Detector Challenges of the Strong-field QED Experiment LUXE at the European XFEL

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Strong-Field Quantum Electro-Dynamics at LUXE

At DESY in Hamburg, we have access to a **high-quality, high-energy electron beam** in the EuXFEL – up to 17.5 GeV, with bunch population of around 1.5 x 10^9

Strongest electric fields in the lab come from extremely **powerful & short 'chirped' LASER pulses**

LUXE will **collide LASER pulses in two modes with both high-energy electron bunches (e-laser) and photons (γ-laser).** The photons are produced via the electrons radiating via bremsstrahlung or Inverse Compton Scattering

With the combination of the focussed high-power LASER pulse and high-energy particles, LUXE is expected to reach and **exceed the Critical Field and so achieve χ > 1, as yet unexplored parameter space**, in a clean environment with opportunity to **measure interactions with high statistics**

- Applicable to LASER beams, the unitless intensity parameter ξ :

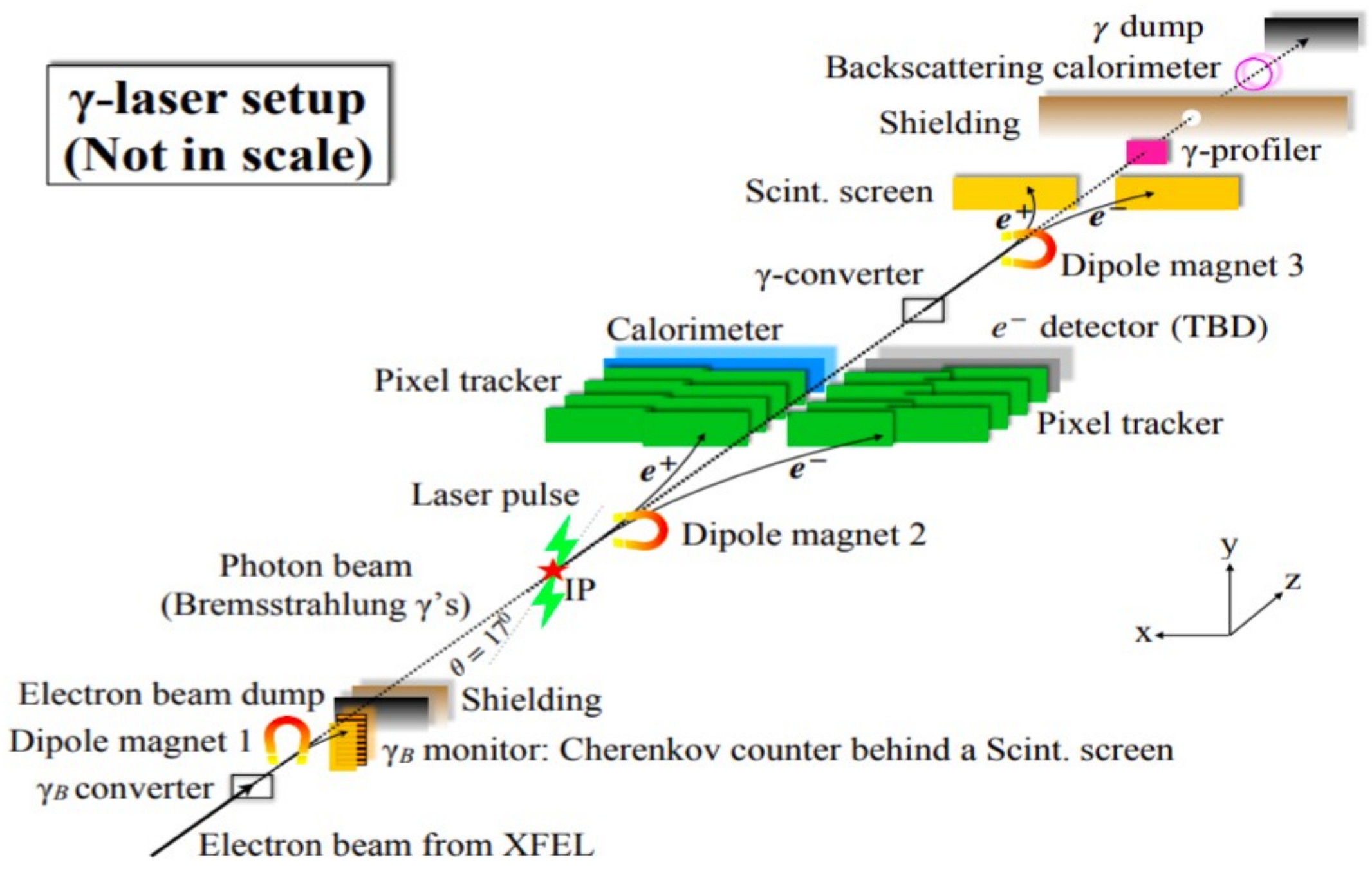
$$\xi = \frac{eE_L}{m_e\omega_L c} = \frac{m_e E_L c^2}{\omega_L E_{Schw.}\hbar}$$

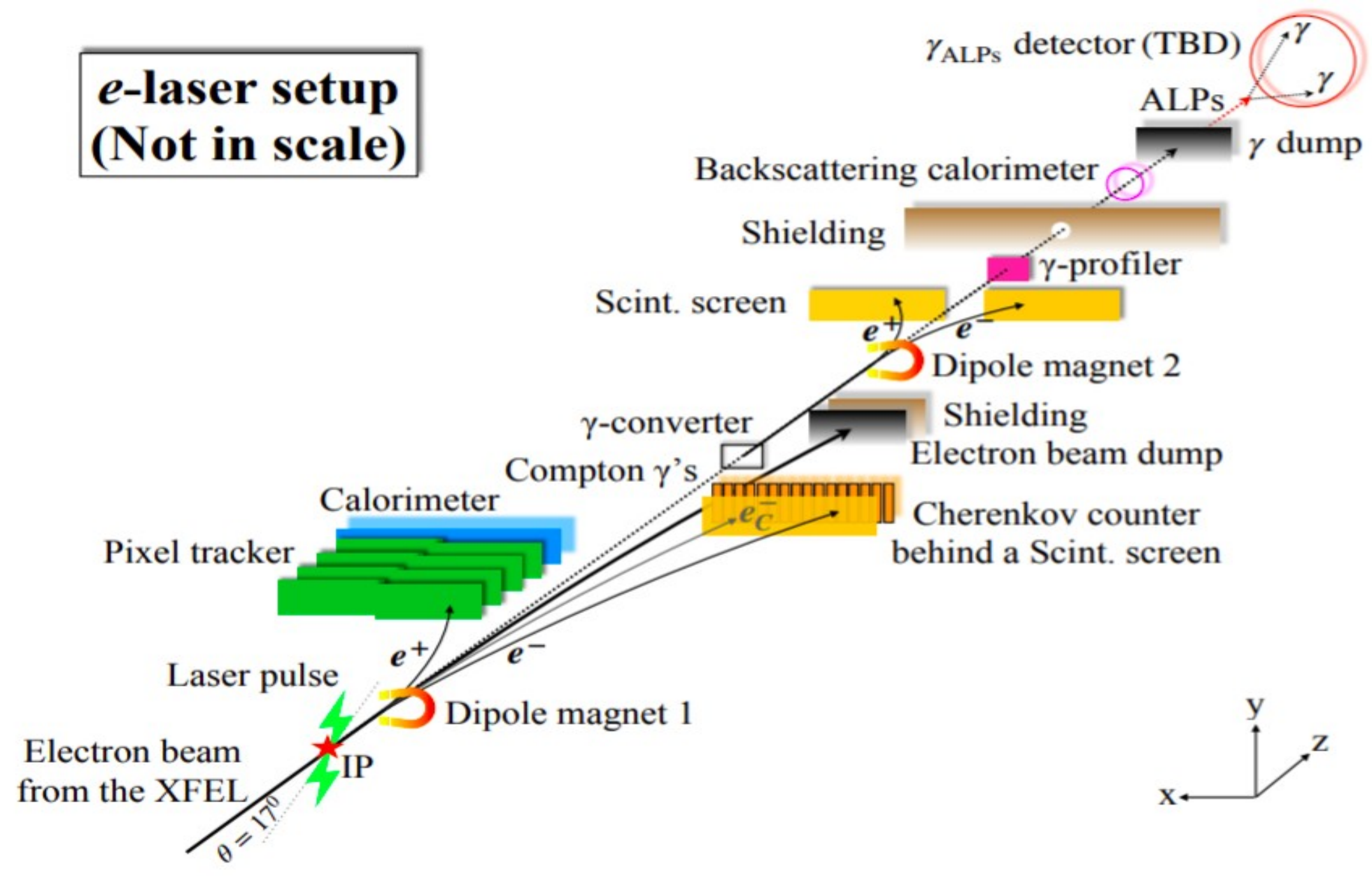
$$E_{Schwinger} \equiv m_e^2c^3/e\hbar = 1.32 \times 10^{18}\ Vm^{-1}$$

- Electric field experienced by relativistic particles is **Lorentz-Boosted**

$$\chi = \frac{E_p}{E_{Schw.}} = \frac{p}{m_e}\frac{E_L}{E_{Schw.}}(1+\beta cos(\theta)) = 2\gamma_p\frac{E_L}{E_{Schw.}}$$

- Quantum non-linearity parameter χ where **χ = 1 denotes transition into a tunneling regime**

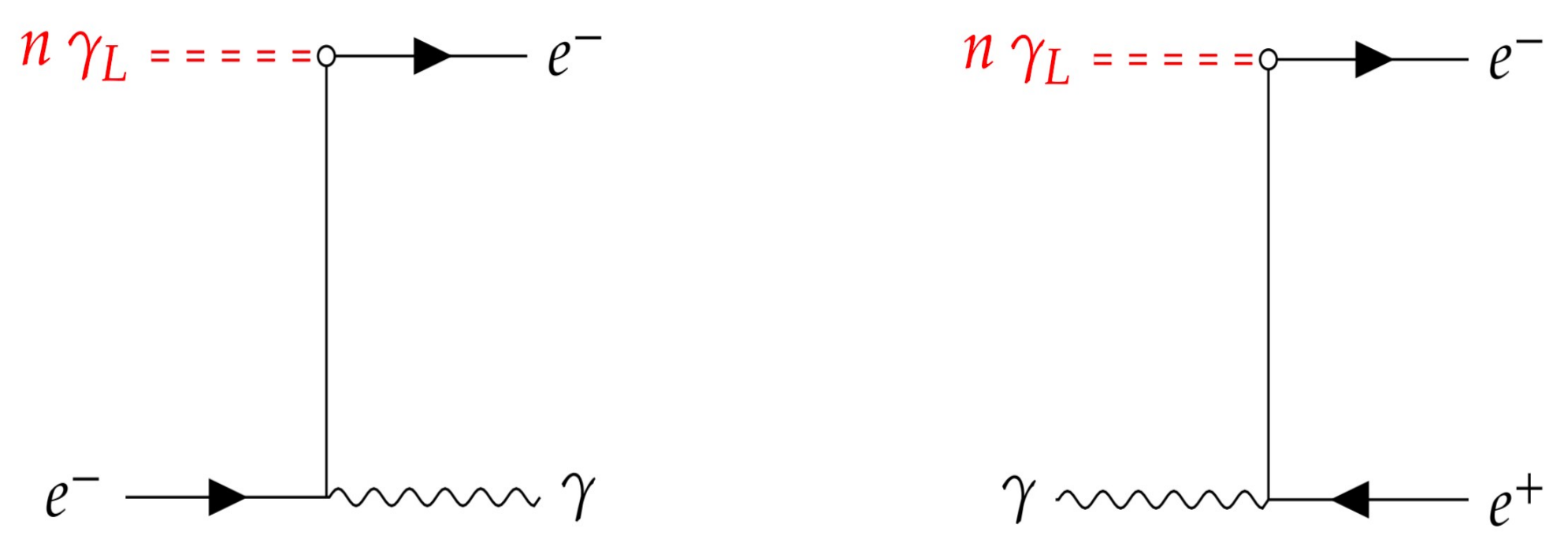




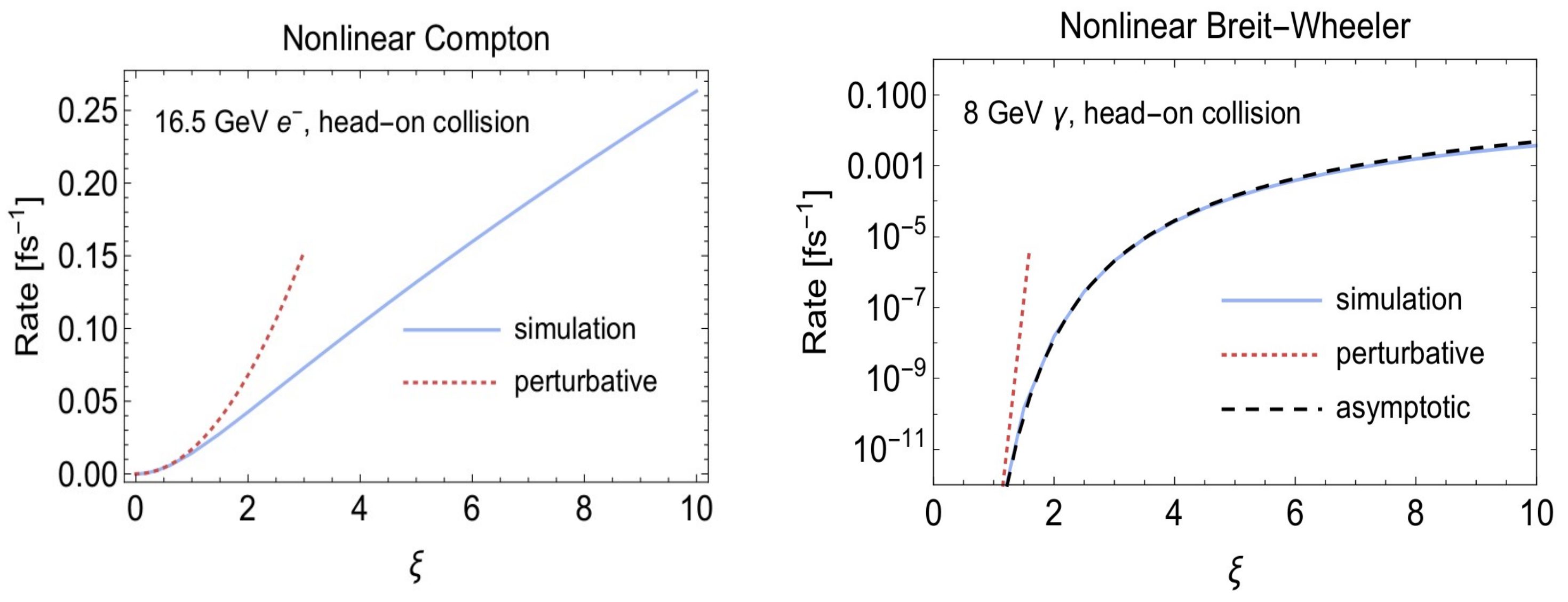
Key Detection challenges:

1. ~10GeV electrons, in fluxes 10^7-10^9
2. ~10GeV photons, in fluxes 10^7-10^9 + directly measuring beam shape
3. ~5GeV positrons, in fluxes 10^{-2}-10^5 + in high background environment

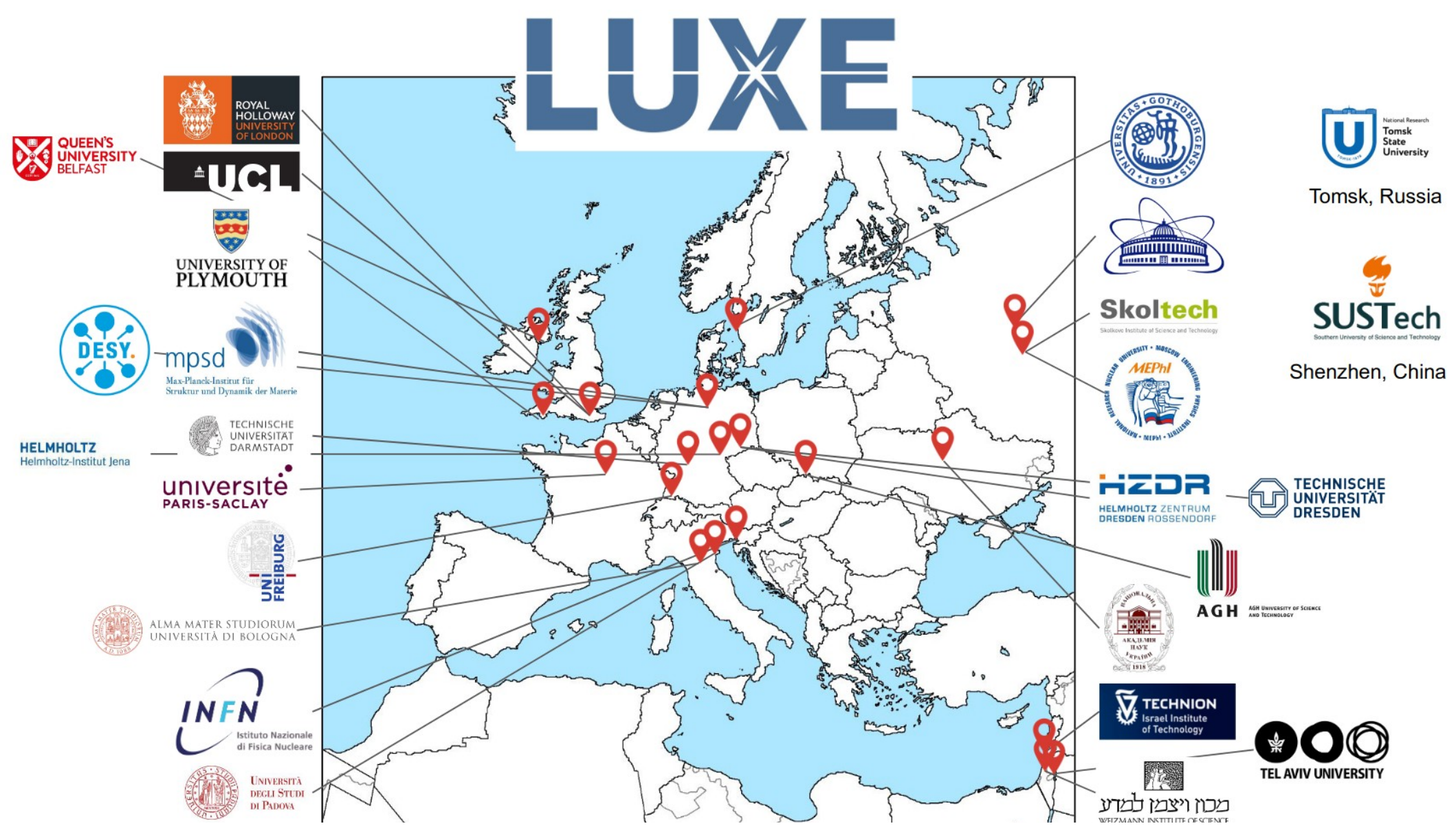
Interactions



Electrons in a Strong EM Field can undergo **Non-Linear Compton Scattering** (left) and photons can produce an e− e+ pair in a spontaneous boiling of the vacuum (right) or **Non-Linear Breit-Wheeler Process**

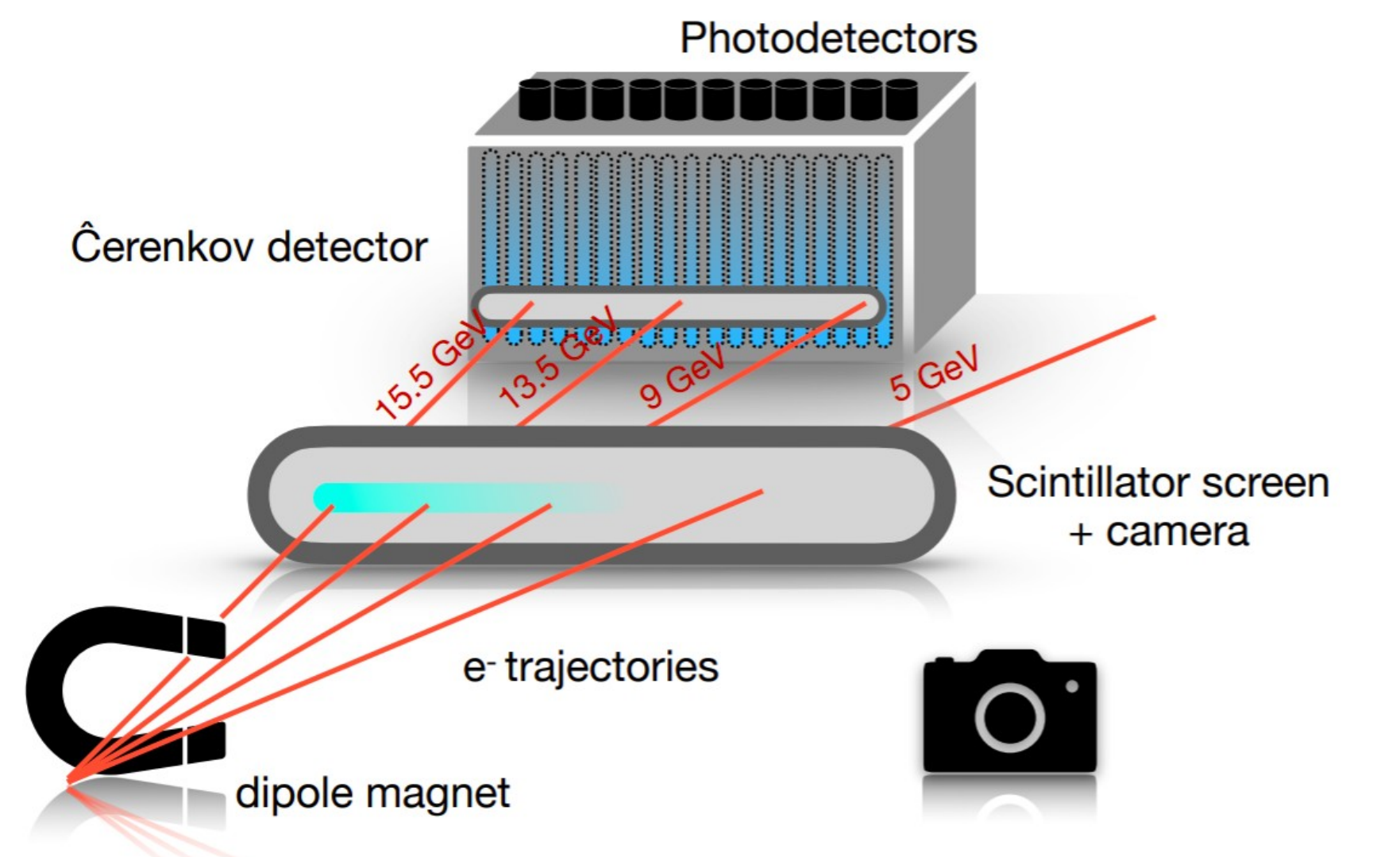


Simulated expected rates for each of the two interactions above. For comparison is an extrapolation for the perturbative solution at low ξ.



Electron Detection

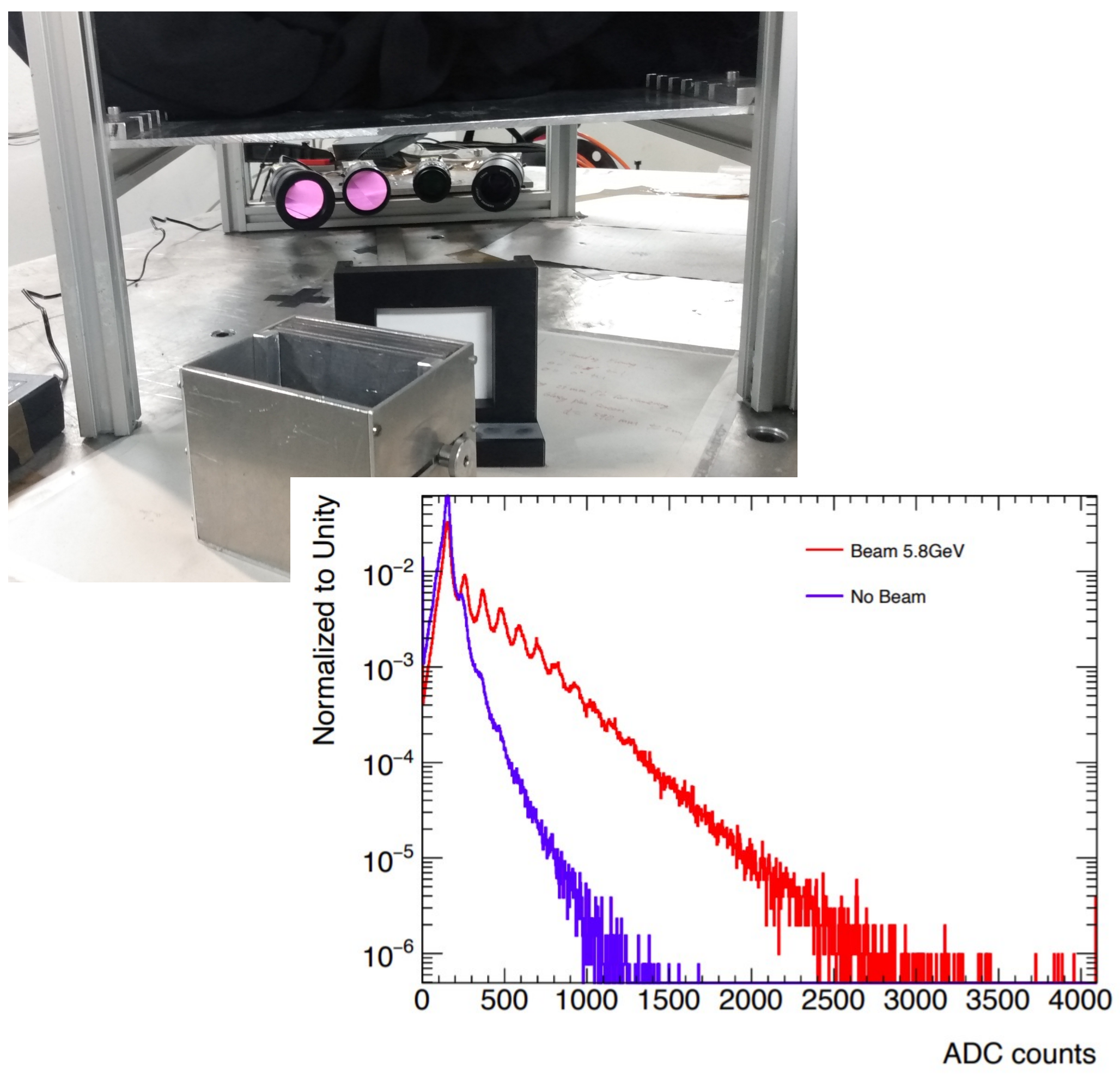
Non-linear Compton-scattered electrons are produced in high numbers and are **counted and reconstructed with respect to energy**, rather than analysed individually, **using magnetic fields as spectrometers**



A **screen of scintillating material** is used in this region in conjunction with a **segmented Cherenkov detector**

The high flux gives high light levels, allowing **remote optical cameras** to detect signal at high position resolution

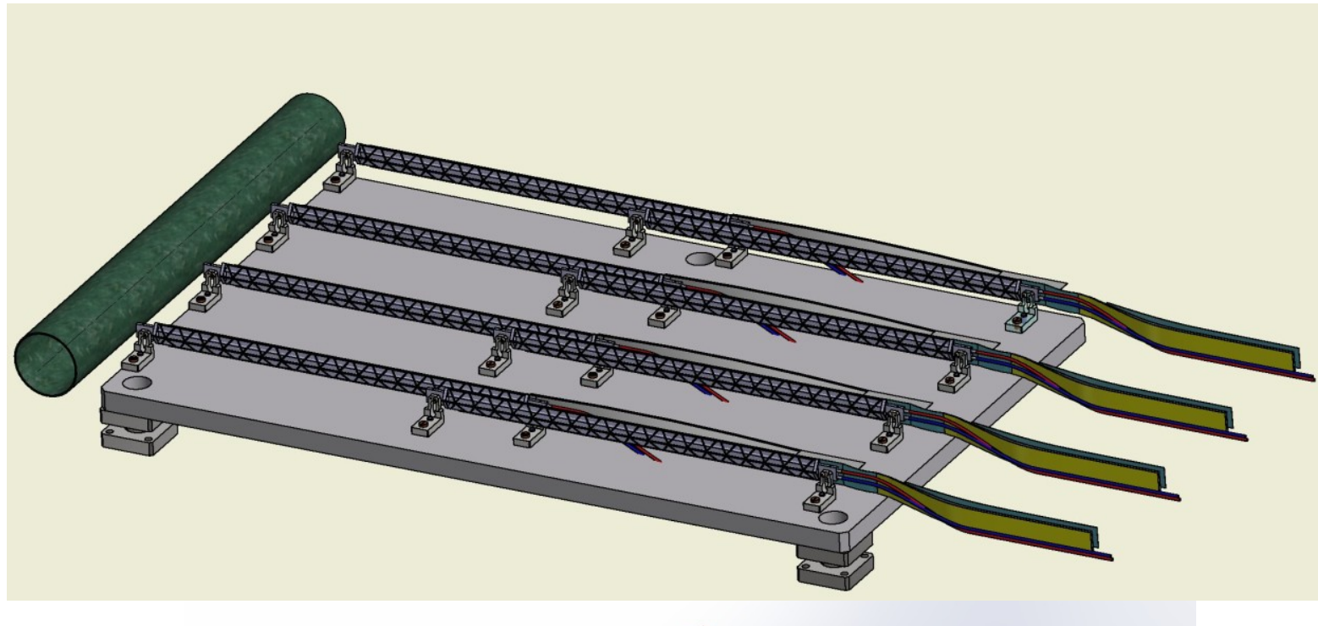
High flux means **Cherenkov medium with low refractive index** (e.g. Air) can be used, which provides few signal photons but excludes low energy (background) charged particles E < 20 MeV

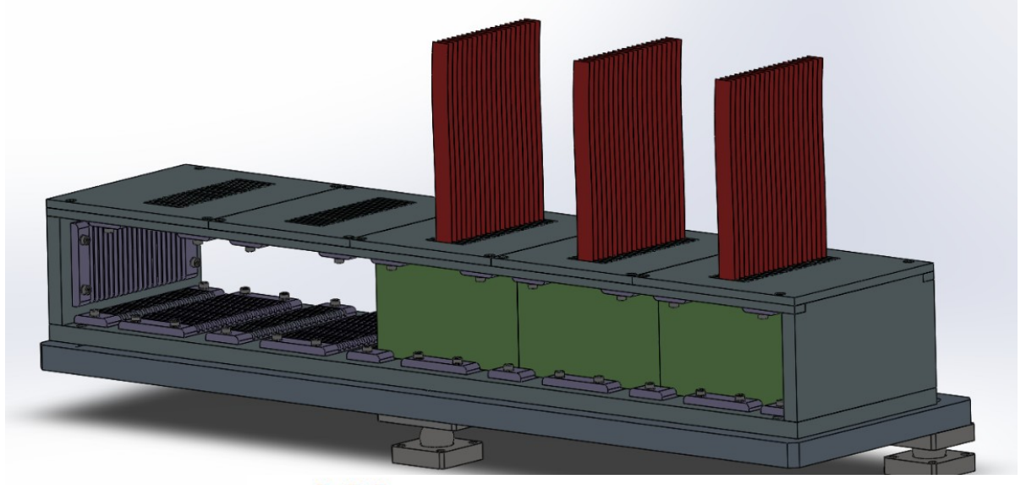


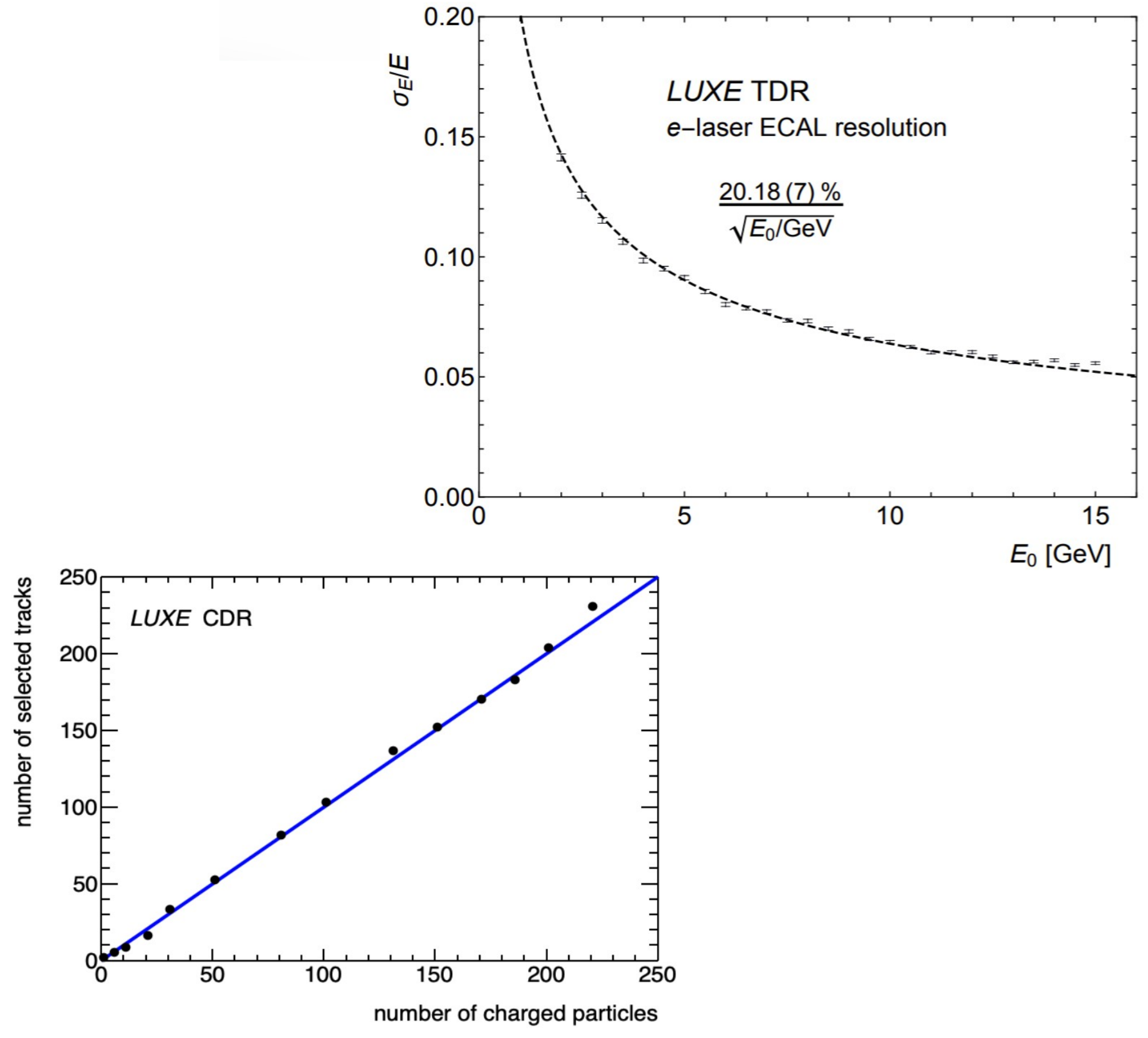
Left: a prototype of the **Scintllation Screen & Camera system** in testbeam (DESY-II).
Right: The result of a prototype of one single channel of the **Cherenkov Detector** in 5.8 GeV electron testbeam at DESY-II. The ADC signal, measuring the cherenkov emission within oil via Silicon PM, is plotted for beam and no-beam.

Positron Detection

The low rates expected for the Breit-Wheeler process motivates the use of **Silicon pixel-trackers** and **Silicon/GaAs calorimeter(s)** to **resolve individual positrons above considerable background**







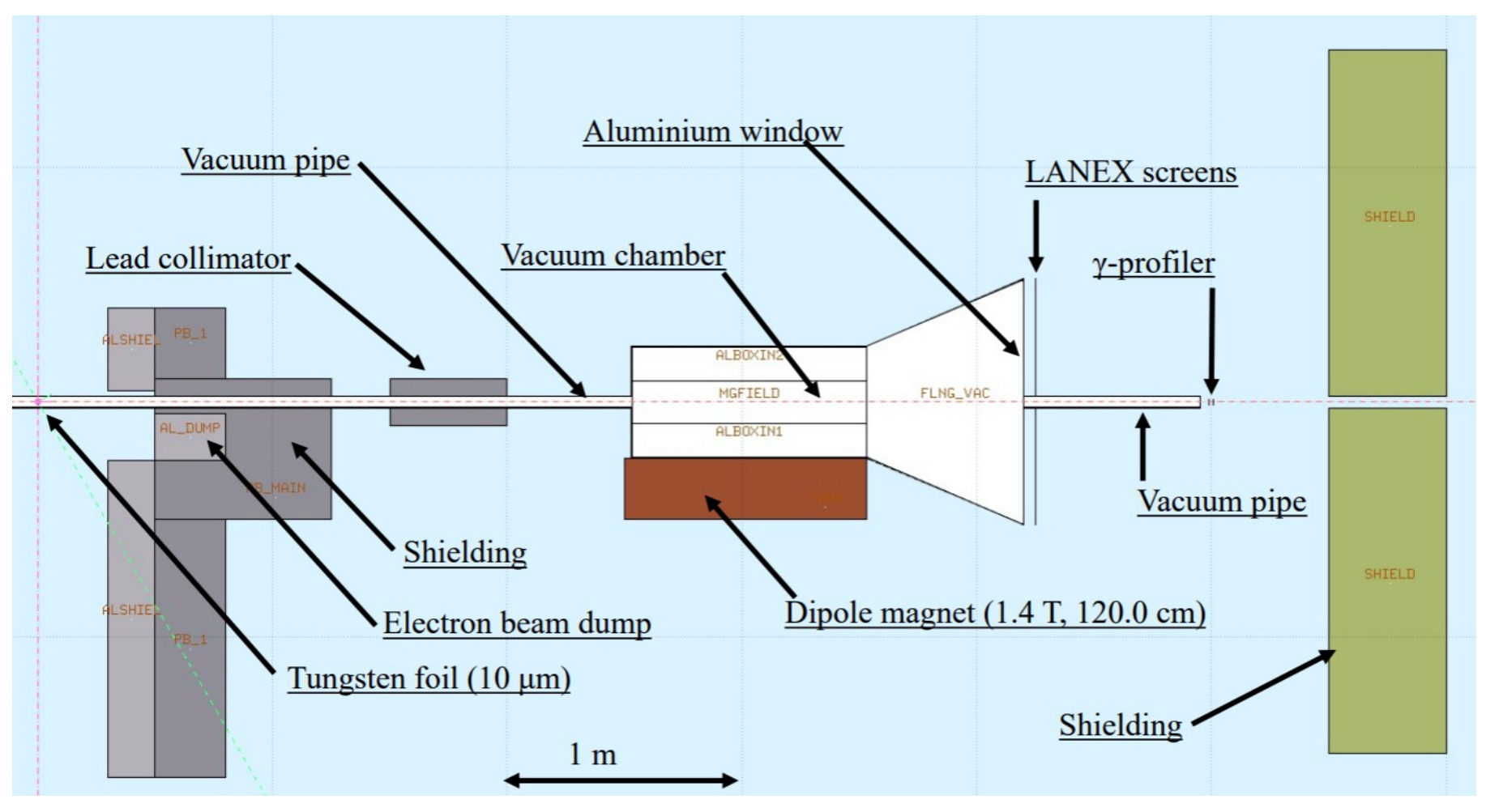
Track multiplicity reconstruction (left) for simulation of the Tracker. Expected ECAL Calorimeter Energy resolution (right).

The **Sampling Calorimeter** uses 20 Tungsten plates to induce showering within the detector, then sampled by Silicon or GaAs layers to reconstruct energy and position of tracks

The **Pixel Tracker** similarly tracks the position of ionising radiation through 4 layers of thin silicon wafers. Its high efficiency, position resolution and the use of algorithms (including quantum computing) allows **high-quality resolving of tracks and their energy**

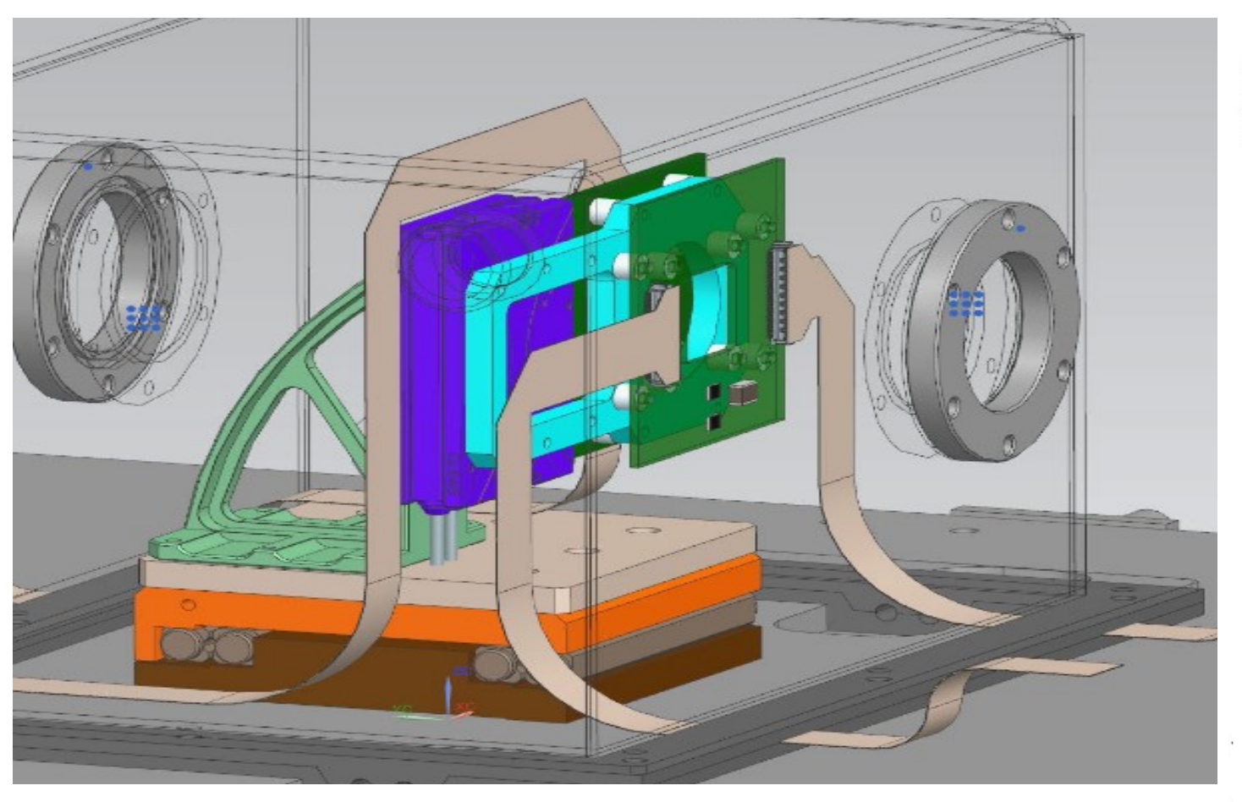
Photon Detection

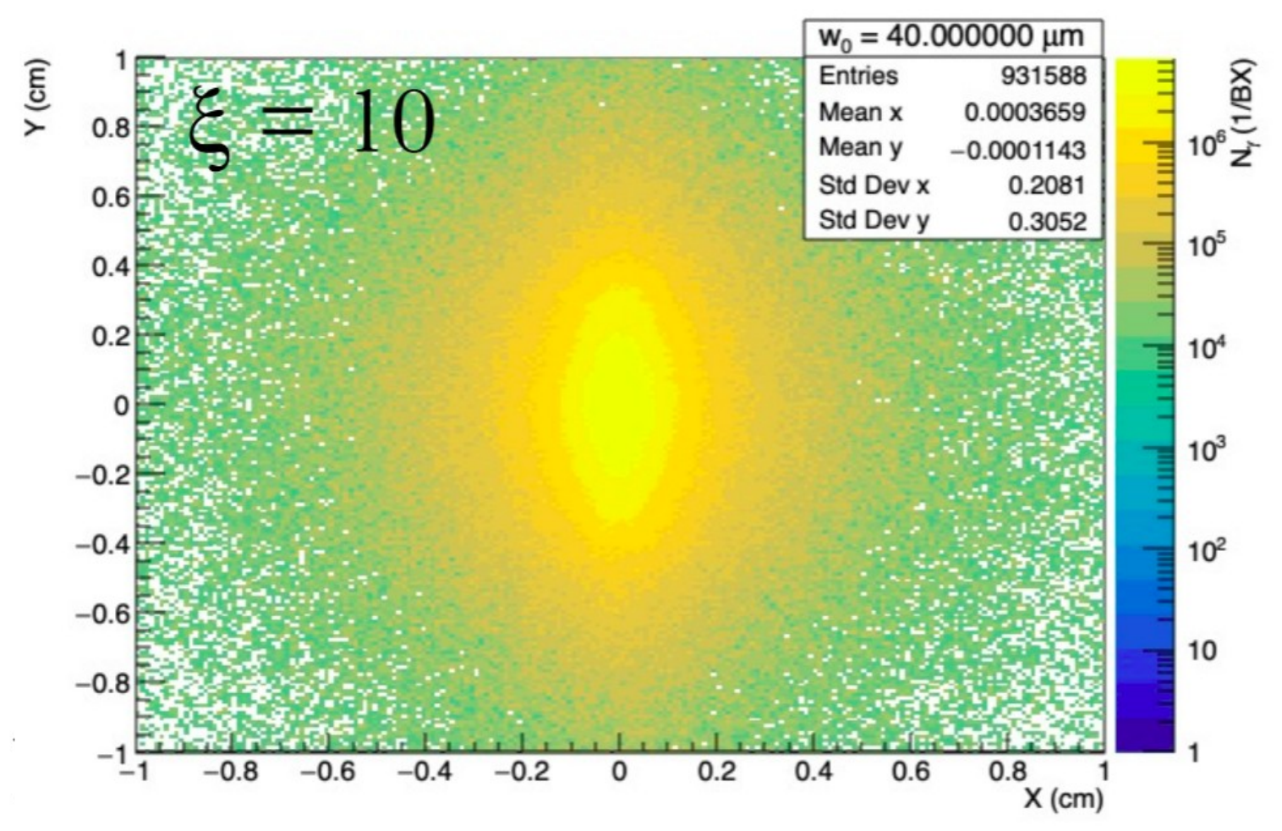
Three independent detectors are used to measure various characteristics of the gamma beam



The **Gamma Spectrometer** uses a thin Tungsten target to convert a proportion (~1%) of the gamma beam to e^- e^+ pairs, and using a Bethe-Heitler deconvolution algorithm and the summed energy of the e^- e^+ pair, the gamma beam is reconstructed by absolute energy distribution

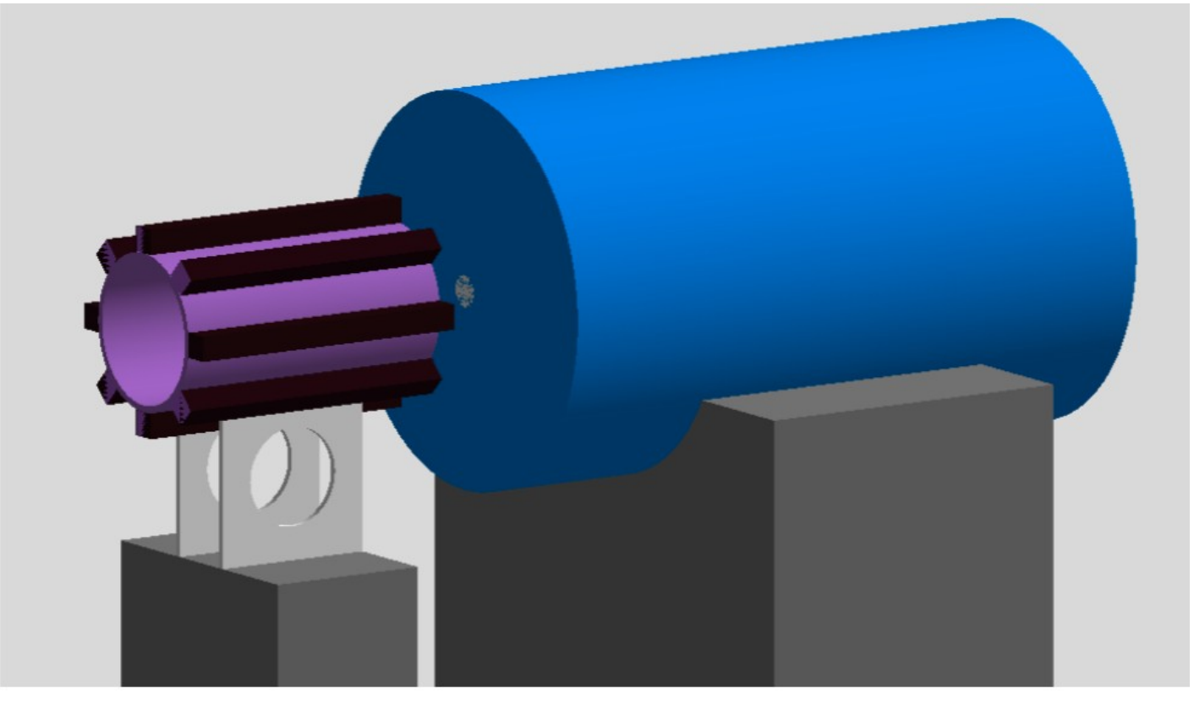
- **The energy profile of the e^-, e^+ are reconstructed with another Scint. Screen & Camera system**





A **Sapphire-Microstrip Gamma Beam Profiler** measures the flux and physical shape of the produced Gamma beam

This shape is crucial as it informs us immediately the quality of the particle-LASER interaction from bunch-to-bunch



Finally, in front of the gamma beam dump, a **Backscattering Calorimeter** measures the total photon flux using photon backscatters from the Copper dump

8 Lead-glass blocks are arranged around the beampipe; electromagnetic showering within the glass leads to **Cherenkov light which is detected by Photomultiplier Tubes**

Further Reading: Conceptual Design Report for the LUXE Experiment, H. Abramowicz et al., *Eur. Phys. J. Spec. Top.* (2021) https://arxiv.org/abs/2102.02032v2;
LUXE-NPOD: new physics searches with an optical dump at LUXE, Z. Bai, https://arxiv.org/abs/2107.13554;
The DESY-II Testbeam Facility: Ralf Diener et el., https://arxiv.org/abs/1807.09328;