Testing the Standard Model with Parity-Violating Electron Scattering – Where It’s Been and Where It’s Going

Mark Pitt* Virginia Tech

Hadronic and Electroweak Physics at MIT-Bates Retrospective and Future Prospects

Follow historical path of PV $e^{-}e^{+}$ and $e^{-}N$ - parity-violating neutral weak current processes
→ trace both technological developments and physics impact

• 1970’s: SLAC e-$d$ experiment
• 1980’s: MIT-Bates $^{12}C$, Mainz MAMI $^{9}Be$
• 1990’s: SLAC E158
• 2000’s: JLAB $Q_{\text{weak}}$
• 2010’s: JLAB e$2$ePV and PV-DIS

* Work partially supported by the National Science Foundation
Electromagnetic and Weak Interactions: Historical View

**Electromagnetic (EM) Interaction:**
\[ e + p \rightarrow e + p \] elastic scattering

\[ M = J_{\mu}^{EM,p} \left( -\frac{e^2}{Q^2} \right) J_{\mu,EM}^{e,p} = \left( \psi_p \gamma_{\mu} \psi_p \right) \left( -\frac{e^2}{Q^2} \right) \left( \psi_e \gamma^\mu \psi_e \right) \]

**Weak Interaction:**
\[ n \rightarrow e^- + p + \bar{\nu}_e \] neutron beta decay

**Fermi (1932):** contact interaction, form inspired by EM

\[ M = J_{\mu}^{\text{weak,N},p} G_F J_{\mu,\text{weak},e} = \left( \psi_p \gamma_{\mu} \psi_n \right) G_F \left( \psi_e \gamma^\mu \psi_{\bar{\nu}_e} \right) \]

**Parity Violation (1956, Lee, Yang; 1957, Wu):** required modification to form of current - need axial vector as well as vector to get a parity-violating interaction

\[ M = J_{\mu}^{\text{weak,N},p} G_F J_{\mu,\text{weak},e} = \left( \psi_p \gamma_{\mu} \left( 1 - \gamma^5 \right) \psi_n \right) G_F \left( \psi_e \gamma^\mu \left( 1 - \gamma^5 \right) \psi_{\bar{\nu}_e} \right) \]

\[ (V - A) \times (V - A) \]

Note: weak interaction process here is charged current (CC)
But Zel'Dovich Suggests - What About Neutral Weak Currents? (1959)

LETTERS TO THE EDITOR

PARITY NONCONSERVATION IN THE FIRST ORDER IN THE WEAK-INTERACTION CONSTANT IN ELECTRON SCATTERING AND OTHER EFFECTS

Ya. B. ZEL’DOVICH

Submitted to JETP editor December 25, 1958

(March, 1959)

We assume that besides the weak interaction that causes beta decay,

$$g (\bar{P}ON) (\bar{e}^0 O e) + \text{Herm. conj.,} \quad (1)$$

there exists an interaction

$$g (\bar{P}OP) (\bar{e}^- O e^-) \quad (2)$$

with $g \approx 10^{-49}$ and the operator $O = \gamma_\mu (1 + i\gamma_5)$ characteristic of processes in which parity is not conserved.*

---

Zel'dovich '59:
- Is there a neutral analog to beta-decay?
- Would determine sign of $G_F$
The Neutral Current, Zel'Dovich continued

Then in the scattering of electrons by protons the interaction (2) will interfere with the Coulomb scattering, and the nonconservation of parity will appear in terms of the first order in the small quantity $g$. Owing to this it becomes possible to test the hypothesis used here experimentally and to determine the sign of $g$.

**parity nonconservation via weak-electromagnetic interference**

The matrix element of the Coulomb scattering is of the order of magnitude $e^2/k^2$, where $k$ is the momentum transferred ($\hbar = c = 1$). Consequently, the ratio of the interference term to the Coulomb term is of the order of $gk^2/e^2$.

**parity violating asymmetry**

In the scattering of fast ($\sim 10^8$ ev) longitudinally polarized electrons through large angles by unpolarized target nuclei it can be expected that the cross-sections for right-hand and left-hand electrons (i.e., for electrons with $\sigma \cdot p > 0$ and $\sigma \cdot p < 0$) can differ by 0.1 to 0.01 percent. Such an effect is a specific test for an interaction not conserving parity.

\[ A_{LR} = \frac{\sigma^- - \sigma^+}{\sigma^- + \sigma^+} \approx \frac{A_{\text{weak}}}{A_{\gamma}} \approx \frac{G_F Q^2}{4 \pi \alpha} \]

\[ Q^2 \sim 0.1 - 1 \text{ GeV}^2 \]

\[ A_{LR} \lesssim 10^{-6} - 10^{-4} \]

from Krishna Kumar
Standard Model of Electroweak Interactions (1967)

Glashow-Weinberg-Salam Model (1967): electroweak - unified EM and weak → SU(2)_L x U(1) gauge theory with spontaneous symmetry breaking

\[
\begin{pmatrix}
\nu_e \\
e^{-}
\end{pmatrix}_L, \begin{pmatrix}
u_l \\
u_{l'}
\end{pmatrix}_L, \ldots
\]

\[
e_R^- , u_R , d'_R , \ldots
\]

Interaction of fermions with gauge bosons:

\[e^\gamma^\mu\]

\[\gamma\]

\[\frac{g}{2\sqrt{2}} (\gamma^\mu - \gamma^\mu \gamma^5)\]

\[\frac{g}{2\cos \theta_W} (c_V^f \gamma^\mu - c_A^f \gamma^\mu \gamma^5)\]

\[c_V^f = t_3^f - 2\sin^2 \theta_W Q_f\]

\[c_A^f = t_3^f\]

Standard model tests:

- Measure a variety of electroweak processes with couplings to all possible fermions
- Extract values of \((\sin^2 \theta_W)_{\text{eff}}\) in a consistent renormalization scheme from all processes → consistency among these
  → success of Standard Model
Neutral Current Observable - Parity-Violating Asymmetry

\[ \sigma \propto \begin{vmatrix} e \gamma N e \rangle \end{vmatrix}^2 + h_e \begin{vmatrix} e \gamma N e \rangle \end{vmatrix}^2 \]

\[ \propto \begin{vmatrix} e \gamma N e \rangle \end{vmatrix}^2 \]

\( \tilde{e} + N \)

(2) (elastic scattering)

\[ A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \]

\[ = \left[ -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \right] \times F[\text{form factors, } \sin^2 \theta_W] \approx 10^{-5} - 10^{-6} \]
"Textbook physics" - SLAC E122 Experiment, 1978-79
Charles Prescott and collaborators:
$e^- + d \rightarrow e^- + X$, deep inelastic scattering at SLAC $Q^2 \sim 1.6 \text{ GeV}^2$

first result in 1978: $A = -(152 \pm 26) \times 10^{-6}$
$\rightarrow$ first measurement of parity-violation in the neutral weak current

$\sin^2 \theta_W = 0.224 \pm 0.020$
Prescott et al., PLB 77, 347 (1978)
Prescott et al., PLB 84, 524 (1978)
"Textbook physics" - SLAC E122 Experiment, 1978-79, continued

"Finally, parity-violation in the neutral currents was discovered at the expected level in electron-nucleon scattering at SLAC in 1978, and after that most physicists took it for granted that the electroweak theory is essentially correct."

Steven Weinberg
"The Making of the Standard Model"
on the occasion of the CERN 30th anniversary celebration of discovery of neutral currents AND 20th anniversary celebration of discovery of W/Z bosons
hep-ph/0401010
SLAC E122 Experimental Details

E122 had essentially all the features that continue to be used in PV e-e, e-N:
- Polarized source: photoemission from GaAs polarized source
- Rapid, pseudo-random helicity reversal
- Integrate phototube outputs instead of pulse counting (~700 MHz inst. rates)
- Slow helicity reversal – calcite prism
- g-2 precession check
- Accurate measurement and control of beam properties (applied corrections procedure for helicity-correlated beam properties)

E122 parameters:
- $E \sim 16.2 - 22.2 \text{ GeV}$
- $\theta = 4^\circ$
- Pulsed, 1.5 $\mu$s at 120 Hz
- Average currents ~ 2 - 8 $\mu$A
- Electron polarization ~ 37%
- Two independent detectors: Čerenkov and Xo Pb-glass shower counter
Parity-Violating Electron Scattering Tests of the Standard Model over the Decades

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<td>-152 ( \pm 18 ) ( \pm 18 )</td>
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MIT-Bates $^{12}C$ Experiment, 1979-89

Spokespersons: Stanley Kowalski
Paul Souder

$e^- + ^{12}C \rightarrow e^- + ^{12}C$ elastic $Q^2 \sim 0.02 \text{ GeV}^2$

\[
T = 0 \quad J^\pi = 0^+ \quad A = + \frac{G_F Q^2}{\pi \alpha \sqrt{2}} \sin^2 \theta_W
\]

$A = 0.60 \pm 0.14 \pm 0.02 \text{ ppm}$

$\sin^2 \theta_W = 0.204 \pm 0.048 \pm 0.014$

Souder et al., PRL 65, 694 (1990)

→ smallest PV electron scattering achieved to that point
→ very important experiment for identifying and minimizing many critical systematic effects
Bates $^{12}$C Experimental Details

Bates $^{12}$C parameters

• $E = 250$ MeV, $\theta = 35^\circ$
• pulsed, 17 $\mu$sec at 60 Hz
• average currents $\sim 30-60$ $\mu$A
• electron polarization $\sim 37$
• quadrupole + lucite Cerenkov

Phototube signals were integrated by wide-gate integrators and then digitized by 16 bit ADCs.
Bates $^{12}$C Experimental Details – polarized source

Cates et al., NIM A278, 293 (1989)

• Polarized electron sources: maintaining high quantum efficiency and lifetime → challenging
  requires proper preparation in UHV conditions
• One of key technical improvements in PV experiments → currently achieving ~ 85% polarizations with "superlattice" GaAs
Helicity Correlated Beam Properties: False Asymmetry Corrections

\[ A_{\text{meas}} = A_{\text{phys}} + \sum_{i=1}^{N} \frac{1}{2Y} \left( \frac{\partial Y}{\partial P_i} \right) \Delta P_i \]

\( \Delta P = P_+ - P_- \)

\( Y = \text{Detector yield} \)

\( (P = \text{beam parameter}) \sim \text{energy, position, angle, intensity} \)

Example:
\[ \frac{1}{2Y} \left( \frac{\partial Y}{\partial x} \right) \sim 1.0 \% / \text{mm}, \Delta x = 100 \text{ nm} \]

\[ A_{\text{false}} = \frac{1}{2Y} \left( \frac{\partial Y}{\partial x} \right) \Delta x \sim 10^{-6} = 1 \text{ ppm} \]

Typical goals for run-averaged beam properties

Intensity:
\[ A_1 = \frac{I_+ - I_-}{I_+ + I_-} < 1 \text{ ppm} \]

Position:
\[ \Delta x, \Delta y < 2 - 20 \text{ nm} \]

\( \Delta P = P_+ - P_- \) \rightarrow keep small with feedback and careful setup

\( \frac{1}{2Y} \left( \frac{\partial Y}{\partial P} \right) \) \rightarrow keep small with symmetrical detector setup
Bates $^{12}$C – Control of Helicity-Correlated Beam Properties

1. Helicity-correlated Intensity - “PITA effect”
   - Polarization Induced Transport Asymmetry
     caused by imperfect circular polarization
   - minimized via active feedback

2. Helicity-Correlated Beam Position
   - Caused by the helicity-defining Pockels cell
     • “Lensing”: minimized by adjusting transverse position of cell
     • Point-to-Point imaging from cell to photocathode with converging lens

A even deeper understanding of Pockels cell systematics came in later experiments (HAPPEX, E158 – see Humensky et al., NIMA 521, 261 (2004).
“Broader Impacts” of $^{12}\text{C}$

Prof. Gordon Cates  
U. Virginia

Dr. Bob Michaels  
Staff Member, JLAB

Prof. Krishna Kumar  
U. Mass. Amherst
Mainz MAMI $^9$Be Experiment

$e^- + ^9$Be quasi-elastic $Q^2 \sim 0.2$ GeV$^2$

$A = -9.4 \pm 1.8 \pm 0.5$ ppm

$\sin^2 \theta_W = 0.221 \pm 0.014 \pm 0.004$

$^9$Be experiment parameters

- $E \sim 300$ MeV, $\theta = 115 - 145^\circ$
- pulsed, 1.5 $\mu$sec at 120 Hz
- average currents $\sim 7$ $\mu$A
- electron polarization $\sim 44$
- air Cerenkov detector
Model Independent Semi-Leptonic Analysis

Particle Data Group way of analyzing low energy neutral current processes uses effective neutral current:

\[ L_{e-q}^{PV} = \frac{G_F}{\sqrt{2}} \sum_q \left[ C_{1q} \bar{e} \gamma^\mu \gamma^5 e \bar{q} \gamma^\mu q + C_{2q} \bar{e} \gamma^\mu e \bar{q} \gamma^\mu \gamma^5 q \right] \]

\[ C_{1u} = g_A^e g_v^u = -\frac{1}{2} + \frac{4}{3} \sin^2 \theta_W \]
\[ C_{1d} = g_A^e g_v^d = \frac{1}{2} - \frac{2}{3} \sin^2 \theta_W \]
\[ C_{2u} = g_v^e g_A^u = -\frac{1}{2} + 2 \sin^2 \theta_W \]
\[ C_{2d} = g_v^e g_A^d = \frac{1}{2} - 2 \sin^2 \theta_W \]
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Final results of LEP/SLC era of measurements on the Z-pole
hep-ex/0509008

Best single measurements ($A_{LR}$ (SLD) and $A_{FB}^{b}$) have
~ 0.12% precision on $\sin^2 \theta_W$, but they disagree by $3\sigma$. 
Running coupling constants in QED and QCD

QED (running of $\alpha$)

QCD (running of $\alpha_s$)

What about the running of $\sin^2 \theta_W$?
“Running of $\sin^2\theta_W$” in the Electroweak Standard Model

- Electroweak radiative corrections
  $\rightarrow \sin^2\theta_W$ varies with $Q$

- All “extracted” values of $\sin^2\theta_W$ must agree with the Standard Model prediction or new physics is indicated.
Why are Precision Measurements far Below the Z-pole Sensitive to New Physics?

Precision measurements well below the Z-pole have more sensitivity (for a given experimental precision) to new types of tree level physics, such as additional heavier Z' bosons.

\[ A_Z \propto \frac{g^2}{-q^2 + M_Z^2 + iM_Z\Gamma_Z} \]

\[ A_{Z'} \propto \frac{g^2}{-q^2 + M_{Z'}^2 + iM_{Z'}\Gamma_{Z'}} \]

At Z-pole, \( q^2 \sim M_Z^2 \), \( A \sim \frac{1}{M_Z\Gamma_Z} + \frac{1}{M_Z^2} \), \( \sim 0.1\% \) precision \( \rightarrow M_{Z'} < 500 \text{ GeV} \)

At low energy, \( q^2 \ll M_Z^2 \), \( A \sim \frac{1}{M_Z^2} + \frac{1}{M_{Z'}^2} \), \( \sim 0.1\% \) precision \( \rightarrow M_{Z'} < 2.5 \text{ TeV} \)
Low energy weak charge “triad” (M. Ramsey-Musolf) probed in weak neutral current experiments

SLAC E158: parity-violating Møller scattering
\[ \bar{e} + e \rightarrow e + e \quad Q^e_w \approx -(1 - 4 \sin^2 \theta_w) \]

Leptonic

Cesium Atomic Parity Violation: primarily sensitive to neutron weak charge
\[ Q^A_w \approx -N + Z(1 - 4 \sin^2 \theta_w) \approx -N \]

Semi-Leptonic

JLAB \( Q^p_{\text{weak}} \): parity-violating \( \bar{e} \)-p elastic scattering
\[ \bar{e} + p \rightarrow e + p \quad Q^p_w \approx 1 - 4 \sin^2 \theta_w \]

These three types of experiments are a complementary set for exploring new physics possibilities well below the Z pole.
Atomic Parity Violation in the Cesium Atom

\[(B \times E) \cdot \sigma\]

Boulder $^{133}$Cs experiment (Wood et al., Science 275, 1759 (1997)):
• Measures modification of neutral weak current to the S-P Stark mixing in an applied electric field
• Isolate the parity non-conserving piece (PNC) with five different reversals

PNC expt. + atomic theory: $Q_{W}^{(133)Cs} = -72.84 \pm (0.29)_{\text{expt}} \pm (0.36)_{\text{theor}}$

Standard Model prediction: $Q_{W}^{(133)Cs} = -73.09 \pm (0.03)$

after a turbulent 2-year period as the atomic theory was successively improved.

Future direction: try to measure APV in chain of isotopes to eliminate atomic structure uncertainties
$Q^e_{\text{weak}}$: Electron Weak Charge - SLAC E158 Experiment

Parity-violating Moller scattering

$Q^2 \sim .026 \text{ GeV}^2$

$\theta \sim 4 - 7 \text{ mrad}$

$E \sim 48 \text{ GeV}$

at SLAC End Station A

Final results: hep-ex/0504049, PRL 95 081601 (2005)

$A_{PV} = -131 \pm 14 \text{ (stat)} \pm 10 \text{ (syst)} \text{ ppb}$

$\sin^2 \theta_{\text{eff}}(Q^2=0.026 \text{ GeV}^2) = 0.2397 \pm 0.0010 \pm 0.0008$

Running of $\sin^2 \theta_{\text{eff}}$ established at $6\sigma$ level in pure leptonic sector
“Running of $\sin^2 \theta_W$” : Current Status and Future Prospects

**present:**
- “d-quark dominated” : Cesium APV ($Q^A_W$): SM running verified at ~ 4σ level
- “pure lepton”: SLAC E158 ($Q^e_W$): SM running verified at ~ 6σ level

**future:**
- “u-quark dominated” : $Q_{\text{weak}}$ ($Q^p_W$): projected to test SM running at ~ 10σ level
- “pure lepton”: 12 GeV e2ePV ($Q^e_W$): projected to test SM running at ~ 25σ level
Overview of the Q^p_{Weak} Experiment at Jefferson Lab

\[ \bar{e} - p \text{ elastic scattering} \]

**Elastically Scattered Electron**

**Region III**
- Drift Chambers

**Region II**
- Drift Chambers
- GEM Detectors

**Region I**
- GEM Detectors
- Collimator with 8 openings

**35cm Liquid Hydrogen Target**

**Polarized Electron Beam**

**Eight Fused Silica (quartz) Čerenkov Detectors**

**Toroidal Magnet**

**Luminosity Monitors**

Experiment Parameters (integration mode)

- Incident beam energy: 1.165 GeV
- Beam Current: 180 μA
- Beam Polarization: 85%
- LH₂ target power: 2.5 KW

- Central scattering angle: 8.4° ± 3°
- Phi Acceptance: 53% of 2\pi
- Average Q²: 0.030 GeV²
- Acceptance averaged asymmetry: −0.29 ppm
- Integrated Rate (all sectors): 6.4 GHz
- Integrated Rate (per detector): 800 MHz
Q^p_{Weak} Toroidal Magnet - QTOR

- 8 toroidal coils, 4.5m long along beam
- Resistive, similar to BLAST magnet
- Pb shielding between coils
- Coil holders & frame all Al
- \int B \cdot dl \sim 0.7 \, T\cdot m
- bends elastic electrons \sim 10^\circ
- current \sim 9500 \, A

Status: • Being assembled at MIT-Bates
The $Q_p^{\text{Weak}}$ Liquid Hydrogen Target

**Target Concept:**
- Similar in design to SAMPLE and $G^0$ targets
  - longitudinal liquid flow
  - high stream velocity achieved with perforated, tapered "windsock"

**$Q_p^{\text{Weak}}$ Target parameters/requirements:**
- Length = 35 cm
- Beam current = 180 $\mu$A
- Power = 2200 W beam + 300 W heater
- Raster size ~4 mm x ~4 mm square
- Flow velocity > 700 cm/s
- Density fluctuations (at 15 Hz) < $5 \times 10^{-5}$
Beam Polarimetry - A Cautionary Tale from SLC

SLC had Compton as primary polarimeter, but could cross compare with Moller polarimeter. (1994)

\[ P_e = 80.0 \pm 0.9 \pm 3.4\% \]
\[ P_e = 69.0 \pm 0.8 \pm 2.9\% \]

Levchuk effect: importance of target electron motion effects depends on acceptance (Levchuk NIMA345, 496 (1994))

Upcoming experiments (Q_{weak}, e2ePV) need ~1% precision polarimetry: new things being studied - atomic hydrogen targets, Moller polarimetry at high currents
Future Prospects at JLAB

**e2ePV: Parity-Violating Moller scattering at 12 GeV JLAB**
(Mack, Reimer, et al.)

- Achieve Moller focus with long, narrow resistive toroidal magnet,
- Radiation hard detector package
- \( E = 12 \text{ GeV} ~ Q^2 = 0.008 \text{ GeV}^2 \), \( \theta \sim 0.53 - 0.92^\circ \), \( A_{PV} = -40 \text{ ppb} \)
- 150 cm, 5 kW target!
- In 4000 hours, could determine \( Q_e^W \) to 2.5% (compare to 12.4% for E158)
- \( \delta(\sin^2 \theta_W) \sim 0.0003 \); comparable to best single measurements

**DIS-Parity at 6 GeV (approved), 12 GeV**
(Paschke, Reimer, Souder, Zheng)

- \( e^- - d, e^- - p \) DIS at 6 GeV and 12 GeV
- Improve errors on \( C_{2u}, C_{2d} \)
- Measure near NuTeV \( Q^2 \)
- Additionally, a broad program of hadronic issues will be studied
  - charge symmetry violation
  - \( d/u \) at high \( x \)
  - higher twist effects
Energy Scale of an “Indirect” Search for New Physics

- Parameterize **New Physics** contributions in electron-quark Lagrangian

\[ L_{e-q}^{PV} = L_{SM}^{PV} + L_{NEW}^{PV} = -\frac{G_F}{\sqrt{2}} \bar{e} \gamma_\mu \gamma_5 e \sum_q C_1 q \bar{q} \gamma^\mu q + \frac{g^2}{4\Lambda^2} \bar{e} \gamma_\mu \gamma_5 e \sum_q h^q \bar{q} \gamma^\mu q \]

- A 4% $Q^p_{\text{Weak}}$ measurement probes with 95% confidence level for new physics at energy scales to:

\[ \frac{\Lambda}{g} \approx 2.3 \text{ TeV} \]

- If LHC uncovers new physics, then precision low $Q^2$ measurements will be needed to determine charges, coupling constants, etc.
\( Q^{p}_{\text{weak}} \) & \( Q^{e}_{\text{weak}} \) - Complementary Diagnostics for New Physics

- \( Q^{p}_{\text{weak}} \) measurement will provide a stringent stand alone constraint on Lepto-quark based extensions to the SM.
- \( Q^{p}_{\text{weak}} \) (semi-leptonic) and E158 (pure leptonic) together make a powerful program to search for and identify new physics.

Relative Shifts in Proton and Electron Weak Charges due to SUSY Effects

R parity (B-L conservation)
RPC SUSY occurs only at loop level

RPV SUSY occurs at tree level

Erl er, Ramsey-Musolf, Su hep-ph/0303026
Z-pole: $A_{LR}$ vs. $A_{FB}^b$

W. Marciano (CIPNAP06):

$$M_H^{exp} > 114.4 \text{ GeV} \quad \text{(direct limit)}$$

Implications of:

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<th>$A_{FB}^b$</th>
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<td>$M_H = 3!\pi$</td>
<td>0.23098 ± 0.00026</td>
<td>0.23099 ± 0.00053</td>
</tr>
<tr>
<td>Standard Model ruled out!</td>
<td>3$\sigma$</td>
<td></td>
</tr>
<tr>
<td>$A_{FB}^b = 0$</td>
<td>0.23221 ± 0.00029</td>
<td></td>
</tr>
<tr>
<td>$M_H = 48$</td>
<td>0.23159 ± 0.00041</td>
<td></td>
</tr>
<tr>
<td>$S=+.55$</td>
<td>0.2300 ± 0.0003</td>
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→ Room for 10 heavy chiral doublets
Favors technicolor!
Rules out SUSY!

JLAB e2e PV:

$\delta(\sin^2\theta_W) \sim 0.0003$

→ very competitive
→ could aid in resolving discrepancy
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<td>2011?</td>
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<td>± 0.00075</td>
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<td>2017?</td>
<td>JLAB e2e</td>
<td>0.040 ± 0.0007 ± 0.00067</td>
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Conclusions: • Technical progress in both statistics (beam currents, polarizations, target power) and systematics (beam polarimetry, helicity-correlated beam parameters) has been steady over the past three decades
• The dream is that one of the future experiments will turn out to be as important and influential as the first one!