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Polarized Møller Scattering Asymmetries

Outline

1. Precision Measurements

2. $A_{LR}(e\vec{e}^- \to e\vec{e}^-)$ Møller Scattering
   - i) SLAC E158 $Q^2 = 0.025\,GeV^2$
   - ii) EW Radiative Corrections & $\sin^2\theta_W(Q^2)$
   - iii) "New Physics" Sensitivity

3. $A_{LR}(e\vec{e}^- \to e\vec{e}^-)$ at a Linear Collider
   - i) Fixed Target $Q^2 \simeq 0.13\,GeV^2$
   - ii) Collider $e\vec{e}^-$ ($Q^2 \simeq 10^5\,GeV^2$)
   - iii) "New Physics" Sensitivity

4. Concluding Remarks

1. Precision Measurements

$\alpha^{-1} = 137.035999959(40)$

$G_\mu = 1.16637(1) \times 10^{-5}\,GeV^{-2}$

$m_Z = 91.1867(21)\,GeV$

$\sin^2\theta_W(m_Z)^{exp}_{\overline{MS}} = 0.23091 \pm 0.00021$ leptonic Z decays (R_{Le}, A_{FB})

vs Standard Model Expectation (incl. R.C.)

$\sin^2\theta_W(m_Z)_{\overline{MS}} = (0.23119 \pm \underbrace{0.00016}_{\Delta m_t} \pm \underbrace{0.00006}_{\Delta\alpha(had)})(1 + 0.00226\,\ln(\frac{m_H}{115\,GeV}))$

suggests light Higgs $m_H = 65^{+35+28+9}_{-20-21-8}\,GeV$

Future improvements: Δm_t + $\Delta\alpha(had)$, $\sin^2\theta_W(m_Z)_{\overline{MS}}$?

Goal: $\Delta\sin^2\theta_W(m_Z)_{\overline{MS}} \simeq \pm 0.00002$! $\pm 0.01\%$!

$\frac{\Delta m_H}{m_H} \simeq \pm 5\%$! (2 loop EW required!)

Giga Z $A_{LR} \rightarrow \Delta\sin^2\theta_W(m_Z)_{\overline{MS}} \simeq \pm 0.00001_{stat}$ $\pm$ systematics (Polarization)

$\frac{\Delta Pol}{Pol} \simeq \pm 0.1\% \rightarrow \pm 0.00002$ very hard (e^+ pol.)

± 0.00006 more likely

Other $A_{FB}(Z \to b\bar{b})$, $A_{FB}(Z \to l^+l^-)$ ... Helped by stats

Alternative Utility $\sin^2\theta_W(Q^2)$

$Q^2 = m_Z^2$ vs $Q^2 \ll m_Z^2$ & $Q^2 \gg m_Z^2$ (Future)

Deviation → "New Physics" eg. Z', Anomalous Moment, Contact Int...

Currently Atomic P.V., $\nu_\mu N$... probe $m_{Z'} \lesssim 800$ GeV

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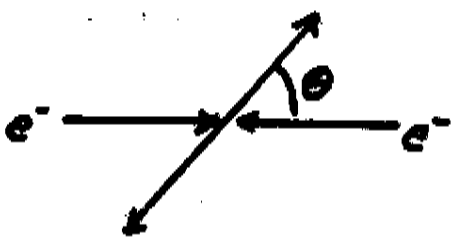
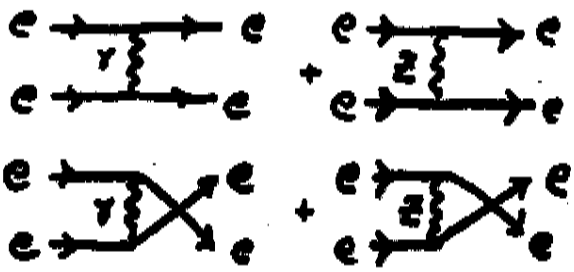
2. $A_{LR}(e^-e^- \to e^-e^-)$ Moller Scattering



$A_{LR} = \dfrac{d\sigma_L - d\sigma_R}{d\sigma_L + d\sigma_R}$ single pol.



Parity Violation $\sim 1 - 4\sin^2\theta_W$

$Q^2 = ys$, $y = \dfrac{1-\cos\theta}{2}$, $0 \le y \le 1$

small Q^2 $\quad A_{LR} = \dfrac{G_\mu Q^2}{\sqrt{2}\pi\alpha} \dfrac{1-y}{1+y^4+(1-y)^4}(1-4\sin^2\theta_W)$ very small

SLAC E158 $e \xrightarrow{50\,\text{GeV}} \cdot e$ (rest) $\quad Q^2 \simeq 0.025\,\text{GeV}^2$

$\mathcal{L} \simeq 4\times10^{38}\,\text{cm}^{-2}/\text{s}$! → $\Delta\sin^2\theta_W \simeq \pm 0.0007 \to 0.0004$!

ii) **EW Radiative Corrections + $\sin^2\theta_W(Q^2)$** A. Czarnecki + WM

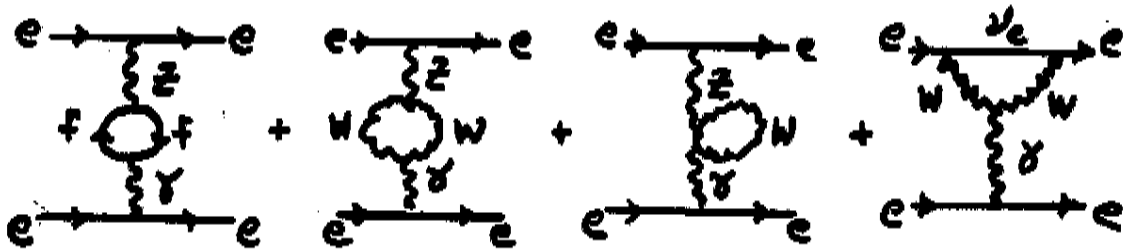
Some loop effects not suppressed by $1-4\sin^2\theta_W$

Potentially Large

g

$\sim \frac{\alpha}{4\pi\sin^2\theta_W}$ → ~4% enhancement of A_{LR}

More Important: γZ Mixing + Anapole Moment $g^2 \bar{e}\gamma_\mu\gamma_5 e$



$\sin^2\theta_W^0 \rightarrow \kappa(q^2)\sin^2\theta_W(m_Z)_{\overline{MS}} \equiv \sin^2\theta_W(Q^2)$

$\kappa(0) = 1.0301 \pm 0.0025$ Reduces A_{LR} by 38%!

had. unc. ±10% of loop (Note $\Delta\alpha(\text{had}) < \pm 1\%$)

$\sin^2\theta_W(0) = 0.2382 \rightarrow 1-4\sin^2\theta_W \rightarrow 0.047$

Total R.C. to $A_{LR} \simeq -40 \pm 3\%$ Reduces Pol. Uncertainty!

$\Delta\sin^2\theta_W \simeq \pm 0.0007$ E158 Goal

Check A_{PV} + νN deviations (?)

Probes: $\Lambda_{comp} \sim 10\text{-}15$ TeV

$m_{Z_R} \sim 800$ GeV

$g^2/M^2_{\Delta^{--}} \sim 0.01 G_F$

* (SUSY loops ?)

3. $R_{\mu e}(e\bar{e}\to e\bar{e})$ at a Linear Collider

i) Fixed Target at $Q^2 \simeq 0.13\,GeV^2$ $\quad e \xrightarrow[250GeV\ (500GeV)]{} \cdot e(rest)$

F.O.M $\sim E_e$
Higher Luminosity
Higher Current
} K. Kumar (Snowmass 1996)

$\Delta \sin^2\theta_W \to \pm 0.00006$! smaller pol. unc than Z pole studies

10x Better than E158 !

● Probes: $\Lambda_{comp} \simeq 50\,TeV$

$m_{Z'} \simeq 2.5\,TeV$

$g^2/m^2_{\Delta^{--}} \sim 0.003 G_\mu$

Other? (eg SUSY, extra dim. etc.)

Note $\frac{\Delta m_H}{m_H} \simeq \pm 15\%$ (Average with Giga Z)

Need to reduce hadronic unc. by factor ~10! $\to \pm 1\%$
$e^+e^- \to$ hadrons data (dispersion rel.)

F. Jegerlehner
A. Sirlin + W.M.
} Possible eg lattice $\to \pm 1\%$?
or isospin decomp of data { In progress

Normalize with $\alpha(m_Z)_{had}$

ii) Collider e^-e^-

2 Polarized Beams, $\sqrt{s} \simeq 100 - 1500$ GeV, $\mathcal{L} \simeq 10^{33} - 10^{34}\ cm^{-2}/s$

$P_{eff} = \frac{P_1 + P_2}{1 + P_1 P_2} \simeq 0.9945 \pm 0.0004$ (Kuny)

$$A_{LR}^{(1)} = \frac{d\sigma_{LL} + d\sigma_{LR} - d\sigma_{RL} - d\sigma_{RR}}{d\sigma_{LL} + d\sigma_{LR} + d\sigma_{RL} + d\sigma_{RR}} \sim (1 - 4\sin^2\theta_W)$$

$$A_{LR}^{(2)} = \frac{d\sigma_{LL} - d\sigma_{RR}}{d\sigma_{LL} + d\sigma_{RR}} \sim \underline{(1 - 4\sin^2\theta_W)}$$

R.C. (Denner + Pozzorini) Large

$\Delta\sin^2\theta_W \simeq \pm 0.0002 - \pm 0.0001$ (Hard) statistics, { More likely ± 0.0004

Physics Probed $\frac{Q^2 + m_Z^2}{\Lambda^2}$ gain factor $\frac{Q^2}{m_Z^2} \simeq 25$!

Easily Probes $\Lambda_{comp} \simeq 150$ TeV
$m_{Z_\chi} \simeq 12$ TeV
$g^4/m_{\Delta^{--}}^4 \simeq 5 \times 10^{-5} G_F$
} ! powerful
etc.

Complements $e^+e^- \to \mu^+\mu^-$, hadrons ...

Similar sensitivity

But, not competitive for precision $\sin^2\theta_W$ (giga-Z)

4. Concluding Remarks

SLAC E158 e^-e^- } best low energy $\sin^2\theta_W$ (see fig)
T.J. Lab e^-p } "new physics?"

Future High Precision $\Delta\sin^2\theta_W \to \pm 0.00006$ (or better)

Giga-Z A_{LR}, A_{FB} } together
e^-e^- Fixed Target Program } $\Delta\sin^2\theta_W \simeq \pm 0.00002$! $\frac{\Delta m_W}{m_W} \simeq \pm 5$‰

(Requires improved m_t, m_H $\simeq \pm 1\%$) (Lattice?)
Data (e^+e^-)

Hard bremsstrahlung effects (small) - Detailed Calc.

e^-e^- & e^+e^- at $\sqrt{s} \simeq$ 500-1500 GeV

More sensitive by $\frac{Q^2}{m_Z^2}$ (but lower stats)

Z', Z'' (extra dim) $\to$ 15 TeV!, $\Lambda_{comp} \to$ 150 TeV

Precision studies complement: SUSY, Higgs ... Discoveries (eg $e^-e^- \to \tilde{e}^-\tilde{e}^-$ ...)

New Discoveries $\to$ New Precision Measurements of New Parameters
$\pm 1\% \to 10 \times \Lambda_{\text{New Physics}}$ Probed

Many Future R.C. Calculations

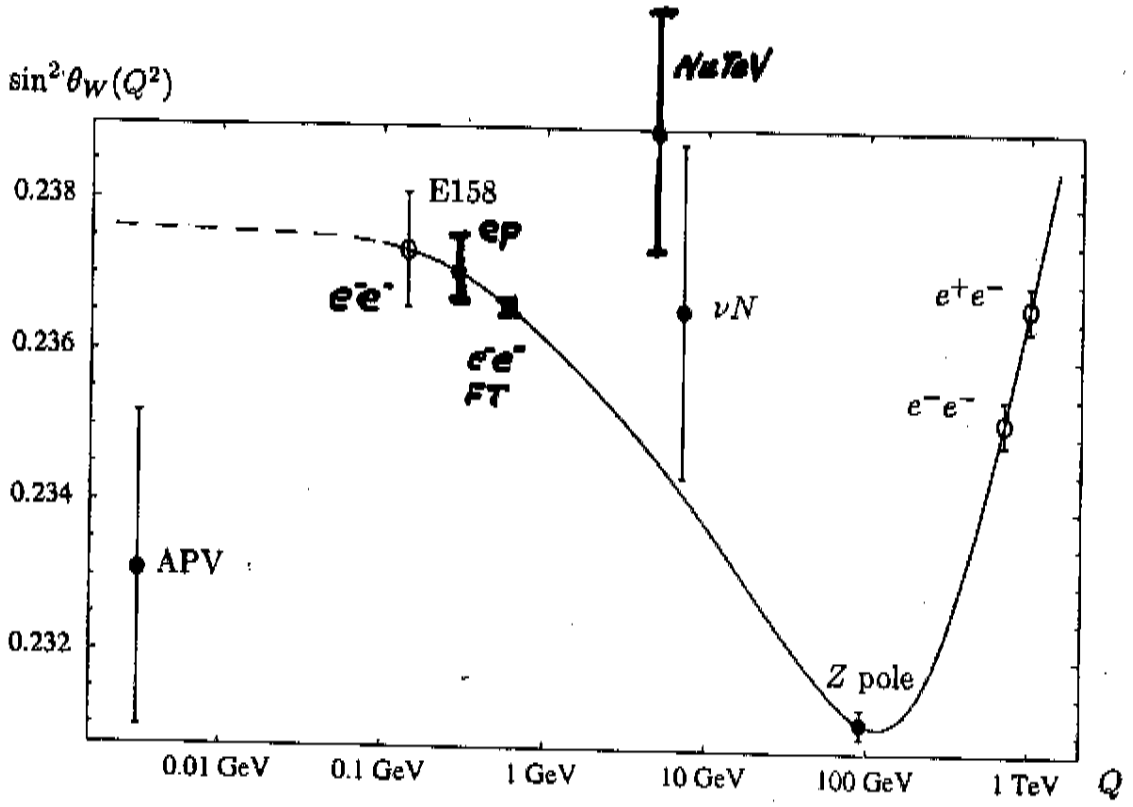


Fig. 1. Predicted running of $\sin^2\theta_W(Q^2)$ and evidence from existing experiments (dark circles) along with expectations from potential future Møller and e^+e^- asymmetry measurements at $\sqrt{s} =$ 1 TeV.