JLab Compton Detectors – Lessons learned

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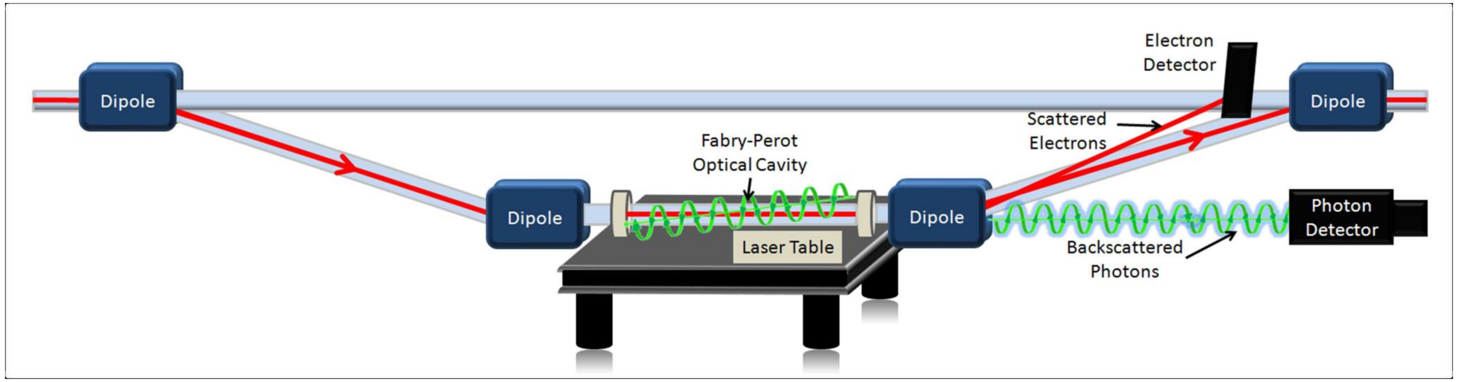
Jefferson Lab



FCC EPOL Workshop

September 19-30, 2022

Jefferson Lab Polarimetry Map

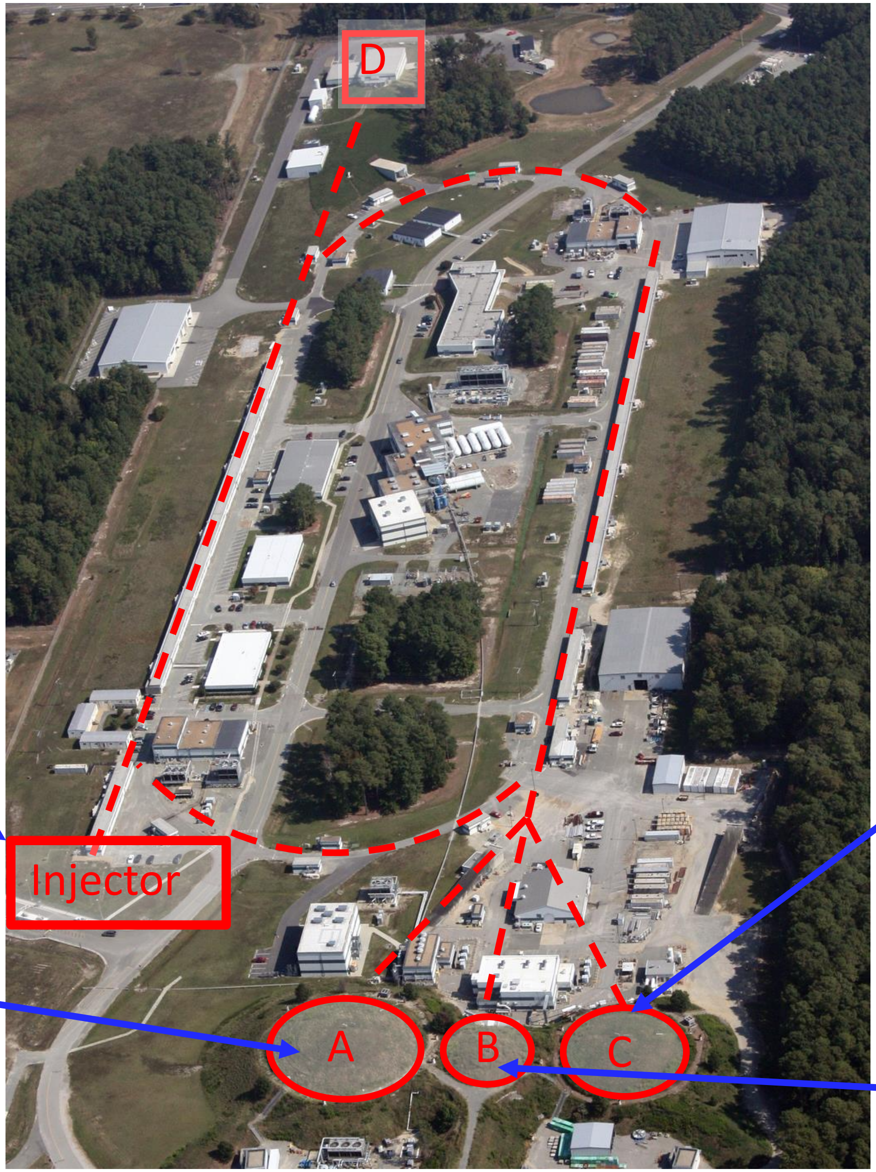
E_{beam}=1-12 GeV
I_{beam} ~ 100 μA

P=85-90%

Injector
5 MeV Mott Polarimeter

Hall A
Compton Polarimeter
- IR → Green laser

Møller Polarimeter
- In plane, low field target → out of plane saturated iron foil



Hall C
Compton Polarimeter
- Installed 2010 (Q-Weak)

Møller Polarimeter
- Out of plane saturated iron foil

Hall B
Møller Polarimeter
- In plane, low field target

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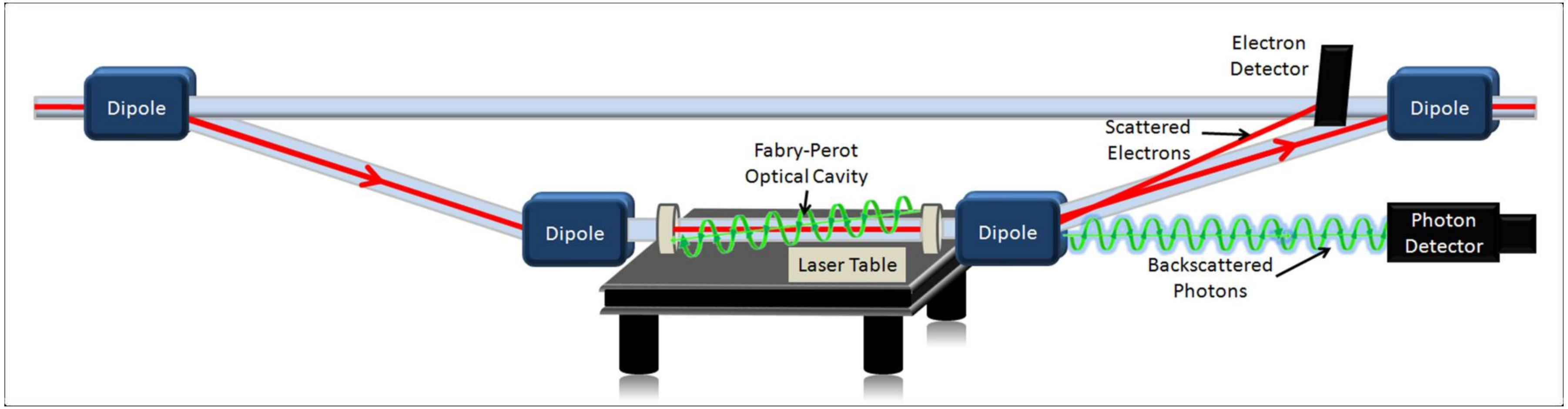
Compton Polarimeter Subsystems

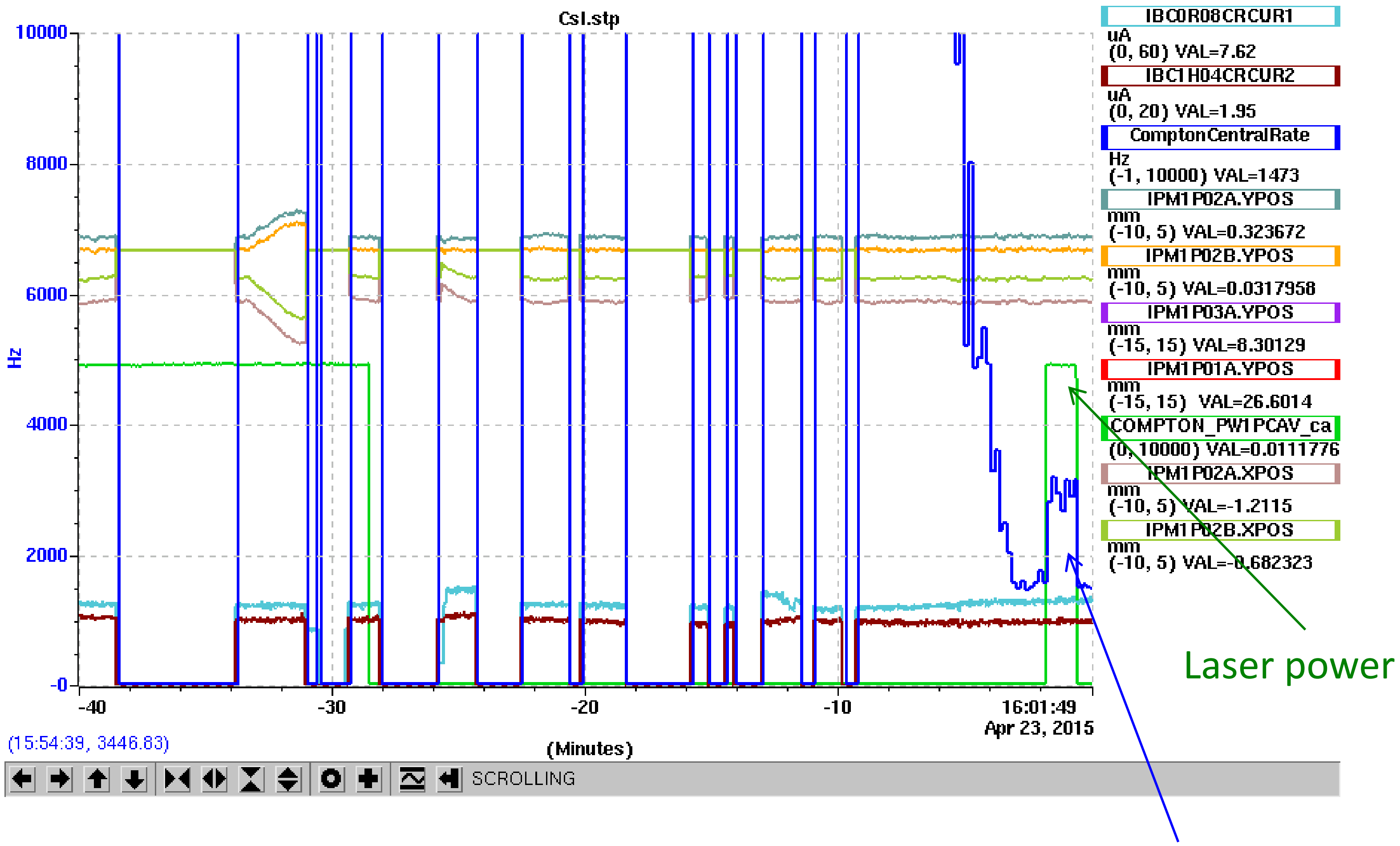


- Laser – both Hall A and Hall C use Fabry-Perot cavities to store >1 kW of laser power
  - Hall A: Originally used 1064 nm narrow linewidth laser alone. Later upgraded to a frequency-doubled (532 nm) system → modest input power (up to 1 W), high Finesse cavity
  - Hall C: Started with 532 laser (Coherent Verdi) → higher input power (10 W), modest Finesse cavity
- Photon detector
  - Hall A: started with multi-channel lead-tungstate detector. Now use GSO (low energy) or ”single channel” lead-tungstate in integrating mode
  - Hall C: lead tungstate, integrating mode
- Electron detector
  - Hall A: silicon strip, Hall C, diamond strip
  - Both will be upgrading detectors to larger area diamond strip

Beam tuning

Typical initial beam tuning

Initially, backgrounds were not terrible, but still too large to see collisions – tuning required

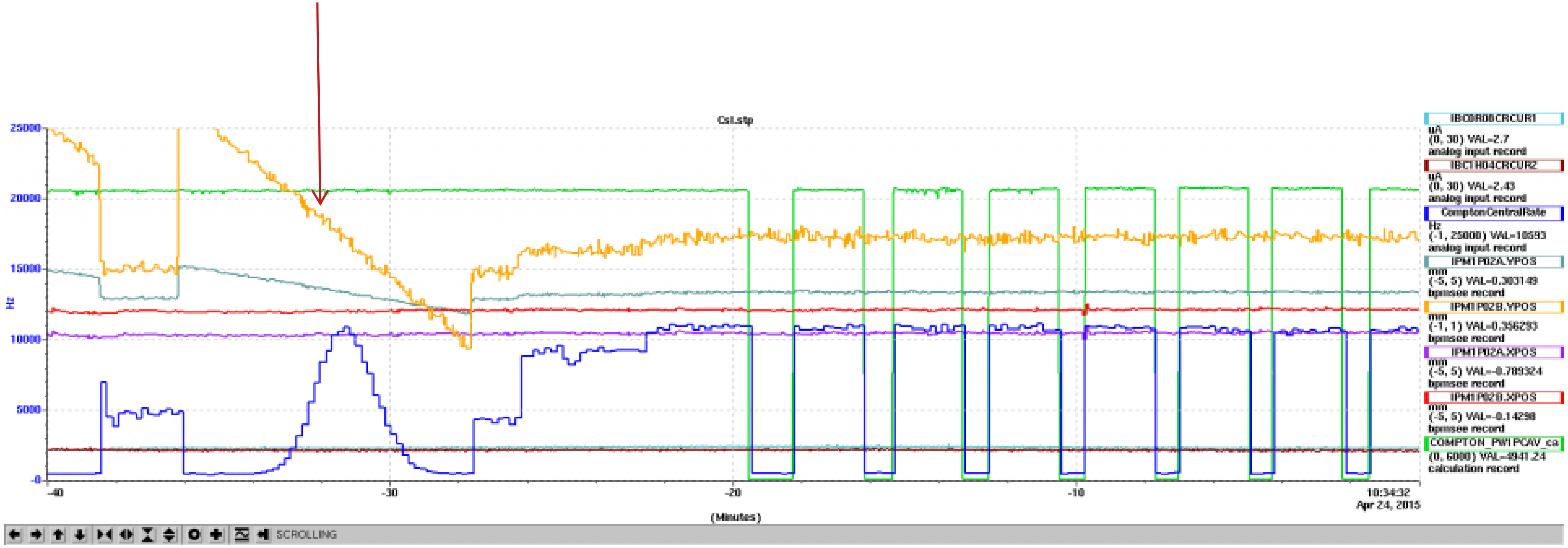


https://logbooks.jlab.org/entry/3334743

Photon detector rate

Collisions with Great Signal to Noise

Vertical beam position scan



Once see collision optimize laser and electron beam interaction

Compton Operation Mode

Laser locks and unlocks regularly to allow measurement of backgrounds

→ Backgrounds highly dependent on beam quality

→ Sometimes extensive tuning is required to achieve good backgrounds – ***dominant background from beam interaction with apertures in beamline***

→ ***Prebuncher phase setting can improve background – linked to bunch length and beam halo***

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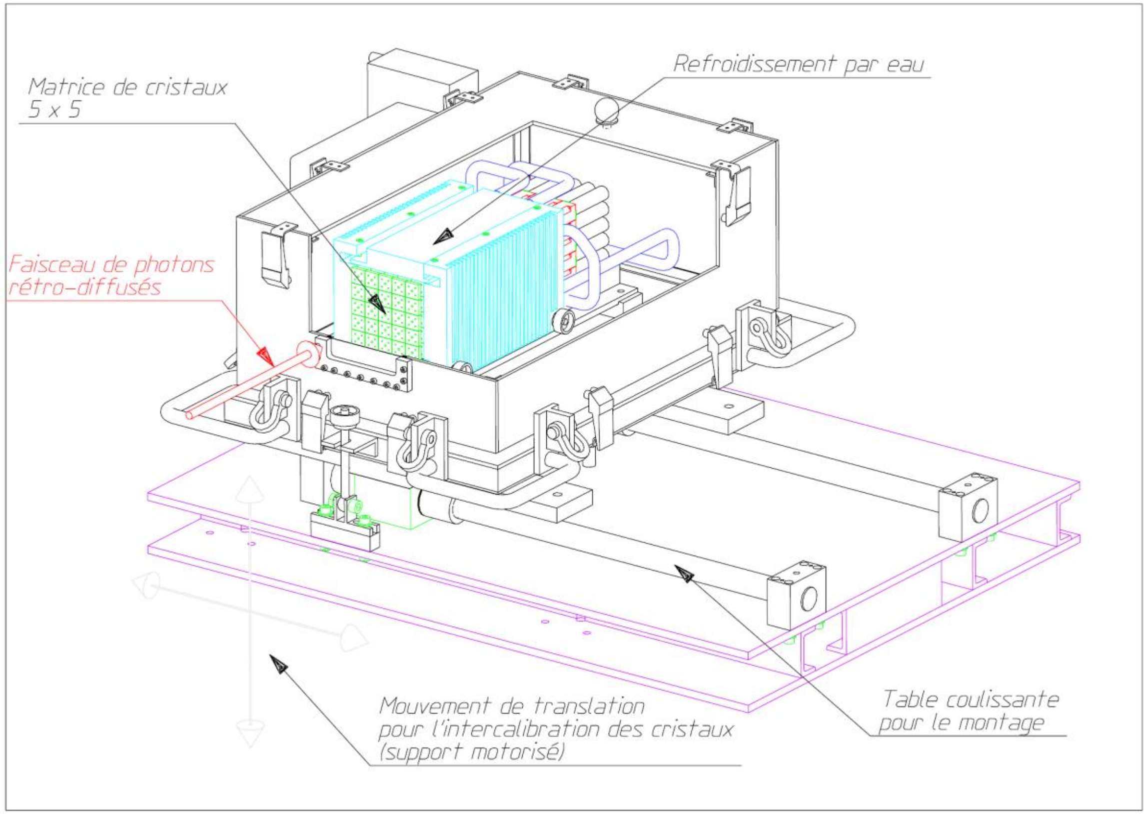
Photon detector

First measurement HAPPEX experiment differential method

- Happex experiment 3.3 GeV

[hep-ex/0203012v1] First electron beam polarization measurements with a Compton polarimeter at Jefferson Laboratory (arxiv.org)



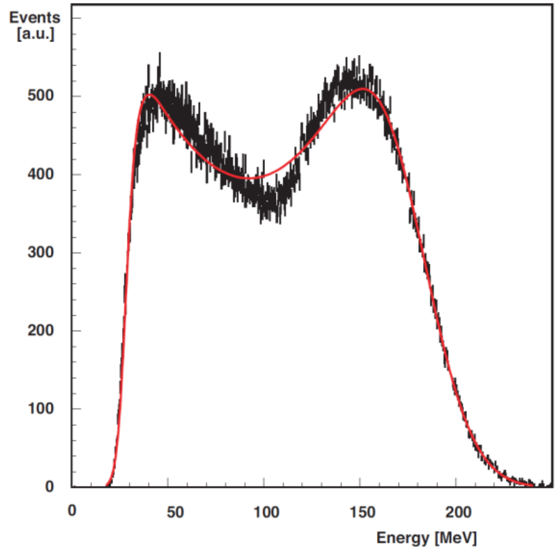


TABLE I. Average relative error budget.

Source			Systematic	Statistical
P_γ			1.1%	
A_{exp}	Statistical			1.4%
	B/S	0.5%		
	A_B	0.5%	1.4%	
	A_F	1.2%		
A_{th}	Non-linearities	1%		
	Calibration	1%	2.4%	
	Efficiency/Resolution	1.9%		
Total			**3.0%**	**1.4%**

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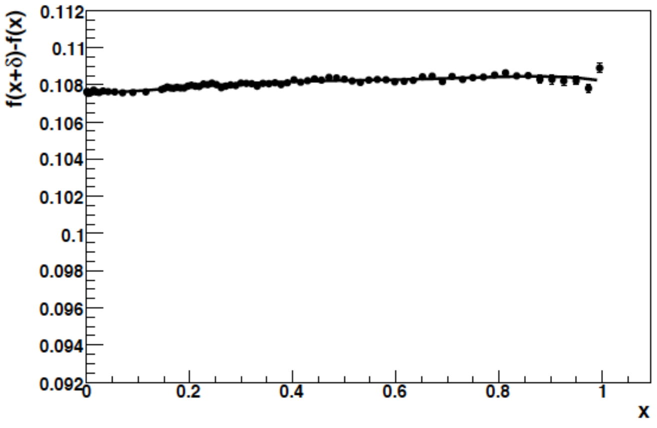
Photon Detectors

Hall A originally extracted polarization by fitting asymmetry vs. energy using lead-tungstate detector
→ Carnegie-Mellon group suggested measured energy-weighted asymmetry – asymmetry integrated over helicity window

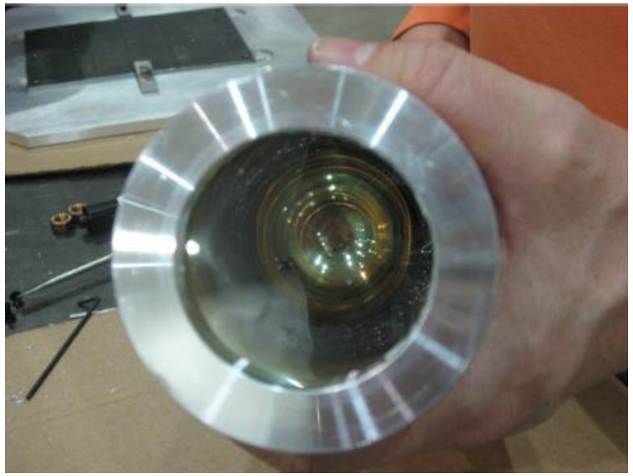
$$E^{\pm} = LT\int_0^{E_{\max}} \varepsilon(E)E\frac{d\sigma}{dE}(E)\left(1 \pm P_e P_\gamma A_l(E)\right)dE \longrightarrow A_{Exp} = \frac{E^+ - E^-}{E^+ + E^-}$$

Same technique used in Hall C

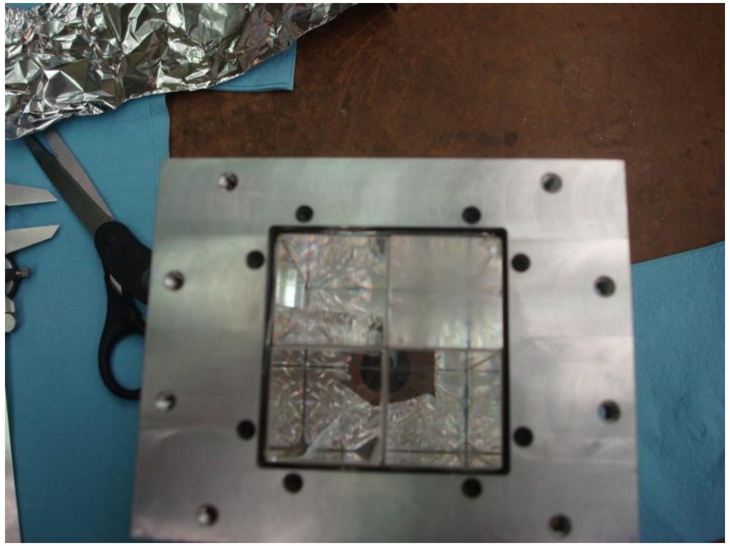
→ No threshold, so analyzing power well understood
→ Less sensitive to understanding detector resolution
→ Understanding detector non-linearity over relevant range of signal size most significant challenge → LED pulser system



Linearity measurement



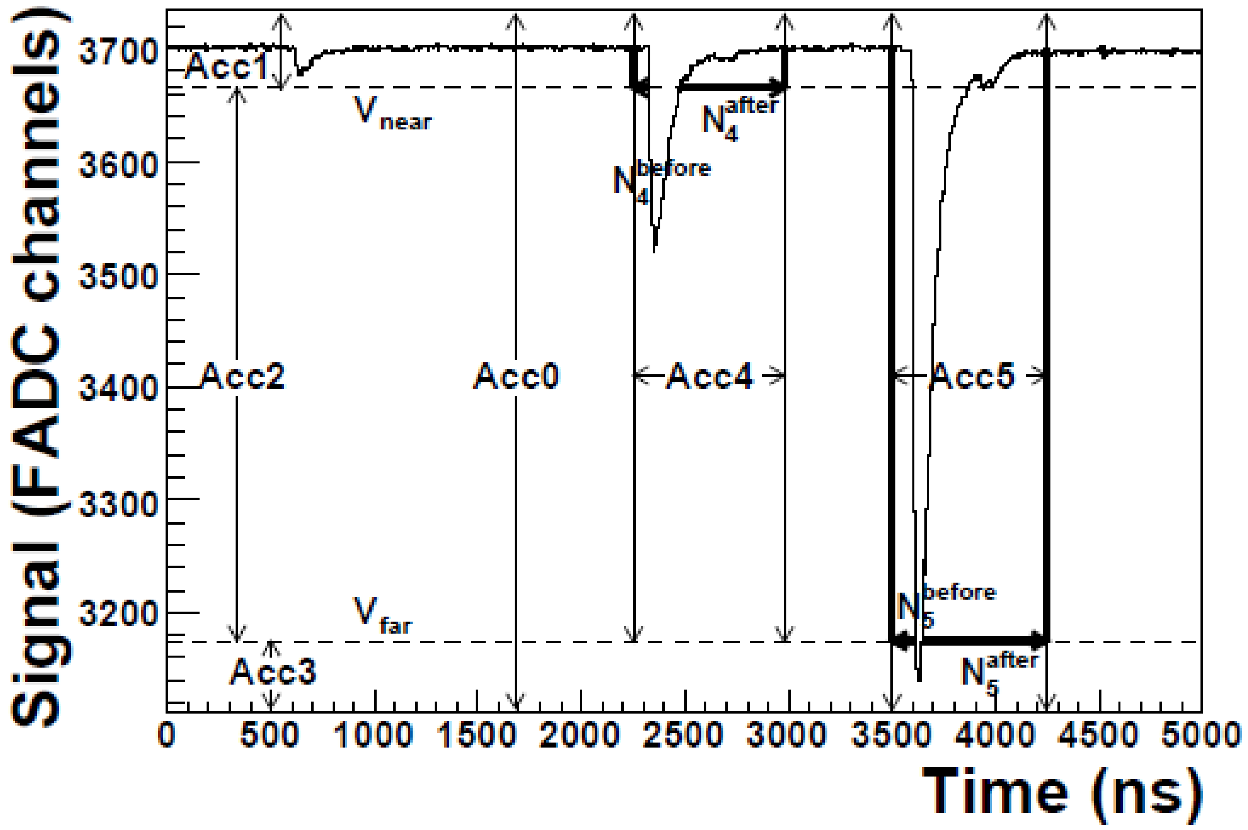
GSO - low energy



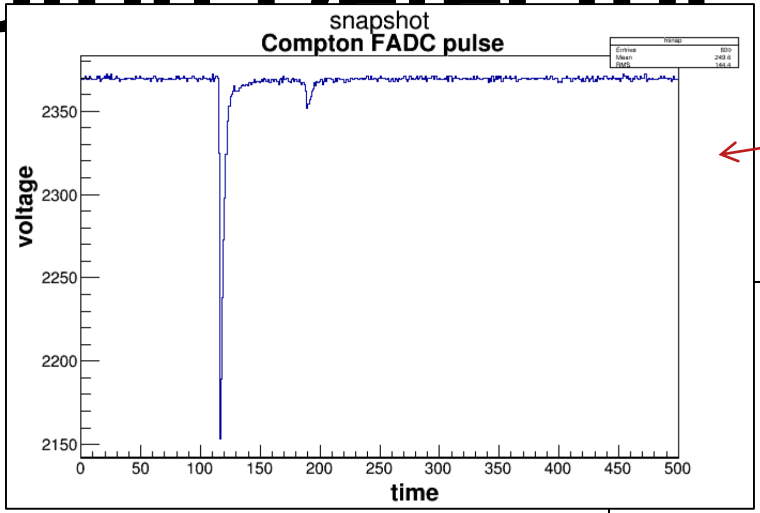
Lead-tungstate – high energy

Hall A Photon detector

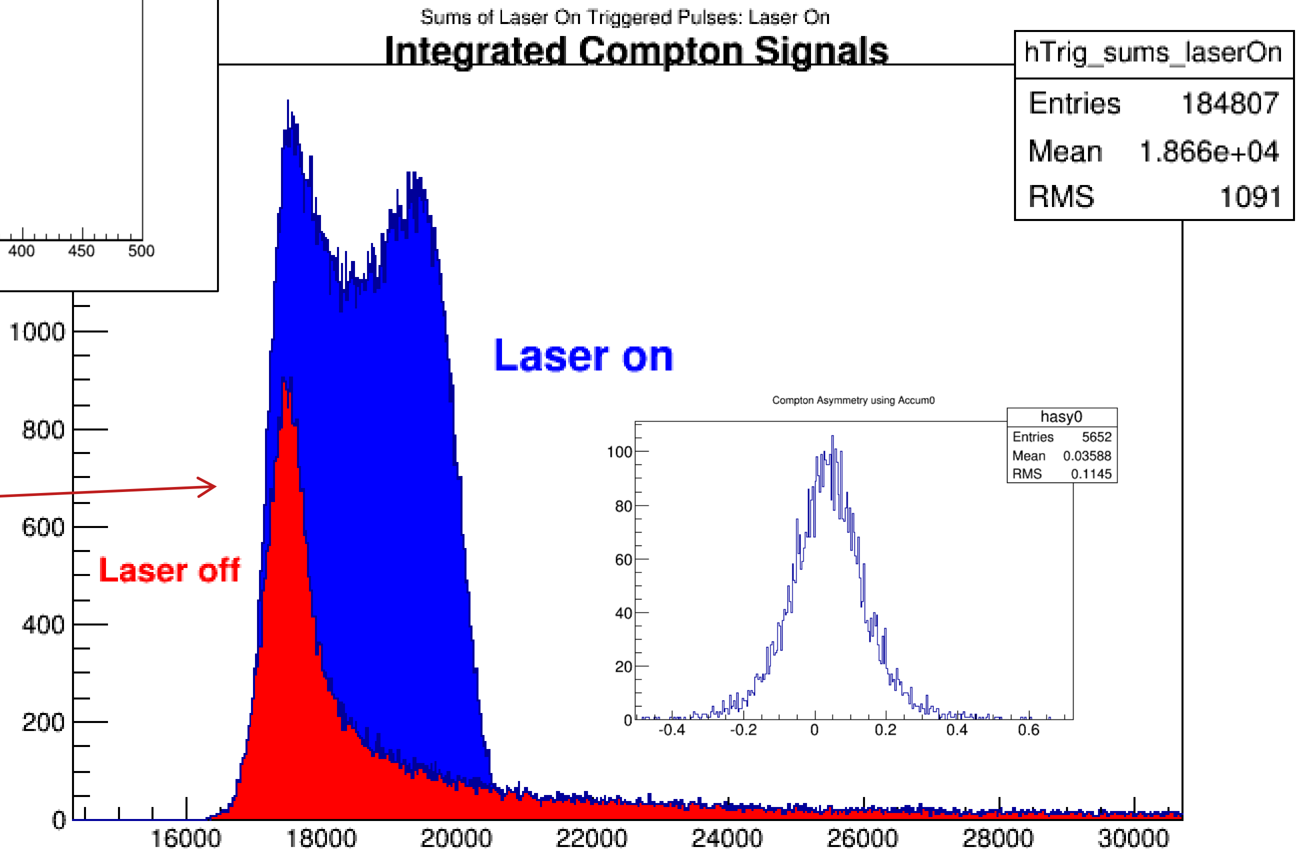
- FADC readout SIS3320 250 MHz FADC
- Digital integration



Photon Detector Signals



Single snapshot



Integrated spectrum – has characteristic Compton shape

Raw asymmetry ~ 3.6%

Right order of magnitude

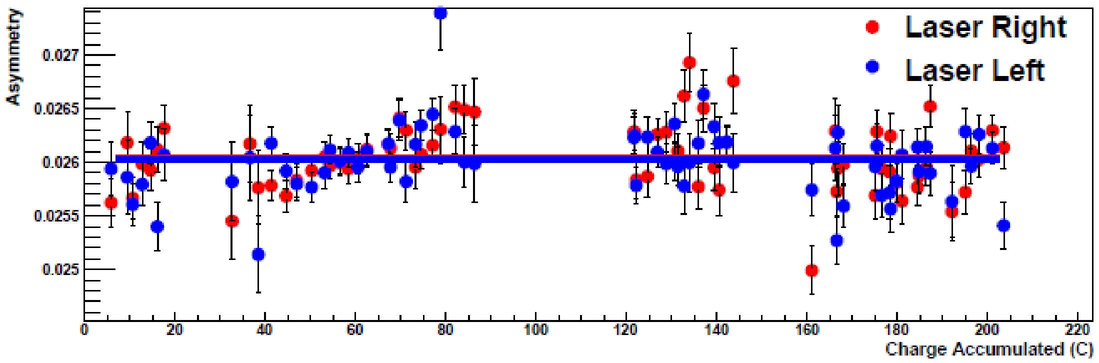
Photon integrated method

- 1 large detector block containing all the shower gives best results because of simpler detector response

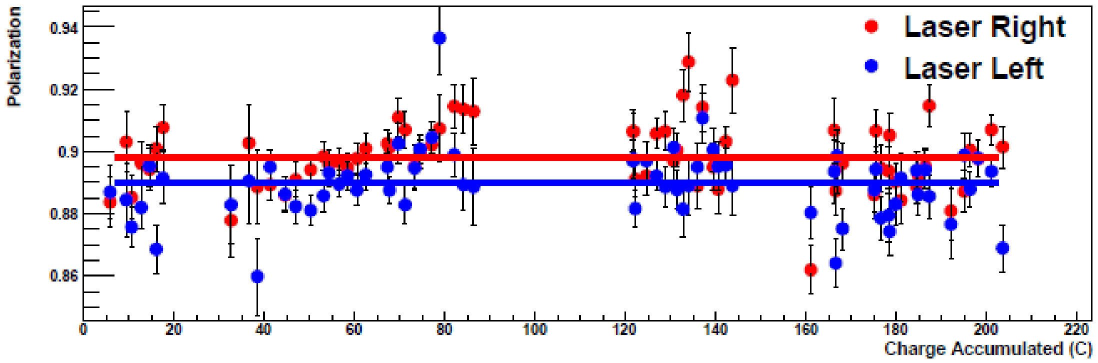
- Very successful at low energies with GSO : 1 to 3 GeV best polarization accuracies at 1% level at 1 GeV and ~0.6% at 3 GeV

- More sensitive to background
  - Low energy PREX : GSO sensitive to neutron background
  - 6 GeV data : accumulator 0 odd behavior, most likely due to large low energy background from synchrotron
    - Optimize shielding in front of calorimeter
    - Use thresholds to reduce background
  - Still need to take more high energy data

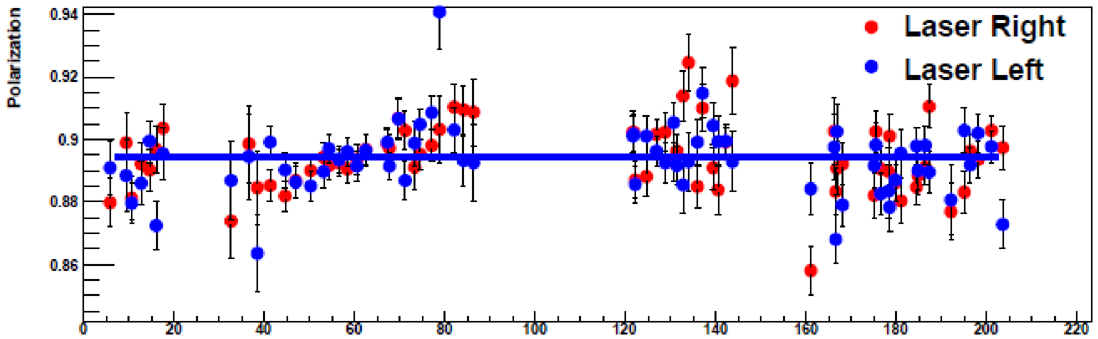
Happex III results



(a)



(b)



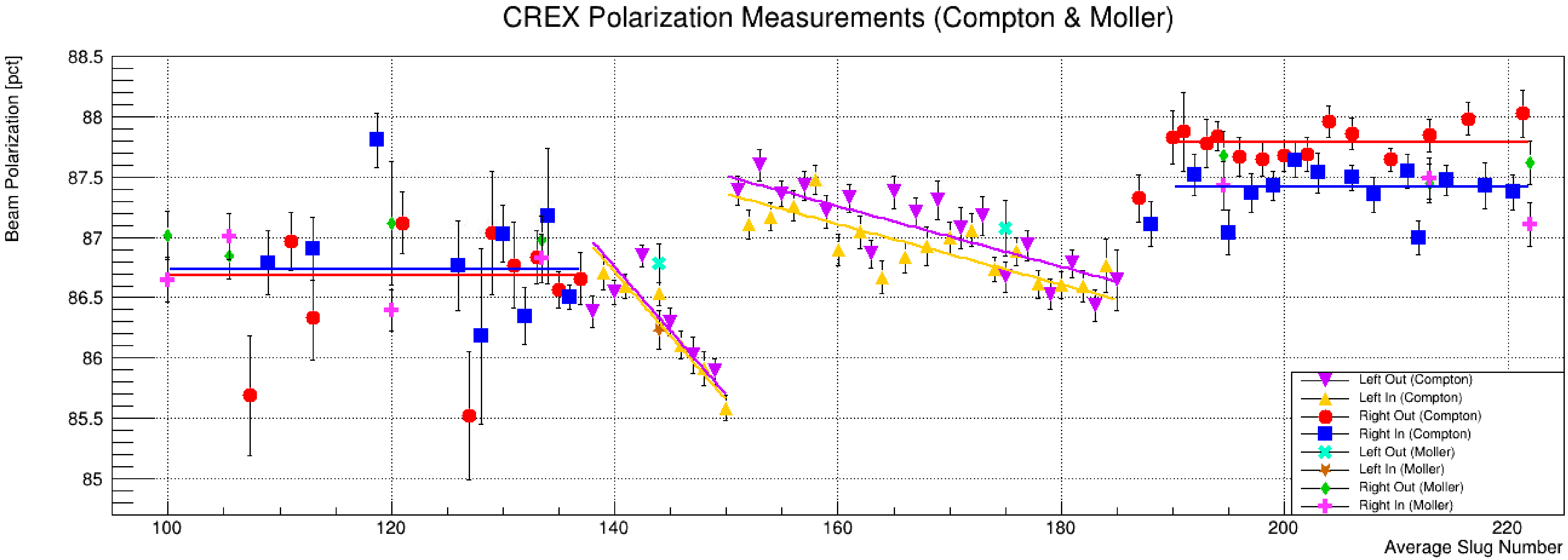
Upgraded photon calorimeter with integrating readout for Hall A Compton Polarimeter at Jefferson Lab

Friend Nucl.Instrum.Meth. A676 (2012) 96-105

Friend Phd Thesis CMU 2012

Hall A Compton Polarimeter – Recent Results

CREX Experiment – 2019-2020



CREX Compton analysis: dP/P = 0.52% Photon detector only (electron detector not fully functional)

CREX Compton Systematic Uncertainties

Photon detector for polarization measurements
→ Electron detector installed, but used primarily for tests and commissioning new VETROC-based DAQ

Photon detector measurements made using threshold-less, energy-integrating technique

$$E^{\pm} = LT\int_0^{E_{\max}} \varepsilon(E)E\frac{d\sigma}{dE}(E)\left(1 \pm P_e P_\gamma A_l(E)\right)dE$$

$$A_{Exp} = \frac{E^+ - E^-}{E^+ + E^-}$$

Results in reduced sensitivity to absolute detector response

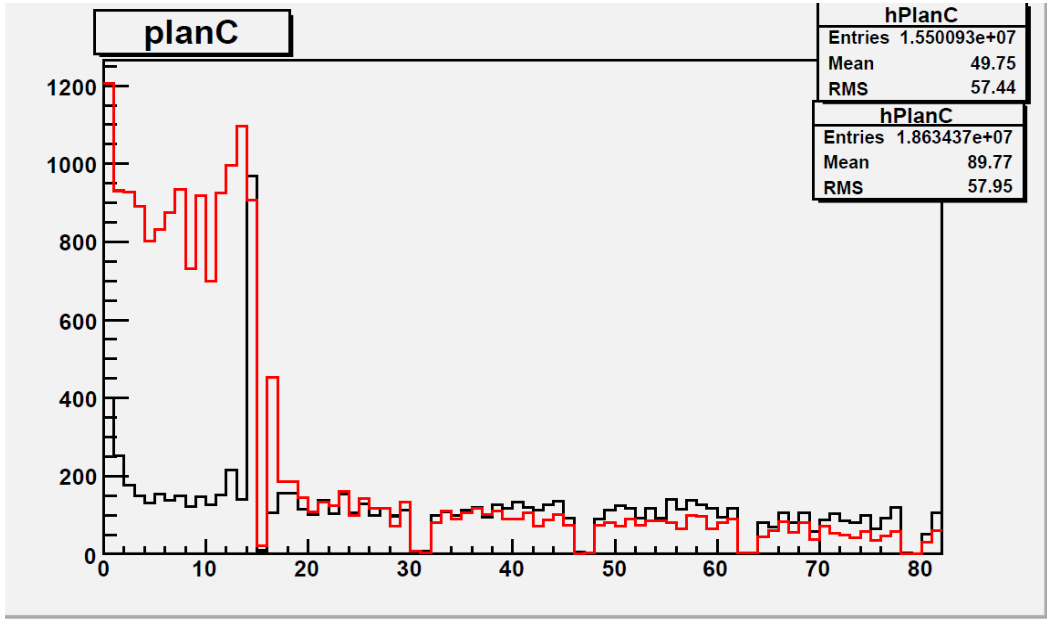
Source	$\frac{dP}{P}$ (%)
Collimator offset	0.20
Laser DOCP	0.45
Gain shift	0.15
Nonlinearity	0.02
Model	0.05
Beam energy	0.05
Statistics	0.02
Total	**0.52**

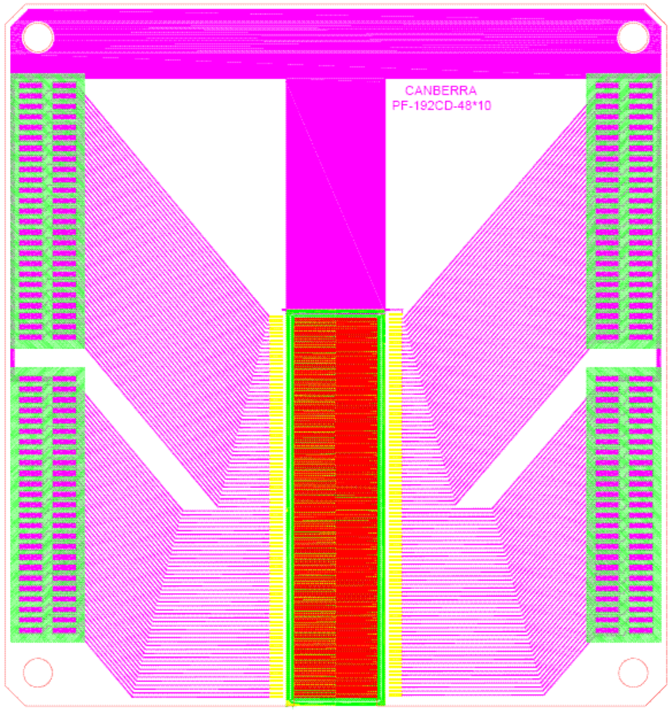
Electron detectors

Hall A Compton Electron Detector

Silicon strip electron detector worked well for most of 6 GeV → replaced around the same time as upgrade of laser system

→ Updated system did not perform well – excess noise required high thresholds, resulting in low efficiency





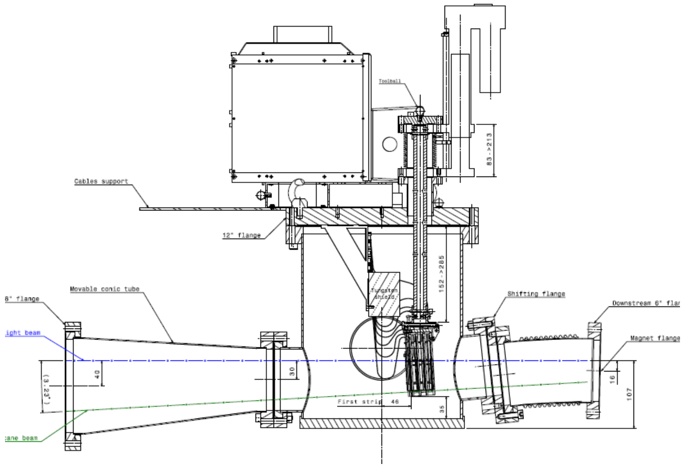
Hall A: silicon strip

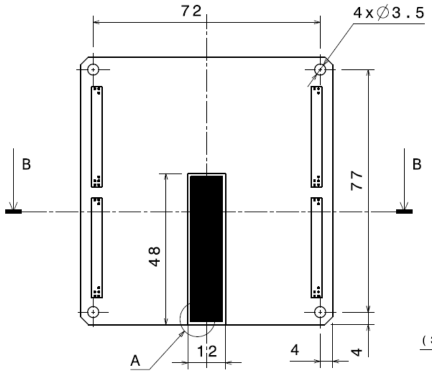
→ 4.6 cm vertical coverage

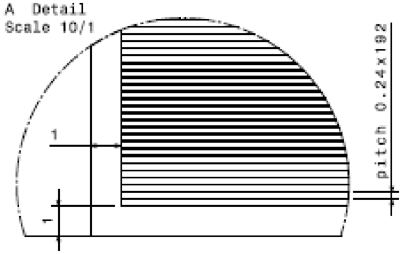
→ 192 strips, 240 μm pitch

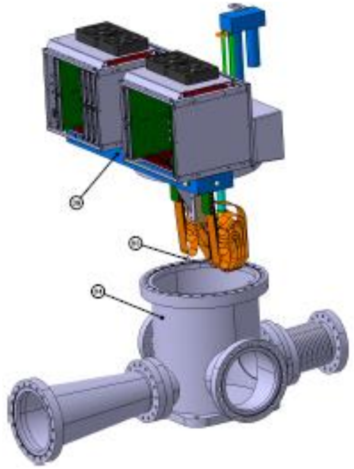
Hall A Compton electron detector

- Silicon microstrip detector
- 500 μm thick 250 μm thick
- 192 strips = 4.8 cm
- 4 planes
- 768 channels
- Vertical motion
- Detector -> Flex -> PCB -> Electronics

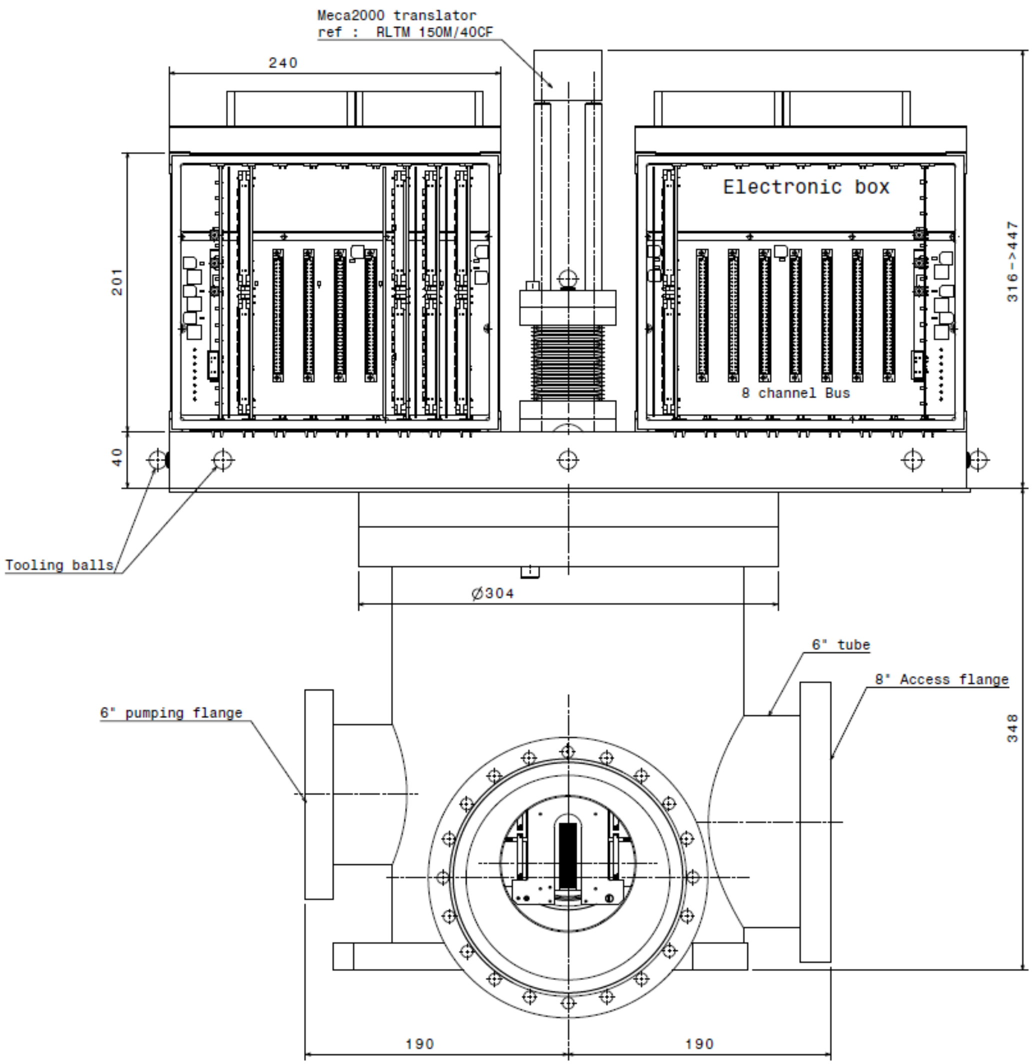


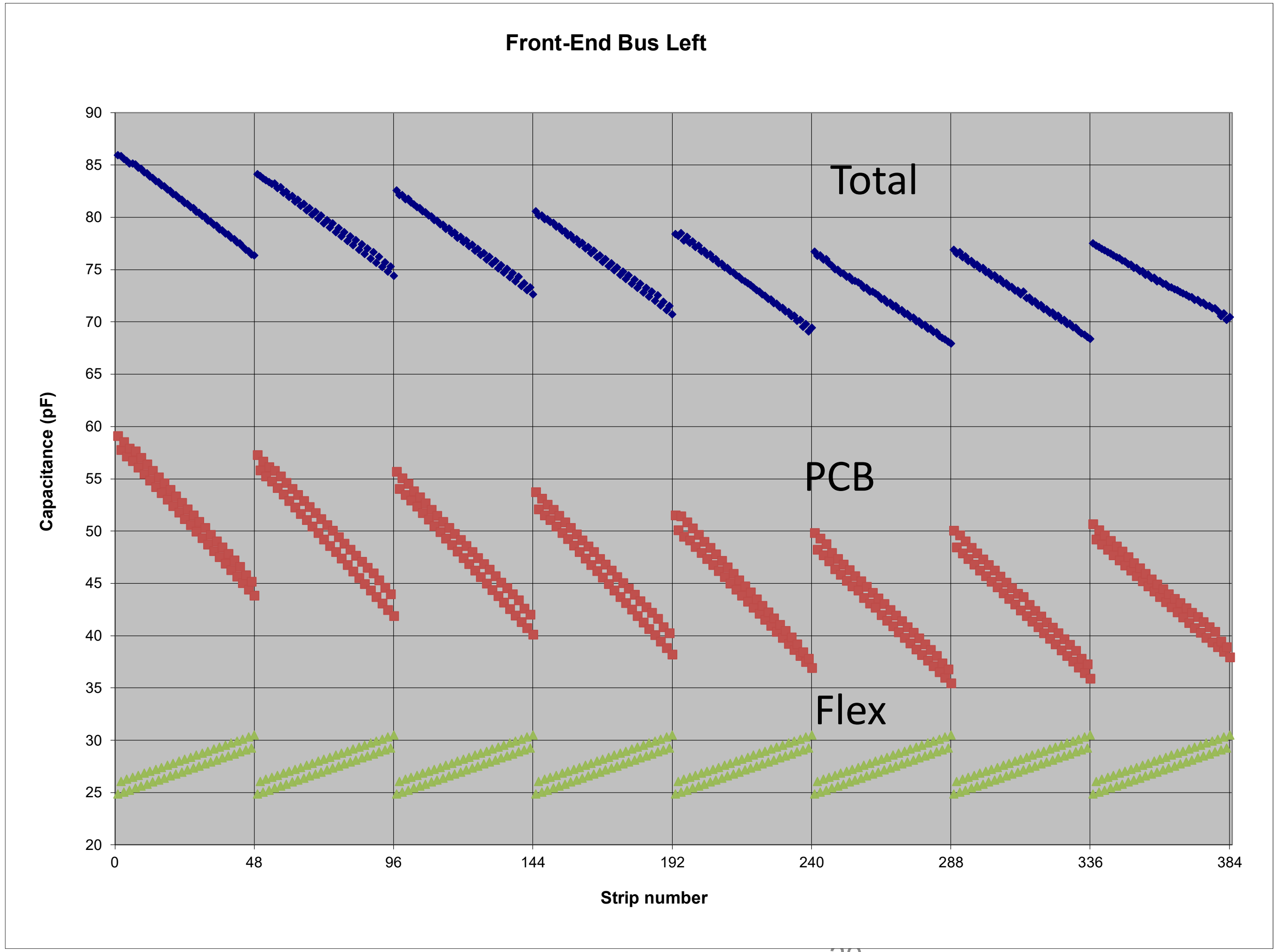




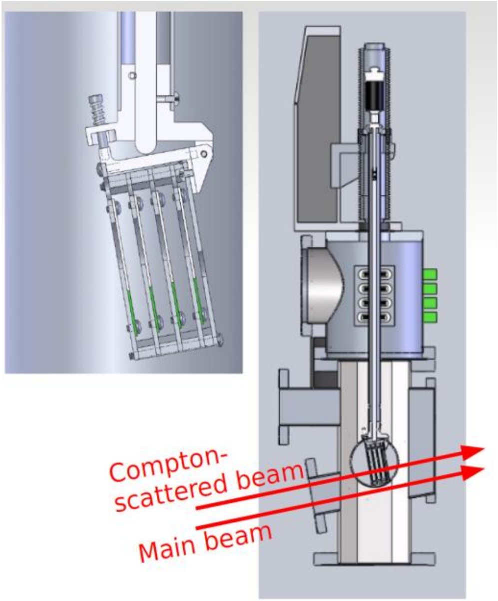


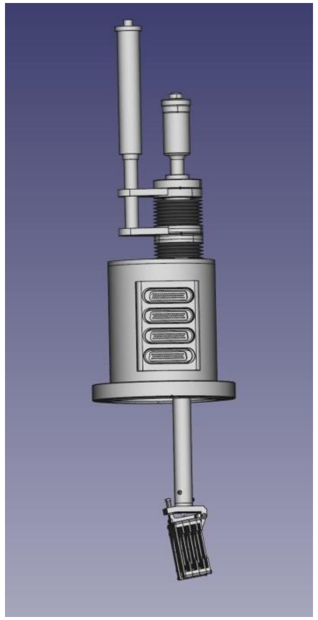
Capacitance from PCB boards

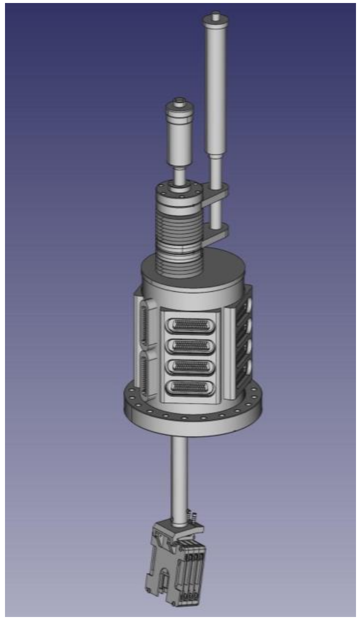




Hall A possible fix







- Same chambers as diamond detector with similar cable length and electronics
- Also investigating ASIC on detector for best signal to noise

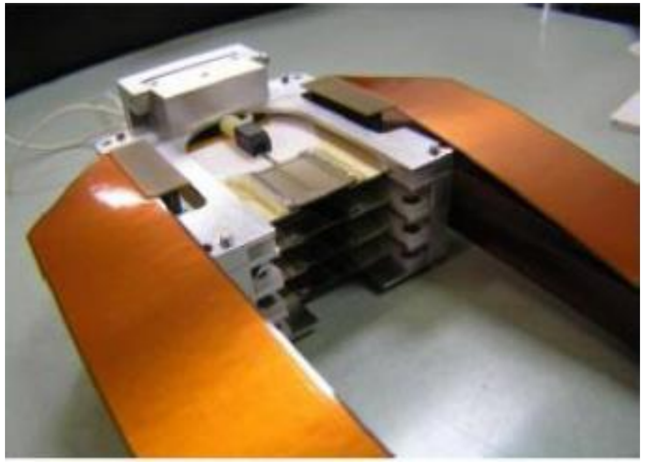
Hall C Compton Electron Detector

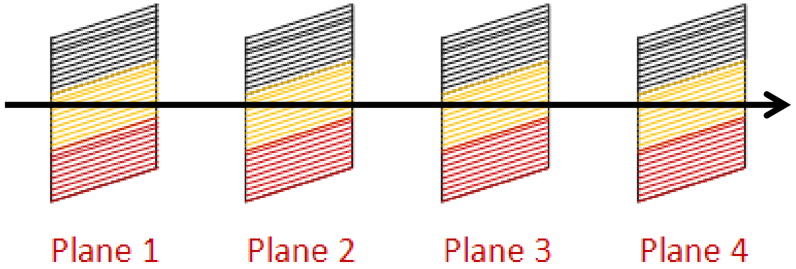
Diamond microstrips used to detect scattered electrons

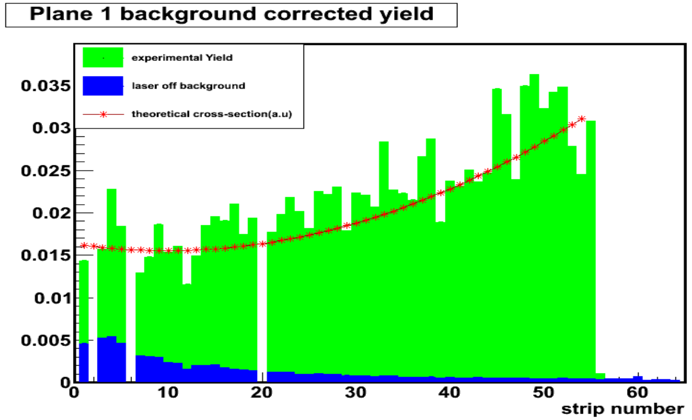
→ Four 21mm x 21mm planes each with 96 horizontal 200 μm wide micro-strips.

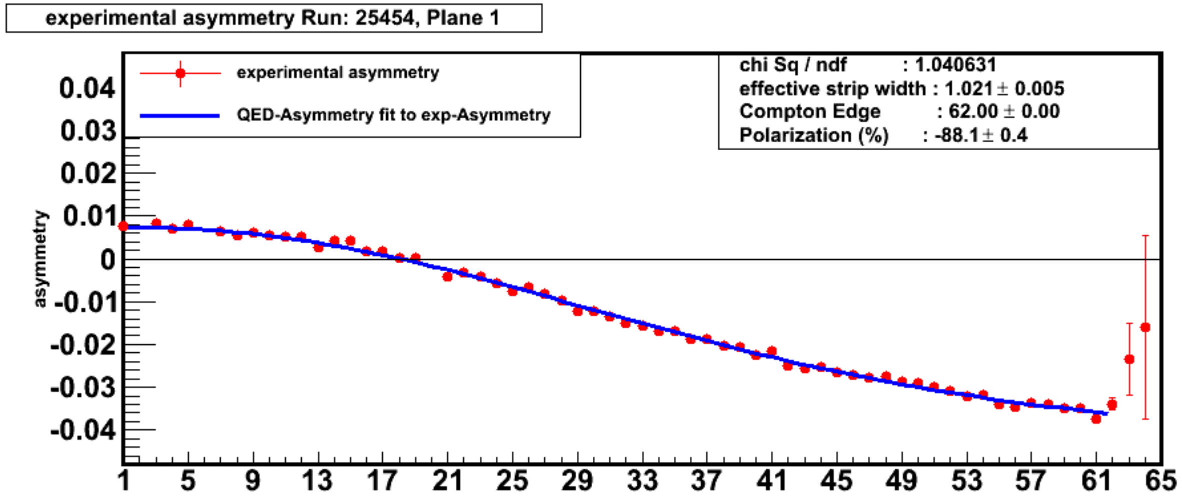
→ Rough-tracking based/coincidence trigger suppresses backgrounds

→ Detector inside vacuum can – electronics outside → efficiency ok (>80%), but some variation strip-to-strip



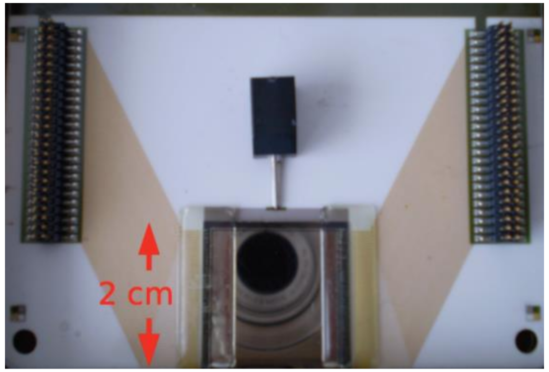


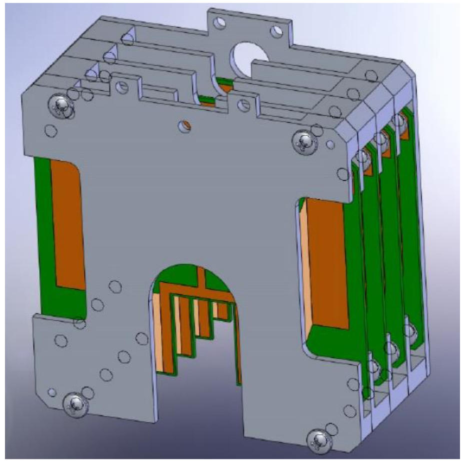


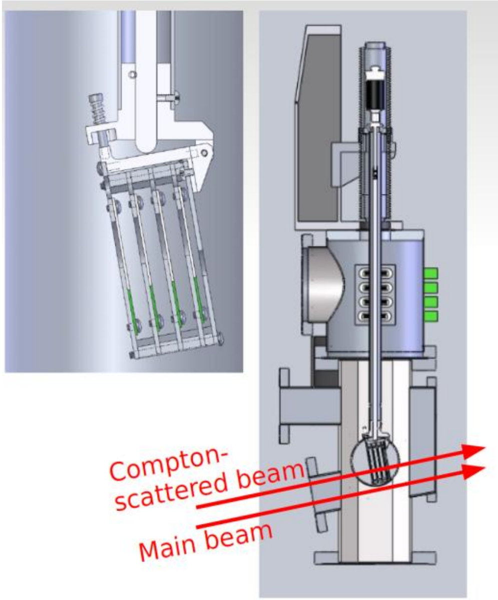


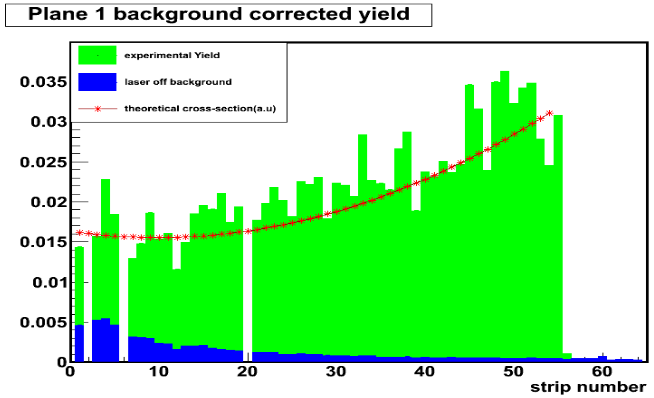
Compton polarimeter electron detector

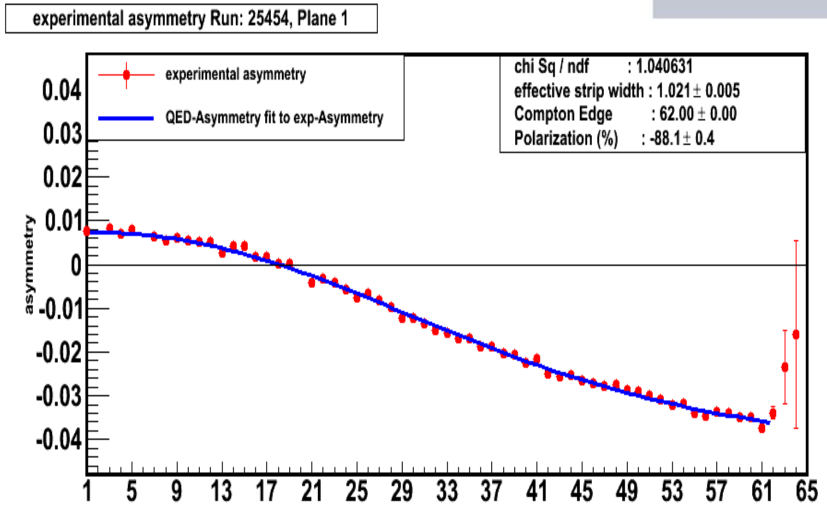
- Silcon or diamond strip option
- About 200 to 250 strips 250 μm width
- 5 cm length to catch zero crossing











Hall C Compton Systematic Uncertainties (electron detector)

Scale uncertainty = 0.42%

Point-to-point uncertainty = 0.41%

Total systematic uncertainty = 0.59%

Hall C Compton performance summarized in:

Narayan *et al*, *Phys.Rev.X* 6 (2016) 1, 011013

Photon detector had significantly larger systematic uncertainties – difficult to constrain non-linearity under load

Source	Uncer-tainty	$\Delta P/P$ (%)
Laser polarization	0.18 %	0.18
3^{rd} Dipole field	0.0011 T	0.13
Beam energy	1 MeV	0.08
Detector Z position	1 mm	0.03
Trigger multiplicity	1-3 plane	0.19
Trigger clustering	1-8 strips	0.01
Detector tilt (X)	1°	0.03
Detector tilt (Y)	1°	0.02
Detector tilt (Z)	1°	0.04
Strip eff. variation	0.0 - 100%	0.1
Detector Noise	$\leq$20% of rate	0.1
Fringe Field	100%	0.05
Radiative corrections	20%	0.05
DAQ ineff. correction	40%	0.3
DAQ ineff. pt-to-pt		0.3
Beam vert. angle variation	0.5 mrad	0.2
helicity correl. beam pos.	5 nm	$<$ 0.05
helicity correl. beam angle	3 nrad	$<$ 0.05
spin precession through chicane	20 mrad	$<$ 0.03
Total		0.59

Summary

- Hall A and C have leveraged many years of polarization measurements to incrementally improve polarimeters to achieve high precision
- Compton require some dedicated beam tuning time as sometime injector setting need to be tuned for background
- Hall A GSO photon detector very successful with integrated method in 1 to 3 GeV range
- Electron detector
  - Diamond worked well with reasonable efficiency with careful setup
  - Silicon strip
    - Issues in Hall A
      - Capacitance
      - Scaling from 48 to 192 channels not trivial : cross talk
    - Upgrade to diamond detector, new chamber and on-detector electronics
- Developments ongoing for 12 GeV Moller experiment