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MSSM charged Higgs production in the 1 TeV domain and large $\tan\beta$ determination

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In the last few years, considerable effort has been devoted to the study of electroweak effects in pair production at future lepton colliders, since, within the SM, for c.m. energies of a few TeV size, it has been realized [1,2] that unexpectedly large virtual effects arise at the one-loop level. These terms have the analogous dependence on energy as those originally determined in QED by Sudakov [3]; at one loop, they can either be of squared logarithmic (leading) (DL) or of linear logarithmic (subleading) (SL) kind.

The aim of this note is precisely to study the feasibility and the possible advantages of performing such an effective logarithmic one-loop expansion, implemented by a next-to-subleading term, in the energy region around 1 TeV, for the MSSM.

As a first process to be examined in this spirit, we have chosen charged Higgs pair production.

A complete description of the scattering amplitude of the considered process at one loop requires the calculation of several classes of diagrams. Since all the relevant discussion has been fully given in [5], we shall only give the final expression valid for the relevant observable that we have considered, i.e., the cross-section for charged Higgs pair production, writing the asymptotic relative effect in the form:

$$\Delta(q^2) = \frac{\sigma^{\text{Born+1 loop}} - \sigma^{\text{Born}}}{\sigma^{\text{Born}}}, \tag{1}$$

where, in $\sigma^{\text{Born+1 loop}}$ we are retaining only the genuine one-loop terms $\mathcal{O}(\alpha/\pi)$.

The logarithmic expansion of Δ has been derived analytically and is given by the expression

$$\Delta(q^2) = -\left(\frac{\alpha}{2\pi s_W^2}\right)\left(\frac{1+2s_W^4}{1+4s_W^4}\right)\log^2\frac{q^2}{M_W^2}$$
$$-\left(\frac{\alpha}{4\pi s_W^2 c_W^2}\right)\left(\frac{1+2s_W^4+8s_W^6}{1+4s_W^4}\right)\log^2\frac{q^2}{M_Z^2}$$
$$-\left(\frac{3\alpha}{4\pi s_W^2 M_W^2}\right)\left(m_t^2\cot^2\beta+m_b^2\tan^2\beta\right)\log\frac{q^2}{m_t^2}$$
$$+\left(\frac{\alpha}{3\pi s_W^2 c_W^2}\right)\left(\frac{11-16s_W^2+32s_W^4+72s_W^6}{1+4s_W^4}\right)\log\frac{q^2}{M_Z^2}$$
$$+\Delta_{\rm rem}(q^2), \tag{2}$$

where the fourth line contains all single logarithms with the exception of those of Yukawa origin (third line). The last term $\Delta_{\rm rem}(q^2)$ is the difference between the full one-loop result and its asymptotic Sudakov expansion including all the double and single logarithms, and will be called the next-to-subleading term.

The next step now is to investigate whether there exists a region of energy and of parameters where the rigorous calculation at one loop can be reproduced by the effective Sudakov expansion (eq. (2)), and to determine the relevant features of the next-to-subleading term $\Delta_{\rm rem}(q^2)$. With this aim, we shall study the dependence of $\Delta_{\rm rem}(q^2)$ on the c.m. energy for given values of the parameters of the chosen MSSM model. We retained the following five (standard) free parameters:

$$\tan\beta, \quad \mu, \quad M_A, \quad M_2, \quad M_S. \tag{3}$$

For the purposes of this note, we have chosen to work in an energy region between 800 GeV and 1 TeV. Given the fact that we have to deal with four massive parameters, we have performed four different analyses, in each one of which three parameters were fixed at values that we considered 'light' with respect to the chosen energy range, and one parameter was allowed to vary. In all these analyses we fixed $\tan\beta$ at the value $\tan\beta = 20$, that can be considered as an average value in the range that we have explored, roughly $2 \lesssim \tan\beta \lesssim 40$.

Fixing different values of $\tan\beta$ does not change the results of the four analyses, that we chose in the following way:

(a) variable μ, fixed $M_A = 200$ GeV, $M_2 = 100$ GeV, $M_S = 350$ GeV;
(b) variable M_A, fixed $\mu = 300$ GeV, $M_2 = 100$ GeV, $M_S = 350$ GeV;
(c) variable M_2, fixed $\mu = 300$ GeV, $M_A = 200$ GeV, $M_S = 350$ GeV;
(d) variable M_S, fixed $\mu = 300$ GeV, $M_A = 200$ GeV, $M_2 = 100$ GeV.

Our analysis was performed by computing numerically the quantity $\Delta(q^2)$ with the specific code (SESAMO) [4] that we have built for our purposes. From the computed quantity we then subtracted all the logarithms of eq. (2) and obtained the remaining, next-to-subleading term $\Delta_{\rm rem}(q^2)$. Typical results of our analysis are shown in figure 1. As one sees, $\Delta(q^2)$ remains indeed 'essentially' constant in the considered energy interval.

We have verified that this requirement is met for values of all the parameters below, approximately, 350 GeV.

The next topic is the relevance of the Sudakov expansion for the problem of determining $\tan\beta$ under the assumption that the mass scales are in the 'safe' range

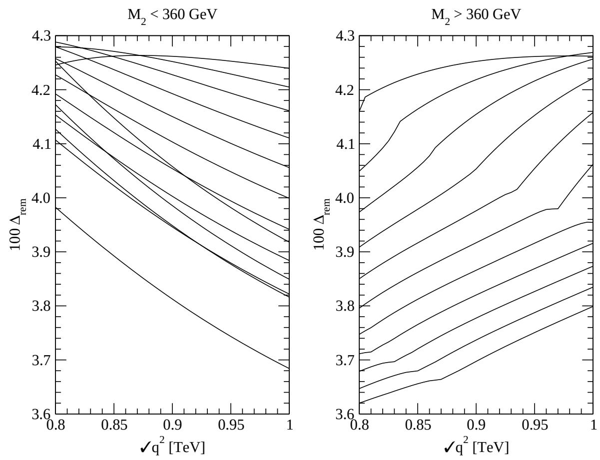

Figure 1. Variable M_2: plot of Δ_{rem} for various M_2 between 100 and 560 GeV. The various curves have values of M_2 spaced by 20 GeV.

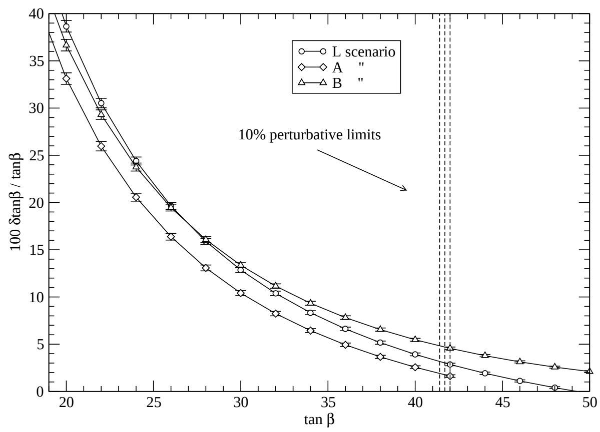

Figure 2. Variable $\tan\beta$ in the (L, A, B) scenarios: percentual relative error in the determination of $\tan\beta$ at various $\tan\beta$.

that we have just discussed. With this aim, we begin by subtracting explicitly from Δ all the 'known' logarithms, i.e., all the terms in the Sudakov expansion with the exception of the Yukawa contribution. Therefore, we defined the quantity

$$\widetilde{\Delta}(q^2) = F(\tan\beta)\log q^2 + \Delta_{\text{rem}}(q^2), \tag{4}$$
$$F(\tan\beta) \equiv -\frac{3\alpha}{4\pi s_{\text{w}}^2 M_W^2}(m_t^2\cot^2\beta + m_b^2\tan^2\beta),$$

and tried to fit the measured values of the residual effect $\widetilde{\Delta}(q^2)$ with a logarithmic expansion in q^2 of the form

$$A_{\rm fit} \log q^2 + B_{\rm fit}. \tag{5}$$

The result of the fit, $A_{\rm fit}$, can be compared with F at the value of $\tan\beta$ we are working. The error of the determination will be mostly fixed by the fact that Δ is not rigorously, but only 'essentially' constant in the considered range, as shown in [5]. We analysed three specific scenarios, belonging to the determined 'safe' parameter range. We assumed the existence of 10 equally spaced experimental measurements in the range 800 GeV–1 TeV with a relative 1% precision and generated them by means of our numerical code. The scenarios are defined as follows: (L) $\mu = 300$, $M_A = 250$, $M_2 = 100$, $M_S = 350$; (A) $\mu = 300$, $M_A = 250$, $M_2 = 200$, $M_S = 350$; (B) $\mu = 400$, $M_A = 250$, $M_2 = 200$, $M_S = 350$.

In figure 2 we combine the various results. One can see that, for $\tan\beta$ larger than 20, a determination of this parameter to better than a relative 40% would be possible. For values larger than $\simeq$30, the error would be reduced below a remarkable $\simeq$10% limit. Given the fact that the determination of $\tan\beta$ for large values from other processes seems to be not easy, we consider our approach as a possibility of determining this parameter in a relatively safe and unbiased way.

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