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POLARIZED MØLLER SCATTERING ASYMMETRIES*

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The utility of polarized electron beams for precision electroweak studies is described. Parity violating Møller scattering asymmetries in $e^-e^- \to e^-e^-$ are discussed. Effects of electroweak radiative corrections and the running $\sin^2\theta_W(Q^2)$ are reviewed. The sensitivity of E158 (a fixed target e^-e^- experiment at SLAC) and future e^-e^- collider studies to "new physics" is briefly outlined.

1. Polarization and Precision Measurements

Polarized beams provide powerful tools for testing the Standard Model and probing "new physics" effects. They can be used to enhance signals, suppress backgrounds, study particle properties, and carry out precision measurements. A beautiful illustration of the last possibility is provided by the SLD measurement of A_{LR} at the Z pole

$$A_{\rm LR} \equiv \frac{\sigma\left(e^+e^-_L \to \text{hadrons}\right) - \sigma\left(e^+e^-_R \to \text{hadrons}\right)}{\sigma\left(e^+e^-_L \to \text{hadrons}\right) + \sigma\left(e^+e^-_R \to \text{hadrons}\right)}. \tag{1}$$

That quantity is very sensitive to $\sin^2\theta_W$

$$A_{\rm LR} = \frac{2(1-4\sin^2\theta_W)}{1+(1-4\sin^2\theta_W)^2} \qquad \text{(Tree level)}. \tag{2}$$

In fact, for $\sin^2\theta_W \simeq 0.23$, one finds $\Delta\sin^2\theta_W/\sin^2\theta_W \simeq -\frac{1}{10}\Delta A_{\rm LR}/A_{\rm LR}$. Hence, a $\pm 1\%$ measurement of $A_{\rm LR}$ determines $\sin^2\theta_W$ at the $\pm 0.1\%$ level.

Based on about 500 thousand Z decays and employing a polarized e^- beam with polarization reaching $P_{e^-} \simeq 77\%$, the SLD collaboration has reported[1] the single best measurement of the weak mixing angle (defined here by modified minimal subtraction)

$$\sin^2\theta_W(m_Z)_{\overline{MS}} = 0.23073 \pm 0.00028, \tag{3}$$

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which weighs heavily in the (leptonic) Z pole average (from SLD and LEP)

$$\sin^2\theta_W(m_Z)_{\overline{MS}} = 0.23091 \pm 0.00021. \tag{4}$$

Taken on their own, the quantities in eqs. (3) and (4) are merely precise numbers. They become interesting when interpreted in the context of a complete (renormalizable) theory such as the $SU(3)_C \times SU(2)_L \times U(1)_Y$ Standard Model or its various extensions. Then, symmetries provide natural relationships among couplings and masses which can be tested by comparing different precision measurements. For example, the fine structure constant, Fermi constant, and Z mass

$$\begin{aligned} \alpha^{-1} &= 137.03599959(40) \\ G_\mu &= 1.16637(1) \times 10^{-5}\ \text{GeV}^{-2} \\ m_Z &= 91.1871(21)\ \text{GeV} \end{aligned} \tag{5}$$

can be compared with the weak mixing angle via

$$\sin^2 2\theta_W(m_Z)_{\overline{MS}} = \frac{4\pi\alpha}{\sqrt{2}G_\mu m_Z^2\,[1-\Delta\hat{r}(m_t, m_h)]} \tag{6}$$

where $\Delta\hat{r}$ represents finite, calculable quantum loop effects which depend on the top quark and Higgs scalar masses. Taking $m_t = 174.3 \pm 5.1$ GeV and $m_h \simeq 100$ GeV leads to $\Delta\hat{r} = 0.05940 \pm 0.0005 \pm 0.0002$, where the errors correspond to Δm_t and hadronic loop uncertainties.

Leaving m_h arbitrary, eq. (6) leads to the prediction[2]

$$\sin^2\theta_W(m_Z)_{\overline{MS}} = (0.23112 \pm 0.00016 \pm 0.00006)\left(1 + 0.00226 \ln\frac{m_h}{100\ \text{GeV}}\right). \tag{7}$$

Comparing that prediction with the world average in eq. (4) suggests a relatively light Higgs,

$$m_h \simeq 65^{+35+28+9}_{-20-21-8}\ \ \text{GeV}, \tag{8}$$

which is centered somewhat below the LEP II direct search bound[3]

$$m_h > 106\ \text{GeV} \qquad (95\%\ \text{C.L.}). \tag{9}$$

In fact, the SLD value in eq. (3) favors an even smaller m_h. If the Higgs mass turns out to be well outside the range in eq. (8), then one must append "new physics" to the Standard Model either through loop effects or small tree level contributions.

It would be nice to push the current $\pm 0.1\%$ test in eq. (6) as far as possible. Indeed, α, G_μ, and m_Z are all already known to much better than $\pm 0.01\%$ (and will be or can be further improved). Can one reduce the uncertainty in $\sin^2\theta_W(m_Z)_{\overline{\text{MS}}}$ from its current $\pm 0.1\%$ to $\pm 0.01\%$? If so, it would provide a sensitivity to m_h at the incredible $\pm 5\%$ level (assuming m_t and hadronic loop uncertainties are also improved).

The only known way to improve $\sin^2\theta_W(m_Z)_{\overline{\rm MS}}$ is to carry out a clean high statistics study of asymmetries such as $A_{\rm LR}$. In that regard, the NLC (Next Linear Collider) will be capable at an early stage of sitting at the Z resonance and collecting $10^8 - 10^9$ Z decays in a relatively short time. With such statistics, $\sin^2\theta_W(m_Z)_{\overline{\rm MS}}$ can, in principle, be obtained via $A_{\rm LR}$ to better than $\pm 0.01\%$. Systematics then become the issue. The dominant systematic uncertainty at the SLD was a $\pm 0.5\%$ polarization error which contributes to $\Delta\sin^2\theta_W$ at the ± 0.0001 level. One would need to reduce the polarization uncertainty to $\pm 0.1\%$ to reach $\pm 0.01\%$ in $\sin^2\theta_W(m_Z)_{\overline{\rm MS}}$. Such a reduction would be possible if both the e^+ and e^- beams were polarized. Then, the effective polarization (they add like relativistic velocities)

$$P_{\rm eff} = \frac{P_{e^-} - P_{e^+}}{1 - P_{e^-}P_{e^+}} \tag{10}$$

enters

$$\frac{N_{LR} - N_{RL}}{N_{LR} + N_{RL}} = P_{\rm eff}A_{\rm LR}, \tag{11}$$

where N_{LR} denotes the number of $e^-_L e^+_R$ induced hadronic Z decays. For $|P_{e^-}| = 0.9000 \pm 0.0045$ and $|P_{e^+}| = 0.6500 \pm 0.0065$ (i.e. $\pm 1\%$ e^+ polarization), one finds $P_{\rm eff} = 0.9779 \pm 0.0012$ as required for a $\pm 0.01\%$ determination of $\sin^2\theta_W(m_Z)_{\overline{\rm MS}}$.

Improving the direct measurement of $\sin^2\theta_W(m_Z)_{\overline{\rm MS}}$ can have other applications. The Z pole determination is relatively pure and free of "new physics." Below, we demonstrate its utility for comparison with polarized Møller scattering asymmetries which could exhibit effects from "new physics" beyond the Standard Model.

2. Polarized Møller Scattering – Fixed Target

Møller scattering $e^-e^- \to e^-e^-$ has been a well studied, classic low energy reaction.[4] Employing polarized electrons, one can, in principle, measure parity violating weak interaction asymmetries.[5] At tree level, the $A_{\rm LR}$ in Møller scattering comes from an interference among the diagrams in Fig. 1. For a single polarized e^-, the asymmetry corresponds to

$$A^{(1)}_{\rm LR} \equiv \frac{{\rm d}\sigma_{\rm LL} + {\rm d}\sigma_{\rm LR} - {\rm d}\sigma_{\rm RL} - {\rm d}\sigma_{\rm RR}}{{\rm d}\sigma_{\rm LL} + {\rm d}\sigma_{\rm LR} + {\rm d}\sigma_{\rm RL} + {\rm d}\sigma_{\rm RR}} \tag{12}$$

while in the case of both e^- polarized, a second asymmetry becomes possible[6]

$$A^{(2)}_{\rm LR} \equiv \frac{{\rm d}\sigma_{\rm LL} - {\rm d}\sigma_{\rm RR}}{{\rm d}\sigma_{\rm LL} + {\rm d}\sigma_{\rm RR}}. \tag{13}$$

The subscripts denote the initial e^-e^- states' polarizations. As we subsequently show, both asymmetries would be measurable at a high energy e^-e^- collider where polarizations of 0.90 for each beam are likely. Since ${\rm d}\sigma_{LR} = {\rm d}\sigma_{RL}$ by rotational invariance, they differ only in their denominators.

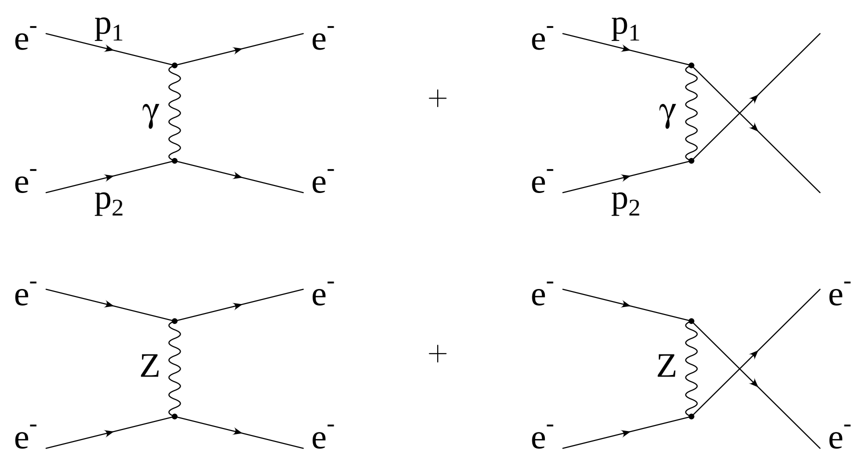

Fig. 1. Neutral current direct and crossed e^-e^- scattering amplitudes leading to the asymmetry A_{LR} at tree level.

Let us begin by considering a fixed target scenario in which a 50 GeV polarized electron beam scatters off a fixed target of electrons. That case will be addressed in the near future by SLAC experiment E158.[7]

In the center-of-mass frame, the differential cross section is characterized by the scattering angle θ with respect to the beam axis or

$$y = \frac{1-\cos\theta}{2}, \qquad 0 \le \theta \le \pi. \tag{14}$$

The variable y relates the momentum transfer $Q^2 = -q^2$ and center-of-mass energy $\sqrt{s}$ via

$$Q^2 = ys, \qquad 0 \le y \le 1. \tag{15}$$

Since the cross section grows as $1/y^2(1-y)^2 s$, very high statistics are possible at small angle and/or small s. However, the asymmetry grows with s. All things considered, it is generally better to measure $A_{\rm LR}$ at high s, but lower energy fixed target facilities can compensate by having very large effective luminosities. For example, E158 at SLAC will have $s \simeq 0.05\,{\rm GeV}^2$ and aims to measure (with high precision) a very small asymmetry $A_{\rm LR} \sim 1.5 \times 10^{-7}$. That is only possible because their luminosity will be $\mathcal{L} \simeq 4 \times 10^{38}{\rm cm}^{-2}/s$.

At small $Q^2 = ys \ll m_Z^2$, the left-right polarization asymmetry in Møller scattering is given by (at tree level)[5]

$$A_{\rm LR}^{(1)}(e^-e^- \to e^-e^-) = \frac{G_\mu s}{\sqrt{2}\pi\alpha}\frac{y(1-y)}{1+y^4+(1-y)^4}(1-4\sin^2\theta_W), \tag{16}$$

or for comparison with the Z pole asymmetry

$$A_{\rm LR}^{(1)}(e^-e^- \to e^-e^-)$$

$$= \frac{12}{\alpha} \frac{y(1-y)}{1+y^4+(1-y)^4} \frac{s\Gamma(Z \to e^+e^-)}{m_Z^3} A_{\rm LR}(e^+e^- \to Z \to \text{hadrons}). \quad (17)$$

To be at all competitive with the ± 0.00028 uncertainty in $\sin^2\theta_W$ found by SLD, very high statistics are required or equivalently, a very good determination of $A_{\rm LR}$,

$$\frac{\delta \sin^2\theta_W}{\sin^2\theta_W} \simeq -\frac{1-4\sin^2\theta_W}{4\sin^2\theta_W} \frac{\delta A_{\rm LR}}{A_{\rm LR}}. \quad (18)$$

Again, one sees the enhanced sensitivity to small changes in $\sin^2\theta_W$. E158 aims for a ± 0.0007 to ± 0.0004 measurement of $\sin^2\theta_W$ which will make it the best low energy determination of that quantity. As we subsequently illustrate, it will be sensitive to the running of the weak mixing angle as well as "new physics" effects.

3. Polarized Møller Scattering at Collider Energies

Møller scattering, $e^-e^- \to e^-e^-$, at the NLC can also be used for precision tests of the Standard Model as well as direct and indirect searches for "new physics."[8,9] Indeed, in some cases it can provide a more powerful probe than e^+e^-. One can assume with some confidence that both e^- beams will be polarized with $|P_1| = |P_2| = 0.9$ and about $\pm 0.5\%$ uncertainty each. The effective polarization will therefore be (with like sign P_1 and P_2)

$$P_{\rm eff} = \frac{P_1+P_2}{1+P_1P_2} = 0.9945 \pm 0.0004. \quad (19)$$

We see that $P_{\rm eff}$ will be very large and has essentially negligible uncertainty compared to P_1 and P_2.

The differential cross section in high energy collider Møller scattering is also characterized by a single parameter, the scattering angle θ with respect to the beam axis or

$$y = \frac{1-\cos\theta}{2}, \qquad 0 \le \theta \le \pi. \quad (20)$$

The cross section grows as $1/y^2$ for small angle scattering. Hence, very high statistics are possible in the small angle region. Good angular coverage is therefore important for precision measurements. As before, the variable y relates s and the momentum transfer $Q^2 = -q^2$ via $Q^2 = ys, 0 \le y \le 1$. Note, that y and $1-y$ correspond to indistinguishable events. Very forward (small angle) e^-e^- events will therefore be composed of high and low Q^2 contributions.

As previously noted, one can consider two distinct but similar parity violating Møller asymmetries: the single spin asymmetry $A_{\rm LR}^{(1)}$ defined in eq. (12) and double spin asymmetry $A_{\rm LR}^{(2)}$ in eq. (13).

Experimentally, one can and probably will flip the individual polarizations (pulse by pulse) and measure $N_{\rm LL}$, $N_{\rm LR}$, $N_{\rm RL}$, and $N_{\rm RR}$ (the number of events in each mode) for fixed luminosity and polarization. From those measurements, the polarizations and $A^{(2)}_{\rm LR}(y)$ can be simultaneously determined using[6,10]

$$\frac{N_{\rm LL}+N_{\rm LR}-N_{\rm RL}-N_{\rm RR}}{N_{\rm LL}+N_{\rm LR}+N_{\rm RL}+N_{\rm RR}} = P_1 A^{(1)}_{\rm LR}(y), \tag{21}$$

$$\frac{N_{\rm RR}+N_{\rm LR}-N_{\rm RL}-N_{\rm LL}}{N_{\rm RR}+N_{\rm LR}+N_{\rm RL}+N_{\rm LL}} = -P_2 A^{(1)}_{\rm LR}(y), \tag{22}$$

$$\frac{N_{\rm LL}-N_{\rm RR}}{N_{\rm LL}+N_{\rm RR}} = P_{\rm eff} A^{(2)}_{\rm LR}(y)\left(\frac{1}{1+\frac{1-P_1P_2}{1+P_1P_2}\frac{\sigma_{\rm LR}+\sigma_{\rm RL}}{\sigma_{\rm LL}+\sigma_{\rm RR}}}\right), \tag{23}$$

$$P_{\rm eff} = \frac{P_1+P_2}{1+P_1P_2}.$$

For $P_1 = P_2 = 0.9$, the correction term in parentheses of Eq. (23) is small but must be accounted for. Using Eq. (23), $A^{(2)}_{\rm LR}$ (which depends on $\sin^2\theta_W$) can be extracted from data and compared with the Standard Model prediction. A deviation from expectations would signal "new physics."

In general the $\mathrm{d}\sigma_{ij}$ for Møller scattering are somewhat lengthy expressions[10] with contributions from direct and crossed γ and Z exchange amplitudes (see Fig. 1). To simplify our discussion, we consider for illustration the case ys and $(1-y)s \gg m_Z^2$; so, terms of relative order m_Z^2/ys and $m_Z^2/(1-y)s$ can be neglected. In that limit, one finds at tree level[10]

$$\begin{aligned}
\frac{\mathrm{d}\sigma_{\rm LL}}{\mathrm{d}y} &= \sigma_0 \frac{1}{y^2(1-y)^2}\frac{1}{16\sin^4\theta_W}, \\
\frac{\mathrm{d}\sigma_{\rm RR}}{\mathrm{d}y} &= \sigma_0 \frac{1}{y^2(1-y)^2}, \\
\frac{\mathrm{d}\sigma_{\rm LR}}{\mathrm{d}y} &= \frac{\mathrm{d}\sigma_{\rm RL}}{\mathrm{d}y} = \sigma_0\frac{y^4+(1-y)^4}{y^2(1-y)^2}\frac{1}{4},
\end{aligned} \tag{24}$$

and the asymmetries become

$$A^{(1)}_{\rm LR}(y) = \frac{(1-4s_W^2)(1+4s_W^2)}{1+16s_W^4+8\left[y^4+(1-y)^4\right]s_W^4}, \tag{25}$$

$$A^{(2)}_{\rm LR}(y) = \frac{(1-4s_W^2)(1+4s_W^2)}{1+16s_W^4}. \tag{26}$$

Expanding about $\sin^2\theta_W = 1/4$, Eq. (26) becomes

$$A^{(2)}_{\rm LR}(y) = (1-4\sin^2\theta_W) + \mathcal{O}[(1-4\sin^2\theta_W)^2]. \tag{27}$$

For arbitrary s, the asymmetries are maximal at $y = 1/2$. There we find, up to terms of $\mathcal{O}[(1-4\sin^2\theta_W)^2]$,

$$\begin{aligned}
A^{(1)}_{\rm LR}(y=1/2) &\approx (1-4\sin^2\theta_W)\frac{16\,x\,(3+2\,x)}{3\,(27+34\,x+11\,x^2)}, \\
A^{(2)}_{\rm LR}(y=1/2) &\approx (1-4\sin^2\theta_W)\frac{2\,x}{3+2\,x}, \qquad x \equiv \frac{s}{m_Z^2}.
\end{aligned} \tag{28}$$

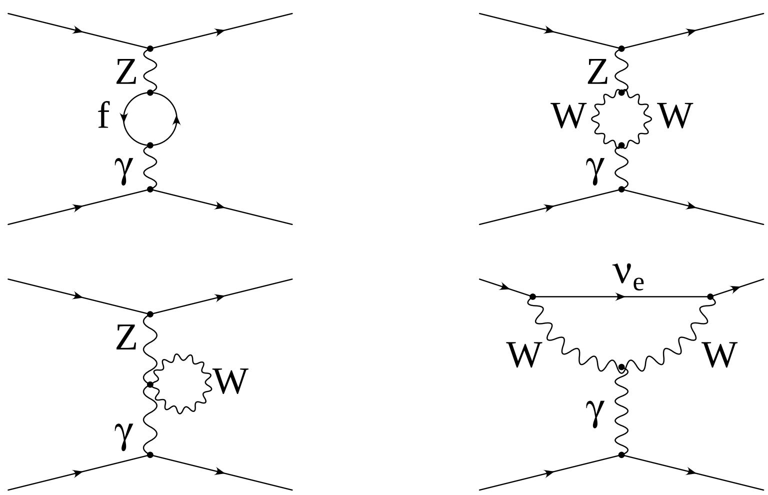

Fig. 2. $\gamma - Z$ mixing diagrams and W-loop contribution to the anapole moment.

Because of the $(1 - 4\sin^2\theta_W)$ dependence of $A_{\rm LR}(e^-e^-)$, even with relatively modest angular coverage limited to $0.1 \le y \le 0.9$, Møller scattering can be used to measure $\sin^2\theta_W$ rather precisely, to about ± 0.0003 at $\sqrt{s} \approx 1$ TeV. Although not likely to compete with future potential very high statistics Z pole measurements, it will be competitive with present day measurements. In addition, Møller scattering can be used as a powerful probe for "new physics" effects. Indeed, for electron composite effects parametrized by the four fermion interaction[11] $\frac{2\pi}{\Lambda^2}\overline{e}_L\gamma_\mu e_L\overline{e}_L\gamma^\mu e_L$ one finds $\Delta A_{\rm LR} \approx sy(1-y)c_W^2/\alpha\Lambda^2$ for e^-e^- Møller scattering. It can, therefore, be more sensitive than $e^+e^- \to e^+e^-$ (about 50% better) and could probe $\Lambda \sim$ 150 TeV.

If one is interested in an even more precise determination of $\sin^2\theta_W$ via Møller scattering, extremely forward events must be detected. For example, assuming detector acceptance down to about 5° ($y = 0.0019$), Cuypers and Gambino[6] have shown that $\Delta\sin^2\theta_W \approx \pm 0.0001$ may be possible at a $\sqrt{s} = 2$ TeV e^-e^- collider with $P_1 = P_2 = 90\%$.

4. Radiative Corrections and $\sin^2\theta_W(Q^2)$

The tree level $A_{\rm LR}$ for both E158 and future e^-e^- collider studies are proportional to $1 - 4\sin^2\theta_W$ and hence suppressed because $\sin^2\theta_W \simeq 0.23$. Since some electroweak radiative corrections are not suppressed by $1 - 4\sin^2\theta_W$, they can be potentially very large. A complete calculation has been carried out[12] for small s as appropriate to E158. There it was shown that such effects reduce $A_{\rm LR}$ by 40% and must be included in any detailed study. Here, we comment on the primary sources of those large corrections and show how much of the effect can be incorporated into a running $\sin^2\theta_W(Q^2)$. We also discuss how those large effects carry over to collider energies. For a complete study of radiative corrections to Møller scattering at high energies, see ref. 13, 14, 15.

The largest radiative corrections to $A_{\rm LR}$ at low energies come from three sources:

1. WW box diagrams,
2. Photonic vertex and box diagrams,
3. γZ mixing and the anapole moment.

The first two are of order +4% and −6% respectively.[12] γZ mixing along with the anapole moment in Fig. 2 is the largest effect. It effectively replaces the tree level $1-4\sin^2\theta_W$ in $A_{\rm LR}$ by[12]

$$1-4\kappa(0)\sin^2\theta_W(m_Z)_{\overline{\rm MS}} \tag{29}$$

where

$$\kappa(0)=1.0301\pm 0.0025 \tag{30}$$

represents a 3% shift in the effective $\sin^2\theta_W$ due to loop effects illustrated in Fig. 2. That +3% increase in the effective $\sin^2\theta_W$ appropriate for low Q^2 gives rise to a −38% reduction in $A_{\rm LR}$. Interestingly, that reduction actually makes E158 more sensitive to $\sin^2\theta_W(m_Z)_{\overline{\rm MS}}$ as well as "new physics."

In the case of very large Q^2, appropriate for e^-e^- colliders, the electroweak radiative corrections will change and must be reevaluated. In particular, the WW box diagram gives a large negative contribution to $A_{\rm LR}$. The effects of γZ mixing and anapole moment can also be very large, but they are easy to obtain from the loops in Fig. 2. One finds for arbitrary Q^2 that they replace $1-4\sin^2\theta_W$ in the tree level asymmetry by

$$\begin{aligned} 1-4\kappa(Q^2)\sin^2\theta_W(m_Z)_{\overline{\rm MS}} &\equiv 1-4\sin^2\theta_W(Q^2), \\ \kappa(Q^2)=\kappa_f(Q^2)+\kappa_b(Q^2), & \end{aligned} \tag{31}$$

where the subscripts f and b denote fermion and boson loops, and $\sin^2\theta_W(Q^2)$ is a running effective parameter. In perturbation theory (i.e. without QCD dressing)

$$\begin{aligned} \kappa_f(Q^2) &= 1-\frac{\alpha}{2\pi\sin^2\theta_W}\left\{\frac{1}{3}\sum_f\left(T_{3f}Q_f-2\sin^2\theta_W Q_f^2\right)\right. \\ &\qquad \left.\times\left[\ln\frac{m_f^2}{m_Z^2}-\frac{5}{3}+4z_f+(1-2z_f)p_f\ln\frac{p_f+1}{p_f-1}\right]\right\}, \\ z_f &\equiv \frac{m_f^2}{Q^2}, \qquad p_f\equiv\sqrt{1+4z_f}, \end{aligned} \tag{32}$$

with $T_{3f}=\pm 1/2$, $Q_f=$ fermion charge, and the sum is over all fermions;

$$\kappa_b(Q^2) = 1-\frac{\alpha}{2\pi\sin^2\theta_W}\left\{-\frac{42\cos^2\theta_W+1}{12}\ln\cos^2\theta_W+\frac{1}{18}\right.$$

$$
\begin{aligned}
& -\left(\frac{p}{2}\ln\frac{p+1}{p-1}-1\right)\left[(7-4z)\cos^2\theta_W+\frac{1}{6}(1+4z)\right] \\
& -z\left[\frac{3}{4}-z+\left(z-\frac{3}{2}\right)p\ln\frac{p+1}{p-1}+z\,(2-z)\ln^2\frac{p+1}{p-1}\right]\Bigg\}, \\
z \;\; \equiv \;\; & \frac{m_W^2}{Q^2}, \qquad p\equiv\sqrt{1+4z}.
\end{aligned} \tag{33}
$$

(Note, Eqs. (28) and (29) of ref. 10 contain misprints in the $\kappa(Q^2)$ expressions.)

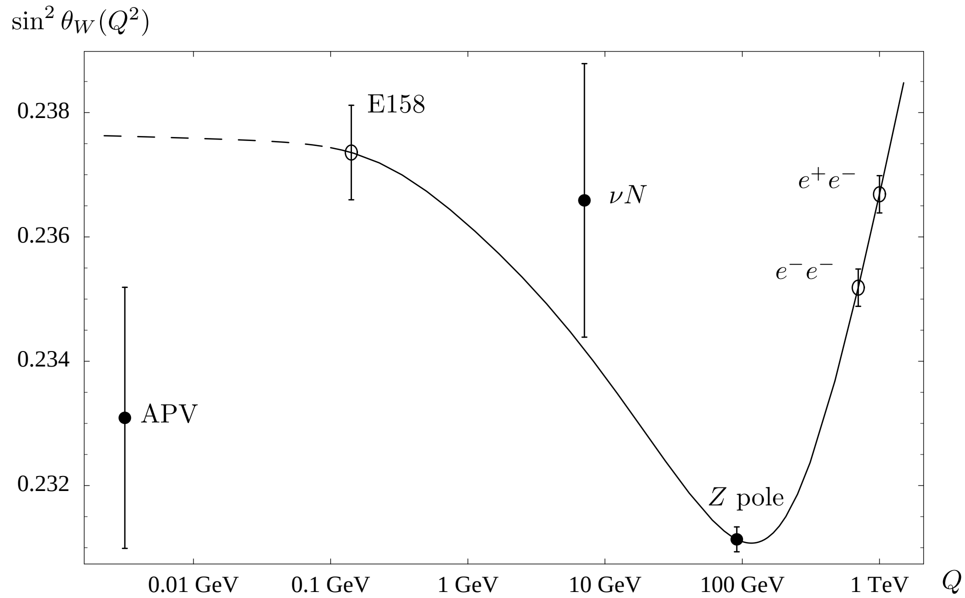

Fig. 3. Predicted running of $\sin^2\theta_W(Q^2)$ and evidence from existing experiments (dark circles) along with expectations from potential future Møller and e^+e^- asymmetry measurements at $\sqrt{s}=$ 1 TeV.

In Fig. 3 we illustrate the expected dependence of $\sin^2\theta_W(Q^2)$ on Q and show how well it has already been measured for several Q^2. We also illustrate the approximate potential of E158 and future e^-e^- and e^+e^- collider measurements at $\sqrt{s}=1$ TeV. One notices a 2σ discrepancy in the atomic parity violation result as compared with Standard Model expectations. That issue could be resolved or made even more interesting by results from E158 at SLAC.

In the case of e^-e^- collider studies, one can actually map out the variation in $\sin^2\theta_W(Q^2)$ in a single experiment through measurements at different θ. We illustrate in Fig. 4 the type of running that one is predicted to find at a $\sqrt{s}=1$ TeV e^-e^- collider. Notice, that by going to small angles (low Q^2), one can obtain very high precision. Of course, within the Standard Model, the measurements at

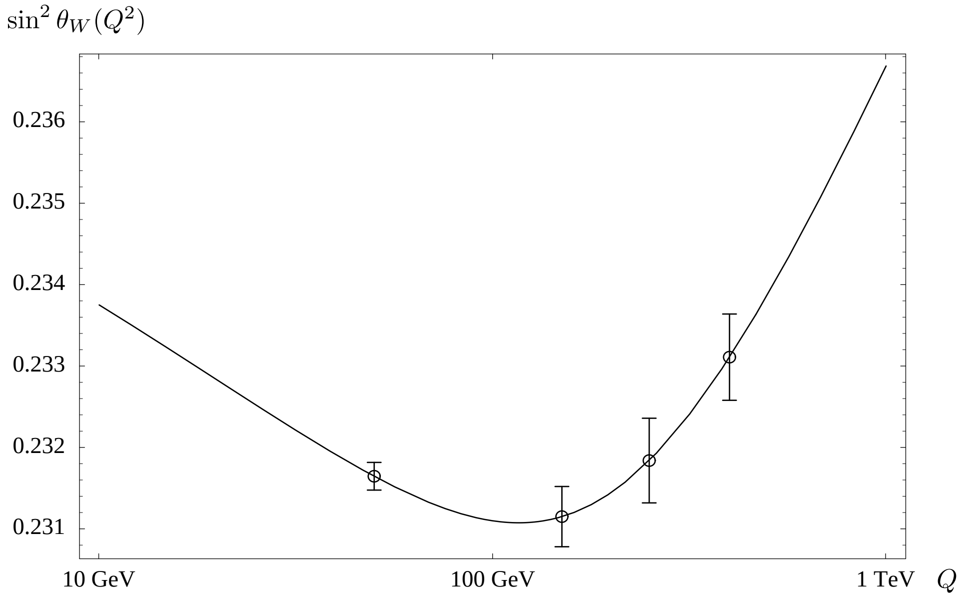

Fig. 4. Running of $\sin^2\theta_W(Q^2)$ compared with potential future e^-e^- collider measurements at $\sqrt{s} = 1$ TeV.

different Q^2 would be radiatively corrected to provide a single precise determination of $\sin^2\theta_W(m_Z)_{\overline{\rm MS}}$. However, demonstrating the running of $\sin^2\theta_W(Q^2)$ over a large range in Q^2 in a single experiment will be an added bonus.

5. "New Physics" Effects

The real utility of high precision $A_{\rm LR}$ measurements away from the Z pole is to search for or constrain "new physics." A disagreement with the extracted $\sin^2\theta_W(m_Z)_{\overline{\rm MS}}$ value from Z pole determinations could signal the presence of additional tree or loop level neutral current effects. Examples that have been considered include Z' bosons, compositeness, anomalous anapole moment effects, doubly charged scalars Δ^{--}, extra dimensions, etc. For example, if E158 meets its phase one goal of a ± 0.0007 determination of $\sin^2\theta_W(m_Z)_{\overline{\rm MS}}$, it will probe the m_{Z_χ} of SO(10) at about the 800 GeV level, compositeness at the 10–15 TeV scale, the anapole moment at 10^{-17} cm (or the X parameter[16] at ± 0.15), and $g^2/m^2_{\Delta^{--}} \sim 0.01 G_\mu$.

At an e^-e^- collider, the larger value of s would significantly improve the "new physics" reach. Roughly, at $\sqrt{s} \simeq 500$ GeV one could do a factor of 10 better in m_{Z_χ} and $\Lambda_{\rm comp}$ than E158. In the case of the doubly charged Higgs, $g^2/m^2_{\Delta^{--}} \sim 5 \times 10^{-5} G_\mu$ would be probed. Of course, the sensitivity would further improve as higher $\sqrt{s}$ values are reached.

Parity violating left-right asymmetries have played key roles in establishing the validity of the Standard Model. From the classic SLAC polarized eD measurement to the Z pole asymmetry, polarized electron beams have proved their worth. They will continue to provide valuable tools during the NLC era both in the e^+e^- and e^-e^- modes. In the case of precision studies of parity violating left-right scattering asymmetries, short–distance physics up to $\mathcal{O}(150\ \text{TeV})$ will be indirectly explored. Even more exciting is the possible direct detection of new phenomena such as supersymmetry at these high energy facilities. If "new physics" is uncovered, polarization will help sort out its properties and decipher its place in nature.

Acknowledgments

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