

Testing the MSSM with the Mass of the W Boson

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Abstract. We review the currently most accurate evaluation of the W boson mass, M_W , in the Minimal Supersymmetric Standard Model (MSSM). It consists of a full one-loop calculation, including the complex phase dependence, all available MSSM two-loop corrections as well as the full Standard Model result. We analyse the impact of the phases in the scalar quark sector on M_W and compare the prediction for M_W based on all known higher-order contributions with the experimental results.

Keywords. MSSM, W boson, precision observables

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1. Introduction

The relation between the massive gauge-boson masses, M_W and M_Z , in terms of the Fermi constant, G_μ , and the fine structure constant α , is of central importance for testing the electroweak theory:

$$\frac{G_\mu}{\sqrt{2}} = \frac{e^2}{8 \left(1 - \frac{M_W^2}{M_Z^2}\right) M_W^2} (1 + \Delta r). \quad (1)$$

It is usually employed for predicting M_W in the model under consideration, where the loop corrections enter via Δr . This prediction can then be compared with the corresponding experimental value. The current experimental accuracy for M_W , obtained at LEP and the Tevatron, is $\delta M_W = 29$ MeV (0.04%) [1,2]. This experimental resolution provides a high sensitivity to quantum effects involving the whole structure of a given model. The M_W – M_Z interdependence is therefore an important tool for discriminating between the Standard Model (SM) and its minimal supersymmetric extension (MSSM) [3], see Ref. [4] for a recent review. Within the MSSM the W boson mass, supplemented with other electroweak precision observables, exhibits a certain preference for a relatively low scale of supersymmetric particles, see e.g. Refs. [5,6]. Consequently, a precise theoretical prediction for M_W in terms of the model parameters is of utmost importance for present and future electroweak precision tests. A precise prediction for M_W in the MSSM is also needed as a part of the “SPA Convention and Project”, see Ref. [8].

In Ref. [7] the currently most up-to-date evaluation of M_W (i.e. Δr) in the MSSM has been presented. It consists of the full one-loop calculation, taking into account the complex phase dependence (the phases had been neglected so far in all previous calculations), the full SM result [9] and all available MSSM two-loop contributions [10–13]. The corresponding Fortran program for the calculation of precision observables within the MSSM will be made publicly available [14].

In the numerical analysis below, except for the parameter scan in Sect. 3., for simplicity we choose all soft SUSY-breaking parameters in the diagonal entries of the sfermion mass matrices to be equal ($\equiv M_{\tilde{f}}$). In the neutralino sector the GUT relation $M_1 = 5/3 s_w^2/c_w^2 M_2$ has been used (for real values). We have fixed the SM input parameters as¹

$$\begin{aligned} G_\mu &= 1.16637 \times 10^{-5}, & M_Z &= 91.1875 \text{ GeV}, & \alpha_s(M_Z) &= 0.117, \\ \alpha &= 1/137.03599911, & \Delta\alpha_{\text{had}}^{(5)} &= 0.02761, & \Delta\alpha_{\text{lep}} &= 0.031498, \\ m_t &= 172.5 \text{ GeV [16]} & m_b &= 4.7 \text{ GeV}, & m_\tau &= m_c = \dots = 0 \end{aligned} \quad (2)$$

The complex phases appearing in the MSSM are experimentally constrained by their contribution to low energy observables such as electric dipole moments (see Ref. [4] and references therein). Accordingly (using the convention that $\phi_{M_2} = 0$), in particular the phase ϕ_μ is tightly constrained [17], while the bounds on the phases of the third generation trilinear couplings are much weaker. The Higgs sector parameters are obtained from the program FeynHiggs2.2 [18].

2. Dependence on the complex phases in the squark sector

Here we show the dependence of M_W on the phases of the scalar quark sector. The physical phases are $\phi_{A_t} + \phi_\mu$ and $\phi_{A_b} + \phi_\mu$, where $A_{t,b}$ are the trilinear Higgs- \tilde{t}, \tilde{b} coupling and μ is the Higgs mixing parameter. We focus here on the mass shift δM_W arising from changing Δr by the amount Δr^{SUSY} ,

$$\delta M_W = -\frac{M_W^{\text{ref}}}{2} \frac{s_w^2}{c_w^2 - s_w^2} \Delta r^{\text{SUSY}}. \quad (3)$$

Here Δr^{SUSY} represents the one-loop contribution from the supersymmetric particles of the considered sector of the MSSM and $M_W^{\text{ref}} = 80.425 \text{ GeV}$, see Ref. [7] for more details.

The leading one-loop SUSY contributions to Δr arise from the \tilde{t}/\tilde{b} doublet. The complex parameters in the \tilde{t}/\tilde{b} sector are μ , A_t and A_b , entering via the off-diagonal entries of the \tilde{t} and \tilde{b} mass matrices, $X_{t,b}$. In Ref. [7] it has been shown at the analytical level that the phases $\phi_{X_{t,b}}$ drop out entirely in the full one-loop calculation of Δr and have no influence on M_W . Hence, the phases and absolute values of μ , A_t and A_b enter the sfermion-loop contributions (at one-loop order) only via a shift in the \tilde{t} and \tilde{b} masses and mixing angles.

¹Using the most up-to-date value for the top quark mass, $m_t = 171.4 \text{ GeV}$ [15], would lead to slightly lower absolute M_W values, while the impact on δM_W (see below) is negligible.

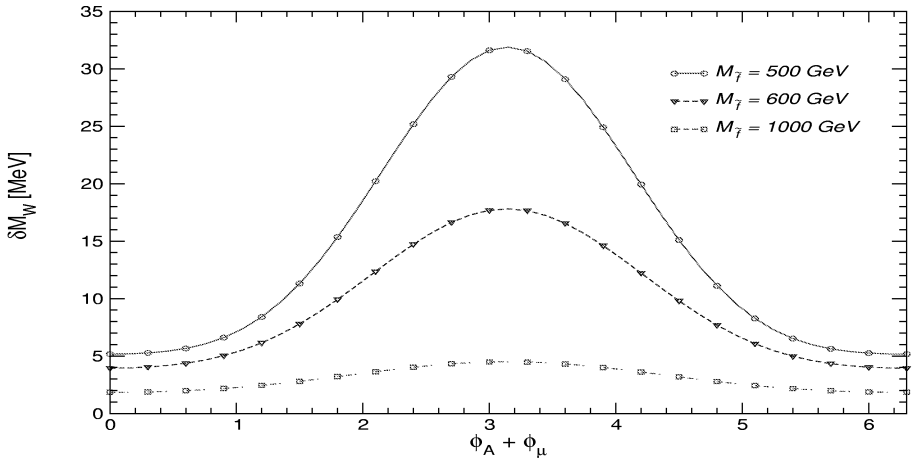


Figure 1. Squark contributions to δM_W as function of the phase $(\phi_A + \phi_\mu)$, where $\phi_A \equiv \phi_{A_t} = \phi_{A_b}$, for different values of the common sfermion mass $M_{\tilde{f}} = 500, 600, 1000$ GeV. The other relevant SUSY parameters are set to $\tan \beta = 5$, $|A_{t,b}| = 2M_{\tilde{f}}$, $|\mu| = 900$ GeV.

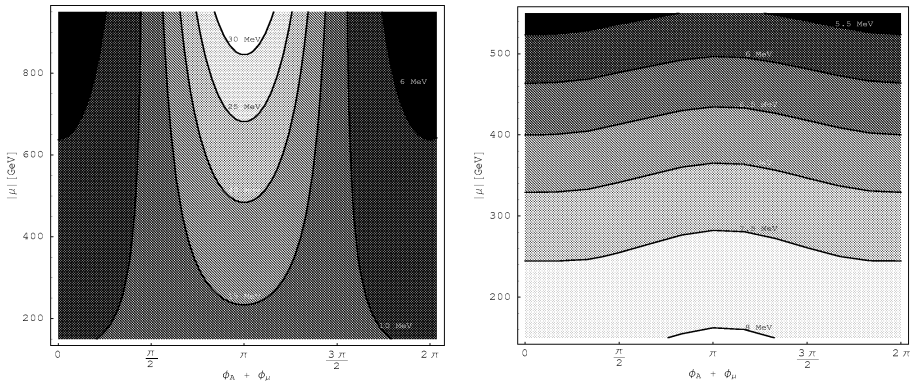


Figure 2. Contour lines of the squark contributions to δM_W in the plane of $(\phi_A + \phi_\mu)$ and $|\mu|$, where $\phi_A \equiv \phi_{A_t} = \phi_{A_b}$. The left plot shows a scenario with $\tan \beta = 5$, $M_{\tilde{f}} = 500$ GeV, $|A_{t,b}| = 1000$ GeV, while in the right plot $\tan \beta = 30$, $M_{\tilde{f}} = 600$ GeV, $|A_{t,b}| = 1200$ GeV.

The phase dependence is illustrated in Figs. 1 and 2. Fig. 1 shows the effect on δM_W from varying the phase $(\phi_A + \phi_\mu)$ for a fixed value of $|\mu| = 900$ GeV and $M_{\tilde{f}} = 500, 600, 1000$ GeV, while in Fig. 2 the squark sector contributions to δM_W are shown as contour lines in the plane of $(\phi_A + \phi_\mu)$ and $|\mu|$. In the scenario with $\tan \beta = 5$ (Fig. 1 and left panel of Fig. 2) the variation of $(\phi_A + \phi_\mu)$ can amount to a shift in M_W of more than 20 MeV. The most pronounced phase dependence is obtained for the largest sfermion

mixing, i.e. the smallest value of $M_{\tilde{f}}$ and the largest value of $|\mu|$. The right panel of Fig. 2 shows a scenario with $\tan\beta = 30$. The plot clearly displays the resulting much weaker phase dependence compared to the scenario in the left panel of Fig. 2. The variation of the complex phase gives rise only to shifts in M_W of less than 0.5 MeV, while changing $|\mu|$ between 100 and 500 GeV leads to a shift in M_W of about 2 MeV.

3. The MSSM parameter scan

Here we show the overall behaviour of M_W in the MSSM by scanning over a broad range of the SUSY parameter space. All relevant SUSY parameters are varied independently of each other, see Ref. [7] for details. We have taken into account the constraints on the MSSM parameter space from the LEP Higgs searches [19,20] and the lower bounds on the SUSY particle masses from Ref. [21].

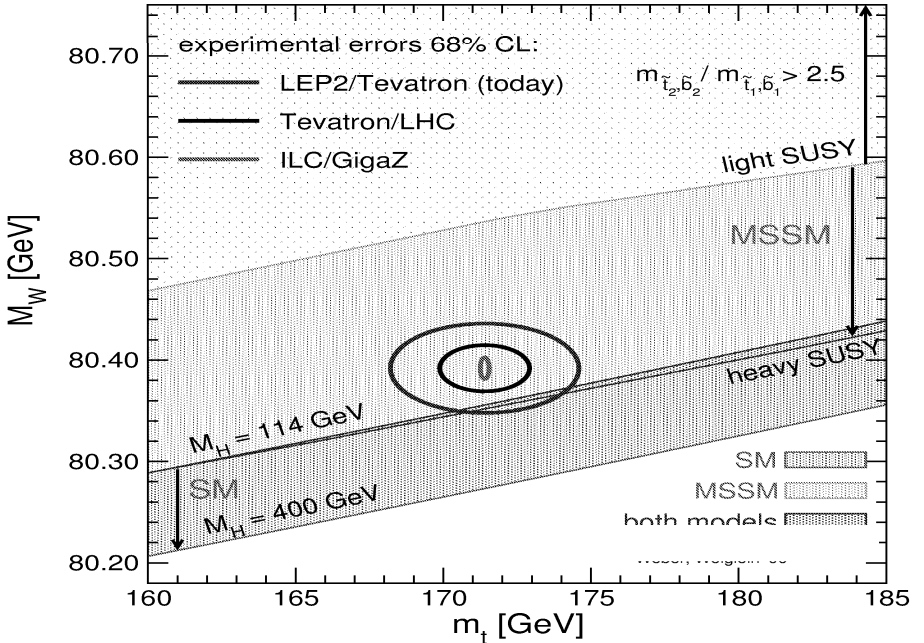


Figure 3. Prediction for M_W in the MSSM and the SM as a function of m_t in comparison with the present experimental results for M_W and m_t and the prospective accuracies (using the current central values) at the Tevatron / LHC and at the ILC. Values in the very light shaded region can only be obtained in the MSSM if at least one of the ratios $m_{\tilde{t}_2}/m_{\tilde{t}_1}$ or $m_{\tilde{b}_2}/m_{\tilde{b}_1}$ exceeds 2.5.

In Fig. 3 we compare the SM and the MSSM predictions for M_W as a function of m_t as obtained from the scatter data (the plot shown here is an update of Refs. [4,7,22]). The predictions within the two models give rise to two bands in the m_t - M_W plane with only a relatively small overlap region (indicated by a dark-shaded (blue) area in Fig. 3). The very

light-shaded (light green), the light shaded (green) and the dark-shaded (blue) areas indicate allowed regions for the unconstrained MSSM. In the very light-shaded region at least one of the ratios $m_{\tilde{t}_2}/m_{\tilde{t}_1}$ or $m_{\tilde{b}_2}/m_{\tilde{b}_1}$ exceeds 2.5. The current 68% C.L. experimental results $m_t^{\text{exp}} = 171.4 \pm 2.1$ GeV and $M_W^{\text{exp}} = 80.392 \pm 0.029$ GeV are indicated in the plot. As can be seen from Fig. 3, the current experimental 68% C.L. region for m_t and M_W exhibit a slight preference of the MSSM over the SM.

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