The LUXE - Laser und XFEL Experiment

Era of strong fields QED

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Outlook

Physics Motivation

- Introduction: Schwinger process
- Strong fields non-perturbative QED

The LUXE Project at DESY

- XFEL Accelerator and Laser
- Particle Detection and MC Simulation
- Summary/Conclusions

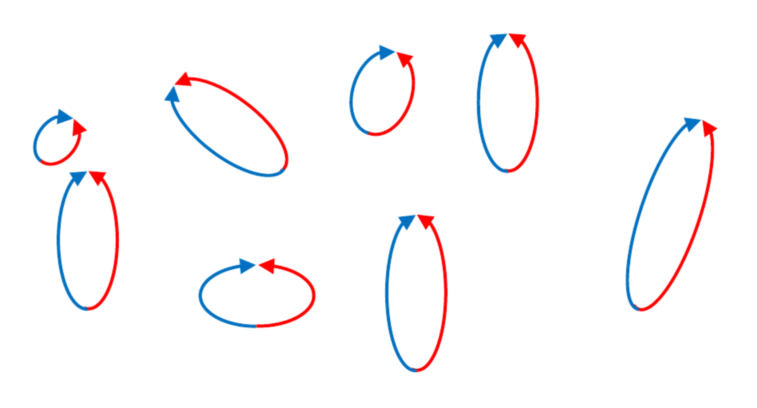
based on

- *Letter of Intent for the LUXE Experiment*, arXiv:1909.00860v1
- Beate Heinemann : *Proposal for a new experiment using a Laser and XFEL to test quantum physics in the strong-field regime*,
  DESY Colloquium, August 27th and 28 th 2019.

The Void (The Nothing)

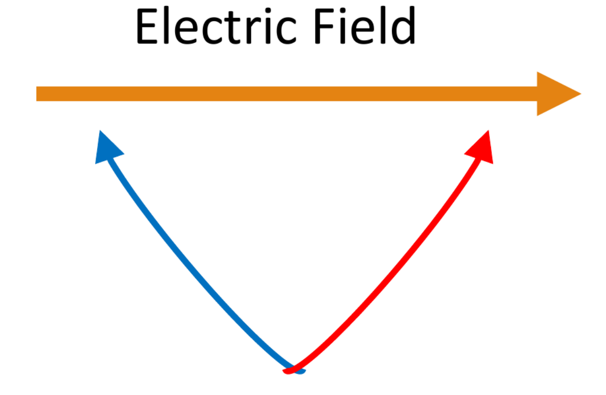
- long exposure time

The virtual Void



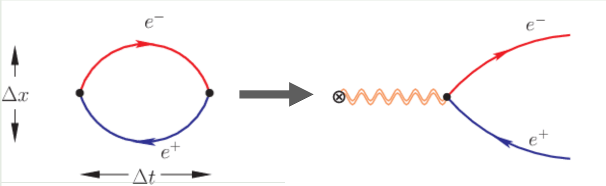
- short exposure time: internal life of quantum vacuum

The Something



- opening of the virtual loop in the strong field
- production of e^+e^- pairs
  by field-induced tunneling out of the vacuum

Schwinger effect



- the electric force: $F = e\mathcal{E}$
- energy to separate the e^+e^- pair: $E = Fd_{min}$
- Heisenberg:
  $\Delta t \geq \frac{\hbar}{\Delta E} \rightarrow \Delta t_{min} = \frac{\hbar}{2mc^2} \rightarrow d_{min} = 2c\Delta t_{min} = \frac{\hbar}{mc} = \lambda_c$
- virtual pair becomes real if: $E = Fd_{min} = \frac{\hbar e\mathcal{E}}{mc} > 2mc^2$
- possible if: $\mathcal{E} > \frac{2m^2c^3}{\hbar e} = 2\mathcal{E}_{cr} \rightarrow$ critical field $(1.3 \cdot 10^{18}\,\mathrm{V/m})$
- $P \sim \exp\left(-\frac{d}{\lambda_c}\right) = \exp\left(-2\frac{m^2c^3}{\hbar e\mathcal{E}}\right) = \exp\left(-2\frac{\mathcal{E}_{cr}}{\mathcal{E}}\right)$
  (NB.: full calculation: $2 \rightarrow \pi$)

Schwinger effect

Schwinger pair production in a constant electric field:

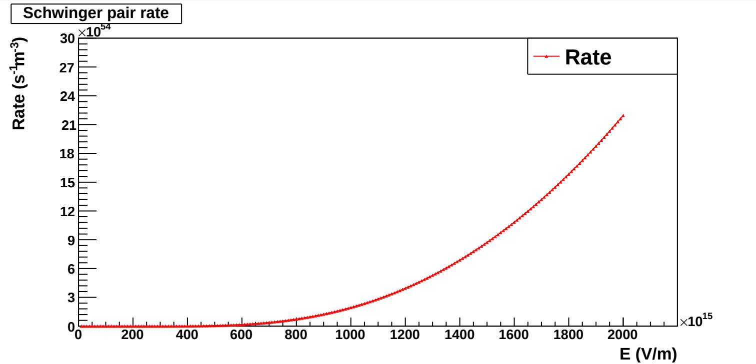
$$\Gamma = \frac{\mathrm{d}N}{\mathrm{d}^3x\mathrm{d}t} = \frac{(e\mathcal{E})^2}{4\pi^3 c\hbar^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\mathrm{e}^{-\frac{\pi m_e^2 c^3 n}{e\mathcal{E}\hbar}} = \frac{(e\mathcal{E})^2}{4\pi^3 c\hbar^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\mathrm{e}^{-\frac{\pi n\mathcal{E}_{cr}}{\mathcal{E}}},$$

where:

- Γ - rate per unit volume,
- $\mathcal{E}$ - electric field, $\mathcal{E}_{cr}$ - critical electric field,
- m_e - electron mass,
- e - electron charge
- NB.: this is exact solution, not perturbative (order α^n) approximation

J. Schwinger:
"On Gauge Invariance and Vacuum Polarisation", Phys. Rev. **82** (1951) 664.

Schwinger pair rate



- first term only
- in SI units: $\sim 10^{55}$ per sec. per m^3 for $\mathcal{E} \sim \mathcal{E}_{cr}$
- very fast "discharging" or electric field !

Precursors: Heisenberg, Euler and Sauter

“Folgerungen aus der Diracschen Theorie des Positrons”

Zeitschrift für Physik, **98** (1936) pp. 714-732.

Folgerungen aus der Diracschen Theorie des Positrons.

Von **W. Heisenberg** und **H. Euler** in Leipzig.

Mit 2 Abbildungen. (Eingegangen am 22. Dezember 1935.)

Aus der Diracschen Theorie des Positrons folgt, da jedes elektromagnetische Feld zur Paarerzeugung neigt, eine Abänderung der Maxwellschen Gleichungen des Vakuums. Diese Abänderungen werden für den speziellen Fall berechnet, in dem keine wirklichen Elektronen und Positronen vorhanden sind, und in dem sich das Feld auf Strecken der Compton-Wellenlänge nur wenig ändert. Es ergibt sich für das Feld eine Lagrange-Funktion:

$$\mathfrak{L} = \frac{1}{2}(\mathfrak{E}^2-\mathfrak{B}^2)+\frac{e^2}{\hbar c}\int_0^\infty e^{-\eta}\frac{d\eta}{\eta^3}\left\{ i\eta^2(\mathfrak{E}\mathfrak{B})\cdot\frac{\cos\left(\frac{\eta}{|\mathfrak{E}_k|}\sqrt{\mathfrak{E}^2-\mathfrak{B}^2+2i(\mathfrak{E}\mathfrak{B})}\right)+\text{konj}}{\cos\left(\frac{\eta}{|\mathfrak{E}_k|}\sqrt{\mathfrak{E}^2-\mathfrak{B}^2+2i(\mathfrak{E}\mathfrak{B})}\right)-\text{konj}} + |\mathfrak{E}_k|^2+\frac{\eta^2}{3}(\mathfrak{B}^2-\mathfrak{E}^2)\right\}.$$

($\mathfrak{E}, \mathfrak{B}$ Kraft auf das Elektron.
$|\mathfrak{E}_k| = \frac{m^2c^3}{e\hbar} = \frac{1}{„137“}\frac{e}{(e^2/mc^2)^2}$ = „Kritische Feldstärke“.)

One of the most important consequences is that, even in the vacuum, the Maxwell equation have to be exchanged by more complicated formulas. In general, it will be not possible to separate processes in the vacuum from those involving matter since electromagnetic fields can create matter if they are strong enough.

Schwinger limit

Minimal electric field for the vacuum nonlinearity:

$$\mathcal{E}_{cr} = \frac{m_e^2 c^3}{e\hbar} = 1.3 \times 10^{18}\,\mathrm{V/m},$$

- electromagnetic field is expected to become nonlinear
- Maxwell's equations are not sufficient

At present impossible to achieve a static DC field of such magnitude

(on next pages natural units are used: $c = \hbar = \varepsilon_0 = 1$)

Technological breakthrough

The era of High Power Lasers (HPL)

- recent progress of HPL technology and focusing:
  very strong electric fields at optical frequency
- RMS values of the laboratory $\mathcal{E}$ filed only few orders of magnitude lower then the Schwinger field $\mathcal{E}_{cr}$
- still not enough...
- idea: collide such laser-beam with $\sim$GeV electron-beam
- in the rest frame of the e^- the $\mathcal{E}$ is larger by factor $\gamma_e = E_e/m_e$
- for $E_e \geq 5$ GeV : $\gamma_e \geq 10^4$
- enough, electrons shall see the electric field $\mathcal{E} \geq \mathcal{E}_{cr}$!
- (similar for $\sim$GeV gamma photons collided with laser photons γ_L)

Laser beam: field characteristic

dimensionless intensity parameter (filed energy density) ξ^2

- $\xi^2 = (\frac{e\mathcal{E}_L}{m_e\omega_L})^2 = (\frac{m_e\mathcal{E}_L}{\omega_L\mathcal{E}_{cr}})^2$, $\leftarrow$ “classical picture”
  ω_L - laser frequency
- $\xi^2 = 4\pi\alpha\lambda\!\!\!^{-}_L\lambda\!\!\!^{-2}_C n_L$, $\leftarrow$ “quantum picture”
  $\lambda\!\!\!^{-}_L$ and $\lambda\!\!\!^{-}_C$ - reduced laser and Compton wavelengths,
  n_L - number density of laser photons
- for low and moderate $\xi \lesssim 1$ the probability of net absorption of n laser photons $\propto (\xi^2)^n \sim \alpha^n$
  (consistent with perturbative QED vertex counting)

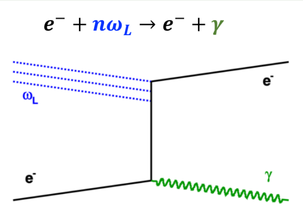
Laser beam: field characteristic

dimensionless quantum parameter χ_e

- $\chi_e = (2\gamma_e \frac{\omega_L}{m_e})\xi = 2\gamma_e \frac{\mathcal{E}_L}{\mathcal{E}_{cr}}$
- ratio of the laser RMS field in the e^- rest frame to the critical field
- accounts of the quantum nonlinear effect in e-laser collision ($E_e = m_e\gamma_e$)

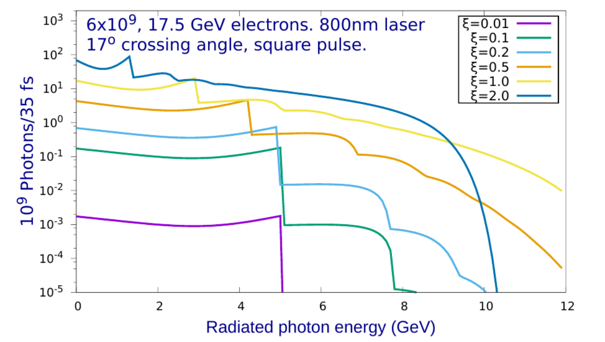
Dominant processes in e^--HPL experiments

non-linear Compton scattering



- $e^- + n\gamma_L \rightarrow e^- + \gamma$
- multi-photon absorption of n “soft” photons from laser EM field
- emission of “hard” gamma (Compton) photon in final state

Non-linear Compton γ spectrum



- low laser intensity (ξ) $\rightarrow$ Klein–Nishina process
- $\xi \nearrow$: shift of Compton edge with laser intensity
- additional structure due to multi-photon absorption

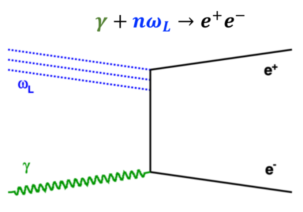
Non-linear Compton γ spectrum

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

- for monochromatic, circularly polarized laser pulse: $|\vec{\mathcal{E}}| = const$
- circural motion of electron with frequency ω_L
- electron transverse momentum: $P_\perp \sim \xi m$
- $E^2 = m^2 + P_\perp^2 + P_\parallel^2 \sim (1+\xi^2)m^2 + P_\parallel^2$
- electron effective mass: $\overline{m} = m\sqrt{1+\xi^2} \to$ effective momentum
- $\to$ shift of the lowest order Compton edge (scaling as $1/\sqrt{1+\xi^2}$)

Dominant processes in γ-HPL experiments

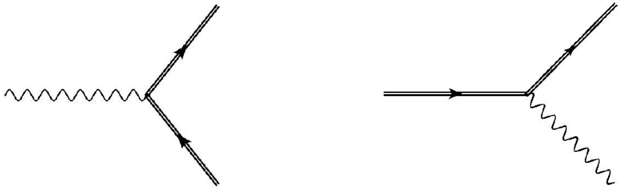
non-linear Breit-Wheeler e^+e^- pair production



- $\gamma + n\gamma_L \rightarrow e^+e^-$
- multi-photon absorption of n “soft” photons from laser EM field
- extra source of “hard” gamma γ from bremsstrahlung
- process possible even if centre-of-mass-energy of $\gamma\gamma_L$ system below $2m_e$

Dominant processes: Volkov picture

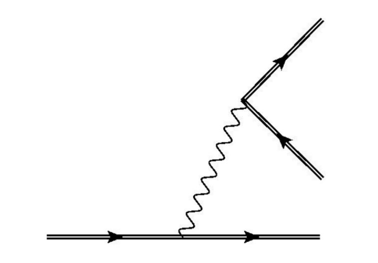
Volkov electrons

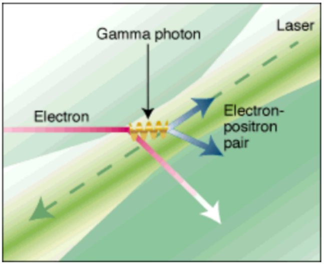


- Double lines: laser dressed (Volkov) electrons and positrons
- left: laser stimulated photon decay into e^+e^- pair
- right: nonlinear photon emission

Laser stimulated trident process

trident process: $e^- + \gamma_L \rightarrow e^- + e^+e^-$

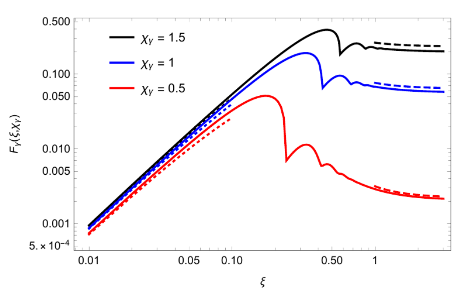




- cutting through the internal photon line
  $\rightarrow$ the two dominant processes
- "two-step" trident: involving real photons
  (traveling "macroscopic" distance)
- "one-step" trident: quasi-instantaneous, involving virtual photons
  $\rightarrow$ different kinematics !

Rate of e^+e^- pair production

full calculation and asymptotic behavior (dotted-dashed)



- in a constant static field: $\propto \exp\left(-\pi \frac{\mathcal{E}_{cr}}{\mathcal{E}}\right)$ (Schwinger process)
- in plane wave laser (asymptotic): $\propto \exp\left(-\frac{8}{3}\frac{1}{1+\cos\theta}\frac{m_e}{\omega_L}\frac{\mathcal{E}_{cr}}{\mathcal{E}}\right)$
- good agreement for $\xi \ll 1$ and $\xi > 1$

QED: Quantum electrodynamics

- relativistic field theory of electromagnetic interactions
- perturbation theory in terms of coupling constant $\alpha \approx \frac{1}{137}$ (small !)
- most precisely tested physics theory
- anomalous magnetic moment $g-2$ of electron:
  - zero at leading order
  - precisely measured and calculated (up to α^5 terms)
  - extract: $\frac{1}{\alpha} = 137.035\,999\,070\,(98)$
  - 10^{-9} precision
- Lamb shift
  (hyper-fine splitting between $2S_{1/2}$ and $2P_{1/2}$ states in hydrogen)

SFQED: Strong Field QED: *terra incognita*

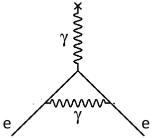
some open questions

- propagation of electrons and photons in very strong $\mathcal{E}$ field
- unstable vacuum, for example around nucleus with $Z > 137$ spontaneous creation of e^+e^- pairs ($\rightarrow$ “boiling of vacuum”)

historical perspective

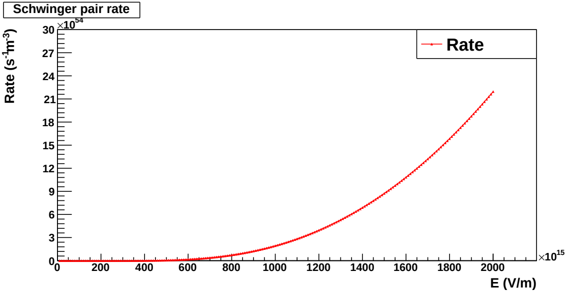
- 1930s: Sauter, Euler, Heisenberg: first discussion related to strong EM fields, introducing the critical field $\mathcal{E}_{cr}$
- 1951: First non-perturbative calculations by Julian Schwinger
- 1990s: E144 experiment at SLAC (more on next pages)

Towards non-perturbative QED



- QED not limited to perturbatively solved problems
- 1930s: prediction: if $\mathcal{E}$ very strong
  $\rightarrow$ kinetic $E_e \sim m_e$ over distance $d \sim \lambda_C$
  (electron Compton wavelength $1/m_e = 3.86 \cdot 10^{-13}$ m)
  perturbation approaches not applicable !
- novel phenomena occur:
- e^+e^- pair production out of $\mathcal{E}$ field
- light-light scattering
- non-linearities in the optical properties of vacuum

Towards non-perturbative QED



- in ordinary perturbation theory expansion in powers of $\alpha = e^2/(4\pi)$
- famous example of non-perturbative QED process:
- spontaneous e^+e^- pair production in static $\mathcal{E}$ field
  $\Gamma \sim \exp\left(-\pi m_e^2/(e\mathcal{E})\right)$
- no Taylor expansion in α (or e),
  all derivatives $\frac{\mathrm{d}^n\Gamma}{\mathrm{d}\alpha^n} = 0$ to all orders of n ($\Gamma \in C^\infty$)

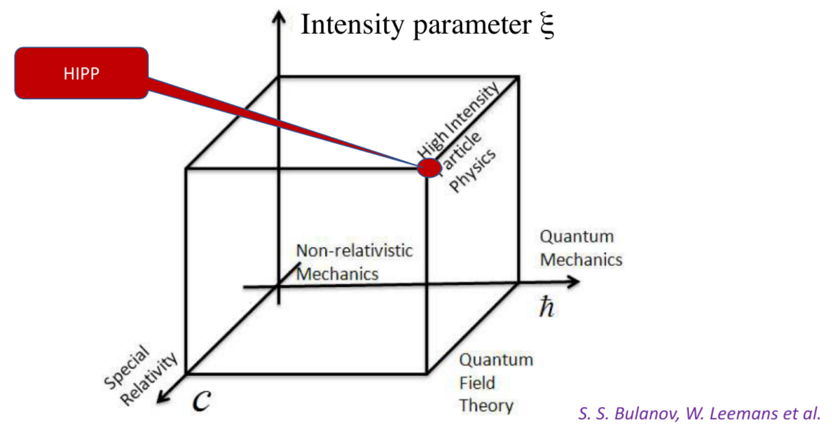
Towards non-perturbative QED

- $\xi \ll 1$ - perturbative regime : Taylor series in α^n
  fast convergence, few terms provide high precision
  lowest order $\rightarrow$ single photon processes
  (event rates $\propto \xi^2 \sim \alpha$)
- $\xi \lesssim 1$ - still perturbative regime but slow convergence
  onset of multi-photon processes
  (event rates $\propto (\xi^2)^n \sim \alpha^n$)
- $\xi \gtrsim 1$ - each n contribute with comparable weight
  (requires solutions to "all orders", the series cannot be truncated)
  (event rates faster then $\propto (\xi^2)^n$)
- $\xi \gg 1$ - non-perturbative regime, expansion breaks down
  (no perturbation series can be defined)

The non-perturbative regime of QED still awaits experimental investigations !

Deviation from power-law will be the experimental signature of strong fields QED.

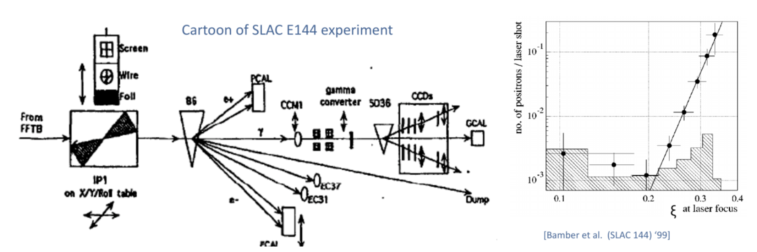
New dimension of particle physics



- HIPP: High Intensity Particle Physics

Pioneering experiment

The landmark: SLAC E144 (1990s)

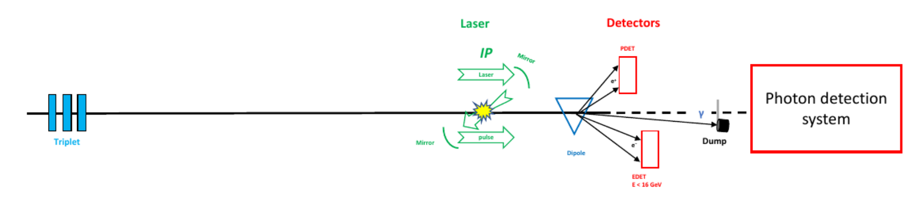


- SLC e-beam: $E_e = 46.6$ GeV and green laser: 1 TW power
- achieved $\xi \simeq 0.4$ and $\chi \leq 0.25$
- observed non-linear Compton scattering with up to $n = 4$ laser photons
- observed non-linear Breit-Wheeler pair production using back scattered laser photons $E_\gamma = 29.2$ GeV: $\gamma + n\gamma_L \to e^+e^-$
  (threshold for pair creation required absorption of $n \geq 5$ laser photons !)
- saw the strong rise $\propto \xi^{2n}$ but did not reach the critical field

The LUXE: Laser und XFEL Experiment

Idea of e-laser experiment

Compton and trident processes

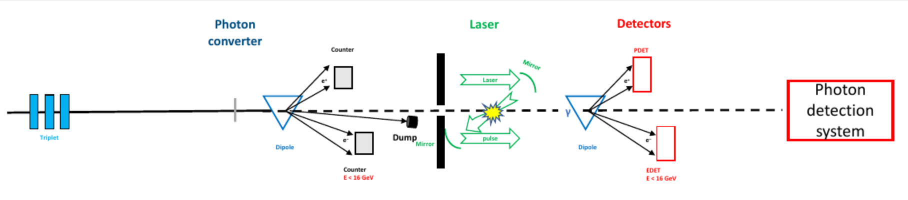


$e^- + n\gamma_L \to e^- + \gamma$ and $e^- + n\gamma_L \to e^- + e^+e^-$

- extract and focus single electron bunch from XFEL
- electron - laser interaction area
- e^+, e^- and γ detectors behind dipole magnet
- e-laser crossing angle: 17° (well defined reaction plane)

Idea of γ-laser experiment

Breit–Wheeler pair production



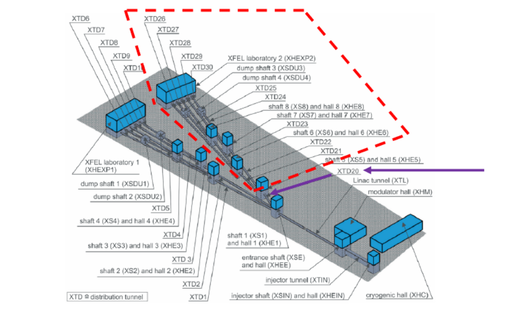
$\gamma + n\gamma_L \rightarrow e^+e^-$

- converter (tungsten foil)
- additional detectors before shielding to remove e^+e^- pairs and monitor photon flux
- gamma - laser interaction area
- different location of the beam dump

Location and accelerator

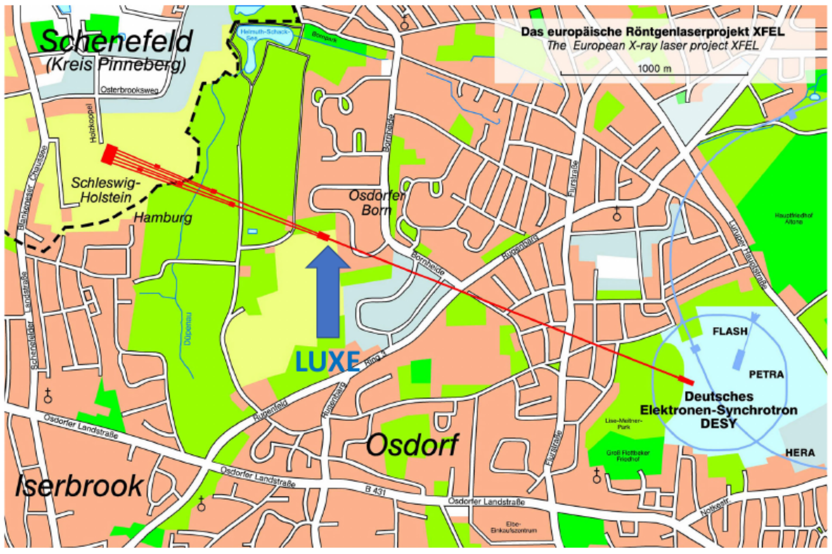
Location of the LUXE experiment within XFEL

XFEL: European X-ray Free-Electron Laser at DESY

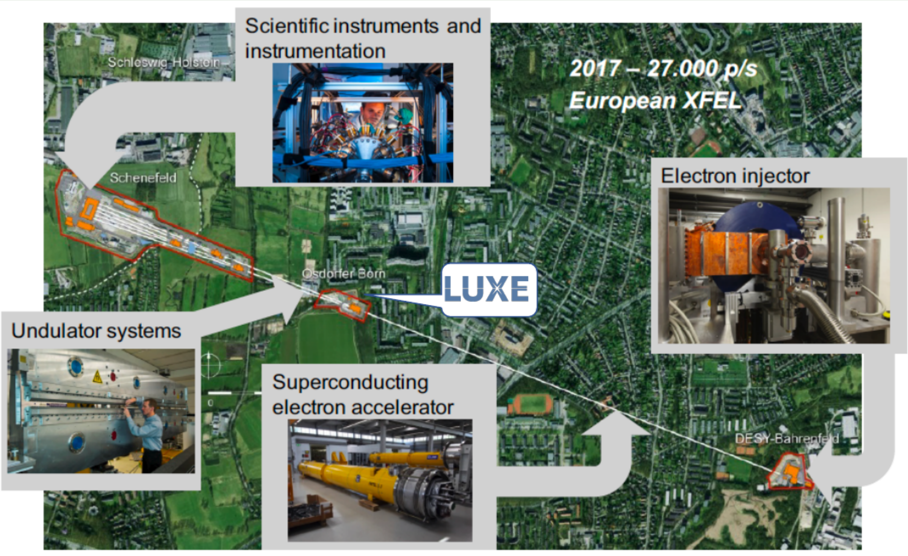


- annex of the XS1 shaft → at the end of electron linac
- build for 2^{nd} phase of EU-XFEL (late 2020s - - - dashed area)
- no impact on photon science programme
- use only 1 of the 2700 bunches in XFEL bunch train

Location of the LUXE experiment

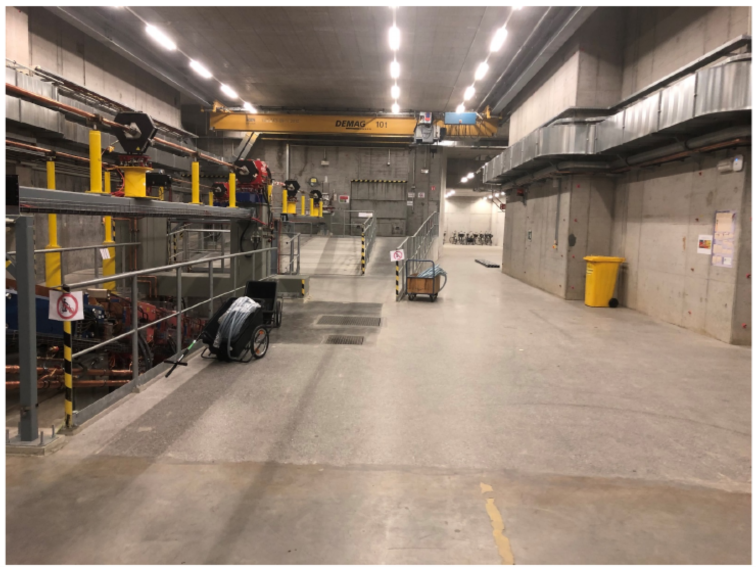


Location of the LUXE experiment

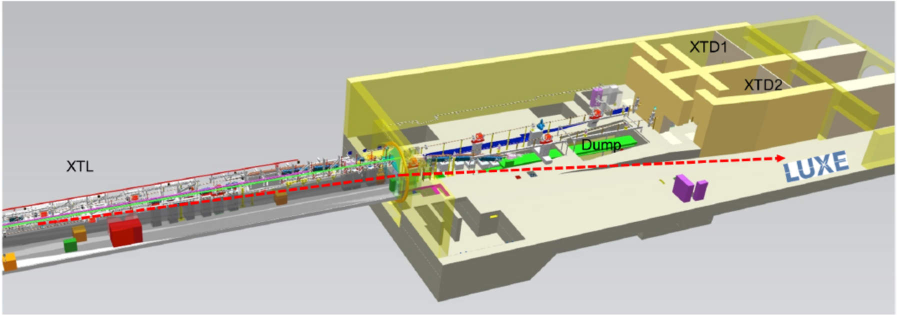


Location of the LUXE experiment

Experimental area: the cavern

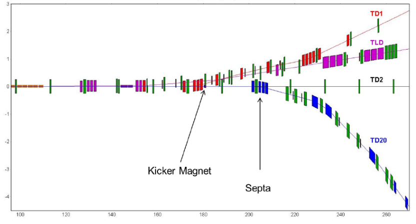


Experimental area



- size of the annex: 60m long, 5.4m wide, 5m high

Beam extraction from XFEL



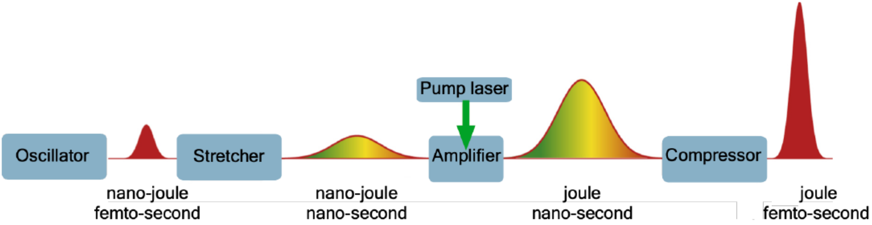
Parameter	Value
Beam Energy [GeV]	up to 17.5
Bunch Charge [nC]	0.25–1.0
Number of bunches	1
Repetition Rate [Hz]	up to 10
Spotsize at the IP [μm]	5–20

- no of electrons per bunch: $1.5 \div 6 \cdot 10^9$
- beam energy : $E_e = 14 \div 17.5$ GeV

LUXE

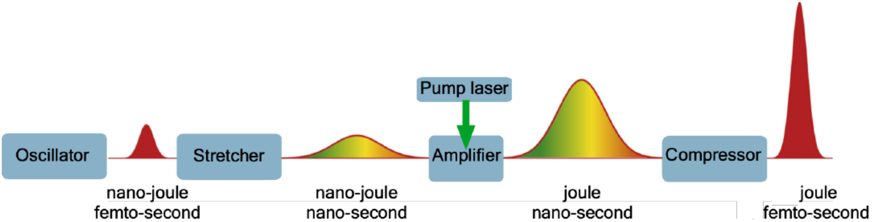
Laser

High Power Laser Technology: idea



- chirped pulse amplification (CPA) technique
- 2018 Nobel: Donna Strickland and Gerard Mourou
  "for method of generating high-intensity, ultra-short optical pulses"
- energy focused very strongly in time and space → high intensity

High Power Laser Technology: idea (cont.)

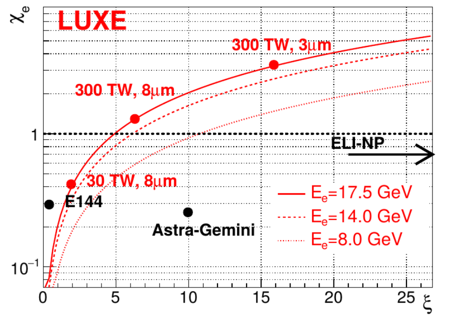


- **Front end:** ultra-short (∼fs), low-energy (∼nJ) oscillator (≈ 75 MHz) plus pre-amplification of selected pulses (~ 10 Hz) to about 1 mJ
- **Pulse stretcher:** all-reflective 1500 lines/mm grating (4 passages)
- **Amplifier:** Ti:Sapphire power amplifier pumped with green (532 nm) laser pulses (beam expanded to remain below optical damage threshold)
  expandable: 3 stages: $\rightarrow 30$ TW, 5 stages: $\rightarrow 300$ TW peak power
- **Compressor:** large, gold-coated diffraction gratings
  repetition rate: 1 Hz limited by thermal abberations
  final pulse: duration: ∼fs, energy: ∼J

Laser parameters

Parameter	Initial stage	Stage 1	Stage 2
Laser energy after compression [J]	0.9	9	
Percentage of laser in focus [%]	40	40	
Laser energy on focus [J]	0.36	3.6	
Laser pulse duration [fs]	30	30	
Laser repetition rate [Hz]	1	1	
Laser-beam crossing angle [degrees]	17	17	
Laser focal spot FWHM [μm]	8	8	3
Peak intensity [10^{19} W/cm^2]	**1.6**	**16**	**110**
Peak intensity parameter ξ	**2**	**6.2**	**16**
Peak quantum parameter χ: **Ebeam=17.5 GeV** **Ebeam=14.0 GeV**	 **0.41** **0.32**	 **1.3** **1.0**	 **3.3** **2.6**

Parameter space

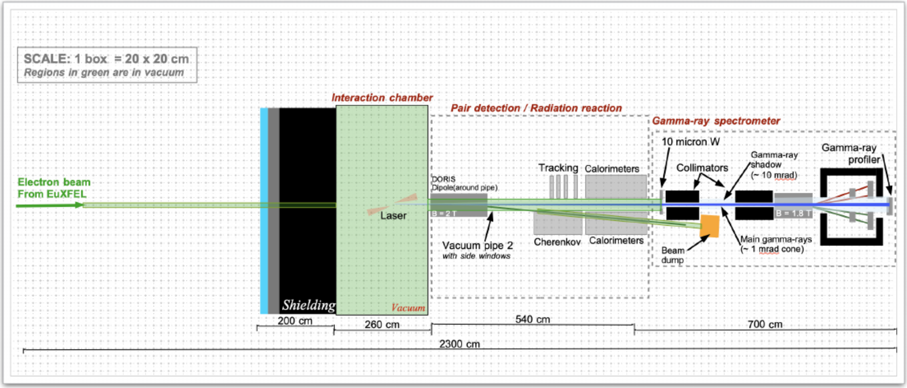


laser power to reach the Schwinger field ($\chi \sim 1$)

- non-relativistic photons : $I = 2 \cdot 10^{29}$ W/cm^2 (beyond currently achievable values)
- EU-XFEL: $E_\gamma \approx 10$ GeV: $I = 10^{20}$ W/cm^2 (well-tested laser technology)
- ELI-NP: $E_\gamma \approx 1$ GeV: $I = 10^{22}$ W/cm^2 (state-of-the-art laser needed)

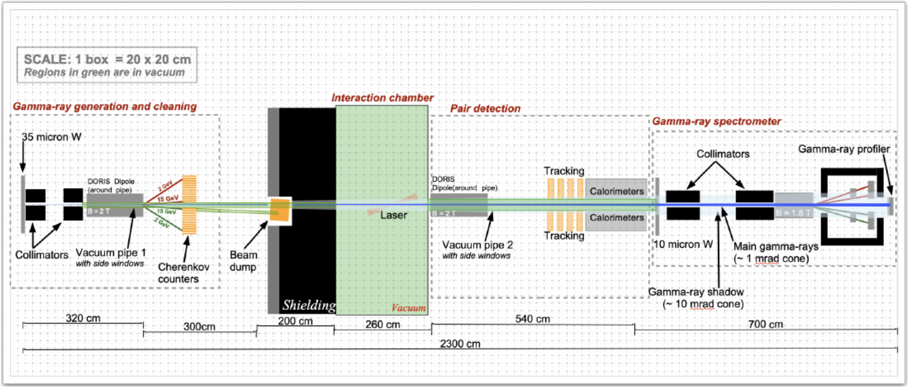
Detectors and MC

Details of e-laser setup



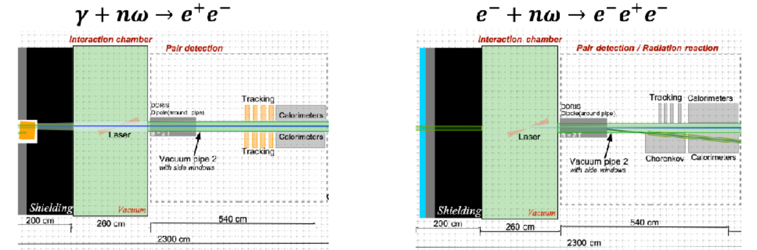
- signal: Compton and trident process
- e^+, e^- and γ detectors behind dipole magnet
- e-laser crossing angle: $17°$

Details of γ-laser setup



- signal: Breit–Wheeler pair production
- converter (tungsten foil) and additional detectors before shielding
- different location of the beam dump

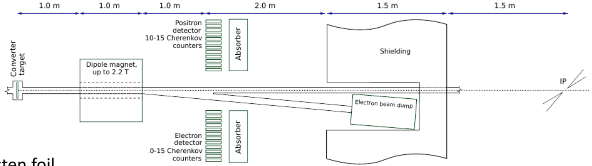
Electron and positron detectors

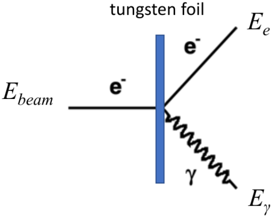


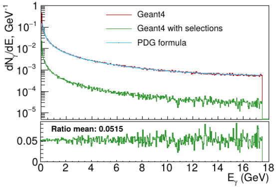
- e^+e^- pairs rate: $10^{-2} \div 10^{2}$ Hz
  $\rightarrow$ silicon pixel detectors and calorimeters
- trident: e^+ rate: $10^{-2} \div 10^{2}$ Hz
  $\rightarrow$ silicon pixel detectors and calorimeters
- trident: e^- rate: $10^{6} \div 10^{9}$ Hz
  $\rightarrow$ Cerenkov counters and calorimeter/absorber

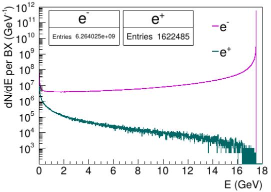
Photon target area: high-energy photon flux

converter →



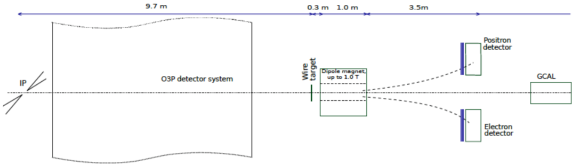


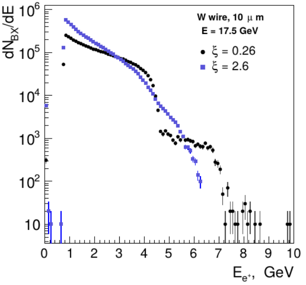




- photon production via bremsstrahlung
- tungsten target with $0.01X_0$ ($35\mu m$ foil) : 1% at IP
- flux: by observing e^+e^- pairs after dipole magnet
- Geant4: converter simulations of e^+, e^-, and γ spectra
- e^- spectrum dominated by beam-electrons

Detection of Compton photons (forward photon spectrometer)



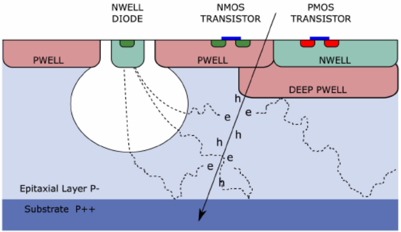


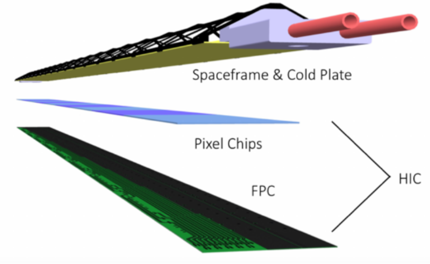
photon detection system for Compton scattering

- very high photon flux ($> 10^7$ per laser shot)
- thin wire to convert fraction of photons to e^+e^- pairs
- Compton edge visible in e^+ spectrum for low laser intensity ξ

Silicon pixel tracking detectors

ALPIDE pixel detectors developed by ALICE collaboration

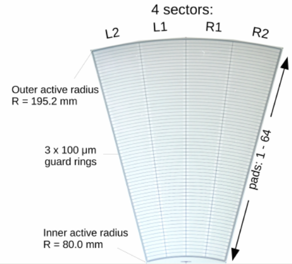


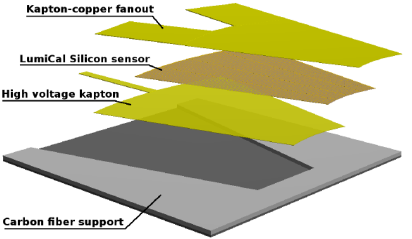


- MAPS technology: Monolithic Active Pixel Sensors
- ladders of 27 cm length, sensor size 1.5×1.5 cm^2 (full coverage with two ladders next to each other)
- pixel size: 27×29 μm^2 $\rightarrow$ spatial resolution ~ 5 μm
- four layers staggered behind each other

Calorimeters

High granularity silicon Tungsten calorimeter (LUMICAL)

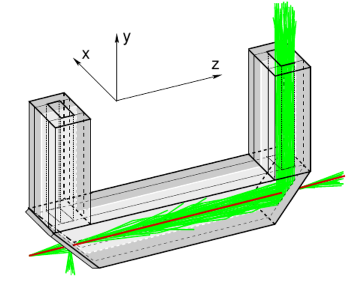


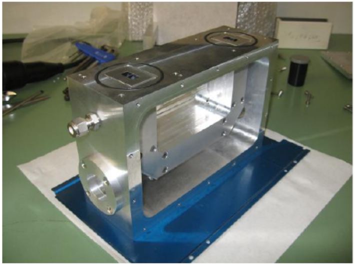


- developed for luminosity measurement at linear e^+e^- colliders
- 20 tungsten absorber plates (3.5 mm), Si layers in gaps (320 μm)
- geometry fits LUXE needs (~ 50 cm long, vertical spread < 1 mm)
- Moliere radius 8 mm, prototype for test beam available

Cherenkov detectors

Cherenkov detectors in high-flux regions





- design developed for ILC polarimeters
- linearity better than 0.1% over dynamic range spanning 10^3
- threshold of ~ 10 MeV
  $\rightarrow$ robust against background from low energy radiation
- array of 15 detectors with cross section of 2×2 cm^2

Phases of the LUXE experiment

Phase	Power [TW] nominal	Power [TW] actual	focus FWHM [μm]	Intensity [10^{19} W/cm^2]	ξ	χ_e for E_e/GeV 17.5	χ_e for E_e/GeV 14.0
A	30	12	8	1.6	2	0.41	0.32
B	300	120	8	16	6.2	1.3	1.0
C	300	120	3	110	16	3.3	2.6

- 3 phases: from 30 to 300 TW laser power, increasing focusing
- phase A: repeat the E144 results (non-linear, perturbative regime)
- phase B-C: non-linear, non-perturbative regime
- schedule/milestones (up to 2027):

Winter 2019/2020 and 2020/2021: Installation is assumed to extend over two winter shutdowns
2022: prototype experiment with 30 TW laser in e–laser setup. Commissioning, data taking and publication of results
2023: prototype experiment with 30 TW laser in γ_B–laser setup. Commissioning, data taking and publication of results
2024: Install 300 TW laser
2025-2027: Commissioning an data taking with 300 TW laser in e–laser and γ_B–laser in subsequent years

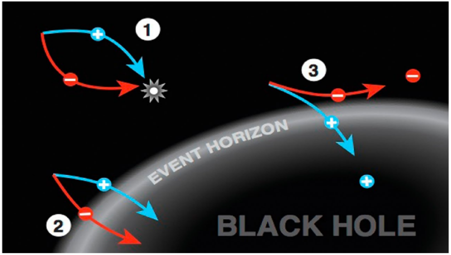
Summary

- We are witnessing the birth of new experimental research area: Strong Fields QED
- LUXE is an experiment to test what happens when high energy electrons or photons observe a very intense laser field
  - will probe quantum physics in new regime
  - measure several phenomena predicted more than 70-90 years ago
- Schwinger field has never been reached in controlled/clean environment
- Exciting to be the first to explore this... what can be discovered ?
- **S. Weinberg: "My advice is to try crazy ideas and innovative experiments. Something will come up."**

Backup plots

- backup plots...

Analogy to Hawking radiation



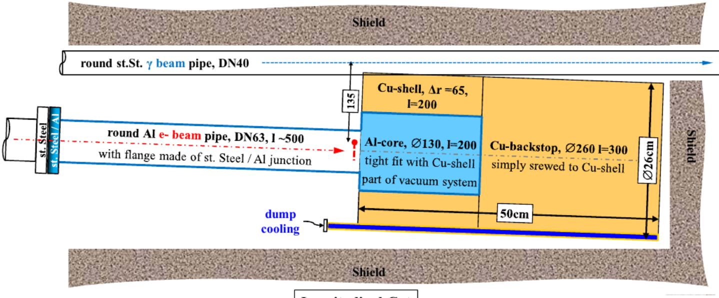
- Energy to create on-shell e^+e^- pair: $\Delta E = 2mc^2$
- Gravitational force at the horizon: $F = \frac{G_N M m}{r_S^2}$
- Schwarzschild radius: $r_S = \frac{2G_N M}{c^2} \rightarrow F = \frac{mc^4}{4G_N M}$
- Energy to separate pair: $E = F d_{min} = \frac{mc^4}{4G_N M} \cdot \frac{\hbar}{mc} = \frac{\hbar c^3}{4G_N M}$
- Hawking radiation (virtual pair becomes real): $\frac{\hbar c^3}{4G_N M} > 2mc^2$

HIPP: Connections to other research areas

High Intensity Particle Physics

- astrophysics: strong fields on the surface of magnetars (strongly magnetized neutron stars), Hawking radiation, early Universe
- beam-beam interaction in future linear e^+e^- colliders
- particle acceleration in plasma
- atomic and nuclear physics (atoms with atomic number $Z > 137$)
- QCD: so far the only QFT tested in non-perturbative regime $\rightarrow$ large α_s
- gluon saturation at low x-Bjorken (color glass condensate) $\Longleftrightarrow$ large number of interaction laser photons forming a classical field
- deeper understanding of quantum physics

Beam dump

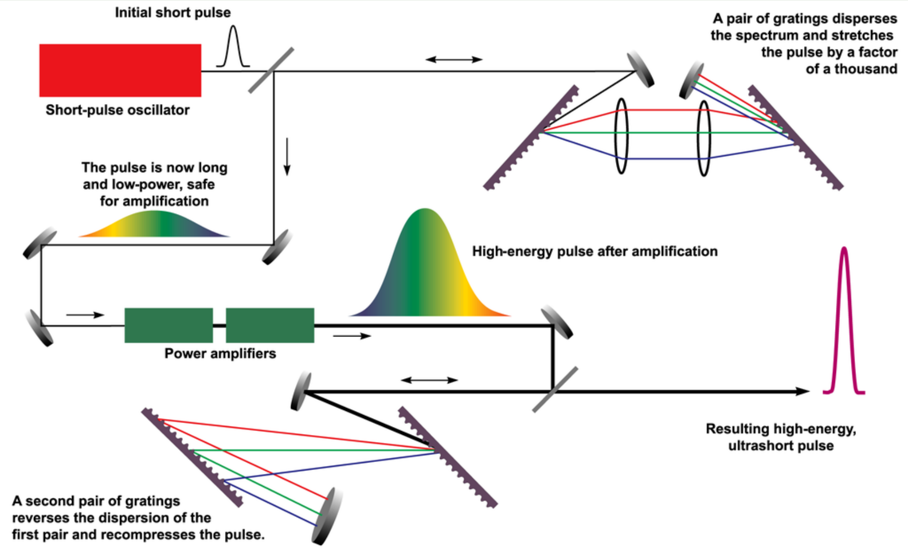


Longitudinal Cut

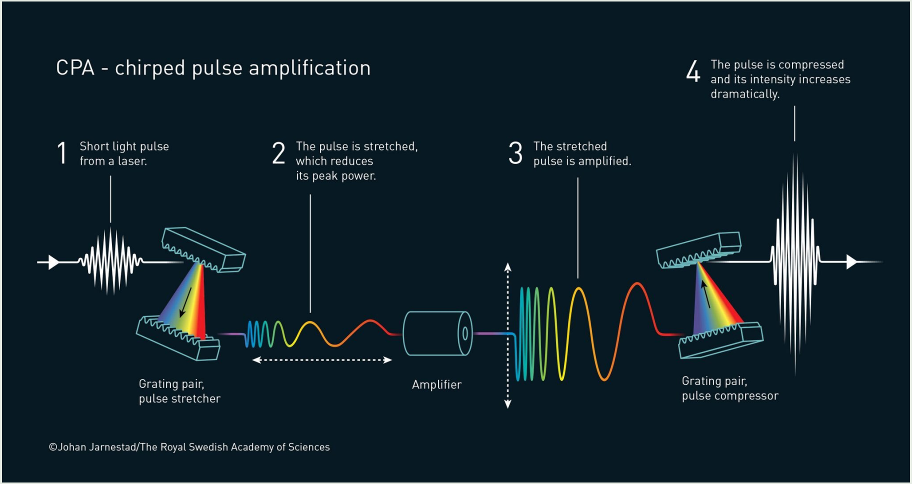
lenghts without units are in mm

- beam power: $P = 200$ W
- charge 1 nC ($6 \cdot 10^9$ e/bunch), rate 10 Hz, energy $E = 20$ GeV

CPA: Chirped pulse amplification

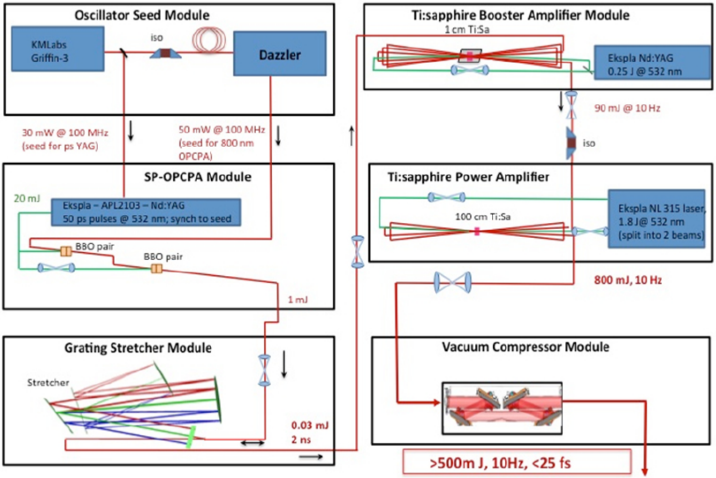


CPA: Chirped pulse amplification II



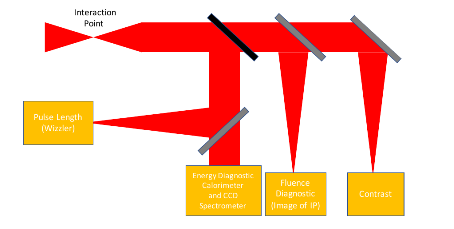
A chirp is a signal in which the frequency increases (up-chirp) or decreases (down-chirp) with time.

High Power Laser Technology: typical layout



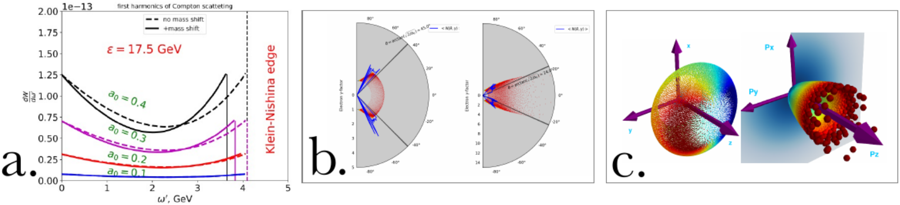
- footprint: for 30 TW mode: 20 m^2, for 300 TW mode: 40 m^2
- temperature and humidity controlled clean-room environment

Laser diagnostic



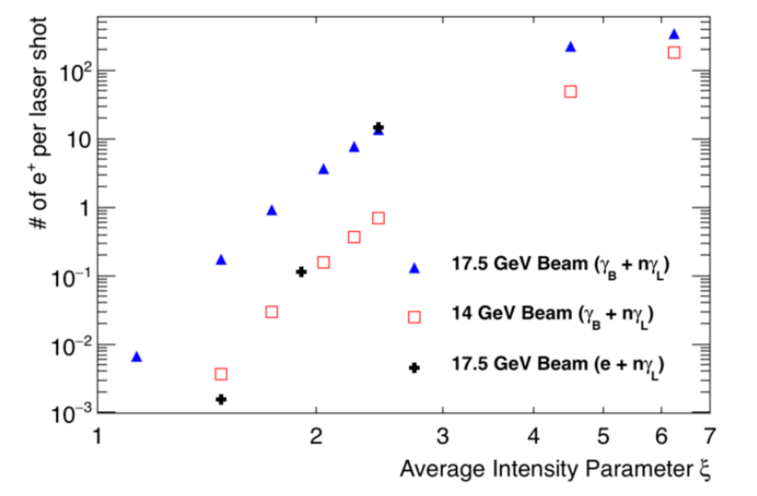
- Laser shots can vary by $\sim 15\%$ for stable laser at this power
- control intensity at level of $5-10\%$
  tag intensity of individual shots
- several subsystems to monitor:
- Energy
- Fluence (Energy/area)
- Pulse length

Peak electric field in focus



- different methods: ...

Positron multiplicity



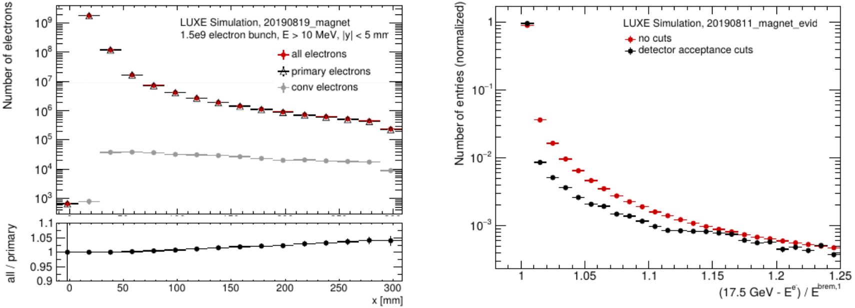
Particle rates per bunch in e-laser and γ-laser mode

Location	particle type	rate for $\xi = 2.6$	rate for $\xi = 0.26$
e^- detector	e^-, $E_e < 16$ GeV	1.5×10^9	6×10^6
e^+ detector	e^+	15.3	< 0.01
Photon detector	γ	6×10^{10}	1×10^7
Photon detector (W foil)	e^+ and e^-	6×10^6	1×10^4
Photon detector (W wire)	e^+ and e^-	1.5×10^5	1×10^2

Location	particle type	rate for $\xi = 6.5$	rate for $\xi = 1.2$
e^- detector behind converter	e^-, $E_e < 13$ GeV	2×10^7	
e^+ detector behind converter	e^+	9×10^4	
photons after converter	γ	1.3×10^8	
$e^\pm$ detector behind IP	e^-/e^+	350	1×10^{-2}
Photon detector	γ	1.3×10^8	
Photon detector	e^+ and e^-	160	

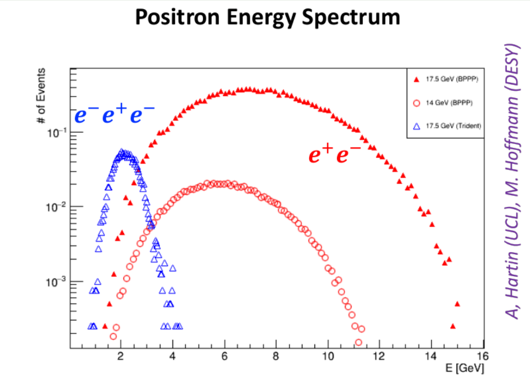
- very different rates of particles $\rightarrow$ different det. technologies

Bremsstrahlung: photon energy reconstruction



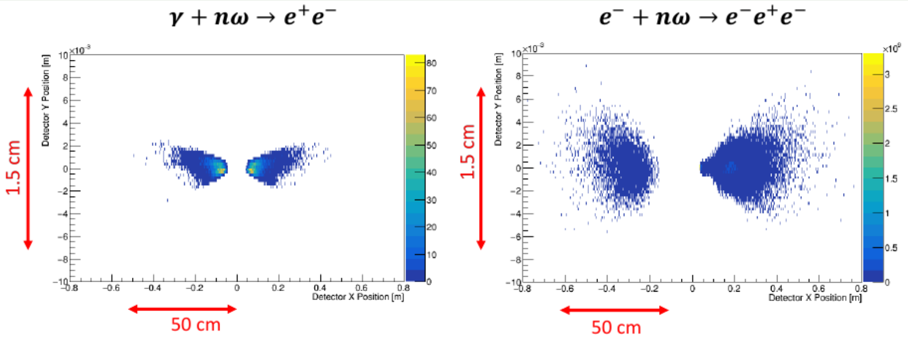
- 2T magnet followed by array of Cherenkov detectors $\rightarrow$ flux vs impact position $\rightarrow$ photon energy spectrum
- $E_\gamma = E_{beam} - E_{e'}$

Positron spectra from e^+e^- pairs



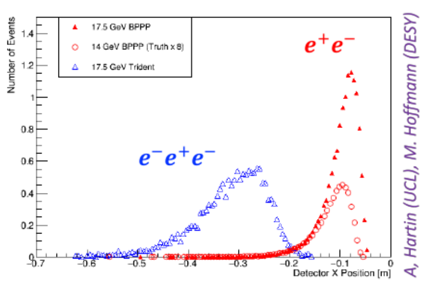
- energy spectrum ranges between $1 \div 15$ GeV
- significantly lower for trident process

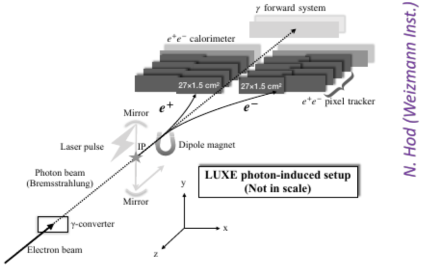
e^+e^- XY occupancy after IP



- XY [cm] position on the pixel detectors after dipole, $B = 1.4$ T
- all particles close to the reaction plane
- very small spread in vertical direction
- horizontal spread $\sim \pm 50$ cm

e^+e^- acceptance





- 2D setup of detectors
- e^+e^- detectors span ± 50 cm for $> 95\%$ acceptance
- trident acceptance $\sim 95\%$
- Breit-Wheeler pairs acceptance $> 99\%$