Benemérita Universidad Autónoma de Puebla

and

Dual C-P Institute of High Energy Physics, México

BSM Higgs studies

Jaime Hernandez -Sanchez

in collaboration with:

S. P. Das, A. Rosado, R. Xoxocotzi (BUAP, México)
S. Moretti (U. of Southampton, UK)

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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 → bs,τμ, H+ —> cb, ts, decays are sensitive to the pattern of Yukawa texture.
- Benchmarks scenarios are found and one could have a BR(h,H→bs) ~ 0.1 keeping h-decays compatible with SM.
- we analyze $e^- p \to q(h,H)\nu_e$ 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) (~SM).

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

Andreas Crivellin, Phys.Rev. D83 (2011) 056001

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 copules to donw (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 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

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

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

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

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

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

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

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

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

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

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

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

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: $\chi^f_{kk} \sim 1$ and $|\chi^f_{ij}| \leq 0.5$,

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 3HDM with flavor symmetries
Alfredo Aranda, Cesar Bonilla, J.Lorenzo Diaz-Cruz. Phys.Lett. B717 (2012) 248-251

As the four-zero texture controls the FCNC, then the most general Higgs potential could be considered for the 2HDM-III

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

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

Others phenomenological consequences

- If we combine:

- The effects of texture in the coupling.
- The general Higgs potential.
-

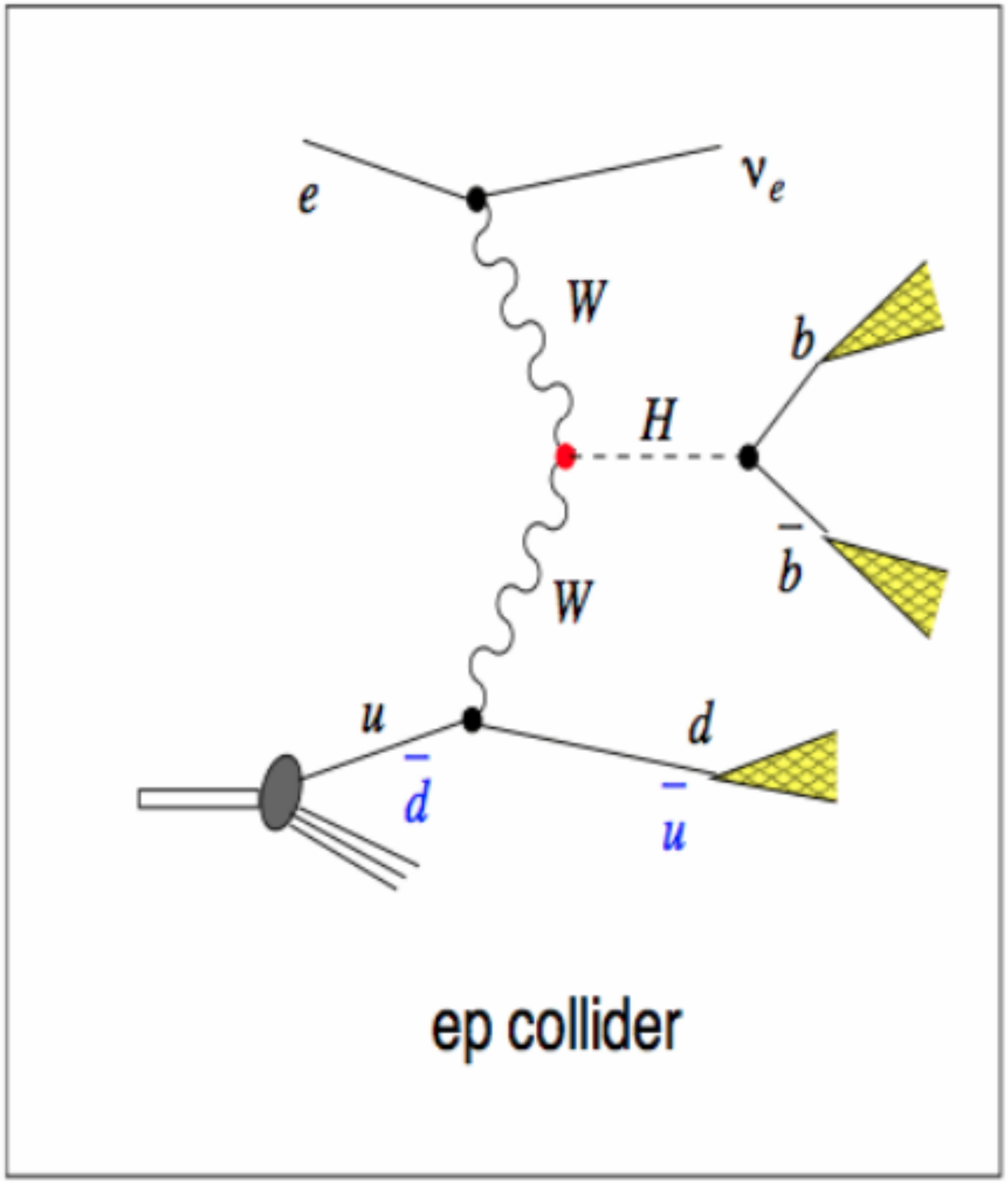
It’s possible to enhacement processes at one-loop-level, e.g.

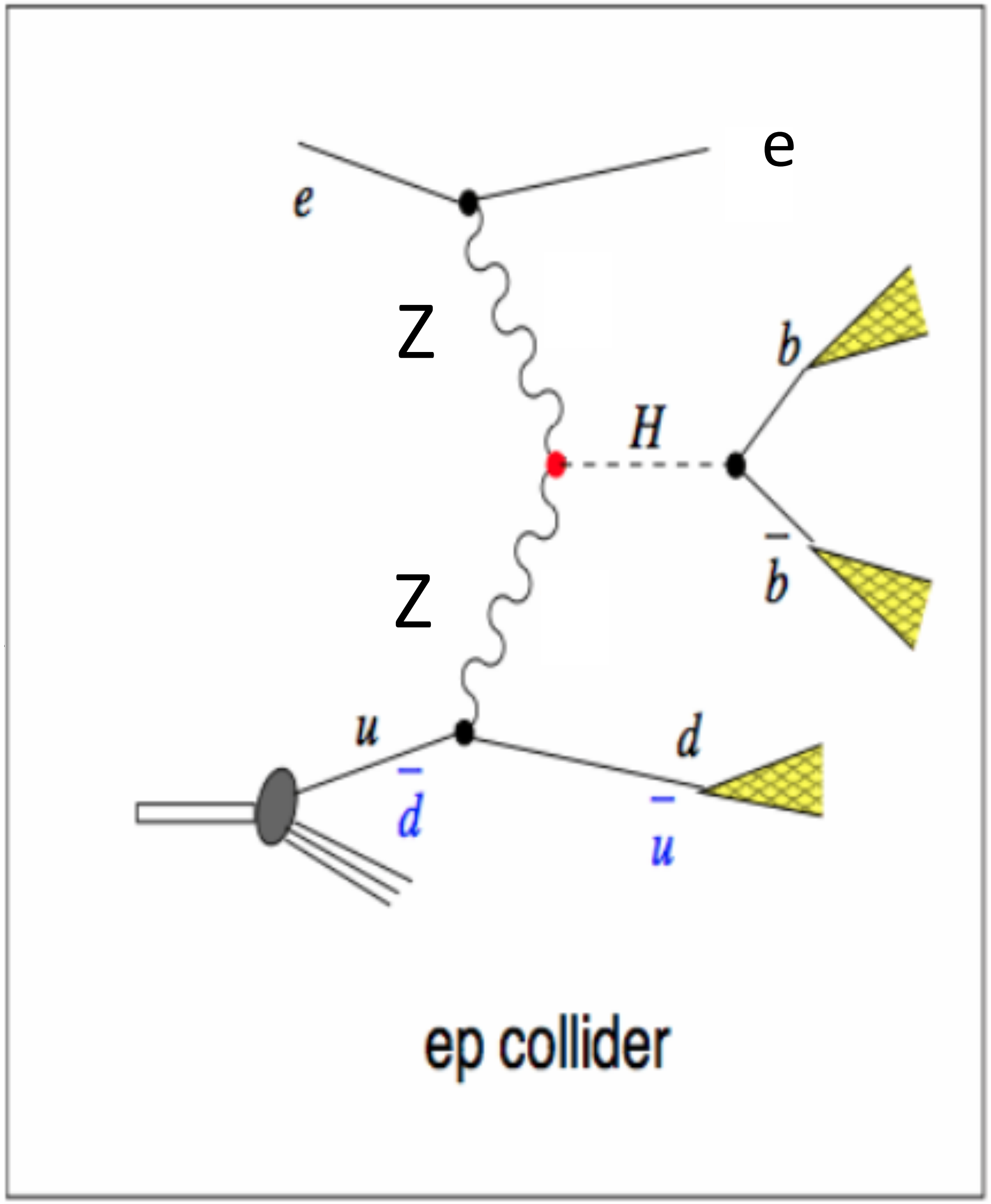
- H,h→ γγ
- H^+→ W^+ γ, W^+ Z

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

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

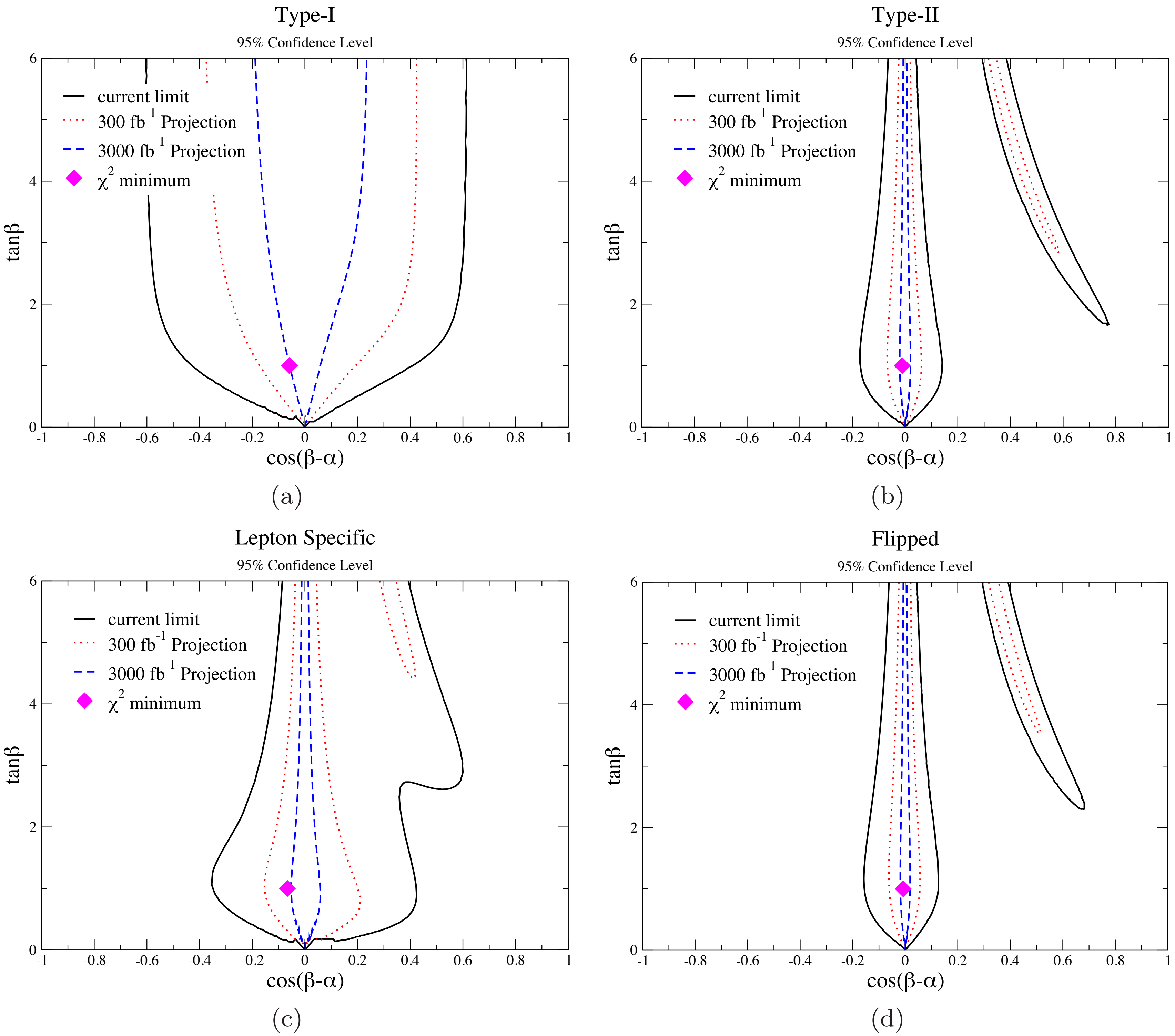
J.E. Barradas, F. Cazares-Bush, A. Cordero-Cid, O. Félix-Beltrán, J. Hernández-Sanchez, R. Noriega-Papaqui, J.Phys. G37 (2010) 115008





In the 2HDM; H= h0, H0

For H0 the coupling VVH0 is proportional to Cos(β-α) and VVh0 to Sin(β-α)



(a) (b)

(c) (d)

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

- **Scenario Ia**: 2HDM-III as 2HDM-I, with the couplings $\phi f f$ given by $g^{\phi f f}_{2HDM-III} = g^{\phi f f}_{2HDM-I} + \Delta g$ and $\cos(\beta-\alpha) = 0.1$, $\chi^u_{kk} = 1.5$ (k=2,3), $\chi^d_{22} = 1.8$, $\chi^d_{33} = 1.2$, $\chi^{u,d}_{23} = 0.2$, $\chi^\ell_{22} = 0.5$, $\chi^\ell_{33} = 1.2$, $\chi^\ell_{23} = 0.1$, $m_A = 100$ GeV and $m_{H^\pm} = 110$ GeV, taking $Y = -X = -Z = \cot\beta = 2, 15, 30$.

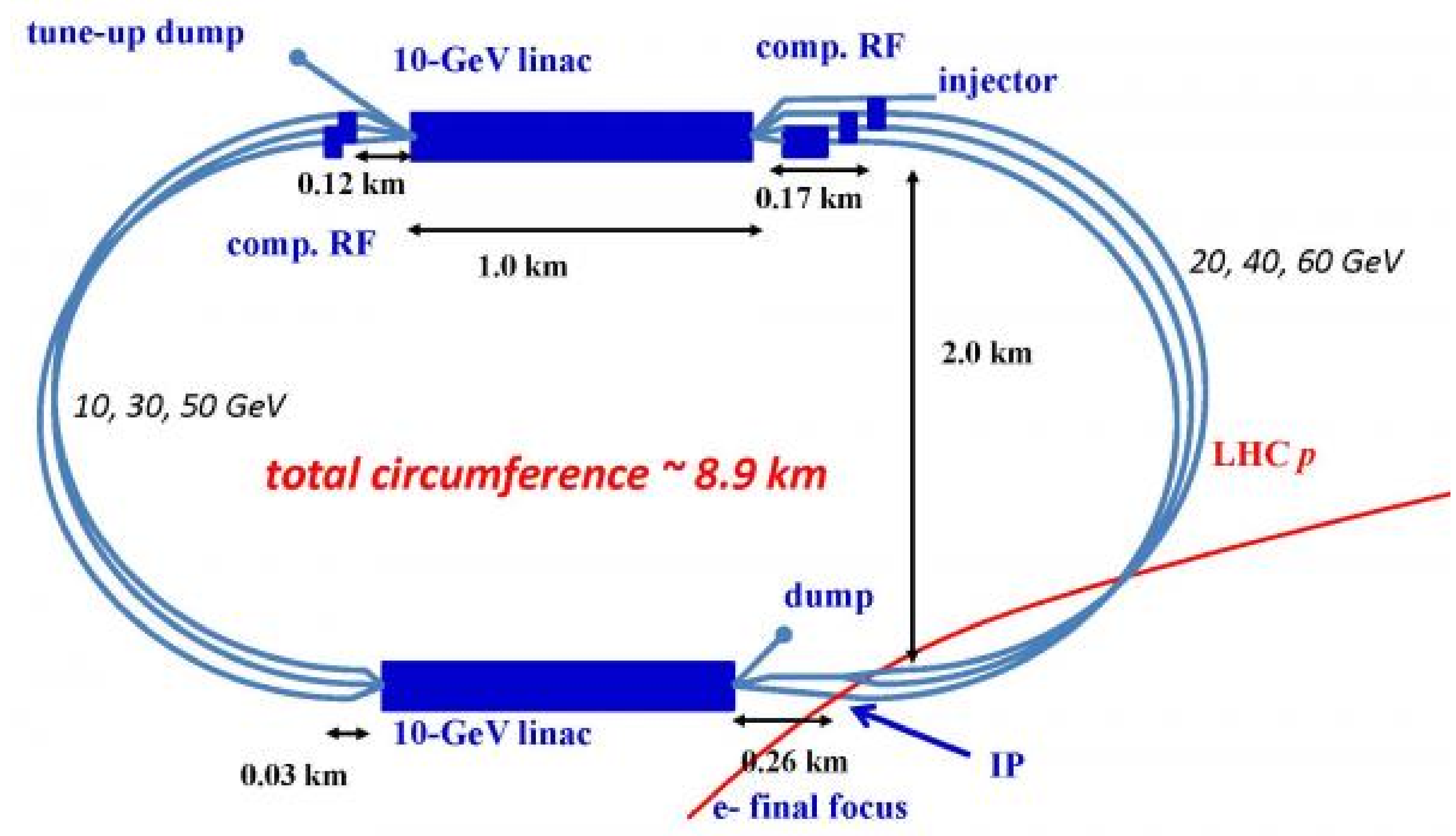
- **Scenario Ib**: the same as scenario Ia but with $\cos(\beta-\alpha) = 0.5$.

- **Scenario IIa**: 2HDM-III as 2HDM-II, namely, the couplings $\phi f f$ given by $g^{\phi f f}_{2HDM-III} = g^{\phi f f}_{2HDM-II} + \Delta g$ and $\cos(\beta-\alpha) = 0.1$, $\chi^u_{22} = 0.5$, $\chi^u_{33} = 1.4$, $\chi^d_{22} = 2$, $\chi^d_{33} = 1.3$, $\chi^u_{23} = -0.53$, $\chi^d_{23} = 0.2$, $\chi^\ell_{22} = 0.4$, $\chi^\ell_{33} = 1.2$, $\chi^\ell_{23} = 0.1$, $m_A = 100$ 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 $g^{\phi f f}_{2HDM-III} = g^{\phi f f}_{2HDM-Y} + \Delta g$ and $\cos(\beta-\alpha) = 0.1$, $\chi^u_{22} = 0.5$, $\chi^u_{33} = 1.4$, $\chi^d_{22} = 2$, $\chi^d_{33} = 1.3$, $\chi^u_{23} = -0.53$, $\chi^d_{23} = 0.2$, $\chi^\ell_{22} = 0.4$, $\chi^\ell_{33} = 1.1$, $\chi^\ell_{23} = 0.1$, $m_A = 100$ 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.



$\sqrt{s} = \sqrt{(E_e E_p)} = 1.296$ 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.

2HDM	tan β	X	Y	Z	h=125		H=130		H=150		H=170	
					bs	σ.bs	bs	σ.bs	bs	σ.bs	bs	σ.bs
Ia2	2	-cot β	cot β	-cot β	0.76	0.29	0.75	0.330	0.22	0.077	0.011	0.003
Ia15	15				12.0	11.7	0.71	0.006	0.58	0.004	0.20	0.001
Ia30	30				12.8	19.1	3.16	0.088	2.50	0.027	0.80	0.005
Ib2	2	-cot β	cot β	-cot β	0.76	0.30	0.75	0.33	0.22	0.077	0.011	0.003
Ib15	15				8.6	7.6	23.6	5.16	8.34	1.39	0.49	0.065
Ib30	30				10.9	11.5	25.2	7.5	16.9	3.18	1.85	0.240
IIa2	2	tan β	cot β	tan β	0.008	0.007	15.6	0.17	4.68	0.033	0.58	0.003
IIa15	15				0.48	0.41	13.1	0.14	12.6	0.090	8.84	0.046
IIa30	30				2.34	1.97	13.1	0.14	13.1	0.092	11.7	0.061
Y2	2	tan β	cot β	-cot β	1.33	1.12	2.62	0.026	1.90	0.013	0.50	0.0026
Y15	15				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 σ.bs > 0.15 fb; at least 15 events for 100 fb^(-1)

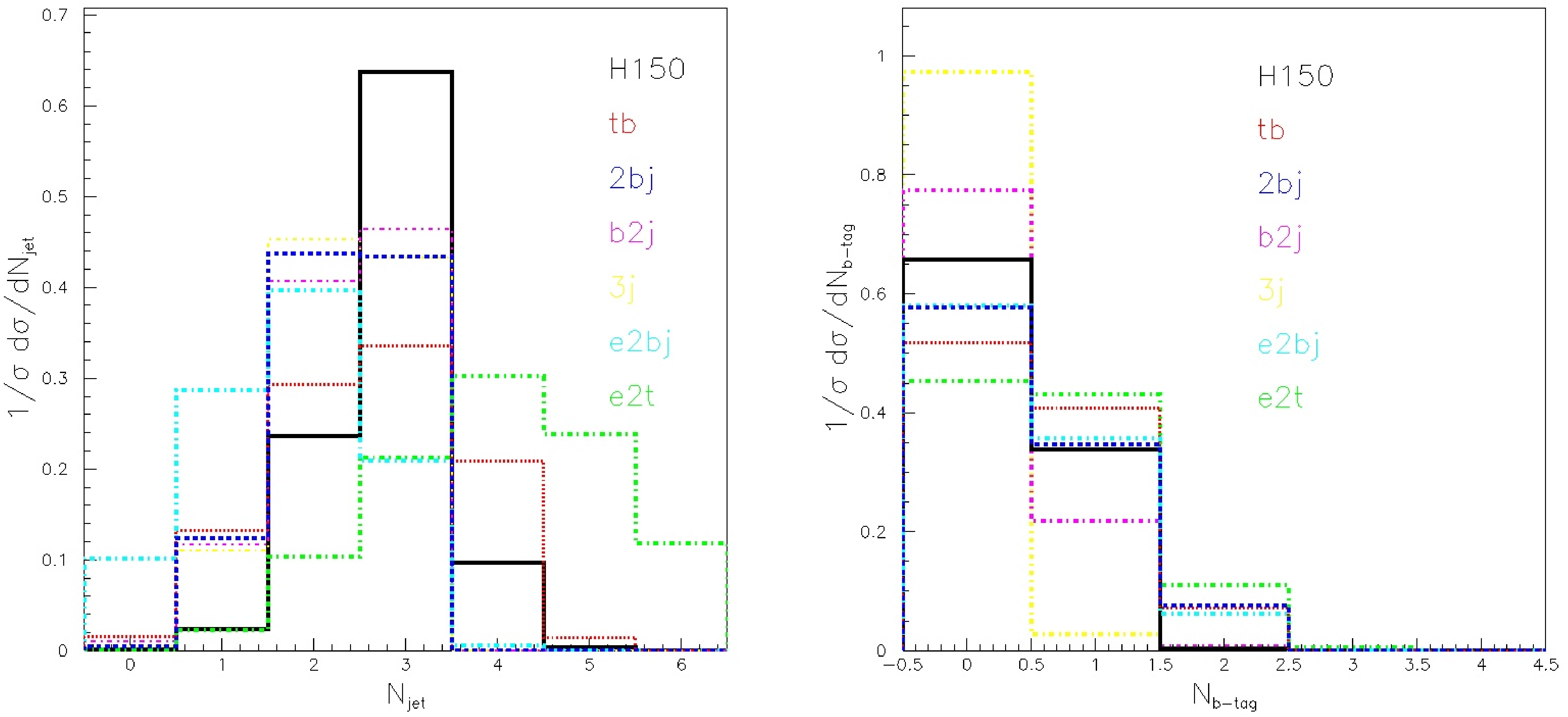
We applied the following basic preselections:

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

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

Njet and Nbtag

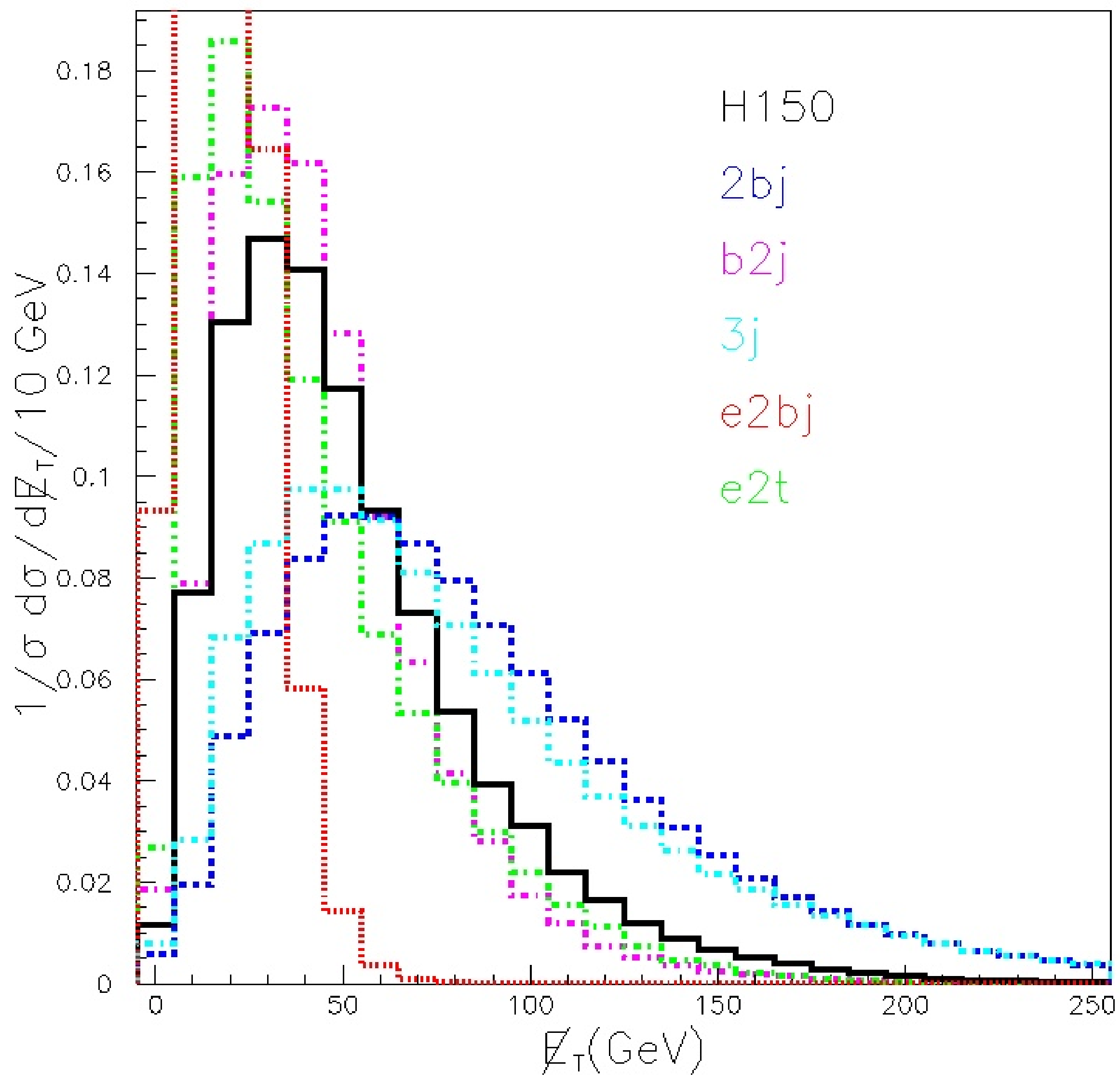
The charged-current backgrounds: $\nu t\bar{b}$, $\nu b\bar{b}j$, $\nu b2j$, $\nu 3j$ and the photo-production backgrounds: $e^- b\bar{b}j$, $e^- t\bar{t}$.

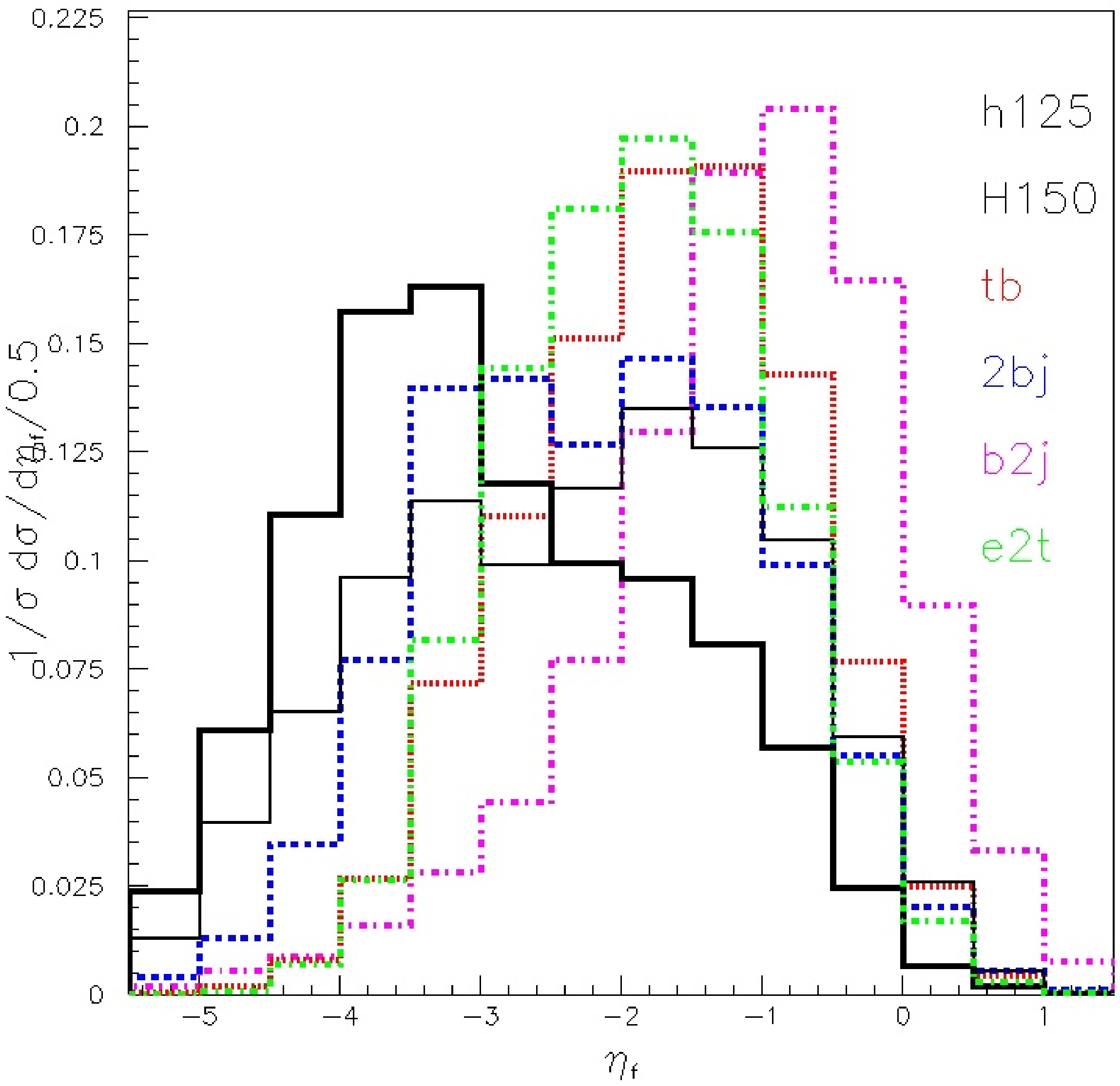


Njet peaks around 3 (for Signal)

Nb − tag peaks around 1 (for Signal) and almost vanish for 3*j*

MET($\not{E}_T$) and Rapidity of forward jet (η_f)

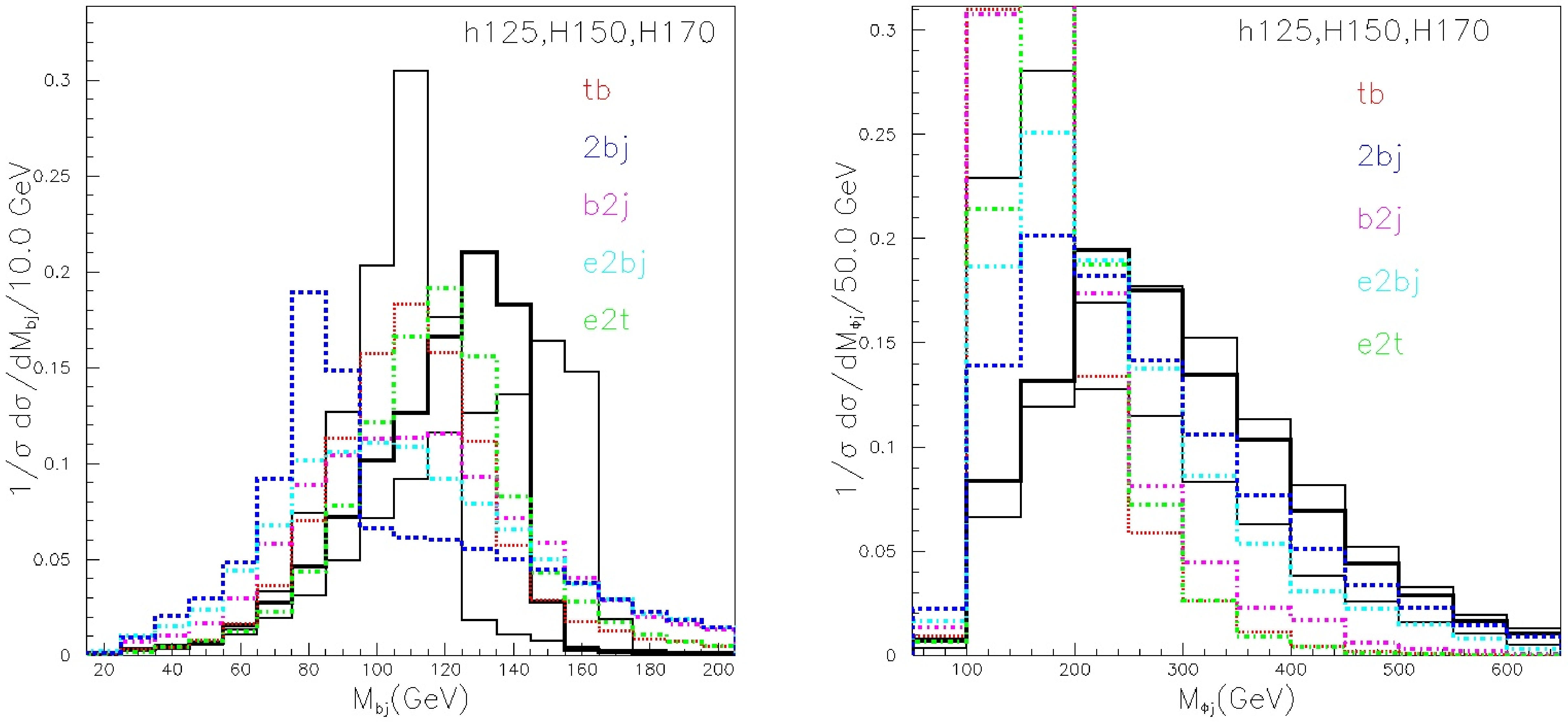




$\not{E}_T$ for Signal and charged current BGs are large

η_f is asymmetric (forward jet-tagging)

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



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

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

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

Details in arXiv: 1503.01464

- 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)

Proc	RawEvt	a	b	cd	e	f	g	h	i	$\mathcal{S}$
Ia2	29.9	21.1	8.3	4.6	4.4	1.8	1.5	1.3	0.8	0.06(0.19)
Ia15	1166.3	814.3	320.2	173.0	166.6	67.3	56.6	44.2	27.7	2.12(6.7)
Ia30	1911.1	1294.7	539.0	282.7	274.6	102.5	78.7	46.6	29.3	2.24(7.1)
Ib2	30.0	21.0	8.1	4.5	4.3	1.8	1.5	1.3	0.8	0.06(0.19)
Ib15	761.5	521.0	212.5	113.3	109.6	42.1	33.5	23.2	15.0	1.15(3.6)
Ib30	1145.3	776.2	323.1	170.6	165.3	63.3	48.6	29.5	18.8	1.44(4.55)
IIa15	40.6	28.6	11.1	6.1	5.9	2.3	2.0	1.7	1.1	0.08(0.25)
IIa30	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	
$\nu b\bar{b}j$	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	B=170.8
$\nu 3j$	948064.2	410393.4	15560.9	0.0	0.0	0.0	0.0	0.0	0.0	$\sqrt{B}$=13.1
$eb\bar{b}j$	256730.1	55099.8	36353.6	1432.0	200.7	54.1	24.8	18.0	4.5	
$et\bar{t}$	783.3	685.0	384.5	179.3	26.2	11.6	10.5	3.9	0.3	

Results in () is for 1000 fb^(-1)

mH=130 **3-jet+$\not{E}_T$ with 100 fb^{-1}**

- 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 $\not{E}_T > 20 GeV$
- 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 $-5.5 < \eta < -1.0$
- H: $m_{\phi j_f} >$ 190 GeV

Proc	RawEvt	A	B	CD	E	F	G	H	I	$\mathcal{S}$
Ia2	32.8	23.6	9.2	6.1	5.8	2.0	1.7	1.5	0.9	0.07(0.22)
Ib2	32.8	23.7	9.2	6.1	5.8	2.1	1.7	1.5	1.0	0.08(0.25)
Ib15	516.0	370.0	145.0	94.7	90.9	30.3	24.6	21.1	13.5	1.11(3.5)
Ib30	750.9	520.6	210.7	134.2	129.2	42.8	31.2	23.1	14.2	1.17(3.7)
IIa2	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	
$\nu b\bar{b}j$	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	B=147.8
$\nu 3j$	948064.2	410393.4	15560.9	0.0	0.0	0.0	0.0	0.0	0.0	$\sqrt{B}$=12.2
$eb\bar{b}j$	256730.1	55099.8	36353.6	1826.6	284.1	56.4	31.6	22.6	11.3	
$et\bar{t}$	783.3	685.0	384.5	190.8	27.8	10.9	9.3	3.9	0.3	

mH=150 3-jet+$\not{E}_T$ with 100 fb^{-1}

- 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 $\not{E}_T > 20 GeV$
- 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 $-5.5 < \eta < -1.0$
- H: $m_{\phi j_f} >$ 210 GeV

Proc	RawEvt	A	B	CD	E	F	G	H	I	$\mathcal{S}$
Ib15	139.6	108.2	41.7	31.6	29.9	7.0	5.9	5.3	3.7	0.48(1.5)
Ib30	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	
$et\bar{t}$	783.3	685.0	384.5	199.0	29.1	3.5	3.0	1.2	0.1	

mH=170 3-jet+$\not{E}_T$ with 100 fb^{-1}

- 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 $\not{E}_T > 20 GeV$
- 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 $-5.5 < \eta < -1.0$
- H: $m_{\phi j_f} > 230$ GeV

Proc	RawEvt	A	B	CD	E	F	G	H	I	$\mathcal{S}$
Ib30	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	
$eb\bar{b}j$	256730.1	55099.8	36353.6	2638.4	453.3	29.3	18.0	11.3	4.5	
$et\bar{t}$	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 $\phi \to b\bar{s}$ at LHeC, leads to 3j+$\not{E}_T$ 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 1-2σ for Ia, Ib with $Y = -X = 15$ or 30.
- H = 150 would have 1-σ 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.

Outlook

We are studying the production of cp-odd neutral Higgs (A0) and the charged Higgs (H+) in ep collider.