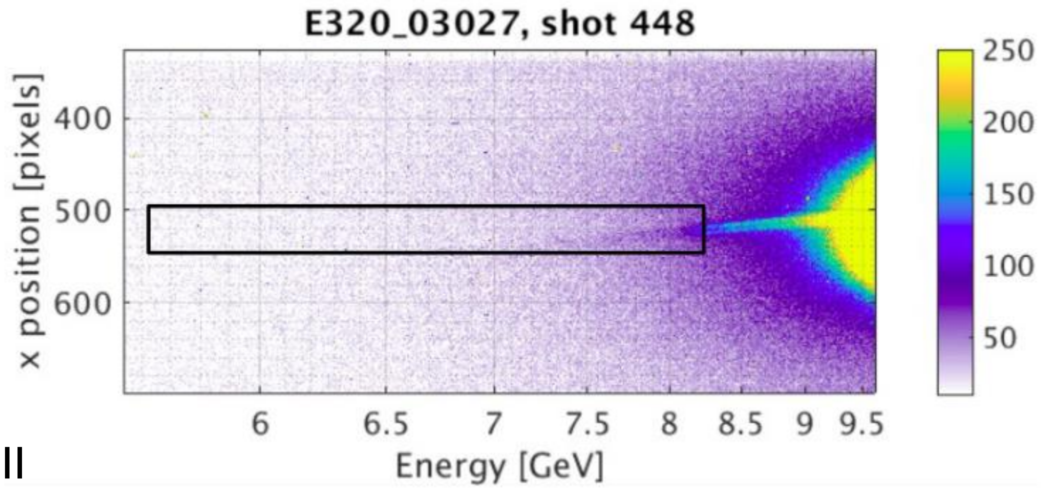
LUXE : Three orders of magnitude more powerful laser than E144, will enter non-perturbative regime

E-320 experiment at SLAC

[Link](#) to E320 overview by S. Meuren

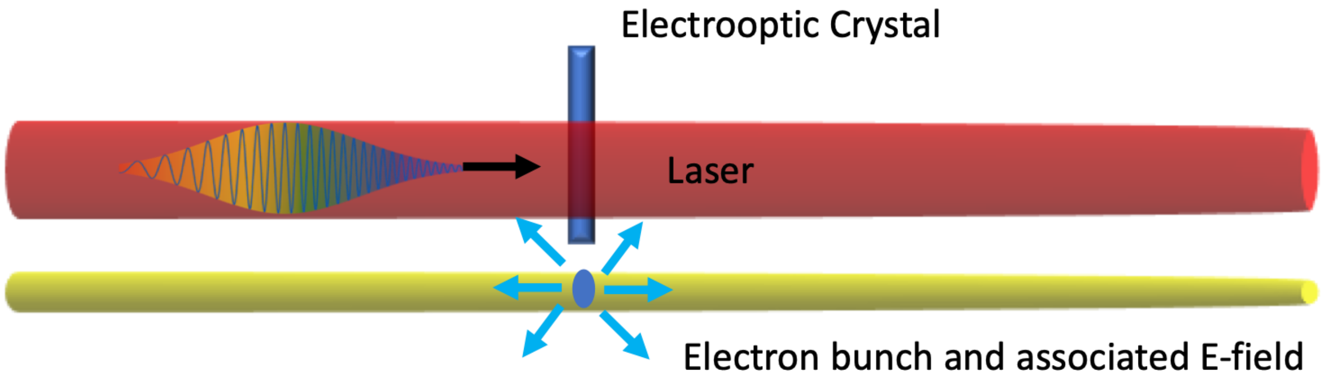


- E320: ongoing SF-QED experiment at SLAC using 13 GeV electron beam (FACET-II) and 16 TW optical Laser
- first electron-LASER collisions in 2022
- By design: similar parameter reach as LUXE (after Laser and Detector upgrades)
- Main differences to LUXE:
  - electron-Laser collision mode only
  - E-320 data-taking time limited due to other users of FACET-II



Synchronization

- critical: spatial and temporal overlap of electron beam and LASER
- temporal overlap requirement (30fs LASER pulse, >100fs electron bunch)
  → at least half the pulse width (50fs)
- XFEL developed world-leading syncronization system
  → sychronization of two RF signals to <13fs
- synchronise the XFEL.EU master clock oscillator to the oscillator of the Laser
  → already used across XFEL to sychronize LASERS and accelerator
  → fine-tune repetition rate via piezo-elements controling LASER cavity size
- stability against temperature variations: isolation and active feedback loops
- spatial overlap: beam pointing monitoring systems for both electron and LASER beam



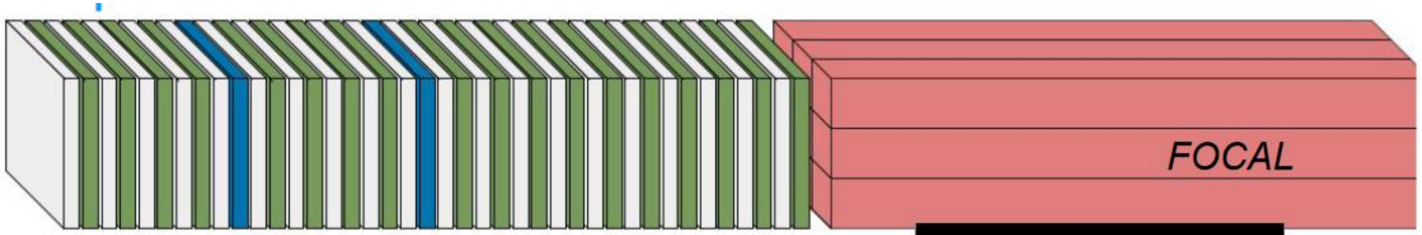
LUXE-NPOD Dump and Detector Optimization

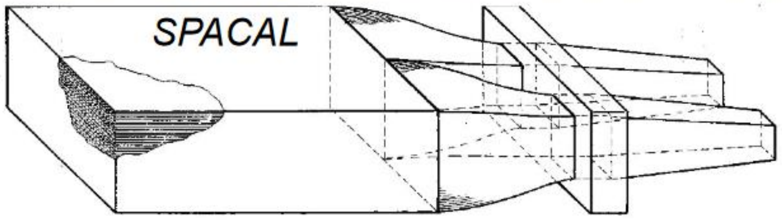
- Optimised photon dump geometry to minimise background and maximise signal
  → Computing challenge: simulate O(10^9) electrons with Geant4 for each geometry
- Optimal detector characteristics for signal detection and background rejection:
  - Signal efficiency (Photon separation ~2cm)
  - Background suppression (neutrons: shower shape and timing <1ns, radius r<0.5m)
  - Precise ALP invariant mass (photon direction and energy, non-resonant rejection)

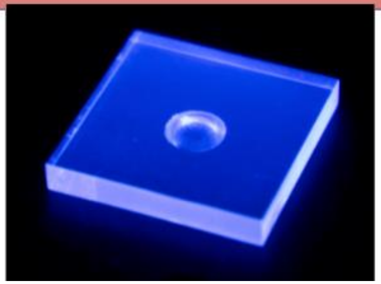
  → Ideal: Tracking calorimeter

Existing detector options:

- Alice FoCal.
- H1 SPACAL.
- Calice SiPM on Tiles







Calice tile

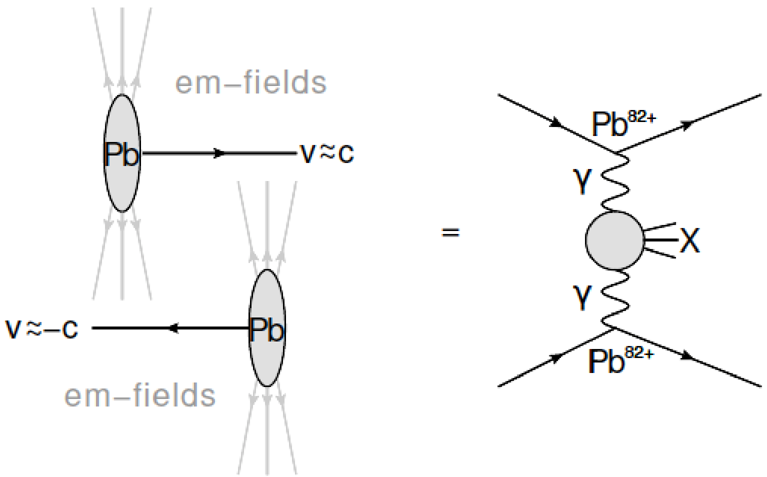
How does LUXE relate to LHC light-by-light scattering?

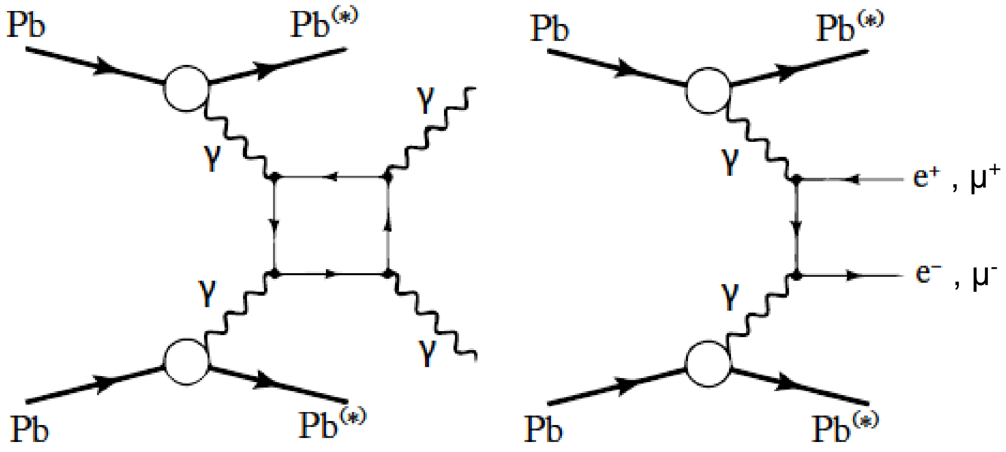
- LHC: photon-photon interaction in ultra-peripheral heavy-ion collisions (UPC)
  → e.g. $\gamma\gamma \rightarrow \gamma\gamma$, $\gamma\gamma \rightarrow \mu\mu$

- UPC: fields above the Schwinger limit can be reached in the lab

- main difference to LUXE: in UPC, EM field is extremely short-lived, cannot travel over macroscopic distances

- this regime is still covered by linear perturbative QED





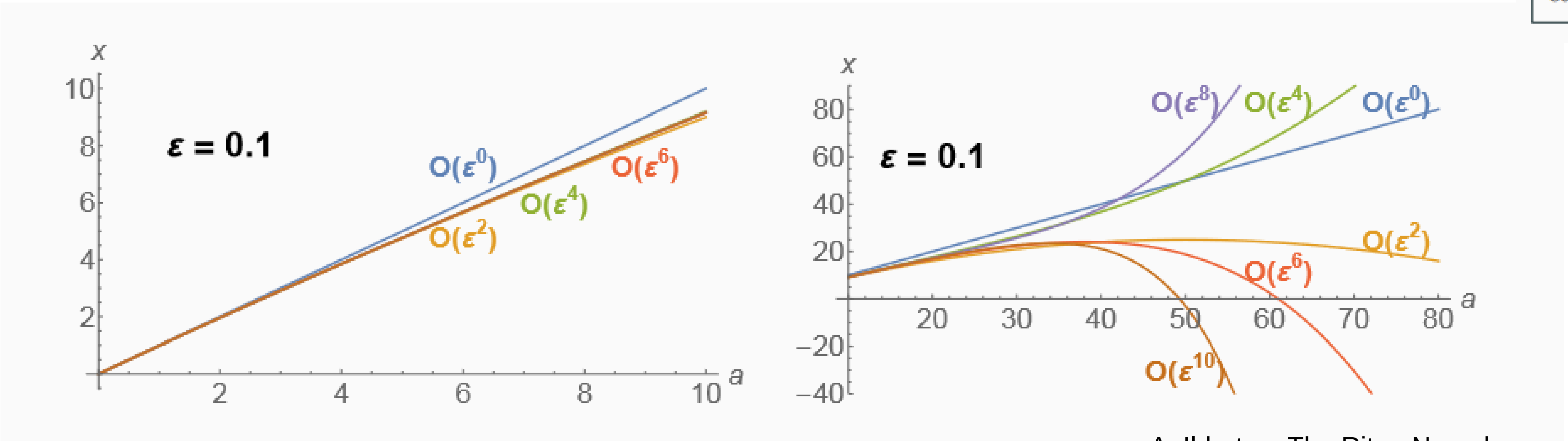
Figures from: arXiv:2010.07855v3
(Also a nice review to read, if you want to know more!)

Ritus-Naroshny Conjecture

- Ritus-Naroshny Conjecture: in the vicinity of sufficiently strong fields, the Furry expansion breaks down → perturbative QED coupling α is modified by the field strength: $\alpha \to \alpha\chi^{2/3}$

- Conjecture interpreted to hold for any „locally constant“ background (field constant over formation length scale of physics process)

$$a \leftrightarrow a_0,\ \varepsilon^2 \leftrightarrow \alpha$$



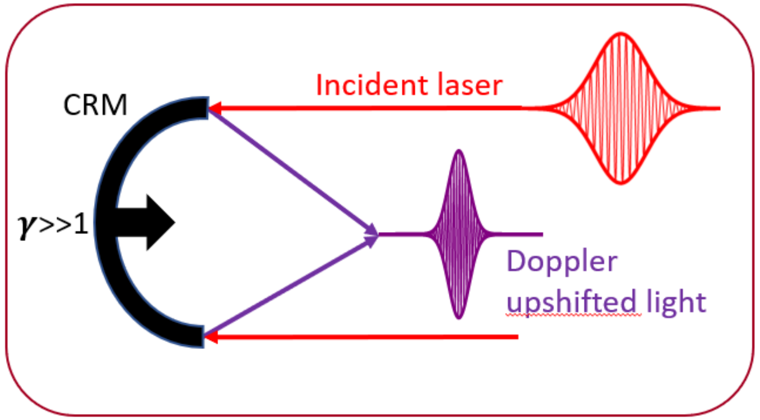
A. Ilderton: The Ritus-Naroshny conjecture: A tutorial

Creating strong fields in experiments

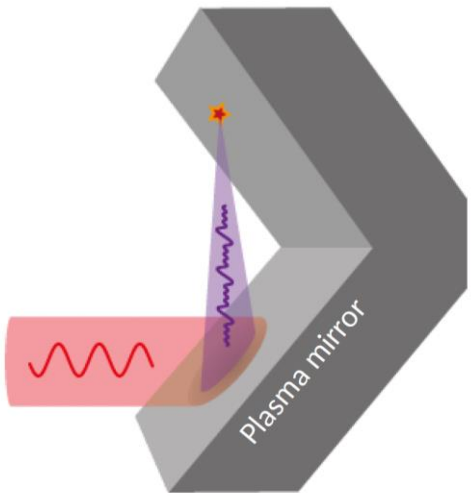
C. Thaury et al, Nat. Phys (2007)
Dromey et al, Nat. Phys (2009)

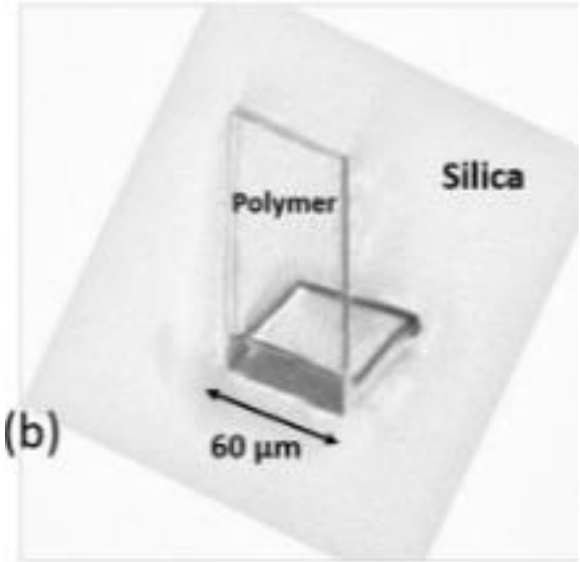
3) Relativistic curved mirrors

- Doppler-boosting Laser intensity using curved relativistic mirrors
- „Plasma mirrors“ ejected by impinging laser light on solid state taget
  → currently under study in simulation (cf.)
- solid-state fixed target experiment, or collision with particle beam
  → reach extreme regions of SF-QED phase space



L-shaped target





Vincenti et al, Nat. Comm. (2014)
Fedeli et al, PRL (2021)

Contact

Deutsches Elektronen-
Synchrotron DESY

www.desy.de

Ruth Jacobs
DESY-FHR
ruth.magdalena.jacobs@desy.de