Flavor violating signature of Higgs boson at the LHeC

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in collaboration with:


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Brief introduction of 2HDM-III and how four-zero Yukawa texture is the mechanism that controls the FCNC.

The 2HDM-III agrees with main flavor constraints from low energy processes.

Phenomenology of neutral and charged Higgs bosons could be quiet different.

Some interesting channels decays at tree level: $H, h, A \rightarrow bs, \tau \mu, H^+$ $\rightarrow cb, ts$, decays are sensitive to the pattern of Yukawa texture.

Benchmarks scenarios are found and one could have a $\text{BR}(h, H \rightarrow bs) \sim 0.1$ keeping $h$-decays compatible with SM.

e+p\rightarrow q(h,H)\nu_e$ with flavor violating decays of the Higgs bosons $(h,H)$: cross sections, some distributions and cuts.

e+p \rightarrow q\nu H^-$, considering $H^- \rightarrow cb$
Yukawa textures in the 2HDM-III

The Yukawa textures are consistent with the relations between quarks masses and flavor mixing parameters.

Yukawa textures could come from a theory more fundamental and it could be a flavor symmetry.


Yukawa sector in 2HDM type III

\[ \mathcal{L}_Y = Y_1^u \bar{Q}_L \Phi_1 u_R + Y_2^u \bar{Q}_L \Phi_2 u_R + Y_1^d \bar{Q}_L \Phi_1 d_R + Y_2^d \bar{Q}_L \Phi_2 d_R, \]

\[ M_f = \frac{1}{\sqrt{2}} (v_1 Y_1^f + v_2 Y_2^f), \quad f = u, d, l, \]

\[ \tilde{M}_f = V_{fL}^\dagger M_f V_{fR}. \]

The off-diagonal terms are constrained by CKM

Seesaw mechanism in MSSM

Flavor Violation among the Sleptons. In the leptonic sector, we begin with a Lagrangian:

\[- \mathcal{L} = \overline{E}_R Y_E L_L H_d + \overline{\nu}_R Y_\nu L_L + \frac{1}{2} \nu_R^\dagger M_R \nu_R \]

\[
\frac{d}{d \log Q} (m_L^2)_{ij} = \left( \frac{d}{d \log Q} (m_L^2)_{ij} \right)_{\text{MSSM}} + \frac{1}{16\pi^2} \left[ m_L^2 Y_\nu^\dagger Y_\nu - Y_\nu^\dagger Y_\nu m_L^2 + 2(Y_\nu^\dagger m_{\nu_R}^2 Y_\nu + m_{H_u}^2 Y_\nu^\dagger Y_\nu + A_\nu^\dagger A_\nu) \right]_{ij}
\]

\[
(\Delta m_L^2)_{ij} \simeq -\frac{\log(M/M_R)}{16\pi^2} \left( 6m_0^2(Y_\nu^\dagger Y_\nu)_{ij} + 2 \left( A_\nu^\dagger A_\nu \right)_{ij} \right)
\]

where \(m_0\) is a common scalar mass evaluated at the scale \(Q = M\), and \(i \neq j\). If we further assume that the \(A\)-terms are proportional to Yukawa matrices, then:

\[
(\Delta m_L^2)_{ij} \simeq \xi \left( Y_\nu^\dagger Y_\nu \right)_{ij}
\]

Some arguments o motivations

The 2HDM-II could be transformed into 2HDM-III through the loops-effects of sfermions and gauginos
Andreas Crivellin, Phys.Rev. D83 (2011) 056001

In models with more than one Higgs doublet the MFV case is more stable in suppressing FCNCs than the hypothesis of NFC when the quantum corrections are taken into account.

Similar phenomenology in MHDM with flavor symmetries (Nearest-Neighbor-Interaction texture)

2HDMs is studied in renormalization group evolution of the Yukawa couplings and the cases when the Z2-symmetry is broken, called non-diagonal models.
J. Bijnens, J. Lu and J. Rathsman, Constraining General Two Higgs Doublet Models by the Evolution of Yukawa Couplings , JHEP 05 (2012) 118
2HDM-III + Yukawa texture contain the following information:

It could come from a more fundamental theory (susy models with seesaw mechanism).

+ Yukawa texture is the flavor symmetry of the model and do not require of the discrete flavor symmetry.

+ The Higgs potential must be expressed in the most general form.

J. Hernandez-Sanchez, S. Moretti, R. Noriega-Papaqui, A. Rosado, JHEP 1307 (2013) 044
\[ \mathcal{L}^\phi_{ij} = - \left\{ \frac{\sqrt{2}}{v} u_i \left( m_{d_j} X_{ij} P_R + m_{u_i} Y_{ij} P_L \right) d_j H^+ + \frac{\sqrt{2} m_{l_j}}{v} Z_{ij} \bar{P}_L \bar{l}_R H^+ + \text{H.c.} \right\} \\
- \frac{1}{v} \left\{ \bar{f}_i m_{f_j} h_{ij}^f h^0 + \bar{f}_i m_{f_j} h_{ij}^f h^0 - \bar{f}_i m_{f_j} A_{ij}^f f^\gamma g_1 A^0 \right\}, \]

where \( \phi_{ij} (\phi = h, H, A) \), \( X_{ij} \), \( Y_{ij} \) and \( Z_{ij} \) are defined as:

\[ \phi_{ij}^f = \xi_{\phi}^f \delta_{ij} + G(\xi_{\phi}^f, X), \quad \phi = h, H, A, \]
\[ X_{ij} = \sum_{i=1}^{3} (V_{\text{CKM}})^{ii} \left[ X \frac{m_{d_i}}{m_{d_j}} \delta_{ij} - \frac{f(X)}{\sqrt{2}} \sqrt{\frac{m_{d_i}}{m_{d_j}}} \tilde{\chi}_{i} \right], \]
\[ Y_{ij} = \sum_{i=1}^{3} \left[ Y \delta_{ij} - \frac{f(Y)}{\sqrt{2}} \sqrt{\frac{m_{u_i}}{m_{u_j}}} \tilde{\chi}_{i} \right] (V_{\text{CKM}})_{ij}, \]
\[ Z_{ij} = \left[ Z \frac{m_{l_i}}{m_{l_j}} \delta_{ij} - \frac{f(Z)}{\sqrt{2}} \sqrt{\frac{m_{l_i}}{m_{l_j}}} \tilde{\chi}_{i} \right]. \]

With this structure in different limits one can have different 2HDM

\[ g_{2HDM - III}^{f_u i f_d j H^+} = g_{2HDM - any}^{f_u i f_d j H^+} + \Delta g_{2HDM - any}^{f_u i f_d j H^+} \]

J. Hernandez-Sanchez, S. Moretti, R. Noriega-Papaqui, A. Rosado, JHEP07 (2013) 044
The 2HDM-III as effective Lagrangian that induce at tree level flavor violating signatures like $h, H \rightarrow sb, \tau \mu$ and $H^+ \rightarrow cb, ts$, decays can be relevant in the parameter space of the model.

Finally with all these above constraints one can find: $\chi_{kk}^f \sim 1$ and $|\chi_{ij}^f| \leq 0.5,$
\[
\text{BR}(B \rightarrow X_s \gamma)_{NLO} = B_{SL} \left| \frac{V_{ts} V_{tb}}{V_{cb}} \right|^2 \frac{6\alpha_{em}}{\pi \theta(z) \kappa(z)} \left[ |D|^2 + A + \Delta \right],
\]

\[
\delta C_{(7,8)}^{0, eff} (\mu_W) = \left| \frac{Y_{33}^u Y_{32}^u}{V_{tb} V_{ts}} \right| C_{(7,8), YY}(y_t) + \left| \frac{X_{33}^u Y_{32}^u}{V_{tb} V_{ts}} \right| C_{(7,8), XY}(y_t),
\]

\[
\left| \frac{Y_{33}^u Y_{32}^u}{V_{tb} V_{ts}} \right| = \left[ \left( Y - \frac{f(y)}{\sqrt{2}} \chi_{33}^u \right) - \sqrt{\frac{m_c}{m_t}} \left( \frac{V_{cb}}{V_{tb}} \right) \frac{f(Y)}{\sqrt{2}} \chi_{23}^u \right] \left[ \left( Y - \frac{f(y)}{\sqrt{2}} \chi_{33}^u \right) - \sqrt{\frac{m_c}{m_t}} \left( \frac{V_{cs}}{V_{ts}} \right) \frac{f(Y)}{\sqrt{2}} \chi_{23}^u \right]^*,
\]

\[
\left| \frac{X_{33}^u Y_{32}^u}{V_{tb} V_{ts}} \right| = \left[ \left( X - \frac{f(X)}{\sqrt{2}} \chi_{33}^d \right) - \sqrt{\frac{m_s}{m_b}} \left( \frac{V_{ts}}{V_{tb}} \right) \frac{f(X)}{\sqrt{2}} \chi_{23}^d \right] \left[ \left( Y - \frac{f(y)}{\sqrt{2}} \chi_{33}^u \right) - \sqrt{\frac{m_c}{m_t}} \left( \frac{V_{cs}}{V_{ts}} \right) \frac{f(Y)}{\sqrt{2}} \chi_{23}^u \right]^*,
\]

\[
B^0 - \bar{B}^0 \text{ mixing}
\]

\[
\left| \frac{Y_{33}^u Y_{32}^u}{V_{tb} V_{ts}} \right| < 0.25, \quad -1.7 < Re \left[ \frac{X_{33}^u Y_{32}^u}{V_{tb} V_{ts}} \right] < 0.7, \quad (80 \text{ GeV} \leq m_{H^\pm} \leq 300 \text{ GeV}).
\]
As the four-zero texture controls the FCNC, then the most general Higgs potential could be considered for the 2HDM-III

\[ V(\Phi_1, \Phi_2) = \mu_1^2(\Phi_1^\dagger \Phi_1) + \mu_2^2(\Phi_2^\dagger \Phi_2) - \left( \mu_{12}^2(\Phi_1^\dagger \Phi_2) + \text{H.c.} \right) + \frac{1}{2} \lambda_1(\Phi_1^\dagger \Phi_1)^2 \]

\[ + \frac{1}{2} \lambda_2(\Phi_2^\dagger \Phi_2)^2 + \lambda_3(\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4(\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) \]

\[ + \left( \frac{1}{2} \lambda_5(\Phi_1^\dagger \Phi_2)^2 + \left( \lambda_6(\Phi_1^\dagger \Phi_1) + \lambda_7(\Phi_2^\dagger \Phi_2) \right)(\Phi_1^\dagger \Phi_2) + \text{H.c.} \right) \]

The custodial symmetry, pertubativity and unitarity are imposed and we obtain the following parameters of Higgs potential:

for \( \tan \beta \leq 10 \):

\[ |\lambda_{6,7}| \leq 1, \quad \lambda_6 = -\lambda_7, \]

\[ \sin(\beta - \alpha) \sim 1, \quad \mu_{12} \sim v, \]

The masses of \( m_a, mH^+ \) and \( MH \) are chosen by STU obliques parameters

A. Cordero-Cid, J. Hernandez-Sanchez, C. Honorato, S. Moretti, A. Rosado, JHEP07 (2014) 057
FIG. 1: Allowed regions in the $(\cos(\beta - \alpha), \tan \beta)$ plane in Type I (a), Type II (b), Lepton Specific (c), and Flipped (d) 2HDMs obtained by performing a $\chi^2$ analysis. The region between the black (solid), red (dotted), and blue (dashed) lines is allowed at 95% confidence level corresponding to the current limits and the projected limits for integrated luminosities of 300 fb$^{-1}$ and 3000 fb$^{-1}$, respectively.
FIG. 1. The allowed region in the plane $X$ vs $Y$, using the constraint Eq. (13), which is obtained from the radiative inclusive decay $B \to X_{sY}$. We obtain the Scenario Ib, which is shown in the left panel, with $0.1 \leq \cos(\beta - \alpha) \leq 0.5$, $\chi^d_{kk} = 1.5$ ($k = 2, 3$), $\chi^d_{22} = 1.8$, $\chi^d_{33} = 1.2$, $\chi^{u,d}_{23} = 0.2$, $\chi^{s}_{22} = 0.5$, $\chi^{s}_{33} = 1.2$, $\chi^{s}_{23} = 0.1$. For Scenario Iia and Y, the allowed region is given in the right panel with $\cos(\beta - \alpha) = 0.1$, $\chi^{d}_{22} = 0.5$, $\chi^{u}_{33} = 1.4$, $\chi^{d}_{22} = 2$, $\chi^{d}_{33} = 1.3$, $\chi^{d}_{23} = -0.53$, $\chi^{d}_{33} = 0.2$, $\chi^{s}_{22} = 0.4$, $\chi^{s}_{33} = 1.2$, $\chi^{s}_{23} = 0.1$. For both cases $m_h = 125$ GeV, $130$ GeV $\leq m_H \leq 300$ GeV, $100$ GeV $\leq m_A \leq 250$ GeV, $110$ GeV $\leq m_{H^\pm} \leq 200$ GeV.
The overall kinematical range accessible at the LHeC is 20 times larger than HERA.

\[ \sqrt{s} = \sqrt{(E_e E_p)} = 1.296 \text{ TeV} \ (e^{-}=60\text{GeV} \ p=7000 \text{ GeV}) \text{ with } 100/\text{fb} \]

Process: \( e^- p \rightarrow \nu_e \phi q_f; \phi \rightarrow b \bar{s} + \text{h.c.} \)

These processes lead to 3-jets + \( \mathcal{E}_T \).

We demanded two jets in the central rapidity region: one tagged b-jet and one low flavor jet.

The remaining jet (q\( \bar{f} \)) has been tagged in the forwards region and the central jet veto (no more than one low flavor jet): are criterions to enhance the signal to the SM backgrounds.

TABLE I. Parameters for few optimistic benchmark points in the 2HDM-III as a 2HDM-I, -II and -Y configuration. Here bs stands for \( \text{BR}(\phi \rightarrow b \bar{s} + \bar{b}s) \), in units of \( 10^{-2} \), where \( \phi = h, H \), while \( \sigma bs \) stands for the cross section multiplied by the above BR as obtained at the LHeC in units of fb. We have analyzed only the benchmarks where the \( \sigma bs \) is greater than 0.15 fb, so that at least 15 events are produced for 100 fb\(^{-1}\).

<table>
<thead>
<tr>
<th>2HDM</th>
<th>( m_h = 125 \text{ GeV} )</th>
<th>( m_H = 130 \text{ GeV} )</th>
<th>( m_H = 150 \text{ GeV} )</th>
<th>( m_H = 170 \text{ GeV} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( X )</td>
<td>( Y )</td>
<td>( Z )</td>
<td>( bs )</td>
</tr>
<tr>
<td>Ib35</td>
<td>28</td>
<td>10</td>
<td>28</td>
<td>15.66</td>
</tr>
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<tr>
<td>Ib57</td>
<td>44</td>
<td>5</td>
<td>44</td>
<td>17.58</td>
</tr>
<tr>
<td>Iia11</td>
<td>20</td>
<td>2</td>
<td>20</td>
<td>1.42</td>
</tr>
<tr>
<td>Iia14</td>
<td>26</td>
<td>2</td>
<td>26</td>
<td>1.44</td>
</tr>
<tr>
<td>Iia26</td>
<td>36</td>
<td>1</td>
<td>36</td>
<td>1.46</td>
</tr>
<tr>
<td>Ya11</td>
<td>20</td>
<td>2</td>
<td>-2</td>
<td>1.42</td>
</tr>
<tr>
<td>Ya12</td>
<td>22</td>
<td>2</td>
<td>-2</td>
<td>1.44</td>
</tr>
<tr>
<td>Ya14</td>
<td>26</td>
<td>2</td>
<td>-2</td>
<td>1.46</td>
</tr>
</tbody>
</table>

We consider only \( \sigma bs > 0.15 \text{ fb} \); at least 15 events for 100 fb\(^{-1}\).

We applied the following basic preselections:

\[ p_T^q > 15.0 \text{ GeV}, \Delta R(q, q) > 0.4 \]

\[ \Delta R = \Delta \eta^2 + \Delta \phi^2 \], where \( \eta \) and \( \phi \) are the pseudo-rapidity and azimuthal angle respectively.
$$h_{SM}=125 \text{ GeV:} 3\text{-jet}+\not{E}_T \text{ with } 100 \text{ fb}^{-1}$$

- a: $N_j \gtrsim 3$
- b: $N_{b-\text{tag}} \gtrsim 1$ (with $\epsilon_b=0.50$, $\epsilon_c=0.10$ and $\epsilon_j=0.01$, where j=u,d,s,g)
- cd: at least two central jets (within $\eta < 2.5$) with $E_T > 20 \text{ GeV}$ → 3j not survive and photo production is reduced
- e: lepton (e or $\mu$) veto with $p_T > 20 \text{ GeV}$ and $\eta < 3.0$
- f: in the central region: $|M_{bj} - M_{h(H)}|$ is minimum and with 15 GeV mass windows.
- g: remaining leading jet with $p_T > 25 \text{ GeV}$ and $-5.5 < \eta < -0.5$
- h: $m_{\phi_{j_{f}}} > 190 \text{ GeV}$

i: We required only one low flavored jet in the central regions (this has severe impact on the processes)

FIG. 3. The same as Fig. 2, but now for the Scenario IIa. Similar results for Scenario Y are obtained.
TABLE II. Expected number of events after different combinations of cuts for signal and backgrounds at the LHeC with an integrated luminosity of 100 fb\(^{-1}\) for \(m_h = 125\) GeV. SimEvt stands for the actual number of events analyzed in the Monte Carlo simulations. RawEvt stands for the number of events with only the generator–level cuts (14) imposed; for the signal as well as for background, these are calculated from the total cross section times branching ratio. In the final column we mention the significances \((S)\) defined as \(S = S / \sqrt{B}\), where \(S\) stands for signal events, background events \(B\) for 100 fb\(^{-1}\) of data after all cuts mentioned in the “i” column. The number in the parenthesis in the final column represent the significances for 1000 fb\(^{-1}\).

<table>
<thead>
<tr>
<th>Proc</th>
<th>SimEvt</th>
<th>RawEvt</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
<th>i</th>
<th>S</th>
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<tbody>
<tr>
<td>Ib35</td>
<td>100 K</td>
<td>639.2</td>
<td>447.6</td>
<td>177.3</td>
<td>117.1</td>
<td>97.4</td>
<td>93.8</td>
<td>37.8</td>
<td>31.7</td>
<td>25.4</td>
<td>15.8</td>
<td>1.2(3.8)</td>
</tr>
<tr>
<td>Ib47</td>
<td>100 K</td>
<td>308.6</td>
<td>216.8</td>
<td>85.1</td>
<td>56.2</td>
<td>47.1</td>
<td>45.5</td>
<td>18.4</td>
<td>15.6</td>
<td>13.0</td>
<td>8.1</td>
<td>0.62(2.0)</td>
</tr>
<tr>
<td>Ib57</td>
<td>100 K</td>
<td>1186.1</td>
<td>833.7</td>
<td>325.7</td>
<td>215.5</td>
<td>180.6</td>
<td>173.9</td>
<td>70.3</td>
<td>59.1</td>
<td>49.3</td>
<td>31.1</td>
<td>2.4(7.5)</td>
</tr>
<tr>
<td>Ita1</td>
<td>100 K</td>
<td>105.5</td>
<td>74.3</td>
<td>29.1</td>
<td>19.2</td>
<td>16.0</td>
<td>15.4</td>
<td>6.3</td>
<td>5.3</td>
<td>4.4</td>
<td>2.8</td>
<td>0.21(0.70)</td>
</tr>
<tr>
<td>Ita4</td>
<td>100 K</td>
<td>165.1</td>
<td>116.1</td>
<td>45.2</td>
<td>30.0</td>
<td>25.4</td>
<td>24.4</td>
<td>9.7</td>
<td>8.3</td>
<td>6.9</td>
<td>4.4</td>
<td>0.33(1.05)</td>
</tr>
<tr>
<td>Ita6</td>
<td>100 K</td>
<td>162.1</td>
<td>114.4</td>
<td>44.7</td>
<td>29.5</td>
<td>24.5</td>
<td>23.6</td>
<td>9.5</td>
<td>8.1</td>
<td>6.8</td>
<td>4.3</td>
<td>0.33(1.03)</td>
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<tr>
<td>Ya11</td>
<td>100 K</td>
<td>108.4</td>
<td>76.3</td>
<td>29.8</td>
<td>19.6</td>
<td>16.4</td>
<td>15.8</td>
<td>6.4</td>
<td>5.4</td>
<td>4.6</td>
<td>2.9</td>
<td>0.22(0.70)</td>
</tr>
<tr>
<td>Ya12</td>
<td>100 K</td>
<td>107.8</td>
<td>76.2</td>
<td>29.6</td>
<td>19.5</td>
<td>16.3</td>
<td>15.7</td>
<td>6.3</td>
<td>5.4</td>
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<td>2.8</td>
<td>0.21(0.67)</td>
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<tr>
<td>Ya14</td>
<td>100 K</td>
<td>144.1</td>
<td>101.7</td>
<td>39.8</td>
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<td>20.8</td>
<td>8.2</td>
<td>7.0</td>
<td>5.9</td>
<td>3.8</td>
<td>0.29(0.92)</td>
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<tr>
<td>(\nu \bar{b})</td>
<td>100 K</td>
<td>50712.1</td>
<td>28338.4</td>
<td>15293.7</td>
<td>9845.0</td>
<td>8144.2</td>
<td>7532.7</td>
<td>2982.1</td>
<td>2058.0</td>
<td>652.2</td>
<td>139.6</td>
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</tr>
<tr>
<td>(\nu b \bar{b})</td>
<td>560 K</td>
<td>14104.6</td>
<td>6122.8</td>
<td>3656.7</td>
<td>1858.5</td>
<td>1787.1</td>
<td>1650.1</td>
<td>257.5</td>
<td>152.5</td>
<td>85.2</td>
<td>15.1</td>
<td></td>
</tr>
<tr>
<td>(\nu b 2j)</td>
<td>90 K</td>
<td>18043.1</td>
<td>8389.2</td>
<td>3013.0</td>
<td>1691.5</td>
<td>1445.5</td>
<td>1373.7</td>
<td>389.5</td>
<td>206.1</td>
<td>77.2</td>
<td>11.3</td>
<td></td>
</tr>
<tr>
<td>(\nu 3j)</td>
<td>300 K</td>
<td>948064.2</td>
<td>410393.4</td>
<td>15560.9</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>(\nu B = 13.1)</td>
</tr>
<tr>
<td>(e \bar{b} \bar{b})</td>
<td>115 K</td>
<td>256730.1</td>
<td>55099.8</td>
<td>36353.6</td>
<td>12659.8</td>
<td>1432.0</td>
<td>200.7</td>
<td>54.1</td>
<td>24.8</td>
<td>18.0</td>
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<tr>
<td>(e \bar{\tau})</td>
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<td>783.3</td>
<td>685.0</td>
<td>384.5</td>
<td>265.9</td>
<td>179.3</td>
<td>26.2</td>
<td>11.6</td>
<td>10.5</td>
<td>3.9</td>
<td>0.3</td>
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</tr>
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</table>
TABLE III. Same as Table II but for $m_H = 130$ GeV. The criterion for jets and $b$-tagging are the same, so that the number of events in column $A$ and $B$ are the same for all SM backgrounds.

<table>
<thead>
<tr>
<th>Proc</th>
<th>SimEvt</th>
<th>RawEvt</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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<tbody>
<tr>
<td>Ib35</td>
<td>100 K</td>
<td>120.9</td>
<td>87.1</td>
<td>34.1</td>
<td>26.9</td>
<td>22.5</td>
<td>21.6</td>
<td>7.5</td>
<td>6.1</td>
<td>5.3</td>
<td>3.4</td>
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</tr>
<tr>
<td>Ib47</td>
<td>100 K</td>
<td>1098.3</td>
<td>790.3</td>
<td>307.1</td>
<td>243.9</td>
<td>204.6</td>
<td>195.7</td>
<td>68.5</td>
<td>56.1</td>
<td>48.6</td>
<td>31.3</td>
<td>2.6(8.1)</td>
</tr>
<tr>
<td>Ib57</td>
<td>100 K</td>
<td>514.0</td>
<td>371.2</td>
<td>144.8</td>
<td>96.0</td>
<td>92.0</td>
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<td>22.7</td>
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<td>1.2(3.7)</td>
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<tr>
<td>Ia11</td>
<td>100 K</td>
<td>9.7</td>
<td>6.8</td>
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<td>1.7</td>
<td>0.6</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.02(0.05)</td>
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<tr>
<td>Ia14</td>
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<td>1.0</td>
<td>0.4</td>
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<td>0.2</td>
<td>0.1</td>
<td>0.01(0.02)</td>
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<td>0.8</td>
<td>0.8</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.01(0.02)</td>
</tr>
<tr>
<td>Ya11</td>
<td>100 K</td>
<td>6.2</td>
<td>4.4</td>
<td>1.8</td>
<td>1.4</td>
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<td>0.2</td>
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<td>0.01(0.02)</td>
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<td>4.0</td>
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<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.01(0.02)</td>
</tr>
<tr>
<td>Ya14</td>
<td>100 K</td>
<td>5.7</td>
<td>4.0</td>
<td>1.6</td>
<td>1.3</td>
<td>1.0</td>
<td>1.0</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.01(0.02)</td>
</tr>
<tr>
<td>$\nu t\bar{b}$</td>
<td>100 K</td>
<td>50712.1</td>
<td>28338.4</td>
<td>15293.7</td>
<td>10976.4</td>
<td>9092.4</td>
<td>8393.6</td>
<td>2550.9</td>
<td>1565.5</td>
<td>617.9</td>
<td>113.7</td>
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<tr>
<td>$\nu b\bar{b}j$</td>
<td>560 K</td>
<td>14104.6</td>
<td>6122.8</td>
<td>3656.7</td>
<td>2145.5</td>
<td>2062.1</td>
<td>1902.9</td>
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<td>141.0</td>
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</tr>
<tr>
<td>$\nu 2j$</td>
<td>90 K</td>
<td>18043.1</td>
<td>8389.2</td>
<td>3013.0</td>
<td>2053.6</td>
<td>1734.0</td>
<td>1650.1</td>
<td>402.8</td>
<td>143.7</td>
<td>64.5</td>
<td>8.1</td>
<td></td>
</tr>
<tr>
<td>$\nu 3j$</td>
<td>300 K</td>
<td>948064.2</td>
<td>410393.4</td>
<td>15560.9</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>$\sqrt{B} = 12.2$</td>
<td></td>
</tr>
<tr>
<td>$e^+b\bar{b}$</td>
<td>115 K</td>
<td>256730.1</td>
<td>55099.8</td>
<td>36353.6</td>
<td>16838.4</td>
<td>1826.6</td>
<td>284.1</td>
<td>56.4</td>
<td>31.6</td>
<td>22.6</td>
<td>11.3</td>
<td></td>
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<tr>
<td>$e^+\bar{t}t$</td>
<td>130 K</td>
<td>783.3</td>
<td>685.0</td>
<td>384.5</td>
<td>280.8</td>
<td>190.8</td>
<td>27.8</td>
<td>10.9</td>
<td>9.3</td>
<td>3.9</td>
<td>0.3</td>
<td></td>
</tr>
</tbody>
</table>

$B = 147.8$
FIG. 5. The missing energy ($E_T$) (left panel) and rapidity ($\eta_{jf}$) (right panel) profile of the forward jet for signals and SM backgrounds. The $E_T$ distributions for all other signal benchmarks as well as the $t\bar{b}$ noise are not shown as they are very similar to the signal distributions of $m_H = 150$ GeV for Scenario Ib with $X = Z = 28$ and $Y = 10$ (shown in thick solid), whereas the thin solid is for $m_h = 125$ GeV for Scenario Ia with $X = Z = 28$ with $Y = 10$. The rapidity distributions profile for $m_H = 130$ (170) GeV is very close to the $m_h = 125$ GeV ($m_H = 130$ GeV) case shown in thin solid, except that for massive Higgs the peaks shift toward the left. Also the corresponding rapidity distribution profile for $e^2bj$ is somewhat similar to the $m_h = 125$ GeV signal case.

FIG. 6. The dijet invariant mass, made up by one $b$-tagged and one light-flavor jet, producing Higgs candidates, $M_\phi = M_{bj}$ (left panel) and the three-jet invariant mass, i.e., the previous two jets combined together with the forward jet, $M_{\phijf}$ (right panel). The mass peaks of the Higgs signals ($M_\phi$) correspond to $m_b = 125$ (thin black) for Scenario Ia, $m_H = 150$ (thick black) and 170 (thin black) for Scenario Ib from left to right. All these are using the parameters $X = Z = 28$ and $Y = 10$. The distribution for $m_H = 130$ is not shown but it lies in between $m_b = 125$ and $m_H = 150$. Among all SM backgrounds, only $2bj$ shows a prominent peak from the $Z$-boson. Notice that $M_{\phijf}$ represents the overall energy scale of the hard-scattering.
a) We require $N(j) = 3$ for the number of jets, one of which has to be $b$-tagged, and place a lepton veto $N(l) = 0$. b) We select a missing energy $\not{E}_T > 20$ GeV and a hadronic tranverse energy $H_T > 130$ GeV. c) We enforce the transverse momentum for the jets to be $p_T(j_b) > 30$ GeV, $p_T(j_1) > 40$ GeV and $p_T(j_2) > 30$ GeV. d) We restrict the jet pseudo-rapidities as $|\eta(j_b)| < 2.5$, $|\eta(j_1)| < 2.5$ (central) and $|\eta(j_2)| > 1.5$ (forward). e) We enable a cone separation amongst jets candidates to $h \Delta R(j_b, j_1) < 3$, it is a central di-jet. We enforce an isolation coditions for $j_1$ and $j_2 \Delta R(j_1, j_2) > 2.5$. f) Finally, we sample on the di-jet invariant mass $(m_\phi - 25$ GeV) $< M_{j_b,j_1} < m_\phi$.

In this analysis we use Madgraph, with Pythia-PGS package. We consider -80% longitudinally polarized electron beam.

<table>
<thead>
<tr>
<th>2HDM-III</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>$m_h = 125$ GeV</th>
<th>$m_H = 130$ GeV</th>
<th>$m_H = 150$ GeV</th>
<th>$m_H = 170$ GeV</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>bs</td>
<td>$\sigma.b$s</td>
<td>bs</td>
<td>$\sigma.b$s</td>
</tr>
<tr>
<td>Ib57</td>
<td>44</td>
<td>5</td>
<td>44</td>
<td>93.22</td>
<td>784</td>
<td>20.2</td>
<td>46.06</td>
</tr>
<tr>
<td>IIa14</td>
<td>26</td>
<td>2</td>
<td>26</td>
<td>1.52</td>
<td>15.2</td>
<td>28.3</td>
<td>10.64</td>
</tr>
</tbody>
</table>

TABLE I. FCC-eh rates for our 2HDM-III BPs, where bs stands for BR($\phi \to b\bar{s} + \bar{b}s$) in units of $10^{-2}$ while $\sigma.b$s stands for the cross section $\sigma(ep \to \nu_e \phi q)$ ($q =$ light flavor quark) times the above BR in units of fb.
TABLE II. Cut flow for signals and backgrounds, and corresponding significance for neutral Higgs bosons

<table>
<thead>
<tr>
<th>$S$</th>
<th>Higgs mass</th>
<th>RawEvt</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>$\Sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ib57</td>
<td>$m_h = 125$ GeV</td>
<td>784 k</td>
<td>21598</td>
<td>11841</td>
<td>6487</td>
<td>2875</td>
<td>1618</td>
<td>1038</td>
<td>11.17(19.36)</td>
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<tr>
<td></td>
<td>$m_H = 130$ GeV</td>
<td>228k</td>
<td>3732</td>
<td>2217</td>
<td>1237</td>
<td>548</td>
<td>299</td>
<td>221</td>
<td>2.38(4.12)</td>
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<tr>
<td></td>
<td>$m_H = 150$ GeV</td>
<td>196k</td>
<td>2935</td>
<td>1789</td>
<td>1024</td>
<td>511</td>
<td>265</td>
<td>93</td>
<td>1.75(3.02)</td>
</tr>
<tr>
<td></td>
<td>$m_H = 170$ GeV</td>
<td>171k</td>
<td>1026</td>
<td>538</td>
<td>260</td>
<td>146</td>
<td>69</td>
<td>15</td>
<td>0.29(0.51)</td>
</tr>
<tr>
<td>IIa14</td>
<td>$m_h = 125$ GeV</td>
<td>1000 k</td>
<td>56973</td>
<td>31397</td>
<td>17146</td>
<td>7346</td>
<td>3905</td>
<td>2600</td>
<td>28(48.5)</td>
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<tr>
<td></td>
<td>$m_H = 130$ GeV</td>
<td>37.6k</td>
<td>2078</td>
<td>1236</td>
<td>698</td>
<td>353</td>
<td>130</td>
<td>67</td>
<td>0.72(1.25)</td>
</tr>
<tr>
<td></td>
<td>$m_H = 150$ GeV</td>
<td>26.4k</td>
<td>1364</td>
<td>941</td>
<td>573</td>
<td>312</td>
<td>129</td>
<td>30</td>
<td>0.56(0.98)</td>
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<tr>
<td></td>
<td>$m_H = 170$ GeV</td>
<td>20.17k</td>
<td>1043</td>
<td>778</td>
<td>499</td>
<td>285</td>
<td>124</td>
<td>25</td>
<td>0.49(0.85)</td>
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</tbody>
</table>

FCC-eh with $L = 1(3) \text{ ab}^{-1}$.

Submitted to CDR of FCC-eh
The $M_{jjl_1}$ distribution for $S$ and $B$ after all cuts in Tab. II with $L = 3 \, \text{ab}^{-1}$ for both BP

TABLE II. Cut flow for signals and backgrounds, and corresponding significance for neutral Higgs bosons


S. P. Das, J. Hernández-Sánchez, S. Moretti, A. Rosado, and R. Xoxocotzi-Aguilar, JHEP


G. Aad

Workshop on Prospects for Charged Higgs Discovery at Colliders (CHARGED 2016): Uppsala, Sweden, October 3-6, 2016

CHARGED2016 et al.

los Andes. JHS, AR, CGH and RX are supported by SNI-CONACYT (México), VIEP-BUAP and by PRODEP-SEP (México) grant no. 645722 (NonMinimalHiggs). SPD acknowledges the High Performance Computing (HPC) facility at Universidad de

The $M_{jjl_1}$ distribution for $S$ and $B$ after all cuts in Tab. II with $L = 3 \, \text{ab}^{-1}$ for both BP
Production of H+ in ep collider

We focus in H+ \rightarrow cb, in 2HDM-III (also in MHDM) could be relevant
BR (H+ \rightarrow cb) \sim 0.9 in 2HDM-III
\sim 0.8 in MHDM PRD 85, 115002 (2012)

J. Hernandez-Sanchez, S. Moretti, R. Noriega-Papaqui, A. Rosado, JHEP07 (2013) 044
### Benchmarks points of 2HDM-III for analysis of H+

<table>
<thead>
<tr>
<th>2HDM-III like</th>
<th>parameters</th>
<th>$\sigma(ep \rightarrow \nu_e H^{\pm}q)[pb]$</th>
<th>$\sigma(ep \rightarrow \nu_e H^{\pm}q)[pb]$</th>
<th>$\sigma(ep \rightarrow \nu_e H^{\pm}q)[pb]$</th>
<th>$\sigma(ep \rightarrow \nu_e H^{\pm}q)[pb]$</th>
<th>$\sigma(ep \rightarrow \nu_e H^{\pm}q)[pb]$</th>
<th>$\sigma(ep \rightarrow \nu_e H^{\pm}q)[pb]$</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
<td>Z</td>
<td>$m_{H^{\pm}} = 110 \text{ GeV}$</td>
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<td>150 GeV</td>
<td>170 GeV</td>
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<tr>
<td>I</td>
<td>0.5</td>
<td>17.5</td>
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<td>$2.56 \times 10^{-2}$</td>
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<td>$3.47 \times 10^{-3}$</td>
<td>$1.35 \times 10^{-4}$</td>
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<td>9.5</td>
<td>3</td>
<td>9.5</td>
<td>$1.32 \times 10^{-2}$</td>
<td>$6.87 \times 10^{-3}$</td>
<td>$1.72 \times 10^{-3}$</td>
<td>$4.64 \times 10^{-5}$</td>
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<tr>
<td>II</td>
<td>2</td>
<td>1.5</td>
<td>2</td>
<td>$2.18 \times 10^{-2}$</td>
<td>$1.13 \times 10^{-3}$</td>
<td>$2.95 \times 10^{-3}$</td>
<td>$5.89 \times 10^{-5}$</td>
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<tr>
<td>Y</td>
<td>13</td>
<td>1.5</td>
<td>-1/13</td>
<td>$6.41 \times 10^{-2}$</td>
<td>$3.27 \times 10^{-3}$</td>
<td>$8.47 \times 10^{-3}$</td>
<td>$2.2 \times 10^{-4}$</td>
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<tr>
<td>X</td>
<td>0.03</td>
<td>1.5</td>
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<td>$6.49 \times 10^{-2}$</td>
<td>$3.39 \times 10^{-2}$</td>
<td>$8.83 \times 10^{-3}$</td>
<td>$2.34 \times 10^{-4}$</td>
</tr>
</tbody>
</table>
For light charged Higgs

\[
\Gamma(H^\pm \rightarrow u_i d_j) = \frac{3G_F m_{H^\pm} (m_{d_j}^2 |X_{ij}|^2 + m_{u_i}^2 |Y_{ij}|^2)}{4\pi\sqrt{2}}
\]

; the case \( Y >>, X,Z \) the channel decay \( H^+ \rightarrow c\bar{b} \)

\[
m_c Y_{cb} = m_c Y_{23} = V_{cb} m_c \left( Y - \frac{f(Y)}{\sqrt{2}} \chi_{22}^u \right) - V_{tb} \frac{f(Y)}{\sqrt{2}} \sqrt{m_t m_c} \chi_{23}^u
\]

\( (H^\pm \rightarrow cs) \)

\[
m_c Y_{cs} = m_c Y_{22} = V_{cs} m_c \left( Y - \frac{f(Y)}{\sqrt{2}} \chi_{22}^u \right) - V_{ts} \frac{f(Y)}{\sqrt{2}} \sqrt{m_t m_c} \chi_{23}^u
\]

\[
\frac{BR(H^\pm \rightarrow cb)}{BR(H^\pm \rightarrow cs)} = R_{sb} \sim \frac{|V_{tb}|^2}{|V_{ts}|^2}
\]
For light charged Higgs

Other case is when \( X >>, Y, Z \), we get the dominants terms \( m_b X_{23}, m_s X_{22} \):

\[
m_b X_{cb} = m_b X_{23} = V_{cb} m_b \left( X - \frac{f(X)}{\sqrt{2}} \chi_{33}^d \right) - V_{cs} \frac{f(X)}{\sqrt{2}} \sqrt{m_b m_s} \chi_{23}^d
\]

\[
m_s X_{cs} = m_s X_{22} = V_{cs} m_s \left( X - \frac{f(X)}{\sqrt{2}} \chi_{22}^d \right) - V_{ts} \frac{f(X)}{\sqrt{2}} \sqrt{m_b m_s} \chi_{23}^d
\]

If \( \chi = O(1) \) and positive then \( X - \frac{f(X)}{\sqrt{2}} \chi_{33}^d \) is small and \( R_{sb} \sim \frac{|V_{cs}|^2}{|V_{cb}|^2} \).

Other situation is when, \( \chi = O(1) \) and negative, then \( R_{sb} \sim \frac{m_b^2 |V_{cb}|^2}{m_s^2 |V_{cb}|^2} \).


J. Hernandez-Sanchez, S. Moretti, R. Noriega-Papaqui, A. Rosado, JHEP07 (2013) 044
Scenario Ia and Ib
\[ \cos(\beta - \alpha) \sim 0.1, 0.5 \]

Scenario IIa and Y
\[ \cos(\beta - \alpha) \sim 0.1 \]
Cut 1: Select 3 jets

Cut 2: Select 2 jet b-tagged for H - \rightarrow cb
1 jet b-tagged for H- \rightarrow \tau \nu

Work in progress, this is a collaboration with O. Flores, C.G. Honorato, S. Rosado and S. Moretti.

PoS CHARGED2016 (2017) 032
Cut 3: PT > 30 GeV
Cut 4: $\eta < |2.5|$ 
Cut 5: MET < 40 GeV

Cut 6: $|M_{bj} - M_{H^+}| < 15$ GeV
CHAPTER 3. THE LHEC PROCESS: $E_\text{P} \rightarrow LQ_\pm \pm$.  

3.2. $H_{\pm} \rightarrow CB$ SIGNAL

Figure 3.19: Set of histograms which show the behavior of forward jets. 

Figure 3.20: Invariant mass histograms, left) is for two central jets (b and no b-tagg). Right) is invariant mass for two light jets (no b-tagg).
• How to compare signal (S) and background (B): S/\sqrt{S+B}.

<table>
<thead>
<tr>
<th>Cuts</th>
<th>Signal (S)</th>
<th>Background (B)</th>
<th>S vs B</th>
</tr>
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<tbody>
<tr>
<td>Initial cut</td>
<td>2151</td>
<td>305124</td>
<td>3.88</td>
</tr>
<tr>
<td>Cut 1</td>
<td>954.0</td>
<td>111988 +/- 263</td>
<td>2.8387 +/- 0.0684</td>
</tr>
<tr>
<td></td>
<td>23.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut 2</td>
<td>312.0</td>
<td>15351 +/- 118</td>
<td>2.49 +/- 0.13</td>
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<tr>
<td></td>
<td>16.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut 3</td>
<td>308.0</td>
<td>14945 +/- 116</td>
<td>2.494 +/- 0.131</td>
</tr>
<tr>
<td></td>
<td>16.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut 4</td>
<td>308.0</td>
<td>14945 +/- 116</td>
<td>2.494 +/- 0.131</td>
</tr>
<tr>
<td></td>
<td>16.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut 5</td>
<td>210.0</td>
<td>8868.0 +/- 91.4</td>
<td>2.204 +/- 0.143</td>
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<td></td>
<td>13.8</td>
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<tr>
<td>Cut 6</td>
<td>197.0</td>
<td>7958.0 +/- 86.8</td>
<td>2.181 +/- 0.147</td>
</tr>
<tr>
<td></td>
<td>13.4</td>
<td></td>
<td></td>
</tr>
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</table>

For LHeC: S vs B at 1000 fb^-1 would be 6.89
If we extrapolate our results for FCC-eh and we obtain a significance of 11.2 at 1000 fb^-1 (work in progress)

PoS CHARGED2016 (2017) 032
Summary

We study the 2HDM-III as effective Lagrangian that induce flavor violating signatures and interesting signals like $h, H \rightarrow sb$.

We study the signal $h, H \rightarrow sb$ in the future ep collider LHeC: $e p \rightarrow q \nu h$. We have a significance up to 5 for $h$ SM-like and for $H$ with mass 130-150 GeV: a significance around to 4 for both colliders LHeC and FCC-eh.

Our study is consistent with flavor physics, Higgs physics and EWPO.

Following the some strategies for the neutral Higgs boson, we study the production of $H^+$ in the channel $cb$ for the future ep collider LHeC and extrapolate our results for FCC-eh.

We show some results for $H^- \rightarrow cb$ (the study is in progress). We have sufficient event rates in order to get a significance 2.18 at 100 fb$^{-1}$ (6.89 at 1000 fb$^{-1}$) for LHeC. For FCC-eh, the significance could reach 11.2 at 1000 fb$^{-1}$.