$A_{PV} = -mE \frac{G_F}{\sqrt{2\pi\alpha}} \frac{16 \sin^2 \Theta}{(3 + \cos^2 \Theta)^2} Q^e_W$

Small, well-understood dilution

$\sigma \propto \frac{1}{E_{lab}}$

Figure of Merit rises linearly with $E_{lab}$

$A_{PV} \propto m_e E_{lab} (1 - 4 \sin^2 \vartheta_W)$

$\frac{\delta(\sin^2 \vartheta_W)}{\sin^2 \vartheta_W} \approx 0.05 \frac{\delta(A_{PV})}{A_{PV}}$

SLAC: Highest beam energy with moderate polarized luminosity

JLab 11 GeV: Moderate beam energy with LARGE polarized luminosity
Comprehensive Search for New Neutral Current Interactions

Important component of indirect signatures of “new physics”

Consider

\[ L_{f_1 f_2} = \sum_{i,j=L,R} \frac{4\pi}{\Lambda_{ij}^2} \eta_{ij} \bar{f}_{1i} \gamma_{\mu} f_{1i} \bar{f}_{2j} \gamma^{\mu} f_{2j} \]

\( \Lambda \)'s for all \( f_1 f_2 \) combinations and \( L,R \) combinations

Many new physics models give rise to non-zero \( \Lambda \)'s at the TeV scale:

Heavy Z's, compositeness, extra dimensions...

One goal of neutral current measurements at low energy AND colliders:

Access \( \Lambda > 10 \) TeV for as many \( f_1 f_2 \) and \( L,R \) combinations as possible

LEPII, Tevatron access scales \( \Lambda \)'s \(~ 10 \) TeV

e.g. Tevatron dilepton spectra, fermion pair production at LEPII

- \( L,R \) combinations accessed are parity-conserving

LEPI, SLC, LEPII & HERA accessed some parity-violating combinations

but precision dominated by Z resonance measurements
Window of opportunity for weak neutral current measurements at $Q^2 \ll M_Z^2$

**Processes with potential sensitivity:**

- neutrino-nucleon deep inelastic scattering
- Atomic parity violation
- parity-violating electron scattering
Probing the TeV-Scale with Parity-Violating Electron Scattering

$$A_{PV} \approx -4 \times 10^{-9} \times E_{beam} \times P_{beam}$$

- ~10 ppb statistical error at highest $E_{beam}$
- ~0.4% error on weak mixing angle

**E158 New Physics Reach**

**LEP II**

$$\begin{align*}
|e_R \times e_R e^2| + |e_L \times e_L e^2|
\end{align*}$$

**Fermilab**

$$q \overleftrightarrow{Z^\prime} e$$

doubly charged scalar exchange

**E158**

15 TeV

compositeness

$$\begin{align*}
|e_R \times e_R e^2| - |e_L \times e_L e^2|
\end{align*}$$

$$\frac{g^2}{2M_\Delta^2} < 0.01 \ G_F$$

$$\begin{align*}
0.5 - 1.0 \ TeV \\
0.5 - 2.5 \ TeV \\
GUTs \\
extra dimensions
\end{align*}$$
\[ A_{PV} = (-131 \pm 14 \pm 10) \times 10^{-9} \]

**g-2 spin precession**

- 45 GeV: 14.0 revs
- 48 GeV: 14.5 revs

**Phys. Rev. Lett. 95 081601 (2005)**

15 May 2008

Probing the TeV-Scale with Parity-Violating Electron Scattering
Physics Implications

\[ \Lambda_{ee}^+ > 7 \text{ TeV} \]

\[ \Lambda_{ee}^- > 16 \text{ TeV} \]

\[ Z \chi > 1 \text{ TeV} \]

Erler and Ramsey-Musolf (2004)

\[ \sin^2 \theta_W(M_Z) \]
Electroweak Constraints

\[ \sin^2 \theta_{\text{eff}} \]

\[ m_t = 172.6 \pm 1.4 \text{ GeV} \]
\[ m_H = 114...1000 \text{ GeV} \]

W-Boson Mass [GeV]

- TEVATRON: 80.430 ± 0.040
- LEP2: 80.376 ± 0.033
- Average: 80.398 ± 0.025
- NuTeV: 80.136 ± 0.084
- LEP1/SLD: 80.363 ± 0.032
- LEP1/SLD/m_t: 80.363 ± 0.020

March 2008
Precision $\sin^2\theta_W$ at Any Scale

The Average: $\sin^2\theta_W = 0.23122(17)$

$\Rightarrow m_H = 89^{+38}_{-28}$ GeV

$\Rightarrow S = -0.13 \pm 0.10$

Rules out Technicolor!
Favors SUSY!

A. LR
(also APV in Cs)

A. FB (Z → bb)
(also Moller @ E158)

$\sin^2\theta_W = 0.2310(3)$

$\Rightarrow m_H = 35^{+26}_{-17}$ GeV

$S = -0.11 \pm 17$

Rules out the SM!

$\sin^2\theta_W = 0.2322(3)$

$\Rightarrow m_H = 480^{+350}_{-230}$ GeV

$S = +0.55 \pm 17$

Rules out SUSY!
Favors Technicolor!

- Precision $\sin^2\theta_W$ measurements at colliders very challenging
- Neutrino scattering cannot compete statistically
- No resolution of this issue in next decade
Møller Scattering at 11 GeV

Parity-Violating Møller Scattering:
Luminosity and Stability at Jlab upgrade makes feasible a factor of 5 improvement over E158
Best new measurement until Linear Collider or Neutrino Factory

Mother of all PV measurements!
Rate ~ 200 GHz!
\[ \delta(A_{\text{exp}}) = 0.6 \text{ ppb!} \]

E158-like Quad concept: same quads provide focus; fits within 25 m

A possible toroid design with better acceptance is being investigated
Does Supersymmetry (SUSY) provide a candidate for dark matter?

- Neutralino is stable if baryon (B) and lepton (L) numbers are conserved
- B and L need not be conserved (RPV): neutralino decay

\[ Q_{\text{weak}}, \text{PVDIS and Møller measurements are complementary} \]

Model-dependent constraints on new particles:
- e.g. \( Z' \) bosons \( \sim 2.5 \) TeV
- Should LHC see anomalies, such measurements extremely valuable
Community Endorsement

- **12 GeV Science Review**
- **Well-attended workshop Dec ‘06**
- **High profile in Long Range Plan**
- **Steering Committee formed:**
  - R. Carlini, G. Cates, K. Kumar, D. Mack, P. Souder, W. van Oers
E158 Design ~ 1997

- **10 nm control of beam centroid on target**
  - R&D on polarized source laser transport elements

- **12 microamp beam current maximum**
  - 1.5 meter Liquid Hydrogen target

- **20 Million electrons per pulse @ 120 Hz**
  - 200 ppm pulse-to-pulse statistical fluctuations
    - Electronic noise and density fluctuations $< 10^{-4}$
    - Pulse-to-pulse monitoring resolution $\sim 1$ micron
    - Pulse-to-pulse beam fluctuations $< 100$ microns
  - 100 Mrad radiation dose from scattered flux
    - State-of-the-art radiation-hard integrating calorimeter

- **Full Azimuthal acceptance with $\theta_{\text{lab}} \sim 5$ mrad**
  - Quadrupole spectrometer
    - Novel design that enclosed primary & scattered beam inside magnets
  - Complex collimation and radiation shielding issues
    - Precision alignment, water cooling and radiation protection
11 GeV JLab Challenges

- **1 nm control of beam centroid on target**
  - R&D on polarized source laser transport elements

- **85 microamp beam current maximum**
  - 1.5 meter Liquid Hydrogen target: 5-6 kW!!

- **200 GHz Rate**
  - Must flip Pockels cell ~ 1 kHz: more R&D needed
  - 50 ppm pulse-to-pulse statistical fluctuations
    - Electronic noise and density fluctuations < 10^{-5}
    - Pulse-to-pulse monitoring resolution ~ 100 nm!

- **Full Azimuthal acceptance with \( \theta_{\text{lab}} \approx 5 \text{ mrad} \)**
  - Aggressive spectrometer design
    - Quadrupole design a la E158
    - New 100% azimuthal acceptance toroids
  - Complex collimation and radiation shielding issues
    - Precision alignment, water cooling and radiation protection
Statistical Error Critical

Extrapolate from E158: 48.3 GeV $\rightarrow$ 10.5 $\mu$Barn

Thick 150 cm LH$_2$ target; real spectrometer geometry

For 11 GeV: 46 $\mu$Barn $\rightarrow$ acceptance not quite up to $|\cos \Theta|$~0.5

$\rightarrow$ 50 $\mu$Barn

90 $\mu$A $\rightarrow$ 186 GHz $\rightarrow$ 4000 hrs $\rightarrow$ $\delta(A_{\text{exp}}) = 0.61$ ppb

Instrumentation noise: 10% (25% for E158)
Background dilution: 5% (8% for E158)
Beam Polarization: 85%

$\delta(A_{PV}) = 0.83$ ppb $\rightarrow$ $\delta(\sin^2 \theta_W) = 0.00026$ $\delta(Q_{W^e}) = 2.25%$

Conclusions:
- Must get aggressive on systematic errors
- Incremental improvements on factors above
Progress to Date

• **Spectrometer Design**
  - Quadrupole
    - *proof of principle*
    - *first attempt at detector placement and collimation*
  - Toroids
    - *novel 100% acceptance*
    - *first attempt at ray traces and field characteristics*

• **Spectrometer choice drives everything else**
Near-Term Plans

- *Run simulations on two spectrometer options:*
  - Collimation
  - Backgrounds
  - Statistical Error

- *Initiate formation of collaboration*

- *Assign tasks for LOI/Proposal preparation*
Meeting Goals

- Lay out technical challenges
- Assign tasks to address them
- Estimate statistical error
- LOI or Proposal?
- Timeline for document
- Next meeting?