Z $J = 1$

THE Z BOSON

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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;
- Z anomalous couplings.

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

The standard 'lineshape' parameters of the Z are determined from an analysis of the production cross sections of these final states in e^+e^- collisions. The $Z \rightarrow \nu\overline{\nu}(\gamma)$ 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 high-resolution detectors 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 was run at energy points on and around the Z mass (88–94 GeV) 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 (~25 %) initial-state radiation (ISR) effects are taken into account by convoluting the analytic expressions over a 'Radiator Function' [1–5] $H(s,s')$. Thus for the process $e^+e^- \to f\overline{f}$:

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

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

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

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

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

where Q_f is the charge of the fermion, $N^f_c = 3(1)$ for quark (lepton) and $\mathcal{G}^f_V$ 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. This fixing of $\sigma^0_{\gamma Z}$ leads to a tighter constraint on M_Z and consequently a smaller error on its fitted value.

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 [9]: $\alpha(s) = \alpha/(1-\Delta\alpha)$. 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 $\mathcal{G}_V$ and $\mathcal{G}_A$ (or alternatively the effective parameters of the $\star$ scheme of Kennedy and Lynn [10]).

$\mathcal{G}^f_V$ and $\mathcal{G}^f_A$ are complex numbers with a small imaginary part. As experimental data does not allow simultaneous extraction of both real and imaginary parts of the effective couplings, the convention $g^f_A = {\rm Re}(\mathcal{G}^f_A)$ and $g^f_V = {\rm Re}(\mathcal{G}^f_V)$ is used and the imaginary parts are added in the fitting code [4].

Defining

$$A_f = 2\frac{g^f_V \cdot g^f_A}{(g^f_V)^2 + (g^f_A)^2} \tag{6}$$

the lowest-order expressions for the various lepton-related asymmetries on the Z pole are [6–8] $A^{(0,\ell)}_{FB} = (3/4)A_eA_f$, $P(\tau) = -A_\tau$, $P(\tau)^{fb} = -(3/4)A_e$, $A_{LR} = A_e$. 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.

The definition of the partial decay width of the Z to $f\overline{f}$ includes the effects of QED and QCD final state corrections as well as the contribution due to the imaginary parts of the couplings:

$$\Gamma(f\overline{f}) = \frac{G_F M_Z^3}{6\sqrt{2}\pi}\ N_c^f(\left|\mathcal{G}_A^f\right|^2 R_A^f + \left|\mathcal{G}_V^f\right|^2 R_V^f) + \Delta_{ew/\mathrm{QCD}} \quad (7)$$

where R_V^f and R_A^f are radiator factors to account for final state QED and QCD corrections as well as effects due to nonzero fermion masses, and $\Delta_{ew/\mathrm{QCD}}$ represents the non-factorizable electroweak/QCD corrections.

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 [11–14]

$$\overline{s} = \overline{M}_Z^2 - i\overline{M}_Z\overline{\Gamma}_Z \quad (8)$$

leading to the relations

$$\begin{aligned}\overline{M}_Z &= M_Z/\sqrt{1+\Gamma_Z^2/M_Z^2} \\ &\approx M_Z\ - 34.1\ \mathrm{MeV} \quad (9)\\ \overline{\Gamma}_Z &= \Gamma_Z/\sqrt{1+\Gamma_Z^2/M_Z^2} \\ &\approx \Gamma_Z\ - 0.9\ \mathrm{MeV}\ . \quad (10)\end{aligned}$$

Some authors [15] choose to define the Z mass and width via

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

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 00Q 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 [16] or TOPAZ0 [17] with the measured value of M_{top}, and $M_{\text{Higgs}} = 150$ 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} (100–1000 GeV). These errors are propagated into the analysis by including them in the systematic error on the e^+e^- final state. As these errors are common to the four LEP experiments, this is taken into account when performing the LEP average.

Errors due to uncertainty in LEP energy determination [18–23]

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.*

Precise energy calibration was done outside normal data taking using the resonant depolarization technique. Run-time energies were determined every 10 minutes by measuring the relevant machine parameters and using a model which takes into account all the known effects, including leakage currents produced by trains in the Geneva area and the tidal effects due to gravitational forces of the Sun and the Moon. The LEP Energy Working Group has provided a covariance matrix from the determination of LEP energies for the different running periods during 1993–1995 [18].

Choice of fit parameters

The LEP Collaborations have chosen the following primary set of parameters for fitting: M_Z, Γ_Z, σ^0_{hadron}, $R(\text{lepton})$, $A^{(0,\ell)}_{FB}$, where $R(\text{lepton}) = \Gamma(\text{hadrons})/\Gamma(\text{lepton})$, $\sigma^0_{\text{hadron}} = 12\pi\Gamma(e^+e^-)\Gamma(\text{hadrons})/M^2_Z\Gamma^2_Z$. 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, $\sigma^0_{\rm hadron}$, $R(e)$, $R(\mu)$, $R(\tau)$, $A_{FB}^{(0,e)}$, $A_{FB}^{(0,\mu)}$, $A_{FB}^{(0,\tau)}$. Assumption of lepton universality leads to a **five-parameter fit** determining M_Z, Γ_Z, $\sigma^0_{\rm hadron}$, $R(\text{lepton})$, $A_{FB}^{(0,\ell)}$.

Combining results from LEP and SLC experiments

With steady increase in statistics over the years and improved understanding of the common systematic errors between LEP experiments, the procedures for combining results have evolved continuously [24]. The Line Shape Sub-group of the LEP Electroweak Working Group investigated the effects of these common errors and devised a combination procedure for the precise determination of the Z parameters from LEP experiments [25]. Using these procedures this note also gives the results after combining the final parameter sets from the four experiments and these are the results quoted as the fit results in the Z listings below. Transformation of variables leads to values of derived parameters like partial decay widths and branching ratios to hadrons and leptons. Finally, transforming the LEP combined nine parameter set to (M_Z, Γ_Z, $\sigma^\circ_{\rm hadron}$, g^f_A, g^f_V, $f = e, \mu, \tau$) using the average values of lepton asymmetry parameters (A_e, A_μ, A_τ) as constraints, leads to the best fitted values of the vector and axial-vector couplings (g_V, g_A) of the charged leptons to the Z.

Brief remarks on the handling of common errors and their magnitudes are given below. The identified common errors are those coming from

(a) LEP energy calibration uncertainties, and

(b) the theoretical uncertainties in (i) the luminosity determination using small angle Bhabha scattering, (ii) estimating the non-s channel contribution to large angle Bhabha scattering, (iii) the calculation of QED radiative effects, and (iv) the parametrization of the cross section in terms of the parameter set used.

Common LEP energy errors

All the collaborations incorporate in their fit the full LEP energy error matrix as provided by the LEP energy group for their intersection region [18]. The effect of these errors is separated out from that of other errors by carrying out fits with energy errors scaled up and down by $\sim 10\%$ and redoing the fits. From the observed changes in the overall error matrix the covariance matrix of the common energy errors is determined. Common LEP energy errors lead to uncertainties on M_Z, Γ_Z, and $\sigma^{\circ}_{\text{hadron}}$ of 1.7, 1.2 MeV, and 0.011 nb respectively.

Common luminosity errors

BHLUMI 4.04 [26] is used by all LEP collaborations for small angle Bhabha scattering leading to a common uncertainty in their measured cross sections of 0.061% [27]. BHLUMI does not include a correction for production of light fermion pairs. OPAL explicitly correct for this effect and reduce their luminosity uncertainty to 0.054% which is taken fully correlated with the other experiments. The other three experiments among themselves have a common uncertainty of 0.061%.

Common non-s channel uncertainties

The same standard model programs ALIBABA [16] and TOPAZ0 [17] are used to calculate the non-s channel contribution to the large angle Bhabha scattering [28]. As this contribution is a function of the Z mass, which itself is a variable in the fit, it is parametrized as a function of M_Z by each collaboration to properly track this contribution as M_Z varies in the fit. The common errors on R_e and $A_{FB}^{0,e}$ are 0.024 and 0.0014 respectively and are correlated between them.

Common theoretical uncertainties: QED

There are large initial state photon and fermion pair radiation effects near the Z resonance for which the best currently available evaluations include contributions up to $\mathcal{O}(\alpha^3)$. To estimate the remaining uncertainties different schemes are incorporated in the standard model programs ZFITTER [5], TOPAZ0 [17] and MIZA [29]. Comparing the different options leads to error estimates of 0.3 and 0.2 MeV on M_Z and Γ_Z respectively and of 0.02% on $\sigma^{\circ}_{\text{hadron}}$.

Common theoretical uncertainties: parametrization of lineshape and asymmetries

To estimate uncertainties arising from ambiguities in the model-independent parametrization of the differential cross-section near the Z resonance, results from TOPAZ0 and ZFITTER were compared by using ZFITTER to fit the cross sections and asymmetries calculated using TOPAZ0. The resulting uncertainties on M_Z, Γ_Z, $\sigma^{\circ}_{\text{hadron}}$, R(lepton) and $A_{FB}^{0,\ell}$ are 0.1 MeV, 0.1 MeV, 0.001 nb, 0.004, and 0.0001 respectively.

Thus the overall theoretical errors on M_Z, Γ_Z, $\sigma^{\circ}_{\text{hadron}}$ are 0.3 MeV, 0.2 MeV, and 0.008 nb respectively; on each R(lepton) is 0.004 and on each $A_{FB}^{0,\ell}$ is 0.0001. Within the set of three R(lepton)'s and the set of three $A_{FB}^{0,\ell}$'s the respective errors are fully correlated.

All the theory related errors mentioned above utilize standard model programs which need the Higgs mass and running electromagnetic coupling constant as inputs; uncertainties on these inputs will also lead to common errors. All LEP collaborations used the same set of inputs for standard model calculations: $M_Z = 91.187$ GeV, the

Fermi constant $G_F = (1.16637 \pm 0.00001) \times 10^{-5}$ GeV^{-2} [30], $\alpha^{(5)}(M_Z) = 1/128.877 \pm 0.090$ [31], $\alpha_s(M_Z) = 0.119$ [32], $M_{\rm top} = 174.3 \pm 5.1$ GeV [32] and $M_{\rm Higgs} = 150$ GeV. The only observable effect, on M_Z, is due to the variation of $M_{\rm Higgs}$ between 100–1000 GeV (due to the variation of the γ/Z interference term which is taken from the standard model): M_Z changes by +0.23 MeV per unit change in $\log_{10} M_{\rm Higgs}/{\rm GeV}$, which is not an error but a correction to be applied once $M_{\rm Higgs}$ is determined. The effect is much smaller than the error on M_Z ($\pm$2.1 MeV).

Methodology of combining the LEP experimental results

The LEP experimental results actually used for combination are slightly modified from those published by the experiments (which are given in the Listings below). This has been done in order to facilitate the procedure by making the inputs more consistent. These modified results are given explicitly in Ref. 25. The main differences compared to the published results are

(a) consistent use of ZFITTER 6.23 and TOPAZ0. The published ALEPH results used ZFITTER 6.10. (b) use of the combined energy error matrix which makes a difference of 0.1 MeV on the M_Z and Γ_Z for L3 only as at that intersection the RF modeling uncertainties are the largest.

Thus, nine-parameter sets from all four experiments with their covariance matrices are used together with all the common errors correlations. A grand covariance matrix, V, is constructed and a combined nine-parameter set is obtained by minimizing $\chi^2 = \mathit{\Delta}^T\, V^{-1}\, \mathit{\Delta}$, where $\mathit{\Delta}$ is the vector of residuals of the combined parameter set to the results of individual experiments.

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, $\text{B}(b \to \ell)$, $\text{B}(b \to c \to \ell^+)$, and $\text{B}(c \to \ell)$, 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 do not appear in the listing below. However, for completeness, we will report at the end of this minireview their values as obtained fitting the data contained in the Z section. All these quantities 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 [33] a procedure for combining the measurements taking into account known sources of correlation. The combining procedure determines twelve 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, $\mathrm{B}(b \to \ell)$, $\mathrm{B}(b \to c \to \ell^+)$, $\mathrm{B}(c \to \ell)$, $\overline{\chi}$, $f(D^+)$, $f(D_s)$, $f(c_{\text{baryon}})$ and $P(c \to D^{*+}) \times \mathrm{B}(D^{*+} \to \pi^+ D^0)$, to take into account their correlations with the electroweak parameters. Before the fit both the peak and off-peak asymmetries are translated to the common energy $\sqrt{s} = 91.26$ GeV using the predicted dependence from ZFITTER [5].

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_{had} hadronic Z decays one has:

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

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

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 essentially grouped in the following categories:

- 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;
- Analyses with $D/D^{*\pm}$ to measure R_c. These measurements make use of several different tagging

techniques (inclusive/exclusive double tag, exclusive double tag, reconstruction of all weakly decaying charmed states) and no assumptions are made on the energy dependence of charm fragmentation;

- Lepton fits which use hadronic events with one or more leptons in the final state to measure $A_{FB}^{b\overline{b}}$ and $A_{FB}^{c\overline{c}}$. Each analysis usually gives several other electroweak parameters. The dominant sources of systematics are due to lepton identification, to other semileptonic branching ratios and to the modeling of the semileptonic decay;
- 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 $A_{FB}^{c\overline{c}}$ 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, kaon, D/D^*, and vertex mass). 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:

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

  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 $A_{FB}^{c\overline{c}}$ and $A_{FB}^{b\overline{b}}$ are corrected for the energy shift from 91.26 GeV to M_Z and for QED (initial state radiation), γ exchange, and γZ interference effects to obtain the corresponding pole asymmetries $A_{FB}^{0,c}$ and $A_{FB}^{0,b}$.

This averaging procedure, using the twelve parameters described above and applied to the data contained in the Z particle listing below, gives the following results:

$$
\begin{aligned}
R_b^0 &= 0.21644 \pm 0.00075 \\
R_c^0 &= 0.1671 \pm 0.0048 \\
A_{FB}^{0,b} &= 0.1003 \pm 0.0022 \\
A_{FB}^{0,c} &= 0.0701 \pm 0.0045 \\
B(b \to \ell) &= 0.1056 \pm 0.0026 \\
\mathrm{B}(b \to c \to \ell^+) &= 0.0807 \pm 0.0034 \\
B(c \to \ell) &= 0.0990 \pm 0.0037 \\
\overline{\chi} &= 0.1177 \pm 0.0055 \\
f(D^+) &= 0.239 \pm 0.016 \\
f(D_s) &= 0.116 \pm 0.025 \\
f(c_{\mathrm{baryon}}) &= 0.084 \pm 0.023 \\
P(c \to D^{*+}) \times \mathrm{B}(D^{*+} \to \pi^+ D^0) &= 0.1657 \pm 0.0057
\end{aligned}
$$

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Z MASS

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the "Note on the Z boson"). 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. This set is believed to be most free of correlations.

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 00Q and ACKERSTAFF 97C for a detailed investigation of both these issues.

VALUE (GeV)	EVTS	DOCUMENT ID		TECN	COMMENT
91.1876±0.0021 OUR FIT					
91.1852±0.0030	4.57M	[1] ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
91.1863±0.0028	4.08M	[2] ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
91.1898±0.0031	3.96M	[3] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
91.1885±0.0031	4.57M	[4] BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
91.1875±0.0039	3.97M	[5] ACCIARRI	00Q	L3	E^{ee}_{cm}= LEP1 + 130–189 GeV
91.185 ±0.010		[6] ACKERSTAFF	97C	OPAL	E^{ee}_{cm}= LEP1 + 130–136 GeV + 161 GeV
91.151 ±0.008		[7] MIYABAYASHI	95	TOPZ	E^{ee}_{cm}= 57.8 GeV
91.187 ±0.007 ±0.006	1.16M	[8] ABREU	94	DLPH	Repl. by ABREU 00F
91.195 ±0.006 ±0.007	1.19M	[8] ACCIARRI	94	L3	Repl. by ACCIARRI 00C
91.182 ±0.007 ±0.006	1.33M	[8] AKERS	94	OPAL	Repl. by ABBIENDI 01A

91.187	±0.007	±0.006	1.27M	[8] BUSKULIC	94	ALEP	Repl. by BARATE 00C
91.74	±0.28	±0.93	156	[9] ALITTI	92B	UA2	$E^{p\overline{p}}_{cm}$= 630 GeV
90.9	±0.3	±0.2	188	[10] ABE	89C	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
91.14	±0.12		480	[11] ABRAMS	89B	MRK2	E^{ee}_{cm}= 89–93 GeV
93.1	±1.0	±3.0	24	[12] ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV

[1] ABBIENDI 01A error includes approximately 2.3 MeV due to statistics and 1.8 MeV due to LEP energy uncertainty.

[2] The error includes 1.6 MeV due to LEP energy uncertainty.

[3] The error includes 1.8 MeV due to LEP energy uncertainty.

[4] BARATE 00C error includes approximately 2.4 MeV due to statistics, 0.2 MeV due to experimental systematics, and 1.7 MeV due to LEP energy uncertainty.

[5] ACCIARRI 00Q interpret the s-dependence of the cross sections and lepton forward-backward asymmetries in the framework of the S-matrix formalism. They fit to their cross section and asymmetry data at high energies, using the results of S-matrix fits to Z-peak data (ACCIARRI 00C) as constraints. The 130–189 GeV data constrains the γ/Z interference term. 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 ±2.3 MeV due to the uncertainty on the γZ interference.

[6] 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.

[7] 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.

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

[9] 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.

[10] First error of ABE 89 is combination of statistical and systematic contributions; second is mass scale uncertainty.

[11] ABRAMS 89B uncertainty includes 35 MeV due to the absolute energy measurement.

[12] ALBAJAR 89 result is from a total sample of 33 $Z \to e^+e^-$ events.

Z WIDTH

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the "Note on the Z boson").

VALUE (GeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2.4952±0.0023 OUR FIT					
2.4948±0.0041	4.57M	[13] ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
2.4876±0.0041	4.08M	[14] ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
2.5024±0.0042	3.96M	[15] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
2.4951±0.0043	4.57M	[16] BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

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

2.5025±0.0041			3.97M	[17] ACCIARRI	00Q	L3	E^{ee}_{cm}= LEP1 + 130–189 GeV
2.50	±0.21	±0.06		[18] ABREU	96R	DLPH	E^{ee}_{cm}= 91.2 GeV
2.483	±0.011	±0.0045	1.16M	[19] ABREU	94	DLPH	Repl. by ABREU 00F
2.494	±0.009	±0.0045	1.19M	[19] ACCIARRI	94	L3	Repl. by ACCIARRI 00C
2.483	±0.011	±0.0045	1.33M	[19] AKERS	94	OPAL	Repl. by ABBIENDI 01A
2.501	±0.011	±0.0045	1.27M	[19] BUSKULIC	94	ALEP	Repl. by BARATE 00C
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	[20] ABRAMS	89B	MRK2	E^{ee}_{cm}= 89–93 GeV
2.7	$^{+1.2}_{-1.0}$	±1.3	24	[21] ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV
2.7	±2.0	±1.0	25	[22] ANSARI	87	UA2	$E^{p\overline{p}}_{cm}$= 546,630 GeV

[13] ABBIENDI 01A error includes approximately 3.6 MeV due to statistics, 1 MeV due to event selection systematics, and 1.3 MeV due to LEP energy uncertainty.

[14] The error includes 1.2 MeV due to LEP energy uncertainty.

[15] The error includes 1.3 MeV due to LEP energy uncertainty.

[16] BARATE 00C error includes approximately 3.8 MeV due to statistics, 0.9 MeV due to experimental systematics, and 1.3 MeV due to LEP energy uncertainty.

[17] ACCIARRI 00Q interpret the s-dependence of the cross sections and lepton forward-backward asymmetries in the framework of the S-matrix formalism. They fit to their cross section and asymmetry data at high energies, using the results of S-matrix fits to Z-peak data (ACCIARRI 00C) as constraints. The 130–189 GeV data constrains the γ/Z interference term. The authors have corrected the measurement for the 0.9 MeV shift with respect to the Breit-Wigner fits.

[18] ABREU 96R obtain this value from a study of the interference between initial and final state radiation in the process $e^+ e^- \rightarrow Z \rightarrow \mu^+ \mu^-$.

[19] The second error of 4.5 MeV is due to a common LEP energy uncertainty.

[20] ABRAMS 89B uncertainty includes 50 MeV due to the miniSAM background subtraction error.

[21] ALBAJAR 89 result is from a total sample of 33 $Z \rightarrow e^+ e^-$ events.

[22] 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 ± 0.19 or $= 2.17^{+0.50}_{-0.37} \pm 0.16$.

Z DECAY MODES

	Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	$e^+ e^-$		(3.363 ±0.004) %	
Γ_2	$\mu^+ \mu^-$		(3.366 ±0.007) %	
Γ_3	$\tau^+ \tau^-$		(3.370 ±0.008) %	
Γ_4	$\ell^+ \ell^-$	[a]	(3.6580±0.0023) %	
Γ_5	invisible		(20.00 ±0.06) %	
Γ_6	hadrons		(69.91 ±0.06) %	
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	$c\overline{c}$		(11.68 ±0.34) %	

Γ_{10}	$b\overline{b}$			(15.13 ± 0.05) %	
Γ_{11}	$b\overline{b}b\overline{b}$			$(3.6 \pm 1.3) \times 10^{-4}$	
Γ_{12}	ggg			< 1.1 %	CL=95%
Γ_{13}	$\pi^0\gamma$			$< 5.2 \times 10^{-5}$	CL=95%
Γ_{14}	$\eta\gamma$			$< 5.1 \times 10^{-5}$	CL=95%
Γ_{15}	$\omega\gamma$			$< 6.5 \times 10^{-4}$	CL=95%
Γ_{16}	$\eta'(958)\gamma$			$< 4.2 \times 10^{-5}$	CL=95%
Γ_{17}	$\gamma\gamma$			$< 5.2 \times 10^{-5}$	CL=95%
Γ_{18}	$\gamma\gamma\gamma$			$< 1.0 \times 10^{-5}$	CL=95%
Γ_{19}	$\pi^{\pm}W^{\mp}$		[b]	$< 7 \times 10^{-5}$	CL=95%
Γ_{20}	$\rho^{\pm}W^{\mp}$		[b]	$< 8.3 \times 10^{-5}$	CL=95%
Γ_{21}	$J/\psi(1S)$X			$(3.51 {}^{+0.23}_{-0.25}) \times 10^{-3}$	S=1.1
Γ_{22}	$\psi(2S)$X			$(1.60 \pm 0.29) \times 10^{-3}$	
Γ_{23}	$\chi_{c1}(1P)$X			$(2.9 \pm 0.7) \times 10^{-3}$	
Γ_{24}	$\chi_{c2}(1P)$X			$< 3.2 \times 10^{-3}$	CL=90%
Γ_{25}	$\Upsilon(1S)$ X $+\Upsilon(2S)$ X $+\Upsilon(3S)$ X			$(1.0 \pm 0.5) \times 10^{-4}$	
Γ_{26}	$\Upsilon(1S)$X			$< 4.4 \times 10^{-5}$	CL=95%
Γ_{27}	$\Upsilon(2S)$X			$< 1.39 \times 10^{-4}$	CL=95%
Γ_{28}	$\Upsilon(3S)$X			$< 9.4 \times 10^{-5}$	CL=95%
Γ_{29}	$(D^0 / \overline{D}^0)$ X			(20.7 ± 2.0) %	
Γ_{30}	$D^{\pm}$X			(12.2 ± 1.7) %	
Γ_{31}	$D^*(2010)^{\pm}$X		[b]	(11.4 ± 1.3) %	
Γ_{32}	BX				
Γ_{33}	B^*X				
Γ_{34}	B^0_sX			seen	
Γ_{35}	B^+_cX			searched for	
Γ_{36}	anomalous $\gamma+$ hadrons		[c]	$< 3.2 \times 10^{-3}$	CL=95%
Γ_{37}	$e^+e^-\gamma$		[c]	$< 5.2 \times 10^{-4}$	CL=95%
Γ_{38}	$\mu^+\mu^-\gamma$		[c]	$< 5.6 \times 10^{-4}$	CL=95%
Γ_{39}	$\tau^+\tau^-\gamma$		[c]	$< 7.3 \times 10^{-4}$	CL=95%
Γ_{40}	$\ell^+\ell^-\gamma\gamma$		[d]	$< 6.8 \times 10^{-6}$	CL=95%
Γ_{41}	$q\overline{q}\gamma\gamma$		[d]	$< 5.5 \times 10^{-6}$	CL=95%
Γ_{42}	$\nu\overline{\nu}\gamma\gamma$		[d]	$< 3.1 \times 10^{-6}$	CL=95%
Γ_{43}	$e^{\pm}\mu^{\mp}$	*LF*	[b]	$< 1.7 \times 10^{-6}$	CL=95%
Γ_{44}	$e^{\pm}\tau^{\mp}$	*LF*	[b]	$< 9.8 \times 10^{-6}$	CL=95%
Γ_{45}	$\mu^{\pm}\tau^{\mp}$	*LF*	[b]	$< 1.2 \times 10^{-5}$	CL=95%
Γ_{46}	pe	*L,B*		$< 1.8 \times 10^{-6}$	CL=95%
Γ_{47}	$p\mu$	*L,B*		$< 1.8 \times 10^{-6}$	CL=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 or 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*
83.91±0.12 OUR FIT					
83.66±0.20	137.0K	ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
83.54±0.27	117.8k	ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
84.16±0.22	124.4k	ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
83.88±0.19		BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV
82.89±1.20±0.89		[23] ABE	95J	SLD	E^{ee}_{cm}= 91.31 GeV

[23] 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*
83.99±0.18 OUR FIT					
84.03±0.30	182.8K	ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
84.48±0.40	157.6k	ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
83.95±0.44	113.4k	ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
84.02±0.28		BARATE	00C	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*
84.08±0.22 OUR FIT					
83.94±0.41	151.5K	ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
83.71±0.58	104.0k	ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
84.23±0.58	103.0k	ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
84.38±0.31		BARATE	00C	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
83.984±0.086 OUR FIT					
83.82 ±0.15	471.3K	ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
83.85 ±0.17	379.4k	ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
84.14 ±0.17	340.8k	ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
84.02 ±0.15	500k	BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

Γ(invisible) Γ_5

We use only direct measurements of the invisible partial width using the single photon channel to obtain the average value quoted below. OUR 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
499.0± 1.5 OUR FIT					
503 ±16 OUR AVERAGE Error includes scale factor of 1.2.					
498 ±12 ±12	1791	ACCIARRI	98G	L3	E^{ee}_{cm}= 88–94 GeV
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
• • • We do not use the following data for averages, fits, limits, etc. • • •					
498.1± 2.6		[24] ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
498.1± 3.2		[24] ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
499.1± 2.9		[24] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
499.1± 2.5		[24] BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

[24] This is an indirect determination of Γ(invisible) from a fit to the visible Z decay modes.

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
1744.4±2.0 OUR FIT					
1745.4±3.5	4.10M	ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
1738.1±4.0	3.70M	ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
1751.1±3.8	3.54M	ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
1744.0±3.4	4.07M	BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

Z BRANCHING RATIOS

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the "Note on the Z boson").

Γ(hadrons)/Γ(e^+e^-) Γ_6/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
20.804± 0.050 OUR FIT					
20.902± 0.084	137.0K	[25] ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
20.88 ± 0.12	117.8k	ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
20.816± 0.089	124.4k	ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
20.677± 0.075		[26] BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

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

20.74 ± 0.18	31.4k	ABREU	94	DLPH	Repl. by ABREU 00F
20.96 ± 0.15	38k	ACCIARRI	94	L3	Repl. by ACCIARRI 00C
20.83 ± 0.16	42k	AKERS	94	OPAL	Repl. by ABBIENDI 01A
20.59 ± 0.15	45.8k	BUSKULIC	94	ALEP	Repl. by BARATE 00C
27.0 $^{+11.7}_{-8.8}$	12	[27] ABRAMS	89D	MRK2	E^{ee}_{cm}= 89–93 GeV

[25] ABBIENDI 01A error includes approximately 0.067 due to statistics, 0.040 due to event selection systematics, 0.027 due to the theoretical uncertainty in t-channel prediction, and 0.014 due to LEP energy uncertainty.

[26] BARATE 00C error includes approximately 0.062 due to statistics, 0.033 due to experimental systematics, and 0.026 due to the theoretical uncertainty in t-channel prediction.

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

$\Gamma(\text{hadrons})/\Gamma(\mu^+\mu^-)$ Γ_6/Γ_2

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the "Note on the Z boson").

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
20.785±0.033 OUR FIT					
20.811±0.058	182.8K	[28] ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
20.65 ±0.08	157.6k	ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
20.861±0.097	113.4k	ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
20.799±0.056		[29] BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
20.54 ±0.14	45.6k	ABREU	94	DLPH	Repl. by ABREU 00F
21.02 ±0.16	34k	ACCIARRI	94	L3	Repl. by ACCIARRI 00C
20.78 ±0.11	57k	AKERS	94	OPAL	Repl. by ABBIENDI 01A
20.83 ±0.15	46.4k	BUSKULIC	94	ALEP	Repl. by BARATE 00C
18.9 $^{+7.1}_{-5.3}$	13	[30] ABRAMS	89D	MRK2	E^{ee}_{cm}= 89–93 GeV

[28] ABBIENDI 01A error includes approximately 0.050 due to statistics and 0.027 due to event selection systematics.

[29] BARATE 00C error includes approximately 0.053 due to statistics and 0.021 due to experimental systematics.

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

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

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the "Note on the Z boson").

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
20.764±0.045 OUR FIT					
20.832±0.091	151.5K	[31] ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
20.84 ±0.13	104.0k	ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
20.792±0.133	103.0k	ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
20.707±0.062		[32] BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

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

20.68	±0.18	25k	ABREU	94	DLPH	Repl. by ABREU 00F
20.80	±0.20	25k	ACCIARRI	94	L3	Repl. by ACCIARRI 00C
21.01	±0.15	47k	AKERS	94	OPAL	Repl. by ABBIENDI 01A
20.70	±0.16	45.1k	BUSKULIC	94	ALEP	Repl. by BARATE 00C
15.2	$^{+4.8}_{-3.9}$	21	[33] ABRAMS	89D	MRK2	E^{ee}_{cm}= 89–93 GeV

[31] ABBIENDI 01A error includes approximately 0.055 due to statistics and 0.071 due to event selection systematics.

[32] BARATE 00C error includes approximately 0.054 due to statistics and 0.033 due to experimental systematics.

[33] 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
20.767±0.025 OUR FIT					
20.823±0.044	471.3K	[34] ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
20.730±0.060	379.4k	ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
20.810±0.060	340.8k	ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
20.725±0.039	500k	[35] BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
20.62 ±0.10	102k	ABREU	94	DLPH	Repl. by ABREU 00F
20.93 ±0.10	97k	ACCIARRI	94	L3	Repl. by ACCIARRI 00C
20.835±0.086	146k	AKERS	94	OPAL	Repl. by ABBIENDI 01A
20.69 ±0.09	137.3k	BUSKULIC	94	ALEP	Repl. by BARATE 00C
18.9 $^{+3.6}_{-3.2}$	46	ABRAMS	89B	MRK2	E^{ee}_{cm}= 89–93 GeV

[34] ABBIENDI 01A error includes approximately 0.034 due to statistics and 0.027 due to event selection systematics.

[35] BARATE 00C error includes approximately 0.033 due to statistics, 0.020 due to experimental systematics, and 0.005 due to the theoretical uncertainty in t-channel prediction.

$\Gamma(\text{hadrons})/\Gamma_{\text{total}}$ — 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 (%)	DOCUMENT ID
69.911±0.056 OUR FIT	

$\Gamma(e^+e^-)/\Gamma_{\text{total}}$ — 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 (%)	DOCUMENT ID
3.3632±0.0042 OUR FIT	

$\Gamma(\mu^+\mu^-)/\Gamma_{total}$ — 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 (%)	*DOCUMENT ID*
3.3662±0.0066 OUR FIT	

$\Gamma(\tau^+\tau^-)/\Gamma_{total}$ — 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 (%)	*DOCUMENT ID*
3.3696±0.0083 OUR FIT	

$\Gamma(\ell^+\ell^-)/\Gamma_{total}$ — 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 (%)	*DOCUMENT ID*
3.3658±0.0023 OUR FIT	

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

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

VALUE (%)	*DOCUMENT ID*
20.000±0.055 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*
1.0009±0.0028 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*
1.0019±0.0032 OUR FIT	

$\Gamma((u\overline{u}+c\overline{c})/2)/\Gamma(\text{hadrons})$ — 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	[36] ACKERSTAFF	97T	OPAL	E^{ee}_{cm}= 88–94 GeV
$0.137^{+0.038}_{-0.054}$	[37] ABREU	95X	DLPH	E^{ee}_{cm}= 88–94 GeV
0.139±0.026	[38] ACTON	93F	OPAL	E^{ee}_{cm}= 88–94 GeV
0.137±0.033	[39] ADRIANI	93	L3	E^{ee}_{cm}= 91.2 GeV

[36] 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.

[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 $C_{2/3} = 0.91^{+0.25}_{-0.36}$ 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 $M_Z = 91.181 \pm 0.022$ 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 $(3C_{1/3} + 2C_{2/3}) = 6.720 \pm 0.076$.

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

This quantity is the branching ratio of $Z \to$ "down-type" quarks to $Z \to$ hadrons. Except ACKERSTAFF 97T the values of $Z \to$ "up-type" and $Z \to$ "down-type" branchings are extracted from measurements of Γ(hadrons), and $\Gamma(Z \to \gamma +$ 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	[40] ACKERSTAFF	97T	OPAL	E^{ee}_{cm}= 88–94 GeV
$0.243^{+0.036}_{-0.026}$	[41] ABREU	95X	DLPH	E^{ee}_{cm}= 88–94 GeV
0.241±0.017	[42] ACTON	93F	OPAL	E^{ee}_{cm}= 88–94 GeV
0.243±0.022	[43] ADRIANI	93	L3	E^{ee}_{cm}= 91.2 GeV

[40] 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.

[41] 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 $(3C_{1/3} + 2C_{2/3}) = 6.66 \pm 0.05$.

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

[43] 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 $C_{1/3} = 1.63 \pm 0.15$ 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, we obtain $R_c = 0.1676 \pm 0.0068$.

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 February 2001) yields $R_c = 0.1709 \pm 0.0034$. The Standard Model predicts $R_c = 0.1723$ for $m_t =$ 174.3 GeV and $M_H = 150$ GeV.

VALUE	DOCUMENT ID		TECN	COMMENT
0.1671±0.0048 OUR FIT				
0.1665±0.0051±0.0081	[44] ABREU	00	DLPH	E^{ee}_{cm}= 88–94 GeV
0.1698±0.0069	[45] BARATE	00B	ALEP	E^{ee}_{cm}= 88–94 GeV
0.180 ±0.011 ±0.013	[46] ACKERSTAFF	98E	OPAL	E^{ee}_{cm}= 88–94 GeV
0.167 ±0.011 ±0.012	[47] ALEXANDER	96R	OPAL	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.1675±0.0062±0.0103	[48] BARATE	98T	ALEP	Repl. by BARATE 00B
0.1689±0.0095±0.0068	[49] BARATE	98T	ALEP	Repl. by BARATE 00B
0.1623±0.0085±0.0209	[50] ABREU	95D	DLPH	E^{ee}_{cm}= 88–94 GeV
0.142 ±0.008 ±0.014	[51] AKERS	95O	OPAL	Repl. by ACKERSTAFF 98E
0.165 ±0.005 ±0.020	[52] BUSKULIC	94G	ALEP	Repl. by BARATE 00B

[44] ABREU 00 obtain this result properly combining the measurement from the D^{*+} production rate ($R_c = 0.1610 \pm 0.0104 \pm 0.0077 \pm 0.0043$ (BR)) with that from the overall charm counting ($R_c = 0.1692 \pm 0.0047 \pm 0.0063 \pm 0.0074$ (BR)) in $c\overline{c}$ events. The systematic error includes an uncertainty of ± 0.0054 due to the uncertainty on the charmed hadron branching fractions.

[45] BARATE 00B use exclusive decay modes to independently determine the quantities $R_c \times$f($c \to$ X), X=D^0, D^+, D^+_s, and Λ_c. Estimating $R_c \times$f($c \to \Xi_c / \Omega_c$)= 0.0034, they simply sum over all the charm decays to obtain $R_c = 0.1738 \pm 0.0047 \pm 0.0088 \pm 0.0075$(BR). This is combined with all previous ALEPH measurements (BARATE 98T and BUSKULIC 94G, $R_c = 0.1681 \pm 0.0054 \pm 0.0062$) to obtain the quoted value.

[46] ACKERSTAFF 98E use an inclusive/exclusive double tag. In one jet $D^{*\pm}$ mesons are exclusively reconstructed 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.

[47] 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.

[48] BARATE 98T perform a simultaneous fit to the p and p_T spectra of electrons from hadronic Z decays. The semileptonic branching ratio B($c \to e$) is taken as 0.098 ± 0.005 and the systematic error includes an uncertainty of ± 0.0084 due to this.

[49] BARATE 98T obtain this result combining two double-tagging techniques. Searching for a D meson in each hemisphere by full reconstruction in an exclusive decay mode gives $R_c = 0.173 \pm 0.014 \pm 0.0009$. The same tag in combination with inclusive identification using the slow pion from the $D^{*+} \to D^0 \pi^+$ decay in the opposite hemisphere yields $R_c = 0.166 \pm 0.012 \pm 0.009$. The R_b dependence is given by $R_c = 0.1689 – 0.023 \times (R_b – 0.2159)$. The three measurements of BARATE 98T are combined with BUSKULIC 94G to give the average $R_c = 0.1681 \pm 0.0054 \pm 0.0062$.

[50] 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.

[51] AKERS 95O use the presence of a $D^{*\pm}$ to tag $Z \to c\overline{c}$ with $D^* \to D^0 \pi$ and $D^0 \to K\pi$. They measure $P_c * \Gamma(c\overline{c})/\Gamma$(hadrons) to be $(1.006 \pm 0.055 \pm 0.061) \times 10^{-3}$, where P_c is the product branching ratio B($c \to D^*$)B($D^* \to D^0 \pi$)B($D^0 \to K\pi$). 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.

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

$R_b = \Gamma(b\overline{b})/\Gamma(\text{hadrons})$ 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. For R_c = 0.1671 (as given by OUR FIT above), we obtain R_b = 0.21625 ± 0.00077. For an expected Standard Model value of R_c = 0.1723, our weighted average gives R_b = 0.21614 ± 0.00077.

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 February 2001) yields R_b = 0.21653 ± 0.00069. The Standard Model predicts R_b = 0.21581 for m_t = 174.3 GeV and M_H = 150 GeV.

VALUE	DOCUMENT ID		TECN	COMMENT
0.21644±0.00075 OUR FIT				
0.2174 ±0.0015 ±0.0028	[53] ACCIARRI	00	L3	E^{ee}_{cm}= 89–93 GeV
0.2178 ±0.0011 ±0.0013	[54] ABBIENDI	99B	OPAL	E^{ee}_{cm}= 88–94 GeV
0.21634±0.00067±0.00060	[55] ABREU	99B	DLPH	E^{ee}_{cm}= 88–94 GeV
0.2142 ±0.0034 ±0.0015	[56] ABE	98D	SLD	E^{ee}_{cm}= 91.2 GeV
0.2159 ±0.0009 ±0.0011	[57] BARATE	97F	ALEP	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.2175 ±0.0014 ±0.0017	[58] ACKERSTAFF	97K	OPAL	Repl. by ABBIENDI 99B
0.2167 ±0.0011 ±0.0013	[59] BARATE	97E	ALEP	E^{ee}_{cm}= 88–94 GeV
0.229 ±0.011	[60] ABE	96E	SLD	Repl. by ABE 98D
0.2216 ±0.0016 ±0.0021	[61] ABREU	96	DLPH	Repl. by ABREU 99B
0.2145 ±0.0089 ±0.0067	[62] ABREU	95D	DLPH	E^{ee}_{cm}= 88–94 GeV
0.219 ±0.006 ±0.005	[63] BUSKULIC	94G	ALEP	E^{ee}_{cm}= 88–94 GeV
0.251 ±0.049 ±0.030	[64] JACOBSEN	91	MRK2	E^{ee}_{cm}= 91 GeV

[53] ACCIARRI 00 obtain this result using a double-tagging technique, with a high p_T lepton tag and an impact parameter tag in opposite hemispheres.

[54] ABBIENDI 99B tag $Z \to b\overline{b}$ decays using leptons and/or separated decay vertices. The b-tagging efficiency is measured directly from the data using a double-tagging technique.

[55] ABREU 99B obtain this result combining in a multivariate analysis several tagging methods (impact parameter and secondary vertex reconstruction, complemented by event shape variables). For R_c different from its Standard Model value of 0.172, R_b varies as $-0.024 \times (R_c - 0.172)$.

[56] 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.

[57] BARATE 97F combine the lifetime-mass hemisphere tag (BARATE 97E) with event shape information and lepton tag to identify $Z \to b\overline{b}$ 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 $-0.019 \times (R_c - 0.172)$.

[58] 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.

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

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

[61] 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 $-0.087 \cdot \Delta R_c$.

[62] 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.

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

[64] 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).

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

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
5.2±1.9 OUR AVERAGE				
$3.6 \pm 1.7 \pm 2.7$	[65] ABBIENDI	01G	OPAL	E^{ee}_{cm}= 88–94 GeV
$6.0 \pm 1.9 \pm 1.4$	[66] ABREU	99U	DLPH	E^{ee}_{cm}= 88–94 GeV

[65] ABBIENDI 01G use a sample of four-jet events from hadronic Z decays. To enhance the $b\overline{b}b\overline{b}$ signal, at least three of the four jets are required to have a significantly detached secondary vertex.

[66] ABREU 99U force hadronic Z decays into 3 jets to use all the available phase space and require a b tag for every jet. This decay mode includes primary and secondary $4b$ production, *e.g*, from gluon splitting to $b\overline{b}$.

$\Gamma(ggg)/\Gamma(\text{hadrons})$ — Γ_{12}/Γ_6

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$\mathbf{<1.6 \times 10^{-2}}$	95	[67] ABREU	96S	DLPH	E^{ee}_{cm}= 88–94 GeV

[67] 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_{13}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$\mathbf{<5.2 \times 10^{-5}}$	95	[68] 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

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

$\Gamma(\eta\gamma)/\Gamma_{total}$ — Γ_{14}/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

$\Gamma(\omega\gamma)/\Gamma_{total}$ — Γ_{15}/Γ

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

$\Gamma(\eta'(958)\gamma)/\Gamma_{total}$ — Γ_{16}/Γ

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

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

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

$\Gamma(\gamma\gamma\gamma)/\Gamma_{total}$ — Γ_{18}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<1.0 \times 10^{-5}$	95	[70] ACCIARRI	95C	L3	E^{ee}_{cm}= 88–94 GeV
$<1.7 \times 10^{-5}$	95	[70] ABREU	94B	DLPH	E^{ee}_{cm}= 88–94 GeV
$<6.6 \times 10^{-5}$	95	AKRAWY	91F	OPAL	E^{ee}_{cm}= 88–94 GeV

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

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

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

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

$\Gamma(\rho^{\pm} W^{\mp})/\Gamma_{total}$ — Γ_{20}/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_{21}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID	TECN	COMMENT
$3.51^{+0.23}_{-0.25}$ OUR AVERAGE Error includes scale factor of 1.1.				
$3.21\pm0.21^{+0.19}_{-0.28}$	553	[71] ACCIARRI 99F	L3	E^{ee}_{cm}= 88–94 GeV
$3.9\ \pm0.2\ \pm0.3$	511	[72] ALEXANDER 96B	OPAL	E^{ee}_{cm}= 88–94 GeV
$3.73\pm0.39\pm0.36$	153	[73] ABREU 94P	DLPH	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$3.40\pm0.23\pm0.27$	441	[74] ACCIARRI 97J	L3	Repl. by ACCIARRI 99F

[71] ACCIARRI 99F combine $\mu^+\mu^-$ and e^+e^- $J/\psi(1S)$ decay channels. The branching ratio for prompt $J/\psi(1S)$ production is measured to be $(2.1\pm0.6\pm0.4^{+0.4}_{-0.2}(\text{theor.}))\times10^{-4}$.

[72] 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).

[73] 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.

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

$\Gamma(\psi(2S)X)/\Gamma_{total}$ Γ_{22}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID	TECN	COMMENT
1.60±0.29 OUR AVERAGE				
$1.6\ \pm0.5\ \pm0.3$	39	[75] ACCIARRI 97J	L3	E^{ee}_{cm}= 88–94 GeV
$1.6\ \pm0.3\ \pm0.2$	46.9	[76] ALEXANDER 96B	OPAL	E^{ee}_{cm}= 88–94 GeV
$1.60\pm0.73\pm0.33$	5.4	[77] ABREU 94P	DLPH	E^{ee}_{cm}= 88–94 GeV

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

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

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

$\Gamma(\chi_{c1}(1P)X)/\Gamma_{total}$ Γ_{23}/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID	TECN	COMMENT
2.9±0.7 OUR AVERAGE				
$2.7\pm0.6\pm0.5$	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

[78] ACCIARRI 97J measure this branching ratio via the decay channel $\chi_{c1}\to\ J/\psi+\ \gamma$, with $J/\psi\to\ \ell^+\ell^-$ ($\ell=\mu$, 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 $\chi_{c1}\to\ J/\psi+\ \gamma$, with $J/\psi\to\mu^+\mu^-$.

$\Gamma(\chi_{c2}(1P)X)/\Gamma_{total}$ — Γ_{24}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<3.2 \times 10^{-3}$	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}.

$\Gamma(\Upsilon(1S)X+\Upsilon(2S)X+\Upsilon(3S)X)/\Gamma_{total}$ — $\Gamma_{25}/\Gamma = (\Gamma_{26}+\Gamma_{27}+\Gamma_{28})/\Gamma$

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
$1.0\pm0.4\pm0.22$	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_{26}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<4.4 \times 10^{-5}$	95	[82] ACCIARRI	99F	L3	E^{ee}_{cm} = 88–94 GeV

[82] ACCIARRI 99F search for $\Upsilon(1S)$ through its decay into $\ell^+\ell^-$ ($\ell = e$ or μ).

$\Gamma(\Upsilon(2S)X)/\Gamma_{total}$ — Γ_{27}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<13.9 \times 10^{-5}$	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_{28}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<9.4 \times 10^{-5}$	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_{29}/Γ_6

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.296\pm0.019\pm0.021$	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_{30}/Γ_6

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.174\pm0.016\pm0.018$	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_{31}/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 $D^0 \to K^-\pi^+$. The new CLEO II measurement of B($D^{*\pm} \to D^0\pi^{\pm}$) = (68.1 ± 1.6) % is used. This is a corrected result (see the erratum of ABREU 93I).

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

$\Gamma(B^0_s X)/\Gamma(\text{hadrons})$ Γ_{34}/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 $\Gamma(B^0_s X)*B(B^0_s \to D_s\mu\nu_\mu X)*B(D_s \to \phi\pi)/\Gamma(\text{hadrons})$ = (18 ± 8) × 10^{-5}.

[90] ACTON 92N find evidence for B^0_s production using D_s-ℓ correlations, with $D^+_s \to \phi\pi^+$ 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 $f(\overline{b} \to B^0_s)\times B(B^0_s \to D^-_s\ell^+\nu_\ell X)\times B(D^-_s \to \phi\pi^-)$ = (3.9 ± 1.1 ± 0.8) × 10^{-4}.

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

$\Gamma(B^+_c X)/\Gamma(\text{hadrons})$ Γ_{35}/Γ_6

VALUE	DOCUMENT ID		TECN	COMMENT
searched for	[92] ACKERSTAFF	98O	OPAL	E^{ee}_{cm}= 88–94 GeV
searched for	[93] ABREU	97E	DLPH	E^{ee}_{cm}= 88–94 GeV
searched for	[94] BARATE	97H	ALEP	E^{ee}_{cm}= 88–94 GeV

[92] ACKERSTAFF 98O searched for the decay modes $B_c \to J/\psi\pi^+$, $J/\psi a^+_1$, and $J/\psi\ell^+\nu_\ell$, with $J/\psi \to \ell^+\ell^-$, $\ell = e,\mu$. The number of candidates (background) for the three decay modes is 2 (0.63 ± 0.2), 0 (1.10 ± 0.22), and 1 (0.82 ± 0.19) respectively. Interpreting the 2 $B_c \to J/\psi\pi^+$ candidates as signal, they report $\Gamma(B^+_c X)\times B(B_c \to J/\psi\pi^+)/\Gamma(\text{hadrons}) = (3.8^{+5.0}_{-2.4} \pm 0.5)\times 10^{-5}$. Interpreted as background, the 90% CL bounds are $\Gamma(B^+_c X)*B(B_c \to J/\psi\pi^+)/\Gamma(\text{hadrons}) < 1.06\times 10^{-4}$, $\Gamma(B^+_c X)*B(B_c \to J/\psi a^+_1)/\Gamma(\text{hadrons}) < 5.29 \times 10^{-4}$, $\Gamma(B^+_c X)*B(B_c \to J/\psi\ell^+\nu_\ell)/\Gamma(\text{hadrons}) < 6.96 \times 10^{-5}$.

[93] ABREU 97E searched for the decay modes $B_c \to J/\psi\pi^+$, $J/\psi\ell^+\nu_\ell$, and $J/\psi(3\pi)^+$, with $J/\psi \to \ell^+\ell^-$, $\ell = e,\mu$. The number of candidates (background) for the three decay modes is 1 (1.7), 0 (0.3), and 1 (2.3) respectively. They report the following 90% CL limits: $\Gamma(B_c^+ X)*B(B_c \to J/\psi\pi^+)/\Gamma(\text{hadrons}) <(1.05\text{–}0.84) \times 10^{-4}$, $\Gamma(B_c^+ X)*B(B_c \to J/\psi\ell\nu_\ell)/\Gamma(\text{hadrons}) <(5.8\text{–}5.0) \times 10^{-5}$, $\Gamma(B_c^+ X)*B(B_c \to J/\psi(3\pi)^+)/\Gamma(\text{hadrons}) < 1.75 \times 10^{-4}$, where the ranges are due to the predicted B_c lifetime (0.4–1.4) ps.

[94] BARATE 97H searched for the decay modes $B_c \to J/\psi\pi^+$ and $J/\psi\ell^+\nu_\ell$ with $J/\psi \to \ell^+\ell^-$, $\ell = e,\mu$. The number of candidates (background) for the two decay modes is 0 (0.44) and 2 (0.81) respectively. They report the following 90% CL limits: $\Gamma(B_c^+ X)*B(B_c \to J/\psi\pi^+)/\Gamma(\text{hadrons}) < 3.6 \times 10^{-5}$ and $\Gamma(B_c^+ X)*B(B_c \to J/\psi\ell^+\nu_\ell)/\Gamma(\text{hadrons}) < 5.2 \times 10^{-5}$.

$\Gamma(B^* X)/[\Gamma(BX) + \Gamma(B^* X)]$ — $\Gamma_{33}/(\Gamma_{32}+\Gamma_{33})$

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 of $(10.1^{+3.9}_{-3.1})$% as given in the 1998 edition of this *Review* OUR AVERAGE becomes 0.74 ± 0.04.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.75 ±0.04 OUR AVERAGE					
0.760±0.036±0.083		[95] ACKERSTAFF	97M	OPAL	E^{ee}_{cm}= 88–94 GeV
0.771±0.026±0.070		[96] BUSKULIC	96D	ALEP	E^{ee}_{cm}= 88–94 GeV
0.72 ±0.03 ±0.06		[97] ABREU	95R	DLPH	E^{ee}_{cm}= 88–94 GeV
0.76 ±0.08 ±0.06	1378	[98] ACCIARRI	95B	L3	E^{ee}_{cm}= 88–94 GeV

[95] 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.

[96] 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.

[97] 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.

[98] 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_{36}/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	[99] AKRAWY	90J	OPAL	E^{ee}_{cm}= 88–94 GeV

[99] 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_{37}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<5.2 \times 10^{-4}$	95	[100] ACTON	91B	OPAL	E^{ee}_{cm}= 91.2 GeV

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

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<5.6 × 10⁻⁴	95	[101] ACTON	91B	OPAL	E^{ee}_{cm}= 91.2 GeV

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

$\Gamma(\tau^+\tau^-\gamma)/\Gamma_{total}$ — Γ_{39}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<7.3 × 10⁻⁴	95	[102] ACTON	91B	OPAL	E^{ee}_{cm}= 91.2 GeV

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

$\Gamma(\ell^+\ell^-\gamma\gamma)/\Gamma_{total}$ — Γ_{40}/Γ

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<6.8 × 10⁻⁶	95	[103] ACTON	93E	OPAL	E^{ee}_{cm}= 88–94 GeV

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

$\Gamma(q\overline{q}\gamma\gamma)/\Gamma_{total}$ — Γ_{41}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<5.5 × 10⁻⁶	95	[104] ACTON	93E	OPAL	E^{ee}_{cm}= 88–94 GeV

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

$\Gamma(\nu\overline{\nu}\gamma\gamma)/\Gamma_{total}$ — Γ_{42}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<3.1 × 10⁻⁶	95	[105] ACTON	93E	OPAL	E^{ee}_{cm}= 88–94 GeV

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

$\Gamma(e^\pm\mu^\mp)/\Gamma(e^+e^-)$ — Γ_{43}/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	$E^{p\overline{p}}_{cm}$= 546,630 GeV

$\Gamma(e^\pm\mu^\mp)/\Gamma_{total}$ — 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
$<2.5 \times 10^{-6}$	95	ABREU	97C	DLPH	E^{ee}_{cm}= 88–94 GeV
<1.7 × 10⁻⁶	95	AKERS	95W	OPAL	E^{ee}_{cm}= 88–94 GeV
$<0.6 \times 10^{-5}$	95	ADRIANI	93I	L3	E^{ee}_{cm}= 88–94 GeV
$<2.6 \times 10^{-5}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(e^\pm\tau^\mp)/\Gamma_{total}$ — Γ_{44}/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}_{cm}= 88–94 GeV
<9.8 × 10⁻⁶	95	AKERS	95W	OPAL	E^{ee}_{cm}= 88–94 GeV
$<1.3 \times 10^{-5}$	95	ADRIANI	93I	L3	E^{ee}_{cm}= 88–94 GeV
$<1.2 \times 10^{-4}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\mu^{\pm}\tau^{\mp})/\Gamma_{total}$ — Γ_{45}/Γ

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

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

$\Gamma(pe)/\Gamma_{total}$ — Γ_{46}/Γ

Test of baryon number and lepton number conservations. Charge conjugate states are implied.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<1.8 × 10^{-6}	95	[106] ABBIENDI	99I	OPAL	E^{ee}_{cm}= 88–94 GeV

[106] ABBIENDI 99I give the 95%CL limit on the partial width $\Gamma(Z^0 \to pe)<$ 4.6 KeV and we have transformed it into a branching ratio.

$\Gamma(p\mu)/\Gamma_{total}$ — Γ_{47}/Γ

Test of baryon number and lepton number conservations. Charge conjugate states are implied.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<1.8 × 10^{-6}	95	[107] ABBIENDI	99I	OPAL	E^{ee}_{cm}= 88–94 GeV

[107] ABBIENDI 99I give the 95%CL limit on the partial width $\Gamma(Z^0 \to p\mu)<$ 4.4 KeV and we have transformed it into a branching ratio.

AVERAGE PARTICLE MULTIPLICITIES IN HADRONIC Z DECAY

Summed over particle and antiparticle, when appropriate.

$\langle N_{\gamma}\rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
20.97±0.02±1.15	ACKERSTAFF	98A	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\pi^{\pm}}\rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
16.99±0.20 OUR AVERAGE				
16.84±0.37	ABE	99E	SLD	E^{ee}_{cm}= 91.2 GeV
17.26±0.10±0.88	ABREU	98L	DLPH	E^{ee}_{cm}= 91.2 GeV
17.04±0.31	BARATE	98V	ALEP	E^{ee}_{cm}= 91.2 GeV
17.05±0.43	AKERS	94P	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\pi^0}\rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
9.76±0.26 OUR AVERAGE				
9.55±0.06±0.75	ACKERSTAFF	98A	OPAL	E^{ee}_{cm}= 91.2 GeV
9.63±0.13±0.63	BARATE	97J	ALEP	E^{ee}_{cm}= 91.2 GeV
9.90±0.02±0.33	ACCIARRI	96	L3	E^{ee}_{cm}= 91.2 GeV
9.2 ±0.2 ±1.0	ADAM	96	DLPH	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\eta} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.95±0.07 OUR AVERAGE				
0.97±0.03±0.11	ACKERSTAFF	98A	OPAL	E^{ee}_{cm}= 91.2 GeV
0.93±0.01±0.09	ACCIARRI	96	L3	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\rho^{\pm}} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
2.40±0.06±0.43	ACKERSTAFF	98A	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\rho^0} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
1.24±0.10 OUR AVERAGE Error includes scale factor of 1.1.				
1.19±0.10	ABREU	99J	DLPH	E^{ee}_{cm}= 91.2 GeV
1.45±0.06±0.20	BUSKULIC	96H	ALEP	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\omega} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
1.08±0.09 OUR AVERAGE				
1.04±0.04±0.14	ACKERSTAFF	98A	OPAL	E^{ee}_{cm}= 91.2 GeV
1.17±0.09±0.15	ACCIARRI	97D	L3	E^{ee}_{cm}= 91.2 GeV
1.07±0.06±0.13	BUSKULIC	96H	ALEP	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\eta'} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.17 ±0.05 OUR AVERAGE Error includes scale factor of 2.4.				
0.14 ±0.01 ±0.02	ACKERSTAFF	98A	OPAL	E^{ee}_{cm}= 91.2 GeV
0.25 ±0.04	[108] ACCIARRI	97D	L3	E^{ee}_{cm}= 91.2 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.068±0.018±0.016	[109] BUSKULIC	92D	ALEP	E^{ee}_{cm}= 91.2 GeV

[108] ACCIARRI 97D obtain this value averaging over the two decay channels $\eta' \rightarrow \pi^+ \pi^- \eta$ and $\eta' \rightarrow \rho^0 \gamma$.
[109] BUSKULIC 92D obtain this value for $x > 0.1$.

$\langle N_{f_0(980)} \rangle$

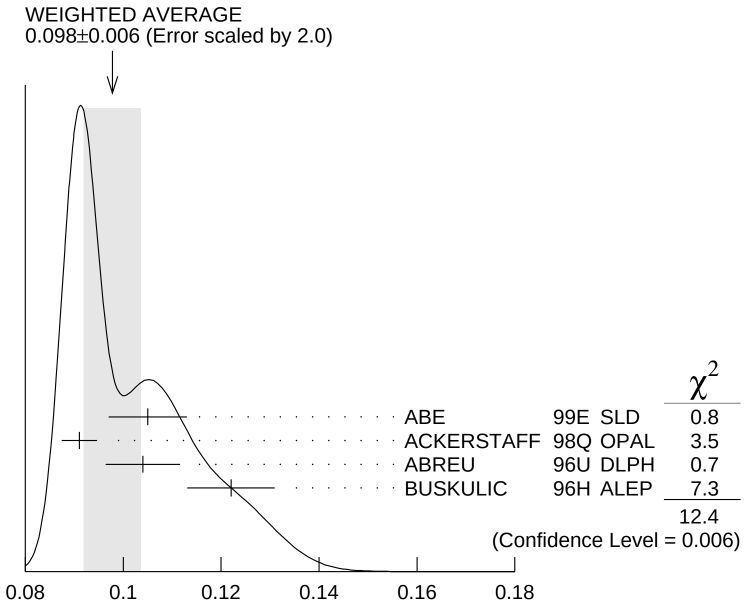
VALUE	DOCUMENT ID		TECN	COMMENT
0.147±0.011 OUR AVERAGE				
0.164±0.021	ABREU	99J	DLPH	E^{ee}_{cm}= 91.2 GeV
0.141±0.007±0.011	ACKERSTAFF	98Q	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{a_0(980)^{\pm}} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.27±0.04±0.10	ACKERSTAFF	98A	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\phi} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.098±0.006 OUR AVERAGE	Error includes scale factor of 2.0. See the ideogram below.			
0.105±0.008	ABE	99E	SLD	E^{ee}_{cm}= 91.2 GeV
0.091±0.002±0.003	ACKERSTAFF	98Q	OPAL	E^{ee}_{cm}= 91.2 GeV
0.104±0.003±0.007	ABREU	96U	DLPH	E^{ee}_{cm}= 91.2 GeV
0.122±0.004±0.008	BUSKULIC	96H	ALEP	E^{ee}_{cm}= 91.2 GeV



$\langle N_{\phi} \rangle$

$\langle N_{f_2(1270)} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.169±0.025 OUR AVERAGE	Error includes scale factor of 1.4.			
0.214±0.038	ABREU	99J	DLPH	E^{ee}_{cm}= 91.2 GeV
0.155±0.011±0.018	ACKERSTAFF	98Q	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{f'_2(1525)} \rangle$

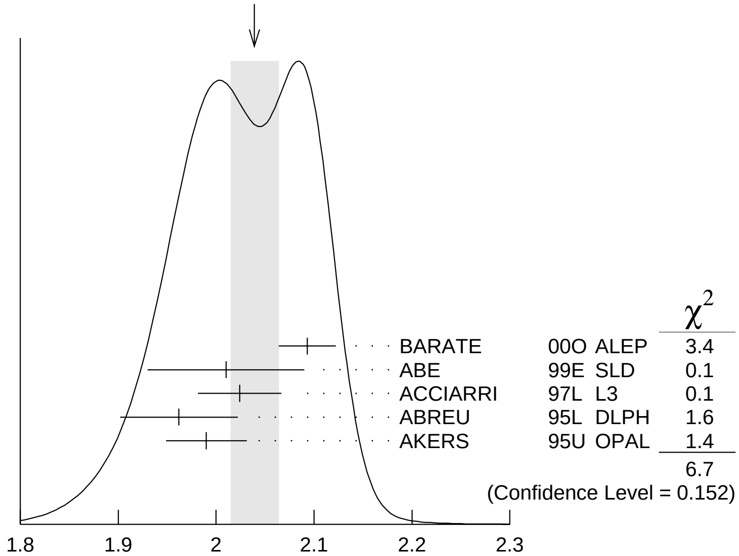
VALUE	DOCUMENT ID		TECN	COMMENT
0.012±0.006	ABREU	99J	DLPH	E^{ee}_{cm}= 91.2 GeV

$\langle N_{K^{\pm}} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
2.25±0.05 OUR AVERAGE				
2.22±0.16	ABE	99E	SLD	E^{ee}_{cm}= 91.2 GeV
2.21±0.05±0.05	ABREU	98L	DLPH	E^{ee}_{cm}= 91.2 GeV
2.26±0.12	BARATE	98V	ALEP	E^{ee}_{cm}= 91.2 GeV
2.42±0.13	AKERS	94P	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{K^0} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
2.039±0.025 OUR AVERAGE	Error includes scale factor of 1.3. See the ideogram below.			
2.093±0.004±0.029	BARATE	00O	ALEP	E^{ee}_{cm}= 91.2 GeV
2.01 ±0.08	ABE	99E	SLD	E^{ee}_{cm}= 91.2 GeV
2.024±0.006±0.042	ACCIARRI	97L	L3	E^{ee}_{cm}= 91.2 GeV
1.962±0.022±0.056	ABREU	95L	DLPH	E^{ee}_{cm}= 91.2 GeV
1.99 ±0.01 ±0.04	AKERS	95U	OPAL	E^{ee}_{cm}= 91.2 GeV



$\langle N_{K^0} \rangle$

$\langle N_{K^*(892)^\pm} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.72 ±0.05 OUR AVERAGE				
0.712±0.031±0.059	ABREU	95L	DLPH	E^{ee}_{cm}= 91.2 GeV
0.72 ±0.02 ±0.08	ACTON	93	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{K^*(892)^0} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.739±0.022 OUR AVERAGE				
0.707±0.041	ABE	99E	SLD	E^{ee}_{cm}= 91.2 GeV
0.74 ±0.02 ±0.02	ACKERSTAFF	97S	OPAL	E^{ee}_{cm}= 91.2 GeV
0.77 ±0.02 ±0.07	ABREU	96U	DLPH	E^{ee}_{cm}= 91.2 GeV
0.83 ±0.01 ±0.09	BUSKULIC	96H	ALEP	E^{ee}_{cm}= 91.2 GeV
0.97 ±0.18 ±0.31	ABREU	93	DLPH	E^{ee}_{cm}= 91.2 GeV

$\langle N_{K_2^*(1430)} \rangle$

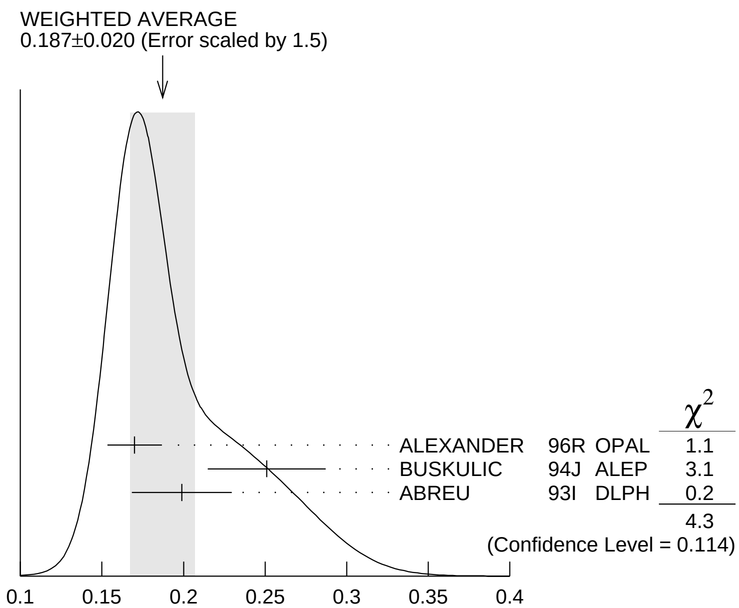
VALUE		DOCUMENT ID		TECN	COMMENT
0.073±0.023		ABREU	99J	DLPH	E^{ee}_{cm}= 91.2 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.19 ±0.04 ±0.06	[110]	AKERS	95X	OPAL	E^{ee}_{cm}= 91.2 GeV

[110] AKERS 95X obtain this value for x< 0.3.

$\langle N_{D^\pm} \rangle$

VALUE		DOCUMENT ID		TECN	COMMENT
0.187±0.020 OUR AVERAGE	Error includes scale factor of 1.5. See the ideogram below.				
0.170±0.009±0.014		ALEXANDER	96R	OPAL	E^{ee}_{cm}= 91.2 GeV
0.251±0.026±0.025		BUSKULIC	94J	ALEP	E^{ee}_{cm}= 91.2 GeV
0.199±0.019±0.024	[111]	ABREU	93I	DLPH	E^{ee}_{cm}= 91.2 GeV

[111] See ABREU 95 (erratum).



$\langle N_{D^\pm} \rangle$

$\langle N_{D^0} \rangle$

VALUE		DOCUMENT ID		TECN	COMMENT
0.462±0.026 OUR AVERAGE					
0.465±0.017±0.027		ALEXANDER	96R	OPAL	E^{ee}_{cm}= 91.2 GeV
0.518±0.052±0.035		BUSKULIC	94J	ALEP	E^{ee}_{cm}= 91.2 GeV
0.403±0.038±0.044	[112]	ABREU	93I	DLPH	E^{ee}_{cm}= 91.2 GeV

[112] See ABREU 95 (erratum).

$\langle N_{D_s^\pm} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.131±0.010±0.018	ALEXANDER	96R	OPAL	$E_{\rm cm}^{ee}$= 91.2 GeV

$\langle N_{D^*(2010)^\pm} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.183 ±0.008 OUR AVERAGE				
0.1854±0.0041±0.0091	[113] ACKERSTAFF	98E	OPAL	$E_{\rm cm}^{ee}$= 91.2 GeV
0.187 ±0.015 ±0.013	BUSKULIC	94J	ALEP	$E_{\rm cm}^{ee}$= 91.2 GeV
0.171 ±0.012 ±0.016	[114] ABREU	93I	DLPH	$E_{\rm cm}^{ee}$= 91.2 GeV

[113] ACKERSTAFF 98E systematic error includes an uncertainty of ±0.0069 due to the branching ratios B($D^{*+} \to D^0 \pi^+$) = 0.683±0.014 and B($D^0 \to K^- \pi^+$) = 0.0383±0.0012.

[114] See ABREU 95 (erratum).

$\langle N_{D_{s1}(2536)^+} \rangle$

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$2.9^{+0.7}_{-0.6}$±0.2	[115] ACKERSTAFF	97W	OPAL	$E_{\rm cm}^{ee}$= 91.2 GeV

[115] ACKERSTAFF 97W obtain this value for x> 0.6 and with the assumption that its decay width is saturated by the $D^* K$ final states.

$\langle N_{B^*} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.28 ±0.01 ±0.03	[116] ABREU	95R	DLPH	$E_{\rm cm}^{ee}$= 91.2 GeV

[116] ABREU 95R quote this value for a flavor-averaged excited state.

$\langle N_{J/\psi(1S)} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.0056±0.0003±0.0004	[117] ALEXANDER	96B	OPAL	$E_{\rm cm}^{ee}$= 91.2 GeV

[117] ALEXANDER 96B identify $J/\psi(1S)$ from the decays into lepton pairs.

$\langle N_{\psi(2S)} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.0023±0.0004±0.0003	ALEXANDER	96B	OPAL	$E_{\rm cm}^{ee}$= 91.2 GeV

$\langle N_p \rangle$

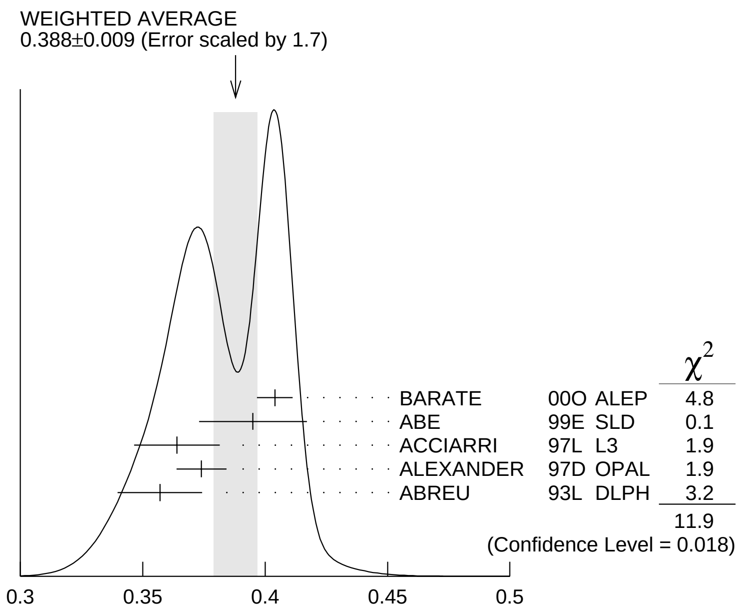
VALUE	DOCUMENT ID		TECN	COMMENT
1.04±0.04 OUR AVERAGE				
1.03±0.13	ABE	99E	SLD	$E_{\rm cm}^{ee}$= 91.2 GeV
1.08±0.04±0.03	ABREU	98L	DLPH	$E_{\rm cm}^{ee}$= 91.2 GeV
1.00±0.07	BARATE	98V	ALEP	$E_{\rm cm}^{ee}$= 91.2 GeV
0.92±0.11	AKERS	94P	OPAL	$E_{\rm cm}^{ee}$= 91.2 GeV

$\langle N_{\Delta(1232)^{++}} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.087±0.033 OUR AVERAGE	Error includes scale factor of 2.4.			
0.079±0.009±0.011	ABREU	95W	DLPH	E^{ee}_{cm}= 91.2 GeV
0.22 ±0.04 ±0.04	ALEXANDER	95D	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\Lambda} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.388±0.009 OUR AVERAGE	Error includes scale factor of 1.7. See the ideogram below.			
0.404±0.002±0.007	BARATE	00O	ALEP	E^{ee}_{cm}= 91.2 GeV
0.395±0.022	ABE	99E	SLD	E^{ee}_{cm}= 91.2 GeV
0.364±0.004±0.017	ACCIARRI	97L	L3	E^{ee}_{cm}= 91.2 GeV
0.374±0.002±0.010	ALEXANDER	97D	OPAL	E^{ee}_{cm}= 91.2 GeV
0.357±0.003±0.017	ABREU	93L	DLPH	E^{ee}_{cm}= 91.2 GeV



$\langle N_{\Lambda} \rangle$

$\langle N_{\Lambda(1520)} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.0224±0.0027 OUR AVERAGE				
0.029 ±0.005 ±0.005	ABREU	00P	DLPH	E^{ee}_{cm}= 91.2 GeV
0.0213±0.0021±0.0019	ALEXANDER	97D	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\Sigma^+} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.107±0.010 OUR AVERAGE				
0.114±0.011±0.009	ACCIARRI	00J	L3	E_{cm}^{ee}= 91.2 GeV
0.099±0.008±0.013	ALEXANDER	97E	OPAL	E_{cm}^{ee}= 91.2 GeV

$\langle N_{\Sigma^-} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.082±0.007 OUR AVERAGE				
0.081±0.002±0.010	ABREU	00P	DLPH	E_{cm}^{ee}= 91.2 GeV
0.083±0.006±0.009	ALEXANDER	97E	OPAL	E_{cm}^{ee}= 91.2 GeV

$\langle N_{\Sigma^+ + \Sigma^-} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.181±0.018 OUR AVERAGE				
0.182±0.010±0.016	[118] ALEXANDER	97E	OPAL	E_{cm}^{ee}= 91.2 GeV
0.170±0.014±0.061	ABREU	95O	DLPH	E_{cm}^{ee}= 91.2 GeV

[118] We have combined the values of $\langle N_{\Sigma^+} \rangle$ and $\langle N_{\Sigma^-} \rangle$ from ALEXANDER 97E adding the statistical and systematic errors of the two final states separately in quadrature. If isospin symmetry is assumed this value becomes 0.174 ± 0.010 ± 0.015.

$\langle N_{\Sigma^0} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.076±0.010 OUR AVERAGE				
0.095±0.015±0.013	ACCIARRI	00J	L3	E_{cm}^{ee}= 91.2 GeV
0.071±0.012±0.013	ALEXANDER	97E	OPAL	E_{cm}^{ee}= 91.2 GeV
0.070±0.010±0.010	ADAM	96B	DLPH	E_{cm}^{ee}= 91.2 GeV

$\langle N_{(\Sigma^+ + \Sigma^- + \Sigma^0)/3} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.084±0.005±0.008	ALEXANDER	97E	OPAL	E_{cm}^{ee}= 91.2 GeV

$\langle N_{\Sigma(1385)^+} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.0239±0.0009±0.0012	ALEXANDER	97D	OPAL	E_{cm}^{ee}= 91.2 GeV

$\langle N_{\Sigma(1385)^-} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.0240±0.0010±0.0014	ALEXANDER	97D	OPAL	E_{cm}^{ee}= 91.2 GeV

$\langle N_{\Sigma(1385)^+ + \Sigma(1385)^-} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.046 ±0.004 OUR AVERAGE	Error includes scale factor of 1.6.			
0.0479±0.0013±0.0026	ALEXANDER	97D	OPAL	E_{cm}^{ee}= 91.2 GeV
0.0382±0.0028±0.0045	ABREU	95O	DLPH	E_{cm}^{ee}= 91.2 GeV

$\langle N_{\Xi^-} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.0258±0.0009 OUR AVERAGE				
0.0259±0.0004±0.0009	ALEXANDER	97D	OPAL	E^{ee}_{cm}= 91.2 GeV
0.0250±0.0009±0.0021	ABREU	95O	DLPH	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\Xi(1530)^0} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.0053±0.0013 OUR AVERAGE Error includes scale factor of 3.2.				
0.0068±0.0005±0.0004	ALEXANDER	97D	OPAL	E^{ee}_{cm}= 91.2 GeV
0.0041±0.0004±0.0004	ABREU	95O	DLPH	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\Omega^-} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.00164±0.00028 OUR AVERAGE				
0.0018 ±0.0003 ±0.0002	ALEXANDER	97D	OPAL	E^{ee}_{cm}= 91.2 GeV
0.0014 ±0.0002 ±0.0004	ADAM	96B	DLPH	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\Lambda_c^+} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.078±0.012±0.012	ALEXANDER	96R	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{charged} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
21.07±0.11 OUR AVERAGE				
21.21±0.01±0.20	ABREU	99	DLPH	E^{ee}_{cm}= 91.2 GeV
21.05±0.20	AKERS	95Z	OPAL	E^{ee}_{cm}= 91.2 GeV
20.91±0.03±0.22	BUSKULIC	95R	ALEP	E^{ee}_{cm}= 91.2 GeV
21.40±0.43	ACTON	92B	OPAL	E^{ee}_{cm}= 91.2 GeV
20.71±0.04±0.77	ABREU	91H	DLPH	E^{ee}_{cm}= 91.2 GeV
20.7 ±0.7	ADEVA	91I	L3	E^{ee}_{cm}= 91.2 GeV
20.1 ±1.0 ±0.9	ABRAMS	90	MRK2	E^{ee}_{cm}= 91.1 GeV

Z HADRONIC POLE CROSS SECTION

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the "Note on the *Z* boson"). This quantity is defined as

$$\sigma_h^0 = \frac{12\pi}{M_Z^2} \frac{\Gamma(e^+e^-)\,\Gamma(\text{hadrons})}{\Gamma_Z^2}$$

It is one of the parameters used in the *Z* lineshape fit.

VALUE (nb)	EVTS	DOCUMENT ID		TECN	COMMENT
41.541±0.037 OUR FIT					
41.501±0.055	4.10M	[119] ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
41.578±0.069	3.70M	ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
41.535±0.055	3.54M	ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
41.559±0.058	4.07M	[120] BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

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

41.23	±0.20	1.05M	ABREU	94	DLPH	Repl. by ABREU 00F
41.39	±0.26	1.09M	ACCIARRI	94	L3	Repl. by ACCIARRI 00C
41.70	±0.23	1.19M	AKERS	94	OPAL	Repl. by ABBIENDI 01A
41.60	±0.16	1.27M	BUSKULIC	94	ALEP	Repl. by BARATE 00C
42	±4	450	ABRAMS	89B	MRK2	E^{ee}_{cm}= 89.2–93.0 GeV

[119] ABBIENDI 01A error includes approximately 0.031 due to statistics, 0.033 due to event selection systematics, 0.029 due to uncertainty in luminosity measurement, and 0.011 due to LEP energy uncertainty.

[120] BARATE 00C error includes approximately 0.030 due to statistics, 0.026 due to experimental systematics, and 0.025 due to uncertainty in luminosity measurement.

Z VECTOR COUPLINGS TO CHARGED LEPTONS

These quantities are the effective vector couplings of the Z to charged leptons. Their magnitude is derived from a measurement of the Z lineshape and the forward-backward lepton asymmetries as a function of energy around the Z mass. The relative sign among the vector to axial-vector couplings is obtained from a measurement of the Z asymmetry parameters, A_e, A_μ, and A_τ. By convention the sign of g^e_A is fixed to be negative (and opposite to that of g^{ν_e} obtained using ν_e scattering measurements). The fit values quoted below correspond to global nine- or five-parameter fits to lineshape, lepton forward-backward asymmetry, and A_e, A_μ, and A_τ measurements. See "Note on the Z boson" for details.

g^e_V

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.03805±0.00059 OUR FIT					
$-0.027\ ^{+0.008}_{-0.006}$	137.0K	[121] ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
−0.0412 ±0.0027	124.4k	[122] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
−0.0400 ±0.0037		BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV
−0.0414 ±0.0020		[123] ABE	95J	SLD	E^{ee}_{cm}= 91.31 GeV

[121] ABBIENDI 01A note that their g^μ_V and g^τ_V errors have large negative correlations with their error on g^e_V.

[122] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

[123] ABE 95J obtain this result combining polarized Bhabha results with the A_{LR} measurement of ABE 94C. The Bhabha results alone give $-0.0507 \pm 0.0096 \pm 0.0020$.

g^μ_V

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.0362±0.0028 OUR FIT					
$-0.049\ ^{+0.011}_{-0.022}$	182.8K	[124] ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
−0.0386±0.0073	113.4k	[125] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
−0.0362±0.0061		BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

[124] ABBIENDI 01A note that their g^{μ}_{V} and g^{τ}_{V} errors have large negative correlations with their error on g^{e}_{V}.
[125] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

g^{τ}_{V}

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$-$0.0364$\pm$0.0014 OUR FIT					
$-0.045\ ^{+0.012}_{-0.021}$	151.5K	[126] ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
-0.0384 ± 0.0026	103.0k	[127] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
-0.0361 ± 0.0068		BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

[126] ABBIENDI 01A note that their g^{μ}_{V} and g^{τ}_{V} errors have large negative correlations with their error on g^{e}_{V}.
[127] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

g^{ℓ}_{V}

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$-$0.03772$\pm$0.00050 OUR FIT					
$-0.0350\ ^{+0.0021}_{-0.0020}$	471.3K	[128] ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
$-0.0397\ \pm0.0020$	379.4k	[129] ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
$-0.0397\ \pm0.0017$	340.8k	[130] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
$-0.0383\ \pm0.0018$	500k	BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

[128] ABBIENDI 01A note that their g^{μ}_{V} and g^{τ}_{V} errors have large negative correlations with their error on g^{e}_{V}.
[129] Using forward-backward lepton asymmetries.
[130] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

Z AXIAL-VECTOR COUPLINGS TO CHARGED LEPTONS

These quantities are the effective axial-vector couplings of the Z to charged leptons. Their magnitude is derived from a measurement of the Z lineshape and the forward-backward lepton asymmetries as a function of energy around the Z mass. The relative sign among the vector to axial-vector couplings is obtained from a measurement of the Z asymmetry parameters, A_e, A_μ, and A_τ. By convention the sign of g_A^e is fixed to be negative (and opposite to that of g^{ν_e} obtained using ν_e scattering measurements). The fit values quoted below correspond to global nine- or five-parameter fits to lineshape, lepton forward-backward asymmetry, and A_e, A_μ, and A_τ measurements. See "Note on the Z boson" for details.

g_A^e

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.50111±0.00035 OUR FIT					
−0.5009 ±0.0007	137.0K	ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
−0.5015 ±0.0007	124.4k	[131] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
−0.50166±0.00057		BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV
−0.4977 ±0.0045		[132] ABE	95J	SLD	E^{ee}_{cm}= 91.31 GeV

[131] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

[132] ABE 95J obtain this result combining polarized Bhabha results with the A_{LR} measurement of ABE 94C. The Bhabha results alone give −0.4968 ± 0.0039 ± 0.0027.

g_A^μ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.50124±0.00055 OUR FIT					
$-0.5004\ ^{+0.0026}_{-0.0013}$	182.8K	ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
−0.5009 ±0.0014	113.4k	[133] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
−0.50046±0.00093		BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

[133] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

g_A^τ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.50207±0.00064 OUR FIT					
$-0.5011\ ^{+0.0024}_{-0.0016}$	151.5K	ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
−0.5023 ±0.0017	103.0k	[134] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
−0.50216±0.00100		BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

[134] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

g_A^ℓ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.50124±0.00026 OUR FIT					
−0.50095±0.00046	471.3K	ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
−0.5007 ±0.0005	379.4k	ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
−0.50153±0.00053	340.8k	[135] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
−0.50150±0.00046	500k	BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

[135] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

Z COUPLINGS TO NEUTRAL LEPTONS

These quantities are the effective couplings of the Z to neutral leptons. $\nu_e e$ and $\nu_\mu e$ scattering results are combined with g_A^e and g_V^e measurements at the Z mass to obtain g^{ν_e} and g^{ν_μ} following NOVIKOV 93C.

g^{ν_e}

VALUE	DOCUMENT ID		TECN	COMMENT
0.528±0.085	[136] VILAIN	94	CHM2	From $\nu_\mu e$ and $\nu_e e$ scattering

[136] VILAIN 94 derive this value from their value of g^{ν_μ} and their ratio $g^{\nu_e}/g^{\nu_\mu} = 1.05^{+0.15}_{-0.18}$.

g^{ν_μ}

VALUE	DOCUMENT ID		TECN	COMMENT
0.502±0.017	[137] VILAIN	94	CHM2	From $\nu_\mu e$ scattering

[137] VILAIN 94 derive this value from their measurement of the couplings $g_A^{e\nu_\mu} = -0.503 \pm 0.017$ and $g_V^{e\nu_\mu} = -0.035 \pm 0.017$ obtained from $\nu_\mu e$ scattering. We have re-evaluated this value using the current PDG values for g_A^e and g_V^e.

Z ASYMMETRY PARAMETERS

For each fermion-antifermion pair coupling to the Z these quantities are defined as

$$A_f = \frac{2g_V^f g_A^f}{(g_V^f)^2 + (g_A^f)^2}$$

where g_V^f and g_A^f are the effective vector and axial-vector couplings. For their relation to the various lepton asymmetries see the 'Note on the Z Boson.'

A_e

Using polarized beams, this quantity can also be measured as $(\sigma_L - \sigma_R)/(\sigma_L + \sigma_R)$, where σ_L and σ_R are the e^+e^- production cross sections for Z bosons produced with left-handed and right-handed electrons respectively.

VALUE			EVTS	DOCUMENT ID		TECN	COMMENT
0.1508	**±0.0024**	**OUR AVERAGE**	Error includes scale factor of 1.2.				
0.15138	±0.00216		537000	[138] ABE	00B	SLD	E_{cm}^{ee}= 91.24 GeV
0.1382	±0.0116	±0.0005	105000	[139] ABREU	00E	DLPH	E_{cm}^{ee}= 88–94 GeV
0.1678	±0.0127	±0.0030	137092	[140] ACCIARRI	98H	L3	E_{cm}^{ee}= 88–94 GeV
0.162	±0.041	±0.014	89838	[141] ABE	97	SLD	E_{cm}^{ee}= 91.27 GeV
0.152	±0.012			[142] ABE	97N	SLD	E_{cm}^{ee}= 91.27 GeV
0.129	±0.014	±0.005	89075	[143] ALEXANDER	96U	OPAL	E_{cm}^{ee}= 88–94 GeV
0.202	±0.038	±0.008		[144] ABE	95J	SLD	E_{cm}^{ee}= 91.31 GeV
0.129	±0.016	±0.005	33000	[145] BUSKULIC	95Q	ALEP	E_{cm}^{ee}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •							
0.1543	±0.0039		153500	[146] ABE	97E	SLD	Repl. by ABE 00B
0.136	±0.027	±0.003		[140] ABREU	95I	DLPH	Repl. by ABREU 00E
0.122	±0.030	±0.012	30663	[140] AKERS	95	OPAL	Repl. by ALEXANDER 96U
0.157	±0.020	±0.005	86000	[140] ACCIARRI	94E	L3	Repl. by ACCIARRI 98H

[138] ABE 00B obtain this value measuring the left-right Z boson cross-section asymmetry. This is equivalent to an effective weak mixing angle of $\sin^2\theta_W^{\rm eff}$= 0.23097 ± 0.00027.

[139] ABREU 00E obtain this result fitting the τ polarization as a function of the polar τ production angle. This measurement is a combination of different analyses (exclusive τ decay modes, inclusive hadronic 1-prong reconstruction, and a neural network analysis).

[140] Derived from the measurement of forward-backward τ polarization asymmetry.

[141] ABE 97 obtain this result from a measurement of the observed left-right charge asymmetry, $A_Q^{\rm obs}$ = 0.225 ± 0.056 ± 0.019, in hadronic Z decays. If they combine this value of $A_Q^{\rm obs}$ with their earlier measurement of $A_{LR}^{\rm obs}$ they determine A_e to be 0.1574 ± 0.0197 ± 0.0067 independent of the beam polarization.

[142] ABE 97N obtain this direct measurement using the left-right cross section asymmetry and the left-right forward-backward asymmetry in leptonic decays of the Z boson obtained with a polarized electron beam.

[143] ALEXANDER 96U measure the τ-lepton polarization and the forward-backward polarization asymmetry.

[144] ABE 95J obtain this result from polarized Bhabha scattering.

[145] BUSKULIC 95Q obtain this result fitting the τ polarization as a function of the polar τ production angle.

[146] ABE 97E measure the left-right asymmetry in hadronic Z production. This value (statistical and systematic errors added in quadrature) leads to $\sin^2\theta_W^{\rm eff} = 0.23060 \pm 0.00050$.

A_μ

This quantity is directly extracted from a measurement of the left-right forward-backward asymmetry in $\mu^+\mu^-$ production at SLC using a polarized electron beam. This double asymmetry eliminates the dependence on the Z-e-e coupling parameter A_e.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.102±0.034	3788	[147] ABE	97N	SLD	$E^{ee}_{\rm cm}$= 91.27 GeV

[147] ABE 97N obtain this direct measurement using the left-right cross section asymmetry and the left-right forward-backward asymmetry in $\mu^+\mu^-$ decays of the Z boson obtained with a polarized electron beam.

A_τ

The LEP Collaborations derive this quantity from the measurement of the τ polarization in $Z \rightarrow \tau^+\tau^-$. The SLD Collaboration directly extracts this quantity from its measured left-right forward-backward asymmetry in $Z \rightarrow \tau^+\tau^-$ produced using a polarized e^- beam. This double asymmetry eliminates the dependence on the Z-e-e coupling parameter A_e.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.141 ±0.006 OUR AVERAGE					
0.1359±0.0079±0.0055	105000	[148] ABREU	00E	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
0.1476±0.0088±0.0062	137092	ACCIARRI	98H	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
0.195 ±0.034		[149] ABE	97N	SLD	$E^{ee}_{\rm cm}$= 91.27 GeV
0.134 ±0.009 ±0.010	89075	[150] ALEXANDER	96U	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
0.136 ±0.012 ±0.009	33000	[151] BUSKULIC	95Q	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.148 ±0.017 ±0.014		ABREU	95I	DLPH	Repl. by ABREU 00E
0.153 ±0.019 ±0.013	30663	AKERS	95	OPAL	Repl. by ALEXANDER 96U
0.150 ±0.013 ±0.009	86000	ACCIARRI	94E	L3	Repl. by ACCIARRI 98H

[148] ABREU 00E obtain this result fitting the τ polarization as a function of the polar τ production angle. This measurement is a combination of different analyses (exclusive τ decay modes, inclusive hadronic 1-prong reconstruction, and a neural network analysis).

[149] ABE 97N obtain this direct measurement using the left-right cross section asymmetry and the left-right forward-backward asymmetry in $\tau^+\tau^-$ decays of the Z boson obtained with a polarized electron beam.

[150] ALEXANDER 96U measure the τ-lepton polarization and the forward-backward polarization asymmetry.

[151] BUSKULIC 95Q obtain this result fitting the τ polarization as a function of the polar τ production angle.

A_s

The SLD Collaboration directly extracts this quantity by a simultaneous fit to four measured s-quark polar angle distributions corresponding to two states of e^- polarization (positive and negative) and to the $K^+ K^-$ and $K^\pm K^0_S$ strange particle tagging modes in the hadronic final states.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.895±0.066±0.062	2870	[152] ABE	00D	SLD	E^{ee}_{cm}= 91.2 GeV

[152] ABE 00D tag $Z \to s\overline{s}$ events by an absence of B or D hadrons and the presence in each hemisphere of a high momentum $K^\pm$ or K^0_S.

A_c

This quantity is directly extracted from a measurement of the left-right forward-backward asymmetry in $c\overline{c}$ production at SLC using polarized electron beam. This double asymmetry eliminates the dependence on the Z-e-e coupling parameter A_e.

VALUE	DOCUMENT ID		TECN	COMMENT
0.66 ±0.11 OUR AVERAGE				
0.642±0.110±0.063	[153] ABE	99O	SLD	E^{ee}_{cm}= 91.27 GeV
0.73 ±0.22 ±0.10	[154] ABE,K	95	SLD	E^{ee}_{cm}= 91.26 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.37 ±0.23 ±0.21	[155] ABE	95L	SLD	Repl. by ABE 99O

[153] ABE 99O tag b and c quarks through their semileptonic decays into electrons and muons. A maximum likelihood fit is performed to extract simultaneously A_b and A_c.

[154] ABE,K 95 tag $Z \to c\overline{c}$ events using D^{*+} and D^+ meson production. To take care of the $b\overline{b}$ contamination in their analysis they use A^D_b= 0.64 ± 0.11 (which is A_b from D^*/D tagging). This is obtained by starting with a Standard Model value of 0.935, assigning it an estimated error of ±0.105 to cover LEP and SLD measurements, and finally taking into account B-$\overline{B}$ mixing ($1-2\chi_{mix}$ = 0.72 ± 0.09).

[155] ABE 95L tag b and c quarks through their semileptonic decays into electrons and muons. A maximum likelihood fit is performed to extract A_b and A_c.

A_b

This quantity is directly extracted from a measurement of the left-right forward-backward asymmetry in $b\overline{b}$ production at SLC using polarized electron beam. This double asymmetry eliminates the dependence on the Z-e-e coupling parameter A_e.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.905±0.051		[156] ABE	99O	SLD	E^{ee}_{cm}= 91.27 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.855±0.088±0.102	7473	[157] ABE	99L	SLD	Repl. by ABE 99O
0.911±0.045±0.045	11092	[158] ABE	98I	SLD	Repl. by ABE 99O
0.91 ±0.14 ±0.07		[159] ABE	95L	SLD	Repl. by ABE 99O

[156] ABE 99O tag b and c quarks through their semileptonic decays into electrons and muons. A maximum likelihood fit is performed to extract simultaneously A_b and A_c. The value of A_b so extracted, 0.910 ± 0.068 ± 0.037, is then combined with A_b from ABE 99L and ABE 99I to obtain the resulting SLD average value quoted here.

[157] ABE 99L obtain an enriched sample of $b\overline{b}$ events tagging with an inclusive vertex mass cut. For distinguishing b and $\overline{b}$ quarks they use the charge of identified $K^\pm$.

[158] ABE 98I obtain an enriched sample of $b\overline{b}$ events tagging with an inclusive vertex mass cut. A momentum-weighted track charge is used to identify the sign of the charge of the underlying b quark.

[159] ABE 95L tag b and c quarks through their semileptonic decays into electrons and muons. A maximum likelihood fit is performed to extract A_b and A_c.

TRANSVERSE SPIN CORRELATIONS IN $Z \to \tau^+\tau^-$

The correlations between the transverse spin components of $\tau^+\tau^-$ produced in Z decays may be expressed in terms of the vector and axial-vector couplings:

$$C_{TT} = \frac{|g_A^\tau|^2 - |g_V^\tau|^2}{|g_A^\tau|^2 + |g_V^\tau|^2}$$

$$C_{TN} = -2\frac{|g_A^\tau||g_V^\tau|}{|g_A^\tau|^2 + |g_V^\tau|^2}\ \sin(\Phi_{g_V^\tau} - \Phi_{g_A^\tau})$$

C_{TT} refers to the transverse-transverse (within the collision plane) spin correlation and C_{TN} refers to the transverse-normal (to the collision plane) spin correlation.

The longitudinal τ polarization P_τ $(= -A_\tau)$ is given by:

$$P_\tau = -2\frac{|g_A^\tau||g_V^\tau|}{|g_A^\tau|^2 + |g_V^\tau|^2}\ \cos(\Phi_{g_V^\tau} - \Phi_{g_A^\tau})$$

Here Φ is the phase and the phase difference $\Phi_{g_V^\tau} - \Phi_{g_A^\tau}$ can be obtained using both the measurements of C_{TN} and P_τ.

C_{TT}

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
1.01±0.12 OUR AVERAGE					
$0.87\pm0.20^{+0.10}_{-0.12}$	9.1k	ABREU	97G	DLPH	E^{ee}_{cm}= 91.2 GeV
1.06±0.13±0.05	120k	BARATE	97D	ALEP	E^{ee}_{cm}= 91.2 GeV

C_{TN}

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.08±0.13±0.04	120k	[160] BARATE	97D	ALEP	E^{ee}_{cm}= 91.2 GeV

[160] BARATE 97D combine their value of C_{TN} with the world average $P_\tau = -0.140 \pm 0.007$ to obtain $\tan(\Phi_{g_V^\tau} - \Phi_{g_A^\tau}) = -0.57 \pm 0.97$.

$A_{FB}^{(0,e)}$ CHARGE ASYMMETRY IN $e^+e^- \to e^+e^-$

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the "Note on the Z boson"). For the Z peak, we report the pole asymmetry defined by $(3/4)A_e^2$ as determined by the nine-parameter fit to cross-section and lepton forward-backward asymmetry data.

ASYMMETRY (%)	STD. MODEL	$\sqrt{s}$ (GeV)	DOCUMENT ID		TECN
1.45±0.25 OUR FIT					
0.89±0.44		91.2	[161] ABBIENDI	01A	OPAL
1.71±0.49		91.2	ABREU	00F	DLPH
1.06±0.58		91.2	ACCIARRI	00C	L3
1.88±0.34		91.2	[162] BARATE	00C	ALEP

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

2.5 ±0.9	91.2	ABREU	94	DLPH
1.04±0.92	91.2	ACCIARRI	94	L3
0.62±0.80	91.2	AKERS	94	OPAL
1.85±0.66	91.2	BUSKULIC	94	ALEP

[161] ABBIENDI 01A error includes approximately 0.38 due to statistics, 0.16 due to event selection systematics, and 0.18 due to the theoretical uncertainty in t-channel prediction.
[162] BARATE 00C error includes approximately 0.31 due to statistics, 0.06 due to experimental systematics, and 0.13 due to the theoretical uncertainty in t-channel prediction.

$A_{FB}^{(0,\mu)}$ CHARGE ASYMMETRY IN $e^+e^- \rightarrow \mu^+\mu^-$

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the "Note on the Z boson"). For the Z peak, we report the pole asymmetry defined by $(3/4)A_e A_\mu$ as determined by the nine-parameter fit to cross-section and lepton forward-backward asymmetry data.

ASYMMETRY (%)	STD. MODEL	$\sqrt{s}$ (GeV)	DOCUMENT ID		TECN
1.69± 0.13 OUR FIT					
1.59± 0.23		91.2	[163] ABBIENDI	01A	OPAL
1.65± 0.25		91.2	ABREU	00F	DLPH
1.88± 0.33		91.2	ACCIARRI	00C	L3
1.71± 0.24		91.2	[164] BARATE	00C	ALEP
• • • We do not use the following data for averages, fits, limits, etc. • • •					
9 ±30	−2	20	[165] ABREU	95M	DLPH
7 ±26	−10	40	[165] ABREU	95M	DLPH
−11 ±33	−25	57	[165] ABREU	95M	DLPH
−62 ±17	−45	69	[165] ABREU	95M	DLPH
−56 ±10	−58	79	[165] ABREU	95M	DLPH
−13 ± 5	−23	87.5	[165] ABREU	95M	DLPH
1.4 ± 0.5		91.2	ABREU	94	DLPH
1.79± 0.61		91.2	ACCIARRI	94	L3
0.99± 0.42		91.2	AKERS	94	OPAL
1.46± 0.48		91.2	BUSKULIC	94	ALEP
$-29.0\ ^{+5.0}_{-4.8}$ ±0.5	−32.1	56.9	[166] ABE	90I	VNS
− 9.9 ± 1.5 ±0.5	−9.2	35	HEGNER	90	JADE
0.05± 0.22	0.026	91.14	[167] ABRAMS	89D	MRK2
−43.4 ±17.0	−24.9	52.0	[168] BACALA	89	AMY
−11.0 ±16.5	−29.4	55.0	[168] BACALA	89	AMY
−30.0 ±12.4	−31.2	56.0	[168] BACALA	89	AMY
−46.2 ±14.9	−33.0	57.0	[168] BACALA	89	AMY
−29 ±13	−25.9	53.3	ADACHI	88C	TOPZ
+ 5.3 ± 5.0 ±0.5	−1.2	14.0	ADEVA	88	MRKJ

$-10.4 \pm 1.3 \pm 0.5$	-8.6	34.8	ADEVA	88	MRKJ
$-12.3 \pm 5.3 \pm 0.5$	-10.7	38.3	ADEVA	88	MRKJ
$-15.6 \pm 3.0 \pm 0.5$	-14.9	43.8	ADEVA	88	MRKJ
-1.0 ± 6.0	-1.2	13.9	BRAUNSCH...	88D	TASS
$-9.1 \pm 2.3 \pm 0.5$	-8.6	34.5	BRAUNSCH...	88D	TASS
$-10.6 {+2.2 \atop -2.3} \pm 0.5$	-8.9	35.0	BRAUNSCH...	88D	TASS
$-17.6 {+4.4 \atop -4.3} \pm 0.5$	-15.2	43.6	BRAUNSCH...	88D	TASS
$-4.8 \pm 6.5 \pm 1.0$	-11.5	39	BEHREND	87C	CELL
$-18.8 \pm 4.5 \pm 1.0$	-15.5	44	BEHREND	87C	CELL
$+2.7 \pm 4.9$	-1.2	13.9	BARTEL	86C	JADE
$-11.1 \pm 1.8 \pm 1.0$	-8.6	34.4	BARTEL	86C	JADE
$-17.3 \pm 4.8 \pm 1.0$	-13.7	41.5	BARTEL	86C	JADE
$-22.8 \pm 5.1 \pm 1.0$	-16.6	44.8	BARTEL	86C	JADE
$-6.3 \pm 0.8 \pm 0.2$	-6.3	29	ASH	85	MAC
$-4.9 \pm 1.5 \pm 0.5$	-5.9	29	DERRICK	85	HRS
-7.1 ± 1.7	-5.7	29	LEVI	83	MRK2
-16.1 ± 3.2	-9.2	34.2	BRANDELIK	82C	TASS

[163] ABBIENDI 01A error is almost entirely on account of statistics.
[164] BARATE 00C error is almost entirely on account of statistics.
[165] ABREU 95M perform this measurement using radiative muon-pair events associated with high-energy isolated photons.
[166] ABE 90I measurements in the range 50 $\leq \sqrt{s} \leq$ 60.8 GeV.
[167] ABRAMS 89D asymmetry includes both 9 $\mu^+\mu^-$ and 15 $\tau^+\tau^-$ events.
[168] BACALA 89 systematic error is about 5%.

$A_{FB}^{(0,\tau)}$ CHARGE ASYMMETRY IN $e^+e^- \rightarrow \tau^+\tau^-$

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the "Note on the Z boson"). For the Z peak, we report the pole asymmetry defined by $(3/4)A_e A_\tau$ as determined by the nine-parameter fit to cross-section and lepton forward-backward asymmetry data.

ASYMMETRY (%)	STD. MODEL	$\sqrt{s}$ (GeV)	DOCUMENT ID		TECN
1.88± 0.17 OUR FIT					
1.45 ± 0.30		91.2	[169] ABBIENDI	01A	OPAL
2.41 ± 0.37		91.2	ABREU	00F	DLPH
2.60 ± 0.47		91.2	ACCIARRI	00C	L3
1.70 ± 0.28		91.2	[170] BARATE	00C	ALEP
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.2 ± 0.7		91.2	ABREU	94	DLPH
2.65 ± 0.88		91.2	ACCIARRI	94	L3
2.05 ± 0.52		91.2	AKERS	94	OPAL
1.97 ± 0.56		91.2	BUSKULIC	94	ALEP
$-32.8 {+6.4 \atop -6.2} \pm 1.5$	-32.1	56.9	[171] ABE	90I	VNS
$-8.1 \pm 2.0 \pm 0.6$	-9.2	35	HEGNER	90	JADE
-18.4 ± 19.2	-24.9	52.0	[172] BACALA	89	AMY
-17.7 ± 26.1	-29.4	55.0	[172] BACALA	89	AMY
-45.9 ± 16.6	-31.2	56.0	[172] BACALA	89	AMY

−49.5 ±18.0	−33.0	57.0	[172]	BACALA	89	AMY
−20 ±14	−25.9	53.3		ADACHI	88C	TOPZ
−10.6 ± 3.1 ±1.5	−8.5	34.7		ADEVA	88	MRKJ
− 8.5 ± 6.6 ±1.5	−15.4	43.8		ADEVA	88	MRKJ
− 6.0 ± 2.5 ±1.0	8.8	34.6		BARTEL	85F	JADE
−11.8 ± 4.6 ±1.0	14.8	43.0		BARTEL	85F	JADE
− 5.5 ± 1.2 ±0.5	−0.063	29.0		FERNANDEZ	85	MAC
− 4.2 ± 2.0	0.057	29		LEVI	83	MRK2
−10.3 ± 5.2	−9.2	34.2		BEHREND	82	CELL
− 0.4 ± 6.6	−9.1	34.2		BRANDELIK	82C	TASS

[169] ABBIENDI 01A error includes approximately 0.26 due to statistics and 0.14 due to event selection systematics.
[170] BARATE 00C error includes approximately 0.26 due to statistics and 0.11 due to experimental systematics.
[171] ABE 90I measurements in the range 50 $\leq \sqrt{s} \leq$ 60.8 GeV.
[172] BACALA 89 systematic error is about 5%.

$A_{FB}^{(0,\ell)}$ CHARGE ASYMMETRY IN $e^+ e^- \rightarrow \ell^+ \ell^-$

For the Z peak, we report the pole asymmetry defined by $(3/4)A_\ell^2$ as determined by the five-parameter fit to cross-section and lepton forward-backward asymmetry data assuming lepton universality. For details see the "Note on the Z boson."

ASYMMETRY (%)	STD. MODEL	$\sqrt{s}$ (GeV)		DOCUMENT ID		TECN
1.71±0.10 OUR FIT						
1.45±0.17		91.2	[173]	ABBIENDI	01A	OPAL
1.87±0.19		91.2		ABREU	00F	DLPH
1.92±0.24		91.2		ACCIARRI	00C	L3
1.73±0.16		91.2	[174]	BARATE	00C	ALEP
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1.77±0.37		91.2		ABREU	94	DLPH
1.84±0.45		91.2		ACCIARRI	94	L3
1.28±0.30		91.2		AKERS	94	OPAL
1.71±0.33		91.2		BUSKULIC	94	ALEP

[173] ABBIENDI 01A error includes approximately 0.15 due to statistics, 0.06 due to event selection systematics, and 0.03 due to the theoretical uncertainty in t-channel prediction.
[174] BARATE 00C error includes approximately 0.15 due to statistics, 0.04 due to experimental systematics, and 0.02 due to the theoretical uncertainty in t-channel prediction.

$A_{FB}^{(0,u)}$ CHARGE ASYMMETRY IN $e^+ e^- \rightarrow u\overline{u}$

ASYMMETRY (%)	STD. MODEL	$\sqrt{s}$ (GeV)		DOCUMENT ID		TECN
4.0±6.7±2.8	**6**	**91.2**	[175]	ACKERSTAFF	97T	OPAL

[175] ACKERSTAFF 97T measure the forward-backward asymmetry of various fast hadrons made of light quarks. Then using SU(2) isospin symmetry and flavor independence for down and strange quarks authors solve for the different quark types.

$A_{FB}^{(0,s)}$ CHARGE ASYMMETRY IN $e^+e^- \rightarrow s\overline{s}$

The *s*-quark asymmetry is derived from measurements of the forward-backward asymmetry of fast hadrons containing an *s* quark.

ASYMMETRY (%)	*STD. MODEL*	$\sqrt{s}$ *(GeV)*	*DOCUMENT ID*		*TECN*
9.8 ±1.1 OUR AVERAGE					
10.08±1.13±0.40		91.2	[176] ABREU	00B	DLPH
6.8 ±3.5 ±1.1	10	91.2	[177] ACKERSTAFF	97T	OPAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
13.1 ±3.5 ±1.3		91.2	[178] ABREU	95G	DLPH

[176] ABREU 00B tag the presence of an *s* quark requiring a high-momentum-identified charged kaon. The *s*-quark pole asymmetry is extracted from the charged-kaon asymmetry taking the expected *d*- and *u*-quark asymmetries from the Standard Model and using the measured values for the *c*- and *b*-quark asymmetries.

[177] ACKERSTAFF 97T measure the forward-backward asymmetry of various fast hadrons made of light quarks. Then using SU(2) isospin symmetry and flavor independence for down and strange quarks authors solve for the different quark types. The value reported here corresponds then to the forward-backward asymmetry for "down-type" quarks.

[178] ABREU 95G require the presence of a high-momentum charged kaon or Λ^0 to tag the *s* quark. An unresolved *s*- and *d*-quark asymmetry of $(11.2 \pm 3.1 \pm 5.4)\%$ is obtained by tagging the presence of a high-energy neutron or neutral kaon in the hadron calorimeter. Superseded by ABREU 00B.

$A_{FB}^{(0,c)}$ CHARGE ASYMMETRY IN $e^+e^- \rightarrow c\overline{c}$

OUR FIT, which is obtained by a simultaneous fit to several *c*- and *b*-quark measurements as explained in the "Note on the *Z* boson," refers to the *Z* pole asymmetry. As a cross check we have also performed a weighted average of the "near peak" measurements taking into account the various common systematic errors. Applying to this combined "peak" measurement QED and energy-dependence corrections, our weighted average gives a pole asymmetry of $(7.07 \pm 0.53)\%$.

ASYMMETRY (%)	*STD. MODEL*	$\sqrt{s}$ *(GeV)*	*DOCUMENT ID*		*TECN*
7.01± 0.45 OUR FIT					
6.59± 0.94±0.35		91.235	[179] ABREU	99Y	DLPH
6.3 ± 0.9 ±0.3		91.22	[180] BARATE	98O	ALEP
6.3 ± 1.2 ±0.6		91.22	[181] ALEXANDER	97C	OPAL
6.00± 0.67±0.52		91.24	[182] ALEXANDER	96	OPAL
8.3 ± 2.2 ±1.6		91.27	[183] ABREU	95K	DLPH
9.9 ± 2.0 ±1.7		91.24	[184] BUSKULIC	94G	ALEP
8.3 ± 3.8 ±2.7	5.6	91.24	[185] ADRIANI	92D	L3

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

$-$ 4.96 $\pm$ 3.68 $\pm$ 0.53		89.434	[179] ABREU	99Y DLPH
11.80 $\pm$ 3.18 $\pm$ 0.62		92.990	[179] ABREU	99Y DLPH
$-$ 1.0 $\pm$ 4.3 $\pm$ 1.0		89.37	[180] BARATE	98O ALEP
11.0 $\pm$ 3.3 $\pm$ 0.8		92.96	[180] BARATE	98O ALEP
3.9 $\pm$ 5.1 $\pm$ 0.9		89.45	[181] ALEXANDER	97C OPAL
15.8 $\pm$ 4.1 $\pm$ 1.1		93.00	[181] ALEXANDER	97C OPAL
$-$ 7.5 $\pm$ 3.4 $\pm$ 0.6	$-$3.5	89.52	[182] ALEXANDER	96 OPAL
14.1 $\pm$ 2.8 $\pm$ 0.9	12.0	92.94	[182] ALEXANDER	96 OPAL
7.7 $\pm$ 2.9 $\pm$ 1.2		91.27	[186] ABREU	95E DLPH
6.99 $\pm$ 2.05 $\pm$ 1.02		91.24	[187] BUSKULIC	95I ALEP
$-$12.9 $\pm$ 7.8 $\pm$ 5.5	$-$13.6	35	BEHREND	90D CELL
7.7 $\pm$ 13.4 $\pm$ 5.0	$-$22.1	43	BEHREND	90D CELL
$-$12.8 $\pm$ 4.4 $\pm$ 4.1	$-$13.6	35	ELSEN	90 JADE
$-$10.9 $\pm$ 12.9 $\pm$ 4.6	$-$23.2	44	ELSEN	90 JADE
$-$14.9 $\pm$ 6.7	$-$13.3	35	OULD-SAADA	89 JADE

[179] ABREU 99Y tag $Z \to b\overline{b}$ and $Z \to c\overline{c}$ events by an exclusive reconstruction of several D meson decay modes (D^{*+}, D^0, and D^+ with their charge-conjugate states).

[180] BARATE 98O tag $Z \to c\overline{c}$ events requiring the presence of high-momentum reconstructed D^{*+}, D^+, or D^0 mesons.

[181] ALEXANDER 97C identify the b and c events using a D/D^* tag.

[182] ALEXANDER 96 tag heavy flavors using one or two identified leptons. This allows the simultaneous fitting of the b and c quark forward-backward asymmetries as well as the average B^0-$\overline{B}^0$ mixing.

[183] ABREU 95K identify c and b quarks using both electron and muon semileptonic decays.

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

[185] ADRIANI 92D use both electron and muon semileptonic decays.

[186] ABREU 95E require the presence of a $D^{*\pm}$ to identify c and b quarks. Replaced by ABREU 99Y.

[187] BUSKULIC 95I require the presence of a high momentum $D^{*\pm}$ to have an enriched sample of $Z \to c\overline{c}$ events. Replaced by BARATE 98O.

$A_{FB}^{(0,b)}$ CHARGE ASYMMETRY IN $e^+e^- \to b\overline{b}$

OUR FIT, which is obtained by a simultaneous fit to several c- and b-quark measurements as explained in the "Note on the Z boson," refers to the Z pole asymmetry. As a cross check we have also performed a weighted average of the "near peak" measurements taking into account the various common systematic errors. Applying to this combined "peak" measurement QED and energy-dependence corrections, our weighted average gives a pole asymmetry of (10.07 $\pm$ 0.27)%. For the jet-charge measurements (where the QCD effects are included since they represent an inherent part of the analysis), we use the corrections given by the authors.

ASYMMETRY (%)	STD. MODEL	$\sqrt{s}$ (GeV)	DOCUMENT ID	TECN
10.03 $\pm$ 0.22 OUR FIT				
9.82 $\pm$ 0.47 $\pm$ 0.16		91.26	[188] ABREU	99M DLPH
7.62 $\pm$ 1.94 $\pm$ 0.85		91.235	[189] ABREU	99Y DLPH
9.60 $\pm$ 0.66 $\pm$ 0.33		91.26	[190] ACCIARRI	99D L3
9.31 $\pm$ 1.01 $\pm$ 0.55		91.24	[191] ACCIARRI	98U L3
10.40 $\pm$ 0.40 $\pm$ 0.32		91.25	[192] BARATE	98M ALEP

9.94 ± 0.52 ± 0.44		91.21	[193]	ACKERSTAFF	97P	OPAL
9.4 ± 2.7 ± 2.2		91.22	[194]	ALEXANDER	97C	OPAL
9.06 ± 0.51 ± 0.23		91.24	[195]	ALEXANDER	96	OPAL
9.65 ± 0.44 ± 0.26		91.21	[196]	BUSKULIC	96Q	ALEP
10.4 ± 1.3 ± 0.5		91.27	[197]	ABREU	95K	DLPH

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

6.8 ± 1.8 ± 0.13		89.55	[188]	ABREU	99M	DLPH
12.3 ± 1.6 ± 0.27		92.94	[188]	ABREU	99M	DLPH
5.67 ± 7.56 ± 1.17		89.434	[189]	ABREU	99Y	DLPH
8.82 ± 6.33 ± 1.22		92.990	[189]	ABREU	99Y	DLPH
6.11 ± 2.93 ± 0.43		89.50	[190]	ACCIARRI	99D	L3
13.71 ± 2.40 ± 0.44		93.10	[190]	ACCIARRI	99D	L3
4.95 ± 5.23 ± 0.40		89.45	[191]	ACCIARRI	98U	L3
11.37 ± 3.99 ± 0.65		92.99	[191]	ACCIARRI	98U	L3
7.46 ± 1.78 ± 0.24		89.43	[192]	BARATE	98M	ALEP
9.24 ± 1.79 ± 0.52		92.97	[192]	BARATE	98M	ALEP
4.1 ± 2.1 ± 0.2		89.44	[193]	ACKERSTAFF	97P	OPAL
14.5 ± 1.7 ± 0.7		92.91	[193]	ACKERSTAFF	97P	OPAL
−8.6 ± 10.8 ± 2.9		89.45	[194]	ALEXANDER	97C	OPAL
−2.1 ± 9.0 ± 2.6		93.00	[194]	ALEXANDER	97C	OPAL
5.5 ± 2.4 ± 0.3	5.5	89.52	[195]	ALEXANDER	96	OPAL
11.7 ± 2.0 ± 0.3	11.4	92.94	[195]	ALEXANDER	96	OPAL
−3.4 ± 11.2 ± 0.7		88.38	[196]	BUSKULIC	96Q	ALEP
5.3 ± 2.0 ± 0.2		89.38	[196]	BUSKULIC	96Q	ALEP
8.9 ± 5.9 ± 0.4		90.21	[196]	BUSKULIC	96Q	ALEP
3.8 ± 5.1 ± 0.2		92.05	[196]	BUSKULIC	96Q	ALEP
10.3 ± 1.6 ± 0.4		92.94	[196]	BUSKULIC	96Q	ALEP
8.8 ± 7.5 ± 0.5		93.90	[196]	BUSKULIC	96Q	ALEP
5.9 ± 6.2 ± 2.4		91.27	[198]	ABREU	95E	DLPH
11.5 ± 1.7 ± 1.0		91.27	[199]	ABREU	95K	DLPH
6.2 ± 3.4 ± 0.2		89.52	[200]	AKERS	95S	OPAL
9.63 ± 0.67 ± 0.38		91.25	[200]	AKERS	95S	OPAL
17.2 ± 2.8 ± 0.7		92.94	[200]	AKERS	95S	OPAL
8.7 ± 1.1 ± 0.4		91.3	[201]	ACCIARRI	94D	L3
8.7 ± 1.4 ± 0.2		91.24	[202]	BUSKULIC	94G	ALEP
9.92 ± 0.84 ± 0.46		91.19	[203]	BUSKULIC	94I	ALEP
$-71 \pm 34 {}^{+7}_{-8}$	−58	58.3		SHIMONAKA	91	TOPZ
−22.2 ± 7.7 ± 3.5	−26.0	35		BEHREND	90D	CELL
−49.1 ± 16.0 ± 5.0	−39.7	43		BEHREND	90D	CELL
−28 ± 11	−23	35		BRAUNSCH...	90	TASS
−16.6 ± 7.7 ± 4.8	−24.3	35		ELSEN	90	JADE
−33.6 ± 22.2 ± 5.2	−39.9	44		ELSEN	90	JADE
3.4 ± 7.0 ± 3.5	−16.0	29.0		BAND	89	MAC
−72 ± 28 ± 13	−56	55.2		SAGAWA	89	AMY

[188] ABREU 99M tag $Z \to b\overline{b}$ events using lifetime and vertex charge. The original quark charge is obtained from the charge flow, the difference between the forward and backward hemisphere charges.

[189] ABREU 99Y tag $Z \to b\overline{b}$ and $Z \to c\overline{c}$ events by an exclusive reconstruction of several D meson decay modes (D^{*+}, D^0, and D^+ with their charge-conjugate states).

[190] ACCIARRI 99D tag $Z \rightarrow b\overline{b}$ events using high p and p_T leptons. The analysis determines simultaneously a mixing parameter $\chi_b = 0.1192 \pm 0.0068 \pm 0.0051$ which is used to correct the observed asymmetry.

[191] ACCIARRI 98U tag $Z \rightarrow b\overline{b}$ events using lifetime and measure the jet charge using the hemisphere charge.

[192] BARATE 98M tag $Z \rightarrow b\overline{b}$ events using lifetime and measure the jet charge using the hemisphere charge. The analysis is performed as a function of the b quark purity and b polar angle.

[193] ACKERSTAFF 97P tag b quarks using lifetime. The quark charge is measured using both jet charge and vertex charge, a weighted sum of the charges of tracks in a jet which contains a tagged secondary vertex.

[194] ALEXANDER 97C identify the b and c events using a D/D^* tag.

[195] ALEXANDER 96 tag heavy flavors using one or two identified leptons. This allows the simultaneous fitting of the b and c quark forward-backward asymmetries as well as the average B^0-$\overline{B}^0$ mixing.

[196] BUSKULIC 96Q tag b-quark flavor and charge using high transverse momentum leptons. The asymmetry value at the Z peak is obtained using a charm charge asymmetry of 6.17%.

[197] ABREU 95K identify c and b quarks using both electron and muon semileptonic decays. The systematic error includes an uncertainty of ± 0.3 due to the mixing correction ($\chi = 0.115 \pm 0.011$).

[198] ABREU 95E require the presence of a $D^{*\pm}$ to identify c and b quarks. Replaced by ABREU 99Y.

[199] ABREU 95K tag b quarks using lifetime; the quark charge is identified using jet charge. The systematic error includes an uncertainty of ± 0.3 due to the mixing correction ($\chi = 0.115 \pm 0.011$). Replaced by ABREU 99M.

[200] AKERS 95S tag b quarks using lifetime; the quark charge is measured using jet charge. These asymmetry values are obtained using $R_b = \Gamma(b\overline{b})/\Gamma(\text{hadrons}) = 0.216$. For a value of R_b different from this by an amount ΔR_b, the change in the asymmetry values is given by $-K\Delta R_b$, where $K = 0.082$, 0.471, and 0.855 for $\sqrt{s}$ values of 89.52, 91.25, and 92.94 GeV respectively. Replaced by ACKERSTAFF 97P.

[201] ACCIARRI 94D use both electron and muon semileptonic decays. Replaced by ACCIARRI 99D.

[202] BUSKULIC 94G perform a simultaneous fit to the p and p_T spectra of both single and dilepton events. Replaced by BUSKULIC 96Q.

[203] BUSKULIC 94I use the lifetime tag method to obtain a high purity sample of $Z \rightarrow b\overline{b}$ events and the hemisphere charge technique to obtain the jet charge. Replaced by BARATE 98M.

CHARGE ASYMMETRY IN $e^+e^- \rightarrow q\overline{q}$

Summed over five lighter flavors.

Experimental and Standard Model values are somewhat event-selection dependent. Standard Model expectations contain some assumptions on B^0-$\overline{B}^0$ mixing and on other electroweak parameters.

ASYMMETRY (%)	STD. MODEL	$\sqrt{s}$ (GeV)	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$-$ 0.76$\pm$0.12$\pm$0.15		91.2	[204] ABREU	92I	DLPH
4.0 $\pm$0.4 $\pm$0.63	4.0	91.3	[205] ACTON	92L	OPAL
9.1 $\pm$1.4 $\pm$1.6	9.0	57.9	ADACHI	91	TOPZ
$-$ 0.84$\pm$0.15$\pm$0.04		91	DECAMP	91B	ALEP
8.3 $\pm$2.9 $\pm$1.9	8.7	56.6	STUART	90	AMY
11.4 $\pm$2.2 $\pm$2.1	8.7	57.6	ABE	89L	VNS
6.0 $\pm$1.3	5.0	34.8	GREENSHAW	89	JADE
8.2 $\pm$2.9	8.5	43.6	GREENSHAW	89	JADE

[204] ABREU 92I has 0.14 systematic error due to uncertainty of quark fragmentation.

[205] ACTON 92L use the weight function method on 259k selected $Z \rightarrow$ hadrons events. The systematic error includes a contribution of 0.2 due to B^0-$\overline{B}^0$ mixing effect, 0.4 due to Monte Carlo (MC) fragmentation uncertainties and 0.3 due to MC statistics. ACTON 92L derive a value of $\sin^2\theta_W^{\rm eff}$ to be 0.2321 $\pm$ 0.0017 $\pm$ 0.0028.

CHARGE ASYMMETRY IN $p\overline{p} \rightarrow Z \rightarrow e^+e^-$

ASYMMETRY (%)	STD. MODEL	$\sqrt{s}$ (GeV)	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •					
5.2$\pm$5.9$\pm$0.4		91	ABE	91E	CDF

ANOMALOUS $ZZ\gamma$, $Z\gamma\gamma$, AND ZZV COUPLINGS

Revised March 2000 by C. Caso (Univ. of Genova) and A. Gurtu (Tata Inst.)

In the reaction $e^+e^- \rightarrow Z\gamma$, deviations from the Standard Model for the $ZV\gamma$ couplings may be described in terms of 8 parameters, h_i^V $(i = 1, 4;\ V = \gamma, Z)$ [1]. In this formalism h_1^V and h_2^V lead to CP-violating and h_3^V and h_4^V to CP-conserving effects. All these anomalous contributions to the cross section increase rapidly with center-of-mass energy. In order to ensure unitarity, these parameters are usually described by a form-factor representation, $h_i^V(s) = h_{i\circ}^V/(1 + s/\Lambda^2)^n$, where Λ is the energy scale for the manifestation of a new phenomenon and n

is a sufficiently large power. By convention one uses $n = 3$ for $h^V_{1,3}$ and $n = 4$ for $h^V_{2,4}$. Usually limits on h^V_i's are put assuming some value of Λ (sometimes ∞).

Above the $e^+e^- \to ZZ$ threshold, deviations from the Standard Model may be described by means of four anomalous couplings f^V_i $(i = 4,5; V = \gamma, Z)$ [2]. The anomalous couplings f^V_5 lead to violation of C and P symmetries while f^V_4 introduces CP violation. These couplings are zero at tree level in the Standard Model.

Reference

1. U. Baur and E.L. Berger Phys. Rev. **D47**, 4889 (1993).
2. K. Hagiwara *et al.*, Nucl. Phys. **B282**, 253 (1987).

h^V_i

Combining the L3 and OPAL results taking common systematics into account the following limits are derived (note LEPEWWG/TGC/2001-02, dated March 30, 2001, accessible at http://www.cern.ch/LEPEWWG/tgc/):

$-0.18 < h^Z_1 < +0.09$, $-0.08 < h^Z_2 < +0.11$,
$-0.21 < h^Z_3 < +0.10$, $-0.06 < h^Z_4 < +0.15$,
$-0.12 < h^\gamma_1 < +0.07$, $-0.07 < h^\gamma_2 < +0.07$,
$-0.11 < h^\gamma_3 < -0.01$, $+0.01 < h^\gamma_4 < +0.10$.

VALUE	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	[206] ABBIENDI,G	00C	OPAL
	[207] ACCIARRI	00O	L3
	[208] ABBOTT	98M	D0
	[209] ABREU	98K	DLPH

[206] ABBIENDI,G 00C study $e^+e^- \to Z\gamma$ events (with $Z \to q\overline{q}$ and $Z \to \nu\overline{\nu}$) at 189 GeV to obtain the central values (and 95% CL limits) of these couplings: $h^Z_1 = 0.000 \pm 0.100$ $(-0.190, 0.190)$, $h^Z_2 = 0.000 \pm 0.068$ $(-0.128, 0.128)$, $h^Z_3 = -0.074^{+0.102}_{-0.103}$ $(-0.269, 0.119)$, $h^Z_4 = 0.046 \pm 0.068$ $(-0.084, 0.175)$, $h^\gamma_1 = 0.000 \pm 0.061$ $(-0.115, 0.115)$, $h^\gamma_2 = 0.000 \pm 0.041$ $(-0.077, 0.077)$, $h^\gamma_3 = -0.080^{+0.039}_{-0.041}$ $(-0.164, -0.006)$, $h^\gamma_4 = 0.064^{+0.033}_{-0.030}$ $(+0.007, +0.134)$. The results are derived assuming that only one coupling at a time is different from zero.

[207] ACCIARRI 00O study 189 GeV $e^+e^- \to q\overline{q}\gamma$ and $e^+e^- \to \nu\overline{\nu}\gamma$ events to derive 95% CL limits on h^V_i. For deriving each limit the others are fixed at zero. They report: $-0.26 < h^Z_1 < 0.09$, $-0.10 < h^Z_2 < 0.16$, $-0.26 < h^Z_3 < 0.21$, $-0.11 < h^Z_4 < 0.19$, $-0.20 < h^\gamma_1 < 0.08$, $-0.11 < h^\gamma_2 < 0.11$, $-0.11 < h^\gamma_3 < 0.03$, $-0.02 < h^\gamma_4 < 0.10$.

208 ABBOTT 98M study $p\overline{p} \rightarrow Z\gamma$ +X, with $Z \rightarrow e^+e^-$, $\mu^+\mu^-$, $\overline{\nu}\nu$ at 1.8 TeV, to obtain 95% CL limits at Λ= 750 GeV: $|h^Z_{30}| < 0.36$, $|h^Z_{40}| < 0.05$ (keeping $|h^\gamma_{30}| < 0.37$, $|h^\gamma_{40}| < 0.05$ (keeping h^Z_i=0). Limits on the *CP*-violating couplings are $|h^Z_{10}| < 0.36$, $|h^Z_{20}| < 0.05$ (keeping h^γ_i=0), and $|h^\gamma_{10}| < 0.37$, $|h^\gamma_{20}| < 0.05$ (keeping h^Z_i=0).

209 ABREU 98K determine a 95% CL upper limit on $\sigma(e^+e^- \rightarrow \gamma +$ invisible particles) < 2.5 pb using 161 and 172 GeV data. This is used to set 95% CL limits on $|h^\gamma_{30}| < 0.8$ and $|h^Z_{30}| < 1.3$, derived at a scale Λ=1 TeV and with n=3 in the form factor representation.

f^V_i

Combining the L3 and OPAL results taking common systematics into account the following limits are derived (note LEPEWWG/TGC/2001-02, dated March 30, 2001, accessible at http://www.cern.ch/LEPEWWG/tgc/):

$$-1.8 < f^Z_4 < +1.8, \qquad -4.7 < f^Z_5 < +2.9,$$
$$-1.1 < f^\gamma_4 < +1.1, \qquad -3.0 < f^\gamma_5 < +2.8.$$

VALUE	*DOCUMENT ID*		*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	210 ABBIENDI	00N	OPAL
	211 ACCIARRI	99O	L3

210 ABBIENDI 00N study ZZ production in e^+e^- collisions at 183 and 189 GeV to derive 95% CL limits on the real and imaginary parts of f^V_i varying each one separately, keeping all others fixed to their Standard Model values. They report: $-2.1 <\mathrm{Re}\, f^Z_4 < 2.1$, $-2.1 <\mathrm{Im}\, f^Z_4 < 2.1$, $-6.2 <\mathrm{Re}\, f^Z_5 < 4.4$, $-6.4 <\mathrm{Im}\, f^Z_5 < 6.4$, $-1.2 <\mathrm{Re}\, f^\gamma_4 < 1.2$, $-1.2 <\mathrm{Im}\, f^\gamma_4 < 1.2$, $-3.9 <\mathrm{Re}\, f^\gamma_5 < 3.6$, $-3.8 <\mathrm{Im}\, f^\gamma_5 < 3.9$.

211 ACCIARRI 99O study ZZ production in e^+e^- collisions at 183 and 189 GeV to derive 95%CL limits on f^V_i. For deriving each limit the others are fixed at zero. They report: $-1.9 < f^Z_4 < 1.9$, $-5.0 < f^Z_5 < 4.5$, $-1.1 < f^\gamma_4 < 1.2$, $-3.0 < f^\gamma_5 < 2.9$.

ANOMALOUS W/Z QUARTIC COUPLINGS

Written January 2001 by C. Caso (Univ. of Genova) and A. Gurtu (Tata Inst.)

The Standard Model predictions for $WWWW$, $WWZZ$, $WWZ\gamma$, $WW\gamma\gamma$, and $ZZ\gamma\gamma$ couplings are small at LEP, but expected to become important at a TeV Linear Collider. Outside the Standard Model framework such possible couplings, a_0, a_c, a_n, are expressed in terms of the following dimension-6 operators [1,2];

$$L^0_6 = -\frac{e^2}{16\Lambda^2}\, a_0\, F^{\mu\nu}\, F_{\mu\nu}\vec{W}^\alpha \cdot \vec{W}_\alpha$$
$$L^c_6 = -\frac{e^2}{16\Lambda^2}\, a_c\, F^{\mu\alpha}\, F_{\mu\beta}\vec{W}^\beta \cdot \vec{W}_\alpha$$

$$L_6^n = -i\frac{e^2}{16\Lambda^2}\, a_n \epsilon_{ijk}\, W_{\mu\alpha}^{(i)}\, W_\nu^{(j)}\, W^{(k)\alpha} F^{\mu\nu}$$

where F, W are photon and W fields, L_6^0 and L_6^c conserve C, P separately and generate anomalous $W^+W^-\gamma\gamma$ and $ZZ\gamma\gamma$ couplings, L_6^n violates CP and generates an anomalous $W^+W^-Z\gamma$ coupling, and Λ is a scale for new physics. For the $ZZ\gamma\gamma$ coupling the CP-violating term represented by L_6^n does not contribute.

At LEP the processes studied in search of these quartic couplings are $e^+e^- \rightarrow WW\gamma$, $e^+e^- \rightarrow \gamma\gamma\nu\overline{\nu}$, and $e^+e^- \rightarrow Z\gamma\gamma$ and limits are set on the quantities $a_0/\Lambda^2, a_c/\Lambda^2, a_n/\Lambda^2$. The sensitive measured variables are the cross sections for these processes as well as the energy and angular distributions of the photon and recoil mass to the photon pair.

Combining results from all LEP experiments and channels, the limits presented at the Osaka Conference [3] are $-0.0049 < a_0/\Lambda^2 < 0.0056$, $-0.0054 < a_c/\Lambda^2 < 0.0098$, $-0.45 < a_n/\Lambda^2 < 0.41$.

References

1. G. Belanger and F. Boudjema, Nucl. Phys. **B288**, 201 (1992).
2. J.W. Stirling and A. Werthenbach, Eur. Phys. J. **C14**, 103 (2000).
3. S. Spagnolo: "Measurement of Quartic Gauge Boson Couplings", Electroweak parallel session, *XXXth International Conference on High Energy Physics*, Osaka, Japan, July 27 – August 2, 2000.

a_0/Λ^2, a_c/Λ^2

VALUE	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	[212] ACCIARRI	00I	L3

[212] ACCIARRI 00I select 48 $e^+e^- \rightarrow Z\gamma\gamma$ events combining 183 and 189 GeV data, with Z decaying hadronically, where $E_\gamma > 5$ GeV, the photons are well isolated, and the hadronic invariant mass is compatible with that of the Z (between 74 and 116

GeV). Fixing one parameter at a time to its Standard Model value, they obtain $a_0/\Lambda^2 = 0.001 \pm 0.004\ \mathrm{GeV}^{-2}$ and $a_c/\Lambda^2 = 0.003 \pm 0.005\ \mathrm{GeV}^{-2}$. A simultaneous fit to both parameters yields 95% CL limits $-0.009\ \mathrm{GeV}^{-2} < a_0/\Lambda^2 < 0.008\ \mathrm{GeV}^{-2}$, $-0.007\ \mathrm{GeV}^{-2} < a_c/\Lambda^2 < 0.013\ \mathrm{GeV}^{-2}$.

Z REFERENCES

ABBIENDI	01A	EPJ C19 587	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	01G	EPJ C18 447	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	00N	PL B476 256	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI,G	00C	EPJ C17 553	G. Abbiendi *et al.*	(OPAL Collab.)
ABE	00B	PRL 84 5945	K. Abe *et al.*	(SLD Collab.)
ABE	00D	PRL 85 5059	K. Abe *et al.*	(SLD Collab.)
ABREU	00	EPJ C12 225	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00B	EPJ C14 613	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00E	EPJ C14 585	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00F	EPJ C16 371	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00P	PL B475 429	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	00	EPJ C13 47	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	00C	EPJ C16 1	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	00I	PL B478 39	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	00J	PL B479 79	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	00O	PL B489 55	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	00Q	PL B489 93	M. Acciarri *et al.*	(L3 Collab.)
BARATE	00B	EPJ C16 597	R. Barate *et al.*	(ALEPH Collab.)
BARATE	00C	EPJ C14 1	R. Barate *et al.*	(ALEPH Collab.)
BARATE	00O	EPJ C16 613	R. Barate *et al.*	(ALEPH Collab.)
ABBIENDI	99B	EPJ C8 217	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	99I	PL B447 157	G. Abbiendi *et al.*	(OPAL Collab.)
ABE	99E	PR D59 052001	K. Abe *et al.*	(SLD Collab.)
ABE	99I	PR D59 092002	F. Abe *et al.*	(CDF Collab.)
ABE	99L	PRL 83 1902	K. Abe *et al.*	(SLD Collab.)
ABE	99O	PRL 83 3384	K. Abe *et al.*	(SLD Collab.)
ABREU	99	EPJ C6 19	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	99B	EPJ C10 415	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	99J	PL B449 364	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	99M	EPJ C9 367	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	99U	PL B462 425	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	99Y	EPJ C10 219	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	99D	PL B448 152	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	99F	PL B453 94	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	99O	PL B465 363	M. Acciarri *et al.*	(L3 Collab.)
ABBOTT	98M	PR D57 R3817	B. Abbott *et al.*	(D0 Collab.)
ABE	98D	PRL 80 660	K. Abe *et al.*	(SLD Collab.)
ABE	98I	PRL 81 942	K. Abe *et al.*	(SLD Collab.)
ABREU	98K	PL B423 194	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	98L	EPJ C5 585	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	98G	PL B431 199	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	98H	PL B429 387	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	98U	PL B439 225	M. Acciarri *et al.*	(L3 Collab.)
ACKERSTAFF	98A	EPJ C5 411	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	98E	EPJ C1 439	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	98O	PL B420 157	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	98Q	EPJ C4 19	K. Ackerstaff *et al.*	(OPAL Collab.)
BARATE	98M	PL B426 217	R. Barate *et al.*	(ALEPH Collab.)
BARATE	98O	PL B434 415	R. Barate *et al.*	(ALEPH Collab.)
BARATE	98T	EPJ C4 557	R. Barate *et al.*	(ALEPH Collab.)
BARATE	98V	EPJ C5 205	R. Barate *et al.*	(ALEPH Collab.)
ABE	97	PRL 78 17	K. Abe *et al.*	(SLD Collab.)
ABE	97E	PRL 78 2075	K. Abe *et al.*	(SLD Collab.)
ABE	97N	PRL 79 804	K. Abe *et al.*	(SLD Collab.)
ABREU	97C	ZPHY C73 243	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	97E	PL B398 207	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	97G	PL B404 194	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	97D	PL B393 465	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	97J	PL B407 351	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	97L	PL B407 389	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	97R	PL B413 167	M. Acciarri *et al.*	(L3 Collab.)

ACKERSTAFF	97C	PL B391 221	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	97K	ZPHY C74 1	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	97M	ZPHY C74 413	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	97P	ZPHY C75 385	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	97S	PL B412 210	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	97T	ZPHY C76 387	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	97W	ZPHY C76 425	K. Ackerstaff *et al.*	(OPAL Collab.)
ALEXANDER	97C	ZPHY C73 379	G. Alexander *et al.*	(OPAL Collab.)
ALEXANDER	97D	ZPHY C73 569	G. Alexander *et al.*	(OPAL Collab.)
ALEXANDER	97E	ZPHY C73 587	G. Alexander *et al.*	(OPAL Collab.)
BARATE	97D	PL B405 191	R. Barate *et al.*	(ALEPH Collab.)
BARATE	97E	PL B401 150	R. Barate *et al.*	(ALEPH Collab.)
BARATE	97F	PL B401 163	R. Barate *et al.*	(ALEPH Collab.)
BARATE	97H	PL B402 213	R. Barate *et al.*	(ALEPH Collab.)
BARATE	97J	ZPHY C74 451	R. Barate *et al.*	(ALEPH Collab.)
ABE	96E	PR D53 1023	K. Abe *et al.*	(SLD Collab.)
ABREU	96	ZPHY C70 531	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	96R	ZPHY C72 31	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	96S	PL B389 405	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	96U	ZPHY C73 61	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	96	PL B371 126	M. Acciarri *et al.*	(L3 Collab.)
ADAM	96	ZPHY C69 561	W. Adam *et al.*	(DELPHI Collab.)
ADAM	96B	ZPHY C70 371	W. Adam *et al.*	(DELPHI Collab.)
ALEXANDER	96	ZPHY C70 357	G. Alexander *et al.*	(OPAL Collab.)
ALEXANDER	96B	ZPHY C70 197	G. Alexander *et al.*	(OPAL Collab.)
ALEXANDER	96F	PL B370 185	G. Alexander *et al.*	(OPAL Collab.)
ALEXANDER	96N	PL B384 343	G. Alexander *et al.*	(OPAL Collab.)
ALEXANDER	96R	ZPHY C72 1	G. Alexander *et al.*	(OPAL Collab.)
ALEXANDER	96U	ZPHY C72 365	G. Alexander *et al.*	(OPAL Collab.)
BUSKULIC	96D	ZPHY C69 393	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	96H	ZPHY C69 379	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	96Q	PL B384 414	D. Buskulic *et al.*	(ALEPH Collab.)
ABE	95J	PRL 74 2880	K. Abe *et al.*	(SLD Collab.)
ABE	95L	PRL 74 2895	K. Abe *et al.*	(SLD Collab.)
ABE,K	95	PRL 75 3609	K. Abe *et al.*	(SLD Collab.)
ABREU	95	ZPHY C65 709 erratum	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95D	ZPHY C66 323	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95E	ZPHY C66 341	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95G	ZPHY C67 1	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95I	ZPHY C67 183	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95K	ZPHY C65 569	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95L	ZPHY C65 587	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95M	ZPHY C65 603	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95O	ZPHY C67 543	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95R	ZPHY C68 353	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95W	PL B361 207	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95X	ZPHY C69 1	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	95B	PL B345 589	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	95C	PL B345 609	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	95G	PL B353 136	M. Acciarri *et al.*	(L3 Collab.)
AKERS	95	ZPHY C65 1	R. Akers *et al.*	(OPAL Collab.)
AKERS	95C	ZPHY C65 47	R. Akers *et al.*	(OPAL Collab.)
AKERS	95O	ZPHY C67 27	R. Akers *et al.*	(OPAL Collab.)
AKERS	95S	ZPHY C67 365	R. Akers *et al.*	(OPAL Collab.)
AKERS	95U	ZPHY C67 389	R. Akers *et al.*	(OPAL Collab.)
AKERS	95W	ZPHY C67 555	R. Akers *et al.*	(OPAL Collab.)
AKERS	95X	ZPHY C68 1	R. Akers *et al.*	(OPAL Collab.)
AKERS	95Z	ZPHY C68 203	R. Akers *et al.*	(OPAL Collab.)
ALEXANDER	95D	PL B358 162	G. Alexander *et al.*	(OPAL Collab.)
BUSKULIC	95I	PL B352 479	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	95Q	ZPHY C69 183	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	95R	ZPHY C69 15	D. Buskulic *et al.*	(ALEPH Collab.)
MIYABAYASHI	95	PL B347 171	K. Miyabayashi *et al.*	(TOPAZ Collab.)
ABE	94C	PRL 73 25	K. Abe *et al.*	(SLD Collab.)
ABREU	94	NP B418 403	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	94B	PL B327 386	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	94P	PL B341 109	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	94	ZPHY C62 551	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	94D	PL B335 542	M. Acciarri *et al.*	(L3 Collab.)

ACCIARRI	94E	PL B341 245	M. Acciarri *et al.*	(L3 Collab.)
AKERS	94	ZPHY C61 19	R. Akers *et al.*	(OPAL Collab.)
AKERS	94P	ZPHY C63 181	R. Akers *et al.*	(OPAL Collab.)
BUSKULIC	94	ZPHY C62 539	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	94G	ZPHY C62 179	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	94I	PL B335 99	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	94J	ZPHY C62 1	D. Buskulic *et al.*	(ALEPH Collab.)
VILAIN	94	PL B320 203	P. Vilain *et al.*	(CHARM II Collab.)
ABREU	93	PL B298 236	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	93I	ZPHY C59 533	P. Abreu *et al.*	(DELPHI Collab.)
Also	95	ZPHY C65 709 erratum	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	93L	PL B318 249	P. Abreu *et al.*	(DELPHI Collab.)
ACTON	93	PL B305 407	P.D. Acton *et al.*	(OPAL Collab.)
ACTON	93D	ZPHY C58 219	P.D. Acton *et al.*	(OPAL Collab.)
ACTON	93E	PL B311 391	P.D. Acton *et al.*	(OPAL Collab.)
ACTON	93F	ZPHY C58 405	P.D. Acton *et al.*	(OPAL Collab.)
ADRIANI	93	PL B301 136	O. Adriani *et al.*	(L3 Collab.)
ADRIANI	93I	PL B316 427	O. Adriani *et al.*	(L3 Collab.)
BUSKULIC	93L	PL B313 520	D. Buskulic *et al.*	(ALEPH Collab.)
NOVIKOV	93C	PL B298 453	V.A. Novikov, L.B. Okun, M.I. Vysotsky	(ITEP)
ABREU	92I	PL B277 371	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	92M	PL B289 199	P. Abreu *et al.*	(DELPHI Collab.)
ACTON	92B	ZPHY C53 539	D.P. Acton *et al.*	(OPAL Collab.)
ACTON	92L	PL B294 436	P.D. Acton *et al.*	(OPAL Collab.)
ACTON	92N	PL B295 357	P.D. Acton *et al.*	(OPAL Collab.)
ADEVA	92	PL B275 209	B. Adeva *et al.*	(L3 Collab.)
ADRIANI	92D	PL B292 454	O. Adriani *et al.*	(L3 Collab.)
ALITTI	92B	PL B276 354	J. Alitti *et al.*	(UA2 Collab.)
BUSKULIC	92D	PL B292 210	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	92E	PL B294 145	D. Buskulic *et al.*	(ALEPH Collab.)
DECAMP	92	PRPL 216 253	D. Decamp *et al.*	(ALEPH Collab.)
LEP	92	PL B276 247	LEP Collabs.	(LEP, ALEPH, DELPHI, L3, OPAL)
ABE	91E	PRL 67 1502	F. Abe *et al.*	(CDF Collab.)
ABREU	91H	ZPHY C50 185	P. Abreu *et al.*	(DELPHI Collab.)
ACTON	91B	PL B273 338	D.P. Acton *et al.*	(OPAL Collab.)
ADACHI	91	PL B255 613	I. Adachi *et al.*	(TOPAZ Collab.)
ADEVA	91I	PL B259 199	B. Adeva *et al.*	(L3 Collab.)
AKRAWY	91F	PL B257 531	M.Z. Akrawy *et al.*	(OPAL Collab.)
DECAMP	91B	PL B259 377	D. Decamp *et al.*	(ALEPH Collab.)
DECAMP	91J	PL B266 218	D. Decamp *et al.*	(ALEPH Collab.)
JACOBSEN	91	PRL 67 3347	R.G. Jacobsen *et al.*	(Mark II Collab.)
SHIMONAKA	91	PL B268 457	A. Shimonaka *et al.*	(TOPAZ Collab.)
ABE	90I	ZPHY C48 13	K. Abe *et al.*	(VENUS Collab.)
ABRAMS	90	PRL 64 1334	G.S. Abrams *et al.*	(Mark II Collab.)
AKRAWY	90J	PL B246 285	M.Z. Akrawy *et al.*	(OPAL Collab.)
BEHREND	90D	ZPHY C47 333	H.J. Behrend *et al.*	(CELLO Collab.)
BRAUNSCH...	90	ZPHY C48 433	W. Braunschweig *et al.*	(TASSO Collab.)
ELSEN	90	ZPHY C46 349	E. Elsen *et al.*	(JADE Collab.)
HEGNER	90	ZPHY C46 547	S. Hegner *et al.*	(JADE Collab.)
STUART	90	PRL 64 983	D. Stuart *et al.*	(AMY Collab.)
ABE	89	PRL 62 613	F. Abe *et al.*	(CDF Collab.)
ABE	89C	PRL 63 720	F. Abe *et al.*	(CDF Collab.)
ABE	89L	PL B232 425	K. Abe *et al.*	(VENUS Collab.)
ABRAMS	89B	PRL 63 2173	G.S. Abrams *et al.*	(Mark II Collab.)
ABRAMS	89D	PRL 63 2780	G.S. Abrams *et al.*	(Mark II Collab.)
ALBAJAR	89	ZPHY C44 15	C. Albajar *et al.*	(UA1 Collab.)
BACALA	89	PL B218 112	A. Bacala *et al.*	(AMY Collab.)
BAND	89	PL B218 369	H.R. Band *et al.*	(MAC Collab.)
GREENSHAW	89	ZPHY C42 1	T. Greenshaw *et al.*	(JADE Collab.)
OULD-SAADA	89	ZPHY C44 567	F. Ould-Saada *et al.*	(JADE Collab.)
SAGAWA	89	PRL 63 2341	H. Sagawa *et al.*	(AMY Collab.)
ADACHI	88C	PL B208 319	I. Adachi *et al.*	(TOPAZ Collab.)
ADEVA	88	PR D38 2665	B. Adeva *et al.*	(Mark-J Collab.)
BRAUNSCH...	88D	ZPHY C40 163	W. Braunschweig *et al.*	(TASSO Collab.)
ANSARI	87	PL B186 440	R. Ansari *et al.*	(UA2 Collab.)
BEHREND	87C	PL B191 209	H.J. Behrend *et al.*	(CELLO Collab.)
BARTEL	86C	ZPHY C30 371	W. Bartel *et al.*	(JADE Collab.)
Also	85B	ZPHY C26 507	W. Bartel *et al.*	(JADE Collab.)
Also	82	PL 108B 140	W. Bartel *et al.*	(JADE Collab.)

ASH	85	PRL 55 1831	W.W. Ash *et al.*	(MAC Collab.)
BARTEL	85F	PL 161B 188	W. Bartel *et al.*	(JADE Collab.)
DERRICK	85	PR D31 2352	M. Derrick *et al.*	(HRS Collab.)
FERNANDEZ	85	PRL 54 1624	E. Fernandez *et al.*	(MAC Collab.)
LEVI	83	PRL 51 1941	M.E. Levi *et al.*	(Mark II Collab.)
BEHREND	82	PL 114B 282	H.J. Behrend *et al.*	(CELLO Collab.)
BRANDELIK	82C	PL 110B 173	R. Brandelik *et al.*	(TASSO Collab.)