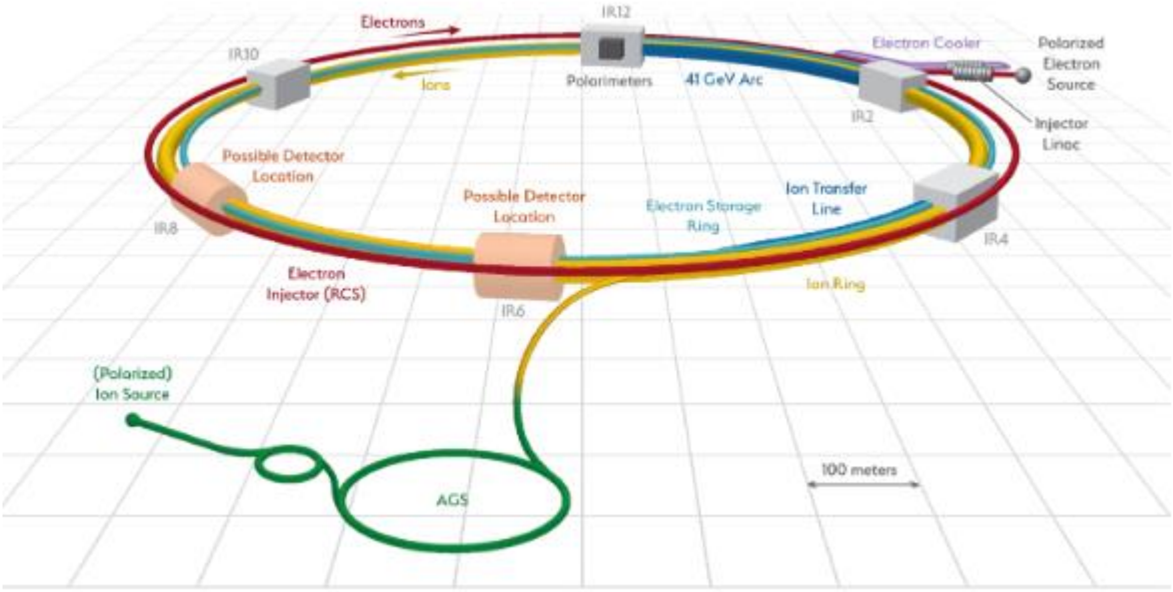
Compton lasers at JLab and the EIC



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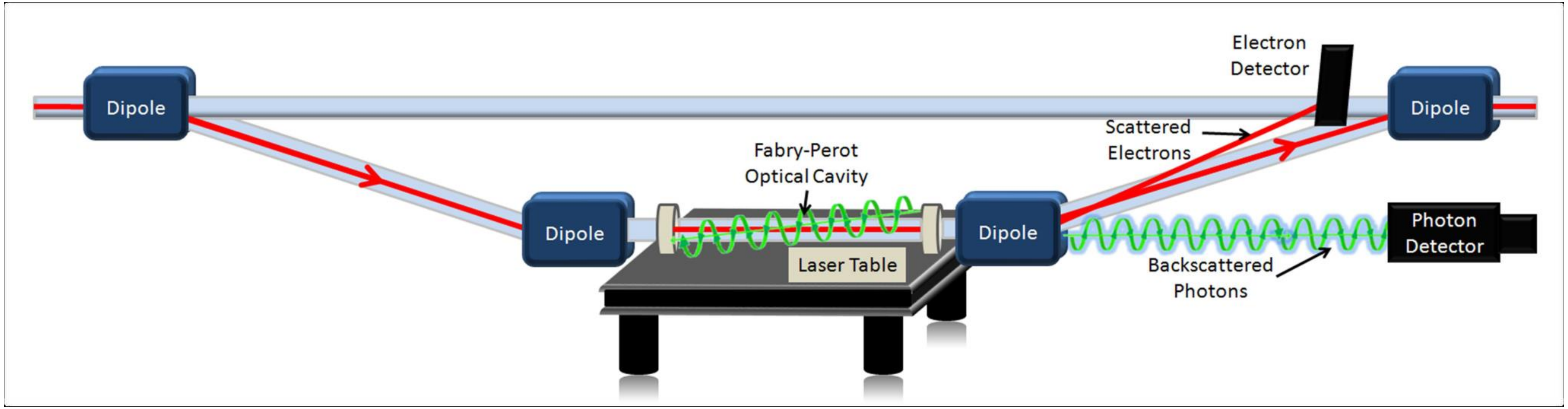
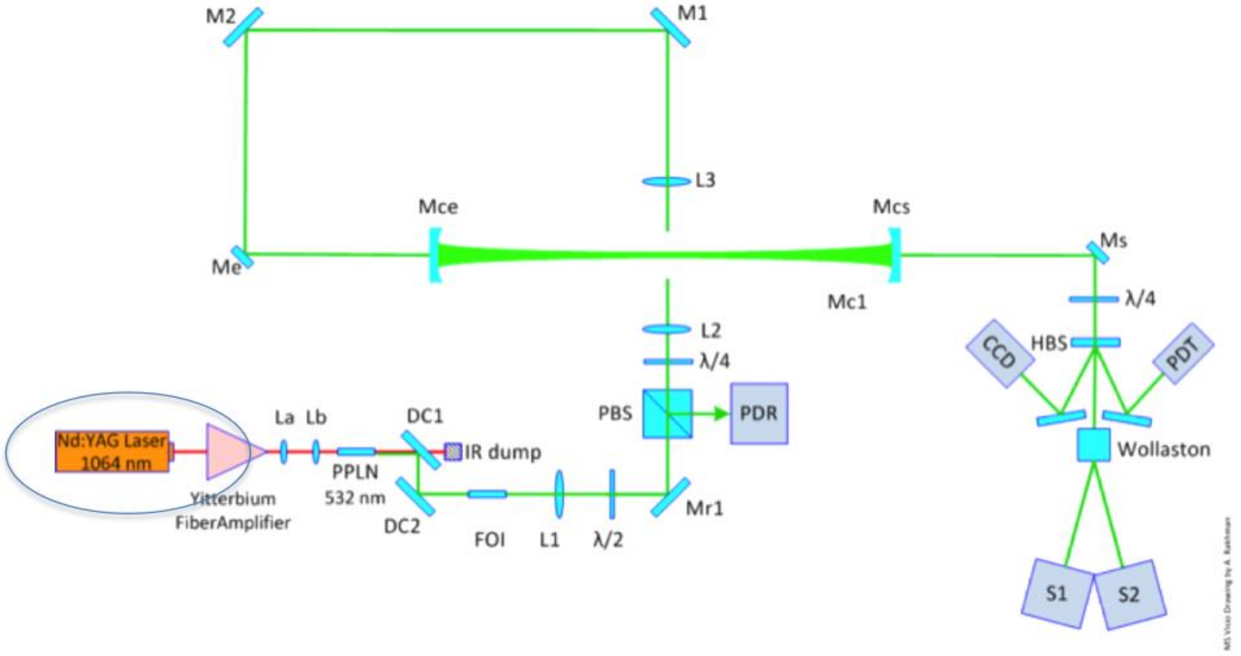
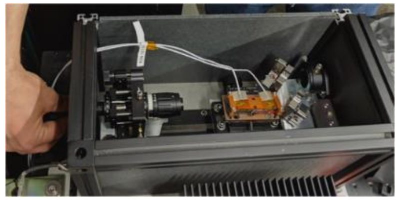
JLab Compton Layout

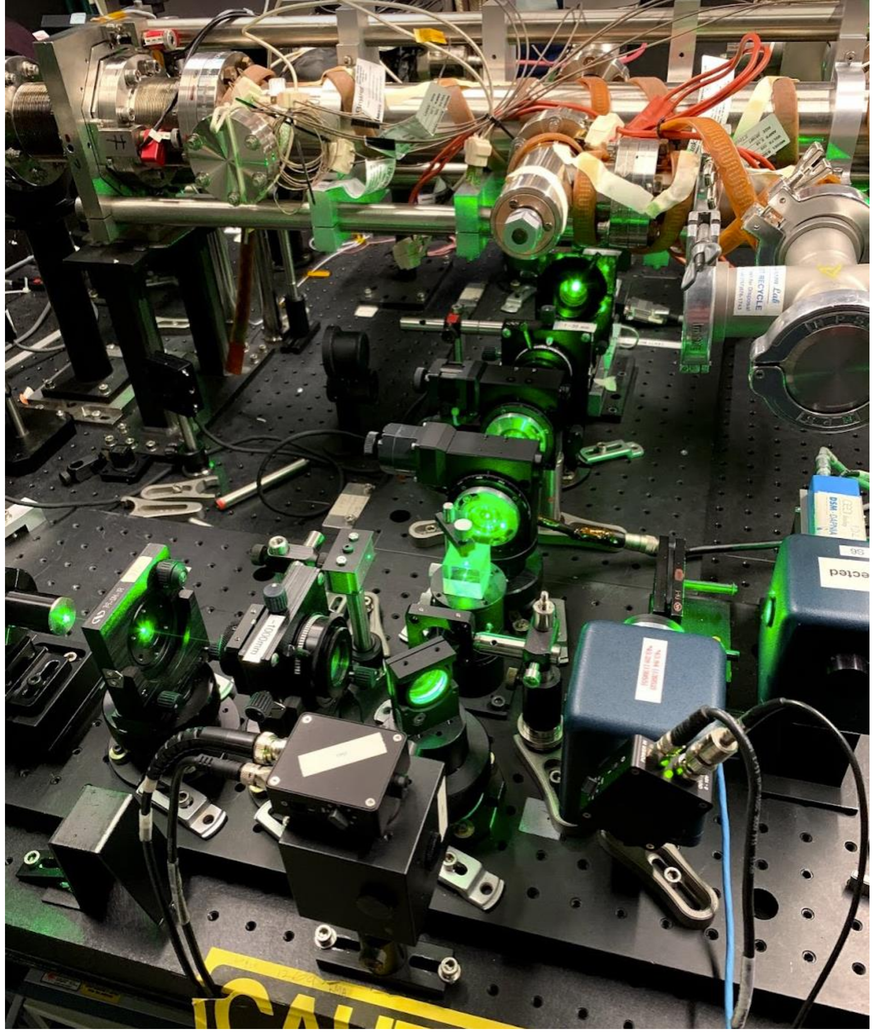


- The Compton setup at Jefferson Lab makes use of a chicane with 4 dipoles to steer the electron beam onto a laser table where interactions with a high power laser beams can occur
- The backscattered photon energy is measured in a calorimeter (crystal depends on the energy of the photons) and the scattered electron is tracked before the last dipole in the chicane to again infer energy loss
- System could in principle be used redundantly but more frequently we ended up using one of the two for the main measurement and used the other for a cross-check

JLab Compton Layout



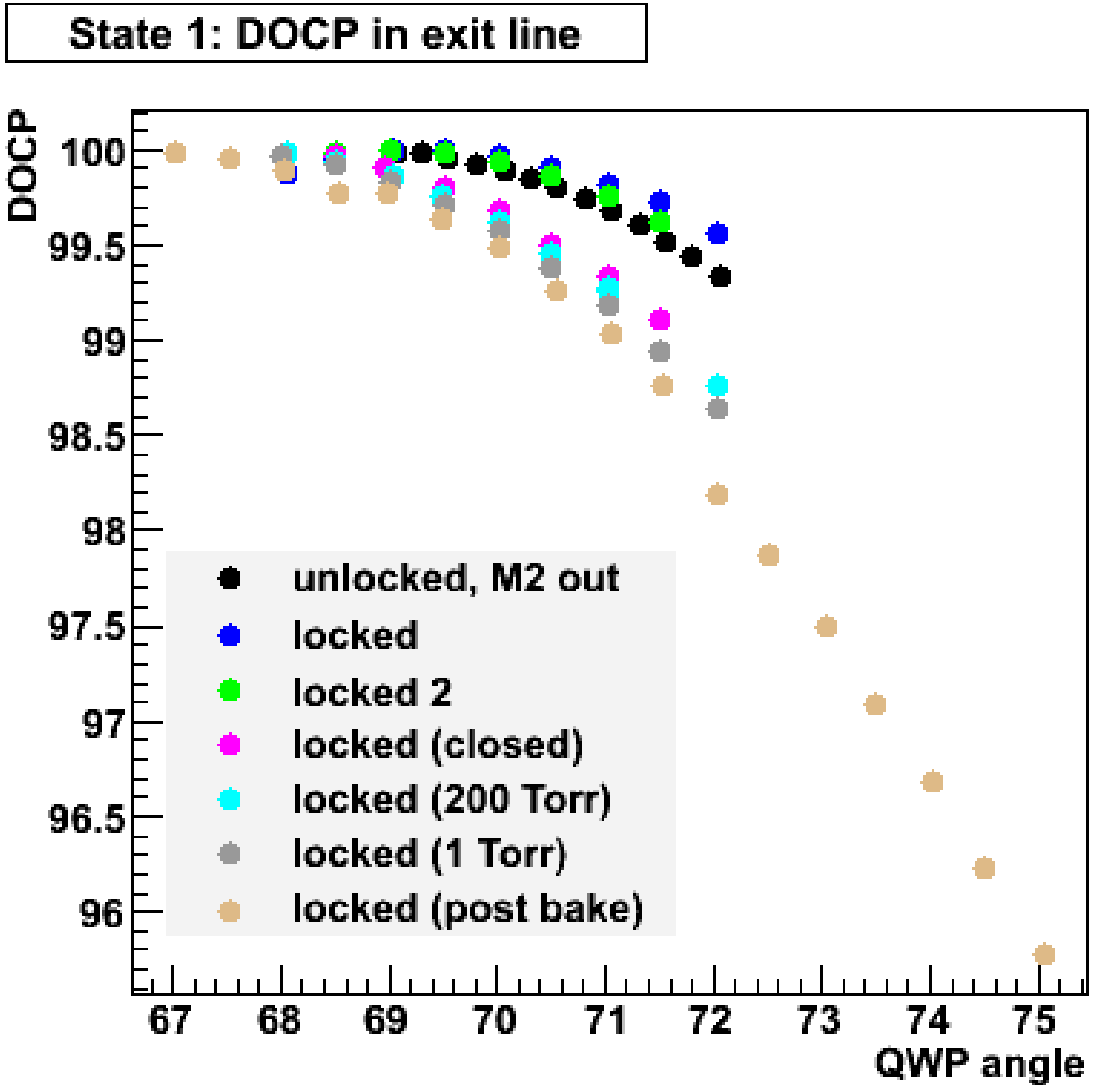




- The Jefferson Lab (Hall A) Compton laser is a CW high power system that enables measurements in integrating mode (multiple interactions per time unit)
- The high power is obtained through the use of Fabry-Perot high gain cavity (10^4) cavity which typically leads to powers on the level of a few kW
- A critical aspect to reaching high precision (recent CREX results had 0.44% precision) is the ability to monitor and measure the degree of circular polarization (DOCP) inside the cavity

DOCP through windows

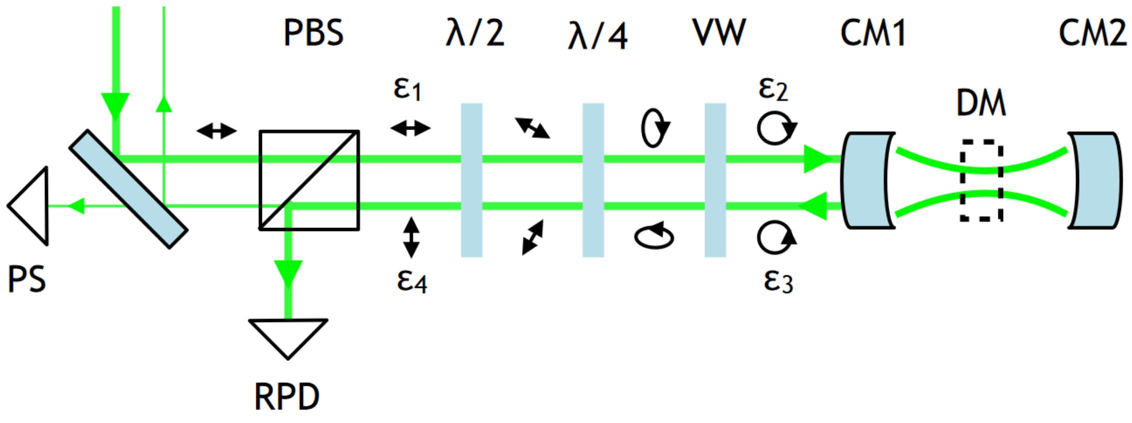
- Tests done with cavity at JLab showed that large differences in the degree of circular polarization can be obtained when straining the windows
- Typically the polarization is monitored through measurements of the transmitted laser light (after the IP)
- The “transfer function” can be measured on the bench but variations (such as tightening bolts or pulling vacuum) change the function making it unusable for the actual data taking

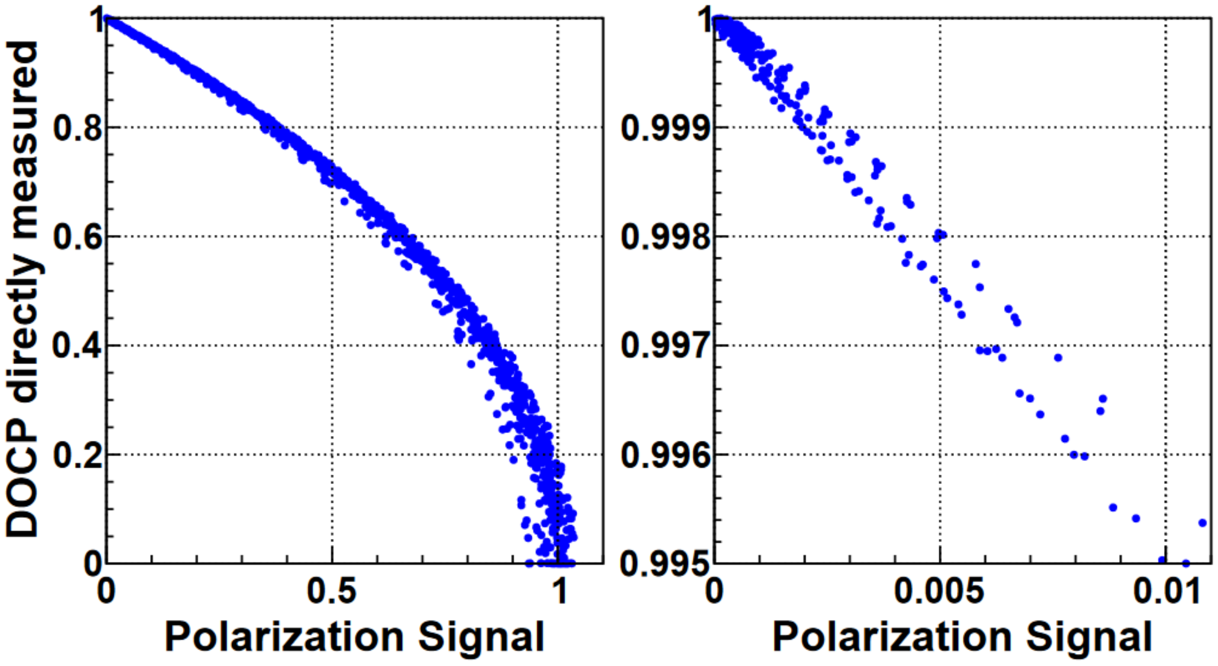


arXiv:1509:06642v2

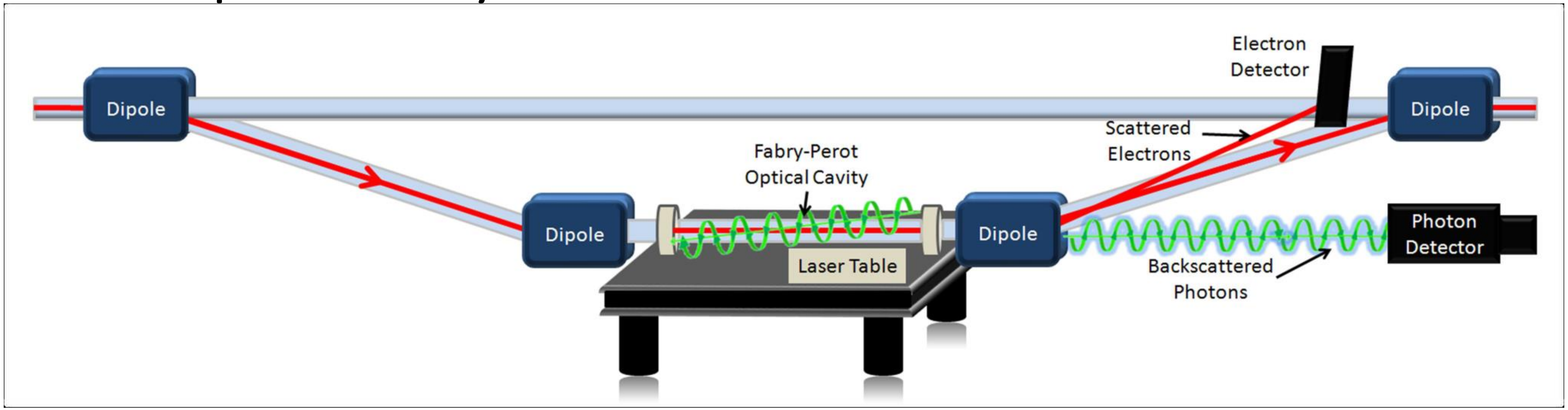
JLab Compton polarimetry

- In order to obtain circular polarization in the cavity one can use the information obtained from the back-reflected light
  - In this case it would be off of mirror M1
- Using the optical reversibility theorem one can relate the amount of light reaching "PS" to the degree of circular polarization inside the cavity
  - M. Dalton and D. Jones showed this to be true in a setup at JLab (previously observed and published by the LPOL group at HERA)
- By performing detailed scans of the half and quarter wave plates one can maximize the circular light at the IP and monitor it throughout the data taking

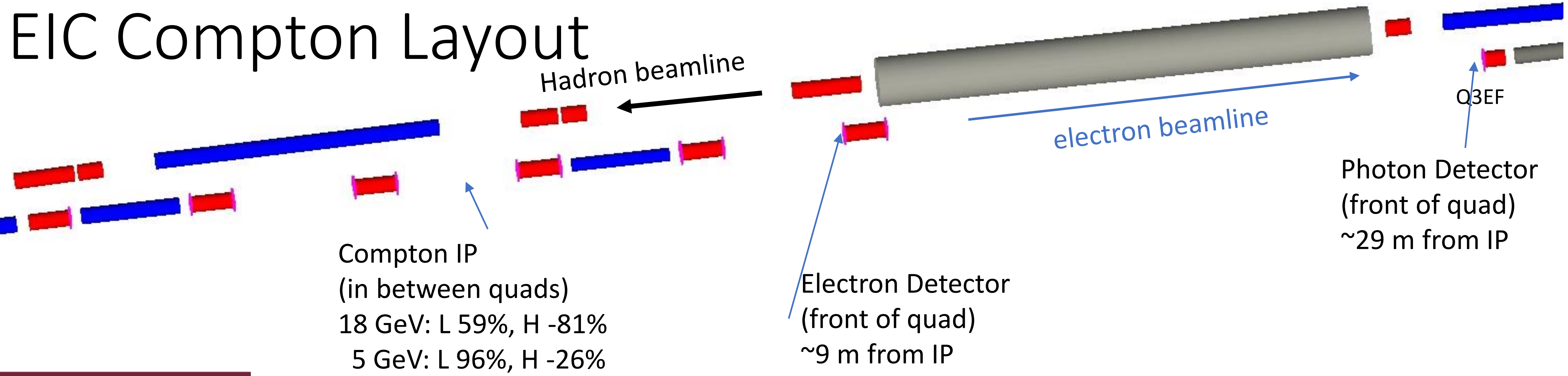




JLab Compton Layout



EIC Compton Layout



e-Polarimetry requirements for the EIC

Fast

- At 18 GeV bunches will be replaced every 1-3 min
  - A full polarimetry measurement needs to happen in a shorter time span
- The amount of electrons per bunch is fairly small ~24 nC
  - will need bright laser beam to obtain needed luminosity
- A fast polarimeter will allow for faster machine setup

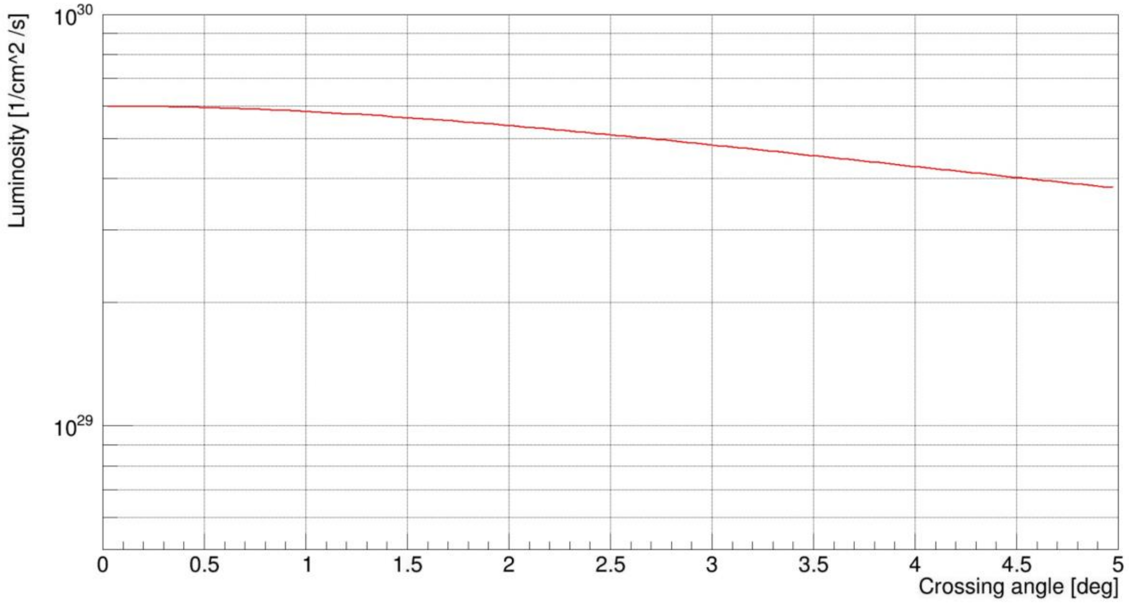
Precise

- Distance between buckets is ~10ns (@5,10 GeV)
  - bunch by bunch measurement cannot be done with a CW laser without very fast detectors
- For systematic studies we would like to have the ability to either measure a single bunch (~78kHz) or have interactions with all 1160 (260) bunches at 10 and 5 GeV (18GeV)
- Backgrounds need to be under control
- Laser polarization needs to be known to a high degree

Luminosity calculations

$$\mathscr{L} = f_0 N_1 N_2 \frac{\cos(\theta/2)}{2\pi} \frac{1}{\sqrt{(\sigma_{x,1}^2 + \sigma_{x,2}^2)}} \times \frac{1}{\sqrt{(\sigma_{y,1}^2 + \sigma_{y,2}^2)\cos^2(\theta/2) + (\sigma_{z,1}^2 + \sigma_{z,2}^2)\sin^2(\theta/2)}} \quad (1)$$

S. Verdu-Andres (CAD): https://www.bnl.gov/isd/documents/95396.pdf



- The dependence of the luminosity of crossing angle needs to take into account the transverse profile of the beam and the length of the pulse
- The estimation on the left is made for a single pulse
- For a 10W 100MHz pulsed laser with a 12ps pulse can provide about $6*10^5$ 1/(barn*s) of luminosity

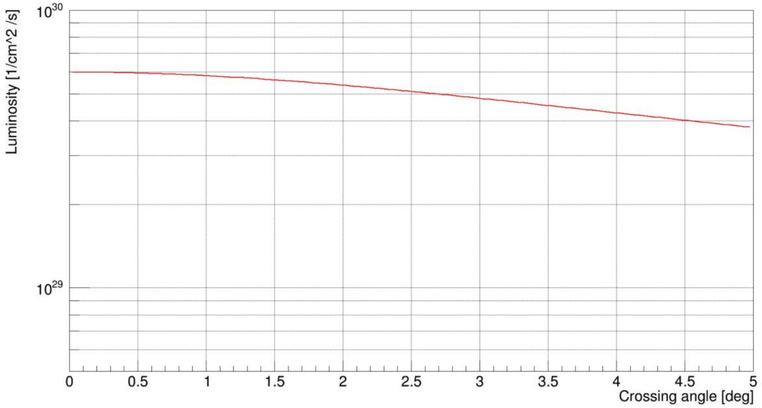
Luminosity calculations

Configuration	Beam energy [GeV]	Unpol Xsec[barn]	A	A^2	L	1/t(1%)	t[s]	t[min]
laser:532nm, photon	18	0.432	0.072	5.18E-03	1.81E+05	2.93E-02	34	0.57
laser:532nm, electron	18	0.432	0.075	5.63E-03	1.81E+05	3.18E-02	31	0.52
laser:1064nm, photon	18	0.333	0.046	2.12E-03	2.35E+05	1.20E-02	84	1.39
laser:1064nm, electron	18	0.333	0.046	2.12E-03	2.35E+05	1.20E-02	84	1.39

$$N_{Compton} = \frac{\mathcal{L} \cdot \sigma_{unpol}}{f_{beam}}$$

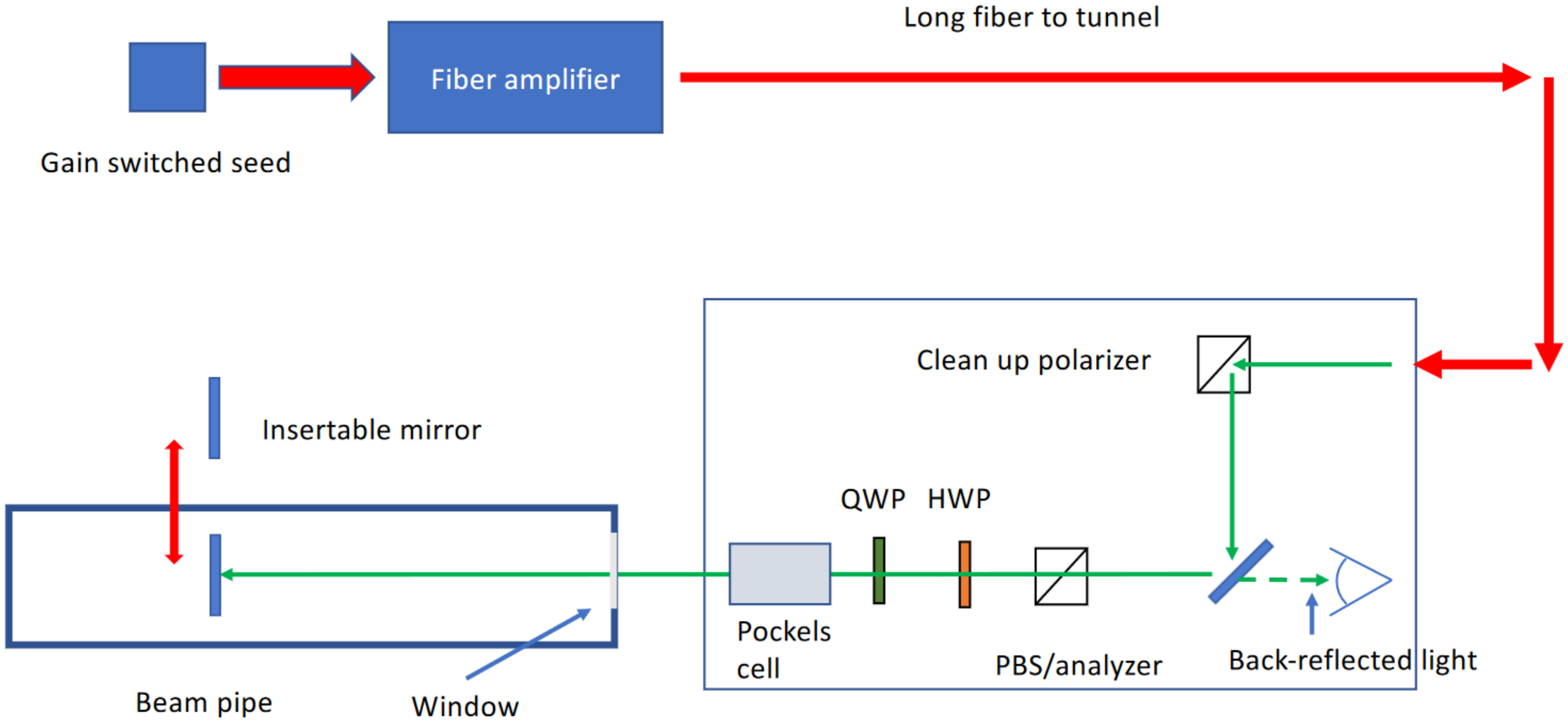
$$t_{meth} = \left(\mathcal{L}\ \sigma_{\text{Compton}}\ \text{P}_c^2 \text{P}_\gamma^2 \left(\frac{\Delta \text{P}_c}{\text{P}_c} \right)^2 \text{A}_{\text{meth}}^2 \right)^{-1}$$

G. Bardin, et al., Conceptual design report of a compton polarimeter in cebaf hall a, JLab Internal note.



- Assuming one scattered particle per bunch would allow us to calculate the luminosity needed and a time estimate for how long it would take to reach a 1% statistical precision
- For all configurations envisioned for the EIC (5-18 GeV) the luminosity requirements are on the level of few 1/(barn*s)
  - Comparing this to the estimate for the 10W laser proves that such a laser will be sufficient
- The times needed to the needed statistics for the signal are on the level 30s at 18 GeV
  - Lower energies are less of a concern due to the longer lived stores
  - This would allow for simultaneous measurement of all bunches

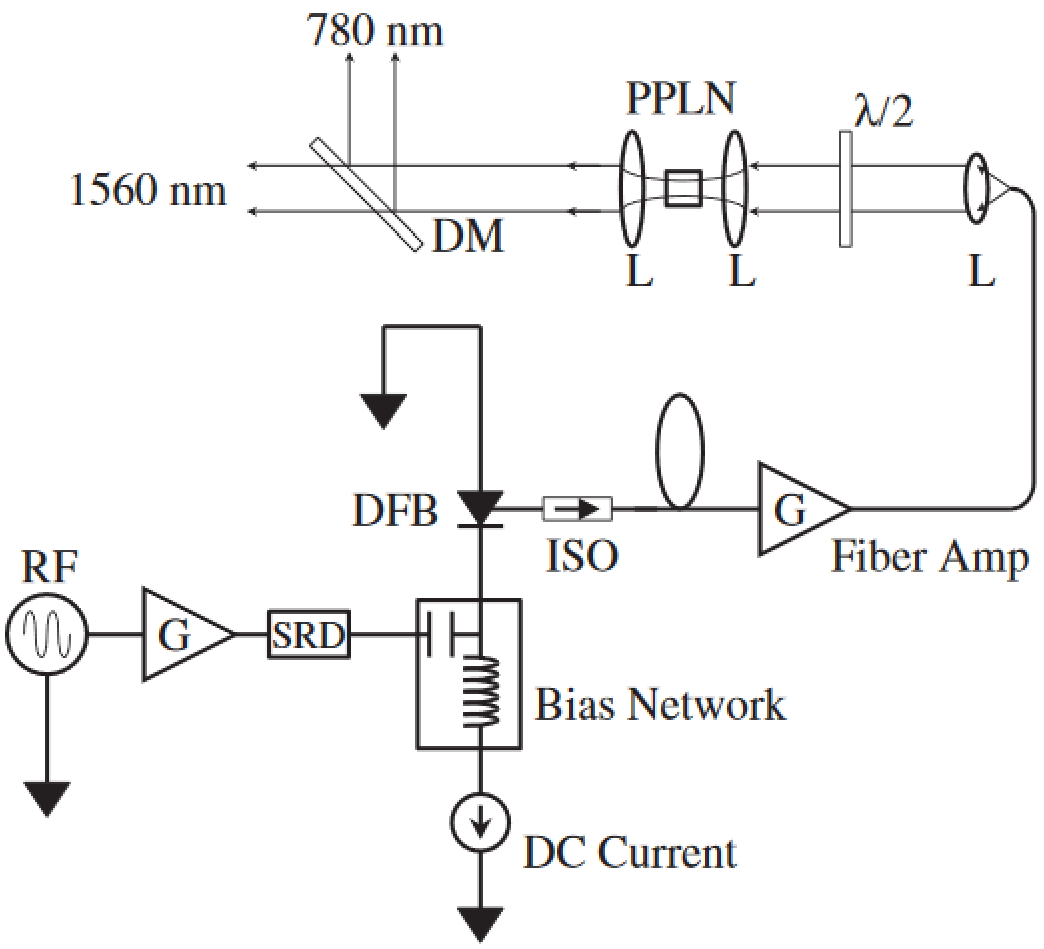
Current design of EIC laser system



- The initial laser system design uses most of the design features highlighted in the previous Compton polarimeter implementations
  - As was before we need the laser system to be away from potential fatal radiation fields inside the tunnel (we plan to evaluate the use of high power laser fiber)
- The vacuum resident insertable mirror will be needed in order to be able to monitor the DOCP at the interaction point

Gain switched seed

- The gain switched seed laser design developed at CEBAF for the injector satisfies all the requirements that we discussed so far
  - The RF lock allows us to synchronize to all or specific electron bunches
  - The pulse longitudinal width will be smaller than the electron bunch (allowing us to potentially measure the longitudinal polarization profile)
  - The PPLN or LBO crystal will allow us to frequency double the 1064nm light to 532
- The system has proven to be very reliable and has been adopted by other facilities (such as the Maintz Microtron)



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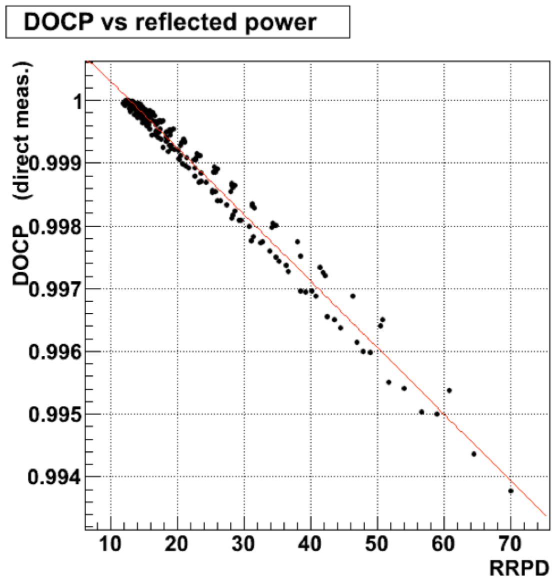
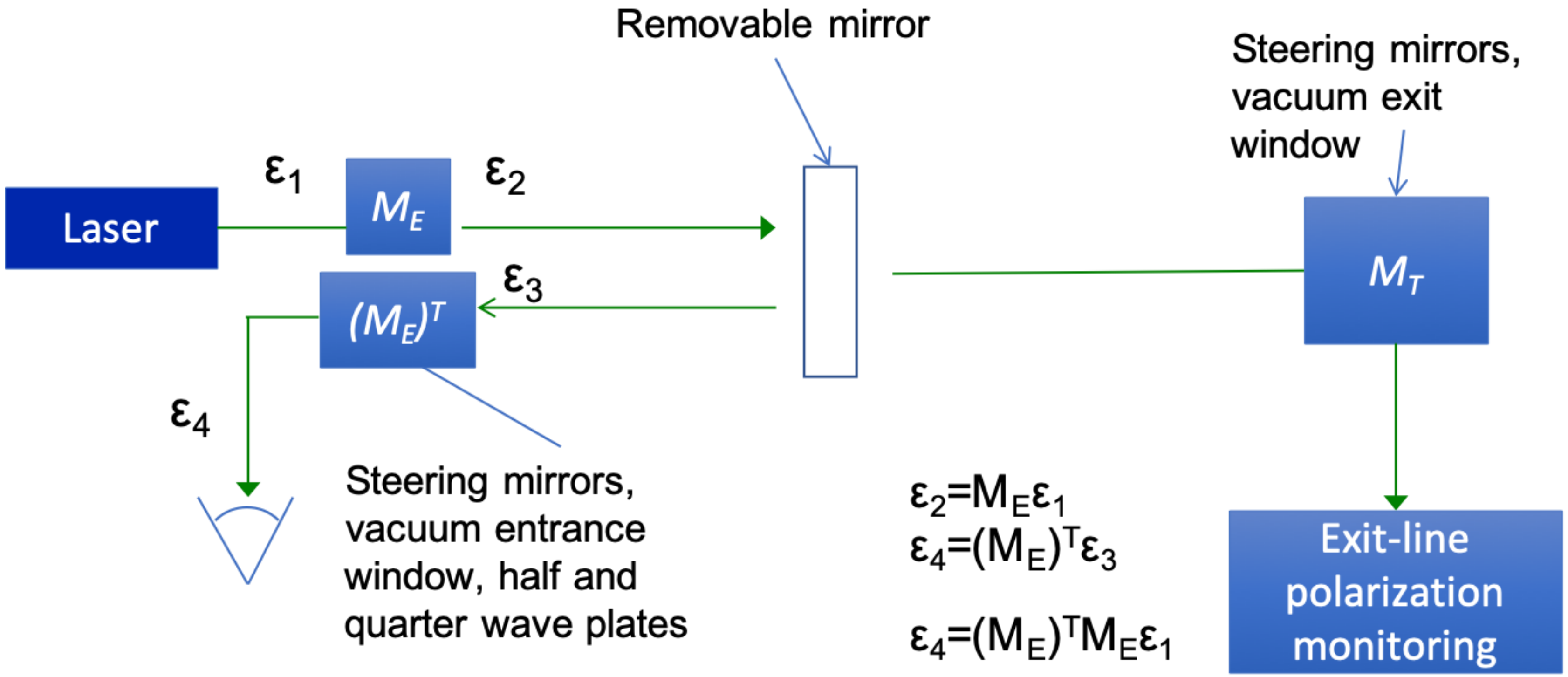
https://journals.aps.org/prab/pdf/10.1103/PhysRevSTAB.9.063501

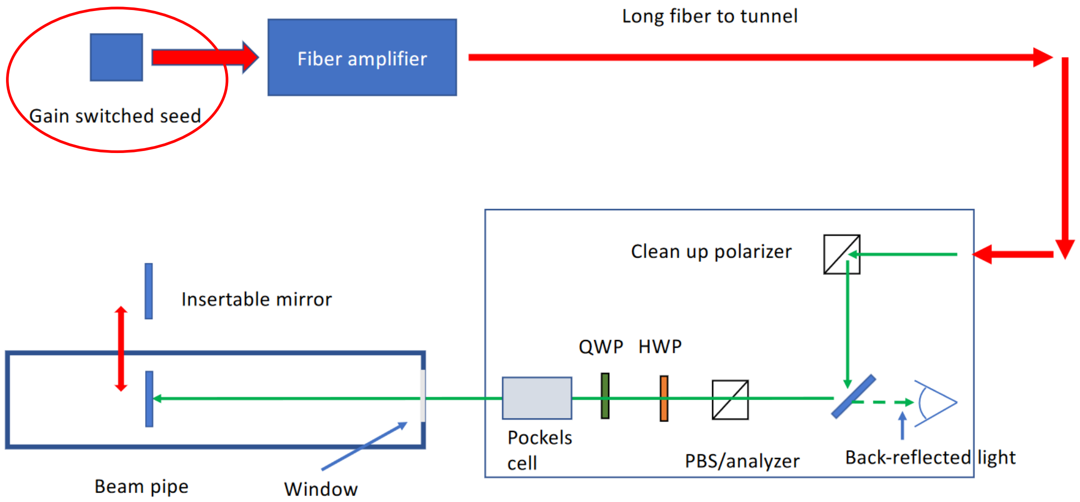
Current design of EIC laser system

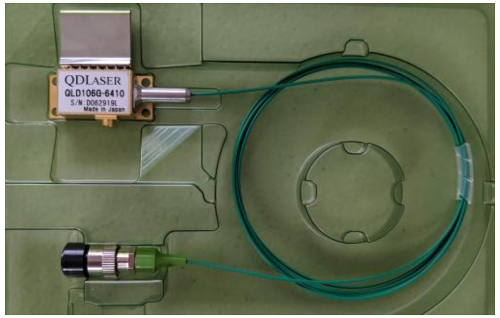


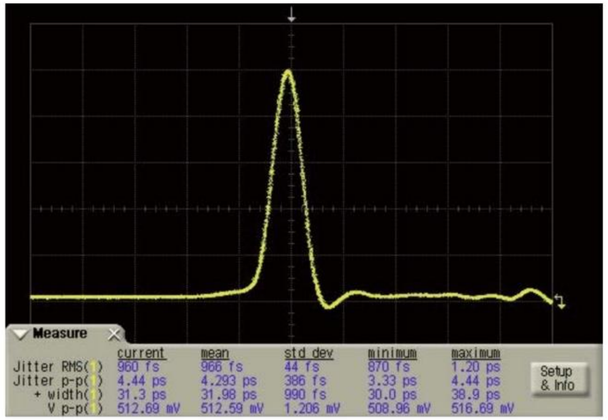


- The polarization setup for the EIC Compton will follow the same logical reasoning as the Jefferson Lab measurements

Work start







- We have started to
- QLD106G-6410 provides 1064nm short pulses (~20ps)
  - Average power 0.1mW @100MHz (-10dBm)
- Electrical pulse generator: 30-230ps pulses, for 1MHz to 1GHz
  - The plan is to have fixed pulse energy at the highest rep rate and use a pulse picker (such as an fiber coupled EOM) to get us the lower frequencies
- A pre-amplifier (YDFA100P) with an output of ~12dBm (getting us to ~16mW) is going to be needed for characterization and input into the fiber amplifier

Conclusions and further questions

- Due to the specifics of the machine at the EIC we cannot make use of the excellent system that has been employed at JLab over the past decade
- A pulsed laser with an average power of 10W will allow for enough luminosity to be able to have (on average) one interaction per collision
- We plan to have the radiation sensitive electronics (such as amplifiers and seed laser) away from the tunnel to increase longevity of the system
- The DOCP monitoring throughout data taking should be possible by making use of the same scheme developed at JLab
- Questions:
  - How will the laser beam parameters (such as polarization) change as they pass through the very long fiber?

Backup