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

THE HIGGS BOSON

(by I. Hinchliffe, LBNL)

The Standard Model [1] contains one neutral scalar Higgs boson, which is a remnant of the mechanism that breaks the $\mathrm{SU}(2) \times \mathrm{U}(1)$ symmetry and generates the W and Z boson masses. The Higgs couples to quarks and leptons of mass m_f with a strength $gm_f/2M_W$. Its coupling to W and Z bosons is of strength g, where g is the coupling constant of the SU(2) gauge theory. Consequently its coupling to stable matter is very small, and its production and detection in experiments is difficult. An exception is its production in the decay of the Z boson. Since large numbers of Z's can be produced and the coupling of the Z to the Higgs is unsuppressed, experiments at LEP are now able to rule out a significant range of Higgs masses. The branching ratio of the Higgs boson into various final states is shown in Fig. 1.

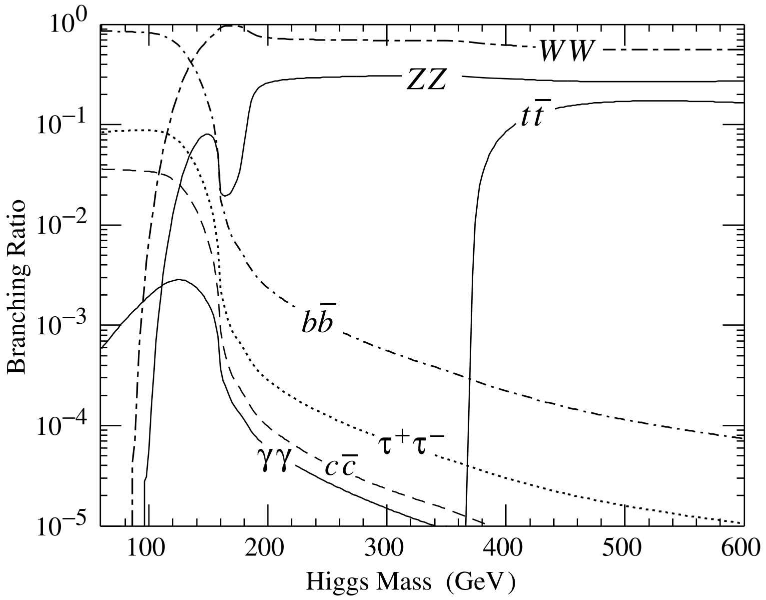

Figure 1: The branching ratio of the Higgs boson into $\gamma\gamma$, $\tau\overline{\tau}$, $b\overline{b}$, $t\overline{t}$, $c\overline{c}$, ZZ, and WW as a function of the Higgs mass. In the latter cases, if $M_H < 2M_Z$ (or $M_H < 2M_W$), the value indicated is the rate to ZZ^* (or WW^*) where Z^* (W^*) denotes a virtual Z (W). The $c\overline{c}$ rate depends sensitively on the poorly-determined charmed quark mass.

If the Higgs mass is very large, the couplings of the Higgs to itself and to longitudinally polarized gauge bosons become large. Requiring that these couplings remain weak enough so that perturbation theory is applicable implies that $M_H \lesssim 1$ TeV [2]. While this is not an absolute bound, it is an indication of the mass scale at which one can no longer speak of an elementary Higgs boson. This fact is made more clear if one notes that the width of the Higgs boson is proportional to the cube of its mass (for $M_H > 2M_Z$) and that a boson of mass 1 TeV has a width of 500 GeV.

It is believed that scalar field theories of the type used to describe Higgs self-interactions can only be effective theories valid over a limited range of energies if the Higgs self-coupling and hence Higgs mass is nonzero. A theory of this type that is valid at all energy scales must have zero coupling. The range of energies over which the interacting theory is valid is a function of the Higgs self-coupling and hence its mass. An upper bound on the Higgs mass can then be determined by requiring that the theory be valid (*i.e.*, have a nonzero value of the renormalized Higgs self-coupling) at all scales up to the Higgs mass [3]. Nonperturbative calculations using lattice [4] gauge theory that can be used to compute at arbitrary values of the Higgs mass indicate that $M_H \lesssim 770$ GeV.

If the Higgs mass were small, then the vacuum (ground) state with the correct value of M_W would cease to be the true ground state of the theory [5]. A theoretical constraint can then be obtained from the requirement that this is not the case, *i.e.*, that our universe is in the true minimum of the Higgs potential. The constraint depends upon the top quark mass and upon the scale (Λ) up to which the Standard Model remains valid. This scale must be at least 1 TeV, resulting in the constraint [7] $M_H > 72$ GeV $+ 0.9$ ($m_{\rm top}$–174 GeV). The bound increases monotonically with the scale, for $\Lambda = 10^{19}$ GeV, $M_H > 135$ GeV $+ 2.1$ ($m_{\rm top}$–174 GeV). This constraint may be too restrictive. Strictly speaking we can only require that the predicted lifetime of our universe, if it is not at the true minimum of the Higgs potential, be longer than its observed age [8,9]. For $\Lambda = 1$ TeV there is no constraint; and for $\Lambda = 10^{19}$ GeV $M_H > 120$ GeV $+ 2.3$ ($m_{\rm top} - 174$ GeV) [10].

Experiments at LEP are able to exclude a large range of Higgs masses. They search for the decay $Z \to HZ^*$. Here Z^* refers to a virtual Z boson that can appear in the detector as

e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, $\nu\overline{\nu}$ (*i.e.*, missing energy) or hadrons. The experimental searches have considered both $H \rightarrow$ hadrons and $H \rightarrow \tau^+\tau^-$. The best limits are shown in the Particle Listings below.

Precision measurement of electroweak parameters such as M_W and the various asymmetries at LEP and SLC are becoming sensitive enough that they can in principle constrain the Higgs mass through its effect in radiative corrections. Currently, the precision tests allow the entire range from the direct LEP limit ($M_H \gtrsim 60$ GeV) to 1 TeV [11] at 95% confidence level although fits prefer the lower end of this range. The recent determination of the top mass has improved the constraint on M_H. See the article in this volume on the "Standard Model of Electroweak Interactions."

The search range for Higgs bosons will expand shortly when LEP begins operation at higher energy. The process $e^+e^- \rightarrow ZH$ [12] should enable neutral Higgs bosons of masses up to $\sim 0.97\ (\sqrt{s} - M_Z)$ to be discovered [13]. If the Higgs is heavier than this, its discovery will probably have to wait until experiments at the LHC have data. If the neutral Higgs boson has mass greater than $2M_Z$, it will likely be discovered via its decay to ZZ and the subsequent decay of the Z's to charged leptons (electrons or muons) or of one Z to charged leptons and the other to neutrinos. A challenging region is that between the ultimate limit of LEP and $2M_Z$. At the upper end of this range the decay to a real and a virtual Z, followed by the decay to charged leptons is available. The decay rate of the Higgs boson into this channel falls rapidly as M_H is reduced and becomes too small for $M_H \lesssim 140$ GeV. For masses below this, the decays $H \rightarrow \gamma\gamma$ and possibly $H \rightarrow b\overline{b}$ [14] are expected to be used. The former has a small branching ratio and large background, the latter has a large branching ratio, larger background and a final state that is difficult to fully reconstruct [15].

Extensions of the Standard Model, such as those based on supersymmetry [16], can have more complicated spectra of Higgs bosons. The simplest extension has two Higgs doublets whose neutral components have vacuum expectation values v_1 and v_2, both of which contribute to the W and Z masses. The physical particle spectrum contains one charged Higgs boson ($H^{\pm}$), two neutral scalars (H_1, H_2),* and one pseudoscalar (A). In the simplest version of the supersymmetric model, the mass the lightest of these scalars depends upon the top quark mass, the ratio v_2/v_1, and the masses of the other supersymmetric particles. For $m_t = 174$ GeV, there is a bound $M_{H_1} \lesssim 125$ GeV [18,19]. In models where all fermions of the same electric charge receive their masses from only one of the two doublets (v_2 gives mass to the charge 2/3 quarks, while v_1 gives mass to the charged leptons and the charge 1/3 quarks), there are, as in the Standard Model, no flavor-changing neutral currents at lowest order in perturbation theory. The H_1, H_2^0, and A couplings to fermions depend on v_2/v_1 and are either enhanced or suppressed relative to the couplings in the Standard Model. Experiments at LEP are able to exclude ranges of masses for neutral Higgs particles in these models. These ranges depend on the values of v_2/v_1. See the Particle Listings below on H_1^0, Mass Limits in Supersymmetric Models.

Charged Higgs bosons can be pair produced in e^+e^- annihilation. Searches for charged Higgs bosons depend on the assumed branching fractions to $\nu\tau$, $c\bar{s}$, and $c\bar{b}$. Data from LEP now exclude charged Higgs bosons of mass less than 43.5 GeV [20]. See the Particle Listings for details of the $H^\pm$ Mass Limit.

A charged Higgs boson could be produced in the decay of a top quark, $t \to H^+ b$. Searches for this decay at hadron colliders should be possible [21].

Notes and References

*H_1 and H_2 are usually called h and H in the literature.

1. S. Weinberg, Phys. Rev. Lett. **19**, 1264 (1967);
   A. Salam, in "Elementary Particle Theory," W. Svartholm, ed., Almquist and Wiksell, Stockholm (1968);
   S.L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. **D2**, 1285 (1970).
2. M. Veltman, Ann. Phys. (NY) **B8**, 475 (1977);
   B.W. Lee, C. Quigg, and H. Thacker, Phys. Rev. **D16**, 1519 (1977);
   D. Picus and V. Mather, Phys. Rev. **D7**, 3111 (1978).
3. L. Maiani, G. Parisi, and R. Petronzio, Nucl. Phys. **B136**, 115 (1978);
   R. Dashen and H. Neuberger, Phys. Rev. Lett. **50**, 1897 (1983).
4. U. M. Heller, M. Klomfass, H. Neuberger, and Pavlos Vranas Nucl. Phys. **B405**, 555 (1993);
   J. Kuti, L. Lin, and Y. Shen, Phys. Rev. Lett. **61**, 678 (1988);
   M. Gockeler, K. Jansen, and T. Neuhaus, Phys. Lett. **B273**, 450 (1991);

U.M. Heller, H. Neuberger, and P. Vranas, Phys. Lett. **B283**, 355 (1992).

5. A.D. Linde, JETP Lett. **23**, 64 (1976) [Pis'ma Zh. Eksp. Teor. Fiz. **23**, 73 (1976)];
S. Weinberg, Phys. Rev. Lett. **36**, 294 (1976).
6. M. Lindner, M. Sher, and H.W. Zaglauer, Phys. Lett. **B228**, 527 (1988).
7. M.J. Duncan, R. Phillipe, and M. Sher, Phys. Lett. **153B**, 165 (1985);
G. Altarelli and I. Isidori, Phys. Lett. **B337**, 141 (1994);
J.A. Casas, J.R. Espinosa, and M. Quiros, Phys. Lett. **B342**, 171 (1995).
8. G. Anderson, Phys. Lett. **B243**, 265 (1990).
9. P.B. Arnold, Phys. Rev. **D40**, 613 (1989).
10. J.R. Espinosa and M. Quiros, Phys. Lett. **B353**, 257 (1995).
11. D. Schaile, in *Proceedings of the XXVII International Conference on High Energy Physics*, Glasgow (Institute of Physics, 1995).
12. J. Ellis, M.K. Gaillard, D.V. Nanopoulous, Nucl. Phys. **B106**, 292 (1976);
J.D. Bjorken, in *Weak Interactions at High Energies and the Production of New Particles*, SLAC report 198 (1976);
B.I. Ioffe and V.A. Khoze, Sov. J. Part. Nucl. **9**, 50 (1978).
13. LEP-2 report, CERN PPE/95-78 (1995).
14. A. Stange, W. Marciano, S. Willenbrock Phys. Rev. **D50**, 4491 (1994);
A. Stange, W. Marciano, S. Willenbrock J.F. Gunion, and T. Han, Phys. Rev. **D41**, 1051 (1995).
15. ATLAS technical proposal, CERN/LHCC/94-43, CMS technical proposal CERN/LHCC/94-38.
16. For a review of these models see, for example, I. Hinchliffe, Ann. Rev. Nucl. and Part. Sci. **36**, 505 (1986).
17. J.F. Gunion, H.E. Haber, G.L. Kane, and S. Dawson, *The Higgs Hunter's Guide* (Addison-Wesley, Redwood City, CA, 1990).
18. J. Ellis, G. Ridolfi, and F. Zwirner, Phys. Lett. **B257**, 83 (1991).
19. M. Carena, J.R. Espinosa, M. Quiros, and C.E.M. Wagner, Phys. Lett. **B355**, 209 (1995).
20. M. Pieri, in *Proceedings of XXVII International Conference on High Energy Physics*, Glasgow (1994);
R. Barbieri, F. Caravaglios, and M. Frigeni, Phys. Lett. **B258**, 167 (1991);
P.H. Chankowski, S. Pokorski, and T. Rosiek, Phys. Lett. **B274**, 191 (1991);
Y. Okada, M. Yamaguchi, and T. Yanagida, Prog. Theor. Phys. **85**, 1 (1991);

H.E. Haber and R. Hempfling, Phys. Rev. Lett. **66**, 1815 (1991).
21. R.M. Barnett, *et al.*, in *Research Directions for the Decade*, Snowmass 1990, World Scientific (1990).

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

[1] 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.

[2] 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.

[3] 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.

[4] 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).

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

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

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

[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} = 0.040–12 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. • • •					
63^{+97}_{-0}		[27] CHANKOWSKI	95	RVUE	
<730	95	[28] ERLER	95	RVUE	
<740	95	[29] MATSUMOTO	95	RVUE	
35^{+205}_{-26}		[30] ELLIS	94	RVUE	
45^{+95}_{-28}		[31] ELLIS	94B	RVUE	
69^{+188}_{-9}		[32] GURTU	94	RVUE	

		[33] MONTAGNA	94	RVUE
$73 \ {}^{+178}_{-\ 13}$		[34] BLONDEL	93	RVUE
$10 \ {}^{+\ 25}_{-\ \ 8}$		[35] ELLIS	93B	RVUE
$10 \ {}^{+\ 60}_{-\ \ 8}$		[36] NOVIKOV	93B	RVUE
		[37] DELAGUILA	92B	RVUE
$>$ 1.4	68	[38] ELLIS	92	RVUE Electroweak
$25 \ {}^{+275}_{-\ 19}$		[39] ELLIS	92E	RVUE
$50 \ {}^{+353}_{-\ \ 0}$		[40] RENTON	92	RVUE
		[41] SCHAILE	92	RVUE

[27] 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).

[28] 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.

[29] 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.

[30] 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 $\alpha_s(m_Z)$= $0.116^{+0.007}_{-0.006}$.

[31] 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.

[32] 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 $\Gamma(Z \rightarrow b\overline{b})/\Gamma(Z \rightarrow$ hadrons) gives $m_H = 120^{+364}_{-\ 60}$ GeV.

[33] 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.

[34] BLONDEL 93 perform two dimensional ($m_t - m_H$) fit to LEP electroweak data available in the spring of 1993. α_s = 0.117 ± 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.

[35] 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 ± 0.006 is used. 95% CL limit for m_H <250 GeV is claimed.

[36] 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 $A^{\ell\ell}_{FB}$.

[37] 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.

[38] 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.

[39] 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 ± 0.008 is used.

[40] RENTON 92 use electroweak data available in 1991 and require m_H >50 GeV. The constraint α_s= 0.114 ± 0.007 was used.

[41] 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 Other Techniques

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[42] CASAS	95	THEO	Vacuum stability
		[43] ESPINOSA	95B	THEO	Vacuum metastability

		[44] ALTARELLI	94	THEO	Vacuum stability
none 0.001–0.072	95	[45] BARABASH	92	BDMP	$\eta' \to \eta H^0$
none 0.0012–0.052	90	DAVIER	89	BDMP	$e^- Z \to e H^0 Z$ ($H^0 \to e^+ e^-$)
none 0.010–0.10	90	[46] EGLI	89	CNTR	$\pi^+ \to e^+ \nu H^0$ ($H^0 \to e^+ e^-$)
		[47] LINDNER	89	THEO	Vacuum stability
none 0.015–0.04	90	[48] YEPES	89	RVUE	$\pi^\pm \to e^\pm \nu H^0$ ($H^0 \to e^+ e^-$)
		[49] DZHELYADIN	81		$\eta' \to \eta H^0$ ($H^0 \to \mu^+ \mu^-$)
		[50] WITTEN	81	COSM	
		[50] GUTH	80	COSM	
		[50] SHER	80	COSM	

[42] 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 Λ = 1 TeV, m_t = 174 GeV, $\alpha_s(m_Z)$ = 0.124.

[43] 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.

[44] 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 Λ = 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.

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

[46] EGLI 89 give a limit for B($\pi^+ \to e^+ \nu H^0$)·B($H^0 \to e^+ e^-$) 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.

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

[48] 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.

[49] DZHELYADIN 81 obtained B($\eta' \to \eta \mu^+ \mu^-$) $< 1.5 \times 10^{-5}$ (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($H^0 \to \mu^+ \mu^-$).

[50] 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. • • •					
		[51] ABREU	95H	DLPH	$Z \to H^0 Z^*$, $H^0 A^0$
		[52] BRAHMACH...	93	RVUE	
		[53] BUSKULIC	93I	ALEP	$Z \to H^0 Z^*$
>65	95	[54] BUSKULIC	93I	ALEP	Invisible H^0
		[55] LOPEZ-FERN...	93	RVUE	
		[56] ADRIANI	92G	L3	$Z \to H^0 Z^*$
		[57] PICH	92	RVUE	Very light Higgs
> 3.57	95	[58] ACTON	91	OPAL	$Z \to H^0 Z^*$
		[59] DECAMP	91F	ALEP	$Z \to H^0 \ell^+ \ell^-$

		[60] DECAMP	91I	ALEP	Z decay
> 0.21	95	[61] AKRAWY	90P	OPAL	$Z \rightarrow H^0 Z^*$
		[62] DAVIER	89	BDMP	$e^- Z \rightarrow e H^0 Z$ ($H^0 \rightarrow e^+ e^-$)
		[63] SNYDER	89	MRK2	$B \rightarrow H^0 X$ ($H^0 \rightarrow e^+ e^-$)
none 0.6–6.2	90	[64] FRANZINI	87	CUSB	$\Upsilon(1S) \rightarrow \gamma H^0$, x=2
none 0.6–7.9	90	[64] FRANZINI	87	CUSB	$\Upsilon(1S) \rightarrow \gamma H^0$, x=4
none 3.7–5.6	90	[65] ALBRECHT	85J	ARG	$\Upsilon(1S) \rightarrow \gamma H^0$, x=2
none 3.7–8.2	90	[65] ALBRECHT	85J	ARG	$\Upsilon(1S) \rightarrow \gamma H^0$, x=4

[51] 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.

[52] 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.

[53] 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.

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

[55] 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.

[56] 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.

[57] 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.

[58] 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 $2m_\mu$ ($2m_\tau$).

[59] 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.

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

[61] 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.

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

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

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

[65] 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_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 ($H^\pm$). H_1^0 and H_2^0 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 $m_{H_1^0} \leq m_Z$, $m_{H_2^0} \geq m_Z$, $m_{A^0} \geq m_{H_1^0}$, 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	[66] ABREU	95H	DLPH	any $\tan\beta$
>44.5	95	[67] AKERS	94I	OPAL	$\tan\beta > 1$
>44	95	[68] BUSKULIC	93I	ALEP	$\tan\beta > 1$
>42	95	[69] ADRIANI	92G	L3	$1 < \tan\beta < 50$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[70] ROSIEK	95	RVUE	
>44.4	95	[71] ABREU	94O	DLPH	$m_{H_1^0} = m_{A^0}$, any $\tan\beta$
>34	95	[72] ABREU	92J	DLPH	$\tan\beta > 0.6$
>29	95	[72] ABREU	92J	DLPH	any $\tan\beta$
> 0.21	95	[73] ABREU	91B	DLPH	any $\tan\beta$
>28	95	[74] ABREU	91B	DLPH	any $\tan\beta$
none 3–38	95	[75] AKRAWY	91C	OPAL	$\tan\beta > 6$
none 3–22	95	[75] AKRAWY	91C	OPAL	$\tan\beta > 0.5$
		[76] BLUEMLEIN	91	BDMP	$pN \rightarrow H_1^0 X$ ($H_1^0 \rightarrow e^+e^-$, 2γ)
>41	95	[77] DECAMP	91I	ALEP	$\tan\beta > 1$
> 9	95	[78] ABREU	90E	DLPH	any $\tan\beta$
>13	95	[78] ABREU	90E	DLPH	$\tan\beta > 1$
>26	95	[79] ADEVA	90R	L3	$\tan\beta > 1$
none 0.05–3.1	95	[80] DECAMP	90E	ALEP	any $\tan\beta$
none 0.05–13	95	[80] DECAMP	90E	ALEP	$\tan\beta > 0.6$
none 0.006–20	95	[80] DECAMP	90E	ALEP	$\tan\beta > 2$
>37.1	95	[80] DECAMP	90E	ALEP	$\tan\beta > 6$
none 0.05–20	95	[81] DECAMP	90H	ALEP	$\tan\beta > 0.6$
none 0.006–21.4	95	[81] DECAMP	90H	ALEP	$\tan\beta > 2$
> 3.1	95	[82] DECAMP	90M	ALEP	any $\tan\beta$

[66] ABREU 95H search for $Z \rightarrow H_1^0 Z^*$ and $Z \rightarrow H_1^0 A^0$. 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.

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

[68] BUSKULIC 93I search for $Z \rightarrow H_1^0 Z^*$ and $Z \rightarrow H_1^0 A^0$. One-loop corrections are included with any m_t, $m_{\tilde{t}} > m_t$.

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

[70] 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 $m_{\tilde{t}} \lesssim 200$ GeV and $\tilde{t}_L$-$\tilde{t}_R$ mixing is large.

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

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

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

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

[75] AKRAWY 91C result from $Z \rightarrow H_1^0 A^0 \rightarrow$ 4jet or $\tau^+\tau^- jj$ or 4τ and $Z \rightarrow H_1^0 Z^*$ ($H_1^0 \rightarrow q\overline{q}$, $Z^* \rightarrow \nu\overline{\nu}$ 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.

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

[77] DECAMP 91I searched for $Z \rightarrow H_1^0 Z^*$, and $Z \rightarrow H_1^0 A^0 \rightarrow$ 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.

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

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

[80] DECAMP 90E look for $Z \rightarrow H_1^0 A^0$ as well as $Z \rightarrow H_1^0 \ell^+ \ell^-$, $Z \rightarrow H_1^0 \nu\overline{\nu}$ 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. $\tan\beta$.

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

[82] DECAMP 90M looked for $Z \rightarrow H^0 \ell\ell$, 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 $e^+ e^- \rightarrow A^0 H_1^0$ 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	[83] ABREU	95H	DLPH	$\tan\beta$ >1, m_t = 170 GeV
>24.3	95	[84] AKERS	94I	OPAL	$\tan\beta$ >1, m_t <200 GeV
>21	95	[85] BUSKULIC	93I	ALEP	$\tan\beta$ >1, m_t = 140 GeV
>22	95	[86] 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	[87] ABREU	94O	DLPH	$m_{H_1^0}$=m_{A^0}, any $\tan\beta$
>44.5	95	[84] AKERS	94I	OPAL	$\tan\beta$ >1, $m_{H_1^0}$=m_{A^0}
		[88] ELLIS	93	RVUE	Electroweak
>34	95	[89] ABREU	92J	DLPH	$\tan\beta$ > 3
> 0.21	95	[90] BUSKULIC	92	ALEP	$\tan\beta$ > 1
none 3–40.5	95	[91] AKRAWY	91C	OPAL	$\tan\beta$ > 1, if 3 GeV < $m_{H_1^0}$ < m_{A^0}
>20	95	[92] DECAMP	91I	ALEP	$\tan\beta$ > 1
>34	95	[93] ABREU	90E	DLPH	$\tan\beta$ > 1, $m_{H_1^0}$ < m_{A^0}
>12	95	[93] ABREU	90E	DLPH	$\tan\beta$ < 1
>39	95	[94] ADEVA	90R	L3	$\tan\beta$ > 1, $m_{H_1^0}$ < m_{A^0}

[83] ABREU 95H search for $Z \rightarrow H_1^0 Z^*$ and $Z \rightarrow H_1^0 A^0$. 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.

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

[85] BUSKULIC 93I search for $Z \rightarrow H_1^0 Z^*$ and $Z \rightarrow H_1^0 A^0$. 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.

[86] ADRIANI 92G search for $Z \rightarrow H_1^0 Z^*$, $Z \rightarrow H_1^0 A^0 \rightarrow 4b$, $bb\tau\tau$, 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<$m_{H_1^0}$ <62 GeV, but is excluded by other experiments.

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

[88] 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.

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

[90] BUSKULIC 92 limit is from $\Gamma(Z)$, $Z \rightarrow H_1^0 Z^*$, and $Z \rightarrow H_1^0 A^0$. 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.

[91] 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 $\tan\beta < 1$.

[92] 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 $m_{\tilde{q}} = 1$ TeV, the limit is $m_{A^0} > 31$ GeV.

[93] 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.

[94] 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	[95] AKERS	94I	OPAL	$m_{H_1^0} < 12$ GeV
		[96] ADRIANI	92G	L3	
>45	95	[97] DECAMP	90H	ALEP	$m_{H_1^0} < 20$ GeV
>37.5	95	[97] DECAMP	90H	ALEP	$m_{H_1^0} < m_{H_2^0}$
none 5–45	95	[98] KOMAMIYA	90	MRK2	$m_{H_1^0} < 0.5$ GeV, $H_2^0 \to q\overline{q}$ or $\tau^+\tau^-$
> 8	90	[99] KOMAMIYA	89	MRK2	$H_1^0 \to \mu^+\mu^-$, $H_2^0 \to q\overline{q}$, $\tau^+\tau^-$
>28	95	[100] LOW	89	AMY	$m_{H_1^0} \lesssim 20$ MeV, $H_2^0 \to q\overline{q}$
none 2–9	90	[101] AKERLOF	85	HRS	$m_{H_1^0} = 0$, $H_2^0 \to f\overline{f}$
none 4–10	90	[102] 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	[101] 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	[101] BEHREND	85	CELL	$m_{H_1^0} = 0$, $H_2^0 \to f\overline{f}$
none 1–11	90	[101] FELDMAN	85	MRK2	$m_{H_1^0} = 0$, $H_2^0 \to f\overline{f}$
none 1–9	90	[101] FELDMAN	85	MRK2	$m_{H_1^0} = m_{H_2^0}$, $H_2^0 \to f\overline{f}$

[95] 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.

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

[97] 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.

[98] 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.

[99] 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.

[100] 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. $E_{\rm cm}^{ee} = 50\text{–}60.8$ GeV.

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

[102] 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($H^+ \to c\overline{b}$) = 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	[103] ABREU	94O	DLPH	B($\tau\nu$) = 0–1
>41	95	[104] ADRIANI	92G	L3	B($\tau\nu$) = 0–1
>41.7	95	[105,106] DECAMP	92	ALEP	B($\tau\nu$) = 0–1
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[107] BUSKULIC	95	ALEP	$b \to \tau\nu_\tau X$
		[108] ABE	94H	CDF	$t \to bH^+$, $H^+ \to \tau^+\nu_\tau$
		[109] ABE	94I	CDF	$t \to bH^+$, $H^+ \to \tau^+\nu_\tau$
		[110] BARGER	93	RVUE	$b \to s\gamma$
		[111] BELANGER	93	RVUE	$b \to s\gamma$
		[110] HEWETT	93	RVUE	$b \to s\gamma$
		[112] ALITTI	92F	UA2	$t \to bH^+$, $H^+ \to \tau\nu_\tau$
		[113] ALBAJAR	91B	UA1	$t \to bH^+$, $H^+ \to \tau^+\nu$
none 8.0–20.2	95	[114] YUZUKI	91	VNS	B($\ell\nu$) = 0–1
>29	95	[105,115] ABREU	90B	DLPH	B($\tau\nu$) = 0–1
>19	95	[105,116] ADACHI	90B	TOPZ	B($\tau\nu$) = 0–1
>36.5	95	[105,117] ADEVA	90M	L3	B($\tau\nu$) = 0–1
>35	95	[105,118] AKRAWY	90K	OPAL	B($\tau\nu$) = 0–1
>35.4	95	[105,119] 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

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

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

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

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

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

[108] 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 $t \to bH^+$, $H^+ \to \tau^+\nu_\tau$ 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.

[109] 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 $t \to bH^+$, $H^+ \to \tau^+\nu_\tau$, τ decaying leptonically. For B($H^+ \to \tau\nu_\tau$)=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.

[110] HEWETT 93 and BARGER 93 analyze charged Higgs contribution to $b \to s\gamma$ in two-doublet models with the CLEO limit B($b \to s\gamma$)< 8.4×10^{-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.

[111] BELANGER 93 make an analysis similar to BARGER 93 and HEWETT 93 with an improved CLEO limit B($b \to s\gamma$) < 5.4×10^{-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.

[112] ALITTI 92F search for $t \to bH^+$, $H^+ \to \tau\nu_\tau$ 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($H^+ \to \tau\nu_\tau$) = 1, 0.5.

[113] 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 $t \rightarrow H^+ b$.

[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($H\ell\ell$) $\gtrsim 7.4 \times 10^{-7}/[m_H/\text{GeV}]^{1/2}$. The limits improve somewhat for ee and $\mu\mu$ decay modes.

H^0 and $H^\pm$ REFERENCES

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)
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.		
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)
PICH	92	NP B388 31	+Prades, Yepes	(CERN, CPPM)
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.)
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)