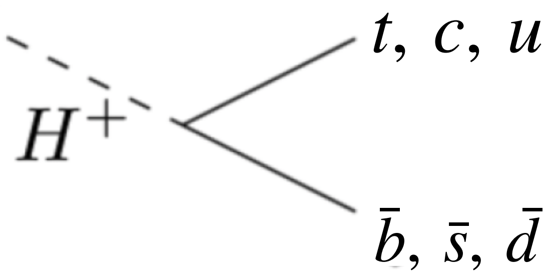
Charged Higgs Bosons in different Left-Right Models at the LHC

Poulose Poulose

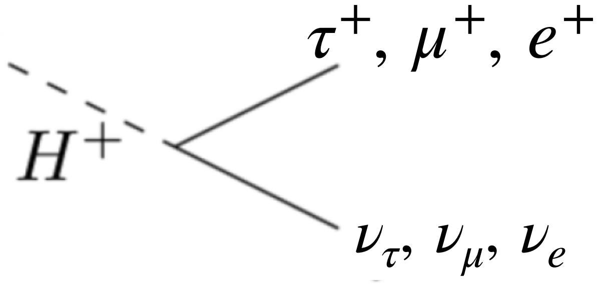
IIT Guwahati, India

Charged Higgs in BSM scenarios

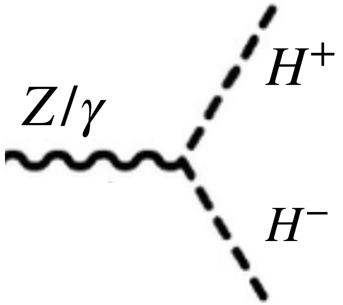


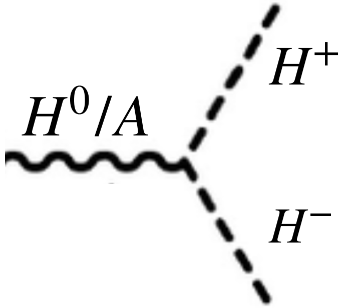
Multi-Higgs Extensions:

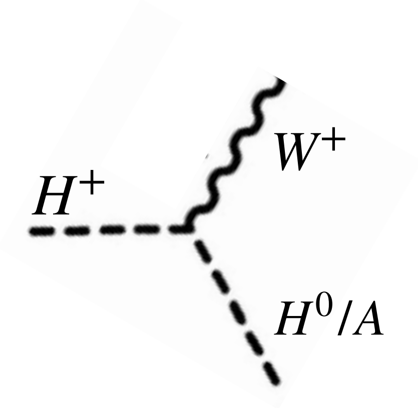
MSSM, 2HDM, 3HDM, LRSM, Alternate Left-Right Models,
Triplet-Higgs extensions, Singlet Charged Higgs extensions.



Non-singlet gauge multiplets necessarily have charged current interactions. This has become a strategy to search for such charged Higgs bosons at the colliders.



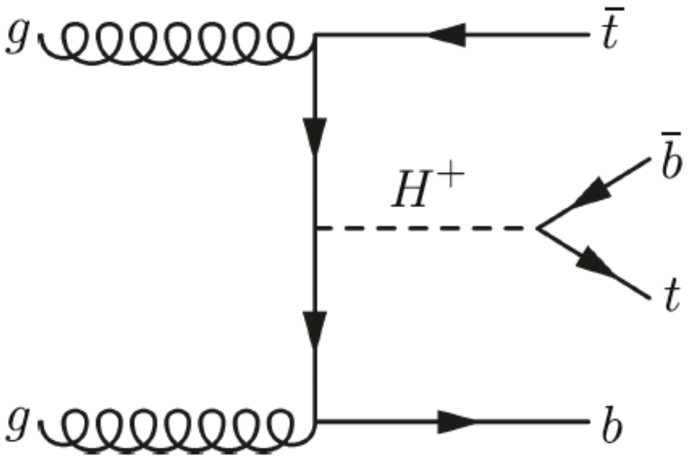


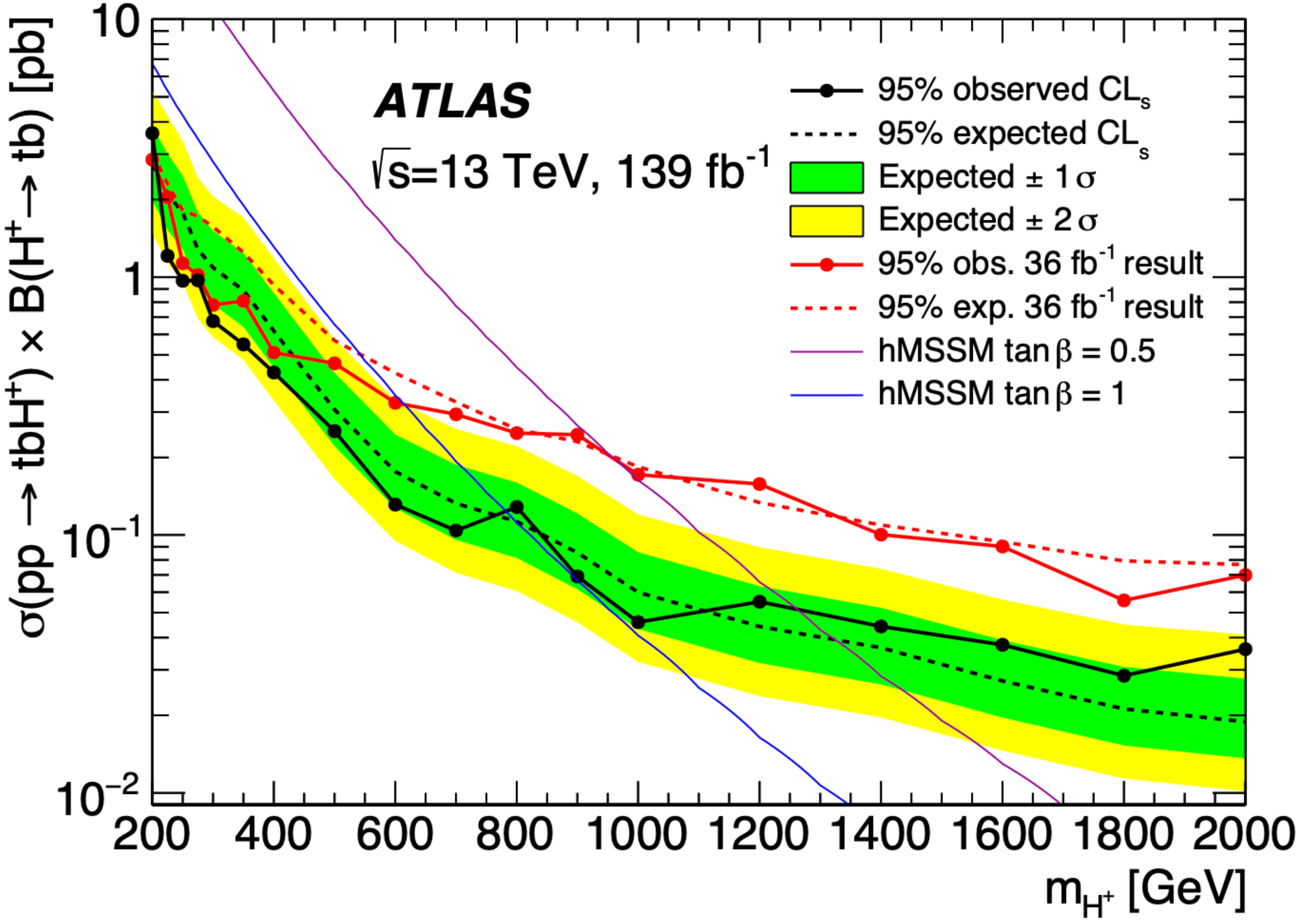


Charged Higgs in BSM scenarios

For $M_{H^+} > m_t$,

dominant decay channel is $H^+ \to t\bar{b}$





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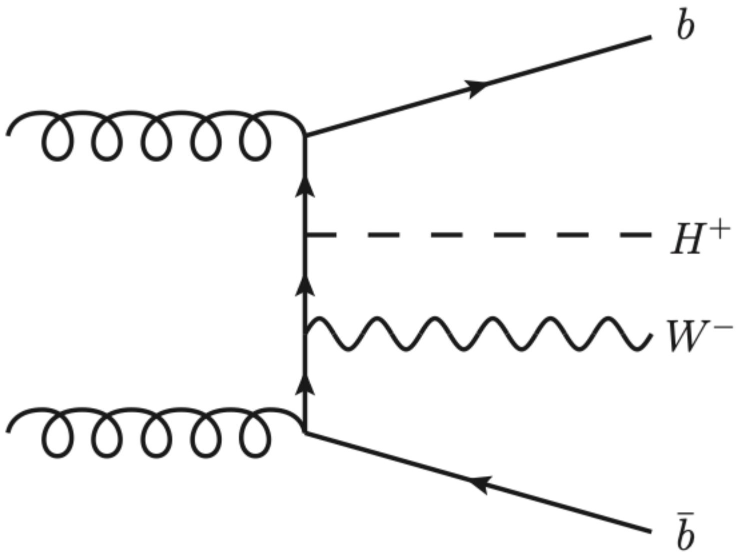
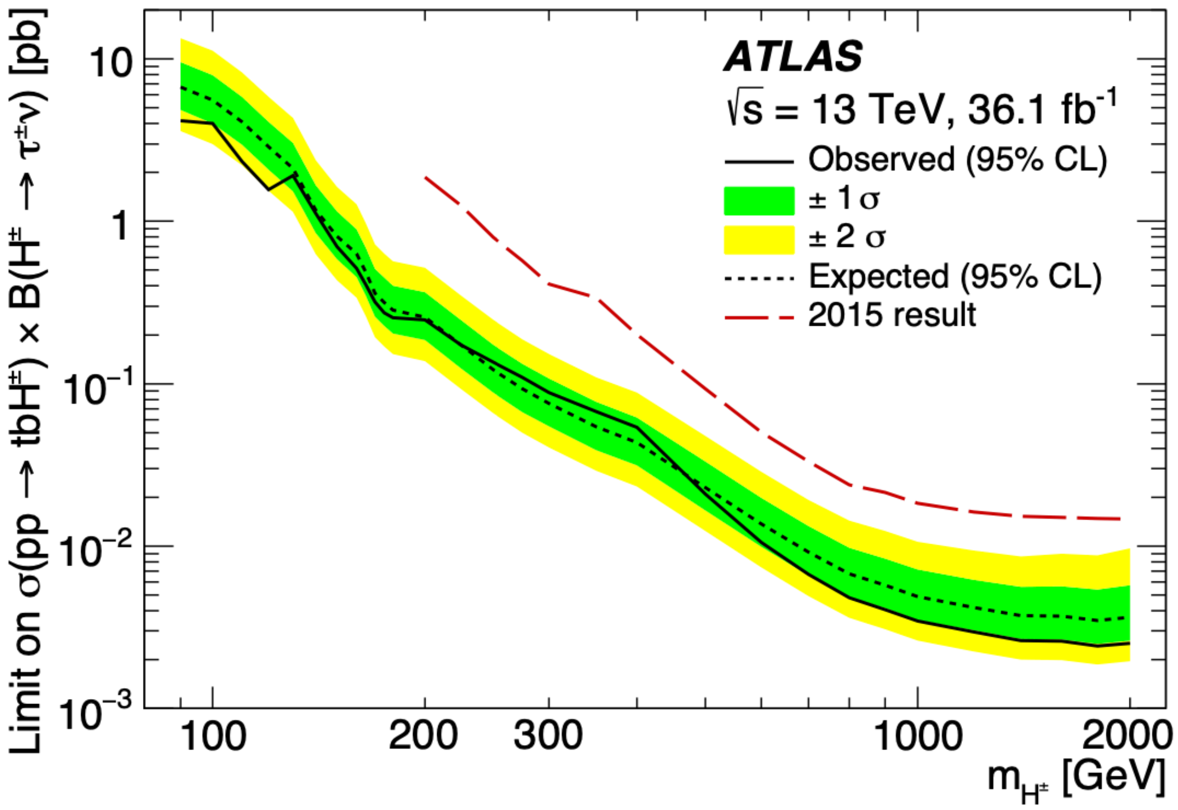
Charged Higgs in BSM scenarios

Another influential interaction for non-singlet gauge multiplets is the interaction with $W^{\pm}$ and neutral Higgs boson.





$$pp \to H^+W^- \; b\bar{b} \qquad H^+ \to \tau^+\nu_\tau$$

ATLAS: **JHEP 09 (2018) 139**

Charged Higgs in BSM scenarios

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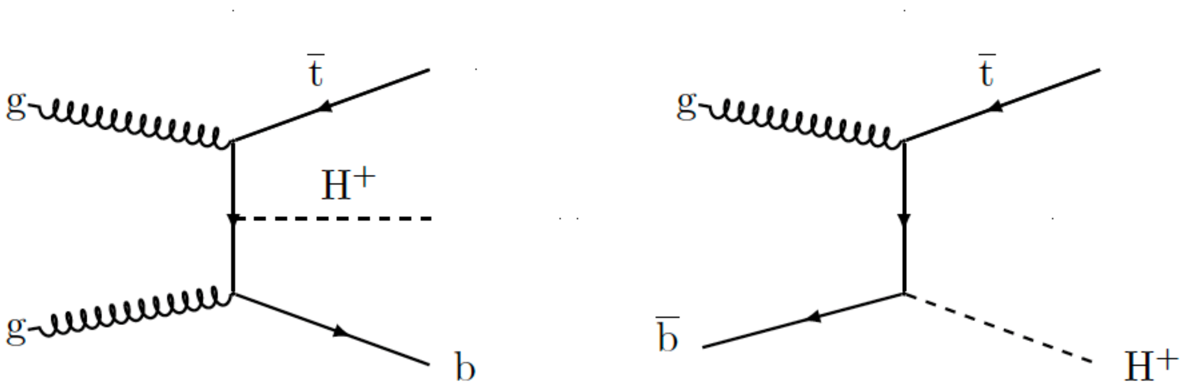
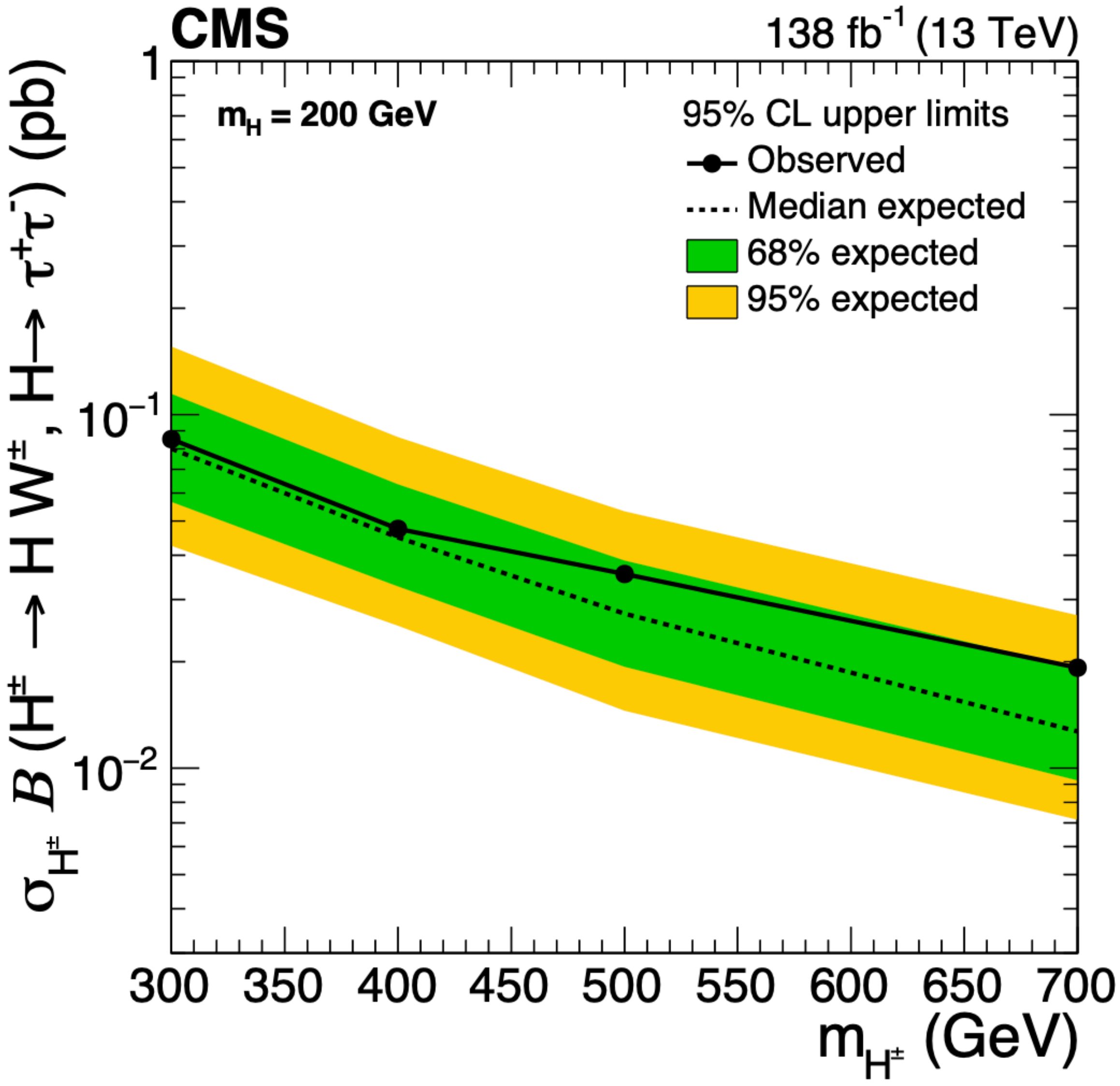


$$H^+ \to HW^+, \quad H \to \bar{\tau}\tau$$



JHEP09(2023)032

Charged Higgs in BSM scenarios

Lighter ones decay to lighter quarks

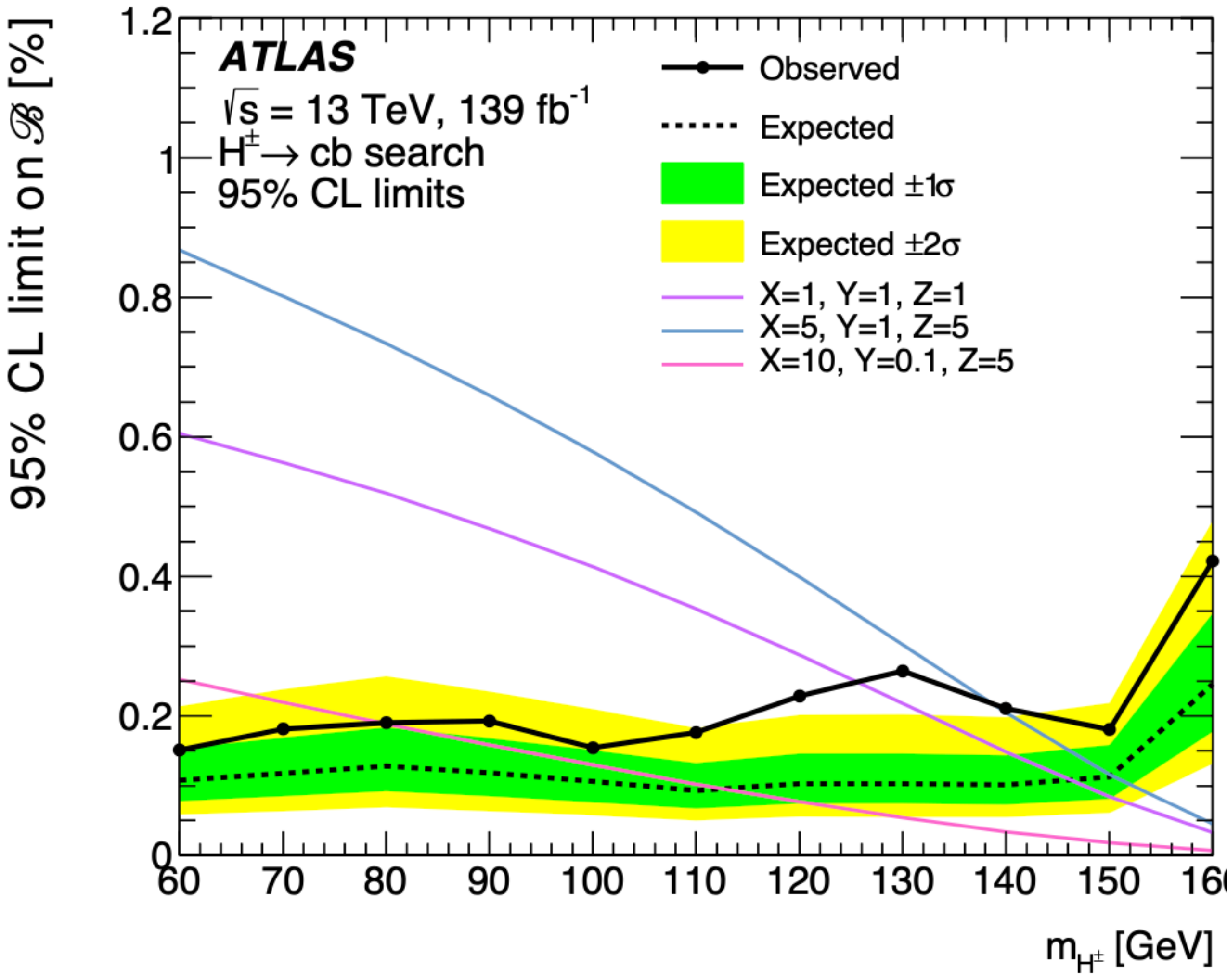
$$pp \to t\bar{t}$$

$$t \to H^+ b$$

$$t \to W^+ b$$

$$H^+ \to c\bar{b}$$

$$W^+ \to \ell^+ \nu$$



$$\mathscr{B} = BR(t \to H^+ b)\ BR(H^+ \to c\bar{b})$$

JHEP09(2023)004

Left-Right Symmetric Models

SM is chiral, the left-handed and right-handed particles differ in their fundamental interaction. Parity is violated maximally.

Left-Right Symmetric models are attempts to understand the origin of the parity violation. We can start with a Left-Right symmetric model at higher energies:

$$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)$$

Left-Right Symmetric Models

SM is chiral, the left-handed and right-handed particles differ in their fundamental interaction.
Parity is violated maximally.

Left-Right Symmetric models are attempts to understand the origin of the parity violation.
We can start with a Left-Right symmetric model at higher energies:

$$SU(3)_C \times SU(2)_L \times \underbrace{SU(2)_R \times U(1)}_{U(1)_Y}$$

This is broken to the SM gauge symmetry

$$\Longrightarrow \quad SU(3)_C \times SU(2)_L \times U(1)_Y$$

The Standard LRSM

Needs additional scalar to break the LR symmetry.

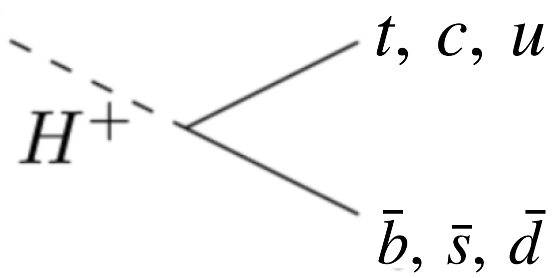
Leads to charged Higgs

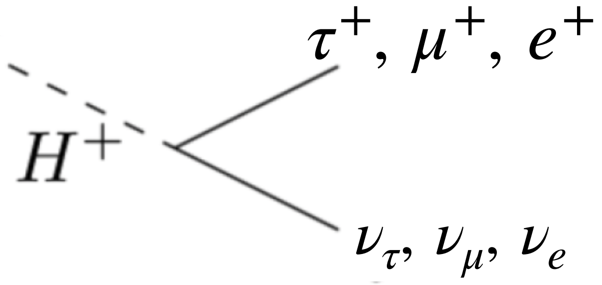
	Particles	$SU(3)_C$	$SU(2)_L$	$SU(2)_R$	$U(1)_{B-L}$
Quarks	$Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$	3	2	1	$\frac{1}{3}$
	$Q_R = \begin{pmatrix} u_R \\ d_R \end{pmatrix}$	3	1	2	$\frac{1}{3}$
Leptons	$L_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	1	2	1	-1
	$L_R = \begin{pmatrix} \nu_R \\ e_R \end{pmatrix}$	1	1	2	-1
Scalars	$\Phi = \begin{pmatrix} \phi_1^0 & \phi_1^+ \\ \phi_2^- & \phi_2^0 \end{pmatrix}$	1	2	2^*	0
	$\Delta_L = \begin{pmatrix} \frac{\delta_L^+}{\sqrt{2}} & \delta_L^{++} \\ \delta_L^0 & -\frac{\delta_L^+}{\sqrt{2}} \end{pmatrix}$	1	3	1	2
	$\Delta_R = \begin{pmatrix} \frac{\delta_R^+}{\sqrt{2}} & \delta_R^{++} \\ \delta_R^0 & -\frac{\delta_R^+}{\sqrt{2}} \end{pmatrix}$	1	1	3	2

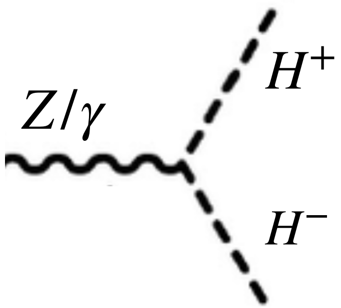
TABLE I: The particle content of LRSM.

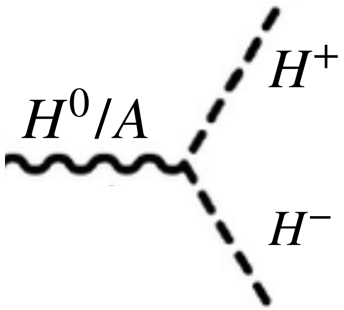
LRSM charged Higgs

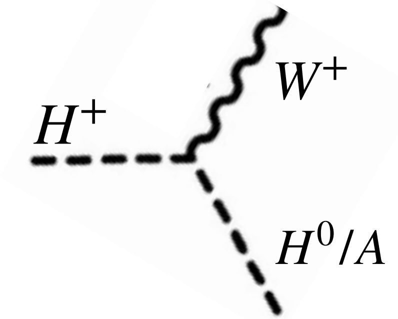
The LHC search results are applicable











Another version of Left-Right Symmetric model

LRSM

	Particles	$SU(3)_C$	$SU(2)_L$	$SU(2)_R$	$U(1)_{B-L}$
Quarks	$Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$	3	2	1	$\frac{1}{3}$
	$Q_R = \begin{pmatrix} u_R \\ d_R \end{pmatrix}$	3	1	2	$\frac{1}{3}$
Leptons	$L_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	1	2	1	-1
	$L_R = \begin{pmatrix} \nu_R \\ e_R \end{pmatrix}$	1	1	2	-1
Scalars	$\Phi = \begin{pmatrix} \phi_1^0 & \phi_1^+ \\ \phi_2^- & \phi_2^0 \end{pmatrix}$	1	2	2^*	0
	$\Delta_L = \begin{pmatrix} \frac{\delta_L^+}{\sqrt{2}} & \delta_L^{++} \\ \delta_L^0 & -\frac{\delta_L^+}{\sqrt{2}} \end{pmatrix}$	1	3	1	2
	$\Delta_R = \begin{pmatrix} \frac{\delta_R^+}{\sqrt{2}} & \delta_R^{++} \\ \delta_R^0 & -\frac{\delta_R^+}{\sqrt{2}} \end{pmatrix}$	1	1	3	2

TABLE I: The particle content of LRSM.

Singlet

Alternate LR Model

	Particles	$SU(3)_C$	$SU(2)_L$	$SU(2)'_R$	$U(1)_{B-L}$	S
Quarks	$Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$	3	2	1	$\frac{1}{6}$	0
	$Q_R = \begin{pmatrix} u_R \\ d'_R \end{pmatrix}$	3	1	2	$\frac{1}{6}$	$-\frac{1}{2}$
	d'_L	3	1	1	$-\frac{1}{3}$	-1
	d_R	3	1	1	$-\frac{1}{3}$	0
Leptons	$L_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	1	2	1	$-\frac{1}{2}$	1
	$L_R = \begin{pmatrix} n_R \\ e_R \end{pmatrix}$	1	1	2	$-\frac{1}{2}$	$\frac{3}{2}$
	n_L	1	1	1	0	2
	ν_R	1	1	1	0	1
Scalars	$\Phi = \begin{pmatrix} \phi_1^0 & \phi_1^+ \\ \phi_2^- & \phi_2^0 \end{pmatrix}$	1	2	2^*	0	$-\frac{1}{2}$
	$\chi_L = \begin{pmatrix} \chi_L^+ \\ \chi_L^0 \end{pmatrix}$	1	2	1	$\frac{1}{2}$	0
	$\chi_R = \begin{pmatrix} \chi_R^+ \\ \chi_R^0 \end{pmatrix}$	1	1	2	$\frac{1}{2}$	$\frac{1}{2}$

TABLE I: The particle content of ALRM.

E. Ma, Phys. Rev. D36, 274 (1987).

	Particles			$SU(2)_R$	$U(1)_{B-L}$
Quarks	$Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$			1	$\frac{1}{3}$
	$Q_R = \begin{pmatrix} u_R \\ d_R \end{pmatrix}$			2	$\frac{1}{3}$
Leptons	$L_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	1	2	1	-1
	$L_R = \begin{pmatrix} \nu_R \\ e_R \end{pmatrix}$			2	-1
Scalars	$\Phi = \begin{pmatrix} \phi_1^0 & \phi_1^+ \\ \phi_2^- & \phi_2^0 \end{pmatrix}$			2^*	0
	$\Delta_L = \begin{pmatrix} \frac{\delta_L^+}{\sqrt{2}} & \delta_L^{++} \\ \delta_L^0 & -\frac{\delta_L^+}{\sqrt{2}} \end{pmatrix}$			1	2
	$\Delta_R = \begin{pmatrix} \frac{\delta_R^+}{\sqrt{2}} & \delta_R^{++} \\ \delta_R^0 & -\frac{\delta_R^+}{\sqrt{2}} \end{pmatrix}$	1	1	3	2

TABLE I: The particle content of LRSM.

$$\begin{pmatrix} u_R \\ d_R \end{pmatrix}$$

$$\begin{pmatrix} \nu_R \\ e_R \end{pmatrix}$$

	Particles			$SU(2)'_R$	$U(1)_{B-L}$	S
Quarks	$Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$			1	$\frac{1}{6}$	0
	$Q_R = \begin{pmatrix} u_R \\ d'_R \end{pmatrix}$			2	$\frac{1}{6}$	$-\frac{1}{2}$
	d'_L			1		
	d_R	3	1	1		
Leptons	$L_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	1	2	1		
	$L_R = \begin{pmatrix} n_R \\ e_R \end{pmatrix}$			2		
	n_L			1		
	ν_R			1		
Scalars	$\Phi = \begin{pmatrix} \phi_1^0 & \phi_1^+ \\ \phi_2^- & \phi_2^0 \end{pmatrix}$			2^*		
	$\chi_L = \begin{pmatrix} \chi_L^+ \\ \chi_L^0 \end{pmatrix}$	1	2	1		
	$\chi_R = \begin{pmatrix} \chi_R^+ \\ \chi_R^0 \end{pmatrix}$	1	1	2		

TABLE I: The particle content of ALRM.

$$\begin{pmatrix} u_R \\ d'_R \end{pmatrix}$$

$$\begin{pmatrix} n_R \\ e_R \end{pmatrix}$$

d_R

d'_L

ν_R

n_L

Some interesting features

ν_R is a Majorana neutrino, as against being part of the couple in the standard LRSM

=> Possibility of Leptogenesis

ν_R along with presence of light (~100 GeV) H^+ can impact the $0\nu\beta\beta$ processes

Phys.Rev.D 102 (2020) 7, 075020 arXiv: 2008.12270

n / H_1^0 : The lightest is a dark matter candidate.

JHEP 12, 032, arXiv:2211.04286

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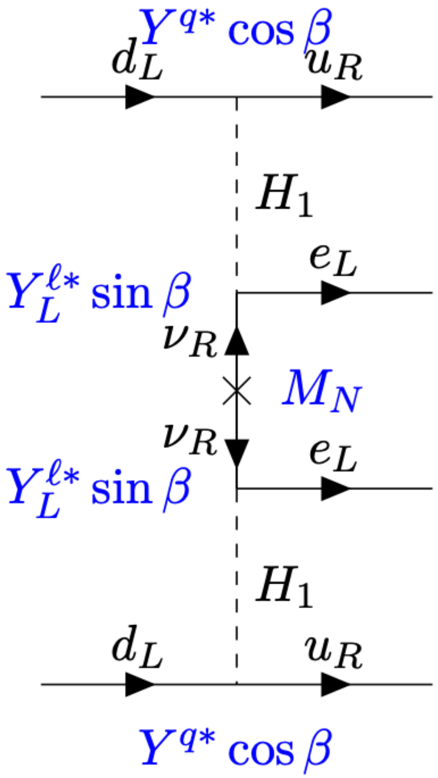
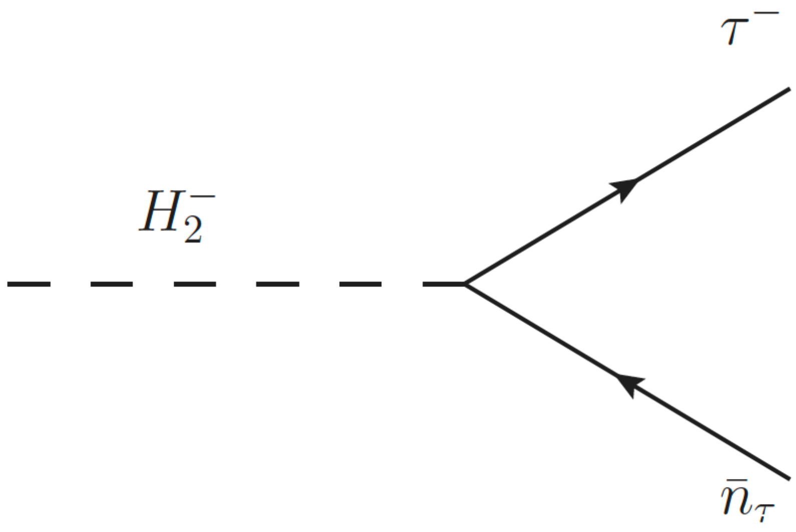


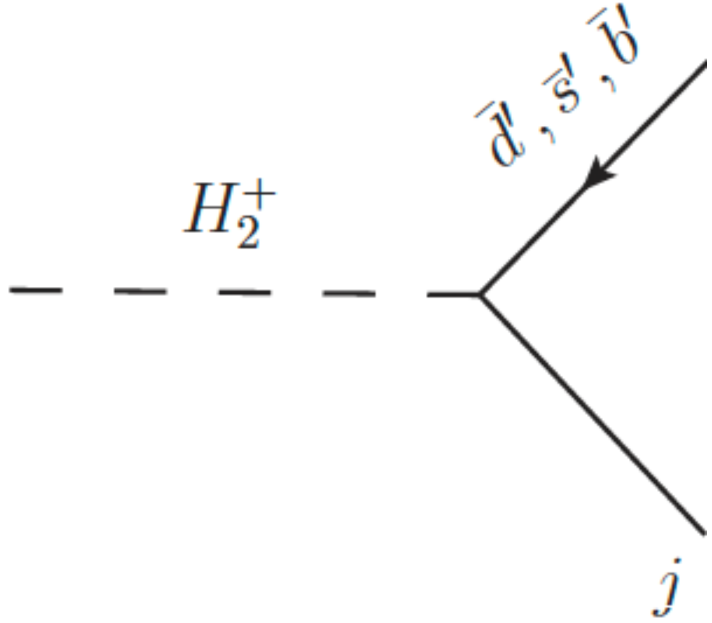
$$-\mathcal{L}_Y = \bar{Q}_L Y^q \tilde{\Phi} Q_R + \bar{Q}_L Y_L^q \chi_L d_R + \bar{Q}_R Y_R^q \chi_R d'_L + \bar{L}_L Y^\ell \Phi L_R + \bar{L}_L Y_L^\ell \tilde{\chi}_L \nu_R + \bar{L}_R Y_R^\ell \tilde{\chi}_R n_L + \text{h.c.}$$

For details of the model:

M. Frank, C. Majumdar, P. Poulose, S. Senapati, and U. A. Yajnik

JHEP 03, 065, arXiv:2111.08582 [hep-ph]
JHEP 12, 032, arXiv:2211.04286 [hep-ph]
Phys.Rev.D 102 (2020) 7, 075020 arXiv: 2008.12270

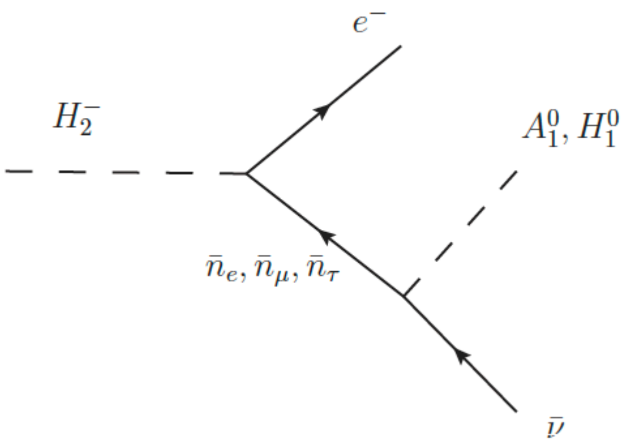


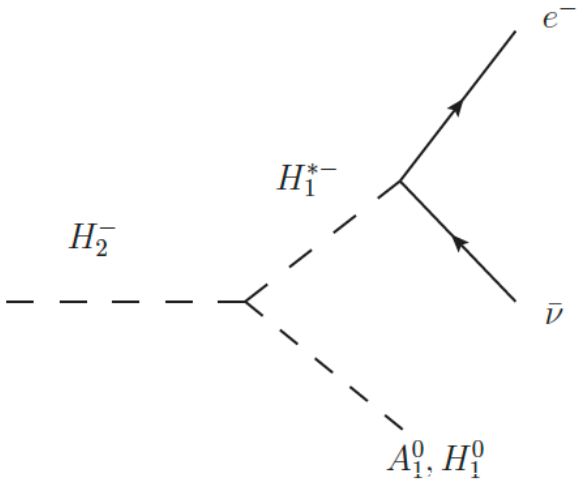


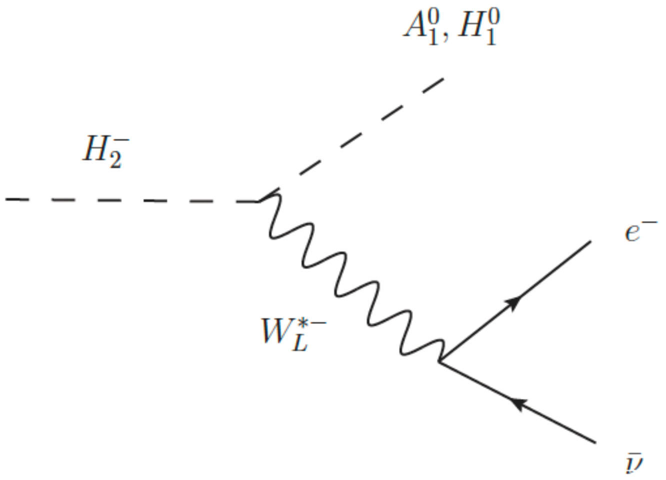
Non-standard decays, which are not searched for at the LHC

Our study: Search for such an H^+ at the LHC and future colliders

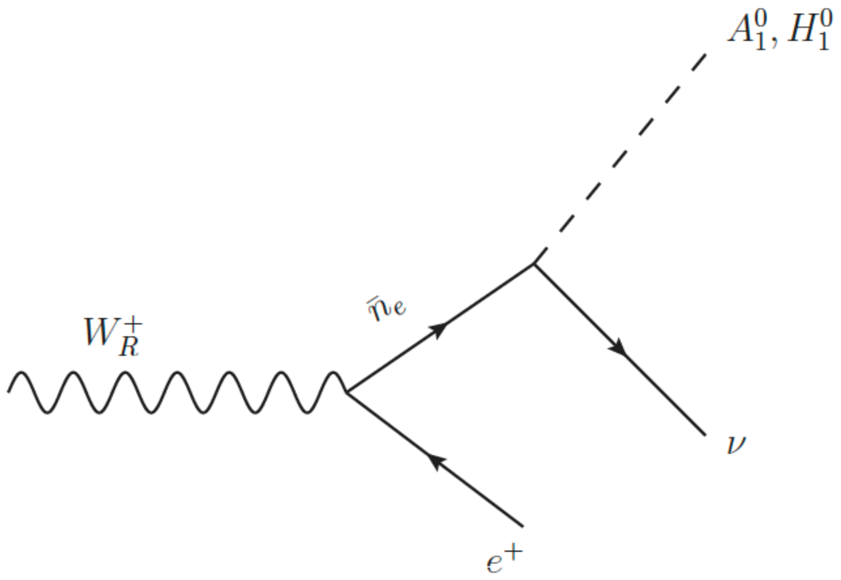
$$pp \to H^+H^-, \quad W_R W_R, \quad W_R H^\pm$$







$$M_{H^+} < m_{n_\ell} < M_{W_R}$$



Completely different topology compared to the Standard LRSM (or 2HDM / MSSM) case

Work in progress With:

M. Frank, C. Majumdar,

S. Senapati, U. Yagnik

An example:

$$pp \to H^+H^-, \quad W_RW_R, \quad W_RH^\pm$$

$M_{W_R} = 1146 \ \ \text{GeV}$

$BR(H^+ \to \tau^+ n_\tau) = 59.6\,\%$

$M_{H^+} = 187 \ \ \text{GeV}$

$BR(n \to H_1^0 \nu_e) = 25.35\,\%$

$m_{d'} = 1.3 \ \ \text{TeV}$

$m_n = 130 \ \ \text{GeV}$

$\sigma \times BR = 108.7 \ \ \text{fb}$

$@ \sqrt{s} = 13 \ \text{TeV}$

Detailed detector level analyses is being done.

Summary

Search strategy of H^+ at the LHC presume their standard charged current interaction.

Considering a well motivated alternate Left-Right Model, H^+ can have non-standard charged current interactions involving exotic fermions (quarks and neutral leptons).

Collider direct searches of H^+ should include such possibilities.

Indirect constraints coming from flavour sector can also be different compared to the standard LRSM.