Hall C Polarimetry at 12 GeV

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Hall C Users Meeting
January 14, 2012

1. Møller Polarimeter
2. Compton Polarimeter
Hall C 12 GeV Polarimetry

Møller Polarimeter

→ 6 GeV operation: uses 2 quads to focus Møller events on detector plane, systematic error $dP/P < 1\%$ at low currents

→ 11 GeV operation requires additional quad, modified optics, systematic error may be slightly larger (still under evaluation)

→ Møller polarimeter will be ready from day 1 (October 2014)

Compton Polarimeter

→ Newly installed for $Q_{Weak}$ – similar to Hall A system (Fabry Perot cavity, diamond strip electron detector, photon detector) – electron detector analysis should yield $dP/P < 1\%$

→ 11 GeV operation requires changes to dipole chicane

  **57 cm deflection → 13 cm**

→ Assuming same laser system (1700 W green) and similar backgrounds in electron detector, 1% measurement in <30 minutes at 11 GeV (10 µA)

→ Design work just began for upgrade – Compton may not be ready for first beam – depends on scope of work, etc.
Basel-Hall C Møller Polarimeter

- 2 quadrupole optics maintains constant tune at detector plane, independent of beam energy
- “Moderate” (compared to Hall A) 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]
Møller Optics

Q1 – horizontally focusing
vertically defocusing

Q2 – horizontally defocusing
vertically focusing

Q2 not strong enough at 11 GeV to deflect scattered electrons to detector – additional quad required

→ Even then, some changes required to optics

Fig. courtesy H. Fenker
Møller Tune at 6 GeV

Quads focus Møller events in an ellipse at detector plane

90 deg. CM Møller events

6 GeV: $\Delta x = 49$ cm $\Delta y = 16$ cm

Quad settings verified by plotting x-coordinate at right detector vs. x-coordinate at left detector for coincidences
Møller Tune at 11 GeV

11 GeV tune requires a “squashed” ellipse

6 GeV: $\Delta x=49 \text{ cm} \quad \Delta y=9 \text{ cm}$

Reducing vertical size of ellipse yields reduced precision in empirical determination/verification of quad optics
Møller Reconfiguration

Re-design of the Møller required to make it “12 GeV” ready

→ 2\textsuperscript{nd} quad does not have sufficient strength to bend electrons onto detector plane at 11 GeV

→ Inserted additional large quad to reach $\Delta x = 49$ cm

→ Region between first and second quads about 30 cm smaller

→ Special pipe required so Møller events do not scrape exiting 3\textsuperscript{rd} quad
Movable Collimators

Movable collimators require some modification for 11 GeV operation
→ Minimum width of collimator 5, collimators 6-7 is +/- 25 mm
→ At 11 GeV, this will block otherwise good coincidence events
→ May not bother to modify collimator 5 – recent experience suggests it only increases backgrounds

Movable collimators for reduction of backgrounds

Accepted Møller coincidences at movable collimator location
Møller Q3 Problems

In spring, noticed Møller tune not always reproducible → cycling the quad did not help

→Rates also somewhat erratic
Nominal = 16 kHz/µA, sometimes as low as 12 kHz/µA

Installed Hall probes in Q3 → found field on beam right side unstable
Møller Q3 Problems

Diagnosis during 6 MSD revealed short in one set of coils

→ Almost all coils “sick” – not surprising since they are about 40 (?) years old

→ 11GeV will require running quads at nearly absolute maximum current

→ New coils will be fabricated before start of 12 GeV running
Predicted systematic error budget for $Q_{\text{Weak}}$ with new Møller configuration

- Low current running only
- Applies to a particular measurement, not polarization for the experiment

$$dP/P = 0.57\%$$

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty</th>
<th>$d\text{Asy.}/\text{Asy.} (%)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam position x</td>
<td>0.5 mm</td>
<td>0.32</td>
</tr>
<tr>
<td>Beam position y</td>
<td>0.5 mm</td>
<td>0.02</td>
</tr>
<tr>
<td>Beam direction x</td>
<td>0.15 mr</td>
<td>0.02</td>
</tr>
<tr>
<td>Beam direction y</td>
<td>0.15 mr</td>
<td>0.01</td>
</tr>
<tr>
<td>Q1 current</td>
<td>2%</td>
<td>0.10</td>
</tr>
<tr>
<td>Q2 current</td>
<td>1%</td>
<td>0.17</td>
</tr>
<tr>
<td>Q2 position</td>
<td>1 mm</td>
<td>0.18</td>
</tr>
<tr>
<td>Multiple Scattering</td>
<td>10%</td>
<td>0.01</td>
</tr>
<tr>
<td>Levchuk effect</td>
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</tr>
<tr>
<td>Collimator positions</td>
<td>0.5 mm</td>
<td>0.06</td>
</tr>
<tr>
<td>Target temperature</td>
<td>50%</td>
<td>0.05</td>
</tr>
<tr>
<td>B-field direction</td>
<td>2°</td>
<td>0.14</td>
</tr>
<tr>
<td>B-field strength</td>
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<td>Spin polarization in Fe</td>
<td></td>
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</tr>
<tr>
<td>Elec. D.T.</td>
<td>100%</td>
<td>0.04</td>
</tr>
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<td>Solenoid focusing</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>0.57</strong></td>
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Nearly all systematic errors will remain the same with the exception of the uncertainty due to the quad currents.

\[ \rightarrow \text{Requires more MC study to determine how well we can determine the correct quad currents empirically} \]

\[ \rightarrow \text{Alternately, we can try to get better field map data} \]

\[ \rightarrow \text{Uncertainties are likely overestimated anyway – ignores correlations in setting of Q1 vs. Q2} \]

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<tr>
<td>Q1 current</td>
<td>2% (?)</td>
<td>0.10</td>
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<tr>
<td>Q2 + Q3 current</td>
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Møller Upgrade Summary

• Additional quad to achieve 11 GeV
  – Can use “2 quad” system up to 6.5 GeV
  – 3 quads required for E>6.5 GeV → optics also slightly different
    – New coils will be fabricated

• Modified beam pipe with “wings” to avoid scraping at Q3 exit

• Moveable collimators must be modified (collimator 5, and 6&7)

• Final systematic error still under evaluation – I do not expect it to be much worse
Compton polarimeter provides:

→ Continuous, non-destructive measurement of polarization under experiment running conditions
→ Independent cross-check of Møller polarimeter

Components

1. **Laser**: Low gain (~100-200) cavity pumped with 10 W green laser
2. **Photon Detector**: Lead-tungstate detector operated in integrating mode
3. **Electron Detector**: Diamond strip detector
4. **Dipole chicane and beamline** modifications
1. **Laser**: new laser system with larger apertures in interaction region desirable, but existing laser system should be “ok”

2. **Photon Detector**: new geometry may pose challenges for photon detector

3. **Electron Detector**: Diamond strip detector (no major changes)

4. **Dipole chicane**: this will require significant modifications
   - New poles for dipoles (exist)
   - Vertical deflection will be reduced from 57 cm to 13 cm
   - New chamber for electron detector (modify old chamber?)

Design work started December 2011
12 GeV Compton: Schedule (?)

<table>
<thead>
<tr>
<th>Name</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compton Upgrade</td>
<td>12/1/11 8:00 AM</td>
<td>12/31/14 5:00 PM</td>
</tr>
<tr>
<td>Chicane Design</td>
<td>1/4/12 8:00 AM</td>
<td>9/28/12 5:00 PM</td>
</tr>
<tr>
<td>Procurement and Fabrication</td>
<td>10/1/12 7:00 AM</td>
<td>10/1/13 5:00 PM</td>
</tr>
<tr>
<td>Installation</td>
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<td>3/31/14 5:00 PM</td>
</tr>
<tr>
<td>Accelerator Run IV</td>
<td>5/1/14 7:00 AM</td>
<td>10/31/14 5:00 PM</td>
</tr>
<tr>
<td>SHMS Commissioning...</td>
<td>9/2/14 7:00 AM</td>
<td>9/8/14 5:00 PM</td>
</tr>
</tbody>
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Slightly outdated – see Arne’s talk yesterday: Accelerator Run IV is now later b/c 12 month down is assumed to be 16 months

Working Compton by start of Hall C 12 GeV program seems feasible assuming:

1. Minimum scope: no modifications to laser system or interaction region
2. Availability of funding for needed procurements starting October 2013
3. Installation manpower available → other beamline work also required. Can Compton + beamline get done all at once?
Compton Polarimeter at 12 GeV

Operation at 11 GeV requires:
1. Changing chicane geometry
   → 57 cm drop becomes 13 cm
2. New poles for dipole (already exist)

Low energy poles: nominal field = 5.5 kG

High energy poles: field=12 kG
Compton Electron Detector

Beam polarization extracted by fitting shape of measured Compton spectrum to theoretical spectrum

→ Requires clean identification of end-point strip
→ Fit has 2 free parameters:
  - Electron polarization
  - Geometrical factor → effective strip pitch
→ This technique works best when the asymmetry “zero-crossing” is in the detector acceptance

Assuming backgrounds comparable to Qweak (??) – zero-crossing should be measurable down to ~ 3 GeV
Compton Electron Detector

- Asymmetry zero-crossing at ~ 2 cm at 11 GeV
- Zero-crossing ~ 5.5 mm at 3 GeV (Q-Weak = 7 mm)
  - This is likely the absolute limit
- Alternatively, fit 2\textsuperscript{nd} geometrical factor at high energy, apply at low energy → only works if we can constrain the dipole field independently

Scattered electron deflections for 12 GeV configuration
Compton Upgrade Summary

- Operation of Compton at 11 GeV requires smaller electron beam deflection: 57 cm → 13 cm
- Significant design and installation effort required to accommodate smaller deflection
  - New stands for dipoles 2 and 3
  - New vacuum pipes between dipoles, new electron detector chamber (?)
- Electron detector should have full functionality down to 3 GeV
  - Systematic errors in 11 GeV configuration should be similar to whatever we end up achieving for $Q_{Weak}$
- Minimal space for photon detector – may need new, more compact option
Additional upgrades to Compton?

- Changes to Compton described in previous slides are the “minimum” required for 11 GeV functionality
- If you desire further changes, feel free to offer suggestions
- Laser is one obvious sub-system that likely could benefit from further upgrades
- Possible laser system upgrades
  - RF pulsed one pass system $\rightarrow$ improved knowledge of $P_{laser}$ via in-situ measurement?
  - Higher gain CW cavity
  - RF pulsed cavity
- Laser options above would offer good luminosity at larger crossing angle $\rightarrow$ smaller backgrounds due to larger apertures in interaction region
Extra
Halo, small apertures and backgrounds

Existing system uses narrow apertures to help protect cavity mirrors from:
- Large beam related backgrounds
- Direct beam strikes

Large beam size, halo will result in huge backgrounds from scraping on narrow apertures → ion chambers, machine protection system shuts off beam.

This system has drawbacks → very small halos can still result in significant backgrounds.

→ Halo may be small enough to run, but there still may be a lot of junk in your detectors.
JLab 12 GeV:
Control of beam halo, spot size likely worse
At 6 GeV, it already takes considerable effort to tune the beam for the Compton
Highly desirable to get mirrors further from beamline without reducing luminosity unduly
→ This could be accomplished by switching from CW cavity, to RF pulsed cavity
→ At non-zero crossing angle, luminosity larger, drops more slowly with crossing angle

RF pulsed cavities have been built – this is a technology under development for ILC among other applications

JLab beam → 499 MHz, Δτ~0.5 ps

RF pulsed laser
CW laser

0.1 degrees
Pulsed vs. CW FP Cavity

CW cavity resonance condition: $2L_{\text{cavity}} = n \lambda$

Additional condition for pulsed laser: $2L_{\text{cavity}} = n \frac{c}{f_{\text{RF}}}$

Cavity gain requires mode-locked laser! → Excite same longitudinal modes in FP cavity

Figs. From F. Zomer, Orsay-LAL
Cavity Design Considerations

- In general – “low-finesse” (gain) cavities are easier than high-finesse
  - Better off if you can start with higher power laser (1 W better than 100 mW)
- Keep mirrors far from beamline
  - Naively, you can just make the cavity longer \(\rightarrow\) same crossing angle, but mirrors further away
  - But, longer cavity results in smaller linewidth at fixed finesse \(\rightarrow\) this may make locking more challenging
- RF pulsed system an intriguing solution
  - Extra degree of freedom in feedback, but has been demonstrated to work
  - Greater sensitivity to helicity correlated pathlength changes in the machine?
Electron Detector

Diamond strip detector built by Miss. State, U. Winnipeg
→ 4 planes of 96 strips
→ 200 μm pitch

Key component (not shown): amplifier-discriminator electronics

Readout using CAEN v1495 boards
→ Should be able to read out either in event mode or in “scaler” mode
Hall C uses high power CW laser (10 W) @ 532 nm coupled to a low gain, external cavity → 1-2 kW of stored power

Laser locked to cavity using Pound-Drever-Hall (PDH) technique