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Pair charged Higgs productions at NLO in e^+e^- collider within the Inert Doublet Model

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In this contribution, we investigate the complete electroweak one-loop radiative correction to the $e^+e^- \to H^+H^-$ within the Inert Higgs Doublet Model (IHDM), at the future Higgs factory such as the ILC, CLIC and CEPC. After taking account of the theoretical and experimental constraints such as LEP, LHC and Dark matter constraints, the calculations are performed using FeynArts/FormCalc (FA/FC) to evaluate the one-loop weak corrections and using Feynman Diagram Calculation (FDC) to compute the QED contribution to the Next-Leading-Order (NLO) cross section, in three energies of collisions 250, 500 and 1000 GeV. By observing the $e^+e^- \to H^+H^-$ process, the detection of the new physics of IHDM can be directly done due to the large production rate and the corrections are significant.

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[*] Speaker

1. Introduction

The discovery of the Higgs boson at the Large Hadron Collider (LHC) [1, 2] in 2012 was the last missing stone to complete and validate the Standard Model(SM). The Higgs coupling to fermions and gauge bosons has been measured at the LHC Run I-II with an uncertainty of 30-50% and 20%, respectively. Those aforementioned measurements will be improved to a precision level of 5-10% at the future High-Luminosity LHC (LHC-HL) and at future electron-positron factories, which offer a clean environment, to reach the percent level.

The SM offers a great explanation to the physical phenomena in the electroweak scale, but there are still many theoretical and experimental concerns that it can not answer, such as the nature of Dark Matter (DM). Because of this, there is a very high motivation for physics Beyond the Standard Model(BSM), which could manifest itself directly or indirectly in the Higgs sector. The IHDM is one of the simplest extensions of the SM [3], which provide a rich scalar sector and a posibility to explain DM.

At lepton colliders, charged Higgs bosons can be produced via the pair production process $e^+e^- \to H^+H^-$. In the case of a successful descovery of a charged scalar boson in such colliders, a precise measurement of its properties will be needed in order to determine its nature. In order to obtain the required level of precision, the radiative corrections of the different production modes of the charged scalar boson must be taken into account. In this contribution, we study the full electroweak one-loop radiative correction to the $e^+e^- \to H^+H^-$ within IHDM. We will consider all theoretical and experimental constraints such as LEP, LHC, and dark matter. The calculations are carried out in three collision energies of 250, 500 and $1000 GeV$.

2. Model and constraints

The IHDM is a version of a two Higgs double model with the exact discrete symmetry $\mathbb{Z}_2$. The most general potential of IHDM is given as follows:

$$V = \mu_1^2|H_1|^2 + \mu_2^2|H_2|^2 + \lambda_1|H_1|^4 + \lambda_2|H_2|^4 + \lambda_3|H_1|^2|H_2|^2 + \lambda_4|H_1^\dagger H_2|^2 + \frac{\lambda_5}{2}\left\{(H_1^\dagger H_2)^2 + \text{h.c}\right\} \quad (1)$$

Where $\mu_{1,2}^2$ and λ_{1-4} are real parameters. In addition to the SM higgs boson h^0, four additional scalar particles appear after the electroweak symmetry breaking : two charged $H^\pm$ and two neutral H^0 and A^0. The model has 5 independent parameters in the scalar sector chosen as follows:

$$\{\mu_2^2, \lambda_2, m_{H^\pm}, m_{H^0}, m_{A^0}\} \quad (2)$$

The trilinear charged scalar coupling is defined as:

$$h^0H^\pm H^\mp = -v\lambda_3 \equiv v\lambda_{h^0H^\pm H^\mp} \equiv v\lambda_{h^0SS}. \quad (3)$$

In order to get the allowed parameter space, we perform a random scan over the IHDM parameter space requiring that each parameter point complies with the theoretical and experimental constraints given in details in our paper [4]. In the following sections two scenarios will be considered, Scenario I where all masses are degenerate and Scenario II where masses are independent.

3. $e^+e^- \longrightarrow H^+H^-$

The total leading order cross section for the pair charged higgs production is given by:

$$\sigma^0 = \frac{\pi\alpha^2\beta^3}{3s}\left[1 + g_H^2 \frac{g_V^2 + g_A^2}{(1 - m_Z^2/s)^2} - \frac{2g_H g_V}{1 - m_Z^2/s}\right] \tag{4}$$

with

$$g_V = \frac{1 - 4s_W^2}{4c_W s_W}, \quad g_A = \frac{1}{4c_W s_W}, \quad g_H = -\frac{c_W^2 - s_W^2}{2c_W s_W} \text{ and } \beta = \sqrt{1 - \frac{4m_{H^\pm}^2}{s}} \tag{5}$$

Where β is the velocity of outgoing $H^\pm$ in the center of mass frame and c_W (s_W) is the cosine (sine) of the Weinberg mixing angle. One can clearly read that this cross section depends only of $m_{H^\pm}$, also due the phase space suppression factor β, the cross section decreases faster as $m_{H^\pm}$ increases.

The 'tHooft-Feynman gauge has been used to evaluate both the weak and the QED corrections. For the renormalization, we use the On-shell renormalization scheme refering to [5] which require two on-shell conditions to fix the mass counter-term and the Higgs wave function renormalization constant,

$$\text{Re}\hat{\Sigma}_{H^+H^-}(m_{H^\pm}^2) = 0, \quad \text{Re}\frac{\partial\hat{\Sigma}_{H^+H^-}}{\partial k^2}\bigg|_{k^2=m_{H^\pm}^2} = 0 \tag{6}$$

Where $\hat{\Sigma}_{H^+H^-}$ is the one-loop renormalized charged scalar self energy. Only two additional counter terms are added to the SM ones,

$$\begin{aligned} \delta\mathcal{L}_{AH^+H^-} &= -ie(\delta Z_e + \delta Z_{H^+} + \frac{\delta Z_{AA}}{2} + g_H\frac{\delta Z_{AZ}}{2})A^\mu H^+ \overleftrightarrow{\partial}_\mu H^- \\ \delta\mathcal{L}_{ZH^+H^-} &= -ieg_H(\delta Z_e + \delta Z_{H^+} + \frac{\delta Z_{ZZ}}{2} - \frac{\delta s_W}{(c_W^2 - s_W^2)c_W^2 s_W} \end{aligned} \tag{7}$$

A decomposition into the virtual, soft, hard collinear, hard non-colinear parts can be performed on the NLO cross section [6] as,

$$d\sigma^1 = d\sigma_V + d\sigma_S + d\sigma_{HC+CT} + d\sigma_{H\overline{C}}. \tag{8}$$

At one-loop level, a Coulomb singularity proportional to $\alpha\pi/\beta$ appears. This singularity can be resumed by modifying the LO cross section as $\sigma^0_{resum.} = |\psi(0)|^2\sigma^0$ where the factor $|\psi(0)|^2$ is given by [7, 8] :

$$|\psi(0)|^2 = \frac{\alpha\pi/\beta}{1 - e^{-\alpha\pi/\beta}} = 1 + \frac{\alpha\pi/\beta}{2} + \cdots \tag{9}$$

The NLO cross section, can be written as the sum of σ^0, and the loop cross section σ^1, namely

$$\sigma^{NLO}_{resum.} = \sigma^0_{resum.} + \sigma^1_{resum.} \equiv \sigma^0_{resum.}(1 + \Delta_{resum.}), \tag{10}$$

Where $\Delta_{resum.}$ is the resummed relative correction. Thus, two gauge-invariant parts are included in the $\Delta_{resum.}$ with $\Delta_{resum.} = \Delta_{weak} + \Delta_{QED,resum.}$ where the resummed QED correction can be written as $\Delta_{\text{QED,resum.}} = \Delta_{\text{QED}} - \dfrac{\alpha\pi}{2\beta}$.

4. Results

The numerical results for σ_V and σ_S, are obtained using (FA/FC) [10, 11, 15] while σ_{HC+CT} and $\sigma_{H\overline{C}}$ with the help of FDC [12]. Numerical calculations of the scalar integrals functions are done with LoopTools [13, 14]. The physical parameters value adopted for this contribtion can be found in [16]. We have also set $\lambda_2 = 2$ and SM Higgs mass to be $m_{h^0} = 125.18$ GeV.

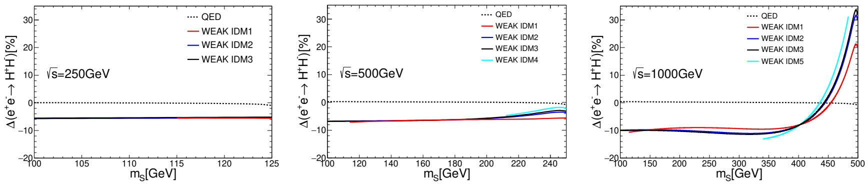

Figure 1: The relative correction of $e^+e^- \longrightarrow H^+H^-$ as function of inert scalar masses $m_S = m_{H^0} = m_{A^0} = m_{H^\pm}$ are shown for different values of $\mu_2^2 = 40000, 6000, 0, -10000$ and -30000GeV^2 named respectively IDM1,2,..,4, in the scenario I.

Fig. 1 shows the relative corrections to $e^+e^- \to H^+H^-$, Δ, in Scenario I, as function of the inert scalars masses m_S. Due to the theoretical constraints, it is observed that the range of the m_S depends of the value of μ_2^2 which explain why there is no IDM4 in the plot with $\sqrt{s} = 250$GeV. It can be read that Δ can be almost independent of m_S for $m_S \leq 200GeV$ at $\sqrt{s} = 250$ and $500GeV$ reaching -6%. However, in CM energy $\sqrt{s} = 1TeV$, the ratio varies from -10% to 30% or higher. Such a behavior can be attributed to the large corrections of triple scalar coupling $h^0H^+H^-$.

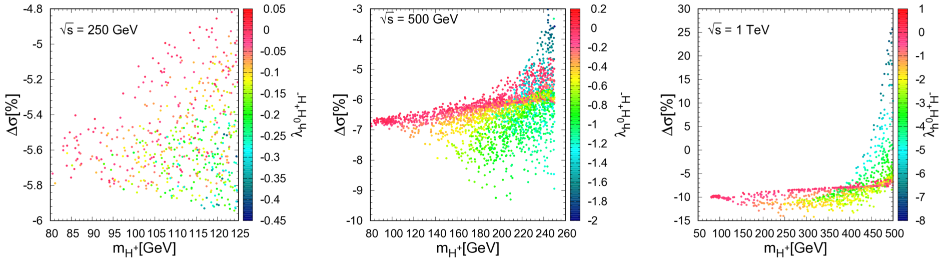

Figure 2: The relative correction of $e^+e^- \longrightarrow H^+H^-$ shown for the Scenario II, in function of $m_{H^\pm}$ in the Y-axis and $\lambda_{h^0H^+H^-}$ in the color bar, at $\sqrt{s} = 250, 500$ and 1000 GeV.

In the Fig.(2) we show, in Scenario II, the ratio of EW corrections as a function of m_{H^+}, while the triple coupling $\lambda_{h^0H^+H^-}/v = -\lambda_3$ is labelled as a color bar. At both $\sqrt{s} = 250$ and 500 GeV the dark matter constraints shrink the allowed range of λ_3 and Δ can only be negative, from -6% to -4.8% and from -9% to -3% for CM energy $\sqrt{s} = 250$ GeV and 500 GeV, respectively. At $\sqrt{s} = 1$ TeV, the allowed range of λ_3 is significally wider, which allowed Δ to reach -15% to 30%.

5. Conclusions

In this contribution, we have demonstrated that the size of radiative corrections is usually around 5-30%. Consequently, it is critical to include these corrections in any studies or analysis at e^+e^- colliders.

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