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 LEP experiments (ALEPH, DELPHI, L3, OPAL) made high-statistics studies of the production and decay properties of the Z. Although the SLD experiment at the SLC collected much lower statistics, it was able to match the precision of LEP experiments in determining the effective electroweak mixing angle $\sin^2\overline{\theta}_W$ and the rates of Z decay to b- and c-quarks, owing to availability of polarized electron beams, small beam size and stable beam spot.

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

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

Determination of the b- and c-quark-related partial widths and charge asymmetries involves tagging the b and c quarks for which various methods are employed: requiring the presence of a high momentum prompt lepton in the event with high transverse momentum with respect to the accompanying jet; impact parameter and lifetime tagging using precision vertex measurement with high-resolution detectors; application of neural-network techniques to classify events as b or non-b on a statistical basis using event–shape variables; and using the presence of a charmed meson (D/D^*) or a kaon as a tag.

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 ($\sim$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 $e^+e^- \to f\overline{f}$:

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

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

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

$$\sigma^0_\gamma = \frac{4\pi\alpha^2(s)}{3s}\ Q_f^2 N_c^f \tag{4}$$

$$\sigma^0_{\gamma Z} = -\frac{2\sqrt{2}\alpha(s)}{3}\ (Q_f G_F N_c^f \mathcal{G}_V^e \mathcal{G}_V^f) \times \frac{(s - M_Z^2)M_Z^2}{(s - M_Z^2)^2 + s^2\Gamma_Z^2/M_Z^2} \tag{5}$$

where Q_f is the charge of the fermion, $N_c^f = 3$ for quarks and 1 for leptons and $\mathcal{G}_V^f$ is the 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. It is possible to relax this constraint and carry out the fit within the S-matrix framework which is briefly described in the next section.

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 [6]: $\alpha(s) = \alpha/(1 - \Delta\alpha)$. On the other hand, weak radiative corrections that depend upon the assumptions of the electroweak theory and on the values of $M_{\rm top}$ 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 [7].

$\mathcal{G}^f_V$ and $\mathcal{G}^f_A$ are complex numbers with small imaginary parts. 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 [8–10] $A^{(0,\ell)}_{FB} = (3/4)A_eA_f$, $P(\tau) = -A_\tau$, $P(\tau)^{fb} = -(3/4)A_e$, $A_{LR} = A_e$. 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:

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

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 most experimental analyses of LEP/SLC data have followed the 'Breit-Wigner' approach, 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]

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

leading to the relations

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

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

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

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 ABBIENDI 04G) 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 $M_{\rm top}$, and $M_{\rm Higgs} = 150$ 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 $M_{\rm top}$ and the unknown value of $M_{\rm Higgs}$ (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, $\sigma^0_{\rm hadron}$, $R(e)$, $R(\mu)$, $R(\tau)$, $A^{(0,e)}_{FB}$, $A^{(0,\mu)}_{FB}$, $A^{(0,\tau)}_{FB}$. Assumption of lepton universality leads to a **five-parameter fit** determining M_Z, Γ_Z, $\sigma^0_{\rm hadron}$, $R(\text{lepton})$, $A^{(0,\ell)}_{FB}$.

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 $\sigma^\circ_{\rm hadron}$.

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, $\sigma^\circ_{\rm hadron}$, 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, $\sigma^\circ_{\rm hadron}$ 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 $\log_{10} M_{\rm Higgs}/\text{GeV}$, 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 (±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 [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 $\chi^2 = \Delta^T V^{-1} \Delta$, where Δ is the vector of residuals of the combined parameter set to the results of individual experiments.

Having verified that the fit parameters for the individual leptons are same within errors, each LEP experiment carried out five parameter fits assuming lepton universality. These results are also combined following the same methodology as for the nine-parameter case. The Z listings give these as the "OUR FIT" values.

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 $A_{FB}^{c\overline{c}}$. The SLD experiment at SLC has measured the ratios R_c and R_b and, utilizing the polarization of the electron beam, was able to obtain the final state coupling parameters A_b and A_c from a measurement of the left-right forward-backward asymmetry of $b-$ and $c-$quarks. The high precision measurement of R_c at SLD was made possible owing to the small beam size and very stable beam spot at SLC, coupled with a highly precise CCD pixel detector. Several of the analyses have also determined other quantities, in particular the semileptonic branching ratios, $\mathrm{B}(b \to \ell^-)$, $\mathrm{B}(b \to c \to \ell^+)$, and $\mathrm{B}(c \to \ell^+)$, the average time-integrated $B^0\overline{B}^0$ 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 fourteen parameters: the six parameters of interest in the electroweak sector, R_b, R_c, $A_{FB}^{b\overline{b}}$, $A_{FB}^{c\overline{c}}$, A_b and A_c and, in addition, $\mathrm{B}(b \to \ell^-)$, $\mathrm{B}(b \to c \to \ell^+)$, $\mathrm{B}(c \to \ell^+)$, $\overline{\chi}$, $f(D^+)$, $f(D_s)$, $f(c_{\mathrm{baryon}})$ 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 energy 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. A second technique, named double-tag measurement, has the advantage that the tagging efficiency is directly derived from the data thereby reducing the systematic error on the measurement.

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;
- 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;
- A measurement of R_c using single leptons and assuming $\mathrm{B}(b \to c \to \ell^+)$;
- Lepton fits which use hadronic events with one or more leptons in the final state to measure the asymmetries $A_{FB}^{b\overline{b}}$ 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. These measurements dominate the combined result;
- 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 and SLD 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 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:

$$R_b = R_b^{\text{meas}} + a(R_c)\frac{(R_c - R_c^{\text{used}})}{R_c} , \qquad (12)$$

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 fourteen parameters described above and applied to the data contained in the Z particle listing below, gives the following results (where the last 8 parameters do not depend directly on the Z):

$$R_b^0 = 0.21629 \pm 0.00066$$

$$R_c^0 = 0.1721 \pm 0.0030$$

$$A_{FB}^{0,b} = 0.0992 \pm 0.0016$$

$$A_{FB}^{0,c} = 0.0707 \pm 0.0035$$

$$A_b = 0.923 \pm 0.020$$

$$A_c = 0.670 \pm 0.027$$

$$B(b \to \ell^-) = 0.1071 \pm 0.0022$$

$$\mathrm{B}(b \to c \to \ell^+) = 0.0801 \pm 0.0018$$

$$B(c \to \ell^+) = 0.0969 \pm 0.0031$$

$$\overline{\chi} = 0.1250 \pm 0.0039$$

$$f(D^+) = 0.235 \pm 0.016$$

$$f(D_s) = 0.126 \pm 0.026$$

$$f(c_{\rm baryon}) = 0.093 \pm 0.022$$

$$P(c \to D^{*+}) \times {\rm B}(D^{*+} \to \pi^+ D^0) = 0.1622 \pm 0.0048$$

Among the non–electroweak observables the B semileptonic branching fraction $B(b \to \ell^-)$ is of special interest since the dominant error source on this quantity is the dependence on the semileptonic decay model for $b \to \ell^-$, with $\Delta B(b \to \ell^-)_{b\to\ell^- -{\rm model}} = 0.0012$. Extensive studies have been made to understand the size of this error. Among the electroweak quantities the quark asymmetries with leptons depend also on the semileptonic decay model while the asymmetries using other methods usually do not. The fit implicitely requires that the different methods give consistent results and this effectively constraints the decay model and thus reduces in principle the error from this source in the fit result.

To obtain a conservative estimate of the modelling error the above fit has been repeated removing all asymmetry measurements. The results of the fit on B–decay related observables are [24]: $B(b \to \ell^-) = 0.1069 \pm 0.0022$, with $\Delta B(b \to \ell^-)_{b\to\ell^- -{\rm model}} = 0.0013$, $B(b \to c \to \ell^+) = 0.0802 \pm 0.0019$ and $\overline{\chi} = 0.1259 \pm 0.0042$.

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CERN-PH-EP/2005-041 (2005), accepted by Phys. Rep.; CERN-PH-EP/2004-069 (2004);
CERN-EP/2003-091 (2003); CERN-EP/2002-091 (2002); CERN-EP/2001-098 (2001); CERN-EP/2001-021 (2001); CERN-EP/2000-016 (1999); CERN-EP/99-15 (1998); CERN-PPE/97-154 (1997); CERN-PPE/96-183 (1996); CERN-PPE/95-172 (1995); CERN-PPE/94-187 (1994); CERN-PPE/93-157 (1993).
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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 ABBIENDI 04G 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. • • •

91.1872	±0.0033			[5] ABBIENDI	04G	OPAL	E^{ee}_{cm}= LEP1 + 130–209 GeV
91.272	±0.032	±0.033		[6] ACHARD	04C	L3	E^{ee}_{cm} = 183–209 GeV
91.1875	±0.0039		3.97M	[7] ACCIARRI	00Q	L3	E^{ee}_{cm}= LEP1 + 130–189 GeV
91.151	±0.008			[8] MIYABAYASHI	95	TOPZ	E^{ee}_{cm}= 57.8 GeV
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] ABBIENDI 04G obtain this result using the S–matrix formalism for a combined fit to their cross section and asymmetry data at the Z peak and their data at 130–209 GeV. The authors have corrected the measurement for the 34 MeV shift with respect to the Breit–Wigner fits.

[6] ACHARD 04C select $e^+ e^- \rightarrow Z\gamma$ events with hard initial–state radiation. Z decays to $q\overline{q}$ and muon pairs are considered. The fit results obtained in the two samples are found consistent to each other and combined considering the uncertainty due to ISR modelling as fully correlated.

[7] 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.

[8] 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.

[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 $Z \rightarrow e^+ e^-$ 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. • • •				
2.4943±0.0041		[17] ABBIENDI 04G	OPAL	E^{ee}_{cm}= LEP1 + 130–209 GeV
2.5025±0.0041	3.97M	[18] ACCIARRI 00Q	L3	E^{ee}_{cm}= LEP1 + 130–189 GeV
2.50 ±0.21 ±0.06		[19] ABREU 96R	DLPH	E^{ee}_{cm}= 91.2 GeV
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] ABBIENDI 04G obtain this result using the S–matrix formalism for a combined fit to their cross section and asymmetry data at the Z peak and their data at 130–209 GeV. The authors have corrected the measurement for the 1 MeV shift with respect to the Breit–Wigner fits.

[18] 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.

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

[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 $\Gamma(Z) < 2.89 \pm 0.19$ 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]	(3.3658 ± 0.0023) %	
Γ_5	invisible		(20.00 ± 0.06) %	
Γ_6	hadrons		(69.91 ± 0.06) %	
Γ_7	$(u\overline{u}+c\overline{c})/2$		(11.6 ± 0.6) %	
Γ_8	$(d\overline{d}+s\overline{s}+b\overline{b})/3$		(15.6 ± 0.4) %	
Γ_9	$c\overline{c}$		(12.03 ± 0.21) %	
Γ_{10}	$b\overline{b}$		(15.12 ± 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}	$D_{s1}(2536)^\pm$X		$(3.6 \pm 0.8) \times 10^{-3}$	
Γ_{33}	$D_{sJ}(2573)^\pm$X		$(5.8 \pm 2.2) \times 10^{-3}$	
Γ_{34}	$D^{*\prime}(2629)^\pm$X		searched for	
Γ_{35}	BX			
Γ_{36}	B^*X			
Γ_{37}	B^+X		(6.03 ± 0.15) %	
Γ_{38}	B_s^0X		(1.55 ± 0.13) %	
Γ_{39}	B_c^+X		searched for	

Γ_{40}	$\Lambda_c^+ X$			(1.54 ± 0.33) %		
Γ_{41}	b-baryon X			(1.51 ± 0.26) %		
Γ_{42}	anomalous $\gamma+$ hadrons		[c]	< 3.2	$\times 10^{-3}$	CL=95%
Γ_{43}	$e^+ e^- \gamma$		[c]	< 5.2	$\times 10^{-4}$	CL=95%
Γ_{44}	$\mu^+ \mu^- \gamma$		[c]	< 5.6	$\times 10^{-4}$	CL=95%
Γ_{45}	$\tau^+ \tau^- \gamma$		[c]	< 7.3	$\times 10^{-4}$	CL=95%
Γ_{46}	$\ell^+ \ell^- \gamma\gamma$		[d]	< 6.8	$\times 10^{-6}$	CL=95%
Γ_{47}	$q\overline{q}\gamma\gamma$		[d]	< 5.5	$\times 10^{-6}$	CL=95%
Γ_{48}	$\nu\overline{\nu}\gamma\gamma$		[d]	< 3.1	$\times 10^{-6}$	CL=95%
Γ_{49}	$e^\pm \mu^\mp$	LF	[b]	< 1.7	$\times 10^{-6}$	CL=95%
Γ_{50}	$e^\pm \tau^\mp$	LF	[b]	< 9.8	$\times 10^{-6}$	CL=95%
Γ_{51}	$\mu^\pm \tau^\mp$	LF	[b]	< 1.2	$\times 10^{-5}$	CL=95%
Γ_{52}	$p e$	L,B		< 1.8	$\times 10^{-6}$	CL=95%
Γ_{53}	$p \mu$	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

$\Gamma(\text{invisible})$ 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. • • •					
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.

Γ(hadrons)/Γ($\mu^+\mu^-$) 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. • • •					
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. • • •				
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. • • •				
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 $Z \to$ "up-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 or 7 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*
0.166±0.009 OUR AVERAGE				
$0.172^{+0.011}_{-0.010}$	[36] ABBIENDI	04E	OPAL	E^{ee}_{cm} = 91.2 GeV
0.160±0.019±0.019	[37] ACKERSTAFF	97T	OPAL	E^{ee}_{cm}= 88–94 GeV
$0.137^{+0.038}_{-0.054}$	[38] ABREU	95X	DLPH	E^{ee}_{cm}= 88–94 GeV
0.137±0.033	[39] ADRIANI	93	L3	E^{ee}_{cm}= 91.2 GeV

[36] ABBIENDI 04E select photons with energy > 7 GeV and use Γ(hadrons) = 1744.4 ± 2.0 MeV and α_s = 0.1172 ± 0.002 to obtain $\Gamma_u = 300^{+19}_{-18}$ MeV.

[37] 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.

[38] ABREU 95X use M_Z = 91.187 ± 0.009 GeV, Γ(hadrons) = 1725 ± 12 MeV and α_s = 0.123 ± 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 $(3C_{1/3} + 2C_{2/3}) = 6.66 \pm 0.05$.

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

$\Gamma((d\overline{d}+s\overline{s}+b\overline{b})/3)/\Gamma(\text{hadrons})$ — 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 or 7 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
0.223±0.006 OUR AVERAGE				
0.218±0.007	[40] ABBIENDI	04E	OPAL	E^{ee}_{cm} = 91.2 GeV
0.230±0.010±0.010	[41] ACKERSTAFF	97T	OPAL	E^{ee}_{cm}= 88–94 GeV
$0.243^{+0.036}_{-0.026}$	[42] ABREU	95X	DLPH	E^{ee}_{cm}= 88–94 GeV
0.243±0.022	[43] ADRIANI	93	L3	E^{ee}_{cm}= 91.2 GeV

[40] ABBIENDI 04E select photons with energy > 7 GeV and use Γ(hadrons) = 1744.4 ± 2.0 MeV and α_s = 0.1172 ± 0.002 to obtain Γ_d = 381 ± 12 MeV.

[41] 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.

[42] ABREU 95X use M_Z = 91.187 ± 0.009 GeV, Γ(hadrons) = 1725 ± 12 MeV and α_s = 0.123 ± 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 $(3C_{1/3} + 2C_{2/3}) = 6.66 \pm 0.05$.

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

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

OUR FIT is obtained by a simultaneous fit to several c- and b-quark measurements as explained in the "Note on the Z boson."

The Standard Model predicts $R_c = 0.1723$ for $m_t = 174.3$ GeV and $M_H = 150$ GeV.

VALUE	DOCUMENT ID		TECN	COMMENT
0.1721±0.0030 OUR FIT				
0.1744±0.0031±0.0021	[44] ABE	05F	SLD	E^{ee}_{cm}=91.28 GeV
0.1665±0.0051±0.0081	[45] ABREU	00	DLPH	E^{ee}_{cm}= 88–94 GeV
0.1698±0.0069	[46] BARATE	00B	ALEP	E^{ee}_{cm}= 88–94 GeV
0.180 ±0.011 ±0.013	[47] ACKERSTAFF	98E	OPAL	E^{ee}_{cm}= 88–94 GeV
0.167 ±0.011 ±0.012	[48] 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	[49] BARATE	98T	ALEP	Repl. by BARATE 00B
0.1689±0.0095±0.0068	[50] BARATE	98T	ALEP	Repl. by BARATE 00B
0.1623±0.0085±0.0209	[51] ABREU	95D	DLPH	E^{ee}_{cm}= 88–94 GeV
0.142 ±0.008 ±0.014	[52] AKERS	95O	OPAL	Repl. by ACKERSTAFF 98E
0.165 ±0.005 ±0.020	[53] BUSKULIC	94G	ALEP	Repl. by BARATE 00B

[44] ABE 05F use hadronic Z decays collected during 1996–98 to obtain an enriched sample of $c\overline{c}$ events using a double tag method. The single c–tag is obtained with a neural network trained to perform flavor discrimination using as input several signatures (corrected secondary vertex mass, vertex decay length, multiplicity and total momentum of the hemisphere). A multitag approach is used, defining 4 regions of the output value of the neural network and R_c is extracted from a simultaneous fit to the count rates of the 4 different tags. The quoted systematic error includes an uncertainty of ±0.0006 due to the uncertainty on R_b.

[45] ABREU 00 obtain this result properly combining the measurement from the D^{*+} production rate (R_c= 0.1610 ± 0.0104 ± 0.0077 ± 0.0043 (BR)) with that from the overall charm counting (R_c= 0.1692 ± 0.0047 ± 0.0063 ± 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.

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

[47] 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.

[48] 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.

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

[50] 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 ± 0.014 ± 0.0009. The same tag in combination with inclusive identification using the slow pion from the $D^{*+} \rightarrow D^0\pi^+$ decay in the opposite hemisphere yields R_c= 0.166 ± 0.012 ± 0.009. The R_b dependence is given by R_c= 0.1689–0.023×(R_b–0.2159). The three measurements of BARATE 98T are combined with BUSKULIC 94G to give the average R_c= 0.1681 ± 0.0054 ± 0.0062.

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

[52] 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 $P_c * \Gamma(c\overline{c})/\Gamma(\text{hadrons})$ to be $(1.006 \pm 0.055 \pm 0.061) \times 10^{-3}$, where P_c is the product branching ratio $B(c \to D^*)B(D^* \to D^0\pi)B(D^0 \to K\pi)$. 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.

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

$R_b = \Gamma(b\overline{b})/\Gamma(\text{hadrons})$ $\qquad\qquad$ 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."

The Standard Model predicts R_b=0.21581 for m_t=174.3 GeV and M_H=150 GeV.

VALUE	DOCUMENT ID		TECN	COMMENT
0.21629±0.00066 OUR FIT				
0.21594±0.00094±0.00075	[54] ABE	05F	SLD	E^{ee}_{cm}=91.28 GeV
0.2174 ±0.0015 ±0.0028	[55] ACCIARRI	00	L3	E^{ee}_{cm}= 89–93 GeV
0.2178 ±0.0011 ±0.0013	[56] ABBIENDI	99B	OPAL	E^{ee}_{cm}= 88–94 GeV
0.21634±0.00067±0.00060	[57] ABREU	99B	DLPH	E^{ee}_{cm}= 88–94 GeV
0.2159 ±0.0009 ±0.0011	[58] BARATE	97F	ALEP	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.2142 ±0.0034 ±0.0015	[59] ABE	98D	SLD	Repl. by ABE 05F
0.2175 ±0.0014 ±0.0017	[60] ACKERSTAFF	97K	OPAL	Repl. by ABBIENDI 99B
0.2167 ±0.0011 ±0.0013	[61] BARATE	97E	ALEP	E^{ee}_{cm}= 88–94 GeV
0.229 ±0.011	[62] ABE	96E	SLD	Repl. by ABE 98D
0.2216 ±0.0016 ±0.0021	[63] ABREU	96	DLPH	Repl. by ABREU 99B
0.2145 ±0.0089 ±0.0067	[64] ABREU	95D	DLPH	E^{ee}_{cm}= 88–94 GeV
0.219 ±0.006 ±0.005	[65] BUSKULIC	94G	ALEP	E^{ee}_{cm}= 88–94 GeV
0.251 ±0.049 ±0.030	[66] JACOBSEN	91	MRK2	E^{ee}_{cm}= 91 GeV

[54] ABE 05F use hadronic Z decays collected during 1996–98 to obtain an enriched sample of $b\overline{b}$ events using a double tag method. The single b–tag is obtained with a neural network trained to perform flavour discrimination using as input several signatures (corrected secondary vertex mass, vertex decay length, multiplicity and total momentum of the hemisphere; the key tag is obtained requiring the secondary vertex corrected mass to be above the D–meson mass). ABE 05F obtain R_b =0.21604 $\pm$ 0.00098 $\pm$ 0.00074 where the systematic error includes an uncertainty of $\pm$0.00012 due to the uncertainty on R_c. The value reported here is obtained properly combining with ABE 98D. The quoted systematic error includes an uncertainty of $\pm$0.00012 due to the uncertainty on R_c.

[55] 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.

[56] 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.

[57] 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).

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

[59] 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.

[60] 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.

[61] 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.

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

[63] 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 $-0.087 \cdot \Delta R_c$.

[64] 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.

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

[66] 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).

$\Gamma(b\overline{b}b\overline{b})/\Gamma(\text{hadrons})$ $\qquad\Gamma_{11}/\Gamma_6$

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
5.2±1.9 OUR AVERAGE				
$3.6\pm1.7\pm2.7$	[67] ABBIENDI	01G	OPAL	E^{ee}_{cm}= 88–94 GeV
$6.0\pm1.9\pm1.4$	[68] ABREU	99U	DLPH	E^{ee}_{cm}= 88–94 GeV

[67] 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.

[68] 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 $b\overline{b}$.

$\Gamma(g g g)/\Gamma(\text{hadrons})$ $\qquad\Gamma_{12}/\Gamma_6$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<1.6 \times 10^{-2}$	95	[69] ABREU	96S	DLPH	E^{ee}_{cm}= 88–94 GeV

[69] 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}.

$\Gamma(\pi^0\gamma)/\Gamma_{\text{total}}$ $\qquad\Gamma_{13}/\Gamma$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<5.2 \times 10^{-5}$	95	[70] 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

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

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

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

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

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

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

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

This decay would violate the Landau-Yang theorem.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<5.2 \times 10^{-5}$	95	[71] 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

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

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<1.0 \times 10^{-5}$	95	[72] ACCIARRI	95C	L3	E^{ee}_{cm}= 88–94 GeV
$<1.7 \times 10^{-5}$	95	[72] ABREU	94B	DLPH	E^{ee}_{cm}= 88–94 GeV
$<6.6 \times 10^{-5}$	95	AKRAWY	91F	OPAL	E^{ee}_{cm}= 88–94 GeV

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

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

$\Gamma(\rho^\pm W^\mp)/\Gamma_{\text{total}}$ — 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.			
$3.21 \pm 0.21^{+0.19}_{-0.28}$	553	[73] ACCIARRI	99F	L3	E^{ee}_{cm}= 88–94 GeV
$3.9 \pm 0.2 \pm 0.3$	511	[74] ALEXANDER	96B	OPAL	E^{ee}_{cm}= 88–94 GeV
$3.73 \pm 0.39 \pm 0.36$	153	[75] ABREU	94P	DLPH	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$3.40 \pm 0.23 \pm 0.27$	441	[76] ACCIARRI	97J	L3	Repl. by ACCIARRI 99F

[73] 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 $(2.1 \pm 0.6 \pm 0.4^{+0.4}_{-0.2}(\text{theor.})) \times 10^{-4}$.

[74] 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).

[75] 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.

[76] 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					
$1.6 \pm 0.5 \pm 0.3$	39	[77] ACCIARRI	97J	L3	E^{ee}_{cm}= 88–94 GeV
$1.6 \pm 0.3 \pm 0.2$	46.9	[78] ALEXANDER	96B	OPAL	E^{ee}_{cm}= 88–94 GeV
$1.60 \pm 0.73 \pm 0.33$	5.4	[79] ABREU	94P	DLPH	E^{ee}_{cm}= 88–94 GeV

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

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

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

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

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
2.9 ± 0.7 OUR AVERAGE					
$2.7 \pm 0.6 \pm 0.5$	33	[80] ACCIARRI	97J	L3	E^{ee}_{cm}= 88–94 GeV
$5.0 \pm 2.1^{+1.5}_{-0.9}$	6.4	[81] ABREU	94P	DLPH	E^{ee}_{cm}= 88–94 GeV

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

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

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<3.2 \times 10^{-3}$	90	[82] ACCIARRI	97J	L3	E^{ee}_{cm}= 88–94 GeV

[82] 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	[83] ALEXANDER	96F	OPAL	E^{ee}_{cm}= 88–94 GeV

[83] 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	[84] ACCIARRI	99F	L3	E^{ee}_{cm}= 88–94 GeV

[84] 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	[85] ACCIARRI	97R	L3	E^{ee}_{cm}= 88–94 GeV

[85] 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	[86] ACCIARRI	97R	L3	E^{ee}_{cm}= 88–94 GeV

[86] 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	[87] ABREU	93I	DLPH	E^{ee}_{cm}= 88–94 GeV

[87] 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	[88] ABREU	93I	DLPH	E^{ee}_{cm}= 88–94 GeV

[88] 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.				
$0.155\pm0.010\pm0.013$	358	[89] ABREU	93I	DLPH	E^{ee}_{cm}= 88–94 GeV
$0.21\ \pm0.04$	362	[90] DECAMP	91J	ALEP	E^{ee}_{cm}= 88–94 GeV

[89] $D^*(2010)^\pm$ 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).

[90] 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)%.

$\Gamma(D_{s1}(2536)^\pm X)/\Gamma(\text{hadrons})$ — Γ_{32}/Γ_6

$D_{s1}(2536)^\pm$ is an expected orbitally-excited state of the D_s meson.

VALUE (%)	EVTS	DOCUMENT ID	TECN	COMMENT
0.52±0.09±0.06	92	[91] HEISTER 02B	ALEP	E^{ee}_{cm}= 88–94 GeV

[91] HEISTER 02B reconstruct this meson in the decay modes $D_{s1}(2536)^\pm \to D^{*\pm}K^0$ and $D_{s1}(2536)^\pm \to D^{*0}K^\pm$. The quoted branching ratio assumes that the decay width of the $D_{s1}(2536)$ is saturated by the two measured decay modes.

$\Gamma(D_{sJ}(2573)^\pm X)/\Gamma(\text{hadrons})$ — Γ_{33}/Γ_6

$D_{sJ}(2573)^\pm$ is an expected orbitally-excited state of the D_s meson.

VALUE (%)	EVTS	DOCUMENT ID	TECN	COMMENT
$0.83\pm0.29^{+0.07}_{-0.13}$	64	[92] HEISTER 02B	ALEP	E^{ee}_{cm}= 88–94 GeV

[92] HEISTER 02B reconstruct this meson in the decay mode $D_{s2}(2573)^\pm \to D^0K^\pm$. The quoted branching ratio assumes that the detected decay mode represents 45% of the full decay width.

$\Gamma(D^{*\prime}(2629)^\pm X)/\Gamma(\text{hadrons})$ — Γ_{34}/Γ_6

$D^{*\prime}(2629)^\pm$ is a predicted radial excitation of the $D^*(2010)^\pm$ meson.

VALUE	DOCUMENT ID	TECN	COMMENT
searched for	[93] ABBIENDI 01N	OPAL	E^{ee}_{cm}= 88–94 GeV

[93] ABBIENDI 01N searched for the decay mode $D^{*\prime}(2629)^\pm \to D^{*\pm}\pi^+\pi^-$ with $D^{*+} \to D^0\pi^+$, and $D^0 \to K^-\pi^+$. They quote a 95% CL limit for $Z \to D^{*\prime}(2629)^\pm \times$B($D^{*\prime}(2629)^+ \to D^{*+}\pi^+\pi^-$) < 3.1 × 10^{-3}.

$\Gamma(B^+ X)/\Gamma(\text{hadrons})$ — Γ_{37}/Γ_6

"OUR EVALUATION" is obtained using our current values for f($\overline{b} \to B^+$) and R_b = $\Gamma(b\overline{b})$/Γ(hadrons). We calculate $\Gamma(B^+ X)$/Γ(hadrons) = R_b × f($\overline{b} \to B^+$).

VALUE	DOCUMENT ID	TECN	COMMENT
0.0863±0.0022 OUR EVALUATION			
0.0887±0.0030	[94] ABDALLAH 03K	DLPH	E^{ee}_{cm} = 88–94 GeV

[94] ABDALLAH 03K measure the production fraction of B^+ mesons in hadronic Z decays f(B^+) = (40.99 ± 0.82 ± 1.11)%. The value quoted here is obtained multiplying this production fraction by our value of R_b = $\Gamma(\overline{b}b)$/Γ(hadrons).

$\Gamma(B^0_s X)/\Gamma(\text{hadrons})$ — Γ_{38}/Γ_6

"OUR EVALUATION" is obtained using our current values for f($\overline{b} \rightarrow B^0_s$) and R_b = $\Gamma(b\overline{b})/\Gamma(\text{hadrons})$. We calculate $\Gamma(B^0_s)/\Gamma(\text{hadrons}) = R_b \times f(\overline{b} \rightarrow B^0_s)$.

VALUE	DOCUMENT ID		TECN	COMMENT
0.0221±0.0019 OUR EVALUATION				
seen	[95] ABREU	92M	DLPH	E^{ee}_{cm}= 88–94 GeV
seen	[96] ACTON	92N	OPAL	E^{ee}_{cm}= 88–94 GeV
seen	[97] BUSKULIC	92E	ALEP	E^{ee}_{cm}= 88–94 GeV

[95] ABREU 92M reported value is $\Gamma(B^0_s X)*B(B^0_s \rightarrow D_s \mu \nu_\mu X)*B(D_s \rightarrow \phi\pi)/\Gamma(\text{hadrons}) = (18 \pm 8) \times 10^{-5}$.

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

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

$\Gamma(B^+_c X)/\Gamma(\text{hadrons})$ — Γ_{39}/Γ_6

VALUE	DOCUMENT ID		TECN	COMMENT
searched for	[98] ACKERSTAFF	98O	OPAL	E^{ee}_{cm}= 88–94 GeV
searched for	[99] ABREU	97E	DLPH	E^{ee}_{cm}= 88–94 GeV
searched for	[100] BARATE	97H	ALEP	E^{ee}_{cm}= 88–94 GeV

[98] ACKERSTAFF 98O searched for the decay modes $B_c \rightarrow J/\psi\pi^+$, $J/\psi a^+_1$, and $J/\psi\ell^+\nu_\ell$, with $J/\psi \rightarrow \ell^+\ell^-$, $\ell = e,\mu$. 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 $B_c \rightarrow J/\psi\pi^+$ candidates as signal, they report $\Gamma(B^+_c X) \times B(B_c \rightarrow J/\psi\pi^+)/\Gamma(\text{hadrons}) = (3.8^{+5.0}_{-2.4} \pm 0.5) \times 10^{-5}$. Interpreted as background, the 90% CL bounds are $\Gamma(B^+_c X)*B(B_c \rightarrow J/\psi\pi^+)/\Gamma(\text{hadrons}) < 1.06 \times 10^{-4}$, $\Gamma(B^+_c X)*B(B_c \rightarrow J/\psi a^+_1)/\Gamma(\text{hadrons}) < 5.29 \times 10^{-4}$, $\Gamma(B^+_c X)*B(B_c \rightarrow J/\psi\ell^+\nu_\ell)/\Gamma(\text{hadrons}) < 6.96 \times 10^{-5}$.

[99] ABREU 97E searched for the decay modes $B_c \rightarrow J/\psi\pi^+$, $J/\psi\ell^+\nu_\ell$, and $J/\psi(3\pi)^+$, with $J/\psi \rightarrow \ell^+\ell^-$, $\ell = e,\mu$. 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: $\Gamma(B^+_c X)*B(B_c \rightarrow J/\psi\pi^+)/\Gamma(\text{hadrons}) < (1.05\text{–}0.84) \times 10^{-4}$, $\Gamma(B^+_c X)*B(B_c \rightarrow J/\psi\ell\nu_\ell)/\Gamma(\text{hadrons}) < (5.8\text{–}5.0) \times 10^{-5}$, $\Gamma(B^+_c X)*B(B_c \rightarrow J/\psi(3\pi)^+)/\Gamma(\text{hadrons}) < 1.75 \times 10^{-4}$, where the ranges are due to the predicted B_c lifetime (0.4–1.4) ps.

[100] BARATE 97H searched for the decay modes $B_c \rightarrow J/\psi\pi^+$ and $J/\psi\ell^+\nu_\ell$ with $J/\psi \rightarrow \ell^+\ell^-$, $\ell = e,\mu$. 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: $\Gamma(B^+_c X)*B(B_c \rightarrow J/\psi\pi^+)/\Gamma(\text{hadrons}) < 3.6 \times 10^{-5}$ and $\Gamma(B^+_c X)*B(B_c \rightarrow J/\psi\ell^+\nu_\ell)/\Gamma(\text{hadrons}) < 5.2 \times 10^{-5}$.

$\Gamma(B^* X)/[\Gamma(B X)+\Gamma(B^* X)]$ — $\Gamma_{36}/(\Gamma_{35}+\Gamma_{36})$

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 (11.8 ± 2.0)% as given in the 2002 edition of this *Review* OUR AVERAGE becomes 0.75 ± 0.04.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.75 ±0.04 OUR AVERAGE					
0.760±0.036±0.083		[101] ACKERSTAFF	97M	OPAL	E^{ee}_{cm}= 88–94 GeV
0.771±0.026±0.070		[102] BUSKULIC	96D	ALEP	E^{ee}_{cm}= 88–94 GeV
0.72 ±0.03 ±0.06		[103] ABREU	95R	DLPH	E^{ee}_{cm}= 88–94 GeV
0.76 ±0.08 ±0.06	1378	[104] ACCIARRI	95B	L3	E^{ee}_{cm}= 88–94 GeV

[101] 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.

[102] 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.

[103] 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.

[104] 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.

$\Gamma(\Lambda_c^+ X)/\Gamma(\text{hadrons})$ — Γ_{40}/Γ_6

VALUE	DOCUMENT ID		TECN	COMMENT
0.022±0.005 OUR AVERAGE				
0.024±0.005±0.006	[105] ALEXANDER	96R	OPAL	E^{ee}_{cm}= 88–94 GeV
0.021±0.003±0.005	[106] BUSKULIC	96Y	ALEP	E^{ee}_{cm} = 88–94 GeV

[105] ALEXANDER 96R measure $R_b \times f(b \to \Lambda_c^+ X) \times B(\Lambda_c^+ \to p K^- \pi^+) = (0.122 \pm 0.023 \pm 0.010)\%$ in hadronic Z decays; the value quoted here is obtained using our best value $B(\Lambda_c^+ \to p K^- \pi^+) = (5.0 \pm 1.3)\%$. The first error is the total experiment's error and the second error is the systematic error due to the branching fraction uncertainty.

[106] BUSKULIC 96Y obtain the production fraction of Λ_c^+ baryons in hadronic Z decays $f(b \to \Lambda_c^+ X) = 0.110 \pm 0.014 \pm 0.006$ using $B(\Lambda_c^+ \to p K^- \pi^+) = (4.4 \pm 0.6)\%$; we have rescaled using our best value $B(\Lambda_c^+ \to p K^- \pi^+) = (5.0 \pm 1.3)\%$ obtaining $f(b \to \Lambda_c^+ X) = 0.097 \pm 0.013 \pm 0.025$ where the first error is their total experiment's error and the second error is the systematic error due to the branching fraction uncertainty. The value quoted here is obtained multiplying this production fraction by our value of $R_b = \Gamma(b\overline{b})/\Gamma(\text{hadrons})$.

$\Gamma(b\text{-baryon } X)/\Gamma(\text{hadrons})$ — Γ_{41}/Γ_6

"OUR EVALUATION" is obtained using our current values for $f(b \to b\text{-baryon})$ and $R_b = \Gamma(b\overline{b})/\Gamma(\text{hadrons})$. We calculate $\Gamma(b\text{-baryon } X)/\Gamma(\text{hadrons}) = R_b \times f(b \to b\text{-baryon})$.

VALUE	DOCUMENT ID		TECN	COMMENT
0.0216±0.0037 OUR EVALUATION				
0.0221±0.0015±0.0058	[107] BARATE	98V	ALEP	E^{ee}_{cm}= 88–94 GeV

[107] BARATE 98V use the overall number of identified protons in b-hadron decays to measure f($b \to$ b-baryon) = 0.102 ± 0.007 ± 0.027. They assume BR(b-baryon$\to$ pX) = (58 ± 6)% and BR($B_s^0 \to$ pX) = (8.0 ± 4.0)%. The value quoted here is obtained multiplying this production fraction by our value of $R_b = \Gamma(b\overline{b})/\Gamma(\text{hadrons})$.

$\Gamma(\text{anomalous }\gamma+\text{hadrons})/\Gamma_{\text{total}}$ Γ_{42}/Γ

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<3.2 × 10^{-3}	95	[108] AKRAWY	90J	OPAL	E^{ee}_{cm}= 88–94 GeV

[108] 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(γ) > 10 GeV.

$\Gamma(e^+e^-\gamma)/\Gamma_{\text{total}}$ Γ_{43}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<5.2 × 10^{-4}	95	[109] ACTON	91B	OPAL	E^{ee}_{cm}= 91.2 GeV

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

$\Gamma(\mu^+\mu^-\gamma)/\Gamma_{\text{total}}$ Γ_{44}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<5.6 × 10^{-4}	95	[110] ACTON	91B	OPAL	E^{ee}_{cm}= 91.2 GeV

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

$\Gamma(\tau^+\tau^-\gamma)/\Gamma_{\text{total}}$ Γ_{45}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<7.3 × 10^{-4}	95	[111] ACTON	91B	OPAL	E^{ee}_{cm}= 91.2 GeV

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

$\Gamma(\ell^+\ell^-\gamma\gamma)/\Gamma_{\text{total}}$ Γ_{46}/Γ

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<6.8 × 10^{-6}	95	[112] ACTON	93E	OPAL	E^{ee}_{cm}= 88–94 GeV

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

$\Gamma(q\overline{q}\gamma\gamma)/\Gamma_{\text{total}}$ Γ_{47}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<5.5 × 10^{-6}	95	[113] ACTON	93E	OPAL	E^{ee}_{cm}= 88–94 GeV

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

$\Gamma(\nu\overline{\nu}\gamma\gamma)/\Gamma_{\text{total}}$ Γ_{48}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<3.1 × 10^{-6}	95	[114] ACTON	93E	OPAL	E^{ee}_{cm}= 88–94 GeV

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

$\Gamma(e^{\pm}\mu^{\mp})/\Gamma(e^+e^-)$ — Γ_{49}/Γ_1

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

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

$\Gamma(e^{\pm}\mu^{\mp})/\Gamma_{\rm total}$ — Γ_{49}/Γ

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

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

$\Gamma(e^{\pm}\tau^{\mp})/\Gamma_{\rm total}$ — Γ_{50}/Γ

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

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

$\Gamma(\mu^{\pm}\tau^{\mp})/\Gamma_{\rm total}$ — Γ_{51}/Γ

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

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

$\Gamma(pe)/\Gamma_{\rm total}$ — Γ_{52}/Γ

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$\mathbf{<1.8 \times 10^{-6}}$	95	[115] ABBIENDI	99I	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV

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

$\Gamma(p\mu)/\Gamma_{\rm total}$ — Γ_{53}/Γ

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$\mathbf{<1.8 \times 10^{-6}}$	95	[116] ABBIENDI	99I	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV

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

B-HADRON FRACTIONS IN HADRONIC Z DECAY

The production fractions for b-hadrons in hadronic Z decays have been calculated from the best values of mean lives, mixing parameters and branching fractions in this edition by the Heavy Flavor Averaging Group (HFAG) (see http://www.slac.stanford.edu/xorg/hfag/).

The values reported below assume:

$f(\overline{b} \to B^+) = f(\overline{b} \to B^0)$

$f(\overline{b} \to B^+) + f(\overline{b} \to B^0) + f(\overline{b} \to B^0_s) + f(b \to b\text{-baryon}) = 1$

The values are:

$f(\overline{b} \to B^+) = f(\overline{b} \to B^0) = 0.399 \pm 0.010$

$f(\overline{b} \to B^0_s) = 0.102 \pm 0.009$

$f(b \to b\text{-baryon}) = 0.100 \pm 0.017$

as obtained using a time-integrated mixing parameter $\overline{\chi} = 0.1259 \pm 0.0042$ given by a fit to heavy quark quantities with asymmetries removed (see the note "The Z boson").

AVERAGE PARTICLE MULTIPLICITIES IN HADRONIC *Z* DECAY

Summed over particle and antiparticle, when appropriate.

For topical interest the 95% CL limits on production rates, N, of pentaquarks per Z decay from a search by the ALEPH collaboration (SCHAEL 04) are given below. (See also the baryons section).

$N_{\Theta(1540)^+} \times B(\Theta(1540)^+ \to pK^0_S) < 6.2 \times 10^{-4}$

$N_{\Phi(1860)^{--}} \times B(\Phi(1860)^{--} \to \Xi^- \pi^-) < 4.5 \times 10^{-4}$

$N_{\Phi(1860)^0} \times B(\Phi(1860)^0 \to \Xi^- \pi^+) < 8.9 \times 10^{-4}$

$N_{\Theta_c(3100)} \times B(\Theta_c(3100) \to D^{*-} p) < 6.3 \times 10^{-4}$

$N_{\Theta_c(3100)} \times B(\Theta_c(3100) \to D^- p) < 31 \times 10^{-4}$

$\langle N_\gamma \rangle$

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

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

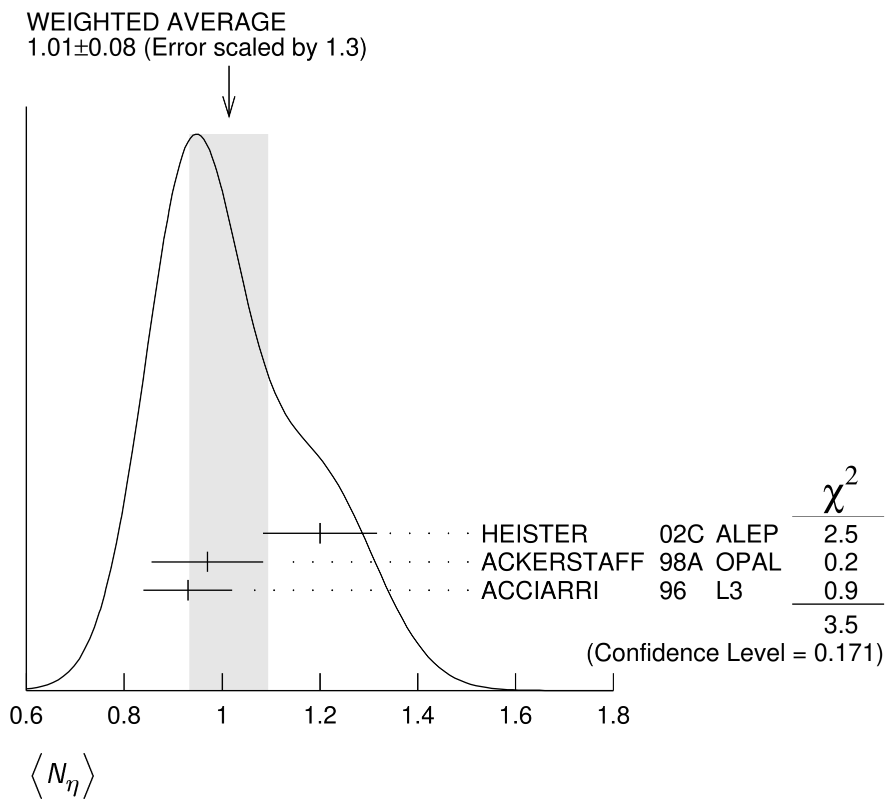
VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
17.03 ±0.16 OUR AVERAGE				
17.007±0.209	ABE	04C	SLD	E^{ee}_{cm} = 91.2 GeV
17.26 ±0.10 ±0.88	ABREU	98L	DLPH	E^{ee}_{cm}= 91.2 GeV
17.04 ±0.31	BARATE	98V	ALEP	E^{ee}_{cm}= 91.2 GeV
17.05 ±0.43	AKERS	94P	OPAL	E^{ee}_{cm}= 91.2 GeV

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

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
1.01±0.08 OUR AVERAGE	Error includes scale factor of 1.3. See the ideogram below.			
1.20±0.04±0.11	HEISTER	02C	ALEP	E^{ee}_{cm}= 91.2 GeV
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
1.02±0.06 OUR AVERAGE				
1.00±0.03±0.06	HEISTER	02C	ALEP	E^{ee}_{cm}= 91.2 GeV
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

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

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	$E_{\rm cm}^{ee}$= 91.2 GeV
0.25 ±0.04	[117] ACCIARRI 97D	L3	$E_{\rm cm}^{ee}$= 91.2 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.068±0.018±0.016	[118] BUSKULIC 92D	ALEP	$E_{\rm cm}^{ee}$= 91.2 GeV

[117] ACCIARRI 97D obtain this value averaging over the two decay channels $\eta' \rightarrow \pi^+ \pi^- \eta$ and $\eta' \rightarrow \rho^0 \gamma$.

[118] BUSKULIC 92D obtain this value for x> 0.1.

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

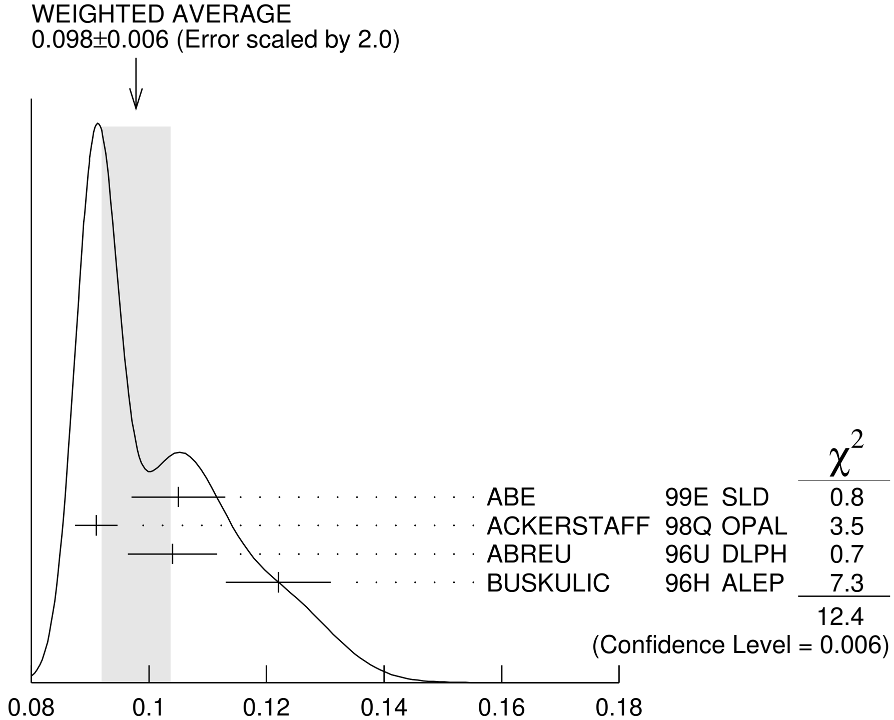
VALUE	DOCUMENT ID	TECN	COMMENT
0.147±0.011 OUR AVERAGE			
0.164±0.021	ABREU 99J	DLPH	$E_{\rm cm}^{ee}$= 91.2 GeV
0.141±0.007±0.011	ACKERSTAFF 98Q	OPAL	$E_{\rm cm}^{ee}$= 91.2 GeV

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

VALUE	DOCUMENT ID	TECN	COMMENT
0.27±0.04±0.10	ACKERSTAFF 98A	OPAL	$E_{\rm cm}^{ee}$= 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	$E_{\rm cm}^{ee}$= 91.2 GeV
0.091±0.002±0.003	ACKERSTAFF 98Q	OPAL	$E_{\rm cm}^{ee}$= 91.2 GeV
0.104±0.003±0.007	ABREU 96U	DLPH	$E_{\rm cm}^{ee}$= 91.2 GeV
0.122±0.004±0.008	BUSKULIC 96H	ALEP	$E_{\rm cm}^{ee}$= 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

$\langle N_{f_1(1285)} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.165±0.051	[119] ABDALLAH	03H	DLPH	E^{ee}_{cm}= 91.2 GeV

[119] ABDALLAH 03H assume a $K\overline{K}\pi$ branching ratio of (9.0 ± 0.4)%.

$\langle N_{f_1(1420)} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.056±0.012	[120] ABDALLAH	03H	DLPH	E^{ee}_{cm}= 91.2 GeV

[120] ABDALLAH 03H assume a $K\overline{K}\pi$ branching ratio of 100%.

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

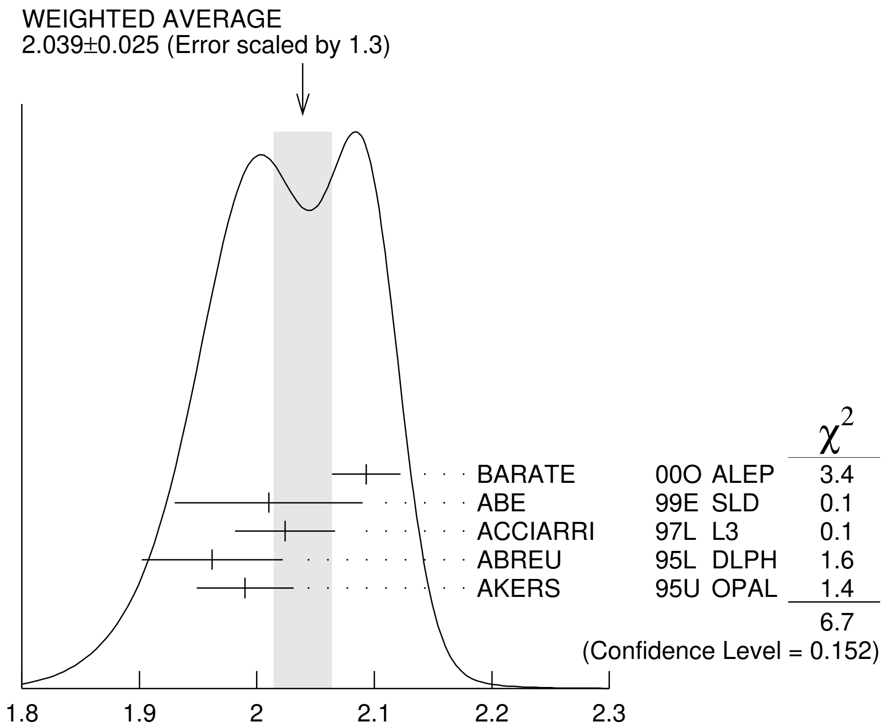
VALUE	DOCUMENT ID		TECN	COMMENT
0.012±0.006	ABREU	99J	DLPH	E^{ee}_{cm}= 91.2 GeV

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

VALUE	DOCUMENT ID		TECN	COMMENT
2.24 ±0.04 OUR AVERAGE				
2.203±0.071	ABE	04C	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

$\langle N_{K^*_2(1430)} \rangle$

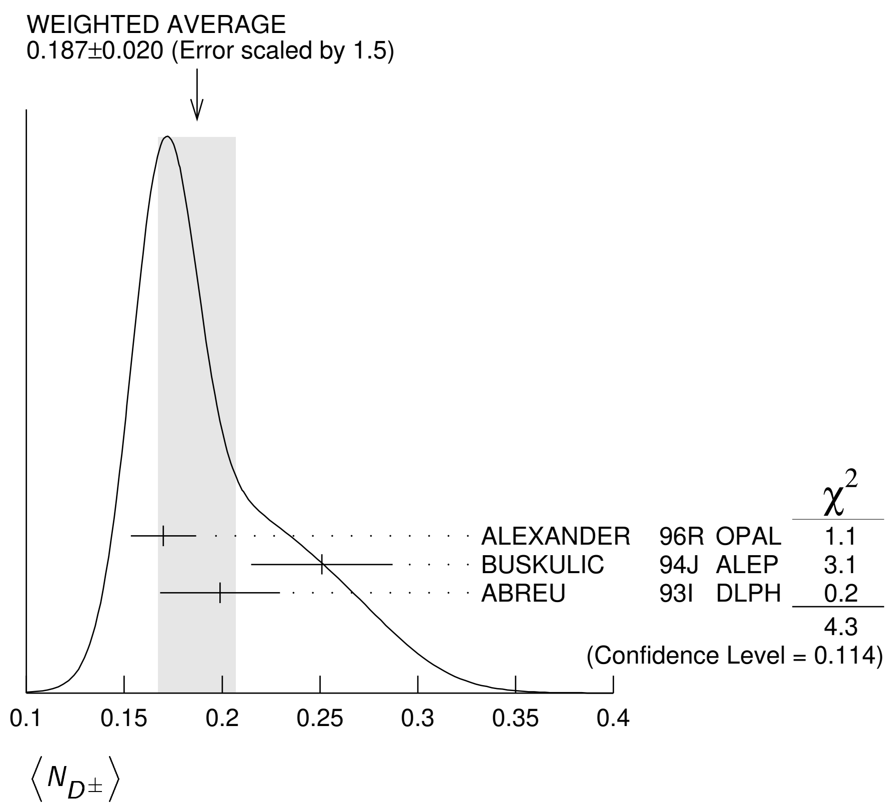
VALUE	DOCUMENT ID		TECN	COMMENT
0.073±0.023	ABREU	99J	DLPH	E^{ee}_{cm}= 91.2 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.19 ±0.04 ±0.06	[121] AKERS	95X	OPAL	E^{ee}_{cm}= 91.2 GeV

[121] 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	[122] ABREU	93I	DLPH	E^{ee}_{cm}= 91.2 GeV

[122] See ABREU 95 (erratum).



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

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	[123]	ABREU	93I	DLPH	E^{ee}_{cm}= 91.2 GeV

[123] 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^{ee}_{cm}= 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	[124]	ACKERSTAFF	98E	OPAL	E^{ee}_{cm}= 91.2 GeV
0.187 ±0.015 ±0.013		BUSKULIC	94J	ALEP	E^{ee}_{cm}= 91.2 GeV
0.171 ±0.012 ±0.016	[125]	ABREU	93I	DLPH	E^{ee}_{cm}= 91.2 GeV

[124] 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.

[125] 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	[126]	ACKERSTAFF	97W	OPAL	E^{ee}_{cm}= 91.2 GeV

[126] 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	[127]	ABREU	95R	DLPH	E^{ee}_{cm}= 91.2 GeV

[127] 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	[128]	ALEXANDER	96B	OPAL	E^{ee}_{cm}= 91.2 GeV

[128] 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^{ee}_{cm}= 91.2 GeV

$\langle N_p \rangle$

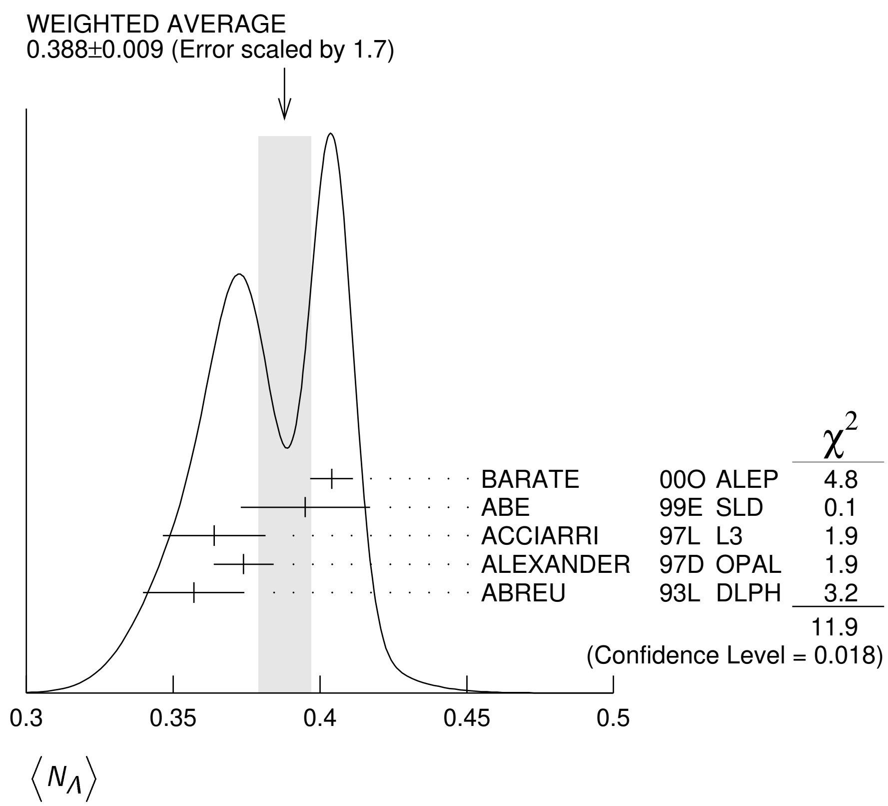
VALUE	DOCUMENT ID		TECN	COMMENT
1.046±0.026 OUR AVERAGE				
1.054±0.035	ABE	04C	SLD	E^{ee}_{cm} = 91.2 GeV
1.08 ±0.04 ±0.03	ABREU	98L	DLPH	E^{ee}_{cm}= 91.2 GeV
1.00 ±0.07	BARATE	98V	ALEP	E^{ee}_{cm}= 91.2 GeV
0.92 ±0.11	AKERS	94P	OPAL	E^{ee}_{cm}= 91.2 GeV

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

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



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

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^{ee}_{cm}= 91.2 GeV
0.099±0.008±0.013	ALEXANDER	97E	OPAL	E^{ee}_{cm}= 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^{ee}_{cm}= 91.2 GeV
0.083±0.006±0.009	ALEXANDER	97E	OPAL	E^{ee}_{cm}= 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	[129] ALEXANDER	97E	OPAL	E^{ee}_{cm}= 91.2 GeV
0.170±0.014±0.061	ABREU	95O	DLPH	E^{ee}_{cm}= 91.2 GeV

[129] 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^{ee}_{cm}= 91.2 GeV
0.071±0.012±0.013	ALEXANDER	97E	OPAL	E^{ee}_{cm}= 91.2 GeV
0.070±0.010±0.010	ADAM	96B	DLPH	E^{ee}_{cm}= 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^{ee}_{cm}= 91.2 GeV

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

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

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

VALUE	DOCUMENT ID		TECN	COMMENT
0.0240±0.0010±0.0014	ALEXANDER	97D	OPAL	E^{ee}_{cm}= 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^{ee}_{cm}= 91.2 GeV
0.0382±0.0028±0.0045	ABREU	95O	DLPH	E^{ee}_{cm}= 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

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

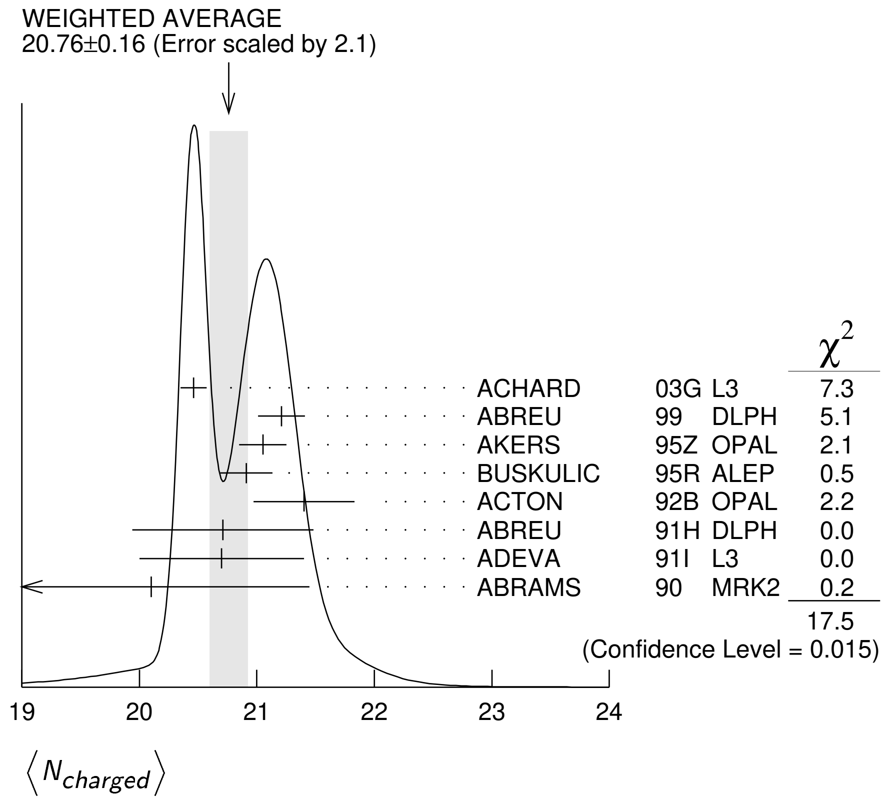
VALUE	DOCUMENT ID		TECN	COMMENT
0.00164±0.00028 OUR AVERAGE				
0.0018 ±0.0003 ±0.0002	ALEXANDER	97D	OPAL	E^{ee}_{cm}= 91.2 GeV
0.0014 ±0.0002 ±0.0004	ADAM	96B	DLPH	E^{ee}_{cm}= 91.2 GeV

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

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
20.76±0.16 OUR AVERAGE	Error includes scale factor of 2.1. See the ideogram below.			
20.46±0.01±0.11	ACHARD	03G	L3	E^{ee}_{cm} = 91.2 GeV
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	[130] 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	[131] BARATE 00C	ALEP	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
42 ±4	450	ABRAMS 89B	MRK2	E^{ee}_{cm}= 89.2–93.0 GeV

[130] 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.

[131] 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. Where $p\overline{p}$ data is quoted, OUR FIT value corresponds to a weighted average of this with the LEP/SLD fit result.

g^e_V

VALUE			EVTS	DOCUMENT ID		TECN	COMMENT
−0.03817±0.00047 OUR FIT							
−0.058	±0.016	±0.007	5026	[132] ACOSTA	05M	CDF	$E^{p\overline{p}}_{\rm cm}$ = 1.96 TeV
−0.0346	±0.0023		137.0K	[133] ABBIENDI	01O	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
−0.0412	±0.0027		124.4k	[134] ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
−0.0400	±0.0037			BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
−0.0414	±0.0020			[135] ABE	95J	SLD	$E^{ee}_{\rm cm}$= 91.31 GeV

[132] ACOSTA 05M determine the forward–backward asymmetry of e^+e^- pairs produced via $q\overline{q} \to Z/\gamma^* \to e^+e^-$ in 15 M(e^+e^-) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial–vector couplings of the Z to e^+e^-, assuming the quark couplings are as predicted by the standard model.

[133] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

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

[135] 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
−0.0367±0.0023 OUR FIT					
$-0.0388^{+0.0060}_{-0.0064}$	182.8K	[136] ABBIENDI	01O	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
−0.0386±0.0073	113.4k	[137] ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
−0.0362±0.0061		BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
−0.0413±0.0060	66143	[138] ABBIENDI	01K	OPAL	$E^{ee}_{\rm cm}$= 89–93 GeV

[136] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

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

[138] ABBIENDI 01K obtain this from an angular analysis of the muon pair asymmetry which takes into account effects of initial state radiation on an event by event basis and of initial-final state interference.

g_V^τ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
−0.0366±0.0010 OUR FIT				
−0.0365±0.0023	151.5K	[139] ABBIENDI 01O	OPAL	E^{ee}_{cm}= 88–94 GeV
−0.0384±0.0026	103.0k	[140] ACCIARRI 00C	L3	E^{ee}_{cm}= 88–94 GeV
−0.0361±0.0068		BARATE 00C	ALEP	E^{ee}_{cm}= 88–94 GeV

[139] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

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

g_V^ℓ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
−0.03783±0.00041 OUR FIT				
−0.0358 ±0.0014	471.3K	[141] ABBIENDI 01O	OPAL	E^{ee}_{cm}= 88–94 GeV
−0.0397 ±0.0020	379.4k	[142] ABREU 00F	DLPH	E^{ee}_{cm}= 88–94 GeV
−0.0397 ±0.0017	340.8k	[143] ACCIARRI 00C	L3	E^{ee}_{cm}= 88–94 GeV
−0.0383 ±0.0018	500k	BARATE 00C	ALEP	E^{ee}_{cm}= 88–94 GeV

[141] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

[142] Using forward-backward lepton asymmetries.

[143] 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. Where $p\overline{p}$ data is quoted, OUR FIT value corresponds to a weighted average of this with the LEP/SLD fit result.

g_A^e

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
−0.50111±0.00035 OUR FIT				
−0.528 ±0.123 ±0.059	5026	[144] ACOSTA 05M	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
−0.50062±0.00062	137.0K	[145] ABBIENDI 01O	OPAL	E^{ee}_{cm}= 88–94 GeV
−0.5015 ±0.0007	124.4k	[146] 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		[147] ABE 95J	SLD	E^{ee}_{cm}= 91.31 GeV

[144] ACOSTA 05M determine the forward–backward asymmetry of $e^+ e^-$ pairs produced via $q\overline{q} \rightarrow Z/\gamma^* \rightarrow e^+ e^-$ in 15 M($e^+ e^-$) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial–vector couplings of the Z to $e^+ e^-$, assuming the quark couplings are as predicted by the standard model.

[145] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

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

[147] ABE 95J obtain this result combining polarized Bhabha results with the A_{LR} measurement of ABE 94C. The Bhabha results alone give $-0.4968 \pm 0.0039 \pm 0.0027$.

g_A^μ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.50120±0.00054 OUR FIT					
−0.50117±0.00099	182.8K	[148] ABBIENDI	01O	OPAL	E^{ee}_{cm}= 88–94 GeV
−0.5009 ±0.0014	113.4k	[149] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
−0.50046±0.00093		BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
−0.520 ±0.015	66143	[150] ABBIENDI	01K	OPAL	E^{ee}_{cm}= 89–93 GeV

[148] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

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

[150] ABBIENDI 01K obtain this from an angular analysis of the muon pair asymmetry which takes into account effects of initial state radiation on an event by event basis and of initial-final state interference.

g_A^τ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.50204±0.00064 OUR FIT					
−0.50165±0.00124	151.5K	[151] ABBIENDI	01O	OPAL	E^{ee}_{cm}= 88–94 GeV
−0.5023 ±0.0017	103.0k	[152] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
−0.50216±0.00100		BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

[151] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

[152] 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
−0.50123±0.00026 OUR FIT					
−0.50089±0.00045	471.3K	[153] ABBIENDI	01O	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	[154] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
−0.50150±0.00046	500k	BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV

[153] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

[154] 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	[155] VILAIN	94	CHM2	From $\nu_\mu e$ and $\nu_e e$ scattering

[155] 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	[156] VILAIN	94	CHM2	From $\nu_\mu e$ scattering

[156] 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

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

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
0.1515±0.0019 OUR AVERAGE					
0.1454±0.0108±0.0036	144810	[157] ABBIENDI	01O	OPAL	E^{ee}_{cm}= 88–94 GeV
0.1516±0.0021	559000	[158] ABE	01B	SLD	E^{ee}_{cm}= 91.24 GeV
0.1504±0.0068±0.0008		[159] HEISTER	01	ALEP	E^{ee}_{cm}= 88–94 GeV
0.1382±0.0116±0.0005	105000	[160] ABREU	00E	DLPH	E^{ee}_{cm}= 88–94 GeV
0.1678±0.0127±0.0030	137092	[161] ACCIARRI	98H	L3	E^{ee}_{cm}= 88–94 GeV
0.162 ±0.041 ±0.014	89838	[162] ABE	97	SLD	E^{ee}_{cm}= 91.27 GeV
0.202 ±0.038 ±0.008		[163] ABE	95J	SLD	E^{ee}_{cm}= 91.31 GeV

[157] ABBIENDI 01O fit for A_e and A_τ from measurements of the τ polarization at varying τ production angles. The correlation between A_e and A_τ is less than 0.03.

[158] ABE 01B use the left-right production and left-right forward-backward decay asymmetries in leptonic Z decays to obtain a value of 0.1544 $\pm$ 0.0060. This is combined with left-right production asymmetry measurement using hadronic Z decays (ABE 00B) to obtain the quoted value.

[159] HEISTER 01 obtain this result fitting the τ polarization as a function of the polar production angle of the τ.

[160] 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).

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

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

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

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
0.142±0.015	16844	[164] ABE	01B	SLD	E_{cm}^{ee}= 91.24 GeV

[164] ABE 01B obtain this direct measurement using the left-right production and left-right forward-backward polar angle asymmetries 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 $Z \to \tau^+\tau^-$. The SLD Collaboration directly extracts this quantity from its measured left-right forward-backward asymmetry in $Z \to \tau^+\tau^-$ 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
0.143 ±0.004 OUR AVERAGE					
0.1456±0.0076±0.0057	144810	[165] ABBIENDI	01O	OPAL	E_{cm}^{ee}= 88–94 GeV
0.136 ±0.015	16083	[166] ABE	01B	SLD	E_{cm}^{ee}= 91.24 GeV
0.1451±0.0052±0.0029		[167] HEISTER	01	ALEP	E_{cm}^{ee}= 88–94 GeV
0.1359±0.0079±0.0055	105000	[168] ABREU	00E	DLPH	E_{cm}^{ee}= 88–94 GeV
0.1476±0.0088±0.0062	137092	ACCIARRI	98H	L3	E_{cm}^{ee}= 88–94 GeV

[165] ABBIENDI 01O fit for A_e and A_τ from measurements of the τ polarization at varying τ production angles. The correlation between A_e and A_τ is less than 0.03.

[166] ABE 01B obtain this direct measurement using the left-right production and left-right forward-backward polar angle asymmetries in $\tau^+\tau^-$ decays of the Z boson obtained with a polarized electron beam.

[167] HEISTER 01 obtain this result fitting the τ polarization as a function of the polar production angle of the τ.

[168] 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).

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	[169] ABE 00D	SLD	E^{ee}_{cm}= 91.2 GeV

[169] 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. OUR FIT is obtained by a simultaneous fit to several c- and b-quark measurements as explained in the note "The Z Boson."

VALUE	DOCUMENT ID	TECN	COMMENT
0.670 ±0.027 OUR FIT			
0.6712±0.0224±0.0157	[170] ABE 05	SLD	E^{ee}_{cm} = 91.24 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.583 ±0.055 ±0.055	[171] ABE 02G	SLD	E^{ee}_{cm}= 91.24 GeV
0.688 ±0.041	[172] ABE 01C	SLD	E^{ee}_{cm}= 91.25 GeV

[170] ABE 05 use hadronic Z decays collected during 1996–98 to obtain an enriched sample of $c\overline{c}$ events tagging on the invariant mass of reconstructed secondary decay vertices. The charge of the underlying c–quark is obtained with an algorithm that takes into account the net charge of the vertex as well as the charge of tracks emanating from the vertex and identified as kaons. This yields (9970 events) $A_c = 0.6747 \pm 0.0290 \pm 0.0233$. Taking into account all correlations with earlier results reported in ABE 02G and ABE 01C, they obtain the quoted overall SLD result.

[171] ABE 02G 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.

[172] ABE 01C tag $Z \to c\overline{c}$ events using two techniques: exclusive reconstruction of D^{*+}, D^+ and D^0 mesons and the soft pion tag for $D^{*+} \to D^0\pi^+$. The large background from D mesons produced in $b\overline{b}$ events is separated efficiently from the signal using precision vertex information. When combining the A_c values from these two samples, care is taken to avoid double counting of events common to the two samples, and common systematic errors are properly taken into account.

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. OUR FIT is obtained by a simultaneous fit to several c- and b-quark measurements as explained in the note "The Z Boson."

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.923 ±0.020 OUR FIT				
0.9170±0.0147±0.0145		[173] ABE 05	SLD	E^{ee}_{cm} = 91.24 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.907 ±0.020 ±0.024	48028	[174] ABE 03F	SLD	E^{ee}_{cm}= 91.24 GeV
0.919 ±0.030 ±0.024		[175] ABE 02G	SLD	E^{ee}_{cm}= 91.24 GeV
0.855 ±0.088 ±0.102	7473	[176] ABE 99L	SLD	E^{ee}_{cm}= 91.27 GeV

[173] ABE 05 use hadronic Z decays collected during 1996–98 to obtain an enriched sample of $b\overline{b}$ events tagging on the invariant mass of reconstructed secondary decay vertices. The charge of the underlying b–quark is obtained with an algorithm that takes into account the net charge of the vertex as well as the charge of tracks emanating from the vertex and identified as kaons. This yields (25917 events) $A_b = 0.9173 \pm 0.0184 \pm 0.0173$. Taking into account all correlations with earlier results reported in ABE 03F, ABE 02G and ABE 99L, they obtain the quoted overall SLD result.

[174] ABE 03F obtain an enriched sample of $b\overline{b}$ events tagging on the invariant mass of a 3-dimensional topologically reconstructed secondary decay. The charge of the underlying b quark is obtained using a self-calibrating track-charge method. For the 1996–1998 data sample they measure $A_b = 0.906 \pm 0.022 \pm 0.023$. The value quoted here is obtained combining the above with the result of ABE 98I (1993–1995 data sample).

[175] ABE 02G 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.

[176] 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 $K^{\pm}$.

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					
$0.87 \pm 0.20^{+0.10}_{-0.12}$	9.1k	ABREU	97G	DLPH	E^{ee}_{cm}= 91.2 GeV
$1.06 \pm 0.13 \pm 0.05$	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	[177] BARATE	97D	ALEP	E^{ee}_{cm}= 91.2 GeV

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

FORWARD-BACKWARD $e^+e^- \rightarrow f\overline{f}$ CHARGE ASYMMETRIES

These asymmetries are experimentally determined by tagging the respective lepton or quark flavor in e^+e^- interactions. Details of heavy flavor (c- or b-quark) tagging at LEP are described in the note on "The Z Boson." The Standard Model predictions for LEP data have been (re)computed using the ZFITTER package (version 6.36) with input parameters M_Z=91.187 GeV, M_{top}=174.3 GeV, M_{Higgs}=150 GeV, α_s=0.119, $\alpha^{(5)}$ (M_Z)= 1/128.877 and the Fermi constant G_F= 1.16637×10^{-5} GeV^{-2} (see the note on "The Z Boson" for references). For non-LEP data the Standard Model predictions are as given by the authors of the respective publications.

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

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	1.57	91.2	[178] ABBIENDI	01A	OPAL
1.71±0.49	1.57	91.2	ABREU	00F	DLPH
1.06±0.58	1.57	91.2	ACCIARRI	00C	L3
1.88±0.34	1.57	91.2	[179] BARATE	00C	ALEP

[178] 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.
[179] 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	1.57	91.2	[180] ABBIENDI	01A	OPAL
1.65± 0.25	1.57	91.2	ABREU	00F	DLPH
1.88± 0.33	1.57	91.2	ACCIARRI	00C	L3
1.71± 0.24	1.57	91.2	[181] BARATE	00C	ALEP

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

9 ±30		−1.3	20	[182] ABREU	95M	DLPH
7 ±26		−8.3	40	[182] ABREU	95M	DLPH
−11 ±33		−24.1	57	[182] ABREU	95M	DLPH
−62 ±17		−44.6	69	[182] ABREU	95M	DLPH
−56 ±10		−63.5	79	[182] ABREU	95M	DLPH
−13 ± 5		−34.4	87.5	[182] ABREU	95M	DLPH
$-29.0\ ^{+\ 5.0}_{-\ 4.8}$	±0.5	−32.1	56.9	[183] ABE	90I	VNS
− 9.9 ± 1.5	±0.5	−9.2	35	HEGNER	90	JADE
0.05± 0.22		0.026	91.14	[184] ABRAMS	89D	MRK2
−43.4 ±17.0		−24.9	52.0	[185] BACALA	89	AMY
−11.0 ±16.5		−29.4	55.0	[185] BACALA	89	AMY
−30.0 ±12.4		−31.2	56.0	[185] BACALA	89	AMY
−46.2 ±14.9		−33.0	57.0	[185] 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 ± 1.3	±0.5	−8.6	34.8	ADEVA	88	MRKJ
−12.3 ± 5.3	±0.5	−10.7	38.3	ADEVA	88	MRKJ
−15.6 ± 3.0	±0.5	−14.9	43.8	ADEVA	88	MRKJ
− 1.0 ± 6.0		−1.2	13.9	BRAUNSCH...	88D	TASS
− 9.1 ± 2.3	±0.5	−8.6	34.5	BRAUNSCH...	88D	TASS
$-10.6\ ^{+\ 2.2}_{-\ 2.3}$	±0.5	−8.9	35.0	BRAUNSCH...	88D	TASS
$-17.6\ ^{+\ 4.4}_{-\ 4.3}$	±0.5	−15.2	43.6	BRAUNSCH...	88D	TASS
− 4.8 ± 6.5	±1.0	−11.5	39	BEHREND	87C	CELL
−18.8 ± 4.5	±1.0	−15.5	44	BEHREND	87C	CELL
+ 2.7 ± 4.9		−1.2	13.9	BARTEL	86C	JADE
−11.1 ± 1.8	±1.0	−8.6	34.4	BARTEL	86C	JADE
−17.3 ± 4.8	±1.0	−13.7	41.5	BARTEL	86C	JADE
−22.8 ± 5.1	±1.0	−16.6	44.8	BARTEL	86C	JADE
− 6.3 ± 0.8	±0.2	−6.3	29	ASH	85	MAC
− 4.9 ± 1.5	±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

[180] ABBIENDI 01A error is almost entirely on account of statistics.
[181] BARATE 00C error is almost entirely on account of statistics.
[182] ABREU 95M perform this measurement using radiative muon-pair events associated with high-energy isolated photons.
[183] ABE 90I measurements in the range 50 $\leq \sqrt{s} \leq$ 60.8 GeV.
[184] ABRAMS 89D asymmetry includes both 9 $\mu^+\mu^-$ and 15 $\tau^+\tau^-$ events.
[185] 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	1.57	91.2	[186] ABBIENDI	01A	OPAL
2.41± 0.37	1.57	91.2	ABREU	00F	DLPH
2.60± 0.47	1.57	91.2	ACCIARRI	00C	L3
1.70± 0.28	1.57	91.2	[187] BARATE	00C	ALEP
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$-32.8 \ {}^{+\ 6.4}_{-\ 6.2} \ \pm 1.5$	−32.1	56.9	[188] ABE	90I	VNS
− 8.1 ± 2.0 ±0.6	−9.2	35	HEGNER	90	JADE
−18.4 ±19.2	−24.9	52.0	[189] BACALA	89	AMY
−17.7 ±26.1	−29.4	55.0	[189] BACALA	89	AMY
−45.9 ±16.6	−31.2	56.0	[189] BACALA	89	AMY
−49.5 ±18.0	−33.0	57.0	[189] 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

[186] ABBIENDI 01A error includes approximately 0.26 due to statistics and 0.14 due to event selection systematics.
[187] BARATE 00C error includes approximately 0.26 due to statistics and 0.11 due to experimental systematics.
[188] ABE 90I measurements in the range 50 $\leq \sqrt{s} \leq$ 60.8 GeV.
[189] 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	1.57	91.2	[190] ABBIENDI	01A	OPAL
1.87±0.19	1.57	91.2	ABREU	00F	DLPH
1.92±0.24	1.57	91.2	ACCIARRI	00C	L3
1.73±0.16	1.57	91.2	[191] BARATE	00C	ALEP

[190] 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.
[191] 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	**7.2**	**91.2**	[192] ACKERSTAFF	97T	OPAL

[192] 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	10.1	91.2	[193] ABREU	00B	DLPH
6.8 ±3.5 ±1.1	10.1	91.2	[194] ACKERSTAFF	97T	OPAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
13.1 ±3.5 ±1.3	10.1	91.2	[195] ABREU	95G	DLPH

[193] 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.

[194] 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.

[195] 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. The experimental values, on the other hand, correspond to the measurements carried out at the respective energies.

ASYMMETRY (%)	STD. MODEL	$\sqrt{s}$ (GeV)	DOCUMENT ID		TECN
7.07± 0.35 OUR FIT					
6.31± 0.93±0.65	6.35	91.26	[196] ABDALLAH	04F	DLPH
5.68± 0.54±0.39	6.3	91.25	[197] ABBIENDI	03P	OPAL
6.45± 0.57±0.37	6.10	91.21	[198] HEISTER	02H	ALEP
6.59± 0.94±0.35	6.2	91.235	[199] ABREU	99Y	DLPH
6.3 ± 0.9 ±0.3	6.1	91.22	[200] BARATE	98O	ALEP
6.3 ± 1.2 ±0.6	6.1	91.22	[201] ALEXANDER	97C	OPAL
8.3 ± 3.8 ±2.7	6.2	91.24	[202] ADRIANI	92D	L3

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

3.1 ± 3.5 ±0.5	−3.5	89.43	[196] ABDALLAH	04F	DLPH
11.0 ± 2.8 ±0.7	12.3	92.99	[196] ABDALLAH	04F	DLPH
− 6.8 ± 2.5 ±0.9	−3.0	89.51	[197] ABBIENDI	03P	OPAL
14.6 ± 2.0 ±0.8	12.2	92.95	[197] ABBIENDI	03P	OPAL
−12.4 ±15.9 ±2.0	−9.6	88.38	[198] HEISTER	02H	ALEP
− 2.3 ± 2.6 ±0.2	−3.8	89.38	[198] HEISTER	02H	ALEP
− 0.3 ± 8.3 ±0.6	0.9	90.21	[198] HEISTER	02H	ALEP
10.6 ± 7.7 ±0.7	9.6	92.05	[198] HEISTER	02H	ALEP
11.9 ± 2.1 ±0.6	12.2	92.94	[198] HEISTER	02H	ALEP
12.1 ±11.0 ±1.0	14.2	93.90	[198] HEISTER	02H	ALEP
− 4.96± 3.68±0.53	−3.5	89.434	[199] ABREU	99Y	DLPH
11.80± 3.18±0.62	12.3	92.990	[199] ABREU	99Y	DLPH
− 1.0 ± 4.3 ±1.0	−3.9	89.37	[200] BARATE	98O	ALEP
11.0 ± 3.3 ±0.8	12.3	92.96	[200] BARATE	98O	ALEP
3.9 ± 5.1 ±0.9	−3.4	89.45	[201] ALEXANDER	97C	OPAL
15.8 ± 4.1 ±1.1	12.4	93.00	[201] ALEXANDER	97C	OPAL
−12.9 ± 7.8 ±5.5	−13.6	35	BEHREND	90D	CELL
7.7 ±13.4 ±5.0	−22.1	43	BEHREND	90D	CELL
−12.8 ± 4.4 ±4.1	−13.6	35	ELSEN	90	JADE
−10.9 ±12.9 ±4.6	−23.2	44	ELSEN	90	JADE
−14.9 ± 6.7	−13.3	35	OULD-SAADA	89	JADE

[196] ABDALLAH 04F tag b– and c–quarks using semileptonic decays combined with charge flow information from the hemisphere opposite to the lepton. Enriched samples of $c\overline{c}$ and $b\overline{b}$ events are obtained using lifetime information.

[197] ABBIENDI 03P tag heavy flavors using events with 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.

[198] HEISTER 02H measure simultaneously b and c quark forward-backward asymmetries using their semileptonic decays to tag the quark charge. The flavor separation is obtained with a discriminating multivariate analysis.

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

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

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

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

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

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. The experimental values, on the other hand, correspond to the measurements carried out at the respective energies.

ASYMMETRY (%)	STD. MODEL	$\sqrt{s}$ (GeV)	DOCUMENT ID		TECN
9.92± 0.16 OUR FIT					
9.58± 0.32± 0.14	9.68	91.231	[203] ABDALLAH	05	DLPH

10.04± 0.56± 0.25	9.69	91.26	[204] ABDALLAH	04F	DLPH
9.72± 0.42± 0.15	9.67	91.25	[205] ABBIENDI	03P	OPAL
9.77± 0.36± 0.18	9.69	91.26	[206] ABBIENDI	02I	OPAL
9.52± 0.41± 0.17	9.59	91.21	[207] HEISTER	02H	ALEP
10.00± 0.27± 0.11	9.63	91.232	[208] HEISTER	01D	ALEP
7.62± 1.94± 0.85	9.64	91.235	[209] ABREU	99Y	DLPH
9.60± 0.66± 0.33	9.69	91.26	[210] ACCIARRI	99D	L3
9.31± 1.01± 0.55	9.65	91.24	[211] ACCIARRI	98U	L3
9.4 ± 2.7 ± 2.2	9.61	91.22	[212] ALEXANDER	97C	OPAL

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

6.37± 1.43± 0.17	5.8	89.449	[203] ABDALLAH	05	DLPH
10.41± 1.15± 0.24	12.1	92.990	[203] ABDALLAH	05	DLPH
6.7 ± 2.2 ± 0.2	5.7	89.43	[204] ABDALLAH	04F	DLPH
11.2 ± 1.8 ± 0.2	12.1	92.99	[204] ABDALLAH	04F	DLPH
4.7 ± 1.8 ± 0.1	5.9	89.51	[205] ABBIENDI	03P	OPAL
10.3 ± 1.5 ± 0.2	12.0	92.95	[205] ABBIENDI	03P	OPAL
5.82± 1.53± 0.12	5.9	89.50	[206] ABBIENDI	02I	OPAL
12.21± 1.23± 0.25	12.0	92.91	[206] ABBIENDI	02I	OPAL
−13.1 ±13.5 ± 1.0	3.2	88.38	[207] HEISTER	02H	ALEP
5.5 ± 1.9 ± 0.1	5.6	89.38	[207] HEISTER	02H	ALEP
− 0.4 ± 6.7 ± 0.8	7.5	90.21	[207] HEISTER	02H	ALEP
11.1 ± 6.4 ± 0.5	11.0	92.05	[207] HEISTER	02H	ALEP
10.4 ± 1.5 ± 0.3	12.0	92.94	[207] HEISTER	02H	ALEP
13.8 ± 9.3 ± 1.1	12.9	93.90	[207] HEISTER	02H	ALEP
4.36± 1.19± 0.11	5.8	89.472	[208] HEISTER	01D	ALEP
11.72± 0.97± 0.11	12.0	92.950	[208] HEISTER	01D	ALEP
5.67± 7.56± 1.17	5.7	89.434	[209] ABREU	99Y	DLPH
8.82± 6.33± 1.22	12.1	92.990	[209] ABREU	99Y	DLPH
6.11± 2.93± 0.43	5.9	89.50	[210] ACCIARRI	99D	L3
13.71± 2.40± 0.44	12.2	93.10	[210] ACCIARRI	99D	L3
4.95± 5.23± 0.40	5.8	89.45	[211] ACCIARRI	98U	L3
11.37± 3.99± 0.65	12.1	92.99	[211] ACCIARRI	98U	L3
− 8.6 ±10.8 ± 2.9	5.8	89.45	[212] ALEXANDER	97C	OPAL
− 2.1 ± 9.0 ± 2.6	12.1	93.00	[212] ALEXANDER	97C	OPAL
$-71 \pm 34 {}^{+7}_{-8}$	−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

[203] ABDALLAH 05 obtain an enriched samples of $b\overline{b}$ events using lifetime information. The quark (or antiquark) charge is determined with a neural network using the secondary vertex charge, the jet charge and particle identification.

[204] ABDALLAH 04F tag b– and c–quarks using semileptonic decays combined with charge flow information from the hemisphere opposite to the lepton. Enriched samples of $c\overline{c}$ and $b\overline{b}$ events are obtained using lifetime information.

[205] ABBIENDI 03P tag heavy flavors using events with 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.

[206] ABBIENDI 02I tag $Z^0 \rightarrow b\overline{b}$ decays using a combination of secondary vertex and lepton tags. The sign of the b-quark charge is determined using an inclusive tag based on jet, vertex, and kaon charges.

[207] HEISTER 02H measure simultaneously b and c quark forward-backward asymmetries using their semileptonic decays to tag the quark charge. The flavor separation is obtained with a discriminating multivariate analysis.

[208] HEISTER 01D tag $Z \rightarrow b\overline{b}$ events using the impact parameters of charged tracks complemented with information from displaced vertices, event shape variables, and lepton identification. The b-quark direction and charge is determined using the hemisphere charge method along with information from fast kaon tagging and charge estimators of primary and secondary vertices. The change in the quoted value due to variation of A^c_{FB} and R_b is given as $+0.103$ (A^c_{FB} – 0.0651) -0.440 (R_b – 0.21585).

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

[210] 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.

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

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

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	[213] ABREU	92I	DLPH
4.0 $\pm$0.4 $\pm$0.63	4.0	91.3	[214] 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

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

[214] 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 $\sin^2\theta^{\rm eff}_W$ 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 2006 by C. Caso (University of Genova) and A. Gurtu (Tata Institute).

In the reaction $e^+e^- \rightarrow Z\gamma$, deviations from the Standard Model for the $Z\gamma\gamma^*$ and $Z\gamma Z^*$ couplings may be described in terms of 8 parameters, h_i^V $(i = 1,4;\ V = \gamma, Z)$ [1]. The parameters h_i^γ describe the $Z\gamma\gamma^*$ couplings and the parameters h_i^Z the $Z\gamma Z^*$ couplings. 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 $h_{1,3}^V$ and $n = 4$ for $h_{2,4}^V$. Usually limits on h_i^V's are put assuming some value of Λ (sometimes ∞).

Above the $e^+e^- \rightarrow ZZ$ threshold, deviations from the Standard Model for the $ZZ\gamma^*$ and ZZZ^* couplings may be described by means of four anomalous couplings f_i^V $(i = 4,5; V = \gamma, Z)$ [2]. As above, the parameters f_i^γ describe the $Z\gamma\gamma^*$ couplings and the parameters f_i^Z the ZZZ^* couplings. The anomalous couplings f_5^V lead to violation of C and P symmetries while f_4^V introduces CP violation.

All these couplings h_i^V and f_i^V are zero at tree level in the Standard Model.

References

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

h_i^V

Combining the LEP results properly taking into account the correlations the following 95% CL limits are derived (CERN-PH-EP/2005-051 or hep-ex/0511027):

$$-0.13 < h_1^Z < +0.13, \qquad -0.078 < h_2^Z < +0.071,$$
$$-0.20 < h_3^Z < +0.07, \qquad -0.05 < h_4^Z < +0.12,$$
$$-0.056 < h_1^\gamma < +0.055, \qquad -0.045 < h_2^\gamma < +0.025,$$
$$-0.049 < h_3^\gamma < -0.008, \qquad -0.002 < h_4^\gamma < +0.034.$$

VALUE	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	[215] ABAZOV	05K	D0
	[216] ACHARD	04H	L3
	[217] ABBIENDI,G	00C	OPAL
	[218] ABBOTT	98M	D0
	[219] ABREU	98K	DLPH

[215] ABAZOV 05K use 290 $p\overline{p} \rightarrow Z\gamma$ + X events with $Z \rightarrow e^+e^-, \mu^+\mu^-$ at 1.96 TeV to determine 95% CL limits on anomalous $Z\gamma$ couplings. For both real and imaginary parts of *CP*–conserving and *CP*-violating couplings these limits are $|h^Z_{10,30}|$ <0.23, $|h^Z_{20,40}|$ <0.020, $|h^\gamma_{10,30}|$ <0.23, $|h^\gamma_{20,40}|$ <0.019 for Λ = 1 TeV. While determining limits on one parameter the values of all others are set at their standard model values.

[216] ACHARD 04H select 3515 $e^+e^- \rightarrow Z\gamma$ events with $Z \rightarrow q\overline{q}$ or $\nu\overline{\nu}$ at $\sqrt{s}$ = 189–209 GeV to derive 95% CL limits on h_i^V. For deriving each limit the other parameters are fixed at zero. They report: $-0.153 < h_1^Z < 0.141$, $-0.087 < h_2^Z < 0.079$, $-0.220 < h_3^Z < 0.112$, $-0.068 < h_4^Z < 0.148$, $-0.057 < h_1^\gamma < 0.057$, $-0.050 < h_2^\gamma < 0.023$, $-0.059 < h_3^\gamma < 0.004$, $-0.004 < h_4^\gamma < 0.042$.

[217] ABBIENDI,G 00C study $e^+e^- \rightarrow Z\gamma$ events (with $Z \rightarrow q\overline{q}$ and $Z \rightarrow \nu\overline{\nu}$) at 189 GeV to obtain the central values (and 95% CL limits) of these couplings: $h_1^Z = 0.000 \pm 0.100$ $(-0.190, 0.190)$, $h_2^Z = 0.000 \pm 0.068$ $(-0.128, 0.128)$, $h_3^Z = -0.074^{+0.102}_{-0.103}$ $(-0.269, 0.119)$, $h_4^Z = 0.046 \pm 0.068$ $(-0.084, 0.175)$, $h_1^\gamma = 0.000 \pm 0.061$ $(-0.115, 0.115)$, $h_2^\gamma = 0.000 \pm 0.041$ $(-0.077, 0.077)$, $h_3^\gamma = -0.080^{+0.039}_{-0.041}$ $(-0.164, -0.006)$, $h_4^\gamma = 0.064^{+0.033}_{-0.030}$ $(+0.007, +0.134)$. The results are derived assuming that only one coupling at a time is different from zero.

[218] 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_i^γ=0), and $|h^\gamma_{30}| < 0.37$, $|h^\gamma_{40}| < 0.05$ (keeping h_i^Z=0). Limits on the *CP*-violating couplings are $|h^Z_{10}| < 0.36$, $|h^Z_{20}| < 0.05$ (keeping h_i^γ=0), and $|h^\gamma_{10}| < 0.37$, $|h^\gamma_{20}| < 0.05$ (keeping h_i^Z=0).

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

f_i^V

Combining the LEP results properly taking into account the correlations the following 95% CL limits are derived (CERN-PH-EP/2005-051 or hep-ex/0511027):

$$-0.30 < f_4^Z < +0.30, \qquad -0.34 < f_5^Z < +0.38,$$
$$-0.17 < f_4^{\gamma} < +0.19, \qquad -0.32 < f_5^{\gamma} < +0.36.$$

VALUE	*DOCUMENT ID*		*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	[220] ABBIENDI	04C	OPAL
	[221] ACHARD	03D	L3

[220] ABBIENDI 04C study ZZ production in e^+e^- collisions in the C.M. energy range 190–209 GeV. They select 340 events with an expected background of 180 events. Including the ABBIENDI 00N data at 183 and 189 GeV (118 events with an expected background of 65 events) they report the following 95% CL limits: $-0.45 < f_4^Z < 0.58$, $-0.94 < f_5^Z < 0.25$, $-0.32 < f_4^{\gamma} < 0.33$, and $-0.71 < f_5^{\gamma} < 0.59$.

[221] ACHARD 03D study Z-boson pair production in e^+e^- collisions in the C.M. energy range 200–209 GeV. They select 549 events with an expected background of 432 events. Including the ACCIARRI 99G and ACCIARRI 99O data (183 and 189 GeV respectively, 286 events with an expected background of 241 events) and the 192–202 GeV ACCIARRI 01I results (656 events, expected background of 512 events), they report the following 95% CL limits: $-0.48 \le f_4^Z \le 0.46$, $-0.36 \le f_5^Z \le 1.03$, $-0.28 \le f_4^{\gamma} \le 0.28$, and $-0.40 \le f_5^{\gamma} \le 0.47$.

ANOMALOUS *W*/*Z* QUARTIC COUPLINGS

Revised March 2006 by C. Caso (University of Genova) and A. Gurtu (Tata Institute).

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];

$$L_6^0 = -\frac{e^2}{16\Lambda^2}\, a_0\, F^{\mu\nu}\, F_{\mu\nu}\vec{W}^{\alpha} \cdot \vec{W}_{\alpha}$$
$$L_6^c = -\frac{e^2}{16\Lambda^2}\, a_c\, F^{\mu\alpha}\, F_{\mu\beta}\vec{W}^{\beta} \cdot \vec{W}_{\alpha}$$
$$L_6^n = -i\frac{e^2}{16\Lambda^2}\, a_n \epsilon_{ijk}\, W_{\mu\alpha}^{(i)}\, W_{\nu}^{(j)}\, W^{(k)\alpha} F^{\mu\nu}$$

$$\widetilde{L}_6^0 = -\frac{e^2}{16\Lambda^2}\,\widetilde{a}_0\; F^{\mu\nu}\;\widetilde{F}_{\mu\nu}\vec{W}^{\alpha}\cdot\vec{W}_{\alpha}$$
$$\widetilde{L}_6^n = -i\frac{e^2}{16\Lambda^2}\,\widetilde{a}_n\epsilon_{ijk}\;W^{(i)}_{\mu\alpha}\;W^{(j)}_{\nu}\;W^{(k)\alpha}\widetilde{F}^{\mu\nu}$$

where F,W are photon and W fields, L_6^0 and L_6^c conserve C, P separately ($\widetilde{L}_6^0$ conserves only C) and generate anomalous $W^+W^-\gamma\gamma$ and $ZZ\gamma\gamma$ couplings, L_6^n violates CP ($\widetilde{L}_6^n$ violates both C and P) and generates an anomalous $W^+W^-Z\gamma$ coupling, and Λ is an energy scale for new physics. For the $ZZ\gamma\gamma$ coupling the CP-violating term represented by L_6^n does not contribute. These couplings are assumed to be real and to vanish at tree level in the Standard Model.

Within the same framework as above, a more recent description of the quartic couplings [3] treats the anomalous parts of the $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings separately leading to two sets parameterized as a_0^V/Λ^2 and a_c^V/Λ^2, where $V = W$ or Z.

At LEP the processes studied in search of these quartic couplings are $e^+e^- \to WW\gamma$, $e^+e^- \to \gamma\gamma\nu\overline{\nu}$, and $e^+e^- \to Z\gamma\gamma$ and limits are set on the quantities $a_0^W/\Lambda^2, a_c^W/\Lambda^2, a_n/\Lambda^2$. The characteristics of the first process depend on all the three couplings whereas those of the latter two depend only on the two CP-conserving couplings. 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.

References

1. G. Belanger and F. Boudjema, Phys. Lett. **B288**, 201 (1992).
2. J.W. Stirling and A. Werthenbach, Eur. Phys. J. **C14**, 103 (2000);
   J.W. Stirling and A. Werthenbach, Phys. Lett. **B466**, 369 (1999);

A. Denner *et al.*, Eur. Phys. J. **C20**, 201 (2001);
G. Montagna *et al.*, Phys. Lett. **B515**, 197 (2001).

3. G. Belanger *et al.*, Eur. Phys. J. **C13**, 103 (2000).

a_0/Λ^2, a_c/Λ^2

Combining published and unpublished preliminary LEP results the following 95% CL intervals for the QGCs associated with the $ZZ\gamma\gamma$ vertex are derived (CERN-PH-EP/2005-051 or hep-ex/0511027):

$$-0.008 < a_0^Z/\Lambda^2 < +0.021$$
$$-0.029 < a_c^Z/\Lambda^2 < +0.039$$

VALUE	*DOCUMENT ID*	*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •		
	[222] ABBIENDI 04L	OPAL
	[223] HEISTER 04A	ALEP
	[224] ACHARD 02G	L3

[222] ABBIENDI 04L select 20 $e^+e^- \to \nu\overline{\nu}\gamma\gamma$ acoplanar events in the energy range 180–209 GeV and 176 $e^+e^- \to q\overline{q}\gamma\gamma$ events in the energy range 130–209 GeV. These samples are used to constrain possible anomalous $W^+W^-\gamma\gamma$ and $ZZ\gamma\gamma$ quartic couplings. Further combining with the $W^+W^-\gamma$ sample of ABBIENDI 04B the following one–parameter 95% CL limits are obtained: -0.007 $< a_0^Z/\Lambda^2 <$ 0.023 GeV^{-2}, -0.029 $< a_c^Z/\Lambda^2 <$ 0.029 GeV^{-2}, -0.020 $< a_0^W/\Lambda^2 <$ 0.020 GeV^{-2}, -0.052 $< a_c^W/\Lambda^2 <$ 0.037 GeV^{-2}.

[223] In the CM energy range 183 to 209 GeV HEISTER 04A select 30 $e^+e^- \to \nu\overline{\nu}\gamma\gamma$ events with two acoplanar, high energy and high transverse momentum photons. The photon–photon acoplanarity is required to be $> 5^\circ$, $E_\gamma/\sqrt{s} > 0.025$ (the more energetic photon having energy $> 0.2\sqrt{s}$), $p_{T_\gamma}/E_{beam} > 0.05$ and $|\cos\theta_\gamma| < 0.94$. A likelihood fit to the photon energy and recoil missing mass yields the following one–parameter 95% CL limits: -0.012 $< a_0^Z/\Lambda^2 <$ 0.019 GeV^{-2}, -0.041 $< a_c^Z/\Lambda^2 <$ 0.044 GeV^{-2}, -0.060 $< a_0^W/\Lambda^2 <$ 0.055 GeV^{-2}, -0.099 $< a_c^W/\Lambda^2 <$ 0.093 GeV^{-2}.

[224] ACHARD 02G study $e^+e^- \to Z\gamma\gamma \to q\overline{q}\gamma\gamma$ events using data at center-of-mass energies from 200 to 209 GeV. The photons are required to be isolated, each with energy $>$5 GeV and $|\cos\theta| < 0.97$, and the di-jet invariant mass to be compatible with that of the Z boson (74–111 GeV). Cuts on Z velocity ($\beta < 0.73$) and on the energy of the most energetic photon reduce the backgrounds due to non-resonant production of the $q\overline{q}\gamma\gamma$ state and due to ISR respectively, yielding a total of 40 candidate events of which 8.6 are expected to be due to background. The energy spectra of the least energetic photon are fitted for all ten center-of-mass energy values from 130 GeV to 209 GeV (as obtained adding to the present analysis 130–202 GeV data of ACCIARRI 01E, for a total of 137 events with an expected background of 34.1 events) to obtain the fitted values $a_0/\Lambda^2 = 0.00^{+0.02}_{-0.01}$ GeV^{-2} and $a_c/\Lambda^2 = 0.03^{+0.01}_{-0.02}$ GeV^{-2}, where the other parameter is kept fixed to its Standard Model value (0). A simultaneous fit to both parameters yields the 95% CL limits -0.02 GeV^{-2} $< a_0/\Lambda^2 <$ 0.03 GeV^{-2} and -0.07 GeV^{-2} $< a_c/\Lambda^2 <$ 0.05 GeV^{-2}.

Z REFERENCES

ABAZOV	05K	PRL 95 051802	V.M. Abazov *et al.*	(D0 Collab.)
ABDALLAH	05	EPJ C40 1	J. Abdallah *et al.*	(DELPHI Collab.)
ABE	05	PRL 94 091801	K. Abe *et al.*	(SLD Collab.)
ABE	05F	PR D71 112004	K. Abe *et al.*	(SLD Collab.)
ACOSTA	05M	PR D71 052002	D. Acosta *et al.*	(CDF Collab.)
ABBIENDI	04B	PL B580 17	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	04C	EPJ C32 303	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	04E	PL B586 167	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	04G	EPJ C33 173	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	04L	PR D70 032005	G. Abbiendi *et al.*	(OPAL Collab.)
ABDALLAH	04F	EPJ C34 109	J. Abdallah *et al.*	(DELPHI Collab.)
ABE	04C	PR D69 072003	K. Abe *et al.*	(SLD Collab.)
ACHARD	04C	PL B585 42	P. Achard *et al.*	(L3 Collab.)
ACHARD	04H	PL B597 119	P. Achard *et al.*	(L3 Collab.)
HEISTER	04A	PL B602 31	A. Heister *et al.*	(ALEPH Collab.)
SCHAEL	04	PL B599 1	S. Schael *et al.*	(ALEPH Collab.)
ABBIENDI	03P	PL B577 18	G. Abbiendi *et al.*	(OPAL Collab.)
ABDALLAH	03H	PL B569 129	J. Abdallah *et al.*	(DELPHI Collab.)
ABDALLAH	03K	PL B576 29	J. Abdallah *et al.*	(DELPHI Collab.)
ABE	03F	PRL 90 141804	K. Abe *et al.*	(SLD Collab.)
ACHARD	03D	PL B572 133	P. Achard *et al.*	(L3 Collab.)
ACHARD	03G	PL B577 109	P. Achard *et al.*	(L3 Collab.)
ABBIENDI	02I	PL B546 29	G. Abbiendi *et al.*	(OPAL Collab.)
ABE	02G	PRL 88 151801	K. Abe *et al.*	(SLD Collab.)
ACHARD	02G	PL B540 43	P. Achard *et al.*	(L3 Collab.)
HEISTER	02B	PL B526 34	A. Heister *et al.*	(ALEPH Collab.)
HEISTER	02C	PL B528 19	A. Heister *et al.*	(ALEPH Collab.)
HEISTER	02H	EPJ C24 177	A. Heister *et al.*	(ALEPH Collab.)
ABBIENDI	01A	EPJ C19 587	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	01G	EPJ C18 447	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	01K	PL B516 1	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	01N	EPJ C20 445	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	01O	EPJ C21 1	G. Abbiendi *et al.*	(OPAL Collab.)
ABE	01B	PRL 86 1162	K. Abe *et al.*	(SLD Collab.)
ABE	01C	PR D63 032005	K. Abe *et al.*	(SLD Collab.)
ACCIARRI	01E	PL B505 47	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	01I	PL B497 23	M. Acciarri *et al.*	(L3 Collab.)
HEISTER	01	EPJ C20 401	A. Heister *et al.*	(ALEPH Collab.)
HEISTER	01D	EPJ C22 201	A. Heister *et al.*	(ALEPH 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	00J	PL B479 79	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	99L	PRL 83 1902	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	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	99G	PL B450 281	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	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.)
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	97K	ZPHY C74 1	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	97M	ZPHY C74 413	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	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.)
BUSKULIC	96D	ZPHY C69 393	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	96H	ZPHY C69 379	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	96Y	PL B388 648	D. Buskulic *et al.*	(ALEPH Collab.)
ABE	95J	PRL 74 2880	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	95G	ZPHY C67 1	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	95C	ZPHY C65 47	R. Akers *et al.*	(OPAL Collab.)
AKERS	95O	ZPHY C67 27	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	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	94B	PL B327 386	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	94P	PL B341 109	P. Abreu *et al.*	(DELPHI Collab.)
AKERS	94P	ZPHY C63 181	R. Akers *et al.*	(OPAL Collab.)
BUSKULIC	94G	ZPHY C62 179	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		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.)
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.)
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		ZPHY C26 507	W. Bartel *et al.*	(JADE Collab.)
Also		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.)