

The Weak Mixing Angle and "New Physics"
(A Tale of Two Numbers)

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The Weak Mixing Angle and “New Physics” (A Tale of Two Numbers)

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Abstract. The two best Z pole determinations of $\sin^2 \theta_W(m_Z)_{\overline{MS}}$ differ by 3 sigma, a feature lost in global fits and averaging. Individually, $\sin^2 \theta_W(m_Z)_{\overline{MS}} = 0.2307(3)$ obtained from A_{LR} , taken together with $m_W = 80.410(32)$ GeV, points to a very light Higgs boson, $m_H \simeq 12 - 63$ GeV, already ruled out experimentally. It is, however, easily redeemed by low mass scale supersymmetry or models with (effectively) $S \simeq -0.12$ and $T \simeq +0.06$. Alternatively, $\sin^2 \theta_W(m_Z)_{\overline{MS}} \simeq 0.2320(3)$ obtained from $A_{FB}(Z \rightarrow \overline{b}b)$, suggests a very heavy Higgs, $m_H \sim 500$ GeV, along with $S \simeq +0.45$ which is suggestive of Technicolor models. Future ways to resolve this discrepancy are briefly discussed.

Keywords: Weak Mixing Angle, New Physics

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The very precisely measured electroweak parameters [1, 2]

$$\alpha^{-1} = 137.035999710(96) \quad (1)$$

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

$$m_Z = 91.1875(21) \text{GeV} \quad (3)$$

along with the averages

$$m_W = 80.410(32) \text{GeV} \quad (4)$$

$$\sin^2 \theta_W(m_Z)_{\overline{MS}} = 0.23122(17) \quad (5)$$

and many other Z pole and low energy observables overconstrain the Standard Model [3]. Indeed, used in conjunction with quantum loop corrections and the recently improved average top quark mass [4]

$$m_t = 171.4(2.1) \text{GeV} \quad (6)$$

they imply a relatively light Higgs boson

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$$m_H = 85_{-28}^{+39} \text{ GeV} < 161 \text{ GeV (95\%CL)} \quad (7)$$

which is consistent with the experimental bound

$$m_H^{exp} \geq 114.4 \text{ GeV} \quad (8)$$

and suggestive of supersymmetry which prefers $m_H \leq 135 \text{ GeV}$.

Global fits to electroweak data also rule out various ‘‘New Physics’’ appendages to the Standard Model. For example, the S parameter [5, 6] is highly constrained

$$S = -0.13(10) \quad (9)$$

to be near zero; whereas N_D new chiral doublets would give [7]

$$S \simeq +N_D/6\pi \quad (10)$$

Taken seriously, eq. (9) rules out a heavy fourth generation with $N_D = 4$, mirror fermions with $N_D = 12$ and most Technicolor models.

The above averaging procedure hides a nagging problem with the determination of $\sin^2 \theta_W(m_Z)_{\overline{MS}}$. The two best determinations of the weak mixing angle at the Z pole [2, 3, 8]

$$\sin^2 \theta_W(m_Z)_{\overline{MS}} = 0.2307(3) \quad A_{LR}(Z) \quad (11)$$

$$\sin^2 \theta_W(m_Z)_{\overline{MS}} = 0.2320(3) \quad A_{FB}(Z \rightarrow b\bar{b}) \quad (12)$$

differ by 3 sigma. Phrased in terms of their individual predictions for the Higgs mass

$$A_{LR} \rightarrow m_H \simeq 30_{-18}^{+33} \text{ GeV} \quad (13)$$

$$A_{FB}(Z \rightarrow b\bar{b}) \rightarrow m_H \simeq 450_{-190}^{+300} \text{ GeV} \quad (14)$$

(Note, the errors roughly scale with the central values.) The difference between eqs. (13) and (14) is very dramatic. However, it is lost in the global averaging. Eq. (13) is already ruled out by the bound in eq. (8) while eq. (14) is at odds with the global fit and m_W . Nevertheless, it is interesting to consider the implications of each value individually.

Consider the predictions for m_W and $\sin^2 \theta_W(m_Z)_{\overline{MS}}$ as functions of $X = \ln \frac{m_H}{115 \text{ GeV}}$ and the ‘‘new physics’’ loop parameters S and T [6, 8, 9]

$$\frac{m_W}{\text{GeV}} = 80.350(13) - 0.055X - 0.0090X^2 - 0.29S + 0.45T \quad (15)$$

$$\sin^2 \theta_W(m_Z)_{\overline{MS}} = 0.23128(7) + 0.00048X + 0.000034X^2 + 0.0036S - 0.0026T \quad (16)$$

where the uncertainties stem mainly from m_t . Combining those relations, one finds

$$S \simeq 120 \left\{ 2 \frac{m_W - 80.350}{80.350} + \frac{\sin^2 \theta_W(m_Z)_{\overline{MS}} - 0.23128}{0.23128} - 7.1 \times 10^{-4}X + 7.7 \times 10^{-5}X^2 \right\} \quad (17)$$

Then, using the value of m_W in eq. (4) together with $\sin^2 \theta_W(m_Z)_{\overline{MS}} = 0.2307(3)$ suggests a very light Higgs (see eq. (13)) that is already ruled out experimentally in the Standard Model. But it can be made consistent with $m_H \simeq 115\text{GeV}$ if $S \simeq -0.12$ and $T \simeq +0.06$, rather minor shifts from zero. One could effectively produce such values in low mass scale SUSY or a variety of other “new physics” scenarios.

If instead, we employ m_W in eq. (4) along with $\sin^2 \theta_W(m_Z)_{\overline{MS}} = 0.2320(3)$, they imply a very heavy Higgs ($\sim 500\text{ GeV}$) along with $S \simeq 0.45$ and $T \simeq 0.07$. Such a scenario favors the addition of new chiral doublets, $N_D \simeq 5 - 12$, as suggested by Technicolor models, additional heavy ordinary fermion generations, mirror fermions, etc. It is a very provocative possibility, but would require that several experimental inputs in global fits are incorrect. Who knows?

Is there other evidence for $\sin^2 \theta_W(m_Z)_{\overline{MS}} \simeq 0.2320$? The two best low energy determinations of the weak mixing angle, polarized e^-e^- scattering and atomic parity violation averaged together give [8]

$$\sin^2 \theta_W(m_Z)_{\overline{MS}} = 0.2317(11) \quad (e^-e^- + \text{APV}) \quad (18)$$

Unfortunately, the error is currently too large to be definitive. It is also interesting to note that SUSY GUT models suggest [10] $\sin^2 \theta_W(m_Z)_{\overline{MS}} \simeq 0.233$; but lower values can be accommodated by relatively small changes in those models.

The current situation is unacceptable. The weak mixing angle is arguably the most important parameter in electroweak physics. Its true value must be resolved once and for all, particularly since it has such dramatic consequences for “new physics.” What new measurements are on the horizon? At JLAB, they expect to measure $\sin^2 \theta_W(m_Z)_{\overline{MS}}$ to ± 0.0008 in polarized ep scattering. Longer term they might get to ± 0.0003 in polarized ee scattering, but that requires a 12 GeV upgrade of their electron beam.

At the LHC, one may be able to use the very high statistics of Z production to study the forward-backward asymmetry in $pp \rightarrow Z \rightarrow \mu^+\mu^-$. It has been estimated [11] that a dedicated effort might determine $\sin^2 \theta_W(m_Z)_{\overline{MS}}$ to ± 0.00008 if the structure functions can be understood well enough. Of course, in the very long term, a polarized e^+e^- linear collider with high luminosity at the Z pole would be capable of reaching ± 0.00002 via left-right asymmetries. That is a worthy goal that should be pursued; but it will not happen overnight.

Resolving the $\sin^2 \theta_W(m_Z)_{\overline{MS}}$ ambiguity has such important consequences that it must be resolved as soon as possible.

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