LUXE: A NEW EXPERIMENT TO STUDY NON-PERTURBATIVE QED

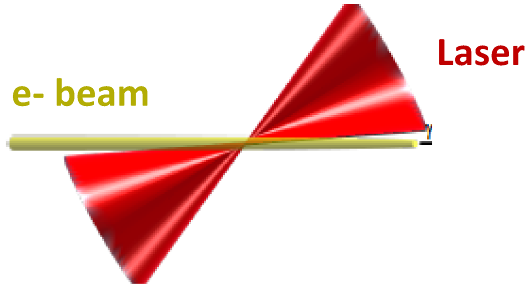
LOUIS HELARY - DESY

BIRMINGHAM PARTICLES PHYSICS GROUP SEMINAR

SEPTEMBER 22ND 2021

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

- Luxe: **L**aser **U**nd **X**FEL **E**xperiment
  - New experiment planned in Hamburg using
    - European XFEL electrons accelerator
    - High-intensity laser
  - Synergy between particle physics and laser physics!
- Main documents describing the experiment:
  - LOI: September 2019: https://arxiv.org/abs/1909.00860
  - CDR: February 2021(New!), published by European Physics Journal ST: https://arxiv.org/abs/2102.02032
- Collaboration is being formed (CDR ~100 authors 29 institutes), from experimental and theory community!
- Discussed in the following:
  - What is strong-field QED and why is it interesting?
  - What does LUXE add compared to previous SF-QED experiments?
  - What are the key technologies to obtain LUXE's measurement goals?



Conceptual Design Report for the LUXE Experiment

H. Abramowicz[1], U. Acosta[2,3], M. Altarelli[4], R. Aßmann[5], Z. Bai[6,7], T. Behnke[5], Y. Benhammou[1], T. Blackburn[8], S. Boogert[9], O. Borysov[5], M. Borysova[5,10], R. Brinkmann[5], M. Bruschi[11], F. Burkart[5], K. Büßer[5], N. Cavanagh[12], O. Davidi[6], W. Decking[5], U. Dosselli[13], N. Elkina[3], A. Fedotov[14], M. Firlej[15], T. Fiutowski[15], K. Fleck[12], M. Gostkin[16], C. Grojean[*5], J. Hallford[5,17], H. Harsh[18,19], A. Hartin[17], B. Heinemann[†5,20], T. Heinzl[21], L. Helary[5], M. Hoffmann[5,20], S. Huang[1], X. Huang[5,15,20], M. Idzik[15], A. Ilderton[21], R. Jacobs[5], B. Kämpfer[2,3], B. King[21], H. Lahno[10], A. Levanon[1], A. Levy[1], I. Levy[22], J. List[5], W. Lohmann[‡5], T. Ma[23], A.J. Macleod[21], V. Malka[6], F. Meloni[5], A. Mironov[14], M. Morandin[13], J. Moron[15], E. Negodin[5], G. Perez[6], I. Pomerantz[1], R.Pöschl[24], R. Prasad[5], F. Quéré[25], A. Ringwald[5], C. Rödel[26], S. Rykovanov[27], F. Salgado[18,19], A. Santra[6], G. Sarri[12], A. Sävert[18], A. Sbrizzi[§28], S. Schmitt[5], U. Schramm[2,3], S. Schuwalow[5], D. Seipt[18], L. Shaimerdenova[29], M. Shchedrolosiev[5], M. Skakunov[29], Y. Soreq[23], M. Streeter[12], K. Swientek[15], N. Tal Hod[6], S. Tang[21], T. Teter[18,19], D. Thoden[5], A.I. Titov[16], O. Tolbanov[29], G. Torgrimsson[3], A. Tyazhev[29], M. Wing[5,17], M. Zanetti[13], A. Zarubin[29], K. Zeil[3], M. Zepf[18,19], and A. Zhemchukov[16]

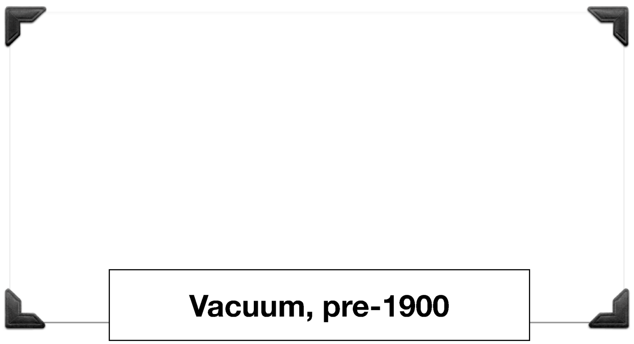
[1]*Tel Aviv University, Tel Aviv, 6997801, Israel*
[2]*TU Dresden, 01062 Dresden, Germany*
[3]*Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany*
[4]*Max Planck Institute for Structure and Dynamics of Matter, 22761 Hamburg, Germany*
[5]*Deutsches Elektronen-Synchrotron (DESY), 22607 Hamburg, Germany*
[6]*Weizmann Institute of Science, Rehovot, 7610001, Israel*
[7]*Department of Physics, Southern University of Science and Technology, Shenzhen 518055, China*
[8]*University of Gothenburg, SE-41296 Gothenburg, Sweden*
[9]*John Adams Institute at Royal Holloway, Department of Physics, Royal Holloway, Egham, TW20 0EX, Surrey, UK*
[10]*Institute for Nuclear Research NASU (KINR), Kyiv, 03680, Ukraine*
[11]*INFN and University of Bologna, Bologna, Italy*
[12]*School of Mathematics and Physics, The Queen's University of Belfast, Belfast, BT7 1NN, UK*
[13]*INFN and University of Padova, Padova, Italy*
[14]*National Research Nuclear University MEPhI, Kashirskoe sh. 31, Moscow, 115409, Russia*
[15]*Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Krakow, Poland*
[16]*Joint Institute for Nuclear Research (JINR), Dubna 141980, Russia*
[17]*University College London, London, WC1E 6BT, UK*
[18]*Helmholtz Institut Jena, 07743 Jena, Germany*
[19]*Friedrich Schiller Universität Jena, 07743 Jena, Germany*
[20]*Albert-Ludwigs-Universität Freiburg, 79085 Freiburg, Germany*
[21]*University of Plymouth, Plymouth, PL4 8AA, UK*
[22]*Department of Physics, Nuclear Research Centre-Negev, P.O. Box 9001, Beer Sheva 84190, Israel*
[23]*Physics Department, Technion—Israel Institute of Technology, Haifa 3200003, Israel*
[24]*Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France*
[25]*LIDYL, CEA, CNRS, Université Paris-Saclay, CEA Saclay, 91 191 Gif-sur-Yvette, France*
[26]*Institute of Nuclear Physics, TU Darmstadt, 64289 Darmstadt, Germany*
[27]*Skolkovo Institute of Science and Technology (Skoltech), Moscow 121205, Russia*
[28]*INFN Trieste, Trieste, Italy*
[29]*National Research Tomsk State University NI TSU, TSU, Russia*

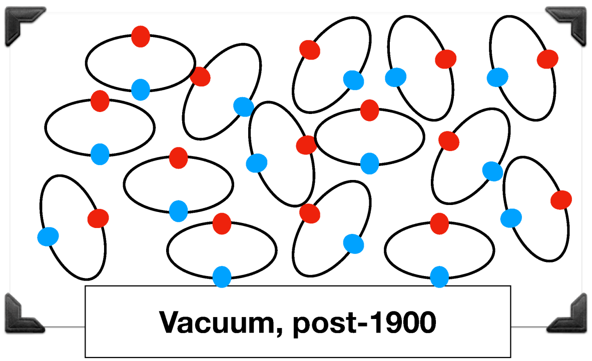
arXiv:2102.02032v1 [hep-ex] 3 Feb 2021

- Quantum Electro Dynamics: the most well-tested physics theory!
  - Calculation in QED based on perturbative theory of α_{EM}.
    - Anomalous moment of electron (g-2) as a precision better than 1 part in a trillion and data in agreement with theory.
      - Interesting tension in the measurement of muon g-2, but sensitive to new physics (and outside scope of this talk)!

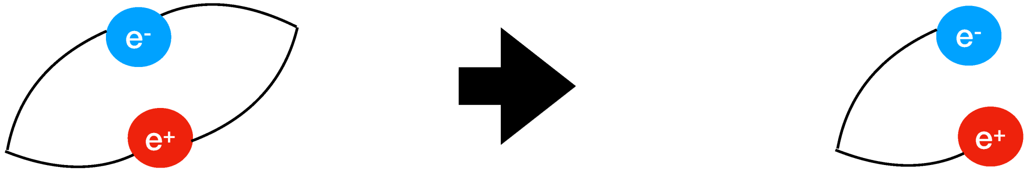
Nobel prize 1965

- The vacuum:
  - State with the lowest energy.
  - (quantum fields): average is zero, but variance is not!
  - vacuum consists of virtual particles that can be charged and couple to fields.
  - Coupling to virtual particles affects physical particle processes





- If one apply a strong electromagnetic field on a vacuum:
  - $E_{field} < 2\ m_e$ $\qquad\qquad$ $E_{field} > 2 m_e$

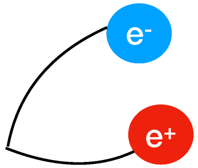


Euler and Heisenberg
Z.Phys. 98 (1936) no.11-12, 714-732
(translation at arXiv:physics/0605038

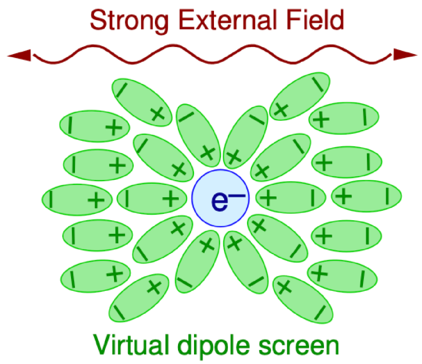
Schwinger
Phys. Rev. 82 (1951), 664

- Vacuum boils if field large enough to create real pairs:
  - "critical field" → Schwinger-Limit: $\varepsilon_{crit} = \frac{m_e^2 c^3}{\hbar e} \simeq 1.3 \cdot 10^{18}\ \mathrm{V/m}$
  - QED becomes non perturbative above Schwinger-limit → Strong field QED (SFQED)!

- Experimental consequences:
  - **Field-induced ("Breit-Wheeler") Pair Creation:**

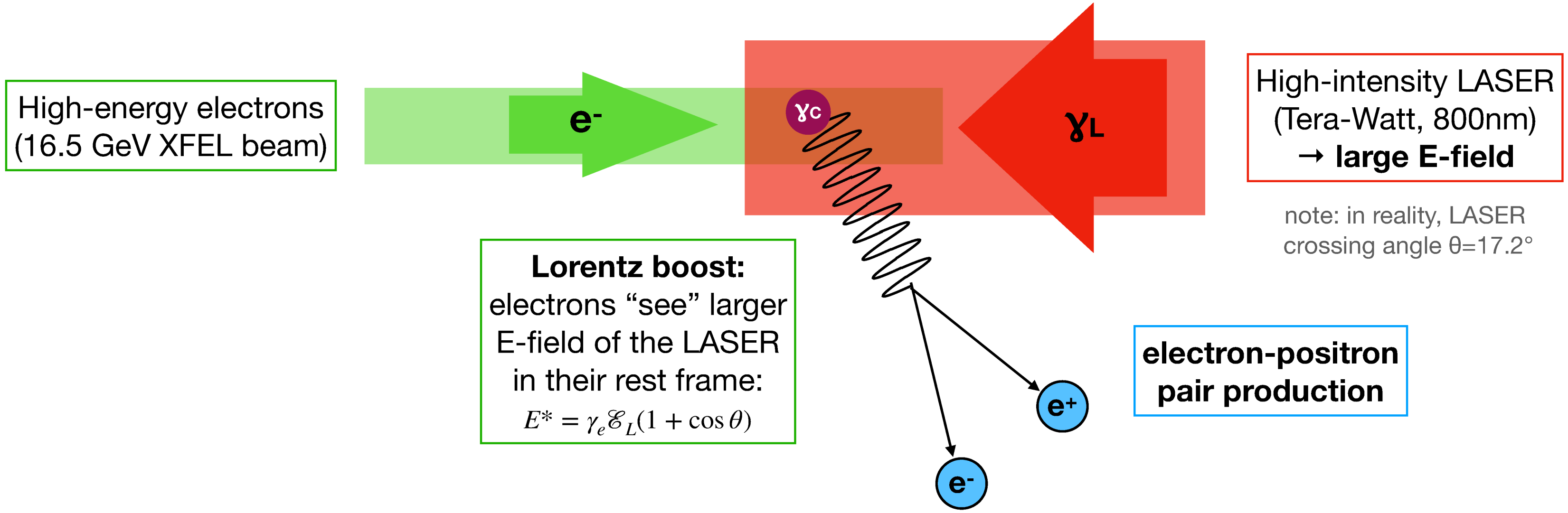


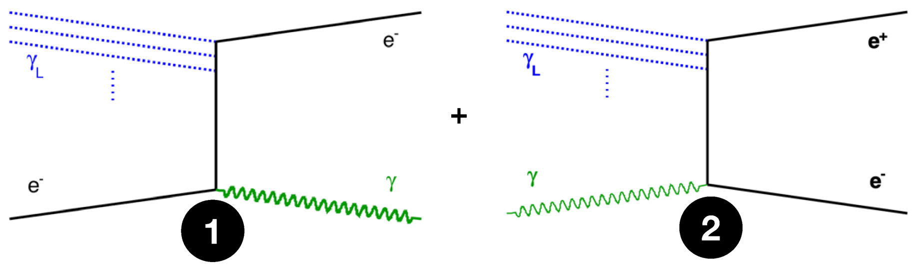
  - **Modified Compton Spectrum:**
    - Effect on Compton edges position.
    - Electrons obtains (significantly) larger effective rest mass.



- Non-perturbative and strong field QED have never been reached in laboratory, accessible by LUXE!

LUXE: ELECTRON-LASER COLLISIONS

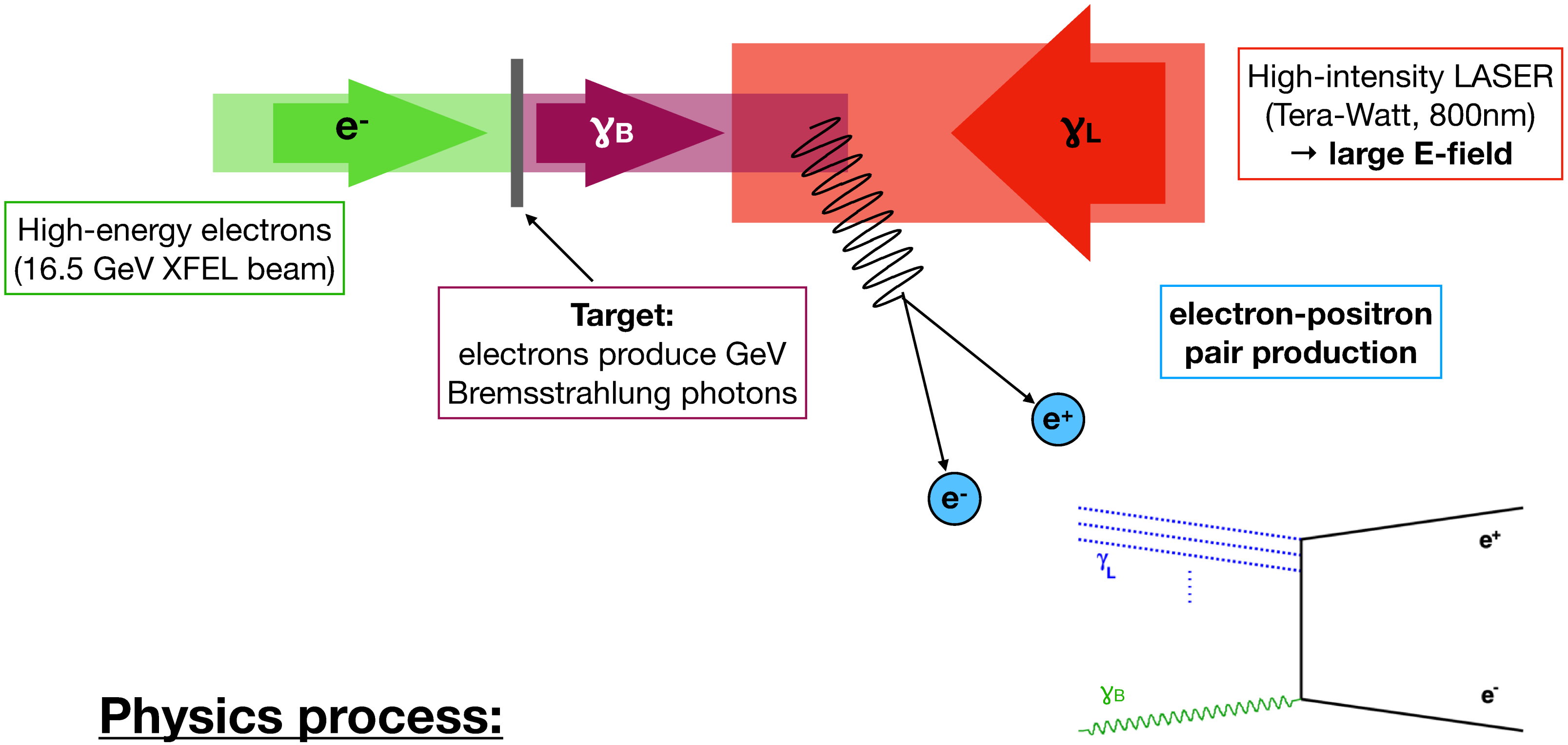




Physics processes:

1. **Non-linear Compton Scattering:** $e^- + n\gamma_L \rightarrow e^- + \gamma_C$
2. **Non-linear Breit-Wheeler pair production :** $\gamma_C + n\gamma_L \rightarrow e^+ + e^-$

LUXE main goal: Measure positron rate as function of LASER intensity



Physics process:

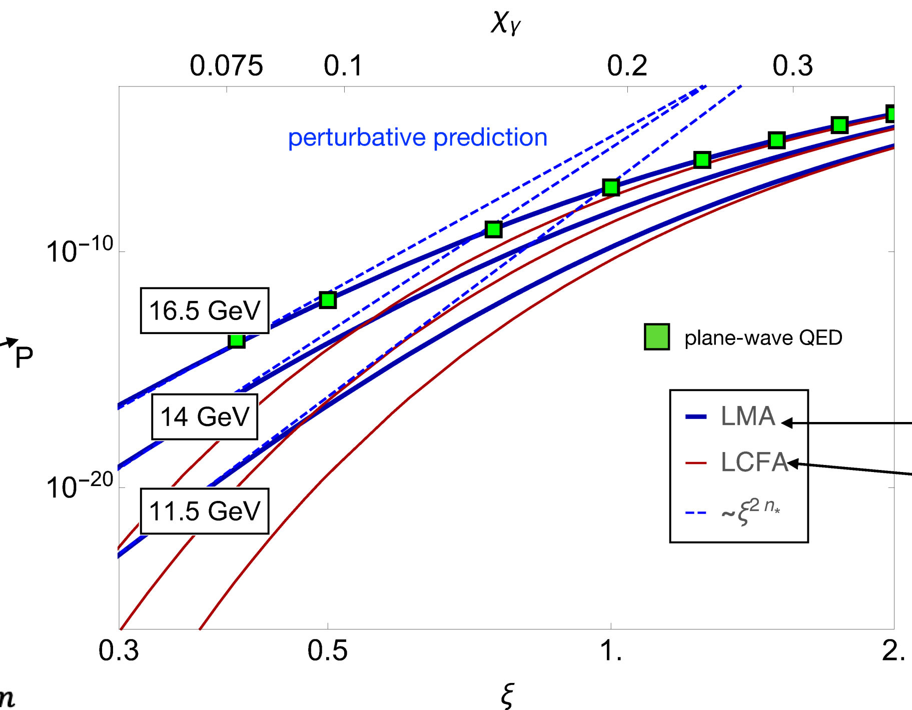
Non-linear Breit-Wheeler pair production : $\gamma_B + n\gamma_L \rightarrow e^+ + e^-$

LUXE: first SF-QED experiment to probe directly photon-photon interaction

- Parameters used in SFQED:
  - ξ = Measure of e-Laser coupling and Laser intensity.
  - Χ² = fraction of Laser energy transferred to electron beam.

$$\xi = \frac{e\varepsilon_L}{m_e \omega_L c} \propto I_{Laser} \qquad \chi \approx \gamma \frac{\varepsilon_L}{\varepsilon_{crit}} \propto \sqrt{I_{Laser}}\, E_{beam}$$

probability of Breit-Wheeler process



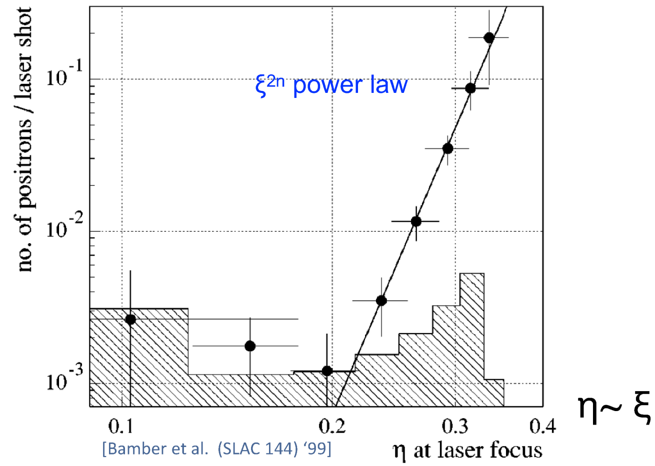
(LMA) Locally Monochromatic Approximation valid at low ξ

(LCFA) Locally Constant Field Approximation valid at high ξ

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

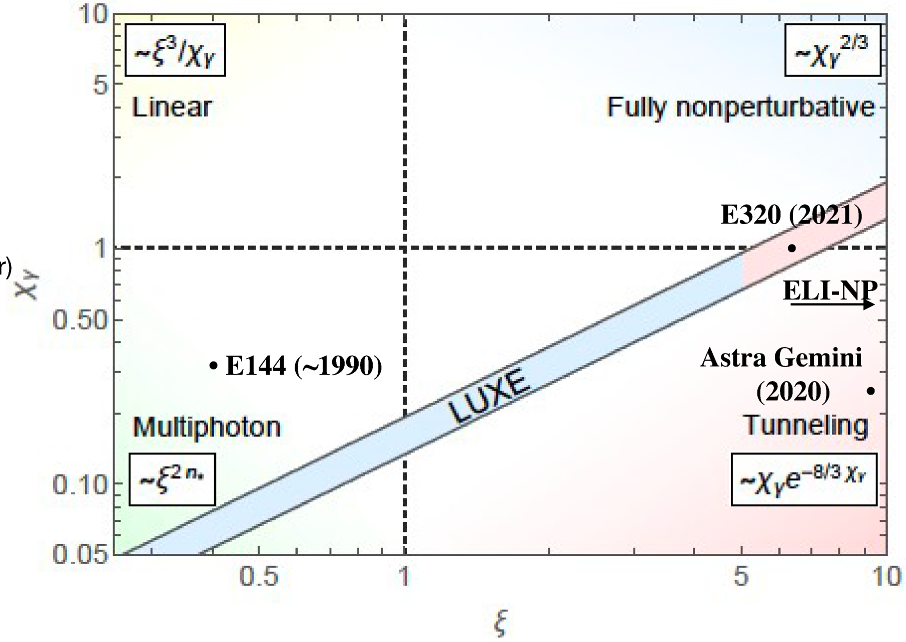
$\xi \gg 1$: $R_{e^+} \propto \chi_\gamma \exp\left(-\frac{8}{3\chi_\gamma}\right)$ — Non-perturbative regime, departure from power law

- Historically SFQED studied first in 1990's at SLAC E144 (experiment)
  - 1TW laser with $I_{Laser}=10^{18}$ W/cm^2
  - e- beam: 46.6 GeV
  - reached ξ<0.4, χ ≤ 0.25
  - observed multi-photon interaction: $e^- + n\gamma_L \rightarrow e^- e^+ e^-$ process
  - observed start of the ξ^{2n} power law, but not departure



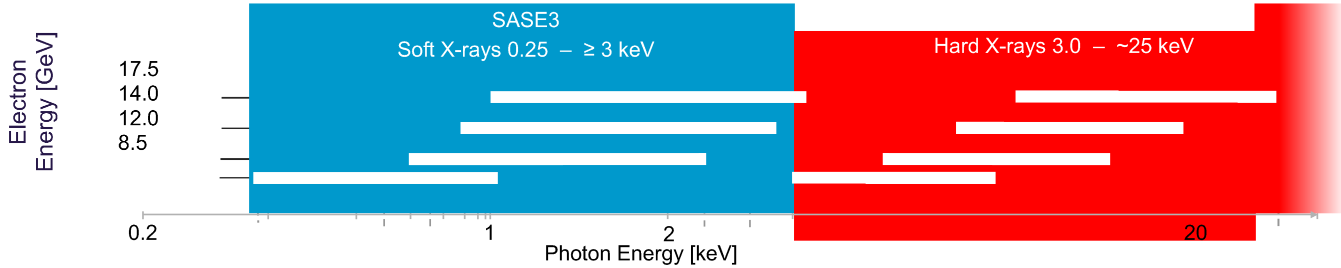
- Nowadays multiple experiments proposed worldwide:
  - SLAC-E320 (US), Astra Gemini (UK), ELI-NP (RO), LUXE (DE)
  - Summary of parameters needed to reach non-perturbative regime

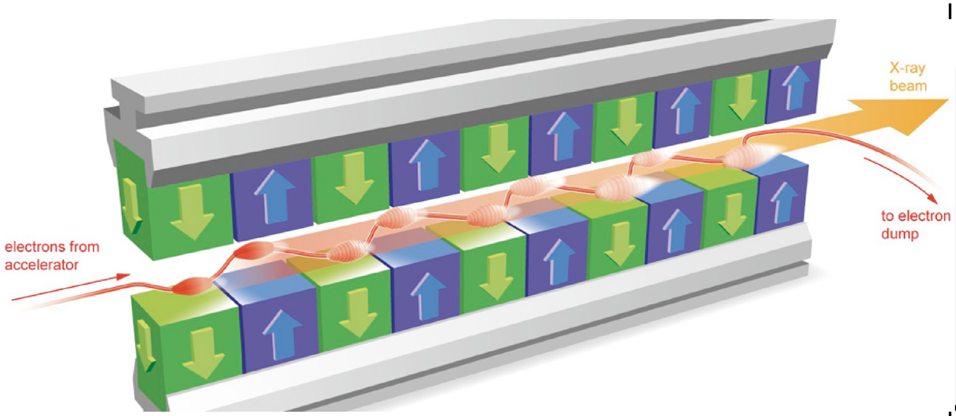
e- Beam	I_{Laser} [W/cm^2]	
1 eV	10^{29}	(Not currently achievable)
1 GeV	10^{22}	(corresponds to 10 PW laser)
10 GeV	10^{20}	(corresponds to 100 TW laser)

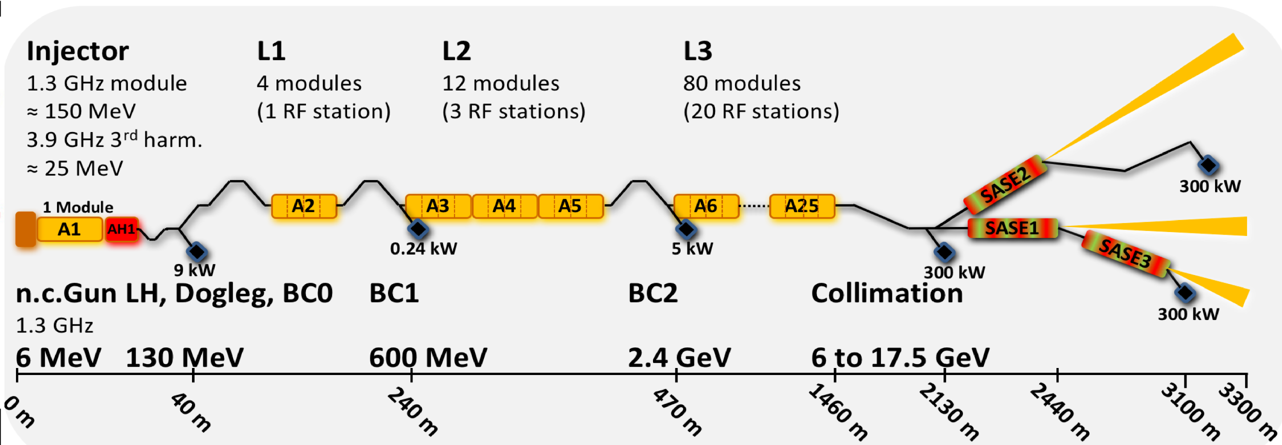


- Luxe allow to measure with precision large part of ξ vs X phase space.
  - Might be the first one to report observation of non perturbative regime.
    - Only experiment proposed to directly explore photon-laser interactions.

- European XFEL:
  - Running since 2017.
  - Provide X-ray photons to 6 experiments.
    - Electron through undulator:
      - SASE (self-amplified spontaneous emission)
    - 0.25 keV to 25 keV.
  - Linear electron accelerator.
    - 1.9 km long.
    - Up to 17.5 GeV.
    - 2700 electron bunches at 10 Hz.
      - Aim to run at 16.5 GeV with 1.5e9 electrons/bunch.

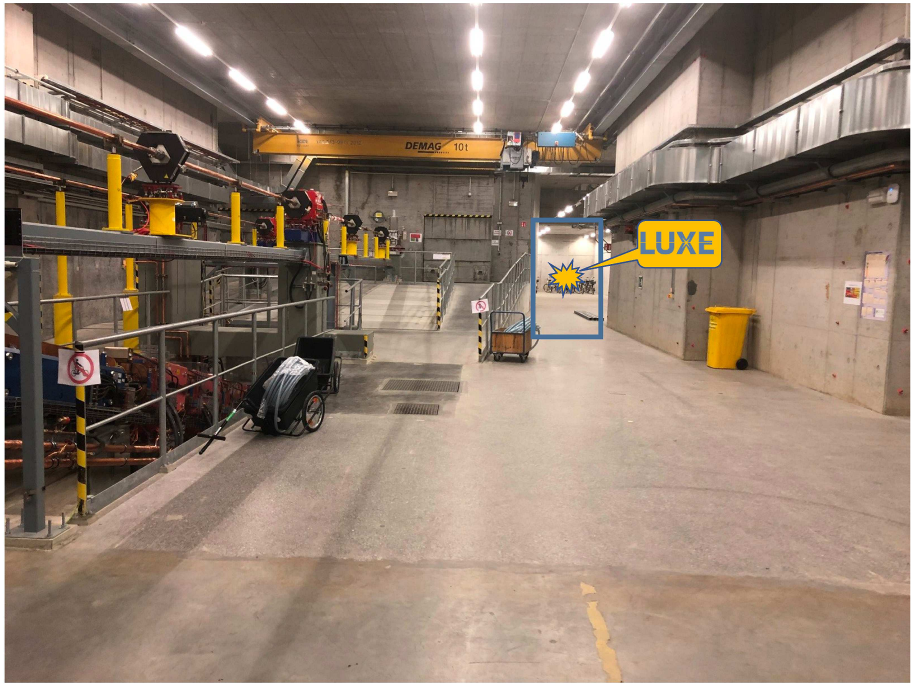


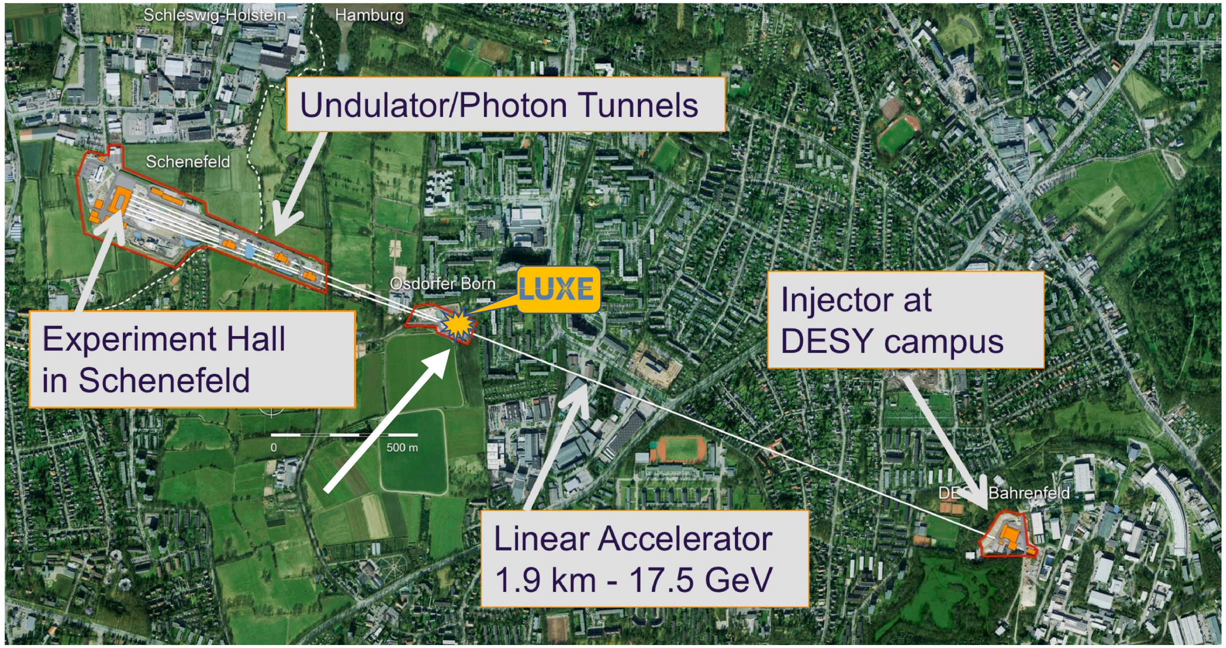


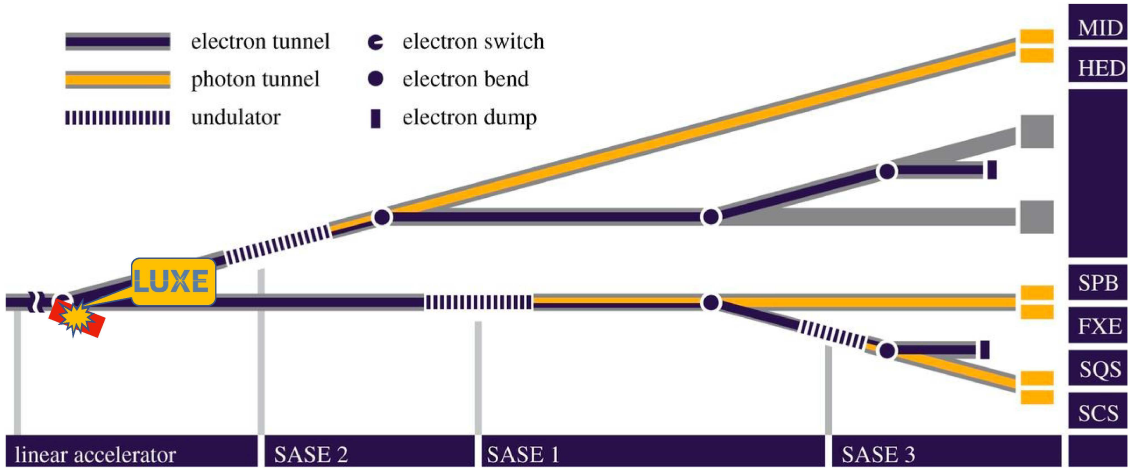


LUXE@EUROPEAN XFEL

- Experiment will be located in annex of XS1 shaft building in Orsdorfer Born.
  - Built for XFEL extension (after 2029).
- Experiment will have no impact on photon science,
  - Only use 1 of the 2700 bunches.







FROM THE ACCELERATOR TO THE EXPERIMENT

- Construct dedicated new extraction line at the end of the LINAC.
  - Reusing magnet design from XFEL.
  - New fast kicker magnets (2 µs: kicks bunch at end of bunch train).
- Independent machine CDR released in 2019 (not public).
  - More information can be found in (or in our CDR): https://accelconf.web.cern.ch/ipac2019/papers/tuprb008.pdf

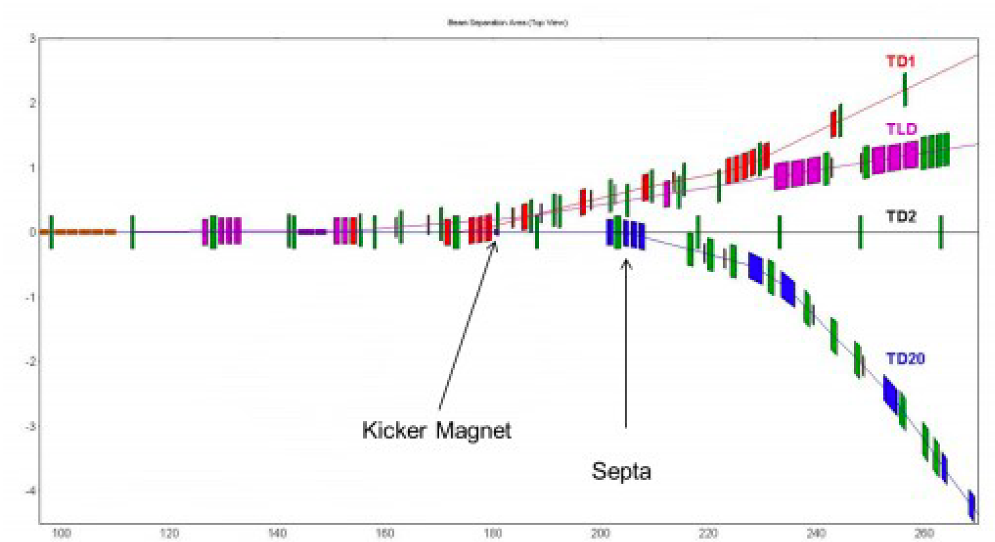
XTD20 Electron Beam Transfer Line

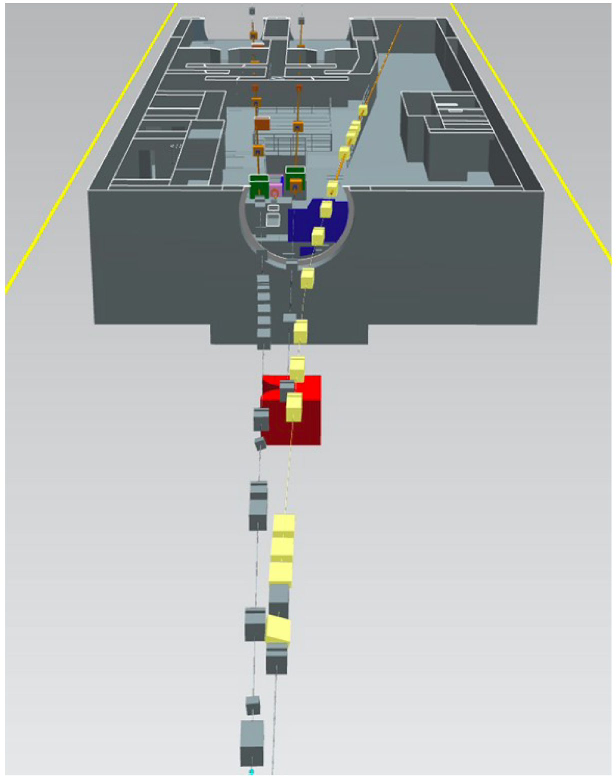
Conceptual Design Report

Editors: Florian Burkart, Winfried Decking

with input from: R. W. Assmann, R. Brinkmann, F. Burkart, W. Decking, H. Eckoldt, N. Golubeva, B. Heinemann, M. Huening, L. Knebel, M. Koerfer, B. Krause, D. Lenz, L. Lilje, C. Martens, M. Scheer, M. Schmitz, F. Obier, R. Platzer

August 2019





LUXE IN XS1 BUILDING

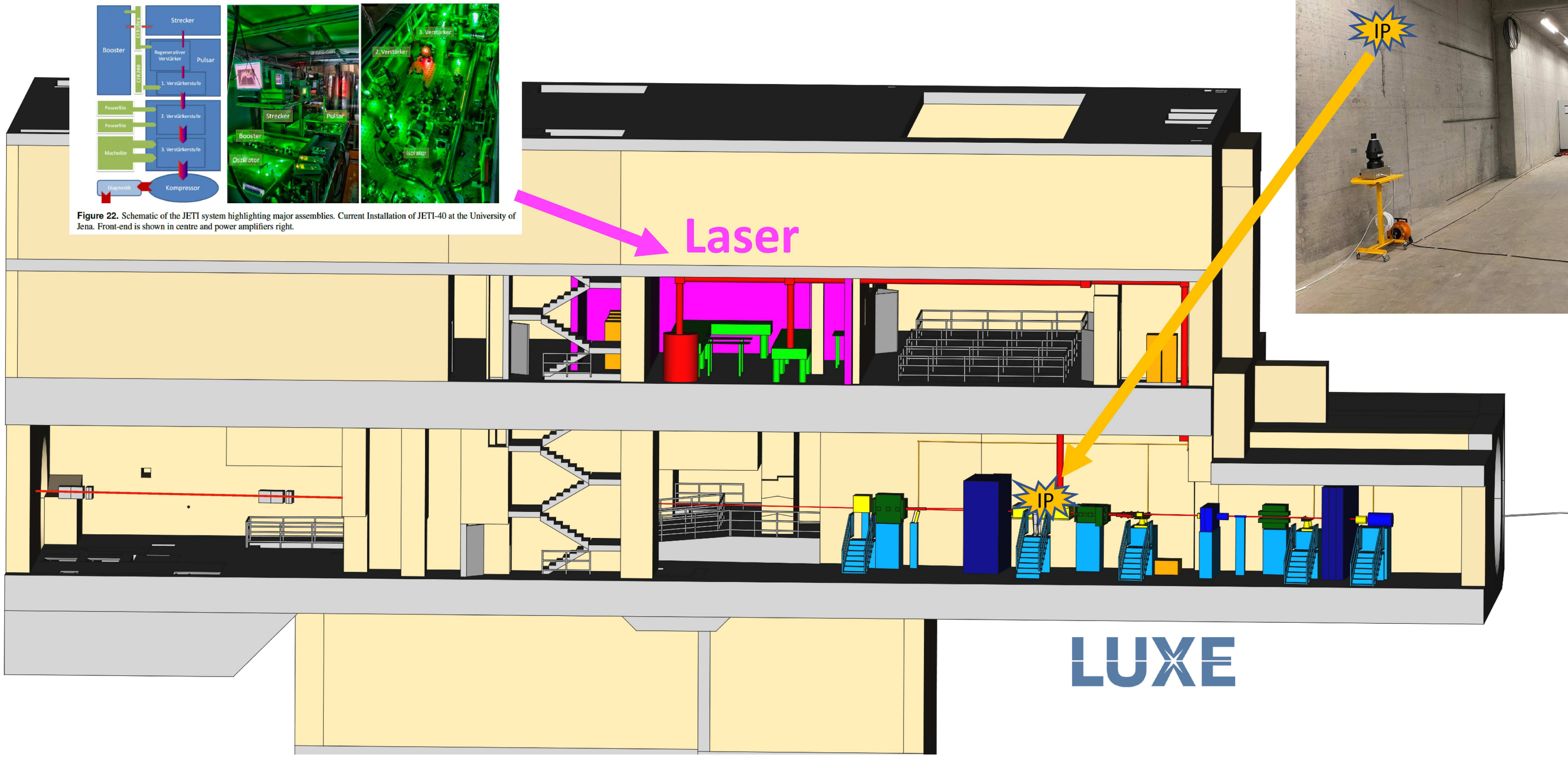
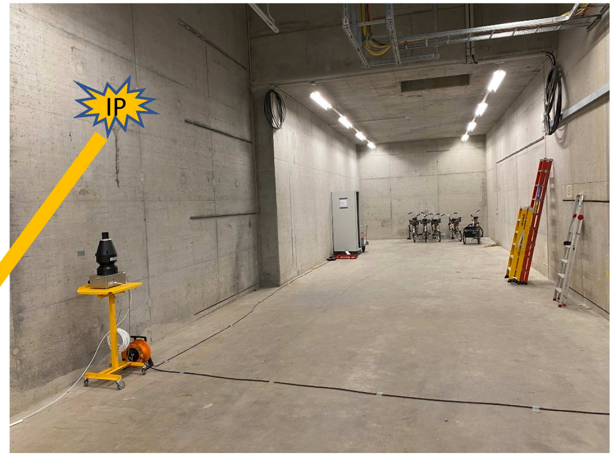
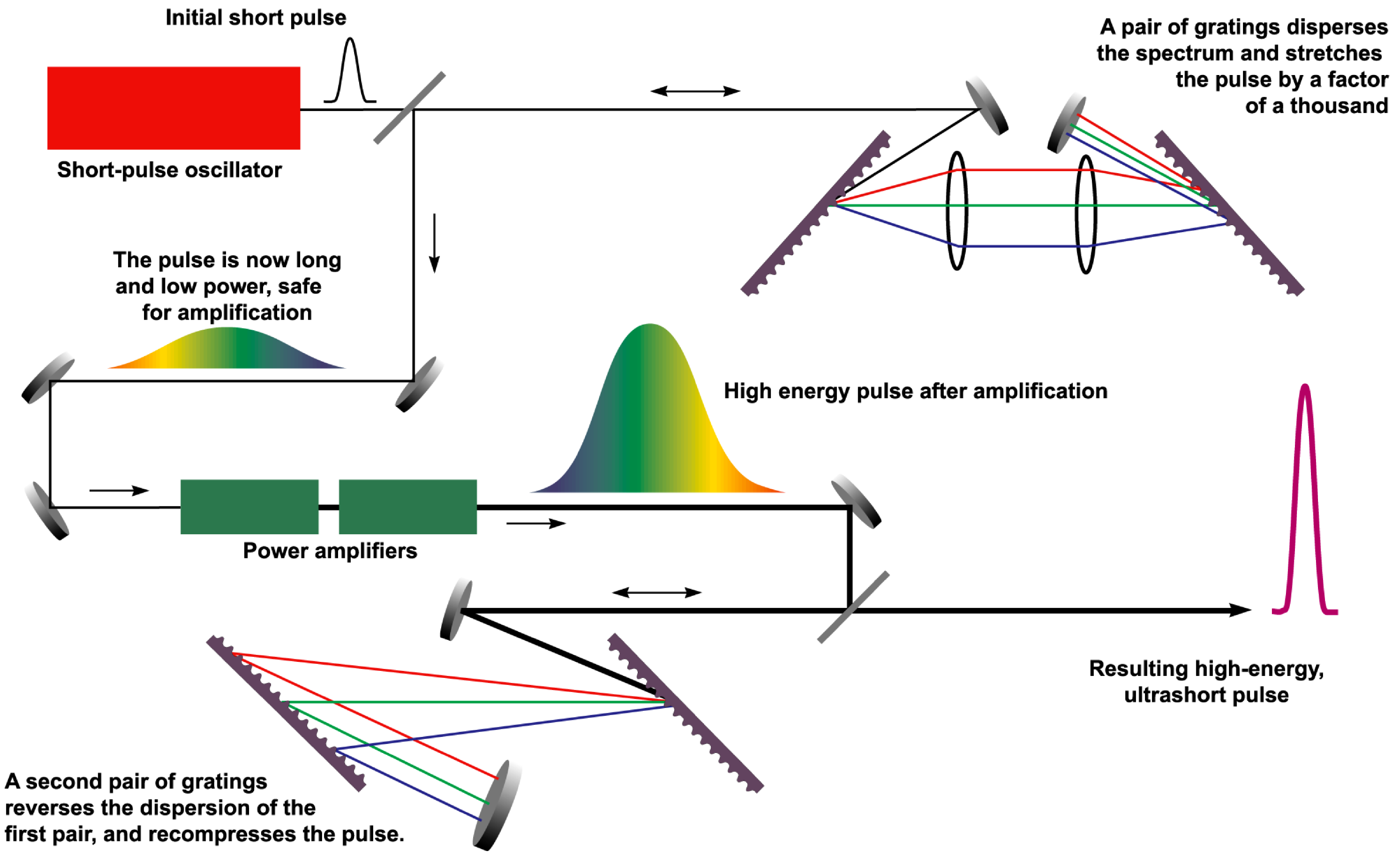


Figure 22. Schematic of the JETI system highlighting major assemblies. Current Installation of JETI-40 at the University of Jena. Front-end is shown in centre and power amplifiers right.

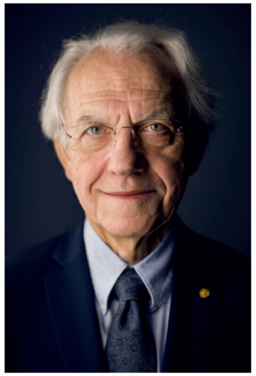


LUXE

ULTRA INTENSE LASER - CPA TECHNIQUE



- Use Chirped Pulse Amplification (CPA) technique
  - Half of the NP 2018 shared by Gerard Mourou and Donna Strickland
    - *"for their method of generating high-intensity, ultra-short optical pulses."*
  - Technological leap to reach very-high intensity with laser!



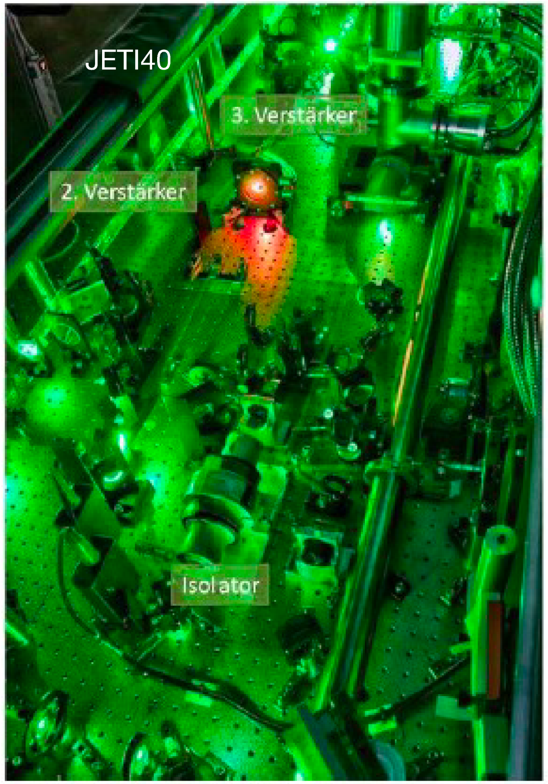
Gérard Mourou
Prize share: 1/4

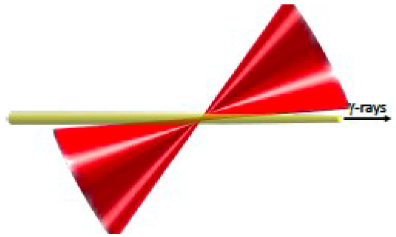
Donna Strickland
Prize share: 1/4

LASER IN LUXE

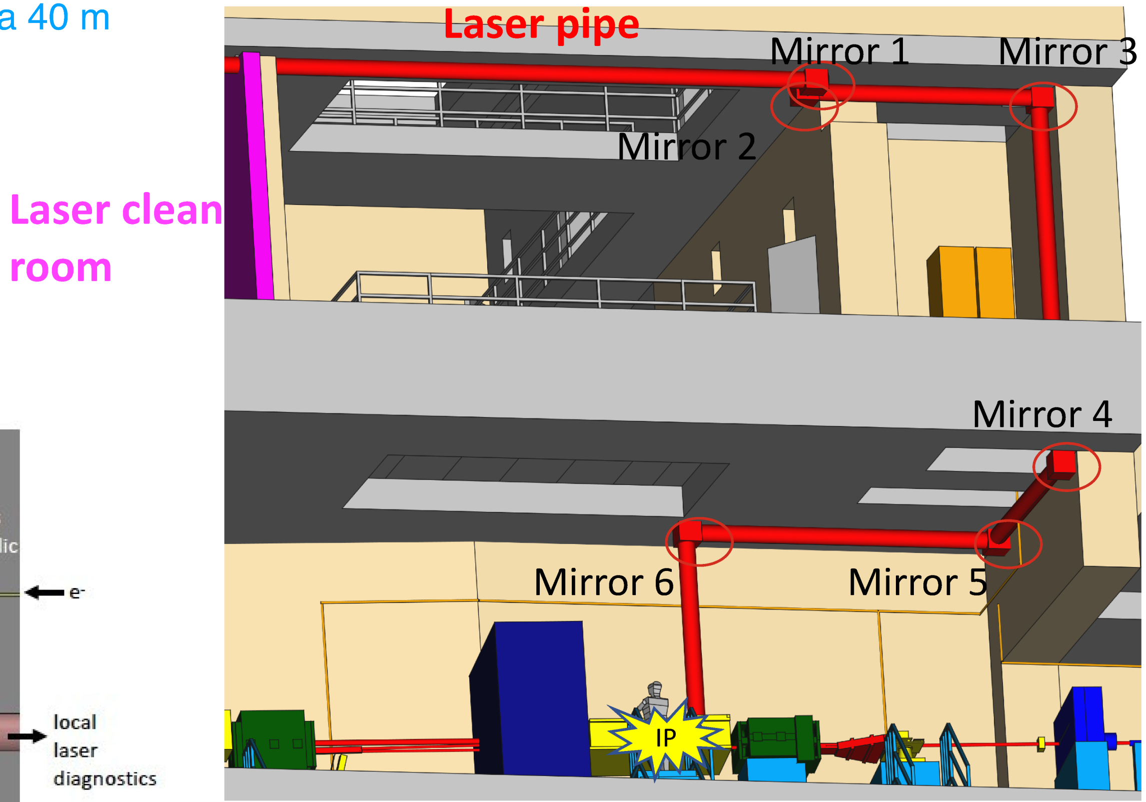
- Use Ti:Sa laser with 800 nm wavelength (E=1.55 eV).
- Energy focused strongly in both time and space to obtain high intensity.
- Two phases:
  - In phase 0 uses JETI40 (Jena custom 40 TW laser).
  - In phase I will use commercial 350 TW laser.
- Laser parameters:
  - Repetition rate: 1Hz.
  - Pulse length 30 fs

Parameter	Phase 0	Phase 0	Phase I
Laser power	40 TW		350 TW
Laser energy after compression [J]	1.2		10
Percentage of laser in focus [%]	50		
Laser focal spot size w_0 [μm]	>8	>3	>3
Peak intensity [10^{19} W/cm2]	1.9	13.3	120
Peak intensity parameter ξ	3.0	7.9	23.6
Peak quantum parameter X E_{beam}=16.5 GeV	0.56	1.5	4.5

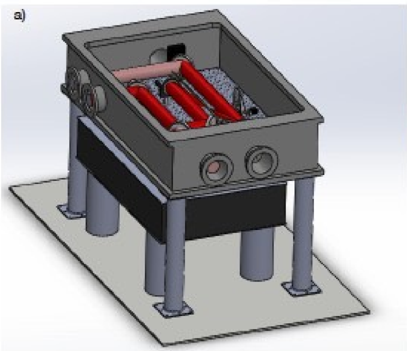


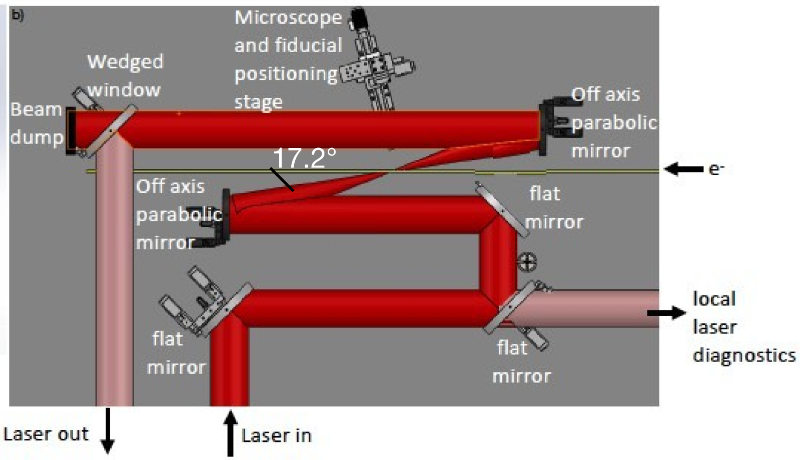


- Laser guided from laser clean room to Interaction Point (IP) via 40 m long pipe and six mirrors.

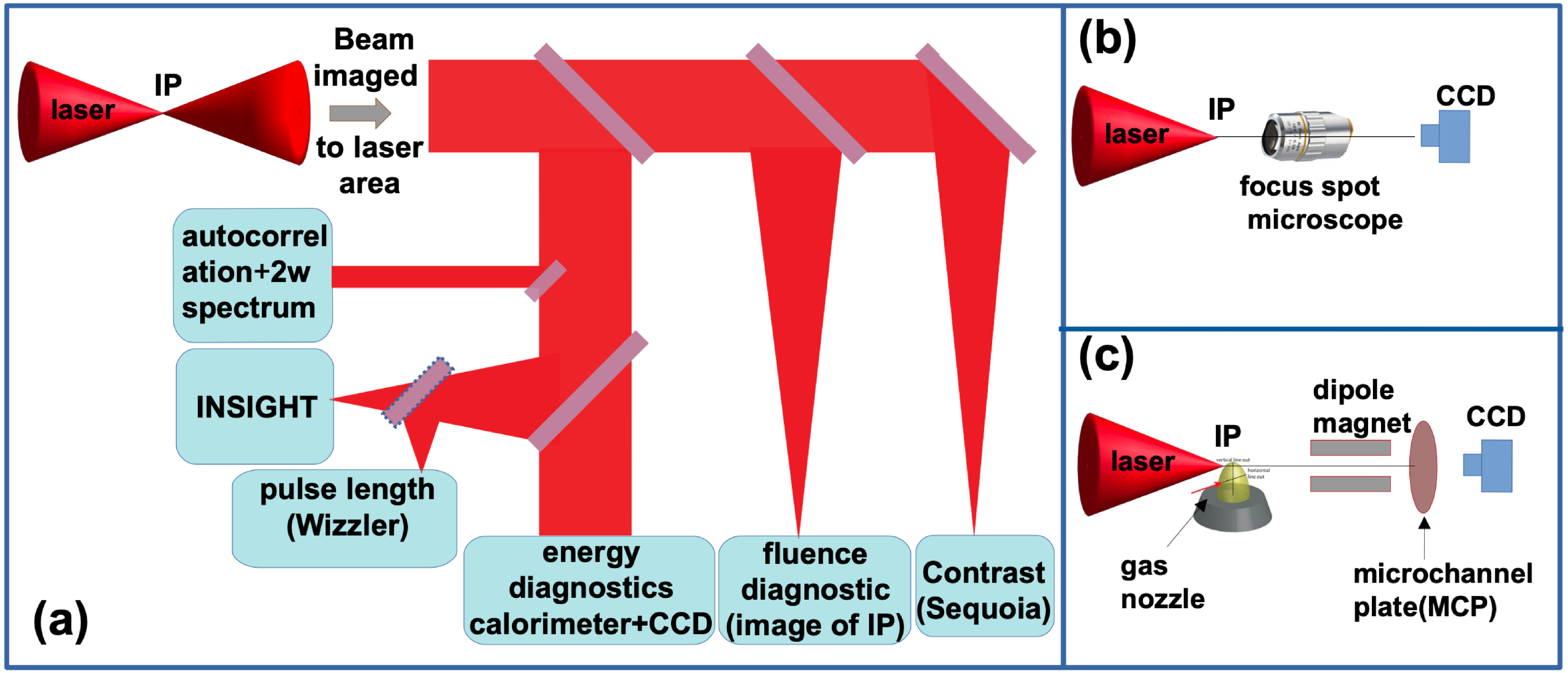


- Final focusing done just before IP in dedicated chamber:





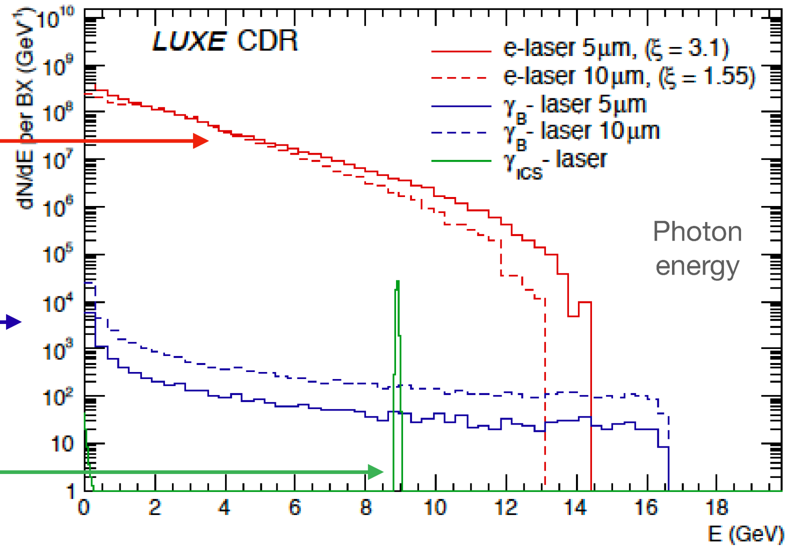
LASER DIAGNOSTICS

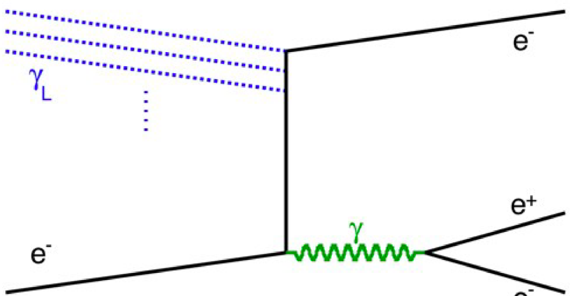


- Laser characterisation quantities: energy, pulse length, spot size
- many (partially redundant) measurements planned
  - Laser is not perturbed by e- beam allow multiple diagnostics
    - In IP chamber and back in laser clean room.
- Laser intensity uncertainty has a large impact on sensitivity
- goal: ≤ 5% uncertainty on Laser intensity, 1% shot-to-shot uncertainty

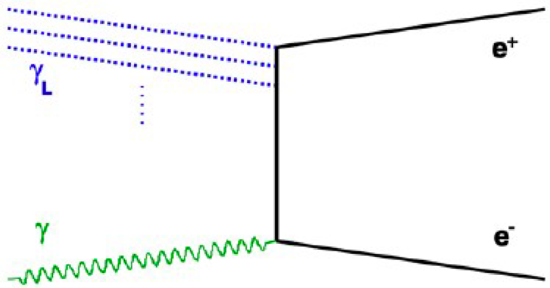
PAIR PRODUCTION MODES

- 3 methods to produce pairs, that allow to probe different regime:
  - Compton scattering with interaction between Compton photon and laser.
    - Largest rate.
      - e-laser mode
  - Bremsstrahlung photons produced upstream (with target).
    - Highest energy available.
      - gamma-laser mode.
  - Compton photon produced upstream.
    - Monochromatic photon source: E=9 GeV.
      - gamma-laser mode via Inverse Compton Scattering

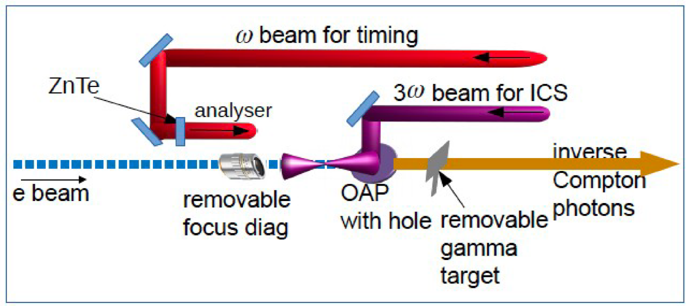


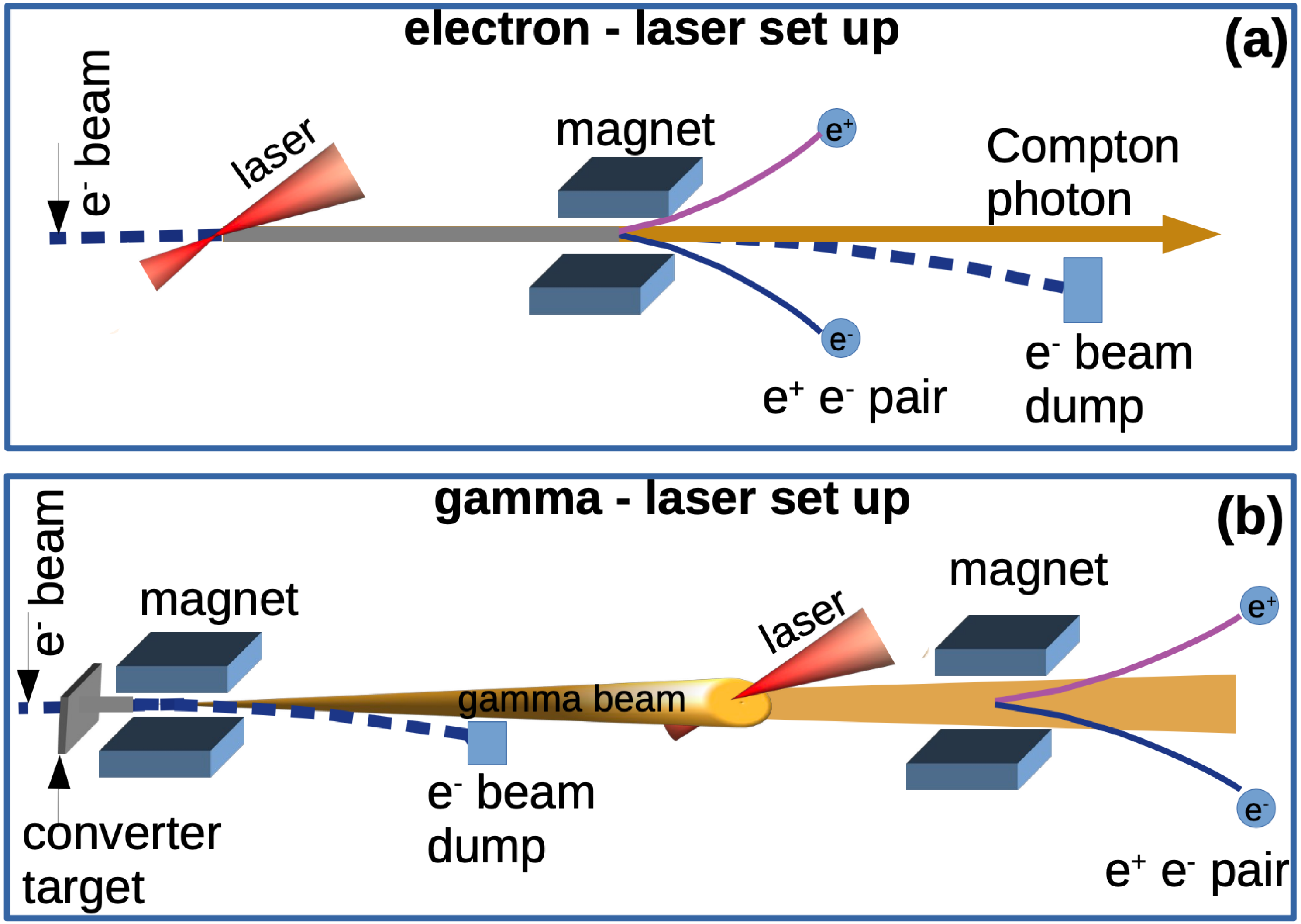


Trident

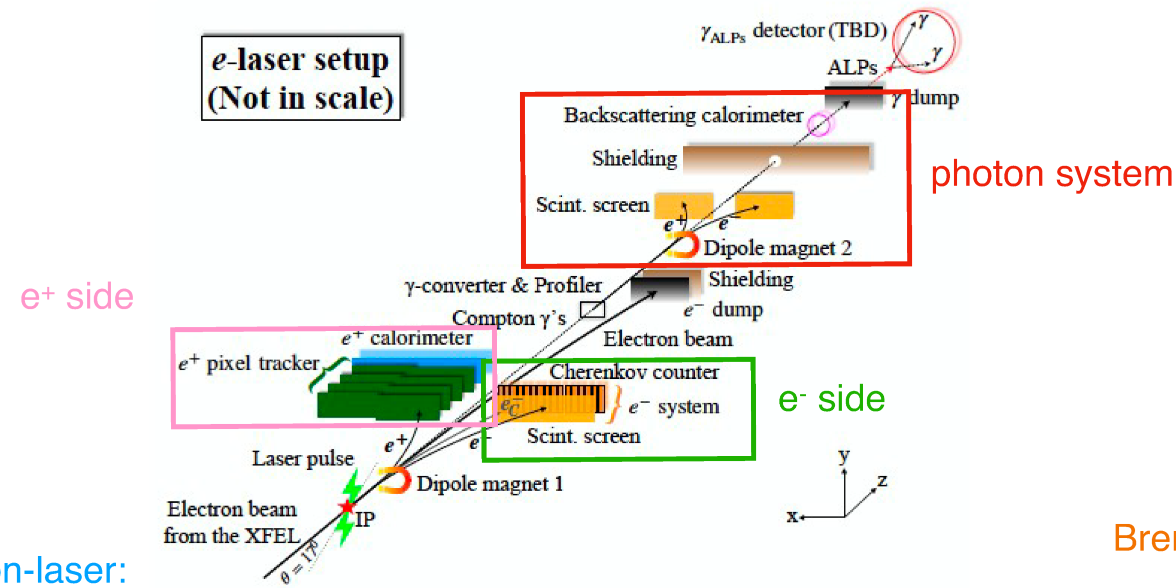


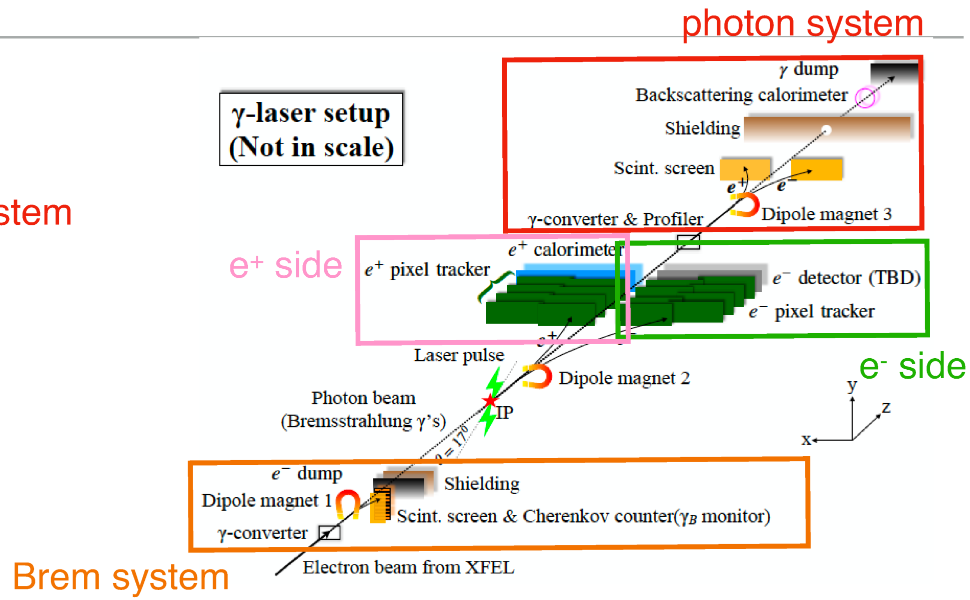
Breit-Wheeler



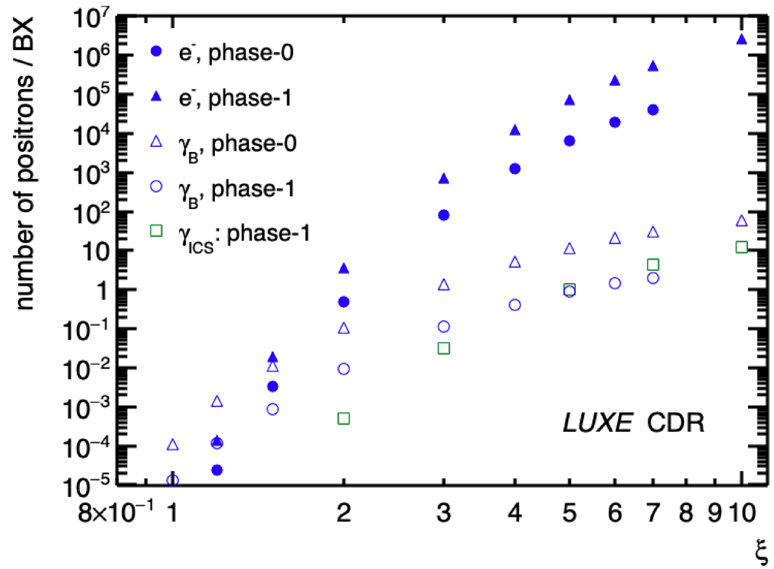

electron - laser set up
(a)
e- beam
laser
magnet
e+
Compton
photon
e-
e+ e- pair
e- beam
dump
gamma - laser set up
(b)
e- beam
magnet
laser
magnet
e+
gamma beam
e-
e- beam
dump
converter
target
e+ e- pair

RATES PAR BUNCH CROSSING





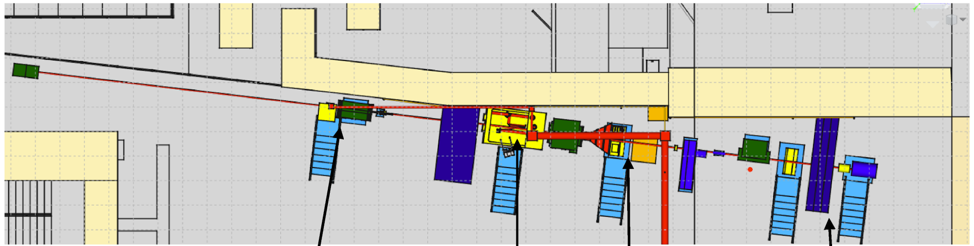
- Electron-laser:
  - Signal pairs created: 10^{-2} to 10^4.
  - Background particles flux and detectors used:
    - e⁻ side: up to 10^9 particles, Cherenkov, and scintillating screen.
    - e⁺ side: up to 10^3 particles, calorimeter and tracker.
- Gamma-laser:
  - Signal pairs created: 10^{-3} to 1.
  - Background particles flux and detectors used:
    - e⁻ side: up to 10 background particles, calorimeter and tracker.
    - e⁺ side: up to 10 particles, calorimeter and tracker.
    - Brem target: 10^6 particles, Cherenkov, and scintillating screen.
- In both setups: Photon detection system up to 10^9 photons to detect uses:
  - scintillating screen, beam profiler, backscattering calorimeter.

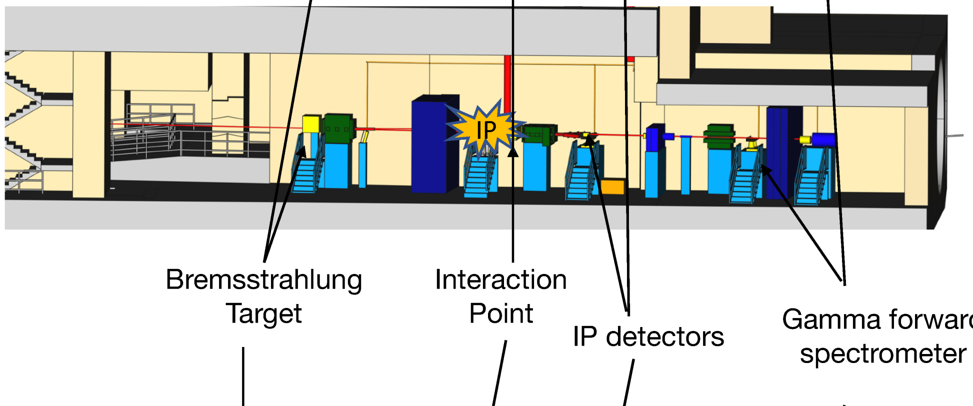


WHAT WILL IT LOOK LIKE?

CAD:

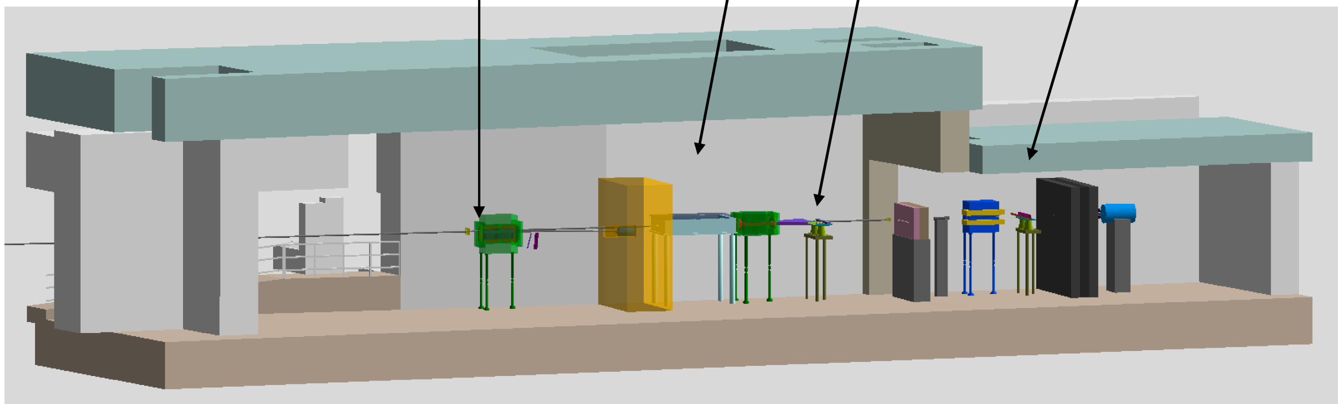
top view of experimental area



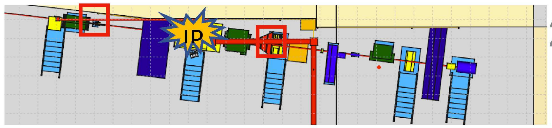


side views of experimental area

Full Geant4 simulation:

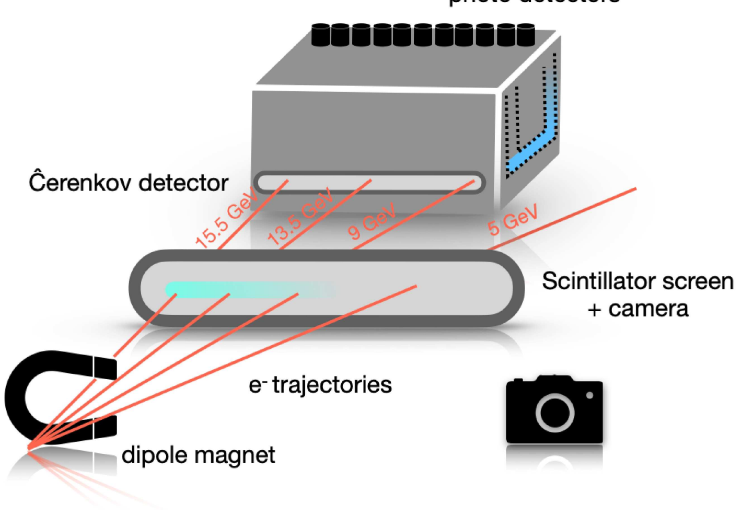


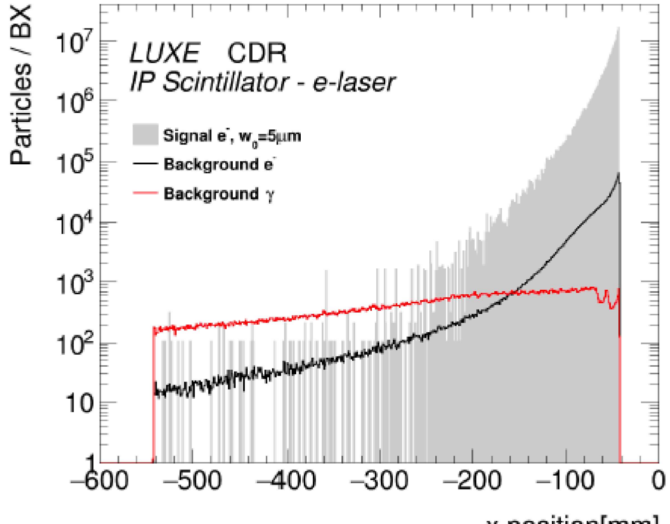
CHERENKOV AND SCINTILLATOR SCREEN (E-LASER: IP DETECTOR ELECTRON SIDE I GAMMA-LASER: BREM TARGET)



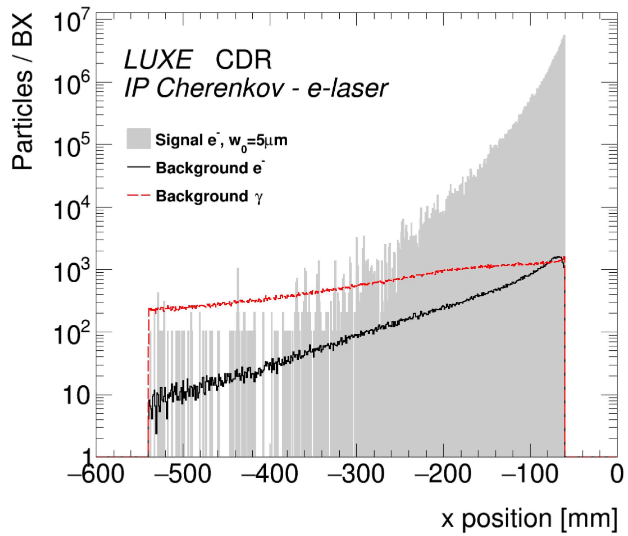
- Scintillator screen with camera:
  - Position of particles on screen determine energy (thanks to the magnetic field).
    - Signal/background ~100
      - Used for instance at AWAKE at CERN

- Cherenkov detector:
  - Developed for ILC polarimetry.
    - Use low refractive gas index (such as Ar) and optical filter to reduce light yield.
      - Fine segmentation (1.5mm) to resolve Compton edges
        - Signal/background>1000
        - Not sensitive to electron <20 MeV.



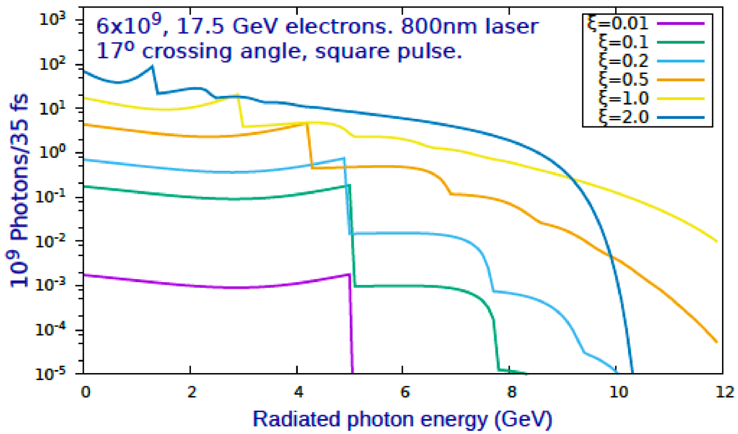


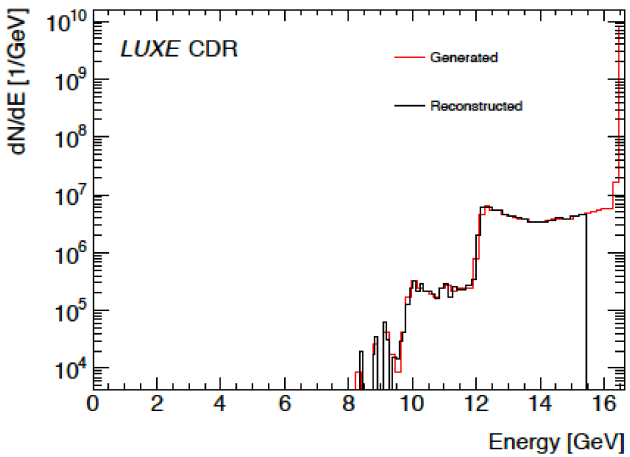
(a)

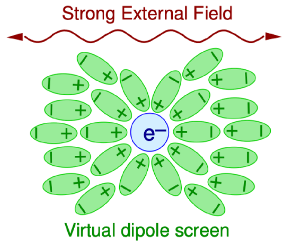


COMPTON EDGE SHIFT

- Need to measure Compton edges, as they will be shifted to lower energies in SFQED!

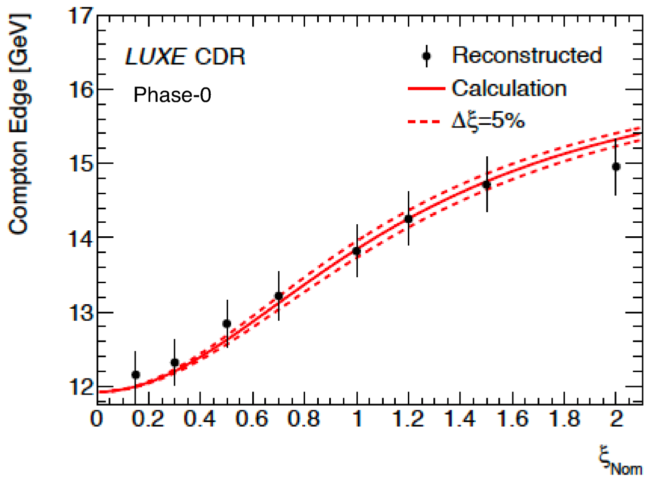


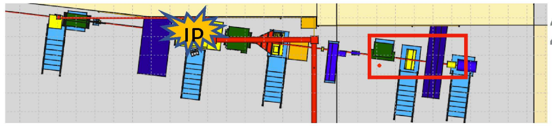




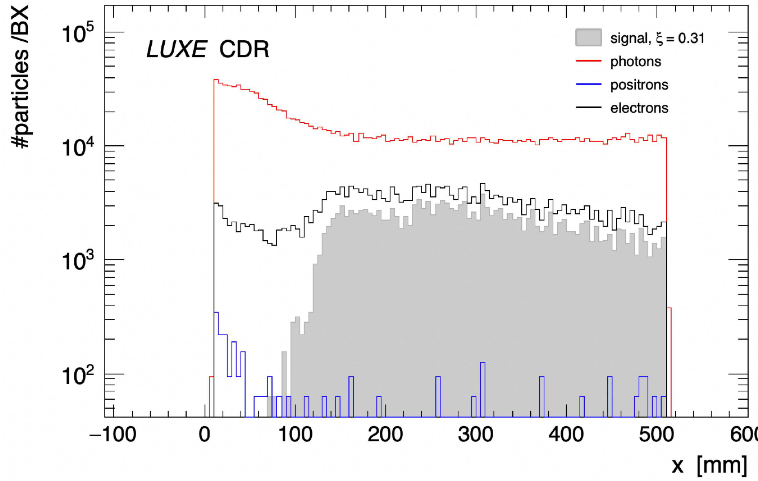
$$E_{\text{edge}} = E\left(1 - \frac{1}{1 + \frac{2E}{m_e c^2}}\right)$$

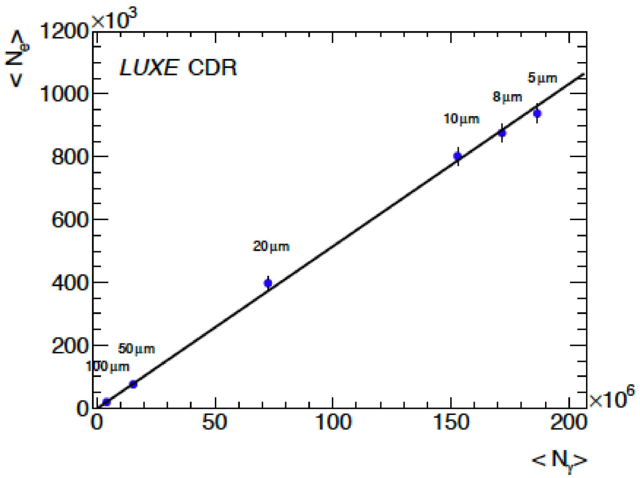
- Electron energy spectrum used to reconstruct Edges using **Finite Impulses Response Filter** (FIR) technique developed for SUSY-ILC search.
- Compare result to theory prediction in phase 0:

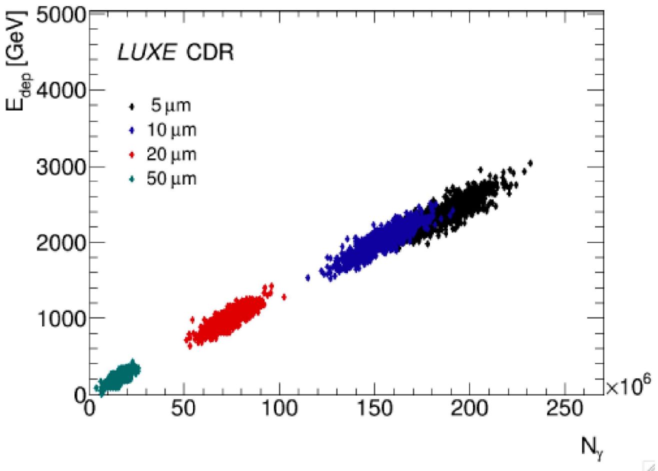


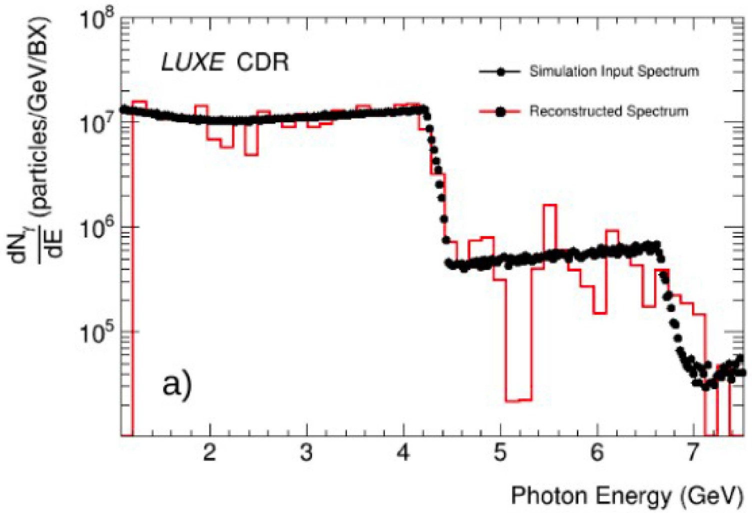


- Three detector technologies
  - Spectrometer with scintillator screens behind converter
    - Measure flux and energy spectrum.
      - Alternative way to reconstruct Compton edges!
  - Backscattering calorimeter using lead glass blocks from HERMES.
    - Measure flux.
  - Gamma profiler (sapphire sensors)
    - Measure location.
      - If use polarized laser, expect angular spectrum of photons to depend on ξ.

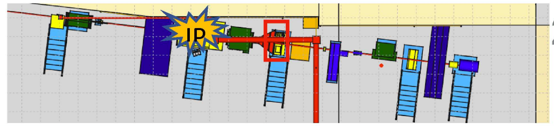




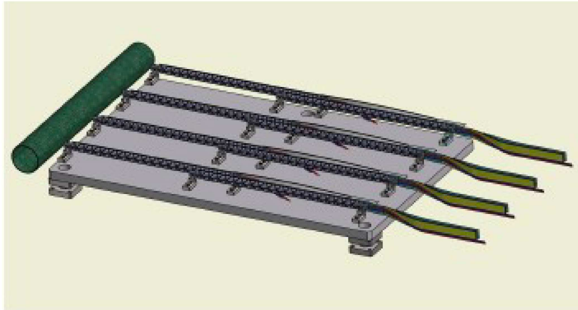


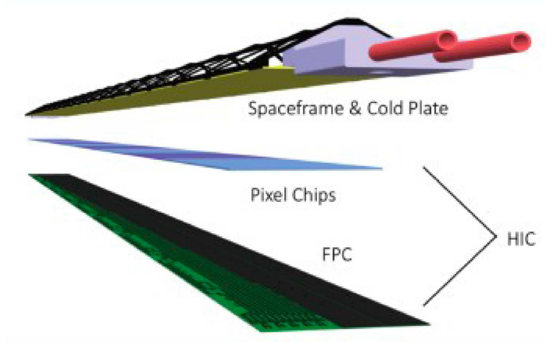


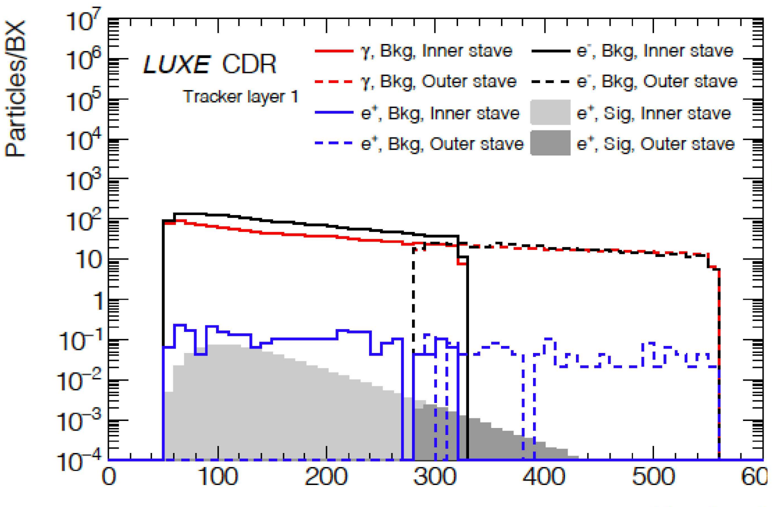
TRACKER (E-LASER: IP DETECTOR POSITRON SIDE | GAMMA-LASER: IP DETECTOR BOTH SIDES)



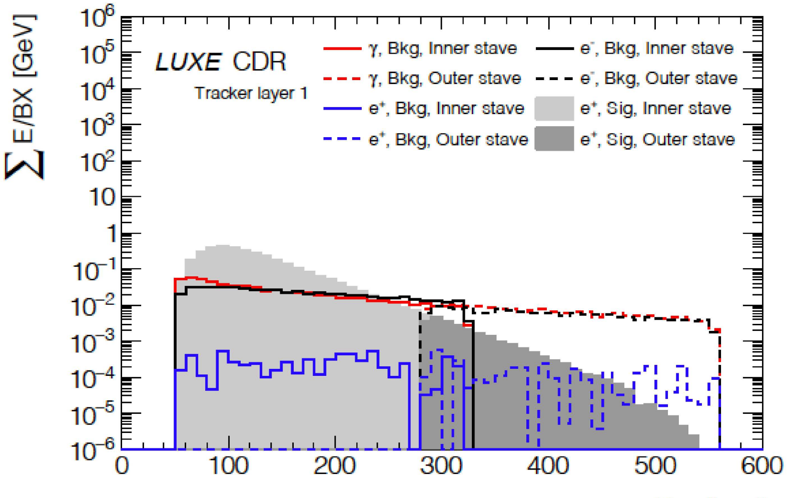
- Use four layers of ALPIDE silicon pixel sensors.
  - Developed for ALICE tracker upgrade.
    - Pitch size: 27 x 29 μm^2 => spatial resolution ~5 µm
- Using tracking algorithm:
  - Background: <0.1 event per bunch crossing
  - Good energy reconstruction



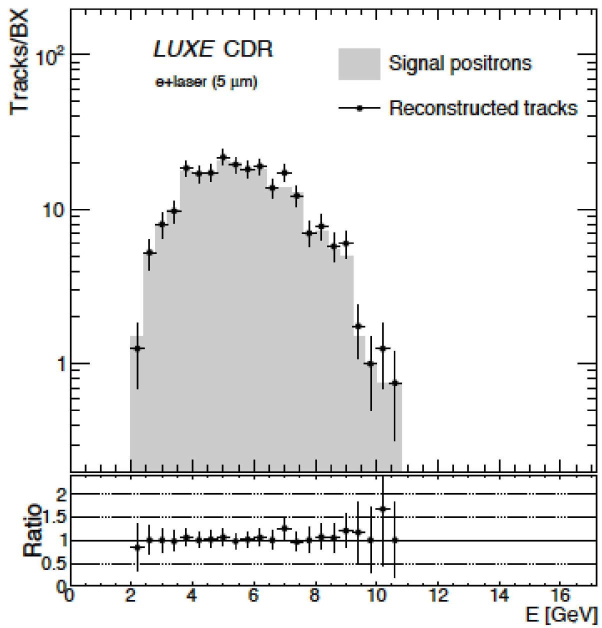


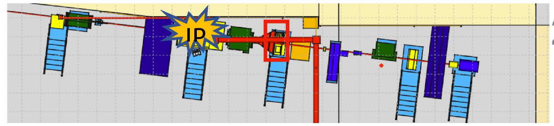


(a)

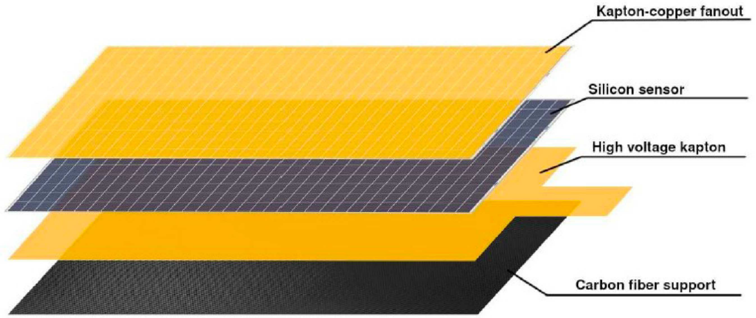


(c)

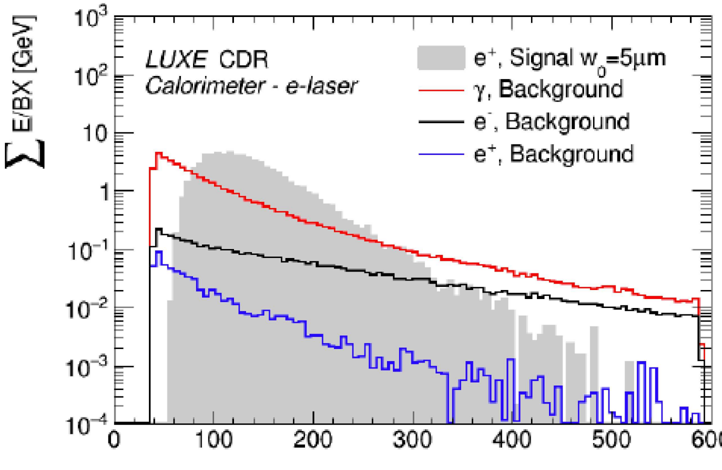




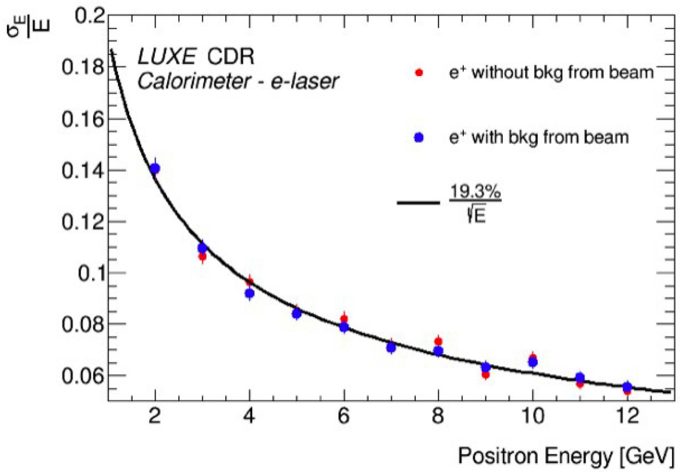
- High granularity Calorimeter developed for ILC FCAL
  - 20 layers of 3.5 mm thick tungsten plates
  - Silicon or GaAs sensors (5x5 cm² pads, 320 µm thick), Moliere radius 8 mm
  - Readout via FLAME ASIC (developed for FCAL)

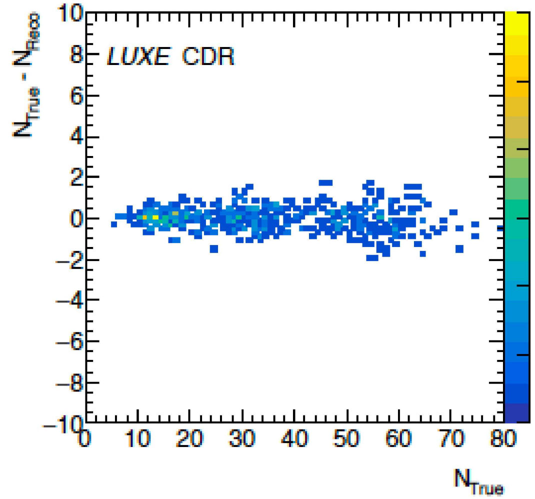


- Resolution:
  - Independent measure of energy via position and calorimetry => $N_{particle}$

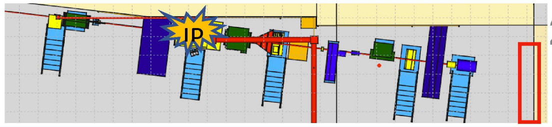


(b)

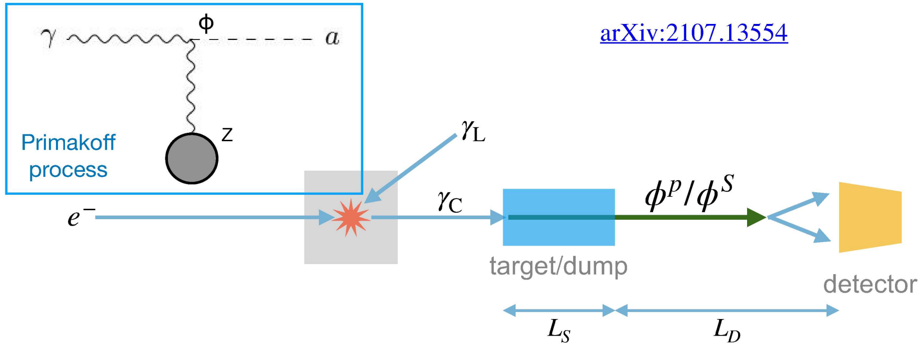




BSM PHYSICS? (DETECTOR TO BE PLACED AT THE END OF THE BEAMLINE)

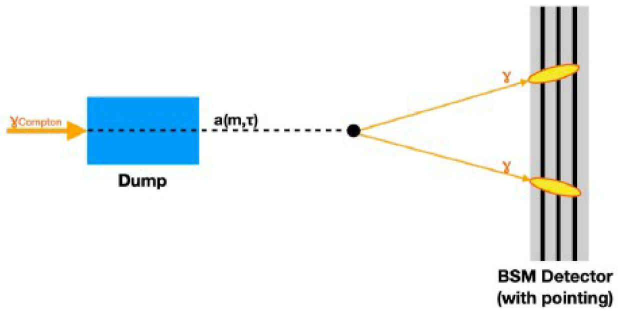


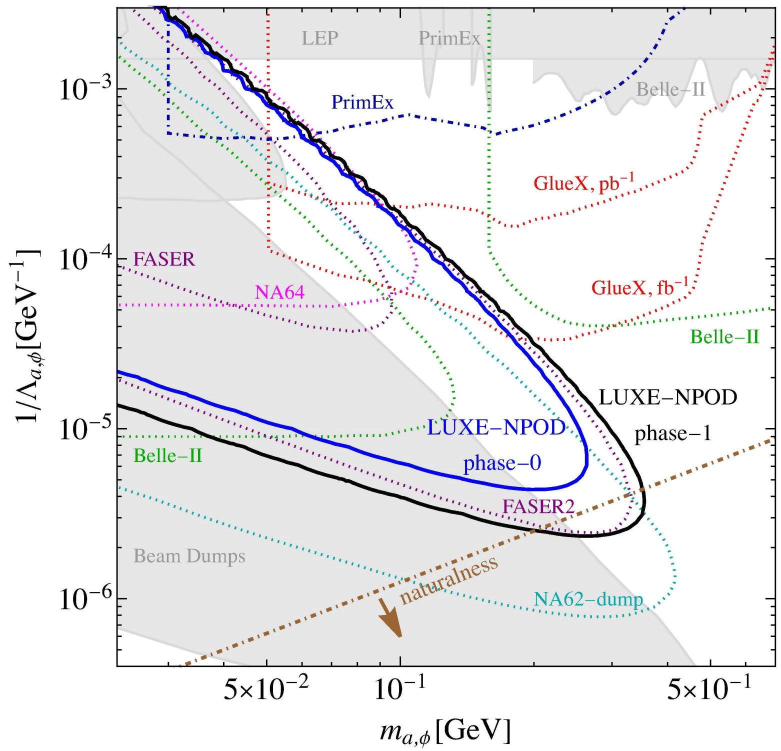
- Explore sensibility to BSM theories.
  - Axion-like particles (ALPs) produced in dump.
  - New neutral particles produced at IP.
  - Milli-charged particles



arXiv:2107.13554

- For ALPs:
  - sensitive to masses m(a)~100 MeV.
  - decay to photons after some lifetime **τ**.
  - Place detector behind dump.
  - Could use calorimeter with good pointing resolution to constrain decay point.



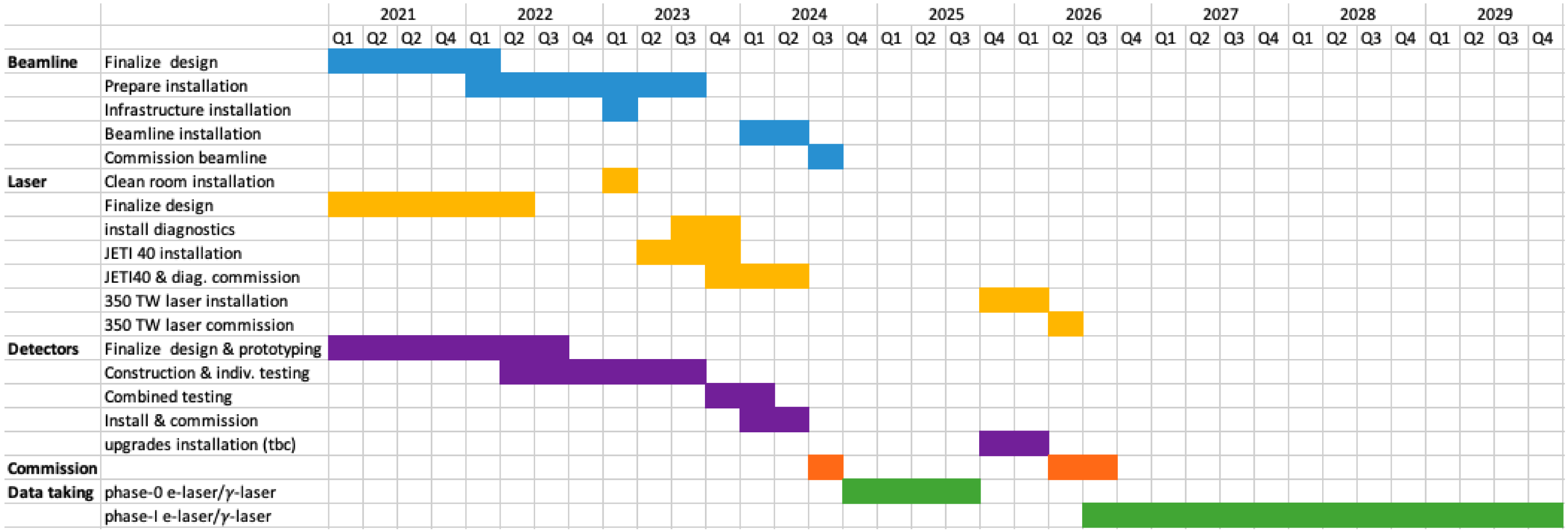


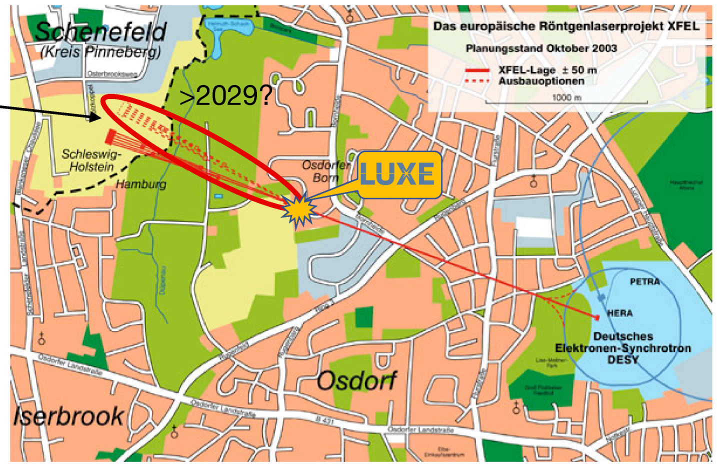
- First sensitivity show very competitive results!
  - After just 1 year of data.

ONE WORD ON THE PLANING

- CDR recently released.
  - Concept of the experiment endorsed by DESY directorate.
  - Under scrutiny of technical groups.
  - Working toward TDR.

- Experiment has to be installed in XS1 by 2024.
  - Long shutdown of the XFEL.
  - Only moment where the beam-line can be installed.
  - Data taking to start in 2024.
    - Start with e-laser.
    - γ-laser to start in 2025.
    - Laser upgrade (350 TW) in 2026.
    - Run until XFEL want to construct new fan (2029 for now).



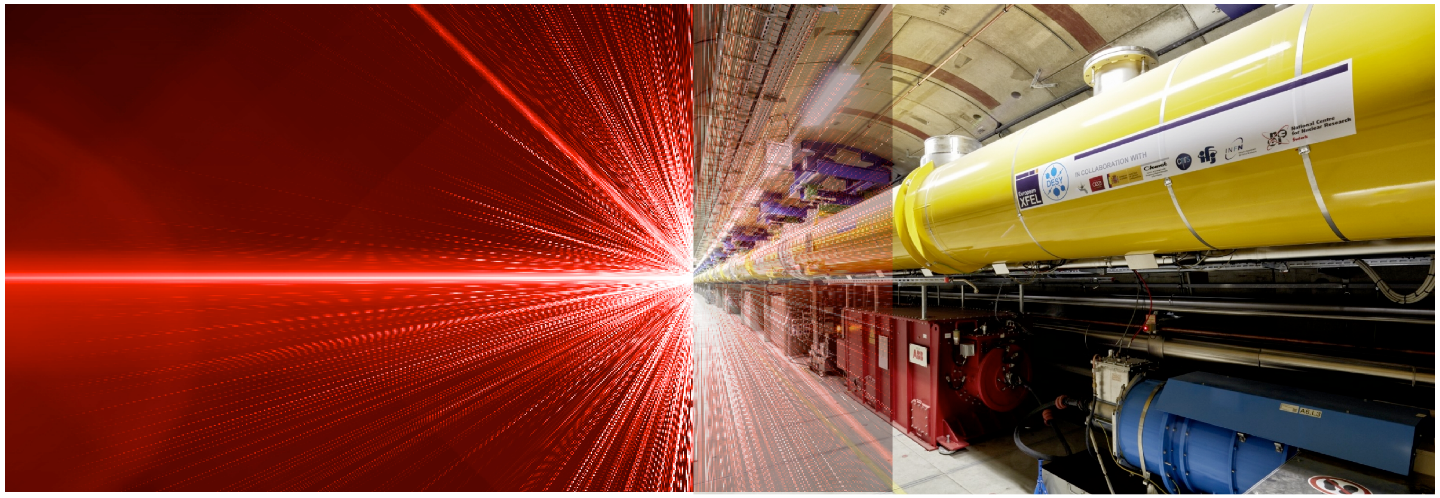


- In parallel of review continue detector R&D, and experiment planification.
  - Plan to perform multiple test-beam campaign in the future.

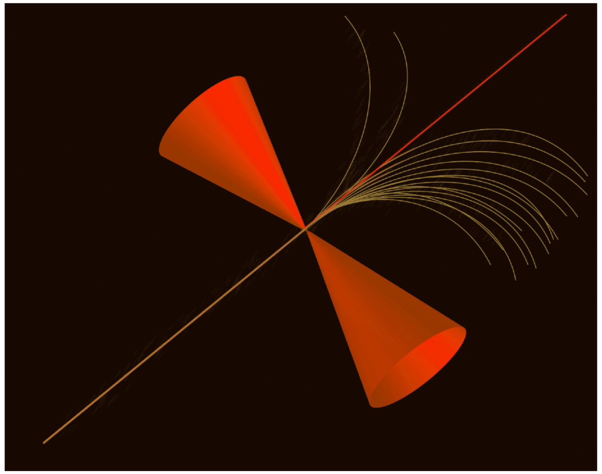
- The LUXE experiment will allow to measure QED in uncharted regime!
  - Might expect some surprises there!

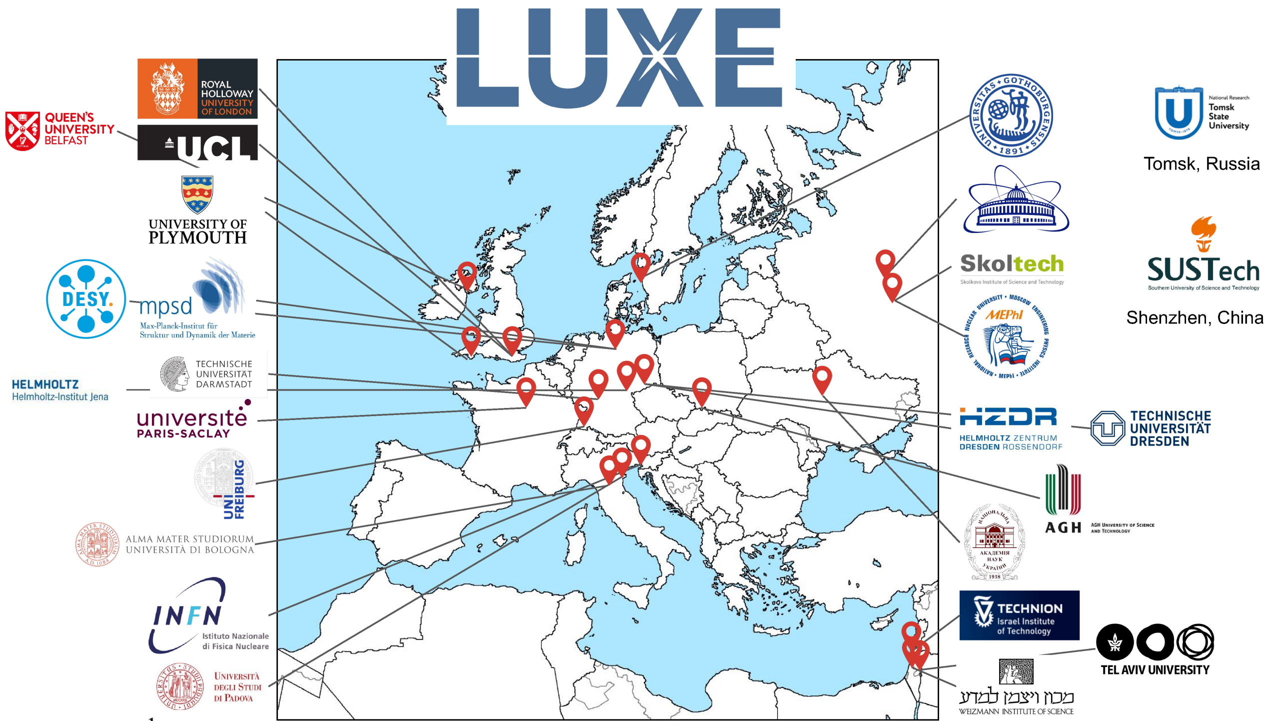
- Synergy experiment between particle physics and Laser physics!
  - Experiment is planing to function on established detector technology to cope with challenging rate of particles to measure!
    - 10^{-2} to 10^{9}.
  - Innovative development for Laser control system, and Laser diagnostics underway.

- LUXE CDR is now out, allowing the review of this exciting experiment!
    - Still lot of works to do before the experiment can be running in 2024.



THANK YOU FOR YOUR ATTENTION!





Conceptual Design Report for the LUXE Experiment

H. Abramowicz[1], U. Acosta[2,3], M. Altarelli[4], R. Aßmann[5], Z. Bai[6,7], T. Behnke[5], Y. Benhammou[1], T. Blackburn[8], S. Boogert[9], O. Borysov[5], M. Borysova[5,10], R. Brinkmann[5], M. Bruschi[11], F. Burkart[5], K. Büßer[5], N. Cavanagh[12], O. Davidi[6], W. Decking[5], U. Dosselli[13], N. Elkina[3], A. Fedotov[14], M. Firlej[15], T. Fiutowski[15], K. Fleck[12], M. Gostkin[16], C. Grojean[*5], J. Hallford[5,17], H. Harsh[18,19], A. Hartin[17], B. Heinemann[†5,20], T. Heinzl[21], L. Helary[5], M. Hoffmann[5,20], S. Huang[1], X. Huang[5,15,20], M. Idzik[15], A. Ilderton[21], R. Jacobs[5], B. Kämpfer[2,3], B. King[21], H. Lahno[10], A. Levanon[1], A. Levy[1], I. Levy[22], J. List[5], W. Lohmann[‡5], T. Ma[23], A.J. Macleod[21], V. Malka[6], F. Meloni[5], A. Mironov[14], M. Morandin[13], J. Moron[15], E. Negodin[5], G. Perez[6], I. Pomerantz[1], R.Pöschl[24], R. Prasad[5], F. Quéré[25], A. Ringwald[5], C. Rödel[26], S. Rykovanov[27], F. Salgado[18,19], A. Santra[6], G. Sarri[12], A. Sävert[18], A. Sbrizzi[§28], S. Schmitt[5], U. Schramm[2,3], S. Schuwalow[5], D. Seipt[18], L. Shaimerdenova[29], M. Shchedrolosiev[5], M. Skakunov[29], Y. Soreq[23], M. Streeter[12], K. Swientek[15], N. Tal Hod[6], S. Tang[21], T. Teter[18,19], D. Thoden[5], A.I. Titov[16], O. Tolbanov[29], G. Torgrimsson[3], A. Tyazhev[29], M. Wing[5,17], M. Zanetti[13], A. Zarubin[29], K. Zeil[3], M. Zepf[18,19], and A. Zhemchukov[16]

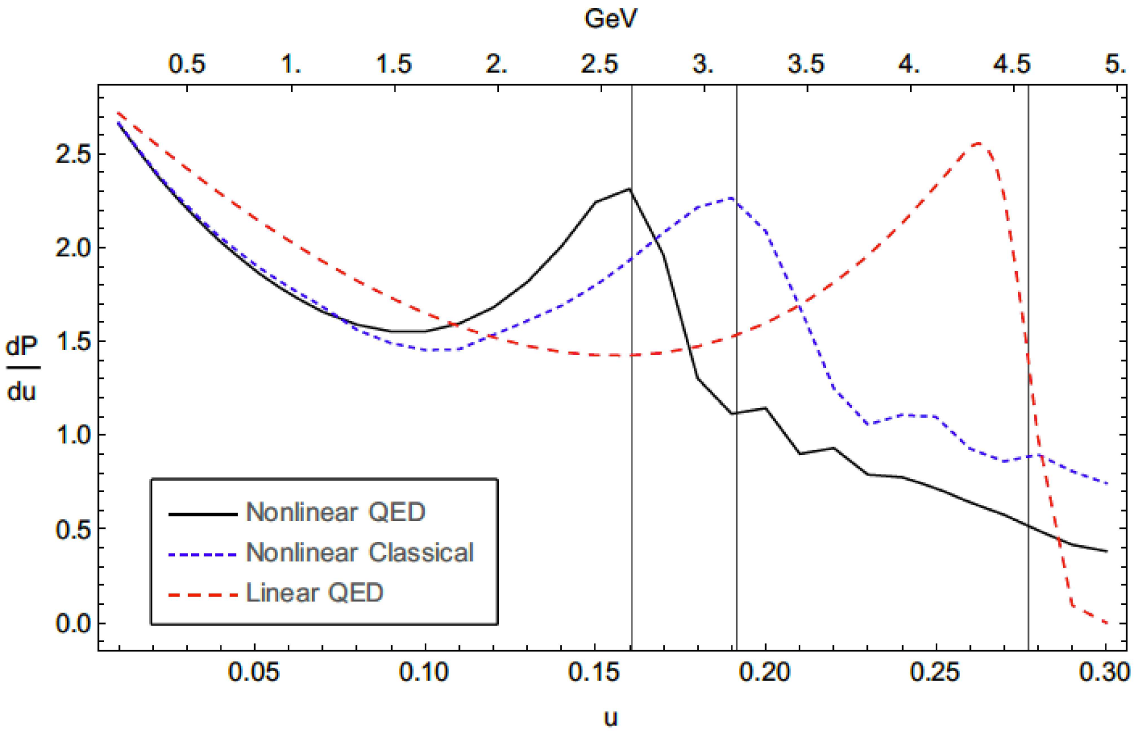
CDR, accepted by European Physics Journal ST:
https://arxiv.org/abs/2102.02032

BACK UP

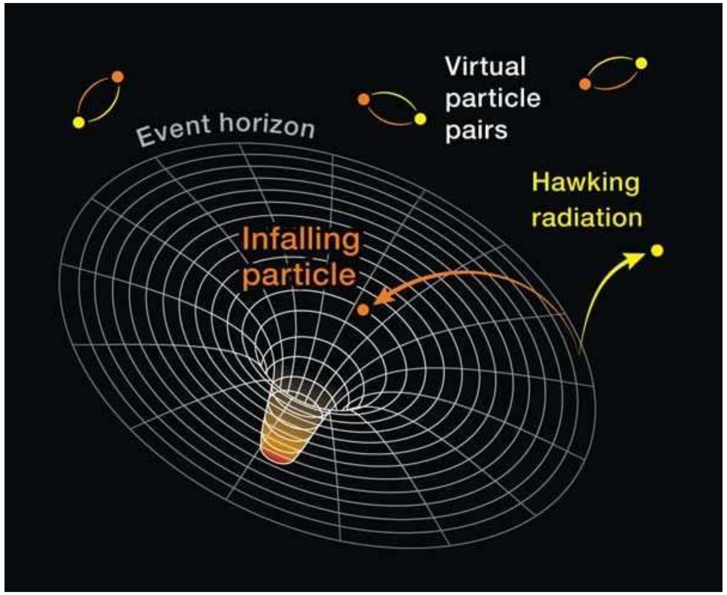
PARAMETERS

	Theory Parameter	Definition	Range accessed in LUXE phase-0	phase-1
ξ	Classical non-linearity parameter	$\xi = \frac{m_e}{\omega_L} \frac{\mathcal{E}_\mathrm{L}}{\mathcal{E}_\mathrm{cr}}$	≤ 6	≤ 19
η_i	Energy parameter	$\eta_i = \frac{\omega_L \varepsilon_i}{m_e^2}(1+\beta\cos\theta)$	$\eta_i \leq 0.2$	
χ_i	Quantum non-linearity parameter	$\chi_i = \frac{\varepsilon_i}{m_e} \frac{\mathcal{E}_\mathrm{L}}{\mathcal{E}_\mathrm{cr}}(1+\beta\cos\theta)$	≤ 1	≤ 3

COMPTON EDGES



BLACK HOLE EQUIVALENT



LUXE may be "the closest we can get" to probing Hawking radiation in the lab

LASER STABILITY

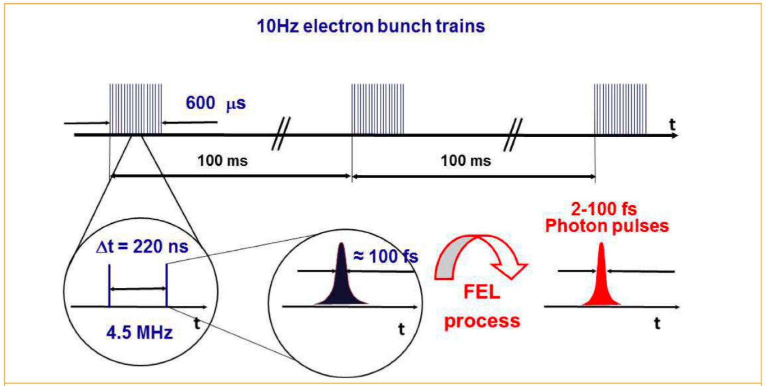
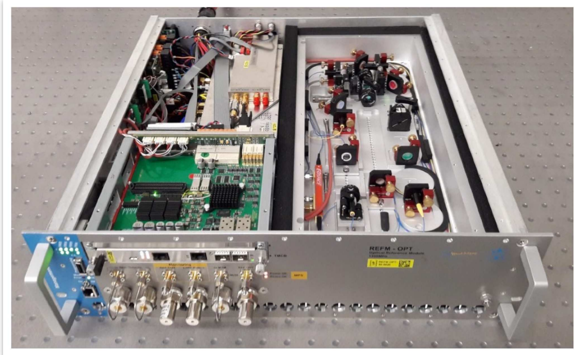


Figure 1: X-ray burst structure at the European X-ray free electron laser.



- **LOI Luxe requirements:**
  - 35 fs laser pulse width
  - 130 fs electron pulse length
- **machine (electrons) stability**

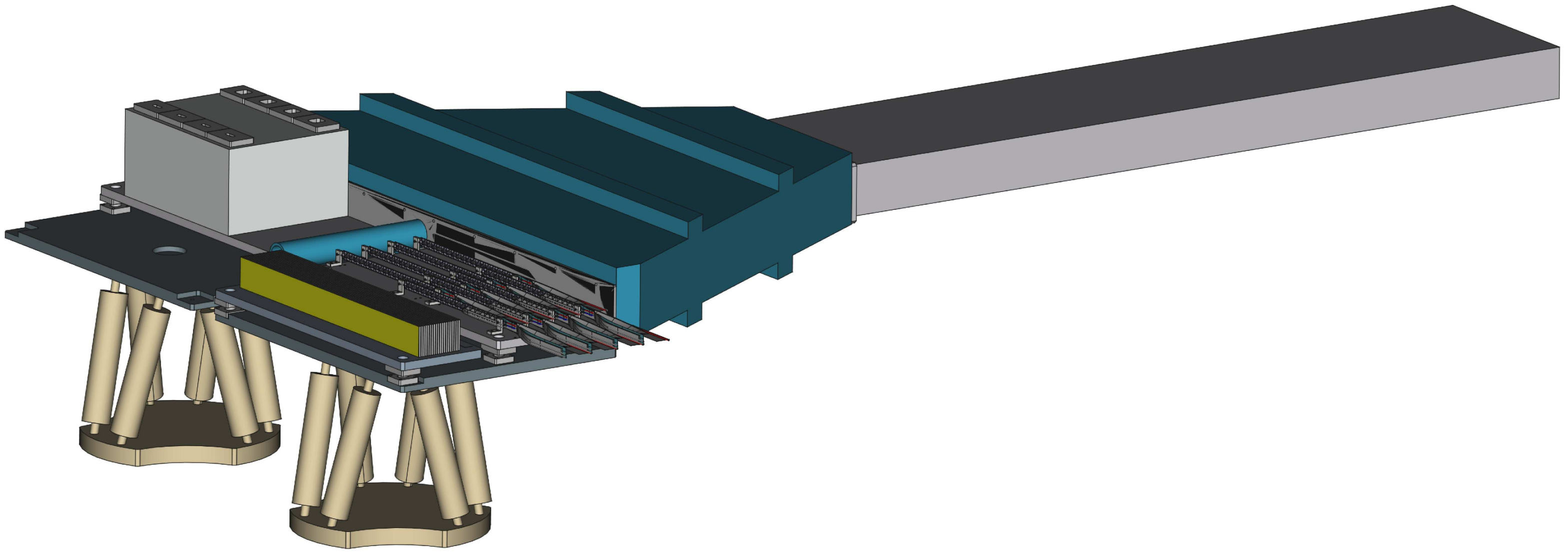
→ BAM diagnostics & feedback, last BAM at end of LINAC (1932m) → **10-15 fs** (rms)

- **laser oscillator stability**

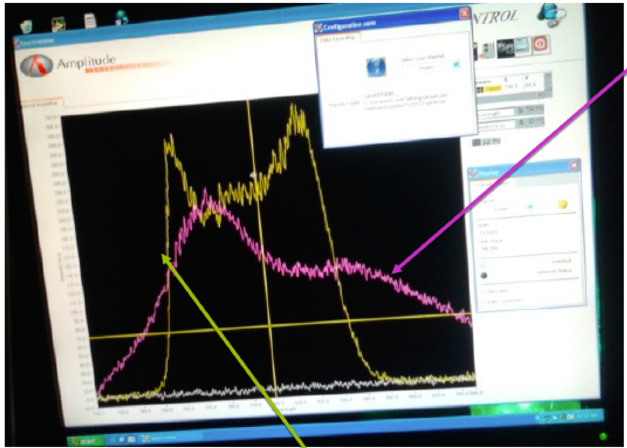
→ optical synchronization → **<10 fs** *(rms)*

Parameter	Value XFEL.EU	Assumed Values for LUXE
Beam Energy [GeV]	$\lesssim 17.5$	16.5
Bunch Charge [nC]	$\lesssim 1.0$	0.25
Number of bunches/train	2700	1
Repetition Rate [Hz]	10	10
Spotsize at the IP [μm]	–	5
Bunch length [μm]	30–50	30–50
Normalised projected emittance [mm mrad]	1.4	1.4

- **laser stability**
  - amplification stages → additional drift measurement and compensation recommended!
  - beam transport to IP (mainly drifts) → option: additional fiber link to IP for drift measurement and compensation



LASER



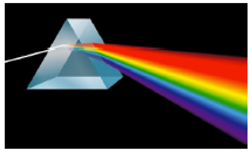
- Oscillator spectrum, >100nm bandwidth

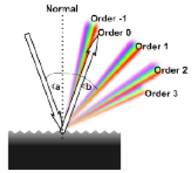
$$\Delta\tau \propto \frac{1}{\Delta\lambda}$$

- This implies that larger the bandwidth, shorter is the pulse length!

- Spectrum after amplification-70nm,
- This is the spectrum going in the compressor

- Typical set up involves dispersive elements like prism or grating





- In the Stretcher, basic idea is to delay the frequency components (eg red and blue) with respect to each other. This is done by adjusting their optical path using geometry of the grating/prism

- Compressor is the reverse of the stretcher