Update on luminosity monitor

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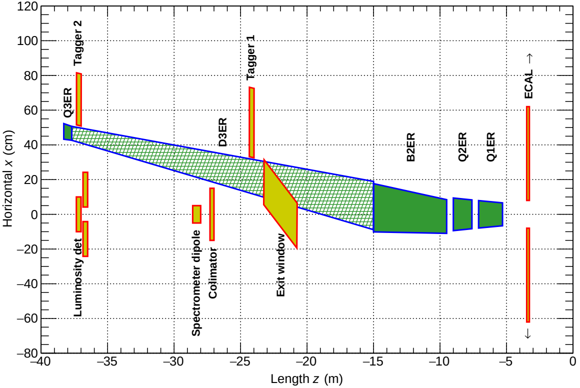
YR Polarimetry & Ancillary Detector Meeting

Outline

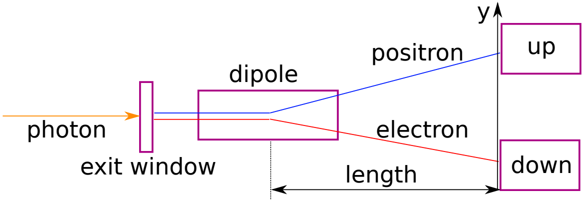
- An overview of previous Geant4 simulations of the luminosity layout was given at the far-forward detectors meeting here
- Now a geometry model for spectrometer acceptance will be shown, following the approach used at ZEUS in Nucl.Instrum.Meth. A565 (2006) 572-588
- Timing of photoelectrons from $PbWO_4$ crystals will be shown, as a result from a full simulation of light collection and detection
- The response is too slow to be able to detect every bunch crossing separately

IR layout, electron outgoing side



- Photon exit window is located at $z = -20.75$ m, spectrometer detectors at $z = -36.5$ m
- Preliminary positions, getting fixed from synrad simulations and beam pipe design
- All components shown here are implemented in Geant4 model, with D3ER drift space transparent

Geometry model for spectrometer acceptance



- Electron/positron gets transverse momentum from the dipole magnet, $p_T = \int B_x \mathrm{d}z$
- Position y on the detector is given by the length l from magnet center to the detector and electron momentum p:

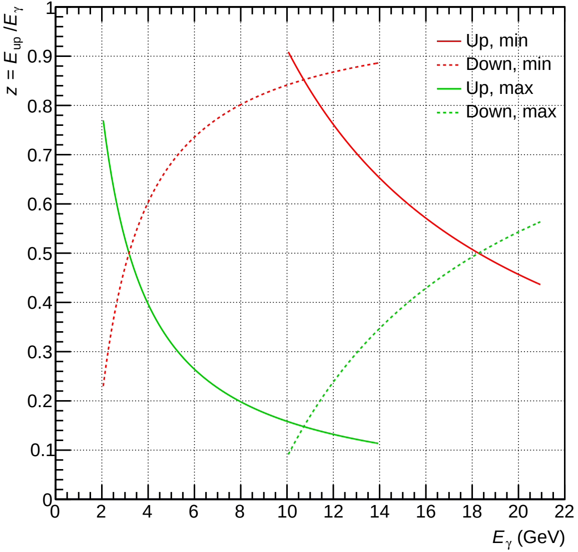
$$y = l\frac{p_T}{p}$$

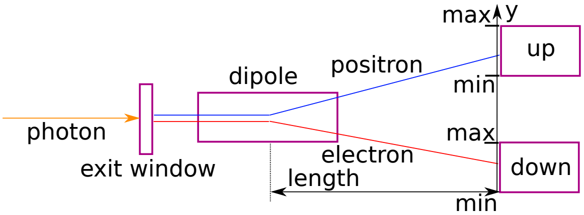
- One electron in the pair has a fraction of photon energy $z = p/E_\gamma$
- The other has a fraction $1 - z$

- Positions of the pair arriving on up and down detectors y_{up} and y_{down} are given by z and E_γ:

$$zE_\gamma = \frac{lp_T}{y_{\mathrm{up}}}, \quad (1-z)E_\gamma = \frac{lp_T}{y_{\mathrm{down}}} \tag{1}$$

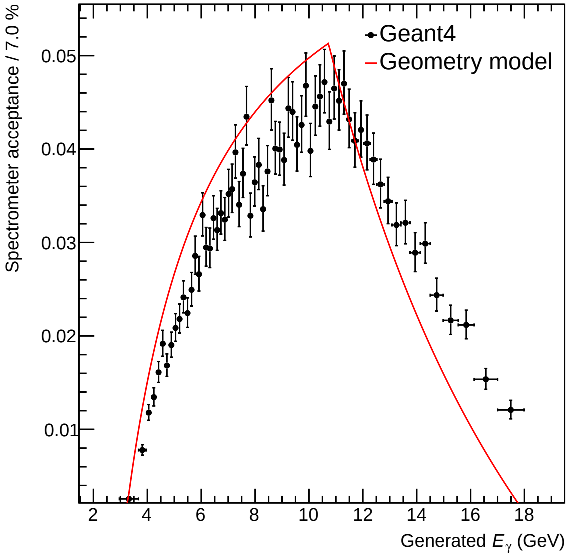
Range of accepted *y* positions in spectrometer detectors





- Both up and down detectors have a minimum and maximum accepted *y*
- The figure shows *z* and E_γ at detector minima and maxima in *y* according to Eq. 1
- Photon is detected when electron and positron are within the accepted range in *y*, it is the enclosed area in the figure
- Spectrometer acceptance at a given E_γ is the range in *z* of the area

Spectrometer acceptance



- Simulation of 1M bremsstrahlung events, 18x275 GeV beams
- Acceptance is a fraction of events with at least 1 GeV in both up and down detector
- The model curve is application of Eq. 1 and min and max intervals from page 5
- Length of the magnet is 0.6 m, field is 0.26 T
- Detectors are spaced symmetrically at $y_{\mathrm{min}} = 42$ mm and $y_{\mathrm{max}} = 242$ mm
- Length from the magnet center to the detectors is 8.2 m
- Good agreement between Geant4 and the model

Light collection and timing in the model of $PbWO_4$ photon detector

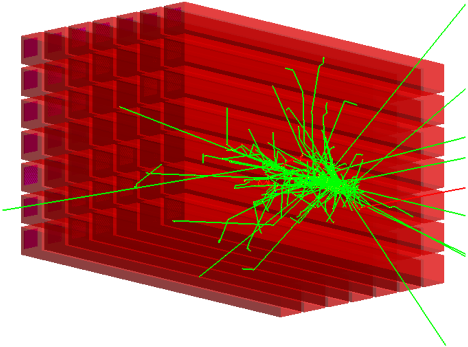


Figure: Photon in $PbWO_4$ calorimeter

- A model of 7x7 cells calorimeter was initially assumed for photon detector and spectrometer detectors
- Time shape of photoelectron signal will be shown in next pages
- The response is slow with respect to expected bunch rate

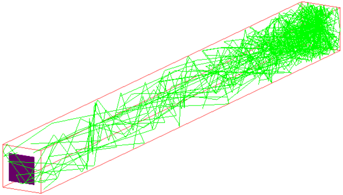
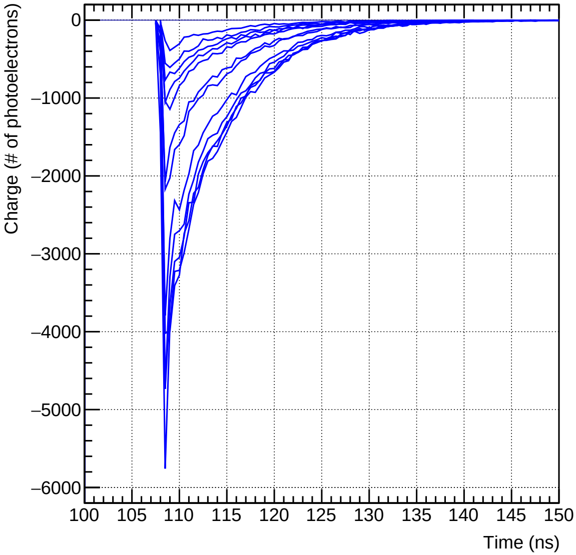


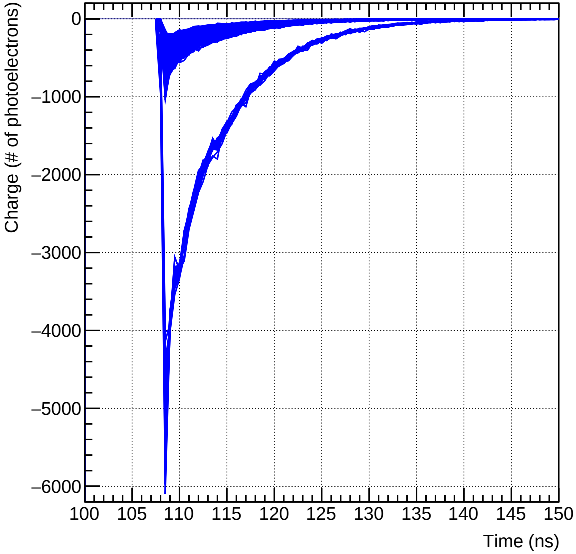
Figure: Light collection in calorimeter cell

Photoelectron pulses from a calorimeter cell



- Charge in number of photoelectrons created in the middle cell in 0.5 ns intervals
- Pulses of 12 consecutive events in Geant4 simulation of photons with uniform energies from 1 to 18 GeV
- An ideal scope would provide image like this
- Decay time depends weekly on pulse amplitude
- About 20 ns for all pulses to completely vanish
- Two times the bunch spacing at lower energies, half at the top energy

Pulses for events with highest and lowest energies



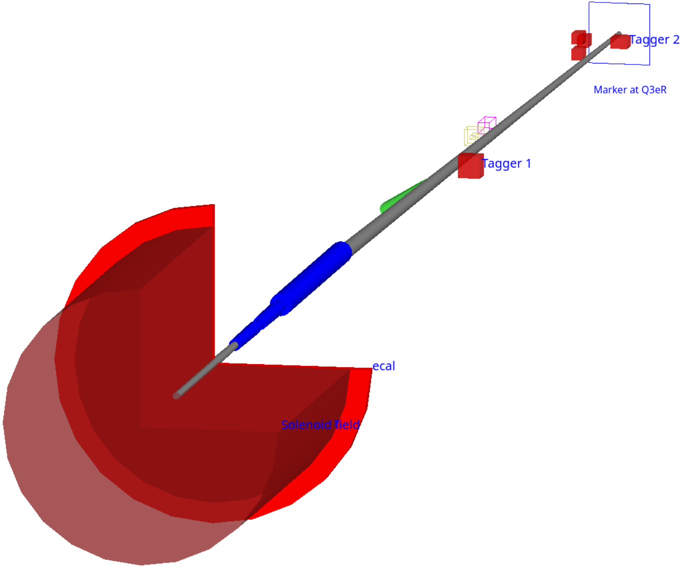
- Signals from events with photons below 3 GeV or above 17.5 GeV
- The same simulation of 1k photons with uniform energies from 1 to 18 GeV as on previous page
- Confirms the conclusion that the decay time is too long with respect to bunch spacing

Summary

- Geometry model for spectrometer acceptance works as a fast approximation to the full simulation
- Response from $PbWO_4$ calorimeter cells would be too slow to separate every bunch crossing
- IR drawing was created using *irview*: github.com/adamjaro/irview
- Bremsstrahlung generator is implemented in *eic-lgen*: github.com/adamjaro/eic-lgen
- Geant4 and analysis codes are in *lmon*: github.com/adamjaro/lmon

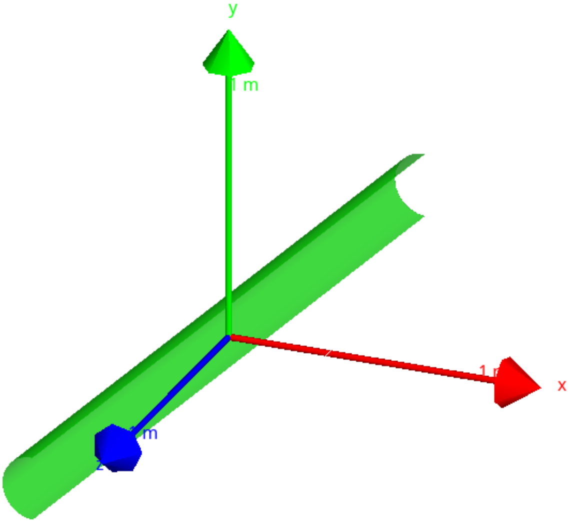
Backup

Geant4 model for electron-outgoing IR



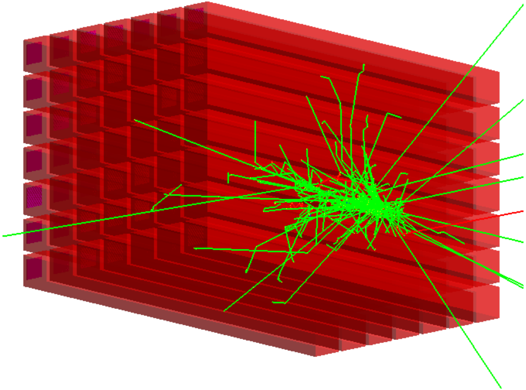
- Drift spaces in grey are transparent to all particles
- Tagger 1,2 and ECAL detectors mark hits by incoming particles
- Solenoid field uses the BeAST parametrization
- Beam magnets are shown in blue
- Components of luminosity monitor are on the opposite side to the taggers
- The layout ends with a marker at Q3eR position

Model of exit window



- Layer of passive material to convert bremsstrahlung photons to e^+e^- pairs
- Also provides shielding against low energy synchrotron radiation
- Implemented as a half-cylinder of 1 mm thick aluminum, 10 cm radius and 100 mrad tilt along vertical y axis
- The tilt angle is motivated by synchrotron radiation studies

Model of photon detector



- Detects direct photons not converted on the exit window
- Calorimeter is composed of 7×7 $PbWO_4$ cells
- Each cell consists of 3×3 cm casing made of carbon fiber, 2 mm thick, holding the $PbWO_4$ crystal inside
- Length of each cell is 35 cm, same for casing and crystal
- Only the crystals, shown in red, are sensitive volume
- Response to a 1 GeV photon is shown on the plot

Optical properties and light detection in model of $PbWO_4$ crystal

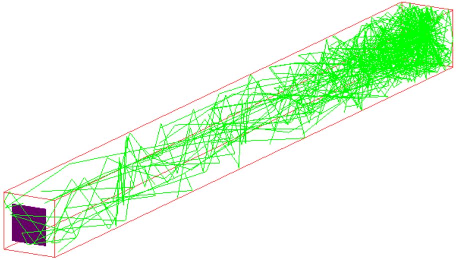


Figure: One calorimeter cell with 2 MeV deposition on the far side (facing the IP) and optical photon detector (magenta) on the opposite side. Optical photons are shown as green lines.

- Scintillation light yield is 200 per MeV with 6 ns decay constant (Knoll textbook)
- Wavelenght 420 nm (peak of emission as measured for ALICE)
- Optical properties approximately according to ALICE TDR
  - Uniform across 350 - 800 nm
  - Refractive index 2.4, absorption length 200 cm
  - Reflectivity 0.8, efficiency 0.9
- Detection by PIN diode, magenta square in the drawing
  - Silicon of 17×17 mm^2 area, 300 μm thickess (following ALICE device)
  - Reflectivity of optical boundary from the crystal is 0.1
  - Quantum efficiency is 0.8
  - Detected photon creates one photoelectron of signal (after applying quantum efficiency)
  - Number of photoelectrons is the output of the detector

Beam effects in eic-lgen event generator

- Vertex spread with Gaussian beam profile
  - Driven by emittance in x and y and bunch length in z
  - Vertex positions are generated from Gaussians in x, y and z of a given width $\sigma_{x,y,z}$
  - Using pCDR high acceptance configuration without hadron cooling for 18 x 275 GeV ep beams:
  - IP RMS beam size is σ_x = 236 μm and σ_y = 16.2 μm, RMS bunch length is σ_z = 1.7 cm
- Angular divergence
  - Separate for horizontal and vertical divergence
  - Implemented as Gaussian rotations of particle 3-momentum in x and y
  - The specific angles are generated with pCDR RMS values of $\sigma_{\theta,x}$ = 163 μrad and $\sigma_{\theta,y}$ = 202 μrad
  - Improvement over the initial studies on luminosity monitor, where only a single σ_θ was used for Gaussian smearing of electron polar angles
- For Pythia6 events the beam effects are implemented with an afterburner approach on the scattered electrons

Bremsstrahlung photons in eic-lgen based on Bethe-Heitler formula

- Bremsstrahlung photons and scattered electrons are generated using cross section as a function of photon energy E_γ and polar angle θ_γ
- Parametrization used at ZEUS is given in terms of electron and proton beam energy E_e and E_p

$$\frac{d\sigma}{dE_\gamma} = 4\alpha r_e^2 \frac{E_e'}{E_\gamma E_e}\left(\frac{E_e}{E_e'} + \frac{E_e'}{E_e} - \frac{2}{3}\right)\left(\ln\frac{4E_pE_eE_e'}{m_pm_eE_\gamma} - \frac{1}{2}\right) \tag{2}$$

- Scattered electron energy is constrained as $E_e' = E_e - E_\gamma$
- Equivalent parametrization from H1 is in terms of $y = E_\gamma/E_e$ and center-of-mass energy s

$$\frac{d\sigma}{dy} = \frac{4\alpha r_e^2}{y}\left[1 + (1-y)^2 - \frac{2}{3}(1-y)\right]\left[\ln\frac{s(1-y)}{m_pm_ey} - \frac{1}{2}\right] \tag{3}$$

- Angular distribution of the photons is given in terms of angle θ_γ relative to electron beam

$$\frac{d\sigma}{d\theta_\gamma} \sim \frac{\theta_\gamma}{\left((m_e/E_e)^2 + \theta_\gamma^2\right)^2} \tag{4}$$

ZEUS: Eur.Phys.J. C71 (2011) 1574, H1: H1-04/93-287