UNIVERSITY of HOUSTON

COLLEGE of NATURAL SCIENCES & MATHEMATICS

Luminosity Detector Studies for the EIC

(EIC Early Career Workshop - 2022)

- Introduction
- Possible Designs
- Geant4 Implementation of the design
- Initial Simulation Results

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07-24-2022

Introduction

- Performance of particle collider : Beam Energy & Luminosity
- Luminosity is the maximum no. of collisions that can be produced in the collider per cm^2 per sec.

$$L = f\, N^2 / 4\, \pi\sigma^2$$

N ~ # particles in the bunch, f ~ bunch crossing frequency & σ ~ transverse size of bunch

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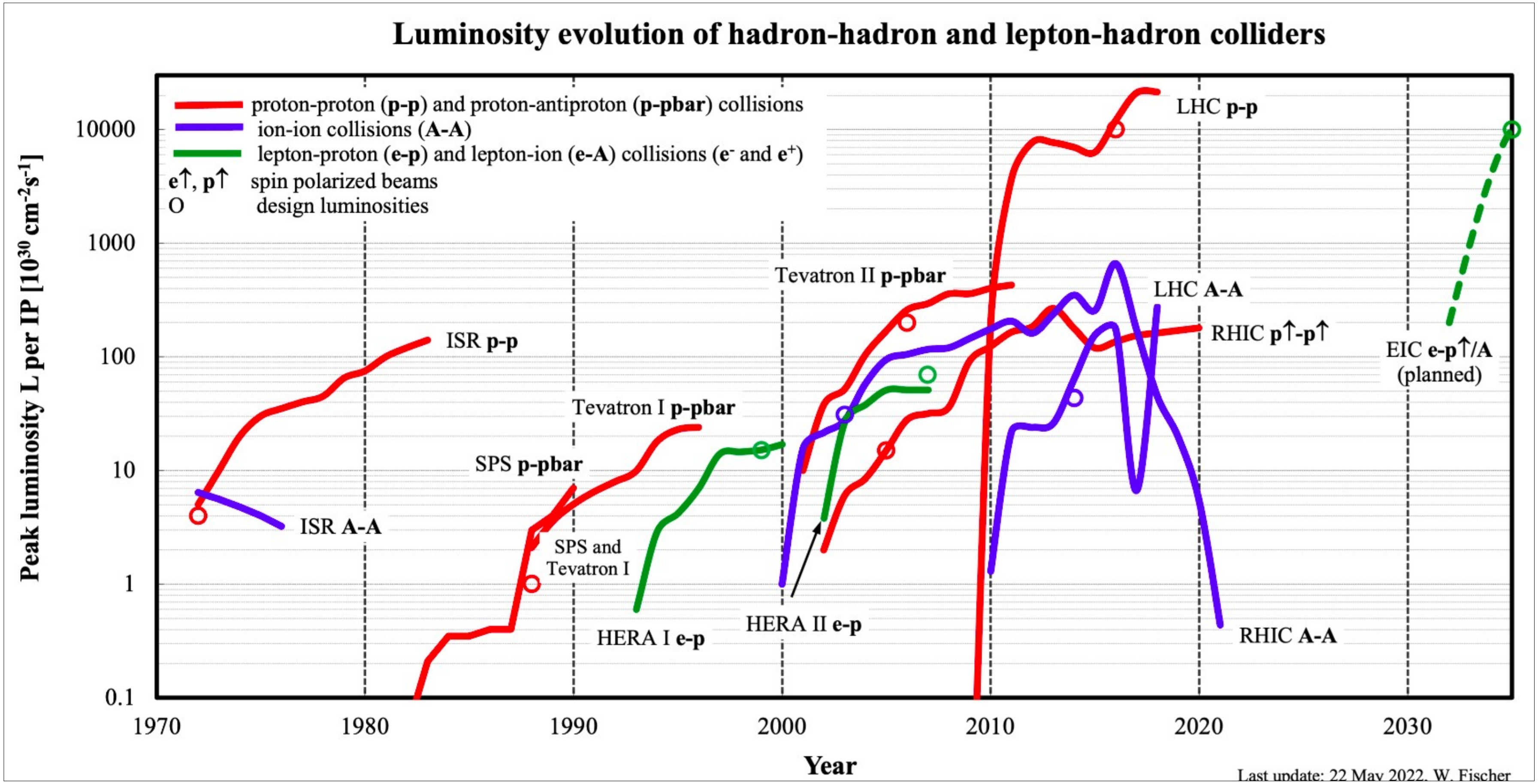
- Rate of any event during collision ∝ cross-section (σ_p) of the associated process.

$$R = L \sigma_p$$

- Precise measurement of L = Precise measurement of σ_p
- At EIC, precision ~ 1% & High Luminosity ~ $10^{33\text{-}34}$ cm^{-2} s^{-1}

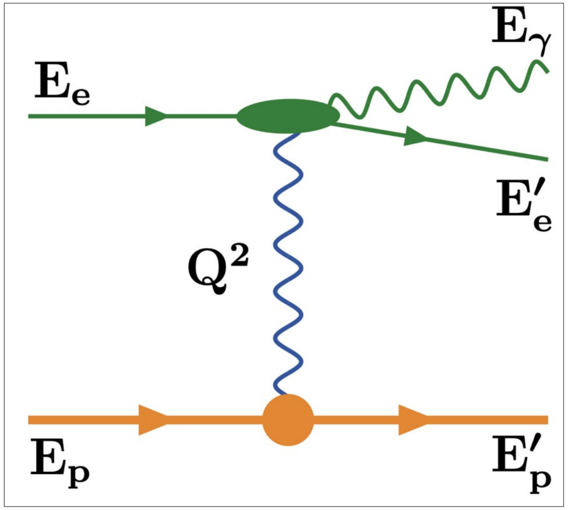
Introduction



https://www.rhichome.bnl.gov/RHIC/Runs/

Bremsstrahlung Radiation

- HERA (predecessor of EIC) measured luminosity via bremsstrahlung (BL) radiation.
- Radiation due to elastic scattering of electron near strong electric field (p / Nu).



https://arxiv.org/abs/1009.2451 https://arxiv.org/abs/2106.08993

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1. Precisely calculable cross-section from QED

$$\frac{d\sigma}{dE_\gamma} = 4\alpha r_e^2 \frac{E'_e}{E_\gamma E_e}\left(\frac{E_e}{E'_e} + \frac{E'_e}{E_e} - \frac{2}{3}\right)\left(\ln\frac{4E_pE_eE'_e}{m_pm_eE_\gamma} - \frac{1}{2}\right)$$

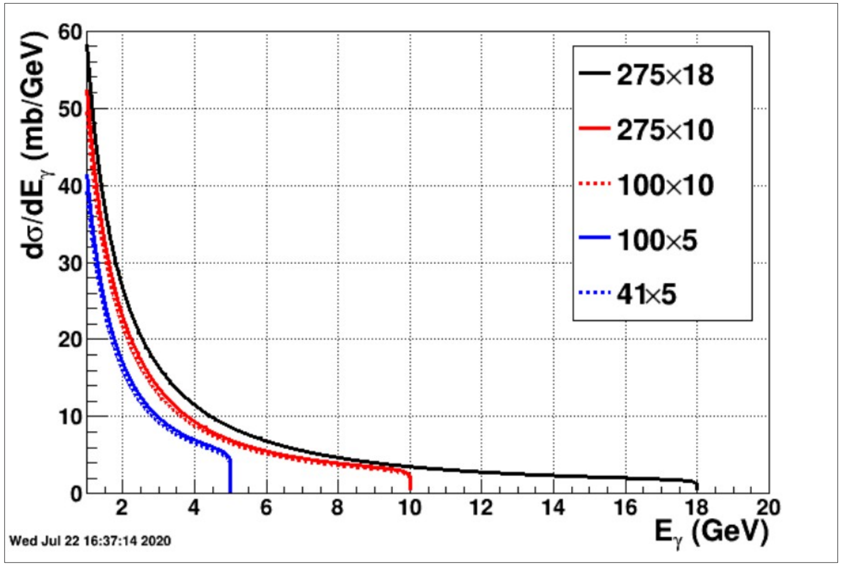

Fig.: Simulated BL photon energy distributions for EIC beam energies (Yellow Report).

1) Diverge as $E_{\text{¥}} \rightarrow 0$.
2) Sharp cut-off at e^- beam energies.

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$$\frac{d\sigma}{d\Theta_\gamma} \sim \frac{\Theta_\gamma}{\left((m_e/E_e)^2 + \Theta_\gamma^2\right)^2}.$$

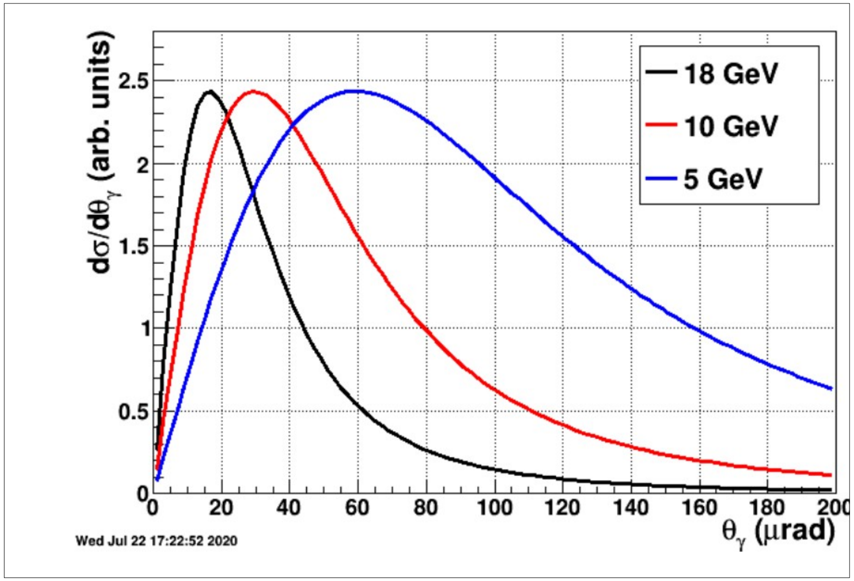

Fig.: Simulated BL photon angular (right) distributions for EIC beam energies (Yellow Report).

1) Strongly peaked at e^- beam direction, $\theta_¥ \sim m_e / E_e$
2) Transverse spread decreases with e^- energy.

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Bremsstrahlung Radiation

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2. High Rate

E_γ (GeV)	σ_{BH} (mb)	Rate (kHz)
0.1 - 0.9	277.0	4155
9.0 - 17.0	25.0	375
17.0 - 26.6	15.6	234
0.1 - 26.6	317.7	4765.5

Source : ZEUS-HERA luminosity monitor measurements

To measure LUMINOSITY !

$$\mathcal{L} = R^{ep} / \sigma_{BH}^{obs}$$

http://www-library.desy.de/preparch/desy/1992/desy92-066.kek.pdf

Luminosity Dectetor at EIC

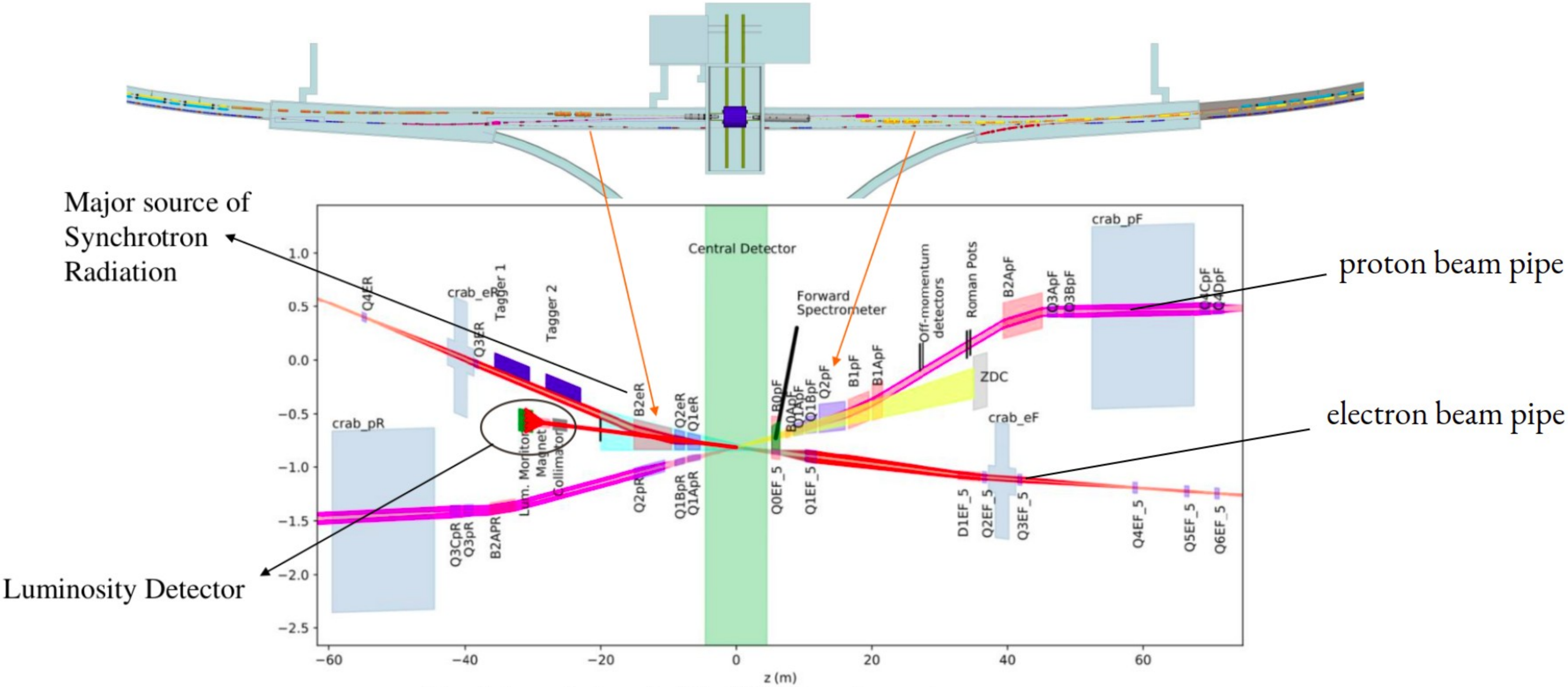


Fig.: Schematic layout of the EIC interaction region

Preview of Lumi. Dec. @ HERA

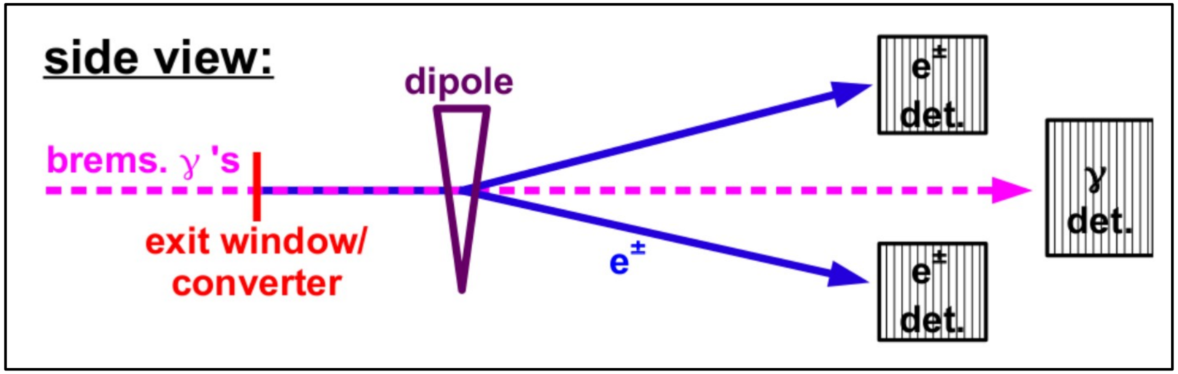


Fig.: Schematic diagram of HERA (ZEUS Exp) luminosity monitor

Two Independent & Complementary Method

Direct PHOT :

- Sensitive to direct synchrotron radiation
- Pileup, high rate of γ per bunch crossing, 10/23 for 18/10 GeV (350 for Nu)
- Simple Implementation

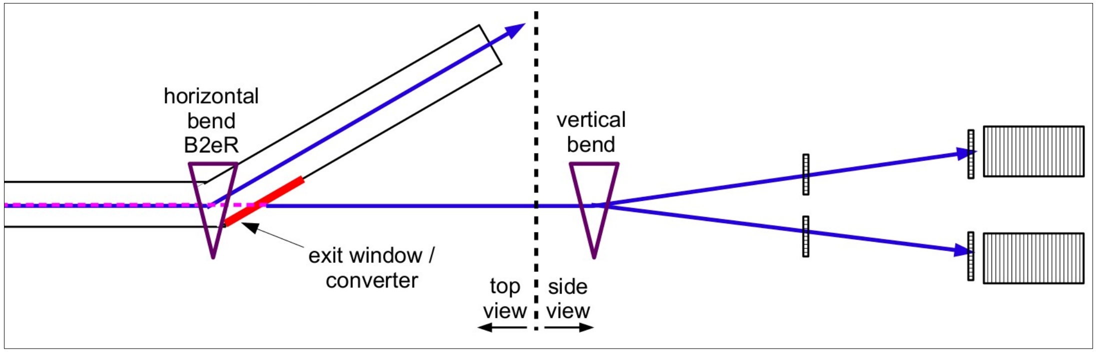
UP & DOWN :

- Outside the direct synchrotron radiation fan; Natural low E_γ cutoff ($\gamma \rightarrow e^- e^+$)
- Deals with pileup, Adjusting the Converter, Dipole |B| & Geometry.
- Complex Implementation

Possible designs for EIC

- Same as ZEUS-HERA but,
- Two trackers added on $e^{\pm}$ path :-
  - Improve acceptance correction
  - Better resolution for pile-up monitoring

Version 1 (Baseline)

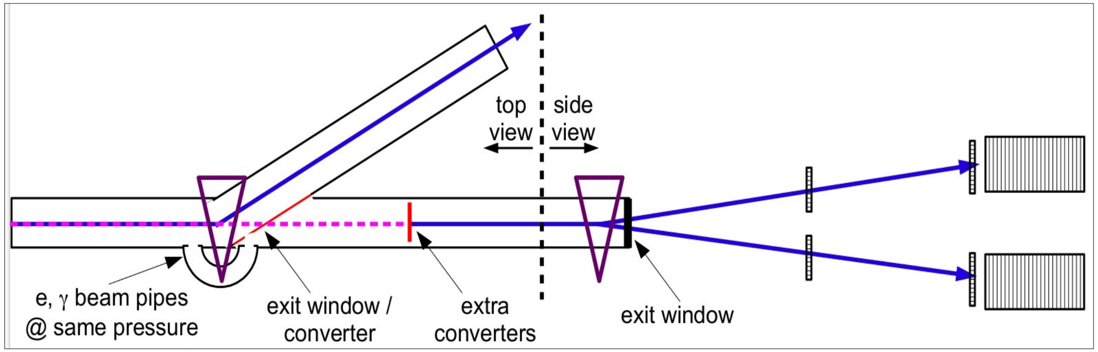


- ✗ Thick Aluminium exit window (EW) , no control over conversion rate
- ✓ ɣ, $e^{\pm}$ multple scattering after EW, large error on angular position

Designs by W. Schmidke @ Far Backward Meeting on 4-28-2022

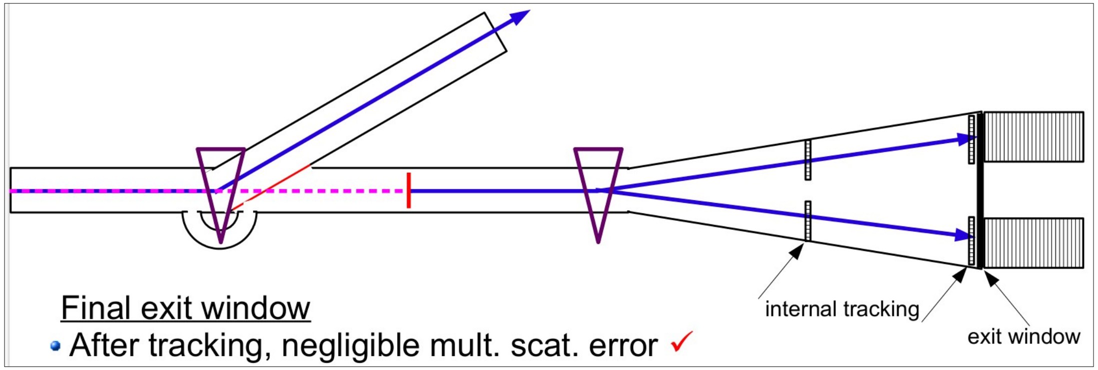
Possible designs for EIC

Version 2



- ✓ Extra movable converters, control over conversion rate for ep & eA collision
- ✗ Thick EW after dipole, leads to scattering ɣ, $e^{\pm}$, error on angular position

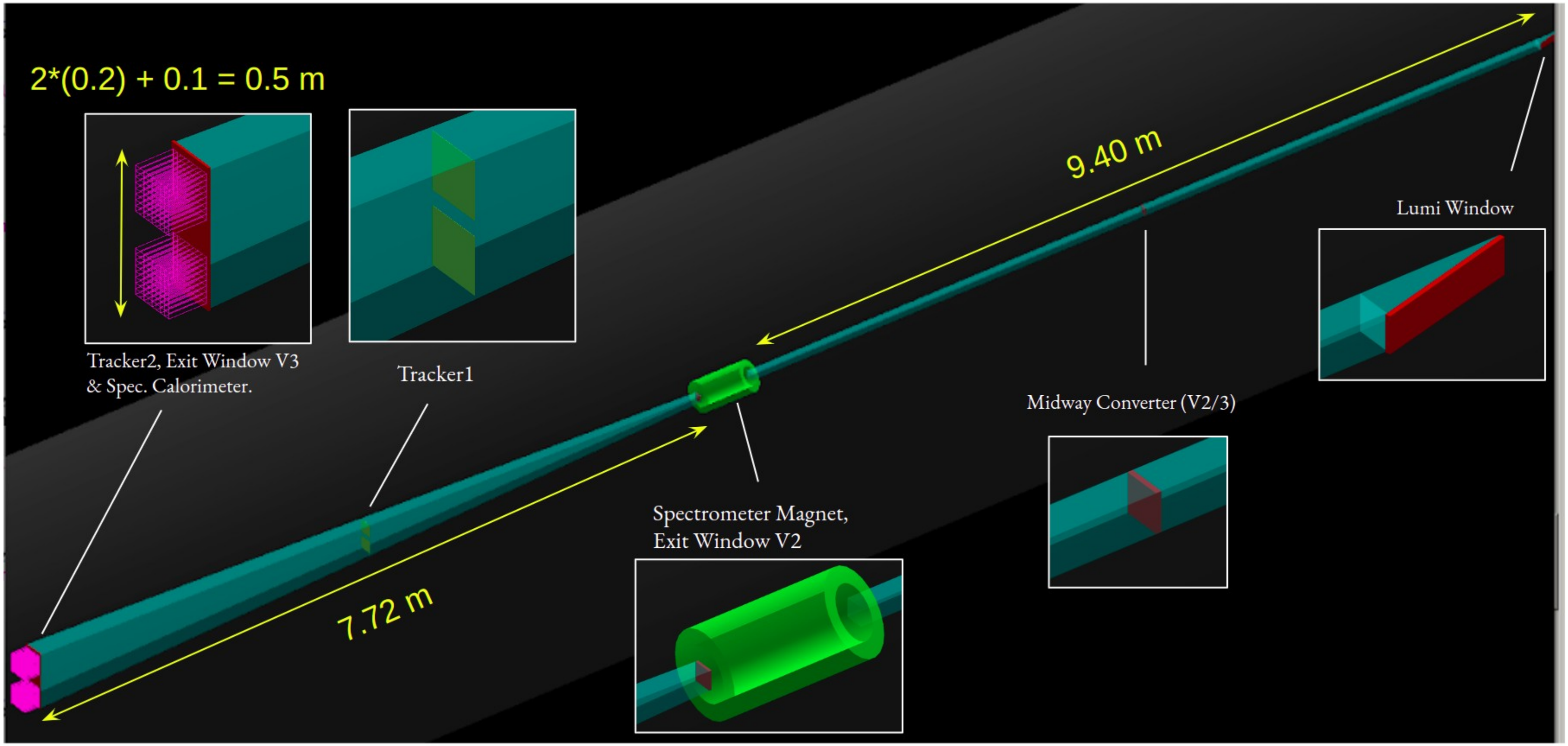
Version 3



- ✓ Thick EW between Tracker2 and Calorimeter.
- ✓ No ɣ, $e^{\pm}$ multple scattering

Designs by W. Schmidke @ Far Backward Meeting on 4-28-2022

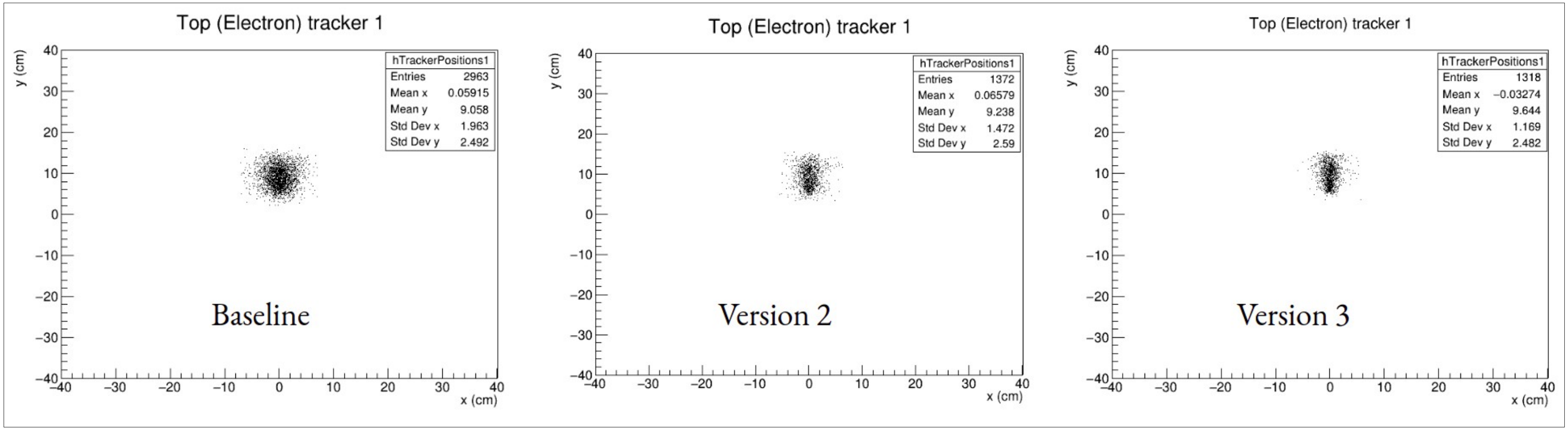
Geant4 implementation of design



- Design is implemented in fun4all software framework
- A/Version detector materials are changed

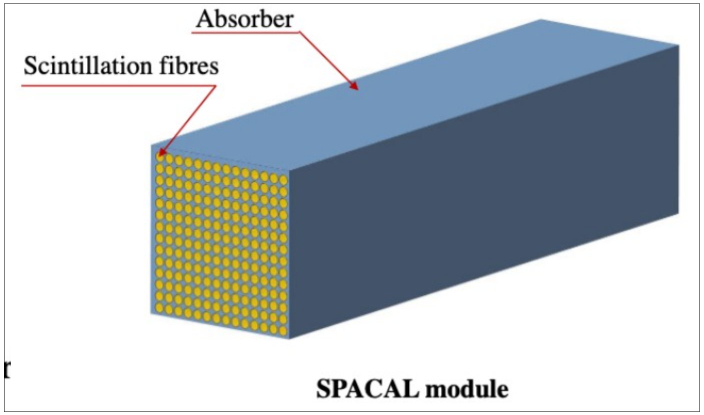
Size and calorimeter design by Jaraslav Adam's Code

Initial simulation test



- 5000 events generated
- 5 GeV photon beam without transverse smearing.
- Hit_points considered only when electron crosses top two trackers and its pair produced positron crosses bottom two trackers.
- ✓ Clear decrease in spread (along x) of hit points across the version

Initial simulation test



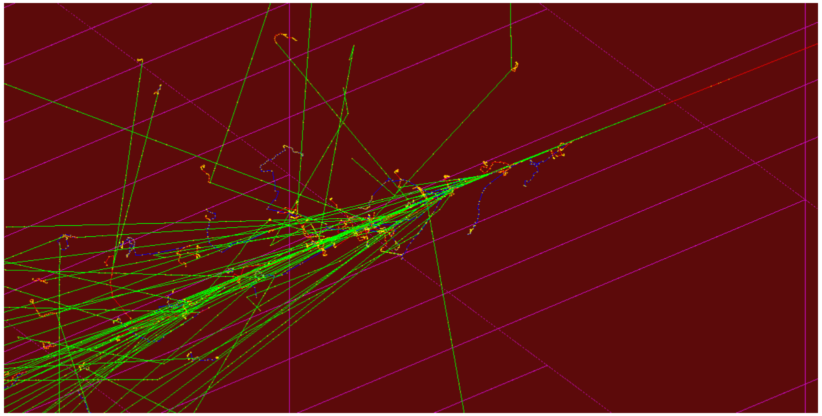
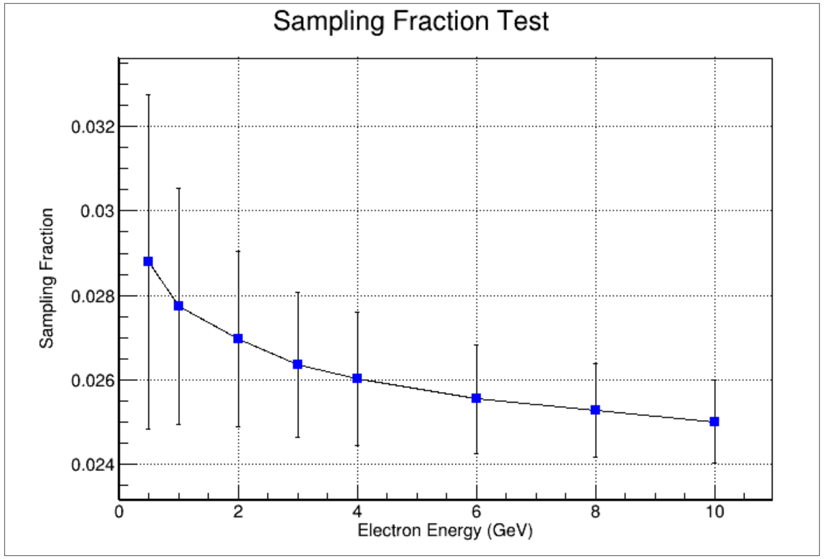


Fig:simulated EM shower in the calorimeter



- UP/DOWN will be Sphagetti Calorimeter
- $f_{sampling}$ = E(active) / E (active) + E (absorber)
- Impact on the energy resolution
- Rate of decrese $f_{sampling}$ decreses with energy

Summary – Next Steps

- Implementation of a Luminosity detector is now available to all in the Fun4All software framework.
  - Repo dir: eic/fun4all_eicdetectors/simulation/g4simulation/g4lumi
  - Spectrometer arm with silicon trackers enabled so far.
  - 3 configurations included: baseline detector + 2 extended vacuum designs.
- Initial simulation results to be shown today:
  - XY distributions of electron/positron hits in trackers
  - Sampling fraction for the calorimeter
- Calculating the photon energy from the pair spectrometer calorimeter.
- Compare E_gen to E_rec for each vacuum configuration to assess the advantages of designs 2 and 3 over the baseline.
- Include beam size effects → 1.