Electron beam gas

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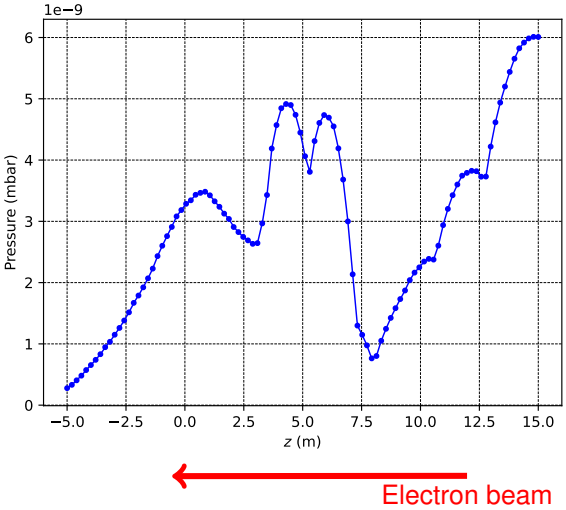
Introduction

- Electron beam - gas bremsstrahlung for electrons at E_e = 10 GeV will be shown here
- Lattice and pressure data are available in indico.bnl.gov/event/10974/contributions/51260/
- Data on pressure are given in `Detector.chamber.vacuum.Aug2021.xlsx`
- Electron lattice for 10 GeV beam is given in `esr-ir6-100-10.txt`
- Beam parameters are explained in readme in indico and in arxiv.org/abs/1404.0923
- Emittance for 10 GeV electrons is ε_x = 20 nm and ε_y = 1.3 nm from EIC_CDR_Final.pdf Table 3.3
- Sample of 100M bremsstrahlung events was generated for 10 GeV electrons on static protons from H_2 gas
- Output in HepMC3 format contains bremsstrahlung photons and scattered electrons
- Interaction vertex follows from pressure and transverse beam size
- Angular divergence is applied to bremsstrahlung photons and scattered electrons according to beam parameters

Chamber pressure

- Pressure of H_2 gas from Detector.chamber.vacuum.Aug2021.xlsx
- Case of 10 000 Ahrs
- The pressure is given as a function of z along the beam
- Points are the data from xlsx, lines are a result of linear interpolation for use in the generator
- The gas represents a fixed target to the electron beam
- Beam-gas vertex distribution along z is given by the pressure

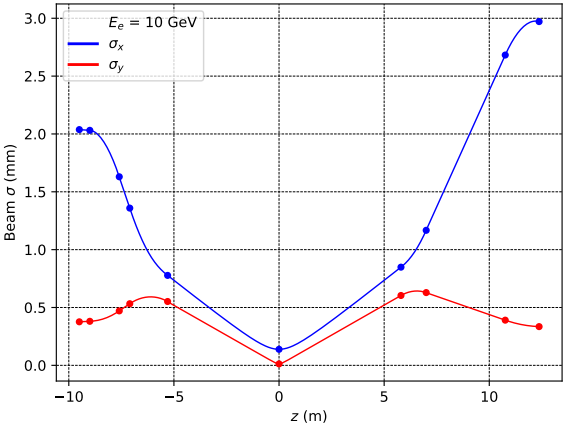


Transverse beam size

- Width of beam in x (horizontal) and y (vertical) directions
- Given by emittance ε and β-function as

$$\sigma_{x,y} = \sqrt{\varepsilon_{x,y}\beta_{x,y}}$$

- ε is a constant and β depends on actual position along the ring
- Points in the plot are data from lattice
- Smooth interpolation by Hermite polynomial is possible thanks to slope of β function α: $\alpha = -\beta'/2$
- Transverse beam width $\sigma_{x,y}$ gives vertex position in x and y

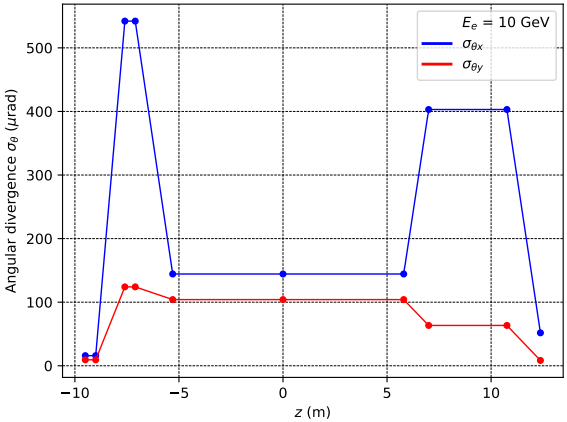


Beam angular divergence

- Angular divergence gives spread in angles of beam particles
- With α and β from electron lattice the divergence is

$$\sigma_\theta = \sqrt{\epsilon \frac{1+\alpha^2}{\beta}}$$

- Points in the plot show data from lattice
- Lines are linear interpolation
- The divergence is applied to generated photon and electron as random Gaussian rotations imposed on particles 3-momenta with the width of $\sigma_{\theta x,y}$



Beam-gas interaction vertex

- Distribution of electron beam - gas interaction vertices
- Shape in x and y is a Gaussian with $\sigma_{x,y}$ at a given location in z
- Shape in z follows the pressure
- Scale in z is in m, scale in x and y is mm

Figure: xz plane

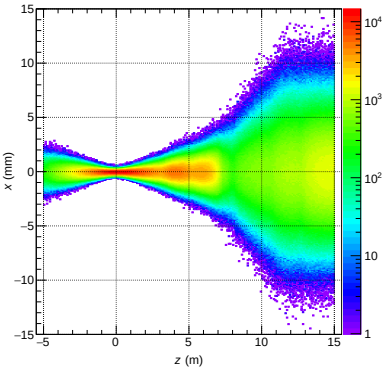
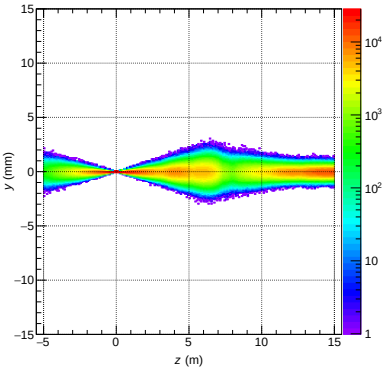
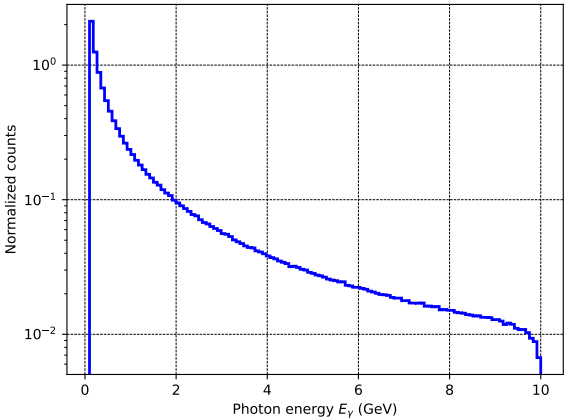


Figure: yz plane



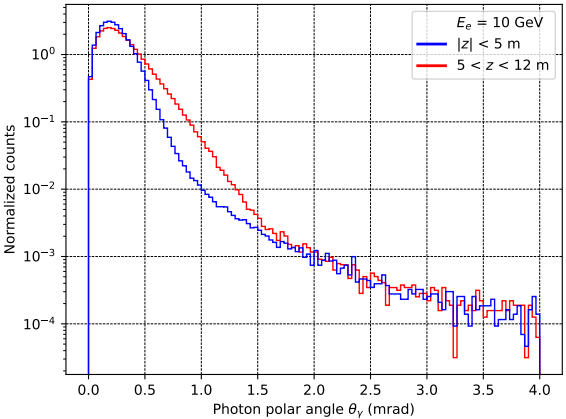
Photon energy spectrum

- Distribution of photon energies for electron beam E_e = 10 GeV on a fixed proton
- Total cross section for $E_\gamma > 0.1$ GeV is σ_{BR} = 150.969 mb



Photon polar angles

- Angular distribution of bremsstrahlung photons
- The shape is more broad in region of higher divergence in z from 5 to 12 m
- Comparison is made to central region $|z| <$ 5 m of smaller divergence



Scattered electron energy and polar angle

Figure: Electron energy

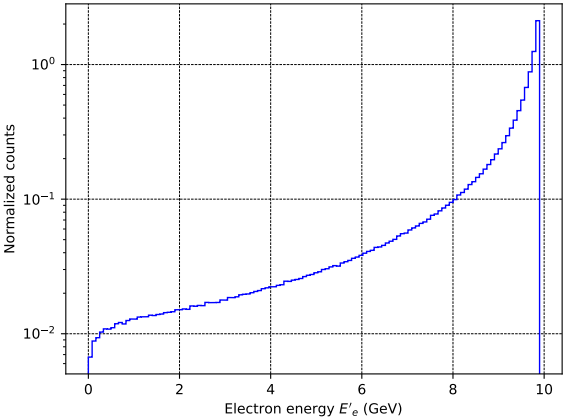
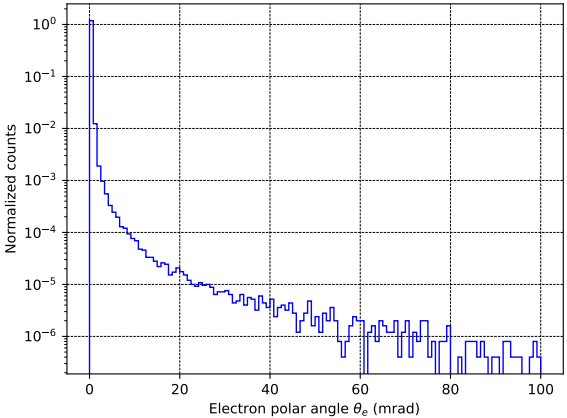


Figure: Electron polar angle



Calculation of event rate by bremsstrahlung on H_2 gas

- Rate R of bremsstrahlung events per second is

$$R = \sigma_{\mathrm{BR}} \times I \times N$$

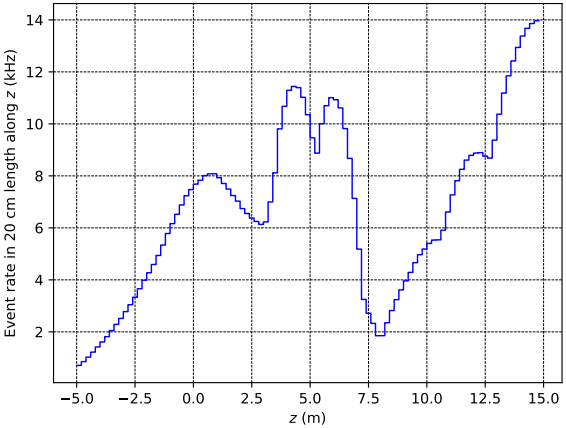
- Total cross section for $E_\gamma > 0.1$ GeV is σ_{BR} = 150.969 mb
- I is beam current in electrons per second, given by current in Amps from CDR Tab. 3.3 (2.5 A) divided by elemental charge in C
- N is surface density as number of protons per m^2 from pressure p, Boltzmann constant R_B and normal temperature T (293.15 K):

$$N = \delta z \times 2 \times p/(R_B \times T)$$

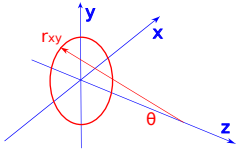
- Factor of 2 stands for two protons in H_2 which makes the pressure p
- δz is slice of length along z

Event rate by electron beam - gas due to bremsstrahlung

- Event rate R along z in δz = 20 cm
- Each interval δz contributes bremsstrahlung beam-gas rate shown in the plot
- Rate from a given range in z is a sum of individual δz contributions within that range

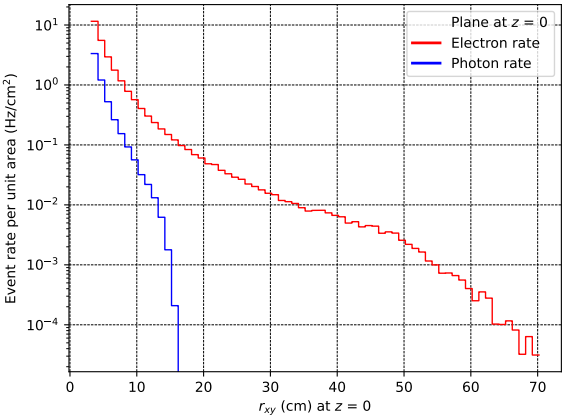


Event rate at transverse plane at the origin



- Bremsstrahlung photons and electrons are projected onto the plane at a given z
- Event rate R_r at a given radial position r_{xy} is:

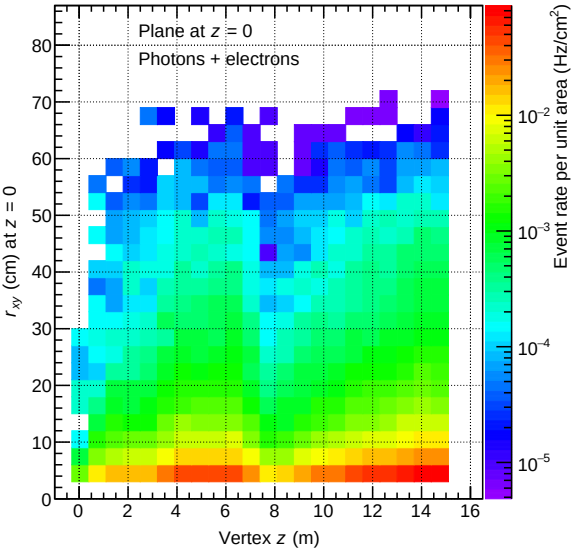
$$R_r = N_r \times \frac{R_{\text{prod}}}{N_{\text{sim}}} \Big/ S_r$$



- N_r is number of hits in interval δr at r_{xy}
- R_{prod} is the total production rate from page 11, N_{sim} is number of all simulated events
- S_r is surface area corresponding to radial interval δr
- Plot shows the rate R_r in intervals δr of 1 cm, beginning at 3.2 cm (inner beam pipe radius)

Event rate and vertex position along z at a plane at the origin

- Even rate (color scale) as a function of r_{xy} and vertex z position
- Shows contribution of production vertex to the rate observed at r_{xy}
- The total rate by photons and electrons incident on the plane at $z = 0$ is 1.14 kHz (integrated over all r_{xy} and z)



Event rate at planes at forward (hadron) ECAL and HCAL

- Procedure for event rate at r_{xy} is repeated for transverse planes at forward ECAL and HCAL locations (hadron going direction)

Figure: Plane at forward ECAL

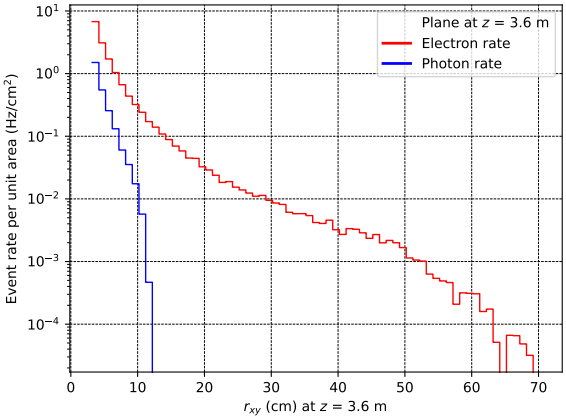
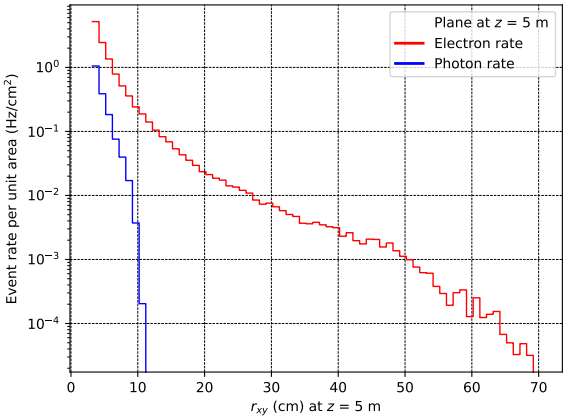


Figure: Plane at forward HCAL



Event rate and z-vertex at forward (hadron) ECAL and HCAL

- Event rate (color scale) as a function of r_{xy} and z of vertex position at forward ECAL and HCAL locations

Figure: Plane at forward ECAL

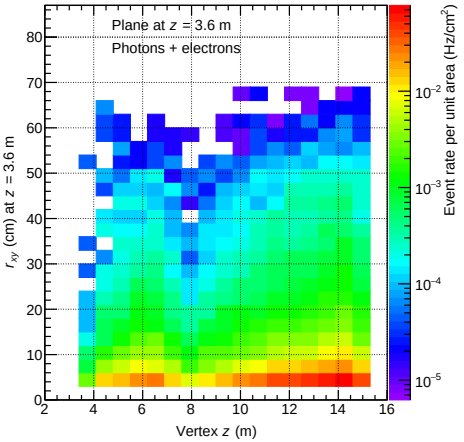
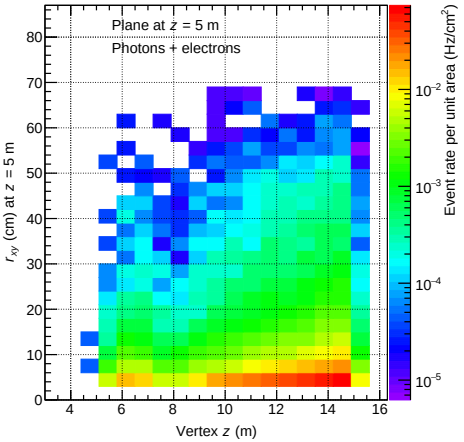


Figure: Plane at forward HCAL



Event rate at planes at backward (electron) ECAL and HCAL

- Procedure for event rate at r_{xy} is repeated for transverse planes at backward ECAL and HCAL locations (electron going direction)

Figure: Plane at backward ECAL

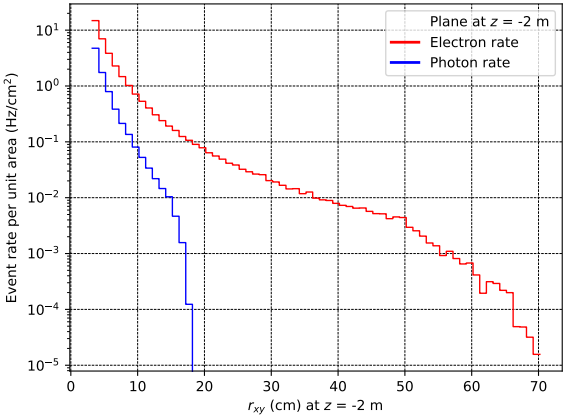
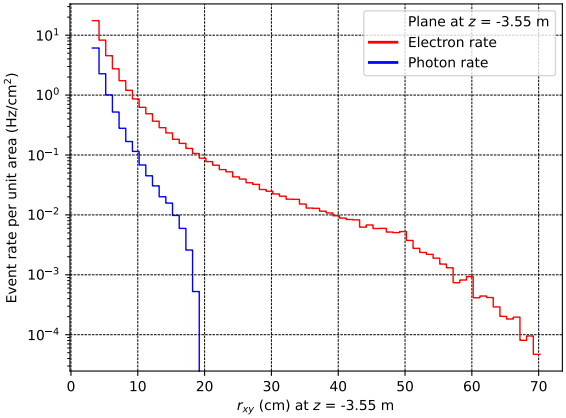


Figure: Plane at backward HCAL



Event rate and z-vertex at backward (electron) ECAL and HCAL

- Event rate (color scale) as a function of r_{xy} and z of vertex position at backward ECAL and HCAL locations

Figure: Plane at backward ECAL

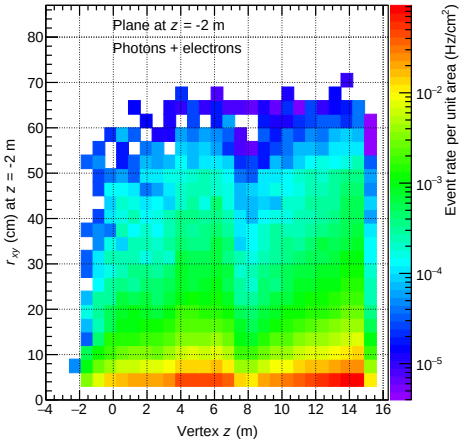
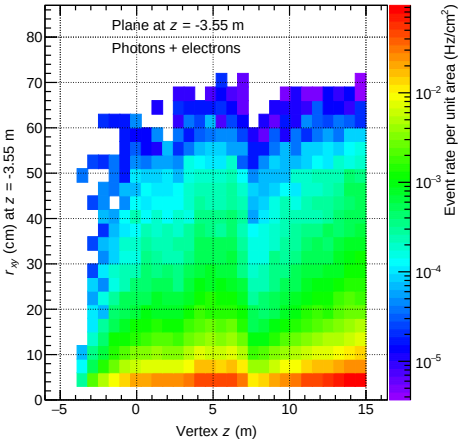
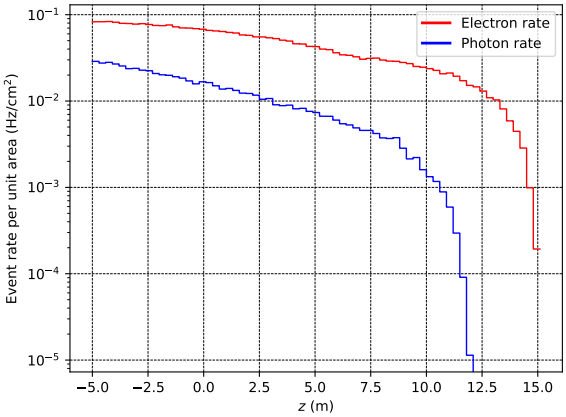


Figure: Plane at backward HCAL



Event rate at the inner surface of the beam pipe

- Photons and electrons are projected on the inner surface of the beam pipe
- Radius of 3.2 cm is assumed over the entire z range
- Event rate per surface area is obtained in as on page 12
- Total rate integrated over all z by photons and electrons together is 2.2 kHz



Summary

- Rates of $\mathcal{O}(1)$ kHz on central and forward/backward detectors
- Some of open questions being addressed:
  - Contribution from heavier gases, since the cross section scales as Z^2
  - Effect of forward quadrupoles to scattered electrons
  - Interactions in beam pipe and detector material
  - Justification of lower limit on photon energies of 100 MeV set in event generation
- Generator implementation (a part of generator for luminosity and tagger studies, arXiv:2105.10570 [hep-ph]) is here: github.com/adamjaro/GETaLM/blob/master/models/gen_beam_gas.py
- Output data of 100M evens in HepMC3 are here, thanks Kolja for setting up RCF for the production:
  `/gpfs02/eic/jadam/GETaLM_data/beam_gas/beam_gas_ep_10GeV_emin0p1_100Mevt.hepmc`