The LUXE Experiment

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DESY

Physics

Explore Quantum Electrodynamics at high fields

Pertubative QED predicts electromagnetic phenomena with excellent precision, e.g. Lamb shift, anomalous magnetic moment of the electron, Bhabha scattering

At high fields, Heisenberg and Euler predicted in Z.Phys. 98 (1936) 714-732
Title:„Folgerungen aus der Dirac`schen Theorie des Positrons“

‘electromagnetic fields can create matter if they are strong enough’

Critical field strength: $|\mathfrak{E}_k| = \frac{m^2 c^3}{e\hbar} = \frac{1}{137} \frac{e}{(e^2/mc^2)^2}$ = 1.32 10^{18} Vm^{-1}

Denoted as ‚Schwinger limit‘!

Physics

$\mathfrak{E}_k$ accelerates an electron over the distance of its Compton wavelength to E_e equal to its mass

For illustration: In a silicon sensor of 300 µm thickness and this field strength:

$$E_e = 400 \text{ TeV}$$

New phenomenon: Field induced tunneling of e^+e^- pairs off the vacuum,
Colloquial: ‚the vacuum starts boiling'

Source of high electrical fields: chirped pulse amplification (CPA) laser,
focal intensity 10^{21} Wcm^{-1}

$\mathfrak{E}_L = 10^{14}$ Vm^{-1}

Electron at high energy in a laser pulse: $\mathfrak{E}^* = \gamma\, \mathfrak{E}_L (1 + \cos\theta)$ $\gamma = E_e/m_e$

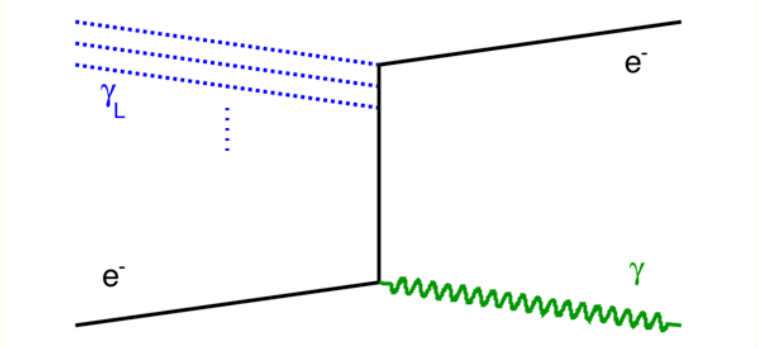
Example:

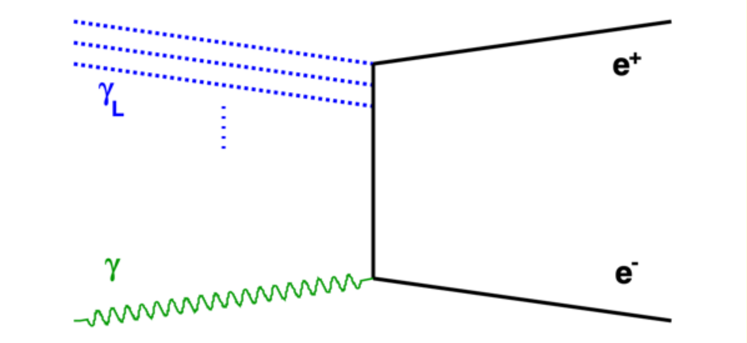
For E_e = 10 GeV, $\gamma \approx 10^4$ ➔ critical field strength $\mathfrak{E}_k$ will be reached !

Processes

Non-linear Compton scattering

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





Breit-Wheeler process (BW)

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

The initial photon might be the γ_C
from non-linear Compton scattering (two step trident)
or a dedicated high-energy photon beam

Physics

Key parameters

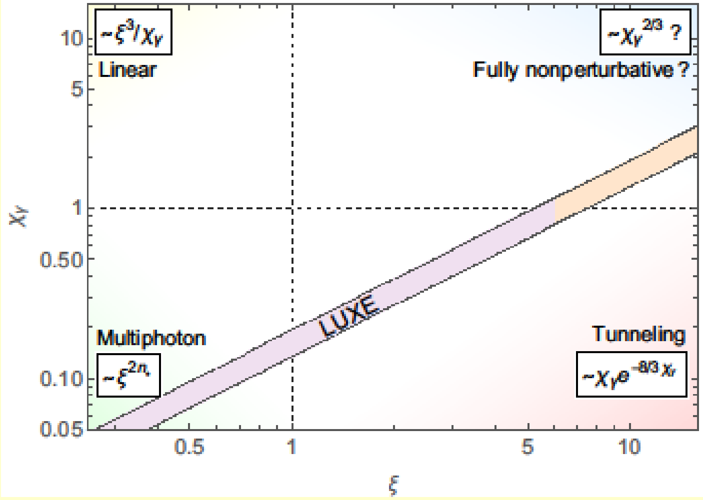
LUXE covered range

	40 TW	350 TW (Laser)
Classical non-linearity parameter: $\xi = \frac{m_e}{\omega_L} \frac{\mathfrak{E}_L}{\mathfrak{E}_k}$	≤ 6	≤ 19
Quantum non-linearity parameter: $\chi = \mathfrak{E}^* / \mathfrak{E}_k$	≤ 1	≤ 3

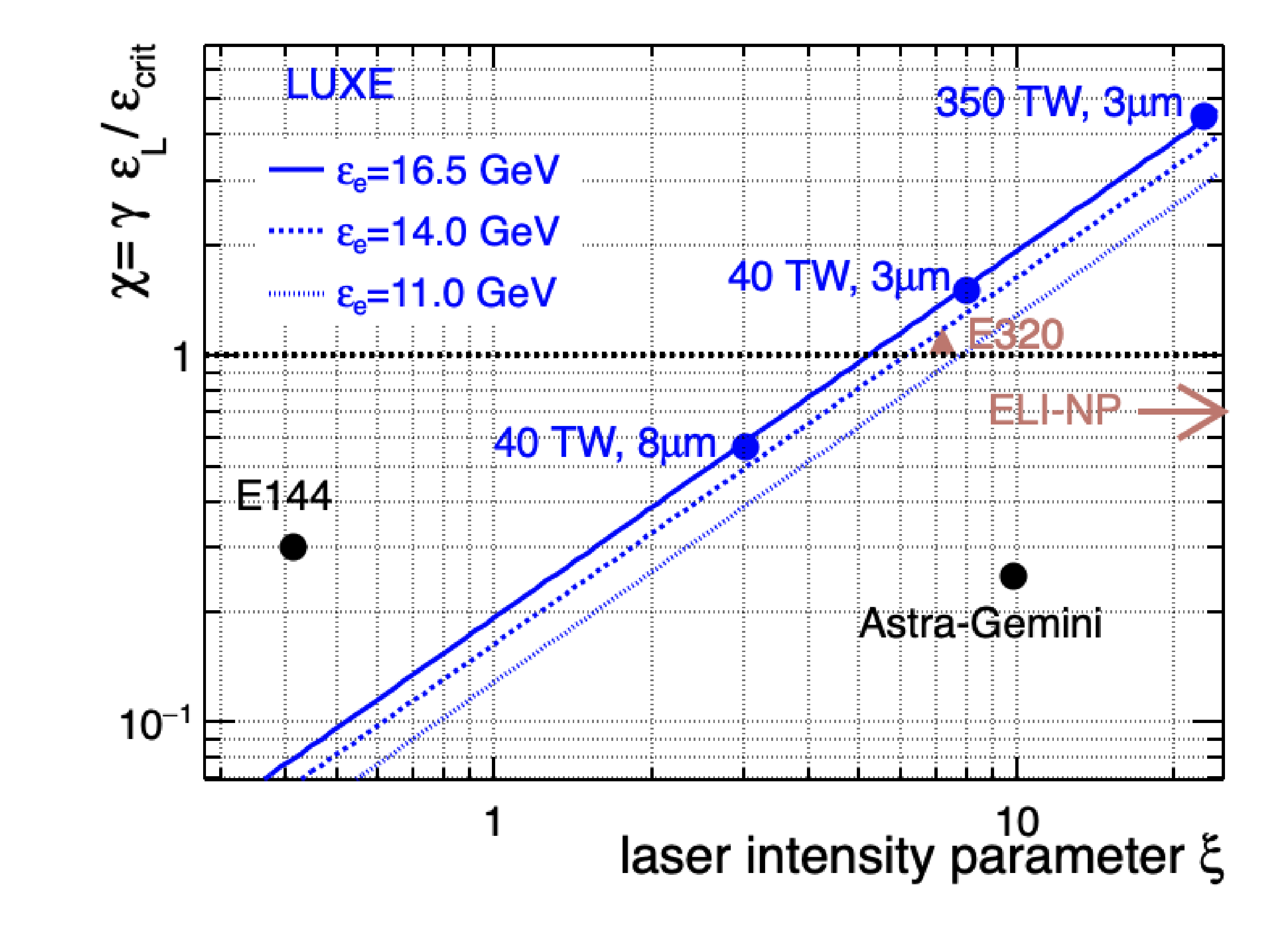
Energy parameter: $\eta = \chi / \xi$

Consider BW: $\gamma + n\gamma_L \longrightarrow e^+ e^-$

Quantity to measure: $\Gamma_{BW} \sim \chi \exp\left(- \frac{8}{3} \frac{1}{\chi}\right)$



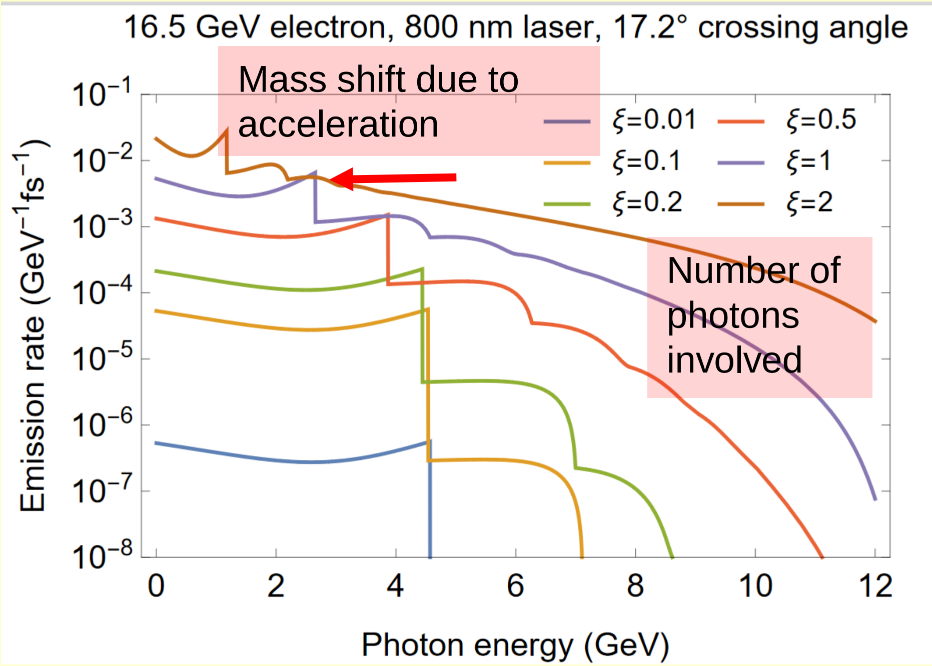
Comparison to similar experiments



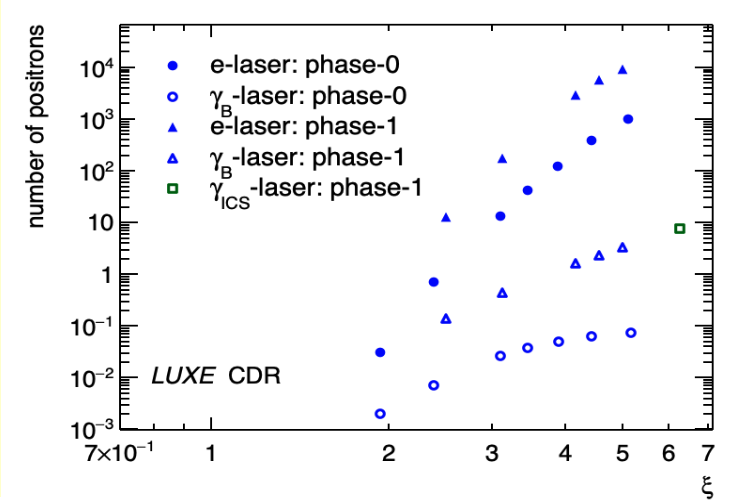
Physics

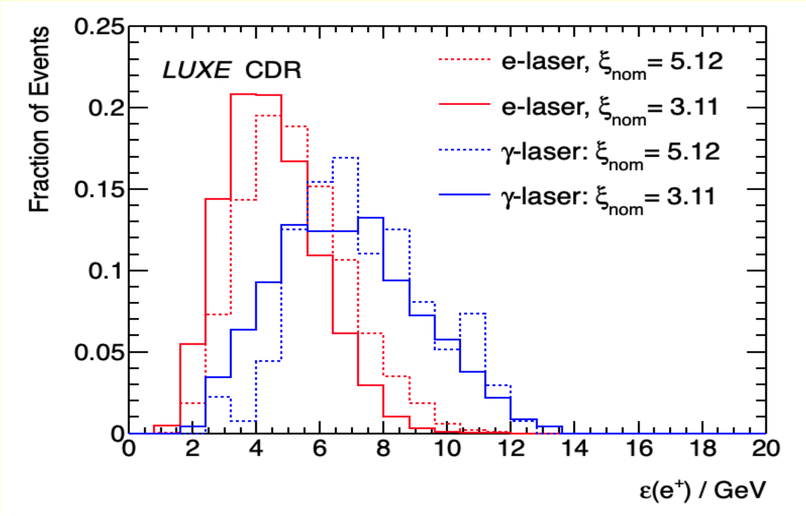
planned measurements

Compton spectra
(number and energy of the scattered laser photons, or the final state electrons)



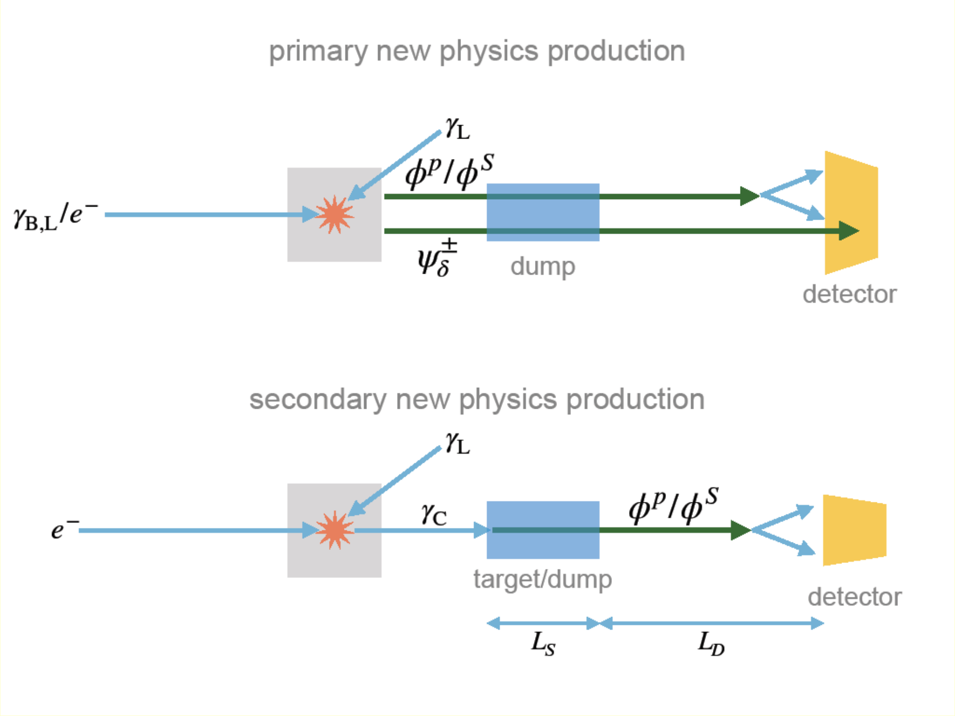
Number and energy of positrons





Search for ALPS

Scalars or pseudoscalars with couplings to photons and electrons



Primary production,
ALPS in the range of a few MeV

Secondary production,
ALPS in the range of a few 100 MeV to GeV

Technicalities

XFEL linear accelerator at DESY

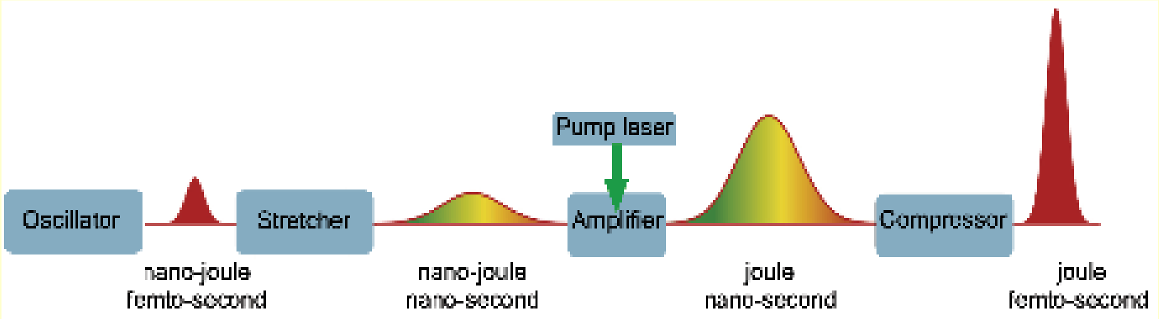
Electron beam

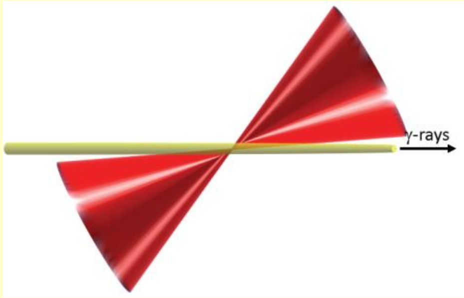
- 1.5 10^9 e^- per bunch,
- E_e = 17.5 GeV,
- rate 10 Hz, one bunch per train for LUXE

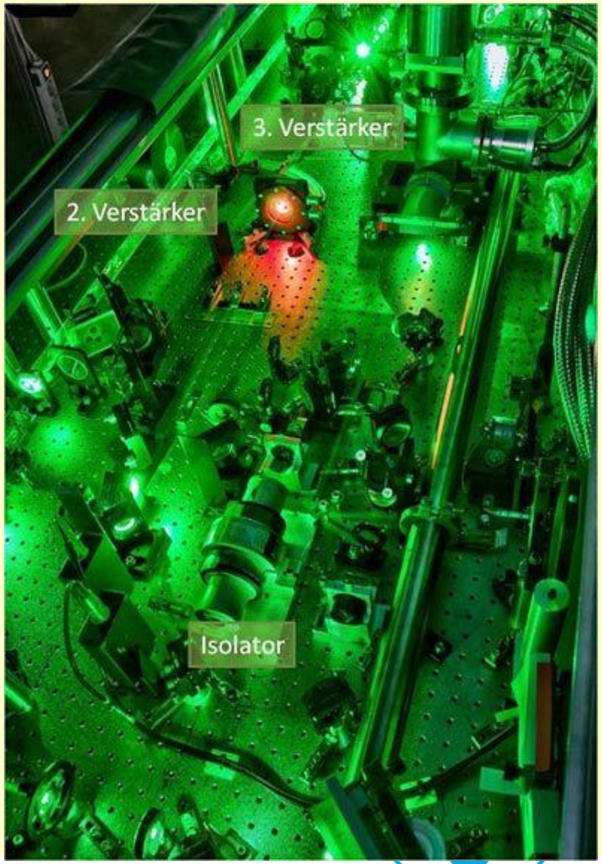
Technicalities

LASER

- first run: 40 TW JETI, intensity 1.5 10^{20} Wcm^{-2} (focal width 3 µm)
- second run: upgrade to 350 TW, intensity 1.1 10^{21} Wcm^{-2}

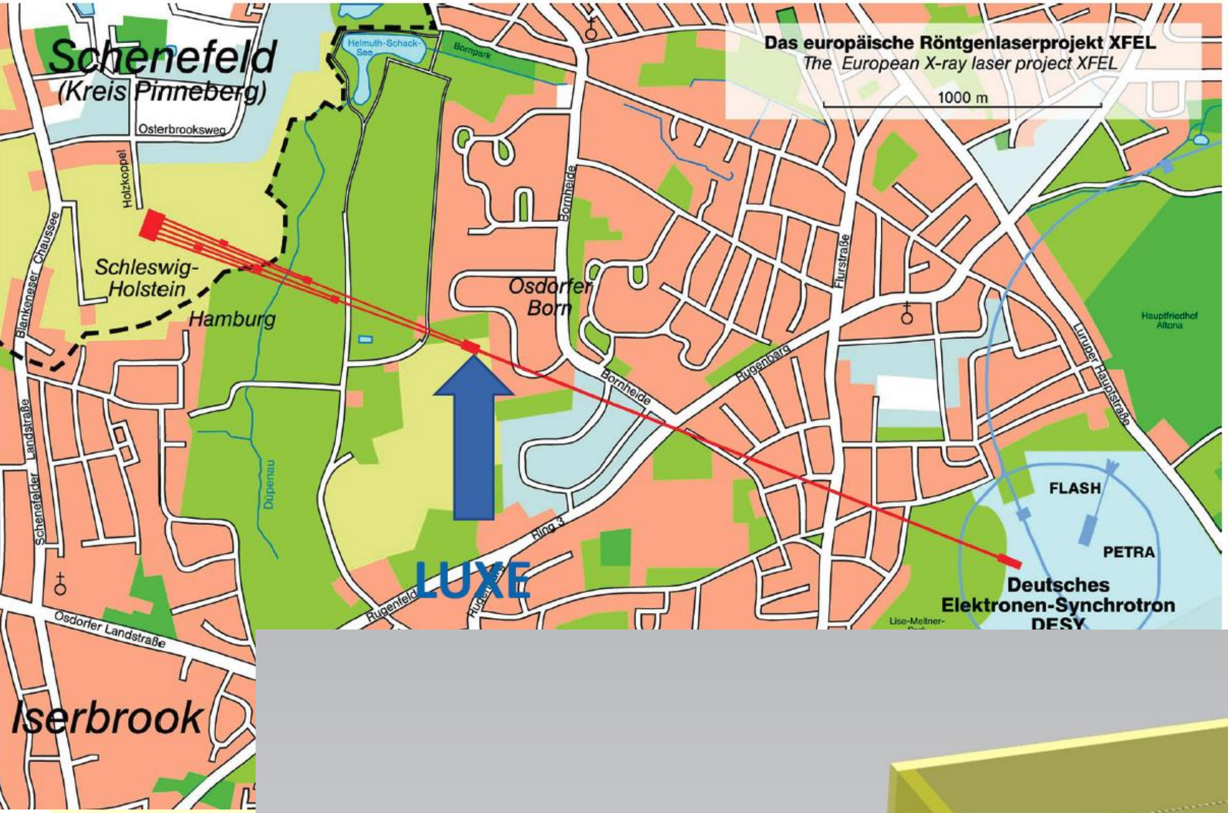






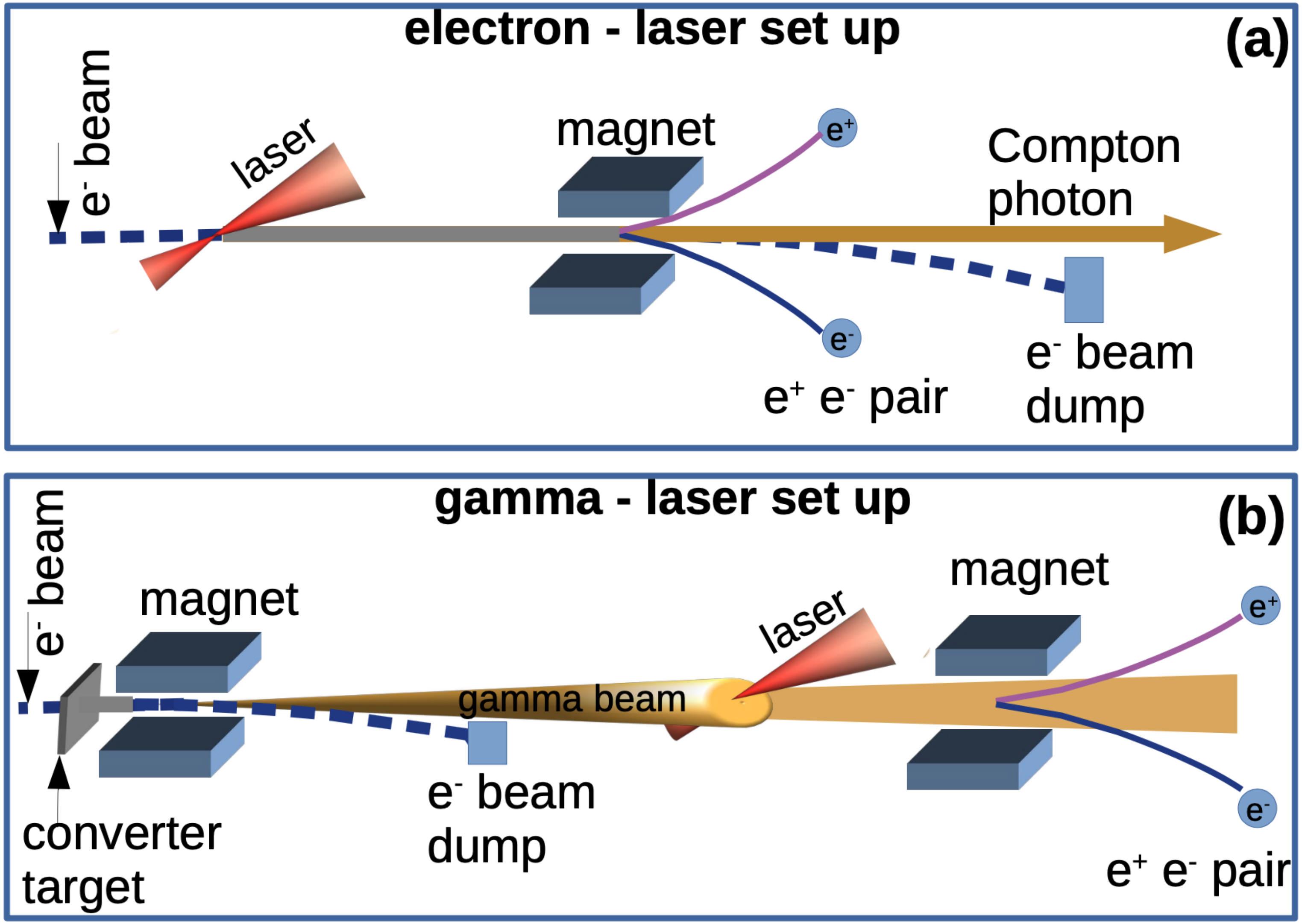
- Pulse length: 30 fs
- Repetition rate: 1 Hz
- Sychronised with the XFEL
- Multiple diagnostics systems to monitor time and spacial pulse positions, pulse energy, and ξ.

area

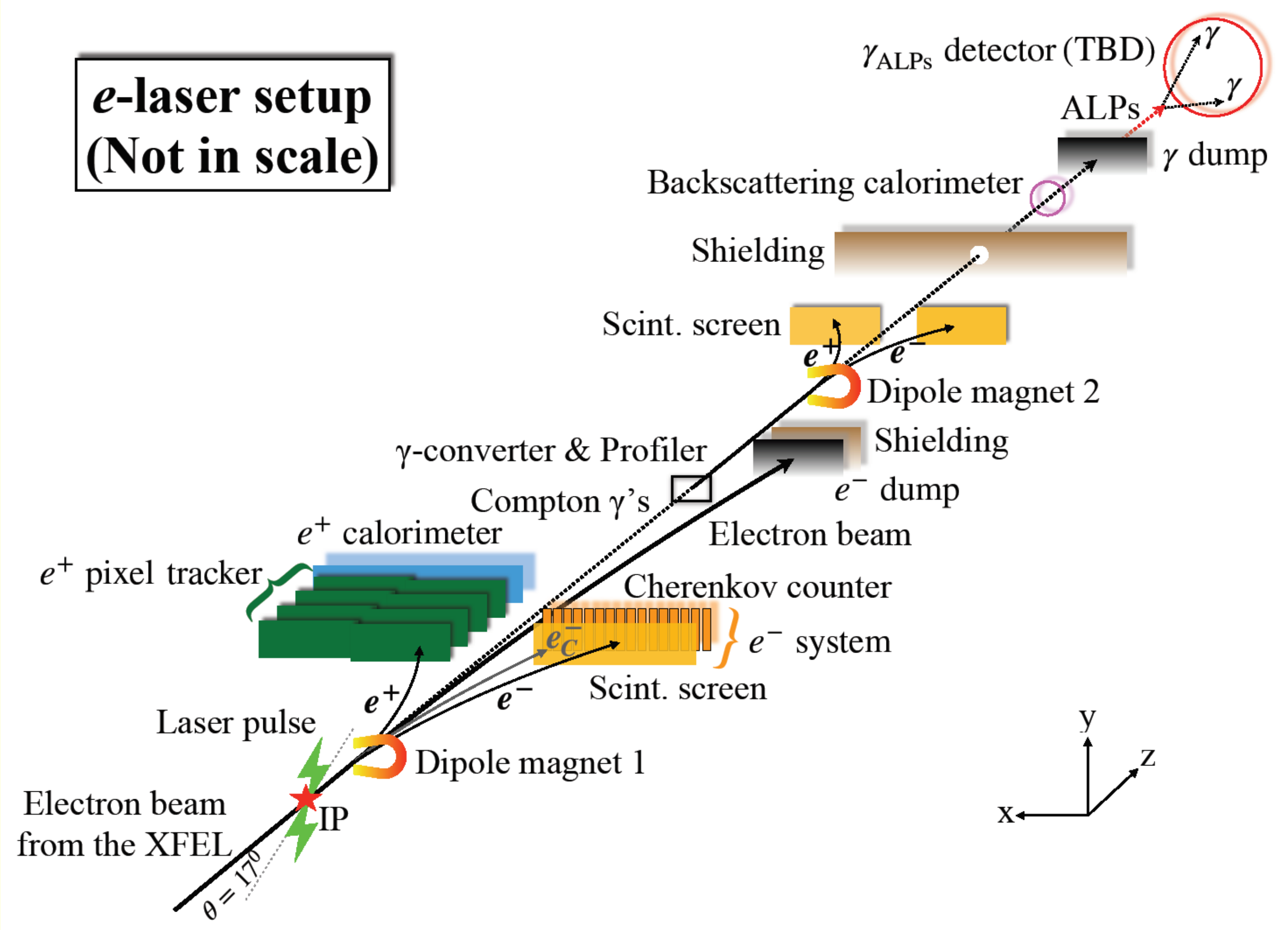

Das europäische Röntgenlaserprojekt XFEL
The European X-ray laser project XFEL
1000 m
Schenefeld
(Kreis Pinneberg)
Osterbrooksweg
Holzkoppel
Schleswig-
Holstein
Hamburg
Osdorfer
Born
Bornheide
Flurstraße
Hugenbarg
Lurup Hauptstraße
Hauptfriedhof
Altona
FLASH
PETRA
Deutsches
Elektronen-Synchrotron
DESY
LUXE
Ring 3
Rugenfeld
Dünenau
Schenefelder Landstraße
Blankeneser Chaussee
Osdorfer Landstraße
Iserbrook


XTD1
XTD2
Dump
XTL
LUXE

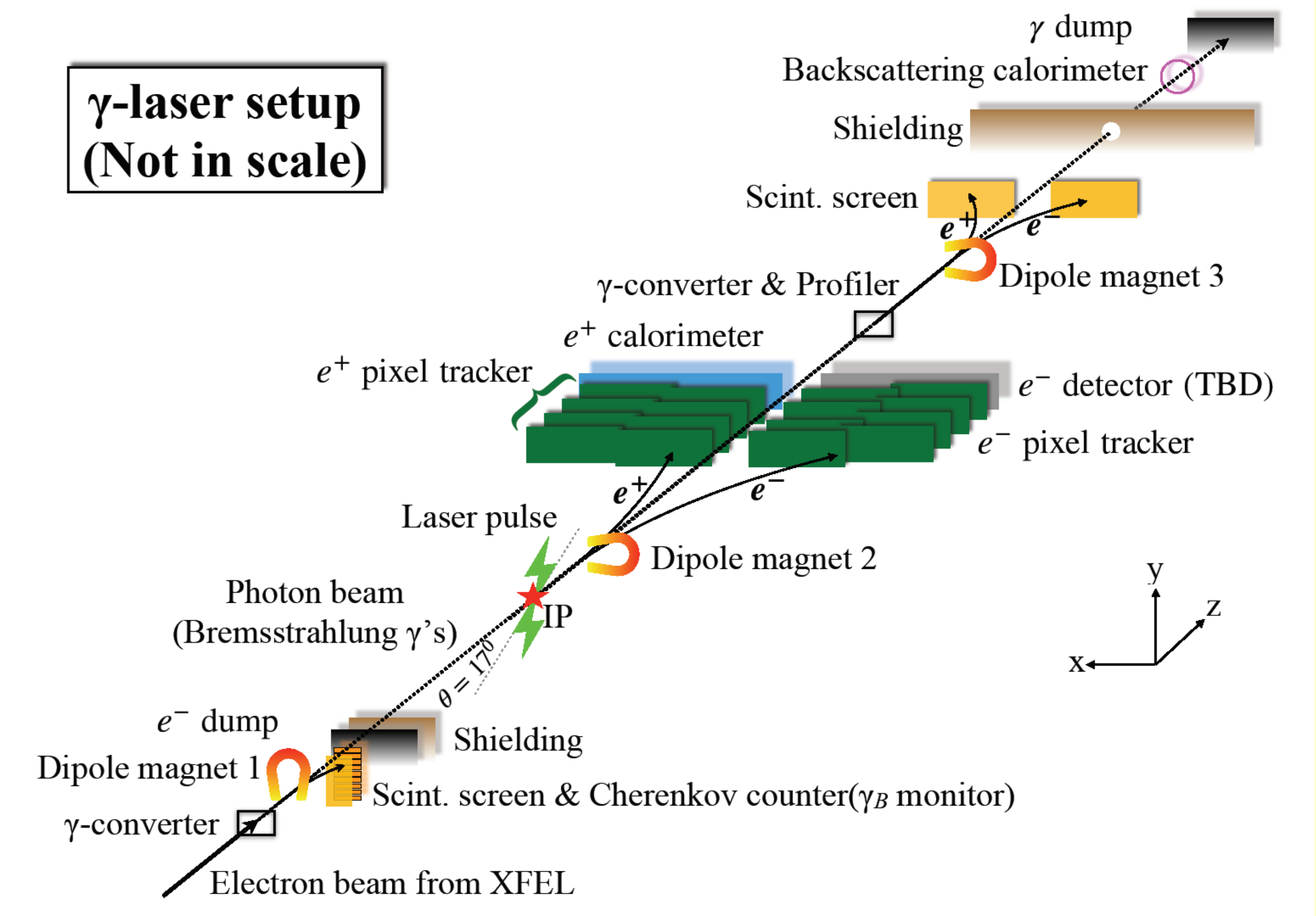
The experiment - schematic



The experiment - schematic

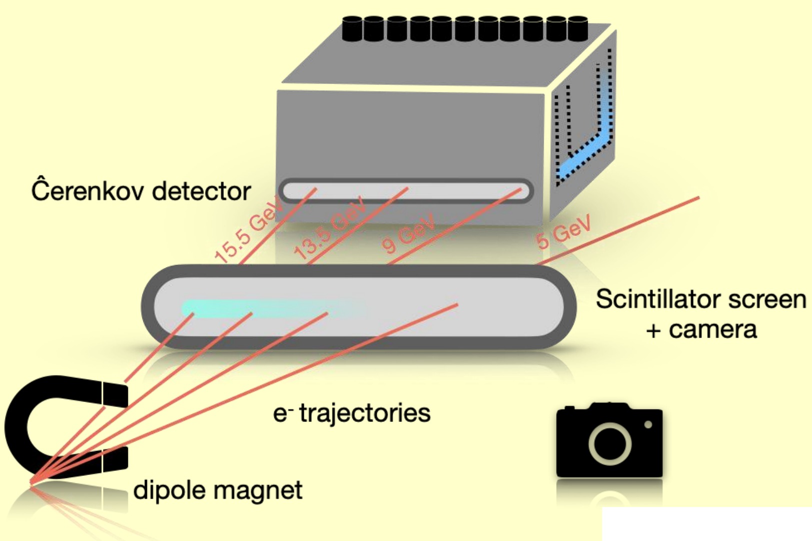


The experiment - schematic



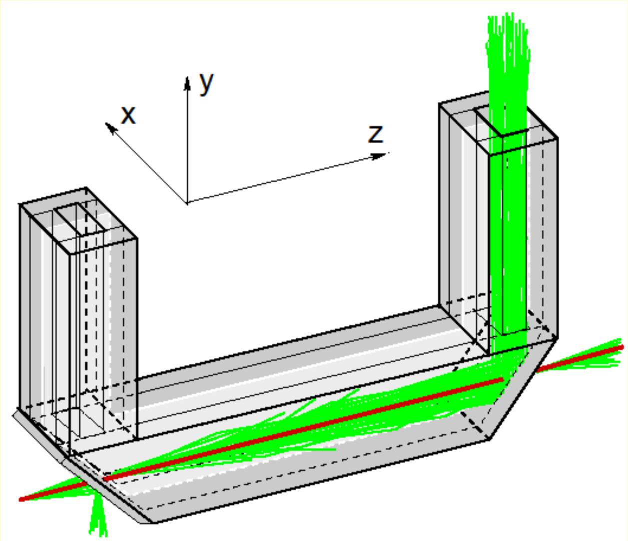
ASSOCIATION

Electron detection system



- Measurement range: 10^4-10^9 electrons per BX
- Scintillation screen covers the full momentum range, the Cerenkov detector 5-8 GeV
- Cerenkov detector developed for polarimetry the the ILC

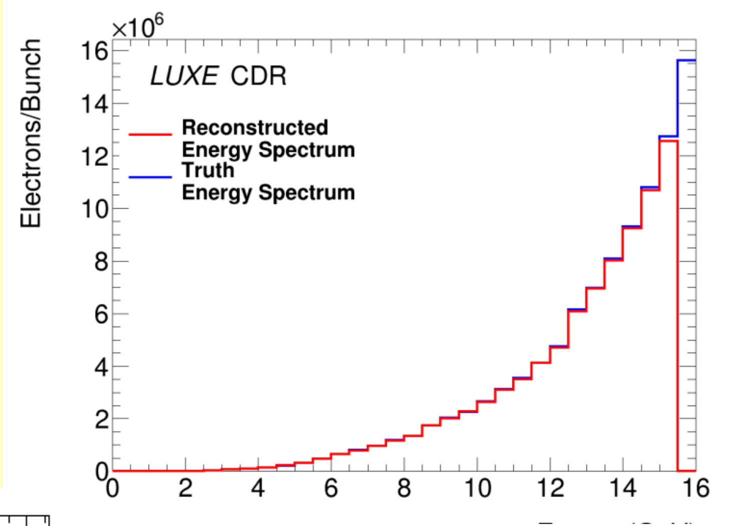
- Screen thicknes: 0.5 mm
- Scintillator: Gandolinium Oxysulfide, Terbium doped
- Position resolution: 500 µm



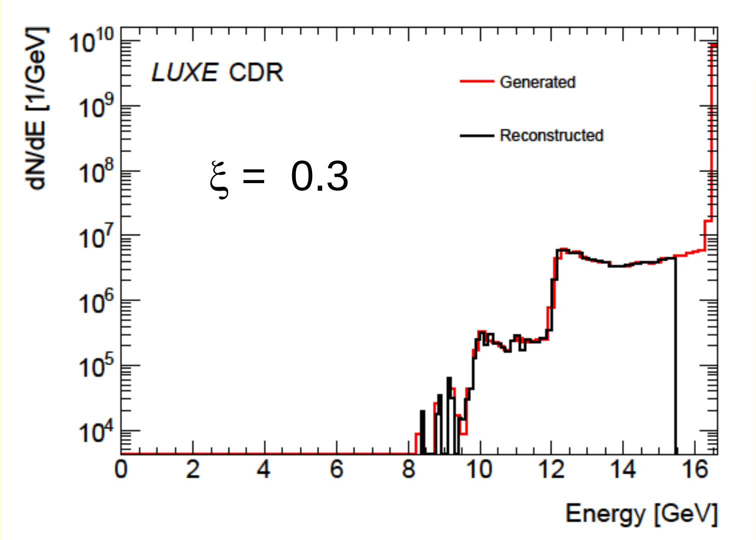
- 50 channels,
- radiator: Ar, to match the dynamic range
- SiPMs

Electron detection system

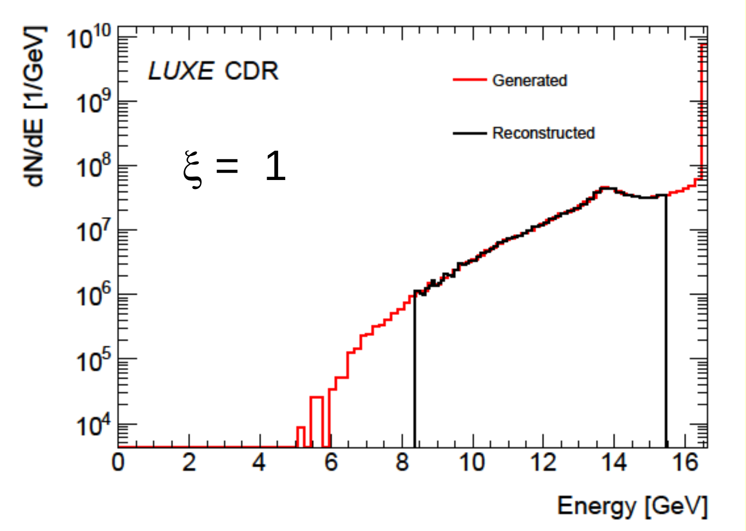
Performance studies



Electron energy spectrum using the scintillator screen

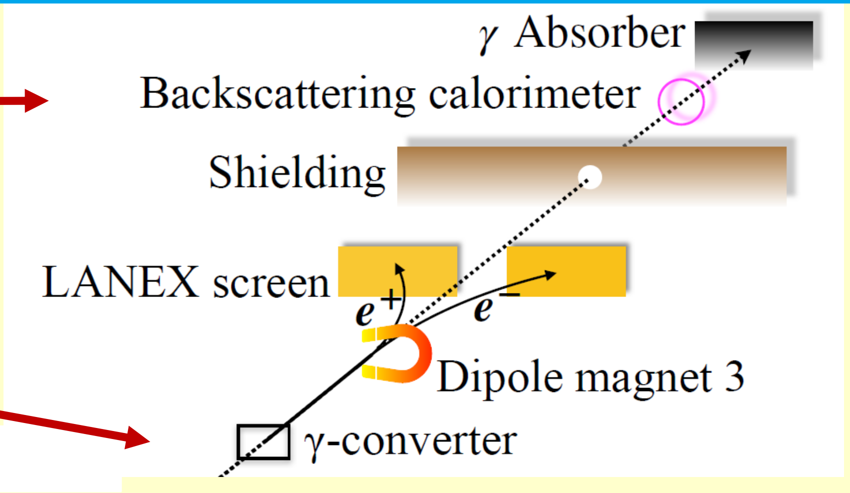


Electron energy spectrum using the Cerenkov detector



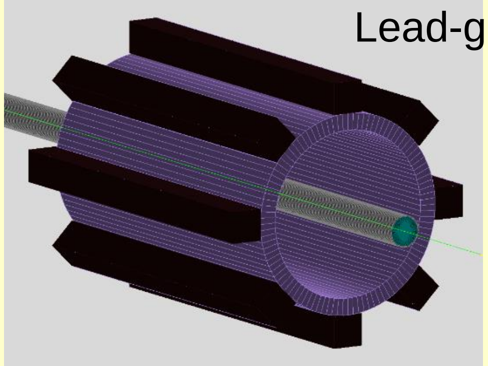
Photon detection systems

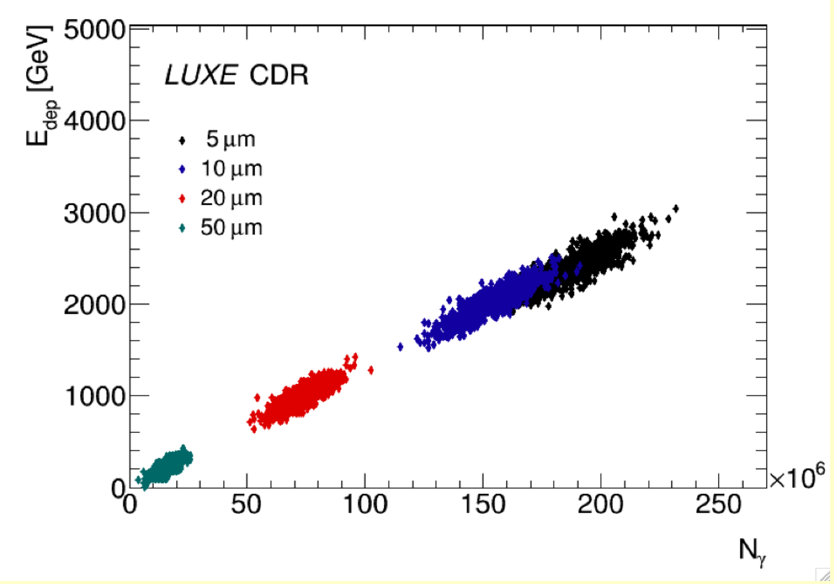
- γ flux monitor
- γ spectrometer
- γ profiler



γ flux monitor

measures the particles backscattered from the photon dump



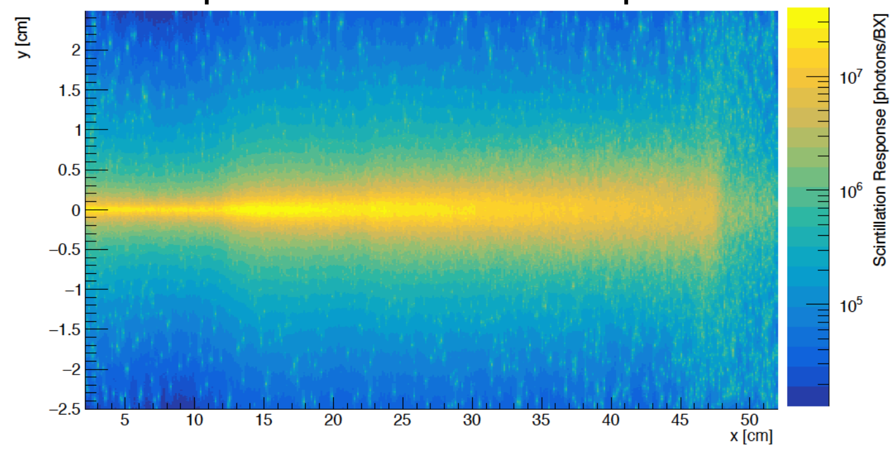


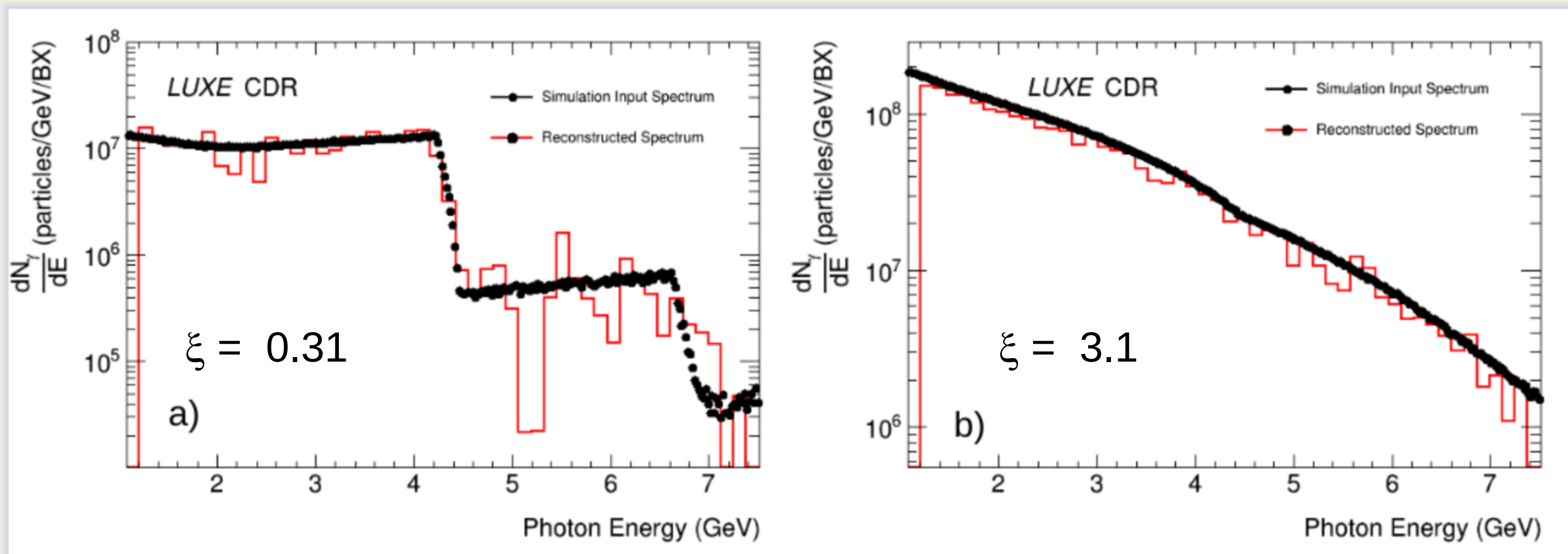
Photon detection systems

γ spectrometer

Photon conversion in a 200 μm Kapton foil
Scintillator screen, Gd_2O_2S:TB, LYSO
Read out using an i-CCD camera

Expected scintillation output





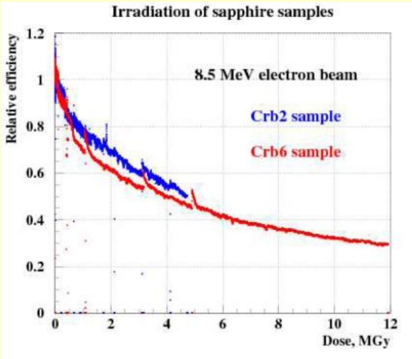
Photon detection system

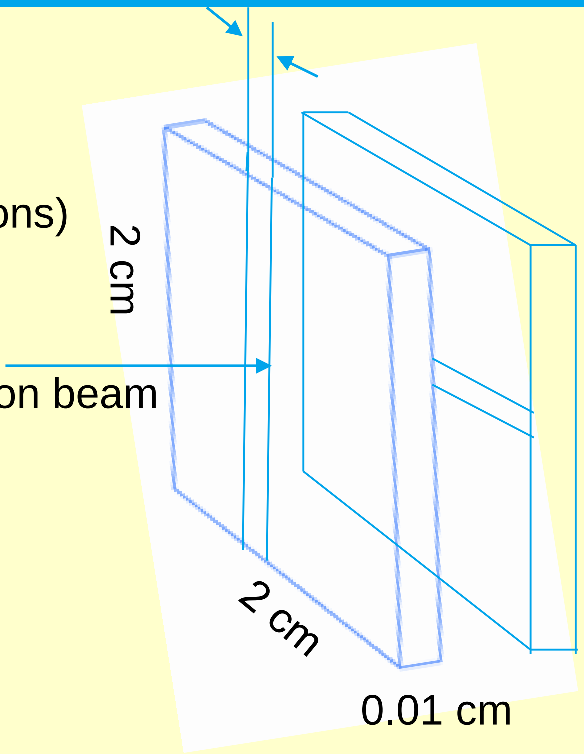
γ profiler

Measurement of the angular spectrum of photons (two stations)

Single crystal sapphire strip sensors

- Low CCE
- Fast
- Radiation hard





Investigation of a direction sensitive sapphire detector stack at the $5\ GeV$ electron beam at DESY-II

200+200 strips
Pitch: 100 μm

•*JINST* 10 (2015) 08, P08008

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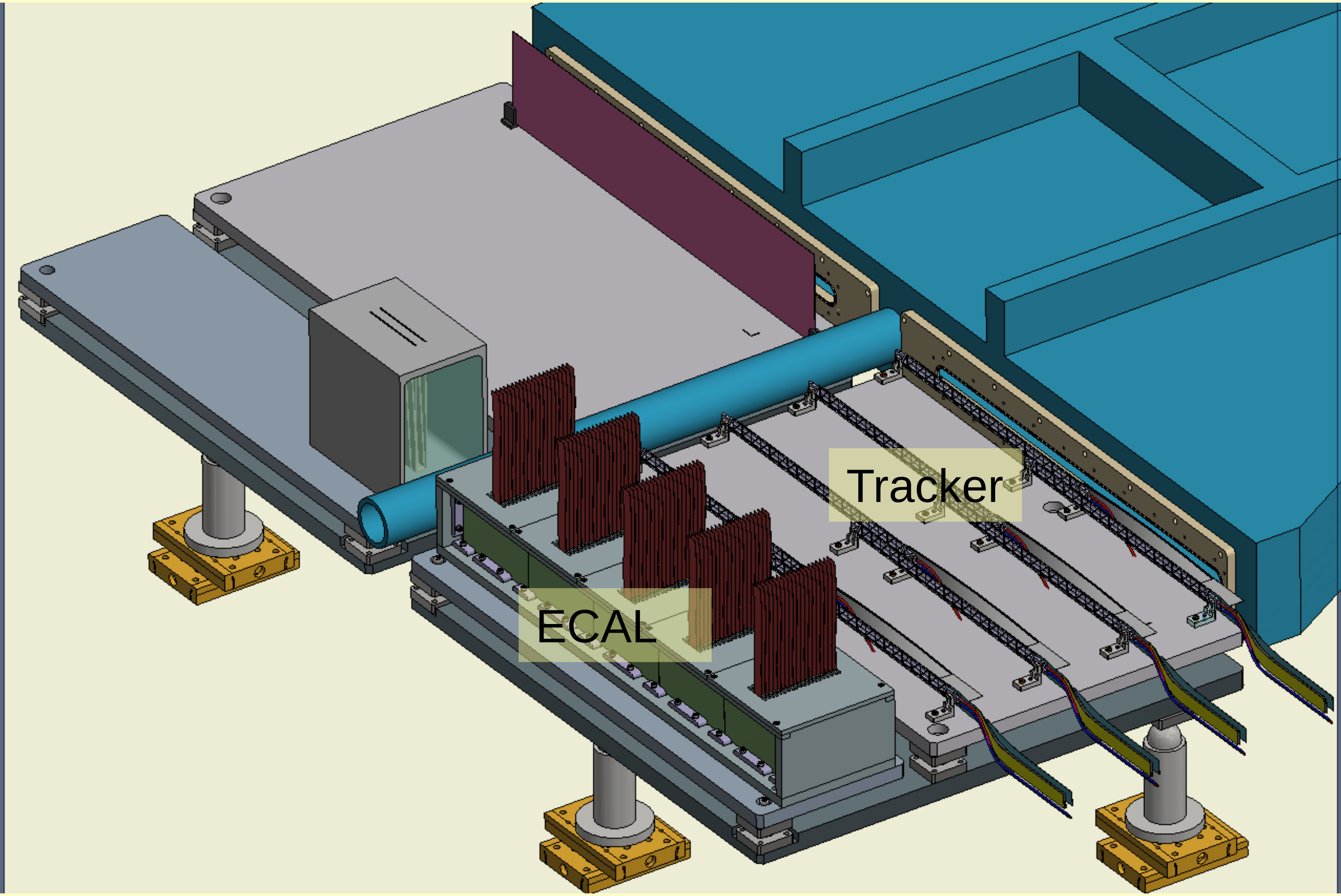
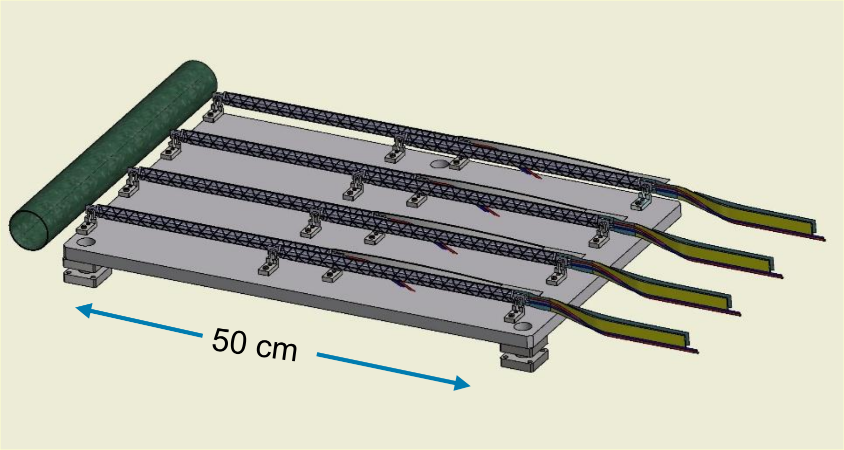
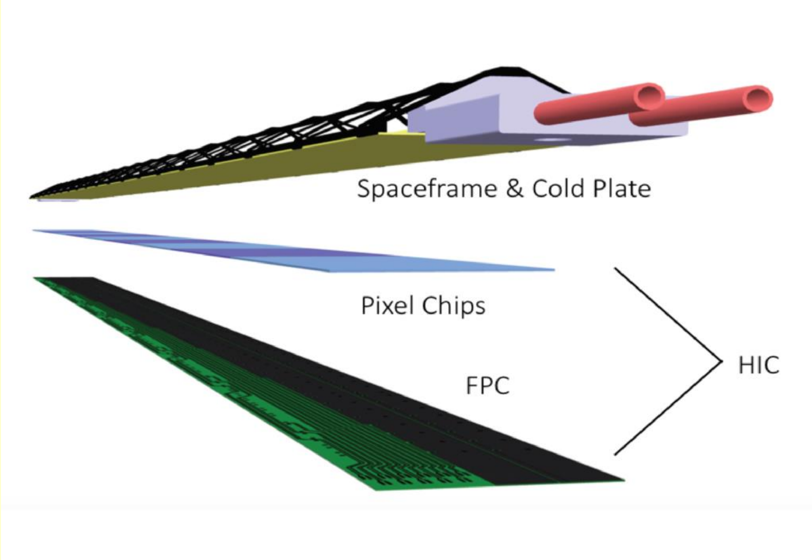
DESY

Positron detection



Tracker



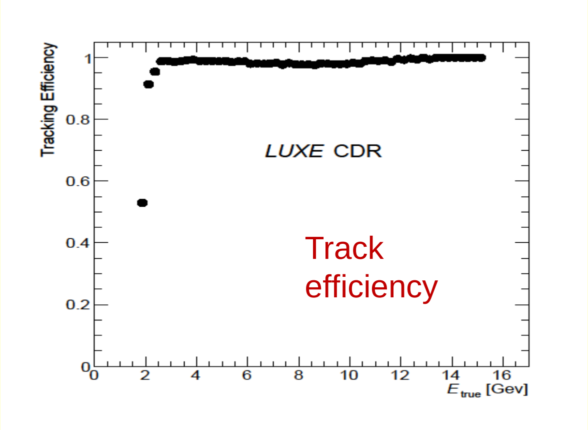


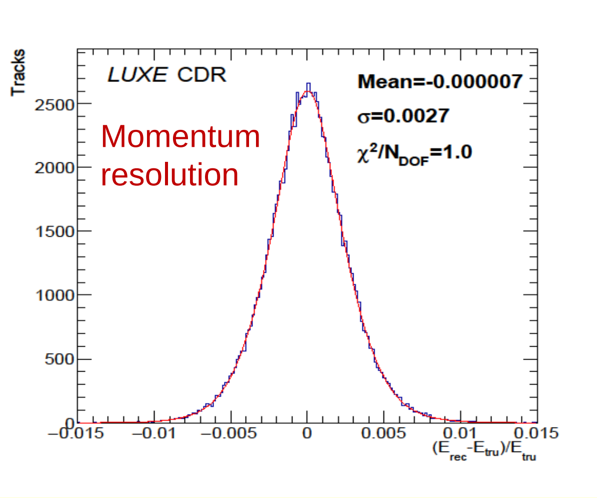
Four layers of ALPIDE silicon pixel sensors

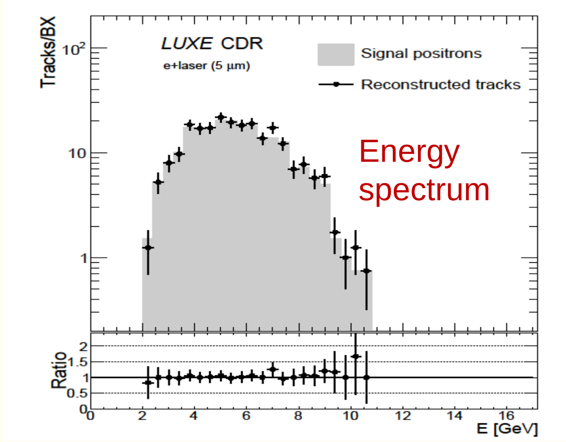
- Pixel size 27x19 μm^2, resolution 5 μm
- binary readout
-
- X/X_0 = 0.357 %
- Detection efficiency 99 %
- Noise rate <10^{-5}
- Used in ALICE ITS

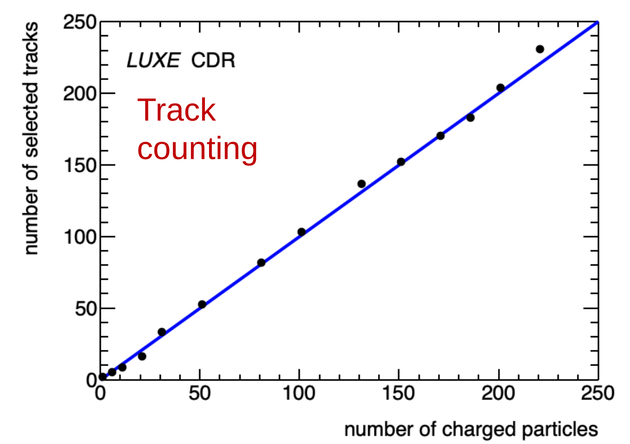
Tracker

Performance studies



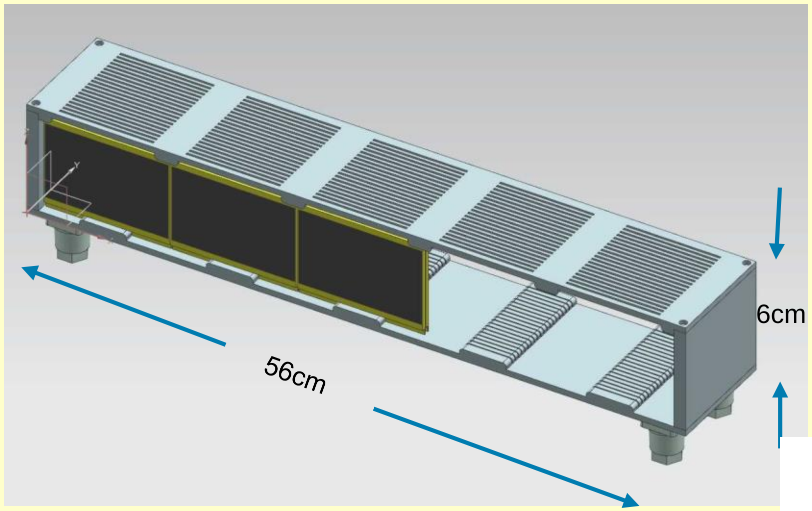






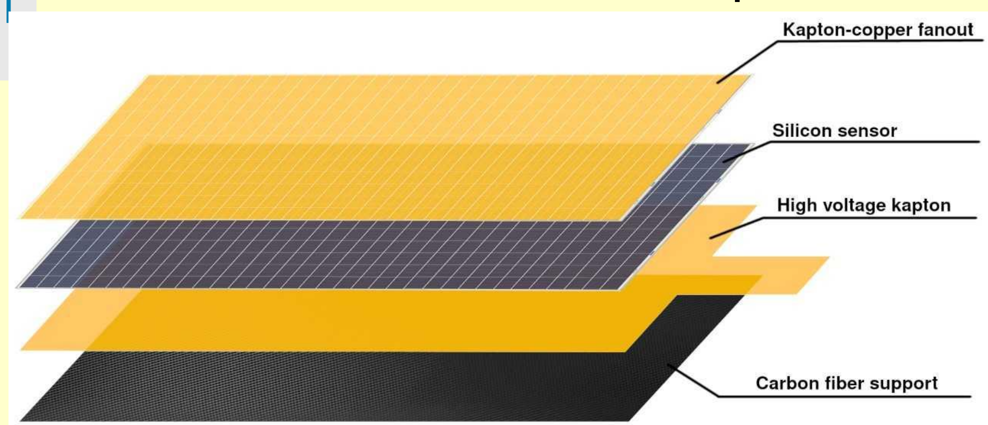
ECAL

Si W (GaAs W) sampling calorimeter



Challenge: small Moliere radius (showers on top of widely spread background)

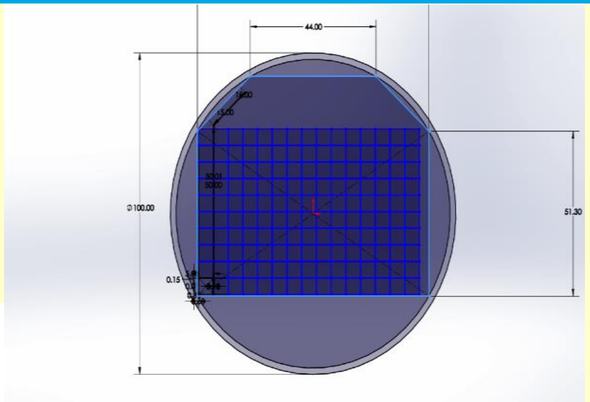
- Pad size: 5x5 cm^2
- W thickness: 1 X_0
- Per tower 20 sensors/plates

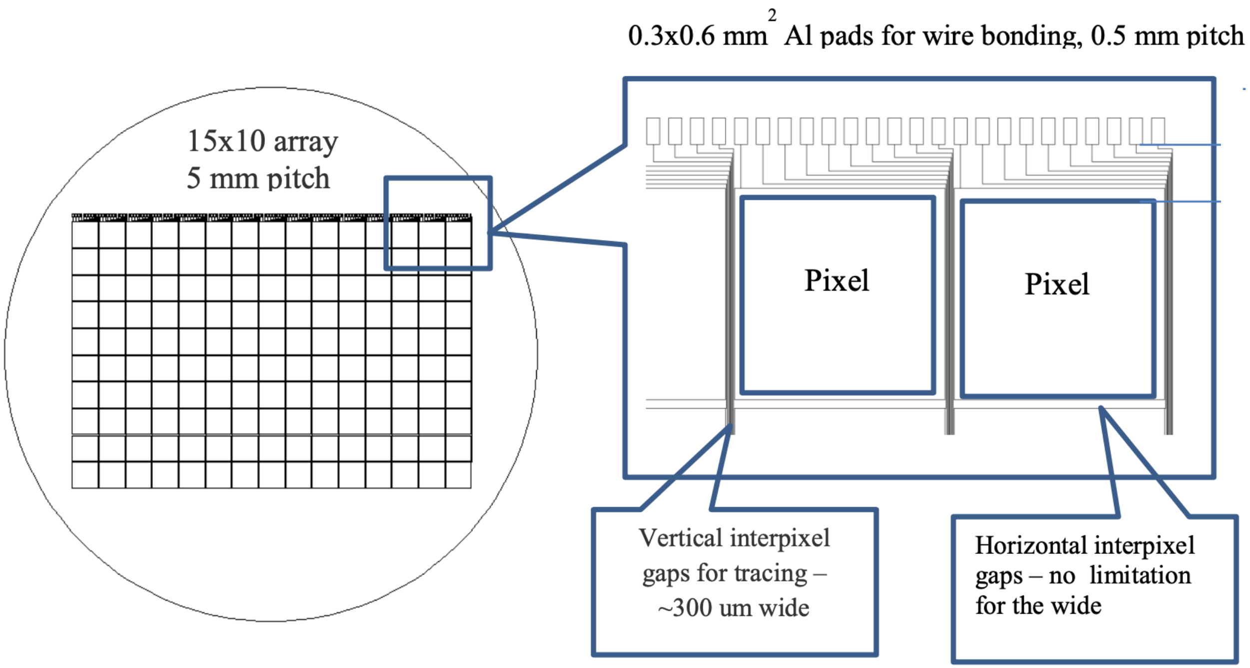


Sensor plane design
FCAL technology

ECAL

Advanced sensor techology (collaboration with Tomsk State University)





- Thickness of the sensor planes below 1mm
- Less cross talk to other pads
- Less lost contacts

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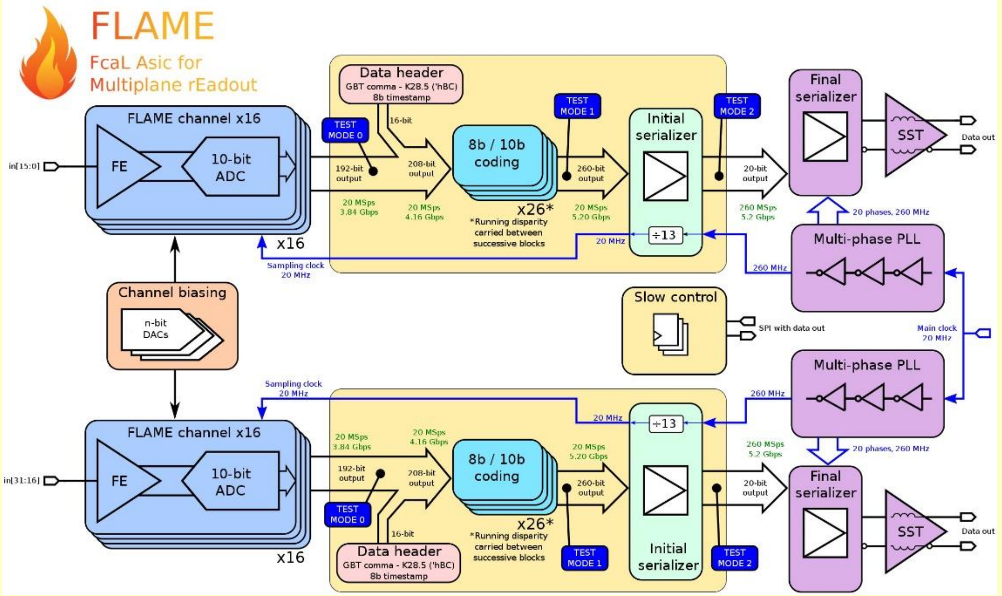
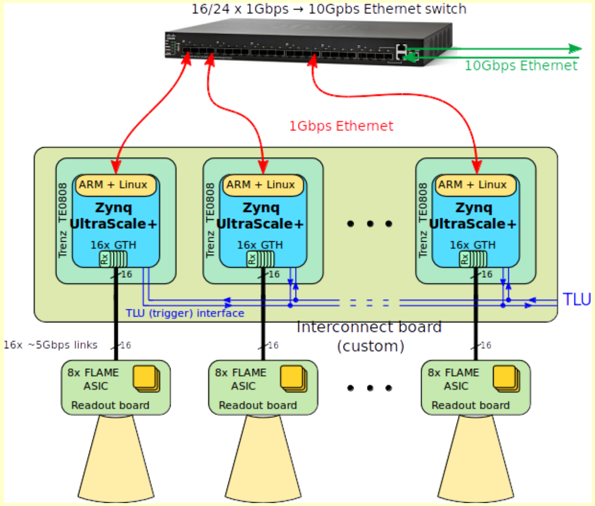
DESY

ECAL

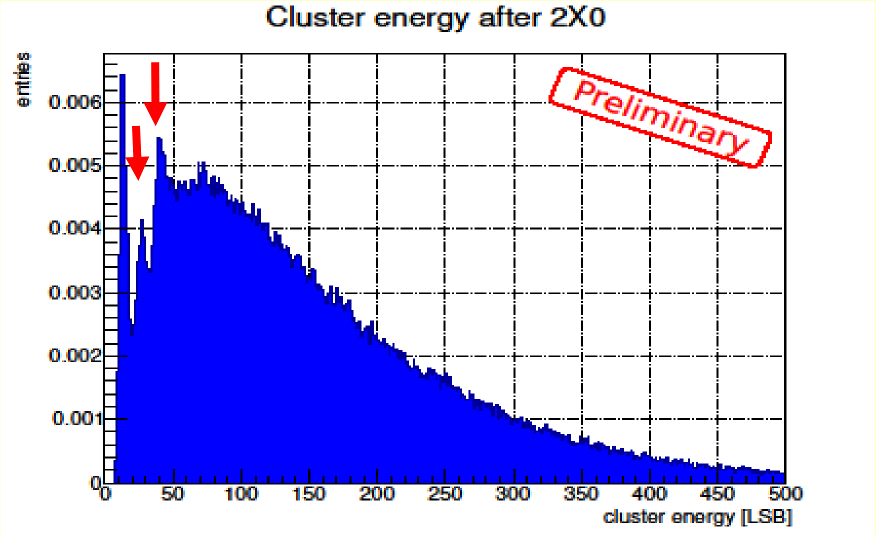
FE electronics

- 130 nm TSMC technology, (charge sensitive peamplifier, 10 bit ADC)
- developed within FCAL, parts also used in the CMS HGCAL upgrade
- Data preprocessing with FPGA

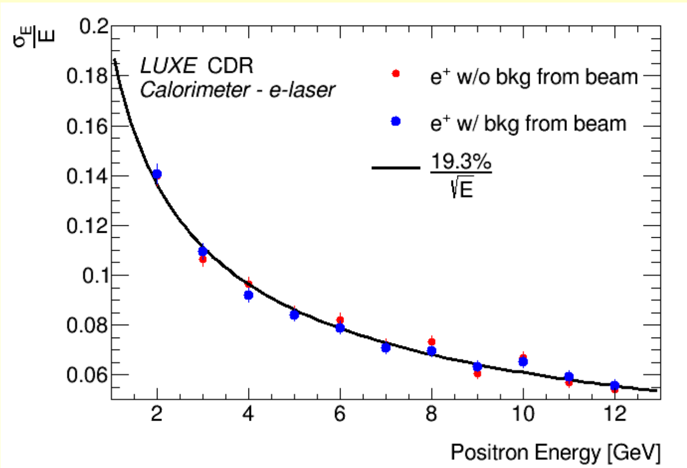


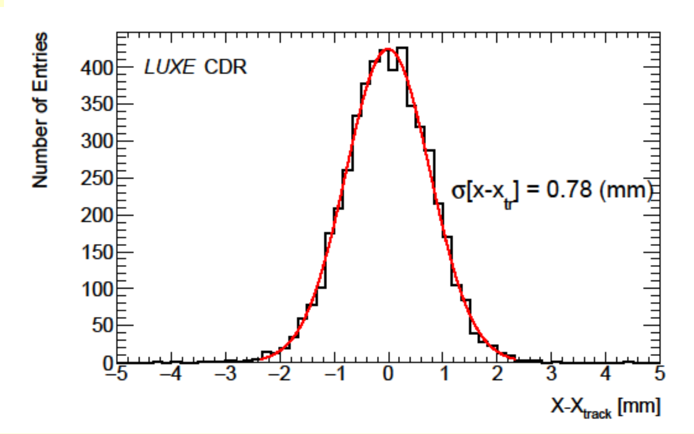


Recent test-beam measurements, depostited energy in layer 3

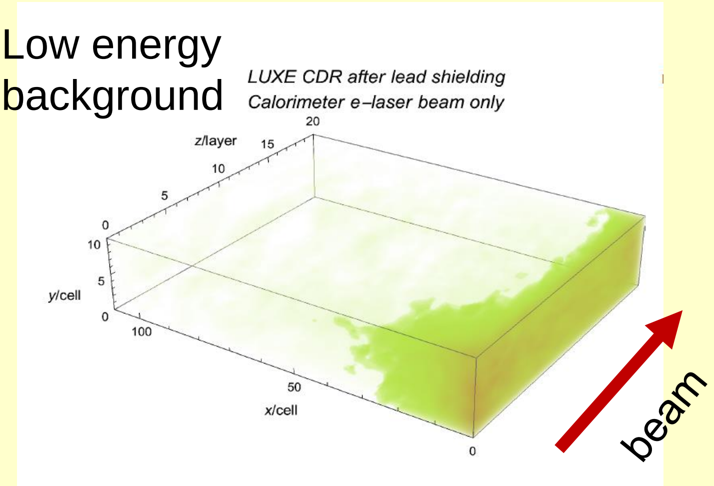


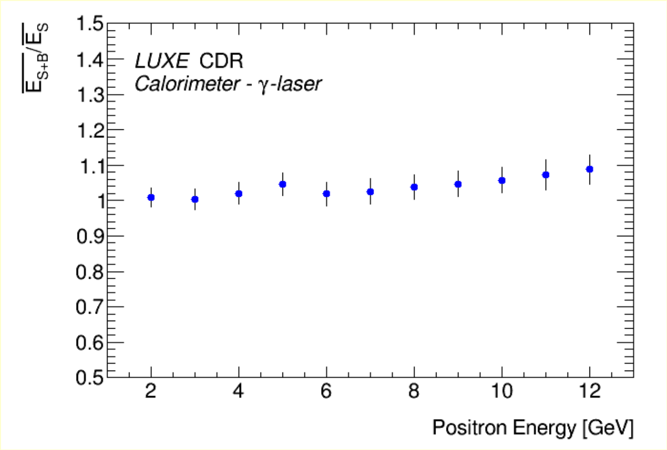
Performance studies





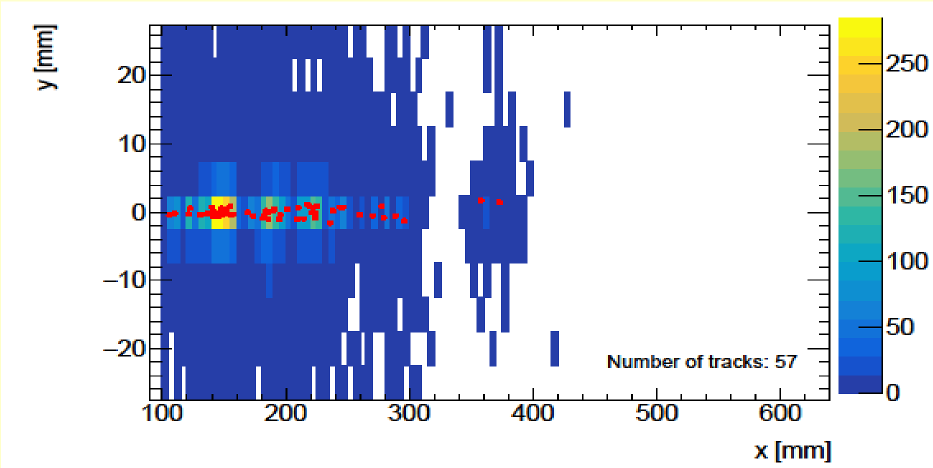
Low energy background



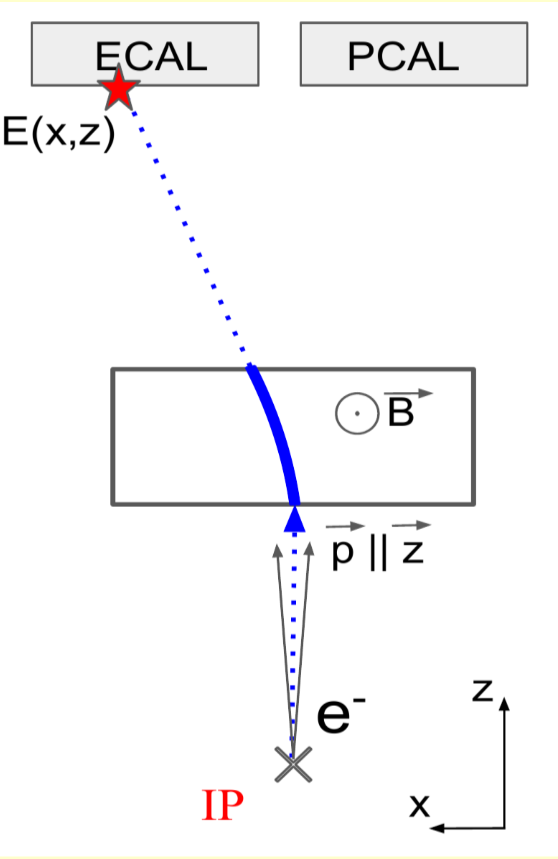


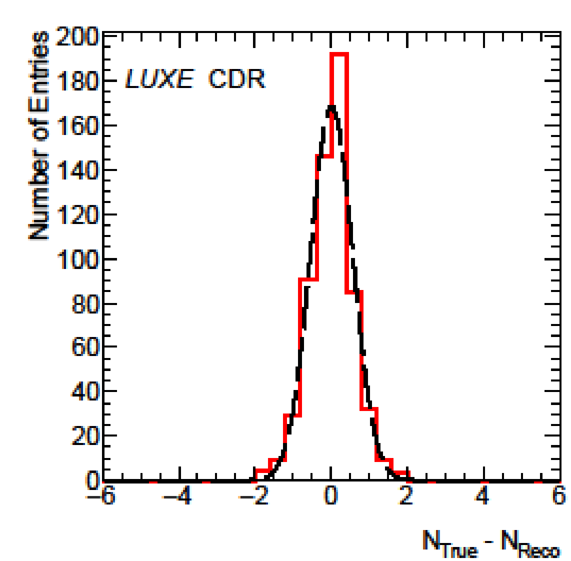
ECAL

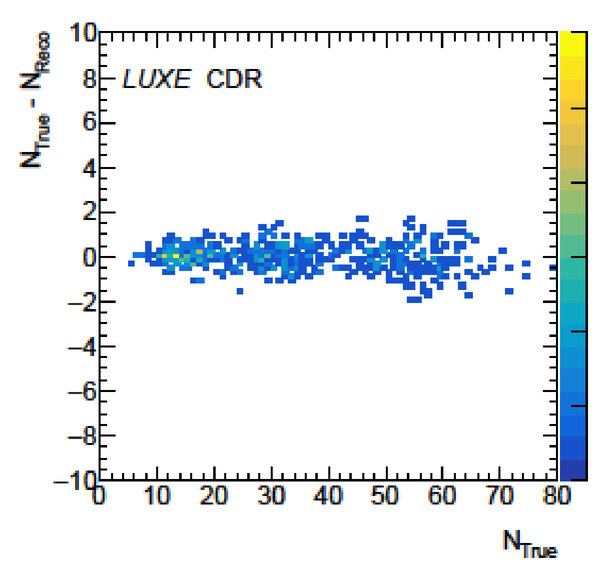
Overlap of showers for a large number of particles



Use the expected deposition as a function of the impact point in x (deflection plane of the magnet)







Resolution of the measured number of positrons

Calice Prototype in LUXE

Version 1:

Supplement or cover part of the ECAL

Fiducial volume 18 x 18 cm^2

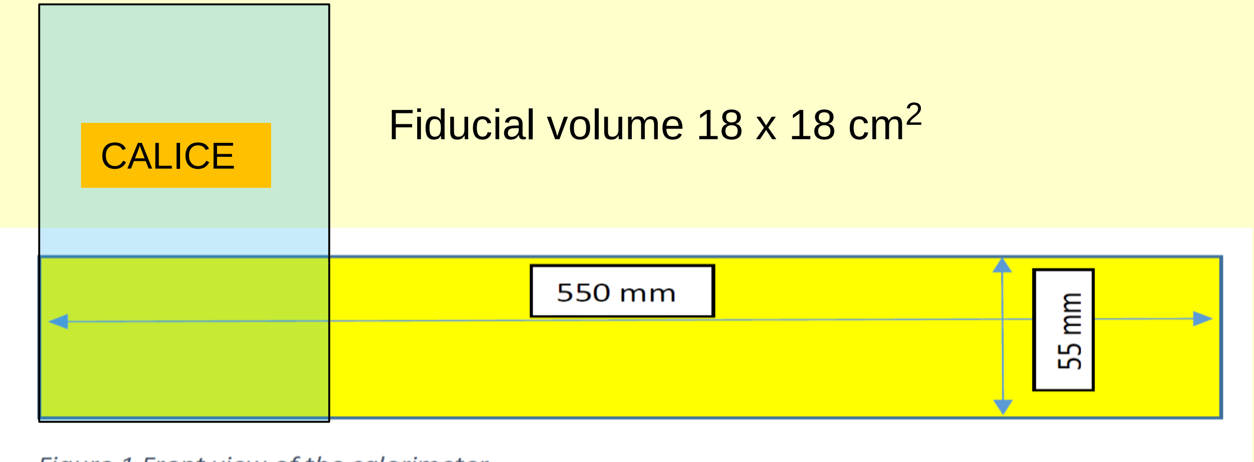
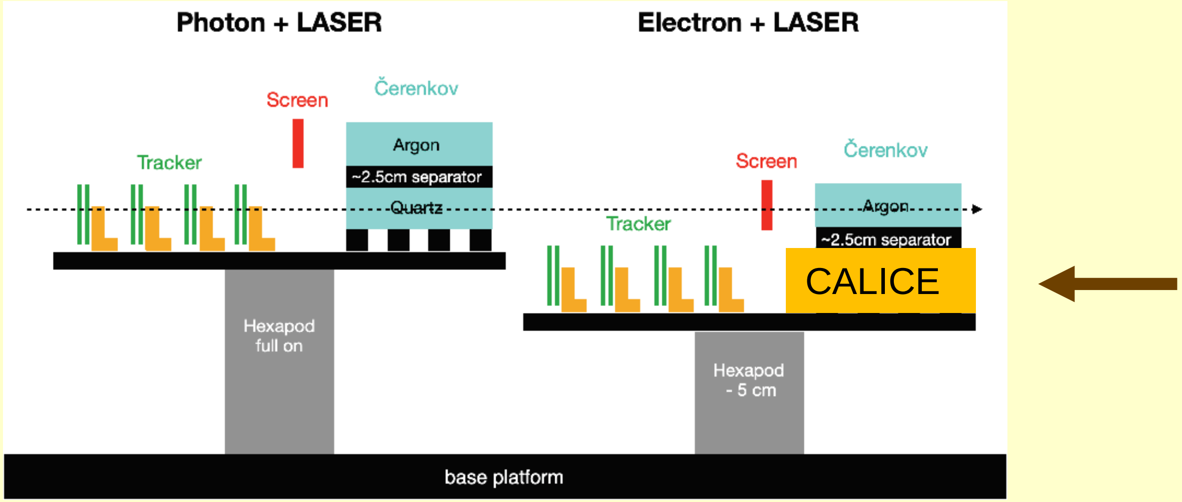


Figure 1 Front view of the calorimeter

Version 2:

Measure electrons in BW studies



Conclusion

Physics

- LUXE will open a new avenue of research probing QED in electron-light and photon-light collisons
- LUXE will cross the Schwinger limit in the quantum non-linear parameter, or the ‚boiling point of the vacuum‘
- New phenomena may occur there

Conclusion

Apparatus and detectors

- LUXE will be an electron-laser scattering experiment using the XFEL superconducting accelerator and a CPA laser (JETI40 ➔ 350 TW)
- Several cutting-edge detector technologies developed for particle physics experiments will be applied
- A key subdetector is a finely grained and highly compact ECAL

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backup

backup

Phase 0 calorimeter

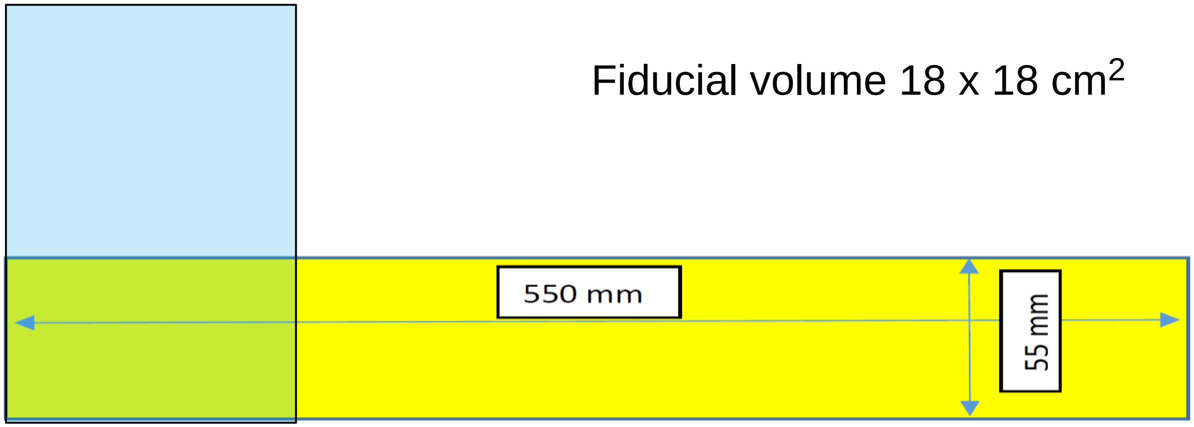
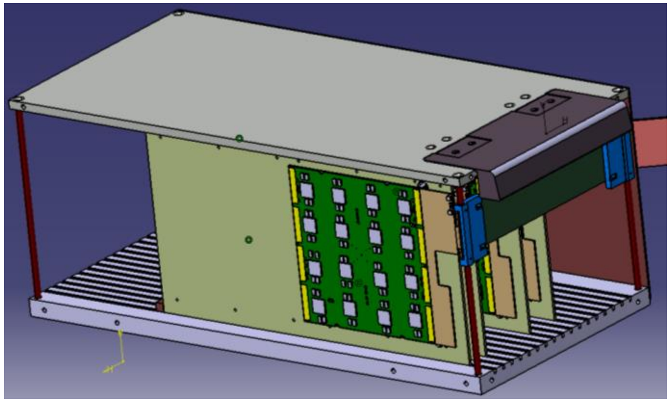


Figure 1 Front view of the calorimeter



- Pad size 5 x 5 mm^2
- 20 detector planes correspond to 12 X_0
- FE chip on sensor (less compact)
- Readout using Calice standard