Detector Challenges of the strong-field QED experiment LUXE at the European XFEL

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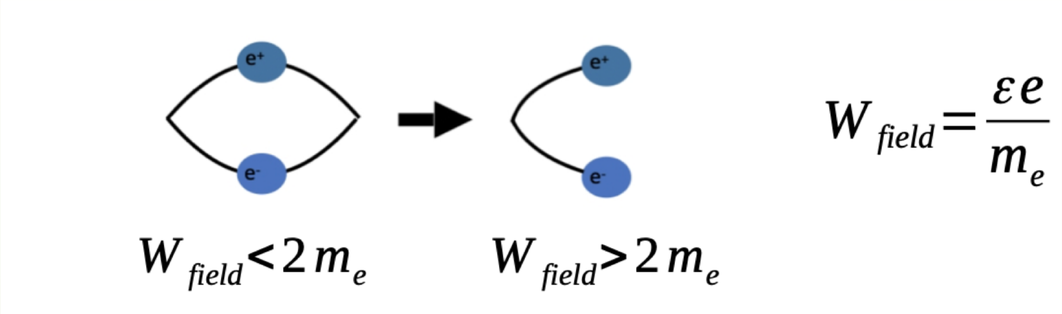
LUXE

LUXE (Laser Und XFEL Experiment)collaboration

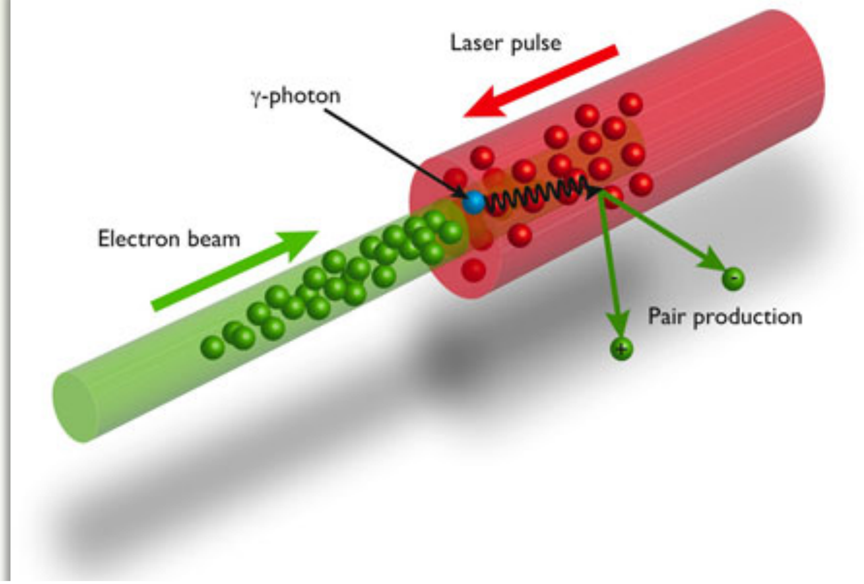
QED and strong fields

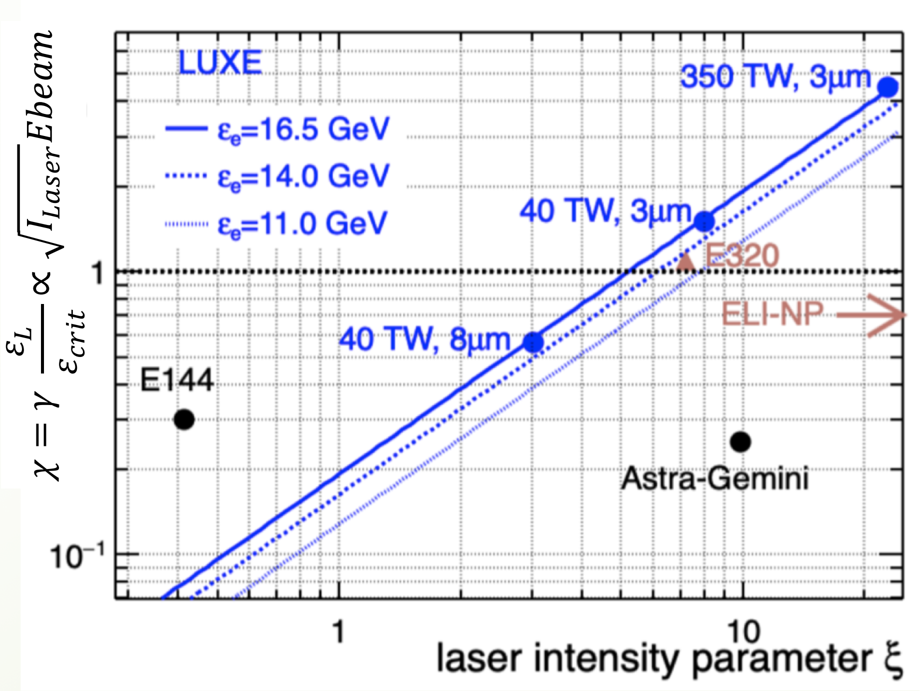
- Although perturbative QED with small background fields is well-understood and well-tested, there is much less understanding of QED in the regime of strong fields.
- For stronger fields, QED perturbation theory breaks down and becomes non perturbative
- At the Schwinger critical field, $\varepsilon_{crit} = m_e^2 c^3 / e\hbar \sim 10^{18}$ V/m, the vacuum becomes unstable to pair production



LUXE experiment

- Such fields have not been reached experimentally in laboratories although they are expected to exist:
  - On the surface of neutron stars.
  - In bunches of future linear e+e− colliders.
- Can be reached by colliding photons with a high-energy electron beam
  - First experiment to try this E144 @ SLAC in 1990s.
  - Nowadays experiments : SLAC-E320 (US), Astra Gemini (UK), ELI-NP (RO)
  - Propose to do this using European XFEL electron beam and high power laser: **LUXE** .



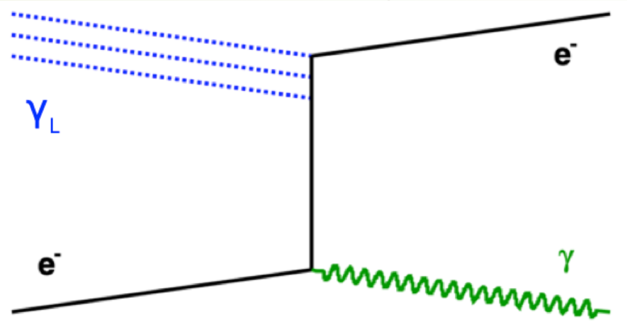


$$\xi = \frac{e\,\varepsilon_L}{m_e \omega_L c} \propto I_{Laser}$$

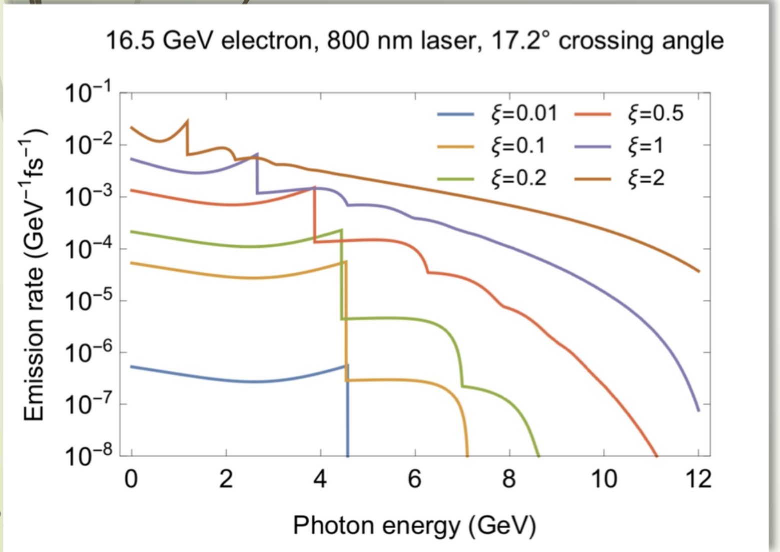
LUXE: physics processes

Non linear Compton scattering

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

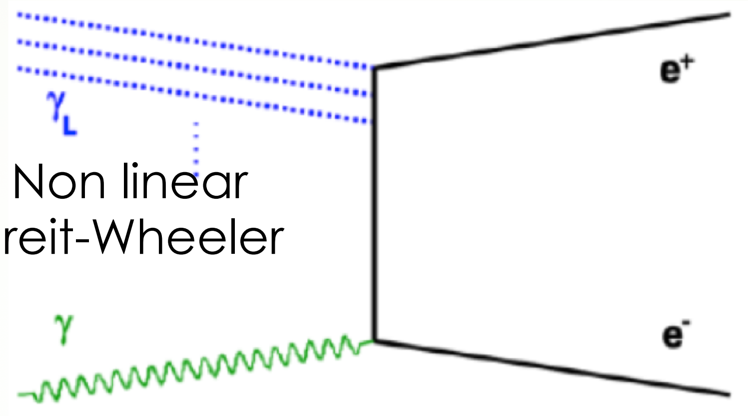


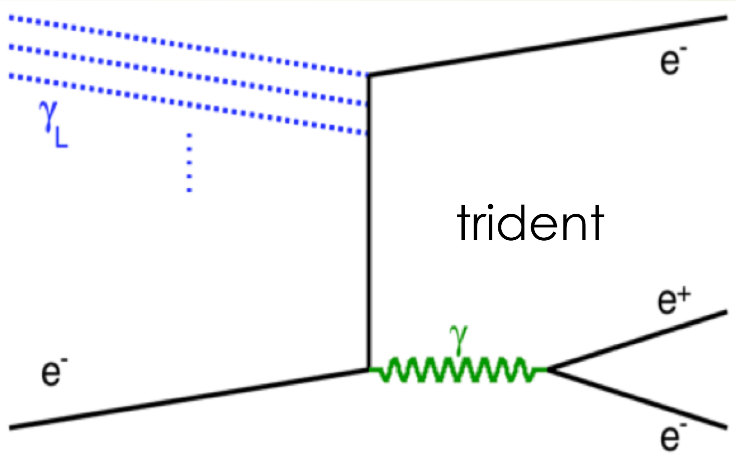
Observables :
- Compton edges
- Intensity of nγ scattering

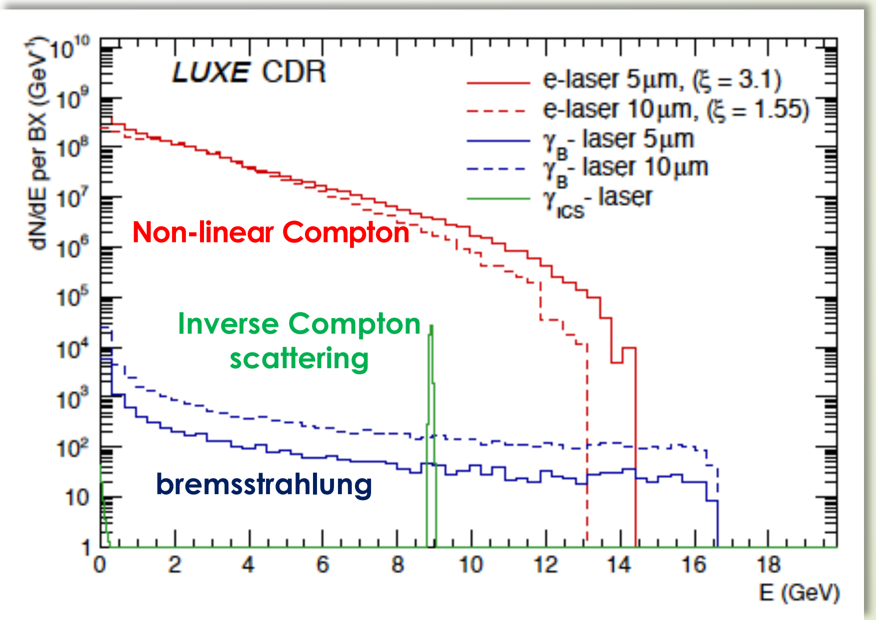


Pair production

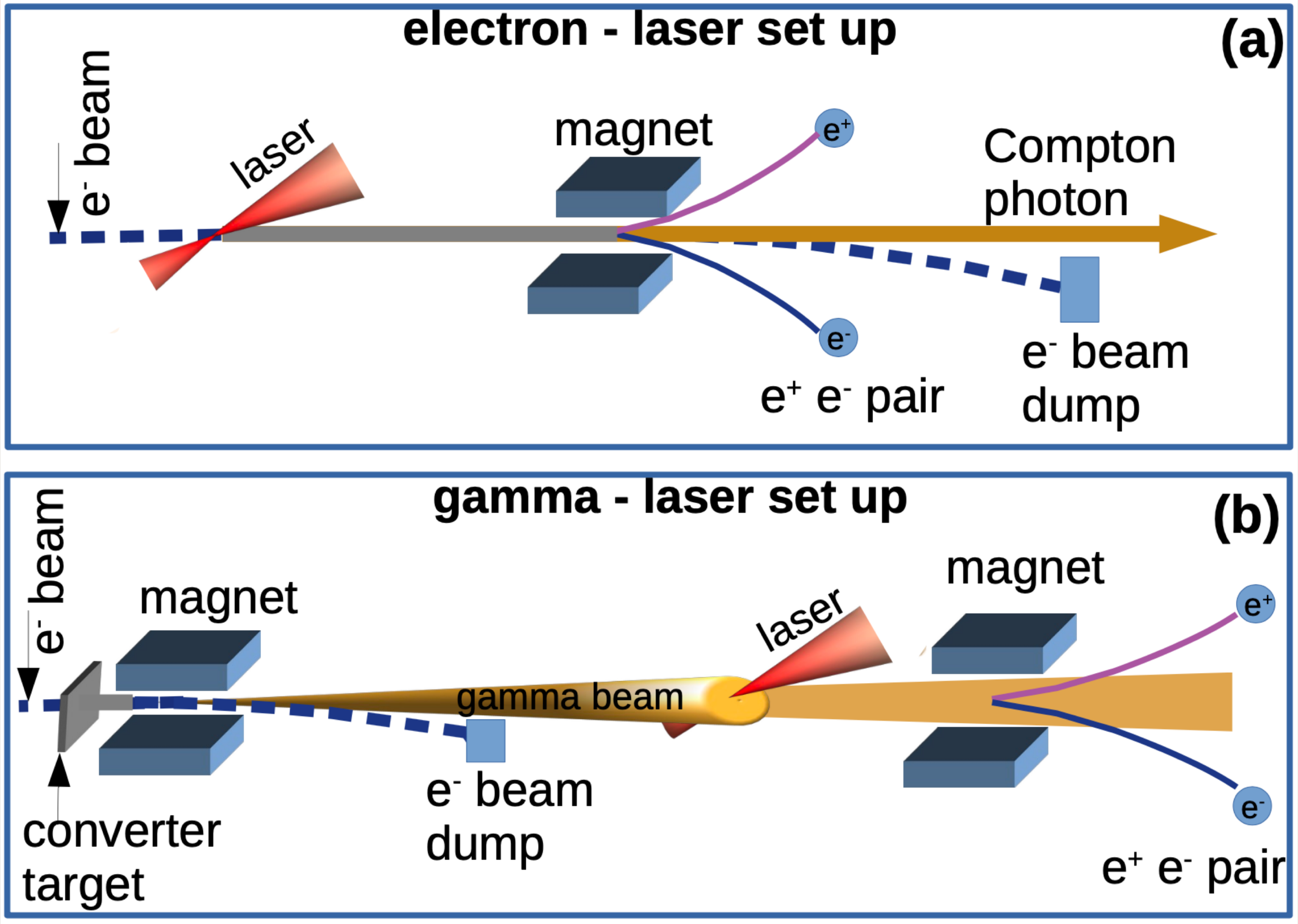
Non linear Breit-Wheeler







LUXE production : two set ups and two phases

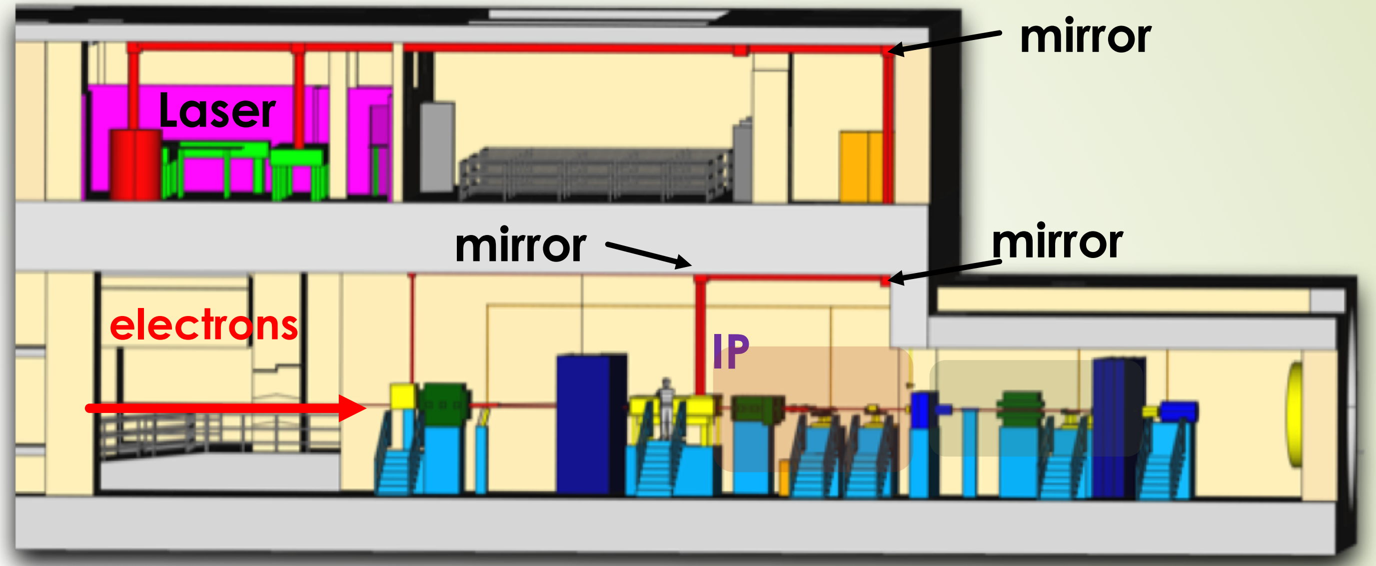


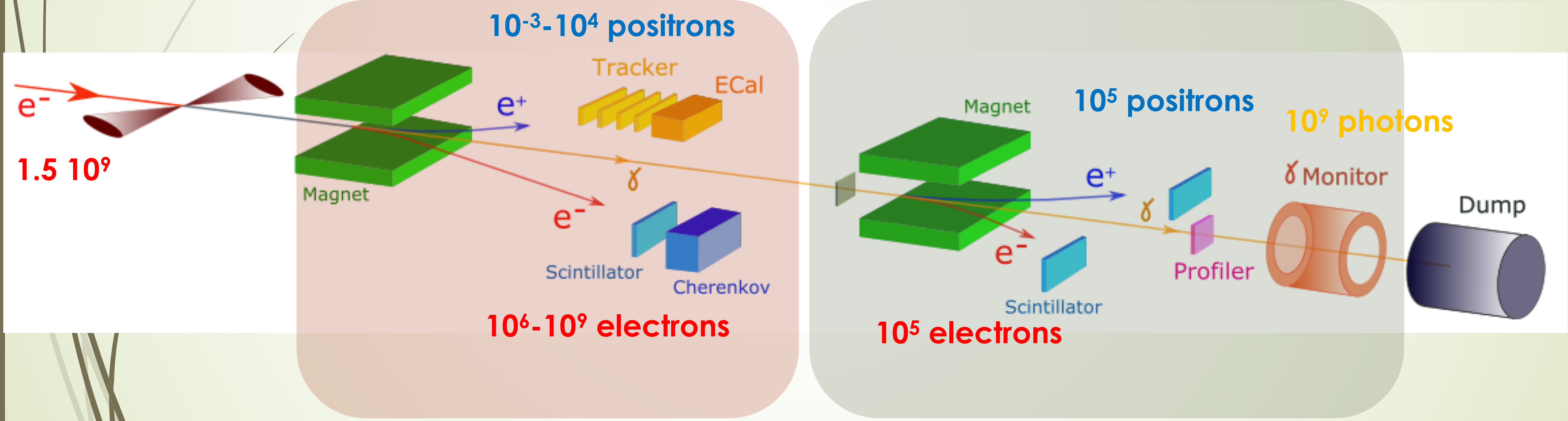
Electron beam:
- 16.5 GeV (possibility 10 and 14 GeV)
- 10 Hz
- LUXE uses one out of 7200 bunches per train
- 10^9 e-/bunch

Laser:
- Wavelength is 800nm
- Rate: 1 Hz
- Focal spot size : 3 or 8 μm

Two phases :
- Phase 0: laser power 40 TW (ξ=7.9)
- Phase 1: laser power 350TW (ξ=23.6)

LUXE detection setup

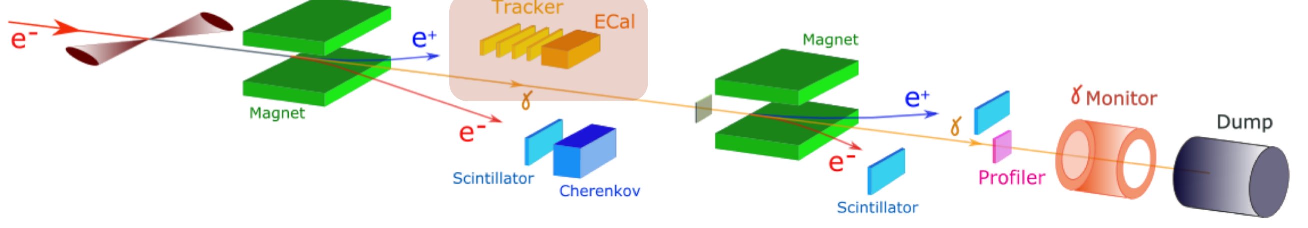




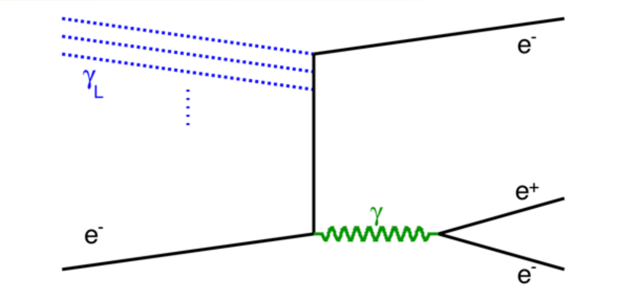
IP detectors: electron positron spectrometers

Forward detectors : photon detection system

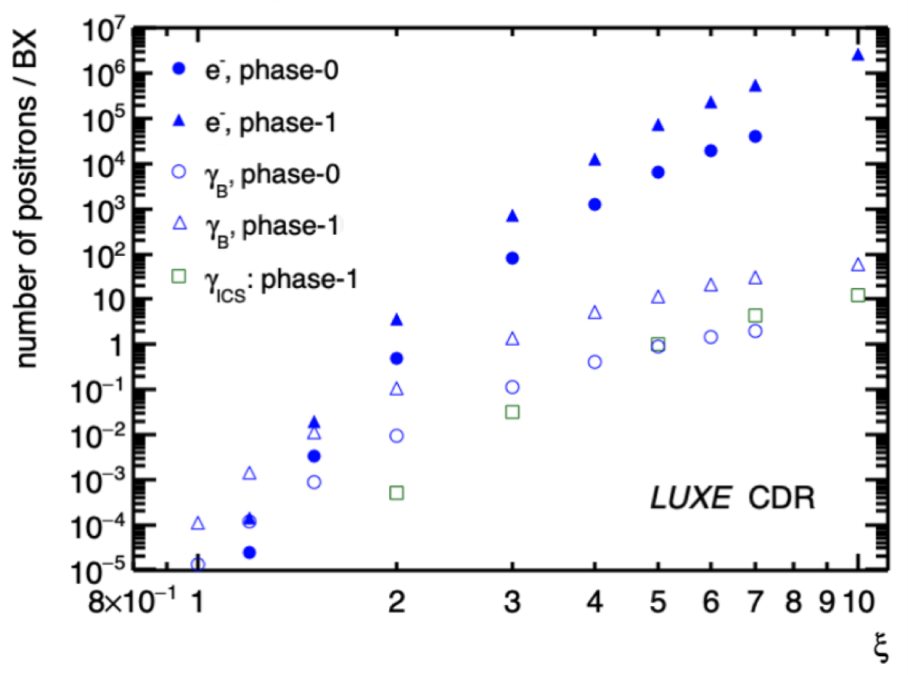
Positron detection

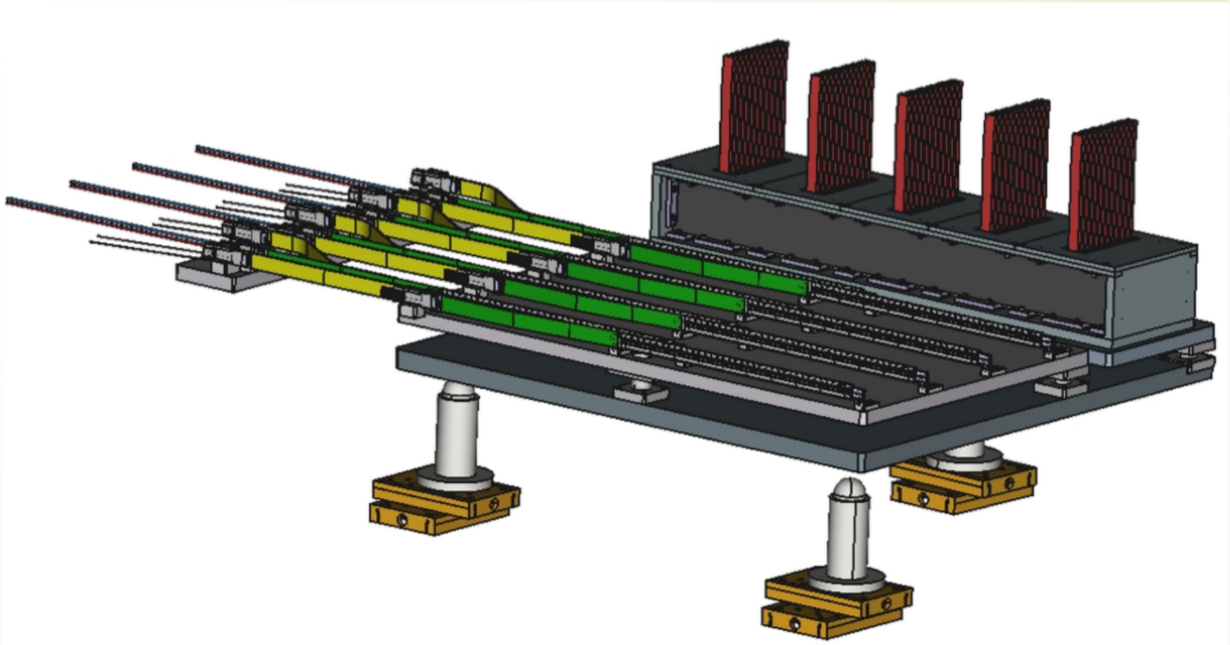


- Study e⁺e⁻ pair

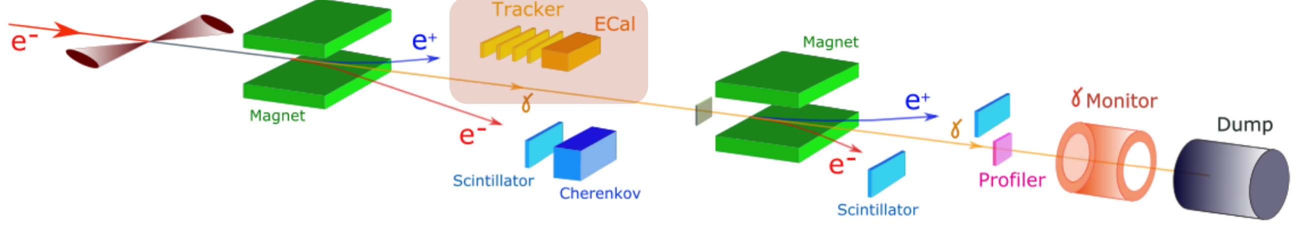


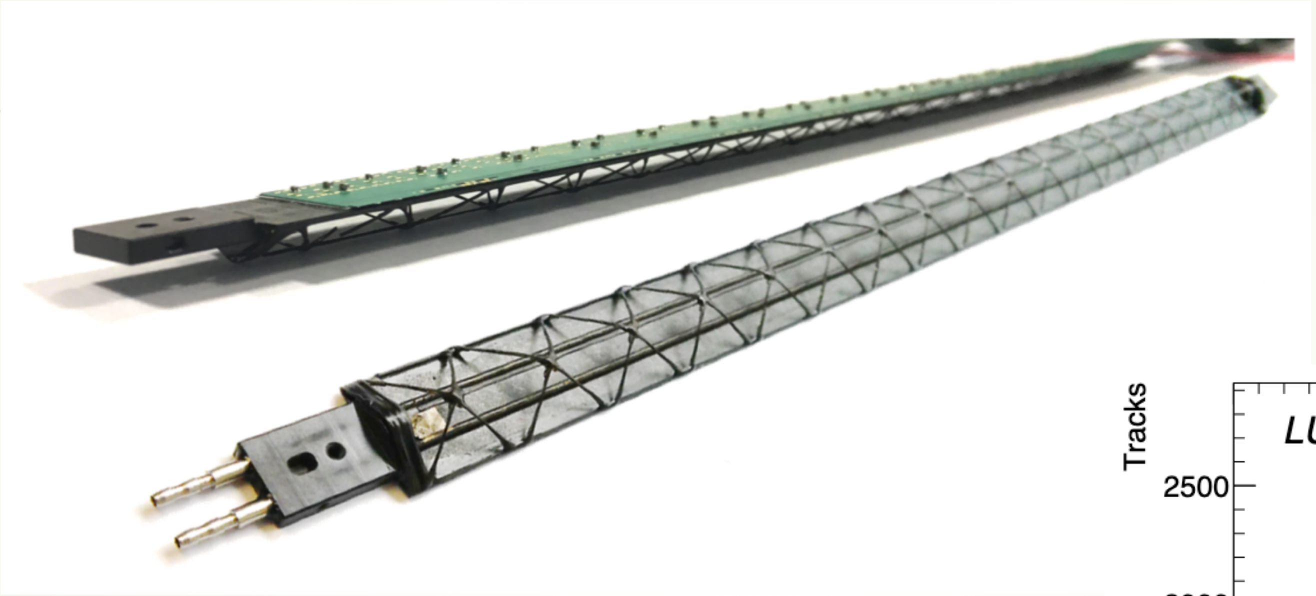
- Rate depends on the laser intensity and production type



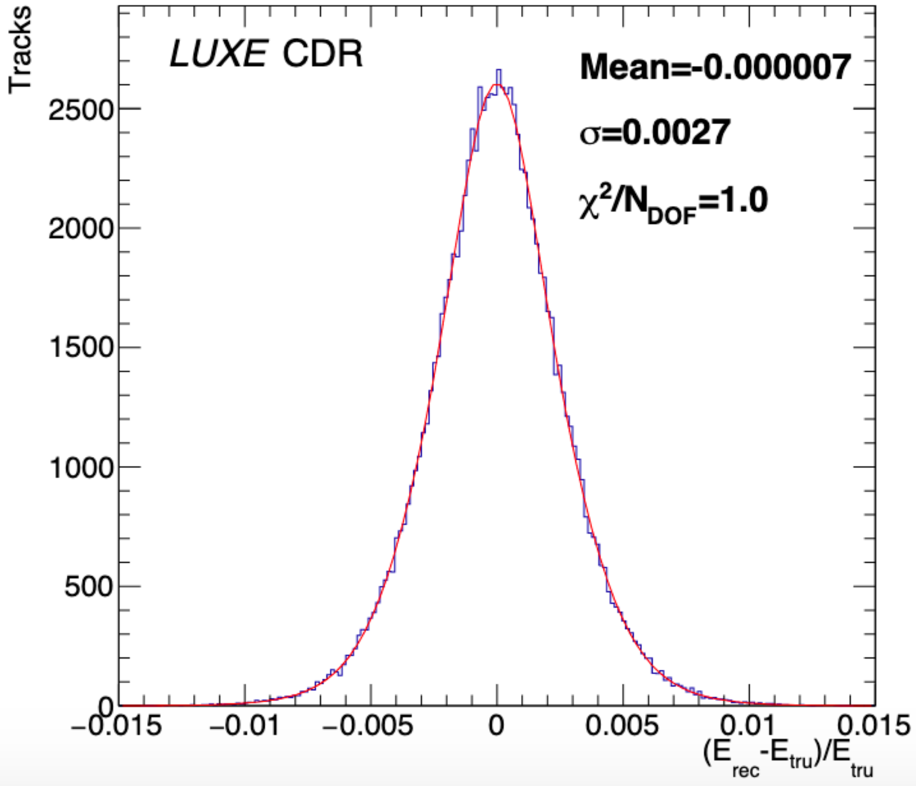


Tracker

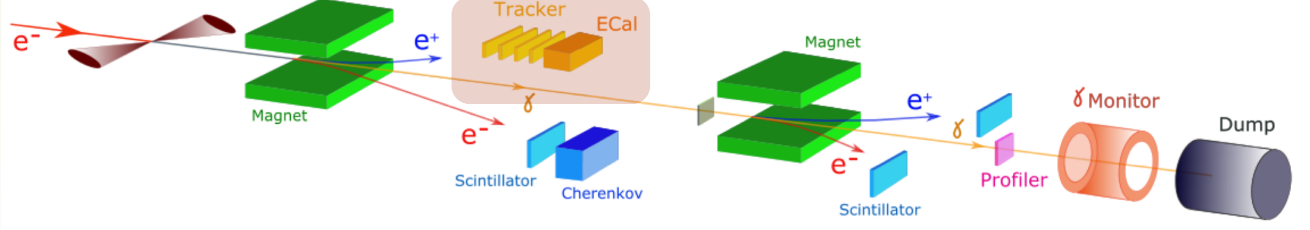




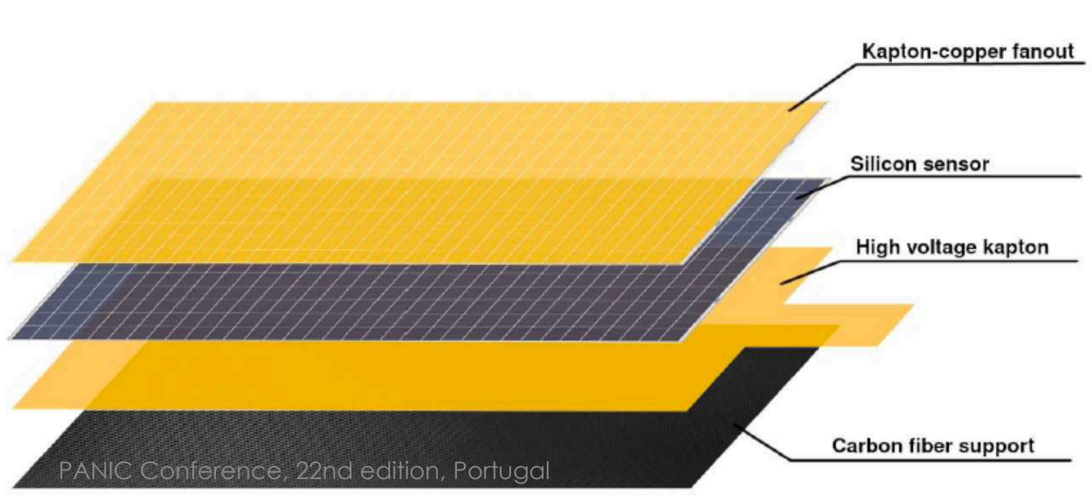
- Four layers of ALPIDE sensor :
  - Developed by ALICE for the phase 1 upgrade
  - Pitch size 27x29 μm^2 with a special resolution of 5 μm
  - Very high tracking efficiency

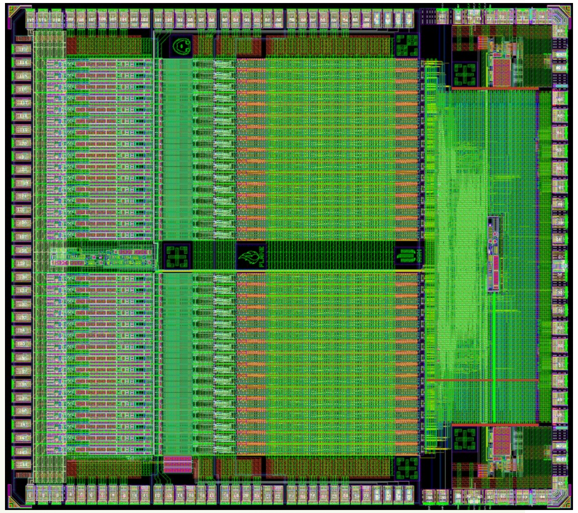


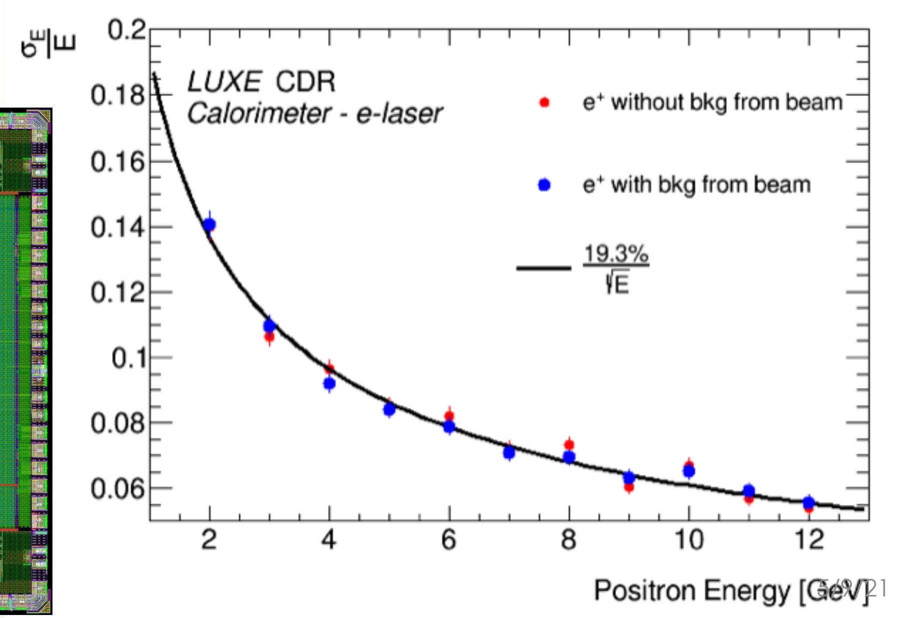
Calorimeter



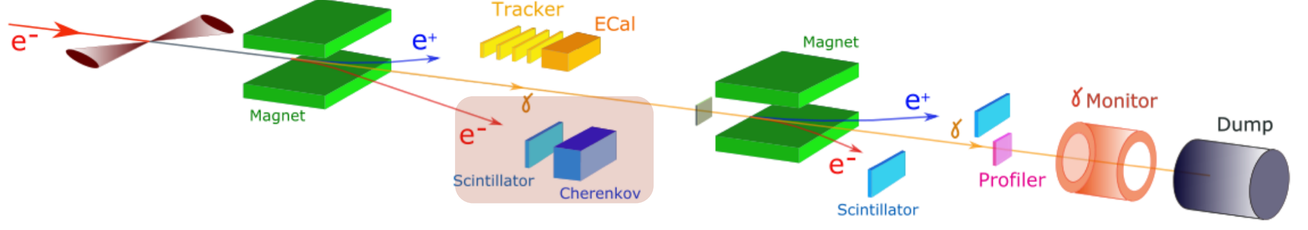
- 20 layers of 3.5 mm thick tungsten plates ($20X_0$) developed for the ILC forward region
- High granularity sensors with pads of 5x5 mm^2. Silicon and GaAs under study.
- Ultra compact (1mm between tungsten planes) to ensure a small Moliere radius so a good spatial resolution
- Dedicated readout FLAME ASIC, designed for ILC and modified to fit the LUXE trigger rates
- Development of strong algorithm for high multiplicity events



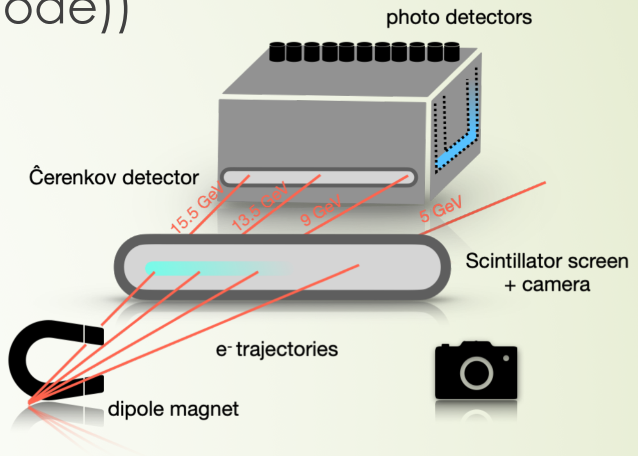


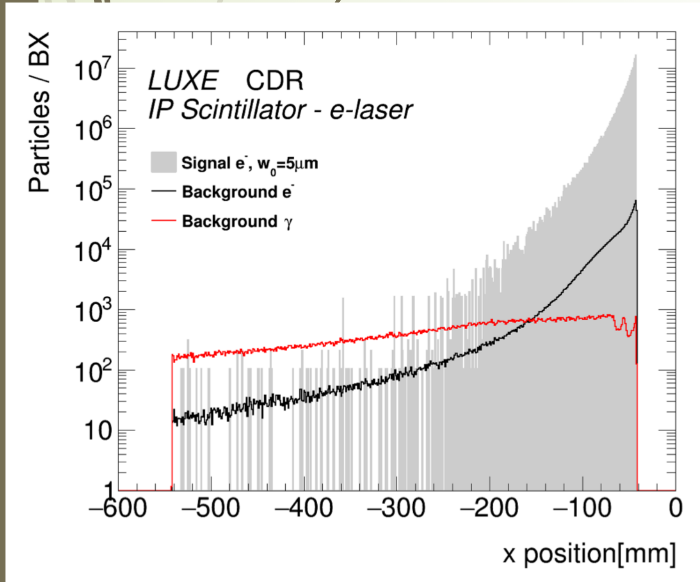


Electron side

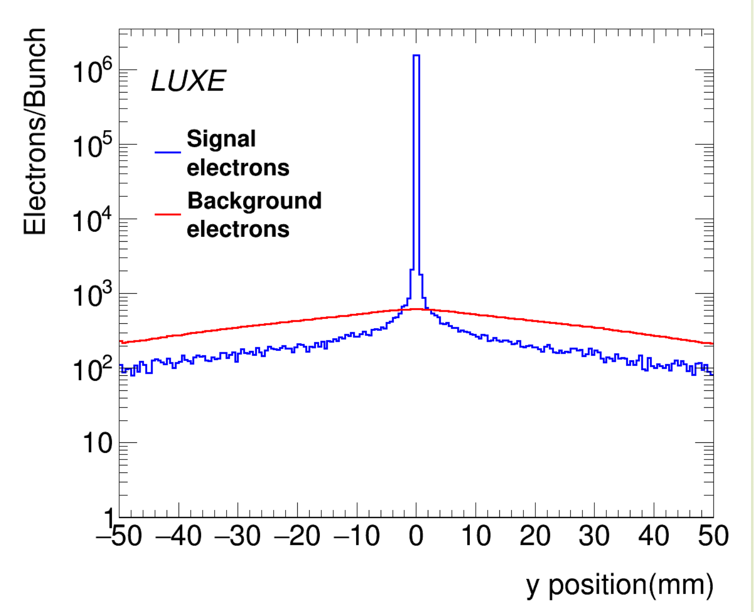


- Challenging because of the event rate (up to 10^9 e^- in electron-laser mode))
- Measurement of the non linear Compton spectrum
- Technology:
  - Scintillator screen
  - Cherenkov gas detector

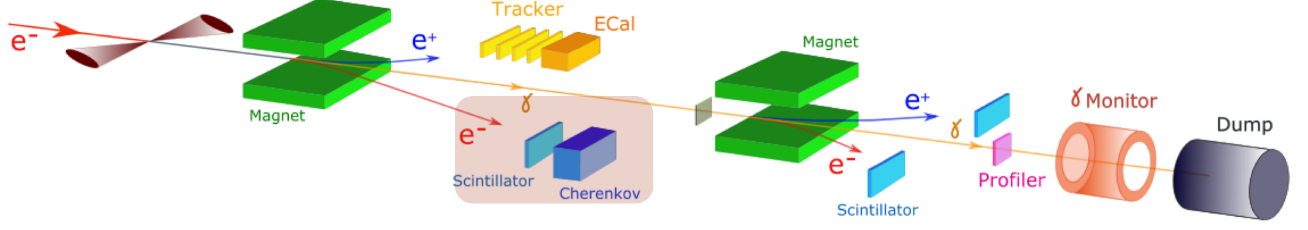




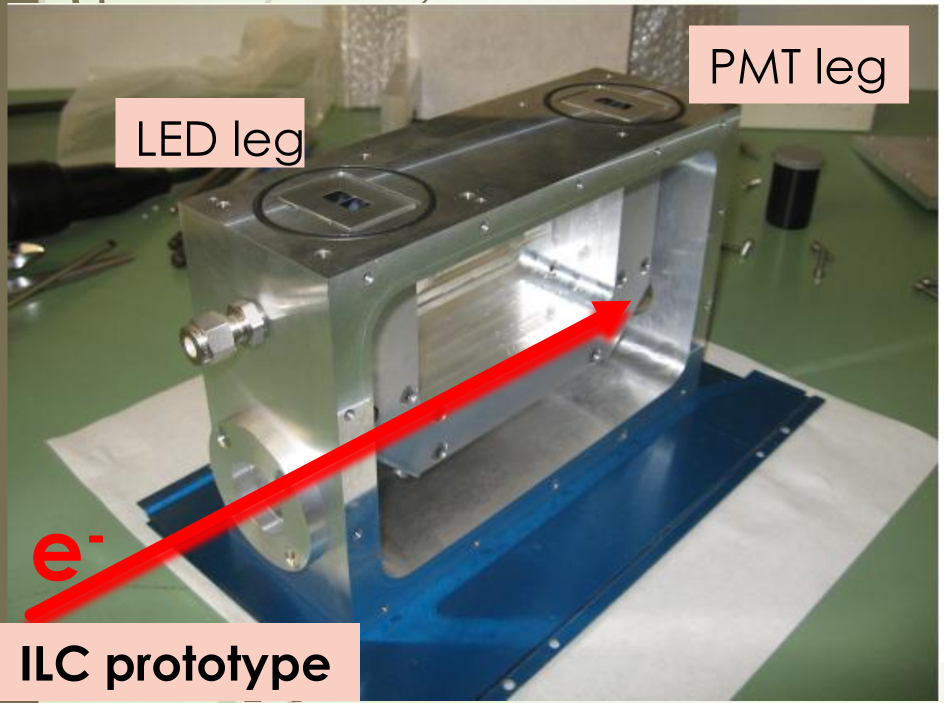
- <u>Scintillator screen</u>
  - Used by the AWAKE collaboration at CERN
  - Camera takes pictures of the scintillation light. Resolution ~ 500 μm.
  - Signal/Background ~100
  - Radiation hard (100 MGy)

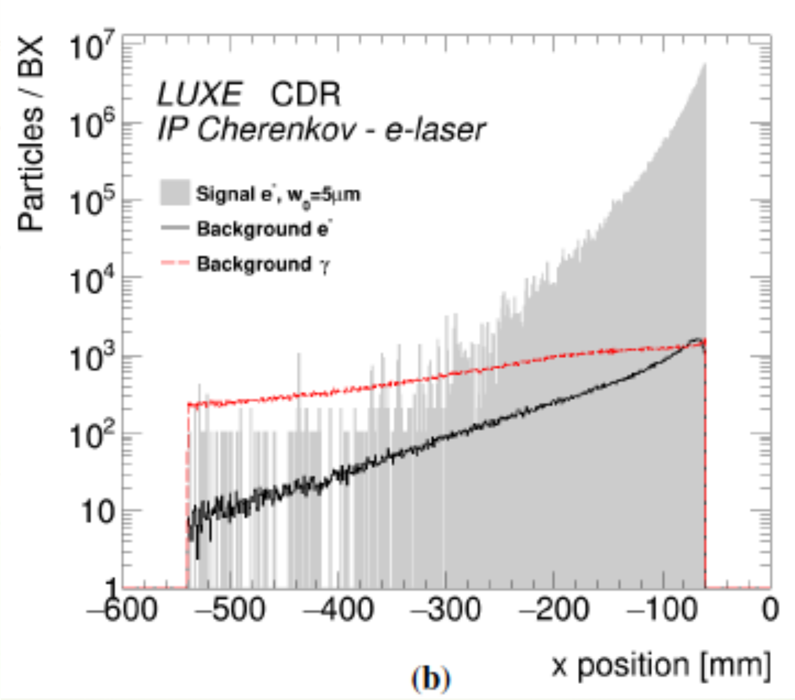


Cherenkov gas detector

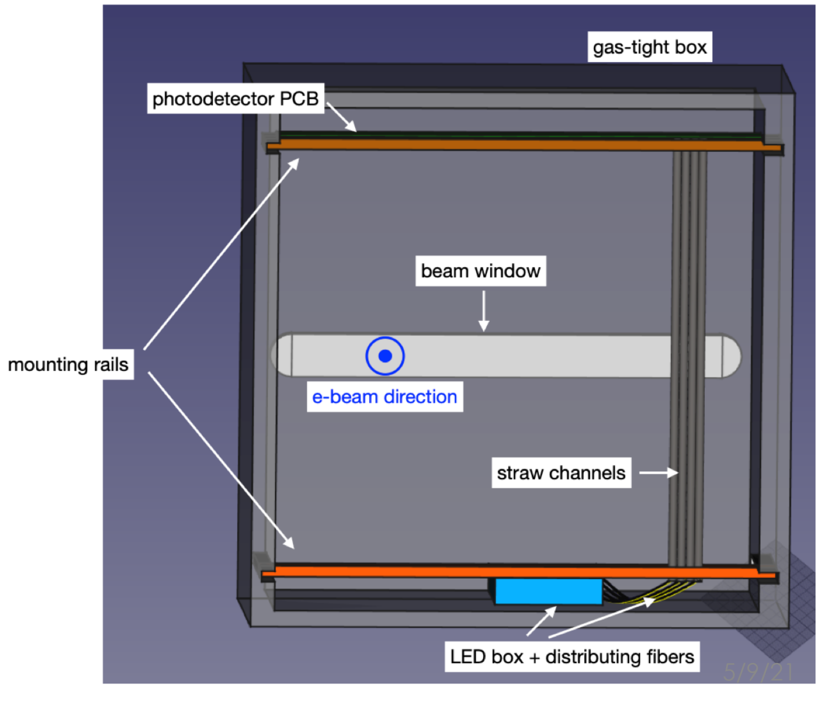


- Ar gas developed for ILC polarimeter
- Low refractive index gas helps to reduce light yield (Cherenkov threshold 20 MeV)
- Signal/background>1000

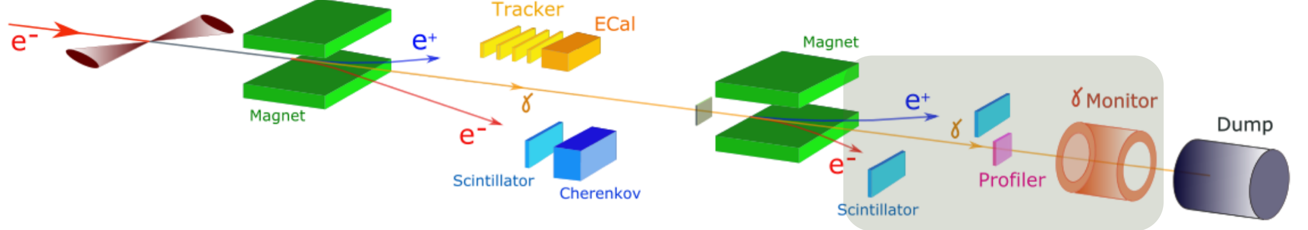




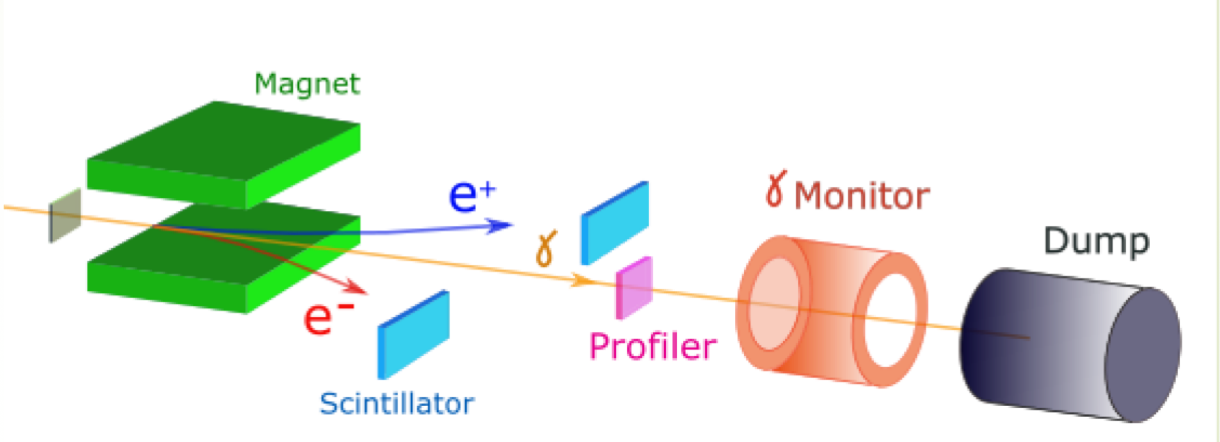
LUXE R&D

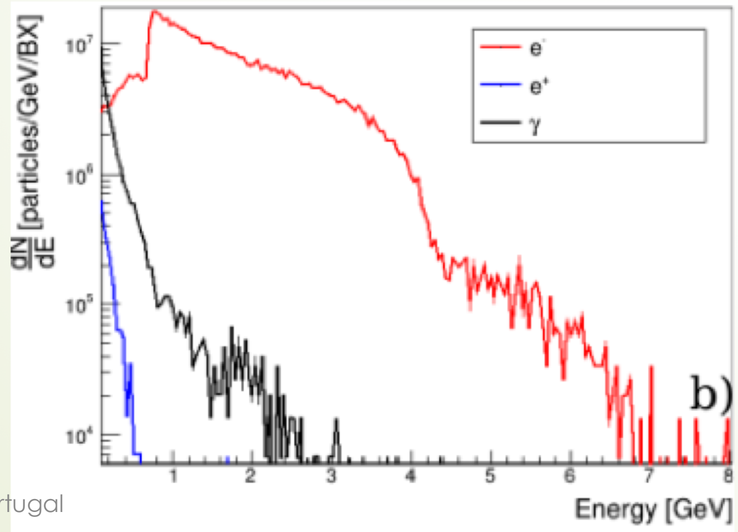


Photon detection

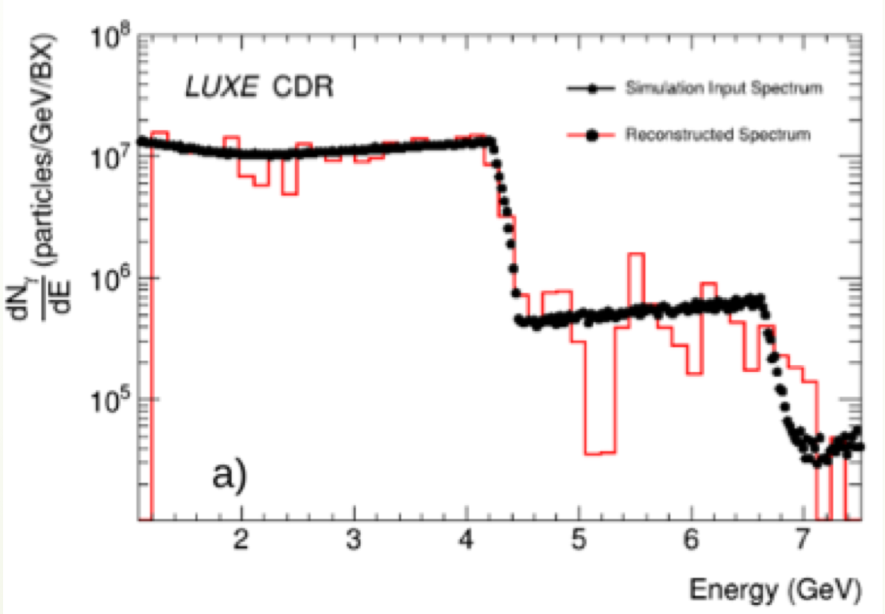


- After the convertor target (10 μm tungsten), production of 10^4-10^5 e^+/e^- pairs and 10^9 photons
- Three technologies in the forward region:
  - Spectrometer with LANEX scintillator screens coupled with photo cameras (for e^+ and e^-)
  - Gamma profiler : sapphire strips sensors to measure transverse profile of the beam
  - Measurement of the flux with a backscattering calorimeter (γ monitor)

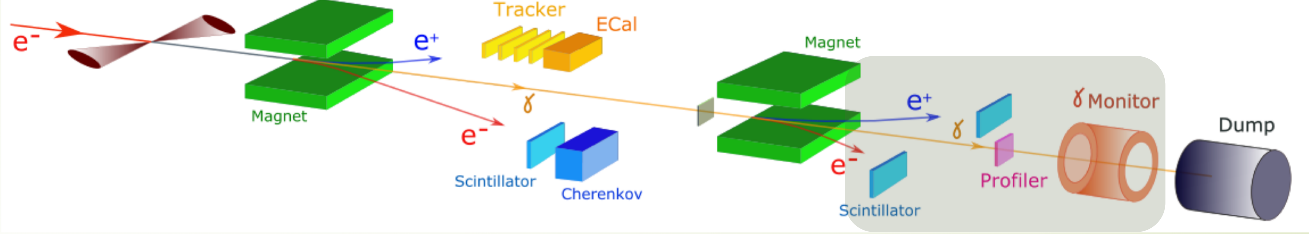




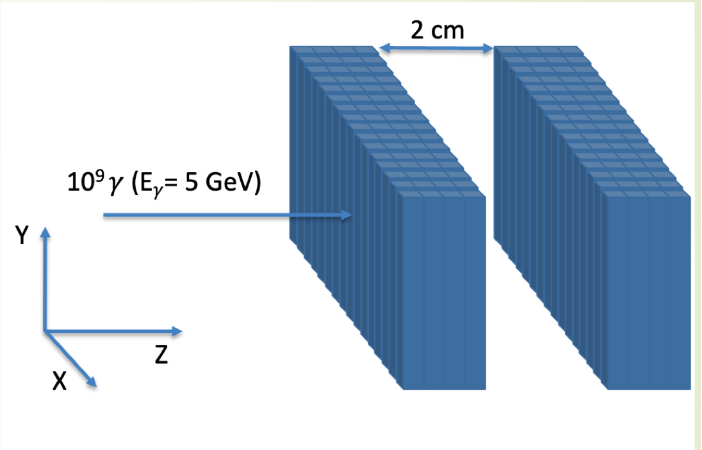
deconvolute

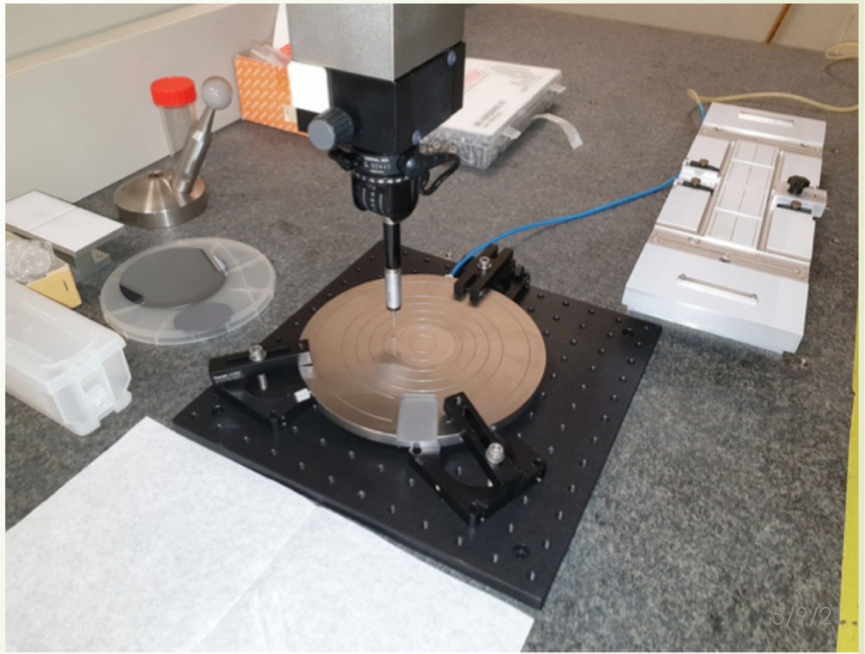


Gamma beam profiler

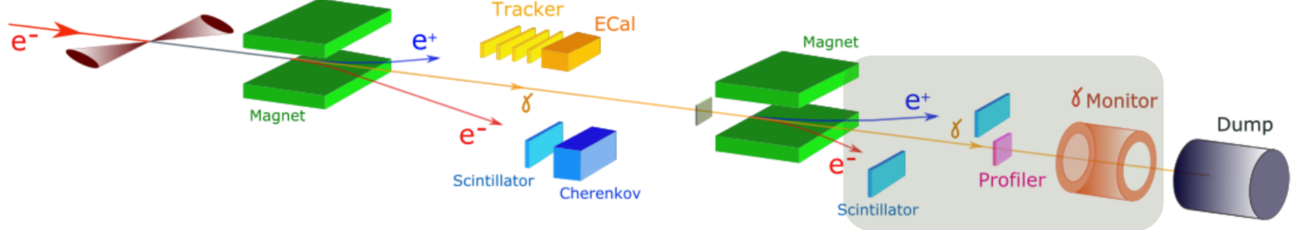


- Two sapphire strip detectors perpendicular to the beam, located on a micron precision xy table:
  - 2x2 cm^2, 100μm thickness with 100μm strip pitch
  - Very radiation hard material (up to 100MGy)
  - 5% precision in laser intensity reconstruction
  - Measurements on wafers started
- Readout from CAEN product based on the CITIROC chip

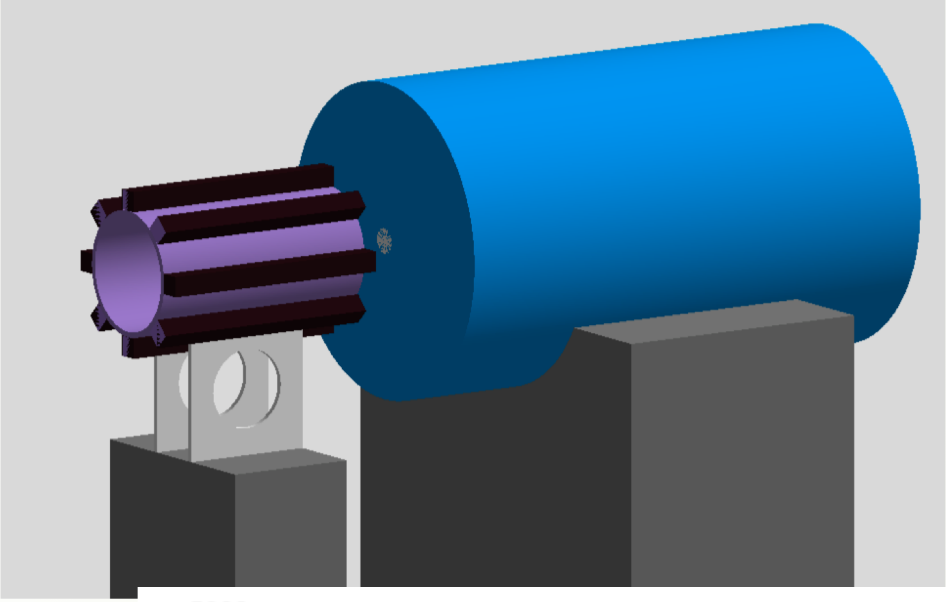


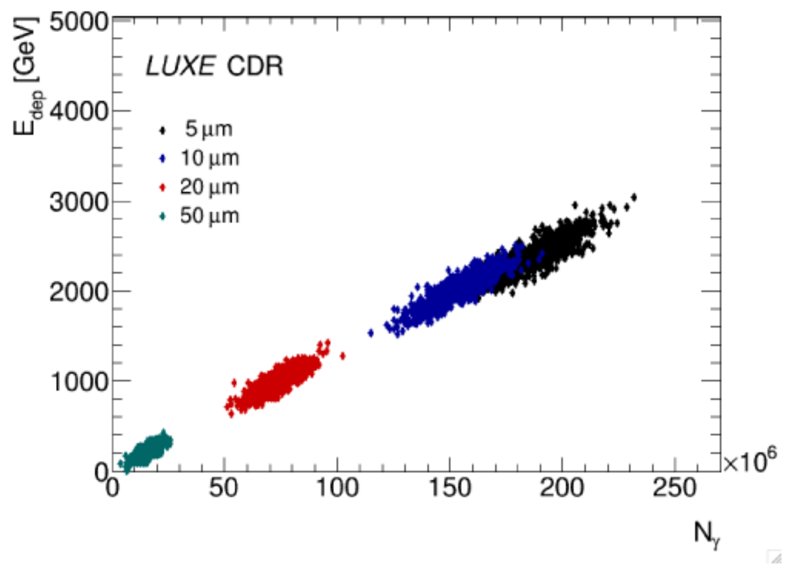


Photon detection : photon flux



- Measure energy flow of particles back scattered from the dump
- For $\xi>1$, the number of photons is larger than 10^8 per bunch crossing
- Optimization of the design to:
  - Reduce radiation damages
  - Measure sufficient fraction of the energy to be sensitive to direct photon flux variation
- Consists of 8 lead glass blocks located 10cm upstream of photon beam dump around beam axis with radius ~ 17cm
- Light is read by PMTs
- Almost linear dependence between the energy deposited and the number of incident photons, with uncertainty between 3% and 10%





Synchronization, trigger and DAQ

- Need to synchronize (spatial and temporal) between electron and LASER beams
  - 30fs LASER pulse, >100fs electron bunch.
  - Temporal : XFEL developed synchronization with optical clock <13fs
  - Spatial : beam pointing monitoring systems for both electron and LASER beam
- Trigger :
  - Signal from the trigger LASER-electron sent to Trigger Logic Unit (TLU)
  - The TLU (latency <25ps) will distribute the trigger to all the detectors. The TLU will also distribute the electron beam trigger for calibration purposes
- The detectors DAQ will use the EUDAQ framework

Summary

- The LUXE experiment will explore strong-field QED predictions using European XFEL and high power laser
- all the detectors have been designed and tuned to cope with rate measurements, from 10^{-2} to 10^{9} per bunch crossing
- Conceptual Design Report has been accepted and the Technical Design Report is in preparation
- Installation is foreseen in 2024 during the extended shutdown of the European XFEL.
- Data taking phase 0 from 2024 and 2025, phase 1 will start in 2026