Production of neutral and charged Higgs bosons at the future collider ep LHeC

Jaime Hernandez-Sanchez

in collaboration with:

O. Flores, C. Honorato, S. Rosado (BUAP, México)
S. Moretti (U. of Southampton, UK)

work based in Arxiv: 1612.06316, 1509.05491 and 1503.01464

HPNP 2017, Toyama, Japan.
Outline

- 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: $H, h, A \to bs, \tau \mu, H^+$ $\to cb, ts$, decays are sensitive to the pattern of Yukawa texture.
- Benchmarks scenarios are found and one could have a $\text{BR}(h, H \to bs) \sim 0.1$ keeping $h$-decays compatible with SM.
- Brief discussion $e p \to q(h, H)\nu_e$ with flavor violating decays of the Higgs bosons ($h, H$): cross sections, some distributions and cuts.
- $e p \to q \nu H^+$, considering $H \to cb$, results at parton level
Yukawa textures

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

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


Yukawa sector in 2HDM type III

\[ \mathcal{L}_Y = Y^u_1 \bar{Q}_L \Phi_1 u_R + Y^u_2 \bar{Q}_L \Phi_2 u_R + Y^d \bar{Q}_L \Phi_1 d_R + Y^d \bar{Q}_L \Phi_2 d_R , \]

\[ M_f = \frac{1}{\sqrt{2}} (v_1 Y^f_1 + v_2 Y^f_2), \quad f = u, d, l, \]

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

The off-diagonal terms are constrained by CKM

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
\[ \mathcal{L}^{\tilde{t} t \phi} = - \left\{ \frac{\sqrt{2}}{v} \bar{u}_i \left( m_{d_j} X_{ij} P_R + m_{u_i} Y_{ij} P_L \right) d_j H^+ + \frac{\sqrt{2}m_{v_i}}{v} Z_{ij} \bar{v}_L H^+ + H.c. \right\} \]

\[ - \frac{1}{v} \left\{ \bar{t}_i m_{i} h^0_{ij} f_i h^0 + \bar{t}_i m_{i} H^0_{ij} f_i H^0 - i \bar{t}_i m_{i} \bar{A}^f_{ij} f_i \gamma_5 A^0 \right\}, \]

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

\[ \phi^f_{ij} = \xi^f_{\phi} \delta_{ij} + G(\xi^f_{\phi}, X), \quad \phi = h, H, A, \]

\[ X_{ij} = \sum_{i=1}^{3} (V_{\text{CKM}})_{ii} \left[ X \frac{m_{d_j}}{m_{d_i}} \delta_{ij} - \frac{f(X)}{\sqrt{2}} \left[ \frac{m_{d_i}}{m_{d_j}} \tilde{\chi}_{ij} \right] \right], \]

\[ Y_{ij} = \sum_{i=1}^{3} \left[ Y \delta_{ij} - \frac{f(Y)}{\sqrt{2}} \left[ \frac{m_{u_i}}{m_{u_j}} \tilde{\chi}_{ij} \right] (V_{\text{CKM}})_{ij} \right], \]

\[ Z^i_{ij} = \left[ Z \frac{m_{i}}{m_{j}} \delta_{ij} - \frac{f(Z)}{\sqrt{2}} \left[ \frac{m_{i}}{m_{j}} \tilde{\chi}_{ij} \right] \right]. \]

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

\[
\left( g_{2HDM-III}^{f u i f d j H^+} = g_{2HDM-III}^{f u i f d j H^+} + \Delta g^{f u i f d j H^+} \right)
\]

J. Hernandez-Sanchez, S. Moretti, R. Noriega-Papaqui, A. Rosado, JHEP07 (2013) 044
\[ \mu - e \text{ universality in } \tau \text{ decays} \]

- Leptonic meson decays \( B \rightarrow \tau \nu, D \rightarrow \mu \nu, D_s \rightarrow \mu \nu, \tau \nu \) and semileptonic decays \( B \rightarrow D\tau \nu \)

- \( B \rightarrow X_s \gamma \) decays

- \( B^0 - \bar{B}^0 \) mixing

- Electro-weak precision test (including S, T, U oblique parameters)

Finally with all these above constraints one can find: \( \chi_{kk}^f \sim 1 \) and \( |\chi_{ij}^f| \leq 0.5, \)
As the four-zero texture controls the FCNC, then the most general Higgs potential could be considered for the 2HDM-III

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

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

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

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 \( m_a, m_{H^+} \) and \( MH \) are chosen by STU obliques parameters

A. Cordero-Cid, J. Hernandez-Sanchez, C. Honorato, S. Moretti, A. Rosado, JHEP07 (2014) 057
The overall kinematical range accessible at the LHeC is 20 times larger than HERA.

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

**Signal**

Charged current (CC) $H \rightarrow bb$ (0.063 pb)

Neutral current (NC) $H \rightarrow bb$ (0.012 pb)

- CC: $H \rightarrow bb$ process is chosen as the signal because the cross section is larger than NC: $H \rightarrow bb$ process and NC rejection cut decreases large number of NC BG.

**Background**

CC $Z$ production (0.29 pb)  
Single top production (0.43 pb)  
NC multi jets
• Mass reconstructed with 1st and 2nd minimum η b-jets.
• Signal region is defined as [100,130] GeV.  

**Events in signal region**

<table>
<thead>
<tr>
<th></th>
<th>Events/100fb⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal H→bb</td>
<td>119±2</td>
</tr>
<tr>
<td>CCjjj no top</td>
<td>9±3</td>
</tr>
<tr>
<td>CC single top</td>
<td>17±2</td>
</tr>
<tr>
<td>CC Z</td>
<td>7±1</td>
</tr>
<tr>
<td>NC Z</td>
<td>0</td>
</tr>
<tr>
<td>PAjjj</td>
<td>73±17</td>
</tr>
<tr>
<td>CCbkg total</td>
<td>33±4</td>
</tr>
<tr>
<td>NCbkg total</td>
<td>73±17</td>
</tr>
</tbody>
</table>

- Errors are weighted

\[ S/\sqrt{B} = 11.5 \]

• We can detect H→bb signal in good efficiency.
• Peak around 80 GeV is Z boson from CC background.
• PAjjj background has large statistical error due to small statistics.
• Electron tagging of Photo-production events could further suppress BG under peak.
The Phenomenological Higgs Landscape (Revisited)

Future ep colliders could make important contribution to Higgs physics!

- Mass
- Width (via VV scattering)
- Spin-Parity
- Coupling
  - $hVV$, $hff$
  - $3h$, $4h$, $hhVV$
  - FCNC coupling

- Exotic Higgs Decay
  - $h$ to invisible
  - $h$ to $4b$
  - ...

- Reducing PDF & $\alpha_s$

Uncertainties in Higgs measurements

See talk given by Voica Radescu

Philosophy could be traced back to

See also:
M. Kumar et al., 1509.04016
U. Klein, talk given at LHeC Workshop 2015

Chen Zhan 12.4.16 (talk at annual FCC week 2016, Rome)
We study the channel $h \rightarrow sb$ for the 2HDM-III

The background is reduced a lot

In the 2HDM; $H = h_0, H_0$

For $H_0$ the coupling $VVH_0$ is proportional to $\cos(\beta-\alpha)$ and $VWh_0$ to $\sin(\beta-\alpha)$
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.
• **Scenario Ia:** 2HDM-III as 2HDM-I, with the couplings $\phi f f$ given by $g_{2HDM-III}^{\phi ff} = g_{2HDM-I}^{\phi ff} + \Delta g$ and $\cos(\beta - \alpha) = 0.1$, $\chi_{kk}^u = 1.5$ ($k=2,3$), $\chi_{22}^d = 1.8$, $\chi_{33}^d = 1.2$, $\chi_{23}^{u,d} = 0.2$, $\chi_{22}^\ell = 0.5$, $\chi_{33}^\ell = 1.2$, $\chi_{23}^\ell = 0.1$, $m_A = 100$ GeV and $m_{H^\pm} = 110$ GeV, taking $Y = -X = -Z = \cot \beta = 2, 15, 30$.

• **Scenario Ib:** the same as scenario Ia but with $\cos(\beta - \alpha) = 0.5$.

• **Scenario Iia:** 2HDM-III as 2HDM-II, namely, the couplings $\phi f f$ given by $g_{2HDM-III}^{\phi ff} = g_{2HDM-II}^{\phi ff} + \Delta g$ and $\cos(\beta - \alpha) = 0.1$, $\chi_{22}^u = 0.5$, $\chi_{33}^u = 1.4$, $\chi_{22}^d = 2$, $\chi_{33}^d = 1.3$, $\chi_{23}^u = -0.53$, $\chi_{23}^d = 0.2$, $\chi_{22}^\ell = 0.4$, $\chi_{33}^\ell = 1.2$, $\chi_{23}^\ell = 0.1$, $m_A = 100$ GeV and $m_{H^\pm} = 110$ GeV, taking $X = Z = 1/Y = \tan \beta = 2, 15, 30$.

• **Scenario Y:** 2HDM-III as 2HDM-Y, namely, the couplings $\phi f f$ given by $g_{2HDM-III}^{\phi ff} = g_{2HDM-Y}^{\phi ff} + \Delta g$ and $\cos(\beta - \alpha) = 0.1$, $\chi_{22}^u = 0.5$, $\chi_{33}^u = 1.4$, $\chi_{22}^d = 2$, $\chi_{33}^d = 1.3$, $\chi_{23}^u = -0.53$, $\chi_{23}^d = 0.2$, $\chi_{22}^\ell = 0.4$, $\chi_{33}^\ell = 1.1$, $\chi_{23}^\ell = 0.1$, $m_A = 100$ GeV and $m_{H^\pm} = 110$ GeV, taking $X = 1/Y = -1/Z = \tan \beta = 2, 15, 30$. 

15
We consider the leading production processes of Higgs bosons signals, the lighter Higgs as well as the heavier Higgs one, for the Scenario IIa.

For the Scenario Ib, which is shown in the left panel, with $\phi_{22} = 0.5, \phi_{33} = 1.4, \phi_{23} = 2, \phi_{33} = 1.3, \phi_{23} = -0.53, \phi_{22} = 0.2, \phi_{22} = 0.4, \phi_{33} = 1.2, \phi_{23} = 0.1$. For Scenario IIa and Y, the allowed region is given in the right panel with $\phi_{22} = 0.1, \phi_{33} = 0.5, \phi_{33} = 1.4, \phi_{22} = 2, \phi_{33} = 1.3, \phi_{23} = -0.53, \phi_{22} = 0.2, \phi_{22} = 0.4, \phi_{33} = 1.2, \phi_{23} = 0.1$. 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.

FIG. 1. The allowed region in the plane $X$ vs $Y$, using the constraint Eq. (13), which is obtained from the radiative inclusive decay $B \rightarrow X_s \gamma$. We obtain the Scenario Ib, which is shown in the left panel, with $0.1 \leq \cos(\beta - \alpha) \leq 0.5, \phi_{kk}^u = 1.5 (k = 2, 3), \phi_{22}^d = 1.8, \phi_{33}^d = 1.2, \phi_{33}^{u,d} = 0.2, \phi_{33}^c = 1.2, \phi_{23}^c = 0.1$. For Scenario IIA and Y, the allowed region is given in the right panel with $\cos(\beta - \alpha) = 0.1, \phi_{33}^{u} = 0.5, \phi_{33}^d = 1.4, \phi_{23}^d = 2, \phi_{33}^c = 1.3, \phi_{23}^c = -0.53, \phi_{22}^d = 0.2, \phi_{22}^c = 0.4, \phi_{33}^c = 1.2, \phi_{23}^c = 0.1$. 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.
Process: $e^- p \rightarrow \nu_e \phi q_f; \phi \rightarrow b \bar{s} + \text{h.c.}$

These processes lead to 3-jets $\not{E_T}$.

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

The remaining jet ($q_f$) 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>
<thead>
<tr>
<th>2HDM</th>
<th>$X$</th>
<th>$Y$</th>
<th>$Z$</th>
<th>$bs$</th>
<th>$\sigma_{bs}$</th>
<th>$bs$</th>
<th>$\sigma_{bs}$</th>
<th>$bs$</th>
<th>$\sigma_{bs}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ib35</td>
<td>28</td>
<td>10</td>
<td>28</td>
<td>15.66</td>
<td>6.392</td>
<td>51.8</td>
<td>1.209</td>
<td>51.6</td>
<td>0.30</td>
</tr>
<tr>
<td>Ib47</td>
<td>30</td>
<td>5</td>
<td>30</td>
<td>16.14</td>
<td>3.086</td>
<td>48.2</td>
<td>10.983</td>
<td>48.0</td>
<td>0.127</td>
</tr>
<tr>
<td>Ib57</td>
<td>44</td>
<td>5</td>
<td>44</td>
<td>17.58</td>
<td>11.861</td>
<td>38.6</td>
<td>5.14</td>
<td>38.4</td>
<td>2.303</td>
</tr>
<tr>
<td>Iia11</td>
<td>20</td>
<td>2</td>
<td>20</td>
<td>1.42</td>
<td>1.055</td>
<td>25.2</td>
<td>0.097</td>
<td>25.0</td>
<td>0.091</td>
</tr>
<tr>
<td>Iia14</td>
<td>26</td>
<td>2</td>
<td>26</td>
<td>1.44</td>
<td>1.651</td>
<td>26.0</td>
<td>0.059</td>
<td>25.8</td>
<td>0.054</td>
</tr>
<tr>
<td>Iia26</td>
<td>36</td>
<td>1</td>
<td>36</td>
<td>1.46</td>
<td>1.621</td>
<td>26.4</td>
<td>0.045</td>
<td>26.2</td>
<td>0.042</td>
</tr>
<tr>
<td>Ya11</td>
<td>20</td>
<td>2</td>
<td>2</td>
<td>1.42</td>
<td>1.084</td>
<td>25.2</td>
<td>0.062</td>
<td>25.0</td>
<td>0.059</td>
</tr>
<tr>
<td>Ya12</td>
<td>22</td>
<td>2</td>
<td>2</td>
<td>1.44</td>
<td>1.078</td>
<td>25.6</td>
<td>0.057</td>
<td>25.4</td>
<td>0.053</td>
</tr>
<tr>
<td>Ya14</td>
<td>26</td>
<td>2</td>
<td>2</td>
<td>1.46</td>
<td>1.441</td>
<td>26.0</td>
<td>0.057</td>
<td>25.8</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

We consider only $\sigma_{bs} > 0.15$ 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.
FIG. 2. Event rates (σ.BR.L) at parton level for the neutral Higgs boson \( h \) (left panel) and \( m_H = 130 \) GeV (right panel), where \( L \) is the integrated luminosity. We show Scenario Ib for 100 fb\(^{-1}\). We consider \( m_h = 125 \) GeV.
$h_{SM} = 125$ GeV: $3$-jet+$\not{E}_T$ with 100 fb$^{-1}$

- **a:** $N_j \gtrsim 3$
- **b:** $N_{b-tag} \gtrsim 1$ (with $\epsilon_b=0.50$, $\epsilon_c=0.10$ and $\epsilon_l=0.01$, where j=u,d,s,g)
- **cd:** at least two central jets (within $\eta < 2.5$) with $E_T > 20$ GeV $\rightarrow 3j$ not survive and photo production is reduced
- **e:** lepton ($e$ or $\mu$) veto with $p_T > 20$ 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 $p_T > 25$ GeV and $-5.5 < \eta < -0.5$
- **h:** $m_{\phi_{ij}} > 190$ GeV
- **i:** We required only one low flavored jet in the central regions (this has severe impact on the processes)

Details in arXiv: 1503.01464

**PRD 94, 055003 (2016)**

---

**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 \(m_t = 125\) 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>
</tr>
</thead>
<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</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>0.6</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</td>
</tr>
<tr>
<td>IIa11</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>0.2</td>
</tr>
<tr>
<td>IIa14</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>0.3</td>
</tr>
<tr>
<td>IIa26</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>0.3</td>
</tr>
<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>0.2</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>
<td>4.5</td>
<td>2.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Ya14</td>
<td>100 K</td>
<td>144.1</td>
<td>101.7</td>
<td>39.8</td>
<td>26.0</td>
<td>21.7</td>
<td>20.8</td>
<td>8.2</td>
<td>7.0</td>
<td>5.9</td>
<td>3.8</td>
<td>0.2</td>
</tr>
</tbody>
</table>

\(\nu\bar{b}\) \(100 K\) 50712.1 28338.4 15293.7 9845.0 8144.2 7532.7 2982.1 2058.0 652.2 139.6

\(\nu\bar{b}j\) \(560 K\) 14104.6 6122.8 3656.7 1858.5 1787.1 1650.1 257.5 152.5 85.2 15.1

\(\nu_{b2}j\) \(90 K\) 18043.1 8389.2 3013.0 1691.5 1445.5 1373.7 389.5 206.1 77.2 11.3 \(B = 170.8\)

\(\nu_{3j}\) \(300 K\) 948064.2 410393.4 15560.9 0.0 0.0 0.0 0.0 0.0 0.0 0.0 \(\sqrt{B} = 13.1\)

\(e\bar{b}\bar{b}\) \(115 K\) 256730.1 55099.8 36353.6 12659.8 1432.0 200.7 54.1 24.8 18.0 4.5

\(e\bar{t}\bar{t}\) \(130 K\) 783.3 685.0 384.5 265.9 179.3 26.2 11.6 10.5 3.9 0.3

Results in () is for 1000 fb\(^{-1}\).
TABLE IV. Same as Table III but for $m_H = 150$ GeV.

<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>
</tr>
</thead>
<tbody>
<tr>
<td>Ib35</td>
<td>100 K</td>
<td>30.0</td>
<td>23.3</td>
<td>9.1</td>
<td>8.2</td>
<td>6.9</td>
<td>6.5</td>
<td>1.5</td>
<td>1.3</td>
<td>1.2</td>
<td>0.8</td>
<td>0.10(0.33)</td>
</tr>
<tr>
<td>Ib47</td>
<td>100 K</td>
<td>12.7</td>
<td>9.9</td>
<td>3.8</td>
<td>3.4</td>
<td>2.9</td>
<td>2.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.5</td>
<td>0.3</td>
<td>0.04(0.12)</td>
</tr>
<tr>
<td>Ib57</td>
<td>100 K</td>
<td>230.3</td>
<td>179.6</td>
<td>69.3</td>
<td>62.6</td>
<td>52.6</td>
<td>49.9</td>
<td>11.7</td>
<td>10.1</td>
<td>9.1</td>
<td>6.4</td>
<td>0.83(2.62)</td>
</tr>
<tr>
<td>IIa11</td>
<td>100 K</td>
<td>9.1</td>
<td>6.9</td>
<td>2.7</td>
<td>2.4</td>
<td>2.0</td>
<td>1.9</td>
<td>0.4</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.026(0.08)</td>
</tr>
<tr>
<td>IIa14</td>
<td>100 K</td>
<td>5.4</td>
<td>4.1</td>
<td>1.6</td>
<td>1.4</td>
<td>1.2</td>
<td>1.1</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.013(0.04)</td>
</tr>
<tr>
<td>IIa26</td>
<td>100 K</td>
<td>4.2</td>
<td>3.2</td>
<td>1.3</td>
<td>1.1</td>
<td>0.9</td>
<td>0.9</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.013(0.04)</td>
</tr>
<tr>
<td>Ya11</td>
<td>100 K</td>
<td>5.9</td>
<td>4.5</td>
<td>1.8</td>
<td>1.6</td>
<td>1.3</td>
<td>1.2</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.013(0.04)</td>
</tr>
<tr>
<td>Ya12</td>
<td>100 K</td>
<td>5.3</td>
<td>4.0</td>
<td>1.6</td>
<td>1.4</td>
<td>1.2</td>
<td>1.1</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.013(0.04)</td>
</tr>
<tr>
<td>Ya14</td>
<td>100 K</td>
<td>5.3</td>
<td>4.0</td>
<td>1.6</td>
<td>1.4</td>
<td>1.2</td>
<td>1.1</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.013(0.04)</td>
</tr>
<tr>
<td>νb</td>
<td>100 K</td>
<td>50712.1</td>
<td>28338.4</td>
<td>15293.7</td>
<td>11810.9</td>
<td>9808.7</td>
<td>9039.0</td>
<td>751.7</td>
<td>476.8</td>
<td>194.5</td>
<td>32.3</td>
<td></td>
</tr>
<tr>
<td>νbνb</td>
<td>560 K</td>
<td>14104.6</td>
<td>6122.8</td>
<td>3656.7</td>
<td>2395.6</td>
<td>2300.1</td>
<td>2120.8</td>
<td>199.3</td>
<td>112.4</td>
<td>70.8</td>
<td>12.4</td>
<td></td>
</tr>
<tr>
<td>νb2ν</td>
<td>90 K</td>
<td>18043.1</td>
<td>8389.2</td>
<td>3013.0</td>
<td>2427.2</td>
<td>2030.3</td>
<td>1933.1</td>
<td>234.2</td>
<td>83.7</td>
<td>41.0</td>
<td>6.3</td>
<td></td>
</tr>
<tr>
<td>ν3ν</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>√B = 7.7</td>
<td></td>
</tr>
<tr>
<td>eνb</td>
<td>115 K</td>
<td>256730.1</td>
<td>55099.8</td>
<td>36353.6</td>
<td>21280.9</td>
<td>2270.8</td>
<td>385.6</td>
<td>36.1</td>
<td>24.8</td>
<td>20.3</td>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>eνν</td>
<td>130 K</td>
<td>783.3</td>
<td>685.0</td>
<td>384.5</td>
<td>291.5</td>
<td>199.0</td>
<td>29.1</td>
<td>3.5</td>
<td>3.0</td>
<td>1.2</td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>
Production of $H^+$ in ep collider

We focus in $H^+ \rightarrow cb$, in 2HDM-III (also in MHDM) could be relevant.

$$\text{BR} (H^+ \rightarrow cb) \sim 0.9 \text{ in 2HDM-III}$$
$$\sim 0.8 \text{ in MHDM \ (A. Akeroyd, S. Moretti and J. Hernandez-Sanchez, PRD 85, 115002 (2012)) .}$$

This channel could be large as an effect of the running quark masses of $b$ and $s$ at the scale $Q = m_{H^+}$ (for MHDM) and Yukawa texture (2HDM-III)
Scenario Ia
Cos (beta-alpha)~0.1

Scenario Ib
Cos(beta-alpha)~0.5
Scenario II

Scenario Y
(Here, $\varepsilon_b = 0.50$, $\varepsilon_c = 0.1$ and $\varepsilon_j = 0.01$, where $j = u, d, s, g$)

<table>
<thead>
<tr>
<th></th>
<th>$S$</th>
<th>$B$</th>
<th>$\mathcal{I} = S/B^{1/2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia ($X = 5, Y = 5$)</td>
<td>243.4</td>
<td>3835.1</td>
<td>3.9</td>
</tr>
<tr>
<td>Ib ($X = 5, Y = 5$)</td>
<td>249.5</td>
<td>3835.1</td>
<td>4.0</td>
</tr>
<tr>
<td>II ($X = 32, Y = 0.5$)</td>
<td>230</td>
<td>3835.1</td>
<td>3.7</td>
</tr>
<tr>
<td>Y ($X = 32, Y = 0.5$)</td>
<td>187.8</td>
<td>3835.1</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**Table 2:** Significances after 100 fb$^{-1}$ for a few optimistic benchmark points in the 2HDM-III as a 2HDM-I, -II and -Y configuration. Here we have considered at parton level the signal reduced by the factor $\varepsilon_b^2 \cdot \varepsilon_c$ while the background from the SM is scaled by $\varepsilon_b^2 \cdot \varepsilon_j$.

These results are at parton level, and we have optimist prospects, taking only the background of $e_b$. (Arxiv: 1612.06316)

We are analyzing exhaustively the background (work in progress).
Conclusions

We show the 2HDM-III and the interesting signals.

We study the signal \( h \rightarrow sb \) in the future ep collider LHeC: \( e p \rightarrow q \nu h \) (consistent with the study of \( h \rightarrow bb \) of the other simulation group), we have a significance \( S/(B^{1/2}) \sim 2.4 \) (7.5) for integrated luminosity 100 fb\(^{-1}\) (1000 fb\(^{-1}\)).

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

Following the same strategies for the neutral Higgs boson, we study the production of \( H^+ \) in the future ep collider LHeC.

We show some results at parton level, and preliminary we have at parton level \( S/(B^{1/2}) \sim 4 \) for integrated luminosity 100 fb\(^{-1}\). Besides, we have spectacular event rates.