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Searches for $pp \rightarrow H^{\pm}h \rightarrow W^{\pm}hh$ Signal in the MSSM Model

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Abstract:
In the experimental search for the light Higgs boson, we considered a new signature of the charged Higgs boson, $pp \rightarrow H^{\pm}h \rightarrow W^{\pm}hh$, which is almost background free as the promising to study of supersymmetry at the LHC with both energy of 13 TeV and 14 TeV. In the framework of the MSSM model we used the latest parameter space, which is consistent with both the experimental constraints obtained at the LHC and theoretical calculations. In the surviving regions with the help of Pythia 8.3 and Feynhiggs programs it was found that production cross sections, $\sigma(pp \rightarrow H^{\pm}h)$, and Branching Ratios, $BR(H^{\pm} \rightarrow W^{\pm}h)$, are the largest at Benchmark Points 4 and 14 correspondingly. The corresponding mass distributions and kinematical cuts of the lightest, h, and charged Higgs boson, $H^{\pm}$, were obtained.
***Key Word**: Higgs boson; MSSM model.*

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I. Introduction

Experimental searches for supersymmetry, associated with a number of key unresolved problems in the Standard Model (SM), are the most privileged channel for the search for new physics beyond the Standard Model (BSM). Searches for the extended Higgs boson sector as the lightest super-particles with masses up to 1 TeV are the most promising in this aspect. This is facilitated by both experimental data on searches for super-particles with masses of up to 100 GeV [1, 2] and theoretical constructions. Among super-symmetric models, the most popular is the 2-Higgs Doublet Model (2HDM) with few Benchmark Points (BPs) which pass all present constraints, both theoretical and experimental. There were performed Monte-Carlo (MC) analysis of different supersymmetry search channels, one of which, $W^{\pm} + 4\gamma$, is very promising [3], as it can be connected with significant excesses at the LHC.

Since 2HDM is a tree-level Minimal supersymmetric standard model (MSSM) [4], the purpose of the article is to carry out calculations for the production cross sections $\sigma(pp \rightarrow H^{\pm}h)$, and Branching Ratios (BR) $BR(H^{\pm} \rightarrow W^{\pm}h)$ using the selected BP scenarios within the extended supersymmetry model, MSSM. It is important to select the most significant events based on the calculation results and find the corresponding masses and momentum distributions of the Higgs bosons. In addition, it is necessary to compare the obtained data with similar calculations within the framework of 2HDM in order to select the most suitable scenarios for the search for supersymmetry.

II. Theory of 2HDM and MSSM Model

Searches for BSM physics, especially super-symmetry, is a privileged area of modern experimental high-energy physics. The most popular theory of supersymmetry is MSSM model. At tree-level this model goes to another model, 2HDM as its low-energy limit with neutral CP-even scalars (h and H), CP-odd pseudo-scalar (A) and two charged Higgs bosons (H±). To show this, it must be noted that in the MSSM, the terms contributing to the scalar Higgs potential VH come from three different sources:

i) the D terms.

$$V_D = \frac{g_2^2}{8} \times$$

$$\times \left[4|H_1^+ \cdot H_2|^2 - 2|H_1|^2|H_2|^2 + (|H_1|^2)^2 + (|H_2|^2)^2 \right] +$$

$$+ \frac{g_1^2}{8}(|H_2|^2 - |H_1|^2)^2$$

ii) the F terms

$$V_F = \mu^2(|H_1|^2 + |H_2|^2)$$

iii) a piece originating from the soft SUSY–breaking scalar Higgs mass terms and the bilinear term

$$V_{soft} = m^2_{H_1} H_1^+ H_1 + m^2_{H_2} H_2^+ H_2 + B\mu(H_2 \cdot H_1 + h.c.)$$

The full scalar potential involving the Higgs fields is the sum of the three terms [5]

$$V_H = (|\mu|^2 + m^2_{H_1})|H_1|^2 + (|\mu|^2 + m^2_{H_2})|H_2|^2 - \\ - \mu B e_{ij}(H_1^i H_2^j + h.c.) + \frac{g_2^2 + g_1^2}{8}(|H_1|^2 - |H_2|^2)^2 + \\ + \frac{1}{2} g_2^2 |H_1^+ H_2|^2$$

The most general supersymmetric potential for two Higgs doublets (H_u and H_d) at tree-level reads [6]

$$V^{LO}_{MSSM} = (m^2_{H_d} + \mu^2)|H_d|^2 + (m^2_{H_u} + \mu^2)|H_u|^2 - \\ - B\mu\varepsilon_{ij}(H_d^i H_u^j + h.c.) + \\ + \frac{g^2 + g'^2}{8}(|H_d|^2 - |H_u|^2)^2 + \frac{g^2}{2}|H_d^* H_u|^2$$

where m_{Hd}^2, m_{Hu}^2, B_μ denote the soft-SUSY breaking mass parameters, g and g' - the $SU(2)_L$ and $U(1)_Y$ gauge couplings. From comparison of formula (1) and (2) we see matching expressions, which confirms the coincidence of 2HDM with the MSSM model at the tree-level. The advantage of 2HDM model is the possibility to avoid large effects of Flavor Changing Neutral Currents.

III. Results of Calculations

Using article data [7] we'll focus on the decay modes of the charged Higgs boson $H^{\pm} \to W^{\pm *}h$ in the 2HDM Type-I satisfying the condition $M_{H\pm} < M_t + M_b$. It is assumed that the properties of heavy scalar H are consistent with the LHC measurements, and h is lighter than 125 GeV. In this paper was emphasized that the production and decay process $pp \to H^{\pm}h \to W^{\pm *}hh \to l^{\pm}\nu + 4\gamma$ is background free, so $W^{\pm} + 4\gamma$ signal would yield significant excesses at the LHC with an integrated luminosity of L = 300 fb^{-1} at both $\sqrt{s}$ = 13 and 14 TeV.

So, this search channel is of particular interest for exploiting a MC analysis at a detector level by including parton shower, hadronization and heavy flavor decays, [8], so that significance only depends upon the signal cross sections and the integrated luminosity. Moreover, the estimate of the signal significance over the Type-I parameter space, could be useful for LHC experimental groups.

To estimate the production cross section of considered signal $\sigma(pp \to H^{\pm}h)$ we choose the input parameters of more general MSSM model in the form of BP of [7], presented in Table 1

Table no 1: Input parameters of MSSM model.

BP	*Mh*	*MA*	*MH*$^{\pm}$	tanβ
BP3	45.34	162.07	128.00	7.57
BP4	53.59	126.09	91.49	8.00
BP5	63.13	85.59	104.99	18.09
BP6	65.43	111.43	142.15	11.52
BP7	67.82	79.83	114.09	8.94
BP9	73.18	108.69	97.34	8.06
BP14	81.53	225.76	168.69	9.75

Then with the help of Pythia 3 [9] we calculated production cross sections at 13 and 14 TeV presented in Table 2 and Table 3

Table no 2: Production cross sections, $\sigma(pp \to H^{\pm}h)$, at 13TeV for the corresponding BPs.

BP	σ (in pb)	statist. err.
BP3	5.235e-01	8.977e-03
BP4	1.104e+00	1.877e-02
BP5	6.715e-01	1.103e-02
BP6	2.813e-01	4.740e-03
BP7	6.287e-01	1.044e-02
BP9	1.506e-01	2.536e-03
BP14	0.000e+00	0.000e+00

Table no 3: Production cross sections, $\sigma(pp \to H^{\pm}h)$, at 14TeV for the corresponding BPs.

BP	σ (in pb)	statist. err.
BP3	5.756e-01	9.561e-03
BP4	1.232e+00	2.076e-02
BP5	7.049e-01	1.161e-02

BP6	3.278e-01	5.297e-03
BP7	7.149e-01	1.190e-02
BP9	1.668e-01	2.783e-03
BP14	0.000e+00	0.000e+00

Using FeynHiggs program [10, 11, 12, 13] we calculated BR($H^{\pm} \rightarrow W^{\pm}h$), presented in Table 4.

Table no 4: Production cross sections, σ($pp \rightarrow H^{\pm}h$), at 14TeV for the corresponding BPs.

BP	BR
BP3	0.002885294
BP4	0.001397527
BP5	0.0005224388
BP6	0.000561978
BP7	0.00259184
BP9	0.001528386
BP14	0.02296814

We received the mass and momentum distributions for the maximal value of production cross section of BP4 for h boson, Fig. 1

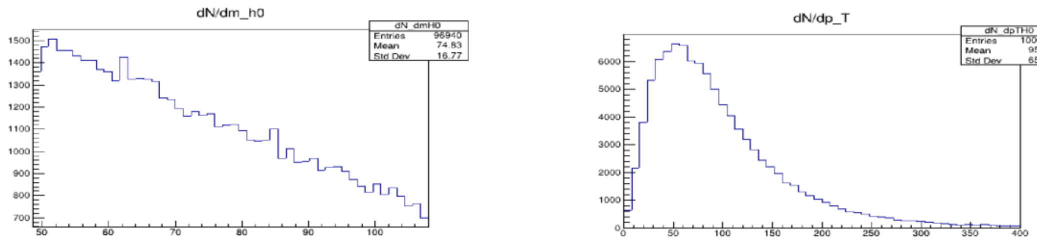

Figure no 1: Mass (up) and momentum (down) distributions of h boson at BP4 scenario.

As for H^{+} boson we obtained the data in Fig. 2

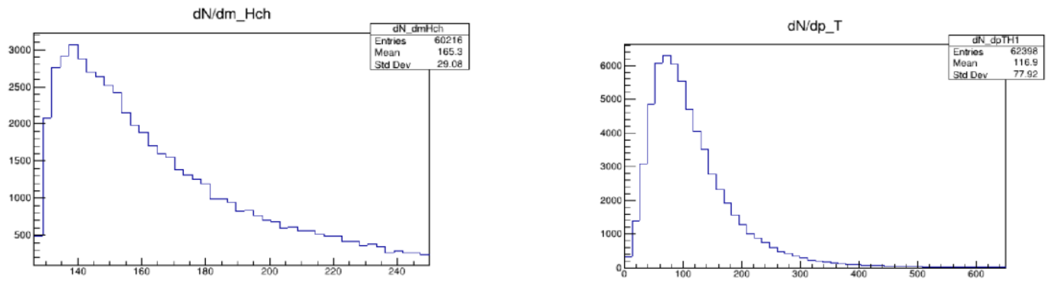

Figure no 2: Mass (up) and momentum (down) distributions of H+ boson at BP4 scenario.

From the data presented in Fig. 1 and Fig. 2, we can conclude that the mass of the lightest Higgs boson is about 50 GeV at a maximum momentum of 50 GeV and the mass of a charged H^{+} boson is about 140 GeV at a maximum momentum of 100 GeV. As for BR, it is not changed with energy and has maximal value for BP14 parameter space without change of the M_h and $M_{H\pm}$ parameters and is equal to 0.02296814.

It should be emphasized that the supersymmetric structure of the theory has imposed very strong constraints on the Higgs spectrum, so for the calculations we used six parameters which describe the MSSM Higgs sector, M_h, M_H, M_A, $M_{H\pm}$, β, α. Out of the six parameters which describe the MSSM Higgs sector, only two parameters, $\tan\beta$ and M_A, are free parameters at the tree-level. In this case, calculations according to Pythia for two parameters, $\tan\beta$ and M_A give almost identical results for any BP choice, which is presented in Table 5.

Table no 5: Production cross sections, σ(pp → $H^{\pm}$h), at 14TeV for the corresponding BPs.

BP	*σ* (in pb)	statist. err.
BP3	2.152e-02	3.688e-04
BP4	2.090e-02	3.577e-04
BP5	2.065e-02	3.420e-04
BP6	2.128e-02	3.594e-04
BP7	2.106e-02	3.608e-04
BP9	2.124e-02	3.619e-04
BP14	0.000e+00	0.000e+00

IV. CONCLUSIONS

We compared MSSM and 2HDM models and demonstrated their coincidence at tree-level. We considered the restricted parameter space of a more general MSSM model with six parameters, connected with the experimental constraints from the LHC in the form of Benchmark Points. In the surviving regions with the help of Pythia 8.3 and Feynhiggs programs it was found that production cross sections, $\sigma(pp \to H^{\pm}h)$, and $BR(H^{\pm} \to W^{\pm}h)$, are the largest at BP4 and BP14 correspondingly. As for the calculations within 2HDM model [7], the largest values of production cross sections are observed for the BP8 scenario at both energies of 13 and 14 TeV. The corresponding mass distribution for the lightest Higgs boson is 50 GeV at a maximum momentum of 50 GeV and the mass of a charged H^+ boson is 140 GeV at a maximum momentum of 100 GeV. As for BR, it has maximal value for BP14 parameter space without change of the M_h and $M_{H\pm}$ parameters and is equal to 0.02296814.

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