Z Boson – THIS IS PART 1 OF 2

To reduce the size of this section's PostScript file, we have divided it into two PostScript files. We present the following index:

PART 1

PART 2

Z

$J = 1$

THE Z BOSON

Revised February 1998 by C. Caso (Univ. of Genova) and A. Gurtu (Tata Inst.)

Precision measurements at the Z-boson resonance using electron–positron colliding beams began in 1989 at the SLC and at LEP. During 1989–95, the four CERN experiments have made high-statistics studies of the Z. The availability of longitudinally polarized electron beams at the SLC since 1993 has enabled a precision determination of the effective electroweak mixing angle $\sin^2\overline{\theta}_W$ that is competitive with the CERN results on this parameter.

The Z-boson properties reported in this section may broadly be categorized as:

- The standard 'lineshape' parameters of the Z consisting of its mass, M_Z, its total width, Γ_Z, and its partial decay widths, Γ(hadrons), and $\Gamma(\ell\overline{\ell})$ where $\ell = e, \mu, \tau, \nu$;
- Z asymmetries in leptonic decays and extraction of Z couplings to charged and neutral leptons;
- The b- and c-quark-related partial widths and charge asymmetries which require special techniques;
- Determination of Z decay modes and the search for modes that violate known conservation laws;
- Average particle multiplicities in hadronic Z decay.

For the lineshape-related Z properties there are no new published LEP results after those included in the 1994 edition of this compilation. The reason for this is the identification in mid 1995 of a new systematic effect which shifts the LEP energy by a few MeV. This is due to a drift of the dipole field in the LEP magnets caused by parasitic currents generated by electrically powered trains in the Geneva area. The LEP Energy Working Group has been studying the implications of this for the Z-lineshape properties which would be obtained after analysis of the high statistics 1993–95 data. The main consequence of this effect is expected to be in the determination of the Z mass.

Details on Z-parameter determination and the study of $Z \to b\overline{b}, c\overline{c}$ at LEP and SLC are given in this note.

The standard 'lineshape' parameters of the Z are determined with increasing precision from an analysis of the production cross sections of these final states in e^+e^- collisions. The $Z \to \nu\overline{\nu}(\gamma)$ state is identified directly by detecting single photon production and indirectly by subtracting the visible partial widths from the total width. Inclusion in this analysis of the forward-backward asymmetry of charged leptons, $A_{FB}^{(0,\ell)}$, of the τ polarization, $P(\tau)$, and its forward-backward asymmetry, $P(\tau)^{fb}$, enables the separate determination of the effective vector ($\overline{g}_V$) and axial vector ($\overline{g}_A$) couplings of the Z to these leptons and the ratio ($\overline{g}_V/\overline{g}_A$) which is related to the effective electroweak mixing angle $\sin^2\overline{\theta}_W$ (see the "Electroweak Model and Constraints on New Physics" Review).

Determination of the b- and c-quark-related partial widths and charge asymmetries involves tagging the b and c quarks. Traditionally this was done by requiring the presence of a prompt lepton in the event with high momentum and high transverse momentum (with respect to the accompanying jet).

Precision vertex measurement with silicon detectors has enabled one to do impact parameter and lifetime tagging. Neural-network techniques have also been used to classify events as b or non-b on a statistical basis using event–shape variables. Finally, the presence of a charmed meson (D/D^*) has been used to tag heavy quarks.

Z-parameter determination

LEP is run at a few energy points on and around the Z mass constituting an energy 'scan.' The shape of the cross-section variation around the Z peak can be described by a Breit-Wigner *ansatz* with an energy-dependent total width [1–3]. The **three** main properties of this distribution, viz., the **position** of the peak, the **width** of the distribution, and the **height** of the peak, determine respectively the values of M_Z, Γ_Z, and $\Gamma(e^+e^-) \times \Gamma(f\overline{f})$, where $\Gamma(e^+e^-)$ and $\Gamma(f\overline{f})$ are the electron and fermion partial widths of the Z. The quantitative determination of these parameters is done by writing analytic expressions for these cross sections in terms of the parameters and fitting the calculated cross sections to the measured ones by varying these parameters, taking properly into account all the errors. Single-photon exchange (σ^0_γ) and γ-Z interference ($\sigma^0_{\gamma Z}$) are included, and the large ($\sim$25 %) initial-state radiation (ISR) effects are taken into account by convoluting the analytic expressions over a 'Radiator Function' [1–4] $H(s,s')$. Thus for the process $e^+e^- \to f\overline{f}$:

$$\sigma_f(s) = \int H(s,s')\ \sigma^0_f(s')\ ds' \tag{1}$$

$$\sigma^0_f(s) = \sigma^0_Z + \sigma^0_\gamma + \sigma^0_{\gamma Z} \tag{2}$$

$$\sigma^0_Z = \frac{12\pi}{M^2_Z}\ \frac{\Gamma(e^+e^-)\Gamma(f\overline{f})}{\Gamma^2_Z}\ \frac{s\ \Gamma^2_Z}{(s-M^2_Z)^2\ +\ s^2\Gamma^2_Z/M^2_Z} \tag{3}$$

$$\sigma^0_\gamma = \frac{4\pi\alpha^2(s)}{3s}\ Q^2_f N^f_c \tag{4}$$

$$\sigma^0_{\gamma Z} = -\ \frac{2\sqrt{2}\alpha(s)}{3}\ (Q_f G_F N^f_c g_{Ve} g_{Vf}) \times \frac{(s-M^2_Z)M^2_Z}{(s-M^2_Z)^2 + s^2\Gamma^2_Z/M^2_Z} \tag{5}$$

where Q_f is the charge of the fermion, $N^f_c = 3(1)$ for quark (lepton) and g_{Vf} is the neutral vector coupling of the Z to the fermion-antifermion pair $f\overline{f}$.

Since $\sigma^0_{\gamma Z}$ is expected to be much less than σ^0_Z, the LEP Collaborations have generally calculated the interference term in the framework of the Standard Model using the best known values of g_V. This fixing of $\sigma^0_{\gamma Z}$ leads to a tighter constraint on M_Z and consequently a smaller error on its fitted value.

Defining

$$A_f = 2\frac{g_{Vf}\cdot g_{Af}}{(g^2_{Vf}+g^2_{Af})} \tag{6}$$

where g_{Af} is the neutral axial-vector coupling of the Z to $f\overline{f}$, the lowest-order expressions for the various lepton-related asymmetries on the Z pole are [5–7] $A^{(0,\ell)}_{FB} = (3/4)A_e A_f$, $P(\tau) = -A_\tau$, $P(\tau)^{fb} = -(3/4)A_e$, $A_{LR} = A_e$. The full analysis takes into account the energy dependence of the asymmetries. Experimentally A_{LR} is defined as $(\sigma_L - \sigma_R)/(\sigma_L + \sigma_R)$ where $\sigma_{L(R)}$ are the $e^+e^- \to Z$ production cross sections with left- (right)-handed electrons.

In terms of g_A and g_V, the partial decay width of the Z to $f\overline{f}$ can be written as

$$\Gamma(f\overline{f}) = \frac{G_F M^3_Z}{6\sqrt{2}\pi}\ (g^2_{Vf}+g^2_{Af})\ N^f_c(1+\delta_{\rm QED})(1+\delta_{\rm QCD}) \tag{7}$$

where $\delta_{\rm QED} = 3\alpha Q_f^2/4\pi$ accounts for final-state photonic corrections and $\delta_{\rm QCD} = 0$ for leptons and $\delta_{\rm QCD} = (\alpha_s/\pi) + 1.409(\alpha_s/\pi)^2 - 12.77(\alpha_s/\pi)^3$ for quarks, α_s being the strong coupling constant at $\mu = M_Z$.

In the above framework, the QED radiative corrections have been explicitly taken into account by convoluting over the ISR and allowing the electromagnetic coupling constant to run [8]: $\alpha(s) = \alpha/(1 - \Delta\alpha)$. On the other hand, weak radiative corrections that depend upon the assumptions of the electroweak theory and on the values of the unknown $M_{\rm top}$ and $M_{\rm Higgs}$ are accounted for by **absorbing them into the couplings**, which are then called the *effective* couplings $\overline{g}_V$ and $\overline{g}_A$ (or alternatively the effective parameters of the $\star$ scheme of Kennedy and Lynn [9]).

S-matrix approach to the Z

While practically all experimental analyses of LEP/SLC data have followed the 'Breit-Wigner' approach described above, an alternative S-matrix-based analysis is also possible. The Z, like all unstable particles, is associated with a complex pole in the S matrix. The pole position is process independent and gauge invariant. The mass, $\overline{M}_Z$, and width, $\overline{\Gamma}_Z$, can be defined in terms of the pole in the energy plane via [10–13]

$$\overline{s} = \overline{M}_Z^2 - i\overline{M}_Z\overline{\Gamma}_Z \tag{8}$$

leading to the relations

$$\begin{aligned}\overline{M}_Z &= M_Z/\sqrt{1+\Gamma_Z^2/M_Z^2} \\ &\approx M_Z \ - 34.1 \text{ MeV} \end{aligned} \tag{9}$$

$$\begin{aligned}\overline{\Gamma}_Z &= \Gamma_Z/\sqrt{1+\Gamma_Z^2/M_Z^2} \\ &\approx \Gamma_Z \ - 0.9 \text{ MeV} \ . \end{aligned} \tag{10}$$

Some authors [14] choose to define the Z mass and width via

$$\overline{s} = (\overline{M}_Z - \frac{i}{2}\overline{\Gamma}_Z)^2 \tag{11}$$

which yields $\overline{M}_Z \approx M_Z - 26$ MeV, $\overline{\Gamma}_Z \approx \Gamma_Z - 1.2$ MeV.

The L3 and OPAL Collaborations at LEP (ACCIARRI 97K and ACKERSTAFF 97C) have analyzed their data using the S–matrix approach as defined in Eq. (8), in addition to the conventional one. They observe a downward shift in the Z mass as expected.

Handling the large-angle e^+e^- final state

Unlike other $f\overline{f}$ decay final states of the Z, the e^+e^- final state has a contribution not only from the s-channel but also from the t-channel and s-t interference. The full amplitude is not amenable to fast calculation, which is essential if one has to carry out minimization fits within reasonable computer time. The usual procedure is to calculate the non-s channel part of the cross section separately using the Standard Model programs ALIBABA [15] or TOPAZ0 [16] with the measured value of M_{top}, and the 'central' value of M_{Higgs} (300 GeV) and add it to the s-channel cross section calculated as for other channels. This leads to two additional sources of error in the analysis: firstly, the theoretical calculation in ALIBABA itself is known to be accurate to $\sim 0.5\%$, and secondly, there is uncertainty due to the error on M_{top} and the unknown value of M_{Higgs} (60–1000 GeV). These additional errors are propagated into the analysis by including them in the systematic error on the e^+e^- final state.

Errors due to uncertainty in LEP energy determination [17–21]

The systematic errors related to the LEP energy measurement can be classified as:

- The absolute energy scale error;
- Energy-point-to-energy-point errors due to the non-linear response of the magnets to the exciting currents;
- Energy-point-to-energy-point errors due to possible higher-order effects in the relationship between the dipole field and beam energy;
- Energy reproducibility errors due to various unknown uncertainties in temperatures, tidal effects, corrector settings, RF status, *etc.* Since one groups together data taken at 'nominally same' energies in different fills, it can be assumed that these errors are uncorrelated and are reduced by $\sqrt{\overline{N}_{\rm fill}}$ where $\overline{N}_{\rm fill}$ is the (luminosity weighted) effective number of fills at a particular energy point.

At each energy point the last two errors can be summed into one point-to-point error.

Choice of fit parameters

The LEP Collaborations have chosen the following primary set of parameters for fitting: M_Z, Γ_Z, $\sigma^0_{\rm hadron}$, R(lepton), $A^{(0,\ell)}_{FB}$, where R(lepton) $=$ Γ(hadrons)/Γ(lepton), $\sigma^0_{\rm hadron} = 12\pi\Gamma(e^+e^-)\Gamma({\rm hadrons})/M^2_Z\Gamma^2_Z$. With a knowledge of these fitted parameters and their covariance matrix, any other parameter can be derived. The main advantage of these parameters is that they form the **least correlated** set of parameters, so that it becomes easy to combine results from the different LEP experiments.

Thus, the most general fit carried out to cross section and asymmetry data determines the **nine parameters**: M_Z, Γ_Z, $\sigma^0_{\rm hadron}$, $R(e)$, $R(\mu)$, $R(\tau)$, $A^{(0,e)}_{FB}$, $A^{(0,\mu)}_{FB}$, $A^{(0,\tau)}_{FB}$. Assumption of lepton universality leads to a **five-parameter fit** determining M_Z, Γ_Z, $\sigma^0_{\rm hadron}$, R(lepton), $A^{(0,\ell)}_{FB}$. The use of **only** cross-section data leads to six- or four-parameter fits if lepton universality is or is not assumed, *i.e.*, $A^{(0,\ell)}_{FB}$ values are not determined.

In order to determine the best values of the effective vector and axial vector couplings of the charged leptons to the Z, the above mentioned nine- and five-parameter fits are carried out with added constraints from the measured values of A_τ and A_e obtained from τ polarization studies at LEP and the determination of A_{LR} at SLC.

Combining results from the LEP and SLC experiments [22]

Each LEP experiment provides the values of the parameters mentioned above together with the full covariance matrix. The statistical and experimental systematic errors are assumed to be uncorrelated among the four experiments. The sources of **common** systematic errors are i) the LEP energy uncertainties, and ii) the effect of theoretical uncertainty in calculating the small-angle Bhabha cross section for luminosity determination and in estimating the non-s channel contribution to the large-angle Bhabha cross section. Using this information, a full covariance matrix, V, of all the input parameters is constructed and a combined parameter set is obtained by minimizing $\chi^2 = \Delta^T V^{-1} \Delta$, where Δ is the vector of residuals of the combined parameter set to the results of individual experiments.

Non-LEP measurement of a Z parameter, (*e.g.,* $\Gamma(e^+e^-)$ from SLD) is included in the overall fit by calculating its value using the fit parameters and constraining it to the measurement.

Study of $Z \to b\overline{b}$ and $Z \to c\overline{c}$

In the sector of c- and b-physics the LEP experiments have measured the ratios of partial widths $R_b = \Gamma(Z \to b\overline{b})/\Gamma(Z \to \text{hadrons})$ and $R_c = \Gamma(Z \to c\overline{c})/\Gamma(Z \to \text{hadrons})$ and the forward-backward (charge) asymmetries $A_{FB}^{b\overline{b}}$ and $A_{FB}^{c\overline{c}}$. Several of the analyses have also determined other quantities, in particular the semileptonic branching ratios, B($b \to \ell$) and B($b \to c \to \ell^+$), the average $B^0\overline{B}^0$ mixing parameter $\overline{\chi}$ and the probabilities for a c–quark to fragment into a D^+, a D_s, a D^{*+} , or a charmed baryon. The latter measurements do not concern properties of the Z boson and hence they are not covered in this section. However, they are correlated with the electroweak parameters, and since the mixture of b hadrons is different from the one at the $\Upsilon(4S)$, their values might differ from those measured at the $\Upsilon(4S)$.

All the above quantities are correlated to each other since:

- Several analyses (for example the lepton fits) determine more than one parameter simultaneously;
- Some of the electroweak parameters depend explicitly on the values of other parameters (for example R_b depends on R_c);
- Common tagging and analysis techniques produce common systematic uncertainties.

The LEP Electroweak Heavy Flavour Working Group has developed [23] a procedure for combining the measurements taking into account known sources of correlation. The combining procedure determines eleven parameters: the four parameters of interest in the electroweak sector, R_b, R_c, $A_{FB}^{b\overline{b}}$, and $A_{FB}^{c\overline{c}}$ and, in addition, B($b \to \ell$), B($b \to c \to \ell^+$), $\overline{\chi}$, $f(D^+)$, $f(D_s)$, $f(c_{\text{baryon}})$ and $P(c \to D^{*+}) \times$ B($D^{*+} \to \pi^+ D^0$), to take into account their correlations with the electroweak parameters.

Before the fit both the peak and off-peak asymmetries are translated to $\sqrt{s} = 91.26$ GeV using the predicted dependence from ZFITTER [4].

Summary of the measurements and of the various kinds of analysis

The measurements of R_b and R_c fall into two classes. In the first, named single-tag measurement, a method for selecting b and c events is applied and the number of tagged events is counted. The second technique, named double-tag measurement, is based on the following principle: if the number of events with a single hemisphere tagged is N_t and with both hemispheres tagged is N_{tt}, then given a total number of $N_{\rm had}$ hadronic Z decays one has:

$$\frac{N_t}{2N_{\rm had}} = \varepsilon_b R_b + \varepsilon_c R_c + \varepsilon_{uds}(1 - R_b - R_c) \tag{12}$$

$$\frac{N_{tt}}{N_{\rm had}} = \mathcal{C}_b \varepsilon_b^2 R_b + \mathcal{C}_c \varepsilon_c^2 R_c + \mathcal{C}_{uds} \varepsilon_{uds}^2 (1 - R_b - R_c) \tag{13}$$

where ε_b, ε_c, and ε_{uds} are the tagging efficiencies per hemisphere for b, c, and light quark events, and $\mathcal{C}_q \neq 1$ accounts for the fact that the tagging efficiencies between the hemispheres may be correlated. In tagging the b one has $\varepsilon_b \gg \varepsilon_c \gg \varepsilon_{uds}$, $C_b \approx 1$. Neglecting the c and uds background and the hemisphere correlations, these equations give:

$$\varepsilon_b = 2N_{tt}/N_t \tag{14}$$

$$R_b = N_t^2/(4N_{tt}N_{\rm had}) \; . \tag{15}$$

The double-tagging method has thus the great advantage that the tagging efficiency is directly derived from the data, reducing the systematic error of the measurement. The backgrounds, dominated by $c\overline{c}$ events, obviously complicate this simple picture, and their level must still be inferred by other means. The rate of charm background in these analyses depends explicitly on the value of R_c. The correlations in the tagging efficiencies between the hemispheres (due for instance to correlations in momentum between the b hadrons in the two hemispheres) are small but nevertheless lead to further systematic uncertainties.

The measurements in the b- and c-sector can be grouped in the following categories:

- Lepton fits which use hadronic events with one or more leptons in the final state. Each analysis usually gives several electroweak parameters chosen among: R_b, R_c, $A_{FB}^{b\overline{b}}$, $A_{FB}^{c\overline{c}}$, $\mathrm{B}(b \to \ell)$, $\mathrm{B}(b \to c \to \ell^+)$ and $\overline{\chi}$. The output parameters are then correlated. The dominant sources of systematics are due to lepton identification, to other semileptonic branching ratios and to the modelling of the semileptonic decay;
- Event shape tag for R_b;
- Lifetime (and lepton) double-tagging measurements of R_b. These are the most precise measurements of R_b and obviously dominate the combined result. The main sources of systematics come from the charm contamination and from estimating the hemisphere b-tagging efficiency correlation. The charm rejection has been improved (and hence the systematic errors reduced) by using either the information of the secondary vertex invariant mass or the information from the energy of all particles at the secondary vertex and their rapidity;

- Measurements of $A_{FB}^{b\overline{b}}$ using lifetime tagged events with a hemisphere charge measurement. Their contribution to the combined result has roughly the same weight as the lepton fits;
- Analyses with $D/D^{*\pm}$ to measure R_c. These measurements make use of several different tagging techniques (inclusive/exclusive double tag, inclusive single/double tag, exclusive double tag, reconstruction of all weakly decaying D states) and no assumptions are made on the energy dependence of charm fragmentation;
- Analyses with $D/D^{*\pm}$ to measure $A_{FB}^{c\overline{c}}$ or simultaneously $A_{FB}^{b\overline{b}}$ and $A_{FB}^{c\overline{c}}$;
- Measurements of A_b and A_c from SLD, using several tagging methods (lepton, D/D^*, and impact parameter). These quantities are directly extracted from a measurement of the left–right forward–backward asymmetry in $c\overline{c}$ and $b\overline{b}$ production using a polarized electron beam.

Averaging procedure

All the measurements are provided by the LEP Collaborations in the form of tables with a detailed breakdown of the systematic errors of each measurement and its dependence on other electroweak parameters.

The averaging proceeds via the following steps:

- Define and propagate a consistent set of external inputs such as branching ratios, hadron lifetimes, fragmentation models *etc.* All the measurements are also consistently checked to ensure that all use a common set of assumptions (for instance since the QCD corrections for the forward–backward asymmetries are strongly dependent on the experimental conditions, the data are corrected before combining);
- Form the full (statistical and systematic) covariance matrix of the measurements. The systematic correlations between different analyses are calculated from the detailed error breakdown in the measurement tables. The correlations relating several measurements made by the same analysis are also used;
- Take into account any explicit dependence of a measurement on the other electroweak parameters. As an example of this dependence we illustrate the case of the double-tag measurement of R_b, where c-quarks constitute the main background. The normalization of the charm contribution is not usually fixed by the data and the measurement of R_b depends on the assumed value of R_c, which can be written as:

$$R_b = R_b^{\rm meas} + a(R_c)\frac{(R_c - R_c^{\rm used})}{R_c} \ , \qquad (16)$$

  where $R_b^{\rm meas}$ is the result of the analysis which assumed a value of $R_c = R_c^{\rm used}$ and $a(R_c)$ is the constant which gives the dependence on R_c;
- Perform a χ^2 minimization with respect to the combined electroweak parameters.

After the fit the average peak asymmetries $A_{FB}^{c\bar{c}}$ and $A_{FB}^{b\bar{b}}$ are corrected for the energy shift and for QED, γ exchange, and γZ interference effects to obtain the corresponding pole asymmetries $A_{FB}^{0,c}$ and $A_{FB}^{0,b}$. A small correction is also applied to both R_b and R_c to account for the contribution of γ exchange.

References

1. R.N. Cahn, Phys. Rev. **D36**, 2666 (1987).
2. F.A. Berends *et al.*, "*Z* Physics at LEP 1", CERN Report 89-08 (1989), Vol. 1, eds. G. Altarelli, R. Kleiss, and C. Verzegnassi, p. 89.
3. A. Borrelli *et al.*, Nucl. Phys. **B333**, 357 (1990).
4. D. Bardin *et al.*, Nucl. Phys. **B351**, 1 (1991).
5. M. Consoli *et al.*, "*Z* Physics at LEP 1", CERN Report 89-08 (1989), Vol. 1, eds. G. Altarelli, R. Kleiss, and C. Verzegnassi, p. 7.
6. M. Bohm *et al.*, *ibid*, p. 203.
7. S. Jadach *et al.*, *ibid*, p. 235.
8. G. Burgers *et al.*, *ibid*, p. 55.
9. D.C. Kennedy and B.W. Lynn, SLAC-PUB 4039 (1986, revised 1988).
10. R. Stuart, Phys. Lett. **B262**, 113 (1991).
11. A. Sirlin, Phys. Rev. Lett. **67**, 2127 (1991).
12. A. Leike, T. Riemann, and J. Rose, Phys. Lett. **B273**, 513 (1991).
13. See also D. Bardin *et al.*, Phys. Lett. **B206**, 539 (1988).
14. S. Willenbrock and G. Valencia, Phys. Lett. **B259**, 373 (1991).
15. W. Beenakker, F.A. Berends, and S.C. van der Marck, Nucl. Phys. **B349**, 323 (1991).
16. K. Miyabayashi *et al.* (TOPAZ Collaboration) Phys. Lett. **B347**, 171 (1995).

17. R. Assmann *et al.* (Working Group on LEP Energy), Z. Phys. **C66**, 567 (1995).
18. L. Arnaudon *et al.* (Working Group on LEP Energy and LEP Collaborations), Phys. Lett. **B307**, 187 (1993).
19. L. Arnaudon *et al.* (Working Group on LEP Energy), CERN-PPE/92-125 (1992).
20. L. Arnaudon *et al.*, Phys. Lett. **B284**, 431 (1992).
21. R. Baily *et al.*, 'LEP Energy Calibration' CERN-SL 90-95.
22. The LEP Collaborations: ALEPH, DELPHI, L3, OPAL, the LEP Electroweak Working Group, and the SLD Heavy Flavour Group:
CERN-PPE/97-154 (1997); CERN-PPE/96-183 (1996); CERN-PPE/95-172 (1995); CERN-PPE/94-187 (1994); CERN-PPE/93-157 (1993).
23. The LEP Experiments: ALEPH, DELPHI, L3, and OPAL Nucl. Instrum. Methods **A378**, 101 (1996).

Z MASS

The fit is performed using the *Z* mass and width, the *Z* hadronic pole cross section, the ratios of hadronic to leptonic partial widths, and the *Z* pole forward-backward lepton asymmetries. We believe that this set is the most free of correlations. Common systematic errors are taken into account. For more details, see the 'Note on the *Z* Boson.'

The *Z*-boson mass listed here corresponds to a Breit-Wigner resonance parameter. The value is 34 MeV greater than the real part of the position of the pole (in the energy-squared plane) in the *Z*-boson propagator. Also the LEP experiments have generally assumed a fixed value of the $\gamma - Z$ interferences term based on the standard model. Keeping this term as free parameter leads to a somewhat larger error on the fitted *Z* mass. See ACCIARRI 97K and ACKERSTAFF 97C for a detailed investigation of both these issues.

A new source of LEP energy variation was discovered in mid 1995: an energy change of a few MeV is correlated with the passage of a train on nearby railway tracks. The LEP energy working group is studying the implications of this effect for the high statistics data recorded since 1993. The main consequence of this is expected to be a shift in the overall LEP energy values leading to a corresponding shift in the value of m_Z. The LEP collaborations have consequently deferred publication of their results on *Z* lineshape and lepton forward-backward asymmetries based on 1993 and later data.

Because of the high current interest, we mention here the following preliminary results, but do not average them or include them in the Listings or Tables.

Combining published and unpublished preliminary LEP results (as of end of February 1998) yields an average Z-boson mass of 91.1867 ± 0.0020 GeV, with a total width of 2.4948 ± 0.0025 GeV.

VALUE (GeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
91.187±0.007 OUR FIT					
91.188±0.007 OUR AVERAGE					
91.187±0.007±0.006	1.16M	[1] ABREU	94	DLPH	E^{ee}_{cm}= 88–94 GeV
91.195±0.006±0.007	1.19M	[1] ACCIARRI	94	L3	E^{ee}_{cm}= 88–94 GeV
91.182±0.007±0.006	1.33M	[1] AKERS	94	OPAL	E^{ee}_{cm}= 88–94 GeV
91.187±0.007±0.006	1.27M	[1] BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
91.193±0.010	1.2M	[2] ACCIARRI	97K	L3	E^{ee}_{cm}= LEP1 + 130–136 GeV + 161–172 GeV
91.185±0.010		[3] ACKERSTAFF	97C	OPAL	E^{ee}_{cm}= LEP1 + 130–136 GeV + 161 GeV
91.162±0.011	1.2M	[4] ACCIARRI	96B	L3	Repl. by ACCIARRI 97K
91.192±0.011	1.33M	[5] ALEXANDER	96X	OPAL	Repl. by ACKERSTAFF 97C
91.151±0.008		[6] MIYABAYASHI	95	TOPZ	E^{ee}_{cm}= 57.8 GeV
91.181±0.007±0.006	512k	[7] ACTON	93D	OPAL	Repl. by AKERS 94
91.195±0.009	460k	[8] ADRIANI	93F	L3	Repl. by ACCIARRI 94
91.187±0.009	520k	[9] BUSKULIC	93J	ALEP	Repl. by BUSKULIC 94
91.74 ±0.28 ±0.93	156	[10] ALITTI	92B	UA2	$E^{p\overline{p}}_{cm}$= 630 GeV
89.2 $^{+2.1}_{-1.8}$		[11] ADACHI	90F	RVUE	
90.9 ±0.3 ±0.2	188	[12] ABE	89C	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
91.14 ±0.12	480	[13] ABRAMS	89B	MRK2	E^{ee}_{cm}= 89–93 GeV
93.1 ±1.0 ±3.0	24	[14,15] ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV

[1] The second error of 6.3 MeV is due to a common LEP energy uncertainty.

[2] ACCIARRI 97K interpret the s-dependence of the cross sections and lepton forward-backward asymmetries in the framework of the S-matrix formalism with a combined fit to their cross section and asymmetry data at the Z peak (ACCIARRI 94) and their data at 130, 136, 161, and 172 GeV. The authors have corrected the measurement for the 34.1 MeV shift with respect to the Breit-Wigner fits. The error contains a contribution of ±3 MeV due to the uncertainty on the γZ interference.

[3] ACKERSTAFF 97C obtain this using the S-matrix formalism for a combined fit to their cross-section and asymmetry data at the Z peak (AKERS 94) and their data at 130, 136, and 161 GeV. The authors have corrected the measurement for the 34 MeV shift with respect to the Breit-Wigner fits.

[4] ACCIARRI 96B interpret the s-dependence of the cross sections and lepton forward-backward asymmetries in the framework of the S-matrix ansatz. The 130–136 GeV data constrains the γZ interference terms. As expected, this result is below the mass values obtained with a standard Breit-Wigner parametrization.

[5] ALEXANDER 96X obtain this using the S-matrix formalism for a combined fit to their cross-section and asymmetry data at the Z peak (AKERS 94) and their data at 130 and 136 GeV. The authors have corrected the measurement for the 34 MeV shift with respect to the Breit-Wigner fits.

[6] MIYABAYASHI 95 combine their low energy total hadronic cross-section measurement with the ACTON 93D data and perform a fit using an S-matrix formalism. As expected, this result is below the mass values obtained with the standard Breit-Wigner parametrization.

[7] The systematic error in ACTON 93D is from the uncertainty in the LEP energy calibration.
[8] The error in ADRIANI 93F includes 6 MeV due to the uncertainty in LEP energy calibration.
[9] BUSKULIC 93J supersedes DECAMP 92B. The error includes 6 MeV due to the uncertainty in LEP energy calibration.
[10] Enters fit through W/Z mass ratio given in the W Particle Listings. The ALITTI 92B systematic error (±0.93) has two contributions: one (±0.92) cancels in m_W/m_Z and one (±0.12) is noncancelling. These were added in quadrature.
[11] ADACHI 90F use a Breit-Wigner resonance shape fit and combine their results with published data of PEP and PETRA.
[12] First error of ABE 89 is combination of statistical and systematic contributions; second is mass scale uncertainty.
[13] ABRAMS 89B uncertainty includes 35 MeV due to the absolute energy measurement.
[14] Enters fit through Z-W mass difference given in the W Particle Listings.
[15] ALBAJAR 89 result is from a total sample of 33 $Z \rightarrow e^+e^-$ events.

Z WIDTH

VALUE (GeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2.490±0.007 OUR FIT					
2.491±0.007 OUR AVERAGE					
2.50 ±0.21 ±0.06		[16] ABREU	96R	DLPH	E^{ee}_{cm}= 91.2 GeV
2.483±0.011±0.0045	1.16M	[17] ABREU	94	DLPH	E^{ee}_{cm}= 88–94 GeV
2.494±0.009±0.0045	1.19M	[17] ACCIARRI	94	L3	E^{ee}_{cm}= 88–94 GeV
2.483±0.011±0.0045	1.33M	[17] AKERS	94	OPAL	E^{ee}_{cm}= 88–94 GeV
2.501±0.011±0.0045	1.27M	[17] BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.494±0.010	1.2M	[18] ACCIARRI	97K	L3	E^{ee}_{cm}= LEP1 + 130–136 GeV + 161–172 GeV
2.492±0.010	1.2M	[19] ACCIARRI	96B	L3	Repl. by ACCIARRI 97K
2.483±0.011±0.004	512k	[20] ACTON	93D	OPAL	Repl. by AKERS 94
2.490±0.011	460k	[21] ADRIANI	93F	L3	Repl. by ACCIARRI 94
2.501±0.012	520k	[22] BUSKULIC	93J	ALEP	Repl. by BUSKULIC 94
3.8 ±0.8 ±1.0	188	ABE	89C	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
2.42 $^{+0.45}_{-0.35}$	480	[23] ABRAMS	89B	MRK2	E^{ee}_{cm}= 89–93 GeV
2.7 $^{+1.2}_{-1.0}$ ±1.3	24	[24] ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV
2.7 ±2.0 ±1.0	25	[25] ANSARI	87	UA2	$E^{p\overline{p}}_{cm}$= 546,630 GeV

[16] ABREU 96R obtain this value from a study of the interference between initial and final state radiation in the process $e^+e^- \rightarrow Z \rightarrow \mu^+\mu^-$.
[17] The second error of 4.5 MeV is due to a common LEP energy uncertainty.
[18] ACCIARRI 97K interpret the s-dependence of the cross sections and lepton forward-backward asymmetries in the framework of the S-matrix formalism with a combined fit to their cross section and asymmetry data at the Z peak (ACCIARRI 94) and their data at 130, 136, 161, and 172 GeV. The authors have corrected the measurement for the 0.9 MeV shift with respect to the Breit-Wigner fits.
[19] ACCIARRI 96B interpret the s-dependence of the cross sections and lepton forward-backward asymmetries in the framework of the S-matrix ansatz. The 130–136 GeV data constrains the γZ interference terms. The fitted width is expected to be 0.9 MeV less than that obtained using the standard Breit-Wigner parametrization (see 'Note on the Z Boson').

[20] The systematic error is from the uncertainty in the LEP energy calibration.
[21] The error in ADRIANI 93F includes 4 MeV due to the uncertainty in LEP energy calibration.
[22] The error in BUSKULIC 93J includes 4 MeV due to the uncertainty in LEP energy calibration.
[23] ABRAMS 89B uncertainty includes 50 MeV due to the miniSAM background subtraction error.
[24] ALBAJAR 89 result is from a total sample of 33 $Z \rightarrow e^+ e^-$ events.
[25] Quoted values of ANSARI 87 are from direct fit. Ratio of Z and W production gives either $\Gamma(Z) < (1.09 \pm 0.07) \times \Gamma(W)$, CL = 90% or $\Gamma(Z) = (0.82^{+0.19}_{-0.14} \pm 0.06) \times \Gamma(W)$. Assuming Standard-Model value $\Gamma(W) = 2.65$ GeV then gives $\Gamma(Z) < 2.89 \pm 0.19$ or $= 2.17^{+0.50}_{-0.37} \pm 0.16$.

Z DECAY MODES

	Mode		Fraction (Γ_i/Γ)	Confidence level
Γ_1	$e^+ e^-$		(3.366±0.008) %	
Γ_2	$\mu^+ \mu^-$		(3.367±0.013) %	
Γ_3	$\tau^+ \tau^-$		(3.360±0.015) %	
Γ_4	$\ell^+ \ell^-$	[a]	(3.366±0.006) %	
Γ_5	invisible		(20.01 ±0.16) %	
Γ_6	hadrons		(69.90 ±0.15) %	
Γ_7	$(u\overline{u}+c\overline{c})/2$		(10.1 ±1.1) %	
Γ_8	$(d\overline{d}+s\overline{s}+b\overline{b})/3$		(16.6 ±0.6) %	
Γ_9	$c\overline{c}$		(12.4 ±0.6) %	
Γ_{10}	$b\overline{b}$		(15.16 ±0.09) %	
Γ_{11}	ggg		< 1.1 %	95%
Γ_{12}	$\pi^0 \gamma$		< 5.2 $\times 10^{-5}$	95%
Γ_{13}	$\eta \gamma$		< 5.1 $\times 10^{-5}$	95%
Γ_{14}	$\omega \gamma$		< 6.5 $\times 10^{-4}$	95%
Γ_{15}	$\eta'(958) \gamma$		< 4.2 $\times 10^{-5}$	95%
Γ_{16}	$\gamma\gamma$		< 5.2 $\times 10^{-5}$	95%
Γ_{17}	$\gamma\gamma\gamma$		< 1.0 $\times 10^{-5}$	95%
Γ_{18}	$\pi^\pm W^\mp$	[b]	< 7 $\times 10^{-5}$	95%
Γ_{19}	$\rho^\pm W^\mp$	[b]	< 8.3 $\times 10^{-5}$	95%
Γ_{20}	$J/\psi(1S)$X		(3.66 ±0.23) $\times 10^{-3}$	
Γ_{21}	$\psi(2S)$X		(1.60 ±0.29) $\times 10^{-3}$	
Γ_{22}	$\chi_{c1}(1P)$X		(2.9 ±0.7) $\times 10^{-3}$	
Γ_{23}	$\chi_{c2}(1P)$X		< 3.2 $\times 10^{-3}$	90%
Γ_{24}	$\Upsilon(1S)$ X $+\Upsilon(2S)$ X $+\Upsilon(3S)$ X		(1.0 ±0.5) $\times 10^{-4}$	
Γ_{25}	$\Upsilon(1S)$X		< 5.5 $\times 10^{-5}$	95%
Γ_{26}	$\Upsilon(2S)$X		< 1.39 $\times 10^{-4}$	95%

Γ_{27}	$\Upsilon(3S)$X			$<$ 9.4	$\times 10^{-5}$	95%
Γ_{28}	$(D^0/\overline{D}^0)$ X			(20.7 $\pm$2.0) %		
Γ_{29}	$D^{\pm}$X			(12.2 $\pm$1.7) %		
Γ_{30}	$D^*(2010)^{\pm}$X		[b]	(11.4 $\pm$1.3) %		
Γ_{31}	BX					
Γ_{32}	B^*X					
Γ_{33}	B_s^0X			seen		
Γ_{34}	anomalous $\gamma+$ hadrons		[c]	$<$ 3.2	$\times 10^{-3}$	95%
Γ_{35}	$e^+e^-\gamma$		[c]	$<$ 5.2	$\times 10^{-4}$	95%
Γ_{36}	$\mu^+\mu^-\gamma$		[c]	$<$ 5.6	$\times 10^{-4}$	95%
Γ_{37}	$\tau^+\tau^-\gamma$		[c]	$<$ 7.3	$\times 10^{-4}$	95%
Γ_{38}	$\ell^+\ell^-\gamma\gamma$		[d]	$<$ 6.8	$\times 10^{-6}$	95%
Γ_{39}	$q\overline{q}\gamma\gamma$		[d]	$<$ 5.5	$\times 10^{-6}$	95%
Γ_{40}	$\nu\overline{\nu}\gamma\gamma$		[d]	$<$ 3.1	$\times 10^{-6}$	95%
Γ_{41}	$e^{\pm}\mu^{\mp}$	LF	[b]	$<$ 1.7	$\times 10^{-6}$	95%
Γ_{42}	$e^{\pm}\tau^{\mp}$	LF	[b]	$<$ 9.8	$\times 10^{-6}$	95%
Γ_{43}	$\mu^{\pm}\tau^{\mp}$	LF	[b]	$<$ 1.2	$\times 10^{-5}$	95%

[a] ℓ indicates each type of lepton (e, μ, and τ), not sum over them.

[b] The value is for the sum of the charge states of particle/antiparticle states indicated.

[c] See the Particle Listings below for the γ energy range used in this measurement.

[d] For $m_{\gamma\gamma} = (60 \pm 5)$ GeV.

Z PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_1

For the LEP experiments, this parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the *Z* Boson.'

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
83.82±0.30 OUR FIT					
82.89±1.20±0.89		[26] ABE	95J	SLD	E^{ee}_{cm}= 91.31 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
83.31±0.54	31.4k	ABREU	94	DLPH	E^{ee}_{cm}= 88–94 GeV
83.43±0.52	38k	ACCIARRI	94	L3	E^{ee}_{cm}= 88–94 GeV
83.63±0.53	42k	AKERS	94	OPAL	E^{ee}_{cm}= 88–94 GeV
84.61±0.49	45.8k	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV

[26] ABE 95J obtain this measurement from Bhabha events in a restricted fiducial region to improve systematics. They use the values 91.187 and 2.489 GeV for the *Z* mass and total decay width to extract this partial width.

$\Gamma(\mu^+\mu^-)$ Γ_2

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
83.83±0.39 OUR FIT					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
84.15±0.77	45.6k	ABREU	94	DLPH	E^{ee}_{cm}= 88–94 GeV
83.20±0.79	34k	ACCIARRI	94	L3	E^{ee}_{cm}= 88–94 GeV
83.83±0.65	57k	AKERS	94	OPAL	E^{ee}_{cm}= 88–94 GeV
83.62±0.75	46.4k	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\tau^+\tau^-)$ Γ_3

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
83.67±0.44 OUR FIT					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
83.55±0.91	25k	ABREU	94	DLPH	E^{ee}_{cm}= 88–94 GeV
84.04±0.94	25k	ACCIARRI	94	L3	E^{ee}_{cm}= 88–94 GeV
82.90±0.77	47k	AKERS	94	OPAL	E^{ee}_{cm}= 88–94 GeV
84.18±0.79	45.1k	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\ell^+\ell^-)$ Γ_4

In our fit $\Gamma(\ell^+\ell^-)$ is defined as the partial Z width for the decay into a pair of massless charged leptons. This parameter is not directly used in the 5-parameter fit assuming lepton universality but is derived using the fit results. See the 'Note on the Z Boson.'

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
83.83±0.27 OUR FIT					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
83.56±0.45	102k	ABREU	94	DLPH	E^{ee}_{cm}= 88–94 GeV
83.49±0.46	97k	ACCIARRI	94	L3	E^{ee}_{cm}= 88–94 GeV
83.55±0.44	146k	AKERS	94	OPAL	E^{ee}_{cm}= 88–94 GeV
84.40±0.43	137.3k	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV

Γ(invisible) Γ_5

We use only direct measurements of the invisible partial width to obtain the average value quoted below. The fit value is obtained as a difference between the total and the observed partial widths assuming lepton universality.

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
498.3± 4.2 OUR FIT					
517 ±22 OUR AVERAGE					
539 ±26 ±17	410	AKERS	95C	OPAL	E^{ee}_{cm}= 88–94 GeV
450 ±34 ±34	258	BUSKULIC	93L	ALEP	E^{ee}_{cm}= 88–94 GeV
540 ±80 ±40	52	ADEVA	92	L3	E^{ee}_{cm}= 88–94 GeV
524 ±40 ±20	172	[27] ADRIANI	92E	L3	E^{ee}_{cm}= 88–94 GeV

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

509.4± 7.0		ABREU	94	DLPH	E^{ee}_{cm}= 88–94 GeV
496.5± 7.9		ACCIARRI	94	L3	E^{ee}_{cm}= 88–94 GeV
490.3± 7.3		AKERS	94	OPAL	E^{ee}_{cm}= 88–94 GeV
501 ± 6		BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV

[27] ADRIANI 92E improves but does not supersede ADEVA 92, obtained with 1990 data only.

Γ(hadrons) Γ_6

This parameter is not directly used in the 5-parameter fit assuming lepton universality, but is derived using the fit results. See the 'Note on the *Z* Boson.'

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1740.7± 5.9 OUR FIT					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1723 ±10	1.05M	ABREU	94	DLPH	E^{ee}_{cm}= 88–94 GeV
1748 ±10	1.09M	ACCIARRI	94	L3	E^{ee}_{cm}= 88–94 GeV
1741 ±10	1.19M	[28] AKERS	94	OPAL	E^{ee}_{cm}= 88–94 GeV
1746 ±10	1.27M	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV

[28] AKERS 94 assumes lepton universality. Without this assumption, it becomes 1742 ± 11 MeV.

Z BRANCHING RATIOS

Γ(hadrons)/Γ(e^+e^-) Γ_6/Γ_1

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
20.77± 0.08 OUR FIT					
20.74± 0.18	31.4k	ABREU	94	DLPH	E^{ee}_{cm}= 88–94 GeV
20.96± 0.15	38k	ACCIARRI	94	L3	E^{ee}_{cm}= 88–94 GeV
20.83± 0.16	42k	AKERS	94	OPAL	E^{ee}_{cm}= 88–94 GeV
20.59± 0.15	45.8k	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
20.99± 0.25	17k	ACTON	93D	OPAL	Repl. by AKERS 94
20.69± 0.21		BUSKULIC	93J	ALEP	Repl. by BUSKULIC 94
27.0 $^{+11.7}_{-8.8}$	12	[29] ABRAMS	89D	MRK2	E^{ee}_{cm}= 89–93 GeV

[29] ABRAMS 89D have included both statistical and systematic uncertainties in their quoted errors.

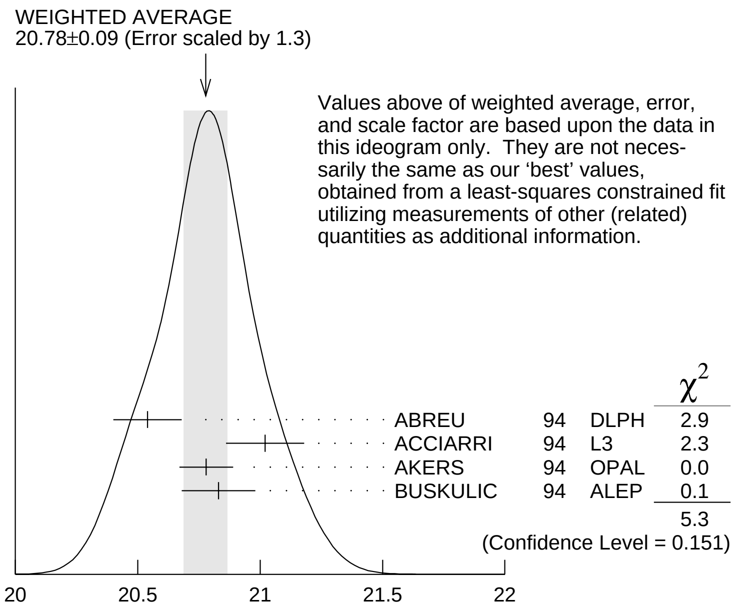
Γ(hadrons)/Γ($\mu^+\mu^-$) Γ_6/Γ_2

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
20.76±0.07 OUR FIT					
20.78±0.09 OUR AVERAGE Error includes scale factor of 1.3. See the ideogram below.					
20.54±0.14	45.6k	ABREU	94	DLPH	E^{ee}_{cm}= 88–94 GeV
21.02±0.16	34k	ACCIARRI	94	L3	E^{ee}_{cm}= 88–94 GeV
20.78±0.11	57k	AKERS	94	OPAL	E^{ee}_{cm}= 88–94 GeV
20.83±0.15	46.4k	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV

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

20.65±0.17	23k	ACTON	93D	OPAL	Repl. by AKERS 94
20.88±0.20		BUSKULIC	93J	ALEP	Repl. by BUSKULIC 94
18.9 $^{+7.1}_{-5.3}$	13	[30] ABRAMS	89D	MRK2	E^{ee}_{cm}= 89–93 GeV

[30] ABRAMS 89D have included both statistical and systematic uncertainties in their quoted errors.



$\Gamma(\text{hadrons})/\Gamma(\mu^+\mu^-)$

$\Gamma(\text{hadrons})/\Gamma(\tau^+\tau^-)$ Γ_6/Γ_3

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
20.80±0.08 OUR FIT					
20.81±0.08 OUR AVERAGE					
20.68±0.18	25k	ABREU	94	DLPH	E^{ee}_{cm}= 88–94 GeV
20.80±0.20	25k	ACCIARRI	94	L3	E^{ee}_{cm}= 88–94 GeV
21.01±0.15	47k	AKERS	94	OPAL	E^{ee}_{cm}= 88–94 GeV
20.70±0.16	45.1k	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV

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

21.22±0.25	18k	ACTON	93D	OPAL	Repl. by AKERS 94
20.77±0.23		BUSKULIC	93J	ALEP	Repl. by BUSKULIC 94
15.2 $^{+4.8}_{-3.9}$	21	[31] ABRAMS	89D	MRK2	E^{ee}_{cm}= 89–93 GeV

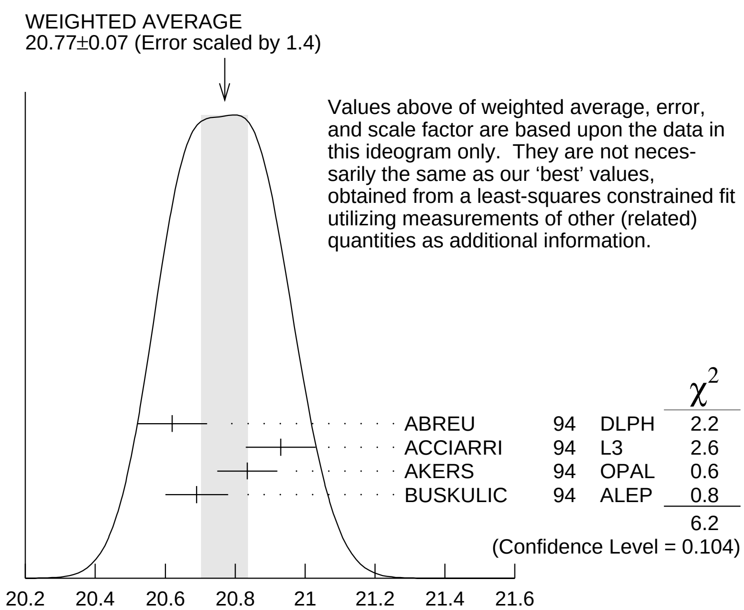
[31] ABRAMS 89D have included both statistical and systematic uncertainties in their quoted errors.

$\Gamma(\text{hadrons})/\Gamma(\ell^+\ell^-)$ Γ_6/Γ_4

ℓ indicates each type of lepton (e, μ, and τ), not sum over them.

Our fit result is obtained requiring lepton universality.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
20.76 ±0.05 OUR FIT					
20.77 ±0.07 OUR AVERAGE		Error includes scale factor of 1.4. See the ideogram below.			
20.62 ±0.10	102k	ABREU	94	DLPH	E^{ee}_{cm}= 88–94 GeV
20.93 ±0.10	97k	ACCIARRI	94	L3	E^{ee}_{cm}= 88–94 GeV
20.835±0.086	146k	AKERS	94	OPAL	E^{ee}_{cm}= 88–94 GeV
20.69 ±0.09	137.3k	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
20.88 ±0.13	58k	ACTON	93D	OPAL	Repl. by AKERS 94
21.00 ±0.15	40k	ADRIANI	93M	L3	Repl. by ACCIARRI 94
20.78 ±0.13		BUSKULIC	93J	ALEP	Repl. by BUSKULIC 94
18.9 $^{+3.6}_{-3.2}$	46	ABRAMS	89B	MRK2	E^{ee}_{cm}= 89–93 GeV



$\Gamma(\text{hadrons})/\Gamma(\ell^+\ell^-)$

$\Gamma(\text{hadrons})/\Gamma_{\text{total}}$ Γ_6/Γ

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.6990±0.0015 OUR FIT					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.6983±0.0023	1.14M	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(e^+e^-)/\Gamma_{total}$ — Γ_1/Γ

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.03366±0.00008 OUR FIT					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.03383±0.00013	45.8k	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\mu^+\mu^-)/\Gamma_{total}$ — Γ_2/Γ

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.03367±0.00013 OUR FIT					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.03344±0.00026	46.4k	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\tau^+\tau^-)/\Gamma_{total}$ — Γ_3/Γ

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.03360±0.00015 OUR FIT					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.03366±0.00028	45.1k	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\ell^+\ell^-)/\Gamma_{total}$ — Γ_4/Γ

ℓ indicates each type of lepton (e, μ, and τ), not sum over them.

Our fit result assumes lepton universality.

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.03366±0.00006 OUR FIT					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.03375±0.00009	137.3k	BUSKULIC	94	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\text{invisible})/\Gamma_{total}$ — Γ_5/Γ

See the data, the note, and the fit result for the partial width, Γ_5, above.

VALUE	DOCUMENT ID
0.2001±0.0016 OUR FIT	

$\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-)$ — Γ_2/Γ_1

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE	DOCUMENT ID
1.000±0.005 OUR FIT	

$\Gamma(\tau^+\tau^-)/\Gamma(e^+e^-)$ — Γ_3/Γ_1

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE	DOCUMENT ID
0.998±0.005 OUR FIT	

$\Gamma\big((u\overline{u}+c\overline{c})/2\big)/\Gamma\big(\text{hadrons}\big)$ Γ_7/Γ_6

This quantity is the branching ratio of $Z \rightarrow$ "up-type" quarks to $Z \rightarrow$ hadrons. Except ACKERSTAFF 97T the values of $Z \rightarrow$ "up-type" and $Z \rightarrow$ "down-type" branchings are extracted from measurements of Γ(hadrons), and $\Gamma(Z \rightarrow \gamma+$ jets) where γ is a high-energy (>5 GeV) isolated photon. As the experiments use different procedures and slightly different values of M_Z, Γ(hadrons) and α_s in their extraction procedures, our average has to be taken with caution.

VALUE	DOCUMENT ID		TECN	COMMENT
0.145±0.015 OUR AVERAGE				
0.160±0.019±0.019	[32] ACKERSTAFF	97T	OPAL	E^{ee}_{cm}= 88–94 GeV
$0.137^{+0.038}_{-0.054}$	[33] ABREU	95X	DLPH	E^{ee}_{cm}= 88–94 GeV
0.139±0.026	[34] ACTON	93F	OPAL	E^{ee}_{cm}= 88–94 GeV
0.137±0.033	[35] ADRIANI	93	L3	E^{ee}_{cm}= 91.2 GeV

[32] ACKERSTAFF 97T measure $\Gamma_{u\overline{u}}/(\Gamma_{d\overline{d}}+\Gamma_{u\overline{u}}+\Gamma_{s\overline{s}}) = 0.258 \pm 0.031 \pm 0.032$. To obtain this branching ratio authors use $R_c+R_b = 0.380 \pm 0.010$. This measurement is fully negatively correlated with the measurement of $\Gamma_{d\overline{d},s\overline{s}}/(\Gamma_{d\overline{d}}+\Gamma_{u\overline{u}}+\Gamma_{s\overline{s}})$ given in the next data block.

[33] ABREU 95X use $M_Z = 91.187 \pm 0.009$ GeV, Γ(hadrons) = 1725 ± 12 MeV and $\alpha_s = 0.123 \pm 0.005$. To obtain this branching ratio we divide their value of $C_{2/3} = 0.91^{+0.25}_{-0.36}$ by their value of $(3C_{1/3} + 2C_{2/3}) = 6.66 \pm 0.05$.

[34] ACTON 93F use the LEP 92 value of Γ(hadrons) = 1740 ± 12 MeV and $\alpha_s = 0.122^{+0.006}_{-0.005}$.

[35] ADRIANI 93 use $M_Z = 91.181 \pm 0.022$ GeV, Γ(hadrons) = 1742 ± 19 MeV and $\alpha_s = 0.125 \pm 0.009$. To obtain this branching ratio we divide their value of $C_{2/3} = 0.92 \pm 0.22$ by their value of $(3C_{1/3} + 2C_{2/3}) = 6.720 \pm 0.076$.

$\Gamma\big((d\overline{d}+s\overline{s}+b\overline{b})/3\big)/\Gamma\big(\text{hadrons}\big)$ Γ_8/Γ_6

This quantity is the branching ratio of $Z \rightarrow$ "down-type" quarks to $Z \rightarrow$ hadrons. Except ACKERSTAFF 97T the values of $Z \rightarrow$ "up-type" and $Z \rightarrow$ "down-type" branchings are extracted from measurements of Γ(hadrons), and $\Gamma(Z \rightarrow \gamma+$ jets) where γ is a high-energy (>5 GeV) isolated photon. As the experiments use different procedures and slightly different values of M_Z, Γ(hadrons) and α_s in their extraction procedures, our average has to be taken with caution.

VALUE	DOCUMENT ID		TECN	COMMENT
0.237±0.009 OUR AVERAGE				
0.230±0.010±0.010	[36] ACKERSTAFF	97T	OPAL	E^{ee}_{cm}= 88–94 GeV
$0.243^{+0.036}_{-0.026}$	[37] ABREU	95X	DLPH	E^{ee}_{cm}= 88–94 GeV
0.241±0.017	[38] ACTON	93F	OPAL	E^{ee}_{cm}= 88–94 GeV
0.243±0.022	[39] ADRIANI	93	L3	E^{ee}_{cm}= 91.2 GeV

[36] ACKERSTAFF 97T measure $\Gamma_{d\overline{d},s\overline{s}}/(\Gamma_{d\overline{d}}+\Gamma_{u\overline{u}}+\Gamma_{s\overline{s}}) = 0.371 \pm 0.016 \pm 0.016$. To obtain this branching ratio authors use $R_c+R_b = 0.380 \pm 0.010$. This measurement is fully negatively correlated with the measurement of $\Gamma_{u\overline{u}}/(\Gamma_{d\overline{d}}+\Gamma_{u\overline{u}}+\Gamma_{s\overline{s}})$ presented in the previous data block.

[37] ABREU 95X use $M_Z = 91.187 \pm 0.009$ GeV, Γ(hadrons) = 1725 ± 12 MeV and $\alpha_s = 0.123 \pm 0.005$. To obtain this branching ratio we divide their value of $C_{1/3} = 1.62^{+0.24}_{-0.17}$ by their value of $(3C_{1/3} + 2C_{2/3}) = 6.66 \pm 0.05$.

[38] ACTON 93F use the LEP 92 value of Γ(hadrons) = 1740 ± 12 MeV and $\alpha_s = 0.122^{+0.006}_{-0.005}$.

[39] ADRIANI 93 use M_Z = 91.181 ± 0.022 GeV, Γ(hadrons) = 1742 ± 19 MeV and α_s = 0.125 ± 0.009. To obtain this branching ratio we divide their value of $C_{1/3} = 1.63 \pm 0.15$ by their value of $(3C_{1/3} + 2C_{2/3}) = 6.720 \pm 0.076$.

$R_c = \Gamma(c\overline{c})/\Gamma(\text{hadrons})$ Γ_9/Γ_6

OUR FIT is obtained by a simultaneous fit to several *c*- and *b*-quark measurements as explained in the "Note on the *Z* boson." As a cross check we have also performed a weighted average of the R_c measurements taking into account the various common systematic errors. Assuming that the smallest common systematic error is fully correlated, we obtain R_c = 0.171 ± 0.009.

Because of the high current interest, we mention the following preliminary results here, but do not average them or include them in the Listings or Tables. Combining published and unpublished preliminary LEP and SLD electroweak results (as of end of February 1998) yields R_c = 0.1734 ± 0.0048. The Standard Model predicts R_c = 0.1723 for m_t = 175 GeV and M_H = 300 GeV.

VALUE	DOCUMENT ID		TECN	COMMENT
0.177 ±0.008 OUR FIT				
0.180 ±0.011 ±0.013	[40] ACKERSTAFF	98E	OPAL	E^{ee}_{cm}= 88–94 GeV
0.167 ±0.011 ±0.012	[41] ALEXANDER	96R	OPAL	E^{ee}_{cm}= 88–94 GeV
0.1623±0.0085±0.0209	[42] ABREU	95D	DLPH	E^{ee}_{cm}= 88–94 GeV
0.165 ±0.005 ±0.020	[43] BUSKULIC	94G	ALEP	E^{ee}_{cm}= 88–94 GeV
0.187 ±0.031 ±0.023	[44] ABREU	93I	DLPH	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.142 ±0.008 ±0.014	[45] AKERS	95O	OPAL	Repl. by ACKERSTAFF 98E
0.151 ±0.008 ±0.041	[46] ABREU	92O	DLPH	E^{ee}_{cm}= 88–94 GeV

[40] ACKERSTAFF 98E use an inclusive/exclusive double tag. In one jet $D^{*\pm}$ mesons are exclusively reconstruced in several decay channels and in the opposite jet a slow pion (opposite charge inclusive $D^{*\pm}$) tag is used. The *b* content of this sample is measured by the simultaneous detection of a lepton in one jet and an inclusively reconstructed $D^{*\pm}$ meson in the opposite jet. The systematic error includes an uncertainty of ±0.006 due to the external branching ratios.

[41] ALEXANDER 96R obtain this value via direct charm counting, summing the partial contributions from D^0, D^+, D^+_s, and Λ^+_c, and assuming that strange-charmed baryons account for the 15% of the Λ^+_c production. An uncertainty of ±0.005 due to the uncertainties in the charm hadron branching ratios is included in the overall systematics.

[42] ABREU 95D perform a maximum likelihood fit to the combined *p* and p_T distributions of single and dilepton samples. The second error includes an uncertainty of ±0.0124 due to models and branching ratios.

[43] BUSKULIC 94G perform a simultaneous fit to the *p* and p_T spectra of both single and dilepton events.

[44] ABREU 93I assume that the D_s and charmed baryons are equally produced at LEP and CLEO (10 GeV) energies.

[45] AKERS 95O use the presence of a $D^{*\pm}$ to tag $Z \rightarrow c\overline{c}$ with $D^* \rightarrow D^0\pi$ and $D^0 \rightarrow K\pi$. They measure $P_c * \Gamma(c\overline{c})/\Gamma(\text{hadrons})$ to be $(1.006 \pm 0.055 \pm 0.061) \times 10^{-3}$, where P_c is the product branching ratio $B(c \rightarrow D^*)B(D^* \rightarrow D^0\pi)B(D^0 \rightarrow K\pi)$. Assuming that P_c remains unchanged with energy, they use its value $(7.1 \pm 0.5) \times 10^{-3}$ determined

at CESR/PETRA to obtain $\Gamma(c\overline{c})/\Gamma(\text{hadrons})$. The second error of AKERS 95O includes an uncertainty of ±0.011 from the uncertainty on P_c.

[46] ABREU 92O use the neural network techinque to tag heavy flavour events among a sample of 123k selected hadronic events. The systematic error consists of three parts: due to Monte Carlo (MC) parametrization (0.023), choice of MC model (0.033) and detector effects (0.009) added in quadrature.

$R_b = \Gamma(b\overline{b})/\Gamma(\text{hadrons})$ Γ_{10}/Γ_6

OUR FIT is obtained by a simultaneous fit to several c- and b-quark measurements as explained in the "Note on the Z boson." As a cross check we have also performed a weighted average of the R_b measurements taking into account the various common systematic errors. We have assumed that the smallest common systematic error is fully correlated. For $R_c = 0.177$ (as given by OUR FIT above), we obtain $R_b = 0.2169 \pm 0.0012$. For an expected Standard Model value of $R_c = 0.1723$, our weighted average gives $R_b = 0.2172 \pm 0.0012$.

Because of the high current interest, we mention the following preliminary results here, but do not average them or include them in the Listings or Tables. Combining published and unpublished preliminary LEP and SLD electroweak results (as of end of February 1998) yields $R_b = 0.2170 \pm 0.0009$. The Standard Model predicts $R_b = 0.2158$ for $m_t = 175$ GeV and $M_H = 300$ GeV.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.2169±0.0012 OUR FIT					
0.2142±0.0034±0.0015		[47] ABE	98D	SLD	E^{ee}_{cm}= 91.2 GeV
0.2175±0.0014±0.0017		[48] ACKERSTAFF	97K	OPAL	E^{ee}_{cm}= 88–94 GeV
0.2159±0.0009±0.0011		[49] BARATE	97F	ALEP	E^{ee}_{cm}= 88–94 GeV
0.2216±0.0016±0.0021		[50] ABREU	96	DLPH	E^{ee}_{cm}= 88–94 GeV
0.2145±0.0089±0.0067		[51] ABREU	95D	DLPH	E^{ee}_{cm}= 88–94 GeV
0.219 ±0.006 ±0.005		[52] BUSKULIC	94G	ALEP	E^{ee}_{cm}= 88–94 GeV
0.222 ±0.003 ±0.007		[53] ADRIANI	93E	L3	E^{ee}_{cm}= 88–94 GeV
0.222 ±0.011 ±0.007		[54] AKERS	93B	OPAL	E^{ee}_{cm}= 88–94 GeV
0.251 ±0.049 ±0.030	32	[55] JACOBSEN	91	MRK2	E^{ee}_{cm}= 91 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.2167±0.0011±0.0013		[56] BARATE	97E	ALEP	E^{ee}_{cm}= 88–94 GeV
0.229 ±0.011		[57] ABE	96E	SLD	Repl. by ABE 98D
0.2217±0.0020±0.0033		[58] ABREU	95D	DLPH	Repl. by ABREU 96
0.2241±0.0063±0.0046		[59] ABREU	95J	DLPH	Repl. by ABREU 96
0.2171±0.0021±0.0021		[60] AKERS	95B	OPAL	Repl. by ACKERSTAFF 97K
0.228 ±0.005 ±0.005		[61] BUSKULIC	93N	ALEP	E^{ee}_{cm}= 88–94 GeV
0.222 $^{+0.033}_{-0.031}$ ±0.017		[62] ABREU	92	DLPH	E^{ee}_{cm}= 88–94 GeV
0.219 ±0.014 ±0.019		[63] ABREU	92K	DLPH	E^{ee}_{cm}= 88–94 GeV
0.232 ±0.005 ±0.017		[64] ABREU	92O	DLPH	E^{ee}_{cm}= 88–94 GeV
0.23 $^{+0.10}_{-0.08}$ $^{+0.05}_{-0.04}$	15	[65] KRAL	90	MRK2	E^{ee}_{cm}= 89–93 GeV

[47] ABE 98D use a double tag based on 3D impact parameter with reconstruction of secondary vertices. The charm background is reduced by requiring the invariant mass at the secondary vertex to be above 2 GeV. The systematic error includes an uncertainty of ±0.0002 due to the uncertainty on R_c.

[48] ACKERSTAFF 97K use lepton and/or separated decay vertex to tag independently each hemisphere. Comparing the numbers of single- and double-tagged events, they determine the b-tagging efficiency directly from the data.

[49] BARATE 97F combine the lifetime-mass hemisphere tag (BARATE 97E) with event shape information and lepton tag to identify $Z \rightarrow b\overline{b}$ candidates. They further use c- and uds-selection tags to identify the background. For R_c different from its Standard Model value of 0.172, R_b varies as $-0.019\times(R_c - 0.172)$.

[50] ABREU 96 obtain this result combining several analyses (double lifetime tag, mixed tag and multivariate analysis). This value is obtained assuming R_c=$\Gamma(c\overline{c})/\Gamma(\text{hadrons}) = 0.172$. For a value of R_c different from this by an amount ΔR_c the change in the value is given by $-0.087 \cdot \Delta R_c$.

[51] ABREU 95D perform a maximum likelihood fit to the combined p and p_T distributions of single and dilepton samples. The second error includes an uncertainty of ±0.0023 due to models and branching ratios.

[52] BUSKULIC 94G perform a simultaneous fit to the p and p_T spectra of both single and dilepton events.

[53] ADRIANI 93E use a multidimensional analysis based on a neural network approach.

[54] AKERS 93B use a simultaneous fit to single and dilepton events (electrons and muons) to tag $Z \rightarrow b\overline{b}$.

[55] JACOBSEN 91 tagged $b\overline{b}$ events by requiring coincidence of ≥ 3 tracks with significant impact parameters using vertex detector. Systematic error includes lifetime and decay uncertainties (±0.014).

[56] BARATE 97E combine a lifetime tag with a mass cut based on the mass difference between c hadrons and b hadrons.

[57] ABE 96E obtain this value by combining results from three different b-tagging methods (2D impact parameter, 3D impact parameter, and 3D displaced vertex).

[58] ABREU 95D obtain this result combining several analyses (double-lifetime tag and mixed tags). The second error contains an uncertainty of ±0.0029 due to the total systematics and an uncertainty of ±0.0016 due to an 8% variation of $\Gamma(c\overline{c})/\Gamma(\text{hadrons})$ around its Standard Model value (0.171 ± 0.014). Combining with their own lepton analysis, ABREU 95D obtain $0.2210 \pm 0.0033 \pm 0.0003$ (models) ±0.0014 $[\Gamma(c\overline{c})/\Gamma(\text{hadrons})]$.

[59] ABREU 95J obtain this value with a multivariate analysis based on event shape and particle trajectories near the interaction point. The second error contains an uncertainty of ±0.0012 due to an 8% variation of $\Gamma(c\overline{c})/\Gamma(\text{hadrons})$ around its Standard Model value (0.171 ± 0.014).

[60] AKERS 95B select events based on the lepton and/or vertex tag independently in each hemisphere. Comparing the numbers of single- and double-tagged events, they determine the b-tagging efficiency directly from data.

[61] BUSKULIC 93N use event shape and high p_T lepton discriminators applied to both hemispheres.

[62] ABREU 92 result is from an indirect technique. They measure the lifetime τ_B, but use a world average of τ_B independent of $\Gamma(b\overline{b})$ and compare to their $\Gamma(b\overline{b})$ dependent lifetime from a hadron sample.

[63] ABREU 92K use boosted−sphericity technique to tag and enrich the b-$\overline{b}$ content with a sample of 50k hadronic events. Most of the systematic error is from hadronization uncertainty.

[64] ABREU 92O use the neural network technique to tag heavy flavour events among a sample of 123k selected hadronic events. The systematic error consists of three parts: due to Monte Carlo (MC) parametrization (0.010), choice of MC model (0.008), and detector effects (0.011) added in quadrature.

[65] KRAL 90 used isolated leptons and found $\Gamma(b\overline{b})/\Gamma(\text{total}) = 0.17^{+0.07}_{-0.06}{}^{+0.04}_{-0.03}$.

$\Gamma(ggg)/\Gamma(\text{hadrons})$ — Γ_{11}/Γ_6

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<1.6 \times 10^{-2}$	95	[66] ABREU	96S	DLPH	E^{ee}_{cm}= 88–94 GeV

[66] This branching ratio is slightly dependent on the jet-finder algorithm. The value we quote is obtained using the JADE algorithm, while using the DURHAM algorithm ABREU 96S obtain an upper limit of 1.5×10^{-2}.

$\Gamma(\pi^0\gamma)/\Gamma_{\text{total}}$ — Γ_{12}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<5.2 \times 10^{-5}$	95	[67] ACCIARRI	95G	L3	E^{ee}_{cm}= 88–94 GeV
$<5.5 \times 10^{-5}$	95	ABREU	94B	DLPH	E^{ee}_{cm}= 88–94 GeV
$<2.1 \times 10^{-4}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV
$<1.4 \times 10^{-4}$	95	AKRAWY	91F	OPAL	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1.2 \times 10^{-4}$	95	[68] ADRIANI	92B	L3	Repl. by ACCIARRI 95G

[67] This limit is for both decay modes $Z \to \pi^0\gamma/\gamma\gamma$ which are indistinguishable in ACCIARRI 95G.
[68] This limit is for both decay modes $Z \to \pi^0\gamma/\gamma\gamma$ which are indistinguishable in ADRIANI 92B.

$\Gamma(\eta\gamma)/\Gamma_{\text{total}}$ — Γ_{13}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<7.6 \times 10^{-5}$	95	ACCIARRI	95G	L3	E^{ee}_{cm}= 88–94 GeV
$<8.0 \times 10^{-5}$	95	ABREU	94B	DLPH	E^{ee}_{cm}= 88–94 GeV
$<5.1 \times 10^{-5}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV
$<2.0 \times 10^{-4}$	95	AKRAWY	91F	OPAL	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1.8 \times 10^{-4}$	95	ADRIANI	92B	L3	Repl. by ACCIARRI 95G

$\Gamma(\omega\gamma)/\Gamma_{\text{total}}$ — Γ_{14}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<6.5 \times 10^{-4}$	95	ABREU	94B	DLPH	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\eta'(958)\gamma)/\Gamma_{\text{total}}$ — Γ_{15}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<4.2 \times 10^{-5}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ — Γ_{16}/Γ

This decay would violate the Landau-Yang theorem.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<5.2 \times 10^{-5}$	95	[69] ACCIARRI	95G	L3	E^{ee}_{cm}= 88–94 GeV
$<5.5 \times 10^{-5}$	95	ABREU	94B	DLPH	E^{ee}_{cm}= 88–94 GeV
$<1.4 \times 10^{-4}$	95	AKRAWY	91F	OPAL	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1.2 \times 10^{-4}$	95	[70] ADRIANI	92B	L3	Repl. by ACCIARRI 95G

[69] This limit is for both decay modes $Z \to \pi^0\gamma/\gamma\gamma$ which are indistinguishable in ACCIARRI 95G.
[70] This limit is for both decay modes $Z \to \pi^0\gamma/\gamma\gamma$ which are indistinguishable in ADRIANI 92B.

$\Gamma(\gamma\gamma\gamma)/\Gamma_{total}$ — Γ_{17}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<1.0 \times 10^{-5}$	95	[71] ACCIARRI	95C	L3	E^{ee}_{cm}= 88–94 GeV
$<1.7 \times 10^{-5}$	95	[71] ABREU	94B	DLPH	E^{ee}_{cm}= 88–94 GeV
$<6.6 \times 10^{-5}$	95	AKRAWY	91F	OPAL	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<3.3 \times 10^{-5}$	95	ADRIANI	92B	L3	Repl. by ACCIARRI 95C

[71] Limit derived in the context of composite Z model.

$\Gamma(\pi^{\pm} W^{\mp})/\Gamma_{total}$ — Γ_{18}/Γ

The value is for the sum of the charge states indicated.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<7 \times 10^{-5}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\rho^{\pm} W^{\mp})/\Gamma_{total}$ — Γ_{19}/Γ

The value is for the sum of the charge states indicated.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<8.3 \times 10^{-5}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(J/\psi(1S)X)/\Gamma_{total}$ — Γ_{20}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
3.66±0.23 OUR AVERAGE					
3.40±0.23±0.27	441	[72] ACCIARRI	97J	L3	E^{ee}_{cm}= 88–94 GeV
3.9 ±0.2 ±0.3	511	[73] ALEXANDER	96B	OPAL	E^{ee}_{cm}= 88–94 GeV
3.73±0.39±0.36	153	[74] ABREU	94P	DLPH	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3.6 ±0.5 ±0.4	121	[74] ADRIANI	93J	L3	Repl. by ACCIARRI 97J

[72] ACCIARRI 97J combine $\mu^+\mu^-$ and e^+e^- $J/\psi(1S)$ decay channels and take into account the common systematic error.

[73] ALEXANDER 96B identify $J/\psi(1S)$ from the decays into lepton pairs. (4.8 ± 2.4)% of this branching ratio is due to prompt $J/\psi(1S)$ production (ALEXANDER 96N).

[74] Combining $\mu^+\mu^-$ and e^+e^- channels and taking into account the common systematic errors. $(7.7^{+6.3}_{-5.4})$% of this branching ratio is due to prompt $J/\psi(1S)$ production.

$\Gamma(\psi(2S)X)/\Gamma_{total}$ — Γ_{21}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.60±0.29 OUR AVERAGE					
1.6 ±0.5 ±0.3	39	[75] ACCIARRI	97J	L3	E^{ee}_{cm}= 88–94 GeV
1.6 ±0.3 ±0.2	46.9	[76] ALEXANDER	96B	OPAL	E^{ee}_{cm}= 88–94 GeV
1.60±0.73±0.33	5.4	[77] ABREU	94P	DLPH	E^{ee}_{cm}= 88–94 GeV

[75] ACCIARRI 97J measure this branching ratio via the decay channel $\psi(2S) \rightarrow \ell^+\ell^-$ ($\ell = \mu$, e).

[76] ALEXANDER 96B measure this branching ratio via the decay channel $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$, with $J/\psi \rightarrow \ell^+\ell^-$.

[77] ABREU 94P measure this branching ratio via decay channel $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$, with $J/\psi \rightarrow \mu^+\mu^-$.

$\Gamma(\chi_{c1}(1P)X)/\Gamma_{total}$ Γ_{22}/Γ

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2.9±0.7 OUR AVERAGE					
2.7±0.6±0.5	33	78 ACCIARRI	97J	L3	E^{ee}_{cm}= 88–94 GeV
$5.0\pm2.1^{+1.5}_{-0.9}$	6.4	79 ABREU	94P	DLPH	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
7.5±2.9±0.6	19	79 ADRIANI	93J	L3	Repl. by ACCIARRI 97J

[78] ACCIARRI 97J measure this branching ratio via the decay channel $\chi_{c1} \rightarrow J/\psi + \gamma$, with $J/\psi \rightarrow \ell^+\ell^-$ ($\ell = \mu$, e). The $M(\ell^+\ell^-\gamma)$–$M(\ell^+\ell^-)$ mass difference spectrum is fitted with two gaussian shapes for χ_{c1} and χ_{c2}.

[79] This branching ratio is measured via the decay channel $\chi_{c1} \rightarrow J/\psi + \gamma$, with $J/\psi \rightarrow \mu^+\mu^-$.

$\Gamma(\chi_{c2}(1P)X)/\Gamma_{total}$ Γ_{23}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
<3.2 × 10^{-3}	90	80 ACCIARRI	97J	L3	E^{ee}_{cm}= 88–94 GeV

[80] ACCIARRI 97J derive this limit via the decay channel $\chi_{c2} \rightarrow J/\psi + \gamma$, with $J/\psi \rightarrow \ell^+\ell^-$ ($\ell = \mu$, e). The $M(\ell^+\ell^-\gamma)$–$M(\ell^+\ell^-)$ mass difference spectrum is fitted with two gaussian shapes for χ_{c1} and χ_{c2}.

$\Gamma(\Upsilon(1S)X + \Upsilon(2S)X + \Upsilon(3S)X)/\Gamma_{total}$ $\Gamma_{24}/\Gamma = (\Gamma_{25}+\Gamma_{26}+\Gamma_{27})/\Gamma$

VALUE (units 10^{-4})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1.0±0.4±0.22	6.4	81 ALEXANDER	96F	OPAL	E^{ee}_{cm}= 88–94 GeV

[81] ALEXANDER 96F identify the Υ (which refers to any of the three lowest bound states) through its decay into e^+e^- and $\mu^+\mu^-$. The systematic error includes an uncertainty of ±0.2 due to the production mechanism.

$\Gamma(\Upsilon(1S)X)/\Gamma_{total}$ Γ_{25}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
<5.5 × 10^{-5}	95	82 ACCIARRI	97R	L3	E^{ee}_{cm}= 88–94 GeV

[82] ACCIARRI 97R search for $\Upsilon(1S)$ through its decay into $\ell^+\ell^-$ ($\ell = e$ or μ).

$\Gamma(\Upsilon(2S)X)/\Gamma_{total}$ Γ_{26}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
<13.9 × 10^{-5}	95	83 ACCIARRI	97R	L3	E^{ee}_{cm}= 88–94 GeV

[83] ACCIARRI 97R search for $\Upsilon(2S)$ through its decay into $\ell^+\ell^-$ ($\ell = e$ or μ).

$\Gamma(\Upsilon(3S)X)/\Gamma_{total}$ Γ_{27}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
<9.4 × 10^{-5}	95	84 ACCIARRI	97R	L3	E^{ee}_{cm}= 88–94 GeV

[84] ACCIARRI 97R search for $\Upsilon(3S)$ through its decay into $\ell^+\ell^-$ ($\ell = e$ or μ).

$\Gamma((D^0/\overline{D}^0)X)/\Gamma(\text{hadrons})$ Γ_{28}/Γ_6

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.296±0.019±0.021	369	85 ABREU	93I	DLPH	E^{ee}_{cm}= 88–94 GeV

[85] The $(D^0/\overline{D}^0)$ states in ABREU 93I are detected by the $K\pi$ decay mode. This is a corrected result (see the erratum of ABREU 93I).

$\Gamma(D^{\pm}X)/\Gamma(\text{hadrons})$ — Γ_{29}/Γ_6

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.174±0.016±0.018	539	[86] ABREU	93I	DLPH	E^{ee}_{cm}= 88–94 GeV

[86] The $D^{\pm}$ states in ABREU 93I are detected by the $K\pi\pi$ decay mode. This is a corrected result (see the erratum of ABREU 93I).

$\Gamma(D^*(2010)^{\pm}X)/\Gamma(\text{hadrons})$ — Γ_{30}/Γ_6

The value is for the sum of the charge states indicated.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.163±0.019 OUR AVERAGE		Error includes scale factor of 1.3.			
0.155±0.010±0.013	358	[87] ABREU	93I	DLPH	E^{ee}_{cm}= 88–94 GeV
0.21 ±0.04	362	[88] DECAMP	91J	ALEP	E^{ee}_{cm}= 88–94 GeV

[87] $D^*(2010)^{\pm}$ in ABREU 93I are reconstructed from $D^0\pi^{\pm}$, with $D^0 \rightarrow K^-\pi^+$. The new CLEO II measurement of B($D^{*\pm} \rightarrow D^0\pi^{\pm}$) = (68.1 ± 1.6) % is used. This is a corrected result (see the erratum of ABREU 93I).

[88] DECAMP 91J report B($D^*(2010)^+ \rightarrow D^0\pi^+$) B($D^0 \rightarrow K^-\pi^+$) $\Gamma(D^*(2010)^{\pm}X)$ / Γ(hadrons) = (5.11 ± 0.34) × 10^{-3}. They obtained the above number assuming B($D^0 \rightarrow K^-\pi^+$) = (3.62±0.34±0.44)% and B($D^*(2010)^+ \rightarrow D^0\pi^+$) = (55±4)%. We have rescaled their original result of 0.26 ± 0.05 taking into account the new CLEO II branching ratio B($D^*(2010)^+ \rightarrow D^0\pi^+$) = (68.1 ± 1.6)%.

$\Gamma(B^0_s X)/\Gamma(\text{hadrons})$ — Γ_{33}/Γ_6

VALUE	DOCUMENT ID		TECN	COMMENT
seen	[89] ABREU	92M	DLPH	E^{ee}_{cm}= 88–94 GeV
seen	[90] ACTON	92N	OPAL	E^{ee}_{cm}= 88–94 GeV
seen	[91] BUSKULIC	92E	ALEP	E^{ee}_{cm}= 88–94 GeV

[89] ABREU 92M reported value is $\Gamma(B^0_s X)$∗B($B^0_s \rightarrow D_s\mu\nu_{\mu}X$) ∗B($D_s \rightarrow \phi\pi$)/Γ(hadrons) = (18 ± 8) × 10^{-5}.

[90] ACTON 92N find evidence for B^0_s production using D_s-ℓ correlations, with $D^+_s \rightarrow \phi\pi^+$ and $K^*(892)K^+$. Assuming R_b from the Standard Model and averaging over the e and μ channels, authors measure the product branching fraction to be $f(\overline{b} \rightarrow B^0_s)$×B($B^0_s \rightarrow D^-_s\ell^+\nu_{\ell}X$)×B($D^-_s \rightarrow \phi\pi^-$) = (3.9 ± 1.1 ± 0.8) × 10^{-4}.

[91] BUSKULIC 92E find evidence for B^0_s production using D_s-ℓ correlations, with $D^+_s \rightarrow \phi\pi^+$ and $K^*(892)K^+$. Using B($D^+_s \rightarrow \phi\pi^+$) = (2.7 ± 0.7)% and summing up the e and μ channels, the weighted average product branching fraction is measured to be B($\overline{b} \rightarrow B^0_s$)×B($B^0_s \rightarrow D^-_s\ell^+\nu_{\ell}X$) = $0.040 \pm 0.011^{+0.010}_{-0.012}$.

$\Gamma(B^*X)/[\Gamma(BX)+\Gamma(B^*X)]$ — $\Gamma_{32}/(\Gamma_{31}+\Gamma_{32})$

As the experiments assume different values of the b-baryon contribution, our average should be taken with caution. If we assume a common baryon production fraction f_{Λ_b} = (13.2 ± 4.1)% as given in the 1996 edition of this *Review* OUR AVERAGE becomes 0.77 ± 0.04.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.75 ±0.04 OUR AVERAGE					
0.760±0.036±0.083		[92] ACKERSTAFF	97M	OPAL	E^{ee}_{cm}= 88–94 GeV
0.771±0.026±0.070		[93] BUSKULIC	96D	ALEP	E^{ee}_{cm}= 88–94 GeV
0.72 ±0.03 ±0.06		[94] ABREU	95R	DLPH	E^{ee}_{cm}= 88–94 GeV
0.76 ±0.08 ±0.06	1378	[95] ACCIARRI	95B	L3	E^{ee}_{cm}= 88–94 GeV

[92] ACKERSTAFF 97M use an inclusive B reconstruction method and assume a (13.2 ± 4.1)% b-baryon contribution. The value refers to a b-flavored meson mixture of B_u, B_d, and B_s.

[93] BUSKULIC 96D use an inclusive reconstruction of B hadrons and assume a (12.2 ± 4.3)% b-baryon contribution. The value refers to a b-flavored mixture of B_u, B_d, and B_s.

[94] ABREU 95R use an inclusive B-reconstruction method and assume a (10 ± 4)% b-baryon contribution. The value refers to a b-flavored meson mixture of B_u, B_d, and B_s.

[95] ACCIARRI 95B assume a 9.4% b-baryon contribution. The value refers to a b-flavored mixture of B_u, B_d, and B_s.

$\Gamma(\text{anomalous } \gamma + \text{hadrons})/\Gamma_{\text{total}}$ — Γ_{34}/Γ

Limits on additional sources of prompt photons beyond expectations for final-state bremsstrahlung.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<3.2 \times 10^{-3}$	95	[96] AKRAWY	90J	OPAL	E^{ee}_{cm}= 88–94 GeV

[96] AKRAWY 90J report $\Gamma(\gamma X) <$ 8.2 MeV at 95%CL. They assume a three-body $\gamma q \overline{q}$ distribution and use $E(\gamma) >$ 10 GeV.

$\Gamma(e^+ e^- \gamma)/\Gamma_{\text{total}}$ — Γ_{35}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<5.2 \times 10^{-4}$	95	[97] ACTON	91B	OPAL	E^{ee}_{cm}= 91.2 GeV

[97] ACTON 91B looked for isolated photons with $E>2\%$ of beam energy ($>$ 0.9 GeV).

$\Gamma(\mu^+ \mu^- \gamma)/\Gamma_{\text{total}}$ — Γ_{36}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<5.6 \times 10^{-4}$	95	[98] ACTON	91B	OPAL	E^{ee}_{cm}= 91.2 GeV

[98] ACTON 91B looked for isolated photons with $E>2\%$ of beam energy ($>$ 0.9 GeV).

$\Gamma(\tau^+ \tau^- \gamma)/\Gamma_{\text{total}}$ — Γ_{37}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<7.3 \times 10^{-4}$	95	[99] ACTON	91B	OPAL	E^{ee}_{cm}= 91.2 GeV

[99] ACTON 91B looked for isolated photons with $E>2\%$ of beam energy ($>$ 0.9 GeV).

$\Gamma(\ell^+ \ell^- \gamma\gamma)/\Gamma_{\text{total}}$ — Γ_{38}/Γ

The value is the sum over $\ell = e, \mu, \tau$.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<6.8 \times 10^{-6}$	95	[100] ACTON	93E	OPAL	E^{ee}_{cm}= 88–94 GeV

[100] For $m_{\gamma\gamma} = 60 \pm 5$ GeV.

$\Gamma(q\overline{q}\gamma\gamma)/\Gamma_{\text{total}}$ — Γ_{39}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<5.5 \times 10^{-6}$	95	[101] ACTON	93E	OPAL	E^{ee}_{cm}= 88–94 GeV

[101] For $m_{\gamma\gamma} = 60 \pm 5$ GeV.

$\Gamma(\nu\overline{\nu}\gamma\gamma)/\Gamma_{\text{total}}$ — Γ_{40}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<3.1 \times 10^{-6}$	95	[102] ACTON	93E	OPAL	E^{ee}_{cm}= 88–94 GeV

[102] For $m_{\gamma\gamma} = 60 \pm 5$ GeV.

$\Gamma(e^{\pm}\mu^{\mp})/\Gamma(e^{+}e^{-})$ — Γ_{41}/Γ_{1}

Test of lepton family number conservation. The value is for the sum of the charge states indicated.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.07	90	ALBAJAR	89	UA1	$E^{p\overline{p}}_{\rm cm}$= 546,630 GeV

$\Gamma(e^{\pm}\mu^{\mp})/\Gamma_{\rm total}$ — Γ_{41}/Γ

Test of lepton family number conservation. The value is for the sum of the charge states indicated.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<2.5 \times 10^{-6}$	95	ABREU	97C	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
$\mathbf{<1.7 \times 10^{-6}}$	95	AKERS	95W	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
$<0.6 \times 10^{-5}$	95	ADRIANI	93I	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
$<2.6 \times 10^{-5}$	95	DECAMP	92	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV

$\Gamma(e^{\pm}\tau^{\mp})/\Gamma_{\rm total}$ — Γ_{42}/Γ

Test of lepton family number conservation. The value is for the sum of the charge states indicated.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<2.2 \times 10^{-5}$	95	ABREU	97C	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
$\mathbf{<9.8 \times 10^{-6}}$	95	AKERS	95W	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
$<1.3 \times 10^{-5}$	95	ADRIANI	93I	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
$<1.2 \times 10^{-4}$	95	DECAMP	92	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV

$\Gamma(\mu^{\pm}\tau^{\mp})/\Gamma_{\rm total}$ — Γ_{43}/Γ

Test of lepton family number conservation. The value is for the sum of the charge states indicated.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$\mathbf{<1.2 \times 10^{-5}}$	95	ABREU	97C	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
$<1.7 \times 10^{-5}$	95	AKERS	95W	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
$<1.9 \times 10^{-5}$	95	ADRIANI	93I	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
$<1.0 \times 10^{-4}$	95	DECAMP	92	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV