Compton Polarimetry at Jefferson Lab

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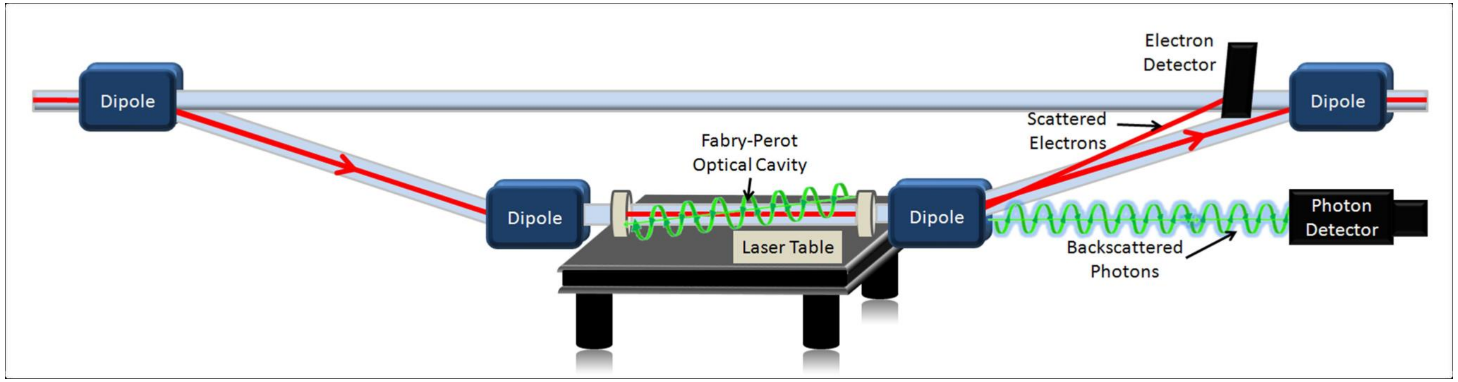
Jefferson Lab



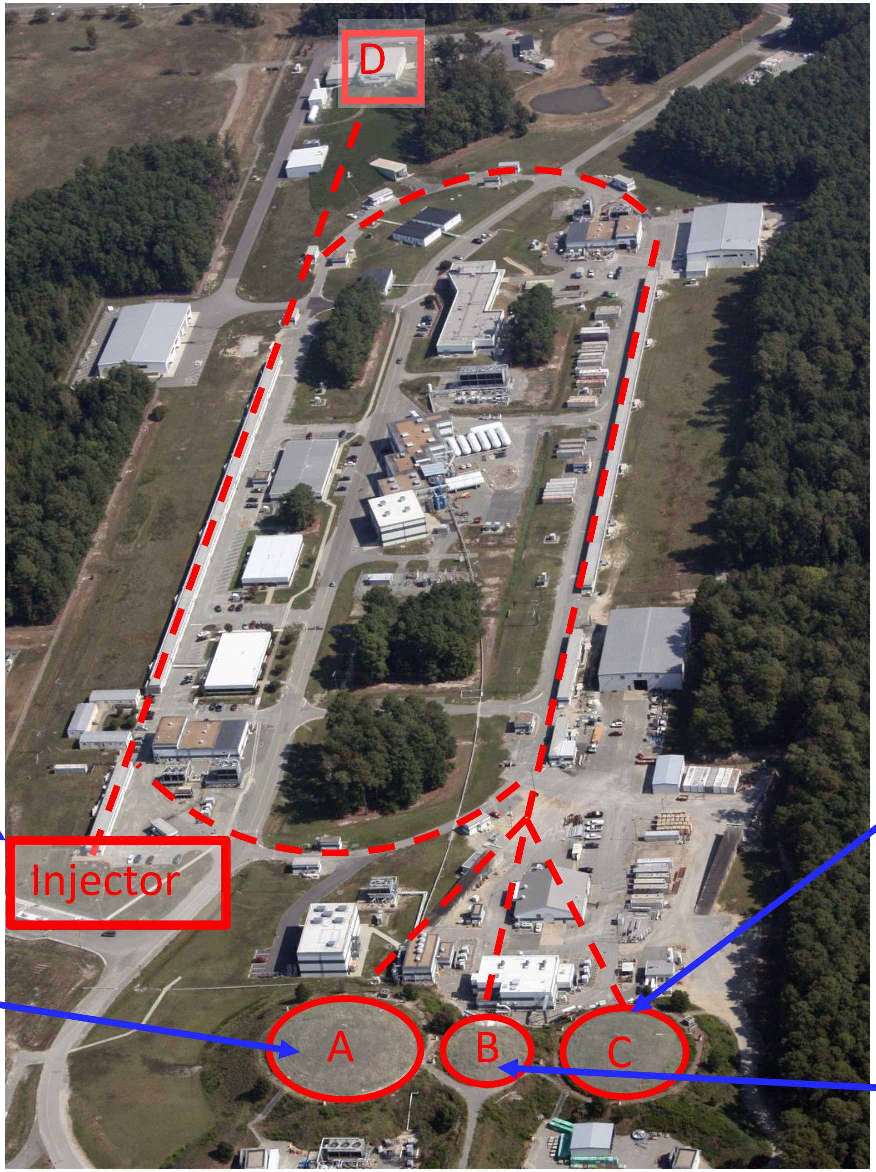
FCC EPOL Workshop

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

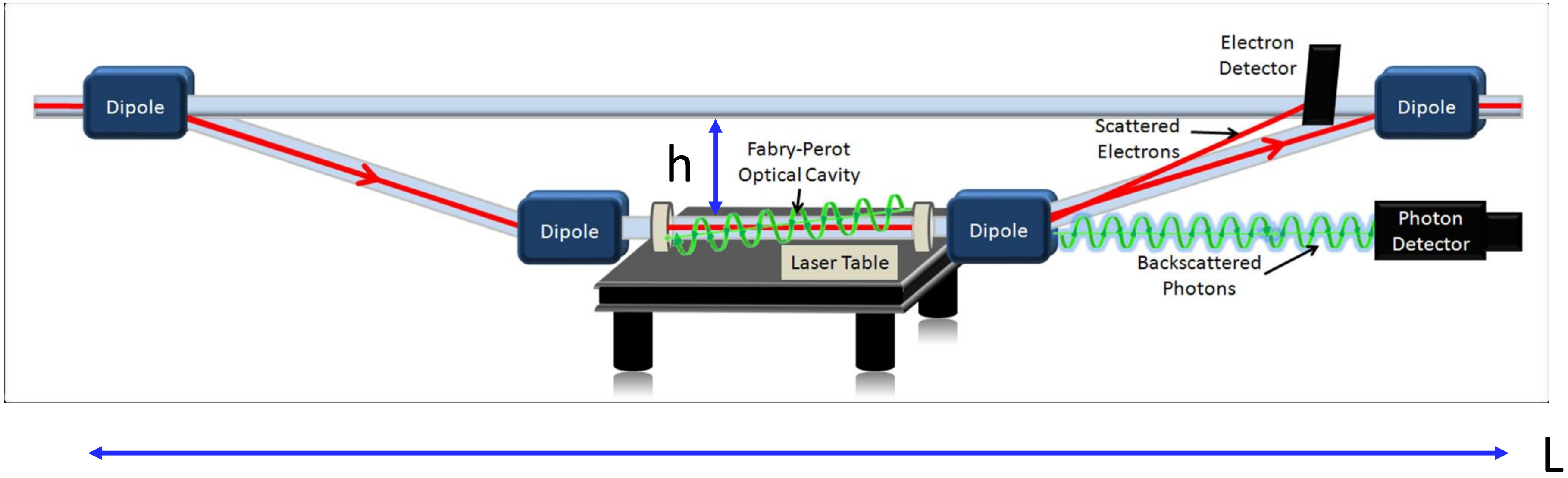
Compton Polarimeter
- Installed 2010 (Q-Weak)

Møller Polarimeter
- Out of plane saturated iron foil

Hall B

Møller Polarimeter
- In plane, low field target

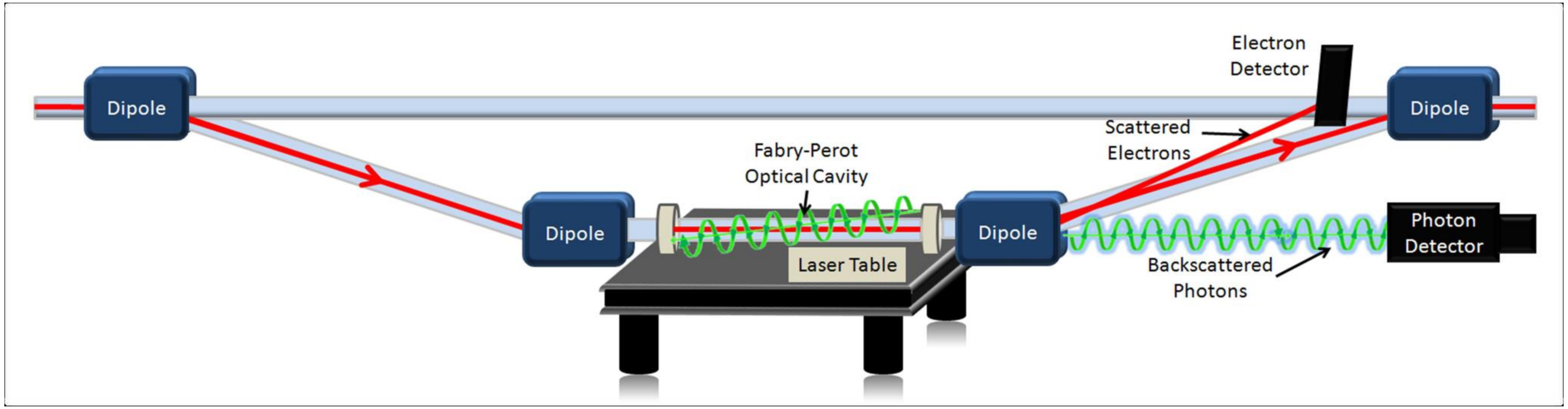
Compton Polarimeter Overview



Halls A and C have similar but not identical Compton polarimeters

- Both designed for measurement of **longitudinal** polarization
- Common layout → 4-dipole chicane to deflect electrons to laser system and back to nominal beam path
- Hall A Compton built as part of original Hall A beamline (1998 first use) by Saclay/JLab
- Hall C Compton built in 2010 by JLab/MIT/UVa/Manitoba/Winnipeg/William and Mary
- Dimensions:
  - Hall C: Overall length: L=11 m. Vertical deflection: originally h=57 cm (6 GeV), now h=12 cm (11 GeV)
  - Hall A: Overall length: L=15 m. Vertical deflection: originally h=30 cm (6 GeV), now h=21.5 cm (11 GeV)

Compton Polarimeter Subsystems

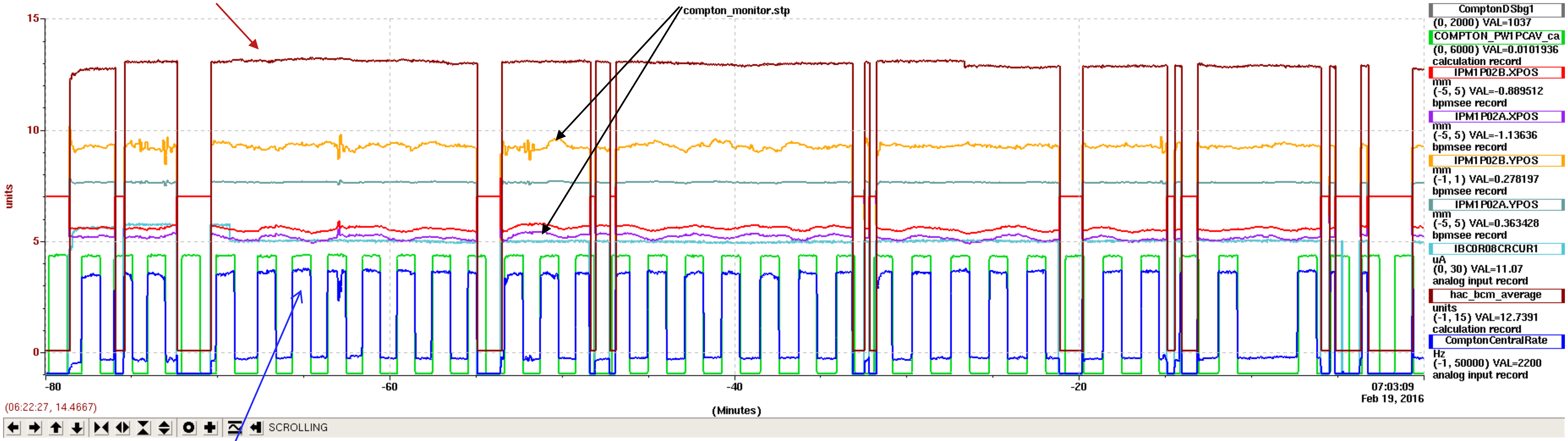


- Laser – both Hall A and Hall C use Fabry-Perot cavities to store >1 kW of laser power
  - Hall A: Originally used 1064 nm narrow linewidth laser alone. Later upgraded to a frequency-doubled (532 nm) system → modest input power (up to 1 W), high Finesse cavity
  - Hall C: Started with 532 laser (Coherent 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

Compton Operation Mode

Beam current

Beam positions



Photon detector rates

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***

Jefferson Lab

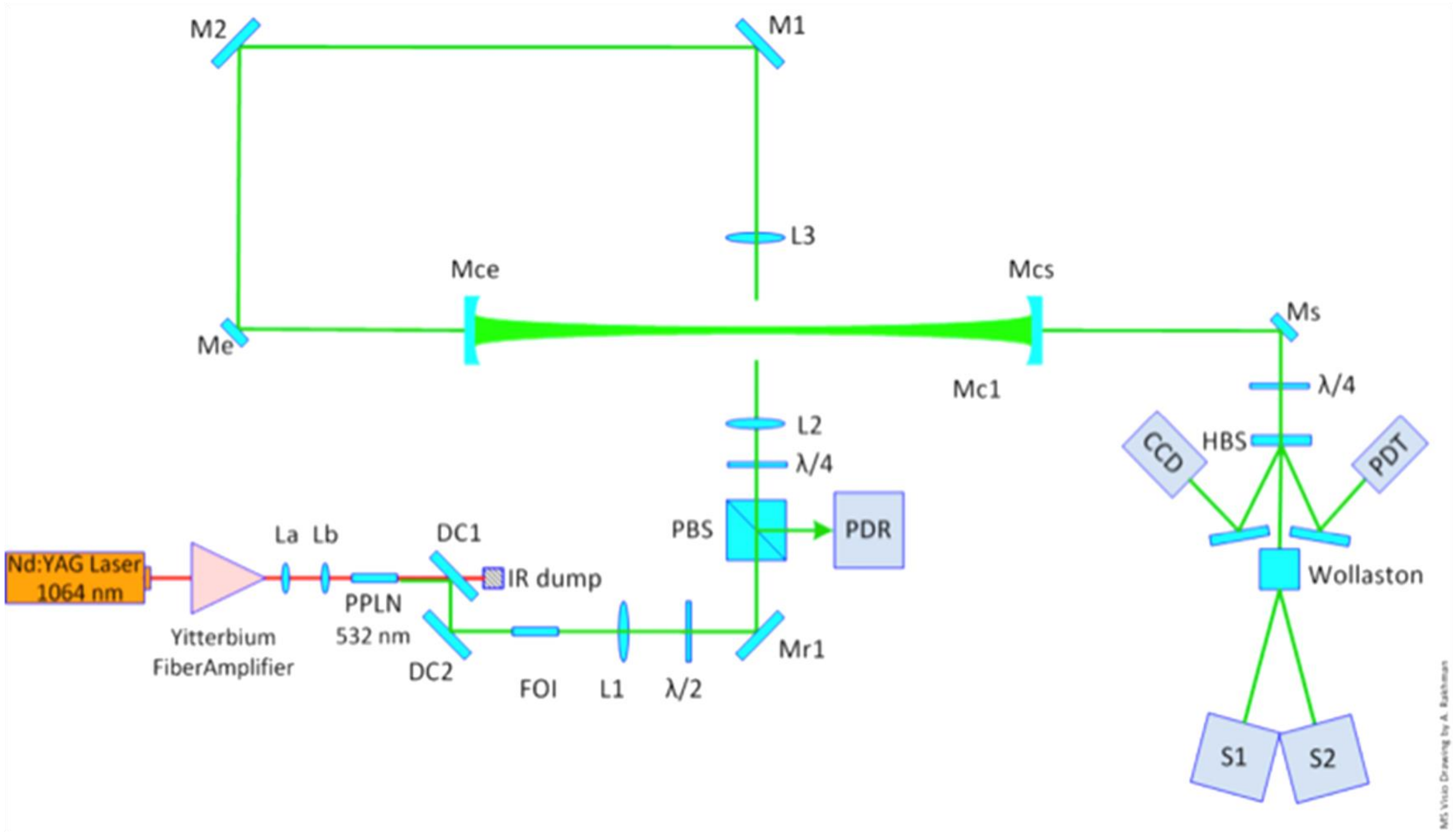
Hall A Laser System

Main components:

- Narrow linewidth 1064 nm seed laser
- Fiber amplifier (>5 W)
- PPLN doubling crystal
- High gain Fabry-Perot cavity
- Polarization manipulation/monitoring optics

Properties:

- 1 W laser power from doubling system
- Mirror reflectivity > 99.98%
- Cavity finesse >=13,000
- Stored power 2-10 kW



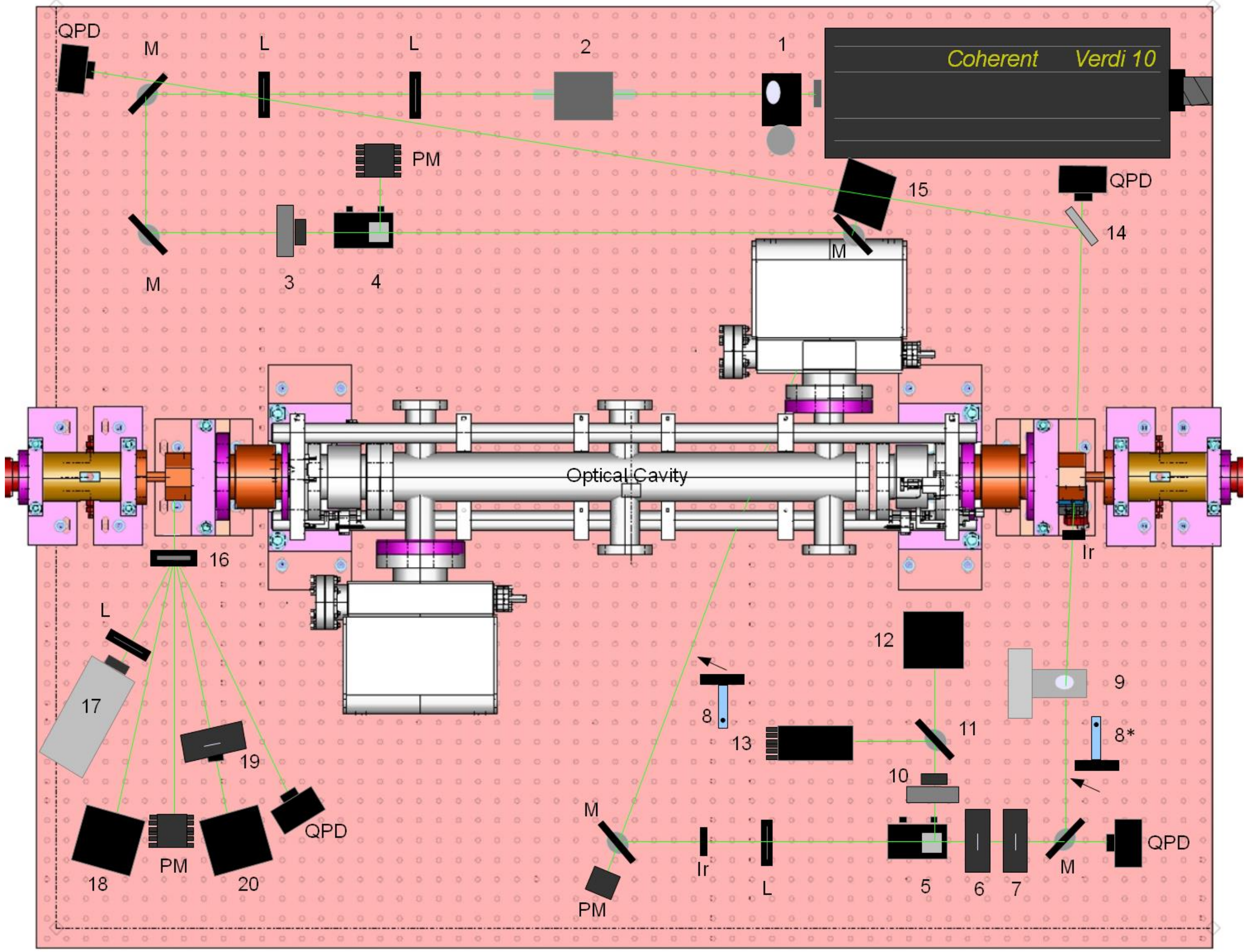
Hall C Laser System

Key differences with Hall A system:

- Higher power green laser → 10 W (Coherent VERDI)
- Large linewidth (1 MHz) means laser can’t be used with narrow linewidth cavity
- Cavity mirrors = 99.5%
- Cavity gain = 200, stored power ~ 1.7 kW

Drawbacks:

- 1.7-2 kW is the ultimate upper limit without increasing laser power
- At 10 W, already ran into issues with distortion of beam shape when used with optical components
- Apparent thermal effects became significant towards end of Q–Weak run – possible damage to vacuum windows or mirrors



Will replace Hall C system with one similar to Hall A → higher powers, better reliability

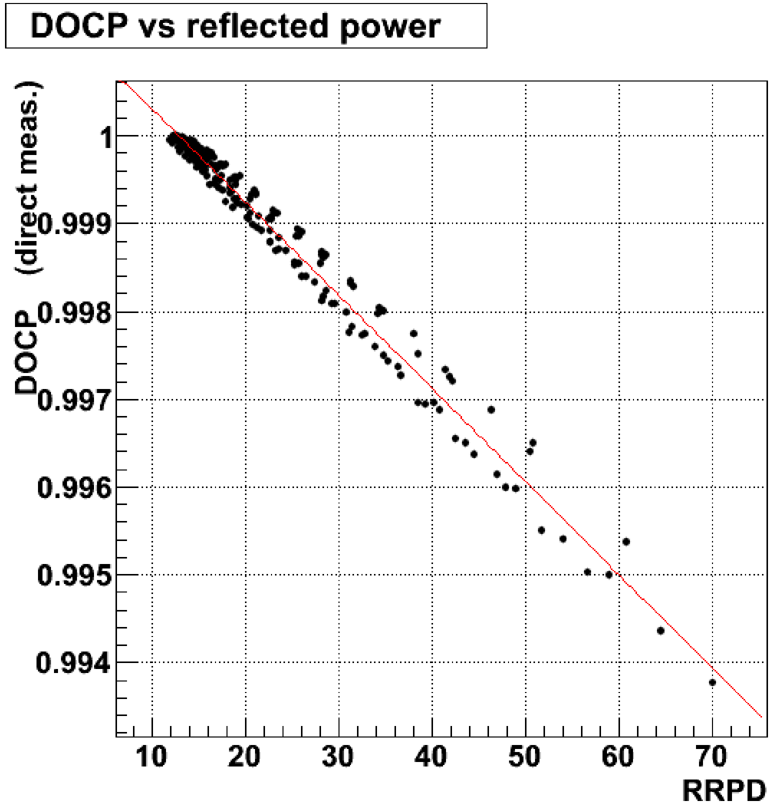
Polarization Measurement and Cavity Birefringence

Both Hall A and C mitigate impact of birefringence due to vacuum entrance window (and other elements) by monitoring light reflected back from cavity when unlocked

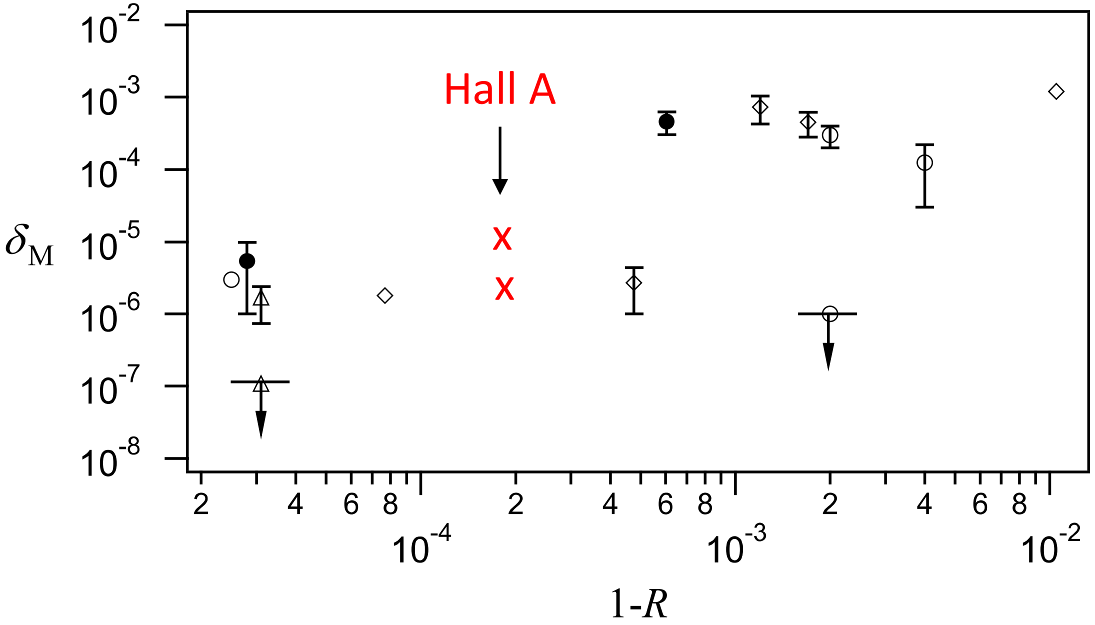
→ Leverages optical reversibility theorems: J. Opt. Soc. Am. A/Vol. 10, No. 10/October 1993, JINST 5 (2010) P06006

→ Birefringence in cavity cannot be ignored – resulted in non-negligible effects in Hall A

Circular polarization at cavity entrance



Measurements of cavity birefringence



F. Bielsa et al. Appl. Phys. B (2009) 97: 457

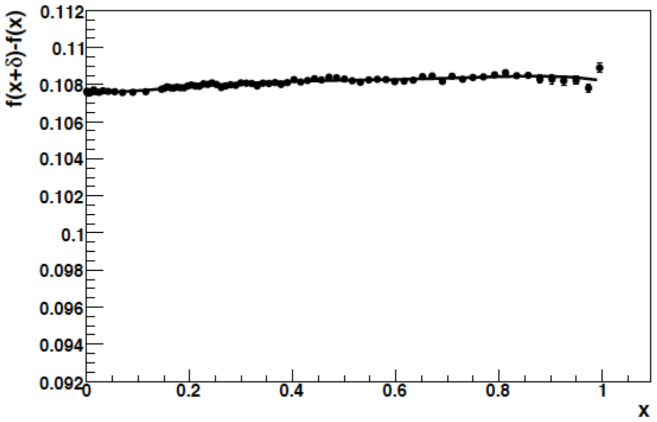
Photon Detectors

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

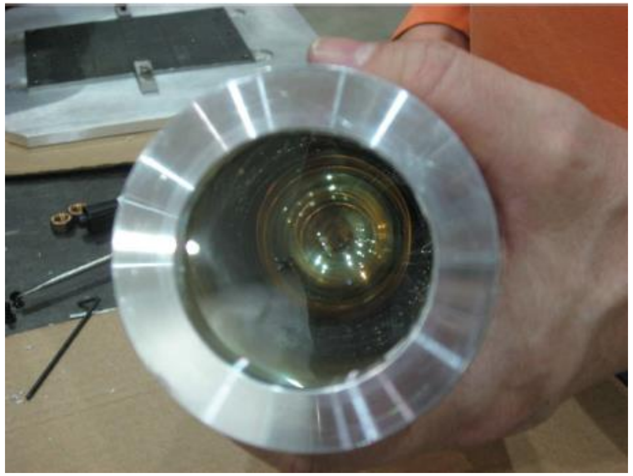
$$E^{\pm} = LT\int_0^{E_{\max}} \varepsilon(E)E\frac{d\sigma}{dE}(E)\left(1 \pm P_e P_\gamma A_l(E)\right)dE \longrightarrow A_{Exp} = \frac{E^+ - E^-}{E^+ + E^-}$$

Same technique used in Hall C

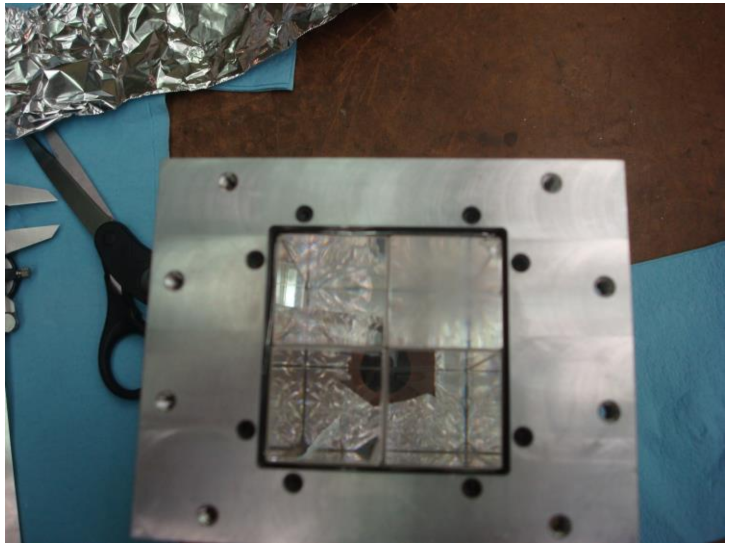
- → No threshold, so analyzing power well understood
- → Less sensitive to understanding detector resolution
- → Understanding detector non-linearity over relevant range of signal size most significant challenge → LED pulser system



Linearity measurement



GSO - low energy



Lead-tungstate – high energy

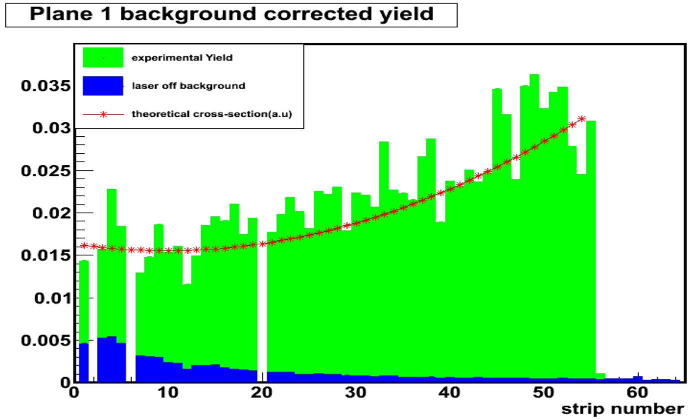
Hall C Compton Electron Detector

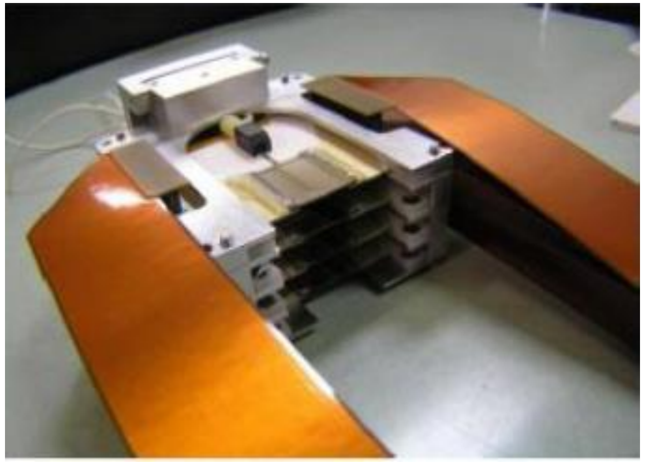
Diamond microstrips used to detect scattered electrons

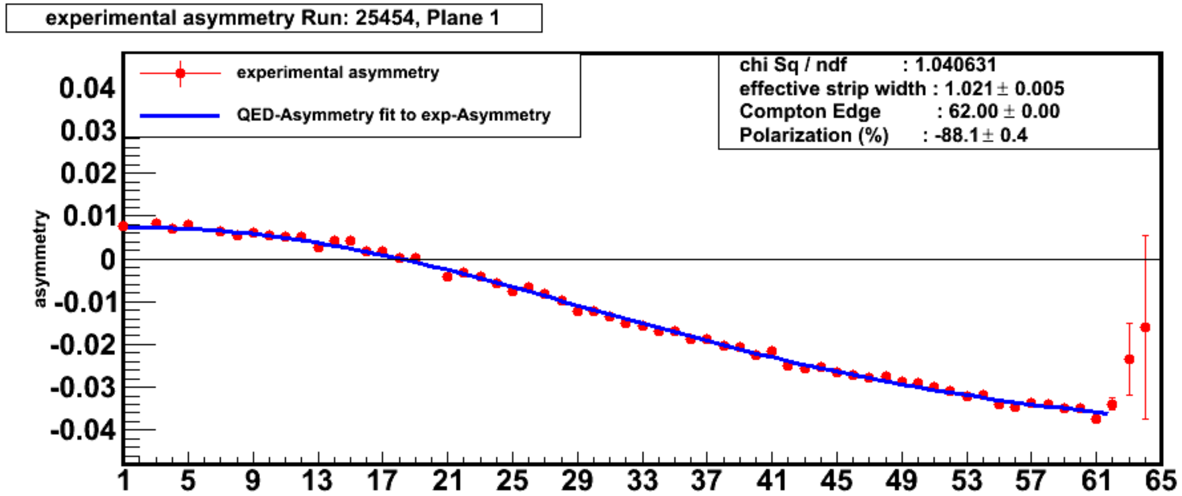
→ Four 21mm x 21mm planes each with 96 horizontal 200 μm wide micro-strips.

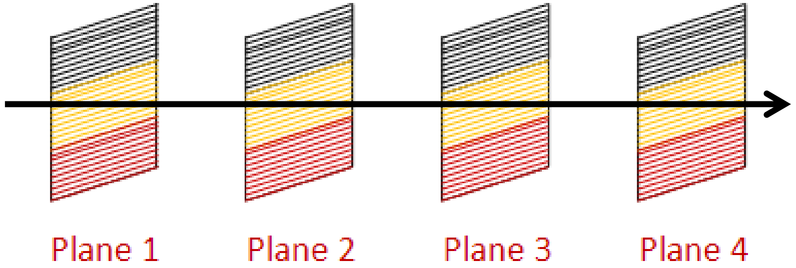
→ Rough-tracking based/coincidence trigger suppresses backgrounds

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









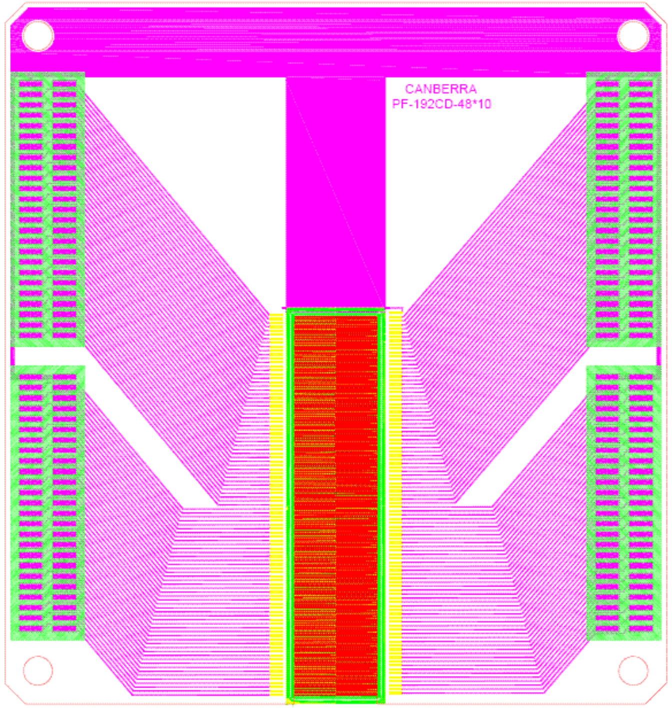
Hall A Compton Electron Detector

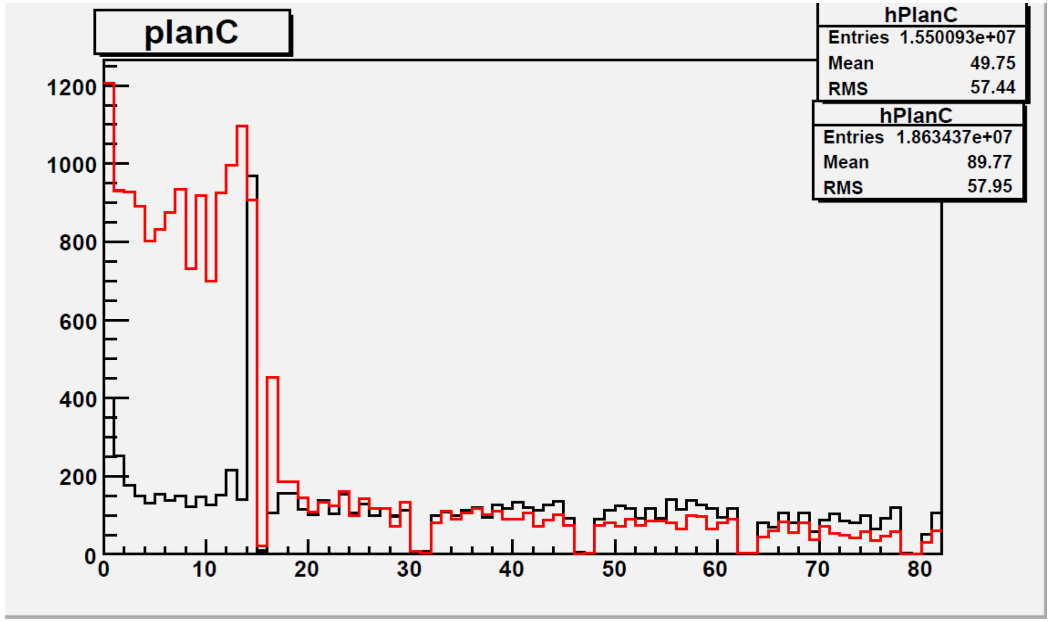
Silicon strip electron detector worked well for most of 6 GeV → replaced around the same time as upgrade of laser system

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

→ Likely due to excess capacitance in signal path

→ In preparation for upcoming MOLLER experiment will be replaced With diamond strip with ASIC on detector plane





Hall A: silicon strip

→ 4.6 cm vertical coverage

→ 192 strips, 240 μm pitch

Hall C Compton Systematic Uncertainties (electron detector)

Scale uncertainty = 0.42%

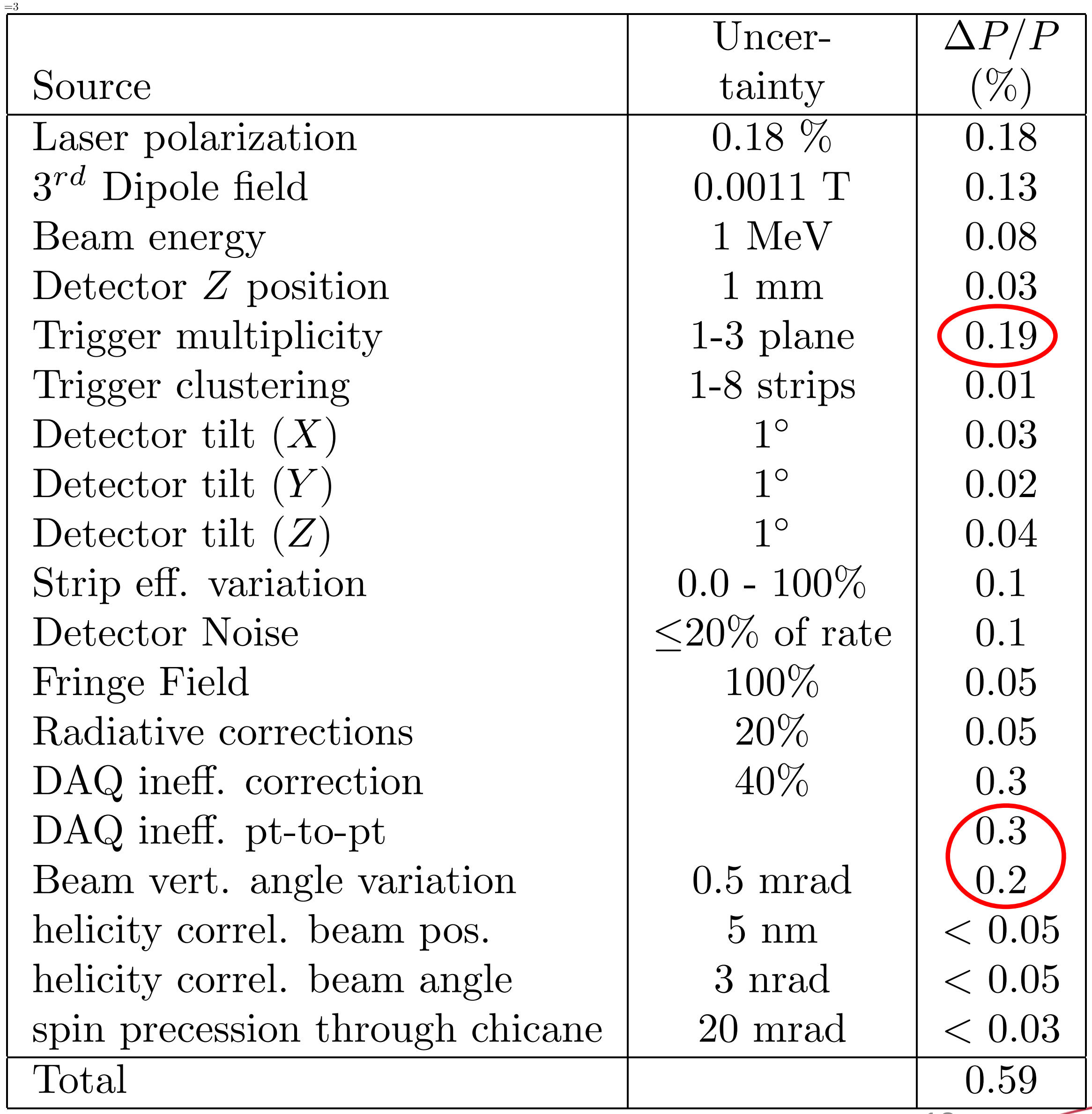
Point-to-point uncertainty = 0.41%

Total systematic uncertainty = 0.59%

Hall C Compton performance summarized in:

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

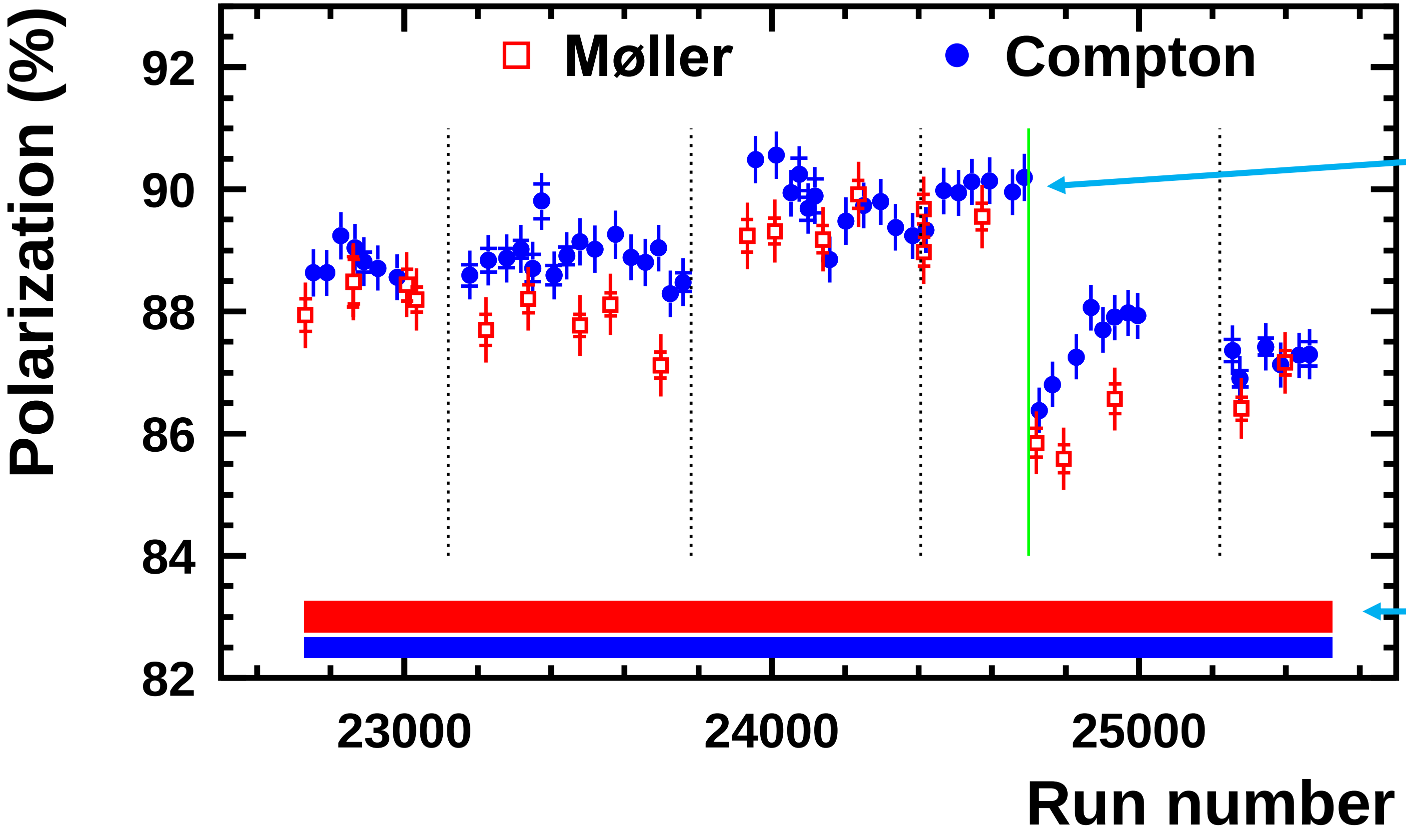
Photon detector had significantly larger systematic uncertainties – difficult to constrain non-linearity under load



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	≤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

Hall C Compton Performance

Q-Weak Run 2 (2011-2012)



Statistical + point-to-point uncertainties

Normalization uncertainties

Compton and Møller results agree to ~ 0.7% → combined norm. unc. = 0.77%

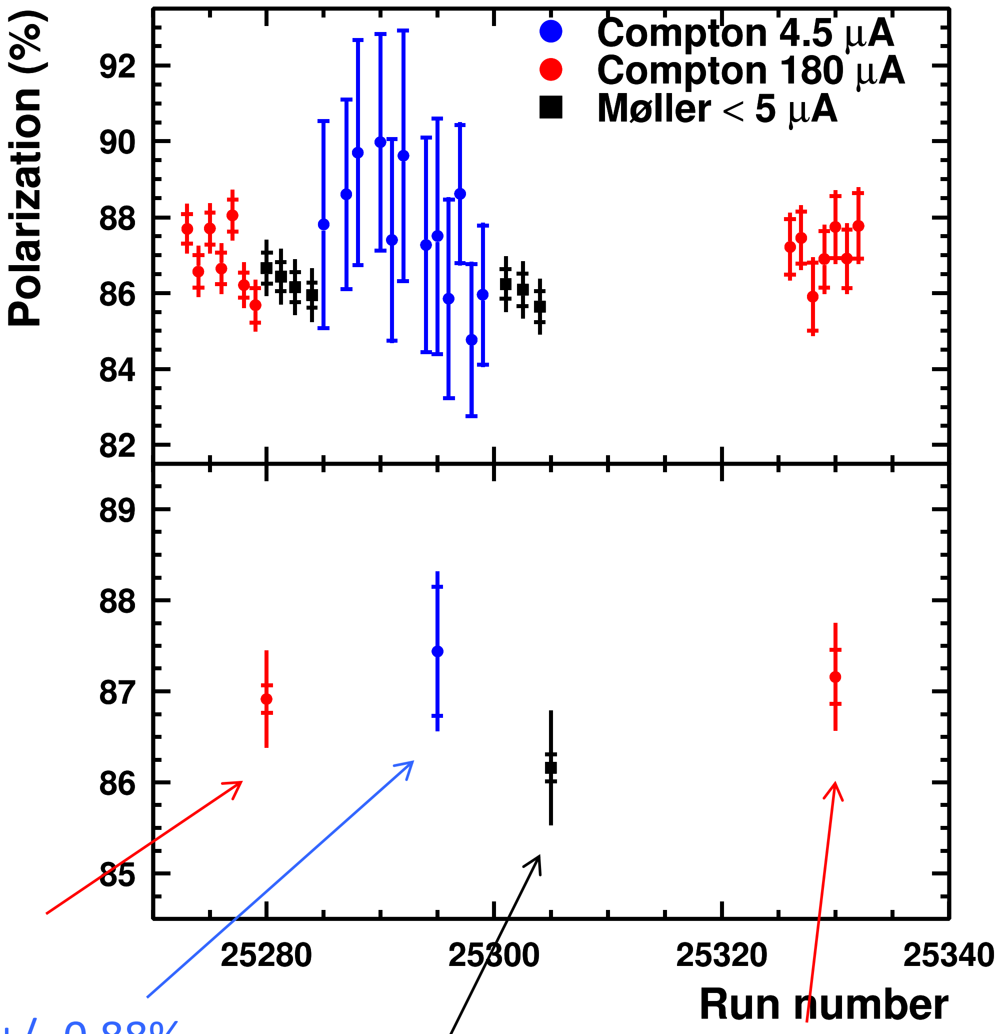
Used weighted average of both polarimeters, polarization unc. for Q-Weak = 0.61%

Polarimetry at Low and High Currents in Hall C

1. Measurements with Møller and Compton at same current to check systematic → agree within uncertainties (<1% relative)

2. Combination of low current (Møller + Compton) and high current (Compton) measurements limits current dependence to <1% over range of 175 μA

Magee *et al*, *Phys.Lett.B* 766 (2017) 339-344



86.92 +/- 0.53%

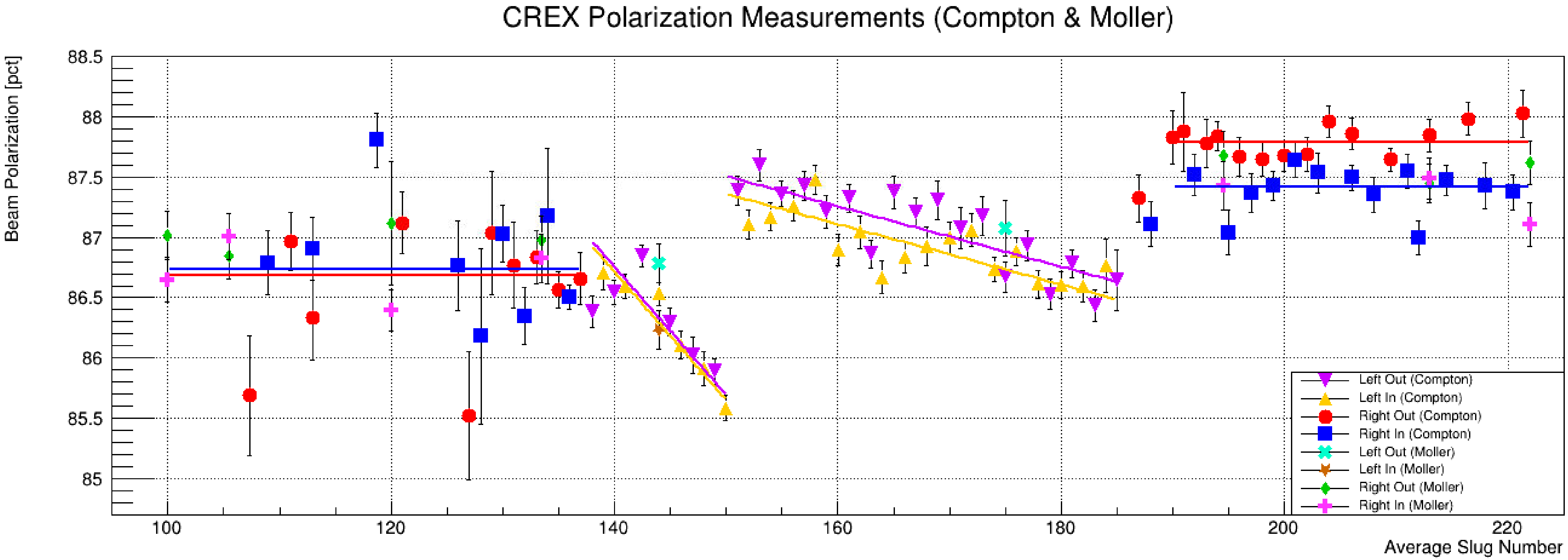
87.44 +/- 0.88%

86.16 +/- 0.63%

87.16 +/- 0.59%

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

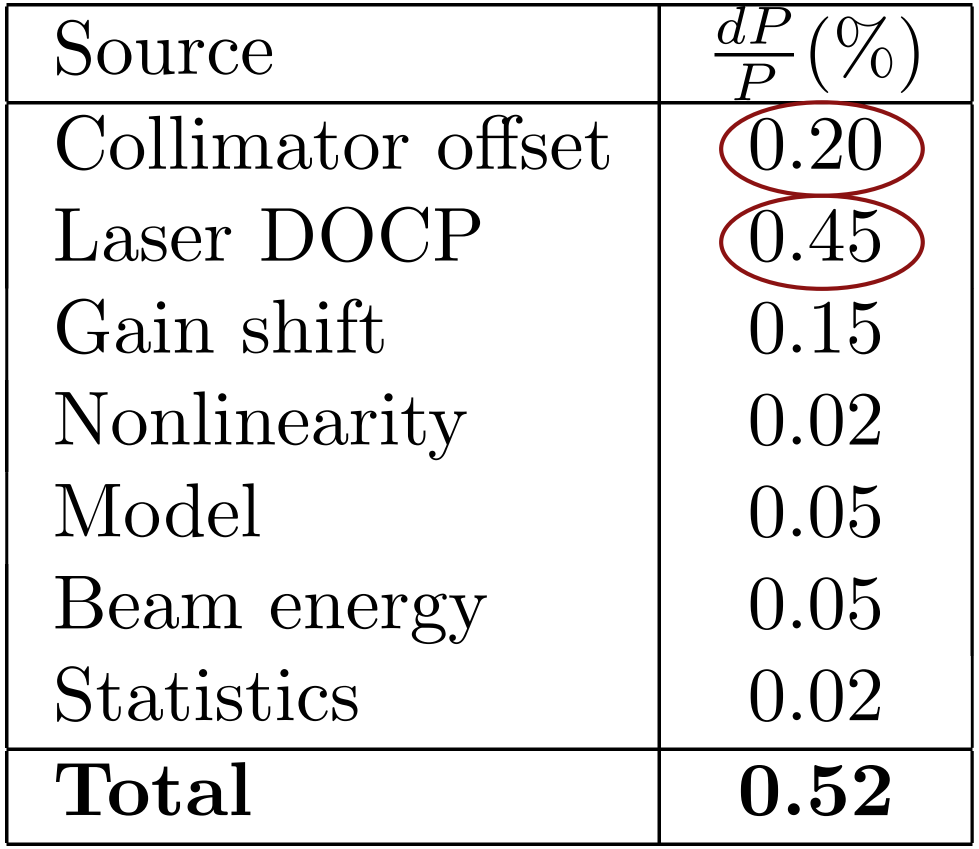
Photon detector for polarization measurements
→ Electron detector installed, but used primarily for tests and commissioning new VETROC-based DAQ

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**

Summary

- Hall A and C have leveraged many years of polarization measurements to incrementally improve polarimeters to achieve high precision
- Moving towards more common systems (laser, electron detectors) to simplify maintenance
- Strong User support and involvement throughout the program
- More details on laser, detectors, backgrounds in talks later this week