

Searching for resonant flavor-changing charged Higgs production at the LHC

Wei-Shu Hou[✉] and Mohamed Krab[✉]

Department of Physics, National Taiwan University, Taipei 10617, Taiwan



(Received 30 September 2024; accepted 22 January 2025; published 7 February 2025)

We suggest a resonant $c\bar{b} \rightarrow H^+$ production search, followed by bosonic $H^+ \rightarrow W^+H$ weak decay at the Large Hadron Collider (LHC). In the general two-Higgs-doublet model (G2HDM) that has flavor-changing neutral Higgs couplings, H^+ is resonantly produced via the top-charm $\rho_{tc}V_{tb}$ coupling at tree level, while $H^+ \rightarrow W^+H$ weak decay occurs within the exotic second doublet, leading eventually to same-sign dilepton signals. We perform a signal-to-background analysis at the 14 TeV LHC and show that discovery seems possible with LHC Run 2 data already at hand.

DOI: [10.1103/PhysRevD.111.L031701](https://doi.org/10.1103/PhysRevD.111.L031701)

Introduction. The discovery of the 125 GeV state compatible with the Standard Model (SM)-like Higgs boson at the LHC [1], which belongs to a weak scalar doublet, is the most significant breakthrough in particle physics. Only the SM Higgs boson h has been found so far, with no sign of extra scalars. However, given the repetition of fermion weak doublets, it is *imperative* to pursue the existence of a second exotic scalar doublet—in particular, its associated charged H^+ boson.

We study the H^+ boson in the general two-Higgs-doublet model (G2HDM), where the usual Z_2 symmetry is absent, as imposing [2] such a symmetry would be plainly *ad hoc*. With two identical Higgs doublets, there are three neutral scalars: the CP -even h, H ; the CP -odd A ; and a charged $H^\pm$ pair.

The discovery potential of H^+ at the LHC has been studied in the G2HDM [3,4]. For $m_{H^+} \sim 300\text{--}500$ GeV, $cg \rightarrow bH^+$ is the most promising. Compared with 2HDM-II, which arises with supersymmetry, the process is not [3] Cabibbo-Kobayashi-Maskawa (CKM) suppressed. In this paper, we promote s -channel resonant H^+ production, the $c\bar{b} \rightarrow H^+$ process of Fig. 1, which has the same $\bar{c}bH^+$ coupling of $\rho_{tc}V_{tb}$, where ρ_{tc} is the flavor-changing top-charm coupling and V_{tb} is a CKM matrix element. We turn to the subsequent decay shortly.

Extra top Yukawa couplings ρ_{tc} and ρ_{tt} are not severely constrained and could be $\mathcal{O}(1)$, and they can *each* drive [5] electroweak baryogenesis (EWBG), and hence account for the baryon asymmetry of the Universe (BAU), a big motivator. At the same time, one can evade the stringent

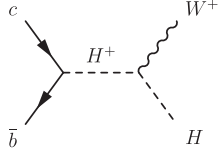
electron–electric dipole moment (eEDM) bounds of ACME [6] and JILA [7], by quite a *natural* flavor cancellation mechanism [8]. In addition, ρ_{tc} and ρ_{tt} at $\mathcal{O}(1)$ facilitate interesting production and decay processes, such as $cg \rightarrow bH^+ \rightarrow bt\bar{b}$ [3] and $\bar{b}g \rightarrow \bar{c}H^+ \rightarrow \bar{c}t\bar{b}$ [4], yielding final states with at least three jets and lepton plus missing energy, giving better signal sensitivity. However, even if kinematically allowed, the bosonic $H^+ \rightarrow W^+H$ decay would be negligible compared to fermionic $H^+ \rightarrow c\bar{b}$ and $H^+ \rightarrow t\bar{b}$ modes when ρ_{tc} and ρ_{tt} are sizable.

We point out that the $H^+ \rightarrow W^+H$ weak decay might become important *if both ρ_{tc} and ρ_{tt} are small enough*, or *if there is large $m_{H^+}-m_H$ mass splitting*, as we shall elaborate. We note that $\text{Im}\rho_{tt} \simeq 0.1$ is still quite robust in driving EWBG [5]. The s -channel $c\bar{b} \rightarrow H^+$ production with $H^+ \rightarrow t\bar{b}$, W^+h was studied in [9–11], and also with $H^+ \rightarrow \tau^+\nu$ in [10–13]. We study resonant H^+ production followed by $H^+ \rightarrow W^+H$ decay, together with $H \rightarrow t\bar{c}$ (see Fig. 1). Assuming the leptonic $t \rightarrow \ell^+\nu b$ ($\ell = e, \mu$) decay mode, we perform a signal-to-background analysis at the 14 TeV LHC to show that LHC Run 2 data at hand might already be sufficient to discover the H^+ .

G2HDM. The G2HDM has two weak scalar doublets with the same quantum numbers. In the Higgs basis where only one doublet breaks the symmetry, the most general CP -conserving Higgs potential is [14,15]

$$\begin{aligned}
 V(\Phi, \Phi') = & \mu_{11}^2 |\Phi|^2 + \mu_{22}^2 |\Phi'|^2 - (\mu_{12}^2 \Phi^\dagger \Phi' + \text{H.c.}) \\
 & + \frac{\eta_1}{2} |\Phi|^4 + \frac{\eta_2}{2} |\Phi'|^4 + \eta_3 |\Phi|^2 |\Phi'|^2 + \eta_4 |\Phi^\dagger \Phi'|^2 \\
 & + \left[\frac{\eta_5}{2} (\Phi^\dagger \Phi')^2 + (\eta_6 |\Phi|^2 + \eta_7 |\Phi'|^2) \Phi^\dagger \Phi' + \text{H.c.} \right],
 \end{aligned} \tag{1}$$

Published by the American Physical Society under the terms of the [Creative Commons Attribution 4.0 International](https://creativecommons.org/licenses/by/4.0/) license. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI. Funded by SCOAP³.

FIG. 1. Diagram for $c\bar{b} \rightarrow H^+ \rightarrow W^+ H$, with $H \rightarrow t\bar{c}$.

where the quartic η_i couplings are *real*, and Φ breaks the EW symmetry spontaneously through a nonzero vacuum expectation value—namely, $\mu_{11}^2 = -\frac{1}{2}\eta_1 v^2$ while $\langle \Phi' \rangle = 0$, hence $\mu_{22}^2 > 0$. A second minimization condition eliminates μ_{12}^2 as a parameter. One can diagonalize the h, H mass-squared matrix by a mixing angle γ ($\equiv \beta - \alpha$ in 2HDM-II convention), which satisfies $s_\gamma c_\gamma = \eta_6 v^2 / (m_H^2 - m_h^2)$ [14,15], with $c_\gamma \equiv \cos \gamma$ ($s_\gamma \equiv \sin \gamma$). In the small- c_γ limit, known as “alignment,” h resembles the SM Higgs boson.

The Yukawa Lagrangian is [15,16]

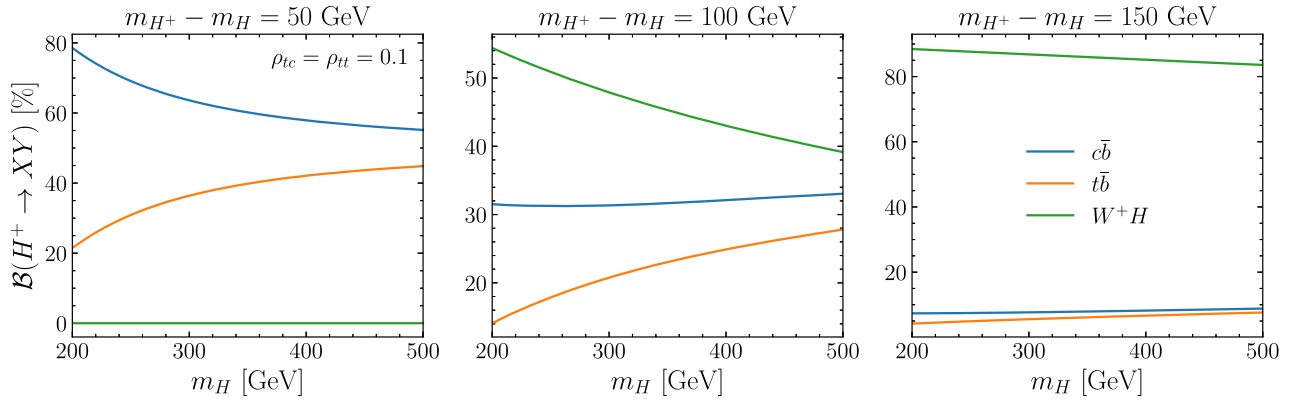
$$\begin{aligned} \mathcal{L}_Y = & -\frac{1}{\sqrt{2}} \sum_{f=u,d,\ell} \bar{f}_i [(\lambda_{ij}^f c_\gamma + \rho_{ij}^f s_\gamma) H \\ & - i \text{sgn} Q_f \rho_{ij}^f A - (\lambda_{ij}^f s_\gamma - \rho_{ij}^f c_\gamma) h] R f_j \\ & - \bar{u}_i [(V \rho^d)_{ij} R - (\rho^{u\dagger} V)_{ij} L] d_j H^+ \\ & - \bar{\nu}_i \rho_{ij}^\ell R \ell_j H^+ + \text{H.c.}, \end{aligned} \quad (2)$$

where $i, j = 1-3$ are generation indices, $\text{sgn} Q_f = +1(-1)$ for $f = u$ ($f = d, \ell$), $L, R = (1 \mp \gamma_5)/2$, and V is the CKM matrix. The 3×3 matrices $\lambda_{ij}^f \equiv \delta_{ij} \sqrt{2} m_i^f / v$, with $v \simeq 246$ GeV, are diagonal and real, while ρ_{ij}^f are non-diagonal and in general complex. For our collider study, we simplify and take ρ_{ij}^f matrices as real.

The leading $\bar{c}bH^+$ coupling is $\rho_{tc} V_{tb}$ [see Eq. (2)], where CKM suppression of 2HDM-II is absent [3,9]. In this paper, we focus on $c\bar{b} \rightarrow H^+ \rightarrow W^+ H$ (see Fig. 1), with $W^+ \rightarrow \ell^+ \nu$ and $H \rightarrow t\bar{c} \rightarrow \ell^+ \nu b\bar{c}$, and we study the resulting same-sign dilepton signal at the 14 TeV LHC.

Parameter space. The parameters in Eq. (1) are required to satisfy vacuum stability, tree-level unitarity, and perturbativity conditions. To generate G2HDM parameters, we first express the quartic couplings η_1, η_{3-6} in terms of $m_{h,H,A,H^+}^2, \mu_{22}^2, \gamma$, and v [15], as these couplings enter the Higgs masses, while η_2 and η_7 do not. Since H^+ coupling to fermions is c_γ -independent [see Eq. (2)], we set $c_\gamma = 0$ ($s_\gamma = 1$) and fix $m_h = 125$ GeV to simplify, hence $\eta_1 = m_h^2/v^2 \simeq 0.258$ and $\eta_6 = 0$. Note that the bosonic H^+ couplings such as hW^+H^- (HW^+H^-) are c_γ (s_γ) suppressed (enhanced). The coupling AW^+H^- is γ independent. We then uniformly scan m_H from 200 to 500 GeV, assuming custodial symmetry ($m_A = m_{H^+}$) and $m_{H^+} = m_H + m'$ ($m' = 50, 100, 150$ GeV) to allow for $H^+ \rightarrow W^+ H$ decay, and we randomly scan the remaining parameters within the following ranges: $|\eta_{2-5,7}| < 5$ (vacuum stability requires $\eta_2 > 0$) and $\mu_{22}^2 \in [0, 10^6]$ GeV² using the 2HDMC-1.8.0 code [17], which is also used to impose theoretical restrictions. We note that constraints from electroweak precision S, T , and U observables, which require $m_{H^+} \simeq m_A$ (custodial, or $m_{H^+} \simeq m_H$ for twisted custodial [18]), are automatically satisfied.

As a scan result, we give H^+ decays to different final states—in particular, $c\bar{b}, t\bar{b}$, and $W^+ H$ pairs. For simplicity, we set all $\rho_{ij} = 0$ except ρ_{tc} and ρ_{tt} . For $\rho_{tc} = \rho_{tt} = 0.1$, we plot in Fig. 2 the branching ratios of $H^+ \rightarrow c\bar{b}, t\bar{b}$, and $W^+ H$ as functions of m_H , for $m_{H^+} - m_H = 50$ (left), 100 (middle), and 150 GeV (right). (Note that theoretical restrictions and the $|\eta_{3-5}| < 5$ requirement are not enforced for better illustration.) We see that when there is not enough phase space ($m_{H^+} - m_H \leq 50$ GeV), $H^+ \rightarrow W^+ H$ is negligible and is hence set to 0, and $c\bar{b}$ decay (with $t\bar{b}$ subdominant) dominates H^+ decays. However, if $m_{H^+} - m_H > 100$ GeV, $H^+ \rightarrow W^+ H$ would dominate with W on-shell (middle and right of Fig. 2). In contrast, for $\rho_{tc} = 0.3$ and $\rho_{tt} = 0.5$, we find that $\mathcal{B}(H^+ \rightarrow t\bar{b}) > 0.5$ for $m_{H^+} - m_H \geq 100$ GeV, while $H^+ \rightarrow W^+ H$ could become important only for $m_{H^+} - m_H \geq 200$ GeV.

FIG. 2. Branching ratios of H^+ as a function of m_H for $m_{H^+} - m_H = 50$ (left), 100 (middle), and 150 GeV (right).

Constraints on ρ_{tc} . The top-charm coupling ρ_{tc} is constrained by flavor physics and also direct searches. Flavor observables such as B_s - $\bar{B}_s$ mixing and $b \rightarrow s\gamma$ do not severely constrain ρ_{tc} due to the small m_c . These observables receive ρ_{tc} contributions through charm- H^+ loops [19]. We reinterpret the limits from Ref. [19] and find that $|\rho_{tc}| \gtrsim 1.3$ (1.7) is excluded by B_s - $\bar{B}_s$ for $m_{H^+} = 300$ (500) GeV. We refer to Refs. [19,20] for more discussion on constraining ρ_{tc} and ρ_{tt} .

The extra top Yukawa coupling ρ_{tc} receives constraints from $t \rightarrow ch$ searches at the LHC. For $c_\gamma \neq 0$, limits are significant, where both ATLAS [21] and CMS [22,23] set 95% CL limits using full Run 2 data. We find that $|\rho_{tc}| \gtrsim 0.5$ is excluded at a 95% CL for $c_\gamma = 0.1$. The limit diminishes for $c_\gamma < 0.1$ and vanishes for $c_\gamma = 0$, which we assume.

LHC data further constrain ρ_{tc} . It was found [3] (and references therein) that the control region for the $t\bar{t}W$ (CRW) background in the CMS $4t$ search [24], defined by a same-sign dilepton (electron or muon), transverse missing energy, and no more than five jets, with two b -tagged, gives the most severe constraint on ρ_{tc} . It was shown [3] that finite ρ_{tc} induces the $cg \rightarrow tH/A \rightarrow t\bar{t}\bar{c}$ process and can feed the CRW of Ref. [24] if both top quarks decay semileptonically, yielding a final state with a same-sign dilepton and $2b$ plus extra jet that is almost identical to CRW. It was found that $|\rho_{tc}| \gtrsim 0.4$ is excluded for $m_H = 272$ ($m_A = 372$) GeV. The signal region SR12 of the CMS $4t$ study [24] constrains ρ_{tc} as well. We refer to Ref. [3] for more discussion.

Recent ATLAS searches [25] for heavy Higgs bosons in multilepton plus b -jet final states, and CMS searches [26] for exotic neutral Higgs bosons via $pp \rightarrow tH/A \rightarrow t\bar{t}\bar{c}$ and $pp \rightarrow tH/A \rightarrow t\bar{t}\bar{u}$ set constraints on ρ_{tc} (and ρ_{tt} , ρ_{tu} , as well). Our chosen benchmark points (BPs) (see Table I) satisfy all constraints stemming from these LHC searches.

Collider study. We study the same-sign dilepton signal at the LHC, with at least two jets, at least one b -tagged, $c\bar{b} \rightarrow H^+ \rightarrow W^+H \rightarrow \ell^+\nu t(\rightarrow \ell^+\nu b)\bar{c} + \text{c.c.}$, in comparison to Refs. [3,4]. We select two BPs with $m_H = 200$, 300 GeV and $m_{H^+} = m_A = 300$, 500 GeV (see Table I), with $H^+ \rightarrow W^+H$ and $H \rightarrow t\bar{c} + \bar{t}c$. The BPs satisfy all constraints mentioned.

TABLE I. G2HDM parameters for selected BPs. All masses in GeV, with $\eta_6 = 0$ and $m_h = 125$ GeV. For BP1, $\rho_{tc} = \rho_{tt} = 0.1$, while for BP2, $\rho_{tc} = 0.3, \rho_{tt} = 0.5$.

BP	η_2	η_3	η_4	η_5	η_7	m_H	m_A	m_{H^+}	μ_{22}^2/v^2
1	1.40	2.00	-0.82	-0.82	-0.55	200	300	300	0.49
2	2.88	4.75	-2.64	-2.64	0.16	300	500	500	1.75

There are two main background sources for our signal. The first category is irreducible,¹ mainly from $t\bar{t}V$ (where V refers to either a W or Z boson) and tZj , with $t\bar{t}h$ and $4t$ subdominant. Other subdominant backgrounds such as $t\bar{t}WW$ and $t\bar{t}\bar{t}$ are neglected in our analysis. The second category is a reducible background, where a fake same-sign dilepton is produced in the detector through events containing electrons with misidentified charge (Q-flip) with 10^{-3} probability [24,27–29], and those including fake leptons (Fake) with 10^{-4} rate [24,27–29], mainly from $t\bar{t} + \text{jets}$ [24,27–29]. We note that our misidentification probabilities and fake rates are conservative. Relevant tW , WZ , and ZZ backgrounds are classified as reducible.

We generate signal and background events at leading order (LO) using MadGraph5_aMC@NLO [30] with a default NN23LO1 [31] parton distribution function (PDF) set, interfaced with Pythia-8.2 [32] for showering and hadronization. We then use Delphes-3.5.0 [33] with a default ATLAS card and anti-kt algorithm [34] with radius parameter $R = 0.5$ for detector simulation. We consider one additional parton for $t\bar{t}W$, $t\bar{t}Z$, tW , WZ , and ZZ background events, and two additional partons for $t\bar{t} + \text{jets}$ using the MLM matching scheme [35]. The tZj , $t\bar{t}h$, and $4t$ backgrounds are estimated without extra partons. We rescale background cross sections using the K -factor method to account for higher-order QCD corrections. K factors are 1.54 (1.50) [36] for $t\bar{t}W^-$ ($t\bar{t}W^+$), 1.40 [36] for $t\bar{t}Z$, 1.44 [30] for tZj , 1.26 [36] for $t\bar{t}h$, and 2.04 [30] for $4t$. The tW , W^-Z (W^+Z), ZZ , and $t\bar{t} + \text{jets}$ backgrounds are rescaled by factors of 1.35 [37], 1.30 (1.26) [38], 1.72 [39], and 1.84 [40], respectively. Signal cross sections are kept at LO. Note that both signal and background events are generated at 14 TeV collision energy.

Signal events are generated up to one merged jet using the MLM scheme [35]; thus, subdominant $cg \rightarrow bH^+$, $c\bar{b} \rightarrow gH^+$, and $\bar{b}g \rightarrow \bar{c}H^+$ effects are included. These contributions are promising, as they have an extra high- p_T (b)-jet that could help suppress the background [3,4].

To minimize backgrounds, we take a cut-based approach. Reconstructed objects are subject to the following selections: a minimum of two jets, of which at least one is b -tagged, with $p_T > 20$ GeV and $|\eta| < 2.5$, exactly two leptons (electron or muon) with the same charge (events with more than two leptons are vetoed), with a leading (subleading) lepton satisfying $p_T > 25$ (20) GeV with $|\eta| < 2.5$, a separation of $\Delta R > 0.4$ between the two same-charge leptons ($\Delta R_{\ell\ell}$), and between any lepton and any jet ($\Delta R_{\ell j}$), a missing energy E_T^{miss} larger than 35 GeV, and a scalar p_T sum of all jets and the two same-sign leptons (H_T) less than 400 GeV.

¹We define an irreducible background as any process that produces one same-charge dilepton and a minimum of two jets, at least one of which is b -tagged.

TABLE II. Background cross sections (fb) after selection cuts.

Background	Cross section
tW	1.61
$t\bar{t}W$	1.09
WZ	0.54
tZj	0.40
$t\bar{t}Z$	0.10
tth	0.05
ZZ	0.02
$4t$	0.0004
Q-flip	0.0018
Fake	0.0002

TABLE III. Signal cross sections (fb) and significance ($\epsilon = 10\%$) for BPs after selection cuts.

BP	Signal	$\mathcal{Z}$ at 300 fb $^{-1}$
1	3.72	7.4
2	4.62	8.8

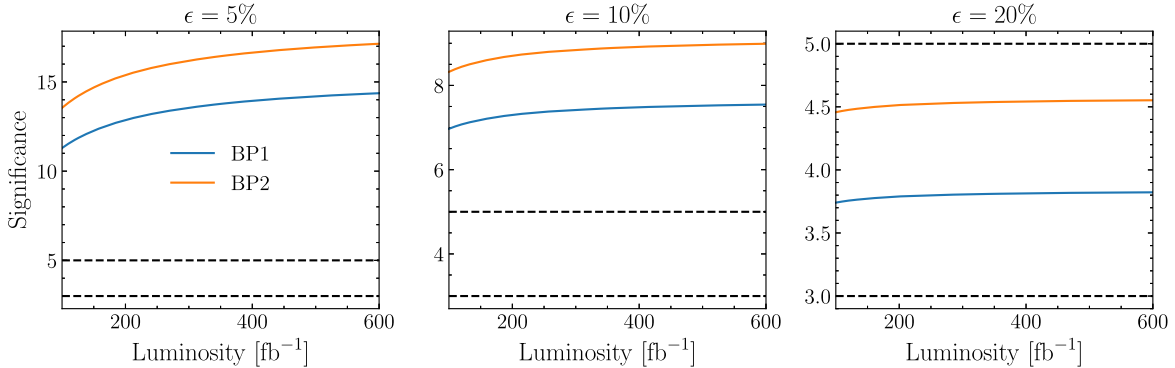
Background cross sections after selection cuts are given in Table II. Signal cross sections for the BPs are shown in Table III along with the significance calculated using the definition from Eq. (1.4) of Ref. [41] (see also Ref. [42]), which is analogous to but more accurate an estimate than $\mathcal{Z} \approx S/\sqrt{S+B+(\epsilon B)^2}$, where S (B) is the number of signal (background) events, and ϵ refers to the systematic uncertainty in the background estimation. Assuming $\epsilon = 10\%$, the significance for $c\bar{b} \rightarrow H^+ \rightarrow W^+H$ is $\sim 7.2\sigma$ and 7.4σ ($\sim 8.5\sigma$, 8.8σ) for BP1 (BP2) at 140 and 300 fb $^{-1}$. Thus, the full Run 2 data may be sufficient for discovery already. Significances as a function of luminosity for systematic errors of 5%, 10%, and 20% are plotted in Fig. 3.

Discussion and summary. There is a good chance that H^+ bosons can be discovered at the LHC with the Run 2 data already at hand. If so, it would not only shed light on the G2HDM, but also the mechanism behind BAU.

We started with the conservative $\rho_{tc}, \rho_{tt} \sim 0.1$ (BP1), rooted in our wish to keep $H^+ \rightarrow W^+H$ dominant for $m_{H^+} - m_H \simeq 100$ GeV (see Fig. 2), and stressed that $\text{Im}\rho_{tt} \simeq 0.1$ is still quite robust for EWBG [5]. Large ρ_{tc}, ρ_{tt} would enhance the production cross section but reduce $\mathcal{B}(H^+ \rightarrow W^+H)$, unless a large $m_{H^+} - m_H$ splitting is imposed. For $\rho_{tc}, \rho_{tt} \sim 0.4$ (BP2), $H^+ \rightarrow W^+H$ would be larger than $t\bar{b}$ and $c\bar{b}$ decays if $m_{H^+} - m_H > 200$ GeV. With $m_H = 300$ GeV and $m_{H^+} = 500$ GeV, $\mathcal{B}(H^+ \rightarrow W^+H)$, $\mathcal{B}(H^+ \rightarrow t\bar{b})$, and $\mathcal{B}(H^+ \rightarrow c\bar{b}) \simeq 49\%$, 35% , and 16% , respectively.

For $\rho_{tc}, \rho_{tt} \sim 0.5$ and $m_{H^+} \sim m_A \sim m_H$ [3,4], $H^+ \rightarrow t\bar{b}$ would be dominant. However, the $c\bar{b} \rightarrow H^+ \rightarrow t\bar{b}$ signal would suffer from large $t\bar{t}$ and single-top backgrounds, and $c\bar{b} \rightarrow H^+ \rightarrow c\bar{b}$ would suffer from overwhelming QCD multijet backgrounds. Therefore, $cg \rightarrow bH^+ \rightarrow b t\bar{b}$ [3] has been suggested to search for H^+ bosons. The $\bar{b}g \rightarrow \bar{c}H^+ \rightarrow \bar{c} t\bar{b}$ signal [4] might also be useful, as it has a high- p_T jet that could help suppress the background. But if ρ_{tc}, ρ_{tt} are small enough (e.g., ~ 0.1), these signals would be buried in the QCD background. Our proposed signal, $c\bar{b} \rightarrow H^+ \rightarrow W^+H \rightarrow \ell^+ \nu t \bar{c}$, with its same-sign dilepton signature, could then be the most promising avenue for discovering H^+ at the LHC.

Turning on ρ_{tu} would induce the $u\bar{b} \rightarrow H^+ \rightarrow W^+H \rightarrow \ell^+ \nu t \bar{c}$ process without CKM suppression. However, ρ_{tu} is severely constrained by flavor physics. It was found that D - $\bar{D}$ mixing and $B \rightarrow \tau\nu$ constrain $|\rho_{tc}\rho_{tu}^*| \lesssim 0.02$ [19] and $2.7 \times 10^{-3} \lesssim |\rho_{tu}| \lesssim 2.0 \times 10^{-2}$ [19], respectively, for $m_{H^+} = 500$ GeV. LHC data [25,26] put severe constraints on ρ_{tu} as well. Taking $\rho_{tu} = 0.01$ ($\rho_{tc} = \rho_{tt} = 0.1$), the significance is $\sim 7.6\sigma$ for BP1 at 300 fb $^{-1}$, slightly enhanced over $\rho_{tu} = 0$ (see Table III). Note that the

FIG. 3. Significance as a function of luminosity for $\epsilon = 5\%$ (left), $\epsilon = 10\%$ (middle), and $\epsilon = 20\%$ (right).

presence of ρ_{tu} would also induce $H^+ \rightarrow u\bar{b}$ and $H \rightarrow t\bar{u}$ decays, but these are practically negligible.

Another important parameter worth mentioning is s_γ , which controls both $H^+ \rightarrow W^+H$ and $H \rightarrow t\bar{c}$ decays. We set $s_\gamma = 1$ (alignment) in our analysis, but it is possible to work a little away from alignment. For example, setting $s_\gamma = 0.95$ ($c_\gamma \simeq 0.3$) would not significantly reduce the total cross sections, and hence the significance. We rescale the signal cross sections and find $\mathcal{Z} \sim 6.3\sigma$ for BP1 at 300 fb^{-1} , assuming $\epsilon = 10\%$.

In this paper, we suggest searching for H^+ through the same-sign dilepton signal by $c\bar{b} \rightarrow H^+ \rightarrow W^+(\rightarrow \ell^+\nu)H$,

with $H \rightarrow t(\rightarrow \ell^+\nu b)\bar{c}$. We estimate the signal sensitivity by a signal-to-background analysis for $m_{H^+} = 300\text{--}500 \text{ GeV}$. Full Run 2 data may be sufficient for discovery already. One would not only discover the H^+ but also measure the top-charm coupling ρ_{tc} . We encourage ATLAS and CMS experiments to consider our suggested new avenue for the H^+ search.

Acknowledgments. This work is supported by NSTC Grant No. 113-2639-M-002-006-ASP of Taiwan, and NTU Grants No. 113L86001 and No. 113L891801. We thank Abdesslam Arhrib for discussion.

-
- [1] G. Aad *et al.* (ATLAS Collaboration), *Phys. Lett. B* **716**, 1 (2012); S. Chatrchyan *et al.* (CMS Collaboration), *Phys. Lett. B* **716**, 30 (2012).
 - [2] S. L. Glashow and S. Weinberg, *Phys. Rev. D* **15**, 1958 (1977).
 - [3] D. K. Ghosh, W.-S. Hou, and T. Modak, *Phys. Rev. Lett.* **125**, 221801 (2020).
 - [4] W.-S. Hou and M. Krab, *Phys. Rev. D* **110**, L011702 (2024).
 - [5] K. Fuyuto, W.-S. Hou, and E. Senaha, *Phys. Lett. B* **776**, 402 (2018).
 - [6] ACME Collaboration, *Nature (London)* **562**, 355 (2018).
 - [7] T. S. Roussy *et al.*, *Science* **381**, 46 (2023).
 - [8] K. Fuyuto, W.-S. Hou, and E. Senaha, *Phys. Rev. D* **101**, 011901(R) (2020).
 - [9] H.-J. He and C. P. Yuan, *Phys. Rev. Lett.* **83**, 28 (1999); C. Balazs, H.-J. He, and C. P. Yuan, *Phys. Rev. D* **60**, 114001 (1999).
 - [10] J. L. Diaz-Cruz, H.-J. He, and C. P. Yuan, *Phys. Lett. B* **530**, 179 (2002).
 - [11] J. L. Diaz-Cruz, J. Hernandez-Sanchez, S. Moretti, R. Noriega-Papaqui, and A. Rosado, *Phys. Rev. D* **79**, 095025 (2009).
 - [12] S. R. Slabospitsky, *arXiv:hep-ph/0203094*.
 - [13] J. Hernández-Sánchez, S. Moretti, R. Noriega-Papaqui, and A. Rosado, *J. High Energy Phys.* **07** (2013) 044; J. Hernández-Sánchez, C. G. Honorato, S. Moretti, and S. Rosado-Navarro, *Phys. Rev. D* **102**, 055008 (2020).
 - [14] W.-S. Hou and M. Kikuchi, *Europhys. Lett.* **123**, 11001 (2018).
 - [15] S. Davidson and H. E. Haber, *Phys. Rev. D* **72**, 035004 (2005).
 - [16] W.-S. Hou and T. Modak, *Phys. Rev. D* **101**, 035007 (2020).
 - [17] D. Eriksson, J. Rathsmann, and O. Stål, *Comput. Phys. Commun.* **181**, 189 (2010).
 - [18] J.-M. Gérard and M. Herquet, *Phys. Rev. Lett.* **98**, 251802 (2007).
 - [19] A. Crivellin, C. Greub, and A. Kokulu, *Phys. Rev. D* **87**, 094031 (2013).
 - [20] B. Altunkaynak, W.-S. Hou, C. Kao, M. Kohda, and B. McCoy, *Phys. Lett. B* **751**, 135 (2015).
 - [21] G. Aad *et al.* (ATLAS Collaboration), *Eur. Phys. J. C* **84**, 757 (2024).
 - [22] A. Tumasyan *et al.* (CMS Collaboration), *Phys. Rev. Lett.* **129**, 032001 (2022).
 - [23] A. Hayrapetyan *et al.* (CMS Collaboration), *arXiv:2407.15172*.
 - [24] A. M. Sirunyan *et al.* (CMS Collaboration), *Eur. Phys. J. C* **80**, 75 (2020).
 - [25] G. Aad *et al.* (ATLAS Collaboration), *J. High Energy Phys.* **12** (2023) 081.
 - [26] A. Hayrapetyan *et al.* (CMS Collaboration), *Phys. Lett. B* **850**, 138478 (2024).
 - [27] M. Aaboud *et al.* (ATLAS Collaboration), *J. High Energy Phys.* **12** (2018) 039.
 - [28] ATLAS Collaboration, Search for supersymmetry with two same-sign leptons or three leptons using 13.2 fb^{-1} of $\sqrt{s} = 13 \text{ TeV}$ pp collision data collected by the ATLAS detector, Report No. ATLAS-CONF-2016-037.
 - [29] E. Alvarez, D. A. Faroughy, J. F. Kamenik, R. Morales, and A. Szykman, *Nucl. Phys. B* **915**, 19 (2017).
 - [30] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H.-S. Shao, T. Stelzer, P. Torrielli, and M. Zaro, *J. High Energy Phys.* **07** (2014) 079.
 - [31] R. D. Ball, V. Bertone, S. Carrazza, L. D. Debbio, S. Forte, A. Guffanti, N. P. Hartland, and J. Rojo (NNPDF Collaboration), *Nucl. Phys. B* **877**, 290 (2013).
 - [32] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, *Comput. Phys. Commun.* **191**, 159 (2015).
 - [33] J. de Favereau, C. Delaere, P. Demin, A. Giammanco, V. Lemaître, A. Mertens, and M. Selvaggi (DELPHES 3 Collaboration), *J. High Energy Phys.* **02** (2014) 057.
 - [34] M. Cacciari, G. P. Salam, and G. Soyez, *J. High Energy Phys.* **04** (2008) 063.
 - [35] J. Alwall *et al.*, *Eur. Phys. J. C* **53**, 473 (2008).
 - [36] D. de Florian *et al.* (LHC Higgs Cross Section Working Group Collaboration), *Handbook of LHC Higgs Cross Sections: 4. Deciphering the Nature of the Higgs Sector* (CERN, Geneva, 2017), Vol. 2. *arXiv:1610.07922*.
 - [37] N. Kidonakis, *Phys. Rev. D* **82**, 054018 (2010).

- [38] F. Campanario, C. Englert, S. Kallweit, M. Spannowsky, and D. Zeppenfeld, *J. High Energy Phys.* **07** (2010) 076.
- [39] F. Cascioli, T. Gehrmann, M. Grazzini, S. Kallweit, P. Maierhöfer, A. von Manteuffel, S. Pozzorini, D. Rathlev, L. Tancredi, and E. Weihs, *Phys. Lett. B* **735**, 311 (2014).
- [40] <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/TtbarNNLO>
- [41] N. Kumar and S.P. Martin, *Phys. Rev. D* **92**, 115018 (2015).
- [42] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, *Eur. Phys. J. C* **71**, 1554 (2011).