

# The low $Q^2$ chicane and Compton polarimeter at the JLab EIC

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**Abstract.** The JLAB EIC (JLEIC) design includes a chicane after the interaction point to detect electron associated with production of quasi-real photon at the interaction. This chicane layout can also be used for Compton polarimetry to measure the electron beam polarization. This proceeding will present the layout of the low  $Q^2$  chicane and the implementation and current R&D of a Compton polarimeter which would be located in the middle of this chicane.

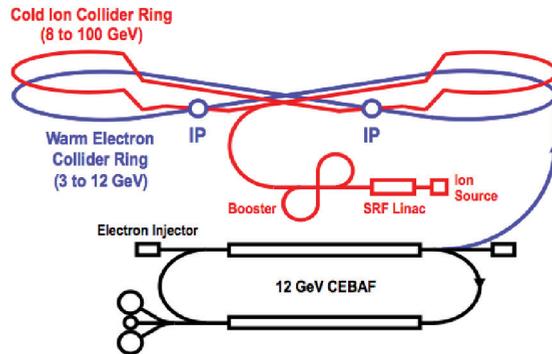
## 1 Introduction

The future Electron Ion Collider will feature availability of both polarized electron and ion beams coupled with a high luminosity from  $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$  up to a few  $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ . Energy of the electrons will be similar to the existing CEBAF from 3 to 10 GeV. The protons or ions will have an energy from 20 to 100 GeV [1].

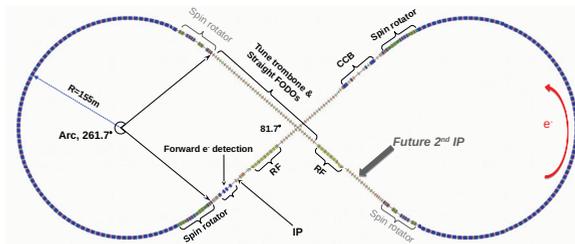
Polarization measurement is important since the machine is designed to run at high luminosity, many measurements will be limited by systematic errors. In the case of inclusive electron measurement, electron polarization can be a major contribution. Polarization also enters the photon production cross-section which can be used to determine the luminosity needed for all the cross section measurements.

### 1.1 Layout

The Jefferson Laboratory EIC design (JLEIC) is a ring ring collider design in a figure of 8 [2] which makes it easier to conserve polarization of ions and electrons since the precession cancels at first order at the interaction point.



**Figure 1.** Figure of 8 layout of the JLEIC electron ring with the chicane after in the interaction point



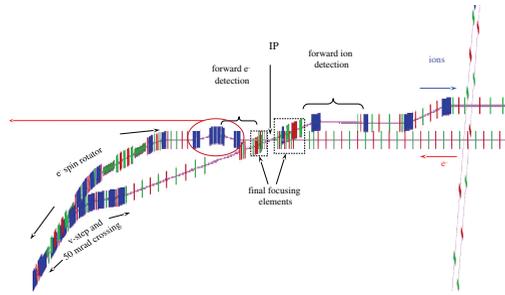
**Figure 2.** Figure of 8 layout of the JLEIC electron ring with the chicane after in the interaction point

Two interaction points are planned, the main interaction point is based on a solenoidal magnet giving an almost hermetic detection as shown in Fig. 4 where one can see the detector with the magnets for the final focusing and the low  $Q^2$  chicane.

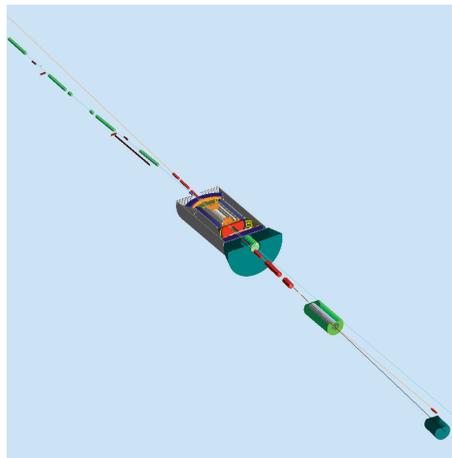
## 1.2 Beam helicity structure

The electron beam will use CEBAF as full energy injector. The CEBAF injector is using a circularly polarized laser on a GaAs source, by switching the laser polarization one can switch the electron polarization to the opposite direction for a certain period of time. The direction of the spin of the polarized electron can be manipulated using Wien filters. Using this CEBAF feature, two large macrobunches of about  $2.3 \mu\text{s}$  with opposite spin direction will be filled in the ring 6 composed of the small bunches of at 476 MHz. As shown in Fig. 5

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**Figure 3.** Detailed layout of the magnet lattice of the chicane at the interaction point with the forward electron detection chicane



**Figure 4.** Overview of the interaction point main detector with the final focusing magnets and the low  $Q^2$  chicane

## 2 The low $Q^2$ chicane

Quasi-real photons can be produced at the interaction point, since they are almost colinear with the beam the corresponding electrons will not be detected in the main detector. In order to detect those electrons a chicane was designed after the interaction point. It consists of 4 dipoles with the first dipole which takes out electrons corresponding to high photon energy which will be bent out and detected by a tracker detector. The designed momentum resolution is  $10^{-3}$  on the electron energy assuming a 1 mm detector resolution. This will allow to study  $J/\psi$ , charm production, real and Time like Compton Scattering for example. A detector closer to the beam similar to roman pots or Compton electron detector could be added to improve the low energy photon energy acceptance if needed. The optimization of the chicane acceptance is being studied. All the magnets are modeled in the GEMC simulation. In Fig. 7 one can see electrons deflected in the detector at the first dipole.

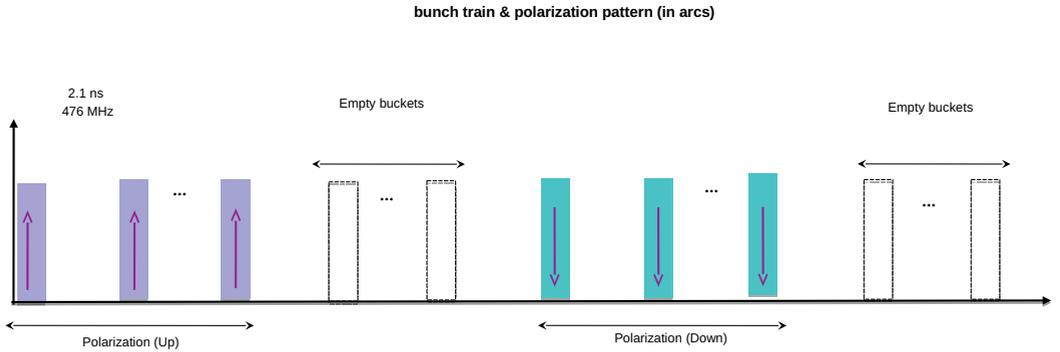


Figure 5. Beam polarization structure, the two 2.3  $\mu$ s macrobunch of opposite

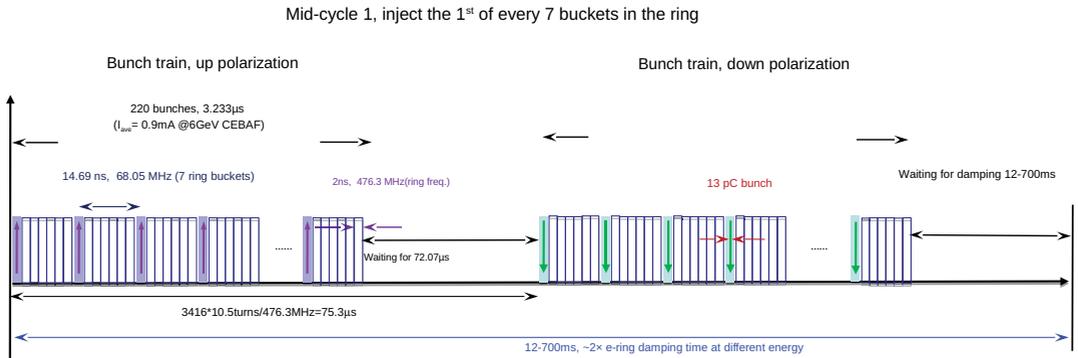
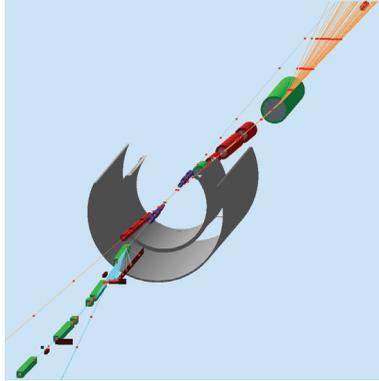


Figure 6. Injection scheme and microbunch helicity structure of the JLEIC beam

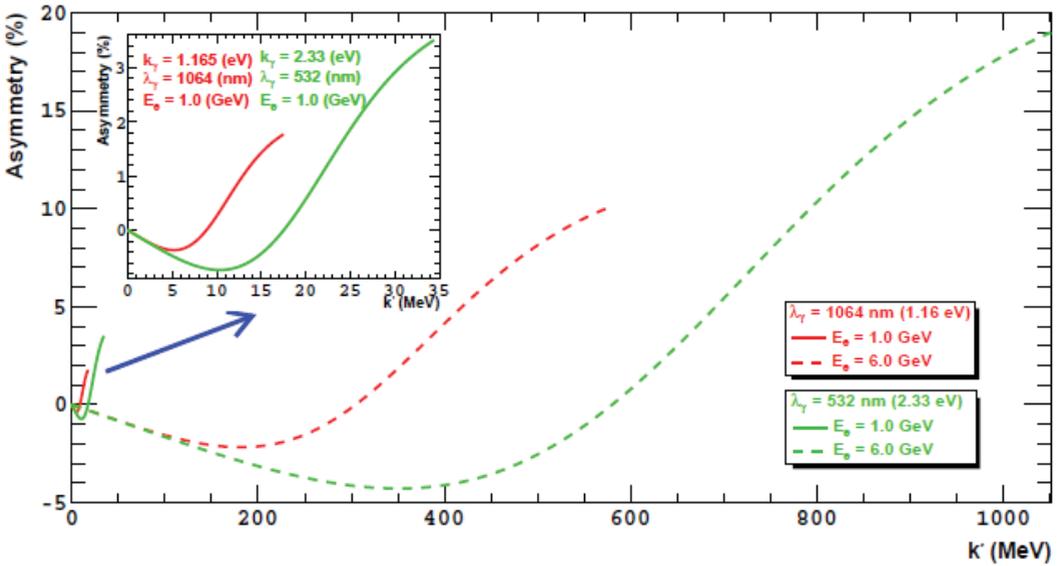
### 3 Performances of the Compton polarimeter at Jefferson Laboratory

#### 3.1 Chicane layout

Compton polarimetry is commonly used to measure polarization for experiment where accuracy on the polarization beam is critical, the interaction cross-section of circularly polarized photons with longitudinally polarized electrons is different depending of the direction of the polarization of either the electron or photons. By varying one of the polarization one can measure the Compton asymmetry which is proportional to both photon and electron polarization. Compton polarimeters are considered non invasive meaning they can continuously monitor the beam polarization as long as the amount of Compton interaction is just a fraction of each electron bunch.



**Figure 7.** Display of a few events detected in the low  $Q^2$  chicane

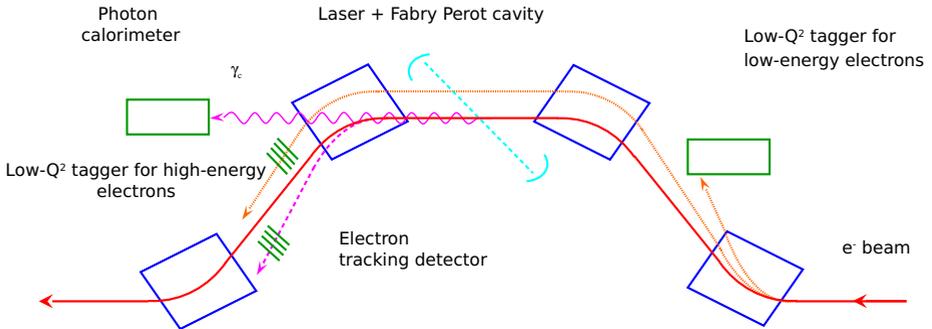


**Figure 8.** Compton asymmetry for different laser and beam energies

The Compton Scattering cross-section can be accurately computed with QED, so one can extract the absolute beam polarization from the measured asymmetry. The Compton asymmetry is particularly well suited for measurement at higher energy where the Compton asymmetry is larger as shown in Fig. 8.

The photon polarization is known accurately to a few tenths of a percent level giving a measurement of the beam polarization. Sub-percent measurement of the polarization was achieved at Jefferson Laboratory in Hall A and Hall C.

The low  $Q^2$  chicane is a good configuration for Compton polarimetry, it allows to separate the Compton electron from the Compton photon. For the current JLEIC design we will rely on a design similar to the one used at Jefferson Laboratory as show in the schematics Fig. 9.



**Figure 9.** Schematic of the low  $Q^2$  chicane layout including the Compton polarimeter

The photon source used at Jefferson Laboratory currently is a green CW laser amplified by a Perot Fabry cavity with a typical gain around 1500. It is placed between dipoles 2 and 3 with a small crossing angle with the electron beam.

Compton polarimetry can be done by detecting either the Compton Photon or Compton Electron, both methods have different systematic and are sensitive to different backgrounds. They can give two independent measurement of the polarization which is a good crosscheck.

### 3.2 Hall A HAPPEX experiment : photon detection using integrated method

A calorimeter is placed in front of the Compton interaction point behind the third dipole of the chicane. The Compton photons go straight in the calorimeter while the electron beam is bent to stay inside of the chicane. For the 12 GeV beam at Jefferson Laboratory, a lead tungstate calorimeter will be used while for energies lower than 6 GeV a GSO crystal was used. Two methods will be used both having different systematic. The one which was used for the HAPPEX experiment is a digital integration. A gate is open corresponding to one helicity window and all the samples are summed digitally [3], this allows to compute the integrated asymmetry without use of any thresholds as shown in Fig. 10.

For the HAPPEX experiment the total errors at 3 GeV are summarized in table 11

This yield a measurement accuracy of 0.93% at 3 GeV, which is the best photon Compton measurement at this energy up to date.

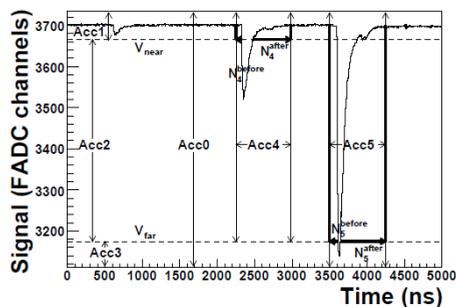


Figure 10. Digital FADC integration

Systematic Errors	
Laser Polarization	0.80%
Analyzing Power:	
Non-linearity	0.3%
Electron Energy Uncertainty	0.1%
Collimator Position	0.05%
MC Statistics	0.07%
<b>Total on Analyzing Power</b>	<b>0.33%</b>
Gain Shift:	
Background Uncertainty	0.31%
Pedestal Uncertainty	0.20%
<b>Total on Gain Shift</b>	<b>0.37%</b>
<b>Total</b>	<b>0.94%</b>

Figure 11. HAPPEX systematic errors summary

### 3.3 Hall C QWeak diamond electron detector

The Compton electrons having lost energy during the Compton interaction are bent more after the third dipole and are detected. A strip detector is placed in the dispersion plane then the electron energy is directly proportional to the position in the detector. In Hall C, a 4 planes with 96 strips per plane diamond detector was used as shown in Fig. 12 and installed as in Fig. 13.

Compton spectra are recorded for each beam helicity as shown in Fig. 14.

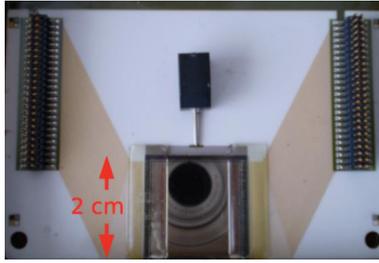
The Compton asymmetry can then be computed Fig. 15 strip by strip and by fitting the asymmetry one has access to the beam polarization.

Beam polarization was measured for the QWeak experiment at 0.6 % accuracy. [4]

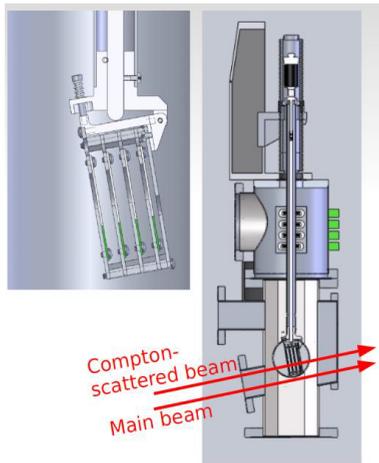
## 4 EIC R&D and preliminary design

### 4.1 Photon source

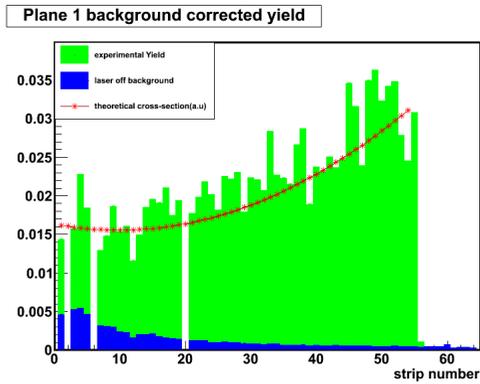
For EIC, the current will be about 1000 higher than at Jefferson Laboratory, so one can envision the use of CW laser which have typical power up to 30 Watts. RF pulsed laser matched to the beam



**Figure 12.** One of the Hall C Compton diamond detector plane

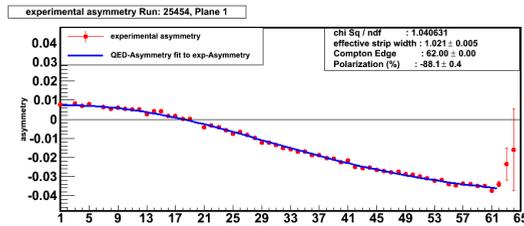


**Figure 13.** Layout of the Hall C Compton Electron detector



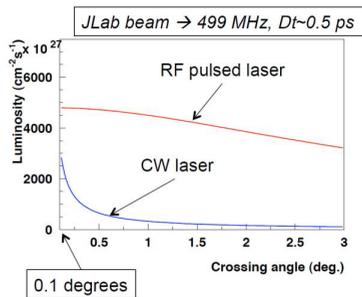
**Figure 14.** Typical Compton energy spectrum

## Physics Opportunities at an Electron-Ion Collider



**Figure 15.** Compton electron detector asymmetry as a function of strip number (energy)

frequency gives a better luminosity with larger crossing angles by concentrating the energy in smaller bunches. This might prove to be useful to fit the space constraints as shown in Fig. 16.



**Figure 16.** Luminosity as a function of crossing angle for CW and RF pulsed lasers

Having a single laser simplifies the design : there are less apertures which could interact with beam halo and one could also consider fast flipping of the laser polarization to be able to sample the polarization within a macrobunch. Though depending of the background, more powerful laser sources might be needed so optical cavities similar to the one used at Jefferson Laboratory could be chosen hence a major effort in simulation and beam tests to evaluate the sources of background. R&D for ILC is also ongoing for pulsed Perot Fabry cavity which would be the most powerful photon source available.

### 4.2 EIC electron detector design

Since the best measurement to date was the SLAC SLD experiment measurement at 21 GeV with a 0.52% measurement accuracy, we proposed to first focus on the Compton polarimetry detecting the Compton electrons for JLEIC. The Compton polarimetry at JLEIC is a bit more difficult than at SLAC because of a lower energy ranging from 3 to 11 GeV and dispersion, this implies having the detector fairly close from the beam making it very sensitive to background. Conditions at EIC are also very different to the current JLAB setup in terms of current, while 80  $\mu\text{A}$  of current is available at JLAB, JLEIC will run high current going from 0.72A up to 3A. At such high currents, background from the electron beam can be significant and also shielding and cooling is needed to protect the detector from the large amount of RF power deposited from the beam. Such additional material can affect the shape of the detector response and introduce systematic errors on the polarization measurement.

Careful R&D and simulation is crucial to optimize the detector design, and make sure the detector reach the 1% accuracy while having sufficient radiation hardness to be able to run for at least a single run period.

With the successful experience of the Hall C detector the JLEIC baseline detector is diamond strip detector which has radiation hardness greater than 10 MRad.

In addition to the design and simulation effort a test stand is proposed at Jefferson Laboratory/ Since two sub-percent Compton polarimeters which can be crosschecked by Moller polarimeters are available at Jefferson Laboratory, it is an ideal place to cross check the simulation and make sure sub-percent polarization can be achieved at lower current in shielding conditions required for JLEIC allowing to control how well we can correct for the effect of additional material.

Another research point is optimizing the timing response of the detectors, silicon and diamond detectors usually require large amplification giving typical response time of the order of a microsecond with usual integration times. For example for eRHIC current design, several electron sources will be used switched at 10.8 MHz, so a detector response shorter than 100 ns is desirable to be able to measure the polarization of each individual source which usually have different polarization. A fast detector can also improve timing resolution which could be useful for example for the low  $Q^2$  detector where an electron corresponding to a quasi-real photon will be recorded in coincidence with the main detector.

## 5 Conclusion

The JLAB EIC is a polarized electron and ion machine. It features a low  $Q^2$  chicane allowing to look at quasi-real photons physics. Expected momentum resolution is  $10^{-3}$ . This chicane will also host a Compton polarimeter. Compton polarization is a natural candidate for electron beam polarization measurements at EIC considering the high energy and high current available. Experience from Jefferson Laboratory has shown that sub-percent electron polarization measurements were feasible for both Compton photon and electron detection for an energy ranging 1 to 3 GeV. With the increase current additional shielding of the detector has to be done. An ongoing R&D effort (eRD15) focusing on the Compton electron detection has been funded from the EIC R&D fund. It will evaluate the effect of the shielding on the measurement will be evaluated through simulation. A test stand will be implemented at Jefferson Laboratory to validate the simulation, test radiation hardness of the detector and electronics and optimize the timing properties of the detector.

## References

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- [2] V. Morozov *et al.*, “Progress on the Interaction Region Design and Detector Integration at JLab’s MEIC,”
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- [4] A. Narayan, Phd Thesis, Mississippi State University, “Determination of electron beam polarization using electron detector in Compton polarimeter with less than 1% statistical and systematic uncertainty”