# Electron Polarimetry at Low Energies in Hall C at Jefferson Lab

***Polarimetry***

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# Electron Polarimeters in Hall C

- Hall C at Jefferson Lab: typical electron beam parameters
  - Energy = 1-6 GeV
  - Currents = 100 nA (polarized target) to 180 μA (Q-Weak)
  - Polarization = “0” to 88%
- 1996-2010: beam polarization was measured using only Møller polarimeter
  - 2010 installed and commissioned a new Compton polarimeter
- Some experiments have used polarized beam at < 1 GeV
  - $GE_N$ → 800 MeV
  - G0 backward angle (PV scattering at 110 deg.)
    → 360 and 680 MeV

# Møller Polarimetry

Møller polarimetry benefits from large longitudinal asymmetry → -7/9

→ Asymmetry independent of energy

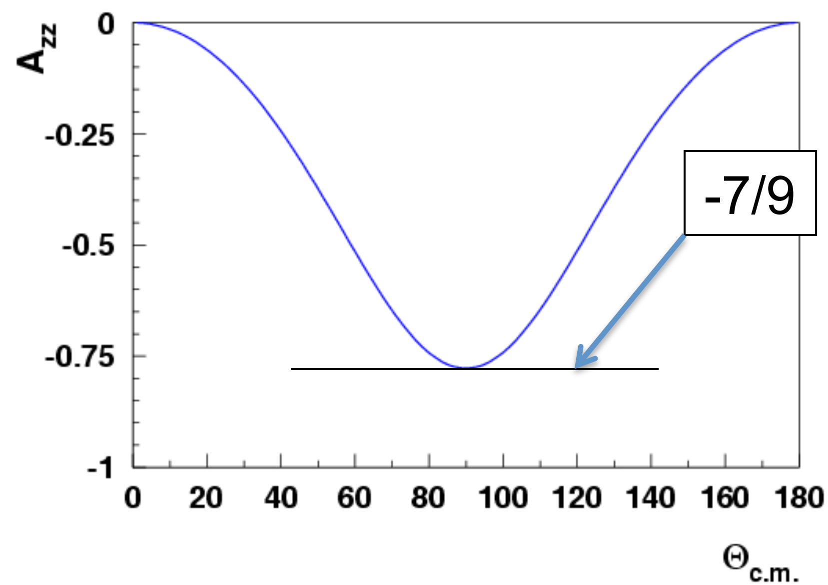
→ Relatively slowly varying near $\theta_{cm}=90^o$

→ Large asymmetry diluted by need to use iron foils to create polarized electrons

$P_e \sim 8\%$

→ Rates are large, so rapid measurements are easy

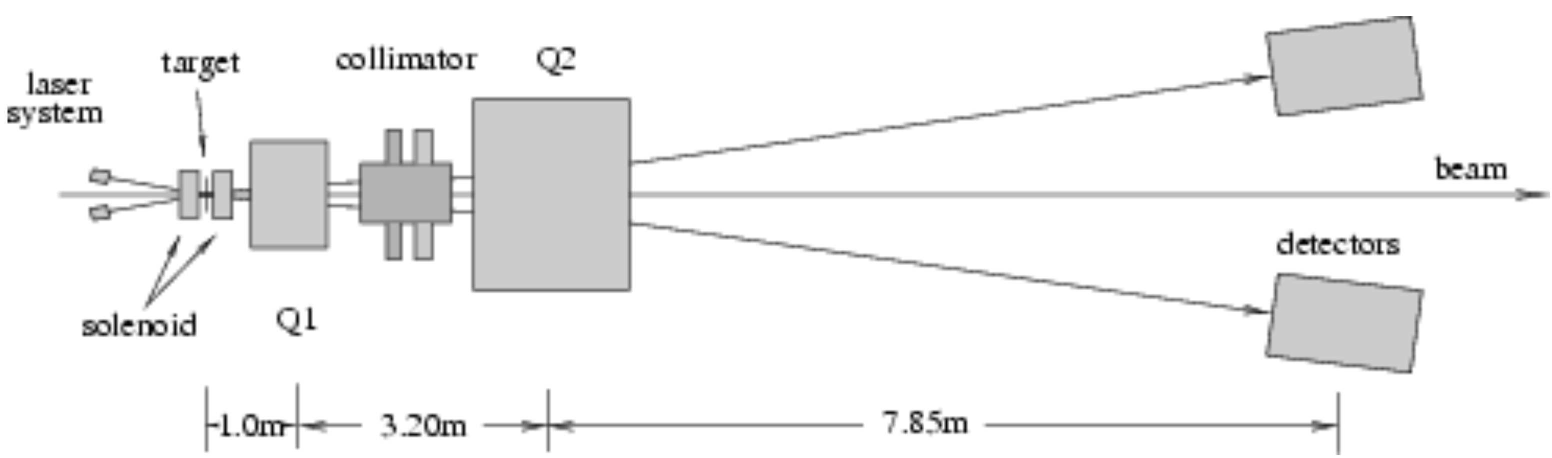
→ The need to use Fe or Fe-alloy foils means measurement must be destructive




Making measurements at high beam currents challenging

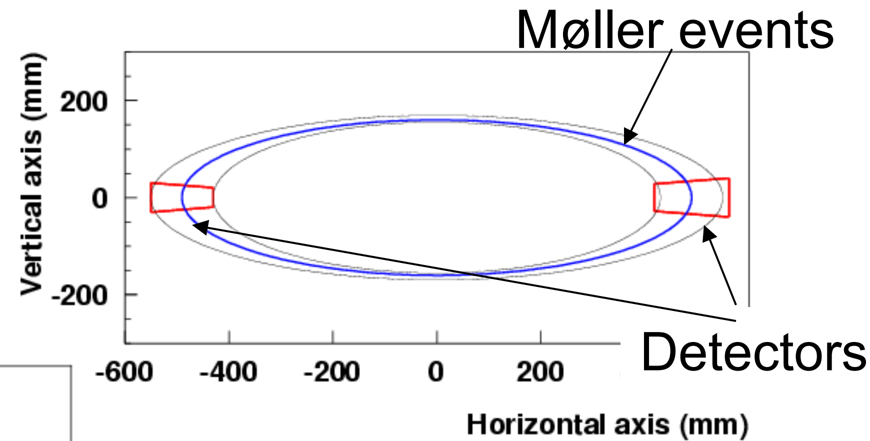
# Basel-Hall C Møller Polarimeter

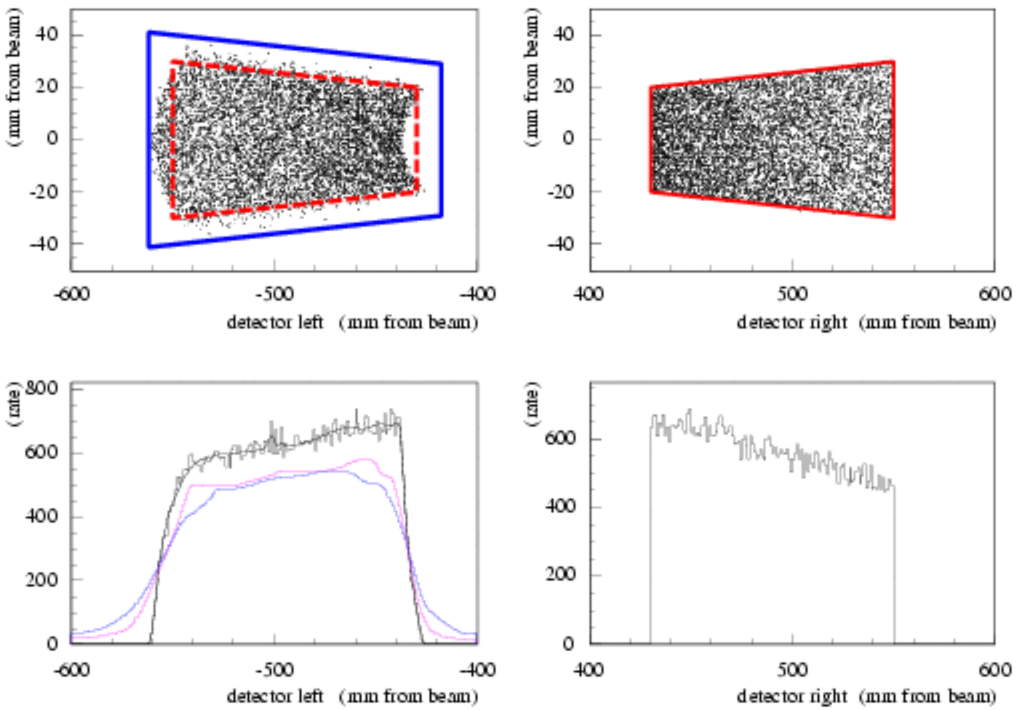
- 2 quadrupole optics maintains constant tune at detector plane
- "Moderate" acceptance mitigates Levchuk effect → still a non-trivial source of uncertainty
- Target = pure Fe foil, brute-force polarized out of plane with 3-4 T superconducting magnet
- Total systematic uncertainty = ***0.47%*** *[NIM A 462 (2001) 382]*



# Hall C Møller Acceptance

Optics designed to maintain similar acceptance at detectors independent of beam energy



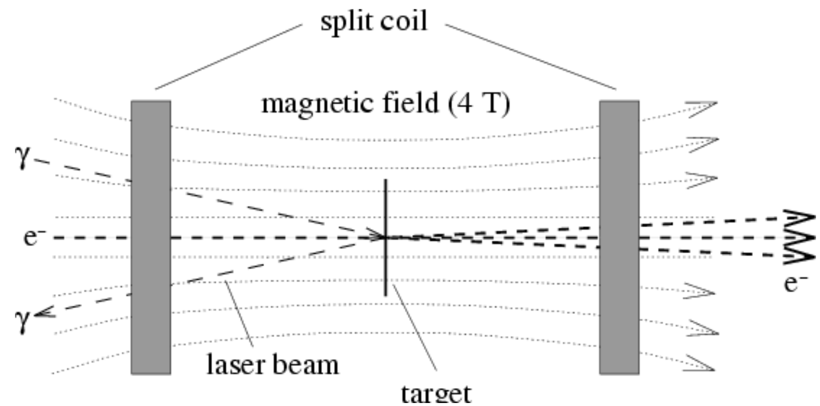




Collimators in front of Pb:Glass detectors define acceptance

One slightly larger to reduce sensitivity to Levchuk effect

# Hall C Møller Target

- Fe-alloy, in plane polarized targets typically result is systematic errors of 2-3%
  - Require careful measurement magnetization of foil
- Pure Fe saturated in 4 T field
  - Spin polarization well known → 0.25%
  - Temperature dependence well known
  - No need to directly measure foil polarization



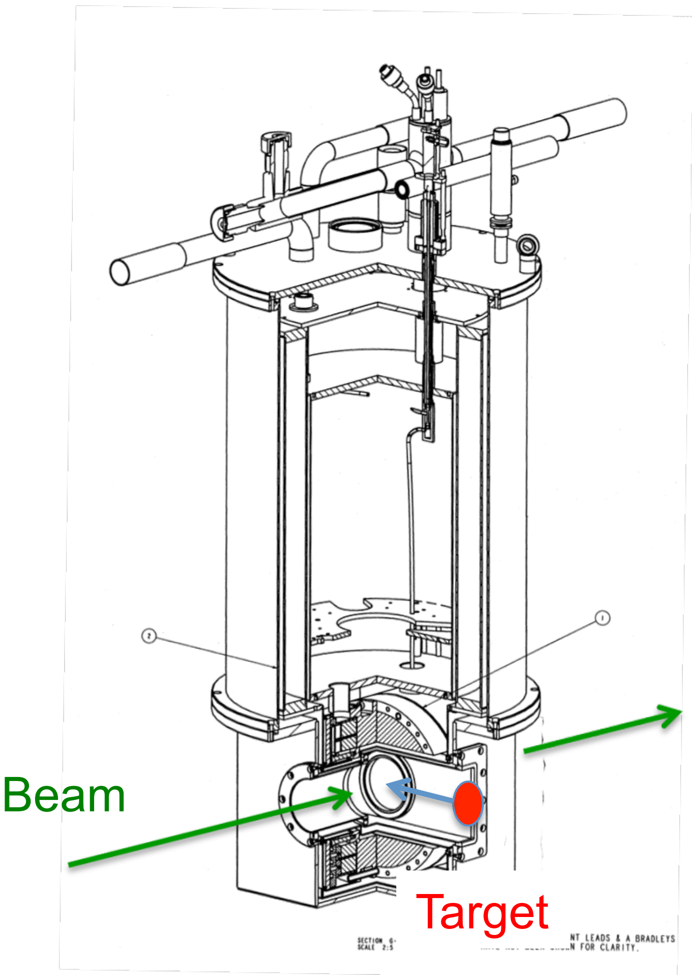

| Effect | $M_s[\mu_B]$ | error |
| --- | --- | --- |
| Saturation magnetization (T→0 K,B→0 T) | 2.2160 | ±0.0008 |
| Saturation magnetization (T=294 K, B=1 T) | 2.177 | ±0.002 |
| Corrections for B=1→4 T | 0.0059 | ±0.0002 |
| Total magnetization | 2.183 | ±0.002 |
| Magnetization from orbital motion | 0.0918 | ±0.0033 |
| Magnetization from spin | 2.0911 | ±0.004 |
| Target electron polarization (T=294 K, B= 4 T) | 0.08043 | ±0.00015 |

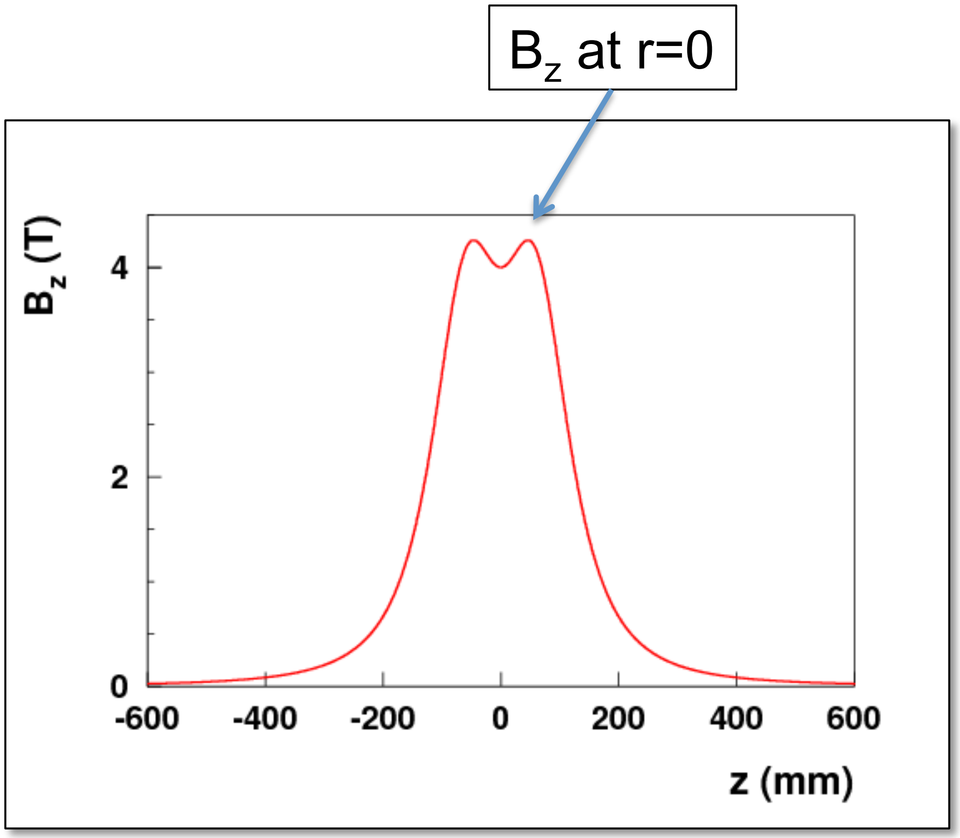
# Hall C Møller at Low Energies

- Hall C Møller designed for operation between 1-6 GeV
- G0 Backward angle experiment ran at 360 and 687 MeV
  - Successfully made polarization measurements at 687 MeV, albeit with larger systematic errors
  - Operation at 687 MeV proved extremely challenging due to solenoid field
  - Only one, very low precision measurement was made at 360 MeV – was not able to operate solenoid at “full” field
- Operation of any high field Møller at low energies likely extremely challenging – issues not unique to Hall C

# Target Solenoid

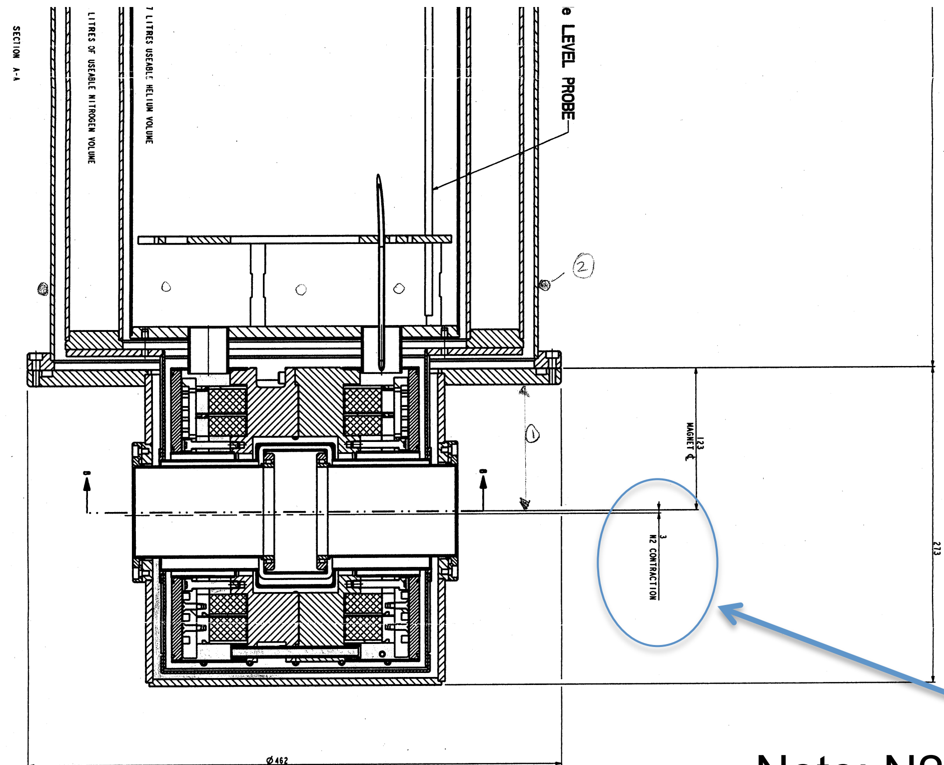
Commercial split-coil superconducting magnet provided by Oxford




$$L_{eff} = \frac{\int B_z dl}{B_0} = 291 \text{ mm}$$

# Target Solenoid – cool down motion

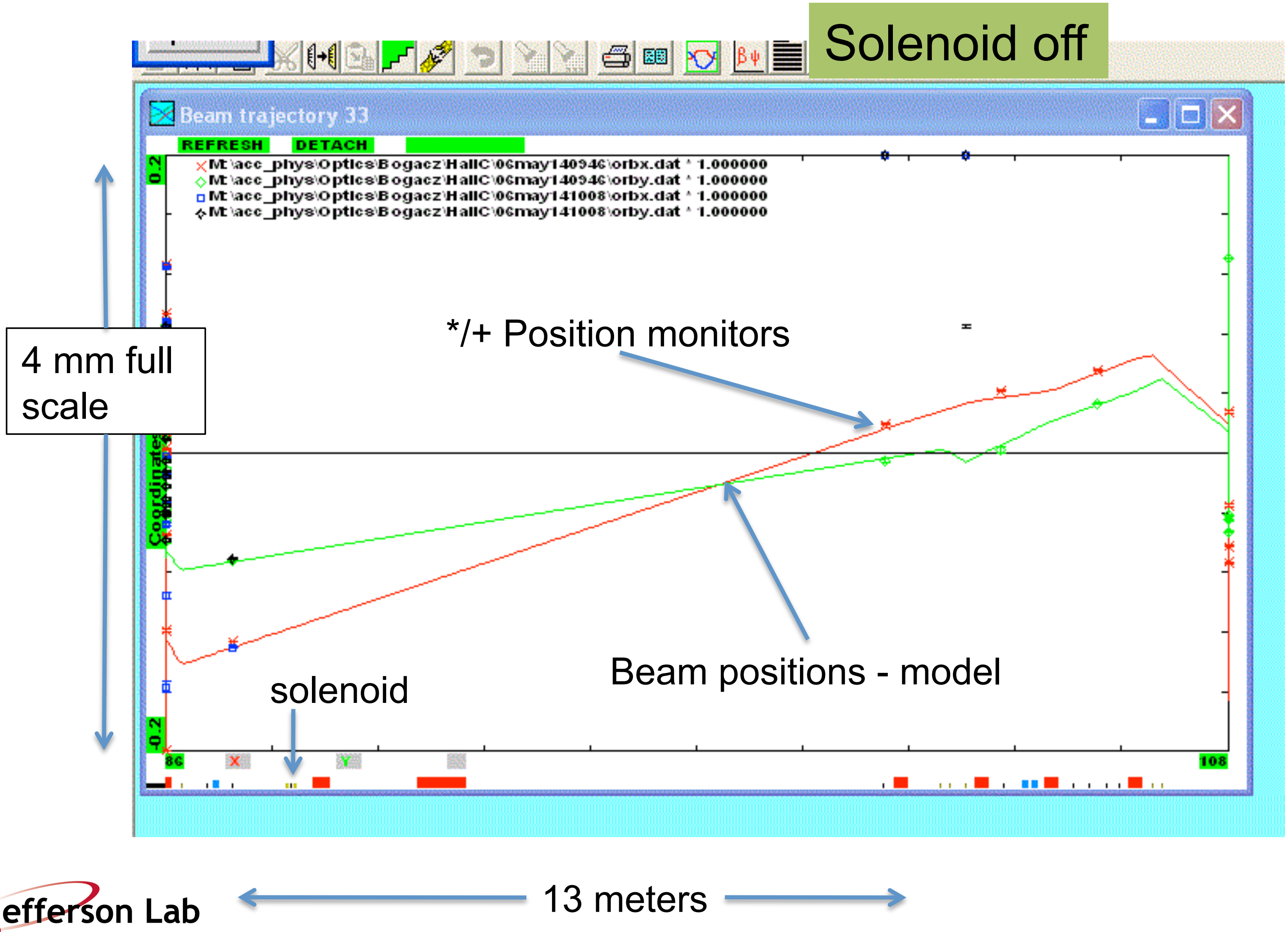



Solenoid was aligned relative to warm bore of magnet cryostat
→ Cooldown to LN2 temperatures results in motion of coils on the order of 3 mm
→ Ignored in initial installation

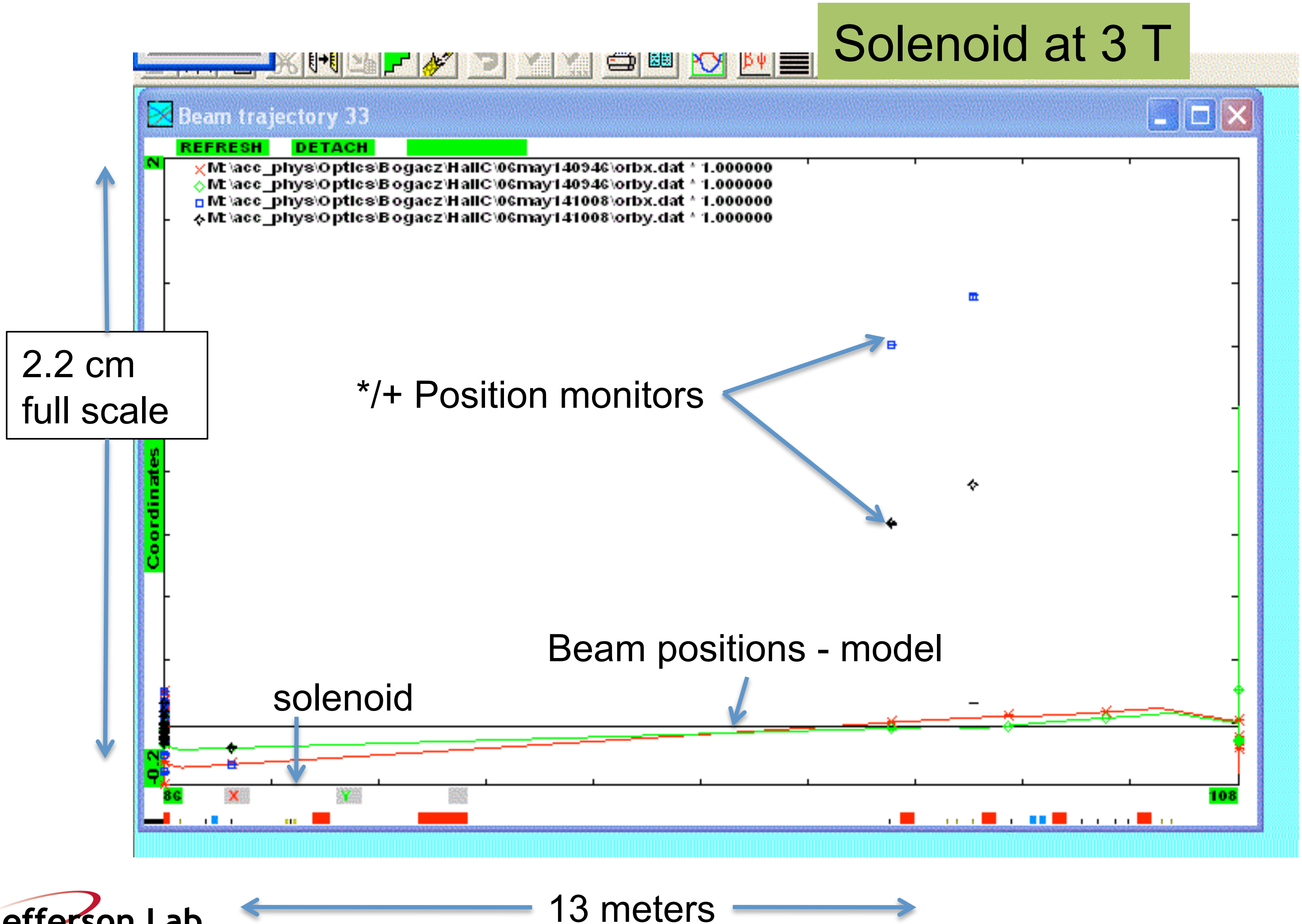
Note: N2 contraction  3 mm

At normal operation energies – this 3 mm offset is inconsequential
→ Low energy running for G0, cannot be ignored

# Solenoid steering at 687 MeV



# Solenoid steering at 687 MeV

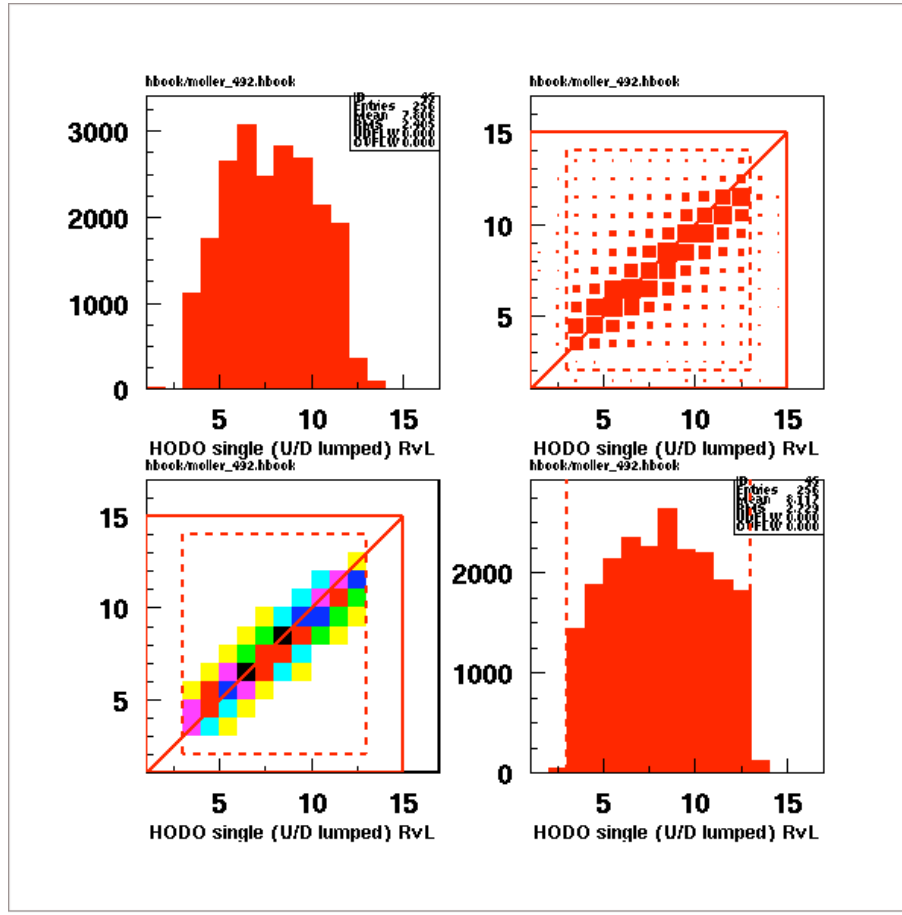


# Solenoid alignment

- Results of beam test at 687 MeV used to re-align the solenoid
  - Vertical offset = 2.5 mm
  - Horizontal offset = 0.5 mm
  - Accuracy estimated to be ~ 0.5 mm
- Subsequent measurements at 687 MeV were easier to set up and execute
- Solenoid is “warm bore”, so field mapping possible
  - Accuracy not likely to surpass that achieved by in-hall beam test
  - Cryogenic motion of coils likely has some variation as well

# Hall C Møller at 360 MeV

Møller quadrupole settings verified using correlation of horizontal position at left and right detectors



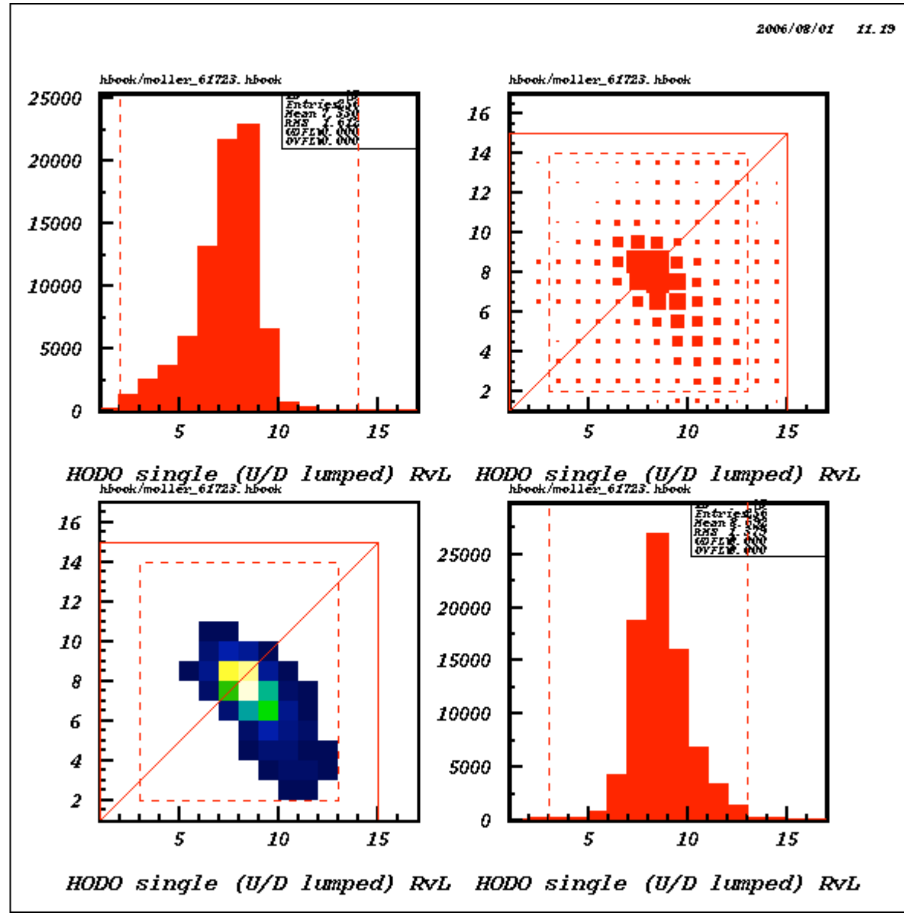
# Hall C Møller at 360 MeV

Møller quadrupole settings verified using correlation of horizontal position at left and right detectors

→ Operation at very low energy required modified optics to see any left-right coincidences

Even with modified optics, measurements were only possible with the solenoid at 0.5 T

→ With great effort (many hours), beam was successfully "transported" at 3 T
→ At large solenoid field, backgrounds were extremely large



# Other Low-energy issues

In addition to simple beam transport issues, Hall C Møller suffered from other complications at low energy

→Solenoid focusing: $$\frac{1}{f_{sol}} = \frac{1}{4}\left(\frac{e}{p}\right)^2 B^2 L_{eff}^2$$ → distorts optics at low *p*

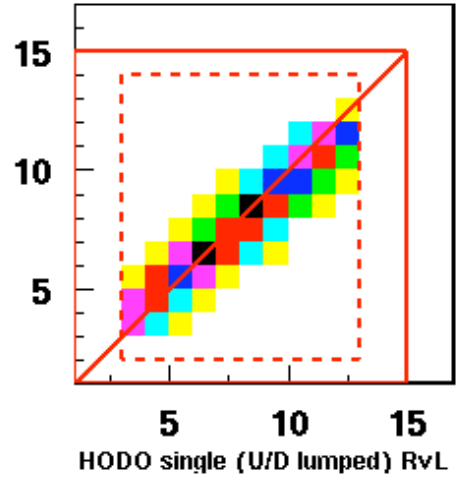
***Optics, "tune" related issues resulted in systematic error contribution of 0.6% at 687 MeV → compared to 0.2% at 3 GeV***

→Larger contributions from random coincidences due to Mott scattering (overall higher rates)

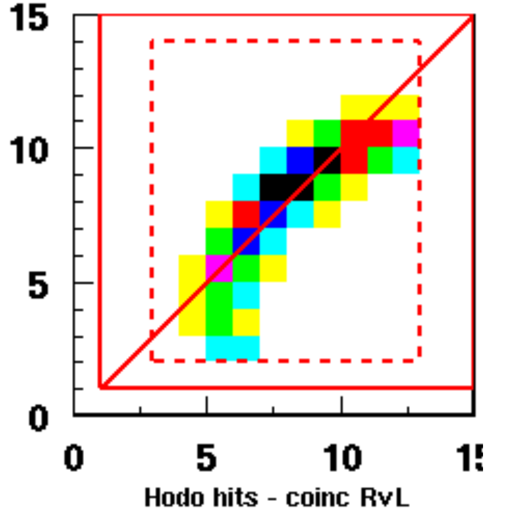
→Analyzing power more sensitive to absolute beam position

→Increased measurement time = fewer measurements

→Greater sensitivity to quadrupole hysteresis




1.16 GeV




687 MeV

# High Target-Field Møller Polarimetry at Very Low Energies

Use of high-field target at low energies may be possible, but requires careful design

1. Polarimeter must be well upstream of physics target/detector

→ Difficult steering requirements make it nearly impossible to satisfy orbit constraints for main experiment and polarimeter at the same time

2. Solenoid must be easily moved and aligned (remotely?)

→ Small misalignments of solenoid have disproportionally large effects on beam orbit

→ Even if "perfectly aligned", imperfect beam orbit may create problems. Ideally, would adjust solenoid to compensate for orbit shifts (feedback loop?)

3. Large solenoid field has large focusing effect at low energies – beamline and polarimeter must incorporate this

# Hall C Compton Polarimeter

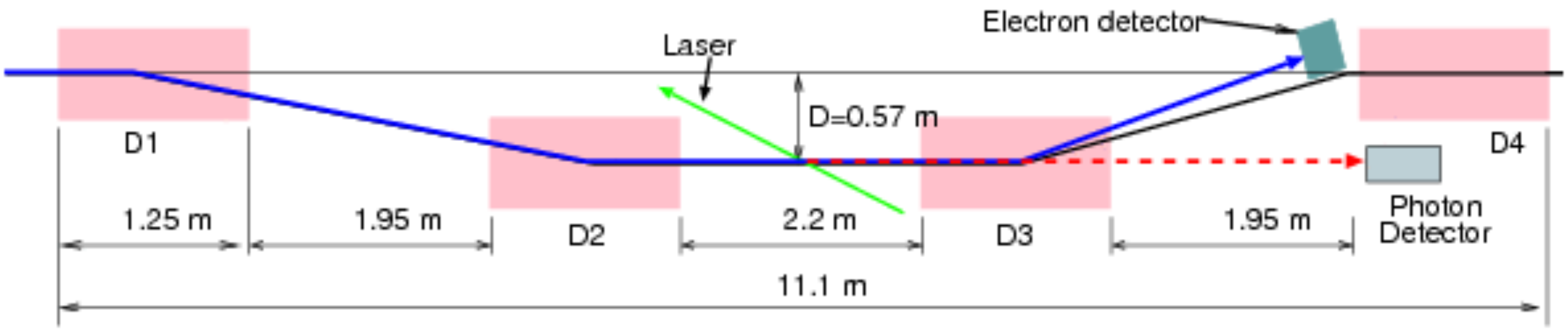
New Compton polarimeter installed just prior to Q-weak experiment

→ Initial layout optimized for ~ 1 GeV running (Q-weak), will be modified for JLab 12 GeV upgrade

→ Systematic error goal = 1%

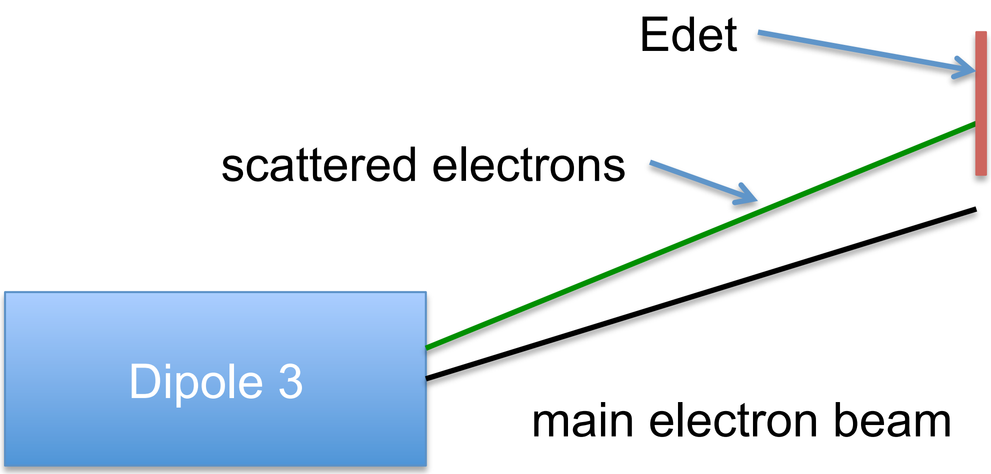
Components

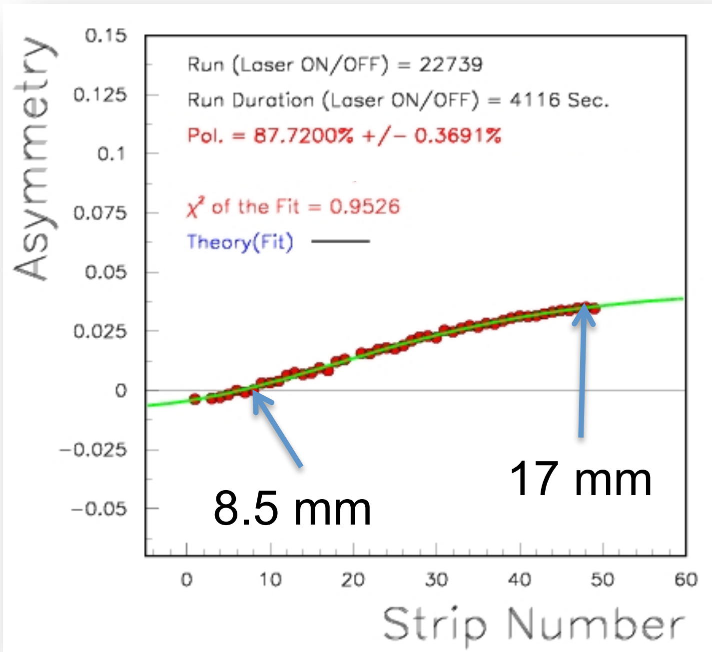
1. Laser: Low gain (~100-200) cavity pumped with 10 W green laser
2. Photon Detector: Lead tungstate
3. Electron Detector: Diamond strip detector
4. Dipole chicane



# Electron Detector

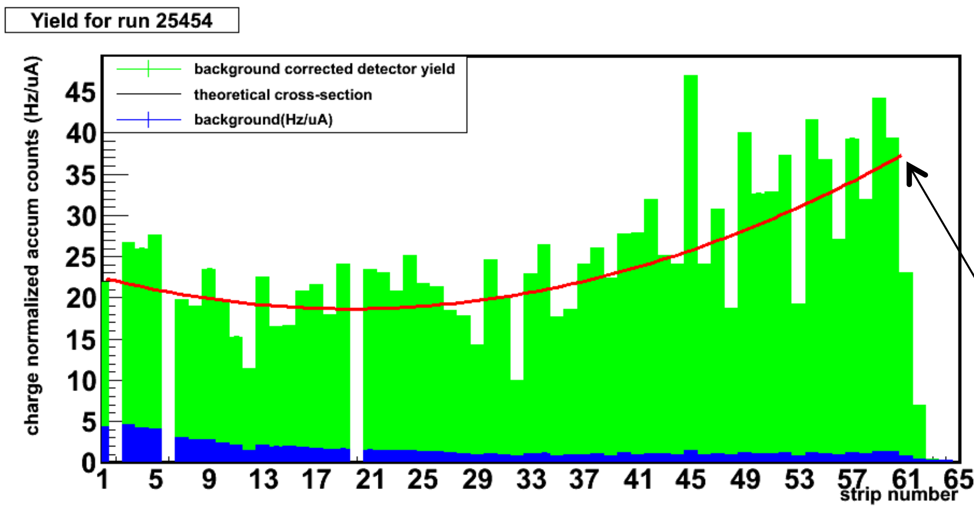
Hall C Compton uses a diamond detector to measure scattered electron
→ 4 planes, 2 x 2 cm
→ 96 strips, 200 μm pitch
→ 3rd dipole momentum analyzes electron
→ Asymmetry vs. strip → scattered electron energy




For Qweak kinematics: Compton endpoint = 17.4 mm from beam
Asy. zero-crossing = 8.7 mm

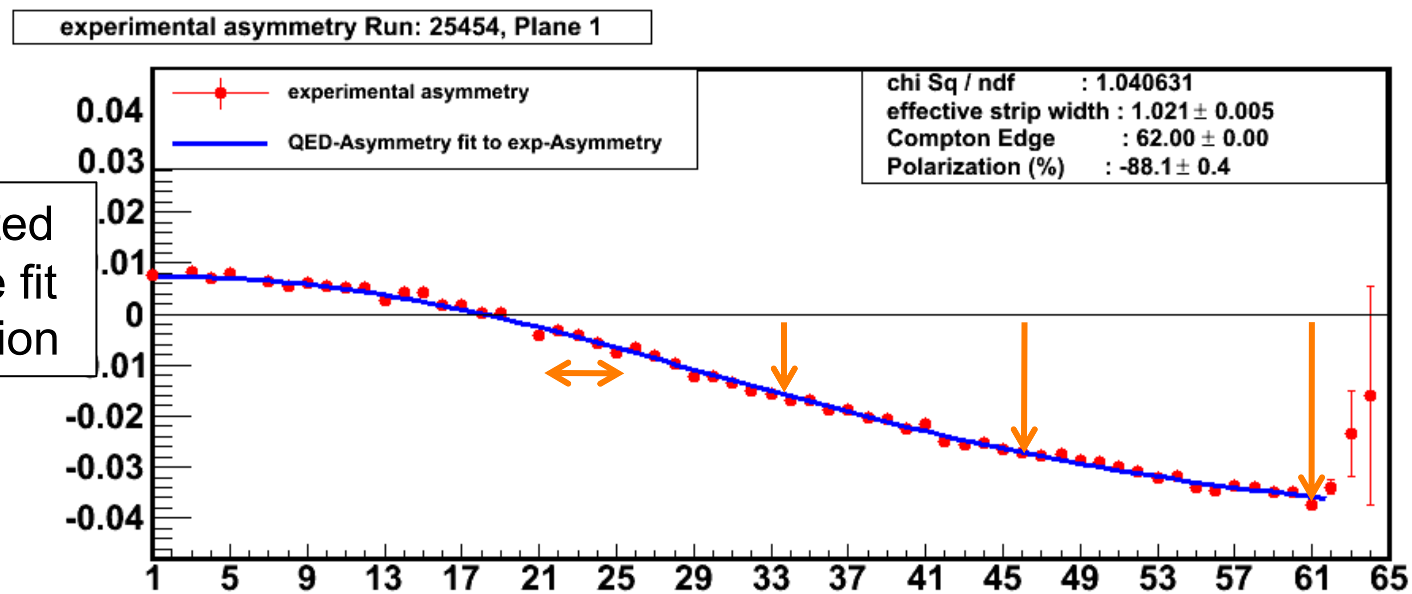
# Polarization from electron detector




Electron detector analysis uses hit spectrum to identify kinematic endpoint – provides energy calibration point for asymmetry spectrum

$E_\gamma$ = *46* MeV
$E_{e'}$ = *1113* MeV

Asymmetry extracted in every strip – use fit to extract polarization



# Electron detector systematics

Extensive studies of electron detector systematics using GEANT3 simulation

Location of Compton edge (inside edge strip) single biggest uncertainty

| Systematic Uncertainty | Uncertainty | Polarization uncertainty (%) |
|---|---|---|
| Compton Edge Location | 90 μm | 0.55 |
| Laser Polarization | 0.4 % | 0.4 |
| Effective Strip pitch | (fit parameter) | 0.2 |
| Fringe Field | -- | 0.15 |
| Plane to Plane | Secondary Particles | 0 - 0.4 |
| Beam Energy | 1 MeV | 0.07 |
| Magnetic Field Strength | 1% | <0.01 |
| Electron Detector Tilt | 1 degree | 0.03 |
| Electron Detector Longitudinal Position | 1 cm | <0.01 |
| **Total Uncertainty** | | **0.73 - 0.83** |

Strip pitch (momentum resolution) determines limiting systematic error
→ 200 μm width was verified at the design stage to provide sufficient resolution to achieve 1% polarimetry → 0.4 MeV/strip resolution

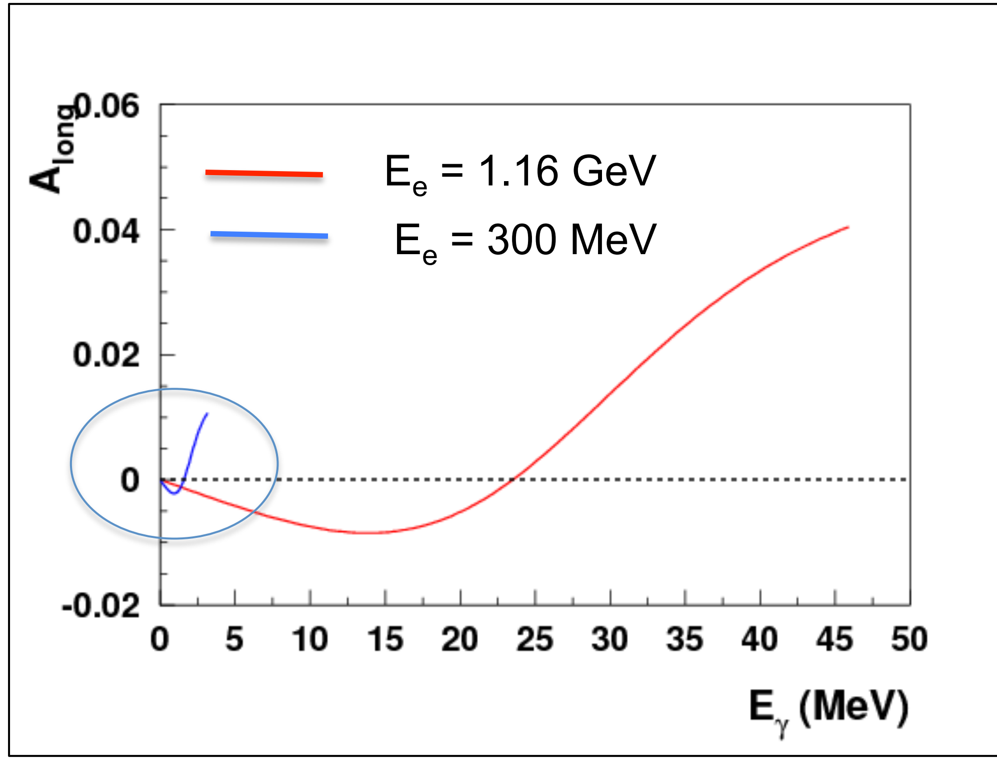
# Compton Polarimetry at 300 MeV

Qweak at 1.16 GeV:
→$E_\gamma$ (max) = 46.1 MeV
→$A_{max}$ = 4%

300 MeV
→$E_\gamma$ (max) = 3.2 MeV
→$A_{max}$ = 1%

Rates very similar, so figure of merit about factor of 16 smaller

→Qweak: 1 hour run yields 0.5% stat. unc. for 180 μA
→300 MeV @ 1 mA, 3 x longer (ok)




Systematic error will depend on "momentum" resolution → chicane should be designed to allow fine mapping of asymmetry spectrum: larger bend and or/ drift

# Summary

- Precision Møller polarimetry requires some kind of "high field" target → iron foil or atomic hydrogen
  - High target field greatly complicates beam transport at low energies
  - Hall C experience suggests that extraordinary care must be taken with solenoid alignment
  - Concurrent Møller measurements and data-taking will require large separation of polarimeter from experiment – decouple beam transport completely

# Summary

- Conventional wisdom in years past has been that Compton polarimetry is best applied at high energies (many GeV)
  - In recent years, this has been shown to be not true
- Hall C Compton polarimeter on track to achieve <1% systematic error (electron detector)
  - Hall A Compton has also achieved <1% at < 1 GeV (photon detector)
- Compton polarimetry at even lower energies (300 MeV) looks plausible with appropriate design
  - Electron detection seems to be easiest way to go
  - 100 MeV? → asymmetries quite small, less feasible

| Variable | Qweak | 300 MeV | 100 MeV |
|---|---|---|---|
| $E\gamma^{max}$ | 46.13 MeV | 3.18 MeV | 0.36 MeV |
| $A^{max}$ | 4.06% | 1.07% | 0.36% |
| Rate | 159 kHz | 164.4 kHz | 165.0 kHz |

# Solenoid and Beamline

Qweak beamline (partial)