Precision Compton Polarimetry for the Q_{Weak} Experiment at Jefferson Lab

Wouter Deconinck

Massachusetts Institute of Technology

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Q_{Weak} Experiment

Measurement of the Weak Charge of the Proton

- Elastic electron scattering off liquid hydrogen target
- Longitudinally polarized electrons, energy of 1.165 GeV
- Rapid electron helicity reversal (1 kHz) at GaAs source
- Current mode: Čerenkov quartz bars, asymmetry $\mathcal{A} \propto P_e$
- Tracking mode: Determination of Q^2 using drift chambers

Projected Uncertainties for 4% Measurement of Q_{Weak}

Statistical precision	3%
Hadronic structure (theoretical)	1.5%
Beam polarimetry (experimental)	1.5%
Other experimental uncertainties	$\leq$ 1.0%

Q_{Weak} Experiment: Polarimetry

Requirements on Beam Polarimetry

- Dominant experimental systematic uncertainty for Q_{Weak}
- Statistical precision of 1% after one hour
- Systematic uncertainty of 1% (for absolute measurements)

Upgrade of Existing Møller Polarimeter

- Operation limited to dedicated low current runs ($I < 8\,\mu$A)
- Development of fast kicker magnet for higher currents

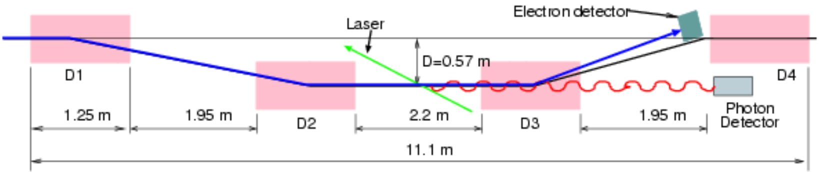
Construction of New Compton Polarimeter

- Will allow continuous measurements with high precision
- Systematic uncertainty of 1% (for absolute measurements)

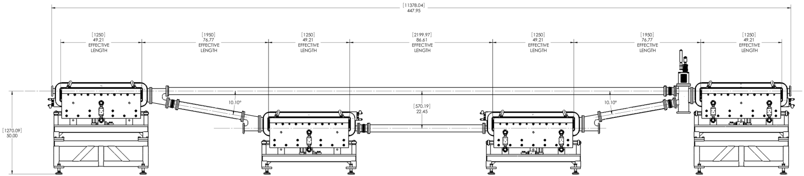
Compton Polarimeter

Overview of subsystems

- Beam: 180 μA at 1.165 GeV (upgradeable to 11 GeV)
- Chicane: interaction region 57 cm below straight beam line
- Laser system: 532 nm green laser
  - Original: RF-pulsed fiber laser with 20 W at 499 MHz
  - Revised: 10 W CW laser with low-gain cavity
- Photons: CsI scintillator in integrating mode ($k' \lesssim 50$ MeV)
- Electrons: Diamond strips with 200 μm pitch ($d \lesssim 23$ mm)



Chicane and Beamline



Motivation

- Displacing Compton photons away from electron beam
- Increased control over beam condition at interaction region

Chicane

- $D = 57\,\mathrm{cm}$ for Q_{Weak}, smaller separation for 11 GeV
- Dipole magnets under construction, delivery after summer
- Interaction region and vacuum design in progress

Laser System

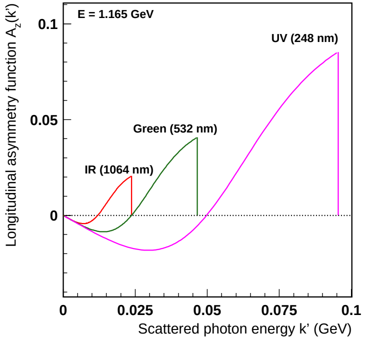
High laser intensity

- Of order 250 W of laser power needed for 1% per hour
- Narrow focussing (diameter $\lesssim$ 1 mm)

Short laser wavelength

- Higher Compton edge
- Larger electron separation

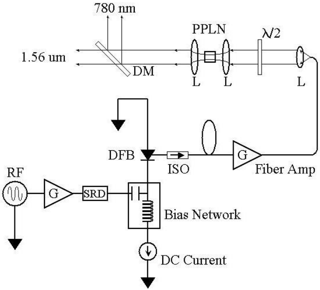
Photon energy	532 nm
Compton edge	50 MeV
Electron separation	23 mm
Asymmetry $\mathcal{A}$	1%



Laser System: Original Design

RF-pulsed fiber laser

- Gain-switched IR seed (499 MHz)
- ErYb-doped fiber amplifier (50 W)



- Frequency-doubling crystal

Advantages

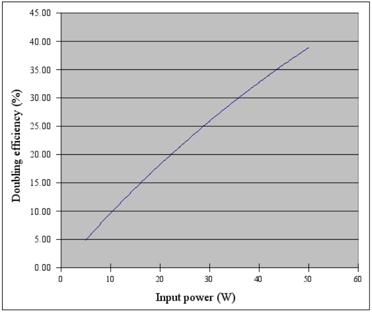
- High power and high duty cycle (50 ps pulses at 499 MHz)
- Off-the-shelf components: intended to be low maintenance

Laser System: Original Design

5 W prototype

- 150 mW out, as expected

50 W fiber amplifier



- Very low doubling efficiency: 6% at various repitition rates
- Expected efficiency 26%
- Very unreliable operation

Fiber amplifier option abandoned

- DC light component? (Amplified Spontaneous Emission)
- Pulsewidth or linewidth after amp too large for doubling?
- Necessary expertise/manpower not available at JLab

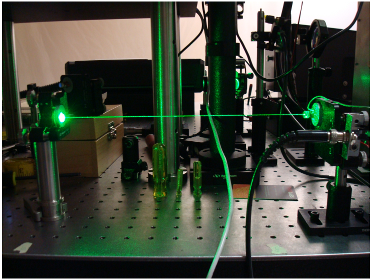
Laser System: New Design

CW laser with low-gain cavity

- 10 W Coherent VERDI laser (532 nm, green, CW)
- Low-gain cavity around interaction region (gain ≈ 100)
- Concern that linewidth is too large for reliable locking
- Comparison with Hall A: gain ≈ 1000

UVa test setup (May 2009)

- First results successful
- Estimated linewidth 5 MHz, 1 MHz should be possible
- Instantaneous linewidth is only 100 kHz (that's good)



Laser System: New Design

Interaction region

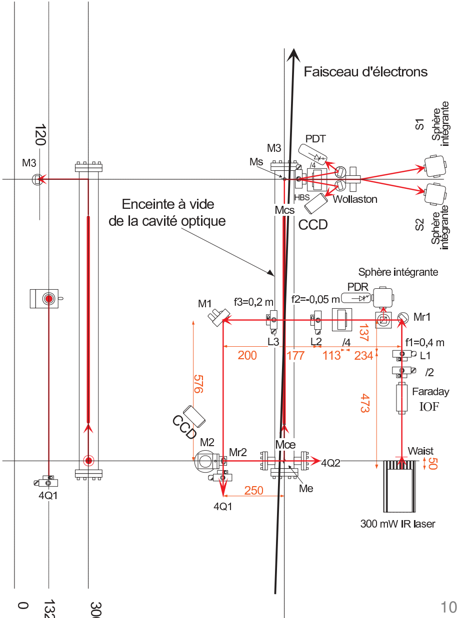
- Laser system chosen
- Cavity-beam vacuum can design started
- Based on Hall A

Hall A design

- High-gain cavity
- IR laser system

Hall C design

- Low-gain cavity
- Green laser system



Detectors

Mode of operation

- Independent measurements of photons and electrons
- Cross-calibration using coincident events
- Integration of deposited energy up to Compton edge

Photon detector

- Compton edge at 50 MeV, detection range 10–50 MeV
- CsI detector recovered from MIT-Bates polarimeter
- Online integration, but event-by-event possible

Electron detector

- Close to primary beam: $\lesssim$ 23 mm (2.5 MRad / 1000 hours)
- Diamond strip detector for radiation hardness

CsI Detector

Pure CsI scintillator crystal

- $10 \times 10 \times 30\,\text{cm}^3$, slightly tapered, MIT-Bates polarimeter
- Emission maximum at 310 nm (fast), 20% at 500 nm (slow)
- Decay time: 16 ns (1000 ns), yield: 2000 γ/MeV (5% of NaI)
- Small yield dependence on temperature (0.6% / $^\circ$C)

Photomultiplier tubes

- Fast rise time (< 3 ns), high gain ($> 10^6$)
- 3 inch 8-dynode Photonis XP3462/B, gain = 10^6 @ HIγS
- 2 inch 12-dynode Photonis XP2262, gain = $3 \cdot 10^7$

Read-out electronics

- 250 MHz sampling ADC with integrated accummulators

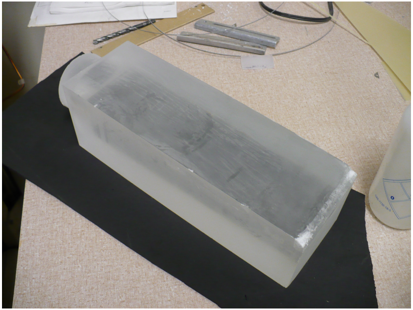
CsI Detector

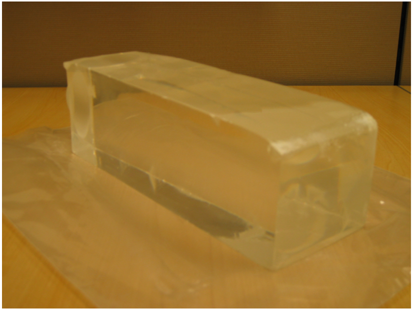
Poor surface quality

- Crystal surface opaque
- Repolishing necessary

After polishing (June 2009)

- Transparency improved
- Ready to add PMT

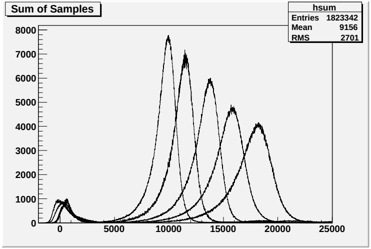




CsI Detector: HIγS

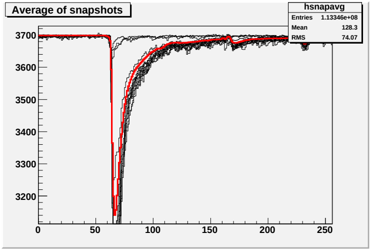
HIγS beam at Duke

- High Intensity γ Source
- Energy from 22 to 40 MeV
- Variable photon intensity



Photon rate (PMT limited)

- 1 kHz and 10 kHz
- 100 kHz: multiple events



Read-out rate (FADC limited)

- Accummulators always on
- 15 kHz sampled events, virtually no dead-time

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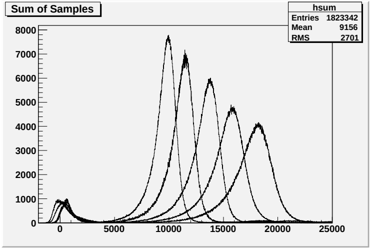
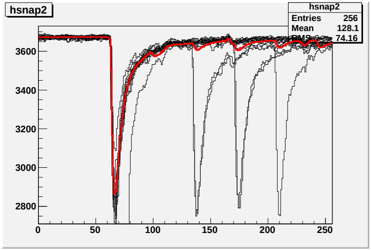


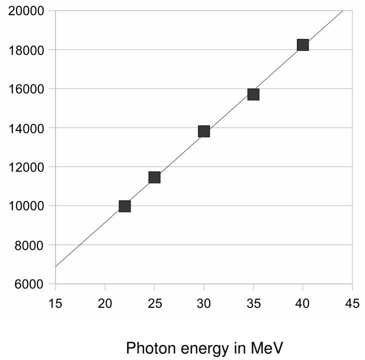


CsI Detector: HIγS

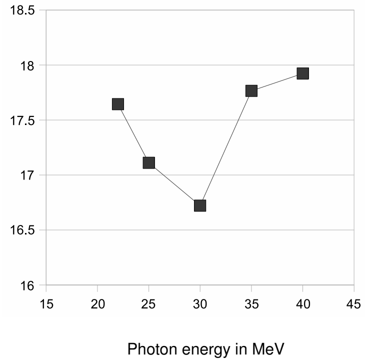
Linearity and resolution

- Preliminary results btained before polishing
- Hope to repeat measurements with higher precision

Response (in a.u.)



Resolution (FWHM in %)

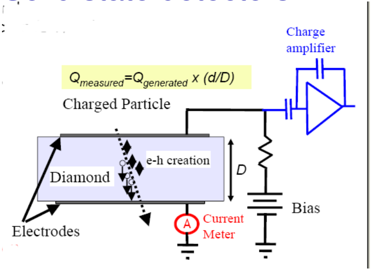


Electron Detector

Diamond strip detector

- Electron displacement at Compton edge is 23 mm
- Radiation hardness of diamond much better
- Advantages: lower leakage current, faster, lower noise
- Disadvantages: smaller signal

Solid state detectors

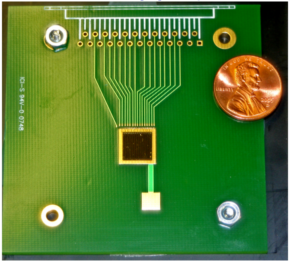


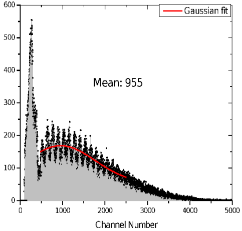
Detector characteristics

- 4 planes of 96 strips with 200 μm pitch
- Bias voltage 1000 V, full metallization on back side

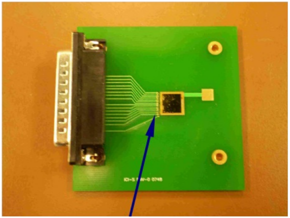
Electron Detector: Prototype Tests with ^{90}Sr

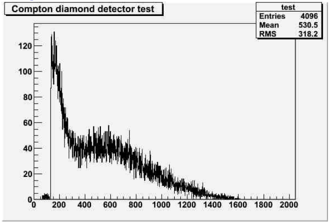
Mississippi (15 strips with 500 μm pitch)





Winnipeg (37 strips with 200 μm pitch)

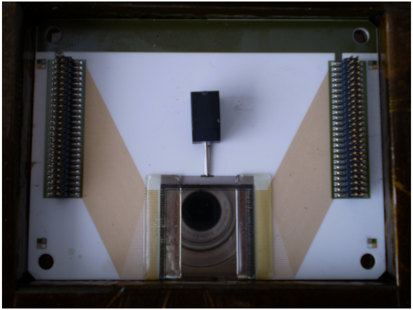


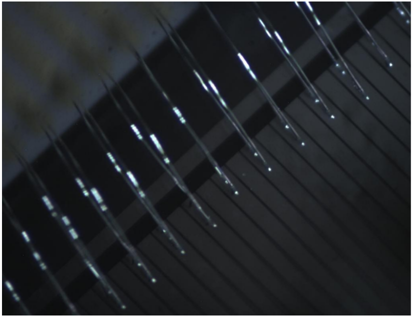


Electron Detector

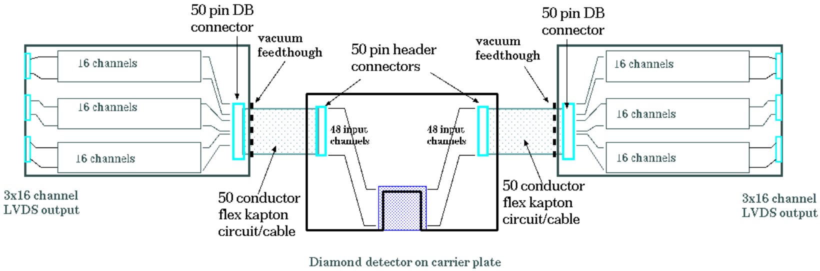
Production complete

- All detector planes produced
- Minor delay due to wire bonding problems





Electron Detector: Read-out



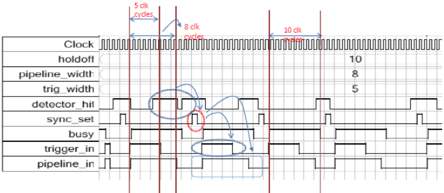
Pre-amplifier boards

- To be mounted on vacuum can
- Developed at TRIUMF, based on AGAM boards
- Gain increased ($\times$ 3–4) without increasing noise

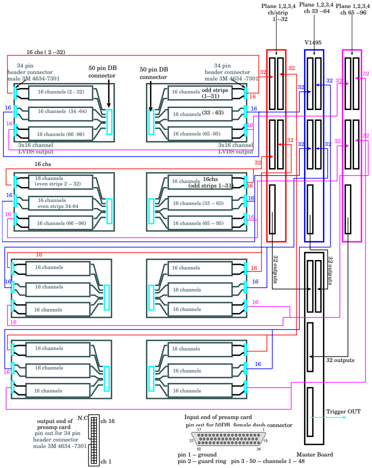
Electron Detector: Read-out

Caen V1495 FPGA modules

- Planes processing: 3 region modules, one master module
- On board testing, integration with CODA in progress



Timing Analysis of the Signal Recondition Circuit



Summary

Schedule for installation

- Now – October 2009: Construction and testing
  - Photon and electron detector assembly
  - Read-out electronics development
  - Analysis and slow control software
- November 2009 – April 2010: Installation
  - Beamline modifications: chicane, interaction region
  - Laser and detectors installation
- May 2010 – October 2010: Q_{Weak} engineering running
  - Commissioning at low current
- November 2010 – May 2012: Q_{Weak} production running

Summary

Precision compton polarimetry for the Q_{Weak} experiment

- Polarimetry: dominant experimental systematic uncertainty
- 1% systematic uncertainty, 1% / hour statistical uncertainty

Status of the Compton polarimeter

- Laser: 10 W CW laser with low-gain cavity in development
- Photon detector: CsI scintillator successfully tested (HIγS)
  - Crystal repolished for improved light output
  - High rate data acquisition with online integration
- Electron detector: diamond planes produced
  - Testing of planes is ongoing
  - FPGA-based trigger/read-out in development

Installation: November 2009 — Production: November 2010

Hall C Compton Group

Jefferson Lab
Thomas Jefferson National Accelerator Facility

HAMPTON UNIVERSITY

OHIO UNIVERSITY

Massachusetts Institute of Technology

MISSISSIPPI STATE UNIVERSITY

YEREVAN PHYSICS INSTITUTE
AFTER A. ALIKHANIAN

THE UNIVERSITY OF WINNIPEG

Additional Material

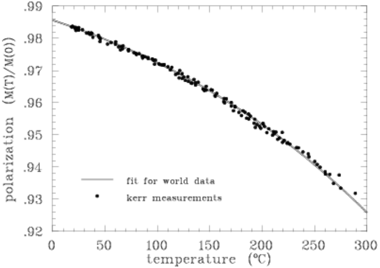
Møller Polarimeter

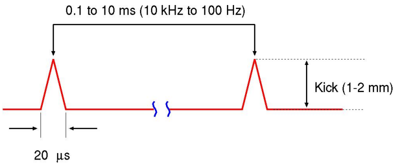
Running strategy for Q_{Weak}

- Cross-checks between Møller and Compton polarimeter

Improvements: fast kicker

- Iron foil depolarization at high currents (ΔP = 1% at 60°C)
- Fast kicker magnet tests: short periods of beam on target





Short kick, long cool-down

Møller Polarimeter: Kicker Tests

Iron wire target (December 2003)

- Kick frequency 100 Hz to 10 kHz, kick duration 20 μs
- Wire too thick (25 μm), random coincidences

Iron strip target (December 2004)

- Kick duration reduced to 10 μs, current to 40 μA
- Target wrinkled in 3 T field, scattered events

Iron foil target (2006)

- Foil broke in target field

Future tests

- Need 2-pass or lower… Dedicated beam time?

Møller Polarimeter during Q_{Weak}

Low beam energy → very high rates

- High rate: 150 kHz at 2 μA on 4 μm foil
- Foil of 1 μm: 1% precision in 5 minutes

High rates → high random rates

- At 100 μA as many random as real coincidences
- Measurement time longer due to dilution

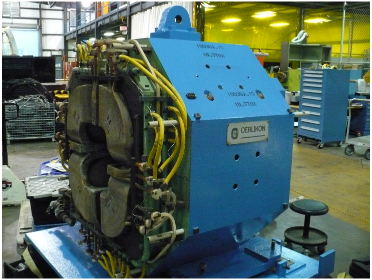
Suggestions

- Thinner foils (now 1 μm, maybe 0.5 μm)
- Shrink collimators to exclude coincidences
- Cross-check Møller at high and low current

Møller Polarimeter after Q_{Weak}

Ready for 12 GeV upgrade?

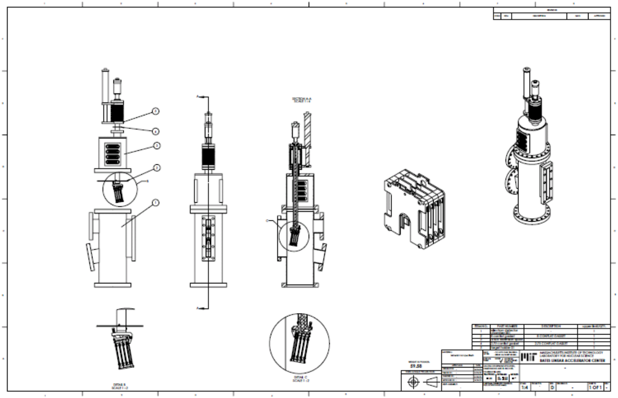
- No big changes to beamline should be needed after Q_{Weak}
- Second Møller quadrupole needed for 11 GeV operation
- Refurbished by Joe Beaufait and Bill Vulcan



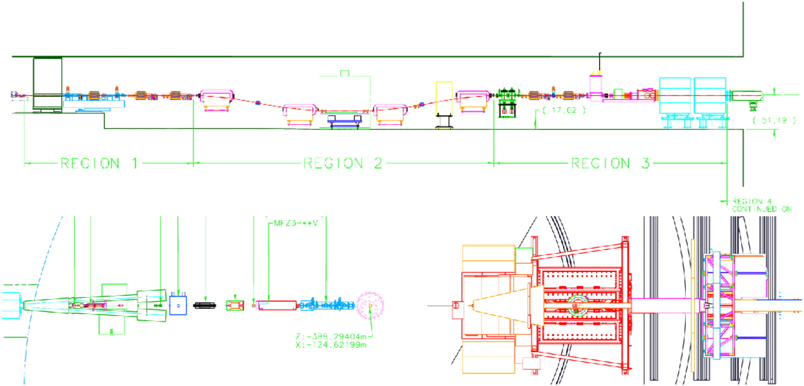
Chicane

Vacuum can and integration

- Electron detector vacuum design in progress
- Interfaces relayed to JLab MEG



Beamline (excluding chicane)



Beamline layout almost finalized

- Some tweaks to design remain (bellows for alignment)
- Integration with chicane dipoles in progress