One-loop radiative corrections to the single and pair Higgs productions at e^+e^- colliders within the Inert Higgs Doublet Model

Hamza abouabid[a], A.Arhrib[a], R.Benbrik[b], J.El Falaki[a], B.Gong[c], W.Xie[c,d], and Q.Yan[d,e]

[a] Département de Mathématiques, Faculté des Sciences et Techniques, Université Abdelmalek Essaadi, B. 416, Tangier, Morocco.
[b] MSISM Team, Faculté Polydisciplinaire de Safi, Sidi Bouzid, B.P. 4162, Safi, Morocco.
[c] Theory Division, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China.
[d] School of Physics Sciences, University of Chinese Academy of Sciences, Beijing 100049, China.
[e] Center for Future High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China.

Abstract

We make a full one-loop calculation of the single and pair Higgs productions at future linear e^+e^- collider in the Inert Higgs Doublet Model (IHDM). In order to benefit from the high precision measurements, we also need a high precision predictions from the theory, which means that there is a need to go beyond the leading order calculations for most processes, hence the full one-loop contributions are thus important for physics analyses at a future linear colliders such as the ILC or CLIC.

Introduction

- The Standard Model particle spectrum has been completed by discovery of the Higgs boson on 4^{th} July 2012, by the ATLAS and CMS expirements at CERN.
- Higgs couplings measurements at the LHC Run I-II, such as the Higgs coupling to fermions and gauge bosons with uncertainty of 30-50% and 20% respectively.
- The future High-Luminosity LHC (HL-LHC) will improve the aforementioned measurements.
- In the clean environment of the future linear colliders, such as as the International Linear Collider (ILC) , the measurements will be greatly improved.

Observable	HL-LHC	ILC	HL-LHC + LC
hbb	4-7%	0.6%	0.6%
H$\tau\tau$	2-5%	1.3%	1.2%
HZZ	2-4%	0.5%	0.3 %

The Inert Higgs Doublet Model

The IHDM is one of the most simplest models for the scalar dark matter, a version of a two Higgs double model with an exact Z_2 symmetry. The SM scalar sector is extended by an inert scalar doublet H_2 which can provide a stable dark matter candidate. Under Z_2 symmetry all the SM particles are even while H_2 is odd and it could mix with the SM-like Higgs doublet. We shall use the following parameterization of the two doublets :

$$H_1 = \begin{pmatrix} G^\pm \\ \frac{1}{\sqrt{2}}(v + h + iG^0) \end{pmatrix} \quad , \quad H_2 = \begin{pmatrix} H^\pm \\ \frac{1}{\sqrt{2}}(H^0 + iA^0) \end{pmatrix} \tag{1}$$

The most general renormalizable, gauge invariant and CP invariant potential is given by :

$$\begin{aligned} V =& \mu_1^2|H_1|^2 + \mu_2^2|H_2|^2 + \lambda_1|H_1|^4 + \lambda_2|H_2|^4 + \lambda_3|H_1|^2|H_2|^2 + \lambda_4|H_1^\dagger H_2|^2 \\ &+ \frac{\lambda_5}{2}\left\{(H_1^\dagger H_2)^2 + \mathrm{h.c}\right\} \end{aligned} \tag{2}$$

The spectrum of this potential will have five scalar particles: two CP even H^0 and h which will be identified as the SM Higgs boson, a CP odd A^0 and a pair of charged scalars $H^\pm$. Their masses are given by:

$$\begin{aligned} m_h^2 &= -2\mu_1^2 = 2\lambda_1 v^2 \\ m_{H^0}^2 &= \mu_2^2 + \lambda_L v^2 \\ m_{A^0}^2 &= \mu_2^2 + \lambda_S v^2 \\ m_{H^\pm}^2 &= \mu_2^2 + \frac{1}{2}\lambda_3 v^2 \end{aligned} \tag{3}$$

where $\lambda_{L,S}$ are defined as:

$$\lambda_{L,S} = \frac{1}{2}(\lambda_3 + \lambda_4 \pm \lambda_5) \tag{4}$$

This model involves 8 independent parameters: five λ, two μ_i and v. One parameter is eliminated by the minimization condition and the VEV is fixed by the W boson mass. Finally, we are left with six independent parameters which we choose as follow :

$$\{\mu_2^2, \lambda_2, m_h, m_{H^\pm}, m_{H^0}, m_{A^0}\} \tag{5}$$

on-shell renormalization

In this work we used the On-shell renormalization scheme, for both processes, such as:

- For the Higgs-Strahlung process the same renormalization scheme as the Standard Model was used.
- In $e^+e^- \to H^0A^0$ process, in addition of the couplings and masses renormalized in SM we have to take account of the on-shell renormalization for the two additional fields: A^0 and H^0 in ZHA and γHA diagrams.

Result

At the one-loop order, the cross section can be obtained by interfering the amplitudes of the tree level diagrams with those arising at the one-loop. Writing the amplitude as follow :

$$\mathcal{M} = \mathcal{M}_{tree} + \mathcal{M}_{loop} \tag{6}$$

The squared amplitude at the one-loop level is then:

$$\sigma = \frac{1}{(2\pi)^2}\int \prod_{k=1}^{3} \frac{d^3\mathbf{p}_k}{2E_k}\delta^{(4)}(q_1 + q_2 - p_1 - p_2) \sum_{spin.pola.} |\mathcal{M}|^2 \tag{7}$$

Where q_1 and q_2 are the 4-momenta of the incoming particles (electrons and positrons), p_1 and p_2 are the momenta of the outgoing particles and factor $\frac{1}{(2\pi)^2}$ aruses from the flux of the initial particles. We define the ratio $\Delta\sigma$ by:

$$\Delta\sigma = \frac{\sigma_{total} - \sigma_{tree}}{\sigma_{tree}} = \frac{\sigma_{loop}}{\sigma_{tree}} \tag{8}$$

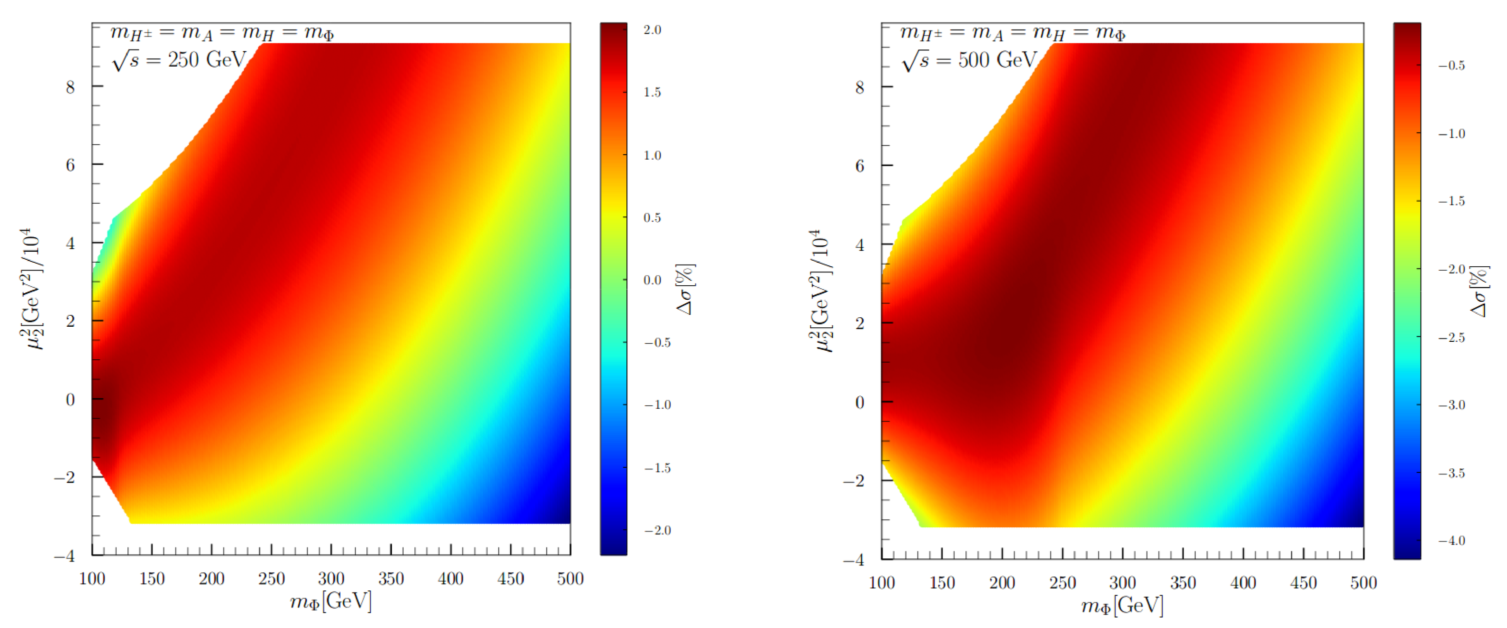

Figure 1: Scatter plot for $\Delta\sigma$ in the plan (m_Φ, μ_2^2) for the Higgs Strahlung process with $\lambda_2 = 2$ and in the left figure we chose $\sqrt{S} = 250 GeV$ and $\sqrt{S} = 500$ for the right.

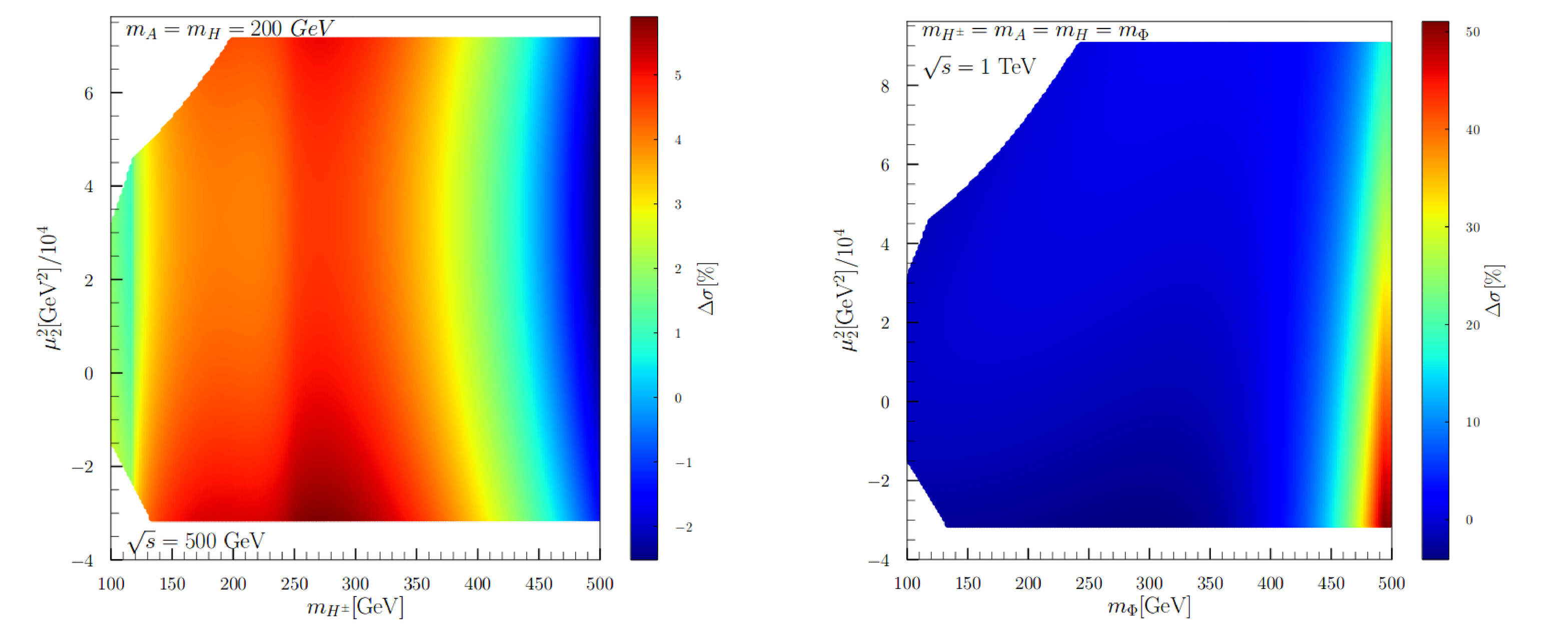

Figure 2: Scatter plot for $\Delta\sigma$ in % for the $e^+e^- \to H^0A^0$ with $\lambda_2 = 2$. For the left figure $m_A = m_{H^0} = 200\ GeV$ and $\sqrt{s} = 500\ GeV$. For the left figure all masses are degenerate and $\sqrt{s} = 1\ TeV$.

Conclusions

- At 1 TeV $\Delta\sigma$ in the $e^+e^- \to H^0A^0$ process we can have very significant radiative corrections which can reach up to 50%.
- The radiative correction of the Higgs Strahlung process are not bigger than can be significant at ILC but they will be more useful at FCC-ee and CEPC.

References

[1] Georges Aad et al. Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC. *Phys. Lett.*, B716:1–29, 2012.

[2] Serguei Chatrchyan et al. Observation of a New Boson at a Mass of 125 GeV with the CMS Experiment at the LHC. *Phys. Lett.*, B716:30–61, 2012.