Electron beam gas

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June 16, 2022

Tracking meeting

Introduction

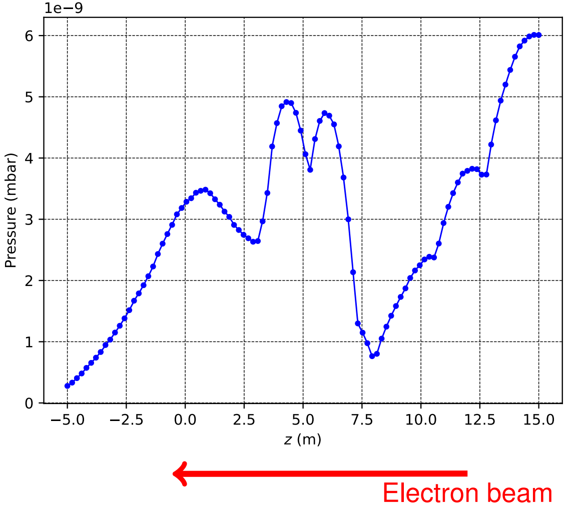
- Beam electron are incident on hydrogen molecules, considered at rest
- Bremsstrahlung photon and scattered electron are produced in the interaction
- Dedicated event generator was incorporated into existing generator in Comput.Phys.Commun. 272 (2022) 108251
- Interaction position follows hydrogen pressure in the vacuum chamber
- Beam angular divergence is also considered
- Data on pressure and beam parameters are in indico.bnl.gov/event/10974/contributions/51260/
- The study was done as a part of ATHENA proposal
- Results on electron beam-gas at 10 GeV are compared with Pythia6 ep collisions at 10x100 GeV

- Background hits in detectors are caused by secondaries from the photon or electron
- The process is continuous over a large range along the beam axis, independent of bunch crossings at nominal IP

Chamber pressure

- Pressure of H_2 gas from Detector.chamber.vacuum.Aug2021.xlsx (indico link on previous page)
- Case of 10 000 Ahrs (the best case)
- 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
- Full range from -5 to +15 meters is considered in the simulation

Beam-gas vertex distribution along z is given by the pressure

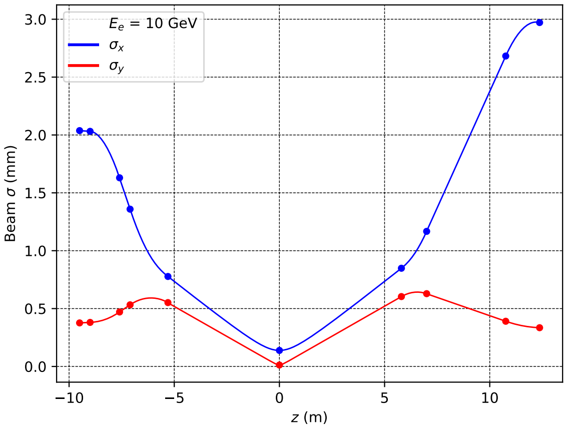


Transverse beam size

- 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-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

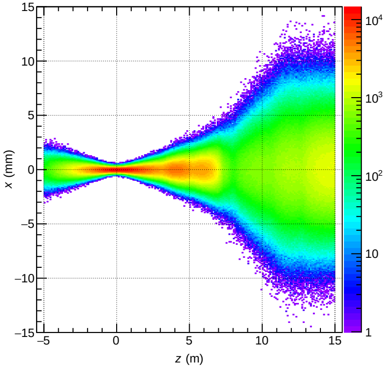
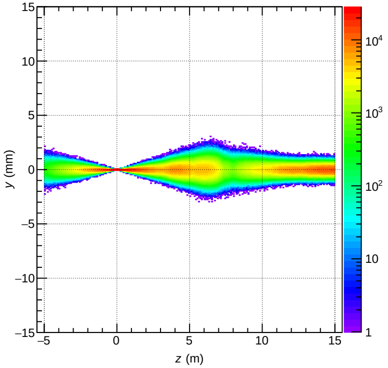


Figure: *yz* plane

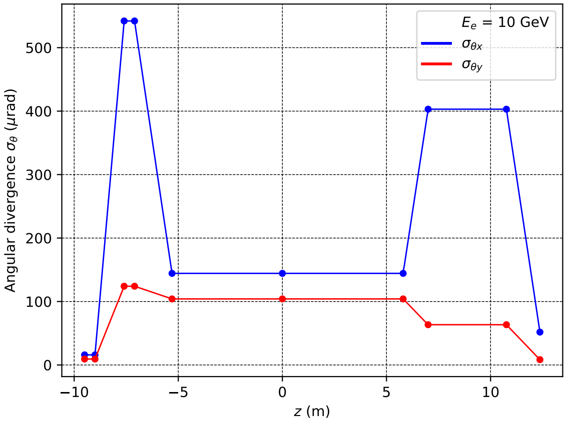


Beam angular divergence

- 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 $\sigma_{\theta x,y}$



Bremsstrahlung beam-gas generator

- Implemented as an extension to the generator for luminosity studies in Comput.Phys.Commun. 272 (2022) 108251
- Double-differential bremsstrahlung cross section as a function of photon energy and polar angle is integrated with `TFoam` (gains precision also for photons at low energies)
- Outcome from the generator is the photon and scattered electron
- Limit on minimal bremsstrahlung photon energy E_γ is set to 10 keV
- Total cross section for E_γ > 10 keV is σ_{BR} = 699.392 $\pm$ 0.041 mb
- The limit was determined by comparing two samples of 10M events with 10 keV and 100 keV limits; no appreciable increase in hit rates was observed, 10 keV is used for all results
- Vertex position is generated according to the beam gas interaction vertex
- Angular divergence is applied to the photon and electron according to its dependence on z of the vertex as shown previously

Generated sample in HepMC3 is input to full detector simulation

Photon energy and angular spectrum

Figure: Photon energy

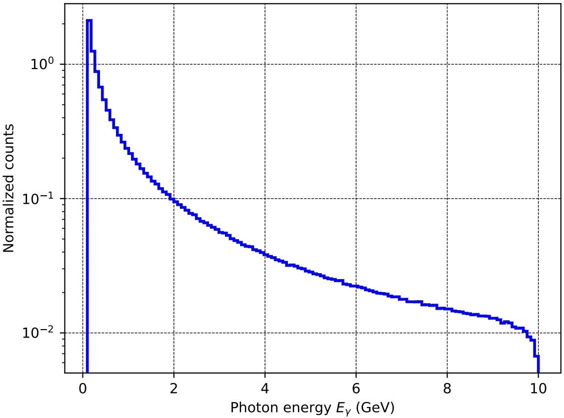
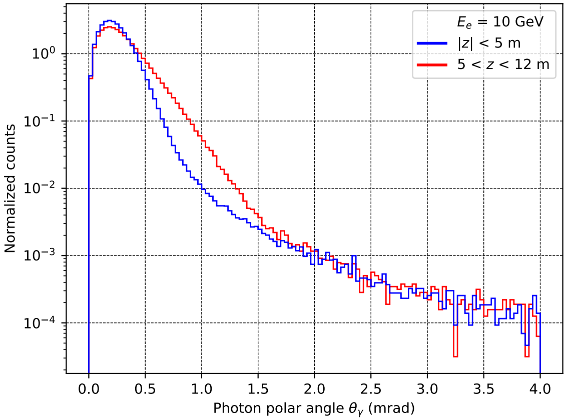


Figure: Photon polar angle



Electron energy and angular spectrum

Figure: Electron energy

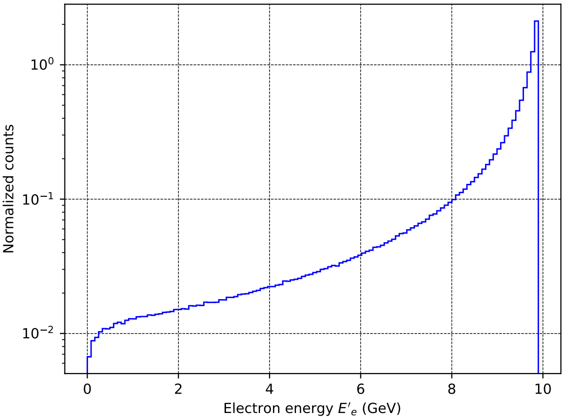
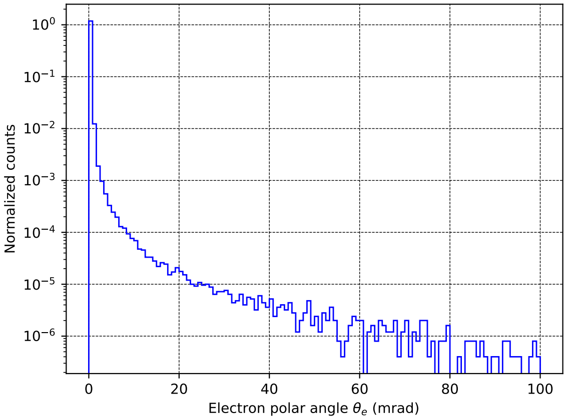
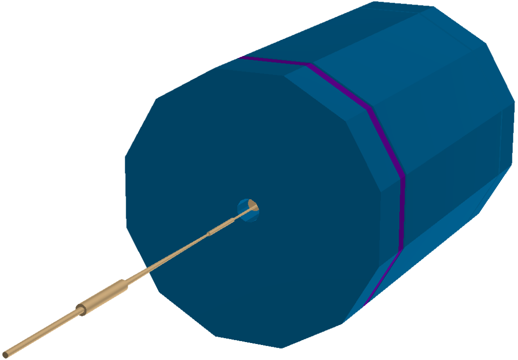


Figure: Electron polar angle

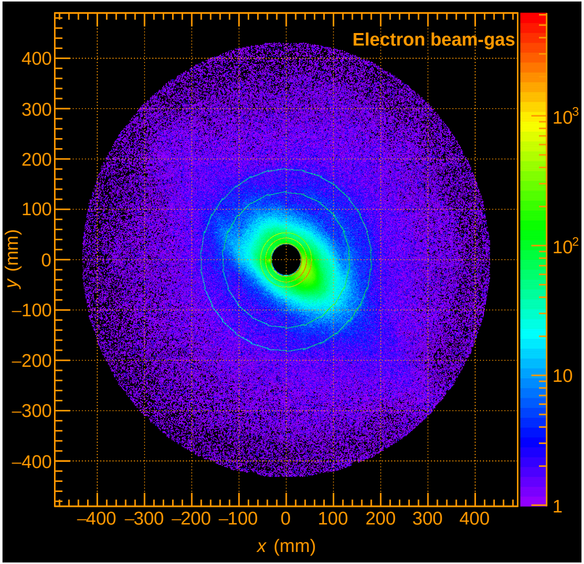


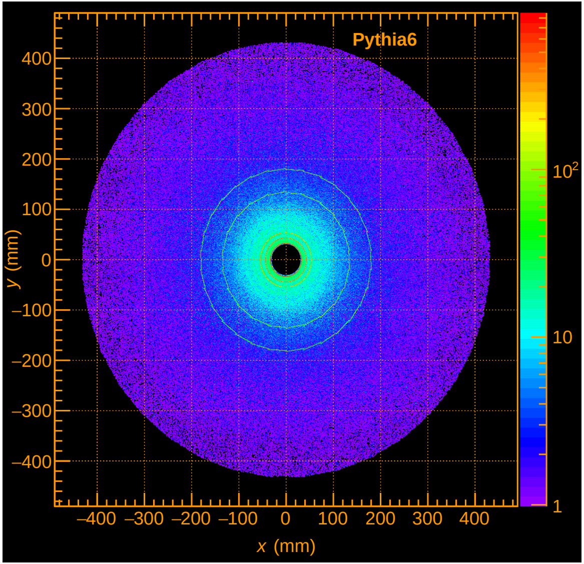
Detector geometry

- Full ATHENA DD4hep geometry was considered
- Thresholds for detector hits are applied according to individual technologies (0.4 keV for MAPS trackers)
- Forward electron beamline is added to the simulation
- Central beampipe is continued in forward direction to $z = +15$ m
- Electron forward quadrupoles Q0eF and Q1eF are added to account for their field acting on scattered electrons from beam-gas events

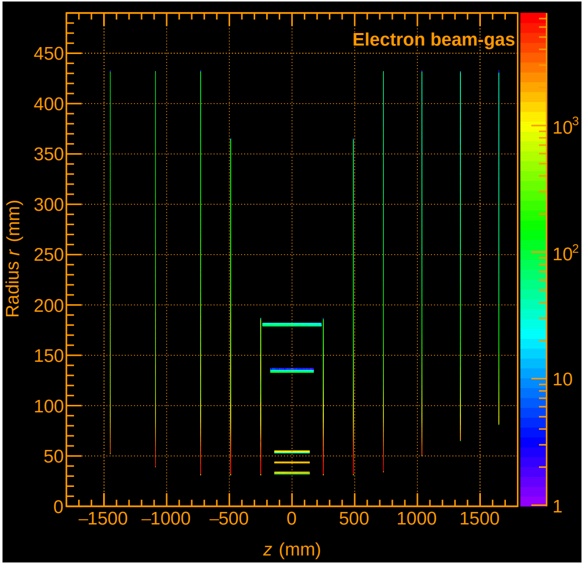


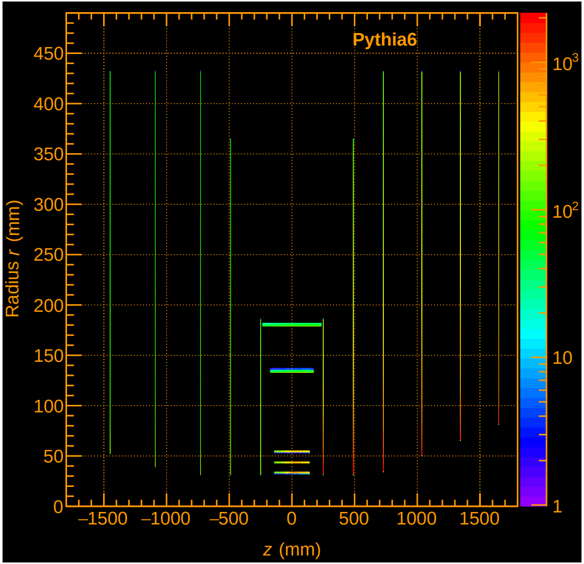
Hit *xy* position in VertexBarrel + TrackerBarrel + TrackerEndcap





Hit radius and z in VertexBarrel + TrackerBarrel + TrackerEndcap

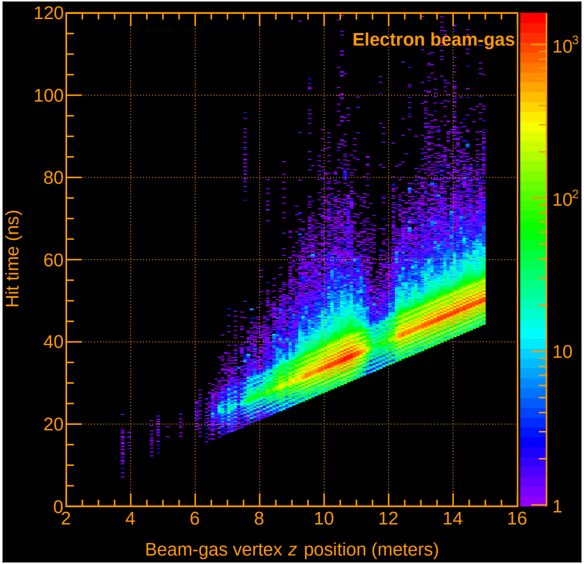




Hit time and beam-gas interaction vertex in tracking detectors

- Tracking detectors VertexBarrel + TrackerBarrel + TrackerEndcap are considered together
- Time for detector hits is shown against *z* position of beam-gas interaction vertex

Beam-gas interactions at large distances still contribute to observed detector hits



Calculation of production rate by bremsstrahlung on H_2 gas

- Rate R_{BR} of bremsstrahlung events per second is

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

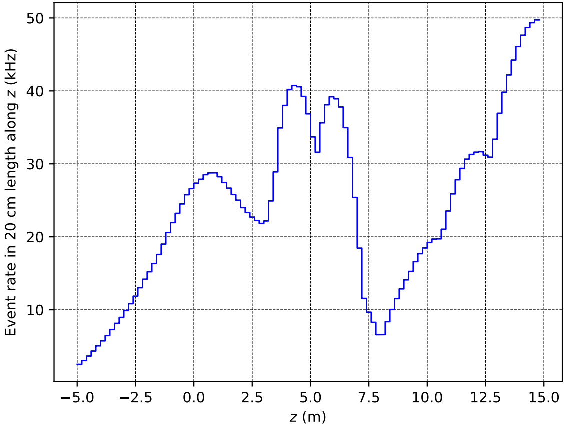
- Total cross section σ_{BR} is on page 7
- I is beam current in electrons per second, given by current in Amps from CDR Tab. 3.3 (2.5 A) divided by elemental charge in C
- N is surface density as number of protons per m^2 from pressure p, Boltzmann constant R_B and normal temperature T (293.15 K):

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

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

Production rate for electron beam-gas due to bremsstrahlung

- Production rate R_{BR} along z is shown for δz = 20 cm
- Procedure from previous page 14 is followed
- Each interval δz contributes bremsstrahlung beam-gas rate shown in the plot
- Total production rate over all z for E_{γ} > 10 keV is 3.177 MHz



Pythia6 production rate

- Pythia6 sample is generated at 10x100 GeV for all $Q^2 > 10^{-9}$ GeV^2, more details are in arxiv:2105.10570
- Production rate R_{py} of Pythia6 events is

$$R_{\mathrm{py}} = \sigma_{\mathrm{py}} \times 10^{-27} \times \mathcal{L}$$

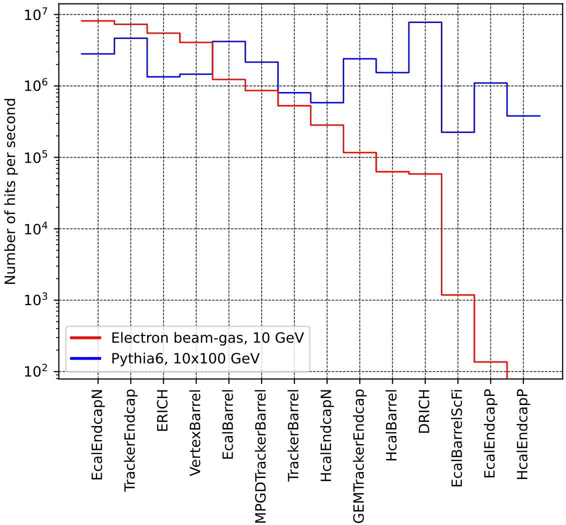
- σ_{py} is total Pythia6 cross section, for 10x100 GeV it is 4.0891×10^{-2} mb
- $\mathcal{L}$ is instantaneous luminosity, according to CDR Table 3.3 for 10x100 GeV it is 4.48×10^{33} cm^{-2}s^{-1}
- 10^{-27} is conversion factor from cm^2 to mb

Results on detector hit rates

- Hit rate R_h as a number of hits per second is calculated as

$$R_h = N_h \times \frac{R_{\mathrm{prod}}}{N_{\mathrm{sim}}}$$

- N_h is number of hits in a given detector
- N_{sim} is number of simulated events used to determine N_h
- R_{prod} is production rate of a given process, R_{BR} or R_{py}
- Production rate for electron beam-gas events R_{BR} is given on page 15
- Production rate for Pythia6 R_{py} is given on page 16



Summary

- Hit rates from electron beam-gas in trackers are comparable to those by Pythia6 ep
- Heavier gases will also be present, not yet considered
- Beam-gas interactions at large distances (> 10 meters) still contribute to observed hits
- The process of beam-gas is continuous, independent of electron-proton bunch crossings
- Timing information will be important to separate the hits from beam-gas background
- Background rejection depends on sensor integration time ($\mathcal{O}(10)$ ns for AC-LGAD)
- Tracks from beam-gas events will point away from expected primary vertex

- The beam-gas events should be embedded into Pythia6 ep events, in proportion of production rates
- Full simulation of such embedded events will give a more definite answer on background rejection