

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

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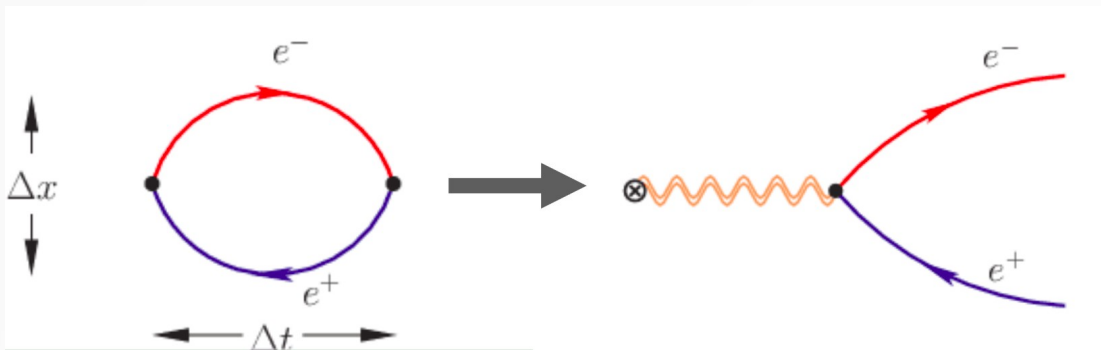
DPG Spring Matter and Cosmos Section Meeting,
22.03.2022, 17:00 – 17:15

LUXE



UCL

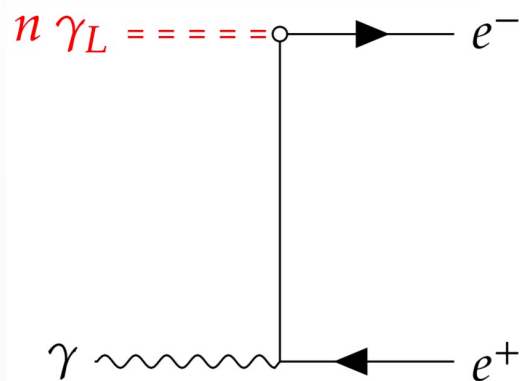
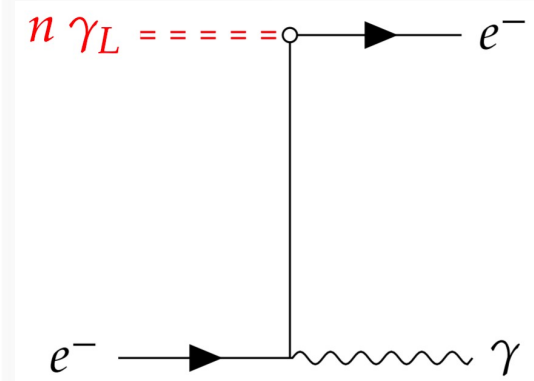
Strong-Field QED



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

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

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



- 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 colliders

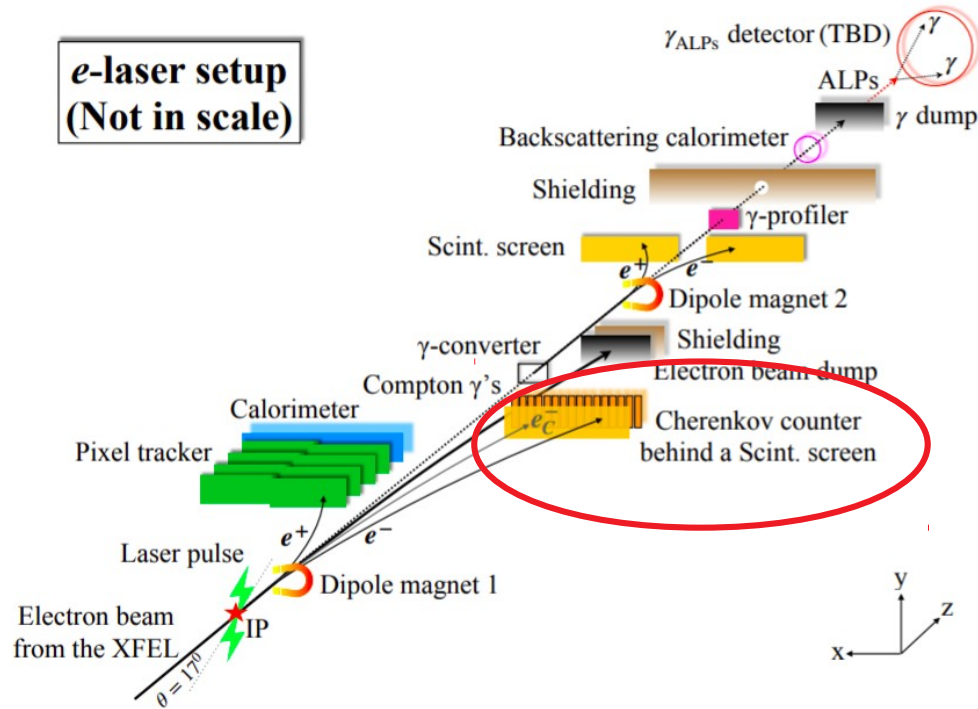
LUXE Experiment



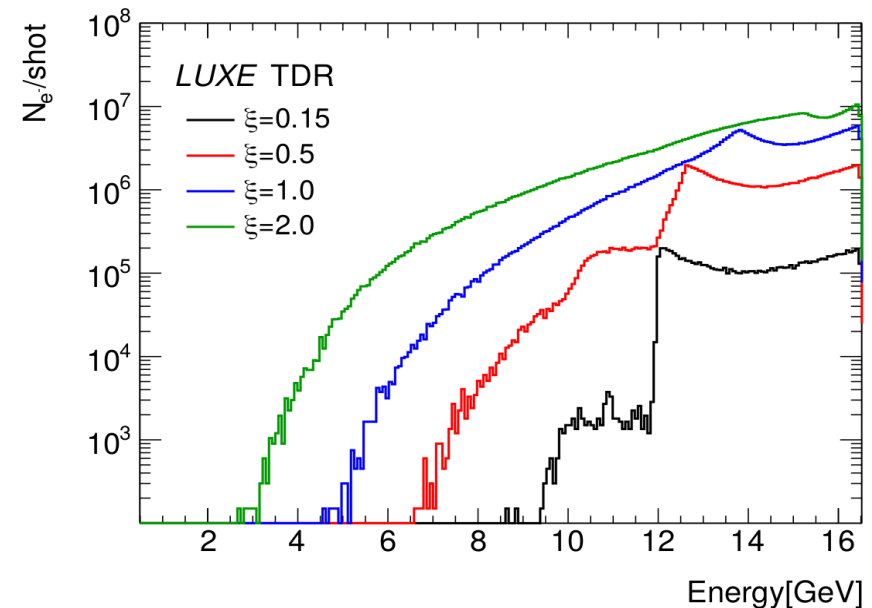
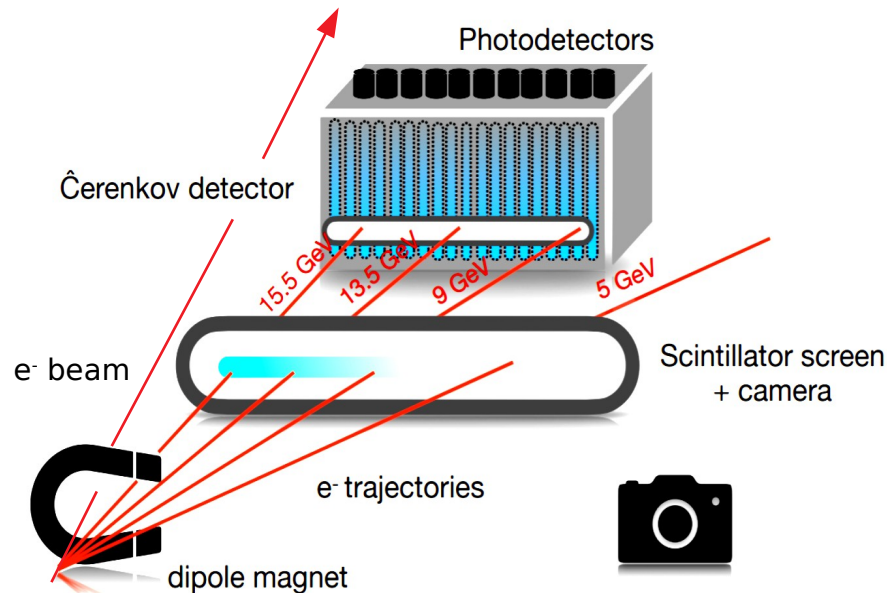
- High-power LASER collided with electrons (e-LASER) or photons (γ -LASER)
- Electrons from EU.XFEL, typical $n=1.5 \times 10^9$ & $E=16.5$ GeV
- Electron bunches delivered at 10Hz, LASER pulses at 1Hz
- Aims to push into new χ parameter space with enough statistics to make high-quality measurements
- Photons produced by bremsstrahlung (W Target) or Inverse-Compton Scattering (Split LASER beam)



Detectors at LUXE

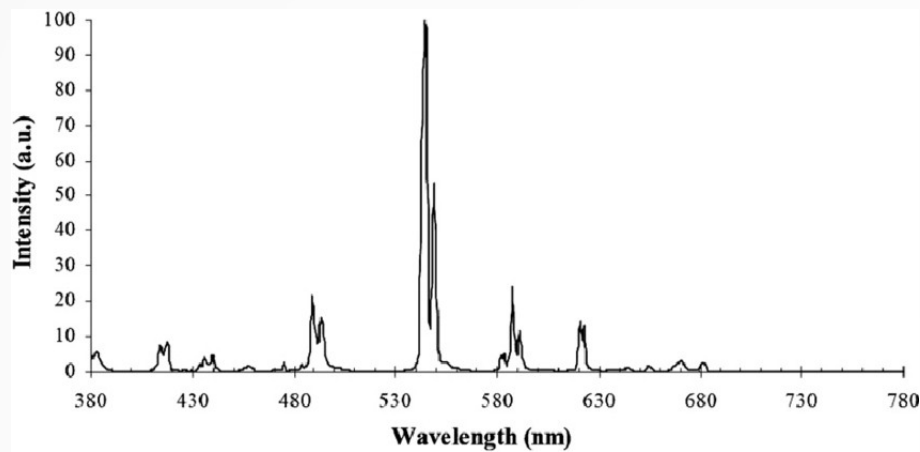


- Electrons are to be detected at e-LASER IP region (total 10^7 to 10^9) at energy between 1-16 GeV for $E_{\text{beam}} = 16.5$ GeV
- Charged particles are diverted by magnetic field, acting as magnetic spectrometer
- Particle Flux measurement with respect to position allows for energy reconstruction
- Electron detection wants to measure total flux/BX and 'Compton Edge' position in energy

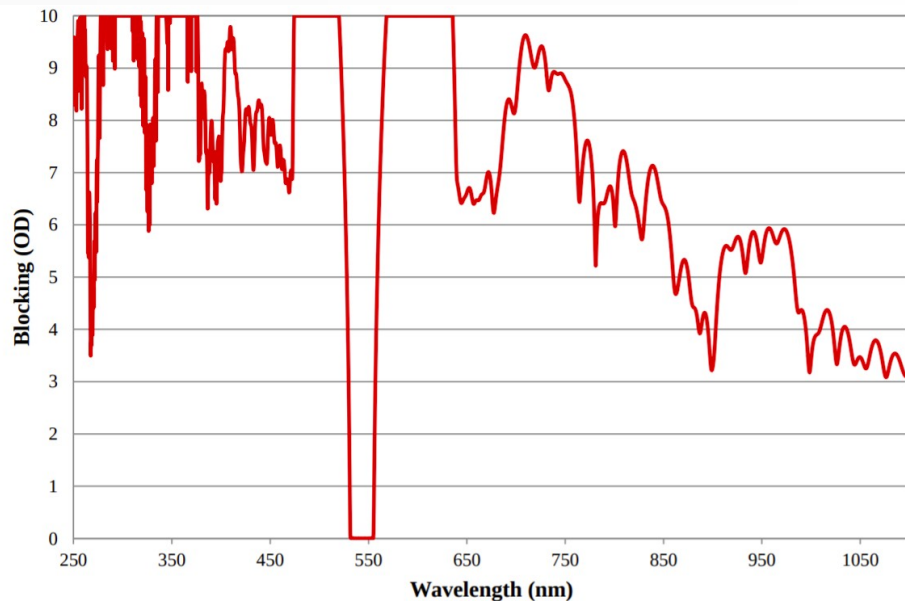


Scintillation Screen, Camera and Filter

GdOx Scintillation Wavelength Emission

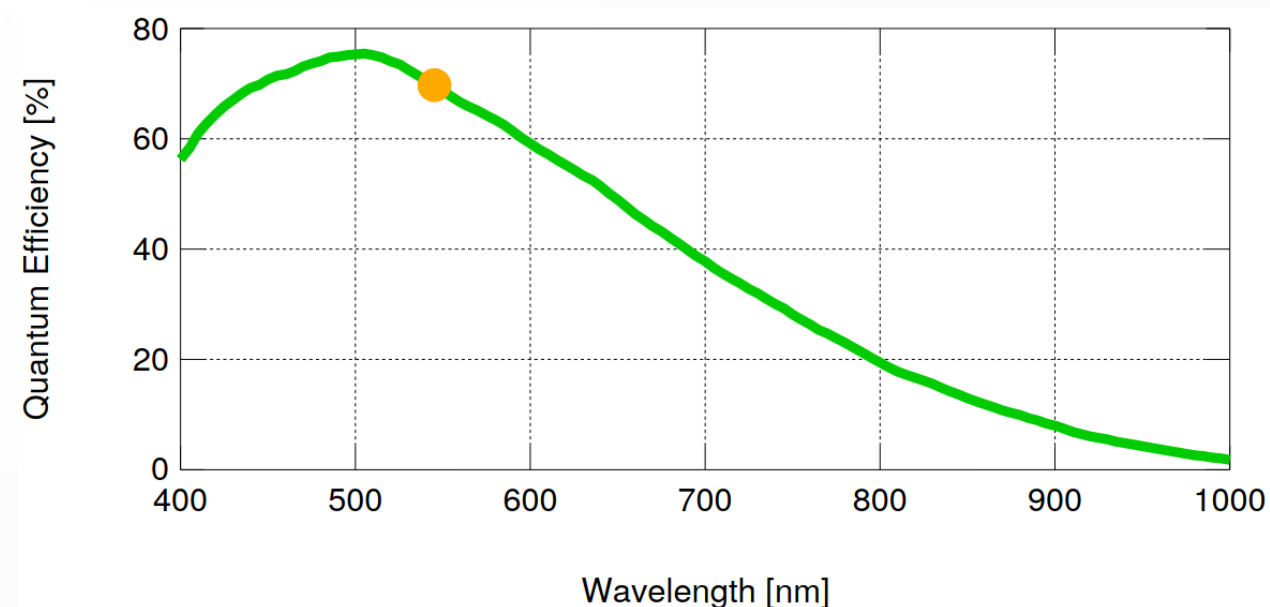


Optical Filter Blocking by Wavelength



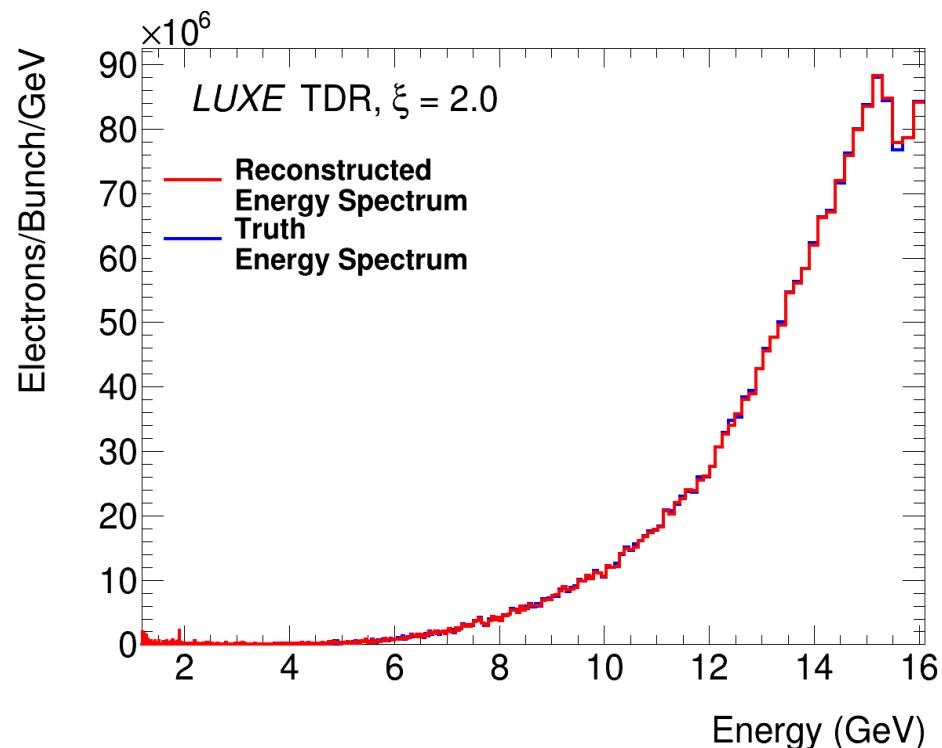
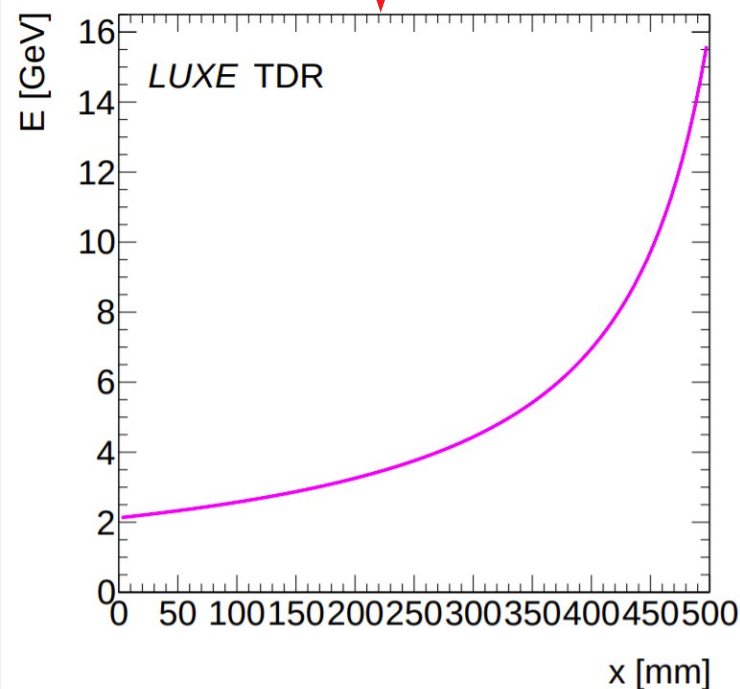
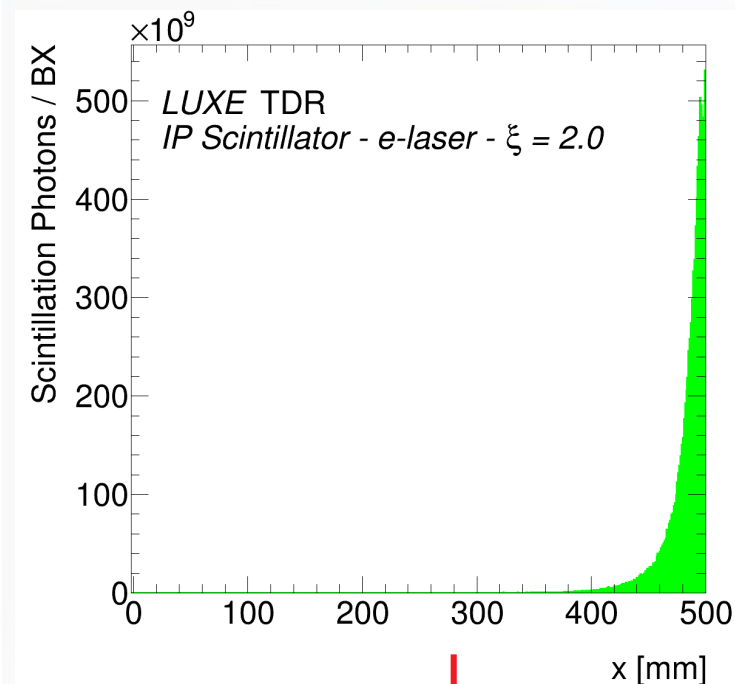
- Scintillator is Gadolinium Oxysulfide, efficiency up to 15%
- Relatively long decay time allows sensor exposure after event
- Optical filter used to remove any ambient light

CMOS Sensor Quantum Efficiency by Wavelength



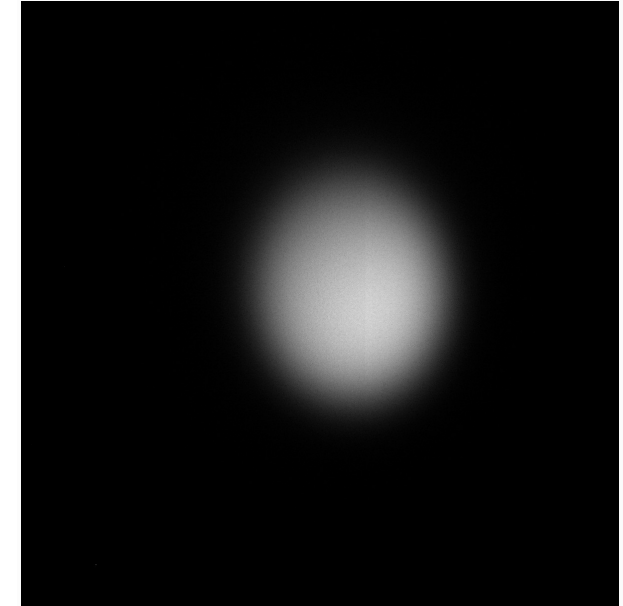
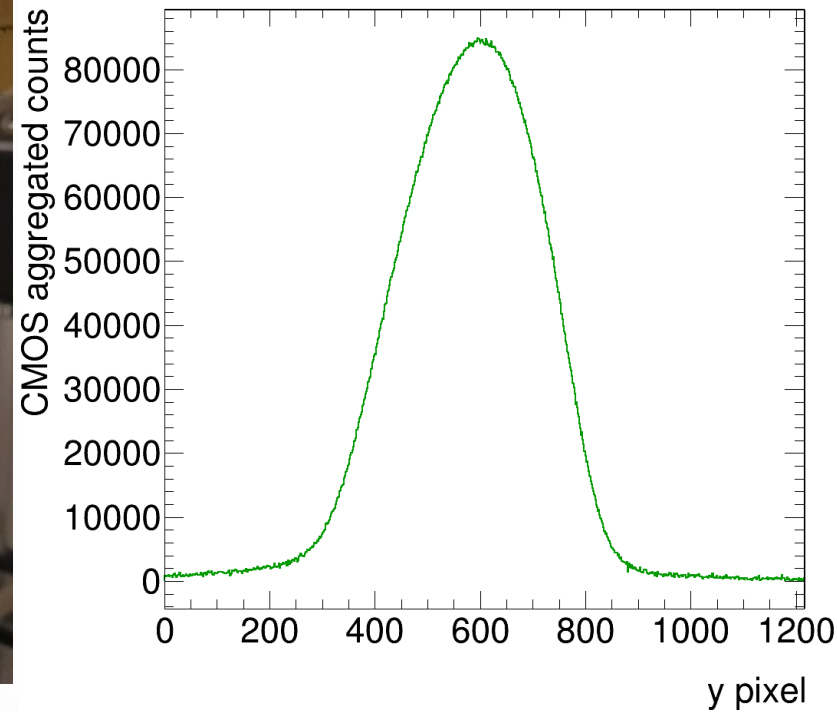
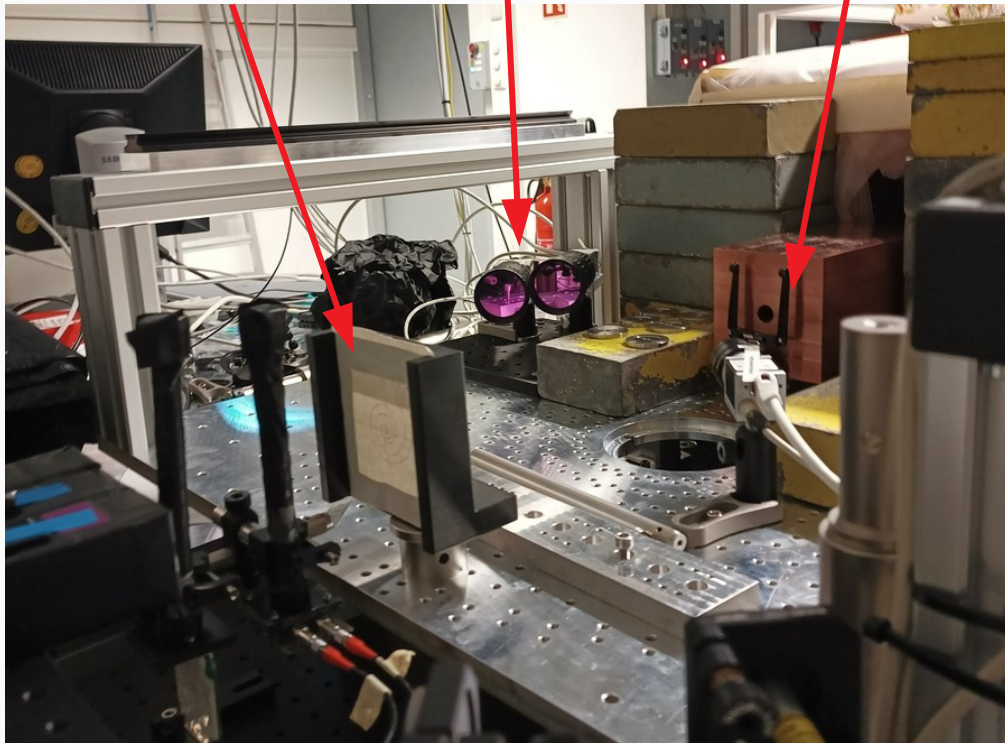
Reconstruction in Simulation

- 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 ($\sim 1\%$) and charge-light calibration ($\sim 1\%$)
- Both total flux of electrons, edge position are wanted



Test-Beam Prototype

Screen Cameras $\varnothing 1\text{cm}$
Collimator



- 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

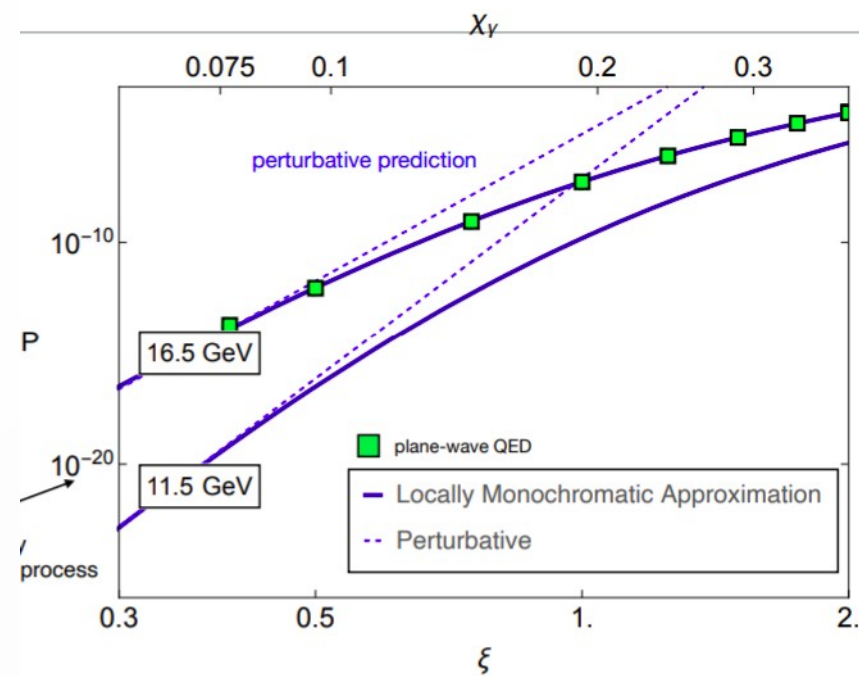
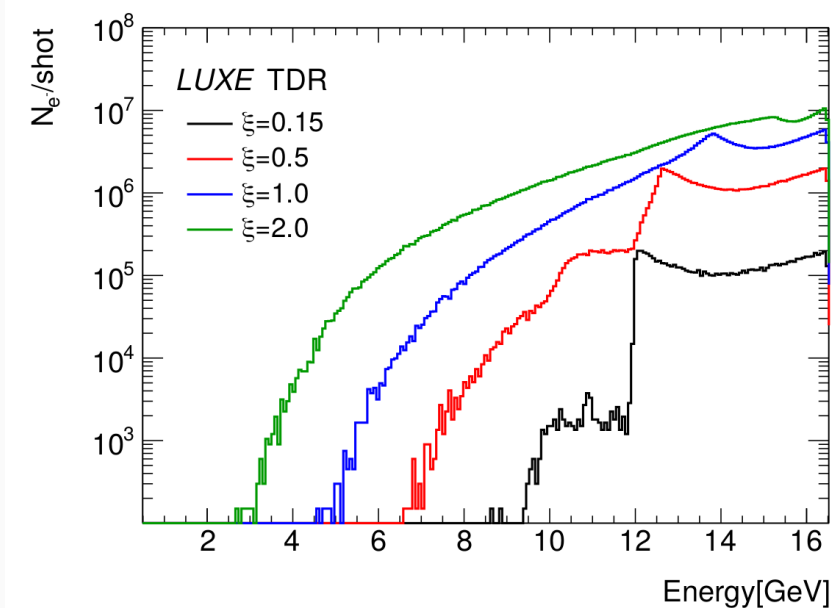
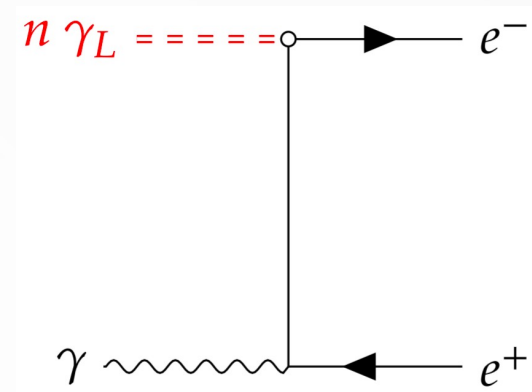
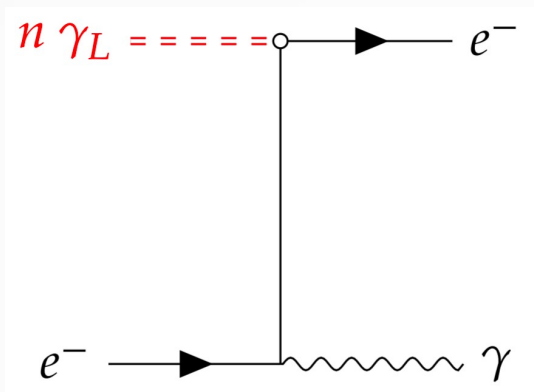
Summary

- 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
arxiv.org/abs/2102.02032

backup

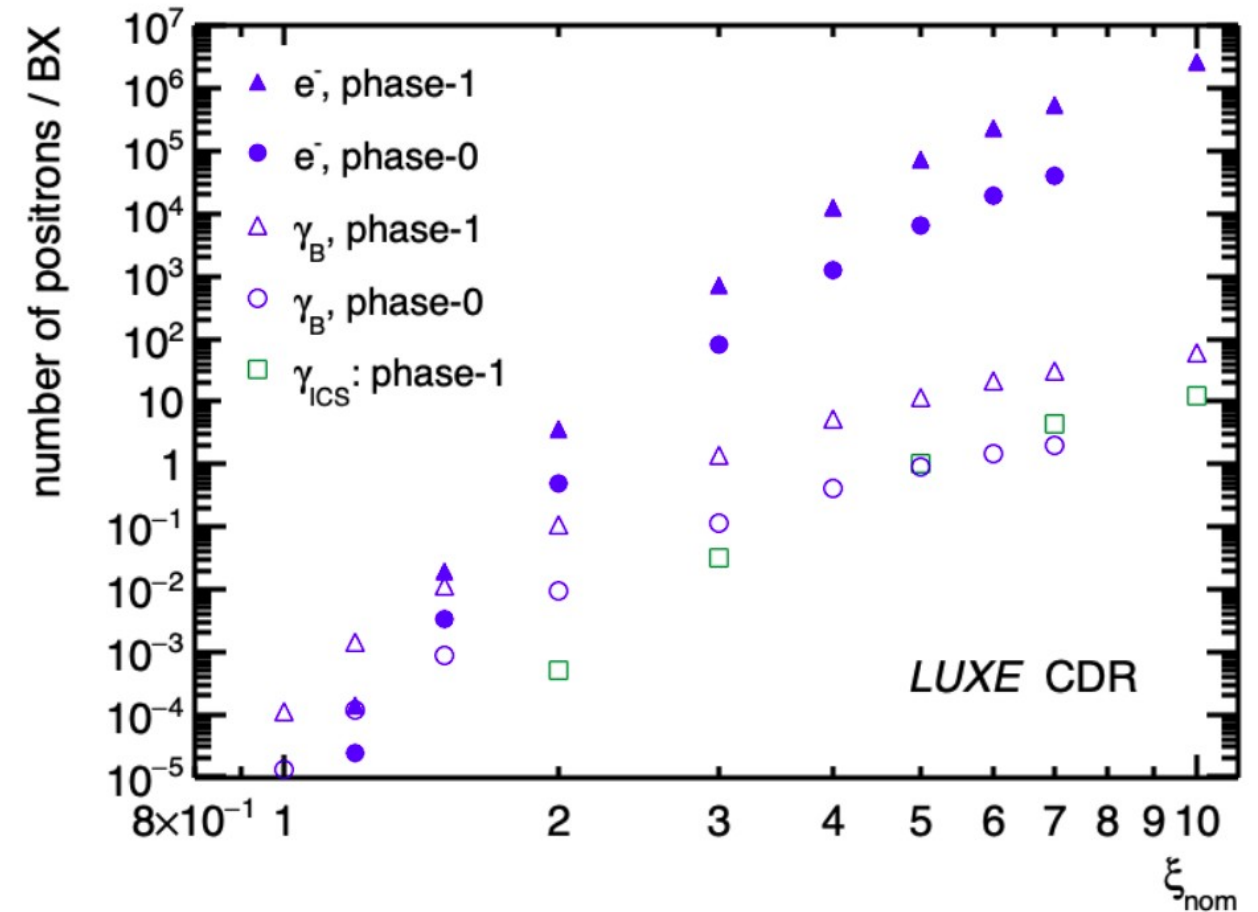
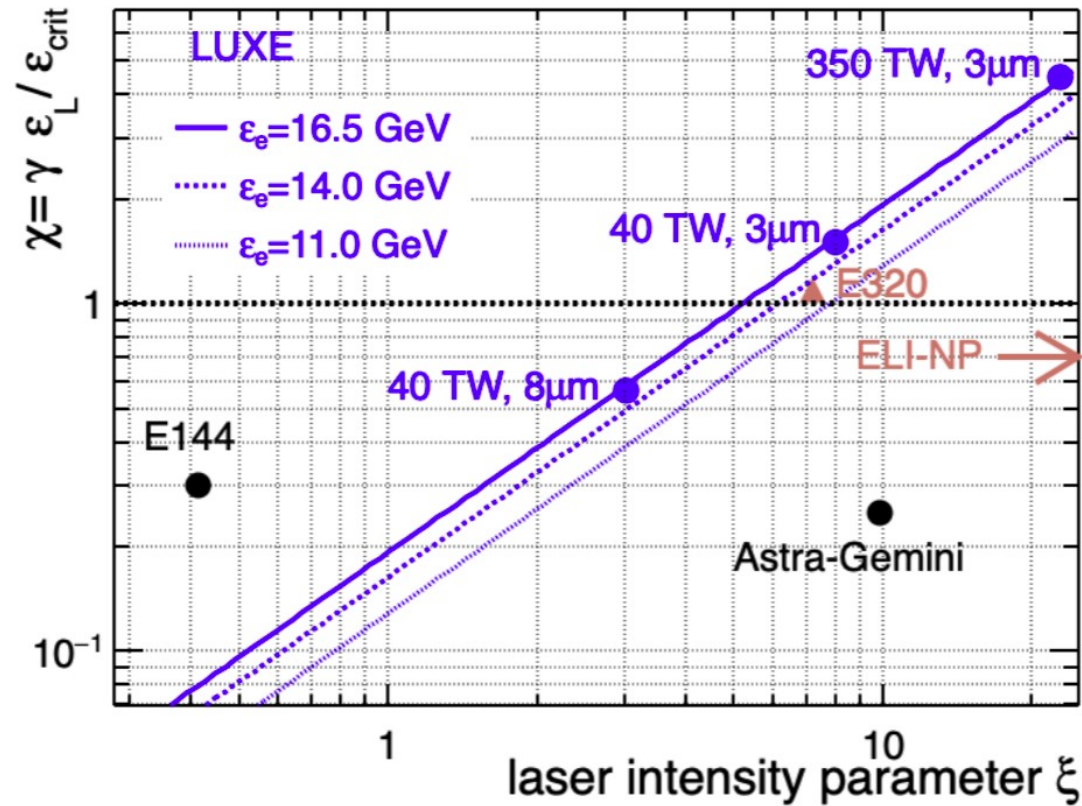
Non-Linear Compton Scattering & Spontaneous Breit-Wheeler



Non-linear Compton Scattering

Multi-Photon Breit-Wheeler Process

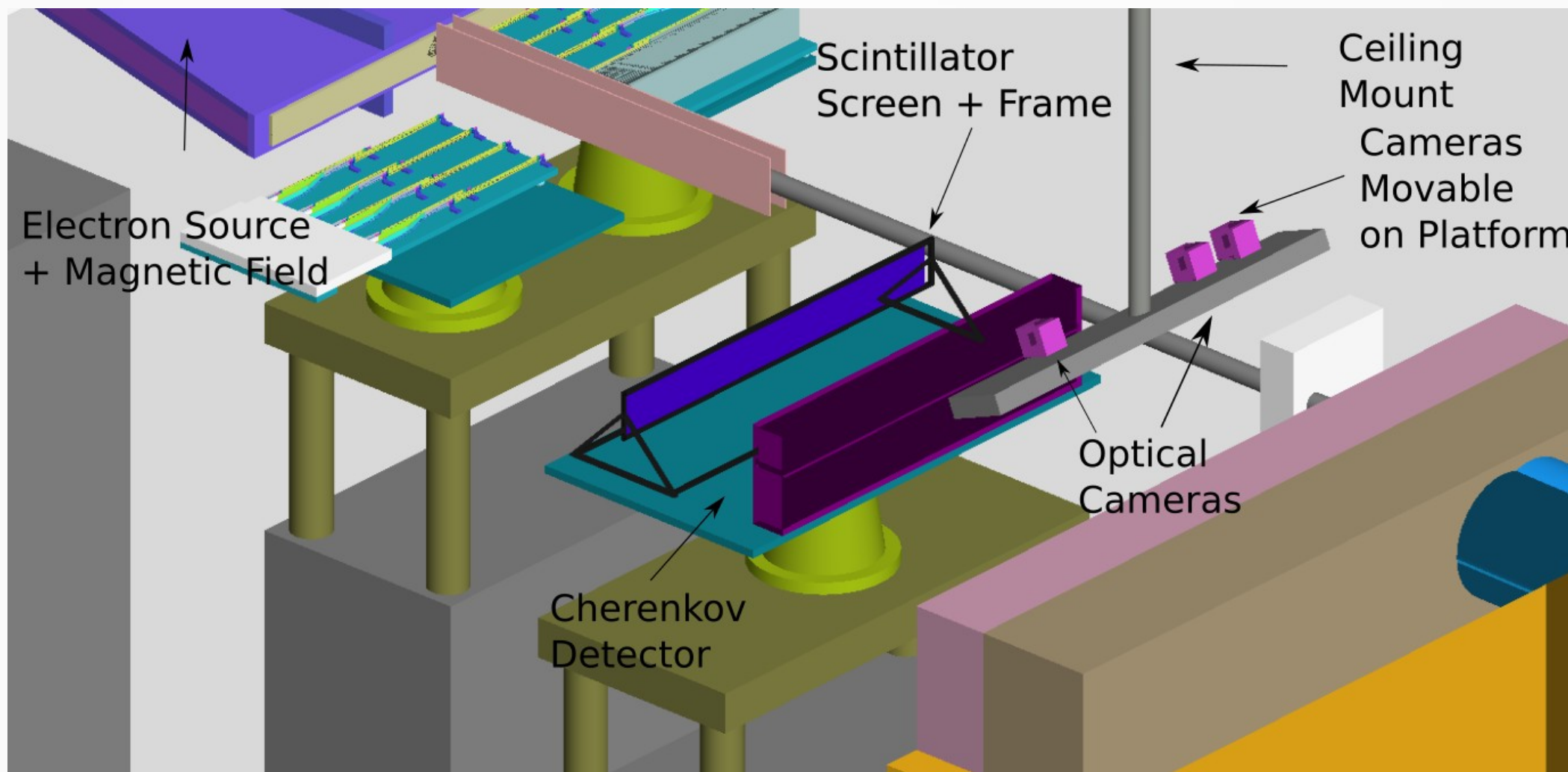
LUXE Physics Expected Results



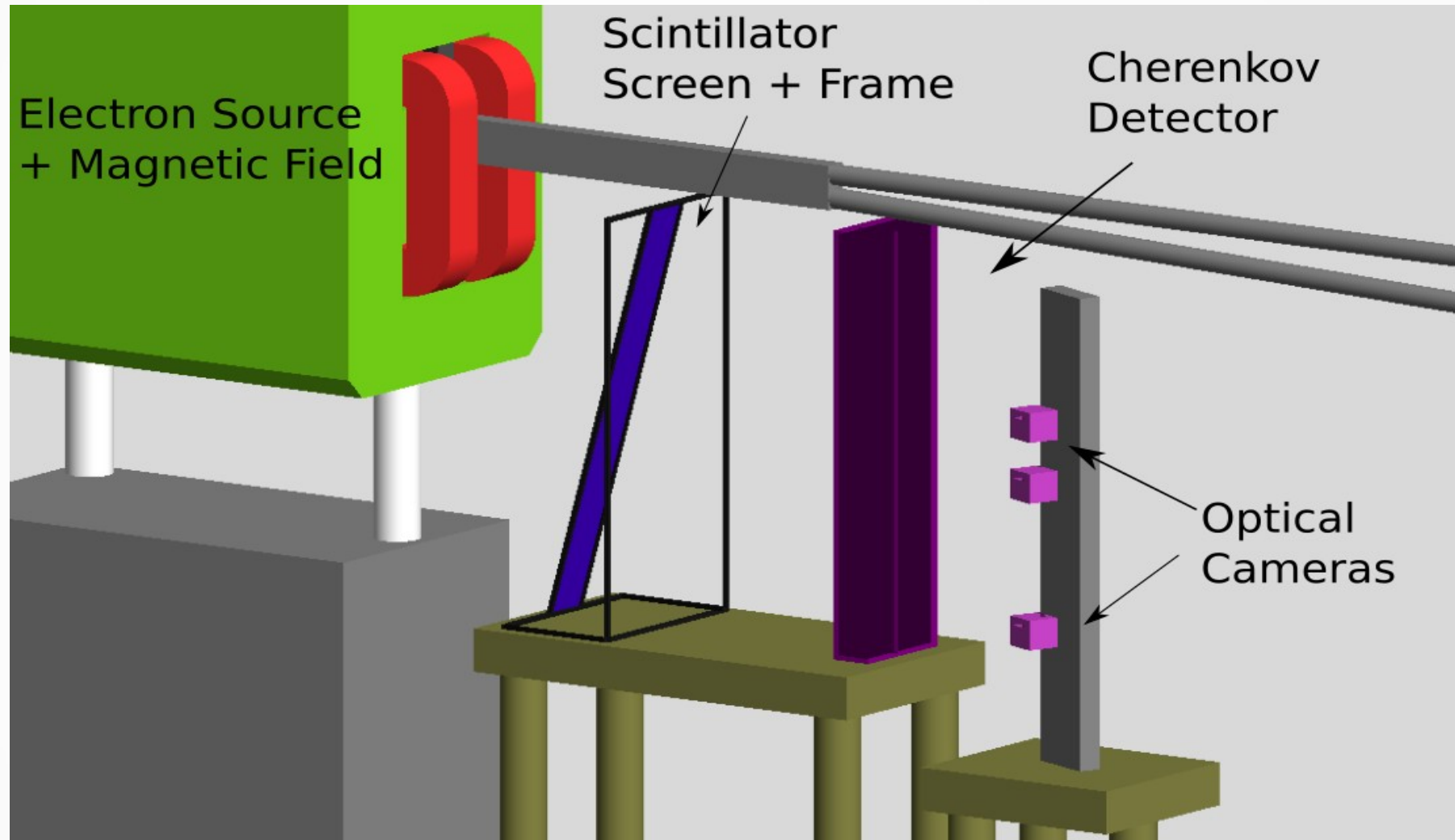
Probing into new parameter-space

Pair-production rate with ξ

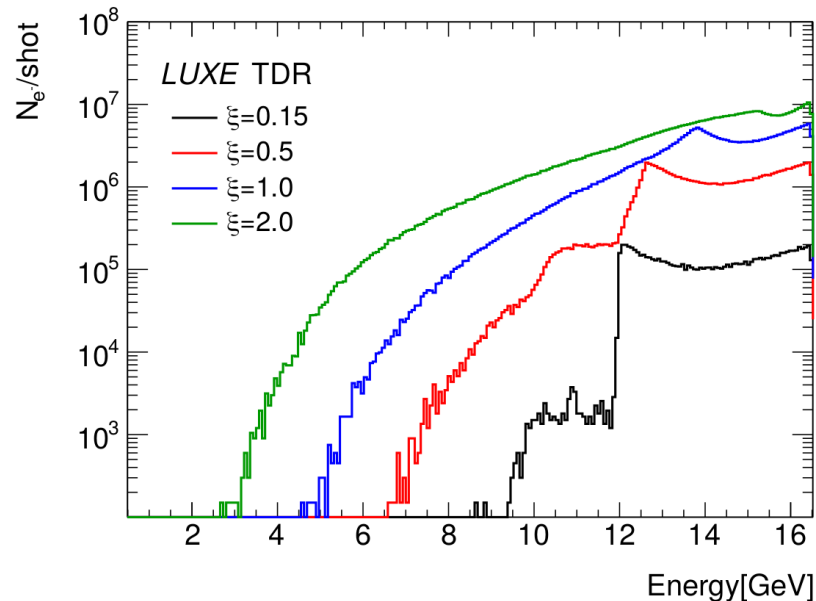
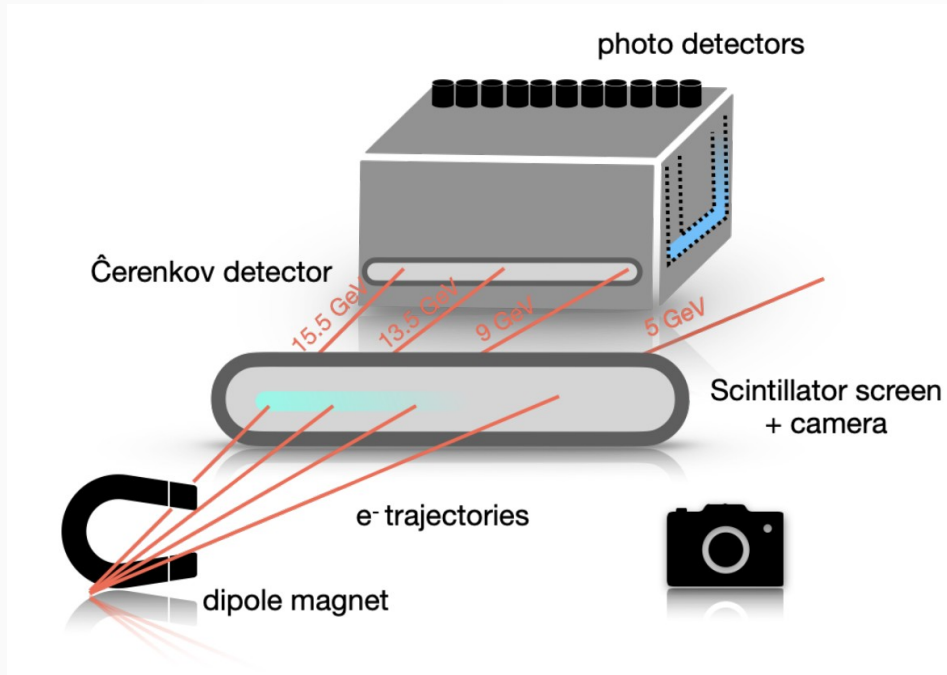
e-LASER IP Electron Detection System



Gamma Beam Generation



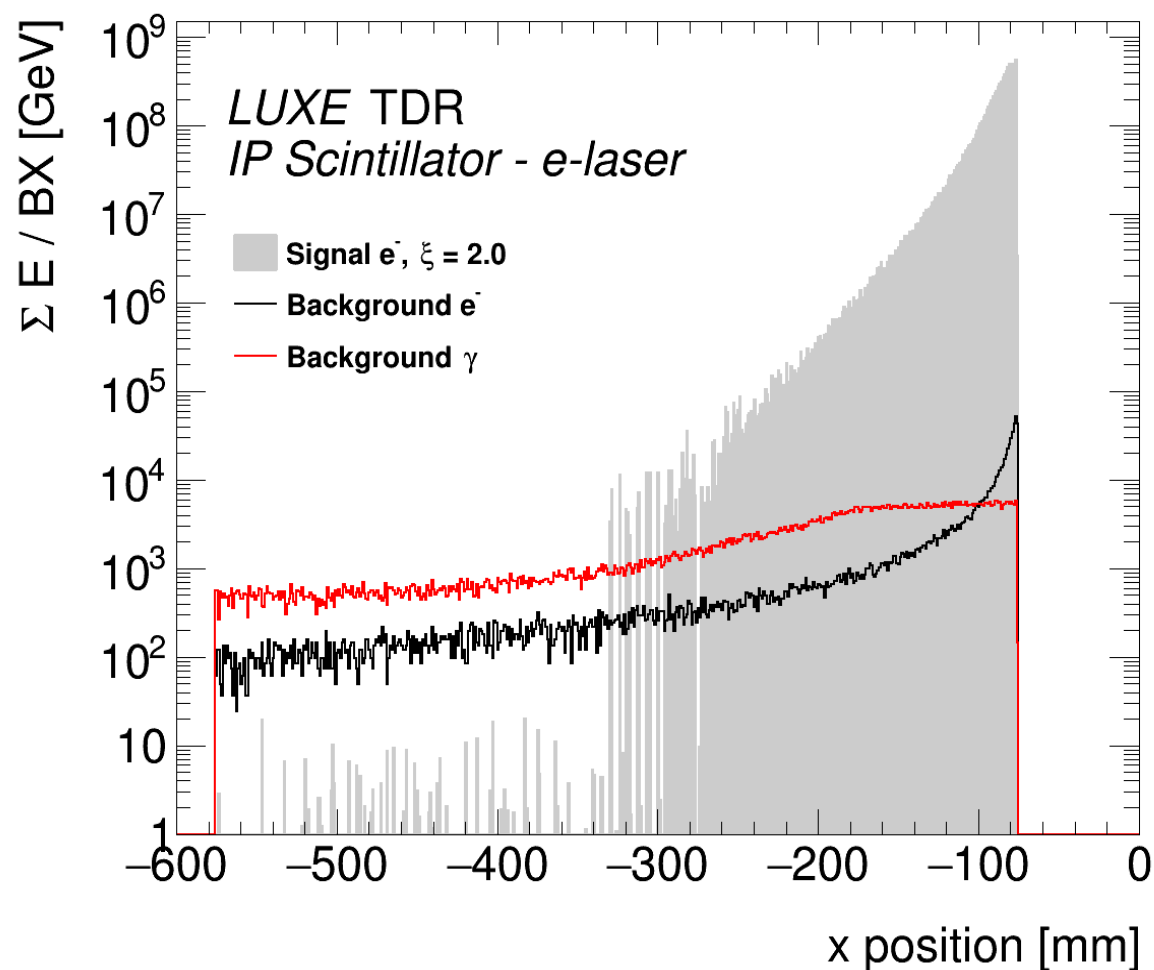
Electron Detection at LUXE



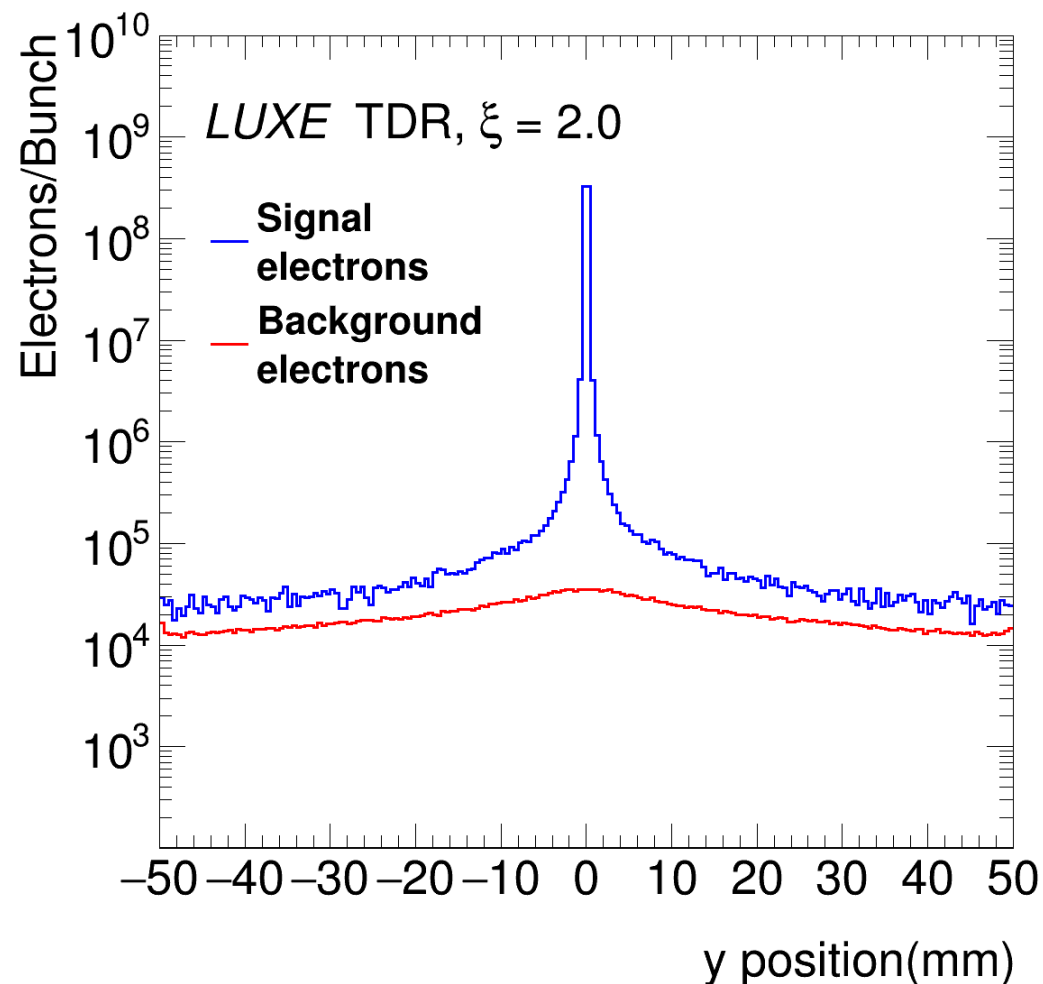
- Position resolution dictates energy resolution
- Charged particles radiating via Cherenkov mechanism, dependent only on β (changes very little for 1-16 GeV energy range)
- A thin scintillating material can then be placed before the Cherenkov detector with virtually no effect on its detection
- Energy deposition dE/dx for electrons of GeV energy in a material is flat, again dependent on only β

Signal and Background

Signal vs Background Incident on Screen in x

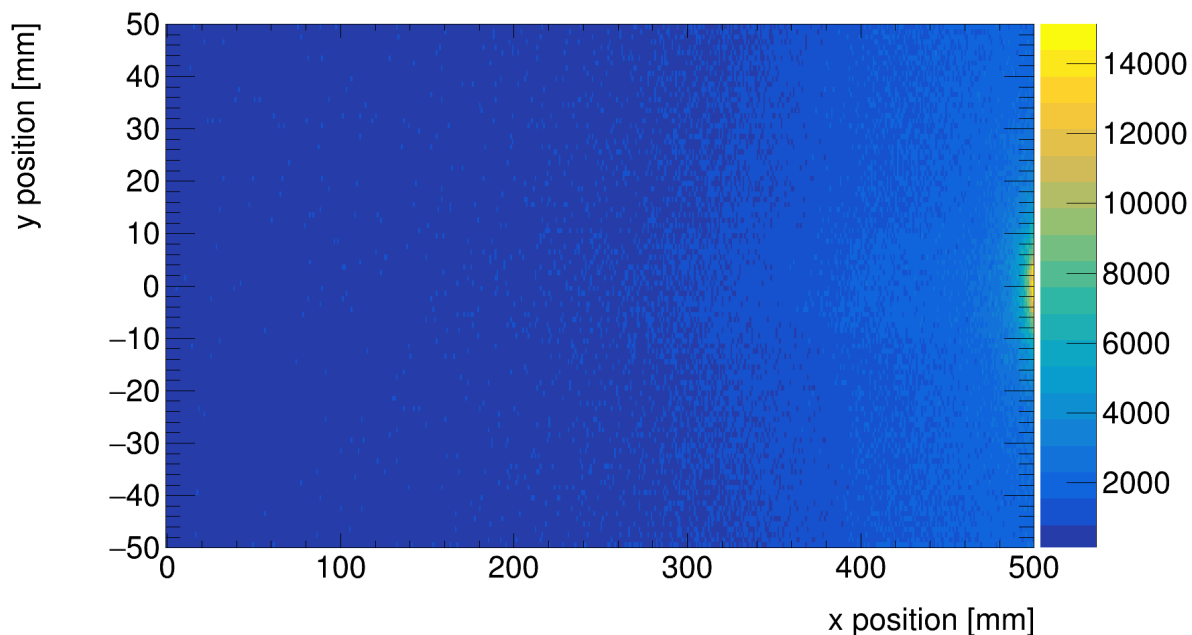
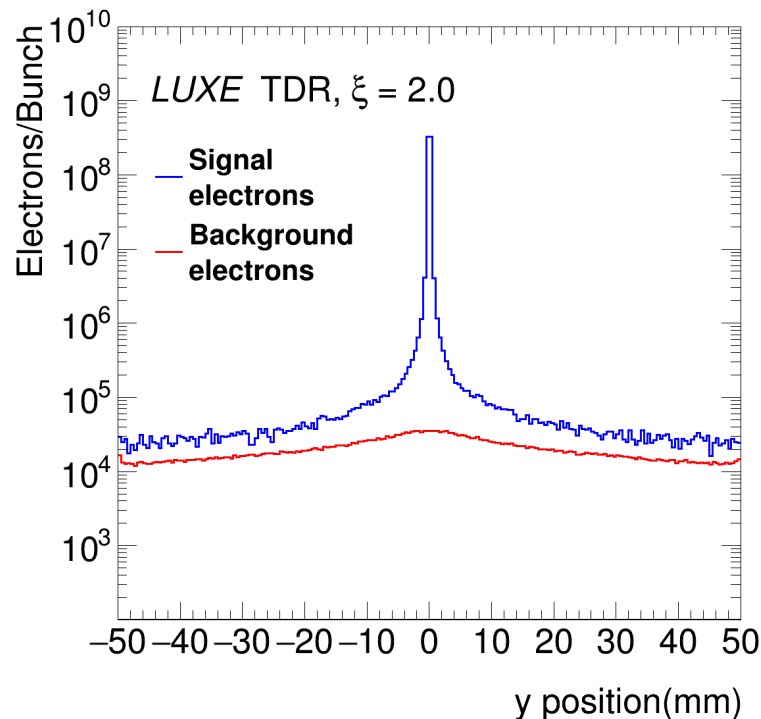
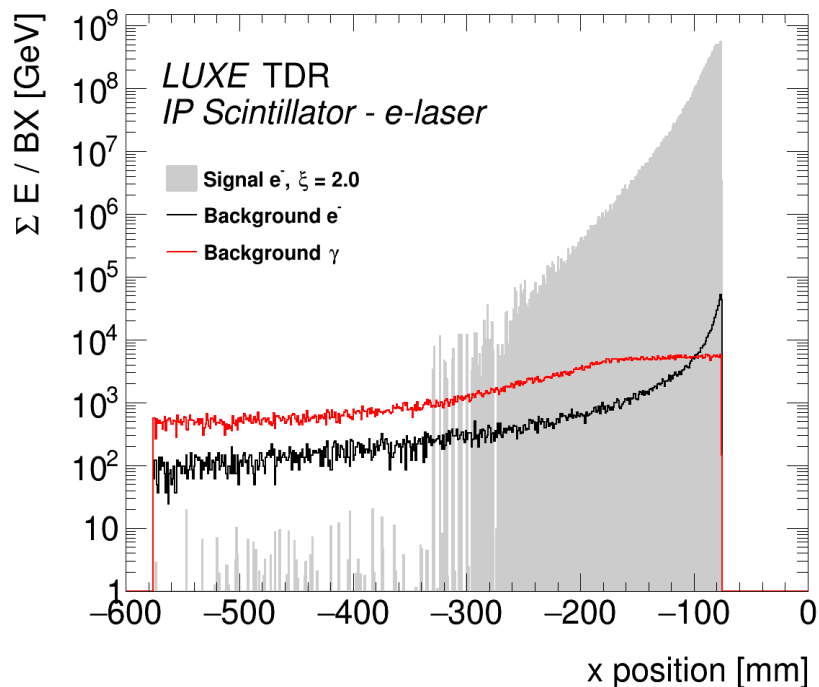


Signal vs Background Electrons Incident on Screen in y



- Whole LUXE Experimental Chamber, simulated in Geant4

Signal and Background



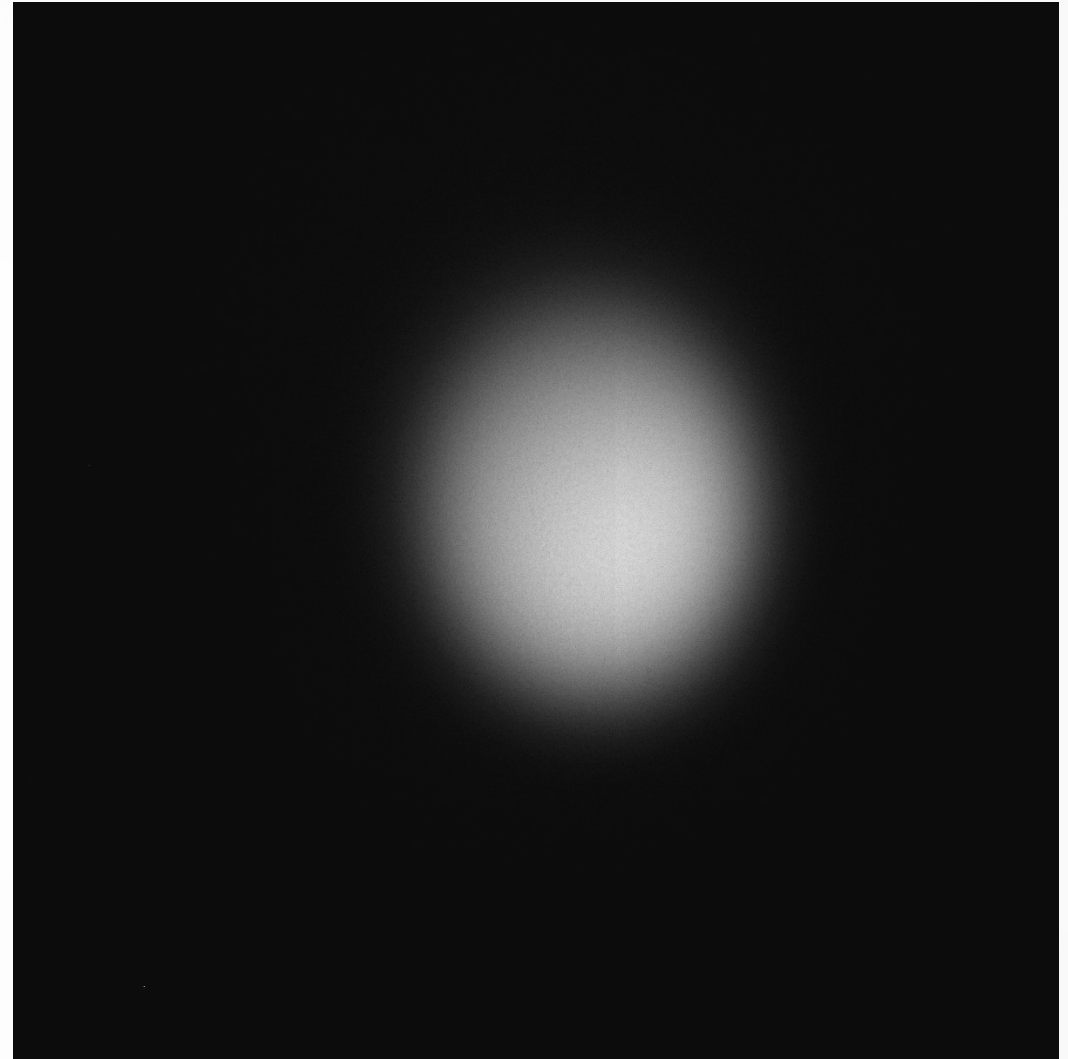
- Electron spectra reconstructions ($\xi = 2.0$) completed in Geant4, using the LUXE e-LASER geometry and simulating the scintillation physics process, but not explicitly optical transport

- 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

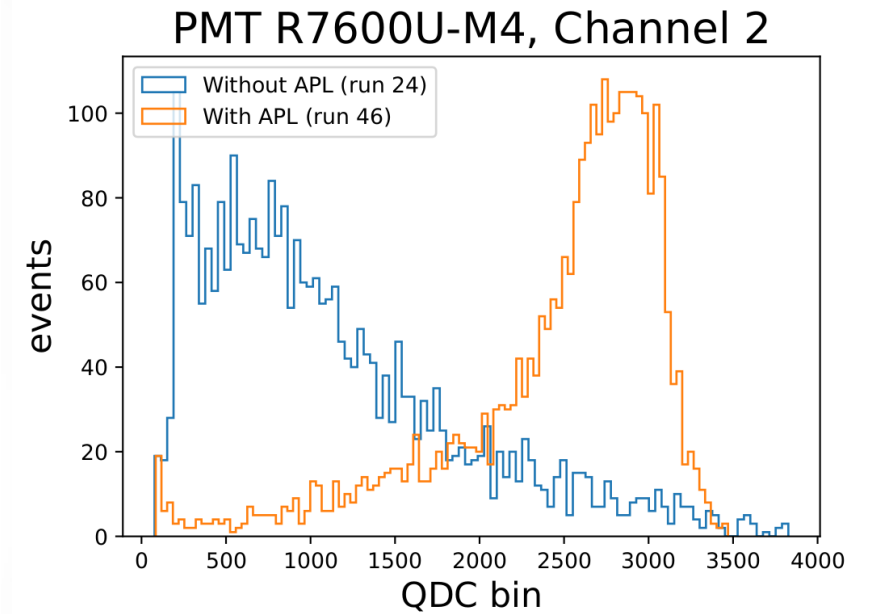
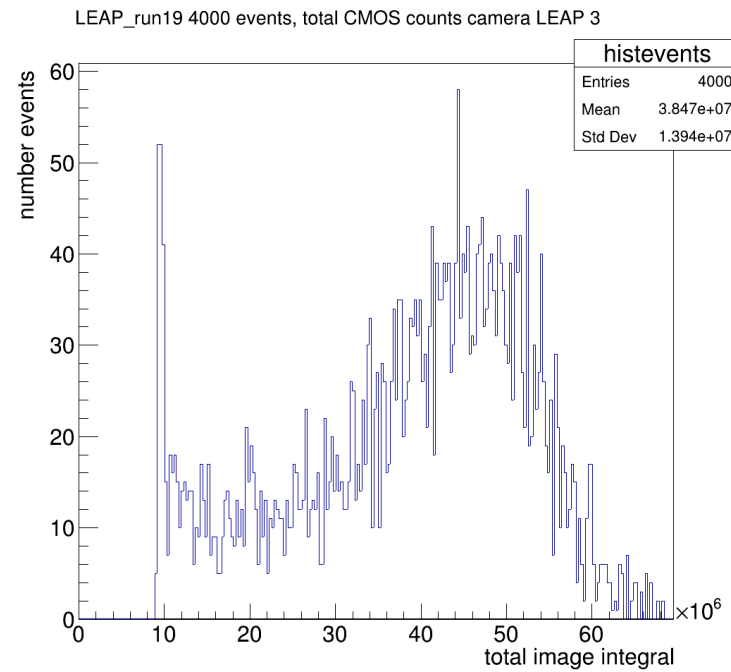
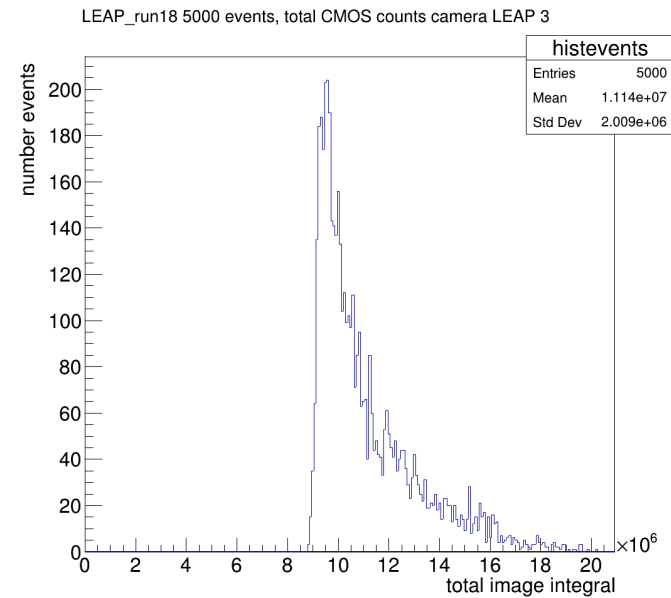
- Beam-only events also used for background estimation

Test-Beam Prototype



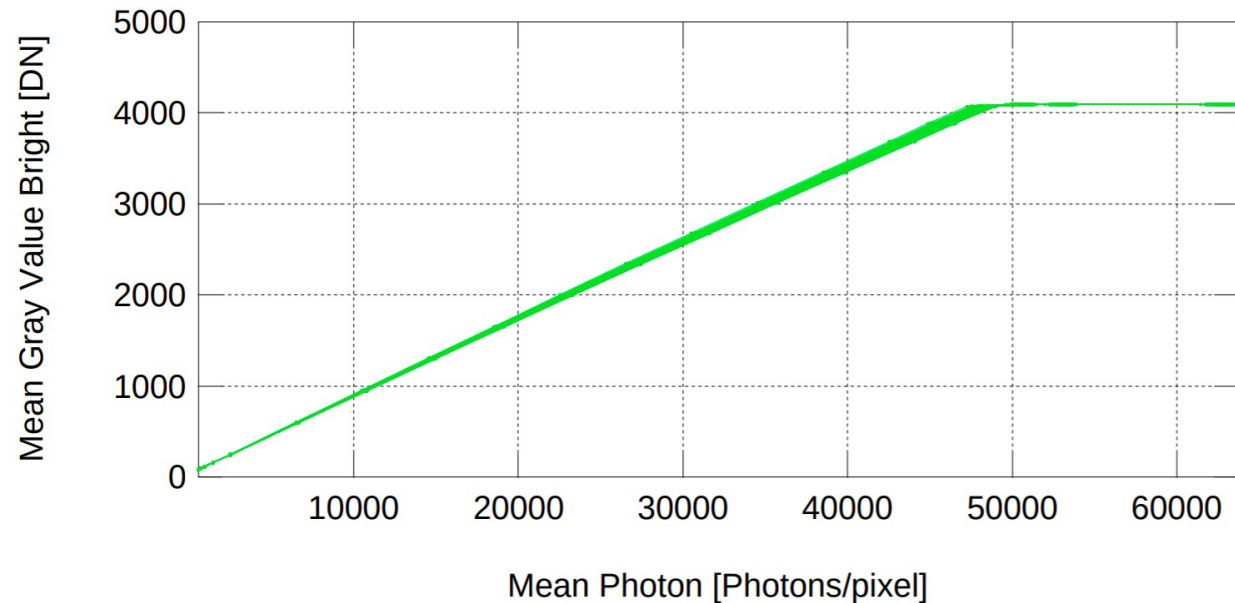
- ~2cm diameter beam

Test-Beam Prototype

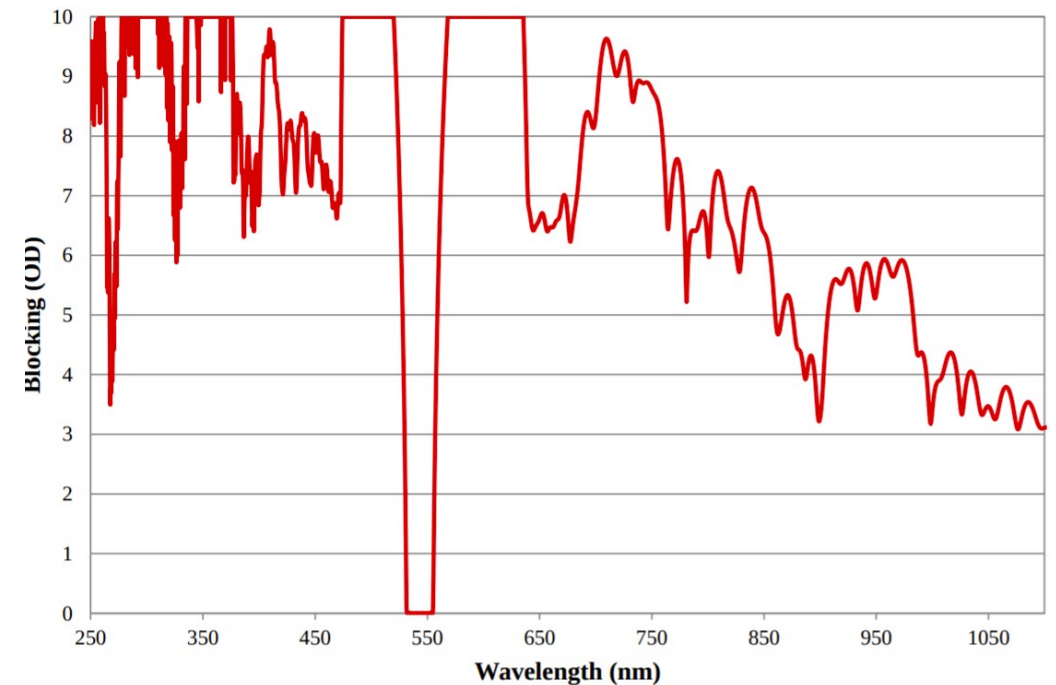


Cameras, Lens, Filter

'acA1920-40gm' (100 cameras), Mean Gray Value Bright

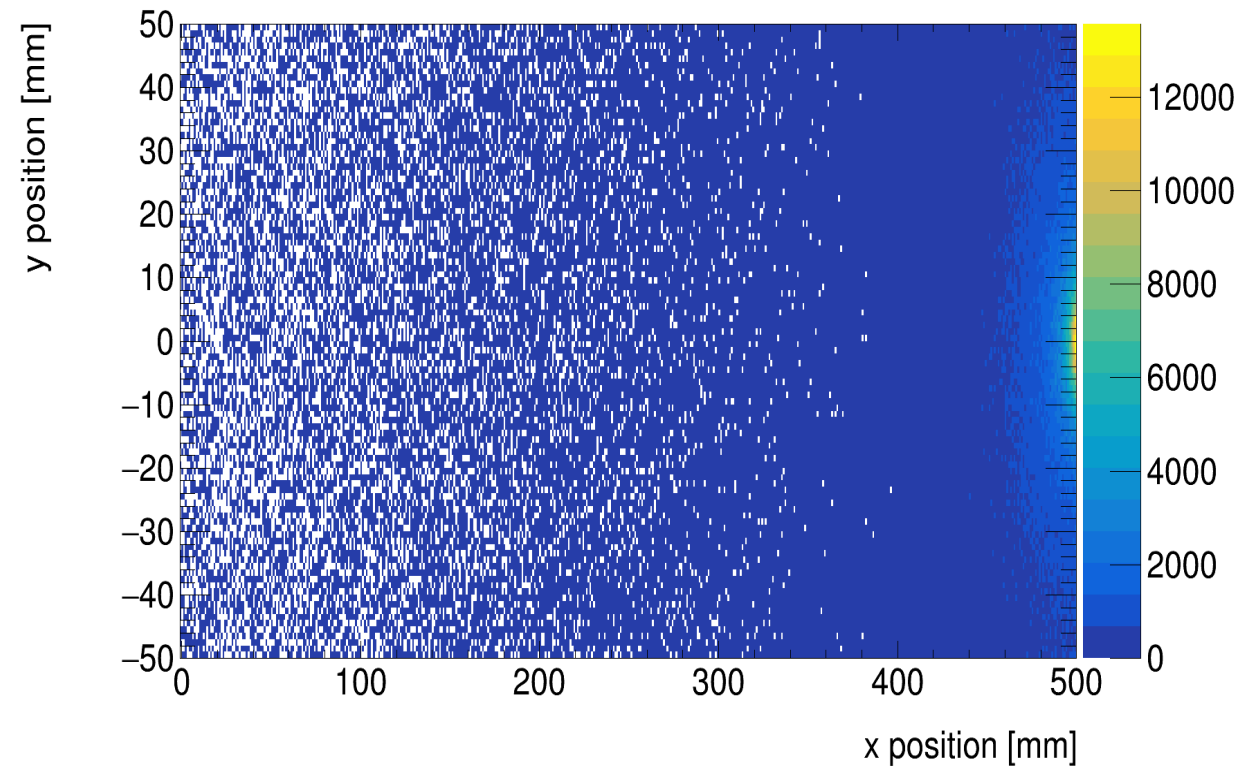
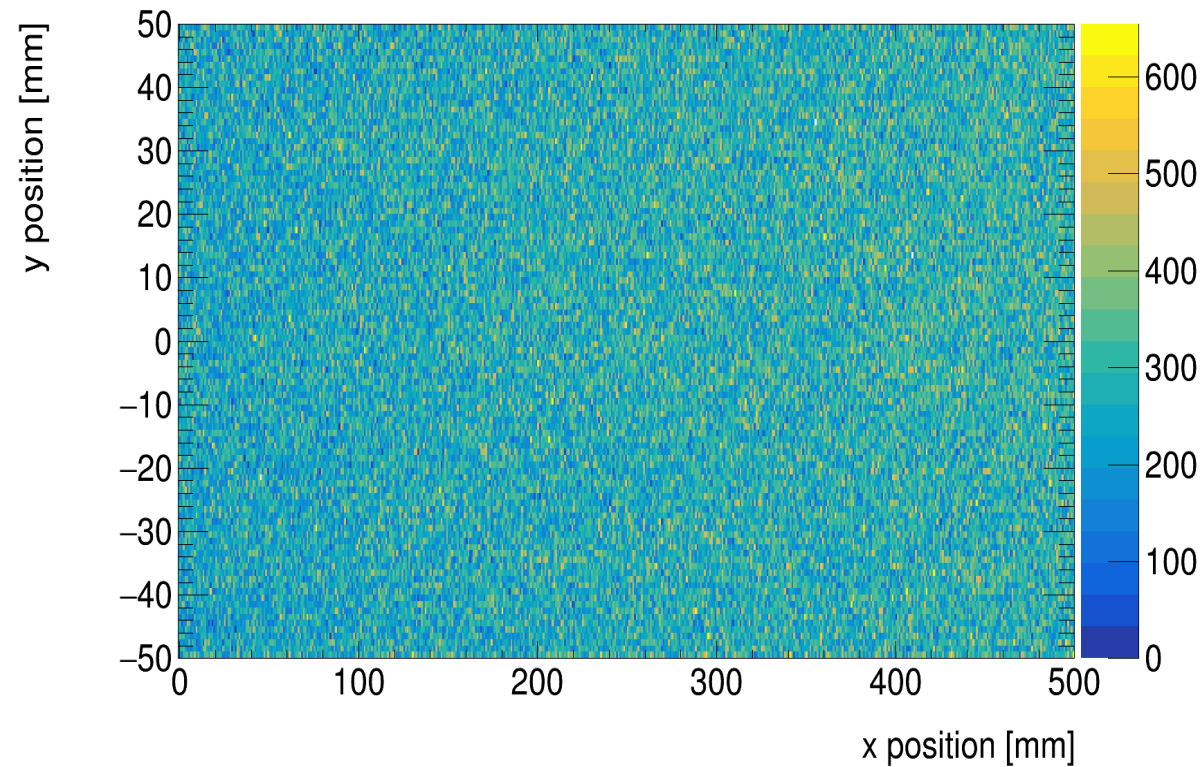


543nm Fluorescence Bandpass Filter OD >6.0 Coating Performance FOR REFERENCE ONLY



- Scintillation light can be imaged remotely to keep electronics out of beam-plane
- Quantum efficiency for photons $\lambda=545\text{nm}$ $\sim 70\%$

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

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
- High-energy Electrons/Photons are collided with a LASER pulse at high repetition rate to build high-statistics measurements for a range of ξ , χ
- 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 is simulated in Geant4 and results used, combined with a developed reconstruction algorithm, to reconstruct energy distributions
- A prototype of the detector has been constructed, and measurements of high-flux testbeam completed (with deeper analysis still underway)

Further Reading: Our Conceptual Design Report
arxiv.org/abs/2102.02032