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

CONTENTS:

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

Unless otherwise stated, LEP limits assume $B(H^+ \to \tau^+\nu)+B(H^+ \to c\overline{s})=1$, 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have conclusively ruled out the existence of a charged Higgs in the region $m_{H^+} \lesssim 45$ GeV, and are meanwhile superseded by the searches in higher energy e^+e^- collisions at LEP.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	$e^+e^- \to H^+H^-$, $E_{cm} \leq$ 209GeV
> 76.3	95	[4] ABBIENDI	12	OPAL	$e^+e^- \to H^+H^-$, $E_{cm} \leq$ 209GeV
> 74.4	95	ABDALLAH	04I	DLPH	$E_{cm} \leq 209$ GeV
> 76.5	95	ACHARD	03E	L3	$E_{cm} \leq 209$ GeV
> 79.3	95	HEISTER	02P	ALEP	$E_{cm} \leq 209$ GeV

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

		[5] AAD	21V	ATLS	$\overline{t}bH^+$, $H^+ \to t\overline{b}$
		[6] SIRUNYAN	21W	CMS	$H^+ \to W^+ Z$
		[7] AAD	20W	ATLS	$H^+ \to t\overline{b}$
		[8] SIRUNYAN	20AO	CMS	$H^+ \to t\overline{b}$
		[9] SIRUNYAN	20AV	CMS	$H^+ \to t\overline{b}$
		[10] SIRUNYAN	20BE	CMS	$t \to bH^+$, $H^+ \to c\overline{s}$
		[11] SIRUNYAN	19AH	CMS	$H^+ \to \tau^+\nu$
		[12] SIRUNYAN	19BP	CMS	$H^+ \to W^+ Z$
		[13] SIRUNYAN	19CC	CMS	$t \to bH^+$, $H^+ \to W^+ A^0$, $A^0 \to \mu^+\mu^-$
		[14] SIRUNYAN	19CQ	CMS	$H^+ \to W^+ Z$
		[15] AABOUD	18BW	ATLS	$\overline{t}bH^+$ or $t \to bH^+$, $H^+ \to \tau^+\nu$
		[16] AABOUD	18CD	ATLS	$\overline{t}bH^+$, $H^+ \to t\overline{b}$
		[17] AABOUD	18CH	ATLS	$H^\pm \to W^\pm Z$
		[18] HALLER	18	RVUE	$b \to s\gamma$
		[19] SIRUNYAN	18DO	CMS	$t \to bH^+$, $H^+ \to c\overline{b}$
		[20] MISIAK	17	RVUE	$b \to s(d)\gamma$
		[21] SIRUNYAN	17AE	CMS	$H^\pm \to W^\pm Z$
		[22] AABOUD	16A	ATLS	$t(b)$ H^+, $H^+ \to \tau^+\nu$
		[23] AAD	16AJ	ATLS	$t(b)$ H^+, $H^+ \to t\overline{b}$
		[24] AAD	16AJ	ATLS	$qq \to H^+$, $H^+ \to t\overline{b}$
		[25] AAD	15AF	ATLS	$tH^\pm$
		[26] AAD	15M	ATLS	$H^\pm \to W^\pm Z$
		[27] KHACHATRY...	15AX	CMS	tH^+, $H^+ \to t\overline{b}$
		[28] KHACHATRY...	15AX	CMS	$tH^\pm$, $H^\pm \to \tau^\pm\nu$
		[29] KHACHATRY...	15BF	CMS	$t \to bH^+$, $H^+ \to c\overline{s}$
		[30] AAD	14M	ATLS	$H^0_2 \to H^\pm W^\mp \to H^0 W^\pm W^\mp$, $H^0 \to b\overline{b}$
		[31] AALTONEN	14A	CDF	$t \to b\tau\nu$
		[32] AAD	13AC	ATLS	$t \to bH^+$
		[33] AAD	13V	ATLS	$t \to bH^+$, lepton non-universality
		[34] AAD	12BH	ATLS	$t \to bH^+$
		[35] CHATRCHYAN	12AA	CMS	$t \to bH^+$
		[36] AALTONEN	11P	CDF	$t \to bH^+$, $H^+ \to W^+ A^0$
>316	95	[37] DESCHAMPS	10	RVUE	Type II, flavor physics data
		[38] AALTONEN	09AJ	CDF	$t \to bH^+$
		[39] ABAZOV	09AC	D0	$t \to bH^+$
		[40] ABAZOV	09AG	D0	$t \to bH^+$
		[41] ABAZOV	09AI	D0	$t \to bH^+$
		[42] ABAZOV	09P	D0	$H^+ \to t\overline{b}$
		[43] ABULENCIA	06E	CDF	$t \to bH^+$
$>$ 92.0	95	ABBIENDI	04	OPAL	$B(\tau\nu) = 1$
$>$ 76.7	95	[44] ABDALLAH	04I	DLPH	Type I
		[45] ABBIENDI	03	OPAL	$\tau \to \mu\overline{\nu}\nu$, $e\overline{\nu}\nu$
		[46] ABAZOV	02B	D0	$t \to bH^+$, $H \to \tau\nu$
		[47] BORZUMATI	02	RVUE	

		[48] ABBIENDI	01Q	OPAL	$B \to \tau \nu_\tau X$
		[49] BARATE	01E	ALEP	$B \to \tau \nu_\tau$
>315	99	[50] GAMBINO	01	RVUE	$b \to s\gamma$
		[51] AFFOLDER	00I	CDF	$t \to bH^+$, $H \to \tau\nu$
> 59.5	95	ABBIENDI	99E	OPAL	$E_{cm} \leq 183$ GeV
		[52] ABBOTT	99E	D0	$t \to bH^+$
		[53] ACKERSTAFF	99D	OPAL	$\tau \to e\nu\nu$, $\mu\nu\nu$
		[54] ACCIARRI	97F	L3	$B \to \tau \nu_\tau$
		[55] AMMAR	97B	CLEO	$\tau \to \mu\nu\nu$
		[56] COARASA	97	RVUE	$B \to \tau \nu_\tau X$
		[57] GUCHAIT	97	RVUE	$t \to bH^+$, $H \to \tau\nu$
		[58] MANGANO	97	RVUE	$B_{u(c)} \to \tau \nu_\tau$
		[59] STAHL	97	RVUE	$\tau \to \mu\nu\nu$
>244	95	[60] ALAM	95	CLE2	$b \to s\gamma$
		[61] 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 21V search for $\overline{t}bH^+$ associated production followed by $H^+ \to t\overline{b}$ 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).

[6] SIRUNYAN 21W search for vector boson fusion production of H^+ decaying to $H^+ \to W^+ Z \to \ell^+\nu\ell^+\ell^-$ 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.

[7] 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, $H^+ \to t\overline{b}$ 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).

[8] 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.

[9] 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.

[10] 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.

[11] 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.

[12] 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.

[13] 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.

[14] 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.

[15] 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.

[16] 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.

[17] 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.

[18] 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($b \rightarrow s\gamma$).

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

[20] 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($b \to s(d)\gamma$).

[21] 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.

[22] 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.

[23] 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.

[24] 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.

[25] 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.

[26] 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.

[27] 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.

[28] 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.

[29] 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.

[30] 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.

[31] 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.

[32] 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.

[33] AAD 13V search for $t\overline{t}$ production followed by $t \to bH^+$, $H^+ \to \tau^+\nu$ through violation of lepton universality with 4.6 fb^{-1} of pp collisions at E_{cm} = 7 TeV. Upper limits on B($t \to bH^+$) between 0.032 and 0.044 (95% CL) are given for m_{H^+} = 90–140 GeV and B($H^+ \to \tau^+\nu$) = 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.

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

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

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

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

[38] AALTONEN 09AJ search for $t \to bH^+$, $H^+ \to c\overline{s}$ 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($t \to bH^+$) between 0.08 and 0.32 (95% CL) are given for m_{H^+} = 60–150 GeV and B($H^+ \to c\overline{s}$) = 1.

[39] ABAZOV 09AC search for $t \to bH^+$, $H^+ \to \tau^+\nu$ 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($t \to bH^+$) between 0.19 and 0.25 (95% CL) are given for m_{H^+} = 80–155 GeV and B($H^+ \to \tau^+\nu$) = 1. See their Fig. 4 for an excluded region in a MSSM scenario.

[40] 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 $t \to bH^+$ branching fractions. Upper limits (95% CL) on B($t \to bH^+$) between 0.15 and 0.40 (0.48 and 0.57) are given for B($H^+ \to \tau^+\nu$) = 1 (B($H^+ \to c\overline{s}$) = 1) for m_{H^+} = 80–155 GeV.

[41] ABAZOV 09AI search for $t \to bH^+$ 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($t \to bH^+$) (95% CL) between 0.15 and 0.19 (0.19 and 0.22) are given for B($H^+ \to \tau^+\nu$) = 1 (B($H^+ \to c\overline{s}$) = 1) for m_{H^+} = 80–155 GeV. For B($H^+ \to \tau^+\nu$) = 1 also a simultaneous extraction of B($t \to bH^+$) and the $t\overline{t}$ cross section is performed, yielding a limit on B($t \to bH^+$) between 0.12 and 0.26 for m_{H^+} = 80–155 GeV. See their Figs. 5–8 for excluded regions in several MSSM scenarios.

[42] ABAZOV 09P search for H^+ production by $q\overline{q}'$ annihilation followed by $H^+ \to t\overline{b}$ 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 $20 \lesssim \tan\beta \lesssim 70$ is excluded (95% CL) for 180 GeV $\lesssim m_{H^+} \lesssim$ 184 GeV in type-I models.

[43] ABULENCIA 06E search for associated $H^0 W$ 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 $t \to W^+ b$ and $t \to H^+ b$ followed by $H^+ \to \tau^+\nu$, $c\overline{s}$, $t^*\overline{b}$, or W^+H^0. Within the MSSM the search is sensitive to the region $\tan\beta < 1$ or

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

[44] 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.

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

[46] 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.

[47] 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.

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

[49] 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).

[50] 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.

[51] 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.

[52] 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.

[53] 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.

[54] 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.

[55] 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).

[56] 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.

[57] 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.

[58] 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.

[59] 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.

[60] 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.

[61] 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 $\overline{t} b H^+$ associated production in 36.1 fb^{-1} of pp collisions at E_{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
>220	95	[1] AABOUD	19K	ATLS	$W^{\pm} W^{\pm}$
>768	95	[2] AABOUD	18BC	ATLS	$e e$
>846	95	[2] AABOUD	18BC	ATLS	$\mu\mu$
>468	95	[3] AAD	15AG	ATLS	$e\mu$
>400	95	[4] AAD	15AP	ATLS	$e\tau$
>400	95	[4] AAD	15AP	ATLS	$\mu\tau$
>169	95	[5] CHATRCHYAN	12AU	CMS	$\tau\tau$
>300	95	[5] CHATRCHYAN	12AU	CMS	$\mu\tau$
>293	95	[5] CHATRCHYAN	12AU	CMS	$e\tau$
>395	95	[5] CHATRCHYAN	12AU	CMS	$\mu\mu$
>391	95	[5] CHATRCHYAN	12AU	CMS	$e\mu$
>382	95	[5] CHATRCHYAN	12AU	CMS	$e e$
> 98.1	95	[6] ABDALLAH	03	DLPH	$\tau\tau$
> 99.0	95	[7] ABBIENDI	02C	OPAL	$\tau\tau$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>350	95	[8] AAD	21U	ATLS	$W^{\pm} W^{\pm}$
>230	95	[9] AAD	21U	ATLS	$H^{\pm\pm} H^{\mp}$ associated production, $H^{\pm\pm} \to W^{\pm} W^{\pm}$, $H^{\pm} \to W^{\pm} Z$

		[10] SIRUNYAN	21W	CMS	$W^\pm W^\pm$
		[11] SIRUNYAN	19CQ	CMS	$W^\pm W^\pm$
		[12] SIRUNYAN	18CC	CMS	$W^\pm W^\pm$
>551	95	[3] AAD	15AG	ATLS	$e e$
>516	95	[3] AAD	15AG	ATLS	$\mu\mu$
		[13] KANEMURA	15	RVUE	$W^{(*)\pm} W^{(*)\pm}$
		[14] KHACHATRY...	15D	CMS	$W^\pm W^\pm$
		[15] KANEMURA	14	RVUE	$W^{(*)\pm} W^{(*)\pm}$
>330	95	[16] AAD	13Y	ATLS	$\mu\mu$
>237	95	[16] AAD	13Y	ATLS	$\mu\tau$
>355	95	[17] AAD	12AY	ATLS	$\mu\mu$
>398	95	[18] AAD	12CQ	ATLS	$\mu\mu$
>375	95	[18] AAD	12CQ	ATLS	$e\mu$
>409	95	[18] AAD	12CQ	ATLS	$e e$
>128	95	[19] ABAZOV	12A	D0	$\tau\tau$
>144	95	[19] ABAZOV	12A	D0	$\mu\tau$
>245	95	[20] AALTONEN	11AF	CDF	$\mu\mu$
>210	95	[20] AALTONEN	11AF	CDF	$e\mu$
>225	95	[20] AALTONEN	11AF	CDF	$e e$
>114	95	[21] AALTONEN	08AA	CDF	$e\tau$
>112	95	[21] AALTONEN	08AA	CDF	$\mu\tau$
>168	95	[22] ABAZOV	08V	D0	$\mu\mu$
		[23] AKTAS	06A	H1	single $H^{\pm\pm}$
>133	95	[24] ACOSTA	05L	CDF	stable
>118.4	95	[25] ABAZOV	04E	D0	$\mu\mu$
		[26] ABBIENDI	03Q	OPAL	$E_{cm} \leq$ 209 GeV, single $H^{\pm\pm}$
		[27] GORDEEV	97	SPEC	muonium conversion
		[28] ASAKA	95	THEO	
> 45.6	95	[29] ACTON	92M	OPAL	
> 30.4	95	[30] ACTON	92M	OPAL	
none 6.5–36.6	95	[31] SWARTZ	90	MRK2	

[1] 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 $p p$ 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.

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

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

[5] CHATRCHYAN 12AU search for $H^{++} H^{--}$ production with 4.9 fb^{-1} of $p p$ 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.

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

[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 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 $E_{\rm cm}$ = 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.

[9] 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 $E_{\rm cm}$ = 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.

[10] 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 $E_{\rm cm}$ = 13 TeV. See their Fig. 8 for limits on cross section times branching ratio for $m_{H^{++}}$ = 0.2–3.0 TeV.

[11] 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 $E_{\rm cm}$ = 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.

[12] 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 $E_{\rm cm}$ = 13 TeV. See their Fig. 3 for limits on cross section times branching ratio for $m_{H^{\pm\pm}}$ between 200 and 1000 GeV.

[13] 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 $W^{(*)}W^{(*)}$.

[14] 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 $E_{\rm cm}$ = 8 TeV. See their Fig. 4 for limits on cross section times branching ratio for $m_{H^{++}}$ between 160 and 800 GeV.

[15] 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.

[16] 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 $E_{\rm cm}$ = 7 TeV. The limit assumes 100% branching ratio to the specified final state.

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

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

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

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

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

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

[23] 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.

[24] 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.

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

[26] 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).

[27] 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.

[28] 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.

[29] 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.

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

[31] 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.

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

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
> 58	95	[1] AABOUD	18BC	ATLS	ee
>723	95	[1] AABOUD	18BC	ATLS	$\mu\mu$
>402	95	[2] AAD	15AG	ATLS	$e\mu$
>290	95	[3] AAD	15AP	ATLS	$e\tau$
>290	95	[3] AAD	15AP	ATLS	$\mu\tau$
> 97.3	95	[4] ABDALLAH	03	DLPH	$\tau\tau$
> 97.3	95	[5] ACHARD	03F	L3	$\tau\tau$
> 98.5	95	[6] ABBIENDI	02C	OPAL	$\tau\tau$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>374	95	[2] AAD	15AG	ATLS	ee
>438	95	[2] AAD	15AG	ATLS	$\mu\mu$
>251	95	[7] AAD	12AY	ATLS	$\mu\mu$
>306	95	[8] AAD	12CQ	ATLS	$\mu\mu$
>310	95	[8] AAD	12CQ	ATLS	$e\mu$
>322	95	[8] AAD	12CQ	ATLS	ee
>113	95	[9] ABAZOV	12A	D0	$\mu\tau$
>205	95	[10] AALTONEN	11AF	CDF	$\mu\mu$
>190	95	[10] AALTONEN	11AF	CDF	$e\mu$
>205	95	[10] AALTONEN	11AF	CDF	ee

>145	95	[11] ABAZOV	08V	D0	$\mu\mu$
		[12] AKTAS	06A	H1	single $H^{\pm\pm}$
>109	95	[13] ACOSTA	05L	CDF	stable
> 98.2	95	[14] ABAZOV	04E	D0	$\mu\mu$
		[15] ABBIENDI	03Q	OPAL	$E_{cm} \leq 209$ GeV, single $H^{\pm\pm}$
		[16] GORDEEV	97	SPEC	muonium conversion
> 45.6	95	[17] ACTON	92M	OPAL	
> 25.5	95	[18] ACTON	92M	OPAL	
none 7.3–34.3	95	[19] SWARTZ	90	MRK2	

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

[2] 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.

[3] 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.

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

[5] 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 $g_{\ell\ell'} \gtrsim 10^{-7}$.

[6] 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 $g(H\ell\ell) \gtrsim 10^{-7}$.

[7] 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.

[8] 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.

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

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

[11] 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.

[12] 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.

[13] 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.

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

[15] 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).

[16] 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.

[17] 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.

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

[19] 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.

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SIRUNYAN	20AV	JHEP 2001 096	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	20BE	PR D102 072001	A.M. Sirunyan *et al.*	(CMS Collab.)
AABOUD	19K	EPJ C79 58	M. Aaboud *et al.*	(ATLAS Collab.)
SIRUNYAN	19AH	JHEP 1907 142	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	19BP	PL B795 281	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	19CC	PRL 123 131802	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	19CQ	PL B798 134985	A.M. Sirunyan *et al.*	(CMS Collab.)
AABOUD	18BC	EPJ C78 199	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	18BW	JHEP 1809 139	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	18CD	JHEP 1811 085	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	18CH	PL B787 68	M. Aaboud *et al.*	(ATLAS Collab.)
HALLER	18	EPJ C78 675	J. Haller *et al.*	(Gfitter Group)
SIRUNYAN	18CC	PRL 120 081801	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	18DO	JHEP 1811 115	A.M. Sirunyan *et al.*	(CMS Collab.)
MISIAK	17	EPJ C77 201	M. Misiak, M. Steinhauser	
SIRUNYAN	17AE	PRL 119 141802	A.M. Sirunyan *et al.*	(CMS Collab.)
AABOUD	16A	PL B759 555	M. Aaboud *et al.*	(ATLAS Collab.)
AAD	16AJ	JHEP 1603 127	G. Aad *et al.*	(ATLAS Collab.)
AAD	15AF	JHEP 1503 088	G. Aad *et al.*	(ATLAS Collab.)
AAD	15AG	JHEP 1503 041	G. Aad *et al.*	(ATLAS Collab.)
AAD	15AP	JHEP 1508 138	G. Aad *et al.*	(ATLAS Collab.)
AAD	15M	PRL 114 231801	G. Aad *et al.*	(ATLAS Collab.)
KANEMURA	15	PTEP 2015 051B02	S. Kanemura *et al.*	
KHACHATRY...	15AX	JHEP 1511 018	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	15BF	JHEP 1512 178	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	15D	PRL 114 051801	V. Khachatryan *et al.*	(CMS Collab.)
AAD	14M	PR D89 032002	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	14A	PR D89 091101	T. Aaltonen *et al.*	(CDF Collab.)
KANEMURA	14	PR D90 115018	S. Kanemura *et al.*	
AAD	13AC	EPJ C73 2465	G. Aad *et al.*	(ATLAS Collab.)
AAD	13V	JHEP 1303 076	G. Aad *et al.*	(ATLAS Collab.)
AAD	13Y	PR D87 052002	G. Aad *et al.*	(ATLAS Collab.)
CARENA	13	EPJ C73 2552	M. Carena *et al.*	
LEP	13	EPJ C73 2463	LEP Collabs	(ALEPH, DELPHI, L3, OPAL, LEP)
AAD	12AY	PR D85 032004	G. Aad *et al.*	(ATLAS Collab.)
AAD	12BH	JHEP 1206 039	G. Aad *et al.*	(ATLAS Collab.)
AAD	12CQ	EPJ C72 2244	G. Aad *et al.*	(ATLAS Collab.)
AAD	12CY	JHEP 1212 007	G. Aad *et al.*	(ATLAS Collab.)
ABAZOV	12A	PRL 108 021801	V.M. Abazov *et al.*	(D0 Collab.)
ABBIENDI	12	EPJ C72 2076	G. Abbiendi *et al.*	(OPAL Collab.)
CHATRCHYAN	12AA	JHEP 1207 143	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12AU	EPJ C72 2189	S. Chatrchyan *et al.*	(CMS Collab.)
AALTONEN	11AF	PRL 107 181801	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	11P	PRL 107 031801	T. Aaltonen *et al.*	(CDF Collab.)
DESCHAMPS	10	PR D82 073012	O. Deschamps *et al.*	(CLER, ORSAY, LAPP)
AALTONEN	09AJ	PRL 103 101803	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	09AC	PR D80 051107	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	09AG	PR D80 071102	V.M. Abazov *et al.*	(D0 Collab.)

ABAZOV	09AI	PL B682 278	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	09P	PRL 102 191802	V.M. Abazov *et al.*	(D0 Collab.)
AALTONEN	08AA	PRL 101 121801	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	08V	PRL 101 071803	V.M. Abazov *et al.*	(D0 Collab.)
ABULENCIA	06E	PRL 96 042003	A. Abulencia *et al.*	(CDF Collab.)
AKTAS	06A	PL B638 432	A. Aktas *et al.*	(H1 Collab.)
ACOSTA	05L	PRL 95 071801	D. Acosta *et al.*	(CDF Collab.)
ABAZOV	04E	PRL 93 141801	V.M. Abazov *et al.*	(D0 Collab.)
ABBIENDI	04	EPJ C32 453	G. Abbiendi *et al.*	(OPAL Collab.)
ABDALLAH	04I	EPJ C34 399	J. Abdallah *et al.*	(DELPHI Collab.)
ABBIENDI	03	PL B551 35	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	03Q	PL B577 93	G. Abbiendi *et al.*	(OPAL Collab.)
ABDALLAH	03	PL B552 127	J. Abdallah *et al.*	(DELPHI Collab.)
ACHARD	03E	PL B575 208	P. Achard *et al.*	(L3 Collab.)
ACHARD	03F	PL B576 18	P. Achard *et al.*	(L3 Collab.)
ABAZOV	02B	PRL 88 151803	V.M. Abazov *et al.*	(D0 Collab.)
ABBIENDI	02C	PL B526 221	G. Abbiendi *et al.*	(OPAL Collab.)
BORZUMATI	02	PL B549 170	F.M. Borzumati, A. Djouadi	
HEISTER	02P	PL B543 1	A. Heister *et al.*	(ALEPH Collab.)
ABBIENDI	01Q	PL B520 1	G. Abbiendi *et al.*	(OPAL Collab.)
BARATE	01E	EPJ C19 213	R. Barate *et al.*	(ALEPH Collab.)
GAMBINO	01	NP B611 338	P. Gambino, M. Misiak	
AFFOLDER	00I	PR D62 012004	T. Affolder *et al.*	(CDF Collab.)
PDG	00	EPJ C15 1	D.E. Groom *et al.*	(PDG Collab.)
ABBIENDI	99E	EPJ C7 407	G. Abbiendi *et al.*	(OPAL Collab.)
ABBOTT	99E	PRL 82 4975	B. Abbott *et al.*	(D0 Collab.)
ACKERSTAFF	99D	EPJ C8 3	K. Ackerstaff *et al.*	(OPAL Collab.)
ABE	97L	PRL 79 357	F. Abe *et al.*	(CDF Collab.)
ACCIARRI	97F	PL B396 327	M. Acciarri *et al.*	(L3 Collab.)
AMMAR	97B	PRL 78 4686	R. Ammar *et al.*	(CLEO Collab.)
COARASA	97	PL B406 337	J.A. Coarasa, R.A. Jimenez, J. Sola	
GORDEEV	97	PAN 60 1164	V.A. Gordeev *et al.*	(PNPI)
		Translated from YAF 60 1291.		
GUCHAIT	97	PR D55 7263	M. Guchait, D.P. Roy	(TATA)
MANGANO	97	PL B410 299	M. Mangano, S. Slabospitsky	
STAHL	97	ZPHY C74 73	A. Stahl, H. Voss	(BONN)
PDG	96	PR D54 1	R. M. Barnett *et al.*	(PDG Collab.)
ALAM	95	PRL 74 2885	M.S. Alam *et al.*	(CLEO Collab.)
ASAKA	95	PL B345 36	T. Asaka, K.I. Hikasa	(TOHOK)
BUSKULIC	95	PL B343 444	D. Buskulic *et al.*	(ALEPH Collab.)
GROSSMAN	95B	PL B357 630	Y. Grossman, H. Haber, Y. Nir	
GROSSMAN	94	PL B332 373	Y. Grossman, Z. Ligeti	
STAHL	94	PL B324 121	A. Stahl	(BONN)
ACTON	92M	PL B295 347	P.D. Acton *et al.*	(OPAL Collab.)
SWARTZ	90	PRL 64 2877	M.L. Swartz *et al.*	(Mark II Collab.)