A Green Fabry-Pérot Cavity for Hall A Compton Polarimetry

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Overview

Many experiments at Jefferson Lab require good knowledge of the polarization of the electron beam. In Hall A, beam polarization measurement is done by using a Compton polarimeter in which the electron beam is scattered from the photons trapped in a high-finesse Fabry-Pérot cavity.

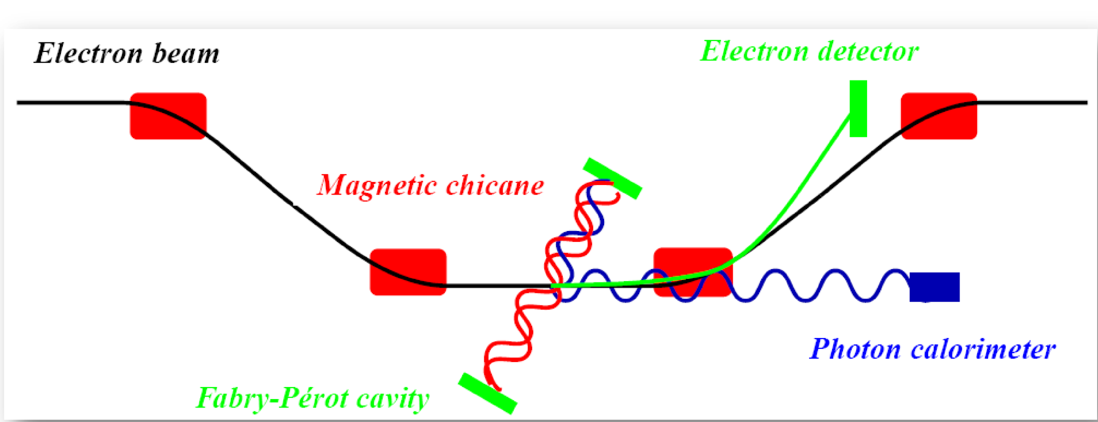
Motivation

Electron beam polarization measurement is achieved by measuring an asymmetry in Compton scattering for two light polarization.

$$A_{exp} = \frac{n^+ - n^-}{n^+ + n^-} = P_\gamma \times P_e \times \langle A_l \rangle$$

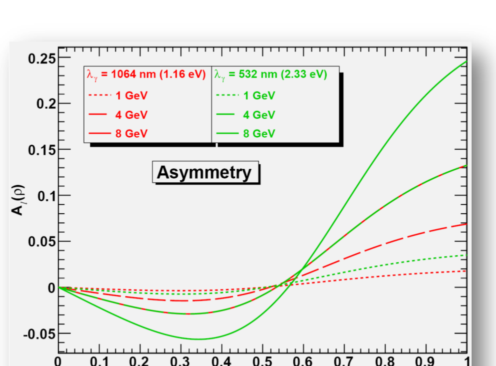
Advantages:

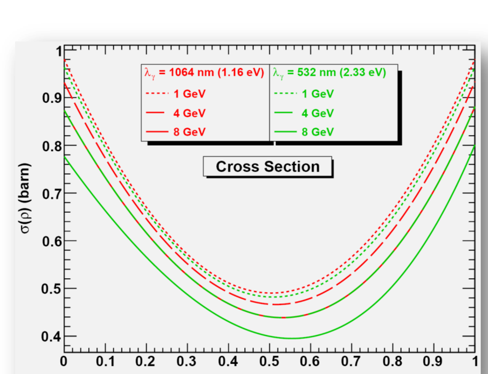
1) measure at the same conditions as data taking
2) measure in parallel to data taking
3) measure the absolute beam polarization



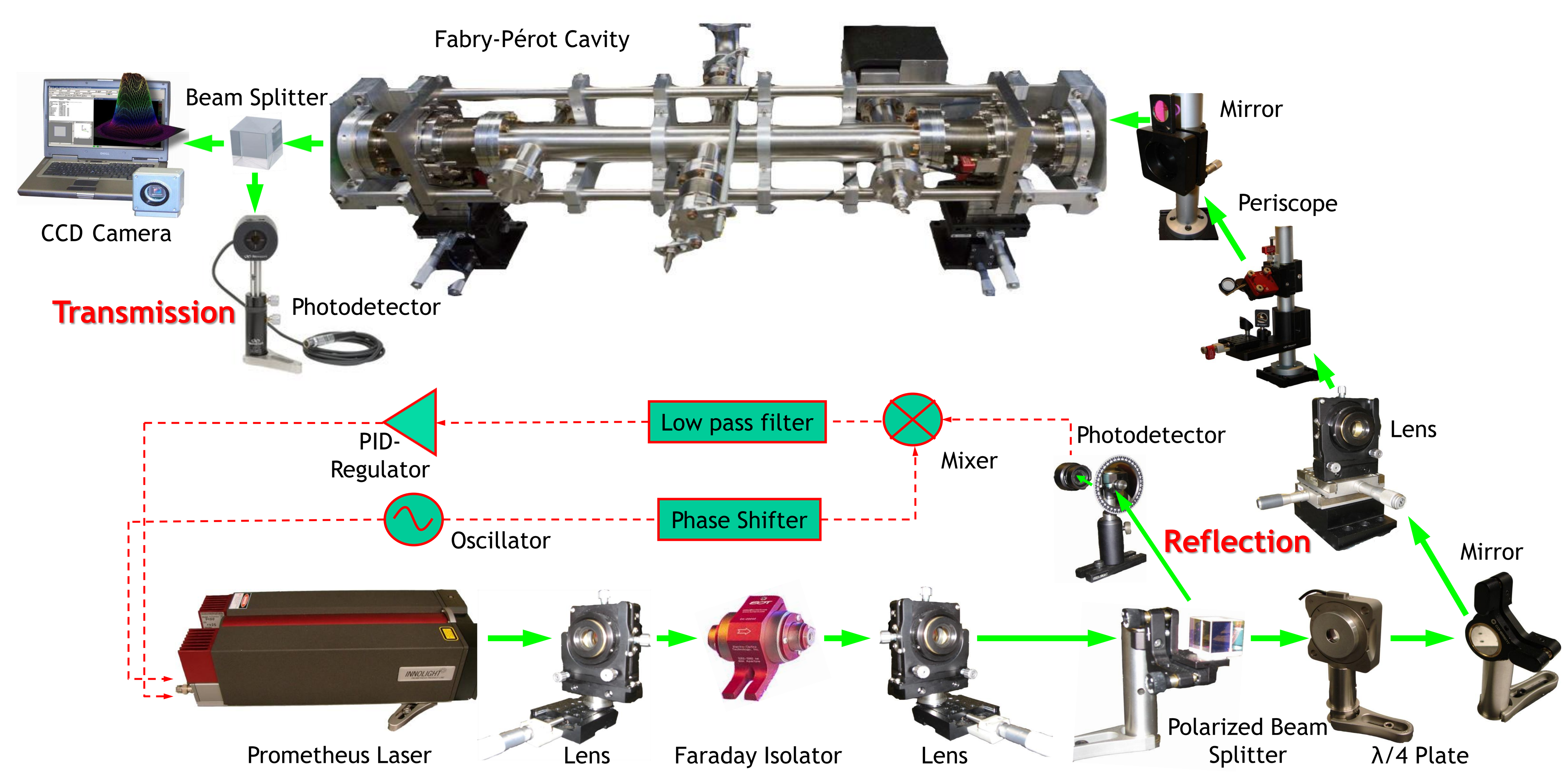
However, some experiments like PREx demands polarization measurement of a lower energy (1 GeV) electron beam at **1% accuracy**, which can not be achieved by the present IR (1064 nm) laser Compton polarimeter in Hall A. Therefore we will employ a green (532 nm) laser cavity to reduce the measurement uncertainty.

$$\frac{\Delta P_e^{stat}}{P_e} \propto \frac{1}{A_l\sqrt{L\sigma\Delta}} \qquad \frac{\Delta P_e^{syst}}{P_e} \propto \frac{1}{A_l}$$



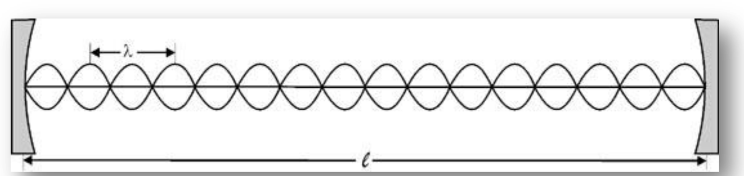


The Fabry-Pérot Cavity



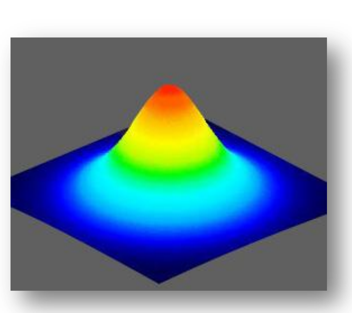
Two highly reflective mirrors are placed an integer number of half-wavelengths apart

$$l = \frac{n}{2}\cdot\lambda, \quad f_{res} = n\cdot\frac{c}{2l}$$

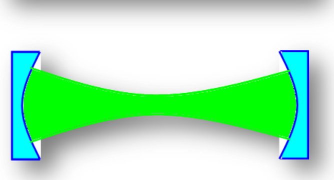


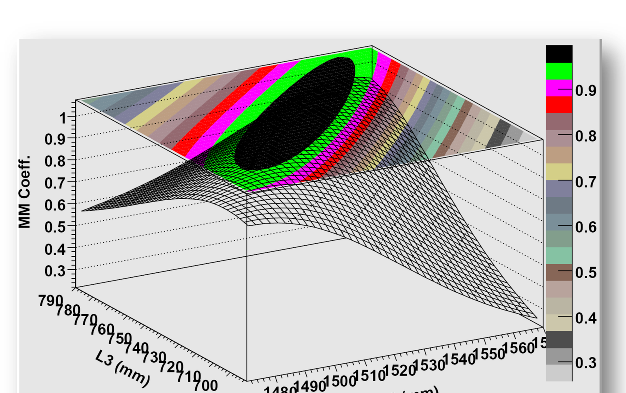
Light at the desired wavelength builds up a resonance inside the cavity and the power of the incident light gets amplified by a large factor.

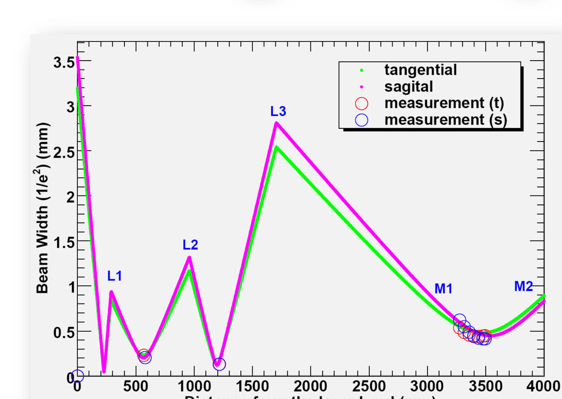
Our laser beam is single mode (TEM_{00}) Gaussian and we want to have the same Gaussian mode for cavity resonance.



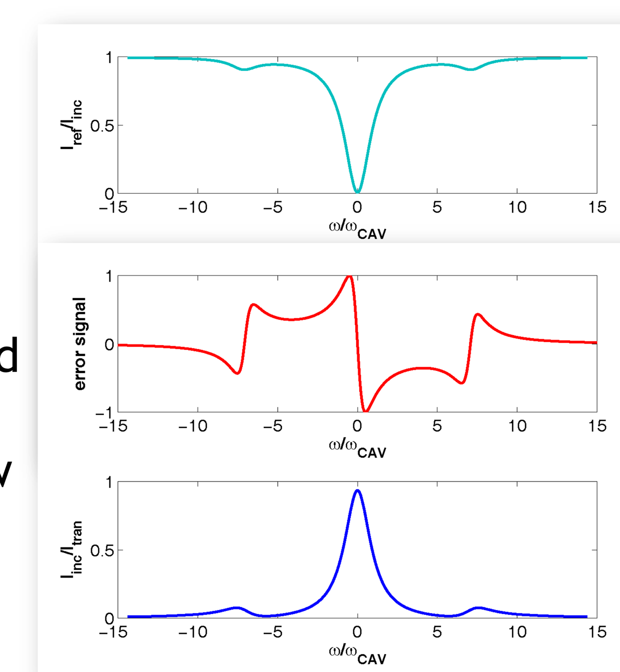
Careful optics simulation is done to achieve better mode matching.







The well-known **Pound-Drever-Hall (PDH)** feedback scheme is applied to continuously detect the phase of the resonance from reflected light therefore tune the laser frequency to follow the variations in cavity length to achieve cavity "locking".



Maintaining a constant resonance at TEM_{00} mode is called "locking".

Cavity should be made of thermally stable materials such as Invar (α_L = 1.3 x 10^{-6}/K).

we are very sensitive to the atomic level change in cavity length.

The linewidth of our cavity is 3.12 kHz, it correspond to the tolerance in change of cavity length is

$$\Delta l = \frac{\Delta f_{res}}{f_{res}}\cdot l \approx 0.47\times10^{-2}\,\text{nm}$$

Design Goal

Wavelength	532 nm
Power	1,500 Watts
Gain	15,000
Q-factor	1.8 x 10^{11}
Length	0.85 m
Mode	CW, TEM_{00}
Free Spectral Range	176 MHz
Cavity Band Width	3.12 kHz
Mirror Reflectivity	99.993666 %
CIP spot size (σ)	87 μm

Solutions :

a) Low power Green Laser -> High Finesse cavity, Feedback to laser PZT to lock.

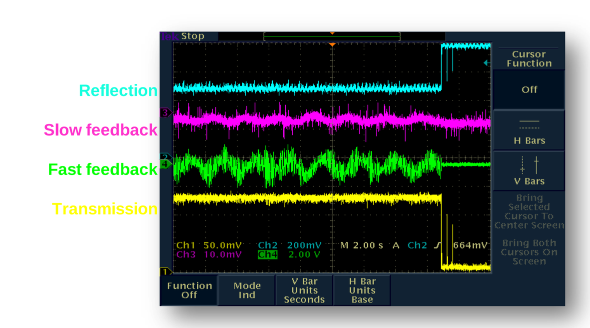
b) High power IR Laser + single pass PPLN SHG -> Low Finesse Cavity, Feedback to laser PZT to lock.

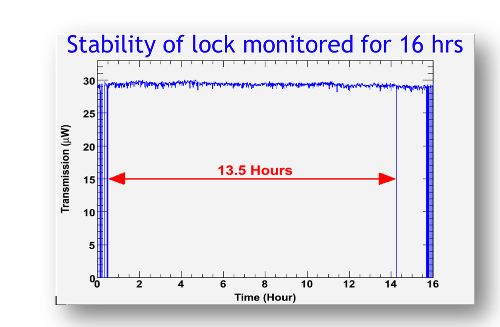
Summary

1) Cavity is fully assembled and tested for mechanical and Ultra-High Vacuum integrity.

2) Complete modeling of cavity mode matching has accomplished.

3) The beam from a 100-mW, 532 nm laser has been locked to our cavity with low power gain.





4) Improve feedback electronics.

5) Attempt locking to higher gain cavities and gradually reach our design goal.