including the direct constraint $M_H \geq 60$ GeV, the best fit is for $M_H = 60$ GeV, with the weak limit $M_H < 840$ GeV at 90% CL. The value of $\widehat{s}^{\,2}_Z = 0.2319 \pm 0.0005$ is in striking agreement with the prediction 0.233 ± 0.003 of grand unified theories based on the minimal supersymmetric extension of the Standard Model, but disagrees with the prediction 0.210 ± 0.003 of nonsupersymmetric unified theories.

One can also determine the radiative correction parameters Δr: including the CDF data, one obtains $\Delta r = 0.040 \pm 0.004$ and $\Delta\widehat{r}_W = 0.068 \pm 0.003$, where the error includes m_t and M_H, in excellent agreement with the predictions 0.041 ± 0.007 and 0.0705 ± 0.0003.

Table 26.3: Principal LEP and other recent observables, compared with the Standard Model predictions for $M_Z = 91.187 \pm 0.007$ GeV, 60 GeV $< M_H <$ 1 TeV, the global best fit value $m_t = 169^{+16}_{-18}$ GeV (for $M_H = 300$ GeV), and $\alpha_s = 0.012 \pm 0.007$. The LEP averages [38] of the ALEPH, DELPHI, L3, and OPAL results include common systematic errors and correlations [38]. $\overline{s}_\ell(A^{(0,q)}_{FB})$ is the effective angle extracted from the quark-charge asymmetry. A^0_{LR} includes both 1992 and 1993 data. The more accurate 1993 run only yields 0.1656 ± 0.0076. In the fits, the values of $A^0_e(P_\tau)$ and A^0_{LR} are combined to give 0.161 ± 0.012, including a scale factor of 1.7. The values of $\Gamma(\ell\overline{\ell})$, Γ(had), and Γ(inv) are not independent of Γ_Z, R, and $\sigma_{\rm had}$. The M_W and M_W/M_Z values are from the PDG fit. In the fits shown here the (uncorrelated) values from the individual experiments are used. The two values of s^2_W from deep-inelastic scattering are from CCFR [25] and the global average, respectively. The $g^{\nu e}_{V,A}$ are from CHARM II [28]. The second error in Q_W (for cesium) is theoretical [31]. Older low-energy results are not listed but are included in the fits. In the Standard Model predictions, the first uncertainty is from M_Z and Δr, while the second is from m_t and M_H. The $\Delta\alpha_s = 0.007$ uncertainty leads to additional errors of 0.004 (Γ_Z), 0.05 (R), 0.04 (σ), 3.7 (Γ(had)).

Quantity	Value	Standard Model
M_Z (GeV)	91.187 ± 0.007	input
Γ_Z (GeV)	2.490 ± 0.007	$2.493 \pm 0.001 \pm 0.004$
R	20.76 ± 0.05	$20.74 \pm 0.01 \pm 0.005$
$\sigma_{\rm had}(nb)$	41.55 ± 0.14	$41.48 \pm 0.01 \pm 0.01$
R_b	0.2210 ± 0.0029	$0.2157 \pm 0 \pm 0.0004$
R_c	0.171 ± 0.020	$0.171 \pm 0 \pm 0$
$A^{(0,\ell)}_{FB}$	0.0159 ± 0.0018	$0.0151 \pm 0.0005 \pm 0.0010$
$A^0_\tau(P_\tau)$	0.141 ± 0.021	$0.142 \pm 0.003 \pm 0.005$
$A^0_e(P_\tau)$	0.127 ± 0.025	$0.142 \pm 0.003 \pm 0.005$
$A^{(0,b)}_{FB}$	0.107 ± 0.013	$0.0995 \pm 0.002 \pm 0.003$
$A^{(0,c)}_{FB}$	0.058 ± 0.022	$0.071 \pm 0.002 \pm 0.003$
A^0_{LR}	0.1637 ± 0.0075	$0.142 \pm 0.003 \pm 0.005$
$\overline{s}^2_\ell(A^{(0,q)}_{FB})$	0.2320 ± 0.0016	$0.2322 \pm 0.0003 \pm 0.0006$
$\Gamma(\ell\overline{\ell})$ (MeV)	83.84 ± 0.27	$83.90 \pm 0.02 \pm 0.16$
Γ(had) (MeV)	1740.7 ± 5.9	$1739.8 \pm 1 \pm 3$
Γ(inv) (MeV)	498.2 ± 4.2	$501.3 \pm 0.4 \pm 0.8$
M_W (GeV)	80.22 ± 0.26	$80.29 \pm 0.02 \pm 0.11$
M_W/M_Z	0.8798 ± 0.0028	$0.8805 \pm 0.0002 \pm 0.001$
Q_W	$-71.04 \pm 1.58 \pm 0.88$	$-72.92 \pm 0.07 \pm 0.07$
$s^2_W = 1 - \frac{M^2_W}{M^2_Z}$	0.2218 ± 0.0059 0.2260 ± 0.0048	$0.2247 \pm 0.0003 \pm 0.0021$
$g^{\nu e}_A$	-0.503 ± 0.018	$-0.506 \pm 0 \pm 0.001$
$g^{\nu e}_V$	-0.025 ± 0.019	$-0.037 \pm 0 \pm 0.001$

Table 26.4: Values obtained for s^2_W (on-shell) and $\widehat{s}^{\,2}_Z(\overline{\rm MS})$ from various reactions assuming the global best fit value $m_t = 169^{+16}_{-18}$ GeV (for $M_H = 300$ GeV), and $\alpha_s = 0.120 \pm 0.007$. The uncertainties include the effect of 60 GeV $< M_H <$ 1 TeV.

Reaction	s^2_W	$\widehat{s}^{\,2}_Z$
M_Z	0.2247 ± 0.0021	0.2320 ± 0.0006
$M_W, M_W/M_Z$	0.2264 ± 0.0025	0.2338 ± 0.0022
Γ_Z, $R, \sigma_{\rm had}$	0.2250 ± 0.0018	0.2322 ± 0.0006
$A^{(0,\ell)}_{FB}$	0.2243 ± 0.0018	0.2315 ± 0.0011
LEP asymmetries	0.2245 ± 0.0017	0.2317 ± 0.0008
A^0_{LR}	0.2221 ± 0.0017	0.2292 ± 0.0010
Deep inelastic (isocalar)	0.2260 ± 0.0048	0.233 ± 0.005
$\nu_\mu(\overline{\nu}_\mu)p \to \nu_\mu(\overline{\nu}_\mu)p$	0.205 ± 0.031	0.212 ± 0.032
$\nu_\mu(\overline{\nu}_\mu)e \to \nu_\mu(\overline{\nu}_\mu)e$	0.224 ± 0.009	0.231 ± 0.009
atomic parity violation	0.216 ± 0.008	0.223 ± 0.008
SLAC eD	0.216 ± 0.017	0.223 ± 0.018
All data	0.2247 ± 0.0019	0.2319 ± 0.0005

Table 26.5: Values of $\widehat{s}^{\,2}_Z$ and s^2_W (in parentheses), α_s, and m_t for various combinations of observables. The central values are for $M_H = 300$ GeV, and the second set of errors is for $M_H \to 1000(+), 60(-)$.

Data	$\widehat{s}^{\,2}_Z$ (s^2_W)	α_s (M_Z)	m_t (GeV)
All indirect	0.2319(5)(2) (0.2247 ± 0.0019)	0.120(7)(2)	169^{+16+17}_{-18-20}
Indirect + CDF direct	0.2319(4)(3) (0.2244 ± 0.0013)	0.120(6)(2)	172^{+11+8}_{-12-9}
All LEP	0.2322(6)(2) (0.2256 ± 0.0023)	0.121(7)(2)	163^{+19+17}_{-22-20}
SLD + M_Z	0.2294(9)(1) (0.2154 ± 0.0032)	—	238^{+20+17}_{-23-20}
Z pole (LEP + SLD)	0.2318(5)(2) (0.2241 ± 0.0021)	0.120(7)(2)	175^{+18+17}_{-19-20}

26.5. Deviations from the Standard Model

The Z pole, W mass, and neutral-current data can be used to search for and set limits on deviations from the Standard Model.

For example, the relation between M_W and M_Z is modified if there are Higgs multiplets with weak isospin $> 1/2$ with significant vacuum expectation values. In order to calculate to higher orders in such theories one must define a set of four fundamental renormalized parameters. It is convenient to take these as α, G_F, M_Z, and M_W, since M_W and M_Z are directly measurable. Then $\widehat{s}^{\,2}_Z$ and ρ_0 can be considered dependent parameters defined by

$$\widehat{s}^{\,2}_Z \equiv A^2_0/M^2_W(1 - \Delta\widehat{r}_W) \tag{26.39}$$

and

$$\rho_0 \equiv M^2_W/(M^2_Z\,\widehat{c}^{\,2}_Z\,\widehat{\rho}) \; . \tag{26.40}$$

Provided that the new physics which yields $\rho_0 \neq 1$ is a small perturbation which does not significantly affect the radiative corrections, ρ_0 can be regarded as a phenomenological parameter which multiplies G_F in Eqs. (26.12)–(26.14), (26.28), and Γ_Z in