Higgs Bosons — H^0 and $H^{\pm}$, Searches for

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H^0 (Higgs Boson) MASS LIMITS

These limits apply to the Higgs boson of the three-generation Standard Model with the minimal Higgs sector. Limits that depend on the $H t\overline{t}$ coupling may also apply to a Higgs boson of an extended Higgs sector whose couplings to up-type quarks are comparable to or larger than those of the standard one-doublet model H^0 couplings.

For comprehensive reviews, see Gunion, Haber, Kane, and Dawson, "The Higgs Hunter's Guide," (Addison-Wesley, Menlo Park, CA, 1990) and R.N. Cahn, Reports on Progress in Physics **52** 389 (1989). For a review of theoretical bounds on the Higgs mass, see M. Sher, Physics Reports (Physics Letters C) **179** 273 (1989).

Limits from Coupling to $Z/W^{\pm}$

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>60.2	95	[1] ACCIARRI	96I	L3	$Z \rightarrow H^0 Z^*$
>60.6	95	[2] ALEXANDER	96L	OPAL	$Z \rightarrow H^0 Z^*$
>63.9	95	[3] BUSKULIC	96R	ALEP	$Z \rightarrow H^0 Z^*$
>55.7	95	[4] ABREU	94G	DLPH	$Z \rightarrow H^0 Z^*$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[5] ACCIARRI	96J	L3	$Z \rightarrow H^0 \gamma$
		[6] ALEXANDER	96H	OPAL	$Z \rightarrow H^0 \gamma$
>56.9	95	[7] AKERS	94B	OPAL	$Z \rightarrow H^0 Z^*$
>57.7	95	[8] ADRIANI	93C	L3	$Z \rightarrow H^0 Z^*$
>58.4	95	[9] BUSKULIC	93H	ALEP	$Z \rightarrow H^0 Z^*$
>60	95	[10] GROSS	93	RVUE	$Z \rightarrow H^0 Z^*$
		[11] ABREU	92D	DLPH	$Z \rightarrow H^0 \gamma$
>38	95	[12] ABREU	92J	DLPH	$Z \rightarrow H^0 Z^*$
>52	95	[13] ADEVA	92B	L3	$Z \rightarrow H^0 Z^*$
		[14] ADRIANI	92F	L3	$Z \rightarrow H^0 \gamma$
>48	95	[15] DECAMP	92	ALEP	$Z \rightarrow H^0 Z^*$
> 0.21	99	[16] ABREU	91B	DLPH	$Z \rightarrow H^0 Z^*$
>11.3	95	[17] ACTON	91	OPAL	$H^0 \rightarrow$ anything
>41.8	95	[18] ADEVA	91	L3	$Z \rightarrow H^0 Z^*$
		[19] ADEVA	91D	L3	$Z \rightarrow H^0 \gamma$
none 3–44	95	[20] AKRAWY	91	OPAL	$Z \rightarrow H^0 Z^*$
none 3–25.3	95	[21] AKRAWY	91C	OPAL	$Z \rightarrow H^0 Z^*$
none 0.21–0.818	90	[22] ABE	90E	CDF	$p\overline{p} \rightarrow (W^{\pm},Z) + H^0 + X$

none 0.846–0.987	90	[22] ABE	90E	CDF	$p\overline{p} \rightarrow (W^{\pm},Z) + H^0 + X$
none 0.21–14	95	[23] ABREU	90C	DLPH	$Z \rightarrow H^0 Z^*$
none 2–32	95	[24] ADEVA	90H	L3	$Z \rightarrow H^0 Z^*$
$>$ 2	99	[25] ADEVA	90N	L3	$Z \rightarrow H^0 Z^*$
none 3.0–19.3	95	[26] AKRAWY	90C	OPAL	$Z \rightarrow H^0 Z^*$
$>$ 0.21	95	[27] AKRAWY	90P	OPAL	$Z \rightarrow H^0 Z^*$
none 0.032–15	95	[28] DECAMP	90	ALEP	$Z \rightarrow H^0 Z^*$
none 11–24	95	[29] DECAMP	90H	ALEP	$Z \rightarrow H^0 Z^*$
$>$ 0.057	95	[30] DECAMP	90M	ALEP	$Z \rightarrow H^0 ee$, $H^0 \mu\mu$
none 11–41.6	95	[31] DECAMP	90N	ALEP	$Z \rightarrow H^0 Z^*$

[1] ACCIARRI 96I searched for $Z \rightarrow H^0 + (e^+e^-, \mu^+\mu^-, \nu\overline{\nu})$ with $H^0 \rightarrow q\overline{q}$. Two $e^+e^- H^0$ candidate events with large recoiling mass (above 30 GeV) were found consistent with the background expectations.

[2] ALEXANDER 96L searched for final states with monojets or acoplanar dijets. Two observed candidate events are consistent with expected backgrounds.

[3] BUSKULIC 96R searched for $Z \rightarrow H^0 + (e^+e^-, \mu^+\mu^-, \nu\overline{\nu})$ with $H^0 \rightarrow q\overline{q}$. Three candidate events in the $\mu\mu$ channel are consistent with expected backgrounds.

[4] ABREU 94G searched for $Z \rightarrow H^0 + (e^+e^-, \mu^+\mu^-, \tau^+\tau^-, \nu\overline{\nu})$ with $H^0 \rightarrow q\overline{q}$. Four $\ell^+\ell^-$ candidates were found (all yielding low mass) consistent with expected backgrounds.

[5] ACCIARRI 96J give $B(Z \rightarrow H^0\gamma)\times B(H^0 \rightarrow q\overline{q}) < 6.9–22.9 \times 10^{-6}$ (95%CL) for 20 $< m_{H^0} <$80 GeV.

[6] ALEXANDER 96H give $B(Z \rightarrow H^0\gamma)\times B(H^0 \rightarrow q\overline{q}) < 1–4 \times 10^{-5}$ (95%CL) and $B(Z \rightarrow H^0\gamma)\times B(H^0 \rightarrow b\overline{b}) < 0.7–2 \times 10^{-5}$ (95%CL) in the range 20 $< m_{H^0} <$80 GeV.

[7] AKERS 94B searched for $Z \rightarrow H^0 + (e^+e^-, \mu^+\mu^-, \nu\overline{\nu})$ with $H^0 \rightarrow q\overline{q}$. One $\nu\overline{\nu}$ and one $\mu^+\mu^-$ candidate were found consistent with expected backgrounds.

[8] ADRIANI 93C searched for $Z \rightarrow H^0 + (\nu\overline{\nu}, e^+e^-, \mu^+\mu^-)$ with H^0 decaying hadronically or to $\tau\overline{\tau}$. Two e^+e^- and one $\mu^+\mu^-$ candidates are found consistent with expected background.

[9] BUSKULIC 93H searched for $Z \rightarrow H^0\nu\overline{\nu}$ (acoplanar jets) and $Z \rightarrow H^0 + (e^+e^-, \mu^+\mu^-)$ (lepton pairs in hadronic events).

[10] GROSS 93 combine data taken by four LEP experiments through 1991.

[11] ABREU 92D give $\sigma(e^+e^- \rightarrow Z \rightarrow H^0\gamma)\cdot B(H^0 \rightarrow \text{hadrons}) <$8 pb (95% CL) for $m_{H^0} <$75 GeV and $E_\gamma >$8 GeV.

[12] ABREU 92J searched for $Z \rightarrow H^0 + (ee, \mu\mu, \tau\tau, \nu\overline{\nu})$ with $H^0 \rightarrow q\overline{q}$. Only one candidate was found, in the channel ee + 2jets, with a dijet mass 35.4 $\pm$ 5 GeV/c^2, consistent with the expected background of 1.0 $\pm$ 0.2 events in the 3 channels e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, and of 2.8 $\pm$ 1.3 events in all 4 channels. This paper excludes 12–38 GeV. The range 0–12 GeV is eliminated by combining with the analyses of ABREU 90C and ABREU 91B.

[13] ADEVA 92B searched for $Z \rightarrow H^0 + (\nu\overline{\nu}, ee, \mu\mu, \tau\tau)$ with $H^0 \rightarrow$ anything, $Z \rightarrow H^0 + \tau\tau$ with $H^0 \rightarrow q\overline{q}$, and $Z \rightarrow H^0 + q\overline{q}$ with $H^0 \rightarrow \tau\tau$. The analysis excludes the range 30 $< m_{H^0} <$ 52 GeV.

[14] ADRIANI 92F give $\sigma(e^+e^- \rightarrow Z \rightarrow H^0\gamma)\cdot B(H^0 \rightarrow \text{hadrons}) <$(2–10) pb (95% CL) for m_{X^0} = 25–85 GeV. Using $\sigma(e^+e^- \rightarrow Z)$ = 30 nb, we obtain $B(Z \rightarrow H^0\gamma)B(H^0 \rightarrow \text{hadrons}) <(0.7–3) \times 10^{-4}$ (95% CL).

[15] DECAMP 92 searched for most possible final states for $Z \rightarrow H^0 Z^*$.

[16] ABREU 91B searched for $Z \to H^0 + \ell\overline{\ell}$ with missing H^0 and $Z \to H^0 + (\nu\overline{\nu}, \ell\overline{\ell}, q\overline{q})$ with $H^0 \to ee$.

[17] ACTON 91 searched for $e^+e^- \to Z^* H^0$ where $Z^* \to e^+e^-$, $\mu^+\mu^-$, or $\nu\overline{\nu}$ and $H^0 \to$ anything. Without assuming the minimal Standard Model mass-lifetime relationship, the limit is $m_{H^0} > 9.5$ GeV.

[18] ADEVA 91 searched for $Z \to H^0 + (\mu\mu, ee, \nu\overline{\nu})$. This paper only excludes $15 < m_{H^0} < 41.8$ GeV. The 0–15 GeV range is excluded by combining with the analyses of previous L3 papers.

[19] ADEVA 91D obtain a limit $B(Z \to H^0\gamma)\cdot B(H^0 \to \text{hadrons}) < 4.7 \times 10^{-4}$ (95%CL) for $m_{H^0} = 30$–86 GeV. The limit is not sensitive enough to exclude a standard H^0.

[20] AKRAWY 91 searched for the channels $Z \to H^0 + (\nu\overline{\nu}, ee, \mu\mu, \tau\tau)$ with $H^0 \to q\overline{q}, \tau\tau$, and $Z \to H^0 q\overline{q}$ with $H^0 \to \tau\tau$.

[21] AKRAWY 91C searched the decay channels $Z \to H^0 + (\nu\overline{\nu}, ee, \mu\mu)$ with $H^0 \to q\overline{q}$.

[22] ABE 90E looked for associated production of H^0 with $W^\pm$ or Z in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV. Searched for H^0 decays into $\mu^+\mu^-$, $\pi^+\pi^-$, and K^+K^-. Most of the excluded region is also excluded at 95% CL.

[23] ABREU 90C searched for the channels $Z \to H^0 + (\nu\overline{\nu}, ee, \mu\mu)$ and $H^0 + q\overline{q}$ for $m_H < 1$ GeV.

[24] ADEVA 90H searched for $Z \to H^0 + (\mu\mu, ee, \nu\overline{\nu})$.

[25] ADEVA 90N looked for $Z \to H^0 + (ee, \mu\mu)$ with missing H^0 and with $H^0 \to ee, \mu\mu, \pi^+\pi^-, K^+K^-$.

[26] AKRAWY 90C based on 825 nb^{-1}. The decay $Z \to H^0\nu\overline{\nu}$ with $H^0 \to \tau\overline{\tau}$ or $q\overline{q}$ provides the most powerful search means, but the quoted results sum all channels.

[27] AKRAWY 90P looked for $Z \to H^0 + (ee, \mu\mu)$ (H^0 missing) and $Z \to H^0\nu\overline{\nu}$, $H^0 \to e^+e^-, \gamma\gamma$.

[28] DECAMP 90 limits based on 11,550 Z events. They searched for $Z \to H^0 + (\nu\overline{\nu}, ee, \mu\mu, \tau\tau, q\overline{q})$. The decay $Z \to H^0\nu\overline{\nu}$ provides the most powerful search means, but the quoted results sum all channels. Different analysis methods are used for $m_{H^0} < 2m_\mu$ where Higgs would be long-lived. The 99% confidence limits exclude $m_{H^0} = 0.040$–12 GeV.

[29] DECAMP 90H limits based on 25,000 $Z \to$ hadron events.

[30] DECAMP 90M looked for $Z \to H^0\ell\ell$, where H^0 decays outside the detector.

[31] DECAMP 90N searched for the channels $Z \to H^0 + (\nu\overline{\nu}, ee, \mu\mu, \tau\tau)$ with $H^0 \to$ (hadrons, $\tau\tau$).

Limits from Other Techniques

H^0 Indirect Mass Limits from Electroweak Analysis

For limits obtained before the direct measurement of the top quark mass, see the 1996 (Physical Review **D54** 1 (1996)) Edition of this Review.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$\lesssim 550$	90	[32] DITTMAIER	96	RVUE
145^{+164}_{-77}		[33] ELLIS	96C	RVUE

185^{+251}_{-134}		[34] GURTU	96	RVUE
$63^{+\ 97}_{-\ \ 0}$		[35] CHANKOWSKI	95	RVUE
<730	95	[36] ERLER	95	RVUE
<740	95	[37] MATSUMOTO	95	RVUE
$45^{+\ 95}_{-\ 28}$		[38] ELLIS	94B	RVUE
$69^{+188}_{-\ \ 9}$		[39] GURTU	94	RVUE
		[40] MONTAGNA	94	RVUE

[32] DITTMAIER 96 fit to m_W, LEP, and SLD data available in the Summer of 1995 (with and without m_t=180 ± 12 GeV from CDF/DØ), leaving out R_b and R_c. They argue that the low Higgs mass obtained in some electroweak analyses is an artifact of including the observed value of R_b, which is incompatible with the rest of the data. Exclusion of the SLD data pushes the 90%CL limit on m_{H^0} above 1 TeV.

[33] ELLIS 96C fit to LEP, SLD, m_W, neutral-current data available in the summer of 1996, plus m_t = 175 ± 6 GeV from CDF/DØ . The fit yields m_t = 172 ± 6 GeV.

[34] GURTU 96 studies the effect of the mutually incompatible SLD and LEP asymmetry data on the determination of m_H. Use is made of data available in the Summer of 1996. The quoted value is obtained by increasing the errors *à la* PDG. A fit ignoring the SLD data yields 267^{+242}_{-135} GeV.

[35] CHANKOWSKI 95 fit to LEP, SLD, and W mass data available in the spring of 1995 plus m_t = 176 ± 13 GeV. Exclusion of the SLD data increases the mass to m_H = $121^{+207}_{-\ 58}$ GeV (m_H <800 GeV at 95% CL).

[36] ERLER 95 fit to LEP, SLC, W mass, and various low-energy data available in the summer of 1994 plus m_t=174 ± 16 GeV from CDF. The limit without m_t is 880 GeV. However, the preference for lighter m_H is due to R_b and A_{LR}, both of which do not agree well with the Standard Model prediction.

[37] MATSUMOTO 95 fit to LEP, SLD, W mass, and various neutral current data available in the summer of 1994 plus m_t=180 ± 13 GeV from CDF/DØ , and the LEP direct limit m_H >63 GeV. $\alpha_s(m_Z) = 0.124$ is used. Fixing $\alpha_s(m_Z) = 0.116$ lowers the upper limit to 440 GeV. Dependence on $\alpha(m_Z)$ is given in the paper.

[38] ELLIS 94B fit to LEP, SLD, W mass, neutral current data available in the spring of 1994 plus m_t = 167 ± 12 GeV determined from CDF/DØ $t\overline{t}$ direct searches. $\alpha_s(m_Z)$ = 0.118 ± 0.007 is used. The fit yields m_t = 162 ± 9 GeV. A fit without the SLD data gives $m_H = 130^{+320}_{-\ 90}$ GeV.

[39] GURTU 94 fit to LEP, SLD, W mass, neutral current data available in the spring of 1994 as well as m_t = 174 ± 16 GeV. A fit without $\Gamma(Z \to b\overline{b})/\Gamma(Z \to \text{hadrons})$ gives $m_H = 120^{+364}_{-\ 60}$ GeV.

[40] MONTAGNA 94 fit to LEP and SLD, W-mass data together with m_t = 174 ± 17 GeV. Although the data favor smaller Higgs masses, the authors do not regard it significant.

From Other Techniques

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[41] CASAS	95	THEO	Vacuum stability
		[42] ESPINOSA	95B	THEO	Vacuum metastability
		[43] ALTARELLI	94	THEO	Vacuum stability
none 0.001–0.072	95	[44] BARABASH	92	BDMP	$\eta' \rightarrow \eta H^0$
none 0.0012–0.052	90	DAVIER	89	BDMP	$e^- Z \rightarrow e H^0 Z$ $(H^0 \rightarrow e^+ e^-)$
none 0.010–0.10	90	[45] EGLI	89	CNTR	$\pi^+ \rightarrow e^+ \nu H^0$ $(H^0 \rightarrow e^+ e^-)$
		[46] LINDNER	89	THEO	Vacuum stability
none 0.015–0.04	90	[47] YEPES	89	RVUE	$\pi^\pm \rightarrow e^\pm \nu H^0$ $(H^0 \rightarrow e^+ e^-)$
		[48] DZHELYADIN	81		$\eta' \rightarrow \eta H^0$ $(H^0 \rightarrow \mu^+ \mu^-)$
		[49] WITTEN	81	COSM	
		[49] GUTH	80	COSM	
		[49] SHER	80	COSM	

[41] CASAS 95 require stability of the vacuum in the *minimal* Standard Model up to the scale Λ and find $m_H > 127.9 + 1.92(m_t - 174) - 4.25(\alpha_s(m_Z) - 0.124)/0.0006$ (units in GeV) for $\Lambda = 10^{19}$ GeV, and m_H >52 GeV for $\Lambda = 1$ TeV, $m_t = 174$ GeV, $\alpha_s(m_Z) = 0.124$.

[42] ESPINOSA 95B require metastability of the vacuum in the *minimal* Standard Model up to the scale Λ and find $m_H > [2.278 - 4.654(\alpha_s(m_Z) - 0.124)]m_t - 277$ GeV for $\Lambda = 10^{19}$ GeV.

[43] ALTARELLI 94 require the stability of the vacuum in the *minimal* Standard Model and find $m_H > 72$ (135) GeV for the cut-off scale $\Lambda = 1$ TeV (10^{19} GeV), if $m_t = 174$ GeV and $\alpha_s(m_Z) = 0.118$. See paper for m_t, α_s, and Λ dependence of the result.

[44] BARABASH 92 is a beam dump experiment that searched for $H^0 \rightarrow e^+ e^-$ and $\gamma\gamma$ produced via the decays $\pi \rightarrow e \nu_e H^0$, $K \rightarrow e \nu_e H^0$, $K \rightarrow \pi H^0$, and $\eta' \rightarrow \eta H^0$. The last process gives the best limit if the theoretical calculation by RUSKOV 87 is used.

[45] EGLI 89 give a limit for $B(\pi^+ \rightarrow e^+ \nu H^0) \cdot B(H^0 \rightarrow e^+ e^-)$ ranging from 10^{-9} to 10^{-11} for the mass range 10–110 MeV. The theoretical prediction they use is too large by a factor of 162/49 (see DAWSON 89, DAWSON 90, and CHENG 89). The lower limit given above is reevaluated by us.

[46] LINDNER 89 require vacuum stability and numerically solve the renormalization equations to two-loop order. If $m_{\rm top} = 100$, 110, 120 GeV, then $m_{\rm Higgs} > 20$, 34, 50 GeV. However, it is possible that the vacuum is not stable but is very long-lived.

[47] YEPES 89 reanalyzed a BNL beam-dump experiment (JACQUES 80) which looked for electron pairs in 7 foot BC downstream from the dump and found none.

[48] DZHELYADIN 81 obtained $B(\eta' \rightarrow \eta \mu^+ \mu^-) < 1.5 \times 10^{-5}$ (CL = 90%), and argued that it excludes H^0 with the standard one-doublet-model couplings in $\mu^+ \mu^-$ channel for $m_{H^0} = 0.25$–0.409 GeV. However, the number 0.409 is not well-determined due to theoretical uncertainties in $B(H^0 \rightarrow \mu^+ \mu^-)$.

[49] Limits from cosmological considerations of SU(2)×U(1) symmetry-breaking phase transition occurring only after extreme supercooling, resulting in too high a ratio of entropy to baryon number. Limits apply to the standard one-doublet model H^0, with 'zero bare mass' whose physical mass is determined by the Coleman-Weinberg mechanism of dynamical symmetry breakdown. These limits depend on the mass of the top quark approximately according to $m_{H^0} > 10.4[1 - 4 m_t{}^4/(2m_W^4 + m_Z^4)]^{1/2}$ GeV when $m_t < 80$

GeV. So for $m_t \approx 80$ GeV, there is no limit. If $m_t > 80$ GeV, then vacuum stability arguments may give bounds on m_H, see LINDNER 89 above.

H^0 (Higgs Boson) MASS LIMITS in Extended Higgs Models

The parameter x denotes the Higgs coupling to charge $-1/3$ quarks and charged leptons relative to the value in the standard one-Higgs-doublet model.

In order to prevent flavor-changing neutral currents in models with more than one Higgs doublet, only one of the Higgs doublets can couple to quarks of charge 2/3. The same requirement applies independently to charge $-1/3$ quarks and to leptons. Higgs couplings can be enhanced or suppressed.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[50] ACCIARRI	96I	L3	$Z \rightarrow H^0 Z^*$
>66.7	95	[51] ACCIARRI	96I	L3	Invisible H^0
		[52] ACCIARRI	96J	L3	$Z \rightarrow H^0 Z^*$, $H^0 \rightarrow \gamma\gamma$
		[53] ALEXANDER	96H	OPAL	$Z \rightarrow H^0 Z^*$, $H^0 \rightarrow \gamma\gamma$
		[54] ABREU	95H	DLPH	$Z \rightarrow H^0 Z^*$, $H^0 A^0$
		[55] BRAHMACH...	93	RVUE	
		[56] BUSKULIC	93I	ALEP	$Z \rightarrow H^0 Z^*$
>65	95	[51] BUSKULIC	93I	ALEP	Invisible H^0
		[57] LOPEZ-FERN...	93	RVUE	
		[58] ADRIANI	92G	L3	$Z \rightarrow H^0 Z^*$
		[59] PICH	92	RVUE	Very light Higgs
> 3.57	95	[60] ACTON	91	OPAL	$Z \rightarrow H^0 Z^*$
		[61] DECAMP	91F	ALEP	$Z \rightarrow H^0 \ell^+ \ell^-$
		[62] DECAMP	91I	ALEP	Z decay
> 0.21	95	[63] AKRAWY	90P	OPAL	$Z \rightarrow H^0 Z^*$
		[64] DAVIER	89	BDMP	$e^- Z \rightarrow e H^0 Z$ ($H^0 \rightarrow e^+ e^-$)
		[65] SNYDER	89	MRK2	$B \rightarrow H^0 X$ ($H^0 \rightarrow e^+ e^-$)
none 0.6–6.2	90	[66] FRANZINI	87	CUSB	$\Upsilon(1S) \rightarrow \gamma H^0$, x=2
none 0.6–7.9	90	[66] FRANZINI	87	CUSB	$\Upsilon(1S) \rightarrow \gamma H^0$, x=4
none 3.7–5.6	90	[67] ALBRECHT	85J	ARG	$\Upsilon(1S) \rightarrow \gamma H^0$, x=2
none 3.7–8.2	90	[67] ALBRECHT	85J	ARG	$\Upsilon(1S) \rightarrow \gamma H^0$, x=4

[50] See Figs. 5 and 6 of ACCIARRI 96I for the excluded region in the (m_{H^0}, $\Gamma(Z \rightarrow Z^* H^0)$) plane (normalized to the Standard Model Higgs) for a general Higgs having a similar decay signature to Standard Model Higgs boson or decaying invisibly.

[51] These limits are for H^0 with the standard coupling to Z but decaying to weakly interacting particles.

[52] ACCIARRI 96J give B($Z \rightarrow H^0 +$ hadrons)$\times$B($H^0 \rightarrow \gamma\gamma$) < 2.3–6.9×10^{-6} for 20 $< m_{H^0} < 70$ GeV.

[53] ALEXANDER 96H give B($Z \rightarrow H^0 + q\overline{q}$)$\times$B($H^0 \rightarrow \gamma\gamma$) $< 2 \times 10^{-6}$ in the range $40 < m_{H^0} < 80$ GeV.

[54] See Fig. 4 of ABREU 95H for the excluded region in the $m_{H^0} - m_{A^0}$ plane for general two-doublet models. For $\tan\beta > 1$, the region $m_{H^0} + m_{A^0} \lesssim 87$ GeV, $m_{H^0} < 47$ GeV is excluded at 95% CL.

[55] BRAHMACHARI 93 consider Higgs limit from Z decay when the Higgs decays to invisible modes. If H^0 coupling to Z is at least $1/\sqrt{2}$ of the Standard Model H^0, the DECAMP 92 limit of 48 GeV changes within ± 6 GeV for arbitrary B($H^0 \rightarrow$ SM-like)+B($H^0 \rightarrow$ invisible)=1.

[56] See Fig. 1 of BUSKULIC 93I for the limit on ZZH^0 coupling for a general Higgs having a similar decay signature to Standard Model Higgs boson or decaying invisibly. If the decay rate for $Z \rightarrow H^0 Z^*$ is >10% of the minimal Standard Model rate, then $m_{H^0} > 40$ GeV. For the standard rate the limit is 58 GeV.

[57] LOPEZ-FERNANDEZ 93 consider Higgs limit from Z decay when the Higgs decays to invisible modes. See Fig. 2 for excluded region in m_{H^0}-ZZH coupling plane with arbitrary B($H^0 \rightarrow$ SM-like)+B($H^0 \rightarrow$ invisible)=1. $m_H > 50$ GeV is obtained if the H^0 coupling strength to the Z is greater than 0.2 times the Standard Model rate.

[58] See Fig. 1 of ADRIANI 92G for the limit on ZZH^0 coupling for a general Higgs having a similar decay signature to Standard Model Higgs boson. For most masses below 30 GeV, the rate for $Z \rightarrow H_1^0 Z^*$ is less than 10% of the Standard Model rate.

[59] PICH 92 analyse H^0 with $m_{H^0} < 2m_\mu$ in general two-doublet models. Excluded regions in the space of mass-mixing angles from LEP, beam dump, and $\pi^\pm$, η rare decays are shown in Figs. 3,4. The considered mass region is not totally excluded.

[60] ACTON 91 limit is valid for any H^0 having $\Gamma(Z \rightarrow H^0 Z^*)$ more than 0.24 (0.56) times that for the standard Higgs boson for Higgs masses below $2m_\mu$ ($2m_\tau$).

[61] DECAMP 91F search for $Z \rightarrow H^0 \ell^+ \ell^-$ where H^0 escapes before decaying. Combining this with DECAMP 90M and DECAMP 90N, they obtain $B(Z \rightarrow H^0 \ell^+ \ell^-)/B(Z \rightarrow \ell^+ \ell^-) < 2.5 \times 10^{-3}$ (95%CL) for $m_{H^0} < 60$ GeV.

[62] See Figs. 1, 3, 4, 5 of DECAMP 91I for excluded regions for the masses and mixing angles in general two-doublet models.

[63] AKRAWY 90P limit is valid for any H^0 having $\Gamma(Z \rightarrow H^0 Z^*)$ more than 0.57 times that for the Standard Higgs boson.

[64] DAVIER 89 give excluded region in m_{H^0}-x plane for m_{H^0} ranging from 1.2 MeV to 50 MeV.

[65] SNYDER 89 give limits on $B(B \rightarrow H^0 X) \cdot B(H^0 \rightarrow e^+ e^-)$ for $100 < m_{H^0} < 200$ MeV, $c\tau < 24$ mm.

[66] First order QCD correction included with $\alpha_s \approx 0.2$. Their figure 4 shows the limits vs. x.

[67] ALBRECHT 85J found no mono-energetic photons in both $\Upsilon(1S)$ and $\Upsilon(2S)$ radiative decays in the range 0.5 GeV $< E(\gamma) < 4.0$ GeV with typically BR< 0.01 for $\Upsilon(1S)$ and BR< 0.02 for $\Upsilon(2S)$ at 90% CL. These upper limits are 5–10 times the prediction of the standard Higgs-doublet model. The quoted 90% limit $B(\Upsilon(1S) \rightarrow H^0 \gamma) < 1.5 \times 10^{-3}$ at $E(\gamma) = 1.07$ GeV contradicts previous Crystal Ball observation of $(4.7 \pm 1.1) \times 10^{-3}$; see their reference 3. Their figure 8a shows the upper limits of x^2 as a function of $E(\gamma)$ by assuming no QCD corrections. We used $m_{H^0} = m_\Upsilon (1 - 2E(\gamma)/m_\Upsilon)^{1/2}$.

H^0_1 (Higgs Boson) MASS LIMITS in Supersymmetric Models

The minimal supersymmetric model has two complex doublets of Higgs bosons. The resulting physical states are two scalars [H^0_1 and H^0_2, where we define $m_{H^0_1} < m_{H^0_2}$], a pseudoscalar (A^0), and a charged Higgs pair ($H^\pm$). H^0_1 and H^0_2 are also called h and H in the literature. There are two free parameters in the theory which can be chosen to be m_{A^0} and $\tan\beta = \nu_2/\nu_1$, the ratio of vacuum expectation values of the two Higgs doublets. Tree-level Higgs masses are constrained by the model to be $m_{H^0_1} \leq m_Z$, $m_{H^0_2} \geq m_Z$, $m_{A^0} \geq m_{H^0_1}$, and $m_{H^\pm} \geq m_W$. However, as described in the "Note on Supersymmetry," recent calculations of one-loop radiative corrections show that these relations may be violated. Many experimental analyses have not taken into account these corrections; footnotes indicate when these corrections are included. The results assume no invisible H^0 or A^0 decays.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>44	95	[68] ABREU	95H	DLPH	any $\tan\beta$
>44.5	95	[69] AKERS	94I	OPAL	$\tan\beta > 1$
>44	95	[70] BUSKULIC	93I	ALEP	$\tan\beta > 1$
>42	95	[71] ADRIANI	92G	L3	$1 < \tan\beta < 50$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[72] ROSIEK	95	RVUE	
>44.4	95	[73] ABREU	94O	DLPH	$m_{H^0_1} = m_{A^0}$, any $\tan\beta$
>34	95	[74] ABREU	92J	DLPH	$\tan\beta > 0.6$
>29	95	[74] ABREU	92J	DLPH	any $\tan\beta$
> 0.21	95	[75] ABREU	91B	DLPH	any $\tan\beta$
>28	95	[76] ABREU	91B	DLPH	any $\tan\beta$
none 3–38	95	[77] AKRAWY	91C	OPAL	$\tan\beta > 6$
none 3–22	95	[77] AKRAWY	91C	OPAL	$\tan\beta > 0.5$
		[78] BLUEMLEIN	91	BDMP	$pN \to H^0_1 X$ ($H^0_1 \to e^+e^-, 2\gamma$)
>41	95	[79] DECAMP	91I	ALEP	$\tan\beta > 1$
> 9	95	[80] ABREU	90E	DLPH	any $\tan\beta$
>13	95	[80] ABREU	90E	DLPH	$\tan\beta > 1$
>26	95	[81] ADEVA	90R	L3	$\tan\beta > 1$
none 0.05–3.1	95	[82] DECAMP	90E	ALEP	any $\tan\beta$
none 0.05–13	95	[82] DECAMP	90E	ALEP	$\tan\beta > 0.6$
none 0.006–20	95	[82] DECAMP	90E	ALEP	$\tan\beta > 2$
>37.1	95	[82] DECAMP	90E	ALEP	$\tan\beta > 6$
none 0.05–20	95	[83] DECAMP	90H	ALEP	$\tan\beta > 0.6$
none 0.006–21.4	95	[83] DECAMP	90H	ALEP	$\tan\beta > 2$
> 3.1	95	[84] DECAMP	90M	ALEP	any $\tan\beta$

[68] ABREU 95H search for $Z \to H^0_1 Z^*$ and $Z \to H^0_1 A^0$. Two-loop corrections are included with m_t=170 GeV, $m_{\tilde{t}}$=1 TeV. Including only one-loop corrections does not change the limit.

[69] AKERS 94I search for $Z \to H^0_1 Z^*$ and $Z \to H^0_1 A^0$. One-loop corrections are included with $m_t <$200 GeV, $m_{\tilde{t}} <$1 TeV. See Fig. 10 for limits for $\tan\beta <1$.

[70] BUSKULIC 93I search for $Z \to H^0_1 Z^*$ and $Z \to H^0_1 A^0$. One-loop corrections are included with any m_t, $m_{\tilde{t}} > m_t$.

[71] ADRIANI 92G search for $Z \to H_1^0 Z^*$, $Z \to H_1^0 A^0 \to 4b$, $bb\tau\tau$, 4τ, $6b$ (via $H^0 \to A^0 A^0$), and include constraints from $\Gamma(Z)$. One-loop corrections to the Higgs potential are included with $90 < m_t < 250$ GeV, $m_t < m_{\widetilde{t}} < 1$ TeV.

[72] ROSIEK 95 study the dependence of $m_{H_1^0}$ limit on various supersymmetry parameters. They argue that H_1^0 as light as 25 GeV is not excluded by ADRIANI 92G data in the region $m_{A^0} \sim 60$ GeV if $m_{\widetilde{t}} \lesssim 200$ GeV and $\widetilde{t}_L$-$\widetilde{t}_R$ mixing is large.

[73] ABREU 94O study $H_1^0 A^0 \to$ four jets and combine with ABREU 94G analysis. The limit applies if the H_1^0-A^0 mass difference is <4 GeV.

[74] ABREU 92J searched for $Z \to H_1^0 Z^*$ and $Z \to H_1^0 A^0$ with $H_1^0, A^0 \to \tau\tau$ or jet-jet. Small mass values are excluded by ABREU 91B.

[75] ABREU 91B result is based on negative search for $Z \to H_1^0 f\overline{f}$ and the limit on invisible Z width $\Gamma(Z \to H_1^0 A^0) <$ 39 MeV (95%CL), assuming $m_{A^0} < m_{H_1^0}$.

[76] ABREU 91B result obtained by combining with analysis of ABREU 90I.

[77] AKRAWY 91C result from $Z \to H_1^0 A^0 \to$ 4jet or $\tau^+\tau^- jj$ or 4τ and $Z \to H_1^0 Z^*$ ($H_1^0 \to q\overline{q}$, $Z^* \to \nu\overline{\nu}$ or e^+e^- or $\mu^+\mu^-$). See paper for the excluded region for the case $\tan\beta < 1$. Although these limits do not take into account the one-loop radiative corrections, the authors have reported unpublished results including these corrections and showed that the excluded region becomes larger.

[78] BLUEMLEIN 91 excluded certain range of $\tan\beta$ for $m_{H_1^0} < 120$ MeV, $m_{A^0} < 80$ MeV.

[79] DECAMP 91I searched for $Z \to H_1^0 Z^*$, and $Z \to H_1^0 A^0 \to$ 4jets or $\tau\tau jj$ or $3A^0$. Their limits take into account the one-loop radiative corrections to the Higgs potential with varied top and squark masses.

[80] ABREU 90E searched for $Z \to H_1^0 A^0$ and $Z \to H_1^0 Z^*$. $m_{H_1^0} < 210$ MeV is not excluded by this analysis.

[81] ADEVA 90R result is from $Z \to H_1^0 A^0 \to$ 4jet or $\tau\tau jj$ or 4τ and $Z \to H_1^0 Z^*$. Some region of $m_{H_1^0} < 4$ GeV is not excluded by this analysis.

[82] DECAMP 90E look for $Z \to H_1^0 A^0$ as well as $Z \to H_1^0 \ell^+\ell^-$, $Z \to H_1^0 \nu\overline{\nu}$ with 18610 Z decays. Their search includes signatures in which H_1^0 and A^0 decay to $\gamma\gamma$, e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, or $q\overline{q}$. See their figures of $m_{H_1^0}$ vs. $\tan\beta$.

[83] DECAMP 90H is similar to DECAMP 90E but with 25,000 Z decays.

[84] DECAMP 90M looked for $Z \to H^0 \ell\ell$, where H_1^0 decays outside the detector. This excludes a region in the ($m_{H_1^0}$, $\tan\beta$) plane centered at $m_{H_1^0} = 50$ MeV, $\tan\beta = 0.5$. This limit together with DECAMP 90E result excludes $m_{H_1^0} < 3$ GeV for any $\tan\beta$.

A^0 (Pseudoscalar Higgs Boson) MASS LIMITS in Supersymmetric Models

Limits on the A^0 mass from e^+e^- collisions arise from direct searches in the $e^+e^- \to A^0 H_1^0$ channel and indirectly from the relations valid in the minimal supersymmetric model between m_{A^0} and $m_{H_1^0}$. As discussed in the "Note on Supersymmetry," at the one-loop level and in the simplest cases, these relations depend on the masses of the t quark and $\widetilde{t}$ squarks. The limits are weaker for larger t and $\widetilde{t}$ masses, while they increase with the inclusion of two-loop radiative corrections. Some specific examples of these dependences are provided in the footnotes to the listed papers.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>27	95	[85] ABREU	95H	DLPH	$\tan\beta > 1$, $m_t = 170$ GeV
>24.3	95	[86] AKERS	94I	OPAL	$\tan\beta > 1$, $m_t < 200$ GeV
>21	95	[87] BUSKULIC	93I	ALEP	$\tan\beta > 1$, $m_t = 140$ GeV
>22	95	[88] ADRIANI	92G	L3	$1 < \tan\beta < 50$, $m_t < 250$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>44.4	95	[89] ABREU	94O	DLPH	$m_{H_1^0} = m_{A^0}$, any $\tan\beta$
>44.5	95	[86] AKERS	94I	OPAL	$\tan\beta > 1$, $m_{H_1^0} = m_{A^0}$
		[90] ELLIS	93	RVUE	Electroweak
>34	95	[91] ABREU	92J	DLPH	$\tan\beta > 3$
> 0.21	95	[92] BUSKULIC	92	ALEP	$\tan\beta > 1$
none 3–40.5	95	[93] AKRAWY	91C	OPAL	$\tan\beta > 1$, if 3 GeV $< m_{H_1^0} < m_{A^0}$
>20	95	[94] DECAMP	91I	ALEP	$\tan\beta > 1$
>34	95	[95] ABREU	90E	DLPH	$\tan\beta > 1$, $m_{H_1^0} < m_{A^0}$
>12	95	[95] ABREU	90E	DLPH	$\tan\beta < 1$
>39	95	[96] ADEVA	90R	L3	$\tan\beta > 1$, $m_{H_1^0} < m_{A^0}$

[85] ABREU 95H search for $Z \to H_1^0 Z^*$ and $Z \to H_1^0 A^0$. One-loop corrections are included with $m_t = 170$ GeV, $m_{\widetilde{t}} = 1$ TeV. The limit becomes weak for larger m_t: at $m_t = 190$ GeV, the limit is 14 GeV. The limit at $m_t = 170$ GeV would increase to 39 GeV if two-loop radiative corrections were included. m_t and $m_{\widetilde{t}}$ dependences are shown in Fig. 6.

[86] AKERS 94I search for $Z \to H_1^0 Z^*$ and $Z \to H_1^0 A^0$. One-loop corrections are included with $m_t < 200$ GeV, $m_{\widetilde{t}} < 1$ TeV. See Fig. 10 for limits for $\tan\beta < 1$.

[87] BUSKULIC 93I search for $Z \to H_1^0 Z^*$ and $Z \to H_1^0 A^0$. One-loop corrections to the Higgs potential are included with any m_t, $m_{\widetilde{t}} > m_t$. For $m_t = 140$ GeV and $m_{\widetilde{t}} = 1$ TeV, the limit is $m_{A^0} > 45$ GeV. Assumes no invisible H^0 or A^0 decays.

[88] ADRIANI 92G search for $Z \to H_1^0 Z^*$, $Z \to H_1^0 A^0 \to 4b$, $b b \tau \tau$, 4τ, $6b$ (via $H^0 \to A^0 A^0$), and include constraints from $\Gamma(Z)$. One-loop corrections are included with $90 < m_t < 250$ GeV, $m_t < m_{\widetilde{t}} < 1$ TeV. The region $m_{A^0} < 11$ GeV is allowed if $42 < m_{H_1^0} < 62$ GeV, but is excluded by other experiments.

[89] ABREU 94O study $H_1^0 A^0 \to$ four jets and combine with ABREU 94G analysis. The limit applies if the H_1^0-A^0 mass difference is <4 GeV.

[90] ELLIS 93 analyze possible constraints on the MSSM Higgs sector by electroweak precision measurements and find that m_{A^0} is not constrained by the electroweak data.

[91] ABREU 92J searched for $Z \to H_1^0 Z^*$ and $Z \to H_1^0 A^0$ with $H_1^0, A^0 \to \tau\tau$ or jet-jet. Small mass values are excluded by ABREU 91B.

[92] BUSKULIC 92 limit is from $\Gamma(Z)$, $Z \to H_1^0 Z^*$, and $Z \to H_1^0 A^0$. The limit is valid for any $m_{H_1^0}$ below the the theoretical limit $m_{H_1^0}$ <64 GeV which holds for $m_{A^0} \sim 0$ in the minimal supersymmetric model. One-loop radiative corrections are included.

[93] AKRAWY 91C result from $Z \to H_1^0 A^0 \to$ 4jet or $\tau^+\tau^- jj$ or 4τ. See paper for the excluded region for the case $\tan\beta < 1$.

[94] DECAMP 91I searched for $Z \to H_1^0 Z^*$, and $Z \to H_1^0 A^0 \to$ 4jets or $\tau\tau jj$ or $3A^0$. Their limits take into account the one-loop radiative corrections to the Higgs potential with varied top and squark masses. For $m_t =$ 140 GeV and $m_{\widetilde{q}} = 1$ TeV, the limit is $m_{A^0} > 31$ GeV.

[95] ABREU 90E searched $Z \to H_1^0 A^0$ and $Z \to H_1^0 Z^*$. $m_{A^0} < 210$ MeV is not excluded by this analysis.

[96] ADEVA 90R result is from $Z \to H_1^0 A^0 \to$ 4jet or $\tau\tau jj$ or 4τ and $Z \to H_1^0 Z^*$. Some region of $m_{A^0} < 5$ GeV is not excluded by this analysis.

MASS LIMITS for Associated Higgs Production in $e^+ e^-$ Interactions

In multi-Higgs models, associated production of Higgs via virtual or real Z in $e^+ e^-$ annihilation, $e^+ e^- \to H_1^0 H_2^0$, is possible if H_1^0 and H_2^0 have opposite *CP* eigenvalues. Limits are for the mass of the heavier Higgs H_2^0 in two-doublet models.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>53	95	[97] AKERS	94I	OPAL	$m_{H_1^0} < 12$ GeV
		[98] ADRIANI	92G	L3	
>45	95	[99] DECAMP	90H	ALEP	$m_{H_1^0} < 20$ GeV
>37.5	95	[99] DECAMP	90H	ALEP	$m_{H_1^0} < m_{H_2^0}$
none 5–45	95	[100] KOMAMIYA	90	MRK2	$m_{H_1^0} < 0.5$ GeV, $H_2^0 \to q\overline{q}$ or $\tau^+\tau^-$
>8	90	[101] KOMAMIYA	89	MRK2	$H_1^0 \to \mu^+\mu^-$, $H_2^0 \to q\overline{q}, \tau^+\tau^-$
>28	95	[102] LOW	89	AMY	$m_{H_1^0} \lesssim 20$ MeV, $H_2^0 \to q\overline{q}$
none 2–9	90	[103] AKERLOF	85	HRS	$m_{H_1^0} = 0$, $H_2^0 \to f\overline{f}$

none 4–10	90	[104] ASH	85C	MAC	$m_{H_1^0} = 0.2$ GeV, $H_2^0 \to \tau^+\tau^-$, $c\overline{c}$
none 1.3–24.7	95	[103] BARTEL	85L	JADE	$m_{H_1^0} = 0.2$ GeV, $H_2^0 \to f\overline{f}$ or $f\overline{f}H_1^0$
none 1.2–13.6	95	[103] BEHREND	85	CELL	$m_{H_1^0} = 0$, $H_2^0 \to f\overline{f}$
none 1–11	90	[103] FELDMAN	85	MRK2	$m_{H_1^0} = 0$, $H_2^0 \to f\overline{f}$
none 1–9	90	[103] FELDMAN	85	MRK2	$m_{H_1^0} = m_{H_2^0}$, $H_2^0 \to f\overline{f}$

[97] AKERS 94I search for $Z \to H_1^0 H_2^0$ with various decay modes. See Fig. 11 for the full excluded mass region in the general two-doublet model, from which the limit above is taken. In particular, for $m_{H_1^0} = m_{H_2^0}$ the limit becomes >38 GeV.

[98] ADRIANI 92G excluded regions of the $m_{H_1^0} - m_{A^0}$ plane for various decay modes with limits B($Z \to H_1^0 H_2^0$) <(2–20) $\times 10^{-4}$ are shown in Figs. 2–5.

[99] DECAMP 90H search for $Z \to H_1^0 e^+ e^-$, $H_1^0 \mu^+ \mu^-$, $H_1^0 \tau^+ \tau^-$, $H_1 q\overline{q}$, low multiplicity final states, τ-τ-jet-jet final states and 4-jet final states.

[100] KOMAMIYA 90 limits valid for $\cos^2(\alpha - \beta) \approx 1$. They also search for the cases $H_1^0 \to \mu^+\mu^-$, $\tau^+\tau^-$, and $H_2^0 \to H_1^0 H_1^0$. See their Fig. 2 for limits for these cases.

[101] KOMAMIYA 89 assume B($H_1^0 \to \mu^+\mu^-$) = 100 %, $2m_\mu < m_{H_1^0} < m_\tau$. The limit is for maximal mixing. A limit of $m_{H_2^0} > 18$ GeV for the case $H_2^0 \to H_1^0 H_1^0$ ($H_1^0 \to \mu^+\mu^-$) is also given. From PEP at $E_{\rm cm} = 29$ GeV.

[102] LOW 89 assume that H_1^0 escapes the detector. The limit is for maximal mixing. A reduced limit of 24 GeV is obtained for the case $H_2^0 \to H_1^0 f\overline{f}$. Limits for a Higgs-triplet model are also discussed. $E_{\rm cm}^{ee} = 50$–60.8 GeV.

[103] The limit assumes maximal mixing and that H_1^0 escapes the detector.

[104] ASH 85 assumes that H_1^0 escapes undetected. The bound applies up to a mixing suppression factor of 5.

$H^{\pm}$ (Charged Higgs or Techni-pion) MASS LIMITS

Most of the following limits assume $B(H^+ \rightarrow \tau^+\nu) + B(H^+ \rightarrow c\overline{s}) = 1$. DECAMP 90I, BEHREND 87, and BARTEL 86 assume $B(H^+ \rightarrow \tau^+\nu) + B(H^+ \rightarrow c\overline{s}) + B(H^+ \rightarrow c\overline{b}) = 1$. All limits from Z decays as well as ADACHI 90B assume that H^+ has weak isospin $T_3 = +1/2$.

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.

For a discussion of techni-particles, see EICHTEN 86.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>44.1	95	[105] ALEXANDER	96I	OPAL	$B(\tau\nu) = 0$–1
>43.5	95	[106] ABREU	94O	DLPH	$B(\tau\nu) = 0$–1
>41	95	[107] ADRIANI	92G	L3	$B(\tau\nu) = 0$–1
>41.7	95	[108,109] DECAMP	92	ALEP	$B(\tau\nu) = 0$–1
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[110] ABE	96G	CDF	$t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu_\tau$
		[111] BUSKULIC	95	ALEP	$b \rightarrow \tau\nu_\tau X$
		[112] BARGER	93	RVUE	$b \rightarrow s\gamma$
		[113] BELANGER	93	RVUE	$b \rightarrow s\gamma$
		[112] HEWETT	93	RVUE	$b \rightarrow s\gamma$
none 8.0–20.2	95	[114] YUZUKI	91	VNS	$B(\ell\nu) = 0$–1
>29	95	[108,115] ABREU	90B	DLPH	$B(\tau\nu) = 0$–1
>19	95	[108,116] ADACHI	90B	TOPZ	$B(\tau\nu) = 0$–1
>36.5	95	[108,117] ADEVA	90M	L3	$B(\tau\nu) = 0$–1
>35	95	[108,118] AKRAWY	90K	OPAL	$B(\tau\nu) = 0$–1
>35.4	95	[108,119] DECAMP	90I	ALEP	$B(\tau\nu) = 0$–1
none 10–20	95	[120] SMITH	90B	AMY	$B(\tau\nu) > 0.7$
>19	95	[119] BEHREND	87	CELL	$B(\tau\nu) = 0$–1
>18	95	[121] BARTEL	86	JADE	$B(\tau\nu)=0.1$–1.0
>17	95	[121] ADEVA	85	MRKJ	$B(\tau\nu)=0.25$–1.0

[105] ALEXANDER 96I search for the final states $H^+H^- \rightarrow \tau\nu_\tau\tau\nu_\tau$, $\tau\nu_\tau c\overline{s}$, $c\overline{s}\overline{c}s$. Limit for $B(\tau\nu_\tau) = 1$ is 45.5 GeV.

[106] ABREU 94O study $H^+H^- \rightarrow c\overline{s}s\overline{c}$ (four-jet final states) and $H^+H^- \rightarrow \tau\nu_\tau\tau\nu_\tau$. Limit for $B(\tau\nu_\tau)= 1$ is 45.4 GeV.

[107] ADRIANI 92G limit improves to 44 GeV if $B(\tau\nu_\tau) > 0.4$.

[108] Studied $H^+H^- \rightarrow (\tau\nu) + (\tau\nu)$, $H^+H^- \rightarrow (\tau\nu) +$ hadrons, $H^+H^- \rightarrow$ hadrons.

[109] DECAMP 92 limit improves to 45.3 GeV for $B(\tau\nu)=1$.

[110] ABE 96G search for a charged Higgs boson in top decays in $p\overline{p}$ collisions at $E_{cm}=$ 1.8 TeV. For the currently observed value of the top mass, the search is not sensitive enough to exclude a charged Higgs boson of any mass.

[111] BUSKULIC 95 give a limit $\tan\beta/m_{H^+} < 0.52$ GeV^{-1} (90%CL) for Type-II models from $b \rightarrow \tau\nu_\tau X$ branching ratio.

[112] HEWETT 93 and BARGER 93 analyze charged Higgs contribution to $b \rightarrow s\gamma$ in two-doublet models with the CLEO limit $B(b \rightarrow s\gamma) < 8.4 \times 10^{-4}$ (90% CL) and find lower limits on $m_{H^\pm}$ in the type of model (model II) in which different Higgs are responsible

for up-type and down-type quark masses. HEWETT 93 give $m_{H^+} >$110 (70) GeV for $m_t >$150 (120) GeV using m_b = 5 GeV. BARGER 93 give $m_{H^+} >$155 GeV for m_t = 150 GeV using m_b = 4.25 GeV. The authors employ leading logarithmic QCD corrections and emphasize that the limits are quite sensitve to m_b.

[113] BELANGER 93 make an analysis similar to BARGER 93 and HEWETT 93 with an improved CLEO limit B($b \rightarrow s\gamma$) $< 5.4 \times 10^{-4}$ (95%CL). For the Type II model, the limit $m_{H^+} >$540 (300) GeV for $m_t >$150 (120) GeV is obtained. The authors employ leading logarithmic QCD corrections.

[114] YUZUKI 91 assume photon exchange. The limit is valid for any decay mode $H^+ \rightarrow e\nu$, $\mu\nu$, $\tau\nu$, $q\overline{q}$ with five flavors. For B($\ell\nu$) = 1, the limit improves to 25.0 GeV.

[115] ABREU 90B limit improves to 36 GeV for B($\tau\nu$) = 1.

[116] ADACHI 90B limit improves to 22 GeV for B($\tau\nu$) = 0.6.

[117] ADEVA 90M limit improves to 42.5 GeV for B($\tau\nu$) = 1.

[118] AKRAWY 90K limit improves to 43 GeV for B($\tau\nu$) = 1.

[119] If B($H^+ \rightarrow \tau^+\nu$) = 100%, the DECAMP 90I limit improves to 43 GeV.

[120] SMITH 90B limit applies for $v_2/v_1 > 2$ in a model in which H_2 couples to u-type quarks and charged leptons.

[121] Studied $H^+H^- \rightarrow (\tau\nu) + (\tau\nu)$, $H^+H^- \rightarrow (\tau\nu)$ + hadrons. Search for muon opposite hadronic shower.

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

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>45.6	95	[122] ACTON	92M	OPAL	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[123] ASAKA	95	THEO	
>30.4	95	[124] ACTON	92M	OPAL	$T_3(H^{++})= +1$
>25.5	95	[124] ACTON	92M	OPAL	$T_3(H^{++})= 0$
none 6.5–36.6	95	[125] SWARTZ	90	MRK2	$T_3(H^{++}) = +1$
none 7.3–34.3	95	[125] SWARTZ	90	MRK2	$T_3(H^{++}) = 0$

[122] 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.

[123] 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.

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

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

H^0 and $H^\pm$ REFERENCES

ABE	96G	PR D54 735	+	(CDF Collab.)
ACCIARRI	96I	PL B385 454	+	(L3 Collab.)
ACCIARRI	96J	PL B388 409	+	(L3 Collab.)
ALEXANDER	96H	ZPHY C71 1	+	(OPAL Collab.)
ALEXANDER	96I	PL B370 174	+	(OPAL Collab.)
ALEXANDER	96L	PL B377 273	+Allison, Altekamp, Ametewee+	(OPAL Collab.)
BUSKULIC	96R	PL B384 427	+	(ALEPH Collab.)
DITTMAIER	96	PL B386 247	+Schildknecht, Weiglein	(BIEL, KARL)
ELLIS	96C	PL B389 321	+Fogli, Lisi	(CERN, BARI)
GURTU	96	PL B385 415		(TATA)
PDG	96	PR D54 1		
ABREU	95H	ZPHY C67 69	+Adam, Adye, Agasi, Ajinenko, Aleksan+	(DELPHI Collab.)
ASAKA	95	PL B345 36	+Hikasa	(TOHOK)
BUSKULIC	95	PL B343 444	+Casper, De Bonis, Decamp, Ghez, Goy+	(ALEPH Collab.)
CASAS	95	PL B342 171	+Espinosa, Quiros	(MADE)
CHANKOWSKI	95	PL B356 307	+Pokorski	(WARS, MPIM)
ERLER	95	PR D52 441	+Langacker	(PENN)
ESPINOSA	95B	PL B353 257	+Quiros	(DESY, CERN)
MATSUMOTO	95	MPL A10 2553		(KEK)
ROSIEK	95	PL B341 419	+Sopczak	(IFIC, CERN)
ABREU	94G	NP B421 3	+Adam, Adye, Agasi, Ajinenko+	(DELPHI Collab.)
ABREU	94O	ZPHY C64 183	+Adam, Adye, Agasi, Ajinenko, Aleksan+	(DELPHI Collab.)
AKERS	94B	PL B327 397	+Alexander, Allison, Anderson, Arcelli+	(OPAL Collab.)
AKERS	94I	ZPHY C64 1	+Alexander, Allison, Anderson, Arcelli, Asai+	(OPAL Collab.)
ALTARELLI	94	PL B337 141	+Isidori	(CERN, ROMA2, ROMAI)
ELLIS	94B	PL B333 118	+Fogli, Lisi	(CERN, BARI)
GURTU	94	MPL A9 3301		(TATA)
MONTAGNA	94	PL B335 484	+Nicrosini, Passarino, Piccinini	(INFN, PAVI, CERN, TORI)
ADRIANI	93C	PL B303 391	+Aguilar-Benitez, Ahlen, Alcaraz, Aloiso+	(L3 Collab.)
BARGER	93	PRL 70 1368	+Berger, Phillips	(WISC, RAL)
BELANGER	93	PR D48 5419	+Geng, Turcotte	(MONT, ISU, AMES)
BRAHMACH...	93	PR D48 4224	Brahmachari, Joshipura, Rindani+	(AHMED, TATA, CERN)
BUSKULIC	93H	PL B313 299	+De Bonis, Decamp, Ghez, Goy+	(ALEPH Collab.)
BUSKULIC	93I	PL B313 312	+De Bonis, Decamp, Ghez, Goy, Lees+	(ALEPH Collab.)
ELLIS	93	NP B393 3	+Fogli, Lisi	(CERN, BARI)
GROSS	93	IJMP A8 407	+Yepes	(CERN)
HEWETT	93	PRL 70 1045		(ANL, OREG)
LOPEZ-FERN...	93	PL B312 240	Lopez-Fernandez, Romao+	(CERN, LISB, VALE)
ABREU	92D	ZPHY C53 555	+Adam, Adami, Adye, Akesson, Alekseev+	(DELPHI Collab.)
ABREU	92J	NP B373 3	+Adam, Adami, Adye, Akesson+	(DELPHI Collab.)
ACTON	92M	PL B295 347	+Alexander, Allison, Allport, Anderson+	(OPAL Collab.)
ADEVA	92B	PL B283 454	+Adriani, Aguilar-Benitez, Ahlen, Akbari+	(L3 Collab.)
ADRIANI	92F	PL B292 472	+Aguilar-Benitez, Ahlen, Akbari, Alcarez+	(L3 Collab.)
ADRIANI	92G	PL B294 457	+Aguilar-Benitez, Ahlen, Akbari, Alcaraz+	(L3 Collab.)
Also	93B	ZPHY C57 355	Adriani, Aguilar-Benitez, Ahlen, Alcaraz+	(L3 Collab.)
BARABASH	92	PL B295 154	+Baranov+	(JINR, CERN, SERP, BUDA, BERL)
Also	92B	SJNP 55 1810	Barabash+	(JINR, CERN, SERP, BUDA, BERL)
		Translated from YAF 55 3247.		
BUSKULIC	92	PL B285 309	+Decamp, Goy, Lees, Minard+	(ALEPH Collab.)
DECAMP	92	PRPL 216 253	+Deschizeaux, Goy, Lees, Minard+	(ALEPH Collab.)
PICH	92	NP B388 31	+Prades, Yepes	(CERN, CPPM)
ABREU	91B	ZPHY C51 25	+Adam, Adami, Adye, Akesson+	(DELPHI Collab.)
ACTON	91	PL B268 122	+Alexander, Allison, Allport+	(OPAL Collab.)
ADEVA	91	PL B257 450	+Adriani, Aguilar-Benitez, Akbari, Alcaraz+	(L3 Collab.)
ADEVA	91D	PL B262 155	+Adriani, Aguilar-Benitez, Akbari, Alcaraz+	(L3 Collab.)
AKRAWY	91	PL B253 511	+Alexander, Allison, Allport, Anderson+	(OPAL Collab.)
AKRAWY	91C	ZPHY C49 1	+Alexander, Allison, Allport, Anderson+	(OPAL Collab.)
BLUEMLEIN	91	ZPHY C51 341	+Brunner, Grabosch+	(BERL, BUDA, JINR, SERP)
DECAMP	91F	PL B262 139	+Deschizeaux, Goy, Lees, Minard+	(ALEPH Collab.)
DECAMP	91I	PL B265 475	+Deschizeaux, Goy, Lees, Minard+	(ALEPH Collab.)
YUZUKI	91	PL B267 309	+Haba, Abe, Amako, Arai, Asano+	(VENUS Collab.)
ABE	90E	PR D41 1717	+Amidei, Appollinari, Atac, Auchincloss+	(CDF Collab.)
ABREU	90B	PL B241 449	+Adam, Adami, Adye, Alekseev+	(DELPHI Collab.)
ABREU	90C	NP B342 1	+Adam, Adami, Adye, Alekseev+	(DELPHI Collab.)
ABREU	90E	PL B245 276	+Adam, Adami, Adye, Alekseev+	(DELPHI Collab.)
ABREU	90I	HEP-90 Singapore unpub.	+Adam, Adami, Adye, Alekseev+	(DELPHI Collab.)
CERN-PPE/90-163				

ADACHI	90B	PL B240 513	+Aihara, Doeser, Enomoto+	(TOPAZ Collab.)
ADEVA	90H	PL B248 203	+Adriani, Aguilar-Benitez, Akbari, Alcaraz+	(L3 Collab.)
ADEVA	90M	PL B252 511	+Adriani, Aguilar-Benitez, Akbari, Alcaraz+	(L3 Collab.)
ADEVA	90N	PL B252 518	+Adriani, Aguilar-Benitez, Akbari, Alcaraz+	(L3 Collab.)
ADEVA	90R	PL B251 311	+Adriani, Aguilar-Benitez, Akbari, Alcaraz+	(L3 Collab.)
AKRAWY	90C	PL B236 224	+Alexander, Allison, Allport+	(OPAL Collab.)
AKRAWY	90K	PL B242 299	+Alexander, Allison, Allport, Anderson+	(OPAL Collab.)
AKRAWY	90P	PL B251 211	+Alexander, Allison, Allport, Anderson+	(OPAL Collab.)
DAWSON	90	PR D41 2844	+Gunion, Haber	(BNL, UCD, UCSC)
DECAMP	90	PL B236 233	+Deschizeaux, Lees, Minard, Crespo+	(ALEPH Collab.)
DECAMP	90E	PL B237 291	+Deschizeaux, Lees, Minard+	(ALEPH Collab.)
DECAMP	90H	PL B241 141	+Deschizeaux, Lees, Minard+	(ALEPH Collab.)
DECAMP	90I	PL B241 623	+Deschizeaux, Goy, Lees, Minard+	(ALEPH Collab.)
DECAMP	90M	PL B245 289	+Deschizeaux, Goy, Lees, Minard+	(ALEPH Collab.)
DECAMP	90N	PL B246 306	+Deschizeaux, Goy, Lees, Minard+	(ALEPH Collab.)
KOMAMIYA	90	PRL 64 2881	+Abrams, Adolphsen, Averill, Ballam+	(Mark II Collab.)
SMITH	90B	PR D42 949	+McNeil, Breedon, Kim, Ko+	(AMY Collab.)
SWARTZ	90	PRL 64 2877	+Abrams, Adolphsen, Averill, Ballam+	(Mark II Collab.)
CAHN	89	RPP 52 389		
CHENG	89	PR D40 2980	+Yu	(AST)
DAVIER	89	PL B229 150	+Nguyen Ngoc	(LALO)
DAWSON	89	PL B222 143		(BNL)
EGLI	89	PL B222 533	+Engfer, Grab, Hermes, Kraus+	(SINDRUM Collab.)
KOMAMIYA	89	PR D40 721	+Fordham, Abrams, Adolphsen, Akerlof+	(Mark II Collab.)
LINDNER	89	PL B228 139	+Sher, Zaglauer	(FNAL, WUSL)
LOW	89	PL B228 548	+Xu, Abashian, Gotow, Hu, Mattson+	(AMY Collab.)
SHER	89	PRPL 179 273		
SNYDER	89	PL B229 169	+Murray, Abrams, Adolphsen, Akerlof+	(Mark II Collab.)
YEPES	89	PL B227 182		(MCGI)
BEHREND	87	PL B193 376	+Buerger, Criegee, Dainton+	(CELLO Collab.)
FRANZINI	87	PR D35 2883	+Son, Tuts, Youssef, Zhao+	(CUSB Collab.)
RUSKOV	87	PL B187 165		(SOFI)
BARTEL	86	ZPHY C31 359	+Becker, Felst, Haidt+	(JADE Collab.)
EICHTEN	86	PR D34 1547	+Hinchliffe, Lane, Quigg+	(FNAL, LBL, OSU)
ADEVA	85	PL 152B 439	+Becker, Becker-Szendy+	(Mark-J Collab.)
AKERLOF	85	PL 156B 271	+Bonvicini, Chapman, Errede+	(HRS Collab.)
ALBRECHT	85J	ZPHY C29 167	+Binder, Harder+	(ARGUS Collab.)
ASH	85	PRL 55 1831	+Band, Blume, Camporesi+	(MAC Collab.)
ASH	85C	PRL 54 2477	+Band, Blume, Camporesi+	(MAC Collab.)
BARTEL	85L	PL 155B 288	+Becker, Cords, Felst, Hagiwara+	(JADE Collab.)
BEHREND	85	PL 161B 182	+Burger, Criegee, Fenner+	(CELLO Collab.)
FELDMAN	85	PRL 54 2289	+Abrams, Amidei, Baden+	(Mark II Collab.)
DZHELYADIN	81	PL 105B 239	+Golovkin, Konstantinov, Kubarovski+	(SERP)
WITTEN	81	NP B177 477		(HARV)
GUTH	80	PRL 45 1131	+Weinberg	(SLAC)
JACQUES	80	PR D21 1206	+Kalelkar, Miller, Plano+	(RUTG, STEV, COLU)
SHER	80	PR D22 2989		(UCSC)
Also	83	ANP 148 95	Flores, Sher	(UCSC, UCI)