Geant for electron-outgoing area

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BNL

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GETaLM: A generator for electron tagger and luminosity monitor

- Generator for bremsstrahlung photons and electrons scattered at small angles (bremsstrahlung or quasi-real photoproduction)
- Used in studies for luminosity monitor and low-Q^2 tagger
- Published as Comput.Phys.Commun. 272 (2022) 108251
- Configuration is given in a steering card
- Output is in HepMC3 or a ROOT tree (`TClonesArray` of `TParticle`s)
- Works in eA for bremsstrahlung
- Effects of vertex spread and angular divergence are implemented
- Recently was extended for electron beam-gas
- Implemented entirely in Python3

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GETaLM: A generator for electron tagger and luminosity monitor for electron - proton and ion collisions ☆,☆☆

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ABSTRACT

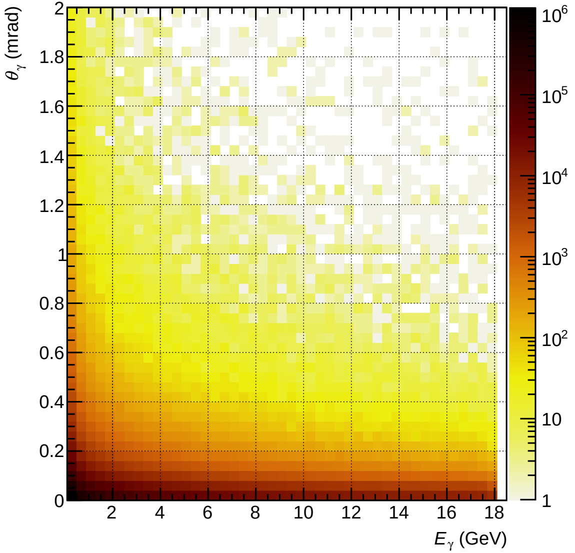
The study of elastic bremsstrahlung and electron tagging in electron-proton or ion collisions is gaining importance with the planned construction of several experimental facilities focused on deep-inelastic scattering (DIS) measurements. This paper describes a program which generates bremsstrahlung photons in electron-proton and electron-ion interactions as well as scattered electrons in bremsstrahlung processes and in a quasi-real photon approximation to the general DIS process. The effects of electron beam divergence and the spread of the interaction vertex are implemented. The program can be used as an input to simulations of instrumentation for bremsstrahlung photon detection, luminosity measurements, electron tagging, and the determination of the cross sections of corresponding processes.

Program summary

Program Title: GETaLM
CPC Library link to program files: https://doi.org/10.17632/pynthy4j43.1
Developer's repository link: https://github.com/adamjaro/GETaLM
Licensing provisions: GNU GPLv3
Programming language: Python
External routines: ROOT
Nature of problem: Photons due to relativistic bremsstrahlung processes are produced in collisions of electrons with protons and with ions. Detection of these bremsstrahlung photons is a promising method for luminosity measurements. The detection of electrons scattered at small angles will impact these measurements. The program generates the bremsstrahlung photons along with final state electrons in the bremsstrahlung process and in an approximation to general electron-proton scattering.
Solution method: Analytic formulas for the cross sections of the specific processes and the relativistic

Bremsstrahlung photons and electrons

- Based on double-differential cross section in photon energy and angle (Lifshitz textbook)
- Approximation neglecting proton or nucleus recoil
- Valid to a good extent according to a more detailed calculation (V. Makarenko)
- Kinematics for scattered electron is given by bremsstrahlung photon and original beam electron



Quasi-real photoproduction

- Electrons produced in photoproduction ep events
- Approximation at low-Q^2 as a function of x and y:

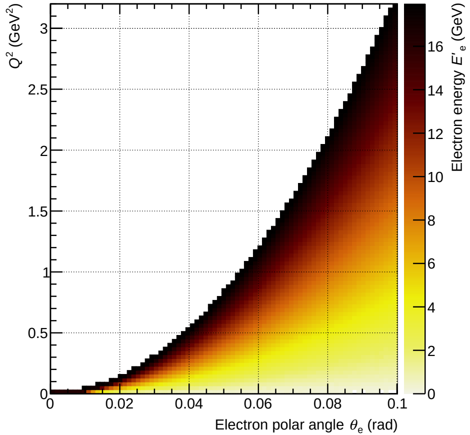
$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}x\mathrm{d}y} = \frac{\alpha}{2\pi}\frac{1+(1-y)^2}{y}\sigma_{\gamma p}(W^2)\frac{1-x}{x}$$

- $\sigma_{\gamma p}$ is empirical photon-proton cross section
- Validation is done against Pythia6 at $10^{-11} < x < 1$, $10^{-4} < y < 0.99$, $Q^2 > 10^{-9}$ GeV^2 and $W > 2$ GeV:

	Total cross section (µb)	
Energy (GeV)	Quasi-real	Pythia 6
18x275	55.1	54.7
10x100	44.8	40.9
5x41	33.4	28.4

- Scattered electron is found by kinematics relations

Figure: Virtuality and energy and angle for scattered electron



Effect of angular divergence

- The divergence is applied as random Gaussian rotations on particles 3-momenta
- Width of the Gaussians in x- and y-directions is given by beam angular divertence
- Polar angles are smeared at very low values
- Electron Q^2 stops to give the true Q^2

Figure: Polar angle for bremsstrahlung photons

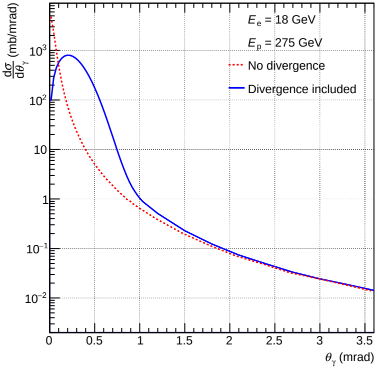
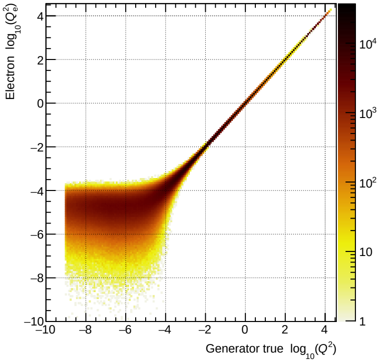


Figure: Electron Q^2 and generator true Q^2



Cross section for scattered electrons

- Direct comparison between bremsstrahlung and photoproduction ($Q^2 > 10^{-9}$ GeV^2)
- Much larger cross section from bremsstrahlung
- Similar range in polar angles

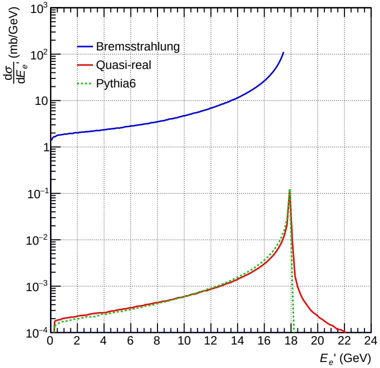


Figure: Electron energy at 18x275 GeV

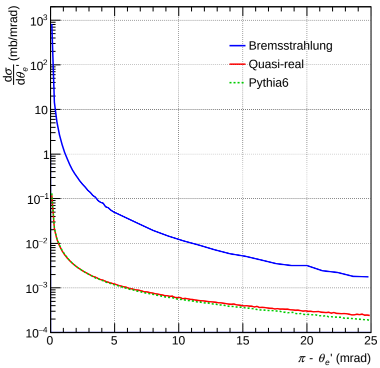
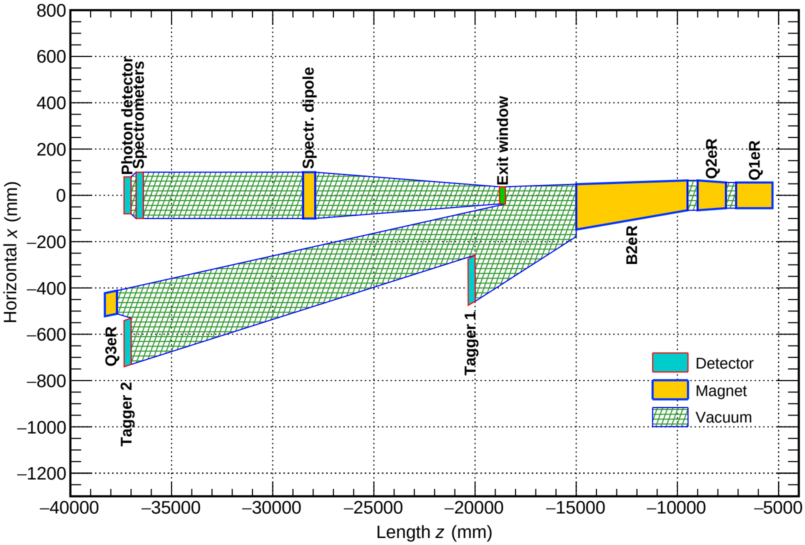
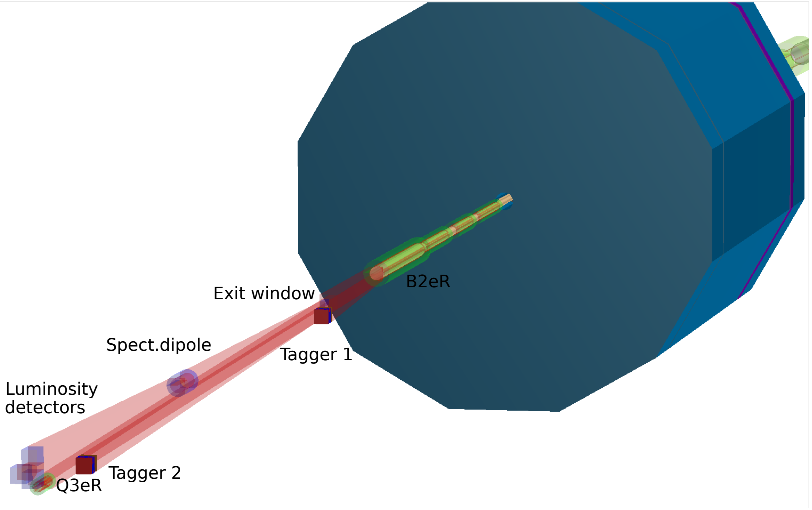


Figure: Electron polar angle at 18x275 GeV

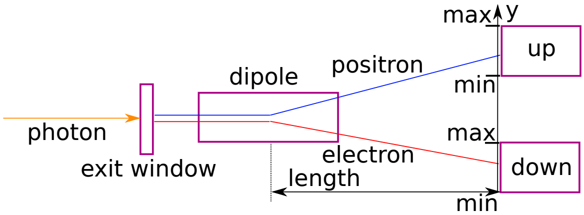
Electron-outgoing layout

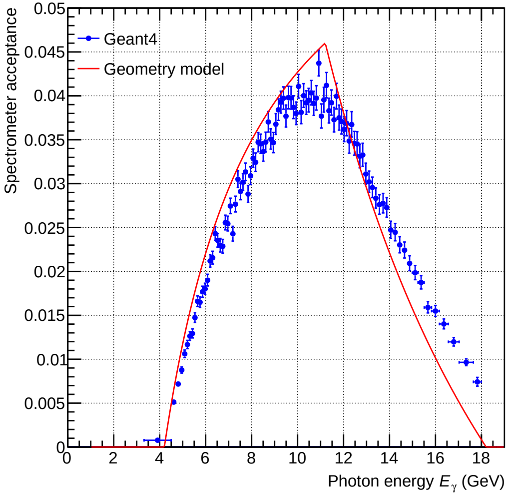


Geant for electron-outgoing area



Acceptance for bremsstrahlung photons for luminosity measurement





- Some of bremsstrahlung photons convert on Al exit window
- Conversion pairs are deflected in dipole magnet
- Up and down detectors are displaced vertically
- Original photon is detected in spectrometer by coincidence in up and down detectors

Tagging acceptance for scattered electrons in energy and polar angle

- Fraction of electrons reaching the tagger out of all generated quasi-real electrons

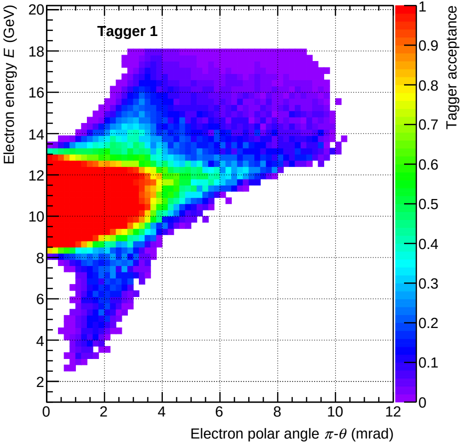


Figure: Tagger 1

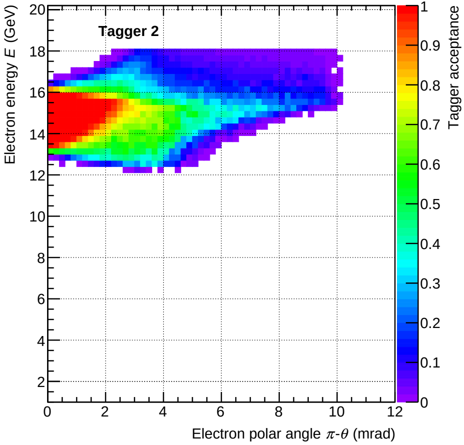


Figure: Tagger 2

Tagging acceptance in polar angle and Q^2

- Fraction of electrons reaching the tagger out of all generated quasi-real electrons

Figure: Tagger 1

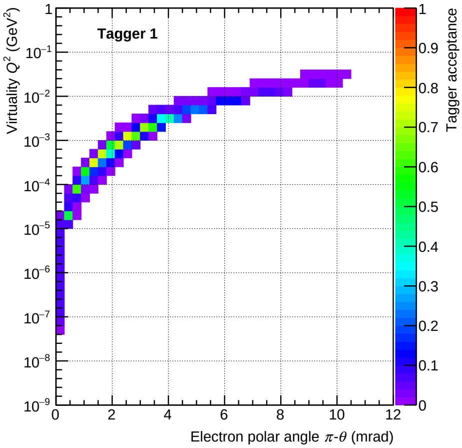
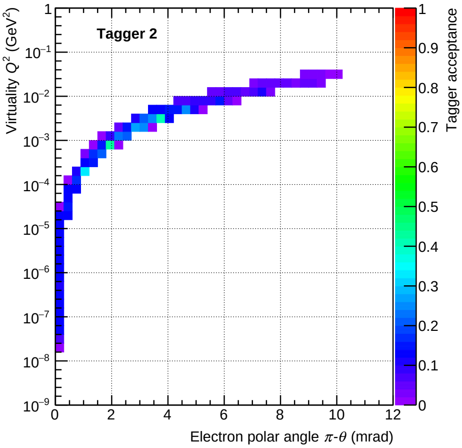


Figure: Tagger 2



Observed event rate per unit area on the front of tagger detectors

- Event rate R_A in $\mathrm{mm}^{-2}\mathrm{s}^{-1}$ observed on surface area A in mm^2 is

$$R_A = \left(1 - e^{-\frac{N_h}{N_i}\lambda}\right) \times \frac{1}{T_b} \times \frac{1}{A}$$

- N_i is number of simulated individual *ep* interactions (bremsstrahlung or quasi-real)
- N_h is number of observed hits on surface area A out of the N_i simulated interactions
- T_b is bunch spacing in seconds
- $\lambda = \sigma \times \mathcal{L}_b$ is mean number of interactions per bunch crossing
- σ is interaction cross section in mb (bremsstrahlung or quasi-real) used for N_i simulated events
- $\mathcal{L}_b = 10^{-27} \times L_i \times T_b$ is luminosity per bunch crossing in mb^{-1}
- L_i is instantaneous luminosity in $\mathrm{cm}^{-2}s^{-1}$ from CDR Table 3.3
- The bunch spacing $T_b = \frac{l}{\beta \times c \times n_b}$ where l = 3834 m is collider circumference, βc is speed of the beam in ms^{-1} and n_b is number of bunches from CDR Table 3.3

Event rates on tagger 1, 18x275 GeV

Figure: Bremsstrahlung, tagger 1

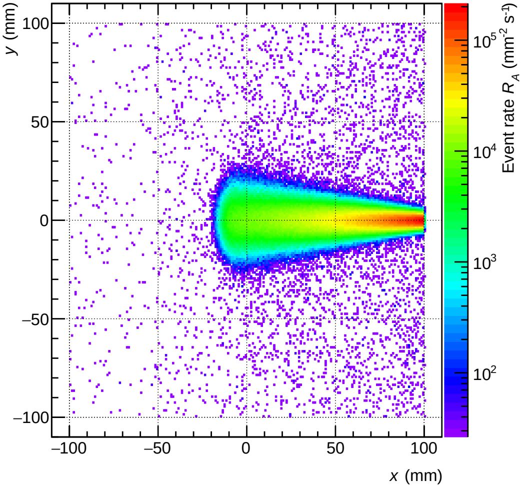
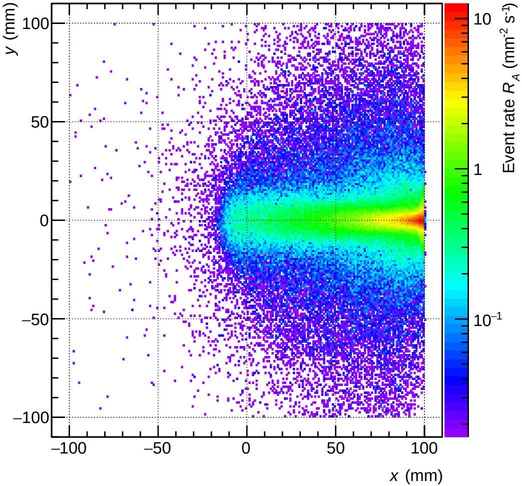


Figure: Quasi-real photoproduction, tagger 1



Event rates on tagger 2, 18x275 GeV

Figure: Bremsstrahlung, tagger 2

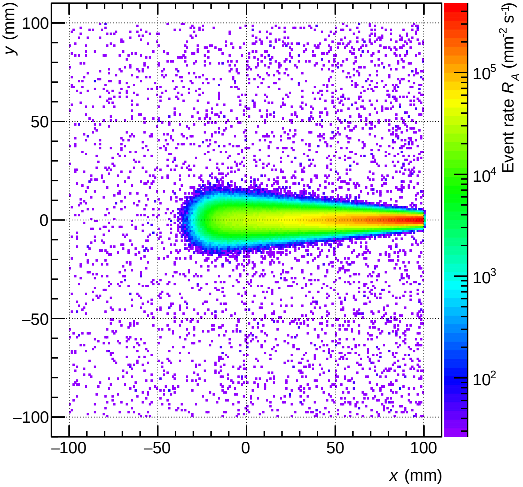
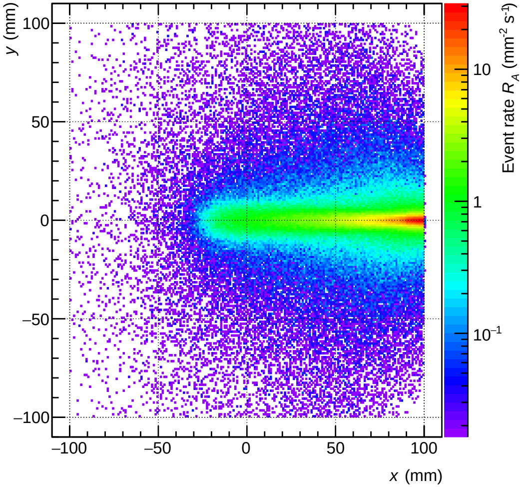


Figure: Quasi-real photoproduction, tagger 2



Summary

- Proposal studies were done with GETaLM generator and Geant4/DD4hep implementations
- Possibility to detect protons from bremsstrahlung in Roman Pots was investigated with tree-level calculation by V. Makarenko (created for HERA)
- Very large event rates on taggers are found for bremsstrahlung, first time there results are shown
- The rates will largely limit feasibility to tag photoproduction electrons
- Investigating possibilities for beam pipe geometry in electron-outgoing area
- Options include calorimeter + tracker or Roman Pot-like detector for electrons