CDF Measurement of $M_W$: Theory implications

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The CDF collaboration recently reported a measurement of the W-boson mass, $M_W$, showing a large positive deviation from the Standard Model (SM) prediction. The question arises whether extensions of the SM exist that can accommodate such large values, and what further phenomenological consequences arise from this. We give a brief review of the implications of the new CDF measurement on the SM, as well as on Higgs-sector extensions. In particular, we review the compatibility of the $M_W$ measurement of CDF with excesses observed in the light Higgs-boson searches at $\sim 95$ GeV, as well as with the Minimal Supersymmetric Standard Model in conjunction with the anomalous magnetic moment of the muon, $(g-2)_\mu$.

I. INTRODUCTION

The mass of the W boson can be predicted from muon decay, which relates $M_W$ to three extremely precisely measured quantities: the Fermi constant, $G_F$, the fine structure constant, $\alpha$, and the mass of the Z boson, $M_Z$. Within the SM and many extensions of it this relation can be used to predict $M_W$ via the expression

$$M_W^2 = M_Z^2 \times \left\{ \frac{1}{2} + \frac{1}{4} \frac{\pi \alpha}{\sqrt{2} G_F M_Z^2} \left[ 1 + \Delta r(M_W, M_Z, m_t, ... \right] \right\},$$

where the quantity $\Delta r$ is zero at lowest order. It comprises loop corrections to muon decay in the considered model, where the ellipsis in Eq. (1) denotes the specific particle content of the model.

The SM prediction for $\Delta r$ includes contributions at the complete one-loop [1, 2] and the complete two-loop level, as well as partial higher-order corrections up to four-loop order (see, e.g., Ref. [3] for a review). This yields a prediction of

$$M_W^{SM} = 80.357 \pm 0.004 \text{ GeV},$$

where the uncertainty originates from unknown higher-order corrections. This value is in agreement at the $\sim 2\sigma$ level with the current PDG average [3]

$$M_W^{PDG} = 80.377 \pm 0.012 \text{ GeV}.$$

Recently the CDF collaboration reported a new measurement using their full data set of 8.8 fb$^{-1}$ of [4],

$$M_W^{CDF} = 80.4335 \pm 0.0094 \text{ GeV},$$

which deviates from the SM prediction by 7.0 $\sigma$. Combining this new value with other measurements of the Tevatron and LEP (but not the LHC) yields,

$$M_W^{Tev+LEP} = 80.4242 \pm 0.0087 \text{ GeV}.$$

A possible new world average including the recent CDF measurement [4], is roughly given by [3, 51],

$$M_W^{exp,new} \approx 80.417 \pm 0.018 \text{ GeV}.$$

The enlarged uncertainty of $M_W^{exp,new}$ reflects the fact that the new CDF measurement is not well compatible with previous experimental results. In the future it will be mandatory to assess the compatibility of the different measurements of $M_W$ and to carefully analyze possible sources of systematic effects. However, naturally the question arises whether extensions of the SM exist that can accommodate such large values, and what further phenomenological consequences arise from this.

Here we will briefly review why the SM is incompatible with $M_W^{CDF}$, and how extensions of the SM Higgs sector can accommodate values substantially above the SM prediction. We furthermore review whether the electroweak (EW) sector of the Minimal Supersymmetric Standard Model (MSSM), while being in agreement with $(g-2)_\mu$ can (or cannot) give rise to such high values of $M_W$, and finally comment on contributions from scalar tops/bottoms.

II. INCOMPATIBILITY OF THE SM

The SM can be tested at the quantum level with electroweak precision observables (EWPO), where many of them are related to properties of the Z and W bosons. Z-boson properties are determined from measurements of $e^+e^- \rightarrow f\bar{f}$ on the Z-pole. A customary set of such (pseudo-observables are the mass of the W boson, see the discussion in Sect. [1] as well as,

$$A_{FB}^f = \frac{\sigma_f(\theta < \frac{\pi}{2}) - \sigma_f(\theta > \frac{\pi}{2})}{\sigma_f(\theta < \frac{\pi}{2}) + \sigma_f(\theta > \frac{\pi}{2})} = \frac{3}{4} A_e A_f,$$

$$A_{LR}^f = \frac{\sigma_f(P_e < 0) - \sigma_f(P_e > 0)}{\sigma_f(P_e < 0) + \sigma_f(P_e > 0)} \equiv A_e |P_e|.$$

Here $\sigma_f$ denotes the cross section $\sigma(e^+e^- \rightarrow f\bar{f})$ measured at $\sqrt{s} = M_Z$, $\theta$ is the scattering angle and $P_e$ is the polarization of the incoming electron beam. The asymmetry parameters are commonly written as

$$A_f = \frac{1 - 4 |Q_f| \sin^2 \theta_{eff}^f}{1 - 4 |Q_f| \sin^2 \theta_{eff}^f + 8 (Q_f \sin^2 \theta_{eff}^f)^2}.$$
Here $Q_f$ denotes the charge of the fermion, and $\sin^2 \theta^l_{\text{eff}}$ is the effective weak (fermionic) mixing angle.

The theory prediction of an EWPO in the SM depends on the mass of the SM Higgs boson, $M_H$, which enters via quantum corrections [1, 2] (see Refs. [3, 4] for related theory uncertainties). The comparison of the experimental results for the EWPOs and their predictions in the SM allows to extract a preferred range for $M_H$ from each observable. This is shown for seven different EWPOs in the first seven lines of Fig. 1. Here it should be noted that the two most precise indirect determinations, based on $A^b_F$ at LEP and $A_i \equiv A^c_{\text{LR}}$ at SLD disagree at the $3\sigma$ level. The average (without $M_W^{\text{CDF}}$) as obtained by the GFitter collaboration is given in the eighth line, $M_H^{\exp} = 90^{+21}_{-18}$ GeV [5], which has to be compared to the experimental value of $8

\begin{equation}
M_H^{\exp} = 125.1 \pm 0.2 \text{ GeV ,}
\end{equation}

an agreement at the $1.8\sigma$ level. Concerning the two most precise indirect determinations of $M_H$ via $A^b_F$ and $A^c_{\text{LR}}$, only the average yields an acceptable agreement with $M_H^{\exp}$. The last line of Fig. 1 shows the preferred $M_H$ range obtained from $M_W^{\text{CDF}}$,

\begin{equation}
M_H^{M_W^{\text{CDF}} - \text{fit}} = 19^{+7}_{-6} \text{ GeV .}
\end{equation}

This value demonstrates the incompatibility of the SM with the newly measured value of $M_W^{\text{CDF}}$.

III. EXTENSIONS OF THE SM HIGGS-BOSON SECTOR

While no conclusive signs of physics beyond the SM (BSM) have been found so far at the LHC, both the measurements of the properties of the Higgs boson at $\sim 125$ GeV (its couplings are known up to now to an experimental precision of roughly $10-20\%$) and the existing limits from the searches for new particles leave significant room for BSM interpretations of the discovered Higgs-boson. Extended Higgs-boson sectors naturally contain additional Higgs bosons with masses larger than 125 GeV. However, many extensions also offer the possibility of additional Higgs bosons that are lighter than 125 GeV.

A. The 2HDM

The Two Higgs Doublet Model (2HDM) extends the SM by a second Higgs doublet (see Ref. [6] for a review). The fields (after EWSB) can be parametrized as

\begin{equation}
\Phi_1 = \left( \frac{1}{\sqrt{2}} (v_1 + p_1 + i\eta_1) \right),
\end{equation}

\begin{equation}
\Phi_2 = \left( \frac{1}{\sqrt{2}} (v_2 + p_2 + i\eta_2) \right),
\end{equation}

where $\Phi_1$ and $\Phi_2$ are the two $SU(2)_L$ doublets with hypercharge 1. The parameters $v_1, v_2$ are the real vacuum expectation values (vevs) acquired by the fields $\Phi_1$ and $\Phi_2$, respectively, with $\tan\beta := v_2/v_1$ and $v^2 = v_1^2 + v_2^2$, where $v$ is the SM vev.

In order to avoid the occurrence of tree-level flavor changing neutral currents (FCNC), a $Z_2$ symmetry is imposed on the scalar potential, under which $\Phi_1 \to \Phi_1$ and $\Phi_2 \to -\Phi_2$. This $Z_2$ symmetry, however, is softly broken by a bilinear term usually written as $m^2_{12}(\Phi_1^* \Phi_2 + \text{h.c.})$. The extension of the $Z_2$ symmetry to the Yukawa sector forbids tree-level FCNCs. One can have four variants of the 2HDM, depending on the $Z_2$ parities of the fermions. The Higgs sector consists (after diagonalization) of the light and heavy CP-even Higgses, $h$ and $H$, the CP-odd Higgs, $A$, and a pair of charged Higgses, $H^\pm$. The mixing angles $\alpha$ and $\beta$ diagonalize the CP-even and -odd part of the Higgs sector, respectively. Here we assume that the light CP-even Higgs is identified with the Higgs boson discovered at the LHC at $\sim 125$ GeV. Once $m_h$ and $v$ are set to $m_h \simeq 125$ GeV and $v \simeq 246$ GeV, all four 2HDM types can be described in terms of six input parameters, which are often chosen as: $\cos(\beta - \alpha)$, $\tan\beta$, $m_H$, $m_A$, $m_{H^\pm}$ and $m_{12}$.

After the CDF result for $M_W$ was published, many articles appeared to describe the CDF value in BSM models, including analyses in the 2HDM, see Refs. [7, 8] for the first papers. Here it should be noted that all these papers focused on $M_W^{\text{CDF}}$, Eq. (1), but not on a possible new world average, see Eq. (6). A first exception of an 2HDM analysis taking into account a possible new world average can be found in Ref. [9].

Constraints from EWPOs on BSM models can in a simple approximation be expressed in terms of the oblique parameters $S$, $T$ and $U$ [10, 11]. Effects from physics beyond the SM on these parameters can be significant if the new physics contributions enter mainly through gauge boson self-energies, as it is the case for extended Higgs sectors, and in particular in the 2HDM. Accordingly, the $W$-boson mass can be calculated as a function of the oblique parameters, given by

\begin{equation}
M_W^2 = M_W^2 \bigg|_{\text{SM}} \left( 1 + \frac{\tan^2 \beta}{c_w^2} \Delta r' \right),
\end{equation}

with

\begin{equation}
\Delta r' = \frac{\alpha}{s_w^2} \left( -\frac{1}{2} S + c_w^2 T + \frac{c_w^2 - s_w^2}{4 s_w^4} U \right).
\end{equation}
FIG. 1: Direct and indirect determinations of \( M_H \) in the SM (see text). The figure (except the new result for \( M_{W}^{CDF} \)) is taken from Ref. [7].

In the 2HDM the largest contribution enters via the \( T \) parameter, with a small correction from \( S \) and negligible contributions from \( U \). The \( T \) parameter is directly connected to the \( \rho \)-parameter via

\[
\Delta \rho = \frac{\Sigma_T^Z(0)}{M_Z^2} - \frac{\Sigma_T^W(0)}{M_W^2} , \tag{15}
\]

where \( \Sigma_{Z,W}^T(0) \) denotes the transversal part of the \( Z \)- or \( W \)-boson self-energy at zero external momentum. The one-loop 2HDM BSM contributions to \( \Delta \rho \) in the alignment limit, \( \cos(\beta - \alpha) = 0 \), are given by [17],

\[
\Delta \rho^{2HDM} = \frac{\alpha}{16 \pi^2 s_w^2 c_w M_W^2} \left\{ \frac{m_A^2 m_H^2}{m_A^2 - m_H^2} \log \frac{m_A^2}{m_H^2} - \frac{m_A^2}{m_A^2 - m_H^2} \log \frac{m_A^2}{m_H^2} \right. \\
- \frac{m_A^2}{m_A^2 - m_H^2} \log \frac{m_A^2}{m_H^2} - \frac{m_A^2}{m_A^2 - m_H^2} \log \frac{m_A^2}{m_H^2} + m_H^2 \right\} . \tag{16}
\]

It vanishes for \( m_A = m_{H^\pm} \) or \( m_H = m_{H^\pm} \). Large positive contributions, required to accommodate \( M_W^{CDF} \), are found for large mass splittings

\[
(m_H - m_{H^\pm})(m_A - m_{H^\pm}) > 0 . \tag{17}
\]

This is demonstrated in Fig. 2 [11], where the plane \( (m_H - m_{H^\pm})(m_A - m_{H^\pm}) \) is shown in the 2HDM (type I) for \( \cos(\beta - \alpha) = 0 \). Black points are the scanned parameter points. Red points are within the 1\( \sigma \) interval of Eq. (4). Taken from Ref. [11].

Using the approximation of the \( T \) parameter, the corrections to the effective weak leptonic mixing angle can be expressed as

\[
\sin^2 \theta_{\text{eff}} = \sin^2 \theta_{\text{eff}} |_{\text{SM}} - \alpha \frac{c_w^2 s_w^2}{c_w^2 - s_w^2} T . \tag{18}
\]

Because of the different sign of the \( T \) parameter contribution w.r.t. Eq. (14) a positive contribution to the prediction of \( M_W \) corresponds to a negative contribution to \( \sin^2 \theta_{\text{eff}} \).

FIG. 2: The \( (m_H - m_{H^\pm})(m_A - m_{H^\pm}) \) plane in the 2HDM (type I) for \( \cos(\beta - \alpha) = 0 \). Black points are the scanned parameter points. Red points are within the 1\( \sigma \) interval of Eq. (4). Taken from Ref. [11].
B. The N2HDM

There are several excesses in the searches for light Higgs-boson around $\sim 95$ GeV. Results based on the first year of CMS Run 2 data for Higgs-boson searches in the diphoton final state show a local excess of about $3 \sigma$ at a mass of 95 GeV [13], where a similar excess of $2 \sigma$ occurred in the Run 1 data at a comparable mass [19]. Combining 7, 8, and first year 13 TeV data (and assuming that the $gg$ production dominates) the excess is most pronounced at a mass of 95.3 GeV with a local significance of $2.8 \sigma$. First Run 2 limits from ATLAS with 80 fb$^{-1}$ in the $\gamma\gamma$ searches below 125 GeV were reported in 2018 [20] and are substantially weaker than the corresponding upper limit obtained by CMS at and around 95 GeV.

CMS recently published the results for the search for additional Higgs bosons in the $\tau^+\tau^-$ channel [21]. Utilizing the full Run 2 data set, in Ref. [21] the CMS collaboration reported an excess in the low-mass region for the gluon-fusion production mode and subsequent decay into $\tau^+\tau^-$ pairs that is compatible with the excess that has been observed by CMS in the diphoton search. For a mass value of 95 GeV CMS reports a local significance of $2.6 \sigma$. Up to now there exists no corresponding result for the low-mass search in the $\tau^+\tau^-$ final state from the ATLAS collaboration in this mass range.

Searches for a low-mass Higgs boson that were previously carried out at LEP resulted in a $2.3 \sigma$ local excess observed in the $e^+e^- \rightarrow Z (H \rightarrow bb)$ searches [22] at a mass of about 98 GeV; due to the $bb$ final state the mass resolution was rather coarse. Because of this limited mass resolution in the $bb$ final state at LEP this excess can be compatible with the slightly lower mass of 95 GeV, where the two CMS excesses have been observed.

In Ref. [23] it was shown that the three excesses can be described consistently in the N2HDM (the Two-Higgs-Doublet Model with an additional real singlet [24,25]). In the N2HDM, contrary to the 2HDM, three CP-even Higgs bosons are present. The three excesses can be accommodated simultaneously in the N2HDM of Yukawa type IV by the lightest CP-even Higgs boson, $h_{95}$, with a mass of $\sim 95$ GeV, which has a large singlet component. At the same time the second lightest CP-even Higgs boson with a mass of $\sim 125$ GeV, $h_{125}$, agrees well with the LHC measurements, and the rest of the Higgs sector is in agreement with the Higgs-boson searches at LEP and the LHC.

In Ref. [26] it was subsequently demonstrated that this model can also “comfortably” accomodate $M_W^{CDF}$. In Fig. 3 [26] we show the predictions for $M_W$ and $\sin^2 \theta_{eff}$ in the N2HDM type IV points that fit well the $\gamma\gamma$, $\tau\tau$ and $bb$ excesses via $h_{95}$, while the $h_{125}$ is in good agreement with the LHC Higgs-boson rate measurements, see Ref. [26] for details. The color coding of the points indicates the value of $T$. The light blue regions corresponds to the new CDF measurement within $\pm 1 \sigma$. The purple and the magenta ellipses indicate the 68% confidence level limits from the two individually most precise measurements of $\sin^2 \theta_{eff}$ via $A_{FB}$ at LEP and $A_{LR}$ at SLD, respectively, whereas the gray ellipse indicates the PDG average. The orange cross indicates the SM prediction. One can see that the parameter points that fit the new CDF measurement of the $W$-boson mass feature also sizable modifications of $\sin^2 \theta_{eff}$ compared to the SM prediction, as mentioned above. The values of $\sin^2 \theta_{eff}$ featured in the parameter points of the scan are smaller than the SM value, not touching the current 1 $\sigma$ ellipse. However, as discussed above, the PDG average is composed of two measurements that are compatible only at the $\sim 3 \sigma$ level: the one using the forward-backward asymmetry in $e^+e^- \rightarrow b\bar{b}$ measured at LEP [27], and the one obtained from the left-right asymmetry in $e^+e^- \rightarrow e^+e^-$ measured at SLD [27]. It can be observed that the data points preferred by the $M_W$ measurement of CDF are in better agreement with the SLD measurement based on $A_{LR}$, whereas the tension increases with the value of $\sin^2 \theta_{eff}$ extracted at LEP based on measurements of $A_{FB}$.

The correlation between the effective weak mixing angle and the mass of the $W$ boson is expected to arise generically in models in which the new CDF measurement of $M_W$ is accommodated mainly via the breaking of the custodial symmetry by means of a non-zero $T$ parameter (and not via, e.g., BSM vertex and box contributions to the muon decay). The presence of
the additional singlet state of the N2HDM compared to the 2HDM has no sizable impact on the distribution of parameter points in Fig. 3 in the investigated scenario, because the mixing between the singlet-like state $h_{02}$ and the heavy CP-even Higgs boson is very small as a result of the large mass difference.

IV. THE MSSM

The $W$-boson mass can be calculated in the Minimal Supersymmetric Standard Model (MSSM) by evaluating the supersymmetric (SUSY) contributions to $\Delta r$, see Eq. (1). The most precise prediction for $M_W$ in the MSSM is based on the full one-loop result for $\Delta r$ \cite{32,33} (see also Ref. 31), supplemented by the leading two-loop corrections \cite{32,34}. The leading one- and two-loop contributions arise from isospin splitting between different SUSY particles and enter via the quantity $\Delta \rho$. At the one-loop level the squarks enter only via self-energy contributions, i.e. predominantly via $\Delta \rho$. The same is true for the corresponding contribution of pure slepton loops, while the contributions of the chargino and neutralino sector enter also via vertex and box diagrams. In our MSSM prediction for $M_W$ the contributions involving SUSY particles are combined with all available SM-type contributions up to the four-loop level as described above. Technically this is done by using a fit formula for the SM contributions beyond one-loop for $\Delta r$ \cite{35}. This ensures that the state-of-the-art SM prediction is recovered in the decoupling limit where all SUSY mass scales are heavy.

In Refs. \cite{36,39} the EW sector of the MSSM was analyzed taking into account all relevant experimental data, i.e. data that is directly connected to the EW sector. It was assumed that the Lightest SUSY Particle (LSP) is the lightest neutralino, $\tilde{\chi}^0_1$, as the Dark Matter (DM) candidate of the model. The experimental results employed in the analyses comprise the direct searches at the LHC \cite{40,41}, the DM relic abundance \cite{42}, the DM direct detection experiments \cite{43,44} together with the deviation on the value of the anomalous magnetic moment of the muon, $a_\mu$. The comparison of the SM prediction \cite{45} with the experimental result \cite{37,38} yields

$$\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (25.1 \pm 5.9) \times 10^{-10}, \quad (19)$$
corresponding to a $4.2 \sigma$ discrepancy.

In Refs. \cite{37,38} five different scenarios were identified that are in agreement with the above listed limits, classified by the mechanism that has the main impact on the resulting LSP relic density. The scenarios differ by the nature of the Next-to-LSP (NLSP). They comprise $\tilde{\chi}^\pm$-coannihilation, $\tilde{l}$-coannihilation with either “left-” or “right-handed” sleptons close in mass to the LSP (“case-L” and “case-R”, respectively), wino DM, as well as higgsino DM. In the first three scenarios the full amount of DM can be provided by the MSSM, whereas in the latter two cases the measured DM density serves as an upper limit. Requiring Eq. (19) at the $2 \sigma$ level, together with the collider and DM constraints, results in upper limits on the LSP masses at the level of $\sim 500$ GeV to $\sim 600$ GeV for all five scenarios. Corresponding upper limits on the mass of the NLSP are obtained for only slightly higher mass values.

In Ref. \cite{49} the contributions to the $M_W$ prediction from the EW MSSM in the five scenarios that are in agreement with all experimental data and in particular with Eq. (19) were analyzed. The results are shown in Fig. 4 in the $a_\mu^{\text{MSSM}} - M_W$ plane. The prediction for $\Delta a_\mu^{\text{MSSM}}$ has been evaluated with the code GM2Calc-1.7.5 \cite{50}. The vertical solid blue line indicates the value of $\Delta a_\mu$ as given in Eq. (19), while its $\pm 1 \sigma$ range is indicated by the blue dashed vertical lines. The displayed points are restricted to the $\pm 2 \sigma$ range of $\Delta a_\mu$. The horizontal lines indicate the old central value for $M_W^{\text{exp}}$ (solid green), together with its $\pm 1 \sigma$ uncertainties (green dashed) and the anticipated ILC $\pm 1 \sigma$ (red dot-dashed) uncertainties. The SM prediction is shown in gray, including the theoretical uncertainty from unknown higher-order corrections.

One can observe that relatively light SUSY particles that are required for larger values of $\Delta a_\mu^{\text{MSSM}}$ give rise to a slight increase in the prediction for $M_W$ that is independent of the variation of the other parameters in the scan. While this lower limit on the predicted value of $M_W$ is very similar in the five DM scenarios, there are important differences in the highest $M_W^{\text{MSSM}}$ values that are reached. The largest predicted values of $M_W^{\text{MSSM}}$, nearly reaching the “old” central value of $M_W^{\exp}$, are obtained for the wino DM case. Accordingly, for the wino DM case the electroweak sector of the MSSM behaves in such a way that the predicted values for $M_W$ and the anomalous magnetic moment of the muon can simultaneously be very close to the experimental central values, while respecting all other constraints on the model. For the $l$-coannihilation case-L the highest obtained $M_W^{\text{MSSM}}$ values are somewhat lower but still within the $\pm 1 \sigma$ range of $M_W^{\exp}$. This analysis demonstrates that the EW sector can yield an increase of $\sim 20$ MeV to the $M_W$ prediction, but cannot yield values close to the new possible world average, Eq. (6).

The result shown in Fig. 4, however, does not imply that a possible new world average of $M_W^{\exp}$ as given in Eq. (6) cannot be reached, as it focused on the contributions from the EW sector of the MSSM. Large corrections to $\Delta \rho$ can originate in the stop/sbottom sector (the SUSY partners of the tops and bottoms), which has been analyzed in Ref. \cite{39}. The results of an extensive MSSM parameter scan are shown as green points in the $m_{l^+_1} - M_W$ plane in Fig. 5 \cite{39}. The gray horizontal band indicates the then current experimen-
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FIG. 4: The $\Delta a_{\mu}^{\text{MSSM}}$-$M_W$ plane with the results for the five considered scenarios (see text). Taken from Ref. [49].

tal $\pm 1 \sigma$ range of $M_W^{\text{exp}}$, and the red line corresponds to the SM prediction. Squarks and gluinos have been chosen above the TeV scale to avoid LHC limits, and the lightest sbottom mass is heavier than 500 GeV. Furthermore, a limit of $2/5 \leq m_{l_i}/m_{l_j} \leq 5/2$ ($i, j = 1, 2$) has been applied. One can observe that for light stops above the TeV scale (very roughly corresponding to current LHC limits) indeed points in the range of a possible new world average, Eq. (6), are found. It should furthermore be noted that even larger values could be obtained by dropping the condition on the ratio of stop and sbottom masses.

V. CONCLUSIONS

The CDF collaboration recently reported a measurement of the $W$-boson mass, $M_W$, showing a large positive deviation from the SM prediction. The question arises whether extensions of the SM exist that can accommodate such large values, and what further phenomenological consequences arise from this. Here we first briefly summarized of the implications of the new CDF measurement on the SM. We demonstrated that the theory prediction of $M_W$ in the SM yields an indirect determination of $M_W^{\text{CDF-fit}} = 19^{+7}_{-6}$ GeV, far below the experimental value.

We briefly reviewed the predictions of $M_W$ in the 2HDM and showed that it is easy to reach a $M_W^{\text{CDF}}$ by an increased mass splitting between the heavy Higgs bosons (assuming that the light CP-even Higgs boson corresponds to the state discovered at $\sim 125$ GeV). The contribution of the additional Higgses, entering dominantly via $\Delta \rho$, on the other hand lower the prediction of the effective weak leptonic mixing angle, $\sin^2 \theta_{\text{eff}}$. For a 2HDM parameter point yielding $\sim M_W^{\text{CDF}}$ the $\sin^2 \theta_{\text{eff}}$ prediction would be incompatible with the determination via $A_{FB}^{\ell}$ at LEP, and also with the current world average, but would be in

FIG. 5: The $m_{l_i}$-$M_W$ plane in the MSSM (see text). Taken from Ref. [50].

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agreement with the $\sin^2\theta_{\text{eff}}$ determination via $A_{\text{LR}}^\text{eff}$ at SLD. Going to the N2HDM, it was shown that parameter points that give a good fit to three independent excesses in the low-mass Higgs-boson searches at $\sim 95$ GeV can also accomodate “comfortably” $M_W^{\text{CDF}}$.

Finally we reviewed the $M_W$ prediction in the MSSM. The EW sector of the MSSM, taking into account all relevant constraints ($\langle g-2 \rangle_\mu$, DM relic density, DM direct detection limits as well as LHC searches) can shift the $M_W$ prediction upwards by up to $\sim 20$ MeV w.r.t. the SM prediction. Taking into account also contributions from the stop/sbottom sector values around a possible new world average of $M_W^{\text{SM}}$, Eq. [6], can be reached.

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[51] It should be noted that the values given so far in Ref. [3] are rather approximate.