Hall A Compton Polarimeter

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PREX/CREX Collaboration Meeting
February 24, 2016

1. Compton requirements for PREX/CREX
2. Laser status and performance
3. Photon Detector (→ Gregg Franklin)
4. Electron detector
5. Running the Compton in the 12 GeV era

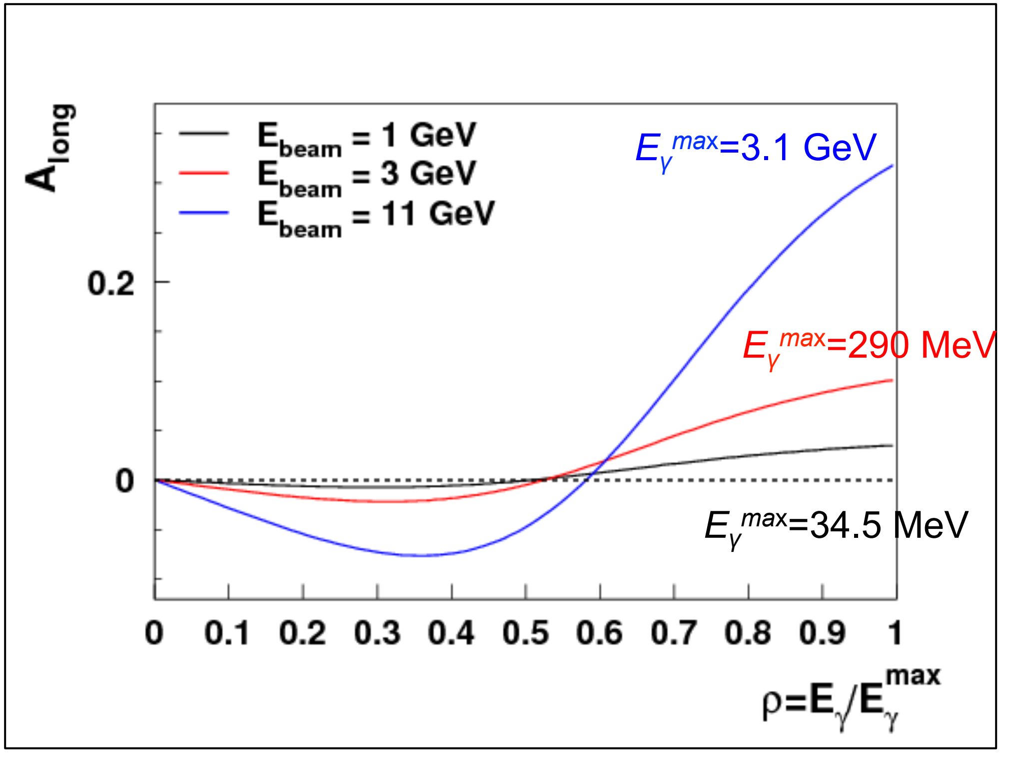
Compton Polarimetry

Compton polarimetry is non-destructive – allows polarization measurements without affecting the experiment

Two main challenges for Compton polarimetry at JLab

→ Relatively low beam currents (~100 μA) - need novel laser technology

→ Relatively small asymmetries (compared to colliders)

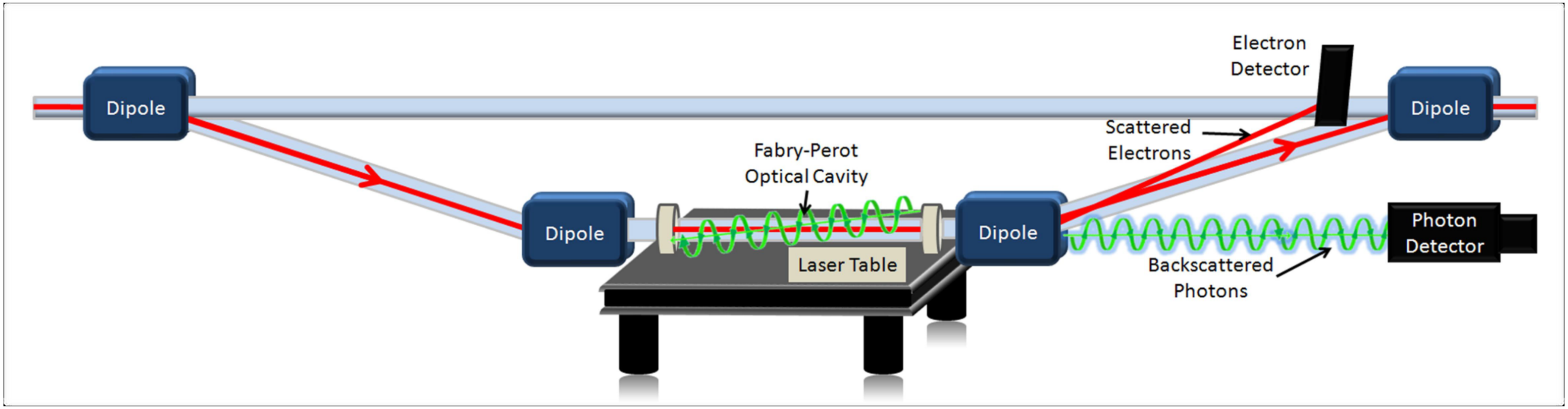


Asymmetry has a strong dependence on backscattered photon energy
→ Understanding detector response is crucial (or is it?..)

Compton Polarimetry at JLab

- Low beam currents → large laser power
  - Achieving sufficient rates for backscattered photons requires large laser power
  - Use low power laser locked to external Fabry-Perot cavity to achieve ~ kW level powers
  - Introduces problems in understanding laser polarization in cavity
- Photon detection and detector response
  - Measurements of differential photon spectrum (asymmetry vs. energy) requires detailed knowledge of detector response
  - CMU approach uses integrating technique to sidestep this issue – just need to understand the detector linearity

Hall A Compton Overview



1. Laser system: 1 W green drive laser coupled to high gain Fabry-Perot cavity → several kW intracavity power
2. Photon detector: GSO crystal operated in integrating mode (low energies) → high energy crystal under study: lead-tungstate?
3. Electron detector: silicon strip detector → 240 μm pitch, 192 strips/plane
4. DAQ: CMU, integrating mode photon DAQ. New counting mode photon DAQ + new electron detector DAQ under development

Compton Polarimetry for PREX/CREX

Compton configuration for PREX/CREX
→ Should be “easy” – been here before
→ Chicane configuration has changed – smaller deflection so photon detector closer to beamline
→ Cannot effectively use electron detector for PREX: Compton edge only ~7 mm from beam
→ Perhaps could be used for CREX: CEDGE @ 1.4 cm, zero-Xing @ 7mm

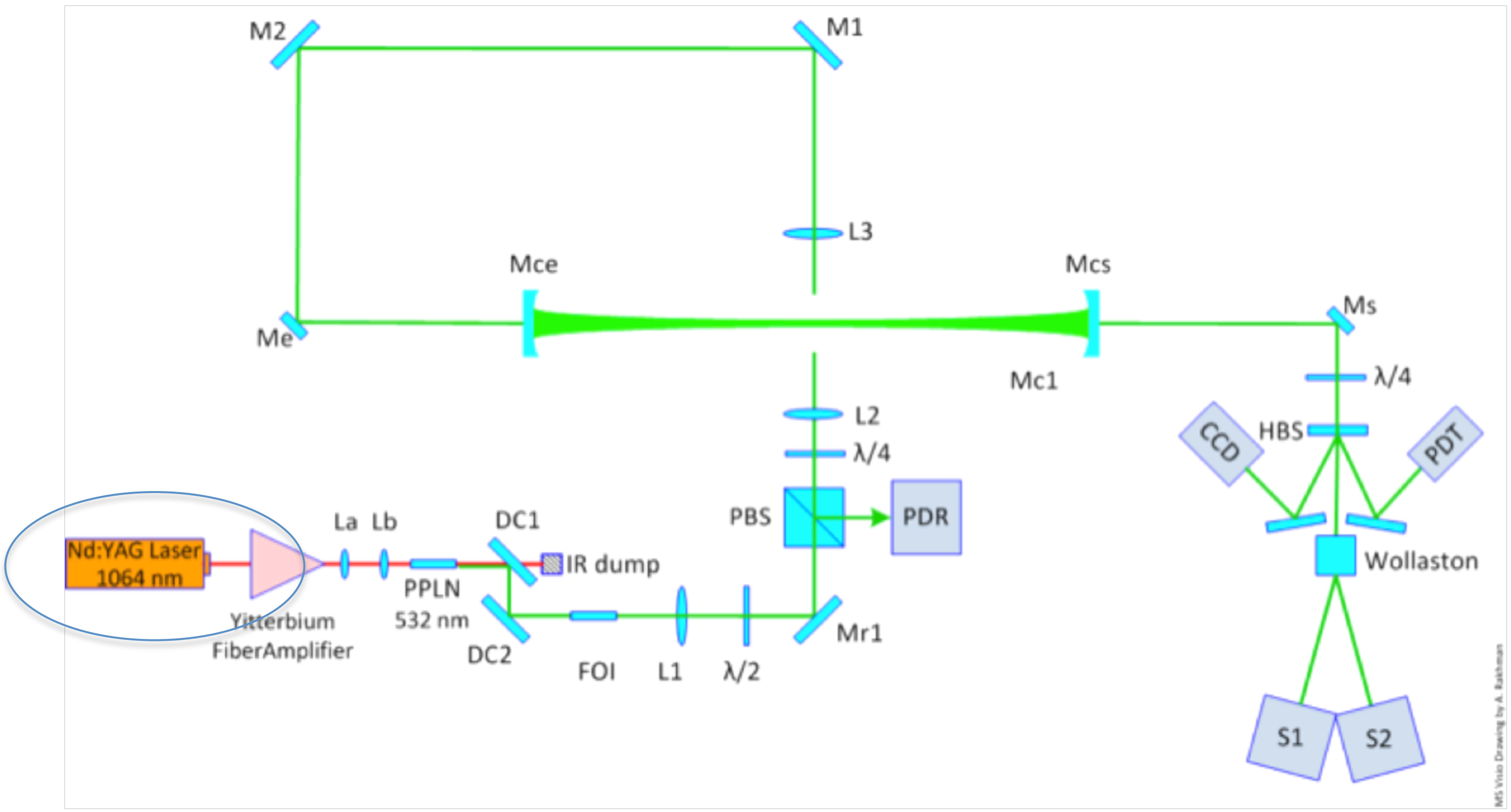
Systematic error of better than 1% should be achievable with straightforward improvements to laser and photon detector

Laser Polarization	0.7%
Gain Shift	0.9%
Collimator Position	0.02%
Non-linearity	0.3%
Total	**1.2%**

Compton systematics for PREX-1
(from PREX-II proposal)

Compton Laser Status

Compton laser system fully functional* - improvements underway
→ Cavity locking at high gain
→ Implementing improved technique for optimizing laser polarization in cavity

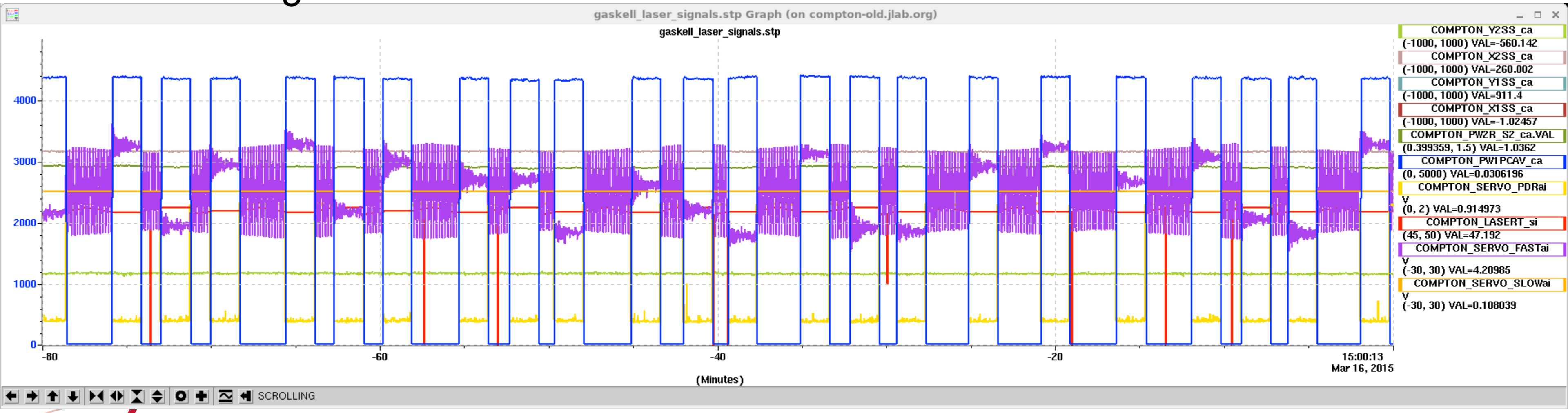


Compton Laser Status

Initially plagued by lower than expected gain after restoring cavity-lock with moderate reflectivity mirrors
→ Excessive loss – problems with mirrors

Replaced moderate *R* mirrors with high *R* (early 2015)

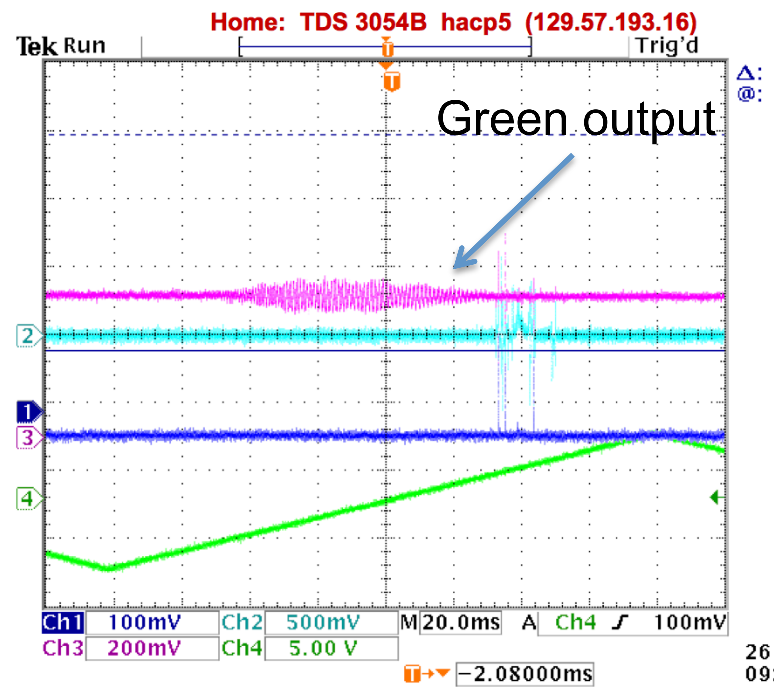
→ Was able to routinely achieving more than 4 kW of stored power
→ More recently, green power out of PPLN has been reduced, so stored power is 2 kW – but cavity gain remains high



Compton Laser Problems

Just before test with beam in December 2015 – Compton laser starting behaving oddly – output very noisy.

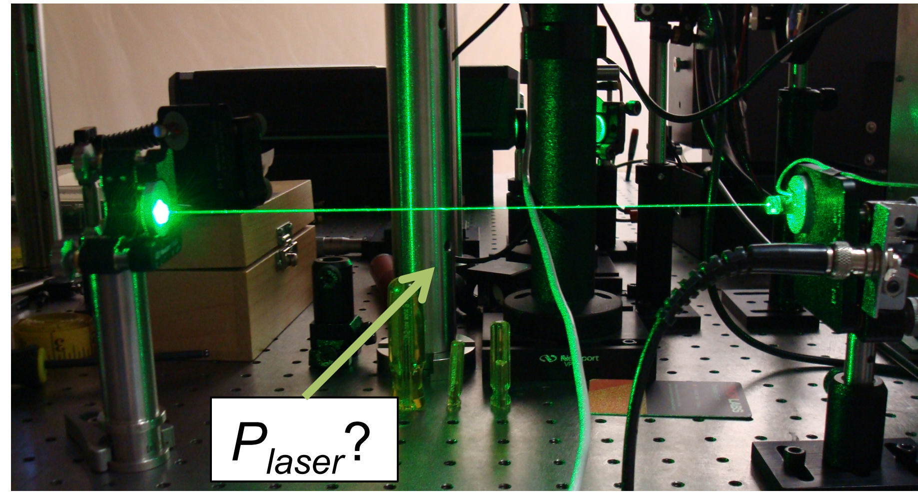
Diagnosis complicated by fact that many components used to generate green light
→ Seed laser appears to be OK, although along the way, had to replace power supply
→ Coupling into fiber was problematic – changed setup to allow easier alignment, improved coupling efficiency (>70%)

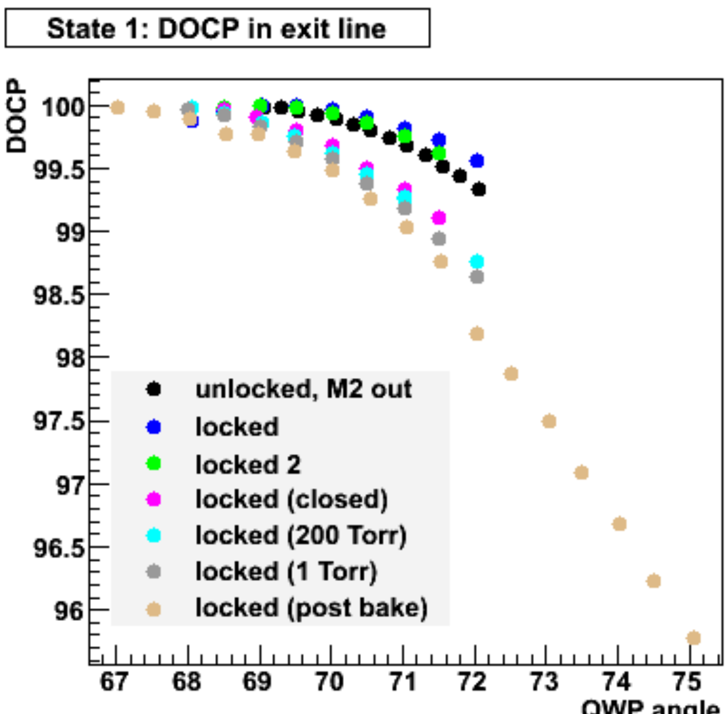


Problem must be with fiber amplifier – slow to ramp to “full power”. Even then, doubling efficiency is low (~ 500 mW). Output sometimes noisy (appears correlated with seed laser power).

Laser Polarization - the Transfer Function

Knowledge of the laser polarization inside cavity is a key systematic uncertainty
→ Polarization usually inferred from measurements of beam transmitted through cavity, after 2nd mirror





Typically a "transfer function" is measured with cavity open to air

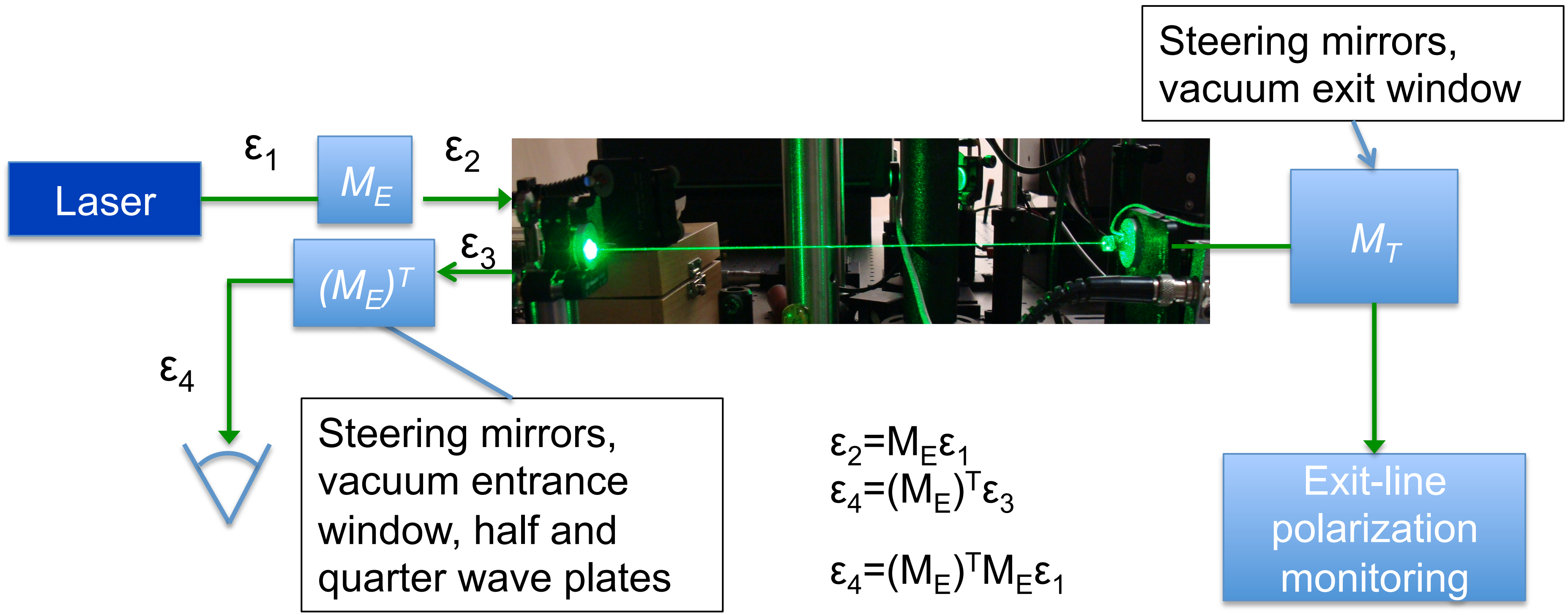
<u>Possible complications due to:</u>
→ Change in birefringence due to mechanical stresses (tightening bolts)
→ Change in birefringence when pulling vacuum

Laser Polarization – the "Entrance" Function

Propagation of light into the Fabry-Perot cavity can be described by matrix, $\boldsymbol{M_E}$

→ Light propagating in opposite direction described by transpose matrix, $(\boldsymbol{M_E})^T$

→ If input polarization (ε_1) linear, polarization at cavity (ε_2) circular only if polarization of reflected light (ε_4) linear and orthogonal to input*



$\varepsilon_2 = M_E \varepsilon_1$

$\varepsilon_4 = (M_E)^T \varepsilon_3$

$\varepsilon_4 = (M_E)^T M_E \varepsilon_1$

JINST 5 (2010) P06006

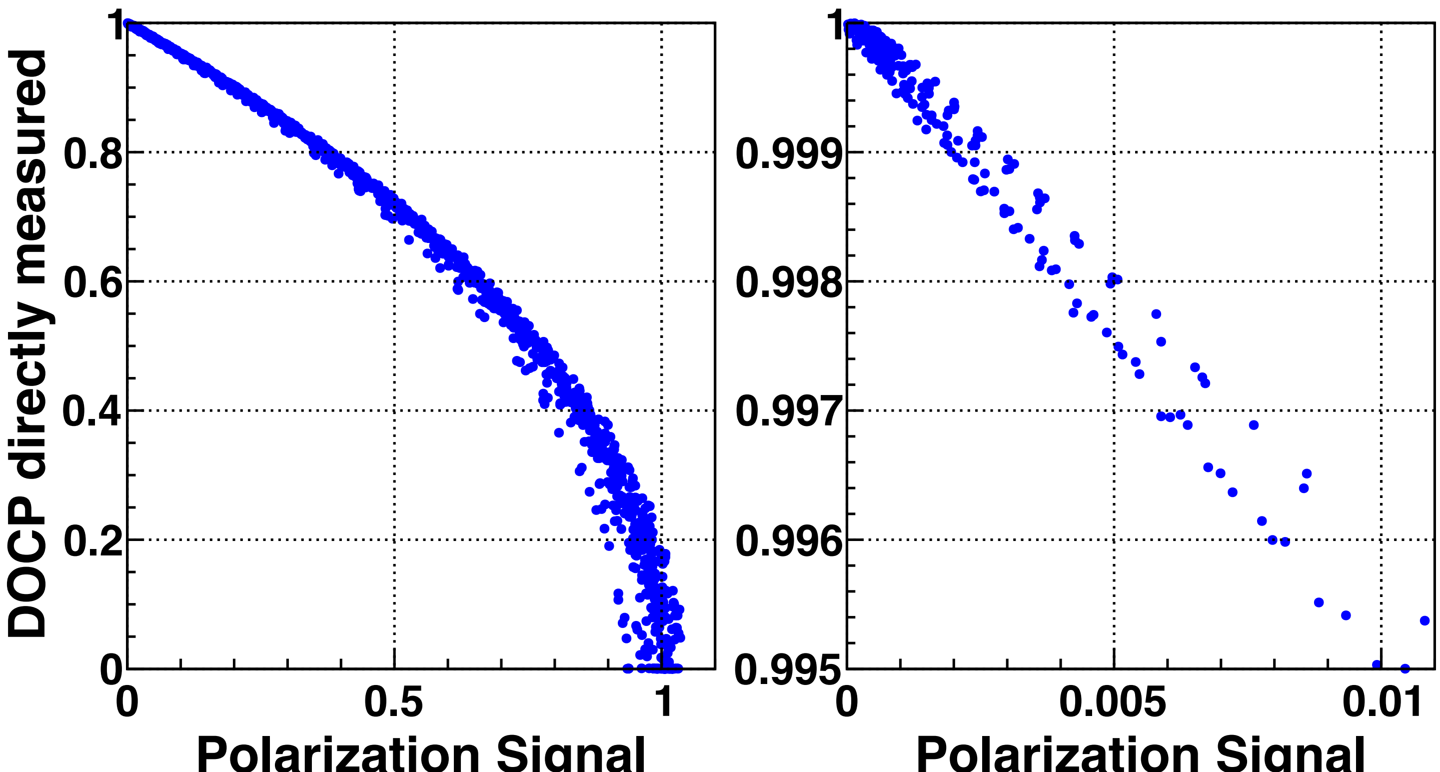
*J. Opt. Soc. Am. A/Vol. 10, No. 10/October 1993

Cavity Polarization via Reflected Power

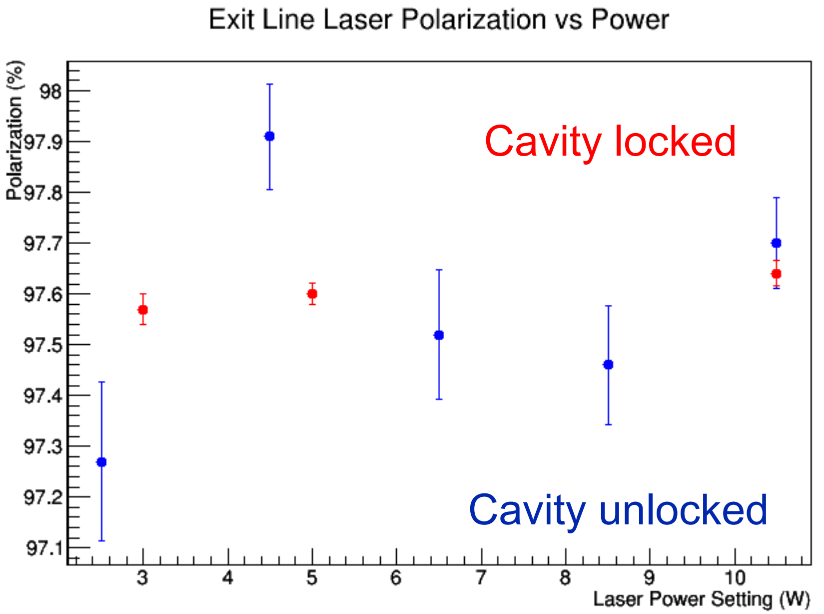
"If input polarization (ε_1) linear, polarization at cavity (ε_2) circular only if polarization of reflected light (ε_4) linear and orthogonal to input"

→ In the context of the Hall A/C systems, this means that the circular polarization at cavity is maximized when retro-reflected light is minimized

→ Above statement was verified experimentally in Hall C (with cavity open) by directly measuring circular polarization in cavity while monitoring retro-reflected power



Laser Polarization Systematic Uncertainty



Cavity polarization optimization scans performed with cavity unlocked
→ No measureable difference in laser polarization when comparing to locked cavity

Additional sources of potential uncertainty due to transmission through input cavity mirror and potential laser depolarization
→ Both constrained by measurement to be very small

Overall systematic error on laser polarization in cavity ~ 0.1%

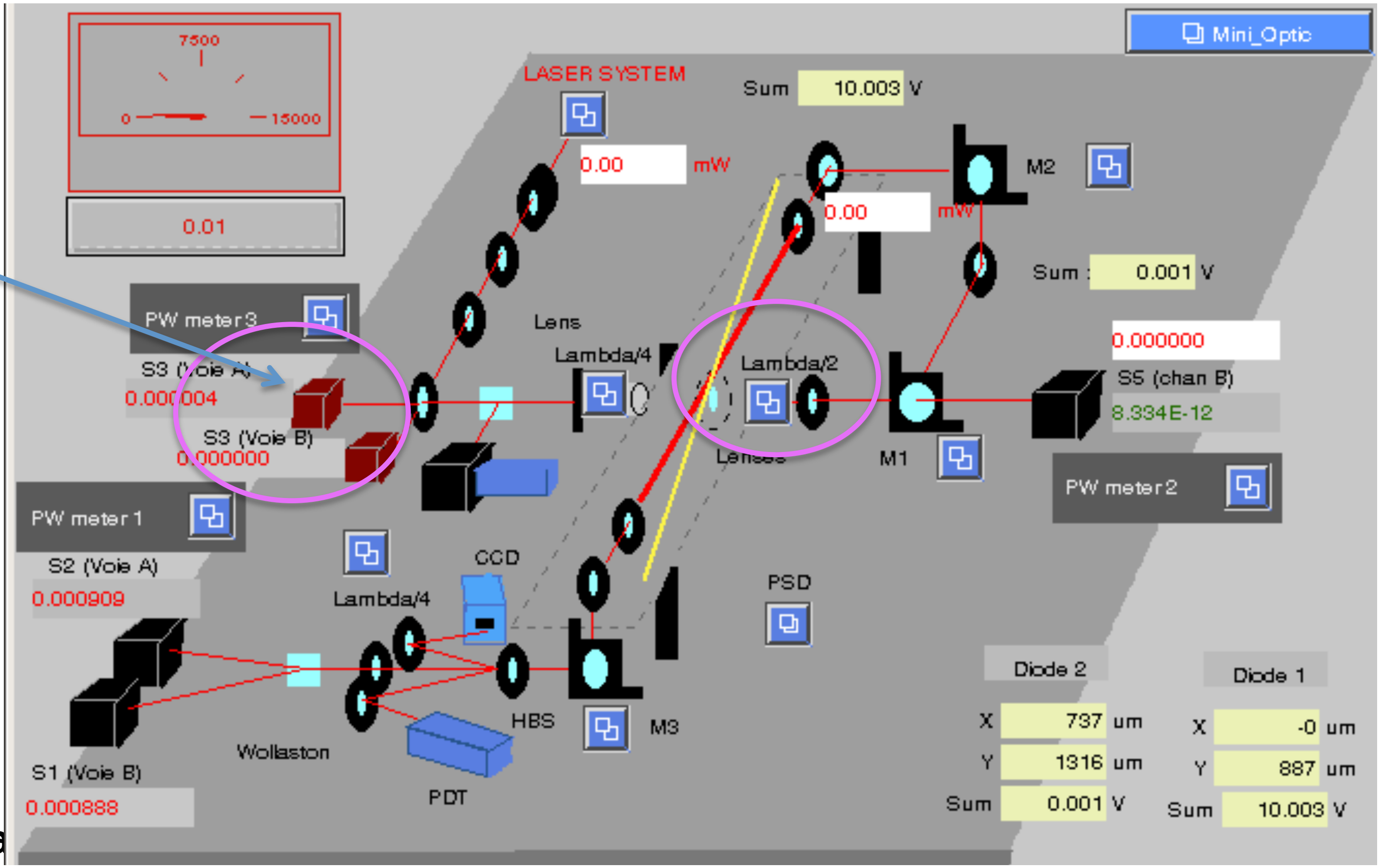
Compton Polarization Optimization

Polarization in cavity optimized by scanning full input polarization phase space and measuring reflected power → requires new (rotating) HWP, power meters

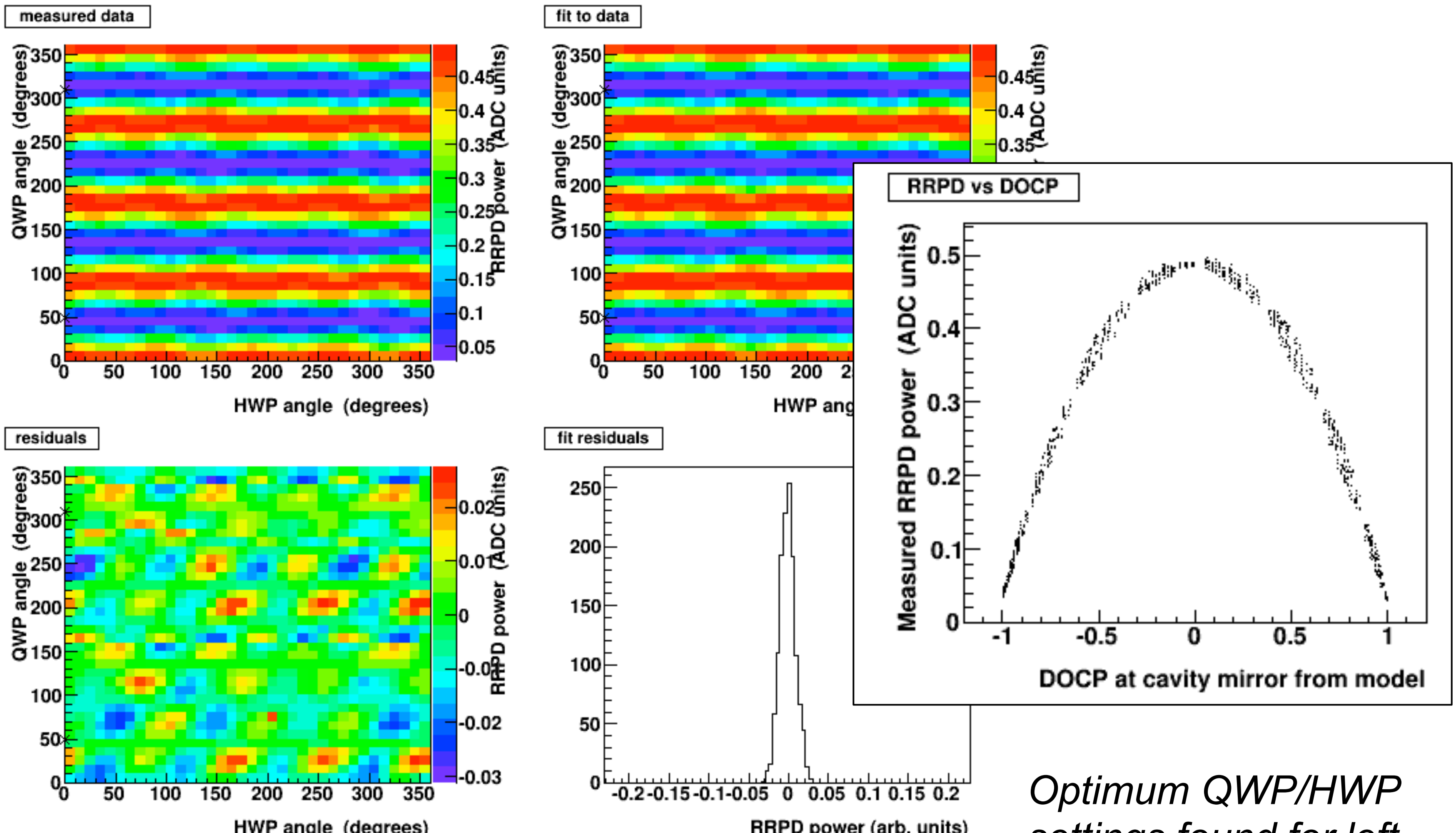
→ Controls updated, power meters installed

→ HWP installed, scanning and fitting routines developed (using Hall C routines from Mark Dalton)

RRPD



Cavity Polarization Optimization

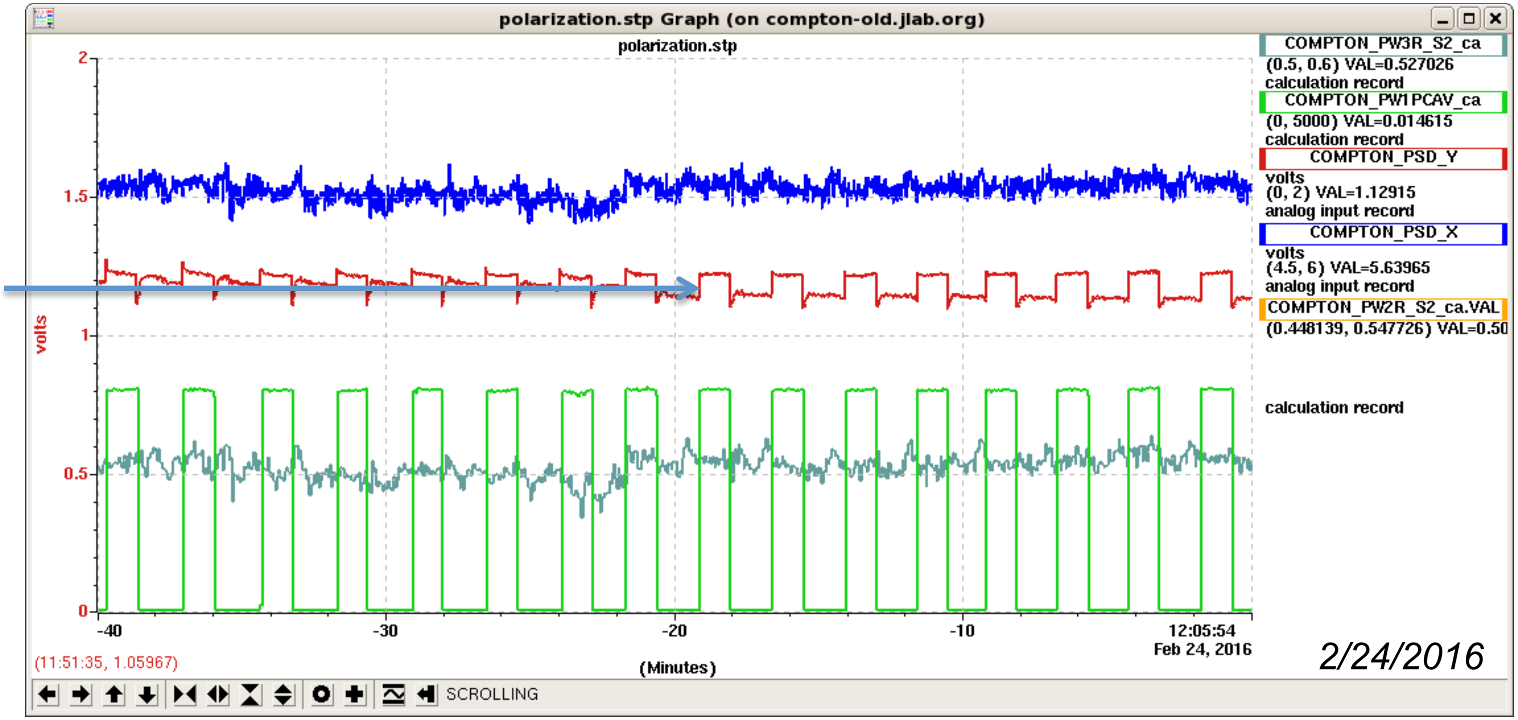


HWP and QWP scan (September 2015)

Optimum QWP/HWP settings found for ~~left~~ right circular polarization

Reflected Power Monitoring

RRPD



QWP/HWP settings for maximum DOCP optimized with cavity unlocked

→ Monitor RRPD to track polarization with time

→ Use locked cavity to help determine (small) pedestal (low power going back to RRPD)

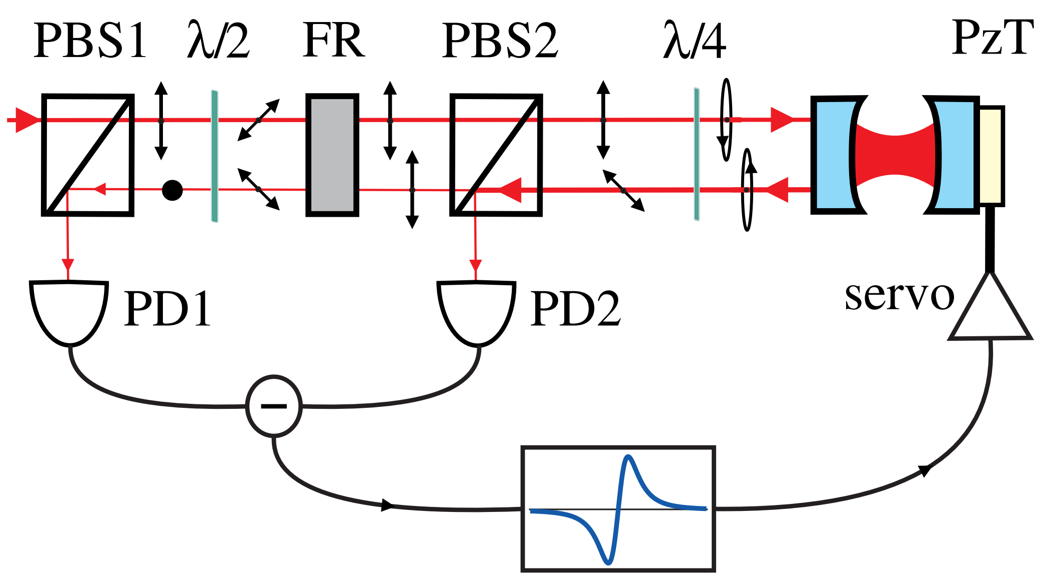
→ Problem: In Hall A system, signal in RRPD is larger when cavity locked! Apparently, output laser power very sensitive to light reflected back into doubling crystal.

Improved Laser Polarization Scheme

Polarization monitoring/setup can be improved by implementing scheme that combines optical isolation with monitoring of back-reflected light

→ Additional polarizing cube + faraday rotator prevents light of arbitrary polarization from reaching laser

→ Position of RRPD (side of cube) hopefully reduces effects of backreflection off optical elements

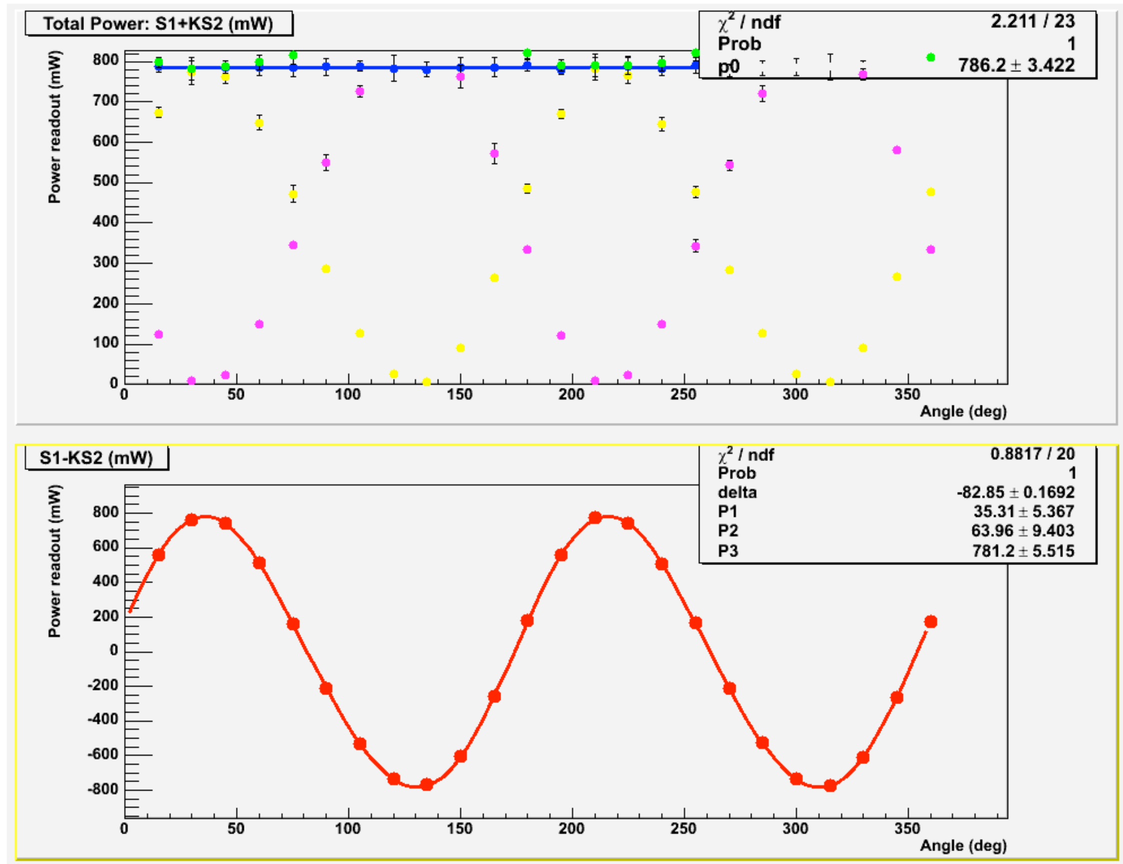


Optics Letters, Vol. 36, No.19 p.3729

Cavity Exit Line Measurement

Recently measured DOCP of light transmitted through the cavity
→ Uses rotating quarter wave plate, Wollaston prism
→ Results:
P=99.4%, ellipse angle=30.5 degrees

DOCP in cavity can be inferred using transfer function



Jefferson Lab

Cavity Exit Line Measurement

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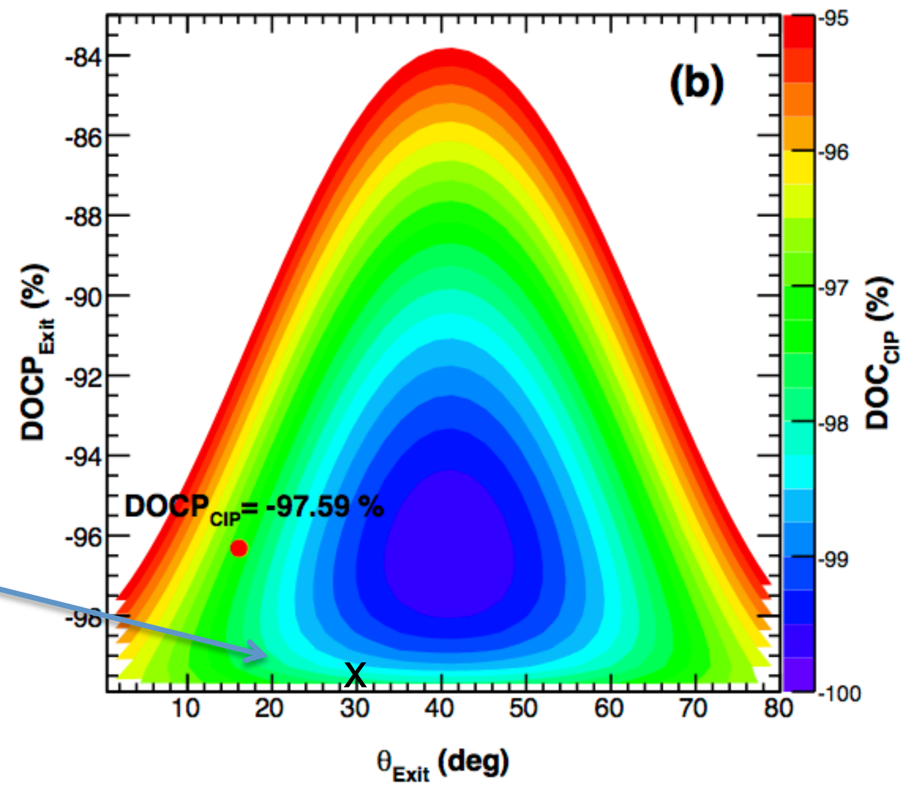


Using transfer function measured by Abdurahim Rakhman, DOCP at IP ~ 98%
→ Pretty good considering TF measured ~ 6 years earlier

Laser To-do list

- Replace fiber amplifier – check PPLN doubling crystal
- QWP/HWP scan for polarization optimization requires improvements to controls
  - Rotating stages not closed-loop! EPICS commands sometime lost in the interwebs – no readback of stage position!
  - Power measurements should be done with photodiodes, not power meters
- Install improved isolation/RRPD scheme → requires a few new components

Beam in Compton: 12 GeV Era

- Spring 2015
  - Dedicated time at ~ 2 GeV
  - First beam through modified chicane
  - Saw collisions using photon detector – good signal to noise
  - No signal seen on electron detector
- December 2015
  - Beam through chicane at 11 GeV!
  - No solid evidence of collisions (limited time to search)
- February 2016
  - Compton in use for DVCS – so far used at 2 pass (4.4 GeV)
  - Plan to use at 4 and 5 pass as well

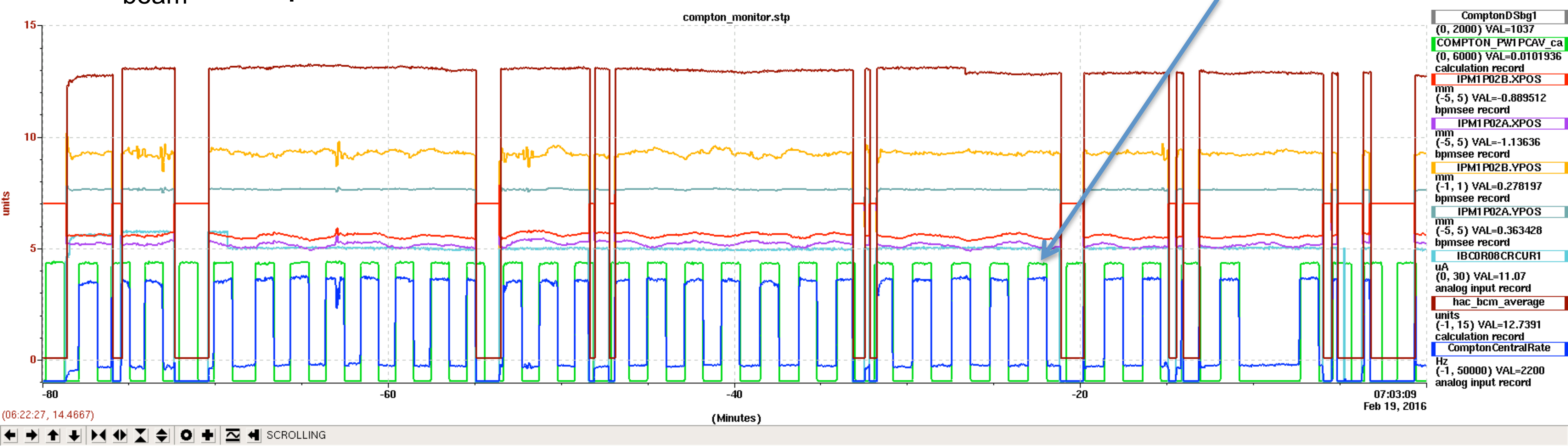
Compton Running During DVCS

- Steering beam through Compton is pretty easy
  - Some mysteries with regard to BPMs in “up” and “down” legs
- Backgrounds almost always large at first → require optics expert on hand (Yves Roblin) to reduce them
- Finding collisions not too hard (if you’ve got the detector/collimator in the right place)
- Beam appears to be rather unstable – backgrounds change regularly

Compton Running During DVCS

I_{beam} ~ 10 μA

Photon detector rates

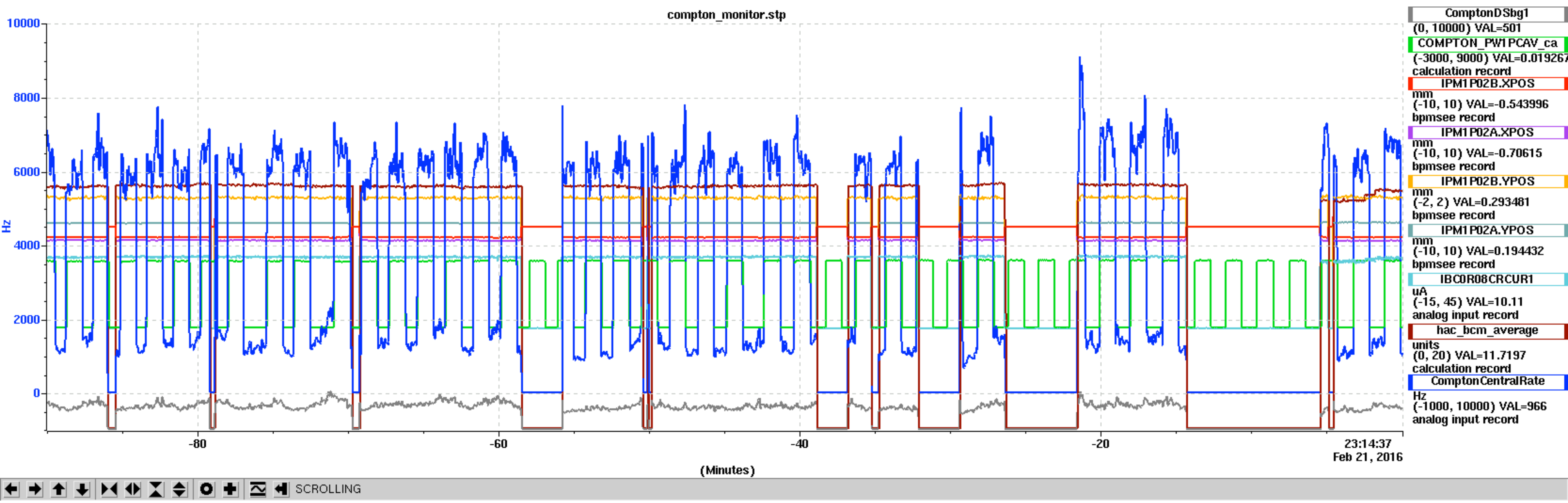


Friday: 2/19/2016 8:33 am

Robust polarization measurements require good signal to noise – stable backgrounds

Compton Running During DVCS

I_{beam} ~ 10 μA

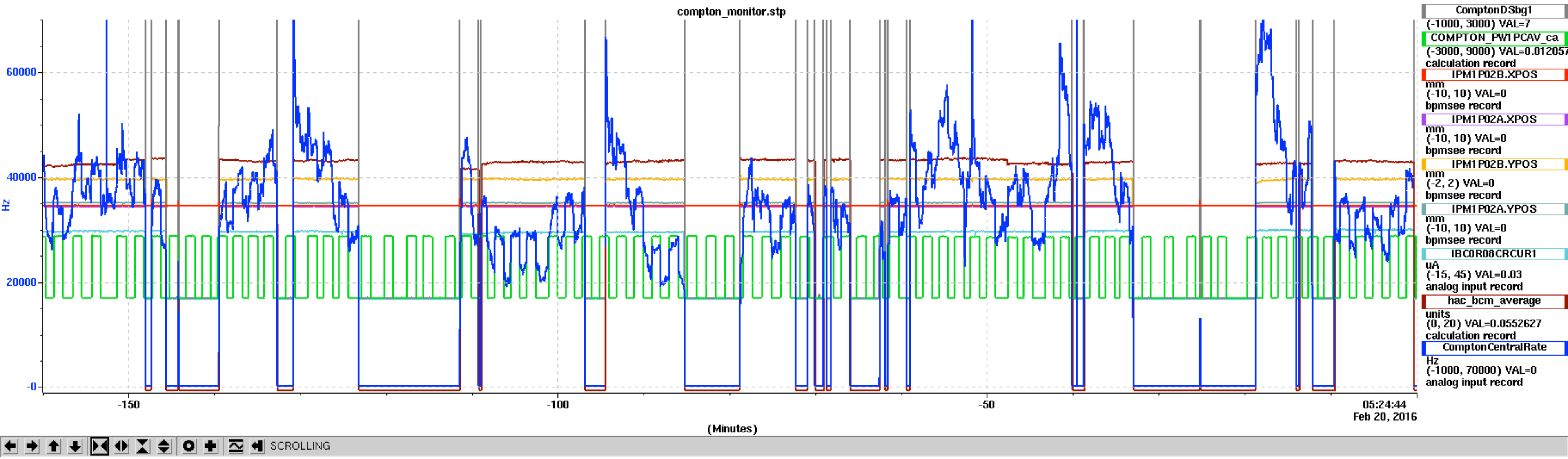


Saturday: 2/20/2016 00:46 am

Good signal/background, but with lots of fluctuations make "local" bakckground subtraction difficult

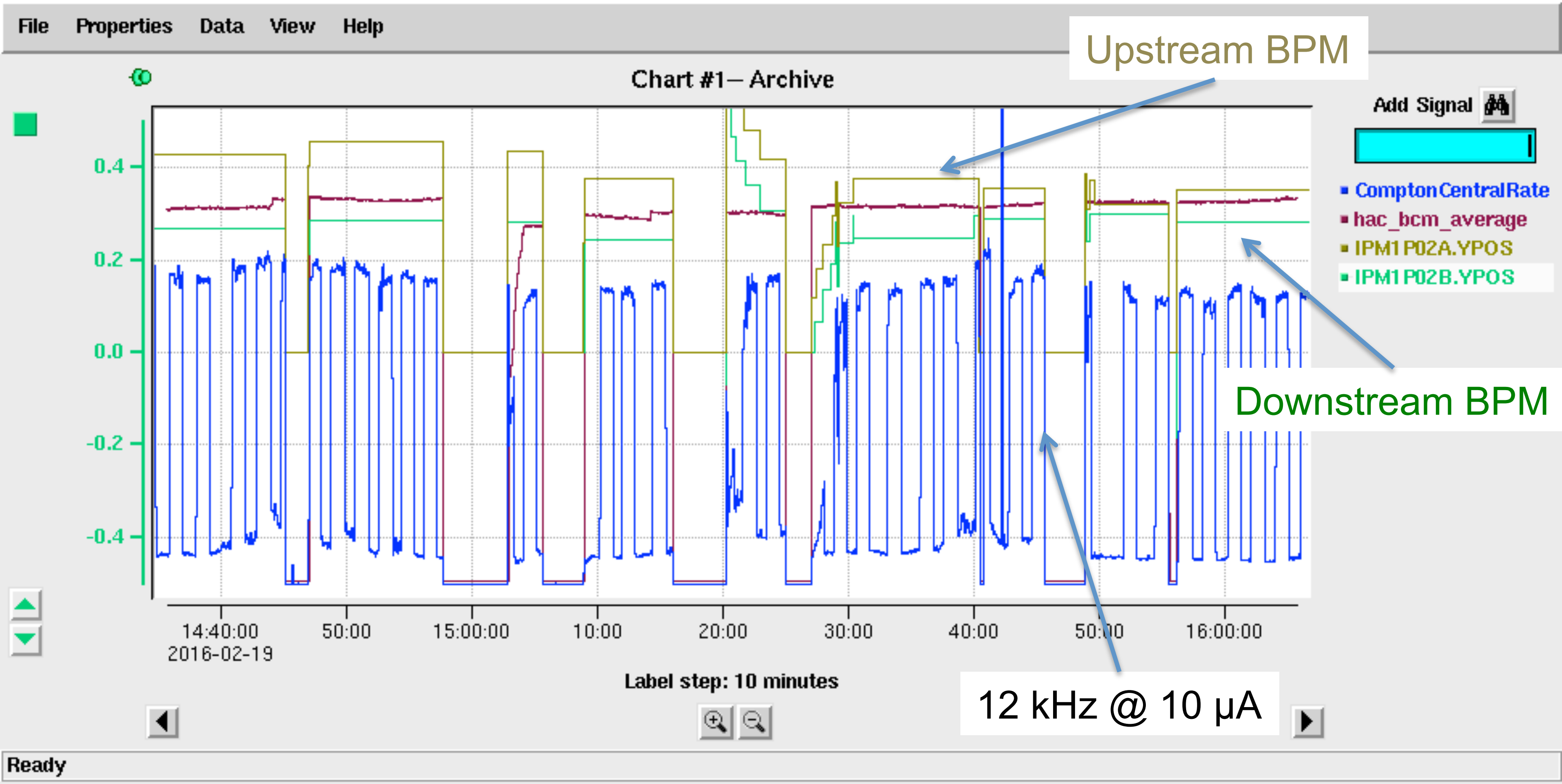
Compton Running During DVCS

I_{beam} ~ 10 μA



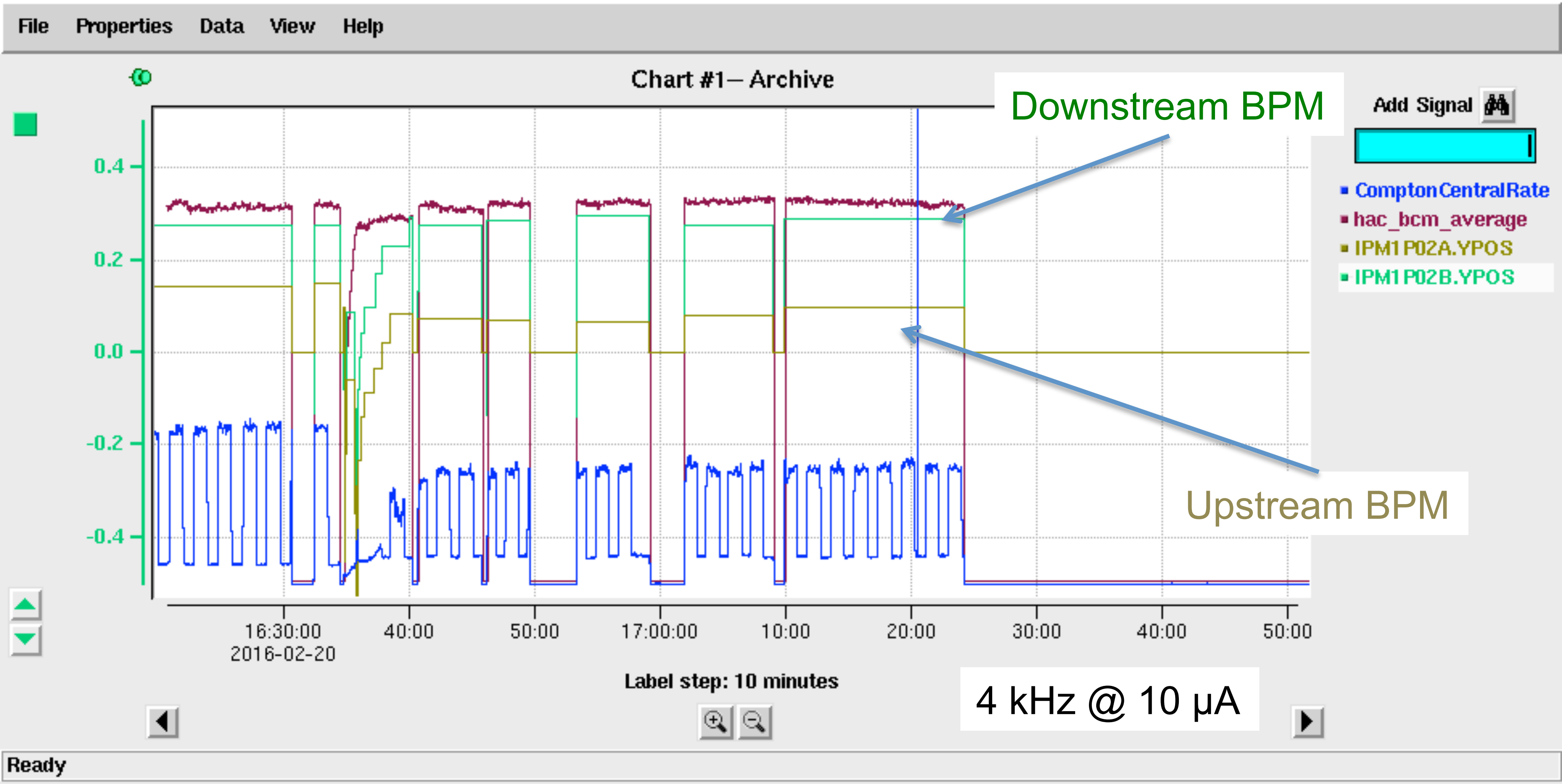
Saturday: 2/20/2016 6:56 am

Compton Running During DVCS



Use current in dipole string to lock beam position using BPM on downstream end of table

Compton Running During DVCS



Beam position on downstream BPM fixed, upstream BPM dropped 0.3 mm → orbit upstream drifted, changing trajectory into Compton

Compton Electron Detector

Existing system suffers from excessive noise, low efficiency

→ For experiments with high luminosity (and/or very long run times), silicon microstrips may not be sufficiently radiation hard

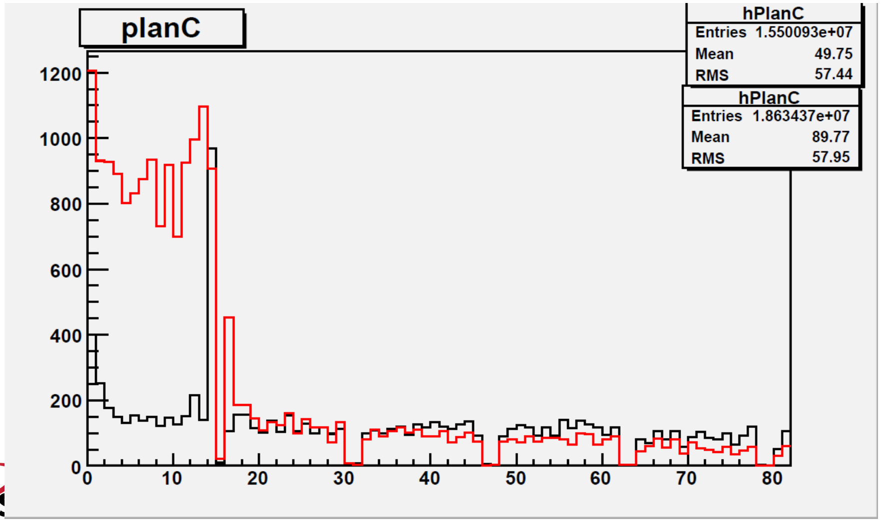
Near term improvement plan (JLab/Manitoba/MSU):

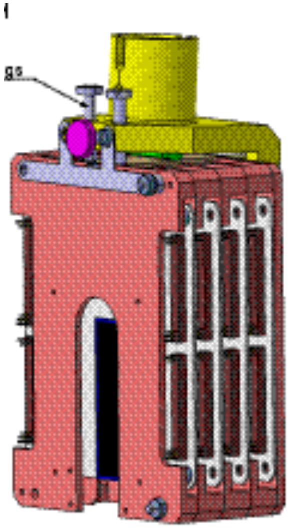
→ Thicker silicon plane (just one) has been installed to see if this helps mitigate noise

→ Tests underway in EEL to see if alternate amplifier-discriminator, or better coupling of of detector to amplifier-discriminator helps

Longer term plans:

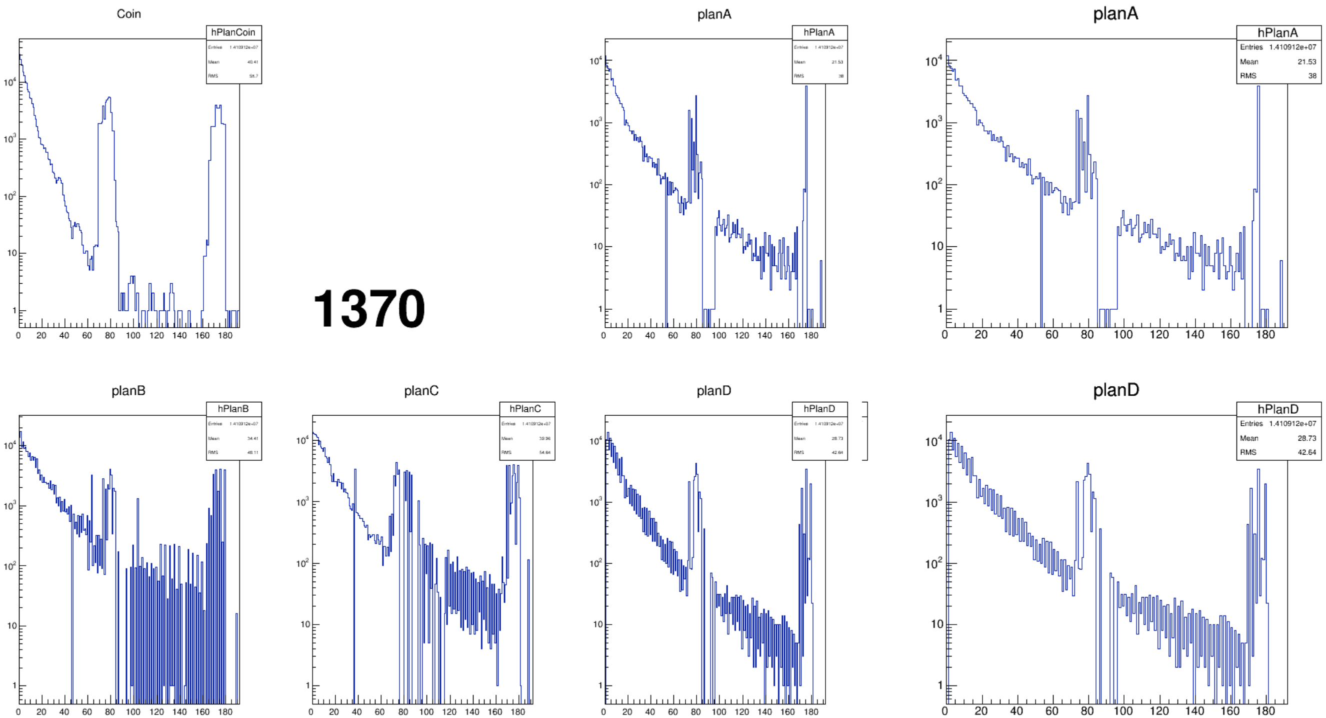
→ Investigate diamond strips (similar to Hall C) as an alternate for far future experiments (MOLLER, SOLID)





*Courtesy Alexandre Camsonne

Electron Detector – Spring 2015



Could not get detector very close to beam (“22 mm”) without seeing rate in photon detector, tripping ion chamber

→ Perhaps this implies large beam vertical displacement – hints of this in 3rd BPM

No sign of real Compton electrons – makes it difficult to make real determination of efficiency

Summary

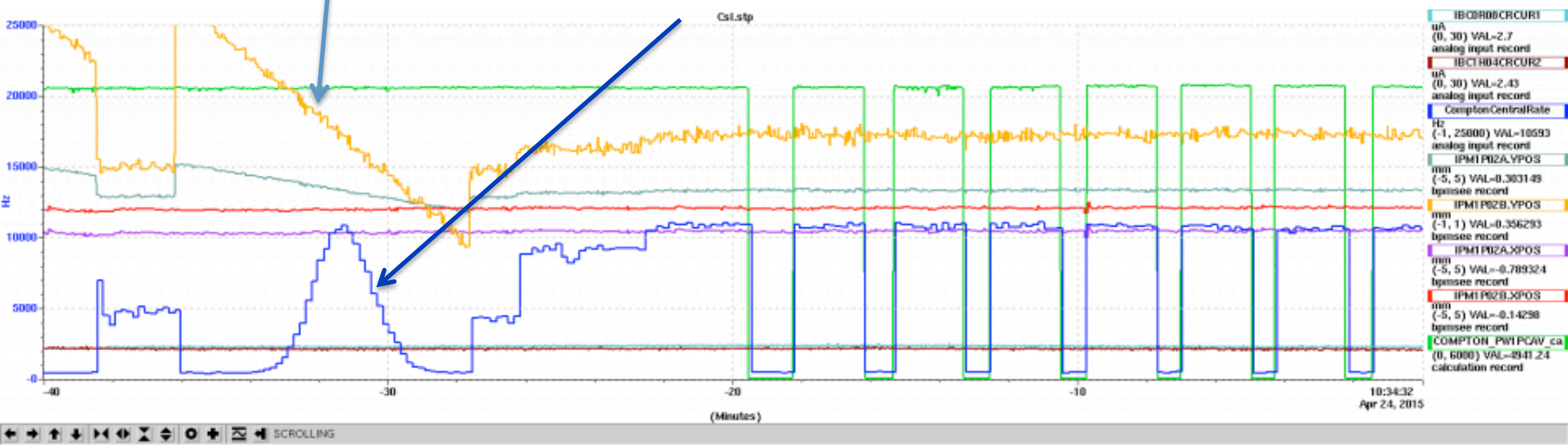
- Compton has been shown to be functioning after upgrades for 12 GeV compatibility
- Upgrades to laser polarization setting/monitoring underway
  - Laser needs repair
  - There may need to be significant controls work/ replacement to reliably implement the “entrance function” technique
- Operation during DVCS (2 pass) has been challenging so far
  - Backgrounds can be brought to reasonable levels with effort
  - Accelerator does not seem to be terribly stable at this point → backgrounds change quickly, as can orbit across the laser table
- Hope to take some time in the near future to look at electron detector performance with thicker silicon plane

EXTRA

Collisions with Great Signal to Background

Vertical beam position scan

Photon detector rate



Second day of commissioning - saw great signal to noise. Compton rates close to simple prediction (4 kHz/μA)

Hall A Compton Commissioning – December 2015

Spent about 1 shift tuning beam through Compton

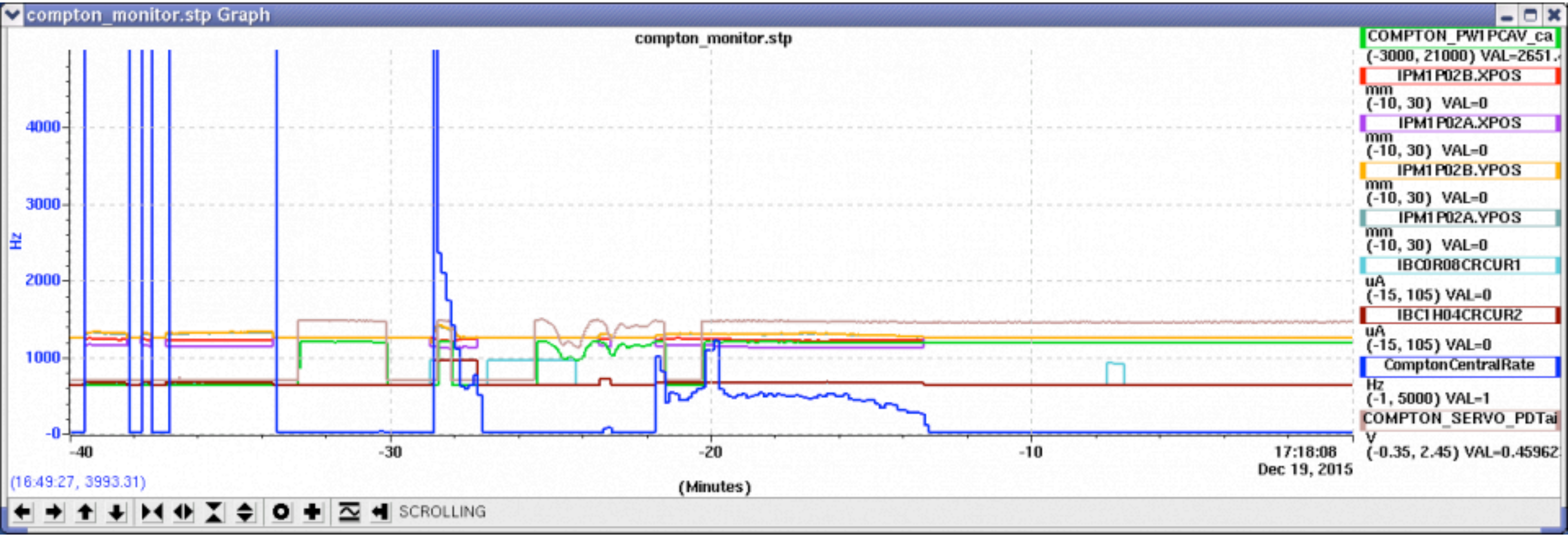
→ CASA + Ops achieved good orbit through Compton at ~ 11 GeV!

→ Vertical position in up/down legs a little puzzling

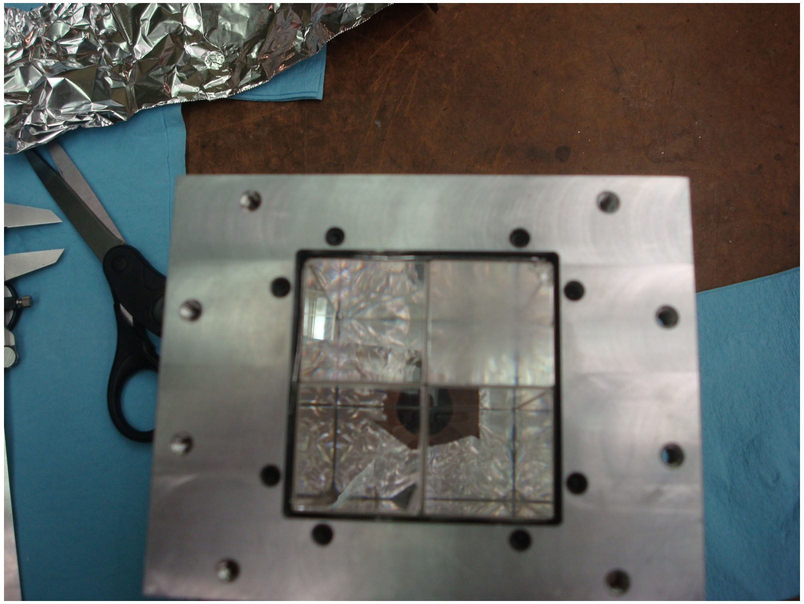
Search for collisions not successful

→ Expected signal rate ~ 2 kHz – similar to observed backgrounds

→ Backgrounds reduced to ~ 500 Hz, but ran out of time before we could look for collisions again



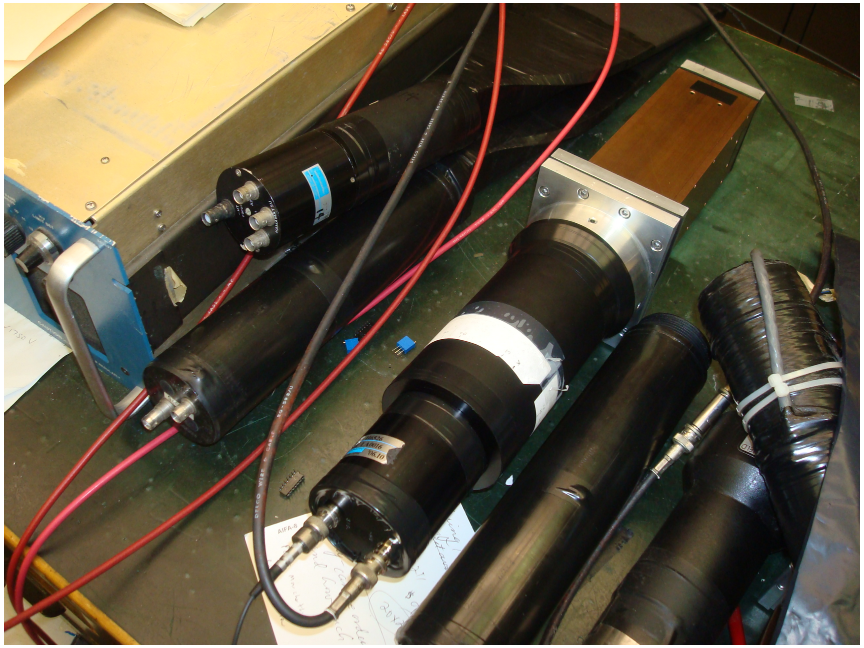
Lead Tungstate Test Detector



Installed a 4-block, lead-tungstate detector to test during 1st DVCS/GMp run

→ Used "found" PMT + base

→ Summer of 2015 – base has been replaced/optimized



Lead-tungstate crystals on loan from Yerevan/Hall C

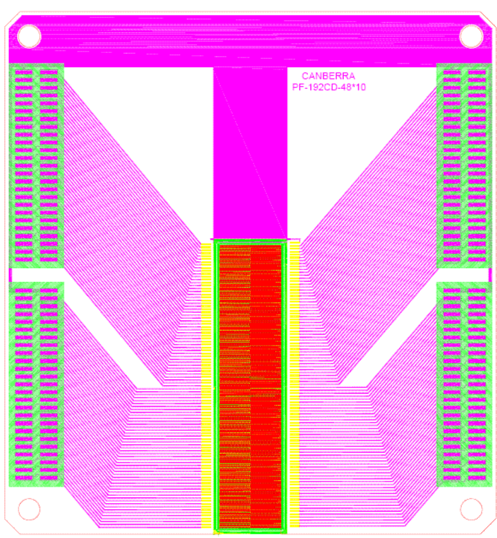
Crystal size = 3 x 3 x 20 cm

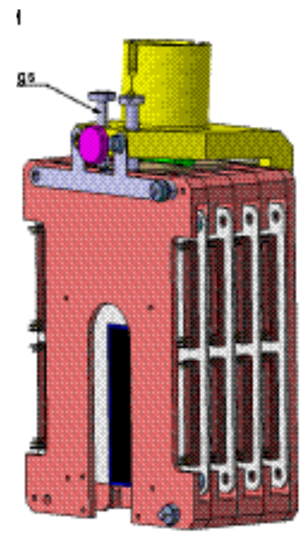
Detector assembled, PMT optimized by CMU (B. Quinn)

Compton Electron Detector*

<u>Current Issues</u>

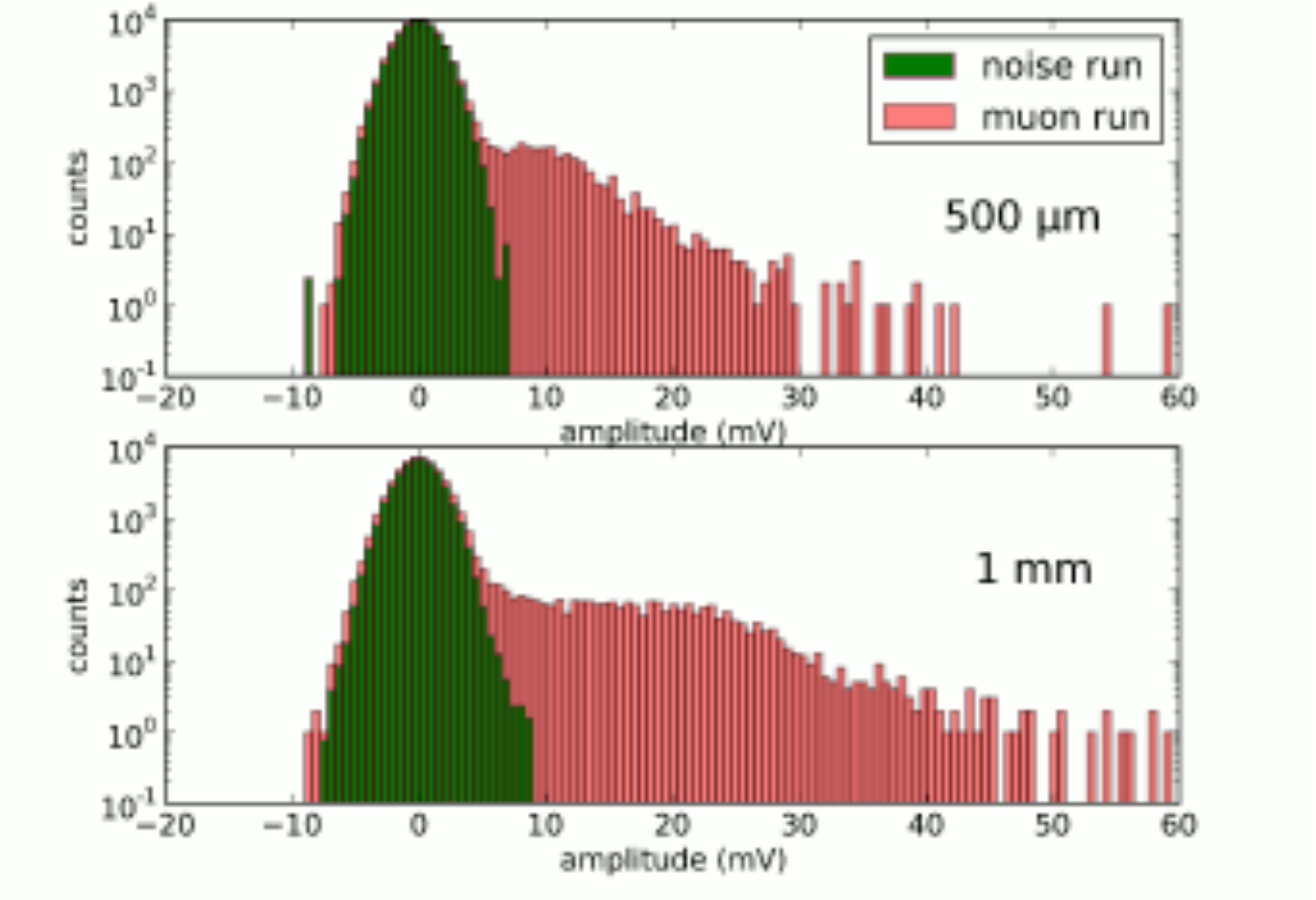
→ Synchrotron radiation (did not work during PVDIS)
→ Contamination of asymmetry by shielding
→ Signal / background ratio
→ Crosstalk - digital with analog (need to be careful of offsets and thresholds)
→ No official support for major development in Clermont
→ Readout with standard Compton DAQ only run at 30 Hz
→ Readout 32 bit BLT only : dead time





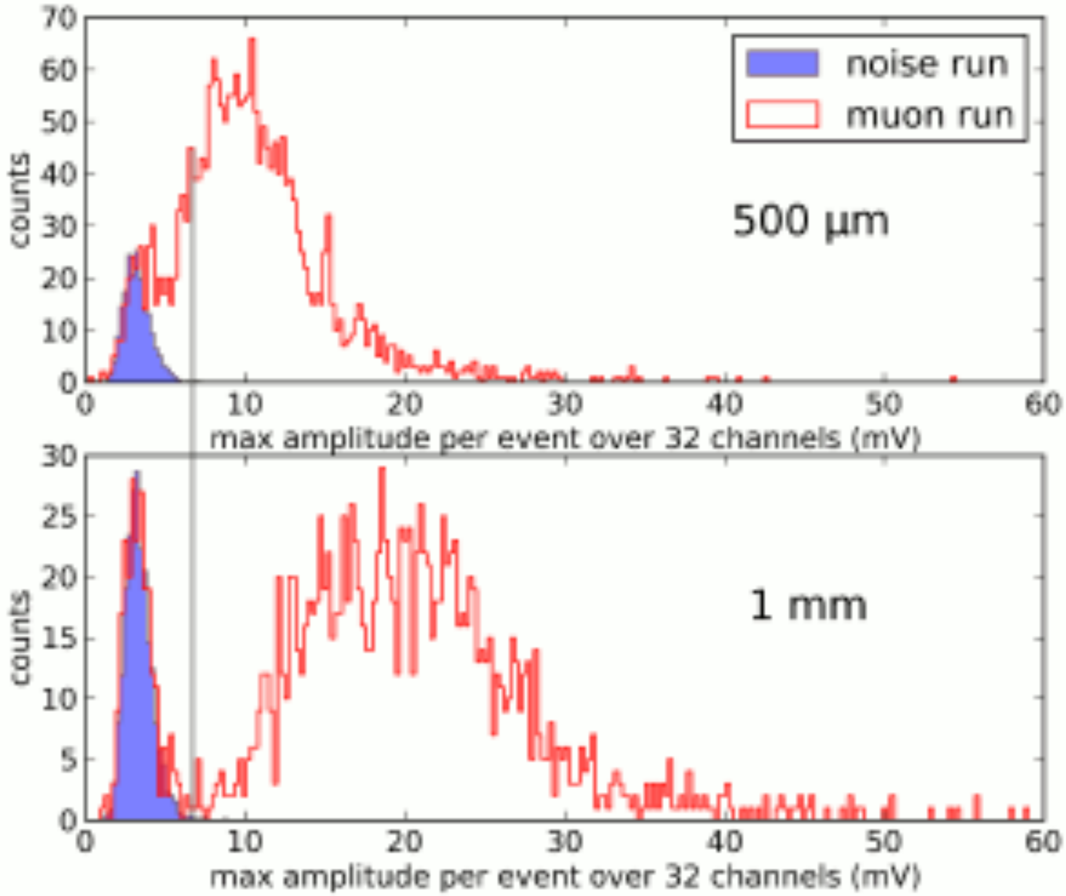
*Courtesy Alexandre Camsonne

Cosmic Tests



Single channel

Cosmic Tests



All channels (sum)

Efficiency curve