and $\hat{s}^2_Z = 0.2311 \pm 0.0007$, $\alpha_s = 0.099 \pm 0.013$. Combining with the CDF direct value of m_t, one does not need to introduce a reference value for m_t. That is, one can determine $S_{\rm new}$, $T_{\rm new}$, $U_{\rm new}$, and γ_b directly, in a simultaneous fit with $\hat{s}^2_Z$, α_s, and m_t. One obtains

$$\begin{aligned} S_{\rm new} &= -0.42 \pm 0.36^{-0.08}_{+0.17} \\ T_{\rm new} &= -0.35 \pm 0.44^{+0.18}_{-0.11} \\ U_{\rm new} &= -1.3 \ \ \pm 1.3 \\ \gamma_b &= \ \ 0.032 \pm 0.017\ , \end{aligned} \tag{27.20b}$$

and the allowed region in $S'_{\rm new} - T'_{\rm new}$ is shown in Fig. 27.1. ($S'_{\rm new}$ includes the M_H dependence explicitly, $S'_{\rm new} \equiv S_{\rm new} + \Delta S_{\rm Higgs}$, and similarly for $T'_{\rm new}$, see Eq. (27.16).) The values in Eq. (27.20*b*) are almost identical to those in Eq. (27.20*a*) except for a small increase in the errors due to the variation of m_t around the best fit value 175 ± 16. The second error bars represent the uncertainty due to M_H ranging from the reference value of 300 GeV to 1000 (upper) or 60 (lower) GeV. From Eq. (27.20*b*) one obtains $S_{\rm new} < 0.09\,(+0.23)$, and $T < 0.27\,(0.43)$ at 90 (95)% CL. If one requires the constraint $S_{\rm new} \geq 0$ then (as in QCD-like technicolor models) $S_{\rm new} < 0.38\,(0.46)$. Allowing arbitrary $S_{\rm new}$, only one heavy generation of ordinary fermions is allowed at 95% CL. The favored value of $S_{\rm new}$ is problematic for technicolor models with many techni-doublets and QCD-like dynamics, as is the value of γ_b. Although $S_{\rm new}$ is consistent with zero, the electroweak asymmetries, especially the SLD left-right asymmetry, favor $S_{\rm new} < 0$. The simplest origin of $S_{\rm new} < 0$ would probably be an additional heavy Z' boson [5], which could mimic $S_{\rm new} < 0$.

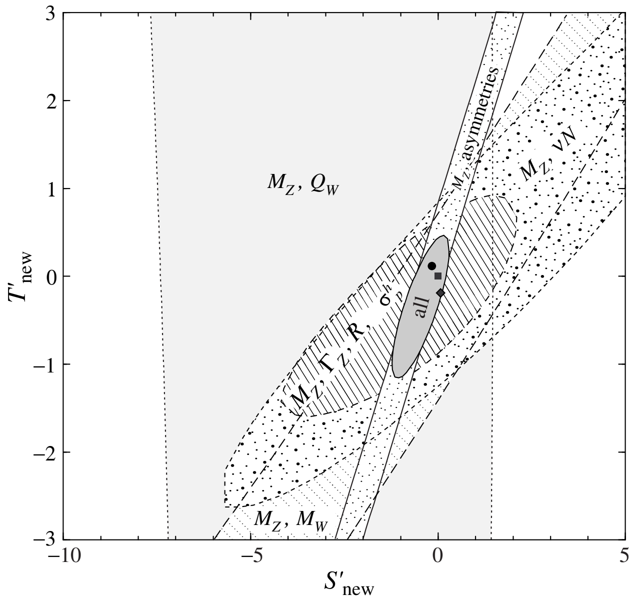

Figure 27.1: 90% CL limits on $S'_{\rm new}$ and $T'_{\rm new}$ from various inputs. $S'_{\rm new}$ and $T'_{\rm new}$ have the m_t dependence removed (it is fit separately), but contain the small M_H dependence. In the Standard Model, one expects $S'_{\rm new} = T'_{\rm new} = 0$ for $M_H = 300$ GeV (indicated by a box). The expected values for $M_H = 60$ GeV (circle) and 1000 GeV (diamond) are also indicated. The fit to M_W and M_Z assumes $U = 0$, while U is arbitrary in the other fits.

There is no simple parametrization that is powerful enough to describe the effects of every type of new physics on every possible observable. The S, T, and U formalism describes many types of heavy physics which affect only the gauge self-energies, and it can be applied to all precision observables. However, new physics which couples directly to ordinary fermions, such as heavy Z' bosons or mixing with exotic fermions cannot be fully parametrized in the S, T, and U framework. It is convenient to treat these types of new physics by parametrizations that are specialized to that particular class of theories (*e.g.*, extra Z' bosons), or to consider specific models (which might contain, *e.g.*, Z' bosons and exotic fermions with correlated parameters). An alternate formalism [21] defines parameters, ϵ_1, ϵ_2, ϵ_3, ϵ_b in terms of the specific observables M_W/M_Z, the leptonic Z width $\Gamma_{\ell\ell}$, the forward-backward asymmetry [2] at the Z pole, $A^{(0,\ell)}_{FB}$, and R_b. The definitions coincide with those for $\hat{\epsilon}_i$ in Eqs. (27.12) and (27.13) for physics which affects gauge self-energies only, but the ϵ's now parametrize arbitrary types of new physics and can also incorporate all of the effects of m_t and M_H on the four basic observables. However, the ϵ's are not related to other observables unless additional model-dependent assumptions are made. Another approach [22] parametrizes new physics in terms of gauge-invariant sets of operators. It is especially powerful in studying the effects of new physics on nonabelian gauge vertices. The most general approach introduces deviation vectors [24]. Each type of new physics defines a deviation vector, the components of which are the deviations of each observable from its Standard Model prediction, normalized to the experimental uncertainty. The length (direction) of the vector represents the strength (type) of new physics.

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