IMPACT OF A PRECISE TOP MASS MEASUREMENT [a]

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The physics impact of a precise determination of the top-quark mass, m_t, at the Linear Collider (LC) is discussed, and the results are compared with the prospective accuracy at the LHC. The importance of a precise knowledge of m_t for electroweak precision observables and for Higgs physics in the MSSM is pointed out in particular. We find that going from hadron collider to LC accuracy in m_t leads to an improvement of the investigated quantities by up to an order of magnitude.

1 Introduction

The mass of the top quark, m_t, is a fundamental parameter of the electroweak theory. It is by far the heaviest of all quark masses and it is also larger than the masses of all other known fundamental particles. The large value of m_t gives rise to a large coupling between the top quark and the Higgs boson and is furthermore important for flavour physics. It could therefore provide a window to new physics. The correct prediction of m_t will be a crucial test for any fundamental theory. The top-quark mass also plays an important role in electroweak precision physics, as a consequence in particular of non-decoupling effects being proportional to powers of m_t. A precise knowledge of m_t is therefore indispensable in order to have sensitivity to possible effects of new physics in electroweak precision tests.

The current world average for the top-quark mass is $m_t = 178.0 \pm 4.3$ GeV[1,2]. The prospective accuracy at the Tevatron and the LHC is $\delta m_t = 1$–2 GeV [3], while at the LC a very precise determination of m_t with an accuracy of $\delta m_t \lesssim 100$ MeV will be possible[4,5]. This error contains both the experimental error of the mass parameter extracted from the $t\bar{t}$ threshold measurements at the LC and the envisaged theoretical uncertainty from its transition into a suitable short-distance mass (like the $\overline{\mathrm{MS}}$ mass).

In the following some examples of the impact of a precise determination

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of m_t are discussed. More details can be found in Ref. [6].

2 Electroweak Precision Observables

Electroweak precision observables (EWPO) can be used to perform internal consistency checks of the model under consideration and to obtain indirect constraints on unknown model parameters. This is done by comparing experimental results of the EWPO with their theory prediction within, for example, the Standard Model (SM) or its minimal supersymmetric extension (MSSM).

There are two sources of theoretical uncertainties: those from unknown higher-order corrections ("intrinsic" theoretical uncertainties), and those from experimental errors of the input parameters ("parametric" theoretical uncertainties). The intrinsic uncertainties within the SM are $\Delta M_W^{\rm intr,today} \approx 4$ MeV, $\Delta \sin^2\theta_{\rm eff}^{\rm intr,today} \approx 5 \times 10^{-5}$ at present [7]. The parametric uncertainties induced by the current experimental error of m_t are $\Delta M_W^{\rm para,today} \approx 26$ MeV and $\Delta \sin^2\theta_{\rm eff}^{\rm para,today} \approx 14 \times 10^{-5}$. They are larger than the uncertainties induced by the experimental errors of all other input parameters and are almost as large as the current experimental errors of M_W and $\sin^2\theta_{\rm eff}$. A future experimental error of $\delta m_t \approx 1.5$ GeV at the LHC will give rise to parametric uncertainties of $\Delta M_W^{\rm para,LHC} \approx 9$ MeV, $\Delta \sin^2\theta_{\rm eff}^{\rm para,LHC} \approx 4.5 \times 10^{-5}$, while the LC precision of $\delta m_t \approx 0.1$ GeV will reduce the parametric uncertainties to $\Delta M_W^{\rm para,LC} \approx 1$ MeV, $\Delta \sin^2\theta_{\rm eff}^{\rm para,LC} \approx 0.3 \times 10^{-5}$. A comparison with the parametric uncertainties induced by the other input parameters [6] shows that the LC accuracy on m_t will be necessary in order to keep the parametric error induced by m_t at or below the level of the other uncertainties. With the LHC accuracy on m_t, on the other hand, δm_t will be the dominant source of uncertainty.

In Fig. 1 the predictions for M_W and $\sin^2\theta_{\rm eff}$ in the SM and the MSSM are shown in comparison with the prospective experimental accuracy obtainable at the LHC and a LC with GigaZ option (low-energy running at the Z-boson resonance and the WW-threshold). The MSSM parameters have been chosen in this example according to the reference point SPS 1b [8], and all SUSY parameters have been varied within realistic error intervals. The figure shows that the improvement in δm_t from $\delta m_t = 2$ GeV to $\delta m_t = 0.1$ GeV strongly reduces the parametric uncertainty in the prediction for the EWPO. In the SM case it leads to a reduction by about a factor of 10 in the allowed parameter space of the M_W–$\sin^2\theta_{\rm eff}$ plane. In the MSSM case, where many additional parametric uncertainties enter, a reduction by a factor of more than 2 is obtained in this example. This precision will be crucial to establish effects of new physics via EWPO.

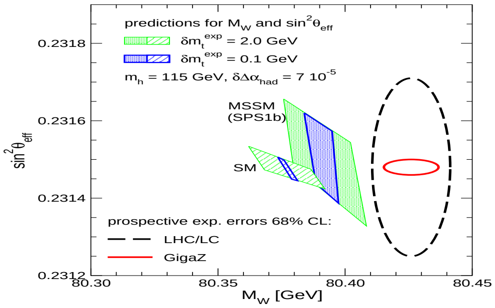

Figure 1: Predictions for M_W and $\sin^2\theta_{\rm eff}$ in the SM and the MSSM (SPS 1b). The inner (blue) areas correspond to $\delta m_t = 0.1$ GeV (LC), while the outer (green) areas arise from $\delta m_t = 2$ GeV (LHC). The anticipated experimental errors on M_W and $\sin^2\theta_{\rm eff}$ at the LHC/LC and at a LC with GigaZ option are indicated.

3 Implications For The MSSM

In contrast to the SM, where the Higgs-boson mass is a free input parameter, the mass of the lightest $\mathcal{CP}$-even Higgs boson in the MSSM, m_h, can be predicted in terms of other parameters of the model. While the tree-level prediction for m_h arises from the gauge sector of the theory, large Yukawa corrections from the top and scalar top sector (for large values of $\tan\beta$, the ratio of the vacuum expectation values of the two Higgs doublets, also from the bottom and scalar bottom sector) enter at the loop level. The leading one-loop correction is proportional to m_t^4. The one-loop corrections can shift m_h by 50–100%.

Since these very large corrections are proportional to the fourth power of the top-quark mass, the predictions for m_h and many other observables in the MSSM Higgs sector strongly depend on the precise value of m_t. As a rule of thumb [9], a shift of $\delta m_t = 1$ GeV induces a parametric theoretical uncertainty of m_h of also about 1 GeV, i.e. $\Delta m_h^{\delta m_t} \approx \delta m_t$.

In Fig. 2 the impact of the experimental error of m_t on the prediction for m_h in the MSSM is shown. The parameters are chosen according to the $m_h^{\rm max}$ benchmark scenario [10]. The band in the left plot [11] corresponds to the present experimental error of m_t [1,2], while in the right plot the situation at the LHC ($\delta m_t = 1, 2$ GeV) is compared to the LC ($\delta m_t = 0.1$ GeV). The figure shows that the LC precision on m_t will be necessary in order to match the experimental precision of the m_h determination with the accuracy of the theory prediction (assuming that the intrinsic theoretical uncertainty can be reduced to the same level, see Ref. [12]).

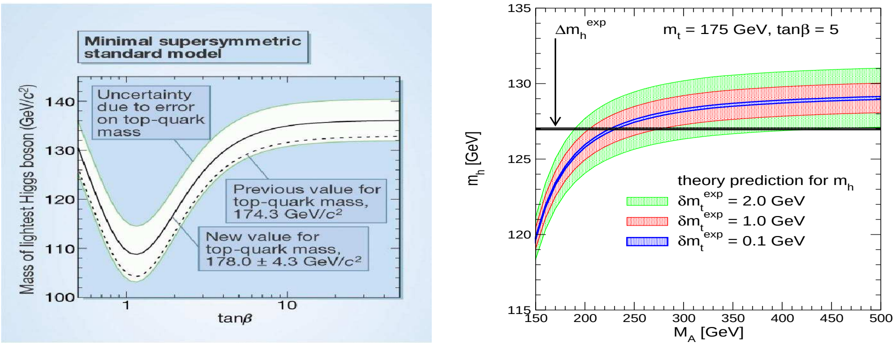

Figure 2: Prediction for m_h in the $m_h^{\max}$ scenario of the MSSM as a function of $\tan\beta$ (left) and the mass of the $\mathcal{CP}$-odd Higgs boson, M_A (right). In the left plot the impact of the present experimental error of m_t on the m_h prediction is shown. The three bands in the right plot correspond to $\delta m_t = 1, 2$ GeV (LHC) and $\delta m_t = 0.1$ GeV (LC). The anticipated experimental error on m_h at the LC is also indicated.

Further examples of the importance of a precise determination of m_t in the MSSM are the prediction of sparticle masses, parameter determinations, and the reconstruction of the supersymmetric high scale theory [6].

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