Implications of light charged Higgs bosons at the LHC Run III in the 2HDM

CLHCP2020

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based on arXiv:2003.11108 [hep-ph]

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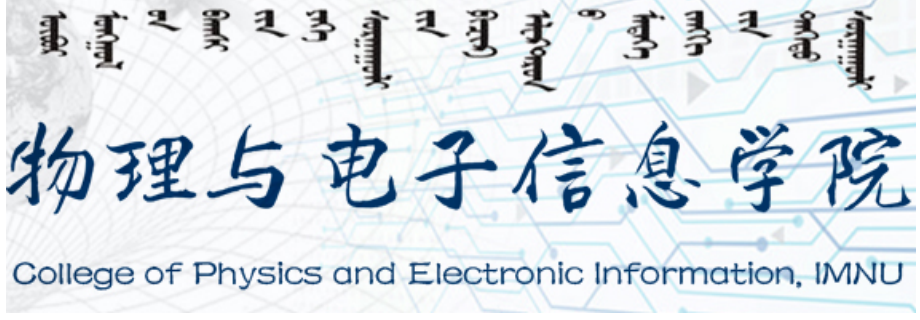


Charged Higgs at the LHC

- A Higgs boson was discovered in 2012 at 125 GeV
- 2HDM: a new physics candidate model, Type I/II/III/..
- Predictions: h^0, A^0, H, $H^\pm$
- Charged Higgs fermionic decays: $H^\pm \to \tau\nu, cs, cb, t^{(*)}b, \mu\nu$
  - $m_{H^\pm} < m_t$: $t\bar{t} \to H^\pm W^\mp b\bar{b}$, $H^\pm \to cs$ (CMS, arXiv:2005.08900)
    $H^\pm \to \tau\nu$ (CMS, arXiv: 1903.04560)
  - $m_{H^\pm} > m_t$: $pp \to H^\pm, H^\pm \to tb$ (CMS, arXiv:2001.07763),
    $pp \to tH^-, H^- \to tb$ (CMS, arXiv:1908.09206).
- Charged Higgs Bosonic decays: $H^\pm \to W^\pm Z/A^0/h^0/\gamma...$
  - $m_{H^\pm} \in [200, 2000]\mathrm{GeV}$ (CMS, arXiv:1705.02942).

We focus on: 2HDM Type I, light charged Higgs, decay to bosons (off-shell decay)

Theoretical constraints

In 2HDM type I model:

- Vacuum stability

$$\lambda_{1,2} > 0, \lambda_3 > -(\lambda_1\lambda_2)^{1/2}, \lambda_3 + \lambda_4 - |\lambda_5| > -(\lambda_1\lambda_2)^{1/2}$$

- Perturbative: $\lambda_i < 8\pi$
- Perturbative unitarity: S-wave component of bosons remain unitary at high energy
- EW Precision Observables

$$\Delta S = 0.05 \pm 0.11, \Delta T = 0.09 \pm 0.13, \Delta U = 0.01 \pm 0.11$$

Experimental constraints

- B-physics observables

$$\begin{aligned} BR(\bar{B} \to X_s\gamma)_{E_\gamma > 1.6GeV} &= (3.32 \pm 0.3) \times 10^{-4}, \\ BR(B_s^0 \to \mu^+\mu^-) &= (3.1 \pm 1.4) \times 10^{-9}, \\ BR(B^+ \to \tau^+\nu_\tau) &= (1.06^{+0.38}_{-0.28}) \times 10^{-4} \end{aligned}$$

- Z width measurement from LEP

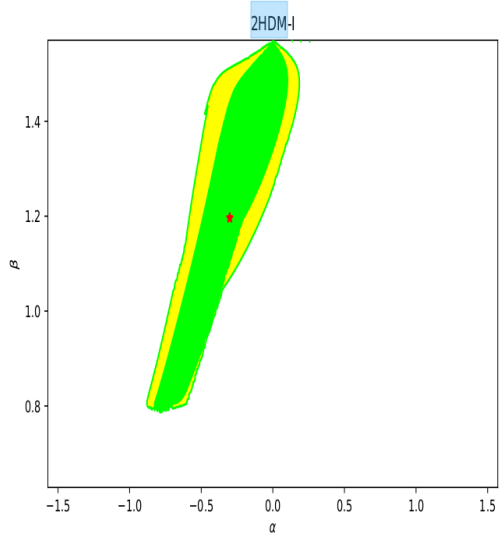
$$\Gamma_Z = 2.4952 \pm 0.0023 \text{ GeV}, \quad \Gamma(Z \to h^0 A^0) < 4.6 \text{ MeV}$$

- Consistency of the mass and signal rates of H^0 with the LHC data on H_{obs} (HiggsSignal)

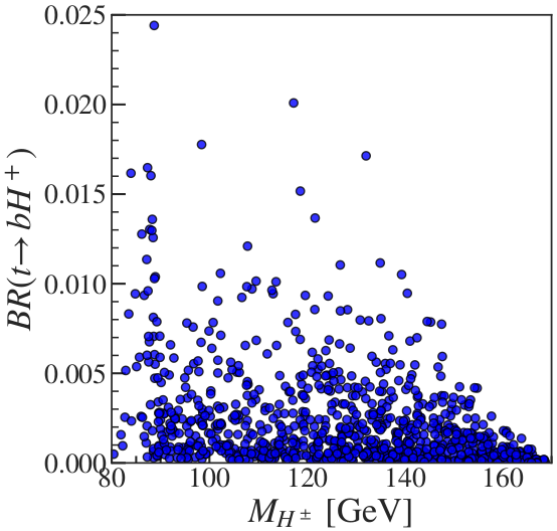
- Consistency of all Higgs states with the direct search constraints from LEP, Tevatron and LHC (HiggsBounds)

Experimental constraints

$\alpha - \beta$ for $m_{H^\pm}$



$t \to bH^\pm$

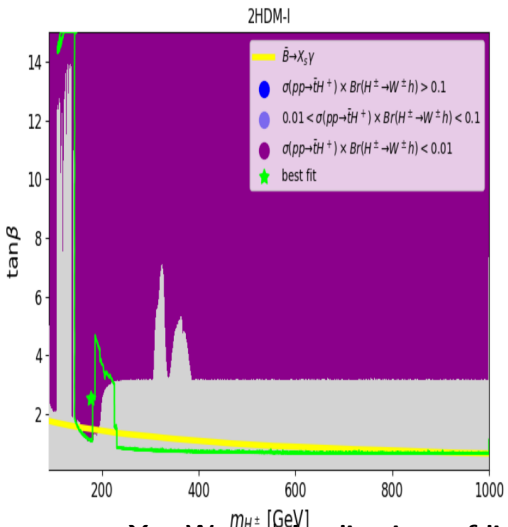


heavy Higgs is SM-like

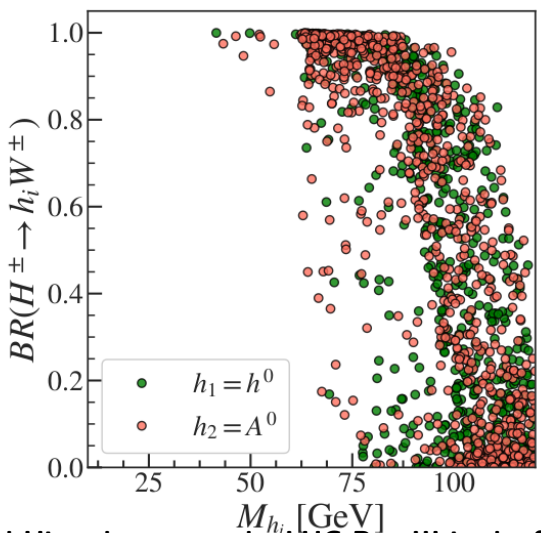
$H^\pm$ could be small $\sim$ 100 GeV

$\mathrm{BR}(\mathrm{H}^\pm \to \mathrm{h}^0/\mathrm{A}^0\mathrm{W}^{\pm *})$ could be dominant

$pp \to tH^-, H^\pm \to h^0 W^\pm$

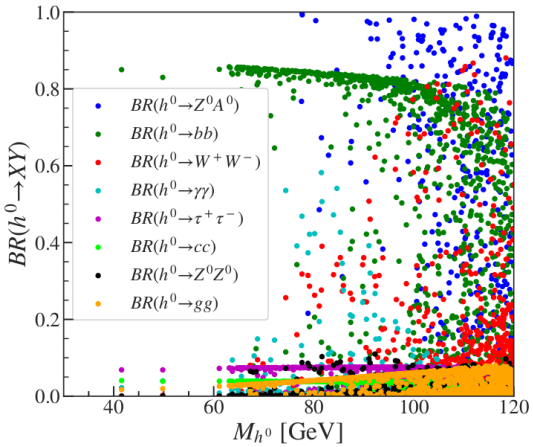


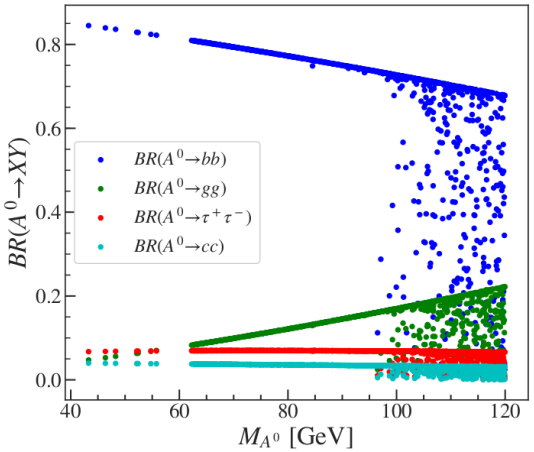
$H^\pm \to h^0 W^\pm$

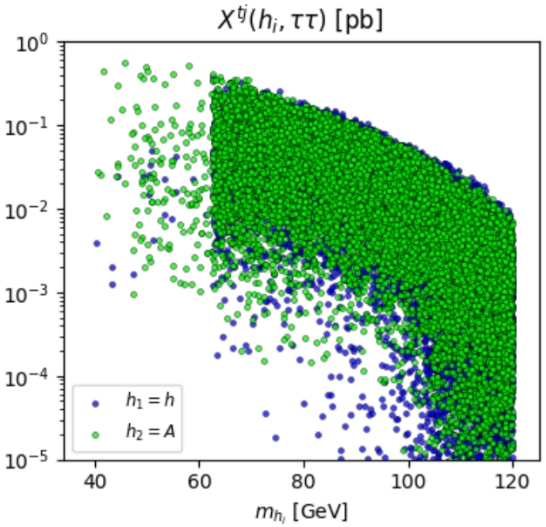


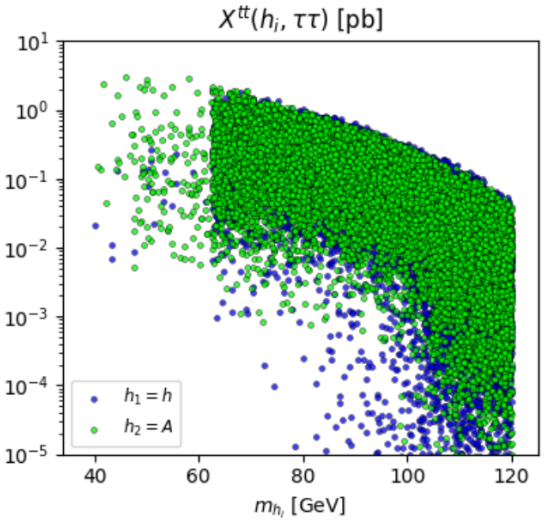
$W^\pm$ off-shell depend on $M_{H^\pm} - M_{A^0/h^0}$

Detector Searching Signal: $H^{\pm} \to W^{\pm} h^0 (W^{\pm} A^0) \to \tau\tau l\nu$









$\sigma(pp \to tj) \times \mathrm{BR}(t \to bH^+)$ $\sigma(pp \to tt) \times \mathrm{BR}(t \to bH^+) \times \mathrm{BR}(t \to bW^+)$

$\mathrm{BR}(H^+ \to h_i W^+) \times \mathrm{BR}(h_i \to \tau\tau) \times \mathrm{BR}(W^+ \to l^+\nu)$

6 BP for simulation

Parameters	BP1	BP2	BP3	BP4	BP5	BP6
M_{H^0}	125	125	125	125	125	125
M_{h^0}	80.772	78.284	85.003	-	-	-
M_{A^0}	-	-	-	64.547	72.896	62.679
$M_{H^\pm}$	124.29	112.8	132.6	117.23	132.05	98.4
$\tan\beta \in [3,6]$, $\sin(\beta-\alpha) \in [-0.15,-0.05]$, $(M_{H^\pm} - M_{h^0/A^0}) \in [30,50]$ GeV						

Detector Simulation: production: $pp \to tj$, $pp \to t\bar{t}$, respectively

Charged Higgs off-shell decay: $t \to bH^+, H^+ \to h_i W^{+*}, h_i \to \underline{\tau\tau}, W^{+*} \to l^+\nu$

three $\tau\tau$ decay cases:

Case A: two tagged τ -jets

Case B: one τ-jet + one lepton, only preserve the same sign lepton as the lepton coming from W

Case C: two leptons + MET

Gen MadGraph+Pythia+Delphes

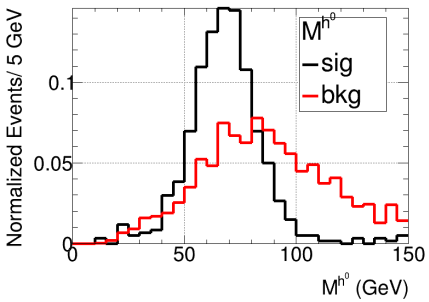
tight preselection cuts: $|\eta(l,j)| < 2.5$, $p_{T,(l,j)} > 20$ GeV, MET > 20 GeV

loose preselection cuts: $p_{T,j} > 20$ GeV, $P_{T,l} > 10$ GeV, MET > 5 GeV

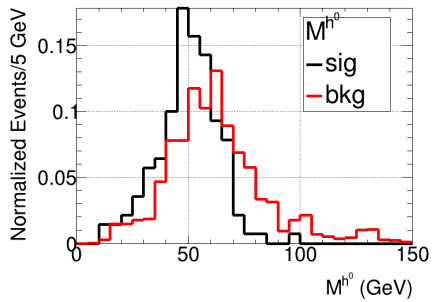
Events Reconstruction: $M_A = 80.7\text{GeV}$, $M_{H^\pm} = 124.3\text{GeV}$

scalar h^0 reconstruction with $\tau\tau$

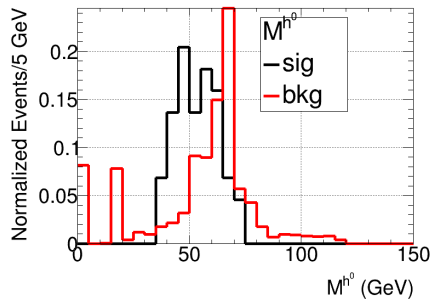
Case A



Case B

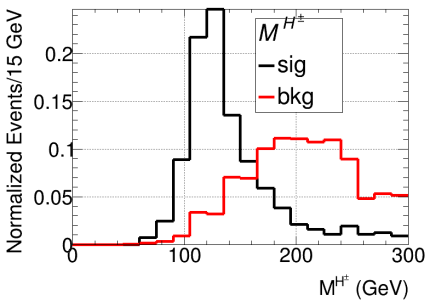


Case C

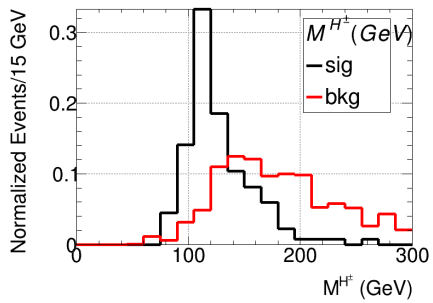


$H^\pm$ reconstruction with $\tau\tau l\nu$

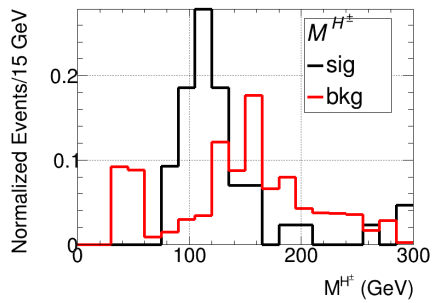
Case A



Case B

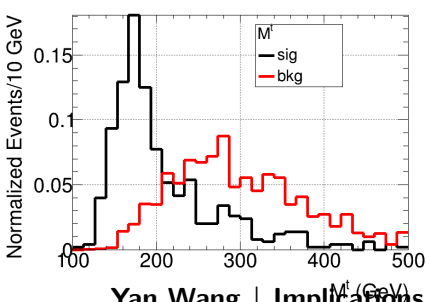


Case C

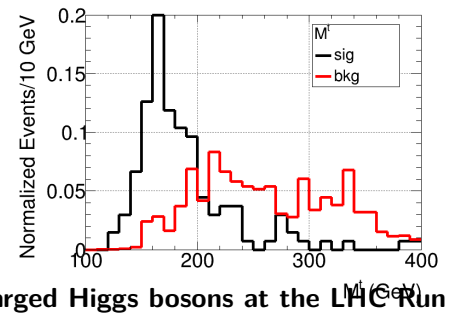


top quark reconstruction with $\tau\tau l\nu b$

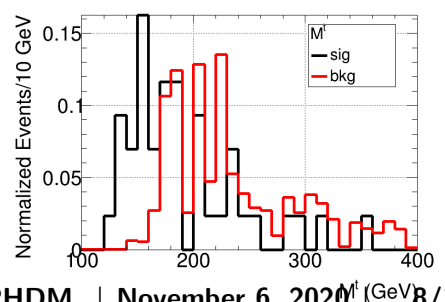
Case A



Case B



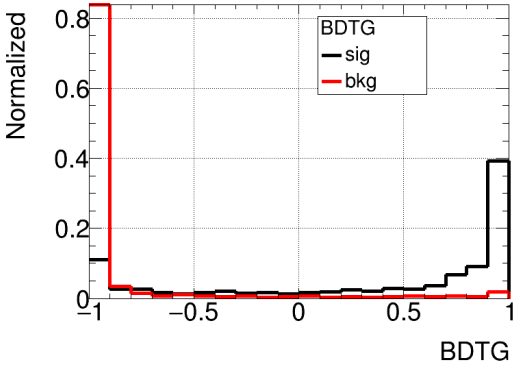
Case C



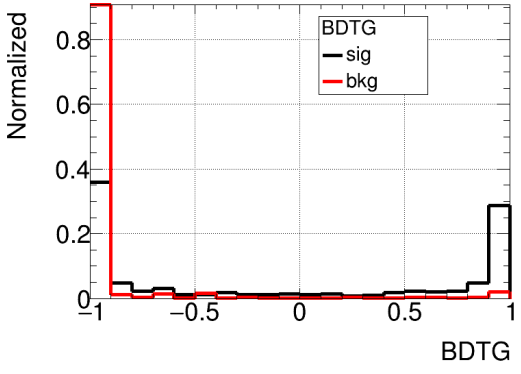
Event Selection

- Cuts for M_{h^0/A^0}, $M_{H^\pm}$, M_t
- Multi-Variate Analysis (BDTG): $PT_{l/j}$, $M_{h^0/A^0/H^\pm/t}$, $PT_{h^0/A^0/H^\pm/t/tj-system}$

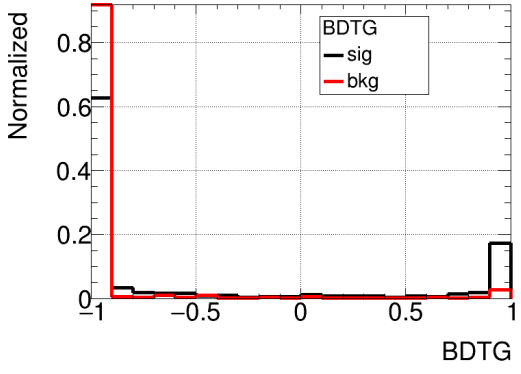
Case A



Case B



Case C



Cuts	Case A	Case B	Case C
M^{h^0}	[40, 100] GeV	[10, 80] GeV	[20, 75] GeV
$M^{H^\pm}$	[80, 300] GeV	[60, 250] GeV	[20, 160] GeV
M^t	[0, 250] GeV	[0, 250] GeV	[0, 250] GeV
BDTG	[0.4,1]	[-0.6,1]	-

Significance for tight preselection cuts

LHC 14 TeV, 300 fb^{-1} for $pp \to tj$ channel

Significance	BP1	BP2	BP3	BP4	BP5	BP6
Case A	3.45	2.65	6.22	6.27	5.68	4.35
Case B	3.07	1.96	4.54	4.07	3.41	3.05
Case C	0.74	0.80	1.47	0.71	1.16	0.80
Combined	3.86	3.05	7.36	7.0	6.39	4.99

LHC 14 TeV, 300 fb^{-1} for $pp \to t\bar{t}$ channel

Significance	BP1	BP2	BP3	BP4	BP5	BP6
Case A	7.60	6.74	5.59	11.45	10.48	9.35
Case B	4.85	5.79	5.04	7.81	7.47	6.30
Case C	2.90	2.15	1.47	4.62	3.60	3.12
Combine	9.35	8.83	7.27	14.46	13.18	11.50

Significance for loose preselection cuts

LHC 14 TeV, 300 fb^{-1} for $pp \to tj$ channel

Significance	BP1	BP2	BP3	BP4	BP5	BP6
Case A	7.43	4.49	11.15	10.72	11.10	8.80
Case B	6.86	3.36	6.04	10.51	10.84	9.58
Case C	4.85	3.69	6.88	8.00	8.24	7.43
Combined	10.91	6.33	14.34	16.37	16.96	14.24

LHC 14 TeV, 300 fb^{-1} for $pp \to t\bar{t}$ channel

Significance	BP1	BP2	BP3	BP4	BP5	BP6
Case A	11.05	11.47	9.66	18.0	15.88	16.32
Case B	10.27	11.33	9.787	14.98	12.92	10.18
Case C	6.409	7.31	5.30	8.16	8.69	9.42
combine	16.32	17.63	14.41	23.78	22.08	21.03

Summary

- 2HDM typeI model, light charged Higgs production, off-shell decay to $W^{\pm}h^0$ or $W^{\pm}A^0$
- detector simulation for $pp \to tj$ and $pp \to t\bar{t}$ processes
- 6 BPs, high significances.

Thank you for your attention!