Q-weak: First Determination of the weak charge of the proton

Nuruzzaman

for the Q-weak Collaboration

Basics and Motivation

The Weak Force

The weak force operates only extremely short distance scales. The strength of the weak force between interacting quarks and other weakly interacting particles can be characterized by their weak charge.

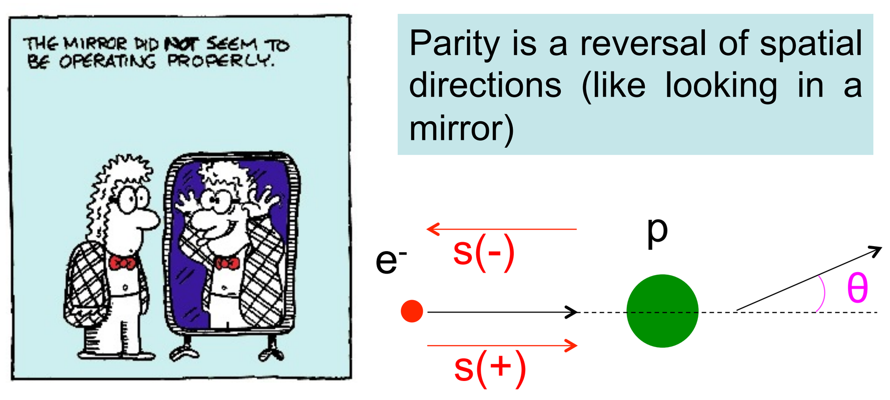

Fig 1: Parity (left), e+p scattering (right)

The weak force violates a fundamental symmetry called parity.

The Standard Model

The Standard Model (SM) is the most successful elementary particle theory developed so far that explains EM, weak, and strong interactions. The weak charge of the proton, Q^p_W, is suppressed in the SM (see Table) and can be expressed as a function of the weak mixing angle θ_W.

Charge / Particle	EM	Weak	
u	2/3	$-2C_{1u} = 1 - (8/3)\sin^2\theta_W$	~ 1/3
d	-1/3	$-2C_{1d} = -1 + (4/3)\sin^2\theta_W$	~ -2/3
p(uud)	1	$Q^p_W = -2(2C_{1u} + C_{1d}) = 1 - 4\sin^2\theta_W$	~ 0.07
n(udd)	0	$Q^n_W = -2(C_{1u} + 2C_{1d})$	~ -1

A search for or constraint on new physics beyond the SM by measuring Q^p_W.

Q-weak

The objective of the Q-weak experiment is to measure Q^p_W with an uncertainty of ~4% (most precise low energy measurement of this SM parameter to date) via the parity violating asymmetry in electron-proton scattering. At small scattering angles and four momentum transferred square (Q^2), the asymmetry can be written as

$$A_{ep} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = -\frac{Q^2 G_F}{4\sqrt{2}\pi\alpha}[Q^p_W + Q^2 B(Q^2)]$$

A_{ep} has a size of ~220 ppb (like finding a hair on top of the Eiffel tower). $B(Q^2)$ is a function of the structure of the nucleon and constrained by other parity violating electron scattering (PVES) experiments.

Uncertainty	$\Delta A_{ep}/A_{ep}$	$\Delta Q^p_W/Q^p_W$
Statistical (~2.5k hours at 150 μA)	2.1%	3.2%
Systematic:		2.7%
Hadronic structure	–	1.5%
Beam polarimetry	1.0%	1.5%
Absolute Q^2 determination	0.5%	1.0%
Backgrounds	0.5%	0.7%
Helicity-correlated beam properties	0.5%	0.8%
Total	2.5%	4.2%

Table: Estimated stat. and sys. uncertainties

The Q-weak Experiment

Jefferson Lab

The Q-weak experiment was performed at Hall-C of Jefferson Lab during November 2010 to May 2012.

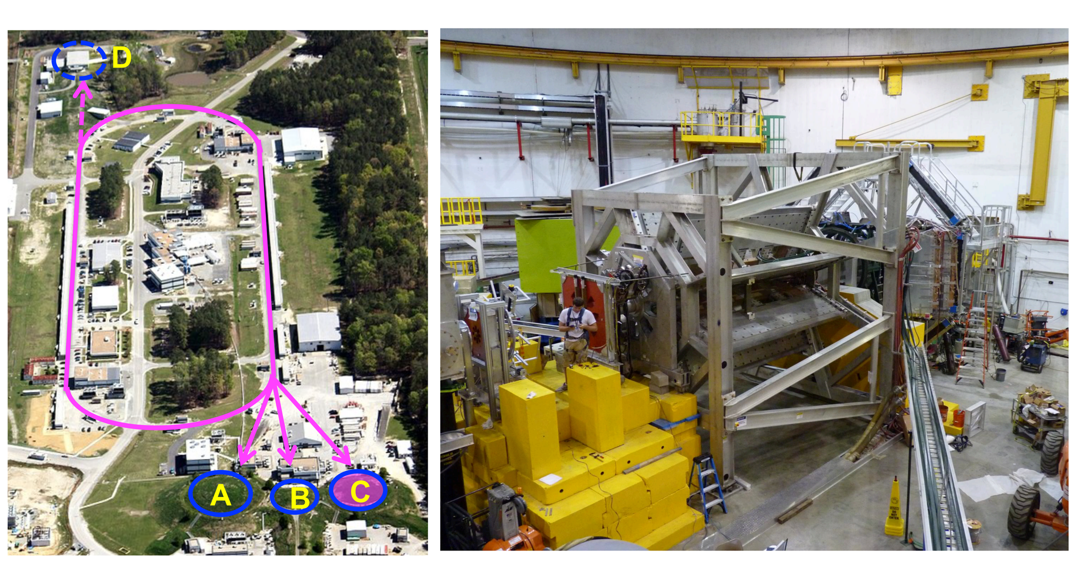

Fig 2: Jefferson Lab (left), Q-weak setup in Hall-C (right)

Hall-C and Q-weak Apparatus

A longitudinally polarized electron beam was incident on a 35 cm long liquid Hydrogen target with beam current 180 μA. A toroidal magnet was used to bend the scattered collimated electrons from the target to the Cherenkov detectors that measured yields (Y).

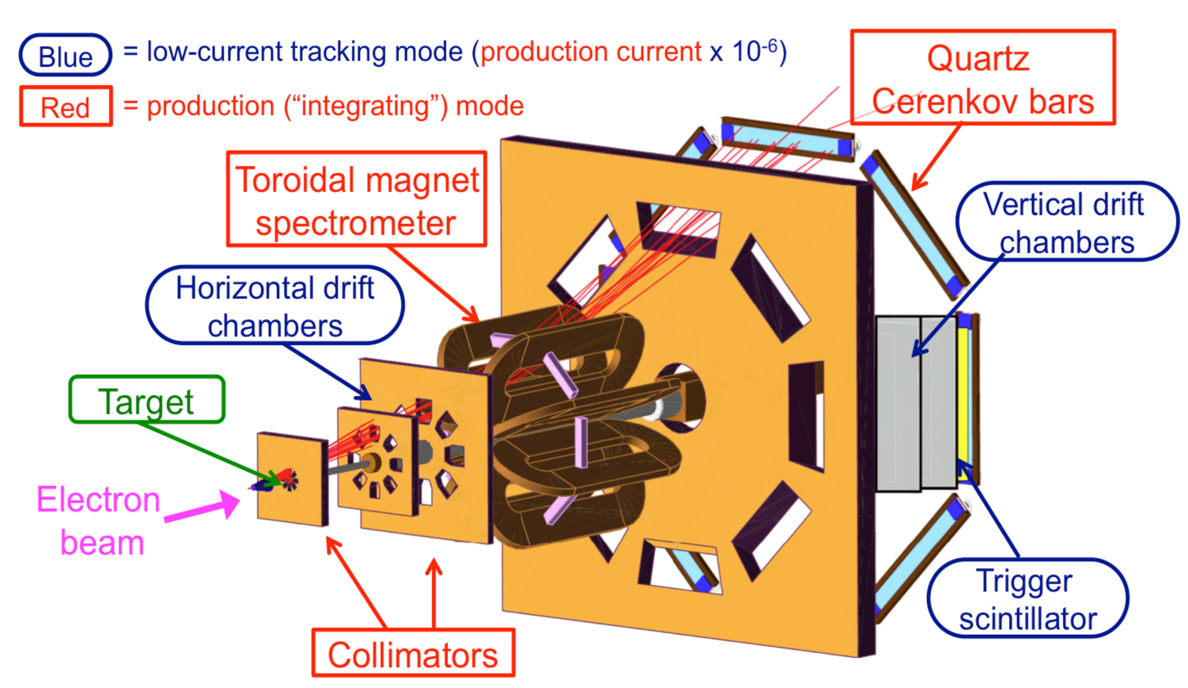

Fig 3: Q-weak schematic diagram

Kinematics

- E_{beam} : 1.16 GeV
- I_{beam} : ~180 μA
- $Q^2 = 0.025$ (GeV/c)^2
- Polarization: ~89%
- Luminosity: 2×10^{39} s^{-1}cm^{-2}
- Target = 35 cm LH_2
- Cryopower = 2.5 kW

Asymmetry Measurement

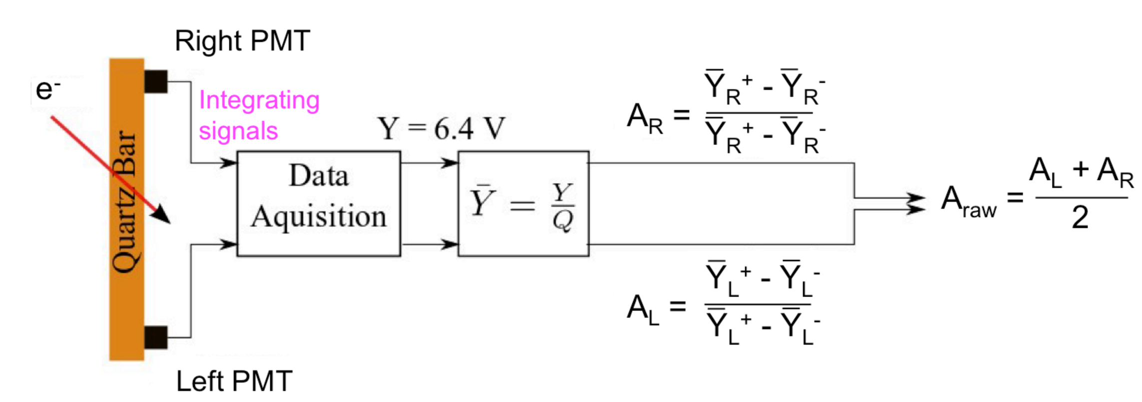

Fig 4: Asymmetries from Cerenkov detector signals

The physics asymmetry is extracted after correcting for false asymmetries, polarization, backgrounds, radiative and other kinematic corrections on raw asymmetry.

$$A_{ep} = R_{total}\left(\frac{A_{msr}/P - \sum_{i=1}^{4} A_{bi} f_{bi}}{1 - \sum_{i=1}^{4} f_{bi}}\right)$$

- A_{msr} - corrected for false asym.
- P - beam polarization
- A_{bi} - Background asym. and f_{bi} - dilutions
- R_{total} - kinematic and radiative corrections

Results

Preliminary Result

Using our commissioning (1/25th of total) dataset, the physics asymmetry found to be

$A_{ep} = -279 \pm 35$ (stat) ± 31 (sys) ppb.

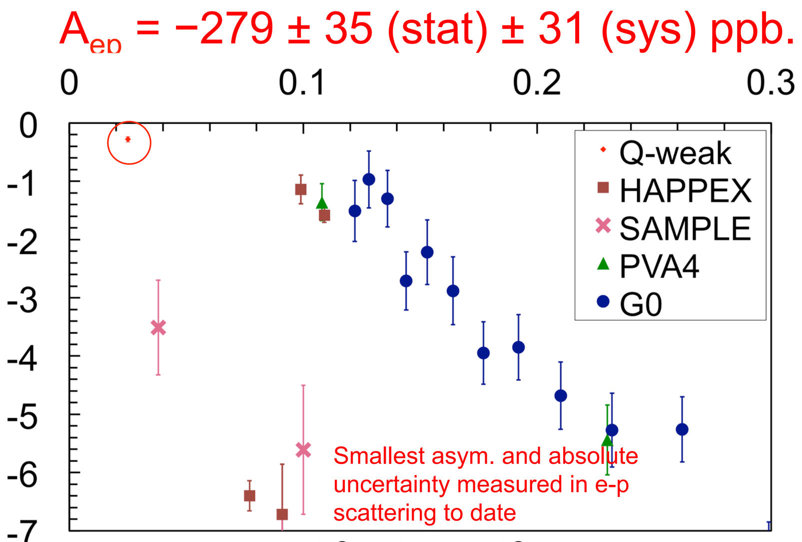

Fig 5: Physics asymmetry vs Q^2

The Q-weak experiment along with available PVES data extracted Q_W^p (Fig 6).

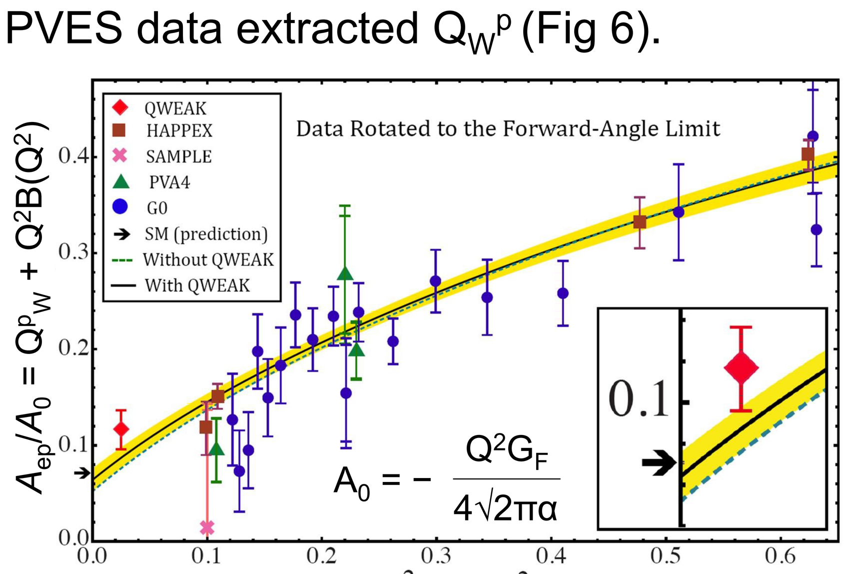

Fig 6: Reduced asymmetry vs Q^2

Quantity	Q-weak Experiment	SM Value
Q_W^p	0.064 ± 0.012	0.0710 ± 0.0007
Q_W^n	-0.975 ± 0.010	-0.9890 ± 0.0007
C_{1u}	-0.1835 ± 0.0054	-0.18850 ± 0.00016
C_{1d}	0.3355 ± 0.0050	0.34150 ± 0.00016

Impact of Q-weak

The SM predicts the running of $\sin^2\theta_W(Q)$ based on the measurement done at the Z-pole. Q-weak will measure $\sin^2\theta_W(Q)$ to 0.3% with full statistics (Fig 7). Any discrepancy from the SM prediction would be indicative of TeV-scale new PV physics. Q-weak + PVES constrained quark charges and extracted the weak charge of neutron (Fig 8). Analysis with full statistics and improvement in systematic uncertainties are in progress.

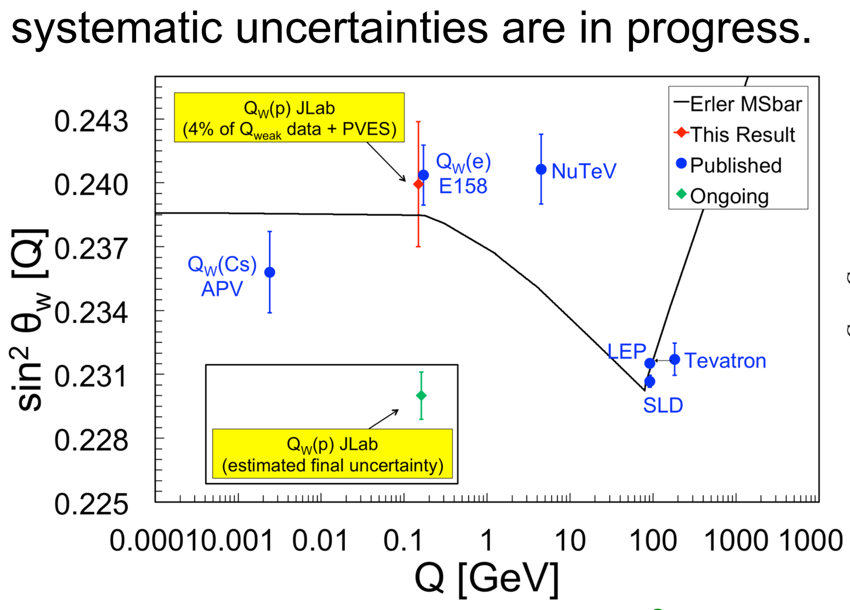

Fig 7: Running of $\sin^2\theta_W$

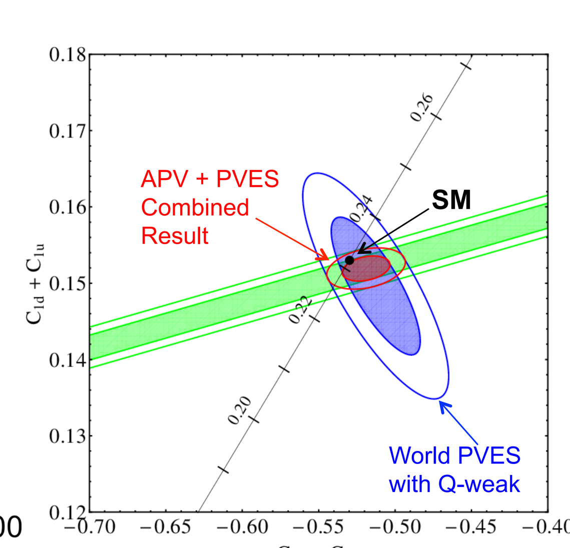

Fig 8: Quark charges

In addition to the ~4% measurement of the proton's weak charge, Q-weak made numerous other interesting ancillary measurements, analysis are ongoing.

Outlook

Simulated result using full dataset. A simulated fit through SM value of Q_W^p. Full dataset has potential to place tight constraints on possible SM extensions and a unique window on possible new physics.

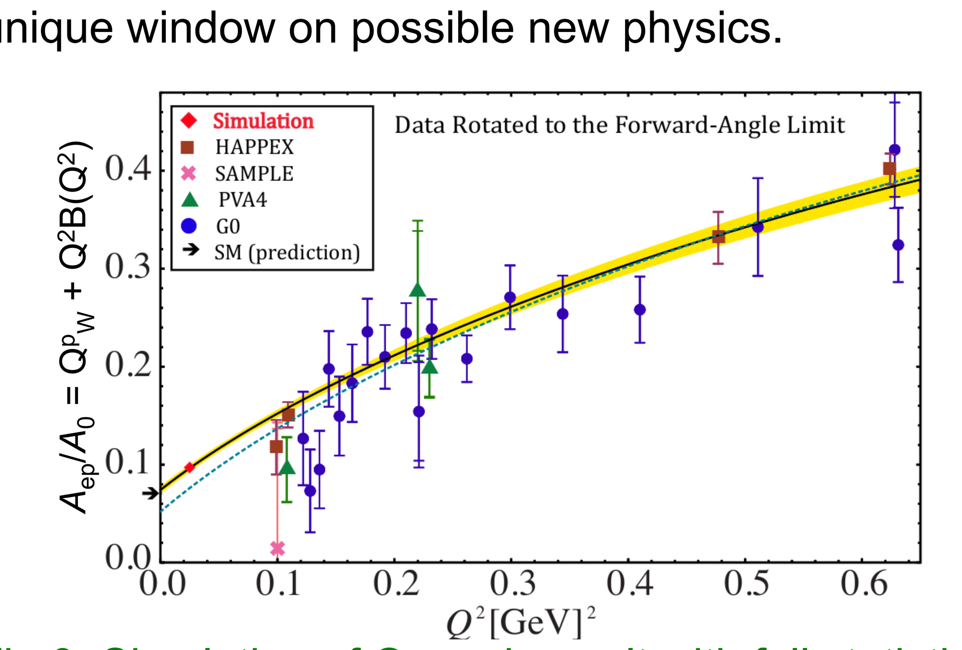

Fig 9: Simulation of Q-weak result with full statistics

Acknowledgements

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