Higgs production in the 1 TeV domain: logarithmic Sudakov expansion and $\tan\beta$ measurement analysis

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Abstract

We consider the production of Higgs boson pairs from elenctron-positron annihilation that will be investigated in the future lepton colliders like LC and CLIC.

At the high collision energy we are interested in, it is reasonable to consider an approximation *of Sudakov type* to apply in the observable calculations at *1 loop* level of perturbation theory, in the scope of *Minimal Supersymmetric Standard Model* (MSSM).

We analize the opportunity to achieve this mathematical tool in order to make the way to extract phenomenological information about the MSSM more direct and efficient. In particular we are interested in an accurate measurement of the parameter $\tan\beta$ by using this process.

1 Scattering amplitude and Sudakov expansion

For the calculations of the transition amplitude

$$e^+e^- \longrightarrow H^+H^-, \;\; H^0A^0, \;\; h^0A^0$$

we consider:

- *Minimal Supersymmetric Standard Model* framework
- Analytical calculations at *1 loop* level in perturbation theory
- Center of mass energy of about 1 TeV
- Asymptotic Sudakov approach in *light* SUSY parameter scenario (explained in the following)

For the H^+H^- we completed a code for numerical analysis, and a similar tool for neutral cases will soon be available.

Following the Sudakov expansion procedure [1] to obtain the asymptotic expression of analitycal observables, the cross section takes the logarithmic form:

$$\sigma \simeq \sum_i \mathbf{a_i} \log^2 \frac{q^2}{M_{ai}^2} + \sum_i \mathbf{b_i} \log \frac{q^2}{M_{bi}^2} + \mathbf{c}$$

where the coefficients of leading, subleading and next-to subleading term have the interesting properties:

$$\text{analytically known} \begin{cases} \mathbf{a_i} & : \text{no SUSY parameters} \\ \mathbf{b_i} & : \tan\beta,\ \alpha \text{ from } \textbf{Yukawa interactions} \end{cases}$$

$$\text{analytically unknown } \mathbf{c} : \text{ all SUSY parameters}$$

The non-logaritmic term **c**, containing in principle a dependence on all SUSY parameters, represents the difference between the complete expression and all the known analytical asymptotic terms: in general it is difficult to know it exactly from the expansion procedure, so the best way to study its behaviour is by achieving a numeric value of total cross section (depending on energy and all parameters). That is the main use of the complete exact calculation of the cross section we are writing in our code.

Our aim whit this numeric analysis can be summarized by the following purposes:

- test the validity of the Sudakov expansion for energy $\sqrt{s} \simeq 0.8 - 1.0\,TeV$
- show the sensitivity of this process to MSSM parameters $\tan\beta$ and α
- show the accuracy of a $\tan\beta$ measurement

The H^+H^- case is already analized in detail in [2]. This more specific work allows us to conclude that at the assumed experimental accuracy (1%) the Sudakov expansion with a non-logarithmic and (essentially) energy independent term (here called **c**) is valid to substitute the complete *1 loop* analytical calculations in an energy regime of about 1 TeV and in a scenario of quite light SUSY mass parameters (**below the bound of some 400 GeV**). In this scenario contributions coming from *1 loop* terms always remain numerically under control (below the 10% of Born terms) and the term **c** shows its meaningful dependence on M_A (the neutral CP-odd Higgs boson mass), M_S (SUSY scale in the role of universal sfermion mass) and $\tan\beta$. In our opinion there is no reason to believe that these features do not hold for neutral cases any more.

2 χ^2 analysis

In order to perform a preliminary analysis including the neutral Higgs case for which our numerical code is still uncomplete, we use a χ^2 minimization procedure based on the asymptotic konwn form of all cross sections we deal with:

$$\chi^2(\alpha, \tan\beta; \alpha^*, \tan\beta^*) = \frac{[\sigma(\alpha, \tan\beta) - \sigma(\alpha^*, \tan\beta^*)]^2}{\delta\sigma^2} \quad ; \quad \frac{\delta\sigma}{\sigma} = \frac{1}{\sqrt{L\sigma}}$$

- contribution to σ from **Yukawa terms**
- 10 hypotetical measurements in the **energy range 0.8-1.0 TeV**
- Luminosity L such that **the relative error on $\sigma(H^+H^-)$ is 1%**
- using the code *FeynHiggsFast* [3] we calculate α as a function of M_A (fixing μ, M_1, M_2, A_u, A_d)
- $\tan\beta$ **error** estimate: $\frac{\delta\tan\beta}{\tan\beta^*} = \frac{|\tan\beta - \tan\beta^*|}{\tan\beta^*}$; for each $\tan\beta^*$, $\tan\beta$ is such that $\chi^2(\tan\beta, \tan\beta^*)$ corresponds to 68%, 90% CL
- analysis for fixed parameters: $M_A = 350\ GeV$, $\mu = 400\ GeV$, $M_1 = 200\ GeV$, $M_2 = 400\ GeV$, $A_u = 0$, $A_d = 0$

To study the uncertainty of $\tan\beta$ coming from its presence in the Yukawa sector of the asymptotic cross sections, we are now able to show in the plane $(M_A, \tan\beta)$ the contour plot of χ^2 corresponding to 68% and 90% of confidence level (figure 1).

The greater is the value of $\tan\beta$ the smaller is its uncertainty and weaker the dependence of the $\tan\beta$ error on M_A values (this last one is a theoretically pretictable feature, because for great values of $\tan\beta$ this parameter results essentially independent from α).

In the figure 2 we show the estimated $\tan\beta$ error. In the pure chrged Higgs boson case (that reproduces our results obtained via numerical code, as a test of the χ^2 analysis) the singularity-like behaviour for small values is just arising from the mathematical functional dependence on $\tan\beta$ of the coefficient of Yukawa asymptotic contribution. It desappears when we consider both charged and neutral Higgs boson final states.

3 Conclusions

For the measurement of $\tan\beta$ we can observe:

- $\tan\beta \lesssim 10$: for accurate $\tan\beta$ measurements this process is probably not competitive with other techniques. Nevertheless it can always offer a consistency test for the theory.
- $\tan\beta \gtrsim 10$: to choose only charged or both charged and neutral Higgs is equivalent for $\tan\beta$ measurements, at the assumed experimental accuracy.
- Only in the case of a drastic reduction of the experimental error in H^0 production (the greatest error for fixed luminosity), the combination of charged and neutral Higgs will be useful to improve the error on $\tan\beta$ in the large ($\gtrsim 30$) range.

To confirm these preliminary results we are preparing a complete (also non-asymptotic) numerical analysis of the neutral case in order to show the behaviour of the relevant Sudakov coefficients and also the numerical size and dependence on SUSY parameters of next-to subleading (energy independent) terms.

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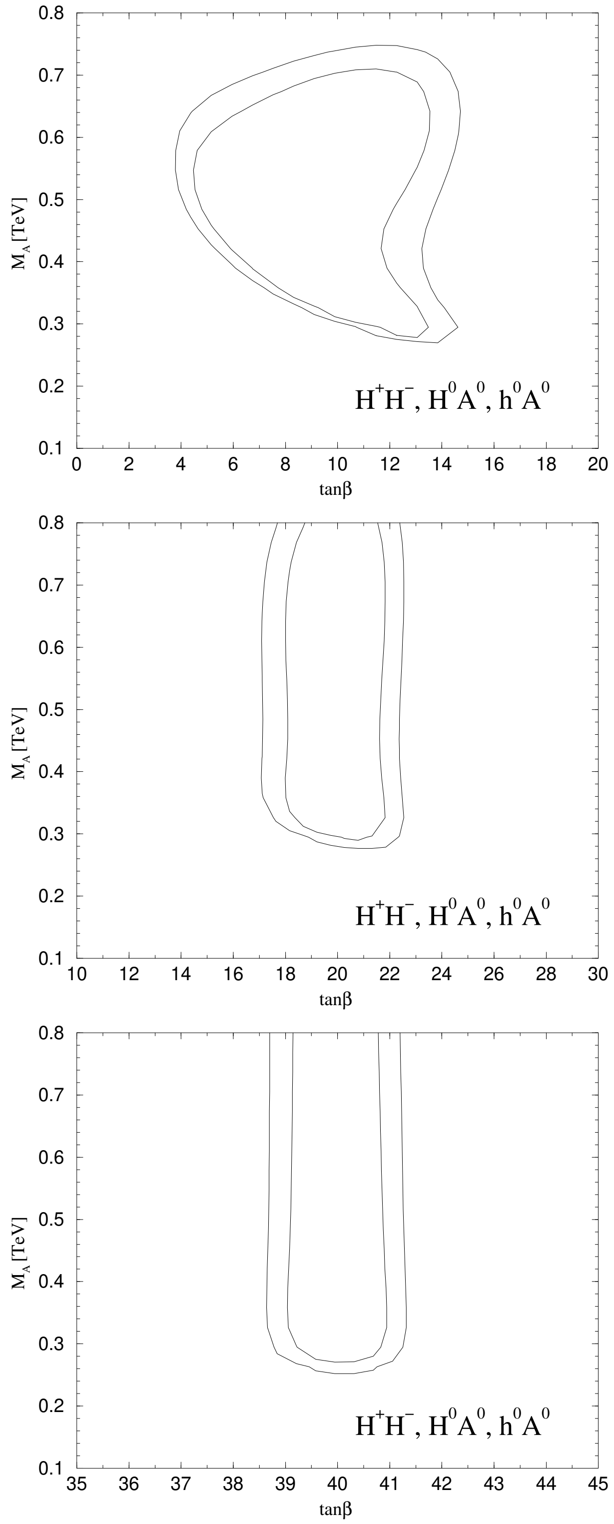

Figure 1: Contour plots at 68% and 90% CL, for $\tan\beta = 10, 20, 40$.

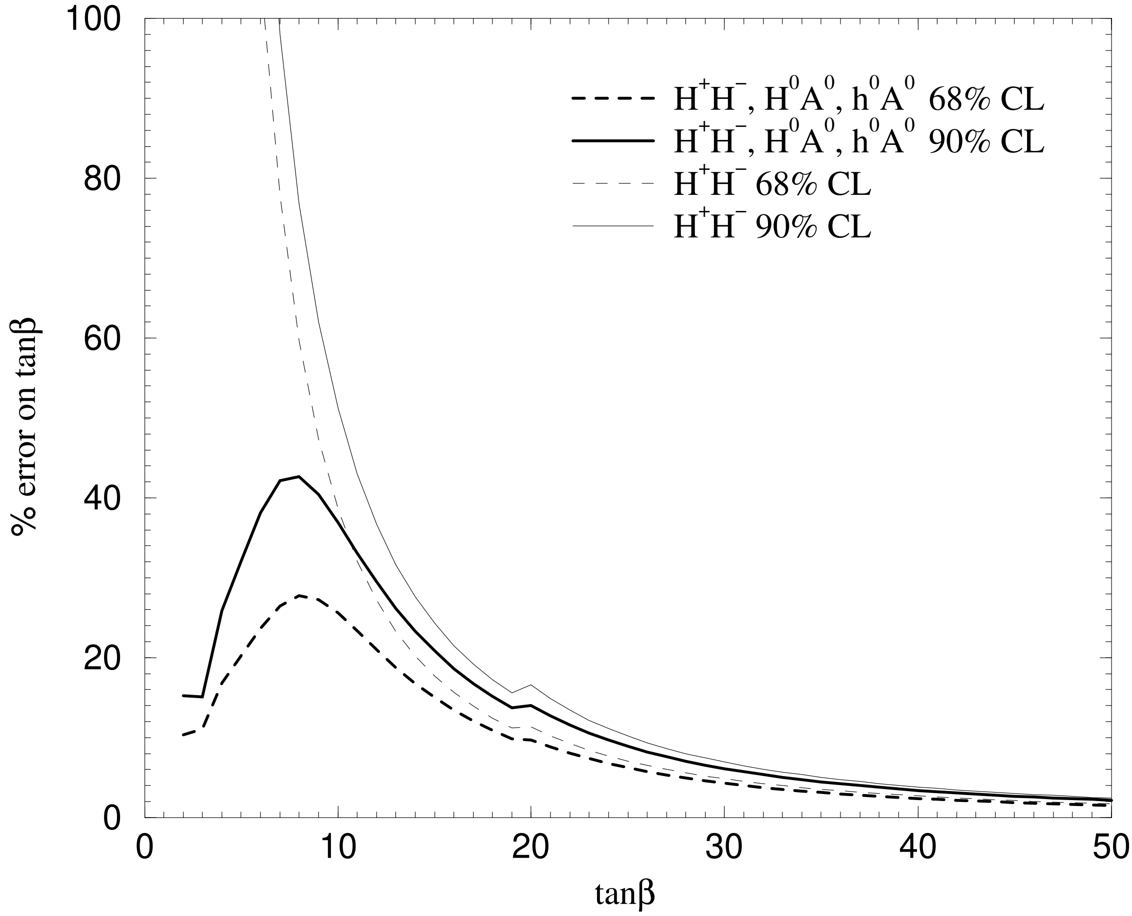

Figure 2: $\tan\beta$ percentual error estimate for values of $\tan\beta$ between 2 and 50.