The Standard Model
(a great achievement, but not a theory of everything)

Too many free parameters (masses, mixing angles, etc.).
No explanation for the 3 generations of leptons, etc.
Not enough CP violation to get from the Big Bang to today’s world
No gravity. (dominates dynamics at planetary scales)
No dark matter. (essential for understanding galactic-scale dynamics)
No dark energy. (essential for understanding expansion of the universe)

What we call the SM appears to be only part of a larger model.
Looking for clues to the new SM is certainly a noble effort.
Upcoming Direct Searches at LHC

Optimistic example:
Additional neutral bosons (Z-primes) are common features of new physics models.

Simulations suggest CMS will discover any Z-primes with SM-like couplings up to 2 TeV with 1 fb$^{-1}$.

They will get 1 fb$^{-1}$ in the first 1-2 years, they will calibrate using $Z^0 \rightarrow \ell^+\ell^-$, they will check the higher mass regions, in 3 years we may know the answer.

I wrote this slide in 2006, and it’s still probably 3 years away due to budget and commissioning problems. But the LHC revolution is coming.

Low Energy SM Tests at JLab
Indirect Searches for New Physics

Rare/forbidden processes - electron EDM, T-violating kaon decays, etc

Precision measurements - muon g-2, beta decay angular correlations, weak charge, etc.

Even in the absence of a signal, wrong models are rejected or constrained as the experiments improve.

Low Energy SM Tests at JLab
Direct and Indirect Searches are Complementary

If a particle is discovered at a collider and its mass determined, it still needs to be identified: Z-prime, graviton, etc?
The forward-backward asymmetry in \( q + \overline{q} \rightarrow X \rightarrow l^+ + l^- \) is a way to get some information, but requires high statistics and good high-\(x\) pdfs.

Dittmar et al., PLB 583 (2004) 111-120.

LHC will have good ID power for 1-2 TeV Z’ by 100 fb\(^{-1}\).
Not as good for higher masses or lower integrated luminosities.

Meanwhile,
• Indirect searches can constrain both the magnitude and **sign** of the coupling to a specific isospin combination of light quarks.
• Because indirect searches are not subject to energy thresholds, they can still constrain physics at >10 TeV scale in strong coupling models.
Jlab SM Test Program

Qweak Experiment \((e+p\rightarrow e+p)\) -

searching for new PV e-quark couplings \((C_1\text{ coefficients})\)

\(e2ePV\) (Moeller) Experiment \((e+e\rightarrow e+e)\) -

world-class measurement of \(\sin^2\Theta_W\)

or

searching for new PV e-e couplings

I will not be covering the broad DISparity program \((e+d \rightarrow e+X)\)

searching for new PV e-quark couplings \((C_2\text{ coefficients})\)

Low Energy SM Tests at JLab
Not Cute, Table-Top Experiments.

• The relevant electron scattering cross sections are small.
• The allowable uncertainties on the asymmetries are expressed in ppb.
• To achieve TeV-scale sensitivity, we need the enormous statistics provided by Jlab's high current, CW electron beam on the world's highest power Liquid Hydrogen target, for 1000's of hours.

By the standards of the nuclear physics community, it's a big effort:

• a large collaboration (100 people),
• external funding ($5M-$10M),
• formally managed project
• a significant fraction of the lab's resources for 5 years (design and engineering, infrastructure upgrades, plus sole occupancy of an endstation for 2-3 years).

Fortunately, no new inventions!

Low Energy SM Tests at JLab
Qweak Experiment

PV in e+p \rightarrow e+p
Weak Charges of Light Quarks

\begin{align*}
q_{up} & = +2/3 & 1 - \frac{8}{3} \sin^2 \theta_W & \approx 1/3 \\
q_{down} & = -1/3 & -1 + \frac{4}{3} \sin^2 \theta_W & \approx -2/3 \\
Q^p & = 2q_{up} + q_{down} & +1 & 1 - 4\sin^2 \theta_W = -0.048 \\
Q^n & = q_{up} + 2q_{down} & 0 & -1
\end{align*}

Note the roles of the proton and neutron are almost reversed (ie, neutron weak charge is dominant, proton weak charge is almost zero!).

This suppression of the proton weak charge in the SM makes it more sensitive to new physics (all other things being equal).

Low Energy SM Tests at JLab
The $Q_{\text{weak}}$ experiment will measure the parity-violating analyzing power $A_z$:

$$A_z = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \approx -3 \times 10^{-7} \quad (-300 \text{ ppb})$$

In the limit of low momentum transfer and forward kinematics, the leading order electric term contains the weak charge, the next higher order term contains proton structure contributions.

$$A_z \xrightarrow{Q^2 \rightarrow 0, \theta \rightarrow 0} -\frac{G_F}{4\pi\alpha\sqrt{2}} \left[ Q^2 Q_{\text{weak}}^p + Q^4 B(Q^2) \right]$$

contains $G_{\gamma E,M}^\gamma$ and $G_{Z E,M}^Z$, constrained by other expts

Our average $Q^2$ of $\sim 0.028 \text{ (GeV/c)}^2$ has been carefully optimized.

Higher order contributions are less than $1/3$ of the total asymmetry.
Interpretability

(If it’s ambiguous, it ain’t a SM test.)

Proton structure backgrounds have been determined by a large program of electron scattering PC and PV form-factor studies. Contributes 2% to $\Delta Q_w$.

EW:

The low energy theory error on $\Delta \sin^2 \theta_W = +0.00016$ is negligible compared to $Q_{\text{weak}}$'s $+0.0007$.

Hadronic:

$$\bar{A}_{LR}^p = A_z/(-G_F Q^2/4\pi \alpha \sqrt{2}) = Q_{\text{weak}}^p + Q^2 B(Q^2)$$

(Ross Young et al., arXiv:0704.2618v2)

Expected Constraints on Light Quark Weak Charges

Previous constraint (PDG 2006, 95% CL)

World data + Future Qweak

isoscalar weak charge

isovector weak charge

(Analysis by Ross Young, JLab)
The Qweak Apparatus Briefly
The Qweak Collaboration


1Co-pokespersons
2Project Manager

California Institute of Technology, College of William and Mary, George Washington University, Hampton University, Idaho State University, Louisiana Tech University, Massachusetts Institute of Technology, Mississippi State University, Ohio University, Thomas Jefferson National Accelerator Facility, TRIUMF, University of Connecticut, University of Manitoba, University of Mexico, University of New Hampshire, University of Northern British Columbia, University of Virginia, University of Winnipeg, Virginia Polytechnic Institute & State University, Yerevan Physics Institute

+ my special thanks to main detector undergraduate students Elliott Johnson (SULI), Mitchell Andersen and Charles Koop (U. Manitoba), Patrick McCarter (NCA&T), and Katie Kinsley (Ohio U.).
Our need to minimize the statistical error leads to rates of ~1 GHz/octant. Our spectrometer has to isolate elastic e+p events at small angles, with the largest acceptance possible, without tracking detectors.

A resistive toroidal spectrometer allows us to capture >50% of the azimuthal acceptance, with only 0.2% corrections from electrons due to pion production.
QTOR Assembly at MIT Bates

Attaching a coil to the support structure

The magnet has been successfully operated at full current, magnet mapping at $\frac{1}{2}$ field is complete ($$$) and the data are under analysis.

BIG effort by Bates/TRIUMF/Jlab.

Low Energy SM Tests at JLab
Cyrotarget Modelling

• The world’s highest power LH$_2$ target (2.5 kWatts) deserves state of the art tools. This is the first target at JLab designed using CFD.

Good longitudinal flow targets are possible, but the transverse flow target under design has important advantages:

- Smaller $dT$ in fluid
- Smaller $dP$ across cell
- Smaller $dE$ for scattered electron
- but a larger flask volume.

Need $v > 2.8$ m/s to keep $dT < 1$ K
# Anticipated Uncertainties

<table>
<thead>
<tr>
<th></th>
<th>$\Delta A_z/A_z$</th>
<th>$\Delta Q_w/Q_w$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Statistical (2200 hours)</strong></td>
<td>1.8%</td>
<td>2.9%</td>
</tr>
<tr>
<td><strong>Systematic:</strong></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><strong>Total:</strong></td>
<td><strong>2.2%</strong></td>
<td><strong>4.1%</strong></td>
</tr>
</tbody>
</table>

I.e., it’s a ~2% measurement of the asymmetry, but hadronic contributions have to be subtracted.

The uncertainties on form factors (strange quark mostly), plus error magnification from the dilution, yield a 4% measurement of $Q_{\text{weak}}(p)$.

Low Energy SM Tests at JLab
Qweak Schedule

Approved (8%)  January 2002
1st Jeopardy Review  January 2005
2nd Jeopardy Review (4%)  January 2008

Upcoming:

Installation  Fall 2009
Commissioning  Summer 2010

Low Energy SM Tests at JLab
Qweak Summary for Busy Theorists

Parity violation in elastic e+p scattering for Q ≪ 1 GeV

PV implies $g_A \times g_V$ - like couplings

Low Q freezes out most hadronic structure other than well-measured nucleon form factors.

Exception is non-asymptotic proton structure in gamma-Z box diagrams.

Measures the weak charge of 2U + 1D combination of quarks for the first time, complementing existing precision Cs APV data

$g_A^{e*} g_V^q$ - axial coupling to electron, vector coupling to quarks ($C_1$)

SM suppression opens a window where 4% accuracy → multiTeV-scale sensitivity

Nominally sensitive to new $g_A^{e*} g_V^q$ couplings (axial electron, vector quark).

A control measurement for models with purely axial or purely vector couplings, or PV models where 2U+1D coupling is suppressed (as in the SM).

In principle, some sensitivity to new $C_2$ couplings $g_A^q \times g_V^e$ (axial quark, vector electron), but suppressed in our kinematics by x3.

Interpretability is well-documented (Erler, Kurylov, Ramsey-Musolf), though the size and uncertainty of the γ-Z box correction may now be in dispute based on a recent, unpublished preprint (Gorchtein and Horowitz).

Installs Fall '09
e2ePV or Moeller Experiment

PV in $e^+e^- \rightarrow e^+e^-$
Determinations of $\sin^2 \theta_W$ at Low Energy

From $Q_w = A + B \sin^2 \theta_W$, one can derive

$$\frac{\Delta \sin^2 \theta_W}{\sin^2 \theta_W} = \frac{\Delta Q_w}{Q_w} \cdot F$$

with error magnification factor

$$F = \frac{A + B \sin^2 \theta_W}{B \sin^2 \theta_W}$$

<table>
<thead>
<tr>
<th>Expt</th>
<th>Mag. Factor F</th>
<th>$\Delta \sin^2 \theta_W / \sin^2 \theta_W$</th>
<th>$\Delta \sin^2 \theta_W$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5% $Q_w$(Cs)</td>
<td>1.4</td>
<td>0.7%</td>
<td>0.0016</td>
</tr>
<tr>
<td>13.1% $Q_w$(e)</td>
<td>0.041</td>
<td>0.5%</td>
<td>0.0013</td>
</tr>
<tr>
<td>4% $Q_w$(p) (under construction)</td>
<td>0.078</td>
<td>0.3%</td>
<td>0.00072</td>
</tr>
<tr>
<td>2.5% $Q_w$(e) (proposal stage)</td>
<td>0.041</td>
<td>0.1%</td>
<td>0.00025</td>
</tr>
</tbody>
</table>

The lack of hadronic dilutions in $e^+e^- \rightarrow e^+e^-$, plus even larger SM suppression than in the $e^+p \rightarrow e^+p$ case, means that we can make a world-class measurement of $\sin^2 \Theta_W$ for about twice the cost of the Qweak experiment.
Standard Model $\sin^2 \theta_W$ Determination at High Energy

The Standard Model value of $\sin^2 \theta_W$ is dominated by two high precision measurements at the $Z$ pole (one leptonic, one semi-leptonic) which are inconsistent. At high energy, matching or improving on these data may require the NLC.

[Diagram showing data points and error bars for leptonic and semi-leptonic measurements, with average $\sin^2 \theta_{W,\text{eff}}$ and $m_H$ values plotted on a graph.]

LEPWG hep-ex/0509008
World Precision Data on $\sin^2\theta_W$

- Cs APV hinted that the SM predicted running was correct.
- SLAC E158 demonstrated the running with higher confidence.
- JLab $Q_w(p)$ should halve the low energy error bar.
- JLab $Q_w(e)$ error would match the best individual measurements at the Z-pole.

Low Energy SM Tests at JLab.
Figure of Merit for $e^+e^- \rightarrow e^+e^-$ Experiments

During E158, everybody “knew” that Jlab’s energy wasn’t high enough to be competitive due to the smaller asymmetry. On closer examination, I found the correct FOM for comparing $e^+e^- \rightarrow e^+e^-$ experiments at different laboratories is basically INTEGRATED BEAM POWER:

- PV asymmetry is proportional to $E$
- CM cross section is proportional to $1/E$
- For fixed target length and CM acceptance, the statistical error is proportional to $1/\sqrt{\text{FOM}}$ where

$$\text{FOM} = A^2 \times \sigma \times I_{\text{beam}} \times \text{time},$$

which is proportional to $E \times I_{\text{beam}} \times \text{time}$ or integrated beam power.

SLAC investment in E158 was only about 0.07 Mwatt-Years.

Proposed JLab e2ePV investment would be about 0.6 Mwatt-Years.

If statistical errors were the only consideration, JLab’s SRF cavities make it the natural place to run a Moeller experiment. The downside is a 4x smaller asymmetry!
Interpretability

• Not so long ago, the interpretability of an improved low energy Moeller measurement was limited by the hadronic corrections in the $\gamma$-$Z$ mixing diagrams.

• A dramatic improvement was published in 2005 by Erler and M.J. Ramsey-Musolf, PRD72, 073003 (2005).

  with a theory error on low energy $\Delta \sin^2 \theta_W = \pm 0.00016$.

  This is only about $\frac{1}{2}$ the projected experimental error.
## Misc. non-SUSY Model Sensitivities

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$Z'$ ( M(Z_X) ) (TeV)</th>
<th>$M(Z_{LR})$ (TeV)</th>
<th>Leptoquarks ( M_{LQ}(\text{up}) ) (TeV)</th>
<th>( M_{LQ}(\text{down}) ) (TeV)</th>
<th>Compositeness (LL) ( e-q ) (TeV)</th>
<th>( e-e ) (TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colliders (LEP2, CDF, Hera)</td>
<td>.67</td>
<td>.80</td>
<td>“1.5”</td>
<td>“1.5”</td>
<td>2.5-3.7</td>
<td>2.2-2.4</td>
</tr>
<tr>
<td>0.5% ( Q_w(Cs) )</td>
<td>1.2</td>
<td>1.3</td>
<td>4.0</td>
<td>3.8</td>
<td>28</td>
<td>---</td>
</tr>
<tr>
<td>13.1% ( Q_w(e) )</td>
<td>.66</td>
<td>.34</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>13</td>
</tr>
<tr>
<td>4% ( Q_w(p) ) under construction</td>
<td>.95</td>
<td>.45</td>
<td>3.1</td>
<td>4.3</td>
<td>28</td>
<td>---</td>
</tr>
<tr>
<td>2.5% ( Q_w(e) ) proposal stage</td>
<td>1.5</td>
<td>.77</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>29</td>
</tr>
</tbody>
</table>

The listed E6 $Z'$ models don't couple to up-quarks, so d-quark rich targets are favored.

scaled from R-Musolf, PRC 60 (1999), 015501
Collider limits from Erler and Langacker, hep-ph/0407097
v1 8 July 2004

Low Energy SM Tests at JLab
Q_{w(e)} at 12 GeV SUSY Sensitivities

- RPV (tree-level) SUSY: allowed pulls as large as $\sim 6\sigma$

- RPC (loop-level) SUSY: allowed pulls up to $3\sigma$

Provides a small window on RPC SUSY without requiring CP violation or high mass thresholds in SS pair production

No dark matter candidate (decayed)

Theory and Experiment bands 95% CL

Updated contours courtesy of Shufang Su (U. Arizona)
Optimistic e2ePV Schedule

Upcoming:

12 GeV PAC January 2009

Installation 2015-6

Presumably, the LHC will turn the world of particle physics upside before our data are available.

Perhaps any new particles will already be identified by then.

However, our experiment should stand the test of time as a precision $\sin^2\Theta_W$ measurement.
Parity violation in elastic $e^+e^-$ scattering for $Q \ll 1$ GeV

PV implies $g_A^* g_V$ - like couplings

No hadronic structure issues, even in $\gamma-Z$ box diagrams.

However, hadronic contributions to $\gamma-Z$ mixing (a vacuum property) need to be understood to relate low $E$ to high $E$ data

Measures the weak charge of the electron with a 5x smaller error bar than E158

$g_A^e* g_V^e$ - axial coupling to electron, vector coupling to electron

SM suppression opens a window where 2.5% accuracy $\rightarrow$ multiTeV-scale sensitivity

and error on $\sin^2 \Theta_W$ of about $\pm 0.00025$

Sensitive to new $g_A^e* g_V^q$ couplings (axial electron, vector electron).

A control measurement for models with purely axial or purely vector couplings.

Interpretability is well-documented (Marciano, Sirlin, Czarnecki, Erler, Ramsey-Musolf).

Proposal will be submitted in a few weeks (December '08).
Jlab SM Summary

• The $Q_{\text{weak}}$ experiment will make the first measurement of the weak charge of the proton, constraining new PV interactions between electrons and light quarks at the TeV scale. It is the essential isospin complement to the existing precision Cs APV data.

• The e2ePV (Moeller) experiment proposes a world-class measurement of $\sin^2 \Theta_W$ with the possibility of discovery-class pulls in RPV SUSY and some $Z'$ models, plus not-insignificant constraints on RPC SUSY phase space.

• This program is possible due to the $1-4\sin^2 \Theta_W$ suppression of $Q_w(p)$ and $Q_w(e)$ in the SM, combined with Jlab’s high polarization, high power, CW beam.

• Message to modelers: Identifying new neutral LHC particles will take more than the mass. How can our low energy precision measurements help constrain your model space?
Jlab Weak Charge Program
Owes Thanks to Theory

• Marciano and Sirlin
  For leading the way in EW hadronic loop corrections
• Czarnecki and Marciano
  For EW radiative corrections in $e^+e^-$
• Ramsey-Musolf
  Who told us to measure $Q_w(p)$ and why
• Erler, Kurylov, and Ramsey-Musolf
  Who showed us how to measure $Q_w(p)$ and expanded the motivation
• Kurylov, Ramsey-Musolf, and Su
  For examining the link between $Q_w(p)$, $Q_w(e)$, and SUSY
• Erler and Ramsey-Musolf
  For dramatically reducing the error on the running of $\sin^2\Theta_w$, so critical to the interpretability of a new, higher precision $e^+e^-$ experiment
• Young et al
  For setting up the machinery to do a global analysis of PVES data which will allow the simultaneous extraction of $Q_w(p)$ and strange quark form factors with the correlated errors.

Low Energy SM Tests at JLab
Extras
Present Constraints on Quark Weak Charges

Isovector weak charge

Isoscalar weak charge

Low Energy SM Tests at JLab
Example: Energy Scale of an Indirect Search

- The sensitivity to new physics Mass/Coupling ratios can be estimated by adding a new contact term to the electron-quark Lagrangian: \((\text{Erler et al. PRD 68, 016006 (2003)})\)

\[
\mathcal{L}_{e-q}^{PV} = \mathcal{L}_{SM}^{PV} + \mathcal{L}_{New}^{PV}
\]

\[
= -\frac{G_F}{\sqrt{2}} \bar{e} \gamma_\mu \gamma_5 e \sum_q C_{1q} \bar{q} \gamma^\mu q + \frac{g^2}{4\Lambda^2} \bar{e} \gamma_\mu \gamma_5 e \sum_q h_{V_q} \bar{q} \gamma^\mu q
\]

where \(\Lambda\) is the mass and \(g\) is the coupling. A new physics “pull” \(\Delta Q\) can then be related to the mass to coupling ratio:

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

which reaches the TeV scale for a 4% Qweak experiment.

(If Qweak didn’t happen to be suppressed, we would have to do a 0.4% measurement to reach the TeV-scale.)
Direct Searches for New Physics

Creating new particles at the energy frontier can leave a fairly unambiguous signal. But it's still subject to the real world of energy thresholds, production rates, branching ratios to observable final states, backgrounds, etc.

\[ p + \bar{p} \rightarrow e^+ e^- X \]

At 95% confidence level, the world’s collection of lepton pair data constrains Z-primes with SM-like couplings to masses >800 GeV/c^2.

LEP EWWB hep-ex/0511027
Nov 2005
The Running of $\sin^2 \theta_W$

Electroweak radiative corrections shift the effective neutral weak couplings in an energy- and reaction-dependent manner.

After regressing out the EW box diagrams, like

the only remaining correction is $\gamma$-$Z$ mixing:

One could remove the $\gamma$-$Z$ mixing as well, but it is a useful convention to leave it.

The shift from $\gamma$-$Z$ mixing is energy-dependent but universal (a property of the vacuum) and so causes $\sin^2 \theta_W$ to "run".

(The real story is a more complicated due to factors of $\sin^2 \theta_W(Q)$ in the EW radiative corrections. Global fits incorporate these properly. )

Low Energy SM Tests at JLab
Scale Dependence of the Weak Mixing Angle

With the normalization defined by Z-pole measurements,

\[ \sin^2 \theta_W \text{(MS-bar)} \]

\[ \begin{array}{c}
\text{e-e coupling } 1 - 4\sin^2 \theta_W \text{ gets stronger due to overall reduced screening.} \\
\text{e-e coupling } 1 - 4\sin^2 \theta_W \text{ gets weaker due to increased screening by } W^+W^- \text{ pairs.}
\end{array} \]

The red curve is a SM prediction which includes \( \gamma-Z \) mixing in addition to the tree-level exchange.

\[ \text{curve by Jens Erler} \]
Averaging of Digitization Noise

• The 18 bit ADCs have ~0.5 LSB rms noise per sample.
• This is reduced by averaging ~500 samples per integration.
• This will only work if raw signal spreads over enough channels.

• Assuming equivalent noise bandwidth 47 kHz ($f_{3db} = 30$ kHz) and 18 bit ADC at mid range:

<table>
<thead>
<tr>
<th>condition</th>
<th>Q (e)</th>
<th>rms noise before integration (mV)</th>
<th>channels (σ)</th>
<th>channels (FWHM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam ON</td>
<td>50,000</td>
<td>69 mV</td>
<td>1420</td>
<td>3339</td>
</tr>
<tr>
<td>LED test</td>
<td>1,000</td>
<td>9.8 mV</td>
<td>201</td>
<td>472</td>
</tr>
<tr>
<td>battery test</td>
<td>1</td>
<td>0.31 mV</td>
<td>6.3</td>
<td>15</td>
</tr>
</tbody>
</table>

➢ So this is OK even for very quiet signals.
Relative Size of $Q_{weak}$ Parity Signal

- for 50 kHz noise bandwidth, rms shot noise is 70 nA
- on a scope, the noise band would be $\approx 100,000 \times$ the signal!

TRIUMF test box will simulate this signal.

Low Energy SM Tests at JLab
$Q^p_{\text{Weak}}$ measures the electron beam helicity correlated asymmetry in the number of elastically scattered electrons from protons in a liquid hydrogen target at very forward angles, corresponding to a momentum transfer of 0.03 GeV $^2$, to extract the weak charge of the proton.

$$A_{LR} \left( \vec{e}, p \right) = \frac{d\sigma_L - d\sigma_R}{d\sigma_L + d\sigma_R} = k\left(A_{Q^p_{W}} + A_{H,V} + A_{H,A}\right)$$

$$A_{Q^p_{W}} = Q^2 Q_{W}$$

$$A_{H,V} = Q^2 Q_{W} \frac{\epsilon G^p_{E} G^{n,\gamma}_{E} + \tau G^p_{M} G^{n,\gamma}_{M}}{\epsilon \left(G^p_{E,\gamma}\right)^2 + \tau \left(G^p_{M,\gamma}\right)^2} + Q^3 \frac{\epsilon G^p_{E,\gamma} G^s_{E} + \tau G^p_{M,\gamma} G^s_{M}}{\epsilon \left(G^p_{E,\gamma}\right)^2 + \tau \left(G^p_{M,\gamma}\right)^2}$$

$$A_{H,A} = Q^2 Q_{W} \frac{\epsilon G^p_{A} G^{p,\gamma}}{\epsilon \left(G^p_{E,\gamma}\right)^2 + \tau \left(G^p_{M,\gamma}\right)^2}$$

Quark structure:
Must know hadronic wave function or measured form-factors

Well constraint from world data:
HAPPEX, G0, A4, and many others

$A_{H,V} \sim -0.101$ ppm
$A_{H,A} \sim -0.012$ ppm

Low Energy SM Tests at JLab
Low Energy SM Tests at JLab

Main Detector

Toroidal spectrometer produces 8 beam spots

- 8 fused silica radiators
  200 cm x 18 cm x 1.25 cm

- Spectrosil 2000
  Rad-hard, low luminescence (expensive)

- 900 MHz e⁻ per bar

- Light collection by TIR
  5 Angstroms rms polish (even more expensive)

- 5” PMTs with gain = 2000

- S20 photocathodes (Iₖ = 3 nA)

- Current mode readout (Iₐ = 6 μA)
**Qweak At A Glance**

- **R-2 HDCs**: (Fabrication underway)
- **GEMs**: (Prototype + parts)
- **Target** (Design)
- **Beam QTOR + Power Supply**: (Installation of coils complete - Bates)
- **R-3 VDC**: (Fabrication to start soon)
- **Main Cerenkov Detectors** (Components at JLab)
- **Downstream Pb Shielding**: (Complete)
- **Lumis** (Design)
- **R-3 Chamber Rotation System**: (ready for assembly)
- **Quartz Scanner** (Design)

**Beam Parameters**

- $E_{\text{beam}} = 1.165 \text{ GeV}$
- $I_{\text{beam}} = 180 \mu\text{A}$
- Polarization ~85%
- Target = 2.5 KW

**Performance**

- Central scattering angle: $8° \pm 2°$
- Phi Acceptance: $>50\%$ of $2\pi$
- Average $Q^2$: $0.028 \text{ GeV}^2$
- Acceptance averaged asymmetry: $-0.28 \text{ ppm}$
- Integrated Rate (all sectors): $\sim 6 \text{ GHz}$
- Integrated Rate (per detector): $\sim 750 \text{ MHz}$
### Misc. non-SUSY Model Sensitivities

**scaled from R-Musolf, PRC 60 (1999), 015501**  
**Collider limis from Erler and Langacker, hep-ph/0407097**  
**v1 8 July 2004**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$Z'$</th>
<th>Leptoquarks</th>
<th>Compositeness (LL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M(Z_X)$</td>
<td>$M(Z_{LR})$</td>
<td>$M_{LQ}(up)$</td>
</tr>
<tr>
<td><strong>Collliders</strong></td>
<td>.67</td>
<td>.80</td>
<td>“1.5”</td>
</tr>
<tr>
<td>(LEP2, CDF, Hera)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>**0.5% $Q_w$(Cs)</td>
<td>1.2</td>
<td>1.3</td>
<td>4.0</td>
</tr>
<tr>
<td>**13.1% $Q_w$(e)</td>
<td>.66</td>
<td>.34</td>
<td>---</td>
</tr>
<tr>
<td>**2.5% $Q_w$(e)</td>
<td>1.5</td>
<td>.77</td>
<td>---</td>
</tr>
<tr>
<td>**4% $Q_w$(p)</td>
<td>.95</td>
<td>.45</td>
<td>3.1</td>
</tr>
<tr>
<td>under construction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>**1% $Q_w$(0$^+$$\rightarrow$$0^+$)</td>
<td>.91</td>
<td>.92</td>
<td>3.0</td>
</tr>
</tbody>
</table>

One has to be careful taking model-dependent sensitivities too seriously. The listed E6 $Z'$ models don't couple to up-quarks, so d-quark rich targets are favored.

However, even for these particular models, a 2.5% $Q_w$(e) measurement looks appealing, in fact irreplaceable as an e-e compositeness test.
How Small is Too Small?

The PV asymmetry decreases by $x4$ from 48 GeV to 12 GeV. How small an asymmetry is TOO SMALL???

Assuming the required statistics, and that backgrounds are proportionate, then we need to look at:
- false asymmetries due to beam properties
- electronic and target noise sources
- nonlinearities

D.J. Mack (TJNAF)
SUSY Sensitivities

- R-parity Violating (tree-level) SUSY: allowed pulls over 3σ

R-parity Conserving (loop-level) SUSY: allowed pull 1σ

Contour 95% CL


Low Energy SM Tests at JLab

Updated contour courtesy of Shufang Su (U. Arizona)