Global Electroweak Fits in the SM and MSSM

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ABSTRACT: A global statistical χ^2 analysis of all electroweak data including new data on the anomalous magnetic moment of the muon and the $b \to X_s\gamma$ decay rate in both the SM and the MSSM has been performed. The total χ^2 of the MSSM is better than in the SM, mainly because of the W-mass, a_μ and $b \to X_s\gamma$, although the total probability is similar in both models due to the larger number of parameters in the MSSM.

1. Introduction

A few year ago a complete electroweak fit program including all possible supersymmetric corrections in the Minimal Supersymmetric Model (MSSM) was developed, mainly to investigate the so-called R_b deviation of the Standard Model (SM)[1]. At present R_b shows no significant deviation from the SM, but the present total χ^2 of all electroweak data is not excellent[2]. In addition, if the new measurements of the anomalous magnetic moment[3] and $b \to X_s\gamma$ [7] are included, the SM fit becomes worse. It is the purpose of the present paper to include these new measurements in the SM fits and compare the SM fit with the MSSM fit.

2. Experimental Data

A summary of the most recent electroweak data from colliders can be found in the report from the Electroweak Working Group (EWWG)[2]. As mentioned above, we included in addition the anomalous magnetic moment of the muon a_μ, which was recently determined by the E821 collaboration from a measurement of g-2 using the polarization in the decays of muons in a muon storage ring. They found a_μ to be slightly above the SM prediction, the difference being $\Delta a_\mu = a_\mu^{exp} - a_\mu^{th} = (43 \pm 16) \cdot 10^{-10}$[3]. However, the largest SM contribution to a_μ comes from the radiative loop corrections to the electromagnetic coupling constant, which consist of an hadronic and leptonic part. The hadronic part cannot be calculated at low Q^2, since it is dominated by non-perturbative contributions of resonances to the photon self-energy. This part is determined from the low energy hadronic

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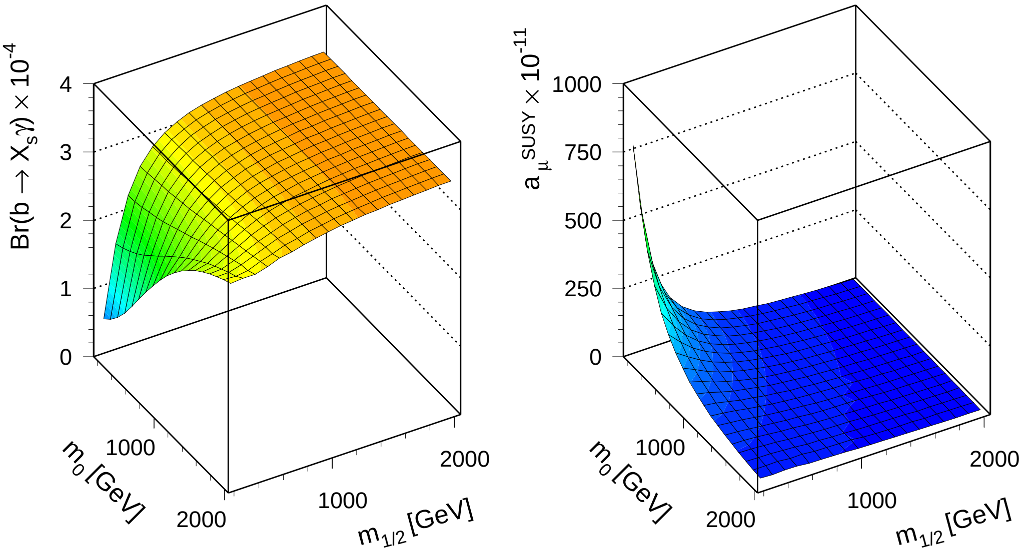

Figure 1: The values of $b \rightarrow X_s\gamma$ and a_μ^{SUSY} in the $m_0, m_{1/2}$ plane for positive μ and $\tan\beta\ = 35$ to be compared with experimental data $b \rightarrow X_s\gamma = (3.23 \pm 0.41) \cdot 10^{-4}$ and $a_\mu^{SUSY} = (333 \pm 173) \cdot 10^{-11}$. One can see that both $b \rightarrow X_s\gamma$ and a_μ^{SUSY} prefer relatively light sparticles.

cross section in e^+e^- annihilation. In Ref. [3] the newest data on e^+e^- annihilation from the Beijing accelerator were not yet considered. A recent evaluation including the newest e^+e^- annihilation data and assuming CVC reduces Δa_μ to $(33 \pm 17) \cdot 10^{-10}$[4]. We will conservatively use this reduced value in the fits below.

The most popular explanation for contributions outside the SM is given in the framework of SUSY theories[5]. Extensive Refs. can be found in [6]. SUSY contributions are also expected to affect the $b \rightarrow X_s\gamma$ rate, for which the most recent world average is: $b \rightarrow X_s\gamma$ =$(3.23 \pm 0.41) \times 10^{-4}$. This value is dominated by the recently published results from CLEO $((3.21 \pm 0.43_{stat} \pm 0.27_{sys} \pm 0.14_{mod}) \times 10^{-4})$ [7], which is consistent with their previous results and results from ALEPH[8] and BELLE[9]. The latter have considerably larger errors. Also the published CLEO result has larger errors than the ones quoted at Moriond 2001 and used in our previous publication[6]. The world average is slightly below, but consistent with a recent SM prediction by Gambino and Misiak of $(3.73 \pm 0.30) \times 10^{-4}$[10]. This value is somewhat higher than previous values, since it uses the running mass for the charm quark in the loops, while keeping the pole mass for the b-quark in the external lines. This gives an additional uncertainty, but the authors found a reduced scale dependence. In our present analysis we conservatively keep a theoretical error of $\pm 0.40 \times 10^{-4}$, but use $m_c(\mu)/m_b = 0.22$. This is not critical, since with the present large experimental error $b \rightarrow X_s\gamma$ hardly constrains the present fit. It is interesting to note, that the positive sign of μ and the relatively light sparticle spectrum, as required by a_μ, yield indeed a value of $b \rightarrow X_s\gamma$ slightly below the SM value, as shown in Fig. 1.

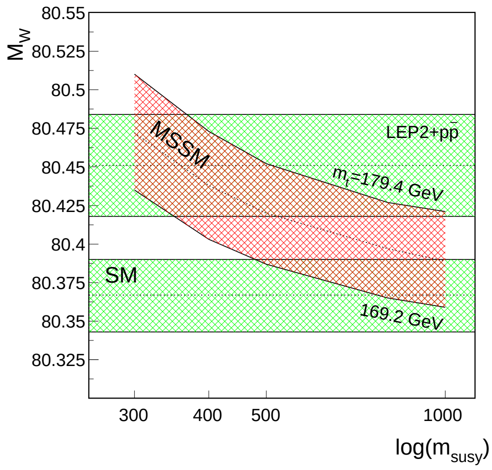

Figure 2: W mass versus sparticle masses, assuming all sparticles have the same mass. The horizontal bands represent the SM prediction from LEP I data and the direct measurements from the LEP II and $p\overline{p}$. The curved band is the MSSM prediction for the case that all sparticles have a given mass m_{susy}. Its width is determined by the uncertainty from the top mass.

The value of M_W becomes higher in the MSSM than in the SM, as shown in Fig. 2, in agreement with the direct measurements of M_W at LEP II and $p\overline{p}$.

None of these measurements, a_μ, $b \to X_s\gamma$ and M_W, show by itself a significant deviation from the SM, but since they all point to supersymmetric contributions, it is interesting to compare a global fit of all data in the SM and MSSM.

3. Fit Results

All electroweak variables were calculated in the SM using ZFITTER6.11[11] and in the MSSM using MSSMFITTER[1]. The deviation between data and theoretical prediction in the SM and MSSM are shown in Fig. 3. Clearly, the largest deviations occur in the forward-backward asymmetry A^b_{FB} for b-quarks and the left-right asymmetry, as measured with the polarized electron beam at SLAC. Both can be translated into a measurement of the electroweak mixing angle, which than turns out to be 3σ apart[2]. In the MSSM the situation does not improve. Since there is no preference for any of the data, we followed the procedure from the Particle Data Group to rescale the errors of A^b_{FB} and A_{LR} in such a way that their χ^2 contributions are about one. This hardly influences any of the other variables, as shown on the right hand side of Fig. 3, but increases the probability from below 5% to 25% (36%) in the SM (MSSM). Also the fitted parameters for the SM and MSSM, shown in Tables 1 and 2, are hardly affected by the rescaling, so this is not a critical issue. The fact that the SM fit prefers a Higgs mass slightly below the experimental limit is not an issue either, since requiring the Higgs mass to be above the limit from the direct searches ($m_h > 114$ GeV, [12]) only causes a minor shift in the top mass in the fit (see Table 1). The $\chi^2/d.o.f.$ in the MSSM is better than in the SM (14.2/13 for MSSM versus 20.5/17 for SM), mainly because of a_μ, $b \to X_s\gamma$ and M_W (see Fig. 3), but the probabilities are comparable due to the larger number of parameters in the MSSM as shown in the tables. The MSSM fits are not very sensitive to $\tan\beta$, provided it is large.

4. Conclusion

It has been shown that a SM electroweak fit including the anomalous magnetic moment and $b \to X_s\gamma$ yields a probability below 5%, even with conservative error estimates. This probability is improved in the MSSM, mainly because of a_μ, $b \to X_s\gamma$ adn M_W. However, in both cases the 3σ discrepancy in $\sin^2\theta_W$ from the A^b_{FB} and A_{LR} is the main source for

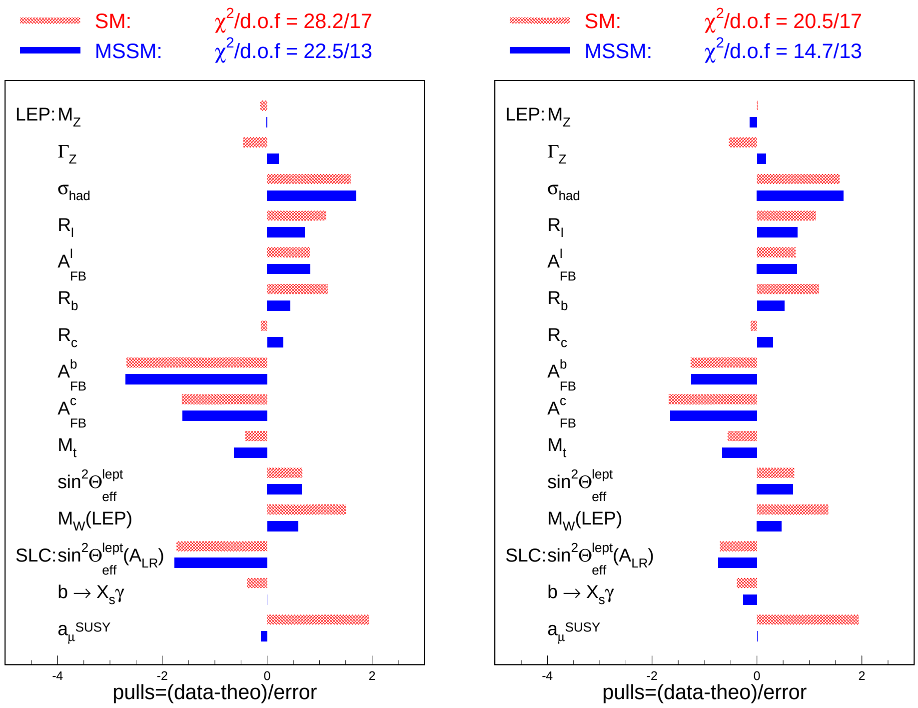

Figure 3: The pulls of the electroweak data for the SM and MSSM

Parameter	SM	SM + higgs	SM + higgs + rescaled
M_Z [GeV]	91.1877(21)	91.1877(21)	91.1875(21)
m_t [GeV]	175.4(3.8)	176.5(3.1)	177.2(3.2)
m_h [GeV]	99^{+53}_{-43}	114.1	114.1
$\alpha_s(M_Z)$	0.1186(27)	0.1185(26)	0.1184(25)
$\Delta\alpha^{(5)}_{\rm had}(M_Z)$	0.02764(33)	0.02763(31)	0.02757(33)
$\sin^2\theta$ ($\overline{\rm MS}$)	0.23140(15)	0.23145(10)	0.23141(12)
$\sin^2\theta^{\rm lept}_{\rm eff}$	0.23140(13)	0.23143(11)	0.23139(13)
M_W	80.393(18)	80.392(18)	80.398(19)
χ^2/d.o.f.	28.1/17	28.2/17	20.5/17
Probability	4.4%	4.3%	24.9%

Table 1: SM fit parameters. The first column uses the input data discussed in the text, which yields as most probable Higgs mass $m_h = 99$GeV; the second column requires the Higgs mass to be above the experimental limit of 114 GeV at 95% C.L.[12]. In both cases the probability of the fit is below 5%, which is mainly caused by the 3σ discrepancy between the $\sin^2\theta_W$ values from A^b_{FB} and A_{LR}. In the last column these errors have been rescaled (see text). The electroweak mixing angles and M_W are derived quantities, not fitted parameters.

the low probability. Since at present no arguments to doubt any of the measurements can be found, we tested the Particle Data Group's procedure to rescale the errors of these two measurements by the corresponding pull. This yields considerably improved fits, both in the SM and MSSM, without significant changes in the fitted parameters.

SUSY Parameters						
				rescaled		
Symbol	$\tan\beta = 35$	$\tan\beta = 20$	$\tan\beta = 50$	$\tan\beta = 35$	$\tan\beta = 20$	$\tan\beta = 50$
m_t[GeV]	177.5	176.0	176.8	177.7	177.0	176.8
α_s	0.1178	0.1179	0.1178	0.1177	0.1181	0.1184
$m_{\tilde{t}_1}$[GeV]	1099	956	968	799	825	690
$m_{\tilde{t}_2}$[GeV]	213	255	251	268	279	297
$m_{\tilde{b}_1}$[GeV]	1087	945	954	783	810	672
$m_{\tilde{b}_2}$[GeV]	1451	921	1213	1140	1170	1867
$m_{\tilde{q}}$[GeV]	1087	945	954	783	810	672
$m_{\tilde{l}}$[GeV]	575	385	894	598	393	716
$m_{\tilde{\chi}_1^\pm}$[GeV]	221	220	221	221	220	222
$m_{\tilde{\chi}_2^\pm}$[GeV]	105	107	105	105	107	105
M_W[GeV]	80.427	80.422	80.422	80.432	80.430	80.427
χ^2/d.o.f.	22.5/13	22.2/13	22.5/13	14.2/13	15.0/13	15.0/13
Probability	4.8%	5.2%	4.8%	32.8	35.9	30.5

Table 2: The best fit parameters for different $\tan\beta$ scenarios are given. The masses are independent, i.e. they were choosen at low energies independent of possible GUT relations. All sparticle masses, which had no influence on the fit, like gluino, pseudoscalar mass, were set to a large value (500 GeV). All squark masses were choosen to be equal, except for the stop masses. Also all slepton masses were choosen to be equal. In the last 3 columns the fit was repeated after rescaling the errors of A^b_{FB} and A^{LR} (see text). The chargino masses correspond to $\mu = 135$GeV and $M_2 = 170$GeV in the notation of Ref. [1]. Note the increase in M_W compared with the one in Table 1.

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