Measurement of the proton’s weak charge at the Qweak experiment

Jean-Francois Rajotte
MIT
(for the Qweak collaboration)

DPF meeting
August 12th, 2011

DOE, NSF, NSERC
Overview

- Qweak the value
- Qweak the experiment
- Run I winter 2011
- Perspective for Run II 2011-2012
**Qweak, the value**

<table>
<thead>
<tr>
<th></th>
<th>$Q^\gamma$</th>
<th>$Q^Z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>u</td>
<td>+2/3</td>
<td>$1 - \frac{8}{3} \sin^2 \theta_w$</td>
</tr>
<tr>
<td>d</td>
<td>-1/3</td>
<td>$-1 + \frac{4}{3} \sin^2 \theta_w$</td>
</tr>
<tr>
<td>p(uud)</td>
<td>+1</td>
<td>$1 - 4 \sin^2 \theta_w$</td>
</tr>
<tr>
<td>n(udd)</td>
<td>0</td>
<td>-1</td>
</tr>
</tbody>
</table>

Qweak $\sim$0.074 (at tree level)
Smallness increases sensitivity to BSM physics
Running of $\sin^2 \theta_w$
Accessing $\text{Qweak}$ through PVES

\[
\sigma \sim \begin{vmatrix}
\gamma
\end{vmatrix}^2 + \begin{vmatrix} z \end{vmatrix}^2 = \begin{vmatrix} \gamma \end{vmatrix}^2 + \begin{vmatrix} z \end{vmatrix}^2 + h(e) \begin{vmatrix} \gamma \end{vmatrix} \cdot \begin{vmatrix} z \end{vmatrix}
\]
Accessing Qweak through PVES

\[ \sigma \sim \left( | \begin{array}{c} \gamma \\ \end{array} \right| + \left| \begin{array}{c} Z \\ \end{array} \right| \right)^2 = \left| \begin{array}{c} \gamma \\ \end{array} \right|^2 + \left| \begin{array}{c} Z \\ \end{array} \right|^2 + h(e) \left| \begin{array}{c} \gamma \\ \end{array} \right| \cdot \left| \begin{array}{c} Z \\ \end{array} \right| \]
Accessing Qweak through PVES

\[ \sigma \sim \left| \begin{array}{c} \gamma \swarrow \searrow \\ \gamma \swarrow \searrow \ \ z \\
\end{array} \right|^2 \]

\[ = \left| \begin{array}{c} \gamma \swarrow \searrow \\
\end{array} \right|^2 + \left| \begin{array}{c} \gamma \swarrow \searrow \\
\end{array} \right|^2 + h(e) \left| \begin{array}{c} \gamma \swarrow \searrow \\
\end{array} \right| \cdot \left| \begin{array}{c} \gamma \swarrow \searrow \\
\end{array} \right|^2 \]

\[ \sigma_R - \sigma_L \]

\[ \sigma_R + \sigma_L \]

\[ A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \sim \left| \begin{array}{c} \gamma \swarrow \searrow \\
\end{array} \right| \cdot \left| \begin{array}{c} \gamma \swarrow \searrow \\
\end{array} \right|^2 \sim -0.23 \text{ppm} \]
Physics beyond the standard model

Examples

• Extra neutral gauge bosons (e.g. SUSY)
• Leptoquarks
• Composite fermions
• etc.

Model independent

\[ \frac{\Lambda}{g} = \frac{1}{\sqrt{2}G_F} \cdot \frac{1}{\sqrt{\Delta Q_w(p)}} \]

4% measurement of Qweak probes 2-3 TeV scale
Physics beyond the standard model

Complementarity of $p$ and $e$ weak charge experiments

$Q_W^p = 0.0716$

$Q_W^e = 0.0449$

SM

Leptoquarks

$E_6 Z'$

RPV SUSY

SUSY Loops

Experiment

$\pm 0.0029$

$\pm 0.0040$
The proton's structure

Increasing $Q^2$
The proton’s structure

\[ A = A_0 \left[ Q_{\text{weak}}^p Q^2 + B(Q^2)Q^4 \right] \]

Increasing \( Q^2 \)

the smaller the \( Q^2 \), the less we are affected by hadronic structure.
Using previous PVES to extrapolate $Q^2 \rightarrow 0$

A precise measurement at low $Q^2$, combined with previous PVES, leads to a precise determination of $Q_{\text{weak}}$. 

$$Q_{\text{w(SM)}}$$

$$Q_{\text{w(Exp.)}}$$

A precise measurement at low $Q^2$, combined with previous PVES, leads to a precise determination of $Q_{\text{weak}}$. 

$$Q^2 (\text{GeV}^2)$$
Qweak the experiment
## Error Budget

<table>
<thead>
<tr>
<th>Source of Error</th>
<th>Contribution to $\Delta A_{phys}/A_{phys}$</th>
<th>Contribution to $\Delta Q_w^P/Q_W^P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counting Statistics (106 days)</td>
<td>2.1%</td>
<td>3.2%</td>
</tr>
<tr>
<td>Hadronic structure</td>
<td>—</td>
<td>1.9%</td>
</tr>
<tr>
<td>Beam polarimetry</td>
<td>1.0%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Absolute $Q^2$</td>
<td>0.5%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Backgrounds</td>
<td>0.5%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Helicity-correlated beam properties</td>
<td>0.5%</td>
<td>0.7%</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td><strong>2.5%</strong></td>
<td><strong>4.1%</strong></td>
</tr>
</tbody>
</table>
Qweak the experiment

- Electron beam
- Target
- Detector system
Qweak the experiment

- Electron beam
- Target
- Detector system
Electron beam: JLab
Electron beam: JLab

Spin flip @ 960Hz

E=1.165GeV
Current: 180uA
Polarization ~85%
Qweak the experiment

- Electron beam
- Target
- Detector system

\[ e \rightarrow e' \]
Qweak the experiment

- Electron beam
- **Target**
- Detector system
Al windows, need to be accounted for in the asymmetry.

2500W cooling power to sustain a 180 uA beam.
Design results in small temperature and pressure inhomogeneities
Target

Monitoring: target dedicated shift
Qweak the experiment

- Electron beam
- Target
- Detector system
Qweak the experiment

- Electron beam
- Target
- Detector system
Schematic of the Qweak Experiment

Elastically Scattered Electrons

Toroidal Magnet

35 cm Liquid Hydrogen Target
Polarized Electron Beam

Eight Fused Silica (quartz) Cerenkov Detectors

Integrating mode
The actual setup
Further considerations
Polarimetry

Precision needed: 1%

- Moller: Invasive, precise
- Compton, Electron: non-invasive, always on
Tracking

Drift chambers before and after magnetic deflection (lower current)

- Need to know $Q^2$ to $\sim 1\%$
Background

\[ A_{\text{meas}} = P_e (1 - f) A_{\text{phys}} (Q^2) + f A_{\text{bkg}} + A_{\text{false}} \]

Dilution: \[ f = \frac{Y_{\text{bkg}}}{Y_{\text{phys}} + Y_{\text{bkg}}} \]

- Aluminum window background: determined with (empty) Al target (~10% correction)
- False Asymmetry: Need to minimize beam correlated beam property (beam properties monitored constantly).
Results

Uncertainty on the measured asymmetry:

\[ \sigma \sim \frac{\sigma}{\sqrt{N_q}} \]

Slow helicity reversal every 8hrs

Unregressed and Blinded!

Slug ~ 8hrs of data
Status and projection

- ~500 Coulombs until now
- 180 uA tested: OK
- Polarization > 85%
- Asym. width ~ 236ppm (expected 233ppm)
- Already better than 5% in statistical precision
Conclusion

• Qweak is well under way and no show stopper to achieve a ~4% precision.

• Search for parity-violating BSM physics up to the ~2TeV scale.

• Data taking will resume this Fall until May 2012

• Lots of work to be done to achieve our goal (all members are very busy)

• Ancillary measurement
  • Aluminum asymmetry
  • Transverse polarization asymmetry
  • N->Delta
More detector

Preradiator: Increases the signal and reduces the background.
More target

3.5 mm Raster Beam Current Scan 1/12/2011
Jiawei Mei ELOG 165

\[ \sigma^2 = \left( \frac{a}{I_b} \right)^2 + \left( b I_b^2 \right)^2 + \left( c I_b \right)^2 \left( d \right)^2 \]

- \( a = 2975.4 \) (counting statistics)
- \( b = 1.2213e-5 \) (target boiling)
- \( c = 6329.8 \) (BCM)
- \( d = 129.1 \) (other)

\( \chi^2 / \text{dof} = 1.7 \)

Amplitude [V/\( \mu \text{A} \)]

Frequency [Hz]

Amplitude [V]

Time [sec]

I=20\( \mu \text{A} \)

I=150\( \mu \text{A} \)
More electron beam

Spin flip @ 960Hz

E=1.165GeV
Current:180uA
Polarization ~85%
More electron beam

Laser table

Photocathode

Spin flip @ 960Hz

E=1.165GeV
Current: 180μA
Polarization ~85%
More electron beam

Spin flip @ 960Hz

E=1.165GeV
Current: 180uA
Polarization ~85%
Beam quality

- Helicity correlated beam properties are constantly monitored.
- Linear regression corrects the asymmetry for HC beam properties.
- Slow helicity reversal (HWP and Wien)

0.077%/mm
Constraints on light quarks weak charges