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

CONTENTS:

$H^{\pm}$ (Charged Higgs) MASS LIMITS

Unless otherwise stated, the limits below 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, tanβ 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.

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have conclusively ruled out the existence of a charged Higgs in the region $m_{H^+} \lesssim 45$ GeV, and are meanwhile superseded by the searches in higher energy $e^+ e^-$ collisions at LEP.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
> 80	95	[1] LEP	13	LEP	$e^+ e^- \to H^+ H^-$,$E_{cm} \leq$ 209GeV
> 76.3	95	[2] 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. • • •

		[3] AABOUD	16A	ATLS	$t(b)\ H^+$, $H^+ \rightarrow \tau^+ \nu$
		[4] AAD	16AJ	ATLS	$t(b)\ H^+$, $H^+ \rightarrow t\overline{b}$
		[5] AAD	16AJ	ATLS	$qq \rightarrow H^+$, $H^+ \rightarrow t\overline{b}$
		[6] AAD	15AF	ATLS	$t \rightarrow bH^+$
		[7] AAD	15AF	ATLS	$tH^\pm$
		[8] AAD	15M	ATLS	$H^\pm \rightarrow W^\pm Z$
		[9] KHACHATRY...	15AX	CMS	$t \rightarrow bH^+$, $H^+ \rightarrow \tau^+ \nu$
		[10] KHACHATRY...	15AX	CMS	tH^+, $H^+ \rightarrow t\overline{b}$
		[11] KHACHATRY...	15AX	CMS	$tH^\pm$, $H^\pm \rightarrow \tau^\pm \nu$
		[12] KHACHATRY...	15BF	CMS	$t \rightarrow bH^+$, $H^+ \rightarrow c\overline{s}$
		[13] AAD	14M	ATLS	$H_2^0 \rightarrow H^\pm W^\mp \rightarrow H^0 W^\pm W^\mp$, $H^0 \rightarrow b\overline{b}$
		[14] AALTONEN	14A	CDF	$t \rightarrow b\tau\nu$
		[15] AAD	13AC	ATLS	$t \rightarrow bH^+$
		[16] AAD	13V	ATLS	$t \rightarrow bH^+$, lepton non-universality
		[17] AAD	12BH	ATLS	$t \rightarrow bH^+$
		[18] CHATRCHYAN	12AA	CMS	$t \rightarrow bH^+$
		[19] AALTONEN	11P	CDF	$t \rightarrow bH^+$, $H^+ \rightarrow W^+ A^0$
>316	95	[20] DESCHAMPS	10	RVUE	Type II, flavor physics data
		[21] AALTONEN	09AJ	CDF	$t \rightarrow bH^+$
		[22] ABAZOV	09AC	D0	$t \rightarrow bH^+$
		[23] ABAZOV	09AG	D0	$t \rightarrow bH^+$
		[24] ABAZOV	09AI	D0	$t \rightarrow bH^+$
		[25] ABAZOV	09P	D0	$H^+ \rightarrow t\overline{b}$
		[26] ABULENCIA	06E	CDF	$t \rightarrow bH^+$
> 92.0	95	ABBIENDI	04	OPAL	$B(\tau\nu) = 1$
> 76.7	95	[27] ABDALLAH	04I	DLPH	Type I
		[28] ABBIENDI	03	OPAL	$\tau \rightarrow \mu\overline{\nu}\nu$, $e\overline{\nu}\nu$
		[29] ABAZOV	02B	D0	$t \rightarrow bH^+$, $H \rightarrow \tau\nu$
		[30] BORZUMATI	02	RVUE	
		[31] ABBIENDI	01Q	OPAL	$B \rightarrow \tau\nu_\tau X$
		[32] BARATE	01E	ALEP	$B \rightarrow \tau\nu_\tau$
>315	99	[33] GAMBINO	01	RVUE	$b \rightarrow s\gamma$
		[34] AFFOLDER	00I	CDF	$t \rightarrow bH^+$, $H \rightarrow \tau\nu$
> 59.5	95	ABBIENDI	99E	OPAL	$E_{cm} \leq 183$ GeV
		[35] ABBOTT	99E	D0	$t \rightarrow bH^+$
		[36] ACKERSTAFF	99D	OPAL	$\tau \rightarrow e\nu\nu$, $\mu\nu\nu$
		[37] ACCIARRI	97F	L3	$B \rightarrow \tau\nu_\tau$
		[38] AMMAR	97B	CLEO	$\tau \rightarrow \mu\nu\nu$
		[39] COARASA	97	RVUE	$B \rightarrow \tau\nu_\tau X$
		[40] GUCHAIT	97	RVUE	$t \rightarrow bH^+$, $H \rightarrow \tau\nu$
		[41] MANGANO	97	RVUE	$B_{u(c)} \rightarrow \tau\nu_\tau$
		[42] STAHL	97	RVUE	$\tau \rightarrow \mu\nu\nu$
>244	95	[43] ALAM	95	CLE2	$b \rightarrow s\gamma$
		[44] BUSKULIC	95	ALEP	$b \rightarrow \tau\nu_\tau X$

[1] LEP 13 give a limit that refers to the Type II scenario. The limit for B($H^+ \rightarrow \tau\nu$) = 1 is 94 GeV (95% CL), and for B($H^+ \rightarrow c s$) = 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 $H^+ \rightarrow A^0 W^*$ with $A^0 \rightarrow b\overline{b}$, 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.

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

[3] AABOUD 16A search for $t(b)\ H^{\pm}$ associated production followed by $H^+ \rightarrow \tau^+\nu$ in 3.2 fb^{-1} of pp collisions at E_{cm} = 13 TeV. Upper limits on $\sigma(t(b)\ H^{\pm})$ B($H^+ \rightarrow \tau\nu$) 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.

[4] AAD 16AJ search for $t(b)\ H^{\pm}$ associated production followed by $H^{\pm} \rightarrow t b$ 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($H^+ \rightarrow t b$) for m_{H^+} = 200–600 GeV.

[5] AAD 16AJ search for $H^{\pm}$ production from quark-antiquark annihilation, followed by $H^{\pm} \rightarrow t b$, 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($H^+ \rightarrow t b$) for m_{H^+} = 400–3000 GeV.

[6] AAD 15AF search for $t\overline{t}$ production followed by $t \rightarrow b H^+$, $H^+ \rightarrow \tau^+\nu$ in 19.5 fb^{-1} of pp collisions at E_{cm} = 8 TeV. Upper limits on B($t \rightarrow b H^+$) B($H^+ \rightarrow \tau\nu$) 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.

[7] AAD 15AF search for $t H^{\pm}$ associated production followed by $H^{\pm} \rightarrow \tau^{\pm}\nu$ in 19.5 fb^{-1} of pp collisions at E_{cm} = 8 TeV. Upper limits on $\sigma(t H^{\pm})$ B($H^+ \rightarrow \tau\nu$) 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.

[8] AAD 15M search for vector boson fusion production of $H^{\pm}$ decaying to $H^{\pm} \rightarrow W^{\pm} Z \rightarrow q\overline{q}\ell^+\ell^-$ 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.

[9] KHACHATRYAN 15AX search for $t\overline{t}$ production followed by $t \rightarrow b H^+$, $H^+ \rightarrow \tau^+\nu$ in 19.7 fb^{-1} of pp collisions at E_{cm} = 8 TeV. Upper limits on B($t \rightarrow b H^+$) B($H^+ \rightarrow \tau\nu$) 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.

[10] KHACHATRYAN 15AX search for $t H^{\pm}$ associated production followed by $H^{\pm} \rightarrow t b$ in 19.7 fb^{-1} of pp collisions at E_{cm} = 8 TeV. Upper limits on $\sigma(t H^{\pm})$ B($H^+ \rightarrow t\overline{b}$) 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.

[11] KHACHATRYAN 15AX search for $t H^{\pm}$ associated production followed by $H^{\pm} \rightarrow \tau^{\pm}\nu$ in 19.7 fb^{-1} of pp collisions at E_{cm} = 8 TeV. Upper limits on $\sigma(t H^{\pm})$ B($H^+ \rightarrow \tau\nu$) 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.

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

[13] AAD 14M search for the decay cascade $H_2^0 \rightarrow H^{\pm} W^{\mp} \rightarrow H^0 W^{\pm} W^{\mp}$, 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.

[14] 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.

[15] 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.

[16] 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.

[17] 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.

[18] 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.

[19] 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.

[20] 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.

[21] 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.

[22] 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.

[23] ABAZOV 09AG measure $t\overline{t}$ cross sections in final states with ℓ + jets (ℓ = 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.

[24] 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 (ℓ = 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.

[25] 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 $\lesssim$ tanβ $\lesssim$ 70 is excluded (95% CL) for 180 GeV $\lesssim$ m_{H^+} $\lesssim$ 184 GeV in type-I models.

[26] 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 $t \rightarrow W^+ b$ 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.

[27] 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.

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

[29] 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 tanβ > 32.0 is excluded at 95%CL. The excluded mass region extends to over 140 GeV for tanβ values above 100.

[30] 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.

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

[32] BARATE 01E give a limit tanβ/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 tanβ/m_{H^+} < 0.49 GeV^{-1} (90% CL).

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

[34] 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 tanβ 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.

[35] 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.

[36] 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 tanβ GeV (95%CL) is obtained for two-doublet models in which only one doublet couples to leptons.

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

[38] 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 tanβ GeV (90% CL).

[39] COARASA 97 reanalyzed the constraint on the ($m_{H^\pm}$,tanβ) 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.

[40] 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.

[41] 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.

[42] 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.

[43] ALAM 95 measure the inclusive $b \to s\gamma$ branching ratio at $\Upsilon(4S)$ and give B($b \to s\gamma$)$< 4.2 \times 10^{-4}$ (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.

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

MASS LIMITS for $H^{\pm\pm}$ (doubly-charged Higgs boson)

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)$_L\times$SU(2)$_R\times$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*
>551	95	[1] AAD 15AG	ATLS	ee
>468	95	[1] AAD 15AG	ATLS	$e\mu$
>516	95	[1] AAD 15AG	ATLS	$\mu\mu$
>400	95	[2] AAD 15AP	ATLS	$e\tau$
>400	95	[2] AAD 15AP	ATLS	$\mu\tau$
>169	95	[3] CHATRCHYAN 12AU	CMS	$\tau\tau$
>300	95	[3] CHATRCHYAN 12AU	CMS	$\mu\tau$
>293	95	[3] CHATRCHYAN 12AU	CMS	$e\tau$
>395	95	[3] CHATRCHYAN 12AU	CMS	$\mu\mu$
>391	95	[3] CHATRCHYAN 12AU	CMS	$e\mu$
>382	95	[3] CHATRCHYAN 12AU	CMS	ee
> 98.1	95	[4] ABDALLAH 03	DLPH	$\tau\tau$
> 99.0	95	[5] ABBIENDI 02C	OPAL	$\tau\tau$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
		[6] KANEMURA 15	RVUE	$W^{(*)\pm} W^{(*)\pm}$
		[7] KHACHATRY... 15D	CMS	$W^\pm W^\pm$
		[8] KANEMURA 14	RVUE	$W^{(*)\pm} W^{(*)\pm}$
>330	95	[9] AAD 13Y	ATLS	$\mu\mu$
>237	95	[9] AAD 13Y	ATLS	$\mu\tau$
>355	95	[10] AAD 12AY	ATLS	$\mu\mu$
>398	95	[11] AAD 12CQ	ATLS	$\mu\mu$
>375	95	[11] AAD 12CQ	ATLS	$e\mu$
>409	95	[11] AAD 12CQ	ATLS	ee
>128	95	[12] ABAZOV 12A	D0	$\tau\tau$
>144	95	[12] ABAZOV 12A	D0	$\mu\tau$
>245	95	[13] AALTONEN 11AF	CDF	$\mu\mu$
>210	95	[13] AALTONEN 11AF	CDF	$e\mu$

>225	95	[13] AALTONEN	11AF	CDF	$e e$
>114	95	[14] AALTONEN	08AA	CDF	$e \tau$
>112	95	[14] AALTONEN	08AA	CDF	$\mu \tau$
>168	95	[15] ABAZOV	08V	D0	$\mu \mu$
		[16] AKTAS	06A	H1	single $H^{\pm\pm}$
>133	95	[17] ACOSTA	05L	CDF	stable
>118.4	95	[18] ABAZOV	04E	D0	$\mu \mu$
		[19] ABBIENDI	03Q	OPAL	$E_{cm} \leq 209$ GeV, single $H^{\pm\pm}$
		[20] GORDEEV	97	SPEC	muonium conversion
		[21] ASAKA	95	THEO	
> 45.6	95	[22] ACTON	92M	OPAL	
> 30.4	95	[23] ACTON	92M	OPAL	
none 6.5–36.6	95	[24] SWARTZ	90	MRK2	

[1] 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.

[2] 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.

[3] 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.

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

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

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

[7] 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 $p p$ 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.

[8] 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.

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

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

[11] AAD 12CQ search for $H^{++} H^{--}$ production with 4.7 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 1 for limits assuming smaller branching ratios.

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

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

[14] 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.

[15] 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.

[16] 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.

[17] 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.

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

[19] 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).

[20] 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.

[21] 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.

[22] 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.

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

[24] 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*
>374	95	[1] AAD	15AG	ATLS	ee
>402	95	[1] AAD	15AG	ATLS	$e\mu$
>438	95	[1] AAD	15AG	ATLS	$\mu\mu$
>290	95	[2] AAD	15AP	ATLS	$e\tau$
>290	95	[2] AAD	15AP	ATLS	$\mu\tau$
> 97.3	95	[3] ABDALLAH	03	DLPH	$\tau\tau$
> 97.3	95	[4] ACHARD	03F	L3	$\tau\tau$
> 98.5	95	[5] ABBIENDI	02C	OPAL	$\tau\tau$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>251	95	[6] AAD	12AY	ATLS	$\mu\mu$
>306	95	[7] AAD	12CQ	ATLS	$\mu\mu$
>310	95	[7] AAD	12CQ	ATLS	$e\mu$
>322	95	[7] AAD	12CQ	ATLS	ee
>113	95	[8] ABAZOV	12A	D0	$\mu\tau$
>205	95	[9] AALTONEN	11AF	CDF	$\mu\mu$
>190	95	[9] AALTONEN	11AF	CDF	$e\mu$
>205	95	[9] AALTONEN	11AF	CDF	ee
>145	95	[10] ABAZOV	08V	D0	$\mu\mu$

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

[1] 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.

[2] 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.

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

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

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

[6] 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.

[7] 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.

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

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

[10] 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.

[11] 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.

[12] 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.

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

[14] 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).

[15] 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.

[16] 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.

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

[18] 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 × $10^{-7}/[m_H/\text{GeV}]^{1/2}$. The limits improve somewhat for ee and $\mu\mu$ decay modes.

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