Models and Phenomenology of Maximal Flavor Violation

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We consider models of maximal flavor violation (MxFV), in which a new scalar mediates large $q_3 \leftrightarrow q_1$ or $q_3 \leftrightarrow q_2$ flavor changing transitions ($q_i$ is an $i$'th generation quark), while $q_3 \leftrightarrow q_3$ transitions are suppressed, e.g., $\xi_{13} \sim V_{tb}$ and $\xi_{33} \sim V_{tb}$, where $\xi_{ij}$ are the new scalar couplings to quarks and $V$ is the CKM matrix. We show that, contrary to the conventional viewpoint, such models are not ruled out by the existing low energy data on $K^0$, $B^0$ and $D^0$ oscillations and rare $K$ and $B$-decays. We also show that these models of MxFV can have surprising new signatures at the LHC and the Tevatron.

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Introduction: The hierarchy problem and the problem of dark matter imply that the Standard Model (SM) is incomplete. Models of new physics (NP) typically predict a large number of new particles at the TeV scale, and in particular, many models predict the existence of new scalars beyond the SM Higgs, which, in principle, can induce flavor violating (FV) currents through Yukawa-like interactions of the form $\xi_{ij} \Phi q_i q_j$. It is traditionally assumed that, to satisfy the precision data, the new particles that mediate FV have to be very heavy (i.e., $\sim 10$ TeV - somewhat in conflict with the solutions to the hierarchy problem and dark matter) or else their FV couplings have to be very small. In general, this leads to the “NP flavor puzzle” since if there is NP at the TeV scale, then there is no underlying principle that would forbid low energy FV signatures at large rates.

A popular solution to the flavor problem is to impose the minimal FV (MFV) ansatz, which states that the NP is “aligned” with the SM, such that all FV transitions are governed by the nearly diagonal CKM matrix $V$. For instance, since the CKM elements satisfy e.g. $V_{td} \ll V_{tb}$, the MFV ansatz imposes the couplings of any new scalar to a pair of top+light quark to satisfy $\xi_{3i} \ll \xi_{33}$ for $i = 1, 2$. As an example, the Minimal Supersymmetric SM (MSSM) soft breaking terms allow in general for $O(1)$ FV sfermion mixings which can mediate unacceptably large contributions to FV processes in meson mixings and decays. In this case sfermion-fermion alignment which leads to MFV is motivated since otherwise the sfermion masses have to be too heavy for addressing the fine-tuning problem.

In this note, we present a new class of scalar mediated FV models, which maximally depart from the MFV ansatz, (in the sense that $\xi_{31}, \xi_{32} \sim O(1) \gg \xi_{33}$) and still satisfy all constraints from flavor physics even with a relatively light scalar $m_\Phi \sim m_{W}$. To emphasize the contrast with MFV models, we will describe these models as having Maximal FV (MxFV). We can further subdivide these MxFV models into MxFV\textsubscript{1} models where $\xi_{31}, \xi_{13} \sim O(1)$ while $\xi_{32}, \xi_{23} \ll O(1)$ and MxFV\textsubscript{2} models if $\xi_{32}, \xi_{23} \sim O(1)$ while $\xi_{31}, \xi_{13} \ll O(1)$, and in both cases $\xi_{ij} \sim 0$ $i, j = 1, 2$. We show that such models may be as viable as the MFV models.

We will begin by presenting a model independent setup where MxFV is mediated by a new scalar with a mass of a few hundred GeV. We then systematically analyze constraints on these models coming from precision data on meson mixing and decays and show that, contrary to expectations, we can indeed have electroweak scale extensions of the SM that fall into the MxFV categories. Finally, we show that such models of MxFV can have surprising new signatures at hadron colliders (LHC & Tevatron). We close with a discussion of future directions.

Models of Maximal Flavor Violation: In what follows, we will consider the more restrictive case (with respect to having tighter constraints from flavor physics) where the new scalar is a doublet of electroweak $SU(2)$. However, the analysis below can be applied to singlets as well.

Let $\Phi_{FV}$ be a new scalar doublet that potentially mediates MxFV through:

$$\mathcal{L}_{FV} = \xi_{ij} \bar{Q}_{iL} \Phi_{FV} U_{jR} + \xi_{ij} \bar{Q}_{iL} \Phi_{FV} d_{jR} + h.c. \quad (1)$$

where $i, j$ are generation indices. Now, flavor changing neutral interactions in the down-quark sector are severely constrained by meson-mixings, implying in general that $\xi^d \ll \xi^u$. We will therefore set $\xi^d \sim 0$ and consider only effects from $\xi^u \equiv \xi$. Defining $\Phi_{FV} = (H^+, H^0)$ (note that in general $H^0$ is complex) we can then re-write as:

$$\mathcal{L}_{FV} \sim \xi_{ij} \cdot (H^0 \bar{u}_i R u_{jL} - H^+ \bar{u}_i R d_{jL}) + h.c. \quad (2)$$

where e.g., $\xi_{31}$ is the coupling of $H^+ t d$ and by $SU(2)$ also of $H^0 t u$.

We wish to construct models where e.g., $\xi_{31}, \xi_{32} \gg \xi_{33}$. We can do that by imposing flavor symmetries. One simple example is a $Z_2$ symmetry under which the SM Higgs and the 1st and 2nd generation quarks are even
while $\Phi_{FV}$ and the 3rd generation quarks are odd:

$$
\Phi_{SM} \to -\Phi_{SM} \ , \ q_i \to q_i \ , \ i = 1,2 \ , \\
\Phi_{FV} \to -\Phi_{FV} \ , \ q_3 \to -q_3 \ .
$$

(3)

This symmetry suppresses the CKM elements $V_{td}, V_{ts}, V_{ub}, V_{cb}$ and simultaneously suppresses the new $H^+tb$ and $H^0tt$ interactions ($\xi_{33}$), therefore under this $Z_2$ symmetry we have

$$
\xi = \begin{pmatrix}
0 & 0 & \xi_{13} \\
0 & 0 & \xi_{23} \\
\xi_{31} & \xi_{32} & 0
\end{pmatrix} \ .
$$

(4)

If the $Z_2$ is broken weakly (e.g., by a very small $\Phi_{FV}$ condensate or by higher dimensional operators), then a small value for the CKM elements $V_{td}, V_{ts}, V_{ub}, V_{cb}$ as well as for all zero entries in (4) are generated. We then expect $\xi_{33} \sim V_{td}, V_{ts}$, while maintaining $\xi_{31}, \xi_{32} \sim V_{tb} \sim \mathcal{O}(1)$.

Another possibility is to have $U(1)$ flavor symmetries. For example, if the three fermion generations have charges $\alpha, \alpha + 1, \beta$ respectively, and $\Phi_{FV}$ has a charge $\alpha - \beta$, then the only tree level coupling of the new Higgs is $\xi_{31}$ while all the other couplings are suppressed. The SM Higgs has charge 0 under the $U(1)$, thus allowing all diagonal mass terms. When the $U(1)$ is weakly broken, we can expect all couplings to be generated, but we will still have $\xi_{31} \gg \xi_{33}$ and $V_{tb} \sim \xi_{31}, V_{td} \sim \xi_{33}$.

Here, we will not restrict ourselves to any model, and instead take a phenomenological approach towards the general MxFV case, where we assume non-zero $\xi_{31}, \xi_{32}, \xi_{13}, \xi_{23}$ and $\xi_{33} \sim 0$ as well as $\xi_{ij} \sim 0$ for $i,j = 1,2$. We then consider the experimental constraints on such textures and show that while some products of the above couplings are bounded to be rather small, the MxFV$_{12}$ scenarios are not ruled out.

The phenomenology of these models depends sensitively on the details of the scalar sector. In general one can have mixing terms between the SM Higgs and the new doublet e.g. a term like $\lambda_D \Phi_{SM} D^\dagger \Phi_{FV}$. After the SM Higgs develops a VEV this term can lead to interactions like $\sim \lambda_{MW} W^+W^- H^0$, which make the phenomenology difficult to analyze without knowing the size of $\lambda$. We shall assume that such mixing terms are absent since we expect them to be very small; indeed, in the models discussed above, the flavor symmetries prohibit such terms, and when they are weakly broken we expect $\lambda \sim \xi_{33} \sim V_{td} \ll 1$. Note that a $WWH^0$ interaction term can also arise from the kinetic term $|D^\mu \Phi_{FV}|^2$, if the flavor symmetry is broken by a small VEV of $\Phi_{FV}$. We shall also ignore the couplings of the new Higgs doublet to leptons.

**Experimental Constraints:** We now consider the existing experimental constraints on the MxFV scenarios described above. For simplicity we will assume that all the new FV couplings are real. We find that the most stringent constraints come from $F^0 - \bar{F}^0$ mixings, $F = K, B_d, B_s, D$ and from rare $K$-decays. Limits from $B$ decays (semi-leptonic or hadronic) are either weaker or

depend on the couplings of $\Phi_{FV}$ to leptons. As will be shown below, the above observables constrain only the following combinations of couplings:

$$
\eta_K \equiv \xi_{31} \cdot \xi_{32} \ , \ \eta_D \equiv \xi_{13} \cdot \xi_{23} \ , \\
\eta_{B_d} \equiv \xi_{31} \cdot \xi_{23} \ , \ \eta_{B_d} \equiv \xi_{31} \cdot \xi_{13} \ , \\
\eta_{B_s} \equiv \xi_{32} \cdot \xi_{23} \ , \ \eta_{B_s} \equiv \xi_{32} \cdot \xi_{13} \ .
$$

(5)

$K^0 - \bar{K}^0$ mass difference and measure of indirect CP-violation in the K system are given by (see e.g. [4]):

$$
\Delta m_K = 2 \text{Re}(M_{12}^K) \ , \ \epsilon_K = \frac{\text{exp}(i\pi/4)}{\sqrt{2}} \text{Im}(M_{12}^K) \ .
$$

(6)

The MxFV contribution to the above observables arises from new $WH$ and $HH$ box diagrams ($H$ stands for the charged scalar), where only the top-quark can propagate in the loops. These new box diagrams shift $M_{12}^K$ by (the contribution of a generic new scalar to meson mixings can be found in [3]):

$$
\delta M_{12}^{MxFV} = \frac{m_K^2 f_B \bar{B}_K \eta_K}{12\pi^2 m_W^2} \frac{4r}{\sin^2\theta_W} \frac{(2\pi\alpha)}{V_{td}V_{ts} \eta_K \left(x_1, x_H\right)} \ ,
$$

(7)

$$
\frac{\eta_K^2}{8} g(x_1, x_H) \right) \right) \ ,
$$

$$
\delta m_{\ell 3} = \frac{m_K^2 f_B \bar{B}_K \eta_K}{12\pi^2 m_W^2} \frac{4r}{\sin^2\theta_W} \frac{(2\pi\alpha)}{V_{td}V_{ts} \eta_K \left(x_1, x_H\right)} \ ,
$$

(8)

where (see e.g. [2]) we use $m_K = 0.498$ GeV, $f_K = 0.159$ GeV, $\bar{B}_K = 0.79$, $\eta_2 = 0.57$, $r = 0.985$ and

$$
\Delta m_K = 0.005301 \text{ ps}^{-1} \text{ is the observed mass splitting} \ ,
$$

$$
\eta_K = 2 \text{Re}(M_{12}^K) \text{ is the SM part and } \eta_K \text{ is the central measured value} \ .
$$

In particular, we have traded uncertainties in the theoretical input for $\epsilon_K$ for a generous 40% deviation from the central observed value. Note that $\text{Im}(\delta M_{12}^{MxFV}) = \text{Im}(V_{td}^*V_{ts})$ since we are taking all $\eta_i$ in (5) to be real.

**Rare K-decays:**

The rare $K$-decays $K^+ \to \pi^+ \nu^+_\ell \bar{\nu}^\ell_L$ and $K^0 \to \pi^0 \nu^+ \bar{\nu}^\ell_L$ (and other $K \to \pi$ decays that go through the $\langle \bar{s}d\gamma^A \rangle$ current) are mediated by the following effective Hamiltonian [4, 5, 6]:

$$
\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} \frac{2\alpha}{\pi s_W^2} (X_{SM} + \delta X^{NP}) \cdot (\bar{s}L\gamma_\mu d_L) (\bar{\nu}_L^\ell \gamma_\mu \nu^\ell_L)(9)
$$

where $X_{SM} \sim 8.3 \times 10^{-4}$ is the SM part and $\delta X^{NP}$ is the new physics contribution. In the MxFV framework,
there are new Z-penguin 1-loop diagrams with $H^+ - t$ exchanged in the loops, which give:

$$\delta X^{MxFV} = \eta_K \cdot \frac{s_W^2}{32\pi\alpha} \cdot \frac{y_t}{1 - y_t} \left(1 + \log(y_t)\right),$$  \hspace{1cm} \text{(10)}$$

where $y_t \equiv m_t^2/m_{H^+}^2$.

In Fig. 1 we plot the allowed range in the $\eta_K - m_{H^+}$ plane by imposing $\delta X^{MxFV} < X_{SM}$.

Let us define ($q = d$ or $s$)

$$R_q = \frac{\Delta m_q}{\Delta m^SM_q} = 1 + \delta_{qNP},$$ \hspace{1cm} \text{(11)}$$

where $\Delta m_q = \Delta m^SM_q + \delta m^NP_q$ is the total $B^0_q - \bar{B}^0_q$ mass splitting and $\delta_{qNP}$ is the portion of NP.

Taking the experimentally observed values $\Delta m^{exp}_{b} = 17.77 \pm 0.17 \text{ ps}^{-1}$ \cite{8} and $\Delta m^{exp}_{d} = 5.070 \pm 0.004 \text{ ps}^{-1}$ \cite{9}, and the SM predictions (averaging between the two HP and JL groups \cite{10} and adding the errors in quadrature) $\Delta m^SM_{q} = 18.7 \pm 4.3 \text{ ps}^{-1}$ and $\Delta m^SM_{d} = 0.69 \pm 0.14 \text{ ps}^{-1}$, we obtain $R_d = 0.74 \pm 0.15$ and $R_s = 0.95 \pm 0.22$. We then require that the MxFV contribution is within 1 standard deviation of the central values of $|R_q - 1|$:

$$|\delta^M_{d/FV}| < 0.27 \land |\delta^M_{d/FV}| < 0.41.$$  \hspace{1cm} \text{(12)}$$

In the MxFV framework the $B^0_q - \bar{B}^0_q$ mass splitting receives a contribution from new $WH$ box diagrams with an exchange of either $t$ and $e$ or $t$ and $u$ quarks in the loop (there are no $HH$ box diagrams within the MxFV setup), which give:

$$\delta^M_{d/FV} = -\frac{s_W^2}{4\pi\alpha} \cdot \frac{V_{cq} \eta^{1}_{B_q} \tilde{f}(x_c) + V_{uq} \eta^{2}_{B_q} \tilde{f}(x_u)}{V_{tb}(V^*_{tb})^2 S_0(x_t)},$$ \hspace{1cm} \text{(13)}$$

where $S_0(x_t) \approx 2.46 \cdot [m_t/170 \text{ GeV}]^{1.52}$ and

$$\tilde{f}(x_t) = \sqrt{x_t x_i} \left(\frac{\log(x_H)}{(x_H - 1)(x_H - x_t)} + \frac{x_t}{x_H x_t} \log(x_t)\right).$$ \hspace{1cm} \text{(14)}$$

In Fig. 1 we plot the allowed range in the $\eta^{1}_{B_q} - m_{H^+}$ planes by imposing \cite{12}.

In the case of $D^0 - \bar{D}^0$ oscillations there are two types of 1-loop box diagrams that contribute due to the new MxFV interaction Lagrangian in \cite{2}: the charged Higgs $WH$ and $HH$ boxes with b-quark exchanges and the neutral Higgs $H^0H^0$ boxes with top-quark exchanges, where $H^0$ corresponds in general to any one of the two (CP-odd or CP-even) neutral Higgs components of $\Phi_{FV}$. We find that the following expression is a good approximation for the $D^0 - \bar{D}^0$ mass difference generated by these MxFV box diagrams:

$$\delta M_{D^{FV}}^M \sim \frac{f_{d}^{2} m_{D}^{2}}{16 \pi^{2}} \frac{A_{D^{FV}}}{m_{W}^{2}} \left(\delta^{WH} + \delta^{HH} + \delta_{1}^{H^{0}} + \delta_{2}^{H^{0}}\right),$$ \hspace{1cm} \text{(15)}$$

where we have absorbed all non-perturbative $\bar{B}$ parameters and additional numeric factors into $A_{D}$ which is then of $O(1)$. For the various $\delta$’s we get:

$$\delta^{WH} \sim \eta_{D} V^{*}_{cb} V_{bc} \frac{2\pi\alpha}{s_{W}^{2}} \frac{x_{b}}{x_{H^{+}}} \log(x_{b}) \log\left(1 - x_{H^{+}}\right),$$ \hspace{1cm} \text{(16)}$$

$$\delta^{HH} \sim \frac{\eta_{D}^{2}}{8} \frac{1}{x_{H^{+}}} \left(1 + 2 \frac{x_{b}}{x_{H^{+}}} \log\left(\frac{x_{b}}{x_{H^{+}}}\right)\right),$$ \hspace{1cm} \text{(17)}$$

and assuming that only one of the neutral components dominates the neutral Higgs exchanges (i.e., $H^0 = H_{1}^0$ and $m_{H_2^0} > m_{H_1^0}$) we have:

$$\delta_{1}^{H^{0}} \sim \frac{\eta_{1} B_{d} + \eta_{2} B_{d}^{*} }{2} \frac{x_{t}}{x_{H^{0}}} \left(1 + \log\left(\frac{x_{t}}{x_{H^{0}}}\right)\right),$$ \hspace{1cm} \text{(18)}$$

$$\delta_{2}^{H^{0}} \sim \frac{\eta_{K} + \eta_{D}^{2}}{2} \frac{x_{t}}{x_{H^{0}}} \left(2 + \log\left(\frac{x_{t}}{x_{H^{0}}}\right)\right).$$ \hspace{1cm} \text{(19)}$$

In the case of the $D^0 - \bar{D}^0$ mass splitting the SM prediction is dominated by long distance effects. Therefore, in deriving the limits on the FV coupling products that enter $D^0$ oscillations, we require $\delta M_{D^{FV}}^M$ not to exceed the measured value $\Delta m^{exp}_{D} = (14.5 \pm 5.6) \cdot 10^{-3} \text{ ps}^{-1}$ \cite{12}.
In Fig. 1 we plot the allowed range in the $\eta_D - m_{H^+}$ plane and $\bar{\eta}_i - m_{\phi_i}$ planes (i.e., $\eta_i = \eta_{i1}, \eta_{i2}, \eta_i$ from $H^0$ exchanges) imposed by $\delta M_D^{Mx\overline{FV}} < 20.1 \text{ ps}^{-1}$. 

Results and Discussion: Our analysis leads to the following results:

1. Any MxFV model in which only one FV coupling is of $\mathcal{O}(1)$ while all others are $\sim 0$ is not constrained by meson flavor physics, regardless of $m_{\phi_{FV}}$.

2. In MxFV models where the new FV Higgs field couples only to the third and first generations, the only constraint comes from $B^0_d - B^0_s$ mixings. This constraint is, however, rather weak as it allows e.g., $m_{H^+}, m_{h^0} \sim 200 \text{ GeV}$ even with $\mathcal{O}(1)$ couplings, $\xi_{11} \sim \xi_{13} \sim 0.3$.

3. If $m_{H^+} \gtrsim 600 \text{ GeV}$, then both MxFV1 and MxFV2 models with the corresponding $\xi_{ij} \sim 1$ are not excluded even if $m_{H^0} \sim 100 \text{ GeV}$.

4. If $H^0$ decouples or $\phi_{FV}$ is a charged singlet, then the constraints from $H^0$-exchanges in $D^0 - \bar{D}^0$ mixing do not apply. In this case, MxFV models which have $\xi_{32} \sim \xi_{13} \sim \mathcal{O}(1)$ and $m_{H^+} \sim m_{H^0}$ are also viable.

This rather surprising window of allowed $\mathcal{O}(1)$ MxFV couplings can have very interesting phenomenological implications associated with $\phi_{FV}$ production and decays at hadron colliders. Many aspects of this MxFV phenomenology can be understood by noting that in MxFV models there is an approximately conserved number $(-1)^{n_y_{FV} + n_l + n_h}$ (similar to the b-parity of $\overline{\text{E}_6}$), i.e., in any process involving $\phi_{FV}$ the total number of the new FV Higgs particles and third generation quarks is conserved modulo 2 (this symmetry is broken by terms of order $\xi_{13} \sim \mathcal{O}(1)$ and $m_{H^+} \sim m_{H^0}$ are also viable). This follows that $\phi_{FV}$ particles are produced either in pairs, mainly through $gq \rightarrow \phi_{FV}\phi_{FV}$ ($q$ is a light quark), or in association with a single top or single b-quark via e.g., $gg \rightarrow \phi_{FV}tq, gq \rightarrow \phi_{FV}t, \phi_{FV}b$, unless there is a b-quark in the initial state (see below).

Consider for example the MxFV1 setup and assume $m_{h^0}, m_{H^+} > m_t$. In this case, the MxFV set of processes fall into four very well defined categories and are therefore very distinctive at hadron colliders:

1. $t\phi_{FV}$ production

- 1a) $dg \rightarrow tH^- \rightarrow t\bar{t}j, tbj + h.c.$ (20)
- 1b) $ug \rightarrow tH^0 \rightarrow ttj, t\bar{t}j + h.c.$ (21)

where $j(=u \text{ or } d)$ is a light-quark jet.

2. $\phi_{FV}\phi_{FV}$ production

- 2a) $u\bar{u}, d\bar{d} \rightarrow H^+ H^- \rightarrow t\bar{t}jj, tbjj, \bar{b}bjj, bbjj$ (22)
- 2b) $u\bar{u} \rightarrow H^0H^0 \rightarrow ttjj, \bar{t}\bar{t}jj, t\bar{t}jj$ (23)

3. s-channel $\phi_{FV}$ resonance

A very interesting feature of this class of MxFV models is the specific dynamics of resonance production of $\phi_{FV}$. In particular, within the class of MxFV models described in this paper, the neutral scalar component $H^0$ cannot be produced on resonance at hadron colliders. On the other hand, $H^+$ can resonate via $u\bar{u} \rightarrow H^+$. This can lead to a resonance peak in the invariant mass of a $t\bar{t}$ pair or, more generally, to the following 1b or 2b-jets $H^+$-production channels:

$$1b – tag : \ u\bar{u} \rightarrow H^+ \rightarrow t\bar{t}, bj + h.c. \quad (24)$$
$$2b – tag : \ ug \rightarrow H^+b \rightarrow tbj, bbj + h.c. \quad (25)$$

4. t-channel $\phi_{FV}$ exchanges

- 3a) $uu \rightarrow tt + h.c.$ ($H^0$ exchange) (26)
- 3b) $ud \rightarrow t\bar{h} + h.c.$ ($H^+$ exchange) (27)
- 3c) $u\bar{d} \rightarrow t\bar{t}$ ($H^+ & H^0$ exchanges) (28)
- 3d) $u\bar{u} \rightarrow bb$ ($H^+$ exchanges) (29)
- 3e) $d\bar{b}(dg) \rightarrow t\bar{u}(t\bar{b}h) + h.c.$ ($H^+$ exchange) (30)
- 3f) $u\bar{b}(ug) \rightarrow ub(ubb) + h.c.$ ($H^+$ exchange) (31)
- 3g) $ug \rightarrow t\bar{t}u, ttu + h.c.$ ($H^0$ exchange) (32)

An interesting limit to study is $m_t < m_{h^0} \ll m_{H^+}$ such that $H^+$ decouples at energies relevant for the Tevatron and the LHC. In this case we expect a noticeable signal of same-sign top-quark pairs $pp, pp \rightarrow tt + nj + X$, where $n$ is the number of light-quark jets ($j$), from the hard processes in (21), (23), (26) and (32). When both top-quarks decay leptonically, the process $pp, pp \rightarrow tt + nj + X$ has a striking low background signature of two same-sign leptons, missing energy and two b jets, see (14). Note that, as opposed to the usual expectations, this new $H^0$ will not be seen on resonance.

The opposite case of $m_t < m_{H^+} \ll m_{h^0}$ with a decoupled $H^0$ can also have very interesting phenomenological implications (i.e., allowing $\xi_{32} \sim \xi_{13} \sim \mathcal{O}(1)$, see above). Attractive signatures of this limiting case will be enhanced production of $tH^-$ pairs at the LHC via $dg \rightarrow tH^-$ [reaction (20)], and enhanced resonance production of $H^-$ via the 1 b-tag and 2 b-tag processes in (21) and (24). For example, we find $\sigma(pp)(dg) \rightarrow tH^- + X) \sim 100 \text{ pb}$ for $\xi_{31} \sim 1$ and $m_{H^+} = 200 \text{ GeV}$. This is an enhancement by a factor of about 50 compared to what is considered to be the conventional channel $bg \rightarrow tH^-$, e.g. in the MSSM. In the resonance $H^-$ production channels we also expect a huge enhancement over e.g., the MSSM or "standard" multi Higgs models for which the leading resonance channels are $cs \rightarrow H^\pm, cb \rightarrow H^\pm$, with couplings $m_{c_{\pm}}/m_{t_{\pm}} \ll 0.1$. It would be of great interest to analyse these signals in the existing Tevatron data, as well as the upcoming LHC data. We shall leave the detailed discussion and analysis of these signals to an upcoming work [14].

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