Parity-Violating Møller Scattering
Status and Plans for a 11 GeV Proposal

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Møller Scattering

\[ A_{PV} = -mE \frac{G_F}{\sqrt{2}\pi\alpha} \frac{16\sin^2 \Theta}{(3 + \cos^2 \Theta)^2} Q_e^e \]

Purely leptonic reaction

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

Small, well-understood dilution

\[ \sigma \propto \frac{1}{E_{lab}} \]

Figure ofMerit rises linearly with \( E_{lab} \)

SLAC: Highest beam energy with moderate polarized luminosity

JLab 11 GeV: Moderate beam energy with LARGE polarized luminosity

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

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

$\Rightarrow m_H = 89^{+38}_{-28} \text{ GeV}$
$\Rightarrow S = -0.13 \pm 0.10$

Rules out Technicolor!
Favors SUSY!

W. Marciano

$A_{LR}$
(also APV in Cs)

$A_{FB}$ (Z$\rightarrow$ bb)
(also Moller@E158)

$\sin^2\theta_W = 0.2310(3)$
$m_H = 35^{+26}_{-17} \text{ GeV}$
$S = -0.11 \pm 17$

Rules out the SM!

$\sin^2\theta_W = 0.2322(3)$
$m_H = 480^{+350}_{-230} \text{ GeV}$
$S = +0.55 \pm 17$

Rules out SUSY!
Favors Technicolor!

- Precision $\sin^2\theta_W$ measurements at colliders very challenging
- Neutrino scattering cannot compete statistically
- Good goal: $\delta(\sin^2\theta_W) < 0.0003$
Comprehensive Search for New Neutral Current Interactions

Important component of indirect signatures of “new physics”

Consider $f_1 \bar{f}_1 \rightarrow f_2 \bar{f}_2$ or $f_1 f_2 \rightarrow f_1 f_2$

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

Eichten, Lane and Peskin, PRL50 (1983)

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 $\sim 10$ TeV

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

$\sin^2\theta_W$ to $\pm 0.00025$

$\Lambda_{ee} \sim 25$ TeV reach

$Z\chi \sim 2.2$ TeV
Community Endorsement

Best new low energy weak neutral current probe of "new physics" until Linear Collider or Neutrino Factory

- 12 GeV Science Review: April ‘06
- Well-attended workshop Dec ‘06
- High profile in Long Range Plan
E158 Result

$A_{PV} = (-131 \pm 14 \pm 10) \times 10^{-9}$

g-2 spin precession

45 GeV: 14.0 revs
48 GeV: 14.5 revs

Kinematics

Quadrupole Quadruplet
- primary & scattered electrons enclosed in quadrupoles
- Mollers (e-e) focused, Motts (e-p) defocused
- full range of azimuth

upstream of quads
30m after quads

"Mollers"
"ep's"
Quadupoles and Dipoles

Major Breakthrough: 7 magnetic elements from historic 8 and 20 GeV spectrometer elements
Collimation

150 cm LH$_2$: 18% radiator $\rightarrow$ ~ 1 MW beam begins to shower!

~ 150 kW photon beam (must go to beam dump)

Don’t try to stop photons: you just make them mad!

~ 10 kW charged particles

Target
• Dispense with low energy particles well upstream
• Tungsten at edges, otherwise copper
• Alignment & beam tune non-trivial
• Beam containment requires careful coordination
Integrating Statistics

Basic Idea:

- Integrating Statistics
- electron flux
- shielding
- Radial and azimuthal segmentation

Components:
- quartz
- copper
- light guide
- PMT
- shielding

Radial and azimuthal segmentation

Corrections for beam fluctuations
- Average over runs
- Statistical tests
- Beam polarization and other normalization

Graphs:
- observed left-right asymmetry distribution
- raw asymmetry distribution in one PMT
  - RMS ~ 3460 ppm
- charge normalized distribution in one PMT
  - RMS ~ 1108 ppm
- Distribution regressed for energy, position, angle in one PMT
  - ~ 1.8 Million electrons/pulse
  - $\sigma = 527$ ppm
- ~ 15 Million electrons/pulse
  - $\sigma = 194$ ppm
- Grand width
  - -0.1% to 0.1%
Integrating Calorimeter

• 20 million 17 GeV electrons per pulse at 120 Hz
• 100 MRad radiation dose: Cu/Fused Silica Sandwich

- State of the art in ultra-high flux calorimetry
- Challenging cylindrical geometry

- Single Cu plate
- “ep” ring
- “Møller” ring
- End plate
- Lead shield
- Lead shield
- Light guide
- PMT holder
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 $\theta_{lab} \sim 5$ 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 ~ 1 micron at 1 kHz

- **Full Azimuthal acceptance with \( \theta_{\text{lab}} \sim 5 \text{ mrad} \)**
  - 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 → 10.5 µBarn
Thick 150 cm LH₂ target; real spectrometer geometry

For 11 GeV: 46 µBarn → acceptance not quite up to |cosθ|~0.5
50 µBarn

90 µA → 186 GHz → 4000 hrs → δ(A_exp) = 0.61 ppb

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

δ(A_{PV}) = 0.83 ppb → δ(sin^2θ_W) = 0.00026 → δ(Q^e_W) = 2.25%

Conclusions:
• Must get aggressive on systematic errors
• Incremental improvements on factors above
11 GeV Kinematics

Highest figure of merit at $\theta_{CM} = 90^\circ$

Only take forward or backward from center of mass, otherwise you are only double-counting (identical particles).

Backward (CMS) angles selected for ease (highest lab angles)
Quadrupole Spectrometer Design

- Backup Design
- Proof of Principle
- E158 Experience

Units: Centimeters

Dark Blue: X (Møllers)
Red: Y (Møllers)
Light Blue, Green: e-p elastic

L. Mercado

Collimators

E158 Experience
Lab Scattering Angle $\theta$ (rad)

Asymmetry (ppb)

Lab Scattering Angle (rad) vs Asym (ppb)

Momentum Transfer $Q^2$ (GeV)

GEANT4 Simulation

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### Statistical Error

**Simulation Results**

| $E$ (GeV) | 11.0 |
| $E'$ | 2.5 - 8.0 |
| $\theta_{cm}$ | 53° - 133° |
| $\theta_{lab}$ | 0.29° - 1.03° |
| $\langle Q^2 \rangle$ | 0.0064 (GeV/c)$^2$ |

Integrated Luminosity:
- Current ($\mu$A) | 85 |
- Target Length (cm) | 150 |
- $\rho_{tgt}$ (T= 20K, P = 35 psia) | 0.0715 g/cm$^3$ |
- Luminosity $cm^{-2}sec^{-1}$ | 3.4 \times 10^{39} |
- Time in weeks (hours) | 30 (5040) |
- Luminosity*Time $cm^{-2}$ | 6.2 \times 10^{46} |

Statistical noise:
- $\sigma$ ($\mu$Barn) | 60.6 |
- Rate (GHz) | 206 |
- Counting Statistics (2 kHz reversal) | 73.8 ppm/pair |

#### Asymmetry:

\[
P_{beam} \quad \langle A_{pv} \rangle \\
\langle A_{expt} \rangle = P \langle A_{pv} \rangle \\
\Delta A_{stat} = \frac{1}{P} \frac{1}{\sqrt{N}} \\
\Delta A_{stat}/ \langle A_{expt} \rangle = 1.9\%
\]

Cumulative Systematic Error: Must keep well under 1%
Toroid Concept

- This allows 50% of the azimuth for magnet coils... plenty of space for coils!
- Toroids naturally have rapid variation of field with radius
- Accepting high-momentum tracks means ep backgrounds are closer... can they be removed effectively?
All of those rays of $\theta_{\text{CM}}=[90,120]$ that you don’t get here... ...are collected as $\theta_{\text{CM}}=[60,90]$ over here!
"Nested" Toroid

- More complicated magnet geometry used to control integral Bdl without extensive defocusing
- Pre-bender magnet pushes highest angle tracks above high field region, and focuses other tracks

Focus at 22.5 meters

- ep
- ee, 60°-75°
- ee, 75°-105°
- ee, 105°-120°

1.5 meter target, full range of theta and phi
“Nested” Toroidal coils

6 separate current returns so downstream end of magnet is much stronger than upstream end

Very modest power, ~500 kW

- Small beam bore
- First magnet is close to target (6m to center). Power density?
- Complicated design... is it robust?
- Tighter focus, more separation?
Latest GEANT4 Results

Yesterday!
M. Dalton (UVa)
Summary

A 12 GeV upgrade Møller Parity-Violation Experiment

- Unprecedented Opportunity
- Extremely Challenging
- Well worth the effort!
- Proposal being prepared for Jan 09 PAC