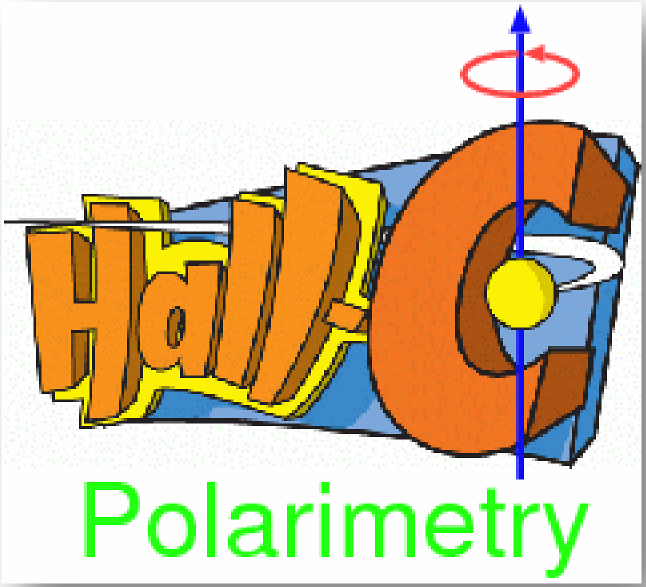
Polarimetry for QWEAK

Vladas Tvaskis
(University of Manitoba)
Hall C Users Meeting
January 2012

1. **Polarimetry Strategy**
2. **Møller Polarimeter**
3. **Compton Polarimeter**
4. **Summary**



Polarimetry Strategy

- Q_{Weak} requires measurement of the beam polarization <u>to dP/P = 1%</u>
  Which leads to a contribution to the uncertainty on dQ_{Weak}/Q_{weak} of 1.5%

- **Global strategy for achieving 1% polarimetry**
  1. Use existing Hall C Møller polarimeter to measure absolute beam polarization to <1% at low beam currents
  2. Use new Compton polarimeter to provide continuous, non-destructive measurement of beam polarization

Periodic tests in which Møller and Compton run "simultaneously" will be used to provide the absolute cross-check of the polarimetry

Overall Status

1. ***Use existing Hall C Møller polarimeter to measure absolute beam polarization to <1% at low beam currents***

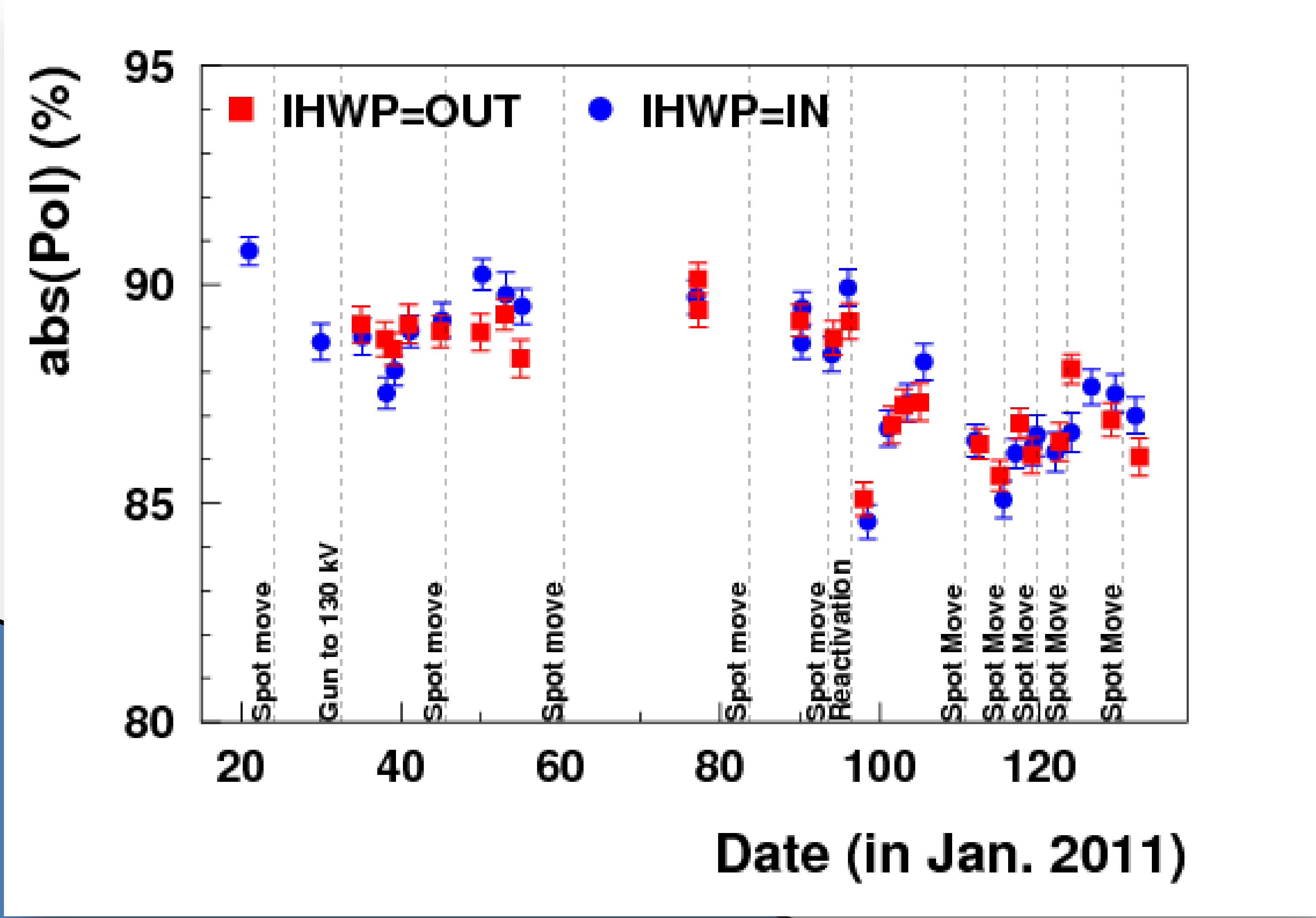
   - **Partially successful → Møller successfully re-commissioned, but problems with Q3, occurring coincidentally near large change in polarization due to cathode re-activation; may lead to larger systematic error (pass-1). Looks fine for Pass-2.**

2. ***Use new Compton polarimeter to provide continuous, non-destructive measurement of beam polarization***

   - **Initial results with photon detector are problematic due to "glowing" CsI**
     Replacement lead-tungstate yields reasonable asymmetries.

   - **Result with electron detector provides good mesurements (Pass-1, Pass-2)**
     Compton gave us early additional clue that Møller had trouble
     Electron detector analysis looks very robust → data from spring may result in <1% systematic errors

Moller (PASS-1)



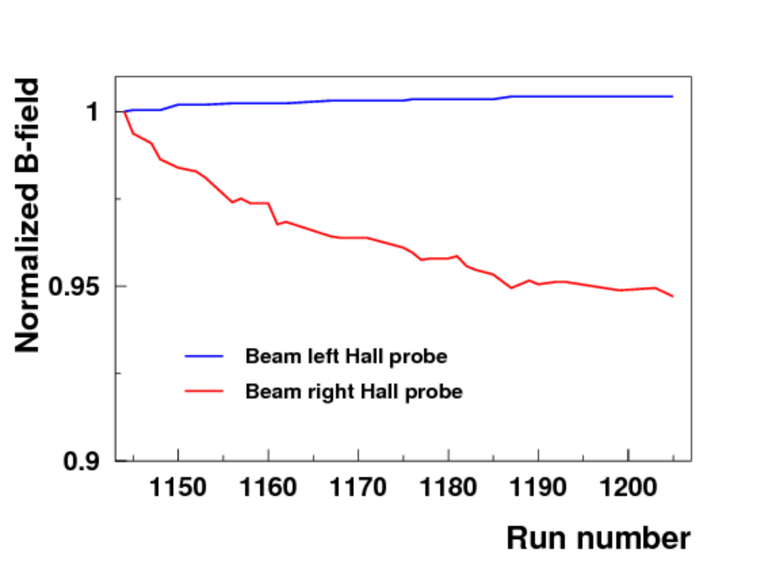
Online results – corrected values are coming "soon"

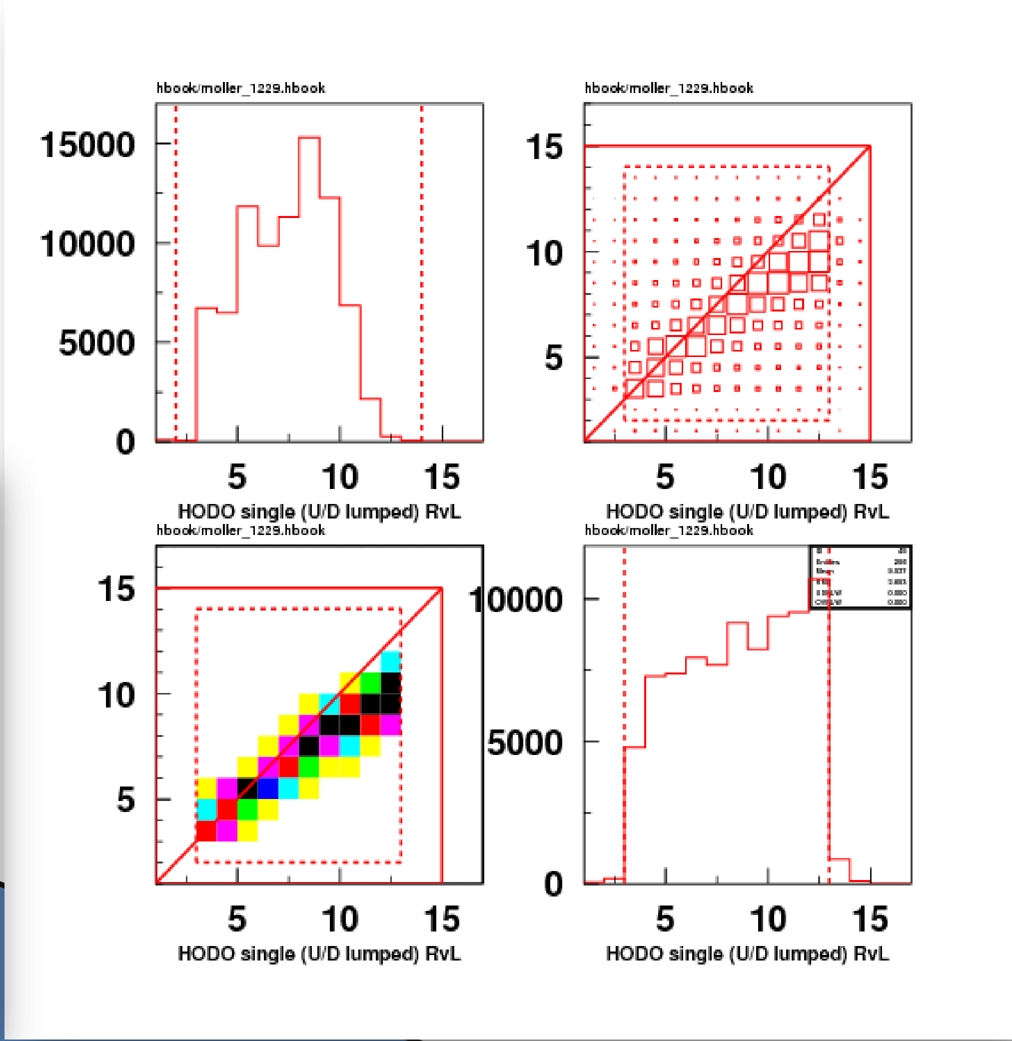
Moller Q3 Problems

In spring, noticed Møller tune not always reproducible

- quad cycling did not help
- Rates also somewhat erratic

Nominal = 16 kHz/mA, sometimes as low as 12 kHz/mA





MOLLER Q3 Problems

Diagnosis during 6 MSD revealed short in one set of coils

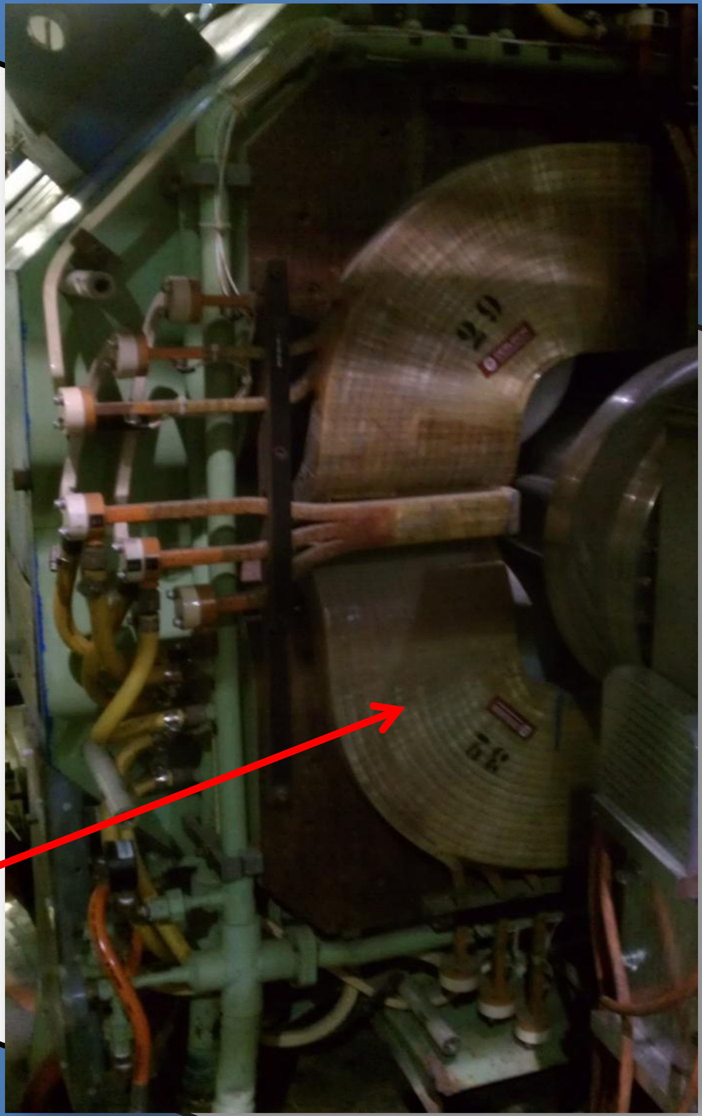
→POISSON simulations underway to model effect of bad coil

→ 2D map inserted in Møller simulation

→ Analyzing power *is* affected – polarization will need correction

<u>Problem resolved</u> for Run-2 by swapping in "spare" quad

Bad coil



Hall C Moller Systematics

Predicted systematic error budget for Q_{Weak} with new Møller configuration

→low current running only

→applies to a particular measurement, not polarization for the experiment

~~*dP/P = 0.57%*~~

dP/P > 0.57%

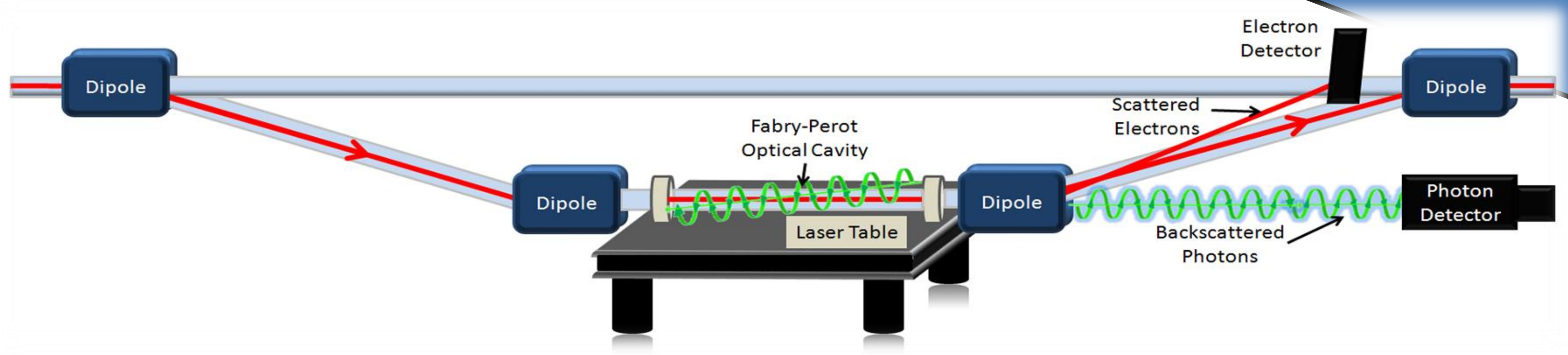
Final value for Run 1 is still under investigation: Preliminary estimate between 1% and 1.8%

For Pass-2, 0.57 % is achievable

Source	Uncertainty	dAsy./Asy. (%)
Beam position x	0.5 mm	0.32
Beam position y	0.5 mm	0.02
Beam direction x	0.15 mr	0.02
Beam direction y	0.15 mr	0.01
Q1 current	2%	0.10
Q2 current	1%	0.17
Q2 position	1 mm	0.18
Multiple Scattering	10%	0.01
Levchuk effect	10%	0.20
Collimator positions	0.5 mm	0.06
Target temperature	50%	0.05
B-field direction	2º	0.14
B-field strength	5%	0.03
Spin polarization in Fe		0.25
Elec. D.T.	100%	0.04
Solenoid focusing	100%	0.10
Total		*0.57*

Hall C Compton

In Compton polarimetry, polarized photons from a laser are scattered from polarized electrons in the electron beam. Scattering rates measured in electron and photon detectors determine the cross-section asymmetry and hence polarization.



Laser: **External green laser. e^- beam passes directly through the cavity. Gain of about 100 gives 700-800 Watts of power in the cavity (pass-1)**

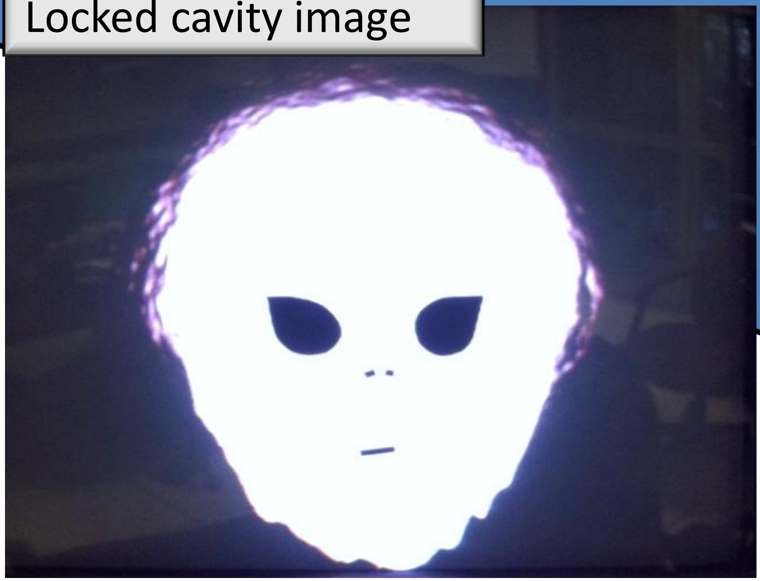
Scattered electron will be detected in the electron detector. (diamond strip tracker).

- **Independent single-arm measurement of Polarization.**
- **Calibration of photon detector (coincidence mode).**
- ***The ultimate goal in precision on Compton is 1% systematic error on absolute polarization determination and 1% statistical error determination per hour.***

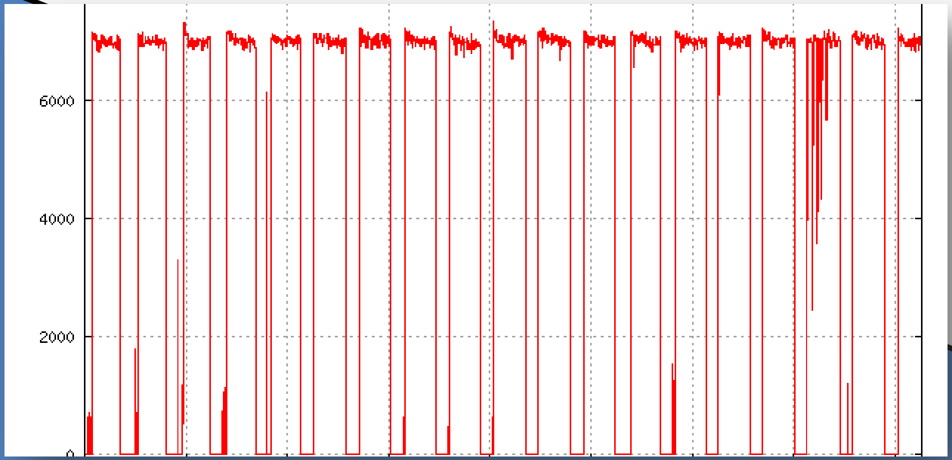
Laser Performance

- During Run-1, used lowest reflectivity mirrors in FP cavity
- Gain ~ 100 x 8 Watts into cavity = 700-800 Watts stored power
- Run-2 use higher R mirrors
  stored power = 1500-1600 Watts

Locked cavity image



FP cavity lock cycled on and off for background subtraction



Fabry-Perot cavity power vs. time

Overall cavity performance is pretty good
→ Late in run, some issues with cavity lock stability

→ Unclear if this was related to laser itself, or back-reflected light

We have swapped in "spare" laser – locking looks pretty robust so far

Determining Laser Polarization

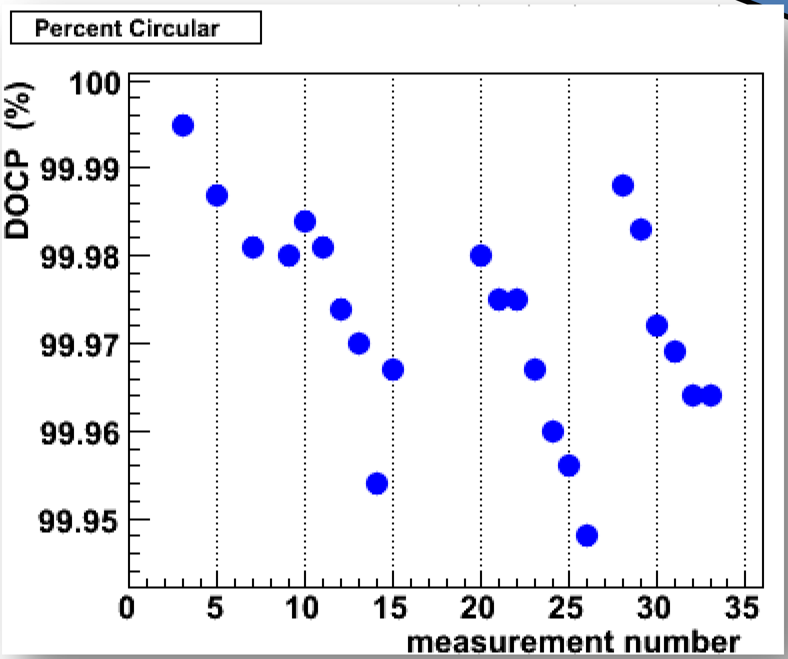
With new techniques (using reflected light) we believe we can get close to 100% laser polarization in the cavity.

We measure it outside the cavity weekly and will use a measured Transfer Function to calculate the intracavity circular polarization

Work is underway to get this systematic error as small as possible since it is common to the photon and electron detectors

For pass-1 syst. error for laser polarization is ~0.4-0.5%

Measurements taken during last April show variations at the 0.05% level

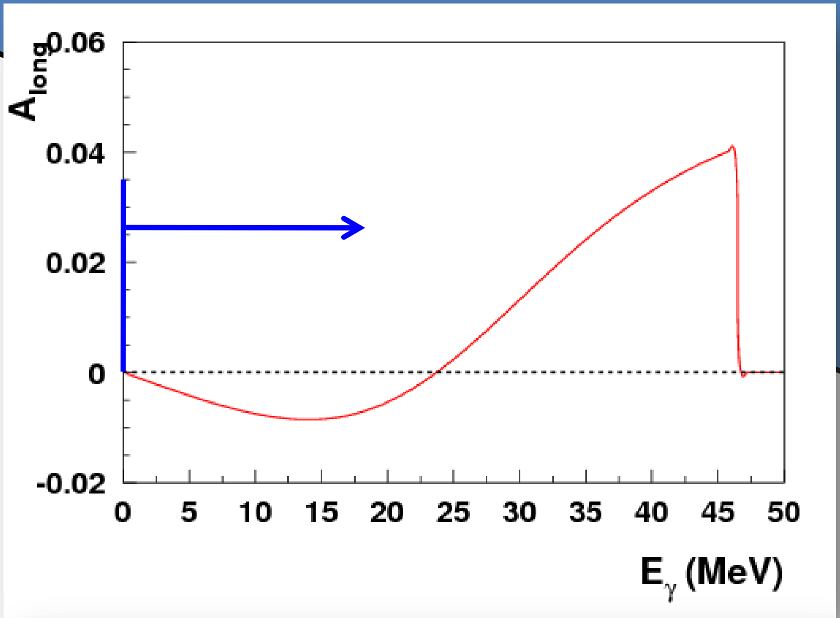


Polarization after cavity
(DOCP - degree of circular polarization)

Photon Detector

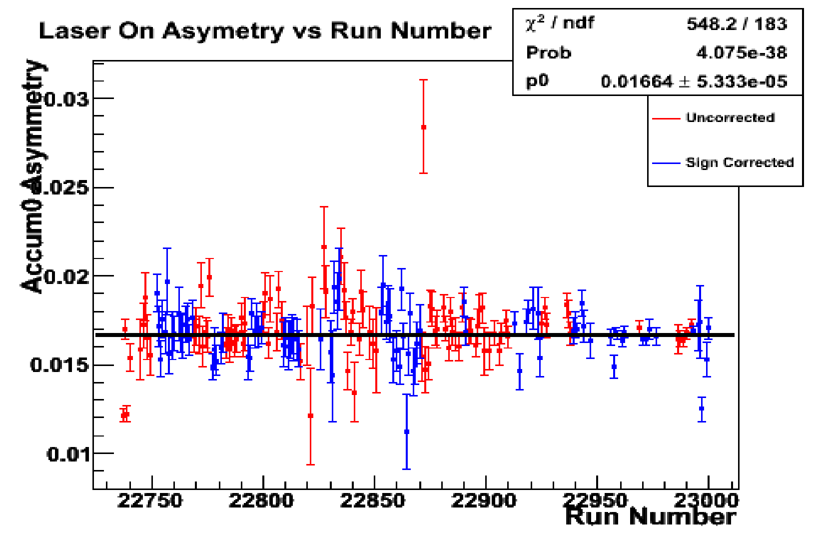
Photon detector operates in energy-weighted integrating mode with no threshold

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



Initially, used undoped CsI detector from MIT-Bates Compton

→ Raw asymmetry was about a factor of 3 too small!
A~0.6%*, we expected closer to *2%
→Borrowed Hall A GSO detector: asymmetries close to 2%



Problem attributed to phosphorescence in CsI → affects background subtraction and possibly raw asymmetry calculation

Photon Detector

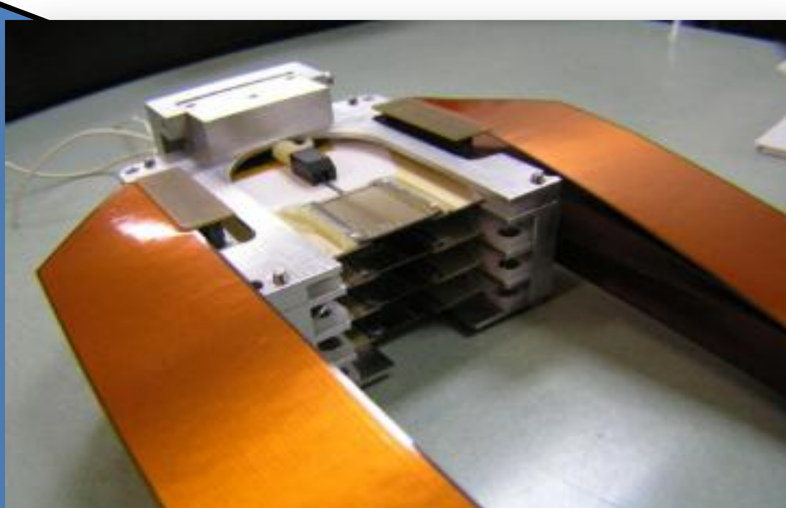
- Hall A GSO detector worked well, but they needed it back
- Installed existing lead-tungstate prototype in mid-April
- Lead-tungstate yielded reasonable asymmetries indicating no pathologies
- Lead-tungstate is being used for Run 2
- Cooling system will improve resolution
- LED system to monitor linearity (for PMT and Detector)

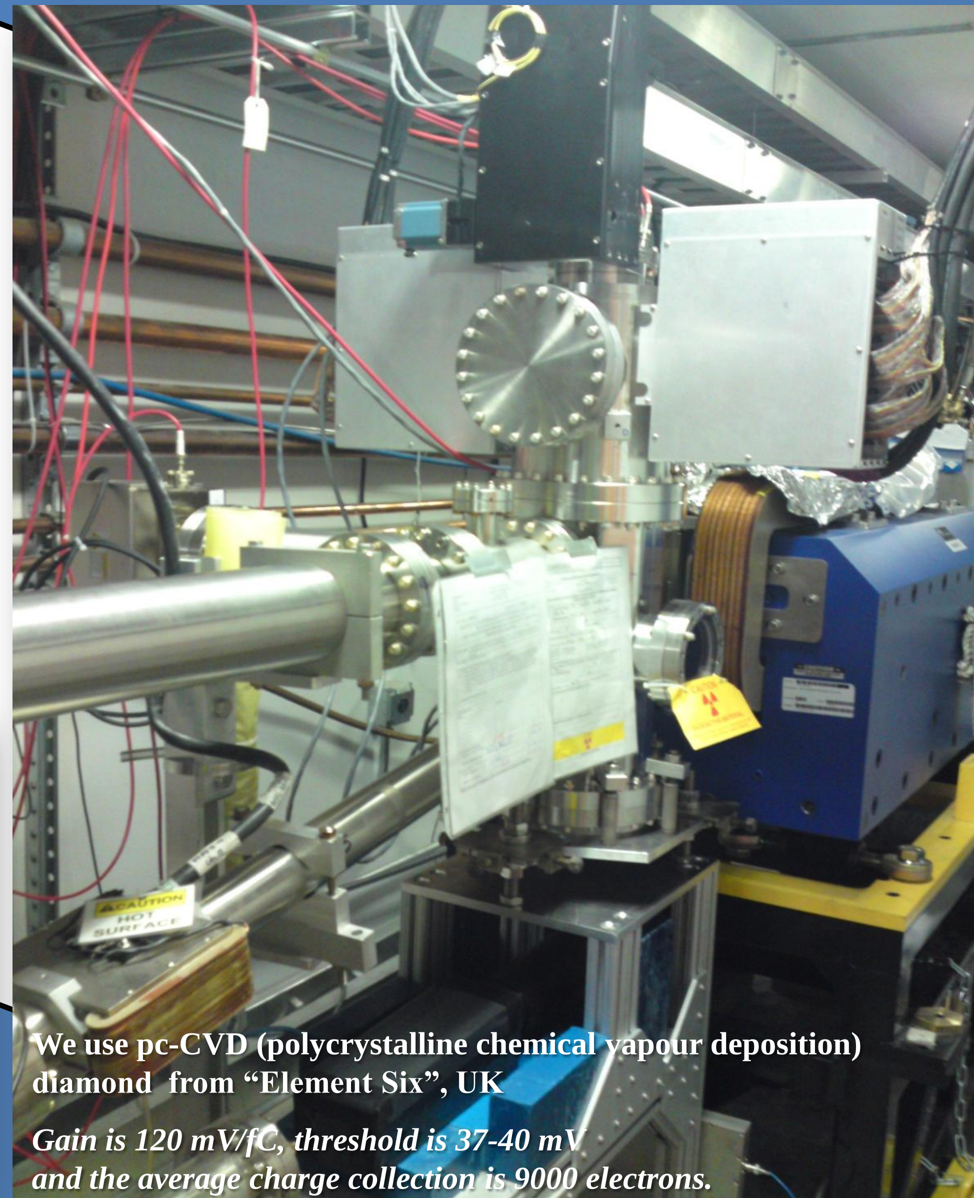
System nearly ready for installation
(End of January – Beg. Of February)

Electron Detector

- *Independent single-arm measurement of Polarization.*
- *Calibration of photon detector (coincidence mode).*

- ***Width of Active Area 2.1 cm***
- ***Height of Active Area 2.1 cm***
- ***Thickness of the Detector 500 µm***
- ***Strip Pitch 200 µm***
- ***Offset from Beam 5 mm (~4-8 mm)***
- ***Rotation Angle ~ 10^o***
- ***Number of planes 4***
- ***Distance Between planes 1 cm***
- ***96 strips per plane***
- ***Metallization: TiPtAu***





We use pc-CVD (polycrystalline chemical vapour deposition) diamond from "Element Six", UK

Gain is 120 mV/fC, threshold is 37-40 mV and the average charge collection is 9000 electrons.

Electron Detector

Electron detector:

- **4 planes, diamond strip detector**
- **Pitch = 200 mm**

Typical operational mode integrates hits in a single strip over a full helicity window

- **Quasi-tracking based trigger reduces backgrounds**

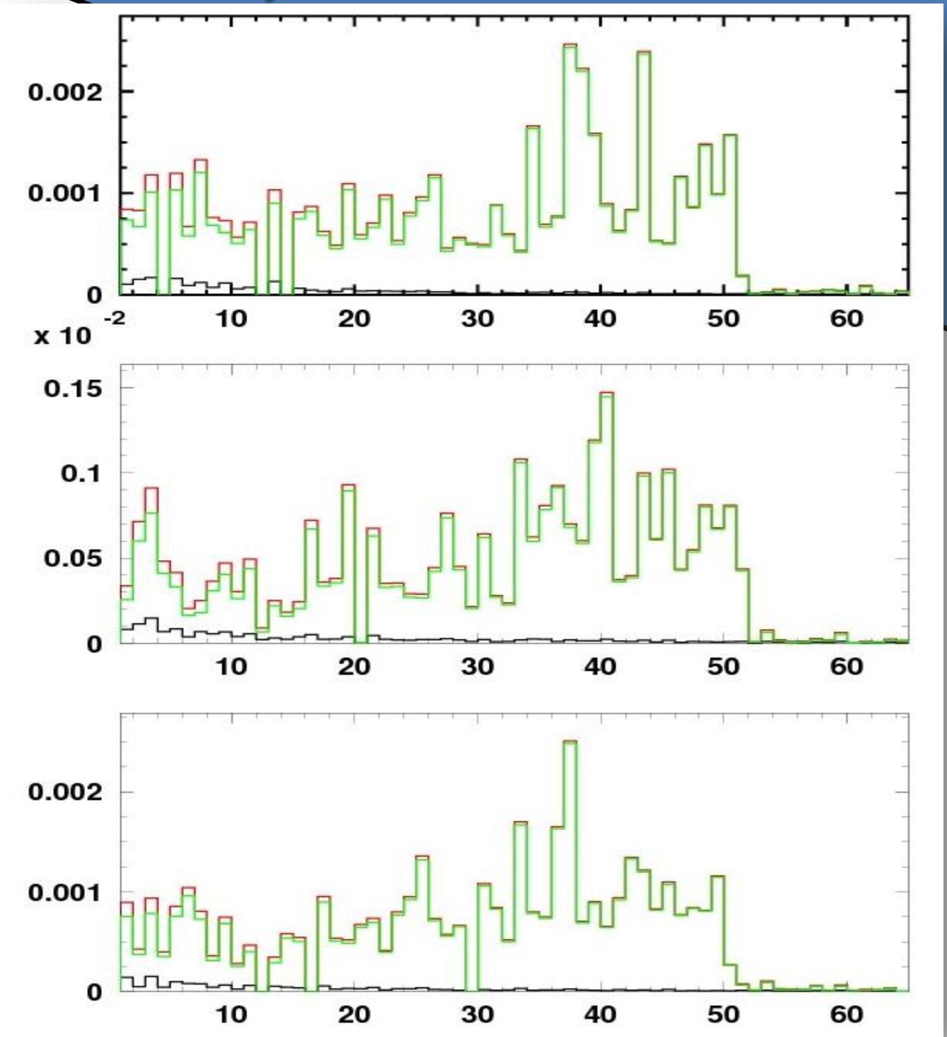
Run-1 issues

- **Flex cables connecting planes to amplifier-discriminators not optimal resulting in smaller signal**

- **Amplifier-discriminator manufacturing issues led to lots of noise, requiring high thresholds**

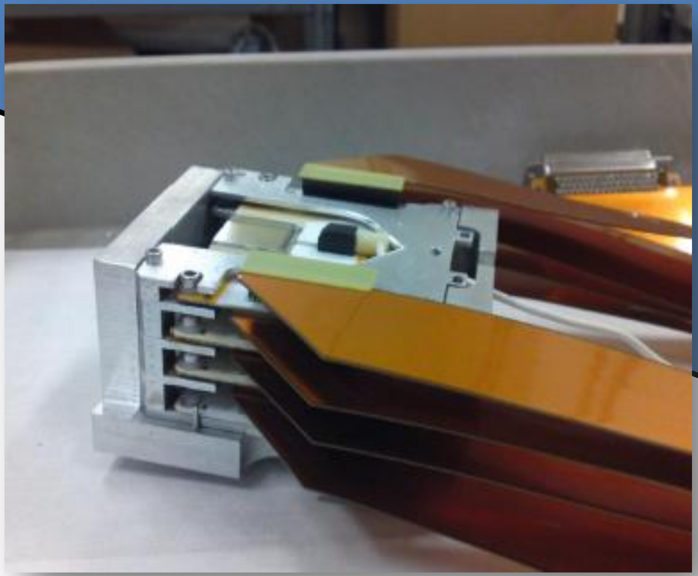
Result – somewhat non-uniform spectra

Normalized yield

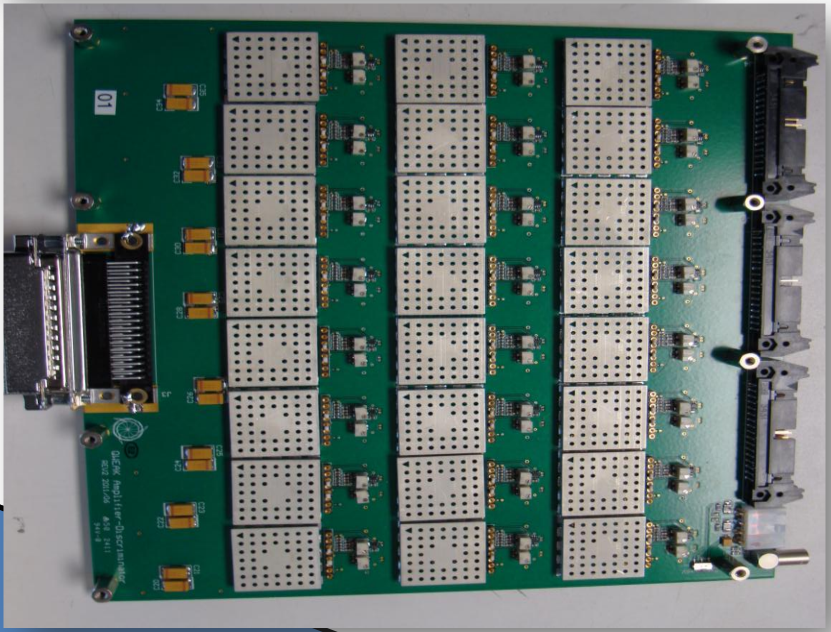


Improvements since Pass-1

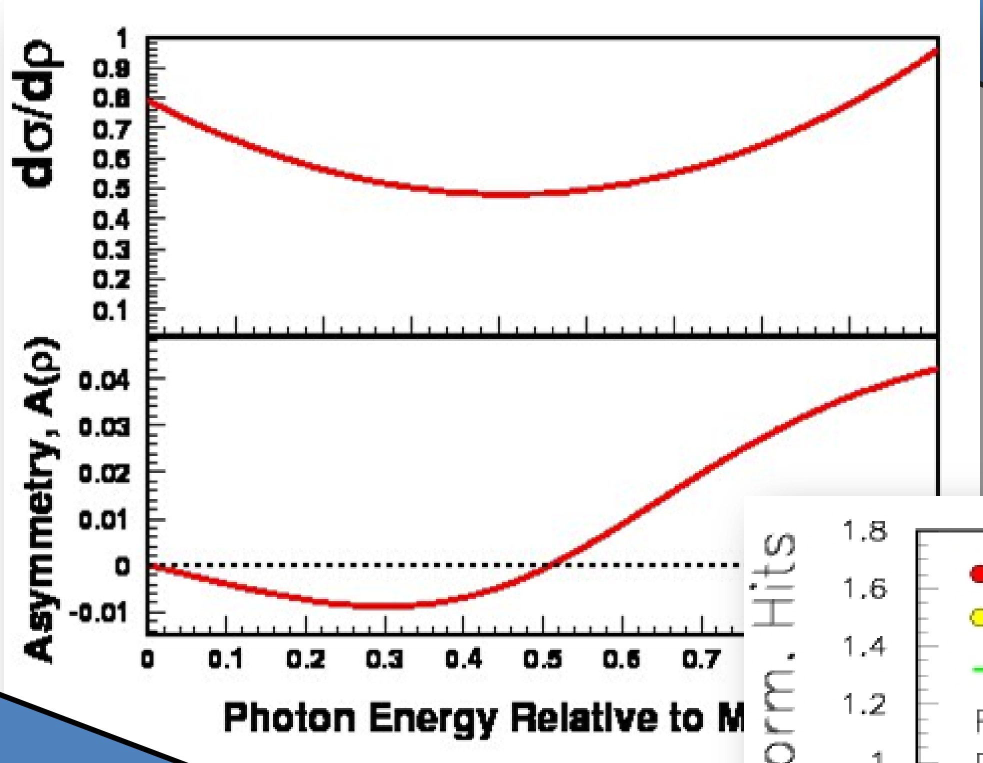
- *Detector planes installed using traveling microscope with a near-zero offset*
- *New Flex Cables – with smaller capacitance ~50 pF (old cables ~ 200 pF). Signal increased by factor ~2.*
- *Higher power laser would improve the statistic (~2x) in the same run-time.*



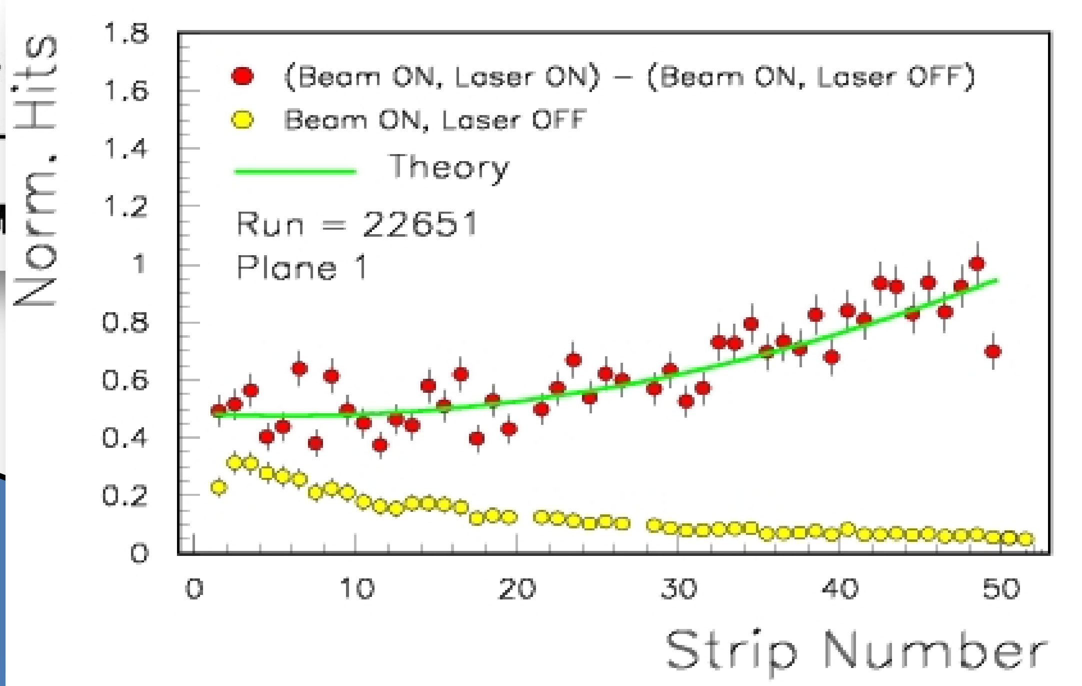
- *New version (3) of QWADs has better shielding from noise and does not have any inter-channel correlation.*
- *Wider threshold range available on QWADs which are also remotely controllable.*
- *New design has 8 layers*
- *Individual RF shields cover analog part of each channels*
- *Additional capacitors included (on board's power lines) to improve stability against digital noise.*



Run-2 Performance



Input Parameters	Value
Beam Energy (E_{beam})	1.159 GeV
Laser Wavelength (λ)	532 nm
Magnetic Field (F)	0.544 T
Chicane bend angle (θ_{bend})	10.131 deg



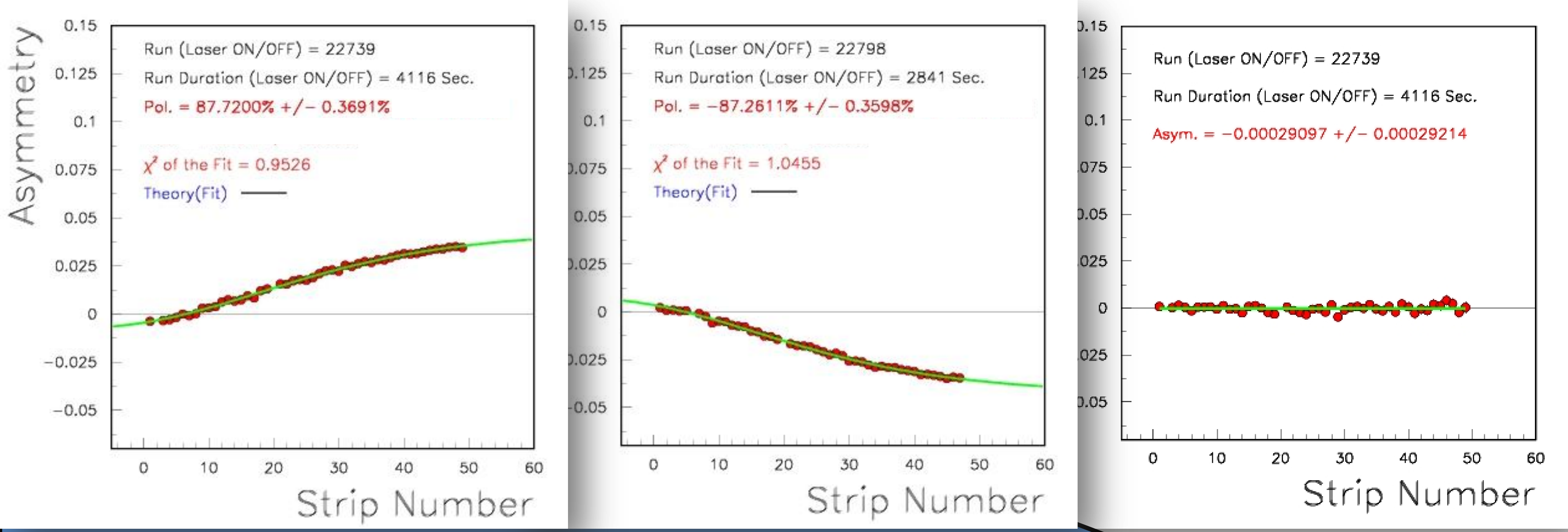
$$D = Max(D) - 0.2 \times (Par. - SN)$$

Asymmetry/Polarization

$$A_{\exp} = \frac{N^+ - N^-}{N^+ + N^-} = P_e P_\gamma A_l$$

$$P_e = \frac{A_{\exp}}{P_\gamma A_l}$$

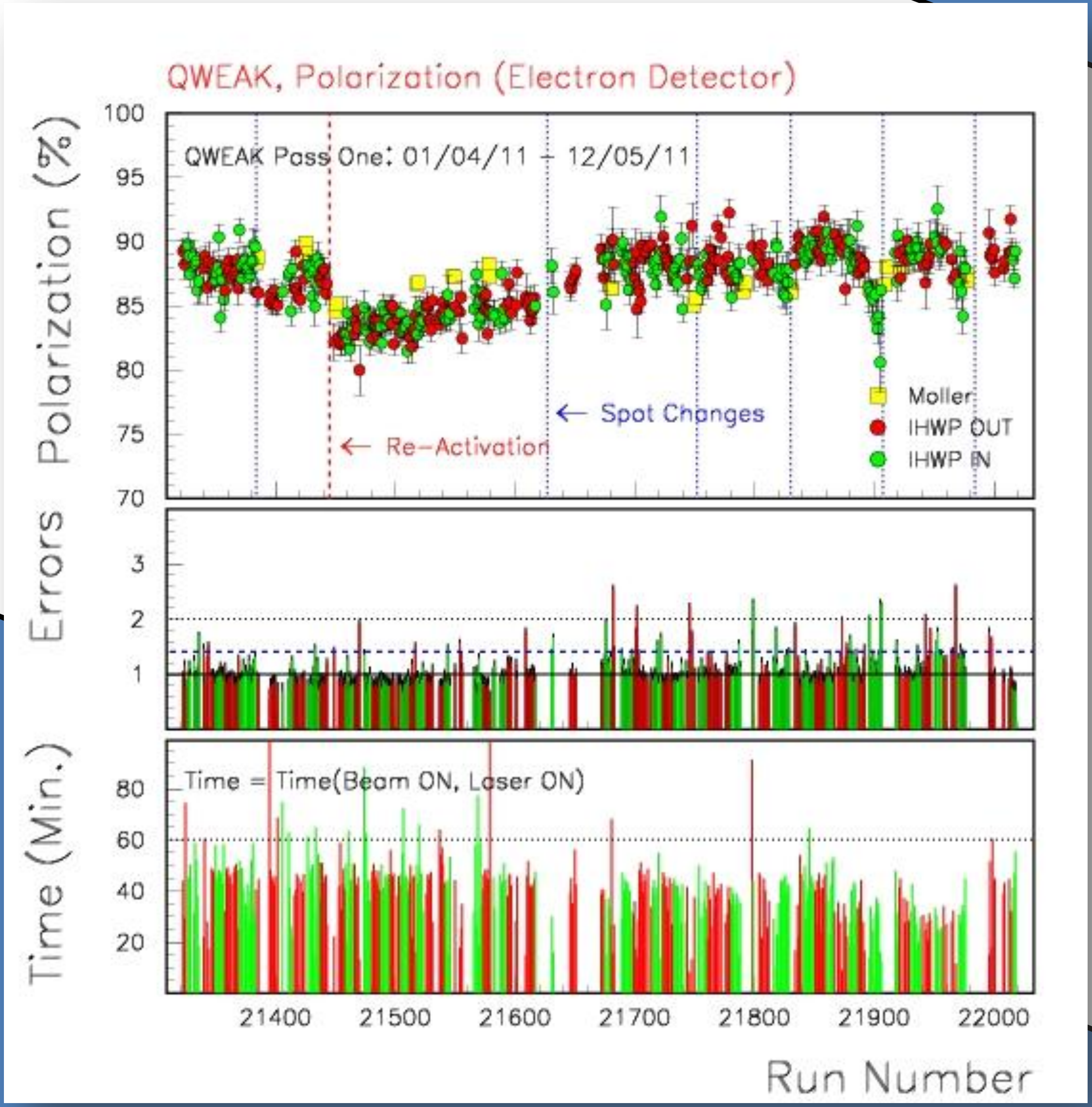
Calculation of polarization requires
- **Laser off - Background**
- **Electronic noise**
- **Theory (Asymmetry)**
- **Laser Polarization**



Syst. Errors

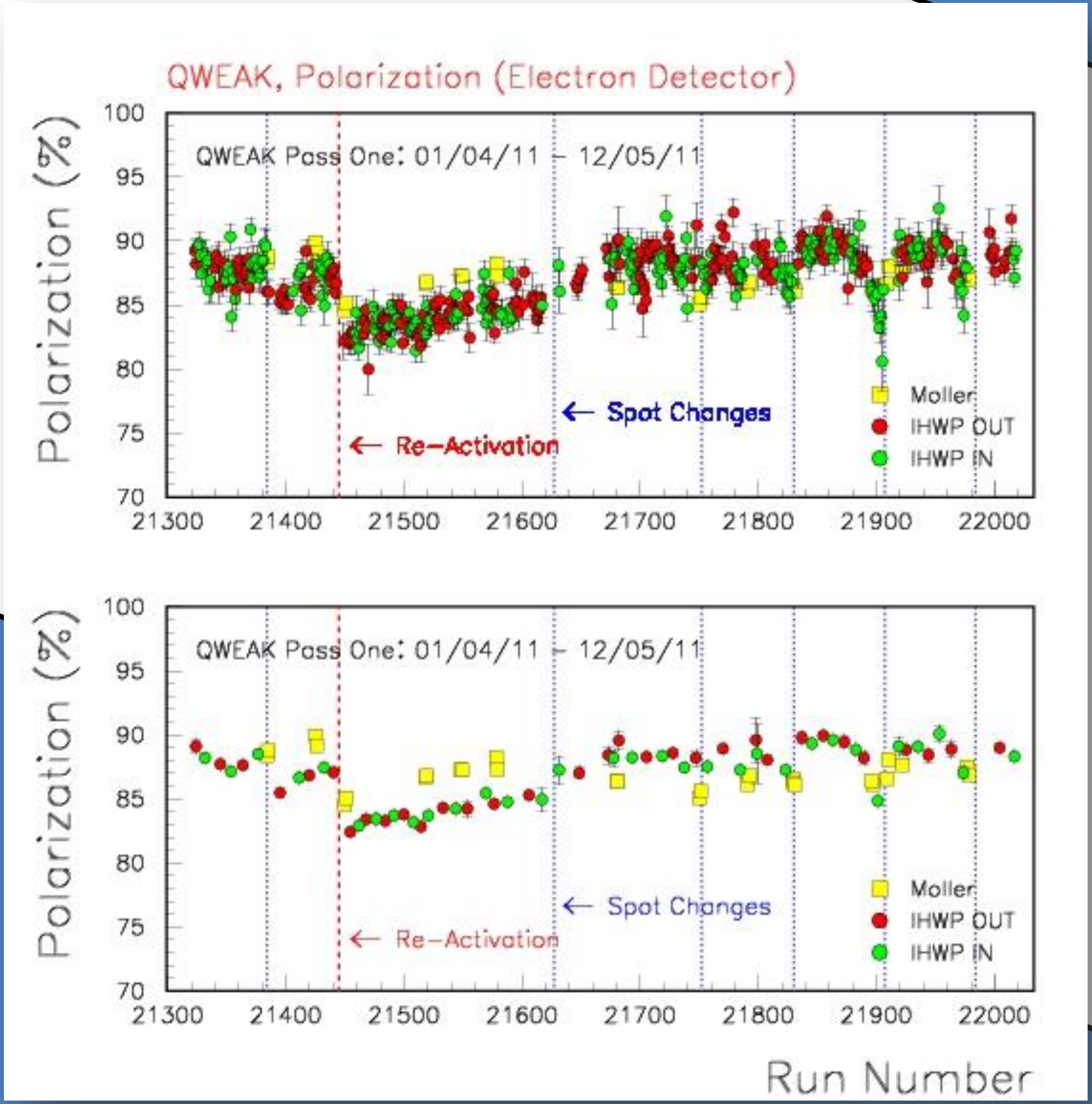
№	Syst. Error due to …	Value (%)
1	Size of the Strip	0.2
2	Strip Separation	0.35
3	Difference between planes	0.2
4	Magnetic Field (Abs. Value)	0.05
5	Magnetic Field (F. Field)	? (MC)
6	Dead Time	? (very small)
7	Charge Asymmetry	0.01
8	Beam/Laser Position	? (MC)
9	Laser Polarization	0.4 (very preliminary)
10	TBD	?
TOTAL:		0.605

Polarization (QWEAK-Pass-1)



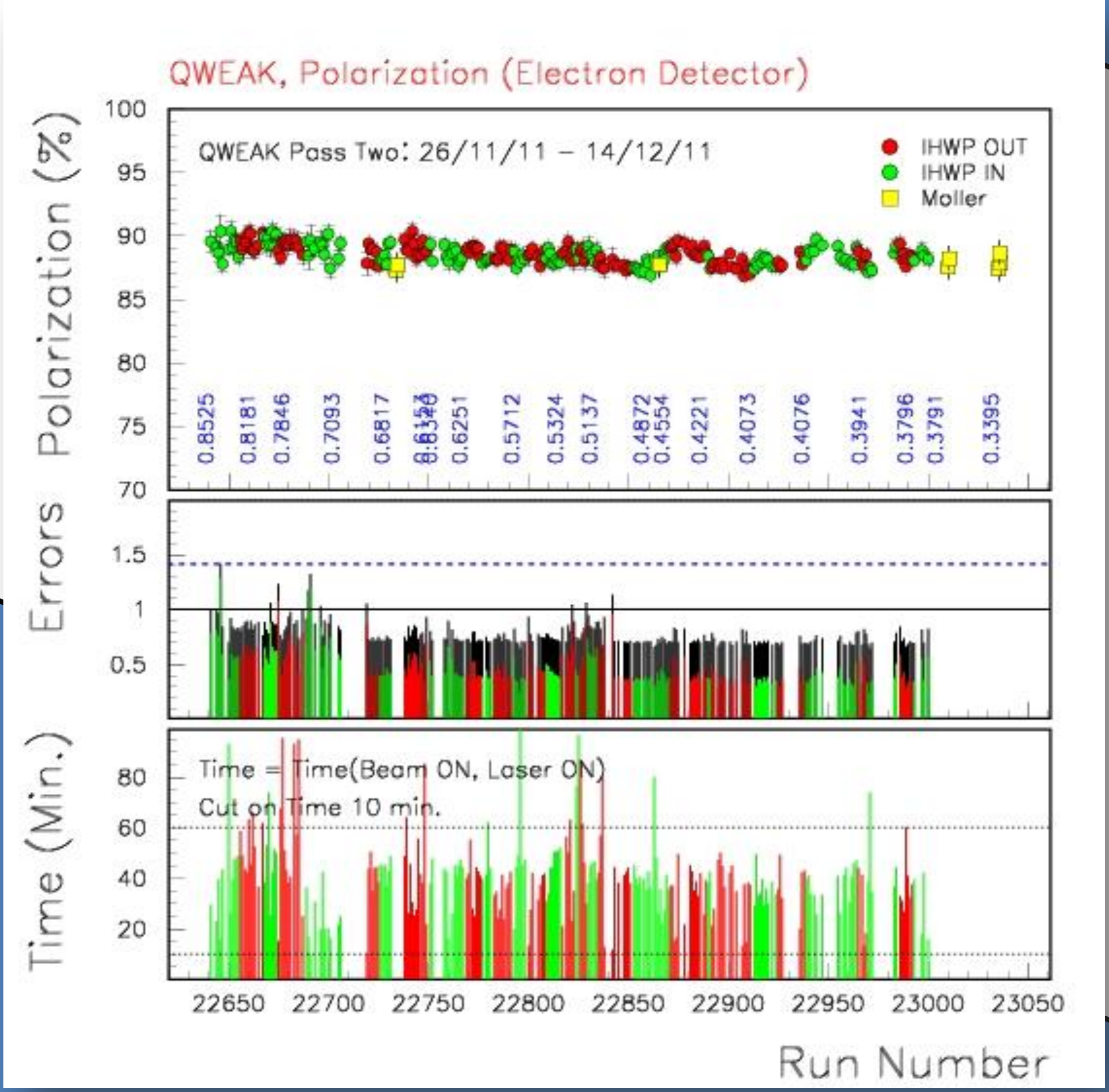
- Edet Data - shown from 01/04/2011 till 12/05/2011
- Each Point represents a Run (~1h)
- Each Run = 2-5 sub-runs
- Statistical Errors ~ 1% for "Good' Runs
- Stat. and Full Errors are shown
- dotted lines – spot changes (on photocathode)
- Solid line – re-activation
- Time = Total time of the run when Laser and Beam are ON.
- Beam Current ~160 μA
- Trigger – 2/3

Slugs (Average per IHWP IN/OUT)



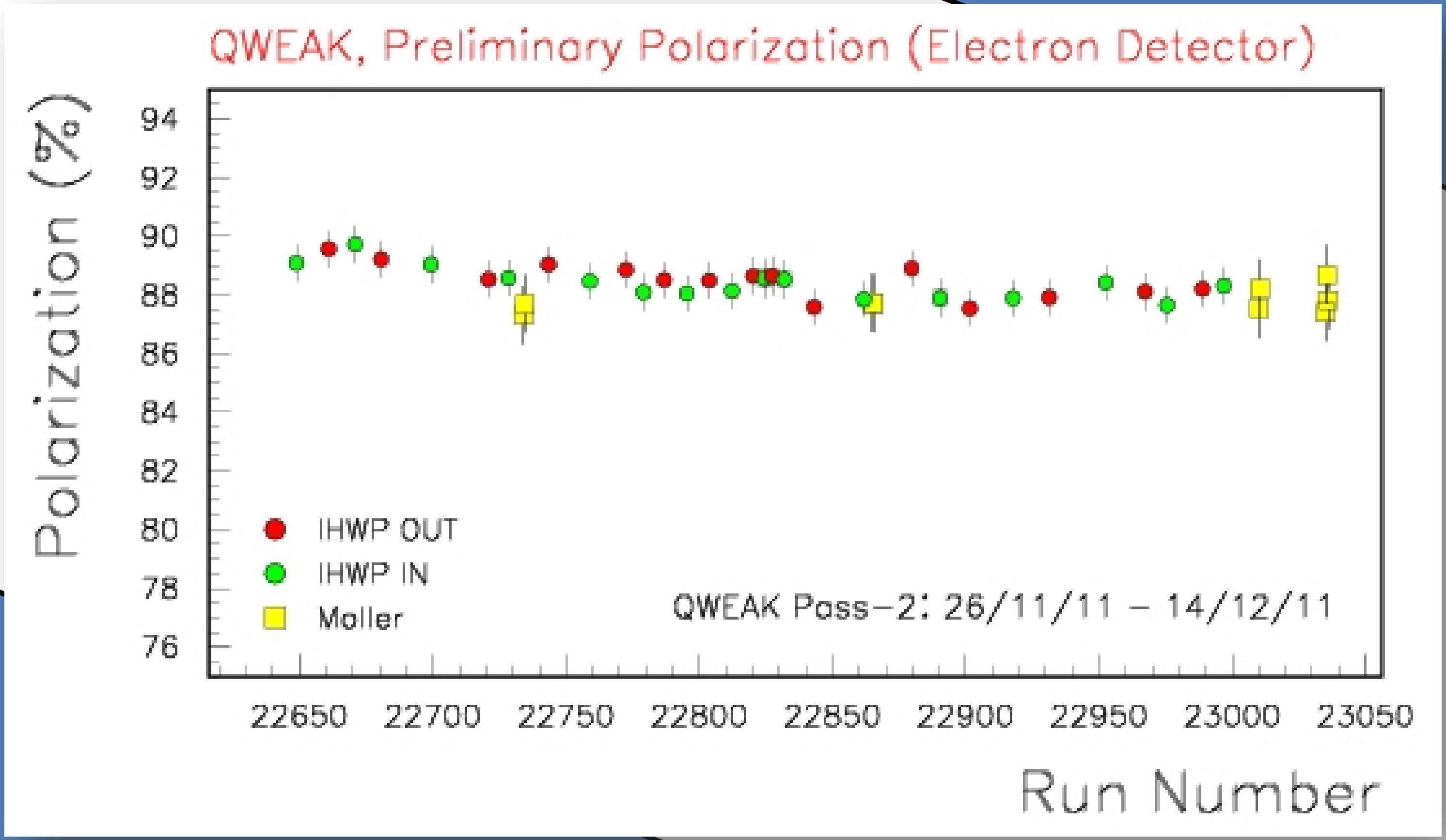
- Edet Data - shown from 01/04/2011 till 12/05/2011
- Each Point represents a Run (~1h)
- Each Run = 2-5 sub-runs
- Statistical Errors ~ 1% for "Good' Runs
- Stat. and Full Errors are shown
- dotted lines – spot changes (on photocathode)
- Solid line – re-activation
- Time = Total time of the run when Laser and Beam are ON.
- Beam Current ~160 μA
- Trigger – 2/3

Polarization (QWEAK-Pass-2)



- Edet Data - shown from 26/11/2011 till 14/12/2011
- Each Point represents a Run (~1h)
- Each Run = 2-7 sub-runs
- Statistical Errors ~ 0.5 % for "Good' Runs
- Stat. and Full Errors are shown
- dotted lines – spot changes (on photocathode)
- Solid line – re-activation
- Time = Total time of the run when Laser and Beam are ON.
- Beam Current ~160 - ~170 μA
- Trigger – 2/4

Polarization (QWEAK-Pass-2)



Summary

- Continue taking data
- Preliminary (1st level online analysis) results
- Work on Syst. Errors
- Install LED system for Photon Detector
- Final Analysis/Results

Institutions Involved

Alphabetical List

College of William and Mary, Jlab, Mississippi State University, MIT Bates, TRIUMF, University of Manitoba, University of Virginia, University of Winnipeg, Yerevan Physics Institute.

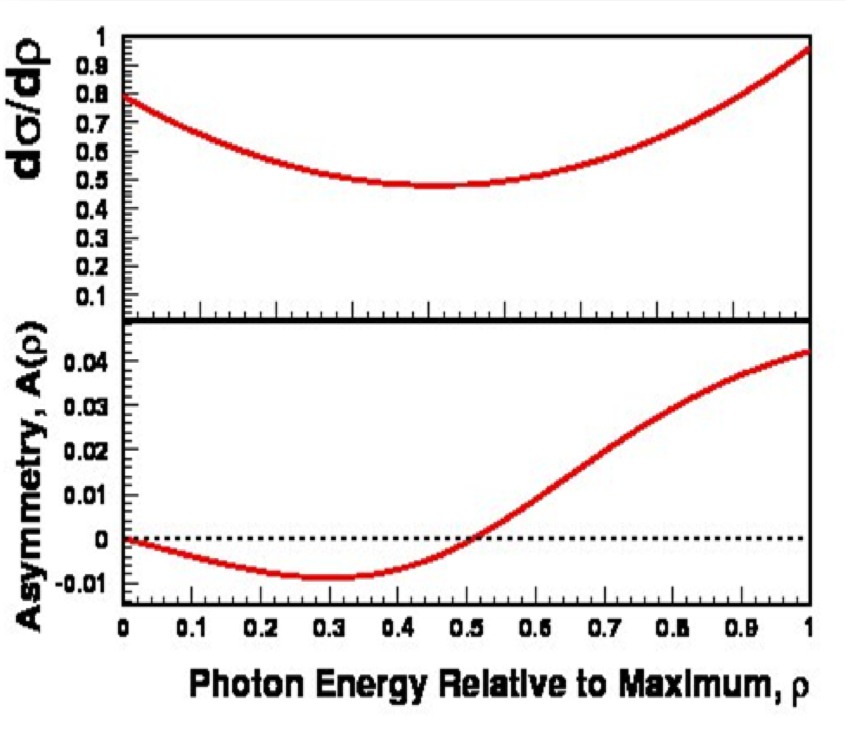
Add. Slides

Hall C Compton

Input Parameters	Value
Beam Energy (E_{beam})	1.159 GeV
Laser Wavelength (λ)	532 nm
Magnetic Field (F)	0.544 T
Chicane bend angle (θ_{bend})	10.131 deg

$$\frac{d\sigma}{d\rho} = 2\pi\ r_0^2 a \left[\frac{\rho^2(1-a)^2}{1-\rho(1-a)} + 1 + \left(\frac{1-\rho(1+a)}{1-\rho(1-a)} \right)^2 \right]$$

$$A = \frac{2\pi\ r_0^2 a}{\frac{d\sigma}{d\rho}} (1-\rho(1+a)) \left(1 - \frac{1}{(1-\rho(1-a))^2} \right)$$

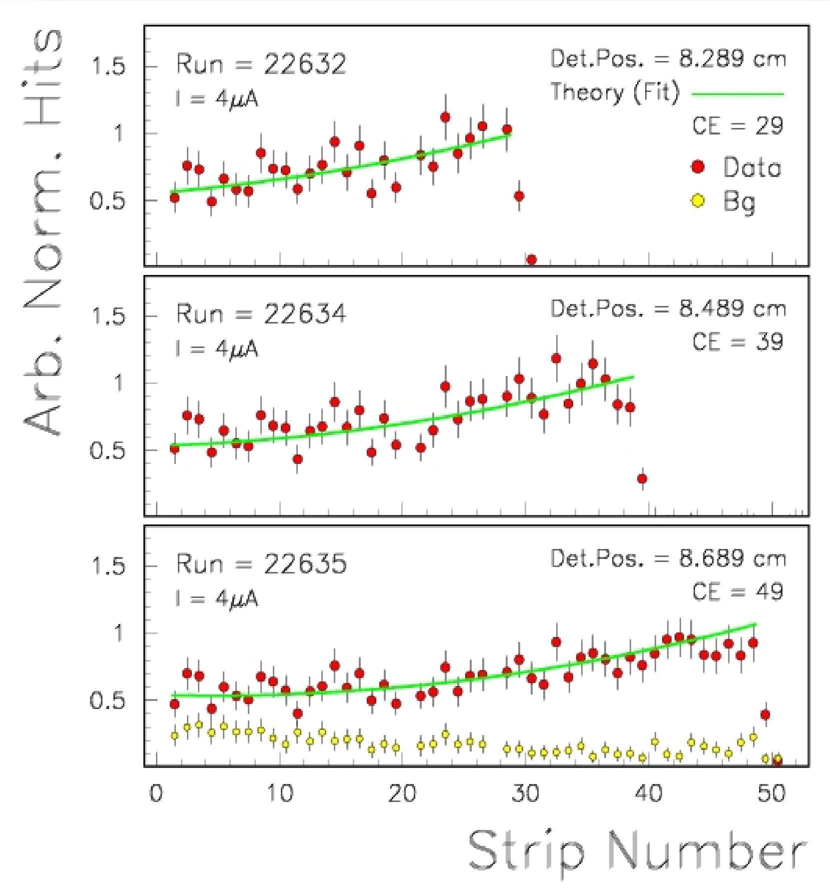


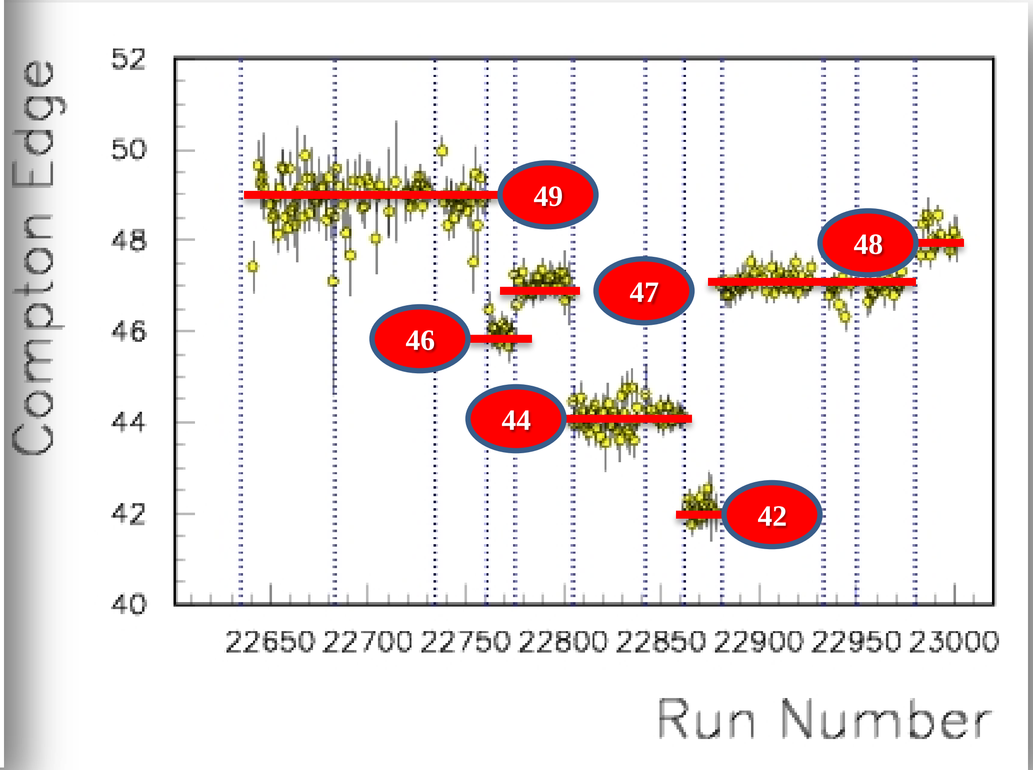
Output Parameters	Value
Asymmetry at Compton Edge	0.04046
Max. Electron Displacement (m)	0.01772
e^- Displacement at Asymmetry 0 (m)	0.00886
Max. Scattered Photon Energy (GeV)	0.04597
Photon Energy at Asymmetry 0 (GeV)	0.02345

$$A_{exp} = \frac{N^+ - N^-}{N^+ + N^-} = P_e P_\gamma A_l$$

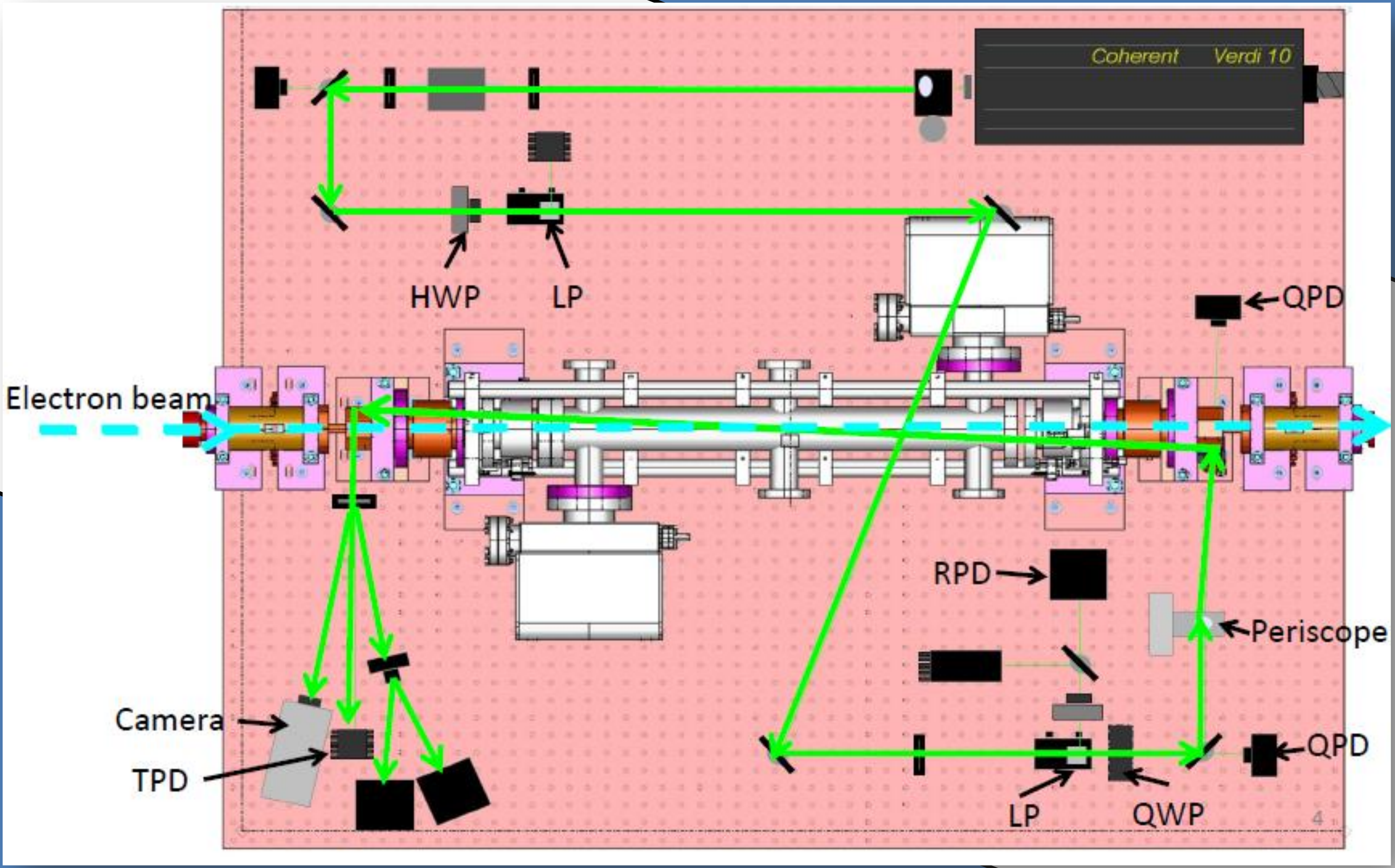
$$P_e = \frac{A_{exp}}{P_\gamma A_l}$$

CE Determination

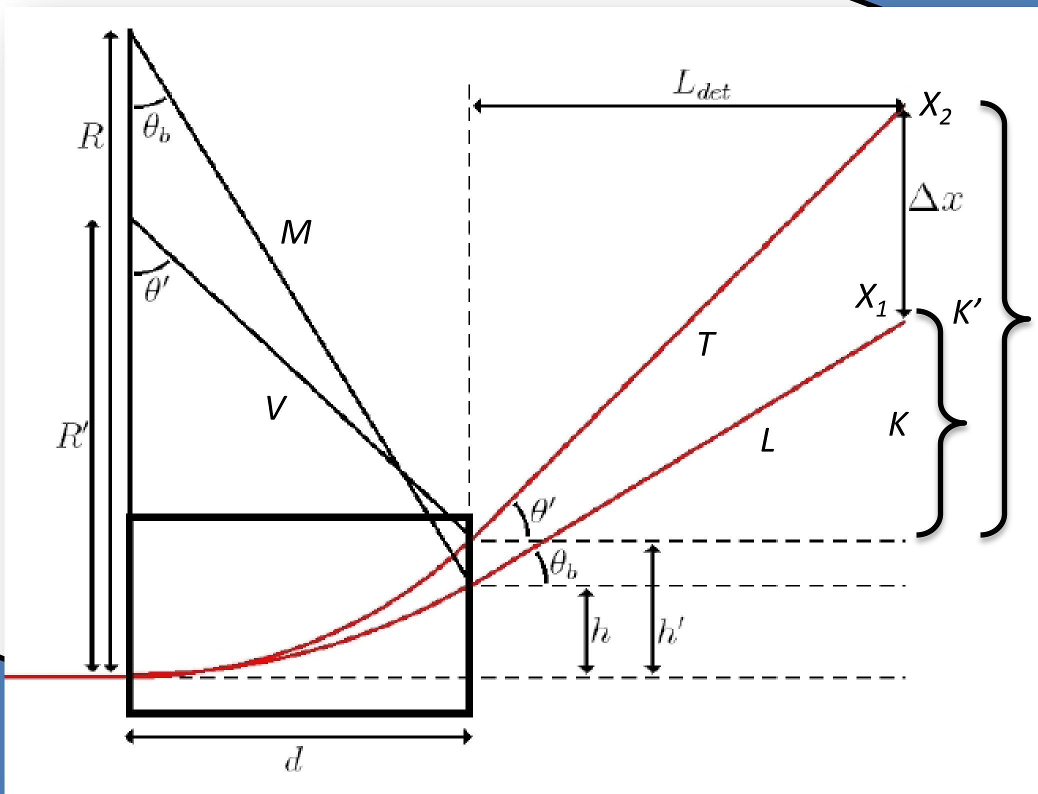




Laser


Coherent Verdi 10
HWP
LP
QPD
Electron beam
RPD
Periscope
Camera
TPD
LP
QWP
QPD
4

Geometry



$$L_{\det} = L \times \cos\theta_b$$

$$L \times \sin\theta_b = K$$

$$K = L_{\det} \times tg\,\theta_b$$

$$K^{/} = L_{\det} \times tg\,\theta^{/}$$

$$R = M\cos\theta_b + h$$

$$\cos\theta_b = \frac{R-h}{M}$$

$$d = M \times \sin\theta_b$$

$$\sin\theta_b = \frac{d}{M}$$

$$tg\,\theta_b = \frac{\sin\theta_b}{\cos\theta_b} = \frac{d}{M} : \frac{R-h}{M} = \frac{d}{R-h}$$

$$d = (R-h) \times tg\,\theta_b$$

$$h = \frac{R\,tg\,\theta_b - d}{tg\,\theta_b} \qquad h^{/} = \frac{R^{/}\,tg\,\theta^{/} - d}{tg\,\theta^{/}}$$

$$x_1 = h + K \qquad x_2 = h^{/} + K^{/}$$

Inputs:

E_b = 1.159 GeV
λ = 532.0 nm
Θ_b = 10.131°
Mag_F=0.544 T
d = 1.25 m
L_{det}= 1.645 m

R = 7.09484 m
$R^{/}$= 6.8134 m
$\theta^{/}$ = 10.554 degree
X_1 = 0.39324 m
X_2 = 0.41091 m
X_0 = 0.40207 m
Max Displacement = 0.017665 m
Disp. at Asum 0 = 0.008829 m