The Qweak : Measuring the Weak Charge of the Proton by Parity Violating Experiment

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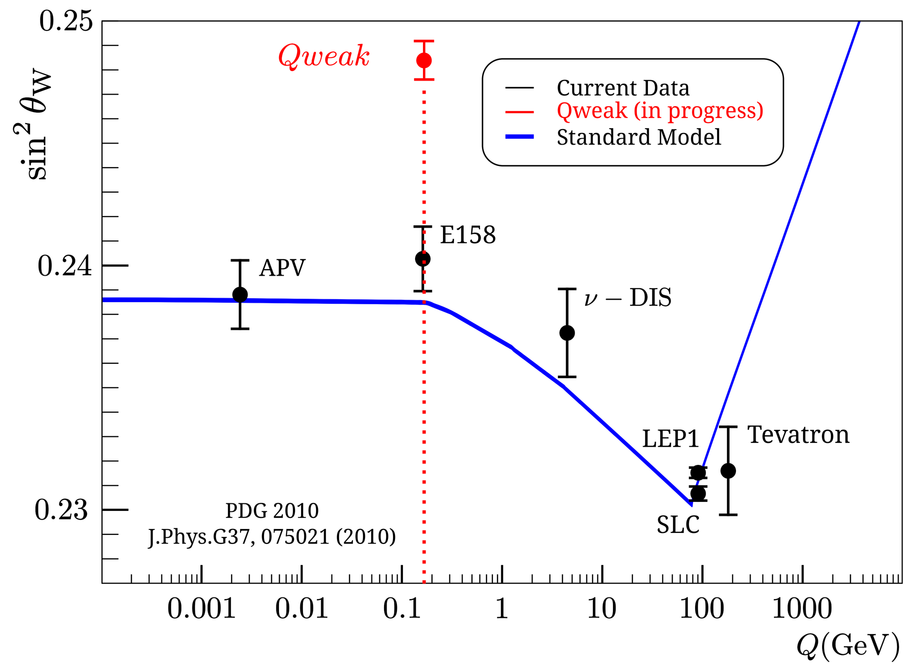
The Qweak Experiment

The Qweak collaboration is measuring the Parity Violating Asymmetry (PVA) in the elastic scattering of longitudinally polarized electrons by unpolarized protons in a liquid hydrogen target at very low momentum-transfer Q^2 and forward angles at Thomas Jefferson National Accelerator Facility (Jefferson Lab), located at Newport News, VA. By measuring PVA, we could extract the weak charge of the proton

$$Q^p_{\mathrm{W}} = 1 - 4\sin^2\theta_{\mathrm{W}},$$

where $\sin^2\theta_{\mathrm{W}}$ is the weak mixing angle (or Weinberg angle). In the Standard Model (SM), this angle varies as a function of Q, thus we call it *the running of the weak mixing angle* that is shown with the existing data in the following plot.



The SM makes a firm prediction for $\sin^2\theta_{\mathrm{W}}$. Any significant deviation from the prediction at low Q^2 would give us a glimpse of physics that might be like in the future. Otherwise, the Qweak measurement will provide an approximately 0.3% measurement of $\sin^2\theta_{\mathrm{W}}$ that will help us to determine the weak couplings to quarks and to improve the present knowledge within the SM framework.

What the weak charge is?

- the electric charge is the key element to understand the electromagnetic(EM) force.
- Physicists introduced the weak charge in order to understand the weak force in the similar way they did for the EM force.

How to extract Q^p_{W} from measurements and the existing data set

The Parity Violation (PV) physics asymmetry A^{PV}_{phy} at forward angle scattering is defined as

$$A^p_{\mathrm{LR}} = A_0\left[\boldsymbol{Q^p_{\mathrm{W}}}Q^2 + B(Q^2)Q^4 + \cdots\right],$$

where A_0 is $-\frac{G_F}{4\sqrt{2}\pi\alpha}$, G_F the Fermi coupling constant, and α the fine structure constant. And we are measuring the PV experimental asymmetry $A^{\mathrm{exp}}_{\mathrm{LR}}$ is defined as

$$A^{\mathrm{exp}}_{\mathrm{LR}} = \frac{N^R - N^L}{N^R + N^L},$$

where $N^R(N^L)$ is the number of elastic scattering events for the right-handed (left-handed) polarization state of electrons. So, two asymmetries are connected as follows:

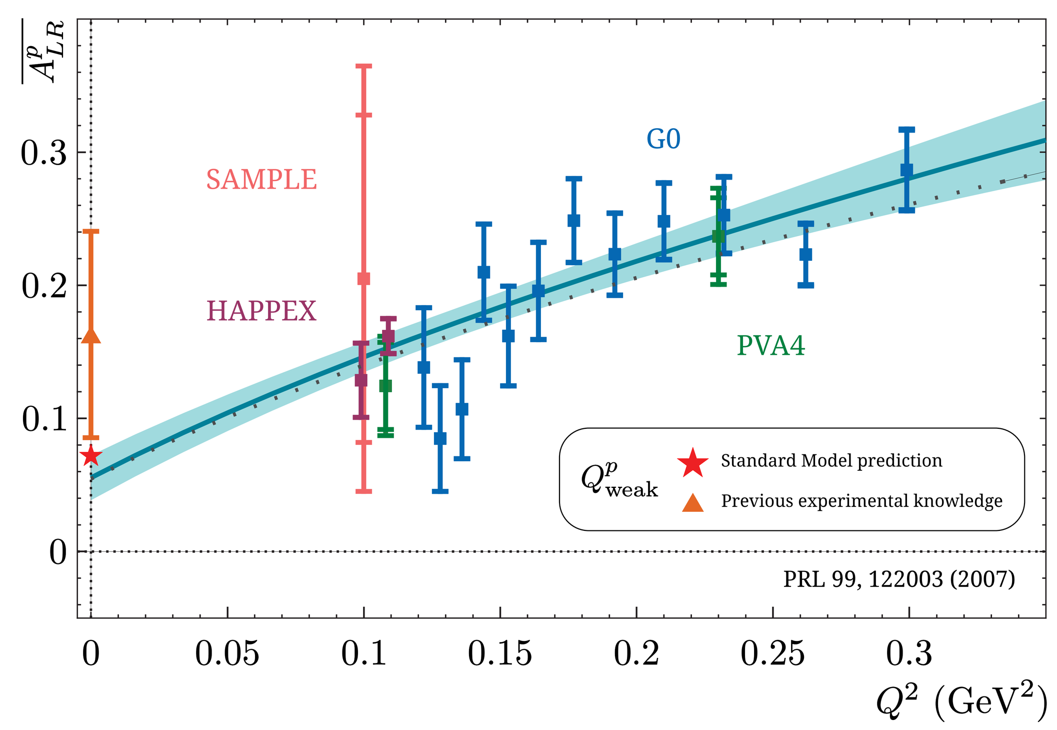
$$A^{\mathrm{exp}}_{\mathrm{LR}} = P_e \cdot A^p_{\mathrm{LR}},$$

where P_e is the longitudinal polarization of the electron beam. And a normalized PV asymmetry is

$$\overline{A^p_{\mathrm{LR}}} = \boldsymbol{Q^p_{\mathrm{W}}} + B(Q^2)Q^2 + \cdots,$$

where $\overline{A^p_{\mathrm{LR}}} := A^{\mathrm{exp}}_{\mathrm{LR}}/(P_e \cdot A_0 Q^2)$.

The normalized PV asymmetry measurements on a proton target are shown in



Therefore, if we know $A^{\mathrm{exp}}_{\mathrm{LR}}$, P_e, and Q^2, we can extract $\boldsymbol{Q^p_{\mathrm{W}}}$.

The Qweak experiment has two run modes to measure the PV asymmetry $A^{\mathrm{exp}}_{\mathrm{LR}}$ and the four-momentum transfer Q^2. In addition, there are two different types of polarimetry. In summary,

- $A^{\mathrm{exp}}_{\mathrm{LR}} \leftarrow$ **Parity Mode** by Cherenkov Detectors (MD), Luminosity Monitors (LUMI), and Beam Current and Positions Monitors (BCM/BPM)
- $Q^2 \leftarrow$ **Tracking Mode** by Trigger Plastic Scintillator (TS), Horizontal and Vertical Drift Chambers (HDC/VDC), BCM/BPM, and MD
- $P_e \leftarrow$ Polarization Measurement by offline Møller and online Compton Polarimeters
- $B(Q^2) \leftarrow$ Extrapolation from the existing Parity Experiments

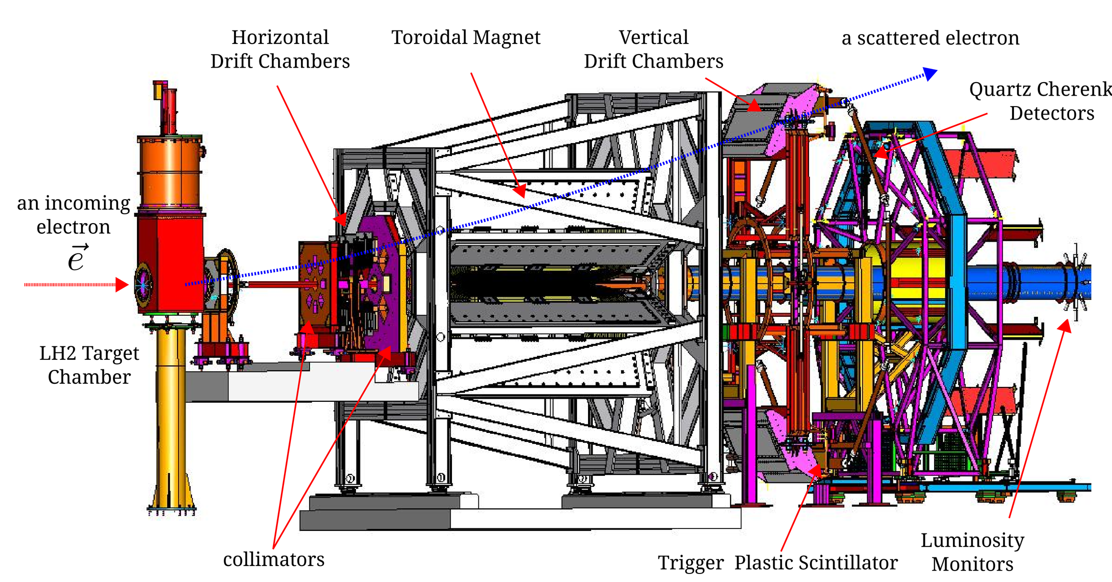
What Q^2 is?

- it is called the *4-momentum transfer* in a reaction, which is the elastic scattering for Qweak.
- $Q^2 = (p_e^{\mathrm{incoming}} - p_e^{\mathrm{scattering}})^2$, where $p_e = (E, \mathbf{p})$ that is the relativistic notation for total energy E and the momentum $\mathbf{p}$ of an incoming and a scattering electron.

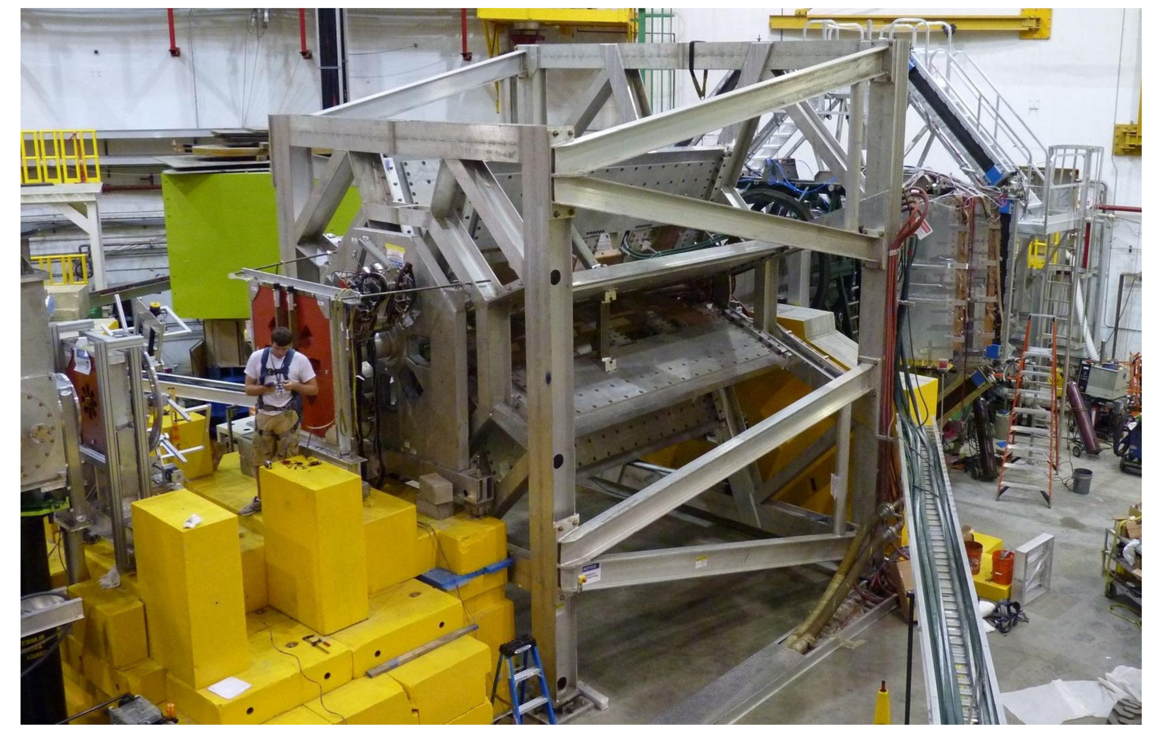
Overview of the Experiment

The principal components of the experimental apparatus are the polarized electron beam, the 2.5kW LH2 target, the 8 segment toroidal magnet, the 8 Cherenkov detectors, beamline instrumentation for beam diagnostics, collimators which define the Q^2 acceptance, the 2 drift chambers, and the plastic scintillators for triggers.

Experimental Layout in Hall C at Jefferson Lab



The elastically scattered electrons are focused through collimators and through the toroidal magnet toward Cherenkov detectors. The Cherenkov detectors are arranged symmetrically around the beamline. The current signals of the Cherenkov detectors are converted to voltage signals by custom low-noise high-gain current-to-voltage converters. These voltage signals are then digitized by custom 18-bit sampling ADCs in sync with the beam-helicity reversal rate. At the same time, various real-time beam properties such as beam current, beam x/y positions, etc are digitized in the same way as the detector signals do.



Experiment Basic Parameters

Incident Beam Energy	1.165 GeV
Beam Polarization	85%
Beam Current	180 μA
Acceptance Averaged A^p_{LR}	-0.234 ppm

Error Estimate for the experiment

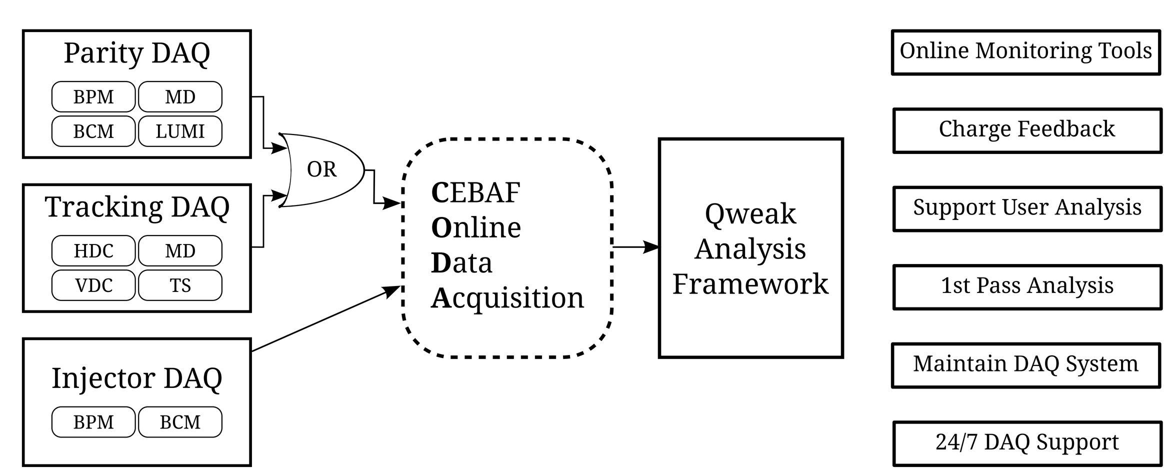
Source of error	$\Delta A^p_{\mathrm{LR}}/A^p_{\mathrm{LR}}$	$\Delta Q^p_{\mathrm{W}}/Q^p_{\mathrm{W}}$
Statistics	2.1%	3.2%
Hadronic structure	-	1.5%
Polarimetry	0.5%	1.0%
Absolute Q^2	0.5%	1.0%
Backgrounds	0.5%	0.7%
Helicity-correlated beam properties	0.5%	0.7%
Total	2.5%	4.1%

Contribution of the Ohio NEWS

The Ohio NEWS (**N**ucleon **E**lectro-**W**eak **S**tructure) group consists of two faculty members, one postdoctoral fellow, and two graduate students and is one of leading members for the Qweak experiment. Its contribution to the Qweak experiments are:

- Setup and Maintain Data Acquisition (DAQ) Systems
- Develop Qweak Analysis Framework (Various on-line and offline software tools for the Parity, the Tracking, and the Injector Studies)
- Monitor Helicity-Correlated Beam Parameters

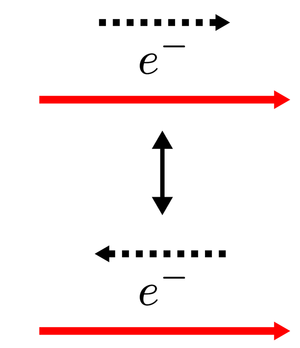
Maintain DAQ Systems and Develop Qweak Analysis Framework



- Cherenkov Detector rate 800MHz each, total 6.4GHz in Parity Mode
- Parity Mode Raw data is about 20GiB/hr or about 480GiB/day
- 22 sampling ADCs for Parity DAQ, 12 sampling ADCs for Injector DAQ, 18 TDCs for Tracking DAQ, and others ADCs and scalers.

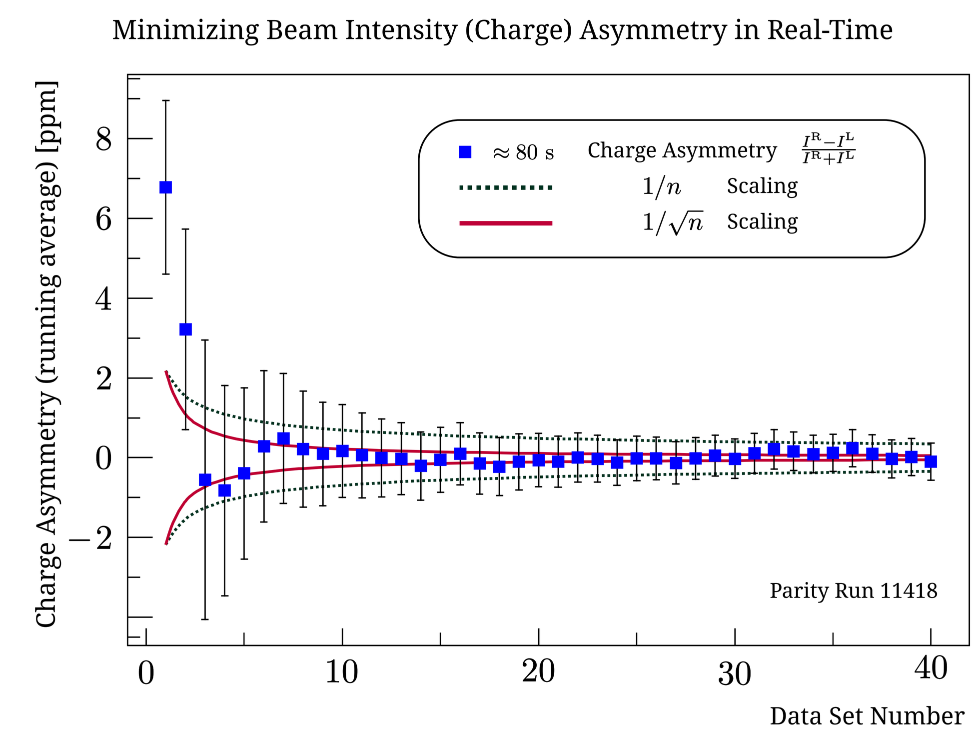
Monitor Helicity-Correlated Parameters

When switching the beam helicity with 960Hz, in practice, beam positions, angles, intensity, and energy are also changed. These changes modify the asymmetry A^p_{LR}. Therefore it is mandatory to monitor and minimize such helicity correlated differences as well as to measure the sensitivities of measure asymmetry to these changes.



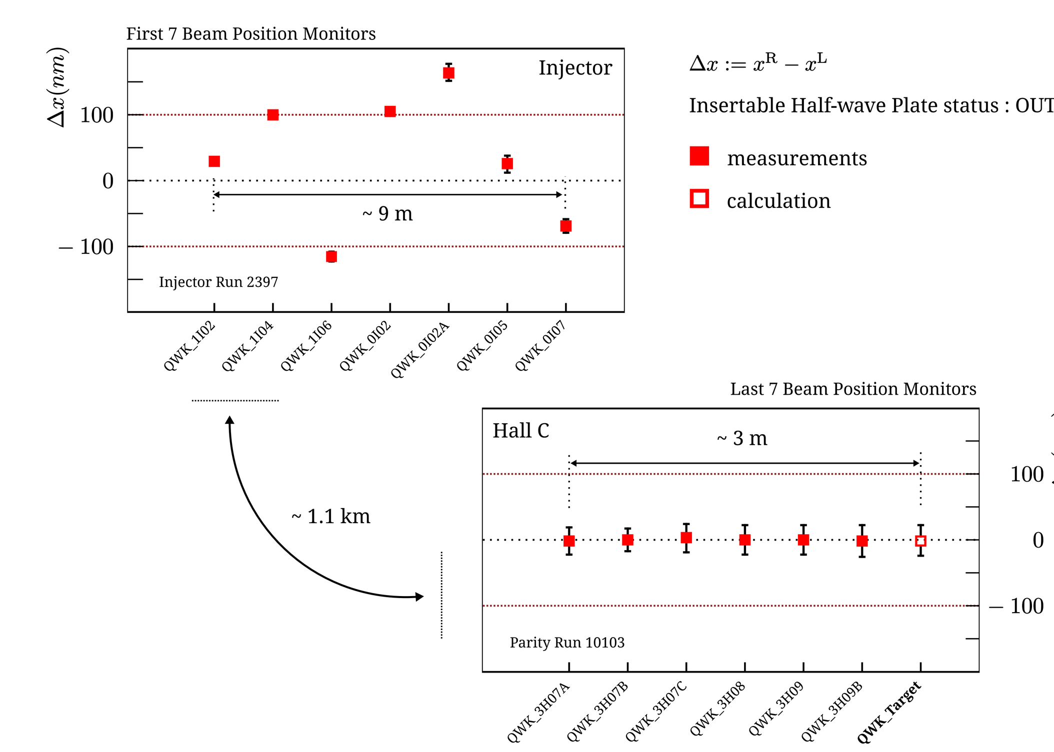
Monitor Beam Intensity Asymmetry

During a data taking, we run a beam intensity feedback program simultaneously. Thus we can minimize the helicity-correlated beam intensity below 0.1 ppm. The following plot shows its result during one run period, which is usually 1 hour.



Monitor Beam Position Difference

We also monitor and record the beam position differences between two helicity states at the beginning of the beam line (Injector) and at the experimental Hall for Qweak (Hall C). And recorded data are used to extract the position sensitivities to the asymmetry A^p_{LR}. So far we have achieve the position sensitivities contribution to A^p_{LR} below 0.2 ppm.



Conclusion and Outlook

We, the Ohio NEWS group, have succeeded in developing online and offline monitoring tools for Qweak experiment and maintains the Qweak Analysis Framework continuously. In addition, we successfully did setup the data acquisition for the Qweak experiment and are maintaining them well. Further, by using the monitoring tools, we have clearly seen that we could minimize these helicity-correlated beam parameters and the helicity-correlated parameters are acceptable during the first run period (Run I, 01/2011-05/2011) . We are looking forward to extract physics results from the Run I during this summer and are preparing and upgrading our tools for the second run period (Run II, 11/2011-05/2012).