Production of High Mass Charged Higgs Boson at FCC-hh

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Abstract

Possible extensions of the Higgs sector can be searched for a wide range of parameter space in the high energy proton-proton collisions. The searches of the heavy Higgs bosons have special challenges at present high energy colliders. One of the future international projects currently under consideration is the Future Circular Collider (FCC) which has the potential to search for a wide parameter range of new physics. The FCC-hh collider is to provide proton-proton collisions at nearly an order of magnitude higher energy than the LHC. We have studied the production and decay of charged Higgs boson at FCC-hh with a center of mass energy of 100 TeV, which extends the parameter space of Higgs sector with high luminosity of 100-500 fb^{-1}. The decay modes of the charged Higgs boson can be well similar to the background reactions from top and bottom quarks and other sources. The charged Higgs boson signal can be distinguished from the background for m_{H-} up to 1.5 TeV.

Introduction

The Higgs sector of the Standard Model (SM) is in the minimal form, which contains a complex doublet of scalar fields (ϕ^+, ϕ^0), resulting a physical neutral CP-even Higgs boson (h^0) which has been discovered at the LHC by ATLAS [1] and CMS [2] Collaborations. However, the extended Higgs sectors are more relevant to the specific problems of the SM. A charged Higgs boson $H^\pm$ appears in the extended scalar sectors such as two Higgs doublet model (THDM). In this model, two complex scalar field φ_1 and φ_2 have eight degrees of freedom, three of them are identified as Goldstone bosons (they are absorbed as longitudinal components of massive $W^\pm$ and Z), the remaining are interpreted as five physical states: neutral scalars (h^0,H^0,A^0) and charged scalars (H^+,H^-).

We study different scenarios of the model parameters. Phenomenologically, the two Higgs doublet model includes free parameters: model type parameters, mixing angle, ratio of the vacuum expectation values (tanβ=v2/v1), and masses of Higgs bosons.

In this work, in the search of charged Higgs bosons through the production of a pair of top quarks and associated bottom quarks in the proton-proton collisions at very high energy frontier, we consider the parameters obtained from the spectrum calculator 2HDM for different scenarios (from A to F) [3].

The FCC-hh collider [4] is to provide proton-proton collisions at 100 TeV center of mass energy.

Charged Higgs Boson Production and Decay

We have studied the charged Higgs boson production process pp→th⁻ + X for different scenarios at the FCC-hh. The relevant diagrams for the production of charged Higgs boson are given in Fig. 1.

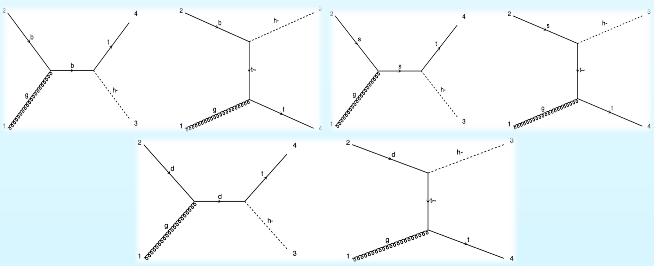

Figure 1: Contributing diagrams for charged Higgs boson (h⁻) production.

The cross sections for scenario A1 are given in Table 1, while the cross sections for different scenarios are shown in Fig. 2. The charged Higgs boson decay width and branchings are given in Table 2.

Table 1: Cross section for charged Higgs boson production process pp→tH⁻ + X within the THDM scenario A1 [3] with the parameters, m_h = 125 GeV, m_H = 150-600 GeV, tanβ = 10 , cos(β-α) = 0.1.

m_{H^0}(GeV)	σ(pb)	m_{H^-}(GeV)
150	2.29×10^{-1}	379.05
300	1.48×10^{-1}	458.80
450	7.42×10^{-2}	567.34
600	3.62×10^{-2}	691.23

Table 2: Decay widths and branching ratios obtained from the spectrum calculator 2HDM for scenario A11-A14 with the parameters given in Ref. [3].*

	S: A11	S: A12	S: A13	S: A14
	Γ=8.656 GeV	Γ=4.121 GeV	Γ= 1.886 GeV	Γ=1.415 GeV
	m_{H+}=379 GeV	m_{H+}=458 GeV	m_{H+}=567 GeV	m_{H+}=691 GeV
	Branching ratio	Branching ratio	Branching ratio	Branching ratio
$H^+ \to W^+H^0$	9.72×10^{-1}	9.00×10^{-1}	6.14×10^{-1}	1.19×10^{-1}
$H^+ \to t\bar{b}$	1.57×10^{-2}	4.48×10^{-2}	1.29×10^{-1}	2.17×10^{-1}
$H^+ \to W^+h^0$	1.20×10^{-2}	5.42×10^{-2}	2.54×10^{-1}	6.62×10^{-1}
$H^+ \to t\bar{s}$	2.49×10^{-5}	7.19×10^{-5}	2.09×10^{-4}	3.52×10^{-4}

* Decay channels with branching ratios <10^{-5} are not included in the table.

Signal and Background

In this section, we calculate the signal and background cross sections. Mass of the charged Higgs boson (m_{H^-}) changes for different scenarios. We see that in these scenarios the cross section decreases with the increase of mass m_{H^-}.

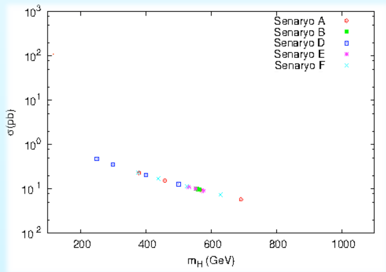

Figure 2: Cross sections for the scenarios with charged Higgs boson mass ranges 250 - 700 GeV at FCC-hh 100 TeV.

The main background cross section for the process pp→ttb+X is found to be 455 pb at FCC-hh.

Analysis on Results

Statistical significance SS=√2[(S+B)ln(1+S/B)-S] is defined in terms of signal (S) and background (B) events. SS values for different scenarios at the FCC-hh are shown in Fig. 3.

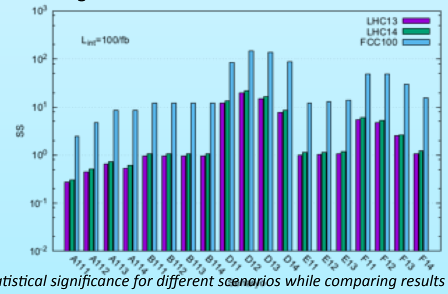

Figure 3: Statistical significance for different scenarios while comparing results at LHC and FCC-hh

We obtain large values of SS for the scenario D while the lowest values are obtained for scenario A as the parameters obtained from 2HDM.

Conclusion

Possible extensions of the Higgs sector can be searched for a wide range of parameter space in the high energy proton-proton collisions. The decay modes of the charged Higgs boson can be well similar to the background reactions from top and bottom quarks and other sources. We find that the FCC-hh has the potential to cover interested parameter space for these scenarios at 100/fb. It is also shown that with an integrated luminosity of 500 fb^{-1} at the center of mass energy √s=100 TeV of FCC-hh collider, the charged Higgs boson signal can be distinguished from the background for m_{H-} up to 1.5 TeV [5]. There are theoretical uncertainties in the calculation of cross sections at very high energies, such as the scales of renormalization and factorization as well as different schemes for the parton distribution functions, however the complete next to leading order results will reduce the scale dependence and theoretical uncertainties. Provided with the detector properties within the FCC-hh software, a detector simulation of top associated charged Higgs boson would be beneficial.

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