SUSY AND PRECISION ELECTROWEAK DATA

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The present Standard Model fit of precision data has a low confidence level, and is characterized by a few inconsistencies. We look for supersymmetric effects that could improve the agreement among the electroweak precision measurements and with the direct lower bound on the Higgs mass. We find that this is the case particularly if the 3.6σ discrepancy between $\sin^2\theta_{eff}$ from leptonic and hadronic asymmetries is finally settled more on the side of the leptonic ones. After the inclusion of all experimental constraints, our analysis selects light sneutrinos, with masses in the range 55–80 GeV, and charged sleptons with masses just above their experimental limit, possibly with additional effects from light gauginos. The phenomenological implications of this scenario are discussed.

I report in this talk on our recent work [1] about possible SUSY effects in electroweak precision tests. The results of the electroweak precision tests as well as of the searches for the Higgs boson and for new particles performed at LEP and SLC have now been presented in a close to final form. Taken together with the measurements of m_t, m_W and the searches for new physics at the Tevatron, and with some other data from low energy experiments, they form a very stringent set of precise constraints to compare with the Standard Model (SM) or with any of its conceivable extensions. When confronted with these results, on the whole the SM performs rather well, so that it is fair to say that no clear indication for new physics emerges from the data. However, if we look at the results in detail, there are a number of features that are either not satisfactory or could indicate the presence of small new physics effects.

One problem is that the two most precise measurements of $\sin^2\theta_{eff}$ from A_{LR} and A^b_{FB} differ by 3.5 σ [2]. More in general, there appears to be a discrepancy between $\sin^2\theta_{eff}$ measured from leptonic asymmetries and from hadronic asymmetries. The result from A_{LR} is actually in good agreement with the leptonic asymmetries measured at LEP, while all hadronic asymmetries are better compatible with the result of A^b_{FB}. It is well known that this discrepancy is not likely to be explained by some new physics effect in the $b\bar{b}Z$ vertex. In fact A^b_{FB} is the product of lepton- and b-asymmetry factors: $A^b_{FB} \propto A_\ell A_b$, where $A_f = 2g^f_A g^f_V/({g^f_A}^2 + {g^f_V}^2)$. The sensitivity of A^b_{FB} to A_b is limited, because the A_ℓ factor is small, so that, in order to reproduce the measured discrepancy, the new effect should induce a large change of the b couplings with respect to the SM. But then this effect should be clearly visible in the direct measurement of A_b performed at SLD using the LR polarized b asymmetry, even within the moderate precision of this result, and it should also appear in the accurate measurement of $R_b \propto {g^b_A}^2 + {g^b_V}^2$. Neither A_b nor R_b show deviations of the expected size. One concludes that most probably the observed discrepancy is due to a large statistical fluctuation and/or to an experimental problem. Indeed, the measurement of A^b_{FB} not only requires b identification, but also distinguishing b from $\bar{b}$, and therefore the systematics involved are different than in the measurement of R_b. At any rate, the disagreement between A^b_{FB} and A_{LR} implies that the ambiguity in the measured value of $\sin^2\theta_{eff}$ is larger than the nominal error obtained from averaging all the existing determinations.

Another point of focus is the relation between the fitted Higgs mass and the lower limit on this mass from direct searches, $m_H > 113$ GeV, as it was recently stressed in ref. [3]. The central value of the fitted mass is systematically below the limit. In particular, given the experimental value of the top mass, the measured results for m_W (with perfect agreement between LEP and the Tevatron) and $\sin^2\theta_{eff}$ measured from leptonic asymmetries, taken together with the results on the Z_0 partial widths, push the central value of m_H very much down. In fact, if one arbitrarily excludes $\sin^2\theta_{eff}$ measured from the hadronic asymmetries, the fitted value of m_H becomes only marginally consistent with the direct limit, to a level that depends on the adopted value and the error for $\alpha_{QED}(m_Z)$. Consistency is reinstated if the results from hadronic asymmetries are also included, because they drive the fitted m_H value towards somewhat larger values.

In conclusion, if one takes all available measurements into account the χ^2 of the SM fit is not good, with a probability of about 4%, partly because the measurements of $\sin^2\theta_{eff}$ are not in good agreement among them. If, on the other hand, one only takes the results on $\sin^2\theta_{eff}$ from the leptonic asymmetries, then the χ^2 of the SM fit considerably improves, but the consistency with the direct limit on m_H becomes marginal.

In Ref. [1] we enlarged the discussion of the data from the SM to the Minimal Supersymmetric Standard Model (MSSM). We looked for regions of the MSSM parameter space where the corrections are sufficiently large and act in the direction of improving the quality of the fit and the consistency with the direct limit on m_H with respect to the SM, especially in the most unfavourable case for the SM that the results on $\sin^2\theta_{eff}$ from the hadronic asymmetries are discarded. We show that, if sleptons (and, to a lesser extent, charginos and neutralinos) have masses close to their present experimental limits, it is possible to considerably improve the overall picture. In particular the possible MSSM effects become sizeable if we allow the sneutrino masses to be as small as allowed by the direct limits on $m^2_{\tilde\nu}$ and by those on charged slepton masses, which are related by $m^2_{\tilde\ell^\pm_L} = m^2_{\tilde\nu} + m^2_W|\cos 2\beta|$. At moderately large values of $\tan\beta$ (*i.e.* for $|\cos 2\beta| \sim 1$), light sneutrinos with masses as low as 55 GeV are not excluded by present limits, while charged sleptons must be heavier than 96 GeV. These low values of the sneutrino mass can still be compatible with the neutralino being the lightest supersymmetric particle. We recall that $\tan\beta \gtrsim 2-3$ is required by LEP, and large $\tan\beta$ and light sleptons are indicated by the possible deviation observed by the recent Brookhaven result [4] on the muon $g-2$, if this discrepancy is to be explained by a MSSM effect. We find it interesting that, by taking seriously the small hints that appear in the present data, one can pinpoint a region of the MSSM which match the data better than the SM, and is likely to be within reach of the present run of the Tevatron and, of course, of the LHC.

For this analysis in the MSSM we used the technique of the epsilon parameters ϵ_1, ϵ_2, ϵ_3 and ϵ_b, introduced in ref. [5]. The variations of ϵ_1, ϵ_2 and ϵ_3 due to new physics contributions are proportional to the shifts in the T, U, and S parameters [6], respectively, if one keeps only oblique contributions (*i.e.* terms arising from vacuum polarization diagrams), expanded up to the first power in the external momentum squared. But in the MSSM not all important contributions are of this kind. We recall that the starting point of the epsilon analysis is the unambiguous definition of the ϵ_i in terms of four basic observables that were chosen to be $\sin^2\theta_{eff}$ from A^μ_{FB}, Γ_μ, m_W and R_b. Given the experimental values of these quantities, the corresponding experimental values of the ϵ_i follow, independent of m_t and m_H, with an error that, in addition to the propagation of the experimental errors, also includes the effect of the present ambiguities in $\alpha_s(m_Z)$ and $\alpha_{QED}(m_Z)$.

If one assumes lepton universality, which is well supported by the data within the present accuracy, then the combined results on $\sin^2\theta_{eff}$ from all leptonic asymmetries can be adopted together with the combined leptonic partial width Γ_ℓ. At this level the epsilon analysis is model-independent within the stated lepton universality assumption. As a further step we can observe that by including the information on the hadronic widths arising from Γ_Z, σ_h, R_ℓ, the central values of the ϵ_i are not much changed (with respect to the error size) and the errors are slightly decreased. Thus one may decide of including or not including these data in the determination of the ϵ_i, without affecting the results.

Different is the case of including the results from the hadronic asymmetries in the combined value of $\sin^2\theta_{eff}$. In this case, obviously, the determination of ϵ_i is sizeably affected and one remains with the alternative between an experimental problem or a bizarre effect of some new physics in the b coupling (not present in the MSSM). But if we remain within the first stage of purely leptonic measurements plus m_W and R_b, the ϵ_i analysis is quite general and, in particular, is independent of an assumption of oblique correction dominance.

The comparison with the SM can be repeated in the context of the ϵ_i (see Fig. 1). The predicted theoretical values of the ϵ_i in the SM depend on m_H and m_t, while they are practically independent of $\alpha_s(m_Z)$ and $\alpha_{QED}(m_Z)$. If we only take the leptonic measurements of $\sin^2\theta_{eff}$, for $m_H = 113$ GeV and $m_t = 174.3$ GeV one finds that the experimental value of ϵ_1 agrees within the error with the prediction, while both ϵ_2 and ϵ_3 are below the theoretical expectation by about $1\ \sigma$. We recall that m_W is related to ϵ_2 and the fact that the experimental value is below the prediction for this quantity corresponds to the statement that m_W would prefer a value of m_H much smaller than $m_H = 113$ GeV. Similarly the smallness of the fitted value of ϵ_3 with respect to the prediction has to do with the marked preference for a light m_H of $\sin^2\theta_{eff}$ from all leptonic asymmetries. The agreement between fitted value and prediction for ϵ_1, which, contrary to ϵ_2 and ϵ_3, contains a quadratic dependence on m_t, reflects the fact that the fitted value of m_t is in agreement with the measured value. The other variable that depends quadratically on m_t is ϵ_b. The agreement of the fitted and predicted values of ϵ_b reflects the corresponding present normality of the results for R_b.

Now we want to investigate whether low-energy supersymmetry can reconcile a Higgs mass above the direct experimental limit with a good χ^2 fit of the electroweak data, in the case of $\sin^2\theta_{eff}$ near the value obtained from leptonic asymmetries. Our approach is to discard the measure-

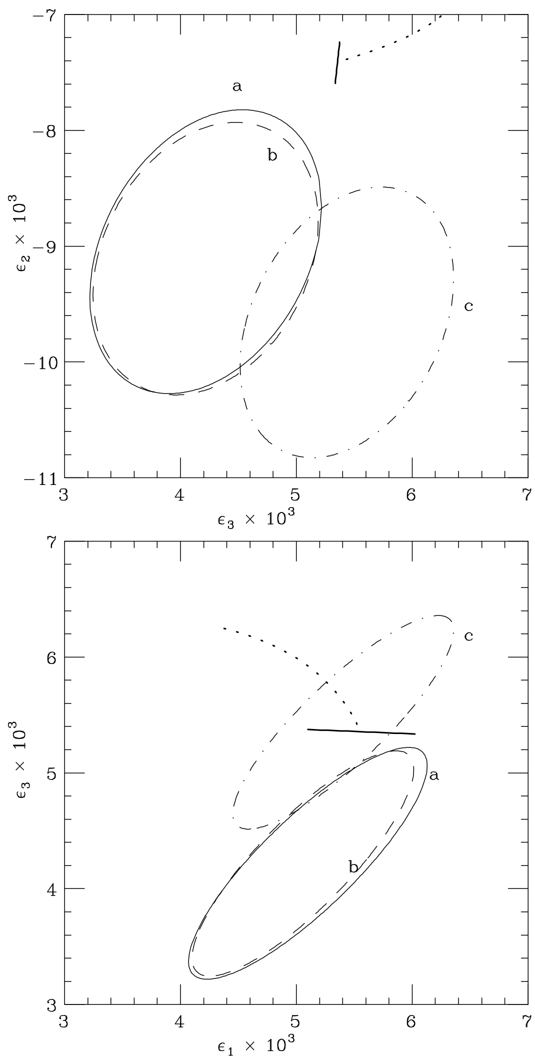

Figure 1. One-sigma ellipses in the $\epsilon_3 - \epsilon_2$ (left) and in the $\epsilon_1 - \epsilon_3$ (right) planes obtained from: a. m_W, Γ_ℓ, $\sin^2\theta_{eff}$ from all leptonic asymmetries, and R_b; b. the same observables, plus the hadronic partial widths derived from Γ_Z, σ_h and R_ℓ; c. as in b., but with $\sin^2\theta_{eff}$ also including the hadronic asymmetry results. The solid straight lines represent the SM predictions for $m_H = 113$ GeV and m_t in the range 174.3 ± 5.1 GeV. The dotted curves represent the SM predictions for $m_t = 174.3$ GeV and m_H in the range 113 to 500 GeV..

ment of A_{FB}^b, which cannot be reproduced by conventional new physics effects, fix the Higgs mass above its present limit, and look for supersymmetric corrections that can fake a very light SM Higgs boson. As we have discussed in the previous section and as summarized in fig. 1, this can be achieved if the new physics contributions to the ϵ parameters amount to shifting ϵ_2 and ϵ_3 down by slightly more than 1 σ, while leaving ϵ_1 essentially unchanged.

Squark loops cannot induce this kind of shifts in the ϵ parameters, since their leading effect is a positive contribution to ϵ_1. Thus, we will assume that all squarks are heavy, with masses of the order of one TeV. Since the mass of the lightest Higgs m_H receives a significant contribution from stop loops, we can treat m_H as an independent parameter and, in our analysis, we fix $m_H = 113$ GeV. Varying the pseudoscalar Higgs mass m_A does not modify the results of our fit, and therefore we fix $m_A = 1$ TeV. The choice of the right-handed slepton mass has also an insignificant effect on the fit. Therefore, we are left with four relevant supersymmetric free parameters: the weak gaugino mass M_2, the higgsino mass μ, the ratio of the Higgs vacuum expectation values $\tan\beta$ (which are needed to describe the chargino–neutralino sector), and a supersymmetry-breaking mass for the left-handed sleptons, $\tilde{m}_{\ell_L}$ (lepton flavour universality is assumed). The choice of the B-ino mass parameter M_1 does not significantly affect our results and, for simplicity, we have assumed the gaugino unification relation $M_1 = \frac{5}{3}M_2\tan^2\theta_W$.

As described in Ref. [1], we have computed the supersymmetric one-loop contributions to ϵ_1, ϵ_2 and ϵ_3. Figure 2 shows the range of the ϵ parameters that can be spanned by varying M_2, μ, $\tan\beta$, and $\tilde{m}_{\ell_L}$, consistently with the present experimental constraints. We have imposed a limit on charged slepton masses of 96 GeV, on chargino masses of 103 GeV, and on the cross section for neutralino production $\sigma(e^+e^- \to \chi_1^0\chi_2^0 \to \mu^+\mu^-/E) < 0.1$ pb. We have also required that the supersymmetric contribution to the muon anomalous magnetic moment, $a_\mu = (g-2)/2$, lie within the range $0 < \delta a_\mu < 7.5\times10^{-9}$. As apparent from fig. 2, light particles in the chargino–neutralino sector and light left-handed sleptons shift the values of ϵ_i in the favoured direction, and by a sufficient amount to obtain a satisfactory fit.

In fig. 3 we show an alternative presentation of our results directly in terms of the shifts in the observables m_W, $\sin^2\theta_{eff}$ and Γ_ℓ induced by supersymmetry.[1] For reference, we also display in fig. 3 the difference between the measured values of the observables (excluding the hadronic asymmetries) and the corresponding SM predictions for $m_H = 113$ GeV, $m_t = 174.3$ GeV. Supersymmetric contributions can bring the theoretical predictions in perfect agreement with the data. An interesting observation is that sparticle effects can increase m_W by δm_W up to ~ 100 MeV, which corresponds to approximately three standard deviations, and decrease $\sin^2\theta_{eff}$ by $\delta\sin^2\theta_{eff}$ up to about -8×10^{-4} ($\sim 4\ \sigma$). Note the marked anticorrelation between δm_W and $\delta\sin^2\theta_{eff}$. Γ_ℓ is moved upwards, but only by less than 90 keV, or about 1 σ.

To summarize, the request of an improved electroweak data fit is making precise demands on the supersymmetric mass spectrum. The left-handed charged sleptons have to be very close to their experimental bounds, the sneutrino mass is selected to be below about 80 GeV, the squarks are in the TeV range, and $\tan\beta \gtrsim 4$, while there is no information on right-handed slepton masses. The lightest chargino, preferably a gaugino state with mass below about 150 GeV, further improves the fit. This range of supersymmetric parameters is very adequate in explaining the alleged discrepancy between the experimental and theoretical values of the muon anomalous magnetic moment [4]. In practice, requiring the supersymmetric contribution to $g-2$ to be in the range indicated by the data amounts to determining a precise value of $\tan\beta$ and selecting a sign (positive in our conventions) of the parameter μ. We recall that, for moderately large $\tan\beta$, the negative sign of μ is disfavoured by the present measurements of the $B \to X_s\gamma$ branching ratio.

[1] A good approximation of the relations between shifts in the physical observables and in the ϵ parameters is given by $\delta m_W = (0.53\delta\epsilon_1 - 0.37\delta\epsilon_2 - 0.32\delta\epsilon_3)\times10^5$ MeV; $\delta\Gamma_\ell = (1.01\delta\epsilon_1 - 0.22\delta\epsilon_3)\times10^5$ keV; $\delta\sin^2\theta_{eff} = -0.33\delta\epsilon_1 + 0.43\delta\epsilon_3$.

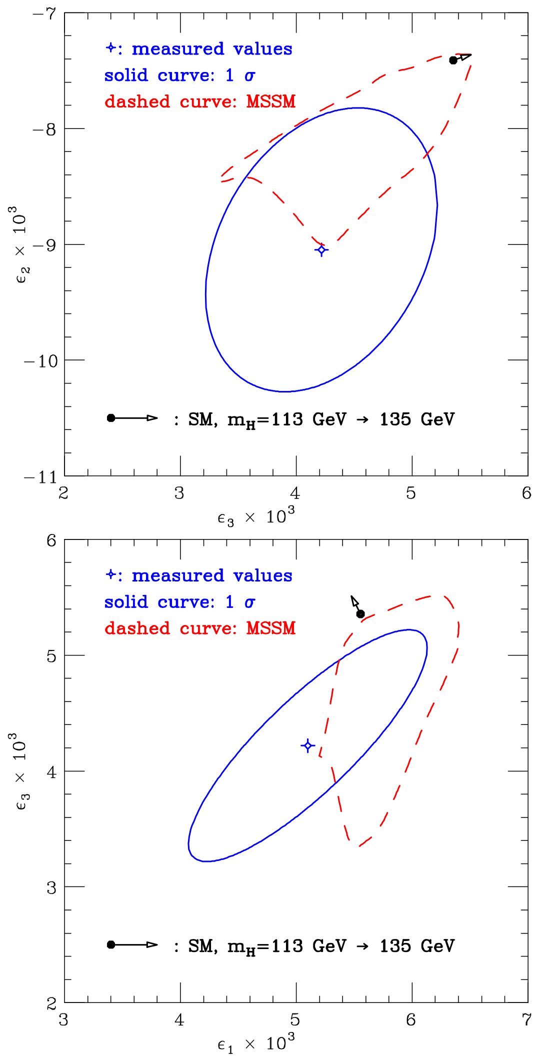

Figure 2. Measured values (cross) of ϵ_3 and ϵ_2 (left) and of ϵ_1 and ϵ_3 (right), with their 1 σ region (solid ellipses), corresponding to case a of fig. 1. The area inside the dashed curves represents the MSSM prediction for $m_{\tilde{e}_L}$ between 96 and 300 GeV, m_{χ^+} between 105 and 300 GeV, -1000 GeV $< \mu <$ 1000 GeV, $\tan\beta = 10$, $m_{\tilde{e}_L} = 1$ TeV. and $m_A = 1$ TeV.

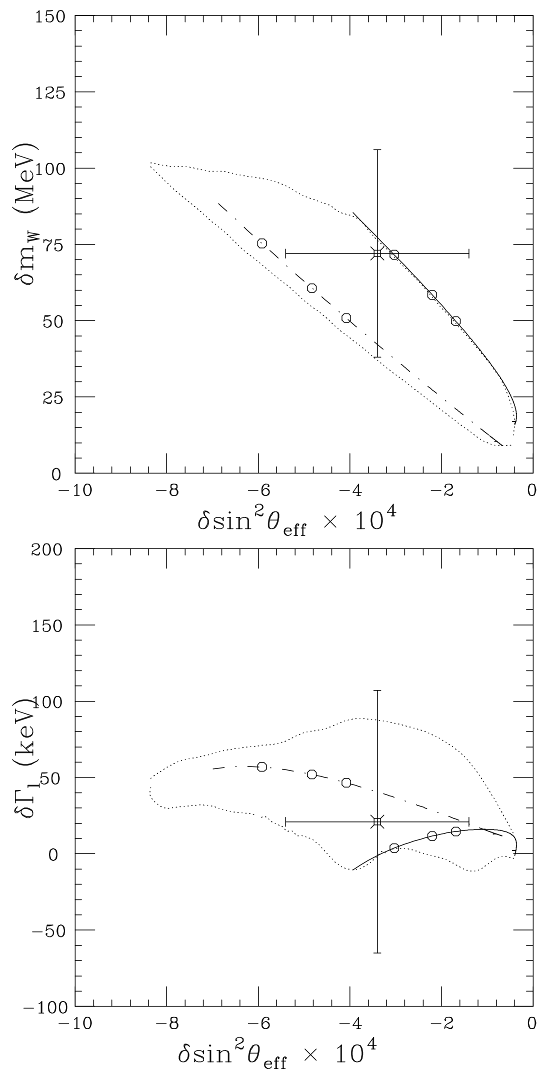

Figure 3. *The area inside the dotted curves represents the shifts in the values of* $\sin^2\theta_{eff}$, m_W *and* Γ_ℓ *induced by supersymmetric corrections, for the same parameter region as in fig. 2. The shifts necessary to reproduce the central values of the data with* $m_t = 174.3$ *GeV and* $m_H = 113$ *GeV are also shown, together with the corresponding experimental errors. The dot-dashed lines are obtained by varying the left slepton masses, with all other supersymmetric particle decoupled. The solid curve is obtained analogously, but also keeping a gaugino-like chargino of* 105 *GeV. In each curve, the circles correspond to* $m_{\tilde{\nu}} = 60, 70, 80$ *GeV from left to right.*

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