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Flavor violating signatures of lighter and heavier Higgs bosons within Two Higgs Doublet Model type III at the LHeC

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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 quite different.
- Some interesting channels decays at tree level: $H, h \rightarrow bs, \tau\mu, \gamma\gamma$ and γZ decays are sensitive to the pattern of Yukawa texture.
- Benchmark scenarios are found and one could have a $BR(h, H \rightarrow bs) \sim 0.1$ keeping h-decays compatible with SM.
- we analyze $e^+p \rightarrow q(h, H)\nu_e$ with flavor violating decays of the Higgs bosons (h, H): cross sections, some distributions and cuts.

Versions of the 2HDM

Type I: one Higgs doublet provides masses to all quarks (up- and down-type quarks) (\sim SM).

Type II: one Higgs doublet provides masses for up-type quarks and the other for down-type quarks (\sim MSSM).

Type III: the two doublets provide masses for up and down type quarks, as well as charged leptons.

We could consider this model as a generic description of physics at a higher scale (i. e. Radiative corrections of the MSSM Higgs sector* or from extradimension**).

*J. L. Díaz-Cruz, R. Noriega-Papaqui and A. Rosado, Phys. Rev. D 71, 015014 (2005).

**A. Aranda, J.L. Díaz-Cruz, J. Hernández-Sánchez, R. Noriega-Papaqui, Phys. Lett. B 658, 57 (2007).

Absence of (tree-level) FCNCs

→ constraints on Higgs couplings

In SM FCNC automatically absent as same operation diagonalising the mass matrix automatically diagonalises the Higgs-fermion couplings.

- There are three ways:
- (1) Discrete symmetries. This choice is based on the Glashow–Weinberg's theorem concerning FCNC's in models with several Higgs doublets.
(MSSM: $Y=-1$ ($+1$) doublet couples to down (up)-type fermion, as required by SUSY)
- (2) Radiative suppression. When a given set of Yukawa matrices are present at tree-level, but the other ones arise only as a radiative effect: i.e. the 2HDM-II, it is transformed into 2HDM-III through loops-effects of sfermions and gauginos.
- (3) Flavor symmetries. Suppression of FCNC effects can also be achieved when a certain form of the Yukawa matrices that reproduce the observed fermion masses and mixing angles is implemented in the model, i.e. THDM-III. (Yukawa textures)

J.L. Diaz-Cruz, R Noriega-Papaqui, A. Rosado. Phys. Rev. D69,095002 (2004)

Yukawa textures

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

Yukawa textures could come from 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

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

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

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

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

$$\begin{aligned} (\tilde{Y}_2^l)_{ij} &= \frac{\sqrt{m_i m_j}}{v} \tilde{\chi}_{ij} \\ &= \frac{\sqrt{m_i m_j}}{v} \chi_{ij} e^{i\vartheta_{ij}}, \end{aligned}$$

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

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

$$\mathcal{L}^{\bar{f}_i f_j \phi} = - \left\{ \frac{\sqrt{2}}{v} \bar{u}_i (m_{d_j} X_{ij} P_R + m_{u_i} Y_{ij} P_L) d_j H^+ + \frac{\sqrt{2} m_{l_j}}{v} Z_{ij} \bar{\nu}_L l_R H^+ + H.c. \right\} - \frac{1}{v} \left\{ \bar{f}_i m_{f_i} h_{ij}^f f_j h^0 + \bar{f}_i m_{f_i} H_{ij}^f f_j H^0 - i \bar{f}_i m_{f_i} A_{ij}^f f_j \gamma_5 A^0 \right\},$$

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

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

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

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

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

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 $B \rightarrow \tau\nu$, $D \rightarrow \mu\nu$, $D_s \rightarrow \mu\nu, \tau\nu$ 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

$$\begin{aligned}
 V(\Phi_1, \Phi_2) = & \mu_1^2(\Phi_1^\dagger\Phi_1) + \mu_2^2(\Phi_2^\dagger\Phi_2) - \left(\mu_{12}^2(\Phi_1^\dagger\Phi_2) + \text{H.c.} \right) + \frac{1}{2}\lambda_1(\Phi_1^\dagger\Phi_1)^2 \\
 & + \frac{1}{2}\lambda_2(\Phi_2^\dagger\Phi_2)^2 + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) \\
 & + \left(\frac{1}{2}\lambda_5(\Phi_1^\dagger\Phi_2)^2 + \left(\lambda_6(\Phi_1^\dagger\Phi_1) + \lambda_7(\Phi_2^\dagger\Phi_2) \right) (\Phi_1^\dagger\Phi_2) + \text{H.c.} \right)
 \end{aligned}$$

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

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

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

The masses of m_a , m_{H^\pm} and M_H are chosen by STU oblique parameters

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

Others phenomenological consequences

- If we combine:
- The effects of texture in the coupling.
- The general Higgs potential.
-

It's possible to enhance processes at one-loop-level, e.g.

- $H, h \rightarrow \gamma\gamma$
- $H^+ \rightarrow W^+ \gamma, W^+ Z$

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

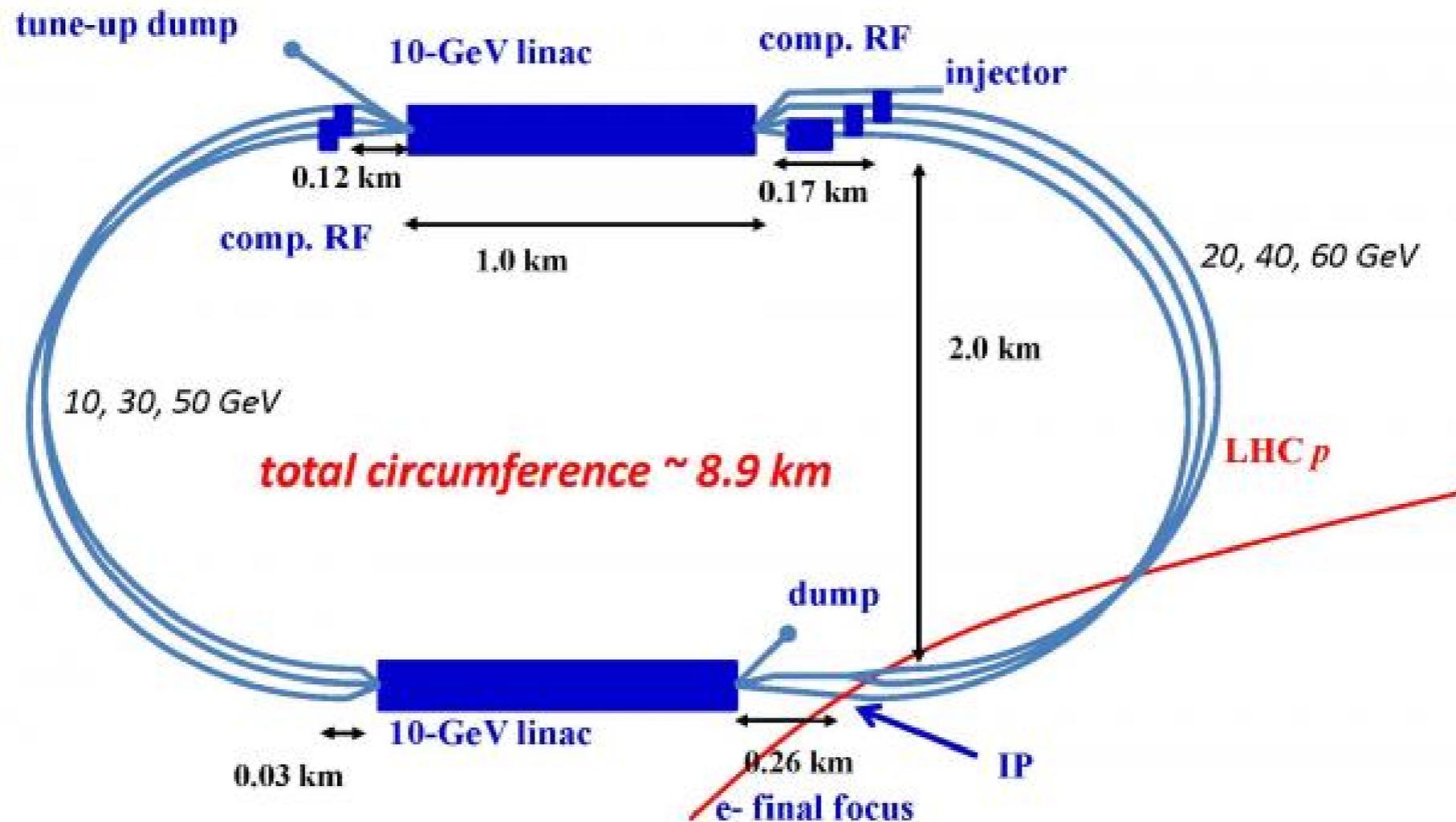
J. Hernández-Sánchez, C. G. Honorato, M.A. Pérez, J.J. Toscano, PRD85:015020 (2012).

J.E. Barradas, F. Cazares-Bush, A. Cordero-Cid, O. Félix-Beltrán, J. Hernández-Sanchez, R. Noriega-Papaqui, J.Phys. G37 (2010) 115008

- **Scenario Ia:** 2HDM-III as 2HDM-I, with the couplings ϕff 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 ϕff 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 ϕff 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 $X = 1/Y = -1/Z = \tan \beta = 2, 15, 30$.

LHeC Collider

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



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

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

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

These processes lead to 3-jets+ \cancel{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.

2HDM	$\tan \beta$	X	Y	Z	h=125		H=130		H=150		H=170	
					bs	$\sigma.bs$	bs	$\sigma.bs$	bs	$\sigma.bs$	bs	$\sigma.bs$
la2	2				0.76	0.29	0.75	0.330	0.22	0.077	0.011	0.003
la15	15	$-\cot \beta$	$\cot \beta$	$-\cot \beta$	12.0	11.7	0.71	0.006	0.58	0.004	0.20	0.001
la30	30				12.8	19.1	3.16	0.088	2.50	0.027	0.80	0.005
lb2	2				0.76	0.30	0.75	0.33	0.22	0.077	0.011	0.003
lb15	15	$-\cot \beta$	$\cot \beta$	$-\cot \beta$	8.6	7.6	23.6	5.16	8.34	1.39	0.49	0.065
lb30	30				10.9	11.5	25.2	7.5	16.9	3.18	1.85	0.240
lla2	2				0.008	0.007	15.6	0.17	4.68	0.033	0.58	0.003
lla15	15	$\tan \beta$	$\cot \beta$	$\tan \beta$	0.48	0.41	13.1	0.14	12.6	0.090	8.84	0.046
lla30	30				2.34	1.97	13.1	0.14	13.1	0.092	11.7	0.061
Y2	2				1.33	1.12	2.62	0.026	1.90	0.013	0.50	0.0026
Y15	15	$\tan \beta$	$\cot \beta$	$-\cot \beta$	0.29	0.24	20.2	0.220	4.94	0.036	0.57	0.0030
Y30	30				3.98	3.36	46.8	0.518	46.0	0.336	39.2	0.2071

$\phi = h, H$; bs units of 10^{-2} and $\sigma.bs$ units of fb.

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

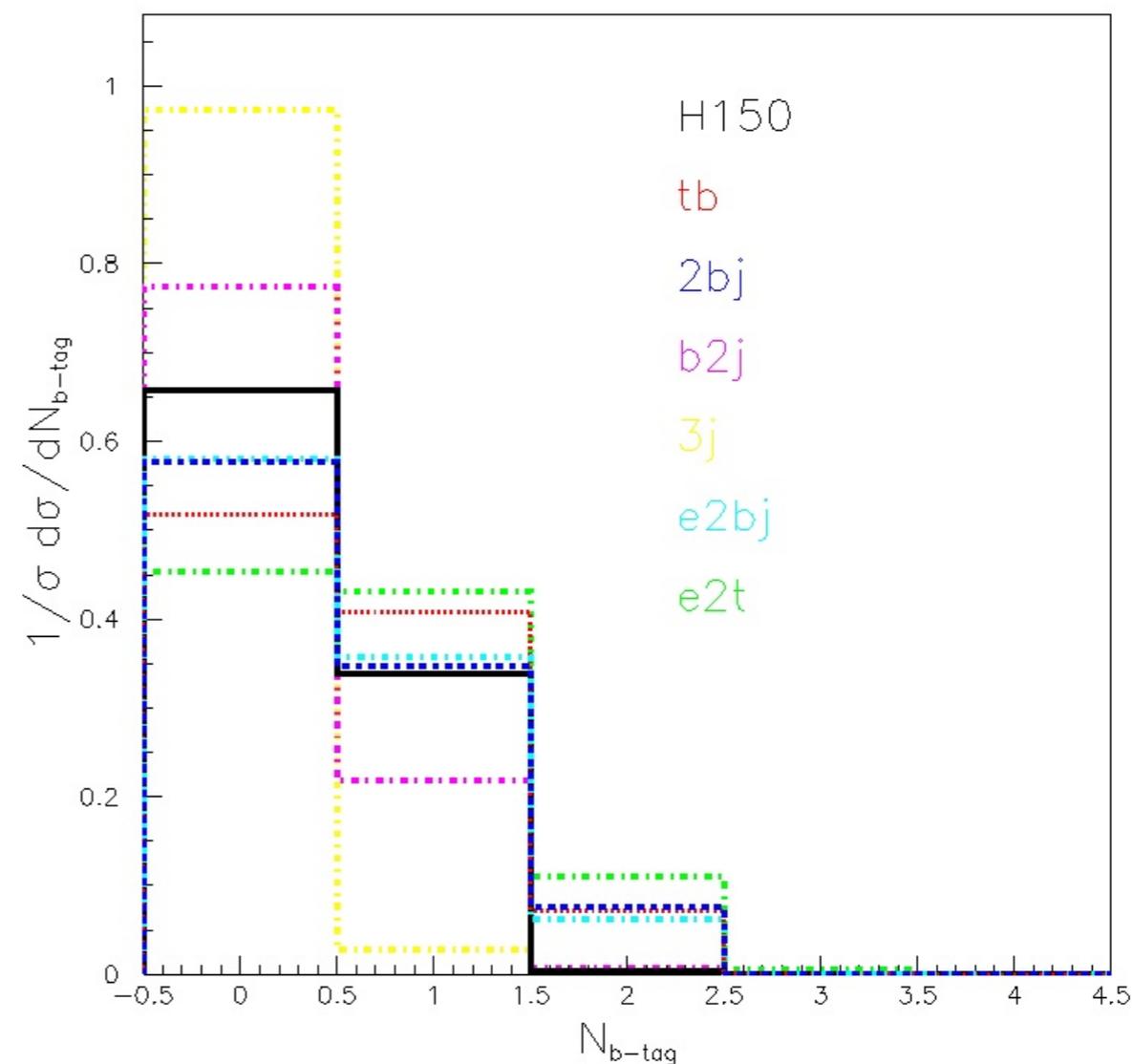
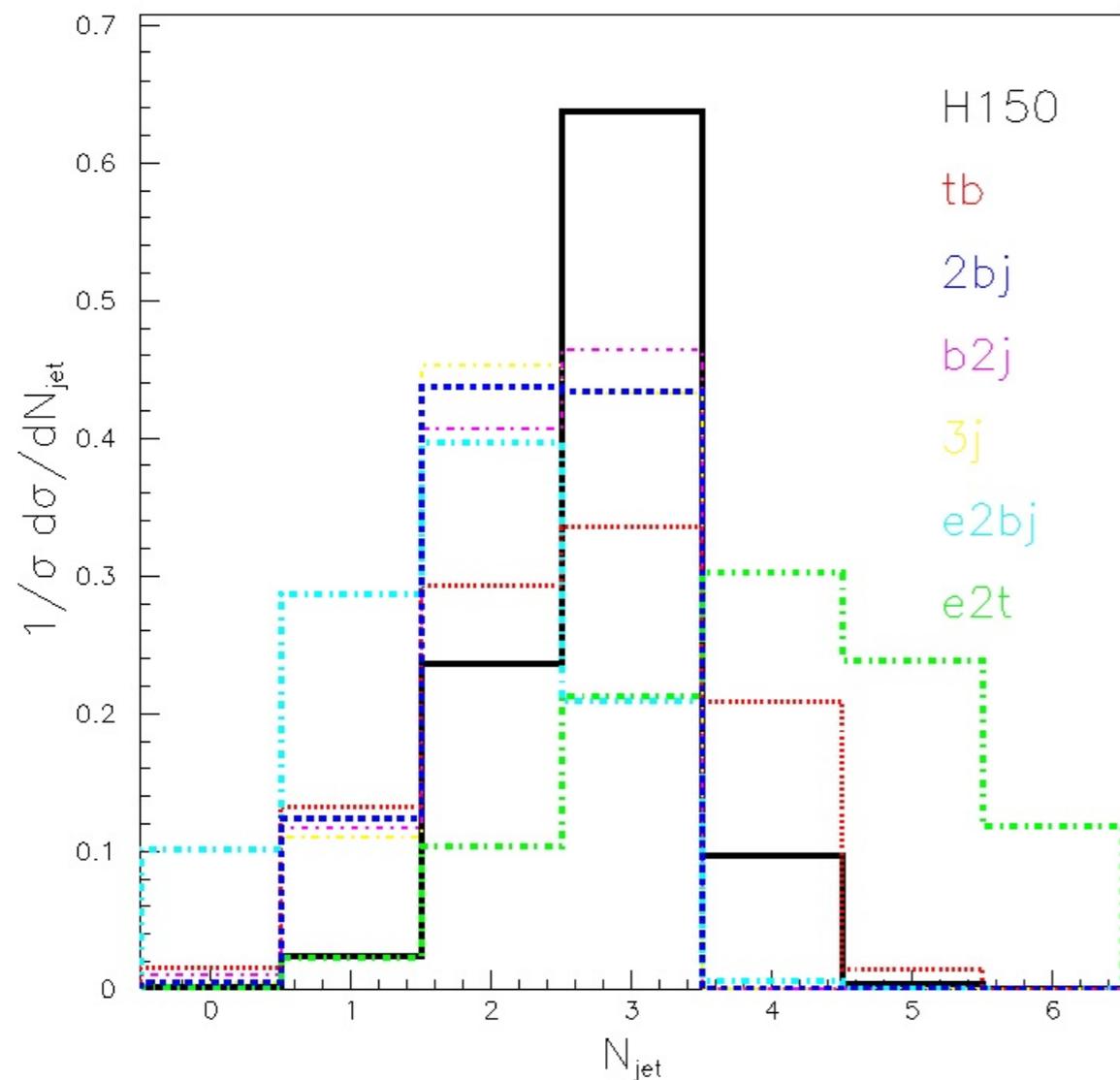
We applied the following basic preselections:

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

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

Njet and Nbtag

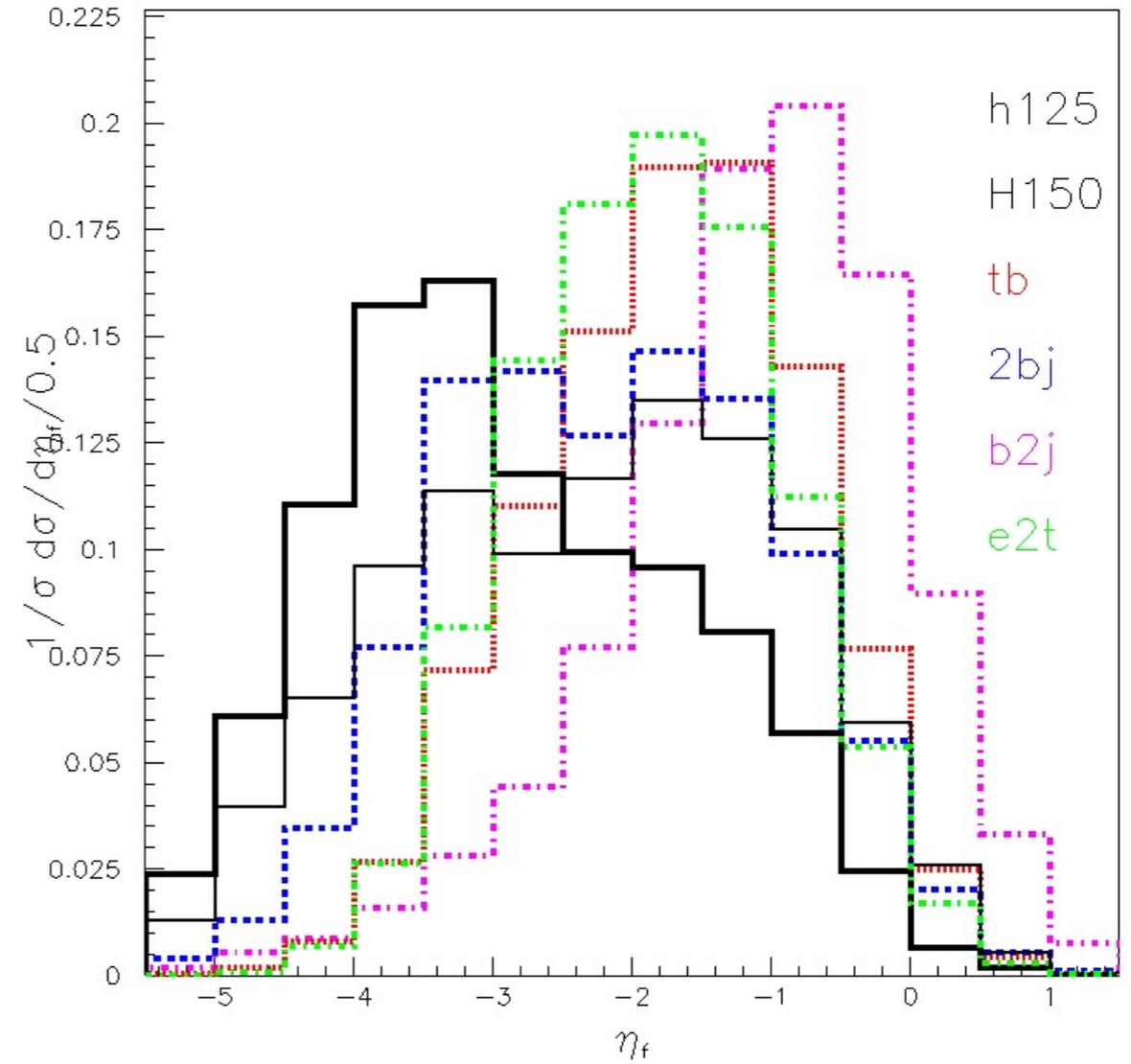
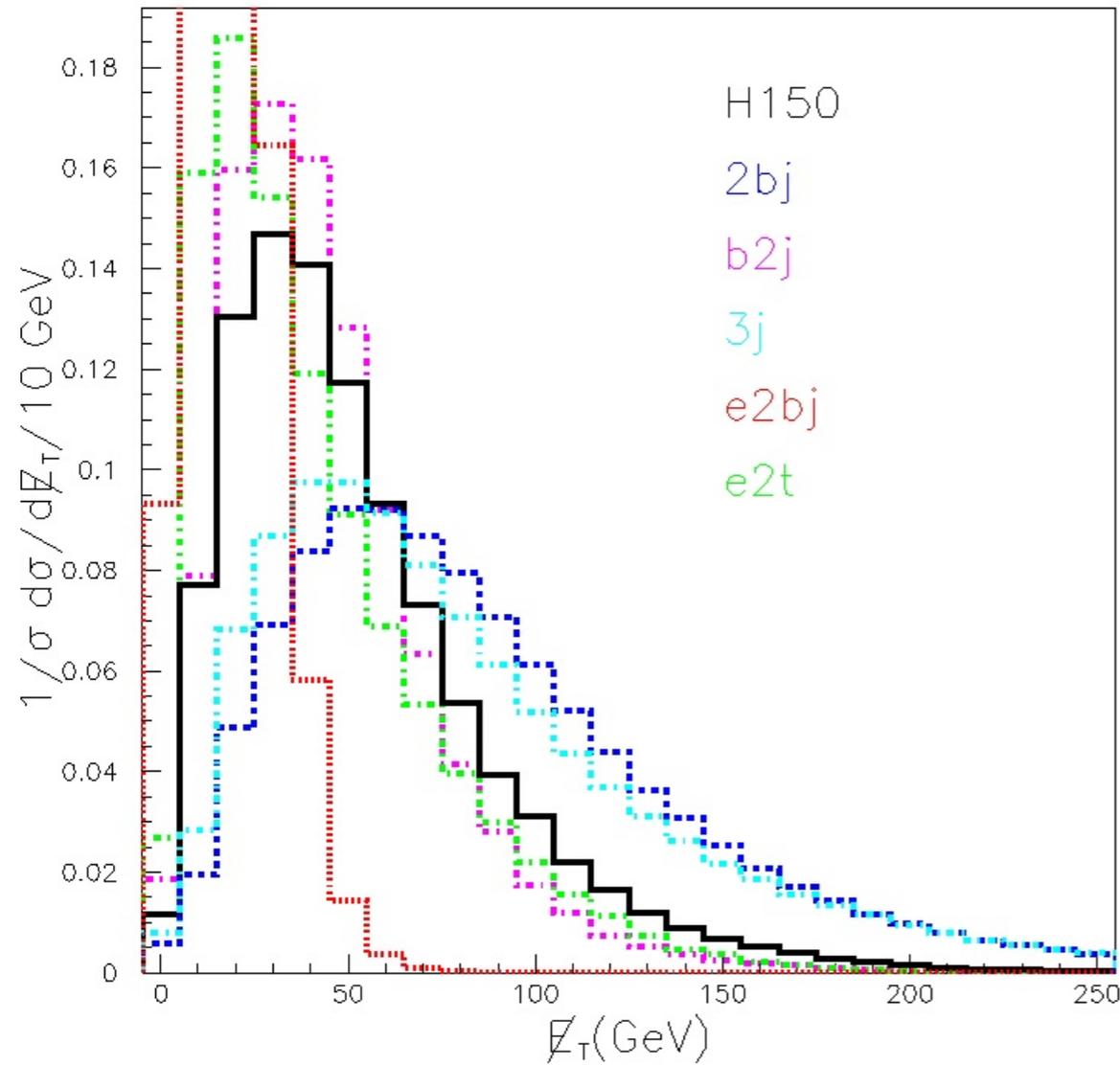
The charged-current backgrounds: $\nu t\bar{b}$, $\nu b\bar{b}j$, $\nu b2j$, $\nu 3j$ and the photo-production backgrounds: $e^-b\bar{b}j$, $e^-t\bar{t}$.



N_{jet} peaks around 3 (for Signal)

N_{b-tag} peaks around 1 (for Signal) and almost vanish for $3j$

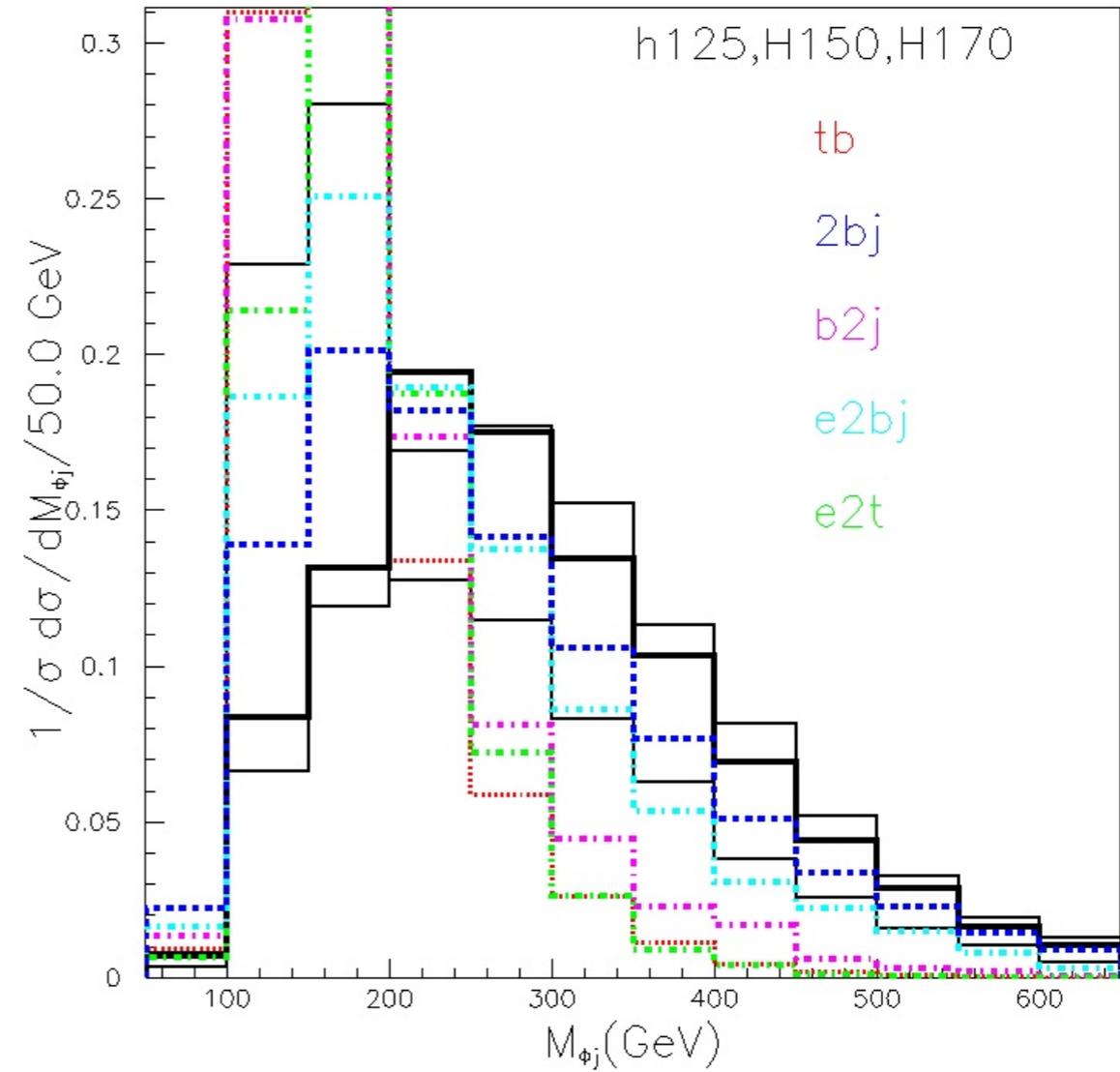
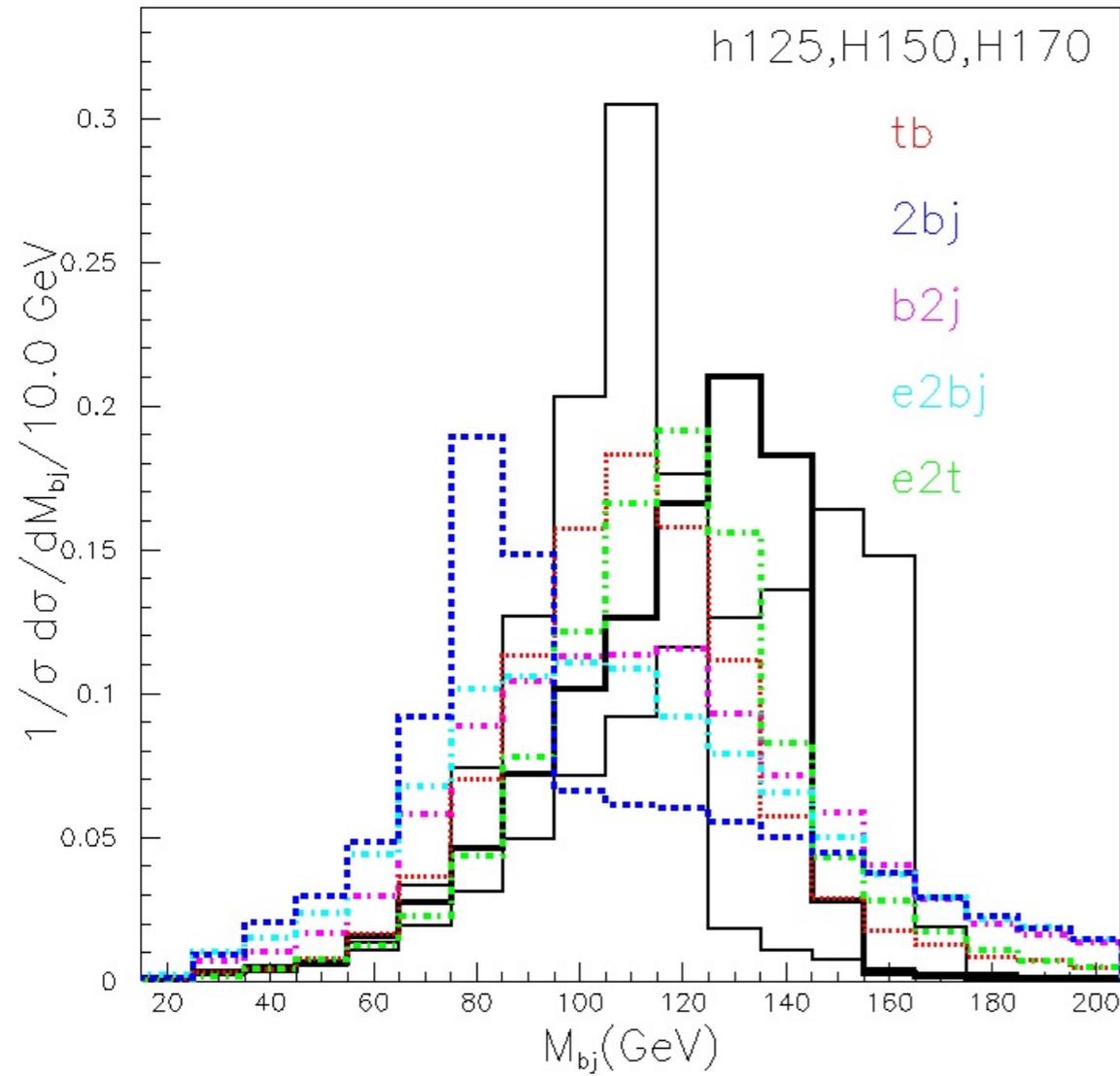
MET(\cancel{E}_T) and Rapidity of forward jet (η_f)



\cancel{E}_T for Signal and charged current BGs are large

η_f is asymmetric (forward jet-tagging)

$$m_\phi = m_{bs} \text{ and } m_{\phi j_f} = m_{bs j_f}$$



$m_{bs} = m_\phi$ (Signal show the peaks over BGs)

$m_{bs j_f} = m_{\phi j}$ (For heavier Higgs masses the peaks shift higher side)

$h_{SM}=125$ GeV:3-jet+ \cancel{E}_T with 100 fb^{-1}

Details in arXiv: 1503.01464

- 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 $\cancel{E}_T > 20\text{GeV} \rightarrow 3j$ 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)

Proc	RawEvt	a	b	cd	e	f	g	h	i	\mathcal{S}
la2	29.9	21.1	8.3	4.6	4.4	1.8	1.5	1.3	0.8	0.06(0.19)
la15	1166.3	814.3	320.2	173.0	166.6	67.3	56.6	44.2	27.7	2.12(6.7)
la30	1911.1	1294.7	539.0	282.7	274.6	102.5	78.7	46.6	29.3	2.24(7.1)
lb2	30.0	21.0	8.1	4.5	4.3	1.8	1.5	1.3	0.8	0.06(0.19)
lb15	761.5	521.0	212.5	113.3	109.6	42.1	33.5	23.2	15.0	1.15(3.6)
lb30	1145.3	776.2	323.1	170.6	165.3	63.3	48.6	29.5	18.8	1.44(4.55)
lla15	40.6	28.6	11.1	6.1	5.9	2.3	2.0	1.7	1.1	0.08(0.25)
lla30	197.0	139.3	53.9	30.0	28.9	11.6	10.0	8.4	5.2	0.39(1.23)
Y2	112.2	79.0	30.5	16.9	16.3	6.4	5.5	4.6	2.9	0.22(0.69)
Y15	24.2	17.0	6.6	3.7	3.5	1.4	1.2	1.0	0.6	0.05(0.15)
Y30	336.0	237.7	92.8	52.1	50.2	20.1	17.1	14.4	9.2	0.70(2.2)
$\nu t\bar{b}$	50712.1	28338.4	15293.7	8144.2	7532.7	2982.1	2058.0	652.2	139.6	$B=170.8$ $\sqrt{B}=13.1$
$\nu b\bar{b}j$	14104.6	6122.8	3656.7	1787.1	1650.1	257.5	152.5	85.2	15.1	
$\nu b2j$	18043.1	8389.2	3013.0	1445.5	1373.7	389.5	206.1	77.2	11.3	
$\nu 3j$	948064.2	410393.4	15560.9	0.0	0.0	0.0	0.0	0.0	0.0	
$eb\bar{b}j$	256730.1	55099.8	36353.6	1432.0	200.7	54.1	24.8	18.0	4.5	
ett	783.3	685.0	384.5	179.3	26.2	11.6	10.5	3.9	0.3	

$m_H=130$ 3-jet+ \cancel{E}_T with 100 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 $\cancel{E}_T > 20 \text{ GeV}$
- E: lepton (e or μ) 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 $-5.5 < \eta < -1.0$
- H: $m_{\phi j_f} > 190 \text{ GeV}$

Proc	RawEvt	A	B	CD	E	F	G	H	I	\mathcal{S}
la2	32.8	23.6	9.2	6.1	5.8	2.0	1.7	1.5	0.9	0.07(0.22)
lb2	32.8	23.7	9.2	6.1	5.8	2.1	1.7	1.5	1.0	0.08(0.25)
lb15	516.0	370.0	145.0	94.7	90.9	30.3	24.6	21.1	13.5	1.11(3.5)
lb30	750.9	520.6	210.7	134.2	129.2	42.8	31.2	23.1	14.2	1.17(3.7)
lla2	16.7	11.8	4.8	3.1	3.0	0.9	0.7	0.5	0.3	0.02(0.06)
Y15	22.0	15.4	6.1	3.9	3.7	1.3	0.9	0.7	0.5	0.04(0.12)
Y30	51.8	36.3	14.8	9.7	9.3	3.0	2.2	1.6	1.1	0.09(0.28)
$\nu t\bar{b}$	50712.1	28338.4	15293.7	9092.4	8393.6	2550.9	1565.5	617.9	113.7	$B=147.8$ $\sqrt{B}=12.2$
$\nu b\bar{b}j$	14104.6	6122.8	3656.7	2062.1	1902.9	266.6	141.0	87.5	14.4	
$\nu b2j$	18043.1	8389.2	3013.0	1734.0	1650.1	402.8	143.7	64.5	8.1	
$\nu 3j$	948064.2	410393.4	15560.9	0.0	0.0	0.0	0.0	0.0	0.0	
$e\bar{b}j$	256730.1	55099.8	36353.6	1826.6	284.1	56.4	31.6	22.6	11.3	
$e\bar{t}\bar{t}$	783.3	685.0	384.5	190.8	27.8	10.9	9.3	3.9	0.3	

$m_H=150$ 3-jet+ \cancel{E}_T with 100 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 $\cancel{E}_T > 20 \text{ GeV}$
- E: lepton (e or μ) 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 $-5.5 < \eta < -1.0$
- H: $m_{\phi j_f} > 210 \text{ GeV}$

Proc	RawEvt	A	B	CD	E	F	G	H	I	\mathcal{S}
lb15	139.6	108.2	41.7	31.6	29.9	7.0	5.9	5.3	3.7	0.48(1.5)
lb30	317.6	234.5	91.5	68.6	65.2	14.7	11.7	10.5	7.4	0.95(3.0)
Y30	33.6	25.3	9.9	7.5	7.1	1.7	1.4	1.2	0.9	0.12(0.38)
$\nu t\bar{b}$	50712.1	28338.4	15293.7	9808.7	9039.0	751.7	476.8	194.5	32.3	$B=60.1$ $\sqrt{B}=7.7$
$\nu b\bar{b}j$	14104.6	6122.8	3656.7	2300.1	2120.8	199.3	112.4	70.8	12.4	
$\nu b2j$	18043.1	8389.2	3013.0	2030.3	1933.1	234.2	83.7	41.0	6.3	
$\nu 3j$	948064.2	410393.4	15560.9	0.0	0.0	0.0	0.0	0.0	0.0	
$eb\bar{b}j$	256730.1	55099.8	36353.6	2270.8	385.6	36.1	24.8	20.3	9.0	
ett	783.3	685.0	384.5	199.0	29.1	3.5	3.0	1.2	0.1	

$m_H=170$ 3-jet+ \cancel{E}_T with 100 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 $\cancel{E}_T > 20 \text{ GeV}$
- E: lepton (e or μ) 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 $-5.5 < \eta < -1.0$
- H: $m_{\phi j_f} > 230 \text{ GeV}$

Proc	RawEvt	A	B	CD	E	F	G	H	I	S
lb30	24.2	19.9	7.6	6.1	5.7	1.0	0.9	0.8	0.6	0.10(0.32)
Y30	20.7	17.2	6.6	5.3	5.0	0.9	0.8	0.8	0.5	0.09(0.28)
$\nu t\bar{b}$	50712.1	28338.4	15293.7	10299.7	9465.2	209.7	144.5	75.9	13.2	$B=31.7$ $\sqrt{B}=5.6$
$\nu b\bar{b}j$	14104.6	6122.8	3656.7	2465.8	2272.4	103.7	60.8	37.4	8.7	
$\nu b2j$	18043.1	8389.2	3013.0	2278.1	2171.4	99.5	40.0	25.2	5.3	
$\nu 3j$	948064.2	410393.4	15560.9	0.0	0.0	0.0	0.0	0.0	0.0	
$ebb\bar{j}$	256730.1	55099.8	36353.6	2638.4	453.3	29.3	18.0	11.3	4.5	
$ett\bar{t}$	783.3	685.0	384.5	204.5	29.9	1.0	0.8	0.5	0.0	

Summary:

- Finding multiple Higgses simultaneously, can hint for some new physics beyond SM.
- 2HDM-III with Yukawa textured enhance Flavor violating Higgs bosons decays.
- Flavor enhanced decay with $h_{SM}=125$ GeV, as well as $H = 130, 150$ and 170 GeV simultaneously possible.
- We consider: $\nu_e \phi q^\pm$ with $\phi \rightarrow b\bar{s}$ at LHeC, leads to $3j + \cancel{E}_T$ with two central jets (one must be a b-jet) and one forward jets.
- LHeC: $\sqrt{s} = 1.3$ TeV with luminosity: 100 fb^{-1} .
- BGs charged-current: $\nu t\bar{b}$, $\nu b\bar{b}j$, $\nu b2j$, $\nu 3j$ and photo-production: $e^- b\bar{b}j$, $e^- t\bar{t}$
- Applied various kinematical cuts, by seeing important distributions, and found that $h_{SM}=125$ GeV will be seen with $1-2\sigma$ for Ia, Ib with $Y = -X = 15$ or 30 .
- $H = 150$ would have $1-\sigma$ in large X and only for scenario Ib.
- At the end of LHeC running, by 2030, the total luminosity: 1000 fb^{-1} . This leads the significance enhancement in all the scenarios by factor of: 3.2
- Flavor-violating decays of Higgses would be observable at LHeC can hint for signature of 2HDM-III with Yukawa texture.