Summary of Compton Polarimetry Studies at Manitoba

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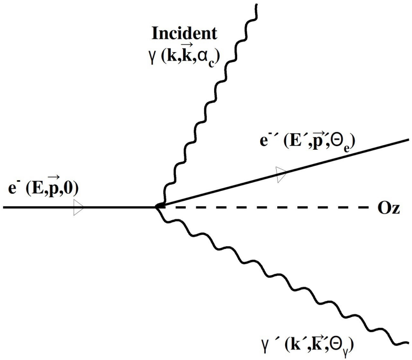
Compton Scattering

Compton scattering is the interaction between two particles which collide and exchange energies, in our case, these particles are electrons and photons, and both are not at rest. This process depends on various things such as electron and photon beam intensities, and angle of collision; this process can be demonstrated as such:



https://wiki.bnl.gov/conferences/index.php/File:EIC_Compton_LOI_Jan-2020.pdf

Incident beams:

Electron (e):

E = initial energy
$\vec{p}$ = initial momentum

Photon (γ):

k = initial energy
$\vec{k}$ = initial momentum

Scattered beams:

Electron (e'):

E' = scattered energy
$\vec{p}$' = scattered momentum

Photon (γ'):

k' = scattered energy
$\vec{k}$' = scattered momentum

Considering Certain Quantities:

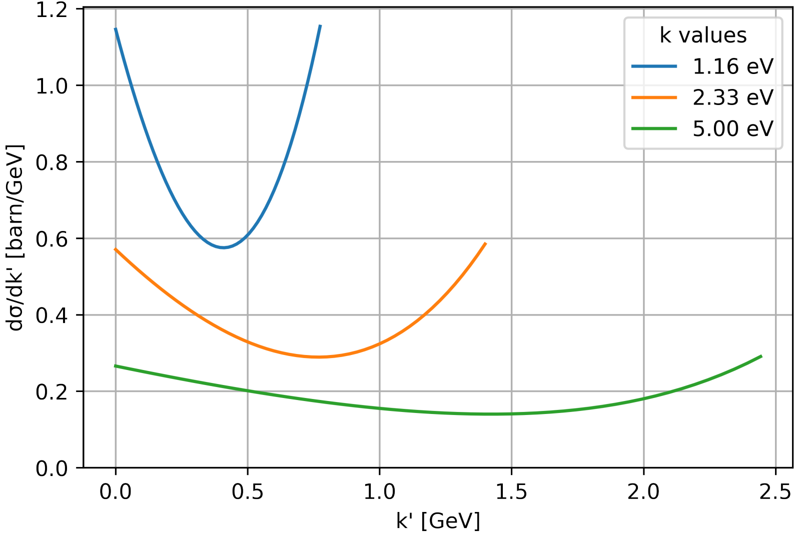
The incident laser photon energy values (k) are 1.16 eV, 2.33 eV, and 5 eV, or wavelengths (λ) of 248 nm, 532 nm, and 1064 nm respectively.
SuperKEKB's electron energy is E $=$ 7GeV

1. Differential Cross-Section (vs Energy and vs Distance From Original Beam)

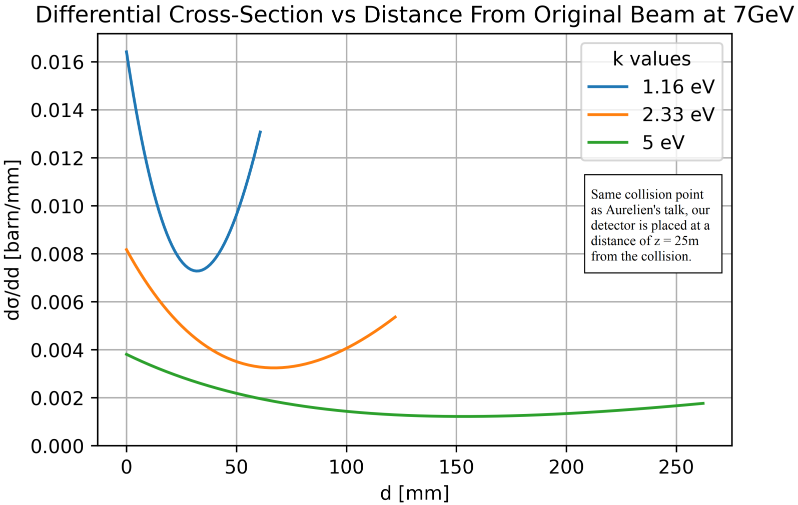
2. Transverse Asymmetry

3. Longitudinal Asymmetry

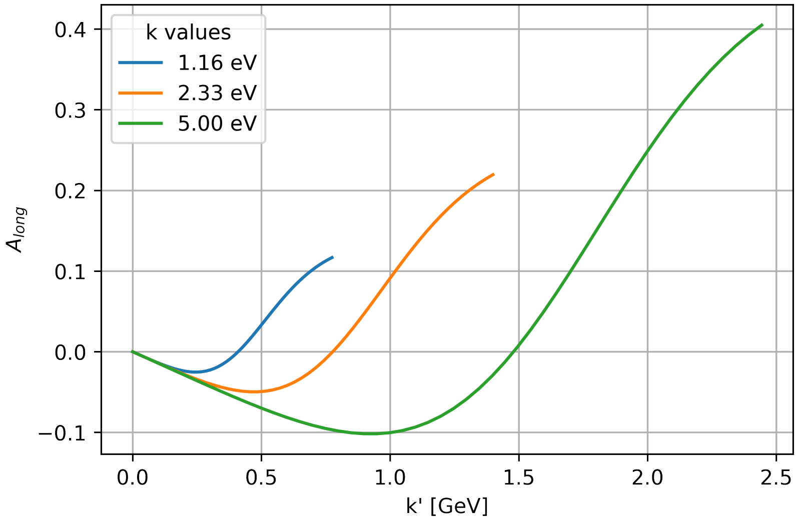
Differential Cross-Section vs Energy



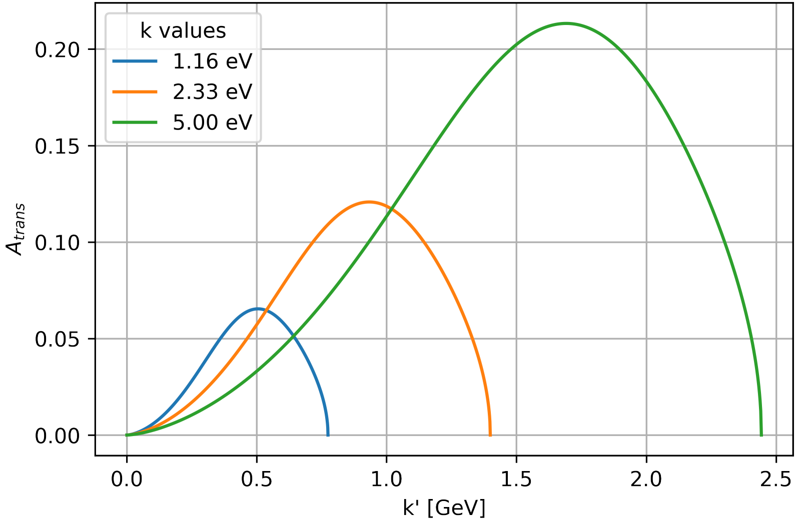
Differential Cross-Section vs Distance From Original Beam



Longitudinal Asymmetry vs Backscattered Photon Energy



Transverse Asymmetry vs Backscattered Photon Energy



CW vs Pulsed Lasers

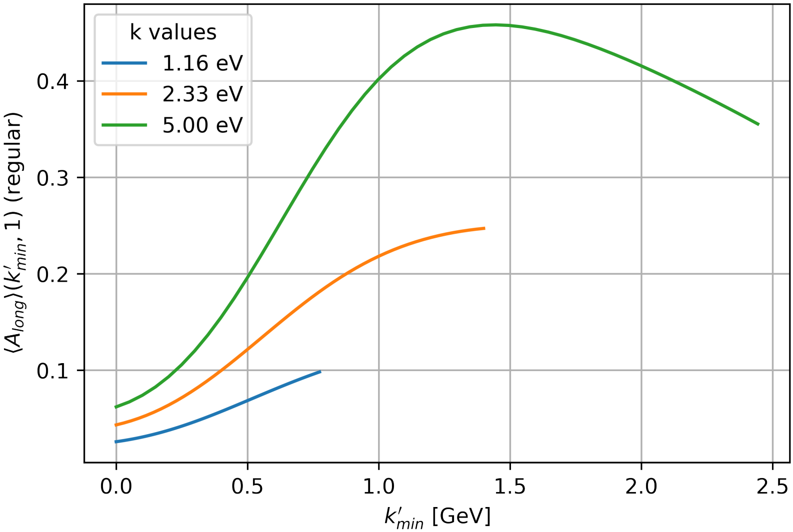
There are two possible laser operations we can employ:

- Continuous Wave (CW)
- Pulsed

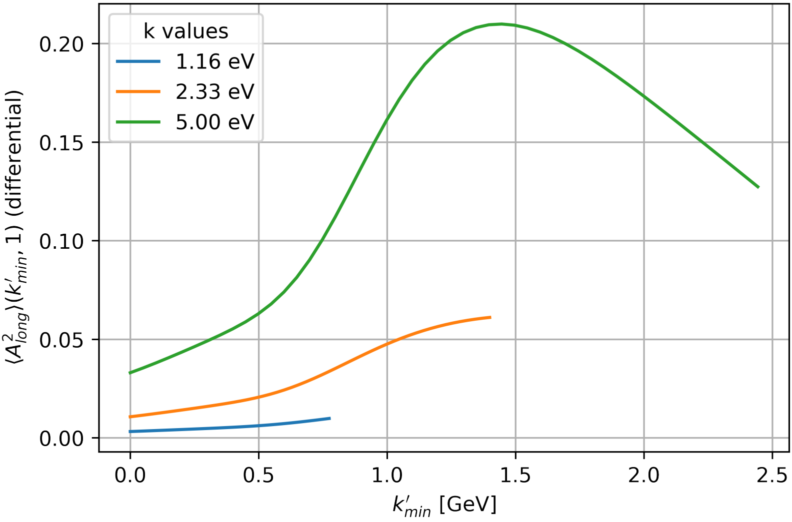
Pulsed lasers are synchronised to the electron beam leading to significantly higher luminosity (1-2 orders of magnitude higher). They are able to maintain this higher luminosity because the laser is only sent out in short bursts, as opposed to continuously sending out a laser beam. This allows for a higher luminosity without increasing the power. There are various averaging methods that we consider:

1. Regular ($< A >$)
2. Differential ($< A^2 >$)
3. Integrated ($< A >^2$)
4. Energy-Weighted Integrated ($\frac{<EA>^2}{<E^2>}$)

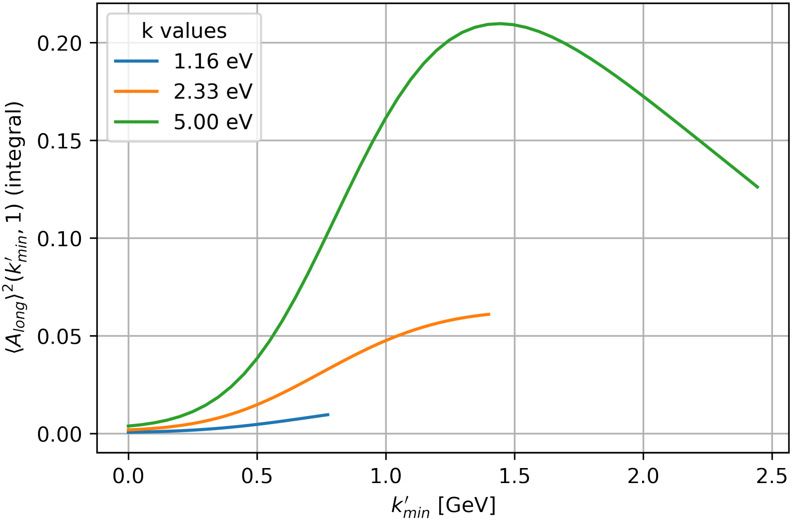
Regular Average ($< A >$)



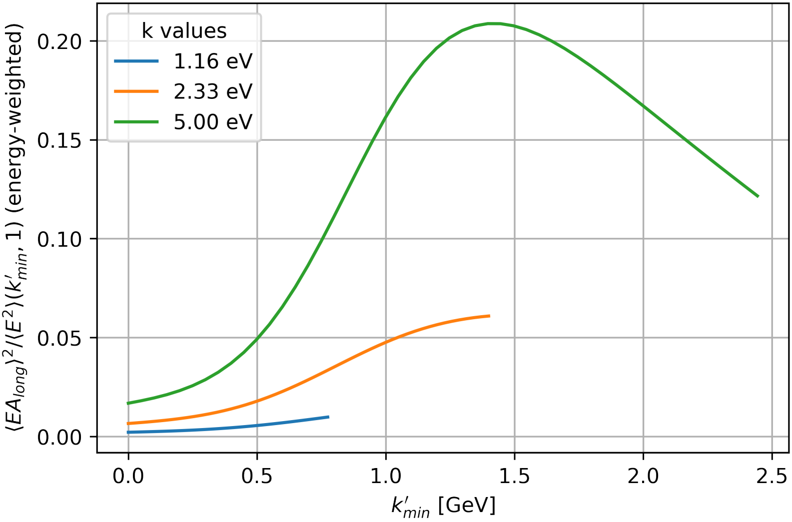
Differential Average ($< A^2 >$)



Integrated Average ($< A >^2$)



Energy-Weighted Integrated Average ($\frac{<EA>^2}{<E^2>}$)



Comparison of Averaging Methods at k = 2.33 eV

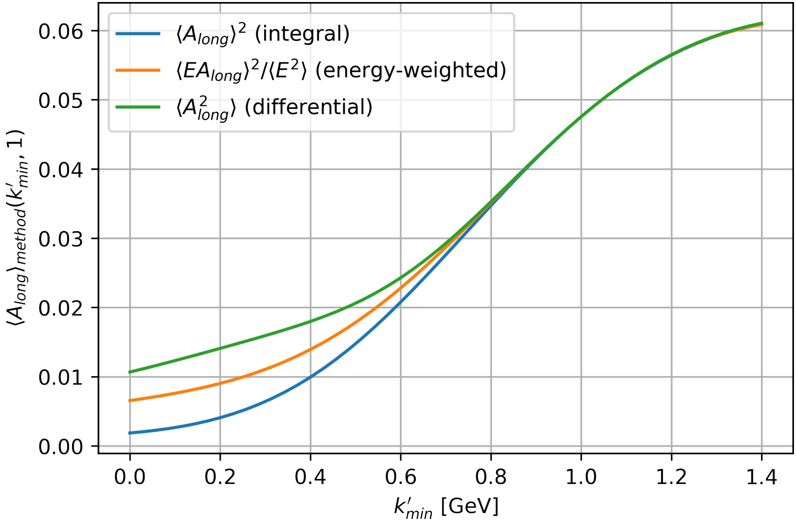


Table of Averaging Methods & Times to 1% Precision

k [eV]	$< A^2 >$	time [s]	$< A >^2$	time [s]	$\frac{<EA>^2}{<E^2>}$	time [s]
1.16	0.0032	37	0.0007	174	0.0021	55
2.33	0.0107	12	0.0019	69	0.0065	20
5.00	0.0330	5	0.0038	40	0.0168	9

It is clear from the table that the time to 1% statistical precision is approximately inversely proportional to the photon beam energy (k).

Luminosity Comparison of Pulsed vs CW Beams (1/4)

Our main comparison is between pulsed and continuous wave beams, within this however, we attempt two methods for pulsed beams, the original method found in the EIC proposal and an alternative method (alt pulsed). We will first show the formulas for CW and pulsed beams, then compare them. We start with CW:

$$\mathcal{L} = \frac{1+\cos\alpha}{\sin\alpha}\frac{I}{e}\frac{P_L\lambda}{hc^2}\frac{1}{\sqrt{2\pi}\sqrt{\sigma_{e,y}^2+\sigma_{\gamma,y}^2}}.$$

I = beam current [A] = 0.00078	c = speed of light [m/s]
λ = wavelength [m] = 515×10^{-9}	h = planck's constant [J s]
P_L = photon power [W] = 1000	α = angle of collisions [rad]

https://wiki.bnl.gov/conferences/images/1/1b/EIC_Compton_LOI_Jan-2020.pdf

Original vs Alternative Pulsed (2/4)

$$\mathcal{L} = \frac{1+\cos\alpha}{\sin\alpha}\frac{I}{e}\frac{c}{f}\frac{P_L\lambda}{hc^2}\frac{1}{\sqrt{2\pi}\sqrt{\sigma_{e,y}^2+\sigma_{\gamma,y}^2}}\frac{1}{\sqrt{2\pi}\sqrt{\sigma_{e,z}^2+\sigma_{\gamma,z}^2+\frac{\sigma_{e,y}^2+\sigma_{\gamma,y}^2}{\sin^2\alpha/2}}}$$

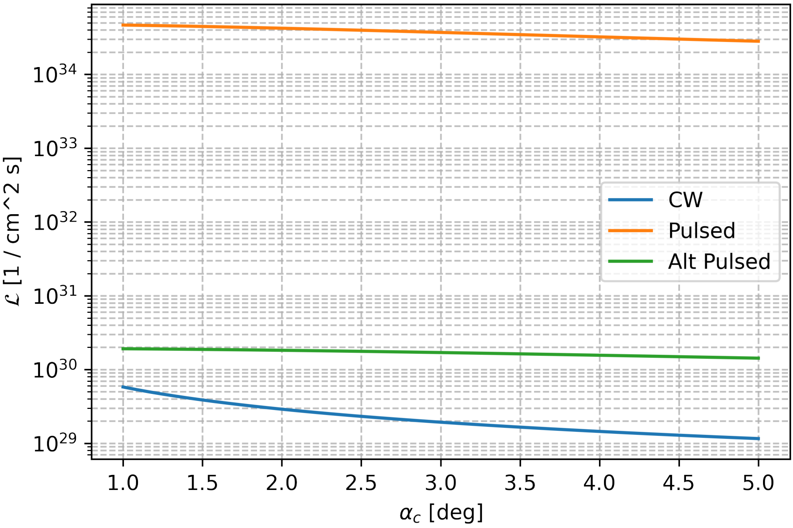
$$\mathcal{L}_{alt} = N_e N_\gamma f\frac{cos(\alpha/2)}{2\pi}\frac{1}{\sqrt{\sigma_{e,y}^2+\sigma_{\gamma,y}^2}\sqrt{(\sigma_{\gamma,x}^2+\sigma_{e,x}^2)cos^2(\alpha/2)+(\sigma_{e,z}^2+\sigma_{\gamma,z}^2)sin^2(\alpha/2)}}$$

I = beam current [A] = 0.00078
λ = wavelength [m] = 515×10^{-9}
f = repetition rate [Hz] = 250×10^{6}
P_L = photon power [W] = 1000
c = speed of light [m/s]

N_γ = number of photons
N_e = number of electrons
α = angle of collisions [rad]
h = planck's constant [J s]

https://wiki.bnl.gov/conferences/images/1/1b/EIC_Compton_LOI_Jan-2020.pdf
https://iopscience.iop.org/article/10.1088/1748-0221/7/01/P01021

Luminosity Comparison of Pulsed vs CW Beams (3/4)



Luminosity Comparison of Pulsed vs CW Beams (4/4)

There are a couple of issues with our plot, for one: our alternative pulsed plot (Alt Pulsed) is based on the formula derived by T. Akagi et al, which is different from the one shown in the EIC report.

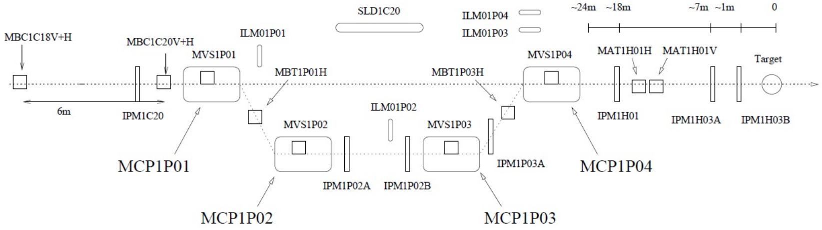
$$\mathcal{L} = N_e N_\gamma f \frac{cos(\alpha/2)}{2\pi} \frac{1}{\sqrt{\sigma_{e,y}^2 + \sigma_{\gamma,y}^2}\sqrt{(\sigma_{\gamma,x}^2 + \sigma_{e,x}^2)cos^2(\alpha/2) + (\sigma_{e,z}^2 + \sigma_{\gamma,z}^2)sin^2(\alpha/2)}}$$

https://iopscience.iop.org/article/10.1088/1748-0221/7/01/P01021

Using this, we are able to reproduce the result from the original EIC report, the second issue we ran into is that our CW plot is very slightly off, by roughly a sixth. Our plot ends just above 10^{29}, while the EIC report ends just under 10^{29}.

The last issue is with the different plots presented in the EIC presentation on January 30th, 2020. These plots are scaled much higher, and also further apart, the original CW scale ends at about 10^{28}, the updated presentation ends at about 10^{31}, the same applies to pulsed with 10^{30} and 10^{34} respectively.

Magnetic Chicane Schematics



These are the chicane schematics pulled from Jefferson Laboratory, the components of interest are the dipoles MCP10P01, MCP10P02, MCP10P03, & MCP10P04, these are dipoles 1 through 4.

Reference: https://www.jlab.org/compton/Magnet/

Magnetic Chicane Size

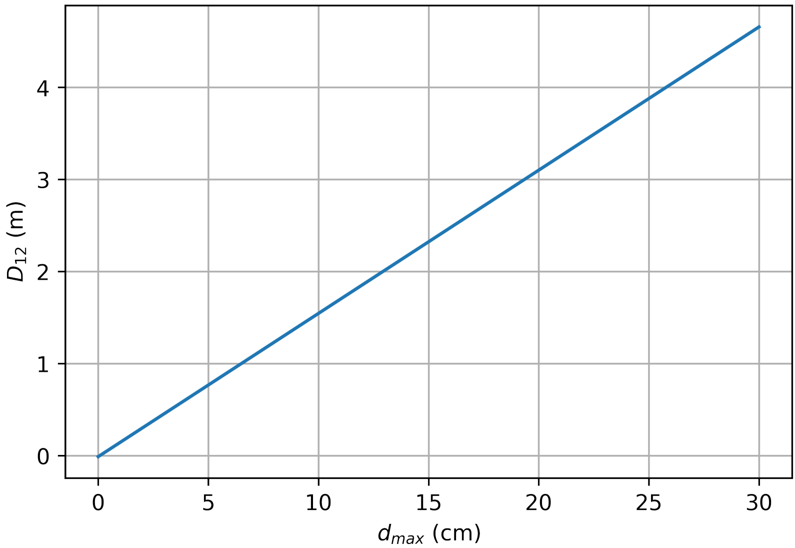
With a magnetic field strength of B = 1.5T, a photon beam energy of 7GeV, and a dipole length of L = 1m, we aim to have a maximum horizontal deviation of $d_{max} = 12$, the formula for this is:

$$d_{max} = 0.3 \frac{B}{p} L(L + D_{12})$$

Following this formula, we can easily write this as as function of d_{max}, this produces a D_{12} value of 1.86m, assuming a symmetrical setup by the center ($D_{12} = D_{34}$), and a D_{23} value of $\frac{D_{12}}{2}$, we get a total chicane size of 8.65m. This function is later graphed:

Reference: Bardin, G, Cavata, C, Neyret, D, Frois, B, Jorda, J P, Legoff, J M, Platchkov, S, Steinmetz, L, Juillard, M, Authier, M, Mangeot, P, Rebourgeard, P, Colombel, N, Girardot, P, Martinot, J, Sellier, J C, Veyssiere, C, Berthot, J, Bertin, P Y, Breton, V, Fonvieille, H, Roblin, Y, & Chen, J P. Conceptual design report of a compton polarimeter for CEBAF hall A. France.

Distance Between Dipoles 1 & 2 as a Function of Maximum Horizontal Deviation



Configuration of comptonRad

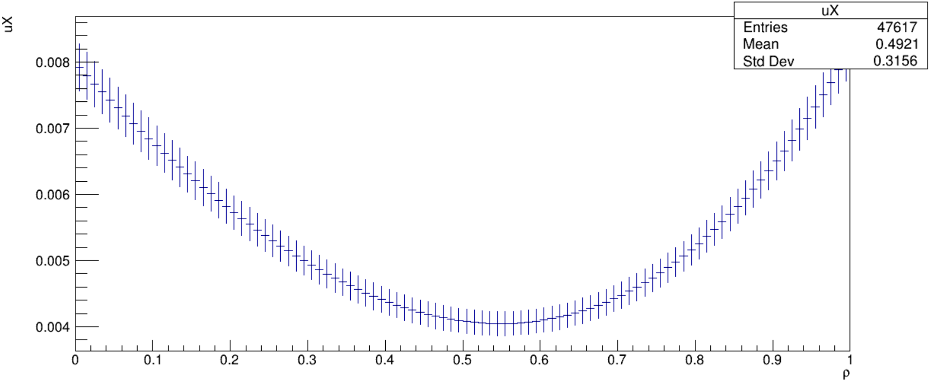
We are using the Compton event generator provided by Dr. Morris Schwartz[1], and other files by Ciprian Gal and Zhengqiao Zhang[2] our configuration includes an electron beam energy of 7GeV and a photon energy of 2.33eV. We simulated 100,000 events. The particles were longitudinally polarized.

We will first show plots of the unpolarized and polarized parts of the cross sections, assuming 100% electron polarization for the latter. After that, we'll present plots for electron and photon distributions at 25m and 6m away from the interaction respectively. We have 5 types of plots to present for both the electrons and photons:

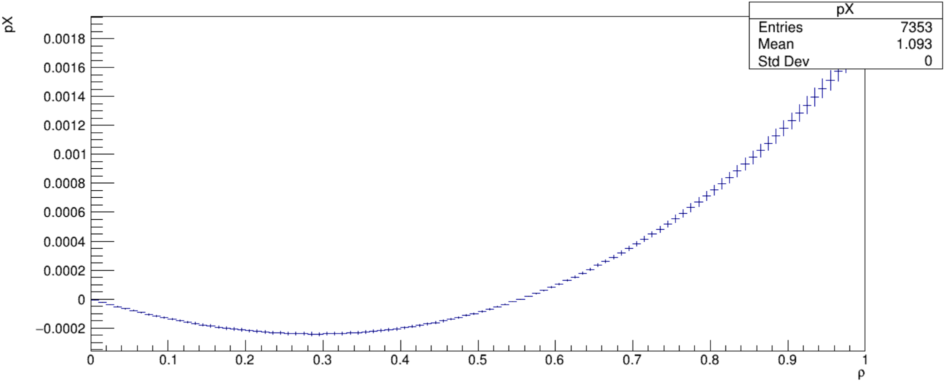
1. Particle count
2. Unpolarized Cross-section
3. Polarized Cross-section
4. Energy $\times$ Unpolarized Cross-section
5. Energy $\times$ Polarized Cross-section

[1] https://arxiv.org/abs/hep-ph/9711447
[2] https://gitlab.com/eic/mceg/comptonRad

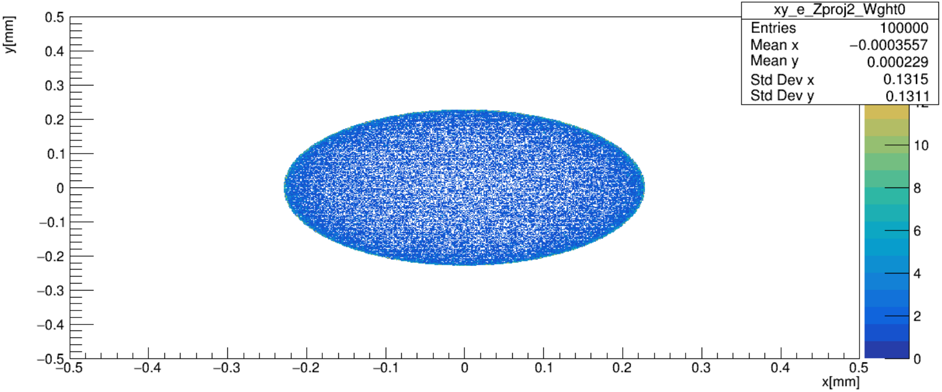
Unpolarized Cross-section vs Energy



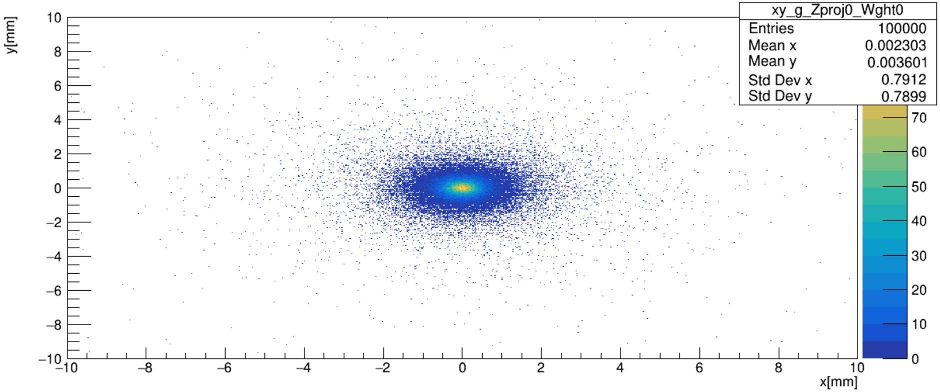
Polarized Cross-section vs Energy



Electron Counts (z = 25m)



Photon Counts (z = 6m)



Future Work

- Using fun4all to run more detailed simulations with magnets included.
- Including our results from comptonRad to build simulations on it.
- Including other effects such as background radiation.