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,
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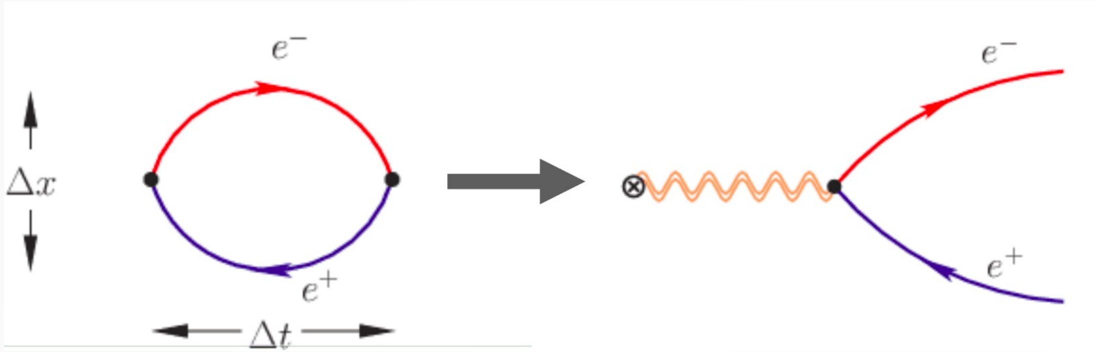
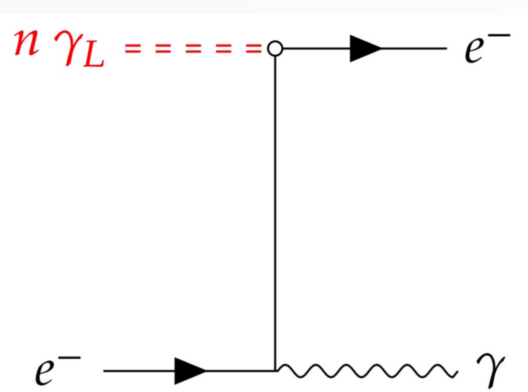
Strong-Field QED

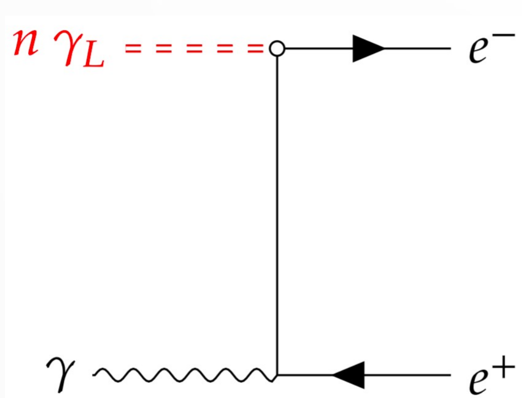


$$E_{Schwinger} \equiv m_e^2 c^3 / e\hbar = 1.32 \times 10^{18}\ Vm^{-1}$$

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

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





- QED is the most quantitatively accurate physical theory in history

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

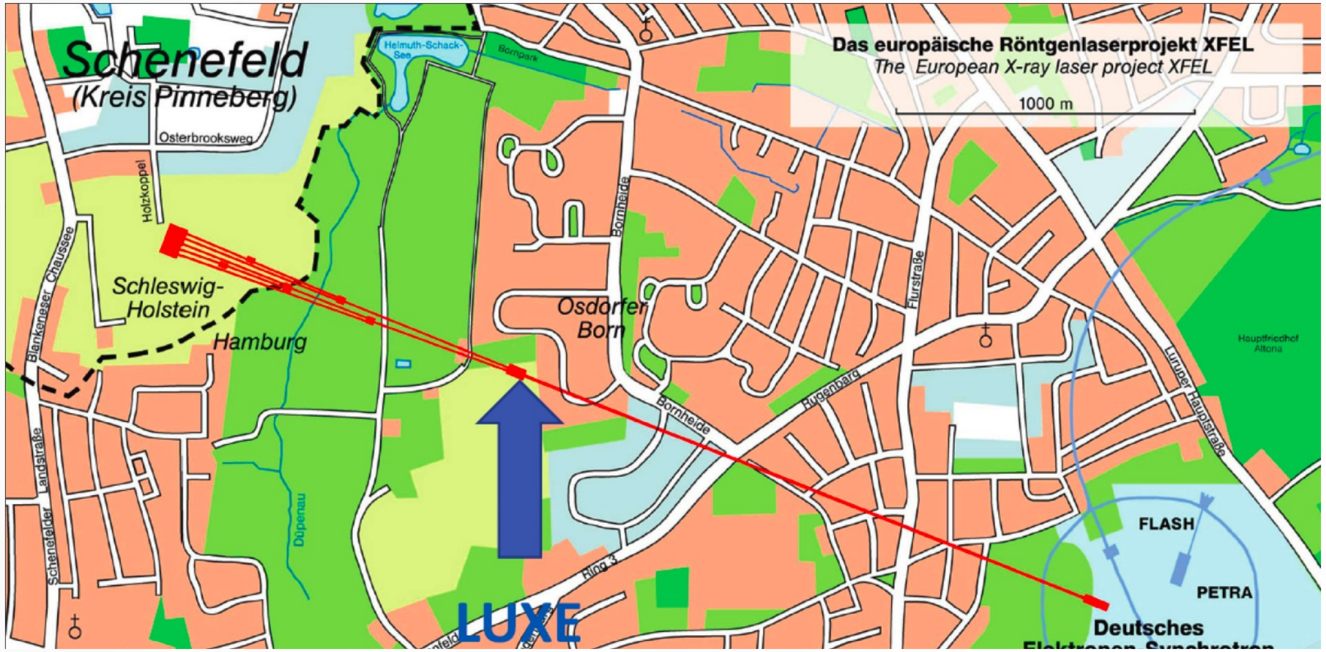
- Spontaneous pair production observed around the Schwinger Limit

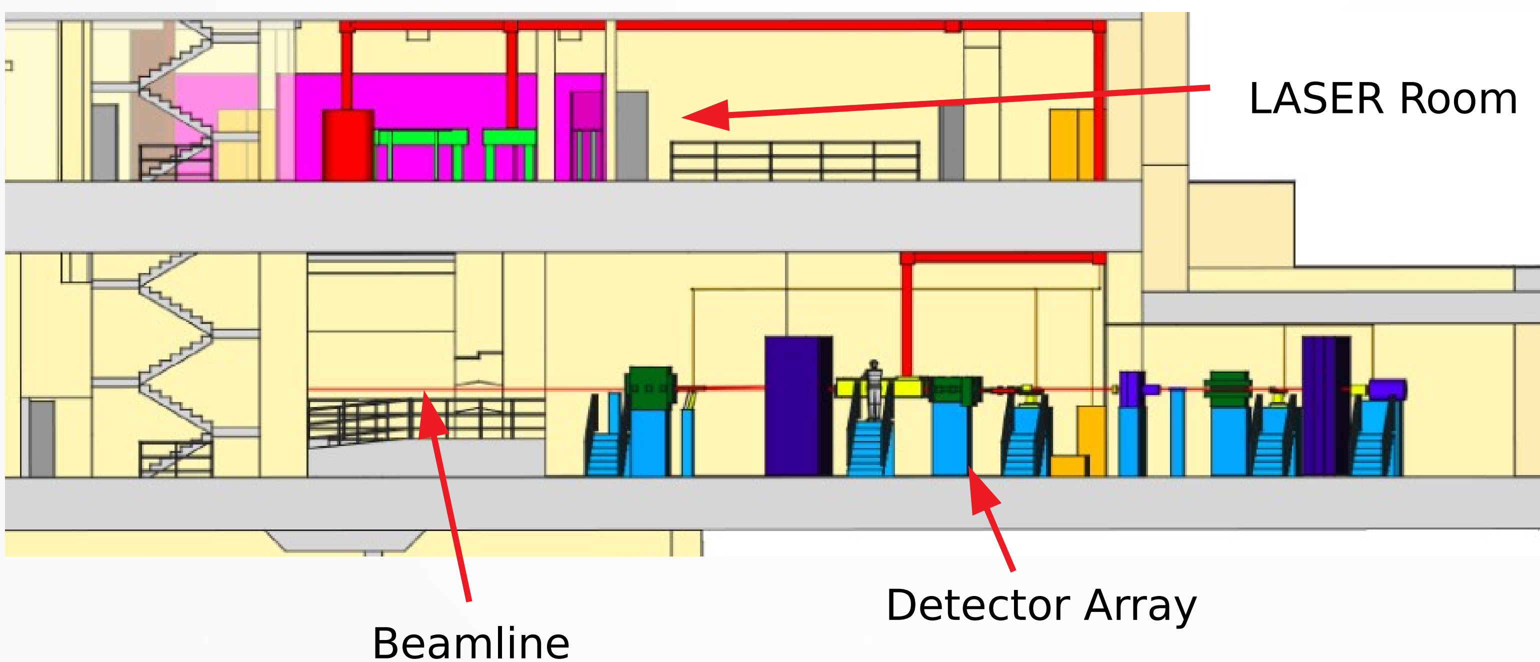
- Useful to define unitless parameters **ξ, χ**

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

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

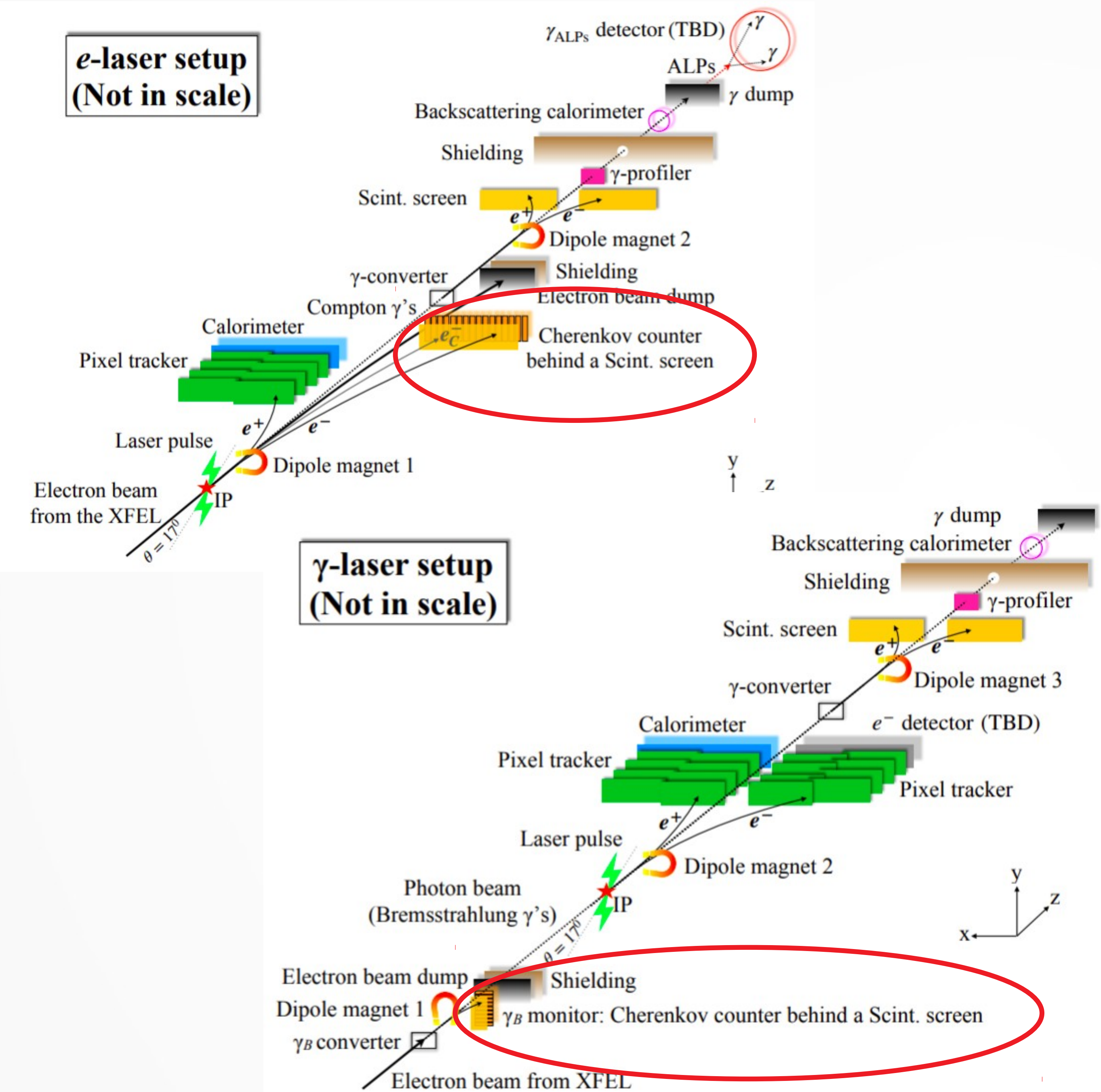
LUXE Experiment





- 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
- Electron bunches delivered at 10Hz, LASER pulses at 1Hz
- Photons produced by bremsstrahlung (W Target) or Inverse-Compton Scattering (Split LASER beam)
- Aims to push into new χ parameter space with enough statistics to make high-quality measurements

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_{beam} = 16.5 GeV

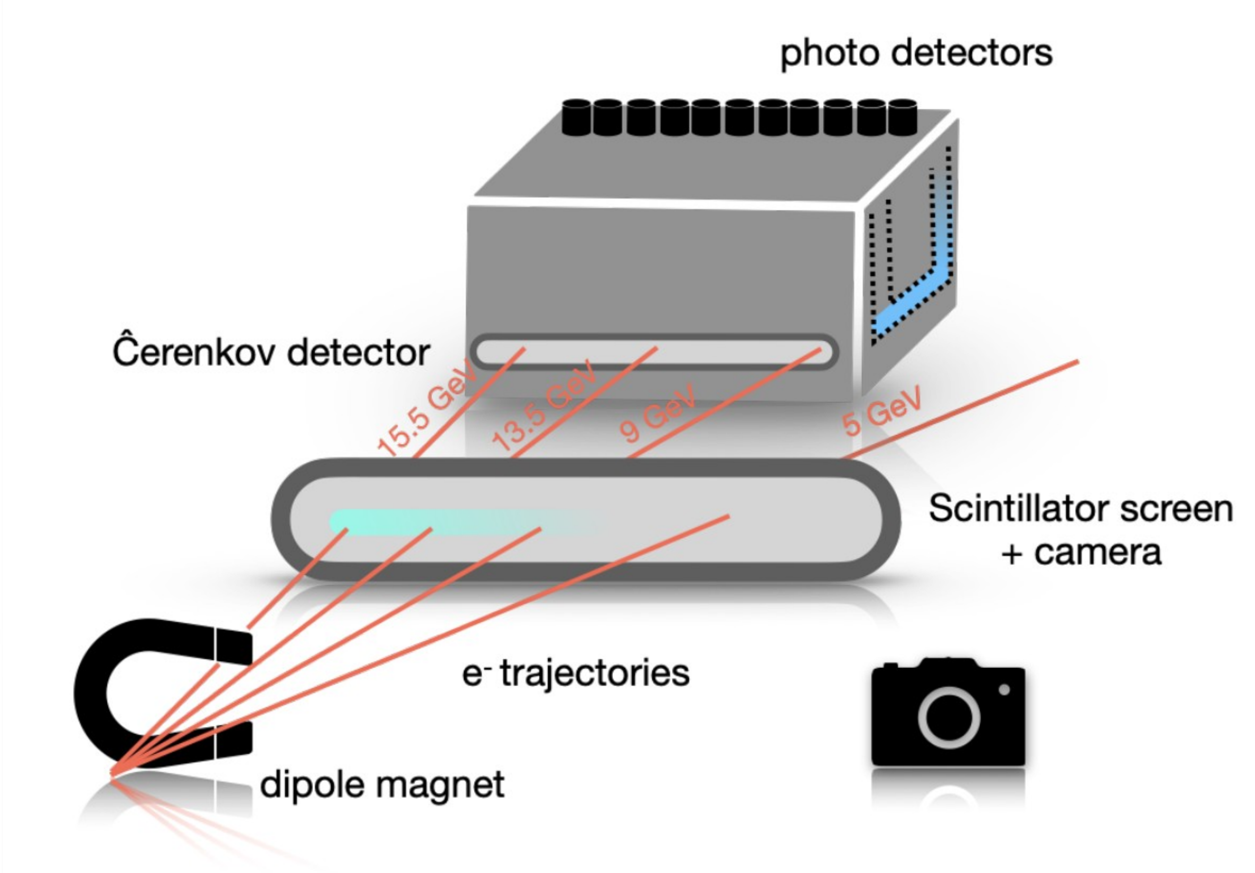
- Charged particles are diverted by magnetic field, acting as magnetic spectrometer

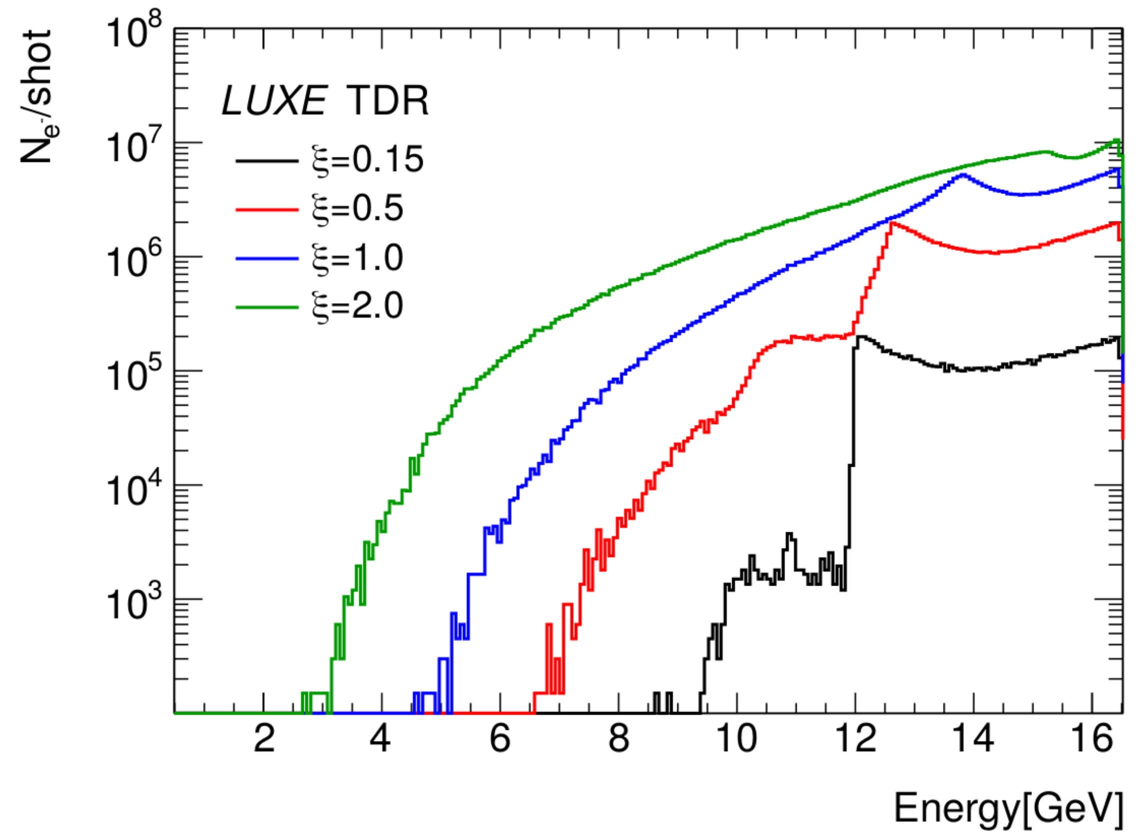
$$R = \frac{E_{\mathrm{eV}}}{Bc}$$

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

- Position resolution dictates energy resolution

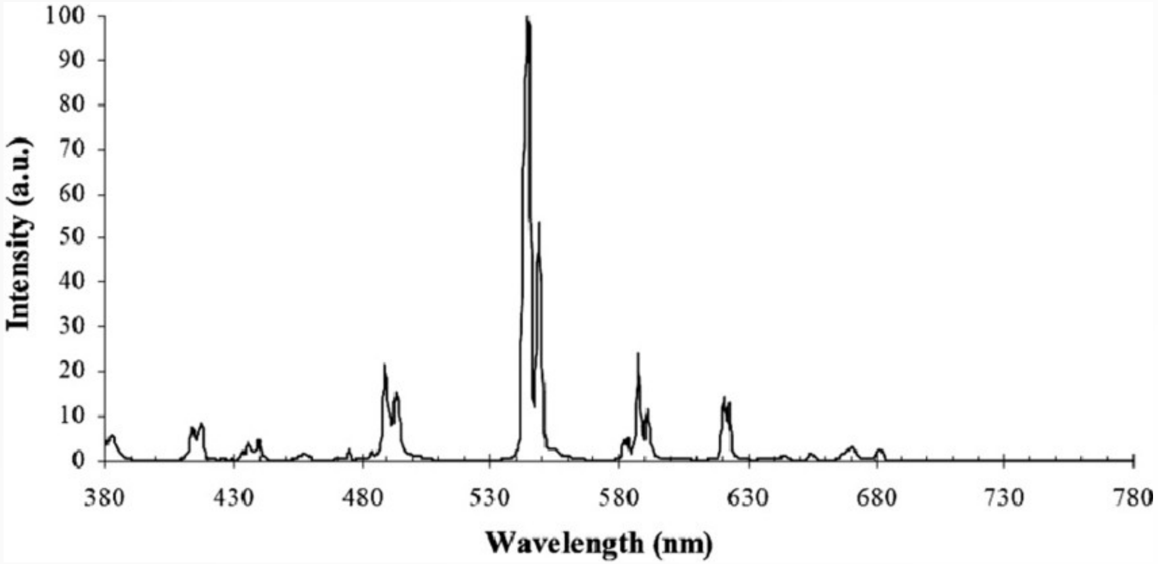
Electron Detection at LUXE



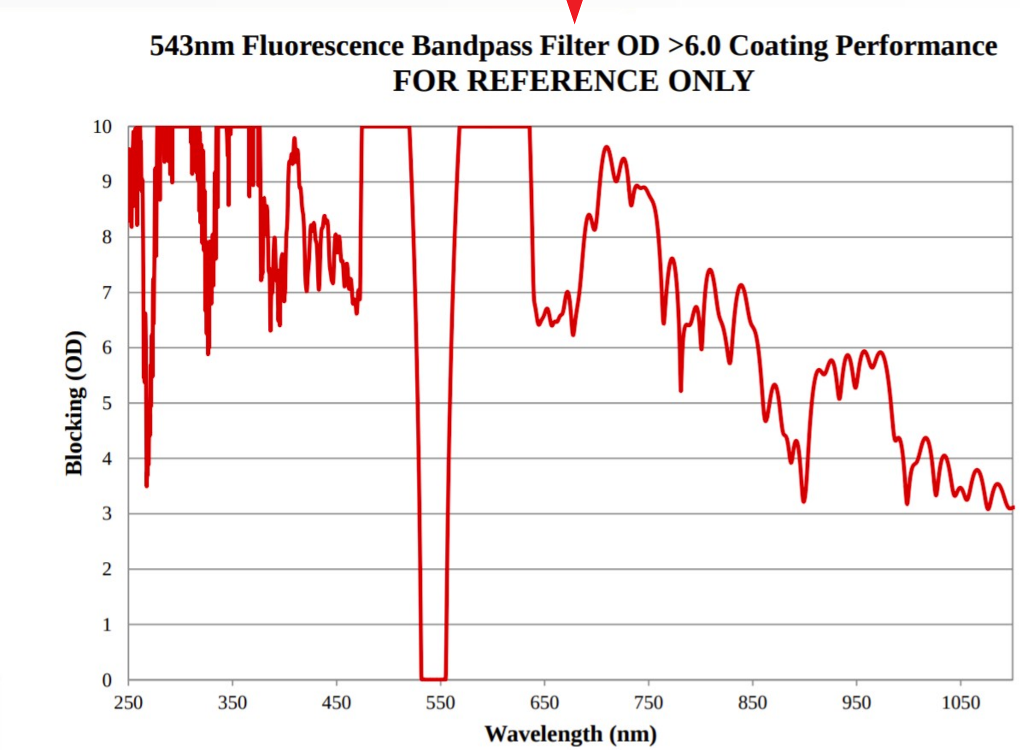


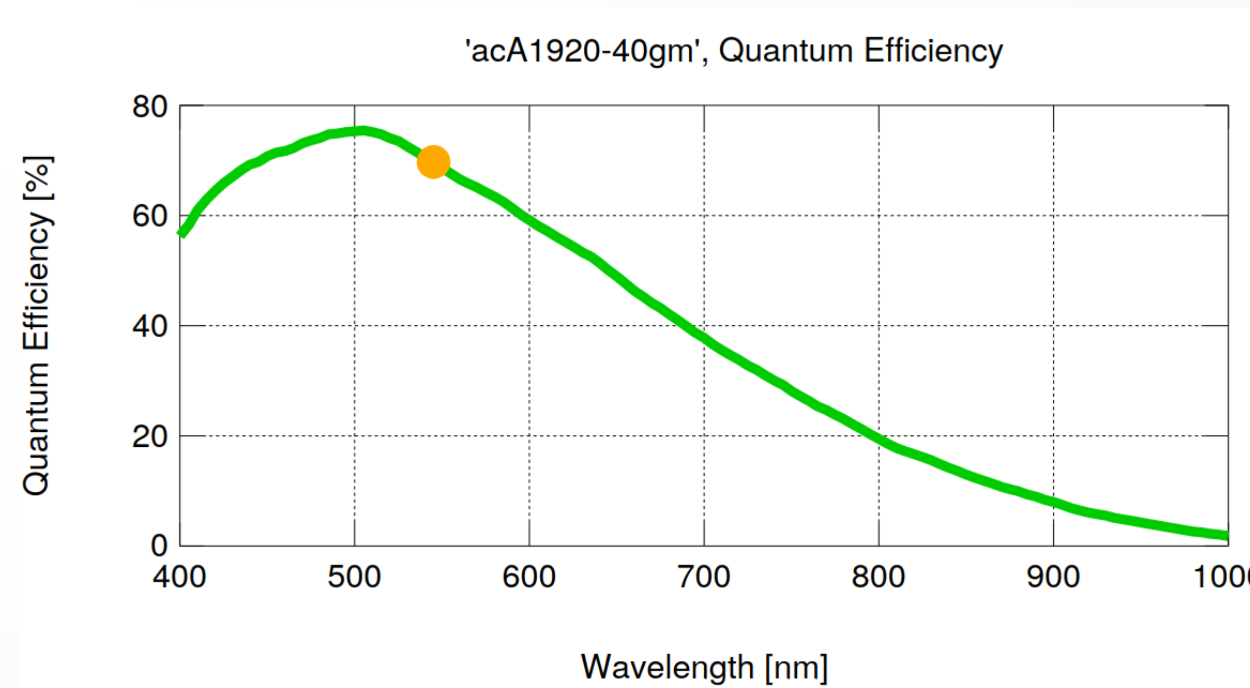
- Compton Edge energy (right) position has physical significance, so is of great interest to measure

Scintillation Screen, Camera and Filter

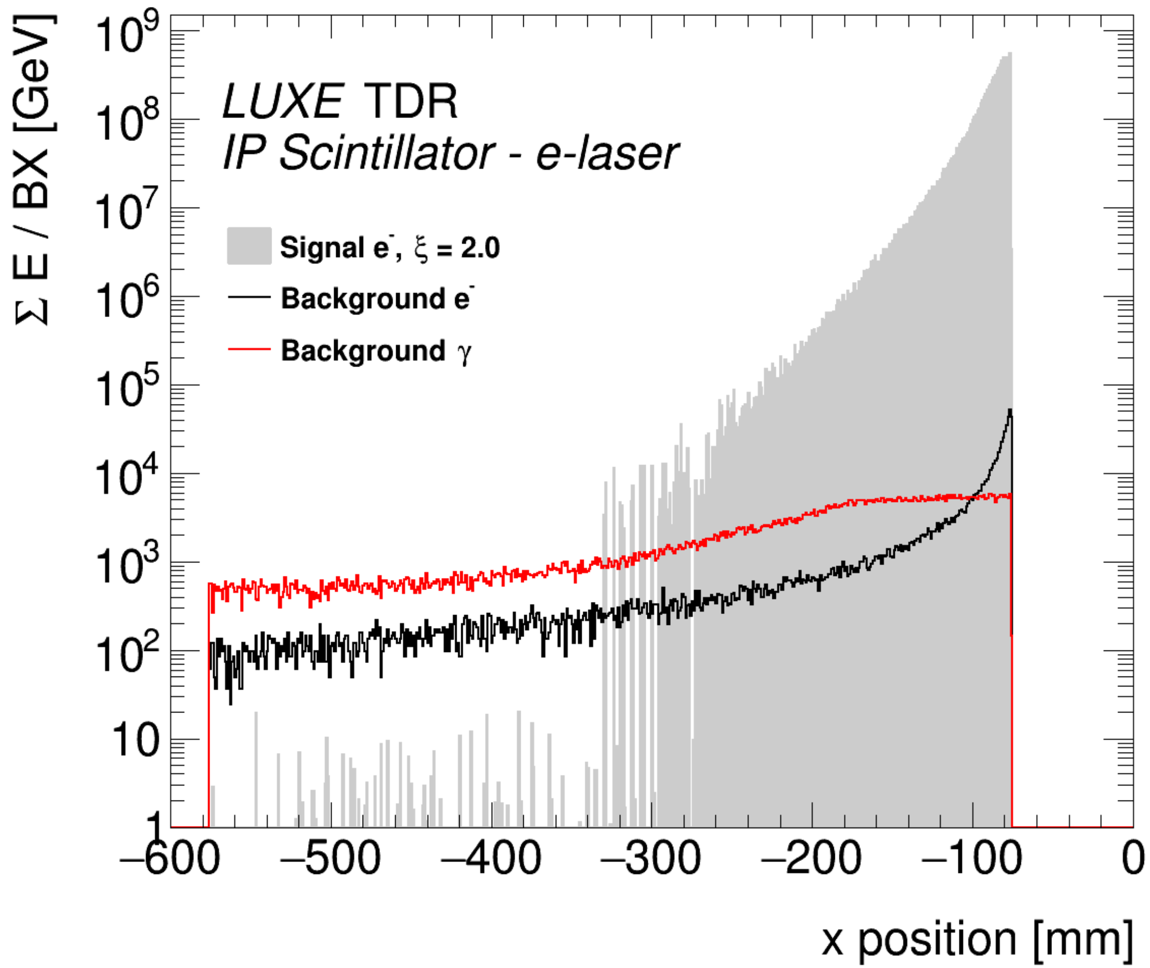


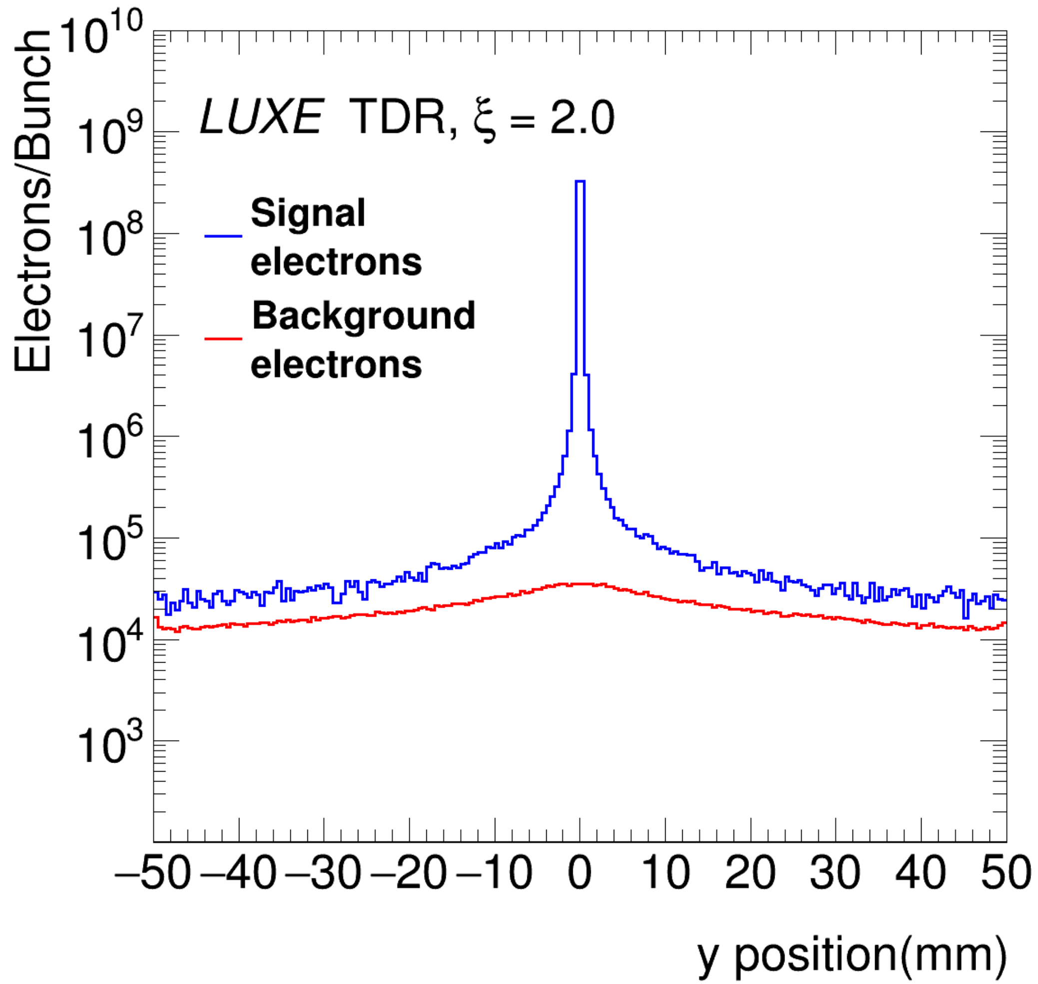
- Scintillator is Gadolinium Oxysulfide, efficiency up to 15%
- Relatively long decay time allows sensor exposure after event
- Optical filter used to remove any ambient light





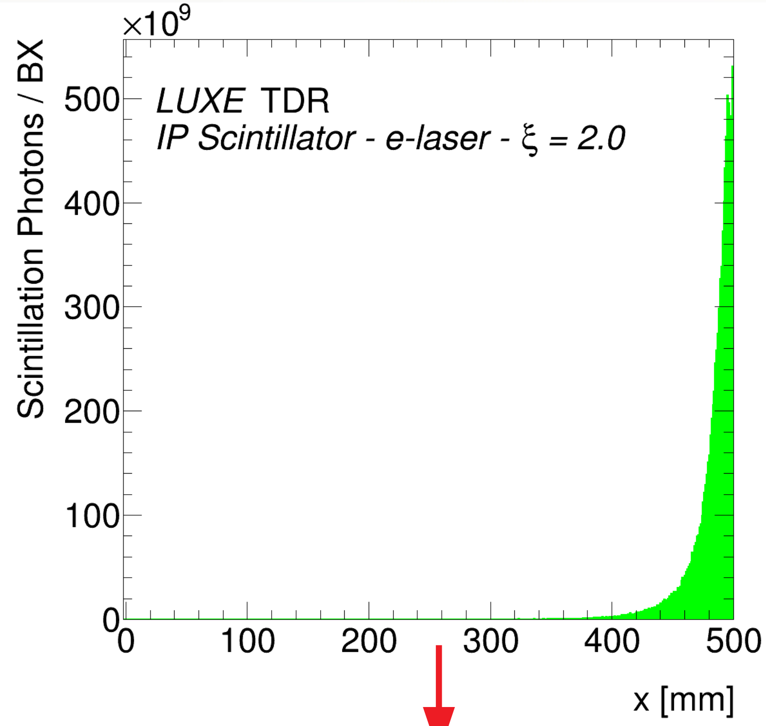
Signal and Background

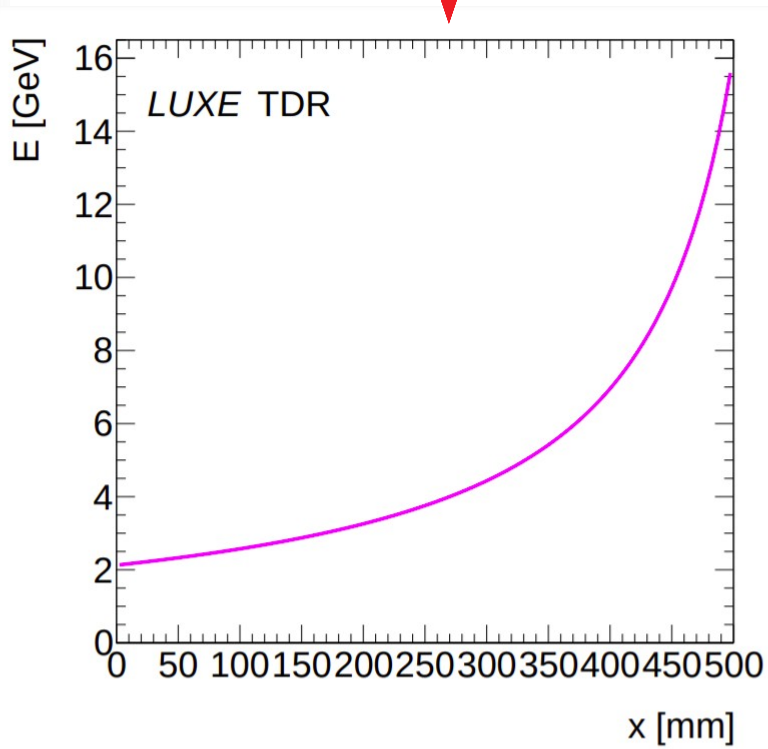




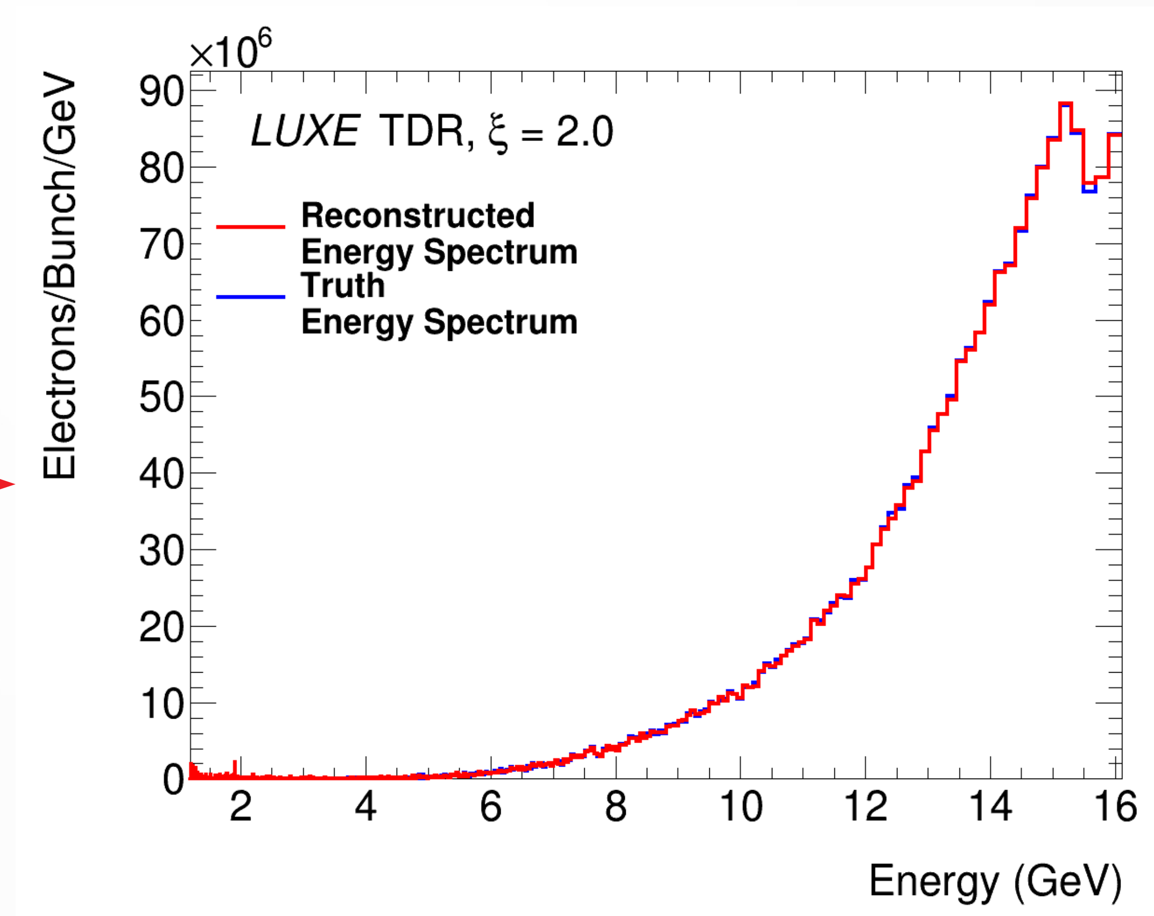
- Simulated in Geant4

Reconstruction in Simulation

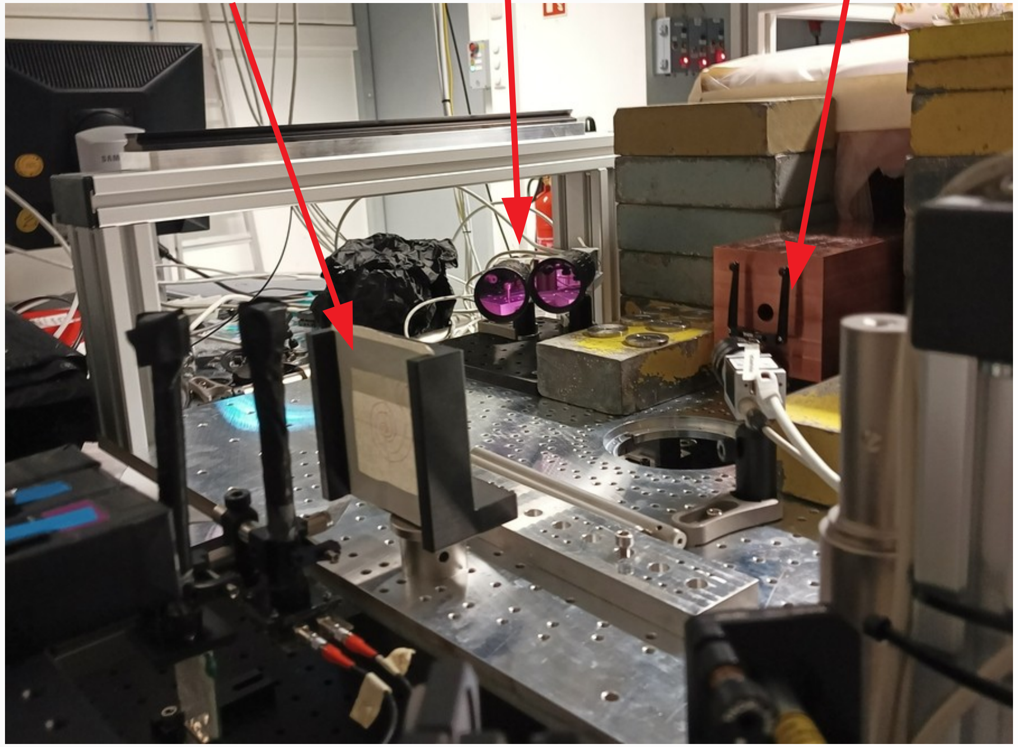


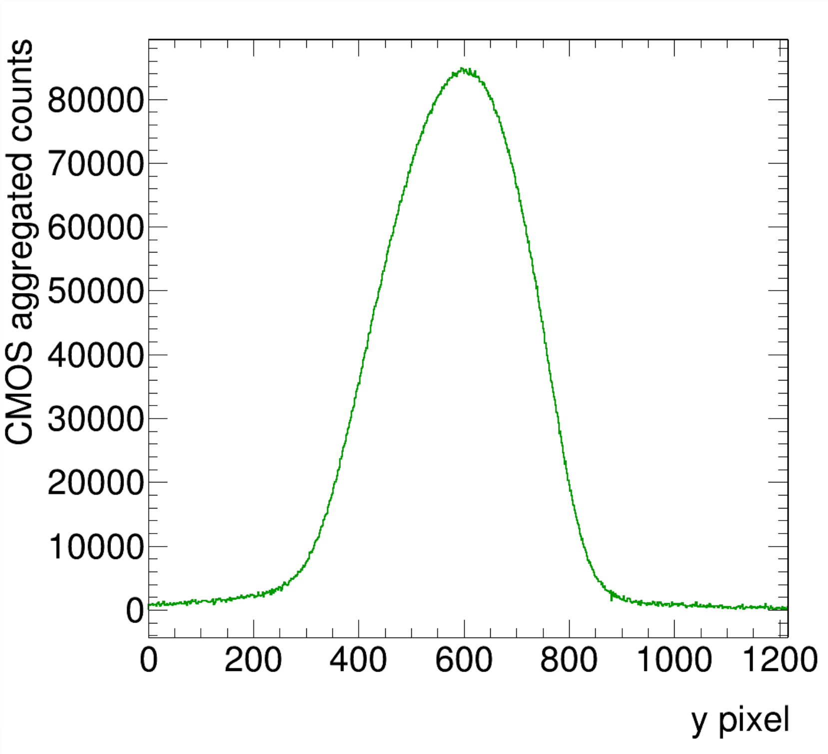


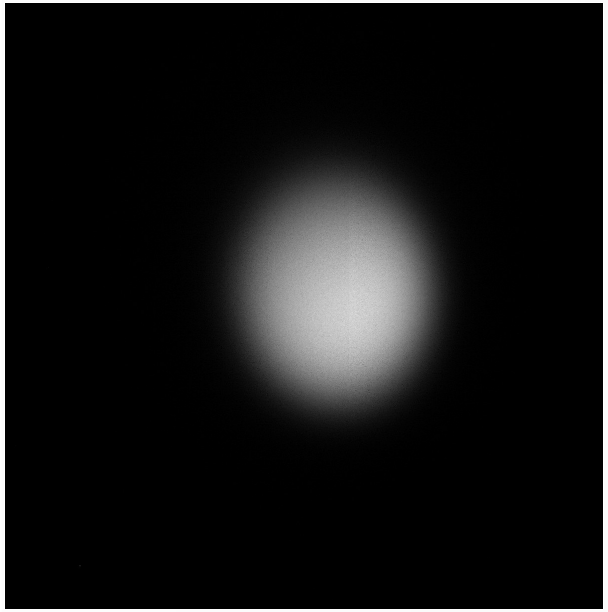
- Input Geant4 Signal Spectrum reconstructed well
- Process delivers high energy resolution for realistic 125 micron position resolution, and just one beam-LASER event
- This uncertainty <1%, expected to be less than B-field uncertainty (~1%) and charge-light calibration (~1%)
- Reconstruction does not explicitly model electronic noise, but effect is expected to be small for this high-flux measurement



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

backup

Summary

- LUXE is an experiment under design & planning to probe Strong Electric Fields

- High-energy Electrons/Photons are collided with a LASER pulse

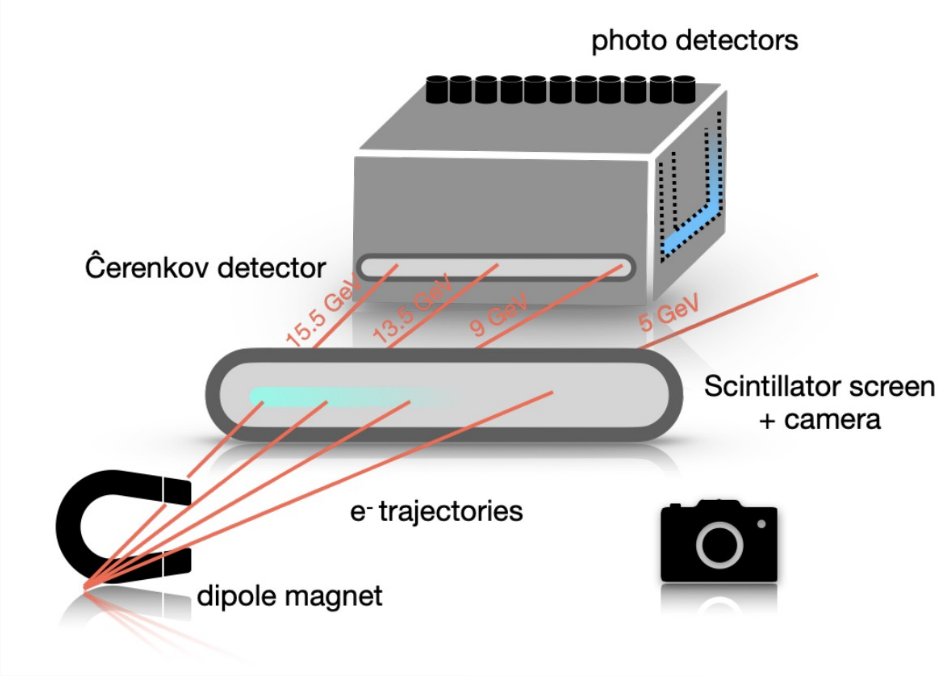
- Measurement of Compton-Scattered electrons, deflected by magnetic field, is required

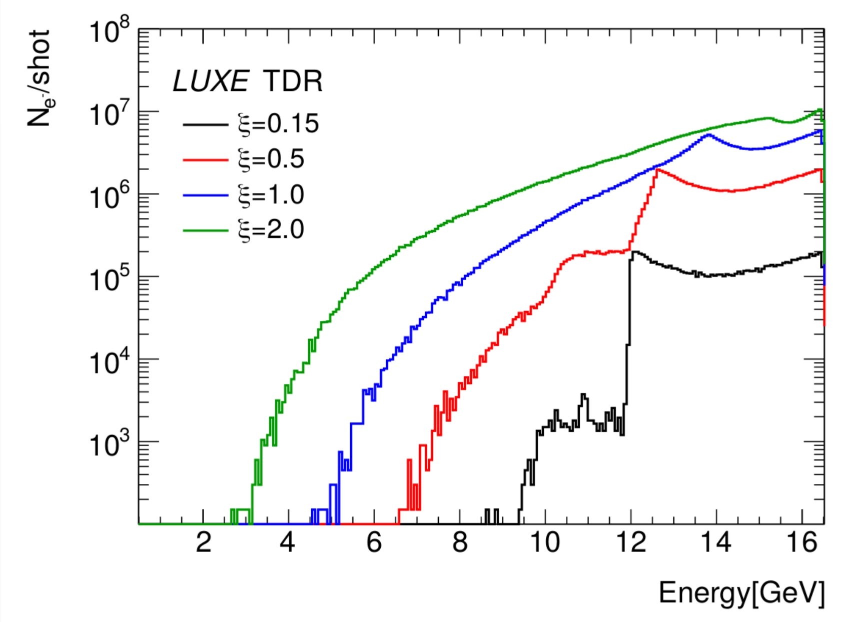
- A scintillator screen and camera system is chosen to measure the high-flux high-energy electrons

- The setup is simulated in Geant4 and used, combined with a reconstruction algorithm, to emulate reconstructed energy distributions

- A prototype of the detector is constructed, and measurements of high-flux testbeam completed (with deeper analysis still underway)

Electron Detection at LUXE





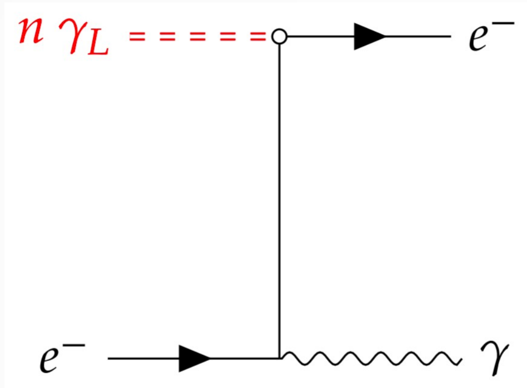
- Position resolution dictates energy resolution

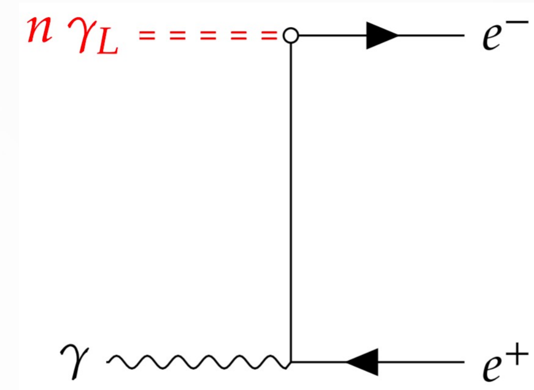
- Charged particles radiating via Cherenkov mechanism, dependent only on β (changes very little for 1-16 GeV energy range)

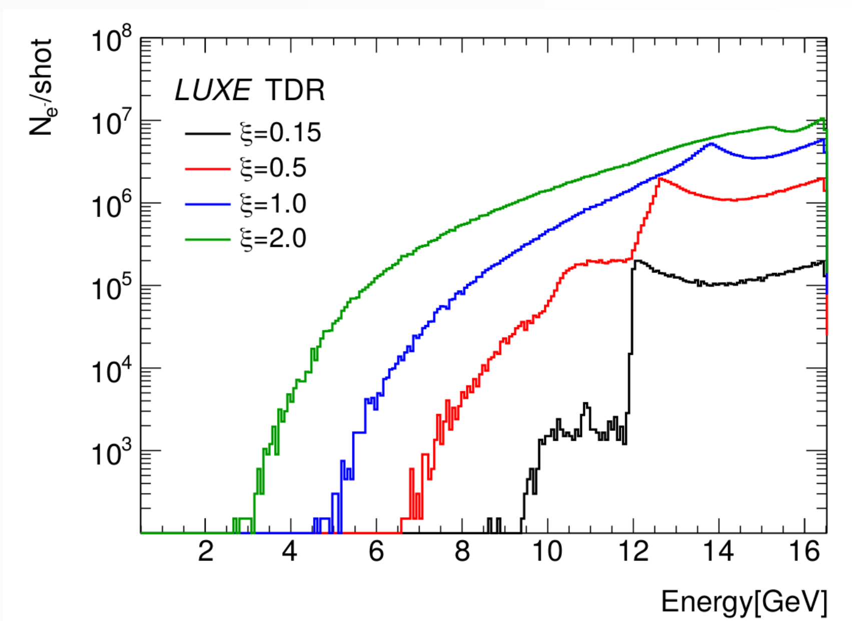
- A thin scintillating material can then be placed before the Cherenkov detector with virtually no effect on its detection

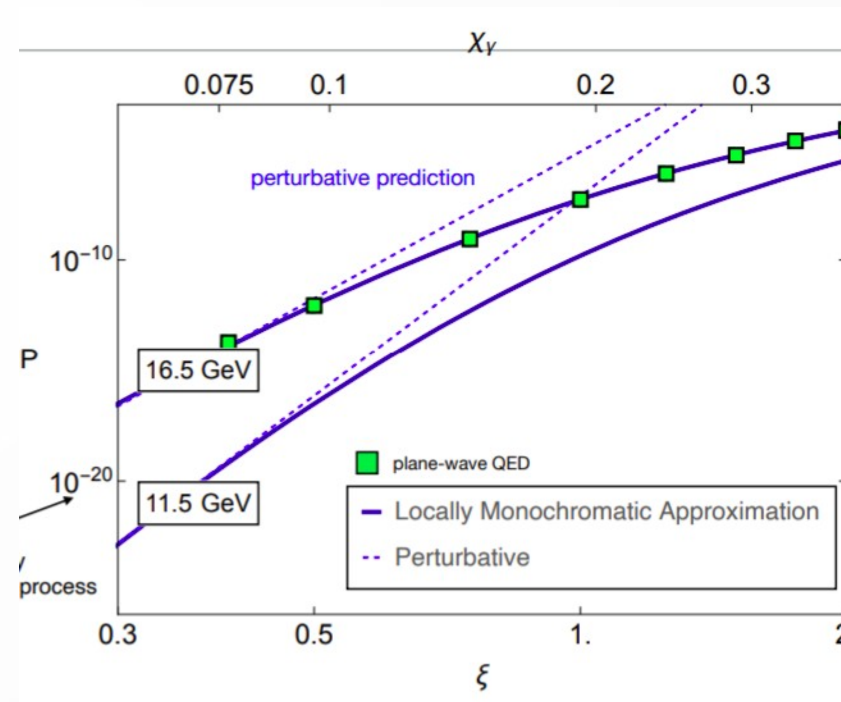
- Energy deposition dE/dx for electrons of GeV energy in a material is flat, again dependent on only β

Non-Linear Compton Scattering & Spontaneous Breit-Wheeler





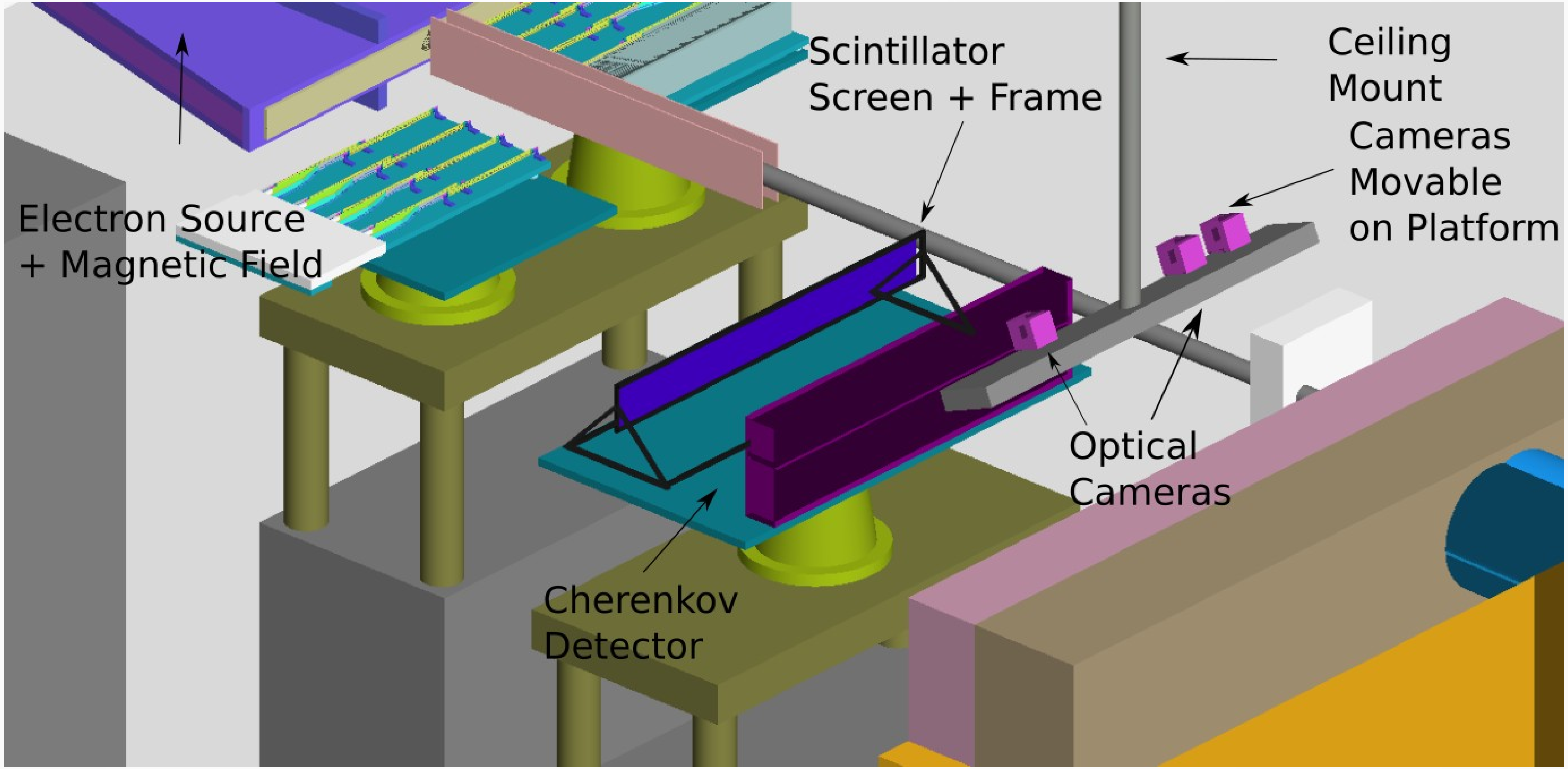




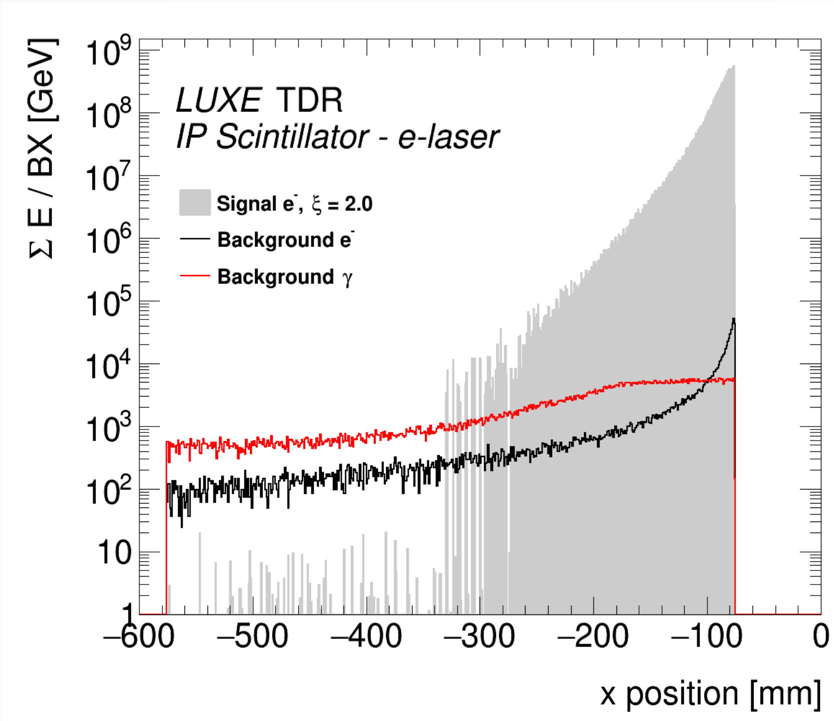
Non-linear Compton Scattering

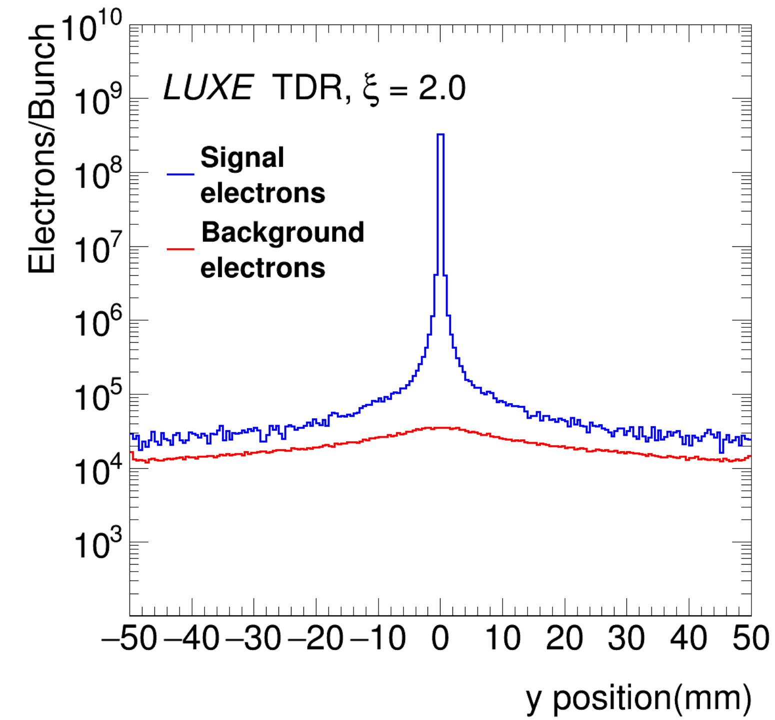
Multi-Photon Breit-Wheeler Process

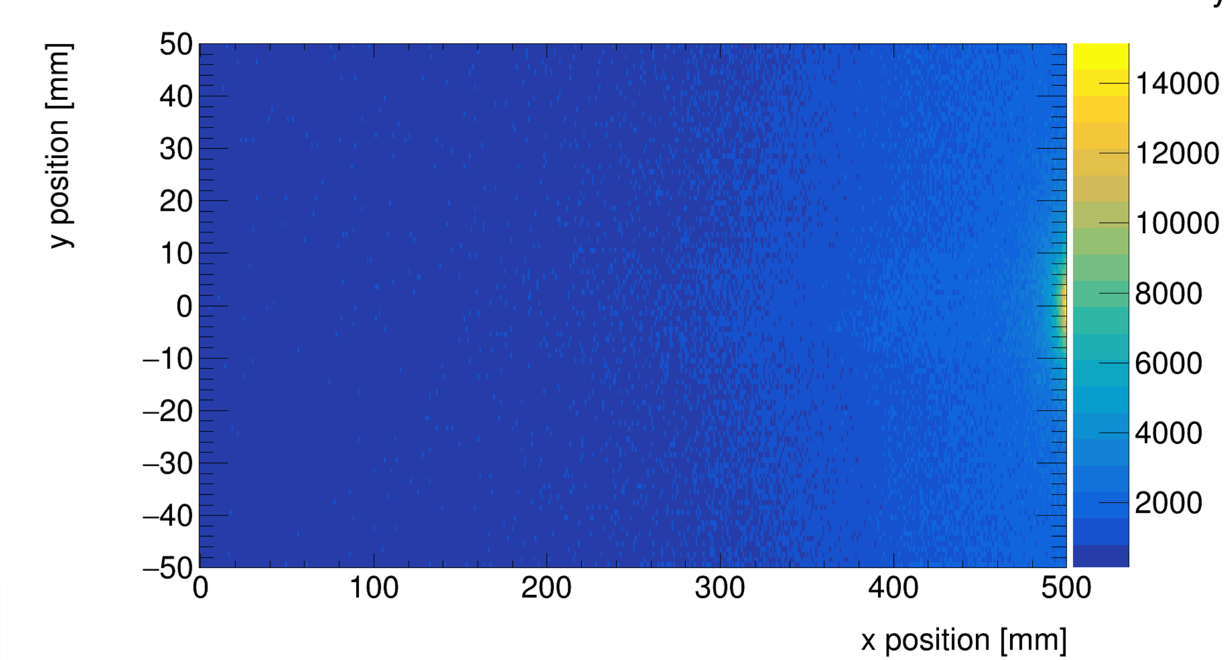
e-LASER IP Electron Detection System



Signal and Background







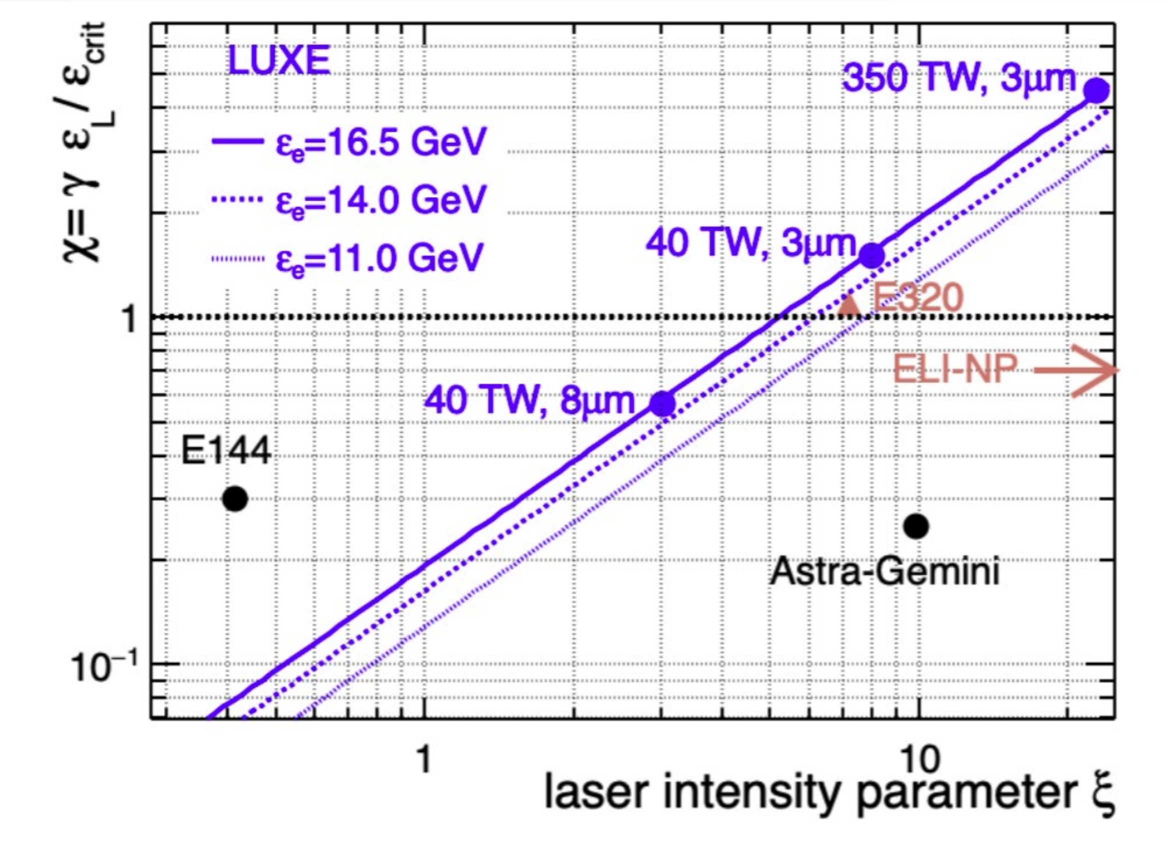
- Electron spectra reconstructions (**ξ** = 2.0) completed in Geant4, using the LUXE e-LASER geometry and simulating the scintillation physics process, but not explicitly optical transport

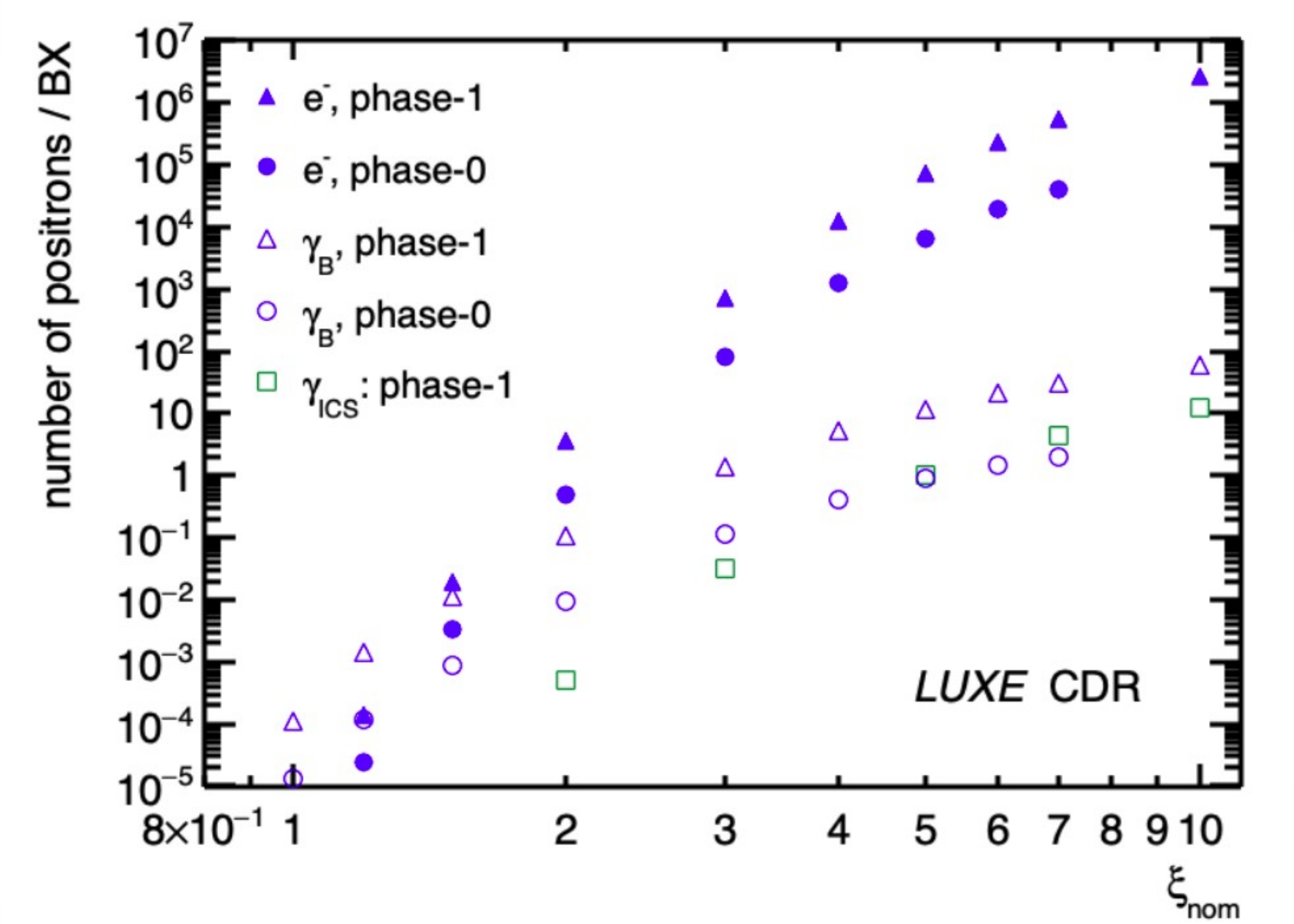
- High Signal / Background for radiation incident upon screen. Signal is more collimated within center of screen, so we use only this for signal measurement

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

- Beam-only events also used for background estimation

LUXE Physics Expected Results

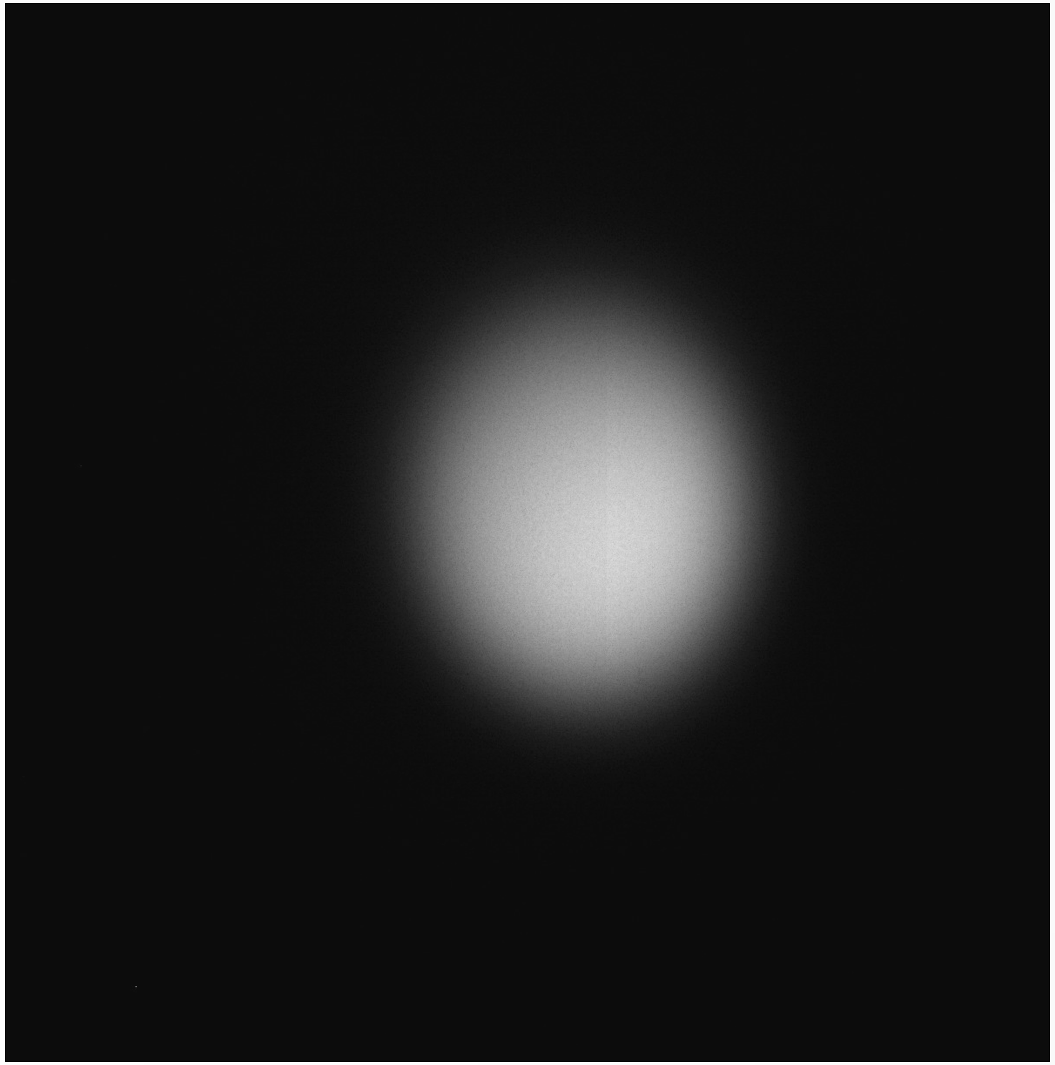




Probing into new parameter-space

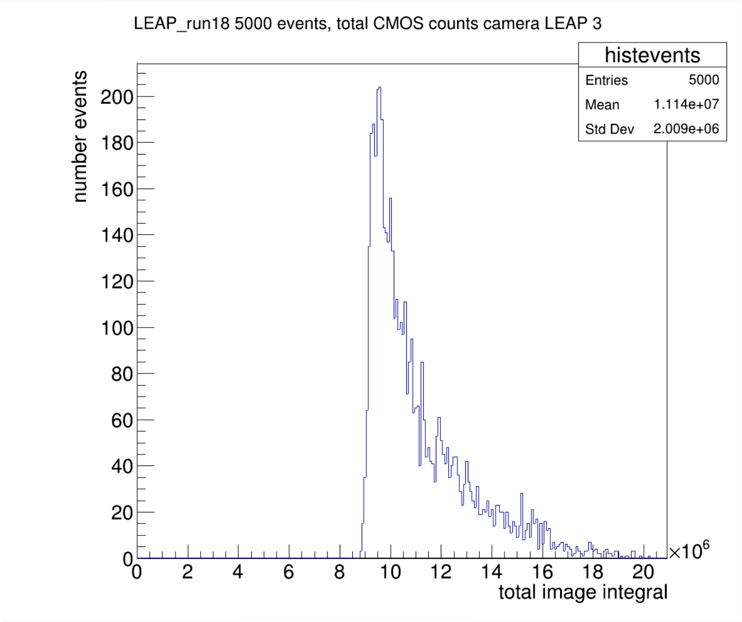
Pair-production rate with ξ

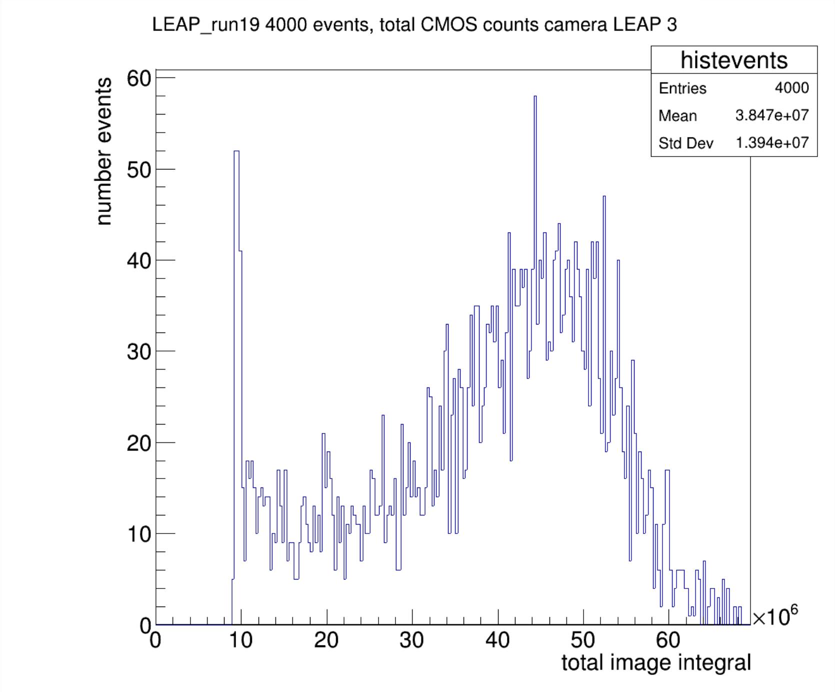
Test-Beam Prototype

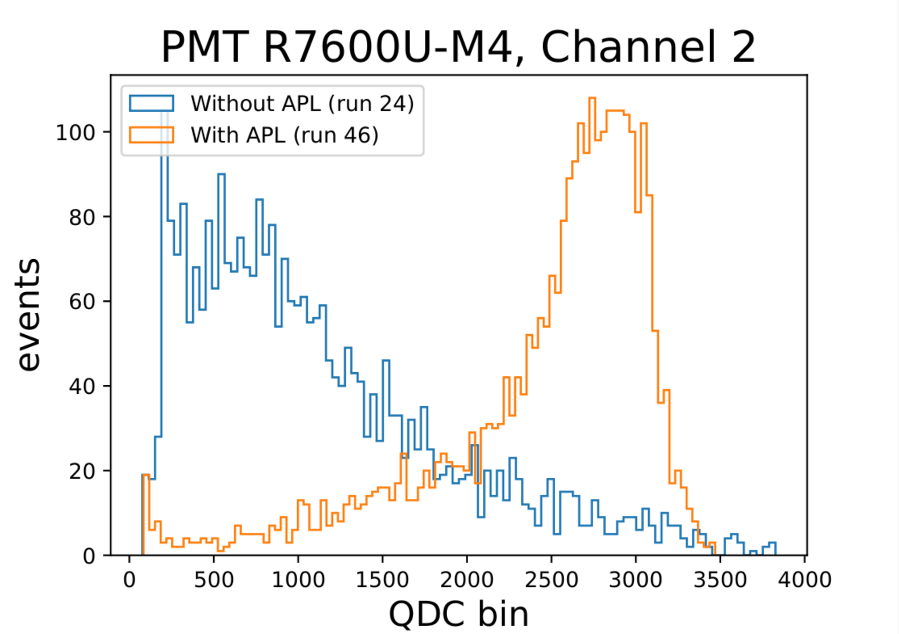


- ~1cm radius beam

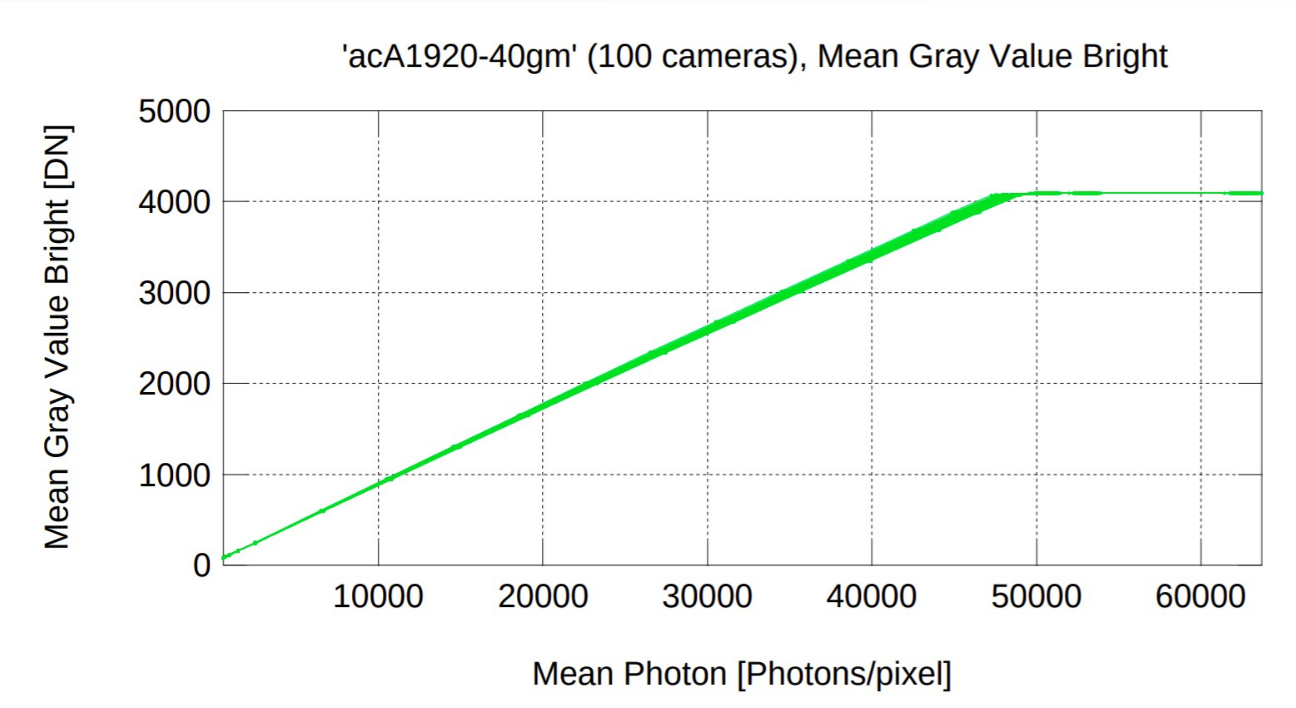
Test-Beam Prototype







Cameras, Lens, Filter



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

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

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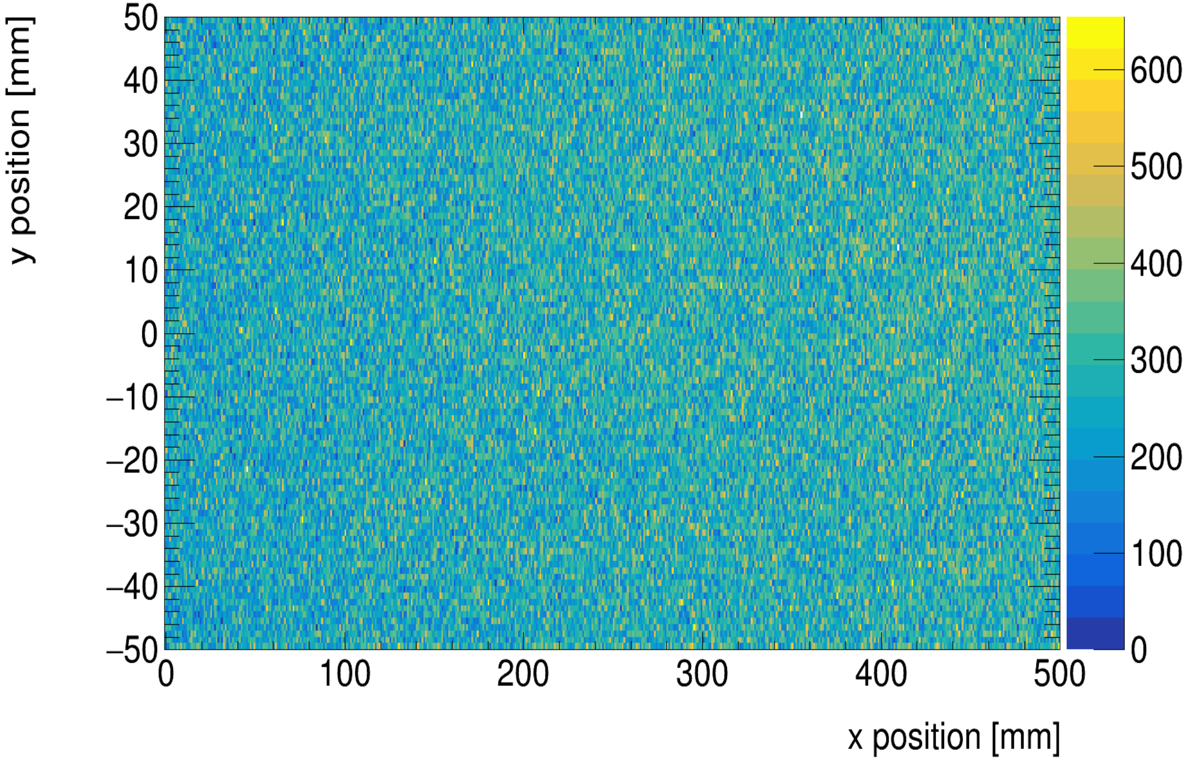
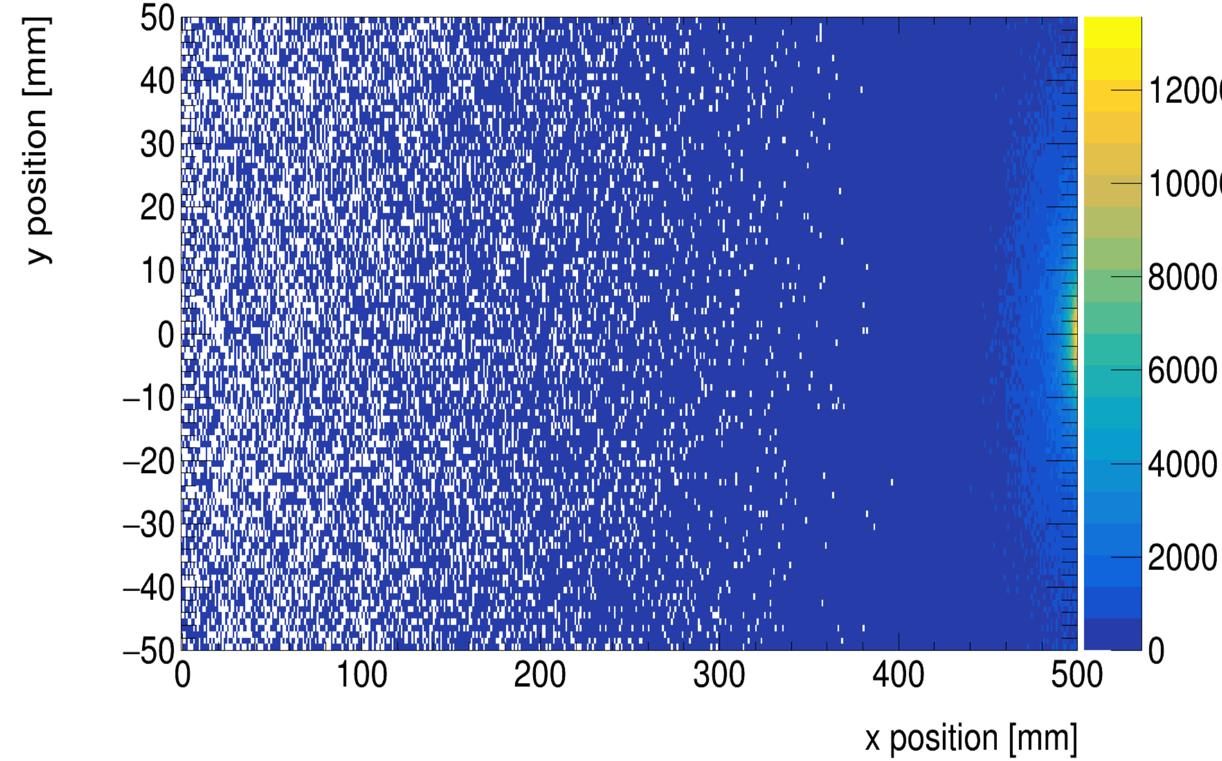
Background





- 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

Gamma Beam Generation