# Electron beam gas

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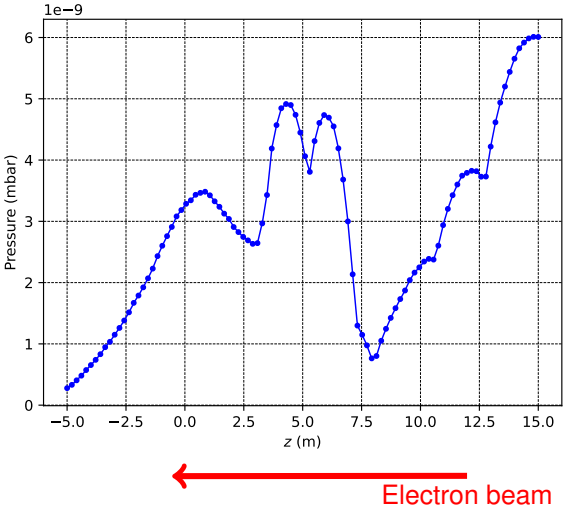
# Introduction

- 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 $\varepsilon_x$ = 20 nm and $\varepsilon_y$ = 1.3 nm from EIC_CDR_Final.pdf Table 3.3
- Sample of 10M 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 10000 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

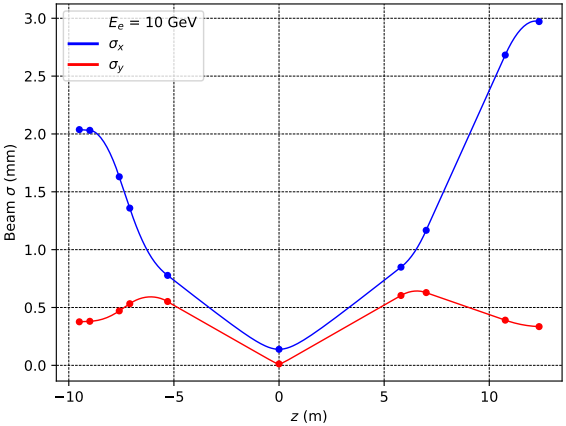


# Transverse beam size

- Width of beam in $x$ (horizontal) and $y$ (vertical) directions
- Given by emittance $\varepsilon$ and $\beta$-function as

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

- $\varepsilon$ is a constant and $\beta$ 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 $\beta$ function $\alpha$: $\alpha = -\beta'/2$
- Transverse beam width $\sigma_{x,y}$ gives vertex position in $x$ and $y$

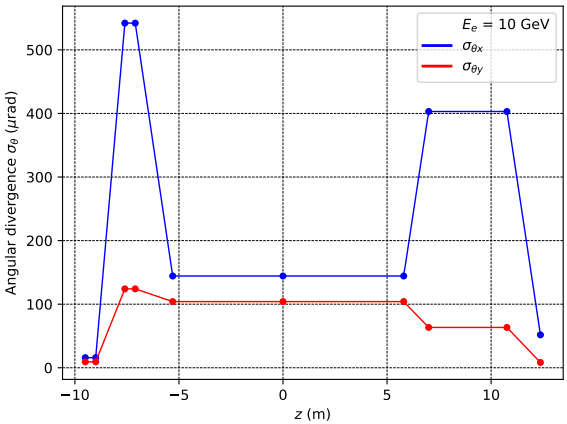


# Beam angular divergence

- Angular divergence gives spread in angles of beam particles
- With $\alpha$ and $\beta$ 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

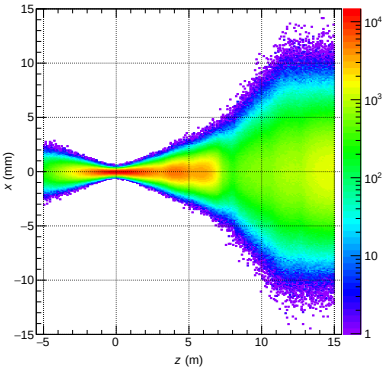
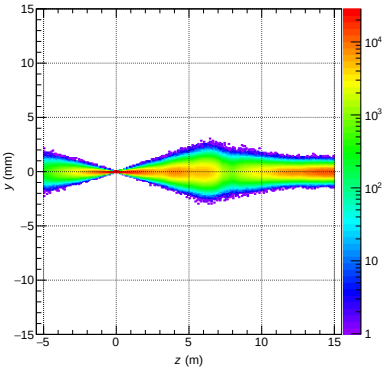
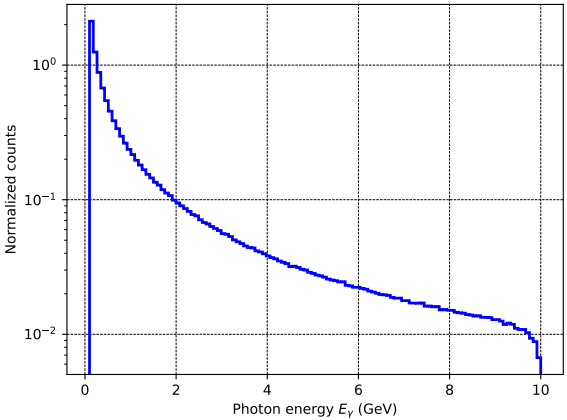



Figure: $yz$ plane



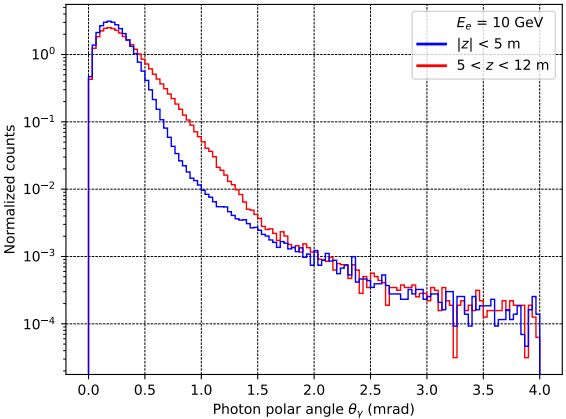
# Photon energy spectrum

- 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 $\sigma_{\mathrm{BR}}$ = 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

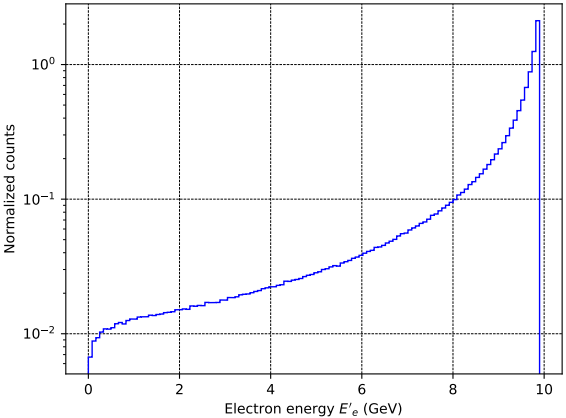
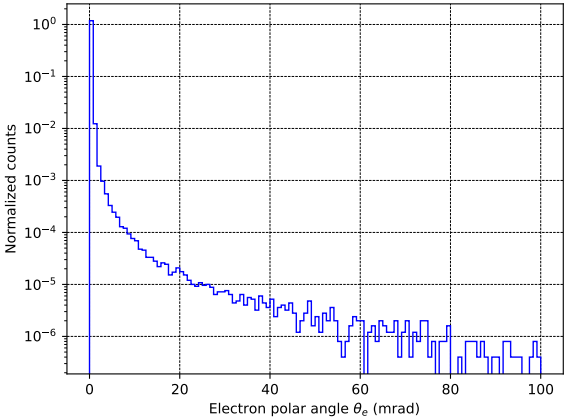



Figure: Electron polar angle



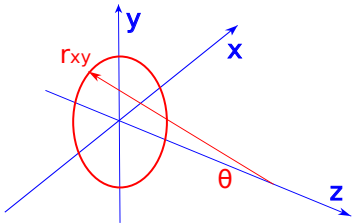
# Photon projection onto $xy$ plane at $z = 0$

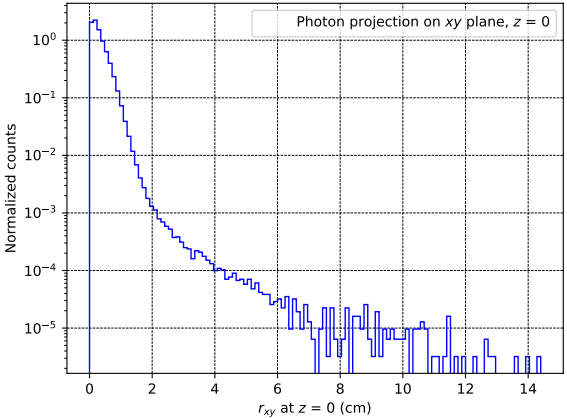
- Bremsstrahlung photons are projected onto radial position $r_{xy}$ on $xy$ plane at the origin

- Projected radial position $r_{xy}$ is given by photon polar angle $\theta_\gamma$ and vertex position $x$, $y$ and $z$:

$$r_{xy} = z \times \tan\theta_\gamma + \sqrt{x^2 + y^2}$$

- Correction to transverse vertex position $\sqrt{x^2 + y^2}$ is $\mathcal{O}(1)$ cm



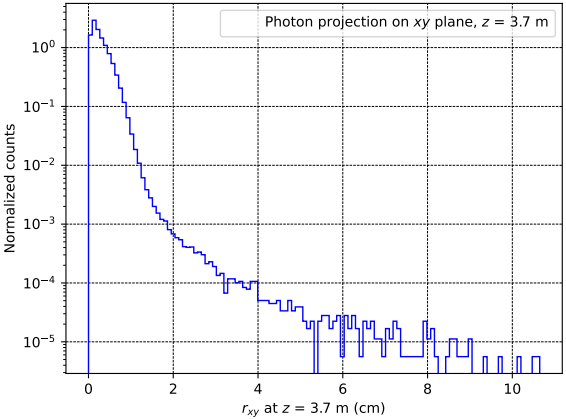



# Photon projection onto $xy$ plane at $z$ = 3.7 m

- Photons projection $r_{xy}$ on $xy$ plane is done at approximate forward ECAL position, $z$ = 3.7 m
- Projected radial position $r_{xy}$ is given by photon polar angle $\theta_\gamma$ and vertex position $x$, $y$ and $z$:

$$r_{xy} = z \times \tan\theta_\gamma + \sqrt{x^2 + y^2}$$

- Correction to transverse vertex position $\sqrt{x^2 + y^2}$ is $\mathcal{O}(1)$ cm



# Scattered electron projection onto *xy* plane

- Projection $r_{xy}$ is done for scattered electrons, same locations in $z$ as for the photons

Figure: $z = 0$

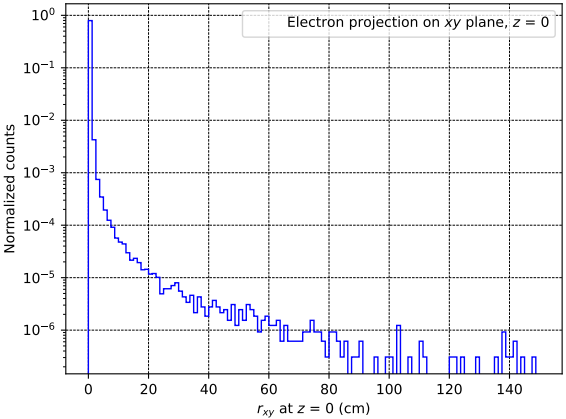
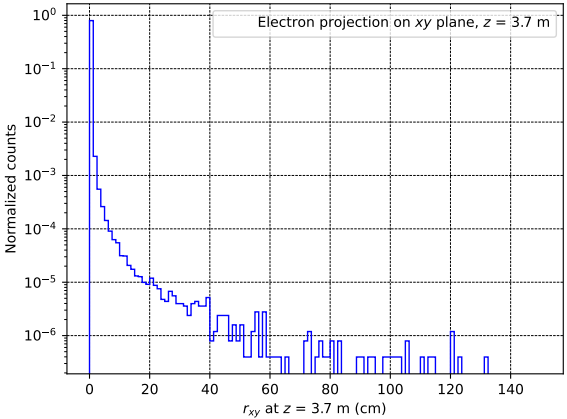



Figure: $z = 3.7$ m



# Calculation of event rate by bremsstrahlung on $H_2$ gas

- Rate $R$ of bremsstrahlung events per second is

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

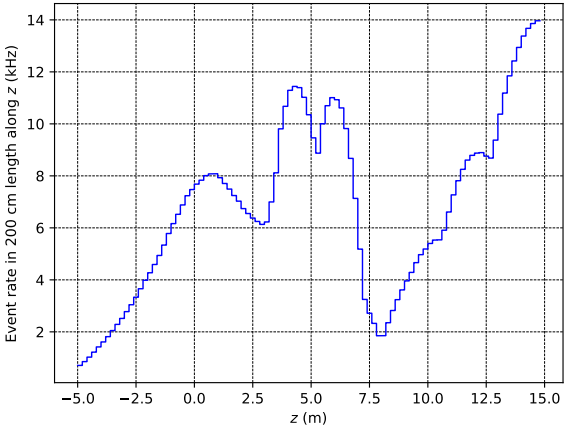
- Total cross section for $E_\gamma > 0.1$ GeV is $\sigma_{\mathrm{BR}}$ = 150.969 mb
- $I$ is beam current in electrons per second, given by current in Amps from CDR Tab. 3.3 (2.5 A) divided by elemental charge in C
- $N$ is surface density as number of protons per $m^2$ from pressure $p$, Boltzmann 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 $p$
- $\delta z$ is slice of length along $z$

# Event rate by electron beam - gas due to bremsstrahlung

- Event rate $R$ along $z$ in $\delta z$ = 200 cm
- Each interval $\delta z$ contributes bremstrahlung beam-gas rate shown in the plot
- Rate from a given range in $z$ is a sum of individual $\delta z$ contributions within that range



# Summary

- Even rates are estimated as $\mathcal{O}(10)$ kHz in regions of higher pressure, in slices per 200 cm
- Regions of larger divergence give more broad angular distribution
- Generator implementation is here:
  github.com/adamjaro/GETaLM/blob/master/models/gen_beam_gas.py
- It is a part of generator for luminosity and tagger studies described in
  arxiv.org/abs/2105.10570
- Output data in HepMC3 are in:
  `/gpfs02/eic/jadam/GETaLM_data/beam_gas/beam_gas_ep_10GeV_emin0p1_10Mevt.hepmc`