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

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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 $Ht\overline{t}$ 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
>58.4 (CL = 95%) OUR LIMIT					
>55.7	95	[1] ABREU	94G	DLPH	$Z \to H^0 Z^*$
>56.9	95	[2] AKERS	94B	OPAL	$Z \to H^0 Z^*$
>57.7	95	[3] ADRIANI	93C	L3	$Z \to H^0 Z^*$
>58.4	95	[4] BUSKULIC	93H	ALEP	$Z \to H^0 Z^*$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>60	95	[5] GROSS	93	RVUE	$Z \to H^0 Z^*$
		[6] ABREU	92D	DLPH	$Z \to H^0 \gamma$
>38	95	[7] ABREU	92J	DLPH	$Z \to H^0 Z^*$
>52	95	[8] ADEVA	92B	L3	$Z \to H^0 Z^*$
		[9] ADRIANI	92F	L3	$Z \to H^0 \gamma$
>48	95	[10] DECAMP	92	ALEP	$Z \to H^0 Z^*$
> 0.21	99	[11] ABREU	91B	DLPH	$Z \to H^0 Z^*$
>11.3	95	[12] ACTON	91	OPAL	$H^0 \to$ anything
>41.8	95	[13] ADEVA	91	L3	$Z \to H^0 Z^*$
		[14] ADEVA	91D	L3	$Z \to H^0 \gamma$
none 3–44	95	[15] AKRAWY	91	OPAL	$Z \to H^0 Z^*$
none 3–25.3	95	[16] AKRAWY	91C	OPAL	$Z \to H^0 Z^*$
none 0.21–0.818	90	[17] ABE	90E	CDF	$p\overline{p} \to (W^{\pm}, Z) + H^0 + X$
none 0.846–0.987	90	[17] ABE	90E	CDF	$p\overline{p} \to (W^{\pm}, Z) + H^0 + X$
none 0.21–14	95	[18] ABREU	90C	DLPH	$Z \to H^0 Z^*$
none 2–32	95	[19] ADEVA	90H	L3	$Z \to H^0 Z^*$
> 2	99	[20] ADEVA	90N	L3	$Z \to H^0 Z^*$
none 3.0–19.3	95	[21] AKRAWY	90C	OPAL	$Z \to H^0 Z^*$
> 0.21	95	[22] AKRAWY	90P	OPAL	$Z \to H^0 Z^*$
none 0.032–15	95	[23] DECAMP	90	ALEP	$Z \to H^0 Z^*$
none 11–24	95	[24] DECAMP	90H	ALEP	$Z \to H^0 Z^*$
> 0.057	95	[25] DECAMP	90M	ALEP	$Z \to H^0 ee$, $H^0 \mu\mu$
none 11–41.6	95	[26] DECAMP	90N	ALEP	$Z \to H^0 Z^*$

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

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

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

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

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

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

[7] ABREU 92J searched for $Z \to H^0 + (ee, \mu\mu, \tau\tau, \nu\overline{\nu})$ with $H^0 \to q\overline{q}$. Only one candidate was found, in the channel ee + 2jets, with a dijet mass 35.4 ± 5 GeV/c^2,

consistent with the expected background of 1.0 ± 0.2 events in the 3 channels e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, and of 2.8 ± 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.

[8] 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.

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

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

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

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

[13] ADEVA 91 searched for $Z \rightarrow H^0 + (\mu\mu, ee, \nu\overline{\nu})$. 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.

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

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

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

[17] 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.

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

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

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

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

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

[23] DECAMP 90 limits based on 11,550 Z events. They searched for $Z \rightarrow H^0 + (\nu\overline{\nu}, ee, \mu\mu, \tau\tau, q\overline{q})$. The decay $Z \rightarrow H^0\nu\overline{\nu}$ 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 $m_{H^0} = 0.040\text{–}12$ GeV.

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

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

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

Limits from Other Techniques

H^0 Indirect Mass Limits from Electroweak Analysis

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
35^{+205}_{-26}		[27] ELLIS	94	RVUE	
45^{+95}_{-28}		[28] ELLIS	94B	RVUE	
69^{+188}_{-9}		[29] GURTU	94	RVUE	
		[30] MONTAGNA	94	RVUE	
73^{+178}_{-13}		[31] BLONDEL	93	RVUE	
10^{+25}_{-8}		[32] ELLIS	93B	RVUE	
10^{+60}_{-8}		[33] NOVIKOV	93B	RVUE	
		[34] DELAGUILA	92B	RVUE	
> 1.4	68	[35] ELLIS	92	RVUE	Electroweak
25^{+275}_{-19}		[36] ELLIS	92E	RVUE	
50^{+353}_{-0}		[37] RENTON	92	RVUE	
		[38] SCHAILE	92	RVUE	

[27] ELLIS 94 fit to LEP, SLD, W-mass, and neutrino data available in the summer of 1993. The fit to m_H, m_t, and α_s yields $m_t = 140^{+21}_{-22}$ GeV and $\alpha_s(m_Z) = 0.116^{+0.007}_{-0.006}$.

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

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

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

[31] BLONDEL 93 perform two dimensional ($m_t - m_H$) fit to LEP electroweak data available in the spring of 1993. $\alpha_s = 0.117 \pm 0.005$ is used and $m_t >$108 GeV, $m_H >$ 62.5 GeV imposed. $m_{H^0} = 1$ TeV is compatible with the data within two standard deviations.

[32] ELLIS 93B fit to LEP and neutrino data available in the summer of 1993. m_t is adjusted to minimize χ^2 and $\alpha_s(m_Z) = 0.123 \pm 0.006$ is used. 95% CL limit for $m_H <$250 GeV is claimed.

[33] NOVIKOV 93B use a subset of the most accurate and "gluon-free" data available in the spring of 1993. They use m_W, $\Gamma(\ell\ell)$, and $A^{\ell\ell}_{FB}$.

[34] DELAGUILA 92B perform two dimensional ($m_t - m_H$) fit to various LEP, neutrino, eH, and $p\overline{p}$ data available through 1991 with direct limits on m_t, m_H. The result $m_H = 65^{+245}_{-\ \ 4}$ is not expected from the statistical sensitivity of the data but due to deviation of the data from the Standard Model expectation.

[35] ELLIS 92 result is from a fit to electroweak data from LEP and elsewhere. They also find $m_H <$160 GeV at 68%CL and $0.5 < m_H <$1500 GeV at 90%CL with m_t unconstrained.

[36] ELLIS 92E perform fit to electroweak data available in the spring of 1992. m_t is adjusted to minimize χ^2 and $\alpha_s(m_Z) = 0.118 \pm 0.008$ is used.

[37] RENTON 92 use electroweak data available in 1991 and require $m_H >$50 GeV. The constraint $\alpha_s = 0.114 \pm 0.007$ was used.

[38] SCHAILE 92 performs fit to LEP electroweak data (as of summer 1991) as well as m_W (UA2/CDF) and νN (CDHS/CHARM). The fit with the constraint $m_H >$50 GeV gives $m_H = 50^{+192}_{-\ \ 0}$ GeV. However, the m_H dependence of the χ^2 is not consistent from that expected from the present statistics and the sensitivity to m_H arises from the fact that the measured values of g_A and A^b_{FB} deviate from the Standard Model expectation. Therefore, the result is not considered to be significant.

From Quarkonium Decay

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>0.086	90	[39] ANTREASYAN	90C	CBAL	$\Upsilon(1S) \rightarrow H^0\gamma$
none 0.29–0.57	90	[40] ALBRECHT	89	ARG	$\Upsilon(1S) \rightarrow H^0\gamma$ ($H^0 \rightarrow \pi^+\pi^-$)
none 0.21–5	90	[41] LEE-FRANZINI	88	CUSB	$\Upsilon(1S,3S) \rightarrow \gamma H^0$
		[42] DRUZHININ	87	ND	$\phi \rightarrow \gamma H^0$ ($H^0 \rightarrow \pi^0\pi^0$)

[39] ANTREASYAN 90C obtain B($\Upsilon(1S) \rightarrow H^0\gamma) < 3.5 \times 10^{-5}$ at 90% CL for $m_{H^0} < 2m_e$ and similar limits for heavier Higgs masses. The listed limit assumes the QCD/relativistic reduction factor for the width of 0.5. The limit is reduced to 39 MeV if 0.25 is used instead.

[40] ALBRECHT 89 give a limit B($\Upsilon(1S) \rightarrow H^0\gamma$)·B($H^0 \rightarrow \pi^+\pi^-) <$ 3–4.5 $\times 10^{-5}$ for $m_{H^0} =$ 290–570 MeV, which is lower than the predition including first order QCD corrections and assuming B($H^0 \rightarrow \pi^+\pi^-) >$ 45%.

[41] LEE-FRANZINI 88 presents updated results from the CUSB experiment (see FRANZINI 87 for more details). First order QCD correction included with $\alpha_s \simeq 0.2$ ($\Lambda = 0.2$ GeV and $n(f) = 4$). The order α_s correction reduced the rate for $\Upsilon(1S) \rightarrow H^0\gamma$ by a factor of 2 (yielding these limits). The impact of order α_s^2 and of relativistic corrections are unknown. If they amounted to another factor of 2 suppression, the above limit would be essentially eliminated.

[42] DRUZHININ 87 sets limit B($\phi \rightarrow \gamma H^0$)·B($H^0 \rightarrow \pi^0\pi^0) < 8 \times 10^{-5}$ at CL=90% for $m_{H^0} =$ 0.6–1 GeV which is still far from the standard Higgs model prediction and does not exclude the existence of light Higgs bosons.

From B Decay

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
none 0.21–3.57		[43] DAWSON	90	RVUE	$B \to \mu^+\mu^- X$; $B \to K(\mu^+\mu^-, \pi^+\pi^-, K^+K^-)$
none 0.21–1.0	90	[44] ALAM	89B	CLEO	$B \to H^0 K$, $(H^0 \to \mu^+\mu^-, \pi^+\pi^-)$
none 1.0–3.6	90	[44] ALAM	89B	CLEO	$B \to H^0 X$ $(H^0 \to \mu^+\mu^-)$
none 3.6–4.6		[45] EILAM	89	RVUE	$B \to H^0 X$ $(H^0 \to \mu^+\mu^-)$
none 0.211–0.700		[46] RABY	89	RVUE	$B \to \mu^+\mu^- X$ $m_{\text{top}} > 80$ GeV
none 0.07–0.21	90	[47] SNYDER	89	MRK2	$B \to H^0 X$ $(H^0 \to e^+e^-)$
none 0.00103–3.57		[46] CHIVUKULA	88	RVUE	$B \to H^0 X$, $m(\text{top}) > 80$ GeV
none 2–3.7		[46] GRINSTEIN	88	RVUE	$B \to H^0 X$, $m(\text{top}) > 80$ GeV

[43] Based on ALTHOFF 84G, ALAM 89B, and ALBRECHT 87D. Some processes considered require the assumption $B(B \to H^0 K)/B(B \to H^0 X) > 0.01$. Other processes require theoretical assumptions regarding $B(H \to \pi^+\pi^-)$ when considering masses in the interval 0.9–1.2 GeV.

[44] ALAM 89B searched for inclusive and exclusive decays of B mesons into H^0 and can exclude the mass range $2m_\mu$–$2m_\tau$ with a wide margin provided $m_t \gtrsim m_W$, possibly except for masses near $\chi_0(3410)$, where the mixing effect can reduce $B(H^0 \to \mu^+\mu^-)$ significantly.

[45] EILAM 89 assume $m_{\text{top}} > 90$ GeV and vary $|V_{ub}/V_{cb}|^2$ from 0 to 0.026.

[46] Limits assume $m(\text{top}) > 80$ GeV and $|V_{ts}V^*_{tb}/V_{cb}| \approx 1$. CHIVUKULA 88 excludes m_{H^0} between $2m_e$ and $2m_\tau$ from the limits on $B \to \mu^+\mu^- + X$ by taking the $B(H^0 \to \mu^+\mu^-)$ estimate of VOLOSHIN 86. GRINSTEIN 88 argues that this estimate of VOLOSHIN 86 is unreliable, and excludes m_{H^0} between 2 GeV and 3.7 GeV where perturbative QCD is used to estimate $B(H^0 \to \mu^+\mu^-)$.

[47] SNYDER 89 exclude the mass range 70–210 MeV with a wide margin provided that $m_t \gtrsim m_W$. A limit $B(B \to H^0 X) \cdot B(H^0 \to e^+e^-) < 22\%$ (90% CL) is given for $m_{H^0} = 50$ MeV.

From K Decay

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>0.026	90	[48] ATIYA	90	CNTR	$K^+ \to \pi^+ H^0$
		[49] ATIYA	90B	CNTR	$K^+ \to \pi^+ H^0$, $H^0 \to \gamma\gamma$
none 0.012–0.211	90	[50] BARR	90	NA31	$K^0_L \to \pi^0 H^0$ $(H^0 \to e^+e^-)$
>0.32		[51] DAWSON	90	RVUE	K decays
>0.3		[52] LEUTWYLER	90	RVUE	$K^+ \to \pi^+ H^0$
none 0.22–0.32		[53] ATIYA	89	CNTR	$K^+ \to \pi^+ H^0$ $(H^0 \to \mu^+\mu^-)$
>0.28		[54] CHENG	89	RVUE	$K^\pm \to \pi^\pm H$
>0.36		[55] CHIVUKULA	88	RVUE	$K \to \pi^+ H^0$
	90	[56] BAKER	87	CALO	$K^\pm \to \pi^\pm H^0$ $(H^0 \to e^+e^-)$
none 0.05–0.211		[57] WILLEY	86	RVUE	$K^\pm \to \pi^\pm H^0$ $(H^0 \to e^+e^-)$

[48] ATIYA 90 sets limits on $B(K^+ \to \pi^+ H^0)$ varying from $< 6.4 \times 10^{-9}$ for $m_{H^0} \approx 0$ MeV to $< 10^{-6}$ for $m_{H^0} = 26$ MeV.

[49] ATIYA 90B give 90% CL limits on $B(K^+ \to \pi^+ H^0) \cdot B(H^0 \to \gamma\gamma)$ for $m_{H^0} < 100$ MeV ranging from 10^{-4} to 10^{-7} depending on the mass.

[50] BARR 90 set m_{H^0}-dependent limits on $B(K^0_L \to \pi^0 H^0)$ in the region where $B(H^0 \to e^+e^-) \approx 1$. The limit varies from $B(K^0_L \to \pi^0 H^0) < 10^{-7}$ at $m_{H^0} = 12$ MeV to $< 2 \times 10^{-8}$ for $50 \leq m_{H^0} \leq 211$ MeV. BARR 90 allow for nonzero H^0 lifetime.

[51] Based on ASANO 81B, YAMAZAKI 84, BAKER 87, ATIYA 89, and BARR 90. DAWSON 90 used theoretical calculations and various assumptions such as $m_t > 80$ GeV and Im $V^*_{td}V_{ts} > 0.2 \sin^5\theta_c$.

[52] LEUTWYLER 90 give a consistent analysis of the $K \rightarrow \pi H^0$ amplitude based on chiral theory and find that all contributions except the t-quark loop are unimportant numerically provided the t-quark mass is of order or bigger than 100 GeV. Hence, a light Higgs can probably be ruled out.

[53] ATIYA 89 give a limit $B(K^+ \rightarrow \pi^+ H^0) \cdot B(H^0 \rightarrow \mu^+ \mu^-) < 1.5 \times 10^{-7}$ (90% CL) for m_{H^0} = 220–320 MeV, which is lower than the prediction unless there is an accidental cancellation in the CP-conserving part of the amplitude and the CP-violating part is unexpectedly small. See WILLEY 89 and CHENG 89.

[54] CHENG 89 concludes even if real part of $K^+ \rightarrow \pi^+ H$ amplitude is cancelled accidentally, the imaginary contribution alone rules out $m_H < 2m_\pi$.

[55] CHIVUKULA 88 uses chiral perturbation theory to estimate $K \rightarrow \pi^+ H^0$ amplitudes with a conservative sign assignment for the relative sign of the $\Delta I = 1/2$ term, and exclude m_{H^0} below 0.36 GeV barring cancellation among terms, by using the limits on $K \rightarrow \pi^+ X$ with $X = \mu^+\mu^-$, e^+e^-, or missing particles. For a criticism see DAWSON 90.

[56] BAKER 87 sets limit $B(K^\pm \rightarrow \pi^\pm H^0) \cdot B(H^0 \rightarrow e^+e^-) < 8 \times 10^{-7}$ at CL=90% for $m_{H^0} < 100$ MeV if H^0 travels much less than 1.4 cm in the lab frame ($p(K^+)$ = 5.8 GeV). The expected lifetime of the standard H^0 is too long to be effectively detected by the experiment and their limit on the branching ratio is significantly weakened accordingly. In view of the uncertainty in the theoretical prediction for $B(K \rightarrow \pi H)$, no definite conclusion can be drawn from the result. See also DAWSON 90.

[57] WILLEY 86 re-examined the theoretical estimate of the decay $K^\pm \rightarrow \pi^\pm H^0$ rate via the one-loop sdH^0 coupling. The experimental bound $B(K \rightarrow \pi\mu\mu) < 2.4 \times 10^{-6}$ is not strong enough to rule out $2m_\mu < m_{H^0} < 2m_{\pi^0}$. For a criticism see DAWSON 90.

From Coupling with Nucleons

Some of the experiments for a light Higgs utilize its coupling with nucleons. We parameterize the Higgs-nucleon coupling (which is dominantly isoscalar) as $g_{HNN} = \eta_{HNN}(\sqrt{2}G_F)^{1/2}\, m_N$. The limits depend on the value of η_{HNN} used. Shifman *et al.* [Physics Letters **78B** 443 (1978)] obtained $\eta_{HNN} = 0.22$ assuming three heavy flavors. More recently, T.P. Cheng [Physical Review **D38** 2869 (1988)], H.-Y. Cheng [Physics Letters **B219** 347 (1989)], and Barbieri and Curci [Physics Letters **B219** 503 (1989)] took into account the strange-quark content of the proton as well as the heavy quark effects, and derived $\eta_{HNN} = 0.56$.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>0.0009	95	[58] BLUEMLEIN	92	BDMP	$pN \rightarrow H^0 X$, $H^0 Z \rightarrow \ell^+\ell^- Z$ (ℓ=e,μ)
>0.0128	90	[59] LEEB	92	RVUE	$nN \rightarrow nN$
none 0.001–0.08	95	BLUEMLEIN	91	BDMP	$pN \rightarrow H^0 X$ ($H^0 \rightarrow e^+e^-$, 2γ)
>0.018		[60] GRIFOLS	89	RVUE	$\sigma_{total}(n\text{Pb})$
none 0.03–0.20		[61] YEPES	89B	RVUE	$pN \rightarrow H^0 X$ ($H^0 \rightarrow e^+e^-$)
>0.010	68	[62] BELTRAMI	86	SPEC	Muonic atoms
none 0.003–0.012	95	[63] FREEDMAN	84	CNTR	$\text{He}^* \rightarrow \text{He}H^0$ ($H^0 \rightarrow e^+e^-$)
none 0.00103–0.00584		[64] MUKHOPAD...	84	RVUE	$\text{O}^* \rightarrow \text{O}H^0$ ($H^0 \rightarrow e^+e^-$)
		[65] HOFFMAN	83	CNTR	$\pi p \rightarrow nH^0$ ($H^0 \rightarrow e^+e^-$)
>0.006		[66] BARBIERI	75	RVUE	$nN \rightarrow nN$

[58] BLUEMLEIN 92 exclude very light Standard Model Higgs using bremsstrahlung Higgs production from beam dump followed by Bethe-Heitler production of lepton pairs by H^0 on nuclei. If combined with BLUEMLEIN 91, the range $m_H < 0.08$ GeV is excluded.

[59] LEEB 92 use the neutron-lead total cross section measurement by SCHMIEDMAYER 91 as well as neutron optics data to obtain bounds on new long-range neutron interactions. The limit uses $\eta_{HNN} = 0.56$.

[60] GRIFOLS 89 use the neutron-lead total cross-section measurement at kinetic energies of 50 eV – 50 keV by SCHMIEDMAYER 88 and argue that the agreement of the measured energy dependence with the prediction of a hard-core potential model is lost by light-Higgs exchange. The limit of 18 MeV is obtained for $\eta_{HNN} = 0.56$ and is reduced to 12 MeV for $\eta_{HNN} = 0.22$. LEEB 92 argue against the use of a hard-core potential and obtain a weaker limit.

[61] YEPES 89B reanalyzed a Fermilab experiment (BECHIS 78), which looked for a long-lived neutral lepton and found none, and argues that their limit is many orders of magnitude lower than expected from low-mass Higgs bremsstrahlung production followed by the decay to e^+e^-.

[62] BELTRAMI 86 measured the wavelengths of the $3d_{5/2}$–$2p_{3/2}$ X-ray transitions in muonic ^{24}Mg and ^{28}Si and found the deviation from QED $\delta\lambda/\lambda = (-0.2 \pm 3.1) \times 10^{-6}$.

The listed limit uses $\eta_{HNN} = 0.23$. The experiment excludes $m_{H^0} \lesssim 1$ MeV by more than 3 s.d.

[63] FREEDMAN 84 is ANL experiment with dynamitron proton bombarding tritium to form He*. $\eta_{HNN} = 0.30$ is used to derive the limit . They also reanalyze KOHLER 74 He* data to find no mass region is excluded by that data. See also footnote for MUKHOPADHYAY 84 below.

[64] MUKHOPADHYAY 84 examine KOHLER 74 He* and C* data. Claim that no mass region can be excluded by 74 He* data since He* decay width to proton is large [B(He* $\rightarrow$ H^0 He) $= 3.4 \times 10^{-11}$ is very small]. Above limit is from KOHLER 74 O* decay data.

[65] HOFFMAN 83 looked for e^+e^- peak from Higgs produced in $\pi^- p \rightarrow H^0 n$ at 300 MeV/c. Set CL = 90% limit $d\sigma/dt$ B$(e^+e^-) < 3.5 \times 10^{-32}$ cm^2/GeV^2 for 140 $< m_{H^0} <$160 MeV, which does not exclude H^0 with the standard one-doublet-model couplings.

[66] BARBIERI 75 studied Higgs boson exchange effect in neutron-lead scattering data of ALEKSANDROV 66 and found limit $(g^2_{H^0 nn}/4\pi)\,(m_{H^0}/\text{MeV})^{-4} \lesssim 3.4 \times 10^{-11}$ for $m_{H^0} \gtrsim 1$ MeV. This gives the listed limit for $\eta_{HNN} = 0.2$ and 10 MeV for $\eta_{HNN} = 0.56$. Lighter mass region $m_{H^0} \lesssim 1$ MeV would be incompatible with the measured angular distribution.

From Other Techniques

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[67] ALTARELLI	94	THEO	Vacuum stability
none 0.001–0.072	95	[68] 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	[69] EGLI	89	CNTR	$\pi^+ \rightarrow e^+ \nu H^0$ $(H^0 \rightarrow e^+e^-)$
		[70] LINDNER	89	THEO	Vacuum stability
none 0.015–0.04	90	[71] YEPES	89	RVUE	$\pi^\pm \rightarrow e^\pm \nu H^0$ $(H^0 \rightarrow e^+e^-)$
		[72] DZHELYADIN	81		$\eta' \rightarrow \eta H^0$ $(H^0 \rightarrow \mu^+\mu^-)$
		[73] WITTEN	81	COSM	
		[73] GUTH	80	COSM	
		[73] SHER	80	COSM	

[67] 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.

[68] 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.

[69] 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.

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

[71] 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.

[72] 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$(H^0 \rightarrow \mu^+\mu^-)$.

[73] 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 $m_{H^0} > 10.4[1-4m_t^4/(2m_W^4+m_Z^4)]^{1/2}$ 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. • • •					
		[74] BRAHMACH...	93	RVUE	
		[75] BUSKULIC	93I	ALEP	$Z \to H^0 Z^*$
>65	95	[76] BUSKULIC	93I	ALEP	Invisible H^0
		[77] LOPEZ-FERN...	93	RVUE	
		[78] ADRIANI	92G	L3	$Z \to H^0 Z^*$
		[79] PICH	92	RVUE	Very light Higgs
> 3.57	95	[80] ACTON	91	OPAL	$Z \to H^0 Z^*$
		[81] DECAMP	91F	ALEP	$Z \to H^0 \ell^+ \ell^-$
		[82] DECAMP	91I	ALEP	Z decay
> 0.21	95	[83] AKRAWY	90P	OPAL	$Z \to H^0 Z^*$
		[84] DAVIER	89	BDMP	$e^- Z \to e H^0 Z$ $(H^0 \to e^+ e^-)$
		[85] SNYDER	89	MRK2	$B \to H^0 X$ $(H^0 \to e^+ e^-)$
none 0.6–6.2	90	[86] FRANZINI	87	CUSB	$\Upsilon(1S) \to \gamma H^0$, x=2
none 0.6–7.9	90	[86] FRANZINI	87	CUSB	$\Upsilon(1S) \to \gamma H^0$, x=4
none 3.7–5.6	90	[87] ALBRECHT	85J	ARG	$\Upsilon(1S) \to \gamma H^0$, x=2
none 3.7–8.2	90	[87] ALBRECHT	85J	ARG	$\Upsilon(1S) \to \gamma H^0$, x=4

[74] 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($H^0 \to$ SM-like)+B($H^0 \to$ invisible)=1.

[75] 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 $Z \to H^0 Z^*$ is >10% of the minimal Standard Model rate, then $m_{H^0} >$40 GeV. For the standard rate the limit is 58 GeV.

[76] BUSKULIC 93I limit for H^0 with the standard coupling to Z but decaying to weakly interacting particles.

[77] 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($H^0 \to$ SM-like)+B($H^0 \to$ 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.

[78] 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 $Z \to H^0_1 Z^*$ is less than 10% of the Standard Model rate.

[79] 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.

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

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

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

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

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

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

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

[87] 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($\Upsilon(1S) \to H^0 \gamma$) $< 1.5 \times 10^{-3}$ 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_1^0 (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_1^0 and H_2^0, where we define $m_{H_1^0} < m_{H_2^0}$], a pseudoscalar (A^0), and a charged Higgs pair ($H^\pm$). 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 $m_{H_1^0} \le m_Z$, $m_{H_2^0} \ge m_Z$, $m_{A^0} \ge m_{H_1^0}$, and $m_{H^\pm} \ge m_W$. However, as describe 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
>44.4	95	[88] ABREU	94O	DLPH	$m_{H_1^0}=m_{A^0}$, any $\tan\beta$
>44.5	95	[89] AKERS	94I	OPAL	$\tan\beta > 1$
>44	95	[90] BUSKULIC	93I	ALEP	$\tan\beta > 1$
>29	95	[91] ABREU	92J	DLPH	any $\tan\beta$
>42	95	[92] ADRIANI	92G	L3	$1 < \tan\beta < 50$
none 3–22	95	[93] AKRAWY	91C	OPAL	$\tan\beta > 0.5$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>34	95	[91] ABREU	92J	DLPH	$\tan\beta > 0.6$
> 0.21	95	[94] ABREU	91B	DLPH	any $\tan\beta$
>28	95	[95] ABREU	91B	DLPH	any $\tan\beta$
none 3–38	95	[93] AKRAWY	91C	OPAL	$\tan\beta > 6$
		[96] BLUEMLEIN	91	BDMP	$pN \to H_1^0 X$ ($H_1^0 \to e^+e^-$, 2γ)
>41	95	[97] DECAMP	91I	ALEP	$\tan\beta > 1$
> 9	95	[98] ABREU	90E	DLPH	any $\tan\beta$
>13	95	[98] ABREU	90E	DLPH	$\tan\beta > 1$
>26	95	[99] ADEVA	90R	L3	$\tan\beta > 1$
none 0.05–3.1	95	[100] DECAMP	90E	ALEP	any $\tan\beta$
none 0.05–13	95	[100] DECAMP	90E	ALEP	$\tan\beta > 0.6$
none 0.006–20	95	[100] DECAMP	90E	ALEP	$\tan\beta > 2$
>37.1	95	[100] DECAMP	90E	ALEP	$\tan\beta > 6$
none 0.05–20	95	[101] DECAMP	90H	ALEP	$\tan\beta > 0.6$
none 0.006–21.4	95	[101] DECAMP	90H	ALEP	$\tan\beta > 2$
> 3.1	95	[102] DECAMP	90M	ALEP	any $\tan\beta$

[88] 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.

[89] 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, $m_{\tilde{t}}$ <1 TeV. See Fig. 10 for limits for $\tan\beta < 1$.

[90] BUSKULIC 93I search for $Z \to H_1^0 Z^*$ and $Z \to H_1^0 A^0$. One-loop corrections are included with any m_t, $m_{\tilde{t}} > m_t$. Assumes no invisible H^0 or A^0 decays.

[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] 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, $m_t < m_{\tilde{t}} < 1$ TeV.

[93] 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.

[94] 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 $m_{A^0} < m_{H_1^0}$.

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

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

[97] 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.

[98] 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.

[99] 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.

[100] DECAMP 90E look for $Z \rightarrow H^0_1 A^0$ as well as $Z \rightarrow H^0_1 \ell^+ \ell^-$, $Z \rightarrow H^0_1 \nu\overline{\nu}$ with 18610 Z decays. Their search includes signatures in which H^0_1 and A^0 decay to $\gamma\gamma$, $e^+ e^-$, $\mu^+ \mu^-$, $\tau^+ \tau^-$, or $q\overline{q}$. See their figures of $m_{H^0_1}$ vs. $\tan\beta$.

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

[102] DECAMP 90M looked for $Z \rightarrow H^0 \ell\ell$, where H^0_1 decays outside the detector. This excludes a region in the ($m_{H^0_1}$, $\tan\beta$) plane centered at $m_{H^0_1}$ = 50 MeV, $\tan\beta$ = 0.5. This limit together with DECAMP 90E result excludes $m_{H^0_1} < 3$ GeV for any $\tan\beta$.

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

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>44.4	95	[103] ABREU	94O	DLPH	$m_{H^0_1}=m_{A^0}$, any $\tan\beta$
>24.3	95	[104] AKERS	94I	OPAL	$\tan\beta > 1$
>44.5	95	[104] AKERS	94I	OPAL	$\tan\beta > 1$, $m_{H^0_1}=m_{A^0}$
>21	95	[105] BUSKULIC	93I	ALEP	$\tan\beta > 1$
>34	95	[106] ABREU	92J	DLPH	$\tan\beta > 3$
>22	95	[107] ADRIANI	92G	L3	$1 < \tan\beta < 50$
none 3–40.5	95	[108] AKRAWY	91C	OPAL	$\tan\beta > 1$, if 3 GeV $< m_{H^0_1} < m_{A^0}$
>12	95	[109] ABREU	90E	DLPH	$\tan\beta < 1$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[110] ELLIS	93	RVUE	Electroweak
> 0.21	95	[111] BUSKULIC	92	ALEP	$\tan\beta > 1$
>20	95	[112] DECAMP	91I	ALEP	$\tan\beta > 1$
>34	95	[109] ABREU	90E	DLPH	$\tan\beta > 1$, $m_{H^0_1} < m_{A^0}$
>39	95	[113] ADEVA	90R	L3	$\tan\beta > 1$, $m_{H^0_1} < m_{A^0}$

[103] ABREU 94O study $H^0_1 A^0 \rightarrow$ four jets and combine with ABREU 94G analysis. The limit applies if the H^0_1-A^0 mass difference is <4 GeV.

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

[105] BUSKULIC 93I search for $Z \rightarrow H^0_1 Z^*$ and $Z \rightarrow H^0_1 A^0$. 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.

[106] ABREU 92J searched for $Z \rightarrow H^0_1 Z^*$ and $Z \rightarrow H^0_1 A^0$ with H^0_1, $A^0 \rightarrow \tau\tau$ or jet-jet. Small mass values are excluded by ABREU 91B.

[107] ADRIANI 92G search for $Z \rightarrow H^0_1 Z^*$, $Z \rightarrow H^0_1 A^0 \rightarrow 4b$, $bb\tau\tau$, 4τ, $6b$ (via $H^0 \rightarrow A^0 A^0$), 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 $42 < m_{H^0_1} < 62$ GeV, but is excluded by other experiments.

[108] AKRAWY 91C result from $Z \rightarrow H^0_1 A^0 \rightarrow$ 4jet or $\tau^+ \tau^- jj$ or 4τ. See paper for the excluded region for the case $\tan\beta < 1$.

[109] ABREU 90E searched $Z \rightarrow H^0_1 A^0$ and $Z \rightarrow H^0_1 Z^*$. m_{A^0} < 210 MeV is not excluded by this analysis.

[110] 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.

[111] BUSKULIC 92 limit is from $\Gamma(Z)$, $Z \rightarrow H^0_1 Z^*$, and $Z \rightarrow H^0_1 A^0$. The limit is valid for any $m_{H^0_1}$ below the the theoretical limit $m_{H^0_1}$ <64 GeV which holds for $m_{A^0} \sim 0$ in the minimal supersymmetric model. One-loop radiative corrections are included.

[112] DECAMP 91I searched for $Z \rightarrow H^0_1 Z^*$, and $Z \rightarrow H^0_1 A^0 \rightarrow$ 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.

[113] ADEVA 90R result is from $Z \rightarrow H^0_1 A^0 \rightarrow$ 4jet or $\tau\tau jj$ or 4τ and $Z \rightarrow H^0_1 Z^*$. 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	[114] AKERS	94I	OPAL	$m_{H_1^0} < 12$ GeV
		[115] ADRIANI	92G	L3	
>45	95	[116] DECAMP	90H	ALEP	$m_{H_1^0} < 20$ GeV
>37.5	95	[116] DECAMP	90H	ALEP	$m_{H_1^0} < m_{H_2^0}$
none 5–45	95	[117] KOMAMIYA	90	MRK2	$m_{H_1^0} < 0.5$ GeV, $H_2^0 \to q\overline{q}$ or $\tau^+\tau^-$
> 8	90	[118] KOMAMIYA	89	MRK2	$H_1^0 \to \mu^+\mu^-$, $H_2^0 \to q\overline{q}$, $\tau^+\tau^-$
>28	95	[119] LOW	89	AMY	$m_{H_1^0} \lesssim 20$ MeV, $H_2^0 \to q\overline{q}$
none 2–9	90	[120] AKERLOF	85	HRS	$m_{H_1^0} = 0$, $H_2^0 \to f\overline{f}$
none 4–10	90	[121] 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	[120] 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	[120] BEHREND	85	CELL	$m_{H_1^0} = 0$, $H_2^0 \to f\overline{f}$
none 1–11	90	[120] FELDMAN	85	MRK2	$m_{H_1^0} = 0$, $H_2^0 \to f\overline{f}$
none 1–9	90	[120] FELDMAN	85	MRK2	$m_{H_1^0} = m_{H_2^0}$, $H_2^0 \to f\overline{f}$

[114] 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.

[115] 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.

[116] 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.

[117] 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.

[118] 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.

[119] 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.

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

[121] 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($H^+ \to \tau^+\nu$) + B($H^+ \to c\overline{s}$) = 1. DECAMP 90I, BEHREND 87, and BARTEL 86 assume B($H^+ \to \tau^+\nu$) + B($H^+ \to$

$c\overline{s}$) + 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 a discussion of techni-particles, see EICHTEN 86.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>43.5	95	[122] ABREU	94O	DLPH	$B(\tau\nu) = 0$–1
>41	95	[123] ADRIANI	92G	L3	$B(\tau\nu) = 0$–1
>41.7	95	[124,125] DECAMP	92	ALEP	$B(\tau\nu) = 0$–1
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[126] ABE	94H	CDF	$t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu_\tau$
		[127] ABE	94I	CDF	$t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu_\tau$
		[128] BARGER	93	RVUE	$b \rightarrow s\gamma$
		[129] BELANGER	93	RVUE	$b \rightarrow s\gamma$
		[128] HEWETT	93	RVUE	$b \rightarrow s\gamma$
		[130] ALITTI	92F	UA2	$t \rightarrow bH^+$, $H^+ \rightarrow \tau\nu_\tau$
		[131] ALBAJAR	91B	UA1	$t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu$
none 8.0–20.2	95	[132] YUZUKI	91	VNS	$B(\ell\nu) = 0$–1
>29	95	[124,133] ABREU	90B	DLPH	$B(\tau\nu) = 0$–1
>19	95	[124,134] ADACHI	90B	TOPZ	$B(\tau\nu) = 0$–1
>36.5	95	[124,135] ADEVA	90M	L3	$B(\tau\nu) = 0$–1
>35	95	[124,136] AKRAWY	90K	OPAL	$B(\tau\nu) = 0$–1
>35.4	95	[124,137] DECAMP	90I	ALEP	$B(\tau\nu) = 0$–1
none 10–20	95	[138] SMITH	90B	AMY	$B(\tau\nu) > 0.7$
>19	95	[137] BEHREND	87	CELL	$B(\tau\nu) = 0$–1
>18	95	[139] BARTEL	86	JADE	$B(\tau\nu)$=0.1–1.0
>17	95	[139] ADEVA	85	MRKJ	$B(\tau\nu)$=0.25–1.0

[122] 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.

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

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

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

[126] ABE 94H search for $t\overline{t}$ production in $p\overline{p}$ collisions at $E_{\rm cm}$ = 1.8 TeV, followed by the decay chain $t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu_\tau$ τ decaying hadronically. The search is sensitive to the region $m_{H^+} < m_t - m_b < m_W$. See their Fig. 3 for the excluded region for $\tan\beta \geq 0.5$ and their Fig. 4 for that in the two-Higgs-doublet model.

[127] ABE 94I search for $t\overline{t}$ production in $p\overline{p}$ collisions at $E_{\rm cm}$=1.8 TeV, followed by the decay chain $t \rightarrow bH^+$, $H^+ \rightarrow \tau^+\nu_\tau$, τ decaying leptonically. For $B(H^+ \rightarrow \tau\nu_\tau)$=1 (0.5), the region $m_{H^+} < m_t - m_b$, m_t <(95–110) GeV (70 GeV) is excluded at 95% CL. See Fig. 3 for the excluded parameter region in the two-Higgs-doublet model.

[128] 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.

[129] 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.

[130] ALITTI 92F search for $t \rightarrow bH^+$, $H^+ \rightarrow \tau\nu_\tau$ with τ decaying hadronically in $p\overline{p}$ collisions at $E_{\rm cm}$ = 630 GeV. m_{H^+} between 40 and 65 GeV is excluded if $m_t - m_H = m_b + (\lesssim$ a few–10 GeV). See Figs. 5, 6 for the excluded region for $B(H^+ \rightarrow \tau\nu_\tau)$ = 1, 0.5.

[131] ALBAJAR 91B search for $W \rightarrow t\overline{b}$ and $t\overline{t}$ production in $p\overline{p}$ collisions with the decay chain $t \rightarrow H^+b$, $H^+ \rightarrow \tau^+\nu$, in single muon plus jets and dimuon channels. For m_t = 60 GeV, m_{H^+} < 47 GeV is excluded at 95%CL if $\tan\beta$ > 2.3. The search is restricted to small values of m_t, and no limit on m_{H^+} is obtained if m_t > 61 GeV. Note that existing limits on m_t are not valid if $t \rightarrow H^+b$.

[132] 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.

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

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

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

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

[137] If B($H^+ \to \tau^+ \nu$) = 100%, the DECAMP 91I limit improves to 43 GeV.
[138] 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.
[139] Studied $H^+ H^- \to (\tau\nu) + (\tau\nu)$, $H^+ H^- \to (\tau\nu)$ + 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	[140] ACTON 92M	OPAL	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
>30.4	95	[140] ACTON 92M	OPAL	$T_3(H^{++})= +1$
>25.5	95	[141] ACTON 92M	OPAL	$T_3(H^{++})= 0$
none 6.5–36.6	95	[142] SWARTZ 90	MRK2	$T_3(H^{++}) = +1$
none 7.3–34.3	95	[142] SWARTZ 90	MRK2	$T_3(H^{++}) = 0$

[140] 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.
[141] ACTON 92M from $\Delta\Gamma_Z$ <40 MeV.
[142] 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.

H^0 and $H^\pm$ REFERENCES

ABE 94H PRL 72 1977 +Albrow, Amidei, Anway-Wiese, Apollinari+ (CDF Collab.)
ABE 94I PRL 73 2667 +Albrow, Amidei, Antos, Anway-Wiese+ (CDF Collab.)
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 94 PL B324 173 +Fogli, Lisi (CERN, BARI)
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)
BLONDEL 93 PL B311 346 +Verzegnassi (EPOL, TRSTT, TRSTI)
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)
ELLIS 93B PL B318 148 +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)
NOVIKOV 93B PL B308 123 +Okun, Vysotsky, Yurov (SERP, CERN)
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.)
ALITTI 92F PL B280 137 +Ambrosini, Ansari, Autiero, Bareyre+ (UA2 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.
BLUEMLEIN 92 IJMP A7 3835 +Brunner, Grabosch+ (BERL, BUDA, JINR, SERP)
BUSKULIC 92 PL B285 309 +Decamp, Goy, Lees, Minard+ (ALEPH Collab.)
DECAMP 92 PRPL 216 253 +Deschizeaux, Goy, Lees, Minard+ (ALEPH Collab.)
DELAGUILA 92B NP B381 451 del Aguila, Martinez, Quiros (GRAN, CERN)
ELLIS 92 PL B274 456 +Fogli, Lisi (CERN, BARI)
ELLIS 92E PL B292 427 +Fogli, Lisi (CERN, BARI)
LEEB 92 PRL 68 1472 +Schmiedmayer (TUW, HARV, RIS)
PICH 92 NP B388 31 +Prades, Yepes (CERN, CNRS)
RENTON 92 ZPHY C56 355 (OXF)
SCHAILE 92 ZPHY C54 387 (FREIE)
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.)
ALBAJAR 91B PL B257 459 +Albrow, Allkofer, Ankoviak, Apsimon+ (UA1 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.)
SCHMIEDM... 91 PRL 66 1015 Schmiedmayer, Riehs, Harvey, Hill (TUW, ORNL)
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.)
ANTREASYAN 90C PL B251 204 +Bartels, Besset, Bieler, Bienlein+ (Crystal Ball Collab.)
ATIYA 90 PRL 64 21 +Chiang, Frank, Haggerty, Ito, Kycia+ (BNL 787 Collab.)
ATIYA 90B PRL 65 1188 +Chiang, Frank, Haggerty, Ito, Kycia+ (BNL 787 Collab.)
BARR 90 PL B235 356 +Clark+ (CERN, EDIN, MANZ, LALO, PISA, SIEG)
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.)
LEUTWYLER 90 NP B343 369 +Shifman (BERN)
SMITH 90B PR D42 949 +McNeil, Breedon, Kim, Ko+ (AMY Collab.)
SWARTZ 90 PRL 64 2877 +Abrams, Adolphsen, Averill, Ballam+ (Mark II Collab.)
ALAM 89B PR D40 712 +Katayama, Kim, Li, Lou, Sun+ (CLEO Collab.)
Also 89C PR D40 3790 erratum Alam, Katayama, Kim, Li, Lou, Sun+ (CLEO Collab.)
ALBRECHT 89 ZPHY C42 349 +Boeckmann, Glaeser, Harder+ (ARGUS Collab.)
ATIYA 89 PRL 63 2177 +Chiang, Frank, Haggerty, Ito, Kycia+ (BNL 787 Collab.)
BARBIERI 89 PL B219 503 +Curci
CAHN 89 RPP 52 389
CHENG 89 PR D40 2980 +Yu (AST)
CHENG 89B PL B219 347
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.)
EILAM 89 PL B231 184 +Nakada, Wyler (PSI, ZURI)
GRIFOLS 89 PRL 63 1346 +Masso, Peris (BARC)
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.)
RABY 89 PR D39 828 +West, Hoffman (LANL)
SHER 89 PRPL 179 273
SNYDER 89 PL B229 169 +Murray, Abrams, Adolphsen, Akerlof+ (Mark II Collab.)
WILLEY 89 PR D39 2784 (PITT)
YEPES 89 PL B227 182 (MCGI)
YEPES 89B PL B229 156 (MCGI)
CHENG 88 PR D38 2869
CHIVUKULA 88 PL B207 86 +Manohar (BOST, MIT)
Also 89 PL B217 568 erratum Chivukula, Manohar (BOST, MIT)
GRINSTEIN 88 PL B211 363 +Hall, Randall (LBL, UCB)
LEE-FRANZINI 88 Munich HEP Conf. p. 1432 (CUSB Collab.)
SCHMIEDM... 88 PRL 61 1065 Schmiedmayer, Rauch, Riehs (TUW)
Also 88B PRL 61 2509 erratum Schmiedmayer, Rauch, Riehs (TUW)
ALBRECHT 87D PL B199 451 +Andam, Binder, Boeckmann+ (ARGUS Collab.)
BAKER 87 PRL 59 2832 +Gordon, Lazarus+ (BNL, SIN, WASH, YALE)
Also 88 PRL 60 472 erratum Baker, Gordon+ (BNL, SIN, WASH, YALE)
BEHREND 87 PL B193 376 +Buerger, Criegee, Dainton+ (CELLO Collab.)
DRUZHININ 87 ZPHY C37 1 +Dubrovin, Eidelman, Golubev+ (NOVO)
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.)
BELTRAMI 86 NP A451 679 +Aas, Beer, Dechambrier, Goudsmit+ (ETH, FRIB)
EICHTEN 86 PR D34 1547 +Hinchliffe, Lane, Quigg+ (FNAL, LBL, OSU)
VOLOSHIN 86 SJNP 43 495 +Okun (ITEP)
Translated from YAF 43 779.
WILLEY 86 PL B173 480 (PITT)
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.)
ALTHOFF 84G ZPHY C22 219 +Braunschweig, Kirschfink+ (TASSO Collab.)
FREEDMAN 84 PRL 52 240 +Napolitano, Camp, Kroupa (ANL, CHIC)
MUKHOPAD... 84 PR D29 565 Mukhopadhyay, Goudsmit+ (RPI, SIN, LISB)
YAMAZAKI 84 PRL 52 1089 +Ishikawa, Taniguchi, Yamanaka+ (INUS, KEK)
HOFFMAN 83 PR D28 660 +Frank, Mischke, Moir, Schardt (LANL, ARZS)
ASANO 81B PL 107B 159 +Kikutani, Kurokawa, Miyachi+(KEK, TOKY, INUS, OSAK)
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)
BECHIS 78 PRL 40 602 +Chang, Dombeck, Ellsworth, Glasser, Lau+ (UMD)
SHIFMAN 78 PL 78B 443 +
BARBIERI 75 PL 57B 270 +Ericson (CERN)
KOHLER 74 PRL 33 1628 +Watson, Becker (LOCK)
ALEKSANDROV66 JETPL 4 134 +Samosvat, Sereeter, Tsoi (JINR)
Translated from ZETF 4 196.