Luminosity measurement at the EIC

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High Luminosity-EIC, CFNS

Principle of luminosity measurement

- The measurement is based on event counts corresponding to the process of elastic bremsstrahlung
- Photon and scattered electron is produced in the final state, $ep \to e\gamma p$, $e\mathrm{Au} \to e\gamma\mathrm{Au}$
- Large cross section, peaked for photons at small angles

> The cross section is precisely known from QED

Figure: Cross section vs. photon energy

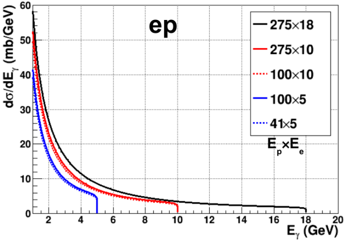
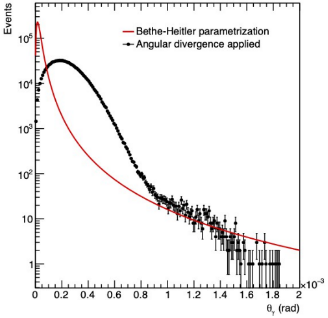
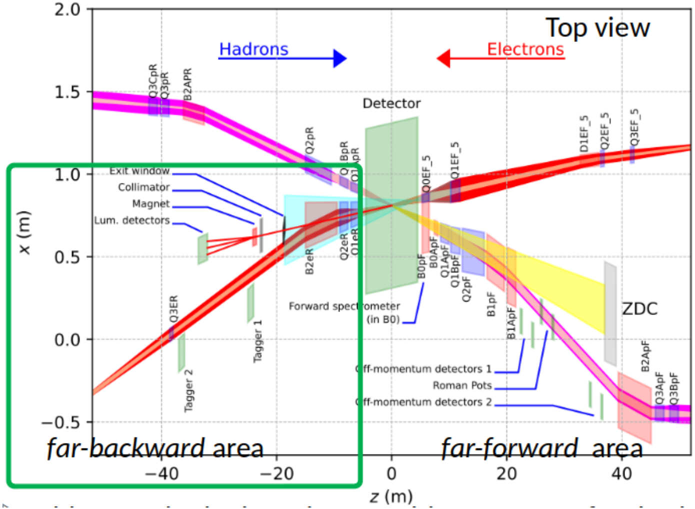


Figure: Angular distribution



Implementation in the interaction region

- Luminosity system is a part of far-backward instrumentation (electron direction is towards negative z)



Methods for photon detection

- Two methods for γ detection: direct detector and $e^{\pm}$ spectrometer
- Direct photon detector provides approximate measurement, mainly for collider performance

Figure: Detector layout

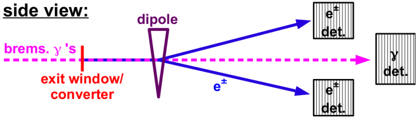
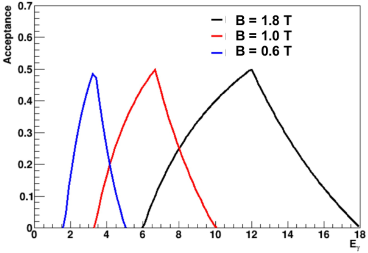


Figure: Spectrometer acceptance



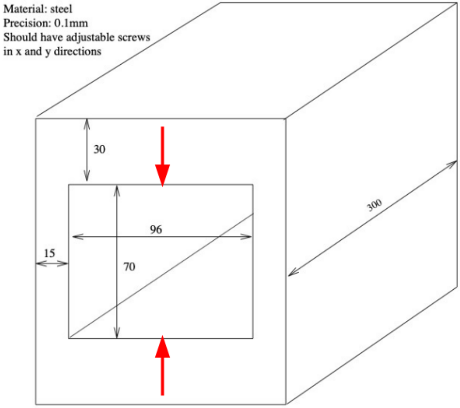
- Spectrometer detects e^+e^- pairs from converter layer
- Acceptance is given by dimensions and dipole field
- The spectrometer is not sensitive to synchrotron radiation

Spectrometer provides precise measurement for physics results

Photon aperture by a collimator

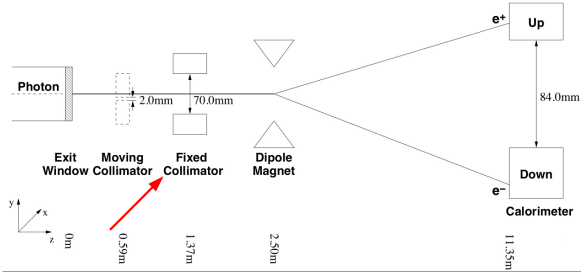
- The collimator limits maximal angles of the photons, experience from ZEUS at HERA
- System of collimators was placed before the spectrometer magnet

Figure: ZEUS collimator

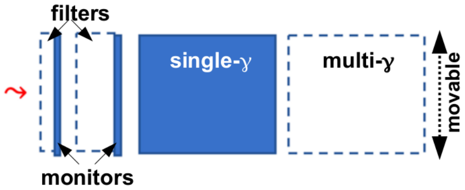


> Photon aperture is well defined by collimator dimensions

Figure: Placement of ZEUS collimator



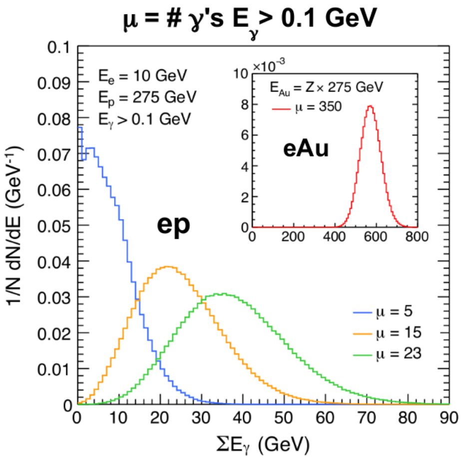
Direct photon detector



- Direct counts of bremsstrahlung photons
- Simple concept, approximate measurement
- More γ are incident in every bunch crossing because of large cross section (and luminosity)
- Results in a peculiar spectrum of expected measured energies

Important for online machine performance

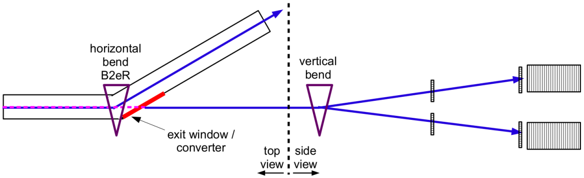
Figure: Energy spectrum in direct photon detector



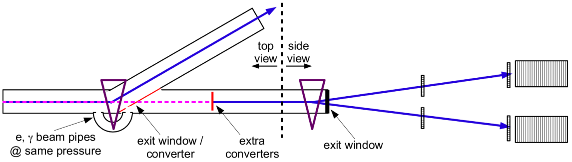
Vacuum system for pair spectrometer

- Conversion layer is part of beam layout
- Need for precise knowledge of conversion probability
- Heat load from synchrotron radiation is incident on the layer
- Several considerations for the design:

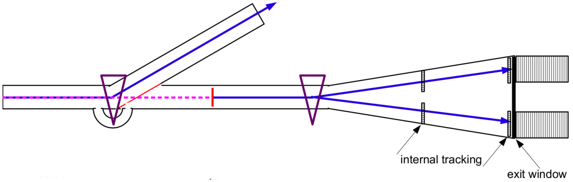
I: baseline design, converter holds the vacuum



II: thin converter in vacuum

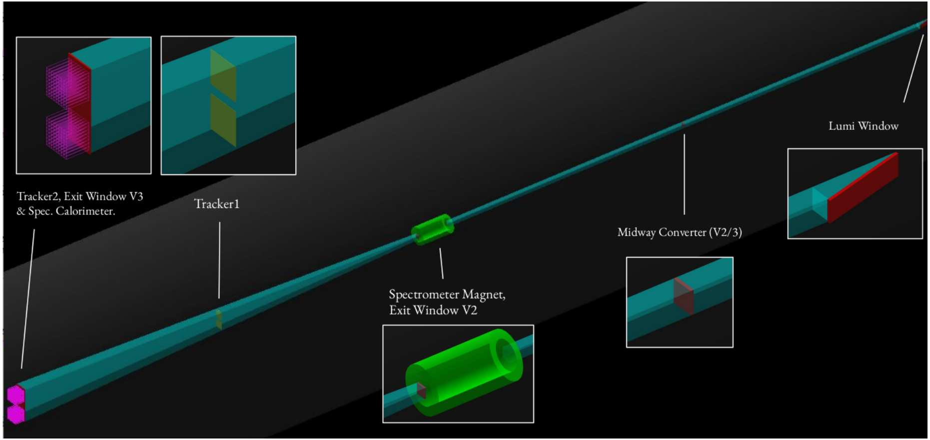


III: vacuum up to detectors



Overall layout in Geant4

- Several layout concepts are implemented in Geant4
- Studies are ongoing in terms of photon aperture, acceptance and event rates

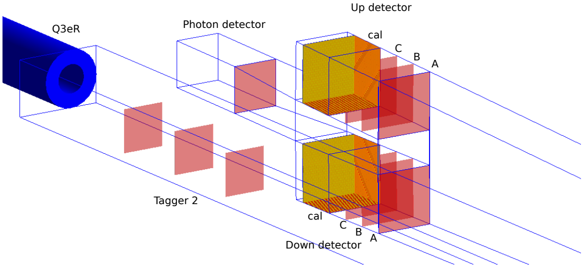


Credit to Aranya Giri

Spectrometer section in Geant4

- Detailed view at detector part for e^+e^- conversion pairs
- Tracking layers (A, B, C) are followed by calorimeters, both in up and down detectors
- Direct photon detector is placed behind the spectrometer detectors
- Outgoing electron beam passes through the Q3eR magnet besides the detectors

Figure: Detector section in Geant4



Photon reconstruction in the spectrometer

- Prototype machine learning algorithm for bremsstrahlung photon reconstruction
- Only tracking information from up and down detectors is input to the algorithm
- Additional calorimeter data will improve the resolution and/or provide systematics

Figure: Energy

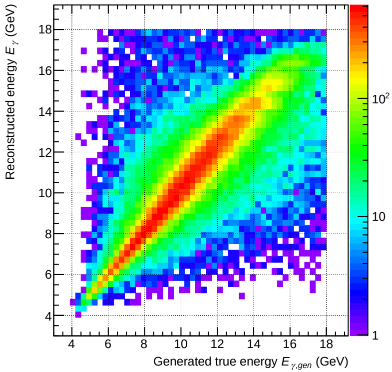


Figure: Polar angle

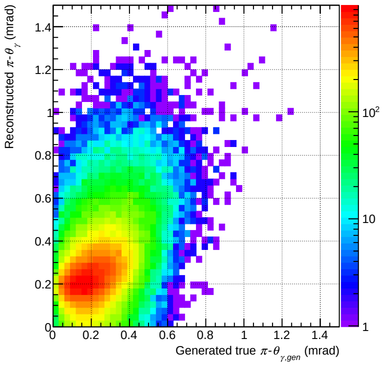
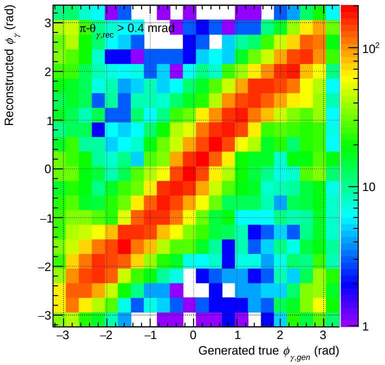


Figure: Azimuthal angle



Detection of scattered electrons

- Electrons scattered at very small angles (Tagger 1 and 2) are part of far-backward area
- Primary aim is for photoproduction processes at $Q^2 < 0.1$ GeV^2
- A dedicated calibration run will allow to detect both bremsstrahlung photon and scattered electron

Figure: Interaction region

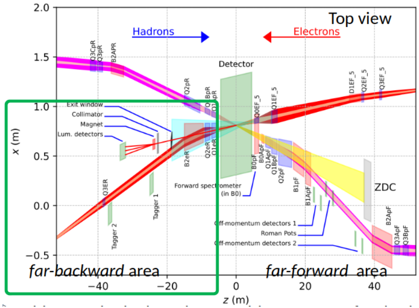
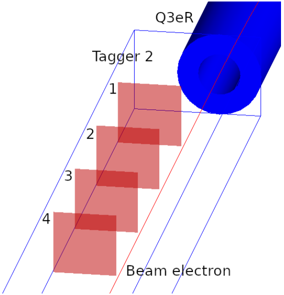


Figure: Tracking planes for Tagger 2, in front of Q3eR magnet



Method for data-driven estimate for spectrometer acceptance and conversion probability

Detector technologies for luminosity measurement

- Data are present at every bunch crossing (rates in $\mathcal{O}(100)$ MHz)
- Radiation hard components are needed because of large event rates
- Calorimeters by W-spaghetti quartz fibers or PWO calorimeters, fast PMTs or SiPM readout
- Trackers could use AC-LGAD or MAPS technology
- Relatively small channel count because of small size ($\mathcal{O}(10)$ cm) for individual components

- Good time resolution and integration time is needed to associate the data with the respective bunch crossing
- DAQ has to cope with large data rates and volumes, also should provide online machine performance

Summary

- Known QED cross section for elastic bremsstrahlung is used to determine the luminosity
- Similar concept was used by ZEUS experiment at HERA
- At EIC we have to cope with large event rates, never experienced before
- Heat load from synchrotron radiation gives constraints to conversion layer for e^+e^- pair spectrometer
- Active group in the project detector is involved in the design, seeking for help in the adventure