The Qweak Collaboration


¹Spokespersons
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Experiment Overview


- Scheduled for 223 days at a nominal energy of 1.165 GeV. Begin installation late ~2009 with final run period ending ~May 2012.

- Science that Jlab is uniquely positioned to conduct. >100 man years have been invested to date.

- 7 graduate students on board to date. 8 faculty planning sabbaticals.

- Precision measurement of the proton’s weak charge in the simplest system. Parity violation in e-p scattering at $Q^2 = 0.026 \text{ (GeV/c)^2}$. 

  ✓ Hadronic background determined from existing PVES data!

  - Determine the weak charge of the proton to 4%
  - Extract $\sin^2\theta_W$ to 0.3%
  - Completes the set of PV measurements needed to determine the $C_{1u}$ and $C_{1d}$ quark coupling constants.
  - Set limit on parity violating new physics at energy scale of ~2.3 TeV.

- Measurement is unlikely to be repeated in the foreseeable future - so there is a need to push the precision envelope.
Extraction of $Q^p_{\text{weak}}$

The $Q_{\text{weak}}$ experiment measures the parity-violating analyzing power $A_z = \varepsilon / P_z$

$$A_z = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \simeq -3 \times 10^{-7}$$

$$A_z \xrightarrow{Q^2 \to 0, \theta \to 0} \frac{-G_F}{4\pi\alpha\sqrt{2}} [Q^2 Q^p_{\text{weak}} + Q^4 B(Q^2)]$$

Contains $G^\gamma_{E,M}$ and $G^Z_{E,M}$, Extracted using global fit of existing PVES experiments!

$$Q^p_{\text{weak}} = 1 - 4\sin^2 \theta_W \sim 0.072 \text{ (at tree level)}$$

- $Q^p_{\text{weak}}$ is a well-defined experimental observable
- $Q^p_{\text{weak}}$ has a definite prediction in the electroweak Standard Model
Nucleon Structure Contributions to the Analyzing Power

\[ A = A_{Q^2} + A_{\text{hadronic}} + A_{\text{axial}} \]
\[ = -0.19 \text{ ppm} - 0.09 \text{ ppm} - 0.01 \text{ ppm} \]

**hadronic:**
(31% of asymmetry)
- contains \(G^{\gamma}_{E,M} G^{Z}_{E,M}\)
Constrained by HAPPEX, \(G^0\), MAMI PVA4

**axial:**
(4% of asymmetry)
- contains \(G^{e}_{A}\)
has large electroweak radiative corrections.
Constrained by \(G^0\) and SAMPLE

**Constraints on \(A_{\text{hadronic}}\) from other Measurements**
\[ A_{\text{hadronic}} = Q^4 B(Q^2) \]

Projected Hadronic Uncertainties from Planned Experiments

**Quadrature sum of expected**
\(\Delta A_{\text{hadronic}} = 1.5\%\) and \(\Delta A_{\text{axial}} = 1.2\%\) errors contribute \(\sim 1.9\%\) to error on \(Q^2_{W}\)
Use global fit to extract slope at $0^\circ$ and $Q^2 = 0$.
Anticipated $Q^p_W$ Weak Uncertainties

<table>
<thead>
<tr>
<th></th>
<th>$\Delta A_{phys}/A_{phys}$</th>
<th>$\Delta Q^p_{weak}/Q^p_{weak}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical (2200 hours production)</td>
<td>1.8%</td>
<td>2.9%</td>
</tr>
<tr>
<td>Systematic:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hadronic structure uncertainties</td>
<td>--</td>
<td>1.9%</td>
</tr>
<tr>
<td>Beam polarimetry</td>
<td>1.0%</td>
<td>1.6%</td>
</tr>
<tr>
<td>Absolute $Q^2$ determination</td>
<td>0.5%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Backgrounds</td>
<td>0.5%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Helicity-correlated Beam Properties</td>
<td>0.5%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.2%</td>
<td>4.1%</td>
</tr>
</tbody>
</table>

4% error on $Q^p_W$ corresponds to $\sim 0.3\%$ precision on $\sin^2\theta_W$ at $Q^2 \sim 0.03$ GeV$^2$

$$Q^p_W(p) = [\rho_{NC} + \Delta_e][1 - 4\sin^2\hat{\theta}_W(0) + \Delta_e']$$

$$+ \Box_{WW} + \Box_{ZZ} + \Box_{\gamma Z}.$$ 

(Erler, Kurylov, Ramsey-Musolf, PRD 68, 016006 (2003))

$Q^p_W = 0.0716 \pm 0.0006$ theoretically

0.8% error comes from QCD uncertainties in box graphs, etc.
All Data & Fits Plotted at 1 σ

\[ Q_{1w}^u = -2(2C_{1u} + C_{1d}) \]

HAPPEx: H, He
G0: H,
PVA4: H
SAMPLE: H, D
The Basic Qweak Apparatus

- Build on JLab expertise with parity quality polarized beams.
- Dual Moeller & Compton polarimetry.
- Use (resistive) toroidal magnet to isolate the elastics from inelastics and neutral background.
- Use quartz Cerenkov detectors:
  
  - Rad hard (stable) and rejection of non-relativistic events.
  - Low gain PMT’s operated in linear current integrating mode.
  - Precision 18-bit ADC rapid sampling (equivalent to 26 bit).
- Counting mode (sub-nA beam currents) for $Q^2$ calibrations.
- Worlds highest power LH$_2$ cryogenic target (~2.5 kW).
- Rapid flipping 125 Hz of beam helicity (perhaps as high as 500 Hz) to suppress beam systematics and potential target “boiling noise”.
Schematic of the $Q^p_{\text{Weak}}$ Experiment

- Elastically Scattered Electron
- Region III Drift Chambers
- Toroidal Magnet
- Region II Drift Chambers
- Region I GEM Detectors
- Primary Collimator with 8 openings
- 35 cm Liquid Hydrogen Target
- Polarized Electron Beam, 1.165 GeV, 180 µA, $P \sim 85\%$

Region I, II and III detectors are for $Q^2$ measurements at low beam current.
Q² Acceptance and Efficiency Mapping of Quartz Bars

(I_{beam} \sim 100 \text{ pA to 1 nA})

Collimator 1
Collimator 3
Defining Collimator

e^- beam
target

Quartz Cherenkov bar
(insensitive to non-relativistic particles)

Location Region 3
2 Vertical Drift chambers

Location Region 2
2 Horizontal Drift chambers

GEM
Gas Electron Multiplier

Location Region 1

Region 1 + 2 chambers: Absolute Q² acceptance
Region 3 chamber: Efficiency map of quartz detectors

Expected Q² distribution

![Graph showing Q² distribution]
Main Detector

Toroidal Spectrometer
Produces 8 Beam Spots

Each focus is ~2 meters long

- 8 fused silica radiators
  200 cm x 18 cm x 1.25 cm
- Spectrosil 2000
  Rad-hard, low luminescence (expensive)
- ~800 MHz e⁻ per bar
- Light collection by TIR
  5 Angstroms rms polish
  (even more expensive)
- 5” PMTs with gain = 2000
- S20 photocathodes ($I_k = 3 \text{ nA}$)
- Current mode readout ($I_a = 6 \mu\text{A}$)
Collimator 3
In its frame

Collimator 1
Photo shows status after 2 openings cut.
(It is now fully machined)
Custom 18 bit ADC

Light Output Uniformity of Quartz Bar

All detector electronics / quartz / tubes at JLab

20 p.e. per event
50,000 e per event
800 MHz

x 2500

1 MΩ I-V

6.4 µA

6.4 V

in shielding

outside hall

Custom 18 bit ADC

Run 182: Channel 8, Input voltage = 4.823 V

Beam Left-Right Hit Location [cm]

Number of photoelectrons

Number of quartets

Quartet asymmetry in channel 8 ADC readout
CAD Drawing – (only partial shielding shown)
CAD Drawing – (only partial shielding shown)
QTOR Pre-Ops Tests at MIT-Bates

Attaching a Coil to the Support Structure

Assembled Magnet with Mapper

Limited duration 9,500 Amp powered test completed and mapping at 4000 amps underway at MIT/Bates.
3 NSF-funded Tracking Sub-systems to Measure Acceptance, Backgrounds, $Q^2$, etc.

Front-end Rotator and GEM detector
LaTech Idaho State

Front-end HDC’s – VPI (full-scale region II chamber)

VDC Construction at W&M (Foils & HV planes completed)
2.5 kW LH$_2$ Cryotarget Under Construction

- Fluid dynamics simulation code used in the design effort to minimize “boiling noise” risk - in the liquid volume or at the windows.

- Fast helicity reversal 125 Hz up to 500 Hz. Common mode rejection of “boiling” noise increases as helicity reversal/readout rate is raised.

- First cold test of target pump conducted – only partially successful because correct cryo-bearing was not available.
Beam Polarimetry: Need 1% at 180 µA

- Existing “saturated Fe” Moeller polarimeter achieves ±0.5% to ±1.0% accuracy, but at currents well below 180 µA and the measurement is invasive.
- Jlab has developed a low duty factor “kicker” technique to allow Moeller to operate at ~40 µA, with plans to push towards higher currents.

1 µm Fe foil for good real/random ratio, low duty factor to minimize heating/depolarization.

- Compton polarimeter (1 to 11 GeV) construction. Design goal is ±1% absolute accuracy.
- **Cross-calibrate against existing Moeller** to save time and simplify initial operation at ~1 GeV during the Qweak experiment.
Technical Progress Highlights

1. Successfully obligated all FY08 procurements.

1. Detailed “draft” installation plan developed.

2. Region 3 rotator assembly to begin this November in test lab.

3. Placement of chicane magnet order eminent at MIT/Bates

1. Target:

   Crucial, critical path pump test imminent.
   Heater designs finished.

1. VDC wire stringing and HV foil mounting finished.

1. Primary detector gluing method established.

2. QTOR (magnet) & power supply tested to full current + 10%.
   Mapping underway.