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Flavor violating signature of Higgs boson at the LHeC

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in collaboration with:

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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 $\rightarrow$ bs,$\tau\mu$, H+ —> cb, ts, decays are sensitive to the pattern of Yukawa texture.
- Benchmarks scenarios are found and one could have a BR(h,H$\rightarrow$bs) ~ 0.1 keeping h-decays compatible with SM.
- e p$\rightarrow$q(h,H)ν_e with flavor violating decays of the Higgs bosons (h,H): cross sections, some distributions and cuts.
- e p —> q nu H-, considering H- —> c b

Yukawa textures in the 2HDM-III

The Yukawa textures are consistents 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.

H. Fritzsch, Z. Z. Xing, Prog.Part. Nucl. Phys. 45 (2000)1.
H. Fritzsch, Z. Z. Xing, Phys. Lett. 555 (2003)63.

Yukawa sector in 2HDM type III

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

$$(\tilde{Y}_2^l)_{ij} = \frac{\sqrt{m_i m_j}}{v} \tilde{\chi}_{ij}$$

$$= \frac{\sqrt{m_i m_j}}{v} \chi_{ij} e^{\vartheta_{ij}},$$

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

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

$$M_f = \begin{pmatrix} 0 & C_f & 0 \\ C_f^* & \tilde{B}_f & B_f \\ 0 & B_f^* & A_f \end{pmatrix}.$$

The off-diagonal terms are constrained by CKM

F. González, O. Félix-Beltrán, J.Hernandez-Sanchez, S. Moretti, R. Noriega, A. Rosado, Phys.Lett. B742 (2015) 347-352.
J. Hernandez-Sanchez, L. Lopez-Lozano, R. Noriega, A. Rosado, Phys.Rev. D85 (2012) 071301

Seesaw mechanism in MSSM

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

$$-\mathcal{L} = \overline{E}_R Y_E L_L H_d + \overline{\nu}_R Y_\nu L_L + \tfrac{1}{2}\nu_R^\top M_R\, \nu_R \tag{1}$$

$$\begin{aligned}\frac{d}{d\log Q}(m^2_{\tilde{L}})_{ij} &= \left(\frac{d}{d\log Q}(m^2_{\tilde{L}})_{ij}\right)_{\rm MSSM} \\ &+\frac{1}{16\pi^2}\left[m^2_{\tilde{L}}Y_\nu^\dagger Y_\nu + Y_\nu^\dagger Y_\nu m^2_{\tilde{L}} + 2(Y_\nu^\dagger m^2_{\tilde{\nu}_R} Y_\nu + m^2_{H_u} Y_\nu^\dagger Y_\nu + A_\nu^\dagger A_\nu)\right]_{ij}\end{aligned} \tag{2}$$

$$\left(\Delta m^2_{\tilde{L}}\right)_{ij} \simeq -\frac{\log(M/M_R)}{16\pi^2}\left(6m_0^2(Y_\nu^\dagger Y_\nu)_{ij} + 2\left(A_\nu^\dagger A_\nu\right)_{ij}\right) \tag{3}$$

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:

$$\left(\Delta m^2_{\tilde{L}}\right)_{ij} \simeq \xi\left(Y_\nu^\dagger Y_\nu\right)_{ij} \tag{4}$$

K.S. Babu, C. Kolda, Phys. Rev. Lett. 89,241802 (2002).

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.

A.J. Buras, M.V. Carlucci, S. Gori and G. Isidori, Higgs-mediated FCNCs: Natural Flavour Conservation vs. Minimal Flavour Violation , JHEP 10 (2010) 009 [arXiv:1005.5310].

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

G. C. Branco, L. Lavoura and F. Mota, Phys. Rev. D 39, 3443 (1989)

Alfredo Aranda, Cesar Bonilla, J.Lorenzo Diaz-Cruz. Phys.Lett. B717 (2012) 248-251

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. L. Diaz-Cruz, J. Hernandez-Sanchez, S. Moretti, R. Noriega, A. Rosado, Phys.Rev. D79 (2009) 095025
J. Hernandez-Sanchez, S. Moretti, R. Noriega-Papaqui, A. Rosado, JHEP 1307 (2013) 044

$$
\begin{aligned}
\mathcal{L}^{\bar{f}_i f_j \phi} &= -\left\{ \frac{\sqrt{2}}{v} \bar{u}_i \left(m_{d_j} X_{ij} P_R + m_{u_i} Y_{ij} P_L \right) d_j \, H^+ + \frac{\sqrt{2} m_{l_j}}{v} Z_{ij} \overline{\nu_L} l_R H^+ + H.c. \right\} \\
&\quad - \frac{1}{v} \left\{ \bar{f}_i m_{f_i} h^f_{ij} f_j h^0 + \bar{f}_i m_{f_i} H^f_{ij} f_j H^0 - i \bar{f}_i m_{f_i} A^f_{ij} f_j \gamma_5 A^0 \right\},
\end{aligned}
$$

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

$$
\begin{aligned}
\phi^f_{ij} &= \xi^f_\phi \delta_{ij} + G(\xi^f_\phi, X), \quad \phi = h, H, A, \\
X_{ij} &= \sum_{l=1}^{3} (V_{\rm CKM})_{il} \left[X \, \frac{m_{d_l}}{m_{d_j}} \, \delta_{lj} - \frac{f(X)}{\sqrt{2}} \sqrt{\frac{m_{d_l}}{m_{d_j}}} \, \tilde{\chi}^d_{lj} \right], \\
Y_{ij} &= \sum_{l=1}^{3} \left[Y \, \delta_{il} - \frac{f(Y)}{\sqrt{2}} \sqrt{\frac{m_{u_l}}{m_{u_i}}} \, \tilde{\chi}^u_{il} \right] (V_{\rm CKM})_{lj}, \\
Z^l_{ij} &= \left[Z \, \frac{m_{l_i}}{m_{l_j}} \, \delta_{ij} - \frac{f(Z)}{\sqrt{2}} \sqrt{\frac{m_{l_i}}{m_{l_j}}} \, \tilde{\chi}^l_{ij} \right].
\end{aligned}
$$

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

$$
\left(g^{f_u i f_d j H^+}_{2HDM-III} = g^{f_u i f_d j H^+}_{2HDM-any} + \Delta g^{f_u i f_d j H^+} \right)
$$

J. Hernandez-Sanchez, S. Moretti, R. Noriega-Papaqui, A. Rosado, JHEP07 (2013) 044

2HDM-III	X	Y	Z	ξ_h^u	ξ_h^d	ξ_h^l	ξ_H^u	ξ_H^d	ξ_H^l
2HDM-I-like	$-\cot\beta$	$\cot\beta$	$-\cot\beta$	c_α/s_β	c_α/s_β	c_α/s_β	s_α/s_β	s_α/s_β	s_α/s_β
2HDM-II-like	$\tan\beta$	$\cot\beta$	$\tan\beta$	c_α/s_β	$-s_\alpha/c_\beta$	$-s_\alpha/c_\beta$	s_α/s_β	c_α/c_β	c_α/c_β
2HDM-X-like	$-\cot\beta$	$\cot\beta$	$\tan\beta$	c_α/s_β	c_α/s_β	$-s_\alpha/c_\beta$	s_α/s_β	s_α/s_β	c_α/c_β
2HDM-Y-like	$\tan\beta$	$\cot\beta$	$-\cot\beta$	c_α/s_β	$-s_\alpha/c_\beta$	c_α/s_β	s_α/s_β	c_α/c_β	s_α/s_β

- $\mu - e$ universality in τ decays
- Leptonic meson decays $B \to \tau\nu$, $D \to \mu\nu$, $D_s \to \mu\nu, \tau\nu$ and semileptonic decays $B \to D\tau\nu$
- $B \to X_s\gamma$ decays
- $B^0 - \bar{B}^0$ mixing
- Eelectro-weak precision test(including S,T,U oblique parameters)

Finally with all these above constraints one can find: $\chi_{kk}^f \sim 1$ and $|\chi_{ij}^f| \leq 0.5$,

The 2HDM-III as effective Lagrangian that induce at tree level flavor violating signatures like h,H —> sb, τμ and H+ —> cb, ts, decays can be relevant in the parameter space of the model.

$$\mathrm{BR}(B \to X_s\gamma)_{NLO} = B_{SL} \left|\frac{V_{ts}^* V_{tb}}{V_{cb}}\right|^2 \frac{6\alpha_{em}}{\pi\theta(z)\kappa(z)} \left[|D|^2 + A + \Delta\right] ,$$

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

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

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

$B^0 - \bar{B}^0$ **mixing**

$$\left|\frac{Y_{33}Y_{32}^*}{V_{tb}V_{ts}}\right| < 0.25, \qquad -1.7 < Re\left[\frac{X_{33}Y_{32}^*}{V_{tb}V_{ts}}\right] < 0.7.$$

$(80\ \mathrm{GeV} \leq m_{H^\pm} \leq 300\ \mathrm{GeV})$.

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:

$$\text{for } \tan\beta \leq 10: \qquad |\lambda_{6,7}| \leq 1, \qquad \lambda_6 = -\lambda_7,$$

$$\sin(\beta-\alpha) \sim 1, \qquad \mu_{12} \sim v,$$

The masses of ma, mH+ and MH are chosen by STU obliques parameters

A. Cordero-Cid, J. Hernandez-Sanchez, C. Honorato, S. Moretti, A. Rosado, JHEP07 (2014) 057

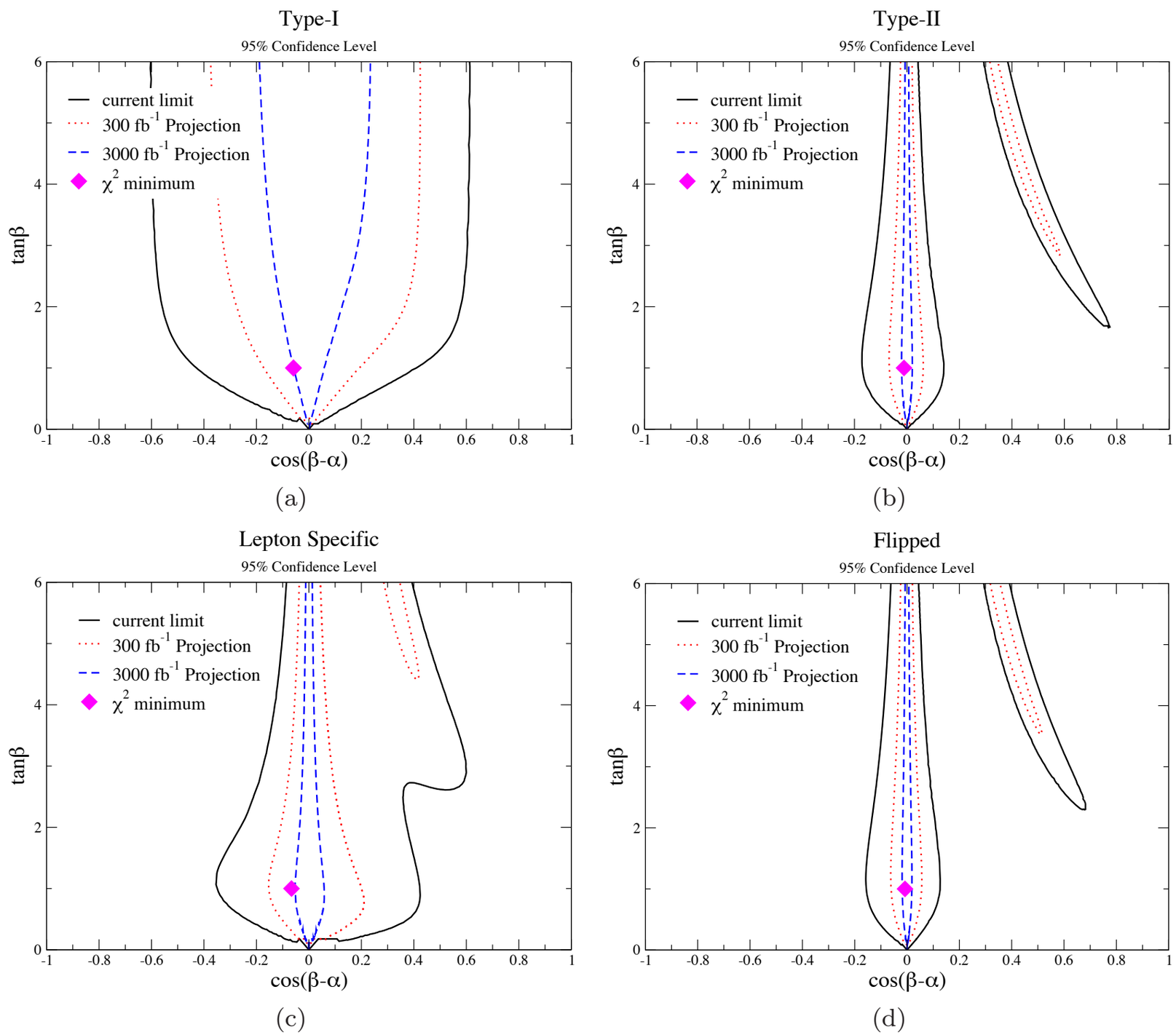


FIG. 1: Allowed regions in the $(\cos(\beta-\alpha), \tan\beta)$ plane in Type I (a), Type II (b), Lepton Specific (c), and Flipped (d) 2HDMs obtained by performing a χ^2 analysis. The region between the black (solid), red (dotted), and blue (dashed) lines is allowed at 95% confidence level corresponding to the current limits and the projected limits for integrated luminosities of 300 fb^{-1} and 3000 fb^{-1}, respectively.

Chien-Yi Chen, S. Dawson, Marc Sher. Phys.Rev. D88 (2013) 015018, Phys.Rev. D88 (2013) 039901

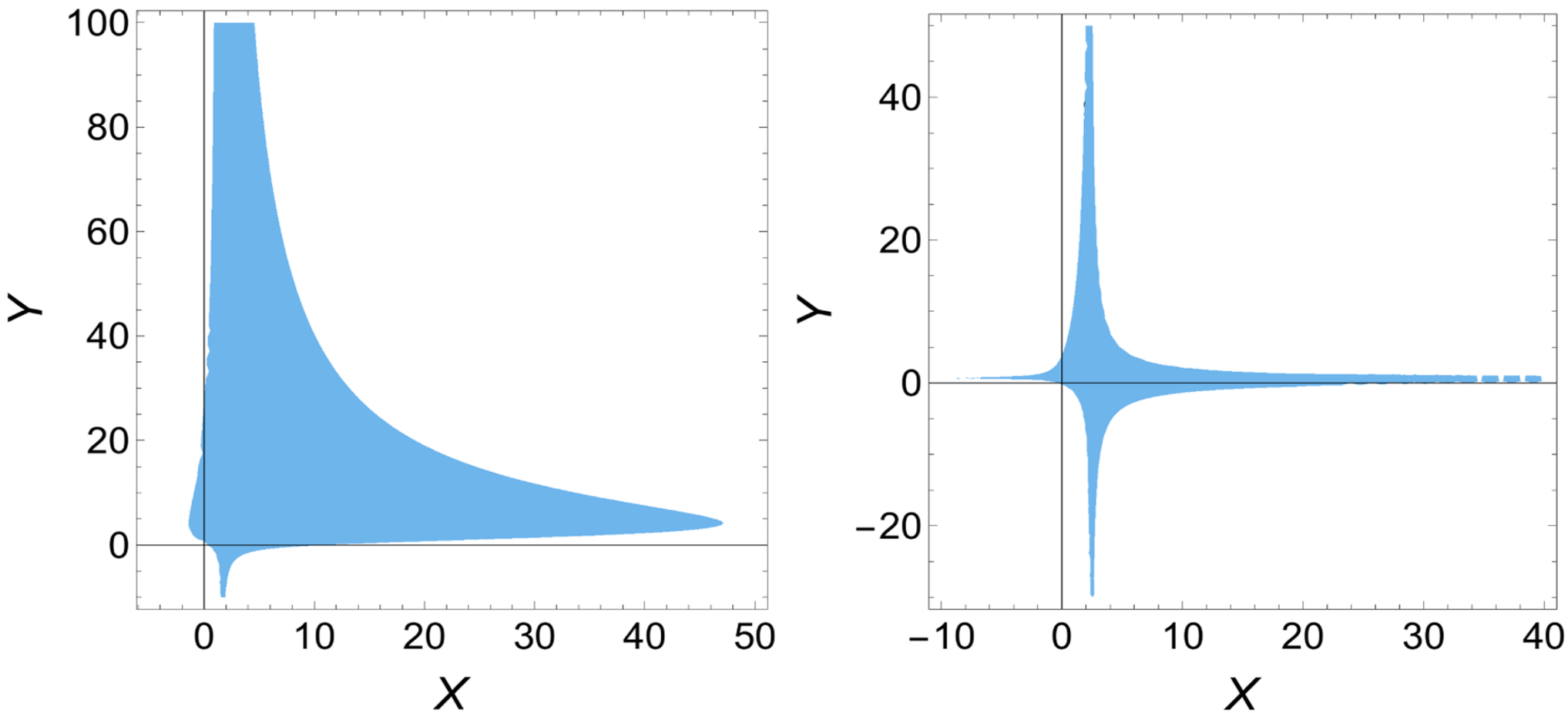
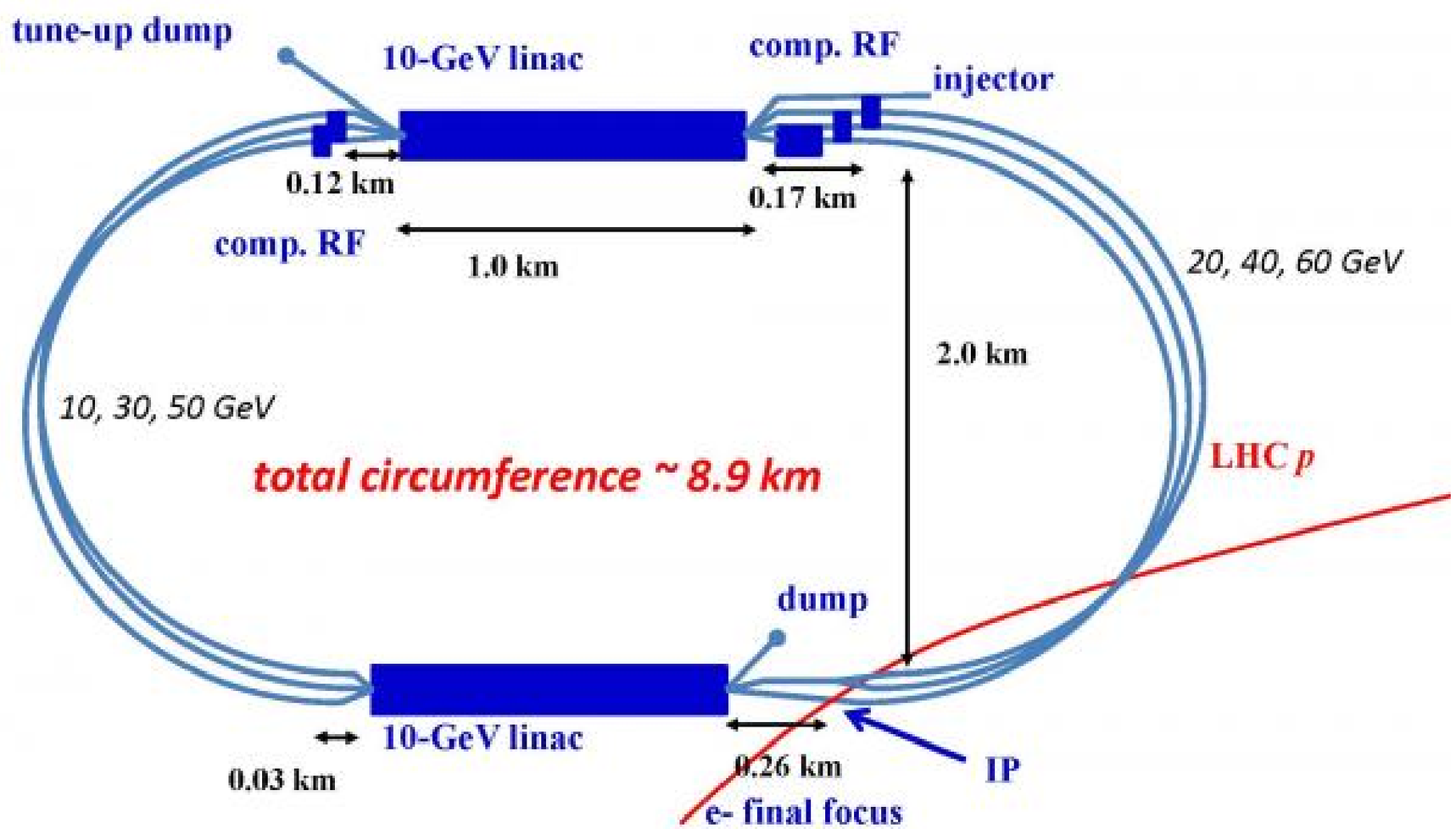


FIG. 1. The allowed region in the plane X vs Y, using the constraint Eq. (13), which is obtained from the radiative inclusive decay $B \to X_s\gamma$. We obtain the Scenario Ib, which is shown in the left panel, with $0.1 \leq \cos(\beta - \alpha) \leq 0.5$, $\chi^u_{kk} = 1.5$ $(k = 2, 3)$, $\chi^d_{22} = 1.8$, $\chi^d_{33} = 1.2$, $\chi^{u,d}_{23} = 0.2$, $\chi^\ell_{22} = 0.5$, $\chi^\ell_{33} = 1.2$, $\chi^\ell_{23} = 0.1$. For Scenario IIa and Y, the allowed region is given in the right panel with $\cos(\beta - \alpha) = 0.1$, $\chi^u_{22} = 0.5$, $\chi^u_{33} = 1.4$, $\chi^d_{22} = 2$, $\chi^d_{33} = 1.3$, $\chi^u_{23} = -0.53$, $\chi^d_{23} = 0.2$, $\chi^\ell_{22} = 0.4$, $\chi^\ell_{33} = 1.2$, $\chi^\ell_{23} = 0.1$. 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.

LHeC Collider

The overall kinematical range accesible at the LHeC is 20 times larger than HERA.



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

J. L. Abelleira Fernandez [arXiv:1206.2913 [physics.acc-ph]]

Process: $e^- p \to \nu_e \phi q_f$; $\phi \to b\bar{s}$ +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 I. Parameters for few optimistic benchmark points in the 2HDM-III as a 2HDM-I, -II and -Y configuration. Here bs stands for $\mathrm{BR}(\phi \to b\bar{s} + \bar{b}s)$, 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}.

				$m_h = 125$ GeV		$m_H = 130$ GeV		$m_H = 150$ GeV		$m_H = 170$ GeV	
2HDM	X	Y	Z	bs	$\sigma.bs$	bs	$\sigma.bs$	bs	$\sigma.bs$	bs	$\sigma.bs$
Ib35	28	10	28	15.66	6.392	51.8	1.209	51.6	0.30	1.58	0.117
Ib47	30	5	30	16.14	3.086	48.2	10.983	48.0	0.127	1.80	0.839
Ib57	44	5	44	17.58	11.861	38.6	5.14	38.4	2.303	3.68	0.137
IIa11	20	2	20	1.42	1.055	25.2	0.097	25.0	0.091	24.8	0.085
IIa14	26	2	26	1.44	1.651	26.0	0.059	25.8	0.054	25.6	0.049
IIa26	36	1	36	1.46	1.621	26.4	0.045	26.2	0.042	26.0	0.038
Ya11	20	2	−2	1.42	1.084	25.2	0.062	25.0	0.059	24.8	0.054
Ya12	22	2	−2	1.44	1.078	25.6	0.057	25.4	0.053	25.2	0.048
Ya14	26	2	−2	1.46	1.441	26.0	0.057	25.8	0.053	25.6	0.049

We consider only σ.bs > 0.15 fb; at least 15 events for 100 fb^(-1)

We applied the following basic preselections:

$$p_T^q > 15.0 \quad \mathrm{GeV}, \Delta R(q,q) > 0.4$$

$\Delta R = \Delta\eta^2 + \Delta\phi^2$, where η and ϕ are the pseudo-rapidity and azimuthal angle respectively.

h_{SM}=125 GeV:3-jet+$\not{E}_T$ with 100 fb^{-1}

Details in arXiv: 1503.01464
PRD 94, 055003 (2016)

- a: $N_j \gtrsim 3$
- b: $N_{b-tag} \gtrsim 1$ (with ϵ_b=0.50, ϵ_c=0.10 and ϵ_j=0.01, where j=u,d,s,g)
- cd : at least two central jets (within $\eta < 2.5$) with $\not{E}_T > 20 GeV$ → 3j not survive and photo production is reduced
- e: lepton (e or μ) 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: $m_{\phi j_f} > 190$ GeV

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

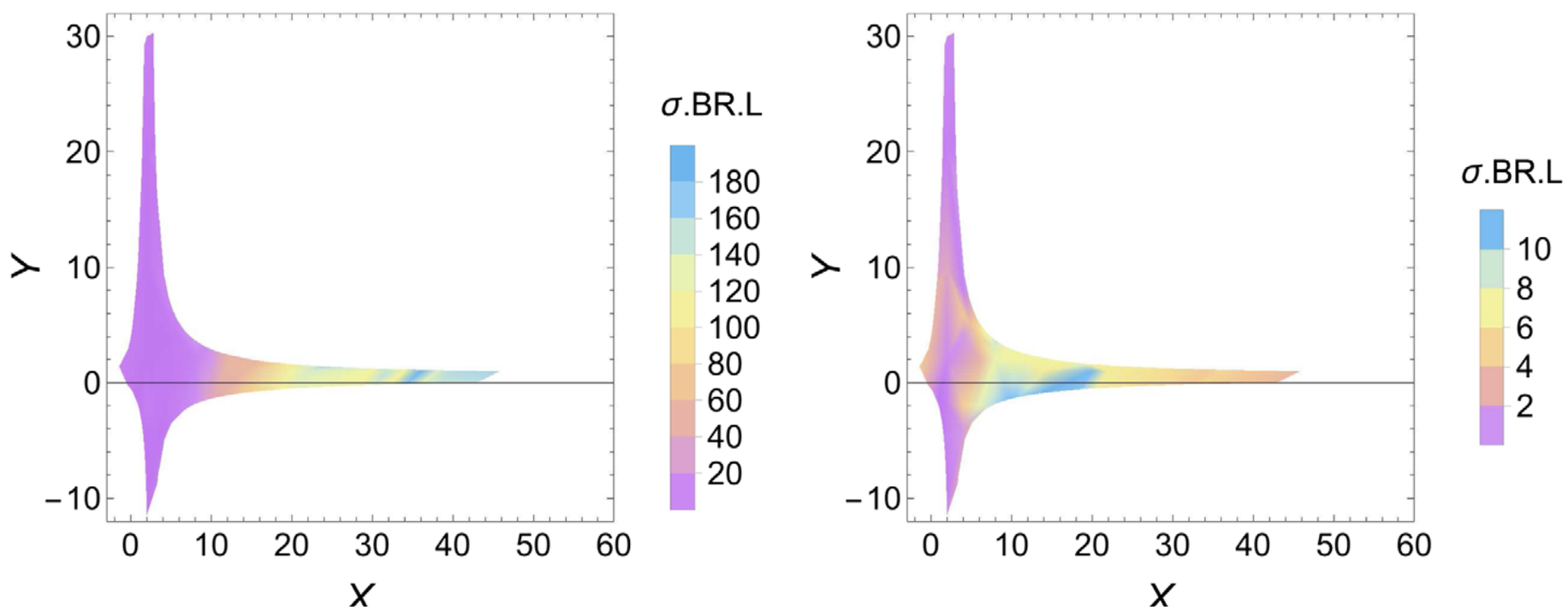


FIG. 3. The same as Fig. 2, but now for the Scenario IIa. Similar results for Scenario Y are obtained.

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($\mathcal{S}$) defined as $\mathcal{S} = S/\sqrt{B}$, 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}.

Proc	SimEvt	RawEvt	a	b	c	d	e	f	g	h	i	$\mathcal{S}$
Ib35	100 K	639.2	447.6	177.3	117.1	97.4	93.8	37.8	31.7	25.4	15.8	1.2(3.8)
Ib47	100 K	308.6	216.8	85.1	56.2	47.1	45.5	18.4	15.6	13.0	8.1	0.62(2.0)
Ib57	100 K	1186.1	833.7	325.7	215.5	180.6	173.9	70.3	59.1	49.3	31.1	2.4(7.5)
IIa11	100 K	105.5	74.3	29.1	19.2	16.0	15.4	6.3	5.3	4.4	2.8	0.21(0.70)
IIa14	100 K	165.1	116.1	45.2	30.0	25.4	24.4	9.7	8.3	6.9	4.4	0.33(1.05)
IIa26	100 K	162.1	114.4	44.7	29.5	24.5	23.6	9.5	8.1	6.8	4.3	0.33(1.03)
Ya11	100 K	108.4	76.3	29.8	19.6	16.4	15.8	6.4	5.4	4.6	2.9	0.22(0.70)
Ya12	100 K	107.8	76.2	29.6	19.5	16.3	15.7	6.3	5.4	4.5	2.8	0.21(0.67)
Ya14	100 K	144.1	101.7	39.8	26.0	21.7	20.8	8.2	7.0	5.9	3.8	0.29(0.92)
$\nu t\bar{b}$	100 K	50712.1	28338.4	15293.7	9845.0	8144.2	7532.7	2982.1	2058.0	652.2	139.6	
$\nu b\bar{b}j$	560 K	14104.6	6122.8	3656.7	1858.5	1787.1	1650.1	257.5	152.5	85.2	15.1	
$\nu b2j$	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	$\sqrt{B} = 13.1$
$eb\bar{b}j$	115 K	256730.1	55099.8	36353.6	12659.8	1432.0	200.7	54.1	24.8	18.0	4.5	
$et\bar{t}$	130 K	783.3	685.0	384.5	265.9	179.3	26.2	11.6	10.5	3.9	0.3	

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.

Proc	SimEvt	RawEvt	A	B	C	D	E	F	G	H	I	$\mathcal{S}$
Ib35	100 K	120.9	87.1	34.1	26.9	22.5	21.6	7.5	6.1	5.3	3.4	0.28(0.88)
Ib47	100 K	1098.3	790.3	307.1	243.9	204.6	195.7	68.5	56.1	48.6	31.3	2.6(8.1)
Ib57	100 K	514.0	371.2	144.8	115.0	96.0	92.0	31.7	25.8	22.7	14.3	1.2(3.7)
IIa11	100 K	9.7	6.8	2.7	2.1	1.8	1.7	0.6	0.4	0.3	0.2	0.02(0.05)
IIa14	100 K	5.9	4.2	1.7	1.3	1.1	1.0	0.4	0.3	0.2	0.1	0.01(0.02)
IIa26	100 K	4.5	3.1	1.3	1.0	0.8	0.8	0.3	0.2	0.1	0.1	0.01(0.02)
Ya11	100 K	6.2	4.4	1.8	1.4	1.1	1.1	0.4	0.3	0.2	0.1	0.01(0.02)
Ya12	100 K	5.7	4.0	1.6	1.3	1.0	1.0	0.3	0.2	0.2	0.1	0.01(0.02)
Ya14	100 K	5.7	4.0	1.6	1.3	1.0	1.0	0.3	0.2	0.2	0.1	0.01(0.02)
$\nu t\bar{b}$	100 K	50712.1	28338.4	15293.7	10976.4	9092.4	8393.6	2550.9	1565.5	617.9	113.7	
$\nu b\bar{b}j$	560 K	14104.6	6122.8	3656.7	2145.5	2062.1	1902.9	266.6	141.0	87.5	14.4	
$\nu b2j$	90 K	18043.1	8389.2	3013.0	2053.6	1734.0	1650.1	402.8	143.7	64.5	8.1	$B = 147.8$
$\nu 3j$	300 K	948064.2	410393.4	15560.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	$\sqrt{B} = 12.2$
$eb\bar{b}j$	115 K	256730.1	55099.8	36353.6	16838.4	1826.6	284.1	56.4	31.6	22.6	11.3	
$et\bar{t}$	130 K	783.3	685.0	384.5	280.8	190.8	27.8	10.9	9.3	3.9	0.3	

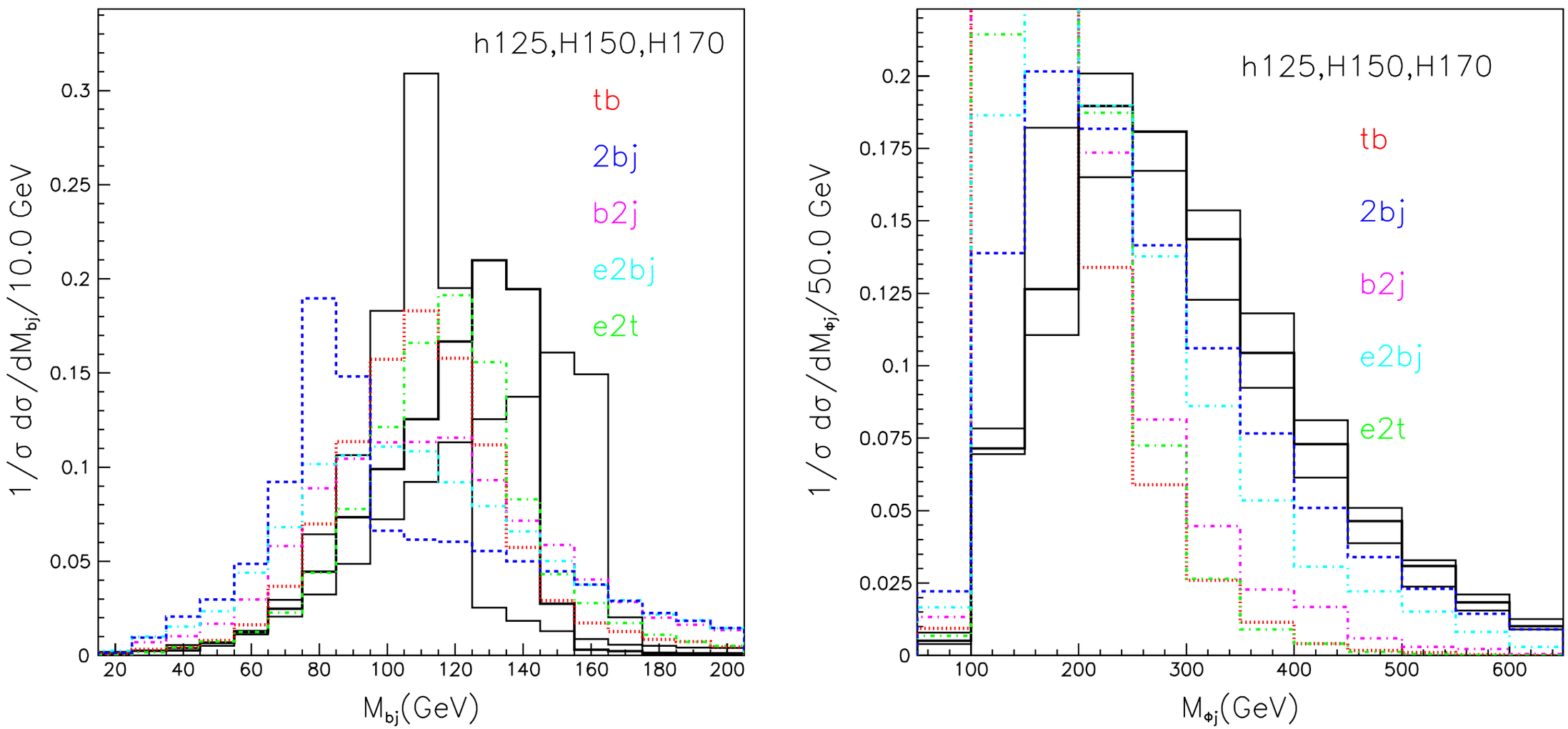


FIG. 6. The dijet invariant mass, made up by one b-tagged and one light-flavor jet, producing Higgs candidates, $M_\phi = M_{bj}$ (left panel) and the three-jet invariant mass, i.e., the previous two jets combined together with the forward jet, $M_{\phi j_f}$ (right panel). The mass peaks of the Higgs signals (M_ϕ) correspond to $m_h = 125$ (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 $m_h = 125$ and $m_H = 150$. Among all SM backgrounds, only $2bj$ shows a prominent peak from the Z-boson. Notice that $M_{\phi j_f}$ represents the overall energy scale of the hard-scattering.

FCC-eh Collider

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 $\not{E} > 20$ 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 o H $\Delta R(j_b, j_1) < 3$, it is a central di-jet. We enforce a 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 $(m_\phi - 25 \text{ GeV}) < M_{j_b j_1} < m_\phi$.

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

2HDM-III	X	Y	Z	$m_h = 125$ GeV		$m_H = 130$ GeV		$m_H = 150$ GeV		$m_H = 170$ GeV	
				bs	$\sigma.bs$	bs	$\sigma.bs$	bs	$\sigma.bs$	bs	$\sigma.bs$
Ib57	44	5	44	93.22	784	20.2	46.06	17.12	33.56	3.54	6.05
IIa14	26	2	26	1.52	15.2	28.3	10.64	28.4	7.51	28.4	5.72

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 σ.bs stands for the cross section $\sigma(ep \to \nu_e \phi q)$ (q = light flavor quark) times the above BR in units of fb.

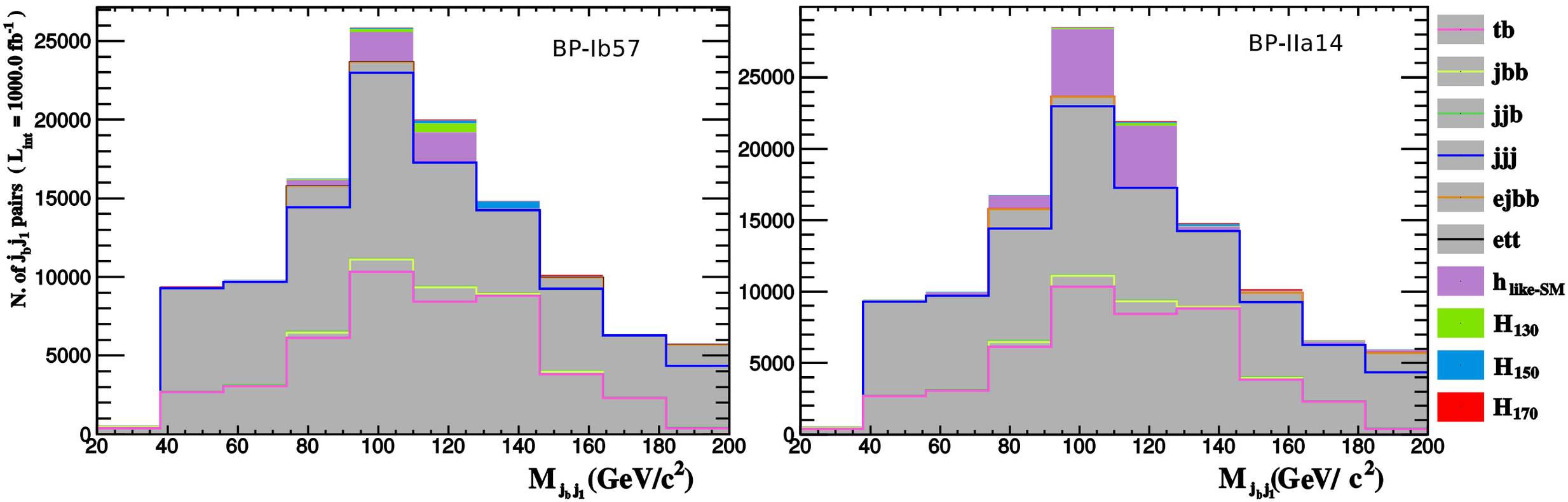
FCC-eh Collider

S	Higgs mass	RawEvt	a	b	c	d	e	f	Σ
Ib57	$m_h = 125$ GeV	784 k	21598	11841	6487	2875	1618	1038	11.17(19.36)
	$m_H = 130$ GeV	228k	3732	2217	1237	548	299	221	2.38(4.12)
	$m_H = 150$ GeV	196k	2935	1789	1024	511	265	93	1.75(3.02)
	$m_H = 170$ GeV	171k	1026	538	260	146	69	15	0.29(0.51)
IIa14	$m_h = 125$ GeV	1000 k	56973	31397	17146	7346	3905	2600	28(48.5)
	$m_H = 130$ GeV	37.6k	2078	1236	698	353	130	67	0.72(1.25)
	$m_H = 150$ GeV	26.4k	1364	941	573	312	129	30	0.56(0.98)
	$m_H = 170$ GeV	20.17k	1043	778	499	285	124	25	0.49(0.85)
$\nu t\bar{b}$		13050k	415871	217059	107189	53849	16461	3956	
$\nu b\bar{b}j$		370k	19966	11621	5695	2231	814	488	
$\nu b2j$		170k	3737	1348	603	284	114	23	$B = 8622$
$\nu 3j$		92100k	837783	310678	111704	48871	23563	3927	$\sqrt{B} = 92.85$
$eb\bar{b}j$		44800k	222537	17329	6384	3420	1596	228	
$et\bar{t}$		395k	134	95	67	36	12	0	

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

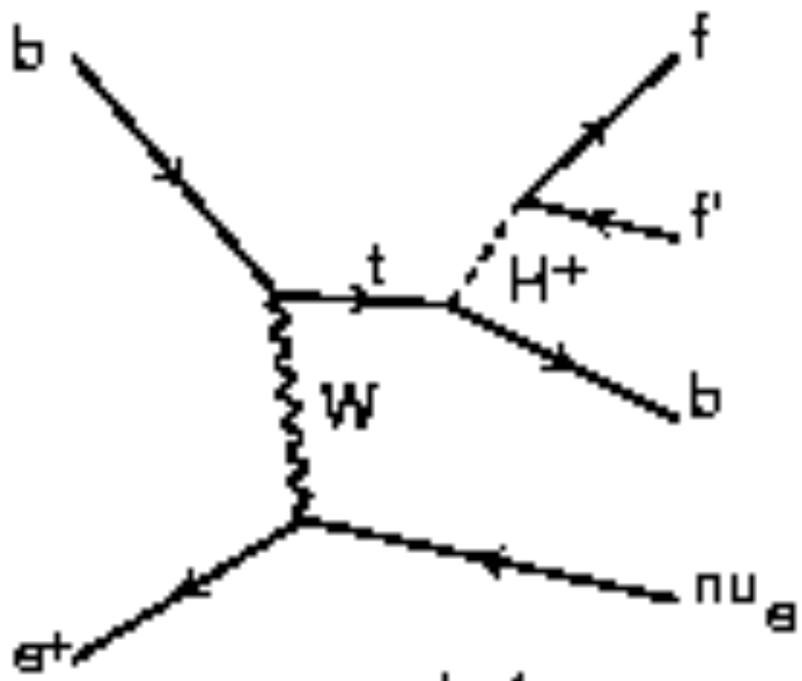
Submitted to CDR of FCC-eh

FCC-eh Collider

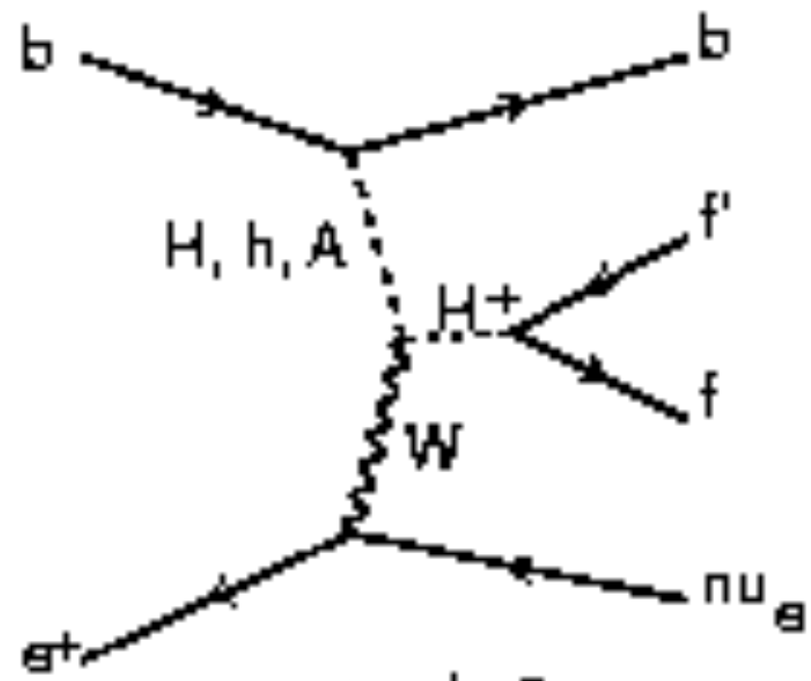


The $M_{j_b j_1}$ distribution for S and B after all cuts in Tab. II with $L = 3$ ab^{-1} for both BP

Production of H+ in ep collider



graph 1



graph 2

We focus in H+ —> cb, in 2HDM-III (also in MHDM) could be relevant

BR (H+ —> cb) ~ 0.9 in 2HDM-III

~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+

2HDM-III like	parameters			$\sigma(ep \to \nu_e H^{\pm} q)[pb]$				$BR(H^{\pm} \to cb)$	$BR(H^{\pm} \to \tau\nu_{\tau})$
	X	Y	Z	$m_{H^{\pm}} = 110\ GeV$	$130\ GeV$	$150\ GeV$	$170\ GeV$	$m_{H^{\pm}} = 110\ GeV$	$m_{H^{\pm}} = 110\ GeV$
I	0.5	17.5	0.5	2.56×10^{-2}	1.30×10^{-2}	3.47×10^{-3}	1.35×10^{-4}	9.57×10^{-1}	2.5×10^{-4}
	9.5	3	9.5	1.32×10^{-2}	6.87×10^{-3}	1.72×10^{-3}	4.64×10^{-5}	9.34×10^{-2}	8.98×10^{-1}
II	2	1.5	2	2.18×10^{-2}	1.13×10^{-2}	2.95×10^{-3}	5.89×10^{-5}	9.9×10^{-1}	2.22×10^{-4}
Y	13	1.5	-1/13	6.41×10^{-2}	3.27×10^{-2}	8.47×10^{-3}	2.2×10^{-4}	9.91×10^{-1}	6.12×10^{-3}
X	0.03	1.5	-33.33	6.49×10^{-2}	3.39×10^{-2}	8.83×10^{-3}	2.34×10^{-4}	9.28×10^{-2}	9.04×10^{-1}

For light charged Higgs

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

; the case $Y >>, X, Z$ the channel decay $H^+ \to c\bar{b}$

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

$(H^\pm \to cs)$

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

$$\frac{\mathrm{BR}(H^\pm \to cb)}{\mathrm{BR}(H^\pm \to cs)} = R_{sb} \sim \frac{|V_{tb}|^2}{|V_{ts}|^2}$$

For light charged Higgs

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

$$m_b X_{cb} = m_b X_{23} = V_{cb} m_b \left(X - \frac{f(X)}{\sqrt{2}} \chi^d_{33} \right) - V_{cs} \frac{f(X)}{\sqrt{2}} \sqrt{m_b m_s} \chi^d_{23}$$

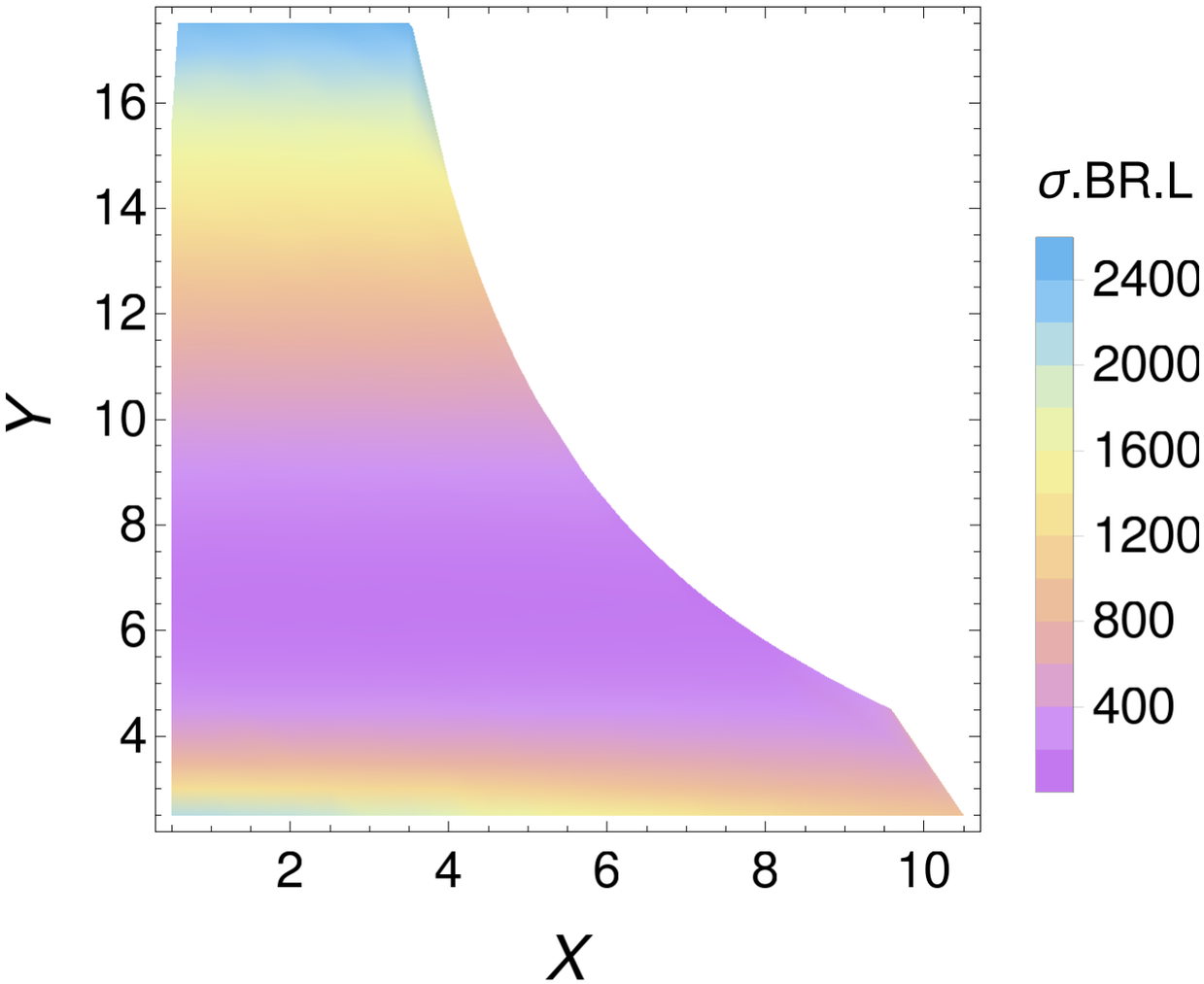
$$m_s X_{cs} = m_s X_{22} = V_{cs} m_s \left(X - \frac{f(X)}{\sqrt{2}} \chi^d_{22} \right) - V_{ts} \frac{f(X)}{\sqrt{2}} \sqrt{m_b m_s} \chi^d_{23}$$

If $\chi = O(1)$ and positive then $\left(X - \frac{f(X)}{\sqrt{2}} \chi^d_{33} \right)$ is small and $R_{sb} \sim \frac{|V_{cs}|^2}{|V_{cb}|^2}$,

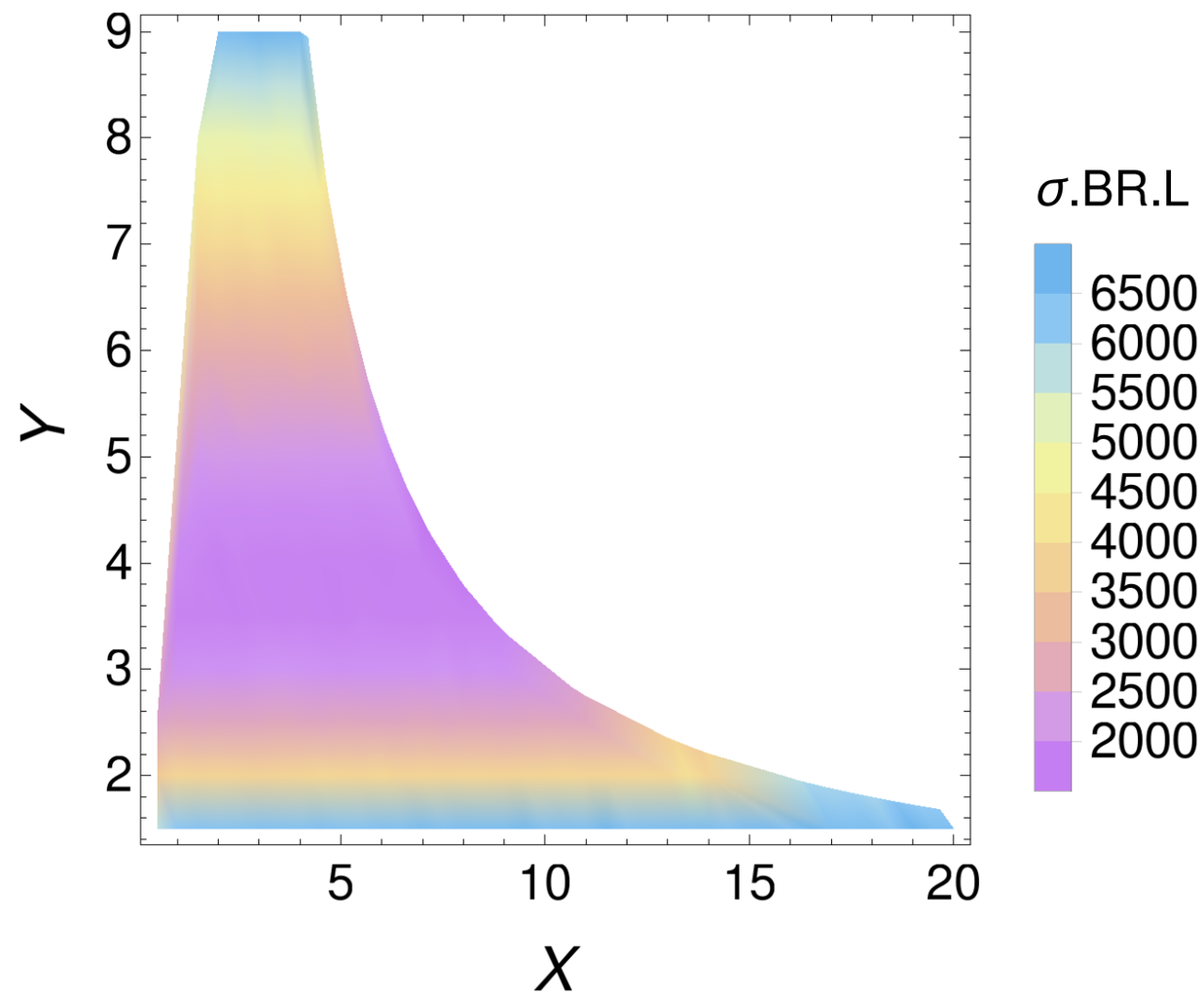
Other situation is when, $\chi = O(1)$ and negative, then $R_{sb} \sim \frac{m_b^2 |V_{cb}|^2}{m_s^2 |V_{cb}|^2}$;

A.G. Akeroyd, S. Moretti and J. Hernández-Sánchez, PRD85:115002 (2012)

J. Hernandez-Sanchez, S. Moretti, R. Noriega-Papaqui, A. Rosado, JHEP07 (2013) 044



Scenario Ia and Ib
Cos (beta-alpha)~0.1,0.5



Scenario IIa and Y
Cos(beta-alpha)~0.1

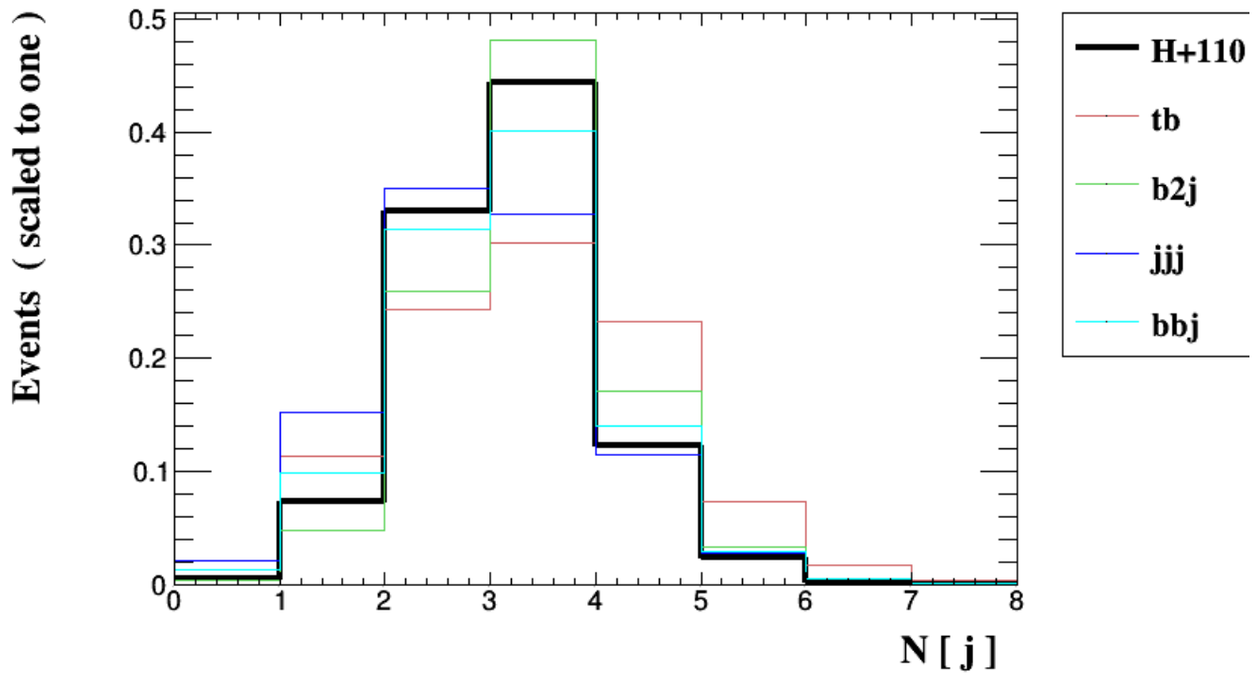


Figure 1.

Cut 1: Select 3 jets

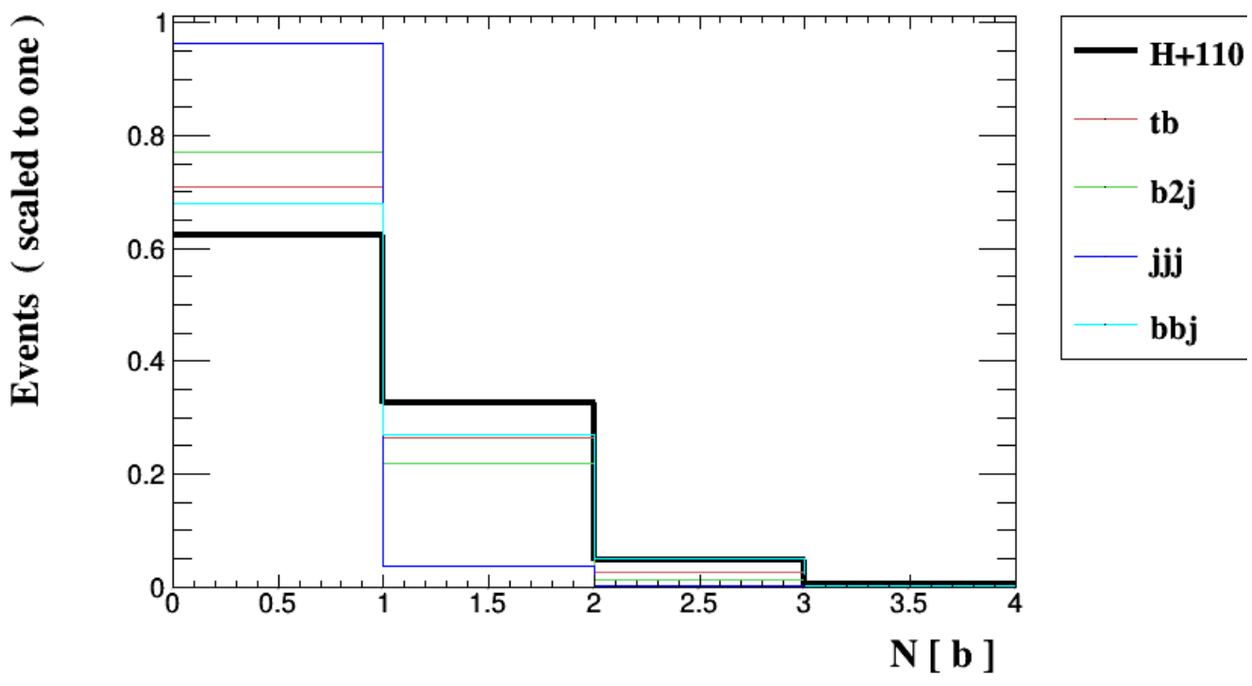


Figure 2.

Cut 2: Select 2 jet b-tagged for H - —>cb
1 jet b-tagged for H- —>tau nu

Work in progress, this is a collaboration with O. Flores, C.G. Honorato, S. Rosado and S. Moretti. **PoS CHARGED2016 (2017) 032**

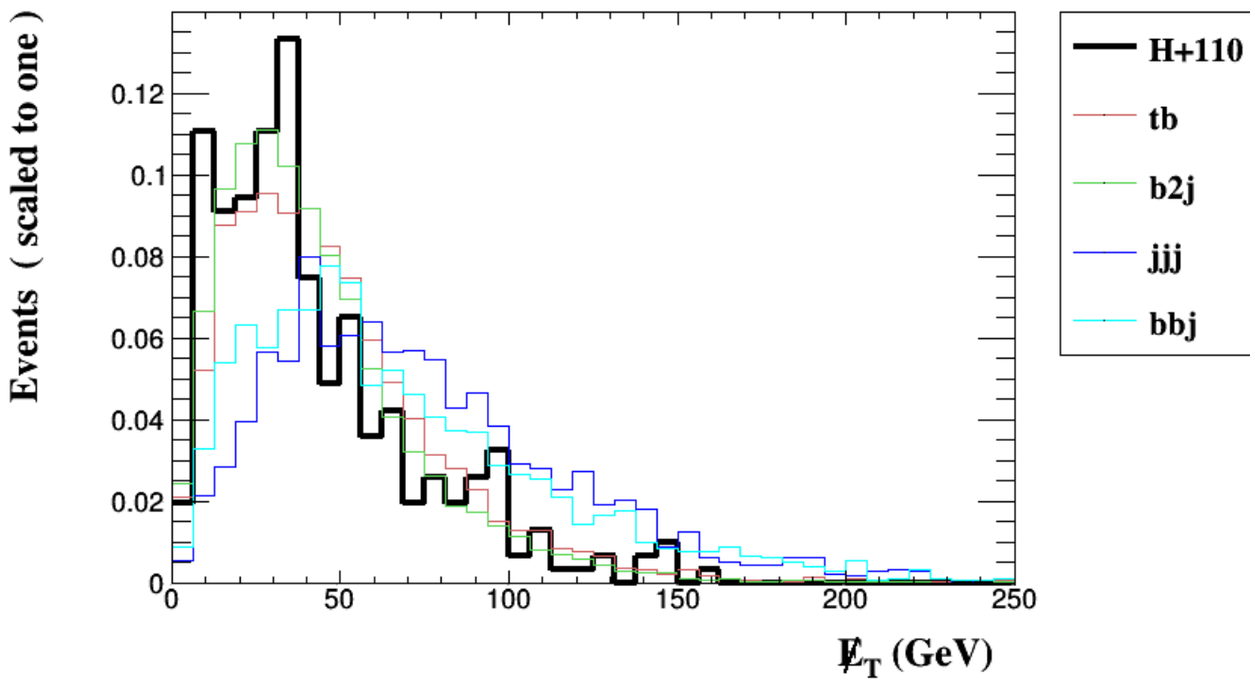
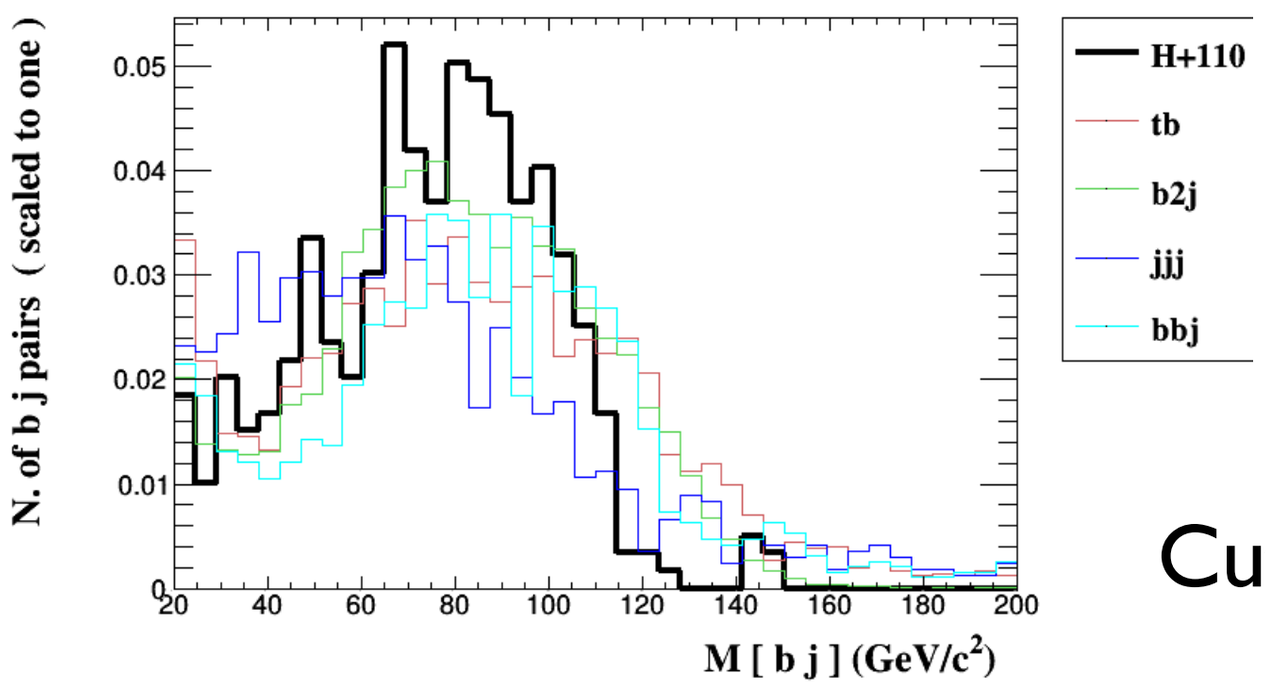
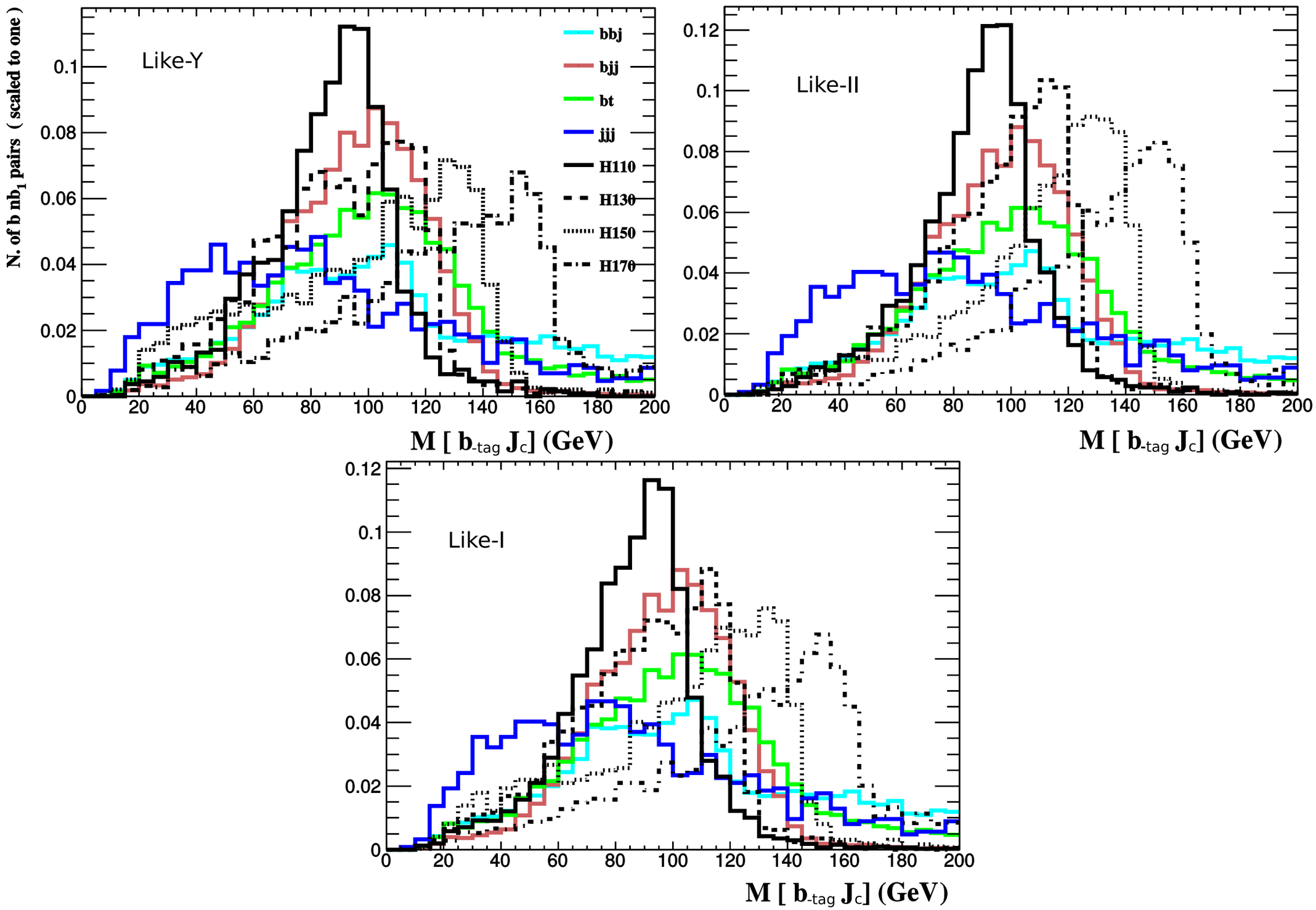


Figure 5.

Cut 3: PT > 30 GeV
Cut 4 : eta<|2.5|
Cut 5: MET < 40 GeV



Cut 6: |Mbj—MH+|<15 GeV


Like-Y
Like-II
Like-I
bbj
bjj
bt
jjj
H110
H130
H150
H170
N. of b nb$_1$ pairs (scaled to one)
M [b$_{\text{-tag}}$ J$_c$] (GeV)

- How to compare signal (S) and background (B): S/sqrt(S+B) .

Table 7. Signal and Background comparison

Cuts	Signal (S)	Background (B)	S vs B
Initial (no cut)	2151	305124	3.88
Cut 1	954.0 +/- 23.0	111988 +/- 263	2.8387 +/- 0.0684
Cut 2	312.0 +/- 16.3	15351 +/- 118	2.49 +/- 0.13
Cut 3	308.0 +/- 16.2	14945 +/- 116	2.494 +/- 0.131
Cut 4	308.0 +/- 16.2	14945 +/- 116	2.494 +/- 0.131
Cut 5	210.0 +/- 13.8	8868.0 +/- 91.4	2.204 +/- 0.143
Cut 6	197.0 +/- 13.4	7958.0 +/- 86.8	2.181 +/- 0.147

At 100 fb^-1

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 —> sb.

We study the signal h,H —> sb in the future ep collider LHeC: e p —> 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- —>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 at1000 fb^-1) for LHeC. For FCC-eh, the significance could reach 11.2 at 1000 fb^-1