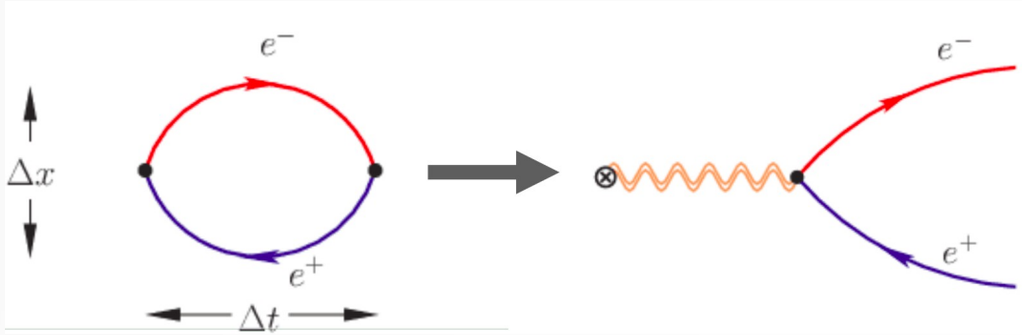
Detection and Reconstruction of High-Flux Electron Energy Spectra in the Strong-Field QED Regime with LUXE

John Hallford, Prof. Matthew Wing

University College London / DESY

Institute of Physics Conference, 3rd - 6th April
06.04.2022, 11:00 – 11:15

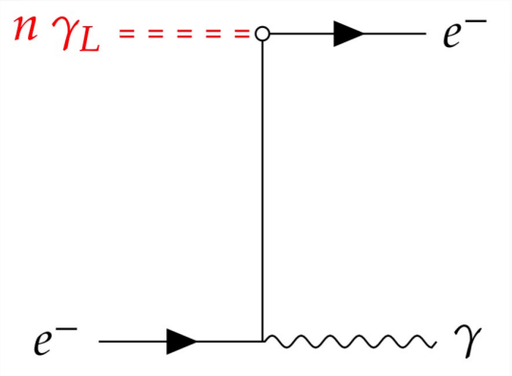
Strong-Field QED

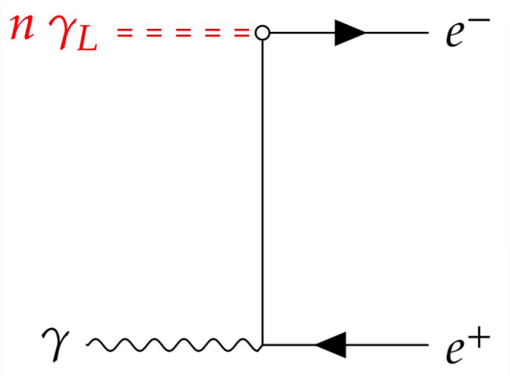


$$E_{Schwinger} \equiv m_e^2 c^3 / e\hbar = 1.32 \times 10^{18}\ Vm^{-1}$$

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

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





- QED is the one of the most quantitatively accurate physical theories in history

- Breaks down for high energy scales, high external EM fields

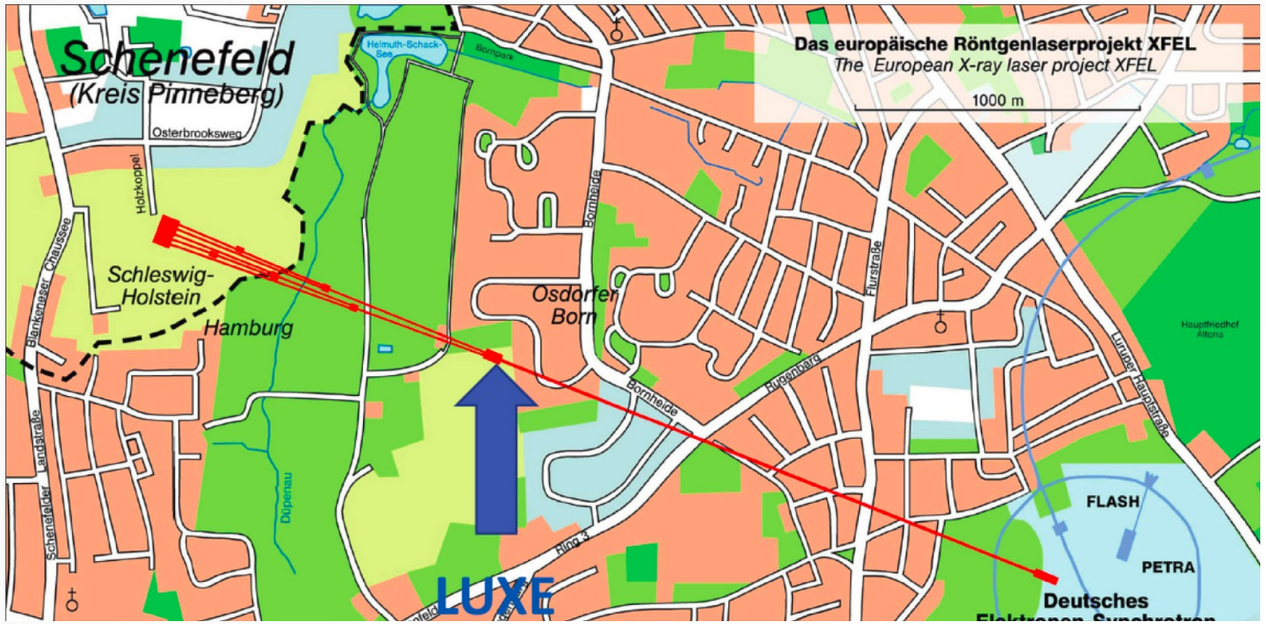
- Spontaneous pair production observed around the Schwinger Limit

- Useful to define unitless parameters **ξ, χ**

- Key interactions are Non-Linear Compton Scattering, Multiphoton Breit-Wheeler process

- Analogous to Hawking Radiation for gravitational field; such EM fields expected in magnetars, future lepton collliders

LUXE Experiment



- Most intense electric fields in the lab currently come from short-lived LASER pulses

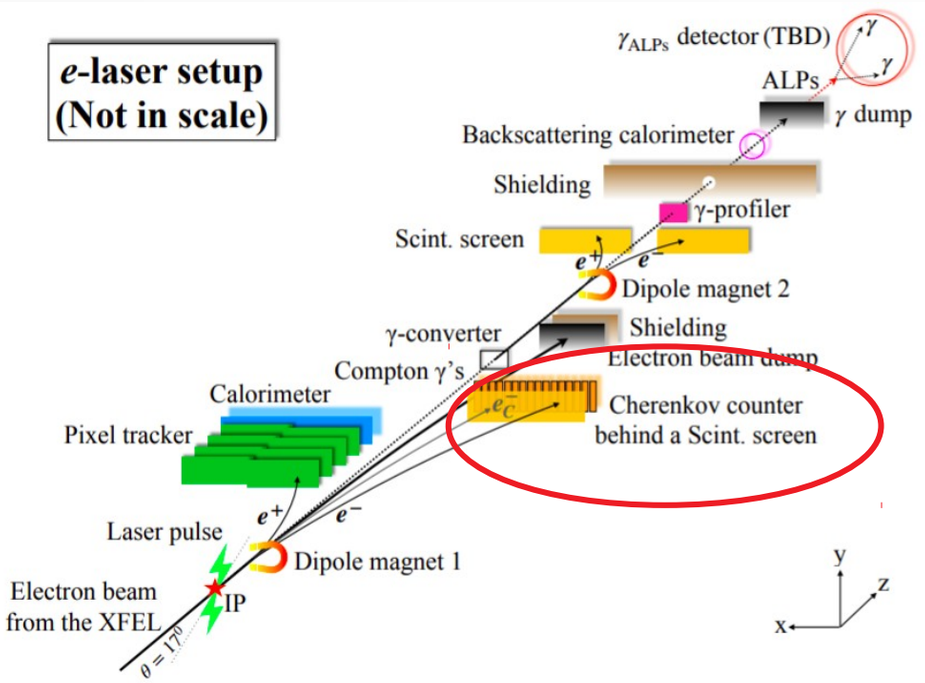
- High-power LASER collided with electrons (e^--LASER) or photons (γ-LASER)

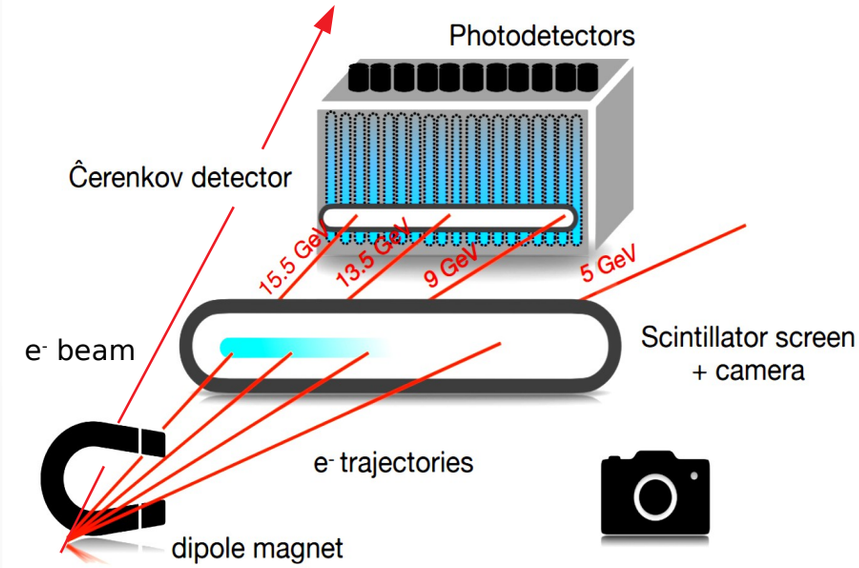
- Electrons from EU.XFEL, typical $n=1.5\times10^9$ & E=16.5 GeV, Bunch crossings at 1Hz

- Aims to push into new χ parameter space with enough statistics to make high-quality measurements

- Photons produced by bremsstrahlung (W Target) or Inverse-Compton Scattering (Split LASER beam)

Detectors at LUXE





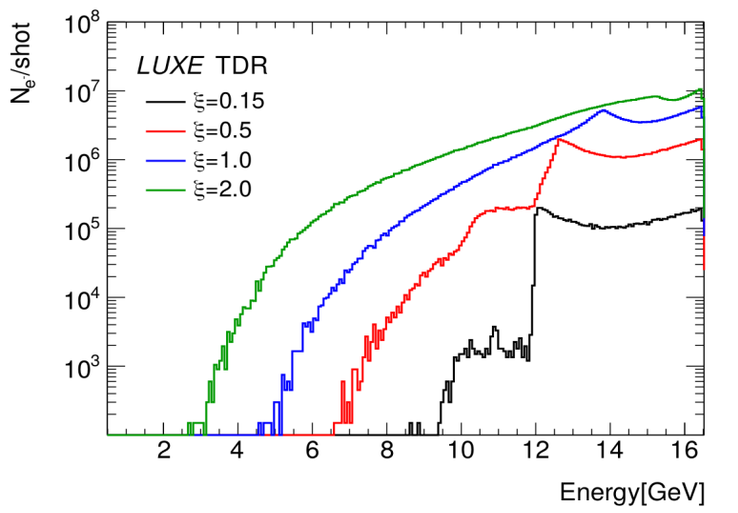
- Electrons are to be detected at e-LASER IP region (total 10^7 to 10^9) at energy between 1-16 GeV

- Measured by segmented Cherenkov detector and a thin screen of Scintillator, imaged remotely by optical cameras

- Charged particles are diverted by magnetic field, acting as magnetic spectrometer

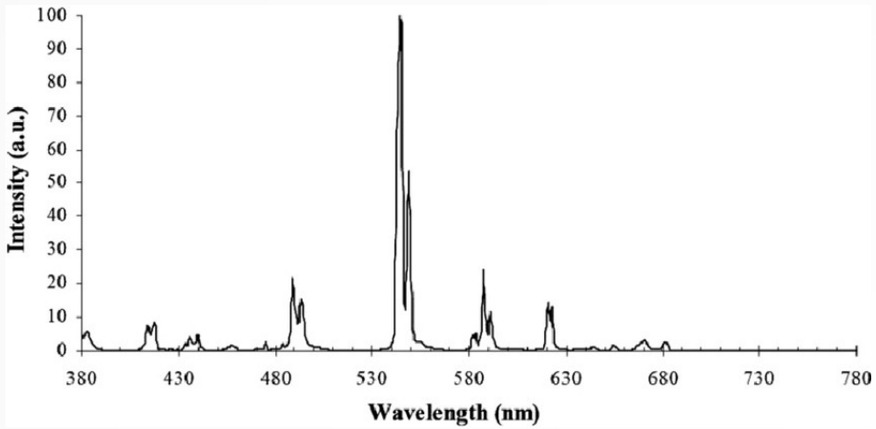
- Particle Flux measurement with respect to position allows for energy reconstruction

- Electron detection goal is to measure total flux/BX and 'Compton Edge' position in energy



Scintillation Screen, Camera and Filter

GadOx Scintillation Wavelength Emission



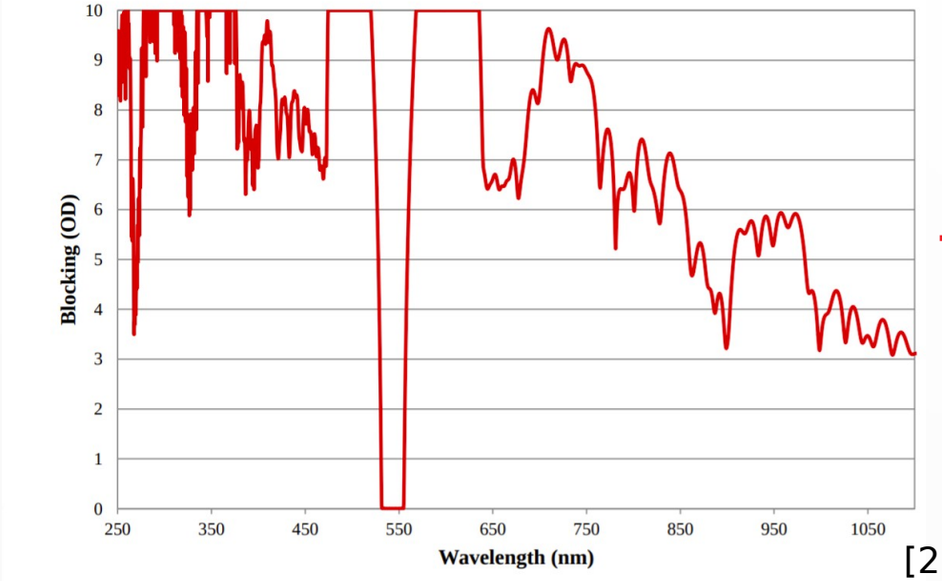
[1]

- Scintillator is Gadolinium Oxysulfide, efficiency up to 15%

- Relatively long decay time allows sensor exposure after event

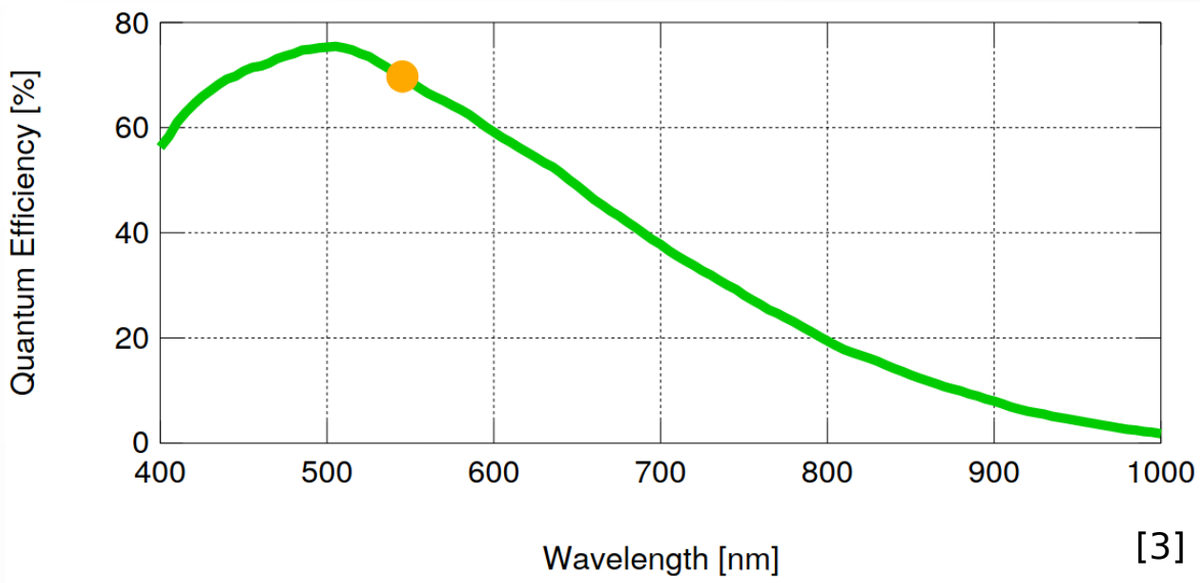
- Optical filter used to remove any ambient light

Optical Filter Blocking by Wavelength



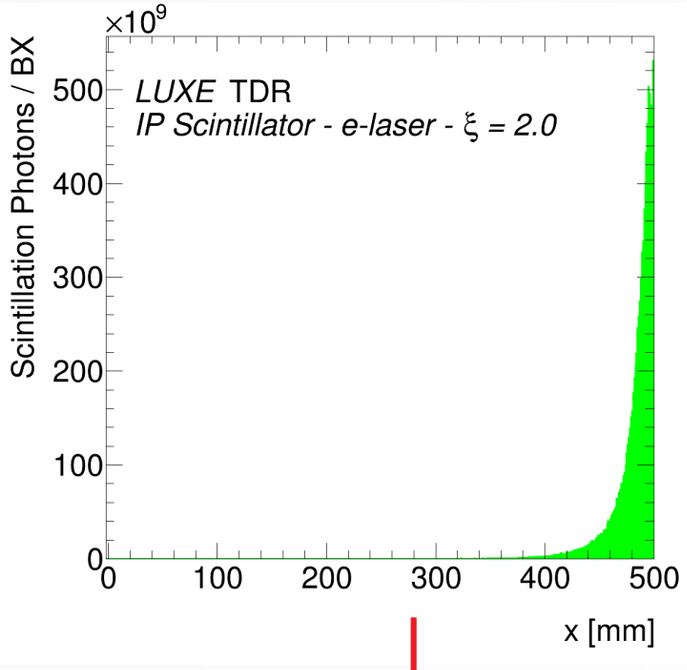
[2]

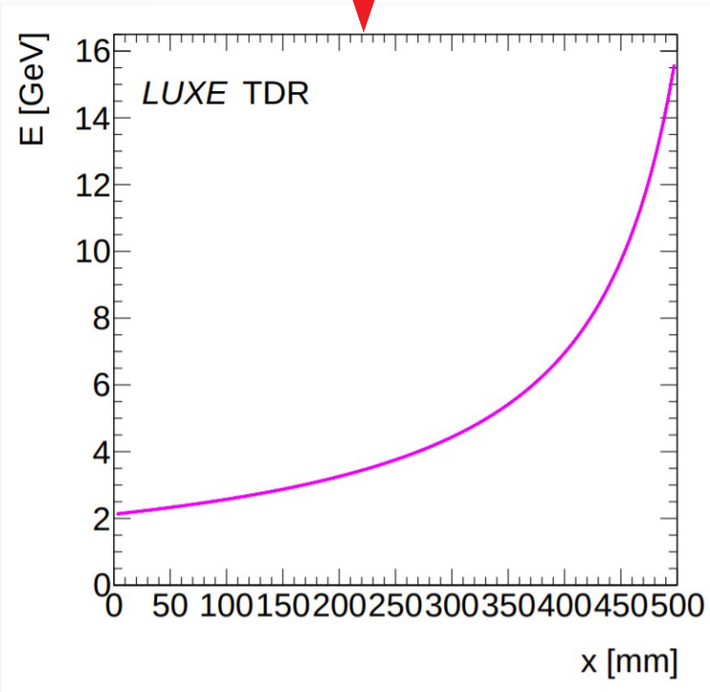
CMOS Sensor Quantum Efficiency by Wavelength



[3]

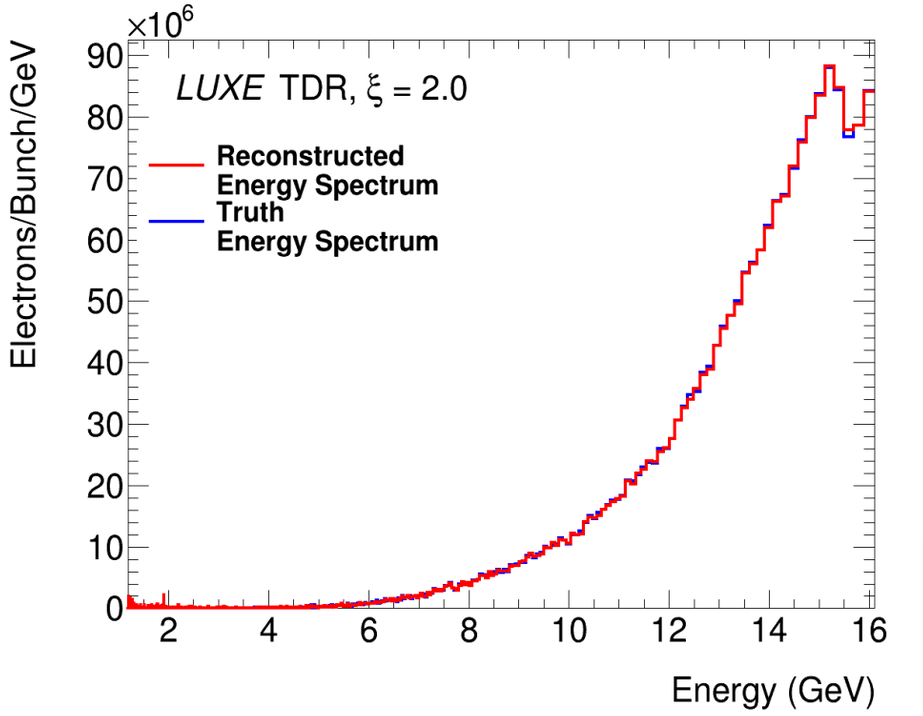
Reconstruction in Simulation



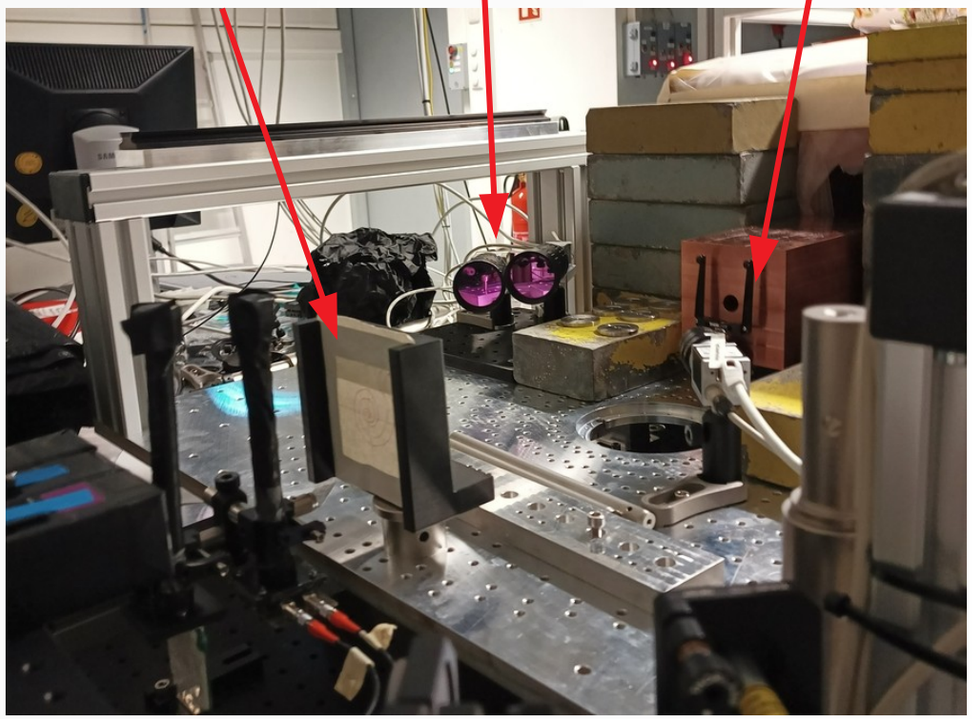


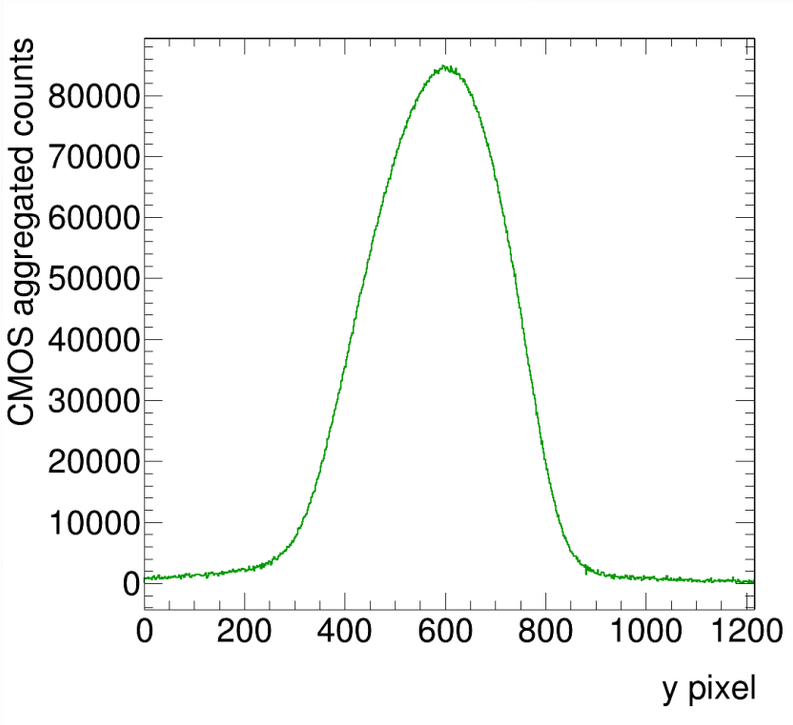
- Geant4 simulation + reconstruction delivers high energy resolution for realistic 125 micron position resolution, and just one beam-LASER event

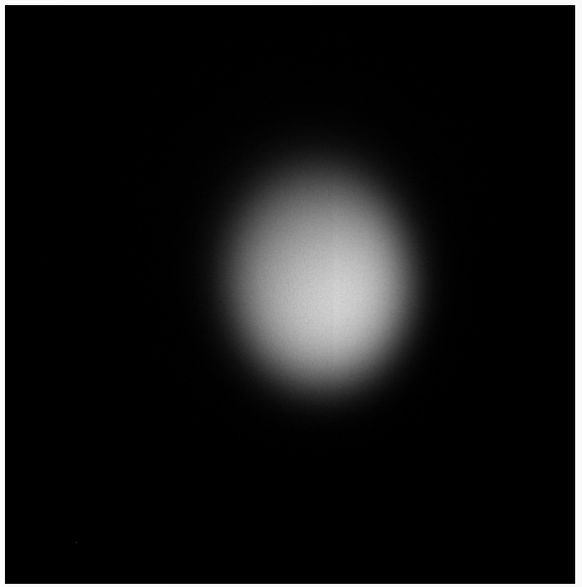
- This discrepancy between truth & reconstruction, expected to be less than B-field uncertainty (~1%) and charge-light calibration (~1%)



Test-Beam Prototype







- High-flux LASER-plasma testbeam at DESY used to test Screen & Camera prototype

- Shown: result of 4000 events of up to 10^7 e^- at ~60 MeV

Summary

- LUXE is an experiment under design & planning, intending to push into new parameter space of χ, with intent to measure rates & kinematics of Non-Linear Compton Scattering & Multiphoton Breit-Wheeler Process

- A scintillator screen & camera system is chosen to measure the high-flux high-energy electrons; with a magnetic field, the system acts as magnetic spectrometer with high energy resolution

- The setup has been constructed in Geant4, a reconstruction algorithm developed & tested, and a prototype of the detector system constructed and tested in high-flux beam

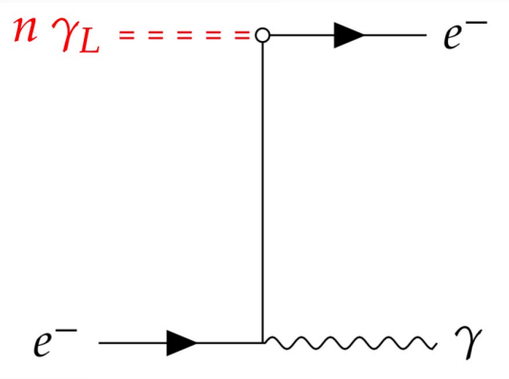
Further Reading: Our Conceptual Design Report

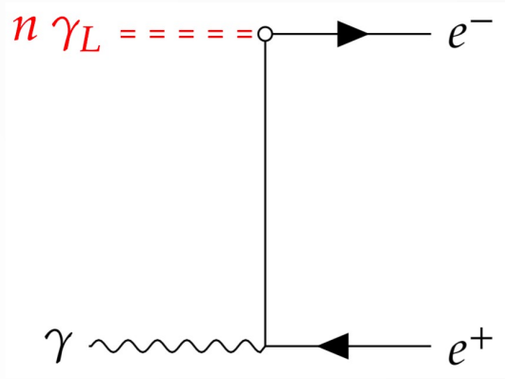
H. Abramowicz et al., Conceptual design report for the LUXE experiment, *The European Physical Journal Special Topics* 230 (Sep, 2021) 2445–2560 arxiv.org/abs/2102.02032

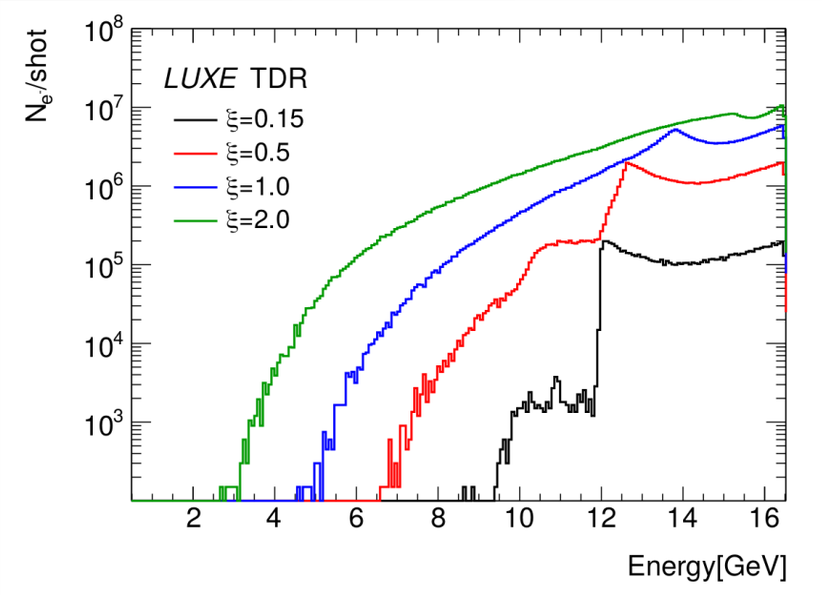
[1] Jung, Im & Cho, Min & Lee, Sang & Bae, Kong & Jung, Phill & Lee, Chi & Lee, Jae & Yun, Seungman & Kim, Ho Kyung & Kim, Seong & Ko, Jong. (2008). Flexible Gd2O2S:Tb scintillators pixelated with polyethylene microstructures for digital x-ray image sensors. *Journal of Micromechanics and Microengineering*. 19. 015014. 10.1088/0960-1317/19/1/015014.
[2] Edmund Optics, 543nm cwl, 50mm diameter, 22nm bandwidth, od 6 fluorescence filter, 2021. https://www.edmundoptics.com/p/543nm-cwl-50mm-dia-22nm-bandwidth-od-6-fluorescence-filter/21586/
[3] Basler AG, Basler aca1920-40gm, camera specification, document number: Bd000940, version v01, 2021.

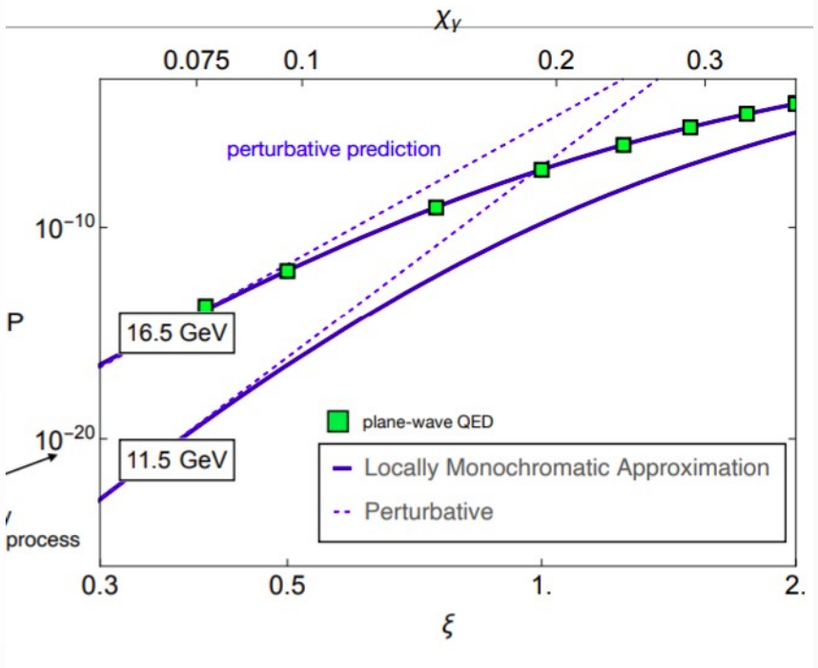
backup

Non-Linear Compton Scattering & Spontaneous Breit-Wheeler





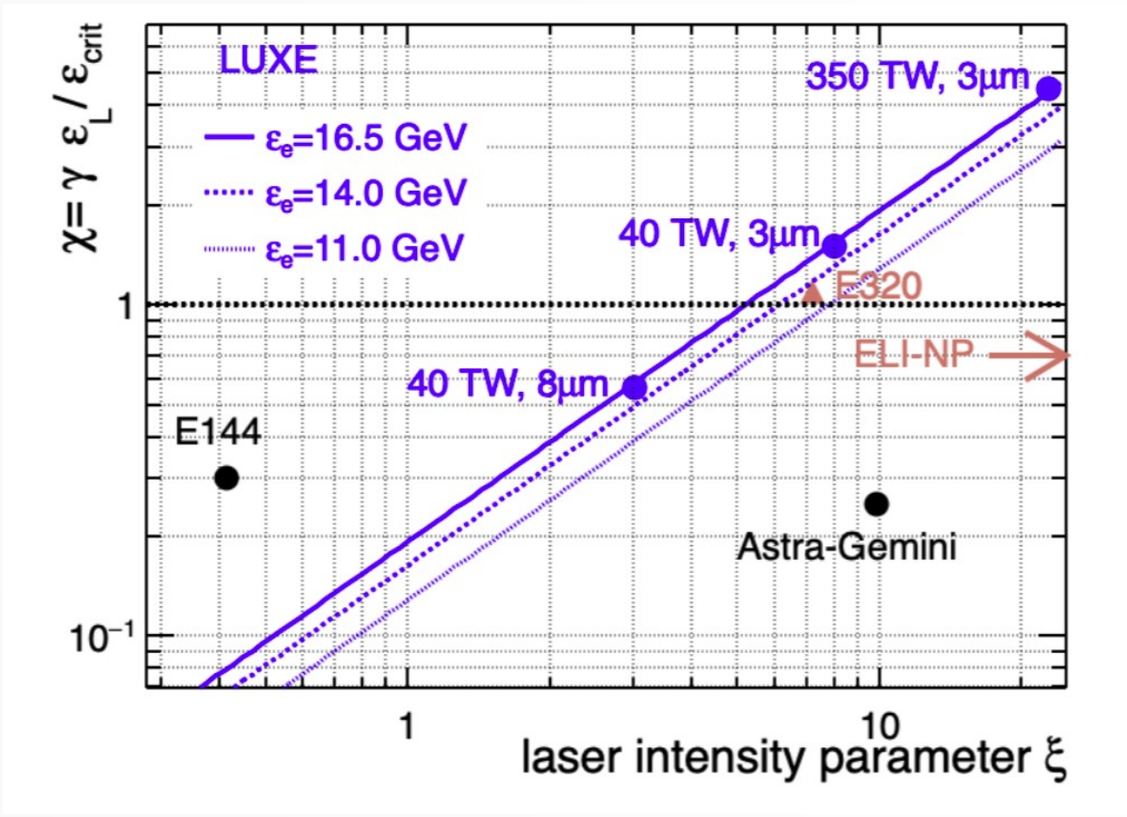


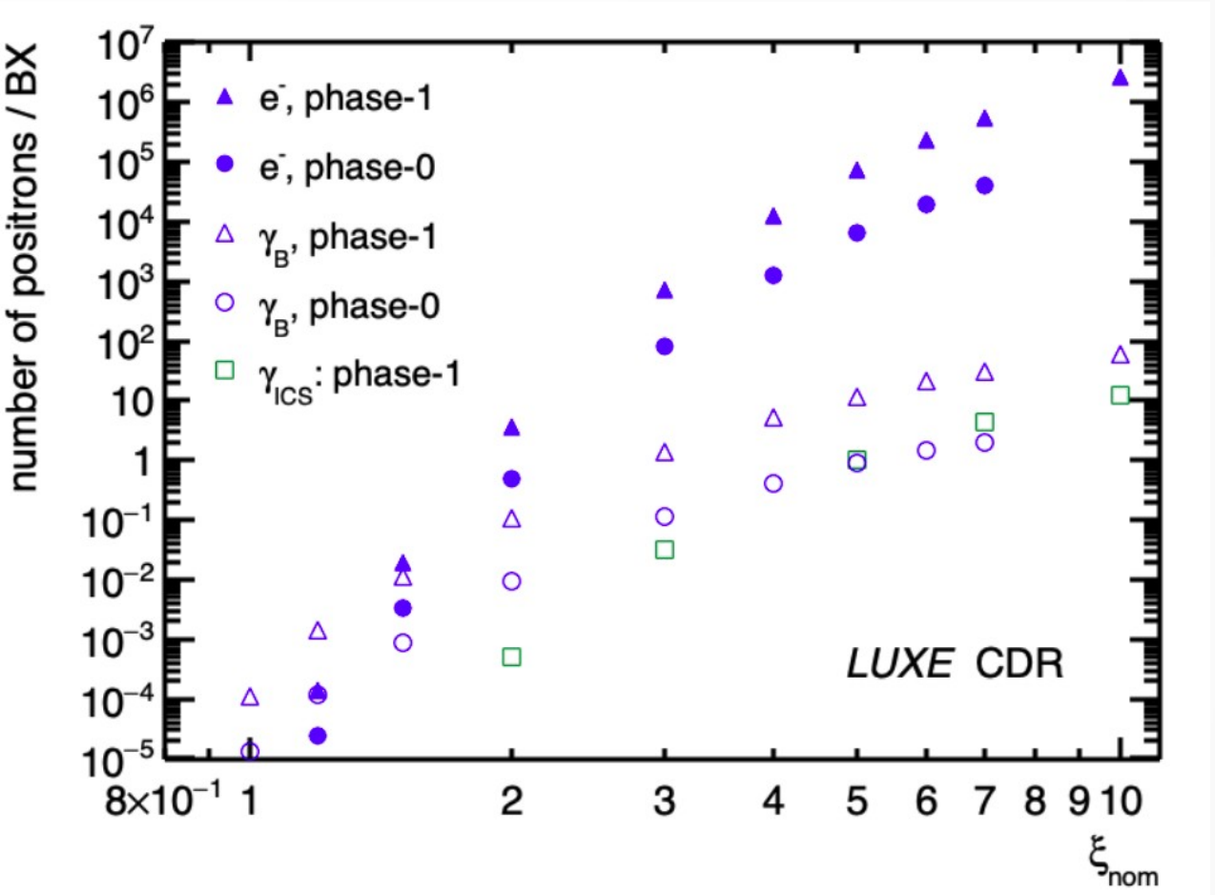


Non-linear Compton Scattering

Multi-Photon Breit-Wheeler Process

LUXE Physics Expected Results

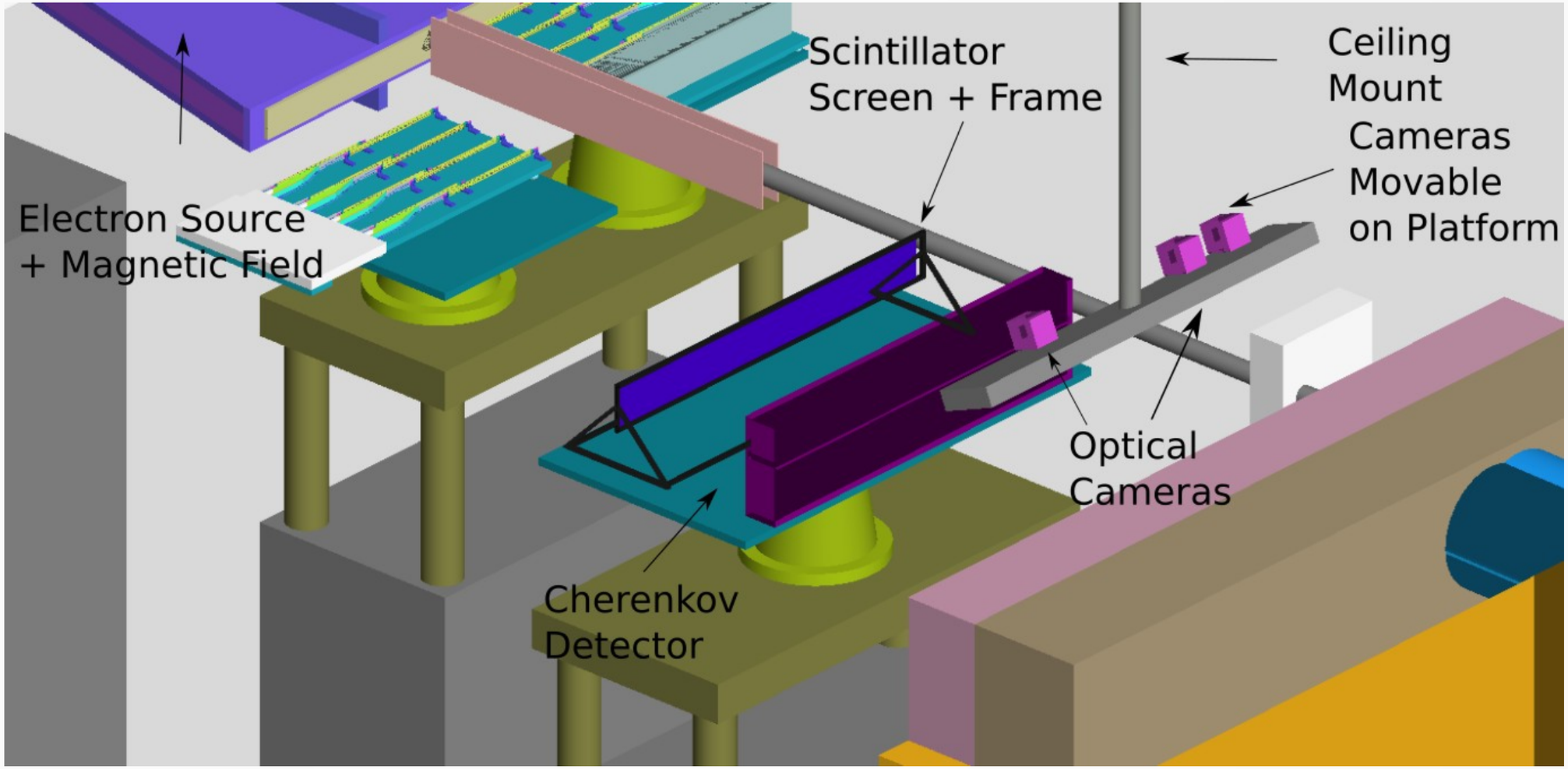




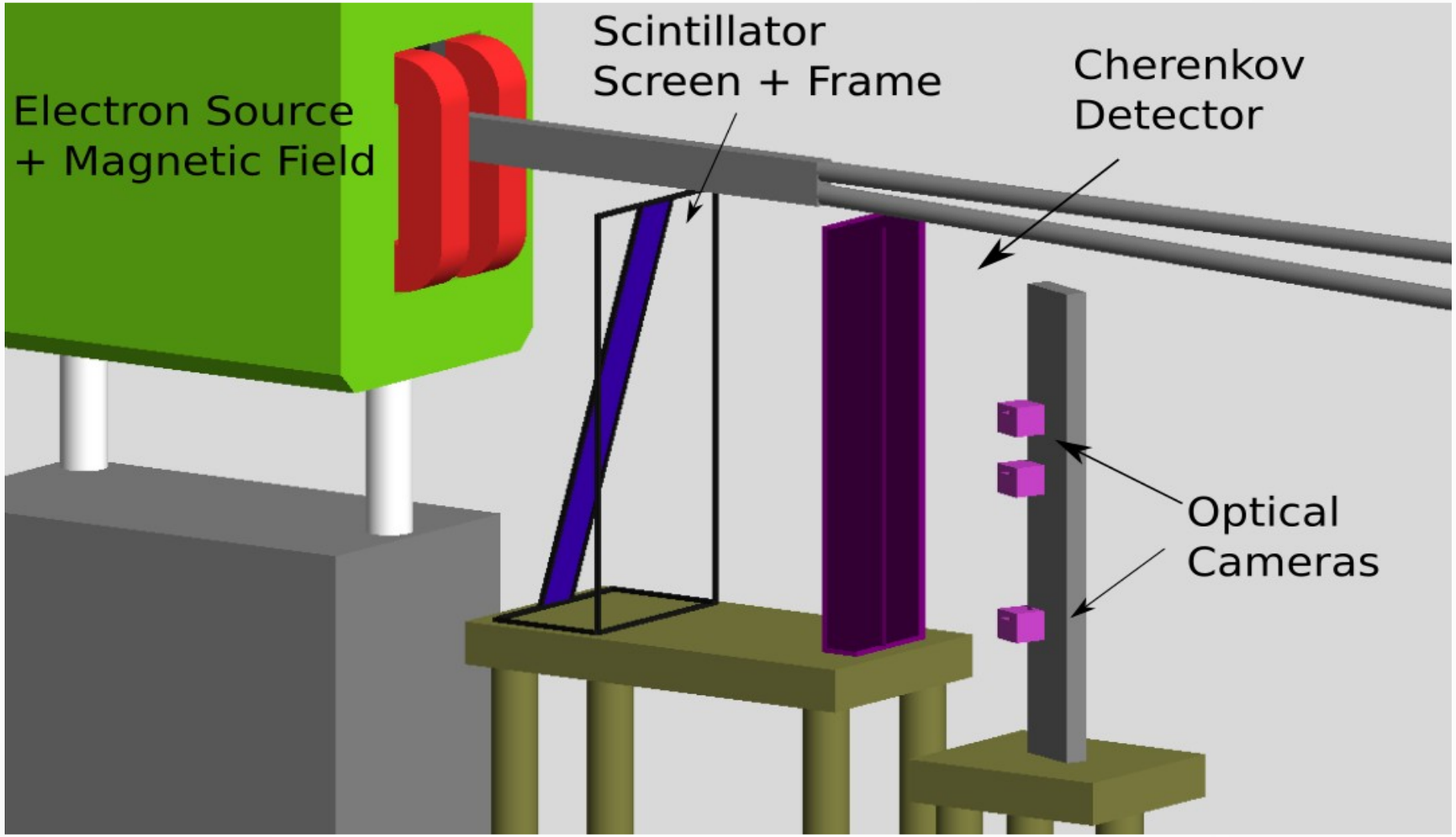
Probing into new parameter-space

Pair-production rate with ξ

e-LASER IP Electron Detection System

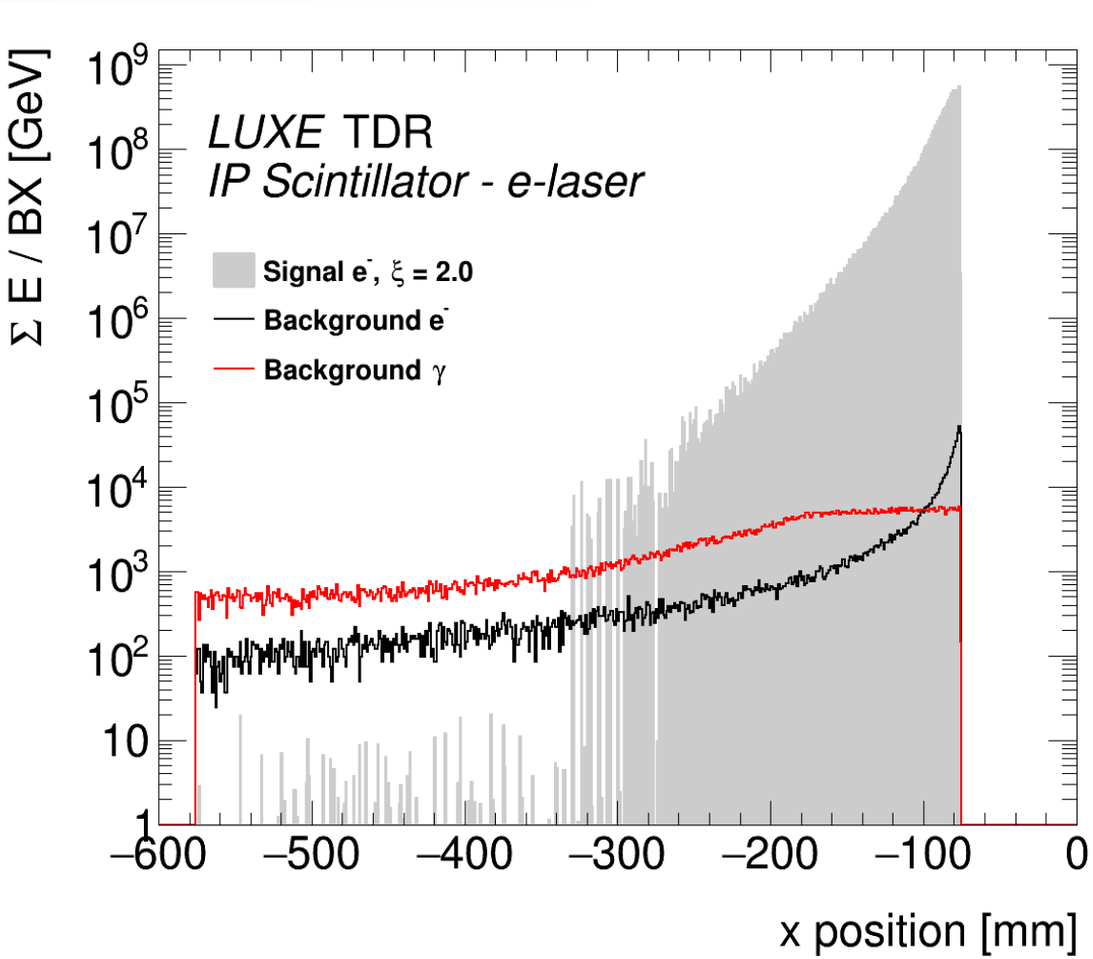


Gamma Beam Generation

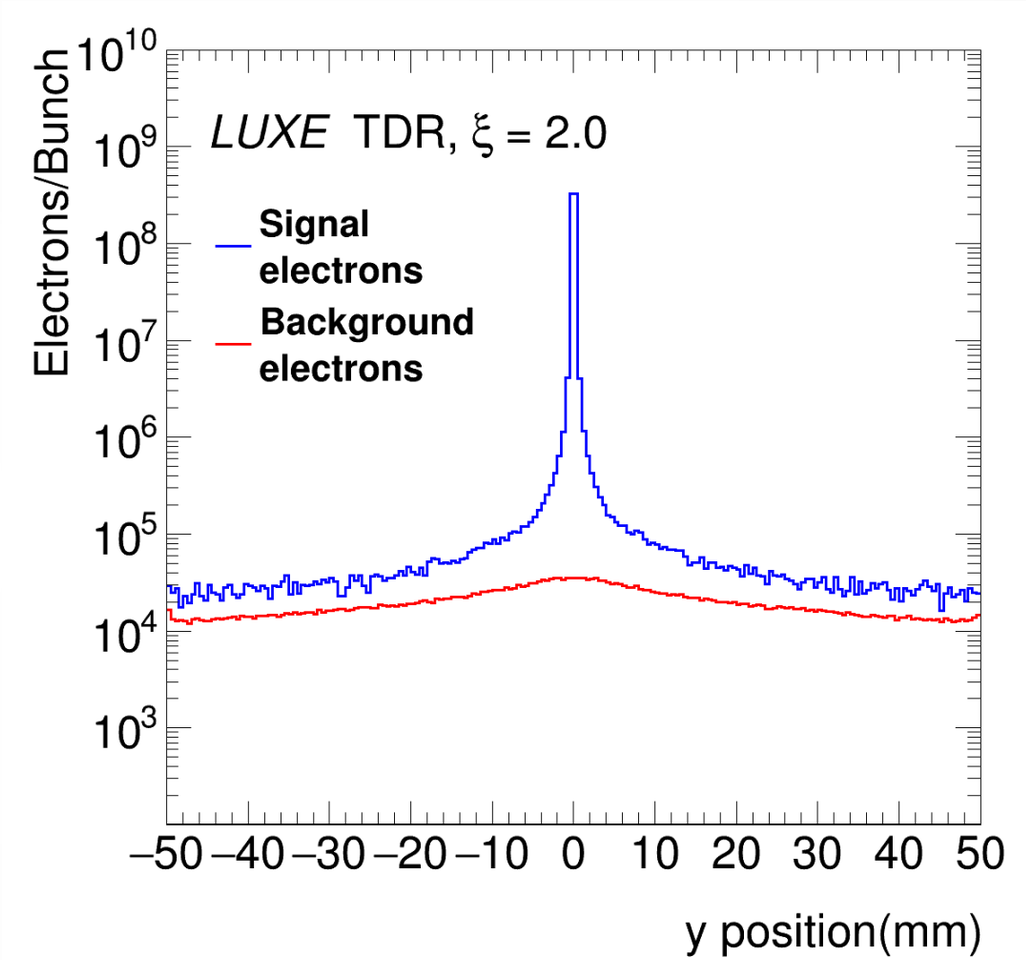


Signal and Background

Signal vs Background Incident on Screen in x

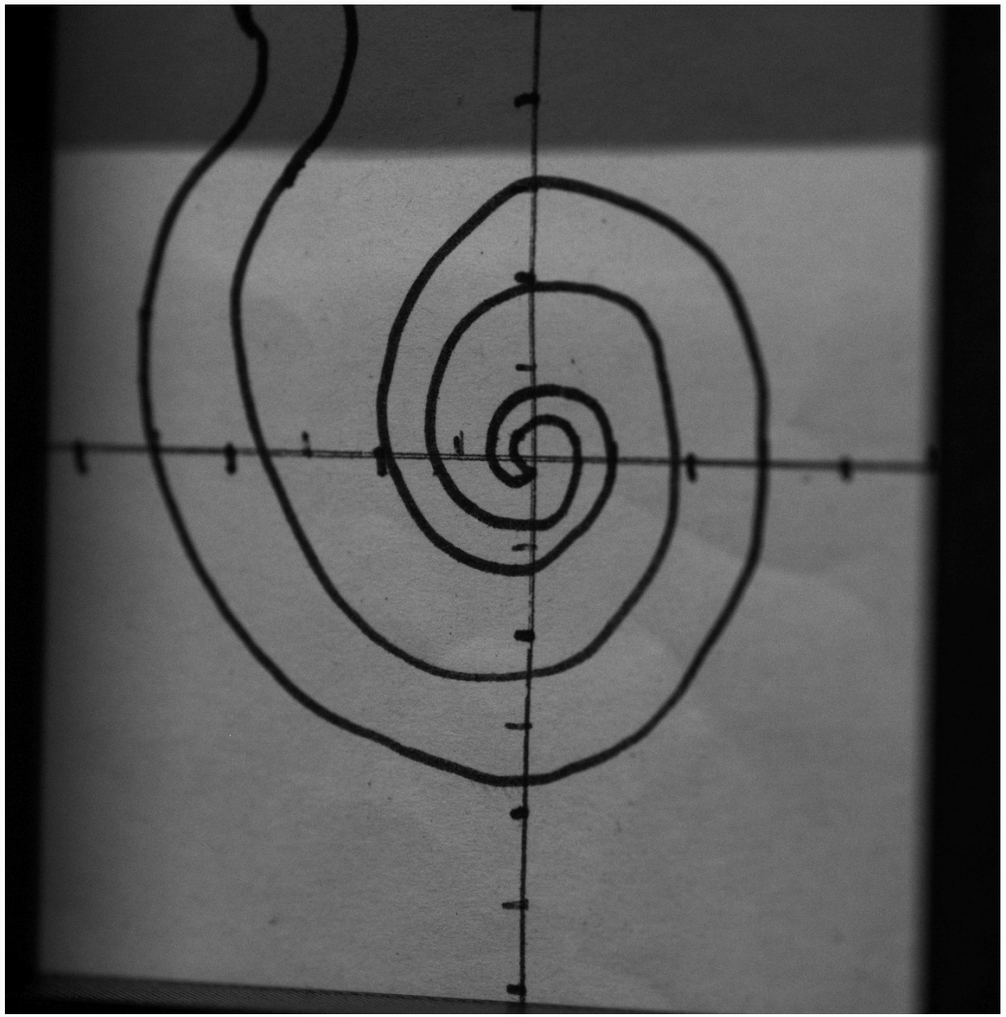


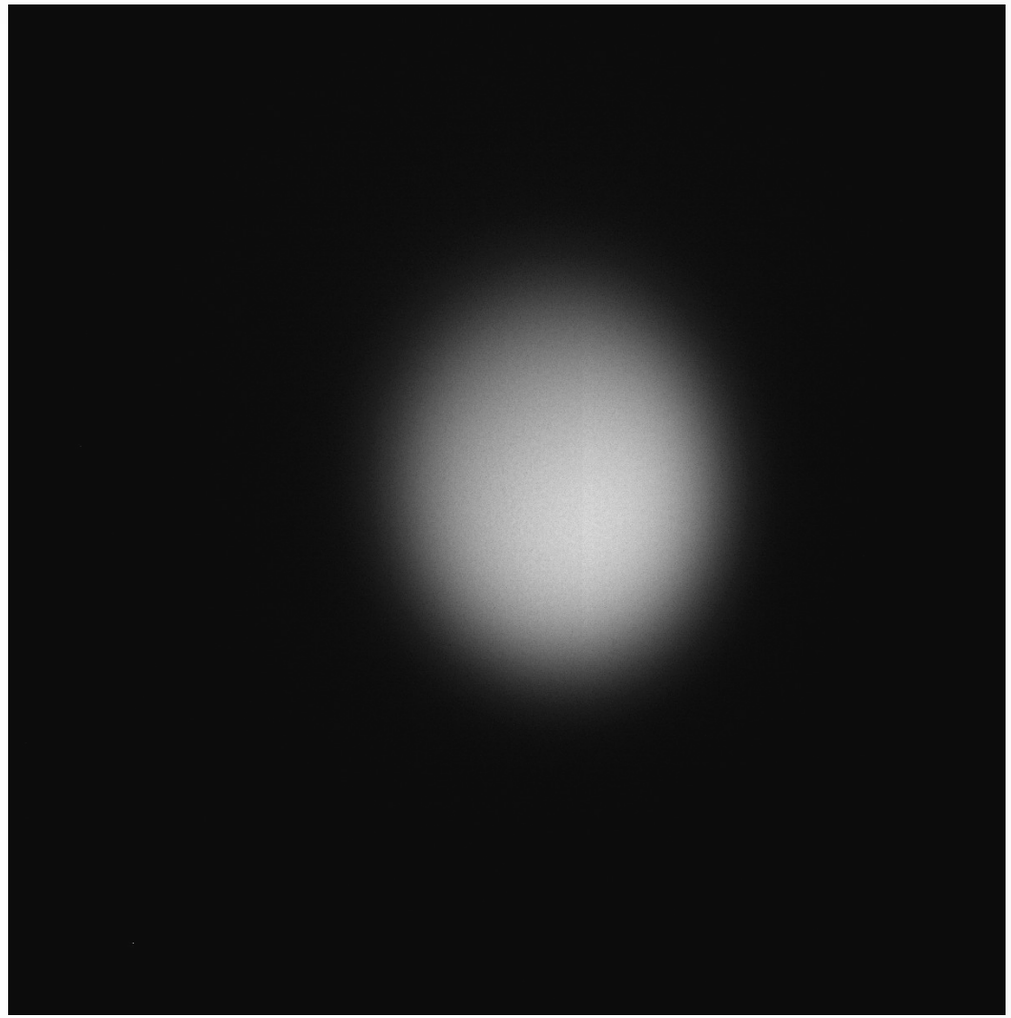
Signal vs Background Electrons Incident on Screen in y



- Whole LUXE Experimental Chamber, simulated in Geant4

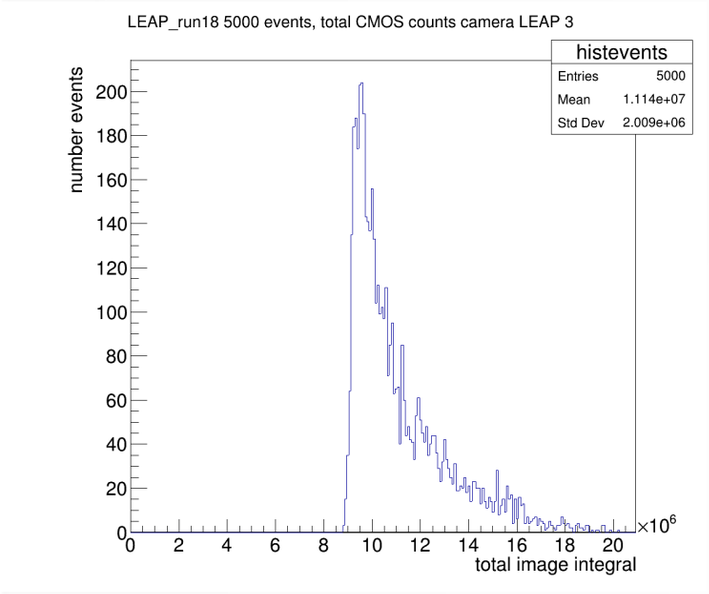
Test-Beam Prototype

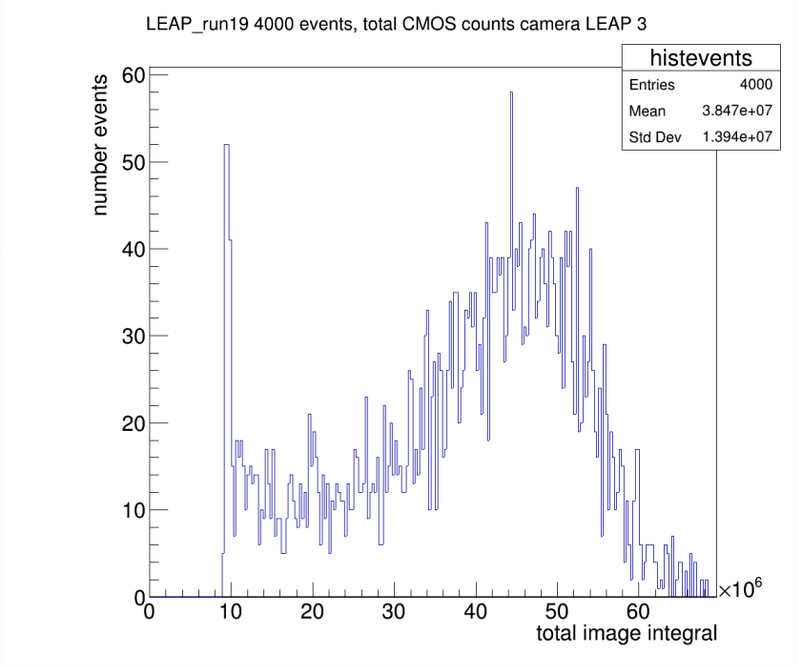


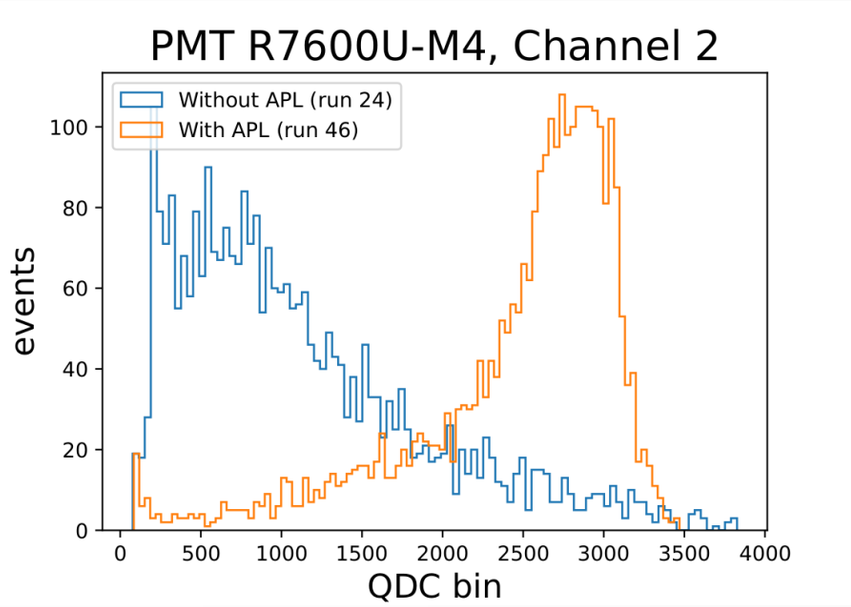


- ~2cm diameter beam

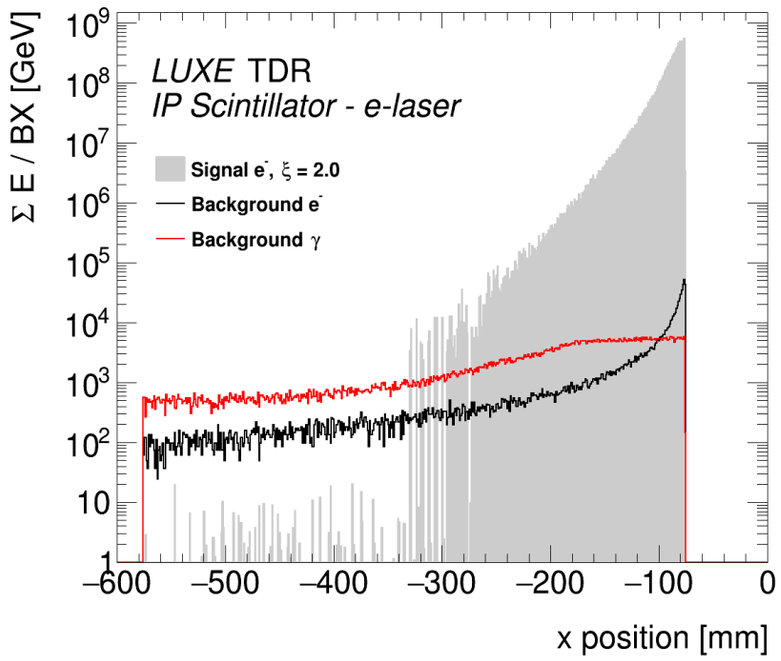
Test-Beam Prototype

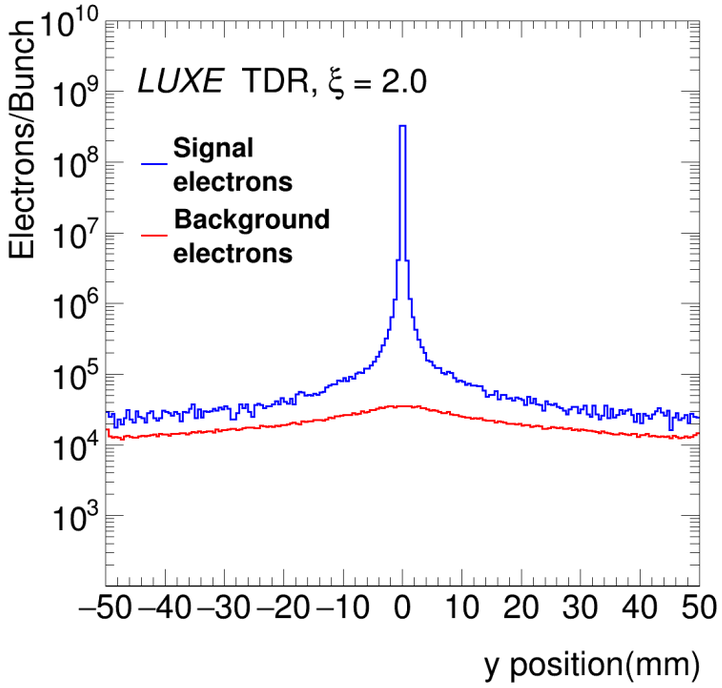


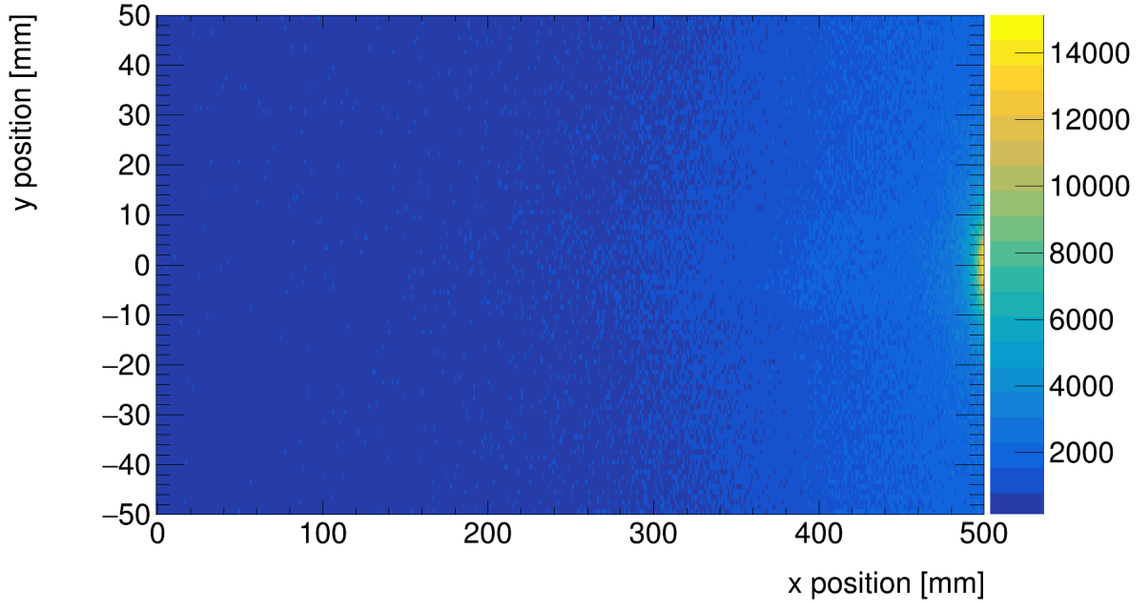




Signal and Background







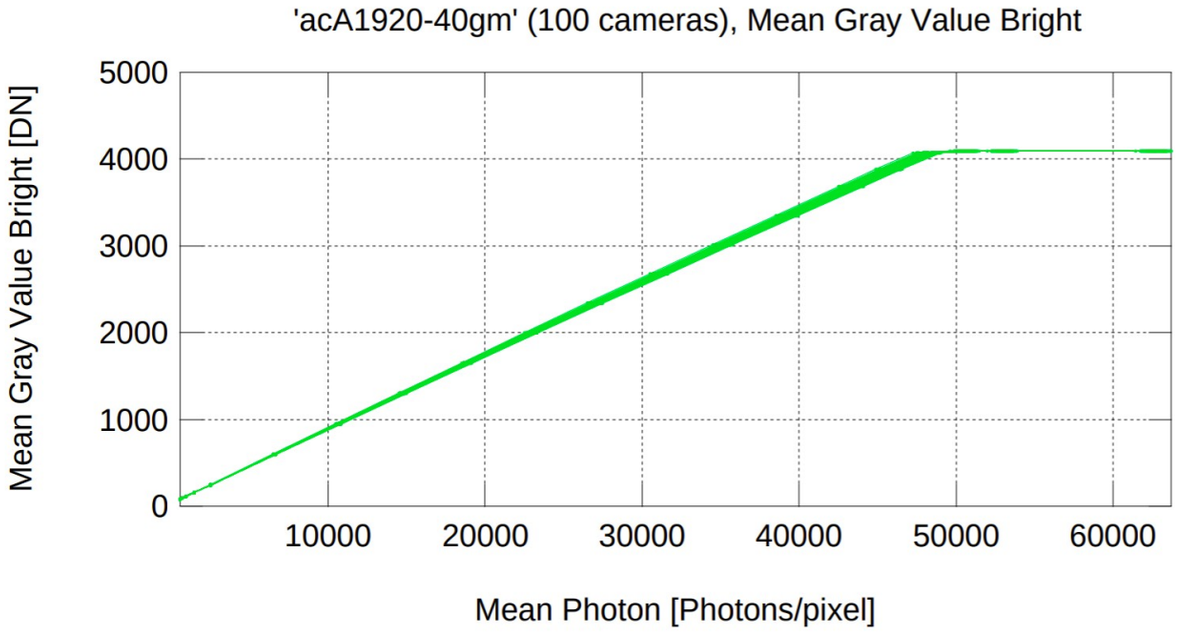
- Electron spectra reconstructions ($\xi = 2.0$) completed in Geant4, using the LUXE e-LASER geometry and simulating the scintillation physics process, but not explicitly optical transport

- High Signal / Background for radiation incident upon screen. Signal is more collimated within center of screen, so we use only this for signal measurement

- Profile of Background radiation along surface of screen is symmetrical around beam axis

- Beam-only events also used for background estimation

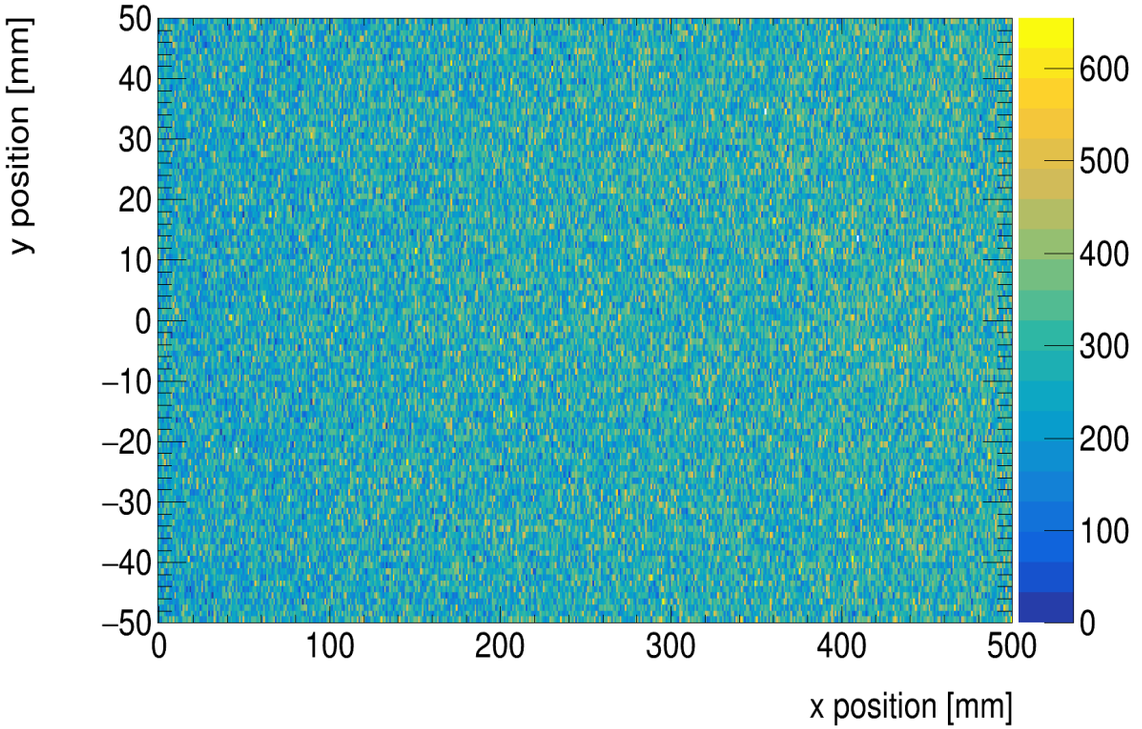
Cameras, Lens, Filter

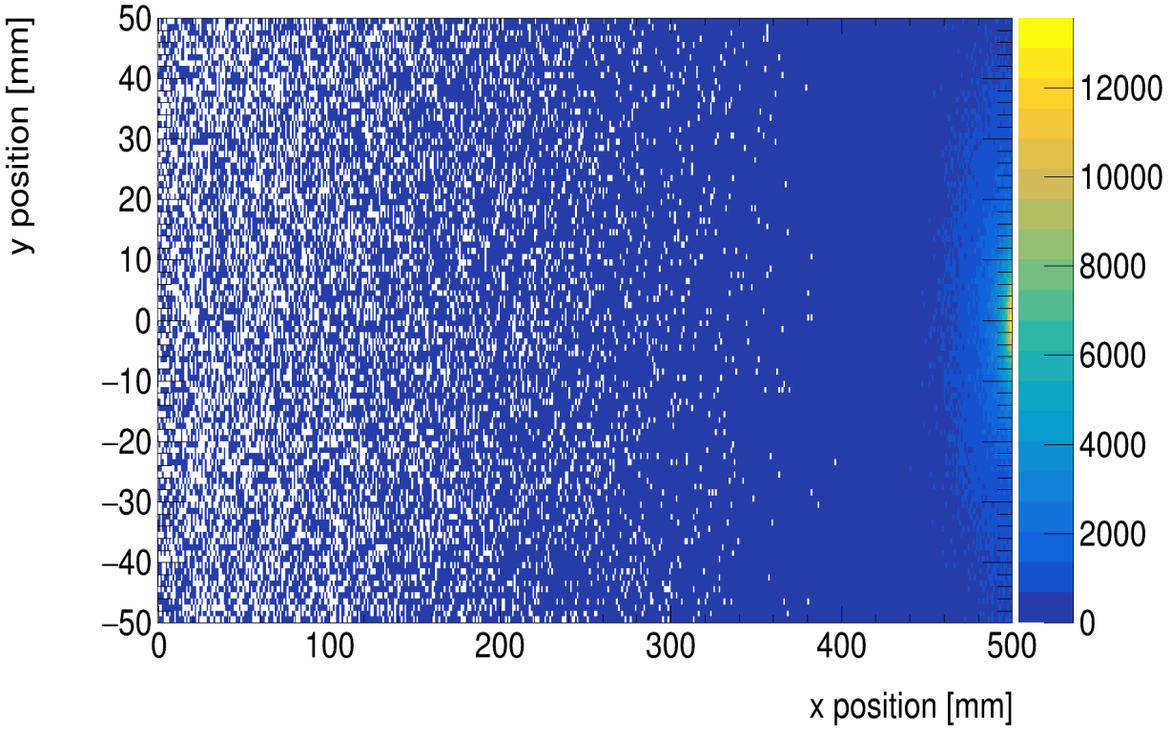


- Scintillation light can be imaged remotely to keep electronics out of beam-plane

- Quantum efficiency for photons λ=545nm ~70%

Background





- Background scattering composed of relatively flat profile superimposed with one symmetric around e^- beam axis

- Background neutron flux (left) vs. background electron flux (right)

- Background profiles can be built from no-LASER bunches, accumulating up to 9Hz for every 1Hz of signal