Charged Higgs Bosons ($H^{\pm}$ and $H^{\pm\pm}$), Searches for

CONTENTS:

$H^{\pm}$ (charged Higgs) mass limits for $m_{H^+} < m(top)$

Unless otherwise stated, LEP limits assume $B(H^+ \to \tau^+ \nu)+B(H^+ \to c\bar{s})=1$, and hold for all values of $B(H^+ \to \tau^+ \nu_\tau)$, and assume H^+ weak isospin of $T_3=+1/2$. In the following, $\tan\beta$ is the ratio of the two vacuum expectation values in two-doublet models (2HDM).

The limits are also applicable to point-like technipions. For a discussion of techniparticles, see the Review of Dynamical Electroweak Symmetry Breaking in this Review.

Limits obtained at the LHC are given in the m_h^{mod-} benchmark scenario, see CARENA 13, and hold for all $\tan\beta$ values.

For limits obtained in hadronic collisions before the observation of the top quark, and based on the top mass values inconsistent with the current measurements, see the 1996 (Physical Review **D54** 1 (1996)) Edition of this Review.

Searches in e^+e^- collisions at and above the Z pole have conclusively ruled out the existence of a charged Higgs in the region $m_{H^+} \lesssim 45$ GeV, and are meanwhile superseded by the searches in higher energy e^+e^- collisions at LEP. Results that are by now obsolete are therefore not included in this compilation, and can be found in a previous Edition (The European Physical Journal **C15** 1 (2000)) of this Review.

In the following, and unless otherwise stated, results from the LEP experiments (ALEPH, DELPHI, L3, and OPAL) are assumed to derive from the study of the $e^+e^- \to H^+H^-$ process. Limits from $b \to s\gamma$ decays are usually stronger in generic 2HDM models than in Supersymmetric models.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
none 80–140	95	[1] AAD	15AF	ATLS	$t \to bH^+$
none 90–155	95	[2] KHACHATRY...	15AX	CMS	$t \to bH^+$, $H^+ \to \tau^+\nu$
> 80	95	[3] LEP	13	LEP	$e^+e^- \to H^+H^-$,$E_{cm} \le$ 209GeV
> 76.3	95	[4] ABBIENDI	12	OPAL	$e^+e^- \to H^+H^-$,$E_{cm} \le$ 209GeV
> 74.4	95	ABDALLAH	04I	DLPH	$E_{cm} \le 209$ GeV
> 76.5	95	ACHARD	03E	L3	$E_{cm} \le 209$ GeV
> 79.3	95	HEISTER	02P	ALEP	$E_{cm} \le 209$ GeV

• • • We do not use the following data for averages, fits, limits, etc. • • •

[5] AAD	25	ATLS	$H^{\pm} \rightarrow W^{\pm} Z$
[6,7] AAD	25AI	ATLS	$t \rightarrow bH^{+}$, $H^{+} \rightarrow c\overline{s}$
[6,8] AAD	25K	ATLS	$t \rightarrow bH^{+}$, $H^{+} \rightarrow \tau^{+}\nu$
[6,9] AAD	25K	ATLS	$H^{+} \rightarrow \tau^{+}\nu$
[10] AAD	25U	ATLS	$H^{+} \rightarrow W^{+} H$
[11] HAYRAPETY...	24AV	CMS	$H^{\pm} \rightarrow W^{\pm}\gamma$
[12] AAD	23AH	ATLS	$H^{\pm} \rightarrow W^{\pm} Z$
[6,13] AAD	23BB	ATLS	$t \rightarrow bH^{+}$, $H^{+} \rightarrow c\overline{b}$
[6,14] AAD	23BW	ATLS	$t \rightarrow bH^{+}$, $H^{+} \rightarrow W^{+}A^{0}$, $A^{0} \rightarrow \mu^{+}\mu^{-}$
[15] TUMASYAN	23AV	CMS	$H^{\pm} \rightarrow H_2^0 W^{\pm}$
[16] TUMASYAN	22B	CMS	$H^{\pm} \rightarrow W^{\pm}\gamma$
[17] AAD	21V	ATLS	$\overline{t}bH^{+}$, $H^{+} \rightarrow t\overline{b}$
[18] SIRUNYAN	21W	CMS	$H^{+} \rightarrow W^{+} Z$
[19] AAD	20W	ATLS	$H^{+} \rightarrow t\overline{b}$
[20] SIRUNYAN	20AO	CMS	$H^{+} \rightarrow t\overline{b}$
[21] SIRUNYAN	20AV	CMS	$H^{+} \rightarrow t\overline{b}$
[22] SIRUNYAN	20BE	CMS	$t \rightarrow bH^{+}$, $H^{+} \rightarrow c\overline{s}$
[23] SIRUNYAN	19AH	CMS	$H^{+} \rightarrow \tau^{+}\nu$
[24] SIRUNYAN	19BP	CMS	$H^{+} \rightarrow W^{+} Z$
[25] SIRUNYAN	19CC	CMS	$t \rightarrow bH^{+}$, $H^{+} \rightarrow W^{+}A^{0}$, $A^{0} \rightarrow \mu^{+}\mu^{-}$
[26] SIRUNYAN	19CQ	CMS	$H^{+} \rightarrow W^{+} Z$
[27] AABOUD	18BW	ATLS	$\overline{t}bH^{+}$ or $t \rightarrow bH^{+}$, $H^{+} \rightarrow \tau^{+}\nu$
[28] AABOUD	18CD	ATLS	$\overline{t}bH^{+}$, $H^{+} \rightarrow t\overline{b}$
[29] AABOUD	18CH	ATLS	$H^{\pm} \rightarrow W^{\pm} Z$
[30] HALLER	18	RVUE	$b \rightarrow s\gamma$
[31] SIRUNYAN	18DO	CMS	$t \rightarrow bH^{+}$, $H^{+} \rightarrow c\overline{b}$
[32] MISIAK	17	RVUE	$b \rightarrow s(d)\gamma$
[33] SIRUNYAN	17AE	CMS	$H^{\pm} \rightarrow W^{\pm} Z$
[34] AABOUD	16A	ATLS	$t(b)\, H^{+}$, $H^{+} \rightarrow \tau^{+}\nu$
[35] AAD	16AJ	ATLS	$t(b)\, H^{+}$, $H^{+} \rightarrow t\overline{b}$
[36] AAD	16AJ	ATLS	$qq \rightarrow H^{+}$, $H^{+} \rightarrow t\overline{b}$
[37] AAD	15AF	ATLS	$tH^{\pm}$
[38] AAD	15M	ATLS	$H^{\pm} \rightarrow W^{\pm} Z$
[39] KHACHATRY...	15AX	CMS	tH^{+}, $H^{+} \rightarrow t\overline{b}$
[40] KHACHATRY...	15AX	CMS	$tH^{\pm}$, $H^{\pm} \rightarrow \tau^{\pm}\nu$
[41] KHACHATRY...	15BF	CMS	$t \rightarrow bH^{+}$, $H^{+} \rightarrow c\overline{s}$
[42] AAD	14M	ATLS	$H_2^0 \rightarrow H^{\pm}W^{\mp} \rightarrow H^{0}W^{\pm}W^{\mp}$, $H^{0} \rightarrow b\overline{b}$
[43] AALTONEN	14A	CDF	$t \rightarrow b\tau\nu$
[44] AAD	13AC	ATLS	$t \rightarrow bH^{+}$
[45] AAD	13V	ATLS	$t \rightarrow bH^{+}$, lepton non-universality
[46] AAD	12BH	ATLS	$t \rightarrow bH^{+}$
[47] CHATRCHYAN	12AA	CMS	$t \rightarrow bH^{+}$
[48] AALTONEN	11P	CDF	$t \rightarrow bH^{+}$, $H^{+} \rightarrow W^{+}A^{0}$

>316	95	[49] DESCHAMPS	10	RVUE	Type II, flavor physics data
		[50] AALTONEN	09AJ	CDF	$t \to bH^+$
		[51] ABAZOV	09AC	D0	$t \to bH^+$
		[52] ABAZOV	09AG	D0	$t \to bH^+$
		[53] ABAZOV	09AI	D0	$t \to bH^+$
		[54] ABAZOV	09P	D0	$H^+ \to t\overline{b}$
		[55] ABULENCIA	06E	CDF	$t \to bH^+$
> 92.0	95	ABBIENDI	04	OPAL	$B(\tau\nu) = 1$
> 76.7	95	[56] ABDALLAH	04I	DLPH	Type I
		[57] ABBIENDI	03	OPAL	$\tau \to \mu\overline{\nu}\nu$, $e\overline{\nu}\nu$
		[58] ABAZOV	02B	D0	$t \to bH^+$, $H \to \tau\nu$
		[59] BORZUMATI	02	RVUE	
		[60] ABBIENDI	01Q	OPAL	$B \to \tau\nu_\tau X$
		[61] BARATE	01E	ALEP	$B \to \tau\nu_\tau$
>315	99	[62] GAMBINO	01	RVUE	$b \to s\gamma$
		[63] AFFOLDER	00I	CDF	$t \to bH^+$, $H \to \tau\nu$
> 59.5	95	ABBIENDI	99E	OPAL	$E_{cm} \leq 183$ GeV
		[64] ABBOTT	99E	D0	$t \to bH^+$
		[65] ACKERSTAFF	99D	OPAL	$\tau \to e\nu\nu$, $\mu\nu\nu$
		[66] ACCIARRI	97F	L3	$B \to \tau\nu_\tau$
		[67] AMMAR	97B	CLEO	$\tau \to \mu\nu\nu$
		[68] COARASA	97	RVUE	$B \to \tau\nu_\tau X$
		[69] GUCHAIT	97	RVUE	$t \to bH^+$, $H \to \tau\nu$
		[70] MANGANO	97	RVUE	$B_{u(c)} \to \tau\nu_\tau$
		[71] STAHL	97	RVUE	$\tau \to \mu\nu\nu$
>244	95	[72] ALAM	95	CLE2	$b \to s\gamma$
		[73] BUSKULIC	95	ALEP	$b \to \tau\nu_\tau X$

[1] AAD 15AF search for $t\overline{t}$ production followed by $t \to bH^+$, $H^+ \to \tau^+\nu$ in 19.5 fb^{-1} of pp collisions at $E_{cm} = 8$ TeV. Upper limits on $B(t \to bH^+)$ $B(H^+ \to \tau\nu)$ between 2.3×10^{-3} and 1.3×10^{-2} (95% CL) are given for $m_{H^+} = 80$–160 GeV. See their Fig. 8 for the excluded regions in different benchmark scenarios of the MSSM. The region $m_{H^+} < 140$ GeV is excluded for $\tan\beta > 1$ in the considered scenarios.

[2] KHACHATRYAN 15AX search for $t\overline{t}$ production followed by $t \to bH^+$, $H^+ \to \tau^+\nu$ in 19.7 fb^{-1} of pp collisions at $E_{cm} = 8$ TeV. Upper limits on $B(t \to bH^+)$ $B(H^+ \to \tau\nu)$ between 1.2×10^{-2} and 1.5×10^{-3} (95% CL) are given for $m_{H^+} = 80$–160 GeV. See their Fig. 11 for the excluded regions in different benchmark scenarios of the MSSM. The region $m_{H^+} < 155$ GeV is excluded for $\tan\beta > 1$ in the considered scenarios.

[3] LEP 13 give a limit that refers to the Type II scenario. The limit for $B(H^+ \to \tau\nu) = 1$ is 94 GeV (95% CL), and for $B(H^+ \to cs) = 1$ the region below 80.5 as well as the region 83–88 GeV is excluded (95% CL). LEP 13 also search for the decay mode $H^+ \to A^0 W^*$ with $A^0 \to b\overline{b}$, which is not negligible in Type I models. The limit in Type I models is 72.5 GeV (95% CL) if $m_{A^0} > 12$ GeV.

[4] ABBIENDI 12 also search for the decay mode $H^+ \to A^0 W^*$ with $A^0 \to b\overline{b}$.

[5] AAD 25 combine AAD 23AH and AAD 24AD and derive limits on the isotriplet contribution to the gauge boson masses in the Georgi-Machacek model. See their Fig. 5(c).

[6] Charge conjugated states are also implied.

[7] AAD 25AI search for $t\overline{t}$ production followed by $t \to bH^+$, $H^+ \to c\overline{s}$ using 140 fb^{-1} of pp collisions at $E_{cm} = 13$ TeV. See their Fig. 6 for limits on the product of branching ratios for $m_{H^+} = 60$–168 GeV.

[8] AAD 25K search for $t\overline{t}$ production followed by $t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu$ using 140 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 7(b) for limits on the product of branching ratios for m_{H^+} = 60–160 GeV.

[9] AAD 25K search for H^+ production in association with top quark, in the decay mode $H^+ \rightarrow \tau^+\nu$, using 140 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 7(a) for limits on cross section times branching ratios for m_{H^+} = 80–3000 GeV, and Fig. 8 for excluded regions in m_{H^+}–$\tan\beta$ plane in hMSSM and M_h^{125} MSSM scenarios.

[10] AAD 25U search for H^+ production in association with tb, in the decay mode $H^+ \rightarrow W^+H$, $H \rightarrow b\overline{b}$ in 140 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 15 for limits on cross section times branching ratios for m_{H^+} = 0.25–3 TeV.

[11] HAYRAPETYAN 24AV search for production of scalar resonance decaying to $W^\pm\gamma$ with $W \rightarrow \ell\nu$ in 138 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 7 for limits on cross section times branching ratio for the mass range 0.3–2.0 TeV for a narrow and a broad width. Combined limits with TUMASYAN 22B are shown in Fig. 8.

[12] AAD 23AH search for vector boson fusion production of $H^\pm$ decaying to $H^\pm \rightarrow W^\pm Z \rightarrow \ell^\pm\nu\ell^+\ell^-$ in 139 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 9 for limits on cross section times branching ratio in the Georgi-Machacek model for $m_{H^\pm}$ = 0.2–1.0 TeV, and also for limits on the triplet vacuum expectation value fraction.

[13] AAD 23BB search for $t\overline{t}$ production followed by $t \rightarrow bH^+$, $H^+ \rightarrow c\overline{b}$ in 139 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 8 for limits on the product of branching ratios for m_{H^+} = 60–160 GeV.

[14] AAD 23BW search for $t \rightarrow bH^+$ from pair produced top quarks, with the decay chain $H^+ \rightarrow W^+A^0$, $A^0 \rightarrow \mu^+\mu^-$ using 139 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 5(b)-(d) for limits on the product of branching ratios for m_{H^+} = 120, 140, 160 GeV, and m_{A^0} = 15–72 GeV.

[15] TUMASYAN 23AV search for production of $H^\pm$ in association with a top quark, decaying to $H_2^0 W^\pm$, $H_2^0 \rightarrow \tau^+\tau^-$, using 138 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 9 for limits on production cross section times branching ratios for $m_{H^\pm}$ = 0.3–0.7 TeV and $m_{H_2^0}$ = 0.2 TeV.

[16] TUMASYAN 22B search for production of scalar resonance decaying to $W^\pm\gamma \rightarrow qq\gamma$ in 137 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 5 for limits on cross section times branching ratio for the mass range 0.7–6.0 TeV, assuming narrow width or Γ/M = 0.05.

[17] AAD 21V search for $\overline{t}bH^+$ associated production followed by $H^+ \rightarrow t\overline{b}$ in 139 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 6 for upper limits on cross section times branching ratio for m_{H^+} = 0.2–2 TeV. See also their Fig. 7 for the excluded region in the parameter space of the hMSSM and the following MSSM benchmark scenarios: M_h^{125}, $M_h^{125}(\widetilde{\chi})$, $M_h^{125}(\widetilde{\tau})$, M_h^{125}(alignment), $M_{h_1}^{125}$(CPV).

[18] SIRUNYAN 21W search for vector boson fusion production of H^+ decaying to $H^+ \rightarrow W^+Z \rightarrow \ell^+\nu\ell^+\ell^-$ in 137 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 8 for limits on cross section times branching ratio for m_{H^+} = 0.2–3.0 TeV, and also for limits on the fraction of the triplet vev contribution to the W mass in the Georgi-Machacek model.

[19] AAD 20W search for dijet resonances in events with isolated leptons using 139 fb^{-1} of pp collisions at E_{cm} = 13 TeV. As a byproduct, $H^+ \rightarrow t\overline{b}$ produced in association with $\overline{t}b$ is searched for. Limits on the product of cross section times branching ratio for m_{H^+} = 0.6–2 TeV are given in their Fig. 5(c).

[20] SIRUNYAN 20AO search for $H^+ \rightarrow t\overline{b}$ produced in association with $t(b)$ in all jet final states in 35.9 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 6 for limits on the product of cross section times branching ratio for m_{H^+} = 0.2–3 TeV. Limits for

s-channel production are also given for m_{H^+} = 0.8–3 TeV. See also Fig. 7 for the corresponding limits in scenarios in the minimal supersymmetric standard model. Cross section limits from combined results with SIRUNYAN 20AV are given in Fig. 8.

[21] SIRUNYAN 20AV search for $H^+ \rightarrow t\overline{b}$ produced in association with $t(b)$ in final states with one or two leptons, in 35.9 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 5 for limits on the product of cross section times branching ratio for m_{H^+} = 0.2–3 TeV, and their Fig. 6 for the corresponding limits in scenarios in the minimal supersymmetric standard model.

[22] SIRUNYAN 20BE search for $t \rightarrow bH^+$ followed by the decay $H^+ \rightarrow c\overline{s}$ in pair produced top quark events using 35.9 fb^{-1} of pp collisions at E_{cm} = 13 TeV. Limits on the branching ratio in the range 1.68–0.25% (95%CL) are given for m_{H^+} = 80–160 GeV, see their Fig. 4.

[23] SIRUNYAN 19AH search for H^+ in the decay of a pair-produced t quark, or in associated tbH^+ or nonresonant $b\overline{b}H^+W^-$ production, followed by $H^+ \rightarrow \tau^+\nu$, in 35.9 fb^{-1} of pp collisions at E_{cm} = 13 TeV. Upper limits on cross section times branching ratio between 6 pb and 5 fb (95% CL) are given for m_{H^+} = 80–3000 GeV (including the non-resonant production near the top quark mass), see their Fig. 6 (left). See their Fig. 6 (right) for the excluded regions in the $m_h^{\text{mod}-}$ scenario of the MSSM.

[24] SIRUNYAN 19BP search for vector boson fusion production of H^+ decaying to $H^+ \rightarrow W^+Z \rightarrow \ell^+\nu\ell^+\ell^-$ in 35.9 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 7 for limits on cross section times branching ratio for m_{H^+} = 0.3–2.0 TeV, and also for limits on the fraction of the triplet vev contribution to the W mass in the Georgi-Machacek model.

[25] SIRUNYAN 19CC search for $t \rightarrow bH^+$ from pair produced top quarks, with the decay chain $H^+ \rightarrow W^+A^0$, $A^0 \rightarrow \mu^+\mu^-$ in 35.9 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 2 for limits on the product of branching ratios for m_{A^0} = 15–75 GeV.

[26] SIRUNYAN 19CQ search for vector boson fusion production of H^+ decaying to $H^+ \rightarrow W^+Z \rightarrow \ell^+\nu q\overline{q}$ or $q\overline{q}\ell^+\ell^-$ in 35.9 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 5 for limits on cross section times branching ratio for m_{H^+} = 0.6–2.0 TeV, and also for limits on the triplet vacuum expectation value fraction in the Georgi-Machacek model.

[27] AABOUD 18BW search for $\overline{t}bH^+$ associated production or the decay $t \rightarrow bH^+$, followed by $H^+ \rightarrow \tau^+\nu$, in 36.1 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 8(a) for upper limits on cross section times branching ratio for m_{H^+} = 90–2000 GeV, and Fig. 8(b) for limits on B($t \rightarrow bH^+$) B($H^+ \rightarrow \tau^+\nu$) for m_{H^+} = 90–160 GeV. See also their Fig. 9 for the excluded region in the hMSSM parameter space.

[28] AABOUD 18CD search for $\overline{t}bH^+$ associated production followed by $H^+ \rightarrow t\overline{b}$ in 36.1 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 8 for upper limits on cross section times branching ratio for m_{H^+} = 0.2–2 TeV. See also their Fig. 9 for the excluded region in the parameter space of the $m_h^{\text{mod}-}$ and hMSSM scenarios of the MSSM. The theory predictions overlaid to the experimental limits to determine the excluded m_{H^+} range are shown without their respective uncertainty band.

[29] AABOUD 18CH search for vector boson fusion production of $H^\pm$ decaying to $H^\pm \rightarrow W^\pm Z \rightarrow \ell^\pm\nu\ell^+\ell^-$ in 36.1 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 7 for limits on cross section times branching ratio for $m_{H^\pm}$ = 0.2–0.9 TeV, and also for limits on the triplet vacuum expectation value fraction in the Georgi-Machacek model.

[30] HALLER 18 give 95% CL lower limits on m_{H^+} of 590 GeV in type II two Higgs doublet model from combined data (including an unpublished BELLE result) for B($b \rightarrow s\gamma$).

[31] SIRUNYAN 18DO search for $t\overline{t}$ production followed by $t \rightarrow bH^+$, $H^+ \rightarrow c\overline{b}$ in 19.7 fb^{-1} of pp collisions at E_{cm} = 8 TeV. See their Fig. 3 for upper limits on B($t \rightarrow$

$b H^+$) for m_{H^+} = 90–150 GeV assuming that B($H^+ \to c\overline{b}$) = 1 and B($t \to bH^+$) + B($t \to bW^+$) = 1.

[32] MISIAK 17 give 95% CL lower limits on m_{H^+} between 570 and 800 GeV in type II two Higgs doublet model from combined data (including an unpublished BELLE result) for B($b \to s(d)\gamma$).

[33] SIRUNYAN 17AE search for vector boson fusion production of $H^\pm$ decaying to $H^\pm \to W^\pm Z \to \ell^\pm \nu \ell^+ \ell^-$ in 15.2 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 3 for limits on cross section times branching ratio for $m_{H^\pm}$ = 0.2–2.0 TeV, and also for limits on the triplet vacuum expectation value fraction in the Georgi-Machacek model.

[34] AABOUD 16A search for $t(b)$ $H^\pm$ associated production followed by $H^+ \to \tau^+ \nu$ in 3.2 fb^{-1} of pp collisions at E_{cm} = 13 TeV. Upper limits on $\sigma(t(b)\ H^\pm)$ B($H^+ \to \tau\nu$) between 1.9 pb and 15 fb (95% CL) are given for m_{H^+} = 200–2000 GeV, see their Fig. 6. See their Fig. 7 for the excluded regions in the hMSSM scenario.

[35] AAD 16AJ search for $t(b)$ $H^\pm$ associated production followed by $H^\pm \to tb$ in 20.3 fb^{-1} of pp collisions at E_{cm} = 8 TeV. See their Fig. 6 for upper limits on $\sigma(t(b)\ H^\pm)$ B($H^+ \to tb$) for m_{H^+} = 200–600 GeV.

[36] AAD 16AJ search for $H^\pm$ production from quark-antiquark annihilation, followed by $H^\pm \to tb$, in 20.3 fb^{-1} of pp collisions at E_{cm} = 8 TeV. See their Fig. 10 for upper limits on $\sigma(H^\pm)$ B($H^+ \to tb$) for m_{H^+} = 400–3000 GeV.

[37] AAD 15AF search for $tH^\pm$ associated production followed by $H^\pm \to \tau^\pm \nu$ in 19.5 fb^{-1} of pp collisions at E_{cm} = 8 TeV. Upper limits on $\sigma(tH^\pm)$ B($H^+ \to \tau\nu$) between 760 and 4.5 fb (95% CL) are given for m_{H^+} = 180–1000 GeV. See their Fig. 8 for the excluded regions in different benchmark scenarios of the MSSM.

[38] AAD 15M search for vector boson fusion production of $H^\pm$ decaying to $H^\pm \to W^\pm Z \to q\overline{q}\ell^+\ell^-$ in 20.3 fb^{-1} of pp collisions at E_{cm} = 8 TeV. See their Fig. 2 for limits on cross section times branching ratio for $m_{H^\pm}$ = 200–1000 GeV, and Fig. 3 for limits on thetriplet vacuum expectation value fraction in the Georgi-Machacek model.

[39] KHACHATRYAN 15AX search for $tH^\pm$ associated production followed by $H^\pm \to tb$ in 19.7 fb^{-1} of pp collisions at E_{cm} = 8 TeV. Upper limits on $\sigma(tH^\pm)$ B($H^+ \to t\overline{b}$) between 2.0 and 0.13 pb (95% CL) are given for m_{H^+} = 180–600 GeV. See their Fig. 11 for the excluded regions in different benchmark scenarios of the MSSM.

[40] KHACHATRYAN 15AX search for $tH^\pm$ associated production followed by $H^\pm \to \tau^\pm \nu$ in 19.7 fb^{-1} of pp collisions at E_{cm} = 8 TeV. Upper limits on $\sigma(tH^\pm)$ B($H^+ \to \tau\nu$) between 380 and 25 fb (95% CL) are given for m_{H^+} = 180–600 GeV. See their Fig. 11 for the excluded regions in different benchmark scenarios of the MSSM.

[41] KHACHATRYAN 15BF search for $t\overline{t}$ production followed by $t \to bH^+$, $H^+ \to c\overline{s}$ in 19.7 fb^{-1} of pp collisions at E_{cm} = 8 TeV. Upper limits on B($t \to bH^+$) B($H^+ \to c\overline{s}$) between 1.2×10^{-2} and 6.5×10^{-2} (95% CL) are given for m_{H^+} = 90–160 GeV.

[42] AAD 14M search for the decay cascade $H_2^0 \to H^\pm W^\mp \to H^0 W^\pm W^\mp$, H^0 decaying to $b\overline{b}$ in 20.3 fb^{-1} of pp collisions at E_{cm} = 8 TeV. See their Table III for limits on cross section times branching ratio for $m_{H_2^0}$= 325–1025 GeV and m_{H^+}= 225–925 GeV.

[43] AALTONEN 14A measure B($t \to b\tau\nu$) = 0.096 ± 0.028 using 9 fb^{-1} of $p\overline{p}$ collisions at E_{cm} = 1.96 TeV. For m_{H^+}= 80–140 GeV, this measured value is translated to a limit B($t \to bH^+$) < 0.059 at 95% CL assuming B($H^+ \to \tau^+\nu$) = 1.

[44] AAD 13AC search for $t\overline{t}$ production followed by $t \to bH^+$, $H^+ \to c\overline{s}$ (flavor unidentified) in 4.7 fb^{-1} of pp collisions at E_{cm} = 7 TeV. Upper limits on B($t \to bH^+$) between 0.05 and 0.01 (95%CL) are given for m_{H^+}=90–150 GeV and B($H^+ \to c\overline{s}$)=1.

[45] AAD 13V search for $t\overline{t}$ production followed by $t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu$ through violation of lepton universality with 4.6 fb^{-1} of pp collisions at E_{cm} = 7 TeV. Upper limits on B($t \rightarrow bH^+$) between 0.032 and 0.044 (95% CL) are given for m_{H^+} = 90–140 GeV and B($H^+ \rightarrow \tau^+\nu$) = 1. By combining with AAD 12BH, the limits improve to 0.008 to 0.034 for m_{H^+} = 90–160 GeV. See their Fig. 7 for the excluded region in the m_h^{max} scenario of the MSSM.

[46] AAD 12BH search for $t\overline{t}$ production followed by $t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu$ with 4.6 fb^{-1} of pp collisions at E_{cm} = 7 TeV. Upper limits on B($t \rightarrow bH^+$) between 0.01 and 0.05 (95% CL) are given for m_{H^+} = 90–160 GeV and B($H^+ \rightarrow \tau^+\nu$) = 1. See their Fig. 8 for the excluded region in the m_h^{max} scenario of the MSSM.

[47] CHATRCHYAN 12AA search for $t\overline{t}$ production followed by $t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu$ with 2 fb^{-1} of pp collisions at E_{cm} = 7 TeV. Upper limits on B($t \rightarrow bH^+$) between 0.019 and 0.041 (95% CL) are given for m_{H^+} = 80–160 GeV and B($H^+ \rightarrow \tau^+\nu$)=1.

[48] AALTONEN 11P search in 2.7 fb^{-1} of $p\overline{p}$ collisions at E_{cm} = 1.96 TeV for the decay chain $t \rightarrow bH^+$, $H^+ \rightarrow W^+A^0$, $A^0 \rightarrow \tau^+\tau^-$ with m_{A^0} between 4 and 9 GeV. See their Fig. 4 for limits on B($t \rightarrow bH^+$) for 90 < m_{H^+} < 160 GeV.

[49] DESCHAMPS 10 make Type II two Higgs doublet model fits to weak leptonic and semileptonic decays, $b \rightarrow s\gamma$, B, B_s mixings, and $Z \rightarrow b\overline{b}$. The limit holds irrespective of tanβ.

[50] AALTONEN 09AJ search for $t \rightarrow bH^+$, $H^+ \rightarrow c\overline{s}$ in $t\overline{t}$ events in 2.2 fb^{-1} of $p\overline{p}$ collisions at E_{cm} = 1.96 TeV. Upper limits on B($t \rightarrow bH^+$) between 0.08 and 0.32 (95% CL) are given for m_{H^+} = 60–150 GeV and B($H^+ \rightarrow c\overline{s}$) = 1.

[51] ABAZOV 09AC search for $t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu$ in $t\overline{t}$ events in 0.9 fb^{-1} of $p\overline{p}$ collisions at E_{cm} = 1.96 TeV. Upper limits on B($t \rightarrow bH^+$) between 0.19 and 0.25 (95% CL) are given for m_{H^+} = 80–155 GeV and B($H^+ \rightarrow \tau^+\nu$) = 1. See their Fig. 4 for an excluded region in a MSSM scenario.

[52] ABAZOV 09AG measure $t\overline{t}$ cross sections in final states with ℓ + jets ($\ell = e$, μ), $\ell\ell$, and $\tau\ell$ in 1 fb^{-1} of $p\overline{p}$ collisions at E_{cm} = 1.96 TeV, which constrains possible $t \rightarrow bH^+$ branching fractions. Upper limits (95% CL) on B($t \rightarrow bH^+$) between 0.15 and 0.40 (0.48 and 0.57) are given for B($H^+ \rightarrow \tau^+\nu$) = 1 (B($H^+ \rightarrow c\overline{s}$) = 1) for m_{H^+} = 80–155 GeV.

[53] ABAZOV 09AI search for $t \rightarrow bH^+$ in $t\overline{t}$ events in 1 fb^{-1} of $p\overline{p}$ collisions at E_{cm} = 1.96 TeV. Final states with ℓ + jets ($\ell = e$, μ), $\ell\ell$, and $\tau\ell$ are examined. Upper limits on B($t \rightarrow bH^+$) (95% CL) between 0.15 and 0.19 (0.19 and 0.22) are given for B($H^+ \rightarrow \tau^+\nu$) = 1 (B($H^+ \rightarrow c\overline{s}$) = 1) for m_{H^+} = 80–155 GeV. For B($H^+ \rightarrow \tau^+\nu$) = 1 also a simultaneous extraction of B($t \rightarrow bH^+$) and the $t\overline{t}$ cross section is performed, yielding a limit on B($t \rightarrow bH^+$) between 0.12 and 0.26 for m_{H^+} = 80–155 GeV. See their Figs. 5–8 for excluded regions in several MSSM scenarios.

[54] ABAZOV 09P search for H^+ production by $q\overline{q}'$ annihilation followed by $H^+ \rightarrow t\overline{b}$ decay in 0.9 fb^{-1} of $p\overline{p}$ collisions at E_{cm} = 1.96 TeV. Cross section limits in several two-doublet models are given for m_{H^+} = 180–300 GeV. A region with 20 $\lesssim$ tanβ $\lesssim$ 70 is excluded (95% CL) for 180 GeV $\lesssim m_{H^+} \lesssim$ 184 GeV in type-I models.

[55] ABULENCIA 06E search for associated H^0W production in $p\overline{p}$ collisions at E_{cm} = 1.96 TeV. A fit is made for $t\overline{t}$ production processes in dilepton, lepton + jets, and lepton + τ final states, with the decays $t \rightarrow W^+b$ and $t \rightarrow H^+b$ followed by $H^+ \rightarrow \tau^+\nu$, $c\overline{s}$, $t^*\overline{b}$, or W^+H^0. Within the MSSM the search is sensitive to the region tanβ < 1 or

$>$ 30 in the mass range m_{H^+} = 80–160 GeV. See Fig. 2 for the excluded region in a certain MSSM scenario.

[56] ABDALLAH 04I search for $e^+ e^- \rightarrow H^+ H^-$ with $H^\pm$ decaying to $\tau\nu$, cs, or $W^* A^0$ in Type-I two-Higgs-doublet models.

[57] ABBIENDI 03 give a limit $m_{H^+} > 1.28\tan\beta$ GeV (95%CL) in Type II two-doublet models.

[58] ABAZOV 02B search for a charged Higgs boson in top decays with $H^+ \rightarrow \tau^+\nu$ at E_{cm}=1.8 TeV. For m_{H^+}=75 GeV, the region $\tan\beta > 32.0$ is excluded at 95%CL. The excluded mass region extends to over 140 GeV for $\tan\beta$ values above 100.

[59] BORZUMATI 02 point out that the decay modes such as $b\overline{b}W$, $A^0 W$, and supersymmetric ones can have substantial branching fractions in the mass range explored at LEP II and Tevatron.

[60] ABBIENDI 01Q give a limit $\tan\beta/m_{H^+} < 0.53$ GeV^{-1} (95%CL) in Type II two-doublet models.

[61] BARATE 01E give a limit $\tan\beta/m_{H^+} < 0.40$ GeV^{-1} (90% CL) in Type II two-doublet models. An independent measurement of $B \rightarrow \tau\nu_\tau X$ gives $\tan\beta/m_{H^+} < 0.49$ GeV^{-1} (90% CL).

[62] GAMBINO 01 use the world average data in the summer of 2001 B($b \rightarrow s\gamma$) = $(3.23 \pm 0.42) \times 10^{-4}$. The limit applies for Type-II two-doublet models.

[63] AFFOLDER 00I search for a charged Higgs boson in top decays with $H^+ \rightarrow \tau^+\nu$ in $p\overline{p}$ collisions at E_{cm}=1.8 TeV. The excluded mass region extends to over 120 GeV for $\tan\beta$ values above 100 and B($\tau\nu$) = 1. If B($t \rightarrow bH^+$) $\gtrsim$ 0.6, m_{H^+} up to 160 GeV is excluded. Updates ABE 97L.

[64] ABBOTT 99E search for a charged Higgs boson in top decays in $p\overline{p}$ collisions at E_{cm}=1.8 TeV, by comparing the observed $t\overline{t}$ cross section (extracted from the data assuming the dominant decay $t \rightarrow bW^+$) with theoretical expectation. The search is sensitive to regions of the domains $\tan\beta \lesssim 1$, 50 $< m_{H^+}$(GeV) $\lesssim$ 120 and $\tan\beta \gtrsim 40$, 50 $< m_{H^+}$ (GeV) $\lesssim$ 160. See Fig. 3 for the details of the excluded region.

[65] ACKERSTAFF 99D measure the Michel parameters ρ, ξ, η, and $\xi\delta$ in leptonic τ decays from $Z \rightarrow \tau\tau$. Assuming e-μ universality, the limit $m_{H^+} > 0.97 \tan\beta$ GeV (95%CL) is obtained for two-doublet models in which only one doublet couples to leptons.

[66] ACCIARRI 97F give a limit $m_{H^+} > 2.6 \tan\beta$ GeV (90% CL) from their limit on the exclusive $B \rightarrow \tau\nu_\tau$ branching ratio.

[67] AMMAR 97B measure the Michel parameter ρ from $\tau \rightarrow e\nu\nu$ decays and assumes e/μ universality to extract the Michel η parameter from $\tau \rightarrow \mu\nu\nu$ decays. The measurement is translated to a lower limit on m_{H^+} in a two-doublet model $m_{H^+} > 0.97 \tan\beta$ GeV (90% CL).

[68] COARASA 97 reanalyzed the constraint on the ($m_{H^\pm}$,$\tan\beta$) plane derived from the inclusive $B \rightarrow \tau\nu_\tau X$ branching ratio in GROSSMAN 95B and BUSKULIC 95. They show that the constraint is quite sensitive to supersymmetric one-loop effects.

[69] GUCHAIT 97 studies the constraints on m_{H^+} set by Tevatron data on $\ell\tau$ final states in $t\overline{t} \rightarrow (Wb)(Hb)$, $W \rightarrow \ell\nu$, $H \rightarrow \tau\nu_\tau$. See Fig. 2 for the excluded region.

[70] MANGANO 97 reconsiders the limit in ACCIARRI 97F including the effect of the potentially large $B_c \rightarrow \tau\nu_\tau$ background to $B_u \rightarrow \tau\nu_\tau$ decays. Stronger limits are obtained.

[71] STAHL 97 fit τ lifetime, leptonic branching ratios, and the Michel parameters and derive limit $m_{H^+} > 1.5 \tan\beta$ GeV (90% CL) for a two-doublet model. See also STAHL 94.

[72] ALAM 95 measure the inclusive $b \rightarrow s\gamma$ branching ratio at $\Upsilon(4S)$ and give B($b \rightarrow s\gamma$)$< 4.2 \times 10^{-4}$ (95% CL), which translates to the limit $m_{H^+} >[244 + 63/(\tan\beta)^{1.3}]$ GeV in the Type II two-doublet model. Light supersymmetric particles can invalidate this bound.

[73] BUSKULIC 95 give a limit $m_{H^+} > 1.9 \tan\beta$ GeV (90% CL) for Type-II models from $b \rightarrow \tau\nu_\tau X$ branching ratio, as proposed in GROSSMAN 94.

$H^{\pm}$ (charged Higgs) mass limits for $m_{H^+} >$ m(top)

Limits obtained at the LHC are given in the m_h^{mod-} benchmark scenario, see CARENA 13, and depend on the tanβ values.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
> 181	95	[1] AABOUD	18BW	ATLS	tanβ = 10
> 249	95	[1] AABOUD	18BW	ATLS	tanβ = 20
> 390	95	[1] AABOUD	18BW	ATLS	tanβ = 30
> 894	95	[1] AABOUD	18BW	ATLS	tanβ = 40
>1017	95	[1] AABOUD	18BW	ATLS	tanβ = 50
>1103	95	[1] AABOUD	18BW	ATLS	tanβ = 60

[1] AABOUD 18BW search for $\overline{t}bH^+$ associated production in 36.1 fb^{-1} of pp collisions at $E_{\rm cm}$ = 13 TeV. See also their Fig. 9 for the excluded region in the hMSSM parameter space.

$H^{\pm\pm}$ (doubly-charged Higgs boson) mass limits

This section covers searches for a doubly-charged Higgs boson with couplings to lepton pairs. Its weak isospin T_3 is thus restricted to two possibilities depending on lepton chiralities: $T_3(H^{\pm\pm}) = \pm1$, with the coupling $g_{\ell\ell}$ to $\ell^-_L \ell'^-_L$ and $\ell^+_R \ell'^+_R$ ("left-handed") and $T_3(H^{\pm\pm}) = 0$, with the coupling to $\ell^-_R \ell'^-_R$ and $\ell^+_L \ell'^+_L$ ("right-handed"). These Higgs bosons appear in some left-right symmetric models based on the gauge group SU(2)$_L$×SU(2)$_R$×U(1), the type-II seesaw model, and the Zee-Babu model. The two cases are listed separately in the following. Unless noted, one of the lepton flavor combinations is assumed to be dominant in the decay.

Limits for $H^{\pm\pm}$ with $T_3 = \pm1$

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>1020	95	[1] AAD	23AI	ATLS	$\ell\ell$
none 200–220	95	[2] AABOUD	19K	ATLS	$W^{\pm}W^{\pm}$
> 768	95	[3] AABOUD	18BC	ATLS	ee
> 846	95	[3] AABOUD	18BC	ATLS	$\mu\mu$
> 468	95	[4] AAD	15AG	ATLS	$e\mu$
> 400	95	[5] AAD	15AP	ATLS	$e\tau$
> 400	95	[5] AAD	15AP	ATLS	$\mu\tau$
> 169	95	[6] CHATRCHYAN	12AU	CMS	$\tau\tau$
> 300	95	[6] CHATRCHYAN	12AU	CMS	$\mu\tau$
> 293	95	[6] CHATRCHYAN	12AU	CMS	$e\tau$
> 395	95	[6] CHATRCHYAN	12AU	CMS	$\mu\mu$
> 391	95	[6] CHATRCHYAN	12AU	CMS	$e\mu$
> 382	95	[6] CHATRCHYAN	12AU	CMS	ee
> 98.1	95	[7] ABDALLAH	03	DLPH	$\tau\tau$
> 99.0	95	[8] ABBIENDI	02C	OPAL	$\tau\tau$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[9] AAD	25	ATLS	$W^{\pm}W^{\pm}$
		[10] AAD	24AD	ATLS	$W^{\pm}W^{\pm}$
> 350	95	[11] AAD	21U	ATLS	$W^{\pm}W^{\pm}$
> 230	95	[12] AAD	21U	ATLS	$H^{\pm\pm}H^{\mp}$ associated production, $H^{\pm\pm} \to W^{\pm}W^{\pm}$, $H^{\pm} \to W^{\pm}Z$

		[13] SIRUNYAN	21W	CMS	$W^{\pm}W^{\pm}$
		[14] SIRUNYAN	19CQ	CMS	$W^{\pm}W^{\pm}$
		[15] SIRUNYAN	18CC	CMS	$W^{\pm}W^{\pm}$
> 551	95	[4] AAD	15AG	ATLS	ee
> 516	95	[4] AAD	15AG	ATLS	$\mu\mu$
		[16] KANEMURA	15	RVUE	$W^{(*)\pm}W^{(*)\pm}$
		[17] KHACHATRY...	15D	CMS	$W^{\pm}W^{\pm}$
		[18] KANEMURA	14	RVUE	$W^{(*)\pm}W^{(*)\pm}$
> 330	95	[19] AAD	13Y	ATLS	$\mu\mu$
> 237	95	[19] AAD	13Y	ATLS	$\mu\tau$
> 355	95	[20] AAD	12AY	ATLS	$\mu\mu$
> 398	95	[21] AAD	12CQ	ATLS	$\mu\mu$
> 375	95	[21] AAD	12CQ	ATLS	$e\mu$
> 409	95	[21] AAD	12CQ	ATLS	ee
> 128	95	[22] ABAZOV	12A	D0	$\tau\tau$
> 144	95	[22] ABAZOV	12A	D0	$\mu\tau$
> 245	95	[23] AALTONEN	11AF	CDF	$\mu\mu$
> 210	95	[23] AALTONEN	11AF	CDF	$e\mu$
> 225	95	[23] AALTONEN	11AF	CDF	ee
> 114	95	[24] AALTONEN	08AA	CDF	$e\tau$
> 112	95	[24] AALTONEN	08AA	CDF	$\mu\tau$
> 168	95	[25] ABAZOV	08V	D0	$\mu\mu$
		[26] AKTAS	06A	H1	single $H^{\pm\pm}$
> 133	95	[27] ACOSTA	05L	CDF	stable
> 118.4	95	[28] ABAZOV	04E	D0	$\mu\mu$
		[29] ABBIENDI	03Q	OPAL	$E_{cm} \leq$ 209 GeV, single $H^{\pm\pm}$
		[30] GORDEEV	97	SPEC	muonium conversion
		[31] ASAKA	95	THEO	
> 45.6	95	[32] ACTON	92M	OPAL	
> 30.4	95	[33] ACTON	92M	OPAL	
none 6.5–36.6	95	[34] SWARTZ	90	MRK2	

[1] AAD 23AI search for $H^{++}H^{--}$ production using 139 fb^{-1} of pp collisions at E_{cm} = 13 TeV. Decay branching ratios B($H^{++} \rightarrow \ell^+\ell'^+$) for the six flavor combinations are assumed to be equal, adding up to unity. If the $T_3 = 0$ states are degenerate with the $T_3 = \pm1$ states, the limit becomes 1080 GeV.

[2] AABOUD 19K search for pair production of $H^{++}H^{--}$ followed by the decay $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$ in 36.1 fb^{-1} of pp collisions at E_{cm} = 13 TeV. The search is interpreted in a doublet-triplet extension of the scalar sector with a vev of 0.1 GeV, leading to B($H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$) = 1. See their Fig. 5 for limits on the cross section for $m_{H^{++}}$ between 200 and 700 GeV.

[3] See their Figs. 11(b) and 13 for limits with smaller branching ratios.

[4] AAD 15AG search for $H^{++}H^{--}$ production in 20.3 fb^{-1} of pp collisions at E_{cm} = 8 TeV. The limit assumes 100% branching ratio to the specified final state. See their Fig. 5 for limits for arbitrary branching ratios.

[5] AAD 15AP search for $H^{++}H^{--}$ production in 20.3 fb^{-1} of pp collisions at E_{cm} = 8 TeV. The limit assumes 100% branching ratio to the specified final state.

[6] CHATRCHYAN 12AU search for $H^{++}H^{--}$ production with 4.9 fb^{-1} of pp collisions at E_{cm} = 7 TeV. The limit assumes 100% branching ratio to the specified final state. See their Table 6 for limits including associated $H^{++}H^{-}$ production or assuming different scenarios.

[7] ABDALLAH 03 search for $H^{++}H^{--}$ pair production either followed by $H^{++} \rightarrow \tau^+\tau^+$, or decaying outside the detector.

[8] ABBIENDI 02C searches for pair production of $H^{++}H^{--}$, with $H^{\pm\pm} \rightarrow \ell^\pm\ell^\pm$ (ℓ,ℓ' = e,μ,τ). The limit holds for ℓ=ℓ'=τ, and becomes stronger for other combinations of leptonic final states. To ensure the decay within the detector, the limit only applies for $g(H\ell\ell) \gtrsim 10^{-7}$.

[9] AAD 25 combine AAD 23AH and AAD 24AD and derive limits on the isotriplet contribution to the gauge boson masses in the Georgi-Machacek model. See their Fig. 5(c).

[10] AAD 24AD search for production of $H^{\pm\pm}$ by $W^\pm W^\pm$ fusion, in the decay to $W^\pm W^\pm$, using 139 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 12 for limits on cross section times branching ratio for $m_{H^{\pm\pm}}$ between 0.2 and 3.0 TeV. Limits on the isotriplet contribution to the gauge-boson masses in the Georgi-Machacek model are also shown.

[11] AAD 21U search for pair production of $H^{++}H^{--}$ followed by the decay $H^{\pm\pm} \rightarrow W^\pm W^\pm$ in 139 fb^{-1} of pp collisions at E_{cm} = 13 TeV. The search is interpreted in a triplet extension of the SM Higgs sector with a triplet vev of 0.1 GeV, leading to B($H^{\pm\pm} \rightarrow W^\pm W^\pm$) = 1. See their Fig. 9(a) for limits on the cross section for $m_{H^{++}}$ between 200 and 600 GeV.

[12] AAD 21U search for associated production of $H^{\pm\pm}H^\mp$ followed by the decays $H^{\pm\pm} \rightarrow W^\pm W^\pm$, $H^\pm \rightarrow W^\pm Z$ in 139 fb^{-1} of pp collisions at E_{cm} = 13 TeV. $H^{\pm\pm}$ and $H^\pm$ are assumed to be degenerate in mass within 5 GeV. The search is interpreted in a triplet extension of the SM Higgs sector with a triplet vev of 0.1 GeV, leading to B($H^{\pm\pm} \rightarrow W^\pm W^\pm$) = 1. See their Fig. 9(b) for limits on the cross section for $m_{H^{++}}$ between 200 and 600 GeV.

[13] SIRUNYAN 21W search for vector boson fusion production of $H^{\pm\pm}$ decaying to $H^{\pm\pm} \rightarrow W^\pm W^\pm \rightarrow \ell^\pm\nu\ell^\pm\nu$ in 137 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 8 for limits on cross section times branching ratio for $m_{H^{++}}$ = 0.2–3.0 TeV.

[14] SIRUNYAN 19CQ search for $H^{\pm\pm}$ production by vector boson fusion followed by the decay $H^{\pm\pm} \rightarrow W^\pm W^\pm \rightarrow qq\ell\nu$ in 35.9 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 5 for limits on cross section times branching ratio for $m_{H^{\pm\pm}}$ between 0.6 and 2 TeV.

[15] SIRUNYAN 18CC search for $H^{\pm\pm}$ production by vector boson fusion followed by the decay $H^{\pm\pm} \rightarrow W^\pm W^\pm$ in 35.9 fb^{-1} of pp collisions at E_{cm} = 13 TeV. See their Fig. 3 for limits on cross section times branching ratio for $m_{H^{\pm\pm}}$ between 200 and 1000 GeV.

[16] KANEMURA 15 examine the case where H^{++} decays preferentially to $W^{(*)}W^{(*)}$ and estimate that a lower mass limit of $\sim$ 84 GeV can be derived from the same-sign dilepton data of AAD 15AG if H^{++} decays with 100% branching ratio to $W^{(*)}W^{(*)}$.

[17] KHACHATRYAN 15D search for $H^{\pm\pm}$ production by vector boson fusion followed by the decay $H^{\pm\pm} \rightarrow W^\pm W^\pm$ in 19.4 fb^{-1} of pp collisions at E_{cm} = 8 TeV. See their Fig. 4 for limits on cross section times branching ratio for $m_{H^{++}}$ between 160 and 800 GeV.

[18] KANEMURA 14 examine the case where H^{++} decays preferentially to $W^{(*)}W^{(*)}$ and estimate that a lower mass limit of $\sim$ 60 GeV can be derived from the same-sign dilepton data of AAD 12CY.

[19] AAD 13Y search for $H^{++}H^{--}$ production in a generic search of events with three charged leptons in 4.6 fb^{-1} of pp collisions at E_{cm} = 7 TeV. The limit assumes 100% branching ratio to the specified final state.

[20] AAD 12AY search for $H^{++}H^{--}$ production with 1.6 fb^{-1} of pp collisions at E_{cm} = 7 TeV. The limit assumes 100% branching ratio to the specified final state.

[21] AAD 12CQ search for $H^{++}H^{--}$ production with 4.7 fb^{-1} of pp collisions at E_{cm} = 7 TeV. The limit assumes 100% branching ratio to the specified final state. See their Table 1 for limits assuming smaller branching ratios.

[22] ABAZOV 12A search for $H^{++}H^{--}$ production in 7.0 fb^{-1} of $p\overline{p}$ collisions at E_{cm} = 1.96 TeV.

[23] AALTONEN 11AF search for $H^{++}H^{--}$ production in 6.1 fb^{-1} of $p\overline{p}$ collisions at E_{cm} = 1.96 TeV.

[24] AALTONEN 08AA search for $H^{++}H^{--}$ production in $p\overline{p}$ collisions at E_{cm}= 1.96 TeV. The limit assumes 100% branching ratio to the specified final state.

[25] ABAZOV 08V search for $H^{++}H^{--}$ production in $p\overline{p}$ collisions at E_{cm}= 1.96 TeV. The limit is for B($H \to \mu\mu$) = 1. The limit is updated in ABAZOV 12A.

[26] AKTAS 06A search for single $H^{\pm\pm}$ production in ep collisions at HERA. Assuming that H^{++} only couples to $e^+\mu^+$ with $g_{e\mu}$ = 0.3 (electromagnetic strength), a limit $m_{H^{++}}$ > 141 GeV (95% CL) is derived. For the case where H^{++} couples to $e\tau$ only the limit is 112 GeV.

[27] ACOSTA 05L search for $H^{++}H^{--}$ pair production in $p\overline{p}$ collisions. The limit is valid for $g_{\ell\ell'} < 10^{-8}$ so that the Higgs decays outside the detector.

[28] ABAZOV 04E search for $H^{++}H^{--}$ pair production in $H^{\pm\pm} \to \mu^\pm\mu^\pm$. The limit is valid for $g_{\mu\mu} \gtrsim 10^{-7}$.

[29] ABBIENDI 03Q searches for single $H^{\pm\pm}$ via direct production in $e^+e^- \to e^\mp e^\mp H^{\pm\pm}$, and via t-channel exchange in $e^+e^- \to e^+e^-$. In the direct case, and assuming B($H^{\pm\pm} \to \ell^\pm\ell^\pm$) = 1, a 95% CL limit on h_{ee} < 0.071 is set for $m_{H^{\pm\pm}}$ < 160 GeV (see Fig. 6). In the second case, indirect limits on h_{ee} are set for $m_{H^{\pm\pm}}$ < 2 TeV (see Fig. 8).

[30] GORDEEV 97 search for muonium-antimuonium conversion and find $G_{M\overline{M}}/G_F < 0.14$ (90% CL), where $G_{M\overline{M}}$ is the lepton-flavor violating effective four-fermion coupling. This limit may be converted to $m_{H^{++}}$ > 210 GeV if the Yukawa couplings of H^{++} to ee and $\mu\mu$ are as large as the weak gauge coupling. For similar limits on muonium-antimuonium conversion, see the muon Particle Listings.

[31] ASAKA 95 point out that H^{++} decays dominantly to four fermions in a large region of parameter space where the limit of ACTON 92M from the search of dilepton modes does not apply.

[32] ACTON 92M limit assumes $H^{\pm\pm} \to \ell^\pm\ell^\pm$ or $H^{\pm\pm}$ does not decay in the detector. Thus the region $g_{\ell\ell} \approx 10^{-7}$ is not excluded.

[33] ACTON 92M from $\Delta\Gamma_Z$ <40 MeV.

[34] SWARTZ 90 assume $H^{\pm\pm} \to \ell^\pm\ell^\pm$ (any flavor). The limits are valid for the Higgs-lepton coupling g($H\ell\ell$) $\gtrsim 7.4 \times 10^{-7}/[m_H/\text{GeV}]^{1/2}$. The limits improve somewhat for ee and $\mu\mu$ decay modes.

Limits for $H^{\pm\pm}$ with $T_3 = 0$

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>900	95	[1] AAD	23AI	ATLS	$\ell\ell$
> 58	95	[2] AABOUD	18BC	ATLS	ee
>723	95	[2] AABOUD	18BC	ATLS	$\mu\mu$
>402	95	[3] AAD	15AG	ATLS	$e\mu$
>290	95	[4] AAD	15AP	ATLS	$e\tau$
>290	95	[4] AAD	15AP	ATLS	$\mu\tau$
> 97.3	95	[5] ABDALLAH	03	DLPH	$\tau\tau$
> 97.3	95	[6] ACHARD	03F	L3	$\tau\tau$
> 98.5	95	[7] ABBIENDI	02C	OPAL	$\tau\tau$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>374	95	[3] AAD	15AG	ATLS	ee
>438	95	[3] AAD	15AG	ATLS	$\mu\mu$
>251	95	[8] AAD	12AY	ATLS	$\mu\mu$

>306	95	[9] AAD	12CQ	ATLS	$\mu\mu$
>310	95	[9] AAD	12CQ	ATLS	$e\mu$
>322	95	[9] AAD	12CQ	ATLS	ee
>113	95	[10] ABAZOV	12A	D0	$\mu\tau$
>205	95	[11] AALTONEN	11AF	CDF	$\mu\mu$
>190	95	[11] AALTONEN	11AF	CDF	$e\mu$
>205	95	[11] AALTONEN	11AF	CDF	ee
>145	95	[12] ABAZOV	08V	D0	$\mu\mu$
		[13] AKTAS	06A	H1	single $H^{\pm\pm}$
>109	95	[14] ACOSTA	05L	CDF	stable
> 98.2	95	[15] ABAZOV	04E	D0	$\mu\mu$
		[16] ABBIENDI	03Q	OPAL	$E_{cm} \leq 209$ GeV, single $H^{\pm\pm}$
		[17] GORDEEV	97	SPEC	muonium conversion
> 45.6	95	[18] ACTON	92M	OPAL	
> 25.5	95	[19] ACTON	92M	OPAL	
none 7.3–34.3	95	[20] SWARTZ	90	MRK2	

[1] AAD 23AI search for $H^{++}H^{--}$ production using 139 fb^{-1} of pp collisions at E_{cm} = 13 TeV. Decay branching ratios B($H^{++} \rightarrow \ell^+ \ell'^+$) for the six flavor combinations are assumed to be equal, adding up to unity.

[2] See their Figs. 12(b) and 14 for limits with smaller branching ratios.

[3] AAD 15AG search for $H^{++}H^{--}$ production in 20.3 fb^{-1} of pp collisions at E_{cm} = 8 TeV. The limit assumes 100% branching ratio to the specified final state. See their Fig. 5 for limits for arbitrary branching ratios.

[4] AAD 15AP search for $H^{++}H^{--}$ production in 20.3 fb^{-1} of pp collisions at E_{cm} = 8 TeV. The limit assumes 100% branching ratio to the specified final state.

[5] ABDALLAH 03 search for $H^{++}H^{--}$ pair production either followed by $H^{++} \rightarrow \tau^+\tau^+$, or decaying outside the detector.

[6] ACHARD 03F search for $e^+e^- \rightarrow H^{++}H^{--}$ with $H^{\pm\pm} \rightarrow \ell^\pm \ell'^\pm$. The limit holds for $\ell = \ell' = \tau$, and slightly different limits apply for other flavor combinations. The limit is valid for $g_{\ell\ell'} \gtrsim 10^{-7}$.

[7] ABBIENDI 02C searches for pair production of $H^{++}H^{--}$, with $H^{\pm\pm} \rightarrow \ell^\pm \ell^\pm$ (ℓ,ℓ' = e,μ,τ). the limit holds for ℓ=ℓ'=τ, and becomes stronger for other combinations of leptonic final states. To ensure the decay within the detector, the limit only applies for $g(H\ell\ell) \gtrsim 10^{-7}$.

[8] AAD 12AY search for $H^{++}H^{--}$ production with 1.6 fb^{-1} of pp collisions at E_{cm} = 7 TeV. The limit assumes 100% branching ratio to the specified final state.

[9] AAD 12CQ search for $H^{++}H^{--}$ production with 4.7 fb^{-1} of pp collisions at E_{cm} = 7 TeV. The limit assumes 100% branching ratio to the specified final state. See their Table 1 for limits assuming smaller branching ratios.

[10] ABAZOV 12A search for $H^{++}H^{--}$ production in 7.0 fb^{-1} of $p\overline{p}$ collisions at E_{cm} = 1.96 TeV.

[11] AALTONEN 11AF search for $H^{++}H^{--}$ production in 6.1 fb^{-1} of $p\overline{p}$ collisions at E_{cm} = 1.96 TeV.

[12] ABAZOV 08V search for $H^{++}H^{--}$ production in $p\overline{p}$ collisions at E_{cm}= 1.96 TeV. The limit is for B($H \rightarrow \mu\mu$) = 1. The limit is updated in ABAZOV 12A.

[13] AKTAS 06A search for single $H^{\pm\pm}$ production in ep collisions at HERA. Assuming that H^{++} only couples to $e^+\mu^+$ with $g_{e\mu}$ = 0.3 (electromagnetic strength), a limit $m_{H^{++}} > 141$ GeV (95% CL) is derived. For the case where H^{++} couples to $e\tau$ only the limit is 112 GeV.

[14] ACOSTA 05L search for $H^{++}H^{--}$ pair production in $p\overline{p}$ collisions. The limit is valid for $g_{\ell\ell'} < 10^{-8}$ so that the Higgs decays outside the detector.

[15] ABAZOV 04E search for $H^{++} H^{--}$ pair production in $H^{\pm\pm} \rightarrow \mu^{\pm}\mu^{\pm}$. The limit is valid for $g_{\mu\mu} \gtrsim 10^{-7}$.

[16] ABBIENDI 03Q searches for single $H^{\pm\pm}$ via direct production in $e^+ e^- \rightarrow e^{\mp} e^{\mp} H^{\pm\pm}$, and via t-channel exchange in $e^+ e^- \rightarrow e^+ e^-$. In the direct case, and assuming B($H^{\pm\pm} \rightarrow \ell^{\pm}\ell^{\pm}$) = 1, a 95% CL limit on $h_{ee} < 0.071$ is set for $m_{H^{\pm\pm}} < 160$ GeV (see Fig. 6). In the second case, indirect limits on h_{ee} are set for $m_{H^{\pm\pm}} < 2$ TeV (see Fig. 8).

[17] GORDEEV 97 search for muonium-antimuonium conversion and find $G_{M\overline{M}}/G_F < 0.14$ (90% CL), where $G_{M\overline{M}}$ is the lepton-flavor violating effective four-fermion coupling. This limit may be converted to $m_{H^{++}} > 210$ GeV if the Yukawa couplings of H^{++} to ee and $\mu\mu$ are as large as the weak gauge coupling. For similar limits on muonium-antimuonium conversion, see the muon Particle Listings.

[18] ACTON 92M limit assumes $H^{\pm\pm} \rightarrow \ell^{\pm}\ell^{\pm}$ or $H^{\pm\pm}$ does not decay in the detector. Thus the region $g_{\ell\ell} \approx 10^{-7}$ is not excluded.

[19] ACTON 92M from $\Delta\Gamma_Z$ <40 MeV.

[20] SWARTZ 90 assume $H^{\pm\pm} \rightarrow \ell^{\pm}\ell^{\pm}$ (any flavor). The limits are valid for the Higgs-lepton coupling g($H\ell\ell$) $\gtrsim 7.4 \times 10^{-7}/[m_H/\text{GeV}]^{1/2}$. The limits improve somewhat for ee and $\mu\mu$ decay modes.

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