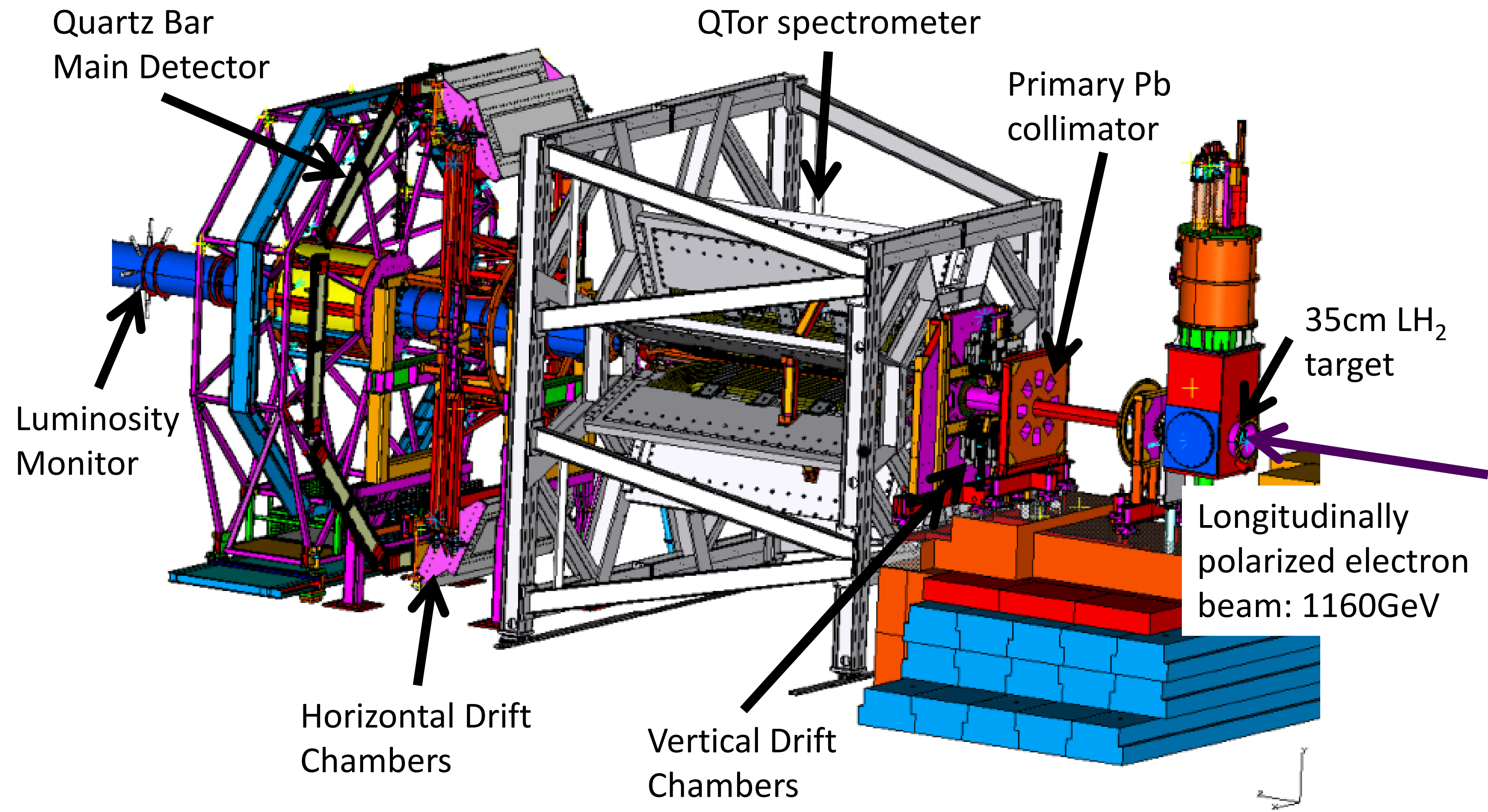
2012 Nuclear Physics Seminar

Donald Jones
University of Virginia

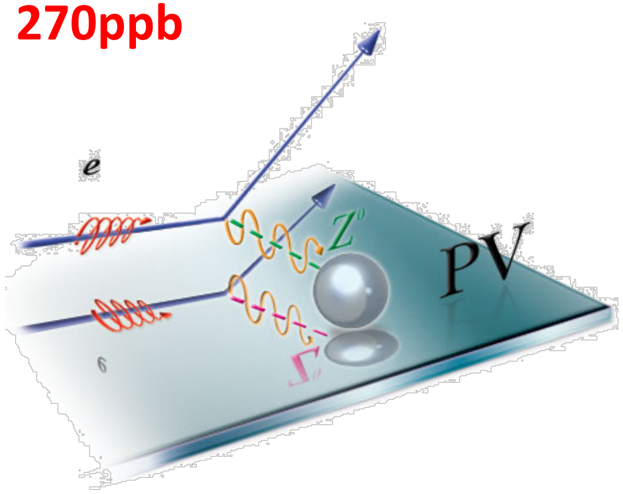
Jefferson Lab

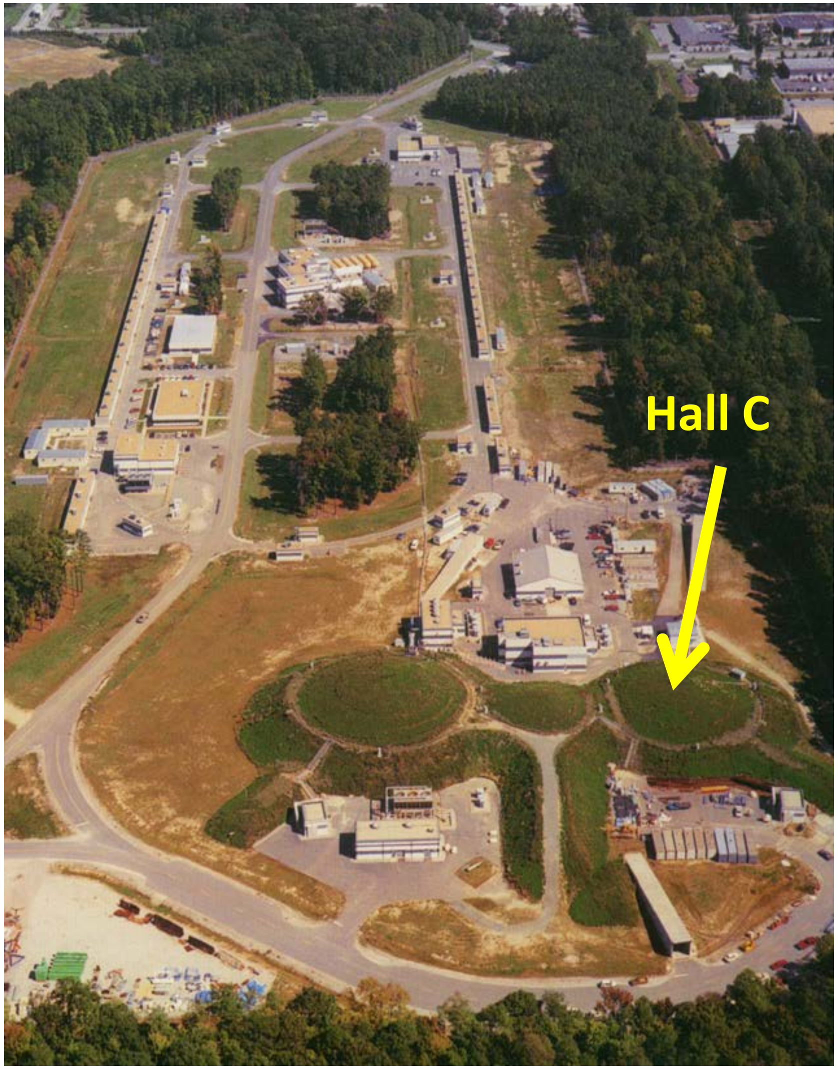
Qweak Experimental Setup



Qweak Experiment

- Goal: measure the weak charge of the proton via parity violating e-p scattering
- Integrating experiment: no thresholds or tracking
- 2200 hours of required beam time in order to reach statistical goal
- PV physics measured by flipping helicity of beam at 960Hz
- The predicted PV asymmetry is **270ppb**





Polarized Electron Beam at Jefferson Lab

- Electron beam is produced by shining a high intensity laser on a "superstrained" GaAs cathode which then emits electrons due to the photoelectric effect.
- If the laser is set up to be 100% circularly polarized, about 85% of the electrons will be emitted with the same spin as the photon beam.
- **Fast HelicityFlip:**

  Circular polarization of the laser is flipped @ 960Hz using a Pockels cell and flipping the polarity of the high voltage.
- **Slow Helicity Flip:**

  Inserting a half-wave plate in the source laser beam (hours). to flip the laser spin and thus the electron helicity relative to the Pockels cell voltage.

  Wien filter with crossed E and B fields cancels translational motion but precesses spin.

Tight Error Budget

Building on experience from "parity" experiments in the past such as HappeX, PreX and G0, Jefferson Lab staff and the Qweak collaboration have made some rather astounding achievements:

- Control beam position at the level of 10's of nanometers
- Maintain charge asymmetry at a few ppb while taking the highest current Jefferson Lab has ever delivered to a single hall

The table shows the main systematic errors of the experiment and what is allowed for each.

My main contribution to the experiment is in electron beam polarimetry.

$$A_{pv} = A_{meas} / P$$

	Asymmetry $\Delta A_z/A_z$	Weak Charge $\Delta Q_w/Q_w$
Statistical (2200 hours)	1.8%	2.9%
Systematic:		
Hadronic structure uncertainties	--	1.9%
Beam polarimetry	**1.0%**	**1.6%**
Absolute Q2 determination	0.5%	1.1%
Backgrounds	0.5%	0.8%
Helicity correlated beam properties	0.5%	0.8%
Total:	2.2%	4.1%

Polarimetry for Qweak/Hall C

Existing Moller polarimeter

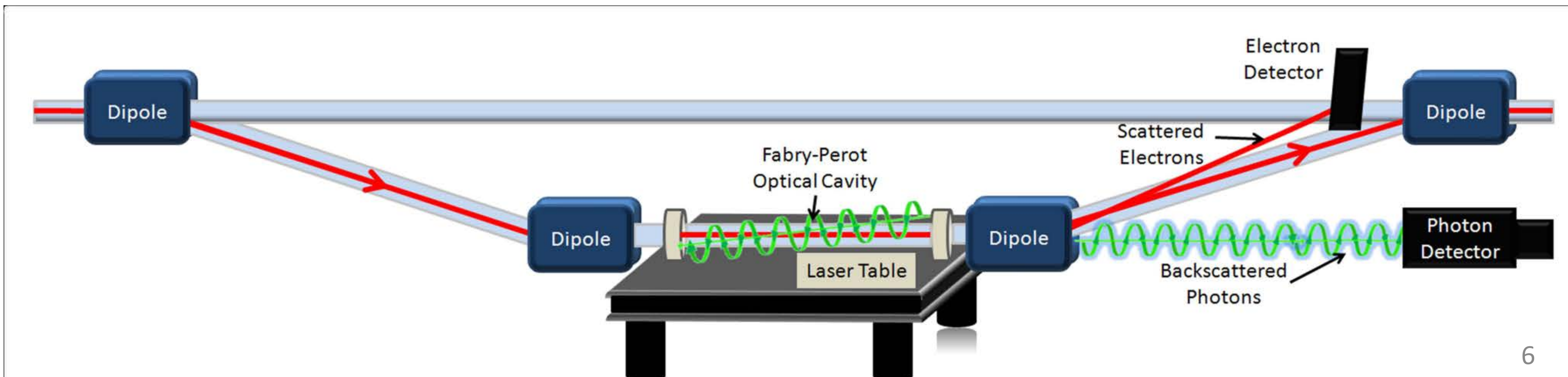
- In use for the past ten years
- well understood absolute standard but works only at low currents
- invasive measurement requiring several hours of dedicated beam time each week

New Compton polarimeter

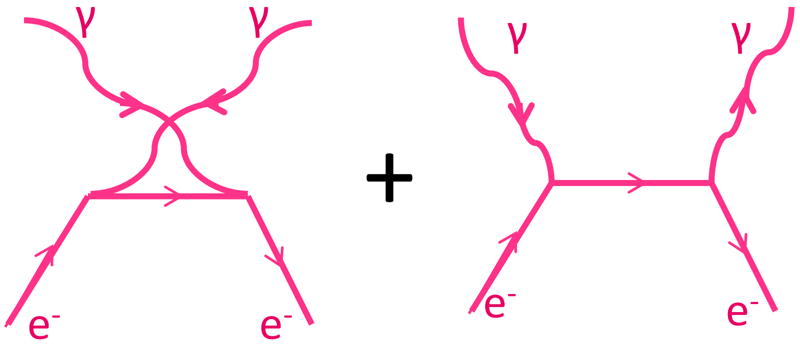
- non-invasive, continuous measurement
- two independent measurements using scattered e^-'s and γ's:
  coincidence useful for calibration
- the more current the better (Qweak: 160 μA)
- more difficult at low energies (Qweak: 1.16 GeV)

New Compton Polarimeter for Hall C

- 4 dipole magnets bend electron beam through chicane – dispersion ~57cm
- Electron beam collides with 10W laser (532nm) locked to Fabry-Perot optical cavity (gain >200)
- >1500W of light focused to 180 micron waist
- Detect scattered electrons and backscattered photons separately
- Provides two somewhat independent measurements



Basics of Compton Polarimetry



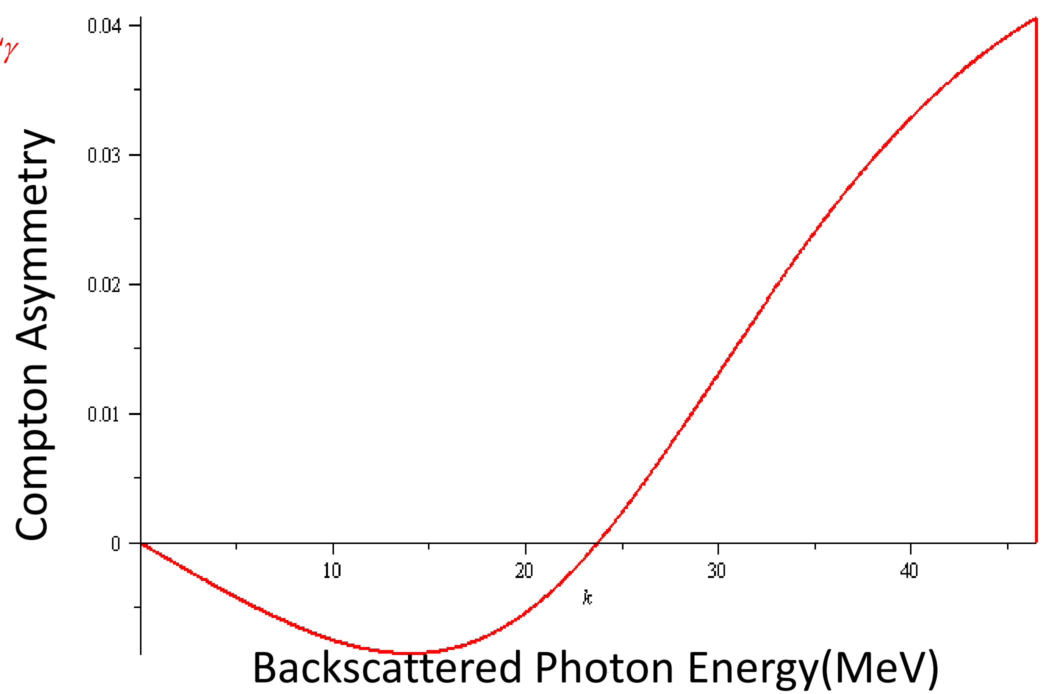
- The cross section of Compton scattering is different for right and left circularly polarized photons on polarized electrons.

$$\sigma_{R_e R_\gamma} = \sigma_{L_e L_\gamma} > \sigma_{L_e R_\gamma} = \sigma_{R_e L_\gamma}$$

$$A_{Comp} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

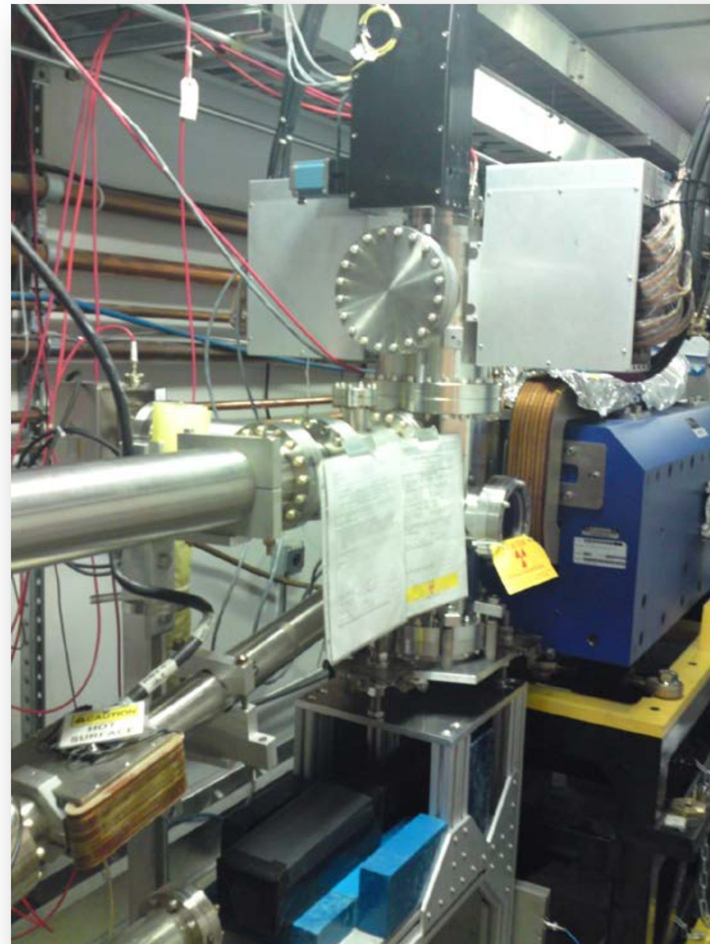
- We use this asymmetry to calculate beam polarization.

$$A_{meas} = P_\gamma P_e A_{Compton}$$

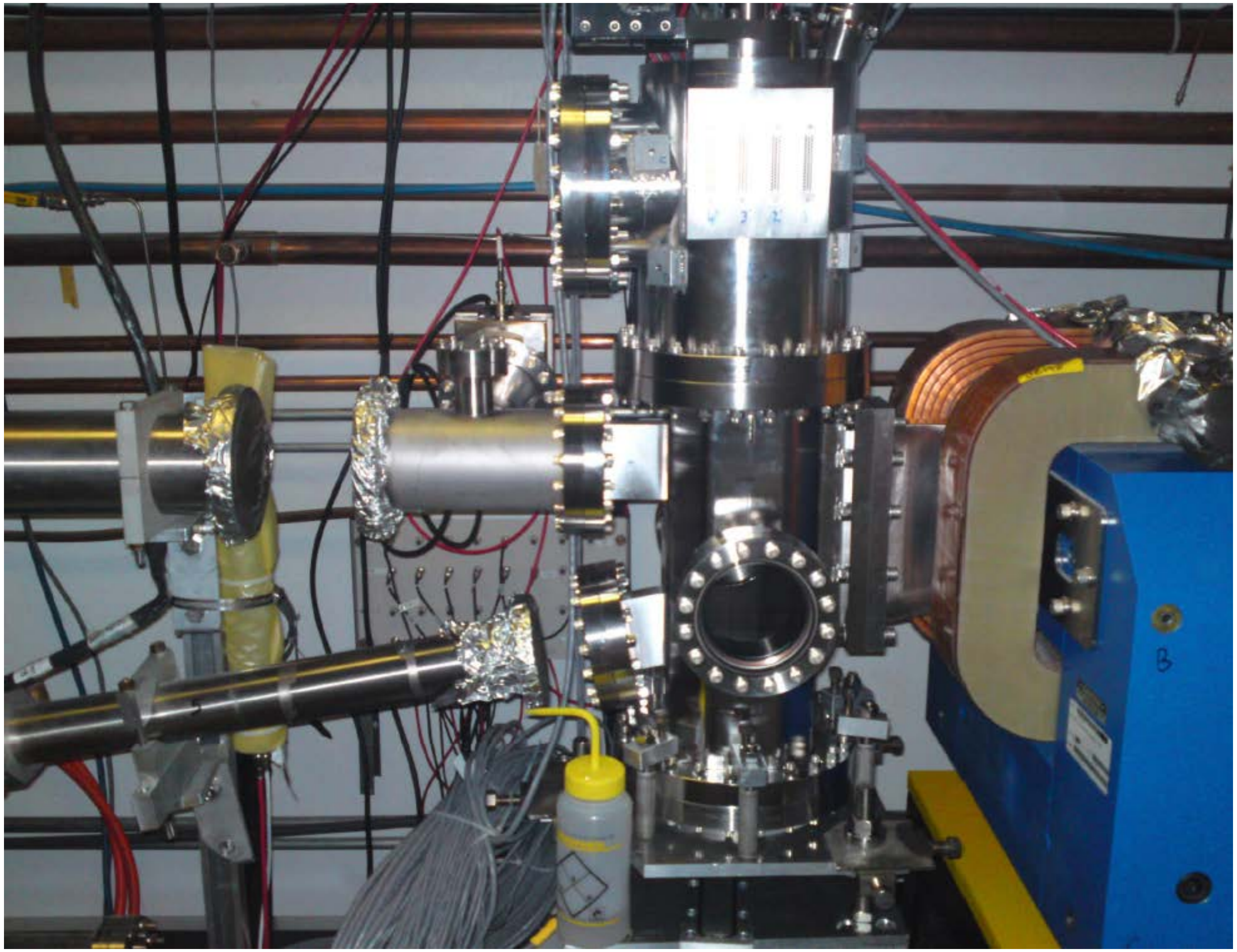


Electron Detector

- Sits about 5mm from the electron beam.
- 3rd dipole acts as a spectrometer to separate scattered electrons by energy
- Uses diamond plates with metal microstrips adhered to the surface
- First diamond strip detector to be used in a Compton polarimeter

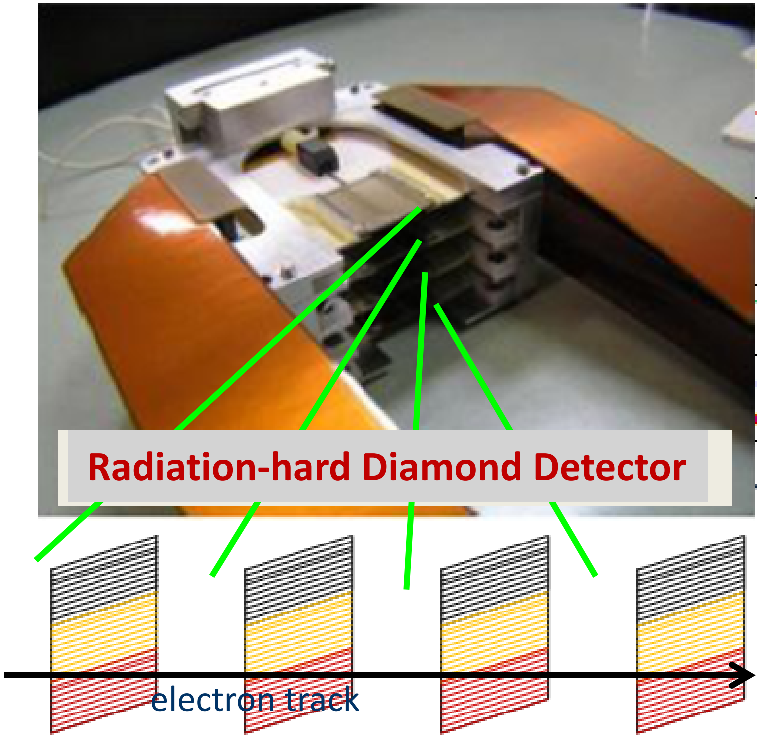


Electron Detector

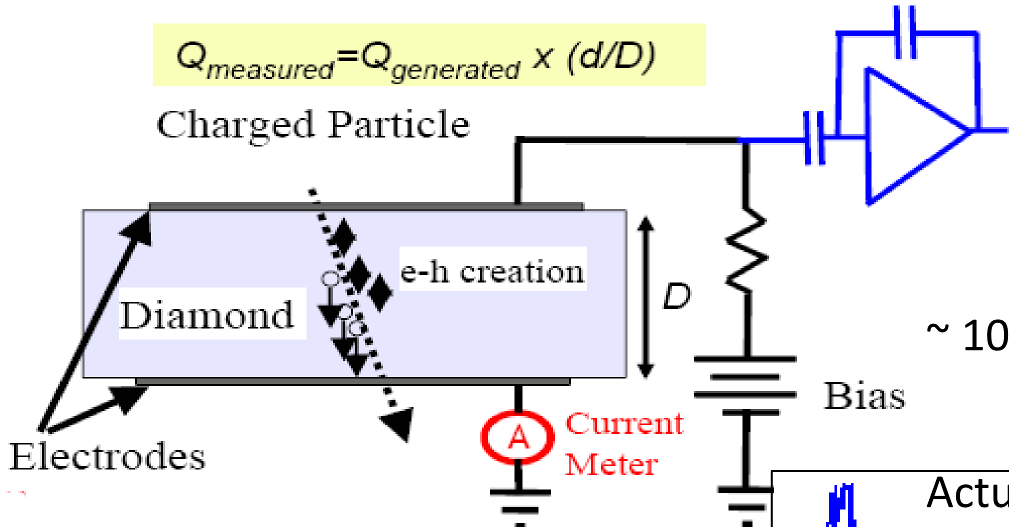


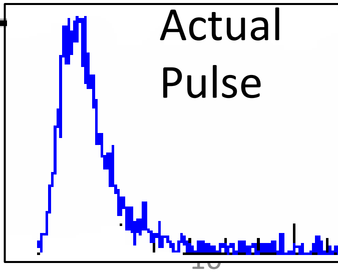
The Diamond Detector

- Diamond is known for its radiation hardness
- We chose artificially grown Diamond (grown by Chemical Vapor Deposition)
- Four 21mm x 21mm planes each with 96 horizontal 200um wide micro-strips.



How does it work?





Electron Detector

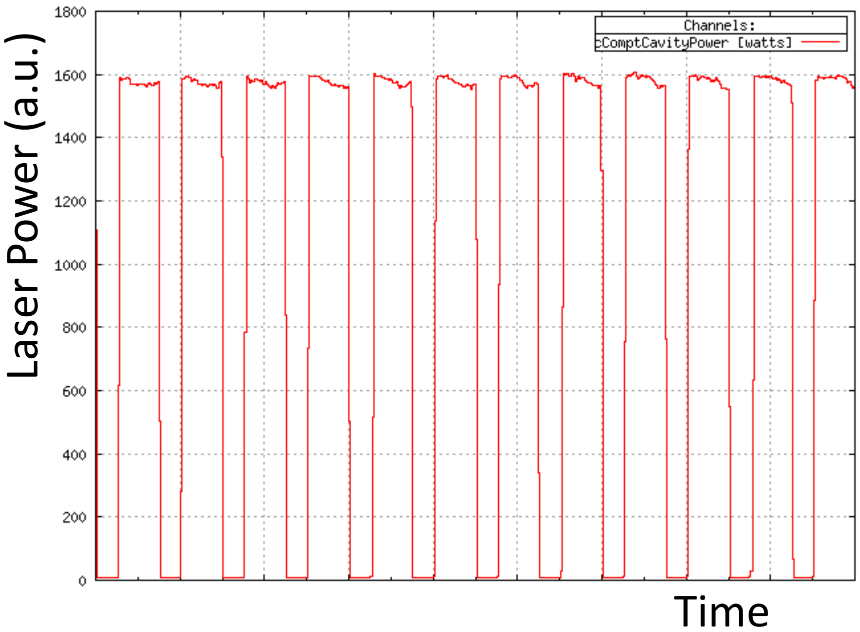
- We cycle the laser continuously on and off to measure backgrounds

$$A_{meas} = \frac{\left(N^+_{On} - a^+ N^+_{Off}\right) - \left(N^-_{On} - a^- N^-_{Off}\right)}{\left(N^+_{On} - a^+ N^+_{Off}\right) + \left(N^-_{On} - a^- N^-_{Off}\right)},$$

$$a^+ = \frac{Q^+_{On}}{Q^+_{Off}}, \quad a^- = \frac{Q^-_{On}}{Q^-_{Off}}$$

$$P_e = \frac{A_{meas}}{P_\gamma A_{Compton}}$$

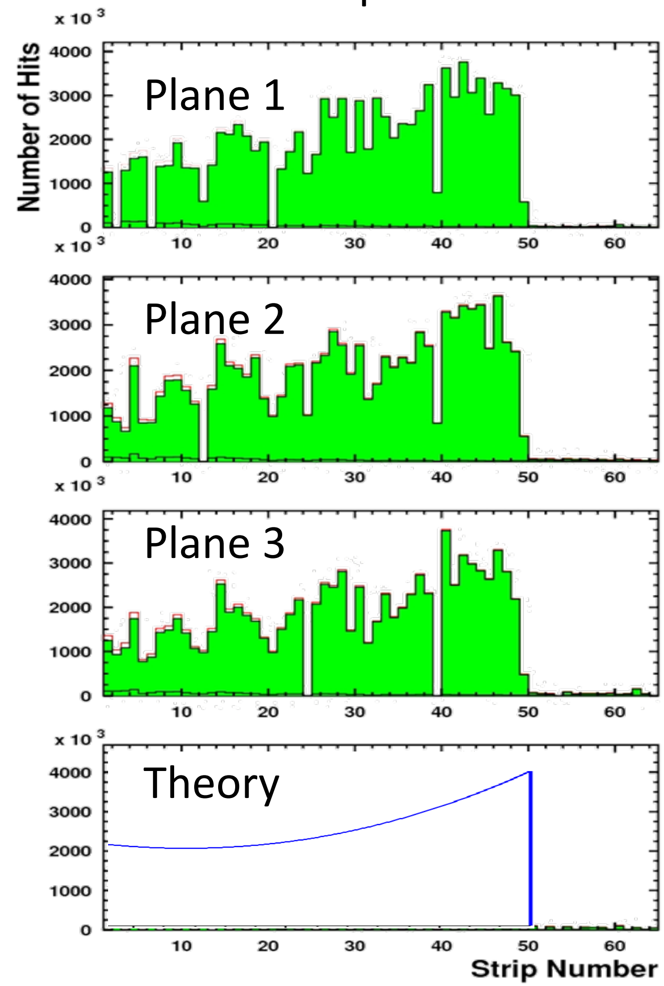
Laser Power vs Time



Electron Detector Spectrum

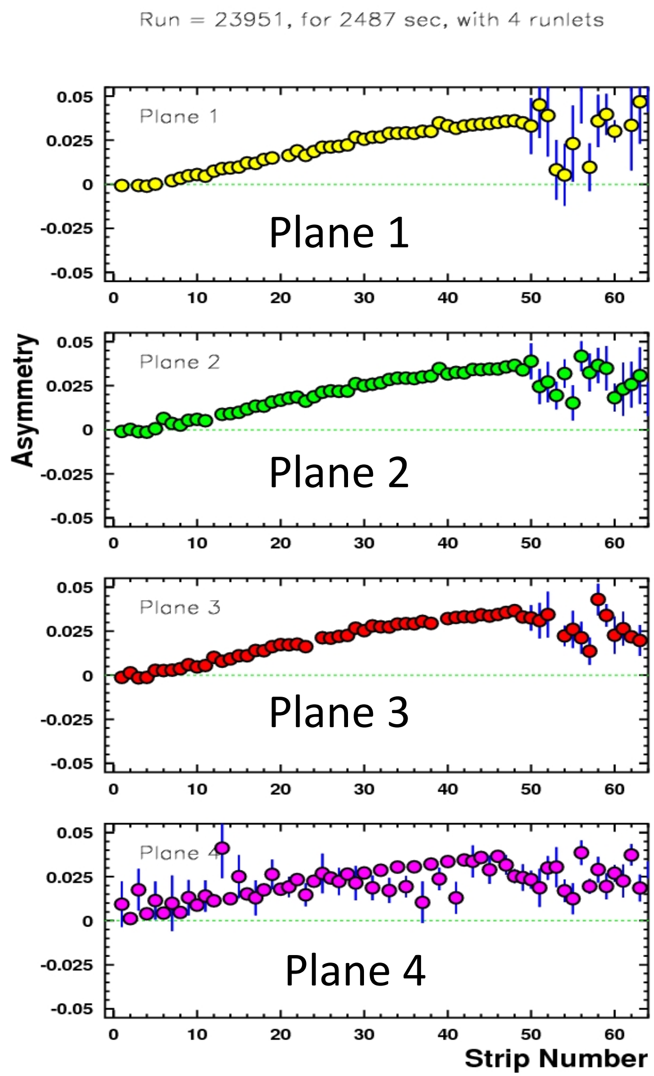
- We run with either a 2 out of 3 or a 3 out of 4 plane trigger
- For a hit to be accepted it must fall within four strips
- Spectrum goes just below asymmetry zero crossing
- Efficiencies vary from strip to strip
- Sum hits of all positive helicities and negative helicities for an entire run (typically 1hr)
- Form asymmetry for each strip

Hits vs. Strip Number



Electron Detector Asymmetry

- Asymmetries formed strip by strip so efficiency differences not important
- Compton edge determined either manually or by using the size of the error in each strip
- Systematic studies are underway to determine the effect of dead time on the asymmetries

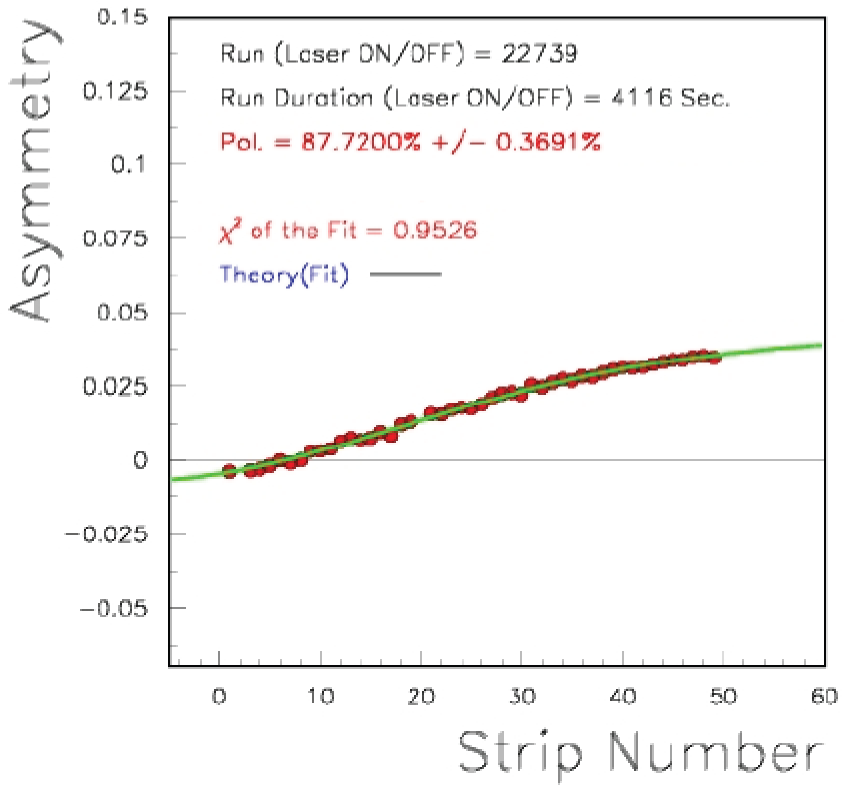


Electron Detector Asymmetry

- Asymmetry fit from theory with two fit parameters. It boils down to the following:

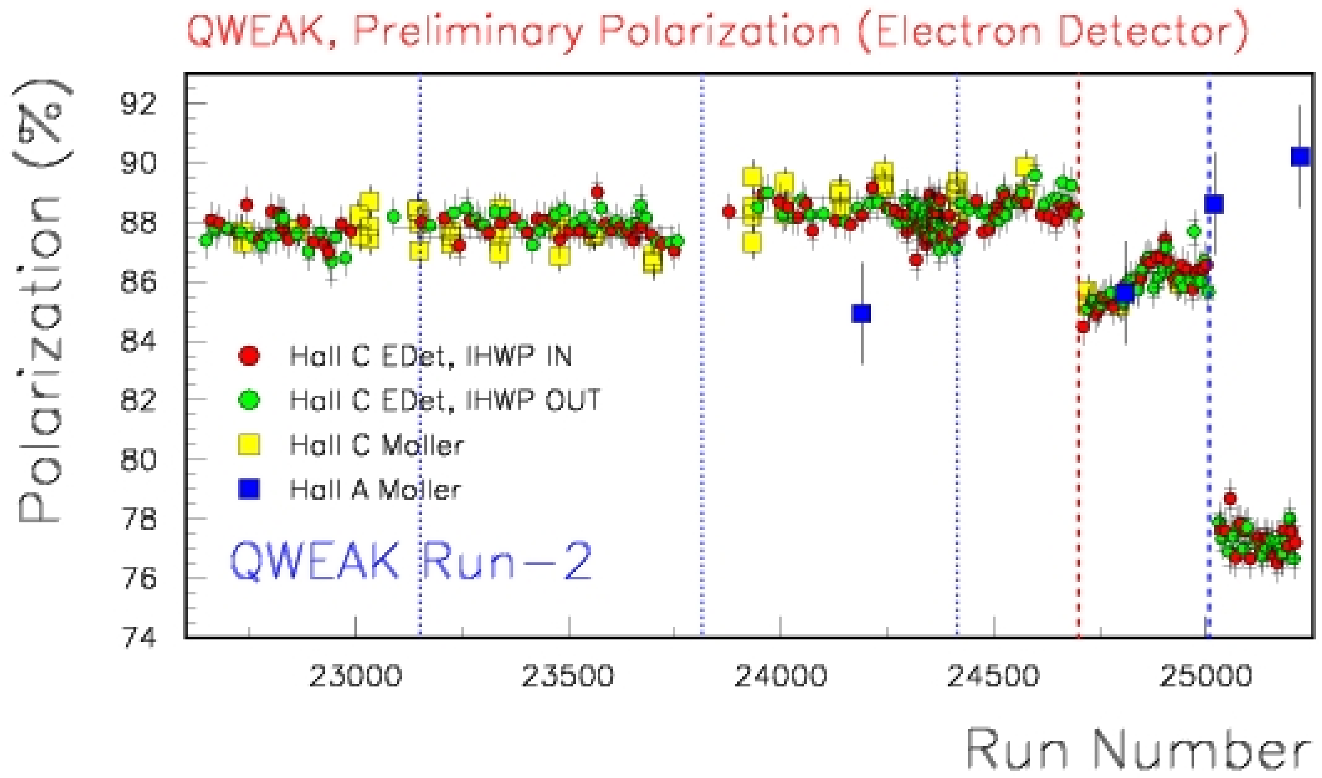
$$A_{meas} = P_e A_{theory}(a \times Strip\#)$$

- The fit to a gives the energy to strip conversion and combines net B.dl through the 3rd dipole, detector plane angle relative to beam, strip separation and the effect of beam motion.
- Makes us relatively insensitive to a host of systematics



Plane 4

Electron Asymmetries over Past Few Months



Routinely achieve <0.6% statistical error per hour

Photon Detector

- Uses a PMT attached to a scintillating crystal
- Integration technique

  -no thresholds

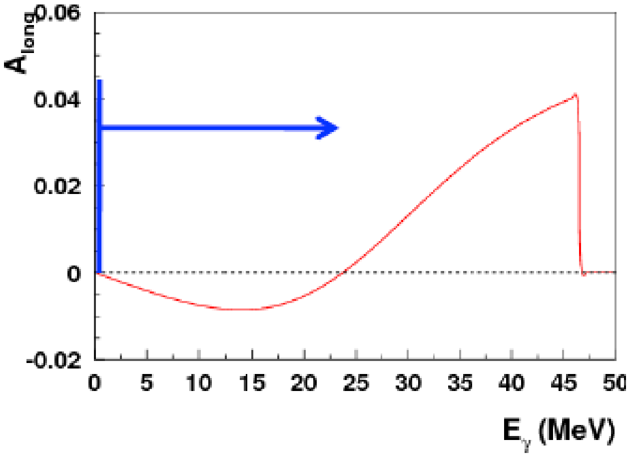
  -200MHz sampling

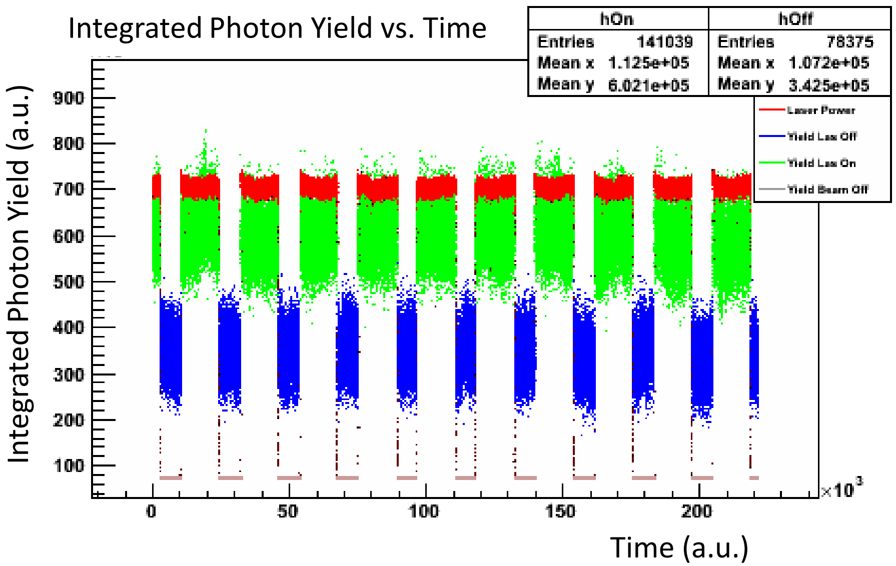
  -stores one value / ms

  - insensitive to gain drifts
- Measuring energy weighted asymmetry. Expect A~2%.

$$A_{meas} = \frac{\int_0^{E_\gamma^{max}} A_{Compton} E_\gamma dE_\gamma}{\int_0^{E_\gamma^{max}} E_\gamma dE_\gamma}$$

- Need to subtract backgrounds carefully

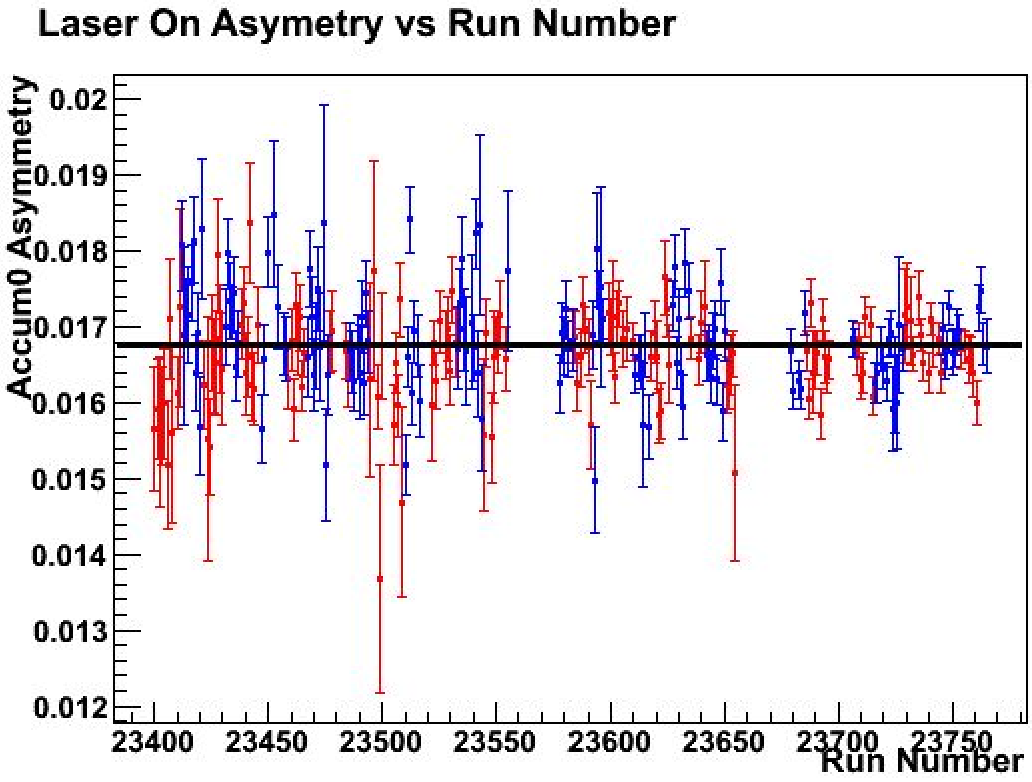




Hall C Photon Detector: a Tale of 3 Crystals

- We chose to go with a 4x4 matrix of $PbWO_4$ crystals
- Total dimensions 6x6x20cm
- Low light yield and poor resolution but integration technique not so sensitive to this
- Yields similar results to GSO
- Increased light yield by about 20% by cooling crystals to 14^{o} C
- Final analyzing power for this crystal will come from GEANT 3 and 4 simulations

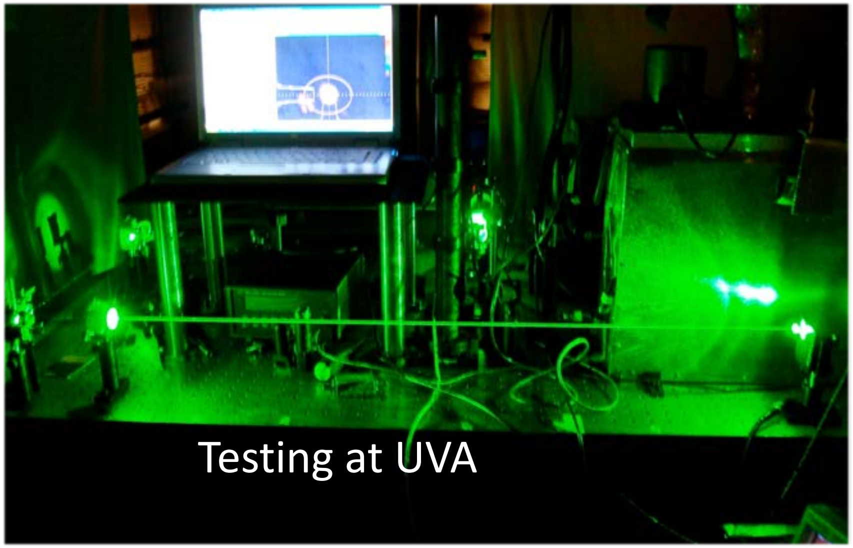
$PbWO_4$ Asymmetries vs. Time

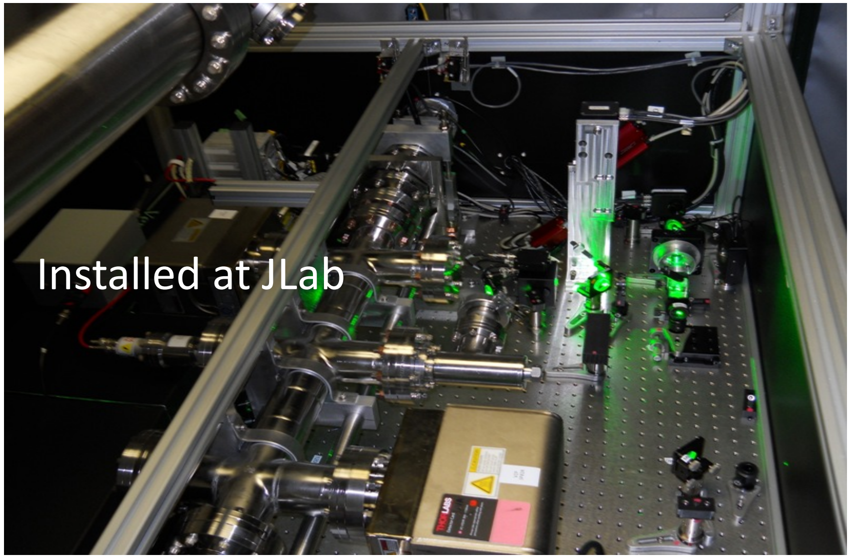


- Recently we have been able to reach 1% statistics in about an hour

Photon Target for Compton Polarimeter

- Requires a tightly focused intense photon beam
- Green 10W laser locked to Fabry-Perot cavity

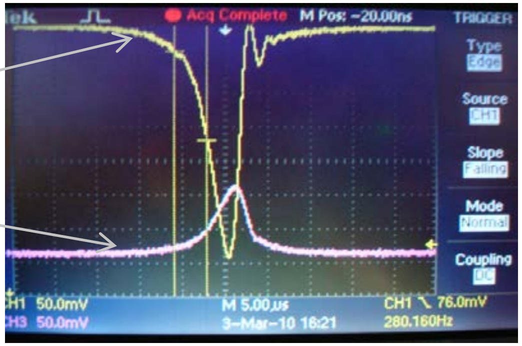




Locking a Fabry-Perot Optical Cavity

Reflected Signal

Transmitted Signal

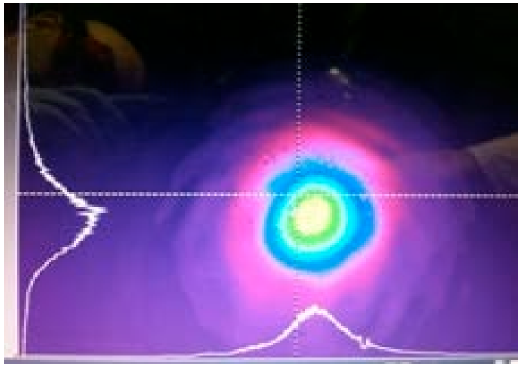


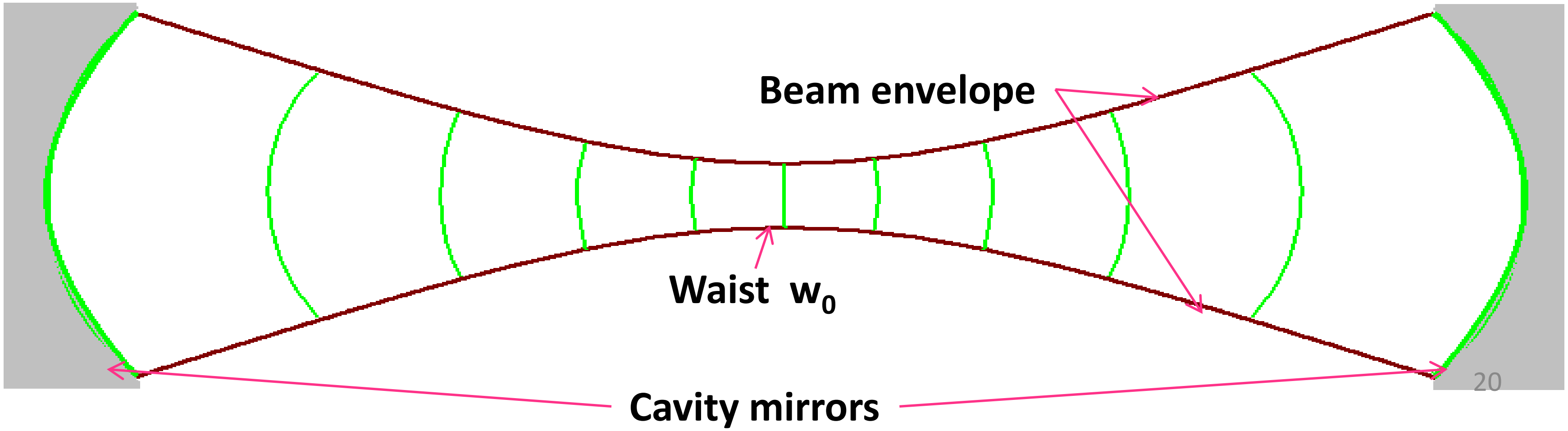
->Resonance Condition:

$$n\lambda = 2L$$

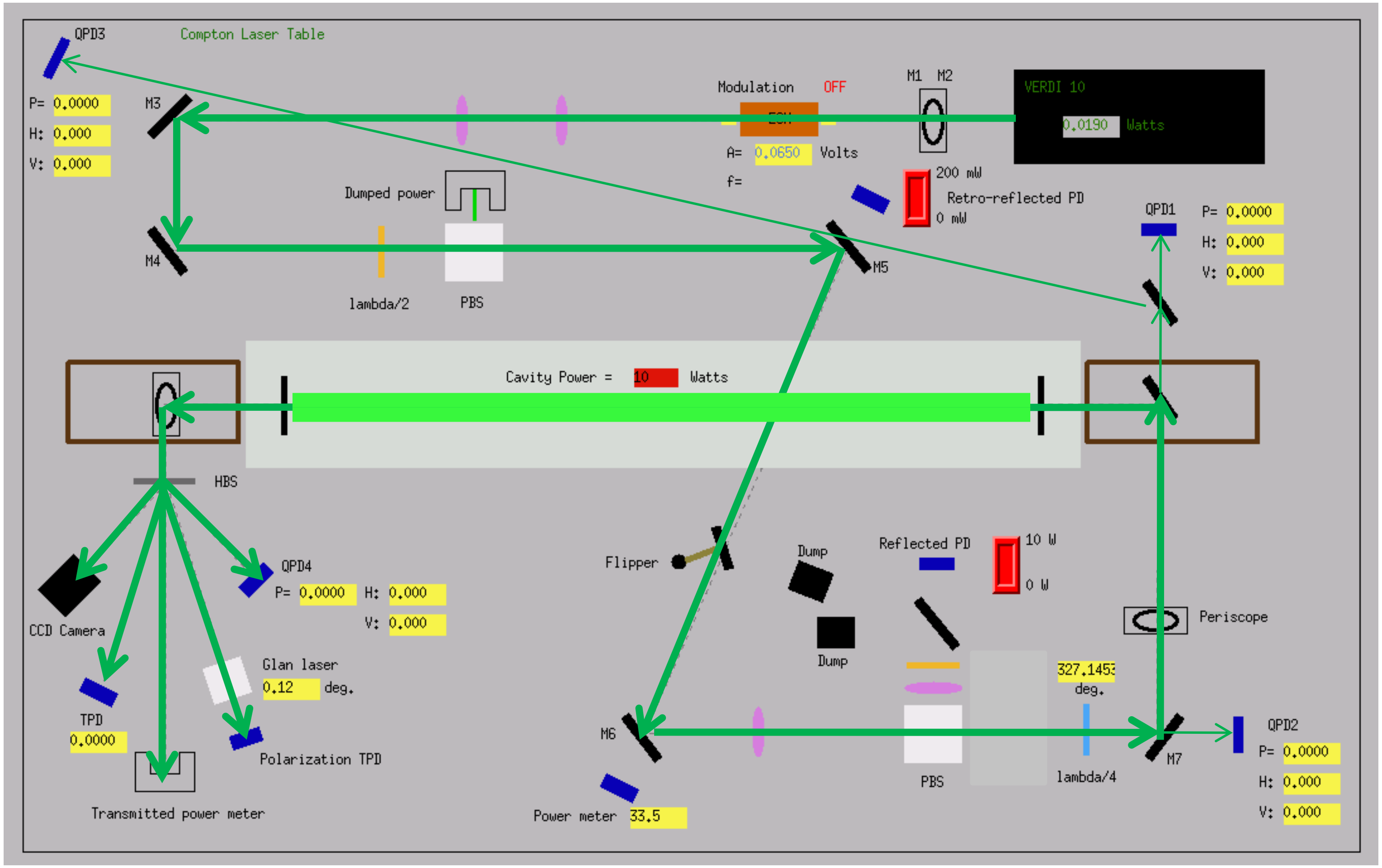
->Mode Matched Gaussian Beam:

- well defined envelope, phase wave front with a radius of curvature, R, and focus to a waist.
- R must match that of the cavity mirrors and waist must be at center of cavity.

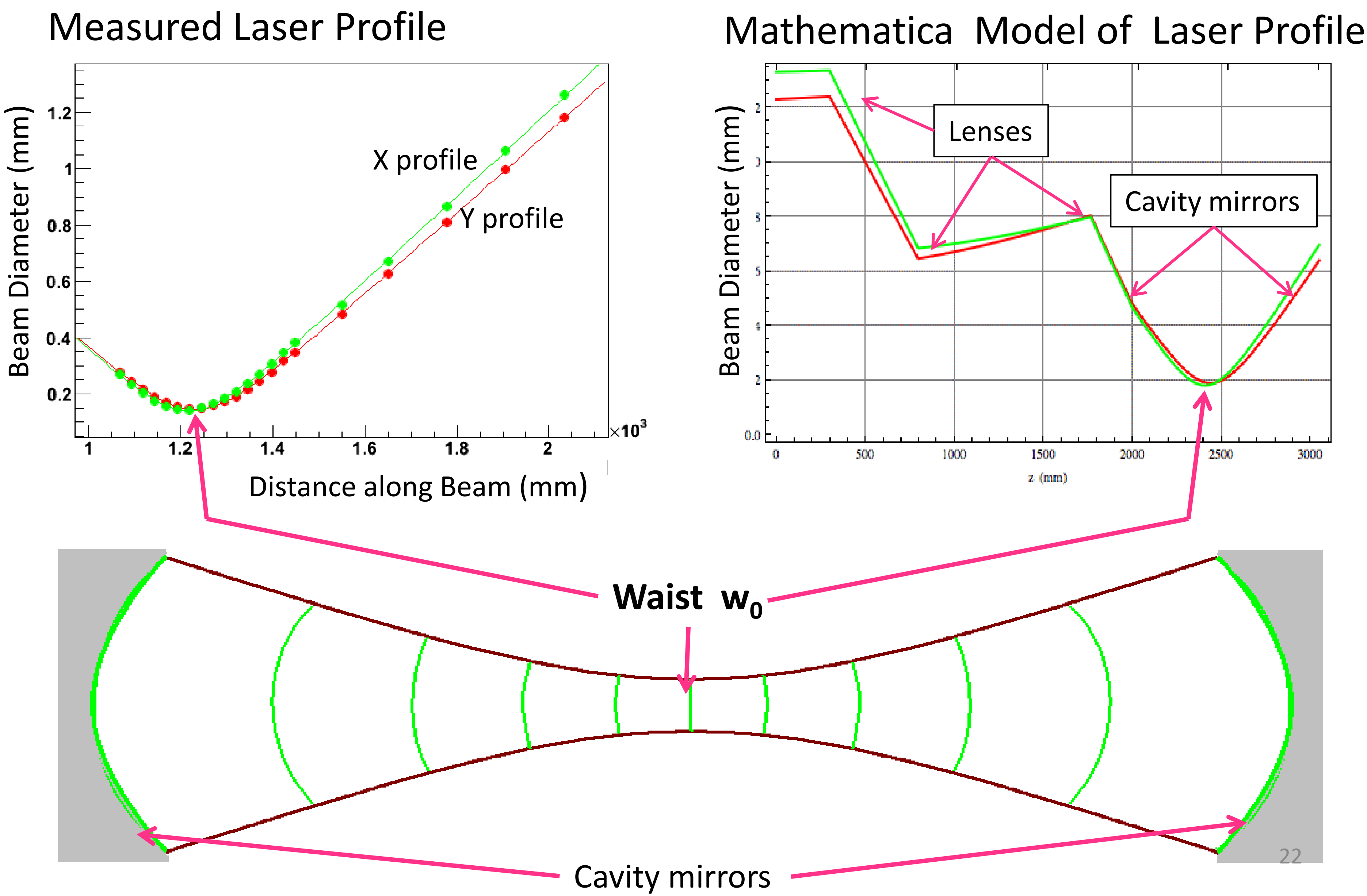




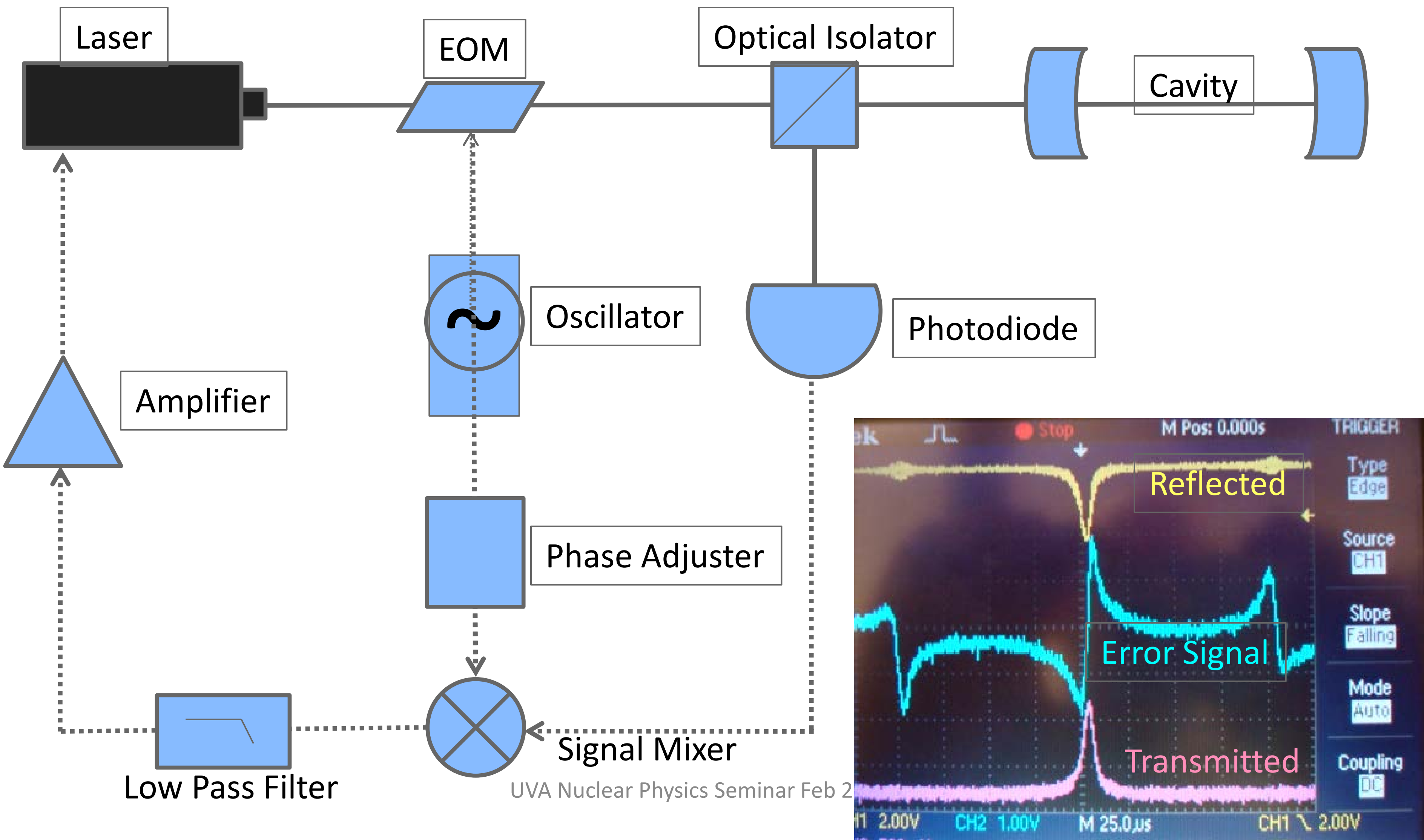
Laser Table Schematic



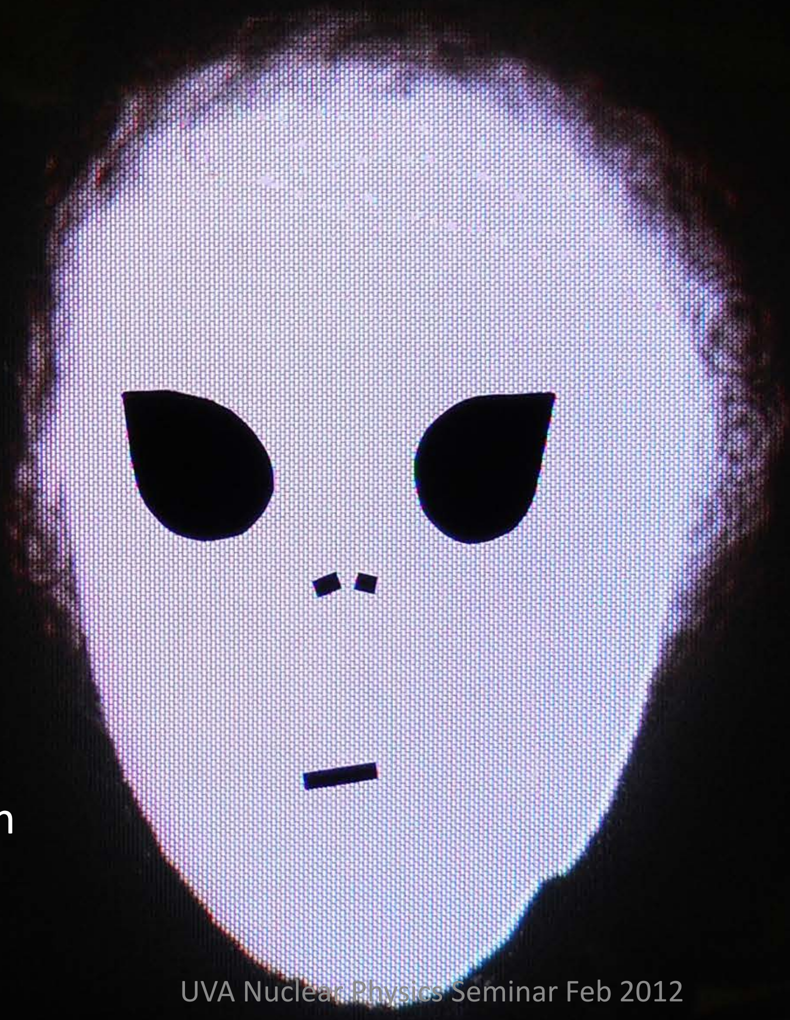
Mode Matching the Laser to the Cavity



Locking with PDH method



Locked Cavity as Seen in on CCD Camera in Counting House



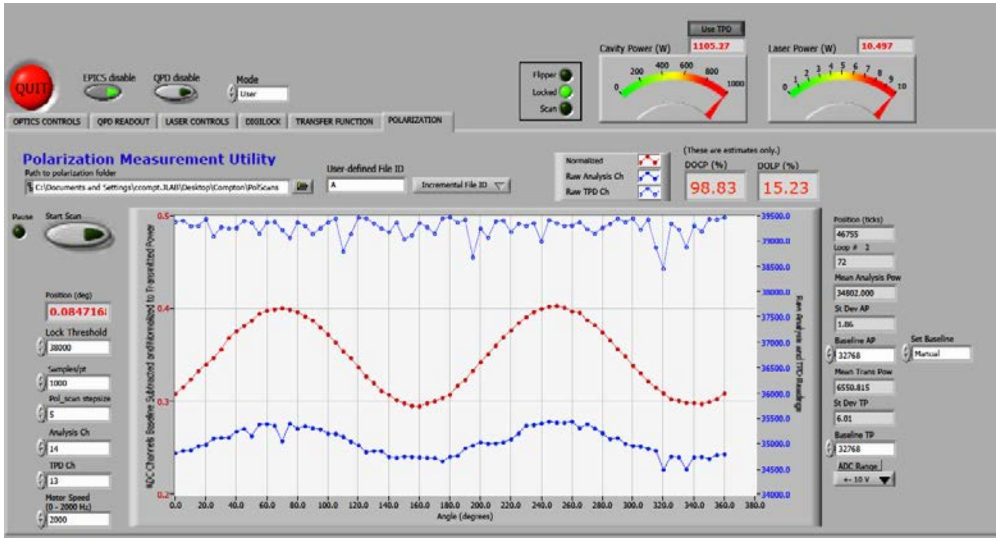
P.S. It doesn't take much to entertain grad students.

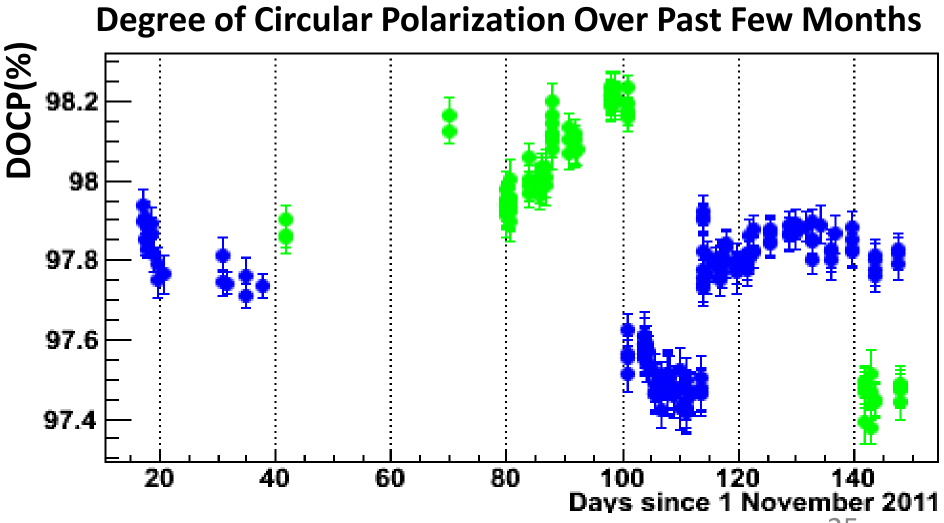
Determining Intracavity Laser Polarization

- Developed a set of tools for measuring polarization of the laser in the exit line

$$P = \frac{Amplitude}{Offset} \approx \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

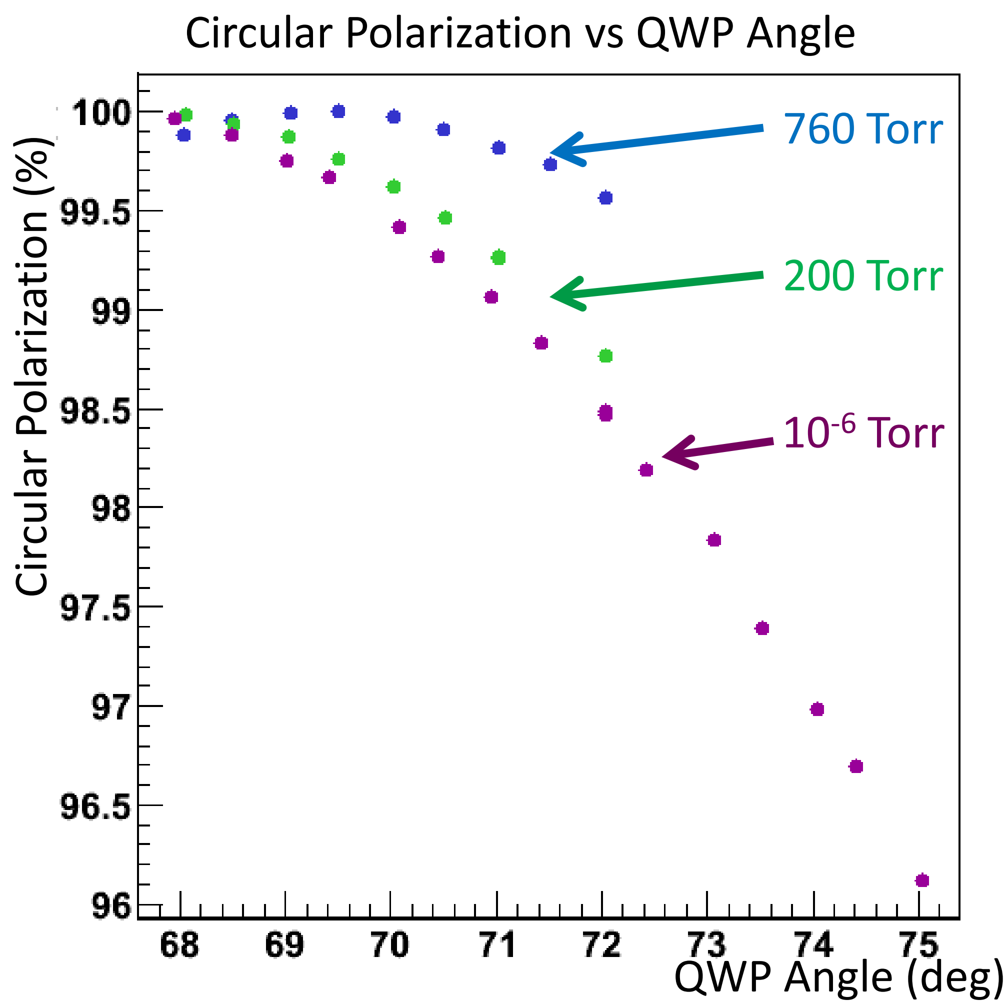
- Decent stability over time as measured in exit line.
- Expect intracavity stability to be better .
- Need to fit parameters of the polarization Transfer Function (TF) to determine intracavity degree of circular polarization (DOCP) from exit line measurement



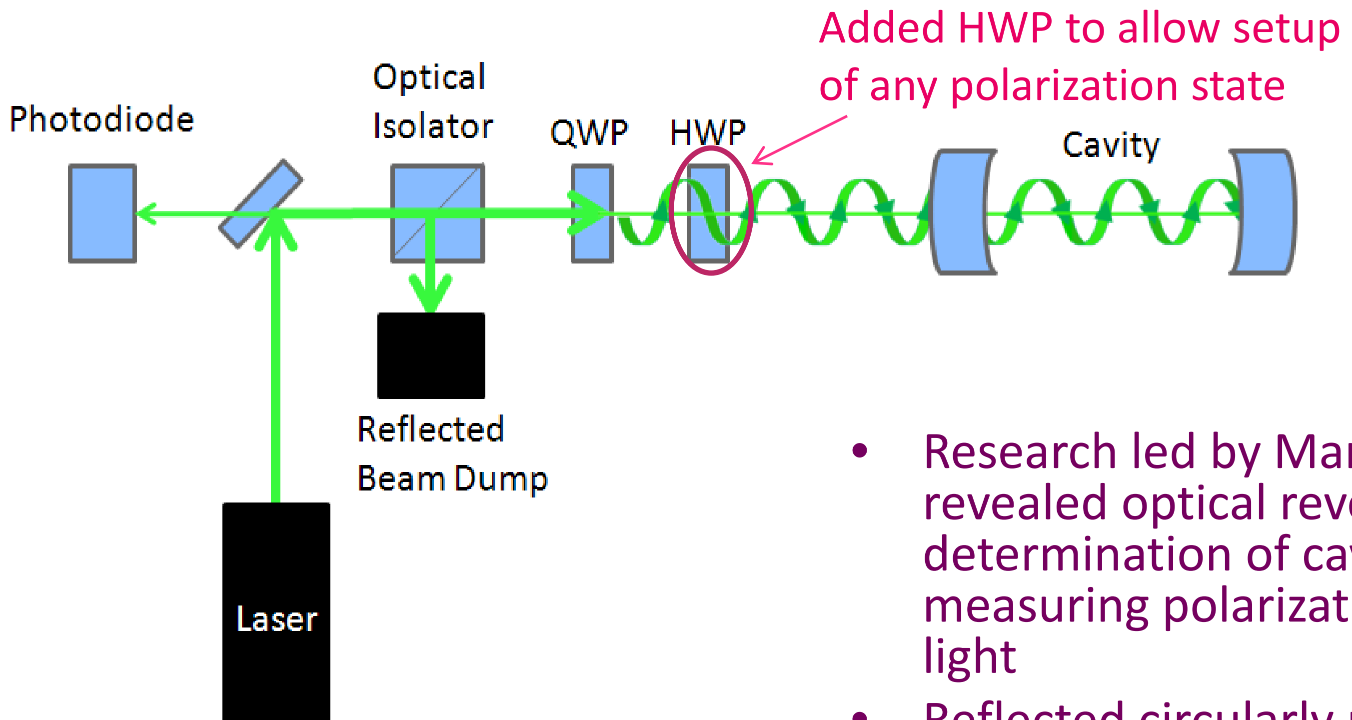


Transfer Function not Constant

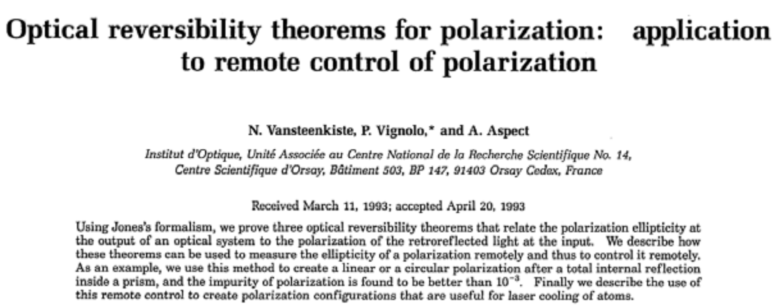
- Takes days and hundreds of careful measurements
- Set up known states of light in cavity and measure them inside and in the exit station
- Fit data to find transfer matrix
- Automated data collection saves us hours
- The TF changed when we tightened the bolts on the vacuum flanges near the windows and when we pulled vacuum.
- How accurate is our TF now?



Making Use of Optical Transport Symmetry



- Research led by Mark Dalton(UVA) revealed optical reversibility allows determination of cavity DOCP by measuring polarization of reflected light
- Reflected circularly polarized light is blocked by the isolator and dumped
- Residual linear polarization “leaks” through: measured by photodiode
- Minimizing “leakage” power in the photodiode maximizes DOCP at cavity



Optical reversibility theorems for polarization: application to remote control of polarization

N. Vansteenkiste, P. Vignolo,* and A. Aspect

Institut d'Optique, Unité Associée au Centre National de la Recherche Scientifique No. 14, Centre Scientifique d'Orsay, Bâtiment 503, BP 147, 91403 Orsay Cedex, France

Received March 11, 1993; accepted April 20, 1993

Using Jones's formalism, we prove three optical reversibility theorems that relate the polarization ellipticity at the output of an optical system to the polarization of the retroreflected light at the input. We describe how these theorems can be used to measure the ellipticity of a polarization remotely and thus to control it remotely. As an example, we use this method to create a linear or a circular polarization after a total internal reflection inside a prism, and the impurity of polarization is found to be better than 10^{-3}. Finally we describe the use of this remote control to create polarization configurations that are useful for laser cooling of atoms.

1. N. Vansteenkiste, P. Vignolo, and A. Aspect, "Optical reversibility theorems for polarization: application to remote control of polarization," J. Opt. Soc. Am. A **10**, 2240-2245 (1993)

Scans of Leakage Power

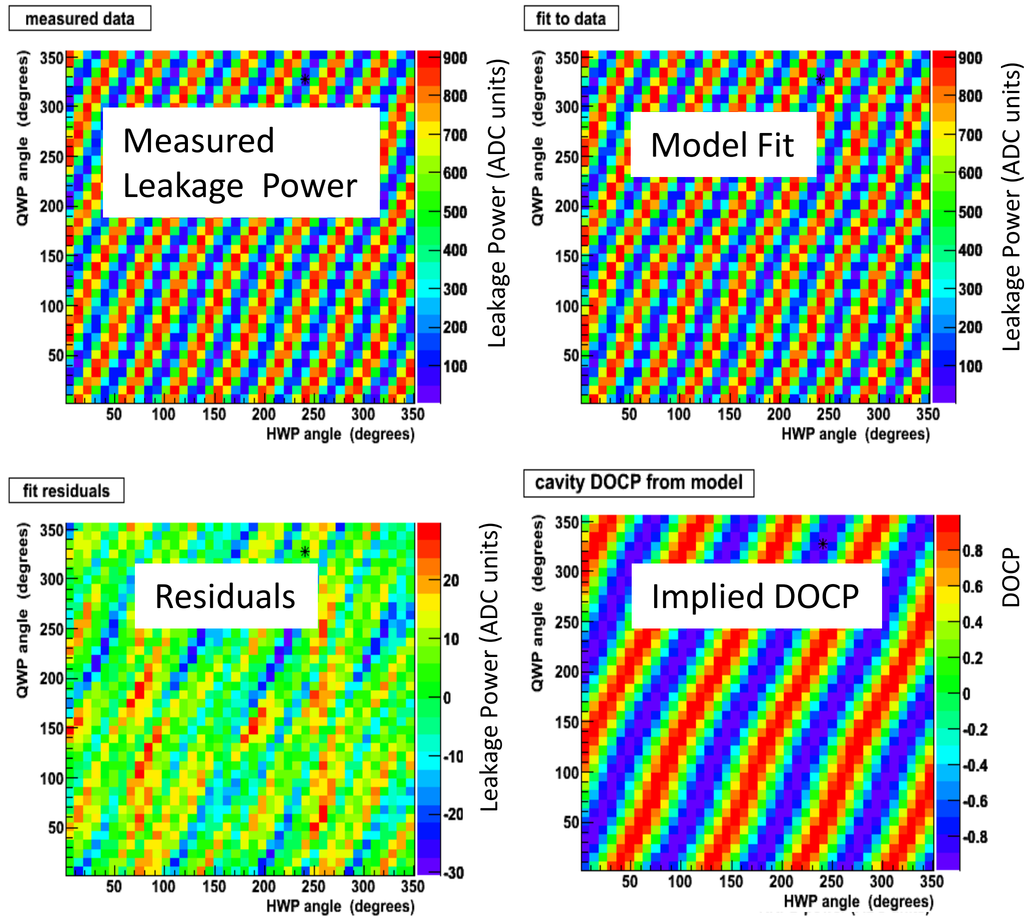
- Took scans of leakage power as measured by the photodiode vs. angle of QWP and HWP over full phase space
- Fit data to a model which includes imperfect HWP and QWP and an arbitrary birefringent element at undetermined angle

>Fit yields:

HWP 3.3% thin

QWP 1.1% thick

Arbitrary Birefringence π/30



plots from fit by M. Dalton

Conclusions

- We have a successfully brought on line a new Compton polarimeter for Hall C and are measuring beam polarization with <1% statistical error each hour
- Studies are ongoing to determine and reduce systematic errors
- I am optimistic that our new method for determining laser polarization will further reduce this key systematic shared by both photon and electron detectors

Contributors

Jefferson Lab, *D. Gaskell and the Hall C staff,* Mississippi State University, *D. Dutta , A. Narayan,* University of Virginia, *K. Paschke , M. Dalton, D. Jones,* University of Winnipeg/TRIUMF, *J. Martin , V. Tvaskis, L. Lee, D. Ramsay, L. Kurchaninov,* College of William and Mary, *W. Deconinck, J. C. Cornejo,* MIT-Bates, *S. Kowalski, E.Ihloff, and technical staff.*

Electron Detector Systematic Uncertainties

Source	dAsy/Asy (%)
Laser polarization*	0.4%
Size of strip	0.2%
Strip separation	0.35%
Plane-to-plane differences	0.2%
Dipole magnetic field	0.05%
Dipole fringe field effects	?
Dead time	?
Beam/laser overlap	?
Time dependence of backgrounds	?
Total	0.6%

Currently working to reduce these.

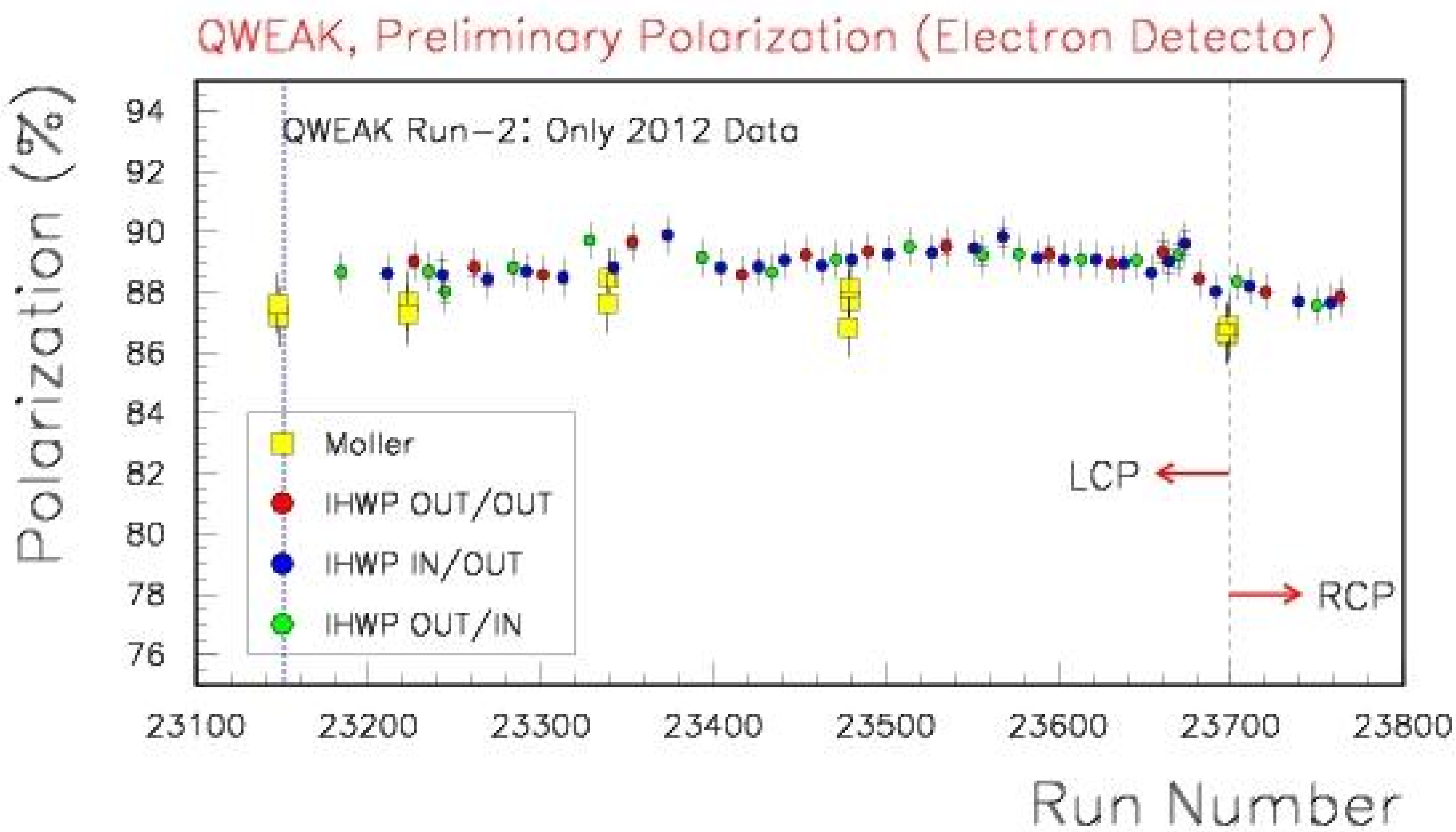
Comparison of Diamond with Silicon

Property	Silicon		Diamond	
Band Gap (eV)	1.12	→	5.45	Low leakage current shot noise
Electron/Hole mobility (cm^2/Vs)	1450/500	→	2200/1600	Fast signal collection
Saturation velocity (cm/s)	0.8×10^7	→	2×10^7	
Breakdown field (V/m)	3×10^5	→	2.2×10^7	
Dielectric Constant	11.9	→	5.7	Low capacitance noise
Displacement energy (eV)	13-20	→	43	Radiation hardness
e-h creation energy (eV)	3.6	→	13	Smaller signal
Av. e-h pairs per MIP per micron	89	→	36	
Charge collection distance (micron)	full	→	~250	

Advantages: lower leakage current, faster, lower noise and Radiation Hard

Disadvantages: signal ~ 40% smaller

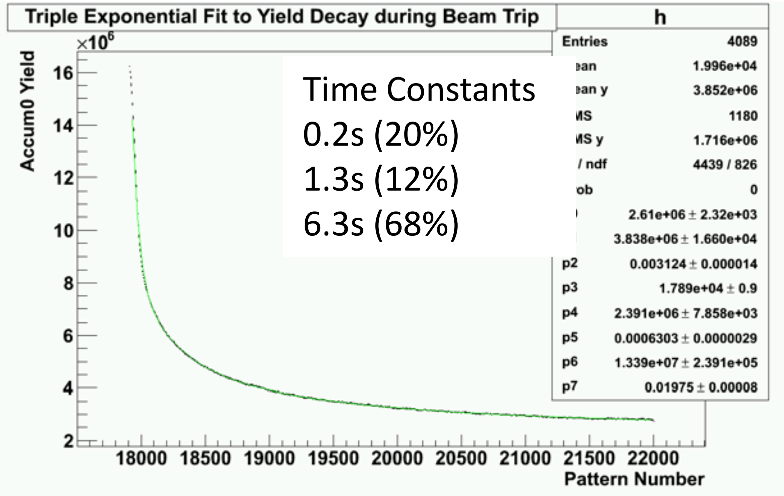
Or Averaged over "Slugs"



Notice that in addition to flipping half-wave plate in the injector, we also check for systematics in the polarization analysis by flipping the spin of the laser from left circularly polarized (LCP) to right circularly polarized (RCP).

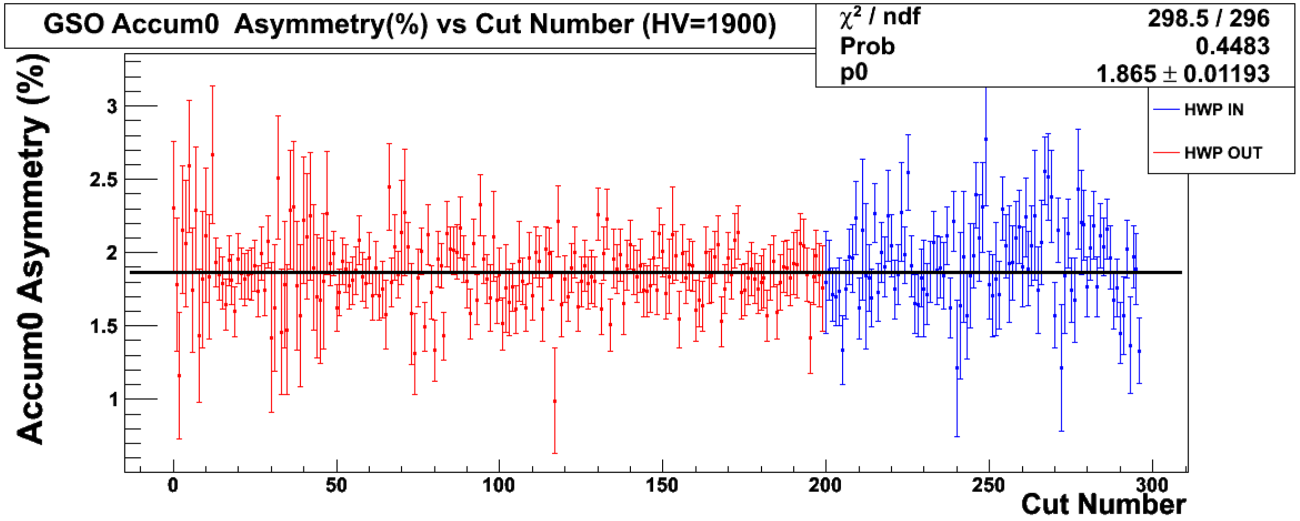
Hall C Photon Detector: a Tale of 3 Crystals

- Started with single undoped CsI crystal
  - -10x10x30cm
  - - good energy resolution
  - - attached to 3” Hamamatzu PMT (gain 5x10 ^{6}, 3ns rise time)
- Measured asymmetries about 0.6%
- Phosphorescence in crystal: is is truly undoped?
- Light with “long” time constants made it difficult to properly subtract background and may have also yield incorrect helicity correlated yield differences.



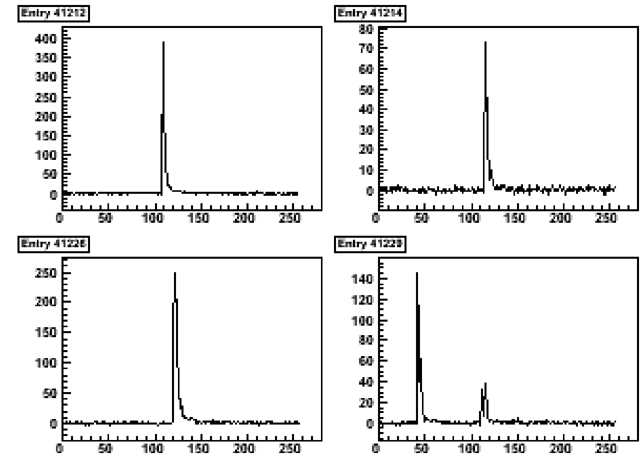
Hall C Photon Detector: a Tale of 3 Crystals

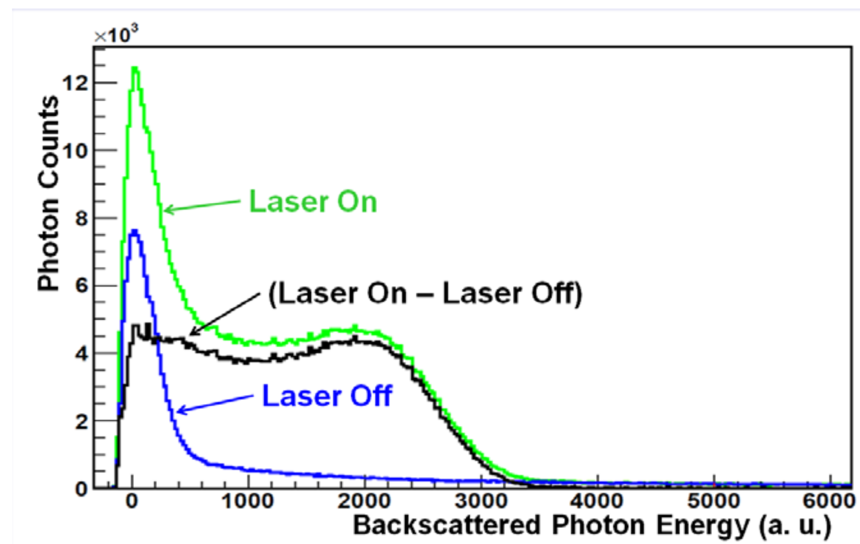
- Borrowed a GSO crystal from Hall A and immediately started seeing reasonable asymmetry values ~1.8%
- Excellent light yield and fast response.
- Good energy resolution. Ideal for Compton polarimetry
- A similar crystal was $70k



PbWO$_4$ Spectrum

- Integrating flash ADC (200MHz) also takes one pulse snapshot per ms
- Using these we can construct an energy spectrum for our detector
- The spectrum will be used to check our simulation





Test of Model

- Varied the laser polarization under stable electron beam conditions according to the model around the peak 100% DOCP
- Results from preliminary electron detector asymmetries verified optical model and position of peak DOCP.